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An objective method for detecting night time fog using MODIS data over northern India

Sasmita Chaurasia and B.S. Gohil
Space Applications Centre, ISRO
Ahmedabad- 380015 (INDIA)
Email: sasmita@sac.isro.gov.in, bsgohil@sac.isro.gov.in

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Abstract: An objective method for detecting night time fog based on bi-spectral difference of 3.9µm and 11µm channel brightness temperature has been developed. The thresholds used in this are dynamically derived, based on the data and have been tested with MODIS AQUA/TERRA data for December 2012-January 2013 and December 2013-January 2014 winter season over northern India. The generated fog maps for December 2012-January 2013 have been validated qualitatively with the fog map generated by IMD (India Meteorological Department) using MODIS data. Quantitative validation has been carried out for January 2014, against visibility data at five locations of Northern India. Fog was detected with 70% success rate using this objective method over this region for the validation period.

Keywords: Fog, MODIS, Bi-spectral, Brightness Temperature Difference (BTD), Indo Gangetic Plains (IGP)

1. Introduction

Fog is a meteorological weather phenomenon in which the cloud has its base very close to ground and the visibility reduces to 1000m or less. Apart from its impact on the transportation system as an important socio-economic factor, it has great impact in the field of meteorology, climate studies as well as on human health and crops. Therefore, an improved understanding, monitoring, forecasting and nowcasting of fog will benefit the society as a whole (Gultepe et al., 2009).

Over northern India, fog occurs for a considerable period particularly during winter season (Singh et al., 2004; Dutta et al., 2004; Tiwari et al., 2011). The Indo-Gangetic (IG) plains along the Himalayan region form a trough region, where cold air drainage flowing from the higher plateau gets collected leading to the enhancement of relative humidity. Under clear sky condition, fog forms basically due to radiative cooling of the earth's surface during winter season. In this period a series of low and high pressure zones moves from NW to NE along the Himalayas. During a low pressure zone, it may rain to add more moisture to the atmosphere. This moisture content immediately after the high pressure zone gets condensed due to radiative cooling of the surface, which may lead to the formation of dense fog over a wide region (Singh et al., 2004). Apart from the meteorological condition the local levels of surface as well as atmospheric conditions also leads to the intensification of fog. Once fog layer is formed it persists for the whole duration of the passage of the high pressure zone and typically may extend from Punjab to the Bay of Bengal region along the trough. In the IG plains, it is also observed that during winter season i.e. from November to February the wheat fields are irrigated which adds to the relative humidity over this region. The pollution over the metro city Delhi and surrounding is also responsible for fog formation due to availability of sufficiently large condensation nuclei (Ram Kripa et al., 2012). Emissions from agricultural waste and biomass burning dominate during winter time among other major source of aerosols.

Even though the effect of winter fog in the north Indian region is very high it has not been studied extensively. Specifically, its formation, spatial extent and evolution are required to be studied in detail. It is difficult to monitor the spatial and temporal extent of fog over large-scale areas such as the IG plains using a limited conventional and ground based observational network, so satellite based fog monitoring becomes popular due to its enhanced spatial, spectral and temporal resolution and offers new opportunities for near real-time fog detection and monitoring.

The night time fog detection is very important because fog at night causes difficulties in aviation, land and marine transport. Numbers of surface observations are also limited during night because many of the stations do not operate during this time. Because of the low density of surface observation at night, and to get information about the complete coverage of fog, remote sensing technology provides better opportunity. Many approaches have been developed to detect fog at night (Eyre et al., 1984; Turner et al., 1986; Bendix, 2002). Detection of fog at night using satellite observation relies on the thermal emission of the surface. As it is not contaminated with solar radiation, the false alarm in night time fog detection is less. Most of these methods are based on the particular emissive properties of fog at 3.9µm and 10.8µm wavelengths (Bendix and Bachmann, 1991). The small droplets found in fog are less emissive at 3.9µm than at ~11µm, whereas for larger drops both emissivities are roughly same (Hunt, 1973). Thus the difference between brightness temperatures at these wavelengths are useful and tested for detecting fog against other clouds and land features. The method has been successfully implemented on Geostationary Operational Environmental satellite which provides the required spectral bands (Ellord, 1995; Wetzel et al., 2004; Lee et al., 1997; Greenwarld and Christopher 2000; Underwood et al., 2004). Recently Cermak and Bendix (2007, 2008) have applied the same algorithm to data of Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board Meteosat Second Generation (MSG). As an extension to earlier work (Chaurasia et al., 2011), in this study an objective approach has been developed for the detection of fog during night time over the IG plains.Asthe brightness temperaturedifference depends on the optical depth, particle size, type of fog etc. (Chaurasia et al., 2011) a fix threshold leads to false detection or there is a probability of miss. In order to minimize this a dynamic thresholding approach has been developed and the thresholds are dynamically set for each image under consideration.

