Upgrade of JMA's Storm Surge Prediction for the WMO Storm Surge Watch Scheme (SSWS)

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1. Introduction

Since 2011, JMA has operated a storm surge model to support its provision of real-time storm surge prediction information to ESCAP/WMO Typhoon Committee Members within the framework of the WMO SSWS (Hasegawa et al. 2012). The Asia-area storm surge model has been upgraded several times, and JMA began issuing storm surge time-series charts for selected locations in 2012. The Agency also extended the model's forecast domain in 2013 and began providing storm surge prediction information for no-typhoon situations associated with the winter monsoon and synoptic eddies in January 2016. A multi-scenario prediction method was incorporated into the model in June 2016 to support the provision of more useful risk management information.

2. Model

Table 1 shows the model's specifications, which essentially have not been updated since the beginning of operation in 2011 (including storm surge dynamics; see JMA 2013 5.5.2.2). The forecast domain was extended in 2013 to cover most of RSMC Tokyo's area of responsibility (Figure 1). The accuracy of the current model is equivalent to that of the original (see JMA 2013 5.5.2.6).

Table 1 Asia-area storm surge model specifications

Model	2-dimensional linear type
Grid	Lat-lon
Region	0 – 42ºN, 95 – 160ºE
Resolution	2' x 2', 1,951 x 1,381 (– 3.7 km)
Time step	8 seconds
Forecast time	72 hours
Cycle	4/day (every 6 hours)
Initial times (UTC)	00, 06, 12, 18
Members	No-typhoon situations: 1 (model GPV) Typhoon situations: 6 (model GPV + bogus)
Model GPV forcing	GSM (0.25 x 0.2º) GEPS (0.5625 x 0.5625º)
Typhoon forcing (bogus)	Pressure: Fujita formula Inflow angle: 30º Velocity for asymmetry

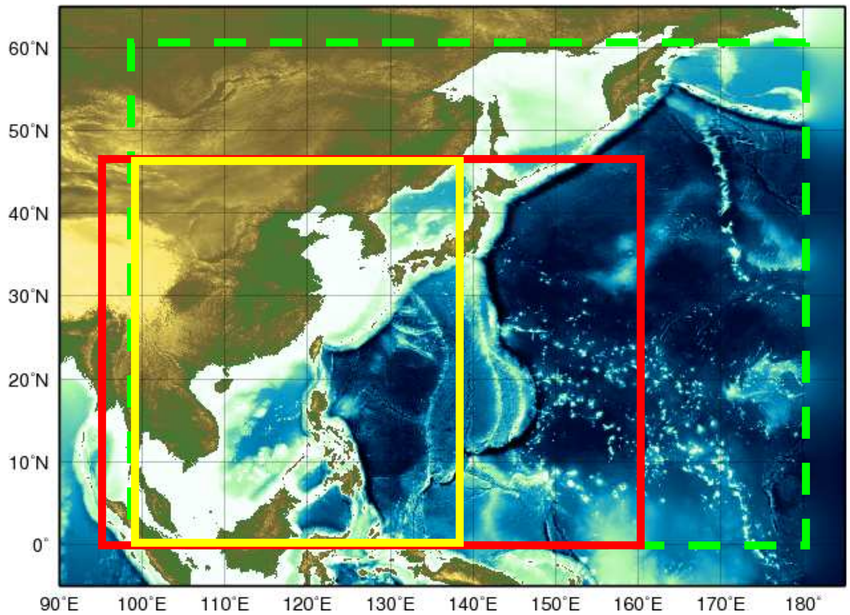

Figure 1 Model domain

The red frame shows the current Asia-area storm surge model domain, the yellow frame shows the previous domain, and the green frame shows RSMC Tokyo's area of responsibility.

2.1 Dynamics

The model's equations are based on linearized two-dimensional shallow water formulae without advection terms. The model includes wind setup due to strong wind and inverse barometer effect associated with pressure drops, but does not incorporate schemes of wave setup, coastal inundation and sea level changes associated with other factors such as sea water temperature.

2.2 Meteorological forcing

A simple parametric tropical cyclone model (typhoon bogus) and products of an atmospheric model are used for meteorological forcing (see JMA 2013 5.5.2.4). Storm surge model calculation requires an atmospheric model that covers the Asia region; as the resolution of the atmospheric model is not sufficient to express typhoon intensity, meteorological forcing is generated by planting a bogus into the atmospheric model GPV.

