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USING THE METEOSAT-9 IMAGES TO THE DETECTION OF DEEP CONVECTIVE SYSTEMS IN BRAZIL

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Abstract

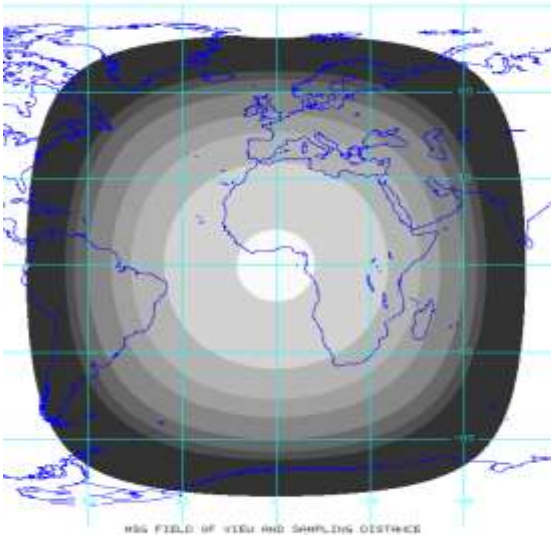
The purpose of this article is to present a simple method of identification of deep convective clouds using water vapor (WV) and thermal infrared (IR) brightness temperature differences from the multispectral images of Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) sensor. The use of this method is part of an international effort to calibrate the radiances of SEVIRI sensor for microphysical properties of deep convective systems. This approach was applied to the image from 08 September 2009 for the demonstration of its efficacy analysis. The results show that the difference values larger than –2º C for BT Differences (WV6.2 μm – WV7.3 μm) and + 50º C (IR3.9 μm –IR10.8 μm) were associated with areas of intense precipitation. The method can be easily implemented and effectively utilized in operational basis to monitor deep convective cloud clusters over Brazil.

Keywords: EUMETCast, MSG, Clouds

1. Introduction

EUMETSAT Meteosat Second Generation (MSG) is a geostationary satellite with a Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board. The MSG satellite was launched on the 29th of August 2002 and data has been available free to the academic and scientific communities since January 2004. The MSG SEVIRI is positioned at 0° longitude and 0° latitude, approximately 36 thousand km above the Gulf of Guinea. This sensor operates with 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 (EUMETSAT, 2008). The primary mission of the second-generation Meteosat satellites is the continuous observation of the Earth's full disk with a multi-spectral imager. The repeat cycle of 15 minutes for full-disk imaging provides multi-spectral observations of rapidly changing phenomena such as deep convection. The imaging is performed by utilizing the combination of satellite spin and scan mirror rotation, a process known as stepping. The images are taken from south to north and east to west. Figure 1 provides an example the view of the sample distance on ground scanned by SEVIRI. Data is then processed and wavelet compressed, then uplinked via the EUMETCast service – a new C-band satellite reception facility to collect data from SEVIRI – to the commercial telecommunication geostationary satellites from which it can be disseminated to meteorological communities.

Figure 1. SEVIRI sampling distance on ground (MSG field of view). Source: EUMETSAT



Satellite studies of deep convective clouds detected by MSG/SEVIRI observations have used the radiative properties measured by visible and infrared radiances that are sensitive only to the top parts of clouds. The key advantage of the MSG SEVIRI sensor is the ability to captures observations for every 15 minutes over 12 bands bands over a 70° field of view centered at the Greenwich Meridian and the equator. Combined with the RGB (Red-Green-Blue) colors can be used for qualitative analysis of cloud microphysics. Although the RGB combinations do not directly provide information on vertical motions (i.e., updraft strength), their contribution in detecting deep convective clouds are relevant (Lensky and Rosenfeld, 2008). Because geostationary satellite data at high temporal resolution may provide the possibility to identify potential instability, especially in places where conventional data are either sparse or unavailable. This study relies on MSG-emitted brightness temperature (BT) as a proxy for potential instability, but without any direct measurement of updrafts (EUMETSAT, 2007). Taking full advantage of the high temporal sampling of MSG and its wide gamma of spectral channels, particularly the three channels 6.2, 7.3, 10.8 μm may be viewed as a measure of convective activity. Severity of convection is largely based on infrared methods that define storm severity as a cloud top temperature than a given threshold. Different thresholds of 208–233 K have been suggested (e.g., Liu et al., 1999; Machado and Laurent, 2004). It is also well documented that cloud top BT is directly related to the cloud top level environment temperature (Schmetz et al., 2002; Barbosa and Ertürk, 2009) – valid only for opaque clouds (i.e., cumulonimbus clouds) and state of thermal equilibrium between the cloud and its environment. However, the BT thresholds alone are not able to distinguish deep convective clouds and cirrus clouds with high precision, in part because the same cold cloud top may be generated from different convective intensities in different convective environments. An alternative approach is the use of BT differences between the WV and IR window bands for detecting convective overshooting clouds – deep convective clouds that plays a key role in transport and mixing in the tropical tropopause layer at typically 14km-16km height (Gettelman et al., 2002).

