Predictability of the July 2018 Heavy Rain Event in Japan Associated with Typhoon Prapiroon and Southern Convective Disturbances

Takumi Honda¹ and Takemasa Miyoshi¹,²
¹RIKEN Center for Computational Science, Kobe, Japan
²RIKEN Cluster for Pioneering Research, Kobe, Japan

Abstract

In July 2018, record-breaking heavy precipitation caused catastrophic disasters almost every year in Japan (e.g., Kawan and Kawamura 2020; Taylor et al. 2021; Tsuguti et al. 2018). It is important to obtain an accurate prediction and estimate its uncertainty with a sufficient lead time for better preparation activities. A common way to estimate forecast uncertainty is to measure the spread growth of ensemble forecasts (Toth and Kalnay 1997).

The evolution of the ensemble spread often shows a characteristic evolution associated with convection. Enomoto et al. (2010) revealed that the analysis ensemble spread rapidly increased before the onset of westerly wind bursts, monsoon, and stratospheric sudden warming. They argued that in these phenomena the differences of convection and associated flow patterns among the ensemble members resulted in the precursory increases of the ensemble spread. In a regional scale, by using convection-permitting model (Kusaka et al. 2001), a Beljaars-type bulk surface-flux parameterization scheme ((Fig. 1 of Lien et al. 2017). The model had 36 vertical levels with a model top of approximately 29 km. A single-layer urban canopy model (Kain and Fritch cumulus parameterization (Kain 2004) were adopted. The simulation domain of this study was the same with that of Lien et al. (2017). Namely, we set up the SCALE-RM with an 18 km mesh domain covering East Asia (Fig. 1 of Lien et al. 2017). The model had 36 vertical levels with a model top of approximately 29 km. A single-layer urban canopy model (Kusaka et al. 2001), a Beljaars-type bulk surface-flux model (Beljaars and Holstlag 1991), the model simulation radiation TRAnsf er code (MSTRN) X (Sekiguchi and Nakajima 2008), and the level-2.5 closure of the Mellor-Yamada-Nakanishi-Niino turbulence scheme (Nakamshi and Niino 2004) were adopted. The Tomita (2008) microphysics parameterization scheme was used together with the Kain-Fritch cumulus parameterization (Kain 2004).
4. Results and discussion

4.1 Ensemble spread

Figure 2 shows that the later the initial time, the better the precipitation forecast as we usually expect. For an earlier initial time, the predicted precipitation amount in west Japan was smaller than that near the East China Sea (Fig. 2a). With the later initial times, the precipitation amount in west Japan increased and became more consistent with the JMA radar data (Figs. 2b, 2c, and 2d). In general, the ensemble mean tends to show broader areas of weak precipitation compared to individual ensemble members. In the forecasts initiated on 3 July, a large amount of precipitation was predicted even in the ensemble mean (Fig. 2d). Besides, most ensemble members predicted the precipitation amount larger than 100 mm. Therefore, in the near-real-time SCALE-LETKF system, the heavy rain event of July 2018 was qualitatively predictable for at least two days in advance. This lead time was shorter than Enomoto’s (2019) hindcast with a global model, probably due to the lack of satellite observations in the SCALE-LETKF system and differences in the models used.

The ensemble-mean precipitation in the west Japan region generally increased for later initial times (Fig. 3a). Interestingly, Fig. 3b shows that the forecast ensemble spread generally increased until 1 July, largely dropped on 2 July, and jumped up again on 3 July. In Sections 4.2 and 4.3, we investigate the spread increases on 1 and 3 July, respectively. These increases of the forecast ensemble spread would be mainly caused by the forecast spread growth rather than differences in the initial ensemble spread. Similar to Enomoto et al. (2010), the analysis ensemble spread gradually increased prior to the onset of the heavy rain event of July 2018, but the variation of the analysis ensemble spread was much smaller than the forecast spread growth (Supplement 1).

4.2 Track forecast of Typhoon Prapiroon

To understand why the forecast ensemble spread generally increased until 1 July, Fig. 4 compares the best and worst two members in terms of the precipitation amount in the west Japan region. The best members predicted Prapiroon located near the Korean Peninsula, which was generally consistent with the JMA best track, although eastward motion was considerably slow. A narrow moisture band was located over the west Japan region,
resulting in a large amount of precipitation. In contrast, the worst two members predicted that Prapiroon stayed over the East China Sea until 6 July. The worst members exhibited a clearly different moisture distribution compared to the best two members and the analysis ensemble mean (Figs. 4c, 4d, 1c, and 1d). These results indicate that the typhoon track and associated moisture transport patterns were key features for predicting the heavy rain event of July 2018.

