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RESEARCH REPORT

Microsat-2B (EOS-07) Microwave Humidity Sounder radiance assimilation in the NCUM System

Tanvi Gupta, S. Indira Rani, Gibies George, John P. George, Sumit Kumar, Laxmikant Dhage, Nishtha Agarwal, Durgesh Nandan Piyush, Navin Chandra, and V. S. Prasad

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National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
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9	Originating Unit	NCMRWF
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सारांश

भारतीय अंतरिक्ष अनुसंधान संगठन (ISRO) ने माइक्रोसैट-2बी (पृथ्वी अवलोकन उपग्रह-07, EOS-07) लॉन्च किया, जो छोटा पृथ्वी अवलोकन उपग्रह है, जिसमें छह चैनल माइक्रोवेव ह्यूमिडिटी साउंडर है, जो लगभग सभी मौसमों में वातावरण की आर्द्रता ध्वनि प्रदान करता है। EOS-07 साउंडर चैनल स्पेक्ट्रम के 183.31 GHz क्षेत्र पर केंद्रित हैं और मेघा-ट्रॉपिक्स उपग्रह पर मौजूद SAPHIR ह्यूमिडिटी साउंडर के लगभग समान हैं।अंतरिक्ष अनुप्रयोग केंद्र, इसरो ने शुरुआत में अप्रैल 2023 की अवधि के लिए EOS-07 नमूना अवलोकनों का एक सेट प्रदान किया। इस रिपोर्ट का उद्देश्य डेटा एसिमिलेशन सिस्टम में नए ह्यूमिडिटी साउंडर डेटा को आत्मसात करने के लिए एनसीएमआरडब्ल्यूएफ के प्रयासों और क्षमताओं को प्रदर्शित करना है जो एनसीएमआरडब्ल्यूएफ एनडब्ल्यूपी मॉडल के लिए प्रारंभिक स्थिति (विश्लेषण) तैयार करता है। एनसीएमआरडब्ल्यूएफ यूनिफाइड मॉडल डेटा एसिमिलेशन (NCUM-DA) सिस्टम में EOS-07 माइक्रोवेव ह्यूमिडिटी साउंडर डेटा के प्रभाव का आकलन करने के लिए ऑब्जर्विंग सिस्टम एक्सपेरिमेंट्स (OSE) को डिजाइन किया गया है। NCUM-DA प्रणाली में EOS-07 डेटा को समाहित करने के लिए आवश्यक विकास किए गए हैं।सीमित उपलब्ध डेटा सेट का उपयोग करते हुए प्रारंभिक प्रयोगों से पता चला कि NCUM-DA प्रणाली में नए आर्द्रता चैनल डेटा का महत्व है। यह प्रदर्शित किया गया है कि इस डेटा ने विश्लेषण में ऊर्ध्वाधर कॉलम में आर्द्रता को संशोधित किया है। तापमान और पवन क्षेत्रों में भी छोटे परिवर्तन देखे जाते हैं। चूँकि डेटा उपलब्धता सीमित और असंतत है, इसलिए यह अध्ययन विश्लेषण क्षेत्रों के मूल्यांकन को सीमित करता है, पूर्वानुमान चर को नहीं।

Abstract

Indian Space Research Organization (ISRO) launched Microsat-2B (Earth Observation Satellite-07, EOS-07), small Indian earth observation satellite having a six channel Microwave Humidity Sounder, to provide humidity sounding of atmosphere, nearly all-weather conditions. The EOS-07 sounder channels centered on 183.31 GHz region of the spectrum and are nearly similar to that of SAPHIR humidity sounder onboard Megha-Tropiques satellite. Space Application Centre, ISRO provided a set of EOS-07 sample observations initially for the period April 2023. The objective of this report is to showcase NCMRWF's efforts and capabilities to assimilate new humidity sounder data in the Data assimilation systems which prepares the initial condition (analysis) for NCMRWF NWP models. Observing System Experiments (OSEs) have been designed to assess the impact of EOS-07 microwave humidity sounder data in the NCMRWF Unified Model Data Assimilation (NCUM-DA) system. Required developments are made to assimilate the EOS-07 data in the NCUM-DA system. The initial experiments using the limited available data set brought out that the importance of new humidity channel data in the NCUM-DA system. It is demonstrated that this data modified the humidity in the vertical column in the analysis. Small changes in the temperature and wind fields are also noticed. Since the data availability is limited and discontinuous, this study limits the evaluation of analysis fields, not the forecast variables.

Keywords: Microsat-2B, EOS-07, 183.31 GHz, Data Assimilation

1. Introduction

Assimilation of satellite data in a Numerical Weather Prediction (NWP) model plays a significant role in improving the weather forecasts. In this study, we aim to understand the impact of the humidity observation from a new satellite Microsat-2B which was launched by the Indian Space Research Organisation (ISRO) on 10 February 2023 from Sriharikota, India. Microsat-2B (Earth Observation Satellite-07, EOS-07) , a micro-satellite, is in a low earth orbit with an inclination angle of 37.2^0 with an orbit height of 450 km. A lower inclination angle provides more observation measurements over the Tropics as compared to polar orbiting satellites. Microsat-2B consists of a cross-track millimetre wave humidity sounder (MHS) comprising six channels centred around 183 GHz that aims to capture the effect of water vapour in the middle and upper atmosphere. Microsat-2B also known as EOS-07 has 75 field of view per swath of width 1050 km and a resolution of 10 km at the nadir. At the edges, it has a spatial resolution of 20 km. The microwave absorption spectrum channels for which the Microsat-2B is designed show that it can affect the diurnal cycle of water vapour (Njoku, E.G. (1982)) and hence, can impact the convective clouds over the tropical belt. Microsat-2B provides a vertical coverage in the atmosphere spanning from lower most channels peaking at around 600 hPa (Channel 6) to the uppermost at 300 hPa (Channel 1).

