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Improving prediction of river-basin precipitation by assimilating every-10-minute all-sky Himawari-8 infrared satellite radiances – a case of Typhoon Malakas (2016)

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ABSTRACT: To operate hydroelectric power dams more effectively, it is essential to obtain accurate precipitation forecasts. This study aims to improve precipitation forecasts by assimilating every-10-minute all-sky Himawari-8 infrared radiance observations. We use an advanced ensemble data assimilation system developed in RIKEN. This study focuses on a single case of Typhoon Malakas (2016) which induced heavy precipitation in the mountain region of central Japan. The results demonstrate that assimilating the Himawari-8 radiance observations significantly improves the representation of Typhoon Malakas (2016) and cloud patterns. Moreover, ensemble forecasts initiated from the Himawari-8 data assimilation provide more accurate precipitation forecasts with uncertainty information. In particular, the forecasts with a longer lead time exhibit a better forecast skill compared to the Japan Meteorological Agency's operational regional model. These promising results suggest that assimilating the every-10-minute all-sky Himawari-8 radiances be effective for improving hydroelectric power dam operations by providing more accurate precipitation forecasts.

RÉSUMÉ: Pour exploiter plus efficacement les barrages hydroélectriques, il est essentiel d'obtenir des prévisions précises des précipitations. Cette étude vise à améliorer la prévision de précipitations en intégrant les observations en rayonnement infrarouge détectées par le satellite Himawari-8 pour toute la planète toutes les dix minutes. Nous utilisons un système avancé d'intégration des données d'ensemble développé par l'institut RIKEN. Cette étude porte sur le cas particulier du typhon Malakas (2016) qui a entraîné de fortes pluies dans les régions montagneuses du Japon central. Les résultats démontrent que l'intégration des observations du rayonnement faites par Himawari-8 améliore de manière importante la représentation du typhon Malakas (2016) et de son couvert nuageux. De plus, les prévisions d'ensemble obtenues à partir de l'intégration Himawari-8 procurent des prévisions de précipitations plus précises avec des informations sur leur incertitude. En particulier, les prévisions à plus long terme présentent une meilleure justesse en termes de pronostic en comparaison avec le modèle régional opérationnel de l'Agence météorologique japonaise. Ces résultats prometteurs suggèrent que l'intégration des radiations infrarouges détectées pour toute la planète par le satellite Himawari-8 toutes les 10 minutes est efficace pour améliorer le fonctionnement des barrages hydroélectriques en fournissant des prévisions plus précises des précipitations.

1 INTRODUCTION

To generate hydro power, water stored by dams is usually channeled to a downstream power station and used to generate power. When heavy precipitation due to typhoons or seasonal rain fronts occurs upstream of dams, stored water has to be released to lower the water level in advance as preparation against soaring water inflow to dams. To operate dams precisely and efficiently amid such heavy precipitation, predicting such precipitation with high precision and sufficient lead time is crucial as well as accurately understanding its location or intensity.

At present, many hydroelectric power dams, in Japan are operated utilizing the short-term precipitation forecast by the Japan Meteorological Agency (JMA) or the precipitation prediction by the Meso-Scale Model (MSM; Saito et al., 2006) by the JMA. In the former, hourly rainfall data up to six hours later (extended to 15 hours later since June 2018) within a 1-km-mesh are provided and updated every half hour. In MSM, on the other hand, precipitation up to 39 hours within the calculation area of Japan and its vicinity is provided by a 5-km-mesh grid and updated eight times daily (every three hours).

Such precipitation predictions provided by the JMA are not necessarily optimal in terms of operating the hydroelectric power dams safely and efficiently, since short-term precipitation forecasts are issued up to six hours ahead and the lead time is insufficient. MSM, conversely, provides longer forecasts, but updated every three hours, which is insufficient to perform dam operations every moment during heavy rain. To compensate for these JMA forecasting issues, there is a need to build and operate a unique precipitation prediction system specialized for the operation of hydroelectric power dams.

