ANALYSIS OF THE EXTREME FLOODING DURING OCTOBER 2007 IN TABASCO, MEXICO USING THE WRF MODEL

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1. INTRODUCTION

Between October 23th and November 1st of 2007 an extreme meteorological event and the opening of the auxiliary spillway of the Peñitas dam caused the largest flooding ever in the low lands of Tabasco State and, in particular, in the city of Villahermosa (Fig. 1). Tabasco is located in southeast Mexico, over the coastal plain of the Gulf of Mexico; it has an extension of 24,475 km^2, equivalent to 1.3% of the Mexican territory. The flooding generated more than one million victims and damage in infrastructure and property estimated in 7 billion dlls. This catastrophe brings up to date the discussion on how the scientific community may collaborate with governmental agencies to prevent similar disasters. Some issues that may be considered are: to study in detail this and other disasters learning from them and to identify the vulnerability of different regions under extreme hydro-meteorological events.

The meteorological analysis of the October 2007 extreme event shows a strong high pressure system coming from the US that penetrated in Mexico producing severe damages in land as well as in the Gulf of Mexico oil platforms. Two extreme events of precipitation were registered: the first one between October 23th and 25th while the cold front (associated with the high pressure system) was crossing the Isthmus of Tehuantepec, and the second one between October 28th and November 1st, that resulted from the interaction between the cold front and a low pressure tropical system located in the Caribbean Sea. The accumulated precipitation reached more than 1,200 mm in some mountainous regions (including both events, see Fig. 2), producing an overflow of the Grijalva River that flooded the Tabasco State (Fig. 1), and in the Gulf of Mexico the intensity of the sustained winds reached 80 km/h affecting oil platforms. Both extreme events were forecasted with a simulation using the WRF model at least 72 hours in advance. The accumulated precipitation forecasted by the model is compared with observations of some weather stations in the region and the simulated winds over the Gulf of Mexico are compared with data from the National Data Buoy Center. Results show high correlation values between forecasts and observations; in addition, the regions with larger precipitation amounts were well delimited by the model.

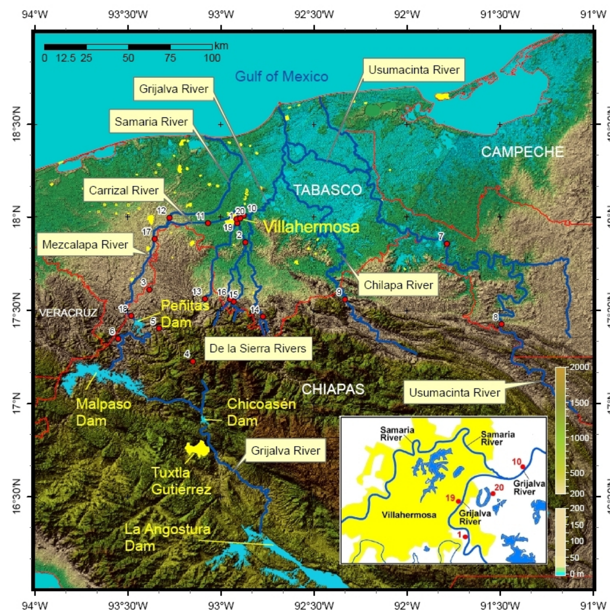

Figure 1. Location of the flooded area in southeast Mexico.

