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Numerical On-line Modelling of Sea State in Coastal Areas for Engineering Purposes

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Abstract

Within a joint PPP-Project of the National Cheng Kung University in Tainan, Taiwan and the University of Rostock, Germany financed by NSC and DAAD, it was planned to develop an on-line wave forecast system. The project is scheduled from 2005-2006. The project comprises the following working steps:

- Development of a catalogue of criteria for on-line simulation
- Development and evaluation of strategies for on-line simulation
- Evaluation and selection of existing sea state models
- Adaptation of the sea state models for on-line simulation
- Transfer and assimilation of available meteorological data
- Initial and continuous calibration of the models for selected areas
- Comparison of simulated and measured data
- Development of tools (database, data-conversion, data-publication and presentation)
- Development of a data storage and data flow strategy

In this paper the adaptation of the wave model SWAN for online simulations and

the setup of the model is described. The simulation area covers parts of the Pacific Ocean and the area around the Taiwan island. The model is developed as a „nested model“, that means that a relatively coarse simulation grid (Pacific Ocean, from 2°N to 45°N and from 100°E to 145°E) covers a wider area and a high resolution simulation area covers the area around Taiwan (from 21.5°N to 25,5°N and from 119.8°E to 122.5°E). The nested model is used to ensure reasonable quality of the results of the simulation with respect to the computational time. Additionally, results of the comparison between the simulated and measured data in model area will be shown in this paper.

1 Introduction

The most densely populated areas in the world are the coastal zones. For the requirements of residents, agriculture and recreation, people defend their settlements against the erosive forces of the oceans or even reclaim lands from the ocean to extend the usable area and resources. The development of coastal zones is a very important topic, especially in countries where many different interests in use of coastal areas exist, like Taiwan and Germany.

In this background, a cooperation of the National Cheng Kung University in Tainan, Taiwan and the University of Rostock, Germany was established. One result of this cooperation is a joint PPP-Project, financed by NSC and DAAD and started in 2005. The topic of this joint project is “Numerical On-line Modelling of Sea State in Coastal Areas for Engineering Purposes”. This comprises several steps. One step is the setup of the numerical forecast model, which is described in this paper. The main goal in the step was not the optimisation of the numerical model (speed, accuracy), but the adaptation as a forecast model. Other important parts of the joint project (data handling, data flow, etc.) are not considered here.

2 The Set Up of the Numerical Forecast Model

The numerical online model that is developed within this PPP-Project is based on the model SWAN. SWAN (acronym for “Simulating WAves Nearshore”) is an international widely accepted so called community model for the prediction of waves and sea state. It was chosen because both sides, Germany and Taiwan, are using this model for other practical applications. SWAN was developed and optimized for small simulation areas and shallow water conditions, but it also works well in simulations for ocean areas. During the project, it was decided to setup the new online wave model for the area around Taiwan. To do this with reasonable expenditure of computational time, it was necessary to set up a nested model.

The Nested Wave Prediction System for Taiwan

In a nested model, the complete model is splitted into two (or more) parts. For the wave forecast model a two step simulation with different characteristics was chosen. The first model (“coarse simulation”) has a wide simulation area (approx 5000km x 5000km of the Pacific Ocean, see Fig. 4), with a coarse resolution (the distance between two simulation points). The second part of the model (“fine simulation”) covers a small area (Fig. 4 and Fig. 5), with a fine resolution to reproduce more or less all effects that occur near the coastline. The aim of the coarse simulation is the determination of boundary conditions for the fine simulation.

As the basis for the wave forecast simulation with a numerical model, different input data are needed:

- the bathymetry in the simulation area
- wind conditions (wind speed and wind directions)
- water levels
- currents
- friction-coefficients

The bathymetric data are described below. For the setup of an online wave forecast model, forecast wind fields are needed. For the project area, these data are supplied by the Central Weather Bureau, Taiwan. The wind fields are described in detail below. Because the influence of water levels for the sea state is small in the area around Taiwan, water levels are unconsidered. The local currents and friction-coefficients are unknown, so default values are used. All physical effects (friction, triads, quadruplets) that SWAN can consider, are activated in the model.

Wind Data

Wind is the driving force for the generation of waves. Hence, the selection and handling of wind input data is a very important task during the set-up of a numerical online wave forecast system. The quality of the results of hindcast and forecast systems can not be better than the accuracy of the wind input-data. The input wind date comprises of three different wind fields with different resolutions and covering different areas.

The coarsest wind-field has a resolution of approx. 45km in both directions. It covers an area from approx. 78°E to 180°E and from 6°S to 52°N. The local information of the wind data is supplied in a kind of Lambert-Coordinates. Hence, it is not possible to describe the wind fields in a rectangular grid. The numerical model was developed in rectangular WGS84-Coordinates and the wind field data has to be converted accordingly. Fig. 1 shows the wind-field (the red dots). It also shows the regridded area for the numerical model (blue box) and the simulation areas for the coarse (green box) and high resolution (red box) simulation.

