# "The role of tidal modulation in coastal flooding on a micro-tidal coast during Central American Cold Surge events"

by Wilmer Rey et al.

## ANSWER TO COMMENTS OF REVIEWER #2

**Referee#2:** Research investigates coastal flooding in Mexico from storm tides. I found the text/descriptions are confusing and could do with improvement please; e.g., if high-pressure cold front event induced flooding I would expect, due to the inverse barometer effect, that storm surge is small and driven exclusively by wind stress? By improving the text will reduce reader fatigue. As the writing needs much improvement to improve readability, it may be easiest to simply re-submit. Moreover, I have a number of concerns with the method and results that I think ought to be addressed before resubmission:

> **Authors response:** Thanks for your comment. On p. 2, l. 15 we mentioned something about it. However, we made some changes in that paragraph. The new paragraph says: "The storm surge is enhanced by the wind shear stress on the sea surface and perturbations in the atmospheric pressure (Lin and Chavas, 2012). Since the inverse barometer effect contribution to storm surge is small during low pressure storm systems (Massey et al., 2007), the storm surge is mainly driven by wind stress especially in shallow waters in the coastal zone (Flather, 2001). Considering that CACS are high-pressure systems, the storm surge is essentially driven by the direct wind effect". The effect of the pressure is relatively small; the rule of thumb is that for every 1 mb drop in pressure there is a 1 cm rise in ocean surface level (Massey et al., 2007). Besides, looking into the Figure 9 (removed from the paper based on major point # 3 of reviewer 1), it is shown that the peak of the residual tide occurs after the peak of the wind intensity (roughly 2 h) and after the minimum pressure (roughly 6 h). It means that the maximum residual occurred when the atmospheric pressure was around 1013 hPa (neutral pressure). By the time the CACS high pressure reached the Peninsula, the residual tide had already decreased. We assumed that this behavior might happen most of the time when CACS reach the Peninsula. In conclusion, the CACS storm surge is mainly driven by the direct wind effect.
>
> On the other hand, we shortened the draft paper significantly and had it reviewed by a technical native English speaker reviewer (please see the answer to reviewer 1 for major point #3).

**Referee#2:** (1) Tide-surge interaction means that "wetting and drying" is likely to be extreme important in the model - yet this is not discussed/perhaps not included in the model?

> **Authors response:** Wetting and drying are included in the model following the work by Zhao et al.(1994) and Sleigh et al. (1998). The user predefines the wetting and drying values so that the elements/cells are considered in the calculation only if the wetting threshold is surpassed. The elements/cells are removed from the calculations when the depth goes below a certain threshold, so that the momentum fluxes are set to zero and only considers the mass fluxes. The depth in each element/cell is monitored, and the elements are classified as dry, partially dry or wet. Besides, the element faces are monitored to identify flood boundaries.

The MIKE 21 wetting-and-drying algorithm performs skillfully inland to the east part of the back-barrier lagoon at Progreso. The inundation area calculated for Event A was of 8 and 149 blocks for the sea and lagoon side, respectively, as shown in Table 1 (blocks of Progreso affected as a function of tidal phase during Event A). We have included this on the discussion part.

**Referee#2:** 2) Why are waves included in the method if not included in the model for the 30 year run? This could be done easily uncoupled - as coupled modelling likely to not be necessary?

**Authors response:** The 30-year sea level hindcast was developed as the basis for the extreme level analysis, which is not possible from measurements due to the lack of tide gauge records. Unfortunately, the computational cost prohibits the modeling of coupled waves and hydrodynamics for that long period. For instance, for a given period of 3 weeks, and the computational domain is shown in Figure 2, the computational time for the uncouple model was 12 h, but increased drastically (up to 2 weeks) for the coupled model version (with waves). Given the computational resources available at that moment, it was not possible to carry out a sea level hindcast including waves. Nevertheless, we considered necessary to do coupled modeling to include wave setup, and wave-current interaction, in the particular cases presented in the study.

We then considered that to know the importance of taking into account the wave setup contribution on the total flood, the two worst storms in terms of maximum residual tide (Event A), and maximum water level (Event B) were chosen to assess the inundation threat on Progreso by means of running the hydrodynamic model in a coupled model. From this, we concluded that at least for Event A the wave set-up was significant given the no linear interaction wave-currents, which induced a relevant wave setup on the Chelem lagoon.

However, the wave setup contribution is usually not taken into account for some inundation modelers mainly because of the computational time cost and because most of the time it is not comparable with the storm surge contribution.

**Referee#2:** 3) The resolution and time-step of the CFSR forcing data needs to be discussed (hourly, 3hourly etc) - including a sensitivity test please.

