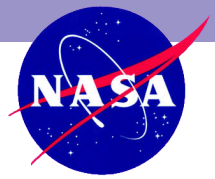
GMAO Hybrid Ensemble 3D-Var

Amal El Akkraoui and Ricardo Todling

Global Modeling and Assimilation Office

Many thanks to: D. Kleist, D. Parish, J. Whitaker, and R. Treadon.



Background and motivation

- Use flow-dependent background error information derived from ensemble techniques but still within the variational framework.
- The 3D-Var cost function:

$$J(\delta\mathbf{x}) = \frac{1}{2}\delta\mathbf{x}^T\mathbf{B}^{-1}\delta\mathbf{x} + \frac{1}{2}(\mathbf{H}\delta\mathbf{x} - \mathbf{y}')^T\mathbf{R}^{-1}(\mathbf{H}\delta\mathbf{x} - \mathbf{y}')$$

- The hybrid 3D-Var cost function:

$$J(\mathbf{x}') = \frac{1}{2}\mathbf{x}'^T(\beta\mathbf{B} + (1-\beta)\mathbf{P}^e \circ \mathbf{S})^{-1}\mathbf{x}' + \frac{1}{2}(\mathbf{H}\mathbf{x}' - \mathbf{y}')^T\mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{y}')$$

$$\mathbf{x}' = \delta\mathbf{x} + \sum_{k=1}^{K} \mathbf{a}_k \circ \mathbf{x}_k^e \quad , \qquad \text{and} \qquad \mathbf{P}^e = \sum_{k=1}^{K} \mathbf{x}_k^e (\mathbf{x}_k^e)^T$$

Current status of GMAO's hybrid ensemble 3D-Var

Control run (Ctl):

- Conventional 3D-Var;
- analysis at 0.5^o;
- forecasts at 0.5^o;
- close run to ops.

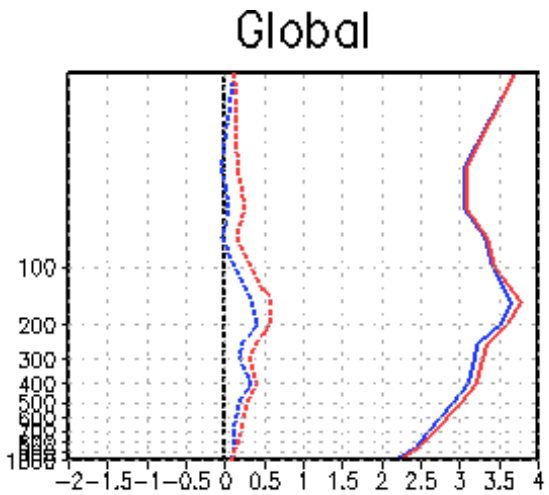
Hybrid run (Hyb):

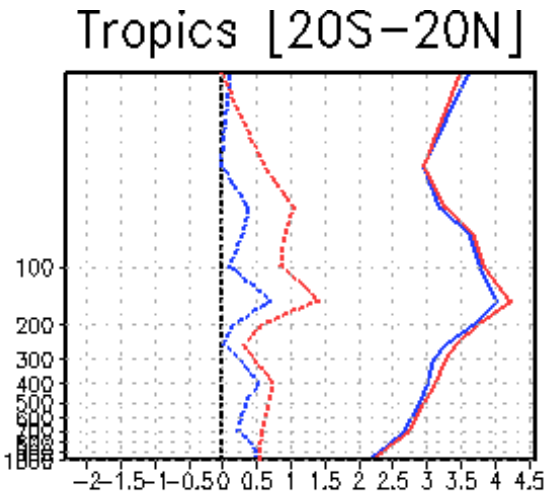
- 32 members at 1^o ; S-EnKF;
- Additive inflation;
- Dual resolution (central at 0.5^o, ensemble at 1^o);
- $\beta = 0.5$;
- members re-centered.

- Time frame: mid-November through end of december 2011. 2-week spin up period, and hybrid starts on Dec 1st.

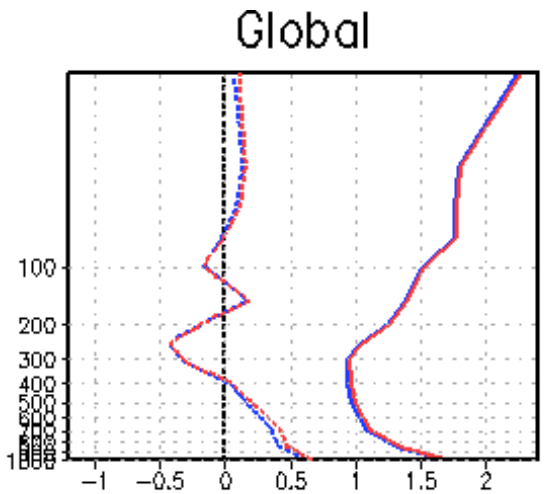
Results: OMF —— Hyb —— Ctl

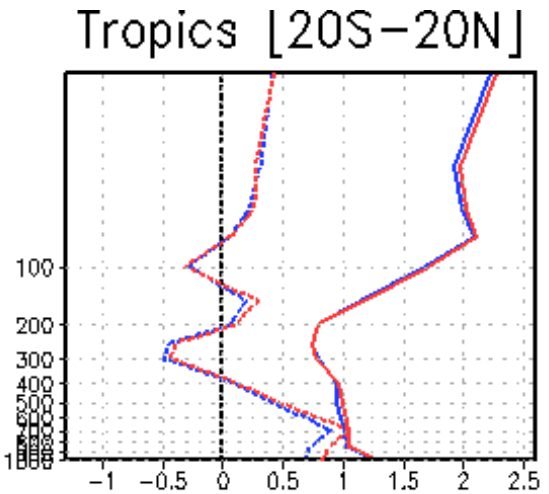
Uwind





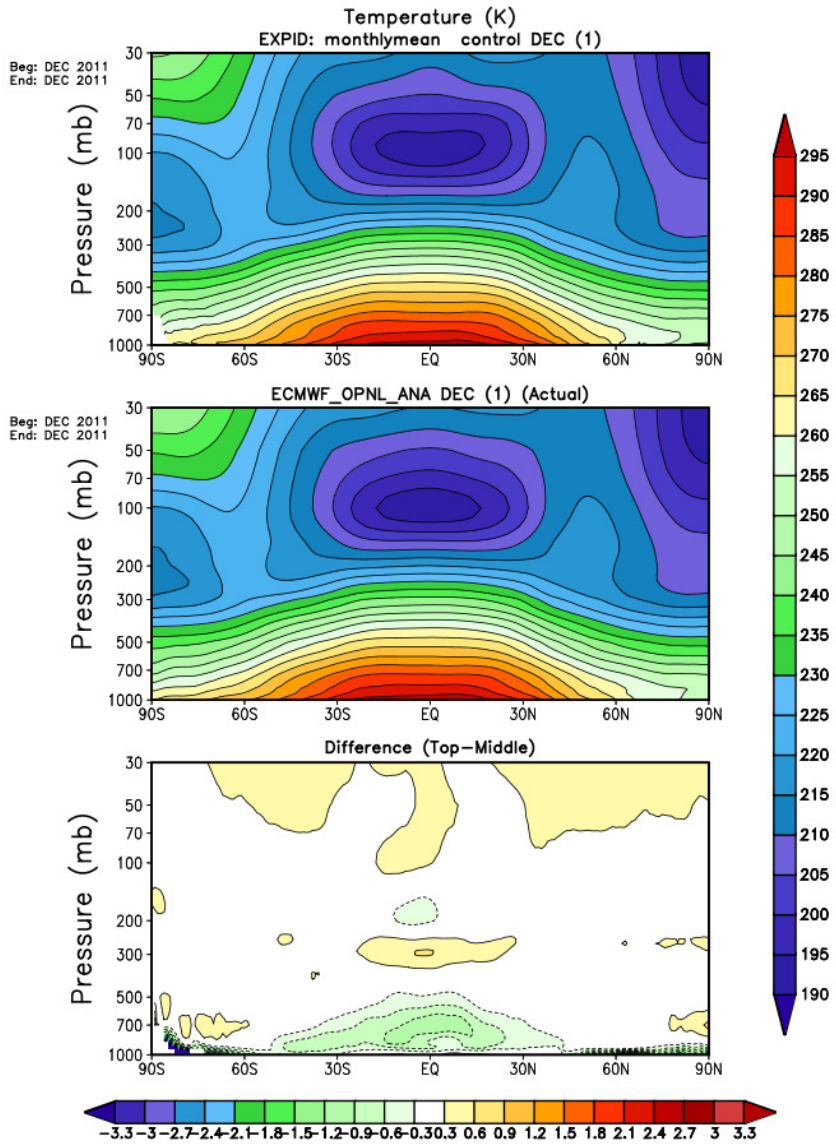
Temp



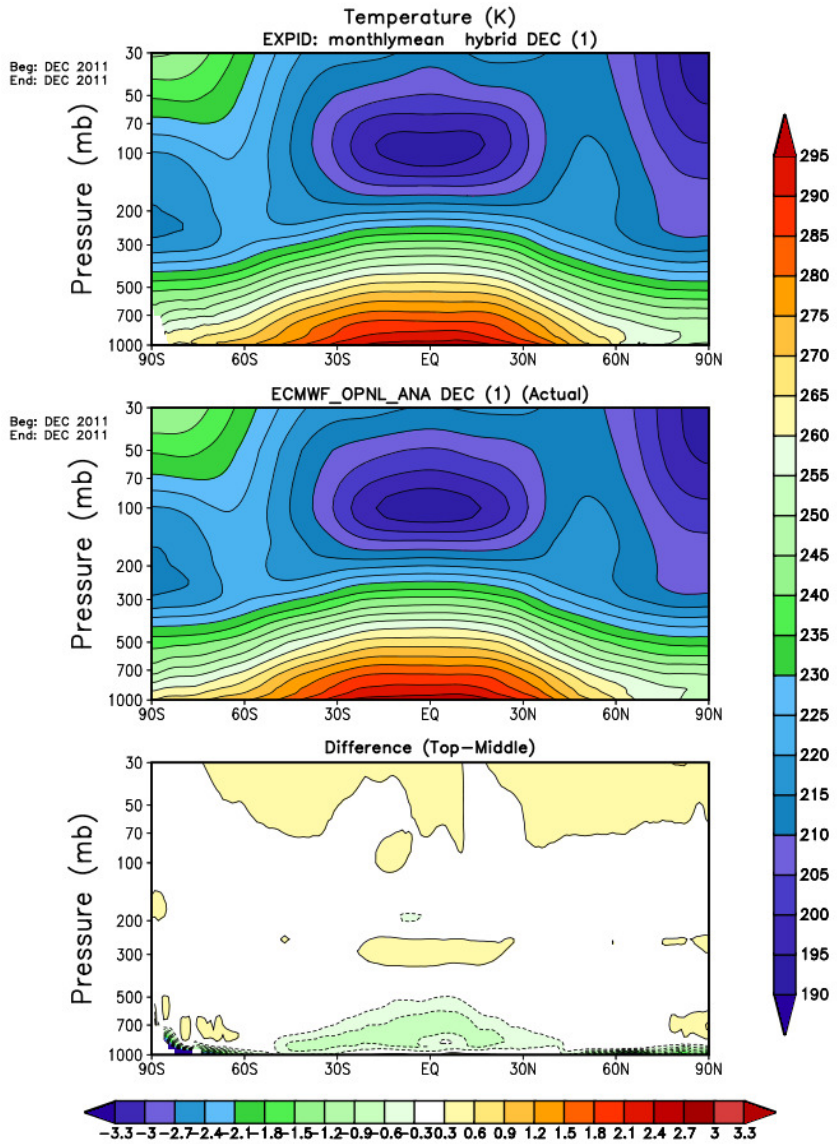


Results: Monthly means (Temperature)

