The cloud-top SEVIRI data for monitoring convective storms

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Abstract. This paper presents the first steps towards an operational use of the multispectral data of Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) for weather monitoring in Brazil. We describe our experiences with acquiring, processing and classifying the high rate information transmission (HRIT) wavelet compressed data received through the EUMETCast stream at Federal University of Alagoas (UFAL). The HRIT data processing at UFAL is based on open-source codes. It is used to convert the HRIT radiances to both the solar reflectance and brightness temperatures (BT) for SEVIRI's solar and thermal (IR) bands. To characterize the cloud-top observations, using a twofold approach: 1) red-green-blue (RGB) "convective storms" color composition to qualitatively identify the cloud-top characteristics on the basis of the combinations of radiances measured in different bands, and 2) a quantitative description of cloud-top in terms of band differences. In particular, the strong convective event, which was estimated to affect most coastal cities of Southeast Brazil by early morning of 8 September 2009, is used as an optimal set of observations to the two analyses. Results show 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 intense convective clouds, and subsequently, storms. In conclusion, the study shows the potential of SEVIRI data in evaluating the intense storm of the examined case study.

Key words: MSG, EUMETCast, weather forecasting, Nowcasting, 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). 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 these communities.

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 m channel are below 0.25 K at 300 K (Schmetz et al., 2002).

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.

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. The raw count data received by this service are referred to as level 1.5 data (EUMETSAT, 2008). 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} $Wm^{-2}sr^{-1}[cm^{-1}]^{-1}$, codified in digital count (DC) form. MSG SEVIRI data have been received at UFAL since 2007 (Fig. 1).

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).

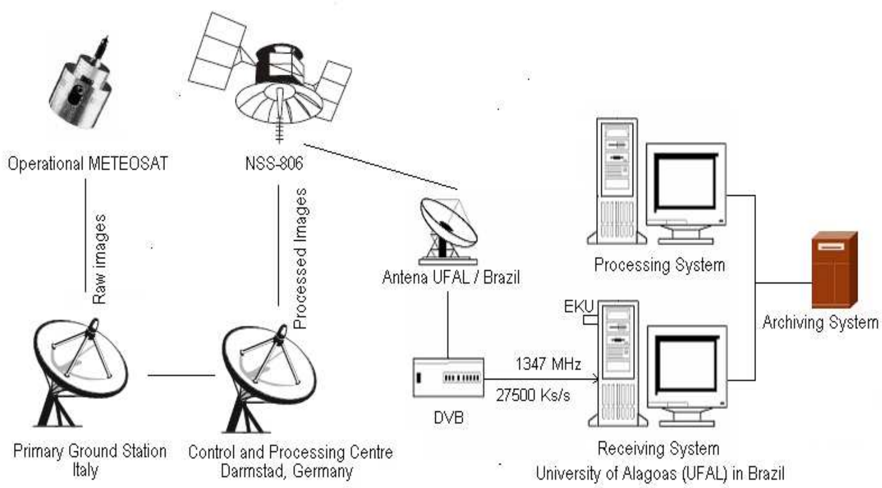

Figure 1. Overview of the broadcasting ground reception and processing system at the University of Alagoas (UFAL) in Brazil.

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. 2). 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)**

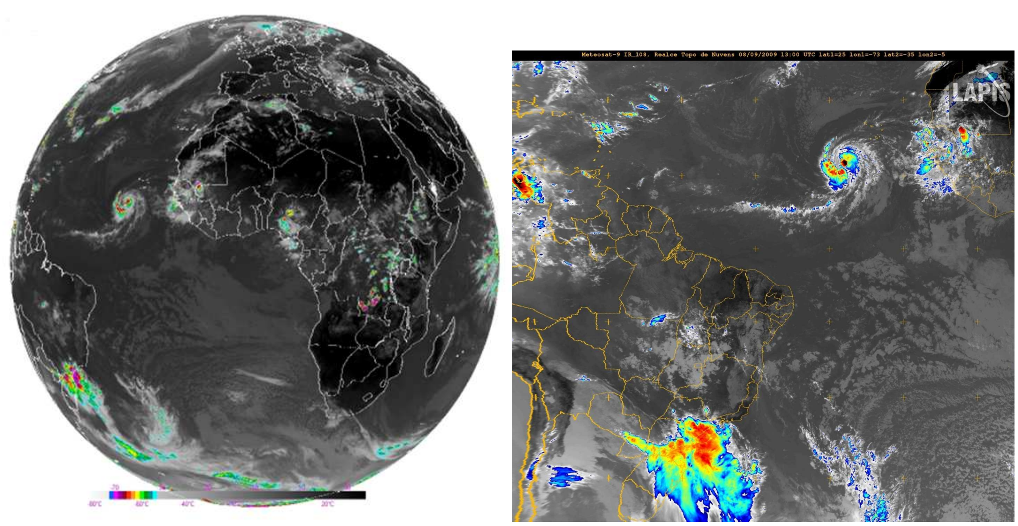

Figure 2. METEOSAT 9 SEVIRI color-enhanced IR 10.8 image dated on 08 September 2008 at 13:00 UTC. (a) For the MSG full disk. (b) For the geographic domain used in the paper.