Fig. 2. (a)−(d) Ensemble mean of 50-member ensemble forecasts valid at 0000 UTC 7 July for the previous 48-h accumulated precipitation amount (mm, color shading) and mean sea level pressure (MSLP) (hPa, contours), initiated at 0000 UTC on (a) 30 June, (b) 1 July, (c) 2 July, and (d) 3 July. (e) JMA radar observation for the same 48-h period accumulated precipitation amount (color shading, mm) and analyzed ensemble-mean MSLP (contours, hPa). The magenta boxes show the west Japan region.

Fig. 3. Forecast (a) ensemble mean (thick black line) and individual ensemble members (thin grey lines) and (b) ensemble spread of 48-h area-averaged accumulated precipitation amount in the west Japan region (Fig. 2, magenta box) on 5 and 6 July as a function of forecast initial times.

The importance of the forecast of Prapiroon’s track is evident by comparing the ensemble forecasts with different initial times, as shown in Fig. 5. In the 28 June ensemble forecast, most members showed westward shifted tracks compared to the best track partially because Prapiroon was not well represented in the initial conditions due to the limited domain size although Enomoto (2019) pointed out the importance of the initial structure of Prapiroon for accurate track prediction. In the 30 June forecast, some members successfully predicted the eastward recurvature of Prapiroon. As shown in Fig. 4, a skillful typhoon track forecast was associated with a good forecast of moisture transport and precipitation. The other members, however, failed to predict the eastward motion of Prapiroon. Good members had deeper initial typhoon vortices than those in bad members, consistently with Enomoto (2019). Therefore, the 30 June ensemble forecast contained both very good and bad track forecasts of Prapiroon and exhibited a large ensemble spread, as shown in Fig. 3. In the 2 July ensemble forecast, the ensemble spread of the typhoon track forecast became small, and consequently the ensemble spread of the precipitation amount was reduced in the west Japan region. Therefore, Prapiroon’s track forecast largely affected the forecast uncertainty as pointed out by Enomoto (2019) with several deterministic forecasts.
4.3 Southern convective disturbances near the Ryukyu Islands

As shown in Fig. 3b, the forecast ensemble spread in the 3 July forecast was larger than that in the 2 July forecast. To understand the spread increase in the 3 July forecast, we compared the composites of the best and worst 10 members from the 3 July ensemble forecast. The best 10 members predicted a large amount of precipitation in the west Japan region (Fig. 6a), whereas in the worst 10 members, the main precipitation band was shifted southeastward (Fig. 6b). Figures 6a and 6b show another notable difference in the southern convective disturbances near the Ryukyu Islands (near 25°N). In the case of the best 10 members, the convective disturbances were strong and had a larger amount of precipitation, lower outgoing longwave radiation (OLR), and a more organized structure than the best 10 members, even at the initial time (Figs. 6c and 6d). Shimpo et al. (2019) also reported that the convective activity near the Ryukyu Islands was enhanced during the heavy rain event. It is likely that the convective disturbances near the Ryukyu Islands largely contributed to the predictability of the heavy rain event.

The location of the main precipitation band was associated with the convective disturbances near the Ryukyu Islands. Composites of the 10 best members showed stronger southerly winds near the Ryukyu Islands than those of the worst 10 members (Figs. 6e and 6f). The southerly winds would transport more moisture to the west Japan region and push the precipitation band northward. Also, the southerly winds were a part of a cyclonic circulation.
Differences in relative vorticity were found even at the initial time of 0000 UTC 3 July (Supplement 2), indicating the importance of the representation of the southern convective disturbances in the initial condition. Takemura et al. (2019) reported that the deep convection near the Ryukyu Islands contributed to maintaining the southwesterly flow by analyzing the potential vorticity budget, and our results were generally consistent. In addition, this study revealed that the southern convective disturbances near the Ryukyu Islands was likely to play a role in shifting the precipitation band location and to be a major source of forecast uncertainty. For quantitative analysis of the role of the southern convective disturbances, sensitivity experiments are necessary by varying only the initial southern convective disturbances, and this is a subject of a future research.

The importance of the southern convective disturbances near the Ryukyu Islands was also evident in the ensemble-based correlations shown in Fig. 7. The meridional wind near the Ryukyu Islands exhibited a dipole pattern in the east at 0000 UTC 4 July, indicating that cyclonic circulation near the Ryukyu Islands was closely associated with the precipitation amount over the west Japan region. The ensemble-based correlations became more evident at 0000 UTC 5 July. The importance of southerly wind has also been highlighted in previous studies (Sekizawa et al. 2019; Shimpo et al. 2019; Takemura et al. 2019).

5. Conclusion

On 5 and 6 July 2018, record-breaking precipitation occurred in the west Japan region and caused catastrophic destruction. Using ensemble forecasts from the SCALE-LETKF analyses, we investigated the predictability of the heavy rain event. In the SCALE-LETKF system, the heavy rain event was predicted 2 days in advance. The ensemble mean of the precipitation amount increased monotonically as the initial time progressed. Interestingly, the ensemble spread of the precipitation amount, a measure of forecast uncertainty, did not exhibit a monotonic reduction as the initial time progressed. Namely, the ensemble spread generally increased until the initial time of 1 July, suddenly dropped on 2 July, and then jumped up again on 3 July. We inves-
tigated the spread increases on 1 July and 3 July.

