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TECHNICAL REPORT

Assimilation of INSAT-3D Land Surface Temperature in EKF based Land Data Assimilation System

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May 2019

National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
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Abstract

Land surface temperature (LST) is a critical land surface variable which influences the surface energy budget. A reduction in the uncertainty in the NWP model initial condition of LST can be achieved by using LST analysis prepared using satellite observations. The assimilation of INSAT-3D LST observations in the NCUM global forecast system is described in this report. A pre-processing system is developed for preparation of INSAT-3D LST observation in the required format for the assimilation. The pre-processed observations are assimilated in the EKF based Land Data Assimilation System (LDAS) at NCMRWF. The technical details of the observation preprocessing system and land data assimilation system as well as initial results of the assimilation-forecast experiments are presented in this report. INSAT land surface temperature assimilation shows improvement in NCUM global model forecast of maximum and minimum temperature forecast over India. Nearly one day gain is achieved in the forecast of reduction in mean error in maximum temperature over Indian domain.

1. Introduction

Land Surface Temperature (LST) plays an important role in energy and moisture exchanges with the atmosphere. Land parameters such as skin temperature and soil moisture, exhibit a strong influence on boundary layer forecast of humidity and temperature (Candy et al., 2014). Thus, constraining the land state through assimilation of land observations in the Numerical Weather Prediction (NWP) model is important for improving the model forecast (Reichle et al., 2010). An Extended Kalman Filter (EKF) based land data assimilation system adapted from UK Met Office is used at NCMRWF for global soil moisture assimilation (Lodh et al., 2016). This EKF based land data assimilation system can also be used for assimilation of soil temperature and skin temperature. The accuracy of prediction of Land Surface Temperature (LST) plays an important role in determining the predictive skill of the model, as surface skin temperature has strong influence on the latent heat and sensible heat fluxes. This report presents the details of our efforts to assimilate the skin temperature retrieval from INSAT-3D and its impact on the forecast. Limited set of NWP model verifications studies with LST analysis are also included in this report.

2. Significance of INSAT LST pre-processing

Indian National Satellite (INSAT-3D), positioned at 82°E (Singh et al., 2016) was launched in 26 July 2013. INSAT-3D carries two meteorological payloads, an imager and a sounder. The imager has six channels centered at 0.65, 1.7, 3.9, 6.8, 10.8, and 11.9 μm. The 3.9 μm, 10.8 μm, and 11.9 μm channels are in infrared windows with little water vapour absorption. The resolution of these window channels are 4 km x 4 km. The sounder has eighteen narrow spectral channels in shortwave infrared, middle infrared and long wave infrared regions and one channel in the visible region. The INSAT LST algorithm uses 10.8 and 11.9 μm imager window channels.

The important steps in the pre-processing of INSAT-3D LST data for its use in the EKF land data assimilation system is depicted in the flowchart given below (Figure 1). Level 2 land surface temperature (LST) observation from INSAT-3D is available in half an hour interval from Indian Space Research Organisation data repository (MOSDAC) in HDF5 (Hierarchical Data Format) format. Details about the nomenclature of observational INSAT - LST files from MOSDAC are given in Appendix A.

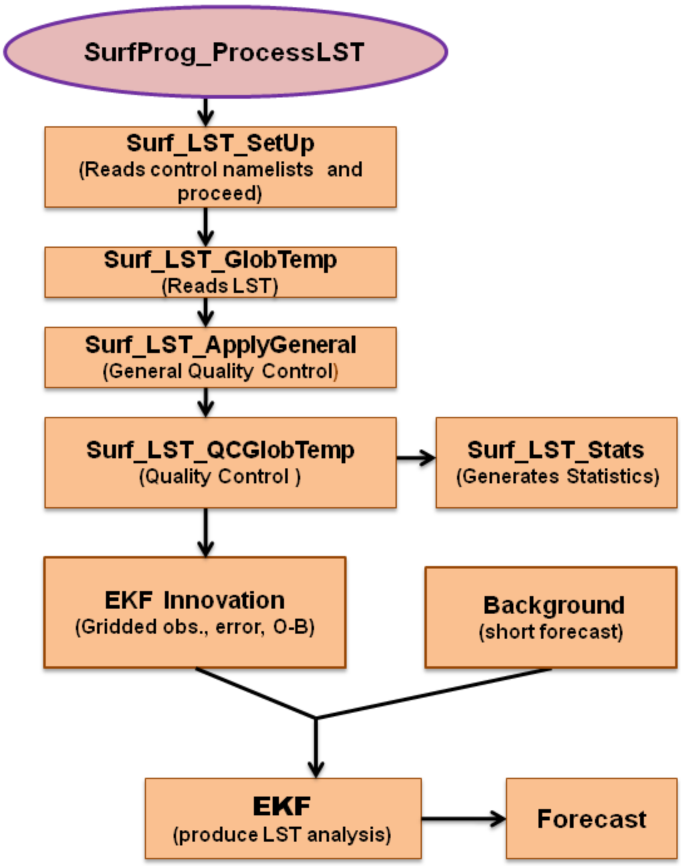


Figure 1: Schematic of pre-processing of INSAT LST assimilation done at NCMRWF

3. Land surface temperature assimilation

The components of the EKF based system for land surface temperature assimilation are: (a) Pre-processing of satellite derived INSAT LST data (b) LST assimilation in EKF system. The scientific and technical details of EKF based land data assimilation system and its components are described:

3.1 Pre-processing of INSAT-3D LST for its use in the EKF

The INSAT - LST files are converted from HDF5 format to netcdf format to make it readable by the surface processing system (SURF) program of the NCMRWF Unified Model (NCUM) system. In the Rose-Cylc (framework for development and run the meteorological suites) setup, the app "gl_surf_insat_ekf" performs the pre-processing of the INSAT LST observations to produce gridded LST observations in fields file format. The gridded observational file is quality controlled and used in the EKF system. The "SURF_ProcessLST" program writes the LST statistics i.e. Satellite name, product type, number of total observations, number of observations passing QC, mean and standard innovation (K) for each cycle of data assimilation.

The preprocessor program *"SurfProg_LST"* for satellite LST data creates an **"**EKFob**"** file containing gridded LST innovations from quality controlled satellite retrievals of LST, ready for use in Land DA. SURF already have a capacity to assimilate LST from satellites such as SEVIRI, MODIS etc. and here in this report we have extended this capacity to assimilate INSAT-3D LST data too, within the SURF system. The primary input data is received from Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC) repository of Space Application Centre (SAC) - Indian Space Research Organisation (ISRO), Ahmedabad. The time lag of receiving the INSAT3D LST (L2) observation data from MOSDAC is 30 minutes (See Figure 2). The python script converts the INSAT3D LST data from HDF5 to NetCDF4 format over the Indian region, where GeoX and GeoY values range between **(**1000, 1800) and (530, 1350), respectively, using PYTHON - UVCDAT utility. For L2B products from ISRO, GeoX is dimension for pixel direction and GeoY is dimension for scan direction of TIR1, TIR2 and MIR channels, respectively.

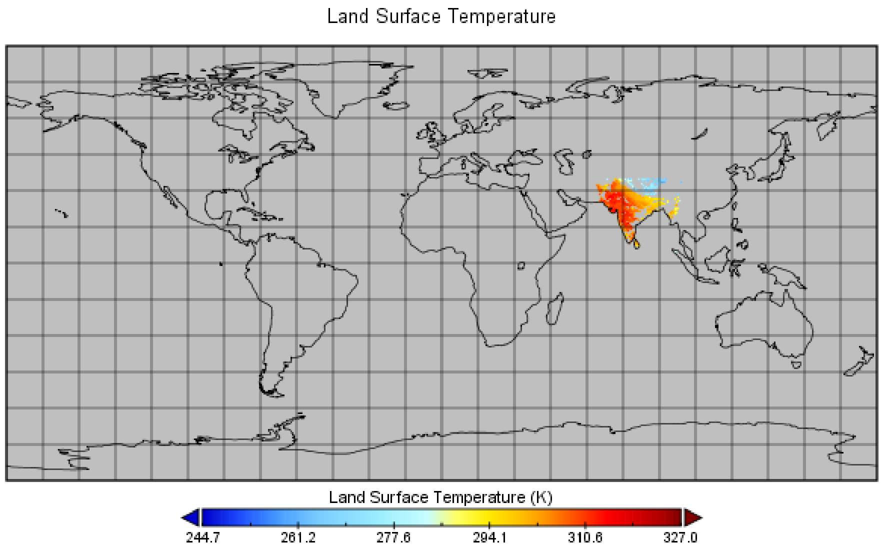


Figure 2: Half an hourly INSAT-3D LST observations (12UTC; 20180501) used in the assimilation for a typical data assimilation cycle.

The important attributes to be present in the header of the INSAT LST data (to be assimilated in the SURF system) are : product creation time, acquisition end time, station id, conventions, sensor name, nominal central point coordinates (degrees) for Latitude and Longitude, title, left longitude, source, acquisition start time, unique Id, sensor id, satellite name, version of the software, nominal altitude in km, format of output, acquisition date, lower latitude, type of product, institute, acquisition time in GMT, upper latitude, right longitude, processing level, HDF product file name, ground station.

