MODELLING THE ORIGIN AND FATE OF WASTE MATERIALS ON THE SOUTH-EASTERN ADRIATIC COAST (CROATIA)

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I. INTRODUCTION

On 21st of November 2010, waste accumulation has been observed on the southeast coast of Pelješac Peninsula, Mljet, Korčula and Lastovo Islands as well in inlets and beaches in the vicinity of Dubrovnik, Croatia (Fig 1). The heaps of waste were composed mostly of plastic packages, glass, clothes and other typical floating trash. The labels on the waste items suggested that it arrived mostly from Albania. It is not unusual that a few pieces of waste from Albania reach Croatian coast in late autumn, but the event was much larger than in other years. We think that strong southeasterly "jugo" (sirocco) wind has intensified the sea current system that brought the floating waste materials from Albania. Furthermore, the waste was washed into the sea by strong flash floods as a consequence of the torrential rain. Those hypotheses are investigated using available meteorological, oceanographic and hydrological data as well numerical models.

FIG. 1: The South Adriatic region.

II. MEASURED AND MODELLED RESULTS

The meteorological conditions prior and during those events were analysed using available remote sensing - satellite data, *in situ* measurements based on SYNOP, climatological and rain-gauge measurements from Croatia, Montenegro and Macedonia as well as the NWP model data obtained using ALADIN (Tudor and Ivatek-Šahdan, 2010) model on 8 and 2 km resolution. The hydrological analysis in the area is based on the water level measurements on relevant major rivers in Montenegro and Macedonia. The sea surface currents, responsible for waste transport, are computed using 2 km resolution ROMS ocean model, forced with ALADIN 8 and 2 km outputs, including major Adriatic river inflows as well large scale ocean model data at the open boundary. The results from ocean model are used as input to the backward trajectory computations that could reveal the possible origin of the waste.

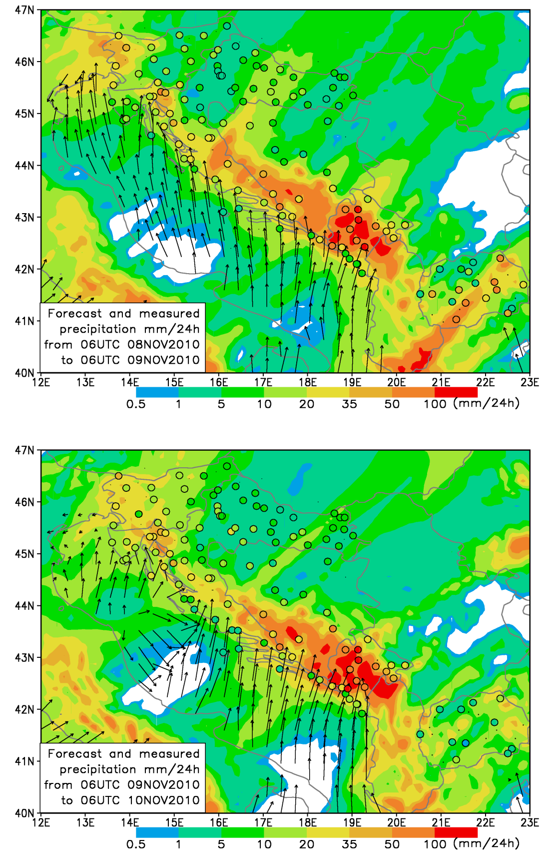

FIG. 2: Forecast wind (vectors), 24 hour accumulated precipitation (shaded) and measured precipitation (circles) for two days.

In November 2010 there were several heavy rainfall events that could have initiated flash floods in the area. Unfortunately *in situ* measurements of rainfall from Albania were not available to the authors. Therefore, available remote sensing satellite data are used to describe the events, supported by the measurements on the meteorological stations from the surrounding areas (Croatia, Montenegro, Macedonia and Greece).

