COMPENDIUM OF ABSTRACTS

International Science Workshop on High-Resolution Thermal Earth Observation

TRISHNA

Space Applications Centre, ISRO
Ahmedabad, India

19-21 November, 2024

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डॉ.एस. सोमनाथ / Dr. S. SOMANATH
अध्यक्ष / Chairman

MESSAGE

I am happy to introduce the first International Science Workshop on "High-Resolution Thermal Earth Observation" in India. This workshop will lay the scientific foundation for ISRO-CNES joint upcoming TRISHNA space-borne Earth Observation mission. This mission providing unprecedented opportunities to monitor and analyse critical ecosystem processes across a wide range of environments and biomes for deeper understanding of Earth System Science and Applications.

By capturing optical-thermal information from space, the TRISHNA mission will play a key role in several critical areas such as Ecosystem Monitoring especially agriculture, Water and Resource Management, Urban Heat Island Effect, Coastal Water and Marine Ecosystems, Cryosphere, Solid Earth and Geothermal Monitoring. As we continue to push the boundaries of Earth observation and space exploration, TRISHNA mission serves as a first stepping stone towards more advanced, integrated, and interdisciplinary global mission that will address even more complex environmental and societal challenges.

As global challenges intensify, from climate change for sustainable growth, this workshop promises to provide support both scientific inquiry and practical solutions. I would like to extend my heartfelt gratitude to all the scientists, engineers of ISRO and CNES as well as officials from other agencies and academia who have made this workshop a reality. Wish this international workshop a great success.

November 12, 2024

एस. सोमनाथ / S. Somanath

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Distinguished Scientist &
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MESSAGE

I am pleased to note that this compendium of abstracts of ISRO-CNES International Science Workshop on "High-Resolution Thermal Earth Observation", will provide glimpses of potential science and application in understanding the earth's dynamic systems and processes using simultaneous observations from multi-band thermal infrared and VSWIR payloads at 60m spatial resolution with 3-day revisit period. As technological advancements continue to reshape the landscape of environmental monitoring, thermal-optical remote sensing has emerged as a key tool for a diverse range of applications from radiative and water fluxes in ecosystem and urban settings, cryosphere, coastal and soild earth to assist the water management, climate studies and disaster management.

This workshop compendium intends to provide a comprehensive overview of the new algorithms, methodologies and innovations in thermal-optical remote sensing, offering valuable insights to researchers, practitioners, and policymakers. It highlights the significant contributions of this technology in addressing global challenges, particularly in the realms of environmental conservation, energy efficiency, and disaster preparedness. ISRO-CNES upcoming TIR-VSWIR mission, TRISHNA and subsequent global space missions will provide the high resolution optical-thermal Earth Observation data to address the continuous monitoring of earth dynamics. This data will be instrumental in ecosystem water budgeting, irrigation scheduling, crop health, monitoring urban heat islands, and supporting climate modelling. This compendium would not only serves as a reference for those working at the forefront of this field but also as a call to action for further exploration and innovation with thermal-optical remote sensing technologies in other applications.

I extend my gratitude to all the contributors, researchers and organizations whose dedication and expertise have made this compendium possible.

Wishing the thermal EO workshop a great success.

November 11, 2024

(शांतनु भाटवडेकर / Shantanu Bhatawdekar)

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MESSAGE

U R Rao Satellite Centre (URSC) is the lead centre under Indian Space Research Organisation ISRO with the objective of realising Communication satellite, Navigation satellite, Remote Sensing satellite and Space science missions to meet the requirements of the Nation. ISRO has long association with CNES (French national space agency) and has jointly developed various missions like SARAL and Meghatropiques.

TRISHNA, Joint collaborative project between ISRO & CNES carrying state-of-the-art Thermal InfraRed (TIR) and Visible Shortwave InfraRed (VSWIR) payloads enables High Resolution Thermal Imaging of natural resources. The high resolution data will be simultaneously processed at Payload Data Processing Centers (PLDPs), to provide a consistent and systematic record of various biophysical variables along with the surface temperature profile to model surface energy balance. The payload data will enable monitoring of urban heat islands and fluxes along with evapotranspiration (ET) for estimating ecosystem stress and water use.

Considering the importance of the Mission, I am glad to note ISRO and CNES are jointly organizing an International Science Workshop on "High-Resolution Thermal Earth Observation" at Space Applications Center (SAC) Ahmedabad during 19-21, November 2024. The Science workshop will rightfully serve as an excellent platform bringing together Indian and global science community and various user agencies/departments to understand and involve in the utilization of TRISHNA data and science products for the benefit of the mankind. Besides the technical sessions, the organizing committee has also planned a tutorial in the preamble of this workshop on modelling tools for thermal radiative transfer, surface energy balance and evapotranspiration to further enhance the outreach and utility of this unique International Science workshop to the participants.

I am confident that conference will bring together scientific community for better utilization of satellite data for valuable applications and will also further enhance the scope of international cooperation between ISRO and CNES.

I congratulate the organizing committee for their concerted efforts and wish the Conference a grand success.

एम. शंकरन
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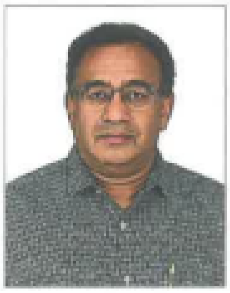
MESSAGE



The emerging climate change scenario has emphasized the need to monitor the hydrological and energy cycle very closely. The satellite based monitoring of hydrological and energy element is the best viable option. However the most of the present thermal sensors available in orbit are suited for global to regional scale monitoring. The present thermal sensors in orbit have coarser resolutions thus limiting the monitoring of water and energy fluxes at a finer scale. The TRISHNA (Thermal InfraRed Imaging Satellite for High-resolution Natural Resource Assessment) mission which is a joint mission of ISRO and CNES has been specifically designed to address this gap. TRISHNA's data from the Visible and Near Infrared and Short Wave Infra-Red (VSWIR) bands will help in monitoring the vegetation characteristics and combined with Thermal InfraRed (TIR) data, will leverage variety of applications such as assessment of heat fluxes, water fluxes and crop water stress. The TRISHNA offers a spatial resolution of 60m in both visible, SWIR and Thermal bands with a revisit of 3 days, which will be the first of its kind.

I am happy that an International Science Workshop on 'High-Resolution Thermal Earth Observation' is being organized as a precursor to the TRISHNA Mission. I hope that this workshop will help in updating the scientific applications using high resolution thermal and optical data, science products generation, validation and in developing the international cooperation on product calibration-validation and its applications.

I am delighted that a compendium document has been prepared, to portray the mission objectives, sensor configurations, science products of this mission and discussion on the calibration-validation protocols of the science products. I sincerely hope that this compendium serves as an information resource, and act as a reference material for the entire life cycle of the TRISHNA mission.

November 14, 2024

(Prakash Chauhan)

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MESSAGE

It is with great enthusiasm that we present this compendium, celebrating the collective efforts toward the TRISHNA mission. TRISHNA represents a significant advancement in high-resolution thermal Earth observation, offering new insights into water resource management, urban heat studies, and ecosystem monitoring. This initiative, a collaboration between ISRO and CNES, highlights our shared commitment to sustainable solutions. TRISHNA is designed to acquire data globally, using four thermal infrared (TIR) bands around noon and midnight, and seven visible and shortwave infrared (VSWIR) spectral bands. With a spatial resolution of 60 meters and a revisit period of 3 days at the equator (more frequent at higher latitudes), it stands as a unique resource for the global community.

We are embarking on a journey to utilize TRISHNA's capabilities to tackle global environmental challenges with precision and impact. As we look forward to the insights and innovations this collaboration will bring, we are reminded of the vital role Earth observation plays in sustainable development. May this compendium serve as a catalyst for knowledge-sharing, research, and progress in our mission to understand and protect our planet for future generations. We hope this workshop fosters valuable collaborations and advancements in the field of Earth observation.

Nagalakshmi A M

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An Overview of the NASA/JPL-ASI Surface Biology and Geology Thermal Infrared (SBG-TIR) Joint Project

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Abstract

In response to recommendations from the American and Italian national users and communities, NASA/JPL and ASI are jointly developing the Surface Biology and Geology - Thermal Infrared Mission (SBG-TIR). This mission will enhance our scientific understanding of climate, ecosystem and natural resources, hydrology and solid earth, by answering open questions about water and energy cycles, fluxes between ecosystems and the atmosphere and the ocean, and how and why they are changing together with questions on the composition of the surface of the earth and how it is changing through geologic processes such as volcanism. The mission will support several applications in agriculture and food security, including surface water management, water quality and coastal zones, conservation, wildfire and volcanic risk, and heat wave events. The mission calls for a NASA/JPL TIR instrument with six TIR bands and two Mid-Wave Infrared (MIR) bands with a ground sampling distance (GSD) of 60 m at nadir and a revisit time of 3 days. The mission also calls for an ASI Visible and Near-Infrared (VNIR) instrument with a Panchromatic (PAN) band with a GSD of 30 m and two VNIR bands with a GSD of 60 m. Both instruments will be mounted on an ASI-provided spacecraft/platform and launched into space on an ASI-provided launch vehicle. A multi-year international development effort will lead to a launch in the second half of this decade to serve the science/research and applications communities during the three year prime mission.

Keywords: Thermal Infrared (TIR), Mid-Wave Infrared (MIR), Visible and Near-Infrared (VNIR), heat, agriculture, water, wildfire, volcanic

TRISHNA-NISAR Synergy for Applications to Terrestrial Ecosystems

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Abstract

Terrestrial ecosystems provide a natural solution to global warming by storing carbon, dissipating radiative fluxes through evapotranspiration, and other physiological processes. TRISHNA mission would provide high (~60m, 3-day revisit) spatio-temporal thermal and visible shortwave infrared (TIR-VSWIR) observations approximately 60m spatial spatial resolution with 3-day revisit period. These will be utilized to derive several biophysical variables such as Land Surface Temperature, Leaf Area Index (LAI) and fractional Absorbed Photosynthetically Active Radiation (fAPAR) and fluxes in the form of surface evapotranspiration (ET) and Water Stress (Ws). On the other hand, NASA-ISRO L&S band Synthetic Aperture Radar (NISAR) mission scheduled for launch in early 2025 will provide high resolution (3m-10m), wide swath (>240km) and high repeat cycle (12days) earth observation data over the global land surface. NISAR and TRISHNA missions would operate simultaneously for substantial period and provide complementary information about the terrestrial ecosystems. While TRISHNA is sensitive to the thermal and optical properties, NISAR is sensitive to the geometric and dielectric properties of the land features. The abstract presents the synergistic use of TRISHNA and NISAR for potential applications to the terrestrial ecosystems.

The combined use of TRISHNA and NISAR science products will provide unique opportunity to estimate crop water productivity at major phenological growth stages by using the ET from TRISHNA and biomass from the NISAR mission at regular interval both for short and tall canopies. NISAR would also provide the surface and rootzone soil moisture that will open the door to estimate the plant transpiration, both from the crop and forest land. The combination of both will be able to narrow down the uncertainties that exist in two-source energy balance ET modelling to separate soil evaporation and plant transpiration to estimate plant water use efficiency. Moreover, all-sky soil moisture products from NISAR will be able to provide necessary data for cloud-gap filled evaporative fraction and cloudy-sky ET. This will be further used to assess the critical crop growth stages responsible to limit the potential crop yield. Further, regular estimates of ET, biophysical variables and biomass would provide opportunity to develop remote sensing driven crop yield models and segregating carbon in the woody and foliage parts of forest vegetation. The biophysical variables from TRISHNA can map forest phenology and discrete changes in morphological characteristics, while regular forest above-ground biomass and soil moisture products from NISAR will aid to generate health indicators and measure consumptive water use to assess forest carbon footprint. This complementarity suggests that a synergistic exploitation of TRISHNA and NISAR data would be an optimal way to monitor vegetation in all-sky condition.

Keywords: SAR, TIR-VSWIR sensing, ecosystem dynamics, biomass

Coastal SST masking recommendations TRISHNA mission

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Abstract

Members of the Committee of Earth Observation Satellites (CEOS) Sea Surface Temperature (SST) and Coastal Observations, Applications, Services and Tools (COAST) Virtual Constellations have noted the requirement of consistent ultra high resolution SST observations in the coastal zone where SST is a vital tracer of sub-mesoscale physical phenomena (the air-sea coupling in coastal regions where these eddies, filaments and fronts dominate). Coastal hydrodynamic model validation and assimilation also require ultra high satellite-derived SST from several sources to be presented in a consistent manner with respect to spatial extent. The advent of ultra high resolution (<100 meter) SST retrievals from existing and future planned thermal infrared (IR) radiometer missions will certainly open a new era of SST observations and remotely sensed coastal oceanography as they are nearly an order of magnitude improvement over the typical "750-1100 meter" observations from traditional thermal IR sensors such as VIIRS, MODIS, SLSTR, AVHRR, METimage etc. The spatial resolution of observation is a key factor but also the size of the area is extremely important so that synoptic ocean observations can be made. All the ultra high resolution sensors have limitations on the quantity of ocean observations obtained as their designed focus has primarily been on land phenomena and telemetry bandwidth requirements preclude total global ocean coverage. We strongly encourage TRISHNA mission planners and project team to obtain coastal SST data in GHRSST format with enough coverage up to minimum 100 km from the coast and make it more scientifically useful for the coastal ocean community and applications. We will share a more detailed analysis of our recommendation during our presentation.

Keywords: coastal, temperature, requirement, SST, resolution

A methodology for quantitative inter-comparison of cloud mask products

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Abstract

Remote sensing observations in optical spectral ranges are often obscured by the presence of clouds. The retrieval of various parameters using these observations require to identification of observations that are affected by the presence of clouds. Hence, the cloud flagging is an essential part of the retrieval algorithm for observations taken in visible to infrared (IR) ranges. The accuracy of the parameters is governed by many factors including the correctness of cloud flagging. It shows that there is a stringent requirement for accurate cloud masking. Many cloud masking algorithms are already proposed and explored for different missions with varying degree of accuracy and complexity. To find the most suitable algorithm for a given mission or to fine tune the various parameters a given algorithm, there is a need for validating the cloud mask generated from the given algorithm.

The validation of cloud mask is generally, an extremely tedious process, as it involves hours of hard work by a trained person to generate a cloud mask from given observations through daunting visual inspection. The method of generating cloud mask through visual inspection, obviously, could not be applied for many number of scenes. Therefore, there is a requirement for objective validation of cloud mask product other than the visual inspection. The validation procedure that could be applied on huge volume of satellite data without much manual intervention. The most viable option could be the validation through inter-satellite comparison. Unlike, inter satellite comparison of other geophysical parameter, the validation of of cloud mask is not straight forward. This work presents a methodology to validate the target cloud mask product with some reference cloud mask product quantitatively. Like any other validation exercise, validation of cloud mask too requires spatial and temporal collocation of target and reference cloud mask products. The proposed validation methodology also has some limitations but may help in improving the accuracy of a given algorithm for cloud flagging or may help in identifying the most suitable algorithms among various available algorithms.

Trishna albedo: presentation of methodology for modeling and validation

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Abstract

The albedo is an essential climate variable (ECV) and is defined as the fraction of the down-welling irradiance reflected by a surface in all wavelengths and directions. It is therefore a key element in the Earth energy budget studies. Instantaneous values of albedo are essential in estimating evapotranspiration, whereas average values of albedo generated over short periods of time (less than a month) are necessary in weather predictions. Knowing albedo values is also useful in the context of global warming in order to study the effects of mitigation measures such as increasing the albedo of crops by keeping a vegetation cover all year or changing the color of buildings' roofs. Estimating the albedo requires a good angular sampling of the irradiant solar spectrum as well as good angular sampling in the observation hemisphere.
Over land, TRISHNA's main mission is to monitor the hydric stress of ecosystems by measuring global surface temperature at 60 m spatial resolution, with a revisiting period of three days. To help interpret the thermal infrared measurements, TRISHNA also includes seven visible, near and short wave infrared spectral bands. The measurements will be obtained at least three times with three different viewing angles over an 8-day cycle, with increasing number of observations at higher latitudes (at least 4 above the whole Europe for instance). Hence, this makes TRISHNA a unique sensor to characterize the Bidirectional Reflectance Distribution Function (BRDF) at the agricultural plot scale, which is required in order to estimate the albedo. The current satellite sensors with a sufficient revisit frequency either only allow a resolution of a few hundreds of meters, thus missing out the agricultural plot scale, or observing close to nadir such as Landsat, Sentinel-2 or even Planet, thus missing out the directional variations within the sampled observations.
The presentation provides a glimpse of the current developmental stage of the albedo retrieval method as described in ATBD. A BRDF kernel-driven model is used to fit TRISHNA observations and then to estimate albedo. The method is inspired from the production of the surface albedo for Copernicus using PROBA-V data where a priori information and recurrent algorithm serve for gap filling. The solar blue-sky albedo combining black-sky albedo and white-sky albedo is the final deliverable. The results of orbital simulations for TRISHNA with synthetic data, simulations with Sentinel-3/OLCI data (which has a similar field of view), and validations on CNES ROSAS surface reflectance measuring stations in La Crau, Gobabeb and Lamasquère, in addition to Indian sites, will also be shown.

Keywords: TRISHNA, albedo, BRDF, energy balance, global warming mitigation

Machine Learning based Atmospheric Correction of Thermal Infrared data for Land Surface Temperature retrieval

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Abstract

The conventional atmospheric correction approach for retrieval of surface leaving and downwelling radiances in the thermal region involves per-pixel based Radiative Transfer (RT) simulations using known atmospheric profiles. However, this method is computationally intensive and depends heavily on the accuracy of input atmospheric profiles. To address these challenges, we propose a machine learning-based approach for computing surface leaving and downwelling radiances terms, which are direct inputs to the Temperature Emissivity Separation (TES) algorithm for Land Surface Temperature (LST) retrieval. We conducted 448,036 radiative transfer simulations to capture a diverse range of environmental conditions, spectral characteristics, and view geometries that affect Top-of-Atmosphere (TOA) total radiance values observed in the Thermal InfraRed (TIR) region. A machine learning model was employed to establish the relationship between key remote sensing inputs and radiative outputs. The network was trained using three primary inputs: TOA total radiance from all thermal bands, View Zenith Angle (VZA), and Total Column Water Vapor (TCWV), and two essential outputs: surface-leaving radiance and downwelling radiance, which are crucial for the TES model. We achieved high retrieval accuracy with R^2 values above 0.99 and a bias of 0.28 for all bands, indicating a strong correlation between true values from RT simulations and machine learning derived surface-leaving and downwelling radiance. Sensitivity analysis was also performed to account for sensor noise and atmospheric uncertainties. The results showed that downwelling radiance is more sensitive to atmospheric uncertainties than sensor noise, while the TES algorithm is sensitive to surface-leaving radiance for LST retrieval. The proposed atmospheric correction method could be utilized in upcoming missions such as ISRO's GISAT and ISRO-CNES' TRISHNA.

Keywords: Land Surface Temperature, Machine Learning, Atmospheric Correction, Radiative Transfer Model, Temperature Emissivity Separation, Thermal InfraRed

Improving the spatiotemporal resolution of Land Surface Temperature in the Indian context– Lessons learned and way forward

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Abstract

High spatiotemporal land surface temperature (LST) is an important variable in various applications. The trade-off between the spatial and temporal resolution of thermal infrared (TIR) sensors have led to the development of multiple disaggregation and data fusion techniques. The lack of concurrent coarse and fine resolution LST image pairs hinder the applicability of the data fusion methods over India which has significant cloud cover. Spatial disaggregation of LST with single or multiple auxiliary variables is a viable option considering that the auxiliary variables are available at much finer spatial resolution than TIR observations. The DisTrad model using NDVI as the auxiliary variable has been tested at multiple spatial scales (from Geostationary to MODIS scale and from MODIS scale to Landsat scale) with typical RMSE of 2-4 K. However, it was demonstrated that the choice of the spectral index in the DisTrad model depends on the dryness of the study area and NDVI should not be used for all conditions. Importantly, the relationship between LST and spectral index such as NDVI has shown to be useful for disaggregating geostationary scale images (5000 m resolution) over an entire day enabling the retrieval of diurnal cycle of LST at MODIS scale (1000 m). The limitations in the univariate DisTrad model have led to the development of the multi-variate principal component regression (PCR) method leading to improved results especially over heterogenous sites (RMSE 2-3 K). The PCR method has been applied with multitemporal MODIS TIR observations (~1000 m resolution) from the Terra and the Aqua platforms producing four fine resolution images (~70 m resolution) in a day. These 70 m resolution images, when combined with a statistical diurnal temperature cycle (DTC) model helps to capture the diurnal cycle of LST at a much finer spatial scale in a simpler manner. This method has been extended further into a hybrid, two-step approach for estimating the DTC at field scale from geostationary observations. Finally, machine learning models are also being developed to downscale day (RMSE 2-4 K) and night (RMSE 2-3 K) MODIS and VIIRS observations to Landsat scale that is suitable for operational purposes. The accuracy of the disaggregated LST is highly dependent on the accuracy of the coarse resolution LST which is used as an input. Most importantly, the resolution of the LST to be disaggregated impacts the ability to capture extreme hot or cool cases that are observed at Landsat or ECOSTRESS resolutions. Further, higher order of disaggregation is possible with a typical RMSE of 2 K when the starting resolution itself is relatively finer. Though multivariate disaggregation is considered superior, the use of univariate disaggregation methods cannot be neglected for estimating LST at 10 m or finer resolutions given that the very high spatial resolution satellites typically contain only visible and near infrared bands. Future research should focus on effective combination of geostationary and polar orbiting satellites to produce field scale diurnal LST for varied applications taking into account the effects of different algorithms and directional differences between sensors and LST products.

