COMPARISON OF GULF OF MEXICO WAVE INFORMATION STUDIES (WIS) 2-G HINDCAST WITH 3-G HINDCASTING

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1.0 INTRODUCTION

The Wave Information Studies (WIS) at the Coastal and Hydraulics Laboratory (CHL), Engineer Research and Development Center (ERDC), Vicksburg, MS, recently completed twenty years (1980-1999) of wave hindcasts for the Gulf of Mexico using the second-generation wave model, WISWAVE. Hourly wave parameter results for coastal stations in 10-20 m of water from this hindcast are available on the WIS website: frf.usace.army.mil.wis. This wave information has been used by the Army Corps of Engineers and private consulting companies for a variety of coastal engineering applications and represents an invaluable resource for the coastal engineering community. WIS is commited to producing high-quality wave information; and thus, it is important to compare the results of this hindcast with hindcast results using the newer third-generation wave modeling technology. These comparisons are valuable for the coastal engineers that use this information and also help WIS evaluate new hindcasting regimes for future wave studies.

This paper shows results of three hindcasts using the same input wind fields and the same nested grid system. Results will be shown at available measurement sites for the 1995 Level 2 (0.25 deg) and Level 3 (1/12 deg spacing) Gulf of Mexico hindcast. The second-generation model results were taken from WIS information calculated using the Corps of Engineers numerical wave model, WISWAVE. Two third-generation models, WAM (Komen et al., 1994, WAMDIG, 1988) and WAVEWATCH III (Tolman, 1991 and 2002), were used to produce comparison results for the 1995 Gulf of Mexico hindcast. Statistical comparisons of significant wave height, mean wave period, and peak wave period for the hindcast results will be shown for measurement sites available in the Gulf of Mexico during 1995. NDBC 42036 and 42001 have directional information during 1995, and circular wave directional comparison statistics are shown for these locations using the circular direction techniques outlined in Tracy (2002).

2.0 HINDCAST GRID

The Gulf of Mexico hindcast application consists of three grid levels. Level 1 (1 deg latitude/longitude grid spacing) includes the Atlantic Ocean and the entrance to the Gulf of Mexico. Level 1 extends from –83.0 to 20.0 deg longitude and 0.0 to 72.0deg latitude. Energy from the Level 1 grid enters the Level 2 grid at boundary locations on the eastern edge of the Gulf of Mexico. Figure 1 shows the Gulf Level 2 and Level 3 hindcast domains. The Level 2 grid extends from –98.0 to –80.0 deg longitude and from 18.0 to 30.5 deg latitude. Level 2 grid spacing is 0.25 deg latitude/longitude. The red line that extends from the Mexican coast to the tip of Florida in Figure 1 shows the boundary locations where energy enters the

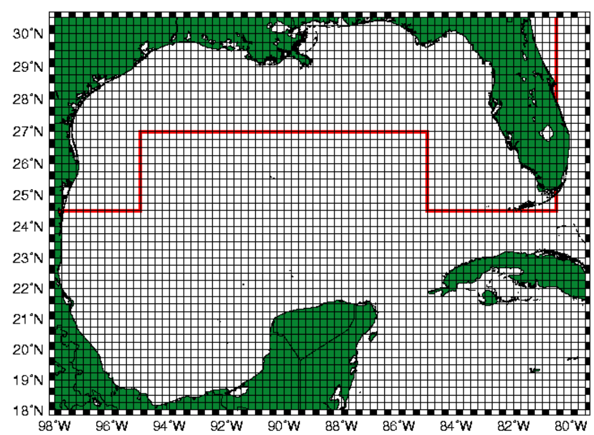

Figure 1. Level 2 and level 3 Gulf of Mexico hindcast grids. Level 3 boundary points are shown by the red line.

Level 3 nest from the Level 2 nest. Level 3 resolution is 1/12 deg. The hindcast encompassed the twelve months of 1995. A cold start was used for the January run and restart files were saved at the end of each run for hindcast continuity.

Hindcast results were saved at the available measurement sites within the Level 2 and Level 3 grids. Table 1 lists the available Level 3 measurement

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sites in 1995; Table 2 lists the available Level 2 1995 measurement sites. Both tables give location information, depth of site, and months available.

Table 1. Level 3 Measurement Sites				
NDBC	Lon.	Lat.	Dep.(m)	Months
42019	-95.00	27.92	100	Jul-Dec
42020	-96.50	27.00	120	Jan-Dec
42040	-88.25	29.17	170	Dec
42035	-94.42	29.25	15	Jan-Dec
42016	-88.17	30.08	19	May
42039	-86.00	28.75	300	Dec
42036	-84.50	28.50	51	Jan-Dec

Table 2. Level 2 Measurement Sites				
NDBC	Lon.	Lat.	Dep.(m)	Months
42001	-89.75	26.00	3165	Jan-Dec
42002	-93.50	26.00	3123	Jan-Dec
42003	-86.00	26.00	3206	Jan-Dec

3. WIND INPUT

The same input wind fields were used for each of the hindcast applications. The 1990-1999 Gulf wind fields were generated by Oceanweather, Inc., in connection with the WIS mission to develop hindcasts for all the US coastlines. Oceanweather, Inc., has vast experience in both the theoretical and practical aspects of wind modeling products. Cox and Cardone (2002) gives an overview of Oceanweather's analysis capabilities.

The Gulf wind fields (0.25 deg spacing) were developed using National Centers for Environmental Prediction (NCEP) wind fields (at 6 hr intervals) available from NOAA. Swail, Ceccacci, and Cox, 2000, describes the NCEP/NCAR reanalysis product which was used for the Gulf wind fields. The NCEP winds have approximately 1.9 deg spacing. Oceanweather's process included interpolation from 6 hours to 1 hour, applying NCEP wind corrections by grid point and assimilation of measured wind information to create a 1-hr product on a 0.25 deg grid. Oceanweather is noted for specification of tropical storm wind fields using their Planetary Boundary Layer wind model described in Thompson and Cardone (1996). Cox and Cardone (2000) describes their tropical storm analysis. Tropical storm winds were assimilated into the final wind field. The final product represents hourly Gulf wind fields utilizing all available information and expert meteorological analysis. These wind fields were used for the Level 2 Gulf hindcast and interpolated to the 1/12-deg grid for the Level 3 hindcast.

The 1 deg Atlantic wind fields for Level 1 were taken from the AES40 Atlantic wind product (Swail, et al., 2000), which was developed by Oceanweather for the Meteorological Service of Canada (formerly called Atmospheric Environment Service). This wind product was derived from the 6-hr NCEP/NCAR reanalysis wind fields. Oceanweather's website (www.oceanweather.com) is available for more details and references on wind analysis.

