A FOG DETECTING RGB COMPOSITE TECHNIQUE BASED ON THERMAL BANDS OF THE SEVIRI INSTRUMENT

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Abstract

On September 15th 2011, a heavy fog hit South-eastern Brazil that caused associated to the road chain accident in the Imigrantes highway nearby in São Paulo city. We applied a RGB composite technique for 24-hour detection of fog and low *stratus* cover for this event, in which was based brightness temperature difference among the IR8.7µm, IR10.8µm, and IR12µm bands of the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) instrument aboard the operational Meteosat Second Generation (MSG) satellites. To provide a consistent comparison, SEVIRI RGB composite image and both the Low Cloud Cover and Total Column Water Vapor parameters provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) were first mapped onto the same geographic projection, grid domain, and at 1200 UTC. And the spectral responses of SEVIRI's cloud top temperature retrieved by the LAPIS's (Laboratório de Análise e Processamento de Imagens de Satélites in Portuguese) SEVIRI software package were considered and a comparison made between them and meteorological data (wind speeds, atmospheric pressure and air temperature observations) at half hourly intervals in order to show which SEVIRI thermal bands are consistent with the meteorological analysis variables obtained from a meteorological station. In conclusion, the case study shows that the 24-h SEVIRI RGB composite image works quite well in reproducing the fog or low *stratus* horizontal structure. This study also reveals a correspondence between MSG SEVIRI thermal bands and ECMWF data, both the Low Cloud Cover and Total Column Water Vapor fields are in general associated SEVIRI RGB composite image, whereas it corresponds to the areas of low *stratiform* water clouds or fog cover.

1 INTRODUCTION

South-eastern Brazil is badly affected by fog mainly during winter and early spring months. Fog is meteorological phenomena with numerous impacts, directly or indirectly on human life. Most important direct impact is on aviation, land transportation and marine traffic due to low visibility caused by fog. While today Numerical Weather Models (NWPs) are one of the main research tools used to predict future states of the Earth system, yet persistent problems limit their acceptance in fog nowcasting at a suitable resolution (Aber, 1997).

The NWP's initial conditions are usually based on large scale analyses, which properly incorporated the synoptic features, but not the mesoscale forcings, due to their low spatial and temporal resolutions. The inability of NWPs for nowcasting of fog properties on a spatio-temporal basis, recommend the use of satellite data. Fog detection using geostationary satellite (GEO) data has some advantages; especially that large areal detecting is possible at the same time. Typical methods for space-borne fog and low stratus detection utilize the brightness temperature difference of spectral bands of the GEO.

The information provided by GEO is very important for fog detection, in particular during night-time there is no source of observation which can provide such spatially extensive observation of fog (Ferreira *et al.* 1998). The information provided by GEO is very important for fog detection, in particular during night-time there is no source of observation which can provide such spatially extensive observation of fog (Ferreira *et al.* 1998). The high temporal frequency, constant viewing angles, and the high spectral discrimination of the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) sensor on board Meteosat Second Generation (MSG) make them an ideal system to support the operational nowcasting application in the large scale (Barbosa, 2013). The current series are operationally known as MSG-1 and MSG-2. The SEVIRI instrument is made up of 11 spectral channels that provide measurements with a resolution of 3

× 3 km^2 at the sub-satellite point every 15 minutes and a High Resolution Visible (HRV) channel whose measurements have a resolution of 1 × 1 km^2. The sensor is used widely to provide frequent qualitative images for meteorological weather forecasting and analyses.

Here, we present an illustrative case for the fog event that occurred over the south-eastern Brazil, on 15 September 2011. A satellite view of this situation is displayed in Fig. 5. During this event in São Paulo city, some flights at Guarulhos Airport (GRU) were cancelled or delayed. Almost 300-vehicle crash hours before a series of pileups killed 1 person and injured 30 others on Imigrantes road nearby São Bernardo do Campo city (Fig. 1). Some cars were crushed beneath the heavier trucks (http://www1.folha.uol.com.br/cotidiano/975971-engavetamento-mata-1-e-envolve-300-carros-diz-pm-pista-da-imigrantes-e-liberada.shtml).

Figure 1: Fog event that occurred over the south-eastern Brazil, on 15 September 2011 and cars crushed.

