ENSEMBLE OCEAN WAVE FORECAST

H. S. Chen
NOAA/NWS/NCEP
5200 Auth Road, Camp Springs, MD 20746
phone: 301-763-8000 x7211
fax: 301-763-8545
email: hsuan.chen@noaa.gov

Abstract

We describe briefly the development and evaluation of the ensemble global ocean wave forecast system (EGOWaFS) at NCEP (National Centers for Environmental Protection). In this context, the EGOWaFS consists of NOAA WaveWatch III (NWW3) wave model, an ensemble of 11 different Global Forecast System (GFS) wind fields and an initial wave field. The initial wave field uses the same one in the operational NWW3. Eleven different wave fields are generated using the NWW3 subject to the forcing of the 11 different wind fields respectively. Ensemble mean, spread and probability with various thresholds are then calculated from the ensemble of these wave and sea surface wind forecasts. Buoy data in the months of May through July 2004 are used for wind and wave comparison between the NWW3 and the ensemble. Bias, root mean square error (RMSE) and correlation of the ensemble mean of winds and waves are very close to those of the NWW3 respectively; the differences are minute. Trends of the ensemble spreads are well correlated to their corresponding RMSE. A storm event on June 03, 2004 at Buoy 46006 indicates that the wind and wave forecasts of the EGOWaFS, realized by the ensemble of wind and wave forecasts of each member, are indeed more reliable and realistic than those of the deterministic NWW3. Currently, the EGOWaFS is still under extensive study. It runs in parallel mode and, hopefully, will become operational in the near future. Experimental ensemble output are post at the temporary website,
http://www.emc.ncep.noaa.gov/projects/wd21hc/ensemb/web/html/.

Key word: Ensemble and deterministic forecast, Ocean waves

1. Introduction

It is the mission of NCEP/EMC (Environmental Modeling Center) to improve numerical weather, marine and climate predictions through a broad program of research in data assimilation and modeling. At NCEP, an ensemble forecasting in meteorology has become operational since December 1992. Since then, extensive experiments in meteorology indicate that the ensemble forecast is positively favored over the operational, deterministic forecast, because it can provide more realistic and reliable guidance for meteorological forecast. This success of the ensemble forecasting in meteorology kindles our interest in applying an ensemble to ocean wave forecasting. Currently, we have developed an ensemble wave forecast system, EGOWaFS.

It is well recognized that the mathematical model used for meteorological forecast is a highly nonlinear dynamic system. Even it be a perfect model, could still produce unpredictable forecasts subject to an infinitesimally small perturbation in the initial condition. This is so called 'the butterfly effect' (Lorenz, 1993). Unfortunately, observation data as well as grid interpolations of a geographical distribution of the observational network always contain some degree of errors, inevitably making the initial condition only of a limited accuracy and never exact. Consequently, the deterministic forecast strays away from the true state of the real world and becomes chaotic at a large forecast time. To improve this shortcoming, the ensemble forecast is utilized to minimize the effect of the error in the initial condition. It is supposed to filter out some of chaotic components and produce a more realistic and reliable forecast. On the other hand, the mathematical model used for ocean wave forecast is merely a weakly nonlinear, highly dissipative dynamic system, in which the signature of the initial wave field dies away monotonically in the first a few forecast days and no butterfly effect is observed. A study by Chen, et al (2004) indicates that perturbation on the initial wave heights has little impact on the wave forecasts except in the first 24 forecast hours and, most prominently, the wind forcing has the most impact throughout the forecast period. Similar conclusion is also made by Farina (2002) who studied the ensemble wave forecast through an initial wave spectrum perturbation. Considering this difference between the meteorological and ocean wave dynamic system as in schematic Figure 0, we would concentrate on variability of the wind forcing rather than on perturbations of the initial condition for the EGOWaFS.

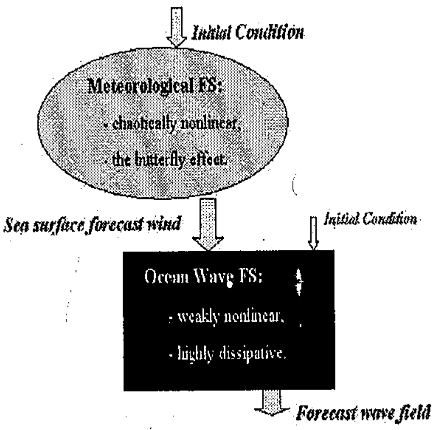

Fig. 0. A schema of meteorological and ocean wave FS.

