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15.

Abstract: An algorithm has been developed for the retrieval of cloud top temperature (CTT) from INSAT-3D. These retrievals are validated (inter-compared) with collocated in-situ (satellite) measurements with specific intent to generate climate-quality data. Comparison of INSAT-3D retrieved CTT at 4km resolution with radiosonde and CALIPSO showed mean absolute error (MAE) less than 3%. Further, CTT products at 4km and 50km resolutions were validated in terms of GCOS requirements by comparing them with concurrent measurements from ground-based hyper-spectral microwave radiometer (MWR). CTT_{4km} and CTT_{50km} agree with MWR retrieved CTTs at respective spatial resolutions, within 4K and 5K respectively, which are close to the GCOS required accuracy of CTT (1-5K) for climate studies. Also adequacy of GCOS standard spatial resolution for CTT (50km) and dependency of spatial resolution on CTT were examined, by comparing CTT_{50km} and CTT_{4km}. Analysis showed deviation of 7K between CTT_{50km} and CTT_{4km}. It is observed that the effect of spatial resolution on CTT is relatively less for opaque clouds (with uncertainty within 3K for 50% cloud fraction) compared to that for semi-transparent cirrus (STC) clouds (within 9K for 50% cloud fraction). These uncertainties are observed to be decreasing with increasing cloud fraction. Thus, INSAT-3D retrieved CTT at 50km resolution agrees with GCOS recommended spatial resolution for opaque clouds. However, caution should be taken in case of STCs. The CTT product is being made available at 30-min interval at 25km resolution and is being disseminated through the NICES web-portal.

Key Words: Cloud top temperature, INSAT-3D, NICES, ECV

List of Abbreviations

BT	-	Brightness temperature
BT_{MWR}	-	BT measurements from IR radiometer of MWR
BT_{TIR1}	-	BT at TIR1 channel of INSAT-3D
BTD	-	Brightness temperature difference
CALIPSO	-	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CTT	-	Cloud Top Temperature
CTT_{4km}	-	CTT at 4km x 4km resolution from INSAT- 3D
CTT_{50km}	-	CTT at 50km x 50km resolution from INSAT- 3D
CTT_{Z}	-	CTT from zenith measurements of MWR
CTT_{ZS}	-	CTT from averaged profiles at zenith and off-zenith direction of MWR
ECV	-	Essential Climate Variable
GCOS	-	Global Climate Observing System
HLO	-	High Level Opaque clouds
INSAT-3D	-	Indian National geostationary Satellite – 3D
LLO	-	Low level opaque clouds
MAE	-	Mean Absolute Error
MBE	-	Mean Bias Error
MWR	-	Hyper-spectral MicroWave Radiometer
NICES	-	National Information system for Climate and Environment Studies
NRSC	-	National Remote Sensing Centre
PC	-	Partial clouds
RMSE	-	Root Mean Squared Error
STC	-	Semi-transparent cirrus cloud

Cloud Top Temperature from INSAT-3D

1. Abstract

An algorithm has been developed for detection of clouds and retrieval of cloud top temperature (CTT) from the Indian geostationary satellite INSAT-3D. These retrievals are validated (inter-compared) with collocated in-situ (satellite) measurements with specific intent to generate climate-quality data. Comparison of INSAT-3D retrieved CTT at pixel level (4km x 4km spatial resolution) product with radiosonde and CALIPSO showed mean absolute error less than 3%. Further, CTT products at 4km and 50km resolutions in terms of GCOS requirements are validated them with concurrent measurements from ground-based hyper-spectral microwave radiometer (MWR). CTT_{4km} and CTT_{50km} agree with MWR retrieved CTTs at respective spatial resolutions, within 4K and 5K respectively, which are close to the GCOS required accuracy of CTT (1-5K) for climate studies. The study also examined adequacy of GCOS standard spatial resolution for CTT (50km) and dependency of spatial resolution on CTT, by comparing CTT_{50km} and CTT_{4km}. Analysis shows deviation of 7K between CTT_{50km} and CTT_{4km}. It is observed that the effect of spatial resolution on CTT is relatively less for opaque clouds (with uncertainty within 3K for 50% cloud fraction) compared to that for semi-transparent cirrus (STC) clouds (within 9K for 50% cloud fraction). These uncertainties are observed to be decreasing with increasing cloud fraction. Thus, our study shows that INSAT-3D retrieved CTT at 50km resolution agrees with GCOS recommended spatial resolution for opaque clouds. However, caution should be taken in case of STCs. The CTT product is available at 30-min interval at 25km resolution and being disseminated through the NICES web-portal.

