OPERATIONAL WAVE FORECAST AND VERIFICATION AT KMA AND NEW IMPLEMENTATION PLAN FOR THE 2nd PHASE KMA SUPERCOMPUTER

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1. INTRODUCTION

In recent years the demand for accurate modeling of atmospheric and oceanic process has steadily grown. The ocean wave modeling is a way of expression the major processes in the interface of ocean and atmosphere. With the definition of energy balance equation and JONSWAP(Hasselmann et al.,1973), the 3rd generation wave model WAM (WAMDI, 1988) becomes available in early 1990's. The Korea Meteorological Administration (KMA) has operated wave prediction model since 1992 adapting 1st generation wave model from France - DSA-5 for Northeast Asia region. The operation of the 1st supercomputer NEC SX5 (224 Giga flops in peak performance) at KMA in 1999 enables upgrading wave model from 1st generation model to 3rd generation one – WAM model, and expanding domain into global addition to regional Northeast Asia (Park, 2000). In section 2, the brief overview is given of the current weather and wave prediction model configuration at Numerical Weather Prediction Division (NWPD/KMA). In section 3, we discuss the verification results of sea surface wind and wave. The global moored buoy data including the coastal ones operated by KMA and the remote sensing data from Topex/Poseidon and QuikSCAT satellite retrieved significant wave height data and wind are used for verification of wave prediction system.

Under the renewal process of power computing packs at KMA on the 2nd half of year 2004 through year 2005, the CRAY X1E system (14.5 Teraflops in peak performance) will replace the NEC SX5. This makes it feasible expanding the present operating models with increased spatial and spectral resolution including optional choice of new physics and numerics. Thus, the newly devised wave operating system will accommodate the costal wave process interaction with sea level and current via adapting public domain model developed for nearshore zones - SWAN (Simulating WAve Nearshore). The characteristics of wave prediction and coastal effects surrounding Korean Peninsula will be addressed along with nesting procedure from larger domains. Besides, the computational aspects of wave models in the process of transplanting and new implementation will be also discussed in section 4.

2. CURRENT NWP MODEL CONFIGURATION

2.1 Operational weather forecasting model

Since the operation of regional model in early 1980's, the numerical weather prediction (NWP) at KMA gradually expands to cover wide range of meteorological phenomena from seasonal forecast to very short-range prediction. Table 1 describes the NWP models on operation at KMA (Lee, 2004). Along with data assimilation system having 6 hourly updating cycle, the Global Data Assimilation and Prediction System (GDAPS) produces 84-hour and 240-hour prognosis for the global scale atmospheric variables. It provides time-dependent lateral boundary conditions for the regional model and steering flow for the typhoon model. The Regional Data Assimilation and Prediction System (RDAPS) runs twice a day for 48-hour forecast, with 12-hour pre-assimilation with dynamic nudging – FDDA (NWPD Report, 2004).

There has been a gradual change in data assimilation scheme besides the increase of model resolution during the last few years. The incorporation of ATOVS satellite radiance with 1-dimension variational data assimilation (1dVar) scheme shows improvement the analysis and forecast particularly over ocean. The 3-dimension variational data assimilation scheme (3dVar) was implemented in both GDAPS and RDAPS (for 10km model only) in early 2004. The operational sensitivity is regularly monitored in terms of observation increment (gradient of Jacobean) for various types of observations. The AWS and QuikSCAT wind are assimilated through 3dVar with the simplified PBL forward and adjoint column operator. Doppler radial wind is assimilated as radiosonde data. Radar reflectivity is assimilated through 3dVar with the simplified forward and adjoint operator representing a warm rain microphysics (Lee, 2004).

Table 1. The operational NWP models at KMA (Lee, 2004)

Model	**Analysis**	**Resolution (Layers)**	**Lead time (Days)**	**Remark**
Global Spectral Model (GDAPS)	3dVar	T213 (55km, 30 levels)	10	
	3dVar	T106 (110km, 30 levels)	8	17 Ensemble
	3dOI	T106 (110km, 21 levels)	90	Ensemble
Regional Model (RDAPS)	3dOI/ 3dVar	30/ 10/ 5km(33)	2	Triple Mesh
Typhoon Model (DBAR)	Bogus	20km (barotropic)	3	Typhoon Track
Wave Model (ReWAM,GoWAM)		0.25°	2	Asian
		1.25°× 1.25°	10	Global
Statistical Model		-	2	Temp, PoP

2.2 Operational wave forecasting model

Although the first operational wave model was implemented in 1992, the main progress in numerical wave prediction was made in 1999 with introduction of 1st supercomputer at KMA. Two wave prediction systems – GoWAM (Global WAve Model), ReWAM (Regional WAve Model) are running operationally since then (Park, 2000). The two systems are set up on a fairly standard configuration. The table 2 summarizes this. The wave spectrum is resolved into 24 angle bins at 15 degree resolution and 25 frequency bins from 0.0418 Hz to 0.4114 Hz. The source terms and propagation terms are integrated every 6 minutes for ReWAM and 12 minutes for GoWAM, and the model assumes deep water. The GDAPS (T-213) provides the sea surface wind in every 12-hour interval for GoWAM and the RDAPS (30km resolution) for ReWAM in every 3-hour interval. As the wave observational data is not assimilated in both systems, the previous job time's 12-hour forecast wave spectrum is used as an initial spectrum for the next job time integration.

2.3 Operational job scheduling

Two types of global forecast are produced at KMA. The GDAPS for 84-hour projection runs at 00 UTC and 12 UTC with 2.5-hour data cutoff. This projection is used for short-range weather forecast and for the provision of lateral boundary conditions for the RDAPS. The GDAPS for 10-day projection runs at 12 UTC with 10-hour data cutoff in order to utilize as much observation as available. The 10-day projection is used for weekly forecast (NWPD Report, 2004). The GoWAM uses the GDAPS 10-day projection sea surface wind at 12 UTC and the ReWAM uses the RDAPS 48-hour projection sea surface wind at 00 UTC and 12 UTC. The figure 1 summarizes the wave model job scheduling.

