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Chapter 2

SIGMA: A Web-based GIS for Environmental Applications

2.1. Introduction

The large amount of climatological and meteorological information produced by many countries during the last decades facilitated the creation of a huge and varied database. Meteorological agencies spread all over the world yield lots of information about atmospheric conditions and their interactions with oceanic and continental surfaces. The different types of data produced by numerical models, satellites, telemetric stations and others present different formats and bring information which reproduces the weather conditions in different areas and in different temporal and spatial resolutions.

The information produced by numerical models and also by satellite displays values in fields which can be represented by vectors (isolines) or grid points (pixels). Thus, they represent variables whose main characteristic is their spatial continuity. Variables measured by telemetric stations display punctual values; however, they can become continue in space when interpolated by a mathematical method.

All of this data has a strong relationship with the physical space and, in order to be analyzed in a context which involves human and natural aspects, this information requires advanced tools to aid its processing when searching for inferences from the processing of data with different nature and formats. In this sense, Geographical

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Information Systems (GIS) assume an important role in meteorology and climatology because it is one of the most powerful and efficient tools to manipulate spatial data.

According to [CAM 96] a GIS not only makes it possible to capture, model, handle and retrieve, but also to analyze georeferenced data by using dedicated hardware and software. The GIS can create and display maps and can also carry out tasks used in the planning and management of different cases. Among all applications, the GIS is largely employed in agriculture, environment, forestry, meteorology, networks monitoring services, etc. [LON 01].

The majority of commercial GIS has functionalities which make it possible to process and analyze spatial data, however, in some cases those functionalities are not enough and it is necessary to develop specific functions and procedures. In this way, the customization of GIS is a fact and has become common in recent years. Moreover, the feasibility of making a GIS available on the Internet, where users can use it instead of installing it on their desktop increases the power of this technology.

The complexity of the information hosted in a GIS requires standardization for different data patterns in order to increase their interoperability and/or data exchange. This issue has been discussed by different communities which deal with georeferenced data. Some patterns have been proposed by the OpenGIS (Open Geographic Interoperability Specification) [BUE 98, GAR 96]. The suggestions of the OpenGIS are disseminated by the Open Geospatial Consortium (OGC; http://www.opengeospatial.org), which is a non-profit, international, voluntary consensus standards organization that is leading the development of standards for geospatial and location based services. Through the OGC's member-driven consensus programs, OGC works with the government, private industry and academia to create open and extensible software application programming interfaces for GIS and other mainstream technologies.

2.2. CPTEC-INPE

The "Centro de Previsao de Tempo e Estudos Climaticos" of the "Instituto Nacional de Pesquisas Espacias" (CPETC-INPE) produces a large amount of data in different temporal and spatial resolutions which is used for different purposes. CPTEC is an operational weather forecast center and the data produced by its internal departments is made available to users mainly on the Internet.

Considering that the Internet is the main communication channel between users and CPTEC, it is necessary to offer users an efficient interface which facilitates the search for information and gives them extra tools to integrate, visualize and analyze data of different sources and patterns.

Bearing that in mind, CPTEC has developed an interface of integration and visualization of products by using Mapserver technology which is in accordance with the recommendations suggested by the OpenGIS. According to the official MapServer website (http://mapserver.gis.umn.edu) it is an open source development environment for building spatially-enabled Internet applications. MapServer excels at rendering spatial data (maps, images and vector data) for the Web. Although MapServer is not a full-featured GIS system, it meets the requirements needed to become one. Depending on the needs of the user, it is possible to develop tools and applications dedicated to GIS applications by using embedded programs.

The use of Mapserver technology to create the GIS hosted at the INPE/CPTEC Website is the issue with which this chapter deals. This GIS is named SIGMA (GIS for Environmental Applications) and is described in the next sections.

2.3. SIGMA

For an ordinary user who searches meteorological information to plan his daily activities, the use of a GIS is much more than a simple "look at a single map" which usually shows static and isolated information about a specific theme. By using a GIS it is possible to combine a lot of information and visualize the result in form of layers which contain different data. The integration of data is one of the primary functionalities of a GIS.

