Radar Data Assimilation in the Canadian High Resolution Ensemble Kalman Filter System

Kao-Shen Chung¹, Weiguang Chang², and Luc Fillion¹

Collaborators:
Isnatar Zawadzki², M.K Yau², Frederic Fabry²

1. Meteorological Research Division, Environment Canada
2. Dept of Atmospheric and Oceanic Sciences, McGill University

Kao-Shen Chung
May 13, 2013
10th SRWNO-Workshop
Outline

- Introduction of the Canadian High Resolution Ensemble Kalman Filter (HREnKF) system
- Strategy of assimilating radar data and experiments designed
- Impact of assimilating radar data and verifications (two summer cases)
- Summary and future works
High Resolution Ensemble Kalman Filter System (HREnKF)

Initial guess → Ensemble members → Perturbed observations

Add random perturbations

Data assimilation → Observation

Perturbed observations

Analysis step

Add random perturbations (model error)

Forecast step

GEM-LAM forecast for all the members.

Global system (1998) → limited area

A: LAM15
B: LAM2p5
C: LAM1 300x300 (MTL region)
Features of the system

Sequential process to assimilate observations

Localization strategy

Partitioning the ensemble --- no inflation factor
(to deal with the underestimation of the error structure)
Assimilation of McGill Radar data in HREnKF

Assimilation of radial wind component

- Doppler winds are assimilated.
- Reflectivity is used for terminal velocity only.

\[ V_r = (U \sin \varphi + V \cos \varphi) \cos \alpha + (W + V_T) \sin \alpha \]

- Data thinning is performed in 3 dimensions.

Depends on different cases

<table>
<thead>
<tr>
<th>Radial wind (VR)</th>
<th>Total number of observations</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data</td>
<td>10000~15000</td>
<td>100%</td>
</tr>
<tr>
<td>4 km Data thinning</td>
<td>3000~5000</td>
<td>~30%</td>
</tr>
</tbody>
</table>

1/3 of the observations have been assimilated in each case
Some features of the current set up:

For the HREnKF

• Control variables: U, V, W, T, HU (specific humidity)
• Observations are perturbed according to its variance (no correlation).
• Simplified random perturbations to consider the model errors
• Localization: 10-km in horizontal; 2 * ln( Pressure levels ) in vertical

For the GEM_LAM model at 1-km resolution

• Cycling hydrometeor variables
• Microphysical scheme: double moment scheme (Milbrandt and Yau, 2005)
• Fixed lateral boundary conditions for all ensemble members
Control run: deterministic prediction, no radar assimilation, and provides background fields for HREnKF

2.5-hr model integration

HREnKF: cycling for 60-min and launch the short-term forecast

Radar radial wind (assimilating every 5-min)

Cycling procedure

(Verification)

(new analyses)

Very short-term forecast (1.5hr)
Impact of assimilating radial wind component

Is it able to propagate information to other control variables?

\[ V_r = (U \sin \varphi + V \cos \varphi) \cos \alpha + (W + V_T) \sin \alpha \]
For real cases study, unfortunately, the truth is unknown. However, Radar observations provides part of the truth to examine:

- Simulted radial wind v.s. observed radial wind:
  
  **Bias** and **RMSE** (Root Mean Square Error) of radial component of the wind in each elevation angle (all observations, no data thinning)

- Precipitation

  **Level 1: Qualitatively:** (subjective examination)
  
  Are we able to trigger the convections? (locations, intensities)
  Is the system able to last as long as radar observed? (locations, intensities, and patterns)

  **Level 2: Quantitatively:** (Objective examination)
  
  Traditional scores are not good to examine the precipitation at cloud-resolving scale.

