Real-time precipitation forecasting using 1000-member ensemble Kalman filter with dual phased array radar assimilation during the Osaka, Kansai Expo 2025

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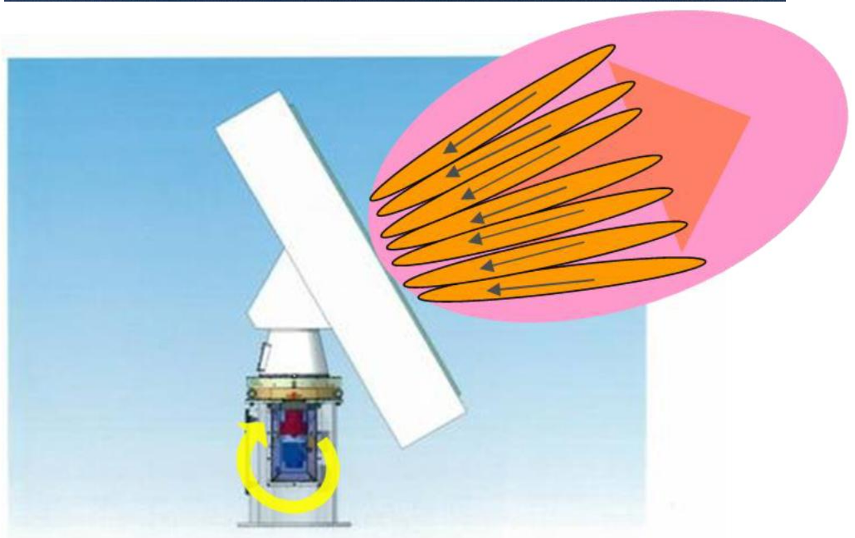
1. Introduction

Torrential rainfall events from convective weather systems represent one of the leading hazardous natural events in Japan, risking the triggering of landslides and flash flooding of rivers that can lead to the loss of life and property. These events are extremely challenging to predict due to their highly non-linear and rapid evolution. In this study we perform real-time 30-minute precipitation forecasts every 30-seconds using a real-time precipitation forecasting system that is updated every 30-seconds with MP-PAWR. The experiment took place for a period of 1 month in August 2025 during the Osaka Expo 2025 (Figure 1). We extend the development of the real-time system by implementing dual MP-PAWR assimilation from two radars simultaneously, becoming the first NWP system to perform dual MP-PAWR assimilation. Here we present results of the Osaka Expo demonstration.

Multi-Parameter Phased Array Weather Radar (MP-PAWR)

Multi-Parameter Phased Array Weather Radar (MP-PAWR) are an advanced X-band radar that observes reflectivity and Doppler radial velocity at a range of 80km every 30 seconds on approximately 100 elevation angles. MP-PAWR uses a mechanically rotating antenna for azimuthal scans and an electronic scan for the elevation angle, with the transmitted beam formed as a fan beam (Figure 1).

In the Kansai region, two PAWRs have been installed, one in Kobe and another in Suita, Osaka (Figure 1), providing dual MP-PAWR coverage across the Kobe/Osaka region.



