Detection and analysis of fog/low cloud using Ceilometer and INSAT-3D satellite data over Delhi Earth Station, New Delhi

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Abstract: Fog/low cloud base height has been continuously monitored using ground based Ceilometer during the fog season of 2016-17 over Delhi Earth Station, New Delhi. The INSAT-3D fog product results have been validated with the in-situ observations. Fog/low cloud has been successfully detected by both Ceilometer and INSAT-3D during single layer cloud in most of the cases. Fog/low cloud detection using INSAT-3D observed to be a difficult task in multi-layer clouds whereas both single and multi-layer clouds has been well captured by Ceilometer. Since fog is a near surface phenomenon, ground based observation like Ceilometer could be the most effective approach for the detection of fog and however, to get information about the complete spatial coverage of fog, remote sensing technology provides better opportunity. Satellite remote sensing is an important tool in the detection and now casting of fog events. A collective approach is required which consider both ground based Ceilometer and satellite based observations for an improved and continuous monitoring of fog/low cloud.

1. INTRODUCTION

Clouds play an important role in the Earth-Atmosphere energy radiation budget (Schneider 1972, Raschke 1973) also an essential part of hydrological cycle and climate system (Hack et al. 2006, Fontana et al. 2013). Fog is a meteorological phenomenon consists of suspended water droplets reduces the horizontal visibility and is identified once the visibility reduced below 1km (NOAA 1995). Fog, which often occurs during winter (November-February) in Indo-Gangetic plains, is a major obstacle for aviation, marine and land traffic.

In the Indo-Gangetic plains, radiation and advection fog are the major categories of fog depending on the mechanism of formation. Radiation fog is a night time phenomenon under clear sky, high relative humidity and calm wind condition due to radiation cooing near Earth's surface. Advection fog is due to the advection of warm moist air over cooler surface leads to temperature inversion. Radiative characteristics study of fog over Indo-Gangetic plains suggested that foggy winter will be colder than non-foggy winter (Sathiyamoorthy et al., 2016). Western disturbance, an extra tropical storm is responsible for clod wave, winter rain and dense fog condition over the Indo-Gangetic plains (Dimri et al. 2006). Agricultural crop burning (Badrinath et al. 2009) and many thermal power plants in the IG plains (Prasad et al. 2006) are the key sources of aerosol loading favourable for fog formation. The IG plains having a low elevation, Himalayan ranges, calm wind conditions and the network of river Ganga and its tributaries are responsible for dense fog conditions.

Satellite remote sensing has been used for detection and now casting of fog since many years (Eyre et al. 1984, Bendix and Bachmann 1991, Lee et al., 1997, Bendix et al. 2002). Brightness temperature simulation using two different spectral channels (3.9µm and 10.7-11.2µm) is a common method for fog detection (Ellrod 1995, Chaurasia et al., 2011, Riswan et al. 2014). Recently, a new fog detection algorithm has been developed which employs temporal differencing technique and spatial homogeneity test to identify day time fog using INSAT-3D satellite data (Chaurasia et al., 2015). Fog Stability Index (FSI) based on atmospheric temperature and humidity profile information along with surface wind condition is more promising for fog detection (Yun young and Yum, 2013, Wantuch, 2001).

LIDAR's have been widely used for the observation of cloud base height from the ground and used to investigate the vertical visibility and the planetary boundary layer structure (Gaumet et al. 1998, Emies et al. 2004, Munkel et al. 2007, Martucci 2010). A combination of satellite and ground observations can improve the analysis of cloud base height (Forsythe et al. 2000, Kotarba et al. 2009, Stefan et al. 2014, Sharma et al 2016). Lidar determines the cloud base and cloud top height as well as the altitude of the maximum return signal by using an automated method (Pal et al. 1992). Structure of the Atmosphere (STRAT) algorithm has been designed (Morille et al. (2007) to retrieve the vertical distribution of clouds and aerosols. The low level clouds are well captured by Ceilometer while the Satellite based measurements provides better estimation of high level clouds (Stefan et al. 2014, Sharma et al. 2016). Night time cloud base height has been successfully determined (Hutchison et al. 2006) by using Visible Infrared Imaging

Radiometer Suite (VIIRS) algorithm which employs thermal emission properties. Cloud base height analyses are ideal when a single cloud layer exists as well as accurate cloud top height and cloud top phase information are available.