Presently available other humidity sensitive channels from satellite measurements either have a lower number of passes over the tropics (polar satellites), or they have less vertical coverage in the microwave water vapour spectrum. For e.g: 1) Advanced Technology Microwave Sounder (ATMS) onboard National Oceanographic and Atmospheric Administration (NOAA) satellites has comparable channels in the microwave humidity spectrum with Microsat-2B, but has fewer passes over the tropics and, 2) Microwave Humidity Sounder (MHS) onboard NOAA and MetOp series of satellites provide a lower vertical coverage of humidity sensitive channels. Table 1 gives a snapshot of the channel frequencies of humidity sensitive microwave sensors in the 183.31 GHz region onboard different satellites.

To reduce the water vapour measurement gap both vertically and temporally over the tropics, Megha-Tropiques (MT) was first launched by ISRO in 2011 and was eventually decommissioned in March, 2023. With frequent passes over tropical regions and better vertical coverage, SAPHIR, the sounder onboard MT, improved the representation of moisture in the NWP models and hence forecasts (Rani et al., 2016; Doherty et al., 2018; Kumar et al. 2018, Choudhury et al., 2020). After decommissioning of MT-SAPHIR, there is a dearth in water vapour observations over the tropics both spatially and vertically. MT-SAPHIR was a low earth orbit satellite with an inclination angle of 20°. The lower inclination angle led to more passes over the tropics ranging from 3-6 times per day, resulting in 3.8 times more data being assimilated in the NWP model's data assimilation systems (Chambon et al., 2015). MT-SAPHIR covers between 30º S and 30º N. Microsat-2B is similar to MT-SAPHIR in the following manner: 1) an inclination angle of 37.2°, slightly more tilted than MT-SAPHIR, but still supposed to give a good data coverage over tropical region, and 2)

Similar channel frequency and channel peaking height (except Channel 6 for Microsat-2B with a frequency of 183±15.75GHz). A comparison of the orbital features of Microsat-2B and MT-SAPHIR is listed in Table 2. Unlike MT, the Microsat-2B approximately covers between 45° S and 45° N. There are slight differences in the channel frequencies of Microsat-2B and SAPHIR. Table 3 shows the comparison of MT-SAPHIR and Microsat-2B channels. The frequency band of respective Microsat-2B channels are slightly higher than that of SAPHIR channels. Hence the peaking heights of various Microsat-2B channels are slightly lower than the corresponding channels of SAPHIR. Figure 1a shows the weighting functions of SAPHIR (dotted) and Microsat-2B (continuous) channels over a tropical location. The shape of the weighting function will be different over different regions depending on the atmospheric conditions.

In this study, we aim to evaluate Microsat-2B's ability to be a substitute for SAPHIR and try to quantify the impact of Microsate-2B on the analysis. The article is organized in the following sections. The data, model and the experiment design are discussed in section 2. Section 3 covers the analysis from the assimilation of Microsat-2B data in the NCUM Data Assimilation system. Lastly, section 4 summarizes and concludes the results.

Table 1: Channel frequency of humidity sensitive microwave sensors in the 183.31 GHz region used for comparison in this study

Instrument	Channel Number												
Channel frequency offset from 183.31 GHz	±0.	±0.96	±1.0	±1.1	±2.8	±3.0	±4.2	±4.5	±5.8	±6.2	±11.0	±11.56	±15.75
Microsat-2B		1			2			3	4			5	6
SAPHIR (Till 2021)	1			2	3		4			5	6		
MHS (Onboard NoAA, MetOp1 (B), MetOp3 (C))			3			4							

Table 2: Specifications for Microsat-2B and MT-SAPHIR orbital parameters

Parameter	**Microsat-2B**	**MT-SAPHIR**
Orbit Height	425 km	870 km
Pixels	75	130
Swath	1050	1700
Inclination Angle	37.2°	20°

