A TOOL FOR SEVERE CONVECTIVE STORM EVALUATION USING SATELLITE INFRARED AND LIGHTNING NETWORK OBSERVATIONS

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I. INTRODUCTION

Lightning is a critical parameter in nowcasting for storm intensity and plays a paramount role in atmospheric dynamics. Each lightning discharge generates a pulse of very short duration that passes between a storm cloud and the ground, or between or within storm clouds in typically less than one millisecond. Acceleration in lightning flash density can signal increased storm intensity that may likely lead to an increase in the frequency of extreme precipitation events as well as an increase in the proportion of precipitation resulting from extreme events (Trenberth, 1999), a phenomenon which has already been observed in certain regions (Folland and Karl, 2001). Convective rainfall is closely linked to lightning activity, although the relationship varies in different environmental conditions (Keighton et al. 1991). Moreover, various studies (e.g., Saunders et al. 1993) have shown that lightning activity is well correlated with the ice content of the precipitating cloud. For instance, Petersen and Rutledge (1998) found the presence of large ice particles and strong updrafts in the mixing region (0 and -20ºC). Similarly, Machado et al. (2009) related strong convective updrafts to high flash rates, and suggest that the frequency of lightning may be a measure of convective activity. They have found that flash rates are inversely proportional to the satellite brightness temperature observations.

Storm research has focused on combining satellite thermal infrared band data with lightning location networks to estimate storm intensity in what is termed a nowcasting approach. The synergies between both sources of information offer an opportunity for the identification of the most important rainy areas associated with any deep convective cloud where lightning occurs. Due to the synergistic effect, lightning is produced by the collision of ice particles embedded in intense cloud updrafts. Integration of satellite and lightning data can be applied for indicating the intensity of storm. However, there is a definitive need for a dynamic viewing tool with integration and visualization capacities for application to convective storms through satellite and lightning data. Such a tool would ideally be constructed following the model of an automatic viewing tool that incorporates time into the visualization and allows local or remote users to access images and lightning data very close to real time. In both datasets, it would be necessary to perform some preprocessing and then transmit a subset of the data to one or more processes or visualization servers to display. Utilizing the Google Earth platform could be extremely useful in affording end users the capability to interactively view data.

The present research addresses the use of the thermal infrared band satellite with lightning data over Brazil for nowcasting and very short range forecasting by means of producing input files in a format suitable for ingestion into the Google Earth platform. We describe the methods and tools used to transform the data into an appropriate format for the Google image-lightning ingestion routine. To accomplish these operations, some open-source tools have been selected.

II. PRESENTATION OF RESEARCH

The satellite measurements are obtained from the SEVIRI (Spinning Enhanced Visible and Infrared Imager) on board Meteosat-9 positioned at 0° longitude and 0° latitude in geostationary orbit 36,000 km above the Gulf of Guinea. The radiometric values from the two selected SEVIRI bands are the primary retrieved data for cloud top temperature and water absorption. The infrared (IR) 9.80 – 11.80 μm and the water vapor (WV) 5.35 – 7.15μm bands from MSG are used to identify deep convective clouds. This data consists of geographical arrays of 3712 × 3712 pixels and a sampling distance of 3 × 3 km^2 at the sub-satellite point, i.e., the point on the Earth's surface directly below the satellite. Each pixel contains 10 bit data that represent radiance value, expressed in 10^{-3} Wm-2sr^{-1}[cm^{-1}]$^{-1}$, codified in digital count form. The full earth image (for channels IR and WV) is composed by 8 segment files, each consisting of 464 lines. This framework defines the so-called High Rate Image Transmission (HRIT) segment files (EUMETSAT, 2009c). Each file is compressed by means of a wavelet algorithm.

The IR and the WV measurements are transmitted to a ground segment for the reception of SEVIRI data, which is located at the Laboratory for Analyzing and Processing Satellite Images (LAPIS) in Maceió, Brazil. The station has been in operation since April 2007. All received SEVIRI image data are distributed via EUMETCast service to the LAPIS data processing and archiving facility. This service provides Level 1.5 processed SEVIRI images of raw satellite data (designated as Level 1.0 data). Using standard Digital Video Broadcast (DVB) technology the SEVIRI dissemination is performed by commercial telecommunication geostationary satellites (NSS-806 at present) to distribute files and allows users to receive images and data in nearly real time. A metadata base of received and archived (Level 1.5) images is available on the LAPIS Web page which can be also contacted for data requests. Thanks to extensions of the existing software libraries it is possible to process the SEVIRI data in this standard processing environment.

