Additional Ensemble Perturbations to Correct the Atmospheric Field through Assimilation of Radar Reflectivity

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1. Introduction

cause → result

Atmospheric Field (wind, temperature, pressure, humidity) —Forecast→ **Precipitation** (cloud water, cloud ice, rain, snow, graupel)

Atmospheric Field: should be modified by reflectivity assimilation

Precipitation: observed by radars

To improve rainfall forecast by direct assimilation of radar reflectivity, atmospheric field should be modified based on correlation between the Atmospheric Field and Precipitation

- [3DVar] given climatologically (difficult to be estimated)
- [4DVar] calculated by linear model (difficult to make the model)
- [EnKF] calculated by ensemble forecasts (this study)

2. Problem of Reflectivity Assimilation

Reflectivity assimilation with EnKF

First guess: mean of ensemble forecasts $(u^f, v^f, w^f, T^f, p^f, q_v^f, q_c^f, q_{ci}^f, q_r^f, q_s^f, q_g^f)$

Analysis

$$\mathbf{x}^a = \mathbf{x}^f + \mathbf{K}\left[Z_H^{obs} - Z_H^f\right]$$

Kalman gain: weight of average between first guess and observation

$$\mathbf{K} = \mathbf{B}\mathbf{H}^T\left(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R}\right)^{-1}$$

Observed reflectivity (dBZ)

Forecasted reflectivity (dBZ) calculated from (q_r^f, q_s^f, q_g^f)

Obs. covariance

$E\left[\delta\mathbf{x}^f \delta Z_H^f\right]$ $E\left[\delta Z_H^f \delta Z_H^f\right]$ Forecast covariance

If rainfall is not forecasted, $\delta Z_H^f=0$ (no impact of Z_H assimilation)

→Additional δZ_H^f is introduced

$$Z_H^f(q_r^f,q_s^f,q_g^f)=10\log_{10}\left[720N_{0r}\left(\frac{\rho q_r^f}{\pi\rho_r N_{0r}}\right)^{7/4} + 720N_{0s}\left(\frac{\rho q_s^f}{\pi\rho_s N_{0s}}\right)^{7/4}\times 0.23\frac{\rho_s^2}{\rho_r^2} + 720N_{0g}\left(\frac{\rho q_g^f}{\pi\rho_g N_{0g}}\right)^{7/4}\times 0.23\frac{\rho_g^2}{\rho_r^2}\right]$$

(rain; snow; graupel)

Set to be 1 if $T\geq 0$°C (bright band)

Theoretical formulation in 1-moment cloud microphysics

$N_{0r}=8\times10^6[\mathrm{m}^{-4}]$, $N_{0s}=1.8\times10^6[\mathrm{m}^{-4}]$, $N_{0g}=1.1\times10^6[\mathrm{m}^{-4}]$

$\rho_r=1\times10^3[\mathrm{kg\,m}^{-3}]$, $\rho_s=84[\mathrm{kg\,m}^{-3}]$, $\rho_g=3\times10^3[\mathrm{kg\,m}^{-3}]$

cf., Dowell et al. (2011)

