Comparison of WAVEWATCH-III ® model output whitecap fraction with in situ observations

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Parameterization of whitecap fraction in WAVEWATCH-III ®

Whitecaps are the main sink of wave energy and, although exact process still unknown, it is clear that they play a significant role in momentum exchange between atmosphere and ocean, and also influence gas and aerosol exchange. Recently, modeling of whitecap properties was implemented in the spectral wave model WAVEWATCH-III ® (WW3). The two different wave breaking parameterizations which have been developed for WW3 were implemented in special hindcasts over the period 2006-2009 for comparison with in situ observations in the context of the OceanFlux-GHG project.

The model parameterizations use different approaches related to the steepness of the carrying waves to estimate breaking wave probabilities. That of Ardhuin et al. (2010), denoted as T451 in the following, is based on the hypothesis that breaking probabilities become significant when the saturation spectrum exceeds a threshold, and includes a modification to allow for greater breaking in the mean wave direction, to agree with observations. It also includes suppression of shorter waves by longer breaking waves. In the second, denoted as T570 (Filipot and Ardhuin 2012), breaking probabilities are defined at different scales by using wave steepness and then the breaking wave height distribution is integrated over all scales. A further adaptation of the latter to make it self-consistent is described in (Leckler et al, 2012, manuscript in review by Ocean Modelling) which was also implemented in the hindcasts.

The breaking probabilities parameterized by Filipot and Ardhuin (2012) are much larger for the dominant waves than those diagnosed from the other parameterization, and agree better with modeled statistics of breaking crest lengths measured during the FAIRS (Gemmrich and Farmer, 2004) experiment. This stronger breaking also has an impact on the shorter waves via a parameterization of the short wave damping associated with large breakers, and results in different shapes of the distribution of breaking crest lengths. Converted to whitecap coverage using Reul and Chapron (2003), both parameterizations agree reasonably well with the classical empirical fits of whitecap coverage against wind speed and the global whitecap coverage dataset by Anguelova and Webster (2006) derived from space-borne radiometry; breaking of large waves in the Filipot and Ardhuin (2012) parametrization is compensated by intense breaking of smaller waves in parametrization by (Ardhuin et al. 2010).

The model hindcasts were carried out on the PREVIMER operational global grid, with a horizontal resolution of 0.5ºx0.5º and a temporal resolution of 1 hour. Winds from the NCEP Climate Forecast System Re-analysis provided the forcing every 3 hours, and 32 frequencies (0.037-0.72Hz) in 24 directions were used. Output from the model includes whitecap fraction, whitecap thickness (following Reul and Chapron (2003)) and optional dissipation-related parameters such as mean-squared-slope and friction velocity. These variables were interpolated from the model grid in space and time to match the in situ observations.

In situ observations and quality control

Comparisons were made with *in situ* data collected during research cruises in the North and South Atlantic, and the Norwegian Sea in 2007, 2008 and 2009, as outlined in table 1.

Data Set	Colocated data points	Camera Location	Cruise period	Sampling time
Deep Ocean Gas Exchange (DOGEE)	42	Port	June-July 2007	30sec
SEASAW	187	Port	March-April 2007	30sec
HiWASE_NOC	46	Fore	Jan-April 2007	10 minute
HiWASE_NOC	108	Port	Feb-Oct 2008	5 minute
HiWASE_NOC	137	Fore	Feb-Dec 2008	5 minute
HiWASE	60	Port	Sept-Oct 2008	5 minute
HiWASE	43	Fore	Sept-Oct 2008	5 minute
HiWASE	19	Port	August-Oct 2009	5 minute

The colocated model and *in situ* data were averaged over 30 minutes intervals to reduce noise and data from all cruises were combined in the following comparisons.

