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An Early Warning System to Predict Rainfall Event in Attica, Greece: The Case Study of 30 September 2018 †

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Abstract: A forward advection scheme is incorporated in an advanced data assimilation model to provide very short-term predictions. The Local Analysis and Prediction System (LAPS) is implemented in the nowcasting mode in a case study of extreme precipitation event over Attica, Greece. The LAPS assimilated remote sensing data from satellite retrievals and XPOL radar precipitation measurements to produce objective analyses alongside their nowcasts in a forecast window up to 3 h. The results indicate that the assimilation of remote sensing data can increase the short-term precipitation predictability, with varying performance depending on the type and the combination of the assimilated remote sensing data.

Keywords: nowcasting; LAPS; data assimilation; seamless prediction; medicane; weather radar; satellite precipitation; TRMM; GPM; HSAF

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1. Introduction

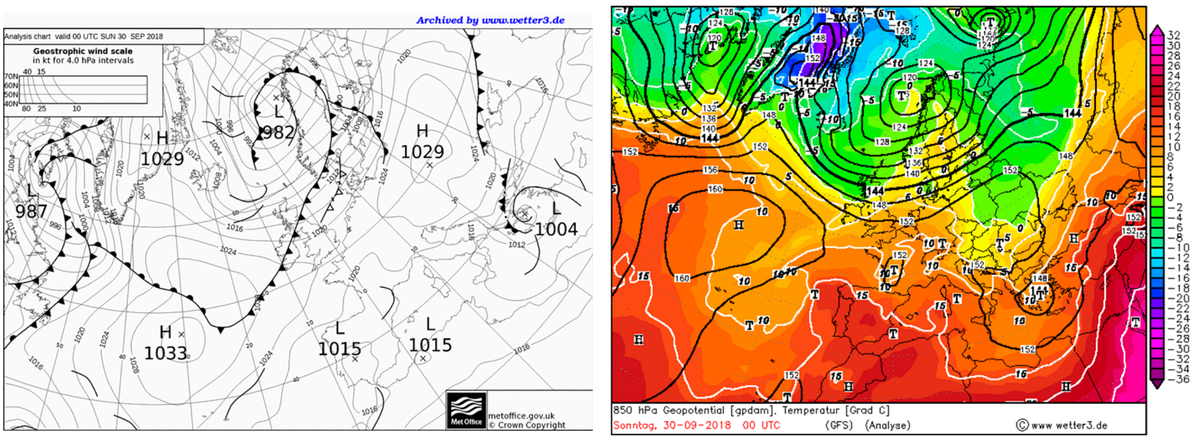
An effective way of increasing the protection from extreme weather events is the use of advanced early warning systems. Reliable forecasts of various atmospheric parameters (e.g., temperature, wind speed, and precipitation) at high spatial and temporal resolution are important to reduce the risks and mitigate the impacts of the extreme events. After all, Spyrou et al. [1] introduced an integrated multi-model system able to nowcast hydrometeorological hazards. Nowcasting is a potent methodology that refers to a forecast with a very short time horizon (usually up to 3 h) [2].

Nowcasting methods usually focus on the estimation of precipitation [3]. Precipitation can be measured either directly with the use of ground-based instruments or indirectly with the use of remote sensing techniques like radar systems and Earth-observing satellites. The measured data are incorporated together with numerical weather predictions (NWPs) in data assimilation systems which eliminate errors and produce analyses and enhanced short-term forecasts.

Therefore, the main objective of this study is to assess the sensitivity of an advanced data assimilation system on ingesting satellite precipitation retrievals and then to evaluate its nowcasting capabilities regarding precipitation. This is an effort to give an in-depth description of an accurate forecast of the location and intensity of precipitation in a short-term horizon. In this context, the system was tested in a case of an intense Mediterranean tropical-like cyclone (medicane) that occurred during the period 27–30 September 2018 [4] and affected Athens (Attica, Greece), mainly on 30 September. Section 2 presents the study area and briefly describes the medicane. Section 3 describes the data used, and Section 4 describes the methods used in this study. The results are demonstrated and discussed in Section 5. Finally, in Section 6, the main conclusions are presented.

2. Description of the Synoptic Conditions

Greece is vulnerable to medicanes because of its location in the eastern Mediterranean Sea. The medicane used as a case study here is a notable incident occurred during the period 27–30 September 2018. It was formed in the Gulf of Sidra (Libya) on 27 September 2018 and, over the following days, was further deepened to 989 hPa and moved towards the Eastern Mediterranean [5]. On 30 September 2018 at 00:00 UTC, the low-pressure system was located over the Aegean Sea Figure 1a,b with minimum pressure at 1004 hPa. It was accompanied by an occluded front over Greece that indicated enhanced atmospheric instability and severe precipitation in the area.