The pre-processing program for land surface (skin) temperature (LST) includes the following steps:

- The first step is to generate the surface temperature (STASH CODE is 00024_0279a978)" background field (glu_pp_smc) at time interval of five minutes from assimilation window of "t+3 to t+6".
- The next step is to determine the instrument and product source. These are read in from the environment variables SURF_SATINSTNAME & SURF_SATPRODUCT. Then obtain the file list of observation LST global temperature data to be assimilated.
- Read in variables for quality control. These are read from a control file of the form: SURF_SATINSTNAME_LST_SURF_SATPRODUCT.nl. The namelists read are lst_control, lst_qualitycontrol, lst_bayseian quality control, lst_gridded. Also, the data over oceans, seas and mountains is rejected.
- Then, the INSAT-3D land surface temperature observations and associated records are read along with the model background fields. Rapidly varying fields are read in for each hour of the assimilation window. Then quality control tests are applied to the satellite LST observations (L2 product) and converted to gridded format/model grid storing a grid point average of the LST value, LST innovation and LST supplied uncertainty (See Figure 3). Simple gridding method is applied to locate all INSAT LST observations on the model grid point in which the LST observations are located. After that quality controlled INSAT - LST data is written as gridded field as an "EKFob" file (Fields File Format). The maximum allowed orographic height is 2000m, minimum allowed LST is 250K and maximum allowed LST is 350K. Further, from in-situ and NWP model results the maximum supplied INSAT LST uncertainty is calculated and supplied as 3.5K (Candy 2013). It is important to mention here that no static bias correction is applied to INSAT LST data here. Control file for INSAT LST data assimilation and the corresponding EKF control file is given in Appendix B and C, respectively.

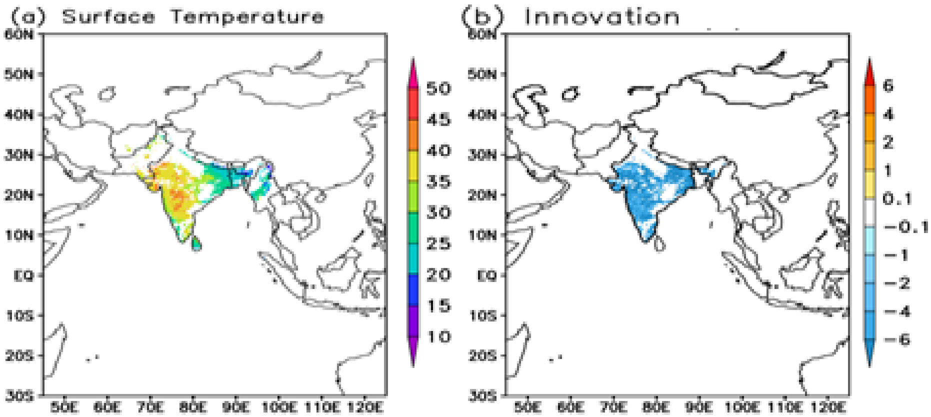


Figure 3: The mean INSAT-3D LST (°C) observations and innovations (i.e. observation - background) in gridded format after SURF pre-processing of observations.

More details about the setup of the EKF based land data assimilation system for LST can be found at the links given below:

- https://code.metoffice.gov.uk/doc/surf/surf-32.0.0/doc/SUDP18.html

3.2 LST assimilation in EKF system

Observation operator provides the link between the observation space and model space. In the EKF system Jacobian of the non-linear observation operator is computed using offline forecast runs (here 3 hr forecast) of JULES model (through finite difference of the forecast). Since the data assimilation system described here can assimilate nine variables (control variables are; soil moisture at 4 levels, soil temperature at 4 levels and LST), it is required to have nine perturbed run of the JULES land-surface model along with one unperturbed run. The atmospheric forcing data for the off-line JULES land surface model run with the data assimilation system (precipitation, surface long wave and short wave radiation, air temperature, surface temperature and humidity, wind speed and surface pressure) are obtained from the NCUM short range forecast.

The pre-processor system generates the quality controlled gridded LST (O-B) innovations on the model grid. For INSAT LST data pre- processing, to compute the innovation, the nearest background LST field consistent to the observation time is used (the current time interval is 30 minutes within the assimilation cycle).

After INSAT - LST assimilation, short forecast is made corresponding to 00, 06, 12 and 18UTC assimilation cycle. With the initial and boundary condition from short forecast (i.e. forecast with shorter lead time), the NCUM model long forecast is made. The maximum and minimum temperature verification is completed.