2. Introduction

Cloud Top Temperature (CTT) is identified as an Essential Climate Variable (ECV) by Global Climate Observing System (GCOS). Accurate information of CTT and its spatial and temporal variations is of paramount importance for climate studies. Indian national geostationary satellite, INSAT-3D, provides a unique opportunity to observe continuously over Indian subcontinent and surrounding regions at 4km spatial and 30mins temporal resolution. The datasets from INSAT satellite series are being widely used for studies on evolution and variation of clouds and their properties (*Gambheer AND Bhat, 2000; Roca and Ramanathan, 2000; Roca et al., 2005*). As part of National Information System for Climate and Environment Studies (NICES) program of ISRO, a new integrated algorithm was developed for retrieving CTT at pixel level (i.e., 4km x 4km resolution) from the Imager on-board INSAT-3D with specific intent to generate climate quality data. Reliability of the retrieved CTT was estimated through inter-comparisons with collocated observations from ground-based radiosonde and space based active sensor, Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard Cloud-Aerosol Lidar and Infrared Pathfinder satellite Observations (CALIPSO). The reported statistics are comparable with that of the same product from other satellites over different regions of the globe (*Hanna 2008; Hamann et al., 2014; Taylor et al., 2017; Huang et al., 2019*). Since the intention of retrieving the CTT is to generate climate quality database, it is critical to assess reliability of the product in terms of GCOS standards (https://gcos.wmo.int). As per GCOS, CTT product is recommended to be at 50km spatial and 3hourly temporal resolution with an uncertainty within 5K. Given this, quality assessment of INSAT-3D retrieved CTT is also carried out by comparing it with the CTT derived from ground-based hyper-spectral microwave radiometer (MWR) for a period of one year from February 01, 2019 to January 31, 2020. MWR is installed at the Atmospheric Science Laboratory (ASL), NRSC, Shadnagar (17.03°N, 78.18°E and 634m above sea level).

3. Data and Methodology

3.1 Data

Imager onboard the Indian geostationary satellite, INSAT-3D provides observations over the Indian region at a temporal interval of 30 minutes (at HH:00 and HH:30) with visible (VIS), shortwave infrared (SWIR), mid-wave infrared (MIR), water vapor (WV) and thermal infrared (TIR1 & TIR2) channels (Katti et al., 2006). Specifications of these channels are given in Table 1. Present study uses level 1C, Asia sector product (ASIA_MER_L1C) from INSAT-3D Imager over India and surrounding regions bounded by 44.5°E-105.5°E and 10°S-45.5°N with spatial resolution of 4km, which is available through the SAC/ISRO web portal, MOSDAC (https://www.mosdac.gov.in). The present algorithm for retrieving CTT makes use of VIS, MIR, WV, TIR1 and TIR2 channels. Spatial resolutions of VIS and WV channels are 1km and 8km respectively, whereas those of MIR and TIR channels are 4km. In order to maintain uniformity, measurements from VIS and WV channels are also provided at 4km spatial resolution to match with that of MIR and TIR channels.

Table 1. Specifications of INSAT-3D Imager channels.

Channels	Spectral Range (μm)	Central wavelength (μm)	Resolution (km)
Visible (VIS)	0.55-0.75	0.65	1.0
Short-wave Infrared (SWIR)	1.55-1.70	1.62	1.0
Mid-wave Infrared (MIR)	3.80-4.00	3.9	4.0
Water Vapour (WV)	6.50-7.10	6.8	8.0
Thermal Infrared I (TIR1)	10.3-11.3	10.8	4.0
Thermal Infrared II (TIR2)	11.5-12.5	12.0	4.0

3.2 Methodology

As a part of the NICES program of ISRO, an integrated algorithm is developed for identification of clouds and pixel level retrieval of cloud top temperature from INSAT-3D Imager. Figure 1 depicts comprehensive flow chart of the developed algorithm.