(a) (b)

Figure 1. (**a**) UK Met Office mean sea level pressure (hPa) analysis map for 30 September 2018 at 00:00 UTC; (**b**) Geopotential height (black contours in gym) and temperature (color-shaded areas and white contours in °C) at 850 hPa on 30 September 2018 at 00:00 UTC. The map is based on analysis data from the Global Forecast System (GFS). The maps were derived from the archive of wetter3.de (http://www1.wetter3.de/ (accessed on 11 May 2023)).

3. Description of the Assimilated Precipitation Data

Remote sensing data from satellite retrievals and X-band dual-polarization (XPOL) were assimilated in this study.

3.1. X-Band Dual-Polarization (XPOL) Radar Data

An X-band dual-polarization (XPOL) round radar is installed on Penteli mountain and operated by the National Observatory of Athens. The XPOL radar provides specific information about the size, orientation, and composition of the precipitation particles. The radar runs in plan position indicator (PPI) mode during precipitation events, taking observations in a 180° sector scan at 0.5°, 1°, and 2.5° elevation sweeps with a range resolution of 120 m. The Self-Consistent Optimal Parameterization-Microphysics Estimation (SCOPE-ME) X-band dual-polarization technique is utilized to obtain the values of precipitation [6].

3.2. Satelite Precipitation Retrievals

TRMM: The distribution and variability of precipitation are also studied using the Tropical Rainfall Measuring Mission (TRMM). Four of TRMM's five instruments—a Precipitation Radar (PR), a five-channel Visible and Infrared Scanner (VIRS), a nine-channel passive Microwave Imager (TMI), and a Lightning Imaging Sensor (LSI)—are used to measure precipitation [7]. The levels of the TRMM products range from 1 to 3. TRMM 3B42 products are employed for the purposes of this study.

GPM: The successor of TRMM is the Global Precipitation Measurement (GPM) program. GPM has better resolution than TRMM, and its main goal is the improvement of weather forecasts, climate modeling, and hydrological modeling [8]. The estimations of the precipitation retrievals are outputs from Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm. GPM IMERG EARLY products, which have a spatial resolution of $0.1^\circ \times 0.1^\circ$ and a temporal resolution up to 30 min, are employed for the purposes of this study.

HSAF: The parameters related to precipitation, soil moisture, and snow are studied in the "EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management" (H-SAF) program. H03B products, which have a high temporal (15 min) and spatial resolution (3 km), are employed for the purposes of this study [9]. Its Blending MW/IR algorithm is based on the "Rapid Update" technique.

4. Methodology

The Local Analysis and Prediction System (LAPS), developed by National Oceanic and Atmospheric Administration (NOAA), is a mesoscale meteorological data assimilation system that assimilates all available data (from meteorological networks, satellites, radar soundings, and aircrafts) and produces a three-dimensional, spatially dispersed, time-evolving representation of atmospheric processes [10]. Global Forecast System (GFS) near-to-analysis forecasts on $0.50^\circ \times 0.50^\circ$ horizontal resolution are used in LAPS to produce the first guess fields, and then data are employed.

Combining the above-mentioned data, LAPS produces an analysis by minimizing the 3-D cost function to reduce the difference between the analyzed and observed fields. For a time horizon of 1–3 h, an advection scheme was embedded in LAPS to predict the movement of precipitation [1]. A simple first-order advection equation in two-dimensional (x,y) is the base of this scheme.

$$\frac{1}{\Delta t}\left(R_{i,j}^{t+1} - R_{i,j}^{t}\right) + \frac{u}{\Delta x}\left(R_{i,j}^{t} - R_{i-1,j}^{t}\right) + \frac{v}{\Delta y}\left(R_{i,j}^{t} - R_{i,j-1}^{t}\right) = 0 \tag{1}$$

where R is the meteorological parameter of precipitation, u and v are the wind components, respectively, Δx is the grid increment in the x direction, Δy is the grid increment in the y direction, Δt is the time-step, and (i,j) is the grid point in the domain of LAPS. The stability of the Equation (1) is controlled by the Courant numbers that are given by the Equation (2). The equation $CU + CV \leq 1$ is used as a stability criterion.

$$CU = u\frac{\Delta t}{\Delta x} \geq 0,\ CV = v\frac{\Delta t}{\Delta y} \geq 0 \tag{2}$$

where CV and CU are the Courant numbers in the y and x directions, respectively. Solving Equations (1) through (2), the value of the precipitation (R) is estimated at time $t + 1$ [1].