Ctl vs. ECMWF

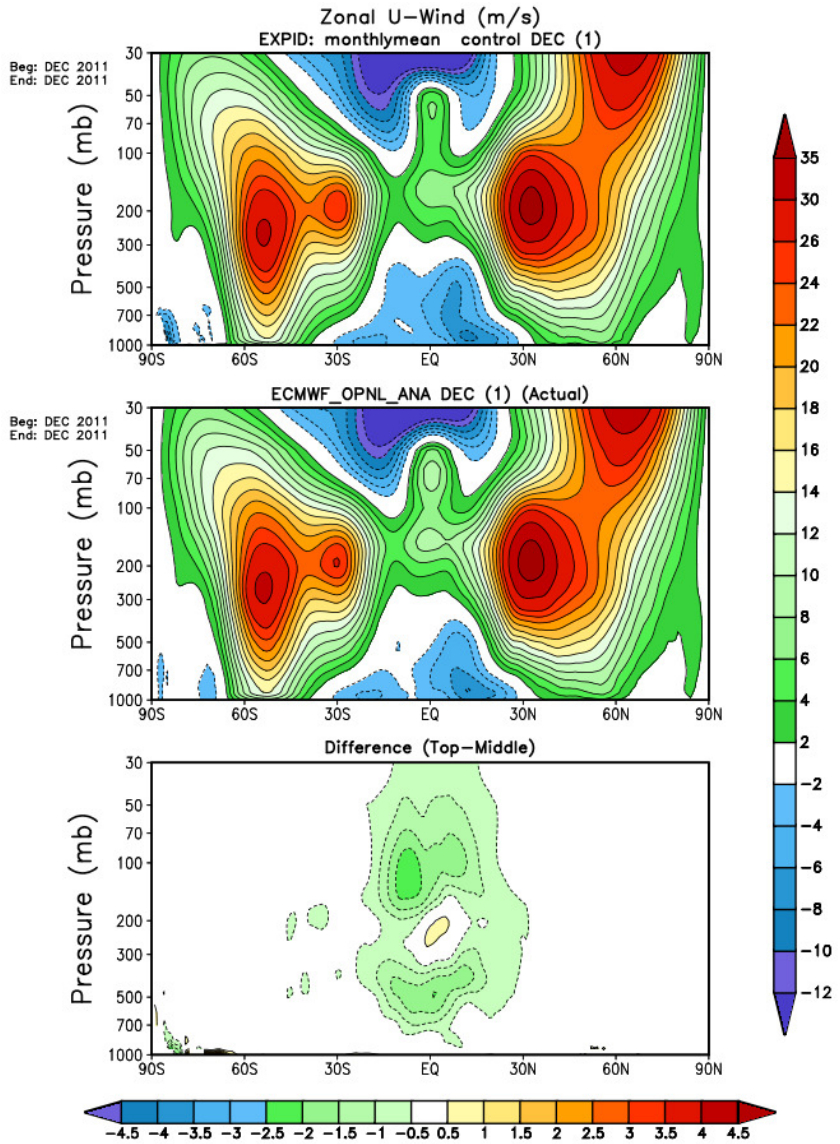


Hyb vs. ECMWF

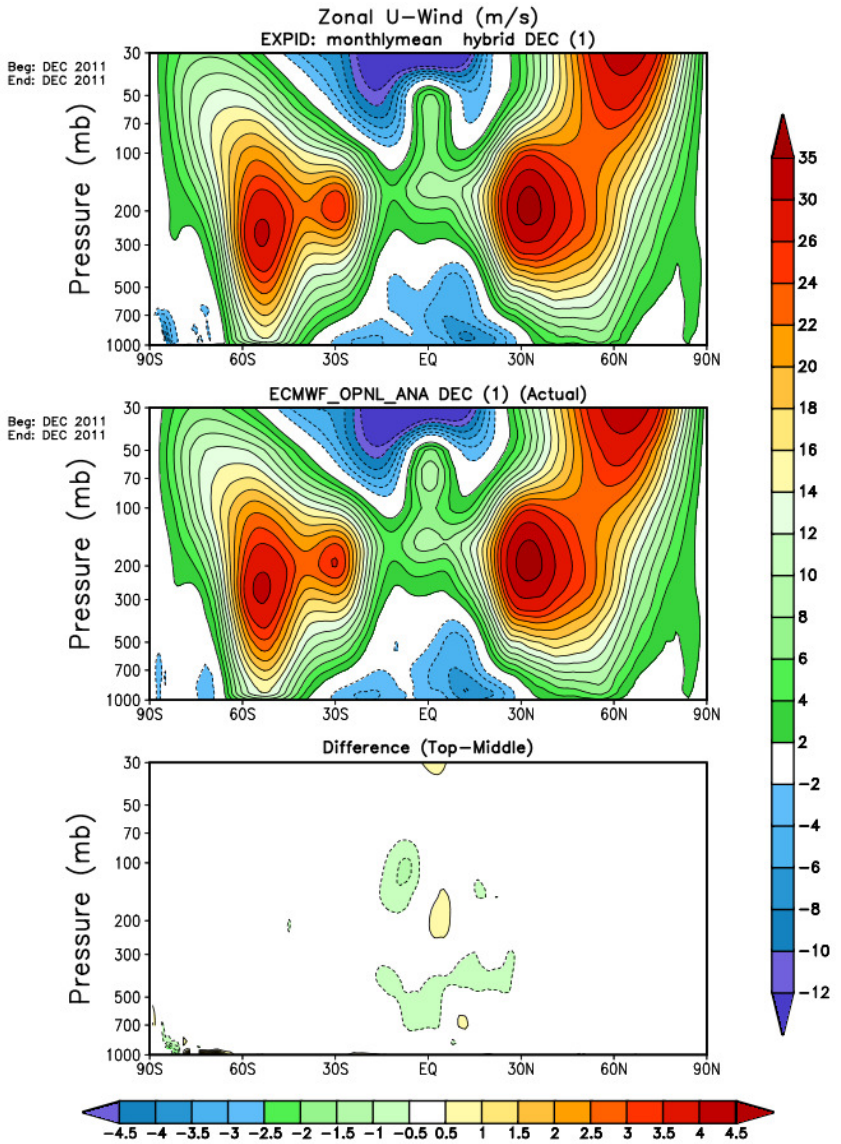


Results: Monthly means (U-winds)

Ctl vs. ECMWF



Hyb vs. ECMWF



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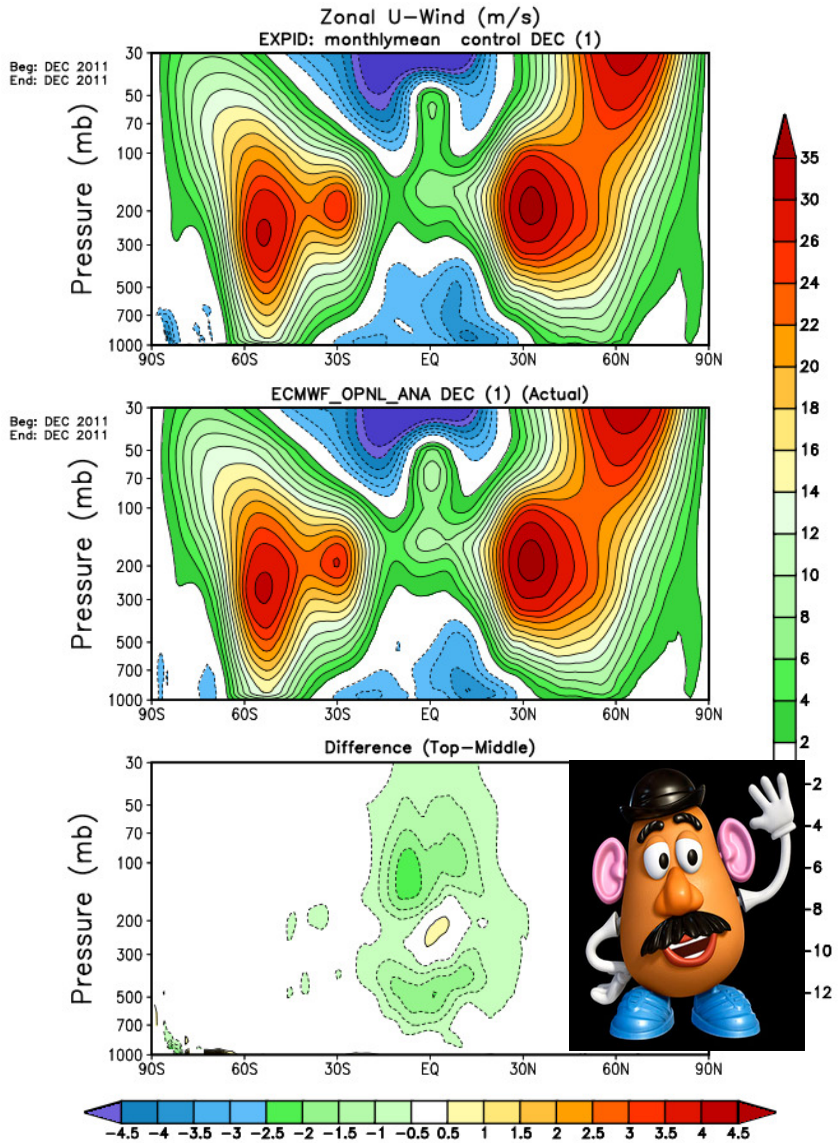

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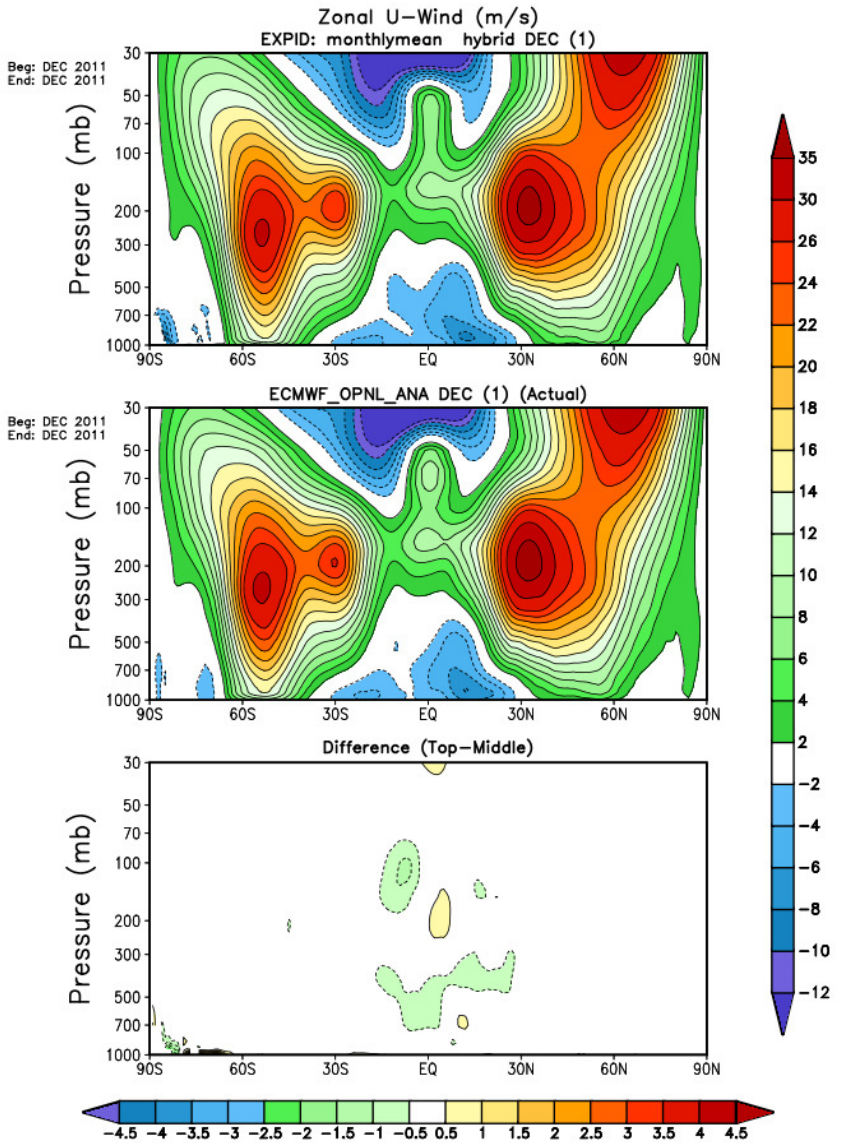
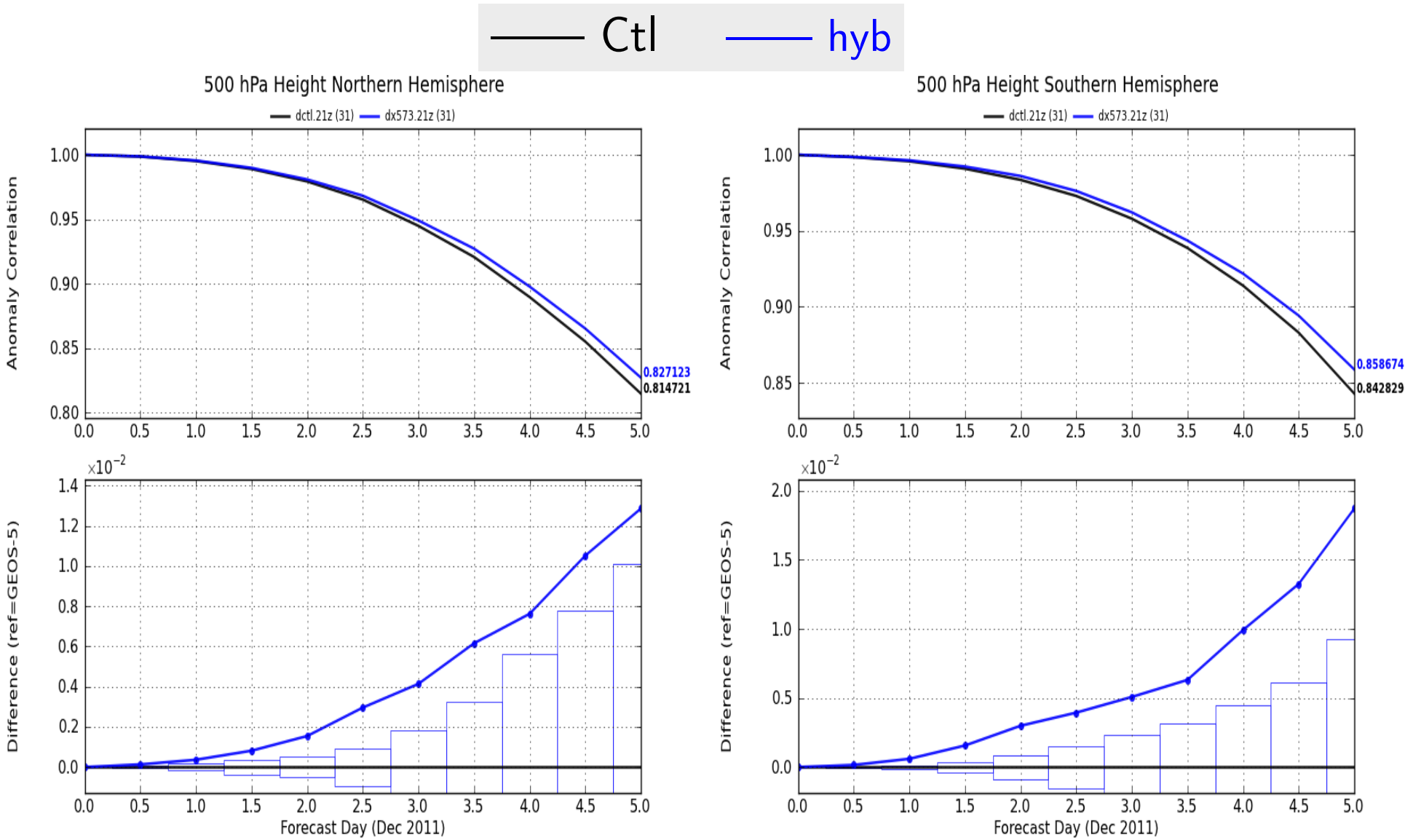
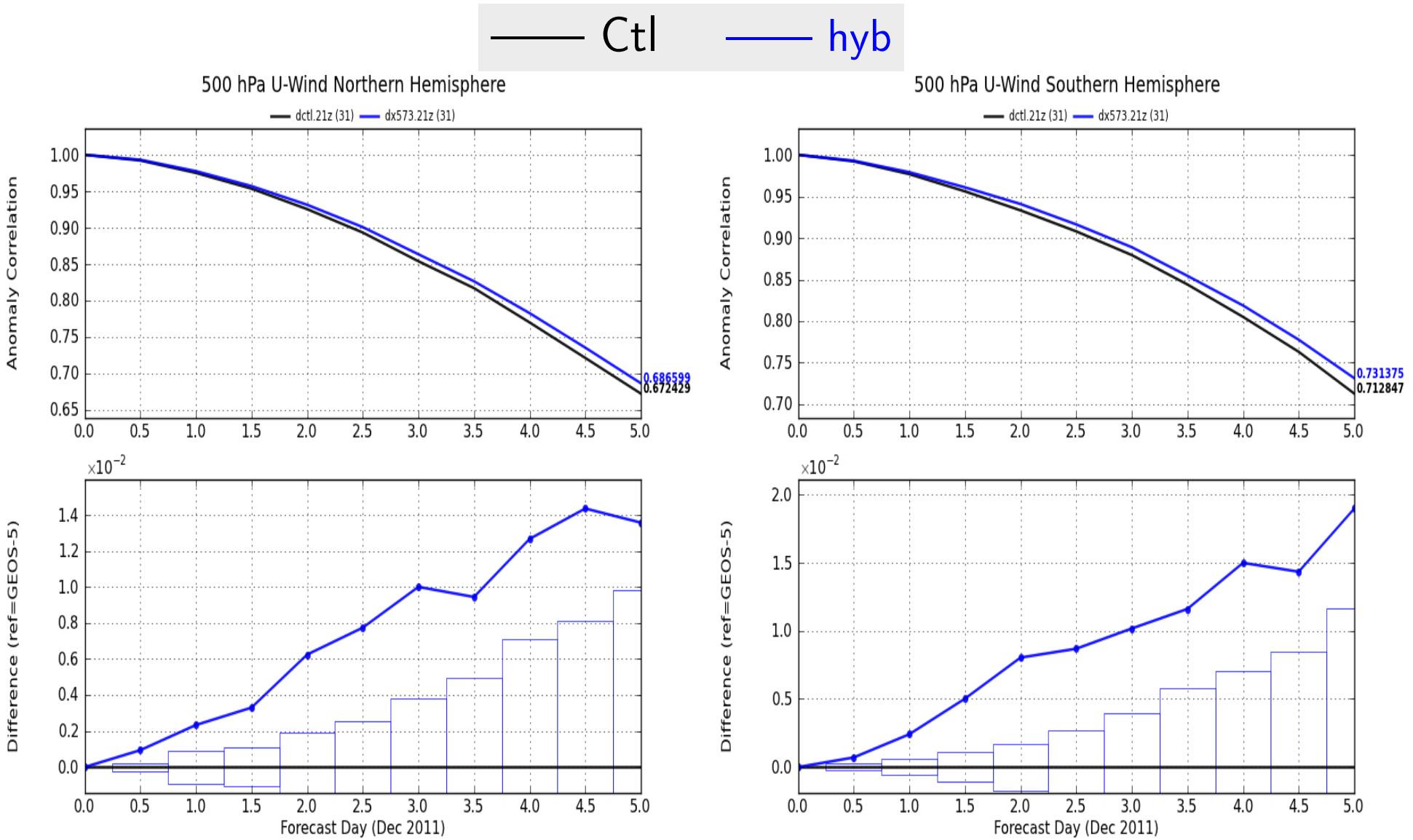


