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

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Overview

3D-Var

$$J(\delta \mathbf{x}) = \tfrac{1}{2}\, \delta \mathbf{x}^T \mathbf{B}^{-1} \delta \mathbf{x} + \tfrac{1}{2}\, (\mathbf{H}\, \delta \mathbf{x} - \mathbf{d})^T \mathbf{R}^{-1} (\mathbf{H}\, \delta \mathbf{x} - \mathbf{d})$$

B Background error covariance matrix;

- Static: climatologically-averaged covariance statistics;
- Poor representation of rapidly evolving instabilities.

Hybrid 3D-Var

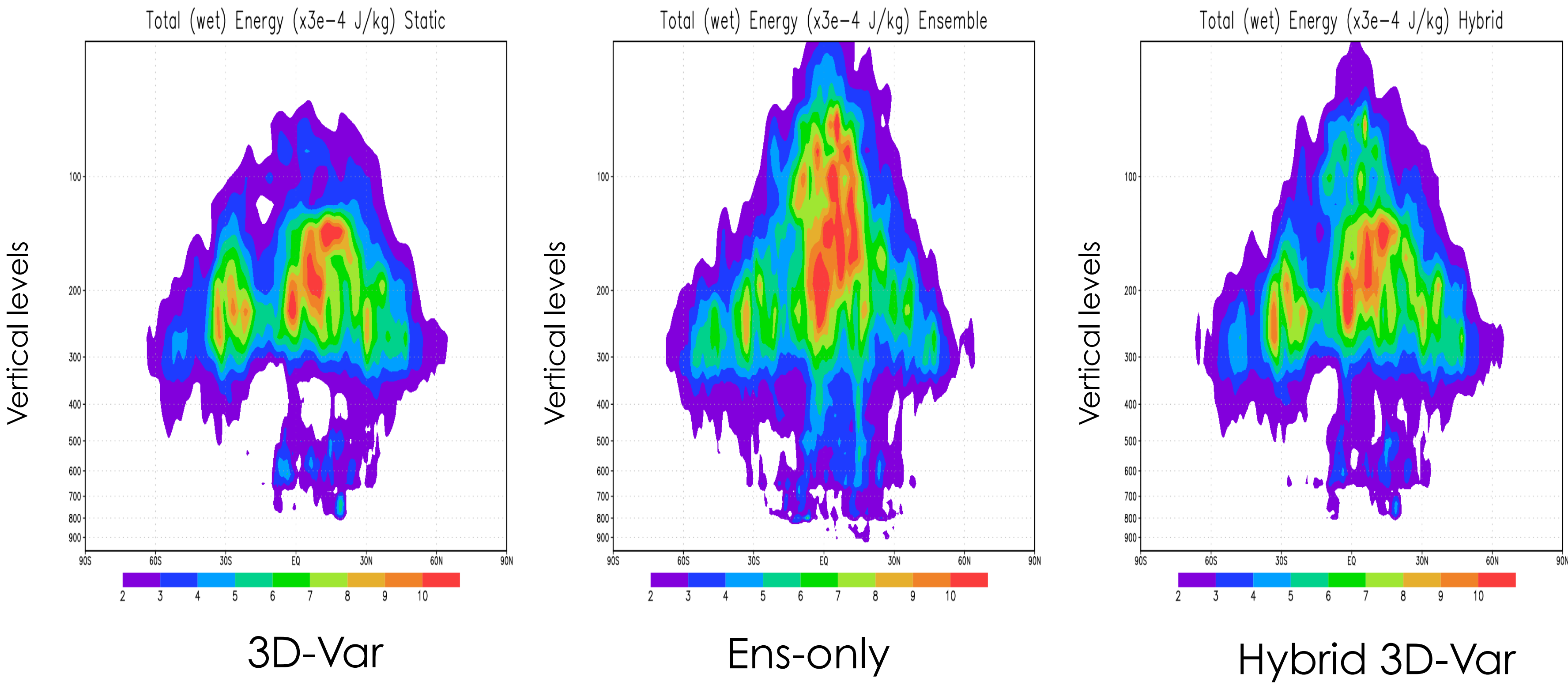
- Use ensemble information to improve the representation of background error covariances within the variational assimilation system.

$$J(\delta \mathbf{x}) = \tfrac{1}{2}\, \delta \mathbf{x}^T \left[\beta\, \mathbf{B}_{static} + (1-\beta)\, \mathbf{B}_{ens}\right]^{-1} \delta \mathbf{x} + \tfrac{1}{2}\, (\mathbf{H}\, \delta \mathbf{x} - \mathbf{d})^T \mathbf{R}^{-1} (\mathbf{H}\, \delta \mathbf{x} - \mathbf{d})$$

where $$\mathbf{B}_{ens} = \sum_m (\mathbf{x}_m - \bar{\mathbf{x}})(\mathbf{x}_m - \bar{\mathbf{x}})^T$$

and β a weighting coefficient

Analysis increment



Zonal mean analysis increment, in total wet energy (J/kg) norm.

