Ocean Sci. Discuss.,
https://doi.org/10.5194/os-2018-63-AC1, 2018

Ocean Science
Discussions

Interactive comment on "Storm surge forecasting: quantifying errors arising from the double-counting of radiational tides" *by* Joanne Williams et al.

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Received and published: 2 August 2018

Thank-you for your helpful review. Please see inline replies.

The manuscript addresses current practices to predict water level changes for various operational marine applications. Such predictions need to include sea surface height changes due to all acting processes including atmospherically induced surge and lunisolar ocean tides. Typically, information on tidal effects and the time evolution of the general ocean circulation are obtained from different sources and are added by means of linear superposition. This assumption of linearity can be, however, questioned in view of distinct periodicities in the atmospheric-induced circulation associated with the

either the seasonal cycle or atmospheric tides. The present manuscript addresses this topic in a way I certainly believe worth to be published in Ocean Sciences. However, a number of points raised below might be addressed in order to increase clarity of the representation and expand the discussion to cover all relevant aspects of the topic:

(1) The nomenclature applied is somewhat problematic: M obviously represents model-based sea surface heights, W apparently stands for observed water levels. H, however, is used for harmonic estimations/predictions for either models, observations, or final combined forecasts. This is difficult to comprehend, so I suggest to reserve capital letters to identifying the source of water level informations (i.e., model (M); tide gauge (G); water level forecasts (W)), and indicate the actual signal component by subscripts (time series of tides (t), harmonic estimates from a time series of tides (th); time series of surge and other meteorological forcings (s); harmonic estimates from a time series of tides and surge and other meteorological forcing (tsh), etc.).

Thank-you for the suggestion. All reviewers commented on the notation, and we've completely revised it. Rather than the double subscript, we've changed to an overhead tilde to indicate "time series derived from harmonics", as the shape is reminiscent of a sine wave. We also switch to F for "Forecast water level" and G for (gauge) observed total water level.

Then the forecast is given by $F = (M_s - M_t) + \tilde{G}$, the harmonic prediction derived from the tide-and-surge model is $\tilde{M}_s$, etc.

(2) W_g is apparently not properly introduced at all.

The observed total water level. Corrected alongside all notation.

(3) The example of Section 2.4 is only partially convincing. What is the usual base period taken to estimate H_g? Isn't it plausible to assume that surge event effects on H_g will cancel out over time? Are there recommendations available on the number of constituents to be considered? What about the treatment of minor tides?

Section 2.4 (on non-linearity, now 2.5) is about the effect on prediction of an individual surge event, given that there exists some discrepancy in phase between model tides M_t and the harmonic prediction from the gauge $\tilde{G}$.

If during such an event the surge causes an advancement of the tide, then $M_r = M_s - M_t$ is decreasing rapidly during High Water (the peak of M_t). The peak of $M_r + \tilde{G}$ is therefore dependent on the relative timing of the peak of $\tilde{G}$ and M_t.

Thank-you for the prompt to look at this again, as it turns out that for a simple tide it can be shown analytically thus (added to section 2.5):

We construct an example with model tide $M_t = A\cos(\sigma t)$, and a surge in which there is an additional uniform water level A_s and an advancement of the tide of $t = \delta$, so model surge is $M_s = A_s + A\cos(\sigma(t+\delta))$. The model residual is given by $M_r = M_s - M_t$.

Suppose the harmonic prediction at the gauge has the same amplitude but the tide is ϵ ahead of the tide-only model, $\tilde{G} = A\cos(\sigma(t+\epsilon))$.

The forecast water level is $F = M_r + \tilde{G}$ and the error in the skew surge forecast is $\max(F) - \max(M_s)$. Substituting in and assuming phase changes are small, the skew surge forecast error is

$$E = A\left(\cos(\sigma\epsilon) - \cos(\sigma(\delta+\epsilon)) + \cos(\sigma\delta) - 1\right).$$

Suppose for example that $A = 3$ m, $\sigma = 2\pi/12.42$, the difference between model and gauge tide is ϵ=0.083 (5 min for M2), and the surge advances the tide by 30 min ($\delta = 0.5$). Then $E = 0.03$ m. This is still below the level of other forecast errors at the moment, but may not be negligible in future.

Although in practice there are many more constituents than M2, a similar relationship will hold in a small window about high tide, with a changing amplitude each day. Indeed, the absence of a small constituent will often manifest as a small phase change in M2. If there are frequent surges, we would expect ϵ to have the same sign as δ, as the gauge

would register water levels more like the surge+tide model than the tide-only model and the harmonic predictions would follow suit.

(4) The effects of the annual tide Sa and the semi-annual tide Ssa might be discussed in more detail, in particular in view of the fact that the ocean circulation might have also a distinct annual periodicity.

There are several contributions to annual cycles that we have omitted from this study, including steric effects, circulation changes, river input, ocean mass changes, gravitational changes... the larger of these are explicitly noted in the introduction. However since these are omitted from both model runs (other than very small effects via the atmosphere) they are not at risk of double counting.

We have added some notes on this in the introduction, and also expanded a little on the results seen for Sa. These in large part follow the local annual cycle in atmospheric pressure, an exception being in the wind-dominated Baltic.

(5) Changes in river discharge and their consequences on local water levels might be not relevant for the U.K. but can have a profound impact for estuaries in other parts of the world. A few comments about this process might be helpful.

Good point. It's a reason that using the tide gauge prediction rather than just model tides may be necessary. Added:

There are other contributors to water level, including steric effects and river flow, that will also create differences between the tide gauge and the forecast water levels, particularly seasonally. The problem of double-counting of periodic changes does not arise if they are omitted from the surge model entirely, but they may contribute to HAT and LAT calculations. These effects are not considered in this study.

A few rather minor points might be also addressed during the revision: (5) It could be mentioned somewhere in the text that M2 is also having a very weak atmospheric pressure signature (see 10.1002/2015JD024243).

Thank-you for the suggestion. Schindelegger 2016 was a very confusing paper till I realised they were using L2 to mean M2 in the atmosphere, when L2 is used in tidal analysis for a subtle lunar elliptical effect at a different frequency! Note added in first paragraph of section 3.

"There is a very small atmospheric tide at M_2, peaking at the equator at about 0.1 mbar [Schindelegger 2016] . "

(6) Figure 1 is difficult to read. Maybe enlarging the vertical extend of the figure would help?

Now enlarged as much as possible.

(7) The frequent change in units between cm and m in the text is rather unfortunate.

The figures all use metres. Text is now consistently cm except where refering to absolute tidal heights, HAT and water levels which are of the order of m.

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