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Localized heavy rainfall prediction using selective cloud radar assimilation based on automated cumulonimbus tracking

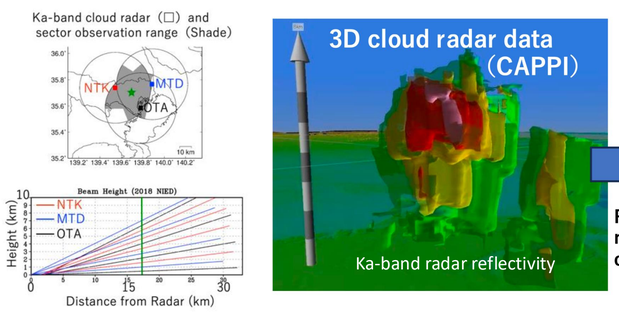
*Ryohei **KATO**, Shingo **SHIMIZU**, Tadayasu **OHIGASHI**, Takeshi **MAESAKA**, Ken-ichi **SHIMOSE**, Koyuru **IWANAMI**
National Research Institute for Earth Science and Disaster Resilience (NIED), Japan

1. Introduction

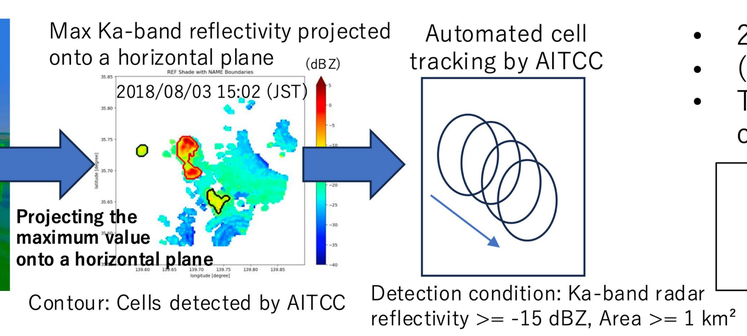
At NIED, we are developing a cloud radar data assimilation method that forecasts localized heavy rain from the cloud stage, before rain begins, using data from Ka-band radars (cloud radars) which can detect small cloud droplets that precede raindrops. Kato et al. (2022, WAF) successfully forecasted localized heavy rain 20 minutes in advance from the pre-precipitation stage by assimilating the 3D structure of cumulonimbus clouds, captured every minute by three cloud radars, using a cloud-resolving numerical model (CReSS) with a horizontal grid spacing of 700m. However, the assimilation method used (nudging-based humidification of cloud regions) assimilated not only developing clouds but also weakening clouds, resulting in unnecessary humidification and false precipitation forecasts. In this presentation, we report on the development of a **selective assimilation method** that automatically tracks cloud radar echoes and selectively assimilates only developing cloud cells to solve this false precipitation problem and improve forecast accuracy, and we introduce the results of its validation.

2. Methodology: Procedure for Selective Assimilation of Cloud Radar Data

① Creation of 3D Ka-band cloud radar data (CAPPI data)



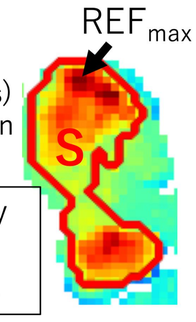
② Automated cloud cell identification and tracking (using AITCC (Shimizu and Uyeda 2012, JMSJ))



③ Calculation of characteristic data for extracted cloud cells

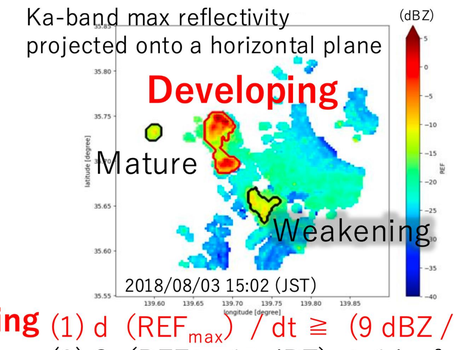
- 2D characteristics
- (3D characteristics)
- Temporal change in characteristics

Max reflectivity (REF_{max}), Area (S), etc.