4. NUMERICAL WAVE MODELS

Wave models used in this study include WISWAVE, WAM, and WAVEWATCH III (version 2.22). These wave models solve the action balance equation:

$$\frac{\partial N}{\partial t} + C_g \cdot \nabla N = \sum_{i=1}^{n} S_i \qquad (1)$$

where N is action density, t is time, C_g group speed, and S_i are source functions consisting of wind input, dissipation, non-linear wave-wave interactions, and bottom effects. Second-generation wave models such as WISWAVE use a parameterization of the non-linear wave-wave interaction source terms and third-generation models like WAM and WAVEWATCH use an approximate calculation of this source term. All wave models strive to represent the physics of wave growth, development, dissipation, and interaction. All the models simulate directional spectra to produce the energy-based significant wave height and details about the wave spectrum such as peak wave period and vector mean wave direction for designated output stations. Brief descriptions of the wave models are given with references. All these models are well-known to the wave modeling community, and they all have excellent reputations.

4.1 WISWAVE

The WIS hindcasts use the numerical wave hindcast model, WISWAVE, developed by Don Resio for the Army Corps of Engineers. WISWAVE has been used extensively in wave hindcasting at U.S. Army Corps of Engineers (USACE) offices and throughout the engineering community. WISWAVE uses the time-dependent wave action balance equation to create a directional spectral matrix with twenty frequencies and 16 direction bands at each grid point on a land-sea mesh derived from a latitude-longitude grid including finite depths for each grid point. Wave growth is based on the Phillips and Miles mechanism; weak nonlinear wave-wave interaction, equilibrium Jonswap and Kitaigorodskii spectral functions, linear refraction, shoaling and dissipation are included in the source function analysis. Propagation is accomplished using a first-order finite-difference scheme. WISWAVE can be run with nested boundary conditions. Details on the wave theory can be found in Resio, 1981, Resio and Perrie, 1989, and Resio et al, 2001. User manual information on WISWAVE can be found in Hubertz, 1992.

4.2 WAM

The WAM model used for this hindcast was WAM Cycle 4.5 which is an update of the WAM Cycle 4 model (Komen et al, 1994, Guenther et al, 1992) using Fortran 90. WAM originated from the Wave Modeling Group directed by Klaus Hasselmann, who developed techniques to calculate the non-linear source function (Hasselmann and Hasselmann, 1985; Hasselmann et al., 1985). This method is known as the discrete interaction approximation (DIA). Wave spectra in WAM are not tied to a specific spectral shape. WAM's basic physics have not changed but the source function integration scheme by Hersbach and Janssen, 1999, has been included in this latest version. WAM does not have options to use different source functions and uses the same physics in all applications. WAM includes an option for sea ice and can be run in nested applications. WAM has been used in USACE hindcast applications (Jensen et al, 2002) in the Alaska area.

4.3 WAVEWATCH III

The third-generation wave model, WAVEWATCH III (WW3) Version 2.22 includes some of the most recent advances in third-generation modeling. Tolman (2002) presents a user manual that describes the physics and gives directions on installing and running the model. This model was developed at the Marine Modeling and Analysis Branch (MMAB) of the Environmental Modeling Center (EMC) of NCEP and has its roots in Dr. Tolman's Delft University research. WW3 has some similarities to the WAM model, and the default set-up uses the DIA for the non-linear source term. WW3 allows the user to select different sets of source functions, and the Tolman and Chalikov (1996) source functions and default set-ups were used in this application. WW3 also has options to include sea ice and currents and has the capability of running in nested mode. WW3 is currently being used as the operational model at NOAA/NCEP. See the following website for an extensive reference listing on WW3: polar.ncep.noaa.gov/waves/reference.html

4.4 COMPUTER PLATFORMS

The three models were run on three different computer platforms. The WIS Gulf hindcasts were run on personal computers; WAM and WW3 were run on two different high-performance computer (HPC) system platforms resident at ERDC. All results were run using single processors although parallel processing options are available for all these models. This paper is focused on model results; computational speed can be attained using suitable compiler and parallel processing options for all three models.

5. GULF LEVEL 2 COMPARISONS

The Gulf Level 2 hindcast grid covers the entire Gulf of Mexico (see Figure 1). NDBC 42001, 42002, and 42003 in the central Gulf of Mexico have measurements available for comparison for the entire year of 1995. Comparison line plots will be shown for October, 1995, which includes Hurricane Opal. Wave direction information is also available at 42001 for October and directional comparisons will be shown. Summary tables of statistics for only NDBC 42001 will be shown since results are similar at NDBC 42002 and 42003. Statistics used for comparison are bias, the root mean square error (RMS), scatter index, skill score, and correlation. Positive bias values indicate that hindcast results are higher than measured. Scatter index values should be low indicating little scatter in the results. Skill scores are reported in decimal values with 1.00 being a perfect match. Correlations are also reported in decimals with 1.00 indicating perfect correlation. Monthly statistics using significant wave height from the WIS, WAM, and WW3 hindcasts in comparison to the measurements at NDBC 42001 are shown in Tables 8-10 in the Appendix. Tables 11-13 in the Appendix show the monthly mean wave period statistics for this same location. Tables 14-16 in the Appendix show monthly peak period statistics for 42001. Tables 3, 4, and 5 are included within this paper's text to summarize the statistical means for all the buoys discussed in this paper.

5.1 WAVE PARAMETER COMPARISONS

Table 3 gives a summary of the mean wave height statistics for all three models for NDBC 42001. Bias statistics for significant wave height in Table 3 show that WAM slightly under-predicts with a mean of –0.08 m for the year. WIS over-predicts with a bias of 0.28 m, and WW3 shows a mean bias of 0.02 m for the year indicating slight over-prediction. RMS statistics for all models are slightly over 0.2 m with WAM having a slightly lower error than the others. The WAM wave height statistics show the lowest mean scatter index and best mean skill score. All mean wave height correlation statistics are within one percentage point. Mean period bias statistics in Table 4 for NDBC 42001 show that WAM and WIS mean periods over the year of measurements tend to be slightly high. WW3 bias is low. WIS mean RMS for mean period is the lowest of the three with 0.59 sec. Skill scores are very close with WIS and WW3 showing means of 0.99; WAM's mean is 0.96. WIS has the highest mean correlation and lowest mean skill score. NDBC 42001 peak period statistics in Table 5 show that WIS and WW3 have negative mean biases, -0.13 and –0.60 m, indicating under-prediction. WAM shows a positive bias of 0.08 sec. All RMS means are slightly over 1 sec. WIS shows slightly better mean statistics for correlation. WW3 and WIS both show a scatter index of 19 compared to WAM's 23. WIS and WAM both have a 0.98 skill score.

