

**RAQRS 2022**

**Programme and  
Abstract Book**



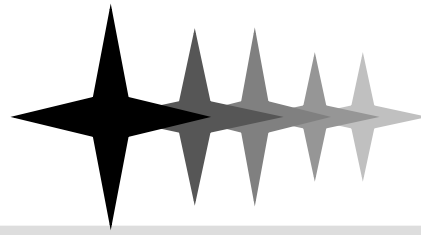
# **RAQRS VI**

## **RECENT ADVANCES IN QUANTITATIVE REMOTE SENSING**

**19-23 SEPTEMBER 2022**  
**TORRENT (VALENCIA) SPAIN**



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Ve a



6<sup>th</sup> INTERNATIONAL SYMPOSIUM



RECENT ADVANCES IN  
QUANTITATIVE  
REMOTE SENSING

# PROGRAMME AND ABSTRACT BOOK

19 - 23 SEPTEMBER 2022  
TORRENT (VALENCIA) SPAIN

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## WELCOME MESSAGE

We are pleased to welcome you to the fifth International Symposium on Recent Advances in Quantitative Remote Sensing, which will be held in Valencia, Spain, from 19 to 23 September, 2022.

The Symposium addresses the scientific advances in connection with real applications, its main goal being to assess the state of the art of both theory and applications in the analysis of Remote Sensing data. This symposium should greatly contribute to define common research priorities.

The Symposium will offer a unique framework for socializing and interacting with the members of the international remote sensing community, at the same time enjoying a stay in Valencia.

Presentations by scientists from around the world will provide an in-depth view and evaluation of the current advances of remote sensing.

See you in Valencia!

Cordially  
José A. Sobrino  
Symposium Chairman  
University of Valencia, Spain  
sobrino@uv.es



## SCIENTIFIC COMMITTEE

### **Presidente / Chairperson:**

J. A. Sobrino University of Valencia, Spain

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### **Presidente / Chairperson:** Symposium, Torrent, Spain

P. Gómez González

### **Miembros/ Members:** University of Valencia, Spain

J. C. Jiménez	D. Skoković	I. Moletto-Lobos	S. Gimeno
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Y. Julien	R. Llorens	M. Sánchez-Torres	D. Salinas
B. Franch	V. Crisafulli	A. Sobrino-Gómez	

## RAQRS 2022 – TIMETABLE

Time	Monday 19 <sup>th</sup> Sep 2022	Tuesday 20 <sup>th</sup> Sep 2022	Wednesday 21 <sup>st</sup> Sep 2022	Thursday 22 <sup>nd</sup> Sep 2022	Friday 23 <sup>rd</sup> Sep 2022			
8:30 - 10:00	REGISTRATION							
10:00 - 10:30	OPENING SESSION	ORAL SESSION 4	ORAL SESSION 8	ORAL SESSION 12	SESSION REPORT BY SESSIONS CHAIRPERSONS (10:00-11:30)			
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22:00 - 24:00								

## PROGRAMA RESUMIDO/PROGRAMME OVERVIEW

LUNES 19 SEPTIEMBRE 2022 - MONDAY 19<sup>th</sup> SEPTEMBER 2022

**8:30 – 10:00**

Inscripción y entrega de documentación / *Welcome and registration.*

AUDITORI de Torrent. C/Vicent Pallardó nº 25, 46900 TORRENT (Valencia)

**10:00 – 10:30** Acto de apertura / *Opening session*

**10:30 – 11:00** Conferencia de Apertura / *Opening Conference*

**11:00 – 11:20** Pausa café / *Coffee break*

**11:20 – 12:00** Sesión Oral 1 / *Oral session 1*

**SESSION 1:** - Land Surface Radiation and Inversion Modelling

Presidente / *Chair:* J. MORENO

**12:00 – 13:30** Sesión Poster 1 / *Poster session 1*

**POSTER 1:** - Land Surface Radiation and Inversion Modelling

- Multispectral and Hyperspectral Remote Sensing and  
Imaging Spectroscopy

- Multiangular and Multitemporal Measurement

- Scaling, fusión, reduction and assimilation of data

- Advances in consolidated datasets of ECV

- Sensor Calibration, Atmospheric correction, and product  
validation

**13:30 – 15:30** Pausa comida / *Lunch break*

**15:30 – 17:00** Sesión Oral 2 / *Oral session 2*

**SESSION 2:** - Land Surface Radiation and Inversion Modelling

- Multispectral and Hyperspectral Remote Sensing and  
Imaging Spectroscopy

- Multiangular and Multitemporal Measurement

Presidente / *Chair:* E. VERMOTE

**17:00 – 17:30** Pausa café / *Coffee break*

**17:30 – 18:30** Sesión Oral 3 / *Oral session 3*

**SESSION 3:** - Earth Observation Missions & Services

Presidente / *Chair:* F. NERRY

**19:00 – 22:00** Acto Social / *Welcome Reception*



MARTES 20 SEPTIEMBRE 2022 – TUESDAY 20<sup>th</sup> SEPTEMBER 2022

**9:00 – 10:30** Sesión Oral 4 / Oral session 4

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- **Multiangular and Multitemporal Measurement**  
- **Advances in consolidated datasets of ECV**

Presidente / Chair: O. HAGOLLE

**10:30 – 11:00** Pausa café / Coffee Break

**11:00 – 12:00** Sesión Oral 5 / Oral session 5

**SESSION 5:** - **Earth Observation Missions & Services**

Presidente / Chair: J. C. ROGER

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- **Sensor Calibration, Atmospheric correction, and product validation**  
- **Earth Observation Missions & Services**

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Presidente / Chair: W. TIMMERMANS

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Presidente / Chair: G. GUTMAN

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Presidente / Chair: F. CAMACHO

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**- Earth Observation Misions & Services**

Presidente / Chair: R. O. GREEN

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**- From R&D to Operacional Agriculture Monitoring**

**- Urban Heat Island**

**- Global Change and sustainable development**

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**-Sensor Calibration, Atmospheric Correction and  
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Presidente / Chair: A. OLIOSO

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**-Global Change and Sustainable Development**

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Presidente / Chair: F. M. GÖTTSCHE

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Presidente / Chairs: Y. KERR

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**SESSION: Supporting Science**

Presidente / Chairs: J. A. SOBRINO

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  - **Passive Microwaves & SAR Data Processing / Applications**
  - **Land Surface Radiation and Inversion Modelling**
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  - **Multiangular and Multitemporal Measurement**
  - **Close Range Remote Sensing**

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- Earth Observation Misions & Services**

Presidente / Chair: J. MORENO

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9:00 – 10:30 Sesión Oral / *Oral session*

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Presidente / Chair: O. HAGOLLE

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17:00 – 17:30 Pausa café / *Coffee break*

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19:00 – 22:00 Cena / *Dinner*

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10:30 – 11:00 Pausa café / *Coffee break*

11:00 – 12:00 Sesión Oral / *Oral session*

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12:00 – 13:30 Sesión Poster / *Poster session*

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#### **- Urban Heat Island**

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15:30– 17:00 Sesión Oral / *Oral session*

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**- Sensor Calibration, Atmospheric Correction and Product Validation**

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17:00 – 17:30 Pausa Café / *Coffee break*

17:30 – 19:00 Sesión Oral / *Oral session*

**SESSION 11: - Urban Heat Island**

**- Global Change and Sustainable Development**

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## JUEVES 22 SEPTIEMBRE 2022 – THURSDAY 22<sup>nd</sup> SEPTEMBER 2022

9:00 – 10:30 Sesión Oral / Oral session

### **SESSION 12: - Sensor Calibration, Atmospheric Correction and Product Validation**

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10:30 – 11:00 Pausa café / Coffee break

11:00 – 12:00 Sesión Oral / Oral session

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12:30 – 13:30 Sesión Poster / *Poster session***POSTER 4: - Land Surface Radiation and Inversion Modelling**

- Multispectral and Hyperspectral Remote Sensing Imaging Spectroscopy

- Multiangular and Multitemporal Measurement

- Remote Sensing of Snow and Ice

- Sensor Calibration, Atmospheric Correction and Product Validation

- Passive and active Microwaves &amp; SAR Data Processing Applications

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**VIERNES 23 SEPTIEMBRE 2022 – FRIDAY 23<sup>rd</sup> SEPTEMBER 2022**

10:00 – 11:30      Conclusiones de sesiones por los presidentes /  
*Session report by session's chairpersons*

Presidente /Chair: J. A. SOBRINO

11:30 – 12:00      Acto de clausura / *Closing ceremony*

12:00 – 13:15      Refrigerio / *Refreshments & Snacks*

## A COMPLETE PACKAGE FOR GROUND BASED VALIDATION OF REMOTELY SENSED SURFACE REFLECTANCE

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The directional surface reflectance product is a critical input for generating downstream products such as Vegetation Indices (VI), Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Bidirectional Reflectance Distribution Function (BRDF), Albedo, and Land Cover. The Surface Reflectance Fundamental Climate Data Record needs to be of the highest possible quality, so that minimal uncertainties propagate in the dependent/downstream products. One challenge is obviously the validation of the surface reflectance. It implies gathering enough surface observations through time and space. Unfortunately the direct validation is limited to episodic field campaigns, or is continuous in time but is extremely limited in space (around 10m x 10m area) over homogeneous site (e.g. RADCALNET) and usually does not address the validation of cloud screening which is at least as important as the atmospheric correction in determining the usability of data. Although, some indirect validation has been used to enable continuous and globally representative validation by using very detailed atmospheric characterization from AERONET data and accurate radiative code, these efforts have inherent limitations to what can be achieved (e.g., adjacency and directional effect correction). Here we propose an automated camera system (CAMSIS) mounted at a height of 123 meters on a TV tower (WLEF) near Park Falls, WI at the Chequamegon National Forest. This system provides data for the continuous validation of surface reflectance over a 200m x 200m area at the pixel level for high spatial resolution sensors (better than 30m). This system is associated with two sky cameras for cloud mask validation (SKYCAM) and is completed by a AERONET Sun Photometer. We present initial results that show good agreement with Sentinel-2A, B and Landsat 8,9 surface reflectance derived from our generic Land Surface Reflectance Code (LaSRC).

## REVISITING THE USE OF RED AND NEAR-INFRARED REFLECTANCES IN VEGETATION STUDIES

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Surface reflectance data acquired in red and near-infrared spectra by remote sensing sensors are traditionally applied to construct various vegetation indices (VIs), which are related to vegetation biophysical parameters. Most VIs use pre-defined weights (usually equal to 1) for the red and NIR reflectance values, therefore constraining particular weights for red and NIR during the VI design phase, and potentially limiting capabilities of the VI to explain an independent variable. In this paper, we propose an approach to estimate biophysical variables, such as Leaf Area Index (LAI), Canopy Chlorophyll Content (CCC) and Fraction of Photosynthetically Active Radiation (FPAR) absorbed by green vegetation, represented as linear combinations



of the red and NIR reflectances with weights determined empirically from observations and radiative transfer model (PROSAIL) simulations. The proof of concept is first tested on available close-range observations over maize and soybean crops in Nebraska, USA. The empirical results compare well with those from PROSAIL model simulations. The proposed LAI model is then used with data from Landsat 8, Sentinel-2 and Planet/Dove, and the results are validated with in situ LAI measurements in Ukraine. We show that the weights on red and NIR reflectances are vegetation-specific and stable in time. The approach is further tested on crops and forests in the conterminous USA and on a global scale using MODIS LAI and FPAR products as proxies for “ground observations”. It is encouraging to see that the derived maps of coefficients/weights exhibit regular patterns over the globe compatible with those of vegetation classes and crop types. Tedious and thorough work on compiling available in situ measurements on various crop types needs to be accomplished prior to large-scale applications, and the method needs to be further tested and proven that it works at a large scale.

The proposed parameterization may be attractive for global studies of various sub-classes of vegetation, once the parameter coefficients are established, validated, tabulated and their stability verified. Ultimately, this approach may provide quantification of vegetation traits for the past decades and be a useful asset for climate models that include satellite-derived land cover classifications and vegetation variables for simulating surface fluxes. This is a conceptual work describing a paradigm, which could ultimately be useful in global models.

## USING UAV & S2 NDVI FOR CALIBRATING REALISTIC 3D MODELS OF MAIZE FIELDS WITH DART AND SIMULATING THEIR RADIATIVE BUDGET

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The perspective of a combined use of Sentinel 2 (S2) products with the futures products of the TRISHNA (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) satellite mission planned for 2025 is a major challenge to provide continuous monitoring on a large scale and at spatial resolutions adapted to the study of soil-plant-atmosphere functioning mechanisms in a context of constraint on water resources. The use of S2 and UAV remote sensing combined with the DART model (Discrete Anisotropic Radiative Transfer Model, <https://dart.omp.eu>) are considered. 1) To validate DART models of 3D landscapes. 2) To better constrain the spatial variability of DART simulations performed at finer resolution. Developed at CESBIO since 1992, patented in 2003, DART is one of the most complete physical 3D models simulating the interaction of Earth-atmosphere radiation in the visible to thermal infrared spectral range. We propose a sensitivity study of fine-scale geometric and radiative properties on simulated satellite and UAV measurements of reflectance and radiation balance in PAR (Photosynthetically Active Radiation, 0.4-0.7  $\mu\text{m}$ ) in function of time. DART models of 2 maize fields, respectively in conventional agriculture and agroecology, were first calibrated in terms of LAI (Leaf Area Index). These fields, located in the Gers, were used as study plots in the BAG'AGES project (2016-2021, Adour-Garonne Water Agency). These LAI were obtained on DART model by a new method of inversion from the NDVI (Normalized Difference Vegetation Index) S2 and UAV. Our approach is to modify the size of the leaves of the DART models to obtain  $\text{NDVI}_{\text{DART}} \approx \text{NDVI}_{\text{S2}}$  or  $\text{NDVI}_{\text{UAV}}$ . This method permits to obtain an LAI value in agreement with the NDVI. Calibration is performed by transforming the DART models into 10m pixel maps of reflectances (Sentinel 2 resolution) and 11.7 cm (UAV resolution). The DART simulations correspond to S2 and UAV observations dates: solar position, atmosphere... The 3D models were validated using reflectance images in the visible and near-infrared (492, 559, 665 and 833 nm) of the S2 satellite and UAV images (550, 660, 735 and 790 nm bands). Moreover thanks

to the fine scale resolution of the UAV data, a validation of the reflectances of the entities (soil, plants) was carried out. Using these realistic models, a sensitivity study was conducted to evaluate the impact of geometric (LAI, plant shape, orientation, plant spacing) and optical (soil) factors on the radiation balance of the canopies. It appeared that the difference in LAI of maize fields significantly affects the reflectance and radiation balance in the visible range. Thus, orientation of the rows in relation to the solar position creates a difference for the radiation intercepted a mean plant around 40W between 11am and 2pm in PAR. This study allowed us to compare the 3D and turbid/1D models and to measure the differences in the radiation balance obtained for these two simulation methods. Our study also focuses on the thermal infrared brightness temperature in the TRISHNA context. A first thermal simulation in brightness temperature has been performed at UAV and TRISHNA resolutions.

## COMPARISON OF HOMOGENEOUS AND HETEROGENEOUS CANOPIES IN RADIATIVE TRANSFER MODELING TO RETRIEVE FOLIAR TRAITS OF FOREST CANOPIES

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Foliar traits are reliable indicators of trees and forest health status since they are strongly linked to plant physiological processes such as photosynthetic activity and hydric status. Foliar traits are related to the biochemical content of leaves such as pigments (chlorophylls, carotenoids), water and dry matter content. For the past decades, several studies demonstrated that foliar traits can be retrieved with from imaging spectroscopy having a larger number of spectral bands and better spectral resolutions enabling to take into account narrow spectral features.

These studies have developed several strategies to map foliar traits of vegetated areas from imaging spectroscopy. These strategies are often classified into three families: empirical, physically based, and hybrid methods. Among these families, hybrid methods gave promising results to estimate foliar traits.

These hybrid methods rely on the use of a radiative transfer model (RTM). A synthetic database is created thanks to a RTM that simulates canopy reflectance. Then a machine learning regression algorithm (MLRA) is trained on this synthetic database. The trained MLRA then constitute an inverse model. Apply this inverse model on imaging spectroscopy data enable to perform estimations of foliar traits of the surveyed area. However, a validation step is required to check the accuracy of the inverse model. Among all MLRA, the Partial Least Square Regression (PLSR) algorithm has been already proved reliable to estimate foliar traits within empirical and hybrid methods, and can deal with the strong collinearity of spectral inputs.

The choice of the RTM and its parametrization is always a key issue. While assessing the accuracy of RTMs to simulate realistic canopy BRDF is a common step in their development, the ability of distinct RTMs to be inverted, and their efficiency to estimate foliar traits are hardly ever compared.

At first, canopy RTM modeled leaf distributions using simple representation inside homogeneous canopies. This first class of canopy RTM is often qualified of 1D RTM, like SAIL. SAIL simulates the behavior of light in homogeneous canopies. SAIL associated with PROSPECT gives the PROSAIL model which has emerged as the major model to retrieve foliar traits over agricultural crops and dense forests. More recently, 3D models, such as DART, has gained computational efficiency making possible estimation of foliar traits by simulating more complex and heterogeneous canopies. DART is able to simulate both heterogeneous and homogeneous canopies. Recent studies assessed the ability of PROSPECT-DART association to retrieve foliar traits over sparser woodland canopies.

This study aims to compare the performance of two hybrid methods based either on SAIL or either on DART to estimate foliar traits on forested areas. Both canopy RTM are associated to the leaf-level RTM PROSPECT and are inverted with PLSR.

To compare the performances of both approaches, we use AVIRIS airborne imaging spectroscopy data (14m GSD) acquired over Sierra Nevada, California, completed with field data collected over three forested sites: two mixed hardwood/conifer forest, Soaproot Saddle and Blodgett Forest; and a high elevation conifer forest, Teakettle experimental forest. These sites offer diversity in species and canopy cover, ranging from sparse canopies to dense canopies.

This work will provide guidelines to choose the proper RTM complexity for hybrid estimations of foliar traits.

## RELATIONS BETWEEN LANDSAT SPECTRAL REFLECTANCES AND LAND SURFACE EMISSIVITY OVER BARE SOILS

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Land surface emissivity is required for deriving surface temperature from thermal infrared radiances. When using single-channel or two-channel thermal infrared sensors, information on emissivity may be derived from spectral reflectance measurements through regression models. Such relations were developed with vegetation index such as NDVI when considering vegetated surfaces. These relations require the knowledge of a baseline value for bare soil which can be derived from spectral reflectances as proposed by some authors.

In this study, we analyzed the relations existing between spectral reflectances in the solar domain and the thermal domain. Correlations between the two domains were analyzed wavelength by wavelength. Two datasets with spectral range spanning over the two domains (between 0.4 and 13  $\mu\text{m}$ ) were used: spectra for 41 soil types, in dry conditions, extracted from the ASTER spectral library and spectra acquired at different soil moistures by Lesaignoux et al. (2013). The correlation analysis made it possible to identify the best wavelengths for estimating bare soil emissivity in the thermal domain from spectral reflectances in the solar domain.

In a second step, the analysis was applied to sensors on board of Landsat platforms and of the future TRISHNA and LSTM missions. When considering all type of soils together, the best relations were obtained between reflectances in the mid-infrared channels (as for examples ETM5 and ETM7) and the various thermal infrared channels with correlation coefficients higher than 0.6. However, the relations between reflectances and emissivities were mostly generated by the variations of soil reflectances due to changes in soil moisture. Correlations were significantly lower when considering only the variations due to soil type, all of them in dry conditions.

## TEMPERATURE AND EMISSIVITY SEPARATION FROM MODIS MULTISPECTRAL TIR DATA

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Accurate retrievals of Land Surface Temperature (LST) from Thermal InfraRed (TIR) data require a precise characterization of the Land Surface Emissivity (LSE). Instead of using traditional approaches based on Fractional Vegetation Cover or Vegetation Indices for LSE estimation, the Temperature and Emissivity Separation (TES) algorithm allows the retrieval of both LST and LSE from only multispectral TIR data. This method respond better to changes in vegetation canopy densities and to changes in surface soil properties which may allow more accurate and representative LST retrievals.

In the framework of ESA LST Climate Change Initiative (CCI) project we propose the application of TES method to Moderate Resolution Imaging Spectroradiometer (MODIS) data, based on 3 channels, which have demonstrated to be the minimum possible configuration for TES application. The work proposed will generate LST and LSE Essential Climate Variable products which can be useful for global trends and for local-scale LST climate applications, such as urban areas, agricultural land, or semi-arid areas. An additional benefit of the computed LSE product is the retrieval of global maps which can be used as input in the classic SW algorithms for generation of long-term LST series. Finally, our retrievals will be compared to other TES products currently used by other entities assessing, in this way, their feasibility and performance.

## **EARTH SURFACE TEMPERATURE EVOLUTION DURING THE YEARS 2003-2021 FROM MODIS DATA**

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The present work shows the estimation of the surface temperature of Planet Earth with MODIS Terra and Aqua Land (LST) and Sea Surface Temperature (SST) products for the years 2003-2021. The results corroborate the temperature anomalies retrieved from climate models and show a rate of warming higher than 0.2 °C per decade. Furthermore, the MODIS surface temperature retrievals are compared with the NOAA's NCDC air temperature estimations, showing high correlations for the global EST (0.96), LST (0.93) and SST (0.94). As an specific application, Lake Surface Water Temperature (LSWT) is estimated for ten of the largest lakes in the world by using MODIS Level 3 SST Thermal IR 8 Day 4km Version 2019.0 product at a high precision during the timespan 2003-2020. The selected lakes are the Caspian Sea, Superior, Victoria, Huron, Michigan, Tanganyika, Baikal, Great Slave Lake, Erie and Ontario lakes. LSWT trends show positive warming rates for every lake, with values ranging between 0.012°C/yr for Victoria Lake and 0.083°C/yr for Baikal Lake. Our LSWT estimations have been validated in the Laurentian Great Lakes, obtaining correlations between 0.96-0.99 respect Moukoma and Blanken (2016) research, which used the MOD11L2 LST product considering the years 2003-2014. Despite MODIS SST product used is designed to retrieve SST by applying a specific SST algorithm, it also provides accurate information about freshwater extension and this work has demonstrated its functionality for estimating LSWT.

## **EXPLORING SPATIO-TEMPORAL SPECTRAL AND FUNCTIONAL VARIABILITY IN MEDITERRANEAN GRASSLANDS**

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Natural and semi-natural grasslands play an essential role in the sustainability of local economies worldwide as they are fundamental for extensive livestock feeding. The long association with traditional grazing practices in these ecosystems can alter their biodiversity and resilience to environmental change. Close range and satellite remote sensing data have been widely used to estimate grassland properties (e.g., biomass, leaf area index, chlorophyll, and nitrogen content) and characterize ecosystem functioning. However, the characterization of plant functional traits from spectral information in these ecosystems remains challenging. The Mediterranean and other grasslands can be highly biodiverse, featuring numerous species that overlap and change in space and time. Such diversity implies dynamic and heterogeneous mixtures of elements with different spectral and functional properties such as green vegetation, senescing vegetation, litter, or flowers which modify the relationships between the spectral and functional properties of grassland patches (or pixels) observable at proximal or remote ranges. These mixtures reduce the potential generalization of empirical models and complicate the usage of physically-based approaches.

This study explores spatio-temporal spectral and functional variability of a drought-prone Mediterranean wooded grassland with an extensive livestock use (<0.3 cows/ha) located in western Spain. This study includes 539 ground measurements collected in a study site of around 1 ha over plots sampled in 23 campaigns from 2017 to 2019. Optical data were acquired using an ASD FieldSpec® 3 spectroradiometer (Analytical Spectral Devices Inc., Boulder, CO, USA) with a spectral range between 350 and 2500 nm, and concomitant grass functional properties (leaf area index, pigments, and water content) were measured in the same plots by destructive sampling. First, we characterized the temporal variability and divided the time series into five main phenological phases (phenophases) in this ecosystem: summer drought, autumn regrowth, winter, spring (biomass peak), and beginning of grass decay as defined by Phenocam phenological transition dates (PTDs). A flowering phase was additionally considered. Then, Spectral Angle Mapper technique classified each spectrum into the five phenophases. Results showed a disagreement between classification and the described general phenology of the ecosystem since plots sampled in the same campaign were often assigned to different phenophases. The spatial variability of vegetation properties or the mixture of different canopy elements induces a strong variability of grass spectral properties. Previous works showed that accounting for phenology improved the retrieval of plant functional traits using spectral information since it reduced the variability of the relationships between both datasets. Our study reveals that spatial variability should also be considered for empirical or semi-empirical modeling to minimize the inconsistency of the correlation patterns. This might be especially relevant at field scales, from medium to high spatial resolution images, including those acquired from planes or drones.

## **OPTICAL WATER TYPE CLASSIFICATION: KNOWLEDGE TRANSFER OF SUPERVISED MACHINE LEARNING METHODS**

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A successful random forest classification of optical types of inland waters was developed for discriminating water types on several lakes on the eastern Iberian Peninsula. The training dataset for the classification is based on manually labelled remote sensing reflectance (Rrs) measured on waters with different dynamics. Sampled optical water types (OWTs) were collected by an expert through analysis the

response of the signal leaving the water, considering the weather situation and inherent dynamics of the water masses. The remote sensing reflectance were extracted from Sentinel 2-MSI atmospherically corrected imagery processed using the C2RCC neural net. Results on the classifications tested, and validation of those results, have been analysed and considerations taken about the transfer of the learning knowledge to other lakes in Europe (e.g Lake Balaton in Hungary); or water bodies extreme cases like Mar Menor (hypertrophic lagoon).

The classifications generated can help to better understand the seasonal and spatial variations of the studied water masses, being a basic support in the monitoring programs of lakes and reservoirs. It is possible to use the OWT classification as final products to analyse changes in water types related to the different water dynamics of the lakes, or they can be considered an intermediate products that could help in the subsequent selection of the water quality data extraction algorithm (for example, chlorophyll concentrations or total suspended matter) generated and adapted to specific types of water (Eleveld et al., 2017, Stelzer et al. 2020). This means that, ideally, this OWT classification should be done before the atmospheric correction. We will derive the TOA radiances corresponding to the training dataset and apply the classification to the time series of Sentinel-2 images available in Google Earth Engine for some of the lakes in our study area.

## EXPLORING THE CAPABILITIES OF SENTINEL-2 REFLECTANCE TO PREDICT SOIL ORGANIC CARBON IN SPAIN

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Soil organic carbon (SOC) is one of the greatest carbon reservoirs in both natural and agricultural ecosystems. While hyperspectral spectroscopy has already demonstrated its effectiveness on estimating SOC from ground samples at the laboratory, multispectral remote sensing is yet to be fully explored in this field, especially with measurements taken from sensors onboard satellites. The current study explores the capability of Sentinel-2 reflectance to predict SOC in Spain. A total of 113 SOC samples from the Land Use/Cover Area frame statistical Survey (LUCAS) database measured during the 2015 campaign were taken as reference SOC, including barelands, croplands, grasslands, shrublands, and woodlands. Sentinel-2 tiles during the 01/04/2017-31/03/2018 period with 10 % cloud cover or less were downloaded through Google Earth Engine. Reflectance from bands 2 (blue), 3 (green), 4 (red), 5 (red edge), 6 (red edge), 7 (red edge), 8 (near infrared), 8A (narrow near infrared), 11 (shortwave infrared) and 12 (shortwave infrared) of dates coincident to all sampling locations were used as predictors. The Random Forest algorithm was used to train both general and land cover dependent models to predict SOC with reflectance. A leave-one-out cross-validation was performed to evaluate the performance of the models. Considering all land covers together, a relative mean biased error (rMBE) of 2 % and a relative root mean squared error (rRMSE) of 63 % were found. The most important predictors were reflectance from band 11 (B11) measured on day of year (DOY) 291, B8A on DOY = 36, B7 on DOY = 36, B12 on DOY = 166 and B2 on DOY = 291. The results generally improved when training models for each land cover. Minimum rMBE (-0.9 %) and minimum rRMSE (28 %) were respectively found for grasslands and bare lands; while maxima rMBE (-4 %) were found for bare lands, shrublands and woodlands, and maximum rRMSE (61 %) was found for shrublands.

## **ESTIMATE OF SURFACE OPTICAL ALBEDO AT HIGH SPATIAL RESOLUTION USING SENTINEL-2 MAJA AND SENTINEL-3 VITO PRODUCTS**

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Surface albedo is an Essential Climate Variable (ECV) which is found useful in number of domains of application: water and carbon balance, agriculture, urban, cryosphere, geology, water bodies, etc. It needs to be produced on a regular basis in order to ensure continuous forcing of radiation and energy budgets. Trade-off between accuracy assessment and frequent coverage depends on target properties and its time scale of evolution.

A surface albedo processing chain is currently developed to obtain high-resolution (HR) products. It merges Sentinel-2 and Sentinel-3 images to obtain sufficient clear scenes at a time scale compatible with vegetation growth, typically 10 days. Sentinel-2 has a spatial resolution of 10m, 20m and to 60m, which is close to the pixel size of the forthcoming TRISHNA. But its small Field-Of-View does not allow sampling the BRDF (Bidirectional Reflectance Distribution Function) and its frequency of revisit is low in case frequent cloudiness. Such shortcomings are solved by using Sentinel-3 of moderate footprint (300 m) offering daily revisit and wider Field-Of-View. A priori information allows filling gaps and ensures continuous time series. Validation is carried on for a series of prairies in France located in various environments.

## **MULTISCALE/MULTI-TEMPORAL STUDY OF THE LAKE SURFACE WATER TEMPERATURE USING IRT SENSORS: VALIDATION IN THE ISSYK-KUL LAKE, KYRGYZSTAN AND GRAND EST LAKES, FRANCE**

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The access and management of water have become crucial due to the importance of this resource in the context of global change. Water bodies, such as lakes or large reservoirs, are sensitive to climatological and meteorological conditions, especially water temperature which determines ecological conditions, influencing water chemistry and biological processes of lakes. Remote sensing technology has contributed to getting more often and enhanced measurements of surface water temperatures. In this context, earth observation data will play an important role in assessing and monitoring this resource. However, it is still challenging to obtain very accurate results due to noise and uncertainty that environmental features can cause such for example atmosphere, clouds, snow, shadow, forest, and built-up areas. In view of the growing societal challenges and technological progress, with the development of partly or totally dedicated missions, Sentinel 1-2-3, and soon SWOT and TRISHNA, the scientific and technological community of the space sector, associated with users and services providers, have fully understood the issues and they are working to meet this challenge. Therefore, this research focuses on the study of the surface temperature parameter, as one of the essential parameters to characterize the water surface, derived from multi-resolution and multi-sensors imagery from high resolution satellites (Landsat 8-9 and ECOSTRESS) and moderate resolution with daily revisit time (Sentinel 3 and MODIS), offering an innovative approach adopted in the thermal infrared domain to define high temporal resolution sequences and dynamic indicators. Moreover, an in situ validation campaign in 2021 was done in the Lake Issyk-Kul (Kyrgyzstan, Central Asia), considered as the seventh deepest lake in the world with 668



m maximum depth, 1607 m elevation and a water surface area of 6,230 km<sup>2</sup>; by using a board (Torrent board) equipped with sensors for measuring humidity, air and water temperatures at the skin level up to 35 cm depth along specific transects, to study spatial variability over the lake. However, due to the lack of good quality derived from multi-sensors imagery, only Sentinel-3 could be validated, showing 1K accuracy between SLSTR and values from the torrent board. Hence, another validation campaign has been planned during the summer 2022 in the lakes Gerardmer, Longemer and Plobsheim, located in the Grand Est region in France, and for this, imagery from ECOSTRESS and Landsat 8-9 will be retrieved. In addition, for this campaign, a thermal imaging camera will be added into the torrent board device to measure and validate the surface temperature of the lakes.

## FIRST APPLICATIONS OF HIGH RESOLUTION BRDF ALGORITHM (HABA) FOR REFLECTANCE NORMALIZATION ON A FUSION DATASET FROM THE SEN2LIKE PROCESSOR

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Normalized Bidirectional Adjusted Reflectance (NBAR) is a key parameter for a consistent time series monitoring over non-lambertian surfaces. The Sen2like is a Virtual Constellation (VC) which harmonizes and fuses Landsat 8 / Landsat 9 & Sentinel 2 dataset giving out a higher spatial and temporal resolution surface reflectance. However, for adequate monitoring of land surface is necessary the correction of sun and sensor angle view across the VC acquisitions. In this context, the High resolution Adjusted BRDF Algorithm (HABA) provides up to 10m NBAR product retrieved from the disaggregation of the Bidirectional Reflectance Distribution Function (BRDF) parameters based on the VJB method applied to MODIS M{O,Y}D09 Climate Model Grid (CMG) at 1km resolution. HABA downscales this product to Sen2Like resolution inverting BRDF parameters (V & R) using the k-means unsupervised classification for each dataset. In order to compensate for the impact on images that do not present sufficient data representativeness due to cloud coverage, the disaggregated parameters are stabilized computing linear trends of time series of Normalized Difference Vegetation Index (NDVI) versus V & R. The model was evaluated on stable sites, such as Sahara Desert (Libya) and Amazonian Forest (Brazil) by comparing the impact of View Zenith Angle (VZA) and Solar Zenith Angle (SZA) of directional reflectance, a static NBAR model and HABA for Near InfraRed (NIR) and red spectrum. Also, the Sen2Like performance was assessed on dynamic sites with a mosaic of land covers across the Belgium tiles, calculating the absolute difference per tile in a 5-day window. The results of stable sites show a decline of linear dependency on the Amazon VZA from R<sup>2</sup> 0.57 (directional) to 0.37 (HABA) in NIR and R<sup>2</sup> 0.04 (directional) to 0.0 (HABA) in red. The Sahara Desert showed a correction of 4% of linear dependency of SZA versus reflectance. Finally, in Belgium, HABA corrected up to 12,74 % the directional effect on the time series. This work contributes to develop a dynamic and operationalization of NBAR correction method based on pixel scale for high resolution datasets.



## AEROSOL PROPERTIES RETRIEVAL IN PARTIALLY CLOUD CONDITIONS

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In this study we approach the really challenging task of retrieving the aerosol properties, as the Aerosol Optical Depth (AOD) and the Angstrom Exponent (AE), in partially cloud conditions of the sky. To this aim we used an all-sky camera sited in Burjassot, at the rooftop of the faculty of Physics at the University of Valencia and a machine learning methodology. The whole sky calibrated radiances are collected from the camera at three RGB channels, with effective wavelengths, namely 615nm, 541nm, 480nm. The principal plane radiance (the line joining the centre of the Sun with the centre of the image) has been shown to be related to aerosol properties of the sky. Our method to obtain the aerosol properties is based on the simulation of the principal plane values of radiances for each channel as if no clouds are present. We achieve this task calculating a proxy of the principal plane signal that well suited our goal, then we evaluate for each point of the signal if clouds are there or not. If not, the signal point radiance is left unaltered, if clouds are present a simulation of clear sky radiance is performed with the Perez method. The presence of the clouds is detected by axial symmetry criterion along the principal plane and a mean Blue to Red Ratio (BRR) near the principal plane, because symmetry alone doesn't ensure clear sky condition near the point. Simulation of the whole signal is needed due to the machine learning method involved that always needs the same length of the input signal. The machine learning method chosen is a Gaussian Process Regression (supervised learning), with a matern 3/2 kernel. To train the model we associate, within a range of 15 minutes in time, AOD and AE values from AERONET database to each signal. The testing phase of the method shows good agreement between the predicted AOD and AE with the testing dataset also provided by AERONET: at least 70% of the prediction falls into the AERONET uncertainty for the AOD (0.01) of the Blue channel (worst case) associated to 440nm AERONET measurements, and 60% of AE prediction into uncertainty of 0.1.

## MACHINE LEARNING FOR AUTOMATIC AIRCRAFT DETECTION AND IDENTIFICATION ON SATELLITE IMAGES

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Object detection and identification play a significant role in many areas such as environmental monitoring, geological hazard detection, land cover mapping, GIS, precision agriculture, spatial planning, and military surveillance. Equipment and weapons analysis is fundamental in times of crisis.

The research aims to automate the detection and identification of aircraft in open-source images, resulting in the developed methodology of automatic/ semi-automatic detection and aircraft identification. The study compared different approaches to detecting and identifying objects, i.e., classical like pixel-based classification, anomaly detection, OBIA and machine learning approach. To detect and identify objects with the use of ML, the YOLO algorithm was used. The architecture of the model used was based on 15 convolutional networks. In the YOLO model, objects are detected based on linking the 3x3 and 1x1 convolution layers into a new network. Simplified blocks replace the existing image blocks and add a new connection to the new network. Thanks to this, the model grows. In order to increase the binding speed of the layers, normalization was applied to all layers. Model programming time was approximately 100 hours. After

programming the network, training began - 50,000 iterations were performed. An image database of military aircrafts was created using images from Google Earth Pro and Yandex to carry out the machine learning process. Aircraft images of 38 types of aircraft have been divided into six groups, i.e., Fighter/Attack, Bombers, Transports), Trainers, Helicopters, and Special Purpose. For the needs of aircraft detection, the created classifier model proved to be very good. It had an average recall (sensitivity) of 98% and an average detection precision of 79%. The algorithm did not detect two of the 178 aircraft on the scenes studied. For aircraft identification, considering their six categories, the created classifier model fulfilled its role to a reasonable degree. The classification model's average recall (sensitivity) in terms of identification for the studied scenes was 84%. Automating the detection and identification of objects using machine learning is a solution to the problem of excess image data. An insufficient number of military analysts may have problems.

## ESTIMATION OF MONTHLY MEAN EXTREME TEMPERATURES IN MURCIA, SPAIN, USING MODIS DATA AND METEOROLOGICAL INFORMATION

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Extreme temperatures (maximum and minimum) are a fundamental agrometeorological variable for the estimation of other variables such as degree-days and chilling hours. From the territorial point of view, the calculation of the spatial distribution of extreme temperatures is usually an several problems when the density of meteorological stations is low. It is therefore necessary to obtain reliable estimates of thermal fields at a spatial resolution appropriate for agricultural applications. The present work shows and application of a simple method to estimate monthly mean extreme temperatures using diurnal and nocturnal land surface temperature (LST) data obtained from the MODIS (Moderate Resolution Imaging Spectroradiometer) products and data obtained from SIAM (Murcia Agricultural Information System) weather station network of IMIDA (Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario). The proposed method is based on the application of a numerical algorithm called geographically weighted linear regressions (GWR). The results show that the spatially explicit regressions were all significant and present a good accuracy for the monthly mean extreme temperatures estimations.

## ASSESSING AND IMPROVING THE CONSISTENCY BETWEEN THE AVHRR/METOP AND SEVIRI/MSG VEGETATION PRODUCTS

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The EUMETSAT Satellite Application Facility on Land Surface Analysis (LSA-SAF) aims to be a Leading Centre for retrieval of information on Land Surfaces from Remote Sensing data, with emphasis on EUMETSAT Satellites. The LSA-SAF provides near-real-time and offline products and user support for a wide

range of land surface variables. All LSA SAF products are distributed according with EUMETSAT data policy and have been classified as essential and are distributed free of charge from the LSA SAF web page (<https://landsaf.ipma.pt/en>). Currently the LSA-SAF generates two operational lines of LSA SAF vegetation products. Firstly, a suite of product (FVC, LAI, FAPAR, GPP) derived from the geostationary SEVIRI (Spinning Enhanced Visible and Infrared Imager) on board MSG (Meteosat Second Generation) 1-4 (Meteosat 8-11). These products are available at two resolutions (daily and 10-day) over the geostationary Meteosat disk, covering Europe, Africa, the Middle East and parts of South America. A climate Data record (CDR) is freely available in the LSA SAF, offering more than eighteen years (2004-present) of homogeneous time series required for climate and environmental applications. Secondly, a suite of global vegetation products based on data from the AVHRR sensor on board MetOp-A, B and C satellites forming the EUMETSAT Polar System (EPS). Unlike the approach to produce SEVIRI/MSG, which relies on stochastic spectral mixture and statistic methods, the EPS algorithm relies on a hybrid approach that blends the generalization capabilities offered by physical radiative transfer models with the accuracy and computational efficiency of machine learning methods. The 10-day vegetation products are level 3 full globe rectified images in sinusoidal projection, with a resolution of 1.1 km x 1.1 km and. The LSA-SAF plans to release a CDR of FVC, LAI, FAPAR EPS products (2007-present) that correspond to a back-processing of existing for NRT/operational products using the most recent algorithm version.

This work assesses the consistency among the two suites of LSA-SAF vegetation products and proposes methods to improve their consistency. Although inputs of MSG and EPS algorithms are similar (i.e. atmospherically corrected cloud-cleared k0 BRDF product at three channels: red, NIR, MIR), discrepancies exist due to various spatial and temporal resolutions, processing lines and differences in the algorithms. Results demonstrate that these differences can be reduced through the adaptation of the EPS algorithm on SEVIRI/MSG data. This work will contribute to enhance the consistency among derived vegetation parameters, which is a priority task previous to the adaptation of the current algorithms to the new processing chains of future EUMETSAT sensors (FCI/MTG, VII/EPS-SG, and 3MI/EPS-SG) to ensure service continuity.

## ASSESSMENT OF SPATIO-TEMPORAL FUSION AND SUPER-RESOLUTION ALGORITHMS BETWEEN THE PROPOSED SENTINEL-HR MISSION AND SENTINEL-2 (NG) MISSIONS

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In 2021, CNES has conducted a phase-0 study for a mission called Sentinel-HR, which aims at providing a higher spatial resolution complement to Sentinel-2 or its next generation Sentinel-2 NG. The mission would acquire imagery at 2 meters resolution every 20 days, in the four 10 meter bands of Sentinel2 (B2, B3, B4 and B8A) and with the same characteristics as Sentinel2: nadir viewing angle, always on instrument, global coverage, free and open data. Yet, because of cloud occurrences, the actual revisit of Sentinel-HR would be way higher than 20 days in some locations, and some users are also interested in both the high resolution and the very frequent revisit. It would therefore make sense to merge information from the Sentinel2 and Sentinel-HR time-series in order obtain a high-resolution, high-revisit synthetic time-series.

In this work, which was part of the phase-0 study at CNES, we compared several methods in order to achieve the best high-resolution, high-revisit time-series. For this, we used data from the French-Israeli VENμS satellite which revisits around 100 sites every 2 days, at 5 m resolution, with 11 spectral bands in the visible and near-infrared.. We first leveraged the simultaneous acquisitions between Venμs, and Sentinel-2: we sampled Venμs images approximately 20 days apart to act as Sentinel-HR (thus working at 5 meter instead of 2 meter), and in between we sampled Sentinel-2 images which had a corresponding Venμs image acquired on the same day. We finally used the VENμS data as a 5 meter reference to assess the quality of various method of fusion of Sentinel-HR and Sentinel-2. Sentinel-2 images were downsampled to 25 meter and 12.5 meter in order to

simulate a resolution ratio of 5 (Sentinel-HR + Sentinel-2) or 2.5 (Sentinel-HR + Sentinel-2 NG). In order to assess the pros and cons of each family of methods, in this benchmark, we chose to include naive solutions (e.g., simple spatial zooming of S2 dates or simple temporal interpolation of Sentinel-HR dates), as well as the well-known STARFM algorithm for spatio-temporal fusion, a Single Image Super-Resolution network called CARN, and a spatial disaggregation method inspired from the literature, extended to multi-temporal input features. Experiments show that for a resolution ratio of 5, the latter offers the best performances with the additional benefits of being able to accurately interpolate partially cloudy scenes. In the case of a 2.5 resolution ratio, Single Image Super-Resolution becomes competitive, with the benefit of simpler operational use and lesser computational cost. Overall those experiments demonstrate the feasibility of such hybrid products, which in turn reinforces the sweet spot of Sentinel-HR specifications.

## ASSESSING THE USEFULNESS OF LAND SURFACE TEMPERATURE SPATIAL DISAGGREGATION FOR WATER STRESS MAPPING IN THE FRAME OF THE PREPARATION OF THE TRISHNA MISSION

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The French – Indian mission Trishna to be launched in 2025, will provide a monitoring of the Land Surface Temperature (LST) every 3 days with 4 spectral bands in the TIR (Thermal InfraRed) range and 7 in the Visible and Near Infrared (VISNIR) bands at a 57-m spatial resolution at Nadir. Scientific themes and applications include ecosystem stress and water use, coastal and inland waters monitoring (design drivers), but also urban micro-climate monitoring, cryosphere, solid Earth and atmosphere science. Trishna will be a precursor to the LSTM ESA mission, which will ensure data continuity over more than a decade.

Water management and water stress services to farmers are an important target for the Trishna mission, and the Nadir spatial resolution of 57 meters, which will degrade to more than 90 meters at both ends of the swath due to the large angular field of view of  $\pm 34^\circ$ , may be slightly too coarse for the monitoring of fine-scale structures like small crops. State-of-the-art methods for the spatial sharpening/disaggregation of the LST with the help of an higher spatial resolution information in the VISNIR seems like a natural solution to this problem. In the Trishna configuration, where VIS, NIR and TIR band will be sampled at the same resolution, the use of auxiliary Sentinel-2 images could be considered.

In this work, we attempt to assess the performances of spatial disaggregation for the estimation of water stress. We leverage 2-m resolution aerial VISNIR and TIR imagery from the 2015 AHSPECT campaign, in order to simulate a TIR source resolution of 60 meters in Trishna spectral bands, as well as a target VISNIR resolution of 20 meters in the Sentinel-2 spectral bands. Reference TIR 20 meter band are also simulated. We measure both the performance of the 20 meter reconstruction on the LST and water stress using the Water Deficit Index, at different stages of spatial disaggregation state-of-the-art algorithms, including Tsharp, HUTS, ATPRK, AATPRK and Data Mining Sharpener (DMS).

Early results on the 4 first aforementioned methods show that the variability of the LST with respect to vegetation state (e.g. from fractional vegetation cover), which is at the heart of water stress measurement, may not be captured well by some of the models relating VIS and NIR features to LST. In this case, proper recovery of this variability is essentially achieved by mean of the residual correction step, which is low-resolution in nature and does not bring back higher resolution details. However, we think that more complex models using more input features, such as DMS, might be able to recover a greater fraction of this variability, which we intend to assess quantitatively in the next steps.

## ASSESSMENT OF 10-M LST FROM THE SYNERGY SENTINEL-2 AND SENTINEL-3 FOR AGRICULTURE APPLICATIONS

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Disaggregation techniques offer a solution to the lack of high-resolution satellite Thermal InfraRed (TIR) data and can bridge the gap until operational TIR missions accomplishing spatio-temporal requirements are available. In this work, we adopt a downscaling method that has already shown good results in previous research based on the combination MODIS/Landsat, and integrate the necessary adjustments to be applied to the tandem Sentinel-2 (S2)/Sentinel-3 (S3). Maps of Land Surface Temperature (LST) with 10-m spatial resolution are obtained as output from the synergy S2-S3 images.

An experiment was conducted in an agricultural area located in the Barrax test site, Spain (39° 03' 35'' N, 2° 06' W), for the summers of 2018-2019. Ground measurements of LST transects collocated with overpasses of the Sea and Land Surface Temperature Radiometer (SLSTR) on board Sentinel-3 were used for a ground validation of the disaggregation approach. A dataset of more than 70 points from 15 different dates were available, covering a variety of croplands and surface conditions. A cross-validation of the LST products was also conducted using an additional set of Landsat-8/TIRS images. As the key input in the downscaling technique, two products for the original 1-km S3 LST data were tested, the SLSTR Level-2 LST operational product and LST values from an adapted split-window algorithm. Despite the large range of temperatures registered (295-330 K), an average RMSE of  $\pm 2.7$ K and a negligible systematic deviation were obtained for the full ground dataset.

