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HAL Id: hal-02420462
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Submitted on 6 Jan 2020

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Indo-French High-resolution Thermal Infrared Space Mission for Earth Natural Resources Assessment and Monitoring - Concept and Definition of TRISHNA


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KEY WORDS: TIR remote sensing, surface energy balance, TRISHNA mission, global monitoring

ABSTRACT:
The Indian and French Space Agencies, ISRO and CNES, have conceptualized a space-borne Thermal Infrared Reflectance (TIR) mission, TRISHNA (Thermal infrared Imaging Satellite for High-resolution Natural Resource Assessment). The primary design drivers of TRISHNA are the monitoring of (i) terrestrial water stress and use, and of (ii) coastal and continental water. A suite of four TIR bands and six optical bands is planned. The TIR bands will be centred at 8.6μm, 9.1μm, 10.3μm and 11.5μm to provide noon-night global observations at 57m nadir resolution over land and coastal regions. The field of view (FOV) is 34° and the orbit of 761 km altitude was designed to allow 3 sub-cycle acquisitions during the 8-day cycle. The optical bands correspond to blue, green, red, and NIR plus two SWIR bands at 1.38μm and 1.61μm. The green, red, NIR and the 1.61μm SWIR bands will have better radiometry quality than those of AWiFS. ISRO and CNES will develop optical and TIR payloads, respectively. Assessing evapotranspiration and furthermore Gross and Net Primary Productivity (GPP and NPP) will in turn assist in quantifying water use in rainfed and irrigated agriculture, water stress and water use efficiency, with expected applications to agricultural drought and early warning, crop yield prediction, water allocation, implementation of water rights, crop insurance business and agro-advisories to farmers. The other scientific objectives of TRISHNA are also briefly described. TRISHNA instrument will fly aboard a ISRO spacecraft scheduled to be launched from 2024 for a minimum period of 5 years’ mission lifetime.

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This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLII-3-W6-403-2019 | © Authors 2019. CC BY 4.0 License.
1. INTRODUCTION

Surface temperature and its day-night contrast over land is the fundamental variable to characterize evapotranspiration from vegetation, lake evaporation, snow melt, urban heat islands and presence of fresh water in turbid coastal fringes, among others. Accurate quantification of surface emissivity helps in improving the accuracy of retrieving land surface temperature (LST) from thermal remote sensing signatures. Satellite thermal remote sensing has been recognized as the only viable means to generate consistent and systematic records of surface temperature at various space-time scales. Landsat-8 having split thermal infrared (TIR) bands and ASTER with multiple thermal bands within 8 – 12 μm provide thermal remote sensing observations at a high spatial resolution varying from 90 – 100 m with satellite overpass time around 10:30 to 11:30 hrs, but with 16-day revisit only. Earlier studies over India, France and elsewhere suggested that evapotranspiration is better estimated using noon-time observations or its derived products in the form of vegetation indices or Leaf Area Index (LAI) / FAPAR (Fraction Absorbed Photosynthetically Active Radiation) retrieved from Canopy Radiative Transfer (CRT) model. Time series data of high resolution multispectral optical remote sensing has been proved to be ideal for crop discrimination especially in those regions or crop growing seasons less covered by cloud presence and persistence. However, it carries less information manifested from physical or physiological growth processes such as transpiration, soil evaporation, photosynthesis and respiration. Surface temperature acts as fundamental coupler between surface energy balance and plant growth processes. Magnitude of surface temperature acts as fundamental coupler between surface energy balance and plant growth processes. Magnitude of temperature acts as fundamental coupler between surface energy balance and plant growth processes. Magnitude of temperature acts as fundamental coupler between surface energy balance and plant growth processes. Generally Single-Source and Dual-Source Surface energy balance modelling approaches are used to estimate ET using thermal IR sensing data. Over the recent years, various ET models have been developed that used remote sensing and ancillary surface and ground-based observations. Till date, several energy balance algorithms are available for calculating ET through remote sensing such as SEBAL (Bastiaansen et.al.1998) and SEBS (Su, 2002). They are single-source model which considers soil and plant as single source. In addition to this, there is dual-source or two-source (soil and vegetation canopy) model, e.g. TSEB (Norman & Becker 1995), SEBI (Menenti and Choudhury 1993) and ALEXI (Anderson et al. 1997). Both parametric and non-parametric modelling structures are being used within the energy balance framework to estimate ET. In the Indian sub-tropics, a set of studies related to ET monitoring from satellite-based thermal remote sensing have been reported primarily using parametric modelling structures during 2007 to 2010. There are set of studies (e.g. Mallick et al., 2009, Bhattacharya et al., 2010, Eswar et al., 2017a, 2017b) that demonstrated the potential of satellite-based thermal infrared and optical remote sensing datasets for the estimation of ET at regional scales, to estimate consumptive water use and crop yield prediction (Mallick et al., 2009). Similarly, in France, Evapotranspiration Assessment from Space (EVAPSPA) (Gallego-Elvira et al. 2013) and Soil Plant Atmosphere and Remote Sensing Evapotranspiration (SPARSE) (Boulet et al. 2015) models have been developed and are being evaluated for large-scale ET estimation and for agricultural applications. The EVAPSPA platform brings several algorithms all together to provide an ensemble simulation with the uncertainty on final ET products (Gallego-Elvira et al, 2013). Large number of global ET products have been derived in recent years, including remote sensing-based products using multiple approaches. However, these products are available at coarse spatial resolution (such as 0.25° × 0.25°) or lower temporal resolution (monthly). The only ET product that is currently available at high spatial (500 m) and reasonable temporal (8 days) resolution is the MODIS 16 ET product (Mu et al., 2011). However, McCabe et al. (2016) mentioned that the reduced performance of the MODIS ET product may be due to the underlying structural and parameterization issues in model formulation, which