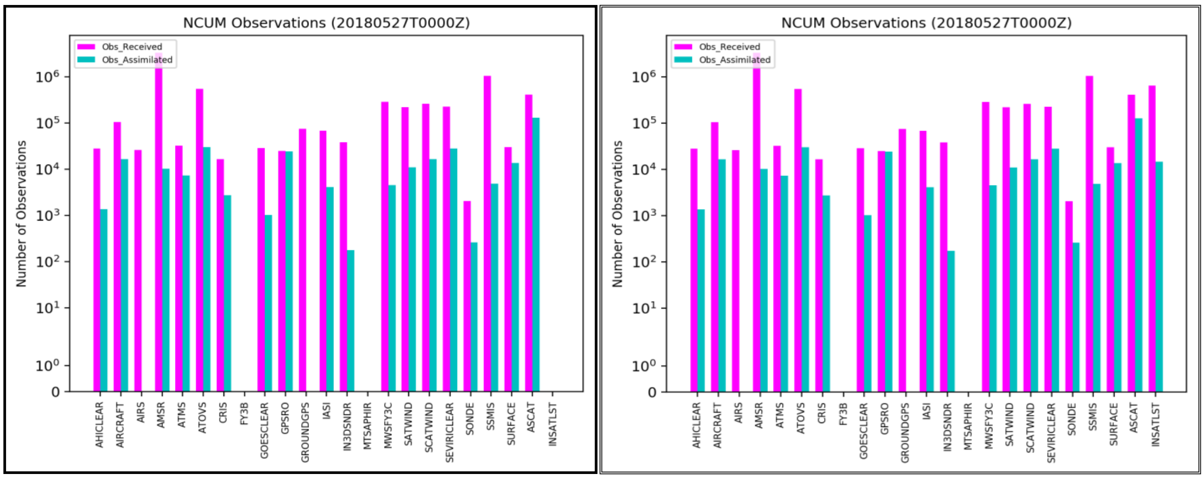
4. Forecast experiments with LST analysis

Assimilation-forecast experiments are carried out to understand the impact of the use of INSAT-3D LST data on numerical weather forecast. Jules land surface scheme is used in the model as well as in the assimilation system. The present set up of land surface has four layers; Surface - 10 cm, 10-35 cm, 35-100 cm, 100-300 cm. The following sets of experiments for one month are performed at N1024 atmospheric model resolution (~12km) :

a) CONTROL experiment in which only soil moisture observations are assimilated in the land data assimilation system (EKF).

b) INSAT LST experiment where INSAT-3D LST observations and soil moisture observations are assimilated.

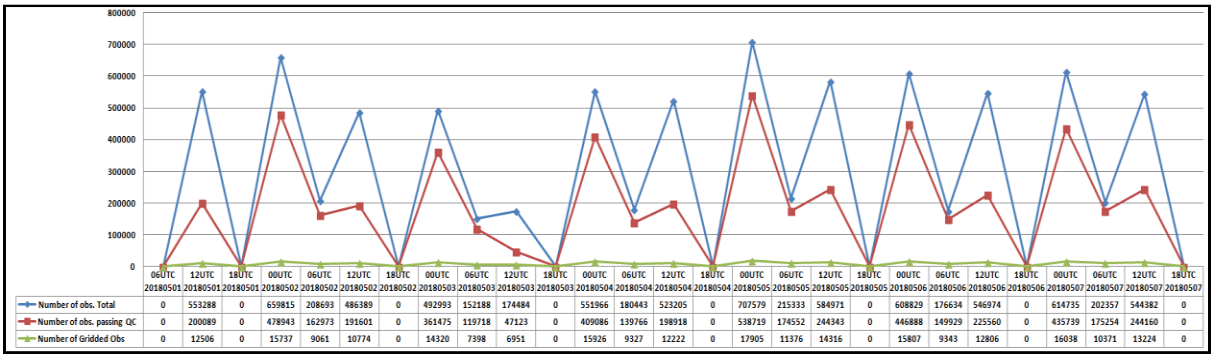
In both experiments for preparation of soil moisture analysis, atmospheric observations of screen temperature and humidity (at height of 1.5m) and ASCAT satellite soil moisture data are assimilated. The assimilation experiments are carried out for the period 1st May 2018 to 31st May 2018. Seven day forecasts are produced based on 00 UTC initial conditions during all days of May, 2018. Figure 4 shows various observations assimilated (over atmosphere and land) in the NCUM model for the (a) CONTROL and (b) INSAT LST experiment in a typical data assimilation cycle eg. (20180527; 00 UTC). In the INSAT LST experiment, INSAT LST data (after pre-processing) along with soil moisture observations are assimilated. Surface analysis and atmospheric analysis produced by EKF and Hybrid 4D-Var system (Kumar et al., 2018) respectively. Land surface analysis of soil moisture and LST are used to initialize the land surface for the forecast run.



