July 2020 heavy rainfall in Japan: Effect of real-time river discharge on ocean circulation based on a coupled river-ocean model

Project Representative
Yasumasa Miyazawa Application Laboratory, Research Institute for Value-Added- Information Generation, Japan Agency for Marine-Earth Science and Technology

Authors
Yu-Lin K. Chang[1], Sergey M. Varlamov[1], Xinyu Guo[1,2], Toru Miyama[1], and Yasumasa Miyazawa[1]

*[1]Application Laboratory, Research Institute for Value-Added-Information Generation, Japan Agency for Marine-Earth Science and Technology
*[2] Center for Marine Environmental Studies, Ehime University

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1. Introduction

In July 2020, a stationary atmospheric front formed in East Asia, extending from China to the east of Japan. The front stayed above Japan for nearly a month, resulting in persistent heavy rainfall. The continuous rain resulted in the historical maximum rainfall record in Kyushu of 496 mm in 24 hours. A high-resolution ocean hindcast and forecast system has been used to monitor the seas around Japan (JCOPE-T DA, [*Miyazawa et al.*, 2021]). JCOPE-T DA has the most updated satellite information assimilated and is expected to provide coastal prediction information during heavy rain periods. Although JCOPE-T DA did include the freshwater discharge, its river discharge input was based on monthly climatology, which was likely unable to reproduce the actual coastal circulation condition due to the overestimation and/or underestimation of short-term river discharge. The objective of this study was to improve the ability to accurately simulate the coastal salinity and currents during heavy rain periods. We introduced real-time hourly river discharge from a river routing model into JCOPE-T DA for simulating the July 2020 heavy rain event in the southwestern Japan region.

2. JAXA Today's Earth and JCOPET-DA models

The river discharge output from the river routing model (Today's Earth [Ma et al. 2021]) operated by Japan Aerospace Exploration Agency was used in the present study. JAXA Today's Earth was a gridded model with 1/60° horizontal resolution. The domain covered from 123°E to 148°E, and from 24°N to 46°N. The hourly data was available from September 2018 to the present. The freshwater discharge at the river mouth used in the ocean model included both the river discharge and floodplain flow. The floodplain flow was generally smaller than river discharge. It accounted for less than 5% of total discharge without rainfall, but could increase to 25–35% of total discharge during heavy rain periods. 368 rivers in Japan were included from the JAXA Today's Earth.

The ocean circulation model used for this study was based on the tide-resolving data-assimilative nowcast and forecast system (JCOPE-T DA; [*Miyazawa et al.*, 2021]). JCOPE-T DA was constructed from the Princeton Ocean Model. The model domain encompassed East Asia (17–50°N and 117–150°E), with a horizontal resolution of 1/36° (~3 km) and 46 vertical layers. The external forcing to drive the model included wind stresses and net heat/freshwater fluxes at the sea surface converted from the hourly atmospheric reanalysis and forecast produced by the global forecast system (GFS) of the National Centers for Environmental Prediction (NCEP). Satellite and in situ temperature and salinity data were assimilated into the model based on a multi-scale three-dimension variational method. The hindcast result of JCOPE-T DA served as the initial condition for the river discharge experiments in the present study. Two experiments were conducted: (1) the river discharge used the default monthly climatology (Exp. Clim), (2) the river discharge used the hourly real-time JAXA Today's Earth (Exp. CamaF) data. The two experiments restarted from the same initial condition, then ran freely for 35 days when the heavy rain ended. Apart from the river discharge, all other parameters were identical among the experiments.

3. Coastal Salinity Improvement

The salinity in the heavy rain regions from the two model experiments was compared against the observations. To examine salinity change in the coastal region, the in-situ observations were examined next. The salinity around 3 m depth in Ise Bay was about 30–31 before the heavy rain started on 3 July and then it gradually dropped with the cumulative rains and reached its minimum of around 21 on 13 July before returning to 30–32 in a week (Fig. 1a). Both modeled salinities showed a positive bias. Salinity in Exp. Clim showed a weak variation, with salinity being changed by the freshwater input by less than 3. Exp. CamaF improved from Exp. Clim by showing a maximum salinity decrease of 6, although the decrease in salinity was still smaller than the observations. Exp. CamaF resulted in a smaller root-mean-squared error (RMSE) of 4.52 in comparison to the 5.58 value of Exp. Clim, yet the difference between the two experiments was not significant at the Ise Bay station ($p>0.1$). Salinity in Ariake Bay was observed at the sea surface, and the model simulation also showed a general positive bias (Fig. 1b, c). The observed salinity at these two stations even dropped to nearly zero on 12 July, suggesting the buoys were directly affected by the heavy rainfall that greatly reduced the salinity values. The modeled salinity, even in the layer nearest to the surface, was below the surface by some distance (mean and standard deviation depth of 0.72±0.14 m), and therefore had a limitation in representing the real surface salinity. Exp. CamaF captured the general salinity variation trend of the observations, and showed a smaller RMSE than Exp. Clim. The salinity improvement from Exp. Clim to Exp. CamaF was significant at both stations in Ariake bay ($p<0.01$). Although the real-time river discharge used in Exp. CamaF improved the salinity, it still had a RMSE of 4–10.