2. EGOWaFS

Currently, the EGOWaFS consists of the NWW3, an ensemble of 11 different GFS wind fields and an initial wave field. The initial wave field uses the same one of the operational NWW3; i.e., the same initial wave field of the NWW3 is used at the initial time for all 11ensemble members. The NWW3 is a third generation wave model and is a current, operational wave model at NCEP. (Chen, et al 2003) Description of the NWW3 can be found in Tolman (1999). Of the 11 members of the wind fields, except one member is the operational wind field to the NWW3, the other 10 members are generated through introducing small, different perturbations to the initial meteorological field using the breeding method. (Zoltan and Eugenia, 1993, 1997) These ensemble wind fields have been operationally generated for up to 84 hour forecast at 00, 06, 12 and 18Z run cycle. These wind fields as an ensemble have been extensively studied. They are found to be more realistic and reliable than the operational, deterministic wind field, as we realize that the deterministic forecast wind field is only one likely scenario of a good number of alternatives, not necessarily the most likely. In the EGOWaFS, we use each of the 11 wind fields as the wind forcing to separately run the NWW3 to generate one member of wave forecast. Thus, a total of 11 wave forecasts are generated and constitute an ensemble for further statistical analysis. Note that, of these 11 members of the wave forecasts, one member is the control forecast. The control forecast simply uses and imports the operational wind and wave forecasts and, therefore, no job runs for it in the EGOWaFS. We also note that it requires a considerable of computer resource to run the EGOWaFS.

3. Results and Remarks

The wind and wave forecasts of the 11 ensemble members can be used to contrive a deterministic and/or probabilistic forecast by applying various kinds of statistical processing. In this context, we study only the significant wave height, H_s, and the sea surface wind speed, U_{10}. We calculate the ensemble mean, the ensemble spread and the conditional probability. The ensemble mean is the average of the forecasts of all 11 members. It is a smoothing of the forecast fields. The ensemble spread is calculated in the same way as the standard deviation in statistics. It relates to the difference between the forecasts of the members. Small spread indicates low forecast uncertainty and large spread high forecast uncertainty. The conditional probability is calculated with a designated threshold by assuming that each member has an equal likelihood. It can be understood like a probability density distribution.

Wind and wave data from about 30 buoys of deep water (mostly NDBC buoys) in the months of May through July 2004 are treated as the true data for comparisons. Figure 2 shows the comparisons of bias, RMSE and correlation of U_{10} between the operational and the ensemble mean. Figure 3 shows the corresponding comparisons of H_s. Figure 2 indicates that while the bias of the ensemble mean of U_{10} is slightly inferior to that of the operational, its RMSE and correlation are slightly superior, particularly in the range of the larger forecast hours. Note that the ensemble spread of U_{10} has a similar trend as the RMSE; the spread increases as the forecast hour increases. Figure 3 indicates that the bias and RMSE of the ensemble mean of H_s are slightly inferior to those of the operational H_s, but their correlations are almost no difference. Also, the ensemble spread of H_s has a similar trend as the RMSE; the spread increases as the forecast hour increases. Figure 4 and 5 respectively show the U_{10} and H_s forecasts of the members, the ensemble mean and the observation data at Buoy 46006 in the storm event on June 03, 2004. Generally speaking, the spread of the member envelope becomes wider at a larger forecast hour. The ensemble means are slightly favored over the corresponding, operational U_{10} and H_s when comparing with the observation data. Table 1 shows the ensemble probability, the operational and the observation data of U_{10} on Beaufort Wind Force Scale, and Table 2 shows those of H_s on the corresponding Beaufort Wave Height Scale. It indicates that, except the U_{10} at the 06, 54 and 72 forecast hour, the ensemble forecasts of U_{10} and H_s hit all the observation data, while the operational miss many.

Over all, the ensemble forecast is favored over the operational or deterministic forecast. We admit this study up to now is still incomplete. A rigorous study is still underway and, hopefully, we can report more products and findings in the near future. We would like to mention that currently we have the ensemble products in parallel runs and post them at the temporary website mentioned in the abstract. Figure 5 illustrates the example graphics of spaghetti, mean and spread and ensemble probability respectively.

References

Chen, H.S., L.D. Burroughs, and H.L. Tolman (2003): "Ocean Surface Waves", NOAA/NWS/NCEP, TPB No. 494. pp.1-16, May 25, 2003.

Chen, H.S., D. Behringer, L.D. Burroughs, and H.L. Tolman (2004): "A Variation Wave Height Data Assimilation System for NCEP Operational Wave Models", NOAA/NWS/NCEP, TPB series no. MMAB/2004-04. pp.1-16, Aug. 6, 2004.

