Evaluation of ERA5 Reanalysis Wind Forcing for use in Ocean Response Modeling

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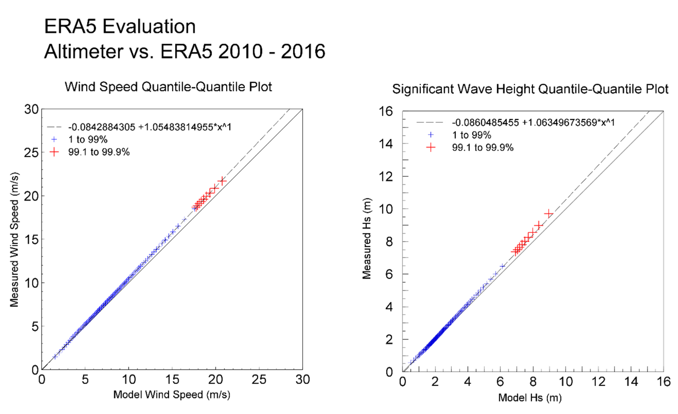
The latest reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), known as the ERA5 provides a detailed dataset of atmosphere, land, and oceanic climate variables on a 30 km global grid (ERA5, 2018). At present, the period of 2010-2016 is available but the reanalysis will extend back to 1950 when complete. Presented here is a preliminary evaluation of the 10 meter winds and significant wave height with focus on the wind forcing in the strongest tropical and extra-tropical events. Wind forcing has been shown to be a dominant source of error when applied in ocean response models for describing the peak events that drive design and operability in offshore and coastal applications. This study is not intended as an all-inclusive validation, but rather to inform potential users as to applicability of the data for use in ocean response modeling. Practical techniques for improving the ERA5 winds, with specific attention to forcing in extreme storms, is also discussed.

The overall statistics comparing ERA5 to altimeter measurements (Ifremer dataset version 11.4) during the period 2010 – 2016 are quite remarkable. One reason the overall statistics are that good is that these measurements are assimilated into the ERA5 hindcast. The quantile-quantile (QQ) plot shown in Figure 1 shows the comparisons with the blue crosses representing the 1-99% and the red crosses the 99.1–99.9%. The statistics for wind speed (WS) show the mean bias, hindcast-measured (H-M), is -0.36 m/s, a scatter index (SI) of 0.16 and a correlation coefficient (CC) of 0.94. The exceptional overall statistics holds true for the significant wave height (HS) comparisons as well. The mean bias for waves is -0.08 m with a SI of 0.11 and a CC of 0.98. Figures 2 and 3 show WS and HS mean biases globally for points with more than 100 comparisons. These two plots confirm the overall statistics in Figure 1 with the exception of the "roaring 60's" and along many coastlines. However, when digging deeper into the mean difference statistics by bins, the higher the WS or HS, the range of errors increases as shown in Figure 4 and Figure 5. These errors are typically associated with extra-tropical systems with Very Extreme Sea States (VESS storms) and tropical cyclones. Examples of both of these cases when a global model is insufficient are shown below.



	Number of Pts	Mean Meas	Mean Hind	Diff (H-M)	RMS Error	Stnd Dev	Scat Index	Ratio	Corr Coeff
Wind Spd. (m/s)	326508877	8.41	8.06	-0.36	1.37	1.32	0.16	0.40	0.94
Sig Wave Ht (m)	326250064	2.70	2.62	-0.08	0.30	0.29	0.11	0.40	0.98