Table 2. The operational wave models at KMA

	GoWAM	ReWAM
Source Code	WAM model cycle 4	WAM model cycle 4
Coordinate	Spherical coordinate	Spherical coordinate
Spatial Domain	70°S-70°N	20°N-50°N, 115°E-150°E
Spatial Resolution (Dim.)	1.25° (288 by 113)	0.25° (141 by 121)
Spectral Resolution	25 frequency 24 direction	25 frequency 24 direction
Integration Time Step	720 second	360 second
Lead Time	240 hour (12UTC)	48 hour (00/12UTC)
Elapsed Time	12 minute	2.5 minute
Initial Condition	Previous 24 hour forecast	Previous 12 hour forecast
Sea Surface Wind Input	GDAPS 12-hour interval	RDAPS 3-hour interval

The KMA supercomputer SX5 has 16 vector processors in 1-node with 128 Gigaflops in peak performance (8 Gigaflops for each processor). The GoWAM (ReWAM) runs on 8 (4) processors with concurrent speed of 5.2 Gigaflops (4.5 Gigaflops). The elapsed time of GoWAM (ReWAM) for 240 (48) hour forecast is around 720 (160) seconds. Besides the operational execution of the model itself, the post-processing jobs of data archiving, collocation of model results with buoy observational data for performance verification, and monitoring wave forecast fields are required to be done routinely. The figures 2 and 3 are typical model forecast map of significant wave height and sea surface wind.

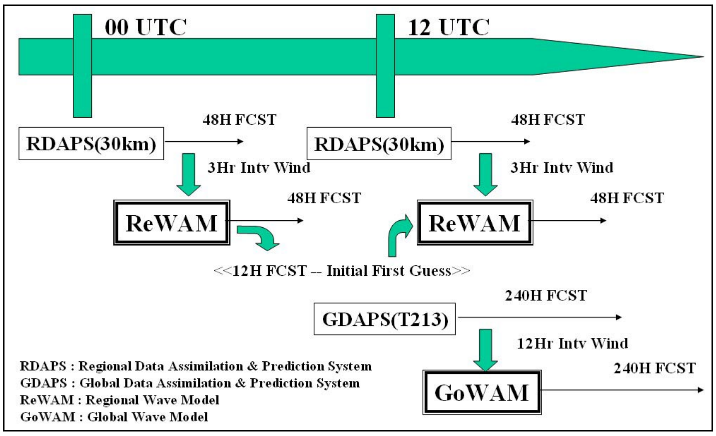

Fig. 1. KMA wave model job scheduling

3. VERIFICATION

An important task of any operational weather centers is the validation of their forecast. The sea surface wind and significant wave height are verified routinely in monthly bases. The global moored buoy data including the coastal ones operated by KMA and remote sensing data from Topex/Poseidon and QuikSCAT satellite retrieved significant wave height data and wind are used for verification of wave prediction system.

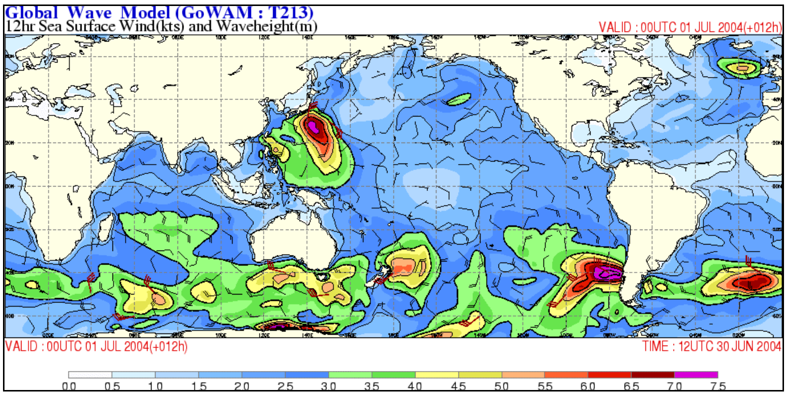

Fig. 2. Global map of GDAPS wind and GoWAM significant wave height 12-hour forecast for 12UTC 30 June 2004

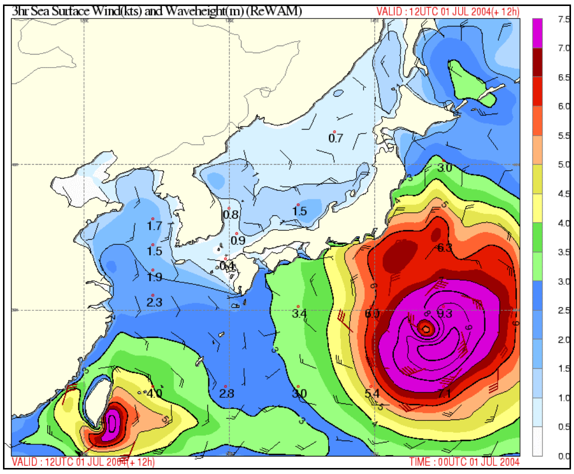

Fig. 3. Regional map of RDAPS wind and ReWAM significant wave height 12-hour forecast for 12UTC 1 July 2004.