SIGMA in its full conception will be a proper Web-based GIS developed to attend the needs of CPTEC's users not only for basic consultation, but also for advanced operations which use special tools designed to obtain new information. The diagram showing the main functionalities of SIGMA is illustrated in Figure 2.1.

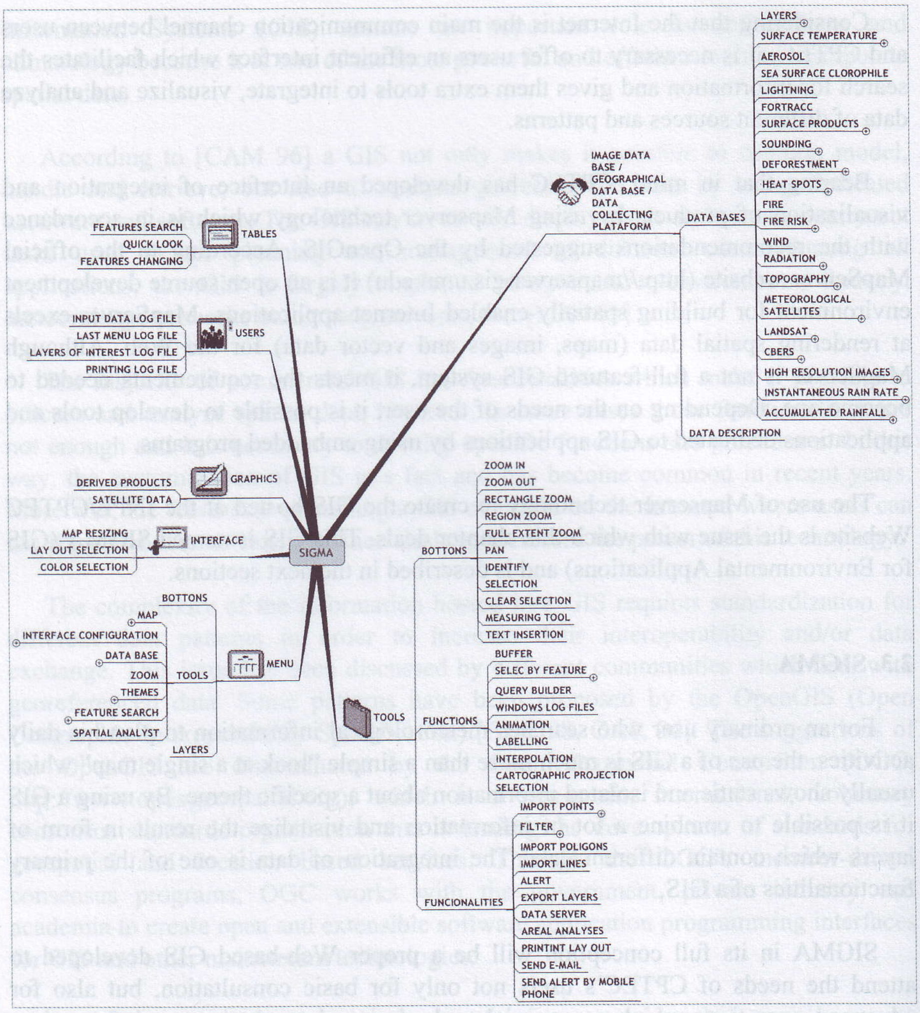

Figure 2.1. *SIGMA diagram and its main functionalities*

SIGMA provides users with resources to visualize, consult and carry out spatial analysis of data which is generated by CPTEC and also enables users to upload external data to be processed together with SIGMA's own data. According to Figure 2.1, users can handle information with spatial and tabular features, monitor weather and environmental conditions in real-time, produce reports and search for historical information in the CPTEC database.