2. Data used

Night time fog detection has been carried out using data from MODIS AQUA/TERRA. The MODIS sensor on board the EOS TERRA and AQUA platforms shows the best spectral resolution from operational Low Earth Observation (LEO) systems with 36 spectral bands from visible to thermal infrared portion of the electromagnetic spectrum (Schueler and Barnes, 1998; Levy et al., 2007) (29 spectral bands with 1km, 5 spectral bands with 500m and 2 spectral bands with 250m nadir pixel dimensions). The MODIS Terra/Aqua Level 1B data for night time over north India were obtained from http://ladsweb.nascom.nasa.gov for the period December 2012 to January, 2013 and December 2013 to January 2014. The data of MODIS AQUA having passes over India around 2000UTC is more appropriate for night time fog analysis, because the formation of fog gets initiated at night and is more intense towards early morning. However, the MODIS Terra data at an earlier over pass time from 1600UTC to 1900UTC is also used, because it covers more area of the IG plains of India.

3. Methodology

The flowchart for the objective dynamical thresholding method as has been developed for the present study is shown in figure 1. Besides using the thresholding scheme in the brightness temperature difference image, an attempt has also been made to eliminate the false alarm due to other cloud types and snow by using behavior of cloud and snow in individual channel.

The Level 1B emissive channels were geo-referenced and the data corresponding to 3.9µm and 10.8µm (Band 22 and 31 of MODIS channels) of MODIS were extracted. The radiance values of both channels were converted to brightness temperature through Planck's function. As mentioned in previous paragraph for gross cloud check the long wave infrared or thermal infrared (TIR) channel centered around 10.8 µm has been used. In the long wave infrared (10.8 µm) channel the radiation from land and fog/cloud is the main radiation source. The higher the temperature greater will be the radiation from surface and fog will have higher temperature compared to medium and high level clouds. Thus brightness temperature of fog will also be higher than that of medium and high clouds. However, in case of fog there is always temperature inversion, so that the temperature of fog is similar or even higher than that of surface. Therefore, long wave IR channel can be used to eliminate medium and high clouds whereas it is very difficult to differentiate between fog and the under lying surface using thermal channel alone. The brightness temperature of the medium/ high cloud is the lowest and almost below 270° K (Yang et al., 2008). In order to determine this threshold dynamically, the histogram of 10.8µm channel brightness temperature are examined. It is smoothed to reduce spikes. The histogram of the images corresponding to both the channels show two maxima around one minimum (shown in figure 2a, 2b). The first maxima correspond to low brightness temperature values, which corresponds to pixels with high clouds and snow. Using the BT corresponding to the minima in TIR channel, high clouds and snow are eliminated. If more than one minimum is found then a threshold of 270°K for the TIR channel can be used to eliminate the high clouds and snow pixels considerably. The new image now contains only low clouds, fog as well as pixels corresponding to land. For bi-spectral differencing brightness temperature difference image ($BTD=BT_{10.8\mu m} - BT_{3.9\mu m}$) is generated.