Keywords: LST disaggregation, diurnal temperature cycle, data fusion

Declining Clear-Sky TOA Shortwave Radiation in Northwest India: The Role of Vegetation Growth

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Abstract

Recent satellite observations reveal a significant greening trend in northwest India, particularly over desert regions, driven by increased vegetation cover, enhanced irrigation, and changes in precipitation patterns. This study investigates the trends in clear-sky shortwave (SW) radiation at the top-of-the-atmosphere (TOA) and explores the underlying mechanisms driving these changes in northwest India from March 2000 to December 2022. Utilizing satellite data from CERES and MODIS, we reveal a significant decrease in clear-sky SW TOA flux over northwest India, particularly centered at 27°N and 73°E, with a decreasing trend of -3.54 ± 0.48 Wm^{-2} per decade. This decline coincides with a 70% increase in normalized difference vegetation index (NDVI) and a 55% reduction in aerosol optical depth (AOD), suggesting that enhanced vegetation cover and reduced aerosols are primary contributors. The NDVI trend is closely linked to irrigation expansion and increased rainfall, particularly since 2010, in regions like the Indira Gandhi Canal area. The analysis also shows a daytime land surface temperature (LST) decrease of -1.67 ± 0.10 K/decade, despite positive SW radiative forcing, attributed to biophysical feedback mechanisms such as enhanced evapotranspiration. Conversely, nighttime LST exhibited a modest increase of +0.42 ± 0.1 K/decade, likely due to downward longwave radiation. Seasonal trends indicate the strongest decrease in clear-sky SW TOA flux occurs during summer, while the NDVI increase is most prominent during the post-monsoon season. Sensitivity analysis further highlights that changes in surface albedo, primarily driven by vegetation, exert a stronger influence on TOA SW flux than AOD variations. These findings underscore the complex interaction between land surface properties, radiation, and temperature in arid regions undergoing significant vegetation changes.

Keywords: Land-atmosphere interaction, Radiative effect, TOA shortwave flux, Vegetation greening, Northwest India

At-sensor signal simulations for the thermal infrared bands of TRISHNA mission using MODTRAN radiative transfer model

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Abstract

The retrieval of Land Surface Temperature (LST) relies on effective atmospheric correction, which is critically dependent on radiative transfer simulations. In this study, At-sensor signal simulations for the upcoming TRISHNA (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) mission (collaborative mission between ISRO and CNES) for its four Thermal InfraRed (TIR) bands (band 1: 8.65 µm, band 2: 9.0 µm, band 3: 10.6, band 4: 11.6 µm) have been carried out. MODerate resolution atmospheric TRANsmittance (MODTRAN) Radiative Transfer Model (RTM) was used for assessing the at-sensor radiance by incorporating sensor viewing geometry and essential input atmospheric variables such as air temperature, relative humidity, ozone concentration, and aerosol. Analysis shows that the At-sensor radiance is very much sensitive to relative humidity and maximum variation is observed in the band 4. It also indicates that there is small variation due to the ozone as well in all the bands, however its effect is comparatively high in the band 2 and 3. Changing air temperature by 2 K in the atmospheric profile, significantly modifies the At-sensor radiance and its effect is maximum in band 2. Changes in aerosol visibility from rural to urban environments have minimal effects across all bands, although band 2 experiences relatively high values. A sensitivity analysis reveals that how at-sensor radiance in each band is influenced by Land Surface Temperature (LST), Land Surface Emissivity (LSE), relative humidity, and viewing zenith angle (VZA) as shown in figure 1. This analysis is helpful in quantifying the sensitivity of At-sensor radiance with different input variables. It helps in generating the large number of simulations with respect to different input variables and its sensitivity to the LST retrieval.

Keywords: TRISHNA, radiative transfer model, land surface temperature, relative humidity

A Legacy of Thermal Remote Sensing and Evapotranspiration Modeling in India: Transition from KALPANA-1 to TRISHNA

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Abstract

Indian space agency and its research collaboration have made significant progress in estimating evapotranspiration (ET), a second important variable in the water cycle, using the Surface Energy Balance (SEB) modeling framework. This framework combines thermal infrared (TIR) and visible-infrared bands. These efforts have culminated in evaluating the potential of SEB models in contextual framework (e.g. S-SEBI) over sub-tropics and creation of analytical model (e.g. STIC-TI), which have improved our understanding of crop water use, agricultural productivity, and agro-hydrological interactions across India. This legacy is further bolstered by India's participation in an international mission, such as the Indo-French TRISHNA satellite, which is set to enhance global monitoring of water resources and agricultural productivity through high-resolution TIR and VSWIR imaging, aimed at mitigating human-induced climate change. The first regional-scale ET estimates at 8 km spatial resolution were made for post-monsoon, clear-sky days over India using single-channel TIR and broad visible band data from the VHRR payload of the Kalpana-1 satellite. These estimates, based on a contextual model of evaporative fraction and radiation fluxes, had an error of 25-32% compared to in situ slow-response measurements. By combining noon-to-night surface temperature differences and vegetation indices within a triangular contextual framework, using data from geostationary satellites like Kalpana-1 and INSAT-3A, researchers found that the triangle's dry-edge provides a strong signal for ET, improving accuracy when analyzed seasonally. All-sky regional ET estimates at 8 km resolution using this method showed errors within 29-35% compared to slow-response measurements. Further improvements were achieved by incorporating split-TIR bands from INSAT 3D, MODIS, and analytical model, which enhanced ET estimates at regional (4 km spatial resolution) and landscape (1 km) scales, with errors reduced to 24% and 17-25%, respectively, when compared to fast-response flux measurements over agricultural areas. Using data from ECOSTRESS at a high resolution of 70 m, combined with the STIC model, ET estimates achieved a root mean square error (RMSE) of 12% against flux tower measurements. This demonstrates that utilizing multi-band TIR observations with higher spatial resolution, alongside advances in SEB models and better validation, can significantly improve ET estimates, even at the farm level. In addition, ensemble modelling approaches using machine learning have further improved the accuracy by 20-25%. The lessons learnt from these legacy work would pave the way of achieving 85% accuracy for farm-scale (~ 60m spatial resolution) daily ET product from TRISHNA TIR-VSWIR simultaneous observations.

Keywords: Multi-scale ET, thermal remote sensing, surface energy balance, India, geostationary satellite, KALPANA-1, TRISHNA

A reflection on closed-form equation linking ET and canopy-scale conductances with thermal remote sensing from global space-borne missions

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Abstract

The Penman-Monteith (PM) formulation is a prominent closed-form physical equation for estimating evapotranspiration (ET) from terrestrial vegetation. It builds upon Penman's equation, which estimates open water evaporation using Earth's radiation balance, flux-gradient theory, and atmospheric demand. One key advantage of the PM equation is its elimination of direct dependence on surface temperature, a feature stemming from its origin under zero water stress conditions. While this formulation improves upon Penman's legacy, applying it to natural ecosystems reveals the critical role of biophysical conductances for accurately estimating ET, particularly under stressed environmental conditions. Two essential conductances are aerodynamic conductance (ga), regulating water vapor and heat exchange between the surface and the atmosphere, and canopy-surface conductance (gcs), governing the carbon exchange during photosynthesis at the cost of transpiration. The exclusion of surface temperature and the absence of closed-form equations for these conductances complicate global-scale ET mapping, especially when integrating the PM equation with thermal remote sensing data. By linking conductances with surface temperature through closed-form equations, here we reflect how reintroduction of land surface temperature (LST) into the PM formulation offers potential for improving ET estimation and ecosystem function analysis from thermal remote sensing. This method is rooted in Surface Energy Balance theory, where ET responses to LST variability are shaped by stomatal control, aerodynamic conductance, soil water availability, and atmospheric aridity. We employed the updated Surface Temperature Initiated Closure (STIC2.0) model, which estimates conductances analytically based on closed-form equations involving radiation, temperature, humidity, and LST. By integrating ECOSTRESS, Landsat and Sentinel-2 thermal-optical data with meteorological forecasts,we tested this method across multiple ecosystems in Europe and the United States. Our findings showed that dual conductances sign ificantly influence ET responses to LSTvariability under diverse soil and atmospheric conditions. This study emphasizes the need to account for LST-stomatal conductance interactions in thermal ET models, instead calculating ET solely as the residual of sensible heat flux. This analysis offers a fresh perspective for understanding ET variability from space, providing a solid foundation for future thermal remote sensing missions such as TRISHNA, LSTM and SBG, ultimately aiding in sustainable ecosystem and water resource management in arid and semi-arid regions.

Keyword*s*: Evapotranspiration, Penman-Monteith, Stomatal conductance, Thermal Remote Sensing, Landsat, ECOSTRESS

Mapping field-scale ET over sugarcane crop in Semi-arid region using combination of Landsat and Sentinel-2 observations

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Abstract

Remote sensing has been emerged as promising and efficient method in regional assessment of evapotranspiration (ET). Now, the need of hour is to compute field scale ET with integration of high spatial and temporal satellite datasets along validation. Downscaling techniques can generally be modulation-based models or statistical regression-based models with be a function of land cover types and radiation received along with incorporation of spectral mixture analysis. Land surface temperature (LST) in general available at moderate resolution from polar or geo-stationary satellites and it limits field scale applications. Thermal sharpening of image with better spatial or temporal coverage can elucidate the ambiguity. A study was carried out to demonstrate down-scaling of LST from LANDSAT OLI using fine resolution Sentinel-2 MSI images and estimating ET at field-scale for sugarcane crop in semi-arid tracts of Saharanpur Tehsil, Uttar Pradesh (UP) In this study, down-scaled LST used to drive a remotely sensed surface energy balance (SEB) model of ET estimation. The technique employed in this research is Non-Linear Disaggregation method (NL- DisTrad). It is based on the spatial disaggregation of images in order to build a relationship between corresponding variables as vegetation index and land surface temperature. Down-scaled LST has quite good agreement with snapshot of thermal images obtained using thermal camera. Simplified-surface energy balance index (S-SEBI) model has been employed using downscaled LST and surface albedo to determine dry and wet edge and finally reasonably accurate estimation of ET at field scale (Fig. 1). Estimated ET was found in good agreement with tower based estimates particularly during growing phase of sugarcane crop (R2 = 0.67)

Key words: Eddy tower, DisTrad, Evapotranspiration, Landsat, Sentinel, Sugarcane

Effect of Diurnal and Angular Thermal Infrared Observations on Field-Scale Evapotranspiration

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Abstract

The water management for precision agriculture need accurate estimation of evapotranspiration (ET) to assess the water foot-printing at field to regional scale. In the recent past, accurate estimation of ET using optical and thermal sensing data surface energy balance approach remains a challenge. Many workers showed that accuracy of land surface temperature (LST) retrieval was dependent on the sensor viewing angle and reported discrepancy up to 16 K for vegetation and 12 K for urban structures. Moreover, daily ET using single acquisition from air-borne and polar orbiting satellite was unable to explain the atmospheric condition for a whole day and hence leads to uncertainty in the daily ET estimation. In this study the ground-based ET was estimated using thermal camera and hyperspectral imager to study (i) difference in ET estimates during morning and afternoon hours over different phenological stages of wheat crop and (ii) effect of view angle of LST on ET estimation. In this study, the field-scale ET is estimated using ground observed LST, NDVI and albedo measured from the ground based thermal and optical sensing study and data was collected at two different agricultural sites Ujjain (Feb 4, March 4) and Vidisha (Feb 5, March 6, 2022) at farmer's field in Madhya Pradesh state. The diurnal behaviour of ET due to crop phenology and view angle of thermal infrared camera was assessed at field-scale. At vegetative stage, substantial change in crop ET was found while in case of physiologically matured crop, not much change in ET was observed between morning to afternoon hours. Land surface emissivity (LSE) remain between 0.95 to 0.98 for all experiment sites. As crop growth progresses from vegetative to maturity its water demand decreases and if there was no rainfall or irrigation diurnal change in ET was negligible in the absence of advection. It clearly conveys that to generate daily ET from instantaneous observation should also consider the crop growth stage in the computation. The angular view geometry of LST observation drastically changes the LST (4 to 26%) which also leads to change in ET up to 22%. Therefore, it is crucial to perform angular normalization of the LST data, by translating LST data obtained in different directions to a specified direction such as the nadir direction.

Keywords: Evapotranspiration, thermal camera, hyperspectral imager

Multi-Tier Surface Energy Balance Mapping for the Water-Energy Nexus using Geospatial Technology: Insights and Foresight for the TRISHNA Mission

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Abstract

An accurate assessment of evapotranspiration (ET) is significantly useful for various aspects of agricultural water management such as seasonal crop water requirement, irrigation scheduling, water budgeting and water stress/ drought monitoring. In this scientific study, geospatial technology, surface energy balance model, crop coefficient method, ET Station and in-situ observations were integrated and analyzed for the estimation and validation of ET at field scale in Tarai region of Uttarakhand. The aim of this study is to estimation crop evapotranspiration by applying the Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC). To address the limitation of availability of optical and thermal satellite datasets during the monsoon and winter season (extreme foggy weather condition due to Tarai region), machine learning based gap fill model for ET was developed to account the seasonal crop water requirement of 2022-23 and 2023-24. The crop coefficient (Kc) based ET and irrigation water requirement were estimated for sugarcane crop for 2022-23. Along this, MODIS derived ET product was compared with observed ET at larger field scale and big size of cropland area. The modelled results were validated using the observations of ET Station, which comprised Large Aperture Scintillometer (LAS) and micrometeorological tower, which augmented GB Pant University of Agriculture, Pantnagar (Uttarakhand) for measurement of the surface energy fluxes and evapotranspiration.

The results revealed that the METRIC derived Latent Energy/ET has the significant relationship with observed LE as 0.80 of coefficient of determination (R2) and 0.87 of index of agreement (IoA). The random forest based machine learning was developed and it had 0.76 of R2 with RMSE of 0.93 mm. After combining both METRIC model and machine learning based gap fill model, the seasonal ET of rice reached up to 641 mm/season and wheat up-to 545 mm/season. Similarly, when crop coefficient method was used to compute the crop water requirement, actual evapotranspiration for sugarcane crop varied between 1423 to 2679 mm. Beside these results, a scientific concept framework will be develop to utilize the TRISHNA mission data to investigate the field scale water-energy nexus for water availability and irrigation management.

Keywords: Surface Energy Balance; METRIC; Crop Coefficient; Irrigation Water Requirement; ET Station

Comparative Analysis of Temporal Upscaling Methods for Daytime Evapotranspiration

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Abstract

Thermal remote sensing-based evapotranspiration (ET) models commonly estimate daytime ET by scaling instantaneous measurements to daily values using various scaling factors. This study two sites, Nawagam and Malegaon. Three different daytime ET values were computed: one from diurnal modeling, another from temporal scaling of instantaneous ET at 10:30 AM, and a third from temporal scaling at 1:30 PM. Both in-situ land surface temperature (LST) and MODIS LST were used as inputs to the ET models. These estimates were then compared with daytime LE obtained from eddy covariance (EC) observations. For MODIS LST-based ET, the LE estimates at diurnal, 10:30 AM, and 1:30 PM overpass evaluates and compares the traditional temporal upscaling of instantaneous ET, derived from models using incoming shortwave solar radiation as the scaling variable, with the average diurnal ET during daytime. The SPARSE ET model was used for the analysis, which was conducted at times were 1.07, 1.11, and 0.97 mm/day, respectively. In comparison, LE values based on in-situ LST for the SPARSE Layer model were 1.51, 1.52, and 1.44 mm/day. For the SPARSE Patch model, MODIS LST-based ET at diurnal, 10:30 AM, and 1:30 PM yielded 1.08, 1.18, and 1.07 mm/day, respectively, while in-situ LST provided values of 1.46, 1.51, and 1.40 mm/day. The overall results suggest that scaling instantaneous ET at 1:30 PM produces slightly better estimates compared to other timeframes. To further investigate this behavior, the percentage error of the estimated ET relative to observed ET, as well as the Nash-Sutcliffe efficiency (NSE), was computed at half-hour intervals from 8:00 AM to 4:00 PM. The findings indicate that the percentage error is lowest between 12:00 PM and 2:00 PM, and higher before and after this period. Similarly, NSE values peak between 12:00 PM and 2:00 PM, signifying optimal model performance during this time. These results explain why ET estimates derived from the 1:30 PM timeframe tend to perform better when scaled to daily values, as the models achieve their highest accuracy and efficiency during midday, aligning closely with observed ET values.

Keywords: Evapotranspiration, SPARSE, Daytime ET

TRISHNA Level-2 products: Daily Evapotranspiration and Water Stress

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Abstract

The joint ISRO/CNES TRISHNA mission (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment), to be launched in 2026, will provide thermal infrared data with high revisit (3 acquisitions every 8 days at equator) and high spatial resolution (60 m). Such data will make it possible unprecedent monitoring of evapotranspiration (ET) and water stress. Evapotranspiration and water stress products will be proposed at level 2 within less than one day after image acquisition.

Here, we present the various options for the operational algorithms that will be used for generating ET and water stress products. For evapotranspiration, two main models will be used:

1- EVASPA (EVApotranspiration monitoring from SPAce, Gallego et al. 2013, Allies et al. 2020) which provides ET maps by combining several models based on the evaporative fraction formulation of surface energy balance based on the S-SEBI and the triangle approaches (contextual approach). As EVASPA provides an ensemble estimation of ET, an estimation of uncertainty in the derivation of ET is also provided (Allies et al. 2020, Farhani et al. 2024, Mwangi et al. 2024)

2-STIC (Surface Temperature Initiated Closure, Mallick et al. 2014, Hu et al. 2023) which is based on the integration of the surface temperature into the Penman-Monteith (PM) formulation at the pixel scale (single-pixel approach). The model was recently implemented within the European ECOSTRESS Hub (Hu et al. 2023).

For water stress indicators, two main indices are foreseen: the evaporative fraction as provided by EVASPA and the ratio of daily ET to reference ET (or maximum ET).

Calculation of evapotranspiration requires a large number of information that will be obtained from different sources:

- surface temperature from TRISHNA thermal channels (using the new DirecTES method
- albedo and vegetation fraction cover from the vis/nir TRISHNA channels
- clear sky incident solar radiation (corrected for topography effect) and incident downward thermal radiation at the time of acquisition as derived from TRISHNA channel data (in particular estimation of aerosol and water vapour content)
- air temperature and air vapour pressure from ECMWF analysis
- daily solar radiation from geostationary satellites (e.g. the new MTG satellite over Europe and Africa) that will be used to upscale instantaneous estimates of ET to daily ET (Delogu et al. 2012, 2021)

At level 2, daily evapotranspiration will be provided for clear sky TRISHNA acquisition (when thermal infrared data are available, depending on satellite orbit and cloud cover). Reconstruction of a continuous serie of daily evapotranspiration will be provided as a level 3 product (Boulet et al. 2023). We will use a simple upscaling method on the basis of the daily evapotranspiration / daily solar radiation ratio, that was shown as usually providing good performances.

Keywords: TRISHNA, Thermal InfraRed, Evapotranspiration, Water Stress

A dive into TRISHNA L2B/L3 processing chains

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Abstract

The TRISHNA mission (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) is a collaborative effort between CNES and ISRO, set to launch in 2026 with a 5-year mission duration. One of the TRISHNA's main mission is to monitor the water stress of terrestrial ecosystems by measuring global surface temperature at 60 m spatial resolution over large areas and with a 3-day revisit. To aid in interpreting thermal infrared measurement, TRISHNA also includes several visible, near infrared and short wave infrared bands. In level 2B, TRISHNA acquisitions will be processed to provide the following biophysical variables: vegetation variables, albedo, downwelling shortwave and longwave radiations, evaporative fraction and daily evapotranspiration (ET). For ET products, two main models will be used: a contextual method, called EVASPA (EVApotranspiration monitoring from SPAce) and a single-pixel pixel method, called STIC (Surface Temperature Initiated Closure) algorithm. Contextual approach is more robust in heterogeneous situations and does not require additional weather data. But, to run efficiently such an algorithm, cross-heterogeneity conditions within the image are needed: hydrological conditions and vegetation cover. Therefore, a single-pixel method is also used as alternative. These daily ET products will be available for each acquisition on clear pixel only. However, many applications of evapotranspiration require to use daily values or integrations over larger time periods from daily values. Therefore, TRISHNA mission has also the objective to provide ET every day as a level 3 product. To produce continuous time series of daily evapotranspiration, level 3 processing is based on gap filling technique. This product will be created from L2B daily evapotranspiration products but also external radiation data and meteorological data for days without TRISHNA acquisition or cloudy pixels. This presentation will describe the current state of development of L2B/L3 processing chains. In particular, we'll be focusing on the strategies for gap-filling envisaged for level 3 product as well as the level 3 product format. The benchmark strategy for algorithm choice, tuning and validation will also be covered, including the assessment of the quality of meteorological data and the validation of the solutions adopted for the spatial and temporal interpolation of meteorological data.