These results are encouraging for the use of this methodology in agroecosystems, and promising since the 10-m pixel size, together with the 3-5 days revisit frequency of S2-S3 satellites, can fulfill the LST input requirements of the surface energy balance methods for a variety of hydrological, climatological or agricultural applications. However, some limitations associated with extreme LST, or irrigated fields under certain conditions, claim the necessity to explore the implementation of soil moisture or vegetation indices sensitive to soil water content as inputs in the disaggregation approach.

## SPATIO-TEMPORAL FUSION OF SENTINEL-2 AND SENTINEL-3 OBSERVATIONS FOR HIGHRESOLUTION AND COST-EFFECTIVE MONITORING OF AFRICAN RANGELAND PHENOLOGY AT CONTINENTAL EXTENT

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Time series of satellite data play a significant role for the monitoring of ecosystems, such as plant phenology. While being the most informative type of data, optical images often present missing observations due to atmospheric aerosols, clouds, or other atmospheric conditions. To compensate for the scarcity of data during cloudy conditions, combination of data sources may be relevant. For example, Sentinel-3 satellites provide a revisit time of nearly one day at the expense of spatial resolution (around 300 m) while Sentinel-2 satellites have a high spatial resolution of 10m but a revisit time of 5 days at the equator. Spatio-temporal fusion (STF) is a cost-effective way to deal with this trade-off. Our study aims at combining Sentinel-2 and Sentinel-

3 optical data to study phenological changes of African rangelands at a high resolution both temporally and spatially. We hereby propose a new algorithm, which matches the performance of existing popular STF methods (STARFM and Fit-FC) while being more computationally efficient. The latter is especially relevant when performing continental or global scale analysis. The time-efficiency is achieved by performing the most computationally costly calculations at Sentinel-3 spatial resolution. In addition, while other methods usually process spectral bands independently, our method relies on principal component analysis (PCA). The dimensionality enhancement from single bands to principal components of multiple bands enables a better parametrization of heterogeneous phenological changes, thus avoiding costly post-processing adjustments at Sentinel-2 resolution. This method is evaluated in various rangelands in Africa and compared with STARFM and Fit-FC. Early results indicate that the proposed method can match the skill of the existing methods in performing cloudfilling of Sentinel-2 data and recreating missing scenes, while achieving computational efficiency improvement by a factor of approximately one hundred. We also show the relevance of increasing the density of acquisition points to monitor phenological changes of rangeland ecosystems during the rainy seasons and detect the greening-up of vegetation at a high spatio-temporal resolution.

## STUDY OF TRENDS IN THE MEDITERRANEAN SEA SURFACE TEMPERATURE IN THE CONTEXT OF CLIMATE CHANGE

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Sea surface temperature (SST) is a key variable for studying past and predicting future climate trends and weather patterns, and thus SST was defined as an Essential Climate Variable (ECV) by the Global Climate Observing System of the World Meteorological Organization (WMO) and also by the Climate Change Initiative (CCI) launched by the European Space Agency (ESA). Other studies have highlighted the significant role that anomalous SSTs in the Mediterranean have played in extreme weather events in the region and a further understanding of the trends and spatial patterns of the SST in the region is essential in predicting and mitigating them. This contribution tries to show some preliminary findings in the framework of the on-going Tool4Extreme research project, lead by the University of Valencia, in which the study of the Mediterranean SST patterns and trends and their relation to observed precipitation trends over the Iberian Mediterranean Basin, in the context of climate change, is one of the objectives.

In this preliminary study, a nine-year period (2003-2011) was analyzed using thermal-infrared data acquired by the Advanced Along Track Scanning Radiometer (AATSR) aboard the ESA's Envisat satellite. First, the accuracy of the SST retrieved from AATSR data with a proposed split-window algorithm was determined by using buoy data, after correcting for bulk-skin temperature differences. Then, trends along the nine-year period were determined. Trends of  $0.086 \pm 0.005^{\circ}\text{C/yr}$  and  $0.069 \pm 0.005^{\circ}\text{C/yr}$  were found for night-time and daytime data, respectively, for the whole Mediterranean Sea for this period. Using clusters analyzed in previous works, trends were identified in different regions and it was found that the Levantine Basin and Black Sea consistently displayed the highest rates of warming, whilst the lowest rates were in the Adriatic Sea in winter and autumn and the Tyrrhenian Sea and Gulf of Lion in spring and summer. Of the 172 clusters analyzed, 77 showed positive SST trends and 26 showed negative trends. For the whole Mediterranean 7 of 12 months showed warming trends and five showed no detectable trend, but none showed a negative trend.

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## **THERMOCITY : GENERATION OF AN ENHANCED QUALITY LAND SURFACE TEMPERATURE DATASET FOR URBAN PLANNING**

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Land Surface Temperature (LST) is an Essential Climate Variable (ECV), like Land Cover (LC), for the study of biosphere processes and climate change. Notably, for urban areas, LST is linked to the Surface Urban Heat Island (SUHI) effect which is defined as the difference in temperature between the densely built areas of a city and its rural surroundings. It can also be used to highlight the thermal activity such as heat losses. THERMOCITY is a Space Climate Observatory (SCO) labelled project, which started in 2021 and continues to end in 2022. It aims to study the SUHI effects in summer and heat losses in winter through the development of thermography analysis tools by incorporating the processing of satellite thermal data that are regularly used to retrieve the LST over urban areas. In doing so, the project has gathered scientists with expertise in urban climatology, remote sensing and building construction materials. As part of THERMOCITY, workshops have been held with three French metropolises namely Montpellier, Strasbourg and Toulouse, to ensure a constant involvement of the final users and a promoting synergy between science and applications. Here we show the generation of a unique thermal dataset over 5 French metropolises: the three aforementioned metropolises plus Paris and Aix-Marseille. Different steps to enhance the LST quality were performed from radiance images acquired by ASTER and ECOSTRESS at a 90 m and a 70 m spatial resolution, respectively: geometric and atmospheric corrections, temperature and emissivity separation with an urban-oriented algorithm, disaggregation from 90 m to 30 m for ASTER and production of a quality index. From this, around 50 LST images are openly available covering different conditions like daytime, nighttime, summer and winter along with the original radiance images and NDVI (Normalized Differential Vegetation Index) ones. This work enables data fusion with other space-borne data or socio-economic information. Indeed, applications using this dataset are illustrated such as: the correlation between land use and LST on specific urban blocks in Montpellier, LST anomalies over buildings in Strasbourg, the evolution of LC over Toulouse or the simulation of the SUHI effect with climate models and compared with the satellite observations. We point out that the THERMOCITY project and the generated thermal dataset are of great interest to pursue research activities related to urban studies as well as assessing processing methods and analysis tools in direct synergy with the needs of the urban stakeholders.

## **SYNCHRONOUS CHANGES IN SURFACE TEMPERATURE AND LEAF AREA INDEX IN THE AMAZONIA BASIN**

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Changes in land-use and land cover are intrinsically linked to modifications in land surface characteristics and, therefore, to changes in biosphere-atmosphere interactions. The Amazon forest, the largest

tropical rainforest on the planet, has faced abusive changes in the past decades and significant efforts are still needed to limit deforestation. Although several studies have focused on land/vegetation – atmosphere feedbacks, the use of satellite-based essential climate variables (ECVs), such as Land Surface Temperature (LST) and Leaf Area Index (LAI), for their full characterization based on observational datasets at regional-to-continental scale, has been less explored. The present study uses both LST and LAI datasets from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra (MOD21C3) and Aqua (MYD21C3) platforms (collection 6.1) and MODIS LAI product MCD15A2H (collection 6.1). We analyze monthly data over the Amazonian Basin, for the 2003-2021 period to identify links between trends in daytime/night-time LST values with changes in LAI. Trends are estimated using Theil-Sen regressions, while their significance is assessed through the non-parametric Mann-Kendall test. Daytime LST products (both from Terra and Aqua) present positive significant ( $p < 0.01$ ) trends ranging from around 0.1 to 0.3 K per year, in the dry period (from May to October) over the southeastern region of the Amazon Basin. Over this region, LAI shows negative trends of the order of -0.05 m<sup>2</sup>/m<sup>2</sup> per year. To further analyze the links between LST and LAI trends, we have plotted LAI trends against daytime LST trends considering only pixels where both are significant. Overall, a negative correlation pattern emerges, for all months, with stronger values (i.e., correlations below -0.5) in June, July and August. The relationship between changes in night-time LST and in LAI is not well defined, especially taking into account that the number of pixels with significant night-time LST trends is considerably lower, which is related to the high number of cloudy pixels or low LST values. Trends in LAI can be mostly attributed to the different land use management and policies adopted. The trends in LST, generally observed for daytime products, suggest an increase in their daily amplitudes, which in turn are likely related to drier and warmer surfaces, even in the Amazon forest.

## VALIDATION OF COPERNICUS PAN-EUROPEAN HIGH RESOLUTION VEGETATION PHENOLOGY AND PRODUCTIVITY - HR-VPP – PRODUCTS

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The Copernicus Land Monitoring Service (CLMS) provides geographical information on land cover and its changes, land use, vegetation state, water cycle and earth surface energy variables to a broad range of users in Europe. Within the Pan-European component, the CLMS produces and disseminates High-Resolution Vegetation Phenology and Productivity product suite (HR-VPP) at high spatial resolution (10m). They are derived from the Sentinel-2 constellation (Sentinel-2A and Sentinel-2B) with a revisit time 5 days. They are generated over the entire EEA39 (32 member countries, the UK and 6 cooperating countries in the Western Balkans) from January 1, 2017, onwards. The HR-VPP product suite contains 3 product groups: (1) **Vegetation Indices**, generated near real-time (NRT) providing for every pixel the status of the vegetation vigor in four variables: Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Normalized Difference Vegetation Index (NDVI) and Plant Phenology Index (PPI). (2) **Seasonal Trajectories (STs)**, products are provided yearly after the end of the vegetation growing season. These are derived as a regular time-series of every 10 days by fitting a smoothing and gap filling double-logistic model function to the raw Plant Phenology Index. (3) **Vegetation Phenology Parameters (VPPs)** products bundle (e.g. start of the season (SOSD), end of season (EOSD), seasonal productivity) are derived from the STs of the PPI index, on a yearly basis, after the end of the growing season.

The aim of this presentation is to summarize the quality assessment of the Sentinel-2 HR-VPP products, with particular attention to the phenometrics. The quality assessment methodology was adapted from CEOS LPV



validation protocol for biophysical products and state-of-the-art of satellite-based phenology product validation. Several criteria of performance were evaluated, including spatial consistency, temporal consistency and error evaluation (accuracy, precision and uncertainty) using two generic approaches: product inter-comparison (i.e., indirect validation) and comparison with ground data (i.e., direct validation). For product inter-comparison, MODIS and EEA MR-VPP phenology products were used, in addition to Copernicus Global Land PROBA-V 300m data, over a network of 3800 evaluation (EVAL) sites defined to be homogeneous in land cover at 1km. For direct validation, data coming from FLUNEXT, PhenoCam and PEP725 database were used. HR-VPP products showed in overall good spatial and temporal consistency, vegetation indices presented good correspondances with similar satellite products, high correlations ( $>0.85$ ) with ground references were found for STs, and phenology metrics were found accurate for the SOSD, as compared to PEP725 observations, with an anticipated EOSD.

## **CONSOLIDATION OF DATASETS OF ESSENTIAL CLIMATE VARIABLES: CASE OF THE LAKE WATER EXTENT EXPLOITING HR IMAGERY AND ALTIMETRY TIMES SERIES WITHIN THE ESA CCI LAKES FRAMEWORK**

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Water bodies are considered of importance in the context of global change, considered as climate sentinel, being also sensitive to climatological and meteorological conditions. By the way lakes were defined as an Essential Climate Variable (ECV) by GCOS. And through the Climate Change Initiative of ESA, 6 essential climate variables (ECV), lake surface temperature (LSWT), water level and extent (LWL & LWE), ice cover and thickness (LIC and LIT), and lake water leaving reflectance (color)(LWLR) are considered to better understand the lake physical response to climate change.

LWE can be expressed as the outline of a water body (a vector or a grid representation) or as the total areal extent of a waterbody (a single number). It is practically very challenging to process the high spatial resolution satellite imagery required to generate maps of water presence for hundreds, if not thousands, of lakes at the accuracy (5%) and temporal frequency (1-10 days) required for climate studies.

For this reason, the strategy adopted within the CCI Lakes project is twofold. First, for each lake, we collect a set of satellite imagery spread out over a long period. To choose the images we use the water level time series (calculated using satellite altimetry) to determine when the lake was at low, medium and high level. A relationship (a first or second order polynomial) can then be established using a set of 10 to 15 data combinations of LWL and LWE and least square adjustment. Knowing the function  $LWE=f(LWL)$  we can then relate LWL from altimetry to LWE using the hypsometry process. This allows us to achieve a high temporal resolution without overwhelming image processing requirements.

However, to calculate the hypsometry coefficients, the processing task remains cumbersome, as it is necessary to generate these temporal sequences of LWE on almost 2000 lakes in the long term.

To determine LWE maps to feed into the hypsometry curve, it is determined from contrasts in the optical and/or radar reflectance of water compared to surrounding land. In Lakes\_CCI, phase 1, both optical and synthetic aperture radar (SAR) approaches are being investigated to generate LWE. However, it was not possible to conclude on the synergy to be implemented between these two types of data, as the comparisons on test sites were often convergent but with some very divergent cases, not allowing to satisfy the required precision conditions. For the Phase II, LWE will be generated exploiting optical HR time series based on in house tool, ExtractEO, a software implementing automated end-to-end chains on satellite data, with a focus on Sentinel1\_3. Water surfaces are detected using a multilayer perceptron algorithm and integrating the GSW database for sampling. Tools have been put in place to identify outliers and, in some cases automatically readjust thresholds

in the selection process of training samples. Validation is done both exploiting exiting high resolution database with the known limitations of their representativity, as well based on VHR optical imagery. Examples of the end to end process are presented over various environment.

## VALIDATION OF COPERNICUS GLOBAL LAND SERVICE SENTINEL-3 OLCI LEAF AREA INDEX, FRACTION OF ABSORBED PAR AND VEGETATION COVER PRODUCTS

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The Copernicus Global Land Service (CGLS) provides continuously a set of bio-geophysical variables describing the dynamics of vegetation, energy budget, water cycle and cryosphere. The service ensures near-real time production and delivery of consistent long-term time series of global bio-geophysical variables. The CGLS portfolio includes leaf area index (LAI), fraction of absorbed photosynthetically active radiation (FAPAR) and fraction of green vegetation cover (FCOVER) products, produced every 10 days in real time mode (RT0) and after one (RT1), two (RT2) and six (RT6) dekads, consolidating the products. They were delivered at 1km (Collection 1km) in the past and are delivered at 300m (Collection 300m) resolution since 2014 based on the PROBA-V mission data (Version 1.0). From the end of the PROBA-V operational mission in June 2020 onwards, the production is continuing based upon the Ocean and Land Colour Instrument (OLCI) data onboard the Sentinel-3 platform (Version 1.1).

This work presents the validation results of the CGLS OLCI V1.1 LAI, FAPAR and FCOVER products. The validation methodology is defined in concordance with the Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) protocols, relying on (i) product intercomparison or indirect validation and (ii) direct validation against up-scaled ground data. The validation exercise focus on the July 2018 - April 2019 period for product intercomparison and extended to July 2020 – December 2021 for direct validation. The product intercomparison is performed using the predecessors products (CGLS PROBA-V V1.0), the NASA Visible/Infrared Radiometer Suite (VIIRS) collection 1 (VNP15A2H C1) and the Vegetation (VEGA) products derived from Advanced Very High Resolution Radiometer (AVHRR) onboard the EUMETSAT Polar System (EPS) provided by the Land Surface Analysis (LSA) of the Satellite Application Facility (SAF). The Copernicus Global Land Ground-Based Observations for Validation (GBOV) dataset and ground-based ESA FRM4Veg 2021 maps over Barrax (Spain) agricultural and Wytham (UK) forest areas were used for direct validation. Main results show a good overall quality with satisfactory spatial and temporal consistency with PROBA-V V1.0, NASA VNP15A2H C1 and LSA SAF EPS products. CGLS OLCI V1.1 as compared with PROBA-V V1.0 showed overall uncertainty (RMSD) of 0.39/0.04/0.06 for LAI/FAPAR/FCOVER over LANDVAL sites, demonstrating the good continuity of time series in the service. The direct validation with ground truth shows RMSD of 0.91/0.11/0.11 in the comparison with GBOV V3 in the July-2020 – December 2021 period. The comparison of RT6 with FRM4Veg data shows overall good results (RMSD=0.12 for FAPAR/FCover) in Wytham and poor results in Barrax (RMSD=1.17/0.20/0.21 for LAI/FAPAR/ FCOVER) as a consequence of a geolocation issue recently identified in the reprojection module of the CLGS processing chain. For RT0 mode, slightly worse results are found (RMSD=0.14/0.15 for FAPAR/FCover) in Wytham and best results (RMSD=0.44/0.09/0.09 for LAI/FAPAR/ FCOVER) in Barrax.

## COPERNICUS GLOBAL LAND LAI, FAPAR AND FCOVER 300M PRODUCTS

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The Copernicus Global Land Service (CGLS) provides continuously a set of bio-geophysical variables describing the dynamics of vegetation, the energy budget, the water cycle and the cryosphere. The service ensures near-real time production and delivery of consistent long-term time series of global bio-geophysical variables. The CGLS portfolio includes the leaf area index (LAI), the fraction of PAR absorbed by vegetation (FAPAR) and the cover fraction of vegetation (FCOVER) products which are derived every 10 days at 300 m (Collection 300m) resolution. The products are delivered with associated uncertainties and quality indicators. The products are accessible free of charge through the CGLS website (<http://land.copernicus.eu/global/>), associated with documentation describing the retrieval methodologies, the technical properties of products, and the quality of variables based on the results of validation exercises. The Collection 300m of LAI, FAPAR and FCOVER products is available from 2014 with PROBA-V and from 2020 with Sentinel-3. Satellite observations of surface reflectance are first transformed into biophysical variables using machine learning techniques. The instantaneous estimates are then composited every 10-day using a specific smoothing temporal filtering which allows near real time estimation. This talk will focus on the retrieval algorithms used to generate CGLS Collection 300m of LAI, FAPAR and FCOVER products. The CGLS products will be assessed based on the comparison with other existing satellite products and ground data. The consistency of the time series will be evaluated with due attention to the switchover from PROBA-V to Sentinel-3. Finally, some applications of the CGLS biophysical products will be presented.

## MODELING SOIL SPECTRAL AND DIRECTIONAL REFLECTANCE IN THE SOLAR DOMAIN (400-2500 NM) AS A FUNCTION OF SOIL MOISTURE CONTENT

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Soil moisture content (SMC) is a key variable at the Earth's surface. Its estimation is essential in many domains such as agriculture, hydrology, climate, defense, and planetary science. Since the 1970s, airborne or satellite remote sensing has emerged as a promising tool for mapping surface SMC over large areas. Water can be probed at different depths in the soil depending on the wavelength domain studied: solar (0.3-3 µm), thermal infrared (3-12 µm), and microwaves (0.5-100 cm). In the solar domain, light penetrates very little into the soil so that SMC is estimated to a maximum depth of about one millimeter. The objective of this work

is to simulate reflectance spectra of rough and wet soils using radiative transfer models. In particular, we want to study the effects of water distribution, illumination and observation angles, but also surface roughness on soil bidirectional reflectance. We have developed the MARMIT-2 model that predicts the reflectance spectra of wet soils with fairly good accuracy. It represents a wet soil as a layer of dry soil topped with a thin layer of a mixture of water and soil particles. The wet soil reflectance is expressed as a function of the dry soil reflectance and three input parameters: the thickness of the water layer, the surface fraction of the wet soil and the volume fraction of soil particles in the water layer. MARMIT-2 was validated on a database of 225 soil samples with reflectance spectra measured in the laboratory at several moisture levels. However, these flat samples are not fully representative of natural soil surfaces, which are much more complex. In order to upscale MARMIT-2 to airborne or satellite hyperspectral images, we investigated the effects of soil roughness on the reflectance by performing BRDF (Bidirectional Reflectance Distribution Function) simulations of rough and wet soils using the DART-Lux ray tracing software developed at CESBIO (<https://www.cesbio.cnrs.fr/dart>). We considered high-resolution DTMs (digital terrain model) of artificial and real terrains cut into microfacets. The facets can be dry or wet and their optical properties modeled as Lambertian or with the RPV (Rahman-Pinty-Verstraete) model. The coupling between MARMIT-2, RPV and DART-Lux allows to simulate the spectral variations of the BRDF of rough and wet soils.

## RETRIEVING ENERGY BUDGET COMPONENTS OVER A VINEYARD IN NORTH-EASTERN SPAIN USING IN-SITU DIRECTIONAL THERMAL INFRARED DATA

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The viability of agricultural production is largely dependent on the efficient use of water resources. With evapotranspiration (ET) accounting for nearly all the water lost from croplands and wooded areas, accurate ET estimation methods are needed for a better understanding of irrigation demands. While surface temperature can help to detect water deficiencies in such environments, it can also be susceptible to directionality influences leading to an incorrect interpretation of observed surface emission signals. In this study, we perform model assessments and check the influence of thermal radiation directionality using flux data over a vineyard located in Verdu (Catalonia, Spain) collected as part of the HiLiaise project. The non-continuous row site is oriented E-W and is drip irrigated. Instrumentation at the site included: net radiometers, an eddy covariance system for turbulent fluxes monitoring, as well as thermal cameras that provided elemental soil and vegetation temperatures. To derive the overall directional surface temperatures (nadir and off-nadir), the measurements were aggregated by weighting the elemental values with their respective cover fractions in the viewing direction. The reconstructed surface temperatures were then used in surface energy balance (SEB) modelling schemes. Here, the soil plant atmosphere remote sensing of evapotranspiration (SPARSE) dual source model together with an extended version which discriminates shaded/unshaded elements (SPARSE4), were used to estimate the energy fluxes. Similar to observations made in an earlier study on crops and orchards, we observed that both model formulations are able to retrieve overall fluxes satisfactorily. The sensitivity of flux and component temperature estimates to the viewing direction of the sensor was tested by using reconstructed sets of thermal data (nadir and oblique) to force the models, where we observed degradation in flux retrieval cross-row with better consistency along rows. Overall, it is nevertheless shown that by using the extended method, the sensitivity to viewing direction can significantly be reduced. The results are encouraging,

and – to complement them – directional temperature reconstruction using a 3D radiative transfer model (DART) is envisioned. Additionally, output from the two-source energy balance (pyTSEB formulations) – applied as part of the SenET programme over the broader Lleida region – is being evaluated using the Verdu dataset hence allowing further inter-comparisons.

## IN-SITU LST OBTAINED FROM BROADBAND HEMISPHERICAL AND NARROWBAND DIRECTIONAL RADIANCES OVER HIGHLY HOMOGENEOUS NAMIB GRAVEL PLAINS

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At validation station Gobabeb (GBB) Plains, Namibia, two independent sets of thermal infrared (TIR) radiometers are available for obtaining in-situ LST: broadband (4.5 - 42  $\mu\text{m}$ ) hemispherical sensors Kipp & Zonen CG4, which are part of a Baseline Surface Radiation Network (BSRN) station operated jointly by the University of Basel (Switzerland) and KIT, and narrow band (9.6 – 11.5  $\mu\text{m}$ ) directional (8.5° full view angle) Heitronics KT15.85 IIP radiometers, which belong to KIT's network of LST validation stations. Both sets of radiometers measure surface-leaving radiance as well as downwelling radiance; additional meteorological sensors provide air temperature and humidity at 2 and 25 m height. Furthermore, in-situ emissivity spectra are available at numerous locations on the gravel plains and in the direct vicinity of station GBB-Plains. The spectra were obtained in 2017 as a contribution to ESA's FRM4STS project by the research institute ONERA, France, during an international LST Field Intercomparison Experiment (FICE). Here, they are used to obtain channel-effective land surface emissivities (LSE) for the two types of ground observing radiometers. Previous experiments have shown that the gravel plains at GBB-Plains are highly homogeneous on the 1 m<sup>2</sup> to 1 km<sup>2</sup> spatial scale and temporally stable. Therefore, the deployed instruments offer the unique opportunity to compare LST derived from directional and hemispherical radiance measurements under ideal conditions with known in-situ emissivities. Furthermore, the mounting height of the ground-observing broadband sensor is 3 m, which results in negligible atmospheric path length between sensor and target. Consequently, any differences between the in-situ LSTs obtained from the two sets of radiometers are primarily due to their different observation geometries. Results for one year of in-situ measurements are presented and compared with in-situ LST retrieved with narrow band emissivity (KT15.85 IIP) and broadband emissivity (CG4); the latter is obtained via a regression relationship from ASTER GED. The differences observed for the two sources of emissivity data are discussed and the corresponding error for site GBB-Plains is quantified.

## LAND SURFACE TEMPERATURE MONITORING (LSTM) MISSION – COPERNICUS EXPANSION MISSION IN SUPPORT OF AGRICULTURAL MONITORING

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The “High Spatio-Temporal Resolution Land Surface Temperature Monitoring (LSTM) Mission” has been identified as one of the Copernicus Expansion Missions. The mission is designed to provide enhanced measurements of land surface temperature in response to presently unfulfilled user requirements related to agricultural monitoring.

High spatio-temporal resolution thermal infrared observations are considered fundamental to the sustainable management of natural resources in the context of agricultural production and with that for global water and food security. Operational land surface temperature (LST) measurements and derived evapotranspiration (ET) are key variables in understanding and responding to climate variability, managing water resources for irrigation and sustainable agricultural production, predicting droughts but also addressing land degradation, natural hazards, coastal and inland water management as well as urban heat island issues. Earth observation (EO) monitoring products based on thermal observations, are therefore considered important for informed policy making, including amongst others the UN Sustainable Development Goals (e.g. SDG 6.4), the UN Convention for Combating Desertification and Land Degradation, the UN Water Strategy, the EU Common Agriculture Policy, the EU Policy Framework on Food Security, the EU Water Framework Directive, the EU 2030 agenda for Sustainable Development and the recent EU Green Deal ambitions.

The existing Copernicus space infrastructure, including in particular the Sentinel-1 and Sentinel-2 missions, already provides useful information for agricultural applications. Although Sentinel-3 routinely delivers global LST measurements, its 1 km spatial resolution does not capture the field-scale variability required for irrigation management, crop growth modelling and reporting on crop water productivity. In view of the foreseen evolution of the Copernicus program, additional high-level observation requirements have been collected by the European Commission as part of a user survey and further assessed at the Copernicus Agriculture and Forestry User Requirement Workshop in 2016, revealing the lack of European spaceborne capability for providing high spatio-temporal resolution Thermal Infrared (TIR) observations. Therefore, a dedicated LSTM mission is foreseen in the frame of the Copernicus expansion with the following mission objectives:

- Primary objective: to enable monitoring evapotranspiration rate at European field scale by capturing the variability of LST (and hence ET) allowing more robust estimates of field scale water productivity.
- Complementary objective: to support the mapping and monitoring of a range of additional services benefitting from TIR observations – in particular soil composition, urban heat islands, coastal zone management and High-Temperature Events.

The LSTM mission will deploy two satellites equipped with TIR instruments optimised to support agriculture management services with the specific mission objectives above. In response to the priority user needs, the Mission Requirements Document (MRD) for the space component has been developed by an international Mission Advisory Group under European Space Agency (ESA) leadership. The key observational requirements

of the LSTM mission, as outlined in the MRD, are systematic global acquisitions of high-resolution (50 meters) observations with a high revisit frequency (1-3 days) in 3-5 thermal bands (8-12.5  $\mu$ m) accompanied by a number of VNIR-SWIR spectral bands. The accuracy for LST measurements shall be better than 1-1.5 K at a 300 K reference temperature. The MRD serves as input for the mission design, by conveying the EU Policy framework, the user needs, the mission objectives and the observation requirements for each Copernicus candidate mission.

ESA is collaborating with partner space agencies to create synergy with relevant international missions such as TRISHNA (CNES, ISRO), Surface Biology Geology SBG (NASA/JPL) and the Landsat program (USGS/NASA) with the aim to achieve the optimal temporal coverage of high-resolution thermal observations. This presentation will provide an overview of the proposed Copernicus LSTM mission including the user requirements, a technical system concept overview, Level-1/Level-2 core products description and a range of use cases addressing the mission objectives. The LSTM mission has started its phase B2 and successfully placed a contract in late 2020 with an industrial consortium led by Airbus Space. In spring 2021 the mission successfully passed the System Requirements Review.

## THE TRISHNA INDO-FRENCH THERMAL INFRARED MISSION: SCIENTIFIC TOPICS AND APPLICATIONS

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Water availability, quality, storage and use are becoming an increasing concern of the decision makers in regard to the food security. Management of the water resource is particularly relevant for agricultural practices, which represent about 70% of the water consumption. Therefore, water stress and evaporation need to be better assessed at global scale at a high spatial and temporal resolution to comply with users requirements. This is the main objective of the forthcoming space mission so-called TRISHNA (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) developed conjointly between the French Space Agency (CNES) and the Indian Space Research Organization (ISRO), and foreseen to be launched in 2025. Key scientific objectives rely on a monitoring of agro-ecosystems stress and coastal areas mixing processes plus inland waters. Other targeted objectives connect to urban microclimates (urban heat islands, mitigation of heat waves effects), to solid Earth (detection of thermal anomalies, volcanology), to cryosphere (glaciers, polar caps) and to atmosphere (water content, clouds).

TRISHNA mission will collect for the first time both optical and thermal information at a high spatial resolution, with a pixel size of 57 meters at nadir. Owing to a wide field of view around 35 degrees, a global coverage will be ensured at the frequency of three times during an 8-days period at low latitudes with more acquisitions as moving towards the poles. The short-time revisit will infer angular effects on the time series of

measurements. Actually, overpass time of TRISHNA will be round 13:00 LST, which corresponds to a maximum of sensitivity to flux estimate but also a minimum of sensitivity to the temperature variations. In the tropics, such acquisition will be impacted by the hot spot phenomenon as view and sun geometries will be closed. Therefore, methods are developed to perform an angular normalization since Land Surface Temperature (LST) could be in error by several degrees K. Another issue is due to the turbulence that may also infer uncertainty on LST by a few K.

It will be presented an overview of the future TRISHNA mission with scientific questions and objectives, plus examples of bio-geo-physical processes for which envisaged deliverables will bring new insights according to the different domains of application.

## **SBG, ECOSTRESS AND HYTES – STATUS AND RESULTS**

***Simon. J. Hook (simon.j.hook@jpl.nasa.gov) and the SBG, ECOSTRESS and HyTES Teams***

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In 2017, the National Research Council released the second Earth Science Decadal Survey (ESDS). The ESDS recommended four sets of measurements referred to as the Decadal Observables. One of these was the Surface Biology and Geology (SBG) Decadal Observable (DO). The Decadal Observable measurements together with measurements from the upcoming NISAR mission are now referred to as the Earth System Observatory (ESO). The SBG-DO called for high spectral and spatial resolution measurements in the visible to shortwave infrared (VSWIR: 0.38-2.4 micrometers) and high spatial resolution multispectral measurements in the mid and thermal infrared (MIR: 3-5 and TIR: 7-12 micrometers). The MIR and TIR (MTIR) measurements would be made every few days and VSWIR measurements every couple of weeks. The VSWIR and MTIR measurements would have spatial resolutions of 30 m and 60 m respectively. After the release of the 2017 ESDS, NASA formed teams to develop architectures for each of the DO's. The SBG team recommended the VSWIR and MTIR measurements be made from two separate platforms in a morning and afternoon orbit respectively. The morning orbit was preferred for the VSWIR measurements to minimize cloud cover and the afternoon preferred for the MTIR to measure the peak temperature stress of plants typically occurring in the early afternoon. The architecture team recommended global revisit times for the VSWIR and MTIR of revisit times of 16 and 3 days respectively, which resulted in swath widths of 185 km and 935 km from the nominal altitudes chosen for the VSWIR and MTIR platforms respectively.

SBG is a global survey mission that will provide an unprecedented capability to assess how ecosystems are responding to natural and human-induced changes. It will help us assess the status of biodiversity around the world and the role of different biological communities on land and within inland water bodies, as well as coastal zones. It will help identify natural hazards, in particular volcanic eruptions, and any associated precursor activity, and it will map the mineralogical composition of the land surface. In summary SBG will advance our scientific understanding of how the Earth is changing as well as provide valuable societal benefit, in particular, in understanding and tracking dynamic events such as volcanic eruptions, wildfires and droughts.

In 2014 the ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) was selected as part of the NASA Earth Ventures Instrument program. ECOSTRESS addresses critical questions on plant–water dynamics and future ecosystem changes with climate. ECOSTRESS has five TIR spectral bands, a spatial resolution of 68m x 38m (crosstrack x downtrack) and a revisit of every few days at varying times of day from the International Space Station (ISS). ECOSTRESS was delivered to the ISS in 2018 and operations began shortly thereafter. ECOSTRESS was planned to operate for one year, however, due to demand as well as the instrument continuing to operate well, NASA extended the mission until 2023. HyTES represents a new generation of airborne TIR imaging spectrometers with much higher spectral resolution and a wide swath. HyTES is a pushbroom imaging spectrometer with 512 spatial pixels over a 50-degree field of view.



HyTES includes many key enabling state-of-the-art technologies including a Dyson-inspired spectrometer and high performance convex diffraction grating. The Dyson optical design allows for a very compact and optically fast system (F/1.6) and minimizes cooling requirements since a single monolithic prism-like grating design can be used which allows baffling for stray light suppression. The monolithic configuration eases mechanical tolerancing requirements which are a concern since the complete optical assembly is operated at cryogenic temperatures (~100K). HyTES originally used a Quantum Well Infrared Photodetector (QWIP) and had 256 spectral channels between 7.5µm to 12µm. In 2021 this was upgraded to a Barrier InfraRed Detector (BIRD) array with 284 spectral channels. The first science flights with the QWIP were conducted in 2013 and the first science flights with the BIRD in 2021. Many flights have been conducted, and the instrument can now be deployed on a Twin Otter or the NASA ER2 aircraft allowing a variety of pixel sizes depending on flight altitude. In 2022 the instrument will also be deployed on the NASA Gulfstream V aircraft. All the data acquired thus far has been processed and is freely available from the HyTES website (<http://hytes.jpl.nasa.gov>). Higher level products surface temperature and emissivity and gas maps are available for the more recent data. This presentation will describe the current status and plans for SBG, ECOSTRESS and HyTES programs as well as provide some recent results from ECOSTRESS and HyTES.

## METHODOLOGY FOR BURNED AREAS DELIMITATION AND FIRE SEVERITY ASSESSMENT USING SENTINEL-2 DATA

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Over the last decades, forest fires have become an environmental problem with serious ecological, economic and social effects. In this sense, the aim of this study is to develop a methodology for the burned areas delimitation and, its subsequent fire severity assessment, in wildfires occurred in Spain between 2018 and 2021. As input data, this study is based on the use of Sentinel-2 spectral indices, which are characterized by having spectral bands in the near-infrared (NIR) and short-wave infrared (SWIR) spectral regions, allowing a high distinction between burned and unburned areas, and between different fire severity degrees too. The most commonly used burn spectral indices in remote sensing as the Burned Area Index (BAI), the Burned Area Index S2 (BAIS2), the Burned Area Index Modified (BAIM), the Mid-Infrared Burn Index (MIRBI), the Normalized Burn Ratio (NBR), the Relativized Burn Ratio (RBR) and the relative differential Normalized Burn Ratio (RdNBR), were analyzed. In addition, in order to delete confusions between burned area and the presence of other land cover areas, the temporal differences (pre-fire and post-fire dates) were obtained for each spectral index. The results obtained were compared by: in the case of burned areas, the Emergency Mapping Service (EMS) and the Galicia forest service; in the case of fire severity, using field plots classified as in Ruiz-Gallardo et al. (2004) study (null, low, moderate and high severity). The final statistic results obtained, show that the 3dBAIS spectral index (a combination of the temporal differences obtained by BAI, BAIM and BAIS2) provides the highest result of burned area delimitation (5% of commission error and 9 % omission error, respectively) whereas, the combination of the BAI and dNBR, used in areas with mixed and full vegetation respectively, provides the highest result for assessing fire severity (kappa statistic equal to 0.75). This work is carried out in the context of the project "Joint Strategy for the Protection and Recovery of ecosystems affected by wildfires" (EPyRIS).

## **THERMAL INFRARED ANISOTROPY MEASUREMENTS IN INDIA AND SOUTHERN EUROPE (TIRAMISU) PROJECT IN PREPARATION OF THE TRISHNA MISSION**

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The TRISHNA mission -scheduled to be launched in 2025- will collect for the first time both optical and thermal information at a high temporal and spatial resolution, with a pixel size of 57 meters at nadir. Owing to a wide field of view around 35 degrees, a global coverage will be ensured at the frequency of three times during an 8-days period at low latitudes with additional acquisitions towards the poles. The short-time revisit will however infer angular effects on the time series of measurements. Although a characterization of directional effects for optical range has been the focus of a wide field of investigation in the past, those concerning the TIR (Thermal Infra-Red) domain, still require research work to be done. Overpass time of TRISHNA will be round 13:00 LST. In the tropics, such acquisition will be impacted by the hot spot phenomenon a large part of the year as view and sun geometries will remain close to the hot spot. Advanced studies concerning the characterization and modeling of TIR directional anisotropy with emphasis on the thermal hot spot effect will be presented. The followed methodology relies on three different types of model: 3D DART model, 1D SCOPE model and the parameterized model RL. It is important to note that the hot spot peak of temperature can reach several degrees Kelvin compared to nadir view based on DART and SCOPE simulations. It appears from simulations over crops that using directional gradients of NDVI and LST that it is possible to find simple relationships in relation to the hot spot geometry as driven by leaf area index and leaf size compared to canopy depth. However, these relationships vary with dry versus wet vegetation canopies, soil moisture and resistance, and wind speed. Emphasis will be given on the strategy that will be adopted to correct directional effects and perform normalization in the frame of TRISHNA, notably in merging optical and thermal observations. For such, results from an ongoing experiment over a dry maize crop located near Toulouse as part of the TIRAMISU project will be shown. It consists of acquiring continuously during the growing season optical multi-spectral (MicaSense camera) and thermal (Optris camera) images from a moving platform located on top of a telescopic mast. The data acquisition protocol consists to measure the multispectral BRDF (Bidirectional Reflectance Distribution Function) within a short period of time. The experimental design also allows data acquisition at high frequency in the TIR to characterize the turbulence and time average the BRDF. A DART mock-up and SCOPE simulations serve to simulate the hot spot effect from which an inverse modeling using RL model is performed in order to calibrate model coefficients.

## **MONITORING AND REPORTING GLOBAL LAND SURFACE TEMPERATURE ANOMALY FROM JPSS SATELLITES**

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Land Surface Temperature (LST) is required as an Essential Climate Variable (ECV) in the Global Climate Observation System (GCOS); it is one of the baseline products for the program of Joint Polar-orbiting Satellite System (JPSS), currently including S-NPP and NOAA-20. To ensure high quality of the JPSS LST product, comprehensive validation has been performed since the launch of both satellites. A near-real-time monitoring system was developed to monitor not only the operational production and performance of the

product itself but also the environment using the data. A set of 6-year (from 2016 to 2021) JPSS LST data has been processed and used to derive a global monthly mean LST dataset. In the JPSS LST monitoring system, global LST anomalies are calculated, analyzed, and reported on a monthly basis since June 2021, with the monthly mean LST data as a reference. In this study, we present technical details of the LST anomaly monitoring including quality control measures in data processing, statistical computation, descriptive analysis, visualization, and web reporting. A number of extreme weather events with very warm and cold temperature worldwide have been identified and analyzed as well.

## EVOLUTION OF THE AEROSOL DAILY DIRECT RADIATIVE EFFICIENCY DURING THE PRE-COVID-19 DECADE USING THE AERONET DATABASE

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Environmental rules, laws and policies have been established around the world to reduce the aerosol concentrations and their climate impact as much as possible. The AERONET network provides instantaneous Aerosol Radiative Impact and the Aerosol Radiative Efficiency (the efficiency is the impact normalized by the aerosol concentration). Thus, we determined the Aerosol Daily Radiative Efficiency (ADRE) using data of each month. While the Aerosol Daily Radiative Impact is directly linked to how much the aerosol impacts the climate, the ADRE is linked to the intrinsic composition of the aerosol, i.e., its chemical composition, and its variability may be relied on the changes in the nature of aerosol emissions (anthropic and/or natural).

We decided to focus on the yearly trend of ADRE within the atmosphere (ATM) and at the bottom of the atmosphere (BOA). We selected the decade before the COVID-19 pandemic 2008-2019. From AERONET, we were able to determine the yearly trend for 247 sites over the world. These sites didn't give a representation at the global scale, but it gives a good idea.

While we observe a small increasing of the yearly trend for the aerosol Single Scattering Albedo (meaning a lower proportion of absorption), we found for ADRE\_ATM and ADRE\_BOA respectively a small decreasing of about -1.0%/year and about -0.5%/year over our sites. It means, we have, in average, an ability of aerosols to slightly slow down the atmospheric heating and the cooling at surface. This average stability hides geographical and economic variabilities with negative yearly trends (when policies look to be applied) and positive ones (some of them are related to natural events (increasing of wildfires and dust storms)). We looked at relationships between ADRE yearly trends and the aerosol microphysical properties. The most significant result is the good correlation with the imaginary part of the refractive index ( $R^2=0.75$ ), itself linked to absorption. It's not a real surprise as the Black Carbon is largely responsible of the Daily Aerosol Radiative Efficiency.

## **NASA EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) IMAGING SPECTROMETER PERFORMANCE FOR QUANTITATIVE REMOTE MEASUREMENT AND NEW UNDERSTANDING OF THE EARTH'S MINERAL DUST CYCLE**

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The Earth Surface Mineral Dust Source Investigation (EMIT), uses new observations from an advanced F/1.8 visible to short wavelength infrared (VSWIR) imaging spectrometer planned for launch to the International Space Station (ISS) on a SpaceX rocket in June 2022. The EMIT instrument is the latest in a series of more than 30 imaging spectrometers and testbeds developed at JPL beginning with the Airborne Imaging Spectrometer (AIS) that first flew in 1982. Mineral dust emitted into the atmosphere plays an important role in the Earth system impacting direct and indirect radiative forcing, atmospheric chemistry, cryosphere melt, surface hydrology, and the biogeochemistry of ocean and terrestrial ecosystems, as well as being a hazard to human populations. The Earth's dust cycle consists of source, transport, and deposition elements. Updated source knowledge is required today to run state-of-the-art Earth System Models (ESMs) to simulate the dust cycle and understand current and future impacts on the Earth system. Currently, detailed knowledge of the composition of the Earth's mineral dust source regions is uncertain and traced to less than 5000 surface sample mineralogical analyses. The EMIT's specific science objectives are to reduce uncertainty in the direct radiative forcing effect of mineral dust in the Earth system today and assess future changes in the effect under a range of climate scenarios. These objectives are addressed by acquiring the first comprehensive maps of mineral composition in the Earth's arid land regions and using these new observations to initialize ESMs. The development of the EMIT imaging spectrometer instrumentation has been completed successfully despite the severe impacts of the COVID pandemic on space hardware development at many levels. The EMIT Science Data System is complete with the implementation of the full set of algorithms required. These tested algorithms are open source and available to the broader community. These include: calibration to measured radiance, atmospheric correction to surface reflectance, mineral composition determination, aggregation to ESM resolution, and ESM runs to address the science objectives. The spectral, radiometric, spatial, and uniformity performance of the EMIT imaging spectrometer as well as the status of the ground system, in-orbit checkout, and prime science measurement observation phase are reported here. EMIT's measurements, products, and updated models will enable a broad set of additional science investigations and will be freely available from the NASA Land Process Distributed Active Archive Center.

## **FLUORESCENCE EXPLORER (FLEX): SCIENCE OBJECTIVES AND MISSION PRODUCTS**

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The Fluorescence Explorer (FLEX) mission was selected in 2015, by the European Space Agency (ESA), as the 8th Earth Explorer within the ESA Living Planet Programme. The key scientific objective of the mission is the quantitative mapping of actual photosynthetic activity of terrestrial ecosystems, as a function of variable vegetation health status and environmental stress conditions, at a global scale and with a spatial resolution adequate to resolve land surface processes associated to vegetation dynamics. To be able to accomplish such objective, the FLEX mission carries the FLORIS spectrometer, specially optimized to derive, spectrally resolved, the vegetation fluorescence emission, and is designed to fly in tandem with Copernicus Sentinel-3. Together with FLORIS, the OLCI and SLSTR instruments on Sentinel-3 provide all the necessary

information to retrieve the emitted fluorescence, and to allow proper derivation of the spatial and temporal dynamics of vegetation photosynthesis from such global measurements, including the compensation for atmospheric effects and the derivation of the additional biophysical information needed to interpret the variability in fluorescence measurements.

FLEX is expected to be launched in 2025, and will provide science products which are not restricted to the basic chlorophyll fluorescence measurements, but include also the estimates of regulated and non-regulated heat dissipation, needed to quantify actual photosynthesis. Together with canopy temperature and other biophysical variables characterizing vegetation status, Level-2 products include instantaneous photosynthesis rates and estimates of vegetation stress based on ratios between actual versus potential photosynthesis and variable PSI/PSII contributions tracking photosynthesis dynamics. Level 3 products are derived by means of spatial mosaics and temporal composites, giving also as a temporal product the activation / deactivation of photosynthesis, growing season length and related vegetation phenology indicators. Finally, by means of data assimilation into advanced dynamical models of FLEX time series and ancillary information, Level-4 products are also provided, including Gross Primary Productivity (GPP) and more advanced dynamical vegetation stress indicators.

Such science products can be directly used by vegetation dynamical models, climate models and different applications. The FLEX Level-2 products are already provided in the same geographical grid as Sentinel-2 products to facilitate multi-mission data exploitation strategies. Usage of common global Lat-Lon multi-resolution spatial grids for high-level L3/L4 products maximizes the inter-operability of FLEX products in global data assimilation approaches and multiple applications. Particular efforts are in place to provide each product with realistic and properly estimated uncertainties, and also to propagate the derived uncertainties from the original satellite data until the final high-level products. Efforts are also in place to guarantee proper cal/val activities and dedicated validation networks for FLEX products. The availability of validated ready-to-use high level science products will allow an extensive scientific usage of FLEX data, with also a high potential for derived applications.

## **CARBON FLUXES ESTIMATION COMBINING SEVIRI/MSG PRODUCTS, MACHINE LEARNING AND IN SITU DATA**

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The characterization of carbon exchanges between biosphere and atmosphere requires detailed information on both spatial and temporal behaviors of CO<sub>2</sub> fluxes. The assessment of these carbon fluxes is key to enhance our knowledge regarding the Earth's climate system modelling and understanding. Ground observations can be acquired by eddy-covariance (EC) towers, which are able to estimate CO<sub>2</sub> net exchanges at very high temporal resolutions. The increasing number of EC towers distributed along the planet fosters the application of statistical regression approaches (machine learning) for carbon fluxes estimation.