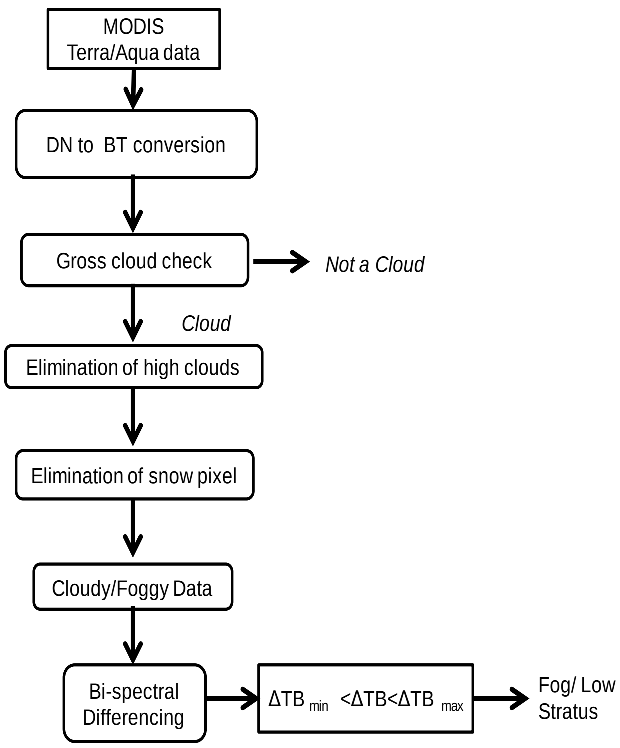


Figure 1: Flow chart for night time detection of fog using MODIS data

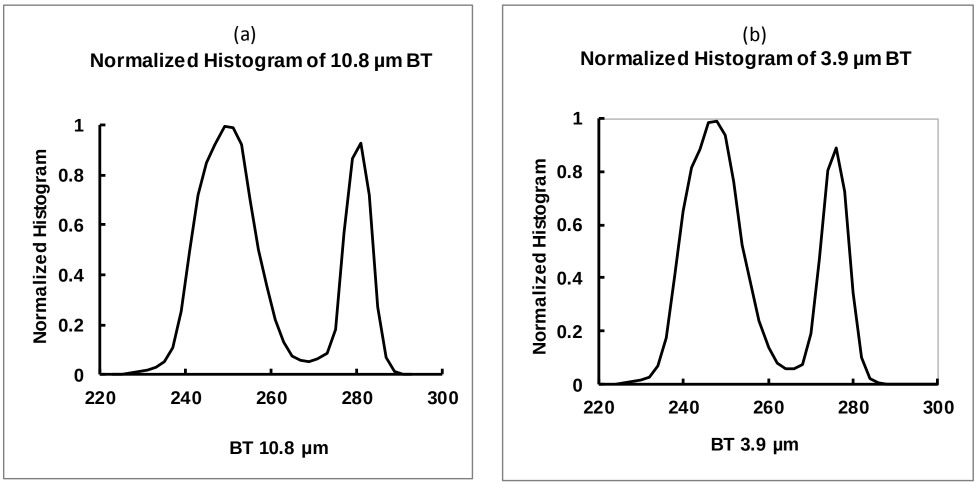


Figure 2: Histogram of brightness temperature in two channels (a) 10.8 µm and (b) 3.9 µm

In order to separate out the fog pixels only, the scatter plot between TIR brightness temperature and BTD values of the image is studied. Figure 3 shows the scatter plot between TIR BT and BTD for a typical case having fog, clear pixels, snow and cloud. From the scatter plot it is seen that for brightness temperature less than 270° K, the brightness temperature difference values are mostly negative or takes a very small positive value. This corresponds to the high level clouds and snow.

