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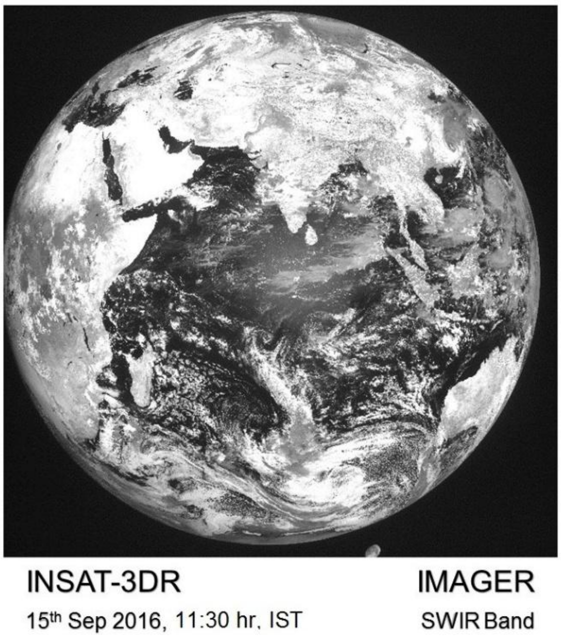
Day-1 INSAT-3DR vicarious calibration for VIS and SWIR channels over Great Rann of Kutch



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9. Abstract	This document describes the day-1 (15th Sep. 2016) vicarious calibration of VIS and SWIR channels of INSAT-3DR imager carried out over Great Rann of Kutch. Top of the atmosphere radiances were simulated using 6SV radiative transfer code and matches well with the INSAT-3DR observed radiances.
10. Key Words	Vicarious Calibration, INSAT-3DR, VIS, SWIR, Radiance, Reflectance.
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Abstract

This study is carried out as the post launch calibration for visible (VIS) and shortwave infrared (SWIR) channels of weather satellite INSAT-3DR which was successfully launched on 8th September, 2016 by GSLV-F05, India's Geosynchronous Satellite Launch Vehicle equipped with the indigenous Cryogenic Upper Stage (CUS) from SDSC-SHAR into a Geosynchronous Transfer Orbit (GTO). The vicarious post launch calibration was performed over a uniform desert site of Great Rann of Kutch in Gujarat on 15th September, 2016 when for the first time INSAT-3DR visible and SWIR Imager camera was switched-on. This calibration activity was performed to monitor sensor/imager performance in space after its launch. A classical approach of surface reflectance and atmospheric variables (columnar water vapor, columnar ozone content and aerosol optical depth) measurements have been adopted during the synchronous scan (1130hrs) of INSAT-3DR. Top-of-the-atmosphere (TOA) radiance of solar reflected surface energy has been modelled using 6S vector version (6SV) of atmospheric radiative transfer model with desert aerosol model. Preliminary results show that VIS and SWIR channel of INSAT-3DR has gain coefficients of 0.974 and 0.820 respectively. The gain coefficient for SWIR channel is relatively higher due to the inhomogeneity of the ground target caused by sufficient sub-surface soil moisture.

Introduction

The advancement and popularity of satellite remote sensing data usage for societal benefits not only requires the development of new and complex satellites but also to improve the quality of satellite sensor and data products. Therefore, it has become even more essential to continually upgrade the ability to provide calibration of sensors. In general, calibration procedure includes on-board calibration (Bruegge et al., 1993) and radiometric calibration (Bruegge et al., 1998) prior to launch. In that case, a post-launch calibration is needed to compensate the degradation of the satellite sensor (Rao, 2001), known as vicarious calibration. Vicarious calibration provides a method for absolute calibration of satellite sensors using reference and precise measurements of spectral reflectance from the ground instruments over a target. This absolute calibration produces the calibration coefficients that can be incorporated for the accurate characterisation of the conversion of digital counts to radiance values.