In this study, the domain of LAPS covered Attica using a very fine horizontal grid spacing of 1 km and 41 vertical levels, resulting in a total of 110 × 110 × 41 = 496,100 grid points (Figure 2). Three sensitivity experiments were carried out with the following inputs: (a) only GFS near-analysis forecasts, (b) GFS near-analysis forecasts combined with Global Precipitation Measurement (GPM), Tropical Rainfall Measuring Mission (TRMM) retrievals, and radar data, and (c) GFS near-analysis forecasts combined with EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF) retrievals and radar data. LAPS initiated at 03:00 UTC providing nowcasts up to 06:00 UTC on 10 min time frequency. Moreover, the above three sensitivity experiments were also carried out with an initial time of LAPS at 06:00 having an extended duration, up to 12:00 UTC, on 180 min time intervals.

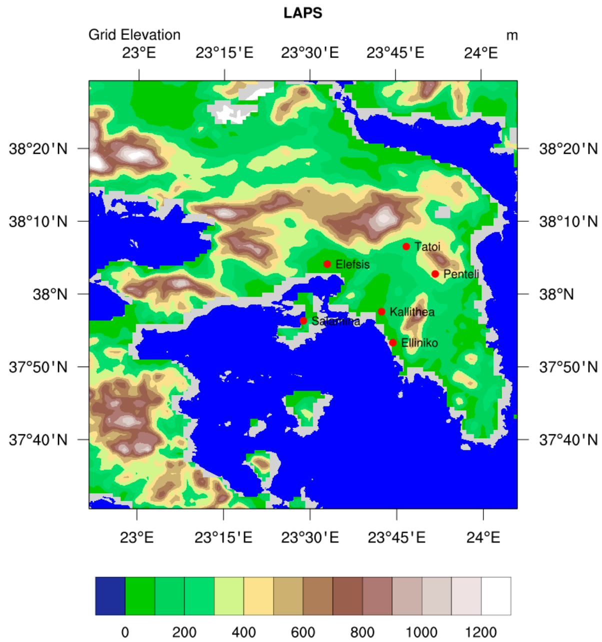
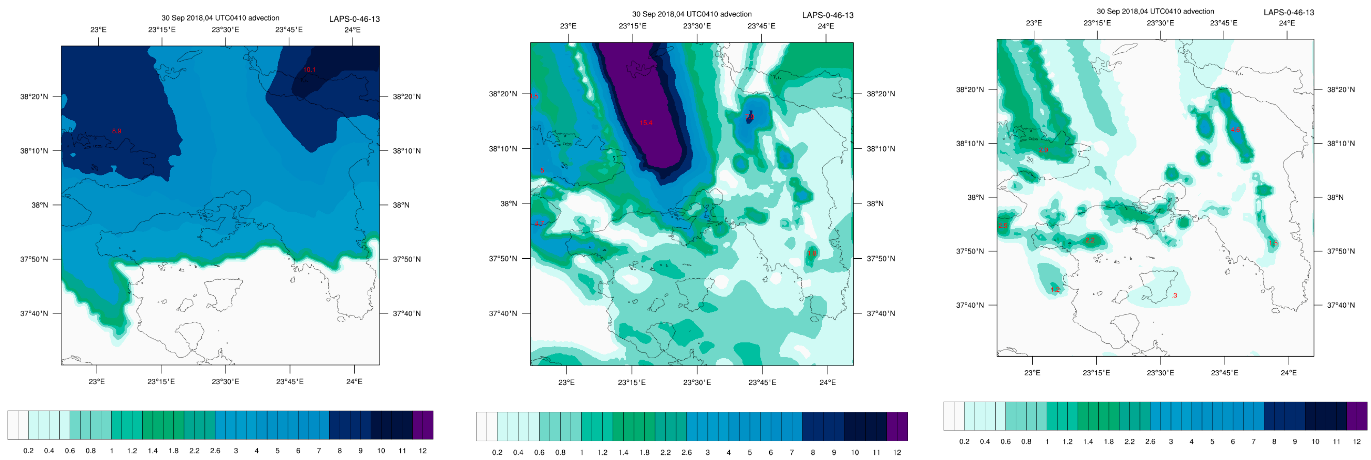


Figure 2. LAPS domain covering Attica and its topography (m). The red spots corresponded to the meteorological stations and the XPOL radar.