3.1 Wind and wave against buoy observation

The buoy data are considered to be ground truth. The buoys used here are identified by WMO ID number. The every hour buoy data are available through Global Telecommunication System (GTS) network, and the data on 00 UTC and 12 UTC are used for verification. The monthly statistical value of model bias (equation (1)), root mean square error (equation (2)) and correlation (equation (3)) with buoy data are calculated. The 4 neighboring model grid value which includes the observation point is interpolated in inverse proportion to distance between the model grid and observation point.

$$BIAS = \frac{1}{N}\sum(Y_{Model} - Y_{Obs}) \tag{1}$$

$$RMSE = [\frac{1}{N}\sum(Y_{Model} - Y_{Obs})^2]^{1/2} \tag{2}$$

$$CORR = \frac{\frac{1}{N-1}\sum(Y_{Model} - \overline{Y}_{Model})(Y_{Obs} - \overline{Y}_{Obs})}{[\frac{1}{N-1}\sum(Y_{Model} - \overline{Y}_{Model})^2]^{1/2}[\frac{1}{N-1}\sum(Y_{Obs} - \overline{Y}_{Obs})^2]^{1/2}} \tag{3}$$

3.1.1 Global domain

There are 4 different regions of buoy data – located at Gulf of Mexico (42000 series), Gulf of Alaska and US west coast (46000 series), US east coast (41000 series), North Sea and UK coast (62000, 63000, 64000 series). The GDAPS sea surface wind bias and rms error against those individual buoy data for June 2004 are shown in figure 4. This type of product is generated in every month. The values are varied each month, and the variation is usually higher during winter season. The bias is within ±2 ms^{-1} range with a tendency of changing from negative to positive as the lead time increased. The rms error increases from $1.5ms^{-1}$ for 24 hour projection to $3.5ms^{-1}$ for 10 day projection.

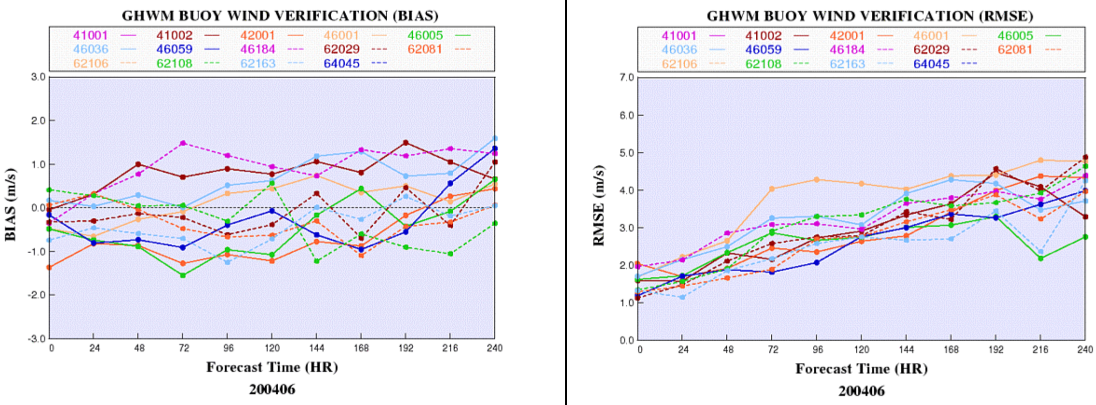

Fig. 4. The bias (left) and rmse (right) of GDAPS sea surface wind for June 2004 against buoy observation.

The annual trend, which started in January 2001 and ended in December 2003, of the GoWAM significant wave height monthly rms error against buoy is shown in figure 5. It shows the weak sign of improvement in recent year. This may be contributed from the refinement of GDAPS analysis and prediction skill. Another change during the 2nd half of 2003 was the increase of GoWAM directional resolution from 30° to 15°. This angular resolution change may cause the improved propagation characteristics and eventually lead to better error statistics. The figure 6 is the same as the figure 4 but for the significant wave height. In summer season the sign of bias shows regional character such as positive in Gulf of Mexico and negative (i.e. model underestimate) in Gulf of Alaska and North Sea. In winter season, however, the sign of bias is negative in most regions. The rms error increases from 0.5 m for 24 hour projection to 1.5 m for 10 day projection.

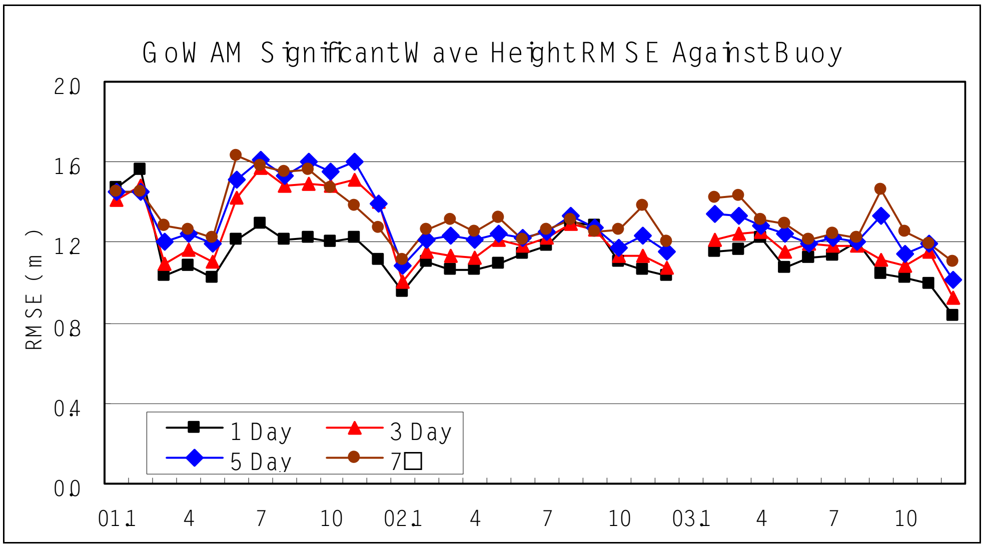

Fig. 5. The annual trend of the GoWAM significant wave height monthly rmse against buoy for the period of January 2001 – December 2003

