WAVE FORECASTING SYSTEM FOR SEAS SURROUNDING JAPAN

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Abstract: A cost effective wave forecasting and hindcasting system has been developed for the seas surrounding Japan by coupling the numerical weather prediction models, GFS and WRF, with the numerical ocean model, SWAN. This system promotes safety by allowing the delivery of real-time sea condition information to recreational marine users in a timely and cost effective manor. In addition to real-time functions, this system is capable of hindcast functions. During system verification the synoptic weather forecast of GFS was found to under predict 10m wind velocities and an error coefficient has been determined for the seas surrounding Japan.

INTRODUCTION

Seashore and marine accidents in Japan are increasing every year, despite preventive measures by the Maritime Safety Agency (Japan Coast Guard) and various marine organizations. According to the Maritime Safety Agency, there were 961 marine accidents involving pleasure boats in 2003 (an increase of 94 from the previous year). Among 961 accidents in 2003, 89 cases were due to insufficient weather information.

Standard practice in wave prediction makes use of pressure maps, tide gauge information, and tropical low pressure system observations. Wind is the most important ingredient in wave prediction as it directly drives ocean conditions. Forecasters analyze available information and predict wave and swell arrival, duration, size, and strength.

Recreational marine users normally venture 10 km away from land at most, but freely available coarse resolution NWP data often fail to resolve the small-scale

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wind systems that play a crucial role in the generation of near shore wind/wave systems. Free information is usually limited to pressure maps with 48 hour lead times and NWP models displayed as weather maps.

Available ocean wave models, mainly produced for commercial shipping and military activities, are not targeted for recreational marine users. Ocean wave models available for the general public were focused on deep-ocean events such as typhoons and tropical disturbances, and not presented for usual marine users to comprehend nor utilize in their ocean recreation activity.

This paper describes the development and execution of a cost effective wave forecasting system (called "Wave Hunter") that couples various high definition NWP forecast models to produce wind and wave fields for the safety of marine users. Additionally, when past meteorological data is employed, the present system served as a wind and wave hindcasting system.

COST EFFECTIVE WIND AND WAVE FORECASTING SYSTEM

Weather is the result of atmospheric processes interacting with each other. NWP models use mathematical equations, representing physical laws, to simulate the interaction and evolution of atmospheric processes. High speed computers are needed to compute the complex series of mathematical equations embedded in NWP models. Modern weather research organizations require powerful high performance computing systems to timely deliver weather products, and processing speed/power is directly proportional to cost. Therefore, in order to minimize cost as processing cycles increase, it becomes more practical to build computational systems by using network servers, rather than by purchasing CPU time on very expensive supercomputer network systems.

While designing the system, the following requirements were taken into consideration:

1) Powerful enough to deliver accurate forecasted information in a timely manner;
2) Economical enough to offer data to users at a reasonable charge or even no charge; and
3) Deliverable to a large audience.

A Class I Linux Beowulf style cluster computer system was selected for the system hardware infrastructure. Beowulf clusters can be built using commodity hardware components connected via Ethernet. Fedora Linux was selected to serve as the system's operating system with MPICH (portable implementation of the Message Passing Interface standard) as the controller for parallel processing. Both Linux and MPICH software are freely available through GNU open source licensing.

PROCESSING SOFTWARE AND REAL-TIME INPUT DATA

With the infrastructure in place, the next step was to seek a source that would provide detailed real-time wind information to be used as input into the ocean model. Ideally the JMA NWP MSM (Meso-Scale Model) was preferred but obtaining the data cost effectively was a deterrent. NCEP (National Centers for Environmental

Prediction, part of the US National Weather Service) offers a real-time global NWP synoptic model called GFS (Global Forecasting System) through its NOMADS (NOAA Operational Model Archive Distributed System) servers on the internet.