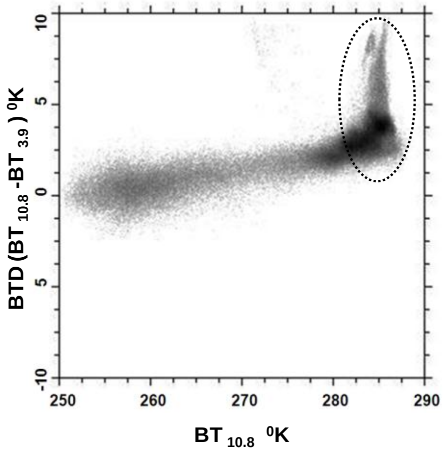


Figure 3: Scatter plot of brightness temperature of 10.8µm and brightness temperature difference (The cluster marked within the ellipse indicates the presence of pixels with fog)

However, for land, low clouds and fog regions where the brightness temperature is more than 280°K, the brightness temperature difference is positive. Due to temperature inversion the brightness temperature of fog is either similar or greater than that of the underlying land. Thus the pixels with TIR brightness temperature greater than 280 and less than 290° K, will correspond to land pixels over laid by fog or low cloud pixels during night (as observed from the figure 3). From the figure it is also observed that for these values of BT the BTD is having large positive value and appear as a separate cluster. It is a remarkable feature (Marked as ellipse in figure 3) which separates out the foggy pixels from the underlying land pixels. The information in this cluster is used to find out the minimum threshold value for BTD and the pixels having BTD value more than the minimum threshold value is classified as fog. The ΔTB_{min} is determined automatically from the histogram, of the BTD image. In a typical fog image, the histogram of BTD image shows one primary maximum, a secondary maximum and a minimum in between (figure 4a). In such a condition, BTD corresponding to the minima value can be considered as the ΔTB_{min} and pixels havingΔTB more than $\Delta TB_{min}$is classified as fog. For such type of scenes, the detection of fog is completely objective as well as dynamic.

However, the MODIS data which has been used for this analysis is in tile form and for each acquisition the frame of the image changes and thus the proportion of different features in the image also changes. Therefore, for some cases in the histogram of BTD image of MODIS data, only single maximum is obtained (figure 4b). In such cases the threshold for BTD (ΔTB_{min}) is set to a point where the slope of the clear sky pixel drops considerably and ΔTB more than $\Delta TB_{min}$is classified as fog. By applying this methodology fog region has been identified with MODIS nighttime data from 01 December 2012 to 31 January 2013 as well as for 01 December 2013 to 31 January 2014 and compared with MODIS fog image of IMD (India Meteorological Department, www.imd.gov.in), whenever available as well as with the early morning MODIS RGB data of next day. However, a quantitative validation of fog map generated for January 2014 has been carried out with visibility data at five different locations i.e. Delhi, Lucknow, Jaipur, Amritsar and Varanasi situated in northern India.

