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Technical Note

An initial look at the CFSR Reanalysis winds for wave modeling[†].

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Abstract

The NCEP Climate Forecast System Reanalysis Reforecast (CFSRR) provides a 30-year homogeneous data set of hourly 1/2 degree spatial resolution winds. The increase in resolution compared to previous reanalyses, especially the temporal resolution, is expected to improve the hindcast results of models driven by these wind fields; and the 30 years of data allows for multi-decadal studies, as well as for detailed wave model validation studies.

The ultimate goal is to use this new data set to generate a wave climatology, but first it is important to test the data. Winds are notoriously difficult to validate, and there is limited ground-truth data to match spatial location and time. For this reason, several approaches have been used in this study: the first compares the hourly wind speed and direction from the CFSRR data with that archived from NDBC buoys over the period of one year (2005). The second assessed monthly wind percentiles for both hemispheres. The third, compares the wave heights at these buoys with the wave heights output by the WAVEWATCH III® model during three months of this same year (February through April). The model is run twice, comparing the results using the archived NWW3 operational winds versus using the CFSRR winds.

Preliminary results show that there is close agreement between the archived operational winds and the CFSRR winds, suggesting that the new reanalysis has a quality similar to that of present operational forecast models. The assessment of the monthly wave quantiles suggests that there are three periods in the 30 year record with slightly different extreme wind behavior in the southern hemisphere.

Acknowledgments. The authors thank Suranjana Saha for making the CFSRR dataset available for this study. The present study was made possibly by funding from various NOAA sources.

This report is available as a pdf file from

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Contents

1 Introduction

Wind speed and direction from the NCEP Climate Forecast System Reanalysis Reforecast (CFSRR, Saha et al., 2010) are compared with archived buoy data for the year of 2005, focusing on the Alaskan region. There are buoys with wind data – the sample distribution is from 68 to 79 per month. Therefore this study is considered as a "glimpse" of how the wind product performs instead of an in-depth analysis. Also included is an analysis of the behavior of monthly hemispherical wind quantiles, as discontinuous behavior of such data has been linked to systematic changes in wave model biases.

An indirect test of the wind fields was performed using sample computations with the nested-grid full-spectral wind-wave model WAVEWATCH III®. This model was run with both the operational ('NWW3') winds, and with the new CFSRR high resolution winds. The test runs cover February through April of 2005 with significant wave height for each buoy location requested every hour, and compared to archived buoy data.

The WAVEWATCH III model is described in the user manual and system documentation (Tolman, 2009). The manual describes the governing equations, numerical approaches, installation, compilation, and running of the model. The nested-grid driver is described in Tolman (2007, 2008), and the grid generation tools used are described in Chawla and Tolman (2007, 2008).

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2 Model Structure

A set of three nested grids was produced for the global ocean and the Alaskan region. The full resolution ETOPO2 bathymetry was used as the reference grid, with the Strait of Juan de Fuca, Puget Sound, Columbia River Estuary, and San Francisco Harbor excluded. The lowest resolution grid (global, 30 min resolution) covers the worlds oceans. Nested inside are the intermediate (AK_int, 10 min resolution) and highest resolution (AK_cos, 4 min resolution) grids, which cover only the Alaskan region. Intermediate and high resolution grids are available for many areas of the globe, but for expediency only these three grids were used in this case.

The wind wave model uses ice and winds (including the air-sea temperature difference) as input. The reanalysis daily ice concentration fields have a 1/2 degree spatial resolution, and are derived from passive microwave from the SMMR and SSMI using the NASA Team algorithm (cf. Grumbine, 1996). The ice fields are updated daily. The wind fields used in the wave model will be described in the following section.

The wave model was started from calm conditions, and run for the months of February through April 2005. Significant wave heights were generated every hour at the buoy locations. Since it takes approximately two weeks for the wave model in the Pacific Ocean to spin up from calm conditions, results will concentrate on the months of March and April.

The model requires spectral information that determine the frequencies that will be considered: a frequency increment factor, first frequency (Hz), number of frequencies (wavenumbers), the number of directions, and the relative offset of the directional increment. In this case, the following were used (from the wave model input file):

1.1 0.035 29 24 0.5

Here the model is intended to study wind waves with a period of no more than 29 seconds, so the first frequency is 0.035 Hz. Note that the present operational models run with higher spectral resolutions, and that the 30 year hindcast studies will be run with the spectral resolution of the present operational global wave models.

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3 Input Wind Fields

3.1 NWW3 Winds

The NWW3 winds are the operational winds that have been archived from WAVEWATCH III® from 1997 to present. These winds are 1 degree resolution in latitude and 1.25 degree resolution in longitude, and available every 3 hours. They cover the globe from 78S—78N. Note that these winds represent an evolution of atmospheric models, both in physics, assimilation, and resolution, and are therefore not considered as a statistically homogeneous climatological dataset. Because of this, these winds should not be used to generate a climatology. An example wind field for the Pacific Ocean is shown in Fig. 3.1.

3.2 CFSRR Winds

The new NCEP Climate Forecast System Reanalysis Reforecast (CFSRR) entails a coupled reanalysis of the atmospheric, oceanic, sea-ice and land data from late 1979 through 2010, and a reforecast run with this reanalysis (Saha et al. (2010). Here, only the reanalysis results will be used. This Reanalysis has much higher horizontal and vertical resolution of the atmosphere than the Global and the North American Reanalyses. The high resolution winds used here are 10m hourly with 1/2 degree in spatial resolution, and cover the globe from 90S—90N. An example wind field for the Pacific Ocean is shown in Fig. 3.2. At first inspection, the NWW3 and CFSRR winds appear compatible, with more sharp details in the wind field with the higher resolution (CFSRR) as expected.