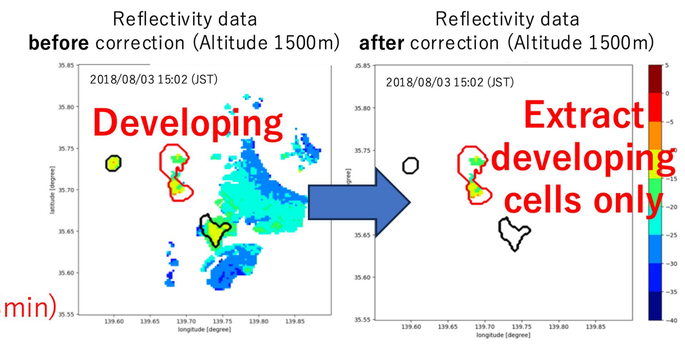
Detection condition: Ka-band radar reflectivity >= -15 dBZ, Area >= 1 km²

④ Determination of clouds for selective assimilation

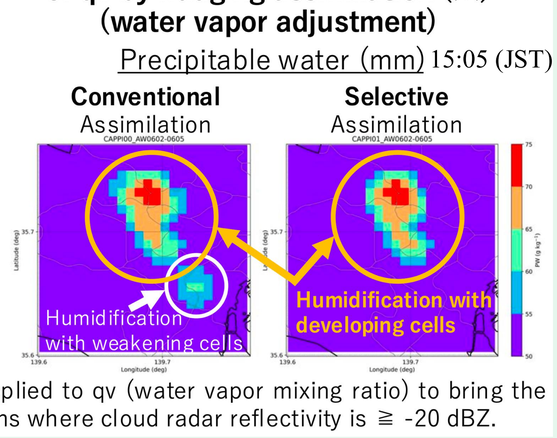


Developing (1) d (REF_{max}) / dt ≧ (9 dBZ / 3min)
Large area (2) S (REF≧-15 dBZ) ≧1 km²
No assimilation for heavy rain (3) REF_{max} < 35 dBZ

⑤ Output of 3D reflectivity data (CAPPI) for selective assimilation



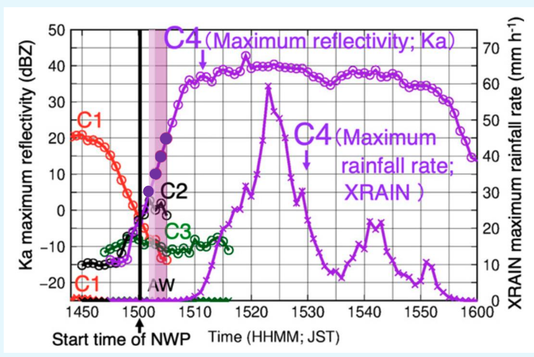
⑥ Modification of forecast initial value of qv by nudging assimilation (※) (water vapor adjustment)



(※) Nudging Assimilation (water vapor adjustment): A forcing is applied to qv (water vapor mixing ratio) to bring the location toward saturation, assuming 100% relative humidity in regions where cloud radar reflectivity is ≧ -20 dBZ.

3. Observation Results

Time-series of Maximum Reflectivity (Ka-band radar) and Maximum Rainfall Rate (XRAIN) for each echo

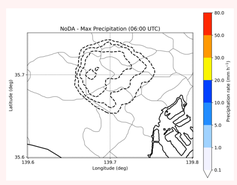


Time-series of the maximum value of Ka-band radar reflectivity projected onto the ground from CAPPI (open circles) and the maximum rainfall rate from X-band radars (XRAIN; x marks) for echoes C1-C4. The shaded area indicates the assimilation window (period) from 15:02 to 15:05 JST, meaning the Ka-band radar data (filled circles) during these 4 minutes were used for data assimilation as a control experiment.

