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Analysis of heavy rainfall events occurred in Italy by using Microwave and Infrared Technique

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On 9 and 10 September 2017 violent rainstorm events affected the centre of Italy. The brunt of the flooding took the city of Livorno where more than 200 mm of precipitation was recorded in few hours causing the overflow of *Rio Maggiore* that led tragic events and did great harms. The case study proposed is analysed by means of three algorithms based on satellite observations: the **Precipitation Evolving Technique** (**PET**) [Di Paola et al., 2012, 2014], the **Rain Class Evaluation from Infrared and Visible observation** (**RainCEIV**) technique [Ricciardelli et al. 2014] and the cloud **Classification Mask Coupling of Statistical and Physics Methods (C-MACSP)** [Ricciardelli et al 2008, 2014].

C-MASCP and RainCEIV

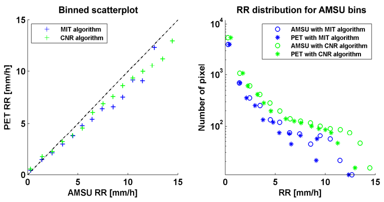
C-MACSP and RainCEIV use the VIS/IR observations from the *Meteosat Second Generation – Spinning Enhanced Visible and Infrared Imager* (MSG-SEVIRI) to provide near real time cloud classification and rain classes maps. C-MACSP classifies a pixel as *clear*, *low/middle cloud*, *high thin cloud, high thick cloud* or *convective cloud*. RainCEIV uses the k-Nearest Neighbour Mean classifier to associate each SEVIRI pixel to the *non rainy* (RR=0 mm/h) class; *light to moderate rain* (0.5<RR<=4 mm/h) class and *heavy to very heavy rain* (RR>4 mm/h) class.

Statistical scores for	Daytime validation data set			Night-time validation data set		
	C_1, C_2	C_1	C_2	C_1, C_2	C_1	C_2
Accuracy	0.97	0.97	0.99	0.96	0.96	0.99
Bias	1.36	1.33	1.65	1.58	1.55	1.89
POD	0.81	0.77	0.86	0.81	0.75	0.65
HSS	0.67	0.65	0.65	0.62	0.57	0.45
FAR	0.39	0.41	0.47	0.48	0.51	0.65

PET

PET is a multi-sensor algorithm for the continuous monitoring of convective rain cells. This technique propagates forward in time and space the last available RR maps obtained from the *Advanced Microwave Sounding Unit* (AMSU) and *Microwave Humidity Sounder* (MHS) observations by tracking MSG-SEVIRI observations. It is based on two different modules:

- the **Morphing module** that drives precipitating cells of the latest available RR map, by modifying their positions and shapes using a multi-scale and multi-threshold pattern recognition approach on two consecutive *Global Convective Diagnostic* (GCD) maps;
- the **Calibration module** that computes a dynamic RR-GCD relationship using a probabilistic histogram matching method to calculate a $RR[t_0+n\Delta t]$ - $\Delta TB^{GCD}[t_0+n\Delta t]$ lookup table (LUT) to be applied to $TB^{GCD}[t_0+(n+1)\Delta t]$ to obtain $RR[t_0+(n+1)\Delta t]$.



A combination of the Morphing and Calibration outputs provides RR map at IR-SEVIRI space and time scale, and the whole procedure is reiterated by using the last PET-RR map output until a new PMW-based RR map is available. Final RR map is obtained as a linear combination of $RR_{Morphing}$ and $RR_{Calibration}$ computed pixel-by-pixel by evaluating the goodness of the Morphing procedure.

Case study analysis

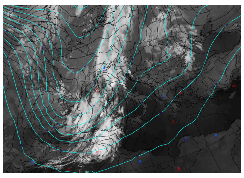


Figure 1: Synoptic analysis at 00 UTC, 10 Sep. 2017: ECMWF 500 hPa geopotential height (cyan lines), ECMWF mean sea level pressure (black lines) with indications of high (H) and Low pressure (L) and Meteosat Second Generation IR10.8– Source: http://www.eumetrain.org.