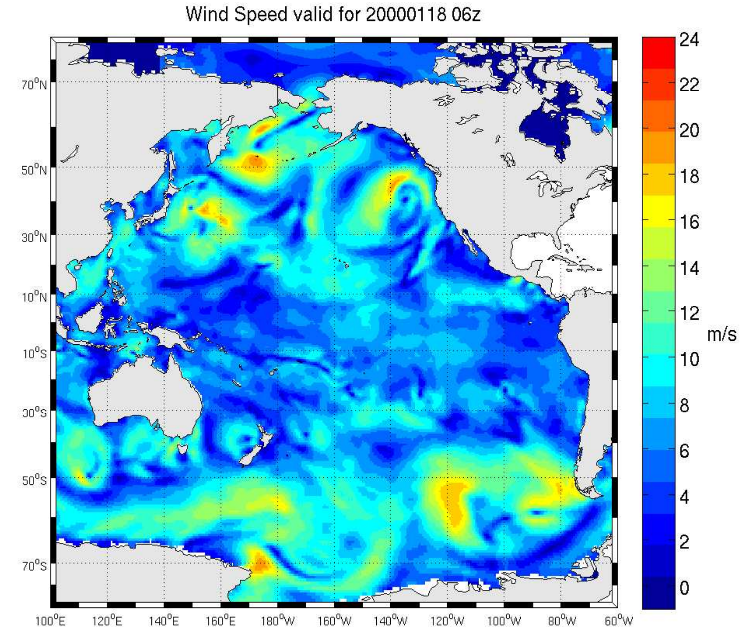


Fig. 3.1 : NWW3 winds valid 2000/01/18 06z.

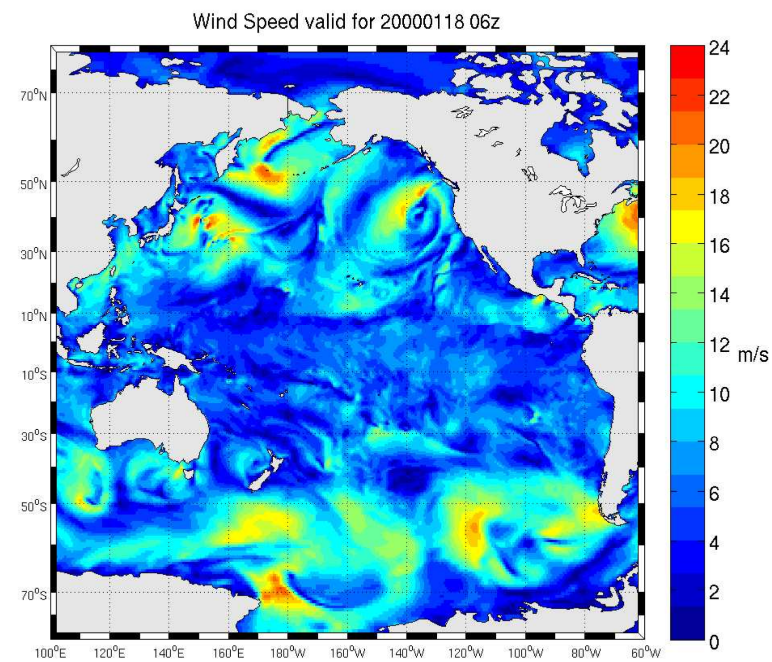


Fig. 3.2 : CFSRR winds valid 2000/01/18 06z.

4 Data Sets and Mean Behavior

The comparison is between three different datasets of hourly wind speed and direction, and significant wave height per buoy: the archived buoy data (labeled "Archive" in the figures), the results of running the wave model using NWW3 operational winds (labeled "NWW3"), and the results using the CFSR reanalysis winds (labeled "CFSW").

4.1 Archived Buoy Data

The archived buoy data are Global Telecommunication System (GTS) buoy observation data from buoys maintained by various operational agencies and programs, and run through a basic quality control check. The wind data must be used carefully, since not all measurements may be at the same height. All buoy data in the archive represent equivalent neutral 10m wind speeds.

As a first measure, the individual monthly means of wind speed and significant wave height for all buoys are compared in Fig. 4.1. There is generally a good agreement between the three datasets. It is noticeable that the mean of the archived wind speeds tend to be the greatest, and the mean of the NWW3 operational wind speeds tend to be the lowest. As for the significant wave heights, those that result from using the CFSRR winds tend to have the highest values, whereas results from the NWW3 operational winds or the archived buoys are very similar as would be expected. With higher resolution winds, any systems are expected to represent stronger and sharper forcing.

The difference in forcing by hourly (CFSW) versus 3-hourly (NWW3) winds can be appreciated by looking at the standard deviation from the archived values (Figure 4.2). The CFSRR winds show a greater monthly mean standard deviation than the NWW3 operational winds, but with the exception of five buoys both wind directions have similar standard deviations from the archived buoys. The sharper forcing also yields significant wave heights that show greater deviation from the archived values.

4.2 Hemispherical Quantile Data

An additional quick test on the homogeneity of the wind fields for the entire 30 year period was performed by computing various monthly quantile wind speeds for the northern and southern hemisphere mid latitude wind speeds. Such an analysis has previously linked changes in model biases in the souther hemisphere to discontinuous quantile wind speed behavior (Chawla et al, poster presentation, 2010 WISE meeting, Brest, France). Results are presented in Figs. 4.3 and 4.4. For the northern hemisphere (Fig. 4.3), consistent behavior is observed for the entire 30 year period. Some variability is found in the highest percentile winds,

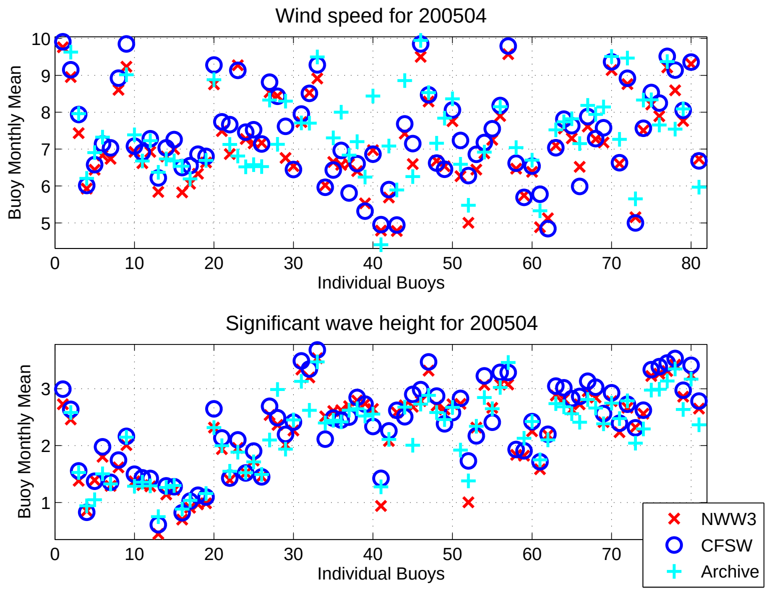


Fig. 4.1 : Monthly mean for individual buoys for April 2005.