Keywords: TRISHNA, radiation, evapotranspiration, processing

Ensemble evapotranspiration estimates and uncertainties: EVASPA

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Abstract

Quantifying evapotranspiration (ET) beyond the local scale is essential for many water-related studies. Remote sensing (RS) has allowed the continuous monitoring ET at larger spatial scales than in-situ instruments. By exploiting the physical relationship between remotely sensed surface biophysical parameters and the Earth's thermal emission, continuous ET at such spatial scales can be obtained. In this study, we applied EVASPA, a tool that provides an ensemble of ET estimates, among other surface energy balance (SEB) variables. Here, we applied MODIS data, which included: Land Surface Temperature/Emissivity (LST/E), NDVI, albedo, among others. Our multi-data multi-method approach resulted in 1215 ET estimates (i.e., 5 LST/E (MYD/MOD 11/21 and VIIRS 21); 3 radiation sources (ERA5Land, MSG, MERRA); 9 Evaporative Fraction methods (5 S-SEBI based, 4 T-VI based), and 9 Ground heat flux methods (based on NDVI and LAI)). Evaluations using in-situ flux data yielded reasonable results even when a simple average was used, with a broad absolute and performance range between the member estimates being observed. Uncertainty analyses were also performed where we analysed how each of the distinct variables (i.e. radiation, LST, EF and G methods) influenced the modelled ET. Irrespective of the combination criteria selected, LST and EF were observed to be the main uncertainty drivers; this was despite instances where radiation resulted in higher uncertainties that were dependent on the combination selected and/or the period of simulation. G flux methods exhibited the least influence on the ensemble simulations. Overall, we showed that ensemble-based contextual modelling can provide enough spread for better flux simulations. This work aims to guide the establishment of an optimal weighting criteria of the members for improved ET estimates within TRISHNA.

Keywords: ET, SEB, contextual ET, multi-method multi-data, ensemble modeling.

Spatially remotely sensed evapotranspiration estimates in Sahel regions using an ensemble contextual model using medium and high spatial resolution data

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Abstract

The Sahel region, identified as a "hot spot" for climate change, is characterized by a water scarcity and an inter-annual variability of water resources. Indeed, ongoing climate changes intensify the evaporative demand which could lead to more frequent period of droughts. Therefore, an important issue in these countries is to provide accurate estimation of evapotranspiration (ET) in a spatially distributed manner. Remote Sensing (RS) data in the thermal infrared domain, used in energy balance models, is particularly useful because it allows for spatial ET estimates at various space-time resolutions. A well-adapted method for the Sahelian context was proposed based on an ensemble contextual energy balance model combining thermal and visible satellite information (EVASPA S-SEBI Sahel method; E3S, Allies et al, 2020, 2022). This contextual method is based on the thermal contrast (hot/dry and cold/wet pixels) observed in a given thermal image to provide an ensemble of instantaneous estimation of evapotranspiration conditions. The applicability and accuracy of this approach suppose: (1) The presence of sufficient heterogeneity between dry and wet pixels within the same image and (2) the correct identification of the driest and wettest pixels, also known as dry and wet boundaries. Therefore, the aim of this study is firstly to allow for a systematic detection of the heterogeneity conditions and a dynamic selection of adapted methods for the determination of wet and dry boundaries by using only the image information without prior knowledge of local conditions. Secondly, our aim is also to assess the added value of using a thermal information from high spatial resolution (Landsat data) compared to medium resolution (Modis data) on the image heterogeneity and consequently on ET estimation. ET simulations from Landsat data provide better ET estimation than ET simulations from Modis data in comparison with eddy-covariance measurements. Indeed, thermal information from higher spatial resolution data provides better assessment in surface heterogeneity and therefore, more accurate ET estimation. The use of high-resolution data also makes this study a good demonstrator for the upcoming thermal earth observation missions like TRISHNA (CNES/ISRO), which this work is part of, LSTM (ESA) and SBG (NASA).

Key words: Droughts, Climate change, Remote sensing, contextual, high resolution

Integrating Thermal Sensor Data with SEBAL for Evapotranspiration Estimation: A case study in deciduous forests of India

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Abstract

Satellite remote sensing observations have been increasingly used for estimating evapotranspiration (ET) spatially as complexity of measuring ET directly makes it difficult and expensive to routinely measure and capture its spatial variation as this requires a dense network of in situ gauging stations. There are multiple remote sensing based surface energy balance models which are used in agro-environments, however their use to estimate ET in natural ecosystems are limited. This study aims to estimate ET in deciduous forest of Betul and Kanha, a dry deciduous and wet deciduous forest ecosystems respectively, where seasonal changes in canopy dynamics have a significant impact on water fluxes. We used a single-layer energy balance model, the Surface Energy Balance Algorithm for Land (SEBAL) that estimates latent heat flux, which is directly linked to evapotranspiration. By integrating thermal sensor data from Landsat 8/9, the model provided spatially explicit ET estimates across the diverse landscapes. The observations from ground eddy covariance based in situ flux tower is used for validation, showing how strong the correlation between remote-sensing-derived ET estimates and field data are. The seasonal variations of ET in both study sites were calculated and validated using the model. The results highlight the spatial heterogeneity of ET across the forest landscape, because of the variations in vegetation density, canopy cover, and microclimatic conditions. Monitoring ET helps in understanding the water-energy balance within the forest, and hence offers more accurate predictions of forest productivity at times of drought, seasonal shifts, and other environmental conditions. This, in turn, contributes toward proper assessment of the health and carbon sequestration potential of the forest ecosystem.

Keywords: Evapotranspiration, SEBAL model, thermal remote sensing, eddy covariance flux tower

Time Series Estimation of Evapotranspiration and Water Use Efficiency in Cumin Crops Using ECOSTRESS and SIF Data

SIF Data Karun Kumar Choudhary*, Visshnu Pompapathi, Abhishek Chakraborty, VM Chowdary and K Sreenivas
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Abstract

Efficient water resource management in agriculture is essential for sustainable crop production, particularly in arid and semi-arid regions. Thermal emission from the crop canopy is a sensitive parameter with respect to its vigor which influences the partitioning of energy and mass fluxes at the earth surface while the Solar induced chlorophyll Fluorescence (SIF) is a proxy for photosynthetic activity and carbon assimilation in crops. This study focuses on estimating evapotranspiration (ET) and assessing water use efficiency (WUE) in cumin crops in a arid ecosystem at CAZRI. Jodhpur using multi-temporal satellite data. The single-source Surface Energy Balance Algorithm for Land (SEBAL) model was applied to ECOSTRESS Land Surface Temperature (LST) to estimate ET over multiple dates in three distinct crop seasons. The methodology involved pre-processing ECOSTRESS and Sentinel-2 data for calculating surface energy components, i.e., net radiation, soil heat flux, sensible heat flux, and latent heat flux, to estimate ET on a temporal scale. The SCOPE model is a vertical one-dimension biophysical model that couples radiative transfer of optical and thermal radiation with the leaf biochemical process. SCOPE model was parametrized using one season data from FLOX Box (Canopy SIF) and Flux tower derived GPP. Further, SCOPE model was inverted to predict the SIF and GPP for the previous two years. The derived time series of ET was validated against flux tower measured ET, showing a significant correlation among each other. The time series of ET and SIF-based GPP were then used to estimate the WUE of cumin crops, defined as the ratio of GPP to ET, reflecting the efficiency of water use in crop production. The temporal dynamics of WUE across the three crop seasons highlighted key periods of water stress and crop growth. The results demonstrate the potential of combining ECOSTRESS and SIF data for monitoring of crop water use which can provide crucial informing on irrigation practices and optimizing water management in arid agricultural systems.

Long Short-Term Memory to Estimate Cloudy-sky Evaporative Fraction in Thermal Remote Sensing: An observational analysis

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Abstract

Evaporative Fraction (EF) represents the proportion of net available energy used for evapotranspiration (ET), making its estimation crucial for determining satellite-based ET in thermal remote sensing. However, modeling EF during cloudy sky conditions (EFcld) presents a challenge, particularly when using thermal remote sensing data. Before EFcld modeling, it is essential to first understand its behavior using flux tower data across various ecosystems. In this study, we modeled EFcld data from past 19-21 years at three AmeriFlux sites (irrigated corn, deciduous broadleaf forest, and grassland) and two OzFlux sites (tropical rainforest and pasture), which span a broad range of annual rainfall (273 to 2232 mm). Daily time series EF, derived from net available energy, latent, and sensible heat fluxes between 10 AM and 2 PM, was trained using a stacked Long Short-Term Memory (LSTM) network. The model incorporated auxiliary variables such as cloud transmissivity, day of the year (DOY), and time of day. The LSTM model was trained on both clear-sky (transmissivity ≥ 0.5) and cloudy-sky (transmissivity < 0.5) EF and validated in forward mode for cloudy-sky conditions. It used previous clear-sky EF values and current transmissivity, along with other ancillary variables. Sequentially adding variables improved validation accuracy across all sites, with an average correlation increase of 20.32% and an RMSE reduction of 24.94% compared to the clear-sky EF-only model. The LSTM model successfully captured temporal variations, both for hourly and daily forecasts. Combining previous-day EF with transmissivity, DOY, and time provided the highest accuracy. Models trained on data encompassing both current clear sky conditions and previous clear sky conditions (if currently cloudy) outperformed models trained exclusively on cloudy sky data. Additionally, hourly training data yielded the best downscaled daily EF predictions for cloudy conditions. The grassland site had the lowest RMSE (0.07, r: 0.86), while the tropical forest site had the highest error (RMSE: 0.13, r: 0.61). These findings demonstrate the potential of time-series LSTM models for predicting EF under cloudy conditions, where surface energy balance models typically fail. This deep learning architecture, combined with traditional surface energy balance models, can produce seamless all-sky terrestrial evapotranspiration and ecosystem stress products. Future research will investigate the impact of additional input features and work toward generalizing the model for different regions.

Keywords: Cloudy-sky, Evaporative Fraction, LSTM, Gap-filling, Thermal Infrared

Estimation of Gross Primary Productivity in Indian region using deep learning

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Abstract

Gross Primary Productivity (GPP) is a crucial parameter for ecosystem and biomass studies. Various methods, including statistical, process-based, and Light Use Efficiency (LUE) models, are used to estimate GPP. When these methods are used over optical satellite data, the generated GPP products often suffer from spatial and temporal gaps due to cloud coverage and missing satellite passes. This paper introduces a semi-physical hybrid LUE model integrating the LUE model with a deep learning-based feed forward dense neural network (FFDNN) model to estimate continuous and gap-filled GPP under all sky conditions. The proposed methodology develops distinct clear-sky and cloudy-sky models based on FFDNN architecture by selecting optimal inputs for each model. The inputs are from multiple sources that include satellite reflectance (MODIS), satellite-derived parameters (INSAT-3D) and climatic model (ERA-5). Within each category of sky conditions, the type-1 model utilizes temporal variables and ERA5 temperatures, while the type-2 model incorporates temporal variables and INSAT-3D Land Surface Temperature (LST). The type-3 model is identical to the type-1 model but excludes historical mean GPP. For both clear and cloudy sky conditions, the type-1 model outperforms the other two models across most land cover classes. When evaluated using 5-fold cross-validation on 2021-22 data, the type-1 model shows satisfactory results in all-sky conditions. The model performance is measured using R-squared and Normalized Root Mean Squared Error (NRMSE). The clear-sky type-1 model demonstrates R-squared of 0.934 and NRMSE of 0.28 while the cloudy-sky model displays R-squared of 0.931 and NRMSE of 0.29. The performance is evaluated by varying seasons and land covers to understand the behaviour of the model in different conditions. The promising results and readily accessible model inputs suggest that this proposed methodology can be extended to future Earth observation satellites, including the TRISHNA mission.

Keyword: GPP estimation, Deep learning, LUE model, Continuous and Gap-filled GPP, TRISHNA

Estimation of actual evapotranspiration using improvised SEBAL model in the semi-arid region of Western Rajasthan

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Abstract

The arid regions of the western region of Rajasthan, India, have had little access to water, and accurate assessment of evapotranspiration (ET) plays an important role in water resource management in a water-scarce region. However, accurate estimation at the regional scale using the conventional methods is challenging due to the region's heterogeneity. In this study, an improvised surface energy balance algorithm for land (SEBAL) model is used to estimate actual ET at the regional scale. The study provides a spatiotemporal variation of regional actual ET using the cloud computing platform for the western region of Rajasthan state, which is further verified with ground station data. When compared with the Penman-Monteith method, the values of coefficient of determination (R2), root-mean-square error (RMSE), and mean bias error (MBE) were 0.88, 0.66, and (-0.10), respectively. The study shall be able to provide actual ET retrieval using remote sensing at the regional scale.

Keywords: evapotranspiration, SEBAL, remote sensing, semi-arid, earth engine.

Estimation of evapotranspiration and soil moisture by integrated use of optical and thermal Infrared observations from MODIS

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Abstract

Evapotranspiration (ET) and soil moisture (SM) are vital agro-hydrological variables that play a key role in understanding water and carbon dynamics in ecosystems. Accurate estimation of ET and SM is crucial for large-scale crop yield forecasting, carbon balance modeling, and water resource management. In India, the current network for measuring these variables lacks the necessary density to represent diverse vegetation, soils, and terrain. Remote sensing methods using optical and thermal satellite data, particularly MODIS land products, have gained widespread acceptance for estimating ET and SM at regional scales, with minimal reliance on ground-based measurements. This study aimed to estimate ET and SM in western Uttar Pradesh using MODIS-derived evaporative fraction (EF) and apparent thermal inertia (ATI). Daily and 8-day composites of surface reflectance (500 m) and land surface temperature (1 km) were collected between December 2007 and April 2008 during the Rabi growing season. EF was parameterized using a triangular Ts/albedo scatter-plot, and net radiation was computed at a 1 km resolution using parameters such as solar radiation, surface emissivity, albedo, surface temperature, and air temperature. Soil moisture estimates were derived from ground measurements taken in April 2008. ATI was calculated based on day/night surface temperature differences and albedo, and soil moisture saturation index (SMSI) was computed by scaling ATI values. Results showed that ET derived from EF was highly correlated with actual ET estimates from the Penman-Monteith method ($R^2 = 0.86$, RMSE = 0.04 mm d^{-1}), while the correlation with the pan evaporation method was lower ($R^2 = 0.56$, RMSE = 0.12 mm d^{-1}). Soil moisture estimates improved with increasing soil depth, and a strong correlation was observed between SMSI-derived soil moisture and in-situ measurements ($R^2 = 0.65$, RMSE = 3.0%). This study demonstrates the effectiveness of using remote sensing-based methods for estimating ET and soil moisture, especially in regions with limited ground measurements.

Paddy crop water status variability detection using UAV-based multispectral and thermal imagery

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Abstract

Water-deficit stress, referred to as water or drought stress, denotes the physiological reactions of plants triggered by insufficient water available resulting from either soil water deficiency or elevated atmospheric evaporative demand. Understanding plant water stress is crucial to ensure the global water and food supply. Water stress is a significant abiotic stressor that constrains plant development, crop yield, and quality in food production. Consequently, understanding crop water status across large agricultural regions holds significant potential for enhancing water utilization in agriculture. Plant responses to water stress are varied and intricate, with physiological effects influencing electromagnetic signals across several spectrum domains. Detecting and monitoring plant water deficiencies by a singular plant response remains challenging. The timing, intensity, and duration of water stress are critical in ascertaining plant physiological responses and their effects on plant metabolism. Recent developments in thermal infrared (TIR) remote sensing by airborne and unmanned aerial vehicles (UAVs) may bridge the gap between low-resolution satellite imagery and small-scale in situ observations. This work used vegetation indices (VIs) and crop water stress index (CSWI) data obtained from weekly field observations obtained by a UAV equipped with multispectral and thermal sensors to carry out linear regression analysis. NDVI had the best correlation (R2>0.7, $p<0.05$) during all crop growth phases. NDVI and all other vegetation indices exhibit an increase in R^2 from the booting to the mature stage. The use of VIs and CWSI data from the late reproductive and maturation stages significantly enhanced the relationships. In summary, integrating data from multi-/hyperspectral TIR and VNIR/SWIR sensors through a multi-sensor methodology can provide significant insights into the current condition of aquatic plants and the underlying causes of physiological and biochemical alterations. Utilizing synergistic sensors will provide scientists with novel opportunities to investigate plant functionality and responses to environmental stress across diverse habitats.

UAV-based thermal imaging for high-resolution crop water condition monitoring: a futuristic spatial cal/val protocol for the TRISHNA mission

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Abstract

The ever-increasing food demand globally exerts a pressing need for developing efficient crop water management in agriculture-intensive regions. While satellite remote sensing has proven invaluable for large-scale precision agriculture, field-scale land surface temperature remains challenging due to the lack of high-resolution thermal and optical Earth observation data. In this study, we present a method to estimate field-scale land surface temperature (LST) from UAV-based thermal imagery, aided with two distinct auxiliary data sources over the upstream and downstream aerial windows (~0.5 km^2) of the agro-intensive Ganga basin Critical Zone Observatory (CZO), India. The two auxiliary data sources differ in the acquisition of synchronous airborne multispectral data and replacing it with ECOSTRESS spectral reflectance whenever unavailable. Apart from the supporting datasets, the methodological framework also differs in the application of LSTs to estimate two key crop water condition (CWC) indices at the plot scale: vegetation temperature condition index (VTCI) and crop water stress index (CWSI). The LST estimation framework incorporates the emissivity and atmospheric radiance components where the atmospheric radiances are estimated using concurrent meteorological data within the MODTRAN radiative transfer model. The emissivity in VTCI-based study is estimated using NDVI-based threshold technique whereas the CWSI study uses emissivity that is sourced from ECOSTRESS spectral reflectance. A significant correlation between aerial LSTs and *in-situ* radiometer observations was revealed, showing an absolute difference ranging from −1.97K to 4.93K. While the mean VTCI in the downstream window reveals a sharp increase in dryness from 22% to 51%, the upstream window dryness increases from 20 to 27% during April-May of 2019. Further, the VTCI variability has been linked to surface soil moisture (SM) as evidenced by its significant positive correlation (r = 0.6 to 0.81, Kendall's τ = 0.5 to 0.82) to ground-based SM during all acquisitions. While VTCI serves as a useful indicator of CWC, we extended our analysis by using airborne and in-situ infrared data for empirical estimation of corresponding CWSIs. A relatively lower radiometer CWSI (CWSI-Rad) during the paddy is revealed, reflecting the influence of monsoon-fed cropping in North India. Alternatively, the airborne CWSI demonstrated a significant correlation (R^2=0.85, p<0.05) to CWSI-Rad and a moderate to strong correlation (R = −0.75–0.97) to concurrent SM. Hence, the proposed approach would provide a useful protocol for upscaling the precision agriculture using the forthcoming high-resolution (57m, 3-days) TIR Earth observation mission, TRISHNA (Thermal InfraRed Imaging Satellite for High-resolution Natural Resource Assessment). Findings of this study therefore highlight the potential of UAV thermal remote sensing for the assessment of CWC and offer an efficient protocol for spatial calibration/validation (cal/val) of the upcoming TRISHNA mission

Evaluation of satellite-based thermal anomalies for assessing crop risk due to mid-term heatwave adversaries

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Abstract

Climate change is increasing the frequency of extreme temperatures (IPCC, 2013). According to the World Meteorological Organization (WMO, 2022), heatwaves (HW) are now 30 times more prevalent in India. Intermittent HW during winter or post-monsoon season in semi-arid and arid climate pose strong thermal anomalies coincident to critical crop growth stages especially for irrigated wheat, mustard etc. with varying intensity, frequency and duration. Crop insurance based on weather index is considered to be effective risk management strategy in India's crop insurance programme, PMFBY, that can provide transparent solutions by linking heatwave directly to crop loss. However, existing indices often struggle to accurately detect mid-season heat stress, leading to inaccuracies in risk assessment and indemnity payments. The present study formulated a Heatwave Magnitude Index (HWMI) using long-term (2003-2022) noon-time eight-day land surface temperature (LST) product from MODIS (Moderate Resolution Imaging Spectroradiometer) AQUA (MYD11A1; Version 6.1) to evaluate mid-term heat stress on irrigated wheat crop during anthesis to maturity stages over HW hotspots of central and western India. Seven classes (normal, moderate, severe, extreme, very extreme, super-extreme, ultra-extreme) of monthly HWMI were identified based on Rossu et al (2015) within the range of 1 to 32 with different binning slabs. Year-to-year comparison of HWMI (2081-2020) showed a strong occurrence of HW in 2018 in parts of central India. However, stronger HWMI was evident in both 2018 and 2019 over parts of western India as compared to 2020. The intra-seasonal dynamics of HWMI during January to March varies substantially across spatial extent. The comparison of HWMI and percent deviation in crop yield (PDY) at district level showed good correlation in the range of 0.45 to 0.99. Additionally, formulation of a composite index (CI), combining HWMI with evaporative and canopy water stresses based on thermal infrared (TIR) and visible shortwave infrared (VSWIR) observations, led to better correlation between CI and PDY in the range of 0.53 to 0.99. The TIR-VSWIR CIs at finer resolution from TRISHNA and similar follow-on missions can better predict the impact of in-season heatwave on crop yield at finer granularity, which will be useful for designing a heatwave weather insurance product for faster claim settlement by farmers.