Figure 2 illustrates example of the so-called weighting functions of the thermal channels – the weighting functions describe the contribution of each atmospheric layer to the radiance by the satellite. Weighting functions depend on the actual atmospheric state and the satellite viewing angle. A visual comparison between WV6.2 and WV7.3 shows how the peak of weighting functions raise in altitude with increasing satellite zenith angle at 60°. Water Vapor has an absorption band around 6 microns and therefore it absorbs radiation from below but emits radiation according to the 2nd Kirchoff law. Therefore the water vapor (WV) channels are indicative of the water vapor content in the upper part of the troposphere. The maximum signal from WV6.2 is at 350 hPa, and for WV7.3 at 500 hPa. It is also assumed that normal pressure at sea level approximate elevation is at 8980 m and 5965 m respectively. The IR channel records the emitted energy from the Earth surface itself. Based on a classification using MSG channel IR10.8 and WV6.2, applying a threshold on the temperature difference of less than 11 Kelvin an approximation of the clouds that have a high likelihood of precipitation can be obtained. This is an empirically determined threshold reported by Kidder et al. (2005).

Several MSG SEVIRI bands provide a powerful tool in detecting convective activities (see Table 1). The main bands used are the visible VIS0.6 channel (centred at 0.6 μm), the near-infrared NIR1.6 channel (centred at 1.6 μm), the water vapor WV6.2 and WV7.3 channels (centred at 6.2 μm and at 7.3 μm, respectively), the infrared IR10.8 window channel (centred at10.8 m) and the difference between the WV6.2 and IR10.8 bands (defined hereafter as BTD). The BTD (WV6.2-IR10.8) is positive (WV warmer than the IR window) above most of the cloud top storms. The calibration accuracy of the solar SEVIRI channels is 5% (Govaerts and Clerici, 2004), while uncertainties in calibration of the SEVIRI 10.8 μm channel are below 0.25 K at 300 K (Schmetz et al., 2002). Differencing the 3.9 μm channel with the 10.8 μm channel allow the determination of liquid water clouds and high cirrus clouds. This is due to the 10.8 μm detecting all clouds close to blackbody temperature. Because of emissivity values of clouds in the 10.8 channel are greater than 0.9. And it detects a warmer cloud top temperature whereas 3.9 μm channel detects much less than a blackbody for water clouds.