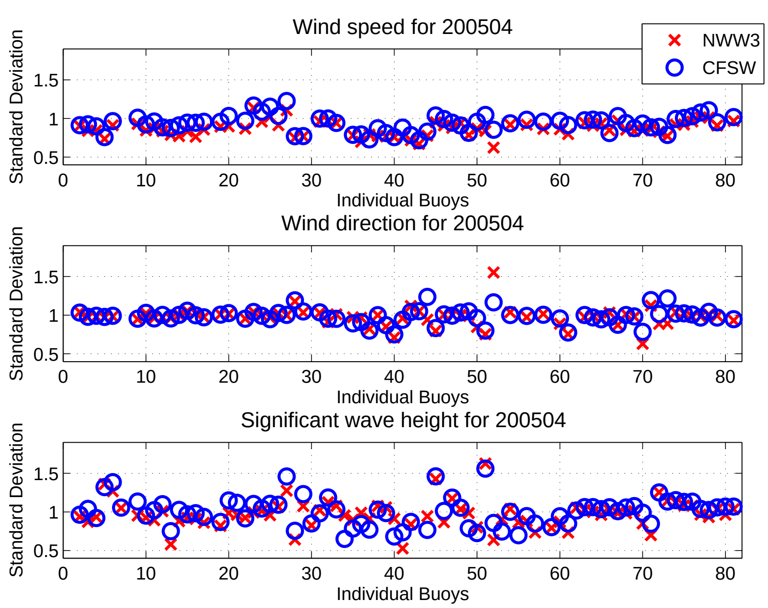


Fig. 4.2 : Monthly mean standard deviation for individual buoys for April 2005.

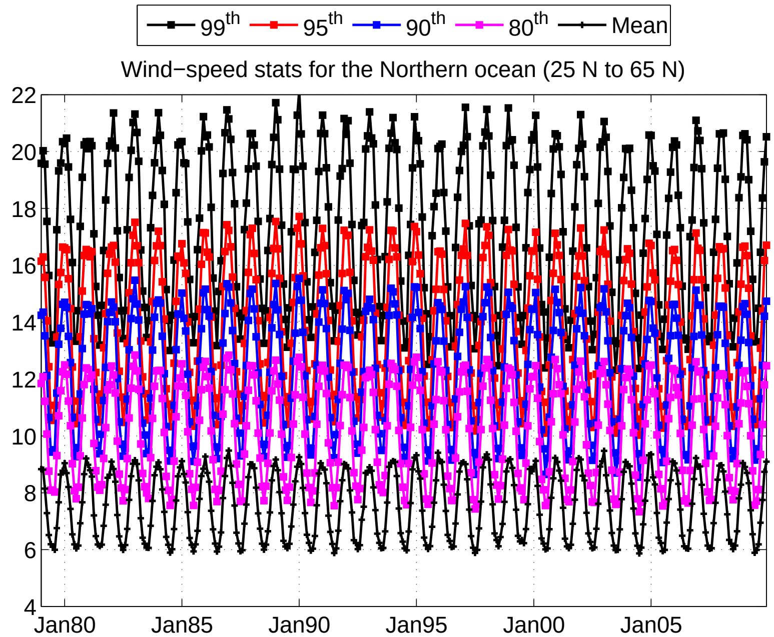


Fig. 4.3 : Monthly wind speed for given probabilities for Northern Hemisphere mid latitudes

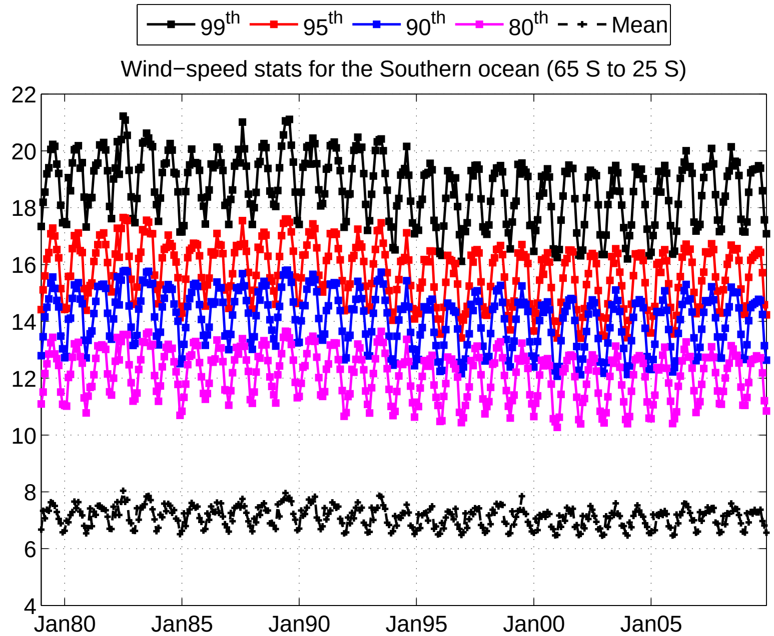


Fig. 4.4 : Monthly wind speed for given probabilities for Southern Hemisphere mid latitudes

but this variability appears to have a random nature as would be expected. For the southern hemisphere, however (Fig. 4.4), three distinct periods can be identified with discontinuously changing behavior of the higher percentile winds. The separations between periods occur around 1995 and 2007. Because the underlying models and analysis systems are kept constant throughout the entire reanalysis, the discontinuities are most likely due to the availability of individual data sources. This behavior will be investigated in more detail at NCEP. For the present study it is sufficient to observe that the three regimes of behavior in the higher percentile winds are likely to result in similar regimes in bias behavior in the wave model in the southern hemisphere.