In the present study, cloud base height over Delhi Earth Station has been monitored during the fog season of 2016-2017 by using Vaisala CL31 Ceilometer. INSAT-3D fog (www.mosdac.gov.in and www.imd.gov.in) has been validated with the Ceilometer observations. A satellite and surface based portrayal has been presented here. In this report, section 2 & 3 describes the data used and methodology. Section 4 presents Results and discussions. Further extensions and conclusions are summarised in section 5.

2. DATA USED

Vaisala Ceilometer CL31 employs pulsed diode laser Lidar technology used to observe cloud base height from ground and vertical visibility with a high temporal and spatial resolution. Cloud base height with a maximum of 7.5km is well captured by the Ceilometer. The technical specification of Ceilometer CL31 is as shown in Table1. Ceilometer CL31 can detect three cloud layers simultaneously as well as vertical visibility with the time interval of 2s to 120s.

Property	Description/Value
Laser source	Indium gallium arsenide (InGaAs) diode laser
Center wavelength	910± 10 nm at 25 ºC (77º F)
Operating mode	Pulsed
Energy	1.2 μWs ± 20 % (factory adjustment)
Width, 50 %	110 ns typical
Reception rate	10.0 kHz
Average power	12.0mW
Max irradiance	760 W cm^{-2} measured with 7mm aperture
Laser classification	Classified as class 1Mlaser device
Beam divergence	±0.4mrad x ±0.7 mrad
Receiver detector	Silicon avalanche photodiode

Table.1. Technical specification of Vaisala CL31 Ceilometer.

INSAT-3D satellite in geostationary orbit at 82ºE is useful for near real time fog detection. INSAT-3D imager fog product having a spatial resolution of 4 km and temporal resolution of 30 minutes are available through www.mosdac.gov.in has been used for the present work. Fog product is being generated using INSAT-3D TIR1 (10.8μm) and MIR (3.9μm) channel data for night time and TIR1 (10.8μm) and visible (0.55-0.75μm) data for day time (Fog product, INSAT-3D ATBD). INSAT-3D imager channel specifications are listed in Table 2.

Channel No	Wavelength (μm)	Resolution (Km)
1	0.55-0.75	1
2	1.55-1.70	1
3	3.8-4.0	4
4	6.5-7.1	8
5	10.2-11.3	4
6	11.5-12.5	4

Table.2. Channel specification of INSAT-3D imager.

3. METHODOLOGY

Vaisala CL31 ceilometer located at Delhi Earth Station (28.6090°N, 77.1813°E), New Delhi. Clouds, aerosols, precipitation etc. will interact with the laser pulses being sent by Ceilometer which will lead to scattering. Backscatter profile (signal strength versus height) has been generated from the component of scattered light is received back by the Lidar receiver. Cloud base height has been estimated by knowing the speed of light and the time delay between the launch of the laser pulse. The CL View software gives continuous status information from internal monitoring. The results obtained have been compared with the fog condition indicated by the INSAT-3D fog product.