5. Results and Discussion

Panel plots in Figure 3 depict 10 min accumulated precipitation (mm) for the LAPS nowcasts on 30 September 2018 from 04:10 to 04:30 UTC by implementing GFS near to analysis forecasts as a background in the control run (Figure 3a,d,g), by additionally assimilating TRMM and IMERG products and XPOL radar data (Figure 3b,e,h) and assimilating H-SAF products and XPOL data (Figure 3c,f,i). Precipitation observations from two independent (i.e., not assimilated) meteorological stations in Attica region (Salamina and Kallithea, Figure 2) were compared to the 10 min precipitation nowcasts, and the results are presented in Tables 1 and 2. LAPS nowcasts, including IMERG, TRMM, and XPOL retrievals, show an overestimation of the precipitation against the in situ records. On the other hand, the assimilation of H-SAF and XPOL retrievals considerably increase the precipitation accuracy.



(**a**) (**b**) (**c**)

Figure 3. *Cont.*

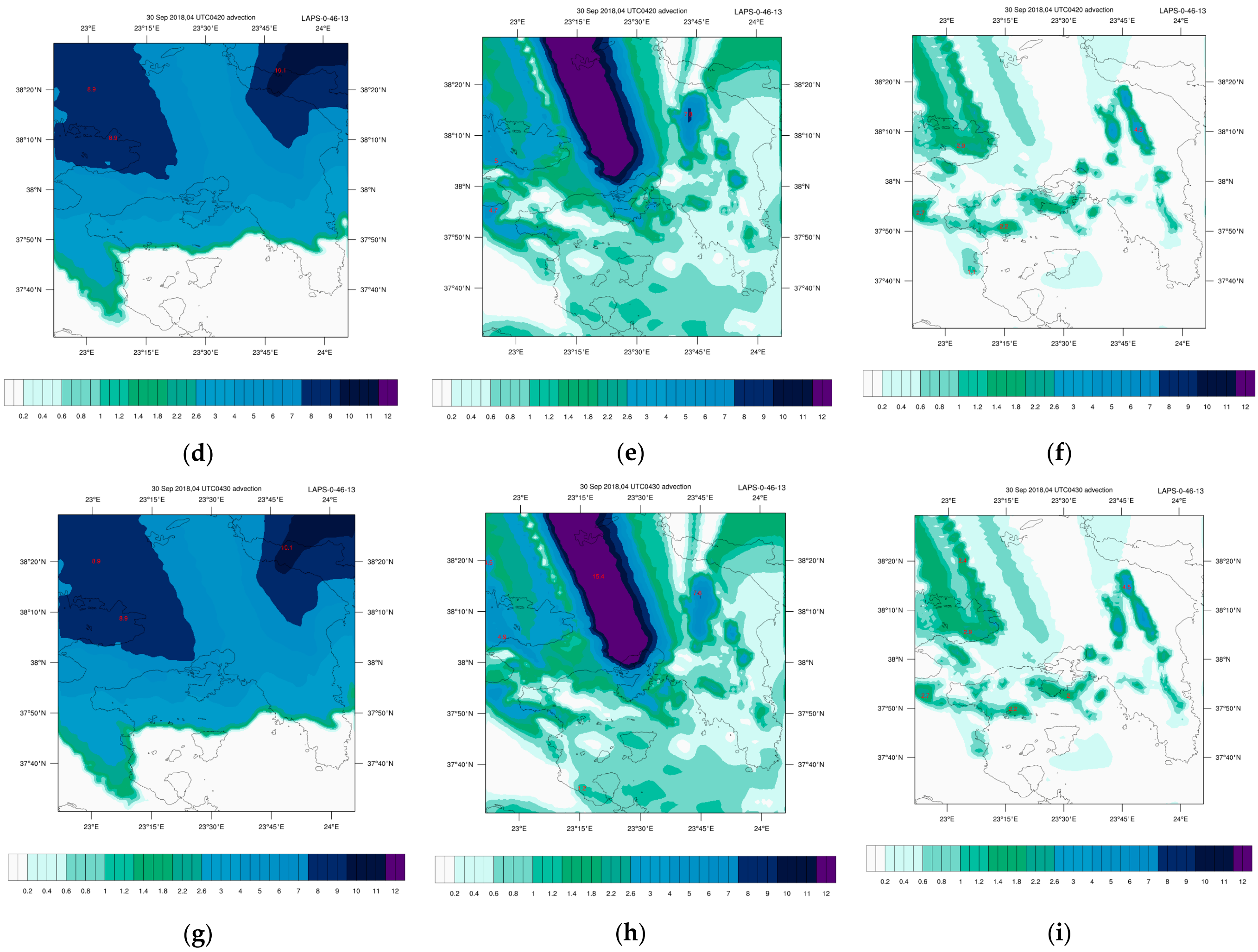


Figure 3. Accumulated precipitation (mm) on 30 September 2018 at 04:10 UTC assimilating (**a**) only GFS, (**b**) GFS/TRMM/IMERG/radar, and (**c**) GFS/H-SAF/radar data, respectively, at 04:20 UTC assimilating (**d**) only GFS, (**e**) GFS/TRMM/IMERG/radar, and (**f**) GFS/H-SAF/radar data, respectively, and at 04:30 UTC assimilating (**g**) only GFS, (**h**) GFS/TRMM/IMERG/radar, and (**i**) GFS/H-SAF/radar data, respectively.

