Wind Forcing in Ocean Wave Modeling

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Wind forcing used to drive modern 3rd generation spectral ocean models and ocean response models in general continues to be a major source of error. While weather prediction models run in reanalysis and forecast modes are improving, there can be regional systematic biases and deficiencies in storm events which if left unchecked will contaminate the ocean response.

Historically, a variety of methods have been applied in hindcast and forecast modes to improve on modeled winds. This presentation describes several approaches applied in the West Africa Normals and Extremes (WANE3, see Figure 1) hindcast and show the impact on the ocean response. An important common aspect of any wind correction methodology relies on the application of in-situ data which has been properly adjusted for height, stability and time averaging to provide a common reference for analysis and modification.

Statistical methods which apply corrections on directional and seasonal basis using satellite measurements are shown to reduce systematic bias. Winds in tropical cyclones, which can be poorly resolved in global simulations, are improved by blending in solutions from high resolution dynamical models. Finally, the impact and application of classic kinematic analysis techniques are presented and impact on the ocean response are shown.

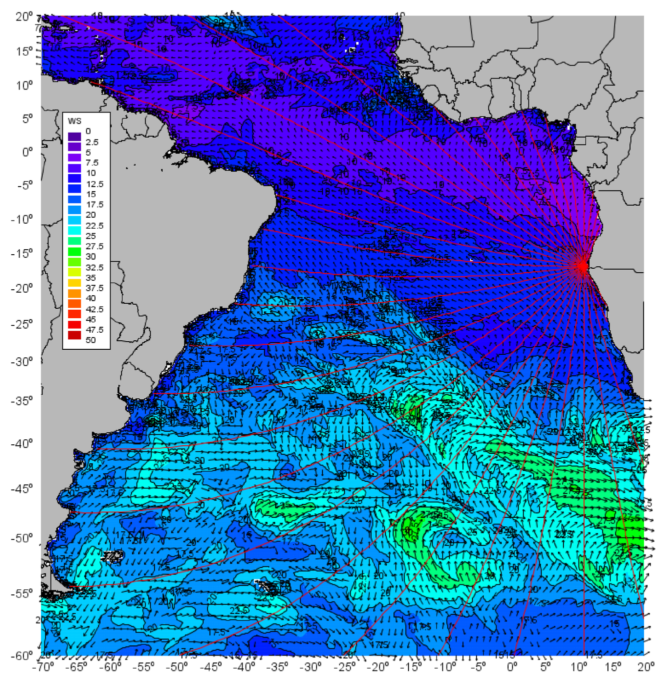

Figure 1. Maximum Wind Speed for Sept-2014
The West Africa coastline poses a variety of wind forcing challenges including local squalls, coastal enhancements and well as swells generated from North Atlantic tropical systems and ocean storms from both hemispheres.