5 Detailed Results

5.1 Basic Statistics

Buoys are also considered individually, and graphics from a few are presented below. These were chosen since they have over 600 data records per month throughout the spring of 2005, and are from different basins: NW Atlantic (Figures 5.1 and 5.2), Hawaii (Figures 5.3 and 5.4), and the NE Pacific (Figures 5.5 and 5.6). These figures show the monthly statistics relative to the individual archived buoy data for the results from the wave model driven by the CFSRR winds.

The correlation between the archived buoy and the model driven with CFSRR winds is greater than 0.8 (Figures 5.1), with the exception of significant wave heights in August (Figures 5.2). This buoy is located off of South Carolina, and summer is the time for hurricanes. During summer of 2005 various storms remained over the open Atlantic (hurricane Irene and tropical storm Lee for example), and in September of 2005 tropical storm Ophelia passed by the eastern shore of the US.

Figures 5.3 and 5.4 show similar stats for a buoy off the coast of Kauai. Although the Hawaiian Islands saw a tropical depression at the beginning of August and two hurricanes from the middle to end of September 2005, the statistics do not reflect this. Both this buoy and the NW Atlantic buoy are deep water buoys.

5.2 Quantile-Quantile Plots

Another way to compare the wind speeds at a buoy is through a Quantile-Quantile plot (also called Q-Q plot), which compares the shapes of two probability distributions by plotting their quantiles against each other. If the distributions are similar, then the points in the Q-Q plot will lie approximately on a line $y = x$. If the distributions are linearly related, the points will also approximately lie on a line but not necessarily on the line $y = x$.

Here we present the Q-Q plots for the model results versus the archived data for both February and April of 2005 at buoy 46002, which is a deep water buoy off the coast of Oregon. These results are typical for all the buoys in the archive. For February 2005 (Figure 5.5), both the NWW3 and the CFSRR wind speeds are similar to the archived wind speeds, but the slope of the CFSRR quantiles is closer to the $y = x$ line and therefore are in better agreement with the archived buoy data. Note that the points lie along a straight line, which suggests that the data are normally distributed.

In April 2005 (Figure 5.6), the slopes of both distributions are similar and very close to the $y = x$ line, but the the points at the tail end (high wind speeds) have a flatter slope, especially in the NWW3 data plot. This implies that the

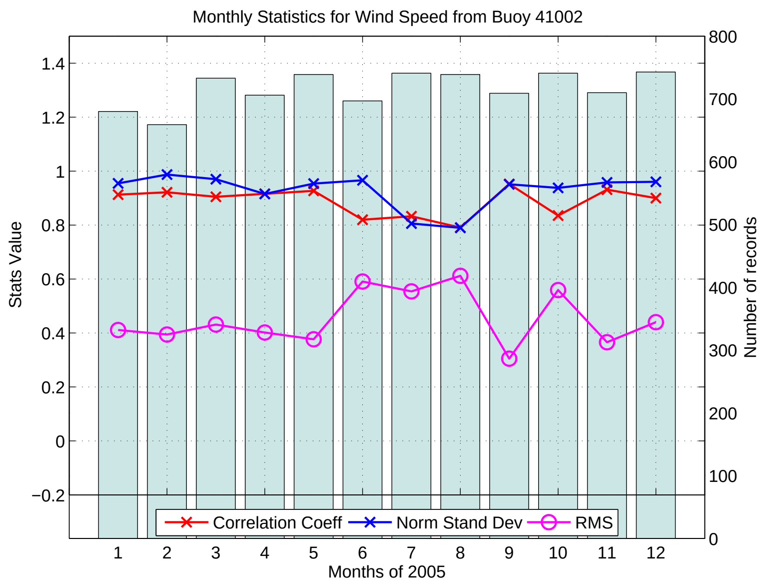


Fig. 5.1 : Monthly statistics for wind speed from buoy 41002.

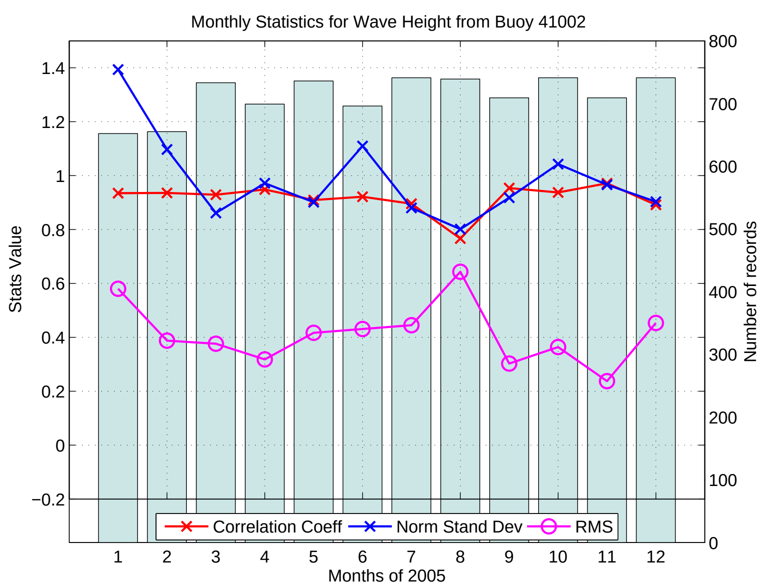


Fig. 5.2 : Monthly statistics for significant wave height from buoy 41002.