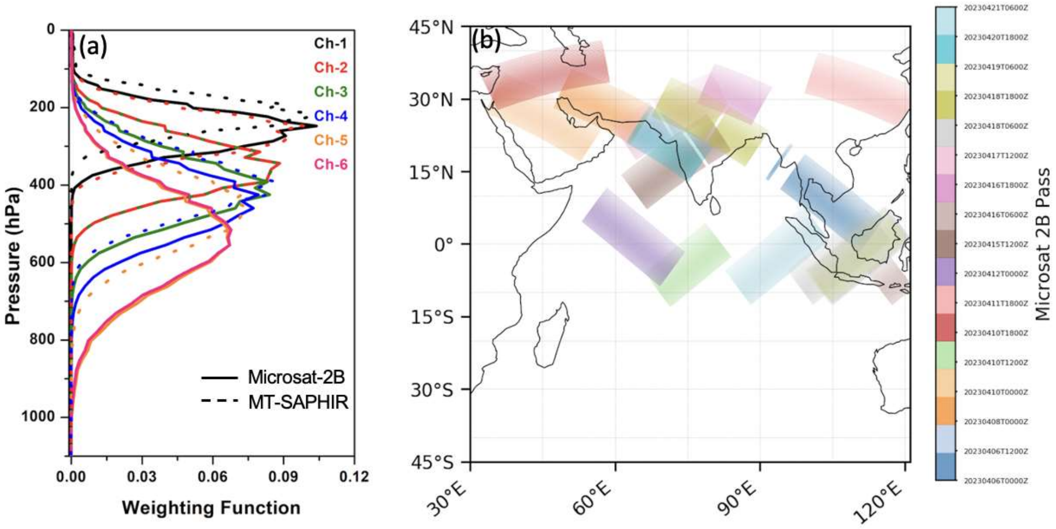

Figure 1: **(a)** Weighting function for Microsat-2B (continuous) and MT-SAPHIR (dotted) channels over a tropical location, and **(b)** Microsat-2B passes that are assimilated in the NWP model in this study.

Table 3: Comparison of Microsat-2B and SAPHIR channel frequencies

Channel No.	Frequency (GHz)	
	Microsat-2B (EOS-07)	**SAPHIR**
1	183.31±0.96	183.31±0.2
2	183.31±2.8	183.31±1.1
3	183.31±4.5	183.31±2.7
4	183.31±5.8	183.31±4.2
5	183.31±11.56	183.31±6.6
6	183.31±15.75	183.31±11

2. Data and Methodology

2.1 EOS-07 (Microsat-2B) Data

Space Application Centre (SAC), ISRO provided a set of limited, but discontinuous EOS-07 dataset for April 2023. The dataset was discretized as per the 6-hour assimilation window that is used in Data Assimilation System for the cycles 0000, 0006, 0012, and 0018 UTCs. Based on the assimilation windows, the EOS-07 data was segregated into 18 time stamps. The satellite passes for each time stamp is shown in Figure 1b.

2.2 Numerical Model and Data Assimilation System

NCMRWF is operationally using the Unified Model (NCUM) global NWP system since 2012 (Rajagopal et al., 2012, George et al. 2016). This system has been adapted from the Unified Model (UM) seamless prediction system of "UM Partnership" and is being upgraded periodically to adapt new scientific and technological advancements. The major components of the NCUM global NWP system include components for data processing, data assimilation and forecast model (Brown et al., 2012, George et al., 2016). Observation pre-processing, observation processing and quality control components of the NCUM system prepare the quality-controlled observation for assimilation. (Jangid et al., 2019, Kumar et al., 2020 and 2021). The main components of NCUM are 1) an observation pre-processing system (OPpS), 2) quality control of data through an Observation Pre-processing System (OPS), 3) a surface analysis preparation model (SURF), 4) Hybrid Four Dimensional-variational (Hybrid-4D-Var) data assimilation (DA) system which create model initial condition (or analysis) and 5) Forecast model: NCUM. At NCMRWF, near-real time global meteorological observations are received from both national and international agencies (Rani et al. 2019). OPpS is an in house developed tool that decodes the data and pack observations into a format that is readable by OPS system (Prasad 2012,; Prasad and Rani, 2014). The quality controlled observations through OPS are passed to 4D var assimilation system as input. Surface data assimilation SURF is used to interpolate the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA), Sea Surface Temperature and sea-ice analysis to the required NCUM resolution. These analysis products are used to initialise the model surface conditions. Further details on extended Kalman Filter based soil moisture assimilation system can be found in Dharssi et al., 2015,and Lodh et al., 2016.

The Variational Bias Correction (VarBC) method is used to correct the systematic errors in the satellite radiances before assimilating them in model (Auligne & McNally, 2007). The Microsat-2B data is presently assimilated in clear-sky conditions where the cloud affected observations are eliminated using O-B threshold check of less than 20K. This study uses Four Dimensional-Variational data assimilation (4D-Var) data assimilation system of NCUM, that was first introduced in the UM system by Rawlins et al. 2007. This variational data assimilation system uses a cost function that is based on the misfit between model state and observation. The cost function is minimized in each iteration to achieve the analysis. Observations that have a non-linear relationship with model variables, such as, satellite radiances and radar measurements can be handled by variational data assimilation methods. The 4D-Var assimilation includes an additional time dimension over 3-D var data assimilation. In NCUM4D-Var DA system is an incremental approach with a simplified perturbation model is used. Climatological background is used to create the error covariance matrix in 4D-Var whereas, the flow dependent background error calculated using the forecast from NCMRWF global ensemble prediction system that is used in the operational Hybrid 4D-Var system. The data thinning is done in two stages at a resolution of 80 km and, gradually to 25 km for the Microsat-2B data.

UM model version 11.2 is used in this study. The NCUM solves a set of equations to describe the time evaluation of atmosphere. The main prognostic variables are zonal and meridional winds, potential temperature and relative humidity. Several assumptions are made to solve the system of equations, such as, no vertical acceleration or non- hydrostatic assumption. Multiple physical processes, such as atmospheric radiation's effects on cloud, water vapour, land surface processes, drag due to sub-grid scale orography, large scale precipitation, gravity waves and effect of convection are parameterized at a sub-grid scale. The NCUM global model used in study has a horizontal resolution of 12 km. It has 70 vertical levels from the surface to 80 km height. Rajagopal et al. (2012) and Rakhi et al.