Tokyo Electric Power Company Holdings, Inc. (TEPCO) and RIKEN began collaborative research in 2017, with the aims which include verifying the effectiveness of the unique precipitation prediction system specializing in the operation of hydroelectric power dams. The study group of RIKEN has shown that the prediction accuracy on aspects such as the intensity of the typhoons and the concentration of heavy rain can be drastically improved, by assimilating high frequent infrared radiance observation data in every 10 minutes of the latest geostationary meteorological satellite Himawari-8 (Bessho et al., 2016) in its own numerical weather prediction (NWP) system (Honda et al., 2018a, b). In particular, Honda et al. (2018b) reported that predicting precipitation and river discharges, which are updated frequently, can be obtained by utilizing the benefits of high frequent infrared radiance observations by Himawari-8 as maximum. This result suggests that Himawari-8 radiances and the data-assimilation system facilitate the operation of hydroelectric power dams.

In the watershed of the hydroelectric power dams owned by TEPCO, heavy precipitation is often triggered by an oncoming typhoon. Honda et al. (2019) showed that the precipitation prediction associated with the typhoon main body could be improved by assimilating with Himawari-8 radiances; citing the case of Typhoon Malakas (2016), which approached Japan in September 2016. In this study, the results of the precipitation forecast by Honda et al. (2019) are compared in more detail with the JMA MSM and the usefulness of the unique NWP system assimilating Himawari-8 radiances is verified.

2 METHOD

Similar to Honda et al. (2019), we focus on a case of significant precipitation occurring in Central Japan, along with the passage of Typhoon Malakas on September 20, 2016. Figure 1 shows the 24-hour accumulated precipitation from 12:00 UTC on September 19 to 12:00 UTC on September 20 based on the Typhoon Malakas route obtained from optimal tracking and synthetic radar-precipitation intensity estimates by the JMA. As the typhoon traversed the south coast of the Japanese archipelago, it triggered considerable precipitation, such as 24-hour accumulated precipitation exceeding 160 mm; in central areas as well as the coastal part of the Pacific coast.

The (NWP) system, SCALE-LETKF, developed by Lien et al. (2017) was used. SCALE-LETKF comprises the regional atmosphere model SCALE-RM (Scalable Computing for Advanced Library and Environment Regional Model, Nishizawa et al., 2015; Sato et al., 2015) and the local ensemble transform Kalman filter (LETKF, Hunt et al., 2007; Miyoshi

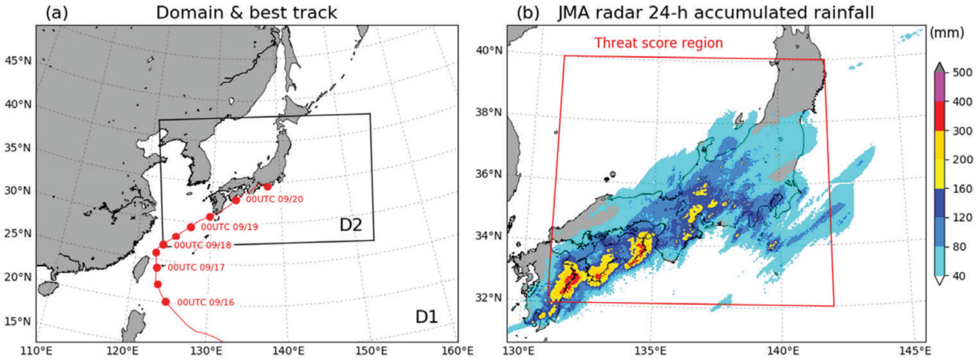

Figure 1. (a) Computational domains and the best track of Typhoon Malakas (2016). The best track of Typhoon Malakas (2016) is plotted by the red curve with red filled circles every 12 hours. (b) 24-h accumulated precipitation amount of JMA radar data from 1200 UTC September 19 to 20, 2016.

and Yamane, 2007). Similar to Honda et al. (2018a), two computational domains (D1 and D2) were set with horizontal mesh spacings of 18- and 6-km respectively. Refer to Honda et al. (2019) for detailed setting of the model.

Like Honda et al. (2018a), in the parent (D1) domain indicated by the outer frame in Figure 1, only the conventional observation data (NCEP PREPBUFR) delivered by the National Centers for Environmental Prediction (NCEP) every six hours were assimilated from September 12, 2016 and the initial ensemble was obtained from the analytical values of the quasi real-time experimental system by Lien et al. (2017).