Journal of Geomatics Vol 10 No. 1April 2016

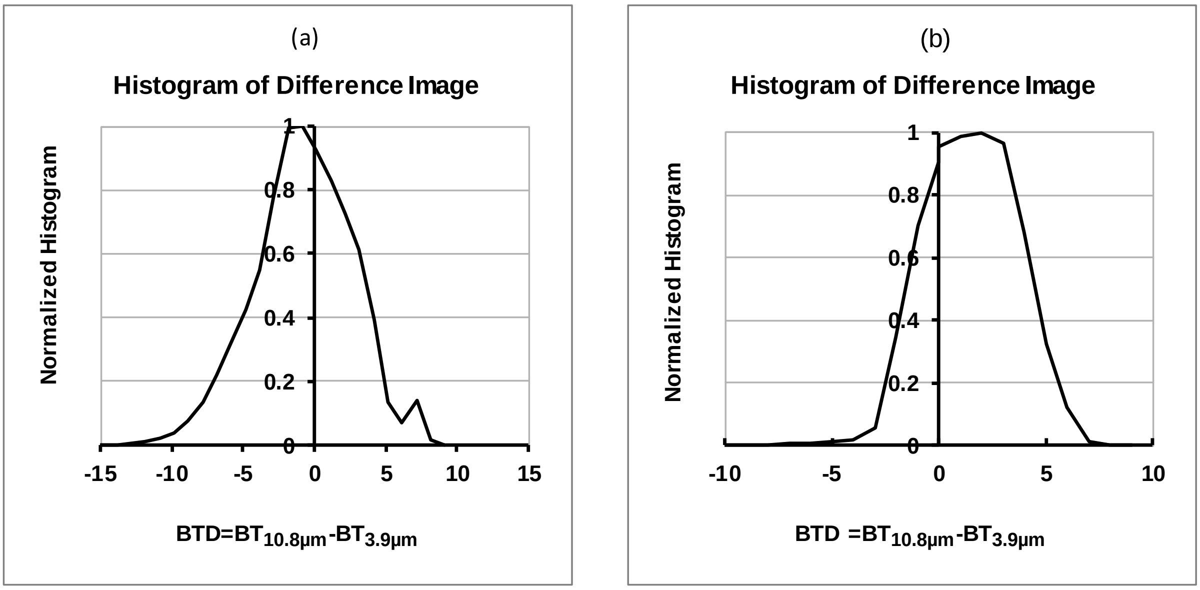


Figure 4: Histogram of brightness temperature difference image (a) BTD image showing double peak (b) BTD image showing single peak

4. Results and discussion

The evolution of fog over Indo-Gangetic plain in December 2012 and January 2013, using MODIS Terra/AQUA data (Different colour shows the BTD values) is shown in figure 5. In order to show the evolution of fog to the maximum extend over the IG plains, both the fog map generated using MODIS AQUA/TERRA has been shown in this figure. Care has been taken to incorporate maximum fog period to show the evolution. Therefore, few days with in December 2012 and January 2013 is missing in the figure 5. As observed from the fog map generated by the above method, the 2012-2013 fog periods started around early December. On December 09, 2012, fog was initiated in the eastern states like Bihar and gradually it extended spatially and covered Bihar and part of Uttar Pradesh by December 15, 2012. The spatial extent continued to increase both from east to west as well as in the southern direction starting from the foot hill of Himalaya. During December 22-25, 2012 it covered the entire Indo-Gangetic plain starting from Bihar at the east to Punjab at the west. This is the time when the wheat cultivation in the four major wheat growing states Bihar, UP, Haryana and Punjab are in full swing and the fields are irrigated, which adds to the local moisture availability apart from the prevailing meteorological condition and temperature inversion in this region which is conducive for fog formation. Similar situation continued till January 07, 2013.

On January 10, 2013 part of north-western region of Uttar Pradesh was covered with fog which extended in width till January 14, 2013. On January 19, 2013 there was heavy fog condition over Punjab and parts of Haryana. On January 21, 2013 again Uttar Pradesh region was engulfed with fog which continued till February 2013 (results shown till end of January). The gradient in the fog map shows the category of fog i.e. shallow, dense and very dense depending on the change in brightness temperature difference. The minimum difference in brightness temperature ΔTB_{min} which is obtained to detect fog varies from 3° to 8° K for the period of analysis. For each image the threshold is found to be different. This change in threshold is attributed to the change in fog optical depth and droplet size (Chaurasia et al., 2011). BTD value of 3° K corresponds to very thin fog. However, for BTD values between 4 to 5° K corresponds to moderately dense fog. BTD value of 6 and >6 °K represents very thick fog. This gradation is empirically made based on our earlier study (Chaurasia et al., 2011) as well as from the visibility data.

The generated fog map has also been compared with the next day morning RGB image and fog map generated by IMD using MODIS data. The qualitative inter-comparison of the two maps is shown in figures 6 and 7 indicating good agreement with each other. Bi-spectral differencing technique has also been used in the generation of fog map by IMD using MODIS data, and a pixel is classified as fog/low stratus when the BTD is greater than 2.5^0 K (Product catalog, www.imd.gov.in). This threshold is fixed for all images. In order to make the two maps comparable instead of showing the variation of BTD over fog, only fog and no- fog regions are generated. The blue colour in both the images shows fog. It is observed from the figure 7 that, for December 25, 2012, there is a systematic data loss in IMD fog map. It is also observed that it has also picked up some of the high cloud part in the southern part of the image, which is filtered by new developed dynamical thresholding algorithm. Similarly, the cloud captured by IMD fog map on January 10, 2013 is also not captured by our algorithm.