Table 3. 1995 Wave Height Statistical Summary

Buoy	Model	Mean Bias (m)	RMS Error (m)	SI	SS	Cor
42001	WIS	0.28	0.28	24.4	0.92	0.91
	WAM	-0.08	0.26	22.4	0.98	0.91
	WW3	0.02	0.28	23.6	0.98	0.90
42020	WIS	0.08	0.35	25	0.96	0.85
	WAM	-0.27	0.38	28	0.96	0.80
	WW3[1]	-0.19	0.43	28	0.96	0.77
42035	WIS	0.17	0.23	26.3	0.93	0.87
	WAM	-0.20	0.21	24.2	0.96	0.86
	WW3[1]	-0.15	0.24	25	0.97	0.83
42036	WIS	0.10	0.30	32.4	0.95	0.90
	WAM	-0.26	0.32	34.3	0.94	0.84
	WW3[1]	-0.19	0.31	28.3	0.96	0.89

Table 4. 1995 Mean Period Statistical Summary

Buoy	Model	Mean Bias (sec)	RMS Error (sec)	SI	SS	Cor
42001	WIS	0.18	0.59	10.8	0.99	0.77
	WAM	0.14	0.74	14.2	0.96	0.70
	WW3	-0.45	0.63	11.6	0.99	0.73
42020	WIS	-0.00	0.60	10.8	0.99	0.76
	WAM	-0.07	0.72	13.2	0.98	0.66
	WW3[1]	-0.84	0.64	11.3	0.98	0.75
42035	WIS	0.25	0.73	15.3	0.98	0.69
	WAM	-0.06	0.80	16.3	0.98	0.56
	WW3[1]	-0.90	0.55	11.0	0.98	0.79
42036	WIS	-0.05	0.77	16.0	0.98	0.61
	WAM	0.00	1.01	12.5	0.91	0.64
	WW3[1]	-0.65	0.59	11.7	0.98	0.78

[1] For months of Jan-Mar 1995 only

Table 5. 1995 Peak Period Statistical Summary

Buoy	Model	Mean Bias (sec)	RMS Error (sec)	SI	SS	Cor
42001	WIS	-0.13	1.17	19.4	0.98	0.63
	WAM	0.08	1.36	23.1	0.92	0.55
	WW3	-0.60	1.15	19.1	0.98	0.58
42020	WIS	-0.36	1.17	18.3	0.98	0.61
	WAM	-0.19	1.31	20.6	0.97	0.54
	WW3[1]	-1.01	1.12	16.7	0.98	0.63
42035	WIS	-0.02	1.54	28.3	0.95	0.53
	WAM	-0.01	1.54	28.4	0.94	0.47
	WW3[1]	-0.97	1.04	18.7	0.97	0.71
42036	WIS	-0.45	1.34	24.8	0.96	0.49
	WAM	-0.02	1.53	29.3	0.97	0.56
	WW3[1]	-0.84	1.01	18.3	0.98	0.68

5.3 HURRICANE OPAL COMPARISONS

Hurricane Opal (a category 4 hurricane) was active in the Gulf of Mexico September 27-October 6, 1995. Figure 2 shows the wave comparison results for WAM at 42001 for October 1995. Figure 3 shows similar results for WIS, and Figure 4 shows the WW3 hindcast comparison. Note that both the WAM and WIS hindcasts slightly over-predict the maximum wave height during Opal. WW3 under-predicts the maximum wave height and also under-predicts the energy after the peak has passed. WIS shows an excellent period comparison for this storm.

5.4 WAVE DIRECTION COMPARISONS

Wave direction comparison results in Figures 2, 3, and 4 are very similar for all three models. Table 6 shows the wave direction statistics for October 1995 for the three models. The table contains the mean direction difference in degrees ($\bar{x}$), a concentration statistic ($\hat{k}$), circular correlation (circor) reported in decimals with 1.00 being perfect correlation, and the number of comparisons. These statistics use the circular direction techniques discussed in Tracy (2002) which is an application of Bowers et al. (2000). The concentration statistic is a measure of how the two distributions compare. Values 5.0 and greater for this statistic indicate that the two directional distributions being compared are similar. These direction statistics were calculated for waves 1m and above. Note that mean directional difference results for all three models indicate hindcast and measurements are within 2 deg.

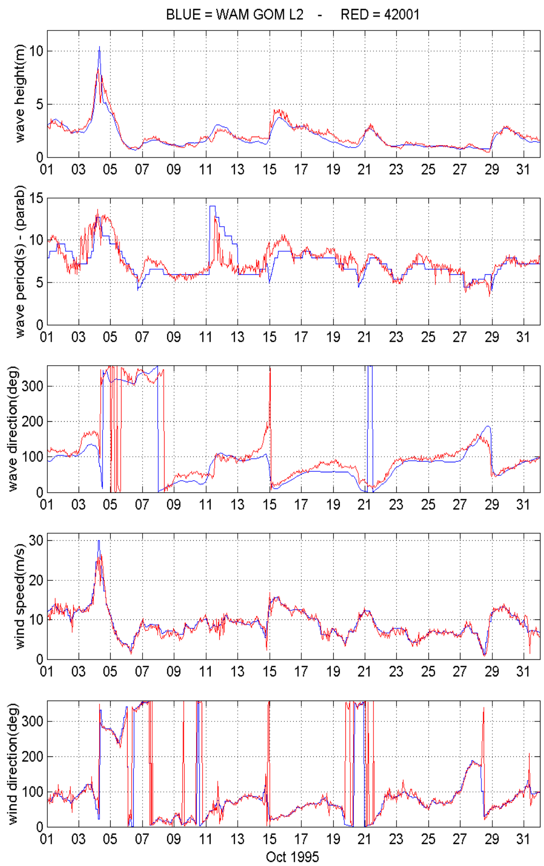

Figure 2. WAM comparison results for October 1995 at NDBC 42001. Measured results in red and WAM results in blue. Plots from top to bottom include significant wave height, wave period, wave direction, wind speed, and wind direction.

All concentration statistics are greater than 5.0 indicating that model directional results and measured directions are very close. Correlations range from 0.85 to 0.88. WAM shows the best comparison although all models show very good directional comparisons.