GMAO Hybrid 3D-Var

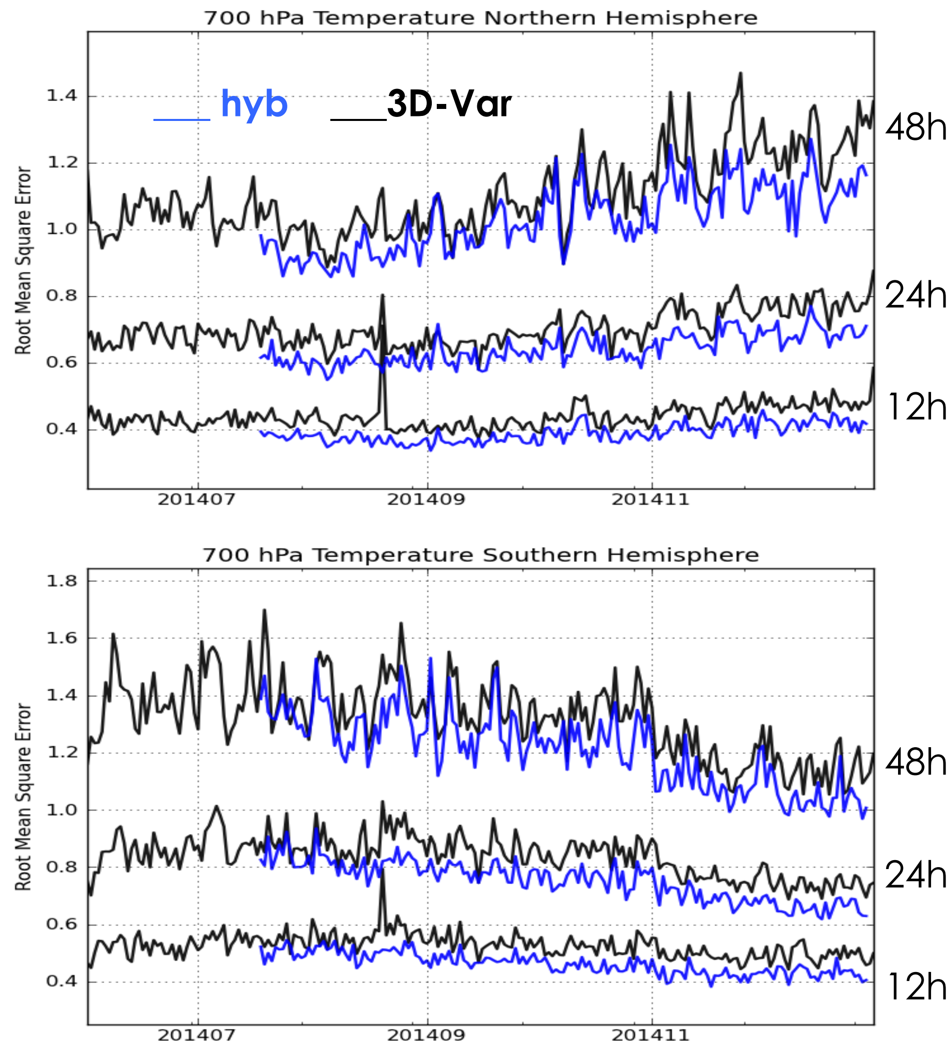
Status update

- 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



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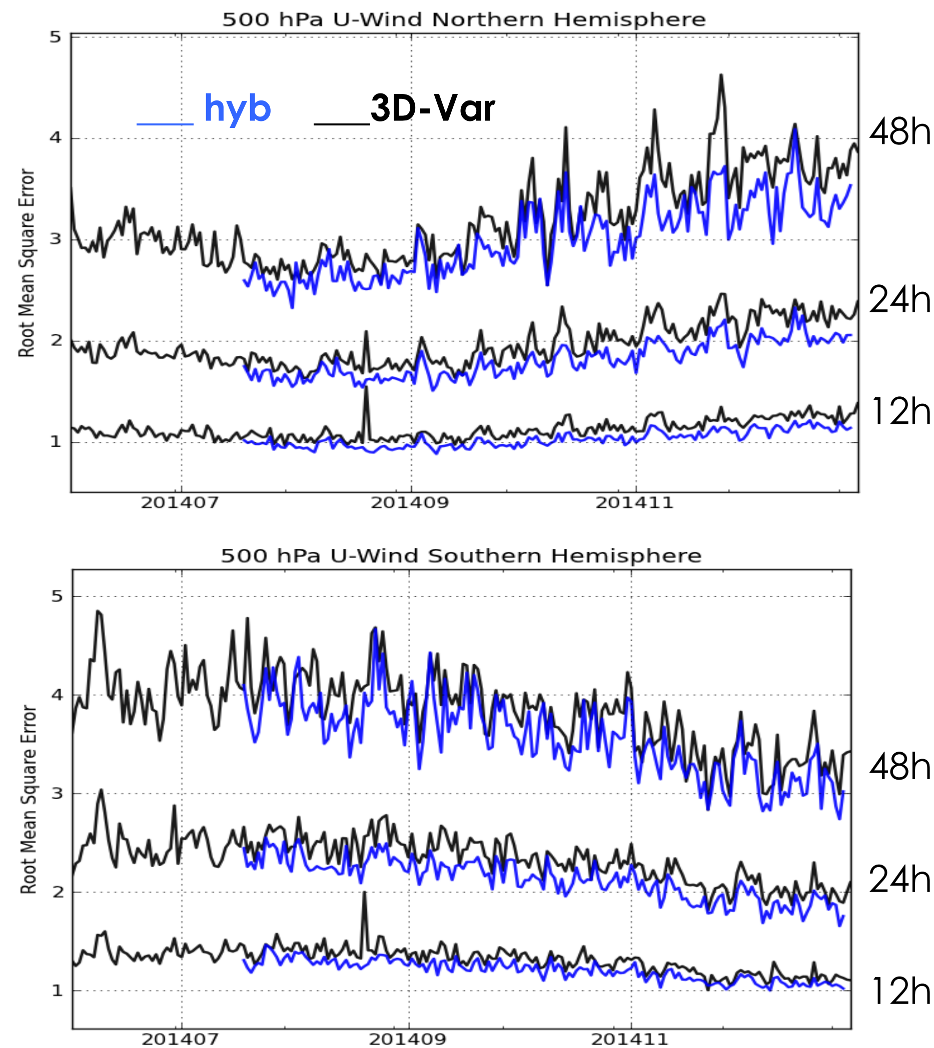
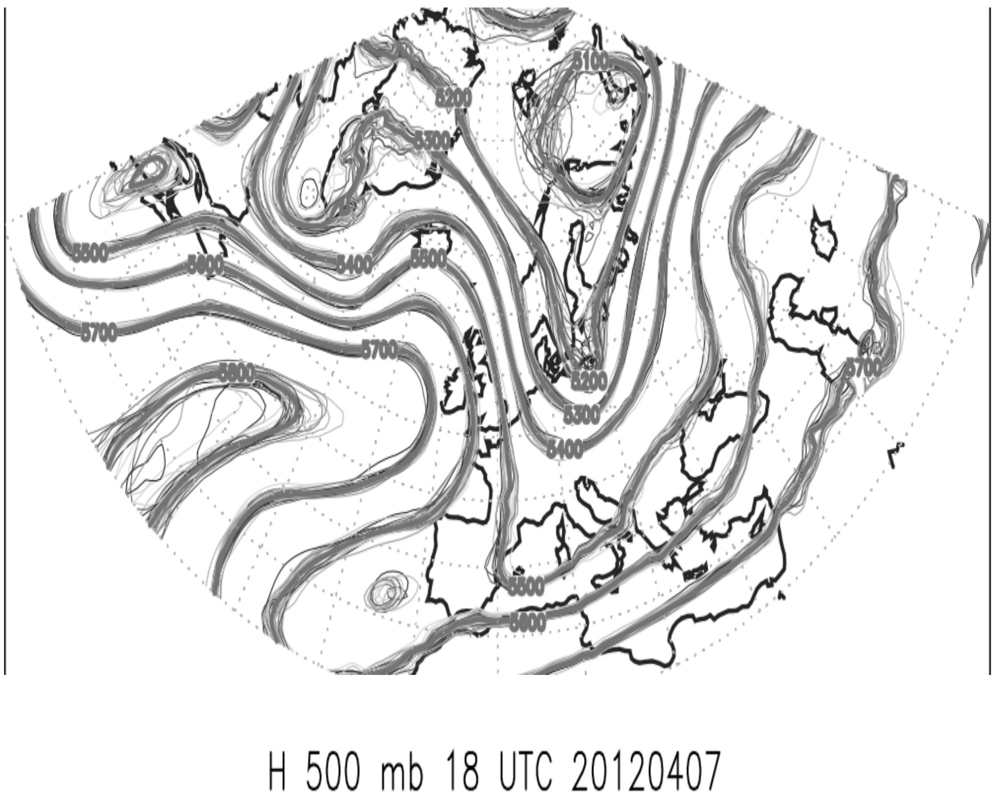


Ensemble Spread

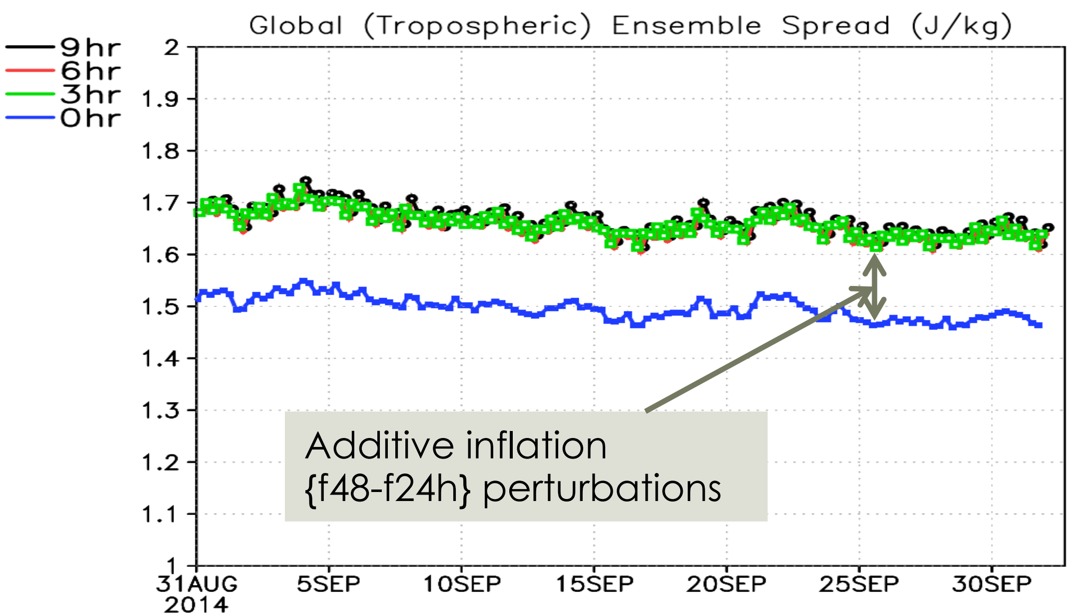


Ens. Mean & Ens. members

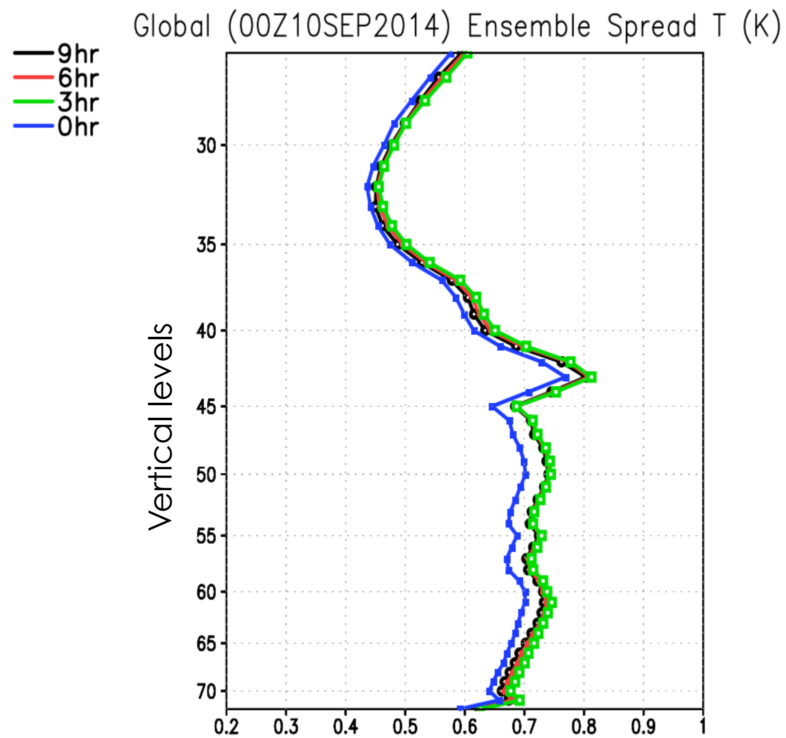
Ens. spread & forecast error

- 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



Slow growth of the ensemble spread within the assimilation window.