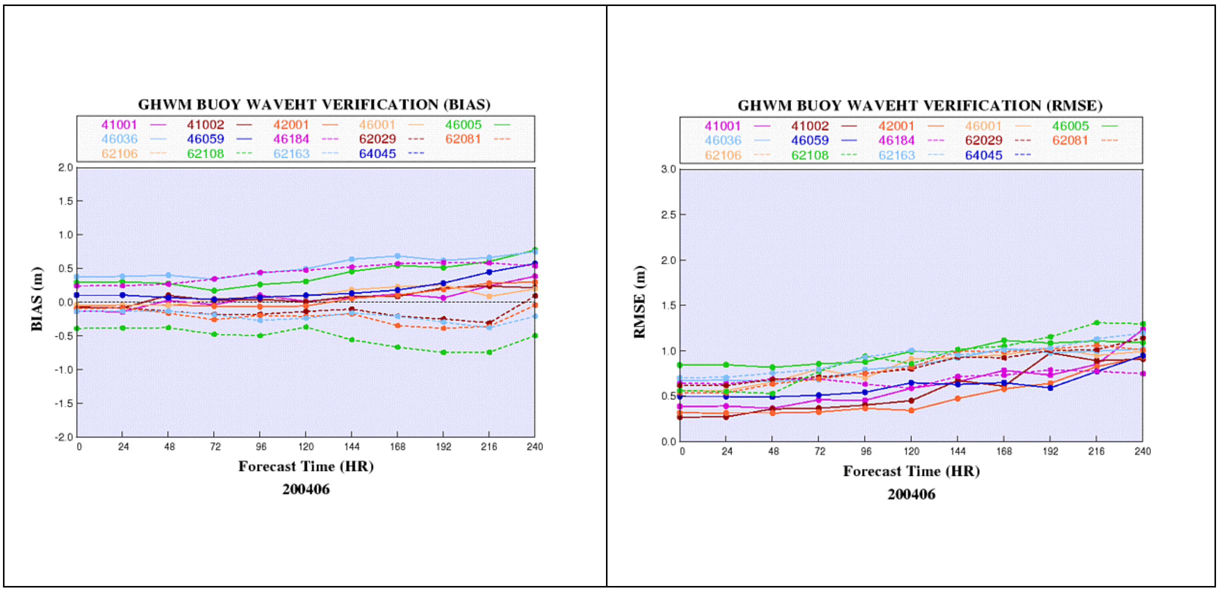

Fig. 6. Same as the fig. 4 but for significant wave height of global wave model

3.1.2 Regional domain

The 3 deep sea moored buoys operated by JMA until May 2000 (East China Sea (22001), East Sea (21002), and Southeast of Kyushu (21001)) were used for verification of ReWAM. The KMA operated coastal buoys were employed since then. There are 2 buoys in Yellow Sea, 2 buoys in South Sea, and 1 buoy in East Sea. The RDAPS sea surface wind bias and rms error against those individual buoy data for June 2004 are shown in figure 7. The wind bias in most of buoys are positive (means model overestimate) except 1 buoy near Geojedo island (22104). This bias pattern was not shown against JMA buoys in deep sea. This is considered as the effect of coastal location of the KMA buoys. The wind rms error ranges from $2ms^{-1}$ to $3.5ms^{-1}$.

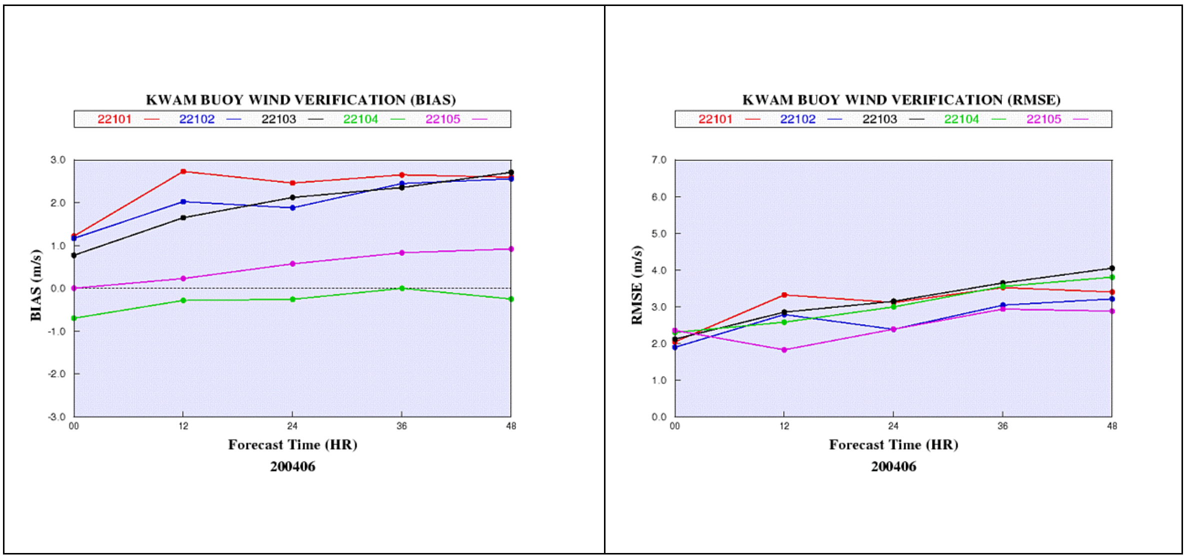

Fig. 7. The bias (left panel) and rmse (right panel) of RDAPS sea surface wind for June 2004 against buoy observation.