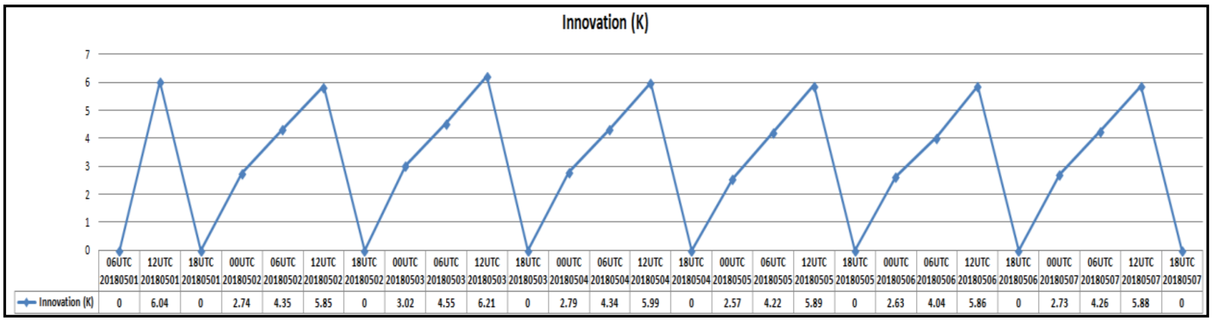
(a) **(b)**

Figure 4: Bar Plots of the various observational data included in (a) CONTROL and (b) INSAT LST assimilation

The INSAT LST observations received from MOSDAC is extracted over the Indian domain (5-40°N; 65-100°E). After quality control, good quality observations are selected for assimilation (Figure 5). It is important to report that INSAT LST observations are received for 00 UTC, 06 UTC and 12 UTC data assimilation cycles but not for 18 UTC cycle routinely (In case of LST +/- 30 min data is used in the data assimilation for each cycle).



(a)



(b)

Figure 5: (a) Total number of INSAT LST observations received and quality controlled (b) Innovation (i.e. observation-background).

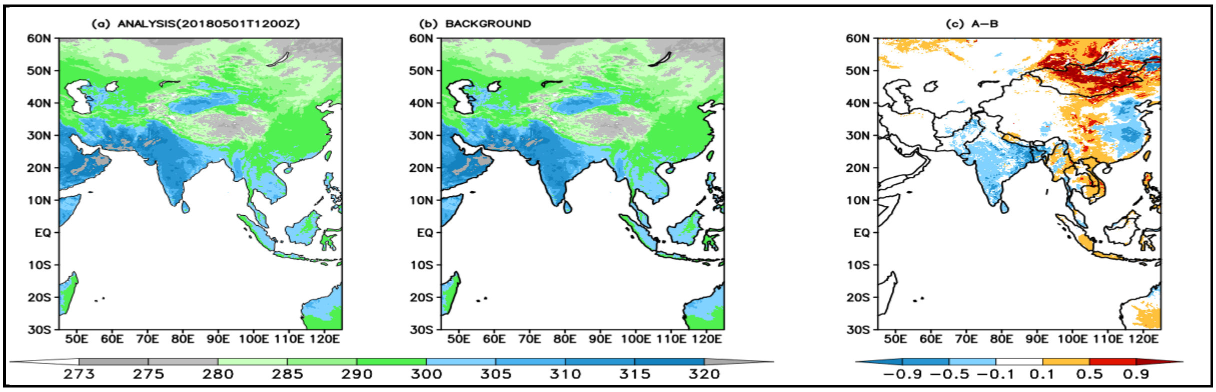


Figure 6: (a) Mean surface soil temperature analysis (˚K) (b) background surface soil temperature (˚K) and (c) "analysis - background" (˚K) on a typical time of 12 UTC.

In LST experiment, surface skin temperature is modified over the regions where INSAT-3D LST data is assimilated (Figure 6). There is reduction in LST upto -0.9 K over India region with respect to the background. There are also changes in the LST values over elsewhere as well where we are not using any observations.

Prior knowledge of land surface state with reasonable confidence yields significant skill in forecasting (Koster and Suarez 2003). This report further conducts the maximum and minimum near surface temperature verification (at 0.5^0x0.5^0 resolution) in line with Singh et al., 2017. IMD's real-time daily gridded (Srivastava et al., 2009) temperature (maximum and minimum) observations data sets are used to verify the forecasts. Along with mean monthly error, the verification metric include Probability of detection (POD) as well. Description about POD is given in Singh et al., 2017.