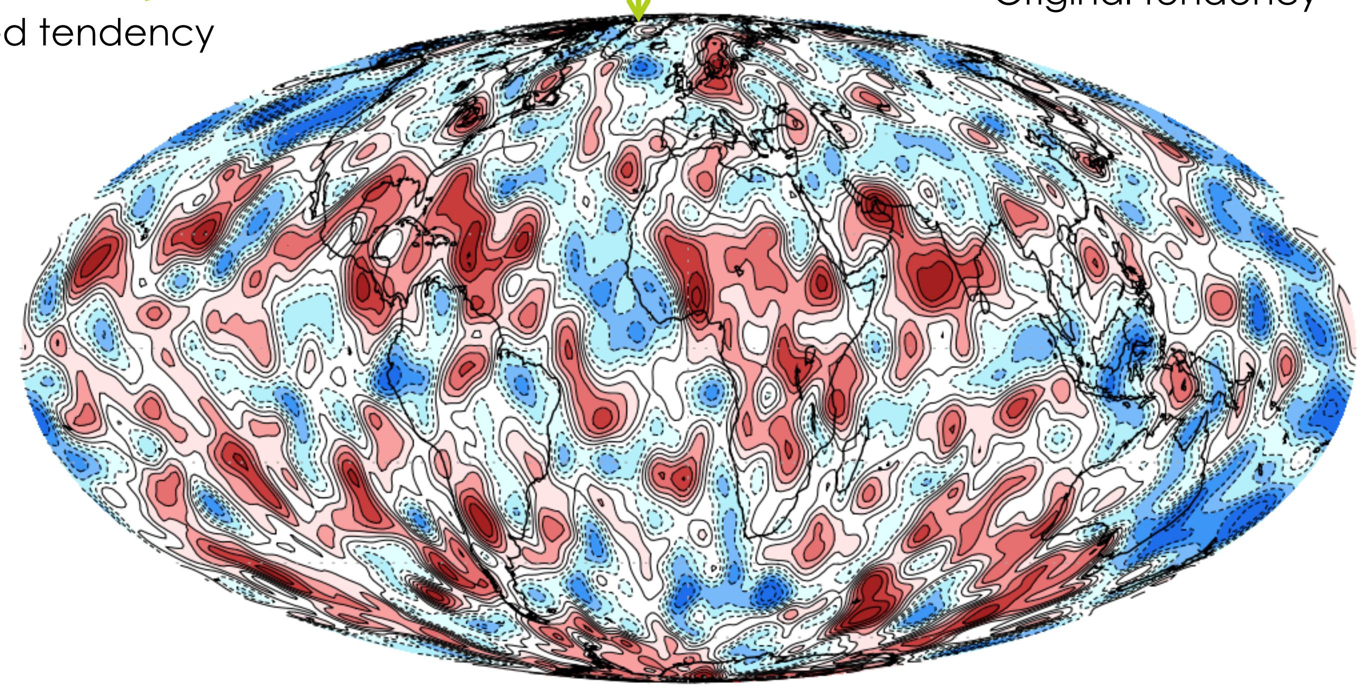
Stochastically Perturbed Physics Tendencies (SPPT)

Aim: to represent some of the uncertainty from processes that the model cannot resolve.

$$X_p = (1 + r\,\mu)X_c$$

Perturbed tendency

Original tendency



μ : vertical weight: 1.0 below 100 hPa, decays to zero between 100&50 hPa.

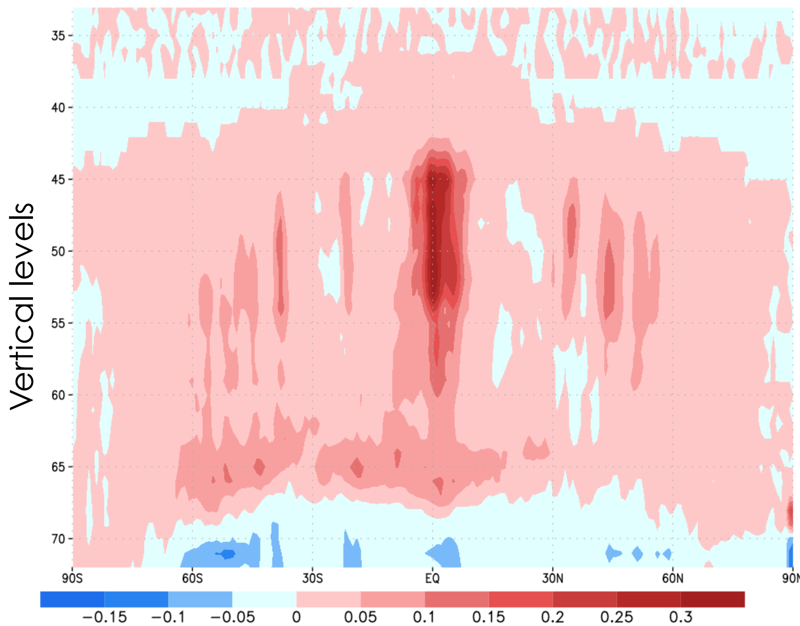
r: horizontal weights: range from -1.0 to 1.0, a red noise process.

- temporal timescale of **6 hours**
- e-folding spatial scale of **500 km.**

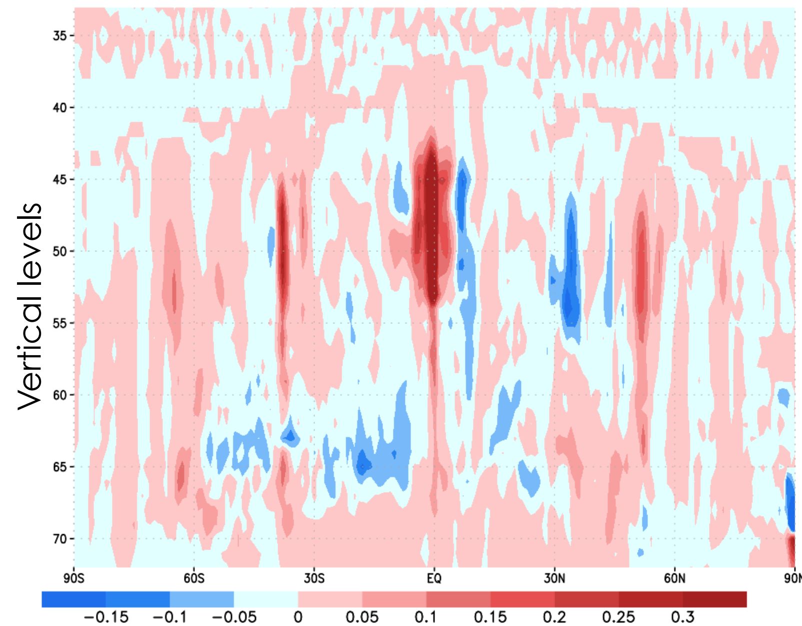
SPPT – Projection on the random patterns