2.3.1. *Basic functions*

The system presents basic functions like zoom in and zoom out, query builder, distance measuring, overlay of multilayers, upload of punctual, etc. Within the SIGMA environment the user can find pre-existent layers like topography, rivers, roads, cities, county and country borders, rail tracks, airports location, LANDSAT/TM mosaic, etc. All of those extra layers cover the entire South America and make SIGMA suitable for users in the whole continent. Operational meteorological products like lightning occurrence, rainfall estimated by satellite and radar, ultraviolet indices, amount of ozone in the atmosphere, burning occurrence, sea surface and continental temperature, etc. which are generated by the CPTEC are also available within the SIGMA.

2.4. Impacts of weather conditions on the economy

The economies of many countries and the way of life of their societies are directly affected by weather conditions. Not only the simple act of going out of our home but also complex tasks like the planning and management of all logistics involved in aerial or terrestrial transportation of people and goods, for instance, can be influenced by weather conditions. Therefore, the monitoring of weather conditions can be beneficial to several areas.

The high demand for information which enables the monitoring of weather conditions requires a special system which integrates the functions of GIS with the operational methods of data generation. This type of system can help decision makers who need an automatic system to monitors weather conditions in order to emit alerts and/or reports when an extreme weather event occurs. This type of system is, nowadays, a new challenge in terms of environmental monitoring.

2.5. Severe Weather Observation System (SOS)

The nowcasting products generated by CPTEC from the detection of lightning occurrence, radar and satellite data are stored within SIGMA in order to improve the monitoring of weather conditions over some parts of South America. An automatic system makes use of that data and evaluates the risk of storms, hail, lightning and flash flood occurrence over a given area. This system is named SOS and is embedded in SIGMA.

2.5.1. *Tracking of convective clouds*

SOS monitors convective clouds and tracks their origin, expansion rate, life cycle and both temporal and spatial evolution, as well as lightning occurrence associated with each convective cell. According to Machado and Laurent [MAC 04] the area of a convective cloud can be estimated as a function of its life duration (in hours) and is expressed by:

$$A(t) = \alpha * e^{at^2+bt+c}$$

where α, a, b and c are parameters extracted from the total life cycle of the convective system. The tracking of a convective system enables estimates of its position in the future and also its propagation speed by a linear extrapolation based on its previous position and speed.

2.5.2. *Risk of lightning occurrence*

According to [SCH 97] and [KUR 97] the positive difference between thermal infrared (10.5 µm) and water vapor (6.7 µm) GOES channels is possibly related to deep convection, once under these circumstances the updrafts can inject water vapor in the high levels of the atmosphere, usually reaching the stratosphere. According to Figure 2.2 when this occurs the brightness temperature of the water vapor channel tends to be greater than the thermal infrared of the cloud tops which are located in upper troposphere.

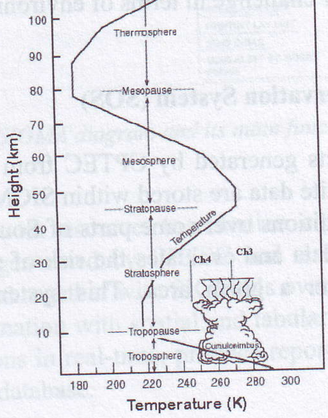

Figure 2.2. *Vertical profile of temperature according to the altitude*

Figure 2.2 shows that above the tropopause there is an inversion in the vertical profile of the temperature which causes the high values of water vapor brightness temperature. Convective clouds which present these characteristics usually produce lots of lightning and it is possible to relate the number of lightning occurrence with the difference between channel 3 and channel 4 of the GOES-12 satellite. According to [MAC 05] the relationship between this difference and the amount of lightning occurrence on the surface is shown in Figure 2.3.