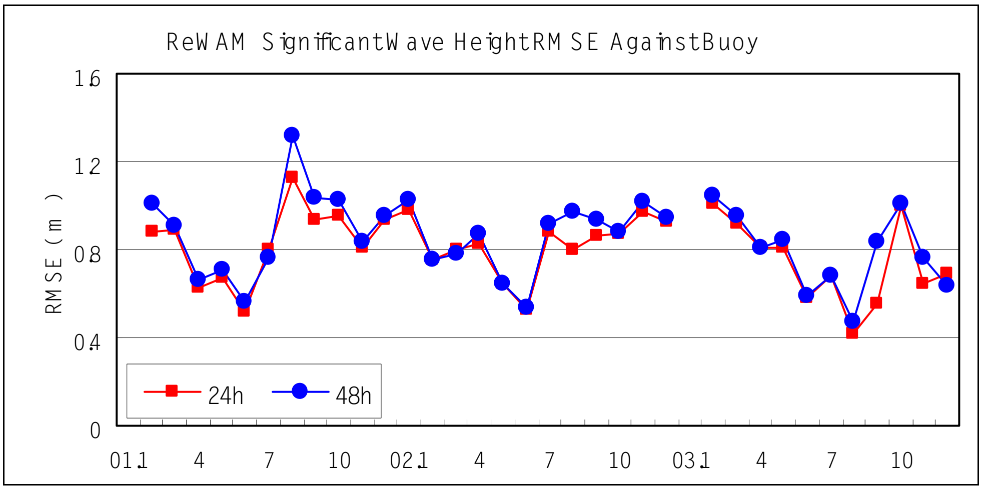

Fig. 8. Same as figure 5 but for ReWAM significant wave height

The annual trend, which started in January 2001 and ended in December 2003, of the ReWAM significant wave height monthly rms error against buoy is shown in figure 8. The value is higher during winter season comparing to summer and also show week trend of better skill in recent year similar to GoWAM (figure 5). The significant wave height bias shows also the positive tendency which portrays the wind bias, and the rms error varies from 0.3m to 0.8m (figure 9).

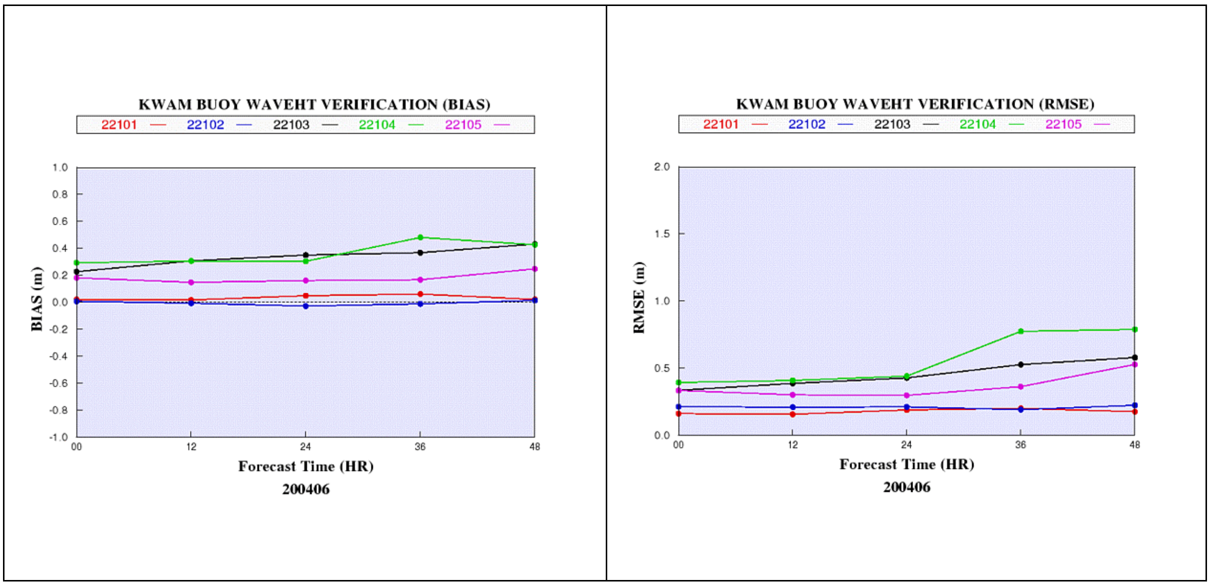

Fig. 9. Same as the fig. 7 but for significant wave height of regional wave model

3.2 Wind and wave against satellite data

The sea surface wind can be validated with scatterometer data from QuikSCAT satellite. The 1800 km swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day. The accuracy of measurement is 2 ms^{-1}. Although the main mission of Topex/Poseidon satellite is measuring the sea surface altimetry, it also provides wave height information along the track. It is determined from the shape of returning pulse of radar altimeter. The orbit covers 95% of the ice-free oceans every 10 days. The resulting model and satellite can be collocated (here, the closest grid point value and the time window of ±3 hours centered at 00 UTC and 12 UTC is assumed to represent the observation point) with the model grid to obtain a global impression of the model behavior. As the global buoy observation network is very limited to specific regions, the satellite data provide a good alternate for model verification.

3.2.1 Global domain

The comparison of QuikSCAT wind, GDAPS sea surface wind, and the difference between the two on same period are shown in figure 10. As the resolution of QuikSCAT wind is about 25km, it depicts some detail features of sea surface wind field while the global model wind blurs or cannot represent those. The monthly error statistics shows model underestimate throughout projection (not shown here). The scatter plot between the QuikSCAT wind and the model sea surface wind, and between the Topex/Poseidon significant wave height and the model one is shown in figure 11. The typical number of QuikSCAT data entry used in monthly validation is close to 20,000 and the correlation is approaching 0.70 for 24-hour projection. The table 3 summarizes the annual variation of the monthly GoWAM error statistics for 24-hour projection against the Topex/Poseidon significant wave height for year 2003. As we have seen in buoy verification, the model underestimate (negative bias) is clear throughout year. The higher rms error range during JJA reflects that the wave variability during southern hemisphere winter is greater than that of northern hemisphere winter.