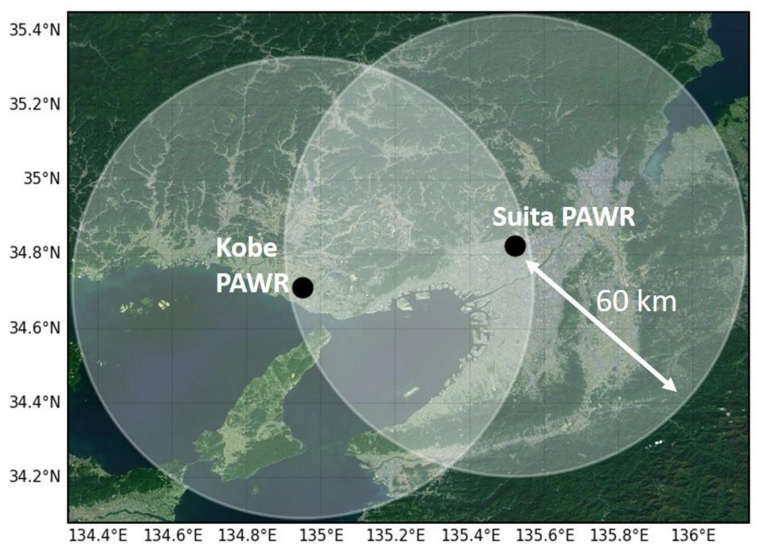


Figure 1: Left: Osaka-Expo 2025 site. Taken from Ibamoto (2025). 大屋根リング夜景全景です [Photograph]. Wikimedia Commons. https://commons.wikimedia.org/wiki/File:大屋根リング夜景全景.jpg. Licensed under CC BY-SA 4.0.

Bottom-left: MP-PAWR schematic. The transmitted beam is formed as a fan beam, and the received beams are formed as multi-beam using DBF technology. Image modified from Wada et al (2016).

Bottom-right: Dual MP-PAWR coverage over Kansai

2. SCALE-LETKF Real-time NWP System

At the core of the system is the SCALE-LETKF numerical weather prediction system (Lien *et al*. 2017), which couples the SCALE regional model with the Local Ensemble Transform Kalman Filter (LETKF). A 1000-member ensemble is used model a 500-m mesh, updated every 30-seconds using observations from the Kobe and Suita MP-PAWR. For this demonstration, we had exclusive access to 26,648 nodes on the Fugaku supercomputer. Figure 3 shows the setup of the model domains, alongside that for the Tokyo 2021 demonstration for comparison. As Figure 3 shows, the Osaka 2025 forecast domain size (inner domain) was 50% larger than for Tokyo 2021 and assimilated two sets of MP-PAWR (Kobe and Suita) instead of one (Saitama). Figures 4 shows the workflow of the system, including the transfer of JMA MSM model data to Fugaku every 3 hours to run outer domain SCALE forecasts and the transfer of MP-PAWR observations every 30-seconds from NICT to perform the inner domain cycling. During real-time operation, new 30-minute extended rain forecast are generated every 30-seconds following the assimilation of MP-PAWR observations and then disseminated to the RIKEN webpage (weather.riken.jp) and to a smartphone company (MTI), allowing the public to view the latest forecast on their phones.

Real-time system setup and workflow

	Osaka 2025 Real-Time Experiment	Tokyo 2021 Real-Time Experiment
Experiment Duration	1 month	1 month
Number of forecasts	>75,000	75,248
Number of Ensemble members (LETKF)	1000 members	1000 member
Number of MP-PAWRs	**2 (Kobe and Osaka MP-PAWR) 2 x Doppler wind and Reflectivity**	**1 (Saitama MP-PAWR) 1 x Doppler wind and Reflectivity**
Inner Domain Size and settings	**192 x 192 km 500-m horizontal res.**	**128 x 128 km 500-m horizontal res.**
# computational nodes	**26,648 (16% of total nodes on Fugaku)**	**11,580 (7%)**