2.3 Multi-scenario prediction

Deterministic forecasting is insufficient for risk management because storm surge behavior is strongly dependent on typhoon tracks. Accordingly, JMA introduced multi-scenario predictions into the model in June 2016. In addition to an official JMA TC track forecast, five additional TC track forecast scenarios generated from 27 ensemble members of the Global EPS (GEPS) replacing the JMA Typhoon Ensemble Prediction

System (TEPS) (Kyouda and Higaki, 2015) have been issued since January 2017 based on Cluster analysis (K-means method):

$$C_k = \frac{1}{N_k} \sum x_i, (k = 1, \cdots, K)$$
$$x_i = (lat_i, lon_i), (i = 1, \cdots, N)$$

where C_k is the cluster center and x_i is the typhoon location. Here, $N = 25$ and $K = 5$.

The K-means method involves the classification of 27 ensemble members into 5 clusters, each of which should have appropriate variance (Figures 2 and 3). Cluster analysis is carried out iteratively until the clusters are converged, and the ensemble member closest to the means of the ensemble members in each cluster is selected. As the horizontal resolutions of the GSM and GEPS are too coarse to allow representation of typhoon structures, a typhoon bogus is introduced into the atmospheric fields of the GSM and the five selected ensemble members.

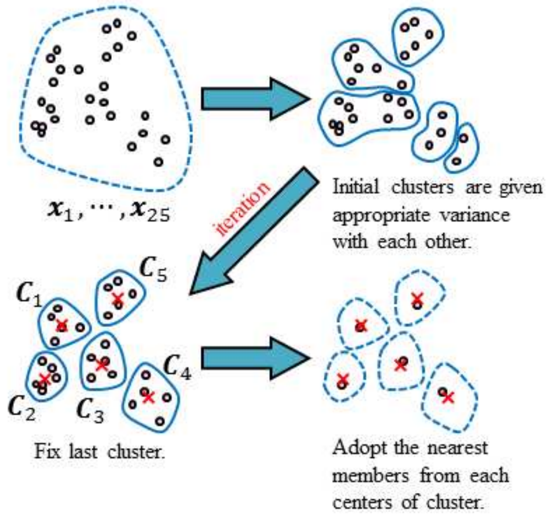

Figure 2 Cluster analysis (K-means method)

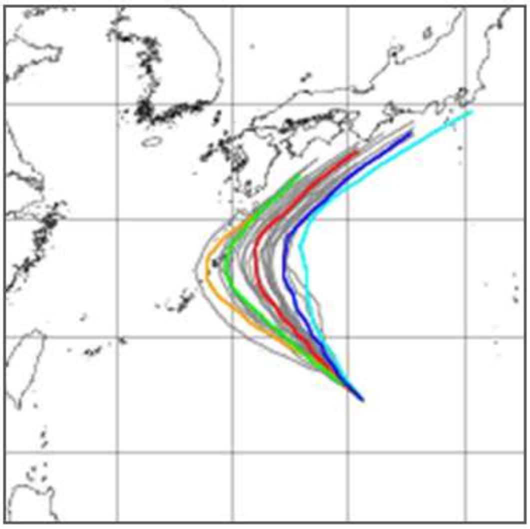

Figure 3 Cluster analysis results

Colored lines show the five selected tracks, and grey lines show all ensemble members.

Figure 4 shows the scheme for generation of multi-scenario storm surge predictions. If no named tropical cyclone is present in the area of responsibility, one storm surge prediction is made each day based on the GSM's atmospheric fields. If one or more named tropical cyclones are present or expected within 24 hours, the storm surge model is run four times a day with the GSM's atmospheric fields for official forecasts of TCs and the five selected ensemble members.