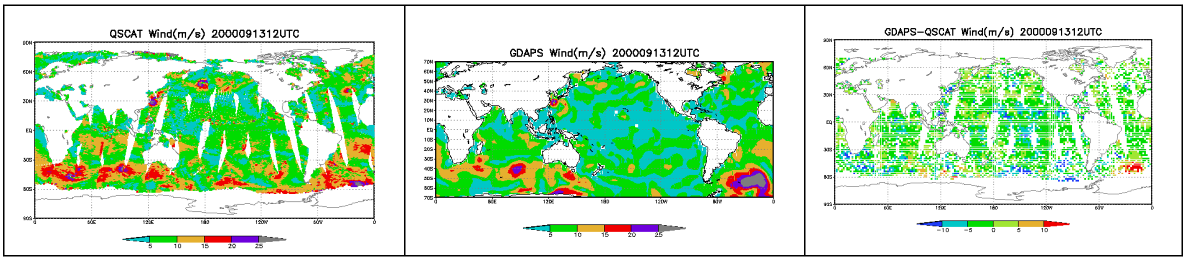

Fig. 10. The QuikSCAT wind (left), the GDAPS sea surface wind (center), and the difference between the two (right) for 13 September 2000 case

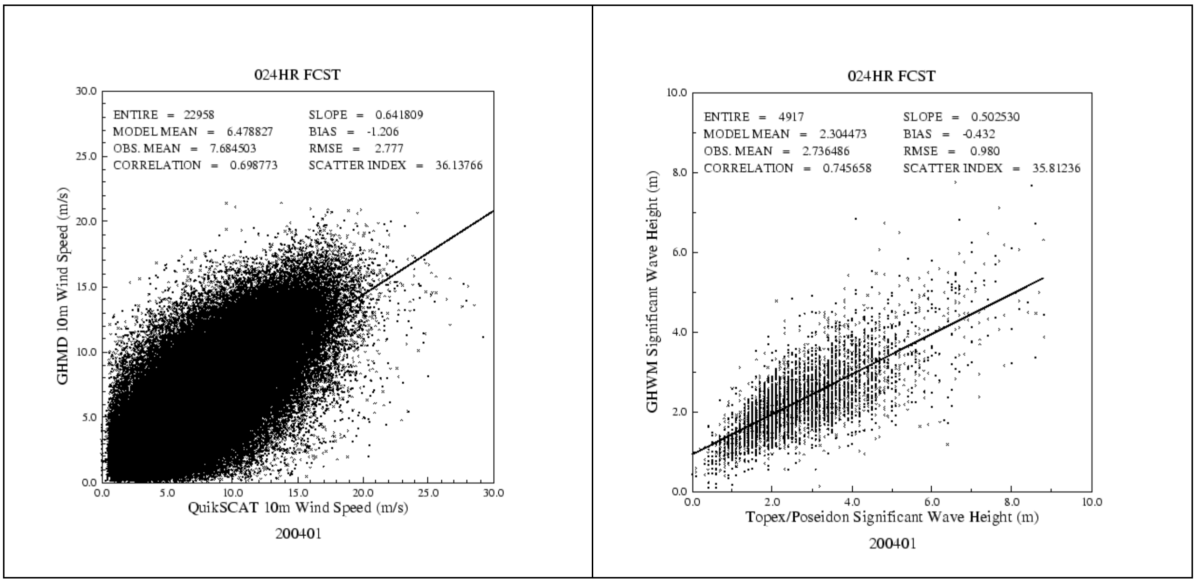

Fig. 11. The monthly scatter plot for 24-hour projection between the QuikSCAT and the GDAPS (left), and the Topex/Poseidon and the GoWAM (right) for January 2004

Table 3. The annual GoWAM monthly error statistics for 24-hour forecast year 2003

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
bias	-0.391	-0.524	-0.534	-0.556	-0.421	-0.456	-0.452	-0.507	-0.452	-0.431	-0.273	-0.248
rmse	1.004	1.155	1.167	1.221	1.079	1.123	1.136	1.206	1.049	1.020	0.995	0.840
corr	0.735	0.695	0.698	0.656	0.749	0.702	0.790	0.614	0.762	0.691	0.675	0.733

3.2.2 Regional domain

The figure 12 shows the comparison between QuikSCAT and RDAPS sea surface wind while the typhoon Saomai was approaching Korean peninsula. The model 24-hour forecast undervalues wind speed along the vicinity of the typhoon. The regional domain error statistics shows better correlation and lower rms error comparing to global domain (figure 13). The number of collocation data with QuikSCAT is about 30,000 and data with Topex/Poseidon is about 1,500. The annual change of the monthly ReWAM error statistics for 12-hour projection against the Topex/Poseidon significant wave height for year 2003 is shown in table 3. As it was in global domain, the model underrates. Any noticeable seasonal error statistics variation cannot be depicted.

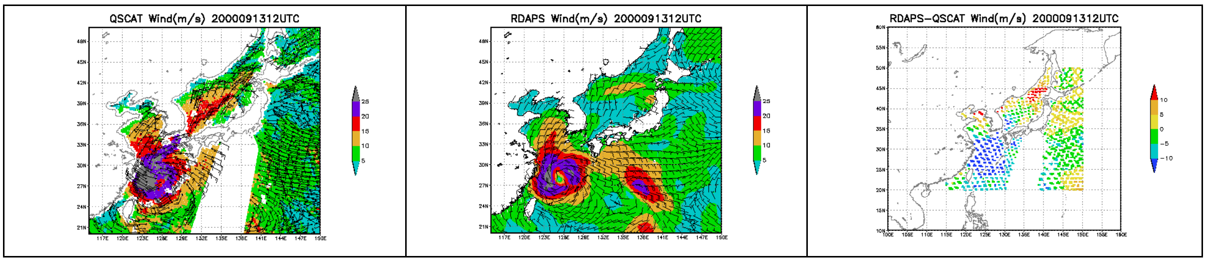

Fig. 12. The QuikSCAT wind (left), the RDAPS sea surface wind (center), and the difference between the two (right) for 13 September 2000 case