(2016) give further details about the NCUM global system. The schematic diagram of the complete NCUM assimilation system is given in figure 2.

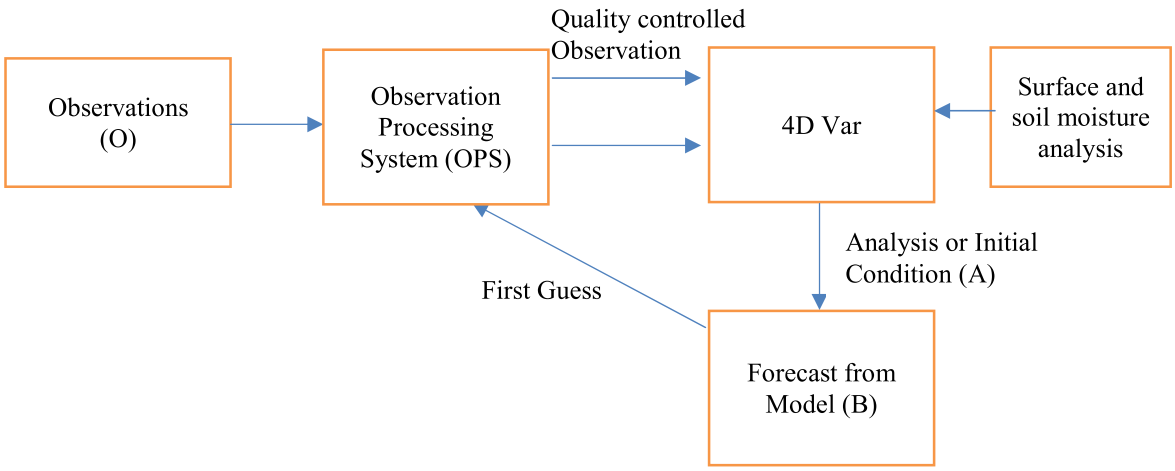

Figure 2: Schematic diagram of NCUM observation processing and DA system

2.3 Observing System Experiments (OSEs)

In this study, two sets of experiments have been carried out. The first one is the baseline experiment (CTRL) which assimilates all the observations listed in Table 4, except Micrsat-2B radiances. In the second experiment (EXP), the Microsat-2B radiances were assimilated along with the observations used in the CTRL. To evaluate the exclusive impact of Microsat-2B radiances in the NCUM-DA system, satellite radiances from other instruments were not assimilated in both the experiments. As mentioned in section 2.1 and Figure 1b, the Microsat-2B data availability is limited and discontinuous. As per the availability of the Microsat-2B data, data assimilation experiments were carried out from 4 to 23 April 2023.

Table 4. Various Observation types assimilated in NCUM 4D Var system in this study

Type of Observations	Description	Variable Assimilated
AIRCRAFT	Upper-air wind and temperature from aircraft	$u, v, and\ T$
SATWIND	Atmospheric Motion Vectors from various geostationary and polar orbiting satellites	$u, and\ v$
SYNOP + METAR+AWS+BUOY+SHIP	Surface synoptic observation from land	u, v, T, q
ASCAT	Advanced Scatterometer in MetOp A & B	u, v
TEMP + DROP + PILOT+WINPRO + SONDE	Radiosonde observations, upper-air wind profile from a pilot balloons and wind profiles	u, v, T, q
MICROSAT-2B	Microsat-2B radiances	$Brightness\ Temperature, T_b$

3. Results

The impact of assimilating Microsat-2B radiances in the NCUM system is discussed in this section. The impact is studied in terms of background innovation term (O-B) and Analysis term.

3.1 Background Innovations (O-B)

Brightness temperatures (T_b) from various channels of Microsat-2B are assimilated in the NCUM-DA system. As discussed in section 2.2, T_b is not a model control variable. Before assimilation, the observed T_b needs to be compared with the model equivalent. A radiative transfer model is required to compute the model equivalent T_b. In NWP, the assumptions made for satellite radiance assimilation are (i) there are no calibration errors for the sensors measuring satellite radiances, (ii) the radiative transfer model is accurate, and 3) there is no systematic error in the short-term forecast that NWP model provides. However, biases vary with time, air mass, scan position of the satellite instrument and the position of the satellite. In NCUM, the background brightness temperature is computed using the Radiative Transfer Model for TOVS, RTTOV-11.2.

Figure 3 shows the observed Microsat-2B T_b, the corresponding model equivalent and the background innovations for all the six channels for a particular assimilation cycle valid for 1200 UTC of 5 April 2023. Though the T_b of various channels is in different range, the background innovations of all the channels are found to be in the range of ± 8 K, but with most of the values between ± 4 K, which is within the assigned observation error values for different channels of the Microsat-2B in the NCUM-DA system.

Figure 4 shows the histogram of background innovations of six channels of Microsat-2B averaged over the study period. The mean of the distribution of background innovations of Microsat-2B channels are not centred at zero as seen from Figure 3. For all the channels, both the RMS and standard deviations of the background innovations are in the approximate range of 3 to 3.5 K. As shown in Figure 3, the background innovations at various locations for different channels are mostly in the range ±4K. However, while averaging, the biases are minimized to ±1K as shown in Figure 3 (μ values indicated for each channels).