Vicarious calibration is a broadly adopted technique for continuous monitoring of radiometric performance of satellite sensor, which involves the uncertainties computation in the calibration coefficients to correct the radiometric response of the sensor (Thome et al., 1998). Vicarious calibration is performed with radiance simulation using ground measured reflectance and atmospheric parameters in the homogenous conditions to those at the satellite level.

INSAT-3DR is an advanced weather satellite of India configured with improved imaging system and atmospheric sounder as compare to earlier Indian National Satellite System (INSAT) missions like INSAT-3D, INSAT-3A and KALPANA-1. Vicarious calibration is performed to monitor the in-orbit performance of VIS and SWIR channels of INSAT-3DR imager on day-1, i.e. when for the first time INSAT-3DR visible and SWIR camera was switched-on. The reflectance-based approach is used with in-situ measurements of surface reflectance and atmospheric parameters for the vicarious calibration. The 6SV radiative transfer (RT) code is used to estimate the TOA spectral radiance using ground measured parameters along with pre-launch laboratory measured spectral response function (SRF). The 6SV simulated TOA spectral radiances were compared with the INSAT-3DR measured TOA spectral radiance to estimate the calibration coefficients for each channel.

INSAT-3DR Specifications

The Indian National Satellite System (INSAT-3DR) is the multipurpose satellite provides meteorological, television broadcasting, telecommunication and search and rescue services. INSAT-3DR is the advanced meteorological satellite, aiming for a significant technological improvement in sensor capabilities as compared to earlier INSAT satellites. The advance technical characteristics of the instrument are offering higher performance both in terms of spatial and vertical resolution. INSAT-3DR satellite was launched successfully on 8th September 2016 using a GSLV MK-II launch vehicle from SDSC-SHAR-ISRO. It is equipped with a 6-channels Imager and a 19-channels atmospheric sounder, which operate in visible to thermal infrared region of the electromagnetic spectrum.

INSAT-3DR imager operates from a geostationary altitude of 36000 km in Visible (VIS) and Short Wave Infra-Red (SWIR) bands with 1 km spatial resolution, while Mid-Wave Infra-Red (MWIR), Thermal Infra-Red 1 (TIR1), Thermal Infra-Red-2 (TIR2) and Water Vapor (WV) bands with 4 km spatial resolutions. INSAT-3DR sounder has 18 Infrared (IR) channels ranging from 3.7 to 14.7 µm and one visible channel for the cloud detection during daytime with a 10-km spatial resolution.

Data and Methodology

The Committee on Earth Observation Satellites (CEOS) Working group on Calibration and Validation identified several sites around the world (Teillet and Chandra, 2010) based on the selection criteria, such as low probability of atmospheric variability, high spatial homogeneity, weak directional effects, flat reflectivity spectrum. Calibration sites are never chosen randomly, and to be adequate they must satisfy a certain number of criteria (Scott et al. 1996; Slater et al. 1996; Slater et al. 1987; Teillet et al. 1997). Based on these criteria, we have selected a desert site in Great Rann of Kutch (GROK) (23.67ºN and 69.66º E and *~4 meter above mean* sea level), Gujarat. This calibration site is extended upto ~10 km square area, presenting a flat and homogenous terrain characterized by a low surface reflectance with high soil moisture content due to excessive water logging during the monsoon season. Figure-1 indicates the observational site in Great Rann of Kutch for the vicarious calibration of INSAT-3DR.