2. Observations

The strong precipitation and the filling of the dams of the Grijalva River basin (Fig. 1) were caused by the interaction of the cold front number 4 of the season and a low pressure system located over the Caribbean Sea. The cold front reached the region on the 23rd of October; it was extremely strong with sustained winds of 80 km/h and an associated high coastal sea surface height, with an anomaly of 65 cm above tide level in Veracruz, measured by the National University of Mexico tide gauge network. The front produced two precipitation events: the first one between the 23rd and 25th of October, while the front was crossing the region, and the second one between October 28 and November 1st. The first event produced intense precipitation in the area, with a maximum of 423 mm registered in Sayula (site-5 in Fig. 1) and an average of 186 mm for all the stations shown in figure 1. On the 27th the cold front interacted with a low pressure system over the western Caribbean Sea and both systems formed a stationary front that moved westward through the center Gulf of Mexico and over Tabasco. The stationary front remained in the area from the 28th to the 31th with a moisture flux along the front towards the Isthmus of Tehuantepec, Tabasco and Chiapas with strong and sustained precipitation that reached 887 mm in Ocotepec (site-4) in only three days and an average for all the stations of 390 mm (Fig 2). The rain gauge data show that the precipitation in the mountains was larger than in the plains producing the largest contribution to the flooding through the rivers stream.

3. The WRF simulation

Precipitation

The WRF-ARW model V2.2 has been used in the *Universidad Nacional Autónoma de México* since several months ago in order to train students in numerical modeling and as a tool for research and to test a forecast system. The model is ran in a domain that includes Mexico using a 137x259 grid with a 20 km horizontal resolution, a time step of 120 s, in a terrain-following vertical grid with 27 levels, and conventional terrain averaging with WPS V2.2. The parameterizations used are the Kain-Fritsch for cumulus, Dudhia for short wave radiation, and RRTM for long wave radiation. The model is run daily in forecast mode for 72 hours, using the 12Z initial conditions from the Global Forecast System. The simulations of the cold front No. 4 of the season are used to analyze its evolution.

The WRF forecast for 72 hrs predicted well both precipitation events. The area of maximum precipitation was located in the highlands of the Isthmus of Tehuantepec. In the first event the model accumulated precipitation reached approximately 120 mm over the highlands and 80 mm over the lowlands, with a similar pattern to that of the rain gauges (Fig. 3). Quantitatively, the precipitation is similar to measurements over the lowlands and underestimates that of the highlands.

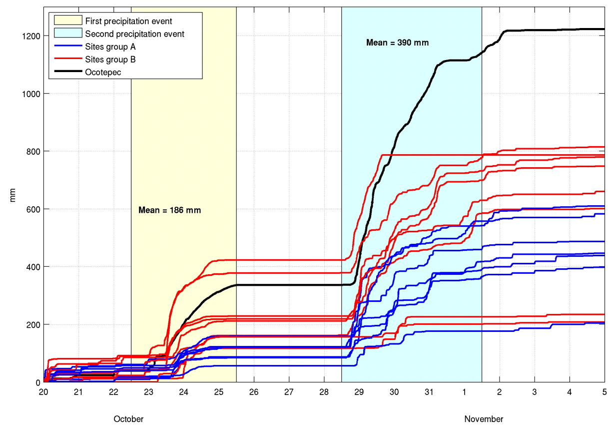

Figure 2. Accumulated precipitation of the sites shown in figure 1. Group A includes sites below 25 m of altitude; Group B sites above 25 m and Ocotepec at 1477 m.

The second precipitation event, between the 28th and the 31st of October, was also well forecasted by the model. Unlike the first event, the precipitation maximum has a *tongue* shape with maximum values over the highlands of the Isthmus of Tehuantepec, reaching 400 mm of accumulated precipitation in 72 hours and 300 mm in the lowlands (Fig. 4). These values are similar to those observed but the maximum is reached slightly westward to that reported by the tide gauges, probably associated with a small shift of the front location.

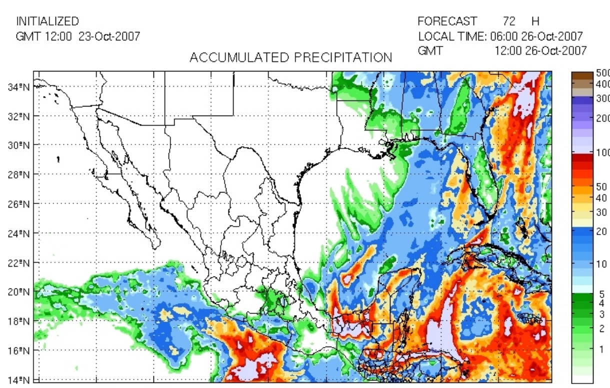

Figure 3. WRF-ARW model forecast of accumulated precipitation after 72 hours starting at 12Z, 23-Oct-2007.