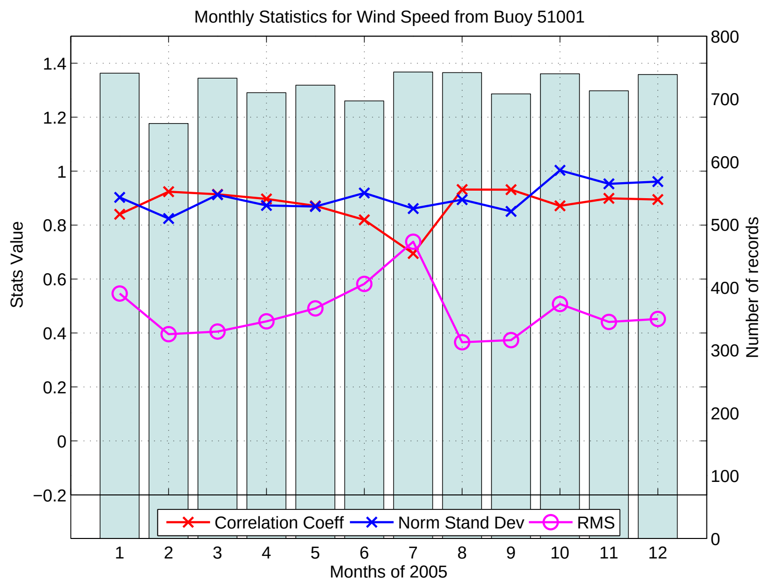


Fig. 5.3 : Monthly statistics for wind speed from buoy 51001.

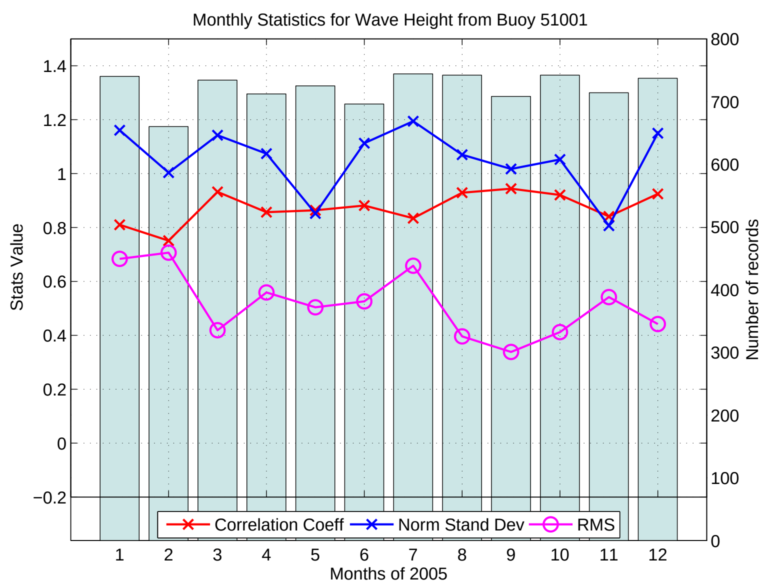


Fig. 5.4 : Monthly statistics for significant wave height from buoy 51001.

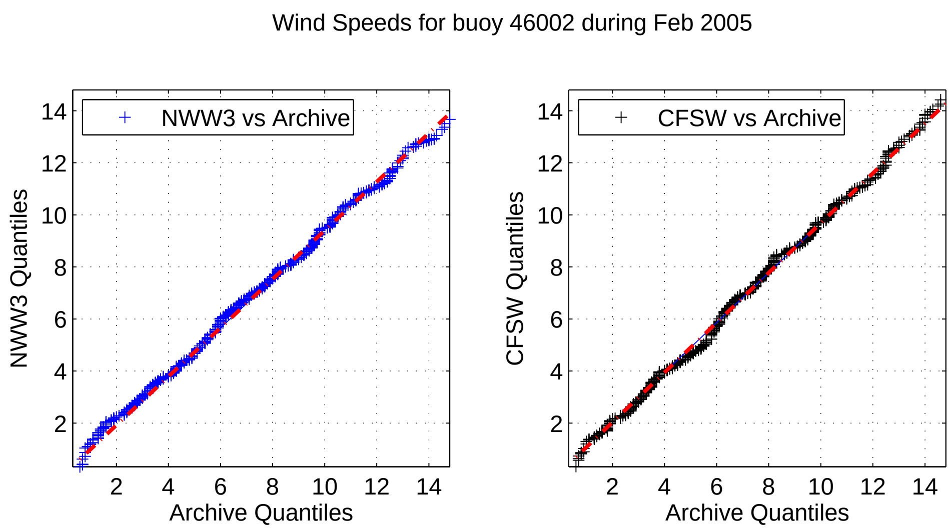


Fig. 5.5 : Q-Q plot of wind speeds from buoy 46002 for February 2005.

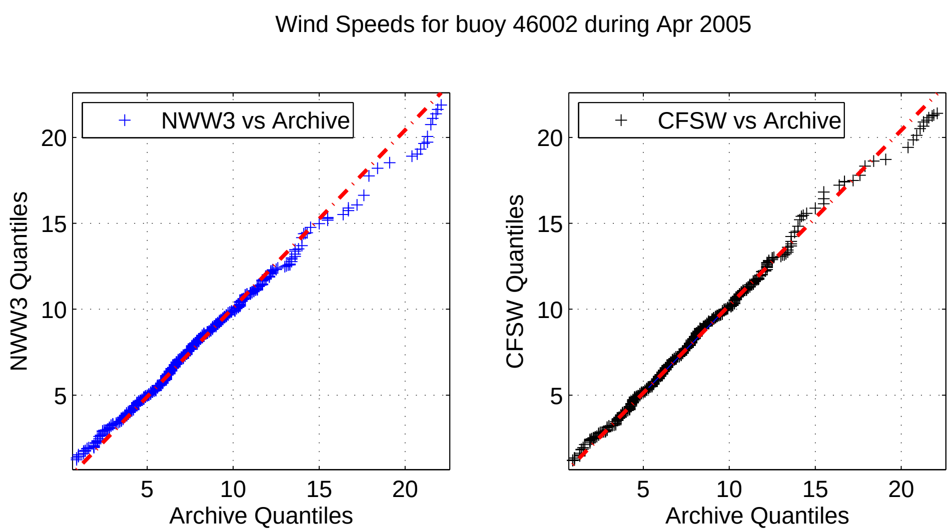


Fig. 5.6 : Q-Q plot of wind speeds from buoy 46002 for April 2005.