Figure 1. QQ plot of WS and HS comparing the ERA5 and altimeter data

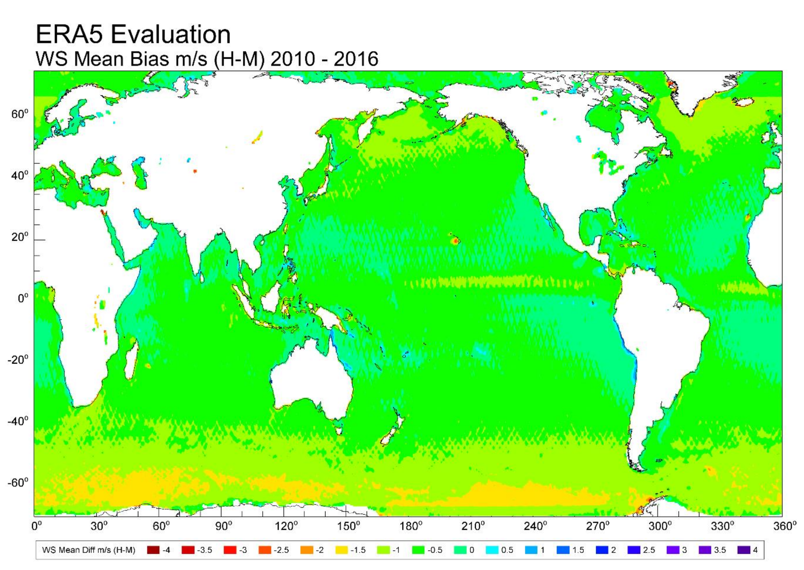


Figure 2. Global WS mean bias, ERA5 vs. altimeter

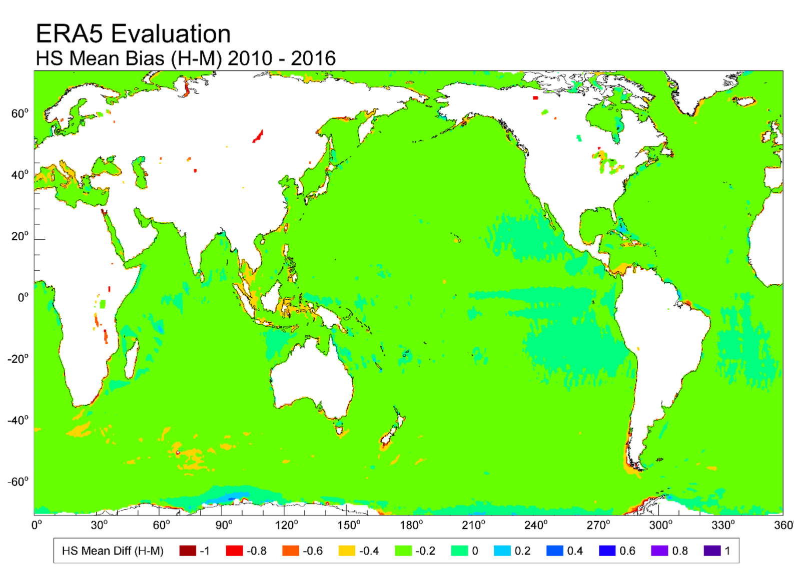


Figure 3. Global HS mean bias, ERA5 vs. altimeter

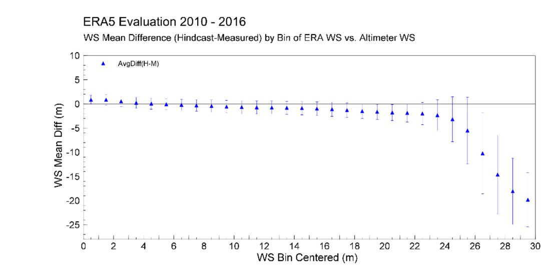


Figure 4. WS mean difference by bin, ERA vs. Altimeter

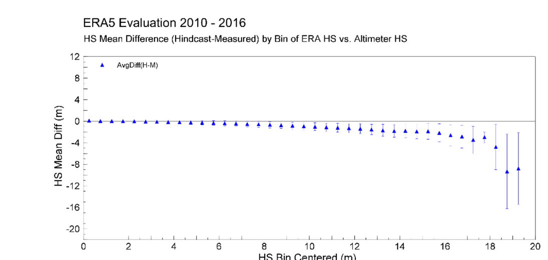


Figure 5. HS mean difference by bin, ERA vs. Altimeter

Tropical cyclones are not typically well represented in global hindcast models in regards to winds and pressures (Hodges et al., 2017). Figure 6 compares the International Best Track Archive for Climate Stewardship (IBTrACS) and ERA5 for sea level pressure (SLP) (mb) and maximum WS (m/s). As shown in Figure 6, there are very large differences with both parameters for stronger tropical systems.

