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A WebGIS Application for Cloud Storm Monitoring

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Abstract. Extreme weather phenomena (i.e. heavy precipitation, hail and lightings) frequently cause damages in properties and agricultural production and usually originate from the cloud storms. Automated systems able to provide timely and accurate monitoring and predictions would contribute to prevent the effects of physical disasters and reduce economic losses. Nowadays, meteorological satellites have a significant role in weather monitoring and forecasting, providing accurate and high resolution data. Such data can be analyzed using Geographical Information Systems (GIS) and modern web technologies to develop integrated automated web based monitoring systems. This study describes a WebGIS application focused on monitoring and forecasting cloud tops of storm evolution. The application has developed using modern tools, to exploit their features through an innovative web based monitoring system. There are used open source framework to ensure mobility, stability and portability of the application.

Keywords: Webgis · Cloud monitoring · Satellite images · Remote sensing

1 Introduction

Most of the times, cloud storms have significant and direct impacts on human lives and properties because of the extreme weather phenomena that they produce like heavy rain, hail, strong winds, tornadoes, lightning, and flooding (e.g. [1–5]). The detection and forecasting of cloud storms evolution is extremely difficult and highly complicated not only due to their small scale internal dynamics but also because they are produced under various favorable conditions depending on topography, synoptic weather conditions, atmospheric instability, wind shear and many other factors ([6–12]).

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Nowadays, the availability of modern geostationary meteorological satellites with their fine time (typically, 15 min) and space (3 km at the sub-satellite point) sampling, comprise a modern alternative approach to face the uncertainness and the restrictions of many numerical models and radars for satellite monitoring/forecasting of cloud storms.

Using satellite images as data inputs along with GIS capabilities and modern web technologies, fully automated applications providing useful information regarding storms evolution, can be developed. Characteristic examples of such integrated systems based on satellite datasets to monitor/forecast cloud storms through web-based applications were developed is the "ForTraCC" system [13], for tracking and forecasting cloud storms over South America using GOES (Geostationary Operational Environmental Satellite) information as well as the fully automated system called "NEFODINA" [14] focused over the Italian peninsula and its surroundings based on multispectral MSG (Meteosat Second Generation) imagery.

This study comprises an analytic description of all the stages regarding the development of a fully automated WebGIS application focused on monitoring and forecasting cloud tops of storms (and/or cloudy areas, which may be evolved to storms and produce extreme weather conditions in the next few hours) using exclusively satellite images. The satellite images come from Meteosat satellite platform. The application domain includes the greater area of the Mediterranean basin.

The system is developed using modern tools and methods like the "MongoDB" database and Google APIs. Innovative characteristics are the provision of monitoring and forecasting capabilities at a 15-min temporal resolution. In addition to this, the forecasting capabilities of the system are extended in four hours, which is one of the most extended statistical forecasts provided through similar systems worldwide (based exclusively on satellite data). Continuous hail and lightning events estimations for such a large geographical area (greater area of the Mediterranean basin) can also be considered as innovative characteristic of the developed system because such information is not provided from other similar systems.

2 Data and Methods

2.1 Data and Parameters

The initial datasets are exclusively satellite images (raw data) coming from the satellite "Meteosat-10", which is the primary European operational meteorological satellite. The images are referred to five channels (multispectral imagery) of the infrared region (Table 1).

The initial multispectral imagery (Table 1) is automatically pre-processed and the images are analyzed in pixel basis to provide operationally monitoring of the cloud tops evolution as well as forecasts up to 4 h ahead (short-range forecasting). All the available information of the five spectral channels (Table 1) is used to calculate the final products of precipitation, hail and lightning as well as their relative interactive maps, using map tiles.