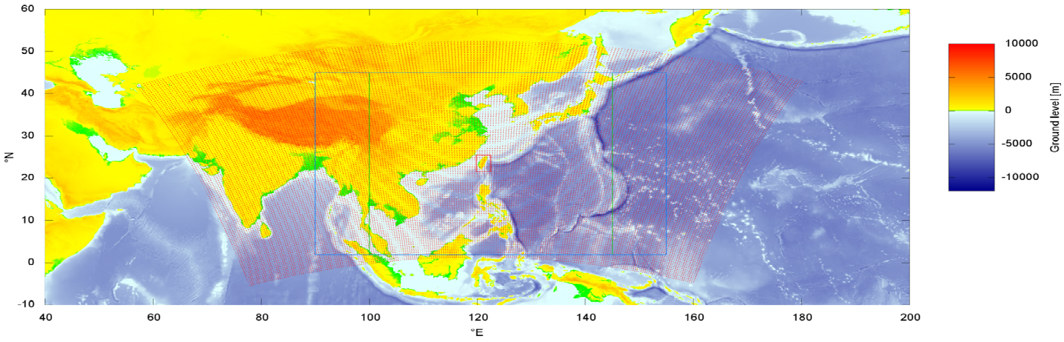

Fig. 1 Coarse resolution wind fields with 45km x 45km resolution (red dots), area of regridded wind field for simulation (blue box), area of coarse (blue box) and fine (red box) simulation

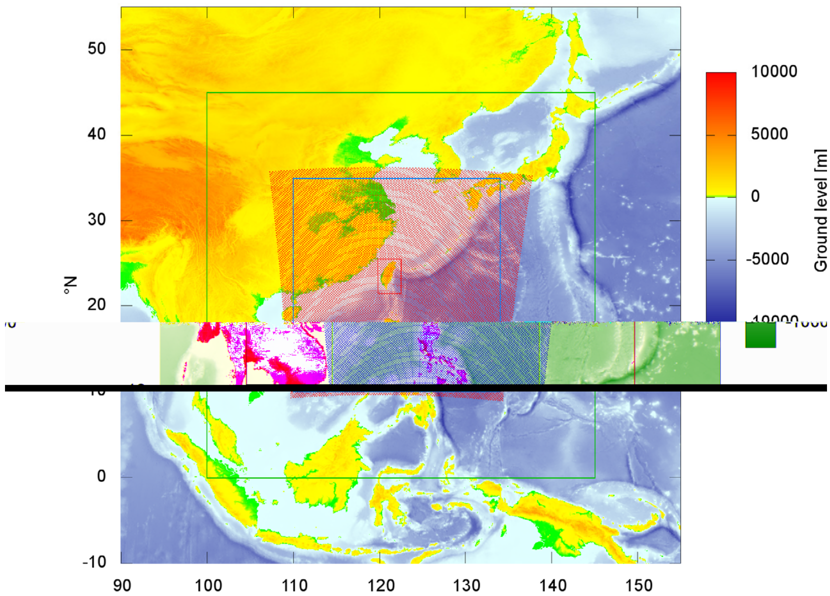

Fig. 2 Medium resolution wind fields with 15km x 15km resolution (red dots), area of regridded wind-field for simulation (blue box), area of coarse (green box) and high resolution (red box) simulation.

The resolution of the *medium resolution wind-field* is approx. 15km. It covers an area of approx. 110°E to 130°E and from 9°N to 36°N. Fig. 2 shows the medium resolution wind-field and also the areas of the regridded wind-field for the simulations and the simulation areas.

The resolution of the third and *highest resolution wind-field* is approx. 5km x 5km. It covers an area of approx. 118°E to 123°E and from 21°N to 26°N. The high resolution wind-field is shown in Fig. 3.

The time-resolution of all three wind-fields is Δt=1h. The forecast-time of the wind-fields is 72 hours, and the Central Weather Bureau supplies a forecast-run every 12 hours (0 and 12 o'clock).

In the beginning of the project it was planned to use the coarsest wind-field (45km resolution) for the coarse simulation and the finest wind-field (5km resolution) for