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

Unperturbed tendency

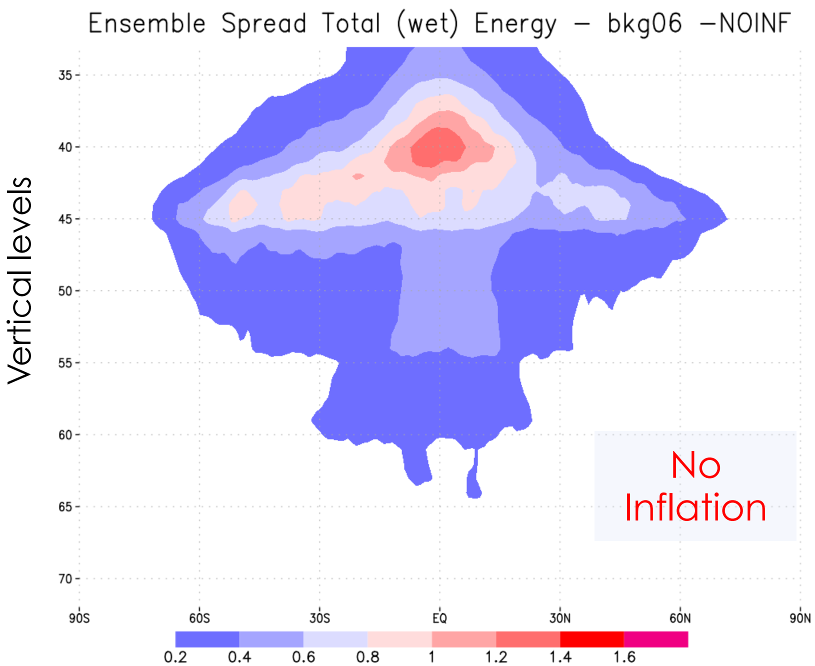


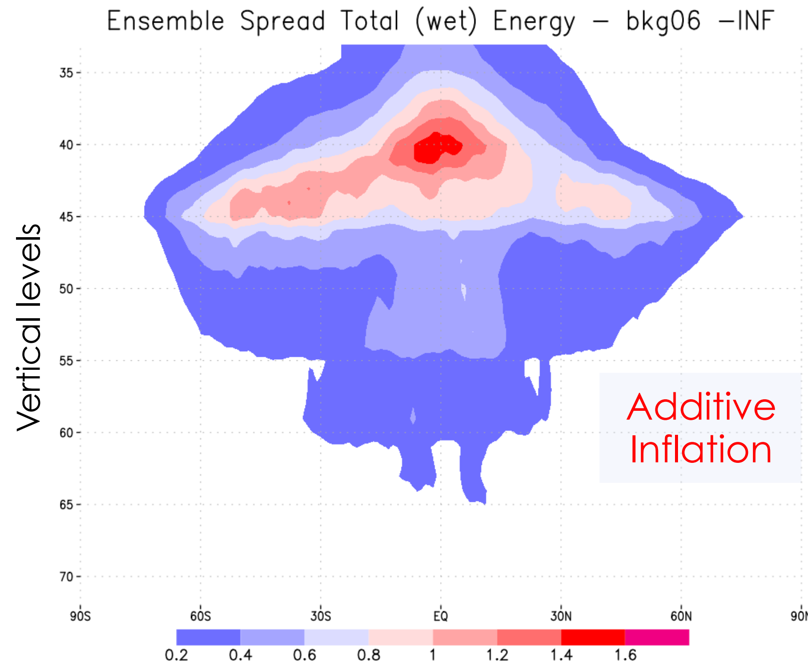
Projection on the random pattern (x10)

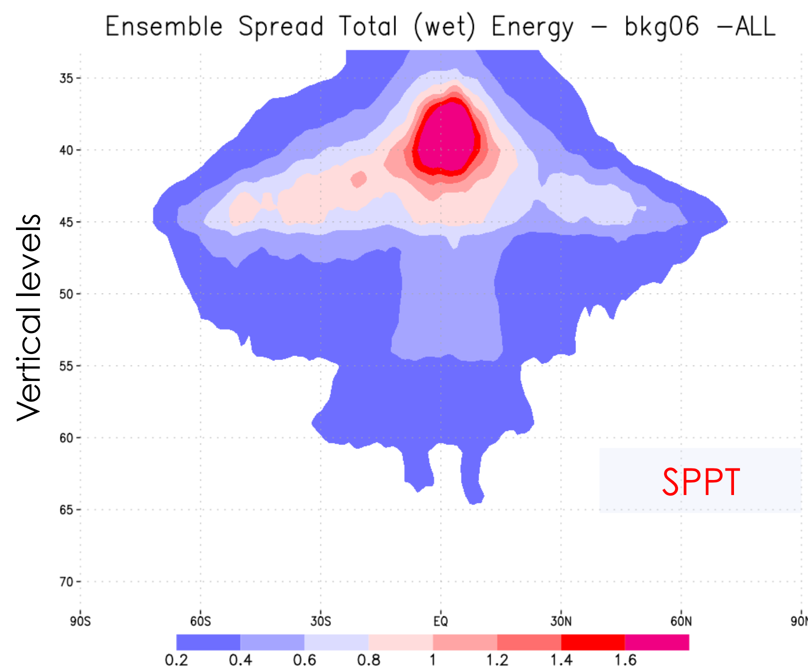


Total tendency = TIR ! Mass-Weighted Temperature Tendency due to Radiation
+ STN ! Mass-Weighted Temperature Tendency due to Turbulent Mixing
+ TTN ! Mass-Weighted Temperature Tendency due to Moist Processes
+ FRI ! Mass-Weighted Temperature Tendency due to Friction (Turbulence)
+ TIG ! Mass-Weighted Temperature Tendency due to GWD
+ TICU ! Mass-Weighted Temperature Tendency due to Cumulus Friction