Table 6. Mean Wave Direction Statistics for Gulf Level 2 October 1995 at NDBC 42001

Model	$\overline{x}$ (deg)	$\hat{k}$	Circor	Number
WIS	14.69	6.6	.85	668
WW3	12.52	7.4	.86	668
WAM	11.38	8.6	.88	668

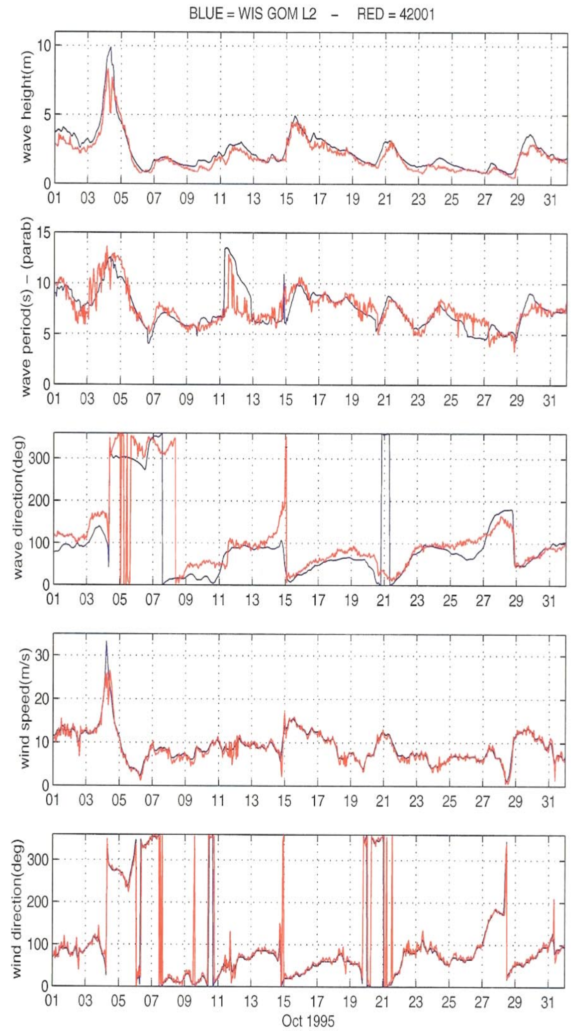

Figure 3. WIS comparison results for October 1995 at NDBC 42001. Measured results in red and WAM results in blue. Plots from top to bottom include significant wave height, wave period, wave direction, wind speed, and wind direction.

6. GULF LEVEL 3 COMPARISONS

Gulf Level 3 (see Figure 1) covers the US Gulf of Mexico coastline with 1/12 deg grid spacing and receives boundary energy from the Level 2 Gulf grid. Tables of wave hindcast comparison statistics will be shown for NDBC 42020, 42035, and 42036. These sites have measurements for all months of 1995. NDBC 42036 also has directional measurements and comparisons of wave direction statistics are given for this site.

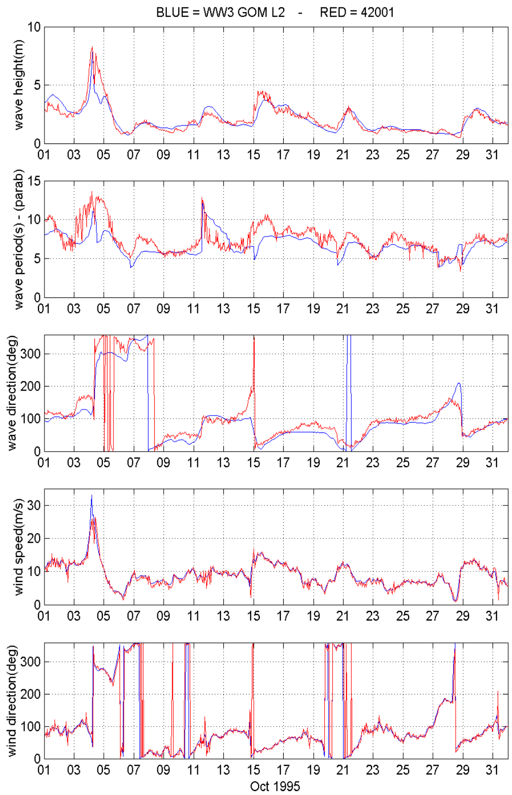

Figure 4. WW3 comparison results for October 1995 at NDBC 42001. Measured results in red and WAM results in blue. Plots from top to bottom include significant wave height, wave period, wave direction, wind speed, and wind direction.

6.1 COMPARISONS AT 42020

Tables 17-19 in the Appendix show the monthly significant wave height statistics for the three hindcasts at NDBC 42020 located near Corpus Christi, TX. Table 19 only includes the first three months of results for WW3 since the last Level 3 hindcast runs are currently in the computer queue. Level 3 WW3 for the full year will be shown at the conference. Looking at the yearly mean statistics for WAM and WIS in Table 3 for 42020, WIS has a small positive bias indicating over-prediction and WAM has a negative bias indicating under-prediction. RMS values are very close with 0.38 m for WAM and 0.35 m for WIS. WW3 shows a negative bias indicating it is lower than the measurements. WW3 RMS error for January through March is similar to both WIS and WAM. WIS shows slightly higher correlation than the other two models for the January through March period, and the WIS yearly correlation mean is slightly higher than WAM.

Mean period statistics in Table 4 for NDBC 42020 show negative bias for all the models indicating mean periods are lower than measurements. The average RMS errors for all models are 0.6-0.7 sec indicating all the models have similar results. WAM shows a slightly lower correlation mean over the year with 0.66 compared to WIS's 0.76. WIS scatter index mean and skill score indicate slightly better comparisons for WIS. Monthly mean period statistics for 42020 are shown in Tables 20-22 in the Appendix. Peak period results for 42020 in Table 5 again show negative period biases for all models. WIS and WW3 show the best mean correlations. Other statistics are similar for all models. Monthly 42020 peak period statistics are shown in Tables 23-25 in the Appendix.

6.2. WAVE COMPARISONS AT 42035

Monthly wave height comparison statistics for NDBC 42035 near Galveston, TX.,are shown in Tables 26-28 in the Appendix. Table 3 shows the mean statistics. The 3G models show negative bias and WIS shows positive bias indicating WIS is slightly over-predicting and the 3G models under-predicting. RMS errors are approximately 0.2 m for all models. WIS shows a slightly higher correlation and WAM and WW3 show slightly better skill scores and scatter indexes.

Mean period statistics for 42035 are shown in Table 4. Monthly statistics are shown in Tables 29-31 in the Appendix. WIS shows a positive bias and WAM and WW3 show a negative bias at this location. WW3 shows the lowest RMS with 0.55 sec (WW3 RMS is for the first three months of 1995). WW3 shows the best correlations and scatter indexes but all models have similar skill scores. All model mean bias statistics for peak period in Table 5 are negative indicating peak period is slightly under-predicted. WAM and WIS have biases of –0.01-0.02 sec indicating very good agreement. Mean RMS error for peak period is 1.54 sec for WAM and WIS with WW3 giving a lower mean of 1.04 sec over the Jan-Mar period. WW3 shows the best values for scatter index, skill score and correlation for Jan.-Mar. Tables 32-34 in the Appendix show monthly peak period statistics.

6.3. WAVE COMPARISONS AT 42036

Significant wave height comparison statistics for NDBC 42036 located west of Tampa, FL, are shown in Tables 35-37 in the Appendix. Using the summary Table 3, WAM and WW3 show negative bias indicating slight under-prediction with WIS showing a positive bias of 0.1m. WW3 shows the lowest RMS statistic for Jan-Mar with 0.31m but WIS has the lowest mean RMS error with 0.3 m. The scatter index and skill score statistics look slightly better for the WW3 results for Jan-Mar. WIS and WW3 both show the lowest mean correlation.

