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# Jason-1 Observation of Typhoon Storm Surge and Analysis Based on Numerical Simulation

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**Abstract.** Storm surge is one of the most disastrous marine disasters to coastal regions. It is greatly essential to research on storm surge and mitigate this damage. In our paper, Typhoon hit the Japan Coast on 31 July, 2004. Jason-1 and two tide-gauge stations all captured the obvious sea level anomalies. The magnitude of this storm surge was approximately 0.4 m. We further used the Unstructured Grid Finite-Volume Community Ocean Model (FVCOM) to simulate this storm surge. The method based on the relationships between the maximum wind speed of best track and that of CFSR data was adopted to reconstruct wind field. This method reduced the root mean squared error (RMSE) from 0.11 m to 0.07 m at Owase station. The accuracy was improved by 35%. Similar to Owase station, the RMSE was reduced from 0.085 m to 0.06 m at Cape Muroto station. The accuracy was improved by 30%.

## 1. Introduction

Satellite altimetry, a technique for measurement of sea surface height, has developed more than 40 years. The spatial resolution has revolutionarily improved from initial meter-level to centimeter-level accuracy today. Much more progress has been made in the ocean application. And satellite altimetry opens up some new possibilities in the study of mesoscale climate variability, coastal currents, ocean tide and terrestrial water storage variations.

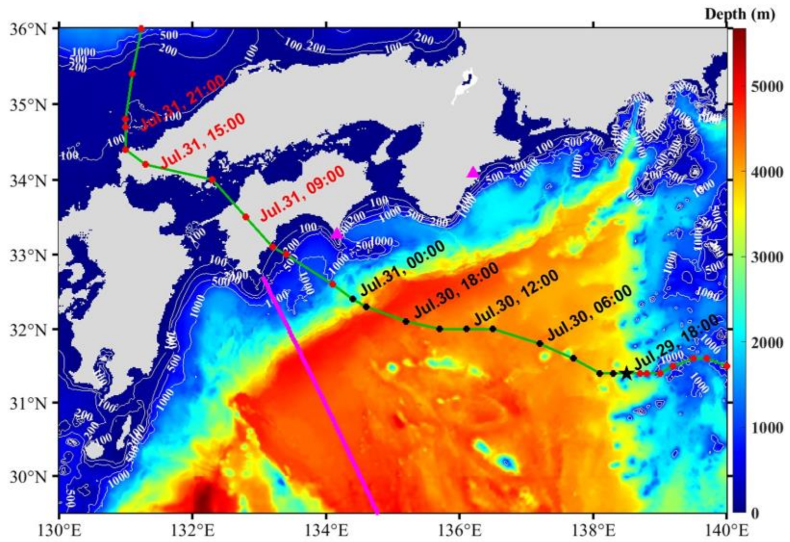


**Figure 1.** Map showing the study area in Japan with bathymetric data in meters. The green line with black dots represents the typhoon track at specific time, and the pink triangles denote the locations of tide-gauge stations. The pink line is the ground track of the Jason-1 altimeter.

However, the application of the altimeter on the storm surge is still in its infancy. In the past decade, some scientific researches show the ability of storm surge observation based on satellite altimetry. On 28 August 2005, the hurricane-induced storm surge was captured by the Geosat Follow-on. The results unveiled the prelude to the altimeter observation of the storm surge [1]. Lillibridge et al. pointed out that HY-2A satellite captured storm surges caused by hurricane Sandy off the coast of New York, and could provide the valuable cross-shelf structure of the storm surge, but the deeper analysis was not conducted [2]. Chen et al. combined the HY-2A satellite and tide-gauge station to further analyze the storm surge induced by hurricane Sandy. The results showed that the storm surge observed by the altimeter was similar to that observed by the tide station. Besides, the cross-shelf exponential decaying scale and the propagation speed were analyzed and discussed. The results indicated that altimeter could reveal some characteristics of the storm surge well to supplement the deficiency of tide-gauge station [3]. Moreover, the storm surge off China Coast was captured by TOPEX/Poseidon altimeter. The accuracy of the model was corrected by the mean of the altimeter and achieved good results unexpectedly. The results showed that the altimeter data had capacity to improve the accuracy of numerical model [4].

In this study, Typhoon Namtheun hit southwestern Japan on 31 July, 2004 and flooded homes and businesses. Before the landfall of Typhoon Namtheun, the Jason-1 flew over the Japan Coast at 17:00 UTC on 29 July (Figure 1) and captured an obvious sea level anomaly (SLA). The rest of this paper is organized as follows. In Section 2, altimeter data, tide-gauge data and numerical model setup are described. In section 3, the SLAs based on altimeter data, tide-gauge data and numerical simulation are further discussed. A conclusion is presented in Section 4.