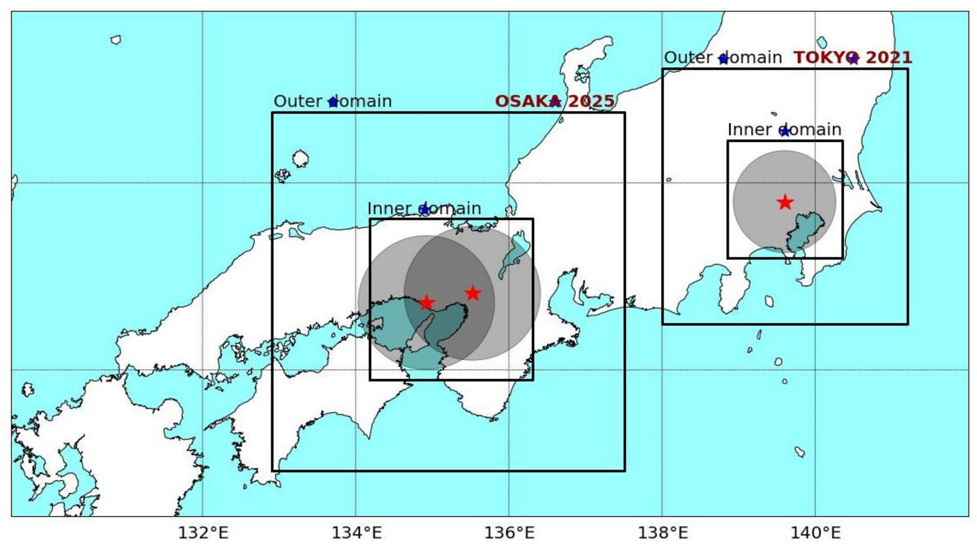


Figure 2: Experiment design (top) and model domain setup (right). We expanded the forecast domain by 50% from the Tokyo 2021 demonstration due to the expanded coverage offered by the Kobe and Suita MP-PAWR