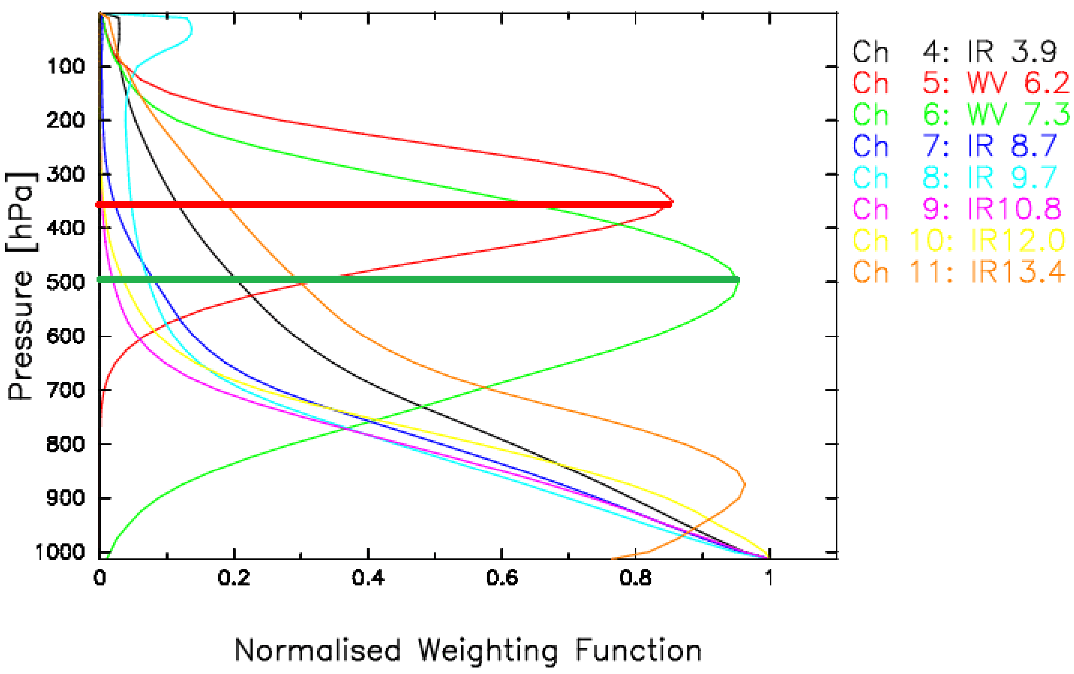


Figure 2. SEVIRI channel normalized weighting functions at 60°. Source EUMETSAT.

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Positive difference between WV6.2-IR10.8 is associated with convective overshooting and moisture injection in the stratosphere. Fritz and Laszlo (1993) have clearly shown that the WV – IR brightness temperature difference is capable of identifying overshooting tops. Because the emitted minimum BT at the coldest overshooting tops is directly proportional to the largest positive values of BTD, it can be viewed as a measure of convective activity. However, this type of analysis with BTD method is not able to compute too high overshooting tops with high precision, in part because their height reduces the total amount of moisture above them (Setvák et al., 2008). An alternative approach is the use of 6.2 μm BT – 7.3 μm BT method to obtain more precise information concerning the overshooting tops in comparison to the WV – IR method when the overshooting tops do not exhibit any BT minimum. The physical mechanisms associated with the overshooting tops are well documented. These were studied on the pioneering work of Fritz and Laszlo, (1993) and from a few other authors since then (e.g., Schmetz et al., 2002; Setvák et al., 2008). The BTD (WV6.2-WV7.3) approach described above can be applied for detection of the overshooting tops.

The LAPIS (Laboratório de Análise e Processamento de Imagens de Satélites in Portuguese – http//www.lapismet.com) laboratory is operationally recording convective storms over the Brazil since 2006. The severity criteria of the U.S. National Weather Service for a convective storm can be classified as severe if it presents on the following characteristics: a) tornado, b) wind gusts ≥ 50 knots (~ 25 m s-1) and c) hailstones with diameter ≥ ¾ inch (~ 2 cm) (http://www.weather.gov/glossary/index.php?letter=t). It is also well documented (Schmetz et al., 2002; Barbosa and Ertürk 2009; Ertürk and Barbosa 2009) that cloud top brightness temperature (BT) directly related to the cloud top level environment temperature – valid only for opaque clouds (i.e., cumulonimbus clouds) and state of thermal equilibrium between the cloud and its environment. In particular, critical to the success of any attempt to spot the satellite-based storm cell is the BT isotherm of~ 240 – 230 K. The atmosphere must already be conditionally unstable and the large-scale dynamics must be supportive of vertical cloud development.

Understanding the characteristics of convective storms that impact the weather conditions in Brazil is of importance to help forecasters to improve their capability as regards to the forecast of strong convective events. Since 2006 there were many cases when deep convective storms developed in Brazil, the 08 September 2009 storm was a strong convective event. Although this study is a preliminary one, and the number of cases is limited to only one event, the next step will be the acquisition of more events and the implementation of a database of the aforementioned information as support to the comprehension of such events and to the forecasting activity. The paper is organized as follows. Section 2 describes the MSG satellite data acquisition, decoding, and analysis. Section 3 details a case study of a deep convective storm over the south-eastern Brazil. Section 4 concludes the paper.

2. Material and methods

2.1 Receiving and processing SEVIRI radiances

In this article, the cloud-top SEVIRI data from 08 September 2008 with a temporal resolution of 15 minutes were retrieved from the EUMETCast service through the reception station at the Federal University of Alagoas (UFAL). EUMETCast is a content delivery network used by EUMETSAT for transporting SEVIRI data (MSG-2 satellite) received at Darmstadt (Germany) to the end users. Raw count data received by this service are referred to as level 1.5 data (EUMETSAT, 2008), that is, image data ready to use with calibration and geo-location information appended. The level 1.5 data have a 10 bit digitization and provide the basis for all further processing and for the derivation of meteorological products. They are processed and uplinked to NSS-806 in wavelet compressed the high rate information transmission (HRIT) format. From there the images can be received with a standard dish receiving system in the EUMETCast C-band. At UFAL they are archived in compressed form on external drives linked to the UFAL network, and accessible through ordinary PCs. The PC system has a built in DVB-S card that is connected to the dish and besides the