GFS is a global spectral model used primarily for aviation weather forecasts which provides the data out to 384 hours at 00, 06, 12 and 18 UTC. GFS offers data global with a one degree grid resolution. For additional information see http://www.emc.ncep.noaa.gov/modelinfo. Wind data at 10 m above the surface is extracted from GFS and used as input into the ocean wave model SWAN (Simulating Waves Nearshore).

SWAN is a third-generation wave model for wind-generated waves, based on a wave action balance equation. See http://fluidmechanics.tudelft.nl/swan/default.htm for model information.

WRF (Weather Research and Forecast) is used to obtain a higher resolution wind field. WRF is a fully compressible, non-hydrostatic model (with a hydrostatic option) of which vertical coordinate is a terrain-following hydrostatic pressure. For more information see http://wrf-model.org. GFS is used as input into WRF, and the resulting wind data is employed as input data for SWAN. Figure 1 shows the flow of data during system processing.

Graphical maps are generated by GrADS (Grid Analysis and Display System). The system is coupled together by Linux scripts that are scheduled by, “cron jobs.”

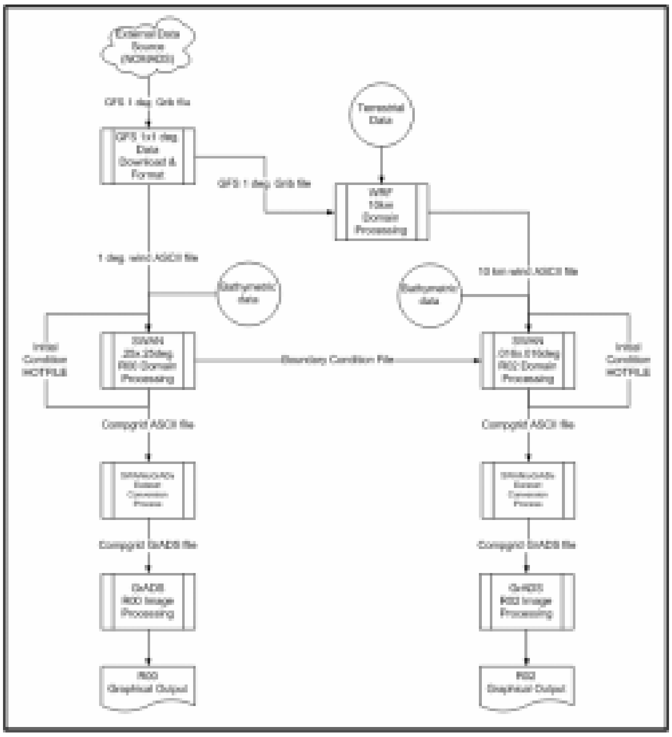

Fig. 1. Data flow diagram

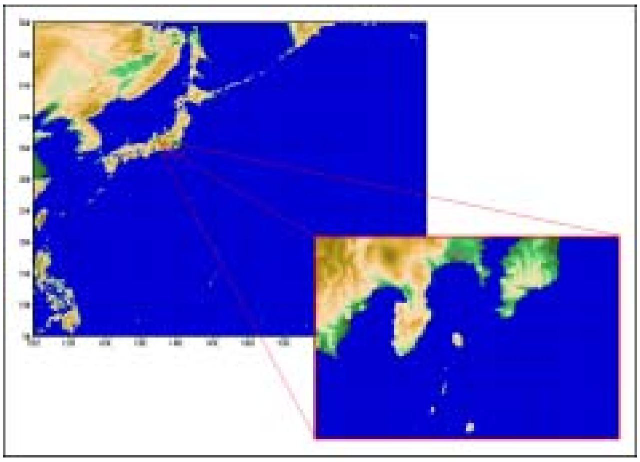

Fig. 2. Target domains for ocean forecast information: outer domain and nested domain

CURRENTLY SERVED INFORMATION

The current system offers ocean forecast information for two domains: one is a large domain with 0.25 degree resolution, shown in Figure 2 (upper left); the other is a nested small domain with 0.0165 degree resolution (Sagami-Bay Area), shown in Figure 2 (lower right), where good beach conditions attract many surfers.