Table 1. Basic characteristics of Meteosat used at the application

Channel (Band)	Spectral region (μm)	Spectral center (μm)
5	5.35–7.15	6.2
6	6.85–7.85	7.3
7	8.3–9.1	8.7
9	9.8–11.8	10.8
10	11–13	12.0

As abovementioned, four types of information are provided and illustrated through this web-based application in pixel basis, either into the monitoring or into the forecasting module:

- Cloud top temperature (^{o}C)
- Precipitation rate (mm/h)
- Hail probability (%)
- Lightnings probability (%)

The typical temporal resolution of the provided information is 15 min because this is the typical temporal resolution for the data flow coming from the Meteosat satellite.

2.2 Monitoring/Forecasting Methodology

For the detection module, a set of criteria has identified (Table 2) to detect all the cloud pixels that either belong to storms or can evolve to storms. Hereinafter, these pixels are referred as convective cloud pixels. The adopted criteria comprise a combination of well-known and recent thresholding methods for the detection of convective cloud patterns based on satellite imagery ([6, 9, 12]).

Table 2. The five citeria used for the detection of the cloud pixels of interest at the Meteosat multispectral imagery.

Criteria
$T_{6.2\mu m} < 240$ K
$(\Delta T_{10.8\mu m}/\Delta T) < -6$ K (15 min)$^{-1}$
$(\Delta T_{(6.2\mu m-10.8\mu m)}/\Delta T) > 3$ K (15 min)$^{-1}$
$\Delta T_{(6.2\mu m-7.3\mu m)} > -20$ K
$\Delta T_{(12.0\mu m-10.8\mu m)} > -3$ K

The forecasting module produces 15-min forecasts using linear multivariate functions (in the current version of the application). More specifically, there are developed five different analytical functions (for each one of the spectral channels) following the general model of the Eq. 1. Each of them forecasts the relative channel temperature on a pixel basis. The coefficients of the functions are calculated using information from four previous timeslots (typical one hour before). For example, for forecasting one hour after the current time (t_o), the mean values (at pixel basis) of the four previous timeslots are used. The general statistical model to estimate channel temperature values is:

$$Y = A_0 + A_1X_1 + \cdots + A_nX_n \quad (1)$$

Where "Y" is the dependent variable (i.e. the pixel temperature of a specific channel at a specific timeslot), A_0 is a specific constant and A_n (with n = 1, 2, 3, …) is the coefficient of the relative independent variable X_n, where the independent variables are referred at the Table 2. As aforementioned, the linear multiple regression analysis is calculated automatically through the programming environment of the application, in pixel basis where the pixel parameter values of the four latest previous timeslots are considered so that to provide forecast for the next specific timeslot ahead of the current time. Figure 1 illustrates an example regarding the accuracy assessment of the temperature forecast for two basic channels (6.2 μm and 10.8 μm). The Mean Absolute Error (MAE) and the Mean Error (ME) between the measured and forecasted values of 10.933 pixels are calculated. The accuracy assessment of the temperature forecasts for all the spectral channels of Table 1 are concluded to quite satisfactory results.

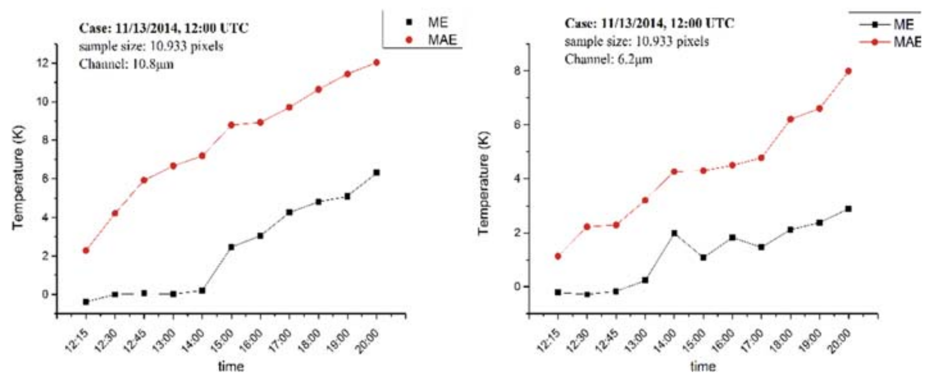

Fig. 1. Accuracy assessment of a sample of temperature pixel values regarding the channels at 6.2 μm and 10.8 μm.

