Initialization of Midlatitude Convective Storms by Assimilation of Single Doppler Radar Observations

P5.5

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1. Introduction

Prediction of convective cells is a very challenging topic for NWP. Nowcasting systems, based on extrapolation of observations, do not capture easy this kind of weather phenomenon because the evolution of convection is too fast. In data assimilation, weather radar can be of use because it is the remote sensing tool that can sample the structure of individual convective cells with high resolution in time and space.

Both the 4D-Var (with strong constraint) and the ensemble Kalman Filter technique are computationally expensive systems. The McGill radar assimilation system treats the model equations as a weak constraint in the cost function, so there is no need to have an adjoint model for integrating backward in time. This treatment not only reduces the computational time to find the optimal analysis, but it also includes the fact that the numerical model is not perfect. Since operational radar networks rarely have two radars making observation of the same location, the McGill data assimilation system assimilates the radial velocity as well as the reflectivity from single Doppler radar to obtain a set of new analysis fields to initialize a regional model. The goal of the present study is to determine how long very short term forecasts can be improved at the convective scale.

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2. Methodology

2.1 Assimilation system

Following Caya (2001), the McGill data assimilation system is based on the variational formalism, and collects the available information from observations and backgrounds. In addition, the cloud-resolving model equations, based on the MC2 (Mesoscale Compressible Community) atmospheric model (Laprise et al. 1997) coupled with the Kessler microphysics (warm cloud), is taken to be a weak constraint. The form of the cost function is:

$$
\begin{aligned}
J &= J_o + J_b + J_m \\
&= \tfrac{1}{2}(x - x_b)^T \mathrm{B}^{-1}(x - x_b) \\
&+ \tfrac{1}{2}\sum_{n=1}^{N}(H(x) - y_0)^T \mathrm{R}^{-1}(H(x) - y_0) \\
&+ \tfrac{1}{2}\varepsilon_q{}^T Q \varepsilon_q
\end{aligned}
$$

where J_o, J_b, J_m are the observation, background and model terms, respectively. The vector x contains the control variables correspond to the model trajectory. The vector y represents the observations and H stands for the observational operator that projects the model space into the observational space. The index n defines observational times. Since the model governing equations perform as the weak constraint in the cost function, the model residuals are represented by the vector ε_q. The B, R, and Q operators are the background-, observation-, and model-error covariance matrices, respectively. The superscripts -1 and T denote the inverse and transpose of the matrix.

The assimilation system has been modified and improved in the background term. First, following Purser et al. (2003), by assuming that the error covariance of the control variables is isotropic and homogeneous the background error covariance matrix is modeled by a recursive filter. Furthermore, in order to avoid the inverse of the background error covariance matrix, B^{-1}, and to speed up the cost function achieving the optimal solution of the

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analysis a preconditioning procedure is done in the assimilation system. Second, a three-hour prior high resolution (1km) model forecasts is used as background fields in the background term of the cost function. This strategy involves the large-scale analysis from the numerical model that plays a crucial role in the assimilation system.

2.2 Strategy of cycling process

Since the phenomena at the convective scales change rapidly with time, one could not expect that one cycle of assimilation is enough to capture the temporal change of the weather system in convective storms. The cycling strategy here is: with an assimilation window of 10 minutes, the assimilation system obtains a set of analysis fields and initializes the MC2 model. The model then performs a 30 min forecast allowing for spinup adjustments. The assimilation system takes the new background fields from the model 30-minute forecasts, and assimilates another 10-minute of radar observations. The new analysis fields then re-initialize the model that performs the forecast forward in time again. Fig.1 shows the procedure of the cycling strategy.