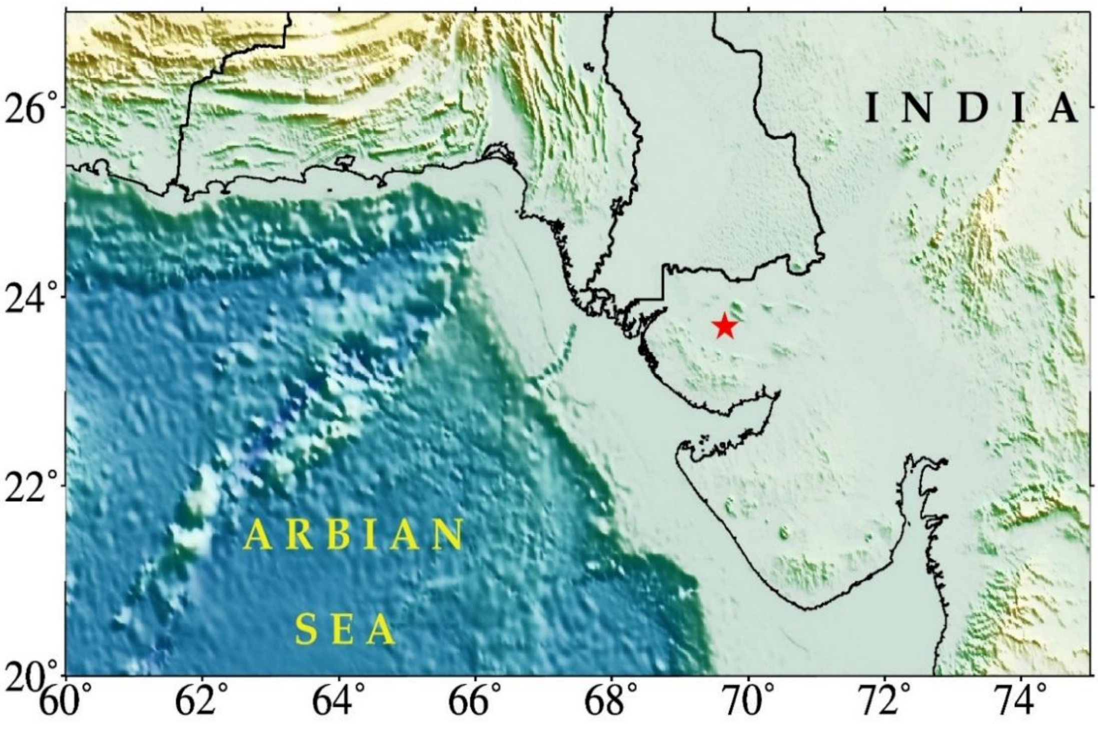

Figure 1: observational site as indicated by solid red-star

Measurements of ground reflectance were carried out with a spectroradiometer (FieldSpec 3, Analytical Spectral Devices (ASD), Inc.), which covered the spectral range from 350 to 2500 nm and were made at random sampling points covering over a region of 4 km^2. In a continuous manner ground-reflectances were measured centred over 11:30hrs for a period of 1 hour (Fig-2). The atmospheric variables were measured from 10:00 to 12:00 hrs with an interval of 15 minutes using hand-held Microtops-II sunphotometer and ozonometer.

