Surface boundary layer thermal stability and its relationship to significant wave height errors obtained from WAVEWATCH III

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Significant wave height (H_s) calculated with the WAVEWATCH III® model deviates from the in-situ measurements from moored buoys. We hypothesize that this deviation would be smaller if the model used a well-calibrated method to account for stability variations within the surface boundary layer (SBL). This research determines a relationship between such errors and the SBL thermal stability. It can be exploited to create an empirical correction to wind speed, an “effective wind speed”.

BACKGROUND

The exchange of properties between the atmosphere and the ocean occurs in a relatively thin layer of few meters from the interface. The atmospheric side of this ocean surface boundary layer (OSBL or SBL) is mainly influenced by the wind speed profile, the differences in temperature and density between both media and the air humidity content. The interaction between the buoyance and mechanical effects within the SBL influences the speed and ultimately, the occurrence of fluxes across the surface.

In order to compare surface wind measurements obtained with different sensors and modalities, it is customary to ‘correct’ the observed wind speed to a ‘neutral’ SBL, where buoyancy balances completely the mechanical forcing. However, the global SBL is mostly unstable (Young et al., 2017; Young and Donelan, 2018), creating a difference between the corrected wind speed and measured wind speed. Modeled wind speed with a neutral SBL would seemingly present the same type of bias.

The accuracy in wave modelling can be enhanced by including the impact of various phenomena not modelled explicitly. Wind gustiness and air density variability are two important examples. Theoretical and numerical studies have showed that wind gustiness has an important role in enhancing wave growth under unstable conditions (Abdalla and Bidlot, 2002). Density variations have less influence, but are still significant.

We want to explore here the effects of temperature variations within the SBL. We know that the SBL would became unstable if air temperature at its top is lower than the surface water temperature. If the thermal stability is not considered, wave height could be over/under estimated. In this context we explore the relationship between the differences model – observations in Hs and the temperature differences within the SBL.

DATA

WAVEWATCH III®: is an spectral ocean wave model capable of predicting wave characteristics at high resolution. The output used in our study involves H_s, wind speed considering a neutral BL, and other relevant measurements obtained during 2015.

NDBC data: Hs was collected by 59 buoys of the National Data Buoy Center (NDBC), all situated at least 50 km from land, together with wind speed and air and water temperature. Data is obtained every 10 min, and re-sampled to hourly data to match the WW3 output temporal resolution. Figure 1 shows the location of the NDBC buoys utilized in this analysis.