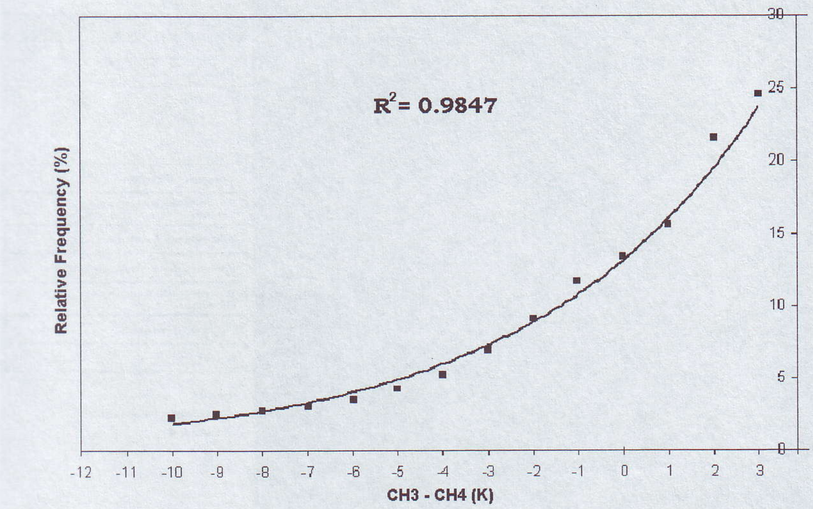

Figure 2.3. *Probability of lightning occurrence. The values shown in the graph represent the frequency of lightning observed on the surface during two consecutive GOES-12 images as a function of the difference of brightness temperature between channel 3 and channel 4*

2.6. SOS interface

Figure 2.4 exhibits the SOS interface which appears in the Web browser when the user logs on the site. Similar to what happens in SIGMA, users can choose which layer and/or products they want to visualize and also see if there is an alert emitted. When a critical situation is registered, for example, if a storm is predicted to occur in one hour's time, the regional borders where this storm will possibly occur will be highlighted in the screen (see Figure 2.4). In this case, SOS can send a message to someone by email and also by mobile phone.

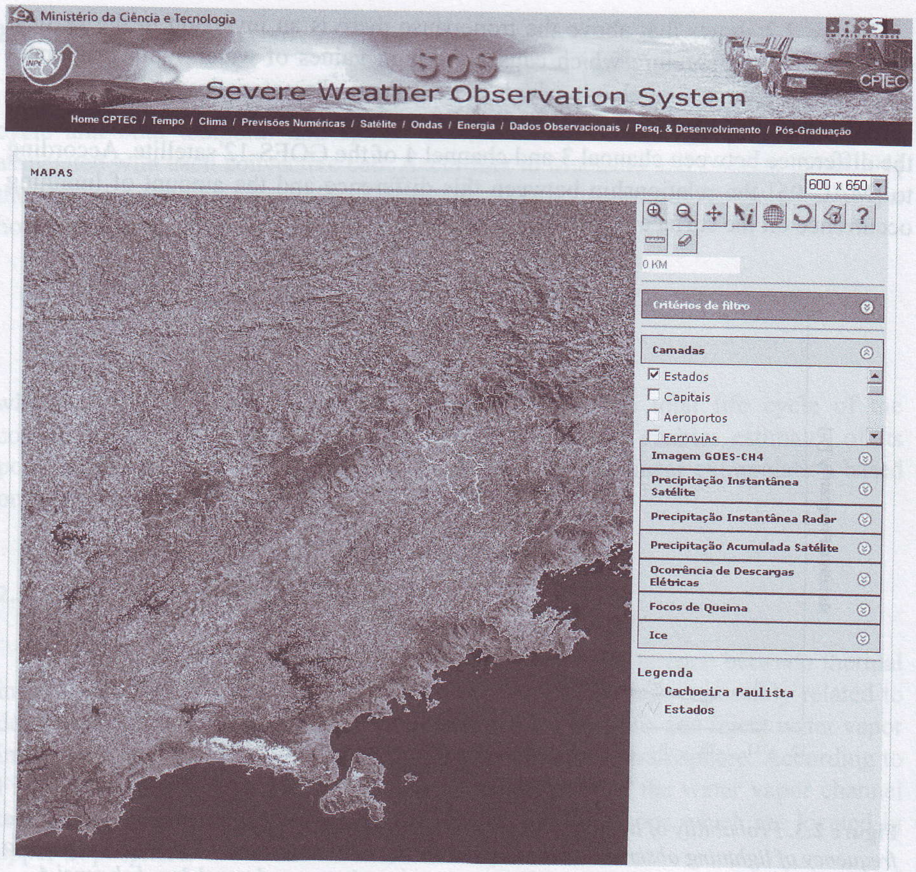

Figure 2.4. *SOS interface for Web browser*

From the SOS interface the user can see the past evolution of an extreme event and also its future evolution which is assessed by the nowcasting techniques. As the SOS is embedded in SIGMA, all visualizations can be integrated with other layers or products which are available in SIGMA. Figure 2.5 illustrates a storm predicted by the tracking of convective clouds and shows the estimated rain rate associated with the storm.