Then, the forecasted temperature values are used to perform pixel based rain, hail and lightning estimations, which are provided as interactive maps through the WebGIS application. There was used the analytic equation proposed by [15] for the rain estimation and the mathematical formula proposed by [16] for the hail estimation. Finally, for the lightning events estimation, a spatiotemporal correlation of lightning data and temperature pixel values in the channel of 10.8 μm, was performed. The analytic equation, after a log-normal fitting to the frequency of occurrence distribution for the temperature values correlated with lightning was used.

2.3 Structure of the System

The WebGIS application comprises a system with interconnected modules as Fig. 2 presents. The system is comprised of a server station used for receiving and storing the continuous flow of the satellite images (in segments) through the satellite antenna. Then, JAVA-written modules automatically implement all the pre-processing steps i.e. georeference, calculation of Brightness Temperatures in pixel basis, errors/missing data checking, unification of different segments of raw images.

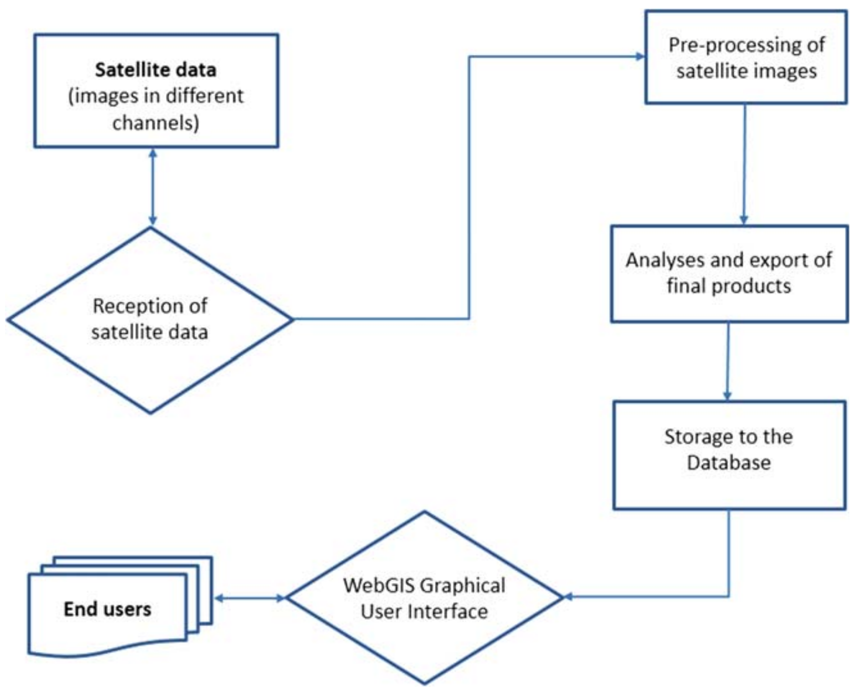

Fig. 2. The overall structure of the system

After the images' pre-processing stage, a threshold (brightness temperature in the 10.8 μm channel smaller than 250 K) is applied to delineate cloud areas, which are favorable for storm developing or represent active storms. At next step, well known mathematical equations are applied to calculate and estimate at pixel basis the values of the precipitation rate, hail and lightning probability. All these data are converted to image files that are visualized as map tiles through the graphical user interface and interactive maps provide by the WebGIS (http://weather.kic.teiep.gr). All the data is also stored in the database of the system for further use.

2.4 Technical Description of the WebGIS

Figure 3 presents the WebGIS general flow of information and the corresponding procedures that are similar to any web based application [17]. The web browser stands for the GUI (Graphical user interface) that interacts with the end users. The web browser transmits any user's requests to the web server and the web server access the corresponding data at the database. The database provides data/information to the web server and the web server shares them through the REST API and the map tiles module.