EUMETCast Key Unit (EKU), which hold the key for encrypting the received data. Each file is compressed by means of a wavelet algorithm. Furthermore the PC system is connected to the UFAL LAN to have the ability to serve the end user with the MSG full disk that is composed by 8 segment files, each one consisting of 464 lines (i.e., HRIT format). This data consists of geographical arrays of 3712 × 3712 pixels. Each pixel contains 10 bit data that represents the radiance value, expressed in 10-3 Wm-2sr-1[cm-1]-1, codified in digital count (DC) form. MSG SEVIRI data have been received at UFAL since 2007 (Fig. 3). This processing level corresponds to image data corrected for radiometric and geometric effects, geolocated using a standard projection, finally calibrated.

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):

$$L_{(i,ch)} = DC_{(i,ch)} * cal\_slope_{(ch)} + cal\_offset_{(ch)} \quad (1)$$

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 (4-11), 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:

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

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).

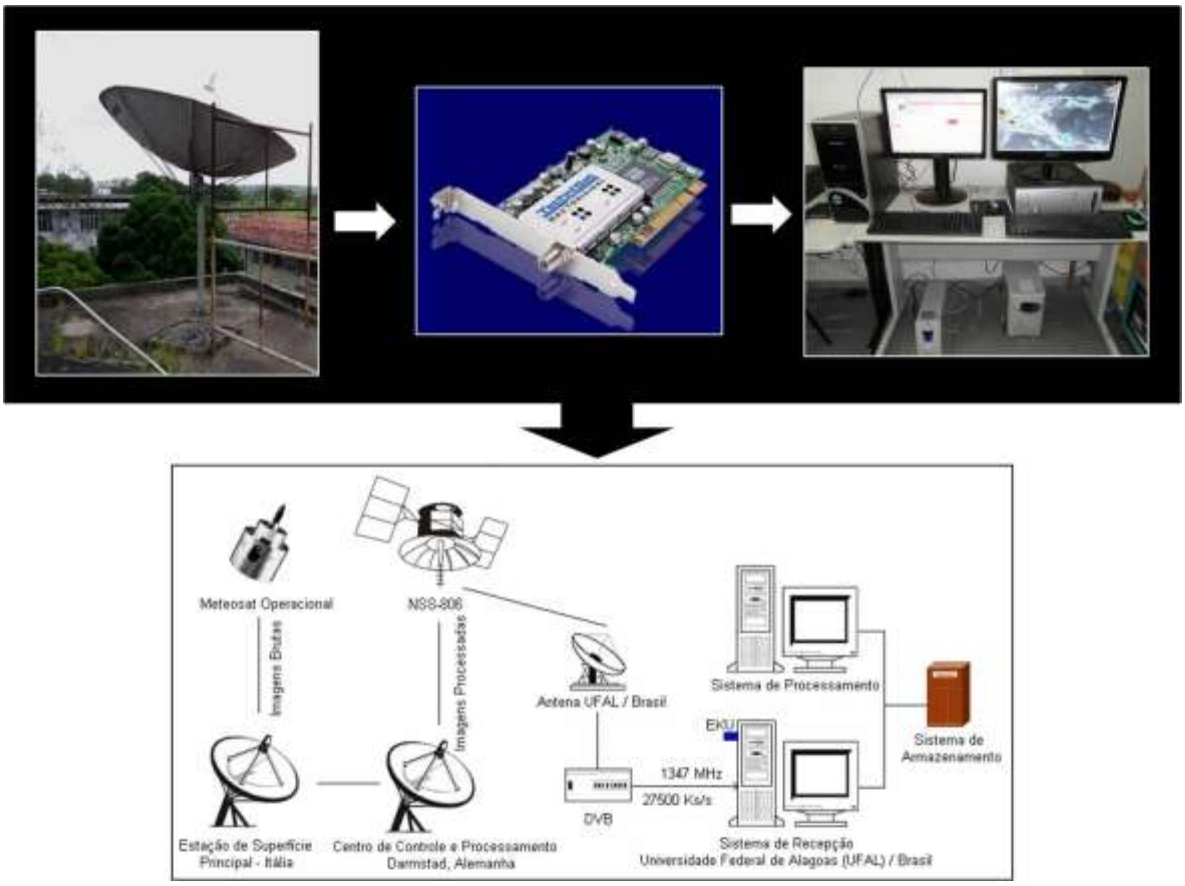


Figure 3. Overview of the broadcasting ground reception and processing system at the University of Alagoas (UFAL) in Brazil.