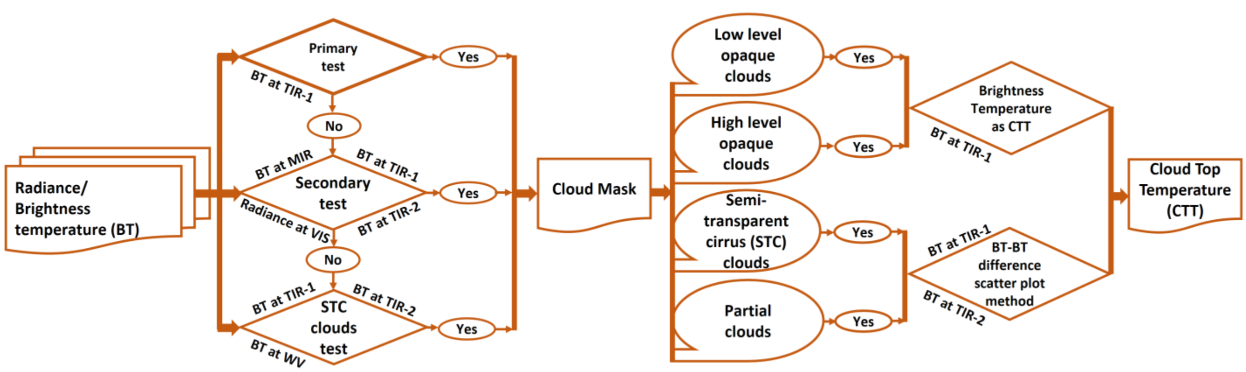

Figure 1: Flow chart depicting the algorithm for retrieving cloud top temperature from INSAT-3D Imager (Detailed flow charts and descriptions of methodology are available in *Lima et al., Remote Sensing, 11, 2811, doi: 10.3390/rs11232811, 2019*).

3.3 Retrieval of Cloud Top Temperature (CTT)

CTT is retrieved from INSAT-3D Imager at 4km (CTT4km), 25km (CTT25km) and 50km (CTT50km) spatial resolutions. Detailed information on CTT4km retrieval is available in Lima et al., 2019 and Lima et al., 2020; however, it is briefly described here. The developed algorithm includes two parts: (i) cloud detection and (ii) CTT retrieval (as shown in Figure 1). Cloud pixels, identified through the cloud detection scheme, are categorized into four classes; high level opaque clouds (HLO), low level opaque clouds (LLO), semi-transparent cirrus clouds (STC) and partial clouds (PC) and are then subjected to CTT retrieval accordingly. For HLO and LLO, satellite measured brightness temperature (BT) at TIR1 (BT_{TIR1}) channel (10.3-11.3μm) is considered as CTT with high confidence. CTT of STCs and PCs is retrieved using a method based on two dimensional scatter plot between BT and difference of BT (BTD) in the two split window channels, by considering an area of 15x15pixels surrounding the STC/PC pixel (*Lima et al.*, 2019; *Lima et al.*, 2020). In order to perform the retrievals at 50km, radiance and BT at 50km are obtained by averaging them at native resolution (i.e., 4km) within each 50km grid. Cloud identification and classification is then carried out by using 50km x 50km radiance/BT. For HLO and LLO clouds, BT_{TIR1} at 50km is taken as the CTT. However, considering an area of 15x15pixels around each STC/PC pixel at 50km resolution for the two dimensional scatter plot method is too large to assume single layer clouds at same altitude. On the other hand, minimizing the area leads to reduction in number of pixels for fitting the BT-BTD curve and this may lead to uncertainties. Thus, both the requirements are optimized by applying the BT-BTD curve to all those 4km pixels which fall within the 50km x 50km area. Using the minimum least square technique, the best fit curve between BT and BTD values are established from the set of BT-BTD curves obtained by varying temperature from 180K to the highest BT_{TIR1} value (that fall within the 50km grid). Efficiency of this method depends on the availability of sufficient number of clear, cloudy and STC/partial pixels within the region of consideration. In the present algorithm, CTT retrieval of STC/partial clouds is carried out, with high confidence, if at least one pixel is available in all the three categories; opaque, clear and STC/partial. The remaining cases are considered for retrieval, if at least 25 cloud pixels are available, but flagged with low confidence. CTT values with high confidence are represented by the quality flag 1 and those with low confidence are represented with quality flag 0. Further details can be found in published papers *Lima et al., 2019* and *Lima et al., 2020*. Figure 2 depicts cloud mask and cloud top temperature retrieved from the INSAT-3D Imager, by employing the present algorithm.