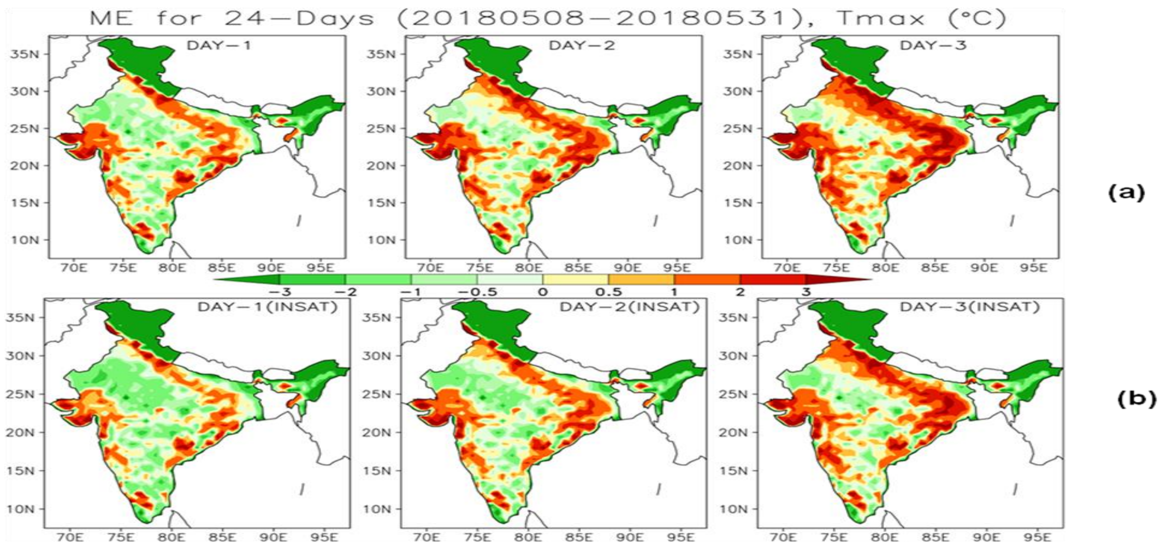


Figure 7: Spatial distribution of mean error in maximum temperature for (a) CONTROL experiment and (b) for INSAT sensitivity experiment for 24 days from 20180508 to 20180531.

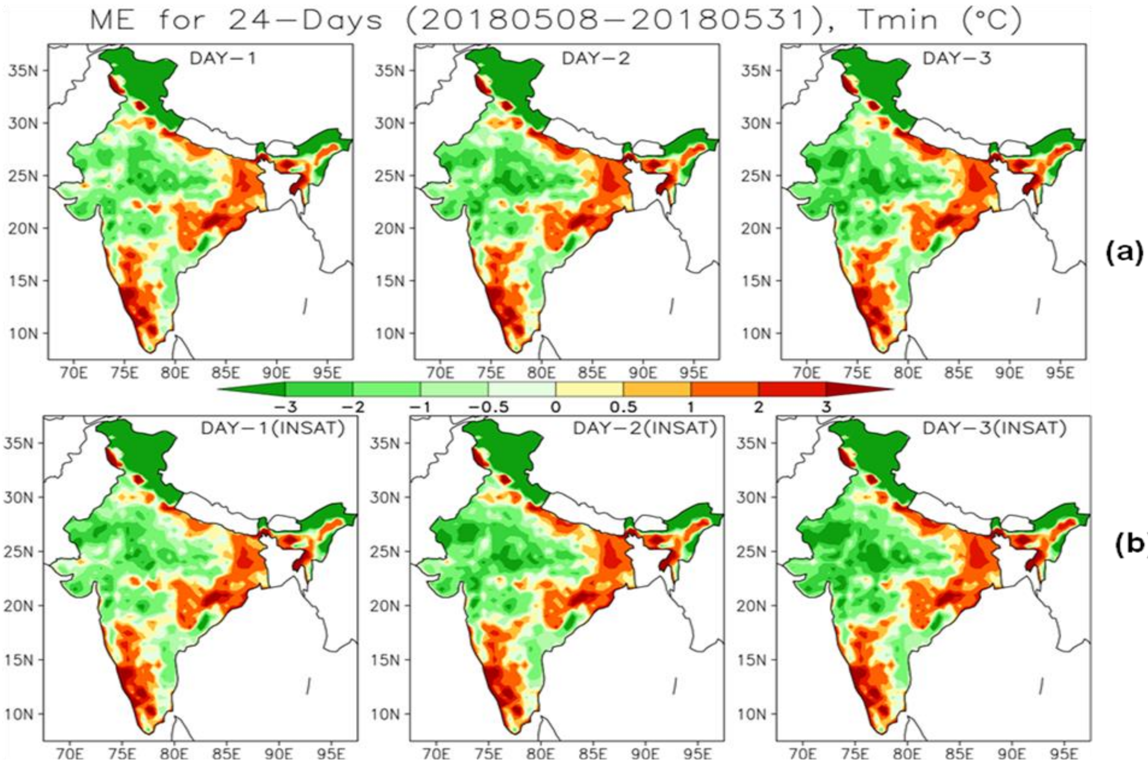


Figure 8: Spatial distribution of mean error in minimum temperature for (a) CONTROL experiment and for (b) INSAT sensitivity experiment for 24 days from 20180508 to 20180531.

From Figure 7 and 8, it is confirmed that by the assimilation of INSAT land surface temperature in the NCUM system, the mean error in maximum temperature forecast (w.r.t IMD maximum temperature) is reduced over India domain in all days by around 0.5 ^{0}C to 1^{0}C. However, in minimum temperature forecast, the mean error is reduced over north-west India only, that too in certain regions.