Forecast skills: Anomaly correlations (500 mb height)



Forecast skills: Anomaly correlations (500 mb Uwind)



Current status of GMAO's hybrid ensemble 3D-Var

Overall

- Hybrid results are significantly positive: largely positive for the tropical winds around 500-200mb, and slightly positive to neutral elsewhere;
- Still need to try to get more impact for temperature;
- More tuning and testing with higher resolution, more members, different localization scales.

Then...

The filter-free scheme results prompted more questions!

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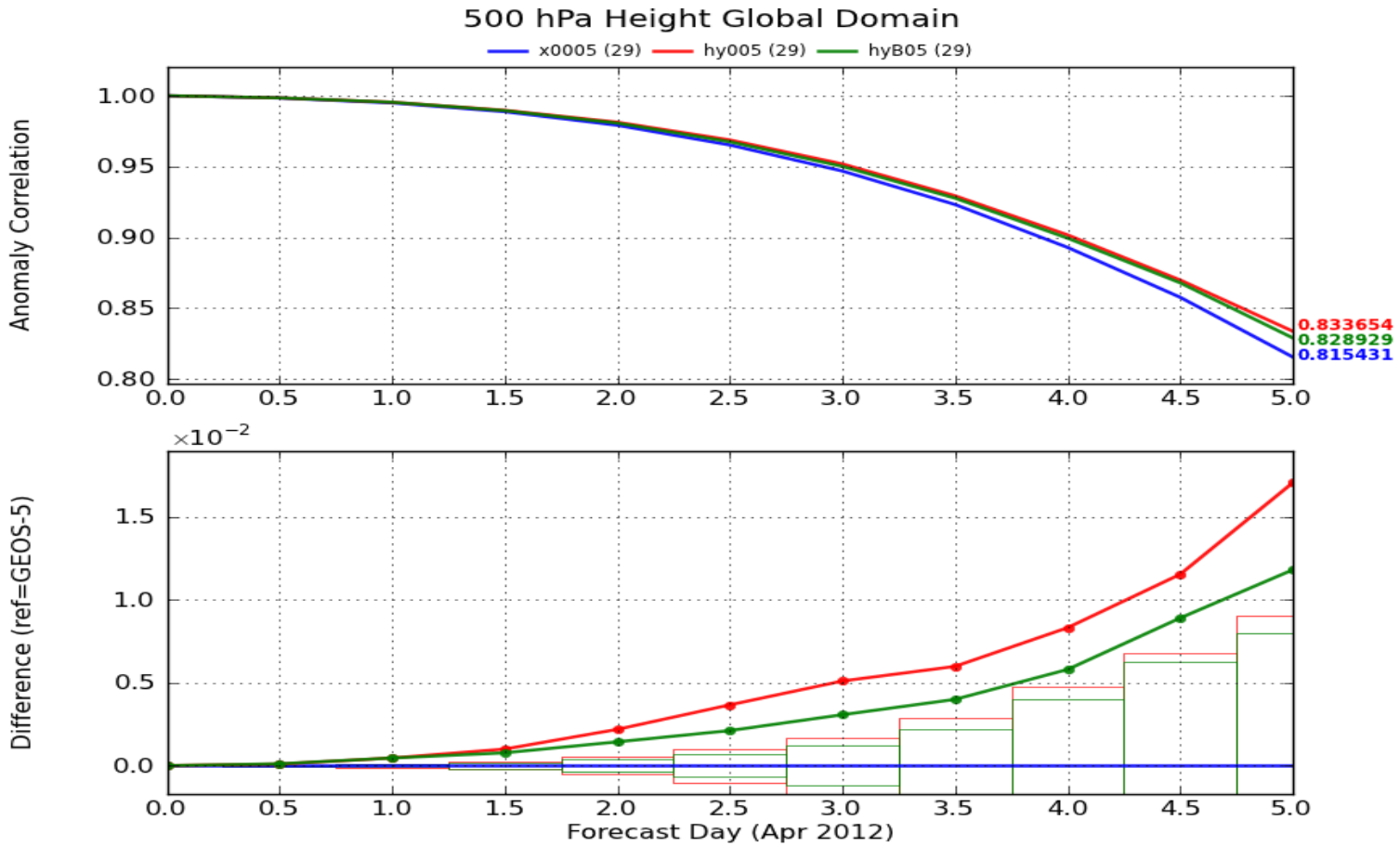
From the Filter-free results:



- Need to examine the role of the two components the filter-free scheme is "borrowing" from the enkf-based scheme: the additive inflation and the re-centering.

New considerations

- Start with the two decoupled schemes: the ensemble (S-EnKF) and the variational (3D-Var).
- Both systems do not need to communicate with each other in order to perform, and then we ask them to work together to the fullest of their potential, hoping for the best outcome.
  - An important aspect of this exercise is how well each system performs when alone.
  - An equally important one is how do they work together as a team when in hybrid mode...
  - ...and how do they both affect each other's performance

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- The EnKF updates : the ensemble mean and the ensemble of background perturbations
- Both products go through some "post-analysis" step before the perturbations are evolved in time to the next cycle :
  - Inflation (additive and/or multiplicative) for the members;
  - Re-centering of the members around a new mean (central)
    $\Rightarrow$ the ensemble mean is modified.

post-analysis

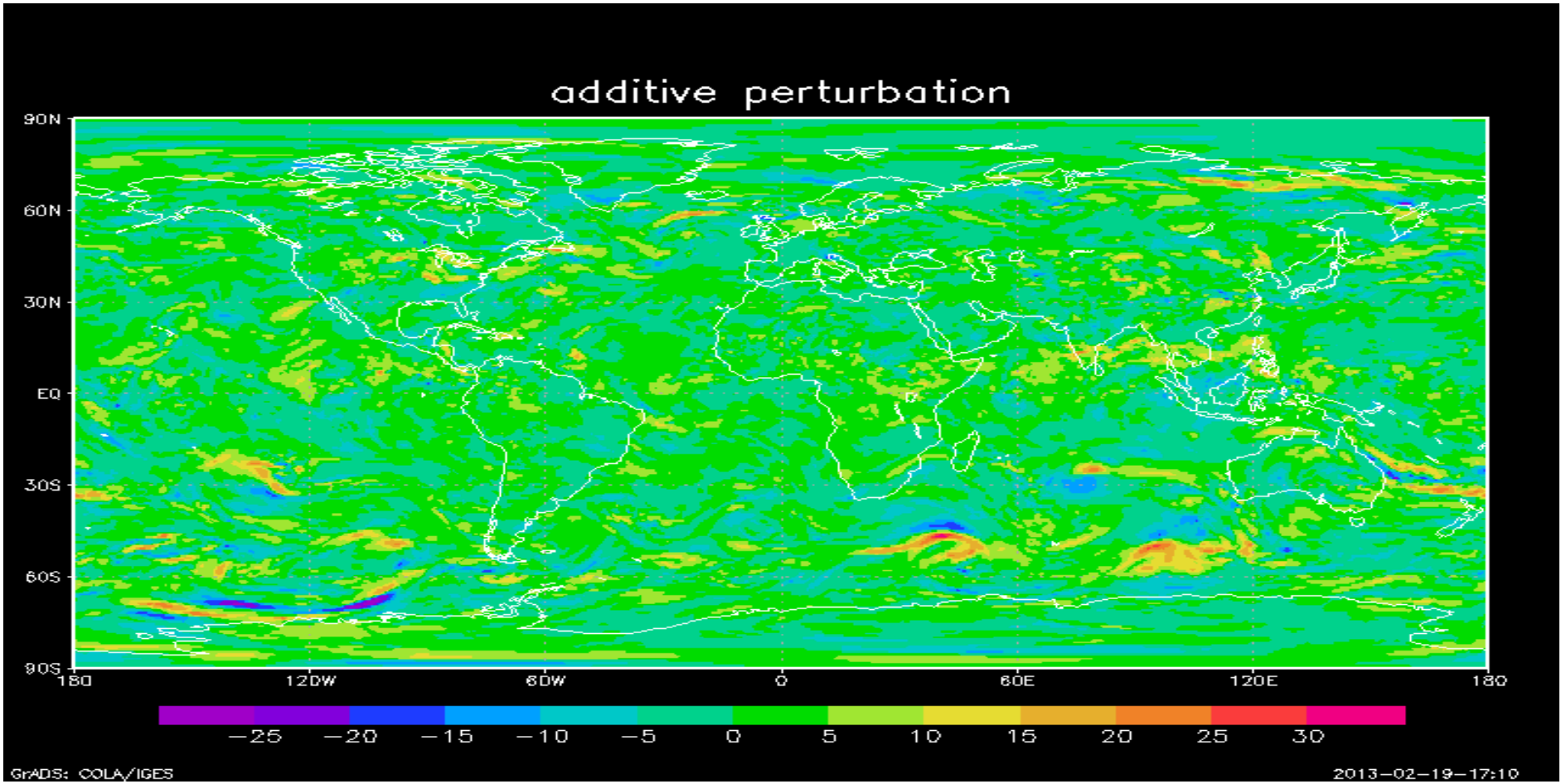
$$\mathbf{x}_i^a \Leftarrow \mathbf{x}_i^a - \bar{\mathbf{x}}^a + \mathbf{x}^c + \alpha\epsilon^{pert}$$

$$\delta\mathbf{x}_i^{ana} \Leftarrow \delta\mathbf{x}_i^{ana} + \delta\mathbf{x}^{rec} + \alpha\delta\mathbf{x}_i^{inf}$$

- How large should the additive inflation be....without compromising the enkf analysis?
- How does the dual resolution affect the size of the re-centering increment?

