Direct Assimilation of Radar Reflectivity Data using a Convective scale EnKF System

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January 24, 2019
Motivation

- Tropical cyclone (TC) intensity forecast is still a challenging problem in research and operational practice.
- Radar is one of few observation platform capable of observing TC internal structure and circulation of precipitation at high spatial and temporal resolution.
- EnKF is able to deal with complex ice and multi-moment microphysics and more suitable to assimilate radar data (Vr and Z) directly.
GSI-based EnKF System

- The reflectivity operator for double-moment is developed by CAPS:

\[
N_x(D) = N_{Tx} \frac{\nu_x}{\Gamma(1 + \alpha_x)} \lambda_x^{\nu_x(1+\alpha_x)} D^{\nu_x(1+\alpha_x)-1} \exp[-(\lambda_x D)^{\nu_x}],
\]

\[
M_x(p) = \int_0^\infty D^p N_x(D) dD = \frac{N_{Tx} \Gamma(1 + \alpha_x + p/\nu_x)}{\lambda_x^p \Gamma(1 + \alpha_x)}.
\]

By setting \( \nu_x = 1 \), (1) reduces to a three-parameter function involving \( N_{Tx} \), \( \alpha_x \), and \( \lambda_x \) as

\[
N_x(D) = N_{0x} D^{\alpha_x} e^{-\lambda_x D}, \tag{3}
\]

where

\[
N_{0x} = N_{Tx} \frac{1}{\Gamma(1 + \alpha_x)} \lambda_x^{1+\alpha_x}. \tag{4}
\]

\[
\lambda_x = \left[ \frac{\Gamma(1 + d_x + \alpha_x) c_x N_{Tx}}{\Gamma(1 + \alpha_x) \rho q_x} \right]^{1/d_x}. \tag{5}
\]

\[
Z_x = M_x(6) = \frac{G(\alpha_x) \rho q_x^2}{c_x^2 N_{Tx}}, \tag{6}
\]

\( q_x \) and \( N_{Tx} \) are prognostic variables \( \alpha_x \) is either specified or diagnosed

\[
G(\alpha_x) = \frac{(6 + \alpha_x)(5 + \alpha_x)(4 + \alpha_x)}{(3 + \alpha_x)(2 + \alpha_x)(1 + \alpha_x)}. \tag{2}
\]

Using Raleigh theory, \( Z_x \) can also be converted to the equivalent radar reflectivity \( Z_{ex} \) using

\[
Z_{ex} = \frac{|K_i|^2}{|K|^2} \left( \frac{c_x}{c_r} \right)^2 Z_x, \tag{7}
\]

with the ratio of the dielectric constants for ice and liquid water \( |K_i|^2/|K|^2 = 0.224 \) (F94), and \( c_r = (\pi/6) \rho_w \), where \( \rho_w \) is the density of water. Equations (4)–(6), along with the microphysical source/sink terms to predict changes in \( N_{Tx} \), \( q_x \), and \( Z_x \), constitute a three-moment bulk scheme to predict the size spectra for hydrometeor category \( x \).

Milbrandt and Yau (2005)
Experimental design

- Forecast model: WRF-ARW v3.9.1, 3km
- DA systems: GSI-EnKF, 40 members
- OBS: composite radar reflectivity

GFS analysis
IC+perturbations

- 5h forecast
- 1h DA
- EnKF every 15 minutes
- With Z

- 06Z28
- 11Z28
- 12Z28
- Deterministic forecast with ensemble mean (Thompson)
- Deterministic forecast with ensemble mean (no DA)
- 06Z29
- First Cycle Starts

Figure 1. Best track positions for Tropical Storm Alberto, 26–31 May 2018.
EnKF for Radar DA with a 2-Moment Microphysics Scheme

\[
\begin{pmatrix}
    u^a \\
v^a \\
w^a \\
\theta^a \\
p^a \\
q_v^a \\
q_c^a \\
q_r^a \\
q_i^a \\
q_g^a \\
N_{Tx}^a
\end{pmatrix}
\begin{pmatrix}
u^f \\
v^f \\
w^f \\
\theta^f \\
p^f \\
q_v^f \\
q_c^f \\
q_r^f \\
q_i^f \\
q_g^f \\
N_{Tx}^f
\end{pmatrix}
+ K (Z - H)
\]

Radar data:
\[Z = Z(q_r + q_s + q_g)\]

K is the Kalman Gain, a function of background and obs error covariances

H is the observation operator
GSI EnKF Radar DA

Z Obs

Background is bkg stronger = NoDA

Radar-DA(ana)
Why Radar DA is better?

Hydrometers analysis Increment

First Cycle

All hydrometers decreased after radar DA.
Other variables

Large-scale variables were updated correctly.

First Cycle

Dynamic consistent
NoDA vs. Radar-DA at final cycle

NoDA

Radar-DA
Track Forecast
Intensity Forecast

Positive Impact
precipitation forecasts

1-hour forecast
precipitation forecasts

Z Observation

NoDA

2-hour forecast

Radar-DA
## Additional Experiments

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<thead>
<tr>
<th>Name</th>
<th>Radar Z DA</th>
<th>Mp-scheme</th>
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<tr>
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![Map and Graph](image-url)
Summary

- A convective-scale EnKF DA system was successfully applied to directly assimilate radar Z data for a TC case.
- Radar Z assimilation has positive impact on both intensity and precipitation forecast, the impact on precipitation maintained at least 1 hour while the impact on intensity can last for 12 hours.
- EnKF well updated not only hydrometers but also other cross-variables \((u,v,t,w)\), so as to produce well-balanced analysis state.
Thanks for your attentions!