A specific example of a tropical cyclone (Hurricane Matthew, October 2016) within the ERA5 database and output from Oceanweather's (OWI) Tropical Planetary Boundary Layer (TropPBL) model are given in several figures. In Figure 7 we compare the ERA5 track, SLP and WS against the IBTrACS database. It shows while the track has many consistencies, the SLP and WS are very different as tropical cyclones gain intensity. OWI has completed an analysis of Matthew using the Tropical Analyst's WorkStation (TAWS). The TAWS is applied to reanalyze the temporal evolution of a tropical cyclone over the period of the storm's history. TAWS allows for the description of the radial pressure distribution in the boundary layer using a single or a double exponential analytical formulation and allows the analyst to iterate the TropPBL, (Cardone et al. 1992; Cardone et al. 1994; Thompson and Cardone, 1996; Cox and Cardone, 2007; MORPHOS, 2009; Cox 2015) model against available wind and pressure measurements. Figure 8 shows an example of a snapshot of several of the input parameters used in the TropPBL model and the comparisons of the model output against available data. Figure 9 compares the SLP and WS of ERA5 and OWI model output while Matthew is near peak intensity. The differences in SLP and WS are quite striking: ERA5 minimum SLP is 991 mb while OWI has a minimum SLP of 940 mb, ERA5 maximum WS is about 23 m/s (average wind, neutral stability at 10 m) while the OWI analysis outputs 51.1 m/s (average wind, neutral stability at 10 m) which is consistent with the Tropical Prediction Center estimate of intensity.

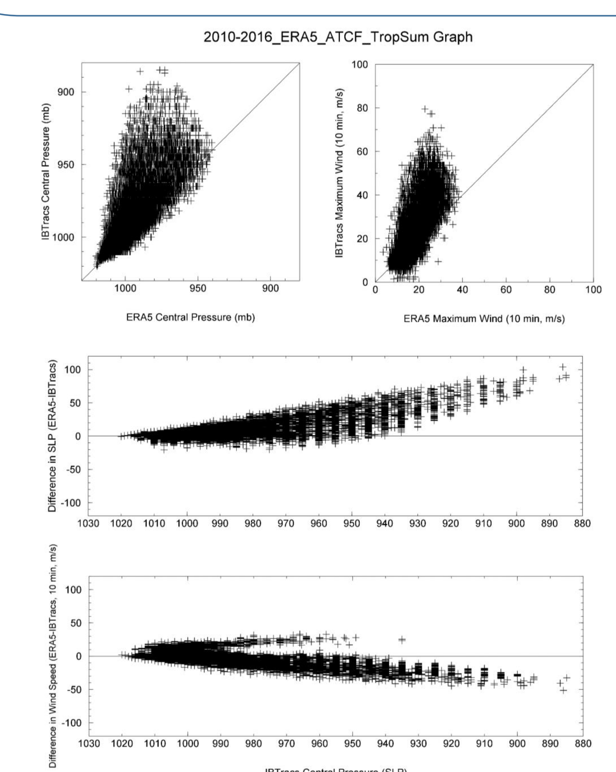


Figure 6. Overall comparison of ERA5 and ATCF winds and pressures for the period 2010 - 2016.