Impact on spread at 06h

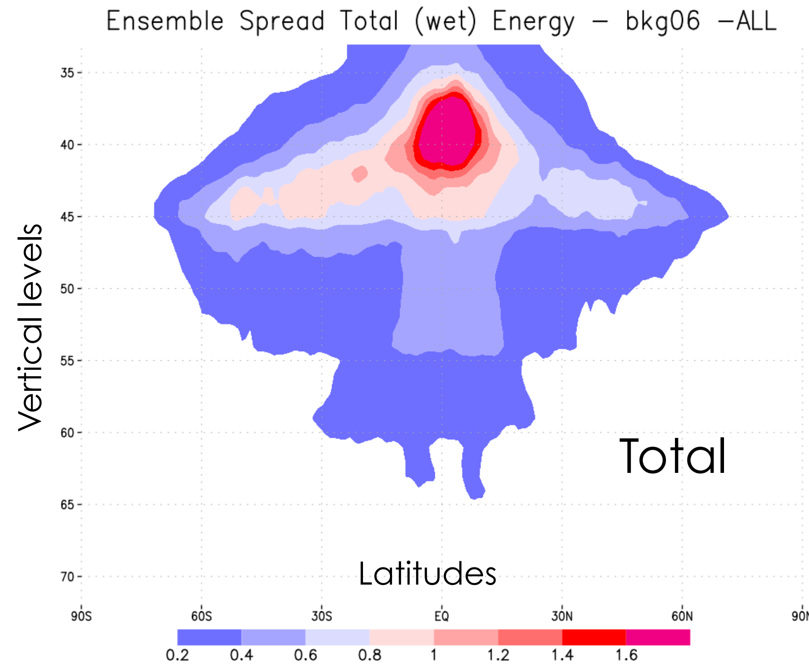


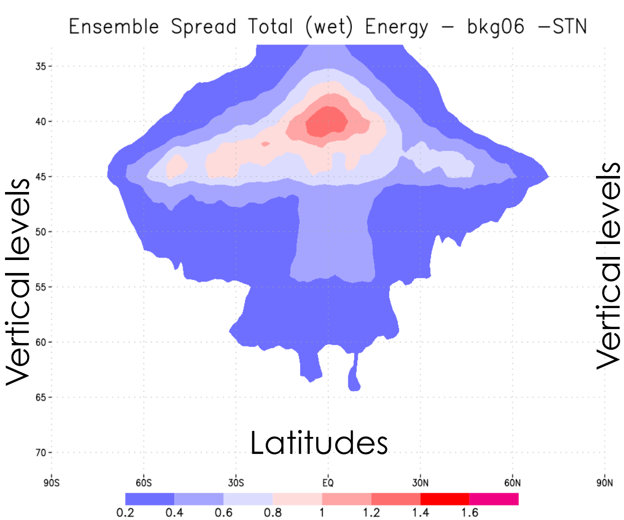




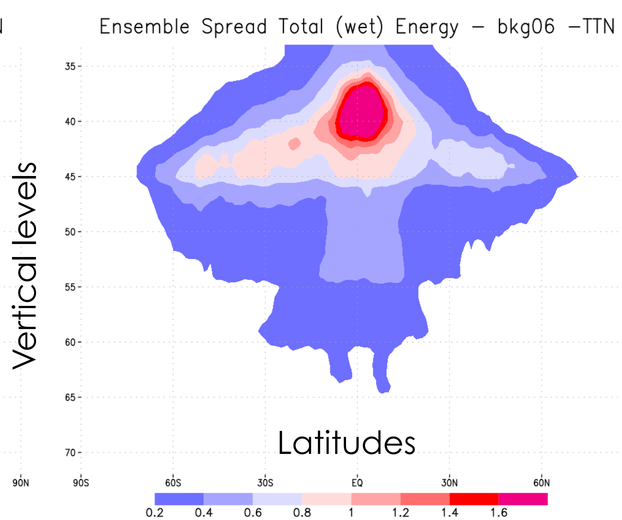
Impact on spread at 06h

- Contributions from different physics components

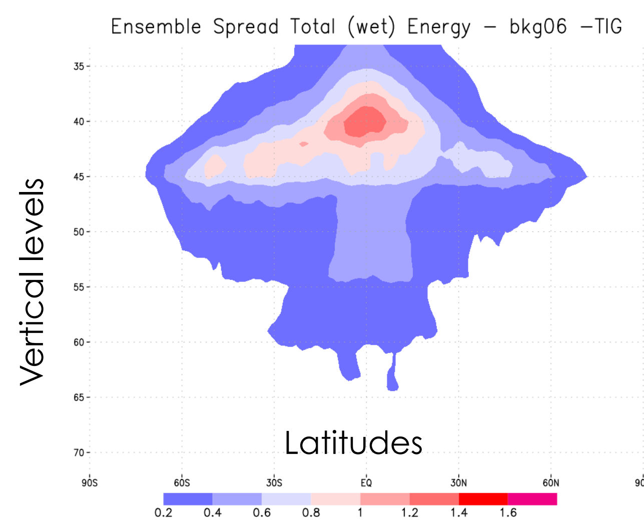




Turbulent Mixing



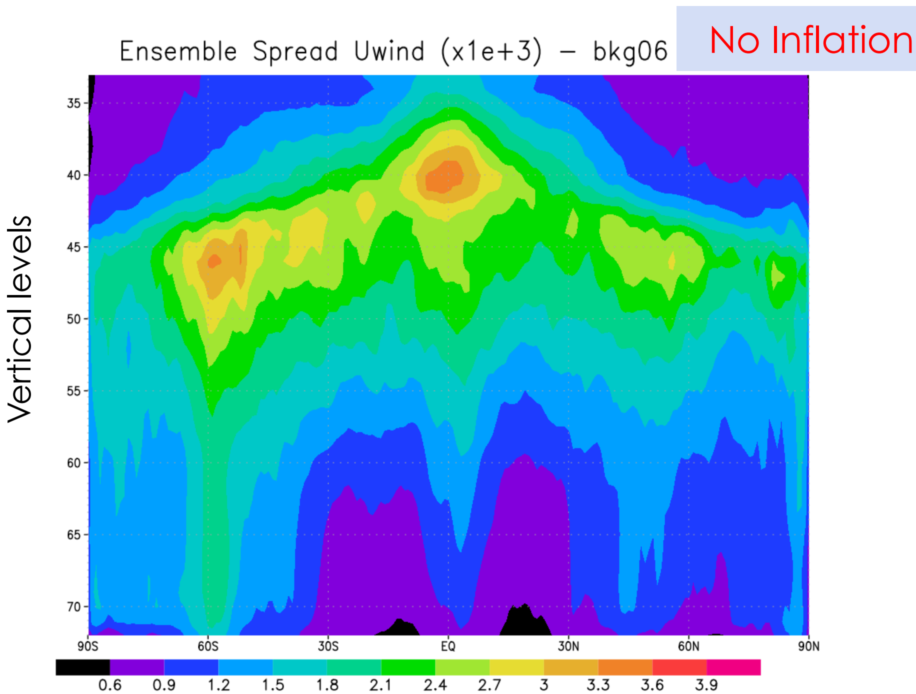
Moist Processes

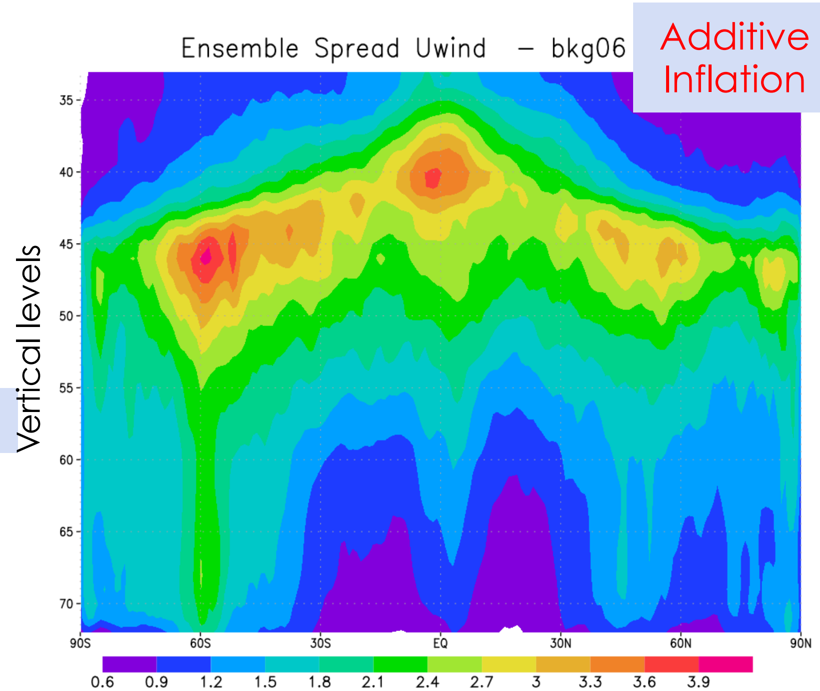