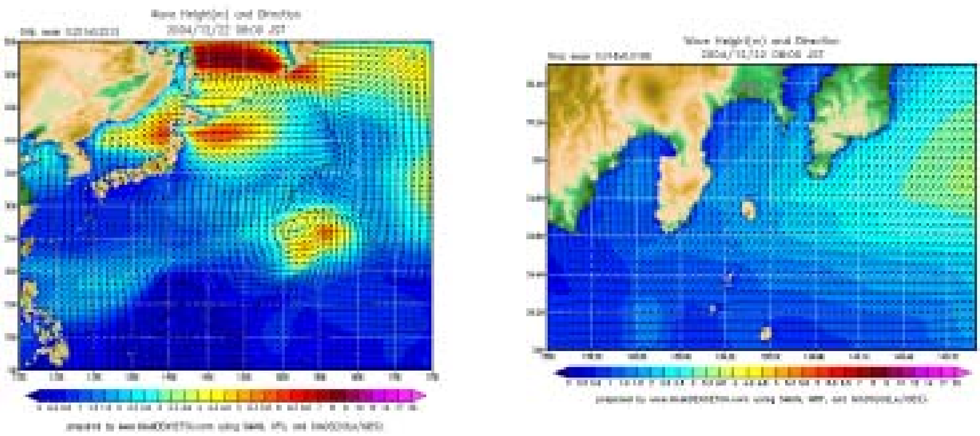

Fig. 3. Forecasted wave heights and directions for outer and nested domains

GFS wind resolution of one degree was found to be too sparse for the nested domain. In order to increase forecast accuracy, the mesoscale weather model WRF was selected to provide the SWAN model with a high definition 10 km grid resolution wind data. WRF uses terrestrial and GFS synoptic forecast data as input and is able to produce a highly detailed wind forecast with a grid resolution down to 1 km.

Figure 3 shows an example of the forecasting of wave heights and directions every hour for the outer and nested domains. Figure 4 displays the wind forecast of 10km grid resolution (left hand side) and forecasted wave height and direction (right hand side).

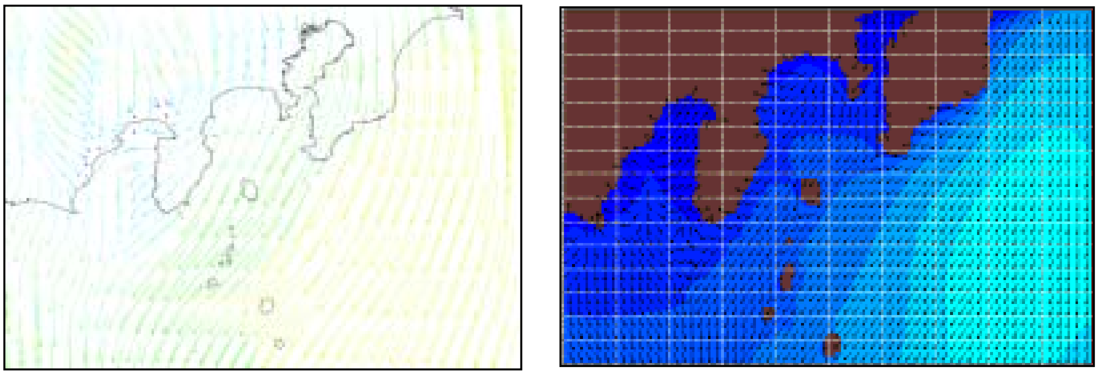

Fig. 4. WRF 10 km wind forecast and resulting wave height and direction for nested domain at 10/23/2004 00:00 GMT

VERIFICATION OF FORECASTING SYSTEM

System verification and validation were performed to ensure the system performed reliably and forecasted accurately. Testing using real-time data was performed to find suitable correlation factors. Seven points were selected, from NOWPHAS (Nationwide Ocean Wave Information network for Ports and HArbourS, Sugahara et al., 1999), to compare the forecasted wave heights and periods with the observed ones. The selected points are shown in Figure 5. These points are situated in locations open to the sea (not in Bays or Inlets).