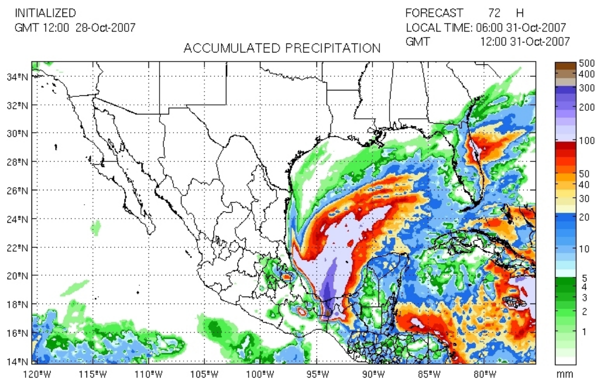

Figure 4. WRF-ARW model forecast of accumulated precipitation after 72 hours starting at 12Z, 28-Oct-2007.

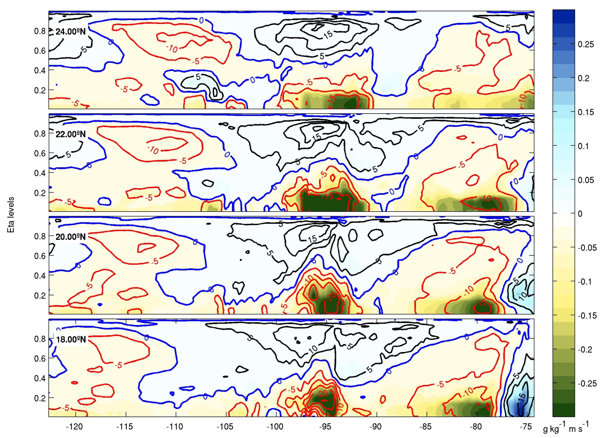

Figure 5. Water vapor transports (g kg^{-1} ms^{-1}) in zonal section at 24 °N, 22 °N, 20 °N, and 18 °N for the 29-Oct-2007, 18:00Z forecasted 42 hours before. Color: Positive (negative) values indicate northward (southward) transports. Contour lines indicate intensity of the meridional component: Black (red) indicate northward (southward) direction.

The extraordinary precipitation of the 28-31 October event was associated with a strong *jet* of water vapor transport along the front and the forced convection by the more than 2,000 m height sierra. Another circumstance was that the front remained stationary during 48 hours advecting water vapor to the Isthmus. The water vapor source was located on the western Caribbean where strong convection activity occurred from the 25^{th} to the 31^{st}. Zonal sections of water vapor transport show that moisture flux was mostly confined along the front (Fig. 5) and covered from surface to middle altitude. Is interesting that in the first precipitation event the moisture flux was not confined (not shown), instead there was a wider and weaker *jet*.

Winds

The cold front No. 4 was also characterized by very strong winds, storm surge, and swell which, among other damages, caused an accident on an oil platform located in the southern Gulf of Mexico with 23 casualties. The magnitude and direction of the winds forecasted by the WRF simulation are compared with the 42001, 42002, and 42055 NOAA buoys (see Fig. 6 for location).

The 3 buoys have wind sensors at 10 m height, the data are hourly and computed as the average of the last 8 min (sustained winds). The buoys also measure wind gusts which were, on average, 25% more intense than the sustained winds (not shown). The model outputs were interpolated to the sites where the buoys are located and reproduces well the magnitude and direction of the winds (Fig. 7).

It is noticeable that the winds near the coast of Veracruz and Tabasco are stronger due to the orographic effect caused by the Sierra Madre Oriental which gets closer to the coast line near 19.5 N (Fig. 8). Sustained winds in the region over the inner continental shelf of the southern Gulf of Mexico reached more than 80 km/h.