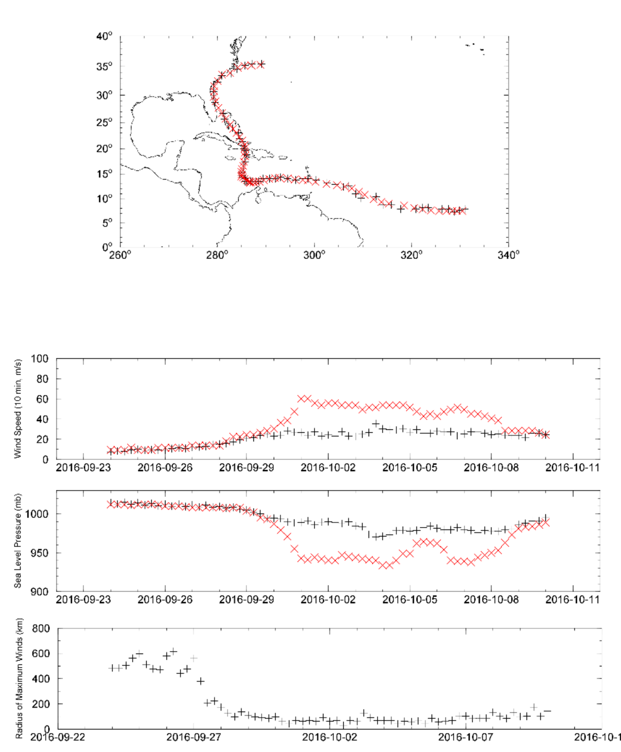


Figure 7. Comparison of ERA5 (black) and ATCF (red) tracks, winds and pressures for Hurricane Matthew, October 2016.

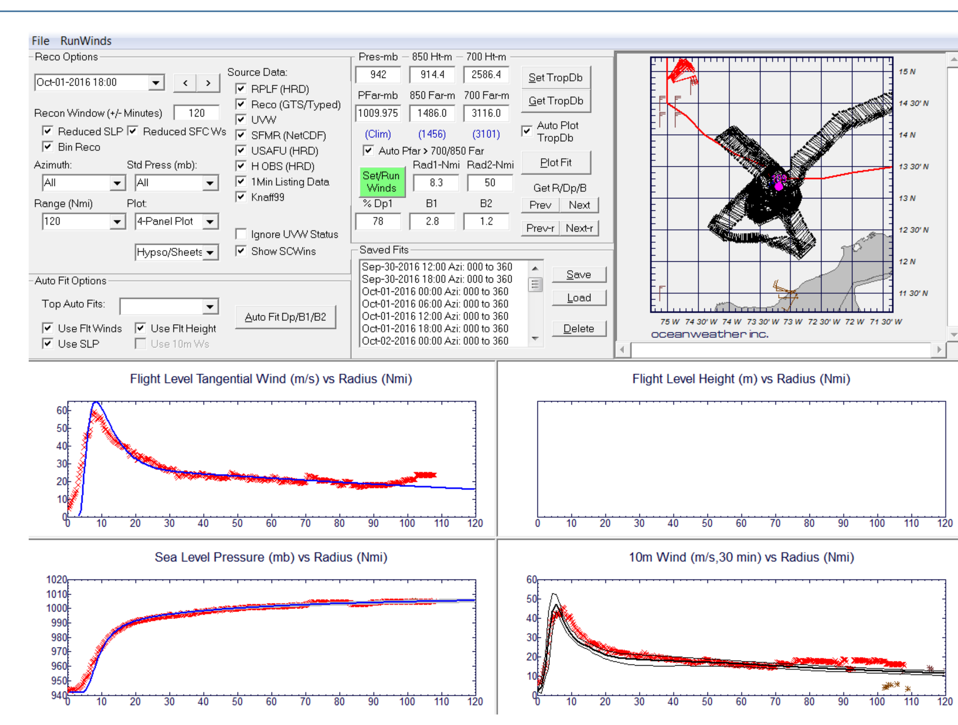


Figure 8. Analysis of Hurricane Matthew in OWI's TAWS at 2016100118 UTC.