How do we examine the impact of assimilation radar observations?
<table>
<thead>
<tr>
<th>Summer cases</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 12, 2011</td>
<td>Very localized convection happened over downtown Montreal area, and heavy rain last for couple hours.</td>
</tr>
<tr>
<td>June 23, 2011</td>
<td>Background field (precipitations) from deterministic prediction is not far from radar observation. In addition, there is phase errors for the convection in south-west.</td>
</tr>
<tr>
<td>July 21, 2010</td>
<td>Multiple cells and convections occurred over the analysis domain. Different stages of convections exist when the HREnKF started assimilating radar observations. In addition, very poor background field (precipitation) from deterministic forecast.</td>
</tr>
<tr>
<td>June 29, 2011</td>
<td>Squall line system passed by southern Quebec region. McGill radar observed very strong reflectivity for 3-hr.</td>
</tr>
</tbody>
</table>
Case study #1: June 23 2011
Background field is not far from radar observed, and some phase errors.
What kind of background field do we have in this case?
Verification of radial wind

2200 UTC

Bias

Std deviation

2300 UTC

2230 UTC

Bias

Std deviation

2330 UTC
Phase correction (Postion correct)

Control run (no assimilation)

2200 UTC

Div

#76
What is the impact of precipitation at **new analysis time (2200 UTC)**

- **obs**
- **ctrl**
- **#26**
- **#76**
What is the impact of short-term forecasts precipitation (2300 UTC, 60-min)
Case study #2: July 21 2010
Multiple cells and convections, poor background field
What kind of background field do we have in this case?
Verification of radial wind

1800 UTC Bias
1830 UTC

1900 UTC

1930 UTC

1800 UTC Std deviation

1900 UTC

1930 UTC
What is the impact of precipitation at new analysis time (1800 UTC)
What is the impact of short-term forecasts precipitation (1900 UTC, 60-min)
2-D CAPE value at 1800 UTC
5. Summary and Future works

- By assimilating radar radial wind observations, it is able to modify other control variables (temperature and humidity fields).

- In general, the verification of the radial component shows that the improvement of short-term forecast is up to 1-hr. (Both bias and root-mean-square errors)

- The HREnKF system is able to trigger stronger convections, and short-term forecast can last for a while (case dependent) under conditions:
  a) background field is not far from reality
  b) stronger signal is observed by radar (intense convections happened)

- CAPE shows that by assimilating radial wind, the EnKF system pushes the new analyses toward right direction. However, is it enough? (When background is very bad, and when the it is weak precipitation)
To increase the ensemble spread & obtain non-fixed lateral boundary conditions

Global ensemble analyses

Regional EnKF system (REnKF)-15km

To capture better Mesoscale system

Downscaling to LAM_10km, LAM_2p5km

Assimilation of radar radial wind

High resolution EnKF (HREnKF)-1km

To obtain ensemble members
• Use more complicated observation operator (Frederic Fabry)

Consider: proper geometry, accurate propagation
Include: the sampling volume, signal and its processing

\[
V_{r-bin} = \frac{\iiint_{beam_i} \frac{Z_e(r,\theta,\phi)\exp(-2\tau)}{r^2} \left\{ \sum_{i=1}^{N} G^2 \left[ (\theta - \theta_i)\cos(\phi'), \phi - \phi_i \right] \right\} d\theta \cos(\phi')d\phi \left[ \sum_{j=1}^{M} W(r - r_j) \right] dr}{\iiint_{beam_i} \frac{Z_e(r,\theta,\phi)\exp(-2\tau)}{r^2} \left\{ \sum_{i=1}^{N} G^2 \left[ (\theta - \theta_i)\cos(\phi'), \phi - \phi_i \right] \right\} d\theta \cos(\phi')d\phi \left[ \sum_{j=1}^{M} W(r - r_j) \right] dr}
\]

• Assimilate both radial wind and reflectivity observations

Reflectivity:
both precipitation and no-precipitation areas

Non-precipitating areas
What is the impact of **short-term forecasts** precipitation (2330 UTC, 90-min)
What is the impact of short-term forecasts precipitation (1930 UTC, 90-min)