In the daughter (D2) domain with a 6-km-mesh, as well as NCEP PREPBUFR observations divided into bins at ten-minute intervals, observations on the central pressure and positions (tropical cyclone vital observations) of Malakas by the JMA best track, which were interpolated at one-hour intervals, were assimilated. We conduct two experiments. The first experiment (NoHim8) assimilates only the NCEP PREPBUFR and vital observations. The second experiment (Him8) assimilates three kinds of observations including Himawari-8 radiances (band 9, 6.9 μm) at ten-minute intervals. Assimilation in D2 started at 12:00 on September 19, after the six-hour spin-up forecast.

3 EVALUATION OF PRECIPITATION FORECASTS

Honda et al. (2019) reported that the typhoon main body, its related cloud patterns and precipitation forecast would be improved by assimilating Himawari-8 radiances. Here, the precipitation prediction from both Him8 and NoHim8 experiments is compared with the forecast by the JMA MSM.

Figure 2 shows the average precipitation of the 50-members ensemble forecast by Him8 and NoHim8 experiments, with the previous three-hour accumulated precipitation forecasted for nine hours by the JMA MSM and the accumulated precipitation by its radar for the same period. As Honda et al. (2019) showed, Him8 predicted heavy precipitation, which was closer to the observations than NoHim8. Even in Him8, however, accumulated precipitation of three hours was under-predicted when compared with the prediction by the JMA MSM and its radar data.

To evaluate the precipitation prediction skill more objectively, the threat score (e.g., Fritch et al. 1998), against the JMA radar data, of forecasts by the two experiments and JMA MSM were compared. The threat score is a measure of forecast skill. A high thread score value

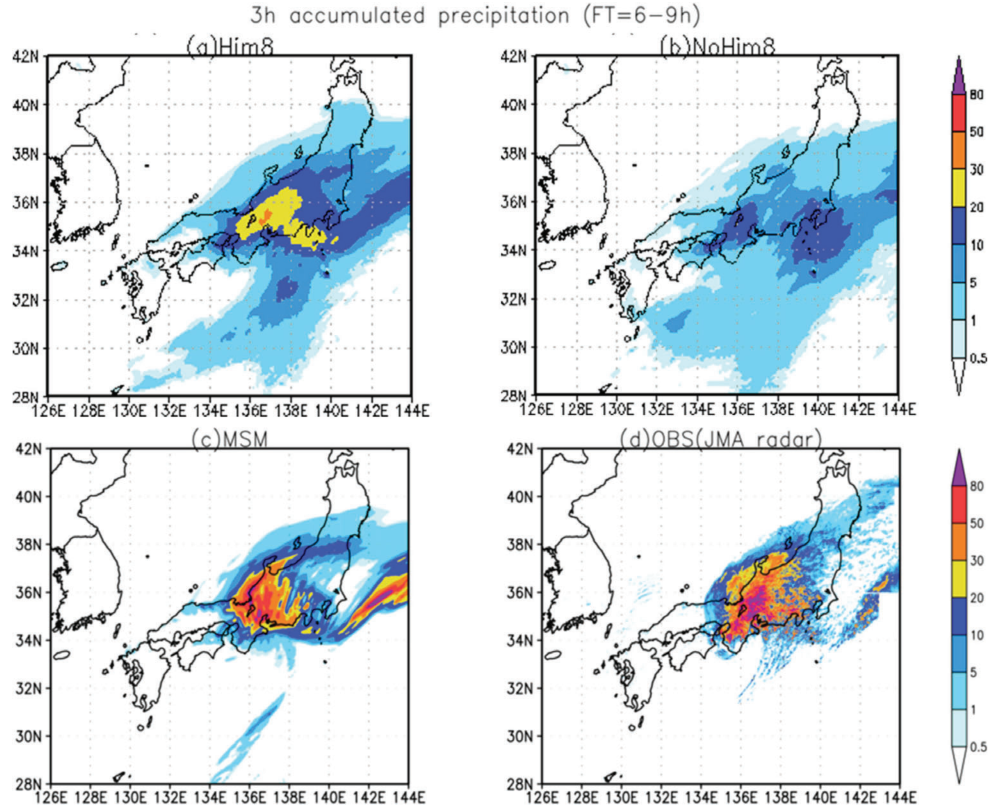

Figure 2. Horizontal maps of 3-h accumulated precipitation amount (mm) of (a) NoHim8 and (b) Him8 for 6–9-h forecasts initiated from the 50 ensemble member at 00:00 UTC September 20, (c) MSM and (d) the corresponding JMA radar data.