Key words: Crop insurance, thermal remote sensing, mid-term weather adversaries, satellite

Integrating vegetation index-based evapotranspiration disaggregation and crop water balance model for farm-scale vineyard irrigation estimation

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Abstract

Estimating irrigation water use at the field scale is crucial for effective agricultural water management. However, irrigation is not commonly monitored, and field-scale data is rarely available. Nevertheless, remote sensing evapotranspiration (ET) data can facilitate these estimates. In developed countries like the USA, remote-sensing ET products, such as those from the OpenET portal, are available at the Landsat scale (30 m). However, in our initial study, OpenET data did not capture variations in ET demand at the block level. This study aims to bridge that gap by combining vegetation-index-based spatial disaggregation of ET with a crop water balance model to estimate irrigation at the field scale for vineyards in California, USA, over the growing season mid-May-September 2018. The research was conducted in four experimental blocks in Madera, California, as part of the GRAPEX project, where four eddy covariance flux towers and eight time-domain reflectometry soil moisture sensors were installed under the grapevine. Daily ET data from the eddy covariance system, root zone soil moisture (RZSM), and precipitation data from the nearby Fresno station of the California Irrigation Management Information System (CIMIS) were utilized. Satellite data included daily MODIS Land Surface Temperature (LST) at 1 km resolution, Sentinel-2A and -2B Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), and field data such as air temperature, relative humidity, wind speed, and incident solar radiation at satellite instantaneous time scales. These inputs were used in two-source Soil Plant Atmosphere and Remote Sensing Evapotranspiration (SPARSE model). The model's output was spatially disaggregated from the MODIS scale (960 m) to the Sentinel scale (60 m) using vegetation-index-based techniques like the Disaggregation of Solar Radiation factor (DiSoRa), which was validated using eddy covariance ET data. An FAO-56 crop water balance model was set up to simulate irrigation events whenever the root zone depletion at the start of the day exceeded the readily available water (RAW), the irrigation dose to match RAW, and the model adjusted it with observed field irrigation values. The model was tested using field ET data, field ET + RZSM data, OpenET data, OpenET + RZSM data, and disaggregated ET. Results indicated that spatial disaggregation of ET at the field scale is highly recommended and significantly aids in quantifying irrigation volumes accurately.

Keywords: FAO-56 crop water balance model, ET disaggregation, SPARSE ET model, OpenET

Water stress monitoring of Sweet orange (Sinensis) orchard using high resolution UAV based thermal data.

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Abstract

Assessment of stress conditions specially water stress in the sweet orange orchard plays an important role on yield. Further, it also helps in developing the strategies for customized input fertilizer applications in precision farming. In this study, water stress condition was assessed using very high resolution multi-spectral and thermal data acquired using MicaSenseAltum-PT sensor data, which was mounted on UAV flight during 28th,May, 2023. The UAV flight was acquired data by covering part of Gurrampodu mandal, Nalgonda district, Telangana state, which is one of the major sweet orange growing district in the Telangana state. The main objective of the study is to detect water stress and classify the stress levels of the sweet orange trees within the orchard using UAV based high resolution thermal data(35 cm). In this study, Vegetation Temperature Condition Index(VTCI) i.e. formation of NDVI and LST triangle computed using UAV based Normalized Difference Vegetation Index(NDVI) and Land surface temperature (LST) was envisaged for assessing the stress condition in sweet orange orchards. Real time monitoring of stress condition using NDVI alone may not be helpful due to lagged vegetation response. Hence, integration of surface temperature and NDVI provides vegetation and moisture condition simultaneously. The Normalized Difference Vegetation Index(NDVI) and Land Surface Temperature (LST) was generated using the multispectral and thermal (10.5micro meters) data of UAV flight. In order to identify the water stress levels of the sweet orange trees in the orchards, the Vegetation Temperature Condition Index (VTCI), which is more closely related to crop water stress, was generated by using the combined effect of NDVI and LST. The VTCI index ranges between 0 to 1, where 0 and 1 signifies severe stress and healthy conditions, respectively. In this study, sweet orange trees in the orchards were classified into different stress levels using VTCI.

Key words: NDVI, LST, VTCI, Thermal data, Multispectral Data

Addressing challenges of land surface temperature monitoring in forests using a cross instrumentation approach

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Monitoring the land surface temperature (LST) of forests is a key motivation behind upcoming high spatial and temporal resolution satellites such as TRISHNA, SBG and LSTM. Transpiration, evaporation and soil water- and heat transfer are the critical processes driving the thermal regime over forests. Given increased extreme events and forest stress, monitoring the response and changes in these processes is of paramount importance. The surface brightness temperature observed by satellites is influenced by spectral and directional variations driven by shadowing, distribution of canopy-component temperatures and topography, as well as weather conditions (e.g., air temperature, humidity, turbulence, clouds). Such effects can lead to significant biases in retrieved LST, whereby accurate and efficient schemes to understand and account for these effects are critical.

This contribution aims to understand some of the main challenges of retrieving accurate forest LST using a variety of experimental techniques. One challenge is the effect of directionality on LST retrievals. We propose an approach that utilises a laboratory-based goniometer in combination with surfaces that are dominant in geometric or volumetric scattering to quantify respective directionality impacts, where the key to our approach is to scale down the forest to within the goniometer footprint whilst keeping the same structure observed at different scales. Additional challenges include the impact of topography and weather on the retrieval and variation of LST. We introduce ground-based instrumentation that aims to upscale the laboratory-based directionality experiments and monitor topography and weather effects on LST. Two ground validation sites located in different forested ecosystems in Switzerland have been equipped with the following thermal infrared (TIR) instrumentation: a FLIR A700 thermal camera, a calibration plate, an Apogee SI-441 radiometer, and a Heitronics KT15 radiometer. We introduce this infrastructure and outline current work aimed at producing accurate high-resolution spatio-temporal thermal infrared in-situ data. This data will be used as inputs into 3D radiative transfer modelling to simulate directionality and complement the first study, as well as understand the impact of complex topography on LST and further downstream products (e.g. evapotranspiration) in forests.

Keywords: forest, directionality, goniometer, ground-based validation

Designing new ultra high resolution Sea Surface Temperature products in coastal areas for the future TRISHNA mission

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Abstract

Thermal infrared imagery onboard land dedicated satellite missions - but also covering coastal areas - has been around since 1984 with Landsat series, offering today 100m resolution with a revisit time of the order of 10 days in mid-latitude. In the coastal ocean, this wealth of data has been exploited only through limited and very localized demonstrations, mainly because of low revisiting time. Still they are invaluable for many applications ranging from forecasting system improvement to coastal process understanding and monitoring, and to the support to many economic activities such as aquaculture. Besides new missions (ECOSTRESS on ISS, TRISHNA in 2026, SBG in 2027, Copernicus LSTM in 2028) are now available or on their way, that will provide better radiometric performances, higher spatial resolution and temporal sampling and increase the value and operational capacity of this source of observation. Despite the wide range of coastal applications from such resolution satellite derived observations, there is no dedicated and validated coastal SST product from the existing missions distributed on regional or global scale. The primary objective of this study is to develop a state-of-the-art processing for ultra high resolution SST retrieval in coastal areas from the future TRISHNA mission. To achieve this objective and to fill the gap, the study aims at designing new 100m ultra-high resolution satellite-derived Sea Surface Temperature (SST) products dedicated to coastal waters from the existing Landsat-9 and ECOSTRESS imagery. By designing those new products (called "CALISTA"), the main challenges of the SST retrieval in coastal environment are addressed. The results using ECOSTRESS and Landsat-9 data and the well-known split-window non-linear algorithm over the French coasts will be presented.

Keywords: coastal ocean, remote sensing, sea surface temperature retrievals, sea surface temperature validation

Application of high spatial resolution satellite observations in detecting localized thermal anomalies of the coastal waters: Preparatory work for the upcoming THRISHNA mission

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Abstract

Thermal anomalies in coastal regions refer to localized areas where sea surface temperaturesdeviate from the surrounding waters by a few degrees. Thermal anomalies are mainly associated with the thermal or nuclear power plants, effluent discharge or can also occur due to natural processes like submarine ground water discharge and river plumes. In the present study, we demonstrate the application of high-resolution satellite data in detecting various localized thermal anomalies of the coastal waters along the Indian coastal region. Surface temperature (ST) estimated using Landsat-8/9 TIRS data and ECOSTRESS are used to detect the thermal anomalies of the coastal waters. Thermal plumes are observed at the coastal waters located near Kalpakkam, Chennai coast, Tamil Nadu. The coolant water discharge in the region induces an anomaly in the ST of about 2.5°C - 3°C in the coastal waters that are observed to have seasonal dynamics in the dispersion pattern. The differential heating of surface water of the enclosed coral lagoon with the adjacent open ocean waters for the Lakshadweep Islands are observed through the satellite derived ST. The temperature anomaly here shows a distinct seasonal dynamics, where the lagoon waters warmer during the summer season and cooler during the winter seasons in comparison to the ambient ocean waters. In the coastal waters of Okha region, Gujarat, localized cooling of surface water is observed during the winter season. The possible submarine groundwater discharge (SGD) caused a temperature anomaly of coastal waters in the range of 0.5°C - 2°C. Albeit small in spatial scale, these localized thermal anomalies significantly affects the regional coastal ecosystem, by adversely affecting the marine life. A monitoring program has to be envisaged to decipher the spatio-temporal dynamics of the localized thermal anomalies, where THRISHNA mission due to its high spatial and temporal observations can provide valuable insights.

Keywords: Coastal waters, Thermal anomaly, High spatial resolution, thermal plumes, SGD, coral lagoons.

Identification of Submarine Groundwater Discharge (SGD) near Mangrol coast, Gujarat using Remote Sensing Thermal analysis and Geo-electrical method

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Abstract

Submarine Groundwater Discharge (SGD) refers to the flow of groundwater from coastal aquifers into the ocean, playing a key role in shaping the water chemistry of coastal environments. This transfer of nutrient-rich water from land to sea significantly impacts hydrological processes near coastlines. As a result, identifying and measuring SGD is essential for understanding water balance and the dynamic interactions along coastal areas. Despite extensive studies on SGD, research on the interaction between freshwater and seawater along the Indian coastline remains limited. One promising method for large-scale SGD detection is satellite-based thermal infrared (TIR) remote sensing, which uses TIR sensors to correlate sea surface temperatures and detect less dense, buoyant groundwater plumes, whether fresh or brackish. In our study, we focused on the western coast near Mangrol town in the Junagadh district of Gujarat, where SGD processes are potentially prominent. By analyzing temperature anomalies and incorporating local knowledge, we identified areas of interest. Geo-electric analysis was also conducted to study subsurface water flows. The research revealed that SGD has a profound influence on coastal hydrology. Using Landsat-9 thermal data, we examined brightness temperature (BT) variations within the infrared spectral range (10.6-11.19 µm) and observed localized cooling. The results were validated through field data and ship-based measurements, and further confirmed with geophysical analysis near the identified locations, helping to pinpoint preferential subsurface flows. The investigation encompassed the analysis of spatial variations in brightness temperature (BT) within both coastal and oceanic regions. A distinct spatial pattern, showing reduced temperatures compared to the ocean, suggested the presence of an SGD site. This pattern was rigorously verified with multiyear data to ensure the process was consistent. Areas displaying erratic temperature fluctuations in different satellite passes were excluded. Temporal BT patterns of ocean water, inland water bodies, and the potential SGD sites were also studied to understand how seasonal temperature changes on land influence SGD activity. From December 2020 to March 2023, BT variations in ocean water near the coastal area were analyzed. In December 2021 and January 2023(Fig 1), the water near the coast was cooler than water farther from the coast by 0.8°C. On January 5, 2023(Fig 2), geo-electrical analysis using the electrical resistivity method was performed near the coast, revealing resistivity values ranging from 5.2 to 300 Ω.m. Low resistivity values (5.2 to 7 Ω.m) suggest groundwater as a major contributor in the analyzed sections, correlating with the observed temperature anomalies near the coast during winter. This indicates that groundwater discharge significantly influences the coastal environment during this season. This study highlights the importance of using a combination of satellite-based remote sensing, field measurements, and geophysical analysis to detect and understand SGD. The findings underscore the significant impact of SGD on coastal hydrology and emphasize the need for continued research to improve our understanding of this critical process.

Keywords: Submarine Groundwater Discharge, Thermal Remote Sensing, Brightness Temperature, Electrical Resistivity

Assessing the role of mangrove vegetation community and density on canopy temperature-a geospatial perspective

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Abstract

Forest vegetation canopy are typically composed of an assemblage of several species, and variation in canopy density- that therefore differ in its morphological and physiological form. Variations in vegetation species and density can have significant impact on canopy temperatures. Lowering of temperature due to increasing canopy density are well-studied, though explaining temporal variations in coastal regions vis-a-vis density can pose a challenge due to the influence of many other parameters. INS-2TD data (brightness temperature) for Sundarbans mangrove was studied to understand the canopy temperature variation and the role of dominant species in controlling the environment, while the mangroves in the Gulf of Kutchch were studied for canopy temperature with respect to the vegetation density . Vegetation community map with 12 dominant communities was used to assess variation in canopy temperature. The study indicated distinct pattern of lower temperature on areas with dominant Sundari species (*Heritiera fomes*). Another 3 communities where *Heritiera fomes* is dominant also showed relatively lower temperature. It is important to note that this is one of the most important species in Sundarban region (owing to its dominance, the region has got its name) and has indicated its good adaptability and also favorable environment by indicating lowest mean canopy temperature among 12 dominant communities. Variations in temperature were studied over varying Mangrove densities in the Gulf of Kutchch, Gujarat. The study indicated lowest mean temperature over open mangrove areas situated little away from the coast. Very dense vegetation that is closer to the coast showed warmer temperature. This variation in temperature can be explained with the time of data collection. The area closer to the coast are likely to get warmer in the morning hours compared to the area away from the coast, although the former is covered with very dense vegetation. The finding not only indicates strong adaptability of the mangrove species but also role of density and spatio-temporal variation in controlling the environment. The findings can help further in choosing local species for afforestation / plantation.

Keywords: Canopy temperature, vegetation community, mangroves, vegetation density

Estimation of Chlorophyll a and TSM in the Coastal Water of Sundarban and Comparing with Satellite Data Using Sentinel-3

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Abstract

The study pursuits to explore the monthly variability in spatio-temporal characteristics of water in the Indian Sundarbans. Reliable retrieval of near surface parameters such as water temperature, salinity, pH, and majorly concentration of Chlorophyll a and Total suspended particle in numerous aquatic ecosystems. Optically active substances (OAS) such as Chlorophyll a (Chl a), Total suspended matter (TSM) play a significant role in health assessment of aquatic ecosystem. Temporal and spatial variability in OAS play significant role in modulating coastal water ecology. This demand for a continuous study on OAS in coastal water but my present study highlights on 10 station and for 6 months (Jan'24– Jun'24). Majority of the study sites were observed with large variation of Chlorophyll a and TSM. The study also used the application of C2RCC processor. A One-Way ANOVA was performed on the data, the null hypothesis was rejected.

Keywords: Chlorophyll a, TSM, OAS, C2RCC, Remote Sensing.

Dynamics of Sea Surface Temperature and Net Primary Productivity in Gujarat Potential Fishing Zone: Insights for Sustainable Fisheries

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Abstract

Sea Surface Temperature (SST) is an essential parameter for assessing ocean Net Primary Productivity (NPP), which in turn is an important factor for estimating Potential Fishing Zones. This study uses SST for the estimation of monthly NPP during 2003-2005. Along with SST, chlorophyll-a (Chl-a), diffuse attenuation coefficient (Kd) and photosynthetically active radiation (PAR) obtained from MODIS data have been used for NPP computation in coastal waters of Gujarat (Arabian Sea) up to Exclusive Economic Zone (EEZ). An inverse correlation is observed between SST and NPP indicating that lower SSTs are associated with higher NPP values. Seasonally strongest negative correlation was found in the summer-monsoon (June, July, August) ($r = -0.768$, $p = 0.1297$), while the weakest was in the inter-monsoon season (March, April, May) ($r = 0.544$, $p = 0.343$). These findings highlight the potential of SST data for estimating NPP to assess Potential Fishing Zones. Understanding this correlation can help in fisheries management, ecosystem health assessments and responses to climate change, as shifts in SST could significantly influence local marine productivity. Furthermore, the TRISHNA mission, which aims to deliver high-resolution SST data, has the potential to improve high-resolution NPP estimationin coastal zones when combined with other ancillary factors.

Keywords: Sea surface temperature, Net primary productivity, Potential fishing zones Potential Fishing Zone, TRISHNA

High-resolution lake surface water temperature remote sensing: Calibration and validation efforts from Swiss Lakes

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Abstract

Lake Surface Water Temperature (LSWT) is often considered the most important lake essential climate variable. Satellite thermal imagery has been one of the key sources of LSWT monitoring. However, today's operational LSWT services are limited to 1 km spatial resolution and cover only the world's thousand largest lakes. High-resolution, high-revisit thermal Earth Observation (EO) missions, such as TRISHNA, ECOSTRESS, LSTM, and SBG, represent an important step forward in extending such services to hundreds of thousands of smaller lakes. But the large viewing zenith angles and individual radiometric properties of these missions require dedicated product calibration and validation. Hence, our research, in the frame of TRISHNA – Science and Electronics Contribution (T-SEC) project, focuses on validating and improving high-resolution LSWT products of current and future for inland and coastal waters. For this purpose, we operate automated reference stations across an altitudinal gradient in Switzerland, namely Lake Geneva (372 m.a.s.l.), Lake Aegeri (724 m.a.s.l.) and Lake Bianco (2234 m.a.s.l.). We evaluated Landsat 7/8/9 LSWT products from USGS Collection-2 Level-2 data and the single-band Acolite-TACT algorithm. Our matchup comparisons yielded a Mean Absolute Error (MAE) of < 1.3 °C, a Mean Bias Error (MBE) < 0.4 °C and a correlation coefficient (R2) of > 0.94. Level-2 ECOSTRESS data obtained from NASA AρρEEARS API exhibited a weaker performance (MAE > 2.4 °C, MBE < -2 °C, and R2 < 0.85). This highlights the need for further cal/val and algorithm development, particularly regarding emissivity corrections, for ECOSTRESS products, and for other upcoming EO missions. Ultimately, our research will contribute to ongoing lake monitoring and modeling activities in Switzerland, including assimilation of LSWT data into existing 1D and 3D numerical models of Swiss lakes (https://www.alplakes.eawag.ch).

Keywords: Lake Surface Water Temperature, Calibration and Validation, Matchup Analysis, In Situ Measurements.

Current and future challenges in monitoring urban microclimate using data from the future TIR TRISHNA satellite mission

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Abstract

Urban areas are one of the main scientific focuses of the forthcoming TRISHNA (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) satellite joint-mission between CNES (Centre National d'Etudes Spatiales) and ISRO (International Space Research Organization). Satellite data, particularly which acquired in the thermal infrared (TIR), is essential for studying and monitoring urban climate. The spatial resolution (60 m) and revisit (3 times every 8 days) of the TRISHNA satellite will allow unprecedented investigations of the urban microclimate at neighborhood level. At this scale, urban environments have a specific radiative behavior due to the high spatial variability of illuminance as a function of the 3D structure, the large heterogeneity of natural and man-made materials, and the directional effects of brightness temperature. Neglecting these behaviors can lead to errors in land surface temperature (LST) estimates of several Kelvin, depending on the case. Data processing specific to the urban environment is therefore crucial to provide reliable LST estimates for cities, which is one of the main objectives of the TRISHNA Urban Mission Group. In addition to the estimation of accurate LST, another challenging objective is to move on to air temperature, which is essential to improve the comfort and quality of life in cities, as well as to protect citizens' health. The aim of this presentation is to provide an overview of the research activities carried out within the TRISHNA Urban Mission Group to achieve these two main objectives. Starting from the identified challenges at the scale of the TRISHNA mission, latest developments in LST retrieval algorithms dedicated to urban areas are presented, along with current work on spatial disaggregation approaches. This is followed by a description of the recent work initiated on the link between LST and air temperature, and related studies on the potential use of TRISHNA IRT data in an urban planning context. In addition, field experiments designed to acquire an urban reference dataset to answer the need for data to evaluate the proposed approaches are presented. Finally, some perspectives on the planned work of the TRISHNA Urban Mission Group are given.

Keywords: thermal infrared, LST, urban climate, air temperature, comfort

A short-term predictive meta-model of the surface temperature and air temperature at the district scale

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Abstract

In the context of global climate extremization, the DIAMS project aims to develop a diagnostic tool to assess urban districts vulnerable to heatwaves, using thermal infrared (TIR) satellite data and microclimate modeling. TIR satellites offer promising potential for cost-effectiveness and broader spatial coverage. While current TIR satellites are limited by low revisit frequency and spatial resolution, these challenges are expected to be mitigated by upcoming missions like TRISHNA, scheduled for launch in 2026. Within the DIAMS framework, a predictive model is developed to forecast surface and air temperatures at the district scale over the next three days, using TIR satellite data. This model is a meta-model which considers both spatial indicators (morphological, material, and optical) and temporal indicators (air temperature, relative humidity, global horizontal radiation, wind speed), producing predictions of equivalent air temperature (Teq) and mean surface temperature (Tse) for selected districts based on numerical simulations conducted using Solene-microclimate. The meta-model is based on urban archetypes classified by the "GENIUS" tool [1], which identifies seven archetypes based on their morphological properties. In practice, morphological and spatial information can be obtained from BD TOPO maps provided by French National Institute of Geographic and Forest Information (IGN), while TIR satellite data is used to parametrize the thermal (effusivity) and optical properties of materials (albedo, emissivity). Temporal data is sourced from weather stations. Currently, the meta-model has been developed for the "Continuous Blocks" archetype.In initial tests, weather data from the same period (August 9th to August 13th) oversix years (2003-2008) was applied to a case from this archetype, and Solenemicroclimate numerical simulations were conducted to obtain Teq and Tse for the six-year period. Meta-models were developed based on these simulations, and weather data from the same period in 2009 was subsequently applied to the metamodels to predict Teq and Tse. The results were compared with those obtained from numerical simulations for the same period in 2009, showing good accuracy, with an RMSE of 0.458°C for Teq and 1.09°C for Tse. In the future, we will adapt the meta model to more archetypes.