NCUM DA system assimilates radiances from similar 183±31 GHz channels from instruments onboard many polar orbiting satellites. Microwave Humidity Sounder (AMSU-B/MHS) onboard various satellites, NOAA-19, MetOp-B and MetOp-C are operationally assimilated in the NCUM Hybrid-DA system. A comparison of the background and analysis innovations of MHS/AMSU-B channels from the operational run and the EXP run (with Microsat-2B radiances) for the same assimilation cycle is listed in Table 5. It is noted from Table 5 that innovations in the analysis is less than the background innovations. This shows that the DA system is robust. Innovations (both background and analysis) of the AMSU-B channels are less than that of Microsat-2B. This could be due to the continuous assimilation of AMSU-B radiances in the operational assimilation system, compared to the limited data availability of Microsat-2B.

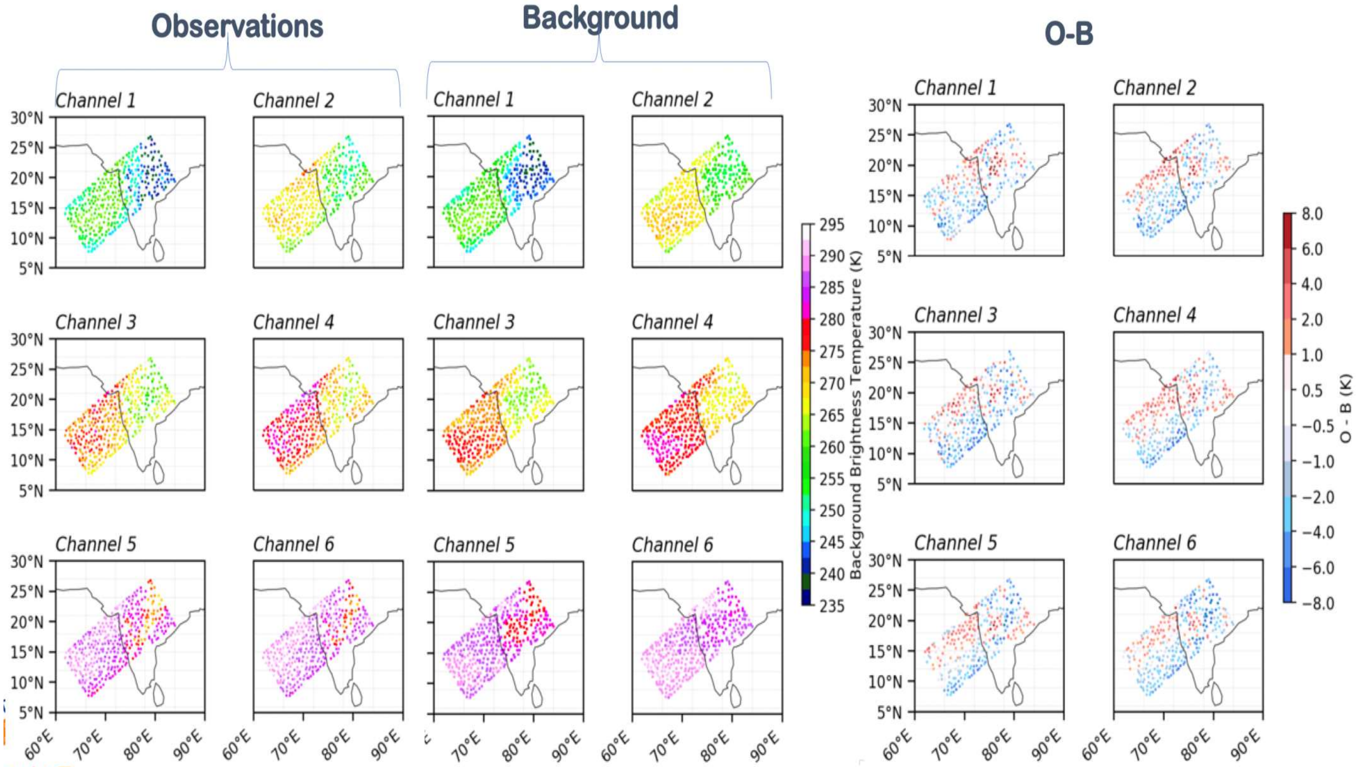

Figure 3: Observed Brightness Temperature (K) in first two columns, model equivalent Brightness Temperature (K) in the third and fourth columns, and the background innovations in last two columns valid for a particular assimilation cycle, 1200 UTC of 5 April 2023.