## 2. Data and Methods

### *2.1. Jason-1 Data*

The Jason-1 satellite was launched on 7 December, 2001. This satellite is mainly used for measurement of sea level height, significant wave height and wind speed. The cycle is about 10 days. To improve the accuracy of coastal altimeter data, the Center for Topographic studies of the Ocean and Hydrosphere (CTOH) in France reprocessed the Geophysical Data Record products by using the X-TRACK processor. Thus, Jason-1 track 112 SLAs of cycle 94 in this paper were obtained by CTOH [5].

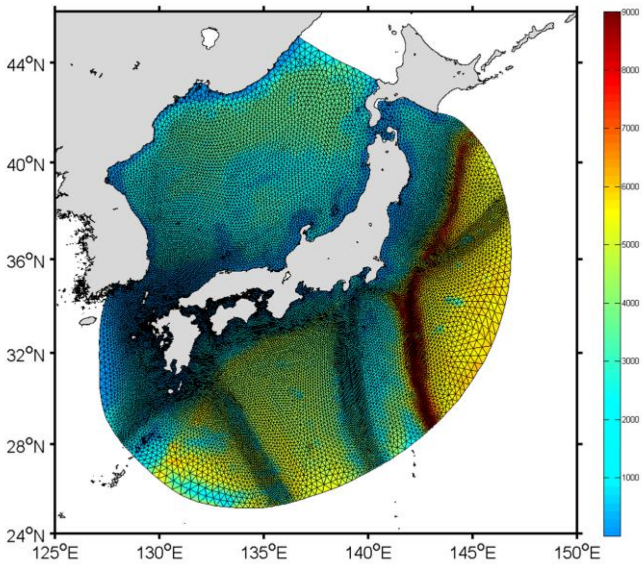


**Figure 2.** The research area was discretized with 52036 grids and 26829 nodes. The water depth distribution was from the Etopo1 dataset.

### *2.2. Tide-Gauge Data*

Hourly tide-gauge data at Cape Muroto station and Owase station were obtained from the Japan Meteorological Agency (JMA, http://www.data.jma.go.jp/gmd/kaiyou/db/tide/genbo/index.php). The data period is from 28 July to 06 August.

### *2.3. Numerical Model Setup*

In our study, the Unstructured Grid Finite-Volume Community Ocean Model (FVCOM) was used to simulate the storm surge caused by Typhoon Namtheun. The details of FVCOM can be found in [6]. Figure 2. shows that the grid of the research area, and the grid was generated by the Surface-water Modeling Solution (SMS). The maximum grid size is about 20 km, and the minimum grid size near Shikoku, Japan is about 1 km.

At the open boundary, the model was driven by the tide height data generated by the Oregon State University (OSU) Tidal Inversion Software (OTIS). At the sea surface, the model was forced by the sea surface wind and pressure data obtained from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) 6-hourly products. During the Typhoon Namtheun, two numerical experiments were conducted. One still was forced by the CFSR wind at the sea surface, another was forced by the reconstructed wind field that we discussed in Section 2.3.

### *2.4. Wind Field Reconstruction*

The accuracy of the wind force is essential for the numerical simulation. Generally, the CFSR wind data underestimate the maximum wind speed of the typhoon. Based on the relationship between the maximum wind speed of best track and that of CFSR, the approach in [4] was adopted as follows:

$$V_w = \left(\frac{r}{R} \times ntimes + \frac{R-r}{R}\right) \times V_{ncep}, \qquad 0 < r \le R \# (1)$$

$$V_w = \left(\frac{4 \times R - r}{3 \times R} \times ntimes + \frac{r-R}{3 \times R}\right) \times V_{ncep}, \qquad R < r \le 4 \times R \# (2)$$

Where $V_w$ is the reconstructed wind speed, $r$ is radial distance from the typhoon center, $R$ is the radius of the maximum wind, *ntimes* is a parameter, and $V_{ncep}$ is background wind speed.

### 3. Results and Discussion
During the Typhoon Namtheum event, Jason-1 captured the obvious SLAs. We can see that the SLAs had the significant increase from 29.7° toward the coast. In order to explore the coastal SLAs induced by Typhoon Namtheun, the tide-gauge results were represented by blue lines in Figure 4. Obviously, the SLAs around 31 July had the significant increase at Owase station and Cape Muroto station. The maximum magnitude of SLAs recorded by Owase station was approximately 0.41 m, and the maximum magnitude of SLAs recorded by Cape Muroto was approximately 0.34 m. Note that the SLAs of two stations both have residual oscillation after Typhoon Namtheun passing.

