The Next Generation's Storm Surge Prediction System in Japan Meteorological Agency

Hiroshi HASEGAWA, Nadao KOHNO, Masakazu HIGAKI and Masaki ITOH
Office of Marine Prediction, Global Environment and Marine Department, Japan Meteorogical Agency

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Abstract

Japan Meteorological Agency (JMA) is planning to upgrade storm surge prediction system in the next JMA super computer system (from 2018). This upgrade includes introducing Ensemble Prediction System (EPS) and large change of model schemes. In the JCOMM International Workshop on Wave Hindcasting and Forecasting 5th & Coastal Hazard Symposium (Key West, Florida, U.S.A., November 2015), JMA presented development of storm surge model which includes multi-scenario prediction system and unstructured grid model. In June 2016, JMA introduced multi-scenario prediction system. In the next JMA super computer system, JMA plans to extend multi-scenario prediction system and introduce storm surge Ensemble Prediction System (EPS) and probabilistic forecast. JMA is considering introducing also unstructured grid storm surge model and developing Finite Element Method (FEM) and Finite Volume Method (FVM) schemes.

1 Current sytem

JMA routinely operates two storm surge models (Figure 1). One is Japan area storm surge model which is used for mainly issuing storm surge warnings in domestic region. Another model, which is Asia area storm surge model, is operated for the purpose of providing real time storm surge information for Typhoon Committee members in the framework of the Storm Surge Watch Scheme (SSWS).

1.1 Japan area storm surge model

JMA, which is responsible for issuing storm surge warnings, has operated a numerical storm surge model since 1998 to provide basic information for the warnings. Numerical storm surge prediction started in July 1998 only when a typhoon exists. The storm surge model has been modified in enlarging the model domain, prediction for

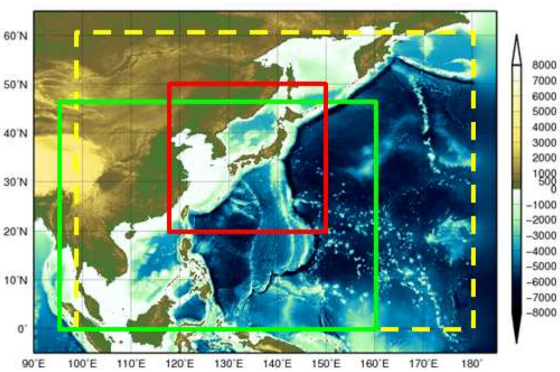

Figure 1: Model domain. The red frame shows Japan area storm surge model domain, the green frame shows Asia area storm surge model domain, and the yellow frame shows RSMC Tokyo's area of responsibility

the extratropical cyclone case, extending of forecast time and adding advection terms, etc. Since May 2010, for more detailed information and warnings, a new storm surge model with higher resolution (approximately 1 km mesh) and the gridded astronomical tide analysis method have been operated.

Table 1 shows the model's specifications. The Japan area storm surge model is based on normal finite difference method, but the model adopts Adaptive Mesh Refinement (AMR) (Berger and Oliger, 1984[2]) as a grid system (Figure 2). The fields of surface wind and atmospheric pressure predicted by the JMA Meso-Scale Model (MSM) are required as external forcing for the storm surge model. When a tropical cyclone (TC) exists around Japan, a simple parametric TC model is also used. The simple parametric TC model (or referred to as bogus) is introduced in order to take into account the error of TC track forecast and its influence on storm surge forecasting. To consider the influence of TC track uncertainty on the occurrence of storm surge, we conduct

Table 1: Specifications of the Japan area storm surge model

Model	2-dimensional model
Grid	Lat-Lon Arakawa-C grid
Region	20°N - 50°N, 117.5°E - 150°E
Resolution	approximately 1, 2, 4, 8, 16 km (AMR)
Time step	4 seconds
Initial time	00, 03, 06, 09, 12, 15, 18, 21 (UTC)
Forecast time	39 hours
Member	TC case: 6 members (MSM+5 bogus) no TC case: 1 member (MSM)

five runs of the storm surge model with five possible TC tracks (Figure 3). These TC tracks are prescribed at the center and at four points on the forecast circle within which a TC is forecasted to exist with a probability of 70%:

1. Center track
2. Fastest track
3. Rightward biased track
4. Slowest track
5. Leftward biased track

Details of the model specification are described in JMA (2013)[7].

