A brief look at ensemble inflation in GMAO’s hybrid 3D-Var system

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Overview

3D-Var

\[ J(\delta x) = \frac{1}{2} \delta x^T B^{-1} \delta x + \frac{1}{2} (H \delta x - d)^T R^{-1} (H \delta x - d) \]

\( B \) Background error covariance matrix;
- Static: climatologically-averaged covariance statistics;
- Poor representation of rapidly evolving instabilities.

Hybrid 3D-Var

- Use ensemble information to improve the representation of background error covariances within the variational assimilation system.

\[ J(\delta x) = \frac{1}{2} \delta x^T \left[ \beta B_{\text{static}} + (1 - \beta) B_{\text{ens}} \right]^{-1} \delta x + \frac{1}{2} (H \delta x - d)^T R^{-1} (H \delta x - d) \]

where \( B_{\text{ens}} = \sum_m (x_m - \bar{x})(x_m - \bar{x})^T \)

and \( \beta \) a weighting coefficient
Zonal mean analysis increment, in total wet energy (J/kg) norm.
GMAO Hybrid 3D-Var

Status update
- Hybrid 3D-Var is now the operational data assimilation system at GMAO.

Configuration
- 32-member ensemble; S-EnKF;
- Dual resolution (central analysis at 0.5°, ensemble at 1°); Re-centering.
- Covariance weights: $\beta = 0.5$ (50% static B + 50% ensemble B), full static above 1mb;
- Blending above 5mb + transition 5-1mb;
- Vertically varying localization scales;
- Multiplicative+ additive inflation.

Improved forecast skills
GMAO Hybrid 3D-Var

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Ensemble Spread

- Ensemble spread provides good information about the predictability of a flow.
- Less predictable events should have wider error range (difficult to forecast).
- Spread should be consistent with the forecast error growth.
Ensemble Spread

Time series

Additive inflation \{f48-f24h\} perturbations

Slow growth of the ensemble spread within the assimilation window.
Aim: to represent some of the uncertainty from processes that the model cannot resolve.

\[ X_p = (1 + r \mu)X_c \]

- **\( \mu \)**: vertical weight: 1.0 below 100 hPa, decays to zero between 100 & 50 hPa.
- **\( r \)**: horizontal weights: range from -1.0 to 1.0, a red noise process.
  - temporal timescale of **6 hours**
  - e-folding spatial scale of **500 km**.
SPPT – Projection on the random patterns

Mass-weighted Temperature tendency due to moist processes (zonal mean)

Unperturbed tendency

Projection on the random pattern (x10)

Total tendency = \( \text{TIR} + \text{STN} + \text{TTN} + \text{FRI} + \text{TIG} + \text{TICU} \)

- \( \text{TIR} \) ! Mass-Weighted Temperature Tendency due to Radiation
- \( \text{STN} \) ! Mass-Weighted Temperature Tendency due to Turbulent Mixing
- \( \text{TTN} \) ! Mass-Weighted Temperature Tendency due to Moist Processes
- \( \text{FRI} \) ! Mass-Weighted Temperature Tendency due to Friction (Turbulence)
- \( \text{TIG} \) ! Mass-Weighted Temperature Tendency due to GWD
- \( \text{TICU} \) ! Mass-Weighted Temperature Tendency due to Cumulus Friction
Impact on spread at 06h

- Ensemble Spread Total (wet) Energy – bkg06 – NOINF
- Ensemble Spread Total (wet) Energy – bkg06 – INF
- Ensemble Spread Total (wet) Energy – bkg06 – ALL

No Inflation
Additive Inflation
SPPT
Impact on spread at 06h

- Contributions from different physics components

- Turbulent Mixing
- Moist Processes
- Gravity wave drag
Impact on spread - Uwind

Zonal mean wind ensemble spread

Ensemble Spread Uwind (x1e+3) – bkg06

No Inflation

Additive Inflation

SPPT
Impact on spread - T

Zonal mean temperature ens spread

Ensemble Spread Temperature – bkg06

No Inflation

Additive Inflation

SPPT
Spread growth – 00h

- No Inflation
- Additive Inflation
- SPPT
Spread growth – 03h

Additive Inflation

No Inflation

SPPT
Spread growth – 06h

Ensemble Spread Total (wet) Energy –06h

Vertical levels

Latitudes

Additive Inflation

No Inflation

SPPT

Vertically levels

Latitudes

Vertically levels

Latitudes

Vertically levels

Latitudes
Spread growth – 09h

Ensemble Spread Total (wet) Energy –09h

Vertical levels

Latitudes

0.2  0.4  0.6  0.8  1  1.2  1.4  1.6

No Inflation

Additive Inflation

SPPT
Summary and future work

- NMC-like perturbations provide an ad-hoc (yet, efficient) tool to increase ensemble spread at the analysis time, but spread growth is slow and not consistent with the forecast error growth.

- SPPT scheme can be used to represent some of the uncertainty from processes that the model cannot resolve. These “more ergonomic” perturbations induce more spread/growth in the tropics, driven mainly by the most processes.

- More work still needed to examine the contributions from the different components of the physics tendencies.

- Extending hybrid 3D-Var to 4D-EnVar: Preliminary testing is underway.