3. Results

3.1 The 08 September 2009 storm

The case study for which results are presented here is a frontal system over southeast 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. 3), suggests that a strong pressure gradient produced high winds bringing the cold air from South to Southeast 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. 3). It covers from 25N to 35°S and from 5 to 73°W.

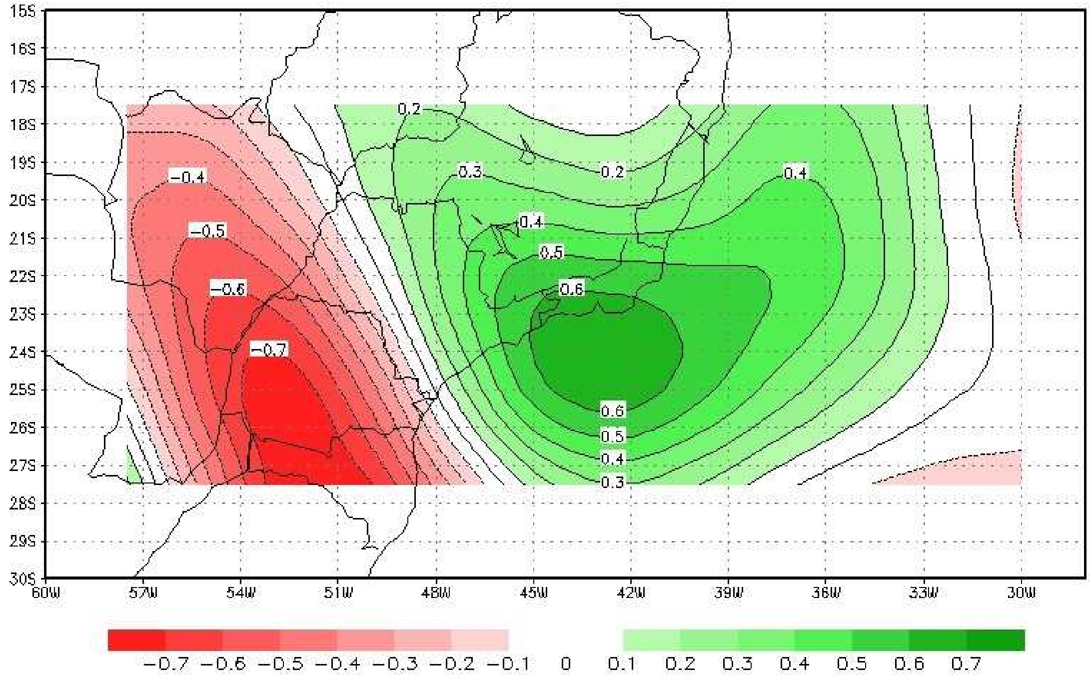

Figure 3. Relative Vorticity field (2.5°×2.5° resolution) for 200 hPa derived from the NCEP reanalysis data base over Southeast Brazil on 08 September 2009.

The "convective storms" (Fig. 4) RGB composite help us to locate the strong convective clouds take place. The figure 4 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 Southeast Brazil. Associated with this, it is relatively evident (shown in the synoptic chart (Fig. 1)) 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.

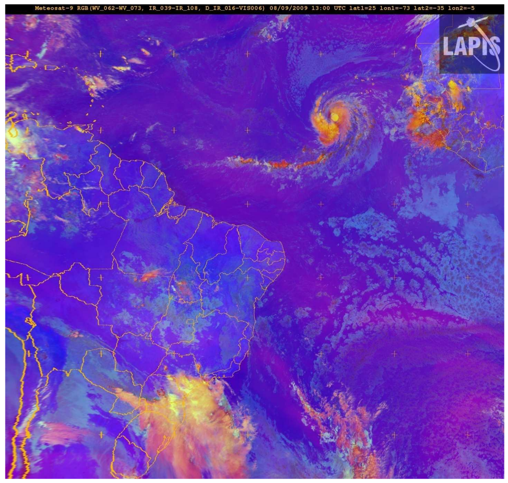

Figure 4. “Convective storms” RGB composite image dated on 08 September 2009 at 13:00 UTC.