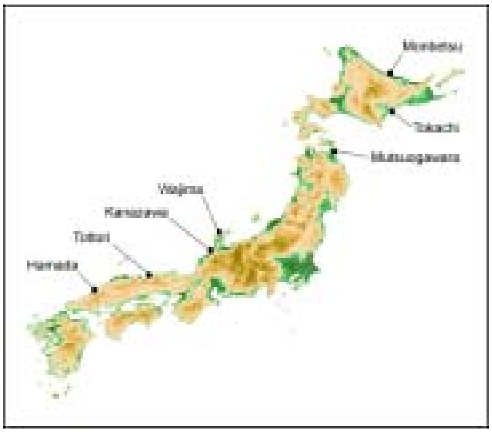

Fig. 5. Test locations of NOWPHAS wave gauges

Testing was performed over a two months period from November 1st to December, 31st 2004 (partial winter season in Japan). The testing focused on a large domain which encompasses the deep-sea regions around Japan. The computational grid of domain was set to 0.25 degrees under GFS's 10 m wind input with a resolution of one degree. Processing was started at 09:00 JST daily and output was saved for analysis. Saved data included forecasted wave heights and wave periods at 5hr, 11hr, 23hr, 35hr, 47hr and 59hr ahead of the processing start time (09:00JST). System modification was frozen and limited to, “emergency only maintenance.”

During the course of two months no major problems occurred but the following areas of concern in system design were uncovered:

1) Due to data unavailability, the system failed to process on two occasions. GFS data was unavailable for download from the NOMADS server, due to heavy server load. The system is dependent on real-time GFS wind data and cannot function without this vital input. A chain of data sources that will allow GFS data download 100% of the time is required to ensure continuation of data processing.
2) During system failure, manual intervention was required to continue processing. An automated recovery method of restoring, "hotfiles," after system failure is needed.

