Assimilation of Near Surface Observations over Complex Terrain: EnKF Versus 3DVAR

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Problem

- Surface observations are the main conventional observations. They have been very important for weather forecasting.
  - Temperature at 2 meters height (2-meter temperature)
  - Wind at 10 meters height (10–meter wind)

However,

- In modern Numerical Weather Prediction (NWP), the use of the surface data remains a unique challenge (Mesinger et al. 2006)

2-meter temperature data were not assimilated in the North American Regional Reanalysis and current operational systems
Problem (Cont.)

Challenges in data assimilation over complex terrain

- Variable terrain and representativeness errors
Objective

• To compare two popular data assimilation methods (3DVAR and EnKF) in surface data assimilation.

• To understand the fundamental scientific problems and major obstacles associated with assimilation of surface observations.
Model and data assimilation systems

- WRF ARW model (Skamarock et al. 2005 & 2008)
- WRF 3DVAR (Barker et al. 2004)
- NCAR Data Assimilation Research Testbed (DART, Anderson et al. 2009) Ensemble Kalman Filter system for WRF (DART WRF)
- 27km horizontal grids and 36 sigma levels vertically
- 32 ensemble members are used in EnKF experiments
Single Observation Experiment: 3DVAR vs. EnKF
Analysis increment at lowest model level; over complex terrain
Single Observation Experiment: 3DVAR vs. EnKF

Analysis increment at lowest model level; over flat terrain

3DVAR

EnKF
Fundamental differences between 3DVAR and EnKF

- **3DVAR**

\[
J(x) = J^b + J^o - \frac{1}{2} (x - x^b)^T B^{-1} (x - x^b) + \frac{1}{2} \sum_{i=0}^{n} (y - y_i^o)^T O_i^{-1} (y - y_i^o)
\]

Fixed B, defined by NMC method based on statistics

- **EnKF**

\[
X^a = X^f + K [H(X^f) - y]
\]

\[
K = P^f H^T (HP^f H^T + R)^{-1}
\]

\[
P^f \approx \frac{1}{k-1} \sum_{k=0}^{K} (x_k^f - x_f^f)(x_k^f - x_f^f)^T
\]

Flow-dependent background error term
OI correlation and cross-correlation functions for the geostrophic increment assumption

3DVAR analysis increments

Gustaffson 1981 and Kalnay 2003
Analysis increment vs. ensemble spread
3DVAR: Influence of horizontal length scale

EnKF: Influence of horizontal localization
700hPa temperature, 50 AGL wind speed & wind barbs at 00 UTC 5 June 2008.
Distributions of the surface observations
Profiles of mean wind speed over the key regions of LLJ

Over flat terrain, for LLJ case, both method works although EnKF performs better.
Time-latitude cross section of temperature averaged over main frontal area at AGL 500m
Error comparison between EnKF and 3DVAR

- RMSEs are calculated for each analysis against nature run
- RMSE\_EnKF \textit{minus} RMSE\_3DVAR
- Negative value means EnKF has less error

Temperature

Wind speed
Terrain mismatch: Data Rejection Experiment
Time-latitude cross section of temperature averaged over main frontal area at AGL 500m

Mismatched observations are rejected
Concluding remarks

- 3DVAR has problem to deal with variable terrain when assimilating surface observations; EnKF can overcome at least part of the problem through its flow-dependent background term.

- Both 3DVAR and EnKF has ability to extend information from surface to boundary layer. Over the flat terrain, both methods work well, though EnKF does slightly better

- Over complex terrain, model terrain mismatch could cause problem in surface data assimilation. Since data are sparse over the complex terrain, data rejection may not be best solution to deal with errors in terrain representation