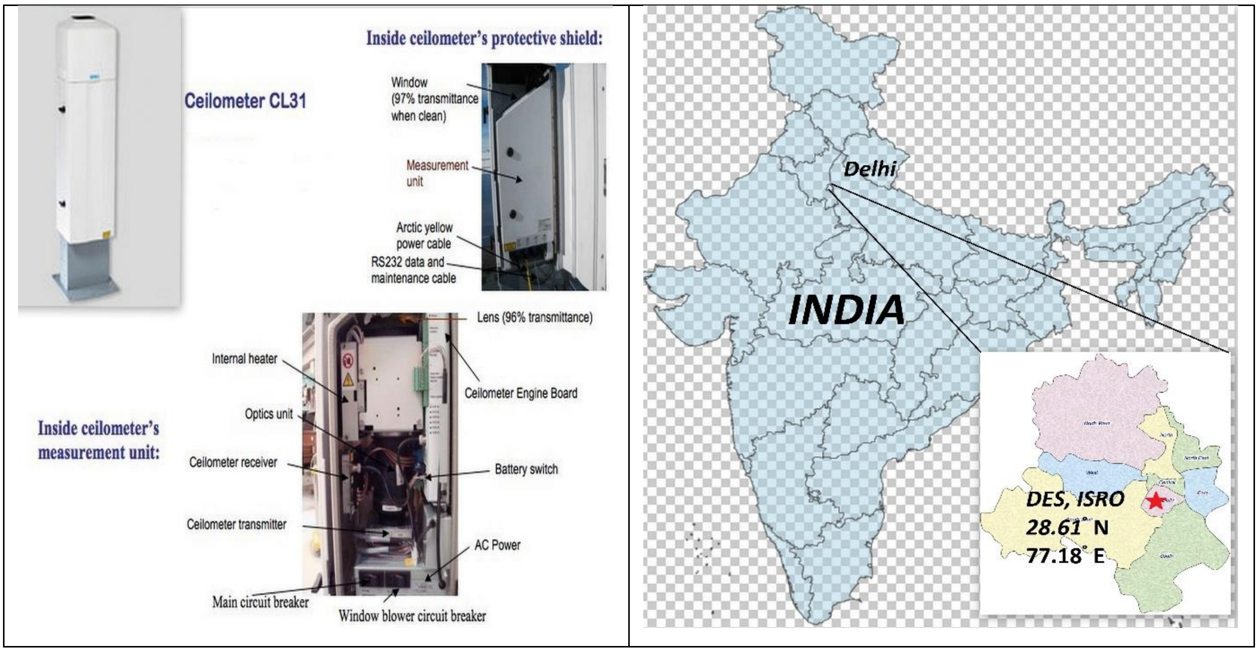

Figure.1. Vaisala Ceilometer CL31 and Study region (Delhi Earth Station, New Delhi)

4. RESULTS AND DISCUSSIONS

The present analysis has been carried out during winter season of 2016-17 over Delhi Earth Station, New Delhi. Fog/low cloud usually occur below 2000m, cloud base height in the range of 0-2000m only been considered in the present analysis. Temporal variation of Ceilometer cloud base height over Delhi Earth Station on 30 December 2016 has been shown in Figure 2. It has been observed a single layer cloud has been detected from 00:00 to 10:30 IST and followed by a multi-layer cloud which persisted throughout the day. Dense fog condition has also been indicated by INSAT-3D fog product over Delhi earth Station during the period when the single layer cloud of height less than 200m exist. INSAT-3D fog product unable to detect fog during multi-layer clouds. Since fog is a near surface phenomenon, ground observations can provide an improved understanding and monitoring of cloud base height.

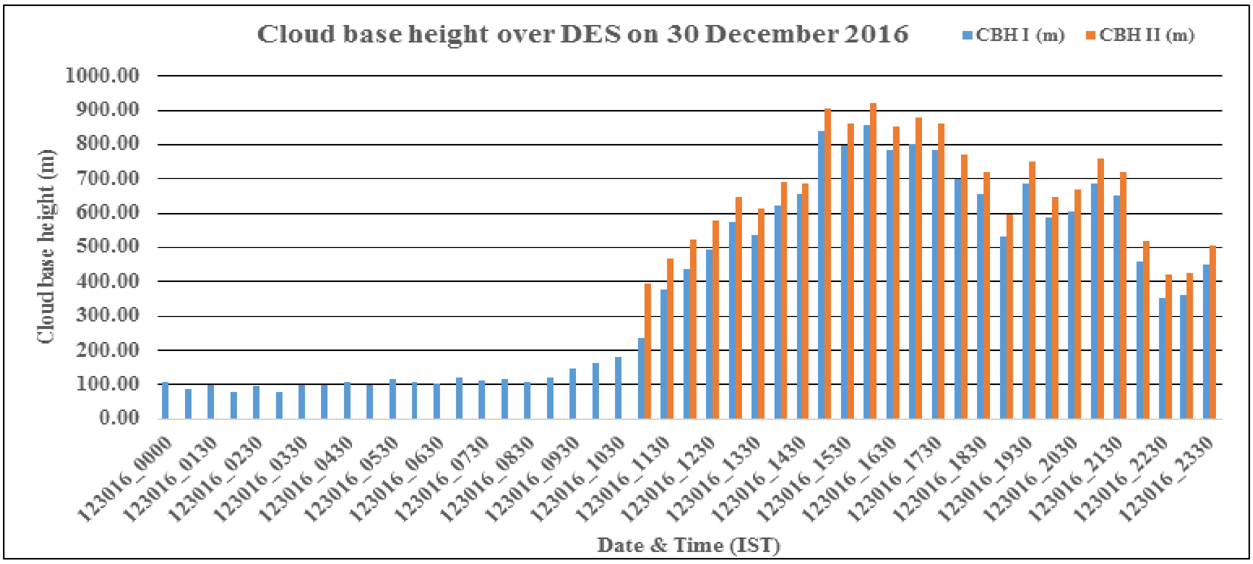

Figure.2. Temporal variation of Ceilometer cloud base height over Delhi Earth Station on 30 December 2016.