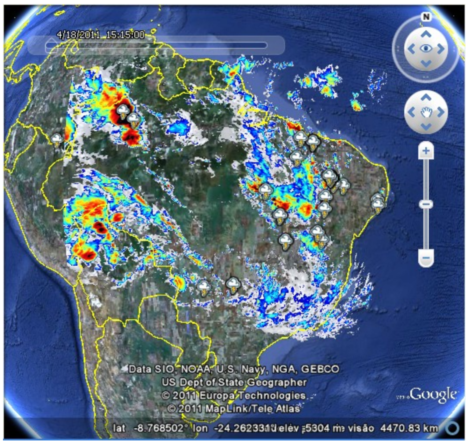
The lightning information comes from the ground-based World Wide Lightning Location Network (WWLLN) composed of many individual receiver stations. The WWLLN is a network of lightning location sensors that computes the precise time of arrival of the received lightning strike impulse ("sferic") in the VLF (very low frequency) band (3 – 30 kHz) and the exact position of the sferic. Currently, this network consists of 65 VLF lightning receiver stations distributed around the world and the central processing server at University of Washington in Seattle, which includes the VLF LAPIS station in Maceió. The hardware of each receiver station consists of a short (1.5m) whip antenna, a GPS receiver, a VLF receiver, and an internet connection to the central processing server. Atmospheric discharges emit radio frequency energy over a wide range of frequencies. Each receiver station computes the vertical electric field as a time series, which represents the sferic's waveform, and includes a time stamp synchronized by the Global Positioning System (GPS) clock. The sferic positions are made available in raw format to all users (e.g., LAPIS) that transmit their data to the server. This information includes date, time, latitude and longitude coordinates, residual error, and the number of WWLLN stations that detected the lightning strike. At least four stations are needed to compute strike positions. The computation of strike positions is currently only done by the central server.

We combine different approaches to carry out the ingestion of both SEVIRI imagery and WWLLN lightning information into Google Earth platform, specifically over Brazil. The goal is accurately identifying storm severity. The first step to implement the ingestion of SEVIRI images in the IR and WV spectral bands into Google Earth is their conversion from DN to physical variables like brightness temperature, their geographic projection, and the transformation of images into a format compatible with the Google ingestion routine.

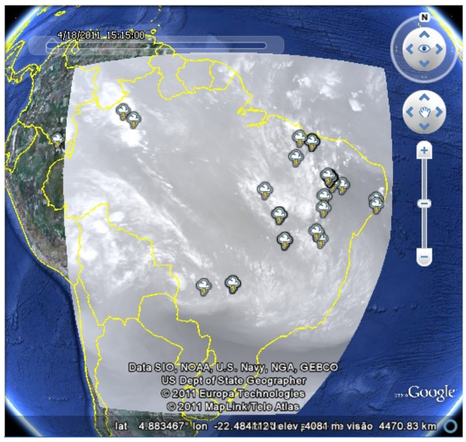
To accomplish these operations, some open-source tools have been utlized. Among the available open-source tools used are: EUMETSAT WaveLet Transform Software (EUMETSAT, 2009c), the tool used to decompress SEVIRI HRIT data files; NetCDF (Unidata, 2009), a set of software library data formats that supports creation, access, and sharing of array-oriented scientific data; Geospatial Data Abstraction Library (GDAL, 2009a) that enables us to read and write in many geographic data formats and encode geographical information into files. The second step in the ingestion of WWLLN lighting information into Google Earth consists of ingesting the data from its current simple text format to Google using Keyhole Markup Language (KML).