Keywords: Microclimate, Meta-model, Predictive modeling, urban thermal comfort

A synergistic thermal image sharpening approach to analyse the cooling effects of urban biodiversity parks

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Abstract

Urban green spaces are emerging as nature-based solutions for sustainable cities. They are proven to mitigate heat by cooling the surrounding regions from their shading effect, water regulation and carbon sequestration and provide thermal comfort. The cooling effect of green spaces is influenced by the species composition, vegetation configuration, geometry and location of the green spaces and the surrounding urban form. This poses a need to understand the cooling effect and intensity of urban parks and urban forests thoroughly. Moreover, in fast developing cities and most megacities, such as Delhi, the urban form varies at local distances of 10s of meters. Hence, like most weather events, surface urban heat islands and land surface temperature (LST) are also characterised by high spatial as well as temporal variability. Traditional satellites such as Landsat, GOES, MODIS etc lack diurnal capabilities and are available at lower spatial resolutions. Here, 70 m LST data from ECOSTRESS is combined with 10 m spectral index data from Sentinel 2 to sharpen the thermal image to a finer scale of 10 m using the DisTrad regression model and assess cooling effect of two biodiversity parks in Delhi, Aravalli Biodiversity Park and Neela Hauz, for two seasons- March and May. A number of spectral indices were compared and the one with highest R-squared value was used to develop a regression model for estimation of sharpened LST using 70 m ECOSTRESS data and 10 m Sentinel data. Further, a buffer analysis with 17 buffer zones of 30 m intervals to justify the sharpened spatial resolution, was performed on the sharpened LST data around both the study locations to analyse 4 indicators of cooling effect, viz., cooling distance, park cooling intensity, park cooling area (PkCA) and park cooling efficiency. Normalised Difference Building Index was the best predictor of LST in May and Vegetation Fraction in March with R2 values of 0.59 and 0.19, respectively. The sharpened LST successfully captured significant variations at the local scale, with higher accuracy to ground. The average LST for the parks was 1.5 °C lower in March and 1.13 °C lower in May, while the average PkCA was 28.5 ha in March and 27.6 ha in May.

Keywords: ECOSTRESS, Downscaling, DisTrad, Urban Green Spaces, Buffer Analysis, Cooling Effect

Thermal Remote Sensing and WRF-WUDAPT Simulations for Identifying and Mitigating Urban Heat Islands in Patna City, India

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Abstract

The Urban Heat Island (UHI) effect refers to a measurable increase in urban air temperatures, primarily caused by the reduction of green spaces and the rise of heat-absorbing infrastructure such as buildings, roads, pavements, and concrete surfaces. Factors like low albedo (poor surface reflectivity), limited greenery, high population density, narrow streets, and tall buildings that trap heat all contribute to and intensify the UHI effect. To explore and map UHIs and their driving factors in Patna, LANDSAT-8 data was analyzed using Google Earth Engine (GEE), in combination with WRF simulations integrated with the World Urban Database and Access Portal Tools (WUDAPT). The results show that Didarganj, Bariya Bus Stand, Patna Airport, Danapur, and the New Secretariat are hotspots characterized by limited greenery and low surface reflectivity. These UHIs exhibit temperatures up to 3.5°C higher compared to areas with more green cover in the city. WRF-WUDAPT simulations suggest that introducing green infrastructure, such as urban forests and parks, could lower temperatures in these hotspots by up to 5°C. Time-series analysis of LANDSAT-8 data provided insights into the evolution of UHI intensity in Patna over the past decade. The results highlight the role of rapid urbanization and changing land-use patterns in exacerbating urban air temperatures and contributing to the formation of UHIs. High-resolution satellite data, combined with WRF-WUDAPT simulations, will be useful for identifying UHIs and recommending area-specific mitigation measures. This will guide urban planners in enhancing resilience and making urban areas more hospitable and safe. The aim of this research is to inform effective UHI mitigation strategies and support sustainable urban development in Patna. Mean Urban Heat Island for Patna City (2019-24: LANDSAT-8).

Keywords: Urban Heat Island, Patna City, Landsat-8, GEE, WRF

Analysing the diurnal dynamics of land surface temperature and surface urban heat island effect over Delhi during heatwave using a hybrid downscaling approach

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Abstract

The record-breaking heatwaves marked by increasing intensity, frequency and spatial extent poses significant environment, social and economic challenges. These impacts are particularly severe in densely populated urban areas where the Surface Urban Heat Island (SUHI) effect coupled with heatwaves further exacerbate the heat stress. Though high spatial resolution thermal infrared (TIR) data from Landsat and ECOSTRESS are available, they may not be available during severe heatwave days and further, they will not capture the diurnal evolution of Land Surface Temperature (LST) and SUHI intensity. Here, we employed a disaggregation technique to estimate the high spatial resolution LST at 70 m from the four MODIS Terra/Aqua daily observations at 980 m, facilitating more accurate and finer representation of the diurnal variation of LST. We focused on the urbanised areas of Delhi, India on 16th June 2024, a day reported as severe heatwave. For calculating the SUHI, the average LST of urban vegetation patches was treated as reference LST. The results showed that the SUHI intensified during heatwaves compared to non-heatwave day. The afternoon showed the highest SUHI attributed to the increased heating from heatwaves and the urban structures and impervious surfaces showed the positive SUHI values during night due to heat retention. Barren surfaces demonstrated the highest positive SUHI values during daytime transitioning to negative values at night due to high thermal conductivity. In contrast, urban green spaces such as urban park and grasslands of golf club showed a decreasing negative SUHI during the day and an increasing value at night could be attributed to the thermal inertia of vegetation. Understanding these patterns is crucial for urban planning and the design of green spaces to mitigate the effects of urban heat islands, especially in the context of climate change and increasing urbanization.

Keywords: LST, Surface Urban Heat Island, High spatiotemporal resolution, Heatwaves, diurnal temperature dynamics, disaggregation

Assessing Urban Growth and its impacts on Surface Urban Heat Island using remote sensing in the Cochin Region, Kerala (India)

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Abstract

Urbanization is characterized by the increasing concentration of population in urban areas, resulting in the expansion and densification of cities, which in turn affects the local climate. This study analyzes changes in land surface temperature (LST) and Surface Urban Heat Island (SUHI) phenomenon over the Cochin region in Kerala, India. The changes are assessed for Cochin Corporation and five adjacent municipalities (CCM), from the period 2003 to 2020 using a spatio-temporal gap-filled MODIS LST data from Zhang et al. (2022). The analysis is done for pre-monsoon (March to May), post-monsoon (October to November), and winter (December to February) seasons, except for monsoon months (June to September) due to large cloud cover in the season. Our study shows that the highest daytime and nighttime LST is observed during winter, followed by pre-monsoon. The mean daytime LST increased by about 1.1°C, 0.43°C, and 0.73°C per decade for the pre-monsoon, post-monsoon, and winter periods, respectively. For nighttime, these changes are 0.52°C, 0.41°C, and 0.07°C per decade, respectively. Relative to a 20 km wide sub-urban region, an average daytime SUHI of about 1.5°C observed during the pre-monsoon and post-monsoon and about 1°C during the winter. In summer, nighttime SUHI observed is approximately 1°C relative to the sub-urban region. The impact of changes in Land-use/Land-cover (LULC) in LST are analyzed using Landsat data, which reveal a significant expansion of the built-up area in the study region. Over the 18 years, the built-up area increased from about 26.94% to 61.33% of the total area (~209 km2), with approximately 76.37 km2 of vegetation cover converted into the built-up area. Our results show a notable decline in vegetation cover in the urban region, raising concerns over ecological balance and sustainability. The study provides valuable insights for policy-making, urban planning, and UHI mitigation strategies of the Cochin region.

EO based assessment of Spatio-Temporal Variations of Urban Energy Fluxes and impact of Planning Interventions

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Abstract

Rapid urbanization and increasing human activities in urban areas are significantly affecting surface energy equilibrium, especially in developing regions like Delhi. This study investigates the impact of urbanization on the surface energy dynamics in Delhi from 1990 to 2022 using an Earth Observation (EO)-based Surface Energy Balance (SEB) model. Traditional inventory-based methods to estimate Anthropogenic Heat Flux (AH) require detailed data on vehicle emissions, population density, and fuel consumption, which are often unavailable at finer spatial resolutions in developing regions. To address this limitation, the study utilized EO data from the Landsat series and meteorological data from ECMWF ERA-5 to estimate key energy flux components, including net radiation, sensible heat flux, latent heat flux, and ground heat flux, with anthropogenic heat calculated as a residual. Results show that AH increased significantly from 172 W/m² in 1990 to 281 W/m² in 2022, with peak fluxes occurring during the summer months. Net radiation values ranged from 650 to 700 W/m², while sensible and latent heat fluxes ranged from 250 to 300 W/m², and ground heat flux varied between 30 and 120 W/m². The spatial analysis of energy fluxes demonstrated a clear correlation with land use patterns: AH values were highest in built-up areas (200–350 W/m²), followed by barren land (180–200 W/m²), vegetation (120–150 W/m²), and agricultural land (80–120 W/m²). The study also highlights the role of strategic urban interventions, such as the adoption of CNG for public transportation and the Odd-Even vehicle restriction scheme, which temporarily reduced AH fluxes. While these interventions were effective in the short term, the study emphasizes that long-term policy measures are essential to ensure lasting reductions in anthropogenic heat emissions. The findings demonstrate the utility of EO-based approaches in estimating urban energy fluxes, especially where inventory data is scarce, and emphasize the influence of land use, seasonal variations, and policy measures on energy flux trends. The study underscores the importance of sustained, proactive urban planning to mitigate the adverse impacts of urbanization on energy fluxes and environmental emissions.

Keywords: Urban Energy Fluxes; Landsat; Delhi; Surface Energy Balance; Planning Interventions

TRSforUClimate: Thermal Remote Sensing based Cooling Efficacy Assessment of Urban Green Space and Wetlandscape

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Abstract

Rapid urbanization and climate change significantly raise temperatures in urban areas through the Urban Heat Island (UHI) effect, especially in megacities like Delhi. This study analyzed seasonal changes in green spaces (GS) and water bodies (WB) and their impact on Land Surface Temperature (LST) from 1992 to 2023 using Google Earth Engine. Findings revealed that GS area increased across all seasons, while WB decreased in every season except post-monsoon. Over 31 years, the LST of GS and WB, along with the average LST for Delhi, consistently rose, indicating that human activities intensified UHI effects, outweighing the cooling benefits of GS and WB. In 2022-23, the post-monsoon season had the largest GS area (431.81 km²) and WB area (13.29 km²). In the pre-monsoon season, the cooling efficacy of GS and wetlands was measured at 8.13°C and 11.17°C, respectively. Landscape metrics such as Mean Patch Size (MPS), Percent Cover, and Largest Patch Index (LPI) were highest in the post-monsoon season and lowest in the pre-monsoon. The study emphasizes the relevance of India's Smart Cities Mission by highlighting the need for increased green spaces (GS) and water bodies (WB) to mitigate the impacts of climate change and urbanization in Delhi. It reveals that the effectiveness of these natural features is declining due to human activities and changing climatic conditions. Consequently, more GS and WB will be necessary in the future to address the growing urban challenges.

Keywords: Google Earth Engine (GEE), Urban Cooling Island (UCI), urban green spaces, urban ecosystems, urban wetland

Assessment of Temperature Variations in Peri-Urban Land Cover Features using UAV based Thermal Imaging

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Abstract

Developing sustainable urban planning strategies are crucial, in view of global warming and climate change. Assessment of urban green-infrastructure is essential to enhance environmental quality and understand heat-island effects. In this context, temperature variations were analysed for different peri-urban land cover features, viz. buildings, roads and vegetation cover in Indian Institute of Horticulture Research and surroundings, located in Hesaraghatta, Bengaluru Urban district, India. UAV datasets were acquired by National Remote Sensing Centre, ISRO using Trinity F90+ drone at 120m flying height in February 2024. UAV RGB (2cm), multispectral (6cm) and DSM/DTM layers (20cm) were used for feature identification and height comparison. Altum-PT camera, with radiometrically calibrated FLIR LWIR in thermal infrared-region (7.5-13.5μm), recorded high-resolution thermal images (33cm) capturing minute variations. Detailed feature-analysis utilised seamless surface temperature map from same sortie. Mean temperatures were derived using zonal-statistics from multiple samples and kernel-density estimation. Impervious land-cover, buildings and road surfaces showed larger temperature variations depending upon their constituent material. Analysis indicated temperature variations between 27-390C amongst roofing materials with metal sheets recording highest and solar panels, lowest. Concrete roof-top, terracotta/clay tiles and semi-transparent high-density polyethylene sheets recorded values in-between. Similarly, 27-300C Land Surface Temperature (LST) range among roads showed tar road, pavement, concrete road and mud/kachha road in decreasing order. Soil with grass recorded 4.5-5.00C lower temperature, compared to bare soil. Urban vegetation significantly contributes in moderating local ambient and LST with shading-cooling effect, depending upon tree canopy architecture. Canopy Surface Temperatures (CST) ranged from 22-270C. Among large trees, umbrella-shaped Raintree and dense Banyan tree had lower CST than medium trees. In medium trees with similar canopy-height ratios, Tamarind showed lower CST compared to Mango, Jamun and Sapota. Jackfruit with thick leathery, glossy leaves had higher CST. Palms with limited canopy-expanse showed decreasing CST in date palm, coconut, royal palm and arecanut. Thermal heat-map was generated for representing temperature variations spatially. This research provides essential planning inputs for selection of suitable roofing materials and tree species for improving green-spaces and urban microclimate under climate change scenarios. Further work is in progress to characterise temperature trends in diverse urban ecosystems for micro-level planning.

Key words: UAV, thermal imaging, urban land cover, roofing material, tree species

Geospatial Analysis of Heating Intensity and Land Surface Temperature Dynamics in Haryana's Sonipat, Panipat, and Jhajjar Districts Using Landsat Data

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Abstract

Land use changes and urbanization have a significant impact on the local climate, primarily through increasing surface temperature and the formation of Urban Heat Islands (UHIs). In this paper, a geospatial analysis of warming intensity and Land Surface Temperature (LST) dynamics was carried out in central circle districts of Haryana comprising Sonipat, Panipat and Jhajjar located in northern India. The study used multi-temporal Landsat satellite data and indices such as the Normalized Difference Built-up Index (NDBI), the Normalized Difference Vegetation Index (NDVI) and GIS software ArcGIS. The standardized LST values for the period from 1993 to 2023 showed a trend of extremities with respect to increasing temperature, majorly in winter, with increasing Z-scores ranging between 4.21 to 6.95 for winter maximums between 1993-2023, which is in positive correlation with concomitant increase in UHI effect. Low Z-scores ranging from -14.55 to -4.15 to between 1993-2023 winters implied that temperature in rural and vegetated areas was on the rise. Summer of 2003 showed remarkable increase in LST temperature when incidence of extreme heat wave was noted. In 1993, The NDVI low was found to be -0.37, and the high as 0.60. By 2023, the NDVI value for low had improved to -0.18, and the high had dropped to 0.48. The declining NDVI values between 1993 and 2023 indicated a deterioration in the health and cover of the vegetation. The 1993 NDBI had a high of 0.45 and a low of -0.59. The NDBI low improved to -0.36 in 2024, while the high increased to 0.55. A higher NDBI indicates more urbanization, while lower indicates a decrease in undeveloped or natural land. This implies that rural and vegetated areas will continue to lose ground to urban areas as they expand. The combined analysis of LST, NDVI and NDBI confirms that the difference in the urban-rural temperature is widening as warming was amplified over the built-up areas. The data reveals a clear pattern of increasing land surface temperatures, particularly during winter months, which is strongly associated with urban expansion. The positive feedback of vegetated areas could not offset the impact of increasing built-up area due to shrinking of vegetation cover. It highlights the impact of increasing urbanization and changing climatic conditions on regional temperature dynamics. Therefore, the need for sustainable urban planning and establishment of green infrastructure that would mitigate rising temperatures is emphasized.

Keywords: Land Surface Temperature, Urban Heat Island, ArcGIS, NDVI, NDBI, Central Circle Districts Haryana

Monitoring and modeling the energy efficiency of Soviet and post-Soviet buildings (Kaunas, Lithuania)

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Abstract

Kaunas, a city in Europe's north-northeast, characterized by vigorous winters and continental summers, was built using a combination of 19th, 20th and 21st century urban planning and development methods, making it an ideal location for urban analysis, thanks to its great architectural variety and the implementation of urban analysis methods using space and airborne remote sensing, particularly in the spectral thermal domain. Questions of energy efficiency are at the core of building renovation policies, particularly those dating back to the period of Soviet occupation. They combine the renovation of buildings' energy systems and the construction materials used for facades and roofs. The use of combined thermal infrared images makes it possible to measure the energy behavior of renovated, non-renovated buildings constructed from the 1990s onwards, in winter and summer, and to assess the impact of building standards and materials on building thermal emissions. Combined with vegetation, mineralization and morphometric indices, ANN models highlight the impact of urban forms and structures on thermic levels. They are a powerful instrument in urban planning policies aimed at reducing heat hotspots. This presentation presents the initial results based on the use of Landsat 8/9 TIRS and OLI data series from 2015 to 2023.

Keywords: Energy efficiency, thermal remote sensing, urban forms, renovation, seasonality, Landsat 8/9, Kaunas, Nordic area.

Regional to Local Scale Coal Fire Mapping and Spatiotemporal Characterisation of Coal Fire in the Coalfields of India

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Abstract

The major steps adopted for the detection of thermally anomalous pixels and their characterisation into surface coal fire, subsurface coal fire, and transitional class between coal fire and background pixels include: (1) retrieval of precise land surface temperature (LST) from single-channel TIR data using radiative transfer model (RTM) and from multi-channel TIR data using split-window algorithm (SWA) by efficiently discarding atmospheric effect and near-real emissivity modelling, (2) detection of thermally-anomalous pixels from background pixels, e.g., by (a) field-based pixel-integrated temperature modelling, (b) LST-profile-based algorithm by statistical thresholding of LST values along multiple transects across diverse coal fire locations, (3) Spatiotemporal coal fire dynamics monitoring by multi-temporal coal fire mapping. The present study was conducted on a regional scale for the Gondwana Coalfields of India using coarse resolution spaceborne TIR data (e.g., Terra MODIS and SNPP VIIRS data with spatial resolution 1 km, 750/375 m, respectively) to individual Coalfield levels using medium resolution spaceborne TIR data (e.g., Landsat 4/5 TM6, Landsat 7 ETM+, Landsat 8/9 TIRS, Terra ASTER with a spatial resolution 120m, 60m, 100m and 90m respectively) and finally to high-resolution thermal imaging of selective fire-affected areas (e.g., fire-affected opencast mines) of the coalfields by integrating terrestrial and spaceborne TIR data for achieving 1m-10m spatial resolution.

Spaceborne thermal IR observation shows that many of the 54 Gondwana coal fields in the country are fire-affected. Time series analysis of LST Pixel (LSTP) vectors identifies the temporal dynamics of coal fire pixels into three broad categories: continuous, dormant and new. It also characterises the temporal intensity of coal fire pixels into growing, temporally consistent and diminishing categories. For the Jharia Coalfield, LST-based thermally anomalous pixels were detected and characterised into surface and subsurface coal fire by the anomaly detection algorithms. Spatiotemporal dynamics and coal fire propagation were studied from multi-temporal LST products. During the 1990s and early 2000s, the coal fire area was reduced noticeably. Later, it increased significantly from 2006-2015 owing to extensive opencast mining operations. For high-resolution thermal imaging and improved coal fire mapping in and around the mining areas, medium-resolution spaceborne LST images were merged with high-resolution terrestrial LST images with spatial resolutions of 0.2m - 0.8m.

Keywords: Land surface temperature (LST); Thermal anomaly detection; Coal fire characterisation; Gondwana Coalfields; Jharia Coalfield

Integrated Geophysical and Remote sensing investigations for geothermal mapping at Lasundra (Gujarat), India

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Abstract

India's geothermal fields are non-volcanic and located in ten distinct geothermal provinces of the country. These geothermal provinces contain nearly 340 hot springs having low to medium enthalpy. In collaboration with the Space Applications Centre [(SAC), ISRO], remote sensing studies, and geophysical surveys (magnetotellurics) were carried out jointly to characterize the geothermal zone located at the eastern boundary of the Cambay rift basin. The Cambay rift basin, located in the Gujarat state (west of India), is well known for the presence of several hot springs. Lasundra Hot Spring, situated in district Kheda, is one of them and is relatively less explored Geophysically. In view of this, a remote sensing study was carried out initially in the vicinity of the study area prior to the magnetotellurics (MT) survey. The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite data followed by estimated Land surface temperature (LST) suggested a thermal anomaly in the study area. In addition to this, the temperature variation is also recorded with the help of a handheld thermal infrared camera (FLIR E75). Based on these outcomes, an MT survey is planned to image the subsurface structures/features at the geothermal site. The MT data were acquired along a profile starting from Salod to Porda Fagvel village (district Kheda). The profile was oriented in the NW-SE direction and data were acquired with the help of data acquisition system ADU-07e of M/s Metronix (Germany) with an interstation spacing of 1-2 km. The five components (three belong to the magnetic field while rest two belong to the electric field) were recorded with the help of Induction coils (MFS-06e) and Electric Field Probes (Pb-PbCl2). The data were recorded in the broadband frequency range with a recording duration of 1-2 days. The acquired MT time series data were robustly processed to obtain the resistivity and phase curves. The 2-D inversion of the obtained data set was performed with the help of WinGLink inversion software and some preliminary results were obtained. The obtained resistivity depth section shows some major conductive and resistive features. The conductive feature below the geothermal zone is reflected at a depth of ~2.5 km and inferred as the source zone. Finally, the derived results (geophysical and remote sensing) are appraised and correlated to the geology and hydrochemical datasets which were also obtained within the framework of this project.