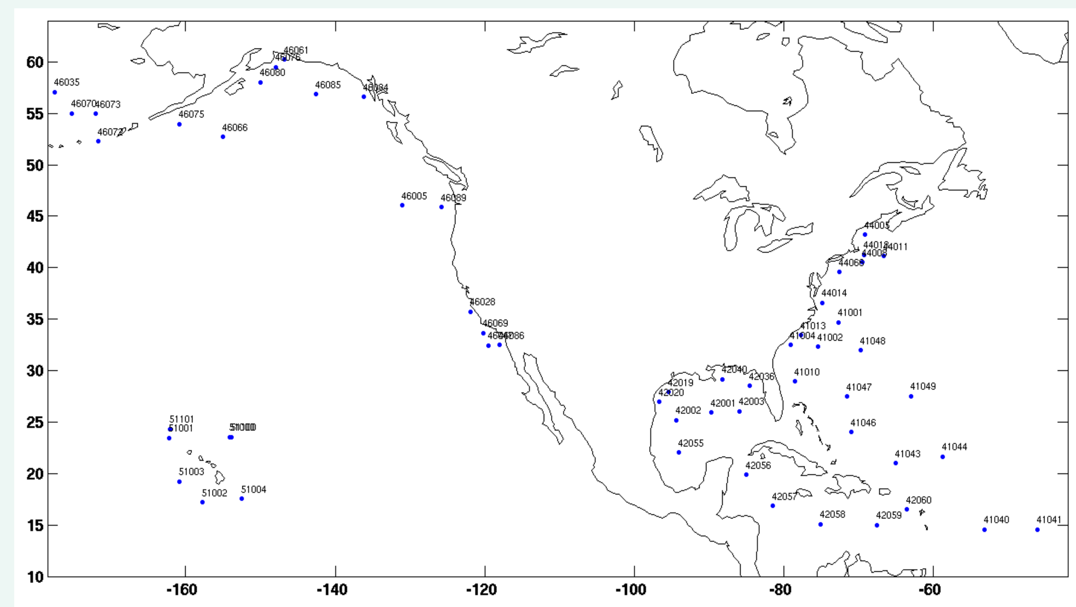

Figure 1: NDBC buoy locations

APPROACH

The model output for 2015 was compared to in-situ measurements (see **NDBC data** above). H_s error (that is, model minus observation) was compared to the air-water temperature difference (ASTD) and to the stability parameter (S) defined by Tolman (2002). He proposed the introduction of this parameter, based on a linear variation between the air and water temperature inside the BL, adding wind speed, a reference temperature and gravity effects as relevant variables. Our analysis also includes alternative stability parameters, such as the Monin-Obukhov stability parameter (MOSP), which also considers the pressure and humidity influence over the ASTD within the SBL (not showed here). Statistically, the analysis consisted in the assembling of comparative density scatter plots, and 1°C-bin data histograms, with mean H_s error per bin. It was performed over the entire data set (shown here), and also over three different groups of buoys, selected by region.

RESULTS

The statistical analysis performed shows strong agreement between the ASTD and the H_s error (in fact, much better than we had hoped), supported the **hypothesis** that *wave model accuracy can be improved by introducing a correction for stability based only on a linear relationship between air-sea temperature difference*. A comparison (not shown) with S (defined by Tolman, 2002) revealed an ambiguous role of the ‘reference temperature’, making S only suitable for a localized correction, i.e., applicable only in small areas, and for a narrow range of wind speed. In addition, MOSP does not show any significant correlation with the H_s bias, suggesting that humidity and pressure play a less significant role in the error.

Figure 2 shows an scatter plot of the H_s bias vs the ASTD, with the colors indicating the quantity of observations per bin (of 1°C). In Table 1 we can observe how the error in H_s changes as the ASTD changes. This effect is more clear in Figure 3, showing histograms of the H_s mean bias per temperature bin, with quantity of observations per bin, over its total number of observations. It shows a strong correlation between H_s bias and ASTD variability.