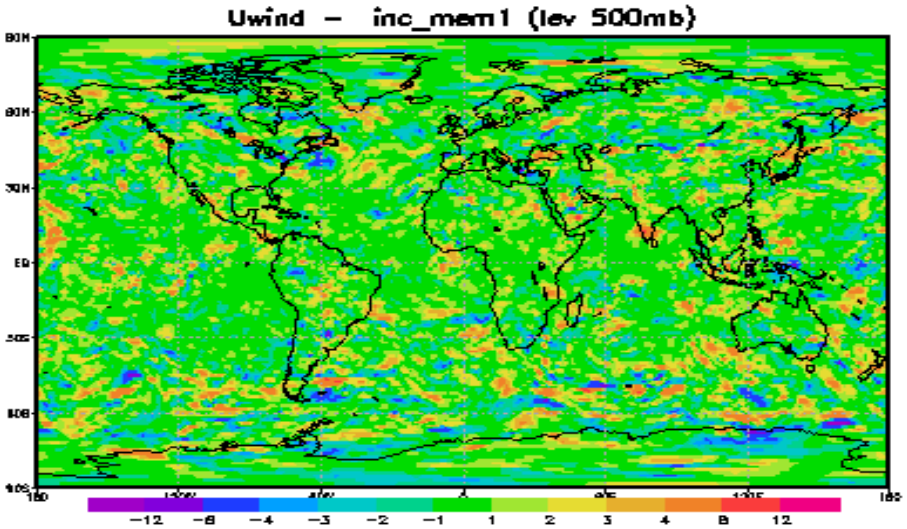
The NMC-like additive perturbations

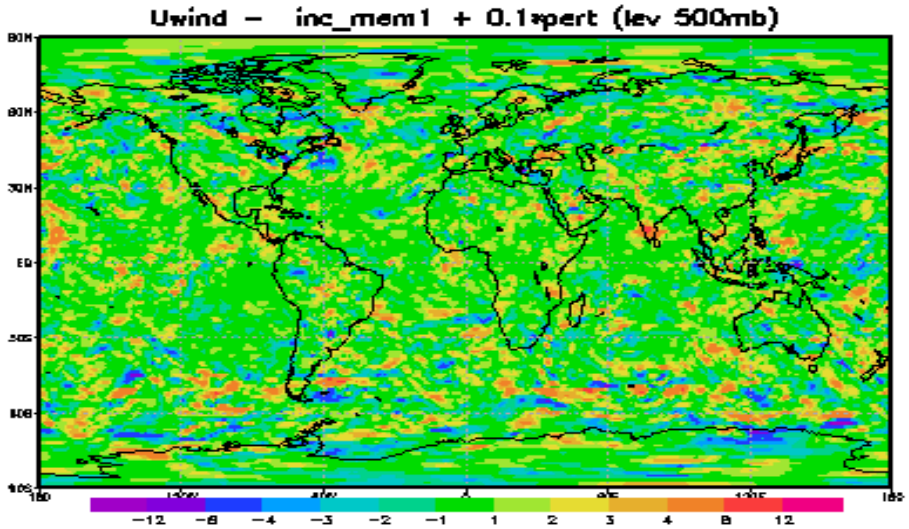
- Uwind 500mb unscaled additive perturbation