3. One Solution: Adding Ensemble Perturbation

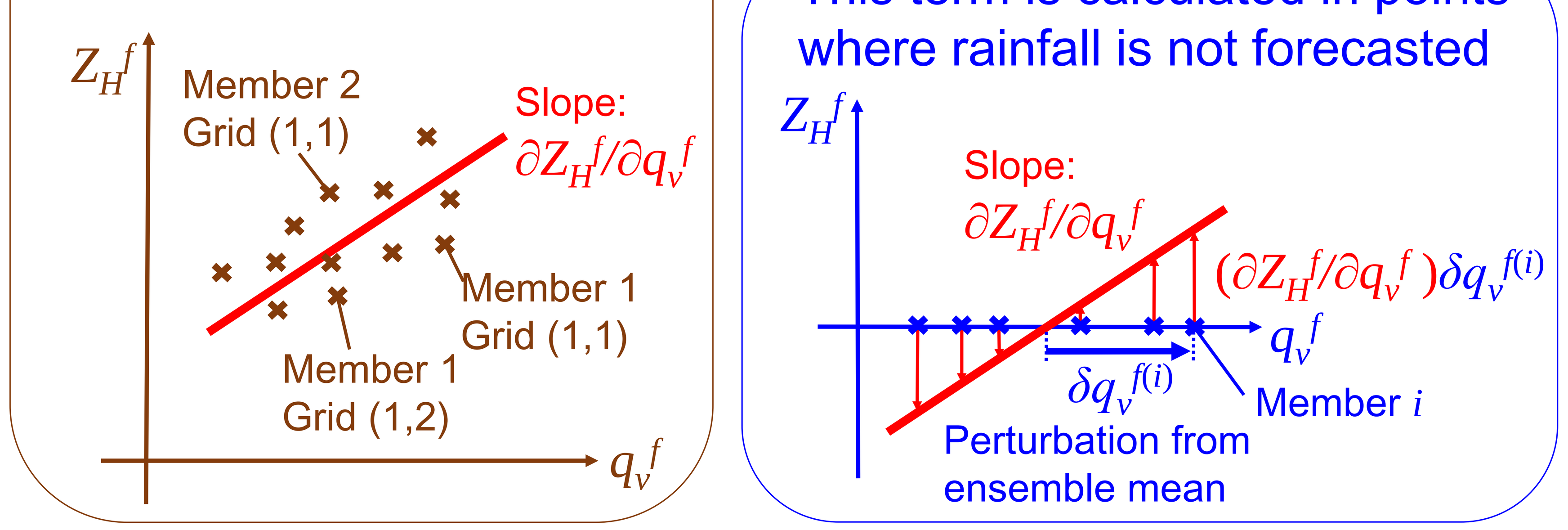
Z_H^f of member i is replaced with following $\delta Z_H^{f(i)}$ before assimilation if rainfall is not forecasted at obs. points in more than half of members

(zonal wind, meridional wind, vertical wind, temperature, water vapor mixing ratio)

$$\delta Z_H^{f(i)} = \frac{\partial Z_H^f}{\partial u^f}\delta u^{f(i)} + \frac{\partial Z_H^f}{\partial v^f}\delta v^{f(i)} + \frac{\partial Z_H^f}{\partial w^f}\delta w^{f(i)} + \frac{\partial Z_H^f}{\partial T^f}\delta T^{f(i)} + \frac{\partial Z_H^f}{\partial q_v^f}\delta q_v^{f(i)} \quad (\star)$$

Slope of regression line of q_v^f for Z_H^f calculated with all grids in each vertical level

