A Satellite-based Automated System to Detect and Forecast Cloud Storms Focused on the Protection of the Greek Agricultural Sector

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Abstract. This study presents a fully automated system based on Meteosat multispectral imagery to detect and forecast cloud storms. The first accuracy assessment results are considered satisfactory, allowing this system to be able to operate in real-time basis and providing realistic and accurate forecasts for the storm activity as well as for dangerous phenomena accompany convective clouds like lightnings, hail and heavy precipitation. The presented system can operate in a more general point of view, as a driver in the adaptation of strategies and legislations that concern the crop productivity, reimbursements for crop losses, the sustainability of the environment and the improvement quality of lives through the efficient protection from storm effects and their impacts in the society.

Keywords: Storms, agricultural sector, automated system, satellite images.

1 Introduction

It is well known that the extreme weather phenomena (many of them are direct effects of the cloud storms) like heavy precipitation, hail, strong winds and lightnings can often cause disasters in infrastructure, private property and agricultural production. Therefore, automated systems that provide timely and accurate information to prevent and reduce disasters caused by such phenomena can be considered of major importance to the sustainable development of a region. More specifically, the majority of the cultivate areas is largely exposed to the weather conditions and often affected by extreme weather events although they comprise a key factor of economic growth. The agri-food sector (including beverages) accounts for 14.7 % of total EU manufacturing output, is the third largest employer in Europe and the second biggest exporter of foodstuffs globally. Moreover, according to the Hellenic agricultural organization “Demeter”, during the period 1990–2006 after the frost, hail and heavy precipitation were the most important weather phenomena for crop losses. Losses in crop production can significantly affect - among others - the commerce and the economy but the complex nature of extreme weather phenomena and the need for accurate and early warnings for possible extreme weather events,

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keep the weather forecasting among the challenging issues for the scientific community.

Especially in the last decade, an important contribution to the improvement in the weather detection and forecasting, comes from meteorological satellites. Multispectral images of high spatial and temporal resolution can be used nowadays in the operational forecasting and provide valuable information and timely warnings for the protection from the extreme weather events.

In this study, the main stages of the development as well as the first accuracy assessment results of a fully automated system to detect and forecast convective clouds (cloud areas that can evolve to storms and produce extreme weather conditions), are described. The system uses satellite images from the Meteosat multispectral imagery. The domain of the system includes the greater areas of Balkan as well as the central and eastern Mediterranean basin but is focused on the Greek periphery.

2 Data and Methods

2.1 Study Area

The domain of the system (Fig. 1) was choosen to include greater areas around Greece in order to eraly detect the existence of "signs" that can evolve to storms after after a few minutes (or hours).

Fig. 1. The red rectangle include the geographical domain of the system operation.

2.1 Data

There are five channels of the satellite instrument SEVIRI (Spinning Enhanced Visible and Infrared Imager) on board on Meteosat satellite platform that their images are used from the system (Table 1). At this point it is noteworthy to pointed out that there is an extensive use of these channels to detect and estimate precipitation and hail (e.g Simeonov and Georgiev, 2003; Lazri et al., 2014).

Table 1. Spectral characteristics of the Meteosat channels are used for the system.

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

2.2 Characteristics of the system

The system comprises an algorithm written in Visual Basic 2012 programming language. The system consists of two main modules, the detection module and the forecasting module. In the detection module, a set of criteria is used (Table 2) to detect all the cloud pixels belong to storms (or can evolve in the next minutes or hours to storms). Hereinafter, these pixels are referred as convective cloud pixels. These criteria comprise a combination well known and recent thresholding techniques for the detection of convective cloud patterns in the satellite imagery (Bedka, Mecicalski 2011; Merk and Zinner, 2013; Kolios and Stylios, 2014).

Table 2. The five citeria are used for the detection of the cloud pixels of interest in 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

In the Fig. 2, it can be seen how the detection module of the system isolates the cloud pixels of interest (convective cloud pixels). The white colored areas refer to cloud areas. The whiter they are seen in the color composite of the Fig. 2, the most possible to evolve to cloud storm areas, are. All the pixels that fulfill the set of criteria of the Table 2, are stored in relative image files and in a central internal database of the system.