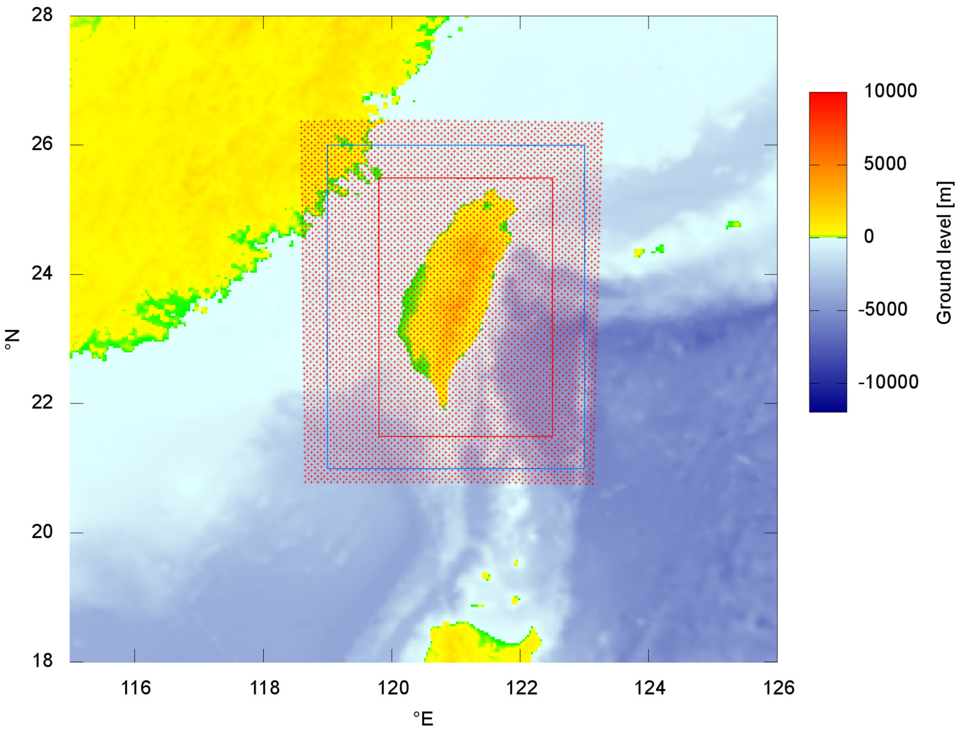

Fig. 3 High resolution wind fields with 5km x 5km resolution (red dots), area of regridded wind-field for simulation (blue box), area of high resolution simulation (red box)

the fine simulation. To integrate these wind-fields into the on-line simulation system, it was needed to adapt the format and to build a new grid based on WGS84-Coordinates. Unfortunately, there are some inconsistencies in the wind-data of the 15km-resolution as well as in the 5km-resolution wind fields. It was not possible to solve these problems so far and, hence, all simulations are performed using the wind-data of the 45km x 45km-resoluted wind-field.

The Coarse Simulation

The area for the coarse simulation covers wide parts of the Pacific Ocean. The bathymetry for the model is taken from the "ETOPO2" database. ETOPO2 data are global relief information, compiled by the National Geophysical Data Center (NGDC), Part of U.S. Department of Commerce, National Ocean and Atmospheric Administration (NOAA), National Geophysical Data Center (2001). The simulation area extends from 2°N to 45°N and from 100°E to 145°E. The "ETOPO2" bathymetry of the simulation area for the coarse simulation is shown in Fig. 4. The resolution of the bathymetry is dx=dy=2 minutes.

For the coarse simulation a resolution of $\Delta x=\Delta y=0.125°=7.5'$ was choose. Hence, 360x344 calculation points are used. The timestep for the coarse simulation is $\Delta t=1h$.

The simulation results are not stored completely. Only selected points at the locations of the buoys of COMC and the information for the boundary conditions of the fine simulation are stored.