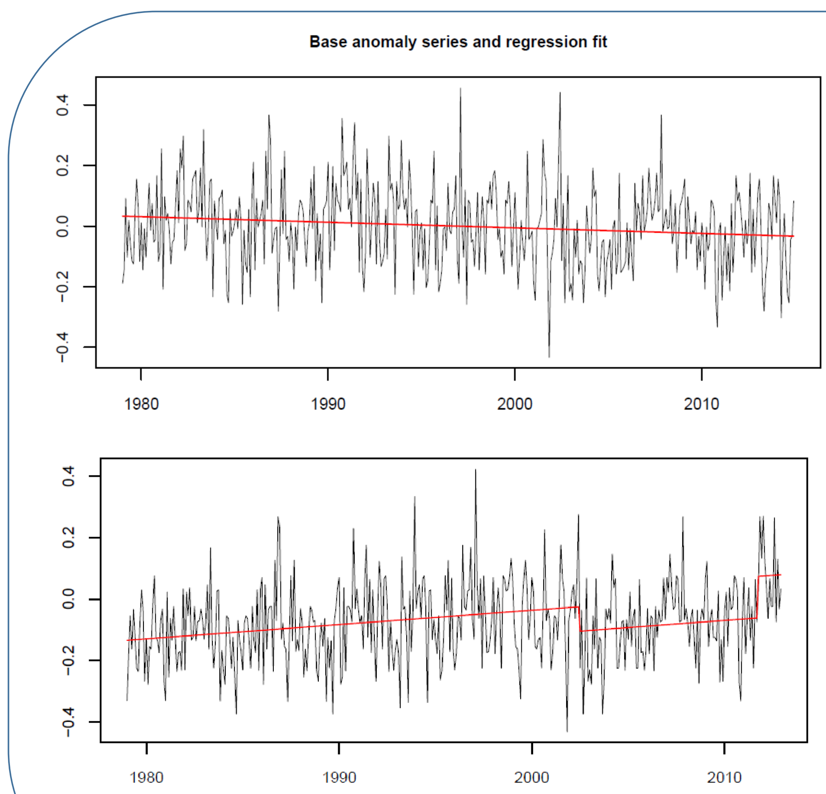

Figure 2. RHTest analysis of mean South Atlantic winds from CFSR (top) and ERA-Interim (bottom)

Assessment of wind reanalysis products using in-situ and satellite data is essential for determining model skill. Wind measurements need to be adjusted for height, stability, exposure and averaging period to ensure an unbiased assessment. Most modern reanalysis products include assimilation of common wind observations, making independent determination of skill a challenge.

The increasing number of wind observation platforms assimilated in atmospheric models can lead to inhomogeneity issues in developing long-term hindcasts over time. Tools, such as RHTest (Wang 2008), can detect shifts/step changes in mean or hourly (Wang et al 2010) model output. The RHTest analysis shown in Figure 2 indicates two step changes in the ERA-Interim mean winds in June 2002 and Sept 2011 – likely due to changes in ingested data applied in the reanalysis modeling system.

Overall systematic bias in reanalysis winds may be reduced by statistical method which assesses the bias in the 1-99% Quantile-Quantile (Q-Q) comparison on a grid point basis when comparisons are stratified on a directional, seasonal/monthly and hourly basis.

In this procedure, matched pairs of model/measurements are grouped (see Figure 3 for example) in "Levels" (see Table 1) which include increasing overlap of spatial, directional, seasonal and hour of the day and subjected to fit testing. If a grouping passes the goodness of fit test, a correction factor is determined by a linear fit to the Q-Q.

Overlap of selected stratification in each level is essential to maintain consistency in correction factors. Figure 4 depicts the geospatial coverage of the four levels applied in the correction process. Reduction in wind bias is shown in Figure 5, and later confirmed by comparison of resultant waves after running the model for comparison (not shown).

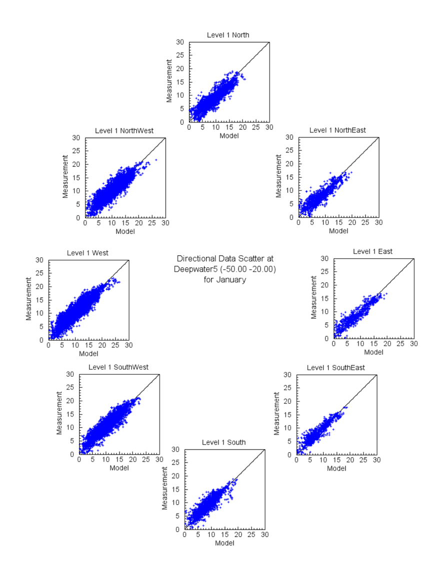

Figure 3. Directional matched pairs during January offshore West Africa.

Level	Spatial Box	Directional Bandwidth	Months	Hours
1	+/- 112 km	45 +/- 30 deg	+/- 2	All
2	+/- 112 km	45 +/- 30 deg	+/- 3	All
3	+/- 140 km	45 +/- 60 deg	+/- 3	All
4	+/- 140 km	45 +/- 90 deg	+/- 3	All

