Intersatellite Calibration of Kalpana Thermal Infrared Channel Using AIRS Hyperspectral Observations


Abstract—This letter presents the results from the intersatellite calibration of Kalpana observations using hyperspectral observations from the Atmospheric Infrared Sounder (AIRS). The intercalibration statistics have been generated for January, April, July, and October in 2009. Kalpana-observed brightness temperatures are found to be close to those of the AIRS observations with standard deviations of about 0.4 K during daytime and 0.3 K during nighttime. However, there are a large cold bias of 1.6 K in Kalpana observations during nighttime and a relatively small cold bias of 0.6 K during daytime. This calibration problem during nighttime is similar to that seen in the Geostationary Operational Environmental Satellites (GOES) infrared channels.

Index Terms—AIRS, intercalibration, Kalpana Thermal Infrared channel.

I. INTRODUCTION

The intercalibration of satellite-measured radiances from different satellite instruments with high spectral resolution capability has proven important to monitor the satellite sensor health and to a variety of applications, such as radiance assimilation in the numerical weather prediction models. Intercalibration is also important for newly launched satellites, as these comparisons with existing operational satellite instruments will provide confidence in the measured radiance from a new instrument. The bias present in the satellite radiance measurement would result in a bias in the geophysical products retrieved from the observation [1]. Intercalibration is also required for climate monitoring in order to detect small changes in the atmospheric parameters [2]. The intersatellite calibration has been demonstrated in the recent past [3]–[5] using spatiotemporally collocated observations from different geostationary satellites with a polar-orbiting operational satellite.

More recently, hyperspectral sounders have provided very high spectral resolution data for intersatellite calibration. Wang et al. [6] and Tobin et al. [7] have shown the intercalibration of polar satellite observations using hyperspectral observations from the Atmospheric Infrared Sounder (AIRS). Gunshor et al. [8] carried out satellite intercalibration of operational geostationary satellite imagers by comparing with the AIRS observations.

Currently, India maintains two geostationary satellites, Kalpana and INSAT-3A, for meteorological applications. Radiance measured by these satellite channels are used to derive various geophysical parameters, such as upper tropospheric humidity, outgoing longwave radiation, and sea surface temperature. In this letter, we present the results of the intercalibration of Kalpana using AIRS observations. The present study is performed under the Global Space-based Inter-Calibration System where we plan to continuously update the correction procedure along with the coefficients for all current and future Indian satellites.

II. DESCRIPTION OF SATELLITE SENSORS

The geostationary satellite Kalpana was launched by India in September 2002 and is positioned at 74° E. Kalpana has a very high resolution radiometer (VHRR) on board that takes observations at 30-min interval in three bands: visible (VIS) channel (0.55–0.75 μm), water vapor (WV) absorption channel (5.7–7.1 μm), and thermal infrared (TIR) window channel (10.5–12.5 μm) with spatial resolutions of 2 km for the VIS channel and 8 km for the WV and TIR channels at nadir. Fig. 1 shows the spectral response function (SRF) of the Kalpana WV and TIR channels overlaid on AIRS brightness temperature spectra.

The AIRS on board the Aqua satellite was launched on May 4, 2002, and is providing a wealth of highly accurate atmospheric and surface information using 2378 high-spectral-resolution (ν/Δν = 1200) infrared channels ranging from 650 to 2675 cm⁻¹, with two major gaps between 1135 to 1215 cm⁻¹ and 1615 to 2170 cm⁻¹. The maximum scan angle of AIRS is 49.5° in the cross-track direction with the swath width of 1650 km and a footprint of 13.5 km at nadir.

It is clear from Fig. 1 that the AIRS spectra only partially cover the Kalpana WV channel; therefore, in the present study, only the TIR channel is considered for the intersatellite calibration. The AIRS and Kalpana radiances are obtained for 2009 and processed for four months, January, April, July, and...
October, to represent different seasons in order to investigate seasonal behavior of the bias if any.

III. METHODOLOGY

We have adopted the standard procedure documented by the National Oceanic and Atmospheric Administration in the Algorithm Theoretical Basis Document for Geostationary Operational Environmental Satellites (GOES)—AIRS intercalibration [9]. The AIRS granules (6-min observation) have been collocated in space and time with the Kalpana observation. The radiance observations from AIRS were first convolved over the Kalpana TIR channel, followed by different collocation criteria. These procedures are briefly described as follows.