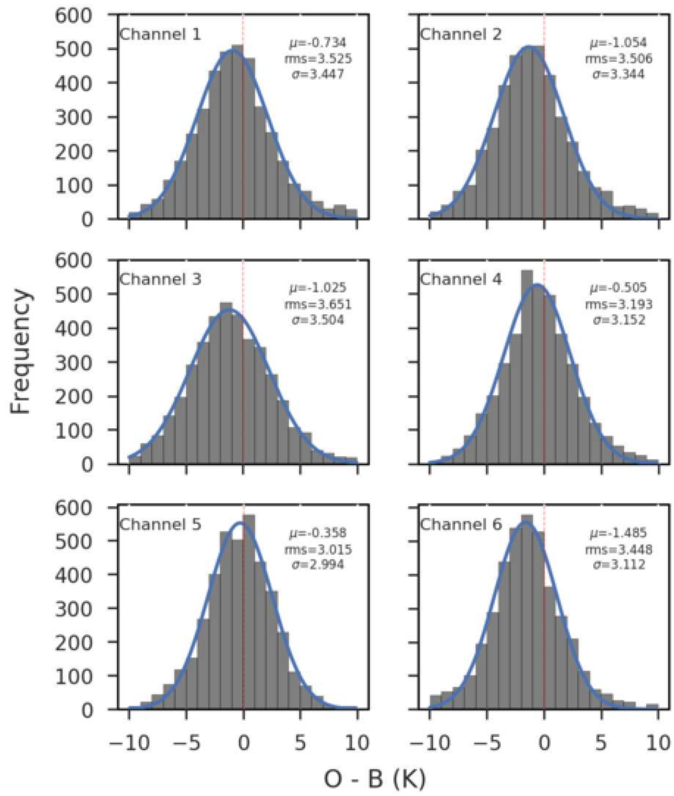

Figure 4: Histogram of background innovations (K) of Microsat-2B channels averaged over the study period ('μ' represent average bias, 'rms' is the root mean square error, 'σ' represents standard deviation).

Table 5: Comparison of RMS errors in the background and analysis innovations of Microsat-2B and AMSU-B radiances during the study period.

Microsat 2B	Channel1	Channel2	Channel3	Channel4	Channel5	Channel6
O-A (RMS)	2.12	1.91	2.22	1.57	1.80	2.17
O-B (RMS)	3.45	3.34	3.50	3.15	2.99	3.11
MHS	Channel3	Channel4				
O-A (RMS)	1.23	0.74				
O-B (RMS)	1.83	1.40				

3.2 Analysis Increments

Analysis increments quantify the influence of all the observations assimilated in the NWP system. In this study we have compared the analysis increments in specific humidity, potential temperature and wind components from both CTRL and EXP experiments. Figure 5 shows the differences in the analysis increments of specific humidity (left panel) and potential temperature (right panel) at three different pressure levels representing lower, middle and upper levels (850 hPa, 500 hPa and 200 hPa) between EXP and CTRL experiments valid for 0012 UTC of 5 April 2023 (for the satellite pass shown in Figure 3). Impact of the assimilation of Microsat-2B humidity sounder radiances can be seen in the lower (850 hPa) and middle (500 hPa) atmosphere. Though the Microsat-2B channel-1 peaks approximately at 200 hPa, we did not see any impact in the upper level humidity where genereally humidity does not make any sense, however included the plot for completeness. The analysis increments in specific humidity and potential temperature at 700 hPa are nearly similar to that at 700 hPa (not included here). In general, assimilation of Microsat-2B radiances produced a moistening effect in the lower and middle levels. We also noticed a drying effect due to the assimilation of Microsat-2B radiances.

Analysis increments in the potential temperature (Figure 5 right panel) are not confined over a particular region as seen in the case of specific humidity. Analysis increments in the potential temperature due to the assimilation of Microsat-2B radiances produced a cooling effect in the lower and middle levels. When combine the analysis increments in the specific humidity and potential temperature, it can be noticed a cool moistening with an adjacent warm drying effect. Unlike specific humidity, the analysis increment differences in the potential temperature are spatially spread. This might be due to the use of the flow dependent background error matrix used in the 4D-Var assimilation system. Analysis increments in the potential temperature is also noticed in the upper levels as seen from Figure 5 right panel. Since the Microsat-2B channels are humidity sensitive, the magnitude of the analysis increments in the humidity is higher than that of potential temperatures. Figure 6 is similar to Figure 5, but for the zonal and meridional wind components. The analysis increments in the wind components are not well organized as that of the mass fields. However, there is a prominent east-west/north-south component has been seen in the middle level (500 hPa) over the area where the Microsat-2B radiances are assimilated.