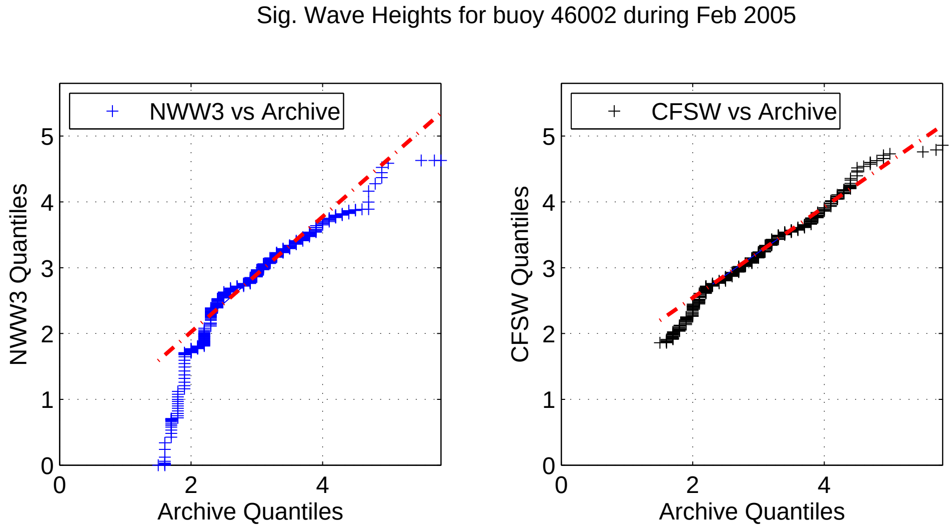


Fig. 5.7 : Q-Q plots for significant wave height from buoy 46002 for February 2005.

archived data are more dispersed than the NWW3 data, or that the observed highest wind data are higher than the modeled results. The CFSRR data is again slightly better than the NWW3 data.

In general, the CFSRR wind speeds have equal or better agreement with the archived data than the NWW3 wind speeds. Note that a better representation of the highest winds in the latter data set could be expected based on the higher spatial and temporal resolution of the latter winds. Ideally, improving the input wind speeds that drive the WAVEWATCH III model should improve the results of the model. Figure 5.7 shows the Q-Q plots of the significant wave heights at buoy 46002 during February 2005. Agreement with the archived data is better when the model is driven with the CFSRR winds.

Figure 5.8 presents wave model results for April for buoy 46002, in which both wind models underestimate the highest wind speeds. Note that the wave model shows an enhanced underestimation of the highest wave heights due to the nonlinear relation between wind speed and wave height. As above, the CFSRR wind speeds result in slightly better wave heights than the NWW3 wind speeds.

5.3 Taylor Diagrams

The statistics shown up to now have highlighted monthly means of all buoys, or time-series of sample individual buoys. Taylor (2001) devised a way to compare the basic statistical measures (correlation, standard deviation, and the centered r.m.s. difference) between results from various models and an observation in one plot called a Taylor Diagram. Here the goal is to display many observations

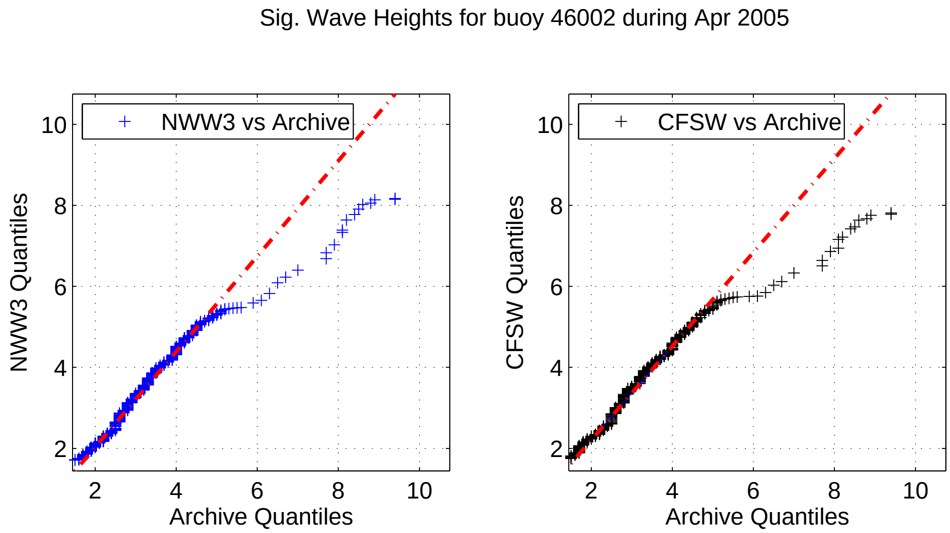
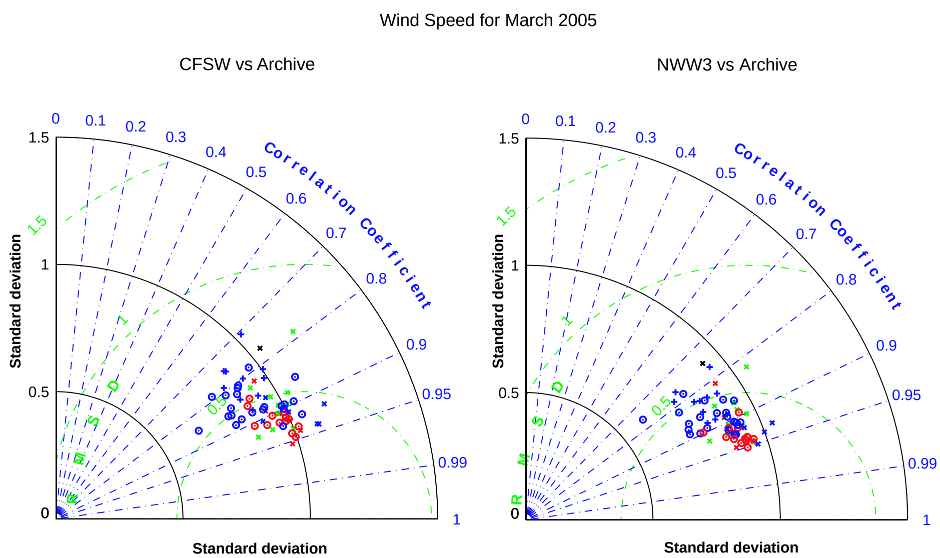


Fig. 5.8 : Q-Q plots for significant wave height from buoy 46002 for April 2005.