In the present study, a collective approach which incorporate both ground based Ceilometer and satellite based measurements has been implemented for the detection and monitoring of fog/low clouds. A collection of 748 observations having height in the range of 0-2000m has been analysed. In 98.38% of cases, cloud base height has been observed to be in the range of 0-1400m. The results are in agreement in 15.37% of cases in which both the Ceilometer and the INSAT-3D identified fog/low clouds. In 84.63% of cases, disagreement has been observed in which the Ceilometer detected cloud base height of less than 2000m while fog is not indicated by INSAT-3D fog product. Since, INSAT-3D fog product is retrieved under clear sky condition, multi-layer cloud could be a barrier for the detection of fog beneath it. It has been observed that in 56.42% of cases multi-layer cloud has been noticed could be the reason for this discrepancy. Variations in the geolocation between the ground based Ceilometer and INSAT-3D satellite as well as the variation in the widespread nature of fog could be the reason for the disagreement in the remaining 28.21 % of cases. Cloud base height in the range of 0-200m has been observed to be in agreement with INSAT-3D fog product observations in 64% of cases. Since, fog/low cloud in the range of 0-200m are observed to be single as well as thinner layer only which is well detected by both the Ceilometer and the INSAT-3D observations. Pie diagram of Ceilometer cloud base height and INSAT-3D fog product has been shown in Figure 3.

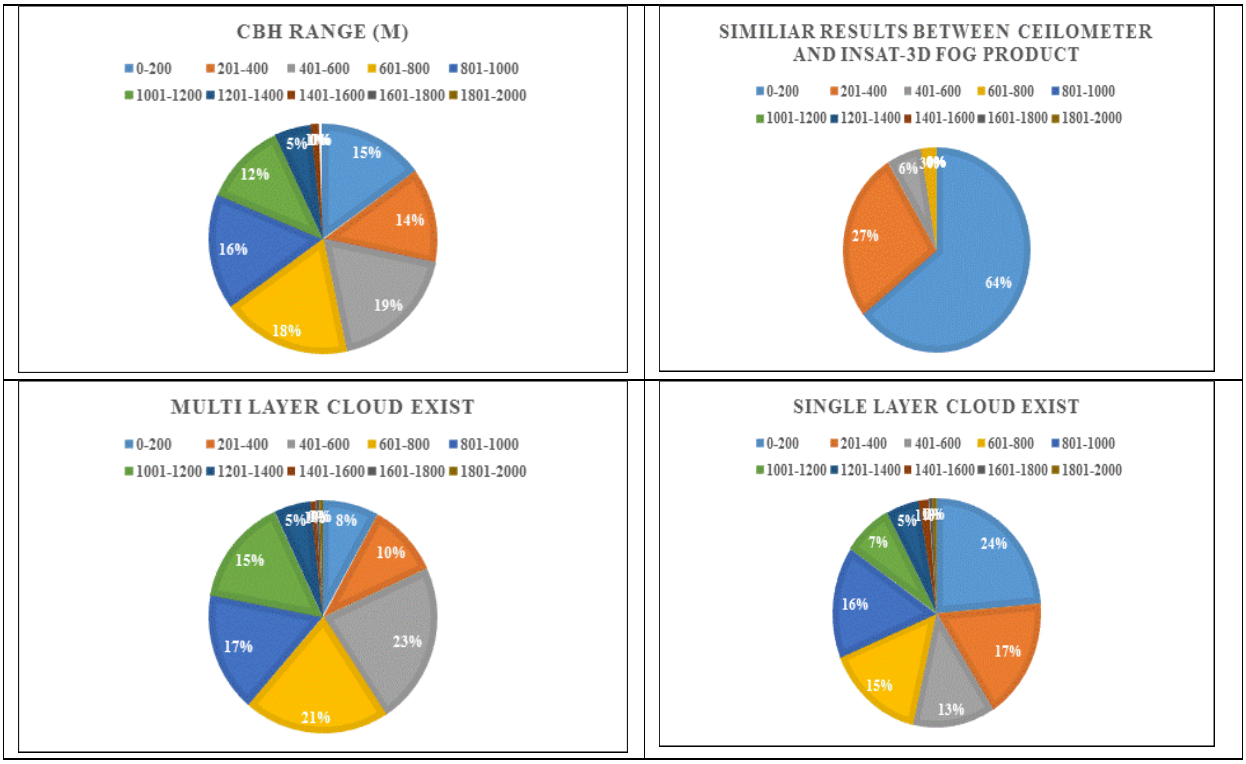

Figure.3. Pie diagram between Ceilometer cloud base height and INSAT-3D fog product.