The Satellite Application Facility for Land Surface Analysis (LSA SAF) aims to take full advantage of EUMETSAT remotely sensed data to measure land surface variables. Among others, LSA-SAF provides products of downward radiation fluxes, land surface vegetation parameters, surface temperature, and evapotranspiration from observations acquired by the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board the Meteosat Second Generation (MSG).

This work aims at assessing the feasibility of estimating CO<sub>2</sub> fluxes such as the gross primary production (GPP), net ecosystem exchange (NEE), and ecosystem respiration (RESP) blending SEVIRI/MSG and EC data by means of machine learning methods. An ensemble of SEVIRI/MSG products were used as inputs for the model: Fraction of Vegetation Cover (FVC), Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Downward Surface Shortwave Flux (DIDSSF), Evapotranspiration (DMET), Reference evapotranspiration (METREF), Land Surface Temperature (MLST), and the BRDF  $k_0$  parameter in the RED,

NIR, and MIR SEVIRI/MSG bands. In addition, CO<sub>2</sub> fluxes from seven European EC towers were selected for pairing *in situ* data with the SEVIRI/MSG observations during the 2015-2019 period. Several machine learning regression methods were used for comparison including tree models (decision, bagging, and boosting trees, random forests, and boosting random trees), neural networks, and kernel methods (support vector regression, kernel ridge regression, and Gaussian process regression).

The results show that the machine learning methods provide accurate and consistent estimates among them. The best performance is found in the case of random forests, in which correlations with GPP, NEE, and RESP reached 0.85, 0.61, and 0.89, respectively. These results encourage the use of data-driven approaches jointly with remote sensing data for carbon fluxes estimation.

## CHARACTERIZATION OF INTERCROPPING PERIODS USING MULTI-TEMPORAL OPTICAL SATELLITE IMAGES

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In a rotation of cash crops, the period between the harvest and the subsequent sowing is referred to as the inter-cropping period. In France, it is mandatory to establish cover crop during these periods, especially in the vulnerable nitrates zones which represent almost 75% of the agricultural area allocated to the cultivation of seasonal crops (Justes et al., 2012). The quantification of the advantages associated with the establishment of the cover crop is then a major stake for a sustainable and reasoned management of agricultural surfaces. In this context, carrying out a balance requires the monitoring of key vegetation descriptors, which are used as a control indicator of advantages of the cover crop. In the present study, the objective is first to characterize the satellite-observed vegetation development during the intercropping period and then to estimate the biomass of cover crop using optical images acquired by Sentinel-2.

On a study site located in south-western France, experimental devices were conducted throughout four successive intercropping periods on a network of plots to collect a dataset making it possible to characterize the variability of cover crop. Time series of images were regularly acquired from October 2017 to April 2021 throughout the growth of the cover crop, together with biomass measurements collected just before the destruction by burial of the vegetation. On the considered plots, two cover crop species were mainly sown after the cultivation of wheat (*i.e.*, faba bean and phacelia), and up to five different species were observed on some plots. Significant variability in cover crop development was observed, with for example, dry biomass extreme values close to 0 and maximum above 7.5 t.ha<sup>-1</sup> over the monitored plots.

Classifications obtained using an unsupervised approach (*i.e.*, K-means based on NDVI (Normalized Different Vegetation Index) times series derived from optical images) allowed to distinguish plots with bare soil and those with different levels of vegetation development. The analysis conducted on 3 satellite tiles allowed us to observe inter-annual differences as well as regional specificities. On a fine scale, the intra-plot heterogeneity was characterized through the determination of the number of days with active vegetation during the intercropping period (by applying a threshold on the daily-interpolated NDVI time series). The results were analyzed for each of the previously defined land cover classes (*i.e.*, classifications using K-means), showing strong heterogeneity regarding the number of days with active vegetation, as well as non-systematically zero durations, even for the "bare soil" class. Finally, after testing different vegetation indices derived from optical images, an empirical relationship was established based on the NDRE (Normalized Difference RedEdge Index). It allowed mapping the maximum of cover crop biomass (using the last image acquired before the destruction of cover crops), estimates being characterized by a level of performance with R<sup>2</sup> ranging from 0.6 to 0.8 (values depending on the number of days between the satellite acquisition and the ground measurement).

## ESTIMATION OF SURFACE ENERGY AND CO<sub>2</sub> FLUXES THROUGH REMOTE SENSING IN A JUNIPER TREE ECOSYSTEM AT THE NATIONAL PARK OF DOÑANA

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Doñana National Park is located in the southwest of the Iberian Peninsula, where water scarcity is recurrent together with high heterogeneity in species and ecosystems. Energy and carbon fluxes monitoring is essential to improve the knowledge of the hydrological cycle, especially in natural vegetation covers. In this work, a first evaluation with flux tower data of the modeling of water and energy fluxes as well as carbon assimilation (GPP) is performed. Energy and water fluxes were estimated through the TSEB model while GPP was done through a LUE model, both models using Terra/Aqua MODIS images during the period 2014-2015 in an experimental plot of juniper (*Juniperus phoenicea*) in the Doñana Biological Reserve. TSEB yielded acceptable results when measuring surface energy fluxes, taking into account the high heterogeneity that this type of vegetation presents. In the case of net radiation, latent heat, sensible heat and soil heat fluxes, evaluation results showed an average RMSE of 54, 47, 63 and 6 W·m<sup>-2</sup>, respectively. The LUE-model, which is based on the relationship between absorbed photosynthetically active radiation and its use by the plant and establishes a maximum value per species or plant functional types that is reduced by environmental conditions, was evaluated in two ways to reduce that maximum efficiency value: 1) forcing it with meteorological variables; 2) forcing it with both meteorological variables and a water stress index from TSEB evapotranspiration retrievals. Both approaches were also evaluated with in situ flux tower data. Results showed that although the application of the LUE with meteorological data had an acceptable error (~0.9 gC/m<sup>2</sup>), the use of the water stress index improved the results in situations of scarcity or abundance of water (summer and winter, respectively).

## ASSIMILATION OF MULTIPLE REMOTE SENSING DATA INTO AN UNDER-CALIBRATED ENERGY-WATER-CROP MODEL FOR IRRIGATION MANAGEMENT

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The agricultural sector is the biggest and least efficient water user, accounting for around 80% of total water use in South Europe, which will be further impacted by climate change in the incoming years. Precision agriculture tools are then needed to increase water use efficiency.

Here, the proposed system couples together remotely sensed land surface temperature (LST), leaf area index (LAI) and ground soil moisture data (SM) with a pixel wise crop-water-energy balances model, for improving irrigation management. The SAFY (Simple Algorithm for Yield) crop model has been fully coupled with the energy water balance FEST-EWB model, exchanging in a double direction the LAI evolution in time from SAFY, which is used by FEST-EWB for evapotranspiration computation, while FEST-EWB provides soil moisture (SM) and LST to SAFY model for constraining crop growth.

A data assimilation framework, based on the Ensemble Kalman filter approach, is implemented to reduce the

requirements for parameters calibration, either for soil assimilating satellite LST and for crop growth using LAI. This framework allows overcoming the issues related to crop exposure to shocks due extreme events non-reproducible by the model alone, as well as nutrient lack, crops hybrids or precise amount of irrigation water. The FEST-EWB-SAFY model has been applied in two Irrigation Consortia in the North and South of Italy which differ for climate and agricultural practices, using data from Sentinel2, Landsat 7 and 8 satellites. The model has then been validated in specific fields where ground measurements of evapotranspiration, soil moisture and crop yields are available.

Overall, the results suggested that the under-calibrated model estimates of LST, LAI, SM and yield are enhanced through the assimilation of satellite data, suggesting the potential for improving irrigation management at both field and Irrigation Consortium scales.

## EVALUATION OF AN OPERATIONAL HIGH-RESOLUTION EVAPOTRANSPIRATION ALGORITHM WITHOUT THERMAL CHANNEL OVER A TEMPERATE BASIN ON CHILOÉ ISLAND

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Evapotranspiration is a key parameter for water budget quantification over ecosystems and set up water requirements for water balance modeling on temperate basins of Chiloé Island. However, public institutions and stakeholders do not have the instrumentation of all land covers over the island to monitor the surface water requirements, henceforth Remote sensing (RS) is an essential tool for contiguous spatial and temporal monitoring. Missions such as Landsat 8 & Landsat 9 provides thermal band which can be used for Actual Evapotranspiration (ETa) estimation using Surface Energy Balance (SEB) models, however, the temporal and spatial resolution can be a restrictive limit for an adequate monitoring in areas with high cloud cover. To mitigate the lack of data, we used Sentinel-2 coupled with the Evapotranspiration model Penman-Monteith-Leuning V2 (PML-V2), a model that does not require the thermal channel to calculate ETa. The model was applied on Pudeto Basin, located in Chiloé, a marine coast climate Island (Cfb), where in-situ data was measured continuously. This model evaluates daily measurements of ETc on a temperate pasture. Evapotranspiration measurements showed a demand range between 1.0 – 6.4 mm day<sup>-1</sup> during growing season (Oct-Jan) and minimum values in winter 0.5 – 3.0 mm day<sup>-1</sup>. The PML-V2 showed a well performance with an R<sup>2</sup> of 0.8 and RMSE of 1.26 mm day<sup>-1</sup>. This model was implemented on an interactive Shiny web-based application and readily available for Chile's National Geology and Mining Service (SERNAGEOMIN). The platform uses Google Earth Engine Python API for remote sensing data retrieval. The aim of this application is to be used for determining the water requirements over different land covers in near-real time for key decision makers as well as a novel input for water balance models at Sentinel-2 temporal frequency for a temperate basin watershed in Chiloé.



## MONTHLY CALIBRATION OF HARGREAVES-SAMANI EQUATION FOR ESTIMATING REFERENCE EVAPOTRANSPIRATION IN CHILE, USING REMOTE SENSING AND METEOROLOGICAL DATA

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Reference evapotranspiration (ET<sub>o</sub>) is a fundamental variable for proper irrigation scheduling in different agricultural systems, however, it is not always possible to calculate it due to limited data in a territory. In this sense, the Hargreaves-Samani (HS) equation can be considered a reliable and widely used method to estimate ET<sub>o</sub>. The HS equation requires less data for its application, specifically, only temperature and solar radiation, making it a suitable method for locations where there is limited meteorological information or that they do not have data on wind speed and relative humidity. However, the literature shows that a local calibration of its empirical parameter (K<sub>HS</sub>) is necessary for a correct application. Consequently, this work shows a calibration for continental Chile of the HS equation. For this purpose, the Penman-Monteith FAO-56 (PM) equation was considered as a reference, using a network of 470 automatic meteorological stations along continental Chile for the period 2001-2020. The calibration was based on the calculation of the ratio of ET<sub>o</sub> calculated by HS and PM to account for the territorial variability of the HS parameter. The spatial distribution of the K<sub>HS</sub> was performed by geographic weighted regressions according to the predictor variables NDVI, land surface temperature and thermal amplitude, while the spatialization of the regression coefficients was performed by ordinary Kriging with an automatic variogram, using as auxiliary variable the digital elevation model from the Shuttle Radar Topography Mission. The calibration process was validated with daily data through all months, with average RMSE value of 1.04 mm for the entire extension compared to the PM method.

## ESTIMATION OF EVAPOTRANSPIRATION IN THE CONTEXT OF FUTURE LAND SURFACE TEMPERATURE MONITORING (LSTM) MISSION

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The LSTM (Land Surface Temperature Monitoring) mission aims to address water, agriculture, and food security issues by monitoring the variability of LST (Land Surface Temperature) and hence ET (evapotranspiration) at the European field scale enabling more robust estimates of water productivity. The LSTM mission observations will support the Copernicus land monitoring services, related European and also global and international policies as well as downstream applications.

In this study, LST estimates with the TES (Temperature and Emissivity Separation) method and ET with the S-SEBI (Simplified Surface Energy Balance Index) model has been obtained from airborne data acquired in the framework of the SurfSense 2018 and LIAISE 2020 experiments in support of the LSTM mission.

LST performance was analysed by the application of TES algorithm to different band configurations of TASI

sensor and simulated bands configuration of the LSTM mission. Integrating LST and VNIR data, instantaneous values of ET were also estimated and validated against eddy covariance measurements.

## **BUILDING AND VALIDATING NOAA-AVHRR ORBITAL DRIFT CORRECTION METHODS BY USING MSG-SEVIRI TEMPERATURE DATA**

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The temperature data acquired by the AVHRR (Advanced Very High-Resolution Radiometer) sensors since the early 80s cannot be used for a better knowledge of climate warming, due to the orbital drift of the NOAA (National Oceanic and Atmospheric Administration) satellite series carrying them. Even though various methods have been presented in the literature to correct this orbital drift effect, the lack of validation data has prevented their practical application. However, basing us on alternative satellite data, namely MSG-SEVIRI (Meteosat Second Generation Spinning Enhanced Visible and InfraRed Imager), we can design and validate orbital drift correction methods. Indeed, this sensor spatial resolution is similar to the footprint of available AVHRR datasets, while its temporal resolution is fifteen minutes, allowing for the simulation of both drifted and reference time series for most land covers. In this work we simulated such time series for 177 land and 500 sea pixels and for all NOAA afternoon satellites (NOAA-7, 9, 11, 14, 16, 18 and 19). Pixels of all land covers show an effect of the orbital drift on surface temperature, although this effect is stronger for semiarid areas and the Southern Hemisphere. Such effect is characterized by the values of the bias and trend of the difference between reference and drifted time series, above 1K and around -1.5K per year respectively for the first four NOAA platforms. The correction we also present decreases difference trend values towards zero on land, except for the first two NOAA platforms (7 and 9), with absolute values around 0.1K per year. As for bias absolute values, these are around 0.3 K. Such correction improves on existing methods, although work is still needed for a complete removal of the orbital drift effect on NOAA-AVHRR derived surface temperatures, for example by including the effect of the daily temperature cycle in the statistical correction.

## **THE SSIRC DATA RESCUE INITIATIVE: ACTIVE REMOTE SENSING DATASETS FOR MAJOR VOLCANIC AEROSOL CLOUDS IN THE STRATOSPHERE: RECOVERY AND RE-CALIBRATION OF LOST OR FORGOTTEN DATASETS FOR NEW CONSTRAINTS FOR VOLCANIC FORCING AND STRATOSPHERIC COMPOSITION CHANGE**

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Climate models simulating the climatic effects of volcanic eruptions in the so-called “post-in-situ pre-satellite era” (~1957-1979) rely primarily on stratospheric aerosol optical depth (sAOD) values derived from ground based observations of solar radiation: direct solar beam, diffuse and total radiation, stellar extinction and lunar brightness during eclipses. However, the vertical profile of the stratospheric aerosol layer was measured from the ground via active remote sensing instruments since the early 1960’s, both lidar, and

searchlight, and also from high altitude balloon.

The Data Rescue Activity of the Stratospheric Sulfur and its Role in Climate (SSiRC) (<http://www.sparc-ssirc.org/> Activities → Data Rescue) has thus far focused mainly on lidar and searchlight datasets within major volcanic periods, aiming to provide new constraints for interactive stratospheric aerosol models and improve the fidelity of volcanic forcings in climate model. The activity also identified and recovered a dataset of balloon borne solar extinction soundings from 1965-67, also identifying recoverable datasets for U-2 aircraft impactors and ozonesondes profiles during the 1963-65 post-Agung period.

Here we present, two recovered active remote sensing datasets that measured the progression of the vertical profile of the northern hemisphere dispersed portion of the Agung volcanic aerosol cloud during 1963-65.

Firstly, a total of 66 nights of lidar profiles of attenuated backscatter at 694nm measured at Lexington (42°N), Massachusetts between January 1964 and July 1965 were recovered from Tables within an MIT PhD thesis processed to derive aerosol extinction profiles ( $\beta_a(z)$ ) at 532 nm. Another 9 lidar profiles of attenuated backscatter at 694nm measured at College (64°N), Alaska in July and August 1964 have been recalibrated to produce  $\beta_a(z)$  at 532 nm. Both lidar datasets have been published as peer-reviewed journal article, and in a public data repository.

Secondly, a searchlight dataset of the Agung aerosol cloud is also presented, recovered by re-digitising Figures within an “Atlas of aerosol attenuation” report documenting observations at White Sands (32°N), New Mexico. The dataset of 105  $\beta_a(z)$  profiles on 36 nights between December 1963 and December 1964 have been recalibrated, contemporaneous measurements of tropospheric aerosol and stratospheric ozone used to recover  $\beta_a(z)$  with particular emphasis on the tropospheric and stratospheric aerosol phase functions (APF). The original APF, used from the surface to 35km, was replaced in the troposphere by the APF from the White Sands AERONET site and in the stratosphere by an AFP computed from four particle size distributions measured by an aircraft at 18km between April and August 1963 around 32°N.

Accounting accurately for variations in tropospheric aerosol and ozone leads to substantial change in the re-calibrated searchlight dataset. Maximum values of  $\beta_a(z)$  in the original and the recalibrated dataset were  $5.7 \times 10^{-3} \text{ km}^{-1}$  and  $8.2 \times 10^{-3} \text{ km}^{-1}$  respectively, a 42% increase. The original sAOD monthly mean was 0.027, the recalibrated 0.033, a 23% of increase. Recalibrated sAOD reasonably agree with sAOD measured at Mauna Loa, 20°N and Mt Locke, Texas, 31°N.

The already rescued and recalibrated  $\beta_a(z)$  datasets provide new information about the spatiotemporal structure and optical properties of the 1963 Agung SA at a subtropical, a midlatitude and a polar site in the northern hemisphere.

## CARACTERIZACIÓN Y VALIDACIÓN DE REFLECTORES DEL CAMPO DE CALIBRACIÓN SAR INTA PARA LA MISIÓN PAZ

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La misión PAZ constituye el elemento radar del Programa Nacional de Observación de la Tierra por Satélite (PNOTS) para el desarrollo, operación y explotación de sensores espaciales de observación de la Tierra. La misión fue declarada operacional en septiembre de 2018 y se encuentra actualmente en fase de operaciones rutinarias dando servicio a usuarios de defensa y seguridad, comerciales y científicos.

El equipo de Sistemas SAR espaciales y calibración de INTA es responsable del centro de Calibración y Validación de PAZ y del aseguramiento las prestaciones de los productos durante toda la vida útil de la misión. Para ello, se lleva a cabo un programa de monitorización de prestaciones continuo sobre los

datos adquiridos y campañas de calibración específicas periódicamente.

Estas actividades de monitorización y calibración se realizan sobre elementos de referencia cuya localización precisa y respuesta a la señal RADAR es conocida y exacta. Generalmente, los elementos de calibración más utilizados son reflectores de esquina, generalmente triédros metálicos, cuya sección transversal RADAR (RCS) se puede caracterizar estimando la energía interceptada por el área de sus caras. Por ser elementos pasivos no introducen retardos electrónicos, lo que les hace ideales para la calibración geométrica.

La exactitud de la calibración radiométrica estará acotada por la estabilidad del instrumento, pero también por la exactitud en la determinación de la RCS de referencia de los elementos de calibración. Las fuentes de error que más afectan a esta determinación son los defectos de fabricación respecto a planitud, ortogonalidad o dimensionamiento y las condiciones ambientales de la medida, como pueden ser interferencias con el entorno o la climatología local, que se tratan de minimizar buscando ubicaciones de despliegue homogéneas y libres de elementos interferentes.

El método más fiable para para minimizar los errores introducidos en el proceso de fabricación consiste en la medida en cámara de la RCS de cada uno de estos reflectores, pero este proceso puede resultar costoso y, especialmente con reflectores de gran tamaño, sujeto a la disponibilidad de instalaciones altamente especializadas.

En este artículo se muestran las actividades realizadas junto con el Laboratorio de Electromagnetismo Computacional y Aplicado del INTA para la definición de un proceso de caracterización de los 40 reflectores del campo de calibración INTA de PAZ basado en su medida dimensional, la generación de un modelo 3-D de los mismos y la simulación de su RCS a partir de ellos. Los resultados se validan con medidas sobre imágenes PAZ, TerraSAR-X y TanDEM-X, obtenidos de los reflectores desplegados en campo.

## **TOWARDS A NEW TECHNIC FOR ONLINE LST DATABASE BUILT ON MQTT AND LORA SENSOR NODES FOR IN-SITU MEASUREMENTS**

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Today, calibration and validation activities of sensors are as important as the product driven, and there is an increasing need for product in-situ based observation validation. In this research, we propose a new method for in-situ LST measurements for Remote Sensing algorithms validation using a Long Range (LoRa) network, which focuses on low-cost and effectiveness with wireless sensors network. Each node is controlled by a microcontroller board and consists of several sensors, i) LST infrared temperature, ii) ambient temperature and relative humidity. Infrared temperature is measured by apogee SI-111 sensor, which operates from -55 °C to 80 °C and has a spectral range of 8 µm to 14 µm, we measure ambient temperature and relative humidity using DHT11 sensor, it can measure temperature from 0 °C to 50 °C and humidity from 20% to 90%. In order to transmit gathered information, a LoRa sx1276 acts as a LoRa wireless communication module for long-range environment data transfer, it is a long-range spread spectrum modulation technique, which starts from 3000 m. For communication protocol, we select the MQTT which is a publish/subscribe protocol data transfer “like a client-server model”. However, MQTT is a simple Open-Source protocol suitable for a limited resource platform with less power, process capacity, memory, and transmission. As a LoRa gateway, we use a microprocessor board where is implemented node-red software, this last is a flow-based programming tool for wiring together hardware devices, APIs, and online services. The LoRa gateway automatically transmits measured data to the virtual private server storage every 5 minutes. Finally, to supervise and control the LoRa network we use a node-red dashboard developed on a virtual server based on Bi Intel Xeon processor (8 Cores 2.1 Ghz) and 2 Go of memory and 20 Go hard drive.

## LONG-TERM ASSESSMENT OF COLUMNAR AEROSOL PROPERTIES AT VALENCIA REGION (SPAIN)

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Aerosols have a great effect on air quality and play a vital role in influencing climate. The characterization of the distribution and changes of aerosols over time is essential for different applications, such as the understanding of the global radiation budget or the validation of satellite based products. Operational aerosol products derived from long-term ground and satellite observations have been used extensively to characterize aerosol distributions and variations. Aerosol optical depth (AOD), which measures the extinction of vertically integrated light throughout the atmospheric column by aerosols, is one of the most commonly obtained parameters by both ground based and satellite platforms. The Ångström's coefficient (AE), and the precipitable water content (CWV) are also very valuable columnar products. The AE provides us with information on the size of the aerosols while the CWV refers to the water vapor content in the atmospheric column. In the 90's, NASA and PHOTONS developed an international network known as the Aerosol Robotic Network (AERONET) to systematically measure the optical properties of aerosols using CIMEL CE318 ground based sun photometers. The objective was both to create an international homogeneous database for climate research and for validation of satellite sensors. Parallel efforts led to the development of SKYNET, mainly in Asia, by using the PREDE POM skyradiometer. Both networks have collocated instruments at Burjassot campus, in Valencia (Spain). Among the many space sensors that routinely provide global aerosol products, the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument is the most widely used. Two MODIS satellite instruments (Terra and Aqua) have provided constant monitoring of aerosol distributions with near-daily global coverage since 2000 (Terra) and 2002 (Aqua). With continuous global data records for nearly two decades, operational MODIS aerosol products have been widely applied for aerosol climatology studies. The main objective of this study is to evaluate a climatology of AOD, AE and CWV over a 13-year time series (2007-2019) using AERONET data from the urban station in Burjassot, Spain (39.5°N, 0.418° W, 104 m a.s.l.) and 5 years (2016-2020) from the rural background station of Aras de los Olmos (39.92°N, 1.13°W, 936 m a.s.l.) to obtain long term trends for the Valencia sites, and validate MODIS products in the region.

## EVALUATION OF THE IMERG PRECIPITATION PRODUCT USING AEMET GROUND DATA IN THE VALENCIAN REGION, SPAIN

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Climate change is a topic of main interest in the current scientific context. Understanding climate change causes and effects is crucial in order to forecast those effects and mitigate them. One effect is the alteration in precipitation regimes around the globe, with more frequent extreme droughts and torrential rains. Therefore, studying precipitation trends associated to climate change can help mitigate or prevent

the consequences of these extreme events. Meteorological satellites, in contrast with ground rain gauges, allow for a more exhaustive precipitation monitoring, both spatially and temporally. However, their accuracy is lower due to them not detecting precipitation directly but estimating it from microwave data, cloud-top parameters from infrared data and theoretical models. One of the most used precipitation products derived from satellite data is the Integrated Multi-satellite Retrievals for GPM (IMERG), developed by the National Aeronautics and Space Administration (NASA), which combines information from the GPM satellite constellation and ground gauge data to estimate precipitation over most part of the globe, with spatial resolution of 0.1° lat/lon and temporal resolution of 30 minutes, 1 day or 1 month.

In this preliminary study, which lies within the framework of the on-going Tool4Extreme research project, we evaluate the IMERG precipitation product accuracy at daily resolution over the Valencian Region (Spain) from June 2000 to September 2021, by comparing it to daily ground gauge data from the Agencia Estatal de Meteorología (AEMET). Specifically, we have selected a set of meteorological stations covering most part of the Valencian Region and we compare their time series with the time series of the associated IMERG pixels (in case some stations fall under the same pixel, their data is averaged). The results proceed as follows: the linear regression between IMERG and AEMET, using all available data, shows Correlation Coefficient ( $R$ )  $> 0.5$ , Root Mean Squared Error (RMSE)  $< 10$  mm day<sup>-1</sup>, Relative Bias (rBias)  $< 10$  %, Probability of Detection (POD)  $> 0.9$ , False Alarm Ratio (FAR)  $< 0.4$  and Critical Success Index (CSI)  $> 0.6$ . When only considering precipitation greater than 1 mm day<sup>-1</sup>, we obtain  $R < 0.5$ , RMSE  $< 20$  mm day<sup>-1</sup> and  $|rBias| < 10$  %, which denotes that most of the agreement between both datasets takes place when precipitation is low or null. Additionally, the linear regression between monthly accumulated IMERG and monthly accumulated AEMET gives  $R > 0.7$ , RMSE  $< 50$  mm month<sup>-1</sup> and  $rBias < 10$  %; thus, rBias is slightly worse but  $R$  improves significantly, probably due to IMERG overestimates and underestimates cancelling out each other when aggregating up to a coarser time scale. More extensive research, including broader AEMET stations sets, may result in more reliable estimation of IMERG accuracy in the Valencian Region.

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## AMPLIACIÓN DEL CAMPO DE CALIBRACION INTA EN ISLA DECEPCIÓN

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PAZ es el satélite español Radar de Apertura Sintética (SAR) en Banda X del Programa Nacional de Observación de la Tierra por Satélite (PNOTS) lanzado en febrero de 2018. Actualmente, el Instituto Nacional de Técnica Aeroespacial (INTA) se encarga de realizar el seguimiento de las constantes geométricas y radiométricas para analizar su estabilidad temporal usando para ello reflectores de esquina como calibradores. Dichos reflectores se encuentran desplegados en diferentes áreas de la península ibérica, conformando el Campo de Calibración INTA.

En el marco de la XXXV Campaña Antártica (2021-2022) se instalaron tres reflectores en la Isla Decepción, situada en el archipiélago de Shetland en la Antártida, pudiendo, así, verificar el comportamiento del sistema a diferentes latitudes y obtener información para realizar estudios geodésicos basados en el uso de productos imagen SAR. Además, estos reflectores son utilizados como puntos de control que servirán de base para la explotación de técnicas como la interferometría SAR, para la generación de mapas de elevación digitales (DEM) o mapas de deformaciones.

Este artículo incluye una breve descripción de la infraestructura de calibración INTA en Isla

Decepción (tres reflectores de esquina de cara triangular), los requisitos de su ubicación y la geometría de las adquisiciones óptimas para cubrir los objetivos de la campaña. Posteriormente se exponen y analizan los resultados de los análisis geométricos que confirman la estabilidad del sistema observada hasta ahora, lo que permite incluir estos reflectores como elementos válidos dentro del campo de calibración INTA. Asimismo, se observa y analiza el efecto de la deriva continental mediante las medidas geométricas sobre reflectores en la imagen radar.

Por último, aprovechando el despliegue de dichos reflectores y la disposición de medidas GPS precisas de su localización, se presentan los criterios elegidos para la generación de un DEM sobre la zona sur de Isla Decepción a partir de los productos PAZ obtenidos durante la campaña, que a su vez pueda ser utilizado como base para el estudio de movimientos del terreno y erosión costera.

## ECOSTRESS PRODUCTS FOR DROUGHT MONITORING OVER DIFFERENT LAND COVERS

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Droughts are one of the most complex natural hazards having large negative impacts on society, economy and the environment. In the face of global climate change, the drought situation in many regions has already become more severe, with predicted increases in drought frequencies. Thermal infrared remote sensing data acquired from Earth Observation sensors allows the retrieval of information about the energy exchange between the surface and the atmosphere, and therefore it provides a valuable tool for drought monitoring. In this work, we show the results obtained in the validation of the LST product (level 2) derived from ECOSTRESS data over different land covers, including tropical forests, croplands, and semi-arid areas. We also analyze ECOSTRESS evapotranspiration indicators (levels 3 and 4) to assess its suitability for drought monitoring.

## REFLECTANCE CORRECTION IN TREE SHADOWS IN HIGH SPATIAL RESOLUTION IMAGING SPECTROSCOPY USING RADIATIVE TRANSFER SIMULATIONS AND MACHINE LEARNING

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With the development of high spatial resolution imaging spectroscopy, getting an accurate surface reflectance retrieval is a crucial issue in deriving a quantitative assessment of relevant physical variables used in the fields of land cover mapping, soil, vegetation and cultures monitoring or characterization of impervious surfaces condition in urban areas for instance. One hindering factor is the treatment of shadows. Indeed, 3D atmospheric correction models already successfully manage opaque shadows by accounting for the buildings and the terrain. But, they mostly fail for shadows caused by semi transparent medias such as

tree ones. As part of the irradiance in the shadow is directly transmitted through the tree crown and comes from the multiple scatterings with it, there is a need to properly account for it in the radiative budget modelled in atmospheric correction codes.

This transmitted irradiance depends on many parameters that could be divided in 3 parts : (1) Scene parameters : tree properties (e.g. dimensions, leaf optical properties - LOPs), environment (e.g. soil and aerosol) and illumination conditions (e.g. sun zenithal angle), (2) Spatial parameters : position of the pixel in the shadow relatively to the tree location (3) spectral parameter : spectral bands.

A past study designed a reflectance correction in tree shadows by working on two scene parameters (1) namely the sun zenithal angle and the leaf area index (LAI). But it was based on a reference tree model with fixed dimensions and only 3 different LOPs. Then concerning the spatial (2) and spectral (3) parameterization, a mean spectral tree crown transmittance was predicted and weighed by a tree viewing angle depending on the pixel position to finally aim for building a correction factor. From these aforementioned limitations, a new study is ongoing to avoid the previous separability hypothesis between spectral and spatial dependencies in the computation of the correction factor, by experimenting new regression techniques from machine learning approaches and taking into account both tree structural and leaf biochemical traits (instead of LOPs).

Therefore, based on (1), (2) and (3) variability, there is a need to have the best comprehension of the complex radiation phenomenon happening in tree crowns and their shadows. We first carried out 3D physical simulations with the radiative transfer code DART, in order to perform a sensibility analysis, based on Sobol's indices computation, highlighting key scene parameters. We have built different metamodels based on gaussian processes and polynomial regressions considering both spectral and spatial variation to predict the tree crown transmittance. The treatment of spatial and spectral information was made using Karhunen-Loeve decomposition or autoencoders, reducing the data dimension and the computation time simultaneously. Hence, it's not necessary to train a specific metamodel for each spectral band and pixel but only a few ones to retrieve global dependencies. Finally, we obtain a new spatial and spectral dependent correction factor which will be tested on airborne hyperspectral images. The results will be compared to those obtained with the past tree shadow correction model.

## **SPATIAL HOMOGENEITY ANALYSIS OF THE LST VALIDATION SITE KIT FOREST AND VALIDATION OF FOUR MODERATE RESOLUTION SATELLITE LST PRODUCTS**

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The validation of the Sea and Land Surface Temperature Radiometer (SLSTR) Land Surface Temperature (LST) operational product is one of the main objectives of the project 'Copernicus Space Component Validation for Land Surface Temperature, Aerosol Optical Depth and Water Vapour Sentinel-3 Products (LAW)'.

Five new ground LST stations were deployed in the LAW project to validate SLSTR LST over previously unrepresented canopy biomes. The first station started to operate in August 2020 in the KIT Forest site (49.091 N, 8.425 E). The KIT Forest Site covers about 6 x 3 km<sup>2</sup> of the 'Hardtwald', located between the city of Karlsruhe and Campus North of the Karlsruhe Institute of Technology (KIT). The site is covered by dense mixed forest dominated by *pinus sylvestris* (pine tree) and *fagus sylvatica* (beech tree). The site's thermal homogeneity has been analyzed using Landsat 8 – TIRS LST scenes. The results show a variability (standard deviation, SD) of 0.3 K over 1.5 x 1.5 km<sup>2</sup> and 0.5 K over 3 x 3 km<sup>2</sup>. This indicates that the site is suitable for



performing accurate validations of high and moderate spatial resolution LST products.

As all Copernicus LAW stations, KIT Forest station is equipped with two Heitronics KT15.85 IIP radiometers: one looking downwards at a viewing angle from nadir of 40° and one looking upwards at a zenith angle of 53°. The radiometers are mounted at the top of a 200 m high meteorological measuring tower located at the south-western corner of KIT Campus North. The KT15.86 IIP radiometers cover the spectral range from 9.6 to 11.5  $\mu\text{m}$  and have a field of view of 8.5° and an associated uncertainty of  $\pm 0.3$  K. The acquired brightness temperatures are used with a representative surface emissivity ( $0.988 \pm 0.005$  for KIT Forest) to retrieve in-situ LST with an uncertainty of  $\pm 0.5$  K. Additionally, the station is equipped with a Scientific Campbell Hygrovue10 air temperature and relative humidity sensor and a GPS receiver for accurate and stable timing.

The full time series of KIT Forest data was used to validate the Sentinel3 – SLSTR LST product for the LAW project. Additionally, the LST products derived from the Advanced Very High Resolution Radiometer (AVHRR) on-board Metop satellites provided by the Satellite Application Facility on Land Surface Analysis (LSA-SAF) and the LST MOD11\_L2 and MOD21\_L2 products derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board Terra satellite provided by NASA were included in this study. The results showed median deviations (robust standard deviation; RSD) of -0.2 (0.6) K, -0.3 (1.6) K, -0.5 (1.0) K and 0.2 (1.4) K for Sentinel3 – SLSTR, Metop – AVHRR and MOD11\_L2 and MOD21\_L2 Terra – MODIS LST products, respectively. The four satellite LST products show a similar performance over the LAW site KIT Forest and indicate a high quality and stability of the in-situ LST data.

## AEROSOL MODELS FROM THE AERONET DATABASE: APPLICATION TO SURFACE REFLECTANCE VALIDATION

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Aerosols play a critical role in radiative transfer within the atmosphere, and they have a significant impact on climate change. In this presentation, we will describe the framework for developing an aerosol model using their microphysical properties. Such microphysical properties as the size distribution, the complex refractive index, and the per-centage of sphericity are derived from the global AERosol RObotic NETwork (AERONET). These measurements, however, are typically retrieved when almucantar measurement procedures are performed (i.e., early mornings and late afternoons with clear sky) and might not have a temporal correspondence to a satellite overpass time, so a valid validation of satellite-derived products cannot be carried out.

To address this problem of temporal inconsistency of satellite and ground-based measurements, we developed an approach to retrieve these microphysical properties (and the corresponding aerosol model) using the optical thickness at 440 nm,  $\tau_{440}$ , and the Ångström coefficient between 440 and 870 nm,  $\alpha_{440-870}$ . Such aerosol models were developed for 851 AERONET sites within the last 28 years. Obtained results suggested that empirically microphysical properties can be retrieved with uncertainties of up to 23 %. An exception is the imaginary part of the refractive index  $n_i$ , for which the derived uncertainties reach up to 38 %.

These specific parametric models of aerosol can be used for studies when retrieval of microphysical properties is required as well as validation of satellite-derived products over land. Specifically, we demonstrated the usefulness of the aerosol models to validate surface reflectance records over land derived from optical remote sensing sensors. We then quantify the propagation of uncertainties in the surface reflectance due to uncertainties with the aerosol model retrieval that is used as a reference from radiative transfer simulations. Results indicate that individual aerosol microphysical properties can impact uncertainties in surface reflectance retrievals between  $3.5 \cdot 10^{-5}$  to  $1.0 \cdot 10^{-3}$  (in reflectance units).

The overall impact of microphysical properties combined yields an overall uncertainty in surface reflectance  $< 0.004$  (in reflectance units). That corresponds, for example, to 1 to 3 % of the retrieved surface reflectance in the red spectral band (620–670 nm) by the Moderate Resolution Imaging Spectro-radiometer (MODIS) instrument (Figure 1). These uncertainty values are well below the specification ( $0.005 + 0.05\rho$ ;  $\rho$  is the retrieved surface reflectance) used for the MODIS atmospheric correction.

## SENTINEL-3 BASED SURFACE ALBEDO PRODUCT FOR THE CONTINUITY OF COPERNICUS CLIMATE CHANGE SERVICE DATA RECORDS

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The Copernicus Climate Change Service (C3S) is one of six thematic information services of the European Union's Earth Observation (EO) Copernicus program implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission. C3S is providing key indicators on climate change drivers, by means of combining observations of the climate system with the latest science to develop authoritative, quality-assured information about the past, current and future states of the climate. The portfolio of products includes the generation of consistent estimates of multiple Essential Climate Variables (ECVs), among them Surface Albedo (SA), primarily based on satellite data and provided as a series of gridded Climate Data Records (CDRs). C3S is providing SA data since 1981 till April 2020 using NOAA-AVHRR, SPOT-VGT and PROBA-V. The products are accessible free of charge through the C3S website (<https://cds.climate.copernicus.eu/>). The continuity is ensured with the transition to Sentinel-3.

This talk will focus on the retrieval methodology used to generate C3S Sentinel-3 SA products, and the preliminary validation results. The methodology uses the existing Sentinel 3 pre-processing chain developed in the Copernicus Global Land Service to retrieve TOC reflectances from Sentinel-3 TOA radiometry. It consists of a selection of cloudiness scenes, an atmospheric correction of the TOA reflectance products, and the retrieval of the per-pixel Bidirectional Reflectance Distribution Function (BRDF) parameters for Sentinel-3 OLCI and SLSTR channels. These level-3 products of kernels spectral BRDF coefficients are used as input for SA retrieval, which performs angular integration and propagates the associated uncertainties to retrieve spectral estimations of Directional-Hemispherical Reflectance (DHR) – also called Black Sky Albedo (BSA) - and the Bi-Hemispherical Reflectance (BHR) - also called White Sky Albedo (WSA). Finally, a narrow-band to broadband conversion is defined in three broadband ranges: visible, near-infrared and total shortwave.

The validation methodology is performed according to Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) guidelines. For that, two main approaches are used: (i) benchmarking with reference satellite products (i.e., C3S PROBA-V SA v1.0, NASA MCD43A3 C6), and (ii) comparison with ground references for accuracy assessment. The C3S Sentinel-3 SA products have reached, in overall, good quality in terms of spatial and temporal consistency compared with reference products. The comparison with ground data showed similar results than MCD43A3 C6 but opposite sign of differences (slight positive in case of Sentinel-3), improving the accuracy of C3S products based on PROBA-V.

## EVALUATION OF SOLAR IRRADIANCE PARAMETERS RETRIEVED WITH THE MAGIC- HELIOSAT METHOD FROM MTSAT-2 AND HIMAWARI-8 GEOSTATIONARY SATELLITE DATA WITH BSRN GROUND MEASUREMENTS

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Surface Solar Irradiance (SSI) is one of the main components of the Earth radiation budget governing surface energy and water exchanges with the atmosphere. Therefore, the Earth radiation budget, including solar irradiance, was established as an essential climate variable (ECV) by the Global Climate Observing System (GCOS) program, and it is directly related to other ECVs, such as the land surface temperature, which trends are being analyzed in the context of Climate Change.

A good assessment of the different SSI parameters is thus needed for climate and weather monitoring and modeling, or for the design and management of solar power plants. Different methods have been developed over the last decades to assess SSI from satellite data, acquired by different missions, based on radiative transfer models or empirical-statistical algorithms. EUMETSAT CM-SAF proposed a hybrid method combining the simplified RTM Mesoscale Atmospheric Global Irradiance Code (MAGIC), which provides SSI for clear-sky atmospheres, and the empirical algorithm Heliosat, which calculates a clear-sky index to quantify the cloud transmission for partial or totally cloudy skies.

This work presents the evaluation of the MAGIC-Heliosat methodology, previously proposed for the European satellite METEOSAT-8, but using data from the MTSAT-2/Imager and Himawari-8/AHI sensors of the Japanese Meteorological Agency over the Asian Pacific coast and Oceania. The calculated SSI parameters were the Global Horizontal Irradiance (GHI) and Direct Normalized Irradiance (DNI). They were compared to ground data measured with pyranometers at six BSRN stations distributed along the observed area during years 2014 and 2016, on an hourly, daily, and monthly basis. The results showed that hourly GHI presented a bias of  $-15 \text{ W m}^{-2}$ , and a standard deviation of  $140 \text{ W m}^{-2}$ , with a relative absolute error of 30%. Hourly DNI had a bias of  $-45 \text{ W m}^{-2}$ , and a standard deviation of  $330 \text{ W m}^{-2}$ , with a relative absolute error of 38%. The results improved for larger time steps, with a bias of  $+10 \text{ W m}^{-2}$  ( $+24 \text{ W m}^{-2}$ ), a standard deviation of  $135 \text{ W m}^{-2}$  ( $125 \text{ W m}^{-2}$ ), and a relative error of 35% (20%) for daily (monthly) estimations, respectively. These results were consistent with the estimations provided by other references. In addition, the results were similar for both satellites, assuring the continuity between the corresponding datasets.

This study was carried out with the financial support of the project Tool4Extreme PID2020-118797RB-I00 funded by MCIN/AEI/10.13039/501100011033, but also by the project PROMETEO/2021/016 funded by the Conselleria d'Innovació, Universitats, Ciència i Societat Digital de la Generalitat Valenciana.

## LONG-TERM LEAF AREA INDEX, FRACTION ABSORBED PAR AND VEGETATION COVER GEOV2-AVHRR PRODUCTS

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Long term global terrestrial vegetation monitoring from satellite Earth Observation system is a critical issue within global climate and earth science modelling applications. This paper describes the GEOV2-AVHRR global vegetation products of leaf area index (LAI), fraction of absorbed photosynthetic active radiation (FAPAR) and vegetation cover fraction (FCover) derived from AVHRR Long Term Data Record (LTDR) series from July 1981 to December 2021. GEOV2-AVHRR products are freely accessible at the Theia portal at 0.05° and 0.5° spatial resolution and 10-day frequency.

The GEOV2-AVHRR algorithm was designed to ensure (i) GCOS requirements and (ii) high consistency with the biophysical products developed in the recent years, and particularly with the Copernicus Global Land GEOV2-CGLS products derived from VEGETATION and PROBA-V sensors. First, neural networks trained with CYCLOPES and MODIS products transform LTDR AVHRR top of the canopy directionally normalized reflectance data into vegetation biophysical variables at 0.05° and at a daily time step. Second, dedicated temporal smoothing and gap filling techniques are applied every 10 days with a 60 to 120 days compositing window, depending on the number of available valid observations. Finally, a 0.5° sub-sampled product useful for climate and meteorological modelling, named Global Change Monitoring (GCM), is generated. The products are delivered with associated uncertainties and quality indicators.

The GEOV2-AVHRR products were validated by comparison with existing GIMMS3g, GLASS and C3S AVHRR products, and with ground measurements (accuracy in terms of root mean square error of 0.78 LAI, 0.10 FAPAR and 0.13 FCover). Consistency with GEOV2-CGLS was successfully checked as well as the temporal consistency across the several AVHRR sensors used to build this long time series.

We will describe the principles of the algorithm used, the results of the validation process and the way to freely access to the archive and associated documentation at the Theia portal.

## PERFORMANCES AND IMPROVEMENT OF L2A SURFACE REFLECTANCE DATA FROM SENTINEL-2 OR TRISHNA PRODUCED WITH MAJA PROCESSOR

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To allow for a quantitative exploitation of the information provided by Copernicus Sentinel-2 satellites or by the future decametric resolution TRISHNA (CNES) and LSTM (Copernicus), users must have access to high quality time series of surface reflectance, which implies both an accurate and robust cloud detection, and a high quality atmospheric correction. Such products are referred to as Level 2A product (L2A). The French Land Data center, Theia, produces and distributes L2A products thanks to the MAJA processor, developed by the French space agency, CNES, and by the Centre d'Etudes Spatiales de la Biosphère (CESBIO), with contributions from the German space agency (DLR). As compared to classical atmospheric processors relying on multi-spectral relations to detect clouds and estimate aerosol content, MAJA involves both multi-spectral and multi-temporal criteria, taking benefit from the usually slower variation of surface reflectance as compared to the atmospheric properties variations due to clouds or aerosols.

A large scale validation effort has been conducted to assess the accuracy of the L2A products generated by MAJA. We developed a method to build reference cloud masks interactively and efficiently, we used atmospheric aerosol measurements from the Aeronet network to validate the atmospheric properties, and we verified surface reflectance using automated ground stations from three sites operated by CNES. The originality of the newest one, jointly operated by CESBIO and CNES, lies in its location within an agricultural field in Lamasquère, southwestern France, leading to a strong temporal and spatial heterogeneity of the surface as compared to the first two located within bright and uniform landscapes. The results of MAJA's validation against ground reflectances derived from in-situ measurements are enriched with statistical metrics to measure the noise on time series. All these tools indicate that the residual noise on time series is lower or close to 0.01 in reflectance units.

After an introduction on the community of users and services that rely on MAJA products or open source software, we will briefly describe the methods behind MAJA processor. We will then present recent findings on adjacency effects extent (larger than previously estimated) and related impact on atmospheric correction thanks to new results obtained using fast 3D radiative transfer model that relies on GPU, SMART-G. We will next briefly explain how we intend to adapt MAJA to the TRISHNA and LSTM missions, which have a much wider field of view than Sentinel-2. Finally, we will provide our most recent validation results

regarding the quality of cloud detection and atmospheric correction.

## MASKING SELECTED FRAGMENTS OF SATELLITE IMAGES WITH THE USE OF GENERATIVE NEURAL NETWORKS

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Due to the need to hide certain objects from publicly available image data, it is necessary to develop methods allowing for their automatic masking. Masks applied to areas containing sensitive information should integrate with the background in such a way that their detection is impossible. Work on masking specific areas of an image has been going on for many years. One of them is the MAP algorithm, which creates likelihood probability density function (PDF). A more extended solution is the Navier-Stokes method which uses classical fluid dynamics for dynamics propagation of isophotic lines. Another solution is Alexandru Telea method, which use the propagation of the smoothness estimator, where the results are similar to Navier-Stokes method (but the solution is much faster and easier to implement). Algorithms using the generative adversarial network have a significant advantage over these solutions. One of the solutions is to iteratively fill in the missing regions by searching for the best sample from the rest of the image. Another method is to choose the best fill by applying a global match for one patch during iteration, but this is a low performance solution. The solution of these problems is the method based on Multi-Patch Match with Adaptive Size, which firstly evaluates the heterogeneity of the image, and on its basis adjusts the sample size. Another proposal is the Sdf-MAN architecture, which combines disparity maps from various sources simultaneously implementing supplementary information. Further improvement is the use of the two-stage loss function, which allows for better color reproduction. Other approach is to use the generator model consisting of many columns, which will allow for more detailed filling of the image fragments. However, most of the presented solutions do not consider the problem of reproduction fragments of satellite images.