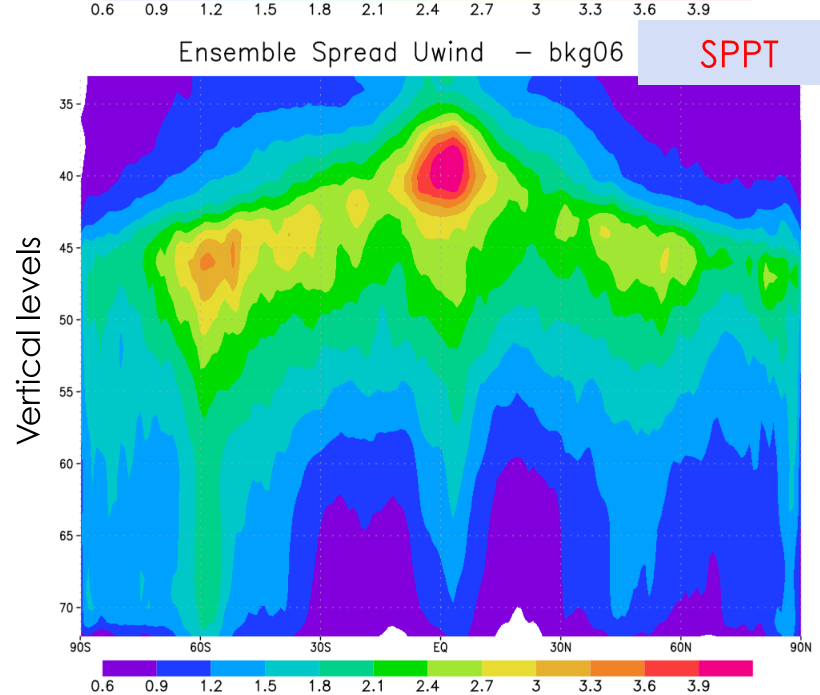
Gravity wave drag

Impact on spread - Uwind

Zonal mean wind ensemble spread

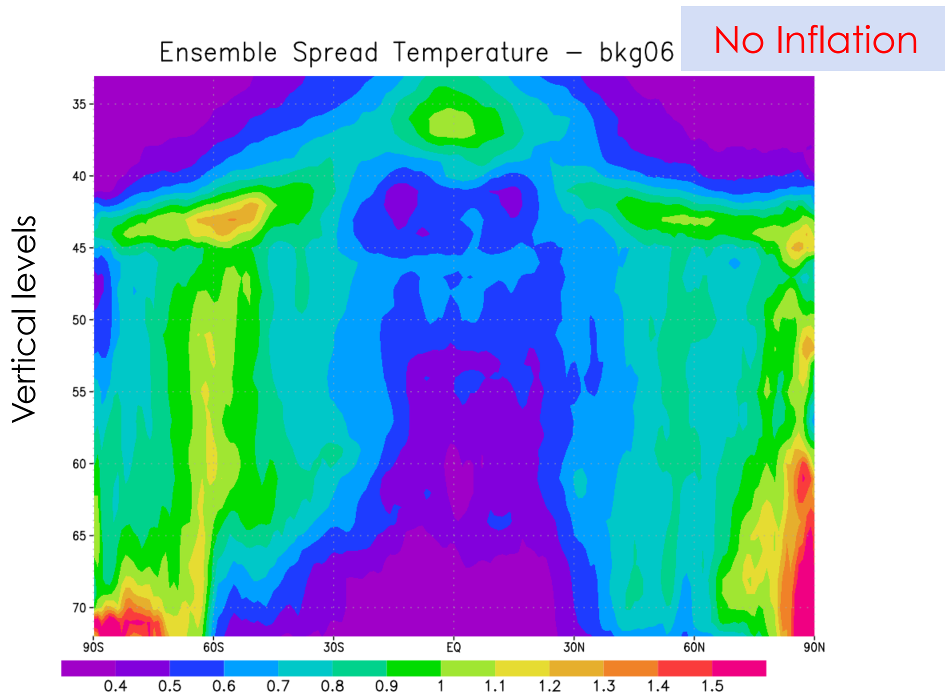


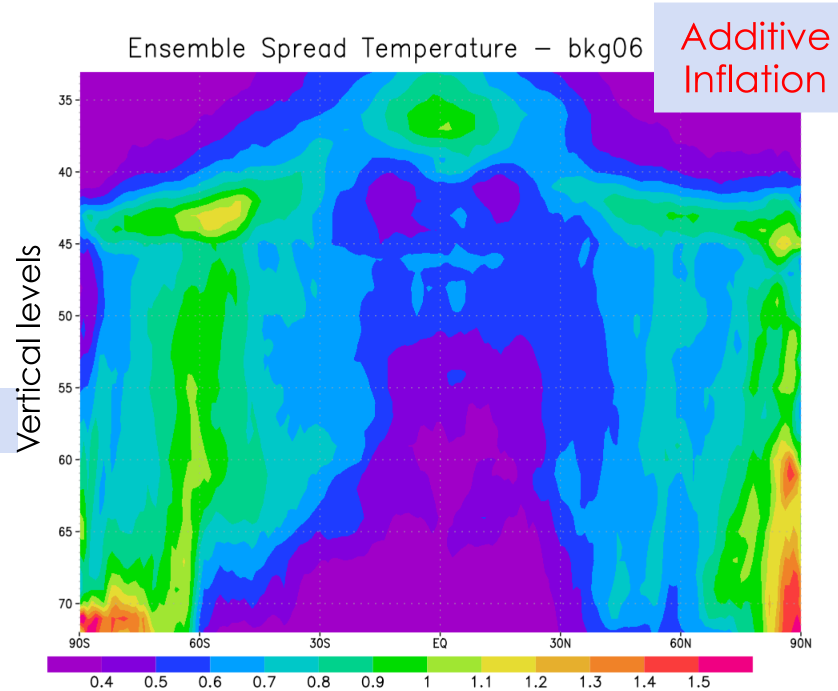


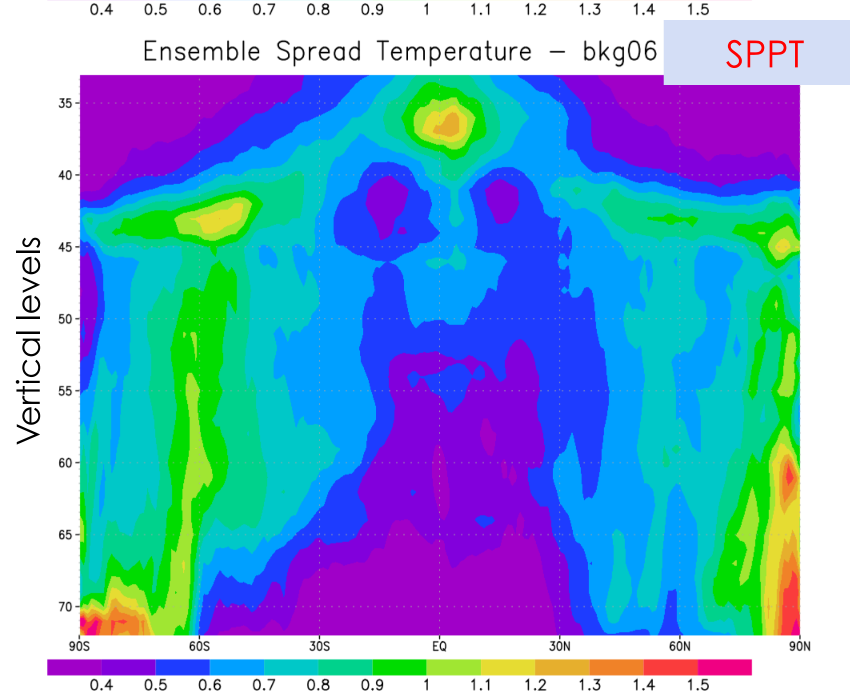


Impact on spread - T

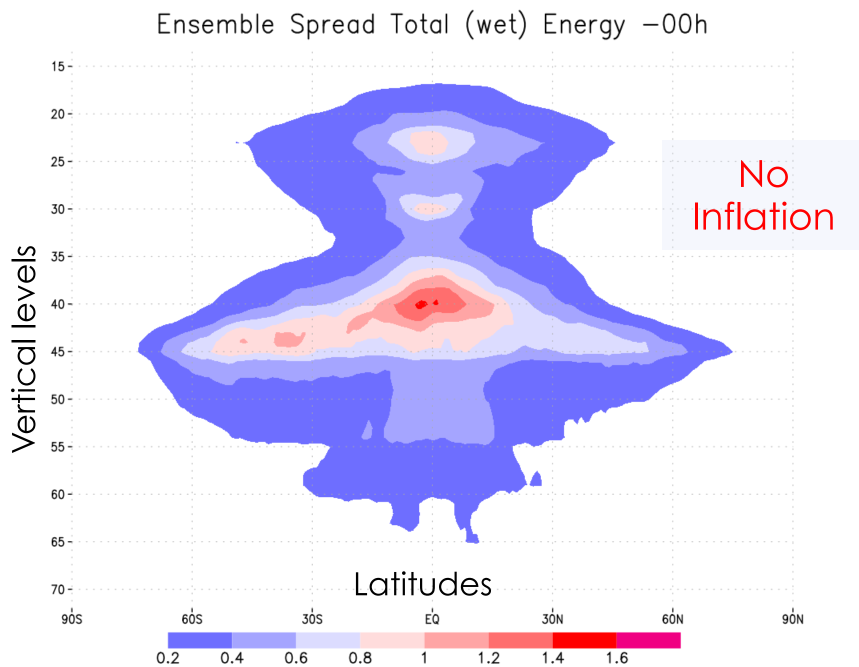
Zonal mean temperature ens spread

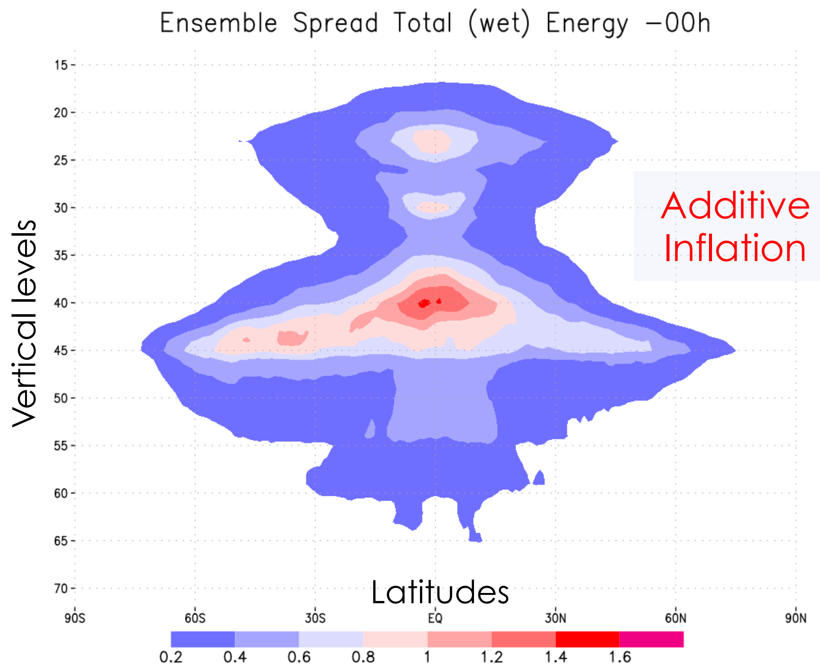


