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Automated Application for Visualizing Rainfall and Hail Estimations Derived from an Algorithm based on Meteosat Multispectral Image Data

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Abstract: The scope of this study is an attempt to develop an automated visualization module to monitor in real-time rainfall and hail estimations highlighting areas with potential risk from extreme weather phenomena. The rainfall/hail products are provided by a known satellite-based algorithm that uses exclusively Meteosat multispectral images. The application is fully automated, written in the Python programming environment using open-source libraries, and provides colored graphs about the spatial variation of the examined parameters with the same temporal resolution as the Meteosat imagery. Additional functions of this application include warnings for extreme situations each time pre-defined threshold values are exceeded, as well as geographical areas that are vulnerable to heavy rainfall and/or hail occurrences. This application is a pilot operating over the Greek periphery. Also, there is a capability to create small video animations for the spatiotemporal evolution of the rainfall and hail estimations up to 6 hours before the latest available satellite images.

Keywords: Visualization; Meteosat; Rainfall estimations; Automated application; Real-time monitoring

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1. Introduction

Extreme weather events are dangerous for lives, properties and infrastructures. Their accurate monitoring needs innovative approaches and still nowadays, remain a challenging research issue. By harnessing the capabilities of meteorological satellites, specifically Meteosat, it's capable for the development of precise algorithms for estimating meteorological parameters and their subsequent visualization [1-3]. Such monitoring capabilities not only offer timely insights but also present the potential to mitigate damages from extreme weather to infrastructure and private properties [4,5].

This study primarily focuses on two meteorological phenomena: rainfall and hail. Rainfall is the process by which water droplets precipitate from atmospheric clouds, whereas hail involves the formation of solid ice within storm systems. Both these meteorological events can have profound impacts. Accurate estimations and forecasts of rainfall and hail serve as crucial tools in disaster preparedness and response. While rainfall can lead to flooding, landslides and disruptions in urban areas, hail can inflict significant damage to crops, vehicles and structures [5-11]. The precise and real-time monitoring of these parameters can aid in issuing early warnings, allowing for preemptive measures, and thereby reducing potential harm.

2. Data and Methods

For the scope of the study data from a satellite-based rain estimation algorithm have been used. The algorithm of Kolios, 2023, first distinguishes rain/non-rain pixels based on a thresholding method. Then, it uses the Brightness Temperature from Meteosat-11 in five spectral bands from 6.0 to 12.0m (channels 5-7, 9 and 10) to calculate pixel-wise rain intensity [12,13]. Moreover, the algorithm automatically provides data every 15 minutes, contingent on its availability from the satellite.

The datasets encompass a range of vital information, including latitude (LAT), longitude (LON), precipitation (Prec), and hail (Hail) data. Prior to analysis, a comprehensive data cleaning process is undertaken using the Pandas library —a powerful tool in data manipulation and analysis— to ensure reliability and precision [14]. This involves the removal of invalid or unhelpful entries, such as negative estimation values and any missing or null values.

Following this preprocessing, the next step involves the visualization of the data. Leveraging libraries Matplotlib —a plotting library— and Cartopy —a library designed for geospatial data visualization— [15,16], the data are transformed into contour maps, offering an optimal representation of the phenomena. These maps are enhanced with a color-bar, further clarifying the visualized data for improved comprehension. It's imperative to note that the visualization is capable of real-time updates. Whenever new data becomes available, an automated process routinely checks and processes these data using the previously described methods.

Upon successful visualization of the data, it's crucial to detect hazardous phenomena. This identification is achieved using the DBSCAN clustering algorithm [17], which is employed after discerning 'danger points' through a thresholding technique. This specific algorithm detects clusters of high-risk points by analyzing their spatial density. After the clustering, the Principal Component Analysis (PCA) is employed to extract key characteristics of each cluster, such as its center, minor axis, and major axis. Utilizing equation 1:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} \leq 1 \quad (1)$$

where,
x, y are the transformed coordinates;
a is the semi-major axis;
b is the semi-minor axis.

the points within each cluster are then generated. Subsequently, these points are matched with city coordinates from corresponding datasets, updating the information and alerts about cities impacted by the weather phenomena.