This work analyzes the impact of GMCNN network training hyperparameters on the masking capabilities of selected areas of satellite imagery. It was noticed that: (1) the lower value of the ratio training coefficient allows for the acceleration of the network learning process, (2) the smaller the Gaussian filter size, the more diverse the filled areas are, (3) for a smaller load the training lasts faster and has better results, (4) the best results occur when the ID-MDF loss is calculated when updating the weights 3, 6, 10, 12 of the VGG-16 network layer. Additionally, the construction of the GMCNN network was modified by the use of residual blocks, which allowed for the improvement of the quality of masked areas.

## **EXPANDING THE USE OF COPERNICUS MARINE SATELLITE DATA: EUMETSAT'S USER SUPPORT AND TRAINING ACTIVITIES**

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EUMETSAT operates the Sentinel-3, Sentinel-6 and Jason-3 satellites, and provides level-1 and level-2 marine data products for ocean colour, sea surface temperature, and altimetry science and applications. User support services include data access, customisation, and visualisation platforms, web-based technical information about products, as well as a helpdesk available to answer a full range of user queries on the products and their use.

Since 2017, the EUMETSAT Copernicus Marine Training Service (CMTS) programme has designed, developed and delivered training activities and user support to a diverse range of audiences, both research and operational, putting trainee needs and interests at the centre of learning objectives. The CMTS consortium is integrated by three private companies, one public research institution and the two Universities signing this communication, in addition to EUMETSAT own resources. Building on four years of successful general courses, EUMETSAT now seeks to develop further specialised training and advanced courses for the marine community thought.

This presentation will showcase existing services and resources, and provide information for planned training events for 2023 and beyond. It will expand on our training approaches and provide further information on opportunities for collaboration with the wider marine community, during the UN ocean decade. Courses are offered in both short and long formats, depending on the audience and learning objectives, and adopt a blended approach; mixing asynchronous, synchronous and stand-alone learning modes to accommodate online learning via our Moodle platform (<https://training.eumetsat.int/>).

## **EVAPOTRANSPIRATION MAPPING FROM REMOTE SENSING DATA: UNCERTAINTIES AND ENSEMBLE ESTIMATES BASED ON MULTIMODEL – MULTIDATA SIMULATIONS**

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Evapotranspiration (ET) is a fundamental element of the hydrological cycle which plays a major role on surface water balance and surface energy balance. At local scale, ET can be estimated from detailed ground



observations, for example using flux towers, but these measurements are only representative of very limited homogeneous area. When regional information is required, e.g. for monitoring ground water resources, ET can be mapped using thermal infrared and spectral reflectance data. Various ET models have been developed but there was no competitive evaluation of them over a large range of situations, so that it is not possible to evaluate the intrinsic performance of one model compared to another. In such situation, ensemble model averaging may be proposed for providing a coherent estimation of ET with an increased overall accuracy. In this work the ensemble modelling approach is extended to a multi-model – multi-data framework that provide ET estimations together with an uncertainty of estimation.

We developed the EVASPA framework for estimating ET through ensemble averaging with the objective of providing estimates of ET together with an estimation uncertainty. In this presentation we examine three test cases. The first test presents a full analysis of the uncertainties of ET estimation in relation to uncertainties in input variables and models. Airborne remote sensing data were acquired over the Grosseto area in Italy in the frame of the ESA SurfSense experiment (high spatio-temporal Resolution Land Surface Temperature Experiment) in support of the LSTM mission project (Copernicus Land Surface Temperature Monitoring). This analysis shows that the main uncertainty sources are related to model formulation, solar radiation, wind speed and air temperature estimates. The second test case presents the monitoring of ET over Sahelian areas in the frame of the AMMA-Catch program using MODIS data. ET was estimated by considering weighted average of ET estimates by several models. The ponderation weights were proposed as a function of the a priori validity of each model depending on the season and the LAI level. The third test case presents an example of Bayesian model averaging over the Crau-Camargue test site in SouthEast France. ET estimates were obtained as weighted averages of several model estimations from MODIS data. The ponderation weights were obtained from each model evaluations against ground measurements of ET. For the two last test cases, ET was estimated with RMSE around 0.5 mm d<sup>-1</sup>.

The EVASPA framework is presently used for the definition of the ET product in the frame of the TRISHNA thermal infrared space mission (CNES/ISRO).

## MODELING OF EVAPOTRANSPIRATION FROM LANDSAT 8 AND REANALYSIS DATA USING ARTIFICIAL NEURAL NETWORKS

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Evapotranspiration (ET) quantification improves the comprehension of the water, heat and carbon interactions and the feedbacks to the climate, being essential for global change research. Remote sensing data have demonstrated great potential in providing spatially continuous estimates of ET over various scales, when appropriately applied with physically accurate and statistically robust models. Given that the estimation of ET remains a challenge, methodologies dependent only on remote sensing and reanalysis data must be constantly investigated. To the best of our knowledge, few studies have explored to retrieve ET focusing on reducing the number of input parameters. We aimed to model ET using artificial neural networks (ANNs) based on Landsat-8 and reanalysis data from the National Centers for Environmental Prediction over the grasslands of the Brazilian Pampa biome. The output variable was the ET trained by eddy covariance (EC) measurements acquired from a flux tower located in Santa Maria, Brazil. ANN was performed using the back-propagation algorithm with four remote sensing input variables (albedo, normalized difference vegetation index, land surface temperature, and surface net radiation). In addition, four meteorological variables from the



Environmental Prediction Climate Forecast System Version 2 hourly product were included in the model (air temperature, atmospheric pressure, relative humid, and wind speed). We analyzed 67 clear-sky scenes between 2014 and 2019. The ANN model was also compared with the widely known simplified surface energy balance index (S-SEBI) model. ANN exhibited a correlation of 0.88 relative to in situ EC data, demonstrating a good linear relationship between ET estimated and measured and producing a root-mean-square error (mean absolute error) of 0.75 (0.58) mm/day. In comparison to the SSEBI model, ANN showed higher correlation with the ET in situ. Moreover, the ANN model had a superior performance in summer and winter seasons in which S-SEBI was found to exhibit more significant errors relative to the ET in situ. This research is the first to assess the ANN-based method for the context of the natural grasslands of the Pampa biome. The model developed represents an alternative to approaches that are dependable on a great number of input variables or in situ data since it only utilizes freely available data. Therefore, it should support future integrated strategies of water resources in the biome.

## **DETERMINATION OF LAND SURFACE HEAT FLUXES AND EVAPOTRANSPIRATION BY USING SATELLITE DATA AND ATMOSPHERIC BOUNDARY LAYER OBSERVATIONS OVER THE THIRD POLE**

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The regional exchange of heat and water vapor fluxes between land surface and atmosphere over the Third Pole region (Tibetan Plateau and nearby surrounding higher elevation region) plays an important role in Asian monsoon, westerlies and the northern hemisphere weather and climate systems. Based on the analysis of the land surface heterogeneity and its effects on the overlying air flow, the SL (Surface Layer) and ABL (Atmospheric Boundary Layer) observations by using the Third Pole Environment (TPE) Integrated Three-dimensional Observation and research Platform (TPEITORP) and satellite remote sensing measurement, one parameterization methodology is developed and demonstrated to estimate the surface heat fluxes and evapotranspiration (*ET*) over heterogeneous landscapes the Third Pole. The distributions of four components of radiation fluxes, net radiation flux, soil heat flux, sensible heat flux, latent heat flux, *ET* and their diurnal and monthly variations and long changing trend have been determined over the Third Pole region. These estimates have been compared with independent ground measurements of fluxes and *ET* in the stations of TPEITORP. At the validation stations relative deviations were less than 10 %. It is therefore concluded that the proposed methodology is successful for the retrieval of land surface heat fluxes over heterogeneous landscape. Further improvement of the methodology was also discussed.

## SENTINEL-2 BASED EMPIRICAL INDICATOR OF CROPLAND ANNUAL CO<sub>2</sub> FLUXES

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Cropland carbon budget monitoring is a key task in a world undergoing climate change. In this context, the H2020 NIVA project (New IACS Vision in Action) aims 1) to modernize the Integrated Administration and Control System (IACS) and 2) to develop tools allowing the mapping of agro-environmental indicators that could be relevant for the future Common Agricultural Policy (CAP): biodiversity, risk of Nitrate leaching, Carbon budget. Those tools rely on published scientific methodologies, remote sensing and IACS data. For each indicator, three methods of increasing complexity have been developed, from 'Tier 1' to 'Tier 3'. Here, we focus first on the C budget indicator Tier 1 (CT1) that allows calculation of the plot scale net annual CO<sub>2</sub> fluxes of croplands. This term, combined with farmers's data on organic amendments and yield allows the calculation of plot scale annual C budgets (TIER 2).

The CT1 indicator is based on this principle: for a whole cropping year, the net annual CO<sub>2</sub> flux of an agricultural parcel is linearly correlated to the number of days it is covered by an active photosynthetic vegetation. This relationship was established on 17 experimental sites in Europe covering a large range of crops and pedoclimatic conditions.

The key point of our approach for calculating the CT1 indicator is that the periods of active vegetation cover can be estimated by remote sensing. Therefore, the Sentinel-2 mission that provides systematic global acquisitions of high-resolution multi-spectral data with a high revisit frequency, was used to calculate NDVI at pixel level. Then the NDVI time series are interpolated daily for each plot according to the LPIS (Land Parcel Identification System) in order to calculate the duration of active vegetation coverage. Then by applying the linear relationship described above, the net annual CO<sub>2</sub> flux is estimated at plot/pixel level. The total uncertainty is also quantified on the net CO<sub>2</sub> flux estimates by considering the native uncertainty of the relationship, of the in-situ CO<sub>2</sub> flux measurements and by considering the gaps in the satellite observations.

Thanks to the technical support of the French Space Agency (CNES), the indicator has been produced over the French metropolitan territory by using the IOTA2 processing chain.

Preliminary results show coherent patterns in net annual CO<sub>2</sub> fluxes:

- contrasts in areas dominated by winter or summer crops.
- regional differences caused by the French regulation concerning cover crops.
- effects of pedoclimatic conditions that affect the crop phenology.

Additionally, we have collected CO<sub>2</sub> flux data from 10 European cropland ICOS flux sites (Integrated Carbon Observation System). By combining the information of the duration of active vegetation coverage with these independent CO<sub>2</sub> fluxes measurement we aim to validate our approach.

Finally, in collaboration with Agrod'Oc, we collected farmer's management data (organic amendments, yield...) over hundreds of plots in South West France to illustrate how those data combined with the TIER1 approach can be used to compute plot scale annual carbon budgets (TIER 2).

## **SENTINEL-HR, A MISSION PROPOSAL TO COMPLETE SENTINEL-2 WITH 2 M RESOLUTION SYSTEMATIC OBSERVATIONS IN THE VISIBLE AND NEAR INFRARED, WITH STEREOSCOPY**

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The Copernicus Sentinel-2 mission whose twin satellites were launched respectively in 2015 and 2017, has met an exceptional success: in 2020, more than 10,000 users have downloaded at least 10 products from the main distribution platform. This success is probably due to the combination of three features: the data quality, the systematic observations, and the free and open data policy.

Regarding Very High Resolution (VHR) images (resolution better than 2.5 m), the earth observation community is still lacking an equivalent mission, with systematic observations and free and open data. In a phase-0 study held in 2021, CNES, the French Space Agency, studied such a mission, with an emphasis on change monitoring. A mission advisory group (MAG) was set-up, whose members studied the mission use cases. As for Sentinel-2, the applications would be very diverse. They include urban footprint extension, urban vegetation, infrastructure, cadaster, hedges, ecological corridors, agro-forestry, forests, clear cuts, water bodies, glaciers and ice sheets...

The MAG confirmed that 2 m spatial resolution, 20 day revisit and 4 bands might be enough, even if better performances would bring improvements. The MAG also stressed the interest of adding stereo-scopic observations to detect elevation changes of 3m (CE90). The stereoscopy would be particularly useful to monitor glacier height, in replacement for the old ASTER instrument, but could be used to detect new buildings, tree cuts, monitor coasts, volcanoes, landslides...

The phase-0 study found out that such Sentinel-HR would be hardly feasible with only two platforms. On the other hand, it could be obtained with 12 slightly modified CO3D satellites. CO3D is a mission in partnership between CNES and Airbus, which will be launched in 2023 to provide a global Digital Elevation Model in three years at a metric resolution, using 4 band images at 50 cm resolution. For Sentinel-HR, the satellites would be on a higher orbit above 800 km, each satellite would have a field of view of 28 km and a 2 m resolution. As Sentinel-HR would rely on rather simple modifications of existing satellites, it could be launched as soon as 2029, provided the funding is available.

During the phase-0 study, we also analyzed the synergy between Sentinel-2 and Sentinel-HR data, by benchmarking different fusion methods to obtain VHR time series with the temporal resolution of Sentinel-2 (5 days). Using a data set acquired by Sentinel-2 and Venus (a high resolution and high revisit satellite), we showed that the data fusion is achievable, with an accuracy close to 0.01 in reflectance units, even on the high resolution contours.

Following this work, the European Union and the European Space agency are studying similar projects, for instance in the framework of Sentinel-2 Next Generation phase-0, and we will provide a perspective on the possible future VHR missions providing systematic observations.

## BIODIVERSITY – Status of the French hyperspectral space mission

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Imaging spectroscopy in the VNIR/SWIR spectral range has demonstrated strong potential for a wide range of applications: biochemical and biophysical characterization of vegetation, biodiversity monitoring, mineralogy, bathymetry and classification of coastal and inland waters, cryosphere, urban land cover, industrial waste, and air or soil pollution.

After Hyperion, space missions have recently become operational (PRISMA, EnMap, DESIS, HISUI), and global missions are under study (CHIME, SBG). Most of them have a ground sampling distance (GSD) of 30 m, a large swath and can therefore cover large areas on Earth to characterize different terrestrial and oceanic ecosystems with a revisit period ranging from 4 to 16 days. Such a spatial resolution is a limiting factor for discriminating heterogeneous areas because it induces a large number of mixed pixels. The French BIODIVERSITY mission (ex-HYPXIM) aims to complement these space missions with a unique combination of characteristics including a GSD of 10 m, a revisit time of up to 5 days, and a spectral range from 0.4 to 2.4  $\mu\text{m}$ . It could thus provide more accurate and in-depth answers to several scientific issues.

Under the supervision of CNES, the French scientific community has been working to identify user requirements in terms of spectral resolution, signal-to-noise ratio (SNR) and calibration. This work is based on a set of applications covering the above topics.

The objective of this presentation is to describe the method for identifying user requirements, and the results obtained on a long list of applications: tree-level species classification, canopy functional trait mapping for Mediterranean forests, shallow water bathymetry and sea bottom classification, mineralogy and soil moisture content estimation, cryosphere (single scattering albedo, black carbon rate), plumes characterization

of industrial sites (aerosols, methane and carbon dioxide), urban land cover and atmospheric properties. A synthesis is then proposed.

## MORERA: EARTH OBSERVATION SYSTEM TO TRANSLATE BIG DATA TO AGRICULTURE

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The MORERA program was selected in 2020 as one of the “Science and Innovation Missions” from the Spanish CDTI, an innovative program targeting solutions for deep social problems through innovation. The main Spanish industry is Agriculture (11% PIB), but this sector is threatened by climate change, as 34% of the Spanish irrigated surface is considered out of balance. The complexity of providing useful and fully processed information to the end users for supporting their decisions severely affect the optimization of the resources. Well informed decisions optimize resources and costs, maximizing productivity. To solve this problem, the development of MORERA, an Earth Observation software-defined optical system, involves in a unique project the complete value chain, from sensor to user, thanks to a solid consortium: TASE (Systems Engineering, AI, video chain), TEPRO (user interface), IAS and UVal (algorithms) ASE Optics Europe (optics), LIDAX (thermomechanics) and INTA (AIT), and it is based on three pillars:

- A compact (Cubesat-compatible) and highly specific freeform optical instrument will be used to estimate evapotranspiration data at farm level with required TIR bandwidth and spatial resolution. Since no present instrument fulfills these requirements, it is being developed in the framework of the project.
- Final personalized irrigation requirements that will be directly provided to the user using a mobile device.
- Input data such as meteorological data (historical and predictive from different sources), satellite images and user inputs such as crop type or location of the farm under study, are ingested, stored and processed using modern algorithms and artificial intelligence techniques (machine learning and big data models) to give the amount of water needed to irrigate the farm under study.

The MORERA concept (compact sensor plus AI processing) can be extrapolated to many remote sensing applications, and to take advantage of this, it has been conceived as a modular system, where each module may be adapted with minor impact. This first system is focused on providing precise irrigation recommendations with a 5-day time horizon, as well as self-learning yield estimations.

## UPDATES ON GLOBAL LAND SURFACE SATELLITE (GLASS) PRODUCTS SUITE

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The Global Land Surface Satellite (GLASS) products suite includes a set of high-level satellite products of land surface essential variables from multiple universities and research institutes. Producing the GLASS products suite has been undertaken since 2010, and the suite spans from the initial five products to the current 16 products, which are generated mostly from the Advanced Very High Resolution Radiometer (AVHRR) and/or Moderate Resolution Imaging Spectroradiometer (MODIS) data. Some of the products have been previously introduced in the literature, and this paper provides an update on the algorithm developments, validation accuracies, and their typical applications in all 16 products. This paper also describes the Hi-GLASS products at 30-m resolution and some perspectives for further improvement and development of the GLASS products in the future.

Estimating land surface variables from satellite observations is an “ill-posed” inversion problem. For each pixel, the number of multispectral bands is usually smaller than the number of environmental variables, and the values of many spectral bands are highly correlated. Some novel solutions have been proposed to solve the problem of insufficient information in generating reliable GLASS products. We can identify at least four approaches. The first is based on the temporal signature of the satellite observations. The typical example is the MODIS leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (FAPAR) products that are generated using 2-year observations simultaneously. The second uses algorithm ensemble. The typical example is the evapotranspiration (ET) product that is based on integration of five estimation algorithms. The third uses multiple satellite observations. For example, the forest aboveground biomass product is based on optical, Lidar, and microwave data products. The last incorporates the physical model to generate the products, such as the gross primary production (GPP) product.

The GLASS products have several unique features compared to similar products on the market, including the following.

- 1) Several products are unique, such as the high-resolution (1-km) broadband emissivity and time-series forest aboveground biomass products.
- 2) Most products have long time series, i.e., over 40 years, while most other similar global products start from

approximately the year 2000, with a time span of approximately 20 years.

3) The radiation products, covering the world's land and ocean surfaces, have a spatial resolution of 5 km, which is an order of magnitude higher than other such products in wide use, e.g., the Global Energy and Water Exchanges (GEWEX), the Clouds and the Earth's Radiant Energy System (CERES), and the International Satellite Cloud Climatology Project (ISCCP), which have spatial resolutions coarser than 100 km.

4) Several long-time-series global products have the highest spatial resolution in the world, such as 250 m for the LAI, FAPAR, and albedo products and 5 km for snow cover extent. In addition, the all-weather LST and near-surface air temperature products have a 1-km resolution.

5) GLASS products are of high quality and accuracy.

So far, over 2,000 peer-reviewed papers based on the GLASS products have been published. Their applications are distributed in many scientific disciplines and societal benefits areas.

We will continue to improve the quality and accuracy of the existing GLASS products, and produce more GLASS products with higher spatial resolutions.

Product	Satellite data	Spatial resolution	Temporal resolution	Temporal extent
Albedo	AVHRR	0.05°	8-day	1981-2020
	MODIS	0.05°	8-day	2000-2020
		1km	8-day	2000-2020
		500m	4-day	2000-2020
		250m	4-day	2000-2020
Downward shortwave radiation	MODIS	0.05°	daily	2000-2020
Photosynthetically active radiation	MODIS	0.05°	Daily	2000-2020
Land surface temperature	AVHRR	0.05°	Daily	1981-2021
			Instantaneous	1981-2000
			Orbit-drifting correction	1981-2000

			monthly	1981-2000
	MODIS	1km	Instantaneous, daily	2000-2020
Emissivity	AVHRR	0.05°	8-day	1981-2020
	MODIS	0.05°	8-day	2000-2020
		1km	8-day	2000-2020
		500m	8-day	2016-2020
Thermal downward and upwelling radiation	AVHRR	0.05°	daily	1981-2018
	MODIS	0.05°	daily	2002-2020
		1km	Instantaneous	2000-2020
All-wave net radiation	AVHRR	0.05°	Daily	1981-2018
	MODIS	0.05°	Day-time average	2000-2020
Evapotranspiration	AVHRR	0.05°	8-day	1981-2020
	MODIS	0.05°	8-day	2000-2020
		1km	8-day	2000-2020
Near-surface air temperature	MODIS	1km	8-day	2000-2020
Leaf area index	MODIS	0.5°	8-day	2000-2021
		0.05°	8-day	2000-2021
		500m	8-day	2000-2021
		250m	8-day	2000-2021
	AVHRR	0.05°	8-day	1981-2018
Faction of absorbed photosynthetically active radiation	MODIS	500m	8-day	2000-2021
	AVHRR	0.05°	8-day	1981-2018
Factional vegetation cover	AVHRR	0.05°	8-day	1981-2020
	MODIS	0.05°	8-day	2000-2020
		500m	8-day	2000-2020
Gross primary productivity	AVHRR	0.05°	8-day	1981-2018
			annual	1982-2018
	MODIS	500m	8-day	2000-2020
			annual	2001-2020
Net primary productivity	AVHRR	0.05°	8-day	1981-2018
			annual	1982-2018
	MODIS	500m	8-day	2000-2020
			annual	2001-2020
Forest above-ground biomass	AVHRR	5km	5-year	1985-2020
North-hemisphere snow cover	AVHRR	0.05°	8-day	1981-2019



## LEVERAGING THE CROP ROTATION AND COPERNICUS DATA WITH A DEEP LEARNING METHOD TO FORECAST THE CROP TYPE AT PARCEL LEVEL

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Large scale Crop type mapping at Field level is an essential information for in-season crop production monitoring, enabling to better quantify the total areas per crop at regional level but also to better monitor crop condition and increase accuracy of the yield forecast. Since the launch of the Copernicus Sentinel missions, the abundance of remote sensing (RS) data with spatial resolution lower than parcel size (for most of the European country) has changed the perspective of crop monitoring system. Operational crop type mapping has already been designed to provide in-season crop type map at regional or national level. However, most of these approaches rely on the availability of in situ data (i.e., parcel crop type identification) of the on-going season. Because of the complexity of in situ campaign, the timing and the availability of in-situ data set represents the main limitation for crop production forecasting. It is thus required to develop approaches that are not based on in situ data from the on-going season and to design a transferable model that are trained on previous seasons. In this study, we propose to evaluate a deep-learning algorithm trained with past-seasons data and Sentinel 1 and 2 RS data to forecast in-season the crop type at parcel level.

As a use case, we considered two studied countries, The Netherlands (NL) and France (FR), which release publicly their geospatial application aid (GSAA) data sets (from 2009 to 2020 for NL, from 2015 to 2019 for FR) and account for a total of 630k and 6M parcels, respectively. The evaluated algorithm is a multimodal and hierarchical Long-Short-Term-Memory (LSTM), validated with last GSAA data set (2021 for NL and 2020 for FR) and trained with all other GSAA data sets. The post-2016 RS-based smooth time series of red and NIR surface reflectances, LAI and FAPAR were derived from the in-house processing of Sentinel-2 and Landsat-8 Level-2, involving biophysical variable processor. We also ingest in the model the Sentinel-1 back-scattering data processed at gamma level and air temperature derived from AgERA5. The crop rotation histories were retrieved by intersecting GSAA data sets since 2009 for NL and since 2015 for FR.

We benchmarked various configurations of learning models varying the inputs: crop rotation, Sentinel-1-based variables, Sentinel-2-based variables, air temperature. Considering the most advanced configuration, involving all mentioned variables, promising results were obtained with overall accuracy (OA) in the range of 84% for FR and 90% for NL when considering all the crop categories as defined in the GSAA. When regrouping the class to focus on major crop categories, the OA increased to up to 95%. Winter soft wheat is well classified with F1-score higher than 90%. We investigated the increase of the F1-scores throughout the season by running monthly models from March to October. While the performances keep increasing till last run, OA outreaches good accuracy as early as in July. These performances equal or exceed traditional crop type mapping approaches achieved with in situ data of the evaluated season.

## ARYA: A REMOTE SENSING BASED METHOD FOR FORECASTING WHEAT YIELD. APPLICATION OVER THE MAJOR EXPORTING COUNTRIES.

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NASA Harvest is the NASA's Food Security and Agriculture program. Its main objective is enhancing the use of satellite data in decision making related to food security and agriculture. Within this context, one of the main priorities is providing valuable information on crop conditions and accurate and timely crop yield forecasts. This work presents the Agriculture Remotely-sensed Yield Algorithm (ARYA), a new EO-based empirical winter wheat yield forecasting model. The algorithm is based on the evolution of the Difference Vegetation Index (DVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) at 1 km resolution and the Growing Degree Days (GDD) from reanalysis MERRA2 data. Additionally, the model includes a correction on crop stress conditions captured by the accumulated daily difference of the Land Surface Temperature (LST) from MODIS and the air temperature at the MODIS overpass time from MERRA2. The model is calibrated at subnational level using historical yield statistics from 2001 to 2019. In each administrative unit, a different calibration coefficient (based on all possible combination of the three regressors in a linear model) is selected depending on the statistical significance of each variable. The model was applied to forecast the national and subnational winter wheat yield in the United States, Ukraine, Russia, France, Germany, Argentina and Australia (over 70% of global wheat exports) from 2001 to 2019. The results show that ARYA provides yield estimations with 5-15 % ( $0.3 \pm 0.1$  t/ha) error at national and 7-20 % ( $0.6 \pm 0.1$  t/ha) error at subnational level starting from 2 to 2.5 months prior to harvest.

Additionally, in this work we explore the applicability of ARYA at within-field scale and how high resolution data can help improving ARYA. Therefore, we test the ARYA calibration equations with Sentinel 2 data and evaluate the results to forecast within-field wheat yield measurements from harvester machines over more than 100ha in Valladolid (Spain) during the 2020 and 2021 seasons.

## ONE DECADE (2011-2020) OF EUROPEAN AGRICULTURAL WATER STRESS MONITORING BY MSG-SEVIRI: INITIAL VALIDATION AND WORKFLOW IMPLEMENTATION IN A VIRTUAL EARTH LABORATORY PLATFORM

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Remotely-sensed Evapotranspiration (ET) estimates can effectively contribute to agricultural water stress detection. Fully operational, high temporal, and moderate spatial resolution ET products derived from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) sensor onboard the Meteosat Second Generation (MSG) satellites make it a suitable candidate for water stress monitoring. However, dedicated efforts are still required to develop simple workflows, preferably executable on cloud-based platforms, to evaluate the potentials, exploit the information content, and demonstrate the capability of SEVIRI ET-products for water stress monitoring at larger scales. In this study, an extensive assessment of daily actual and reference ET (SEVIRI-ET<sub>a</sub> and SEVIRI-ET<sub>0</sub>) products were conducted against in situ measurements collected at 54 Eddy Covariance (EC) sites across Europe distributed in various terrestrial ecosystems (i.e., forest, grassland,

cropland, and peatland) between 2011-2018. The evaluated SEVIRI-ET products were then utilized mainly for two purposes: i) providing inputs to run a proposed water stress detection workflow, based on monthly evaporative stress index (ESI) anomaly, and implemented in cloud-based Virtual Earth Laboratory (VLab) platform to monitor one decade (2011 to 2020) of spatio-temporal water stress variations for entire Europe, and ii) investigating the mean terrestrial ecosystems response to water stress. The direct comparison of in situ ET with their corresponding SEVIRI-ET products resulted in a fair agreement in various ecosystems, albeit with expected inter-site variability. At the monthly time step, the mean  $R^2$  of 0.78, 0.76, 0.88, 0.85 and RMSE of 0.51, 0.60, 0.41, 0.59 mm day<sup>-1</sup> were observed between SEVIRI-ET<sub>a</sub> and in situ ET<sub>a</sub> for forest, cropland, peatland and grassland, respectively. Further, mean  $R^2$  of 0.95, 0.98, 0.96, 0.97 and RMSE of 0.48, 0.36, 0.31, 0.35 mm day<sup>-1</sup> were obtained between SEVIRI-ET<sub>0</sub> and in situ ET<sub>0</sub> for these land cover types. The SEVIRI-ESI-based monthly water stress workflow implemented on the online VLab platform provides spatio-temporal variations of water stress in Europe for the last decade (i.e., 2011 – 2020) that can be further utilized in scientific research and terrestrial applications. The analysis of various ecosystems' responses to water stress revealed that general water stress effects on vegetated ecosystems are “visible” in the SEVIRI-ESI-based water stress values and anomalies. The results from this study highlight the value, support the potentials, and unlock the full capacity of SEVIRI-ET products and the VLab platform for water stress detection at various terrestrial ecosystems at larger domains.

## USING SENTINEL-1 AND SENTINEL-2 IMAGERY FOR ESTIMATING COTTON WATER CONSUMPTION, HEIGHT, AND LEAF AREA INDEX

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In cotton, an optimal balance between vegetative and reproductive growth will lead to high yields and water-use efficiency. An abundance of water and nutrients will result in heavy vegetative growth that promotes boll rot and fruit abscission, making a cotton crop difficult to harvest. Estimating vegetation variables such as crop coefficient ( $K_c$ ), Leaf Area Index (LAI), and crop height using satellite remote sensing can improve irrigation management. Optical and Synthetic Aperture Radar (SAR) satellite imagery can be a useful data source since they provide synoptic cover at fixed time intervals. Furthermore, they can better capture the spatial variability in the field compared to point measurements. Since clouds limit optical observations at times, the combination with SAR can provide information during cloudy periods. This study utilized optical imagery acquired by Sentinel-2 and SAR imagery acquired by Sentinel-1 over cotton fields in Israel. The Sentinel-2-based vegetation indices that are best suited for cotton monitoring were identified and the most robust Sentinel-2 models for  $K_c$ , LAI, and height estimation achieved  $R^2=0.879$ , RMSE=0.0645 (MERIS Terrestrial Chlorophyll Index, (MTCI));  $R^2=0.9535$ , RMSE=0.8 (MTCI); and  $R^2=0.8883$ , RMSE=10 cm (Enhanced Vegetation Index (EVI)), respectively. Additionally, a model based on the output of the SNAP biophysical processor LAI estimation algorithm was superior to the empirical LAI models of the best-performing vegetation indices ( $R^2=0.9717$ , RMSE=0.6). The most robust Sentinel-1 models were obtained by applying an innovative local incidence angle normalization method with  $R^2=0.7913$ , RMSE=0.0925;  $R^2=0.6699$ , RMSE=2.3;  $R^2=0.6586$ , RMSE=18 cm for the  $K_c$ , LAI, and height estimation, respectively. This work paves the way for future studies to design decision support systems for better irrigation management in cotton, even at the sub-plot level, by monitoring the heterogeneous development of the crop from space and adapting the irrigation accordingly to reach the target development at different growth stages during the season.

**USING THE CUTTING EDGE REMOTE SENSING METHODS AND DATA IN  
THE 25 YEARS OF THE NASA LAND-COVER/LAND-USE CHANGE  
PROGRAM**

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Studies of land-cover and land-use change (LCLUC) on a global scale became possible when the first satellite of Landsat series was launched 50 years ago. Since then, land-change science has been rapidly developing to answer the questions on where changes are occurring, what is their extent and over what time scale, what are their causes, their consequences for ecosystems and human societies, their feedbacks with climate change, and what changes are expected in the future. LCLUC studies use a combination of space observations, in situ measurements, process studies and numerical modeling. To get the most out of current remote sensing capabilities researchers strive to utilize data sources, different in space and time resolution and in electromagnetic range. Fusing observations from optical sensors with radar data helps fill the cloud-induced gaps in optical data. The goal is to develop multi-sensor, multi-spectral methods to increase the spatiotemporal coverage and to advance the virtual constellation paradigm for moderate spatial resolution (10-60m) land imaging systems with continental to global scale coverage. Also, the use of commercial satellite very high (meter) resolution is accelerating with more data becoming available and accessible. On the other hand, socioeconomic research plays an important role in land-change science and includes analyses of the impacts of changes in human behavior at various levels on land use. Studies of the resultant impacts of land-use change on society, or how the social and economic aspects of land-use systems adapt to climate change are becoming more and more important as the climate crisis issues draw increasing attention.

The NASA LCLUC Program is developing interdisciplinary approaches combining aspects of physical, social, and economic sciences, with a high level of societal relevance, using cutting-edge remote sensing tools, methods, and data. The Program aims at developing the capability for annual satellite-based inventories of land cover and land use to characterize and monitor changes at the Earth's surface to improve our understanding of LCLUC as an essential component of the Earth System. The Program currently focuses on detecting and quantifying rapid LCLUC in hotspot areas and examining their impact on the environment and interactions with climate and society. This talk will summarize the Program's achievements during the 25 years since its inception with an emphasis on the most recent findings. It will describe the synergistic use of multi-source land imaging data including those from the instruments on the International Space Station. The examples will cover various land-cover and land-use sectors: forests, grasslands, agriculture, urban and wetlands.

## REMOTE SENSING AND DATA MINING TECHNIQUES AS A TOOL TO MONITOR MULTITEMPORAL CHANGES IN WATER AND VEGETATION COVER IN MEDITERRANEAN SHALLOW LAKES.

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The Mediterranean basin holds many shallow lakes and wetlands of high ecological, social, and economic value. Many of these important natural assets have been notably degraded or even destroyed, mainly during the 20th century. In order to accomplish the goals enforced by the European Water Framework Directive and the Habitats Directive, management plans are being developed. These directives establish that all EU countries have to achieve a good ecological status of waterbodies and a favorable conservation status of habitats of community interest, respectively. A key for the design of these management plans is the understanding of the hydrological trend of these waterbodies with a sound monitoring scheme. To do so, an estimation of the temporal evolution of the flooded area for each lake/wetland, and its relationship with the hydrological patterns and the seasonal effect can be achieved using remote sensing techniques. The aim of this work is the development of a remote sensing methodology for the estimation of different surface (water and vegetation) covers in Mediterranean shallow lakes and wetlands using satellite remote sensing images and ground-truth data sets. This study focuses on several Mediterranean lakes located in the semiarid regions of the Iberian Peninsula. These include marshes, salt ponds, and saline and freshwater, permanent and temporary shallow lakes. Some of these water bodies have a marginal belt of ruderal or halophytic plants, and some also have helophytic vegetation mainly in marginal areas. Landsat-5, -7, -8 and Sentinel-2 images were used to fulfill this goal. These images are useful to monitor medium size water bodies (10-50 ha) due to its 30-m (Landsat), and 10-20 m (Sentinel-2) spatial resolution. Genetic programming was used to develop the algorithm for predicting the presence of the different surface covers. Results were compared with ground-truth data and the classification estimates were evaluated by means of the kappa coefficient. Our approach offers a useful tool to estimate the changing water coverage areas and the presence of different kinds of vegetation such as helophytes and halophilous plant communities. These findings might be useful for management strategy-linked lake conservation and specifically to accomplish the goals of both the European Water Framework Directive and the Habitats Directive.

## MEDITERRANEAN CLIMATE ZONES, TIME SERIES ANALYSIS FROM 2015 TO 2022: 100 BIOPHYSICAL INDICES, 300 ALGORITHMS AND 6 SATELLITES

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Due to its impact on our ecosystem (e.g., vegetation, soil, water, etc.), global change has become more significant over time. Therefore, several biophysical indices (i.e., Normalized Difference Vegetation

Index, Modified Soil-Adjusted Vegetation Index, Normalized Difference Water Index, etc.) have been developed to quantify, assess, and monitor the ecosystem's reaction to these changes. Numerous and various satellite imagery (i.e., spatial, spectral, and temporal) might be integrated into multiple mathematical models to carry out this monitoring. One of the efficient models in this field is Time Series Analysis, which allows the decomposition of data into four components (i.e., cyclicity, seasonality, irregularity, and trend). In this review paper, we considered 675 remote sensing algorithms of different satellites sensors (i.e., Landsat MSS [1972-2013], AVHRR [1981-present], Landsat TM [1982-2013], SPOT HRV – HRVIR – HRG – VGT – NAOMI [1986-present], Landsat ETM+ [1999-present], ASTER [1999-present], Landsat OLI [2013 – present], Sentinel-2 MSI [2015-present]). Definitively, 100 biophysical indices have been classified into four different categories (i.e., vegetation algorithm, soil algorithm, water algorithm, and other algorithms). Consequently, 300 algorithms were computed in order to conduct a comparative study of their quarterly time series trends from 2015 to 2022. Thus, 672 hyperspectral remotely sensed images retrieved from six different satellites were used to monitor four Mediterranean climate zones (hot arid, cold arid, warm temperate hot summer, warm temperate warm summer). The study zones were selected based on Köppen Geiger classification. Accordingly, 33600 images have been computed, resulting in 1200 Time Series charts where many biophysical indices have taken specific forms (i.e., Bell curve, Quasi-constant, Inverted Bell curve, and Oscillatory form). Finally, four Look Up Tables have been created, assembling trends components (176 Vegetation trends, 35 Soil trends, 24 Water trends, and 65 Others).

## GENERATING UP-TO-DATE CROP MAPS OPTIMIZED FOR SENTINEL-2 IMAGERY IN ISRAEL

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The overarching aim of this research was to develop a method for deriving crop maps from a time series of Sentinel-2 images between 2017 and 2018 to address global challenges in agriculture and food security. This study is the first step towards improving crop mapping based on phenological features retrieved from an object-based time series on a national scale. Five main crops in Israel were classified: wheat, barley, cotton, carrot, and chickpea. To optimize the object-based classification process, different characteristics and inputs of the mean shift segmentation algorithm were tested, including vegetation indices, three-band combinations, and high/low emphasis on the spatial and spectral characteristics. Four known vegetation indices (VIs)-based time series were tested. Additionally, we compared two widely used machine learning methods for crop classification, support vector machine (SVM) and random forest (RF), in addition to a newer classifier, extreme gradient boosting (XGBoost). Lastly, we examined two accuracy measures—overall accuracy (OA) and area under the curve (AUC)—in order to optimally estimate the accuracy in the case of imbalanced class representation. Mean shift best performed when emphasizing both the spectral and spatial characteristics while using the green, red, and near-infrared (NIR) bands as input. Both accuracy measures showed that RF and XGBoost classified different types of crops with significantly greater success than achieved by SVM. Nevertheless, AUC was better able to represent the significant differences between the classification algorithms than OA was. None of the VIs showed a significantly higher contribution to the classification. However, normalized difference infrared index (NDII) with XGBoost classifier showed the highest AUC results (88%). This study demonstrates that the short-wave infrared (SWIR) band with XGBoost improves crop type classification results. Furthermore, the study emphasizes the importance of addressing imbalanced classification datasets by using a proper accuracy measure. Since object-based classification and phenological features derived from a VI-based time series are widely used to produce crop maps, the current study is also relevant for operational agricultural management and informatics at large scales.

## USE OF UAV AND ASTER DATA FOR UNDERSTANDING THE SURFACE ENERGY BUDGET CLOSURE THROUGH THE ADVECTION TERM

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The surface energy budget (SEB) considers all the energy exchanges taking place in a volume across the atmosphere–surface interface. Formally, it can be derived from the equation of the evolution of the air temperature. In this framework, the four main traditional terms: Net Radiation (Rn), soil heat (G), sensible heat (H), and Latent heat (LE) fluxes, would only balance if no other thermal sources or sinks existed, implying no thermal advection and surface homogeneity. Therefore, once the surface heterogeneity occurs and presence of wind is significant, thermal advection (Ad) will take place, and the usual four-term energy budget will not close anymore. The SEB is then reformulated to account for the imbalance (Imb) as the sum of the heat storage in the volume, the biological thermal exchanges, the temperature tendency, the thermal advection, and any other unaccounted factor ( $Imb = S + B + TT + Ad + Ot$ ). In a study performed in 2016, an Unmanned Aerial Vehicle (UAV), carrying a thermal infrared camera, took photos of the Campus of the University of Balearic Islands, where a SEB station is installed measuring Rn, G, H and LE fluxes continuously, so an imbalance is detected most of the time along the day (except for the night hours). We estimated the advection term for such UAV flights and observed that for the presence of strong winds (speed and direction measured with an anemometer), this term can explain part or fully the imbalance term, with flux values ranging within 100–400 W/m<sup>2</sup>, at spatial resolutions of 90–200 m and within 08:00–14:00 UTC time, if the wind is blowing in the North-East or the East–Southeast direction. Results were also confirmed with satellite data, using ASTER Land Surface Temperature maps.

## GLOBAL MAPS OF ESSENTIAL BIOPHYSICAL VARIABLES CREATED WITH GAUSSIAN PROCESS REGRESSION USING GOOGLE EARTH ENGINE

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The mapping of biophysical variables by means of Earth observing satellites on a global scale provides a spatially-explicit way to analyse the planet's current vegetation state and its dynamics. In this study, Sentinel-3 data was used to create global maps of four key biophysical variables, i.e., Leaf Chlorophyll Content (LCC), Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Fractional Vegetation Cover (FVC). These vegetation products are essential in support of the future FLEX satellite mission, which shall provide fluorescence data to provide means for analysis of the photosynthetic machinery and the health of terrestrial vegetation. For each variable, simulated radiance data as generated by the coupled SCOPE-6S radiative transfer models were used to train a hybrid Gaussian Process Regression (GPR) model directly from the top of atmosphere (TOA). Each model was implemented into Google Earth Engine (GEE), and then applied to Sentinel-3 OLCI TOA radiance data. GEE provides up-to-date satellite data such as Sentinel-3 and enables instantaneous global processing. The global vegetation maps were processed as averaged values of a 10-day time window at a 5 km pixel resolution. Three, 500x500 km, European study areas at different latitudes (Iberian peninsula, Western-Central Europe and in Scandinavia) were selected to retrieve the vegetation products throughout the year of

2019 at 500 m pixel resolution. Time series analysis was conducted to fill up cloud-induced gaps typically present in optical data. The Whittaker smoother was implemented for gap-filling to generate spatiotemporally continuous data streams for the year 2019. Finally, the validity of the LAI and FAPAR annual profiles were per-pixel correlated against corresponding MODIS vegetation products, leading to Pearson correlation and R Squared maps. The correlation maps of the three European study areas all revealed a  $R^2$  above 0.7. Also global correlation maps were produced to evaluate the quality of our S3 vegetation products at the 5 km pixel resolution. Values of  $R^2 \approx 0.5$  were obtained over areas near the Equator and lower latitudes linked to lower seasonality. Altogether, our S3 vegetation products proved to be generally consistent against the corresponding MODIS products, and can serve in support of FLEX' fluorescence products to monitor the planet's vegetation status, health and dynamics.

## MEDITERRANEAN BASIN VEGETATION FORECASTING APPROACHES: ACCURACY ANALYSIS & CLIMATE-LAND COVER-SENSOR NEXUS IMPACTS

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From land degradation and desertification to cyclones and tropical storms, and so on, the repercussions of global change have become increasingly severe in recent years. Consequently, land cover forecasting is now required in order to assess and monitor such environmental impacts, although it remains a challenging task. However, to study and analyze these impacts, several time series forecasting models have been widely developed.

In this study, accuracy of the most used forecasting approaches has been quantified and three impacts (i.e., climate regions, land cover, and satellite sensor) were carried out. Firstly, five different forecasting approaches (i.e., Convolutional Neural Networks, Long Short Term Memory Network, Deep Neural Networks, Recurrent Neural Networks and Centered Moving Average) were used for predicting vegetation biophysical indices (i.e., Normalized Difference Vegetation Index, Enhanced Vegetation Index, Chlorophyll Vegetation Index, etc.). Secondly, eight Mediterranean regions (north and south) were selected (i.e., 2 regions hot arid, 2 regions cold arid, 2 regions warm temperate hot summer, 2 regions warm temperate warm summer) based on Köppen climate classification. Using 672 hyperspectral images retrieved from USGS satellite images database (i.e., MODIS, Landsat 8 OLI/TIRS, and Sentinel 2) from 2015 to 2022. Accordingly, 2688 images were computed resulting in 96 time series forecasted using the aforementioned approaches. Finally, 480 forecasted time series has been determined and compared, and the computed approaches' corresponding accuracies are showing interesting and promising results.

## ESTIMATION OF FIRE SEVERITY USING SENTINEL-2 SPECTRAL INDICES IN THE 2020 GALICIA FOREST FIRES

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Galicia forest areas suffer forest fire events at differing frequencies, intensities, and fire severities. Fire severity is directly related to the amount of biomass consumed, the rate of vegetation recovery and the risk of erosion. Consequently, a correct assessment of fire severity involves selecting the appropriate treatment and minimizing the restoration time of the affected area. In this sense, the objective of this article is to develop a methodology for the fire severity assessment, in forest fires occurred in Galicia in 2020. As input data, this study is based on the use of Sentinel-2 spectral indices, which are characterized by having spectral bands in the near-infrared (NIR) and short-wave infrared (SWIR) spectral regions, allowing a high distinction between different fire severity degrees. All possible combinations between Sentinel-2 bands applied to a spectral normalized difference index (SPI) were analysed, along with one of the most commonly used burn spectral indices in remote sensing: the relative differential Normalized Burn Ratio (RdNBR). In addition, in order to delete confusions between burned area and the presence of other land cover areas, the temporal differences between pre-fire and post-fire dates were obtained for each spectral index (dSPI). The results obtained were compared by field points classified as in Ruiz-Gallardo et al. (2004) study (null, low, moderate and high severity). Previously, the influence of pre-fire vegetation density on fire severity values was analysed. The separability index (SI) was also applied, based on averages and standard deviations, to select the most suitable band combinations. The final statistic results obtained, show that the combination of the Normalized Difference Vegetation Index (NDVI) and the modified Normalized Burn Ratio (NBR2), used in areas with mixed and full vegetation respectively, provides the best results in fire severity assessment (kappa statistic equal to 0.81). This work is carried out in the context of the project "Joint Strategy for the Protection and Recovery of ecosystems affected by wildfires" (EPyRIS).