The two approaches also facilitate the integration of ground-based lightning observation into SEVIRI-derived cloud top temperature (IR), which is related to cloud height. A preliminary comparison was performed as recently as 15:15 UTC on March 5, 2011. The selection of the date was made on the basis of visual observation by looking for consistent convective activity over different areas of Brazil for the investigation. The research focuses on lightning flashes – usually associated with clouds whose very cold tops indicate deep convection – which are a good indication to use for the measure of storm intensity. Because the concept of convective cell intensity is not well established within the context of the use of satellite data, we established different thresholds of differences (δBT) between brightness temperatures (BT) at BTIR (centered at 10.8 µm) and at BTWV (centered at 6.25 µm) as criteria for considering satellite pixels convective (+1K, +0.5 K, +0.25 K, 0 K, -0.25 K, - 0.5 K, - 1 K).

In order to validate pixels as convective, we merely thrust the lightning detection and ascertain whether "deep convective cloud" could have a positive difference (δBT>0) between BTIR and BTWV as found in Schmetz et al. 1997. This means that the quality of the lightning observation is essential for convection detection, particularly when the assimilation tool uses satellite measurements at a resolution of 4 km. If the pixel is established as convective by the lightning information, then this is convective for IR – WV. For any given convective pixel the algorithm computes the δBTs between the IR (TIR) and WV (TWV) bands. A scatterplot of IR against δBTs of IR – WV is also calculated to show how the lightning values indicate the most intensive pixels associated with δBT. Each star corresponds to a pair in a set of 32 selected cloudy pixels over different regions of Brazil for the case under study. In the 32 cases the flashes were observed within the period from 14:14 to 15:16 UTC. The SEVIRI bands do not actually scan the same pixel simultaneously. For instance, there is a delay of 144 microseconds between the IR and WV bands. Thus it is possible for the onset of the lightning flash to occur in the time gap between channels IR and WV. In other words, convection activity is considered constant during the time interval. High convection activity corresponds to strong atmospheric discharge activity in convective-cloudy weather systems, but not in stratiform-cloudy weather.



(a) SEVIRI IR (10.8) + 32 flashes



(b) SEVIRI WV (6.2) + 32 flashes

FIG. 1: The ingestion of thermal infrared band satellite (a) and WWLLN lighting measurements (b) into Google Earth.

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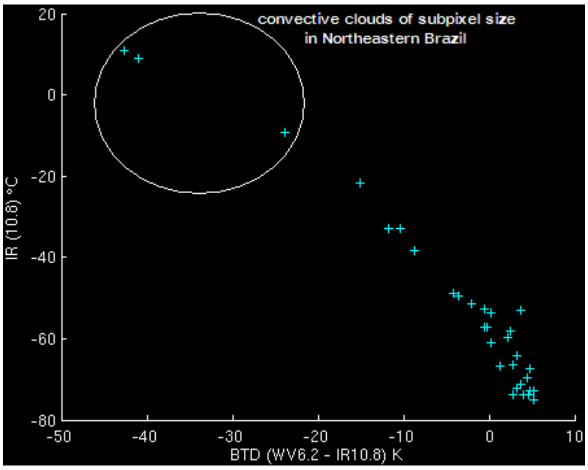

FIG. 2: Scatterplot of spatial distribution of IR against δBTs of IR – WV pixels based on the 32 selected flashes over Brazil (c), on March 5, 2011.

III. RESULTS AND CONCLUSIONS

The case study shows that the ingestion of both the SEVIRI satellite data in the IR and WV spectral bands taken at 15:15 UTC and the 32 cases of lightning flashes recorded by WWLLN data in the time period between 15:14 and 15:16 UTC into Google Earth Plataform works quite well. The results in figure 1(a, b) illustrate the spatial coincidence between the BT of cloudy pixels and flash observations, coincidence which is especially marked in the coldest convective pixels. Contrariwise, the results in figure 2 highlight the flashes in pixels where there are no convective cells. In particular, there are pixels over Northeastern Brazil where lightning flashes are active and the δBTs of IR – WV do not indicate convective pixels. A blend of convective clouds of subpixel size and warm surface is difficult to detect from satellite measurements at a resolution of 4 km, especially in this region. Thus, convective clouds of subpixel size can confound the satellite measurements of storm intensity. In summary, we have developed a tool for inserting satellite imagery and lightning data into Google by representing the presence of lightning as a pixel as well as additional information for storm intensity.

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