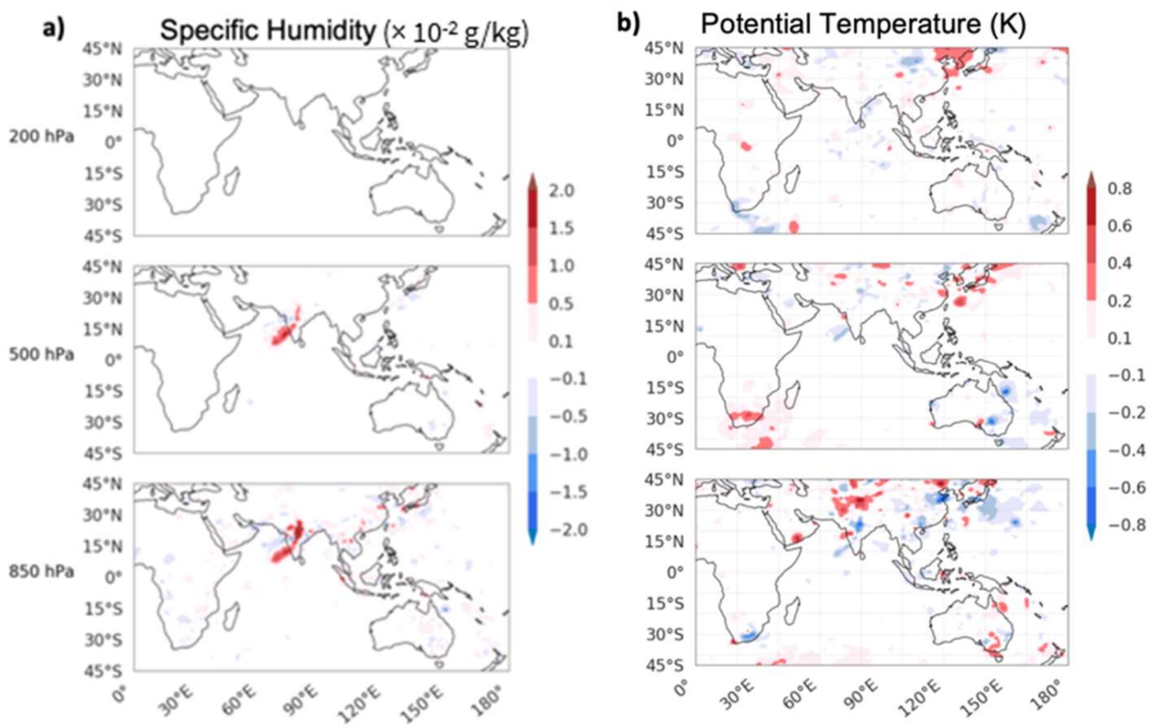

Figure 5: Difference in analysis increments (EXP-CTRL) for **(a)** specific humidity ($\times 10^{-2}$ g/kg) and (**b)** potential temperature (K) at 850, 500 and 200 hPa valid for 1200 UTC of 5 April 2023.

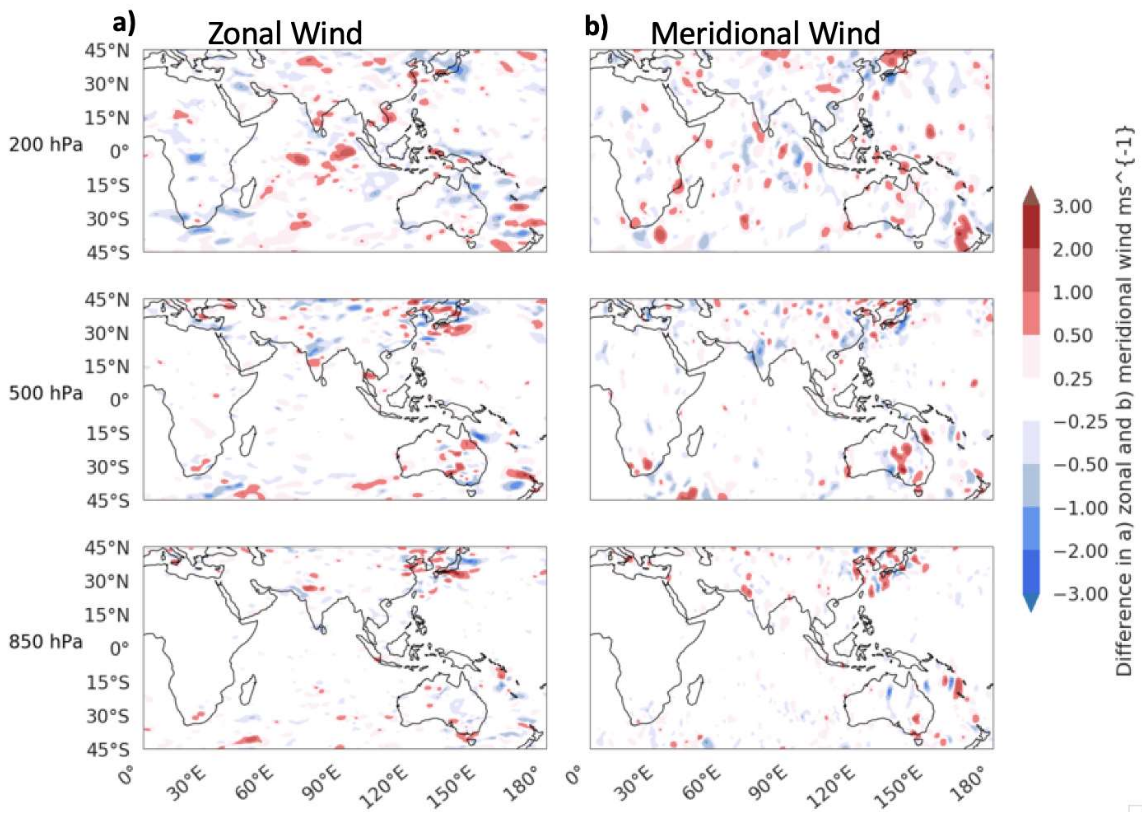

Figure 6: (a) Difference in analysis increments (EXP-CTRL) for zonal wind (m/s) and (**b)** meridional wind (m/s) at 850, 500 and 200 hPa valid for 1200 UTC of 5 April 2023.