The convective rainfall rate and precipitating cloud derived fields from the Meteosat 9 were analyzed. The precipitating clouds field provides probabilities of precipitation intensities and the convective rainfall rate (mm/hr) is computed assuming that clouds being both high and with a large vertical extent are more likely to be raining. Both products are available at http://www.satreponline.org. These fields reveal the cases with strong convection and rainfall over Albania on 8th-10th and 17th-19th November 2010. Both cases are characterized by strong convection and rainfall in the afternoon having periods with little or no rain in between. The precipitating clouds cover much of the area, while the convective rainfall rate is far more localized, but often very intensive. It is important to note that those fields are available on 6 hour interval, heavy rainfall could have occurred during the sampling interval and easily could have been missed. Measurements from the rain-gauges show that rainfall in the period 7th-11th Nov. 2010 was more intensive than in other rainy periods. Stations in Montenegro (larger circles and stars on Fig 2) received more rain than Croatian stations. The operational 8 km resolution ALADIN model did forecast heavy rainfall over Albania for both cases as well as Croatia and Montenegro as observations suggested (Fig 2).

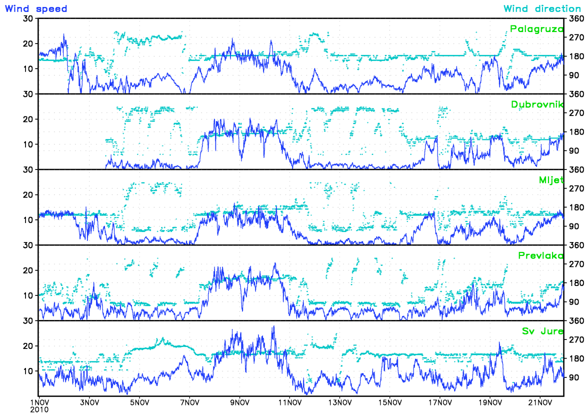

FIG. 3: Measured wind speed (dark blue) and direction (light blue) for November 2010.

Wind measurements (Fig 3) show that wind in the episode of 7th - 11th Nov. 2010 was from south, stronger and lasted longer than other strong wind episodes. In that episode wind measured at Palagruža, Dubrovnik and Prevlaka was stronger than predicted ones while correct at Mljet and Sv. Jure. The wind was stronger on the coast (Dubrovnik and Prevlaka) than off-shore (Mljet), probably as a consequence of channelling by the coastal mountains. In maps of forecast and measured precipitation (Fig 2), the forecast wind is shown as arrows for the term of the end of the 24 hour period.

From 11th - 15th Nov. 2010, wind was weak to moderate with direction typical to the sea breeze diurnal cycle. From 16th of Nov. 2010, the wind strengthens and southeastern direction prevails in Dubrovnik, Mljet and Prevlaka. This wind episode has finally enhanced the sea currents that have transported the waste material to the shore.

The forecast rainfall exceeded 100mm/24hr on various parts of Croatia, Montenegro and Albania for several days in a row (Figure 2). This corresponds to the values measured on rain-gauges although the model exaggerated slightly the rainfall on the coastline and underestimated the rainfall on several locations further inland.

The water level measurements on the rivers that flow into the Adriatic Sea in Montenegro (Fig 4) show significant increase in the water level on 9th of Nov. 2010 that is followed by an increase in the water level of the Skadar lake as well. The water levels of Skadar lake and Bojana river stayed high until the end of November. This suggests that the event of 8th-10th Nov. 2010 has brought the waste material to the sea.

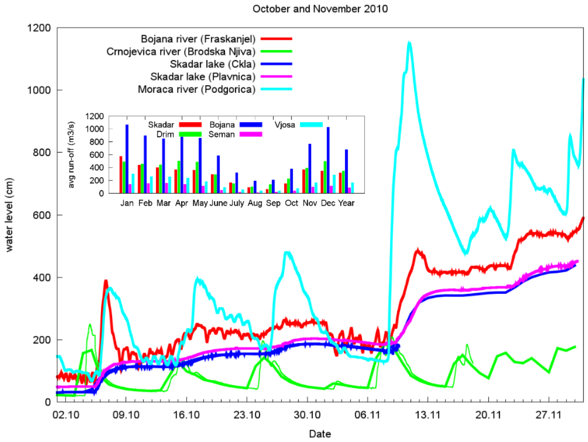

FIG. 4: Measured water levels of rivers in Montenegro and Skadar lake in October and November 2010 and climatological river run-off of Albanian rivers (embedded figure).