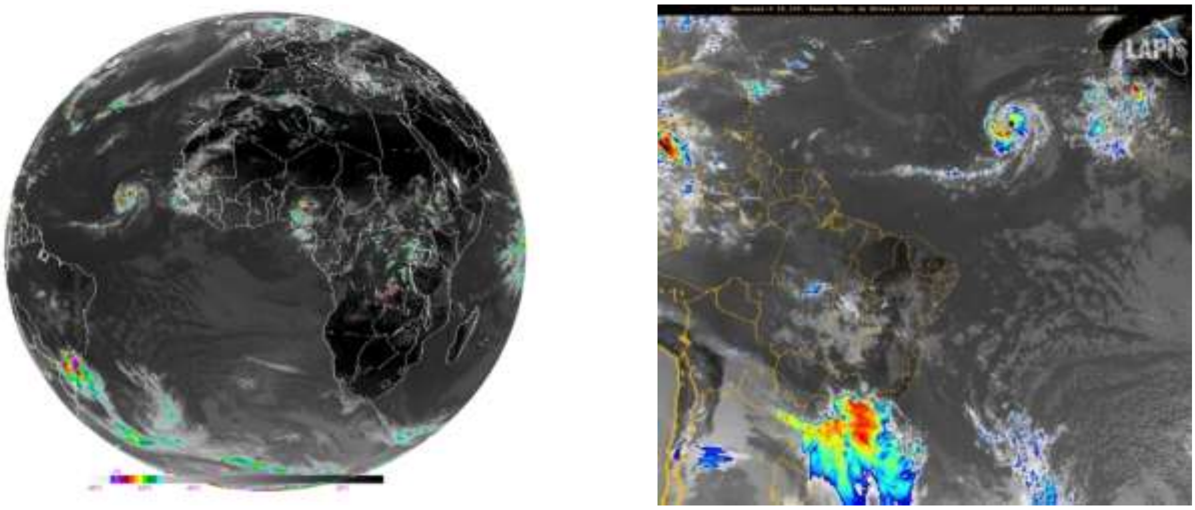
Meaningful RGB combinations can be used for qualitative analysis of cloud microphysics (Lensky and Rosenfeld, 2008). In order to assess RGB composites, ASCII files regarding the 12 spectral bands were extracted using open-source software tools (e.g., EUMETSAT WaveLet Transform Software used to decompress SEVIRI HRIT data files (EUMETSAT, 2009c); Geospatial Data Abstraction Library (Silva Junior et al 2009) used to read and write many geographic data formats), to allow data to be analyzed. These are spectral radiance displayed: reflectance (%) in the solar channels and brightness temperature (K) in the thermal channels. This processing level corresponds to image data corrected for radiometric and geometric effects, geo-located using a standard projection (Silva Junior et al 2009), finally calibrated (Fig. 4). These processing steps were computed by LAPIS, at UFAL, in collaboration with Turkish State Meteorological Service (TSMS).

Analyses of the cloud-top SEVIRI data were done using different bands of RGB color compositions (convective storms). This RGB composition is widely used methods (Kerkmann et al. 2004). The "convective storm" RGB (Fig. 4), based upon the RGB combination of channels (WV 6.2 µm – WV7.2 µm; IR3.9 µm – IR10.8 µm; NIR1.6 µm –VIS0.6 µm), the red color appears in clouds with larger ice particles, while darker orange for smaller ice particles. The spectral images from SEVIRI VIS0.6 (channel 1); NIR1.6 (channel 3); WV6.2 (channel 5); and IR10.8 (channel 9) were processed and displayed into reflectivity (channels 1 and 3) and BT (channels 5, and 9) by exploiting the codes developed by LAPIS. Both the reflectivity and BT time series were geo-rectified and extracted over a grid cell limited between 25°N – 35°S and 5° – 73°W (Fig.5), with pixel spacing of about 5X6 kilometers.

The extracted pixel values over the study grid cell for each channel were then arranged as an input matrix to determine the spatial variations in cloud top. In our analyses, scatter plots through the spatial distribution in both the reflectivity and BTDs were analyzed. At the study grid cell, for each pixel the difference (WV6.2 µm – IR10.8 µm) was used as a proxy for deep convection. In the case, BTs larger at WV6.2 µm than at IR10.8 µm were explained by stratospheric water vapor, i.e. small (positive) difference. The determination of cloud-top radiances obtained from these channels of the radiometer SEVIRI relied on the following two assumptions; that clouds were cumulonimbus so they can consider optically thick and that they were considered blackbodies. These scatter plots were analyzed separately to characterize the spatial heterogeneity of cloud top at these spectra outlined.