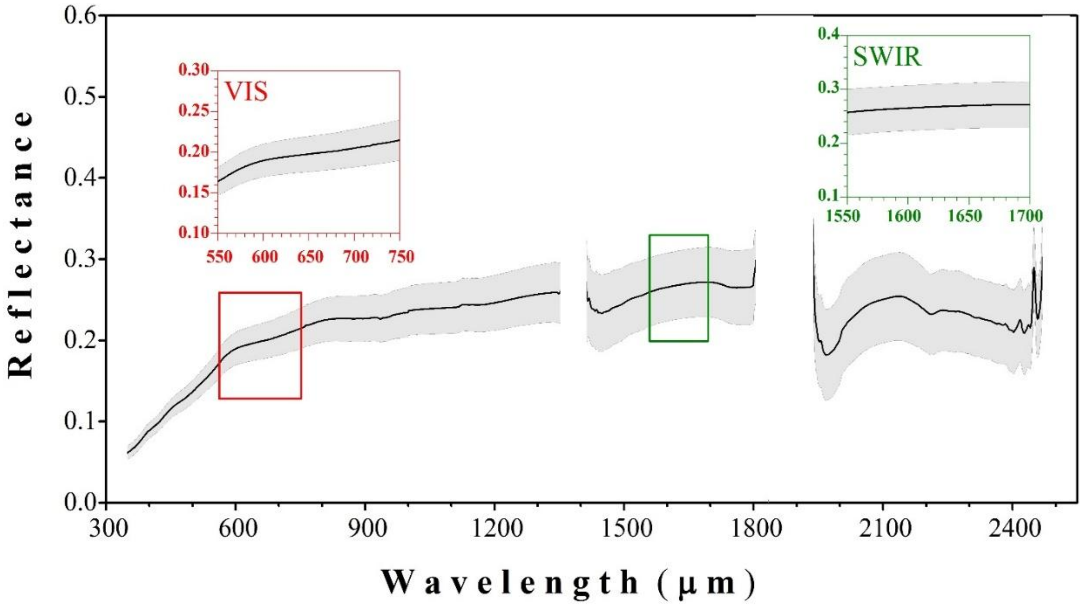

Figure 2: Measured surface spectral reflectance on 15th Sep. 2016 over observational site. Solid black line indicates the mean value and grey shaded portion indicates the spectral standard deviation among all the measurements. The small red and green boxes refer to the reflectance spectra for the corresponding INSAT-3DR wavebands.

Table 1: Mean values of measured atmospheric parameters, i.e. AOD at 500 nm, total columnar ozone and columnar water vapor over Great Rann of Kutch.

Date	AOD @ 500 nm	Total Columnar ozone (DU)	Water Vapor (g cm-2)
15th Sep 2016	0.385	302	2.30

Reflectance-based technique is used in this study, because it is difficult to maintain the radiometric accuracy of the spectral radiometer that measures the surface radiance in the radiance-based technique (Slater et al. 1987). The reflectance-based technique mainly depends on measured ground surface reflectance. The reflectance is characterized by the ratio of measurement of the site to those of a standard reflectance/Spectralon panel for which the bidirectional reflectance factor is precisely determined. The vicarious radiometric calibration depends on the surface reflectance and radiance from the sun to earth's surface and earth's surface to sensor and atmospheric optical thickness over the calibration site at the time of satellite pass. The ground measurements are used as an input for radiative transfer (RT) code for the simulation of absolute radiances in the required bands at the sensor level. The ground measurements are used to define the spectral directional reflectance of the surface and the spectral optical depth that are used to describe the aerosol and molecular scattering effect in the atmosphere (Gellman et al. 1991) along with this we used columnar water vapor to include the water vapor absorption effect. The detailed values of atmospheric parameters are given in Table-1. We have used improved 6SV RT code (Vermote et al. 2006, Kotchenova et al. 2008) to compute the radiance field using ground measurements. 6SV RT code predicts the satellite signal at TOA level using ground reflectance measurements and atmospheric measurements of sunphotometer. 6SV RT model is a physically based model, which is not specified for particular satellite or test sites. Because of that 6SV RT model is used for this study. In addition, 6SV RT model is covered gaseous absorption and scattering by aerosols and molecules. 6SV deals better with atmospheric scattering than other RT models (Markham et al. 1992). 6SV model was formulated for the atmospheric correction in the short wavelengths. 6SV code requires the geometric conditions, including the viewing zenith, viewing azimuth, solar zenith and solar azimuth angles. Viewing zenith and viewing azimuth angles are obtained from INSAT-3DR metadata files and solar zenith and solar azimuth angles are calculated using time and location. Figure-3 describes the detail work flow for the simulation of TOA radiance and estimation of calibration coefficient.