From Figure 9, it can be observed that POD for NCUM maximum temperature forecasts for Day-1, Day-2, Day-3, Day-4 and Day-5 forecasts is improved for the temperature ranges of 32-34^{o}C, 34-36^o, 36-38^{o}C, 38-40^{o}C to 40-42^{o}C. This clearly indicates the skill of forecast is improved for the surface air temperature due to the assimilation of INSAT LST. From Figure 10, it can be observed that for minimum temperature, Day-1 and Day-5 forecasts are improving only in the temperature ranges of 22-24^{o}C, 24-26^{o}C and 26-28^{o}C.

Hence, the work presented here has the potential to improve the forecast of near surface variables in the real-time forecast, especially the forecast of surface temperature.

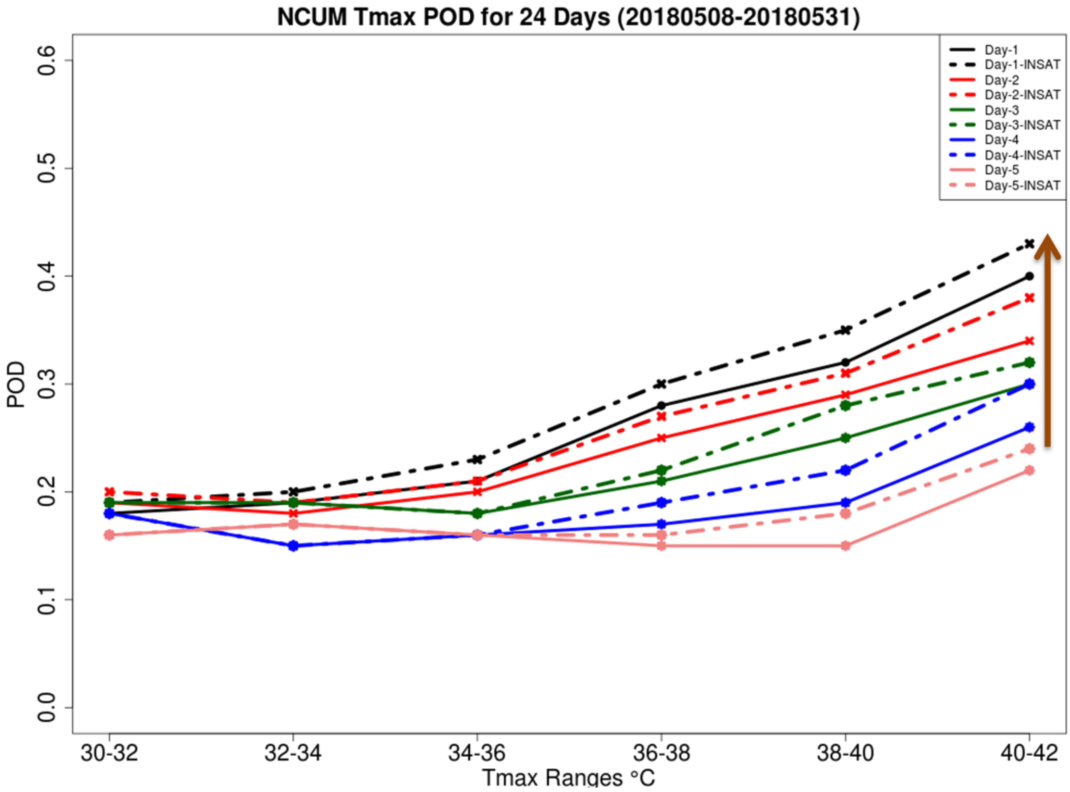


Figure 9: POD for maximum temperature forecasts for (a) CONTROL (straight line) and (b) for INSAT experiment (dashed line).