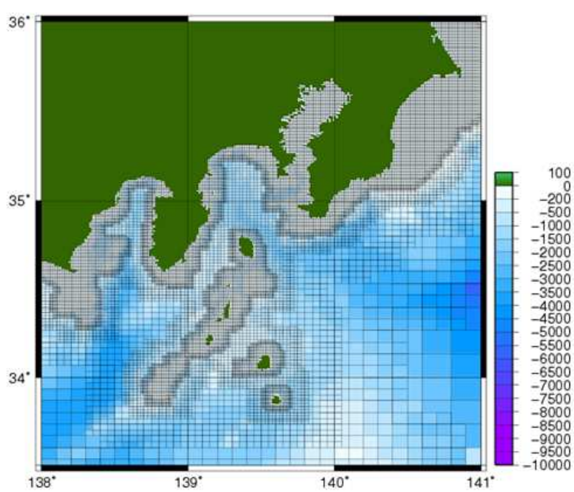

Figure 2: Adaptive Mesh Refinement and water depth (m)

Current five runs with possible TC tracks on the forecast circle don't always have the same possibilities. Storm surge EPS, which include sufficient number of

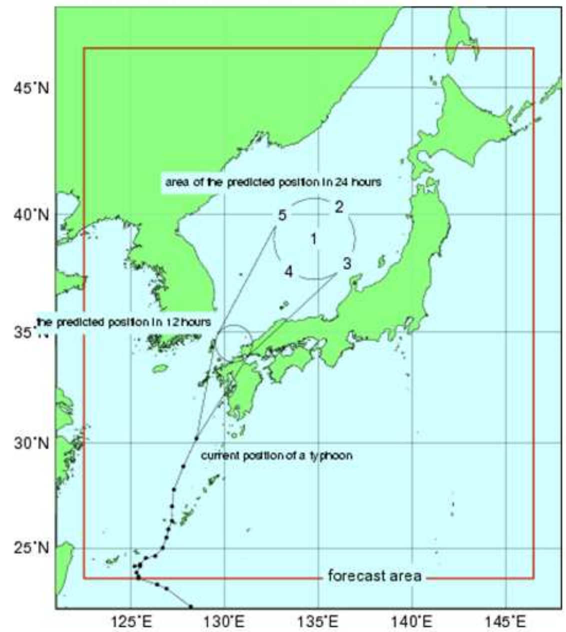

Figure 3: TC tracks on the forecast circle (for Japan area storm surge model

members based on Meso-scale EPS (MEPS [1]), is needed for valid information for risk management.

1.2 Asia area storm surge model

In response to a request by the WMO Executive Council (60th session, June 2008), WMO initiated the development of a regional SSWS in regions affected by tropical cyclones. In relation to the western North Pacific and the South China Sea, the ESCAP/WMO Typhoon Committee (41st session, January 2009) endorsed a commitment by the RSMC (Regional Specialized Meteorological Center) Tokyo - Typhoon Center to prepare storm surge forecasts with the aim of strengthening the storm surge warning capabilities of National Meteorological and Hydrological Services (NMHSs) in the region. JMA began development of a storm surge model for the Asia region in 2010 (Hasegawa et al., 2012[5]), in collaboration with Typhoon Committee members who provide sea level observation and sea bathymetry data. Horizontal distribution maps of predicted storm surges and time series charts have been published on JMA's Numerical Typhoon Prediction (NTP) website.

Specifications of the Asia area storm surge model are basically the same as the ones of the Japan area storm surge model (Table 2). The model has been upgraded

[1] JMA plans to start routinely operating MEPS in the next super computer system.

Table 2: Specifications of the Asia area storm surge model

Model	2-dimensional linear model
Grid	Lat-Lon Arakawa-C grid
Region	0° - 46°N, 95°E - 160°E
Resolution	2-minutes mesh (approximately 3.7 km mesh)
Time step	8 seconds
Initial time	00, 06, 12, 18 (UTC)
Forecast time	72 hours
Member	TC case: 6 members (GSM+GEPS 5 scenarios) no TC case: 1 member (GSM)

several times. In June 2016, a multi-scenario prediction method was incorporated into the model to support the provision of more useful risk management information (Hasegawa et al., 2017[6]). In the method, five additional TC track forecast scenarios generated from 27 ensemble members of the Global EPS (GEPS) based on Cluster Analysis (K-means method) (Figure 4). As the horizontal resolution of the Global model is too coarse to allow representation of typhoon structures, a typhoon bogus is introduced into the atmospheric fields of the five selected ensemble members.