The research presented here is a feasibility study of SEVIRI data as a tool for space-borne fog and low *stratus* detection. The proposed detection tool is based on brightness temperature difference among the IR8.7µm, IR10.8µm, and IR12µm bands of the Meteosat-9 (MSG-2), which requires calibrated and rectified SEVIRI images. The basic assumption of this study is that fog and low *stratus* have a specific spectral feature over thermal bands of the SEVIRI instrument due to its unique microphysical properties.

2 REGION, DATA AND METHOD

The geographic area under consideration is approximately centred over South-eastern Brazil. This region is surrounded by the South Atlantic sea and thus the role of sensible heat fluxes between sea surface and the atmosphere can be very important in intensifying fogs, especially in late austral winter and early austral spring when the sea surface is still relatively cold. The climatology (1980-2000) of Guarulhos International Airport (GRU) in São Paulo is shown in Fig. 2. It shows that a high frequency of fog formation at GRU with visibility less than 1 km, occurs during the May and June time periods.

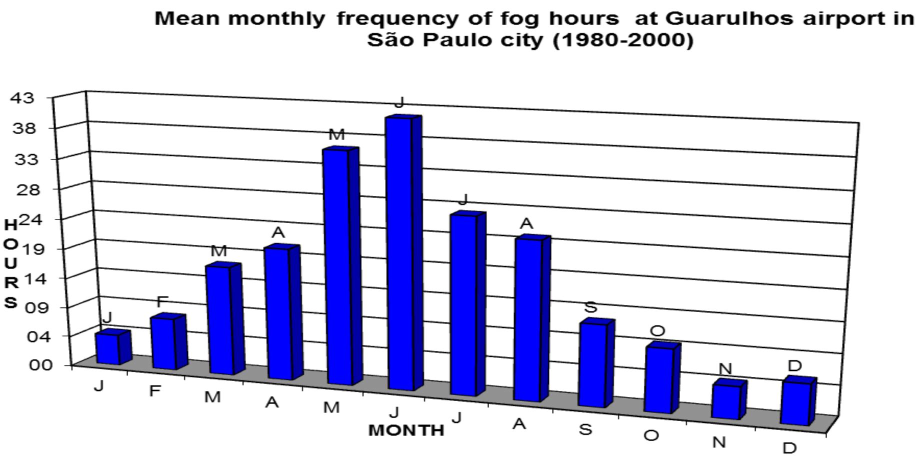

Figure 2: The climatology (1980-2000) of Guarulhos International Airport (GRU) in São Paulo city.

The operational implementations of our fog tool are based on the SEVIRI data available at LAPIS (Laboratório de Análise e Processamento de Imagens de Satélites in Portuguese – http//www.lapismet.com) laboratory through the EUMETCast stream data. This service based on standard Digital Video Broadcast for Satellite (DVB-S) technology (EUMETSAT, 2007) that uses commercial telecommunication geostationary satellites (SES-6 at present) to distribute files and allows users (LAPIS laboratory) to receive images and data in nearly real time (Barbosa, 2013). It provides SEVIRI images processed to Level 1.5 (EUMETSAT, 2007), obtained through the processing of satellite raw data (designated as Level 1.0 data). The three different IR bands (IR8.7µm, IR10.8µm, and IR12µm) from SEVIRI level-1.5 data for 15 September 2011 are used for fog detection. Analysis of SEVIRI data have been carried out by using open source components developed by LAPIS laboratory, Universidade Federal de Alagoas (Fig. 3).

To compute the radiance for each channel scaling parameters (cal_slope and cal_offset) have to be identified. The scaling parameters are contained into the header file named “prologue” of Level 1.5 SEVIRI images (HRIT format). Radiance values can be calculated by means of the following formula (EUMETSAT, 2008): $L_{(i,ch)} = DC_{(i,ch)} * cal\_slope_{(ch)} + cal\_offset_{(ch)}$ (1)

Where $DC_{(i,ch)}$ and $L_{(i,ch)}$ are the digital count and radiance of pixel *i* and channel *ch*, respectively. For SEVIRI thermal channels (IR8.7µm, IR10.8µm, and IR12µm), brightness temperature, expressed in $10^{-3}Wm^{-2}sr^{-1}[cm^{-1}]^{-1}$, can be calculated by simply inverting the Planck function at the channel wavelength, that is:

$$\nu = \frac{10^4}{\lambda_0}, \quad BT = \frac{c_2 \nu}{\ln\left[1 + \nu^3 \frac{c_1}{L}\right]} \qquad (2)$$

Where λ_0 is the central wavelength of the channel expressed in µm and c_1 and c_2 channel varying constants listed in the EUMETSAT documents (EUMETSAT, 2007a).