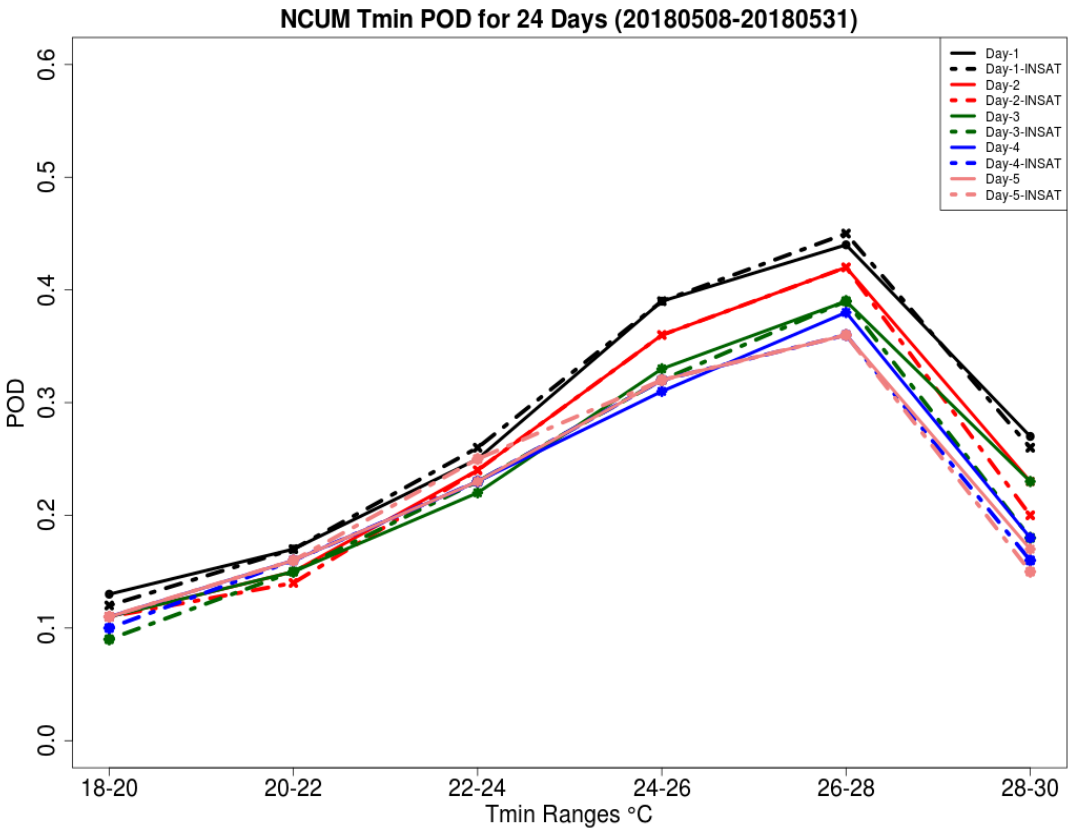


Figure 10: POD for minimum temperature forecasts for (a) CONTROL (straight line) and (b) for INSAT experiment (dashed line).

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Appendix A :

The HDF5 INSAT - LST file names are coined as:

SSNNN_DDMMMYYYY_HHmm_LOP_XXX.h5, where

SS=Satellite ID (e.g. 3D for INSAT- 3D)
NNN=Sensor ID (IMG for Imager, SND for Sounder)
DDMMMYYYY=Date of Acquisition (DD=Day of Month, MMM=Month of the year, YYYY= year of Pass e.g. 01MAY2018)
HHmm=Time of Acquisition (HH=Hour of day mm=minute of the hour)
LOP=Level of Processing (L1B, L1C, L2B, L2G, L2P, L3B, L3G)
XXX=Parameter Name) or STD or Sector Name

e.g. 3DIMG_01MAY2018_2030_L2B_LST.h5

Appendix B :

! File: INSAT_LST_GlobTemp.nl
!
&LST_CONTROL
ApplyStaticBiasCor=F
Reject_SnowPts=T
Check_ModelCloud=F
REJECT_DAYPTS=F
HourlyFieldRange (**1) = -1**
HourlyFieldRange (**2) = 1**
/
!! allow any of met-**8,9,10**
&LST_QC
MaxLSTUnc=**3.5**
CloudThreshold=**0.2**
MinAllowedLST=**250**
MaxAllowedLST=**350**
/

Appendix C : EKF_Control namelist variables

Namelist files are designed to be specific to the instrument and observation type:

Name	Type	Default Value	Description
ApplyStaticBiasCor	L	F	Apply bias correction to the LST gridded obs before generating EKF ob file
Reject_SnowPts	L	T	Reject observations over model snow points
Check_ModelCloud	L	T	Reject ob if nearest model point is not clear
Reject_DayPts	L	T	Reject ob if daytime
HourlyFieldRange	Float array (2)	(/-3,3/)	range of hourly fields extracted with respect to analysis time
UseSatId	Integer array(5)	IMDI	List of satellite ids to use
SnowThreshold	Float	0.05	Minimum value to denote grid point snow (kg/m2)
CloudThreshold	Float	0.2	Maximum cloud fraction in model to denote clear point
MaxAllowedHt	Float	2000	Max allowed surface ht (m) - taken from model Orography
MinAllowedLST	Float	250	Minimum allowed LST (K)
MaxAllowedLST	Float	350	Max allowed LST (K)
MaxLSTUnc	Float	3.5	Maximum allowed LST uncertainty (K)
PriorPGE	Float	0.05	Initial Probability of gross error for Bayesian test
BgErr	Float	2.0	Background Error for LST (K) used in Bayesian probability of gross error calculation
ObErr	Float	2.0	Observation error (K) - used in Bayesian calculation and supplied to EKFob file for each grid point if there is no supplied uncertainty in the LST product
Gridding Option	Integer	1	1 => simple gridding, 2=> locating obs within a certain radius of each grid point