Farina, L., (2002):"On ensemble prediction of ocean waves", Tellus 54A (2002), 2, pp 148-158.

Lorenz, E.N., (1993):"The essence of chaos", University of Washington Press. 227pp.

Tolman, H.L., (1999): "User manual and system documentation of WAVEWATFCH-III version 1.18", NOAA/NWS/NCEP/OMB Technical Note 166. 110 pp.

Toth, Z. and E. Kalnay (1993): "Ensemble Forecasting at NMC: The Generation of Perturbations", Bulletin of the AMS, vol.74, no.12, pp2317-2330, Dec. 1993.

Toth, Z. and E. Kalnay (1997): "Ensemble Forecasting at NMC and the Breeding Method", Monthly Weather Review, AMS, pp.3297-3319, Dec. 1997.

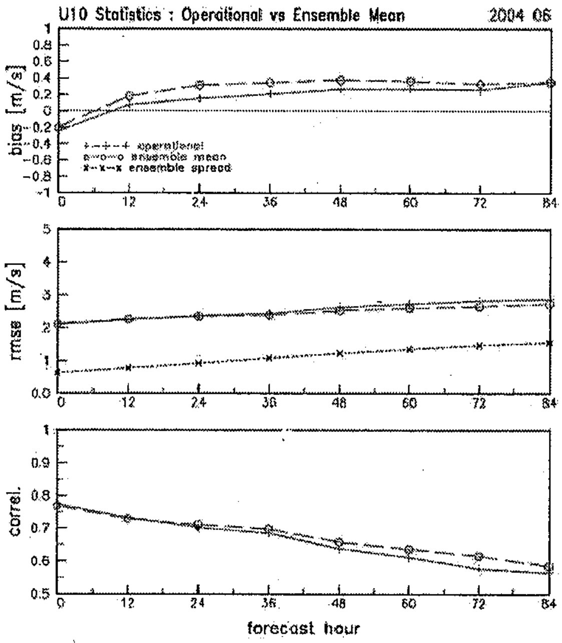

Fig.1 Operational and Ensemble Mean U10 Statistics,
Number of data points for each forecast hour > 1.1k.

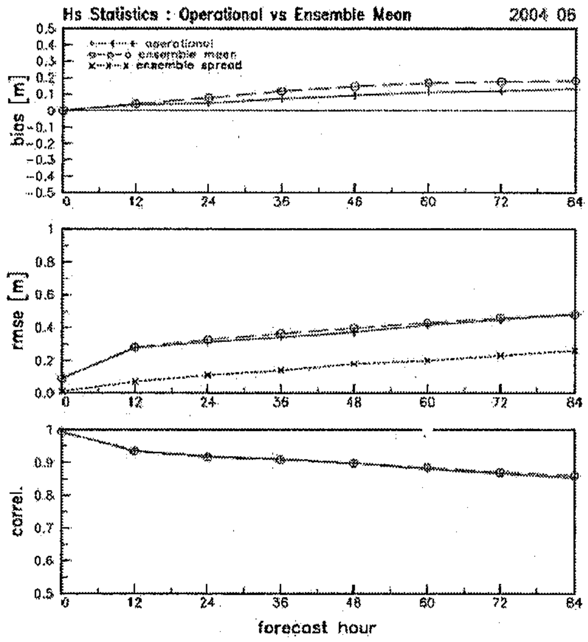

Fig.2 Operational and Ensemble Mean Wave Height Statistics,
Number of data points for each forecast hour > 1.1k.

Green thin lines:	10 ensemble members,
Red dash line with + sign:	**control,**
Blue line with + sign:	**ensemble mean,**
Black dot with o sign:	**observation data.**