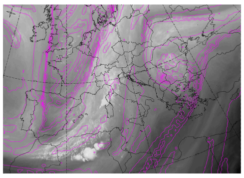


Figure 2: Synoptic analysis at 18 UTC, 09 Sep. 2017: ECMWF height in hPa, where the Potential Vorticity equals 1.5 PV Unit and water vapour channel 6.2 µm of MSG – Source: http://www.eumetrain.org.

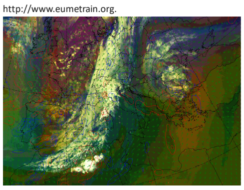


Figure 3: Synoptic analysis at 18 UTC, 09 Sep. 2017: ECMWF 700 hPa temperature advection (red lines warm and blue lines cold), horizontal wind at 925 hPa by ECMWF (green vectors) and MSG AirMass RGB combined by the SEVIRI WV6.2, WV7.3, IR9.7 and IR10.8 channels – Source: http://www.eumetrain.org.

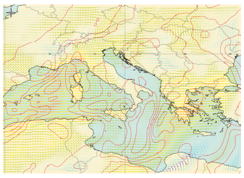
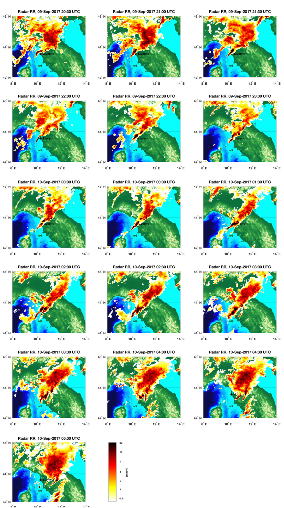


Figure 4: Synoptic analysis at 18 UTC, 09 Sep. 2017: ECMWF 700 hPa horizontal barbs and ECMWF equivalent potential temperature at 850 hPa – Source: http://www.eumetrain.org.

The Livorno flood event was associated with a wide upper level trough extending from Scandinavia to the western Mediterranean basin (Fig. 1) and with a cold front moving eastward, advecting low level moist air towards North-West of Italy (Fig. 3, 4). The West Mediterranean Sea was affected by a strong south-westerly flow and a Warm Conveyor Belt ahead of the cold front advecting warm subtropical air (values of Θ_e at 850 hPa greater than 320 K, Fig. 4) at mid and low levels (20 m s^{-1} at 700 hPa, Fig. 4). The main convective activity was in the warm air ahead of the front and in the narrow cold frontal rain-band. On September 9 at 00 UTC, a shallow cyclone of 1009 hPa developed over the Balearic Islands and moved eastward. A strong Potential Vorticity (PV) anomaly (Fig. 2 and reddish area in Fig. 3) associated with the deep trough and the warm temperature advection at 700 hPa (Fig. 3) allowed for the development of several Mesoscale Convective System (MCS) in the north Tyrrhenian Sea. In the following hours the shallow cyclone reached the Gulf of Genoa, and deepened reaching a value of 999 hPa at 00 UTC of 10 September (Fig. 1), the cut-off low developed over Gulf of Genoa was enhanced by the PV anomaly (Fig. 2). The associated frontal system moved rapidly toward the north-west of Italy, causing moist air advection over the Tyrrhenian Sea and consequent deep convection on the Tyrrhenian coast due to the increase of the potential instability in the lower atmosphere. In the following hours the low tropospheric area moved southward weakening.