Figure 7 shows the time series of area-averaged vertical profiles of the differences in the analysis increments of specific humidity, potential temperature, zonal and meridional wind components between EXP and CTRL experiments. The area average is over the spatial region where the Microsat-2B coverage is confined over India and surrounding Oceanic regions as per the orbital inclination of 37.2º (30° E -120°E and 45°S - 45°N). The analysis increments in the specific humidity are mostly confined over the lower and middle tropospheric levels with a dominant moistening effect. Rani et al., (2016) and Doherty et al. (2018) also reported a similar moistening effect when assimilated the MT-SAPHIR humidity sounder radiances. Though the differences in analysis increments in the humidity field appear to be small, it can produce more impact on the full analysis and forecast fields. The moistening effect varies at different assimilation cycles depending on the data coverage as shown in Figure 1b. Along with moistening there are drying effects as well, but in general the effect is moistening. This shows assimilation of Microsat-2B brightness temperature modifies (either adds or removes) the model humidity in the vertical. Though there are some changes in the analysis increments in potential temperature in the vertical (Figure 7b), they are not that significant compared to that of specific humidity. Some changes in the analysis increments of zonal and meridional wind components are noted in the middle and upper tropospheric levels as seen from figures 7 c and d.

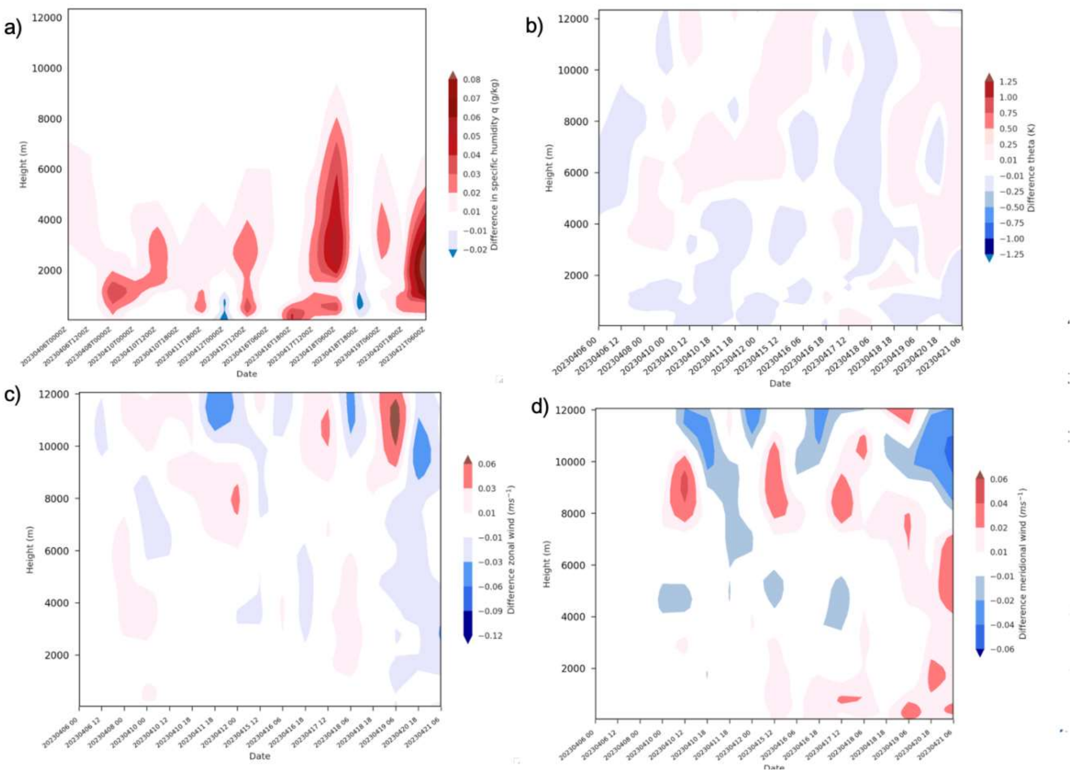

Figure 7: Time series of the area averaged vertical profiles of analysis increment differences (EXP-CTRL) in a) Specific Humidity (g/kg), b) Potential Temperature (K), c) zonal wind (ms^{-1}), and d) meridional wind (ms^{-1}) during the study period.

4. Summary and Future plans

SAC, ISRO has provided a set of sample observations from the new experimental satellite Microsat-2B. Microsat-2B has six humidity sensitive channels in the 183 GHz region of the spectrum with a capability to probe the atmosphere from surface to upper troposphere. ISRO has launched Microsat-2B as continuity to the MT-SAPHIR. The required changes in the DA systems are made to assimilate these observations the NCUM-DA system. This is the first time assimilation of Microsat-2B data in a global NWP system using the 4D-Var technique. The preliminary results shows that the assimilation of Microsat-2B radiances produces similar impact as that of MT-SAPHIR radiance assimilation reported by many operational centres. Generally, a moistening effect in the lower and middle tropospheric levels is noticed due to the assimilation of Microsat-2B during the study period. The impact of assimilation of Microsat-2B radiances on the temperature field is smaller compared to the impact on the humidity field. Also, noticed an impact in the middle and upper level wind fields due to the assimilation of Microsat-2B radiances. Since the data availability period was too short, it is difficult to make a general conclusion on the impact of Microsat-2B assimilation in the NCUM-DA system.

Only clear sky radiances from Microsat-2B for a shorter period were assimilated during the current study. It is planned to access more data from ISRO and to continue the study for a longer period both in clear sky and all-sky conditions. Experiments are also planned to change the thinning distance to 10 km, instead of 25 km. Since only conventional and satellite winds are assimilated in the baseline experiment in this study, OSEs are also planned to include radiances (both infrared and microwave) from other satellites.

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