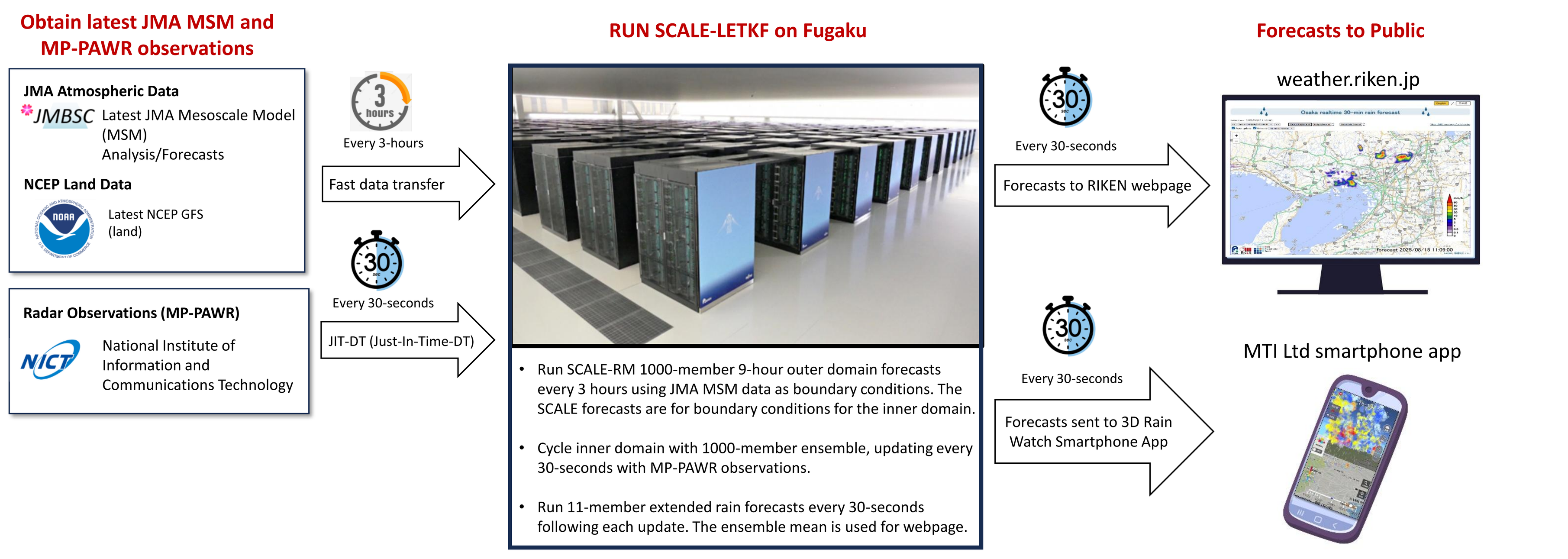
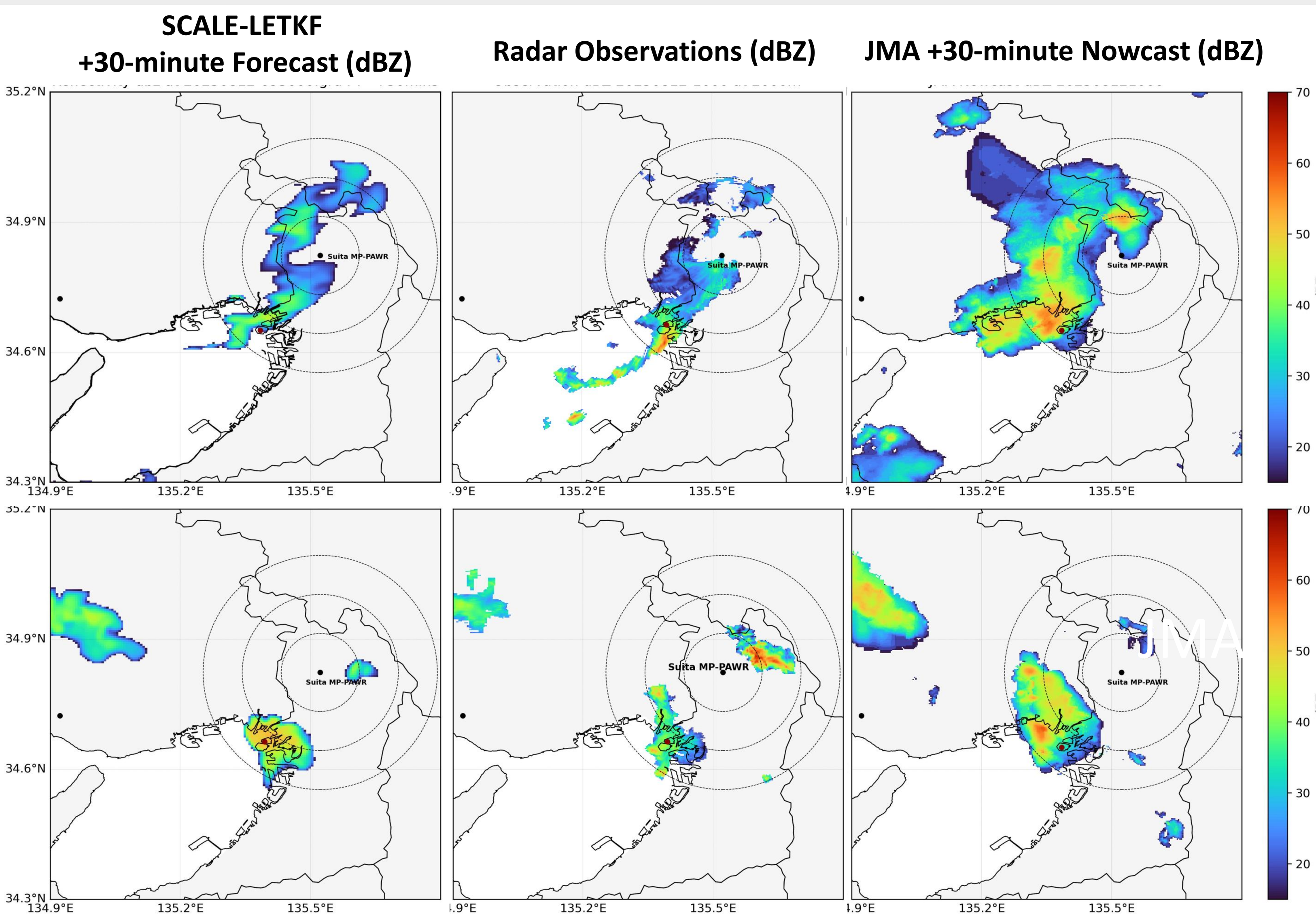


Figure 3: Schematic to show the workflow the real-time system. The system is operated on Fugaku from scripts on team servers. JMA MSM data and MP-PAWR data are rapidly transferred to Fugaku using specially developed software called Just-In-Time (JIT-DT) . The SCALE-LETKF runs outer domain forecasts and inner domain cycling continuously. The latest 30-minute rain forecasts are uploaded to the RIKEN webpage and sent to MTI for their smartphone application every 30-seconds for the public.

3. Results

We performed over 75,000 30-minute forecasts during the 1-month demonstration of the real time system in August 2025. We successfully predicted rainfall passing over the Osaka Expo up to 30-minute lead times, providing visitors with advanced warning of heavy rainfall. We also made skillful forecasts of rapidly evolving convective weather systems over the wider forecast domain, predicting changes to the detailed structures and propagation of these systems as they passed through the Kansai region. Below are a selection of forecasts made during the demonstration.