North Atlantic	X
North East Atlantic	X
North West Atlantic	X
South Atlantic	X
North Pacific	O
North East Pacific	O
North West Pacific	O
South Pacific	O
Gulf of Mexico and Caribbean	+

Fig. 5.9 : Taylor diagram for wind speeds for all buoys during March 2005.

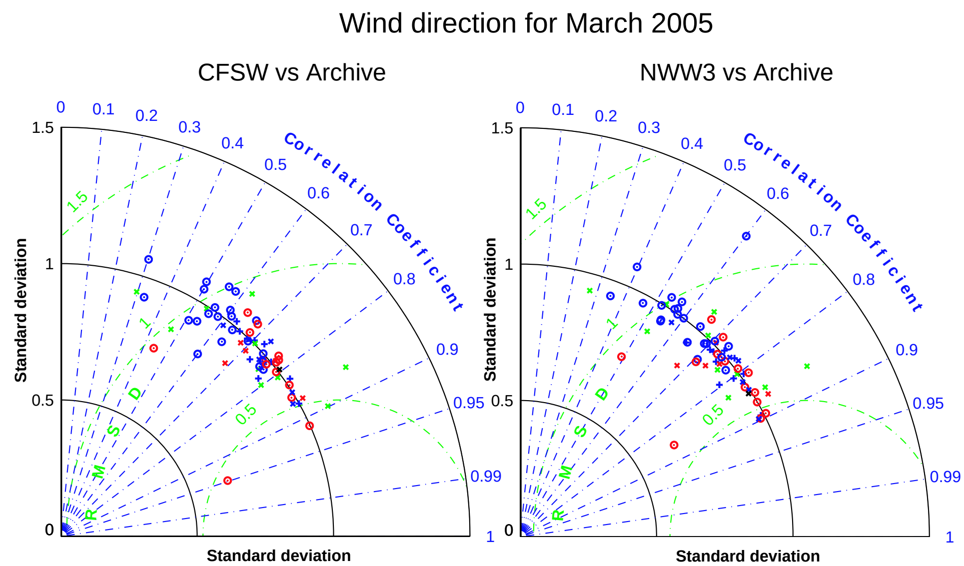


Fig. 5.10 : Taylor diagram for wind direction for all buoys during March 2005.

(archived buoys) versus point results from one model, therefore the standard deviation of both the model output and the observed values are normalized by the standard deviation of the observation. This diagram can then be used to show the accuracy of the output of WAVEWATCH III relative to observations when the model is driven by either of the two different wind sets. Buoys are color coded by their location, to see if the wind sets behave differently in different areas.

Ideally, the statistics between the model and the the observation would have a high correlation coefficient, a (normalized) standard deviation of 1, and low r.m.s errors. Therefore, a point where the archived buoy and the model output were in perfect agreement would be plotted in these Taylor diagrams on the x-axis where the standard deviation is 1 (and cc=1, and rms=0). The Taylor diagrams for the wind speeds during March 2005 are shown in Figure 5.9. The diagram on the left shows the archived buoy values versus the point output from the model forced by the CFSRR winds. The diagram on the right shows the archived buoy values versus the point output from the model forced by the NWW3 operational winds. Note that the agreement between archive and model is better when the model is driven with the CFSRR winds: the points lie along the line with standard deviation equal to one (with the exception of one obvious outlier). The tight cluster, regardless of color and symbol, indicate that there is no basin preference in the wind speed data.

The direction of the winds however, tell a slightly different story (Figure 5.10). Here there is no difference between the two data sets, both have a wide spread in correlation with the observed values. The same effect was seen for the wind

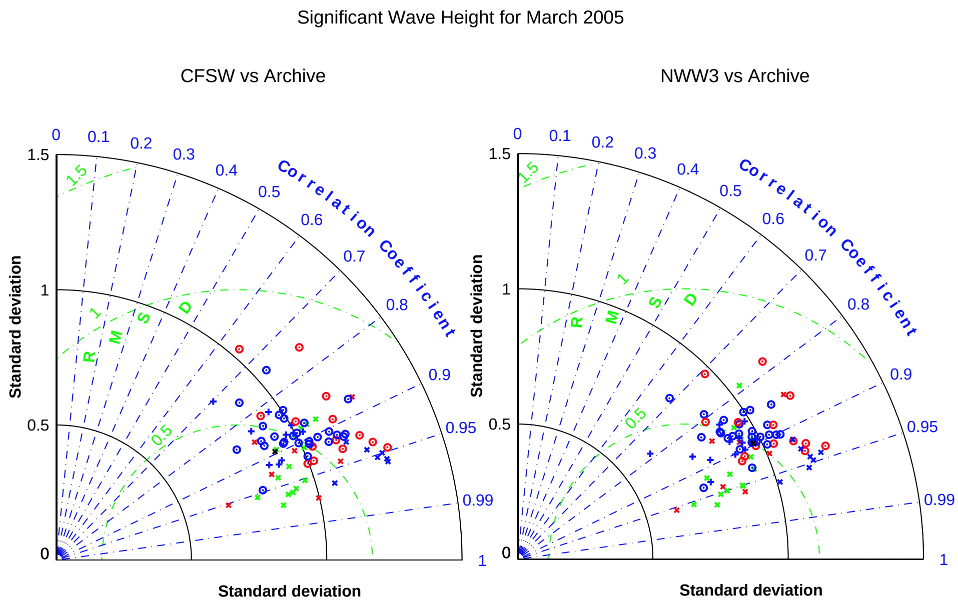


Fig. 5.11 : Taylor diagram for significant wave height for all buoys during March 2005.