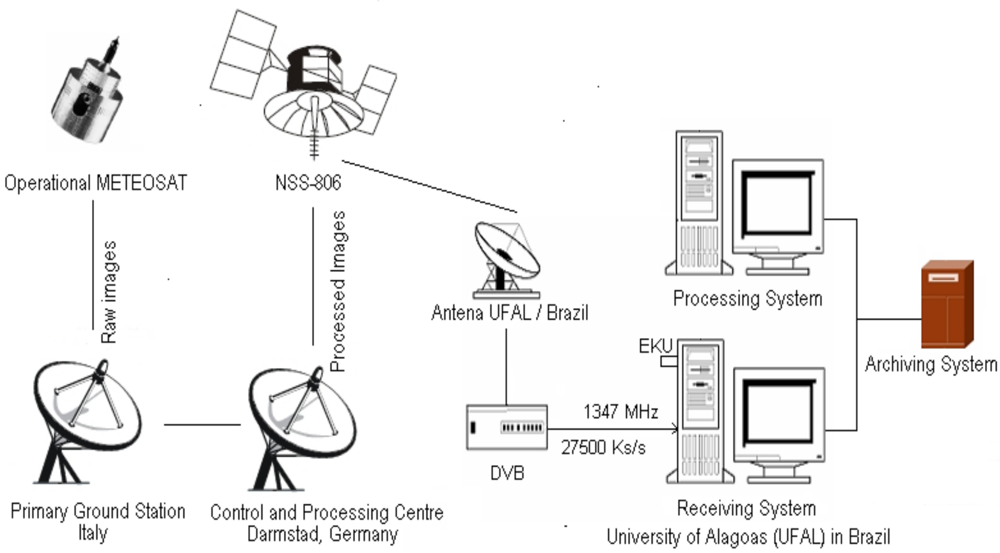

Figure 3: Overview of the broadcasting ground reception and processing system at the University of Alagoas (UFAL) in Brazil.

A RGB composite technique for 24-hour detection of potentially hazardous fog is based on difference of emissivity of cloud water droplet in the three bands (IR8.7µm, IR10.8µm, and IR12 µm). Hence, a SEVIRI RGB based detection tool operational at LAPIS was built up in order to derive the following key steps: i) ASCII files regarding the three spectral bands were extracted using open-source software tools (e.g., EUMETSAT WaveLet Transform Software used to decompress SEVIRI HRIT data files (EUMETSAT, 2009c); and ii) Geospatial Data Abstraction Library (Silva Junior *et al*. 2009; Barbosa, 2013) used to read and write many geographic data formats). These are spectral radiance displayed: brightness temperature (K) in the thermal bands. This processing level corresponds to image data corrected for radiometric and geometric effects, geo-located using a standard projection (Barbosa, 2013), finally calibrated.

The 24-h fog SEVIRI RGB detection is based on a threshold technique which is applied to a resulting RGB image of brightness temperature differences among SEVIRI band IR12µm minus IR10.8µm; SEVIRI band IR10.8µm minus IR8.7µm, and SEVIRI band IR10.8µm (Fig. 4).

Validation of the resulting 24-h fog RGB detection is performed by the European Centre for Medium-Range Weather Forecasts data (ECMWF, http://www.ecmwf.int/): Total Column Water Vapor and Low Cloud Cover fields (in GRIdded Binary (GRIB) format) parameters over South-eastern Brazil and meteorological observations at the Guarulhos' airport (GRU) meteorological station in São Paulo city simultaneous to SEVIRI scan time for the 15 September 2011.