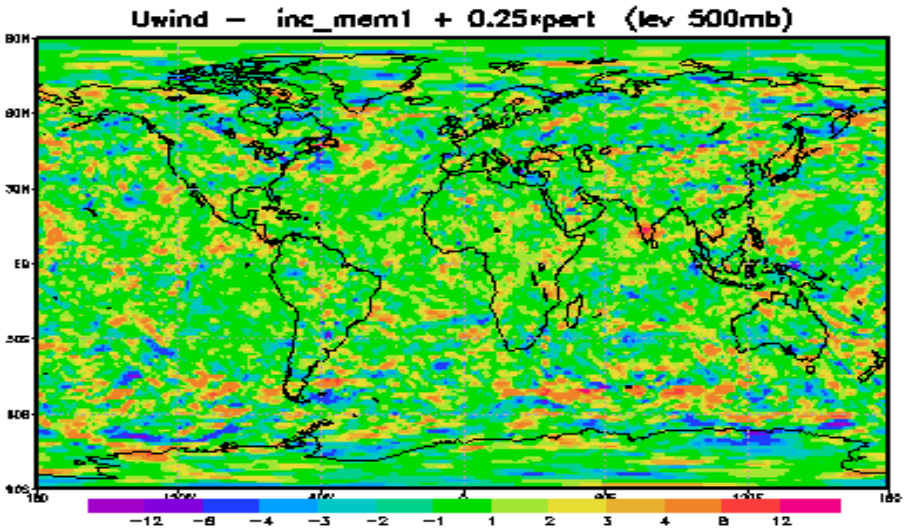


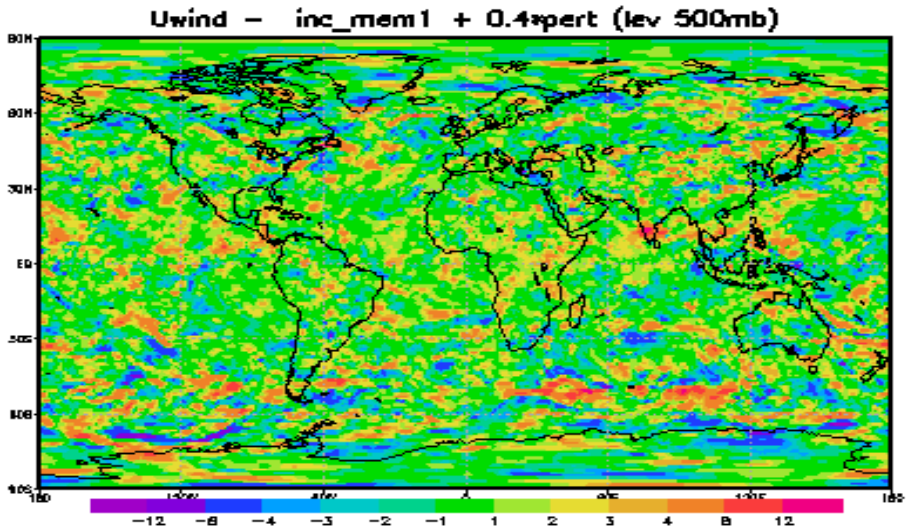
The NMC-like additive perturbations

- Mem1: Uwind analysis incr at 500mb + alpha x additive inflation

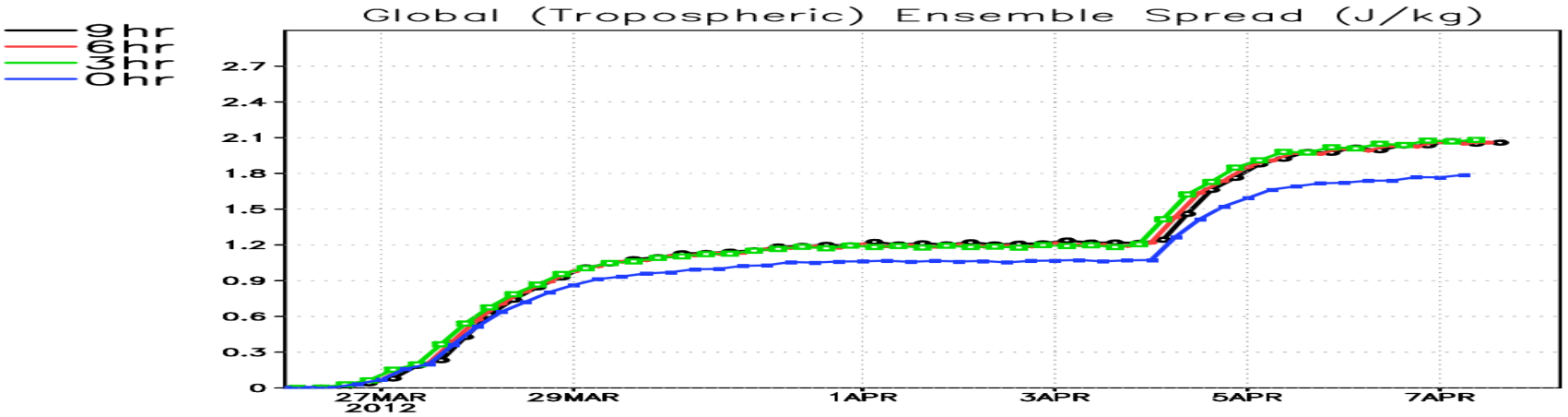


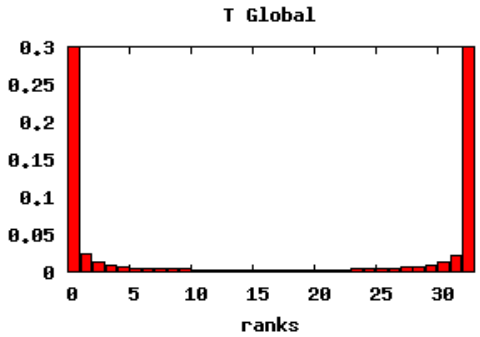


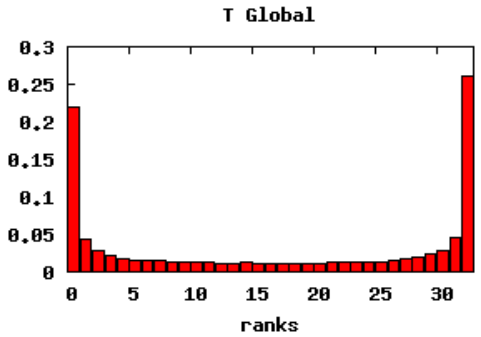


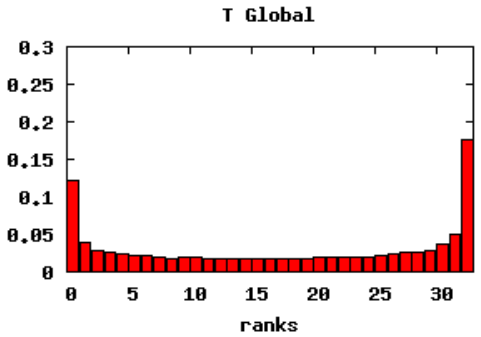


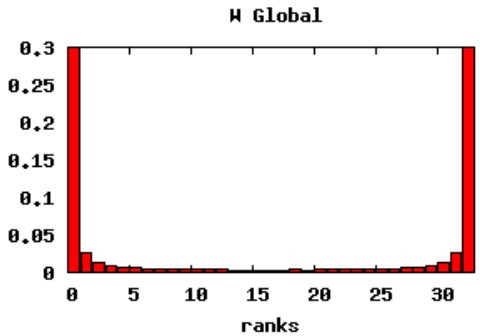
Spread Low-res

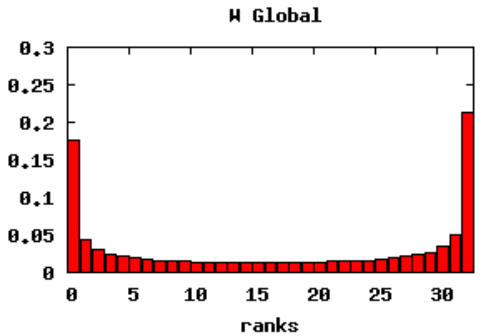


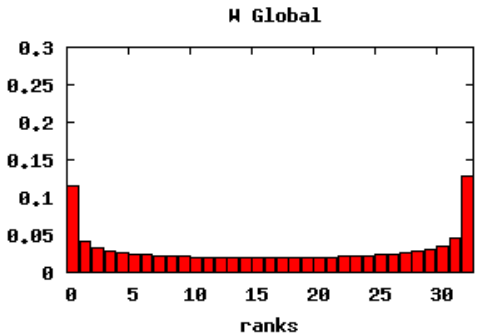




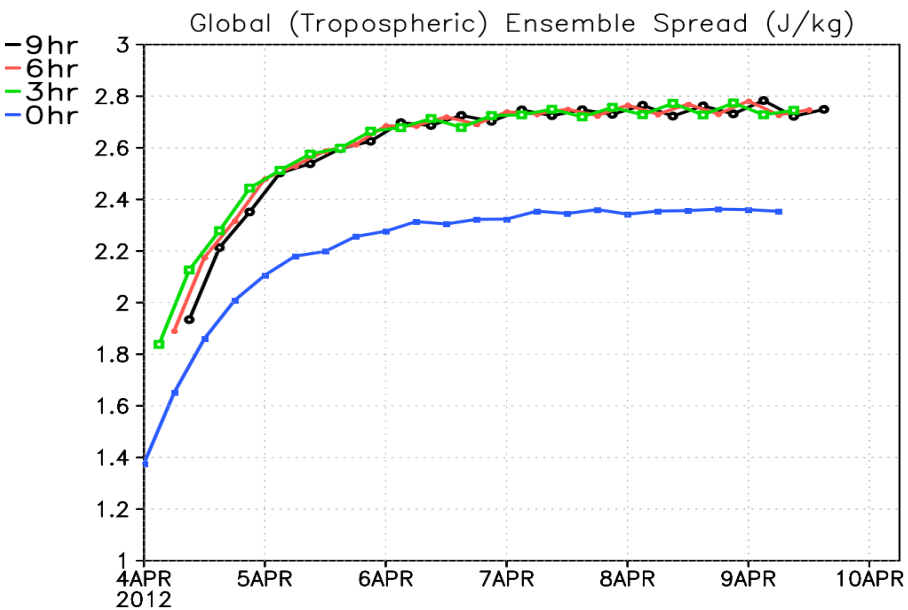


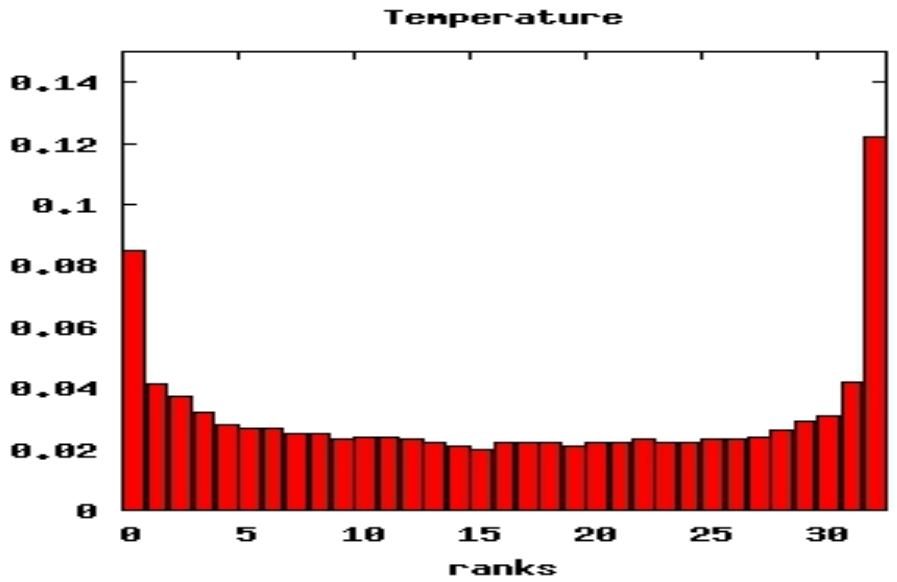


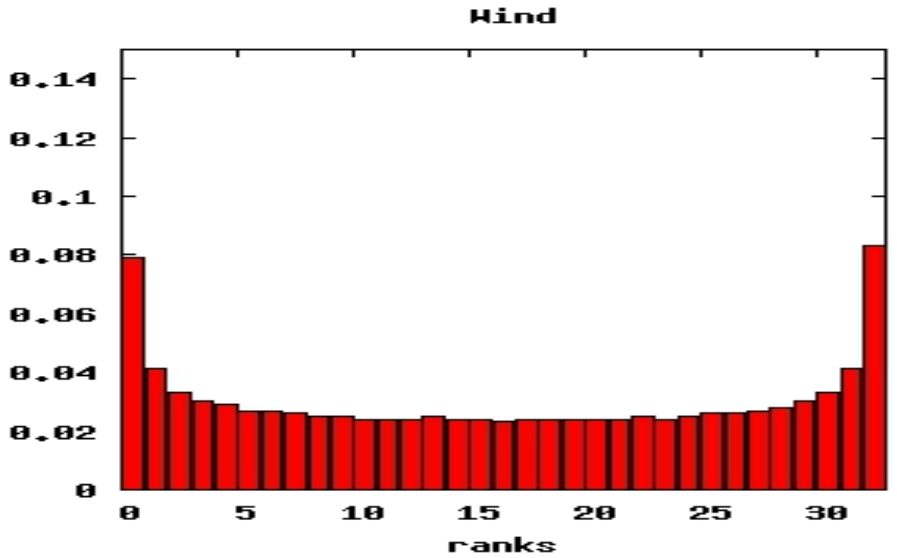




Spread High-res

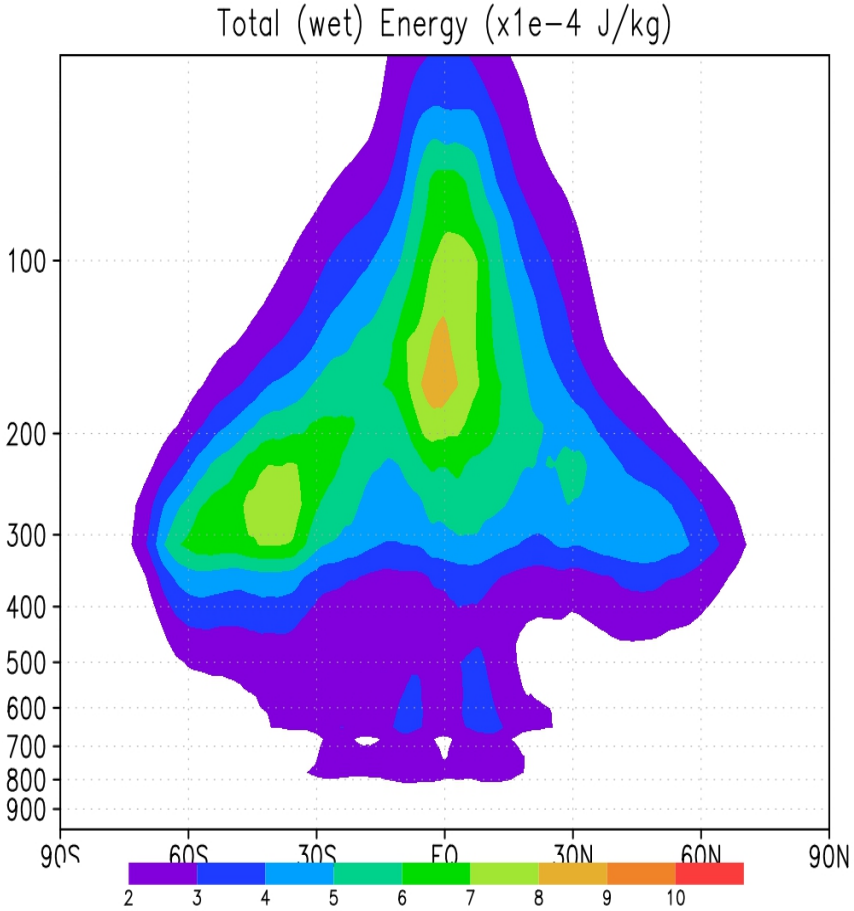


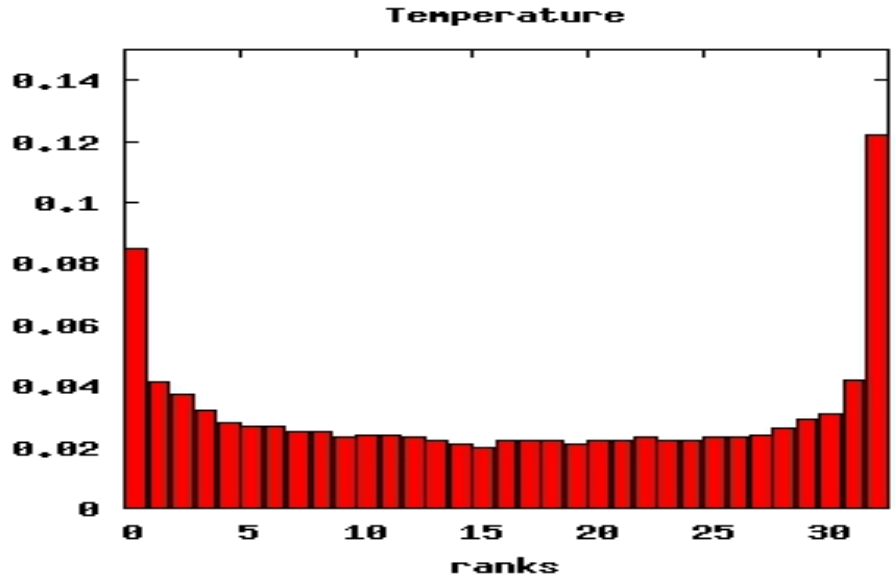