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 southeastern Brazil) at 13:00 UTC are show in Fig. 5a and 5b, 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. 2 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)**

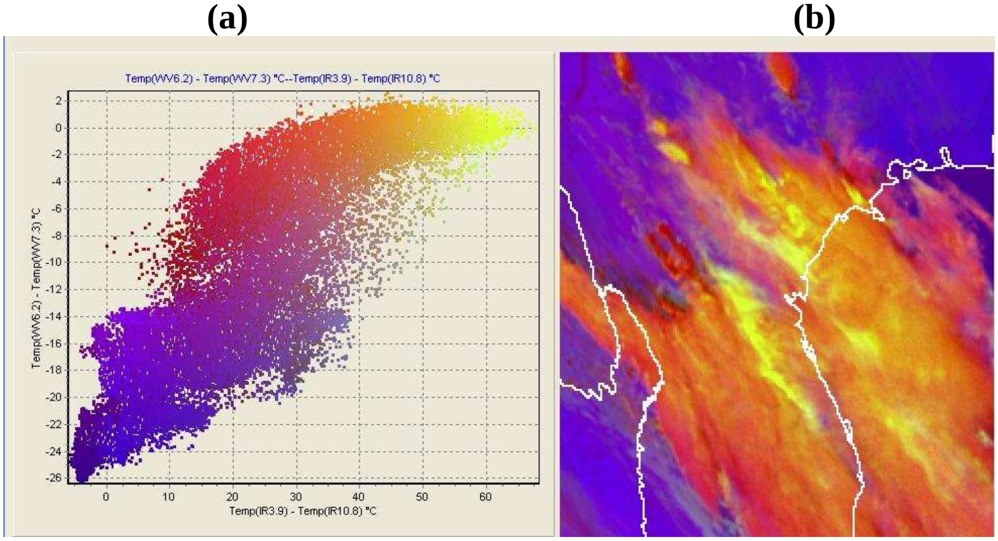

Figure 5. Scatter plot diagram of BTD(WV6.2 μm – WV7.3 μm) as a function of BTD(IR3.9 μm –IR10.8 μm) (a) and their BTD image (zoomed-in southeastern Brazil) dated on September 2009 at at 13:00 UTC (b).

4. Conclusions

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 Southeast 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.

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References

Barbosa, H. A., and Ertürk, A. G. Using multispectral SEVIRI radiances at the top of deep convective storm as a powerful tool for short prediction in Brazil. **5th European Conference on Severe Storms**, Stadtsala Bernlochner – Landsat – Germany, 12-16 October, www.essl.org/ECSS/2009/preprints/007-7-barbosa.pdf, 2009.

EUMETSAT. A planned change to the MSG Level 1.5 image product radiance definition, document n. 0519. Available from: **http://www.eumetsat.int/idcplg?IdcService=GET_FILE&dDocName=PDF_MSG_PLANNED_CHANGE_LEVEL15&RevisionSelectionMethod=LatestReleased]**, 2007a.

EUMETSAT. A simple conversion from effective radiance back to spectral radiance for MSG images, document n. 1053. [available from: **http://www.eumetsat.int/idcplg?IdcService=GET_FILE&dDocName=pdf_msg_conv_effrad2specrad&RevisionSelectionMethod=LatestReleased]**, 2008.

Ertürk, A. G. and Barbosa, H. A. Detecting V-Storms using Meteosat Second Generation SEVIRI image and its applications: A case study over western Turkey. 5th European Conference on Severe Storms, Stadtsala Bernlochner – Landsat – Germany, 12-16 October 2009. **http://www.essl.org/ECSS/2009/preprints/P07-11-erturk.pdf**.

Fritz, Sigmund and Laszlo, Istvan. Detection of water vapor in the stratosphere over very high clouds in the tropics. **Journal of Geophysical Research**, 98(D12), 22959-22967, 1993.

Govaerts, Y. and M. Clerici. MSG-1/SEVIRI Solar Channels Calibration Commissioning Activity Report. **EUMETSAT Doc. EUM/MSG/TEN/04/2004**, 35 pp., 2004.

Lensky, I. M., and D. Rosenfeld. Clouds-Aerosols-Precipitation Satellite Analysis Tool (CAPSAT). **Atmos. Chem. Phys.**, 8, 6739–6753, 2008.

National Weather Service. "Weather Glossary – T". National Oceanic and Atmospheric Administration. **http://www.weather.gov/glossary/index.php?letter=t**. Retrieved 2010-07-23, 2010.

Setvák M., Lindsey D. T., Rabin R. M., Wang P. K., Demeterová A. Indication of water vapor transport into the lower stratosphere above midlatitude convective storms: Meteosat Second Generation satelite observations and radiative transfer model simulations. **Atmos. Research**, 89, 170-180, 2008.

Silva Junior, I. W.; Nobrega, T.; Barbosa, H. A.. VIEWSATT a Decoding and Processing Software Tool for MSG Data. In: WORLDCOMP'09 - **The 2009 World Congress in Computer Science, Computer Engineering, and Applied Computing**, Las Vegas – EUA, 2009.

Schmetz, J., P., Pili, S., Tjemkes, D., Just, J., Kerkmann, S., Rota, and A. Ratier. A Supplement to An Introduction to Meteosat Second Generation (MSG). B. **Am. Meteorol. Soc.**, 83, 991, 2002.