4. Discussion and conclusions

Although the Mexican Weather Service and the Commission of Electricity, which is responsible for the administration of the dams in the Grijalva River basin, forecasted the arrival of the cold front 72 hours in advance their precipitation forecasts are classified in 6 categories with the highest being > 70 mm in 24 hours, while the precipitation reached 300 mm in some regions. This was a limitation for the appropriate operation of the dams which auxiliary spillways were opened at 2000 m^3s^{-1} during 24 hours on the 23^{rd} of October, and later at 1300 m^3s^{-1} during 3 days, contributing to the flooding of the city of Villahermosa, the largest city in the state of Tabasco. The forecasts of both precipitation events from the WRF model were accurate and also the 3-day period without precipitation in between (see Fig. 2). These results suggest that the suitable operation of the dams, based on better forecasts, would have reduced considerably the damages caused by the event. On the other hand, the strong winds associated with the event were successfully validated with 3 buoys. The model shows that the winds were stronger near the coasts of Veracruz and Tabasco, reaching more than 80 km/h.

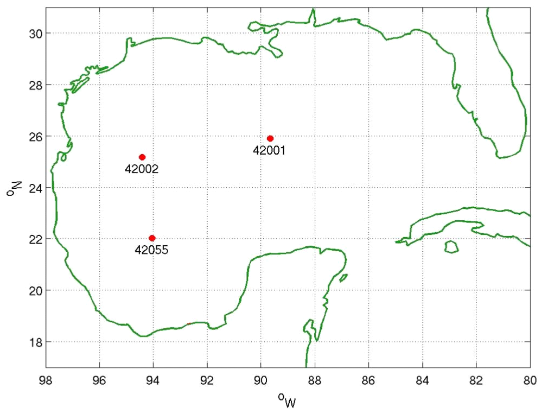

Figure 6. Location of the buoys used for wind comparison with model simulation.

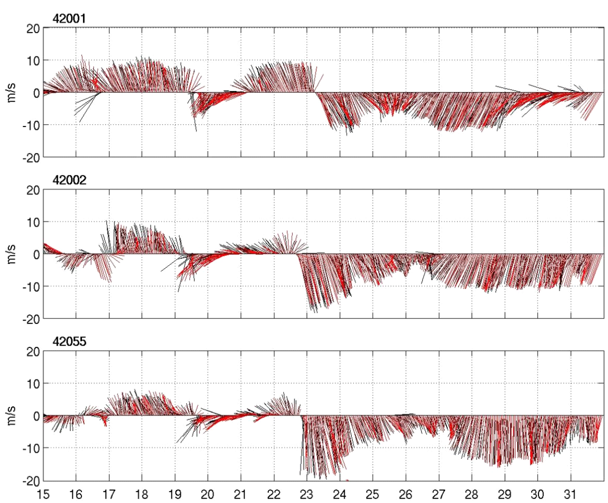

Figure 7. Time series of hourly winds for the period 15-31 of October 2007, from the NOAA buoys in the Gulf of Mexico (black) and from the WRF 24-hour simulations (red).

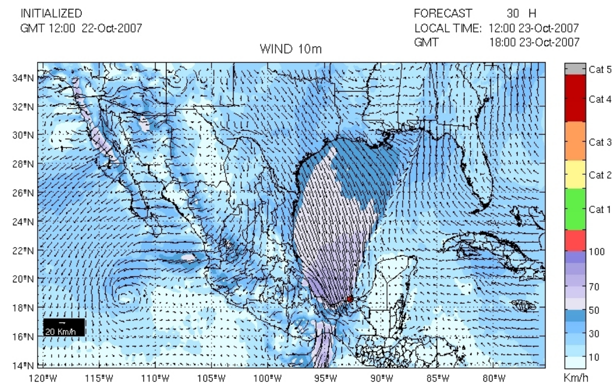

Figure 8. WRF-ARW model forecast of 10 m winds after 30 hours starting at 12Z, 22-Oct-2007.

Acknowledgments

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