2. RELEVANCE TO GLOBAL AGRICULTURAL MONITORING

The use of satellite-based earth observation data for global-scale agricultural monitoring is limited primarily to optical remote sensing observations or its derived products in the form of vegetation indices or Leaf Area Index (LAI) / FAPAR (Fraction Absorbed Photosynthetically Active Radiation) retrieved from Canopy Radiative Transfer (CRT) model. Time series data of high resolution multispectral optical remote sensing has been proved to be ideal for crop discrimination especially in those regions or crop growing seasons less covered by cloud presence and persistence. However, it carries less information manifested from physical or physiological growth processes such as transpiration, soil evaporation, photosynthesis and respiration. Surface temperature acts as fundamental coupler between surface energy balance and plant growth processes. Magnitude of vertical gradients resulted from differences among surface radiometric temperature, aerodynamic temperature, air temperature in soil-canopy cover complex get modulated based on water supply to soil and root system ultimately influence crop-water relations and simultaneous uptake of water and nutrients. Therefore, High-resolution high-repeat thermal remote sensing observations will serve as key data sources for implementing policy implementation related to water rights and water allocation in agriculture, deriving digital global agricultural water footprint in terms of green and blue water use for virtual water trading, early warning for agricultural drought at three stages (early, middle and terminal) as well as crop yield prediction at finer scale to settle yield dispute resolution for crop insurers. Through different countries have been using thermal infrared remote sensing observations from geostationary platform primarily for agricultural drought assessment these did not have global coverage and could not provide thermal IR observations at a scale better than 100m. Therefore, a global high-resolution high-repeat thermal IR mission is ideal for improved crop assessment and water management.

3. RESEARCH OVERVIEW OF THERMAL REMOTE SENSING FOR AGRICULTURE

Generally Single-Source and Dual-Source Surface energy balance modelling approaches are used to estimate ET using thermal IR sensing data. Over the recent years, various ET models have been developed that used remote sensing and ancillary surface and ground-based observations. Till date, several energy balance algorithms are available for calculating ET through remote sensing such as SEBAL (Bastiaansen et.al.1998) and SEBS (Su, 2002). They are single-source model which considers soil and plant as single source. In addition to this, there is dual-source or two-source (soil and vegetation canopy) model, e.g. TSEB (Norman & Becker 1995), SEBI (Menenti and Choudhury 1993) and ALEXI (Anderson et al. 1997). Both parametric and non-parametric modelling structures are being used within the energy balance framework to estimate ET. In the Indian sub-tropics, a set of studies related to ET monitoring from satellite-based thermal remote sensing have been reported primarily using parametric modelling structures during 2007 to 2010. There are set of studies (e.g. Mallick et al., 2009, Bhattacharya et al., 2010, Eswar et al., 2017a, 2017b) that demonstrated the potential of satellite-based thermal infrared and optical remote sensing datasets for the estimation of ET at regional scales, to estimate consumptive water use and crop yield prediction (Mallick et al., 2009). Similarly, in France, Evapotranspiration Assessment from Space (EVAPSPA) (Gallego-Elvira et al. 2013) and Soil Plant Atmosphere and Remote Sensing Evapotranspiration (SPARSE) (Boulet et al. 2015) models have been developed and are being evaluated for large-scale ET estimation and for agricultural applications. The EVAPSPA platform brings several algorithms all together to provide an ensemble simulation with the uncertainty on final ET products (Gallego-Elvira et al, 2013). Large number of global ET products have been derived in recent years, including remote sensing-based products using multiple approaches. However, these products are available at coarse spatial resolution (such as 0.25° × 0.25°) or lower temporal resolution (monthly).
It is decided that ISRO will develop VNIR-SWIR payloads as follows:

- **Spectral bands**
  - VNIR: 0.485, 0.555, 0.650 and 0.860 μm
  - SWIR: 1.650 μm and 1.38 μm.
- Possible degradation of the spatial resolution for blue (0.485 μm) and cirrus (1.38 μm) bands.