In the present analysis, in 43.58% of cases single layer cloud has been observed out of which 23.71% of cases both Ceilometer and INSAT-3D captured fog/low cloud and found to be in agreement. Cloud base height in the range of 0-2000m is well captured by Ceilometer in the remaining 19.87% of cases while INSAT-3D unable to detect fog/low cloud. Variations in the geolocation between the ground based Ceilometer and INSAT-3D satellite as well as the variation in the widespread nature of fog could be the reason for the disagreement in all these cases. The Ceilometer identified Multi-layer cloud in 56.42% of cases. It has been observed that both the Ceilometer and INSAT-3D observations are in agreement in 9.16% of cases out of 56.42% of cases due to thinner layer clouds. Fog/low cloud is well captured by Ceilometer in the remaining 47.26% of cases even in the presence of multi-layer clouds while INSAT-3D failed to capture the fog/low cloud. Figure 4 represents the time series plot of Ceilometer cloud base height and the INSAT-3D fog product. Generally, fog is indicated by INSAT-3D with an output of 1.

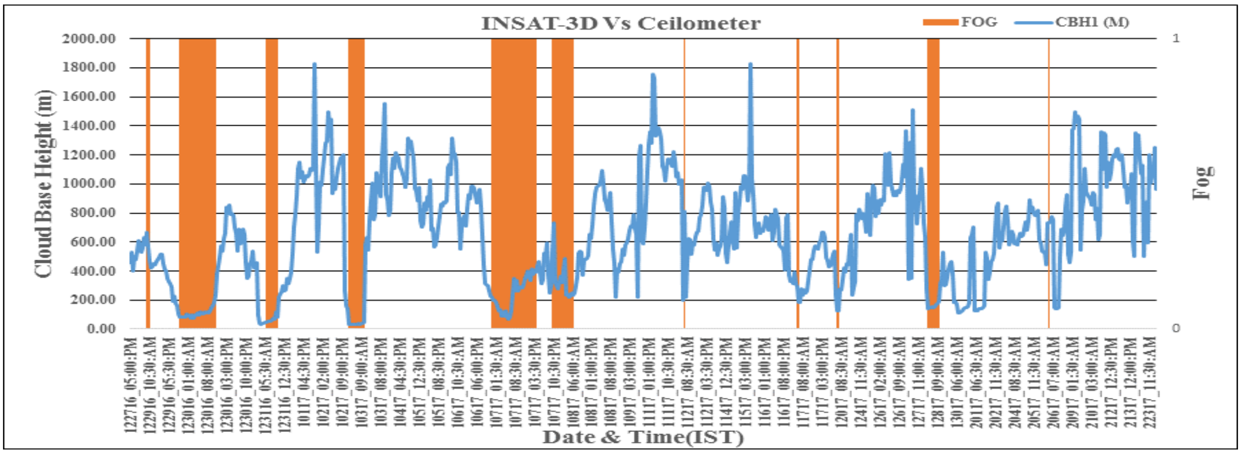

Figure.4. Time series plot between Ceilometer cloud base height and INSAT-3D fog product.

Cloud base height of below 200m has been indicated by the Ceilometer on 30 and 31 of December 2016 and on 07 and 28 of January 2017. INSAT-3D fog product also indicated dense fog condition for the same period. However, fog/low clouds in the range of 0-200m is well detected by both Ceilometer and INSAT-3D and the results are in agreement. Most of the Ceilometer and the INSAT-3D observations are not similar as the cloud base height increase beyond 200m and that could be due to multi-layer clouds. Since, INSAT-3D fog product has been derived under clear sky conditions, multi-layer could be a difficult task for the detection of fog under the higher clouds. Insufficient techniques to identify the boundary layer and to distinguish in between fog and low clouds could be another reason for this disagreement. Figure 5 represents the INSAT-3D fog maps on 03 and 07th of January 2017. Delhi has been covered by dense fog on the same period. Detection of cloud base height of below 200m by the Ceilometer indicating fog/low cloud.