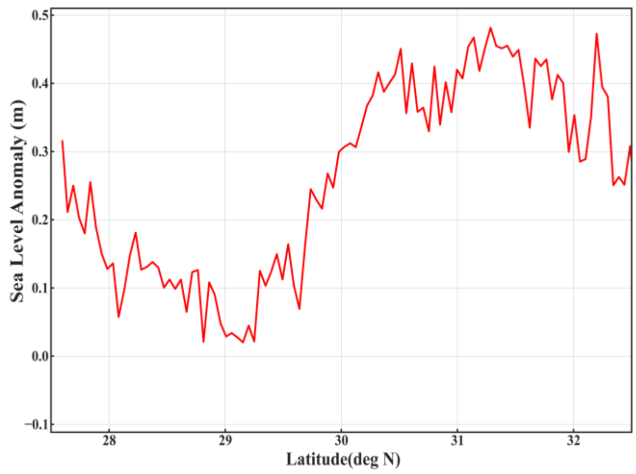


**Figure 3.** Map showing the sea level anomalies of Jason-1 track 112 SLAs of cycle 94.

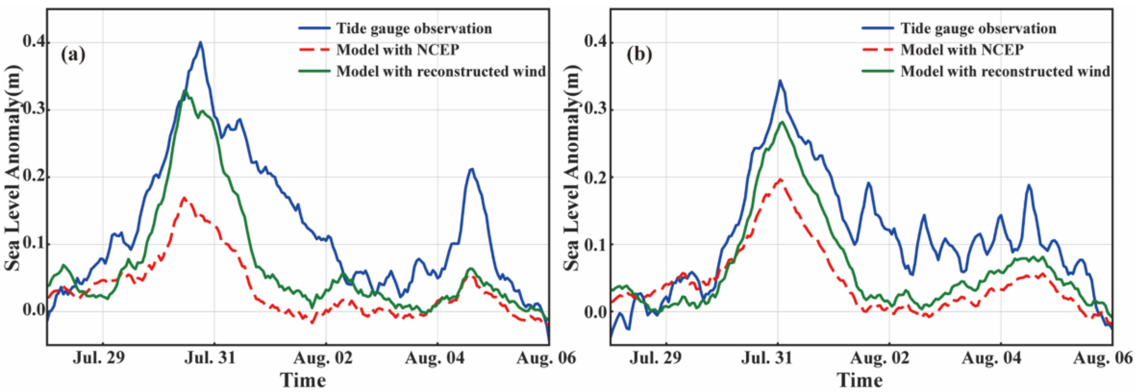


**Figure 4.** Comparison of simulated and observed SLAs. (a) Owase station, (b) Cape Muroto station.

This storm surge was simulated with above CFSR data and reconstructed wind data, respectively. The simulation results are shown in Figure 4. At Owase station, we can see that both peak times were well simulated. However, the peak value of the simulation forced by CFSR wind data was not ideal, the root mean squared error (RMSE) was 0.11 m. The simulation results forced by reconstructed wind data were better, and the RMSE was 0.07 m. The latter accuracy was improved by about 35%. At Cape Muroto station, the simulated SLAs had the similar results. The RMSE of the simulation forced by CFSR wind data was approximately 0.085 m and that of the simulation forced by reconstructed wind data was approximately 0.06 m. The accuracy was improved by about 30%. However, the simulated residual oscillations of these two approaches were both not ideal. Further research about simulation of residual oscillation is needed in the further. In conclusion, the method to reconstruct the wind field in our study is effective.

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## 4. Conclusion
During the Typhoon Namtheun event, the obvious surges were captured by Jason-1 and tide-gauge stations. The magnitude was approximately 0.4 m. This result suggests that altimeter products can be applied to monitor storm surge phenomena. The two ocean dynamical numerical simulations were further conducted to analyzed this storm surge. The results show that the simulated SLAs forced by reconstructed wind (based on the relationships between the maximum wind speed of best track and that of CFSR data) were better than that forced by CFSR wind data. The RMSE was reduced from 0.11 m to 0.07 m at Owase station, and the RMSE was reduced from 0.085 m to 0.06 m at Cape Muroto station. The accuracy can be improved by 30%-35%.

## 5. Acknowledgement
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