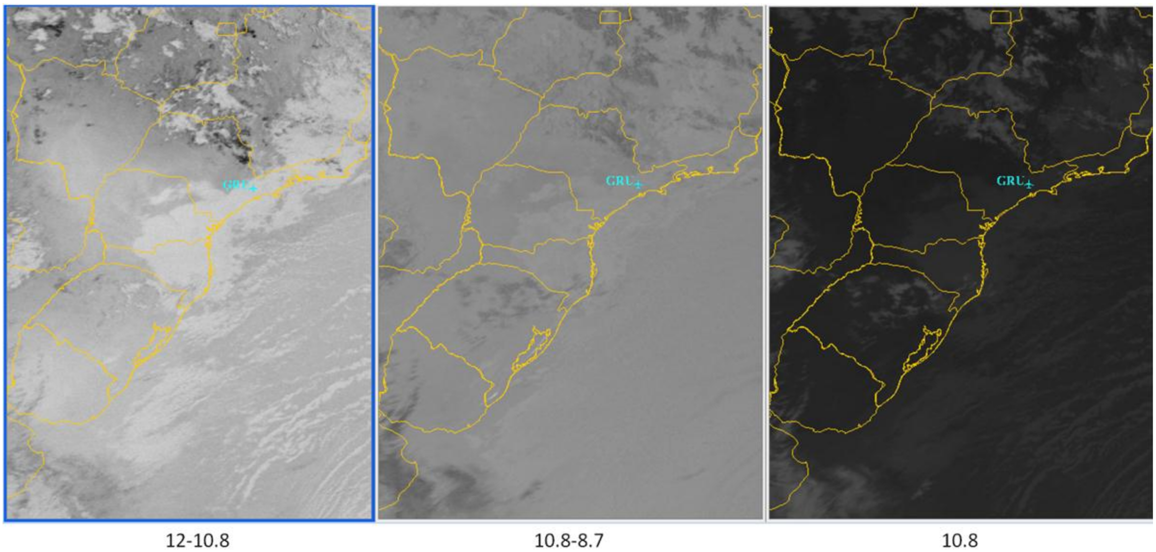

Figure 4: Meteosat-9 SEVIRI sub-image extraction for the geographic domain used in the study. SEVIRI band IR12m – IR10.8m; SEVIRI band IR10.8m – IR8.7m, and SEVIRI band IR10.8m images relative to 15 September 2011 at 1200 UTC.

To provide a consistent comparison, SEVIRI RGB image, Low Cloud Cover and Total Column Water Vapor gridded-parameters were first mapped onto the same geographic projection, grid domain, and at 1200 UTC. And the spectral responses of SEVIRI's cloud top temperature retrieved by the LAPIS's SEVIRI software package were considered and a comparison made between them and meteorological data (wind speeds, atmospheric pressure and air temperature observations) at half hourly intervals in order to show which SEVIRI thermal bands are consistent with the meteorological analysis variables obtained from meteorological station.

The LAPIS's SEVIRI software produces its output at SEVIRI full spatial resolution over any pixel location defined by the user inside the MSG full disk. To allow the ingestion of SEVIRI channel data into LAPIS's SEVIRI software, it has to be taken into account the right conversion from digital number to physical variables like radiance, reflectance or brightness temperature.

3 RESULTS AND CONCLUSION

The spatial extent of fog affecting the South-eastern Brazil, on 15 September 2011 at 1200 UTC, can be observed in Fig. 5, representing the fog RGB map over a selected window. In addition to that, accurate 3D representation features of the 24-h fog SEVIRI RGB composite image in conjunction with the topography were generated to ensure the areas of low *stratiform* water clouds or fog cover (Fig. 6). It is possible to see in bluish colors. These regions (bluish colors) are therefore identified as fog source regions. It is important to note that we define the "fog source region" as an area in which an air parcel absorbed significant amounts of moisture (high amount of small droplets suspended in the air). Otherwise, reddish colors indicate regions where high-level ice clouds dominate. Consequently, air masses located over these regions display a loss of moisture, and these regions are identified as moisture sink.

In Table 1 the results of SEVIRI derived fog RGB image, using difference of (R) band IR12µm minus band IR10.8µm; (G) band IR10.8µm minus band IR8.7µm and (B) band IR10.8µm are shown for 15 September 2011 at 12:00 UTC (Fig. 5). Eronn (2007) has shown that band IR10.8µm provided the best night-time fog (low cloud) detection while band IR 3.9µm produced the worst for detection. Because of the band IR 10.8µm is associated with less noisy for cold scenes and it has no solar, reflected component (hence 24-h capability). To interpret the RGB composite, bluish colors indicate fog or low-level *stratiform* cloud and red colors indicate high-level ice clouds.