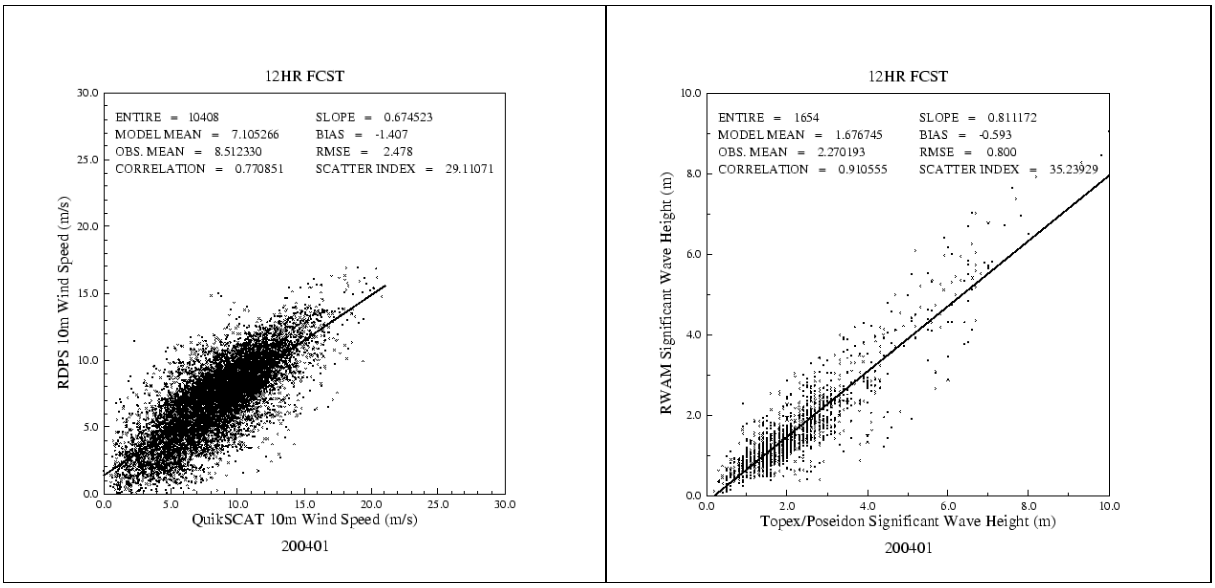

Fig. 13. The monthly scatter plot for 12-hour projection between the QuikSCAT and the RDAPS (left), and the Topex/Poseidon and the ReWAM (right) for January 2004

Table 4. The annual ReWAM monthly error statistics for 12-hour forecast year 2003

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
bias	-0.727	-0.691	-0.616	-0.472	-0.445	-0.214	-0.382	-0.206	-0.295	-0.841	-0.499	-0.572
rmse	0.890	1.006	0.944	0.822	0.806	0.553	0.688	0.440	0.544	1.023	0.626	0.740
corr	0.884	0.757	0.775	0.686	0.685	0.715	0.606	0.671	0.775	0.755	0.879	0.824

4. NEW IMPLEMENTATION PLAN AND ON-GOING WORKS

This section is devoted to introducing the renewal process of KMA wave prediction system in cooperation with Korea Ocean Research and Development Institute (KORDI). The two major demanding elements of these changes are increasing command of resolving coastal wave processes and enhanced capacity of high performance computing which permits expansion of problem dimension, choice of new physics parameterization and numerical schemes. The works which have been partially done are discussed in following subsections.

4.1 New computing environment

The 1st high performance computing environment at KMA was established in 1999. This provides an opportunity of successful progress in research and operation of NWP models. The major implementation of numerical wave prediction has also been accomplished during those periods. Beginning on the 2nd half of year 2004 through year 2005, the new supercomputer will replace the previous one. The 2nd phase of KMA supercomputer migrates from one global shared memory vector processor machine into Massive Parallel Process (MPP) architecture with vector processor. The theoretical peak performance of new system is expected to reach 14.5 Teraflops from 192 nodes (1 node consists of 4 CPUs of 19.2 Gigaflops.). To secure the required model performance in MPP architecture, the Message Passing Interface (MPI) should be realized in model source level. The WAM cycle 4 code in global shared memory machine, the parallelism has been achieved by exploiting the auto-parallelizing compiler features. The wave model, in the 2nd phase of KMA supercomputer, is now required message passing and distributed memory concept to execute the model in multi-node MPP environment.

4.2 New wave prediction system including coastal processes

Establishing of newly devised wave prediction system is underway in conjunction with up-coming computing environment. The main focus of new wave system lies in accommodating coastal wave processes. The west and the south coastal area of Korean peninsular is one of the challenging places in ocean modeling for reasonable prediction of nearshore wave conditions and tides. The SWAN (Simulating WAve Nearshore, Booij et al. (1999)) code has been developed for nearshore zones where complicated shorelines and finite-depth effects become important. One of the main coastal zones in south is chosen for experimental testing with 1/120° mesh size. The directional wave spectra at boundaries were provided from 1/12° modified version of operational ReWAM (KrWAM in figure 14).