## MONITORING WINTER BARLEY WITHIN-FIELD YIELD USING POLSAR, BACKSCATTER COEFFICIENTS AND SURFACE REFLECTANCE DATA

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According to United Nations' Department of Economic and Social Affairs, by the end of this decade, global population will have risen to 8 plus thousands of million people. This manifests the necessity of increasing food production in order to feed our rising population. The previous, in the context of a changing climate and energy vector scarcity, highlights the importance of ensuring and monitoring essential resources such as crops (and specifically winter cereals) to maintain and improve food production. In this work we monitor within-field barley yield based on Earth Observation (EO) data from Sentinel-2 and Sentinel-1. Both satellites' data has been preprocessed granting Sentinel-2 BOA surface reflectance and Sentinel-1  $\gamma_0$  backscatter coefficients and noise free H-A- $\alpha$  decomposition. Yield maps data have been measured by harvest machines during 2020 and 2021 seasons, providing dry yield roughly every 7m, over irregular polygons. Thus, field data has also been preprocessed to achieve spatial consistency and reduce measuring software errors. Training and validation has followed a structure of k-fold cross validation. The main objective of this work is exploring the integration of C-band SAR data (center frequency of 5.405 GHz) to monitor barley yield. On one hand, Sentinel-1 data can increase Sentinel-2 temporal resolution and assure that even in cloudy conditions information on crop development can be retrieved. But on the other side, in cloud free conditions each spectral band and polarization is analyzed to define the combination that is best correlated with the final yield maps. Therefore, linear regression (ordinary and regularized) and machine learning (random forest) algorithms were tested using different spectral bands and polarizations from both Sentinel satellites. An

optimal date for the final model has been selected attending to performance metrics such as R2 coefficient of determination, Root Mean Square Error (RMSE) and Relative RMSE (RRMSE); creating predicted within-field yield maps and tracking their uncertainties.

## SHALLOW MAGMATIC INTRUSION EVOLUTION BELOW LA PALMA BEFORE AND DURING THE 2021 ERUPTION

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La Palma, Canary Islands, underwent a large volcanic unrest which culminated in its largest historical eruption on September 19<sup>th</sup> 2021, on the Tajogaite volcano. We study this unrest along 2021 using satellite radar interferometry (InSAR) with imagery from the C-Band Sentinel-1 constellation and a new improved interpretation methodology, comparing the results with the crustal structure and recent volcanic activity. To achieve reliable results from InSAR in small volcanic islands characterized by steep slopes, like La Palma, a proper atmospheric estimation and filtering must be done. We used data from the ERA5 model to estimate the atmospheric delay and filter it from the interferograms. We reproduce the final phase of La Palma volcanic unrest, highlighting a shallow magma accumulation which begins about 3.5 months before the eruption in a crustal volume characterized by low density and fractured rocks. Our modeling, together with understanding of the crustal structure, allows us to explain the location and type of eruption and to detect failed eruption paths. Our results have implications for understanding volcanic activity in the Canaries and volcano monitoring elsewhere, helping to support decision-making and providing significant insights into urban and infrastructure planning in volcanic areas.

## RADAR INTERFEROMETRY AS A MONITORING TOOL FOR THE RIOTINTO MINE (HUELVA, SPAIN)

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Soil instability is a major hazard facing the mining industry in its role of supplying the indispensable mineral resources that our societal challenges require. We aim to promote the use of radar satellites, especially Sentinel-1, to improve the monitoring capacity of mining stakeholders. We choose the Riotinto Mine in Huelva, Spain, as it is an active mining site which has different kinds of environments converting it in a good test site for this study. We analyzed the deformation field in the Riotinto mine. A historical review of the surface deformation field using the ESA's radar archive has been performed, highlighting the remarkable improvement provided by Sentinel-1. We focused our study on the Atalaya open pit and the abandoned rock dumps. We propose a new method for combining ascending and descending results into a common dataset that provides better resolution. We project the LOS measurements resulting from both geometries to a common reference system without applying any type of geometric restriction. As a projection system, we use the vertical direction in flat areas and the slope in steep topographies. We then identify and remove outliers and artifacts from the joint dataset to finally obtain a deformation map that combines the two acquisition perspectives. The obtained results in the Atalaya pit are highly consistent with GNSS measurements. The movements observed in the rock dumps were unknown before this study. We demonstrate the great potential of the Sentinel-1 satellite as a complementary tool for monitoring systems in mining environments and we call for its use to be standardized to guarantee a safe and sustainable supply of mineral resources necessary for a just technological transition.

## **ESTIMATION OF DEFORESTATION AND MONOCROPS IDENTIFICATION IN NORTHERN COSTA RICA USING RESCALING OF SYNTHETIC APERTURE RADAR (SAR) SENTINEL 1A IMAGERY**

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Synthetic Aperture Radar (SAR) polarimetry is a remote sensing technique known for being applied to monitoring land surface and deforestation. Polarimetry aims at characterizing the land surface through the analysis of its response under different combinations of transmitting and receiving antennas polarization, called polarimetric channels.

Copernicus Sentinel-1 SAR system has been designed to satisfy a core of requirements in global monitoring land-surface for motion risks, mapping for forest, water and soil management and mapping to support humanitarian aid and crisis situations. Its dual polarimetric ability allows vegetation related studies, as vegetation type and height cause different reflection signature in copolarised and cross-polarised radar observations. Sentinel 1 processing allows detection of deforestation events with more than 95% of user's accuracy, which means that the data is reliable and could be used by any users monitoring forest.

On this study, processing of Sentinel-1 Ground-Range Detected (GRD) imagery to radiometrically terrain corrected gamma-naught ( $\gamma_0$ ) backscatter and its correlation with radar vegetation index and Sentinel 2 NDVI was investigated. Then, data provided as gamma-naught ( $\gamma_0$ ) backscatter, mitigates systematic contamination that would otherwise still be present in sets of data acquired with multiple geometries. Finally, we used the form of the normalized radar cross section with gamma-naught ( $\gamma_0$ ) rather than sigma-naught ( $\sigma_0$ ) or beta-naught ( $\beta_0$ ) since the backscatter is normalized by the illumination area under an assumption of scattering uniformity.

The use of vertical/vertical polarization proved to be efficient for estimating the extent of deforested areas and musaceous crops discrimination in northern Costa Rica. To that end, Sentinel-1 images from the European Space Agency has been used, with a calibration/workflow process and a subsequent rescaling that allowed to draw a clear distinction between forested areas and crops more effectively than radar vegetation index based on cross-polarization. We have been experimenting with the Sentinel-1 data processing, analysing the data after first separating them into groups of data before and after the deforestation.

## INTEGRATION OF L-BAND AND C-BAND SAR DATA WITH HIGH RESOLUTION OPTICAL OBSERVATION IN FIELD CROP YIELD ESTIMATION

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Yield forecasting and production estimation of staple crops is a socio-economic challenge that impacts people from the global to farm level scale. In the context of climate change, uncertainty on the future of crop productions is a major issue. The evolution of optical and radar satellites imagery from moderate to very high resolution provides new tools to address yield variability at different spatial scales. The Moderate Resolution Imaging Spectroradiometer (MODIS), and Visible Infrared Imaging Radiometer Suite (VIIRS) tools have provided significant information in the crop yield status at the national and regional levels. But to improve local scale forecasting models, it is necessary to integrate high and very high-resolution data.

We focused our study on the capacity of high and very high optical and radar data to capture the yield variability between fields. We used Planet/Dove-Classic, Sentinel-2, Landsat 8 (through Harmonized Landsat Sentinel-2 - HLS) and SAR data (UAVSAR, RADARSAT-2, Sentinel 1). By averaging yields data at field level from 258 fields of Corn, Soybean and Rice in Arkansas, we observed varying performance between radar index and between crops. In terms of spectral bands, NIR ( $\sim 0.865\mu\text{m}$ ) was the most important for explaining yield variability independent of resolution and crop type ( $R^2_{\text{adj}} > 0.5$ ). In term of polarimetric index, the results showed that in general the results for rice are mostly stable and better than the other crops ( $R^2_{\text{adj}} \sim 0.4$  on average). The best results are obtained for the Sentinel 1  $\text{VH}_{\text{asc}}$  with  $R^2_{\text{adj}} = 0.42$  and for RADARSAT-2 phase difference with  $R^2_{\text{adj}} = 0.42$ . The results for corn are the worst with an  $R^2_{\text{adj}} < 0.35$  for all the indices. The results for soybean are more variable and seem to be highly correlated with certain index such as RADARSAT-2 HV, RADARSAT-2 Volume and RADARSAT-2 Pauli HV with  $R^2_{\text{adj}} > 0.4$ . For optical and radar satellite-derived features, we investigated the day of the years of the maximum correlation for corn, soybean, and rice. The maximum correlation for optical features occurs in a short time range between the day of the year (DOY) 155 and 185 for corn and rice, and DOY 190 and DOY 211 for soybean. It shows a consistency between of the optical derived feature. On the contrary, the maximum of correlation for radar derives features occurs for very variable DOY from DOY 120 to DOY 225. A study of the time series parameters correlation show that the optical parameters are highly correlated, but the radar parameters show strong temporal decorrelation. Through this way we identified six most important radar parameters for rice, four for corn and four for soybean.

We also found that spectral and polarimetric data saturate over high yields and cannot capture yield variability. The results suggest the importance of combining radar data and optical data to integrate other biophysical variables, such as soil moisture and evapotranspiration.

## OPERATIONAL DERIVATION OF HIGH SPATIO-TEMPORAL RESOLUTION AGRONOMIC INDICATORS FROM SENTINEL-2 AND LANDSAT-8 SATELLITE OBSERVATIONS

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Earth observation through the operational use of sensors on board satellites allows the monitoring of

terrestrial climatological and meteorological characteristics. In agro-technology, the knowledge and monitoring in quasi real-time of some variables as, Leaf Area Index (LAI), Land Surface Temperature (LST) or Evapotranspiration (ET) and their evolution with the crop cycle results of vital importance to improve efficiency in agricultural applications, for instance, optimizing the management of water resources. For that, a processing chain has been developed in the project AGRINDSEN-123 (funded by CDTI) to estimate these variables from ESA Sentinel-2 (S2) and U.S. Geological Survey (USGS) Landsat-8 (L8) open distributed images.

The use of synergy of data from both satellites allows increasing the frequency of image acquisition. Thus, optical channels of L8 were harmonized to S2 for sake of consistency (L8HS2). The production chain has been tested in two different areas of interest in Spain: Barrax/Albacete (centered at 39.05°N, 2.10°W) and Moncada/Valencia (centered at 39.05°N, 0.39°W). The main tasks carried out are: (1) The estimation of (Normalized Difference Vegetation Index (NDVI) and biophysical variables (Leaf Area Index – LAI, Fraction of Absorbed PAR – FAPAR and Fraction of green vegetation cover - FCOVER) using Gaussian Process Regression (GPR) matching learning functions and a synthetic database based on PROSAIL, (2) the estimation of the crop type (crop classification) using Random Forest (RF) matching learning method, (3) estimation of re-scaled LST values at 10m, combining synergistically Sentinel-2 and Landsat-8 and (4) estimation of the water needs of the crop, calculating the evapotranspiration (based on the Surface Energy Balance Index (SEBI) method) and computing the hydric balance with pluviometry of the days before. The current portfolio of the processing chain includes: NDVI from S2 and L8 harmonized to S2 (L8HS2), LAI/FAPAR/FCOVER from S2 and S2HL8, Crop classification using S2, LST from S2 and L8, ET from S2 and L8 and water needs (NH) from S2 and L8.

## YIELD FORECAST MODELS AND NITROGEN CONTENT MANAGEMENT IN RICE CROPS IN VALENCIA

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Rice is one of the major commodities traded in the international food market and basic food in the diet of more than half of the world's population, especially in underdeveloped or developing countries. Rice is a crop of economic importance in Spain, that contributes to 28% of the European rice production, being the second major rice producing country in Europe behind Italy with 50% of the total production. Therefore, an accurate and timely crop yield forecasts are necessary for making viable agricultural investments, developing proper agricultural planning, increasing market efficiency and stability, as well as manage food shortages. On the other hand, fertilizers and pesticides are routinely used in rice cultivation to maintain optimal yield and to protect plants from diseases. However, the overuse of fertilizers and pesticides, has adverse effects on the environment and human health, that has led to the regulation of the use on nitrogen in agriculture to minimize its impact. Fertilization management in modern agriculture aims to supply just the fertilizer needed to maximize yields while avoiding their excesses to ensure environmental sustainability.

Precision agriculture is defined as the management of crops based on the knowledge of the spatial and temporal variability in an agricultural holding, to improve the economic return and minimize the environmental impact. Earth Observation data provides timely, objective and accurate information that is critical for precision agriculture applications. In this work we study two main applications of precision agriculture in rice crops based on Sentinel-2 and drone data. Particularly, this study explores the use of remote sensing data to monitor rice crop yield and nitrogen content in the plant, allowing more efficient, sustainable and profitable rice management practices.

First, we develop a rice yield model at field scale based on yield measurements over 78 ha/year around the Albufera in Valencia (Spain) from 2017 to 2020 seasons. The dataset covers the two main varieties, that is JSendra and Bomba, and provides average yields at field scale. Training and validation follow a structure of k-folds cross validation. The main objective is to obtain prediction models based on linear regression and machine-learning that correlate the spectral bands of Sentinel-2 with the final yield data. Preliminary results show that it's possible to forecast rice yield at field level with a Root Mean Square Errors (RMSE) of 0.47 t/ha (5.2%) in JSendra and 0.29 t/ha (6.4%) in Bomba on July 9, about three months before harvest, thus satisfying the important premise of precision agriculture about offering early predictions.

The second objective of this work is to analyse rice crops with different nitrogen level treatments using Sentinel-2 and drone data. This is conducted over an experimental field close to the Albufera that was split into three different areas characterized by different nitrogen treatments: 130.9 kgN/ha, 176.2 kgN/ha and 243.1 kgN/ha. Field data on the within-field yield was collected by harvesting machines. Preliminary results show that NIR band can monitor the rice development over different nitrogen management, and also that when applying a really high nitrogen content, the final yield is comparable to the medium nitrogen content.

## TOWARD AN AUTONOMOUS MOBILE SYSTEM CONTROLLED BY REMOTE SENSING DATA FOR AGRICULTURAL TASKS: DATA COLLECTION PHASE

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During the last decades, the development of agricultural robots has become necessary. Collecting environment data (soil and air) is extremely required before any operation. Therefore, the robot will be able to perform the demanded tasks with precision and high speed. Nevertheless, the current data challenges are increasingly complex; in addition, data must be exploited in new forms.

The idea of the research paper; is to automate the steps of agriculture from the phase of data collection to the phase of application of the tasks by the robot. Our focus is mainly on the data collection phase; will no longer be manual - which is expensive and exhausting – it will be replaced by satellite remote sensing data. These last allows for collecting a huge quantity of information in quasi-real-time with a precision on the plant, soil, and air conditions.

The robot will be a fully autonomous mobile system, from navigation to task execution. It is composed of two main subsystems: i) a flexible manipulator that performs demanding tasks autonomously with the necessary sensor technologies and, ii) an electric mobile platform equipped with four drive wheels and four steering wheels that enhance the traction and steering system to operate in different environments, from open fields to greenhouses to polytunnels. In addition, a compatible positioning system that allows the robot to navigate autonomously along crop rows; the global RTK-GPS sensor will be used to locate the robot and heading angles will be measured by the IMU. ROS is then used to collect and process data in order to generate control commands.

## VALIDATION OF GLOBAL LAI, FAPAR AND FVC PRODUCTS DERIVED FROM AVHRR ONBOARD THE EUMETSAT POLAR SYSTEM

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The Satellite Application Facility for Land Surface Analysis (LSA-SAF) is part of the SAF Network, a set of specialized development and processing centres, serving as EUMETSAT distributed Applications Ground Segment. The main purpose of the LSA-SAF is to take full advantage of EUMETSAT remotely sensed data, to measure land surface variables. In addition to the geostationary satellites, the EUMETSAT Polar System (EPS) operates Meteorological Operational (MetOp) satellites with the AVHRR sensor onboard. This paper describes the main results of the quality assessment of the suite of LSA-SAF EPS operational vegetation (VEGA) products including the leaf area index (ETLAI), the fractional vegetation cover (ETFVC), and the fraction of absorbed photosynthetically active radiation (ETFAPAR). The retrieval algorithm developed by the University of Valencia is based on a hybrid approach (a multi-output Gaussian process regression) that blends the generalization capabilities offered by physical radiative transfer models with the accuracy and computational efficiency of machine learning methods. The EPS vegetation products are delivered at a 10-day frequency and 1 km spatial resolution at a global scale.

The quality assessment is performed in agreement with best practices for validation of global LAI satellite products proposed within the Committee on Earth Observation Satellite (CEOS) Working Group on Calibration and Validation (WGCV) Land Product Validation (LPV) subgroup. The validation is based on two main exercises: direct validation with ground data and satellite product intercomparison (indirect validation). For the direct validation, CEOS LPV endorsed DIRECT V2.1 upscaled maps are used as a reference, as well as Ground-Based Observations for Validation (GBOV) multi-temporal ground-based data. Regarding satellite product intercomparison, equivalent global vegetation products from Copernicus Global Land (PROBA-V Collection 1 km V1) and NASA (MODIS Collection 6) are compared with LSA-SAF EPS products. Validation results show overall good quality in terms of spatial and temporal consistency, and similar accuracy than other satellite products in the comparison with ground observations.

## ESTIMATION OF WBGT THERMAL COMFORT INDEX IN THE CITY OF SANTIAGO, CHILE, USING SPATIALLY EXPLICIT MODELING.

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In the city of Santiago, Chile, higher temperatures could be related to higher mortality risks, especially for the elderly population. Given the projections of future temperature increase in the region where the city is located for the coming years, it is important to quantify thermal comfort for its incorporation into environmental regulations. This work proposes a spatially explicit modeling methodology using satellite products from the MODIS platform and meteorological data from the SINCA and AGROMET networks to calculate the spatial and temporal variation of the WBGT index in Santiago. The climatology of the WBGT index is obtained at 250 m for spatial resolution and eight days for temporal resolution. A cluster analysis is also performed to determine behavior homogeneous areas within the urban area and the significance of the trends in each of them is evaluated. The processing of these data allows estimating the index at the city scale

and observing geographical and urbanistic relationships with the level of thermal discomfort in outdoor spaces. These results could be a contribution to urban planning in terms of the generation of easily accessible information for adaptation and mitigation of the impact on the thermal quality of urban environments.

## **A DATASET OF THE EXPERIMENTAL CAMPAIGN CAMCATT FOR THE VALIDATION OF AN URBAN MICROCLIMATIC TOOL**

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In the frame of the CAMCATT experiment over Toulouse city in June 2021, a dataset was collected to evaluate the microclimatic conditions of a residential area. This campaign consisted of measuring the surface temperature evolution of different facades of a building of interest and its urban surrounding using different sensors during several days. The observed scene is composed of buildings of the same geometry and height and the surrounding ground is made of either lawn or concrete paths. The emissivity and reflectance of the main materials constituting the scene were also measured using an ASD field spectrometer and a SOC410T respectively. The atmospheric conditions were collected nearby thanks to a weather station recording air temperature, humidity and the wind conditions. This set of data will be helpful and used to validate microclimatic tools and to investigate the thermal radiative exchanges at a district scale.

The outside wall surface temperatures as well as the inside and outside air temperatures have been measured by means of several sensors : (1) iButtons measuring directly the material surface temperature by contact (50 sensors on the entire urban scene) during more than a week, (2) a thermal camera acquiring images every five minutes over a portion of one of the instrumented façade during 4 days, (3) KT19 radiometers measuring at a particular time the surface temperature with high accuracy for few locations close to some of the iButtons, (4) HOBO sensors measuring the air temperature in several apartments. The high amount of iButtons is interesting to have a good sampling of the façades but the accuracy of such sensors can be low and their behavior in changing lighting conditions is still poorly documented. Therefore KT19 sensors which are more accurate and the thermal camera providing a spatialized information help investigating and correcting the iButtons uncertainty. The complementarity between all those measurements is useful to have a good dataset to validate microclimatic tools.

The microclimatic model Solene-Microclimat will be used in this paper. It has been developed to investigate the consequences of urban context on local microclimate and indoor thermal conditions. It is dedicated to modeling urban microclimate and building thermal behavior at the district scale. The modeling approach is based on the coupling of radiative, thermal and CFD models. It can simulate a large range of cases encountered in urban projects: modeling of vegetation, water ponds, soils, building energy simulation, and techniques such as cool paints and surface water aspersion.

In this paper, we will describe the measured dataset, how it has been processed and the main limits of each sensor's measurement. Finally, the first comparisons between the simulations with the microclimatic tool Solene-microclimat and the dataset will be presented.



## **ESTIMATION OF WATER VAPOUR ATMOSPHERIC CONTENT VARIABILITY AND ITS IMPACT ON LST ESTIMATION OVER TOULOUSE USING AIRBORNE DATA ACQUIRED DURING THE AI4GEO/CAMCATT CAMPAIGN**

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In the current context of climate change and growing urbanization, accurate estimation of Land Surface Temperature (LST) over urban areas is crucial for many applications such as surface heat urban island monitoring or comfort index calculations in support to urban planning and adaptations measures. Many studies explored the potential of retrieval algorithms adapted to the complexity of city by taking into account the large material heterogeneity and the surface roughness but few investigated the impact of water vapour variations above the urban areas. Indeed, the signal measured from airborne or spaceborne sensors in the thermal infrared (TIR) domain is strongly influenced by the water content of the atmosphere. In most cases, atmospheric corrections over cities are performed using a single value of water vapour content for the entire studied area. However, significant variations can be observed over urbanized area which could potentially lead to LST retrieval errors. This work aims to analyse the water vapour variations that can be observed in a real study case along with estimating its impact on LST estimations. To do so, hyperspectral (0.4-2.5  $\mu\text{m}$ ) and thermal airborne data acquired simultaneously over Toulouse the 15<sup>th</sup> June 2021 during the AI4Geo/CAMCATT campaign are used. The water vapour content is estimated from the hyperspectral data at 1m spatial resolution using COCHISE, a radiative transfer model developed at ONERA. The model generated water vapour maps that are then used to derive at-surface radiance from the airborne TIR data. Finally, LST maps are derived from the atmospherically corrected TIR data using a Temperature Emissivity Separation (TES) approach. Analyses are carried out at several spatial resolutions, from native (1m) to future IRT satellite (50m) spatial resolutions, and using atmospheric profiles coming from radio sounding performed during the campaign or from a reanalysed dataset. The results evaluate the water vapour variability over Toulouse during the AI4Geo/CAMCATT campaign and present its impact on LST estimations for different data configurations to finally conclude on the need or not of considering this variability when retrieving LST over urban areas.

## **ANALYSIS OF SURFACE URBAN HEAT ISLAND EFFECT DURING 2021 USING AUTOMATIC CLASSIFICATION OF SPANISH CITIES WITH DEEP LEARNING ALGORITHMS**

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This work aims to perform an analysis of the surface urban heat island effect (SUHI) during the year 2021 in all major cities in Spain, in order to obtain an estimate of the increase in the surface temperature of each city, with respect to its surrounding green areas. Land Surface Temperature (LST) was used to measure the temperature difference, which is retrieved from the MYD21 and MOD21 products of the Aqua and Terra satellite of MODIS, respectively. This product was chosen for its daily temporal resolution for the areas under study and for using the Temperature Emissivity Separation (TES) algorithm for LST estimation. It is known that the spatial resolution of 1 km per pixel is quite low for the study being pursued, but the proposed

approach aims to apply more complex statistical methods based on Deep Learning algorithms to classify and differentiate urban areas from their surrounding green areas. State-of-the-art models based on natural language processing (NLP), more specifically the 'Transformers' model will be used for classification. This model uses attention mechanisms to search for contextual relationships between image pixels, decreasing the computational and temporal cost and achieving accuracies in the range of 90% to 95% in classification or segmentation of satellite images.

## SENTINEL SATELLITE DATA MONITORING OF AIR POLLUTANTS IN GUAYAQUIL

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Satellite remote sensing is an effective tool to study atmospheric pollutants and has been applied to overcome the limitations of fixed stations. Application of satellite data for air quality monitoring, there are some limitations, such as measurement frequency, cloud cover and wide spatial resolution. This research, applying interpolation methods, is essential for continuous air pollution monitoring at smaller scales. NO<sub>2</sub> data from the Sentinel-5 precursor in the city of Guayaquil were used. Due to the limitation of pixel size, this study used satellite data to apply interpolation techniques and reduce pixels to assess air quality. The empirical Bayesian kriging (EBK) method obtained a R<sup>2</sup> of 0.9546, which was superior to the other methods applied. Finally, the method used in this research can help to monitor air pollutants in cities where continuous monitoring networks do not exist, as the reduction of the pixel size gives us a better pattern of pollutants.

## AEROSOL EPISODES IN THE PERIOD 2017-2021 IN THE EUROPEAN ARCTIC IDENTIFIED BY SUN PHOTOMETRY/AERONET

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The Arctic climate is changing due to global changes because of climate change. The role played by atmospheric aerosols in that pristine area is still not well known since there is a lack of their knowledge about the spatio-temporal distribution. To determine the direct effect of atmospheric aerosols on the Arctic radiative budget is the main objective of the present study.

Aerosol episodes in the Arctic are detected following a methodology developed by Mateos et al. (2020) which

has been adapted to the particular super-site of Ny-Ålesund (79°N). This kind of episodes are mainly caused by long-range transported aerosols. Big forest fires in Canada and Russia are usually the origins of these episodes. Optical and microphysical properties are recorded in Ny-Ålesund by a CIMEL photometer in the AERONET framework (<https://aeronet.gsfc.nasa.gov/>). Once the episode is detected, a detailed analysis of the main aerosol properties are addressed to determine how long-range transport can modify the observed properties with respect to fresh aerosols in the origin.

The aerosol radiative effect (ARE) is obtained in this study as the subtraction of two different radiative transfer simulations by the libRadtran code ([www.libradtran.org](http://www.libradtran.org)). Simulations of surface and top-of-atmosphere net solar fluxes are carried out considering as input data spectral aerosol optical depth (AOD), Ångström exponent, spectral single scattering albedo, and spectral asymmetry factor together with other meteorological data (surface temperature, ozone column, water vapor, surface albedo...). The second simulations are obtained for the same conditions but without aerosols in the atmosphere. The ARE values are, therefore, obtained as the subtraction of these two net quantities. This procedure is carried out for all the instantaneous measurements of CIMEL photometer. All the points belonging to the same episode (even lasting for some consecutive days) are analysed together to derivate the aerosol forcing efficiency as the slope of the linear fit between ARE and AOD.

## COMPARING INTEGRATED WATER VAPOR OBSERVATIONS FROM RADIOSONDES AND SUN PHOTOMETERS OVER THE ARCTIC.

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Scientists, policy makers and society are currently focusing their attention on the amplification of global warming because of the feedbacks associated with the increase in atmospheric moisture and the decrease in sea ice and snow cover in the Arctic. The global warming amplification is the response to increases in precipitation originally caused by climate change. Observations have documented the Arctic predominant increases in specific humidity and precipitation. However, evapotranspiration in the Arctic is poorly known, in part, because accurate in situ and remote sensing observations are spatially and temporally sparse. Although AERONET sun photometer integrated water vapor (IWV) measurements have been conducted in more than 20 observations sites in the Arctic, that information has been barely used. A comparison of the IWV observations from radiosondes and AERONET sun photometers at ten sites located across the Arctic is shown with the goal to document the feasibility of that set of observations to contribute to the ongoing and future research on polar regions. The predominant dry bias of AERONET IWV observations with respect to radiosondes, identified at tropical and midlatitudes, is also present in the Arctic. The statistics of the comparison show robust results at eight of the ten sites, with precision and accuracy magnitudes below 8 and 2 % respectively. The possible causes of the less robust results at the other two sites are discussed. Also, the impact of selecting other temporal coincidence windows in the average sun photometer IWV used in the comparison were tested. An appreciable bias in the statistics used for the comparison could be associated to the autocorrelation in diurnal sun photometer IWV. We suggest using only one pair of values per day, consisting in the daily mean IWV sun photometer and the IWV radiosonde observation value. This feature should be valid also for comparison of IWV from sun photometer and other instruments. When IWV from sun photometer observations are compared with IWV from radiosondes, in the Arctic a maximum 10% error level is found, in the same order of magnitude than at tropical and middle latitudes locations. The feasibility of AERONET IWV observations in the Arctic for research on this variable has been demonstrated. AERONET standard instruments and its centralized-standard processing algorithm allow its IWV observations to be considered a relative standard dataset for the re-calibration of other

instrumental IWW observations assuming radiosondes as the absolute standard dataset.

## **INTER-ANNUAL TRENDS OF FAPAR AND FVC SEVIRI/MSG CLIMATE DATA RECORDS ALONG THE PERIOD 2005-2020**

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The scientific community requires consistent long-term data records with well-characterized uncertainty and suitable for modeling terrestrial ecosystems and energy cycles at regional and global scales. A climate data record (CDR) of different variables for the characterization of terrestrial ecosystems is freely available within the EUMESAT Satellite Application Facility for Land Surface Analysis (LSA SAF) from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board MSG 1-4 (Meteosat 8-11) geostationary satellites. These CDRs offer more than fifteen years (2005-present) of homogeneous time series required for climate and environmental applications.

This work aims to analyse inter-annual trends of land surface vegetation over the geostationary Meteosat disk, covering Europe, Africa, the Middle East and parts of South America. For this purpose, the CDR time series for fraction of absorbed photosynthetically active radiation (FAPAR) and fractional vegetation cover (FVC) are considered. These CDRs offer consistent, homogeneous and continuous 10-day data for the period 2005-2020 derived from the best version of their equivalent near real time FAPAR and FVC products. The multi-resolution analysis (MRA) based on the wavelet transform (WT) was applied to derive the inter-annual trends of FAPAR and FVC time series. The MRA provides a temporal decomposition of the original series, where different components of the signal can be derived removing the contribution of specific temporal resolutions.

The MRA-WT has widely demonstrated, from numerous and previous studies, its the potential to trace the inter-annual variability to detect trends. Our results show a general *greening* in most of the Meteosat disk, which is associated with an increase in precipitation in the period. However, some degraded areas are detected in which photosynthetic activity is no longer observed to increase, although precipitation does. These areas are located in the border region with the Sahara, South of Africa, East of South America, and central part of Europe.

## **ENVIRONMENTAL DRIVERS AND REMOTE SENSING PROXIES OF POST-FIRE THAW DEPTHIN EASTERN SIBERIAN LARCH FORESTS**

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Recent years have been record-breaking for wildfires in Eastern Siberian larch forests. Boreal fires combust parts of the insulating soil organic layer, resulting in a deepening of the seasonally thawed active layer

of permafrost soils. This may result in permafrost degradation and associated longer-term carbon emissions. We collected field data in 13 burned and 7 unburned plots in the Yert fire (Republic of Sakha, Russia) in 2019, about a year after the fire, and assessed how vegetation, topography, and fire co-influenced active layer depth. Specifically, we investigated the statistical relationships between several environmental variables (e.g., topographic position, site moisture, basal area, tree density, species proportion, burn depth) and thaw depth. Our results showed that the mean thaw depth was higher in the burned ( $mean = 127.3$  cm,  $standard\ deviation = 27.7$ ) than in the unburned ( $mean = 98.1$  cm,  $sd = 26.9$ ) plots. Active layer tended to be deeper in well-drained landscape positions, that were characterized by open and mature Cajander larch (*Larix cajanderi*) forests, sometimes intermixed with Scots pine (*Pinus sylvestris*). Furthermore, deeper burning increased thaw depth. Fire severity thus influenced active layer thickening; however, this process was mediated by topography and vegetation characteristics. A multiple linear regression involving field-measured fire severity, vegetation type and density, and topographic position explained 73.4% of thaw depth variability. In addition, we used Landsat 8 (OLI and TIRS) imagery to assess whether remote sensing proxies could predict post-fire thaw depth. We included satellite-derived albedo, land surface temperature (LST), differenced Normalized Burn Ratio (dNBR) and pre-fire Normalized Difference Vegetation Index (NDVI). Altogether, these remote sensing metrics explained 64.9% of the field-measured variability in thaw depth. In particular, the strong correlation between LST and thaw depth ( $R = 0.66$ ,  $p < 0.01$ ) is promising for further spatial upscaling. Our results demonstrate governing process of post-fire thaw depth and show the potential of Landsat imagery to map thaw depth at landscape scale.

### SPATIOTEMPORAL EVOLUTION OF THE LAND COVER OVER DECEPTION ISLAND, ANTARCTICA, ITS IMPACT ON ALBEDO AND ITS RELATIONSHIP WITH METEOROLOGICAL VARIABLES.

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The aim of this work is to provide a quantitative description of the spatiotemporal evolution of land cover over Deception Island (Antarctica). Deception Island is an active volcano with recent eruptions and unrest episodes. It has areas of very dark soil with varying size along summer as well as large areas of snow contaminated with volcanic ash. The variety of surfaces and the active processes in the island make it a suitable location for detecting changes in the land cover. The spatiotemporal evolution of land cover determines the surface energy balance. Although high- and mid- resolution satellite sensors may provide an accurate instantaneous picture of the land cover, their low temporal resolution is a serious drawback to obtain long time series. In this work we use shortwave broadband albedo data (albedo integrated over the range 400-3000 nm) from satellite sensors and from in-situ surveys to calculate the monthly relative abundances of land cover types. In-situ distributed shortwave albedo data were collected over seven types of covers: continuous clean fresh snow (S1); continuous clean old snow (S2); continuous dirty snow (S3); mixture of clean snow, dirty snow and lapilli (S4); mixture of snow and bare soil patches (S5); shallow snow with small bare soil holes (S6); continuous bare soil (S7). The albedo was measured using a portable albedometer consisting of two pyranometers, one facing the sky and another facing the surface. MODIS MCD43A3 daily albedo product was downloaded using the Google Earth Engine API. Data from 2000-2001 to 2019-2020 season are considered in this work. Each season extends from September to March of two consecutive years. Mean summer (December-

January-February) air temperature, surface temperature and solar radiation were collected by an Automatic Weather Station. From the in-situ albedo data, each land cover type was characterized by a shortwave albedo normal distribution. From the satellite data, monthly mean shortwave albedo was calculated for each pixel for each season. For each monthly mean, we calculated the histogram (number of pixels per albedo range). The monthly relative abundance of each cover type was calculated by fitting for each month a linear combination of the normal distributions to the histogram. For each season, we calculated the seasonal mean albedo over the whole island and the seasonal relative abundance of each cover type. The results show that the seasonal mean albedo over the island is driven by the summer mean air temperature. The mean seasonal albedo is highly correlated with the seasonal abundances of S4 and S6. Moreover, the mean seasonal abundance of S4 and S6 exhibits a high correlation with the mean summer air temperature. There is also strong correlation between the relative abundances of S4 and S6: while the relative abundance of S4 diminishes along the season, S6 relative abundance increases. These results provide an accurate picture of the land cover change and its driving mechanisms over Deception Island. The mean albedo of the island is determined by the competition between land covers S4 and S6, the summer air temperature being the driving mechanism.

### **FIDUCIAL REFERENCE MEASUREMENTS FOR VEGETATION (FRM4VEG): APPLYING METROLOGICAL PRINCIPLES TO VEGETATION PRODUCT VALIDATION**

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The Fiducial Reference Measurements (FRM) concept for validation of satellite-based products is a keystone of the ESA calibration/validation strategy. With a strong focus on metrology, it includes the need for traceability and fully characterized uncertainty budgets according to community-agreed-upon measurement protocols and uncertainty evaluation procedures. Within this strategy, the Fiducial Reference Measurements for Vegetation (FRM4Veg) project is aiming to address the challenge of applying metrological principles to vegetation and surface reflectance product validation.

For vegetation product validation, an end-to-end uncertainty evaluation framework has been developed for two main variables: the fraction of absorbed photosynthetically active radiation (fAPAR) and canopy chlorophyll content (CCC), which makes use of leaf area index (LAI) in its calculation. The process involves quantifying the uncertainties associated with individual in situ reference measurements from different instruments (DHP, LAI-2200, AccuPAR, SPAD), and incorporating these uncertainties (and those of the high-resolution satellite image) within the upscaling procedure, which facilitates the validation (uncertainty estimation) and conformity testing of high and moderate spatial resolution satellite products. fAPAR, LAI and CCC FRM over crops (Barrax, Spain) and deciduous broadleaf forest (Wytham Woods, UK) were collected in 2018 and 2021.

This talk will present to the validation community, firstly, the end-to-end evaluation framework developed in FRM4Veg for vegetation variables, from ground measurements to up-scaled maps with per-pixel uncertainties estimates, with particular attention to the different sources of uncertainties contributed by different instruments and data processing methods. Secondly, we will use the FRM data to validate and perform conformity testing of several LAI and fAPAR satellite products, including the ESA Sentinel-3 GI-FAPAR (so-called OGVI) product, the Sentinel-3 OLCI LAI and FAPAR provided by Copernicus Global Land Service, the NASA/NOAA Suomi NPP VIIRS LAI and FAPAR, and the high-resolution LAI and FAPAR products from Sentinel-2 derived in the Copernicus Land Service pan-European High-Resolution Vegetation Phenology

and Productivity (HR-VPP) layer. Finally, perspectives and future validation needs for satellite-based vegetation variables will be addressed.

## SENTINEL-2 LEVEL-2 PROCESSING SEN2COR STATUS AND OUTLOOK OF 2022

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The Sentinel-2 mission is fully operating since June 2017 with a constellation of two polar orbiting satellite units. Both Sentinel-2A and Sentinel-2B are equipped with an optical imaging sensor MSI (Multi-Spectral Instrument) which acquires high spatial resolution optical data products. The Sentinel-2 mission is dedicated to land monitoring, emergency management and security. It serves for monitoring of land-cover change and biophysical variables related to agriculture and forestry, monitors coastal and inland waters and is useful for risk and disaster mapping.

Accurate atmospheric correction of satellite observations is a precondition for the development and delivery of high quality applications. Therefore the atmospheric correction processor Sen2Cor was developed with the objective of delivering land surface reflectance products. Sen2Cor is designed to process single tile Level-1C products, providing Level-2A surface (Bottom-of-Atmosphere) reflectance product together with Aerosol Optical Thickness (AOT), Water Vapour (WV) estimation maps and a Scene Classification (SCL) map including cloud / cloud shadow classes for further processing.

Sen2Cor processor can be downloaded from ESA website as a standalone tool for individual Level-2A processing by the users. It can be run either from command line or as a plugin of the Sentinel-2 Toolbox (SNAP-S2TBX).

In parallel, ESA started in June 2017 to use Sen2Cor for systematic Level-2A processing of Sentinel-2 acquisitions over Europe. Since March 2018, Level-2A products are generated by the official Sentinel-2 ground segment (PDGS) and are available on the Copernicus Open Access Hub.

The objective of this presentation is to provide users with an overview of the Level-2A product contents and up-to-date information about the data quality of the Level-2A products (processing baseline PB.04.00 onwards) generated by Sentinel-2 PDGS since end of January 2022, in terms of Cloud Screening and Atmospheric Correction.

In addition, the presentation will give an outlook on the recent updates of Sen2Cor, which improve L2A Data Quality: updated L2A metadata, updated scene classification, updated fall-back method using meteorological information from the Copernicus Atmosphere Monitoring Service, updated Copernicus DEM.

## **NEW INSIGHTS INTO URBAN HEAT ISLANDS AND SOCIETAL VULNERABILITY FROM ECOSTRESS AND HYTES THERMAL INFRARED IMAGERY**

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Multispectral thermal infrared data (TIR: 8-12 micron) are widely used to produce a variety of critical long-term science data records such as Land Surface Temperature and Emissivity (LST&E), and Evapotranspiration (ET). The ECOSTRESS TIR mission launched in mid-2018, and upcoming TIR missions including LSTM, TRISHNA, and the NASA Surface Biology and Geology (SBG) in 2025-2028 will bring a golden age of high spatial resolution (< 100 m), multispectral TIR data, with a potential for a twice-daily global revisit. NASA's SBG will include both a TIR and VSWIR instrument and is a core component of NASA's new Earth System Observatory (ESO) to improve our understanding of vegetation processes, aquatic ecosystems, urban heat islands and public health, snow/ice, and volcanic activity. In this study we explore the use of high spatial resolution spaceborne ECOSTRESS and airborne HyTES TIR data in urban heat science and applications. Rapid 21st century urbanization combined with anthropogenic climate warming are significantly increasing heat-related health threats in cities worldwide, and partnerships between city policymakers and scientists are becoming more important as the need to provide data-driven recommendations for sustainability and mitigation efforts becomes critical. We will highlight the use of ECOSTRESS and HyTES TIR data in monitoring the variability of intra-urban heat islands during extreme heat events over the diurnal cycle, for pinpointing hotspot locations in cities to optimize urban heat mitigation interventions such as cool roofs, cool pavements, cooling centers, and urban greening; and to better understand the thermal properties of urban man-made materials relative to the urban biosphere.

## **LST AND SUHI RETRIEVAL WITH A MATERIAL-ORIENTED TEMPERATURE AND EMISSIVITY SEPARATION ALGORITHM FOR AIRBORNE AND SPACEBORNE THERMAL SENSORS**

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The LST (Land Surface Temperature) is a key-parameter related to water cycles, wildfires or vegetation stress, etc... Over urban areas, the LST allows to study the Surface Urban Heat Island (SUHI) effect and derive health related indices, thus it is an essential prerequisite to understand the urban climate and to help supporting mitigation strategies, assess urban sprawl or health risk management plans among others.



For multispectral radiometers, the LST is commonly retrieved in the thermal infrared spectral domain. When more than three spectral bands are available, the TES (Temperature and Emissivity Separation) algorithm can be used and is known to provide a 1 K accuracy for natural surfaces. Over urban areas, the LST retrieval is not trivial due to the additional presence of artificial materials, which lead to main error sources when not properly taken into account. Indeed, the spectral variability of artificial materials is larger than the natural ones making the estimation more complex.

The future satellite mission TRISHNA (CNES-ISRO) will carry a 4-band thermal radiometer onboard. We propose a new version of the TES algorithm in order to improve its accuracy for LST retrieval over urban areas. This work showed that a TES algorithm tuned according to the land cover type is better adapted for LST and SUHI retrieval. To do so, TRISHNA—like images were simulated from airborne AHS ones at a 4-m spatial resolution over Madrid in summer, acquired during the ESA-DESIREX campaign in 2008. Two spatial resolutions are analysed: 60 meters, close to the TRISHNA resolution, and 4 meters, the native one, to see their impact on the LST retrieval. To tune the TES algorithm according to the land cover type, a ground cover map separating artificial materials from natural ones is provided as prior information. Instead of one global relationship for the MMD (Maximum-Minimum **Emissivity Difference**, hereafter named 1 MMD) encompassing all material types, two relationships are used and calibrated on a natural-surface-oriented database and an artificial-surface-oriented database respectively. This material-oriented TES is called 2MMD TES. A 1MMD TES, calibrated using the two previously mentioned databases, is also applied to see how using only one MMD relationship impacts the obtained LST both artificial and natural materials.

We compare our 2MMD TES also with ground LSTs and a retrieved LST with a TES algorithm from the state of the art using seven spectral bands (7-band TES). Our 2MMD TES outperforms the 7-band TES and the 1MMD TES for both artificial and natural materials using four spectral bands, which is a great result for future missions like TRISHNA. The RMSE decreases by 1.6 K over artificial materials and 1 K globally compared with the 7-band TES, and decreases by 0.5 K over artificial materials and 0.4 K globally compared with the 1MMD TES. For natural materials, the performances are similar between the 7-band TES and the 2MMD TES and are slightly better than the 1MMD TES. Retrieved SUHI values are found to be in agreement with the values from the literature. The original approach detailed in this work could be investigated with operational ground cover products, for other spaceborne sensors, other climates, other landscapes where the spectral heterogeneity is significant or coupled with other methods to correct for error sources like the 3D effect.

## HEAT ROBUSTNESS IN RELATION TO AGEING CITIES (HERITAGE) PROGRAMME

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Due to ongoing climate change and urbanization, societies face challenges concerning environmental quality, energy management and citizens' health. While many past observational and modelling studies concentrated on understanding urban microclimate and how humans experience this, focus has been on relatively modern infrastructure ("street canyons") regarding modelling and observational efforts which showed less success over historical districts. Many cities have a significant share of aged and historical buildings with unique and different street profiles from modern infrastructure, which raises additional challenges in the energy transition due to low energy-efficiency and restrictions to required interventions. Our research programme will develop a high-tech sensing and design system aiming at detection, reduction and prevention (by monitoring and design) of heat-stress occurring due to ageing

of built environment settings and buildings in cities, through socio-technical solutions. This integral system will detect and forecast spatiotemporal patterns of heat stress at unprecedented resolutions (1m scale), aiming at technological solutions to reduce and mitigate indoor and outdoor heat stress through developing urban design guidelines and connecting the energy transition, housing demands, repurposing areas, climate adaptation and digitalisation.

The HERITAGE high-tech sensing and design system necessitates a multi-disciplinary research ecosystem approach involving earth observation, urban hydro-meteorology and climatology, urban design and sustainable infrastructural energy systems; i.e. expertise-fields well represented by the consortium. Therefore, parallel to the sensing, long-term research lines are rolled out on robust hydro- meteorological, design and energy solutions, both (sensing and technological solutions) at multiple spatiotemporal scales and forms. Concretely, these research lines fill knowledge gaps in climate policies through innovative techniques for analysis, simulation, development and experimental testing of newly designed (1) multiscale urban heritage canopy layer schemes for climate models (2) multiscale form- microclimatic relationships and (3) sustainable energy systems, all ideally suited for application in aged neighbourhoods and buildings.

## USING EARTH OBSERVATIONS TO INFORM CLIMATE-RESILIENT INVESTMENT DECISIONS FOR INTERNATIONAL DEVELOPMENT ASSISTANCE

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Climate change is among the top societal challenges with global impact. It has wide-ranging impacts across socio-economic systems, with the most severe effects being faced by poor and vulnerable communities. Making climate-resilient decisions requires good quality data and information, often lacking in many developing regions of the world. Earth observation (EO) provides large-scale, timely and accurate environmental information, which, when combined with socioeconomic data can give unique insights into managing climate risks. This is especially important in regions where insufficient information is available from in-situ measurements, or where on-the-ground assessments of infrastructure are not possible due to safety concerns. EO data can help governments around the world not only prepare for climate change impacts and natural disasters, but also inform sustainable and climate resilient development planning to account for future climate risks.

ESA has launched a new initiative “Space in support of Sustainable Development”, in a partnership with International Financial Institutions (IFIs) to leverage different financing mechanisms and ‘mainstream’ EO information in development projects. As part of the ESA Earth Observation for Sustainable Development (EO4SD) and the new Global Development Assistance (GDA) initiatives the Climate Resilience Cluster developed and is currently developing user-driven pre-operational EO use cases integrated in the development projects of the World Bank, Asian Development Bank, and the International Fund for Agricultural Development.

Over the past years, the Cluster collaborated with the IFIs to support with EO-based services their corporate climate screening tools, and to facilitate the climate resilience development and adaptation on their investment projects. The topics covered by the cluster include the improvement climate risk management in low-income countries, the monitoring of interventions and estimation of emission reductions, the establishment of drought early warning decision support systems, the provision of climate variables for financial risk

monitoring, or the identification of support Climate Change adjustments for detailed engineering Designs. One example of the Cluster's work is in Monrovia, Liberia, in collaboration with World Bank's Greater Monrovia investment project, which aims identify policies that can help Monrovia be better prepared to absorb urban growth in a context of extreme poverty/informality, fragility and increasing risks from climate change.

Access to the sea of data collected by EO satellites definitively support the implementation of climate adaptation solutions for climate impacted regions. This will go a long way in helping countries improve their preparedness for natural disasters and minimise economic losses, as well as loss of human lives.