Table 1. Comparison between recorded precipitation (mm) at Salamina station and the LAPS precipitation nowcasts (mm) on 30 September 2018 from 04:10 to 04:30 UTC, by assimilating only GFS, GFS/TRMM/IMERG/radar, and GFS/H-SAF/radar data.

Time (UTC)	Control (GFS)	GFS/TRMM/IMERG/XPOL	GFS/H-SAF/XPOL	Salamina
04:10	4.58	1.78	0.26	0.20
04:20	5.28	1.18	0.19	0.20
04:30	6.04	4.56	0.21	0.20

Table 2. As in Table 1, but for the recorded precipitation at Kallithea station.

Time (UTC)	Control (GFS)	GFS/TRMM/IMERG/XPOL	GFS/H-SAF/XPOL	Kallithea
04:10	3.16	0.41	0.00	0.00
04:20	3.33	0.35	0.00	0.20
04:30	4.09	0.78	0.18	0.00

The nowcasted and measured precipitation are compared in Tables 1 and 2. It is shown that nowcasts perform much better when H-SAF satellite products and radar data are assimilated. The assimilation of H-SAF and radar data significantly improved the systematic overestimation of precipitation at the meteorological stations of Salamina and Kallithea in Tables 1 and 2. There is a slight precipitation difference of around 1% between nowcasts (assimilating H-SAF and radar data) in Salamina station, except for 04:10 UTC, when a small overestimation is presented. The same nowcasts slightly underestimated the precipitation in Kallithea station except for 04:30 UTC, where nowcast was 0.18 mm/10 min instead of the recorded 0.00 mm/10 min, and at 04:10 UTC, where nowcast and recorded value are the same with 0.00 mm/10 min.

However, the main core of precipitation was located away from these two stations. So, there is also a comparison between another three independent meteorological stations of the Hellenic National Meteorological Service (HNMS) network (Figure 2) and the nowcasts at 06:00–12:00 UTC, and the results are presented in Table 3. LAPS nowcasts obtained by assimilating only GFS systematically overestimate the precipitation at all three stations. On the other hand, LAPS nowcasts, including IMERG, TRMM, and XPOL retrievals and H-SAF and XPOL retrievals significantly reduce the overestimation of the precipitation at Tatoi and Elliniko stations, but they underestimate the precipitation at Elefsis station. Moreover, the nowcasted values (by assimilating H-SAF and radar data) are even closer to the independent stations' values, except for the Elefsis station, for which the forecasted value is 2.31 mm/6 h instead of the recorded value at 17 mm/6 h. It is noteworthy that the nowcasts are deteriorated as the lead time is increased.

Table 3. Comparison between recorded precipitation (mm) at Tatoi, Elliniko, and Elefsis stations and the LAPS precipitation nowcasts (mm) on 30 September 2018 at 12:00 UTC, by assimilating only GFS, GFS/TRMM/IMERG/radar, and GFS/H-SAF/radar data.

Time (UTC)	Station	Control (GFS)	GFS/TRMM/IMERG/RADAR	GFS/H-SAF/RADAR	Recorded 6 h Precipitation
12:00	Tatoi	31.81	13.10	12.34	9.0
12:00	Elliniko	31.56	2.43	1.81	0.9
12:00	Elefsis	32.26	2.60	2.31	17.0

6. Conclusions

The accuracy of precipitation nowcasts can be increased by including remote sensing data into NWP models. LAPS is applied in nowcasting mode assimilating a number of remote sensing measurements including XPOL weather radar data. Compared with independent measurements, it was revealed that the assimilation of satellite precipitation together with XPOL radar retrievals significantly reduced the systematic overestimation of the precipitation caused by the GFS background. Moreover, the assimilation of the H-SAF product, instead of TRMM & GPM (IMERG), greatly increased the short-term predictability of precipitation. Additional experiments and sensitivity tests with a combination of satellite and weather radar precipitation estimates are in the authors' near-future plans.

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Conflicts of Interest: The authors declare no conflict of interest.

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