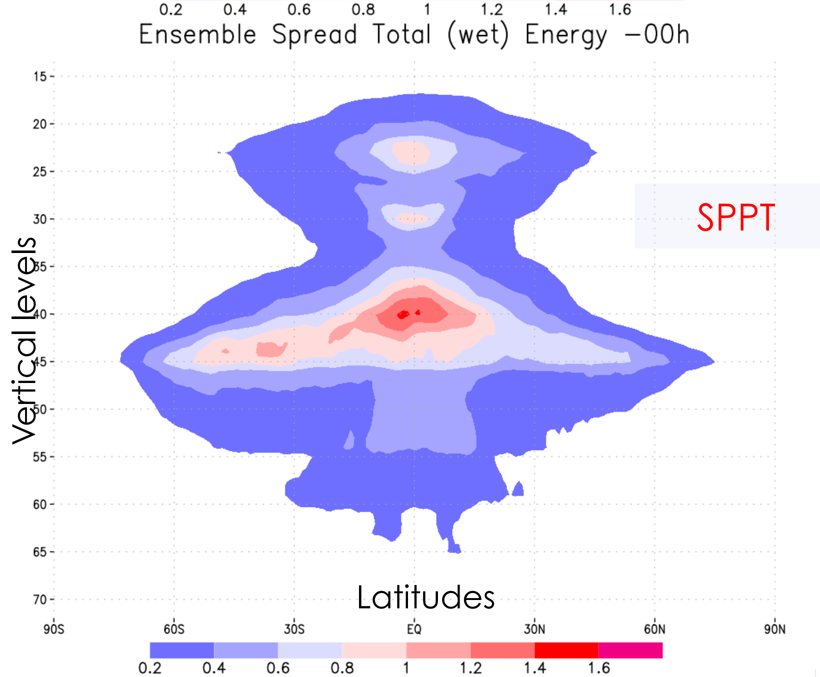




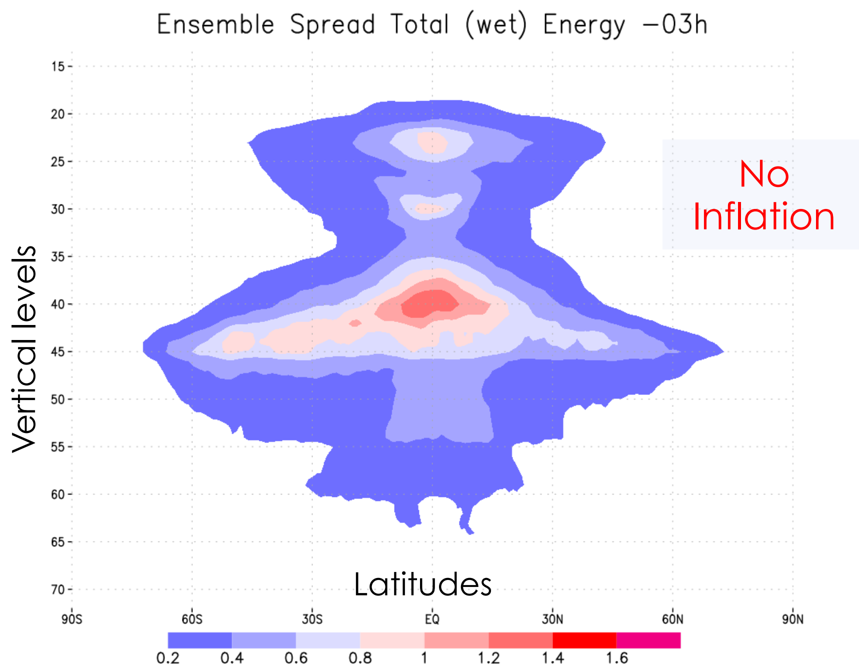
Spread growth – 00h

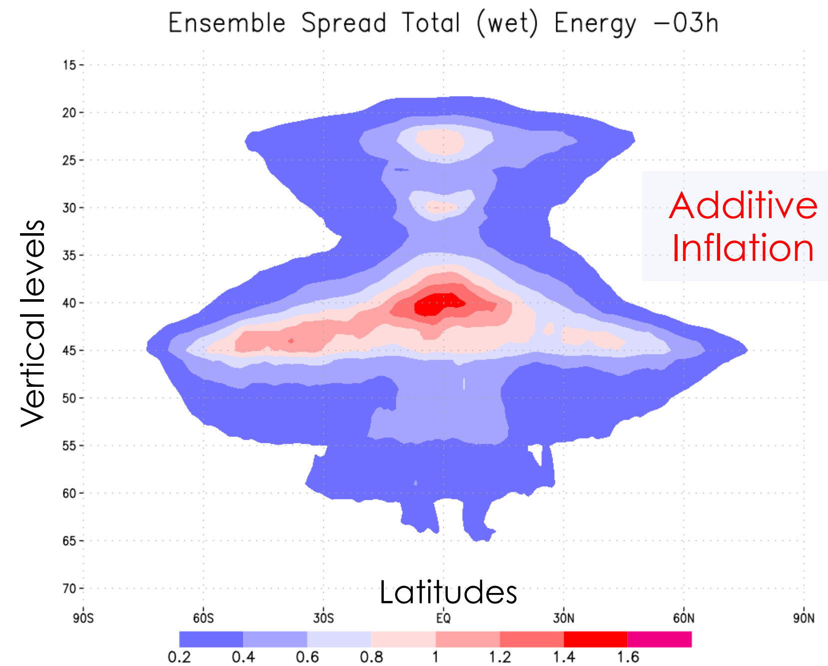


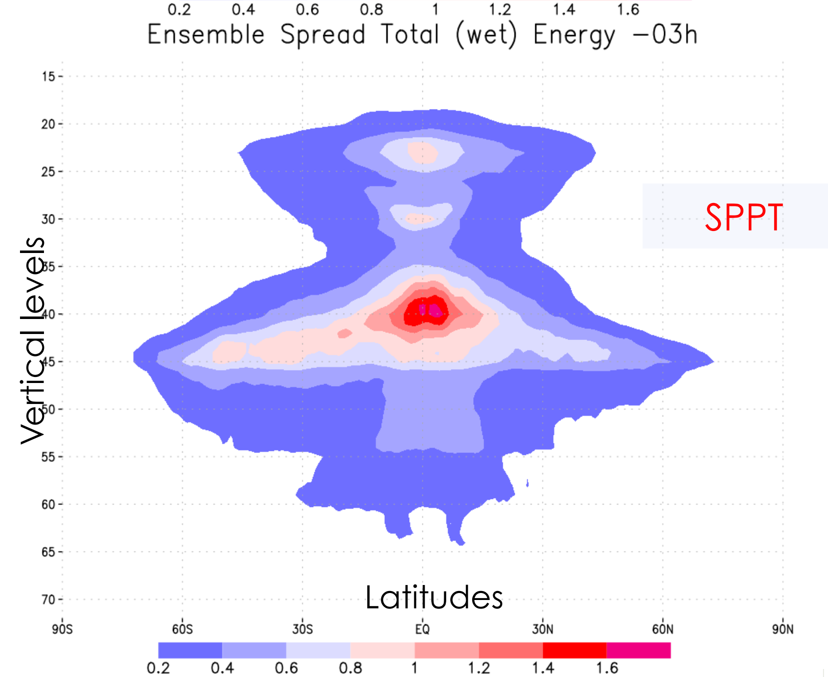




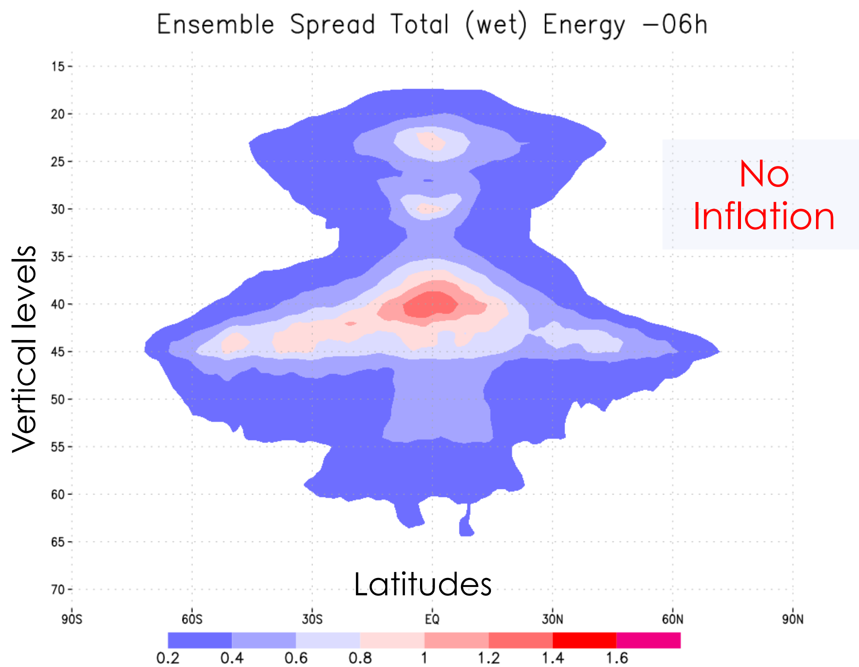
Spread growth – 03h

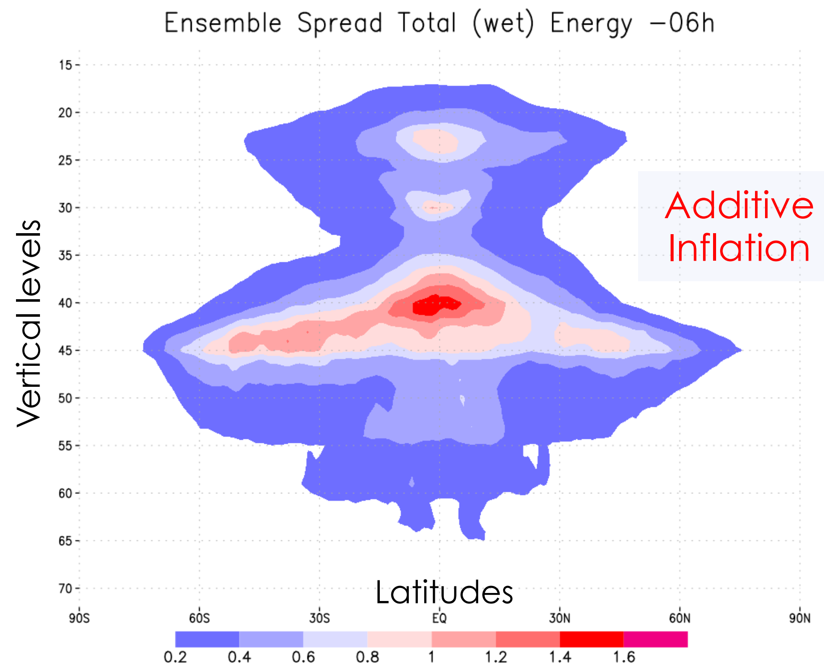


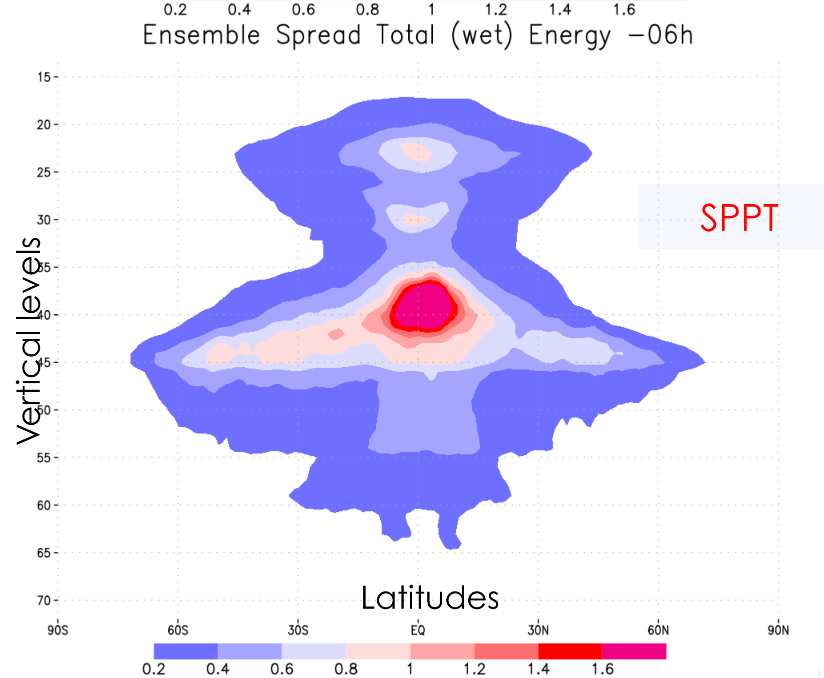




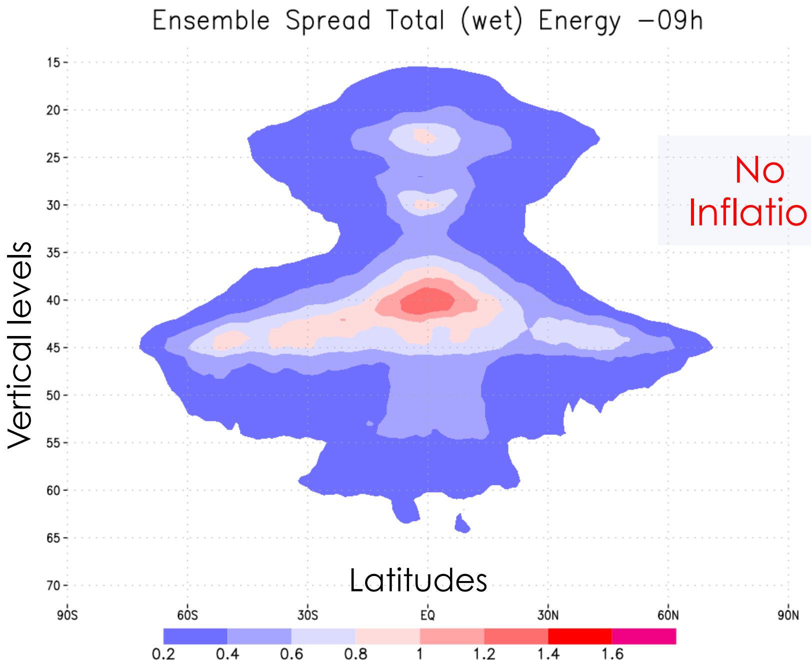