Keywords: Geothermal, Magnetotellurics, ASTER, LST, Lasundra

Monitoring the dynamics of coal fire using time series thermal imagery

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Abstract

The coal seams of Jharia Coal Field (JCF) have been burning for several decades. Coal fires (both surface and sub-surface) pose a significant threat to life and health of residents of JCF. The existing methodologies for coal fire used a temperature threshold which needs to be determined manually. A new approach is proposed to quantify the threshold automatically and map the fire affected areas. The algorithm divides the images into tiles and computes mean and standard deviation of each tile. The tiles are sorted based on standard deviation and a bimodal Gaussian curve is fitted to five tiles showing highest standard deviation. The mean threshold for fire and non-fire detection is computed and implemented over the entire image. The algorithm was tested over images of summer and winter season and performed satisfactorily. Few active fires outside the known Jharia Coal Field were observed and field validated. The algorithm is used to study the spatial and temporal dynamics of coal fires using time series of thermal imagery.

Hydrothermally altered mineral mapping of the Malanjkhand copper mineralization in India using Landsat satellite data

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Abstract

The study evaluates how Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper Plus (ETM+), and Landsat-8 Operational Land Imager (OLI) satellite data can be used to detect and map hydrothermally altered minerals in the Malanjkhand copper mines of Madhya Pradesh, India. The research demonstrates the effectiveness of Landsat series data in identifying copper mineralization and its association with the hydrothermal alteration zone within the granitoid body. By employing band ratio and principal component analysis (PCA) methods, the study generates detailed spatial distributions of hydrothermally altered rocks linked to porphyry copper mineralization in the region. The study also finds that the band ratio combinations and the PCA method effectively distinguished hydrothermally altered minerals, vegetation, and iron oxides in the satellite images. Furthermore, the research reveals that Landsat-8 OLI data outperformed Landsat-5 TM and Landsat-7 ETM+ data in detecting hydrothermally altered minerals using the PCA technique. The correlation of identified minerals with the satellite images from Landsat sensors, supported by spectroscopic and petrographic studies, underscores the comprehensive approach taken in this study to enhance the understanding of hydrothermal alteration zones and improve the efficiency of mineral exploration. In conclusion, the research emphasizes the suitability of Landsat-8 OLI data for visual interpretation of hydrothermal alteration mapping, highlighting its higher radiometric resolution and reduced interference between vegetation and altered minerals compared to Landsat-5 TM and Landsat-7 ETM+ data.

Machine Learning based Prediction of soil organic carbon and available nitrogen using global open-source Thermal-InfraRed spectroscopy

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Abstract

A compendium of publicly available Near-InfraRed (NIR) and Mid-InfraRed (MIR) spectral data compiled from global sources (such as Open Soil Spectral Library or OSSL) serve as an important basis for building robust chemometric models for different soil physico-chemical properties. Specifically the OSSL MIR data is very much useful for the development of calibration models for large-scale soil chemistry mapping. We have utilized the OSSL Thermal-InfraRed (TIR) pseudo-absorbance (log 1/reflectance) data between 8 to 12.6 µm region for predicting soil organic carbon (%) and available nitrogen (%) content. We have used around 63,000 samples collected globally for calibrating the model and the model performance was validated on 15,000 independent held-out test set. An Ensemble Machine Learning (ML) model, Gradient Boosting Machine (GBM) was utilized for training the chemometric model. Different hyper-parameters of the GBM model were tuned using the h2o.ai AutoML framework. Results showed that, the model performed better in case of soil organic carbon prediction than soil nitrogen. The fitted GBM model showed a coefficient of determination (R2) of 0.95 and Root Mean Squared Error (RMSE) of 3% (percent weight basis) for organic carbon over blind test data. While for available nitrogen, testing R2 and RMSE were found to be 0.85 and 0.24% (percent weight basis), respectively. Through feature importance analysis, certain wavelengths such as 8285 nm, 8320 nm, 8630 nm, 8650 nm, 9000 nm, 10300 nm and 12050 nm were identified as sensitive to both organic carbon and nitrogen in soil. These wavelengths corresponds to the presence of C-O and C-C bond vibrations of various aliphatic and aromatic moieties present in soil organic matter. Keeping in view, various thermal earth observation (EO) missions such as ECOSTRESS or upcoming TRISHNA mission, this ground based spectral data can be used to simulate at-sensor TIR signatures in broadbands and utilized for further upscaling at regional scales.

Keywords: Thermal-InfraRed, Soil Carbon, Available Soil Nitrogen, Gradient Boosting Machine

Monthly trends of ERA based Energy Balance over Indus, Ganga and Brahmaputra basin and interlinkage with MODIS based snow cover

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Abstract

Energy Balance study was carried out for Indus, Ganga and Brahmaputra basins from 1950 to 2020 using ERA5 Land monthly gridded data of latent heat, sensible heat and net radiation. Pixel wise slope analysis, by performing linear regression on each pixel, was done for these 71 years,which shows strong variability of energy balance and its parameters. Results show energy balance of Brahmaputra basin varied in the range of -0.07 to +0.09 W/m2/year, that of Ganga Basin varied in the range of -0.05-0.01 W/m2/year and that of Indus Basin varied in the range of -0.03 to +0.03 W/m2/year showing. Monthly anomalies of each energy balance parameter were also temporally analyzed for each basin to find out seasons and months in which energy balance trend is increasing or decreasing. Further, using MODIS snow cover product (MOD10 CMG) at 0.05˚ resolution, basin wise statistics and individual monthly means were analyzed for the period of 2000-2020. Monthly climatology of these 21 years were computed and were compared with computed energy balance to understand its linkage with each other, which confirmed the inverse relationship between available energy balance and snow cover with a time lag of about 2 months.

Understanding the lake-ice phenology of Mansarovar lake in Tibet using microwave and thermal remote sensing data

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Abstract

Lake ice plays an important role in energy and water balance at local scale and any shifts in its melt-freeze phenology can serve as a significant climate change indicator. The region High Mountain Asia is home to many glacial and high altitude lakes which affects the local and regional climate in the region and their rapid growth (glacial lakes) in the recent decades is concerning, especially in Himalaya-Karakoram region. The availability of better resolution multi-sensor datasets, especially the microwave and thermal, has been making the lake-ice monitoring an essential component in cryosphere research, especially for the smaller lakes that are challenging to monitor with the coarser resolution radiometer and thermal observations. This study presents the variability in lake-ice phenology of Mansarovar lake in Tibet for period 2016-2022 using microwave brightness temperature and lake surface temperature observations derived from passive radiometer (SSMIS) and Landsat mission, respectively. Six lake ice phenology (LIP) variables (Freeze Onset, Ice-on, Freezing duration, Melt onset, Ice off, and Melting duration) were estimated and analyzed for the study period. The methodology for brightness temperature were cross-validated on two well studied lakes in China, Quinghai and Great Bear lakes. Results show a delay in the freeze onset period, an advance in melt onset, lesser freezing and melting days of the lake during the studied period. Observations were also verified using the variations of microwave backscatters from Sentinel-1 and air temperature measurements from ERA-5 reanalysis datasets. Lake surface temperature variations at the center of the lake has also been analyzed to better understand the melt-freeze processes. Among the LIP variables, ice-on and ice-off dates have shown the highest variation during the study period. Numerous climatic factors may have governed the observations which are essential to study in an order to understand any climatic impact. We emphasize the potential of better resolution (both temporal and spatial) thermal observations (i.e. TRISHNA), together with optical and microwave observations, to better understand the melt-freeze processes of the lakes and effect of climatic factors on its phenology.

Keywords: Lake-ice phenology, High altitude lake, Mansarovar, Thermal remote sensing, Microwave remote sensing

Close-range thermal infrared remote sensing in complex environments – a cryospheric case study

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Abstract

Mountain regions are among the most affected regions by global climate change. Changing temperature and precipitation regimes heavily impact their ecosystems and alter the occurrence and dynamics of individual landforms. Monitoring mountainous ecosystems in detail remains challenging as accessibility, topography, and spatial resolution of existing data limits finer-scale studies of environmental changes. These limitations can partly be overcome by using close-range remote sensing platforms, such as uncrewed aerial vehicles (UAVs), as well as payloads with optical and thermal infrared multi- and broadband cameras, readily available on the market.
Most of these platforms and payloads are advertised to be used immediately off the shelf. However, the acquisition of thermal infrared (TIR) data, in particular in complex environments like mountains, is challenging and data has to be treated with care. Applications of TIR data, i.e. use of absolute or relative skin temperature values, require thorough data processing including camera characterisation, thermal drift correction, atmospheric correction, thermal calibration, and validation with in situ data. Here, we present challenges and lessons learnt based on a case study over a cryospheric landform in the Swiss Alps. A detailed discussion of the applied correction schemes emphasises the complexity of close-range TIR data acquisition but also highlights opportunities and potential for varying research applications across spheres.

Keywords: close-range remote sensing, UAV, thermal infrared, cryosphere, complex environments

Airborne Hyperspectral Thermal Infrared data for the cryosphere: case study on Alpine glaciers

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Abstract

The Alpine cryosphere is undergoing rapid change, which has accelerated in recent years. Glaciers are shrinking, snow cover is diminishing and permafrost is thawing affecting humankind both directly (e.g, natural hazards), and indirectly (e.g. water scarcity). Our understanding of these processes has advanced considerably thanks to knowledge advancement and new technologies in the past decades. The development of remote sensing platforms opened the possibility to monitor the cryosphere at a large scale and in different wavelengths. In particular, measuring the emitted radiation in the thermal infrared region allows for estimating the skin temperature of an observed object along with its emissivity. So far, most works used satellite or uncrewed aerial vehicle (UAV) derived thermal infrared data. However, shortcomings are reported due to limited spatial resolution (satellite) or coverage (UAV), and high uncertainties arise from the rugged topography of the landforms and the surrounding terrain. In this contribution, we venture in a unique combination of data with unprecedented spatial and spectral resolution over a cryospheric landform. We surveyed two different alpine glaciers in the Swiss Alps, one debris-covered (Zmuttgletscher) and one bare ice (Findelgletscher), with the Hyperspectral Thermal Emission Spectrometer (HyTES) developed at NASA/JPL. HyTES is an airborne imaging spectrometer, featuring 256 bands in the 7.5-11 μm wavelength range at a spatial resolution of about 3 m. Combined with in situ-data, the acquired dataset opens new horizons to study these cryospheric landforms. It allows for testing algorithms and processing schemes in sight of the future satellite missions (TRISHNA, SBG, LSTM), which are limitedly available for the cryosphere using thermal infrared datasets. We present first validation results between HyTES data and in situ observations, and discuss the potential of the next generation TIR satellite data for cryospheric applications. For debris covered glaciers, it is possible to estimate the debris thickness, sub-debris melt (through a surface energy budget approach), classify different rock types, and explore mixed-pixel effects. On the other hand, bare-ice glaciers in summer can act as known temperature calibration surfaces to test the performance of atmospheric and topographic corrections at different elevations, slopes, and aspects, which are known to be impacting parameters in airborne data processing, and that significantly affect the retrieval of accurate skin temperature.

Keywords: hyperspectral thermal infrared, airborne, cryosphere, HyTES

Permafrost Landscape Thermal Pattern Trend Analysis by MODIS Daytime Land Surface Temperature and Land Cover in Yakutia: 2001 to 2020

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Abstract

The thermal pattern of permafrost landscapes can change rapidly as a result of forest fires, permafrost degradation and/or vegetation cover dynamics under the impact of the global warming. Land Surface Temperature (LST), as a critical variable in understanding climate-induced change, could allow insights into the presence of a significant thermal response in permafrost landscapes to global warming and associated land cover change. Using MODIS data, LST trends and land cover change over Yakutia in Eastern Siberia, the largest permafrost region of the World. Daytime 1-km MOD21C3.061 Terra Land Surface Temperature and 3-Band Emissivity Monthly L3 Global seasonal datasets were used to derive seasonal LSTs for spring (March, April, May), summer (June, July and August) and autumn (September, October and November), as well as annual LSTs for the period from 2001 to 2020. The results of the nonparametric Mann-Kendall trend test and Sen's slope test indicate a significant trend of daytime LST warming in the northwestern part of the region and the mountains of the northeastern part. There were no significant cooling trends recorded at any time of the year. The land cover change reveals that these positive LST dynamics are related to the processes of tundra 'greening' and forest expansion in Arctic permafrost landscapes. The average Sen's slope of LST showed an increasing trend year by year (0.034 °C/a) from 2000 to 2020, with the most obvious rise in LST North-West Yakutia and in Novosibirsk Islands (0.066 °C/a) in autumn. The results are an important regional demonstration for studying climate change in Arctic and permafrost regions.

Keywords : Land Surface Temperature, Permafrost Patterns, Landscape Permafrost Monitoring, Trend Analysis, MODIS, Yakutia, Arctic.

Advanced Multimodal Satellite Analytics for Predictive Snow Hydrology in the Himalayas: A Case Study from the Beas Basin

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Abstract

Managing water resources in Himalayan region is particularly challenging due to its intricate landscape and varying weather conditions. This research presents the development of a dynamic system (available at https://onemapggm.gmda.gov.in/jal/ as SW) for a detailed assessment on snow coverage, snow depth, and forecasting snowmelt runoff in the Beas Basin of Himachal Pradesh on a near real-time basis. We applied a combination of satellite data from MODIS, Landsat, Sentinel-2, and high-resolution SRTM digital elevation models to produce accurate maps of snow cover and depth using sophisticated remote sensing technologies and machine learning (ML) algorithms. A specially designed Random Forest classifier, improved with a majority voting technique, was used to consolidate and enhance the snow cover and depth data, ensuring precise and dependable mapping throughout varied environmental settings. An innovative conceptual snowmelt runoff model (SRM) that utilizes a temperature index method along with satellite data on snow coverage and depth with observed temperature and precipitation from Climate Hazards Center InfraRed Precipitation with Station (CHIRPS) and elevation details, enabling precise predictions of runoff resulting from snowmelt. The accuracy of our snow mapping markedly improves the model's forecasting capability, crucial for predicting floods and managing water resources in mountainous regions however, high resolution measurements on temperature may further improves the accuracy. Our results highlight the effectiveness of this integrated approach for similar mountainous areas worldwide, offering a solid method for conducting hydrological studies.

Keywords: Snowmelt Hydrology, Remote Sensing, Machine Learning, Hydrological Forecasting, Himalayan Water Resources, Near-real time

Solar Induced Florescence for Remote Sensing of India's Intensive Agriculture Under Heatwave Conditions

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Abstract

Between 2010 and 2050, global food demand is predicted to increase by 35% to 56% in line with increasing global populations. Environmental pressures such as those caused by a changing climate and more frequent extreme heat events can threaten future food security. Heatwaves and water stress cause many negative plant responses such as decreased transpiration and photosynthetic inhibition leading to reduced crop yields. Satellite observations of solar induced fluorescence (SIF) are an effective way to monitor global vegetation changes as SIF provides information on plant photosynthetic efficiency, which can potentially help us better understand the timescales and intensity of heat stress on crops.

This project primarily focuses on understanding how agricultural water and heat stress manifests in SIF. Many states in India adopt agriculturally intensive rice-wheat cropping systems and many states suffered crop yield losses following the 2022 mega-heatwave. The heatwave was so intense that India stopped wheat exports in 2022. Heatwave conditions combined with torrential rain in 2023 resulted in a predicted ban extension until March 2025. By combining multiple coincident satellite observations, we explore the relationships between SIF, land surface temperature (LST), normalised differential vegetation index (NDVI), and vapour pressure deficit (VPD) in baseline and extreme water stress conditions across agricultural regions of the country.

A multivariate analysis of Sentinel 5p TROPOSIF, VIIRS LST, NDVI, and ERA 5 derived VPD will be presented in the context of government wheat yield statistics data. Early results indicate that SIF is most strongly correlated with state-wise crop yield information. Regional and time series analysis from 2018 to 2024 along with the results of statistical analysis will be used to demonstrate the timescales over which SIF and other parameters capture heat and water stress impacts.

Keywords: TROPOSIF, intensive agriculture, food security, India.

Modelling of Air Temperature using Land Parameters and Downwelling Radiation in Selected Agro-Climatic Settings

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Abstract

Air temperature is an important atmospheric parameter affecting vegetation growth and drive different physiological processes such as transpiration and photosynthesis. Air temperature plays a vital role in modelling these processes, especially evaporation from soil and transpiration from plants. In India, the air temperature is measured in scattered manner through manual and Automatic Weather Stations (AWS) by Indian Meteorological department and other agencies. The spatial interpolation of point-based observations will lead to large error for the estimation of surface evapotranspiration due to elevation and change in land use land cover. Moreover, manual observations measure only maximum and minimum temperature and do not measure instantaneous air temperature. To address this gap, a study is conducted to model air temperature using in situ land surface temperature (LST), albedo and downwelling radiation data. In the present study the four component radiometer data is used to model air temperature over different locations in India covering semi-arid (Nawagam, Gujarat), arid (Jaisalmer, Rajasthan) and sub-humid (Samastipur, Bihar) agro-climatic regions. The multiple year ground data was used to develop the model and validate with independent dataset. In view of limited data points elevation data was not used. Four alternatives were used to derive relationship between various parameters: (i) Air temperature vs LST (ii) Air temperature vs LST and albedo (iii) Air temperature vs LST and total downwelling Radiation and (iv) Air temperature vs LST, albedo and total downwelling Radiation. Corresponding linear regression models were developed. After validation, the model comprising of LST and total downwelling radiation was found to be the best and showed root mean square error (RMSE) of 1 K to 1.5 K and 'coefficient of determination' (R2) was found to be in between 0.90-0.95, for selected three different agro-climatic regions. Further, the model will be upscaled using the high-resolution ECOSTRESS data using these as well as additional parameters and compared with measured air temperature in the aforementioned agro-climatic zones.

Keywords: Land surface temperature, downwelling radiation, evapotranspiration

Bio invasive Species Transmission in Marine and Riverine Ecosystems as Component of Human Health Disaster Management

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Abstract

The applicant ventured to conduct investigations on parasitic populations that were harboured in reef-associated fishes (*Johnius dussumieri* & *Sillago sihama*) as well as coral reef fishes (*Lutjanus malabaricus*) at Grande Island, discovered by Council of Scientific & Industrial Research, India on March 5, 2024. The dynamics of invasive species, *Anisakis typica* of zoonotic significance, as an element of disaster management in public health, opened up newer avenues of investigations. The dolphin reservoir in River Ganges at Fatehpur, some 2000Kms from Goan coast in Arabian Sea, released 2nd stage larvae that were consumed by copepod intermediate hosts, which were, in turn consumed by the freshwater catfish, *Bagarius bagarius*, to complete the life cycle of the nematode of human health significance, *A. typica*. The migration of *B. bagarius* enabled worms to cross estuarine buffer zone for effective transmission onto *S. sihama* in Arabian Sea by consumption of faecal matter of catfish in the estuarine water. The reversal pathway triggered transfer of marine fish parasites, *Rostellascaris spinicaudatum* harboured by sharks, Rhinchodon typus, and catfish, *Arius maculatus* in the estuarine zone, onto the freshwater catfish, *B. bagarius*. This fish migrated from the estuarine zone after feeding on faecal matter of marine fishes in estuarine zone, and thus transmitted infection by eggs and developing stages of *R. spinicaudatum* to riverine fish and freshwater dolphins at Fatehpur, U.P. Two other avenues of worm transfer were – i) by the ballast water through the movement of transport ship of the Shipping Corporation of India, and ii) by migratory birds flying from West coast of India at Goa, to River Ganges at Prayagraj and Fatehpur, U.P.

Keywords: River Ganges, Rostellascaris spinicaudatum , Bioinvasion, Anisakis typical

Dynamic Study of Desertification and Oasification of Western India Using Artificial Intelligence and Google Earth Engine: Opportunities and Challenges

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Abstract

Over the last two decades, Western India has experienced ecological imbalances due to extreme weather events. These events, driven by climate change, have caused significant disruptions to the region's ecosystems, agriculture, and water resources. This study will help to develop a comprehensive desertification assessment model designed to predict both short- and long-term drought conditions vis a vis oasification, facilitating early mitigation strategies to assess the vegetation growth around the arid and semi-arid region of western India. Utilizing a combination of meteorological data, remote sensing technologies, and climate projection models, the assessment system is applied across various agro-ecological zones. The AI-based analysis by the Google Earth engine provided the scenario of the oasification process. The NDVI analysis from LANDSAT-7 data had shown a significant increase in vegetation cover, during the November- December months for the years 2003 and 2021. The results of this study raise many questions on the ecological imbalances and threats to the arid and semi-arid regions of Kachchh district and Rajasthan state. The study also analyses the impact on human beings due to the increase in seasonal outbreaks of vector-borne diseases. This model's long-term forecasting capabilities will enable state-level policymakers to make informed decisions on water resource management, crop planning, and land use policy. Additionally, this study provides a future-oriented framework for strengthening the agricultural sector's resilience to climate variability. This approach highlights the potential for state-level adaptation and preparedness to minimize the adverse effects of extreme weather events and drought on agricultural productivity and rural economies. Early detection allows for timely interventions, such as optimizing water usage, selecting drought-resistant crops, and employing other adaptive agricultural practices. The findings emphasize the importance of adopting proactive severe weather management strategies to enhance the resilience of agriculture in the face of climate change.