This term is calculated in points where rainfall is not forecasted

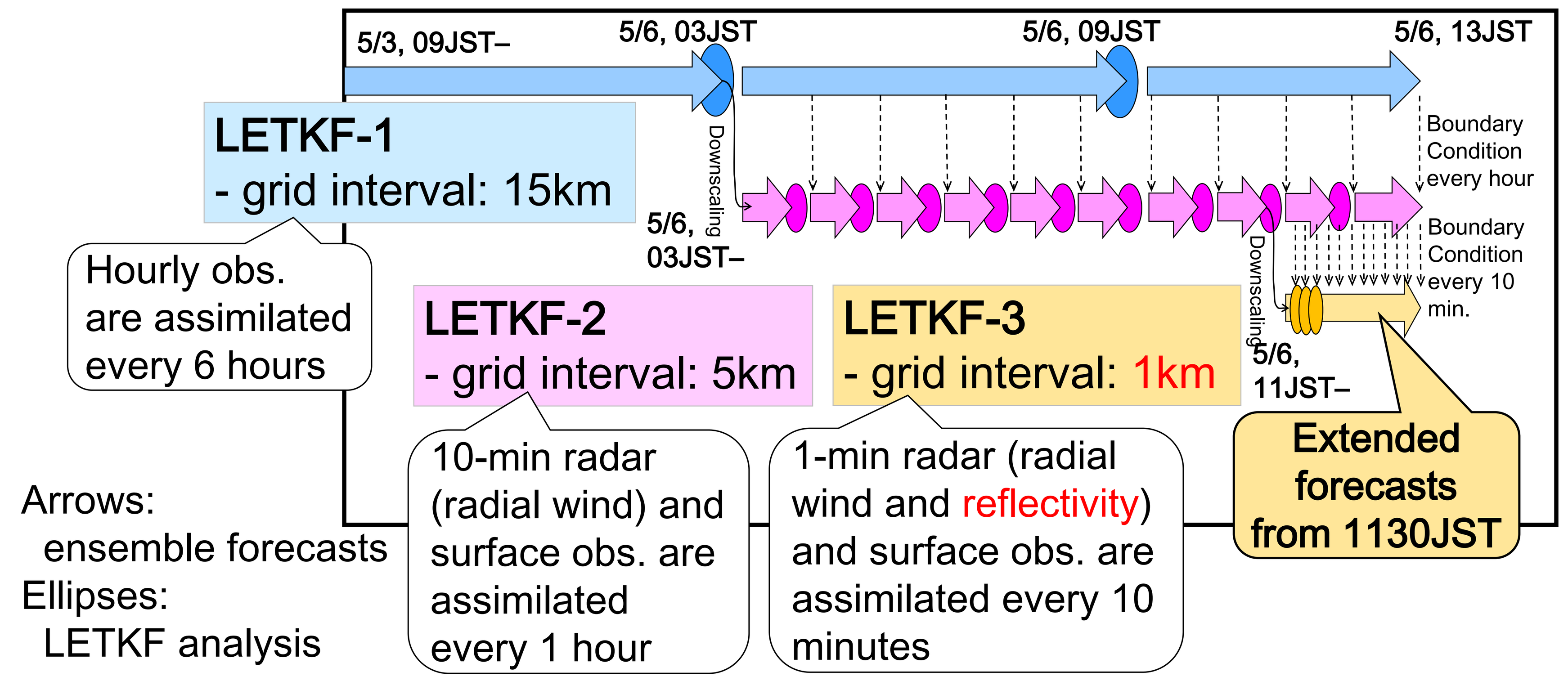


→ Additional δZ_H^f is correlated with $(u^f, v^f, w^f, T^f, q_v^f)$

→ Atmospheric field is modified by Z_H assimilation

4. Experiment to Check Impact of Perturbation

Target: tornadic supercell in 6 May 2012 — 50 members

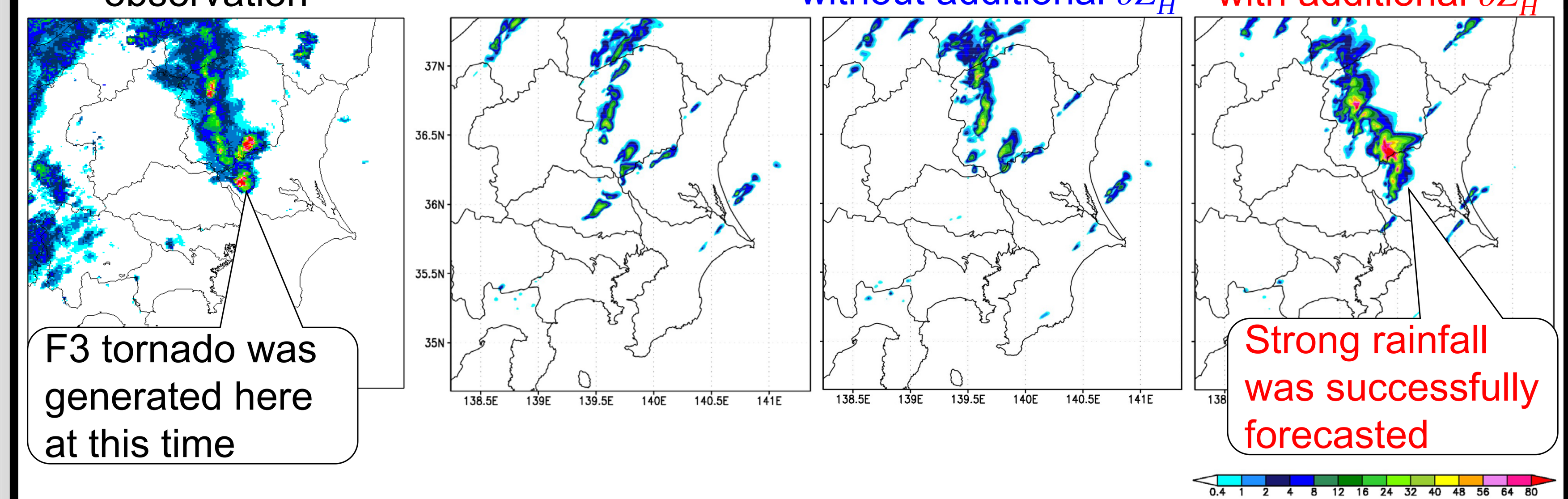


- Observation variance of Z_H^{obs}: $\sigma_Z^2=(5\mathrm{dBZ})^2$