CFD corrections were applied to all wind speed (U10m) data to correct for biases caused by air flow distortion over the ship. This removed / reduced some biases that were related to platform and to relative wind direction. Winds from the stern are also removed since there are no CFD corrections available for these wind directions, and the distortion is likely to be bad. QC of the whitecap data also includes:

a) Removal of data where the ship sheltered, or blocked the flow of wind over, the region of the sea being imaged, as these data had a low-biased W.

b) Removal of periods when the ship was steaming, which removed high-bias W data due to contamination by the bow wake.

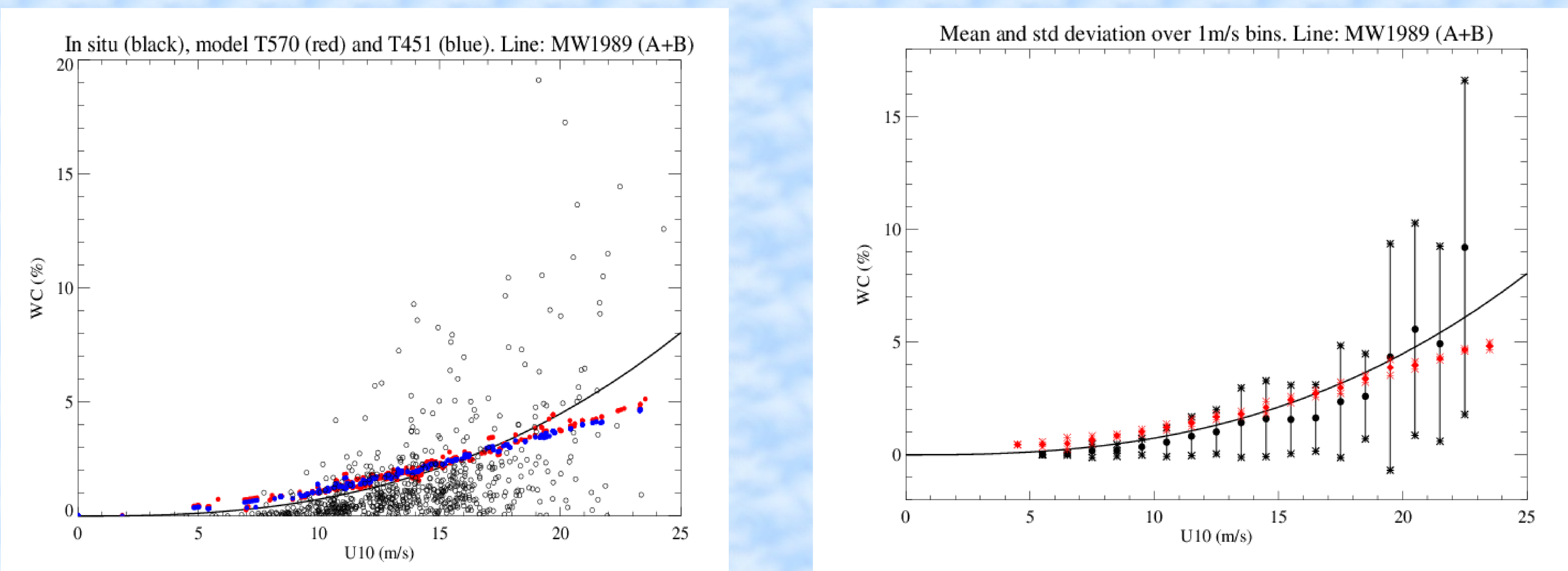

Figure 1. Comparison of model and in situ WC fraction with parameterisation of Monahan and Woolf (1989). Model WC fraction are plotted as a function of model wind speed and in situ WC as a function of observed wind speed.

Comparison of co-temporal, colocated model output with observations

Figure 1 (left) shows the QC'd in situ data and interpolated model data averaged over 30 minute time periods for all 7 cruises. The Monahan and Woolf (1989) parameterisation for combined static and dynamic breakers is plotted as a solid line, representing an 'expected' WC fraction. The model values follow the parameterisation quite well, with a tendency to overestimate at wind speeds up to 16m/s and underestimate at higher wind speeds. Only results from model runs using T570 will be shown in the analysis to follow.