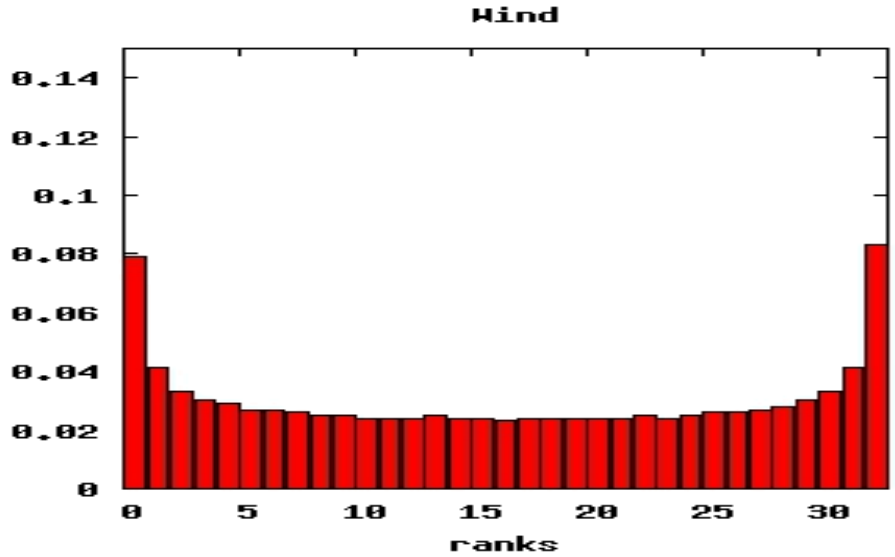


Spread-High res

- **Spread at 00h**

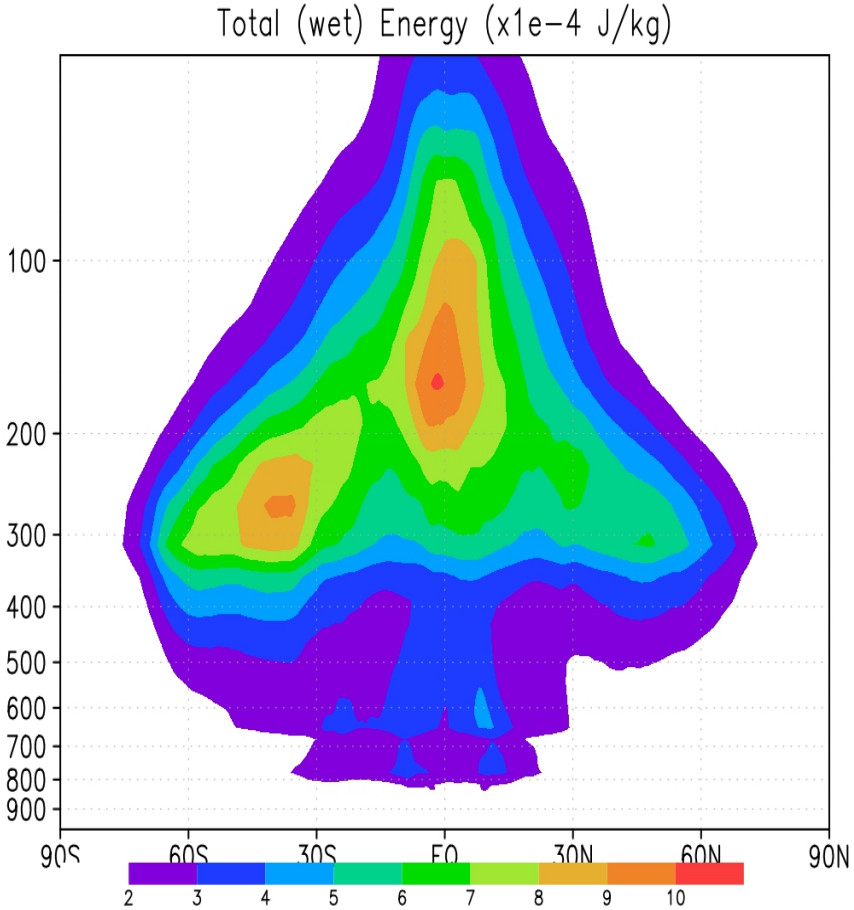


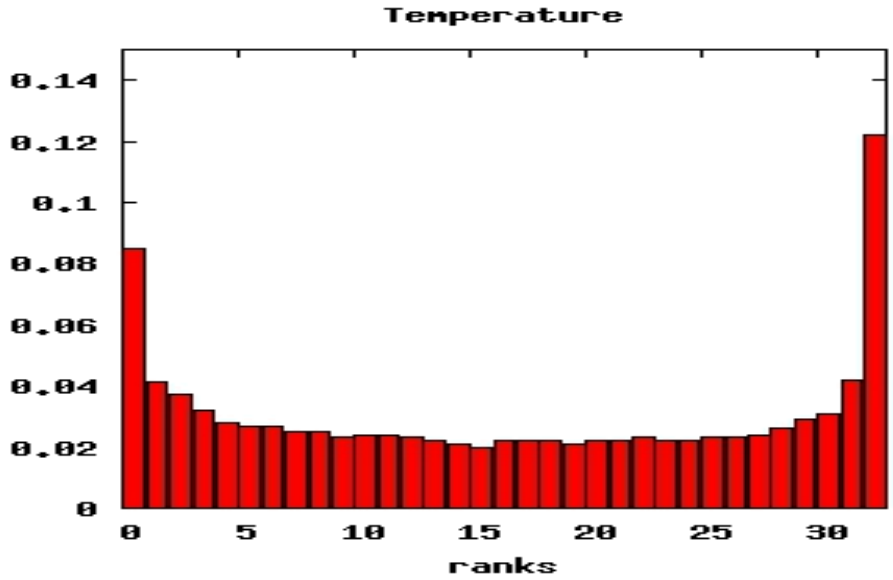


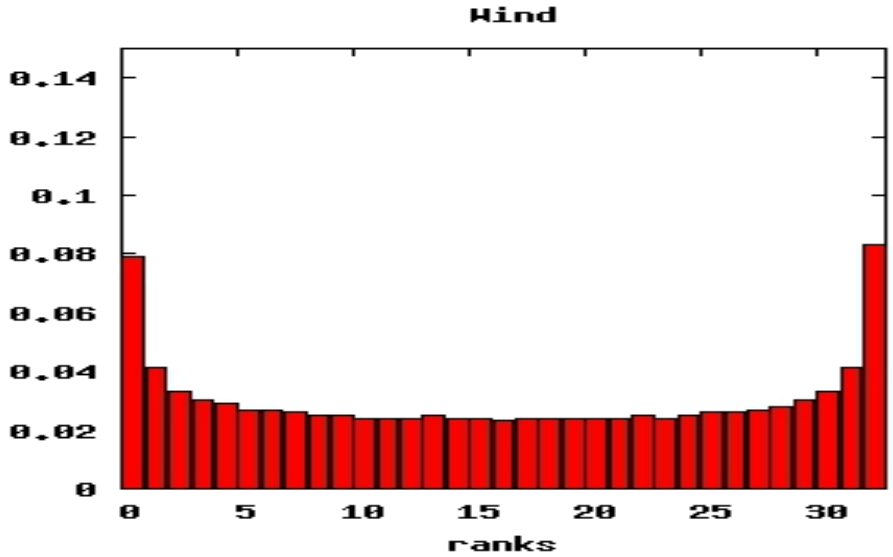


Spread-High res

- **Spread at 03h**

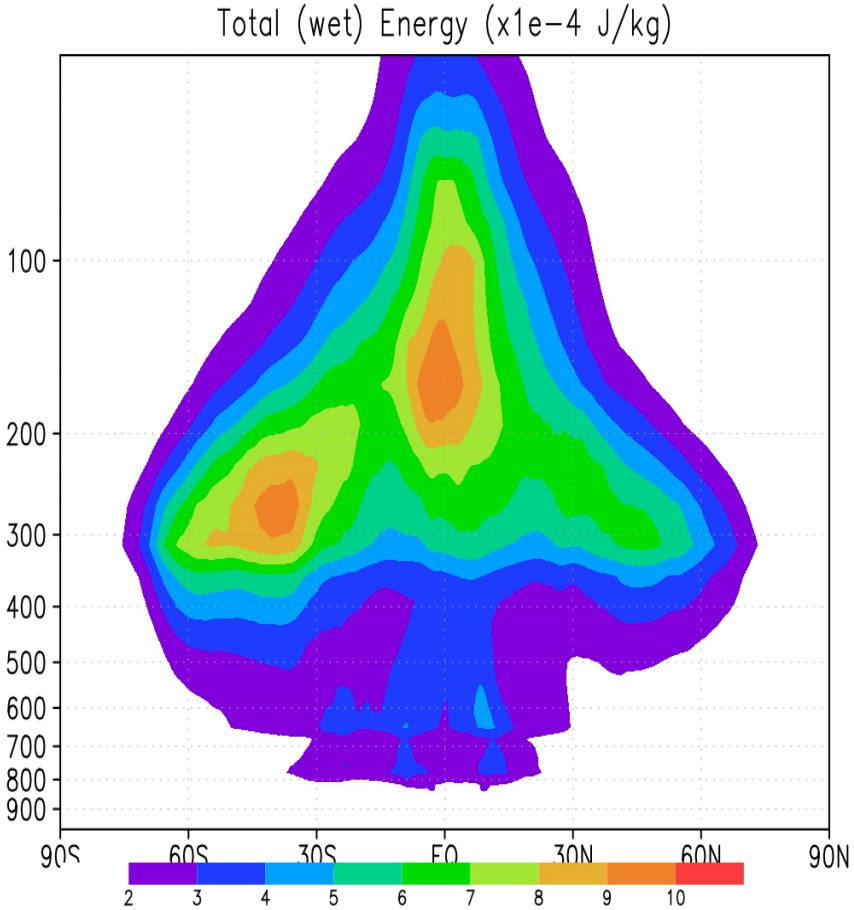


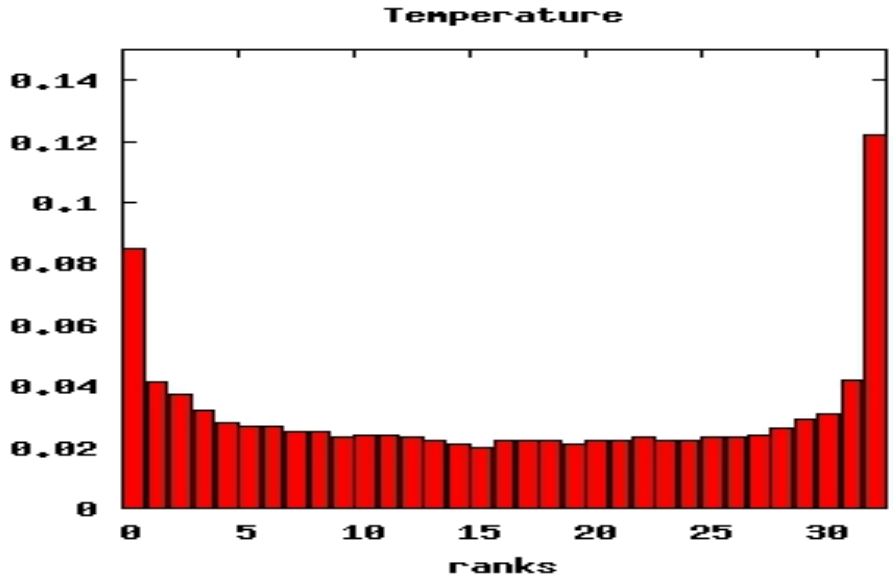


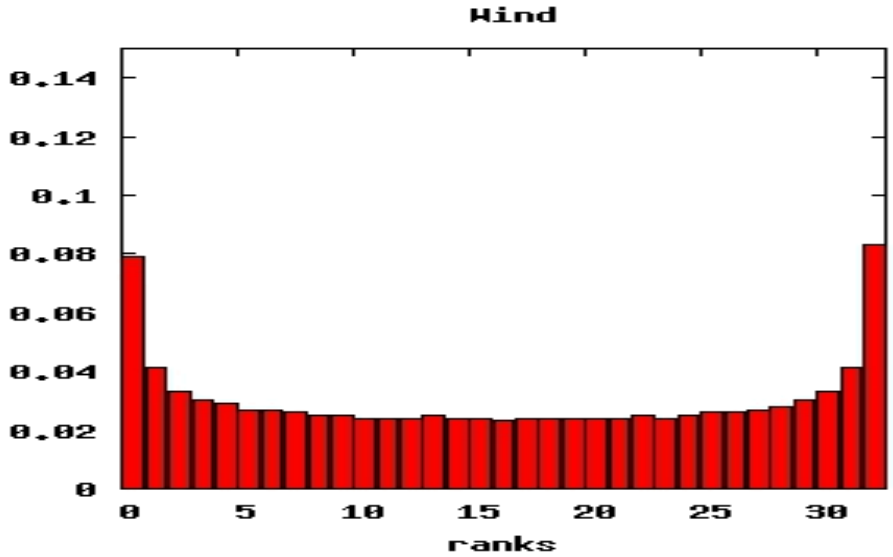


Spread-High res

- **Spread at 06h**







Spread-High res

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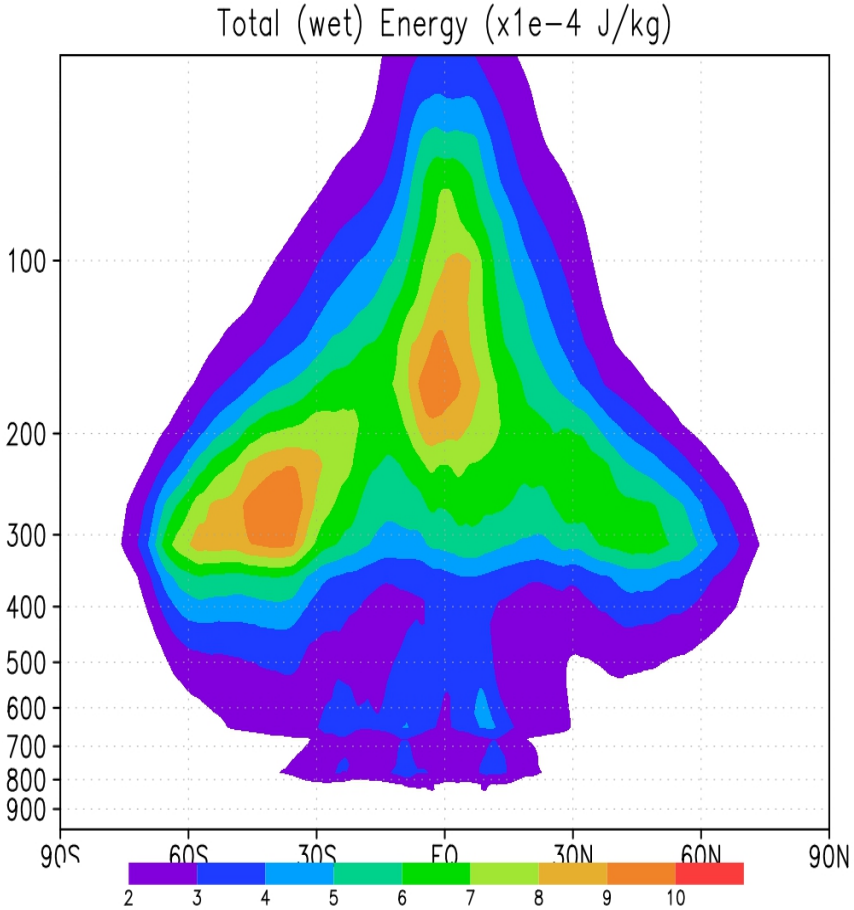
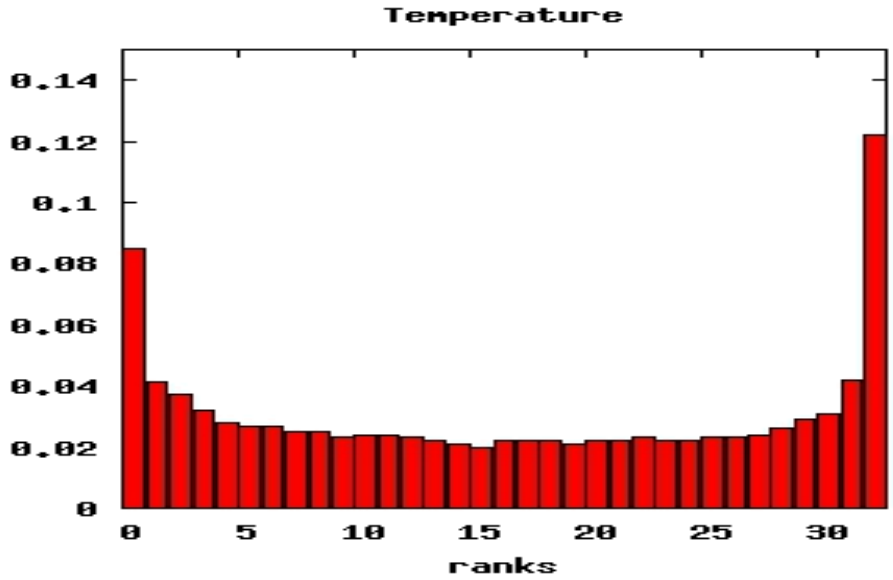
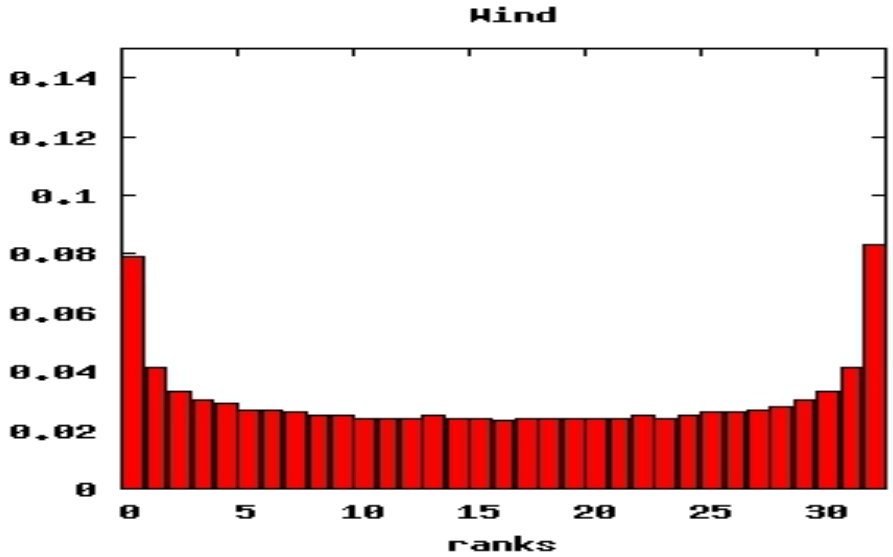
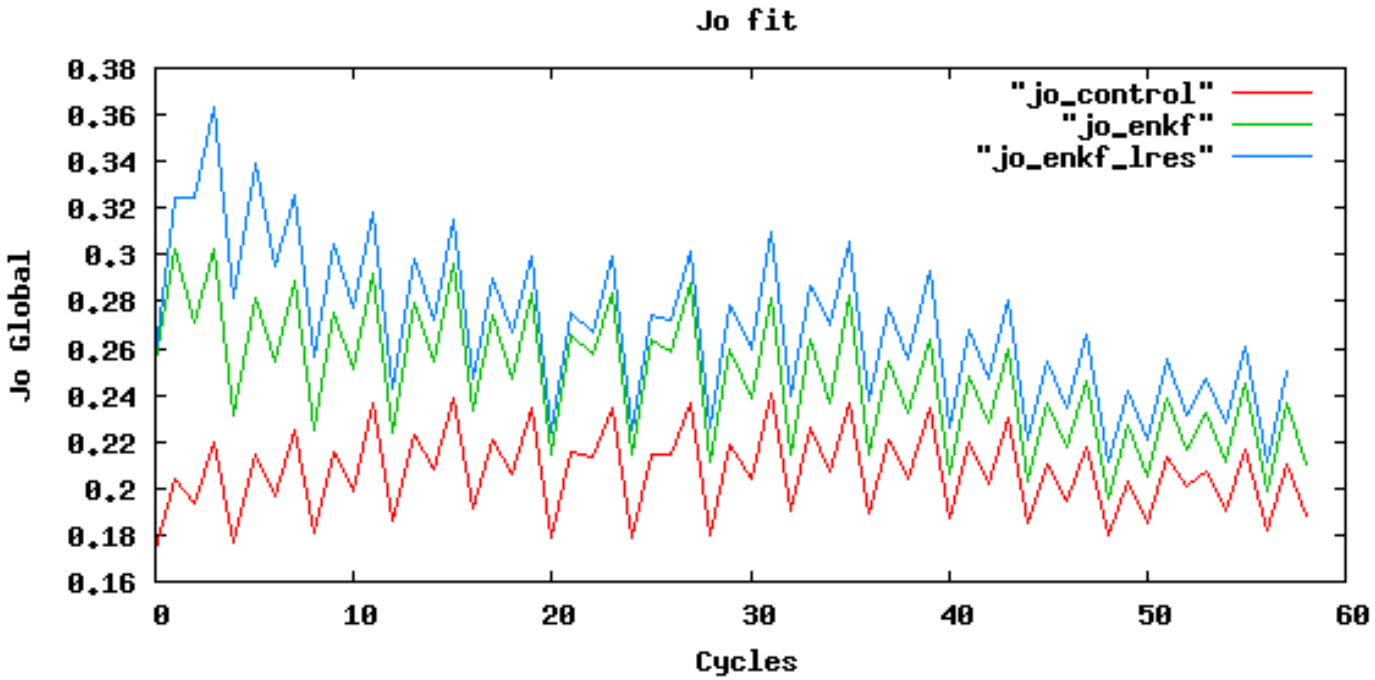
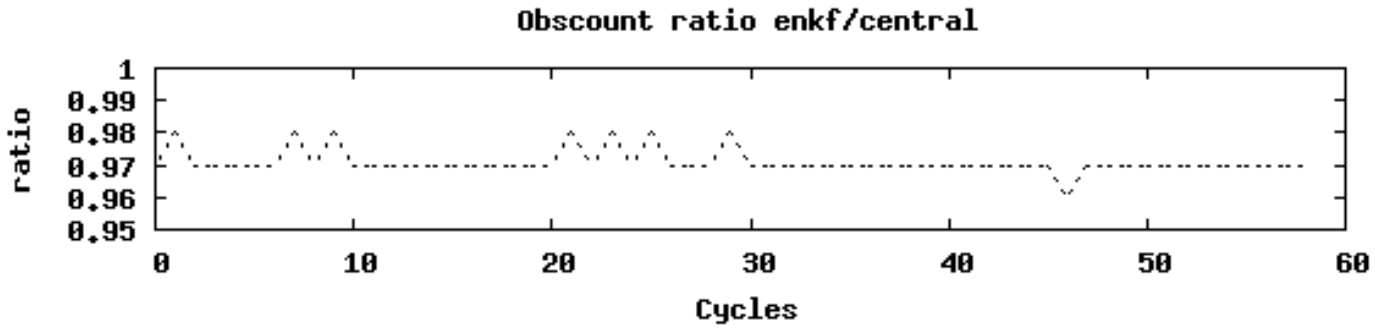