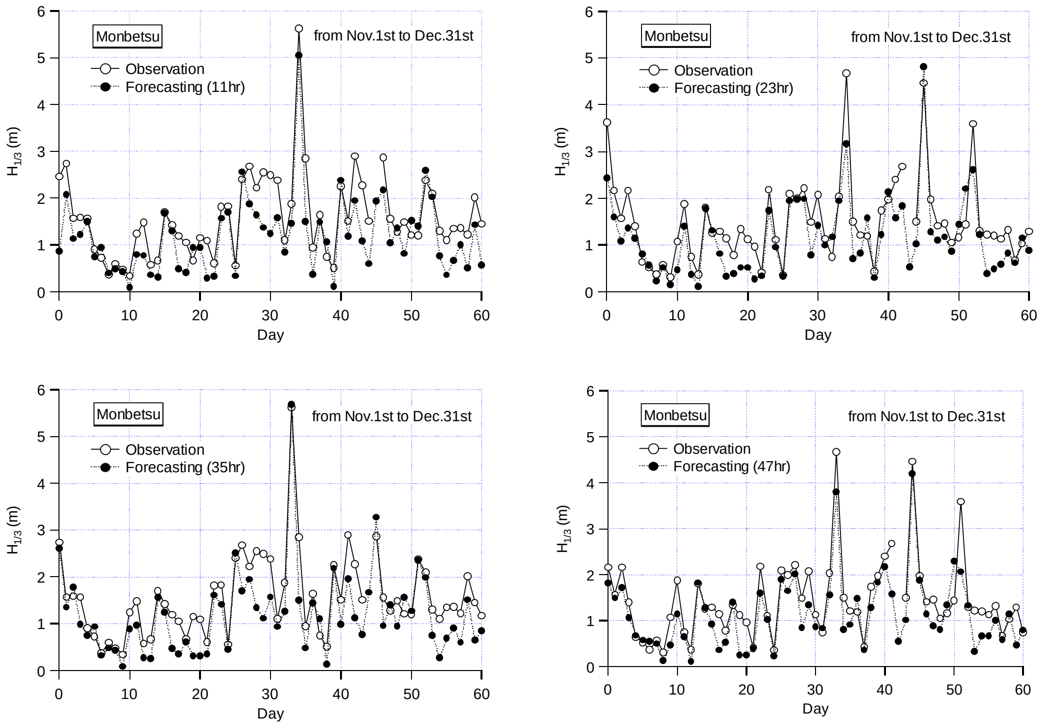

Fig. 6. Observed and forecasted wave heights at Monbetsu

Figure 6 shows an example of the time series of observed wave heights compared with the forecasted significant wave heights at 11hr, 23hr, 35hr and 47hr after the start of forecasting calculation. This figure shows good correspondence of changes in wave heights. But forecasted wave heights tended to be under-reported. Figure 7 shows comparisons of wave heights in a different form.

Figure 8 denotes a summary of correlation coefficients between observed and forecasted wave heights. It can be seen that correlation is good even at the 59hr forecast. If suitable correlation factors were used, the forecasted wave heights become good estimates.

The present analysis indicates that the GFS forecast possesses characteristics of under-predicting 10 m wind strength, causing wave heights to be under-predicted and that different parameter settings for day and night processing exists. The rough resolution of 1 degree GFS wind data cannot represent the wind field near coasts, which is a cause of the differences between observed and forecasted data.