Table 1. Spectral bands of the SEVIRI instrument, commonly used for monitoring of convective storms.

Spectral band	SEVIRI (MSG)
Visible (VIS) and shortwave end of NIR (approx. 0.4 - 1.2 µm)	band 01 VIS 0.6 (0.56-0.71 µm) band 02 VIS 0.8 (0.74-0.88 µm) band 12 HRV (0.5-0.9 µm)
Microphysical bands (NIR) (approx. 1.6 and 3.5 - 4 µm)	band 03 IR 1.6 (1.5-1.78 µm) band 04 IR 3.9 (3.48-4.36 µm)
Water vapor absorption/emission bands (WV)	band 05 WV 6.2 (5.35-7.15 µm) band 06 WV 7.3 (6.85-7.85 µm)
Thermal IR window bands (IRW)	band 07 IR 8.7 (8.30-9.10 µm) band 09 IR 10.8 (9.80-11.80 µm) band 10 IR 12.0 (11.00-13.00 µm)



(a) **(b)**

Figure 4. METEOSAT 9 SEVIRI color-enhanced IR 10.8 image dated on 08 September 2008 at 13:00 UTC. (a) For the MSG full disk. (b) For the geographic domain used in the paper.

3. Results

3.1 The 08 September 2009 storm

The case study for which results are presented here is a frontal system over south-eastern region of Brazil on 08 September 2009 at 13:00 UTC. At this time the cloud storm was already in the mature stage. This anomalous event was characterized by very unstable weather, in particular over the eastern State of São Paulo. The general situation, shown in the synoptic chart (Fig. 5), suggests that a strong pressure gradient produced high winds bringing the cold air from South to South-eastern Brazil, producing upper-level cyclonic vortices. According to reports from meteorological stations, the average velocity of winds in parts of São Paulo city on 08 September was 70km/h. The geographic area under consideration is approximately centred over Brazil (Fig. 5). It covers from 25N to 35°S and from 5 to 73°W.

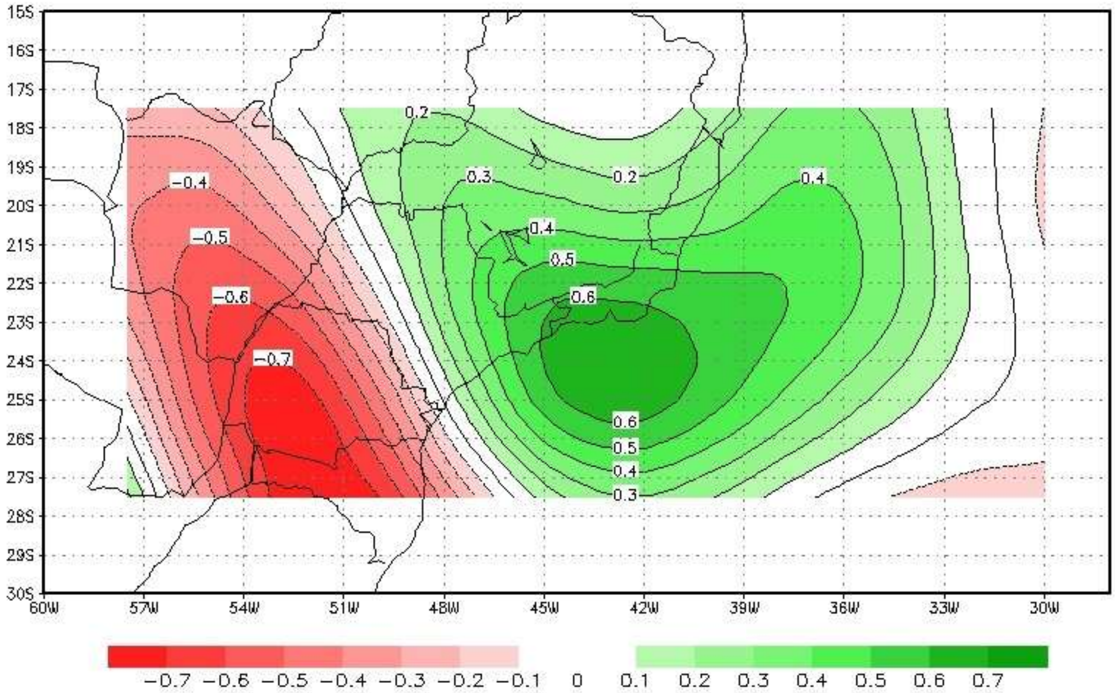


Figure 5. Relative Vorticity field (2.5°×2.5° resolution) for 200 hPa derived from the NCEP reanalysis data base over South-eastern Brazil on 08 September 2009.