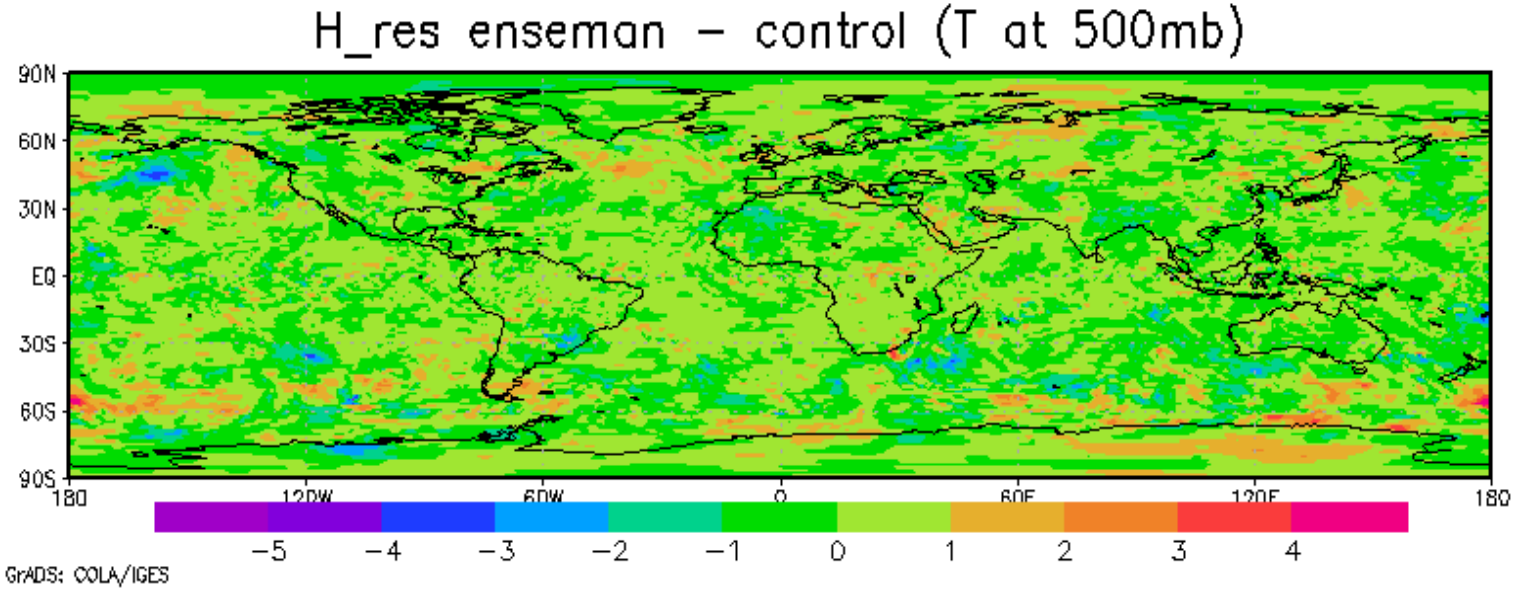


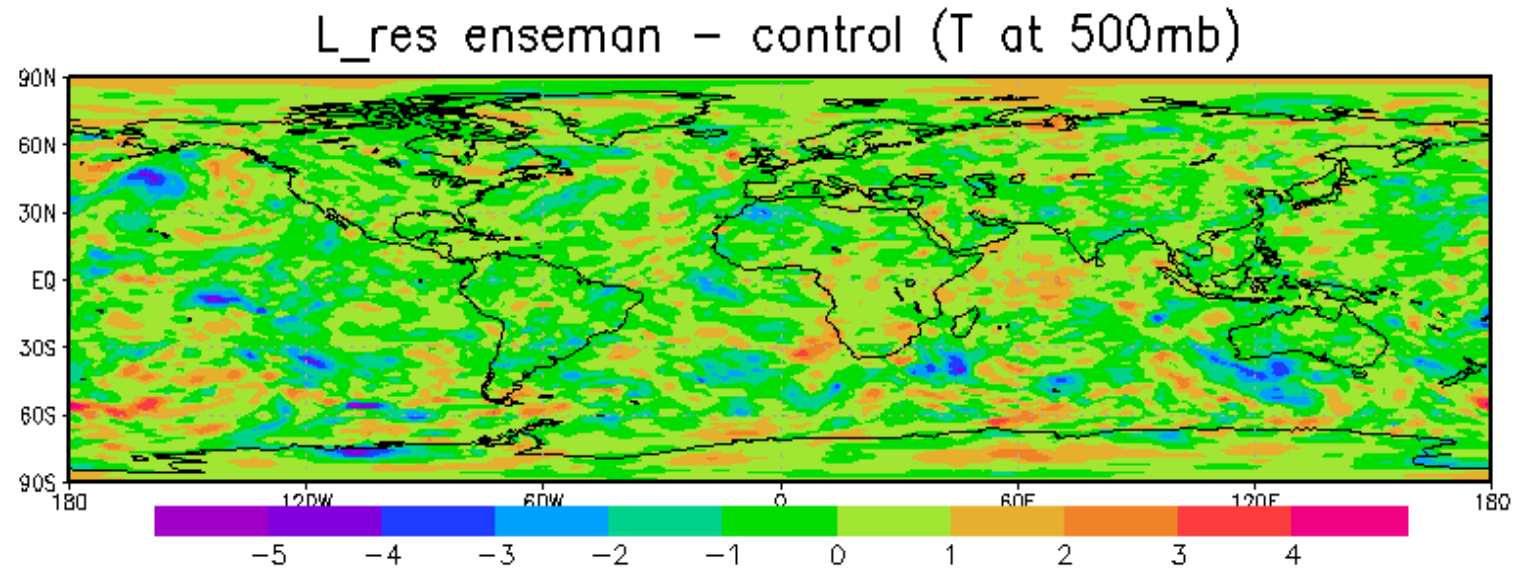
Jo-fits/Nobs


Jo fit
"jo_control"
"jo_enkf"
"jo_enkf_lres"
Jo Global
0.38
0.36
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0
10
20
30
40
50
60
Cycles


Obscount ratio enkf/central
ratio
1
0.99
0.98
0.97
0.96
0.95
0
10
20
30
40
50
60
Cycles

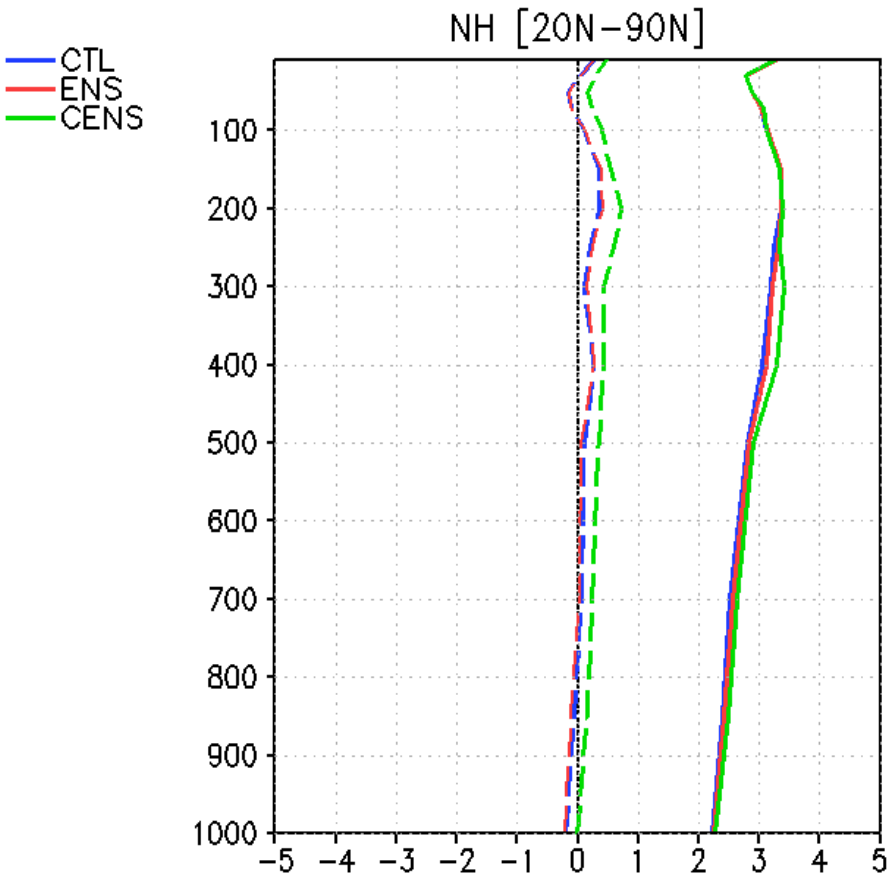
High/Low res Ensemble mean - Control analysis