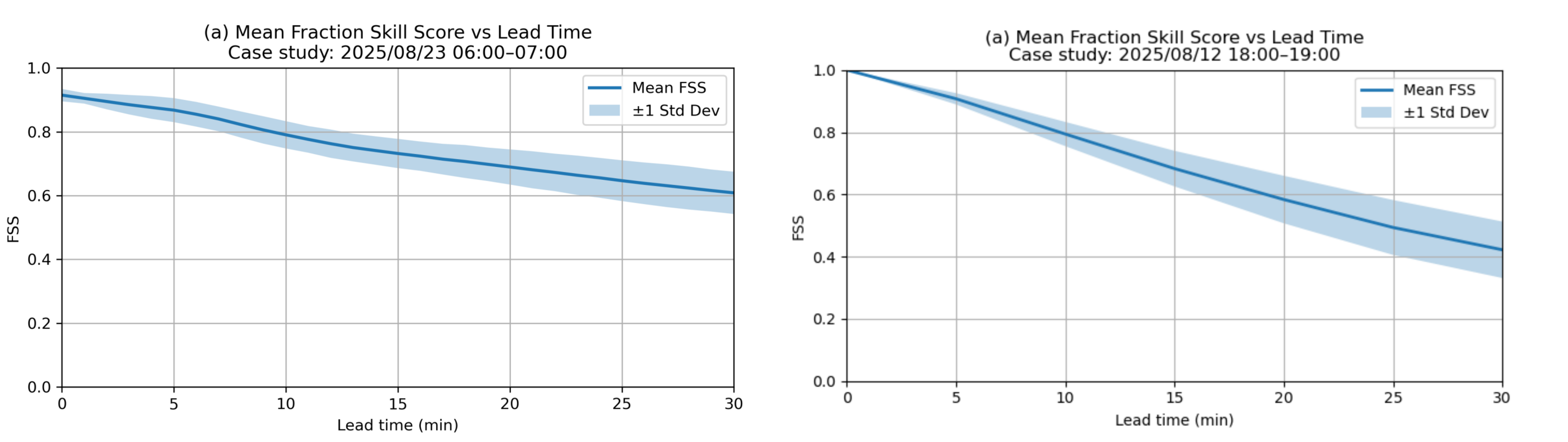


Figure 4 (above): Two case studies showing SCALE-LETKF radar reflectivity 30-minute forecast at 2-km height, radar observations and JMA nowcasts at the equivalent times. The SCALE forecasts show rainfall predicted to pass over Osaka Expo at 19:00 (case study 1) and 18:30 JST (case study 2). In comparison, the JMA nowcast show convective activity over a much larger region compared to the radar observations in both cases.