It is decided that ISRO will develop VNIR-SWIR payloads and CNES will develop TIR payload. TRISHNA will be launched by ISRO spacecraft.

### 5.JUSTIFICATION FOR TRISHNA SPECIFICATIONS

The highest possible revisit period would be desirable in order (i) to cope with the limitations of data availability due to clouds and (ii) to minimize the impact of uncertainty in LST due to atmospheric turbulence on the accuracy of final ET and water budget products. However, the requirement of global coverage severely constrains the swath angle for a single satellite mission. It results that only a 3-day-revisit can be achieved with a reasonable scan angle lower than 35°. An analysis of the size of fields in a typical agricultural landscape in the South West of France led us to recommend a resolution close to 50 m, corresponding to about a hundred meters at the swath edges. In many places of India, the very fragmented landscape makes 50 m at least mandatory (Eswar et al, 2016). However, at lower resolution, the atmospheric turbulence may induce a too significant uncertainty on LST. Technical constraints are also to be considered. In particular, the size of existing/under development detectors is still a technical limitation against the swath. The final trade-off is a 57 m spatial resolution at nadir.

Four reasons led us to recommend a 1 pm overpass time. (1) According to models, it provides the best accuracy on ET retrievals (Delogu et al, 2012), (2) The lower sensitivity of time (dT/LST)dt close to 0 °C/hour at that moment facilitates the combination with surface or meteorological models which have time steps of around half-an-hour. For comparison, around 10:00 (solar time), the variation of LST is about 4 °C/hour. (3) The corresponding night overpass around 1 am is best adapted to measurements over water bodies because late enough to remove possible thermal inertia effects. (4) For mid latitudes, the directional anisotropy error on LST is reduced because the hot spot is situated in a plane perpendicular to the scan line (Duffour et al, 2016).

A detailed analysis of the 3-day orbit at 666 km selected for THIRSTY (Lagouarde et al, 2013) revealed it was not suited for the inter-tropical zone in which data may be affected by hot-spot during several months per year (Duffour et al, 2016). As no robust model close to the hot-spot peak is available today to correct LST data, an alternative orbit with a 8-day revisit (761 km) was retained. Its 3/2/3 sub-cycles could provide at least 2 hot-spot free data out of 3 in the inter-tropical zone.

In the TIR, two bands centered on 10.3 μm and 11.5 μm have been selected to apply the split-window method. Two bands centered at 8.6 and 9.1 μm are added to perform the temperature - emissivity separation using the TES method (Jacob et al, 2017). The exact shape of TIR spectral filters is currently being studied using an end-to-end simulator. Moreover, a study has been conducted to demonstrate that it is mandatory to embark both TIR and VNIR/SWIR instruments on the same platform. In the VNIR domain, the vegetation bands at 0.650 and 0.860 μm are mandatory. A blue band (0.485 μm) with a cirrus band (1.38 μm) both acquired at lower resolution (100-200 m) are required for cloud discrimination. A green band (0.555 μm) is devoted to coastal applications and snow discrimination. Finally, a 1.650
μm SWIR band is added to address aerosol characterization and albedo estimation particularly.

The blue and 1.38μm SWIR bands will be used for cloud detection. Aerosol characterized from blue and 1.61 SWIR bands, atmospheric water vapour extractable from split-window TIR bands (at 10.3 and 11.5μm) and the atmospheric ozone content from 9.1μm TIR band will help to determine accurate surface reflectance. Green, red, NIR and SWIR bands will be used to retrieve surface albedo, vegetation index/vegetation fraction, LAI/FAPAR, water Chlorophyll and water turbidity products. Accurate LST and surface emissivity will be retrieved from the four TIR bands. All these products will be used in surface energy balance and productivity models to estimate global-scale evapotranspiration and vegetation primary productivity.

6. CONCLUSIONS

TRISHNA is currently in ‘A’ phase (feasibility assessment) till end 2019. It will be followed by a one-year B phase. The launch could be foreseen from 2024. The mission will have minimum life-span of 5 years. TRISHNA remains very original in the international context of the high spatio-temporal TIR and to fulfil the need of improved global agricultural monitoring.

7. ACKNOWLEDGEMENTS

The authors are thankful to Director, Space Applications Centre and Chairman, Indian Space Research Organization for encouraging to define this science mission. This work is supported by the ‘Centre National d’Etudes Spatiales’ (CNES) through the TOSCA group (Terre, Océan, Surfaces Continentals, Atmosphere).

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