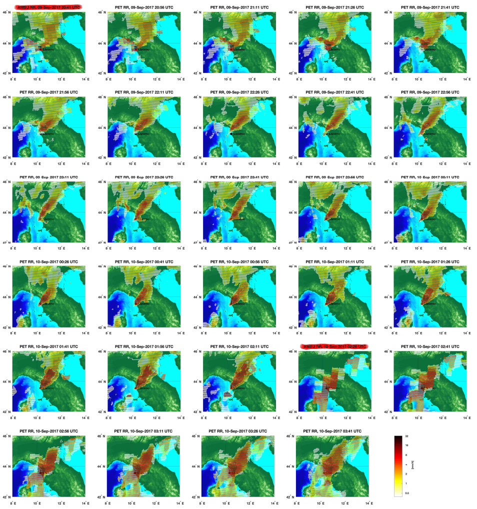
The precipitation starts at 12:00 UTC in the western part of Liguria due to the approaching of the front pumping the warm air. In the following 3 hours the rain band moves eastward reaching a maximum of approximately 40 mm/h near Genoa. In the evening of September 9, the south-westerly flow moved southward shifting the maxima of precipitation in Tuscany and the convective storm developed in Livorno, strengthening fueled by the wet and warm air of the Tyrrhenian Sea. During the night the convective system reached the maximum development at slightly south of Livorno; after the 03:00 UTC of September 10, the storm weakened and moved southward. A maximum of 241 mm/24h and 255 mm/48h with a rainfall peak of 64 mm in only 1 h, between 22:00 and 23:00 UTC of September 9 was recorded at Bocca d'Arno (43.68N, 10.28, located about 25 km from Livorno); the same station observed for 3 consecutive hours (from 19:00 UTC to 22:00 UTC of September 9) a rainfall rate greater than 30 mm/h.

Weather radar network RR maps

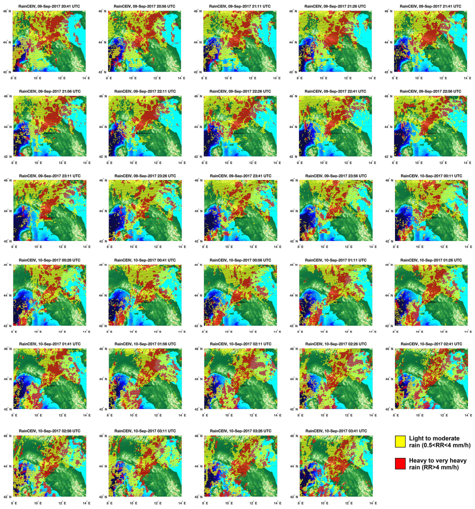


The accumulated precipitation reached up to 260 mm/48h at Valle Benedetta (43.52N, 10.40E, located about 11 km from Livorno), with a detected hourly maximum greater than 90 mm from 01:00 to 03:00 UTC of September 10 and 39 mm in only 15 minutes. At Stagno station (43.60N, 10.35E, located about 10Km from Livorno) precipitation reached 180 mm/48h, with hourly precipitation maxima of 52 mm/h between 19:00 and 20:00 UTC and 41 mm/h between 00:00 and 01:00 UTC. Most of the rain (greater than 40 mm/h) was recorded between 00:00 UTC and 03:00 UTC on 10 September reaching 210 mm/48h at Collesalvetti (43.58N, 10.4E, located about 22 Km from Livorno).

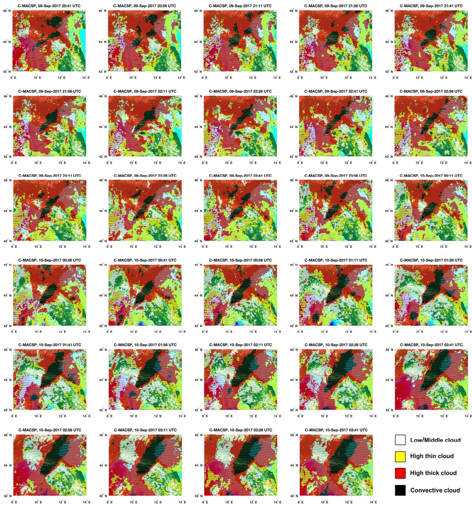
PET RR maps



RainCEIV maps



C-MACSP maps



C-MACSP and RainCEIV are able to produce cloud classification and RR class maps every 15 minutes, full time and on the full Earth disk at native SEVIRI grid, while PET produces RR maps every 15 minutes, only for few hours after the last available PMW observations and only on the region around the PMW radiometer swath observations. C-MACSP, RainCEIV and PET are complementary for near real-time weather condition monitoring, because when the latter is available, the formers give further information about cloud cover and RR class. These algorithms show their ability in the near real time monitoring of convective cell formation and their rapid evolution. Tools like C-MACSP, RainCEIV and PET shall be adopted by civil protection centres to monitor the real time evolution of deep convection events in aid to the severe weather warning service.

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