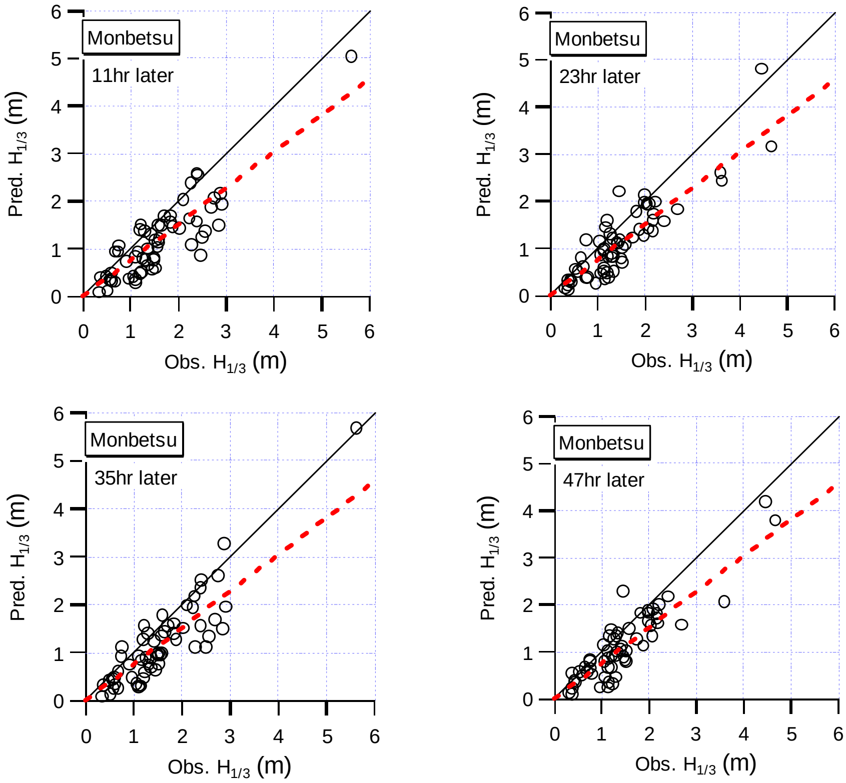

Fig. 7. Comparison of wave heights with observations

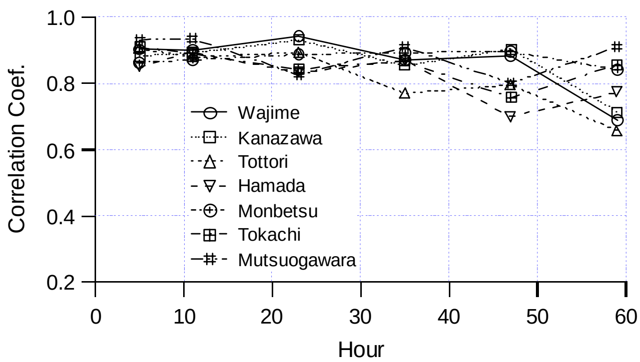

Fig. 8. Correlation coefficients between observed and forecasted wave heights

In summary, causes of wave height forecast error are believed to be from:

1) Wave gauge and forecasted point location were not exact;
2) Synoptic GFS model resolution and computational grid size of the SWAN domain was too large for accurate prediction of close to shore locations;
3) Course resolution of GFS synoptic data fail to resolve the small-scale wind systems that play a crucial role in the generation of near shore wave systems;
4) 10 min bathymetric data resolution too large. Higher resolution data is needed to increase forecast accuracy;
5) GFS and SWAN models both contain computational errors.

Further testing of the outer domain is needed to determine the percentage ratio of error during other seasons where noticeable atmospheric changes occur. In addition, testing of the nested domain (10 km resolution WRF with a SWAN grid resolution of 0.0165 degrees) is required.

HINDCASTING OF WAVES

On October 20th, 2004, described as the deadliest storm in a decade, Typhoon 0423 (named Tokage), made landfall in Japan, causing severe coastal damage. Typhoon 0423 was the tenth typhoon to strike Japan in 2004, already breaking the previous record of six set in 1990 and 1993. The wave forecasting system, developed here, was employed to estimate waves generated by the typhoon.

The GFS data before the typhoon attacked (forecast data) and the final analysis data of GFS (hindcast data) were downloaded. By using the forecast data and hindcast data, waves were estimated.