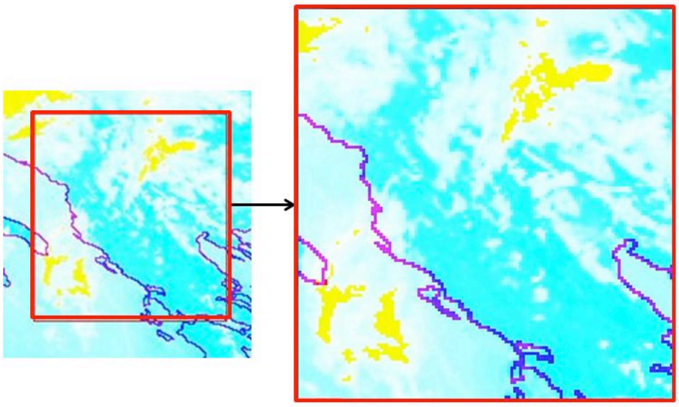

Fig. 2. Detection of pixels of interest from the system. On the left, the greater area of Greece can be seen. On the right, it can be seen, zoomed, the area inside the red rectangle of the left panel. The yellow colored pixels refer to the pixels of interest (convective cloud pixels).

For the accuracy assessment regarding the efficiency of the criteria in the detection of the convective cloud pixels, free datasets with lightnings from ZEUS system, were used (Chronis and Anagnostou, 2006). The lightnings are considered a good indicator for the detection of storm activity (e.g. Williams, 2005; Katsanos et al., 2006). For this reason, a spatiotemporal correlation between the available lightnings datasets and the relative satellite images, was conducted. More specifically, during a two-hour period, for every lightning event, the channel temperatures for the most relative pixel in time and space, was connected. As a result, it was collected a set of 3593 pixels with lightning events along with their relative temperature values in all the used channels. Considering that the lightnings are mainly located in cloud areas with intense storm activity, the threshold values were evaluated regarding their capability to isolate such cloud areas. In this first evaluation of the system detection procedure, three (out of five) criteria of the Table 2 were checked. The results show that there is a tendency for the pixels with lightnings to be connected with low temperatures in the 6.2 μm channel (Table 3 and Fig 3). There is also a second maximum in the distribution of the 6.2 μm channel (Fig. 3) that is connected with stratiform cloud regions where lightnings can also occur. The same reason can explain the significant number of lightnings that not fulfill the "$\Delta T_{(6.2\mu m\ -\ 7.3\mu m)}$" criterion. Conclusively, comparing the values of the distributions of the Fig. 3 along with their cumulative distributions, it is noted that at least the 50% of the total number of the pixels with lightnings, fulfill the threshold values of the relative parameter (Table 2). This result, highlight a satisfactory and efficient detection procedure for the convective cloud pixels.

Table 3. Basic statistics for the pixels with lightnings (K is "Kelvin" unit).**Error! Not a valid link.**

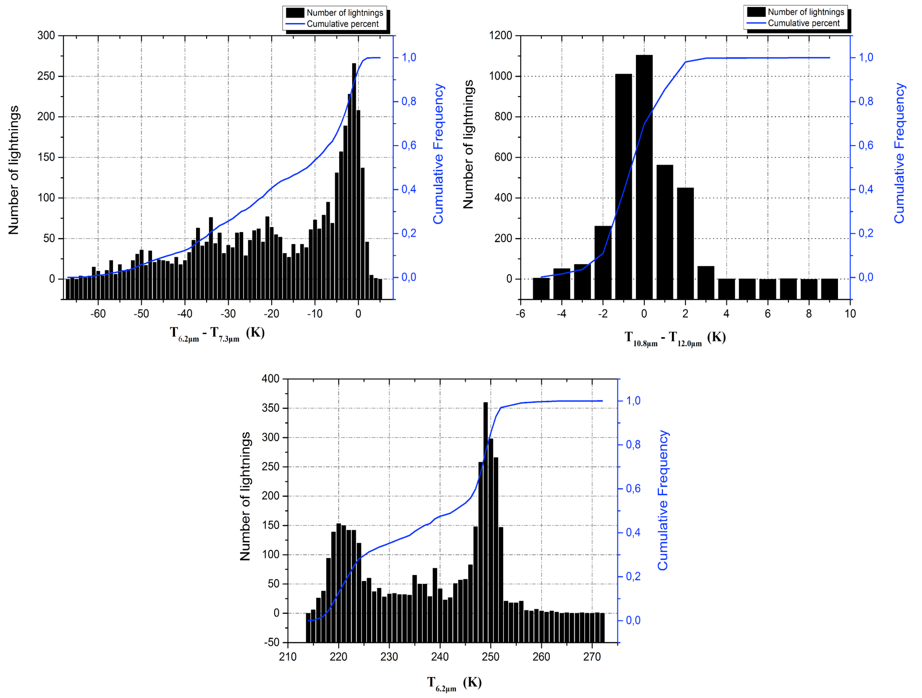

Fig. 3. Graphs that depict the distribution of the values for three parameters ($T_{(6.2\mu m\ -\ 7.3\mu m)}$ above left, $T_{(10.8\mu m\ -\ 12.0\mu m)}$ above right and $T_{6.2\mu m}$ down n the center) for the pixels with lightnings. The blue line represent the cumulative distribution (blue y-axis) and the black columns represent the number of lightnings pixels (black y-axis) for the different parameter values (x-axis).