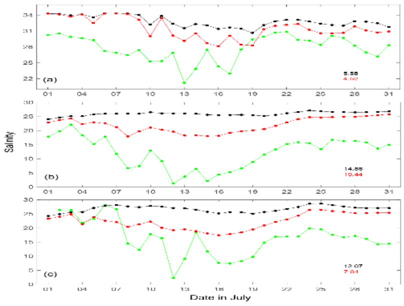

Fig. 1 Time series of salinity at (a) Ise Bay, (b) Kojima, and (c) Nagahama in the Ariake Sea. Salinity measurment observations are shown in green, Exp. Clim in black, and Exp. CamaF in red.

The real-time river discharge did indeed improve the modeled salinity near the coast. Figure 1 shows the salinity and surface current speed differences between the two experiments. Before the heavy rain started, a small salinity difference was observed near the coast (Fig. 2a). After a week of continuous rainfall, the heavy rain regions in the south and west of Japan showed a clear freshening. Eddies and filaments of fresher water extended out from Kii Channel (east of Shikoku) to about 300 km offshore (Fig. 2b). The salinity difference further diffused offshore with time, eventually forming a large circular oval patch of lower salinity surface water 400 km offshore (Fig. 6c). A large region of complex eddy-like salinity differences appeared east of northern Japan where mesoscale eddies were often observed within or north of the Kuroshio Extension. Saltier water was also observed in coastal Japan (Fig. 6c), because the river discharge in the monthly climatology could sometimes be overestimated

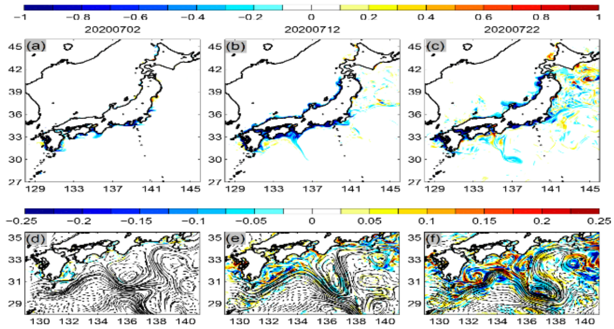

Fig. 2 Surface salinity difference (a-c) and current speed difference (d-f) between Exp. Clim and Exp. CamaF on (a, d) 2 July, (b, e) 12 July, and (c, f) 22 July. The vectors in (d-f) are surface currents for Exp. CamaF.

4. Changes in costal currents

Comparing to the ocean currents in the southern region, the fresher circular water area was located inside the Kuroshio large meander (Fig. 2d-f). The fresher water was entrained into the Kuroshio and brought offshore with the large meander and later returned to the nearshore by the currents. Low salinity water had occasionally been observed on the surface of the Kuroshio and was suggested to originate from south and west of Japan. The freshwater discharge not only changed the salinity, but also influenced the currents (Fig. 2d-f). The currents were modified from the nearshore region to a few hundred kilometers offshore. The surface speed difference from Exp. Clim could exceed 0.2 m/s. The currents in the center of the Kuroshio large meander were weakened, and currents in the outer edge of the Kuroshio were strengthened (Fig. 2f). The absolute vorticity changes from Exp.Clim to Exp. CamaF in the Kuroshio large meander region (135.5–139°E, 28.8–31.5°N) were reduced by -3.38×10^{-7} s^{-1}. The trapping ability of rotating fluid is determined by the rotation versus the translation speed, and the reduction of vorticity in Exp. CamaF suggested the amount of water parcels trapped in the Kuroshio large meander area may be reduced.

Acknowledgement

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References

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