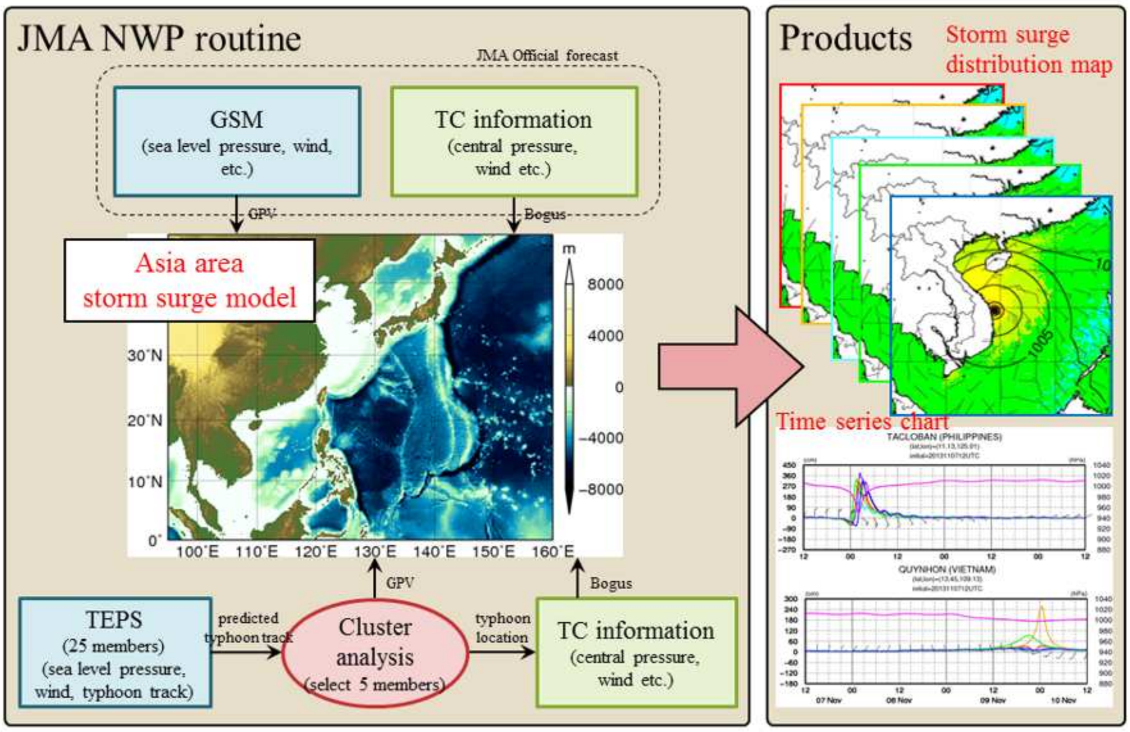

Figure 4 Operational scheme

3. Storm surge products

JMA began issuing storm surge distribution maps for Typhoon Committee Members via its Numerical Typhoon Prediction (NTP) website (https://tynwp-web.kishou.go.jp/) in 2011 (Figure 5), and added storm surge time-series charts for selected locations in 2012. The charts include astronomical tides based on harmonic analysis for locations where observation data are available. Charts for 68 locations are currently provided (Figure 6), and more will be added in response to requests from Typhoon Committee Members. In regard to multi-scenario predictions, storm surge distribution maps for each scenario and a map based on the maxima among all scenarios (i.e., the worst storm surge values) for the forecast time are issued. The maximum map supports risk management by clarifying worst-case scenarios, although the information is approximate and such scenarios may not arise.