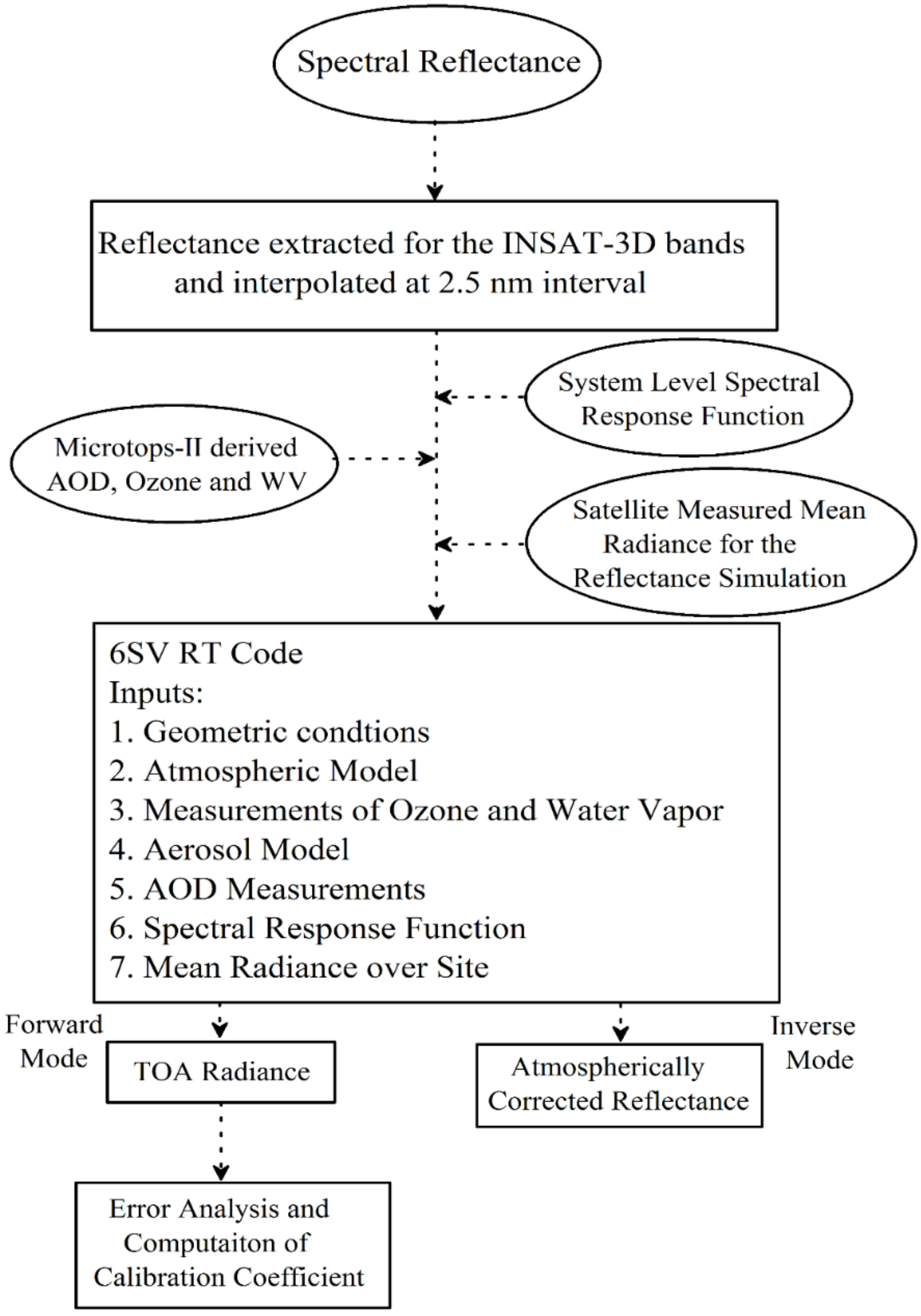

Figure 3: Detailed flow chart for the estimation of TOA radiance.