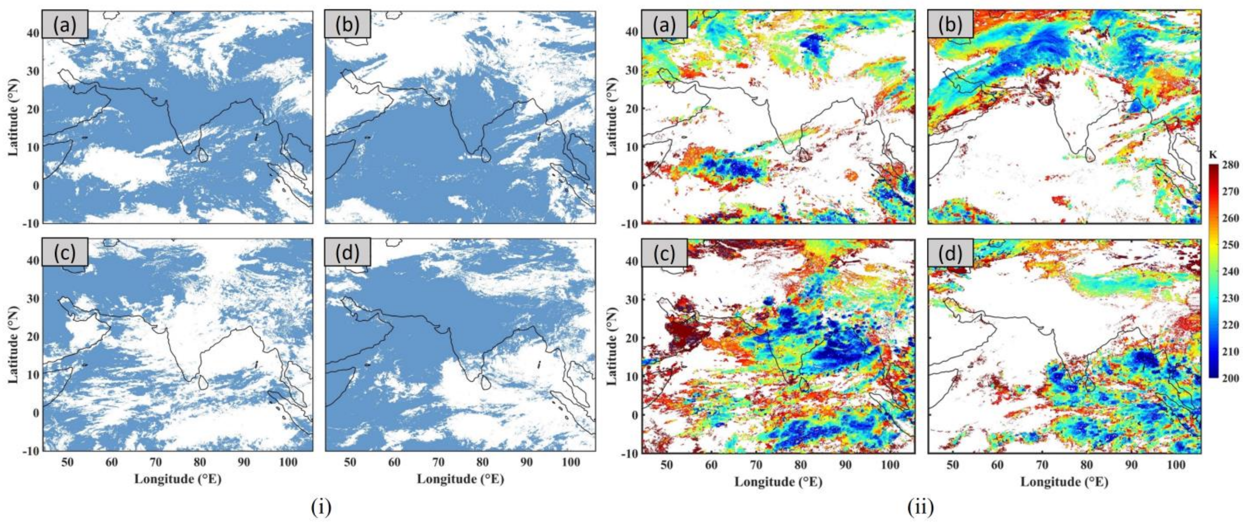

Figure 2: INSAT-3D retrieved (i) cloud mask and (ii) CTT (in Kelvin) at 07:30 UTC on (a) Jan 1 (winter season), (b) April 1 (pre-monsoon season), (c) Aug 1 (monsoon season) and (d) Nov 1(post-monsoon) of the year 2016. The blue and white colored areas in the figure (i) represent clear-sky and cloudy regions respectively (Figures are from Lima et al., Remote Sensing, 11, 2811, doi: 10.3390/rs11232811, 2019).

4. Validation of products

In order to provide weather and climate researchers more confidence on the products, quality of retrieved cloud top temperature (CTT) is assessed through validation and inter-comparison using in-situ and other satellite measurements.

4.1 Validation of INSAT-3D retrieved CTT with Radiosonde data:

Validation of INSAT-3D retrieved CTT is carried out using concurrent radiosonde measurements. Radiosonde data during September, 2014 – December, 2016 from SHAR/ISRO Sriharikota (13.7°N and 80.2°E), situated on the east coast of southern peninsula, has been used for the validation. Radiosonde measurements used for comparison were available at around 14:30 local time. Outcomes of the comparison analysis are presented in terms of mean bias error (MBE), mean absolute error (MAE), root mean square error (RMSE) and coefficient of correlation (r). Figure 3 depicts scatter plot between CTTs from INSAT-3D and collocated radiosonde measurements. Radiosonde measurements above 11km altitude (below ~200hPa) are not considered in the analysis to avoid possibility of errors due to relative humidity uncertainties. This restriction has reduced number of data points available for comparison and limited the minimum CTT value to about 235K. CTT from INSAT-3D and radiosonde agree well within 7.90K, with RMSE of 10.30K and mean bias error of -0.31K. The observed difference in CTT could be partially due to temporal difference between the satellite measurements and radiosonde release times, and inherent biases of the radiosonde method. Thus, it can be concluded that the observed differences in CTT between INSAT-3D and radiosonde, which are within 3%, could be due to the inherent limitations of sensors and methodologies. However, to gain better understanding of these discrepancies over wide range of temperatures, a detailed comparison is carried out with collocated CALIOP measurements over large spatial domain, that includes land and oceanic regions.