Table 1. Levels applied in WANE3 wind corrections

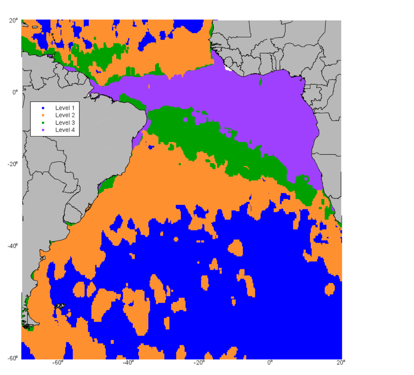

Figure 4. Spatial coverage of Levels applied in WANE3 wind corrections

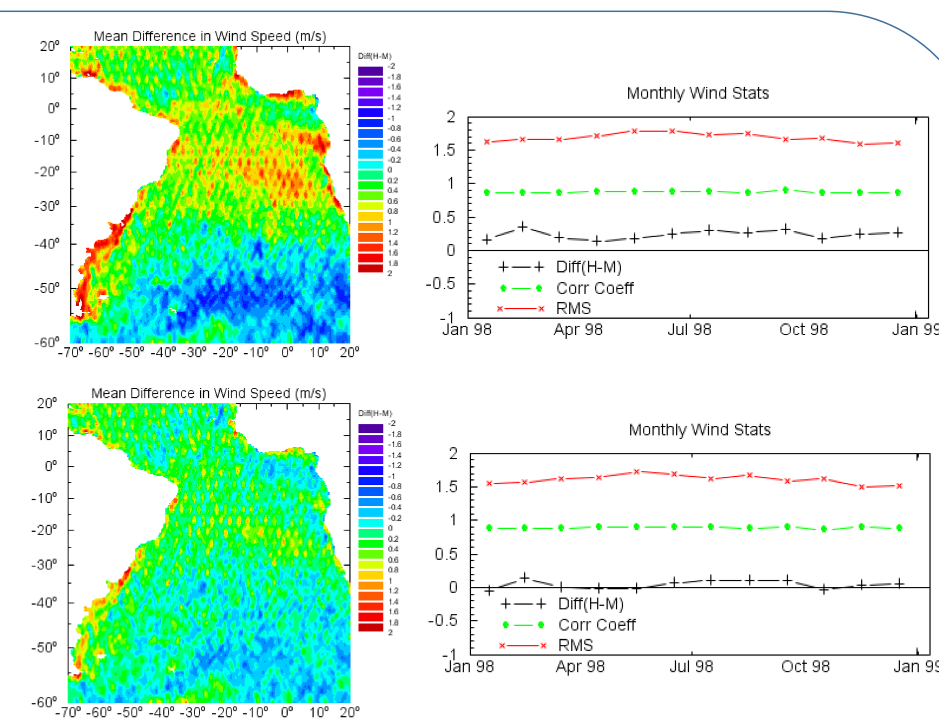

Figure 5. Mean wind speed difference for raw CFSR (top) and corrected CFSR (bottom) against GLOBWAVE wind measurements in 1998 shown by basin (left) and on monthly basis (right)

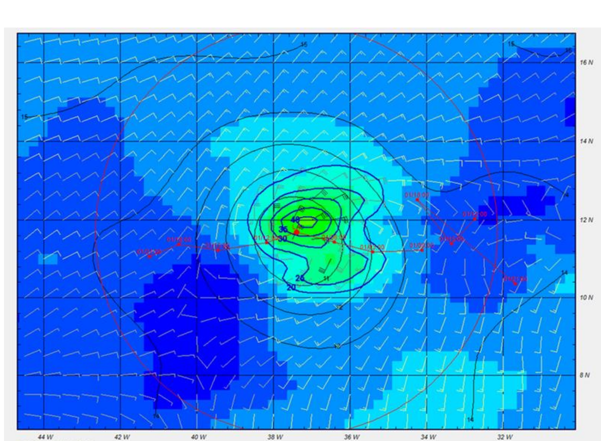

Figure 6. Example of "sub-tropical" storm found in CFSR hindcast output.

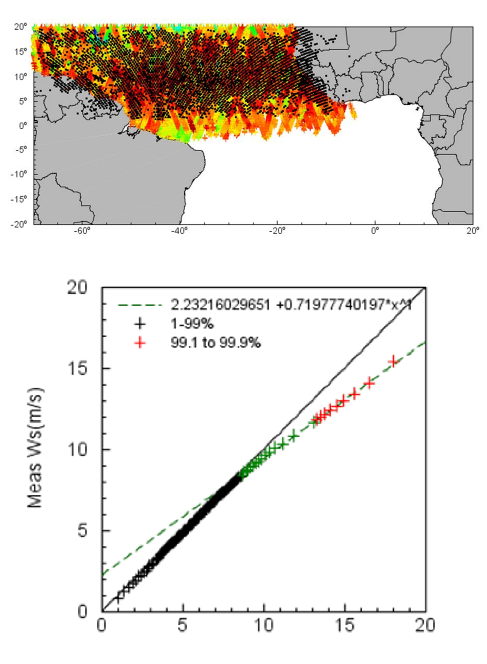

Figure 7. Tracks of sub-tropical storms (top) with Q-Q comparison using GLOBWAVE winds for data within 500km of the storm (bottom).