We have used pre-launch laboratory measurements of spectral response function (SRF) of INSAT-3DR VIS and SWIR channels of Imager as an input to the RT code to compute TOA radiances. The spectral response functions of VIS and SWIR bands are shown in Fig-4. As seen in figure, the spectral response functions are slightly asymmetric from the central wavelength. Here due to heterogeneity of shape in the form of Gaussian curve, the concept of FWHM (full width at half maximum) may not be accurate to evaluate the effective bandwidth, beyond which the SRF is effectively zero. There are non-Gaussian SRF methods available to determine effective bandwidth (Palmer, 1984). In practice, while there is no significant change in the central wavelength, the use of Palmer method to determine effective bandwidth of SRF can result in significant difference in values for effective bandwidth as compared to corresponding FWHM bandwidth values (Pandya, 2007). Both the SRF and ground reflectance data are resampled to 2.5 nm intervals using a spline interpolation method.

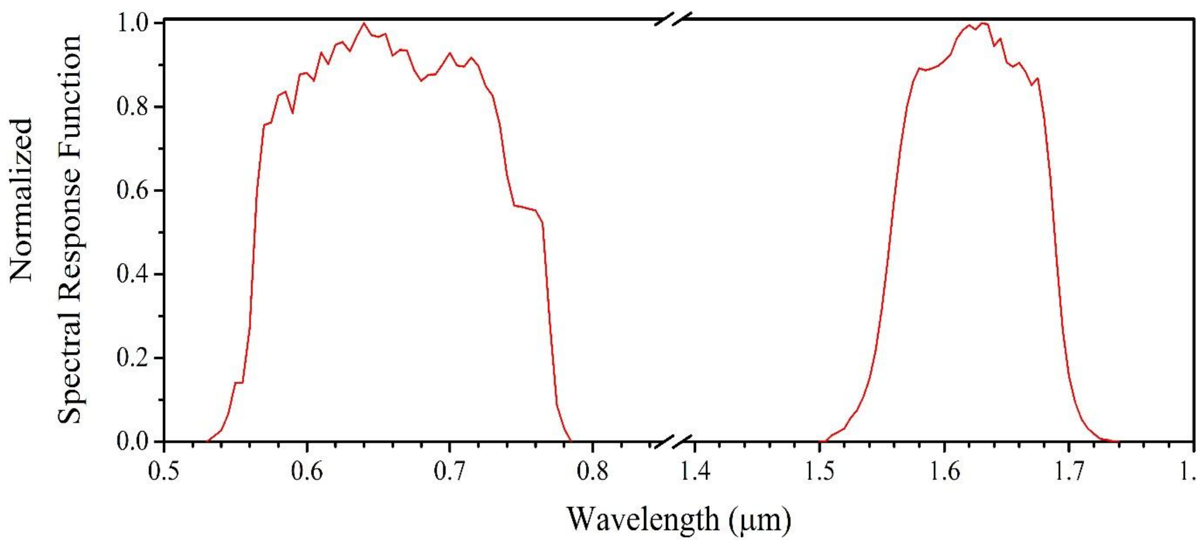

Figure 4: Pre-launch laboratory measurements of spectral response function for VIS and SWIR bands of INSAT-3DR

The 6SV RT model computes TOA radiance in the forward mode, while it computes atmospherically corrected surface reflectance in the inverse mode. 6SV RT model provides an output in the form of TOA radiance, which is divided by the corresponding radiance observed by the INSAT-3DR for particular channel to yield calibration coefficients.