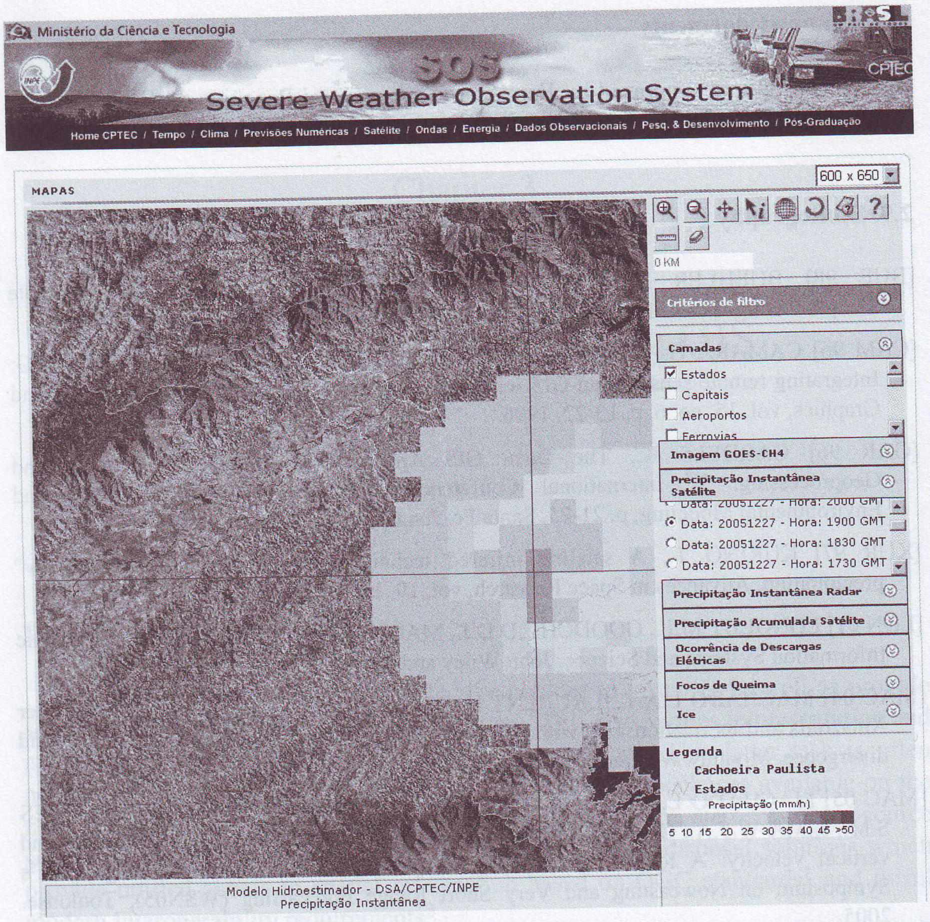

Figure 2.5. *Storm predicted by nowcasting techniques and emission of an alert by the SOS*

2.7. Conclusions

Weather conditions can have an impact on society as a whole and are sometimes responsible for lives and economical losses. Minimizing these losses is one of the main challenges for meteorologists and climatologists because this task requires efficient automatic systems which can predict the occurrence of extreme weather events reliably. Automatic systems developed to alert about bad weather conditions must be built to help decision makers improve their capacity to let authorities know when and where an extreme event will occur. Systems like SOS and SIGMA showed above are examples of the use of GIS technology to offer users advanced tools to aid them in dealing with different types of information at the same time.

2.8. Acknowledgements

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