For a more in-depth understanding, the final feature offers short video animations depicting the spatio-temporal evolution of rainfall and hail estimates up to 6 hours before the last available satellite images. Contour maps are produced for each time point, and with the aid of Library Pillow [18], these are seamlessly integrated into a dynamic animation.

3. Results and Discussion

As shown in Figure 1, using a varied palette, the color bar accurately maps rainfall intensities ranging from 0 to 29 mm/hr. The contour maps, through their distinct color variations, clarify these intensities, providing viewers with a clear sense of the meteorological conditions. The data from which this illustration is derived is for the timestamp 03/06/2023 at 15:15. Such visual tools, because of their clarity, are catalytic for understanding specific atmospheric phenomena.

The results of the visualization and detection of heavy rainfall, derived from the MWAVE (METEOSAT Weather Alert and Visualization Environment) application, can be seen in Figure 2. The Figure depicts detected intense localized precipitation on 03/06/2023 at 13:30, impacting several regions within Greece and adjacent countries. Following the successful detection, the local phenomena are effectively delineated and represented within ellipses. Pertinent information and updates regarding the affected cities are presented on the left side of the graphical interface. The results indicate cities situated in regions such as Western Macedonia, Peloponnese, and Central Greece.

In a further exploration of the data, Figure 3 delves into the detection of hail phenomena for the timestamp of 03/06/2023 at 15:15. Notably, no dangerous hail phenomena are identified during this interval. This absence of high-risk hail activity is clearly reflected in the information section of the graphical interface. If there had been any significant hail occurrences, they would have been highlighted within ellipses, and pertinent details and alerts regarding affected regions would be displayed on the left side of the interface. For the given timestamp, the depicted regions exhibit no discernible hail threats of significance. At this point it noted that the absence of hail risk is referred only in the randomly selected time/day interval. The general accuracy of the product on hail, precipitation and AOD detection is presented in the study [12], [13] and [19], respectively.

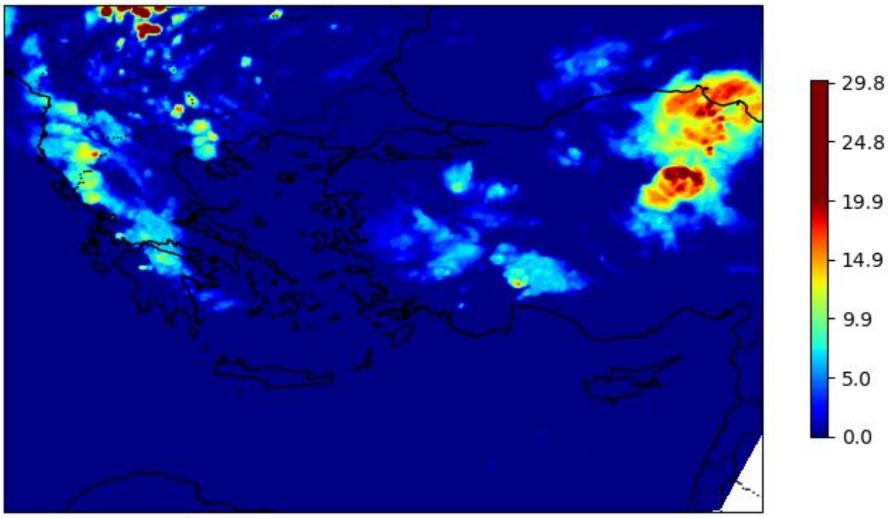

Figure 1. Visualization of rainfall data on a contour map for the date 03/06/2023 15:15.