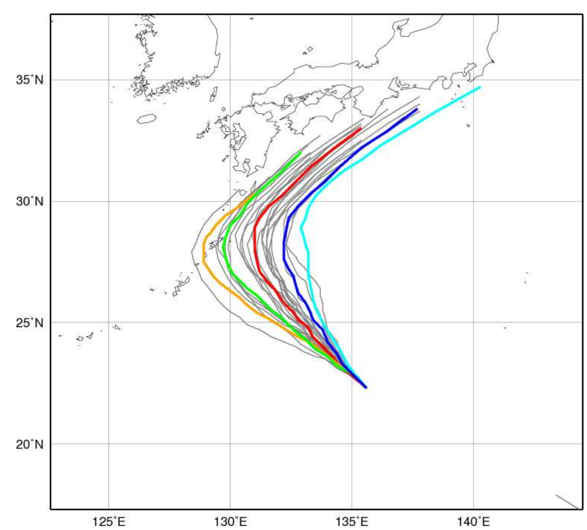

Figure 4: Example of cluster analysis. Colored lines show five selected tracks. Gray lines show all EPS tracks

JMA plans to add scenarios and incorporate probabilistic forecasting into its next super-computer system (from 2018) for further improvement of storm surge prediction information.

2 New sytem

In current system, each two models adopt respective grid systems and typhoon scenarios. Therefore, it is costly to manage the models and it prevents comprehensive development. In the next JMA super computer system, basically, the two models are going to be managed and developed in common programs.

2.1 Un-Structured Grid

JMA had been developing the new storm surge model based on Arakawa A-grid (Arakawa and Lamb, 1977[1]) and FEM with aim of introducing Un-Structured Grid (USG). JMA had shifted to developing the model based on Arakawa B-grid and FVM in terms of computational efficiency, accuracy and energy conservation. In the B-grid discretization, vector values are located in centroids of triangle and scalar values are located in vertices (Figure 5). This discretization is used in FVCOM (Chen et al., 2013[3]) and FESOM2 (Danilov et al., 2017[4]).

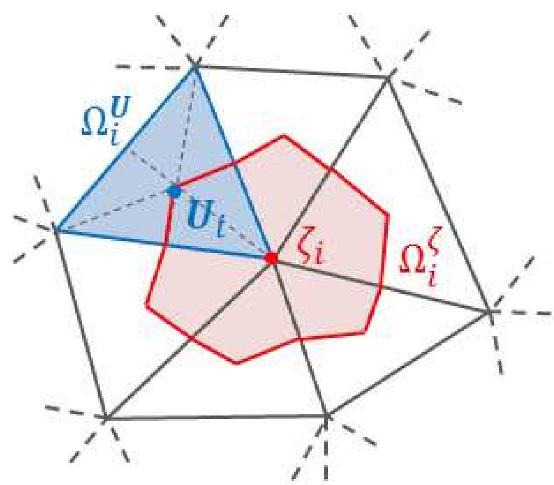

Figure 5: Arakawa B-grid in general triangulation mesh. Storm surge ζ_i is predicted in control volume Ω_i^ζ and current flux vector $\mathbf{U}_i$ is predicted in control volume $\Omega_i^{\mathbf{U}}$.

In JMA's USG, resolutions are unified along target coastlines and depend on length from the coastlines in oceanic region (Figure 6). These resolutions are enough for operational use because storm surges in oceanic region are not important and accuracies in coastal area are guaranteed (Figure 7). GPV size could be largely saved by the USG compared to current grid systems (Table 3). The USG is valid because more computer resources are being required when the storm surge EPS is introduced.