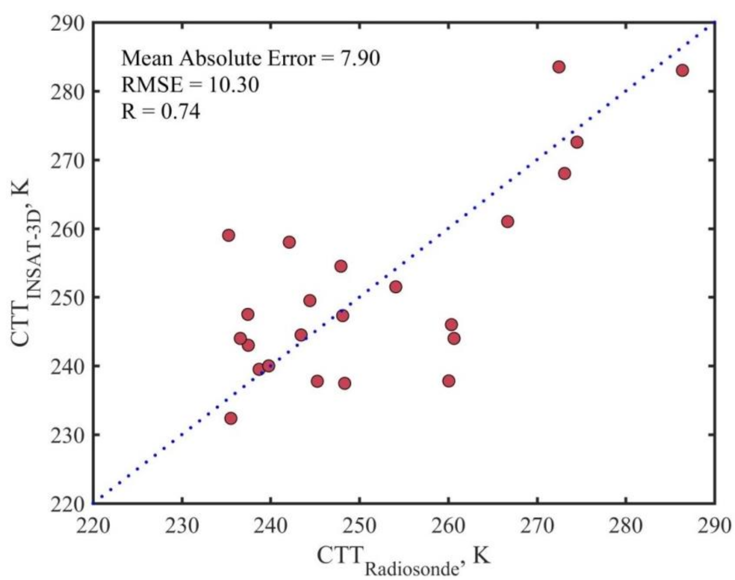

Figure 3: Comparison of retrieved CTT (Kelvin) from INSAT-3D, with that from radiosonde profiles.

4.2 Inter-comparison of INSAT-3D retrieved CTT using CALIPSO

In addition to the validation with radiosonde estimates, INSAT-3D retrieved CTT has been compared with CTT from CALIOP. The results are summarized in Table 2, in which values inside bracket represent comparison statistics of single layer (SL) clouds, whereas those outside represent that of single and multi-layer (ML) clouds together.

Table 2. Inter-comparison of INSAT-3D retrieved CTT against CALIPSO for single and multi-layered clouds with varying COD values of top layer.

Thresholds of COD	**Mean bias error ML (SL)**	**Mean absolute error ML (SL)**	**RMSE ML (SL)**	**Correlation coefficient ML (SL)**
No threshold	12.63 (9.07)	16.27 (13.56)	22.90 (19.40)	0.62 (0.73)
COD > 0.25	10.41 (8.07)	13.93 (12.19)	19.30 (16.91)	0.73 (0.80)
COD > 0.50	8.68 (6.87)	12.38 (11.12)	16.65 (14.99)	0.81 (0.85)
COD > 0.75	8.07 (6.65)	11.80 (10.81)	15.95 (14.51)	0.83 (0.87)
COD > 1.00	7.45 (6.31)	11.23 (10.61)	15.20 (14.32)	0.85 (0.87)

COD: Cloud optical depth; ML: single &multi-layered clouds, SL: single layer cloud only.

When only single layer clouds with COD > 1 are considered for the analysis, mean bias error, mean absolute error, RMSE and coefficient of correlation are observed to be 6.31K, 10.61K, 14.32K and 0.87 respectively, as shown in Figure 4. The improvements in comparison observed here with increase in COD (as shown in Table 2) in the absence of multi-layer clouds only indicate removal of bias due to sensitivity difference between the datasets rather than bias in the retrieval procedure. It can be noted that the reduction in biases observed in the absence of optically thin clouds is not high, which indicate capability of the present algorithm to efficiently retrieve CTT even over optically thin clouds.