The “convective storms” (Fig. 6) RGB composite help us to locate the strong convective clouds take place. The figure 6 exhibits that the active convection cells (yellowish) associated with strong updrafts within Cb clouds became more organized and centered over mostly the eastern edge of Brazil south, to form stronger precipitation at this location. The visual inspection of this composite can indentify the strong cold frontal over South-eastern Brazil. Associated with this, it is relatively evident (shown in the synoptic chart (Fig. 5)) that no upward vertical motions arose as a result of frontogenesis, it just goes to show that this was the closest variable which may have impacted and aided the severe weather, on a synoptic level. More importantly about this RGB composition, however, was the fact could be seen coming up from the moisture sources of the Atlantic Ocean and the Andes Mountains towards southestern Brazil where the cumulus clouds are located. The warmer temperatures lead to lower stabilities also.

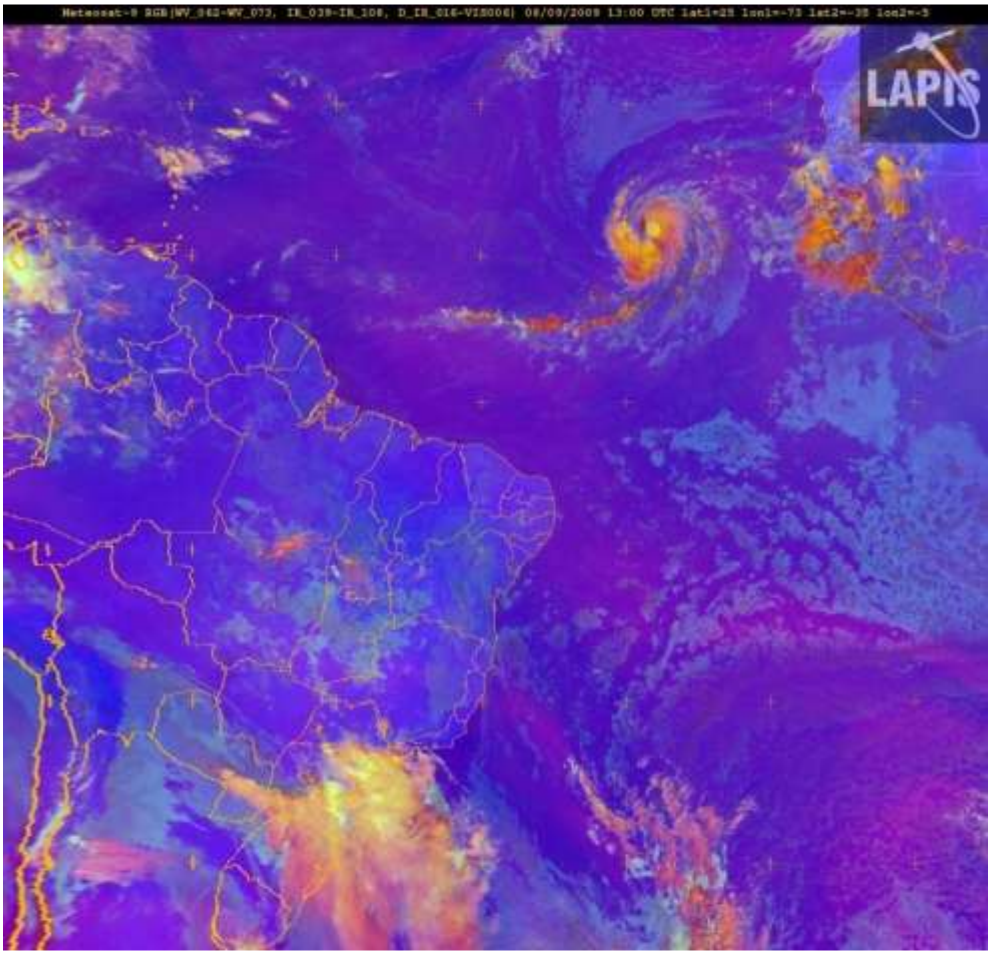
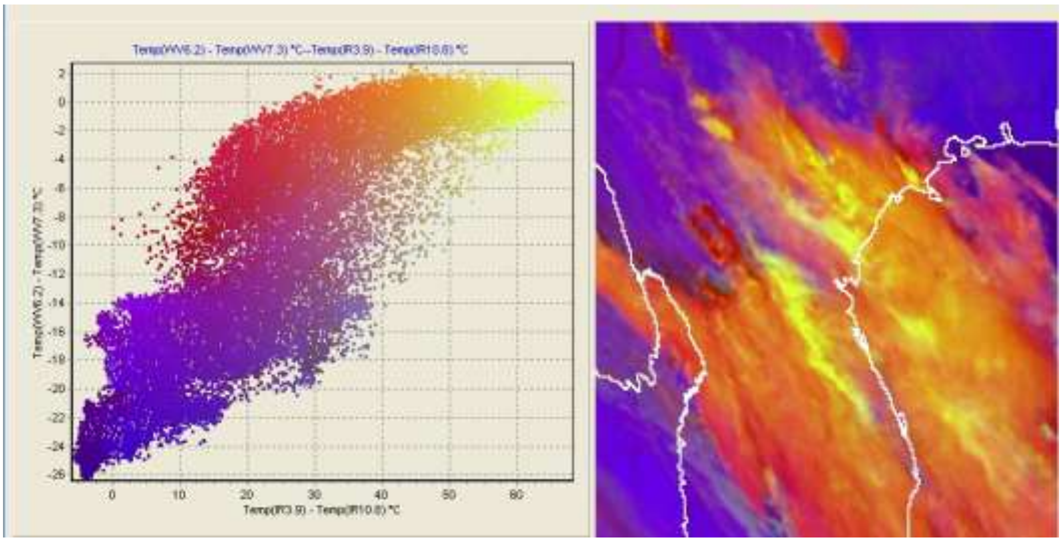