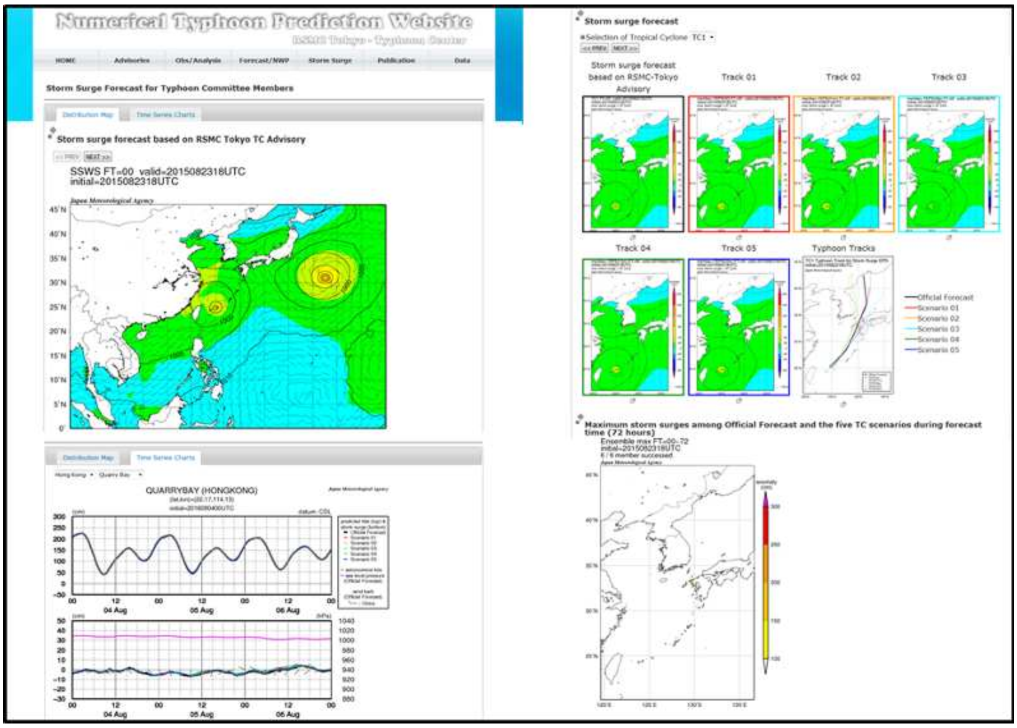

Figure 5 NTP website

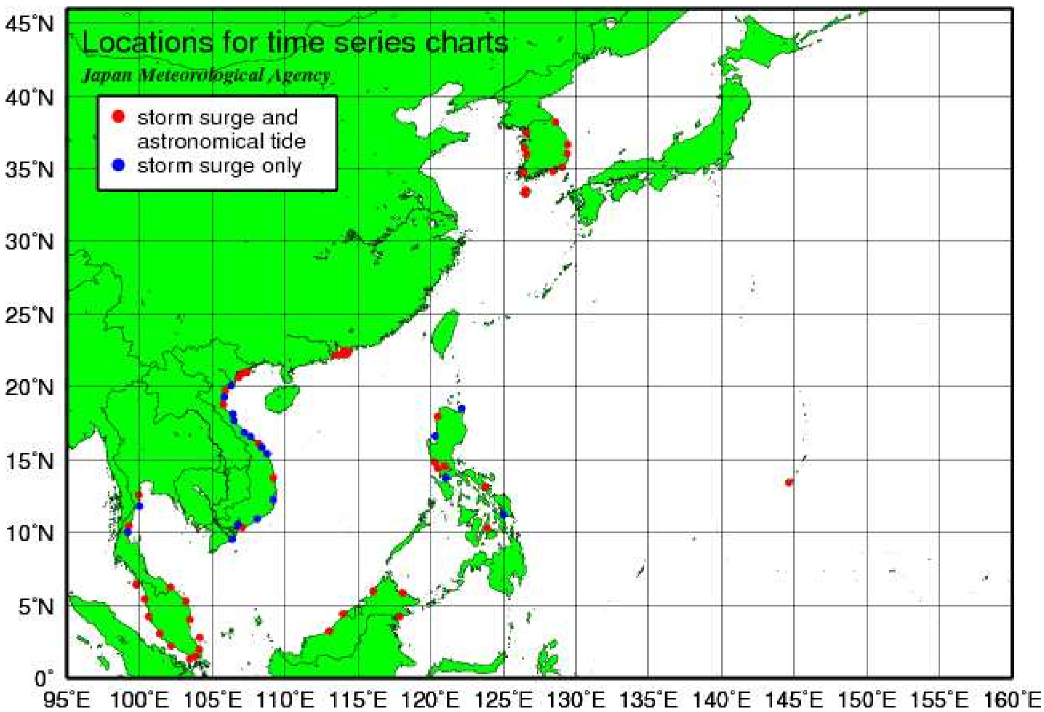

Figure 6 Time-series chart locations

Red dots show locations for which storm surge and astronomical tide information is provided, and blue dots show locations for which only storm surge information is provided.

Typhoon Haiyan (T1330)

Typhoon Haiyan hit the Philippines in November 2013 with a maximum wind speed of 65 m/s and a minimum pressure of 895 hPa, causing serious damage and storm surges that resulted in around 5,000 fatalities. The maximum peak surge was estimated at about 5 – 7 m based on field survey data. Figures 7, 8 and 9 show examples of multi-scenario prediction for the typhoon. Figure 7 shows the five selected typhoon tracks, Figure 8 shows the storm surge distribution maxima among all scenarios for the forecast time, and Figure 9 (left) shows a storm surge time-series chart for Tacloban (the Philippines). The model predicted storm surges reasonably, although the peak value was slightly underestimated. Figure 9 (right) shows a storm surge time-series chart for Quynhon (Vietnam). Peaks on the coast of Vietnam appear in the second half of the forecast time. The predicted peak values differ remarkably for each scenario. Multi-scenario prediction is especially valid for risk management in uncertain situations.