Tables 38-43 in the Appendix show comparison mean period and peak period statistics for the three models at NDBC 42036. Using Table 4, WAM shows a mean positive bias of 0.001 sec in comparison to a negative WIS bias of –0.05 sec. WW3 shows a negative bias of –0.65 sec for Jan-Mar indicating under-prediction of the mean period. WW3 shows the lowest mean RMS for Jan-Mar, 0.59sec. WW3 shows the highest correlation for Jan-Mar; all three models show similar skill score statistics although WAM shows some big differences with measured results in September (see Table 38 in the Appendix). WW3 has slightly better scatter index statistics for Jan-Mar. Peak period correlations shown in Table 5 indicate WW3 has the best statistics for Jan-Mar with a mean value of 0.68. All bias values are negative indicating under-prediction of the peak period. RMS values are all about 1 sec. WW3 and WAM show equal mean values for the lowest scatter index for Jan-Mar. All the models show skill scores in excess of 0.96. Again, WAM shows some problems in the September hindcast of peak period.

6.4. DIRECTIONAL COMPARISONS AT 42036

Figures 5-7 show the line plots from the hindcasts for February 1995 at NDBC 42036. Model results are shown in blue and measured results are shown in red. Directional information was available for this month and Table 7 shows the directional statistics for the three models using wave direction comparisons for waves 1 m and above. WW3 shows the best directional comparison with a mean directional difference of –7.32 deg, a concentration statistic of 11.08 indicating that both the measured and hindcasted directions represent similar distributions. Circular correlation for WW3 is 0.906. WIS shows results almost as good as WW3. WAM shows a concentration statistic below 5.0 indicating that the WAM directional distribution is different from the measured distribution. The WAM wave direction comparison plot in Figure 6 shows major directional differences close to February 25, and this accounts for the low concentration statistic.

Table 7. Mean Wave Direction Statistics for Gulf Level 3 February 1995 at NDBC 42036

Model	$\bar{x}$ (deg)	$\hat{k}$	Circor	Number
WIS	-9.23	10.92	0.861	296
WW3	-7.32	11.08	0.906	296
WAM	-12.92	3.50	0.712	296

Figures 5-7 show some similarities between all three hindcasts. Hindcast wave period results are low in times of low wave height as shown in all plots for February 17-19. A major front passed over the Gulf on February 4 and high winds on the back side of a LOW are noted on February 4. WIS does a good job of tracking the peak of this event while WW3 and WAM are low. WIS and WAM both do a good job on the wave period associated with this event. A LOW in the southeastern Gulf around February 21 produced another event with high winds and a direction change. WIS shows a little over-prediction of this event but captures the before and after characteristics

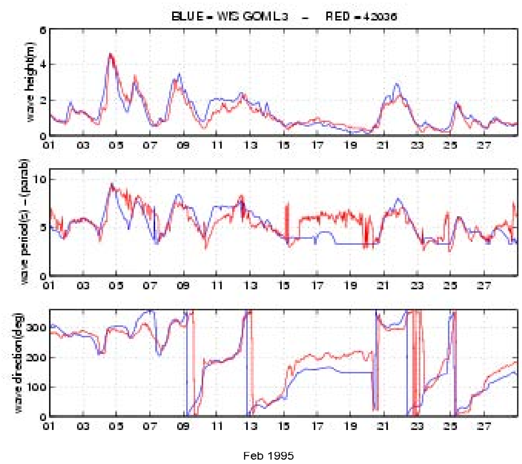

Figure 5. WIS results compared to NDBC 42036 for February 1995. Plots from top to bottom include significant wave height, wave period, and wave direction.

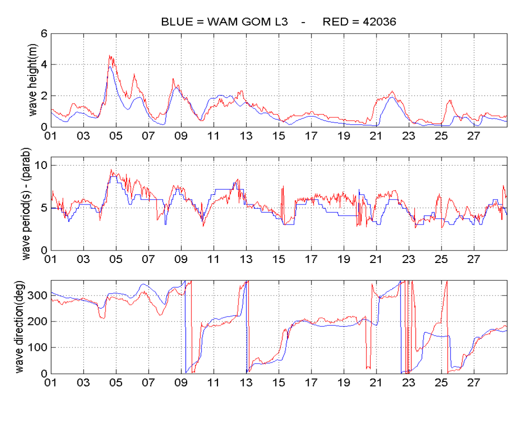

Figure 6. WAM results compared to NDBC 42036 for February 1995. Plots from top to bottom include significant wave height, wave period, and wave direction.

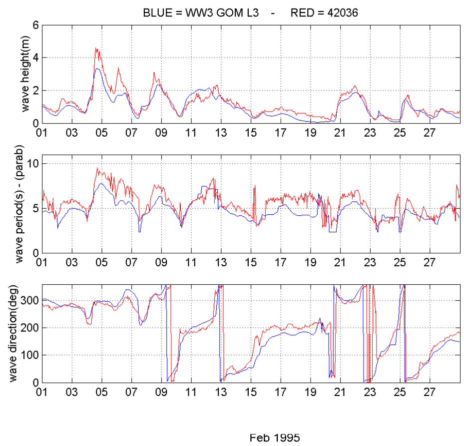

Figure 7. WW3 results compared to NDBC 42036 for February 1995. Plots from top to bottom include significant wave height, wave period, and wave direction.

well. WW3 is low but also captures the event's shape. WAM is a little low on the growth of the event. All the plots and statistics for the February comparisons at NDBC 42036 show excellent hindcast results for all models.

7.0. SUMMARY

All the statistics and line plots presented in this paper show that all three models are excellent hindcasting tools and produce results that agree with measurements. The 2G WIS results are consistent with results from the more complex calculations done in the 3G models. No one model is the clear winner in these comparisons. The 3G models tend to have slightly better directional results. WIS tends to slightly over-predict wave height and the 3G models tend to under-predict. WIS captures storms and hurricane events quite well and is a good tool for the quick frontal changes in the Gulf of Mexico. All the models, 2G and 3G, need work in the area of wave period. Future WIS model comparison work includes a similar study for the Atlantic. WIS is doing the initial model testing for the Pacific basin using a new technique that utilizes wave system diagnostics. Results from these Pacific studies will also be presented at the workshop.