Figure 6. “Convective storms” RGB composite image dated on 08 September 2009 at 13:00 UTC.

Scatter plot diagram of BTD(WV6.2 μm – WV7.3 μm) as a function of BTD(IR3.9 μm –IR10.8 μm) and their BTD image (zoomed-in south-eastern ern Brazil) at 13:00 UTC are show in Fig. 7a and 7b, respectively. Difference values larger than –2º C (for 6.2–7.3 μm) and + 50º C (for 3.9 μm –10.8 μm) are found to correspond well with intense convective clouds (red/orange), and subsequently, storms. The diagram makes it easy to note that positive BTD (WV) is likely to correspond with convective cloud tops that are at or above the tropopause (i.e. overshooting tops). Associated with this, a large number of dots clusters are shown in high yellow colors. In fact, the BTs derived from 10.8 μm shown in Fig. 7 are fundamental for the definition of overshooting Cb clouds that have near zero or slightly positive BTD (6.2-7.3) (high yellow). With these dots clusters merging at the BTs (for 10.8 μm), the concentration areas are characterized by cloud-top temperatures (CTT) above -62°C, which may produce storms throughout much of the eastern portions of Brazil south. Therefore, the combination of 1) larger than –2º C (for 6.2–7.3 μm) that is modulated by mid-level moisture, 2) larger + 50º C (for 3.9 μm –10.8 μm) that is stronger for cold clouds, and 3) minimum CTT of -62°C, led the severe storm at this location at this time.



(a) **(b)**

Figure 7. Scatter plot diagram of BTD(WV6.2 µm – WV7.3 µm) as a function of BTD(IR3.9 µm –IR10.8 µm) (a) and their BTD image (zoomed-in south-eastern ern Brazil) dated on September 2009 at at 13:00 UTC (b).

4. Summary and conclusion

In this paper, we described our experiences with acquiring, processing and classifying the 1.5 Meteosat-9 SEVRI radiances (MSG-2) received through the EUMETCast service using RGB composite for characterizing cloudy (and potentially precipitating) pixel areas relative to a severe convective event, take on 8 September 2009, over the South-eastern Brazil. In this respect, the software tools developed at LAPIS, based on open source codes for geolocation and geographical information systems, written for the transformation of the 1.5 SEVIRI radiances into the geo-physical values (i.e., the solar reflectance in the solar bands and brightness temperature in the thermal bands) were employed. In conclusion, the study shows that difference values larger than –2º C for BT Differences (WV6.2 µm – WV7.3 µm) and + 50º C (IR3.9 µm –IR10.8 µm) were found to correspond well with deep convective storms. The study opens up an avenue for successive validation of the MSG data for weather monitoring, particularly in case of complex and intense events. In this direction its use for nowcasting is to be considered in a short while.

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