A quantitative validation of the generated fog map has been carried against the in-situ visibility data over five different locations on north India i.e. Delhi, Jaipur, Varanasi, Lucknow and Amritsar. Table 1 shows the error statistics of validation. It shows that the percent of detection is 70%, the percent of false detection was 15% and percent of miss was 12.8%. The false detection is because of the presence of low cloud. For which the horizontal visibility at surface level was high but spectral behavior is similar.The brightness temperature difference for low clouds is also very high like fog. The algorithm is not able to detect fog when it is over laid by high clouds due to advection. As this algorithm first eliminates the high cloud region, the fog beneath remains undetected.

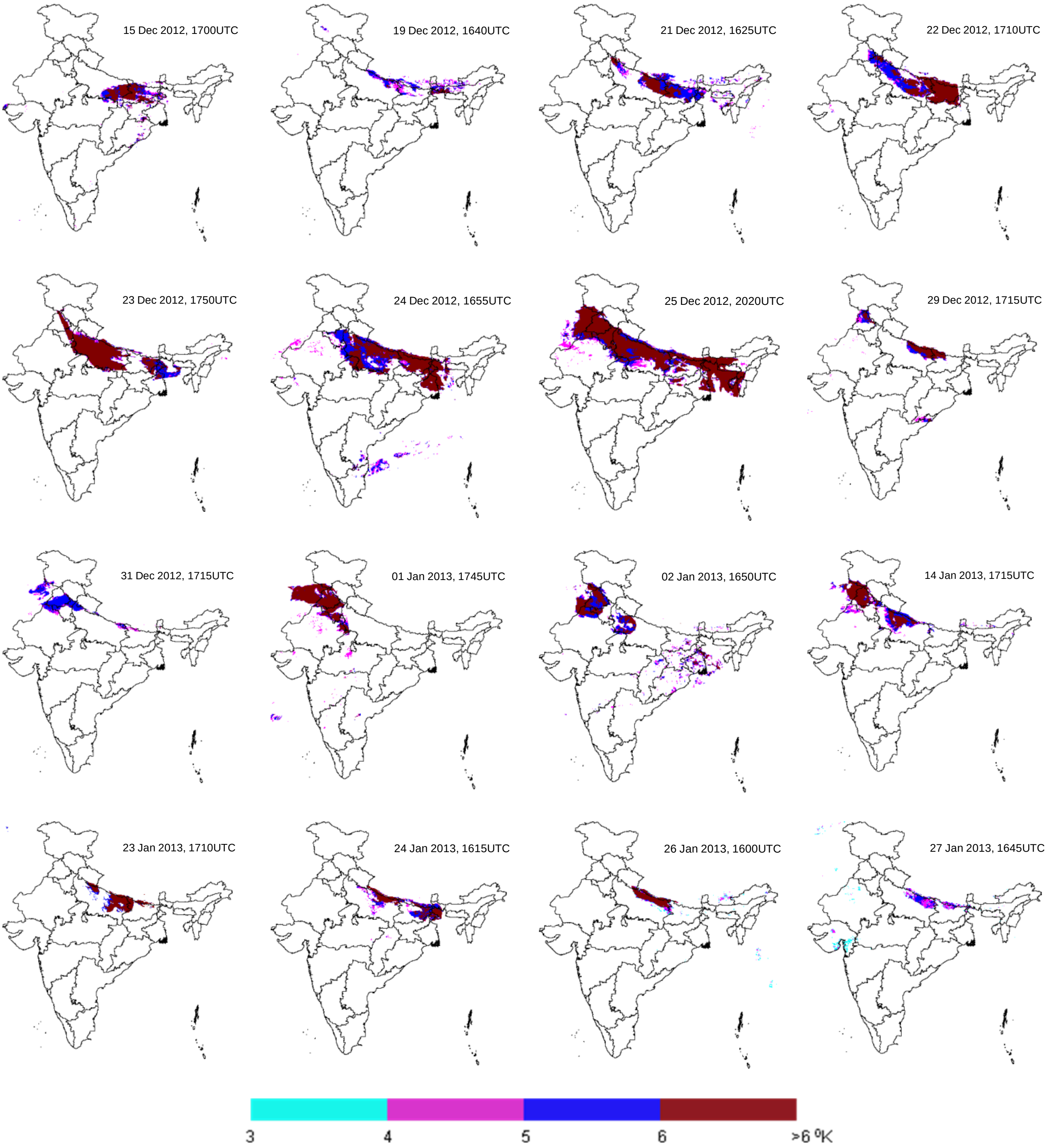
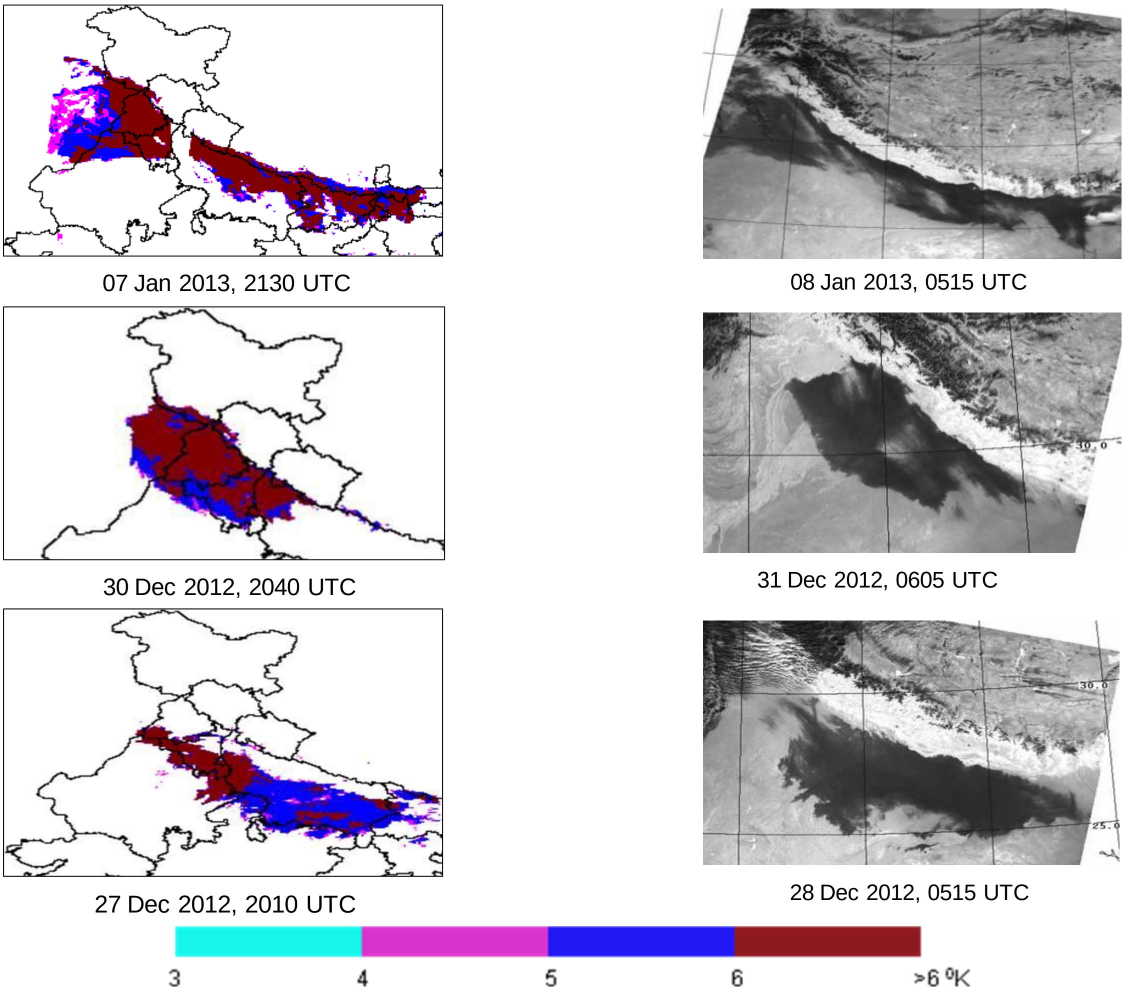