Keywords: Oasification, Draught, Climate, Mitigation, Crop, Ecology

High resolution active fire detection for identifying hotspot trends in fragmented forest landscapes in India

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Abstract

The application of thermal remote sensing in forestry enables enhanced monitoring of fire dynamics and forest health, providing critical information for effective management. This study employs high-resolution (30 m) active fire location data from Landsat 8/9 – Operational Land Imager (OLI) to analyse fire trends in fragmented and degraded forest landscapes across India. Landsat active fire detection is based on an algorithm developed by Schroeder et al. (2016) and primarily uses the fire-sensitive short-wave infrared channel for fire detection, while being supplemented by NIR and Red bands. While Landsat's revisit time of 8 days (with both Landsat 8 and 9) is much longer than that of MODIS Terra/Aqua and JPSS/SNPP VIIRS, which have a twice-daily revisit, its finer spatial resolution can enable more precise detection of fire events in smaller, fragmented patches, providing insights into fire dynamics often overlooked by coarser-resolution sensors. Focusing on the fire seasons from 2021 to 2024, the study examines the relationship between fire occurrences and forest cover metrics, such as Forest Area Density (FAD) and other fragmentation metrics, at three wildlife sanctuaries with significant areas of fragmented and degraded forests: R.V. Nagar Range, Vishakhapatnam, in the Eastern Ghats; Biligirirangan Tiger Reserve in the Western Ghats; and Eravikulam National Park in the Western Ghats. Additionally, the study compares fire trends from MODIS and VIIRS sensors alongside Landsat OLI to evaluate the trends captured by hotspot analysis using fire locations at different resolutions. The findings aim to enhance the understanding of fire dynamics in ecosystems at different scales, ultimately contributing to more effective forest management and conservation strategies.

Keywords: Landsat active fire, Forest Fragmentation, MODIS, VIIRS

Holistic use of optical-thermal sensing system for early detection of diseases and pests in agricultural crops

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Abstract

Plant diseases and pests pose a serious threat to agriculture and forestry globally, leading to substantial economic losses, reduced yields and ecosystem imbalance. These threats can drastically impact food security, livelihoods, and biodiversity. The implementation of non-contact, highly-efficient, and affordable methods for detecting and monitoring plant diseases and pests over large areas is crucial for advancing sustainable plant protection. By providing real-time, precise discrimination of healthy and pest disease infested crop over a vast area can significantly reduce the hazardous use of chemicals, lower costs of crop production and ultimately contribute to better food security and forest management. In recent years, various forms of remote sensing methods have been introduced and applied for detecting and monitoring plant diseases and pests, offering significant advancements in precision agriculture and crop protection. In past in our study we use ground based hyperspectral data to discriminate aphid and Alternaria blight in mustard, leaf curl virus disease and Jassid in cotton. In these studies, we identified different spectral bands and use various machine-learning algorithms to develop models to classify crop stress due to pests using these spectral bands and ground-based data with respect to manually collected pest score and biochemical analysis of the crop plant. These spectral dominantly bands lie 553, 642, 687, 703, 735, 752, and 887nm. The plant analysis showed there is significant decrease in the biochemical content such as green and non-green pigment as well water content of the infested crop plant. These signatures of plant can be early detected using high resolution thermal data. As infestation or stress occurs in crop plants, one of the earliest physiological responses is a decrease in transpiration, which is the process of water movement through the plant and its evaporation from aerial parts, such as leaves. These changes lead to a reduction in water loss and can be detected by a rise in leaf surface temperature, as the evaporative cooling effect of transpiration decreases. Here's how high-resolution optical-thermal data plays a key role in early detection. High-resolution thermal data detects these temperature increases, while optical data captures changes in pigments and water content. By integrating both thermal and optical data, farmers can achieve early detection of pest infestations or diseases, allowing for timely intervention to protect crop yields and improve overall farm management.

Keywords: Remote sensing, Artificial intelligence (AI), machine learning (ML), disease and pests, crop/plant health

Opportunities for Remote Sensing to make Arid Horticulture More Remunerative for Farmers and Environment

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Abstract

Over the past six decades, India has made significant strides in horticultural production and productivity, enhancing both food and nutritional security beyond the achievements of the Green Revolution. However, as the benefits from conventional agricultural technologies diminish, new strategies for managing fruit orchards are becoming essential. Challenges in fruit crop cultivation include managing crop phenology and flowering, optimizing resources like water and nutrients, ensuring plant protection, and handling post-harvest processes. Timely decision-making in these areas is critical, especially in the fragile ecosystems of arid regions. While remote sensing technologies are increasingly used to assess land suitability for various crops, there is a growing need for technologies that aid in timing essential orchard tasks, such as stress induction for flowering and fruiting. Moreover, developing advanced remote sensing tools to optimize water and nutrient usage is crucial, particularly given the low retention efficiency of sandy soils. Pesticide application often occurs reactively, following pest appearances or symptoms, leading to overuse and environmental impact. Implementing early warning systems based on pest monitoring can significantly reduce pesticide reliance. Many orchard management tasks involve evaluating plant responses, where remote sensing can provide vital scientific data to inform decision-making. Harvest timing is also critical for maximizing profit, as many fruits are highly perishable. Therefore, enhancing tools for determining maturity indices can help minimize post-harvest losses. Remote sensing of infrared radiation emitted by soil and plants has proven effective in assessing drought and high-temperature stresses in crops. However, there is significant potential to integrate this information into robust tools for precise micro-irrigation in the water-scarce lands of arid regions. Recent advancements in sensing pathogen and insect pest infections can greatly enhance automated control systems for effective management. Additionally, since fruit maturity involves thermogenic processes, exploring thermal signals from fruits could optimize the timing for harvest. This review highlights the potential of remote sensing technologies, particularly those leveraging thermal signals, to enhance orchard management, ultimately benefiting both farmers and the environment.

Farms on Fire: Measuring Aerosol Concentrations and Understanding Environmental Implications of Rice-Residue Burning in Mixed-Farming Systems of Punjab, India

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Abstract

In the mixed-farming systems of Punjab, India, non-basmati rice residue is often burned due to its unsuitability as livestock fodder. This practice emits coarse and fine aerosols, impacting agriculture, the environment, and health. This study prototypes a high-frequency monitoring framework using thermal remote sensing to track major aerosols from rice residue burning. To carry out the objective, our remote sensing approach has three layers of data acquisition, processing, and analysis activity that consists of (a) mapping the rice area during the Kharif (Monsoon) season (July-November), (b) capturing the area burned under rice cultivation during and after harvesting period, and (c) quantifying the concentration of

PM2.5 during the burning events. Five rice seasons, from 2015 to 2019, were analyzed using Sentinel-1 datasets. To identify burned areas during and after rice harvesting, the Burned Area Index (BAI) was generated using the MODIS Aqua Daily dataset and overlaid with VIIRS active fire point data. The BAI was computed from the Red and Near-IR MODIS bands, which measure the spectral distance of each pixel from a reference spectral point to emphasize charcoal signals in post-fire images. Julian days with peak BAI values from October 1 to December 31 were identified for each analysis year. To assess aerosol

emissions from burning events, MERRA-2 Reanalysis data were used, including mass concentrations of dust, salt, black carbon, organic carbon, and sulfate. Additionally, variations in the chemical representation of sulfate ions and contributions from organic matter were analyzed using respective factor values to explain changes in daily PM2.5 concentrations. The majority of burning events occurred between late October and early December, with a positive correlation (R-squared = 0.44) between burn days and

PM2.5 concentrations, indicating the impact of residue burning on air quality. Considering the regional variations in cropping practices, our research emphasizes the limitations of global datasets in capturing the environmental effects of burning rice residue occurrences. In this instance, high spatiotemporal resolution thermal sensor-based products are needed, especially given the brief duration of these occurrences, to accurately monitor aerosols and burning activities in rice-based cropping systems.

Keywords: Rice residue burning; thermal; PM2.5; aerosols; air quality

Performance Evaluation of Remote Sensing Evapotranspiration Models and Ensemble Approaches in India

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Abstract

The study evaluates the performance of three remote sensing-based evapotranspiration (ET) models – Priestley-Taylor Jet Propulsion Lab (PT-JPL), Soil Plant Atmosphere and Remote Sensing Evapotranspiration (SPARSE), and Surface Temperature Initiated Closure (STIC), across multiple spatial and temporal scales in India. We tested these models using insitu data at the field scale and 1-km scale data from the Moderate Resolution Imaging Spectroradiometer (MODIS). At the field scale, the PT-JPL model had the best performance with a RMSE of 65.56 W/m², followed by SPARSE (69.21 W/m²) and STIC (81.85 W/m²). However, at the 1-km scale, the LST based SPARSE and STIC models performed better, with RMSEs between 30–34 W/m², while the PT-JPL model had a higher RMSE exceeding 40 W/m². This decline in accuracy for PT-JPL at finer scales may be attributed to the resampling of meteorological inputs from coarser data sources. In addition to individual model evaluation, we explored ensemble ET models to improve accuracy. Techniques such as mean ensemble, Bayesian model averaging (BMA), and machine learning methods including k Nearest Neighbors (kNN), Random Forest (RF), and Support Vector Machine (SVM) were applied. The results showed that ensemble models consistently outperformed individual models at both field and 1-km scales. Notably, machine learning-based ensembles provided the most significant improvement, reducing errors by up to 50% compared to individual models. At the 1-km scale, ensemble approaches reduced errors by 5–17 W/m², with machine learning methods further decreasing errors by 22–25 W/m². Leave-one-out cross-validation highlighted the robustness of ensemble models, particularly for predicting ET in locations without in-situ data, when trained with data from similar land cover types. This underscores the importance of land-cover-specific training to improve model accuracy in data-rich regions.

Keywords: Evapotranspiration, PT-JPL, SPARSE, STIC, Ensemble, BMA, kNN, RF, SV

Unveiling Thermal Remote Sensing for Microclimatic Urban Forest Phenology [TRS-UFoP] in Ecosystem Management

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Abstract

Plant phenology, the annual recurring sequence of plant growth stages, affects both biogeochemical and physical processes, which impacts the relationship between vegetation and climate feedbacks. The timing of growth onset and senescence, which determines the length of the growing season, changes with an increase in Tsurf (surface temperature), which also drives annual carbon uptake in urban ecosystems. Large geographic areas will see longer growing seasons as temperature rises, this means there will be more vegetation present for a longer portion of the year. The current study will evaluate long term records (+20 years) of satellite Tsurf data to understand the impacts of changing phenology on vegetation climate feedbacks for urban ecosystem. Plant microclimates can vary significantly from Tair (air temperature) and Tsurf , this difference can be used to calculate how +1º C rise can estimate differences in days shift in phenology. Impacts of shifting phenology could be studied better using thermal remote sensing as it neglects the errors in actual temperature by urban forests microclimate which will give us insights on both dormant and growing seasons for better Urban Ecosystem Management.

Keywords: Thermal Infrared, Remote Sensing, Phenology, Microclimate, Urban Ecosystem.

MODIS Based Night Time LST Trends (2003-2023) for Selected Cities in India

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Abstract

Land Surface Temperature (LST) is identified as one of the key variables in environmental and climate studies. Urban landcovers like buildings, roads and other urban infrastructure accumulate heat representing islands of heat in relation to their rural environment. The increase in night time temperature influence on human health, energy consumption, hydrological and other environmental processes. Night time data reveals the effects of urban heat islands (UHI) more apparently, because of low cooling capacity of the materials used in construction. The present study investigates the distribution of nighttime LST trends over four metropolitan cities (Bengaluru, Mumbai, Ahmedabad, and Delhi) which are rapidly undergoing urbanization in India. Long term remotely sensed LST data were obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor in the form of 8-day composites of night time data at a resolution of 1 km for a 20-year period, *i.e.* from 2003 to 2023. Google earth engine was used for analysis of data. The pure pixel data was used after masking pixels for bad quality and monthly composite images were generated. Winter and summer month's data was used in the analysis since they have relatively less influence of precipitation on LST during these months. Mann-Kendall test was used to study the trends of LST during night time.

The results indicated that all the four cities showed gradual increase night time LST trends. In Bengaluru city, the increase in night time temperature is noticed in the peri-urban areas of city due to rapid urbanization / industrialization activities in the region. The increase in LST ranged 0.1 to 0.6o per year. Similar trend was observed in Ahmedabad city especially in the peri-urban regions with increase in LST ranging from 0.0 to 0.5o per year. Night time temperature trend in Delhi region also showed increase in the temperature by 0.1 to 0.4o per year and this increase is significantly high in the north, west and southern regions of the city. Increase in night time temperature trend was highest in the month of April in Mumbai region, which coincides with summer month and the trend ranged from -0.2 to 0.5o per year.

The present research provides insights into the night-time LST trends in four rapidly developing cities of India. Further work is in progress in analysing peri-urban regions. Understanding the dynamics of LST in urban regions using high spatial resolution datasets that would be available from the upcoming advanced satellite like TRISHNA along with critical inputs like land cover, albedo, aerosol, and other pollutants shall provide better insight into the impact of different environmental and climatic factors on LST.

Keywords: LST, MODIS, Urban

Spatial and Temporal Analysis of Pollution and Land Surface Temperature in Haryana through Advanced Computing and Geospatial Technology

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Abstract

The current study uses advanced computational techniques and geospatial technology to analyze and interpret complex environmental patterns in terms of Land Surface temperature (LST), and air pollution parameters, in Haryana through a dynamic system available at https://myproject-d1db1.projects.earthengine.app/view/airpollutiondataset. By integrating Emerging Hot Spot Analysis (EHSA), Local Moran's I for spatial auto-correlation, and Geographically Weighted Regression (GWR), the study thoroughly examines how pollutant levels and land surface temperature (LST) interact over time. EHSA identifies areas with significant increases in clustering of high or low values for both pollution and LST, pinpointing emerging hot spots. Local Moran's I evaluates spatial auto-correlation, revealing key clusters and outliers with unusual concentrations of pollution and temperature anomalies, thereby providing crucial insights into their spatial distribution and correlation. GWR models the spatially varying relationships between pollution and LST, uncovering localized patterns and trends that traditional global models might miss.

The integration of these methods reveals significant spatial and temporal patterns across Haryana. EHSA highlights urban centers such as Gurgaon and Faridabad as critical hot spots with rising pollution and temperature levels. Local Moran's I confirms a close correlation between high pollution and temperature in these urban areas, emphasizing the need for targeted management. In contrast, rural areas exhibit high temperatures with lower pollution, indicating unique local factors. GWR reveals a stronger association between pollution and temperature in urban areas due to factors such as industrial activities and traffic. These findings underscore the importance of localized analysis for understanding environmental dynamics and support the need for tailored policy interventions. The study demonstrates the effectiveness of advanced computational approaches in environmental analysis, offering valuable insights for informed decision-making and resource management in Haryana. Collecting high-resolution temperature data will provide detailed insights into local temperature variations and their correlation with pollution levels. Implementing advanced monitoring systems with the integration of station data and utilizing high resolution satellite-based temperature measurements will offer precise and granular data, improving the understanding of how temperature fluctuations impact air quality. This targeted approach will enhance the effectiveness of pollution management efforts and contribute to better environmental and public health outcomes.

Keywords: Environmental Monitoring, Pollution, Sentinel P5, MODIS LST, Environmental management

Spatial temporal analysis of Land Surface Temperature using Remote Sensing data – A case study of Kanyakumari district, India.

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Abstract

The Spatial-temporal analysis provides the periodic changes of Land Surface Temperature (LST). In many research papers various parameters are used to derive LST like Brightness Temperature, Radiance, Emissivity, and NDVI. Current study carried out in Kanyakumari District, Tamil Nadu, India, and thereby LST is derived using Satellites namely Landsat-8, MODIS, VIIRS data with the different resolutions using Thermal Infrared band (TIR). Data used for different seasons of the decade (2014-2024) and analysed. Moreover, various features have been identified related to land use namely Settlements, Water Bodies, Forests, Agricultural Lands, etc, to analyse temperature change for a given area. This research work has been carried out to examine Spatio-temporal trend using LST. Result also compared with product generated using Indian satellites, overall the study determines the future scope for understanding Temperature variations, Climate changes, weather analysis.

Keywords: Land Surface Temperature, Google Earth Engine, Thermal Infrared, Brightness Temperature, Emissivity.

Assessing temperature variability and thermal inertia in glacial lakes A decadal study using remote sensing in the Panikhar region, Himalayas

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Abstract

This study aims to assess temperature variability and thermal inertia in glacial lakes in the Panikhar region of the Himalayas over a decade (2013-2023) using satellite data from Landsat 8, the study explores whether large glacial lake retain heat longer than smaller one and how this affects temperature fluctuations throughout the season. The limited availability of weather stations in glacial regions made it necessary to use remote sensing data from Landsat 8 to obtain temperature readings. The thermal data from Landsat 8's Thermal Infrared Sensor (TIRS) Band 10 was combined with temperature readings from a weather station, Shafat, near the study area. The data were processed using Google Earth Engine (GEE) to create a 10-year time series of glacial lake surface temperatures and satellite-derived temperatures were then compared with real-time ground data from 2021 to 2023 for validation. The results showed that the larger glacial lake, located at 4113 meters above sea level, had higher thermal inertia, meaning it retained heat longer than the smaller glacial lake at 4439 meters. During winter, the larger lake's temperature dropped to -16.94°C, while the smaller lake cooled slightly more, reaching -17.19°C and as spring approached, the larger lake warmed more quickly, increasing by 5.62°C per month, and peaked at 9.74°C in July. In contrast, the smaller lake reached a peak of 9.06°C; the satellite-derived temperatures closely matched ground station readings. The larger lake's greater heat capacity made it more resistant to sudden temperature drops, especially in winter, however, in spring, the larger lake warmed faster, likely due to its ability to absorb more solar energy. While satellite data was generally consistent with ground measurements, it tended to overestimate winter temperatures by up to 7°C. This study demonstrates that larger glacial lakes are more thermally stable retaining heat longer. These findings are critical for improving monitoring techniques for glacial lake outburst floods (GLOFs), which pose significant risks to downstream communities. Future research could broaden this analysis to encompass additional regional lakes at varying altitudes, allowing for exploration of these temperature patterns and incorporating data from other satellites to enhance the understanding of temperature dynamics.

Keywords: Glacial Lakes, Thermal Inertia, Remote Sensing, Landsat 8, Temperature Variability

Numerical Modelling of Wave Propagation near the Coastal Water of the Bay of Bengal

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Abstract

Coastal water of a water body is closest to the land part where the wavelength of water wave is greater than the water depth. Any extreme event like a tsunami generates huge waves in this coastal water regions. These extraordinary extreme coastal water waves pose significant threats to coastal communities, maritime operations, and offshore structures, highlighting the need for advanced monitoring techniques to understand their propagation nature better.

These coastal water waves can be modelled appropriately using Shallow Water Equations (SWE's). Here we have tried to develop a numerical model to simulate the propagation of extreme waves in one dimension numerically. These equations have been discretized using the Crank-Nicolson scheme of Finite Difference Method (FDM) for the spatial domain and the forward difference method for the temporal domain. A basic sample model with five grid points is demonstrated to explain model development nature. MATLAB code has been generated using both linear and nonlinear (considering friction and conviction) shallow water models with appropriate initial and boundary conditions for obtaining results for some representative bathymetry. Computational results have successfully shown the wave height increases with time as the wave approaches the shore.

To obtain the wave propagation results along real bathymetry profile of off-coast of Digha, West Bengal, bathymetry data is obtained from GEBCO data source. Comparative results of wave height and speed obtained with both linear and non-linear models are presented.

Keywords: Shallow Water Equation, Finite Difference Method, MATLAB, GEBCO, Coastal Water Waves.

Modified Temperature Emissivity Separation Algorithm for the retrieval of Land Surface Temperature and Emissivity using TRISHNA thermal bands

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Abstract

The simultaneous retrieval of Land Surface Temperature (LST) and Land Surface Emissivity (LSE) presents a challenging underdetermined problem due to the greater number of unknown parameters (LST and LSE) compared to the number of known Top-of-Atmosphere (TOA) observations. The Temperature Emissivity Separation (TES) method is widely used for the retrieval of LST and LSE from multiple thermal band datasets. However, the traditional TES method is less effective for spectrally flat dark targets like water and vegetation. This study proposes a modified TES method to address this drawback. The modified TES approach incorporates convergence checks after all the three TES modules: the normalized emissivity method (NEM), the ratio module, and the Maximum-Minimum Difference (MMD) module, to enhance retrieval accuracy. The Modified Temperature Emissivity Separation (M-TES) method was evaluated for TRISHNA thermal bands by comparing the retrieved LST against true LST values obtained from simulated datasets using MODerate resolution atmospheric TRANsmittance (MODTRAN) Radiative Transfer Model (RTM). The M-TES method demonstrated high accuracy, achieving a Root Mean Square Error (RMSE) of 0.37 K when compared with the true LST. Additionally, the comparison of LST errors from M-TES versus the original TES showed a significant reduction in LST error towards zero. The M-TES retrieved emissivity values compared with known emissivity values showed RMSEs of 0.0106, 0.0095, 0.0086 and 0.0103 for each band, respectively for TRISHNA thermal bands. The robustness of the M-TES method was further validated by examining LST error variations across different conditions, including View Zenith Angle (VZA), Total Column Water Vapor (TCWV), LST, and Land Cover Type (LCT). The analysis revealed consistent error margins, with RMSE remaining within 0.8 K across all sections. These results indicate that the M-TES method is robust across a wide range of conditions, maintaining reliable performance regardless of atmospheric or surface variability.