24-hours fog RGB image			
Beam	Bands	Range (K)	Gamma
R	IR12µm – IR10.8µm	-5 to +3	1.0
G	IR10.8µm – IR8.7µm	+3 to +5	2.0
B	IR10.8µm	265 to 295	1.0

Table 1: Range and enhancements for 24-hours RGB's detecting fog.

Figure 7 and 8 show integration of SEVIRI IR10.8µm image with both the Low Cloud Cover and Total Column Water Vapor fields (derived from the ECMWF data), respectively, expressed as absolute values at 1200 UTC. In general, the preliminary results suggested that the two NWP fields have no significant visual differences in the areas where there are low *stratiform* water clouds or fog cover. In particular, the two NWP fields reproduce the structure generated in SEVIRI RGB composite (Fig.6). However, it is uncertain if the two NWP fields are sensitive enough to discriminate between low *stratiform* water clouds and fog cover.

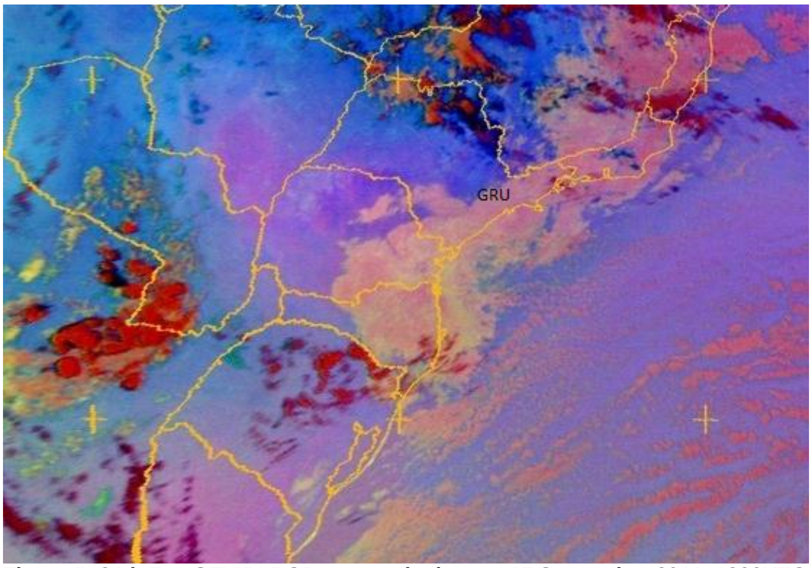

Figure 5: 24-h Fog SEVIRI RGB composite image, 15 September 2011, 1200UTC. GRU (Guarulhos' international airport).

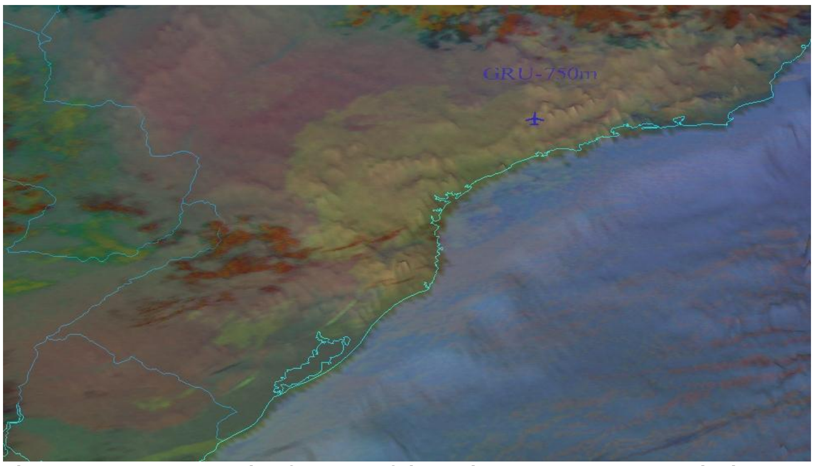

Figure 6: 3D representation features of the 24-h SEVIRI RGB composite image conjunction with the topography, 15 September 2011, 1200UTC. GRU (Guarulhos' international airport).