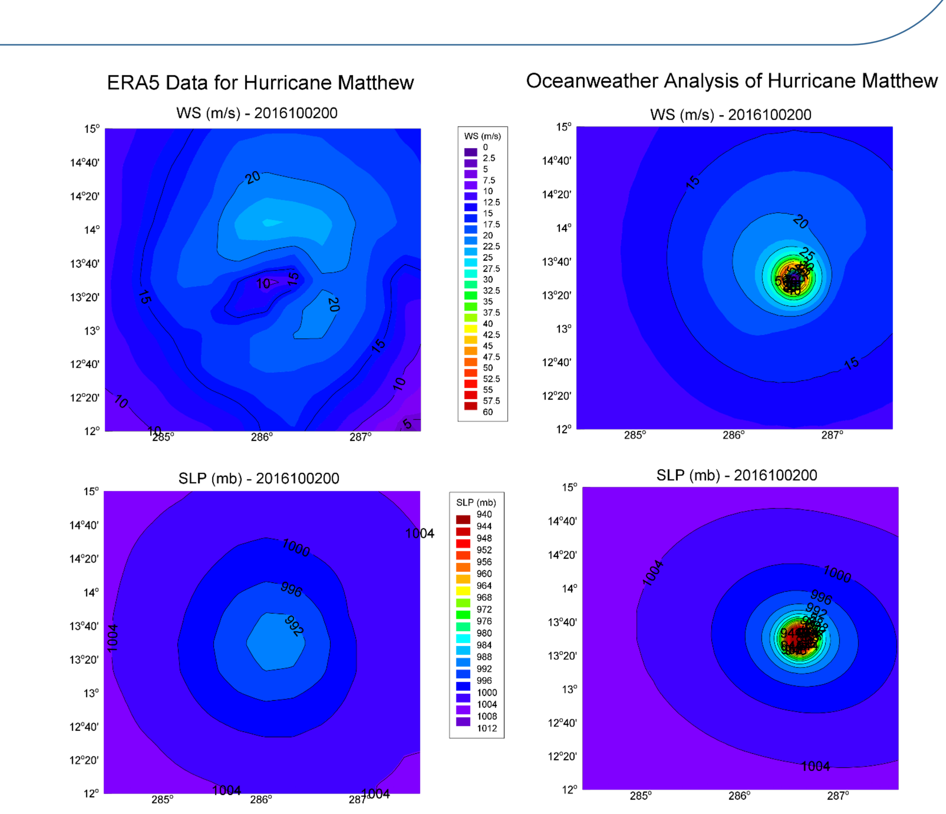


Figure 9. Comparison of ERA5 extracted data and OWI analysis for WS (m/s) and SLP (mb) of Hurricane Matthew at 2016100200 UTC.

VESS occur in storms when the HS exceeds 12 m in at least one altimeter estimate as defined by Cardone et al. 2014. A VESS altimeter segment contains all altimeter observations within an hour of the peak. There has been a tendency for reduced skill and negative bias in the specification of VESS in third-generation spectral ocean wave models (Cardone et al., 2014). When comparing extra-tropical storms within the VESS study using ERA5 model data and altimeter measurements in the period 2010-2016, once again the overall statistics look very good as shown in Figure 10, however the negative bias is HS is increasing for waves greater than 6 m in VESS segments. Figures 11 and 12 show an increasing bias in both WS and HS as the WS and HS increase in value. In a similar pattern to the overall statistics with the altimeter data, the higher the WS and HS, the greater the chance the errors in the model data are going to be more significant. Errors in the ERA5 model data are more pronounced when comparing individual altimeter passes in VESS storms.

Figure 13 compares a VESS South Atlantic storm using the ERA5 model data and the associated altimeter pass at 0800 UTC 2 August 2015. It shows an underestimation of both the winds and the waves. Figure 14 shows OWI reanalyzed winds from the West Africa Normals and Extremes (WANE3) hindcast at 0900 UTC 2 August 2015, 1 hour later than the altimeter pass comparison. In this example wind field from WANE3, an experienced meteorologist used all available data to determine the wind field as the storm progressed. An important aspect of the analysis is generating a moving center file for the center of the lowest pressure as well as a moving center file for the center of maximum winds as it moves with the area of low pressure. The final analyzed wind field (Figure 15) and resultant waves shows that an experienced meteorologist digesting and analyzing available data as well as using a continuity analysis of the winds generates a better result with the wave field than in the ERA5 output which results in a more correct representation of ocean swells impacting the study coastline in West Africa.