The general increase in the ensemble spread until 1 July resulted from the uncertain track forecast of Typhoon Prapiroon. For earlier initial times, most members failed to predict the recurvature of Prapiroon. As the initial time became later, some ensemble members started predicting the recurvature of Prapiroon, whereas the other members still predicted Prapiroon’s track incorrectly. This large departure of forecast tracks among ensemble members resulted in a large ensemble spread.

The other key factor affecting the forecast uncertainty was the southern convective disturbances near the Ryukyu Islands. More active convective activities corresponded to a stronger cyclonic circulation near the Ryukyu Islands and more precipitation in the west Japan region. Ensemble-based correlations also indicated that the southerly wind near the west Japan region was closely associated with the amount of precipitation in west Japan through moisture transport. The differences in the cyclonic circulation near the Ryukyu Islands among the ensemble members were found even in the initial time and grew during the forecast. Therefore, the southern convective disturbances near the Ryukyu Islands played an important role in shifting the main precipitation band in the west Japan region, and its representation in the initial conditions caused forecast uncertainty.

Our results highlighted that the representation of the southern convective disturbances near the Ryukyu Islands and Prapiroon’s track forecast were important for accurately predicting the heavy rain event of July 2018. For accurate representation of these key factors, satellite radiance observations would be useful because both Prapiroon and the convective disturbances were located over the ocean where conventional observations were generally limited. In particular, infrared (IR) radiance observations from geostationary satellites, such as Himawari-8 (Bessho et al. 2016), would be very useful because of their wide coverage and high spatio-temporal resolution. As of July 2018, JMA assimilated only clear sky IR radiances although several studies showed the benefits of all-sky assimilation of satellite IR radiance observations (Honda et al. 2019; Honda et al. 2018a; Honda et al. 2018b; Minamidote and Zhang 2018; Okamoto et al. 2019; Sawada et al. 2019; Zhang et al. 2016). It would be an important future study to investigate how the all-sky Himawari-8 radiance assimilation could improve the predictability of the Heavy Rain Event of July 2018.

This study used an 18-km mesh model and did not discuss the effects of the terrain and the evolution of individual convective systems embedded in the Baiu front. Sueki and Kajikawa (2019) reported the differences in the precipitation systems between the Hiroshima and Osaka regions during the heavy rain event of July 2018. Further investigations with a higher resolution model would be required to investigate these small-scale characteristics.

Acknowledgements

The authors thank Akira Kuwano-Yoshida, an anonymous reviewer, and the editor for constructive comments. This research was partially supported by RIKEN special post-doctoral fellow program, MEXT as “Program for Promoting Researches on the Supercomputer Fugaku” (Large Ensemble Atmospheric and Environmental Prediction for Disaster Prevention and Mitigation), JST AIP (JPMJCR19U2), FOCUS Establishing Supercomputing Center of Excellence, and JSPS KAKENHI grants (20K14558 and 20H04196). This research was conducted using the Fujitsu PRIMERGY CX600M1/CX1640M1 (Oakforest-PACS) in the Information Technology Center, The University of Tokyo (hp200026) and the K computer, provided by RIKEN (hp180062, hp190051, and ra00015). The authors thank Koji Terasaki of the Data Assimilation Research Team, RIKEN for fruitful discussions.

Edited by: T. Kawano

Supplements

Supplement 1: Time series of the domain-averaged forecast ensemble spread for zonal winds at 500 hPa in each ensemble forecast (ms⁻¹).

Supplement 2: Differences in vertical vorticity in the best and worst 10 members in the 3 July forecast.

References

Beljaars, A. C. M., and A. A. M. Holtslag, 1991: Flux parameterization over land surfaces for atmospheric models. J. Appl. Meteor. Climatol., 30, 327–341.

Bessho, K., and co-authors, 2016: An introduction to Himawari-8/9 — Japan’s new-generation geostationary meteorological satellites. J. Meteor. Soc. Japan, 94, 151–183, doi:10.2151/jmsj.2016-009.

Enomoto, T., 2019: Influence of the track forecast of typhoon Prapiroon on the heavy rainfall in Western Japan in July 2018. SOLA, 15A, 66–71, doi:10.2151/sola.15A-012.

Enomoto, T., M. Hattori, T. Miyoshi, and S. Yamane, 2010: Precursory signals in analysis ensemble spread. Geophys. Res. Lett., 37, 1–4, doi:10.1029/2010GL042723.

Honda, T., and co-authors, 2018: Assimilating all-sky Himawari-8 satellite infrared radiances: A case of Typhoon Soudelor (2015). Mon. Wea. Rev., 146, 213–229, doi:10.1175/MWR-D-16-0357.1.