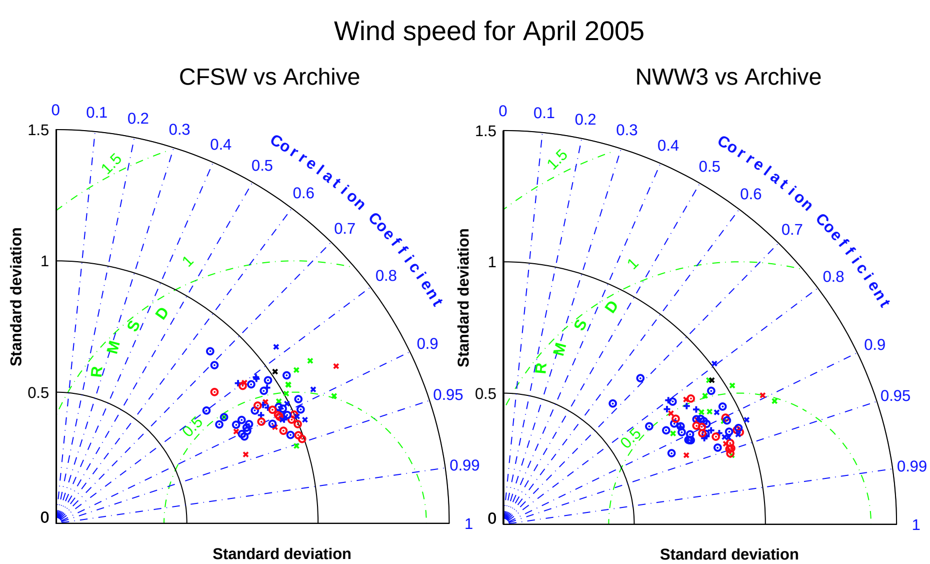


Fig. 5.12 : Taylor diagram for wind speeds for all buoys during April 2005.

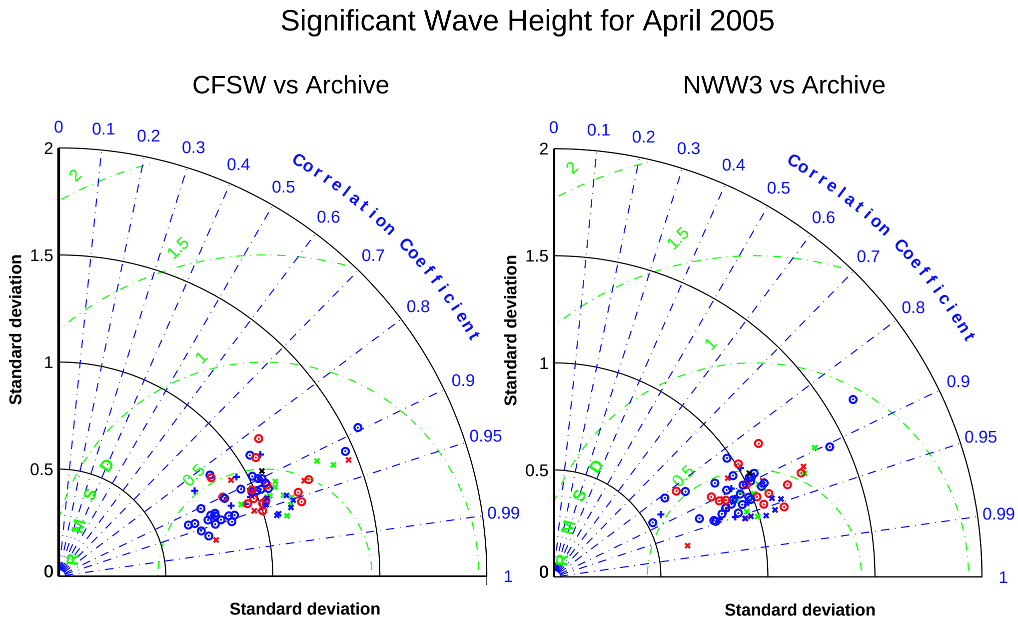


Fig. 5.13 : Taylor diagram for significant wave height for all buoys during April 2005.

direction in February and April 2005. It is much harder to get the direction of the winds to agree with the archived data.

Although the CFSRR wind speeds were in slightly better agreement with the archived values, there is almost no difference in their effect on the significant wave height compared to the model driven by the NWW3 winds (Figure 5.11).

The same pattern repeats in the Taylor diagrams for the wind speeds in April (Figure 5.12). The CFSRR winds statistics cluster along the standard deviation equal to one line, and both CFSRR and NWW3 winds have high correlation with the archived values.

The statistics for the significant wave heights are again similar in April 2005, with both wind sets yielding correlation values greater than 0.8, r.m.s. values mostly less that 0.5, and most of the points clustering along the standard deviation equal to one line (Figure 5.13).

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6 Conclusions

In order to use the WAVEWATCH III model to generate a wave climatology, the model must be forced with a consistent set of wind data, generated by a model and analysis system that is unchanged during the entire period of the climatology considered. The new NCEP Climate Forecast System Reanalysis Reforecast (CFSRR) provides a 30-year homogeneous data set of hourly 1/2 degree spatial resolution winds. This is a much higher temporal and spatial resolution than the operational winds (3 hourly, 1x1.25 degrees). however, some concerns exist on the homogeneity of the wind fields in the southern hemisphere, based on discontinuous behavior of the monthly quantile wind speeds.

The comparison between the archived values of wind speed and significant wave heights at specific buoys during the months of March and April 2005 and the operational (NWW3) and climatology (CFSW) results of the model is encouraging. Naturally the archived wind speeds tend to have the highest values, and the operational (3 hourly averages) the lowest. Tentatively, this is consistent with the lowers temporal and spatial resolution of the NWW3 wind fields.

This preliminary study indicates that using the WAVEWATCH III model driven by the CFSRR winds produces results at least as good and in some cases better than the model does in operational mode (using NWW3 operational winds). However, these are only preliminary results based on a small sample of a possible 30 year wave reanalysis. NCEP intends to complete a full 30 year wave model run and more in depth analysis of the corresponding results in the near future.

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