- Attenuation of Z_H^{obs} is corrected by $Z_H^{obs}+0.073\Phi_{DP}^{obs}\rightarrow Z_H^{obs}$ (Jameson 1992)
- Z_H^{obs} is interpolated to 2-km grid (influence radius: 1km) before assimilation
- Z_H^{obs}=0dBZ $[\sigma_Z^2=(50\mathrm{dBZ})^2]$ is assimilated at points of Z_H^{obs}<15dBZ

→ Compare extended forecasts with and without additional δZ_H^f

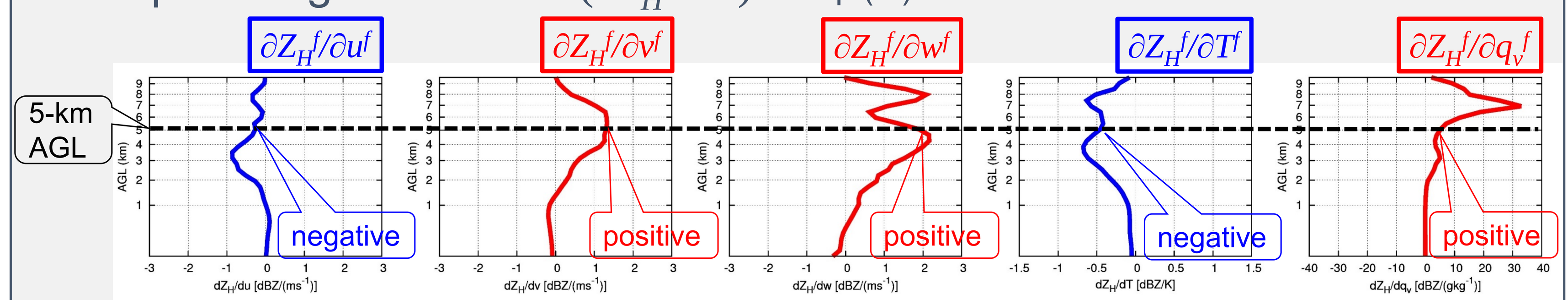
5. Results

Rainfall rate (mm/hour) at 1-km height at 1230JST (1-hour forecast)