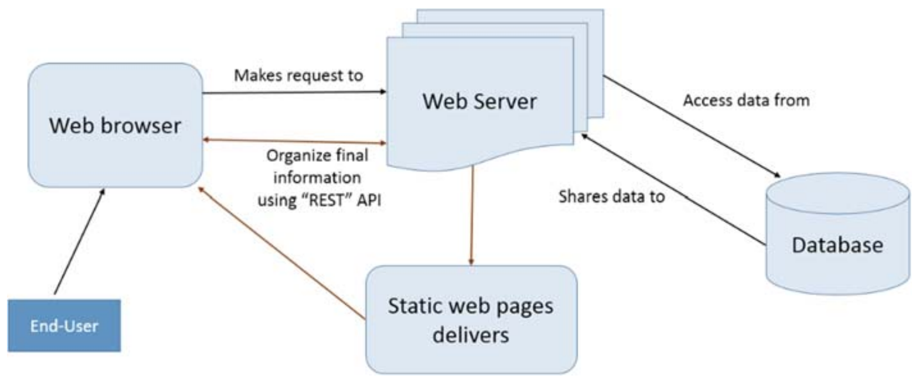

Fig. 3. Schematic diagram presenting the data flow through the applications' modules.

The REST (REpresentational State Transfer) is a general software architectural style of the World Wide Web. Any system conforming to the constraints of REST is called RESTful. RESTful systems typically, but not always, communicate over Hypertext Transfer Protocol (HTTP), which web browsers use to retrieve web pages and to send data to servers. The static web page model, was adopted because in this way, many requests and procedures are managed by user's browsers and not by the server of the application, making the application more stable and quick in responses. And by this way, all the dynamic parts of the interface are loaded apparently via the "REST".

In order to create RESTful services, the SPRING (version 4.2.4) framework with a Controller mechanism has been used, which enrich the features and functionalities on top of the Java EE platform. The SPRING framework is open source, whose core features are used by any Java application and there are many extensions for building web applications (Fig. 4). The Spring Web model-view-controller (MVC) framework is designed around a Dispatcher Servlet that dispatches requests to handlers, with configurable mapping, view resolution, locale, time zone and theme resolution as well as support for uploading files.

The web server (in our case an Apache Tomcat) implements the Java servlets specifications. The server uses Web application ARchive (WAR) package file format, the JAR (Java Archive) and it aggregates any Java class file and associated metadata and resources (text, images, etc.) into one file, which is distributed to application software or libraries on the Java platform.

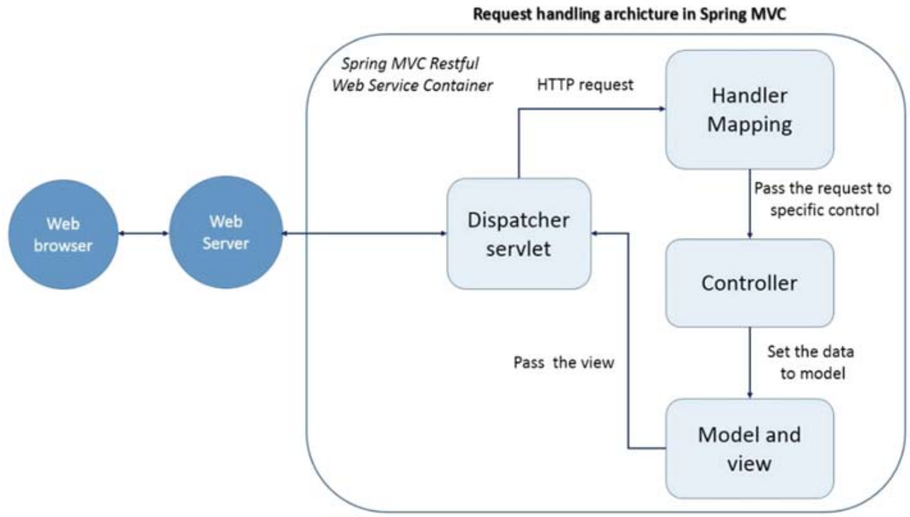

Fig. 4. Schematic diagram showing how the SPRING MVC handles data/information and responses to server and to web browser.