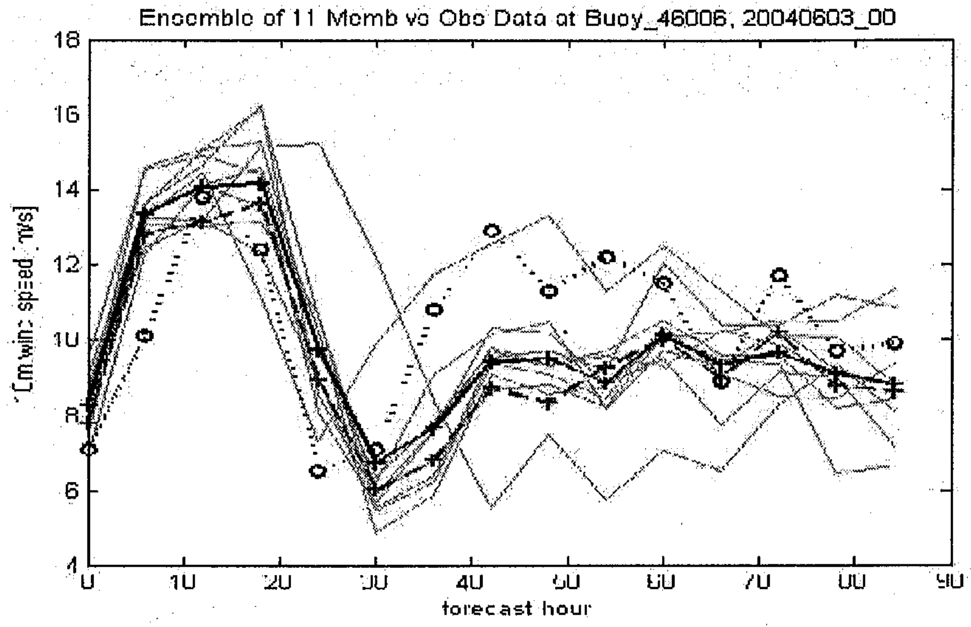

Fig. 3. U_{10} **of 10 members, control, ensemble mean and data.**

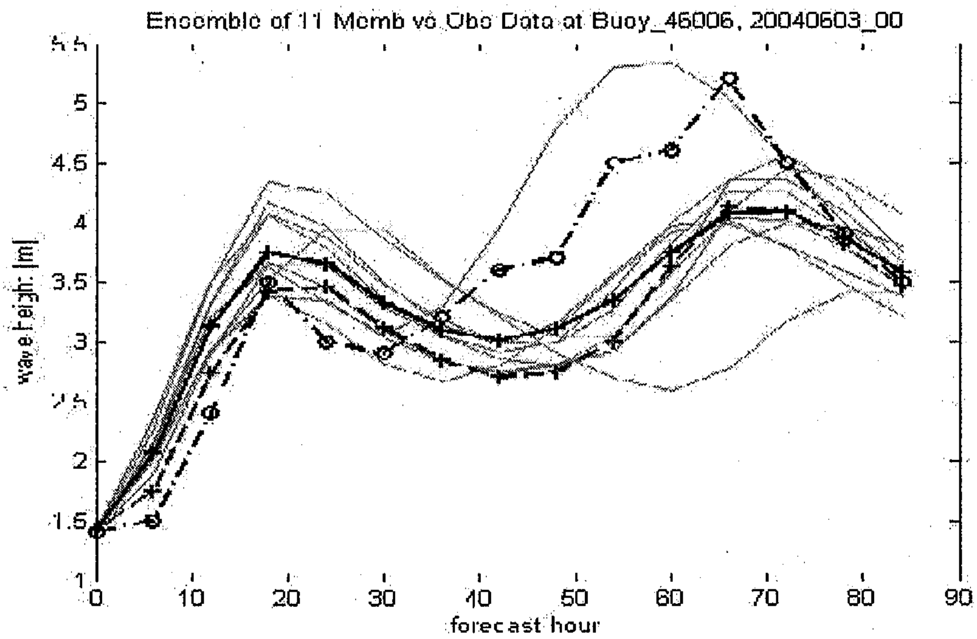

Fig. 4. H_s **of 10 members, control, ensemble mean and data.**

Table 1. Ensemble and NWW3 U_{10} forecasts and Observed Data in the Beaufort Scale.

numerics: ensemble forecast in percentage,
box with a diagonal: NWW3 forecast,
yellow box: observed data.

Ensemble U_{10} Forecasts at Buoy 46006 at 2004 06 03 00

	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84
F10,11, (>=24.67 m/s)															
F9, (>= 21.07 m/s)															
F8, (>= 17.48 m/s)															
F7, (>= 14.39 m/s)		18	45	55	9										
F6, (>= 11.31 m/s)		82	55	36		9	9	9	9		18				9
F5, (>= 8.74 m/s)	36			9	64	9	9	64	64	64	73	82	82	73	46
F4, (>= 5.65 m/s)	64				27	55	82	18	27	36	9	18	18	27	45
F3, (>= 3.60 m/s)						27		9							
F0~2, (<3.60 m/s)															

forecast hour

Table 2. Ensemble and NWW3 H_s forecasts and Observed Data in the Beaufort Scale.

numerics: ensemble forecast in percentage,
box with a diagonal: NWW3 forecast,
yellow box: observed data.