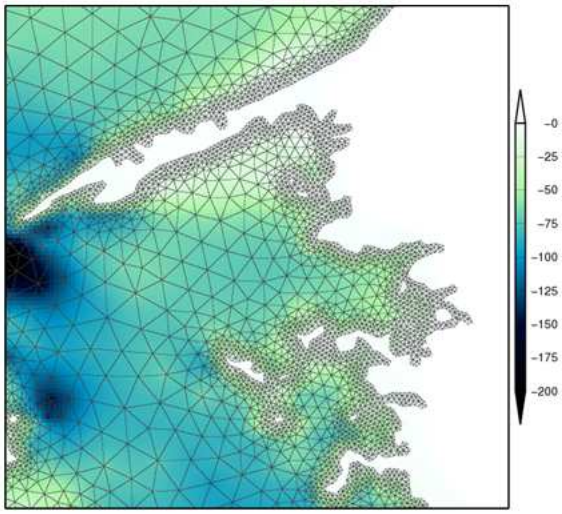

Figure 6: Un-Structured Grid and water depth (m)

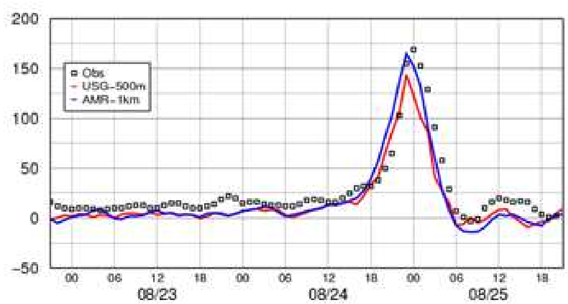

Figure 7: Storm surge time series chart in Chofu for Goni (T1515). Initial time is 18 UTC 23 August 2015. Squares show observation. Blue line shows storm surges predicted by current model (AMR, maximum resolution: 1km). Red line shows the one predicted by FVM model (USG, maximum resolution: 500m.)

Table 3: Comparison of the number of grids between current system and USG

Model	Japan area	Asia area
Current grid	1.1×10^6 (AMR, max: 1km)	1.4×10^7 (2min)
USG	2.0×10^5 (max: 500m)	4.3×10^5 (max: 1min)

2.2 Ensemble Prediction System

JMA plans to introduce storm surge EPS using whole members of atmospheric EPS in the next super computer system. The Japan and Asia area storm surge models are going to use MEPS and GEPS as atmospheric boundary condition, respectively.

For improvement of information for risk management, probabilistic forecast is expected. JMA is considering what information is valid for risk management and how all ensemble members' information should be organized into simple products.

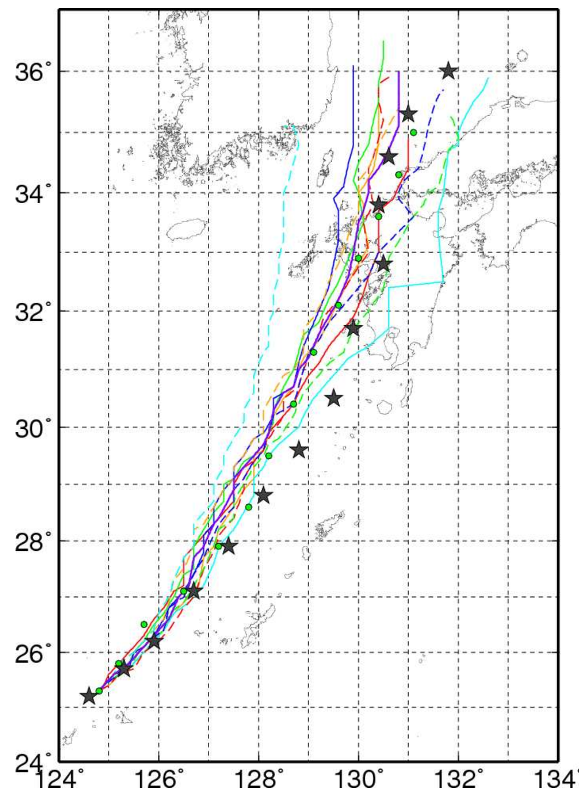

Figure 8: Tracks predicted by MEPS for Goni (T1515). Colored lines shows the predicted tracks (11 members). Stars show analyzed track.