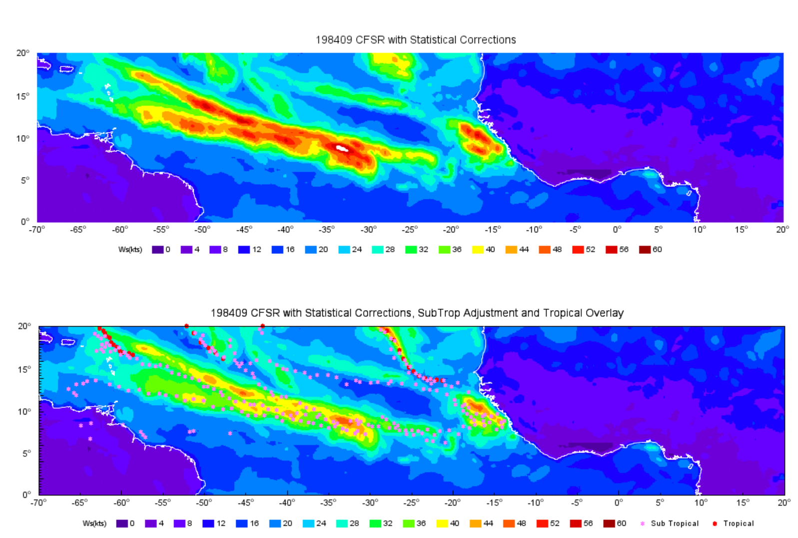

Figure 8. Comparison of CFSR winds during Sept-1984 prior to (top) and after (bottom) sub-tropical correction and inclusion of tropical winds from a high resolution tropical boundary layer model (see Cardone 2009 for description).

Episodic periods of model bias in storms are difficult to correct using the procedure detailed in the section above since conditions exist over a much shorter time frame and translate in space.

During initial analysis of CFSR in the WANE3 basin it was noted that low pressure systems in the North Atlantic tropical belt depicted unusually strong winds (example in Figure 6) that were not supported by observational data. These "sub-tropical" storms sometimes developed into tropical systems and were subject to overlay within the CFSR tropical methodology, but periods prior to tropical storm status or events which did not develop posed a significant source of bias.

Storm systems within the WANE3 domain were determined using STORMTRACKER software (pressure center tracking) and matched with existing tropical database from HURDAT to remove comparisons when tropical cyclones occurred. A comparison of CFSR winds and GLOBWAVE winds within 500 km of each storm center (Figure 7) confirmed the model bias over ~ 9 m/s and corrections for individual storms identified were applied. Figure 8 depicts the changes applied in September 1984 for both sub-tropical adjustment as well as overlay of high resolution tropical model output.

Kinematic analysis, the direct manual reanalysis of wind fields by a skilled marine-meteorologist, is perhaps the most powerful tool in reducing model bias in storm events. It has long been established (Cardone, et al. 1995) that a careful reanalysis of storm winds yields a direct improvement in the ocean response predicted by a wave model. Graphical tools such as the Wind WorkStation (Cox, et al. 1995) make it possible to evaluate and improve the top storm systems within a continuous hindcast.

Storms within the WANE3 hindcast were selected using storms found during the VESS study (Cardone, et al. 2014) and stratified by top events which are likely to send swells to the West Africa coastline (Figure 9). Additional storm periods were selected by analysis of in-situ data (winds and waves) along the coastline as well as evaluation of top events from a global hindcast at select locations.

In all, 194 storm events (both local and swell storms) from the period 1979-2014 were analyzed and storm wind fields like the one shown in Figure 10 were overlaid into the continuous hindcast.

An example of the predicted wave improvement in the generation zone is shown in Figure 11 which depicts an altimeter pass in a South Atlantic storm prior to analysis (GROW2012) and in WANE3 after wind analysis. Waves arriving at the coastline (Figure 12) also show an improvement in the wave hindcast results.