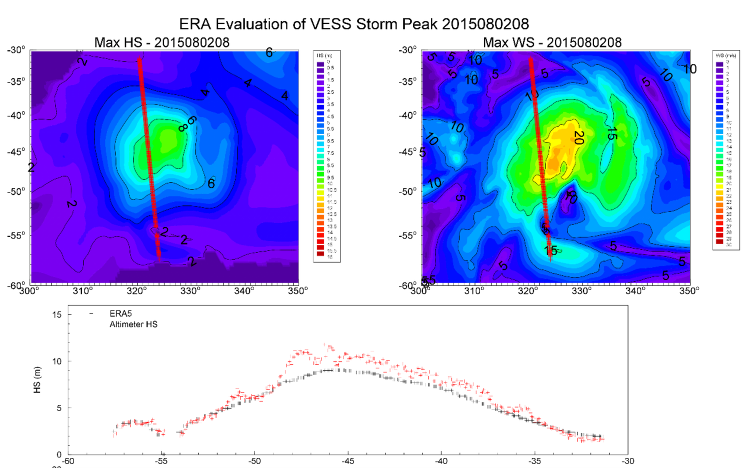


Figure 13. Comparison of ERA5 and altimeter in a South Atlantic VESS storm at 2015080208 UTC.

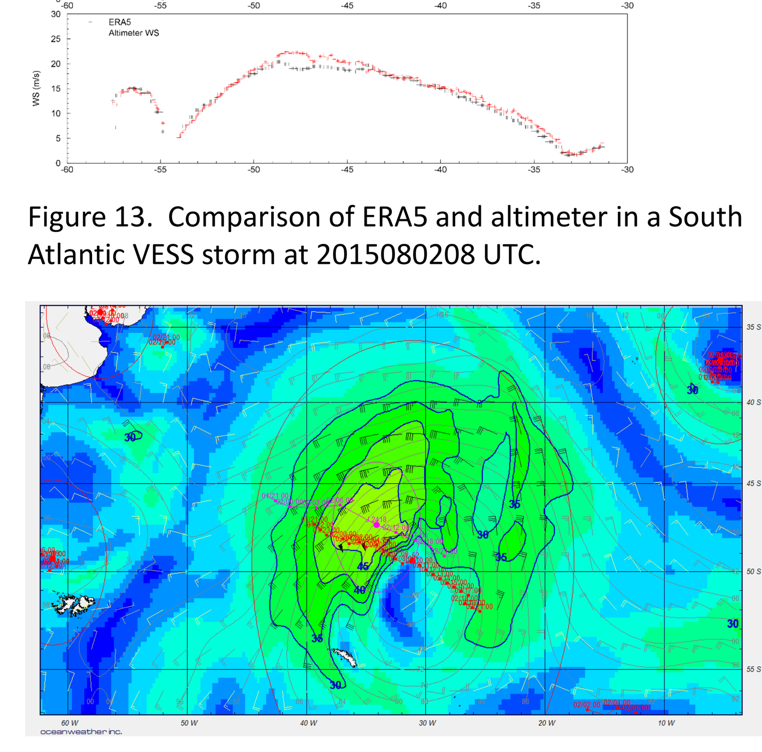
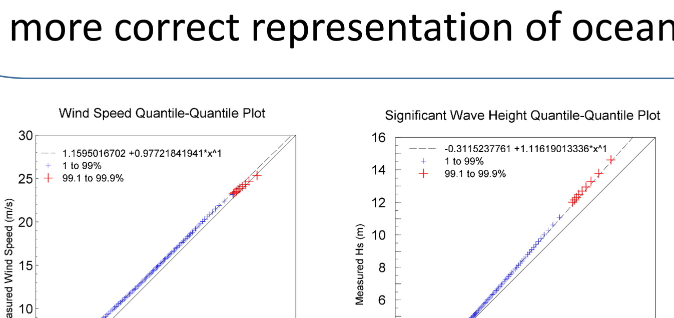


Figure 14. Final wind analysis from OWI's WANE3 hindcast.