Figure 8 shows 11 tracks predicted by MEPS (development version) for Goni (T1515) in 23 August 2015. Goni caused storm surges exceeding 1m over western Japan. Figure 9 and figure 10 show storm surge maxima among all members and probabilities of storm surges exceeding 1m in western Japan, respectively. The maximum map supports risk management by clarifying worst-case scenarios, although the information is approximate and such scenarios may not arise. JMA is also considering adding probability information to time series charts. Figure 11 show the time series of box plot and probabilities histogram in Chofu. Variation of predicted storm surge values could be read from the box plots. The histogram shows probabilities time series of storm surge exceeding 0.5m or 1m. The probabilities histogram could be applied to whether storm tides would exceed warning and advisory tide or not.

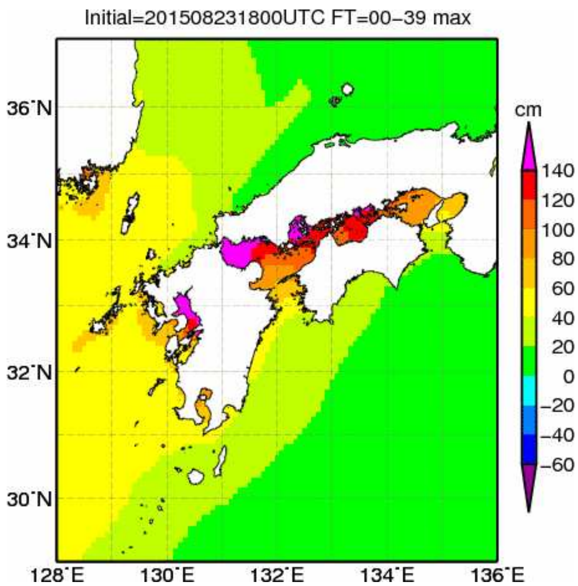

Figure 9: Predicted storm surge maxima among all members in Goni (T1515)

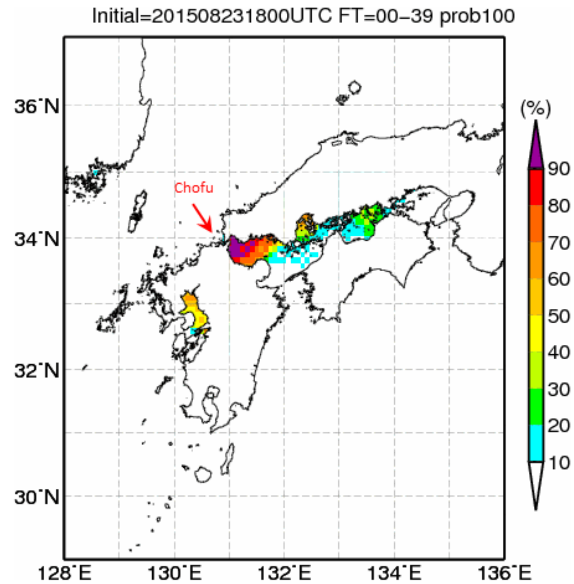

Figure 10: Probabilities of storm surges exceeding 1m in western Japan

3 Summary

JMA operates two storm surge models and their specifications are different with each other. The new model, which is based on the USG and FVM, is being developed for the both two models. Currently, the number of ensemble members is insufficient to further improvement of storm surge prediction information. JMA plans to add ensemble members and issue probabilistic forecasting in the next JMA super computer system.

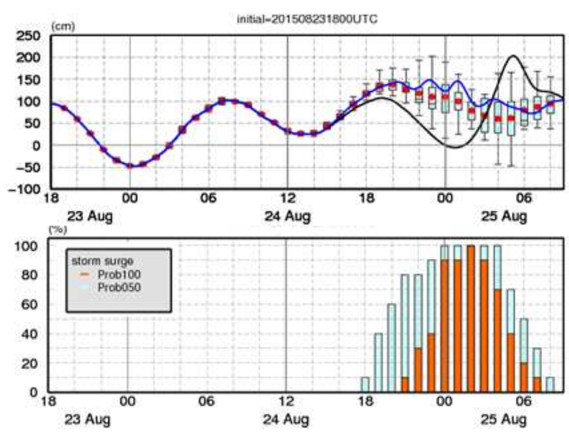

Figure 11: Time series of box plot (upper) and probability hitogram (lower). Blue and orange bars show the probability of storm surge exceeding 0.5 m and 1 m, respectively.

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