The brightness temperature values, the channel differences and the cooling (warming) rates for all the pixels of the study area, are automatically calculated and stored in an internal database of the system. The forecasting methodology produces forecasts every 15 min and is based in linear multivariate functions (in its current version). More specifically, for a defined period, all the Meteosat images were selected and all the appropriate parameters were computed in order to construct the analytical linear multivariate functions (regression analysis). These functions are referred to the temperature values of all the used Meteosat channels (Table 1). The dependent variable is the pixel temperature of a channel and the independent variables as well as their coefficients (Eq.1) is defined from the regression analysis and the evaluation results. Conclusively, there were developed five different analytical functions (for each of the channel temperatures). Each of them is used to forecast the relative channel temperature on a pixel basis. The coefficients of the functions are remaining constant in every forecast and the values of the independent variables are the relative mean values (estimates or observations) of the previous four timesteps (typical one hour before). For example, for the forecast one hour after the current time (t_o), the mean values (at pixel basis) from the three previous timesteps.

$$y = A_0+A_1x_1+\ldots+A_nx_n \quad \textbf{(1)}$$

Where "y" is the dependent variable (pixel temperature of a specific channel), A_0 is a specific constant and A_n (n=1, 2, 3, …) is the coefficient of the relative independent variable x_n .

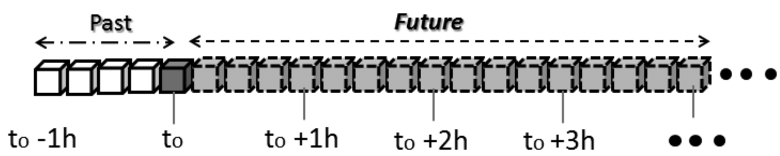

Fig. 4. Schematic diagram of the forecasting methodology of the system. Every cube represents a timestep of 15 min (same as the typical temporal resolution of Meteosat).

In the Table 4, basic statistics [Mean Absolute Error (MAE), Mean Error (ME) and correlation coefficient] of the forecasting procedure regarding the brightness temperature values of 6.2 μm channel in four different trimesters for a selected case study. The statistics were calculated using 603.841 pixel values. As initial time, the Meteosat image channels at 04:00 UTC (25/08/2006) were used.

Table 4.The accuracy of the forecasting procedure about the brightness temperature values of 6.2 μm channel in four different trimesters for a selected case study. As initial time, the Meteosat image channels at 04:00 UTC (25/08/2006) were used.

Forecast	MAE	ME	Adjusted R
15min	0.42	-0.013	0.99
30 min	0.59	0.0004	00.98
60 min	0.87	0.015	0.95
120 min	1.17	0.014	0.94
180 min	1.52	0.057	0.92

In the Table 4, it can be seen that there is a very small overestimation for the temperature pixel values in the 6.2 μm channel (the ME values are positive). The MAE is also very small in the first forecasting timesteps but it is gradually increasing for the next forecast and exceeds 1K after the first hour of the forecasts.

3 Conclusions

A fully automated system for the detection and forecast of the storms in the greater area of Greece was developed. The system is using image data from the operational meteorological European satellite, called “Meteosat”. This system can be established for operational use, having as basic scope the provision of accurate and timely warnings about extreme weather phenomena like hail, strong winds and heavy precipitation that can cause significant losses in the agricultural sector.

The first accuracy assessment results are satisfactory and the overall efficiency of the system for its potentially operational use seems promising for the protection of the agricultural sector.

Future steps include a more quantitative evaluation of the accuracy of the system and the use of nonlinear algorithms in an effort to be provided even more accurate predictions and the further extension of the forecasting capabilities, in time. A detailed digital maps with recent land use and land cover information are also intended to be integrated in the system, in order to provide more detailed warnings, aiming also to operate additional as an autonomous decision support system.

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