Case study 3: Forecast Initialized 06:00 JST 23/08/2025

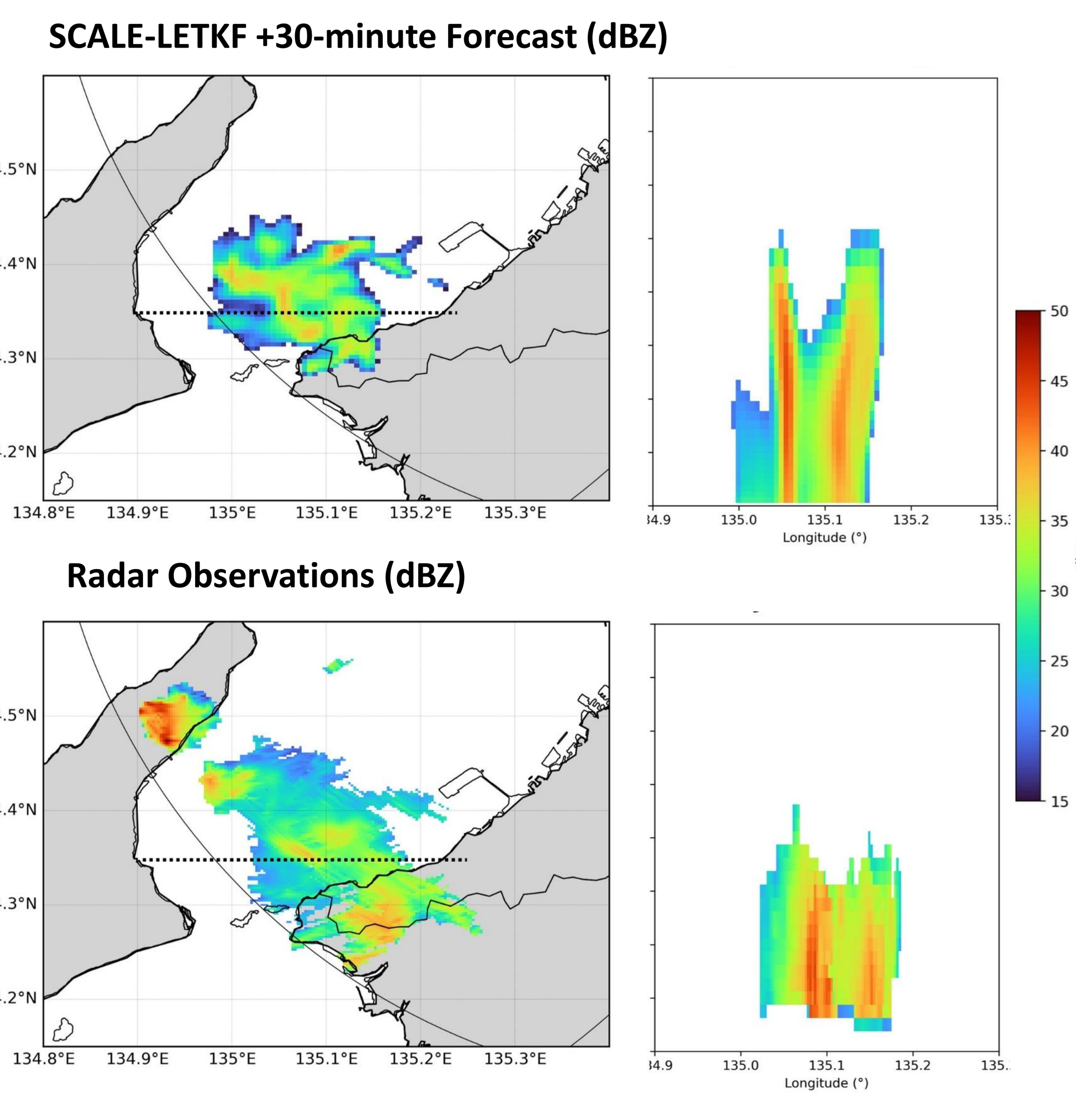


Figure 5 (top-left): Radar reflectivity 30-minute forecast at 2-km height and vertical cross section (dashed lines) initialised at 06:00 JST on 23rd August. (*Bottom-left*) shows the radar observations. The forecast is in good agreement with observations in relation to spatial extent and intensity of convection over Osaka Bay. Furthermore, vertical cross sections show two distinct convective towers of high intensity that are in good agreement with radar observations.

However, the model was unable to predict the rapid development of convective activity over Awaji Island that brought heavy rainfall to the area. It is likely due to insufficient environment conditions in the model, including errors in moisture distribution and quantity.

Fraction skill scores (FSS) were calculated to verify the forecast skill. Overall, the SCALE-LETKF forecasts demonstrated highly skilled forecasts up to 30-minute lead times when compared against radar observations. For example, for the forecast initialized at 18:30 12th , FSS was >0.8 up to 30-minute lead times, indicating high skill. We compared the FSS to the JMA nowcasts using JMA observations as verification, rather than radar observations. The JMA nowcast for 12/08 showed a sharper decrease in skill up to 30-minute lead times, indicating the SCALE-LETKF has greater forecast skill at longer lead times than the operational nowcasting system.

We will continue to develop the real-time system for precipitation forecasting and seek to assimilate new datasets that will improve the prediction of new convection in forecasts.

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