The right-hand panel of figure 1 shows the mean and std dev of the same data over wind speed bins of 1m/s. The scatter in the in situ data means that the parameterised curve falls within +/- 1 standard deviation at all wind speeds excpet for the lowest values, with the in situ mean lower than MW1989 at all wind speeds up to 20m/s. The mean model T570 WC fraction, on the other hand, is higher than both parameterisation and in situ observations up to about 16m/s, but is consistently closer to the parameterised value than the observations at higher wind speeds. This is not unexpected, as the model output has been tuned to this parameterisation to some degree.

One of the possible sources of error is that the model winds may have a wind speed dependent bias compared to the in situ winds, and have less spatial and temporal variability. The difference between the modelled and observed WC fraction was plotted as a function of the difference between the observed and the model wind speeds (figure 2, left) and also as a function of observed wind speed standard deviation over the 30 minute average (figure 2, right). There is a general tendency towards larger WC fraction differences with larger wind speed differences, as expected. The variability of the wind speed over 30 minutes, however, appears to have little impact on the difference between modelled and in situ values.

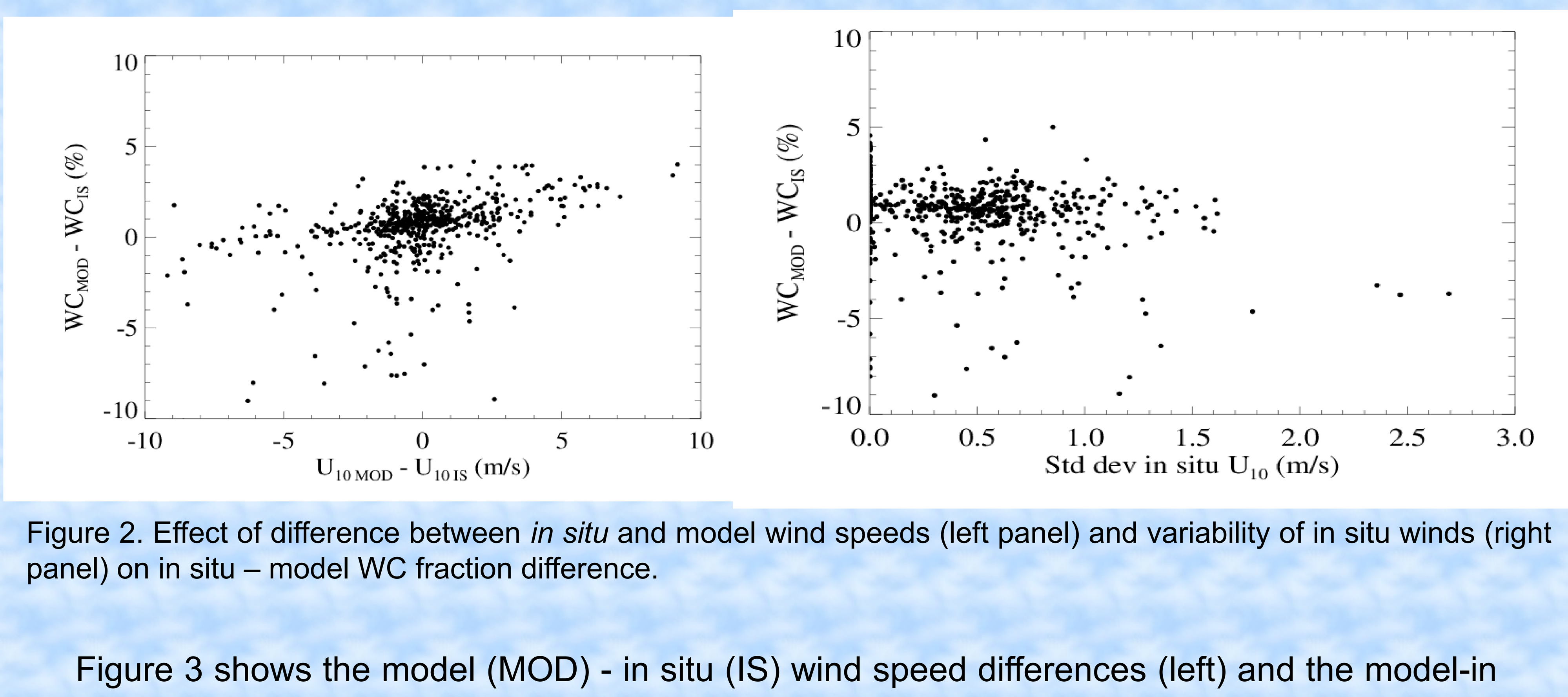

Figure 2. Effect of difference between *in situ* and model wind speeds (left panel) and variability of in situ winds (right panel) on in situ – model WC fraction difference.

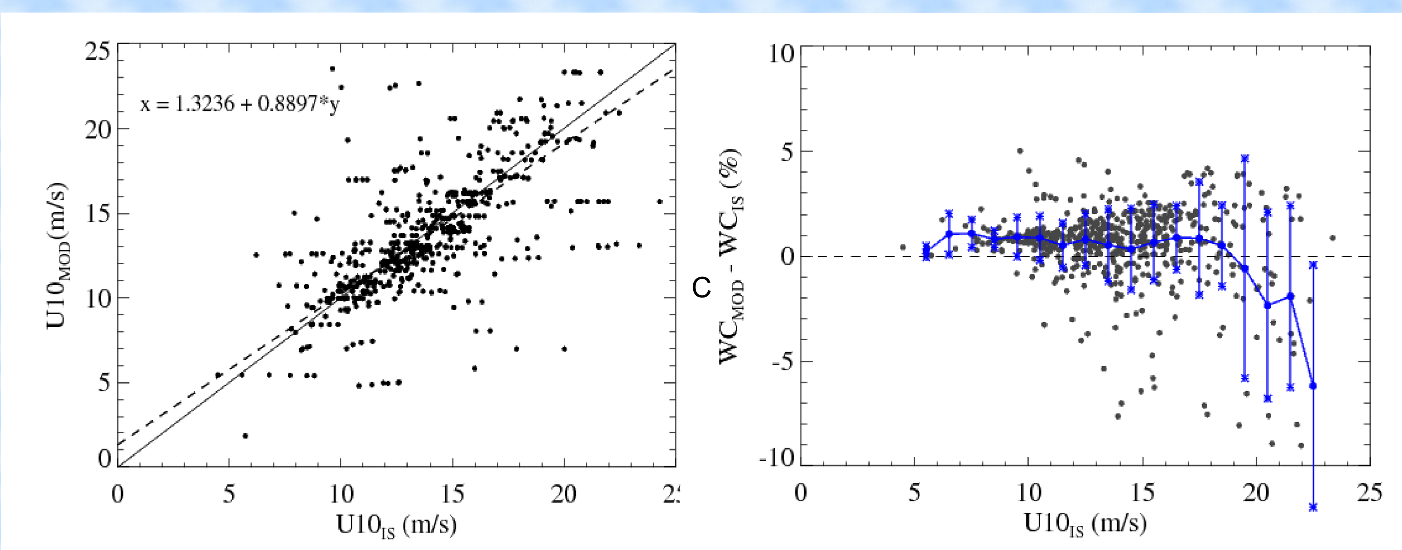

Figure 3 shows the model (MOD) - in situ (IS) wind speed differences (left) and the model-in situ whitecap fraction differences (right) as a function of IS wind speed. It can be seen that the model wind speeds are biased high compared to the in situ wind speed when the wind speeds are low, and similarly the model winds are biased low when the wind speeds are high. This explains the mean differences between the W values shown in the right hand panel of figure 1. In other words, if the modeled wind speds agreed with the in situ winds, then the WC comparisons would agree more closely.

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