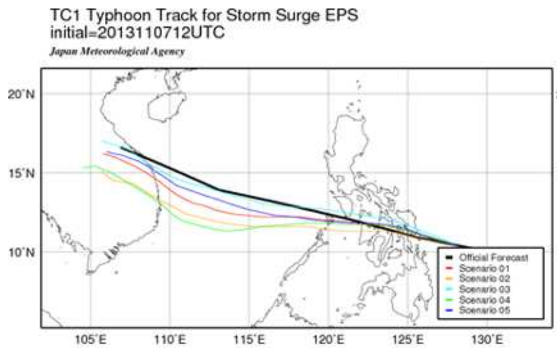

Figure 7 Predicted typhoon tracks for Haiyan

Colored lines show the five selected tracks.

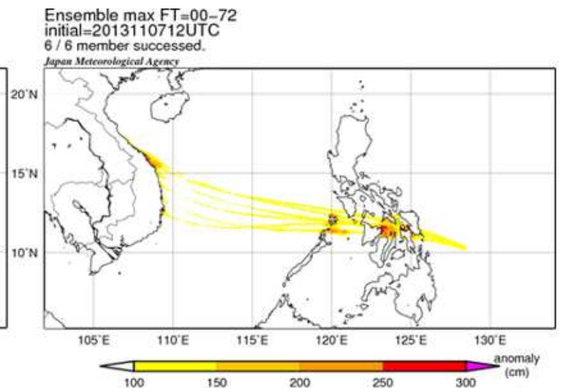

Figure 8 Storm surge distribution maxima among all scenarios during the forecast time for Haiyan

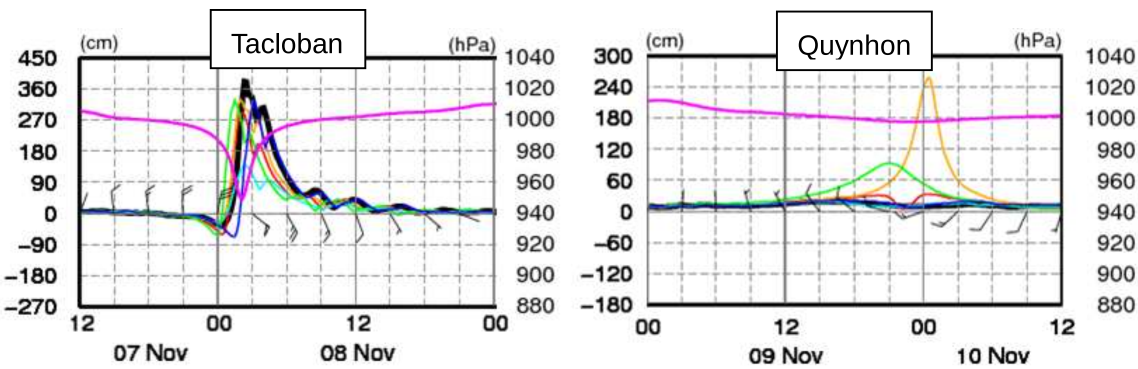

Figure 9 Storm surge time-series charts

Left: Tacloban (Philippines); right: Quynhon (Vietnam)

Line colors correspond to those in Figure 7. Pink lines show sea level pressure.

Typhoon Nida (T1604)

Typhoon Nida hit the southern coast of China in August 2016 with a maximum wind speed of 30 m/s and a minimum pressure of 975 hPa. Storm surge is a concern along the wide, shallow sea area off the Chinese coast because the phenomenon is particularly intensified there. Figure 10 shows selected typhoon tracks, and Figure 11 shows storm surge distribution maxima among all scenarios for the forecast time. JMA predicted that Nida would make landfall near Hong Kong at around high tide. Figure 12 shows storm surge time-series charts for Quarry Bay (Hong Kong). It should be noted that predicted storm surge depends largely on typhoon tracks. The predicted peak storm surge in Quarry Bay was approximately 2 m in the southward-shifted track.