Ensemble H_s Forecasts at Buoy 46006 at 2004 06 03 00

	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84
F10,11, (>=9.0m)															
F9, (>= 7.0 m)															
F8, (>= 5.5 m)															
F7, (>= 4.0 m)				36	9				9	9	18	73	64	27	9
F6, (>= 3.0 m)			55	64	91	91	64	36	27	64	73	18	36	73	91
F5, (>= 2.0 m)		73	45			9	36	64	64	27	9	9			
F4, (>= 1.0 m)	100	27													
F3, (>= 0.6 m)															
F0~2, (< 0.6 m)															

forecast hour

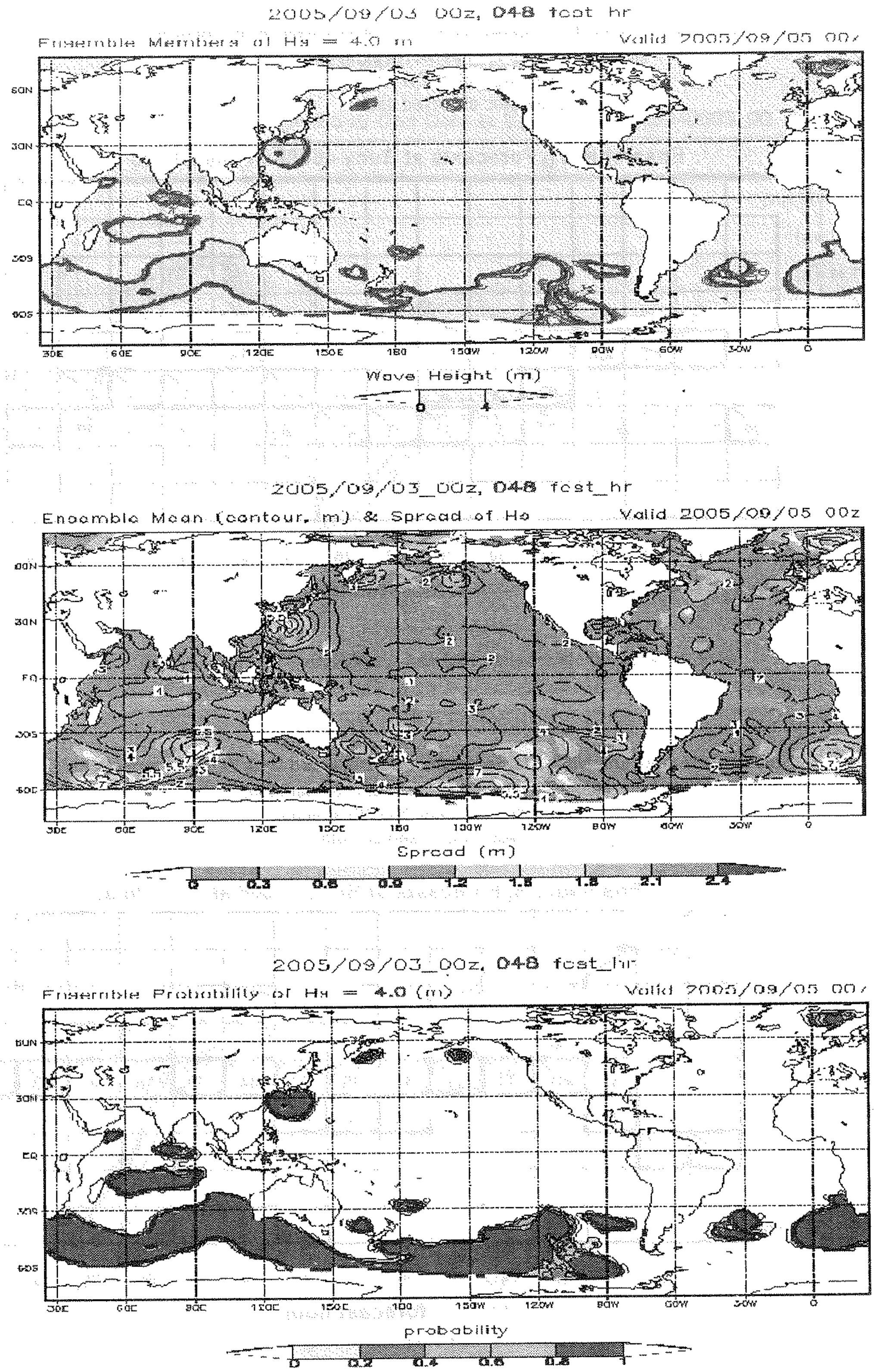

Fig. 5. Illustrated plots of spaghetti, mean and spread and probability of H_s.