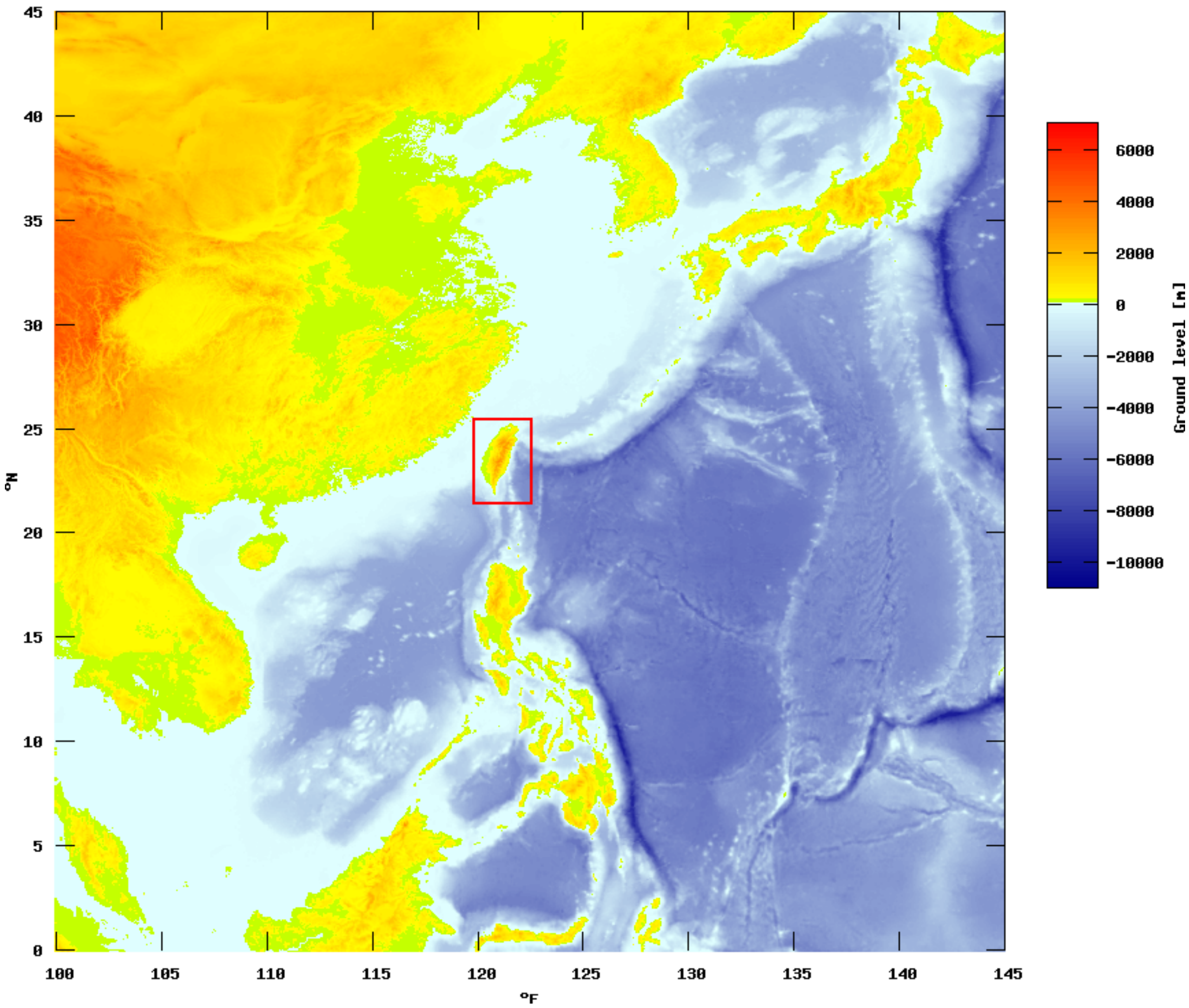

Fig. 4 Bathymetry of area with coarse grid simulation and the nested area fot the high resolution simulation (red box)

The High Resolution Simulation

The simulation area of the high resolution simulation is limited to the region around Taiwan. The bathymetric information for this simulation is based on detailed surveys. The area extends from 21.5°N to 25.5°N and from 119.8°E to 122.5°E. The resolution of the bathymetry is dx=dy=0.005° (0.3 minutes, approx. 550m). The general bathymetry and the simulation area are shown in Fig. . Besides, the positions of the data buoys are indicated in Fig. .

The resolution used for the simulation is lower than the resolution of the bathymetry and was choose dx=dy=0.01° (approx 1km x 1km). Hence, 270x400 points used. The boundary conditions for the fine grid are taken from the coarse grid simulation. The other parts of the model setup are identical to those used in the coarse simulation.