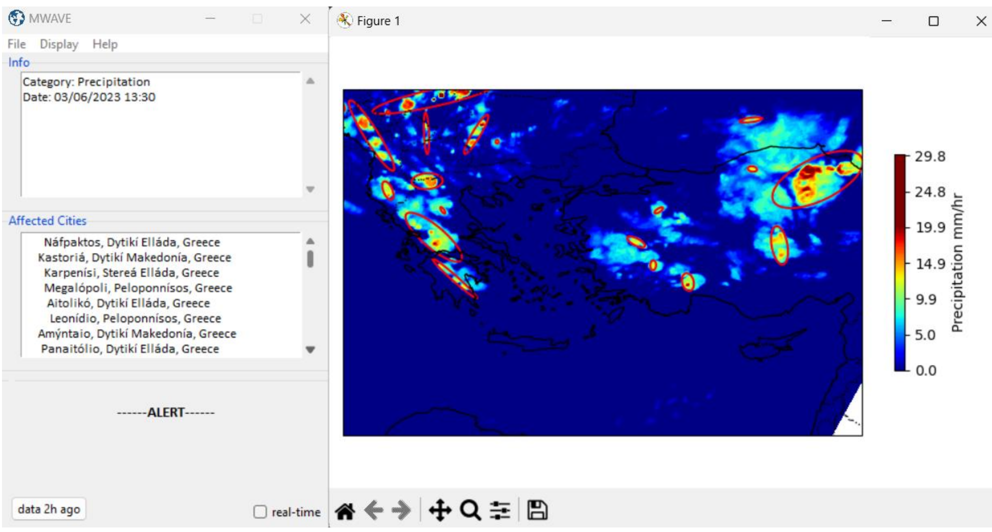

Figure 2. Screenshot of the graphical environment of the application to detect heavy rainfall for the date 03/06/2023 13:30. .

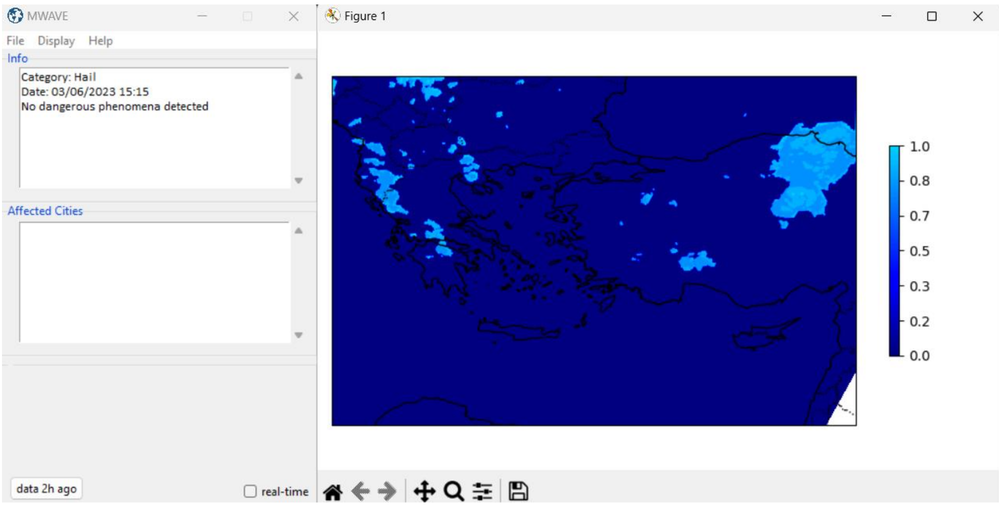

Figure 3. Screenshot of the graphical environment of the application to detect hail for the date 03/06/2023 15:15. .

4. Conclusions

This study showcases the employment of Meteosat multispectral imagery for real-time visualization of rainfall and hail estimations over Greece. Through an automated Python-based application, the detection feature highlights the system's capabilities to detect threats and issue real-time alerts. The results demonstrated the ability of the system to describe rainfall intensities with high accuracy, as shown in Figures 1 and 2, providing information on regional impacts across Greece and neighboring countries. In particular, Figure 3 revealed the absence of significant hail threats during the period analyzed, highlighting the value of the tool for both detecting threats and confirming favorable conditions. Overall, the visual representations, enhanced by a color palette, provide an intuitive understanding of meteorological conditions, demonstrating that they contribute to timely and informed decision-making.

Subsequent versions of the application are projected to incorporate additional features, notably nowcasting capabilities. Such enhancements are expected to provide even more immediate and precise meteorological insights. The integration of these advancements aims to further refine the tool's accuracy and bolster its utility in real-time weather monitoring and informed decision-making.

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