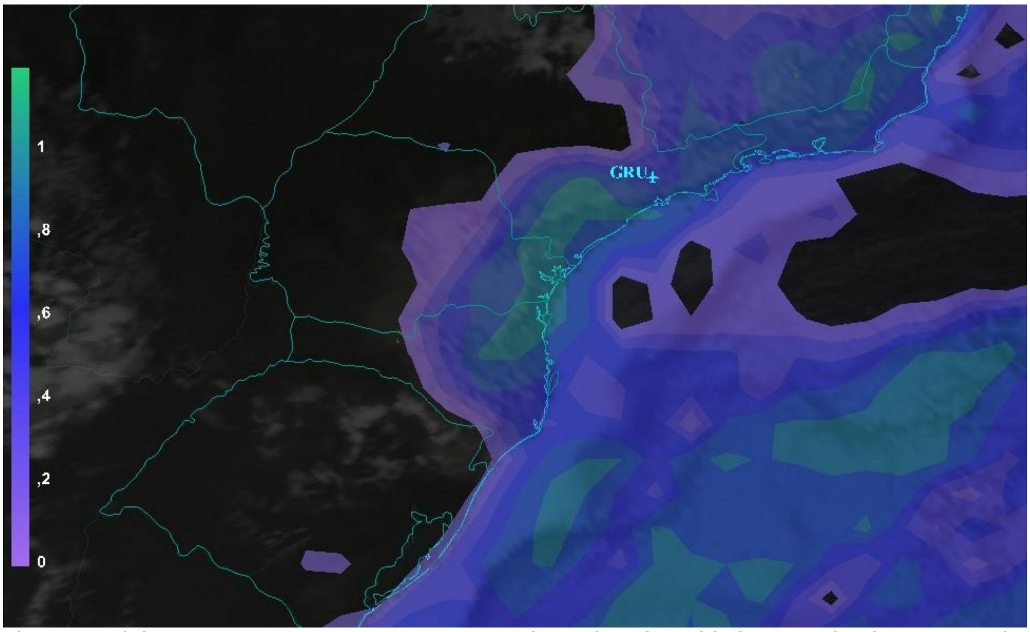

Figure 7: Brightness Temperature SEVIRI IR10.8□m in conjunction with the Low Cloud Cover map (ECMWF parameter), 15 September 2011, 1200UTC. GRU (Guarulhos' international airport).

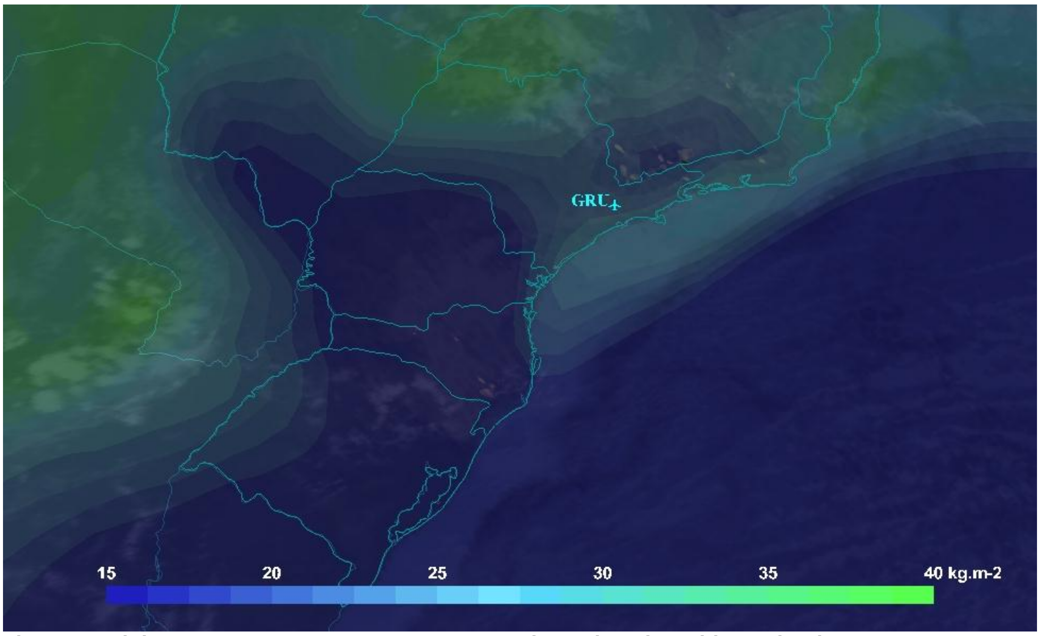

Figure 8: Brightness Temperature SEVIRI IR10.8□m in conjunction with Total Column Water Vapor map (ECMWF parameter), 15 September 2011, 1200UTC. GRU (Guarulhos' international airport).