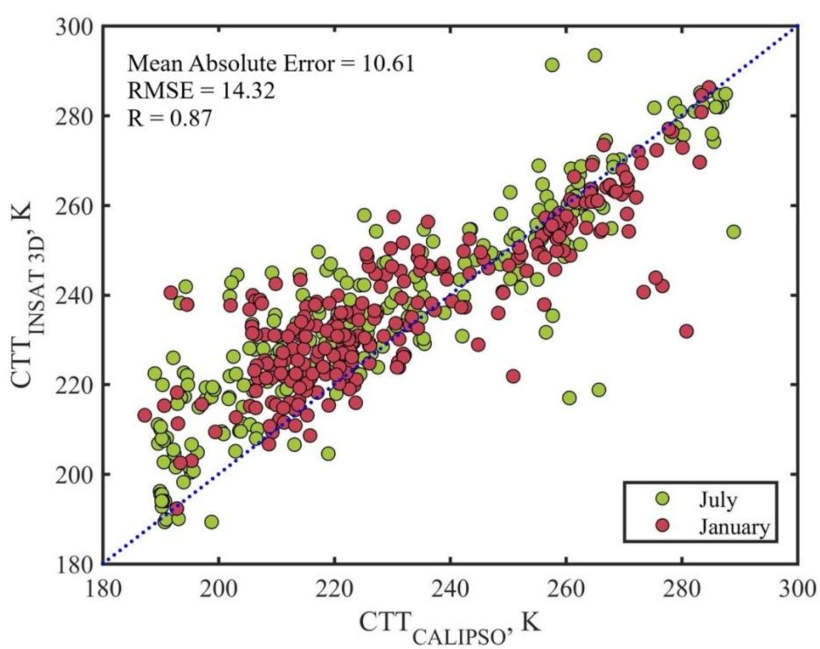

Figure 4: Comparison of retrieved CTT (Kelvin) from INSAT-3D, with that from CALIPSO, by considering only the pixels with full confidence (opaque and STC/partial in conditions (i) and (iv)) from INSAT-3D. 517 points have gone into the analysis.

Thus the validation results indicate that the uncertainty associated with CTT retrieval using INSAT-3D is 3%. Since the intention of retrieving the CTT is to generate climate quality database, it is critical to assess reliability of the product in terms of GCOS standards (https://gcos.wmo.int). As per GCOS, CTT product is recommended to be at 50km spatial and 3hourly temporal resolution with an uncertainty within 5K. Hence, the quality of INSAT-3D retrieved CTT at 50km resolution is also estimated in terms of GCOS standards.

5. Essential Climate Variable (ECV) standards

Quality assessment of INSAT-3D retrieved CTT is carried out by comparing it with the CTT derived from ground-based hyper-spectral microwave radiometer (MWR) for a period of one year from February 01, 2019 to January 31, 2020. MWR was installed at the Atmospheric Science Laboratory (ASL), NRSC, Shadnagar (17.03°N, 78.18°E and 634m above sea level). MWR provides continuous sounding of temperature, water vapor, liquid water and relative humidity along with column integrated amount of vapor and liquid in all weather conditions including clear and cloudy skies with high temporal resolution of about 3mins. Measurements are available at 58 levels from surface to 10km altitude with multiple vertical resolutions; starting with 50m steps from surface to 500m, 100m steps from 500m to 2km and 250m above that. MWR measures at 35 bands, including 21 in K-band (22-30GHz) and 14 in V-band (51-59GHz), at zenith and off-zenith directions (i.e., two off-zenith measurements are set at 20° elevation angle: 20°N and 20°S). Detailed information on MWR instrument, cloud identification and retrieval of CTT from MWR is available in *Lima et al., 2020*.

5.1 Validation of INSAT-3D retrieved CTT at 4km

Quantitative assessment of INSAT-3D retrieved CTT_{4km} is carried out by validating the same against CTT_Z (i.e., CTT from zenith measurements) derived from MWR. While comparing two cloud datasets from different platforms, it is also important to minimize the biases which can be arisen due to the complex cloud fields (such as broken cloudiness, passing clouds etc.), especially when area averaged observations from satellites are compared against point measurements from ground observations. Thus, cloud filtering is carried out to screen out relatively non-uniform cloud fields from both the datasets, as detailed below. This helps to bring out biases mostly due to systematic differences between the two datasets rather than random ones.