A. Convolution

Assuming that the spectral resolution of AIRS is very high, the convolved radiance for the Kalpana TIR channel is computed using

\[ R_{\text{conv}} = \left[ \sum_{i=1}^{n} R_{\text{AIRS}}^i S_{\text{Kalp}}^i \Delta \nu \right] / \left[ \sum_{i=1}^{n} S_{\text{Kalp}}^i \Delta \nu \right] \]  \hspace{1cm} \text{(1)}

where \( R_{\text{conv}} \) is the convolved broadband radiance (TIR in the present case), \( R_{\text{AIRS}} \) is the radiance of AIRS channels, the superscript \( i \) denotes the AIRS channel index, \( S_{\text{Kalp}} \) is the sensor response function of the broadband sensor at the central wavenumber of AIRS channel \( i \), \( \Delta \nu \) is the hyperspectral channel width, and \( n \) is the total number of hyperspectral channels in the broadband sensor’s SRF range. The bad channels in AIRS are filled by averaging the radiances of the nearest two channels. Brightness temperature from the broadband convolved radiances is computed using the equivalent inverse Planck function for the broadband sensor. Kalpana TIR equivalent brightness temperature (\( T_b \)) is computed by inverting the equivalent Planck function

\[ R_{\text{conv}} = \frac{2hc^2\nu^3}{\exp \left\{ \frac{hc}{kT_b} (a_1 + a_2 T_b) \right\} - 1} \]  \hspace{1cm} \text{(2)}

where \( a_1 \) and \( a_2 \) are the band correction coefficients for the Kalpana TIR channel, \( h \) is the Planck constant, \( k \) is the Boltzmann constant, and \( c \) is the speed of light. For the Kalpana TIR channel, \( a_1 = 1.052 \text{ K} \), \( a_2 = 0.996 \), and \( \nu = 885.602 \text{ cm}^{-1} \).

B. Collocation

First, the spatial collocation is performed to search the closest Kalpana and AIRS observation pairs, subject to a maximum spatial difference of 0.2°. Next, the observation time difference check is applied, and a threshold time difference of 15 min is used \( (|t_{\text{AIRS}} - t_{\text{Kalp}}| < 15 \text{ min}) \) as the Kalpana observations are available at every 30-min interval. Furthermore, the environment uniformity test is applied to restrict the collocated measurements over uniform scene conditions in order to avoid the problems arising due to the differences in the time of observation, observation path length, navigation error, etc., mainly due to the cloudy/partially cloudy scenes. For this purpose, the standard deviation (SD) of brightness temperatures in \( 5 \times 5 \) pixels for the Kalpana TIR image and \( 3 \times 3 \) pixels for AIRS surrounding the central pixel is computed, which corresponds to the scene of approximately 50 km \( \times \) 50 km. If the SD is less than 2 K, then the scene is considered as uniform, and the collocated pair at the central pixel is considered for intercalibration. Since AIRS and Kalpana observations are at different zenith angles (\( \beta \)), it is required to compare similar zenith angle observations in order to keep the path length difference small. This is achieved by using the following test:

\[ |\sec(\beta_{\text{AIRS}}) - \sec(\beta_{\text{Kalp}})| < 0.01. \]

IV. RESULTS AND DISCUSSIONS

A collocated data set of brightness temperature from Kalpana (\( T_{b,\text{KALP}} \)) and that convolved from AIRS observations (\( T_{b,\text{AIRS}} \)) is prepared for January, April, July, and October of the year 2009. The observations for daytime (AIRS ascending pass) and nighttime (AIRS descending pass) have been compared separately to examine the bias in the Kalpana observation. The statistics for the collocated pairs in each day have been generated separately for daytime and nighttime observations. The data over oceanic regions are used to avoid large spatial heterogeneity and difficulty in detecting partial cloud cover over land regions.