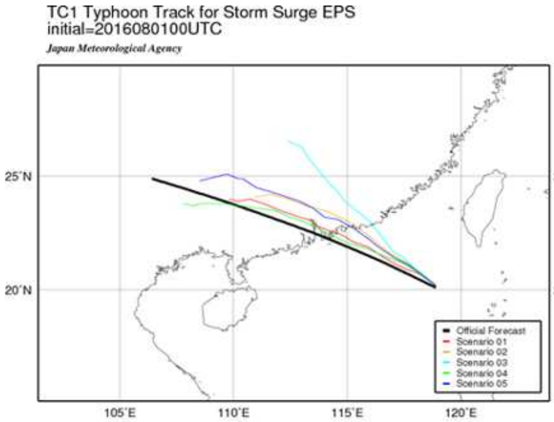

Figure 10 Predicted tracks for Nida

Colored lines show the five selected tracks, and the bold black line shows the official JMA forecast.

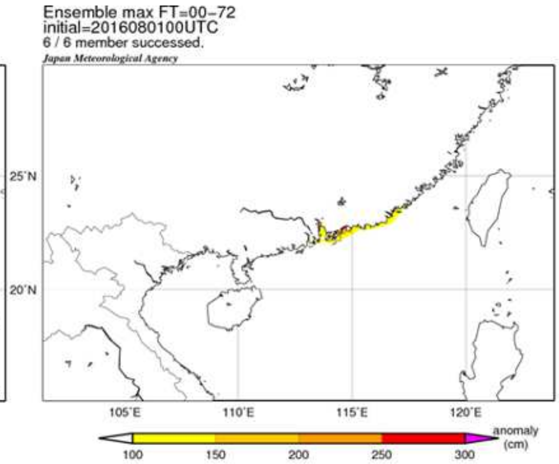

Figure 11 Storm surge distribution maxima among all scenarios during the forecast time for Nida

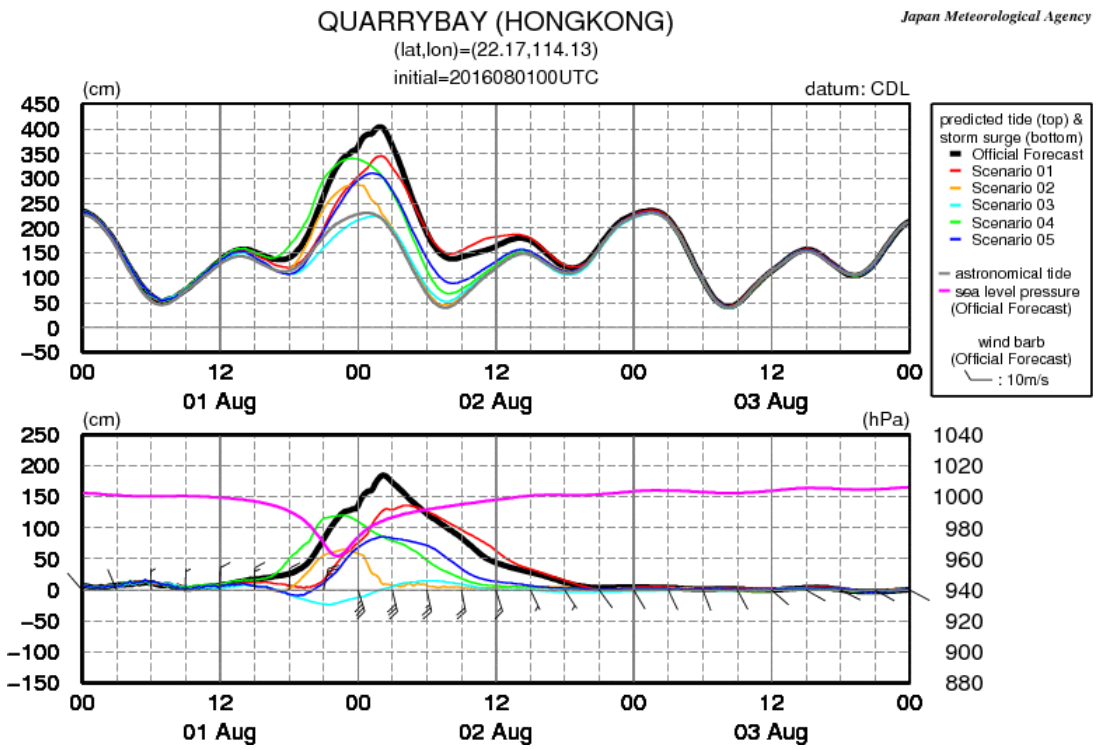

Figure 12 Time-series chart for Quarry Bay (Hong Kong)

Top: storm tide and astronomical tide; bottom: storm surge

Line colors correspond to those in Figure 10. The pink line shows sea level pressure.