Fig. 9 shows the half-hourly evolution of brightness temperature difference (BTD) between IR10.8µm and IR8.7µm, IR12.0µm and IR10.8µm, and IR10.8µm and IR3.9µm. The fog event on 15 September 2011 started in the early morning (around 0300 UTC) and dissipated around 945 UTC. All flights at Guarulhos's international airport were cancelled during that period. The decrease of the BTD IR10.8µm and IR3.9µm started at about 945 UTC (fog dissipation). Note that BTD IR10.8µm and IR3.9µm is constantly around +3K for fog or low clouds. The fog dissipation leads to negative decrease in the BTD 10.8µm minus 3.9µm in the range 0-12K. Generally, such differences are bigger in the areas where there is the absence of small water droplets suspended in the air. Fog reduces this difference to values close to zero or negative.

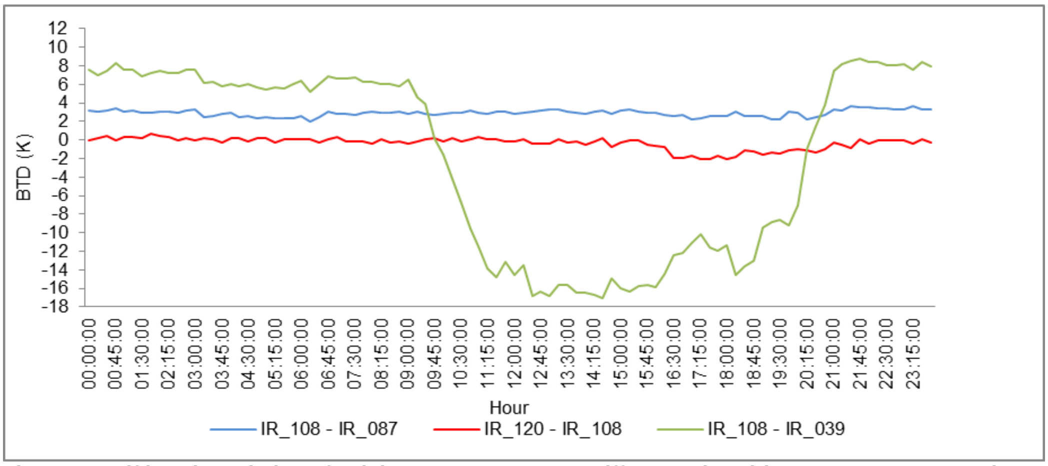

Figure 9: Half hourly variation of Brightness Temperature Difference (BTD) between IR10.8µm and IR8.7µm, IR12.0µm and IR10.8µm, and IR10.8µm and IR3.9µm over the Guarulhos International (GRU) airport.

Meteorological data are crucial in assessing possible fog formation. By comparing Figs. 9, 10 and 11 it is possible to observe the pressure maximum that is located approximately in the middle of the Fig. 6, at 1200 UTC, when the fog event has completely dissipated. It is possible to see that the difference between air temperature and IR10.8µm is bigger than 9K, while fog or low clouds are present. Low wind speeds in the boundary layer also reinforced the absence of fog. The IR10µm minus IR3.9µm variability is mainly dominated by solar diurnal cycle. The IR10.8µm minus IR8.7µm is found to be higher than IR12.0µm minus IR10.8µm. The overall behaviour of IR10.8µm minus IR8.7µm and IR12.0µm minus IR10.8µm observed over Guarulhos's international airport are found to be qualitatively similar.