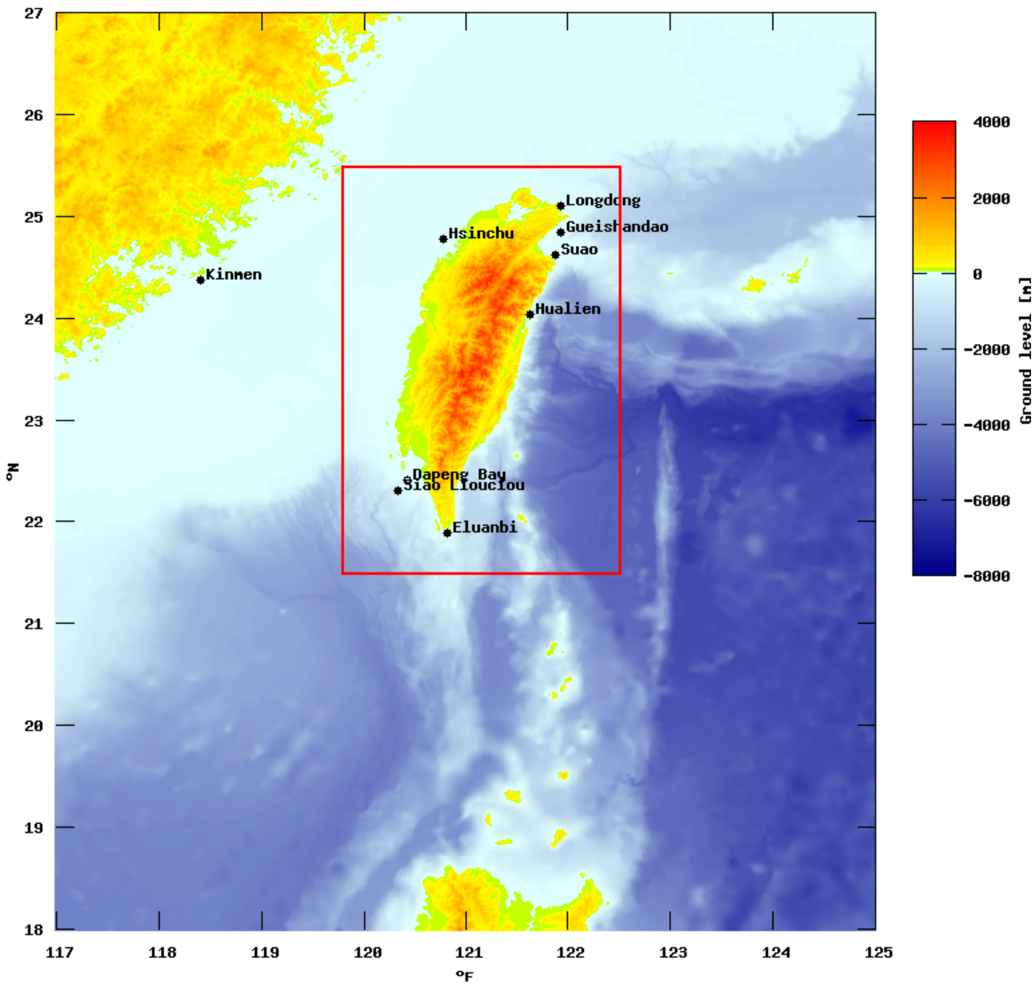

Fig. 5 Fine simulation bathymetry and area (red box) / Position of wave buoys

The Wave Forecast System

An on-line wave-forecast system consists not only in the numerical model which is described above. It contains also a system to import the wind-fields, to implement the data into the numerical model, to run the model and to store the results. The complete data-flow through this system must be reliable and robust. Within this joint project, a wave-forecast system that ensures these demands was developed.

In order to have a robust system, it was decided to make each forecast-run independent from other forecast runs before. The problem in such a system is that the initial conditions of the simulation are unknown. Hence, a so-called "warm-up-period" is needed and has to be implemented into such a robust system. This means that each simulation has to start at a simulation time before the forecast-period starts. In the Taiwan forecast-system, the warm-up-period is 12 hours. For practical reasons and since no measured wind fields are available the warm-up-period is driven with the wind-information from one wind-forecast time step before the actual forecast (Fig. 5) Hence, also the warm-up period is a forecast.

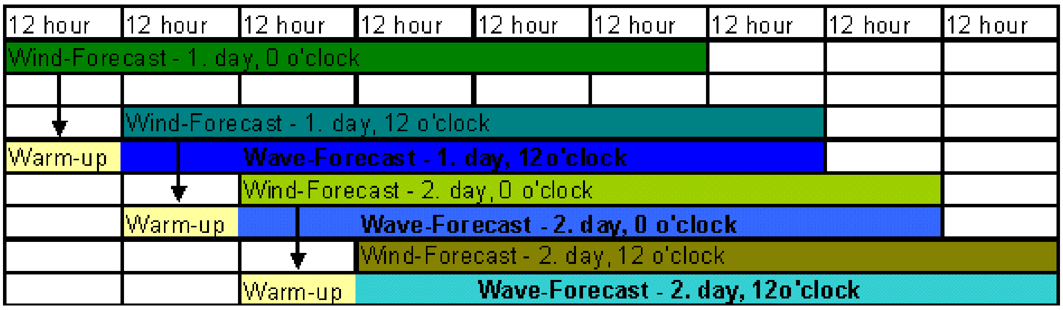

Fig. 5 System of Wave-forecast system

The forecast-period in the wave prediction system was choosing equal to the forecast period of the wind-fields (72 hours). In summary one forecast-run covers 84 hours simulation time (12 hours warm-up + 72 hours forecast). In this setup, one simulation run takes approx. 12 hours calculation time at a 2xXeon 3,06Ghz-System.

3 Results

Unfortunately, only very limited data is available at the moment for research purposes and for the testing of the system. Wind-fields from 2005/27/09 to 2005/03/10 are available, so that 13 forecast runs could be performed only.

Fig. 7 shows a typical time series of significant wave heights in case of relatively small wave heights for Gueishandao. The results of the coarse and fine simulation are more or less in the same range. The average absolute deviation (abs $\Delta\bar{x}$) to wave height data measured with the COMC data buoy is in this case $\Delta\bar{x}$ = 0.35m (coarse simulation) and $\Delta\bar{x}$ = 0.33m (fine simulation) respectively. Fig. 8 shows the wave periods for this case accordingly. The calculated wave periods are to short. The wave direction is illustrated in Fig. 9. It shows a good agreement to the measured data.