## **CAMCATT TRIAL OVER TOULOUSE (FRANCE): A MULTISENSOR EXPERIMENT TO VALIDATE TRISHNA URBAN PRODUCTS**

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An extensive field experiment, CAMCATT-AI4GEO, was conducted during 15 days in June 2021 over Toulouse, to acquire an urban reference dataset combining airborne acquisitions and ground measurements. This presentation aims at introducing the objectives of the campaign and describing the collected data to validate the future TRISHNA products: bottom of atmosphere radiance, land surface temperature (LST) and emissivity (LSE), air temperature, microclimatic models, comfort index.

This experiment includes a large variety of acquisitions. Joint airborne multispectral thermal infrared and VISNIR-SWIR hyperspectral images were acquired along a 30 km transect centred over Toulouse. A second flight was devoted to calibrate these sensors with on-ground reference targets. During and between the flights, two cars acquired air temperature and relative humidity along predefined itineraries across the city with sensors mounted on their roof. During the airborne acquisitions, land surface temperature measurements were performed in three locations in Toulouse for calibration purposes. They were completed outside the flight by spectral optical properties in the VISNIR-SWIR and thermal infrared domains over a large range of manmade and natural materials. A specific in lab session was dedicated to the intercalibration of the on-ground thermal sensors. Atmosphere composition data were monitored using radio-soundings during the airborne acquisitions and completed with continuous measurements from on-ground stations. Finally, a last session was devoted to the validation of a thermo-radiative model. For this purpose, surface temperature sensors were installed at different locations of buildings walls supplemented by a thermal infrared images acquisition for one of the facades in order to continuously monitor its temperature during the 15 days of experiment. Air temperature was also measured at different positions in the district (under trees, in flats, etc).

## INFRARED EMISSIVITY ESTIMATION FROM VIS-NIR REFLECTANCES BY NEURAL NETWORK LEARNING : BENEFIT FOR LST ESTIMATION.

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Temperature-emissivity separation (TES) is the chosen method for TRISHNA project to retrieve the two Essential Climate Variable (ECV) from InfraRed Thermal (IRT) data, that are Land Surface Emissivity (LSE) and Land Surface Temperature (LST). LSE determination and retrieval in particular, remains a critical issue. Therefore, improved determination of the spectral emissivity is mandatory for a full exploitation of future TRISHNA data sets to estimate a reliable LST product with sub-degree absolute accuracy. In this work we evaluated different candidate methods, notably from statistical relationships between LSE and the corresponding reflectances from VIS-NIR channels.

The present work was performed from measured and simulated spectral databases covering the visible and thermal infrared spectra. About 100 000 synthetic spectrum were generated in order to cover the best canopy variability range and where used to derive sufficiently robust and generic empirical relationships at canopy scale between VIS-NIR reflectances (TRISHNA Channels) and spectral LSE (TRISHNA Channels). The work focused on natural cover, and is not extrapolable to artificial cover. The best results were obtained using neural network approaches with rmse on LSE of 0.005, 0.006, 0.003,

0.003 for respectively the IRT channels 8, 9, 10 and 11 of TRISHNA. We attempted to validate the relationships in the context of the TRISHNA and LANDSAT spectral bands using data from the AHSPECT-2015 airborne hyperspectral campaign. Hyperspectral data were converted into TRISHNA-like by spectral responses convolution then we have compared LST estimated from single channel approach by use of LSE estimated from the relationships and LST estimated from the TES processing chain in development for TRISHNA. Both methods requires a good correction of atmospheric effect performed by MODTRAN simulations. Different LSE obtained were evaluated and mean difference obtained between LST from both approach is about 0.5K with variations between land cover surfaces type. Provided emissivity estimates are deemed reliable, we will introduce them into the TES as first guess with the goal to help the method to converge.

## EUROPEAN ECOSTRESS HUB FOR MAPPING LAND SURFACE TEMPERATURE AND EVAPORATION OVER EUROPE AND AFRICA

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Land surface temperature (LST) and evaporation (E) are intrinsic components of climate and water cycle. LST constrains the magnitude and variability of the surface energy balance (SEB) components and is immensely sensitive to evaporative cooling. Therefore, LST is a preeminent variable for retrieving E in thermal-based evaporation models. ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) has been providing high spatio-temporal thermal infrared (TIR) observations (~70 m, multiple revisits per day) since August 2018. Taking advantage of the ECOSTRESS images, the European ECOSTRESS Hub (EEH) aims at producing LST and E data from models with different structures and parameterization schemes over Europe and Africa. In the EEH, LST products are retrieved from the Split Window (SW) and Temperature Emissivity Separation (TES) algorithms. Retrieval of E in the EEH is based on three models, namely Surface Energy Balance System (SEBS) and Two Source Energy Balance (TSEB) parametric models, as well as the analytical Surface Temperature Initiated Closure (STIC) model. Along with the analysis ready data stored on a cloud platform, users can run the selection of models through an interactive interface backed by a distributed cloud computing system. The LST evaluation results based on measurements from 9 sites show that both the EEH SW and TES LST estimates have a RMSE of ~2.5 K, in good agreement with the NASA/JPL ECOSTRESS LST product. The accuracy of the ECOSTRESS LST is also consistent with those of Landsat and ASTER LST. The E evaluation results based on flux measurements from 18 eddy covariance sites reveal comparable performances of STIC and SEBS (RMSE of ~70 W m<sup>-2</sup>). However, the relatively complex TSEB model produces a high RMSE of ~90 W m<sup>-2</sup>. Comparison between STIC E estimate and the operational ECOSTRESS E product shows marked advantage of STIC over PT-JPL, with a difference in RMSE of ~50 W m<sup>-2</sup>. Pronounced overestimation (>80 W m<sup>-2</sup>) exists in PT-JPL E estimates over shrublands and savannas. Overall, the EEH is promising to serve as a support to the next generation Copernicus High Priority Candidate Land Surface Temperature Monitoring (LSTM) mission.

## LONG-TERM DYNAMICS OF LAND SURFACE TEMPERATURE OVER EUROPE: TOWARDS A DAYTIME NORMALIZED AVHRR LAND SURFACE TEMPERATURE PRODUCT

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Land Surface Temperature (LST) is recognized as one of the Essential Climate Variables by the World Meteorological Organization. It is a key parameter for climate models and a direct indicator of global warming. The Advanced Very High-Resolution Radiometer (AVHRR) is the only sensor that has been providing spatially and temporally continuous daily measurements for 40 years. In the TIMELINE project, consistent LST products were developed from AVHRR over Europe. However, the different overpass times and the orbital drift effect hide actual trends and anomalies in LST.

Several methods exist to account for this effect of varying acquisition times on LST time series, which can be classified into physical and statistical methods. An important requirement for these methods is that they preserve the actual trends in LST. However, especially for the period before the year 2000 no independent LST datasets exist to validate these methods. As an approximation, historical measurements of near surface air temperature (Ta) at various stations across Europe provided e.g. by can be used. Despite the known differences

between LST and Ta at short time scales, it is expected, that long term trends correspond in these two variables.

In this study, a representant of a physical and a statistical daytime correction model, respectively, are applied to the TIMELINE LST data and their performance is analyzed at different sites with different land cover across Europe. The physical model by based on the work of builds on information about the daily temperature circle at the given location, which is taken from SERVIRI geostationary LST data. With this model all LSTs are modelled to 13.30h true solar time. The statistical model was proposed by and uses the regression between the LST anomalies and the corresponding SZA anomalies for each day of the year throughout the time series. This allows to remove the orbit drift effect for each sensor. An additional offset is used to adjust the observation times of the sensors. As proposed in, both models are validated against SERVIRI LSTs at the respective sites. In a second step, trends of the normalized LST are compared to trends of Ta for various sites and landcovers across Europe. The first analysis shows promising results regarding both models. This study is taking another step towards a 40-year daytime normalized AVHRR LST product, allowing a wide variety of applications in the context of climate and land surface change.

## SMOS –LESSONS LEARNED AFTER MORE THAN 12 YEARS IN SPACE

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The SMOS has now been in operation for almost 13 years and is still in excellent shape. Throughout those years, several steps had to be done to ensure scientific successes, as it was both the first L band mission and the first interferometer in space. The focus was first on basic variables (soil moisture and sea surface salinity) but very quickly several other science domain and applications emerged. This very rapid transition can be explained by the simple fact that, for the first time, a space instrument (L band radiometer) could give access directly and in an absolute fashion to surface soil moisture, vegetation biomass, sea surface salinity and snow / ice information.

SMOS has been delivering information on soil moisture and root zone soil moisture almost immediately after launch, and is operationally assimilated at the European Centre for Mediumrange Weather Forecast. The first direct application was to infer root zone soil moisture from surface soil moisture using simplified approaches. This led to a number of very interesting research topics such as elaboration of reliable drought indices and analysis of interactions between water storage and vegetation stress. Soil moisture was also used was proved to be also a very important variable when assessing flood risks.

SMOS has also been used over the oceans to infer sea surface salinity and strong winds or oversnow and ice (thin sea ice thickness, freeze thaw). New research venues are now being explored (ET estimates, VOD and Biomass, fires, snow density, snow / ice internal melt, permafrost monitoring etc...)

One limitation of SMOS products is the current spatial resolution (typically 40 km even when distributed on higher resolution grids. So many efforts have been made to infer higher resolution products for use in agriculture and hydrology. Using different disaggregation approaches relying either on optical data sets or on radar/ SAR measurements, high resolution soil moisture fields were derived. They enabled studies on irrigation for example or for locust prevention, but such approaches have also been used to get finer information on other variables such as biomass, water bodies etc.

During the presentation several key examples of SMOS results will be presented, greenhouse gas emissions at high latitude, deforestation monitoring and fire recovery, ocean circulation, etc. We will also compare the relative merits of various means to estimate soil moisture, as well as the ways to validate the different products.

Some time will be used to present synergisms with other sensors to obtain new variables.

The final section will be devoted to describe how a SMOS follow on could be together with the specifications provided by the science community. It is noteworthy to remember that SMOS contributes to 8 CCI and is primary for 2 of them while no follow-on are currently studied in spite of the Successful SMOS-

HR phase A.

## **LA EXPLOTACIÓN CIENTÍFICA DE LA MISIÓN PAZ, UNA HERRAMIENTA DE DIFUSIÓN E IMPULSO SAR**

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La misión PAZ constituye el elemento radar del Programa Nacional de Observación de la Tierra por Satélite (PNOTS) para el desarrollo, operación y explotación de sensores espaciales de observación de la Tierra.

PAZ fue lanzado el 22 de febrero de 2018 y tras superar con éxito las fases de LEOP y puesta en servicio, el sistema fue declarado operacional en septiembre de ese año, iniciándose la fase de operaciones rutinarias en virtud de la cual la misión proporciona servicio a usuarios de defensa y seguridad, comerciales y científicos.

Mediante la Explotación Científica de PAZ, gestionada por el equipo PAZ-Ciencia del Departamento de Programas Espaciales del INTA, se fomenta el conocimiento y uso de los productos PAZ a investigadores, tanto nacionales como internacionales. La Explotación Científica responde al compromiso adquirido por INTA como organismo público de investigación, de impulsar la tecnología SAR en todas sus áreas: del desarrollo tecnológico a la generación de algoritmos de procesamiento y de aplicaciones; dando a conocer los productos PAZ y fomentando la realización de trabajos de investigación apoyados en estos productos en áreas tales como el ámbito marítimo, agricultura, fenología, vulcanología o arqueología, lo que a su vez realimenta el avance de la tecnología SAR con el diseño de nuevos sistemas y misiones cuyos requisitos (tanto de instrumento, modos de operación y tipos de productos) estén fundamentados en el uso pretendido.

La implementación de la Explotación Científica se instrumenta fundamentalmente mediante la publicación de Anuncios de Oportunidad de uso científico de los productos PAZ a la que los investigadores pueden responder con sus propuestas de proyectos en los que se debe definir el objetivo científico perseguido, área de interés, modo de imagen deseado y rango de fechas de cobertura de los productos deseados. Estos proyectos deben ser evaluados y aprobados tanto por INTA, como por el operador de la misión (HISDESAT). Hasta la fecha se han puesto en marcha cuatro anuncios de oportunidad (AO); dos AOs de uso general, el de Lanzamiento de la Fase Científica de PAZ y el Anuncio de Oportunidad conjunto con DLR para uso científico de datos de los satélites TerraSAR-X, TanDEM-X, un AO Educativo para dar soporte a los estudiantes que quieran realizar sus trabajos fin de grado, máster o doctorado basados en el empleo de datos SAR de PAZ y un AO Especial que se lanzó en septiembre de 2021 para dar soporte científico a la erupción del volcán de Cumbre Vieja en La Palma (islas Canarias).

En el artículo final se expondrán algunos de los resultados obtenidos en diferentes proyectos científicos ejecutados en estos anuncios de oportunidad.

## **EVALUATION OF REPEAT-PASS INTERFEROMETRIC COHERENCE FROM SENTINEL-1 ASA VEGETATION INDEX FOR CROP MONITORING**

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Optical and radar data are extensively used for vegetation and crop monitoring, particularly through the use of vegetation indices. In the case of Synthetic Aperture Radar (SAR), these indices are mostly based on backscattered intensity at different polarimetric channels or descriptors extracted from polarimetry. Other features are provided by radar imagery through interferometric data. Pairs of images are combined to produce phase measurements related to properties of the observed scene. A key interferometric observable, the interferometric coherence, is employed as a measure of the quality of the phase. Diverse factors influence the coherence, some of them related to the scene characteristics, giving coherence sensitivity to the properties of crops in a scene. However, few works have considered the use of interferometric coherence as a vegetation index to monitor the evolution of crops.

The use of Sentinel-1 interferometric coherence data as a tool for crop monitoring has been explored in this work. For this purpose, time series of images acquired by Sentinel-1 and 2 spanning 2017 were analysed. The study site is an agricultural area in Sevilla, Spain, where 16 different crop species were cultivated during that year. The time series of 6-day repeat-pass coherence measured at each polarimetric channel (VV and VH), as well as their difference, have been compared to NDVI and to the backscattering ratio (VH/VV). The contribution of different decorrelation sources and the effect of the bias from the space-averaged sample coherence magnitude estimation have been evaluated. The study has been carried for three different orbits, characterised by different incidence angles and acquisition times. All results support using coherence as a measure for monitoring the crop growing season, as it shows good correlations with the NDVI ( $R^2 > 0.7$ ), and its temporal evolution fits well the main phenological stages of the crops. Although each crop shows its own evolution, the performance of coherence as a vegetation index is high for most of them. Crop types featuring low plant density are better tracked by the VH coherence than by the VV one, whereas for the most dense ones the VV coherence is more correlated to NDVI. For a few crop types, such as rice, the backscattering ratio outperforms the coherence in following the growth stages of the plants. Since both coherence and backscattering are directly computed from the radar images, they could be used as complementary sources of information for this purpose. As radar imagery is not affected by the presence of clouds, these can also complement the use of optical data.

The research is currently being extended to a longer time series (2018 to 2021), as well as a comparison with other used vegetation indices. All results will be presented at the conference.

## COMBINING SATELLITE AND METEOROLOGICAL DATA TO QUANTIFY THE EVAPORATION AMOUNTS OF 75 HIGH-ELEVATION LARGE DIMICTIC LAKES ON THE TIBETAN PLATEAU

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Lake evaporation can influence basin-wide hydrological cycle and water budget and is the most



important loss item of endorheic lakes' water resources. Though hundreds of large high-elevation dimictic lakes exist on the Tibetan Plateau (TP), the evaporation amounts are found inconsistent over a lake and the spatial distributions of evaporation amounts are still not reported due to lack of in situ measurements. Here utilizing a reasonable hypothesis of energy balance during ice-free period and constant sublimation value during ice-covered period and combining widely-used and corrected China Meteorological Forcing Dataset and MODIS products, we explore the multi-year (2003-2016) average ice phenology and evaporation amounts of selected 75 lakes (with areas all larger than 90 km<sup>2</sup>), classified into three groups: the "Southern Lakes Group" (SLG) along 31°N, the "Northern Lakes Group" (NLG) along 35°N, and the "Other Lakes Group" (OLG) with low elevations. Lake ice phenology are clearly presented by MODIS 8-day snow cover products, and they show large spatial variability in the duration of ice-free season (SLG > OLG > NLG). The estimated Bowen ratio and evaporation amounts show acceptable accuracies, and display opposite spatial distributions, with the latter being higher in the SLG than in the NLG. On the TP, a lake with a higher elevation, a smaller area and a larger latitude mostly corresponds to a shorter ice-free season (a lower total net radiation), a larger Bowen ratio and finally a lower evaporation amount. The multi-year average evaporation amounts are listed, with the total water evaporated from lake surface being approximately  $29.4 \pm 1.2$  Gt year<sup>-1</sup> for the studied 75 lakes and  $51.7 \pm 2.1$  Gt year<sup>-1</sup> for all Plateau lakes included. Our study provides an example for evaporation amounts estimation in dimictic lakes and shows high significance for future research on catchment-scale water budget, hydrological cycle and water resources management.

## STUDY OF EFFECTS OF DIFFERENT VEGETATION MODEL PARAMETER SETTINGS ON QUANTITATIVE CFD SIMULATION OF URBAN SPATIAL AIR TEMPERATURE AND WIND-FIELD

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The rapid acceleration of urbanization has a serious impact on the urban ecological environment. It is of great significance to carry out numerical simulation research on urban spatial thermal environment for improving urban ecological environment, optimizing building energy consumption and promoting sustainable urban development. At present, in the simulation research of vegetation mitigation of urban thermal environment based on computational fluid dynamics, there are few studies on the influence and accuracy evaluation of different vegetation settings in CFD on the simulation results. Aiming at the quantification of the impact of vegetation changes and vegetation model settings on the numerical simulation of urban three-dimensional thermal environment, this study is carried out from two aspects: 1) Based on the combination of Gaofen-2 remote sensing data and CFD model, the current situation of wind and heat environment in the sparse vegetation-dense building area and the vegetation dense-building sparse area at the block scale was simulated and analyzed; 2) The vegetation model is assumed to be three models, including cold source, constant temperature wall, and porous medium. Based on the heat transfer and cooling mechanism of vegetation, these three different vegetation models and their related CFD parameter settings are used to simulate the thermal environment of urban three-dimensional space. Analysis of applicable scenarios and accuracy studies to optimize vegetation setting parameters. The research results show that: 1) The distribution of temperature has a great correlation with the direction of wind. The temperature distribution at different heights at night did not

show significant differences. Due to indoor heat transfer, the atmospheric temperature in the densely built area is higher than that in the sparsely built area. Due to the obvious convective heat transfer between the building surface and the atmosphere, the temperature in the upwind direction is significantly lower than that in the downwind direction. 2) At a height of 2m and below, setting the vegetation as the wall model has the best performance, and at a height above 5m, the results of the wind and heat environment of the three setting methods are basically similar. The wind environment results of the same vegetation setting are different at different heights.

## RADIOMETRIC CROSS-CALIBRATION OF HJ-2A/IRS SENSOR WITH TERRA/MODIS

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Due to the development of earth observation technology, many operational satellite sensors, such as Landsat/TM, Landsat7/ETM, Terra/MODIS, NPP/VIIRS, HJ-2A/IRS, *etc.* have been launched. While, caused by the working environment, the satellite sensor generally suffers a low-accurate radiometric calibration which needs to be improved. Radiometric cross-calibration is a valuable and operable method to calibrate the sensors without coincident surface measurements through transferring radiometric values between satellite sensors via stable target. In this study, the Chinese Second-Generation Huanjing Disaster Monitoring Satellite (HJ-2A)/IRS will be cross-calibrated against the well-calibrated Terra/Moderate Resolution Imaging Spectrometer (MODIS) after correcting the discrepancy on viewing geometries and spectrum to calibrate their differences. On September 27, 2020, the HJ-2A satellite was successfully launched, which provide a thermal payload including two thermal infrared (TIR) channels with a spatial resolution of 96 m and a visible and near-infrared (VNIR) payload including five VNIR channels with a spatial resolution of 48 m. The successful launch of HJ-2A will improve China's ability to acquire the visible and infrared data, and meet the urgent need for a continuous supply of remote sensing data in related fields.

To cross-calibrate the HJ-2A sensor, five different regions of Wuhai, Geermu, Dunhuang, Baotou, and Qinghai River with relatively uniform surfaces covered by vegetation, rock, soil, and water are selected. Due to the significant differences in spectral response profiles between the two sensors, it is essential to compensate the spectral band differences of multispectral sensors to provide a more accurate cross-calibration between the sensors. Using the MODTRAN radiative transfer model, for the TIR bands, the measured radiances for the two sensors are simulated; for the VNIR bands, the MODIS and IRS top-of-the atmosphere (TOA) reflectances are converted to the surface reflectances which are corrected by the bidirectional reflectance distribution function (BRDF). After the above corrections, for the images of the selected test sites, the linear correlations can be found between radiances estimated from the MODIS and the digital numbers (DN<sub>s</sub>) from the IRS, from which the calibration gains are derived. The gains differ considerably from the pre-launch values and are subject to degradation over time. From the test results, it can be found that the relative errors between the cross-calibration and the on-board calibration are less than 5%.

## **DETECTION AND IDENTIFICATION OF MESOSCALE EDDIES BASED ON YOLOF IN THE SOUTH CHINA SEA**

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Ocean mesoscale eddy is a special mesoscale phenomenon in the ocean, which widely exists in all oceans and marginal seas around the world. Compared with ordinary ocean circulation, mesoscale eddy has fast speed (up to several meters per second), strong velocity and vertical depth of several kilometers. The spatial scale of mesoscale eddy ranges from tens of kilometers to hundreds of kilometers, with a large span, and the time scale ranges from a few days to hundreds of days. It plays an important role in ocean circulation and material transport. It also has an important impact on ship navigation safety and underwater acoustic communication. The traditional mesoscale eddy identification and recognition has great subjectivity and usually depends on the parameters predefined or adjusted by experts, which cannot guarantee the accuracy. With the rise of Deep Learning, Yolo series target recognition models show certain advantages in eddy detection and recognition. Based on the sea level anomaly (SLA) data provided by Copernicus Marine Environment Detection Service in recent 30 years, this paper proposes an ocean mesoscale eddy detection and identification method based on YOLOF (You Only Look One Level Feature). The mesoscale eddies in the South China Sea from 1993 to 2021 are detected and identified. Compared with the traditional recognition methods, this model has better recognition effect, with an accuracy of 91.3%. It avoids the influence of setting the threshold on mesoscale vortex recognition, which improves the detection and recognition speed to a certain extent. At the same time, compared with the detection results by the Detectron2 model, the YOLOF model has a high accuracy. The method proposed in this paper not only promotes the development of deep learning in the field of ocean mesoscale eddy detection and identification, but also provides an effective technical method for the study of mesoscale eddy detection through sea surface height.

## **AN INVERSION METHOD OF SUBSURFACE THERMOHALINE FIELD BASED ON DEEP LEARNING AND REMOTE SENSING DATA**

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Seawater temperature and salinity are basic marine environmental parameters, which can be used to calculate other marine environmental parameters, such as seawater density, sound velocity, etc., and provide basic information for the study of marine phenomena such as jumps, internal waves, and vortices. However, most of the on-site observation data in the ocean have the problems of uneven spatial distribution and time discontinuity, and it is difficult for satellite remote sensing observation methods in continuous time and space to obtain subsurface marine information. In this study, we proposed a deep learning model with combining ocean remote sensing temperature and salinity products as well as in situ measured data by Argo, and the nonlinear relationship was found. Then we realized an effective method of direct inversion for underwater three-dimensional thermohaline structure based on remote sensing temperature and salinity at accurate points on a global scale. The SST data in this study were from the FY3C-VIRR daily sea surface temperature product, the SSS data were from the SMAP Level 3 8-day running averages sea surface salinity product, and the Argo scatter data were from the "Global Ocean Argo Scatter Data Set" that had been quality control by the China Argo data center, which are interpolated to 45 standard layers of 0-1000 meters. Based on the temporal and spatial location information of the data, this paper matched the remote sensing data from 2016 to 2019 with the Argo data, then 66193 valid pairing points were obtained. The training set and verification set were divided

into 44128:22065. The deep learning model was constructed as a multilayer perceptron model with 5 hidden layers. The RMSE of inversion temperature had a maximum value of 1.889 °C in 100 m depth and a minimum value of 0.459 °C in 1000 m depth with an average of 1.196 °C. And the RMSE of inversion salinity had a maximum value of 0.466 psu in 5 m depth and a minimum value of 0.057 psu in 1000m depth with an average of 0.207 psu. Compared with other inversion methods based on fixed mesh products, this paper realized a direct inversion method at any location in the global ocean and improved the accuracy of inversion.

## RETRIEVAL OF SEA SURFACE TEMPERATURE IN BOHAI SEA BASED ON MODIS DATA

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Sea surface temperature (SST) is a basic physical parameter and widely used in marine environment monitoring. SST affects almost all marine dynamic processes directly or indirectly. Traditional on-site measurement methods based on buoys, platforms and volunteer ships make it difficult to obtain large-scale synchronous sea surface temperature data due to time and space constraints. With the innovation of thermal infrared satellite sensors in spatial resolution, thermal infrared remote sensing images are applied step by step to retrieve water temperature, combining satellite remote sensing data with on-site observation data, making full use of their respective advantages. It can effectively reflect the sea surface temperature and provide necessary data support for relevant research and application in the ocean.

Based on MODIS data, the Bohai Sea area is taken as the study area, and the sea surface temperature is retrieved using the improved split window algorithm. Firstly, the MODIS L1B data is preprocessed by geometric correction and cloud removal. Then, the atmospheric transmittance is calculated by using the radiative transfer model-MODTRAN, and the brightness temperature is calculated by using the radiance values of bands 31 and 32 of MODIS data. Finally, the split window algorithm is used to retrieve and verify the sea surface temperature. The inversion results were validated by the existing SST products and *in situ* data. The determination coefficient ( $R^2$ ) is greater than 0.8, and root mean square error (RMSE) is approximately 0.6K, indicating that the inversion accuracy is credible. Combined with the characteristics of sea surface temperature, the inversion algorithm of sea surface temperature is realized automatically by IDL language programming, which provides convenience for fast and real-time acquisition of SST products in the process of ocean research.

## SIMULATION OF CANOPY URBAN HEAT ISLAND AT A BLOCK SCALE BASED ON LOCAL CLIMATE ZONES AND URBAN WEATHER GENERATOR

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The current research on urban heat island effect mostly focuses on the analysis of land use type changes, and most of them focus on the surface urban heat island effect. From the perspective of urban microclimate, there are few studies on the urban canopy heat island effect at the block scale, although the canopy heat island effect is a key factor affecting human thermal comfort. Therefore, this study will combine the local climate zone classification system and the UWG (Urban Weather Generator) model to simulate and

quantitatively analyze the urban canopy heat island effect in Beijing at the block scale. First, based on GF-2 high-resolution remote sensing images, the ResNet (residual neural network) method was used to obtain the local climate zone in Beijing, and the LCZ was verified based on the google earth engine (GEE) platform; Secondly, according to the classification results of local climate zones, the input parameters of the UWG model and the corresponding value ranges are calculated; Finally, the UWG model is used to simulate the canopy temperature in different local climate zones, and the urban canopy temperature is verified based on the meteorological station data. We quantitatively analyze the temperature differences between local climate regions of the same type and different sizes, and temperature differences between different types of climate regions. The results shows that the canopy heat island effect in Beijing gradually weakened outward from the city center. This is mainly due to the relatively dense distribution of compact local climate zones in the center of Beijing, while the surrounding areas of Beijing have lower building density and better natural coverage. From the perspective of local climate zones, the heat island intensity of built-up LCZs is significantly stronger than that of natural-covered LCZs. The variation of the heat island intensity of each built-up type of LCZ shows a certain regularity, that is, the heat island intensity of the compact LCZ is higher than that of the open LCZ with the same building height. However, for LCZs with comparable compactness, the heat island intensity of high-level LCZs is higher than that of low-level LCZs. According to the conclusions drawn from this study, we hope to provide theoretical guidance for the sustainable and healthy development of Beijing and rational planning in the future.

## SENSITIVITY ANALYSIS AND PARAMETER OPTIMIZATION METHOD FOR INFRARED HYPERSPECTRAL INTERFEROMETER SPECTRAL CALIBRATION PARAMETERS BASED ON VARIATIONAL ASSIMILATION

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The observation data of infrared hyperspectral interferometer have the characteristics of high spectral resolution and are widely used in numerical weather forecasting, climate change monitoring, atmospheric trace gas retrieval and other fields. Infrared hyperspectral interferometer is a high-precision instrument, and its spectral calibration accuracy and radiometric calibration accuracy are the prerequisites for quantitative applications. The deviation of spectral frequency directly affects the radiation calibration accuracy. Relabeling of the spectral axis requires three kinds of instrument parameters, such as laser sampling wavelength, detector geometric position and shape, which are generally obtained through ground experiments. The characteristics of infrared hyperspectral hyperfine spectral resolution make the deviation of spectral position have a great influence on the radiometric calibration accuracy. For a typical 287K target, a spectral deviation of 4ppm results in a radiant brightness temperature deviation of 0.25K for the unapodized spectrum. In this study, infrared hyperspectral simulation data was used to analyze the sensitivity of spectral calibration deviation to instrument parameters such as laser sampling wavelength, geometric position and shape of the detector. The results show that the frequency deviation caused by the laser sampling wavelength is the overall deviation. The error of the laser sampling wavelength can cause a large spectral deviation, and the spectral deviation caused by the

geometrical position error of the detector is small. After the laser sampling wavelength is fixed, the geometric position of the detector can be adjusted to improve the spectral calibration accuracy. In addition, after the satellite is in orbit, the spectral calibration parameters cannot be measured, and there is an error in applying the parameters measured by the ground laboratory to the in-orbit data. Based on the idea of variational assimilation (VarCalPOA), a cost function is constructed based on the maximum correlation between the observation spectrum and the reference spectrum, and the optimal spectral calibration parameters are found through the iterative process of the cost function. Therefore, it can provide a new idea for the on-orbit optimization of infrared hyperspectral spectral calibration parameters.

## THE SIGNIFICANT WAVE HEIGHT PREDICTION USING A DEEP LEARNING MODEL AND REMOTE SENSING DATA

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The significant wave height (SWH) is the most widely used indicator to measure the ocean state. In this study, a new inversion model was developed using the Long short-term memory (LSTM) neural networks method based on the National Data Buoy Center (NDBC) buoy observations and the forecast results of SWH from the third-generation shallow ocean wave model (SWAN). The results demonstrated that the SWH predictions achieved significantly increased spatial coverage and satisfied accuracy. In addition, the SWH forecast results were also validated by independent matching with Jason-3 and SARAL/AltiKa products. The results showed that the proposed model provides not only a significantly improved spatial coverage but also an accuracy comparable to that of altimeter satellite observations.

## RESEARCH ON FY-3D MERSI- II DATA CLOUD DETECTION BASED ON COMPREHENSIVE THRESHOLD ANALYSIS

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Cloud is an important factor that affects the quality and utilization of data in the process of acquiring surface information by satellite sensors. How to maximize the detection of the cloud in the application of satellite remote sensing images is one of the current research hotspots. Aiming at the cloud detection method of FY-3D Medium Resolution Spectral Imager (MERSI-II) data, based on the analysis of the spectral characteristics of different underlying surfaces such as bare land, vegetation, water, ice, and snow, combined with the channel characteristics of FY-3D/MERSI-II data, a variety of spectral test methods are selected, and a multispectral comprehensive threshold analysis method for cloud detection is proposed. It is compared with the cloud mask product MOD35 of MODIS and the cloud detection product MERSI-II. The results show that the radiometric calibration results of MERSI-II for the cloud detection band and MODIS corresponding band are highly correlated, the correlation coefficient is in the range of 0.83-0.95, and the bias is in the range of 0.2K-2.2K. The cloud detection rate of MERSI-II overall cloud detection is 79% and the overall accuracy is 87%. After comparing the detection results with the visual interpretation results, it is found that the proposed MERSI-II cloud detection method has high detection accuracy for cloud pixels of different cloud types; The quantitative analysis results show that the cloud pixels and clear sky pixels on different underlying surfaces have high

accuracy, low misjudgment rate and missed judgment rate, and can detect the cloud area more completely. There are few isolated cloud pixels, but the sensitivity to some thin clouds is low. The overall accuracy meets the experimental requirements and provides reliable data for subsequent atmospheric inversion and surface parameter inversion.

## VEGETATION NET PRIMARY PRODUCTIVITY ESTIMATION BASED ON GF-1 WIDE FIELD VIEW DATA IN QINGHAI LAKE BASIN

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NPP (Net primary productivity) is an important factor in regulating ecological processes, and it can reflect the vegetation productivity under natural conditions and the quality of the ecosystem. In recent years, using high-resolution remote sensing images and ecological models to retrieve NPP have become an effective solution. In particular, remote sensing technology with advantages of real-time and large-scale can help us to obtain the characteristics of vegetation primary productivity at different time scales and spatial resolutions. In this paper, in order to better grasp the local ecological situation, we applied the CASA (Carnegie Ames Stanford Approach) model to retrieve the NPP of the Qinghai Lake Basin in 2020 based on the GF-1 wide field view data and meteorological data. The results showed that the NPP value on the shore of Qinghai Lake was the highest and decreased in a ring shape. At the same time, the value of NPP in the southeastern Qinghai Lake Basin was higher than that in northwest. And temporally, the NPP value of the Qinghai Lake in July was the highest, which can reach  $110.44 \text{ gC} \cdot \text{m}^{-2} \cdot \text{month}^{-1}$ , while the value of NPP in March was the lowest, only  $0.02 \text{ gC} \cdot \text{m}^{-2} \cdot \text{month}^{-1}$ . For the whole year of 2020, the NPP per unit area of the Qinghai Lake Basin reached  $310.62 \text{ gC} \cdot \text{m}^{-2} \cdot \text{y}^{-1}$ . As for the correlation between NPP and climate variables, the NPP and the precipitation were significantly positively correlated, whose Pearson Correction Coefficient was approximately 0.84. Therefore, the precipitation had the most significant impact on the NPP, followed by the temperature, and the solar radiance had the lowest impact. What's more, compared with previous studies of the NPP in the Qinghai Lake Basin, the value of NPP had increased significantly in the past 10 years, especially in summer. And further research of NPP should focus on the parameters' settings of the CASA model and the impact of human activities on NPP.

## STUDY ON THE COASTLINE CHANGES USING REMOTE SENSING DATA FOR BOHAI BAY IN RECENT 20 YEARS

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Bohai Bay is one of the three major bays of the Bohai Sea in China, and is located in a semi-encircled area consisting of three important provinces and cities with rich energy and fishery resources. Bohai Bay is not only a maritime gateway and transportation hub; it is also an important industrial base, energy production base and port. This study combines remote sensing technology and GIS technology to extract the coastline of Bohai Bay from 2001 to 2021 using Landsat remote sensing images as the data source and obtain the coastline length variation by refinement vector processing. Sediment as the natural driver was quantitatively analyzed based on the sand transport of the Yellow River and the Hai River. Moreover, port construction as the anthropogenic driver was qualitatively analyzed. The results demonstrated that the coastline of Bohai Bay showed an overall growth trend from 2001 to 2021, with a total increase of 881.05 km in shoreline length, and the main increase

is the artificial shoreline. The two natural drivers, sediment and hydrodynamic conditions are weak, and the anthropogenic drivers, i.e., various human activities, play a dominant role in the shoreline variation of Bohai Bay in the past 20 years. The extracted shoreline information is important for the rational and effective development and utilization of the various natural resources in the coastal zone of Bohai Bay and for development planning of this important area in the future.

## TEMPORAL AND SPATIAL EVOLUTION ANALYSIS OF BEIJING-TIANJIN-HEBEI URBAN AGGLOMERATION BASED ON NPP-VIIRS DATA

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An urban agglomeration is the highest spatial organization form in the mature stage of urban development, which can produce huge agglomeration economic benefits. It is one of the symbols of the rapid development of the national economy and the continuous improvement of the modernization level. To understand the temporal and spatial evolution characteristics of Beijing-Tianjin-Hebei Urban Agglomeration, based on the NPP-VIIRS nighttime light remote sensing data from 2012 to 2021, supplemented by the Landsat data of corresponding years. This paper extracts the urban built-up area range of the study area in the past ten years and analyzes it from three aspects: form, scale, and spatial structure through the methods of light value statistics, urban order scale rule, fractal dimension, and urban correlation measurement. The results show that the total amount of lighting in Beijing-Tianjin-Hebei Urban Agglomeration shows an upward trend, and the growth rate of lighting in Beijing and Tianjin is the highest, more than 5%; Langfang and Shijiazhuang take the second place, at about 3%. The internal shape of urban agglomeration is more compact. The fragmentation and fractal dimension are decreasing. The patches in built-up areas are concentrated and the geometry tends to be regular. the urban expansion is mainly "outward expansion" and "internal filling" is secondary. The center of gravity of the city shifted to the northeast, and the development speed of cities in the North accelerated. The urban scale of Beijing-Tianjin-Hebei Urban Agglomeration is relatively loose, and the regional development is uncoordinated. The lights are concentrated in Beijing and Tianjin, which are high-order cities. Small and medium-sized cities such as Hengshui are not developed enough, showing a serious situation of two-level differentiation. The primacy and Gini coefficient of urban agglomeration first decreased and then increased, and the gap between cities in urban agglomeration first narrowed and then widened. With the advancement of regional transportation integration, the correlation degree between cities has increased as a whole. The overall correlation degree between Beijing and Tianjin is dominant, but the traffic connection between northern cities and central and southern regions is insufficient and the correlation degree is weak. The research proves that the use of night light remote sensing images can effectively reveal the urban spatial form of Beijing-Tianjin-Hebei Urban Agglomeration, and the application of night light data to the study of urban expansion and urban agglomeration has broad development prospects.

## DETERMINATION OF OPTIMAL CHANNEL FOR THERMAL INFRARED REMOTE SENSING INVERSION OF LAND SURFACE TEMPERATURE BASED ON FY-3D MERSI-II DATA

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Land surface temperature (LST) is a very important characteristic physical quantity that characterizes the change in the land surface process, and it is also a direct driving factor of surface-atmosphere energy exchange. Given the uncertainty of the accuracy of the single-channel algorithm using different thermal infrared channels in the surface temperature inversion of FY-3D MERSI-II data, this paper takes the North China Plain of China and the central and eastern United States as the study area constructs a single channel surface temperature inversion model and carries out the research on the inversion of the surface temperature using the 24th and 25th channel of MERSI-II data. Under the conditions of different atmospheric and land cover types, the measured surface data are collected from different local points, and the accuracy of the inversion results is verified through the in-situ measurement data of four SURFRAD stations in the United States (SXF, BND, PSU, GWN) and the MODIS land surface temperature product data. The results show that the RMSE of the inversion results of different land cover types, such as grassland, farmland, vegetation, and bare land, is between 1.12K-1.71K and 1.45K-2.24K respectively, the bias is between 0.12K-0.75K and 0.56K-0.84K respectively, and the R<sup>2</sup> is above 0.95. The inversion results of the two channels are lower than the surrounding site temperature. The inversion result of channel 24 is closer to the real LST. The inversion results of FY-3D data are highly consistent with MODIS temperature products. The inversion results are verified by using MODIS daily temperature products. R<sup>2</sup> is greater than 0.87, and RMSE of 24th channels and 25th channel is between 4.03K-4.35K and 4.87K-5.29K respectively. The research results of this paper have important reference values for the channel selection and the construction of the single-channel LST inversion model of Feng Yun satellite.

## THE OPTIMIZED EXPERIMENTAL RESEARCH ON REMOTE SENSING DETECTION FOR MULTIANGULAR POLARIZED RADIATION OF SEAWATER

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Seawater exhibits obvious polarized characteristics in the process of thermal radiation, While the existing thermal infrared remote sensing of seawater uses only the multiangular information without involving polarization, and the study on the multiangular polarized spectrum plays a vital role on the interpretation of multiangular polarized remote sensing of waters. The influence of five factors, including the detection angle, azimuth angle, waveband, temperature and salinity, on the polarized radiation of seawater is analyzed in this paper based on the mechanism discussion of multiangular polarized radiation remote sensing of seawater. In addition, the orthogonal experiment design is used to measure the difference on polarized radiation of seawater in conditions of distinct factors and levels. The primary factors affecting the polarized radiation of seawater and their interactions are ascertained by variance analysis and statistical tests. It is found that, the polarized radiation decreases with the increase of the detection angle, which follows a cubic curve; It shifts in a parabolic distribution with the azimuth angle, and the peak of the parabola is adjacent to the azimuth angle of 180 °, furthermore, the spectral curve varies significantly with the azimuth angle between 120 ° and 240 °; The polarized radiation in four wavebands, the correlations of which are extremely significant, has obvious difference in the same conditions and it has a higher polarized radiation in 10.3-11.3 μm waveband; The polarized radiation of seawater increases as the temperature rises and there is a cubic curve between the two, while it decreases linearly with the increase of salinity. Quantitative analysis shows that, the detection angle, waveband and temperature are the leading factors affecting the polarized radiation of seawater, and the interactions among these factors does not work significantly. The optimal schemes are different according with distinct evaluation indexes. When the polarized radiance is selected, the detection angle and waveband are the main influencing factors, while it is the temperature according to the polarized brightness temperature. The optimized detection scheme for multiangular polarized remote sensing of seawater is determined on that basis.

This research provides support for the comprehensive application of multispectral remote sensing, multiangular remote sensing and polarized remote sensing. It presents new methods for the identification and monitoring of waters remote sensing, providing theoretical basis for the design of polarized remote sensors, which helps to promote the quantitative development of multiangular polarized remote sensing.

## DRIVING FORCE ANALYSIS OF LAND SURFACE TEMPERATURE CHANGES OVER THE TIBETAN PLATEAU FROM 2003 TO 2020

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As the highest plateau in the world, the Tibetan Plateau (TP) plays a key role in global atmospheric circulation and is very sensitive to climate change. Land surface temperature (LST) plays an important role in the surface water and heat cycle, and can accurately characterize the changes in the surface thermal environment. The driving forces of LST changes in different regions of the TP have important significance for revealing the response of the TP to climate change. However, it is a poor understanding of the dominant driving force for the LST change over the TP. To quantitatively analyze the driving forces of LST changes over the TP, the annual temperature cycle (ATC) model was used to obtain the annual average surface temperature (MAST) of the daytime and nighttime from 2003 to 2020 based on the MODIS/Aqua LST products. The partial correlation was used to quantitatively analyze the influence of five driving factors, including cloud amounts, normalized vegetation index (NDVI), snow cover, precipitation, and air temperature on the MAST changes. The results showed that except for the positive partial correlation between air temperature and MAST in the majority pixels, the relationships between the other four factors and MAST are mainly negative. However, there are all positive partial correlations between the five factors and MAST. Meanwhile, the maximum absolute value of partial correlation between MAST and five driving factors was identified based on each pixel as the main driving force of MAST changes. It was found that cloud amounts were the dominant force influencing the change of LST in the daytime, while it is the air temperature in the nighttime in most regions of the TP. The dominant areas of cloud amounts accounted for 38.17% of the total areas of the TP and the relationship between cloud amounts and MAST was mainly negative partial correlations in the daytime. For the nighttime, the main driving force of MAST change air temperature with positive partial correlations. The dominant area accounts for more than 48% of the TP, which revealed the influence of climate warming on MAST changes at nighttime is stronger than that in the daytime. In general, this study provides important insights into the driving forces of LST changes and helps reveal the influence of climate warming on the TP.

## EVALUATION OF SNOW DEPTH PRODUCTS BY SNOW-COVER PRODUCTS AND IN-SITU OBSERVATION DATA

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Snow depth (SD) is a crucial input parameter for snow cover hydrologic model and climate model, as well as the snow disaster evaluation and prediction. Passive microwave remotely sensing presents the advantages of penetrating cloud cover and obtaining more accuracy SD information. This study firstly accesses three available SD products from The Microwave Radiation Imager (MWRI) equipped Fengyun-3C (FY-3C), Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the Global Change Observation Mission 1-Water (GCOM-W1) and the GlobSnow from European Space Agency (ESA). The Moderate Resolution Imaging Spectroradiometer (MODIS) snow-cover products and in-situ snow depth data over whole Mongolia were used for comparisons and validation.

Generally, by ground observation snow depth data obtained from 350 meteorological stations at the Soum level of Mongolia, correlation analysis and bias with between ground observation SD data and GCOM-W1/AMSR2, FY3C/MWRI and ESA/GlobSnow SD products were analyzed. Better results are demonstrated by GCOM-W1/AMSR2 and FY3C/MWRI SD products. ESA/GlobSnow cannot well express over Mongolian snow depth changes and development. If we see the spatial distribution between GCOM-W1/AMSR2 and FY3C/MWRI, more satisfied results were showed in FY3C/MWRI SD product. It is expected that these findings can contribute to SD product enhancements by fusion and Dzud risk prediction model.

## QUANTITATIVE ANALYSIS ON INFLUENCING FACTORS AND INTERACTIONS FOR THERMAL INFRARED MULTIANGULAR POLARIZATION OF SNOW

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As an essential information source for weighing up the global climate change, snow plays an extremely significant role in the radiation balance of the ground-air system in the high and cold regions. The analysis of spectral characteristics is the basis for the monitoring and inversion of snow. International studies on the reflection characteristics of snow in the visible and near-infrared wavelength, up to the present, have achieved fruitful results, while the combination of multiangular, multispectral and polarized characteristics in thermal infrared wavelength are still in the exploratory phase, which is a new line of research for thermal infrared remote sensing. This paper makes analysis of the mechanism for thermal infrared multiangular polarization of snow, and the impacts of the detection angle, azimuth angle and waveband factors on the thermal infrared polarization of snow by experimental methods. The results show that, there are evident anisotropic characteristics in the thermal infrared polarization of snow. The polarized temperature decreases with the detection angle grows, and it goes down slowly between 0 ° and 40 ° and rapidly when it is more than 40 °. It varies with the azimuth angle, which has significant valleys at 30 ° and 270 °. The spectrum curve of snow shifts in different waveband and the waveband of 11.5-12.5 μm and 10.3-11.3 μm corresponds to the maximum of thermal infrared polarization. On this basis, an orthogonal experiment of three factors and three levels is designed to make quantitatively analysis on the significance of influencing factors and interactions on the thermal infrared polarized characteristics of snow. It is found that the detection angle has extremely significant effect on the thermal infrared polarization of snow; the interactions of the detection angle, the azimuth angle, and the waveband indeed have a significant effect; different waveband also plays a vital role on the thermal infrared polarization of snow. The azimuth angle has a certain influence while its interactions with waveband is not working. Based on the results, it is recommended that the effects of above three factors, especially the interactions among them, should be paid special attention in the quantitative study on the multiangular polarized characteristics of snow. This research provides new ideas and methods for the remote sensing monitoring of snow and makes scientific basis for further development of thermal infrared polarized remote sensing, having essential theoretical significance and broad application prospects.