The database is built in the Mongo DataBase framework. The MongoDB is an open source document-oriented database designed with both scalability and developer agility in mind. Instead of storing data in tables as it would be for a relational database, in MongoDB, data are stored in JSON-like documents with dynamic schemas (document-oriented database). The MongoDB GridFS specification is used for storing the raw satellite data, which provides quick process for real-time image generation. This choice was made to handle and organize efficiently the large archive datasets of the WebGIS application but it could also be used for any procedure such as cloud movement tracking and/or weather station data. The MongoDB is characterized by very fast information searching, it has geospatial indexes and features that are essential for the development of the application and its updates (e.g. the capped collections, the aggregation framework etc.). There are also used the Google APIs, a set of application programming interfaces (APIs) developed by Google, which allow communication with Google Services and their integration to other services.

2.5 The Graphical User Interface

The main interface of the application shows an interactive map of the earth globe (google map) focused at the greater Mediterranean basin (Fig. 5).

Above-right of the interface there is a small menu where the user can select the monitoring/forecasting parameter(s) that would like to present (Figs. 5 and 6). Using this menu, interactive map(s) of the parameter(s) for the whole area of interest are appeared. By checking the small check list box above-left of the map, a series of dates ahead of the current date are displayed. These dates are referred to the available forecasts. By choosing one of these dates, the corresponding maps and the forecasted parameters of interest are seen.

By moving the cursor on the map, the stable table on the down-right shows the corresponding values of the parameters pixel by pixel. By using the zoom button, a specific pixel may be selected and then by clicking, all the available information is providing for the specific point of interest on the map (Fig. 7).

Fig. 5. Main interface of the WebGIS application.

Fig. 6. Cloud areas represent potential or active storms. The blue colored areas present rain.

On the left part of the map, there is a series of past dates providing relevant parameters information. By selecting one of these dates, the chosen one data is considered as current date and all the available information for this particular date are presented. For example, Fig. 6 illustrates the clouds storms existed at 30/01/2016 (02:45, UTC) in the greater area of Balearic Islands. The blue colored cloud areas present rain areas.

For the same case of Fig. 6 but zoomed in the eastern area of Spain can be seen at Fig. 7. The left of Fig. 7 presents the cloud storms (along with the estimated data for rainy areas) for the date of 30/01/2016 (02:45, UTC) at the greater area of Balearic Islands. The right part of Fig. 7 illustrates the same area with the forecasting values for three hours later.

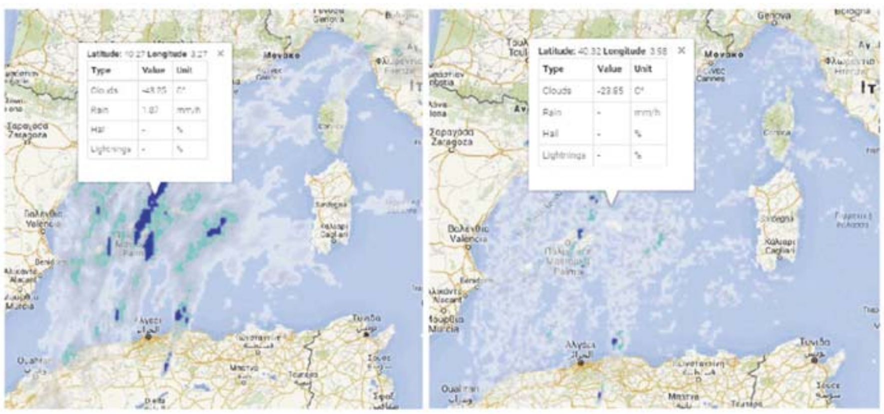

Fig. 7. Cloud storms (along with the estimated rainy areas) at Balearic Islands (left part). On the right, the forecast three hours later (05:45), is displayed.