1) Condition-1: Within the 30min interval of two INSAT-3D observations, MWR makes multiple measurements up to a maximum number of 12. In case of inconsistent cloud fields such as passing clouds or broken clouds over the location, at least one of the MWR measurements can show the presence of clouds, which may not be detected by INSAT-3D. Possibility of such clouds is minimized by considering only the cases in which at least five of the MWR profiles, during each 30mins period of INSAT-3D, show presence of clouds.
2) Condition-2: In order to reduce the effects of broken cloud fields in INSAT-3D retrievals, further screening is carried out by considering only those clouds which span a minimum area of 3x3pixels around the station.
3) Condition-3: After applying the condition-2, cloud uniformity in INSAT-3D observations is ensured by determining the maximum difference between the CTTs falling within the area of 3x3pixels surrounding the station location. If the maximum CTT difference exceeds 6.5K, which indicates different cloud layers of more than 1km separation, those clouds are not considered for the validation.

Table 3 shows the comparison statistics of both the datasets (with and without conditions) in terms of mean absolute error (MAE), root mean square error (RMSE) and coefficient of correlation (R) along with standard deviation of CTT_{4km} (σ_{4km}) and CTT_Z (σ_Z). Even without applying any of the three conditions mentioned above, reasonable agreement, with MAE 5.51K, RMSE 7.96K and r 0.53, is observed between CTT_{4km} and CTT_Z. Improvement in agreement between CTT_{4km} and CTT_Z can be noted, from the table, after moderating the effect of complex cloud fields by applying different conditions.

Table 3: Comparison statistics of INSAT-3D retrieved CTT_{4km} against CTT_z from MWR, along with different screening conditions.

Screen Conditions	MAE (K)	RMSE (K)	r	σ_{4km} (K)	σ_{Z} (K)
Without conditions	5.51	7.96	0.53	8.88	6.84
Condition - 1	5.01	7.49	0.59	8.96	6.78
Condition - 2	5.36	7.65	0.49	8.32	6.91
Condition - 3	4.90	7.22	0.58	8.32	6.91
Conditions – 1&2&3	3.96	5.94	0.64	6.24	6.39

5.2 Validation of INSAT-3D retrieved CTT at 50km

In order to assess the accuracy of CTT_{50km}, in terms of GCOS standards, the same is validated against the CTT_{ZS} from MWR. Horizontal separation between the two off-zenith measurements of MWR varies from 0 to ~38km as the altitude increases from surface to 7km. Thus, the cloud layers and CTT from zenith and off-zenith averaged profiles of MWR can be considered as a representation of prevalent cloud conditions within the large area surrounding the instrument location. Similar to those applied to CTT_{4km}, different screening conditions are performed for minimizing the biases due to presence of complex cloud fields. Condition-1 is the same as that explained in section 5.1. Condition-2 is implemented on INSAT-3D datasets by considering only those cases with at least 50% of the 4km pixels are cloudy within the 50km x 50km area. This is to ensure uniform cloud fields within each 50km grid. σ_{50km} and σ_{ZS}, in the table, denote standard deviation of CTT_{50km} and CTT_{ZS} respectively. The validation statistics show reasonable agreement between CTT_{50km} and CTT_{ZS}, with MAE, RMSE and r 5.01K, 6.77K and 0.72 respectively (table 4) after applying all the conditions.

Table 4: Comparison statistics of INSAT-3D retrieved CTT_{50km} against CTT_{ZS} from MWR, along with different screening conditions.

Screening Conditions	MAE (K)	RMSE (K)	r	σ_{50km} (K)	σ_{ZS} (K)

Without any conditions	7.28	9.80	0.40	7.50	8.11
Condition - 1	5.44	7.54	0.61	7.56	7.59
Condition - 2	6.71	9.05	0.54	7.29	8.14
Conditions – 1&2	5.01	6.77	0.72	0.99	7.64

Thus, the validation using MWR shows uncertainty of 3.96K and 5.01K respectively for INSAT-3D retrieved CTT at 4km and 50km, which are close to the GCOS standard uncertainty range of 1-5K.

However, to examine the effect of cloud coverage, sensitivity analysis is carried out by varying the percentage of cloud fraction of 4km pixel within 50km grid, for each cloud class, from 50% to 80% and the comparison results are given in Table 5. By considering only those 50km pixels with minimum 50% coverage of opaque clouds, comparison between CTT_{50km} and CTT_{4km} shows MAE 2.96K and RMSE 4.74K. When the pixels with more than 80% coverage of opaque clouds are considered, agreement between both of them are observed to be improving, as the MAE and RMSE reduce to 0.79K and 1.32K respectively (Table 5). Consistency between CTT_{50km} and CTT_{4km} in the case of opaque clouds is mainly due to spatial uniformity of the opaque clouds over the area of 50km x 50km surrounding the station.