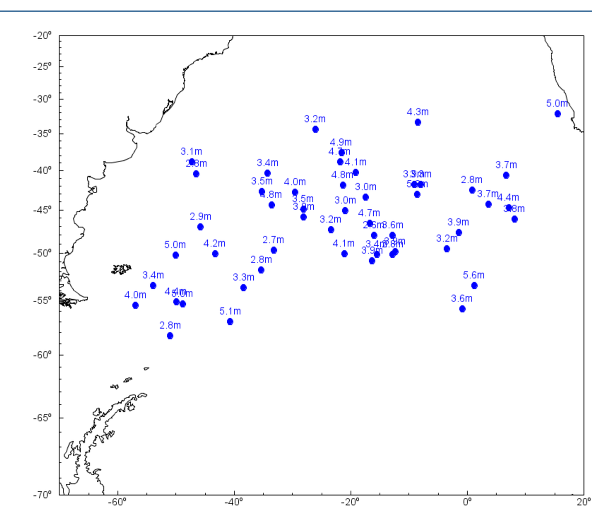

Figure 9. Locations of VESS events for kinematic reanalysis

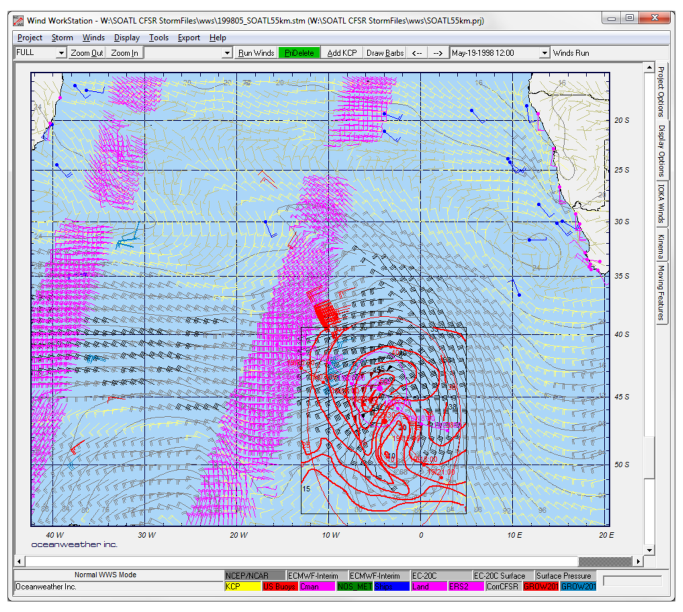

Figure 10. Example kinematic analysis during a South Atlantic storm.

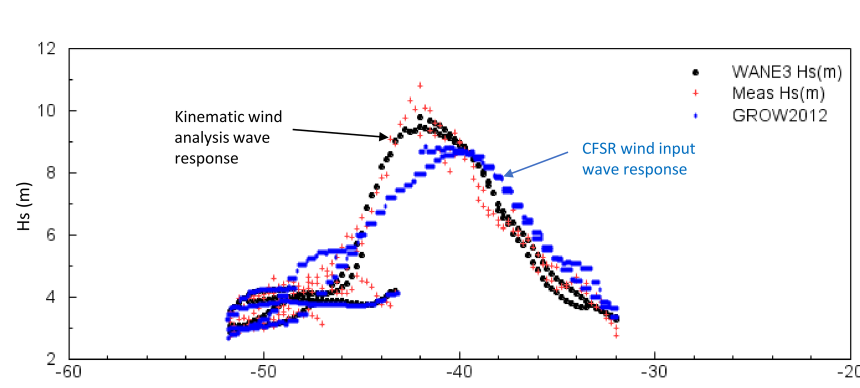

Figure 11. Altimeter comparison of unmodified CFSR (GROW2012, blue) and WANE3 storm analysis (red) during a South Atlantic storm.

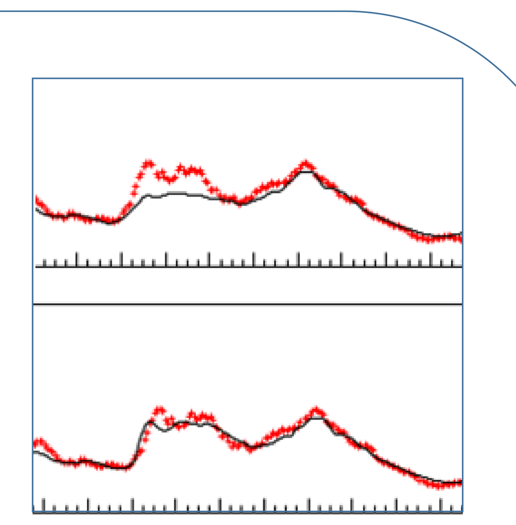

Figure 12. Modelled wave height (black) for unmodified (top) and kinematic storm analysis (bottom) for unspecified industry measurement location in West Africa.

References

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