The surface sea currents were computed using ROMS (Shchepetkin and McWilliams, 2005) model forced with ALADIN meteorological model data (10m wind, 2m temp and relative humidity, sea level pressure, rain, short wave radiation and clouds), climatological values for the Adriatic river run-offs and open boundary values with daily temperature, salinity, currents and sea lever information from AREG (INGV) Mediterranean model.

Model results show development of a strong sea current from south-east (north-west current) direction after jugo episodes and vortices close to the eastern Adriatic coast in weak wind.

During November 2010, three periods of different wind conditions can be distinguished. From 7th - 11th, strong south-east wind initiated strong noth-west currents (Fig 5a) followed by a weak wind period when the sea-current transport was weak (Fig 5b) and the period with moderate to strong south-east wind (Fig 5c) that strengthened the north-west current again.

The trajectories were initiated of the coast of Albania on 8th of Nov. 2010. They reach Mljet by 21st of Nov 2010 (Fig 6a), and several reach Pelješac in the following days (Fig 6b). The reason could be in too weak south-east wind in the model as well as climatological run-off values for the Bojana river used in model forcing. These trajectories have to go through a narrow channel and in the proximity of the coast (edge of the computational domain) where model is showing boundary effects rather than fully developed physics (Fig 6c).

III. CONCLUSIONS

Measured rainfall and NWP model rainfall show that the rain was more intensive in the event of 8th-10th November than in the later one. Measured wind speed and direction show that the episode of strong southeasterly wind was longer in the first event (8th-10th Nov 2010) than in the second one. The strength of the southeasterly wind was underestimated by the operational ALADIN model forecast. Measured 10 minute wind speed was sometimes 50% larger than the forecast one at several locations.

ROMS ocean model surface currents were used as input to the offline trajectory computations. The trajectories were initiated off the coast of Albania. They stop as soon as they reach a coast. Most of the trajectories starting on 8th of Nov. 2010 finish on the coast of Montenegro and south-east Croatia by 28th of Nov. 2010.