4. Forecast Results

4. 1 Difference in Forecast Results with and without Selective Assimilation

Without Cloud Radar Assimilation (CDA)



No rain was forecasted without CDA.

Results of control experiments

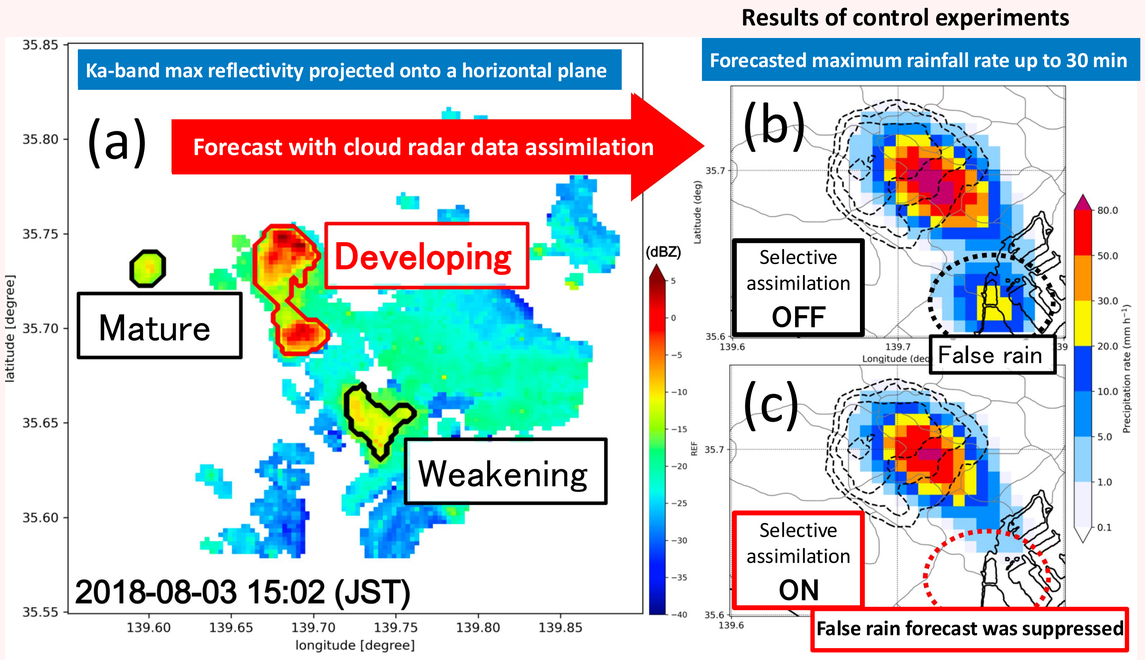
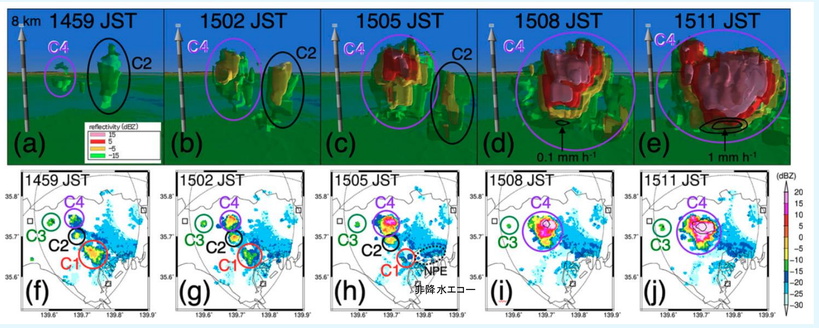


Figure 1. (a) Vertical maximum of cloud radar reflectivity (shade) and cloud cells extracted by AITCC (contours). (b, c) the forecasted maximum rainfall rate (shade) up to 30 minutes after assimilating cloud radar data from 15:02-15:05 for the cases (b) without and (c) with selective assimilation, respectively. The observed surface maximum rainfall rate from XRAIN is overlaid (dashed lines: 1, 5, 20, 50 mm h^{-1}).



