Comparison of the Ensemble Transform and the Ensemble Data Assimilation techniques for background error simulation in ALADIN

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Outline

- Introduction
- The simulation techniques in play  (Ensemble Data Assimilation and Ensemble Transform)
- The LAM experiments
- Diagnostic comparisons
- Impact studies

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**Introduction**

**Aim**: simulation of background errors ($\varepsilon_b$) in order to generate a statistical sample for the computation of the background error covariance matrix ($B$) in the variational analysis:

$$B = E(\varepsilon_b \varepsilon_b^T)$$

$$J_b(x) = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b)$$
The simulation techniques in play

Background error simulation with EDA

\[ x_{b1} = M x_{a1} \]
\[ x_{b2} = M x_{a2} \]
\[ \epsilon_b \approx x_{b1} - x_{b2} \]

(EDA: Ensemble Data Assimilation)
The simulation techniques in play

Background error simulation with ET

\[ x_{b1} = M x_{a1} \]
\[ x_{b2} = M x_{a2} \]
\[ \epsilon_b \approx x_{b1} - x_{b2} \]

(ET: Ensemble Transform)

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The LAM experiments

In a LAM:

• we can take the benefit of global error simulations (in the form of LBCs)
• we would like that the $\varepsilon_b$ sample is suitable to represent background errors on the (smaller) spatial scales of the LAM model
• so we go for global (LBC) + local (initial) perturbations
The LAM experiments

**LBC perturbation** (coupling) for all experiments:
- IFS EDA (Experiment by Isaksen et al., 07/2007, 4DVAR T255/L91)

**Initial perturbation** experiments (period 01-31/07/2007):
- **DSC-EDA**: downscaling of the IFS EDA
  \[
  \mathbf{e}_b \approx M \mathbf{P}^{\text{IFS-EDA}} \mathbf{x}_{1}^{\text{IFS-EDA}} - M \mathbf{P}^{\text{IFS-EDA}} \mathbf{x}_{2}^{\text{IFS-EDA}}
  \]
  \(\mathbf{P}^{\text{IFS-EDA}}\) : global EDA analyses interpolated to the ALADIN domain
- **LAM-EDA**: local EDA initial perturbations
  \[
  \mathbf{e}_b \approx M \mathbf{x}^{\text{LAM-EDA}} \mathbf{x}_{1}^{\text{LAM-EDA}} - M \mathbf{x}^{\text{LAM-EDA}} \mathbf{x}_{2}^{\text{LAM-EDA}}
  \]
  \(\mathbf{x}^{\text{LAM-EDA}}\) : local analyses with perturbed observations
- **LAM-ET**: local ET initial perturbations
  \[
  \mathbf{e}_b \approx M \mathbf{x}^{\text{LAM-ET}} \mathbf{x}_{1}^{\text{LAM-ET}} - M \mathbf{x}^{\text{LAM-ET}} \mathbf{x}_{2}^{\text{LAM-ET}}
  \]
  \(\mathbf{x}^{\text{LAM-EDA}}\) : local analyses with ET perturbations

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Diagnostics

- **Spectral variance**: variance of the simulated error $\rightarrow$ diagnoses how the variance is distributed according to spatial scales

- **Spectral spread-skill**: spread and rmse of the ensemble $\rightarrow$ measures if the error simulation is over or underdispersive (and on which spatial scales)

- **Spectral PECA** (Perturbation vs. Error Correlation Analysis): $\text{corr}\left(\left|\varepsilon_b\right|,\left|\varepsilon_{b}^{\text{ref}}\right|\right)$
  
  $\varepsilon_b = x_b - x_{b,j}$ simulated background error
  
  $\varepsilon_{b}^{\text{ref}} = x_{a}^{\text{verif}} - x_{b,j}$ „real” background error ($x_{a}^{\text{verif}} = x_{a}^{\text{Varpack}} \approx x_t$)

  $\rightarrow$ measures how much the „size” of the simulated error is similar to the size of the „real” (!) background error (and on which spatial scales)
Diagnostic comparisons

Divergence at ~500hPa

Spectral error variance

Normalized spectral error variance

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Diagnostic comparisons

Divergence at \( \sim 1000 \text{hPa} \)

Spectral error variance

Normalized spectral error variance

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Diagnostic comparisons

Spread-skill (spread-rmse relationship for +6h)

Divergence at ~500hPa
Spectral Spread skill: Div level 22

Divergence at ~1000hPa
Spectral Spread skill: Div level 47

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Diagnostic comparisons

Mean Spread skill profiles: Div

Mean Spread skill profiles: Vor

Mean Spread skill profiles: q

Mean Spread skill profiles: T

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Diagnostic comparisons

PECA: Perturbation versus Error Correlation Analysis Analysis

Divergence at ~500hPa

Divergence at ~1000hPa

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PECA profiles

Div

Vor

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Impact studies

**Aim:** test the impact of the different error simulation techniques on the analysis/forecast $\Rightarrow$ computation of $B$ matrices based on the different error simulations $\Rightarrow$ reinject them into real assimilation experiments and verify the analyses and forecasts

**Period:** 01-31/07/2007 $\Rightarrow$ idealized experiments (the period is the same as used for the error simulation)

2 data assimilation/forecast experiments:

**BT00:** assimilation cycle using $B$ based on the **DSC-EDA** error simulation

**BT01:** assimilation cycle using $B$ based on the **LAM-EDA** error simulation

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RMSE against TEMPs and SYNOPs

Wind speed

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Relative humidity

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RMSE against analysis (each experiment against its „own“ analyses)

Experiments: BT00.00 - BT01.00
Par: T Period: 2010/07/05-2010/07/09
Area: geos.kfs.com Score: netRMSE - sign Ref: SKAT Val: -0.1.0.1

Experiments: BT00.00 - BT01.00
Par: U Period: 2010/07/05-2010/07/09
Area: geos.kfs.com Score: netRMSE - sign Ref: SKAT Val: -0.1.0.1

Experiments: BT00.00 - BT01.00
Par: RH Period: 2010/07/05-2010/07/09
Area: geos.kfs.com Score: netRMSE - sign Ref: SKAT Val: -0.1.0.1

Experiments: BT00.00 - BT01.00
Par: V Period: 2010/07/05-2010/07/09
Area: geos.kfs.com Score: netRMSE - sign Ref: SKAT Val: -0.1.0.1
Preliminary conclusions

- **LAM-EDA** adds more variance to **DSC-EDA** and often not only in the small scales (scales of observing network?). **LAM-ET** (inspite of the low variance) puts the most variance to the small scales.

- The tried error simulations are mostly underdispersive (except **LAM-EDA** on the small scales). The Spread-skill relationship is the best for **LAM-EDA** (then **LAM-ET** then **DSC-EDA**). The spread of **LAM-ET** is too low. The rmse is decreased by the LAM experiments compared to **DSC-EDA**.

- PECA correlations are the best for **LAM-EDA** (then for **LAM-ET** then for **DSC-EDA**)

- The 3 diagnostics (Spectral variance, Spread-skill, PECA) are in good correspondance with each-other

- Overall **LAM-EDA** seems to be the best of the 3 simulation techniques, however there is a potential in the **LAM-ET** technique in case of proper inflation (increased spread).

- Assimilation/forecast experiments show an improvement using a **B** matrix based on the **LAM-EDA** simulation compared to the use of **DSC-EDA**
Thank you for your attention!
Diagnostic comparisons

Temperature at ~500hPa

Spectral error variance

Normalized spectral error variance
 Diagnostic compatrisons

Temperature at ~1000hPa

Spectral error variance

Normalized spectral error variance
Diagnostic comparisons

Spread-skill (spread-rmse relationship)

Vorticity at ~500hPa
Spectral Spread skill: Vor level 22

Vorticity at ~1000hPa
Spectral Spread skill: Vor level 47

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Diagnostic comparisons

**Spread-skill**

**Temperature at ~500hPa**

Spectral Spread skill: T level 22

**Temperature at ~1000hPa**

Spectral Spread skill: T level 47

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Diagnostic comparisons

Specific humidity at ~500hPa
Spectral Spread skill: q level 22

Specific humidity at ~1000hPa
Spectral Spread skill: q level 47

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RMSE against TEMPs and SYNOPs

Geopotential

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Diagnostics

Error variance:

\[ \text{Var}(\varepsilon_b) = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\varepsilon_{b,i} - \varepsilon_b)^2} \]

\( N = \text{member size} + \text{time realizations} \)

Spread:

\[ \text{Sp} = \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left( \frac{\sum_{j=1}^{M} x_{b,t,j}}{M} - \sum_{j=1}^{M} x_{b,j} \right)^2} \]

\( T = \text{time realizations} \quad M = \text{member size} \)

RMSE:

\[ \text{RMSE} = \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left( \frac{x_{\text{verif},t} - \sum_{j=1}^{M} x_{b,t,j}}{M} \right)^2} \]

\( T = \text{time realizations} \quad M = \text{member size} \)

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PECA (Perturbation vs. Error Correlation Analysis):

\[
\text{Corr}(\| \varepsilon_b \|, \| \varepsilon_{b}^{\text{ref}} \|) = \frac{\text{Cov}(\| \varepsilon_b \|, \| \varepsilon_{b}^{\text{ref}} \|)}{\sigma(\varepsilon_b)\sigma(\varepsilon_{b}^{\text{ref}})} = \frac{\sqrt{\frac{1}{N} \sum_{i=1}^{N} (\| \varepsilon_b^i \| - \varepsilon_b) (\| \varepsilon_{b}^{\text{ref},i} \| - \varepsilon_{b}^{\text{ref}})}}{\sqrt{\frac{1}{N} \sum_{i=1}^{N} (\varepsilon_b^i - \varepsilon_b)^2} \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\varepsilon_{b}^{\text{ref},i} - \varepsilon_{b}^{\text{ref}})^2}}
\]

\[\varepsilon_b = x_b - x_b,j \quad \text{simulated background error}\]

\[\varepsilon_{b}^{\text{ref}} = x_{a}^{\text{verif}} - x_b,j \quad \text{"real" background error (} \quad x_{a}^{\text{verif}} \approx x_t \quad )\]

N= member size + time realizations

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