Spread growth – 06h



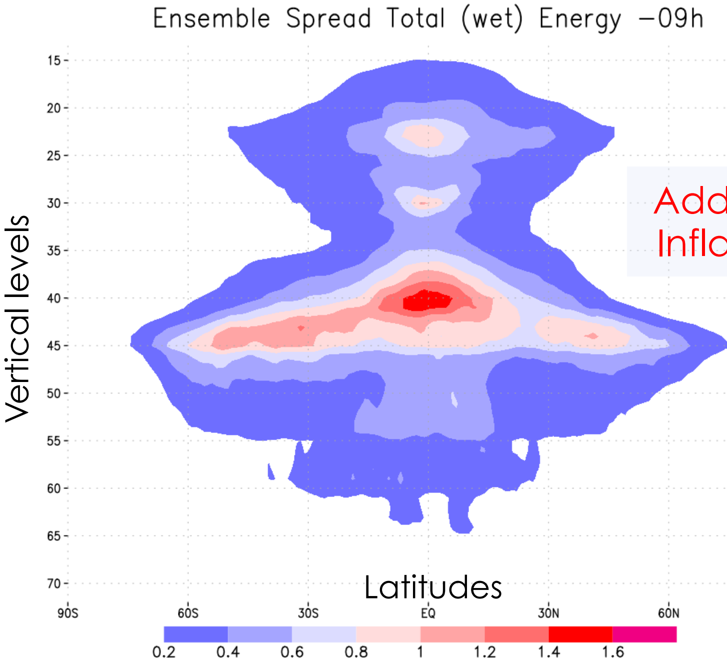




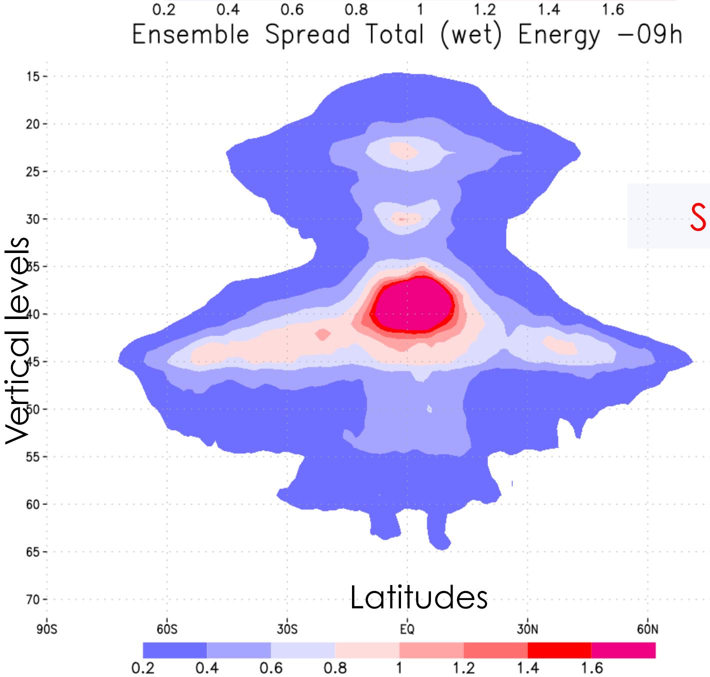
Spread growth – 09h



No Inflation



Additive Inflation



SPPT

Summary and future work

- NMC-like perturbations provide an ad-hoc (yet, efficient) tool to increase ensemble spread <u>at the analysis time</u>, 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.