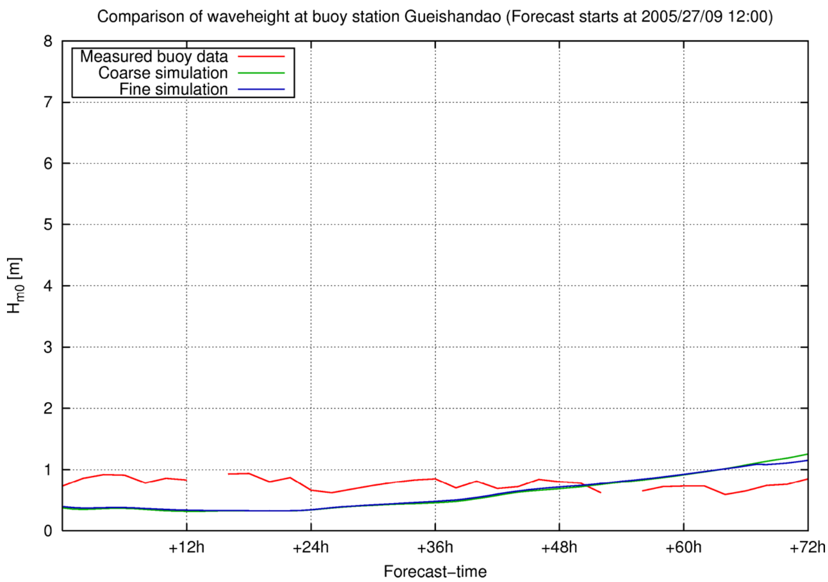

Fig. 6 Comparison of wave heights at Gueishandao

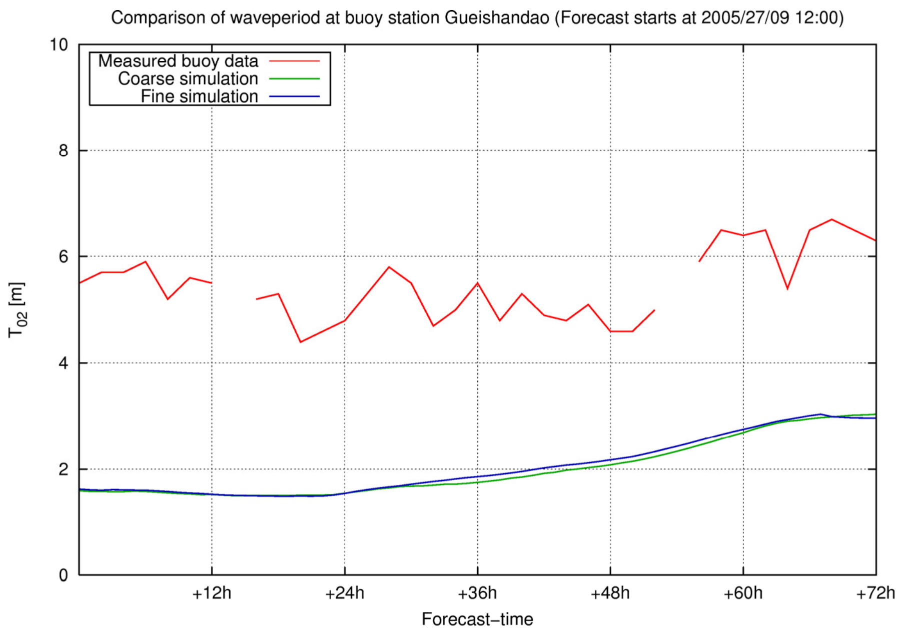

Fig. 7 Comparison of wave periods at Gueishandao

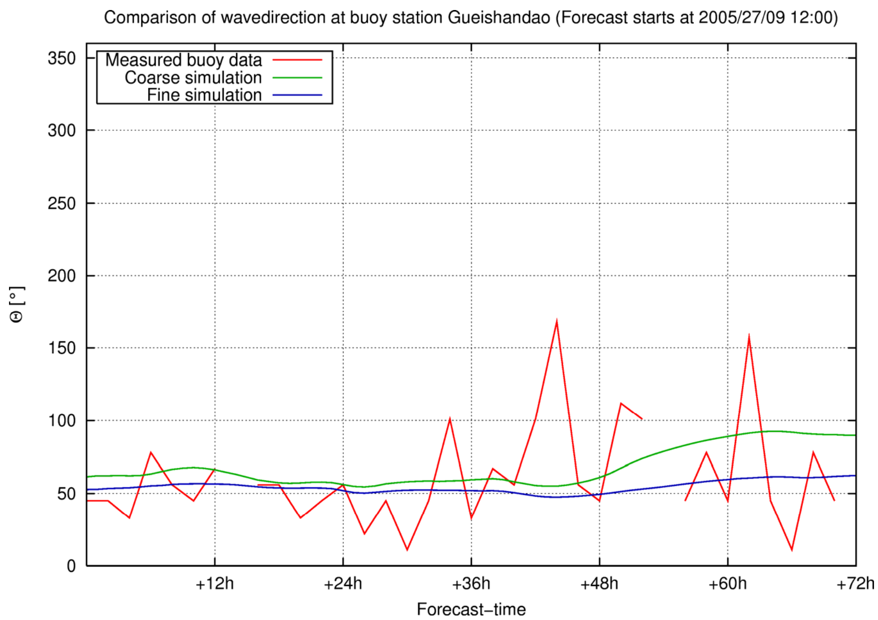

Fig. 8 Comparison of wave directions at Gueishandao

In case of heigher waves the situation differs. Fig. 9 shows such a situation for the wave height of Hsinchu. The figure shows that the calculated wave heights during the first 24 hours of the simulation fit good to the measured data. After this period, the deviation is bigger. An explanation for this is that the wind forecast differs from the reality in this period. It is also noticeable that the calculated values of the coarse and fine simulation differ only a little bit.