Time Evolution during the Rapid Development Stage of Cloud C4, which Caused Localized Heavy Rain

Caption (a-e): (a)-(e) 3D structure of cloud radar reflectivity (view from southwest, shaded) and surface rainfall rate from XRAIN (contours).

Caption (f-j): (f)-(j) Maximum of Ka-band radar reflectivity projected onto the ground from CAPPI (shaded) overlaid with observed surface maximum rainfall rate from XRAIN (dashed lines: 0.1 and 1 mm h^{-1}).

4.2 Forecast Results for Different Assimilation Windows (1-minute shifted experiments)

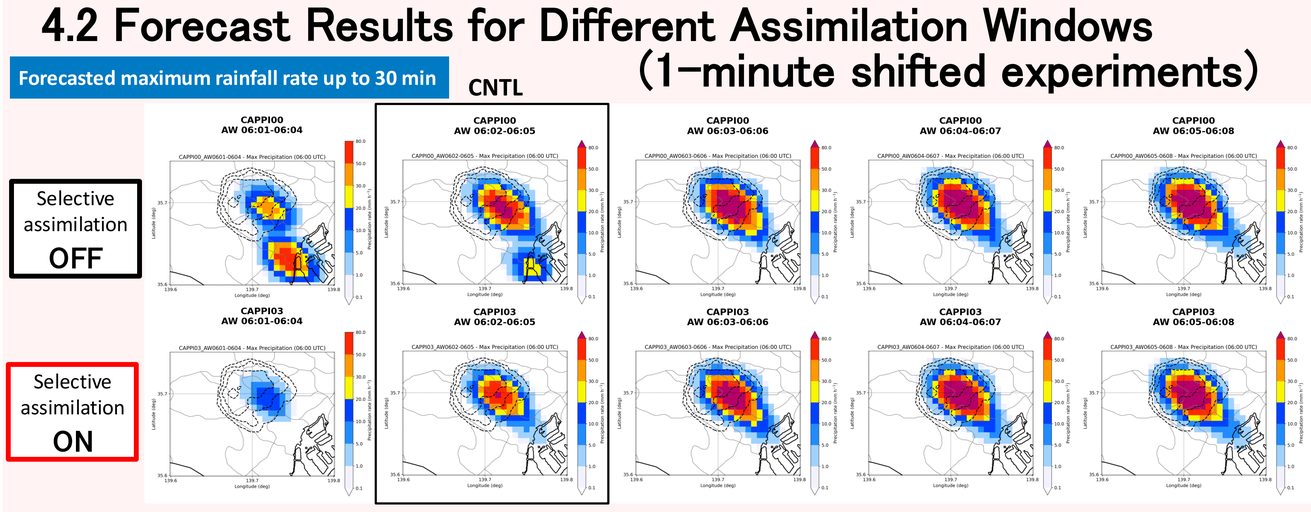


Figure 2. Forecast results for different assimilation windows. (Top row) Selective Assimilation: OFF, (Bottom row) Selective Assimilation: ON. Shading and contours are the same as in Figure 1(b).

In all experiments, the heavy rain forecast was maintained, while the false rain forecast was suppressed.

5. Summary and Future Work

We advanced a cloud radar data assimilation method for high-accuracy forecasting of localized heavy rain before it starts. We developed and validated a **selective assimilation method** that uses AITCC to automatically detect and track cloud radar echoes and selectively assimilates only developing cloud cells. While the conventional assimilation method forecasted false precipitation due to humidification of weakening cells by water vapor nudging, selectively assimilating only developing cells suppressed this false precipitation. The robustness of this method was confirmed through experiments with multiple initial conditions. Future work includes applying this method to numerous cases and developing an assimilation method for situations where clouds and rain co-exist.

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