**Authors response:** Thank you for the question. On p.6 l. 12 something related to this topic is mentioned, and we made some changes in that paragraph. The new version says “On the surface the model was forced with wind and pressure fields from the CFSR database, which has a global atmospheric resolution of 38 km (T382) with 64 levels extending from the surface to 0.26 hPa. The global ocean resolution is 0.25º at the equator, extending to 0.5° beyond the tropics, with 40 levels from the surface to a depth of 4737m. NCEP (National Centers for Environmental Prediction) has created time series products at hourly temporal resolution by combining either 1) the analysis and one- through five-hour forecasts, or 2) the one- through six-hour forecasts, for each initialization time. When using this data product, it has to be kept in mind that only the 0000, 0600, 1200, and 1800 UTC fields are actually analysis, while the in-between hourly data are model forecast. NCEP only created time series for parameter/level combinations that were thought to be most useful to users (Saha et al., 2010, 2014). Time series that do not exist in this dataset can be created from the full 6-hourly products dataset.

Given that the spatial resolution of the CFRS grid is not regular, and the hydrodynamic model only accepts wind and pressure data varying in space from a regular grid, CFSR wind and pressure fields were linearly interpolated from a T382 Gaussian grid resolution to a regular grid with spatial resolution of 0.3125º, which is coincident with the longitude of the T382 grid and close in latitude for the Gulf of Mexico. We assumed this resolution to be adequate to reproduce the CACS storm surge based on the work of Appendini et al. (2013), who showed that the resolution of NCEP/NCAR, ERA-interim and NARR is sufficient for wave modeling of CACS over the Gulf of Mexico. Indeed, given that CFSR data is superior to the above NCEP reanalyses regarding (a) finer resolution, (b) advanced assimilation scheme as well as (c) atmosphere-land-ocean-sea ice coupling, it is expected to be a good compromise for this application. Moreover, the hourly resolution of CFSR allow this dataset to capture extremes, such as storm peak, which other reanalyses may miss, according to Sharp et al. (2015), who found a good correlation between the hourly CFSR dataset and both onshore and offshore in situ measurement for the U.K. For instance, NCEP FNL (Final), ECMWF ERA-Interim (European Centre for Medium Range Weather Forecasts e European Reanalysis) and NCEP-NCAR (National Centre for Atmospheric Research) provide data at 6 hourly intervals (Jørgensen et al., 2005), which may not be too long to capture storm peaks, and from that maximum flooding areas.

On the other hand, the MIKE 21 hydrodynamic model uses a dynamic time step to optimize simulation speed while ensuring stable model runs. Hence, the time step may change during the simulation (large time step under calm conditions, smaller time step when flow becomes stronger). The user is allowed to set the minimum and maximum time step in the model setup. The actual dynamic time steps used are found to be in the range from 5 to 7.5 s. Then, since the time step for the CFSR is 1 h (three orders of magnitude longer than the hydrodynamic model time step), the hydrodynamic model interpolates the CFSR data linearly to its own time step.

**Referee#2:** (4) More model validation please: “In general, a good agreement can be seen for the sea surface elevation during the storms the Pearson correlation ranges from 0.78 to 0.87 and the root mean square error (RMSE) ranges from 0.11 to 0.17" This model validation seems very poor. What is the RMSE as a percentage of the signal (NRMSE) ? Especially as a micro-tidal site and only a few validation locations (and limited time-length) appears to be used for validation.

**Authors response:** We acknowledge your comment. First, as mentioned before, one of the main problems on the study zone is the lack of long tide gauge records. That is the main reason why we made the sea level hindcast. In fact, we only have raw tide gauge records for 5 years and for one location (Progreso port) in the study area. For the model validation, we presented two different events (see figure 6). We calibrated the model based on the Drag Coefficient Cd to reproduce the maximum sea level during the CACS passing (please see for more details the answer to Reviewer 1 for the minor point mentioned on p.6, l.22).

We acknowledge that use of the term “ranges” in the sentence:

> “In general, a good agreement can be seen in the sea surface elevation during the storms the Pearson correlation ranges from 0.78 to 0.87 and the root mean square error (RMSE) ranges from 0.11 to 0.17"

is confusing. Probably, based on this, you suggest that the validation is poor. Let us explain that Figure 6 as follows:

For the event shown on the top panel of Figure 6, the Pearson correlation is 0.78 and the RMSE is 0.1 m., which corresponds to the 20.9 % and 16.6 % of the measured and modeled sea level range, respectively. For the other event shown in the lower panel of Figure 6, the Pearson correlation is 0.87 and the RMSE is 0.17 m., which corresponds to the 16.6 % and 18.3 % of the measured and modeled sea level range, respectively. Based on the above, we considered that model validation is acceptable. For instant, the SLOSH model, which is the only model used by the National Hurricane Center (NHC) to provide real-time hurricane storm surge (Massey et al., 2007) for over two decades, the accuracy of the predicted surge heights is +/-20% when the tropical cyclone is adequately described (Jelesnianski et al., 1992).

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