Figure 5: Evolution of fog over Indo-Gangetic plain in December 2012 and January 2013, using MODIS Terra/AQUA data (Different colour shows the BTD values)



(a) (b)

Figure 6: Inter-comparison of (a) generated fog map using MODIS Terra/AQUA of night time (Different colour shows the BTDvalue) with (b) next day morning MODIS RGB image (recoloured)

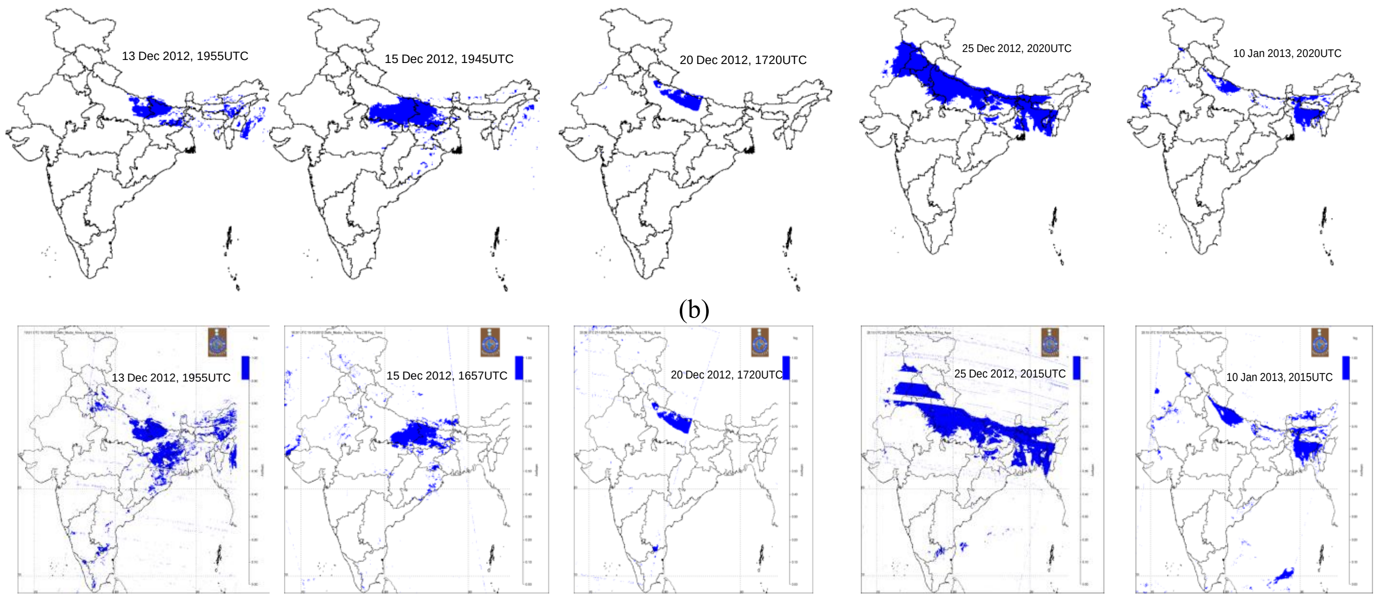


Figure 7: Inter-comparison of generated fog map using (a) MODIS AQUA data with that of (b) IMD fog map using MODIS data (recoloured)

Table 1: Statistics of night time fog detection at five locations (Delhi, Jaipur, Amritsar, Varanasi and Lucknow) in the IG plains from January 01-31, 2014

Total no. of Observations	140
No. of non-concurrent data	25
Number of Hits	81
Number of Miss	16
Number of false detection	18
Percent of Detection (POD)	70%
Percent of False Detection	15%
Percent of Miss	12.8%

5. Conclusions

This technique yields a very good probability of night time fog detection with acceptable false alarm conditions. It has been observed that with the proposed dynamical thresholding, for 70% of the cases the generated fog map successfully detects fog using satellite IR imagery during night time. In future, it may be required to develop algorithm to minimize mis-classification between low clouds and fog.

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