Table 5: Comparison statistics of INSAT-3D retrieved CTT50km against CTT4km for different percentage of cloud fraction in 4km pixels within50km x 50km area.

Cloud type	Statistical scores	Percentage of cloud fraction						
		50	55	60	65	70	75	80
Opaque clouds	MAE (K)	2.96	2.65	2.34	1.88	1.39	1.12	0.79
	RMSE (K)	4.74	4.19	3.78	3.09	2.29	1.79	1.32
	σ4km (k)	20.53	19.85	19.23	18.64	17.30	16.04	15.55
	σ50km (k)	20.28	20.08	19.04	18.94	17.05	16.31	15.30
STC clouds	MAE (K)	8.12	8.21	8.23	8.01	8.16	7.92	6.77
	RMSE (K)	11.30	11.45	11.57	10.91	11.10	10.59	8.92
	σ4km (k)	12.77	9.89	12.99	9.64	12.73	8.24	9.87
	σ50km (k)	10.04	12.63	9.88	12.76	9.14	10.86	6.98
Partial clouds	MAE (K)	6.52	6.64	6.64	6.83	6.78	6.61	5.74
	RMSE (K)	10.00	9.99	10.02	10.31	10.10	9.78	8.51
	σ4km (k)	20.32	19.39	19.66	18.89	17.69	15.69	14.65

	σ50km (k)	19.79	19.95	19.07	19.66	16.47	17.79	12.10

The analysis shows that uncertainty in CTT for STC clouds is relatively more compared to that for opaque clouds. Uncertainty in case of opaque clouds is mainly due to the decrease in fractional coverage of the same cloud within the 50km pixel area. However, effect of fractional coverage is comparatively smaller for the uncertainties associated with retrievals of STCs and PCs (Table 5). As the pixel size increases, cloud fields such as STCs or PCs no longer have spatial uniformity in optical properties and this in turn affect the cloud property retrievals leading to significant scale dependence.

6. Conclusion

Satellite-based datasets of geophysical variables are crucial for climate research as they represent state of the Earth's climate system. These datasets are useful to examine climate and its variability as well as to fine tune atmospheric model developments. Climate quality data of CTT are being generated from INSAT-3D satellite observations. Comparison of CTT at pixel level (4km x 4km resolution) with radiosonde and CALIPSO shows mean absolute error less than 3%. Quality of CTT product, against GCOS recommended requirements, is assessed by performing validation, under different conditions, using ground based measurements from MWR. Adequacy of GCOS specified resolutions is also examined in the study, by investigating the effect of different factors on spatial resolution. Validation using MWR shows uncertainty of 3.96K and 5.01K respectively for INSAT-3D CTT at 4km and 50km, which are close to the GCOS standard uncertainty range of 1-5K. This shows the fidelity of INSAT-3D retrieved CTT, both at 4km and 50km, for climate studies. Comparison between INSAT-3D CTTs at 4km and 50km shows an overall MAE and RMSE 7.22K and 11.82K respectively. Reduction in deviation between CTT4km and CTT50km with increase in cloud fraction shows dependency of cloud fractional coverage on CTT retrieval. While, opaque clouds show deviation within 3K, STCs and PCs show that within 9K and 7K respectively for 50% cloud fraction. Hence, caution should be taken when 50km CTT product is used for applications involving STCs and partial clouds. The CTT product currently generated is referred to as Version 1.0 and is disseminated through NICES web-portal of ISRO.

7. Description of Data

File Name (Daily)	: XXX3D_L3_PPP_50km_VVV01_DDMMMYYYY (X-Satellite, L-Level3, P-Product name, V-version, Y-Year, M-Month, D-Date)
Parameters	: CTT
Geographic Coverage	: 44.5°E-105.5°E and 10°S-45.5°N
Unit	: Kelvin
Spatial Resolution	: 0.50°×0.50°
Temporal Resolution	: Half-hourly
File Format (Data)	: NetCDF
File Format (Image)	: GIF

8. Acknowledgement

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