Fig. 2(a) and (b) shows the time series of the intercalibration statistics in terms of rmse and bias of \( T_{b,\text{KALP}} \) from \( T_{b,\text{AIRS}} \) during daytime and nighttime. It may be noted that the rmse and bias are both within 1 K for most of the period during the daytime. However, Kalpana brightness temperatures are colder than the AIRS convolved brightness temperatures throughout most of the time series. It is interesting to note that the rmse and bias have seasonal characteristics for daytime observations, with low values in January and October (winter months) and high values in April and July (summer months). During nighttime, there is a high cold bias of more than 1 K throughout the year with absence of any seasonal characteristics.

Table I presents monthly statistics of the intercalibration for daytime and nighttime observations. During daytime, the variations in the rmse are mainly due to the variations in the bias. The rmse values of 0.57 K, 0.76 K, 0.99 K, and 0.64 K are due largely to the bias values of 0.43 K, 0.64 K, 0.88 K, and 0.52 K for the months of January, April, July, and October, respectively. The bias is lowest in winter (January) and
largest in the summer (July). During daytime, the temperatures of the sensor system which have bearing on calibration are constant but have seasonal variation. The duration for which the temperature of the sensor system remains nearly constant is 9 h (3 GMT to 12 GMT) in winter, but that for the summer months is about 6 h. Also, the base temperature itself is higher by 10 °C during summer. Yu et al. [10] have attributed the T_b variation to solar viewing geometric conditions and directional emissivity of Earth. The SD of the T_b difference is consistent throughout the year around 0.40 K, which is reasonably low as far as intersatellite calibration is concerned.

The intercalibration results for nighttime show that there is a large cold bias in the Kalpana observations with values of 1.84 K, 1.50 K, 1.54 K, and 1.49 K for the months of January, April, July, and October, respectively. During nighttime observations, the “nonblackness” of the sensor blackbody calibration target comes into picture. When the sensor is viewing at night, the sun shines on the sensor front side. This warms up various optomechanical components of the scan mirror cavity. These components emit thermal radiation which is reflected by the nonblackness of the calibration target and directed onto the sensors. The effect of the sunshine remains almost for 8 h, peaking at satellite local time midnight and then falling away. Thus, the calibration coefficients generated during this time window, midnight ±4 h, will be in error if proper midnight blackbody correction algorithm is not applied [11]. The error in the coefficient derivation results in the noise. The calibration equation generated for Kalpana VHRR is a linear one and does not have a quadratic component which could have taken care of the nonlinear behavior of the sensor under varying operating temperature regimes.

It is interesting to note that, apart from the different biases during the daytime and nighttime, the SDs of the brightness temperature differences are consistently low throughout the year, with slightly lower values during nighttime. The mean annual SDs of the brightness temperature differences are 0.41 K during daytime and 0.33 K during nighttime. The similar values of SD of error for all the months during day as well as night indicate that the simple bias offset is required for the correction. This also indicates that the Kalpana observations are consistent with AIRS hyperspectral observations except for the season-dependent bias during daytime and large uniform bias during the nighttime. These biases need to be removed from Kalpana observations before geophysical products are derived.

V. CONCLUSION

In the present study, an attempt is made to calibrate the Kalpana TIR channel with the AIRS hyperspectral sounder observations, assuming that the AIRS is well calibrated. A methodology has been presented to convolve the Kalpana TIR radiances from the AIRS hyperspectral measurements and to generate a collocated data set for Kalpana and AIRS radiances. The collocated data set was used to compute the daily statistics of rmse, bias, and SD of the difference in Kalpana TIR brightness temperature from that obtained by convolving the AIRS observations. It has been found that the Kalpana TIR channel observations have different bias characteristics during daytime and nighttime. The bias in the daytime shows seasonal variations with small values in the winter (0.43 K in January) and large values in the summer (0.88 K in July). The nighttime bias is high with values around 1.6 K. The issue of high bias during nighttime is also seen in the U.S. GOES infrared channels, known as the “midnight sun problem.” However, the standard deviation of the brightness temperature difference is consistent throughout the year with mean values of 0.4 K during daytime and 0.3 K during nighttime. The large bias in the nighttime observations and the seasonal dependence of the bias during daytime need to be examined in detail and corrected before Kalpana observations are used for geophysical parameter retrieval. For future Indian geostationary satellite INSAT-3D IMAGER and SOUNDER payloads, quadratic calibration equations are generated. Several payload designwise improvements have been incorporated to minimize the effect of sensor temperature on its performance.

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REFERENCES