Initial Results

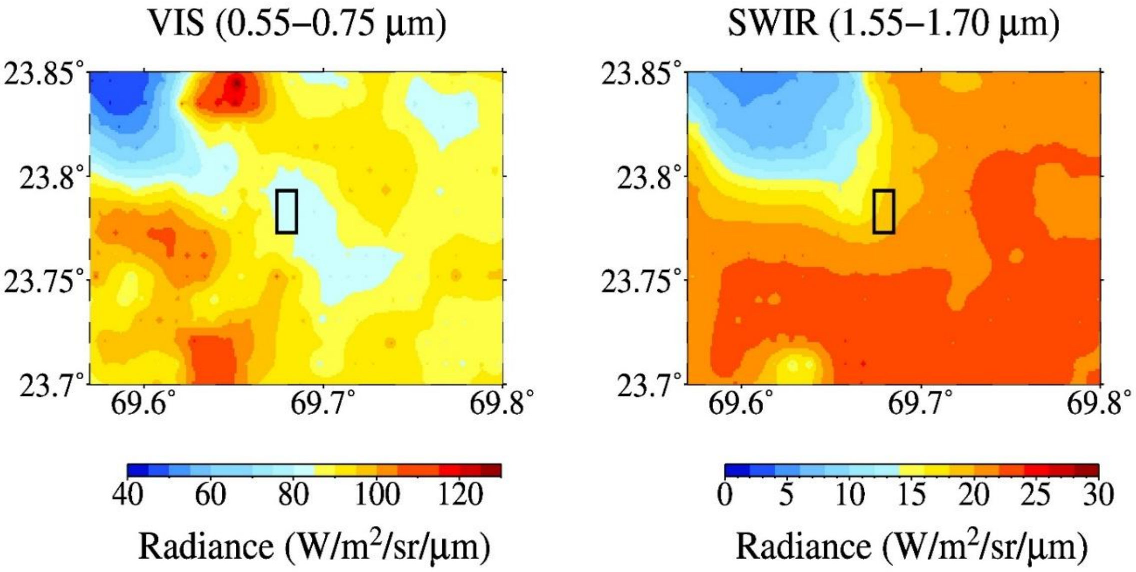

Figure 5: TOA radiance as observed by INSAT-3DR in its VIS and SWIR channels

The top-of-the-atmospheric radiance as observed by INSAT-3DR on 15th Sep. 2016 at 11:30hrs is shown in Fig-4. The site variability is very well observed in its VIS and SWIR bands, the VIS channel is showing more homogeneous radiances with mean value of 81.88 $W/m^2/sr/\mu m$. The SWIR channel shows heterogeneity due to soil moisture content and hence with higher standard deviation as compared with VIS channel and the same nature is also observed in surface reflectance using spectroradiometer. A very large number of hyper-spectral surface reflectance observations (total 350) were collected over a region of 2x2 km by walk around 1130hrs. These spectral reflectance data are subjected to quality control procedure which is based on standard deviation approach with respect to its spectral mean values. Due to high soil moisture content, almost 30% of the collected spectrum are rejected for the final calculation of simulating TOA radiance. The mean simulated TOA radiance and INSAT-3DR measured TOA radiances are given in Table 2 for the VIS and SWIR channels. The gain coefficient is computed between the sensor radiance and simulation. The results reveal that the VIS and SWIR channels of INSAT-3DR has gain coefficients of 0.974 and 0.820 respectively. The gain coefficient for SWIR channel is relatively higher due to the inhomogeneity of the ground target caused by sufficient sub-surface soil moisture.

Table 2: shows the day-1 radiometric performance of INSAT-3DR over the in-situ measurement target against 6SV simulated radiances

Channels	INSAT-3DR Radiance ($W/m^2/sr/\mu m$)	6S simulated Radiance (with synchronous 350 in-situ measurements) ($W/m^2/sr/\mu m$)	Gain coefficients
VIS (0.55-0.75 µm)	81.88 ± 2.87	79.73 ± 5.64	0.974
SWIR (1.55-1.70 µm)	18.87 ± 1.09	15.47 ± 2.37	0.820

Conclusion

The field campaign for day-1 vicarious calibration of INSAT-3DR VIS and SWIR channels are carried out over Great Rann of Kutch on 15th Sep. 2016. Preliminary results show that VIS and SWIR channel of INSAT-3DR has 0.974 and 0.820 respectively, as gain coefficients. The gain coefficient for SWIR channel is relatively higher due to the inhomogeneity of the ground target caused by sufficient sub-surface soil moisture.

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