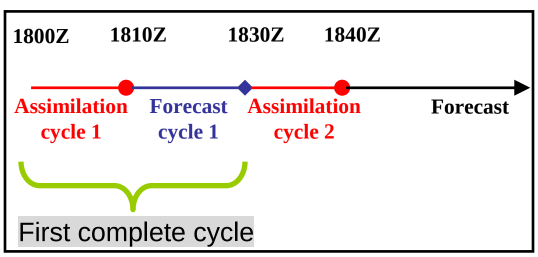
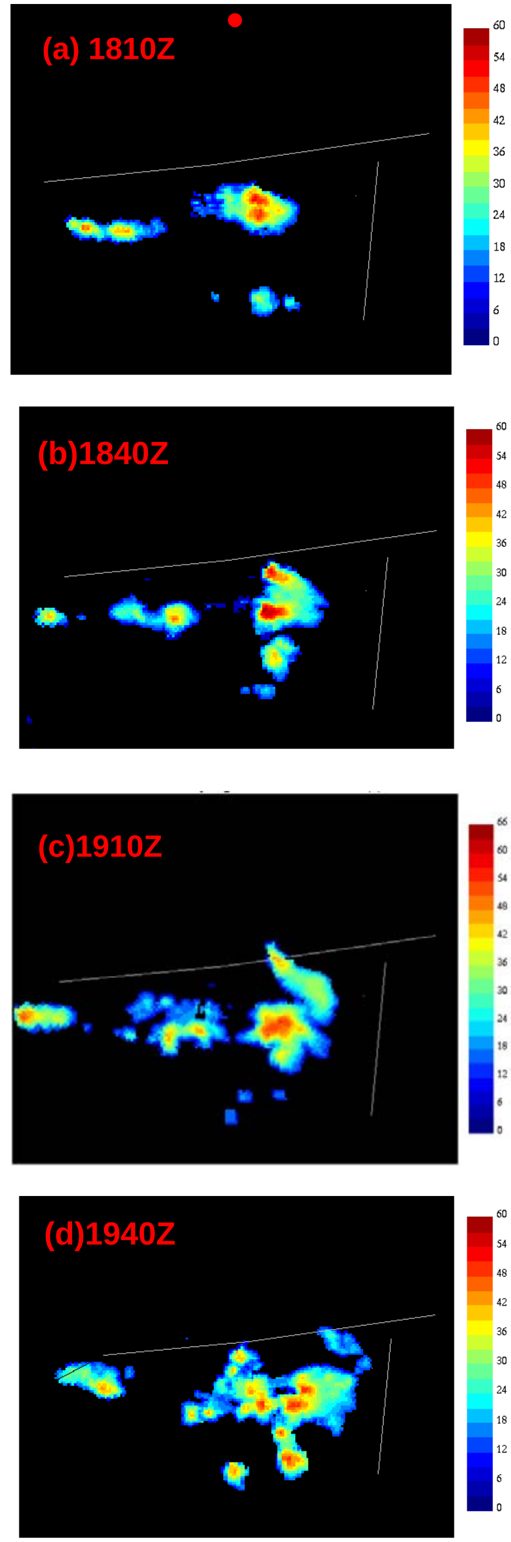


Fig. 1. The scheme of the cycling process.

3. Case Description

In order to investigate the cycling process, the convective storm system on 12th, July 2004 was selected. This was a strong, long-lasting storm with convective scale features. The system was developing, growing, and dissipating for more than two hours. The convective cells were almost stationary. during the life cycle, so the McGill S-band radar could keep track of the different stages. Figs 2(a)-(e) depict the reflectivity radar observed from 1810Z to 2010Z. As seen the evolution of the system was very rapid.



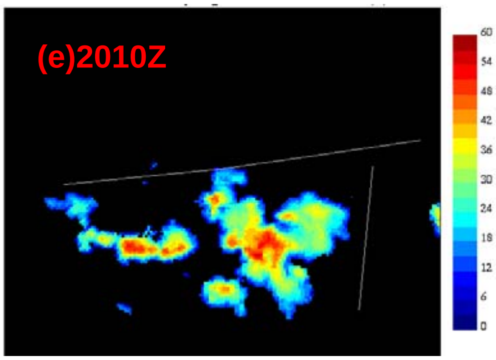


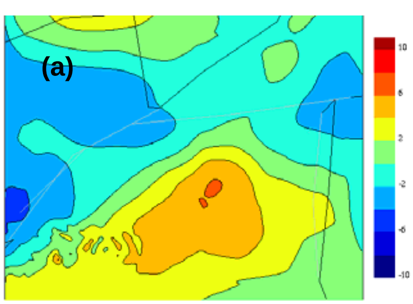
Fig. 2. Reflectivity of the convective storms detected by McGill S-band radar at (a) 1810Z; (b) 1840Z; (c) 1910Z; (d) 1940Z; (e)2010Z. The red dot indicates the location of the radar site. (Unit: dBZ)

4. Results and Verification

Once the new analysis fields are obtained by the assimilation system, they are used as the initial fields in the MC2 cloud-resolving model. The analysis domain is 250 x 200 x 25 km^3. The horizontal resolution is 1km; in the vertical a stretched grid mesh is used; the time step is 6s.

4.1 Initialization

Fig. 3. shows the difference before and after the assimilation in the horizontal wind. When the reflectivity and radial velocity are assimilated, the horizontal wind shows that the increment based on the background fields modified the winds in the observed areas. The analysis from assimilation reveals that the adjustments within the observed areas help to trigger the convective cells in the right place.