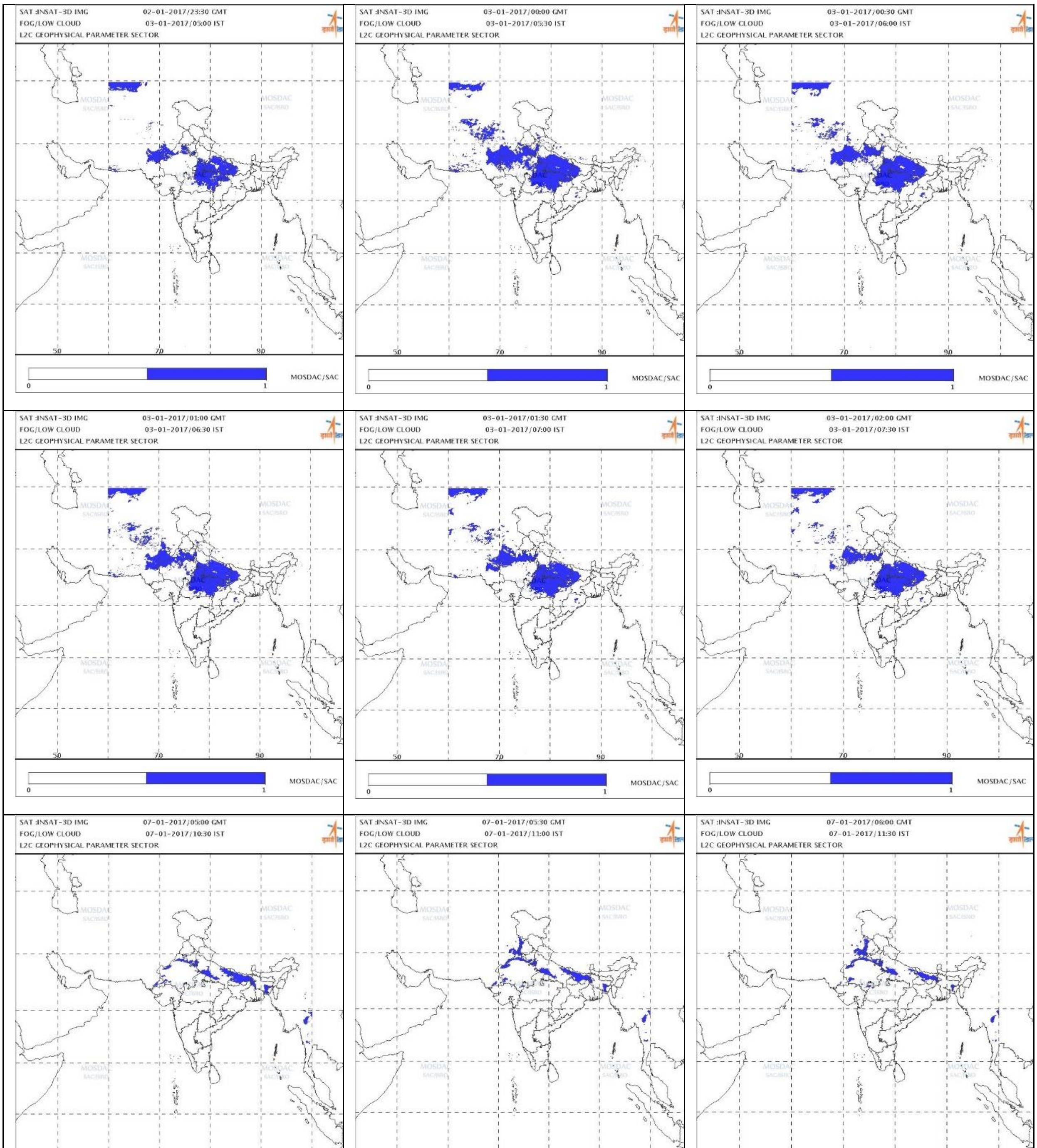

Figure.5. INSAT-3D fog maps on 03 & 07 of January 2017.

5. CONCLUSIONS

Cloud base height over Delhi Earth Station, New Delhi has been continuously monitored during the fog season of 2016-17 by using ground based Ceilometer with a high temporal and spatial resolution. The INSAT-3D fog product has also been used for the validation with the *in-situ* observations. Ceilometer can detect cloud base height with a maximum of 7.2km and vertical visibility as well as two layer clouds simultaneously. Cloud base height analysis are optimal when a single cloud layer exists within the higher cloud system. Single layer cloud in the range of 0-200m is well captured by both Ceilometer and INSAT-3D whereas Ceilometer is more capable during multi-layer clouds. For a better detection and monitoring of fog, a collective approach is required which consider both ground based Ceilometer and space based observations.

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