Figures 8 and 9 illustrate another example for cloud storm monitoring and forecasting.

The same case of Fig. 8 but zoomed in cloud storms areas southern of Crete Island (Greece) is provided at Fig. 9. The blue coloured cloud areas present rain. The right part of Fig. 9 presents the same area with for the forecasting values for three hours later on.

The developed WebGIS includes also capabilities for hail/lightings estimation. Figures 10 and 11 present how this information can seen through the WebGIS interface. The user just has to select the appropriate checkboxes on the right of the interface and the relative information is presented for the time/date which is active in the left of the interface (or the forecast of interest time/date).

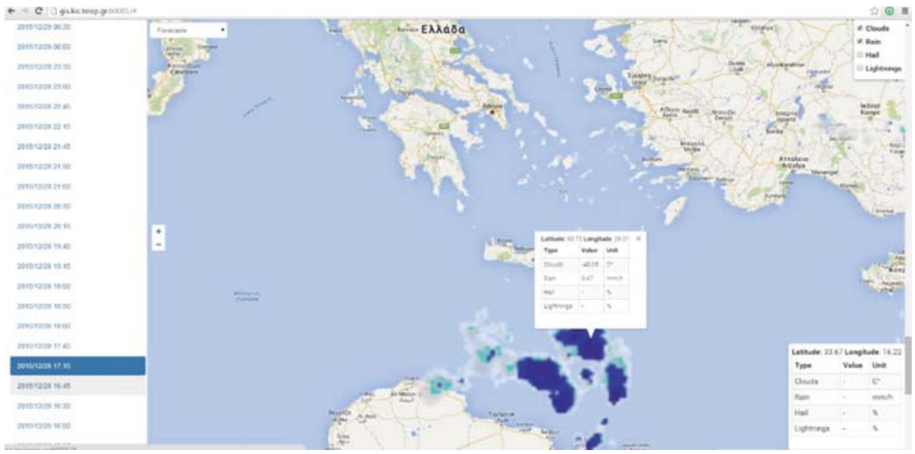

Fig. 8. Cloud storms existed at 28/12/2015 (17:15, UTC) southern of Crete Island (Greece). The blue colored cloud areas present rain.

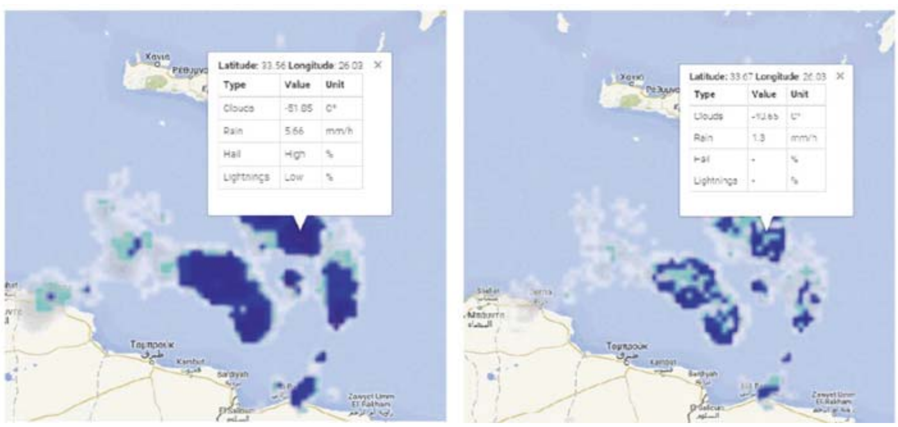

Fig. 9. Cloud storms (along with the estimated rainy areas) southern of Crete Island (Greece) (left part). On the right, the forecast three hours later (Color figure online).