Keywords: Land Surface Temperature, Land Surface Emissivity, Temperature Emissivity Separation, Radiative Transfer Model, Atmospheric Correction, Thermal InfraRed

A long-term monthly analytical study on the relationship of LST with normalized difference spectral indices

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Abstract

This groundbreaking study delves into the long-term monthly variations of land surface temperature (LST) in Raipur City, India, spanning from 1988 to 2020, utilizing 123 Landsat images. Notably, April emerges as the hottest month with an LST of 38.49°C, while January stands as the coldest at 23.04°C, with a remarkably low standard deviation of 1.1022°C. The study unveils an intriguing pattern of LST, showcasing an initial increase followed by a steady decrease in the later stage. The mean linear regression coefficients for LST-NDVI (-0.42), LST-NDBI (0.68), LST-NDWI (0.27), and LST-NDBaI (0.32) raise compelling insights. These coefficients indicate that elevated green vegetation and water bodies act as barriers to the escalation of LST, while barren rock surfaces and built-up areas accelerate it. Moreover, the dynamic interplay between spectral indices and LST values, influenced by the evolving land surface materials, underscores the need for precise consideration of the impact of these factors. The implications of this study extend to town and country planners, equipping them with invaluable insights for making informed decisions regarding future land conversions.

Keywords: Land surface temperature (LST); normalized difference bareness index (NDBAI); normalized difference builtup index (NDBI); normalized difference vegetation index (NDVI); normalized difference water index (NDW).

Downscaling Land Surface Temperature Using Random Forest and Multi-Sensor Satellite Data: A Case Study in Diverse Terrain

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Abstract

Downscaling remote sensing-derived Land Surface Temperature (LST) datasets is crucial for various research areas, such as urban heat studies, irrigation management, and volcanic activity monitoring, among others. In this regard, this study focuses on the downscaling of LST using Landsat and Sentinel-2 data on the Google Earth Engine (GEE) platform. The primary objective was to enhance the spatial resolution of LST to 10 meters using Random Forest Regression (RFR) at two study sites, Kangra and Saharanpur, which exhibit different climatic characteristics. Independent variables such as spectral bands, vegetation indices (e.g., NDVI, NDBI, NDWI), and topographic factors (elevation, slope, aspect, and hillshade) were incorporated into the model. The downscaled LST results were validated using field data from FLIR thermal camera and flux tower measurements of longwave radiation. In the Kangra region, thermal camera-based LST showed a good correlation with downscaled LST ($R^2 = 0.73$, RMSE = 2.70°C), while flux tower-based LST exhibited an even better correlation ($R^2 = 0.86$, RMSE = 1.79°C). In Saharanpur, the downscaled LST demonstrated higher accuracy with thermal camera-based LST ($R^2 = 0.77$, RMSE = 1.98°C). These results show that satellite-derived LST aligns well with tower-based measurements, particularly at flux tower sites, and highlight the importance of accounting for both spatial and temporal variations in LST. Five window sizes were tested, with a window size of 20 providing optimal performance in both regions, resulting in the lowest RMSE values (2.72°C in Kangra and 0.62°C in Saharanpur). The study underscores the significance of incorporating multiple covariates, particularly in complex terrains like Kangra, where topography heavily influences LST distribution. The Random Forest model can outperform traditional methods like TSharp in downscaling LST, especially in heterogeneous landscapes. These findings demonstrate that remote sensing-based LST downscaling using RFR and multi-sensor data provides a reliable tool for enhancing LST resolution, facilitating environmental monitoring, urban heat management, and irrigation planning.

Keywords: Land Surface Temperature, Sentinel-2, Landsat-8, Random forest regressor, FLIR Thermal Camera.

Comparison of Split Window Algorithms for Land Surface Temperature Retrieval over India using ECOSTRESS TIR data

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Abstract

The retrieval of Land Surface Temperature (LST) from very high spatial resolution sensors is very crucial for the study of global warming, vegetation dynamics, and surface morphology. LST retrieval methods are categorized mainly into two approaches: one that utilizes a known Land Surface Emissivity (LSE) and another that addresses the complex problem of simultaneous retrieval of both LST and LSE. For known LSE, several methods have been developed for LST retrieval, among which the Split Window Algorithm (SWA) is widely recognized. Numerous SWAs have been proposed over the past four decades. In this study, 217,836 at-sensor signal simulations were carried out using the MODerate resolution atmospheric TRANsmittance (MODTRAN) Radiative Transfer Model (RTM) under various environmental conditions, surface types, and sensor geometries for the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) TIR bands. These simulations were used to generate the regression coefficients for ten different SWAs, which were compared over India using ECOSTRESS TIR data. Eight water vapor-independent and two water vapor-dependent algorithms were used, with a focus on their computational efficiency and accuracy. It has been observed that, for the simulated dataset, different SWAs exhibit varying performance. The algorithms proposed by Sobrino et al. (1996) and Sobrino et al. (1993) have shown the best performance, achieving RMSE values 0.88 K and 0.97K respectively over the simulated dataset. These ten different SWAs were applied to

ECOSTRESS TIR bands and compared its efficacy with ECOSTRESS LST product

(L2_LSTE). The algorithm by Sobrino et al. (1993) has performed particularly well, with an overall RMSE of 1.4 K with the ECOSTRESS LST product. This study concludes that the Sobrino et al. (1993) algorithm is the most effective alternative for LST retrieval from ECOSTRESS data with known LSE, highlighting the importance of adapting LST retrieval algorithms with less computational requirement.

(**Keywords:** Land surface temperature, split window algorithm, ECOSTRESS)

Level 1A radiometric processing of TRISHNA TIR data

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Abstract

TRISHNA is an Indian-French high spatio-temporal resolution satellite with VNIR, SWIR and TIR capacities. The thermal infrared instrument allows measuring the Earth radiation in four spectral bands between 8µm and 12µm, along a ~1000km swath, with a 57m resolution at nadir. These performances will be obtained thanks to a 600-detector array and a scan mirror to scan the Earth across track, acquiring approximately 16000 pixels in a row, every 5 seconds. Each 16000-pixel Earth acquisition is completed by acquisitions of the on-board calibration device, namely one blackbody (BB) acquisition and two deep space (DS) acquisitions.

The TRISHNA ground segment receives raw measurement data. The goal of the L1A TIR radiometric processing is to convert the digital count Earth image to an instrument-corrected Top-of-Atmosphere brightness temperature Earth image for each TIR spectral band. This processing uses the digital count BB and DS acquisitions, as well as the BB temperature (continuously monitored and measured on-board), information on the Moon position wrt. the DS port center (to check the validity of the DS acquisition) and data coming from pre-launch ground characterization of the instrument.

After a brief presentation of the TIR instrument, the presentation will give an overview of the L1A TIR processing developed for TRISHNA, which mainly consists in the absolute calibration of the instrument using on-board calibration device. Simulation results showing the L1A TIR processing performances will be presented.

Keywords: TRISHNA, blackbody, deep space, absolute calibration, level 1

TIRCalNet: a network for the Top-of-Atmosphere calibration of thermal sensors

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Abstract

To prepare for future TIR missions, such as TRISHNA, LSTM and SBG from CNES-ISRO, ESA and NASA-ASI, the CEOS aims at defining a network of TIR instrumented sites to perform calibration at Top-of-Atmosphere (TOA) level, TIRCalNet. Similarly to the existing network in the VNIR-SWIR domain RadCalNet, TIRCalNet would gather ground-instrumented sites that provide information for TOA calibration in the thermal domain, ensuring intercomparability and harmonization of satellite instrument measures. Such a network does not exist today, although there are some instrumented sites already used for Bottom-of-Atmosphere products validation such as Land and Sea Surface Temperature.

The precision goal for TIRCalNet sites on brightness temperature at TOA level is 0.5K, which is very challenging. TOA signal depends on various parameters coming for the most part from the surface nature, mainly its emissivity and temperature, and atmospheric parameters. These parameters vary over time and are difficult to measure directly and continuously. Moreover, each measurement or estimation comes with an uncertainty, leading to a global uncertainty on TOA brightness temperature.

In this context, CNES has implemented a model to estimate the TOA uncertainty from different assumptions on uncertainty sources and their characteristics with a Monte Carlo approach. This approach, based on the modelling of an instrumented site, allows estimating the impact of each considered uncertainty source. Results on different instrumented sites are given for wet and dry atmospheric conditions.

Keywords: CEOS, calibration, instrumented sites, uncertainty budget

Spatio-Temporal Stability and Calibration Potential of Lanela, Rajasthan: Suitability for TRISHNA Mission and Permanent Instrumentation

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Abstract

Vicarious calibration using Pseudo Invariant Calibration Site (PICS) is a vital technique for ensuring the radiometric accuracy of satellite sensors, especially when onboard calibration mechanisms are unavailable. PICS have become the international standard due to their stable environmental characteristics and minimal variability, making them ideal for ongoing calibration efforts (CEOS, 2019). An Indian site, Lanela has been identified as a key location for the vicarious calibration of Indian remote sensing sensors operating in VNIR and SWIR region with spatial resolution better than 300m. Lanela is also proposed for upcoming TRISHNA VSWIR mission, targeting both campaign-based calibration and for permanent instrumentation.

This study involves an in-depth characterization of Lanela site by analyzing crucial factors like spatial uniformity, temporal consistency, and environmental conditions, including aerosol load, columnar water vapor, ozone, cloud cover, and rainfall. A decade of Landsat-8 Operational Land Imager (OLI) data were used to perform a comprehensive Spatio-temporal analysis and MODIS data to study atmospheric parameters, to assess the site's long-term stability and suitability as a calibration reference.

Located 16 km away from Jaisalmer in Rajasthan, India, the Lanela site features deep Aeolian sandy soils with sparse or null vegetation. The surface reflectance ranges from 0.2 to 0.5 in VNIR and SWIR region matching the reflectance spectra of CEOS-approved sites and remains spectrally flat across the optical spectral range. Additionally, the site demonstrates temporal variability of less than 3%, meeting international standards and a radiometric spatial homogeneity better than 5%. Furthermore, its remote location, far from industrial facilities and human intervention, reduce the impact of anthropogenic aerosols. The arid climate, with annual rainfall of just 16 cm (Rakhecha, 2019), provides a high probability of cloud-free days, increasing opportunities for calibration.

Consequently, the Lanela site not only meets the stringent CEOS criteria for PICS but also represents a promising candidate for the permanent instrumentation and vicarious calibration of the TRISHNA VSWIR mission. This detailed assessment highlights Lanela' s potential to enhance the accuracy of remote sensing measurements, providing valuable insights for the optimal deployment of calibration resources and ensuring high-quality data for scientific and operational applications.

Keywords: PICS, Lanela, Calibration

Vicarious Calibration Monitoring of TRISHNA-TIR sensor

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Abstract

The TRISHNA (Thermal Infrared Imaging Satellite for High-Resolution Natural Resource Assessment) Thermal InfraRed (TIR) sensor provides high-resolution thermal data, supporting a broad range of applications, including agricultural productivity assessment, urban environment monitoring and water stress detection. Periodic monitoring of the calibration status of the Level-1C (L1C) TIR sensor data is crucial to ensure the accuracy of the higher-level data products generated using this data.

This paper presents a methodology to monitor the calibration stability of L1C Thermal Infrared (TIR) sensor data using in-situ ground temperature and atmospheric parameters measurements during satellite overpass. We report the results from three experimental campaigns conducted at the National Remote Sensing Centre (NRSC) calibration site over a red soil target (125 m x 105 m) during the overpass of the Landsat 8/9 Thermal Infrared Sensor (TIRS). High-precision ground temperature data was obtained using a Testo Pt-100 surface contact probe, while atmospheric parameters such as columnar aerosol optical depth (AOD) and water vapor were measured using a MicroTOPS instrument. These measurements were then used to simulate at-sensor radiance through the MODerate resolution atmospheric TRANsmission (MODTRAN-5) radiative transfer code, incorporating emissivity values retrieved from Landsat Level-2 products. The satellite-derived brightness temperatures were subsequently compared with the simulated results. Results of the experiments showed a bias of up to 1 K.

Improved accuracy could be achieved by incorporating a multichannel thermal radiometer for insitu ground measurements, enabling real-time emissivity estimation during the satellite overpass.

Keywords: TRISHNA-TIR, Calibration, Surface Temperature, RT Simulation

Quantifying Ultracold Brightness Temperatures with High Spatial Resolution Thermal Infrared Imaging

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Abstract

The MODIS data record has demonstrated that land surface temperatures on the Antarctic Plateau regularly dip below -90° C (183 K) and VIIRS cloud top brightness temperatures associated with severe convective weather events have been recorded down to -111.2° C (161.96 K). One might anticipate that the TRISHNA, SBG-TIR, and LSTM sensors will observe even colder temperatures given their 50-60-meter class spatial resolutions and high sensitivities. However, validating such ultracold temperatures presents challenges for sensor systems that have been optimized to quantify brightness temperatures in the 5-35° C (278 – 308 K) range. To overcome these challenges, we propose adopting Dome C (75.12 S, 123.395 E, 3233 masl, annual daily mean air temperature of -54.5° C) as a cross-mission vicarious calibration site. Dome C is homogeneous target atop the Antarctic ice sheet with exceptionally low aerosol and atmospheric water vapor, low cloud cover, and its location near the South Pole offers frequent satellite overpass opportunities. An automated weather station (AWS) and AERONET sensors provide continuous atmospheric state characterization while Concordia Research Station provides infrastructure and logistical support for potential field experiments. We discuss the benefits of integrating Dome C into the TRISHNA – SBG-TIR – LSTM harmonization strategy and how it complements other sites in the calibration network.

Keywords: ultracold, brightness temperature, calibration, snow and ice

New Instrumented Site for Future Thermal Infrared Missions Calibration and Validation

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Abstract

Since the 1990's, CNES has developed a strong experience in automated instrumented sites for the calibration of multispectral satellites in a range of wavelengths from 400 to 2500 nm. With the growth of future thermal infrared missions such as Trishna (CNES/ISRO), SBG (NASA) or LSTM (ESA), CNES has the willingness to extend its instrumented sites to the thermal infrared in order to prepare for the in-orbit CAL/VAL of these coming instruments. For this purpose, it has been decided to deploy a new 9 m mast in the La Crau site, which is already a member of RADCALNET, to install and analyze data from several thermal infrared instruments.

The NASA JPL designed an automated robust broadband thermal radiometer which acquires day and night measurements in four different zenithal angles and with an internal active blackbody. This instrument has been deployed by JPL for years on various sites, such as Lake Tahoe, Salton Sea and Russell Ranch. The principle is to adjust the blackbody temperature to match the target and the blackbody measurements made by the instrument. Therefore, this radiometer provides surface brightness temperature in one spectral band. CIMEL, a French company, markets the CE 312, which acquires measurements in five narrow spectral bands and one broad band. Emissivity and temperature of the surface can then be retrieved simultaneously by applying a temperature and emissivity separation algorithm on the data. CNES worked with CIMEL to make this system robust and autonomous for acquire measurements on the long term. Finally, three KT15, from Heitronics company, were deployed with spectral bands similar to those in Trishna instrument. These instruments will allow calibrating Level-1 and validating Level-2 products.

The main characteristics and measurement protocols, and the status of their installation in the La Crau site will be described as well as the processing applied on the measurements. The first results will be discussed and analyzed regarding the final in-orbit calibration objective.

Keywords: Instrumented site, CAL/VAL, Thermal infrared, La Crau

Calibration and Validation Activities towards a Global 2K Precision LST Product with the HiVE Constellation

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Abstract

At constellr, we aim to support globally scalable, high-precision smart farming services by delivering Level 2 georeferenced Land Surface Temperature (LST) data with thermal precision better than 2K. This precision is achieved through careful hardware design and innovative processing techniques.
Each microsatellite in constellr's HiVE constellation is equipped with a multispectral thermal infrared (TIR) cryocooled sensor, ensuring stable data quality and multiple band options for algorithm optimization. To address the lack of an onboard blackbody, a cross-calibration method has been developed using existing geostationary LST products, reducing errors to within 0.4%. This method is applicable to any TIR band independent of the wavelength.
In addition to the TIR sensor, each satellite is equipped with a multispectral visible and near-infrared (VNIR) sensor, with a band set similar to Sentinel-2. This VNIR sensor enhances precise geolocation, improves atmospheric correction, aids in cloud detection, and supports emissivity estimation.
For both cameras extensive ground validation activities have been performed to evaluate spatial, spectral and radiometric characteristics of the payloads.
The proposed presentation will deliver a broad insight into:

- satellite and camera designs
- performed ground calibration activities
- planned in orbit commissioning and calibration activities and procedures
- constellrs ETA+ based Surface Temperature calculation algorithm

and finally, will show the product baseline constellr will deliver to its customers.
For atmospheric correction, we leverage the highly accurate atmospheric profile data from Copernicus ERA5 and CAMS, as well as real-time Modtran (MODerate resolution atmospheric TRANsmission) simulations within the processing pipeline.
To derive the final LST product, we employ an enhanced Equivalent Temperature Approach (ETA+). This method integrates calibrated multispectral TIR radiance data and surface vegetation ratio information from the VNIR sensor, producing an optimized LST product while ensuring reliable emissivity output. This approach allows flexibility in applying the LST derivation method across instruments with various LWIR band configurations. We have successfully applied this approach to data from Landsat and ECOSTRESS. For Landsat, our method not only produced statistically comparable results to the USGS LST product but also delivered better contrast and contextual imagery.

Keywords: HiVE, Thermal Remote Sensing, Calibration and Validation

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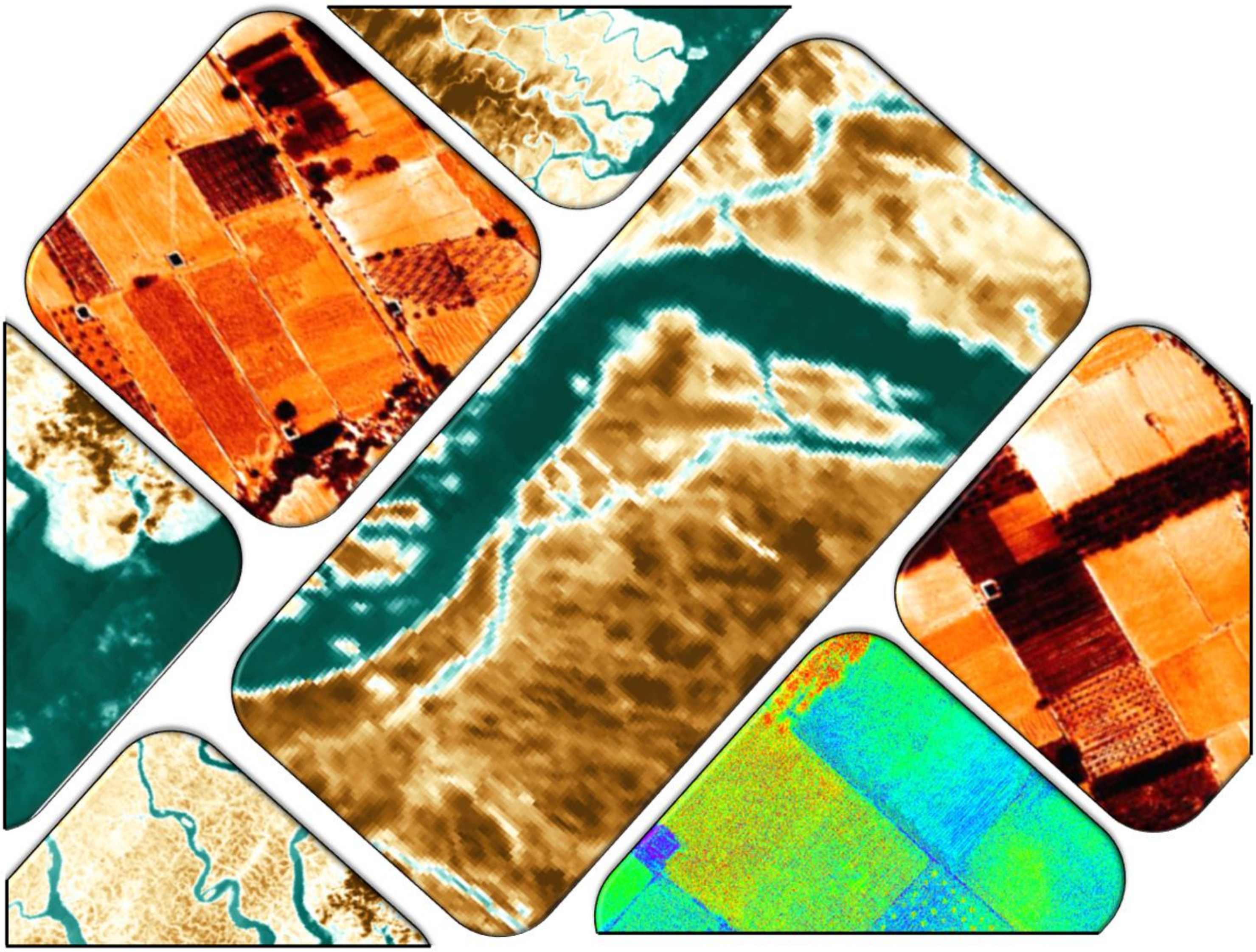

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