An Integrated Ensemble/Variational Hybrid Data Assimilation System

WRF Users Workshop, 2012

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Acknowledgements:
Contributors: Chris Snyder, Glen Romine (NCAR)
Funding: AFWA
Variational/Ensemble Hybrid DA

Ensemble Forecast

- Ensemble Mean (background)
- Complicated
- Costly
- Suboptimal

Ensemble Perturbations

- Ensemble Mean (analysis)
- Positive Impact

Updated Ensemble Perturbations

- Positive Impact
- Ensemble Mean (analysis)
Ensemble Variational Integrated Lanczos (EVIL)
EVIL: Methodology

- Ensemble Covariance included in 3D/4DVAR cost function through state augmentation
- Updates the deterministic analysis: \( x^a = x^b + x' \)

\[
J(x'_1, \alpha) = \beta_1 J_1 + \beta_2 J_e + J_o
= \beta_1 \frac{1}{2} x'_1^T B^{-1} x'_1 + \beta_2 \frac{1}{2} \alpha^T C^{-1} \alpha + \frac{1}{2} (y' - Hx')^T R^{-1} (y' - Hx')
\]

\[
x' = x'_1 + \sum_{k=1}^K (\alpha_k \circ x_k^e)
\]

- Updates to the ensemble perturbations: \( P_a = [J''(x_a')]^{-1} \)
  \[
P_a^{1/2} = [J''(x_a')]^{-1/2} = V^T \Lambda^{-1/2} V P_f^{1/2} \approx V_i^T [I + (\Lambda_i^{-1/2} - I)] V_f P_f^{1/2}
\]
  \[
\delta x^k_a \approx Z_i^T [I + (\Theta_i^{-1/2} - I)] Z_f \delta x_f^k
\]
  with \([\lambda_n, \nu_n]\) eigenpairs of \( J'' \) (rank N) and \([\theta_i, z_i]\) Ritz pairs (from Lanczos minimization) (I << N)

- Maximum Likelihood Square Root Filter (related to MLEF, LETKF and VAR preconditioning)
- Directly and fully “hybrid” (includes VAR radiances, QC, VarBC, etc)
**EVIL: Implementation**

- EVIL algorithm implemented within WRFDA system (Lanczos minimization).
- Expanded the “alpha” control variable for cloud parameters ($q_c, q_i, q_r, q_s$)
- Implementation of an inflation scheme with WRFDA

\[
E(dd^T) = R + \mu HP_f H^T, d = y^o - H(x_b)
\]

\[
\mu \approx \text{Tr}[E(dd^T)] - \frac{\text{Tr}(R)}{\text{Tr}(HP_f H^T)}
\]

\[
\mu \approx \text{Tr}[E(dR^{-1/2}R^{-T/2}d^T)] - \frac{\text{Tr}(I_p)}{\text{Tr}(HR^{-1/2}P_f R^{-T/2}H^T)}
\]

\[
\mu = \frac{2J_o(x_b) - p}{\text{DFS}(x_b)}
\]

- Updated, simplified, automatic scripts for WRFDA, EVIL and DART
- New diagnostic tools for spread in model space
EVIL: Experimental Design

• WRF over CONUS domain, 100km horizontal resolution (June 1\textsuperscript{st} 2009 at 00UTC).

• Assimilation of all conventional observations + Satellite winds + GPS-RO

• 20 ensemble members, no vertical localization

• EVIL in “full ensemble” mode

• Comparison to DART (EAKF, Anderson 2001)

• Metric: Total Dry Energy
Total Dry Energy Spread (J/kg) (10 iterations)

Standardized Deviations (Normalized)

Correlation

TE Post EVIL

TE Post DART

Level 3

North America
Total Dry Energy Spread (J/kg) (140 iterations)
EVIL: Experimental Design

- WRF over CONUS domain, 100km horizontal resolution.
- Assimilation of all conventional observations + Satellite winds + GPS-RO
- 20 ensemble members, no vertical localization
- EVIL in “full ensemble” mode
- Comparison to DART (EAKF, Anderson 2001)
- Metric: Total Dry Energy
- One-week full cycling experiment (2009060100-2009060712)
- Analyses at 00 and 12UTC
- Constant inflation factor (1.02)
Spread after cycling independently for a week
EVIL: “early stopping”

- Inflation is a necessary evil for Ensemble Kalman Filters
  - Un-represented forecast model error
  - Under-estimation of posterior spread

- Each EVIL analysis is an iterative process (like 3D/4DVar)

- In machine learning, “early stopping” is a common technique to avoid over-fitting noisy targets.

- Similarly, “early stopping” can be used in EVIL to avoid “over-confidence” in posterior spread

- Test: stop EVIL minimization after 50 iterations (suboptimal)
RMSE 03-07 Jun 2009 (12-Hourly Cycle) vs. FNL analysis

- Constant Inflation (1.02)
- Adaptive Inflation
- No inflation. Early Stopping

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DART 1.02
Adaptive Inflation
No inflation. Early Stopping
Conclusion

• Introduced a new data assimilation approach: EVIL
  (based on Var/Ens hybrid, updating ensemble perturbations inside the Variational framework):

  • Initial testing in “full-ensemble” mode with no vertical localization & constant inflation: EVIL behaves very similarly to DART.

  • “Early stopping” seems to reduce the need for inflation.

• Future plans:
  • Extended test period
  • Investigate optimal inflation vs. early stopping
  • Test in Hybrid Var/Ens mode
  • Port to GSI