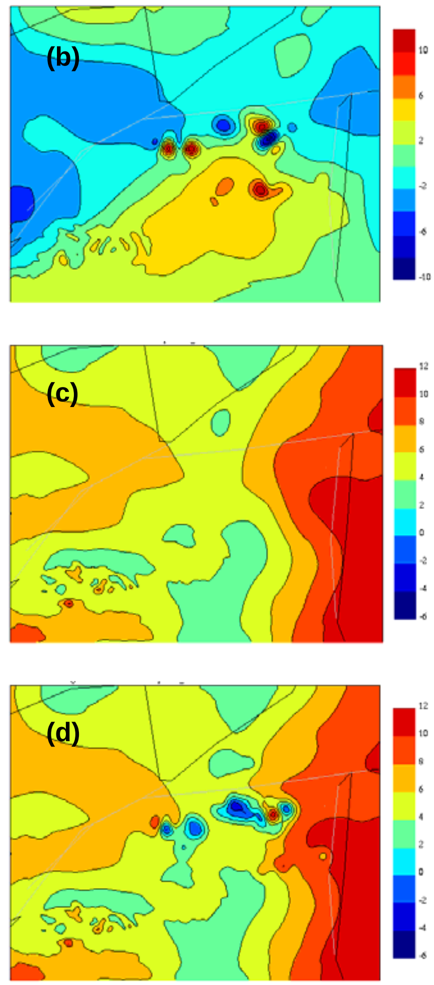


Fig. 3. Analysis field of (a) u component from background; (b) u component from assimilating system; (c) v component from background; (d) v component from assimilating system. (Unit: m/s)

4.2 First complete cycle

Fig. 4. presents the forecast of the precipitation rate. Fig 4(a) shows that the analysis fields from the assimilation system successfully trigger the convective storms in radar observed regions. Without data assimilation, the modeled storms did not occur at the right time and the right place. The precipitation on the surface reveals the feedback of assimilation rain mixing ratio from radar observations, the location and the pattern are consistent to what radar observed at that moment. The discrepancy between forecasts and radar observations are manifest in one hour forecast (Fig. 4(b)), the location of the precipitation no longer

match to what radar observed at 1910Z (Fig. 2(c)).

4.3 Cycling process

Fig. 5. displays the forecasting precipitation rate after the cycling process. Compare the 1-hour forecast of the precipitation rate between Fig 4(b) and Fig 5(a), the cycling process really improves the forecast. With only one complete cycle, the observation in Fig 2(c) and the model forecast in Fig 4(b) imply that the ability of the prediction is limited to 1 hour. The 1-hour forecast after cycling process (Fig 5(a)) is compatible with radar observation (Fig 2(d)), not only in the location, but also in the intensity. However, the 1.5-hour forecast indicates that the system moved away from the radar-detected location although the prediction could capture the intensity of the system.

4.4 Verification

Radar observations are still the only available type of precipitation data, which covered the analysis domain, so the data is going to be used in the verification. Since model outputs include three-dimensional winds, these control variables are used to verify the model forecasts in time. By using the equation: $V_r = u\frac{x}{r} + v\frac{y}{r} + (w + V_t)\frac{z}{r}$, where r is the distance from the radar, and V_t is the fall speed of rainwater from the model. One can compare the difference between the observed radial velocity and the “simulated radial velocity” from the model output. In this study, normalized root mean square error is calculated defined by:

$$\text{NRMS} = \frac{\sqrt{\frac{1}{N}\sum (Vr_{obs} - Vr_{simu})^2}}{\sqrt{\frac{1}{N}\sum (Vr_{obs})^2}}$$

where N is the total number of analysis points, the subscript of “obs” and “simu” indicates the observed and simulated radial velocity, respectively.

Fig 6(a) shows the result from first complete cycle forecast. The comparison between initial time 1810Z (pink line, with data assimilation) and the model background field (blue line, without data assimilation) indicates that the analysis from the assimilation is better in all vertical layers. In addition, the errors of the radial component are smaller in the lower levels than at the higher levels. The error of the radial component after the cycling process is demonstrated in Fig 6(b). The conclusion is consistent with Fig 6(a). The errors in the higher levels are larger than the first complete cycle. This larger error in the high levels may explain why the forecasting system moves away from the radar observation. However, one should notice that the verification here only examines the radial component, and the tangential component cannot be analyzed. Since the assimilation of radial velocity only adjusts the radial component, the forecast errors may also come from poor quality of the tangential component.