Winter monsoon surge

In winter, the Siberian High develops and strong north-east winds become predominant in south-east Asia (phenomena collectively referred to as the winter monsoon). Storm surges often reaching several tens of centimeters are frequently observed along the eastern coast of the Malay Peninsula due to winds associated with the winter monsoon. The predicted distribution for 25th January 2016 in Figure 13 shows storm surge along the eastern coast of the peninsula. Figure 14 shows a storm surge time-series prediction chart for Geting (Malaysia). The predicted peak surge was approximately 40 cm. Thus, the storm surge model predicted winter monsoon surge well.

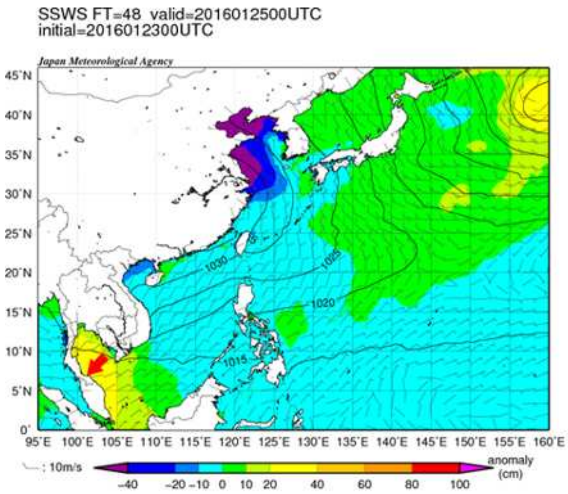

Figure 13 Storm surge distribution map

The red arrow shows the location of Geting.

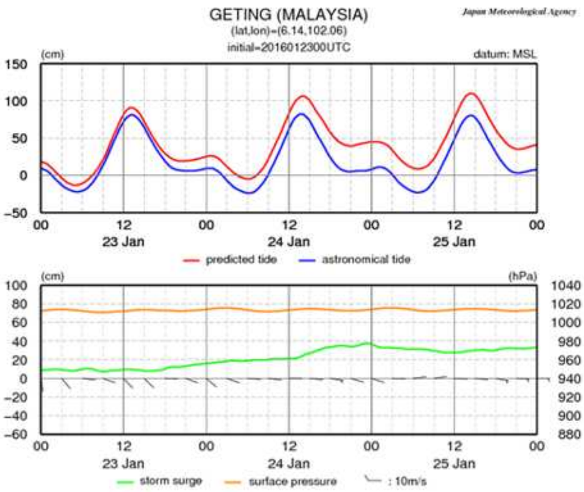

Figure 14 Time-series chart for Geting

Top: storm tide and astronomical tide; bottom: storm surge

The orange line shows sea level pressure.

4. Summary

JMA operates the Asia-area storm surge model within the WMO SSWS framework. The following major upgrades have been applied to the model since 2011:

- Extension of the forecast domain
- Daily provision of storm surge forecasts
- Start of multi-scenario storm surge prediction

JMA provides storm surge prediction information for most of RSMC Tokyo's area of responsibility. Multi-scenario prediction in particular enables the issuance of products that help clarify the risk of high storm surges with sufficient lead time for risk management. JMA plans to add scenarios and incorporate probabilistic forecasting into its next super-computer system (to be introduced in 2018) for further improvement of storm surge prediction information.

References

Kyouda, M. and M. Higaki, 2015: Upgrade of JMA's Typhoon Ensemble Prediction System. Available online at http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/techrev/text17-1.pdf

JMA, 2013: *Outline of the operational numerical weather prediction at the Japan Meteorological Agency. Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System and Numerical Weather Prediction Research*. Japan Meteorological Agency, Tokyo, Japan.