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10.0 APPENDIX OF STATISTICAL TABLES

Table 8. WAM HS Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	-0.04	0.26	19	0.99	0.94
2	-0.09	0.26	21	0.98	0.92
3	-0.12	0.33	24	0.98	0.92
4	-0.17	0.33	25	0.97	0.83
5	-0.08	0.19	19	0.99	0.93
6	0	0.23	28	0.97	0.83
7	-0.03	0.15	26	0.98	0.93
9	-0.07	0.19	26	0.98	0.94
10	-0.12	0.42	21	0.98	0.94
11	-0.09	0.21	15	0.99	0.94
Mean	-0.081	0.257	22.4	0.981	0.912

Table 9. WIS HS Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.37	0.31	22	0.93	0.93
2	0.27	0.31	26	0.93	0.89
3	0.29	0.37	27	0.94	0.9
4	0.26	0.3	22	0.95	0.86
5	0.28	0.22	21	0.92	0.91
6	0.29	0.29	34	0.82	0.81
7	0.15	0.17	30	0.92	0.94
9	0.21	0.19	26	0.92	0.95
10	0.32	0.41	20	0.97	0.95
11	0.36	0.21	16	0.94	0.94
Mean	0.28	0.278	24.4	0.924	0.908

Table 10. WW3 HS Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.07	0.28	20	0.98	0.94
2	0.01	0.25	21	0.98	0.92
3	0.04	0.36	26	0.97	0.92
4	-0.03	0.35	26	0.97	0.8
5	0.04	0.17	17	0.99	0.94
6	0.05	0.25	29	0.96	0.82
7	-0.02	0.15	26	0.98	0.94
9	-0.05	0.18	27	0.97	0.91
10	0	0.52	25	0.98	0.9
11	0.11	0.26	19	0.98	0.92
Mean	0.022	0.277	23.6	0.976	0.901

Table 11. WAM TM Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.1	0.41	7	1	0.9
2	-0.11	0.53	10	1	0.76
3	-0.16	0.83	15	0.99	0.75
4	-0.27	0.5	9	1	0.77
5	-0.01	0.49	10	1	0.77
6	0.05	0.58	11	0.99	0.79
7	0.34	0.66	14	0.99	0.49
9	1.51	2.29	48	0.66	0.05
10	-0.11	0.67	10	0.99	0.85
11	0.08	0.43	8	1	0.85
Mean	0.142	0.739	14.2	0.962	0.698

Table 12. WIS TM Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.34	0.53	10	0.99	0.86
2	0.07	0.57	10	0.99	0.74
3	0.1	0.87	15	0.99	0.73
4	0.15	0.62	11	0.99	0.63
5	0.32	0.55	11	0.99	0.73
6	0.13	0.66	13	0.99	0.74
7	-0.05	0.47	10	1	0.74
9	0.18	0.57	12	0.99	0.76
10	0.24	0.61	9	0.99	0.89
11	0.31	0.41	7	1	0.87
Mean	0.179	0.586	10.8	0.992	0.769

Table 13. WW3 TM Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	-0.44	0.52	9	0.99	0.87
2	-0.62	0.46	8	0.99	0.83
3	-0.65	0.74	13	0.99	0.81
4	-0.62	0.57	10	0.99	0.69
5	-0.4	0.47	10	0.99	0.79
6	-0.49	0.67	13	0.99	0.72
7	-0.14	0.76	16	0.99	0.49
9	-0.38	0.75	16	0.99	0.59
10	-0.56	0.77	12	0.99	0.78
11	-0.24	0.54	9	1	0.76
Mean	-0.454	0.625	11.6	0.991	0.733

Table 14. WAM TP Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.01	0.8	13	0.99	0.82
2	-0.2	1.08	18	0.99	0.53
3	-0.27	1.33	21	0.98	0.63
4	-0.52	0.95	15	0.99	0.56
5	-0.19	1.02	18	0.98	0.65
6	-0.03	1.14	20	0.98	0.66
7	0.48	1.36	27	0.96	0.33
9	1.91	3.76	69	0.37	-0.13
10	-0.18	1.4	19	0.98	0.68
11	-0.18	0.72	11	0.99	0.79
Mean	0.083	1.356	23.1	0.921	0.552

Table 15. WIS TP Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.18	0.85	14	0.99	0.82
2	-0.1	0.98	16	0.99	0.65
3	-0.14	1.33	21	0.98	0.65
4	-0.08	1.11	17	0.99	0.43
5	0.01	1.08	19	0.98	0.63
6	-0.25	1.18	20	0.98	0.68
7	-0.67	1.18	23	0.97	0.53
9	-0.17	2	37	0.94	0.37
10	0.01	1.22	16	0.99	0.76
11	-0.04	0.76	11	0.99	0.77
Mean	-0.125	1.169	19.4	0.98	0.629

Table 16. WW3 TP Statistics at NDBC 42001 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	-0.52	0.83	13	0.99	0.8
2	-0.74	0.85	14	0.99	0.71
3	-0.82	1.12	17	0.98	0.74
4	-0.84	1.02	16	0.98	0.49
5	-0.54	1	18	0.98	0.69
6	-0.66	1.08	19	0.98	0.7
7	-0.28	1.22	24	0.97	0.46
9	-0.48	1.85	35	0.95	0.21
10	-0.74	1.36	18	0.98	0.63
11	-0.4	1.13	17	0.99	0.41
Mean	-0.602	1.146	19.1	0.979	0.584

Table 17. WAM HS Statistics at NDBC 42020 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	-0.19	0.51	32	0.96	0.73
2	-0.33	0.37	27	0.96	0.83
3	-0.33	0.45	29	0.96	0.74
4	-0.25	0.39	25	0.97	0.71
5	-0.39	0.32	21	0.97	0.8
6	-0.22	0.27	24	0.97	0.83
7	-0.32	0.24	23	0.96	0.93
8	-0.24	0.2	22	0.97	0.95
9	-0.23	0.45	52	0.92	0.65
10	-0.36	0.48	24	0.97	0.88
11	-0.3	0.49	30	0.96	0.77
12	-0.13	0.41	27	0.97	0.81
Mean	-0.27	0.38	28	0.96	0.80

Table 18. WIS HS Statistics at NDBC 42020 for 1995

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	0.24	0.5	31	0.94	0.8
2	0.14	0.28	20	0.97	0.91
3	0.07	0.42	27	0.97	0.79
4	0.17	0.37	23	0.96	0.78
5	0.04	0.33	21	0.98	0.84
6	0.03	0.29	26	0.97	0.83
7	-0.04	0.19	19	0.99	0.95
8	0.03	0.14	16	0.99	0.97
9	0.07	0.33	39	0.94	0.83
10	-0.05	0.53	26	0.97	0.84
11	0.16	0.45	27	0.96	0.83
12	0.19	0.4	26	0.96	0.83
Mean	0.08	0.35	25	0.96	0.85

Table 19. WW3 HS Statistics at NDBC 42020 for 1995 Qtr1

Month	Bias (m)	Rms (m)	SI	SS	Cor
1	-0.19	0.55	34	0.95	0.69
2	-0.14	0.35	25	0.97	0.86
3	-0.26	0.41	26	0.97	0.78
Mean	-0.19	0.43	28	0.96	0.77