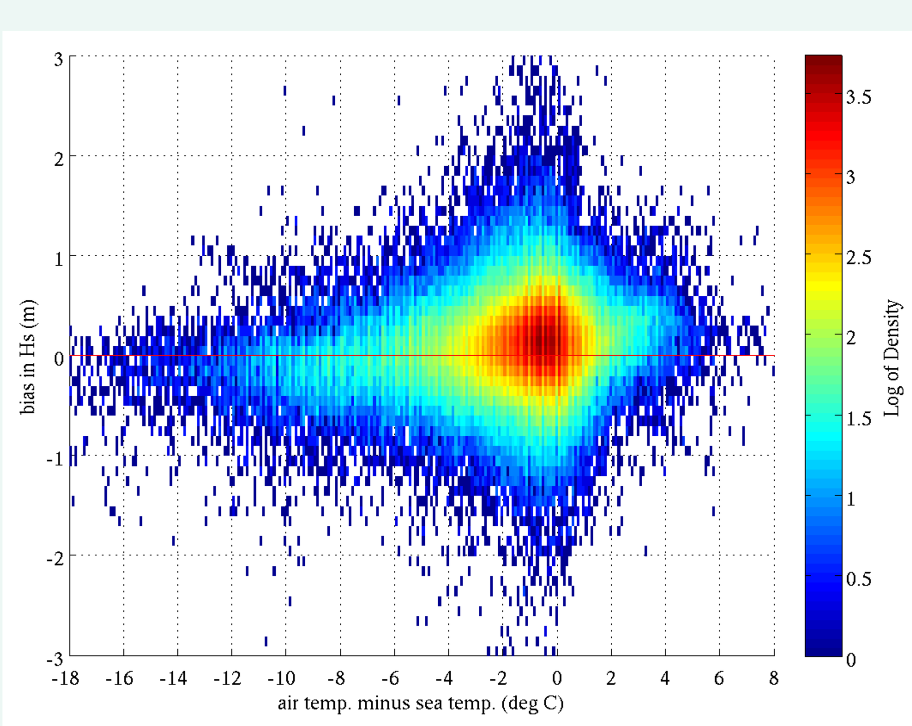

Figure 2. Density Scatter plot for the temperature difference and the mean bias error in H_s . The color bar indicates the density of observations per bin, with the maximum in dark red.

dT (°C)	HsE (m)	N_{ob}
-11	-0.126	994
-10	-0.137	1338
-9	-0.092	1808
-8	-0.063	2181
-7	-0.029	2895
-6	0.011	4717
-5	0.031	7295
-4	0.062	13389
-3	0.103	30187
-2	0.128	79088
-1	0.140	161199
0	0.119	49631
1	0.137	8801
2	0.201	2857
3	0.263	1400
4	0.253	512

Table 1: The first column indicates the temperature bins while the second indicates the mean bias between the H_s calculated through the model and the observed H_s at the buoys. The third column is the number of measurements available for each bin.

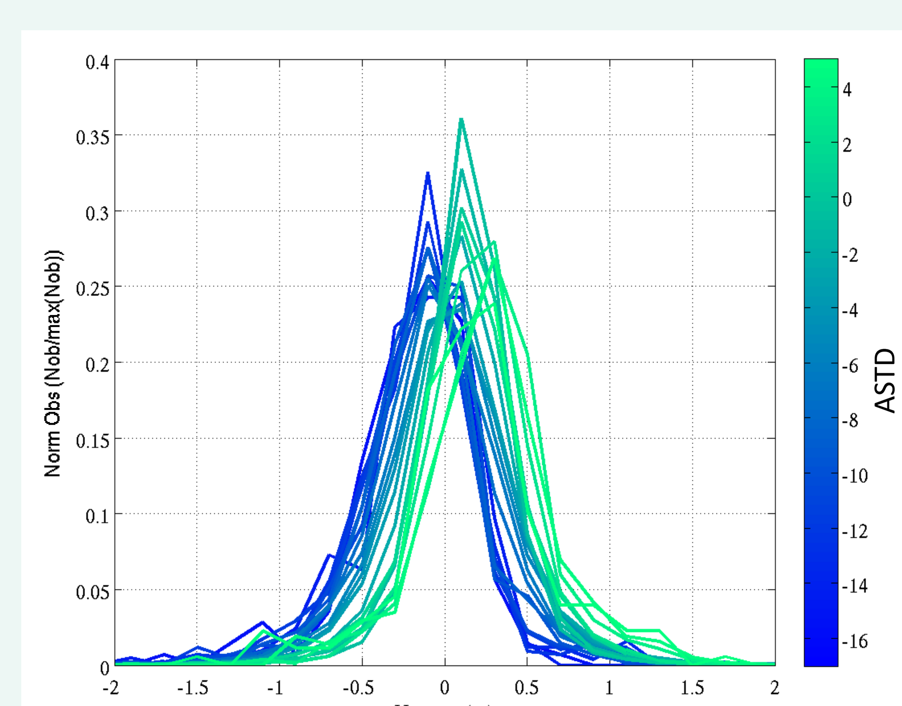

Figure 3: Binned histogram of the H_s error and the ASTD. Note a strong correlation, indicated by the variation from blue to green for each temperature bin. The left axis indicates number of observations per bin over the total number of observations.

CONCLUSIONS

The statistical analysis performed shows strong correlation between the ASTD and the H_s error. Correlation is weak between H_s error and other stability-related parameters. Introducing the effects of thermal stability within the boundary layer through the empirical dependence on ASTD will reduce the error in WW3 calculations. This is under development.

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