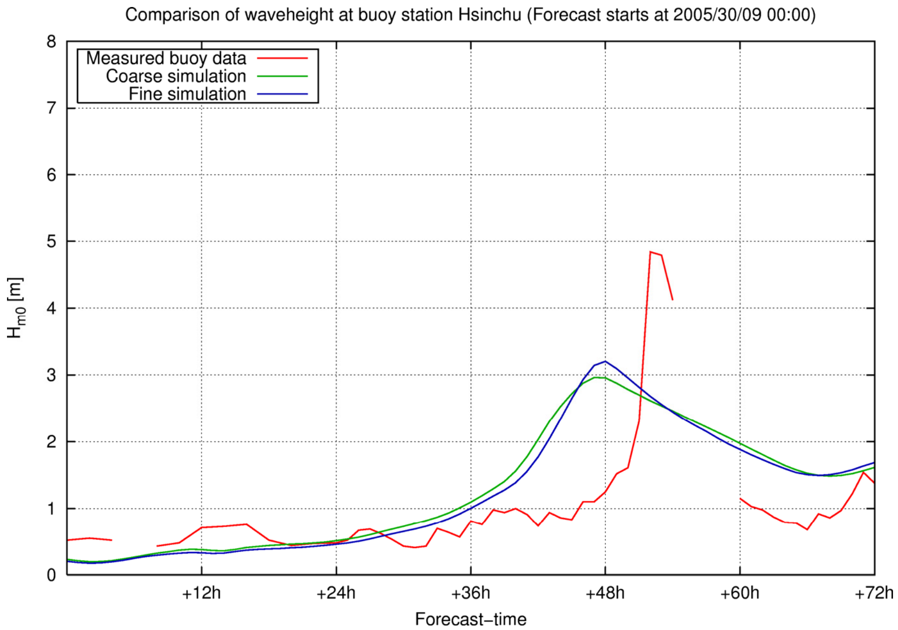

Fig. 9 Comparison of wave heights at Hsinchu

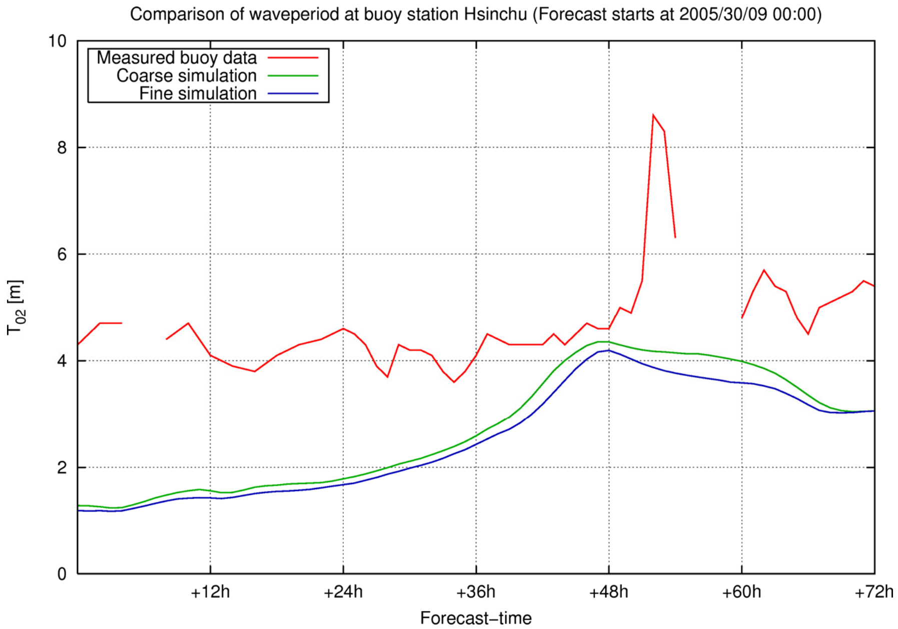

Fig. 10 Comparison of wave periods at Hsinchu

Fig. 11shows the appropriate wave periods for this forecast run. The periods are to short, compared to the measured values. The wave directions have a similar accuracy as in the example above.

To assess the calculations, average absolute deviation values (abs $\Delta\bar{x}$) for all runs have been calculated (Tab. 1). The table shows, that the accuracy of the forecast model is different at different locations. The accuracy of the results at locations at north-east of Taiwan (Longdong, Gueishandao, Suao) are relatively poor. In the south and west of Taiwan (Eluanbi, Dapeng Bay, Siao Liouciou, Hsinchu) the results are more accurate.

Tab. 1 Average absolute deviation of wave heights (- no measured wave data)