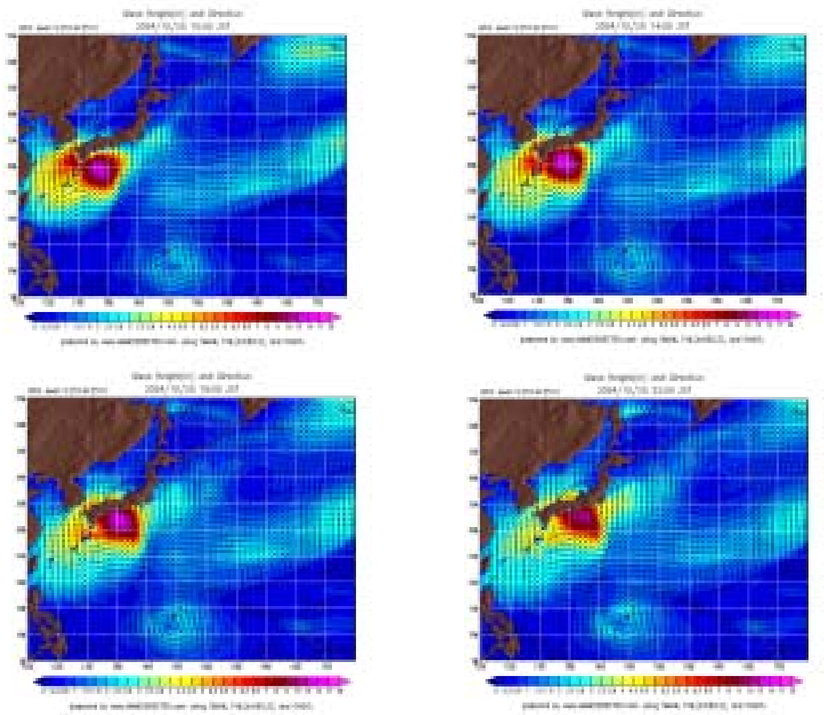

Fig. 9. Estimated wave heights due to Typhoon 0423

Figure 9 denotes the calculated wave height fields by using the hindcasted wind data with a 6 hour time interval. The typhoon caused severe damage along the coastal areas of Shikoku and Wakayama areas. Especially in Muroto City, three people were killed when seawall parapets collapsed. The largest wave recorded at that time by the NOWPHAS gauges was 13.55m and 15.s (the largest recorded wave observation by the gauges since their activation).

Figure 10 shows the comparison of observed wave height change with the forecasted and hindcasted ones. There is little difference between forecasted and hindcasted wave heights. The tendency of change in observed wave height is rapid compared to calculated ones. The typhoon 0423 passed over the observed point; therefore, it is considered that wind direction and strength changed rapidly. Since the time interval of forecasting data is 3 hours and hindcast data is 6 hours, the time interval along with the one degree grid resolution is insufficient to reproduce the rapid change of wind fields, resulting in a smooth change of wave heights shown in Figure 10. Despite the tendency of wave height change, the peak value of wave heights agree fairly well.

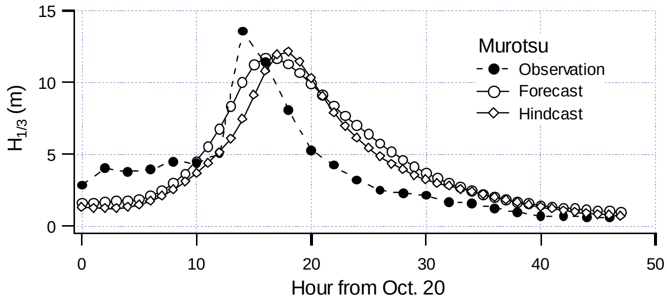

Fig. 10. Comparison of observed wave heights with forecasted and hindcasted

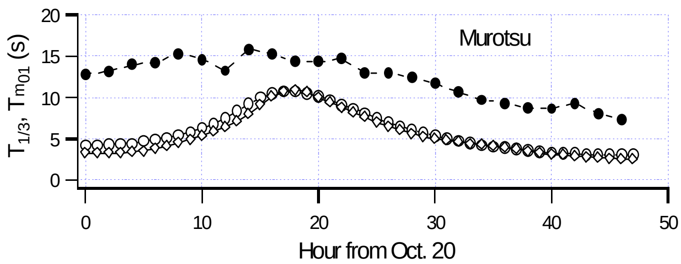

Fig. 11. Comparison of observed wave periods with forecasted and hindcasted

Concerning with wave periods, due to the difference between definitions, the estimated values are smaller than the observed significant wave periods; however, the tendency of change in wave period is nearly the same, shown in Figure 11.

CONCLUSIONS

A wave prediction system suitable for casual marine recreational users has been developed by combining the near shore wave prediction model of SWAN with the synoptic model of GFS, and the high resolution mesoscale model of WRF. Tests have shown that the system is reliable in predicting changes of wave height but wave heights are slightly under-predicted and that an error ratio can be applied to forecasted output to better approximate wave heights. In addition, a reliable source for wind data download is needed to insure system functionality. Further testing is planned to better understand system performance and to isolate areas of improvements. Specifically, testing will be aimed at determining if an error ratio can be uncovered for each season of climatic change in Japan. Wind input quality directly affects wave forecast. Therefore, further study will be performed on improving forecasted WRF wind data, by incorporating real-time observational data into WRF with the WRF3dvar data assimilation module. In addition to the system's real-time forecasting ability, testing has shown that it can be configured as a wind and wave hindcasting system as well.

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