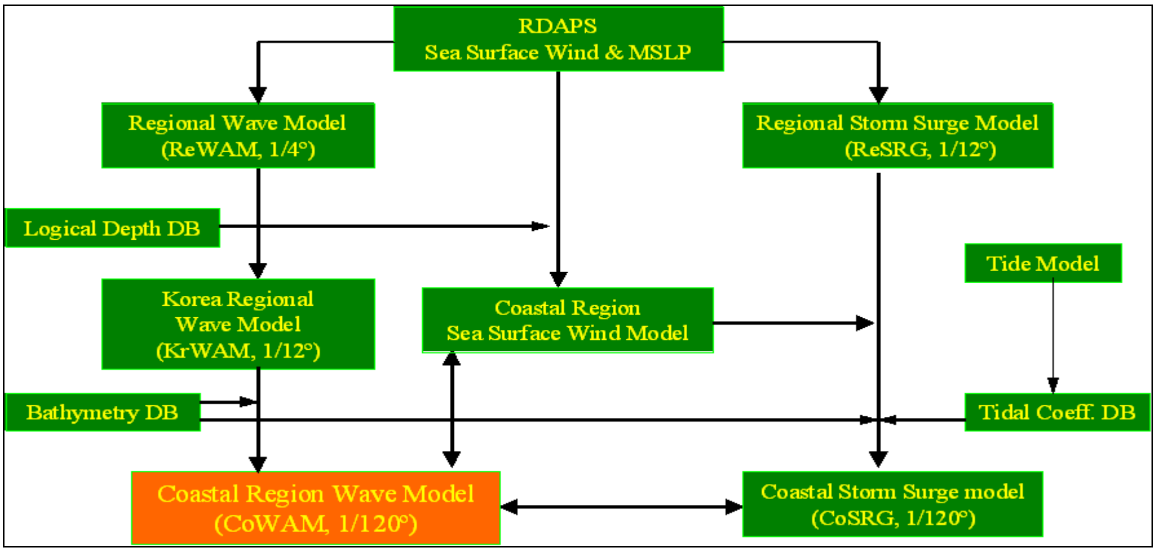

Fig. 14. The schematic diagram of newly devised wave prediction system at KMA

The final shape of wave prediction system will be a downscale nesting with 3-steps (with spatial resolution change: 1/2° > 1/12° > 1/120°) from global to coastal domain. The coastal model will use the water level and currents information from the surge model. The figure 15 shows tentative domains for SWAN simulation. The blue rectangle was the 1st stage and the red rectangle is the 2nd stage, and eventually most of coastal region will be covered. Another testing case while the typhoon Maemi (September 2003) was approaching southern coast of Korea is shown in figure 16. The left panel is the significant wave height and direction forecast and the right panel is sea level elevation and current prediction. The wave height and surge level near inlet area demonstrate detailed spatial distribution and close to observed change in amplitude. This validation needs more analysis when this unripe system is finalized.

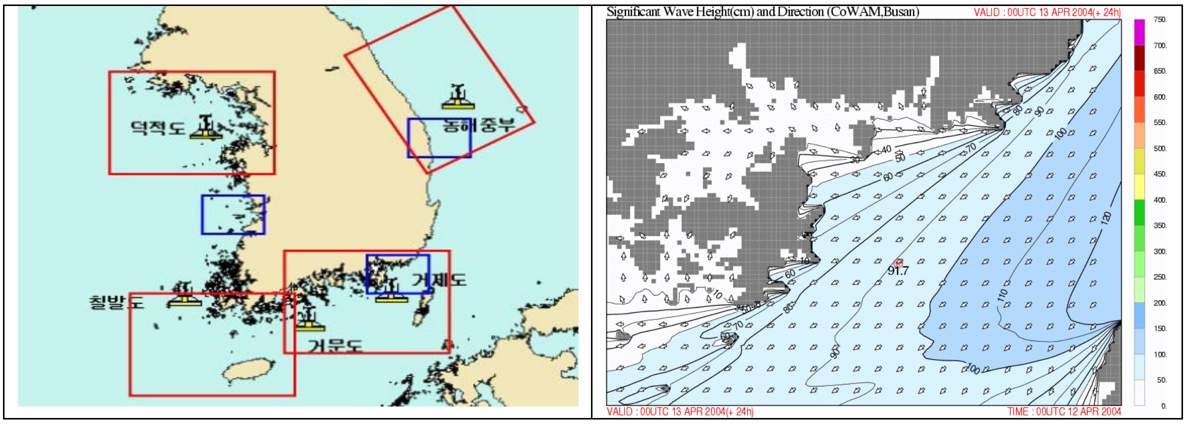

Fig. 15. The tentative domain for SWAN simulation (left) and one site
including Geoje buoy test simulation results (right)

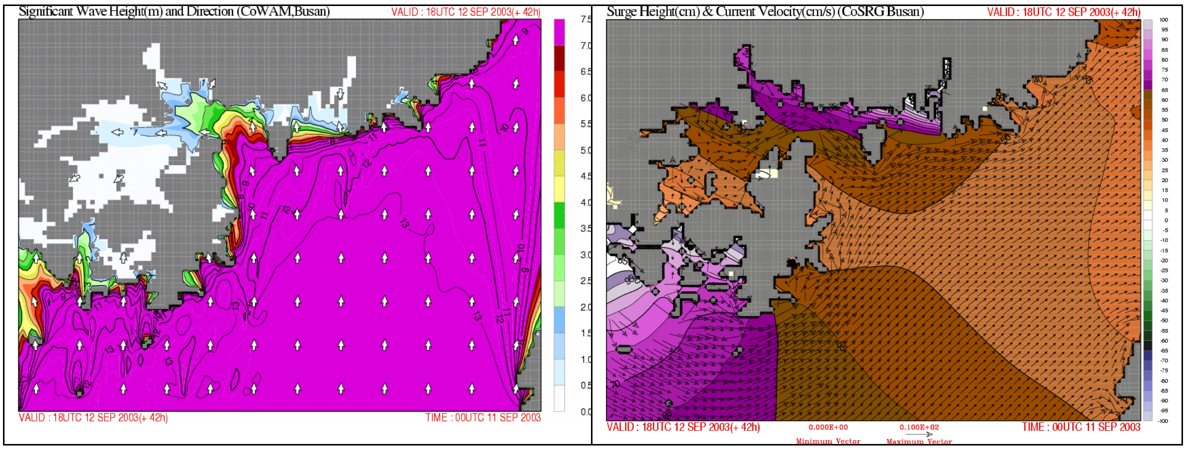

Fig. 16. Demonstration of significant wave height and direction (left) and sea level elevation and current (right) for the case of typhoon advance

The new additions and changes in proposed wave prediction system with the 2nd phase KMA supercomputer can be summarized as follows. First, the model source of GoWAM and ReWAM will be changed from WAM code to Wave Watch III code (Tolman et al., 2002). The latter code is written in Fortran 90 and MPI is used for message passing. Second, the analyzed sea surface wind during the 12-hour FDDA (Four Dimensional Data Assimilation) window of RDAPS will be used to drive the wave fields before the starting time of wave prediction. This will give some benefits within initial several hours of wave forecast. Third, the assimilation of buoy integral wave parameter (wave height and period) will be attempted adapting Optimal Interpolation (OI) scheme for coastal wave system. The impact of observation data is expected having some limitation due to sparse network within domain. And finally, the model variables in post-process will be archived with GRIB format for general access of concerned users.

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