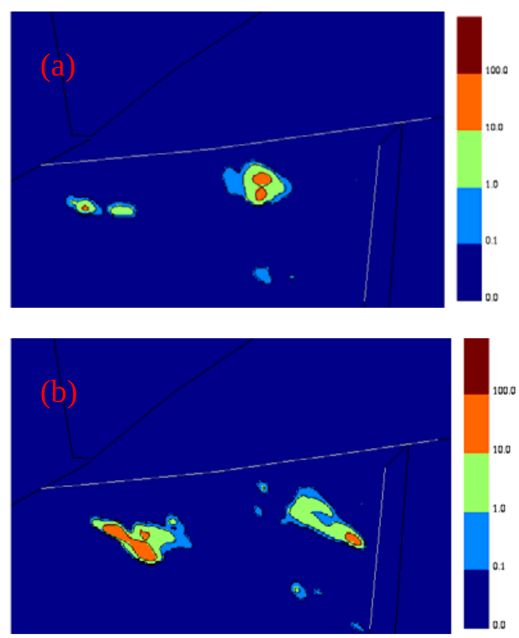
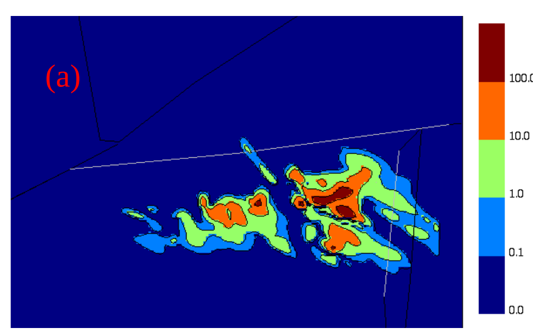


Fig. 4. The first complete cycle process: The precipitation rate from the model forecasts: (a) 1815Z, 5-min forecast; (b) 1910Z, 60-min forecast. (Unit: mm/hr)



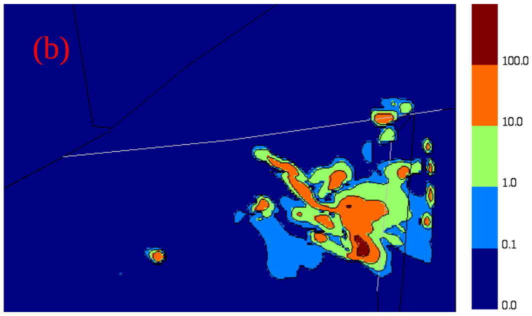
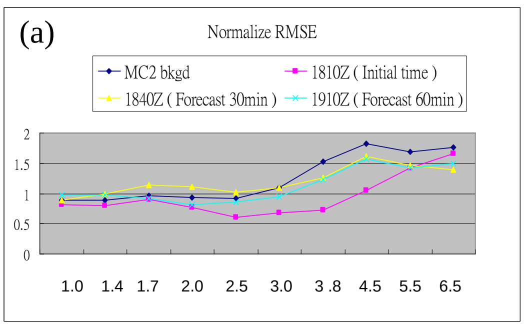


Fig. 5. The cycling process: The precipitation rate from the model forecasts: (a) 1940Z, 60-min forecast; (b) 2010Z, 90-min forecast.



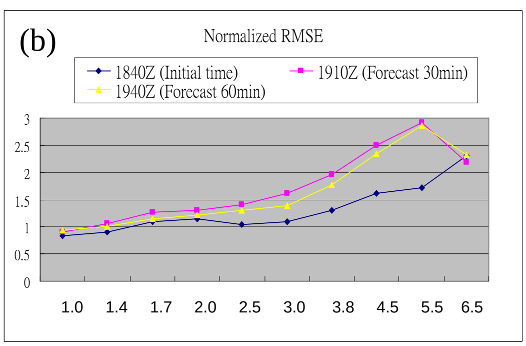


Fig. 6. Verification of the radial velocity: (a) the result from only one cycle forecast; (b) the result from cycling process. X-axis is the vertical height in different layers.

5. Conclusion

In this case study, the McGill radar assimilation system successfully triggered the convective storms at the right time and place with a single assimilation cycle and based on single Doppler radar observations. By using the previous forecast from large-scale analysis as the background fields, the results indicate that the environment did have potential to maintain the convective activity.

The cycling process helps to capture the evolution of the storms, and the intensity and the location of the precipitation. The results displayed indicate that the predictability of the very short-term forecast can be achieved up to 1.5-hour. After 1.5-hour, the environmental flow caused the forecasting system to drift away from the radar observations. The verification of the radial component in time reveals that the errors are larger in the high levels, and this may explain why the predicting system displaced away from the real location.

6. Reference

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