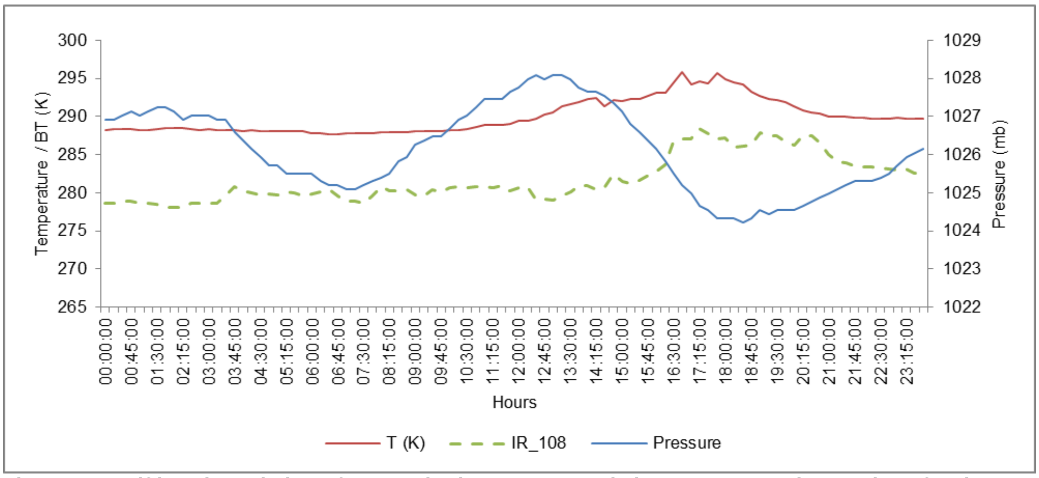

Figure 10: Half hourly variation of atmospheric pressure and air temperature observations for the Guarulhos International (GRU) airport meteorological station, and SEVIRI IR10.8µm over the GRU airport.

The difference in magnitude between air temperature and IR10.8µm of 9K could be due to the air temperature has been made from the ground observations at the Guarulhos' International airport close to earth's surface and pointing skywards. The satellite is downward pointed and the IR10.8µm values are instantaneous during the view of the SEVIRI. They found a good correspondence in temperature obtained from ground-based and SEVIRI measurements over Guarulhos' International airport. The more atmospheric water vapour (moisture) in a given parcel of air, the more heat it retains by absorbing upwelling infrared radiation from the lower atmosphere. Consequently, decreased atmospheric water vapour in the lower atmosphere results in higher temperatures. The low water vapour content in the lower atmosphere during afternoon may also contribute to this.

Pronounced diurnal peak in air temperature are observed from 1545 UTC to 2100 UTC. The variations in IR10.8µm also show similar trend with the values showing an increasing trend with well-marked diurnal peak up to 1630 UTC. On the other hand, the temporal variation of atmospheric pressure shows the occurrence of periodic maxima and minima throughout the day.

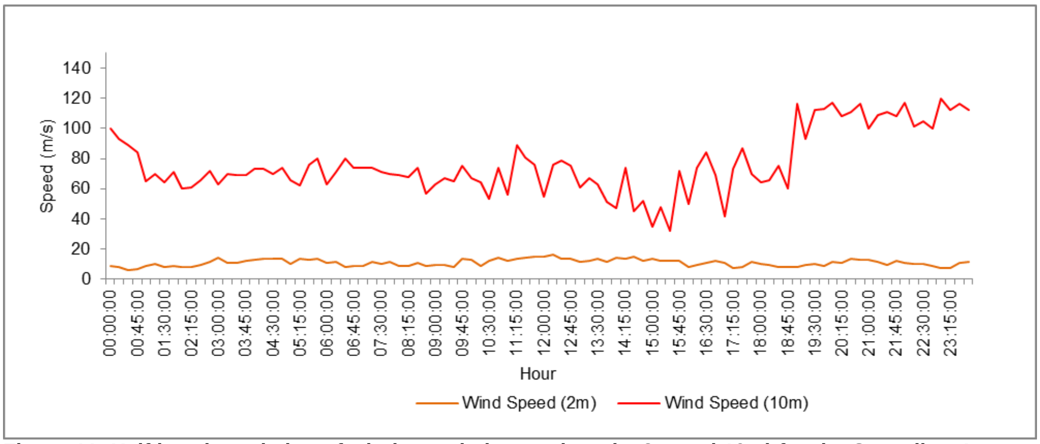

Figure 11: Half hourly variation of wind speed observations (at 2m and 10m) for the Guarulhos International (GRU) airport meteorological station.

In conclusion, the case study shows that the SEVIRI RGB composite image works quite well in reproducing the fog or low stratus horizontal structure. This study also reveals a correspondence between MSG SEVIRI thermal bands and ECMWF data, both the Low Cloud Cover and Total Column Water Vapor fields are in general associated SEVIRI RGB composite image, whereas it corresponds to the areas of low *stratiform* water clouds or fog cover.

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