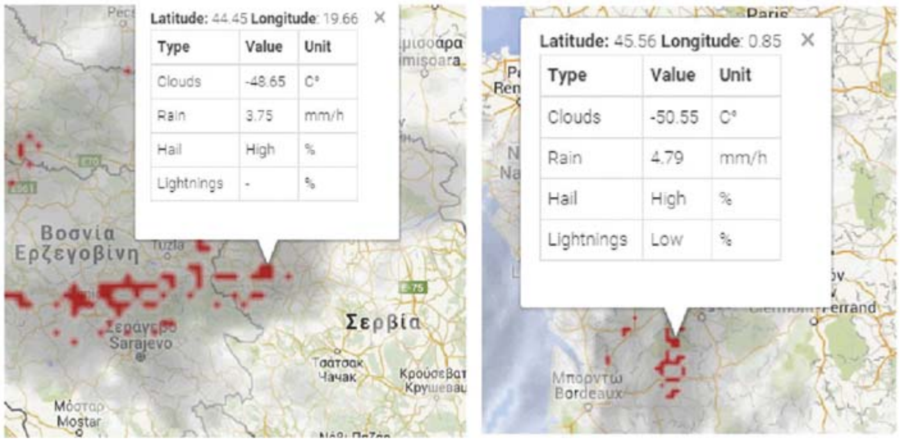

Fig. 10. Hail estimation (red coloured areas) for two cases (a) 03/02/2016, 02:00 UTC (b) 28/01/2016, 08:30 UTC (Color figure online).

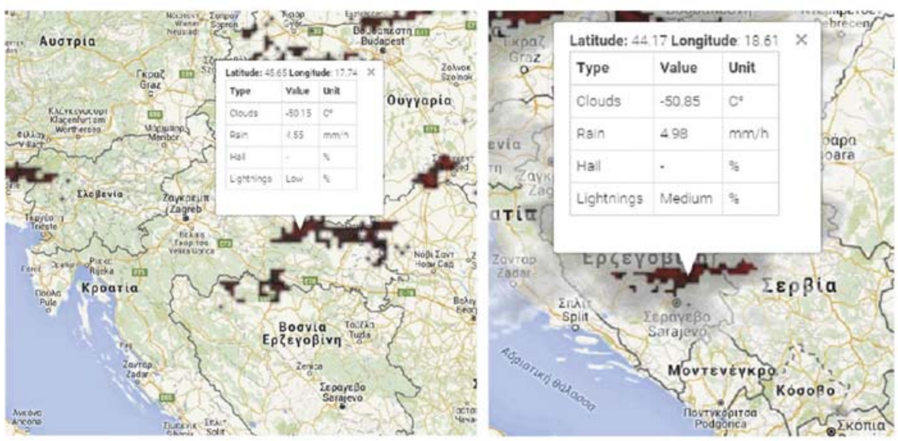

Fig. 11. Lightning estimation (red coloured areas) for two cases (a) 03/02/2016, 02:00 UTC (b) 28/01/2016, 08:30 UTC (Color figure online).

3 Conclusions

A WebGIS application for monitoring and estimating cloud storms has been designed, developed and operated under real-time basis using the map tiles solution for the web mapping. It comprises an automated web interface where basic meteorological data products are visualized at time and space. The data is provided by the Meteosat satellite multispectral imagery. After preprocessing and analysing the data is used for monitoring and short-range forecasting of cloud storms and their potential results (e.g. precipitation, rain and lightnings).

The WebGIS application is developed using modern tools, procedures and frameworks so that to be characterized by easy and immediate access, usage, portability, operational stability and timeless service. It integrates all modern web-technologies, programming and satellite remote sensing techniques and datasets. Thus it provides in a simple way, timely and accurately, useful information for public and private agencies and the general public whose activities and responsibilities can be affected from extreme weather conditions.

There is an on-going work to produce quantitative statistics so that to evaluate the performance of the application and the accuracy of the forecasting/monitoring procedures and products.

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