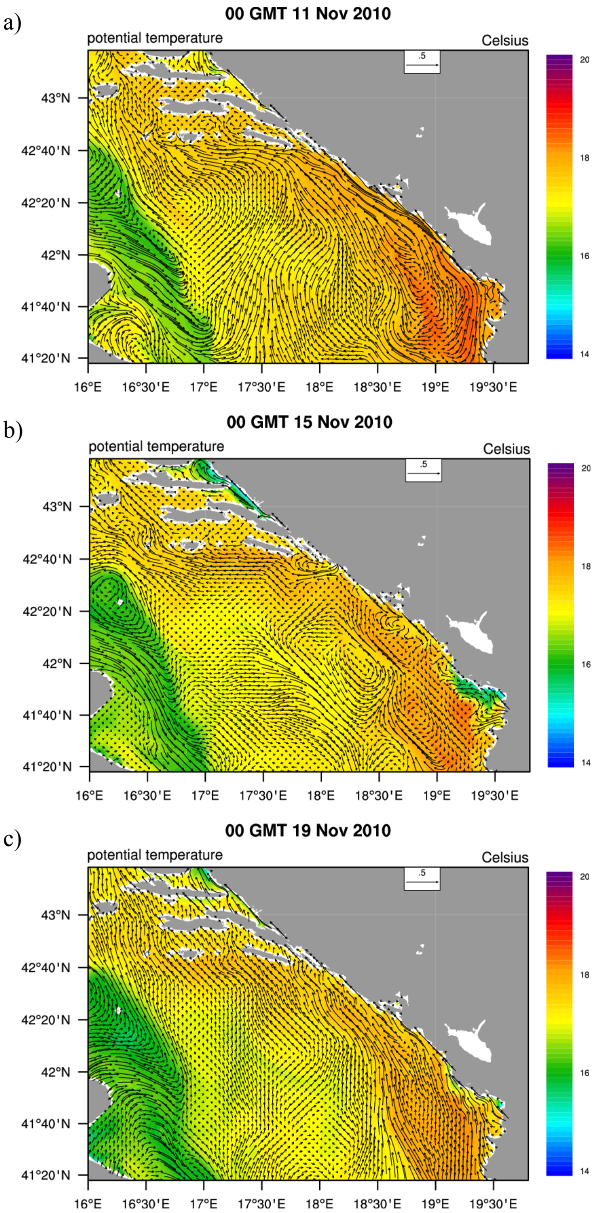

Fig 5: Sea surface currents and temperature for 00 UTC on 11th (a), 15th (b) and 19th (c) Nov 2011.

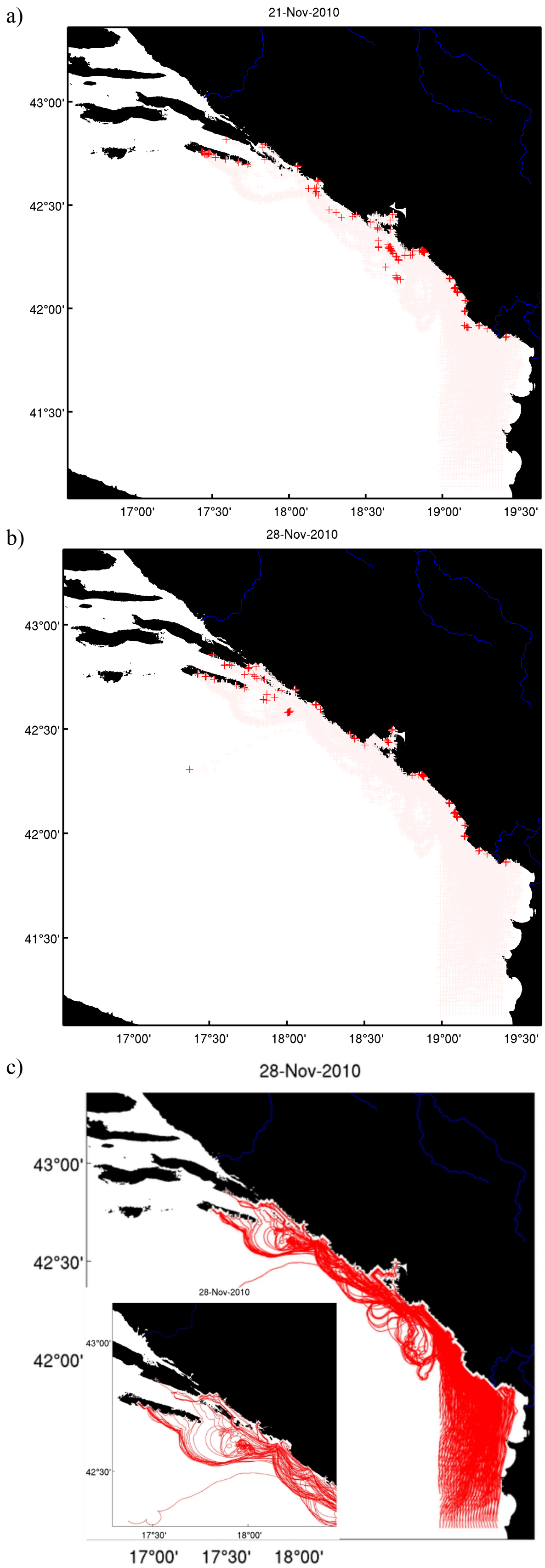

Fig 6: The trajectory end-points for 21st (a) and 28th (b) Nov. 2010 and the trajectory paths (c) from 8th-28th of Nov. 2010.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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