Table 20.WAM TM Statistics at NDBC 42020for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.15	0.75	13	0.99	0.57
2	-0.15	0.69	13	0.99	0.65
3	-0.24	0.75	12	0.99	0.69
4	-0.19	0.57	10	1	0.71
5	-0.32	0.53	9	1	0.8
6	-0.16	0.57	11	0.99	0.65
7	-0.12	0.49	10	1	0.85
8	0.31	0.62	12	0.99	0.75
9	0.45	1.49	31	0.94	0.11
10	-0.13	1.1	17	0.99	0.68
11	-0.08	0.64	11	0.99	0.68
12	-0.14	0.48	9	1	0.83
Mean	-0.07	0.72	13.16	0.98	0.66

Table 21. WIS TM Statistics at NDBC 42020 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.07	0.66	12	0.99	0.76
2	0.14	0.57	11	0.99	0.79
3	-0.09	0.56	9	1	0.8
4	0.12	0.54	9	1	0.74
5	0.03	0.56	9	1	0.77
6	-0.07	0.58	11	0.99	0.65
7	-0.12	0.5	10	1	0.86
8	-0.07	0.56	11	0.99	0.83
9	-0.1	0.58	12	0.99	0.76
10	-0.11	1.01	15	0.99	0.7
11	0.06	0.65	11	0.99	0.69
12	0.12	0.54	10	1	0.77
Mean	-0.001	0.60	10.83	0.99	0.76

Table 22.WW3 TM Statistics at NDBC 42020 for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.96	0.79	14	0.98	0.66
2	-0.67	0.51	10	0.99	0.82
3	-0.9	0.62	10	0.99	0.78
Mean	-0.84	0.64	11.33	0.98	0.75

Table 23.WAM TP Statistics at NDBC 42020 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.3	1.27	19	0.98	0.47
2	-0.22	1.3	21	0.98	0.5
3	-0.52	1.18	17	0.99	0.58
4	-0.46	1.05	15	0.99	0.58
5	-0.59	0.83	12	0.99	0.68
6	-0.31	1.11	17	0.99	0.53
7	-0.32	0.9	15	0.99	0.77
8	0.29	1.64	28	0.96	0.45
9	0.52	2.78	50	0.85	0.07
10	0	1.71	23	0.98	0.63
11	-0.26	1.16	17	0.99	0.5
12	-0.18	0.84	13	0.99	0.75
Mean	-0.19	1.31	20.58	0.97	0.54

Table 24. WIS TP Statistics at NDBC 42020 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.25	1.18	18	0.99	0.67
2	-0.07	1.03	17	0.99	0.71
3	-0.34	1.02	15	0.99	0.67
4	-0.2	1.14	16	0.99	0.55
5	-0.24	0.94	14	0.99	0.67
6	-0.52	1.26	20	0.98	0.48
7	-0.64	0.95	16	0.98	0.78
8	-0.64	1.26	22	0.98	0.68
9	-0.74	1.24	22	0.97	0.53
10	-0.33	2.01	27	0.97	0.48
11	-0.3	1.18	17	0.99	0.53
12	-0.03	0.93	15	0.99	0.62
Mean	-0.358	1.17	18.25	0.98	0.61

Table 25.WW3 TP Statistics at NDBC 42020 for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-1.25	1.22	18	0.98	0.59
2	-0.73	0.92	15	0.99	0.76
3	-1.07	1.22	17	0.98	0.56
Mean	-1.01	1.12	16.66	0.98	0.63

Table 26.WAM HS Statistics at NDBC 42035for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.13	0.27	28	0.97	0.81
2	-0.22	0.23	27	0.96	0.83
3	-0.26	0.25	23	0.97	0.84
4	-0.19	0.17	17	0.98	0.9
5	-0.19	0.22	20	0.98	0.84
6	-0.18	0.18	22	0.97	0.9
7	-0.17	0.19	24	0.97	0.93
8	-0.18	0.14	21	0.97	0.93
9	-0.2	0.2	34	0.94	0.78
10	-0.28	0.24	22	0.97	0.87
11	-0.28	0.28	27	0.96	0.85
12	-0.15	0.22	25	0.97	0.82
Mean	-0.20	0.21	24.16	0.96	0.858

Table 27. WIS HS Statistics at NDBC 42035 for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.27	0.27	28	0.9	0.86
2	0.19	0.23	27	0.93	0.87
3	0.16	0.27	25	0.95	0.83
4	0.23	0.26	25	0.93	0.87
5	0.28	0.25	23	0.91	0.88
6	0.16	0.19	24	0.95	0.9
7	0.15	0.22	29	0.95	0.93
8	0.06	0.16	25	0.97	0.91
9	0.04	0.18	32	0.95	0.83
10	0.11	0.28	26	0.96	0.84
11	0.21	0.29	28	0.93	0.89
12	0.2	0.21	23	0.93	0.87
Mean	0.171	0.23	26.25	0.93	0.87

Table 28. WW3 HS Statistics at NDBC 42035 for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.09	0.25	26	0.97	0.84
2	-0.12	0.21	24	0.97	0.87
3	-0.24	0.28	25	0.97	0.8
Mean	-0.15	0.24	25	0.97	0.83

Table 29.WAM TM Statistics at NDBC 42035for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.07	0.93	19	0.98	0.59
2	-0.02	1.03	22	0.98	0.3
3	-0.3	0.6	11	0.99	0.76
4	-0.26	0.67	13	0.99	0.63
5	-0.13	0.49	9	1	0.82
6	-0.02	0.76	16	0.99	0.59
7	-0.13	0.55	12	0.99	0.76
8	-0.04	0.54	11	0.99	0.72
9	0.38	1.35	31	0.94	0.01
10	0.04	1.45	27	0.96	0.48
11	-0.22	0.61	12	0.99	0.66
12	-0.18	0.61	13	0.99	0.44
Mean	-0.06	0.799	16.333	0.98	0.563

Table 30.WIS TM Statistics at NDBC 42035 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.5	0.76	16	0.98	0.78
2	0.27	0.56	12	0.99	0.74
3	0.14	0.69	13	0.99	0.69
4	0.31	0.65	12	0.99	0.76
5	0.37	0.56	11	0.99	0.79
6	0.19	0.54	12	0.99	0.82
7	0.17	0.63	14	0.99	0.76
8	0	0.54	12	0.99	0.73
9	0.27	1.23	28	0.95	0.42
10	0.5	1.23	23	0.96	0.76
11	0.24	0.75	15	0.99	0.68
12	0.06	0.71	15	0.99	0.42
Mean	0.25	0.73	15.25	0.98	0.69

Table 31. WW3 TM Statistics at NDBC 42035for 995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.92	0.67	14	0.98	0.75
2	-0.78	0.45	9	0.99	0.81
3	-1.02	0.53	10	0.98	0.81
Mean	-0.90	0.55	11	0.98	0.79