corresponds to a high prediction skill. The threat scores for the land area within the red frame in Figure 1 (b) were calculated. Figure 3 shows the result with a threshold value of 3 mm/h. The ensemble forecasts are initiated at 00:00 UTC September 20, 2016. As shown by Honda et al. (2019), Him8 shows higher scores compared to NoHim8, namely, high prediction skill. Similar results were obtained with a different threshold of 1 mm/h (Figures are abbreviated). Honda et al. (2019) indicated improving the typhoon intensity forecast as key to boosting the precipitation prediction skill associated with the typhoon main body at Him8 compared to NoHim8. The threat scores appeared to rise with the forecasting time in both experiments. The initial scores of the forecast were low because many members predicted based on light precipitation areas not seen by observations located in East Japan as well as overlooking the rain accompanying the typhoon main body (not shown). Since the typhoon main body approached such areas, the scores of both experiments rose as the precipitation was initially observed by the JMA radar.

Compared with JMA MSM, Him8 and NoHim8 show low accuracy during the initial forecasting period. This might be because the mesoscale objective analysis, as is initial value of JMA MSM, assimilates the precipitation of JMA radar data corrected by ground rain-gauge observations directly (Koizumi et al., 2006). Conversely, for long forecast times, forecasts outperforming JMA MSM are obtained with Him8. In future, we will try to further improve the short-term precipitation forecasts by assimilating JMA radar data simultaneously with the brightness temperature observations by Himawari-8.

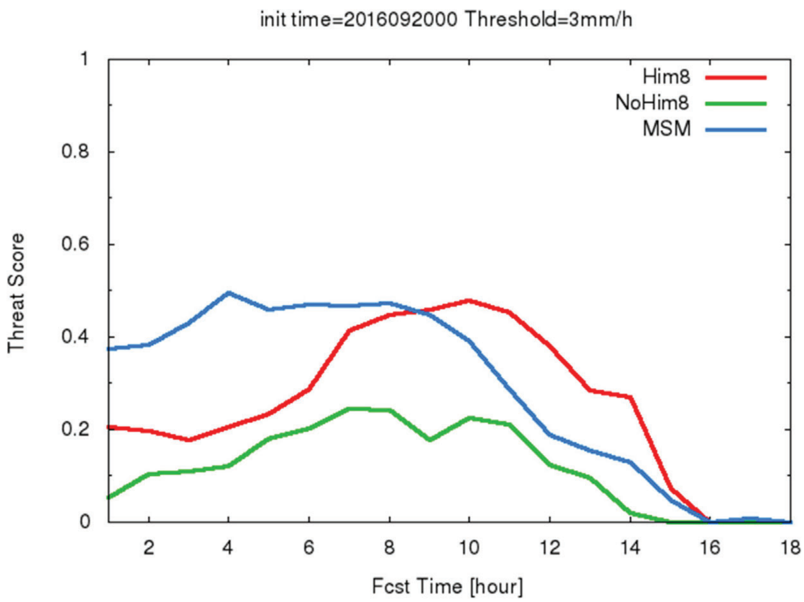

Figure 3. Ensemble mean threat scores of the precipitation forecasts as a function of forecast lead time (h). Red, green and blue curves show Him8, NoHim8 and MSM, respectively.

4 CONCLUSIONS

In this study, the degree of improvement in prediction accuracy for precipitation accompanied by the typhoon main body and assimilating Himawari-8 radiances using SCALE-LETKF was compared with JMA MSM. The predictive results obtained by Him8, NoHim8 and MSM were respectively verified with threat scores. Consequently, MSM accuracy was higher for the initial forecasts and Him8 proved more accurate for longer forecasting periods. In future, further improved precipitation forecasts will be targeted by simultaneously assimilating JMA meteorological radar alongside the brightness temperature observations by Himawari-8 and other precipitation cases will also be verified. In addition, it is important to take dam operations into account for further validation of the benefits of the unique NWP system.

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