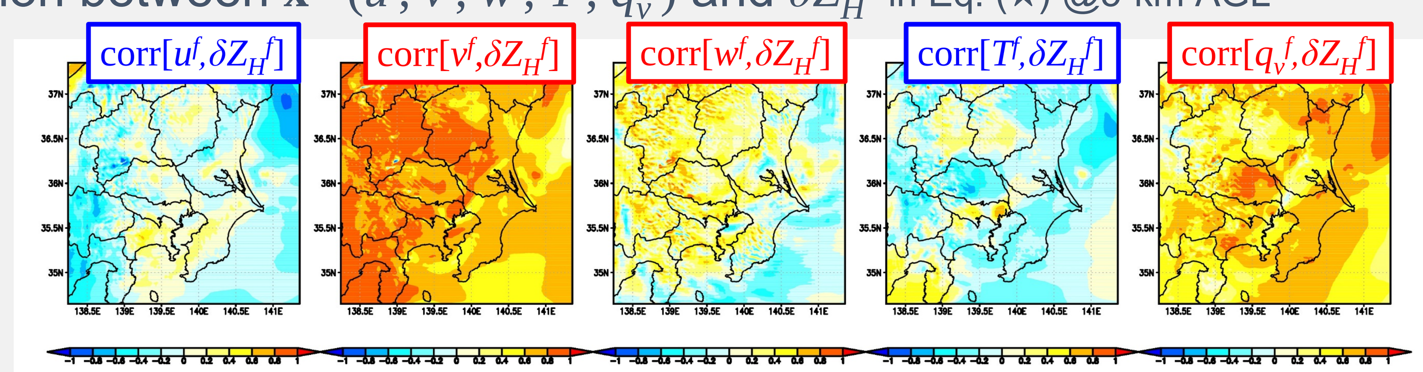


Z_h^{obs} assimilation with additional δZ_H^f at 1110JST

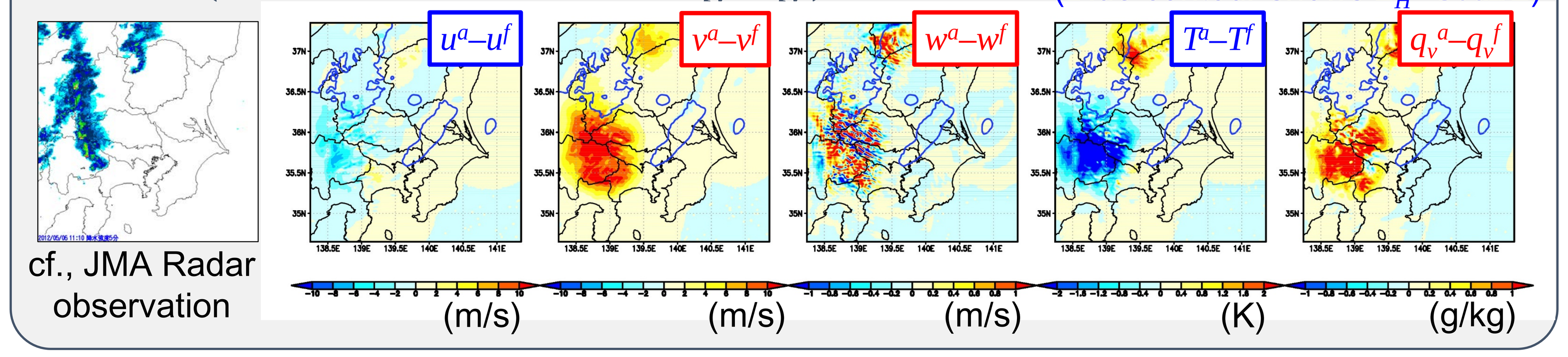
1. Slope of regression line ($\partial Z_H^f/\partial \mathbf{x}^f$) in Eq. (★)



2. Correlation between $\mathbf{x}^f=(u^f, v^f, w^f, T^f, q_v^f)$ and δZ_H^f in Eq. (★) @5-km AGL



3. $\mathbf{x}^a-\mathbf{x}^f=(u^a-u^f, v^a-v^f, w^a-w^f, T^a-T^f, q_v^a-q_v^f)$ @5-km AGL (Blue contour shows Z_H^f=30dBZ)



6. Summary

We suggest to add ensemble perturbations of reflectivity correlated with the atmospheric field before assimilation at points where rainfall was not forecasted. This method has a possibility to improve short-term rainfall forecast.

Acknowledgements

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