Table 32.WAM TP Statistics at NDBC 42035 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.1	1.31	24	0.97	0.66
2	0.06	1.75	34	0.95	0.14
3	-0.31	1.06	18	0.99	0.7
4	-0.47	1.19	19	0.98	0.61
5	-0.24	1.04	17	0.99	0.68
6	0.14	1.52	29	0.96	0.46
7	-0.22	1.04	20	0.98	0.7
8	-0.03	1.06	20	0.98	0.71
9	0.88	3.2	66	0.68	0.03
10	0.35	2.72	44	0.9	0.47
11	-0.3	1.58	29	0.96	0.27
12	-0.11	1.08	21	0.98	0.31
Mean	-0.01	1.54	28.41	0.94	0.47

Table 33.WIS TP Statistics at NDBC 42035 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.4	1.59	30	0.95	0.62
2	0.06	1.17	23	0.98	0.59
3	-0.09	1.34	22	0.98	0.57
4	-0.11	1.38	22	0.98	0.53
5	0.11	1.2	20	0.98	0.62
6	-0.04	1.3	25	0.97	0.65
7	-0.24	1.22	23	0.98	0.67
8	-0.58	1.31	25	0.97	0.57
9	-0.07	2.53	52	0.87	0.26
10	0.44	2.64	43	0.91	0.57
11	0.02	1.74	32	0.95	0.34
12	-0.15	1.13	22	0.98	0.42
Mean	-0.02	1.54	28.25	0.95	0.53

Table 34.WW3 TP Statistics at NDBC 42035 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-1	1.25	23	0.97	0.68
2	-0.8	0.91	17	0.98	0.7
3	-1.13	0.96	16	0.98	0.77
Mean	-0.97	1.04	18.66	0.97	0.71

Table 35.WAM HS Statistics at NDBC 42036 for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.3	0.41	31	0.96	0.88
2	-0.28	0.39	34	0.96	0.87
3	-0.29	0.36	39	0.94	0.77
4	-0.28	0.25	30	0.95	0.84
5	-0.23	0.25	36	0.94	0.79
6	-0.25	0.32	35	0.96	0.93
7	-0.31	0.2	29	0.94	0.89
8	-0.24	0.29	33	0.96	0.92
9	-0.44	0.35	52	0.89	0.58
10	-0.18	0.42	28	0.97	0.93
11	-0.22	0.29	29	0.96	0.88
12	-0.16	0.38	36	0.96	0.87
Mean	-0.26	0.32	34.33	0.94	0.84

Table 36. WIS HS Statistics at NDBC 42036 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.11	0.4	31	0.96	0.89
2	0.12	0.35	31	0.96	0.91
3	0.07	0.29	32	0.95	0.88
4	0.08	0.24	30	0.96	0.88
5	0.02	0.22	31	0.96	0.88
6	0.04	0.32	35	0.96	0.94
7	0.01	0.21	31	0.96	0.91
8	0.09	0.38	45	0.93	0.94
9	0.03	0.22	34	0.96	0.9
10	0.26	0.39	26	0.96	0.94
11	0.24	0.32	32	0.91	0.89
12	0.18	0.33	31	0.95	0.91
Mean	0.104	0.30	32.41	0.95	0.90

Table 37.WW3 HS Statistics at NDBC 42036 for 1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.21	0.36	27	0.97	0.91
2	-0.18	0.32	29	0.97	0.91
3	-0.17	0.27	29	0.96	0.86
Mean	-0.186	0.31	28.3	0.96	0.89

Table 38. WAM TM Statistics at NDBC42036 for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.14	0.65	13	0.99	0.84
2	-0.36	0.67	14	0.99	0.77
3	-0.24	0.62	13	0.99	0.64
4	-0.35	0.66	14	0.99	0.65
5	-0.52	0.59	12	0.99	0.64
6	-0.81	0.68	13	0.99	0.69
7	-0.8	0.56	12	0.98	0.62
8	-0.18	0.77	16	0.99	0.6
9	3.31	4.92			
10	0.01	0.77	15	0.99	0.83
11	-0.02	0.63	14	0.99	0.74
12	0.12	0.68	14	0.99	0.69
Mean	0.001	1.01	12.5	0.906	0.64

Table 39. WIS TM Statistics at NDBC42036for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	0.19	0.74	14	0.99	0.8
2	0.05	0.74	15	0.99	0.73
3	-0.07	0.67	14	0.99	0.62
4	-0.21	0.67	14	0.99	0.64
5	-0.52	0.72	15	0.99	0.47
6	-0.59	0.99	19	0.98	0.43
7	-0.44	0.74	16	0.99	0.37
8	0.13	1.24	26	0.97	0.47
9	-0.18	0.52	12	0.99	0.63
10	0.3	0.9	17	0.98	0.78
11	0.41	0.61	14	0.98	0.78
12	0.25	0.78	16	0.98	0.69
Mean	-0.05	0.77	16	0.98	0.61

Table 40. WW3 TM Statistics at NDBC42036for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.65	0.6	11	0.99	0.87
2	-0.6	0.52	10	0.99	0.84
3	-0.72	0.66	14	0.98	0.63
Mean	-0.65	0.59	11.66	0.98	0.78

Table 41. WAM TP Statistics at NDBC 42036for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.21	0.98	16	0.99	0.81
2	-0.48	1.1	20	0.98	0.66
3	-0.32	0.97	19	0.98	0.57
4	-0.45	1.19	22	0.98	0.56
5	-0.61	1.24	23	0.97	0.45
6	-1.09	1.25	20	0.97	0.51
7	-0.88	1.02	20	0.97	0.54
8	-0.22	1.45	27	0.97	0.34
9	3.61	5.2	109		
10	0.2	1.85	32	0.95	0.55
11	0.14	1	21	0.98	0.61
12	0.05	1.16	22	0.98	0.58
Mean	-0.02	1.53	29.25	0.97	0.56

Table 42. WIS TP Statistics at NDBC42036for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.05	1.15	20	0.98	0.75
2	-0.38	1.29	23	0.98	0.59
3	-0.48	1.2	23	0.97	0.45
4	-0.66	1.26	23	0.97	0.54
5	-1.08	1.35	26	0.96	0.35
6	-1.25	1.71	28	0.96	0.23
7	-0.88	1.33	26	0.97	0.27
8	-0.18	2.08	39	0.93	0.32
9	-0.63	0.92	19	0.98	0.47
10	0.04	1.42	24	0.97	0.69
11	0.25	0.97	20	0.98	0.68
12	-0.04	1.34	26	0.97	0.55
Mean	-0.445	1.335	24.75	0.96	0.49

Table 43. WW3 TP Statistics at NDBC42036for1995					
Month	Bias(m)	Rms(m)	SI	SS	Cor
1	-0.87	1.05	18	0.98	0.8
2	-0.8	0.94	17	0.98	0.73
3	-0.87	1.05	20	0.98	0.53
	-0.84	1.013	18.33	0.98	0.68