## **SIMULATION OF URBAN FUNCTIONAL ZONE AIR TEMPERATURE BASED ON GF-2 REMOTELY SENSED DATA AND URBAN WEATHER GENERATOR (UWG): A CASE STUDY OF BEIJING, CHINA**

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The rapid expansion of urbanization has led to serious urban thermal environmental problems, and the urban heat island phenomenon has become one of the most significant features of climate change in modern cities around the world. It has become a hot issue in current urban ecological environment research. At present, most scholars have studied and analyzed the urban heat island effect on the surface from the perspective of land use types, and there have been few studies on the urban canopy thermal environment from the perspective of urban microclimate spatial scale. Therefore, from the perspective of different land use attributes, studying the typical space outdoor microclimate of each land use attribute has become the focus of this paper. UFZs (Urban Functional Zones) tend to be urban planning units with similar energy consumption and outdoor thermal environment due to their similar spectral characteristics and the same socioeconomic functions. The UWG (Urban Weather Generator) model has good simulation performance in urban microclimate, with low computational complexity and high efficiency. In this paper, the UWG model is used to quantitatively analyze the spatial thermal environment of Beijing. In order to simulate the urban thermal environment more accurately, the underlying surface used in the simulation is replaced with the underlying surface of finely classified urban functional areas. In this paper, high-resolution remote sensing data GF-2 and POI+OSM data are used to classify the functional areas of the underlying surface of Beijing city, and then the UWG model is used to simulate the temperature differences in different functional areas. Temperature verification is carried out based on the measured data of meteorological stations. The canopy temperature differences of different types of urban functional areas and the canopy temperature differences of the same type of urban functional areas with different sizes were quantitatively analyzed. The results show that: (1) The canopy temperature of different urban functional areas from high to low are: commercial area > residential area > public area > road and traffic area > industrial area > green space and square area; (2) The temperature of the outer ring of Beijing is generally lower than that of the inner ring, and the heat island effect in the city center is serious. The existence of commercial and industrial areas will increase the heat island effect in this area, and the existence of green space square area will alleviate the heat island effect in this area; (3) The canopy temperature is proportional to the building density, that is, the denser the building, the higher the temperature. Based on these results, it is possible to deeply understand the thermal environment characteristics, influencing factors and mitigation measures of Beijing, which is of great significance for the sustainable and healthy development of the city and rational planning in the future.

## INVESTIGATION AND EVALUATION OF LAND SURFACE TEMPERATURE DATA WITH HIGH-TEMPORAL RESOLUTION OVER THE TIBETAN PLATEAU

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Land surface temperature (LST) plays a vital role in the interactions between the earth's surface and the atmosphere. The LST with high temporal resolution (e.g., hourly LST) can better contribute to understanding regional diurnal LST variations and monitoring land surface processes. The Tibetan plateau, as the "Asian water tower" and "world roof", has a huge impact on regional and global climate change. Therefore, hourly LST faces an urgent need in the Tibetan Plateau. Currently, the hourly LST can be derived from the geostationary satellites and reanalysis data. This study investigated and evaluated three LST products derived from China's Fengyun-4A (FY-4A), Meteosat Second Generation-Indian Ocean Data Coverage (MSG/IODC) of Europe's Meteorological Satellite Organization (EUMETSAT), and China Land Surface Data Assimilation System (CLDAS) reanalysis data. Validation based on *in-situ* LST four ground sites under clear-sky indicates that the mean RMSEs are 3.53 K (FY-4A), 3.85 K (IODC), and 4.85 K (CLDAS), respectively. Overall, the FY-4A LST is considered to have the best accuracy, and the difference in accuracy between FY-4A LST and IODC LST is small in the Tibetan Plateau. Among them, CLDAS LST has the worst performance, and probably is because the CLDAS has a coarser spatial resolution (0.0625°) than FY-4A (about 0.04°) and IODC (about 0.05°). In addition, the spatial patterns of the three LSTs are compared. The comparing results show that the two remote sensing LSTs (*i.e.*, FY-4A and IODC LST) have consistent spatial patterns in the Tibetan Plateau. In contrast, there is a clear spatial pattern difference between CLDAS and the other two LSTs, especially in the northwest region of the Tibetan Plateau. The possible reason for this phenomenon is that there are few ground observations in the northwest region of the Tibetan Plateau that can be fused into CLDAS. The evaluation results show that the hourly LST from geostationary satellites has more reliable accuracy and spatial patterns than from reanalysis data in the Tibetan Plateau, a region lacking ground observation. This study can provide a reference for the application of these three types of LST data with high temporal resolution in the Tibetan Plateau.

## RESEARCH ON CFD SPATIAL WIND AND HEAT ENVIRONMENT SIMULATION AND SPATIAL PLANNING OF TYPICAL GARDEN LAYOUTS IN DIFFERENT REGIONS OF CHINA

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The design of Chinese classical gardens is mainly based on the concept of harmony between man and nature and the local geographical environment. Modern gardens combine the main design concepts of classical gardens, and integrate people's aesthetics and the sustainable development of the city into the design scheme, which has a good effect on improving the local microclimate of the city. Therefore, it is of great significance to study the wind-heat environment layout of Chinese classical gardens and modern gardens to quantify the impact of local microclimates in cities. To this end, this study intends to simulate the wind-heat environment of Chinese classical gardens and modern gardens based on high-resolution remote sensing data and computational fluid dynamics models. Firstly, based on high-resolution remote sensing data, and using SpaceClaim to create geometric models of each garden; Secondly, import the created geometric model into the CFD meshing software to create mesh elements; Finally, the grid data is imported into Fluent, the boundary conditions are set according to the collected meteorological data and the underlying surface data, and appropriate models and algorithms are used to carry out numerical experiments. In the numerical simulation of the wind-heat environment of classical gardens, we mainly simulated the wind-heat environment of the garden space under four working conditions: the Humble Administrator's Garden in Suzhou (built in the early 16th century), a classical garden in southern China, and the Jingsi Garden in Suzhou, a modern garden (built in 1993); the Summer Palace, a classical garden in northern China (built in 1750) and a modern garden, Taoranting Park (built in 1952). The influence of the spatial layout of classical gardens and modern gardens in southern and northern China on the wind and heat environment of local urban three-dimensional spaces is compared and analyzed. The numerical calculation results show that: comparing the classical gardens in the south with the classical gardens in the north, the gardens in the north have better effect on alleviating the local microclimate in the city; Compared with the classical gardens in the north and the modern gardens, the modern gardens have a better effect on improving the local microclimate in the city; The layout of gardens in different regions can improve the wind and heat environment problems caused by urban modernization.

## A PHYSICS-BASED ALGORITHM FOR RETRIEVING LAND SURFACE TEMPERATURE UNDER LIQUID-PHASE CLOUDS

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Land surface temperature (LST) plays a key role in monitoring the interactions between the earth and the atmosphere in land surface processes. However, the cloud contamination greatly impedes access to high-quality thermal infrared (TIR) remote sensing data. Thus, acquiring the LST under cloudy skies is very pressing for the all-weather mapping of LST. Passive microwave (PMW) remote sensing technology offers an effective way to detect geophysical parameters all over the world. Although significant progress has been made in LST retrieval using PMW data, most researches are inadequate since they neglected the cloud effects and atmospheric radiative transport mechanism. In this paper, a physics-based LST retrieval algorithm was proposed to derive LST under liquid-phase clouds. This algorithm was developed primarily via the ratio of brightness temperature polarization difference for frequencies 18.7 and 23.8 GHz. The emissivity parameter, the ratio of emissivity polarization difference for 18.7 and 23.8 GHz, was calculated using the Advanced

Integral Equation Model. The atmospheric downwelling radiation ( $T_{d18.7}$ ,  $T_{d23.8}$ ) and transmittance ( $\Gamma_{18.7}$ ,  $\Gamma_{23.8}$ ) were estimated using the parameterized relations to cloud liquid water (CLW), mean temperature of cloud ( $T_c$ ), and precipitable water vapor (PWV) in the Community Radiative Transfer Model. Results indicate that the effect of cloud layers on atmospheric parameters at selected channels is non-negligible and that CLW has the most significant impact, followed by PWV and  $T_c$ . Additionally, CLW, PWV, and  $T_c$  are highly associated with atmospheric transmissivity ( $\Gamma_{18.7}$ ,  $\Gamma_{23.8}$ ) and atmospheric downwelling radiation ( $T_{d18.7}$ ,  $T_{d23.8}$ ), which are very conducive to atmospheric correction. The preliminary simulation result of LST shows a root mean square error of 4.32 K under liquid-phase clouds; in particular, the accuracy was 1.95 K when LST was above 280 K, and bias varied from 0.69 K to 5.38 K. In addition, using ERA5 reanalysis skin temperatures as the validation data, the actual application to the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) brightness temperatures and ERA5 profile indicated this algorithm is also encouraging for the LST retrieval under cloudy skies.

## SOIL MOISTURE RETRIEVAL FROM SENTINEL-1 AND SENTINEL-2 DATA USING ENSEMBLE LEARNING OVER VEGETATED FIELDS

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Soil moisture is an important parameter in climate, hydrological models, and agricultural applications. It plays an important role in the global water and energy cycle, especially in climate change, drought monitoring, and so on. The rapid development of remote sensing technology has made it possible to monitor soil moisture changes on multiple temporal and spatial scales. Due to its high sensitivity to soil moisture and its all-weather observation capability, microwave remote sensing has become more and more widely used in the retrieval of soil moisture in bare surface and vegetation-covered areas. In this study, we developed a soil moisture retrieval method using ensemble learning by Sentinel-1 and Sentinel-2 with multi-source datasets. First, using the water cloud model, combined with the Sentinel 2 optical data, the influence of vegetation cover on the backscattering coefficient was removed, and the backscattering coefficient set of bare soil was obtained. Then, the AIEM model is used to establish a data set of backscattering coefficients under different surface parameters, and the influence of various surface parameters on the backscattering coefficients is studied. Finally, combined with other multi-source datasets, a soil moisture inversion model was established based on the ensemble learning algorithm. Two widely used ensemble learning models were explored and compared using ten-fold cross-validation. The Adaptive Boosting (AdaBoost) model performed slightly better than the Random Forest (RF) model. Further the prediction accuracy of the AdaBoost model was verified to be comparable to the SMAP soil moisture product. It shows that it is feasible to use the ensemble learning method to invert soil moisture using radar data. The proposed framework maximizes the potential of WCM, AIEM, AdaBoost model, and multi-source datasets in deriving spatiotemporally continuous soil moisture estimates at 30 m  $\times$  30 m, which should be valuable for soil moisture inversion development.

## AN IMPROVED CHANGE DETECTION METHOD FOR REMOTE SENSING TIME SERIES

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To improve the change detection accuracy of time series based on remote sensing, an improved algorithm based on the combination of ALLSSA (Antileakage Least-Squares Spectral Analysis) algorithm and DBEST (Detecting Breakpoints and Estimating Segments in Trend) algorithm is proposed and applied to the change detection of remote sensing time series. The method uses ALLSSA to decompose the time series and obtain the trend components of the time series. Then the trend segmentation mechanism of the DBEST algorithm is used to detect the trend. In this paper, the improved algorithm is evaluated by using simulated time series data set, multi-breakpoint time series data set and vegetation index calculated by MODIS NDVI remote sensing time series products as data sources. Experimental results show that the comprehensive detection accuracy of the improved algorithm is 97.45% on the simulated time series data set. In the generated simulated NDVI time series data set, the RMSE of trend data is 0.0256 and 0.0307, respectively. On the multi-breakpoint time series data set, the RMSE of trend data is 0.0386. MNRN (Mean Normalized Residual Norm) of the dataset is 0.0252. Finally, the improved method is applied to downloaded Terra MODIS NDVI data to demonstrate the detection capability of the method on real remote sensing data. The MNRN of Terra MODIS NDVI data is 0.0286. Therefore, this method is suitable for remote sensing time series change detection, which can obtain accurate trends and accurately detect the change of time series.

## SPATIAL DOWNSCALING ALGORITHM OF LAND SURFACE TEMPERATURE USING MACHINE LEARNING ALGORITHM

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As a key physical parameter characterizing the state of the earth's surface, land surface temperature (LST) has a close impact on the energy balance and water cycle process of the earth's surface at regional and global scales. It has been widely used in the research of global climate change, surface flux estimation, soil moisture estimation, agricultural drought monitoring, urban thermal environment, geothermal resource exploration and so on. At present, the sensor is still unable to obtain thermal infrared data with high temporal and spatial resolution. Due to the trade-off between high temporal resolution and high spatial resolution of remote sensing LST products, various downscaling algorithms have been developed. However, the selection of explanatory variables of LST and downscaling models are often restricted by study location, which limits the generalization performance of these models. In this paper, a robust downscaling method of LST using Random Forest algorithm is proposed after the evaluation of relationships between six variables, including surface reflectance, spectral indices, terrain factors, land cover types, longitude and latitude information, and atmospheric reanalysis data, to establish a nonlinear relationship between LSTs and the land surface parameters. To validate the model, five regions of China are selected as the study areas, the Moderate Resolution Imaging Spectroradiometer (MODIS) LST product is downscaled by RRF from 1 km to 100 m. Taking the sub regions of two typical surface types in Beijing as the representative study area, a comparison with the Basic-RF (BRF) model and the thermal sharpening (TsHARP) algorithm is also made. The downscaling results of proposed model in the two sub study areas are proved to achieve a more satisfied performance than those of TsHARP and BRF model, with root mean square errors of 2.29 K and 2.23 K, respectively. And further experiment results prove the robustness of proposed model trained in a specific region while being applied to other regions, and indicate that it is feasible to successfully downscale LST with the proposed model in a large area using a few study areas for model training.



## A GRASSLAND DROUGHT PREDICTION METHOD BASED ON RANDOM FOREST

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Drought is the result of a combination of factors such as weather, geography, and hydrology. The occurrence, development, and change of drought are a process of gradual accumulation, and disaster formation is a process of quantitative change leading to qualitative change. Frequent drought disasters have prompted people to focus on how to more accurately predict the occurrence, development, weakening and receding of drought, in order to take effective and timely measures to reduce or mitigate the losses caused by drought disasters. The current role of remote sensing technology in drought prediction is very limited.

This paper is aim to abandon the traditional single point and process model based on meteorological and soil moisture information, giving full play to the characteristics and advantages of multi-source data. Random forest algorithm is used to efficiently and accurately model and simulate the possible development trend of grassland drought in the future combined with remote sensing, meteorological and environment indices. From the overall results, the proposed drought prediction model can accurately and efficiently predict the drought situation of grass in the short-term future(less than three months). The prediction accuracy of different drought degree is evaluated by comparing the temporal changes and spatial distribution of prediction and monitoring results as well as the consistency ratio. The results show that the prediction accuracy of moderate drought is the highest, the average accuracy is above 0.92. The prediction accuracy for one month advance is better. With the increase of the prediction time, the accuracy decreases gradually.

This paper is to develop a short-term prediction method with a prediction time of 0-3 months. From the overall results, the drought prediction method based on the random forest algorithm can accurately and efficiently predict grassland drought in the short-term future. It can obtain high-precision spatiotemporal drought distribution and solve the problem of inaccurate prediction of grassland drought.

## AN IMPROVED EFFECTIVE EMISSIVITY CORRECTION ALGORITHM FOR LAND SURFACE TEMPERATURE RETRIEVAL OVER RUGGED AREAS

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The Landsat series of satellites is the longest collection of continuously acquired high resolution thermal infrared (TIR) remote sensing dataset. The useful dataset has been radiometrically calibrated so that at sensor are well known. However, these values are not easily understood or applied and this dataset has not been utilized to its fullest potential. This work focuses on effective emissivity correction at Landsat pixels which will later be used with other ancillary dataset provided by Landsat LST team to perform LST retrievals. Our focus is the effective LSE calculation, therefore, the Landsat atmospheric auxiliary data from USGS Landsat Collection 2 surface temperature is used for the atmospheric inputs here. The Landsat emissivity calculations are from the ASTER Global Emissivity Dataset (ASTER GED).

In this work, we make effort to enhance the accuracy of the effective LSE over terrain areas.

The terrain fluctuates greatly. On the one hand, the complex terrain leads to the adjacent pixel and cavity effect caused by multiple scattering. On the other hand, the high and low terrain projected on the two-dimensional image of remote sensing observation cannot really represent the real ground area of the terrain area. Therefore, the average LST of pixels observed by remote sensing is not the real average temperature within the region. In order to improve the terrain effect on the real observed surface, the sky view factor (SVF) and the slope are calculated from the 12.5 m spatial resolution of digital elevation model (DEM) datasets obtained from the ALOS (Advanced Land Observing Satellite) (<https://cmr.earthdata.nasa.gov/search/concepts/C1206487504-ASF.html>). The multiple scattering effect on the effective LSE in each DEM 12.5 m range is estimated using the following equation from SVF (Yang, Wong et al. 2015):

$$\varepsilon_e = \varepsilon / (1 - \varepsilon) * (1 - SVF) \quad (2)$$

In which, the SVF is calculated from the relief visualization toolbox (RVT) (Kokalj and Somrak 2019). This effective emissivity calculated by Eq.2 solved the cavity effect caused by multiple scattering. Then, slope with 12.5 m spatial resolution was used to calculate the average value of the effective emissivity within the observed 30 m pixel. The average effective LSE ( $\varepsilon_a$ ) within the Landsat pixel range could be calculated as the following equation from the  $\varepsilon_{e,i}$  retrieved from equation (2):

$$\varepsilon_a = (\sum_0^n \varepsilon_{e,i} / \cos \theta_i) / \sum_0^n 1 / \cos \theta_i \quad (3)$$

$\theta$  is the slope degree, and calculated from DEM with 12.5 m spatial resolution.  $\varepsilon_{e,i}$  is effective emissivity calculated by Eq.2 and the spatial resolution is 12.5 m.

We validate our methodology by comparing the reversed LST both to ground measurements derived from four components measurements at validation sites over China and by inter-comparison with ASTER derived LST, respectively. Results with ground measurements show significant LST details with an  $R^2$  higher than 0.95 and RMSE less than 2 K for different slopes and surface conditions. The inter-comparison results with ASTER LST showed promising results, with over 50% of the pixels from the difference being between -1 K and 1 K and over 80% of the pixels being between -2 K and 2 K. Due to the complex topography and distinct atmosphere condition, these comparison results are encouraging.

## RETRIEVAL OF LAND SURFACE TEMPERATURE IN CLOUD COVERED AREA OF NORTH CHINA PLAIN BASED ON NDVI

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Land surface temperature (LST) is an important parameter to characterize the change in the land surface process. It has been widely used in the research of agricultural drought and crop yield estimation, and cloud cover will affect the acquisition of LST. Based on two FY-3D MERSI-II remote sensing images of the same source and different phases in the North China Plain, using the relatively stable characteristics of NDVI in the short term, the NDVI functional relationship between cloud-free area and cloud-covered area and the functional relationship between NDVI and LST are constructed to estimate the LST of cloud covered area. The results show that the areas with high LST in May are mainly located in the central and southern parts of the North China Plain and Beijing-Tianjin-Hebei region, which is related to the harvest of winter wheat and the urban heat island effect in the same period; The regions with low temperature are mainly located in the north of North China Plain and coastal areas, which are related to local vegetation types, longitude, and latitude and ocean effect. After verifying the accuracy of the results, it can be seen that in a short time, when the vegetation type is relatively stable, there is a linear positive correlation between NDVI in the cloud-free area and cloud-covered area, and there is a linear negative correlation between LST and NDVI; With the increase of the number

of pixels in the cloud coverage area selected in the relationship model, the Mae and RMSE values of the two thermal infrared 24th channel and 25th channel also gradually increase, but both values are less than 1.5k. The two Mae and RMSE values of the 25th channel are smaller than those of the 24th channel, indicating that the LST of the 25th thermal infrared channel of FY-3D MERSI-II deviates less from the real value, the estimation is more accurate and closer to the real value, which can meet the requirements of agricultural drought monitoring, ecological evaluation and the accuracy requirements of practical applications such as crop yield estimation.

## AN ITERATION ALGORITHM OF AEROSOL COMPOSITION AND OPTICAL PROPERTY RETRIEVAL FROM DUAL-WAVELENGTH MIE LIDAR OBSERVATIONS

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An understanding of global aerosol in spatial and vertical distribution is essential for the research fields of environment protection, resident health, climate change, Earth's radiation balance, and etc.. Mie lidar is the most widely used instrument to monitor the optical profiles of aerosols. Fernald method is a common strategy to retrieve aerosol extinction coefficient from the lidar' observations by assuming a functional relationship, which is known as extinction-to-backscatter ratio (also referred to as lidar ratio), between extinction and backscatter coefficients. The accuracy of the retrieval depends on the estimation of lidar ratio. As lidar ratio not only varies with the wavelength but also highly related to the aerosol types, it is illustrated that based on dual-wavelength lidar observations and the intrinsic optical properties of the aerosols, constraints can be induced in the retrieval procedure to improve the accuracy of lidar ratio estimation, facilitating the inversion of extinction coefficient and aerosol composition information.

In this paper, a new strategy for mixed aerosol content profiles retrieval from dual-wavelength lidar observation is promoted. First, by analyzing the historical monthly mean aerosol profiles in local region, an a priori information is first estimated. The corresponding lidar ratio and optical properties are calculated according to the complex refractive index of mixed aerosol and Mie theory by a forward model. Second, the lidar ratio is applied in the Fernald retrieval method, and aerosol extinction coefficient is then obtained from the lidar observation. Comparing the differences of the extinction coefficient and aerosol optical depth between the retrieved and forward simulated routes, the initial guess of aerosol profile and lidar ratio is modified due to the relationship built between aerosol mass profile and the corresponding optical properties. Finally, optimal aerosol profiles, including the content and the optical properties, is gained from the iteration of the above steps. The method is applied in a study region in Inner Mongolia, China and monthly local models are built. By comparing the results before and after iteration, it suggests that the promoted method can enhance the mean accuracy of extinction coefficient by 19.70% and column mass aerosol by 15.11%. The method is further validated by CALIOP data, and the results is accordant with the CALIOP product and the ECMWF reanalysis data. It indicates that the method in this paper can provide confident aerosol composition and facilitate the retrieval accuracy of aerosol optical profiles, and may have application in the future lidar observation data processing.

## SPATIO-TEMPORAL VARIATIONS IN DEW AND ITS RELEVANCE TO DROUGHT IN THE BEIJING-TIANJIN-HEBEI REGION OF CHINA

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Due to intensive agricultural irrigation, rapid urbanization, and a relatively dry climate, the Beijing-Tianjin-Hebei region, which is located in the Haihe River system, now is facing the severe water resources crisis. Dew as a kind of non-rainfall water inputs, can be a sustainable water to maintaining plant growth. However, little is known about the quantitative characteristics, and few studies have examined the ecological relevance of dew to drought in the area. Based on the atmospheric driving field data of the China Meteorological Administration Land Surface Data Assimilation System (CLDAS-V2.0) and cloud fraction ratio data by China's Feng-yun (FY) geostationary (FY-2H), following the regional dew model, we obtain the dew amount in the Beijing-Tianjin-Hebei region from 2008-2021. Besides, based on the scPDSI (self-calibrating Palmer Drought Severity Index) data from 2008-2020, we also explored the spatial-temporal distribution and evolution characteristics of the dry-wet conditions in this area. The results showed that a larger amount of dew was exhibited in the mountainous area (mainly in the northwest), and dew amount was fewer in the plain area (mainly in the southeast) of the study area. Dew increased gradually from April to August, and afterwards decreased. The annual dew amount ranged from 0.70 mm to 50.63mm, and it accounted for 15.6% of annual precipitation in the extreme dry period. During the extreme dry month, monthly dew amount can be 35.1% of precipitation. Our findings suggest that dew can serve a sustainable significant water resource during periods of drought period in the water lacking areas.

## LONG-TERM CHANGES IN DEW OVER THE MU US DESERT (CHINA) DURING THE VEGETATION RESTORATION PERIOD (1999-2018) AND ATTRIBUTION TO CLIMATIC DRIVERS

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The desertification of the Mu Us Desert is severe and the water resources are severely lacking. Dew is an important water source for the growth of animals and plants in arid and semi-arid area. This study intends to use ERA5 data developed by the European for Medium-Range Weather Forecasts (ECMWF), together with the simulation model to analyze the temporal and spatial distribution characteristics of dew in the past 20 years since the vegetation restoration in the 21st century. Besides, the attribution analysis of dew was also analyzed. The results are as follows: The estimated dew amount based on the ERA5 data fits well with the ground observations ( $R=0.54$ , bias=0.007 mm). The temporal distribution of dew is characterized by the fact that the dew first decreased and then increased from January to September, and then gradually decreased from October to December. Monthly dew reaches its minimum in April and its maximum in September. Dew occurs frequently in summer and autumn, but less in spring and winter. The annual dew amount showed an increasing trend during 1999~2018, and the total dew amount of dew in 1999~2008 was higher than that in 2009~2018. The spatial distribution of dew is as follows: the dew yield was lower in the northwest, and it was higher in the southeast, overall showing a decrease trend from southeast to northwest in the Mu Us Desert. The interannual variation of dew is affected by temperature, precipitation, and vegetation cover together. Among them,

temperature and precipitation play a leading role. The research results will help deepen the understanding of the characteristics of non-precipitation water input such as dew in the Mu Us Desert, and will provide a further scientific basis for vegetation restoration and sustainable management of water resources in the sandy area.

## ASSESSMENT OF WATER STRESS AT CHINA'S MAIN RIVER BASIN FOR SUSTAINABLE DEVELOPMENT GOALS (SDG 6)

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The freshwater withdrawal as a proportion of available freshwater resources is an indicator to assess the level of water stress for Sustainable Development Goals (SDG 6). Understanding water stress's spatial and temporal changes are critical to sustainable water resource use. The Food and Agriculture Organization (FAO) of the United Nations, the custodian agency of SDG 6, proposed a global framework for the water stress calculation and evaluated the water stress at the national scale. Based on FAO's water stress definition, this study constructed a method to disaggregate water stress's spatial and temporal distribution in China by combining with multi-source data, including statistical data, remote sensing data, and simulated data from the water resources model. The remote sensing data and the model simulated data provided the spatial and temporal proxy for the renewable water resource and freshwater withdrawal to disaggregate the statistical values at the provincial administrative units. The disaggregated data were used to evaluate the spatial and temporal changes of water stress at China's main river basins. The water stress in each river basin is spatially heterogeneous. The Haihe river basin holds the highest water stress among China's ten first-order river basins, followed by the Huaihe river basin and Northwestern rivers basin. The water stress at these river basins is more than 100%, indicating that the available water resource cannot satisfy the demands of regional water use after considering the environmental flow requirement and the water resource exploitability. There is no water stress in the Southwestern rivers basin because of the abundant renewable water resource and less water use demand. Climate factors and water use change together act on the change of water stress. The water stress shows a W shape change in the season because of the less available water resource in the winter and more water use in summer. From 2002 to 2020, the water stress at the Haihe basin, the Southeastern rivers basin, and Zhujiang river basin was significantly declining because of the increasing precipitation and decreasing water use, which is a beneficial trend for water resources sustainability. However, the significant increasing trend of water stress at the Huaihe and the Northwestern rivers basins because of declining available water resources and increasing water use will suppress the achievement of the Sustainable Development Goals. There is still 33% population in China (about 0.45 billion population) live in high-level water stress regions even though the environmental flow requirement is not considered. The regions with high-level water stress are generally the developed areas with higher population density. The agricultural water stress is higher than in other sectors, especially in the northern river basins of China. Saving water and improving water use efficiency are the main ways to relieve water stress.

## RETRIEVAL OF VEGETATION WATER CONTENT WITH MULTI-FREQUENCY PASSIVE MICROWAVE SENSOR AMSR-E DATA

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As one of the main types of land cover, vegetation plays an important role in maintaining human production and life, regulating climate and maintaining the balance of ecosystem. Among them, vegetation

water content (VWC) is the main factor affecting photosynthesis and biomass of green plants, and it is an indispensable link in many key biogeochemical cycles. Conventional vegetation moisture monitoring is usually carried out in the visible light band, which is mainly proposed based on the reflection characteristics of leaves in the visible near-infrared. In areas with frequent extreme weather such as haze and cloud and rain, these methods are limited to a certain extent. Because of its ability to penetrate haze particles and clouds, passive microwave is more and more used in vegetation properties retrieval. In the first step, Through the analysis of numerical simulations in L, C and X bands by surface emission model, the Advanced Integral Equation Model (AIEM), we found that bare soil surface emissivities at different frequencies can be characterized by a linear function with parameters that are dependent on the pair of frequencies used. Second, we iterative solution only contains unknown parameter equation of vegetation water content under the assumption that polarization dependent on vegetation without a significant impact on signal, based on the radiative transfer model ( $\omega$ - $\tau$  model) and passive microwave vegetation index (MVI) and then calculating the parameters under the condition of different vegetation coverage of vegetation water content of large scale observation. This methodology minimizes the impact of surface signals in monitoring vegetation parameters. In the third step, in order to verify the inversion accuracy of vegetation water content, we compared it with the normalized difference vegetation index (NDVI) obtained from the optical sensor MODIS because it is difficult to obtain a large range of vegetation water content data. It is concluded that the vegetation water retrieved from AMSR-E data has a good consistency and correlation with the NDVI at both spatial and temporal scales. The NDVI value of the regions with less vegetation moisture in the high latitude area in April was small or even negative, which was mainly caused by snow cover and vegetation litter. During the vegetation growing season in July, the NDVI value increased significantly, and the corresponding vegetation moisture increased significantly. The seasonal variation of vegetation moisture and NDVI was obvious from April to July in the middle latitude region. At low latitudes, the range of variation is not large, and both show high levels.

## QUANTIFYING THE ACTUAL IMPACTS OF DEFORESTATION ON SURFACE TEMPERATURE USING CHANGE DETECTION METHOD

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Forest change has received wide attention over the past two decades because of its regulatory effect on climate change through biophysical processes. Observation-driven assessment is considered the most reliable method to provide the impacts of observed forest change on land surface temperature (LST). However, the LST impact is derived using two years with a fixed time interval (i.e., 9 years), which is subject to the influence of climate variability. In addition, differences in the impact of forest loss on LST under different drivers are not clear. To address the aforementioned questions, this paper used an improved change detection method to locate the time window in which forest loss affects LST and analyzed the impacts of different drivers on LST and its attribution. We applied an improved Bayesian Estimator of Abrupt change, Seasonal change, and Trend (improved BEAST) to MODIS LST time series, and the specific time of forest loss was extracted by spatial-temporal matching of forest loss with abrupt changes in LST. The temperature difference between the calculated time window is expressed as the effect of forest loss plus the residual signal due to climate variability. At the same time, the temporal changes of albedo and evapotranspiration (ET) in response to forest loss were detected by using the improved BEAST, and the attribution analysis of the biophysical impact of forest loss on LST under multiple driving factors was carried out. The results showed that, on the global scale, forest loss causes an increase in the albedo of 0.16 %, and a decrease in the ET of

1.13 mm/10D, leading to surface warming (+0.60 K), of which the contribution of trend and seasonality were 65% and 35%, respectively. The biophysical impacts caused by forest loss were highly latitude dependent: the LST in low latitudes increased by 0.95 ~ 1.77 K, which was mainly due to the decrease in trend ET, and the LST in middle and high latitudes decreased by 0.16-1.22 K, which was mainly driven by the increase in albedo in winter. And fire-driven forest loss at high latitudes leads to local warming by significantly decreased ET. The impacts of forest loss on LST under different drivers were + 0.95 K (commodity production), + 0.64 K (shifting agriculture), + 0.58 K (wildfire), + 0.11 K (urbanization), and -0.14 K (forestry), respectively.

## A GENERALIZED METHOD FOR RETRIEVING GLOBAL DAILY MEAN LAND SURFACE TEMPERATURE FROM POLAR-ORBITING THERMAL INFRARED SENSOR INSTANTANEOUS OBSERVATIONS

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Daily mean land surface temperature (LST) is an important indicator for researching global long-term climate change. The polar-orbiting thermal infrared sensor (PTIRS) can provide limited instantaneous LSTs of a single day across the world. Several studies have developed algorithms to retrieve daily mean LST using limited instantaneous daily LST data. However, these algorithms have been specified for one PTIRS, which cannot be used for other PTIRSSs. Therefore, in this study, we determined to develop a generalized method that can be comprehensively applied to PTIRSSs with globally available instantaneous LST data since 1981.

Based on the in situ LST measurements at 227 flux stations operating in globally diverse regions, simple linear regressions of two instantaneous LSTs at different observations moments (once a day and once a night) of PTIRSSs were used to estimate daily mean LST. Taking into account the observed times of all PTIRSSs since 1981, we divided into three categories to estimate the global daily mean LST: (1) combinations of two observations from one PTIRS with approximately fixed overpass times after 2000 contain four cases: 09:30/21:30 (e.g., MetOp AVHRR), 10:00/22:00 (e.g., Envisat AATSR, Sentinel-3 SLSTR, and FY-3C VIRR), 10:30/22:30 (e.g., Terra MODIS), and 13:30/01:30 (e.g., Aqua MODIS, Suomi-NPP VIIRS, and NOAA VIIRS) local solar time; (2) combinations of two observations from one PTIRS with orbital drift effect (i.e., NOAA AVHRR) before 2000 contain eight cases: 13:30–17:00/01:30–05:00 local solar time in 0.5-hour interval; (3) combinations of two observations from different PTIRSSs after 2000 contain 12 cases: 09:30/22:00, 09:30/22:30, 09:30/01:30, 10:00/21:00, 10:00/22:30, 10:00/01:30, 10:30/21:30, 10:30/22:00, 10:30/01:30, 13:30/21:30, 13:30/22:00, and 13:30/22:30. We expect that this generalized method would be useful for generating long-term and high-quality daily mean LST dataset.

## SPATIAL HETEROGENEITY OF DRIVING FACTORS FOR GLOBAL LONG-TERM SURFACE URBAN HEAT ISLAND

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With the rapid development of urbanization, the urban area and population expand and bring about a series of environmental problems. The urban climate deteriorate with the temperature increment and the urban heat islands (UHI) phenomenon ensues. It is convenient to retrieve the long-term global land surface temperature (LST) from satellite remote sensing, through which the surface UHI (SUHI) could be detected. Meanwhile, it is necessary to enhance the theoretical research on drivers for global SUHI to support effective mitigation strategies in urban management. A series of empirical analysis tools have been adopted to investigate the driving mechanisms of SUHI. However, the SUHI is typically quantified with the LST, which is a spatial variable. Spatial heterogeneities might exist among global SUHIs and their associated driving factors, which is hardly detected by traditional statistical models. Therefore, the advanced spatial statistical models are encouraged to be employed to better explore the drivers of the global SUHI. In this study, we determined to delve into the spatial heterogeneity of driving factors for the inter-annual variation of global SUHI.

Based on the prepared dataset of global SUHI, several factors were constructed concerning the surface properties, climate conditions and urbanization process. Specifically, the potential driving factors for annual and seasonal SUHI were explored from both spatial and temporal perspective. Moreover, the spatial non-stationarity of each factor was fully explored by advanced multi-scale geographically weighted regression (MGWR) model.

The results shows that the slope of surface albedo mainly contributes negatively to the slope of nighttime SUHI. The contribution of multiple factors is spatially non-stationary on a global scale. The local regression model, MGWR, with variable bandwidth performs optimal estimation of the contribution coefficient than traditional statistical and GWR models.

## **IDENTIFICATION OF TEA PLANTATIONS IN PLATEAU AREAS BASED ON SENTINEL-1/2 ACTIVE AND PASSIVE REMOTE SENSING DATA**

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The large-scale cultivating of tea has brought economic benefits and caused some ecological and environmental problems in Yunnan, China. Efficiently and accurately identifying the spatial distribution of tea plantations is of great significance for ecological and environmental protection. Since the study area is located in the subtropical plateau region of southwest China, the land is fragmented, the vegetation types are complex, and there are much cloudy and rainy weather, making it very difficult to identify tea plantations only using optical remote sensing data. In order to solve these problems, this paper uses Sentinel-1 (S1) Synthetic Aperture Radar (SAR) data and Sentinel-2 (S2) optical data to design 7 classification schemes to explore the influence of red edge features, radar features, and texture features on the Identification accuracy of tea plantations. The feasibility of Jeffreys-Matusita distance (JM) feature optimization and Recursive Feature Elimination (RFE) feature optimization algorithm to find the optimal feature combination was verified, and the distribution of tea plantations in the study area was obtained by using the object-oriented random forest algorithm. The research shows that (1) the combination of SAR data and optical data performed better in tea plantations identifying than using optical data only. (2) S2 red edge features and S1 radar features can significantly improve the accuracy of the Identification results of tea plantations. (3) After applying the JM distance and RFE feature optimization algorithms, the producer accuracy of tea plantations was improved by 1.39% and 2.38%, and the user accuracy was improved by 1.02% and 1.3%, respectively, compared with the Identification of all features. The overall accuracy of the random forest algorithm combined with RFE is



93.43%, the producer accuracy of the tea plantations Identification results is 91.07%, and the user accuracy is 89.47%. This study provides an effective new approach to identify tea plantations in cloudy and rainy areas in the subtropical plateau of southern China.

## THE USE OF TEMPORAL SAMPLE MIGRATION TO EXPLORE CROP TYPE FROM REMOTELY SENSED DATA

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Accurate and timely crop mapping is crucial for various agricultural production and monitoring. Current supervised classification methods based on remote sensing heavily rely on ground-truth samples collected at high cost, and the years without sampling highly limits the classification work. To address such challenge, we proposed a time-migration method based on historical all-season training samples (2017, 2018, 2020) to conduct supervised crop classification mapping in the target year (2021) without ground-truth samples. We chose Hailun City, Heilongjiang Province of northeastern China as study site, whose major crop production include corn, soybeans, and rice. We reconstructed the time-series Sentinel-2 data, and selected the optimal spectro-temporal features based on the Gini coefficient to construct standard crop phenological curves. We calculated the similarity between the reference spectral and image spectral and designed the rules for tag matching by dynamic time warping algorithm and designed the rules for the label matching to detect and identify the change state of training sample pixels. We obtained the crop types of historical samples in the target year by this method. The results showed that the migration accuracy of the samples can reach 90%, used these samples as training data for the random forest to classify the target year, the overall accuracy can reach 93%. We proposed a new sample time migration method in this study, which can achieve efficient and mass migration of historical samples, which greatly reduced the cost in ground-truth sampling work.

## ESTIMATION OF GROSS PRIMARY PRODUCTIVITY OF XISHUANGBANNA TROPICAL SEASONAL RAINFOREST BASED ON VPM CORRECTION MODEL

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Vegetation photosynthesis model (VPM) is a widely used model for calculating Gross Primary Productivity (GPP). Many studies have shown that it has a good effect in calculating GPP for most Vegetation types. However, the estimation accuracy of VPM model is not high for regions with many and long duration of cloudy weather, such as Xishuangbanna tropical seasonal rain forest. This paper develops a VPM model for estimating GPP under cloudy conditions, which mainly corrects the two parameters,  $W_{\text{scalar}}$  and EVI, that are greatly affected by clouds in the model. First, the water stress factor  $W_{\text{scalar}}$  is replaced by Evaporation Fraction (EF). Secondly, using the good correlation between near surface temperature and EVI, the conversion coefficient between near surface temperature and EVI was fitted to achieve the effective reconstruction of EVI polluted by cloud. The correction of both factors improves the estimation accuracy of the VPM model. The correction of the two factors improved the estimation accuracy of the VPM model, and the comparison

with the observed values of the GPP site in 4 years showed that the correction of EVI had a better improvement, with an increase of 0.22 in  $R^2$  compared with the pre-correction, and the correction of  $W_{\text{scalar}}$  was increased by 0.11 in  $R^2$ . In order to verify the proposed method, the in-situ observation data of Xishuangbanna flux site from 2007 to 2010 are used. The results show that the proposed method effectively improves the accuracy of GPP estimation by VPM model, especially in 2007, when the cloud is heavily affected, and the improvement is significant, with  $R^2$  increased from 0.2 to 0.82. In general, the accuracy of GPP estimation by the proposed method has been significantly improved, with RMSE ( $\text{gC}\cdot\text{m}^{-2}\cdot\text{8 day}^{-1}$ ) decreased from 15, 14.4, 18.1, 14.2 to 8.07, 6.56, 10.33, 11.44, respectively. Therefore, the proposed method can be used to estimate GPP of tropical seasonal rain forest in Xishuangbanna.

## ESTIMATION OF REGIONAL EVAPOTRANSPIRATION BASED ON THE DECOUPLE MODEL AND REMOTE SENSING INFORMATION

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Evapotranspiration (ET) is an important component of the surface energy balance and a key process of hydrological cycle. Continuous and accurate estimations of regional ET are meaningful for water management, agricultural production, and climate change adaptation. Remote Sensing (RS) technique is of important meaning for estimating ET on regional scale. However, there are some problems in the ET estimation model based on RS such as: ① Surface resistance and aerodynamic resistance which are necessary in energy balance method are not easy to estimated accurately, ② Advective energy, which is an important driver of ET in heterogeneous regions, is not accounted for. This study attempts to develop a new method to integrate the remote sensing information and meteorological data based on the Decouple model which is deduced from Penman-Monteith (PM) model. Further, this model could reflect the coupling relationship between the land surface and atmosphere systems by a key parameter  $\Omega$ . However,  $\Omega$  is influenced by these factors such as land surface soil moisture, vegetation condition, wind speed, air temperature, and air humidity, therefore there are no general methods to parameterize  $\Omega$  on regional scale. Firstly, a parameterization method for  $\Omega$  on regional scale based on Soil Vegetation Atmosphere Transfer (SVAT) model. Subsequently, the Decouple model is applied to reverse regional ET in Beijing city, from 1<sup>st</sup>, May to 31<sup>th</sup>, December, 2013. Finally, the results are evaluated based on the measured data and the results from other models. The results show that it produces the smaller absolute BIAS with the value of -0.26 mm/d, than MOD16 products and PT model results compared with the measured datasets. Further, the regions with high ET values agree well with the regions with high soil moisture and air humidity value which suggests that the decouple model is with great potential to generate regional daily ET products.

## HYBRID STATISTICAL AND MACHINE LEARNING METHOD FOR TEMPORAL NORMALIZATION OF POLAR-ORBITING SATELLITE DERIVED LAND SURFACE TEMPERATURE

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Land surface temperature(LST) acquired from remote sensing satellite observations is a commonly used data source in hydrological, meteorological, and climatological scientific research and applications. However, for widely used polar-orbiting satellite derived LST products, such as Moderate Resolution Imaging Spectroradiometer (MODIS), due to the intrinsic observing way of instruments, the observe time differs along the scan lines. To generate time-comparable LST product with a uniform local solar time, this study proposes a general and practical methodology for temporal normalization of the afternoon polar-orbiting satellite LST data. The proposed methodology contains three stages, (1) a statistical model for LST normalization is proposed, according to statistical results of the LST diurnal curve during the afternoon transit time of polar-orbiting satellites based on the ground measurements, (2) prediction model for the coefficients of this statistical model is established using the Gradient Boosting Regression Tree (GBRT) by incorporating multiple source data MODIS product, reanalysis, and ground measurements, (3) temporal normalization for Aqua-MODIS LST is implemented from the statistical model and coefficient prediction model. The algorithm was applied to the Continental United States(CONUS) in the whole year of 2020. The algorithmic validation was implemented by spatial comparison with the Geostationary Operational Environmental Satellite (GOES) R-Series (GOES-R) 16 Advanced Baseline Imager (ABI) LST product. Comparing with the original MODIS LST, the temporal normalized MODIS LST have higher accuracy and better agreements with the GOES-R16 LST. Therefore, the proposed methodology demonstrates good potential for illuminating the temporal effect of the wide-view polar-orbiting satellite observations.

## SPATIO-TEMPORAL VARIATIONS IN DEW AND ITS RELEVANCE TO DROUGHT IN THE BEIJING-TIANJIN-HEBEI REGION OF CHINA

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Due to intensive agricultural irrigation, rapid urbanization, and a relatively dry climate, the Beijing-Tianjin-Hebei region, which is located in the Haihe River system, now is facing the severe water resources crisis. Dew as a kind of non-rainfall water inputs, can be a sustainable water to maintaining plant growth. However, little is known about the quantitative characteristics, and few studies have examined the ecological relevance of dew to drought in the area. Based on the atmospheric driving field data of the China Meteorological Administration Land Surface Data Assimilation System (CLDAS-V2.0) and cloud fraction ratio data by China's Feng-yun (FY) geostationary (FY-2H), following the regional dew model, we obtain the dew amount in the Beijing-Tianjin-Hebei region from 2008-2021. Besides, based on the scPDSI (self-calibrating Palmer Drought Severity Index) data from 2008-2020, we also explored the spatial-temporal distribution and evolution characteristics of the dry-wet conditions in this area. The results showed that a larger amount of dew was exhibited in the mountainous area (mainly in the northwest), and dew amount was fewer in the plain area (mainly in the southeast) of the study area. Dew increased gradually from April to

August, and afterwards decreased. The annual dew amount ranged from 0.70 mm to 50.63mm, and it accounted for 15.6% of annual precipitation in the extreme dry period. During the extreme dry month, monthly dew amount can be 35.1% of precipitation. Our findings suggest that dew can serve a sustainable significant water resource during periods of drought period in the water lacking areas.

## **LONG-TERM CHANGES IN DEW OVER THE MU US DESERT (CHINA) DURING THE VEGETATION RESTORATION PERIOD (1999-2018) AND ATTRIBUTION TO CLIMATIC DRIVERS**

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The desertification of the Mu Us Desert is severe and the water resources are severely lacking. Dew is an important water source for the growth of animals and plants in arid and semi-arid area. This study intends to use ERA5 data developed by the European for Medium-Range Weather Forecasts (ECMWF), together with the simulation model to analyze the temporal and spatial distribution characteristics of dew in the past 20 years since the vegetation restoration in the 21st century. Besides, the attribution analysis of dew was also analyzed. The results are as follows: The estimated dew amount based on the ERA5 data fits well with the ground observations ( $R=0.54$ ,  $\text{bias}=0.007$  mm). The temporal distribution of dew is characterized by the fact that the dew first decreased and then increased from January to September, and then gradually decreased from October to December. Monthly dew reaches its minimum in April and its maximum in September. Dew occurs frequently in summer and autumn, but less in spring and winter. The annual dew amount showed an increasing trend during 1999~2018, and the total dew amount of dew in 1999~2008 was higher than that in 2009~2018. The spatial distribution of dew is as follows: the dew yield was lower in the northwest, and it was higher in the southeast, overall showing a decrease trend from southeast to northwest in the Mu Us Desert. The interannual variation of dew is affected by temperature, precipitation, and vegetation cover together. Among them, temperature and precipitation play a leading role. The research results will help deepen the understanding of the characteristics of non-precipitation water input such as dew in the Mu Us Desert, and will provide a further scientific basis for vegetation restoration and sustainable management of water resources in the sandy area.

## **AEROSOL EVOLUTION AND INFLUENCE FACTORS ANALYSIS DURING HAZE PERIODS IN GUANZHONG AREA OF CHINA BASED ON HYSPLIT AND PHA**

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Aerosols suspended in the atmosphere have implications for air quality, public health and global climate change. Exploring the spatio-temporal evolution of aerosols can help decision-making to improve air quality and respond to climate change. The Guanzhong area of China is selected as the study area. The air quality data from July 2018 to June 2021 were counted daily, and 20 haze periods were adopted for this study.

The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used to simulate the air mass transport trajectory during the haze period to classify the formation of haze. The spatial distribution of aerosol optical depth (AOD) was obtained by processing MODIS data with dark pixel (DP) method. Three factors were used to analyze AOD spatial distribution characteristics based on Perceptual Hashing Algorithm (PHA): GDP, population density and topography. In addition to the spatial distribution, the AOD value at the same location also changes with time. The correlations between aerosol and wind direction, wind speed and precipitation were analyzed using the data from weather stations. The research results show that: The average haze period in Guanzhong lasted about 7.4 days, mainly due to self-produced haze (90%). The aerosol concentrations in Xi'an, Xianyang and Weinan were higher than those in Baoji and Tongchuan. Among the above three factors of influencing AOD spatial distribution, GDP has a greater impact, followed by population density and topography. The statistical results show that the wind direction in Guanzhong area has little influence on the haze level, but the wind speed and precipitation are opposite. The correlation coefficients between wind speed, precipitation and aerosol change level are -0.63, -0.66, respectively. The improvement of air quality were accompanied by a precipitation process. This study provides a reference for the analysis and decision-making of aerosol evolution on the regional scale.