Run	Suao	Eluanbi	Hualien	Hsinchu	Longdong	Gueishandao	Siao Liouciou	Dapeng Bay
2005/27/09 12:00	0.42	0.56	0.28	0.26	0.45	0.33	0.68	0.68
2005/28/09 00:00	0.33	0.41	0.23	0.20	0.34	0.29	0.39	0.45
2005/28/09 12:00	0.37	0.47	0.28	0.22	0.32	0.36	0.36	0.32
2005/29/09 00:00	0.52	0.46	0.41	0.18	0.66	0.63	0.51	0.36
2005/29/09 12:00	1.38	0.49	0.75	0.55	1.07	0.96	1.16	0.98
2005/30/09 00:00	1.42	0.63	0.83	0.65	1.06	1.19	0.46	0.35
2005/30/09 12:00	1.28	0.77	0.79	0.59	0.76	1.00	0.53	0.42
2005/01/10 00:00	1.45	0.89	0.85	0.41	0.69	0.83	0.43	0.36
2005/01/10 12:00	-	-	0.88	0.44	0.80	0.78	0.75	0.59
2005/02/10 00:00	-	-	0.96	0.50	0.78	0.72	0.73	0.55
2005/02/10 12:00	-	-	0.69	0.44	0.61	0.53	0.84	0.67
2005/03/10 00:00	-	-	0.38	0.50	0.41	0.42	0.52	0.46
2005/03/10 12:00	-	-	0.22	0.56	0.33	0.26	0.21	0.23

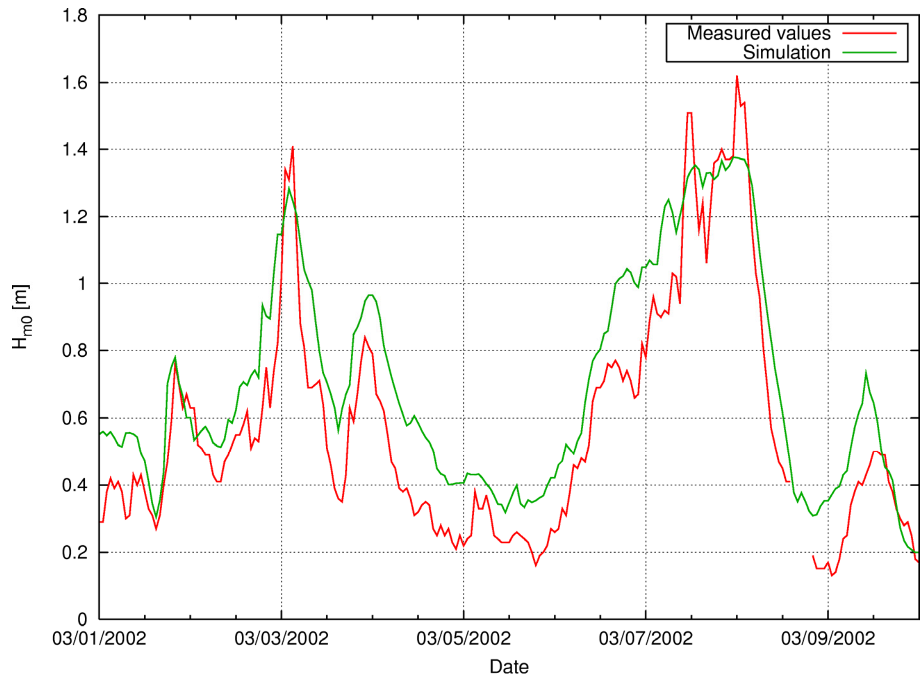

Fig. 11 Example of wave heights from Baltic Sea model at Boergerende

The calculated wave periods are to low in all cases. This is a well known problem in numerical wave simulation systems which could not solve within this project.

The forecasted wave directions have a good agreement to the measured data.

In this context it must be stated than in some cases also the simulated wave parameters at the end of the start-up period differ reasonably from the measured wave parameters, Deviations in this range have never been observed in simulations for the Baltic Sea (Fig. 11). Hence, a significant improvement of the forecast system can be expected if wind fields based on wind measurements can be used for future simulations.

4 Summary

Within a joint PPP-Project of the National Cheng Kung University of Tainan, Taiwan and the University of Rostock, Germany, an on-line wave forecast system has been developed. The system is based on the numerical wave simulation model SWAN which was adapted for forecasts. The system has been implemented for parts of the Pacific Ocean and the area around the Taiwan Island. The numerical simulation is based on a nested model to ensure reasonable quality of the results especially with respect to the computational time of the model. The model is operated using wind-fields, which are provided by the Central Weather Bureau, Taiwan.

The model was used to calculate several forecast runs for periods in September and October 2005. Since this is a relatively limited simulation period, a final and general conclusion about the accuracy of the model can not be drawn.

One problem is that only wind-data with a resolution of 45 km x 45 km could be used, because the wind-fields with higher resolution have shown data inconsistencies.

For the simulation runs which have been performed within the project up to now, the accuracy of the results is varying and clearly depending on the forecast period. The results are better in case of short forecast periods and worse in case of longer forecast periods. This may depend on the accuracy of the input wind-data.

Additionally, the accuracy depends on the location. Results for the north-eastern part of the seas around Taiwan are worse than in other regions around the island of Taiwan. Because the limited simulation periods which have been performed, this effect can not be stated as a general effect.

The predicted wave periods are in general too short, which is a well known problem with simulations using SWAN. The calculated wave directions fit in all investigated cases well to the measured values.

For the future, it is planed to extend the testing and evaluation of the model to assess the accuracy of the simulation results more in general.

The problems with higher resolution wind-fields should also be solved to improve the accuracy of the model. Finally, the system should be tested for real “on-line” cases.