	Number of Pts	Mean Meas	Mean Hind	Diff (H-M)	RMS Error	Stnd Dev	Scat Index	Ratio	Corr Coeff
Wind Spd. (m/s)	3191733	13.67	12.81	-0.86	1.86	1.65	0.12	0.27	0.94
Sig Wave Ht (m)	3189774	5.58	5.27	-0.31	0.66	0.59	0.11	0.29	0.97

Figure 10. QQ plot of WS and HS comparing ERA5 and altimeter data during VESS storms.

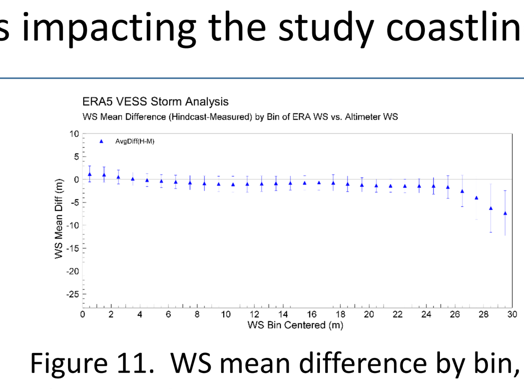


Figure 11. WS mean difference by bin, ERA vs. Altimeter during VESS storms.

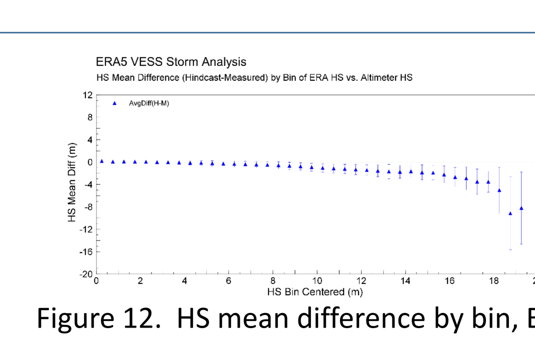


Figure 12. HS mean difference by bin, ERA vs. Altimeter during VESS storms.

In conclusion, the ERA5 hindcast compares well overall against altimeter measurements. Additional validation against public and private buoy data sets (not shown) have shown similar skill. When examining individual events, deficiencies are found, in particular with extreme tropical and extra-tropical cyclones. Application of detailed analyses of tropical and extra-tropical systems can overcome the deficiencies in the ERA5 hindcast, improving its performance for both design and operability.

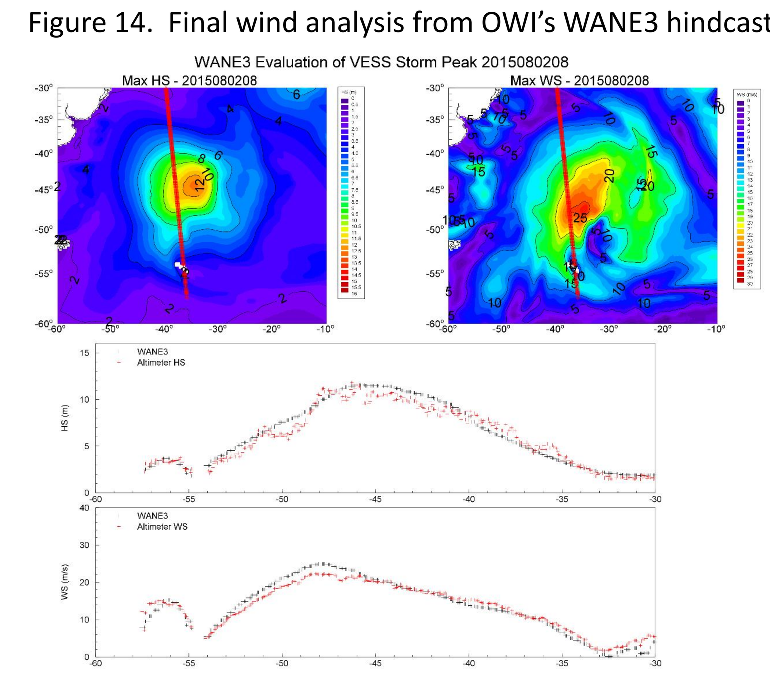


Figure 15. Comparison of WANE3 and altimeter in a South Atlantic VESS storm at 2015080208 UTC.

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