## THE OPTIMAL METHOD FOR WATER QUALITY PARAMETERS RETRIEVAL OF URBAN RIVER BASED ON MACHINE LEARNING ALGORITHMS USING REMOTE SENSING IMAGES

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Eutrophication has become one of the prominent problems of water environmental protection in endorheic rivers. Turbidity, ammonia nitrogen (NH<sub>3</sub>-N) and total phosphorus (TP) are the critical water quality parameters that affect water eutrophication levels. Therefore, water quality parameters retrieval using remote sensing technology is of great significance for the monitoring of inland water environment. But there are still few retrieval methods for water quality parameters in city rivers. In this study, Four machine learning algorithms including Random Forest Regression (RFR), LightGBM, XGboost and U-net deep learning were respectively constructed after establishing the features space with band features and water index features using medium-high resolution Sentinel-2 data collected from January 2021 to January 2022, and validated by the measured data which were obtained with the satellite images simultaneously in the Chan and Ba River of Xi'an city. The results showed that: (1) The RelieF method was used to optimize the features space in case of data redundant with overmuch features, and it is revealed that the features of blue band (490nm) and the band combination were more important to turbidity parameter, the ratio of the red band (665nm) to the short wave infrared band (842nm) was the most significant feature for NH<sub>3</sub>-N and TP parameters. (2) 12 inversion models of Turbidity, NH<sub>3</sub>-N and TP parameters were constructed based on four machine learning algorithms. The estimated values of the three parameters based on RFR model had the best correlation with the measured values, which the determinate coefficients (R<sup>2</sup>) and the root mean square error (RMSE) were 0.87, 0.95, 0.82 and 4.33, 6.93, 2.75, respectively. The RFR model had a better performance than other models (LightGBM, XGboost and U-net deep learning) and more applicable for Chan and Ba River. (3) Analyzing the annual changes of the three kinds of water quality parameters, it was found that water quality in Chan and Ba River had obvious seasonal characteristics and their concentrations were highest in summer and lowest in winter. The variation of turbidity parameters was visible during the rainfall period (June to August). Ecological water

replenishment period (September to October) played an important role in water quality improvement. According to comprehensive evaluation standards, the water quality of Chan and Ba River had improved from

### ESTIMATING DOWNWELLING SURFACE LONGWAVE RADIATION FROM FENGYUN-4A GEOSTATIONARY SATELLITE DATA UNDER ALL-SKY CONDITIONS

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Fengyun-4A (FY-4A) is the latest generation of China's geostationary satellite. The Advanced Geosynchronous Radiation Imager (AGRI) on board FY-4A can provide high-precision, high-frequency observation data, which provides new possibilities for the downwelling surface longwave radiation (DSLRL) estimation with the high spatial and temporal resolution. This work presents a new method for estimating DSLRL under all-sky conditions using a genetic algorithm-artificial neural network (GA-ANN) algorithm based on brightness temperature (BT) from the FY-4A AGRI infrared channels and near-surface air temperature and dew point temperature from the ERA5 reanalysis data. Due to the small number of observation sites and the limitation of FY-4A data download, the calibrated CERES SSF FOV all-sky DSLRL product was used instead of site measured data as the targets, the BT, near-surface air temperature and dew point temperature are used as inputs. The cross-validation method was used to verify the performance of the estimation model, the results showed that the bias and RMSE estimated by the new method were  $-0.03 \text{ W/m}^2$  and  $15.81 \text{ W/m}^2$ , respectively. To verify the accuracy and reliability of the new method, two independent observation sites were used. The all-sky DSLRL retrieval accuracy in terms of bias and RMSE are  $-4.31 \text{ W/m}^2$  and  $35.28 \text{ W/m}^2$ , respectively, which is better than the accuracy of clear-sky DSLRL product provided by the FY-4A satellite products. In addition, the estimation results were compared with CERES SYN all-sky DSLRL products, and the results showed that the bias and RMSE of the two products are  $0.86 \text{ W/m}^2$  and  $26.87 \text{ W/m}^2$ , which indicates that the estimated DSLRL is in good agreement with the CERES product. Compared with the  $1^\circ$  spatial resolution of the CERES SYN all-sky DSLRL product, the product estimated in this study has a spatial resolution of 4 km, which has better spatial and temporal resolution and can show more detailed spatial variation.

### IMPROVING THE ACCURACY OF RIVER WIDTH USING REMOTE SENSED SUBPIXEL DECOMPOSITION IN VEGETATION AREA

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River width, as an essential hydraulic variable, play a vital role in influencing the water cycle, driving the resulting river topography and supporting ecological functioning. However, spatial resolution limitations of commonly used satellite imagery have inhibited quantification of river width because river boundaries often run through pixels that represent a region that is a mixture of water and land. Therefore, in



this study, we proposed a framework combining Sentinel-1 and Sentinel-2 provided by satellite to estimate river width of narrow rivers and to improve the accuracy of large rivers' width. We decomposed the mixed pixels of water and land by establishing the relationship between the backscattering coefficient, the ratio of water and fractional vegetation cover (FVC) of the mixed area after removing the growth factors. A total of 204 sites' river widths were measured in China during 2016–2021 and used for model application and verification. The results showed that enhanced vegetation index (EVI) and backscattering coefficient of non-water areas were positively correlated at each site; the river width calculated by the proposed method is more accurate than that directly extracted by the modified normalized difference water index (MNDWI), with higher  $R^2$  (0.9727), higher NSE (0.96) and lower RMSE values (3.83m) (river width < 90m); the river width estimation error decreases as the river width increases, because the error is mainly caused by the mixed pixels near the river boundary. In addition, through the spatiotemporal analysis of river widths at all sites in China from 2016 to 2022, it was found that the average river widths of different river basins were very different. Rivers with large average river widths in the six years were mainly concentrated in the Yangtze River region (YZ), the Pearl River region (PE), the Yellow River region (YL), the Songliao River region (SL) and the South-West River region (SW), and the average river widths of YL were the largest (155.28m); due to the melting of glaciers and the increase of rainfall, the average river width in flood season and non-flood season in China showed an increasing trend in the past six years, with an average growth rate of 2.26 m/year and 2.17 m/year, respectively. The framework proposed in this study can provide an effective method for extracting the width of all scales of rivers by using satellite images, which can overcome the problems of high uncertainty of river width calculation. The outcome of this study may provide a support for estimating river carbon and  $N_2O$  emissions and related research in fluvial morphology and water resource management.

## SPATIAL-TEMPORAL VARIABILITY ANALYSIS OF TERRESTRIAL WATER STORAGE IN THE WATER SOURCE CONSERVATION AREA OF THE YELLOW RIVER BASIN BASED ON GRACE

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Surface water, soil moisture, groundwater, and snow are important components of terrestrial water storage (TWS), which are critical to the global water cycle and water resource management. Therefore, research on terrestrial water storage change (TWSC) is essential. The GRACE satellite, launched in 2002, can monitor changes in surface water storage, which helps us to study water changes in large watersheds on a global scale. However, Grace data is partially missing in time series. In this study, we used the LSTM neural network model to interpolate the missing TWSC data from the GRACE satellites from 2002 to 2017. Then, MK model and wavelet analysis were used to study the time evolution characteristics of TWSC. At the stage of time results, the hot spot analysis model and contour map were used to identify the variation area of TWSC, and the spatial variation law of TWSC was shown. The results show that: the terrestrial water storage in the study area are less in spring and winter due to drought, and more in summer and autumn due to rain; spatially, the change of water storage decreases from west to east, and the areas where TWSC increases are mainly concentrated in the upper reaches of the Yellow River (annual increase of 3-7mm), the midstream and its eastern regions are in a decreasing trend (annual decrease of 12-18mm). The interpolated data in this study can provide a data basis for scientific research such as exploring changes in water resources in the water conservation area of the Yellow River Basin. The research results can provide a certain scientific basis for ecological protection and economic development in the study area.

## A PRECISE CROP PLANTING STRUCTURE MAPPING METHOD BASED ON MOUTI-SPATIAL-TEMPORAL COLLABORATION OF REMOTE SENSING

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Agricultural is the basic for human living, but the expansion of the population and the deterioration of the global agricultural environment have aggravated the food shortage worldwide. In general, using satellite-based remote sensing technology is almost the only way to classify crops in a large scale. However, the existing researches based on satellite platform are almost difficult to meet the requirements of high-precision and large-scale crop monitoring at the same time, so only one aspect can be considered. In view of this situation, we have tried to achieve fine-scale division of crops in a watershed by taking farmland-parcel as the basic unit and integrating remote sensing data from various satellite platforms. Firstly, submeter-level data were used to extract farmland-parcels, and then Sentinel-2, Landsat and other remote sensing data were used to construct temporal-scale crop features in the farmland-parcel. Finally, a crop classification network based on time series data was designed to classify the major crops in the Yellow River basin of Ningxia region. In particular, we adopted a feature-matching method to fill in the missing values in the process of time series feature construction to avoid the problem that such crops could not be identified.

The results show that this method can achieve a wide range of crop type discrimination in a fine scale, and its overall accuracy can reach 80%. At the same time, this method can avoid the pepper and salt noise phenomenon in the pixel scale crop classification, and thus can be better used for crop mapping.

## EXPLORING THE ABILITY OF SUN-INDUCED CHLOROPHYLL FLUORESCENCE DATA TO PREDICT SUMMER MAIZE YIELD UNDER DROUGHT CONDITIONS USING MACHINE/DEEP LEARNING METHODS

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Maize is one of the most important food crops, and its demand has increased dramatically in recent decades. Timely and accurate forecasting of maize yield is essential to ensure global food security, especially under the increased incidence of extreme climatic and weather events. Traditional vegetation indices have a significant lag in response to drought, which may significantly affect the accuracy for maize yield estimation. Although the solar-induced chlorophyll fluorescence (SIF) is recognized to be more sensitive to environmental stress than traditional satellite vegetation indices, the potential of SIF for maize yield prediction under drought conditions still needs to be further investigated. To this end, the present takes a major corn production region (Hebei Province) in China as an example to investigate maize yield estimation under normal and drought years. We utilize three satellite data (i.e., global spatial continuous SIF at a spatial resolution of 0.05° and two vegetation indices of normalized difference vegetation index and enhanced vegetation index with 1 km resolution), meteorological data and soil data from 2000 to 2019 to predict summer maize yield at the county level, using a machine learning (ML) methods (random forest, RF) and a deep learning (DL) method (long and short-term memory, LSTM). The results showed that the overall accuracy of predicted yield can reach to 90%, and ML method was slightly better than the DL method when it came to predicting summer



maize yield. In normal years, the high-resolution SIF performed similarly to the two vegetation indices in predicting summer maize yield. Nonetheless, compared with two vegetation indices, the performance using high-resolution SIF data was better in predicting summer maize yield in 2002 that has been recongnized as a severe drought year, indicating that SIF has a certain superiority in predicting summer maize yield under drought conditions. As such, our study indicates the potential of using SIF data for crop yield prediction and believes that higher quality SIF products may have a significant advantage to improve crop yield prediction in the future.

## ESTIMATION OF SOIL AND CROP COMPONENTS TEMPERATURES IN CROPLAND USING SENTINEL-3 SLSTR IMAGES

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Land surface temperature (LST) is an important factor to characterize the energy and water exchange between the surface-atmosphere. However, due to the limitation of coarse spatial resolution of thermal infrared (TIR) satellite images, the radiance information of different components with significant LST differences is usually mixed within the pixels, for example, soil and vegetation [1-2], snow and forests [3]. Estimation of component temperatures can improve TIR remote sensing applications, such as evapotranspiration retrieval, drought monitoring, and yield prediction, with four types of algorithms: multi-angle, multi-temporal, multi-channel, and multi-pixel/multi-resolution [4]. The multi-angle images have different spatial resolutions and require high image registration accuracy, and the multi-temporal algorithm is difficult to solve the ill-posed problem of too many unknowns, while the other two algorithms are limited by the strong correlation between TIR channels [5], and the effectiveness of the methods needs to be improved.

In this paper, a new method combining multi-temporal and multi-channel algorithms was proposed based on the Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) data [6]. The method reduces the number of unknowns by reasonable assumptions, introduces the mid-infrared (MIR) channel to decrease the correlation between channels, and utilizes to estimate the soil and crop component temperatures in cropland. Assuming that the farmland includes only the soil pure pixel before sowing, the crop pure pixel before harvest, and the soil-crop mixed pixel during the growing season the observed radiance is the area-averaged data [7] and the proportion of different components can be represented by the fractional vegetation cover [8]. The process of the proposed method includes: (a) calculating the soil emissivity (before sowing), crop emissivity (before harvest), and mixed emissivity (growing season) from nighttime SLSTR images using the MIR/TIR temperature-emissivity separation algorithm [9]. (b) Considering the emissivity constant during the day and night, the split-window algorithm [10] is applied to obtain the mixed LST during the daytime after obtaining the mixed emissivity. (c) The mixed emissivity and LST are substituted into Equation (1), and the component temperatures of soil and crop are calculated separately using the genetic algorithm.

$$\begin{cases} \varepsilon_{MIR} B(T_s) = FVC \cdot \varepsilon_{MIR}^v \cdot B(T_v) + (1 - FVC) \cdot \varepsilon_{MIR}^g \cdot B(T_g) \\ \varepsilon_{TIR1} B(T_s) = FVC \cdot \varepsilon_{TIR1}^v \cdot B(T_v) + (1 - FVC) \cdot \varepsilon_{TIR1}^g \cdot B(T_g) \\ \varepsilon_{TIR2} B(T_s) = FVC \cdot \varepsilon_{TIR2}^v \cdot B(T_v) + (1 - FVC) \cdot \varepsilon_{TIR2}^g \cdot B(T_g) \end{cases} \quad (1)$$

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where the  $\varepsilon_{MIR}$ ,  $\varepsilon_{TIR1}$  and  $\varepsilon_{TIR2}$  are the mixed emissivity of the MIR and TIR channels of the SLSTR data,  $T_s$  is the mixed LST,  $\varepsilon^v$ ,  $\varepsilon^g$  and  $T_v$ ,  $T_g$  are the emissivity and temperature of the crop and soil components,  $FVC$  is the fractional vegetation cover which can be obtained from the visible channels of the SLSTR data.

Hebi City, Henan Province, was selected as the study area, the LST and the Normalized Difference Vegetation Index (NDVI) from April 29, 2021, during the daytime are shown in Figure 1. The cropland is mainly distributed in the eastern part of the image, and its LST is lower than that of the city, while the NDVI is higher. The component temperature estimation results of the cropland are shown in Figure 2. It can be seen that the soil temperature is generally higher than that of the vegetation, but the spatial distribution is similar, with the highest temperatures of 309.62 K and 303.84 K and the lowest temperatures of 296.16 K and 288.84 K for the two components, respectively.

In this paper, a new method combining the multi-temporal algorithm and the multi-channel algorithm is proposed to estimate the crop and soil component temperatures in cropland during the growing season by establishing reasonable assumptions and introducing the MIR channel using the Sentinel-3 SLSTR data. In future work, we will further consider the effects of both sunlit and shade to achieve a more refined temperature estimation of the four components.

## INVERSION OF NITROGEN AND PHOSPHORUS POLLUTION LOADS IN CHANGSHA COUNTY BASED ON GF-6 SATELLITE

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In recent years, a series of problems have appeared in the rapid agricultural development in our country: the irrational application of fertilizers and pesticides, the disposal of breeding wastes, the unreasonable development and utilization of land and so on. As a result, agricultural non-point source pollution caused by total nitrogen and phosphorus in rural areas gradually deteriorates, seriously affecting the survival and health of local people and the sustainable development of agriculture. In this study, the subtropical hilly area of Changsha County in Hunan Province was taken as the research area, and the remote sensing image of GF-6 satellite was used to establish the inversion model of nitrogen and phosphorus content in water body and soil. The spatial distribution of nitrogen and phosphorus pollution load in Changsha County was evaluated, and the main influencing factors were analyzed. The inversion method of nitrogen and phosphorus pollution load was proposed in this study. The inversion model of nitrogen and phosphorus content in Changsha County was established by using the field sampling data and the satellite image of GF-6. The results showed that the total nitrogen content in water and soil of Kaihui and Jinjing towns was high. The total nitrogen pollution values of the townships with high land development and intensive crop cultivation were significantly higher than those of other townships. However, there was little difference in the total phosphorus content among the townships. The results of this nitrogen and phosphorus retrieval method with the advantages of wide range and fast speed are consistent with the ground validation. This also makes it an important means of monitoring non-point source pollution in farmland, providing data support for farmland production management.

## RESEARCH ON REMOTE SENSING MONITORING OF SOIL MOISTURE BASED ON GF-1

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Soil moisture is an important component of surface ecosystems. Timely and accurate acquisition of the spatial distribution of soil moisture is of great importance in maintaining the regional ecological environment. Remote sensing monitoring has become a common method for obtaining soil moisture distribution, as it has advantages over traditional soil moisture acquisition methods in time and space. The high resolution of GF-1 (better than 8m multispectral) gives it an advantage in soil moisture inversion, but with only four bands - Blue, Green, Red and NIR - it is not possible to construct indices that require TIR and SWIR. The existing drought indices based on NIR and Red bands have unsatisfactory accuracy in vegetation-covered areas, and the problems of more complicated quantification and calculation all limit the application of GF-1 in soil moisture inversion.

To address these problems, a two-dimensional  $R_S$ - $R_A$  ( $R_S$  represents the difference between the NIR band reflectance and twice the Red band reflectance,  $R_A$  represents the sum of the NIR band reflectance and Red band reflectance) feature space was constructed by analysing the spectral characteristics of soils and vegetation with different water contents in the NIR and Red bands. The ratio drought index (RDI) was proposed using the distance from the image element to the normal to the origin as a correction factor. In order to verify the accuracy of the RDI under different cover types, Mount Tai, which has a variety of surface cover types, was chosen as the study area. The land cover types of the ground-measured soil moisture sample points were divided into two types: vegetation and bare soil, and the RDI was compared with the vertical drought index (PDI) and modified vertical drought index (MPDI), which were also constructed using NIR and Red bands. The results showed that all three indices could meet the accuracy requirements of soil moisture prediction, among which the correlation coefficients ( $R^2$ ) of RDI with the measured soil moisture data under both bare soil and vegetation types were 0.653 and 0.641, which were better than those of MPDI (0.616 and 0.594) and PDI (0.602 and 0.546), and achieved good accuracy under different cover types; the correlation coefficients of RDI with the measured soil moisture data under both bare soil and vegetation types were 0.653 and 0.641. The root mean square error (RMSE) of RDI at the vegetation sample sites is smaller than that of PDI and MPDI, effectively reducing the influence of vegetation on the soil moisture inversion; similarly, the overall relative analysis error (RPD) of RDI in the validation set is 1.570, which is better than that of MPDI (1.457) and PDI (1.417). The spatial distribution of soil moisture is more heterogeneous and more consistent with the actual situation in the study area.

The results of the study show that the RDI has achieved high accuracy with simple calculation and clear biophysical significance, and does not require additional quantitative remote sensing inversion parameters, which can provide a certain theoretical reference and practical basis for obtaining soil moisture distribution on a large scale

## ESTIMATING AIR-SEA TURBULENT HEAT FLUX BASED ON ENSEMBLE LEARNING

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Air-sea turbulent heat flux constitutes the ocean surface energy budgets and its exchange is a vital process for the coupling of the earth's climate and ocean systems. Accurate estimation of air-sea turbulent heat flux (sensible heat flux and latent heat flux) is helpful to understand the air-sea interaction and related issues of climate variability. The traditional bulk aerodynamic algorithm used to estimate the turbulent heat flux is based on the Monin-Obukhov similarity theory (MOST) with complex parameterizations under different atmospheric restrictions, and the accuracy of output remains to be further improved in global scales for long-term estimation. In this study, we estimated air-sea turbulent heat flux with an ensemble learning strategy which trained multiple machine learning models and combined their outputs for predictions. The model was developed by a combined use of the in-situ flux observations collected from the 120 buoys worldwide, remote sensing data, and reanalysis meteorological data. Three remote sensing-, five reanalysis-, and one hybrid-based turbulent heat flux products were included for cross-comparison. The results showed that the ensemble algorithm could improve the accuracy of turbulent heat flux estimates significantly compared to the stand-alone machine learning model and the bulk algorithm. In addition, the inter-comparison to the nine turbulent heat flux products also shows that there was a strong spatial consistency globally. Finally, we produced a 20-year (from 2001 to 2020), 0.25° global monthly air-sea turbulent heat flux dataset based on the ensemble algorithm.

## INTER-COMPARISON OF THREE WATER STRESS SCALARS FOR SIMULATING GROSS PRIMARY PRODUCTION IN A TWO-LEAF LIGHT USE EFFICIENCY MODEL

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Terrestrial gross primary production (GPP), the total amount of carbon dioxide (CO<sub>2</sub>) sequestered by vegetation through photosynthesis, is the most dominant and uncertain component of CO<sub>2</sub> flux in global ecosystem carbon exchanges. Accurate quantification of GPP, therefore, plays a pivotal role in deepening our understanding of global climate change, carbon budget, and biodiversity, however, is still full of challenges. The light use efficiency (LUE) model, calculating GPP as the product of absorbed photosynthetically active radiation (APAR) and LUE (derived by downscaling the maximum LUE with environmental scalars, e.g., water and temperature), have been widely applied in the regional and global GPP estimations, notably thanks to its superiorities in ease of use and clear-cut physical mechanism. The two-leaf (TL) LUE model, stratifying the canopy into sunlit and shaded leaves and considering the discrepancies of APAR and LUE on them, has been proven to be more efficient and mechanism-based than the big-leaf LUE model, which treats the whole canopy as a big extended leaf. To date, several previous studies have elucidated that water stress is more determinant for vegetation photosynthesis than temperature stress, whereas how the different water stress scalars affect the accuracy of GPP simulations based on the TL-LUE model remains unknown and needs to be addressed urgently. To fill this knowledge gap, we incorporated two water stress scalars [indicated by land surface water index (LSWI) and Bowen ratio] into the original TL-LUE model which uses vapor pressure deficit (VPD) as an indicator of water stress (hereafter referred to as the TL-LUE<sub>LSWI</sub>, TL-LUE<sub>BR</sub>, and TL-LUE<sub>VPD</sub> models, respectively). The GPP simulations based on the three TL-LUE models were validated with the measured GPP at 26 deciduous broadleaf forest sites from the FLUXNET2015 dataset. The inter-

comparison results show that (1) all the three TL-LUE models could well reproduce the GPP measured by eddy-covariance system, and (2) the TL-LUE<sub>LSWI</sub> model had the best performance in GPP simulations, followed by the TL-LUE<sub>BR</sub> and TL-LUE<sub>VPD</sub> models. This study provides meaningful implications for the future modification of the TL-LUE model and is crucial for understanding the global climate change and carbon budget.

## ESTIMATION OF ALL-WEATHER LAND SURFACE TEMPERATURE BASED ON DEEP NEURAL NETWORK BY COMBINING AMSR2 AND MODIS

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Land surface temperature (LST) is an important physical parameter at the surface-atmosphere boundary and a key input parameter for many geochemical models. All-weather LST products can be beneficial for enhancing the temporal resolution of remote sensing products of surface evapotranspiration, soil moisture and net radiation. Through combining MODIS data and microwave AMSR2 data from 2002 to 2021, the 10 km daily LST estimation models are constructed by using deep neural network (DNN) algorithm for cloud and cloud-free conditions. In-situ observations of 143 sites from six representative land cover types in the AmeriFlux and FLUXNET networks are used to evaluate the accuracy of LST estimation by the DNN model. The results demonstrate that the DNN model can effectively establish the relationship between satellite data (AMSR2 and MODIS) and LST. The root mean square error (RMSE) in the validation of the estimated LST for the six land cover types varies between 1.4 K and 3.5 K against in-situ site observations, which could explain 78%-92% of the variation in LST. The DNN model combining MODIS and AMSR2 can overcome the shortcomings of traditional thermal infrared remote sensing models in retrieving LST under cloudy conditions and it achieves a high accuracy under all-weather conditions, which will facilitate the continuous monitoring of the Earth's LST.

## RETRIEVAL OF LAND SURFACE TEMPERATURE UNDER CLOUDY CONDITIONS FROM AMSR2 BRIGHTNESS TEMPERATURE

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Land surface temperature (LST) is an important parameter in many studies including hydrology, meteorology, and ecology. In addition to thermal infrared remote sensing, passive microwave is an effective alternative for LST retrieval, particularly under cloudy conditions. In this study, we analyzed the impact of cloud liquid water in the transfer of microwave radiation in simulation database and presented a

parameterization method to quantify the impact. On this basis, we further put forward an improved physically-based algorithm for the retrieval of LST from Advanced Microwave Scanning Radiometer 2 (AMSR2) brightness temperature measurements at the 18.7 and 23.8 GHz frequencies with precipitable water vapor (PWV) and cloud liquid water (CLW) as auxiliary input. The algorithm is built on the basis of microwave radiative transfer equation and the assumption that surface emissivity at two adjacent channels is linear and the main factor causing brightness temperature difference in two channels is the absorption of PWV and CLW. The LST retrieval algorithm was tested in simulation database. Results indicate that the root mean square error (RMSE) of LST retrieval is approximately 1.6 K. When applied to AMSR2 brightness temperature, the overall accuracy is approximately 4 K in terms of RMSE. The performance of the algorithm was evaluated on several surfaces with different land cover types. Large error can be observed over barren surfaces with obvious negative bias. Over grassland, cropland and forest surfaces, the performance of the algorithm is robust with RMSE in the range between 3.2 K and 4.2 K.

## ESTIMATION OF HIGH-RESOLUTION LAND SURFACE EVAPOTRANSPIRATION FROM CHINESE GF-1 SATELLITE

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Land surface evapotranspiration plays a crucial role in the global hydrology cycle and energy exchange in the atmosphere-vegetation-surface continuum. Accurate retrieval of land surface evapotranspiration on the field scale is indispensable and meaningful for precision irrigation of farmland and the improvement of agricultural water use efficiency. The Chinese Gaofen-1 (GF-1) satellite, the first satellite of the Major National Science and Technology Project of China, has the advantage of providing high spatial resolution data (16 m for WFV sensor, 2 m and 8 m for PMS sensor) with high revisit frequency (almost four days). In particular, the WFV sensor could provide satellite images with almost 800 km wide coverage. However, the application and potential of GF-1 data in the field-scale ET simulation is still not well documented and needs to be further explored. In this study, a simplified Priestley-Taylor model was proposed to estimate land surface ET using the Chinese GF-1 satellite images, in conjunction with the meteorological data from the ERA-5 reanalysis dataset. The estimated ET was validated with the ground-measured ET at five eddy covariance (EC) sites involved in the Heihe Watershed Allied Telemetry Experimental Research (HiWATER) from July 2013 to December 2013, covered by melon, populus forest, tamarix chinensis and bare land. Furthermore, the model was applied to acquiring the regional ET of crop in Hengshui, Hebei. The results showed that the model could well reproduce the ET measured by eddy-covariance system among all five sites, indicated by a coefficient of determination ( $R^2$ ) of 0.93 ( $P < 0.001$ ), a root-mean-square error (RMSE) of 16.52 W/m<sup>2</sup> and a standard deviation (SD) of 5.64 W/m<sup>2</sup>. The measured ET had a range of 0~100 W/m<sup>2</sup> while the estimated ET had a range of 20~140 W/m<sup>2</sup>. Compared to the ET from MOD16 in Hengshui, the estimated ET using GF-1 data had finer texture and higher values. This study increases insight into the potential and application of the GF-1 data in accurate field-scale and regional ET simulation.

## DOWNSCALING OF MODIS EVAPOTRANSPIRATION PRODUCTS WITH SENTINEL-2 DATA

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Evapotranspiration (ET) is the main component of surface heat balance and hydrologic balance in terrestrial systems. Accurate estimation of ET is of great value in practical applications such as climate change prediction and diagnosis, water resources management, drought monitoring, and food production. However, existing ET products either suffer from low spatial resolution or low temporal resolution. It is of great significance to obtain ET products with high spatial and temporal resolution. In this study, based on 500 m ET products of MODIS in Heihe, we utilized Sentinel-2 multispectral data to calculate normalized difference vegetation index (NDVI) with 10 m resolution, and then applied a downscaling method to derive 10 m ET. Specially, a linear regression model between the ET and NDVI both with 500 m resolution was established at first and then applied to predict ET with 500 m resolution after resampling the NDVI with 10 m to 500 m; subsequently, the residual was calculated from the original 500 m ET and predicted one and it was further resampled to 10 m; finally, the estimated linear regression model was applied to the 10 m NDVI by adding the 10 m residual to derive the downscaled 10 m ET. Results showed that (1) the spatial distributions of original 500 m ET and downscaled 10 m ET were strongly consistent; (2) for the ET product after downscaling, it was more abundant in details and the contrast between suburban and urban ETs was obvious. This study provides an effective downscaling method with easy access of necessary parameters for estimating ET with high spatial resolution.

## SEPARATE RETRIEVAL OF SOIL AND VEGETATION TEMPERATURES BASED ON TWO DIFFERENT METHODS

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Soil temperature (Ts) and vegetation temperature (Tv) provide significant information for various practical applications, such as evapotranspiration estimation, the study of water requirement for vegetations, and the drought monitoring. In this study, we estimated soil temperature (Ts) and vegetation temperature (Tv) with a (LST)-vegetation index (VI) trapezoidal space-based method (short for trapezoidal method), which estimates Ts and Tv by assuming the same temperatures in the same soil moisture contour, and a Double-

Angle method in which the estimation equations for  $T_s$  and  $T_v$  were established by thermal infrared observations from two angles and solved with least squares. The  $T_s$  and  $T_v$  estimations were conducted with Moderate Resolution Imaging Spectroradiometer (MODIS) and sentinel-2 remote sensing data from Google Earth Engine, together with some auxiliary meteorological data in Heihe river Basin in 2019.  $T_s$  and  $T_v$  from the trapezoidal and Double-Angle methods were compared with measurements from unmanned aerial vehicle (UAV). It shows that both the trapezoidal method and Double-Angle method performed well when compared to the measurements from the UAV, and a little higher accuracy was obtained from the Double-Angle method. This study gives an advice about the choice of the method for  $T_s$  and  $T_v$  estimations, which may be useful for the rational utilization and more accurate estimates of vegetation and soil water resources at the watershed scale.

#### ANALYSIS OF SEISMIC CAPACITY OF BUILDINGS BASED ON REMOTE SENSING DATA

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Rapid and accurate human mortality assessment is the basis of post-seismic emergency response actions, and in general building damage is one of the major causes of human casualties. Numerous historical seismic data have shown that large differences in human mortality rates can occur when building damage ratios are close, i.e., different types of buildings have different lethality levels after damage. Thus, detailed information on the building structure types is essential for accurate seismic vulnerability and risk modeling, as it reflects the main load-bearing structure of the building. However, for many seismic-prone regions, much of this information is outdated, unavailable, or simply non-existent. For this reason, we propose an effective method to analyze the seismic capacity of regional buildings using remote sensing data to collect information on building structure types and to propose corresponding seismic emergency countermeasures with regional characteristics. This study consists of three major steps: first, the building structure types are classified into four types according to the building lethality level: steel and reinforced concrete structures, brick and wood structures, mixed structures, and other structures; then, the building structure types of seven provinces in central China, Inner Mongolia Autonomous Region, Shanxi Province, Henan Province, Hubei Province, Hunan Province, Jiangxi Province, and Guangdong Province, were extracted from the remote sensing data, and the area and percentage of different building structure types in each province were finally obtained; finally, the obtained building structure information was combined with regional natural conditions, historical seismic conditions, post-seismic secondary disaster risk levels, and road damage prediction levels for comprehensive analysis. The overall characteristics of the seismic damage in each region are obtained, and corresponding emergency preparedness and disposal suggestions are proposed. This method of obtaining building structure information through remote sensing data greatly reduces the time and economic costs of previous field surveys and provides an effective way to quickly obtain regional building structure distribution and building seismic capacity analysis over a large area, which is of great significance to the rapid assessment of post-seismic casualties and seismic emergency and disaster mitigation.

#### INFLUENCE OF HYPERSPECTRAL THERMAL INFRARED SENSOR CHANNEL SELECTION ON LAND SURFACE TEMPERATURE AND EMISSIVITY INVERSION ACCURACY

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Hyperspectral thermal infrared (HTIR) remote sensing data offers a wealth of spectral information, which is getting more and more attention. Because of the various HTIR data channels, it is feasible to extract land surface temperature (LST) and emissivity (LSE) at the same time. However, there must be redundant information because of the significant connections between HTIR channels. Within a certain spectrum section, the majority of the HTIR data channels currently in use are evenly established with preset channel intervals. Additionally, there are few channel selection methods for retrieving land surface parameters. The majority of methods still rely heavily on prior knowledge and choose channels that are in the atmospheric window, which lacks a quantitative representation of the land surface information. Therefore, this work simulated four sets of HTIR data with various channel intervals and spectral coverage to design and optimize the inversion spectrum of LST and LSE. The simultaneous inversions of LST and LSE are effectively accomplished from simulated on-board radiance data using two machine learning methods, Random Forest (RF) and Artificial Neural Network (ANN). In addition, we employed the distribution iteration methodology based on information content to optimize the channel selection in order to choose the channels most sensitive to land surface parameters. As a result, the channel interval, spectrum setting, and channel subset that is sensitive to information about the land surface are chosen by comparison verification and error analysis. The conclusions of this paper are as follows: 1) the inversion accuracy of LST and emissivity in the 8-12.5 $\mu$ m spectrum is superior than that in the 8-10.5 $\mu$ m spectrum. 2) When it comes to LST inversion accuracy, RF outperforms ANN, but LSE inversion accuracy is comparable to that of the two machine learning methods. 3) It is possible to employ the channel subset chosen based on information content as the ideal channels for LST and LSE inversion. The findings of this research can be used to guide the channel selection of a HTIR sensor for earth observation.

## COMBINATION OF THE LANDSAT AND MODIS FOR ESTIMATING 100M ALL-WEATHER HOURLY LAND SURFACE TEMPERATURE

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Land Surface Temperature (LST) is an essential parameter in environmental monitoring and plays a vital role in various fields, such as urban heat island detection, forest fire monitoring, water resources management, and surface aridity evaluation. Among all the methods to obtain LST, remote sensing is the primary way to obtain the spatiotemporal information of LST. However, due to the cloud contamination and the limitations of satellites and sensors, existing temperature products are challenging to provide all-weather high spatiotemporal resolution LST. Moreover, this affects the use of LST and cannot meet the needs of high-precision applications. Some methods for estimating the cloudy LST are proposed to solve the missing value caused by cloud contamination on the LST. Furthermore, the spatiotemporal downscaling methods are used to obtain the high-spatiotemporal-resolution LST. However, the estimation of all-weather and high-spatiotemporal-resolution LST remains vacant. This paper proposes a method combining all-weather hourly LST estimates and spatial downscaling to obtain 100m all-weather hourly LST. This method takes advantage of the high spatial resolution of Landsat 8 images and the high temporal resolution of MODIS images. It consists of three parts. First, a method for estimating 1KM all-weather hourly LST is used. This method consists of two main steps: 1) reconstruct MODIS images using an improved annual temperature cycle model and 2) establish a relationship between LST and skin temperature, which is used to acquire hourly LST. Second, a spatial downscaling method of LST using the Extreme Gradient Boosting Tree (XGBoost) algorithm is applied to hourly LST obtained from the first step to predict the high-resolution LST. This spatial downscaling method is a regression-based downscaling method, which assumes that the regression relationship between LST and related variables is stable at different scales. In this part, spectral indices are selected as regression variables which include Normalized Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Normalized

Building Index (NDBI), Modified Normalized Difference Water Index (MNDWI), and Normalized Difference Drought Index (NDDI), Normalized Multi-band Drought Index (NMDI) and vegetation fraction (FV). Finally, the accuracy of LST is verified. Since it is impossible to obtain high-spatiotemporal-resolution LST directly, this paper uses simulation data and the in-situ LST data to verify the authenticity of the estimation of cloudy LST and hourly LST, respectively, and use high spatial resolution Landsat 8 LST to verify the authenticity of the downscaling results.

## GEOPHYSICAL IMPACT OF LAND SURFACE CHANGES ON LOCAL TEMPERATURE OVER CHINA

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The long-term trends of observed land surface temperature (LST) are the results of anthropogenic forcing and natural climate variability. It is undoubtedly that global warming in recent decades is the consequence of human activities, which include both greenhouse gases emission and land surface forcings. Specifically, land surface changes not only trigger the biochemical feedback but also affect local climate through the radiative process (i.e., solar radiation absorption variation) and non-radiative process (i.e., water and heat diffusion efficiency variation). However, the latter is usually disregarded when assessing historical or future climate changes. In the recent two decades, human land use and land management is universal in China, with rapid urbanization and a series of ecological projects implemented. However, significant uncertainties remain in the net temperature effect of these human-induced land surface changes through geophysical/biogeophysical feedback. Here, stable and consistent remote sensing observations and land surface model simulations are used and we adopt the refined observation minus reanalysis (OMR) method to isolate the temperature footprint of anthropogenic forcing on land surface. Specifically, the directly observed LST reflects climatic and land surface forcings, while the ERA-5 land reanalysis LST (output of CHTESSEL model) only reflects the climatic forcing, as it assumes a static landcover map and the input surface albedo and leaf area index are monthly climatologies. Hence, we analyze the trend difference between 20 years MODIS LST and ERA-5 Land LST to assess the geophysical/biogeophysical feedback of human activities on the local climate. Moreover, the driving factors are further explored spatially and temporally using a statistical model. The OMR results show that southeastern China displays significant warming related to the urbanization process, especially in five urban agglomerations. However, the northeast regions and central plains are dominated by the cooling effect induced by vegetation recovery and agriculture development. Overall, the temperature effect of land surface forcings is spatially heterogeneous and with a considerable magnitude. Thus, we highlight the importance of considering this impact in future regional climate policies.

## RETRIEVAL AND VALIDATION OF THE LAND SURFACE TEMPERATURE FROM FY-3E MERSI-LL

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Land surface temperature (LST) is an important variable reflecting the radiative energy balance at the surface. It plays an irreplaceable role in the study of the energy balance and water balance of the lithosphere, hydrosphere, biosphere, and atmosphere. LST at regional and global scales can be rapidly acquired by thermal infrared remote sensing, and as a result, this technology has received a great deal of attention from researchers. As the world's first civil terminator orbit meteorological satellite, Fengyun-3E (FY-3E) fills the gap in meteorological data around 6:00 local time at descending node, significantly improving the accuracy and timeliness of global numerical meteorological forecasts. The Medium Resolution Spectral Imager-LL (MERSI-LL) on board the FY-3E satellite has two thermal infrared channels with a spatial resolution of 250 m and can be used to retrieve LST. This paper uses the atmospheric radiative transfer model MODTRAN 5 in combination with 1314 atmospheric profiles from The Thermodynamic Initial Guess Retrieval (TIGR) dataset to simulate onboard observations of the thermal infrared channels of the MERSI-LL sensor under different atmospheric conditions. On this basis, the relationship between on-board bright temperature and LST was determined using statistical methods, resulting in coefficients over a range of overlapping atmospheric water vapor content (WVC), land surface emissivity (LSE), LST, and ultimately the construction of a Generalized Split-Window (GSW) LST retrieval model. The MODIS 8-day composite global LSE product (MOD21A2/Terra) and ERA5 global hourly scale WVC assimilation data were used as input to the GSW model to select the most appropriate coefficients to retrieve the LST. Finally, the proposed method was validated using measured surface temperature data from 100 meteorological stations in Northeast China in June 2022. The results show that the root mean square error (RMSE) between the LSTs retrieved by the split-window algorithm and the measured surface temperature at the meteorological stations is 1.68 K. The difference between the measured LSTs and the retrieved LSTs at 46 stations is less than 1 K. The retrieval accuracy achieves the expected target and has a high spatial resolution, which can be used for operational surface temperature inversion. This study can effectively satisfy the demand for regional and global scale surface temperature remote sensing monitoring applications and fill the gap of high spatial resolution satellite meteorological information on LST within the 6-hour assimilation window.

## DETECTION OF ATMOSPHERIC AEROSOL EVENTS IN ANTARCTICA

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The Atmospheric Optics Group (GOA) of the University of Valladolid is one of the official calibration sites for CIMEL solar and lunar photometers of NASA's Aeronet network. In addition to calibration activities, it manages several stations where it has additional instrumentation (all-sky cameras for cloud cover analysis, carrying out international campaigns, etc.) and deploys equipment at polar stations in the Arctic (as in the case of Ny -Alesund in the Svalbard archipelago) and Antarctica (scientific bases of Marambio, on Seymour Island and Juan Carlos I, on Livingston Island).

In 2018, a CIMEL photometer and a 360° vision camera were installed for the first time at the Marambiobase, operated by the National Antarctic Directorate and the National Meteorological Service of Argentina. In January 2022, the GOA carried out the equipment replacement to keep the instruments in proper calibration. The base has Internet connection coverage for receiving data from the photographer and images from the camera in real time.

This Antarctic station is located very close to the Antarctic Circle (location: 64°14'S 56°38'W), which makes it very suitable for monitoring events in which the dynamics of the atmosphere play an important role in the transport of atmospheric components. One type of event detected at this Antarctic station has been the emissions from the great fires in Australia in 2020.

In this work, some results found throughout the time in which the aerosol characterization equipment is operational are presented. These events are analysed together with the aerosol index data from the VIIRS sensor (Visible Infrared Imaging Radiometer Suite) on board the Suomi NPP and NOAA-20 satellites. In addition, this work analyses the results of the VIS and UV aerosol index from the OMI sensor and AOD (Aerosol Optical Depth) data from MODIS.

The inversion algorithm of the Aeronet network allows, in addition to the determination of the AOD at different wavelengths, the determination of the Angstrom exponent that allows the characterization of the size of the observed aerosol. These data are of great importance for the characterization of the type of aerosol and, therefore, the determination of its climatic characteristics related to radiative forcing for the extraction of conclusions from the scientific reports of the IPCC.

## RETRIEVAL OF APPARENT FLUORESCENCE QUANTUM EFFICIENCY FROM FLEX–FLORIS 500-780 NM

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The solar-induced vegetation fluorescence, emitted by the Chlorophyll *a* molecules as a small radiative flux in the 650–850-nm range has become new quantitative information in the understanding of vegetation status from the leaf to the landscape and global scales. However, to quantitatively exploit the obtained fluorescence signal and obtain the link between vegetation fluorescence and the core photosynthetic light reaction dynamics, advanced signal processing is required. Full spectral information in the region 500–800 nm is hereby used as input for the processing of the top-of-canopy fluorescence emission from a bottom-up leaf level approach.

As part of the FLEX L1B-to-L2 Algorithm Retrieval and Product Development Study, retrieval strategies for photosynthesis-related products are being developed based on the synergistic FLEX–FLORIS and Sentinel 3–OLCI spectral information. One of these products is the **fluorescence quantum efficiency** which is the ratio between the emitted fluorescence and the absorbed radiation that triggers the emission. The latter refers to the radiation absorbed by the light-harvesting pigments, with Chlorophyll *a* as the dominant photoreceptors of the solar incoming radiance. Disentangling the absorption of the overlapping pigments is shown based on the spectral fitting of the FLORIS–HR 500-780 nm reflectance product using individual pigment absorption features and a non-negative least squares fitting approach. The spectrally-resolved fAPAR contribution for Chlorophyll *a* is retrieved. The apparent fluorescence quantum efficiency (FQE) is calculated as the ratio of the spectrally-integrated fluorescence emission and the PAR absorbed by Chl, both converted to photon flux units. Retrieved FQE values are small (1-2%) but promising validation results are achieved. The apparent FQE indicates the downregulation of the excitation pressure on the Chlorophyll molecules and the energy provided to the final reaction centres. Hence, FQE provides a first proxy for the photosynthetic efficiency of the vegetation surface. Despite the relationship tends to be more complex due to the activation of non-photochemical quenching mechanisms which changes the qualitative coupling between fluorescence and photosynthesis, FQE is a first proxy of the downregulation of harvested light.

With these advances in the quantitative interpretation of the vegetation fluorescence signal the actual light use through photosynthesis and vegetation growth with carbon assimilation will be better quantified.

Hence, by the retrieval of FQE, combined with additional information on the dynamic regulation of the energy pathways in the light reactions, promising opportunities are presented to improve our understanding of the vegetation dynamics in the global carbon cycle.

## **SOLAR-INDUCED CHLOROPHYLL FLUORESCENCE (SIF) DATA ACQUISITION FROM THE LEAF TO THE SATELLITE SCALE – AN OVERVIEW ON CURRENT ACTIVITIES TO BETTER UNDERSTAND THE PHOTOSYNTHETIC PERFORMANCE OF PLANTS**

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Remote sensing of solar-induced chlorophyll fluorescence (SIF) measured with remote sensing sensors is a key parameter to better understand plant functioning at different spatial and temporal scales. Due to the direct relationship between SIF and photosynthetic activity, SIF is important for the monitoring of gross primary productivity (GPP) and the early detection of vegetation stress before it becomes measureable with conventional reflectance-based remote sensing proxies (e.g., vegetation indices) (Ač et al., 2015, Cheng et al., 2013).

The SIF signal is immediately released from chloroplasts after the absorption of sun light and emitted as a continuous spectrum in the range of red and far-red light (650–850 nm). Since SIF is only a small part of reflected radiance (1–5%), its detection is challenging and requires precisely calibrated spectrometers providing spectral high-resolution data and a high signal-to-noise-ratio (Porcar-Castell et al., 2021). In previous years, several studies have already demonstrated the potential of proximal (Pinto et al., 2016), unmanned aerial vehicle (UAV) (Bendig et al., 2020), airborne (Rascher et al., 2015), and satellite sensors (Köhler et al., 2018) measuring SIF at different spatial scales and temporal resolutions.

In this presentation, we want to give an overview about different SIF sensors and measurement techniques currently used at the different spatial scales, which challenges this implies and which possibilities arise for plant science to quantitatively relate SIF to actual rates of photosynthesis. In this context, we want to address i) the advantages and disadvantages of imaging and non-imaging proximal and UAV measurement systems in the context of phenotyping, demonstrated by comparing application possibilities of the imaging sensors HyScreen (Peng et al., submitted) and SIFcam (Kneer et al., submitted) as well as non-imaging sensors FloX and AirFloX (Bendig et al., submitted), ii) the scaling of airborne SIF measurements from the canopy to the leaf level, demonstrated by diurnal dynamics in different crops, recorded by the imaging spectrometer HyPlant (Siegmann et al., 2021, 2019), iii) and the application of SIF for phenological studies and vegetation stress, demonstrated by SIF measurements collected from a tower to measure and monitor the greening of a boreal forest during spring recovery (Junker-Frohn et al., submitted) and the relation of airborne and satellite SIF data to plant available water in the soil as an indicator for the early detection of drought stress (Quiros et al., submitted).

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