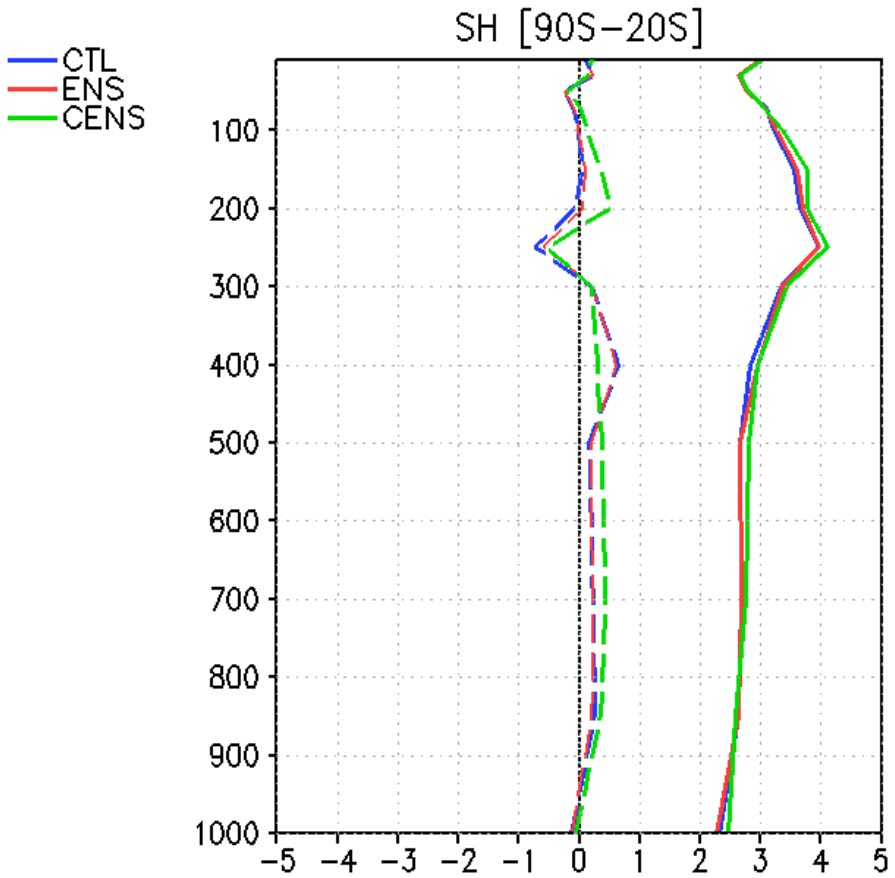




OMF - Conventional ops only

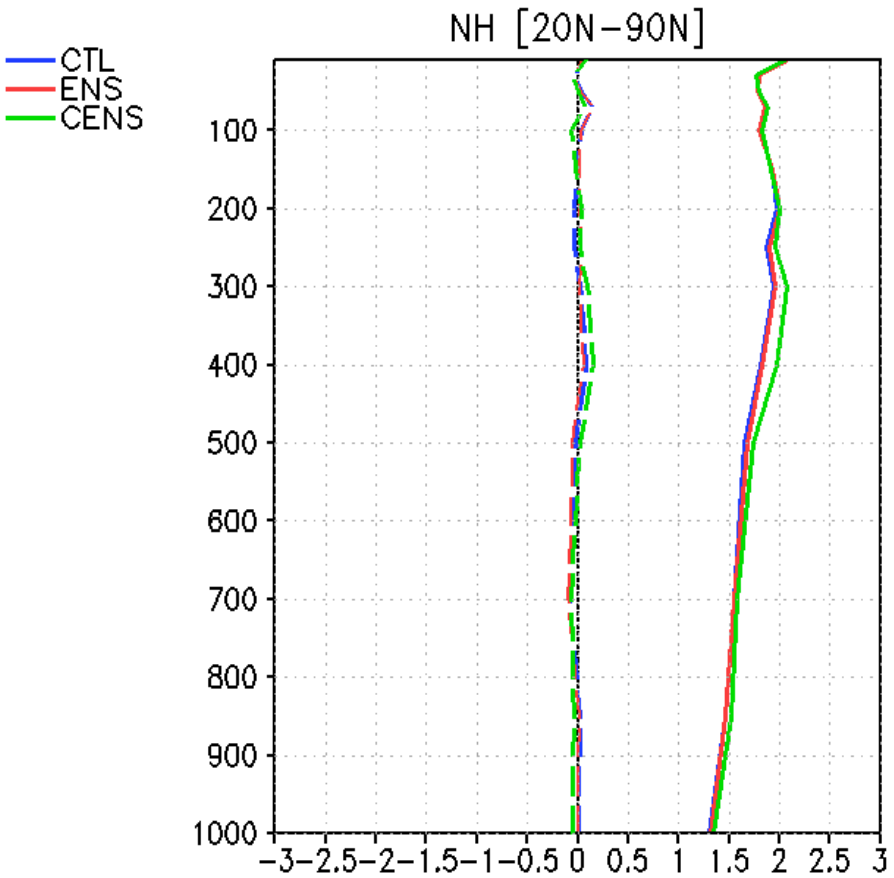
- OMF Uwndraob

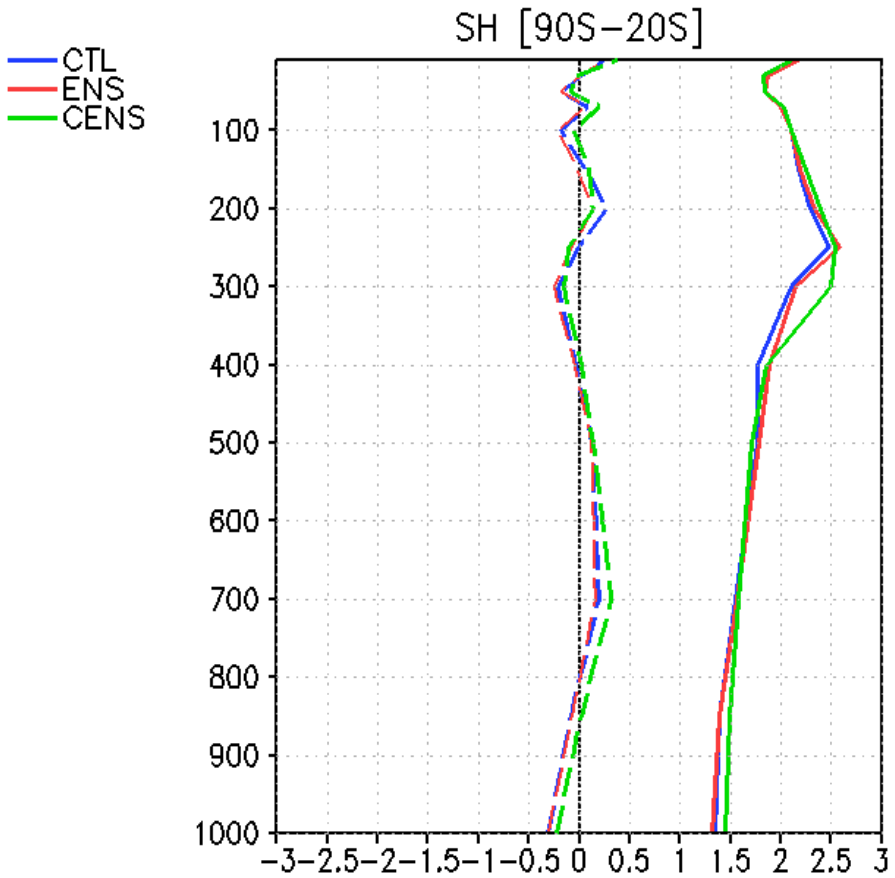




OMF - Conventional ops only

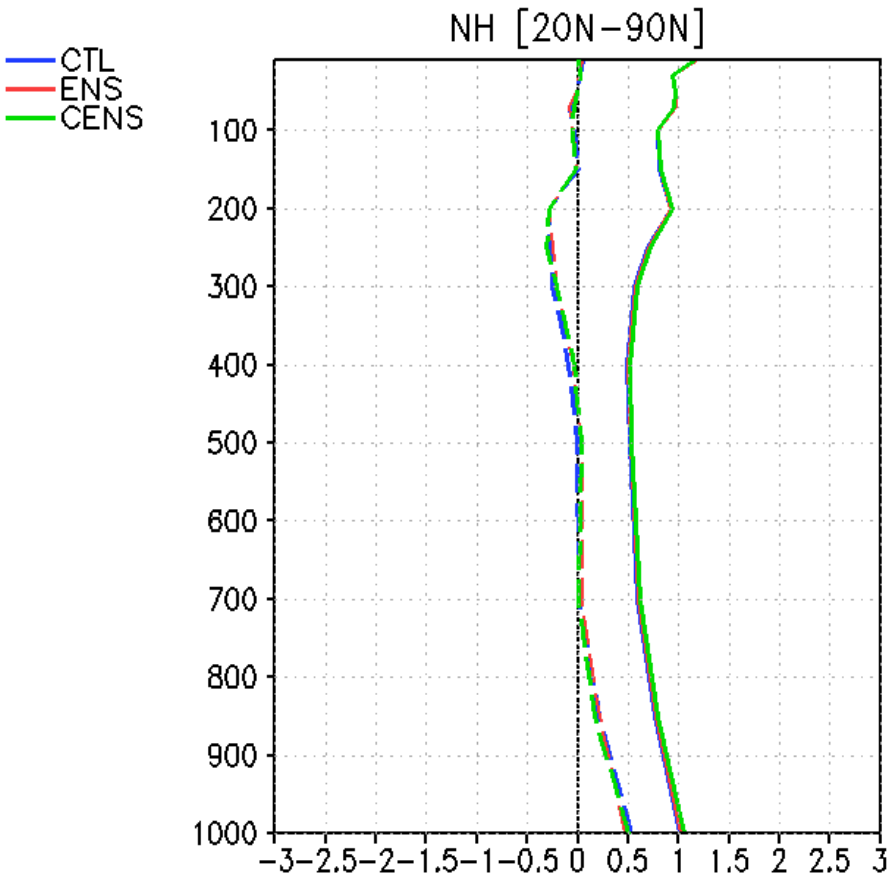
- OMF Vwndraob

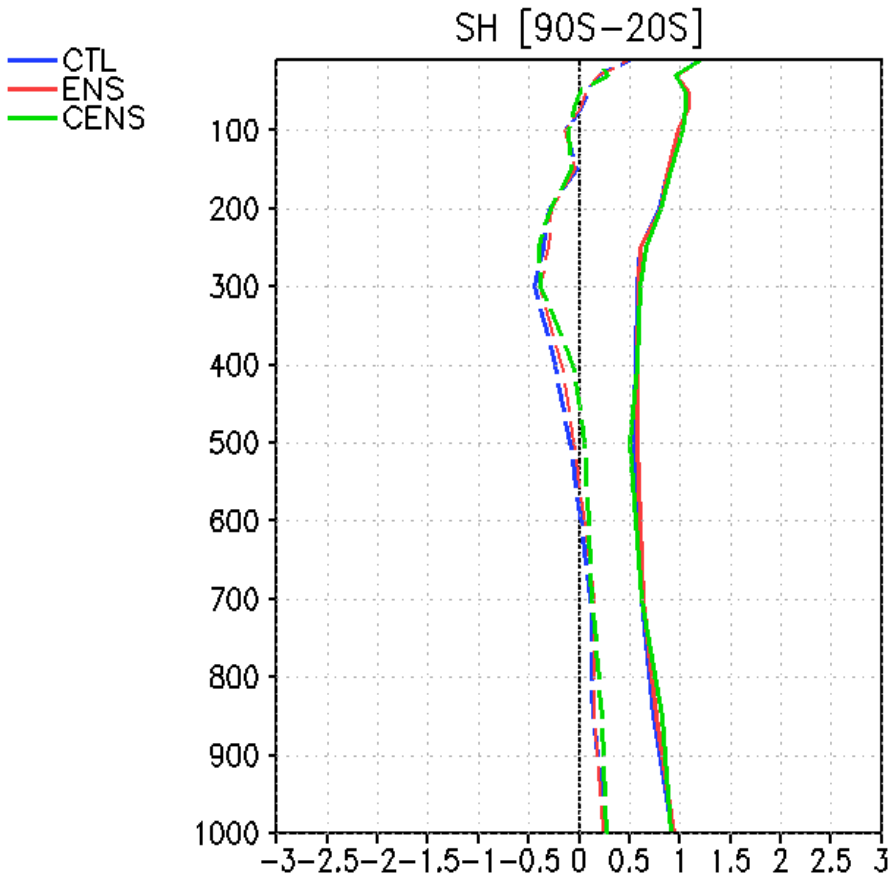




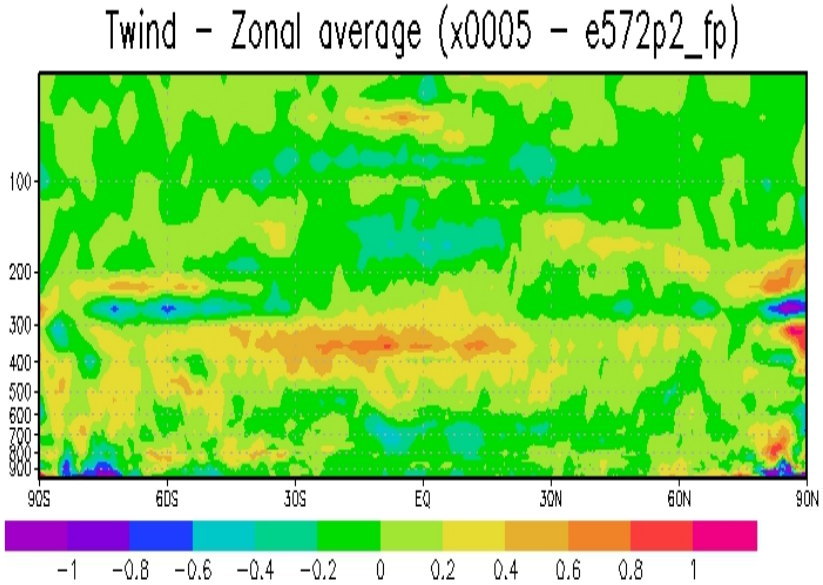
OMF - Conventional ops only

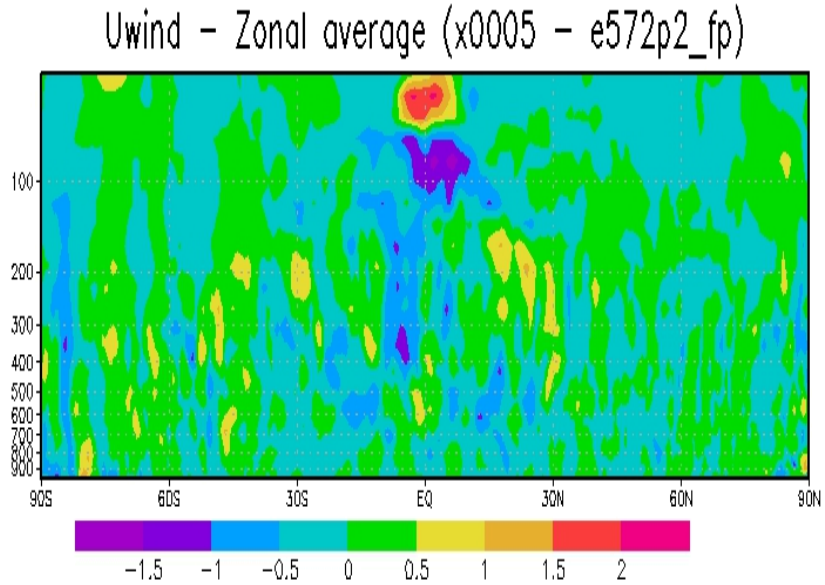
- OMF Tv raob

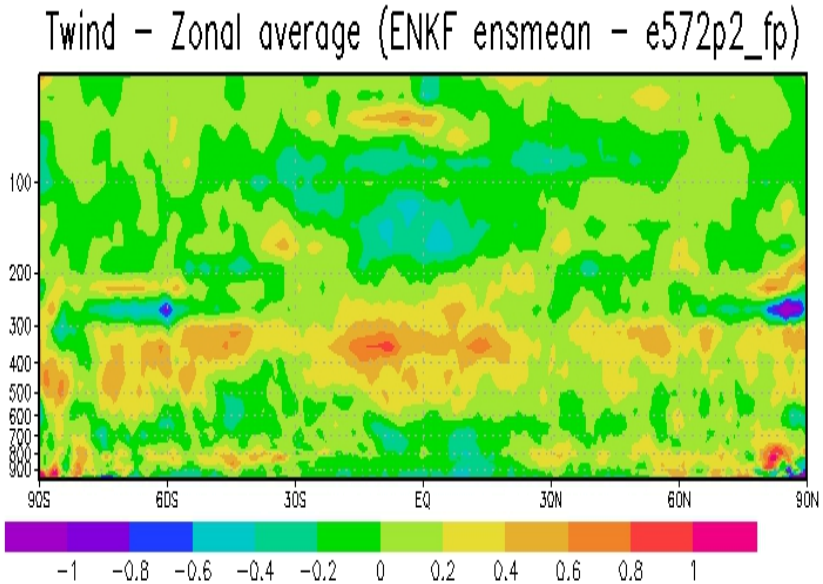


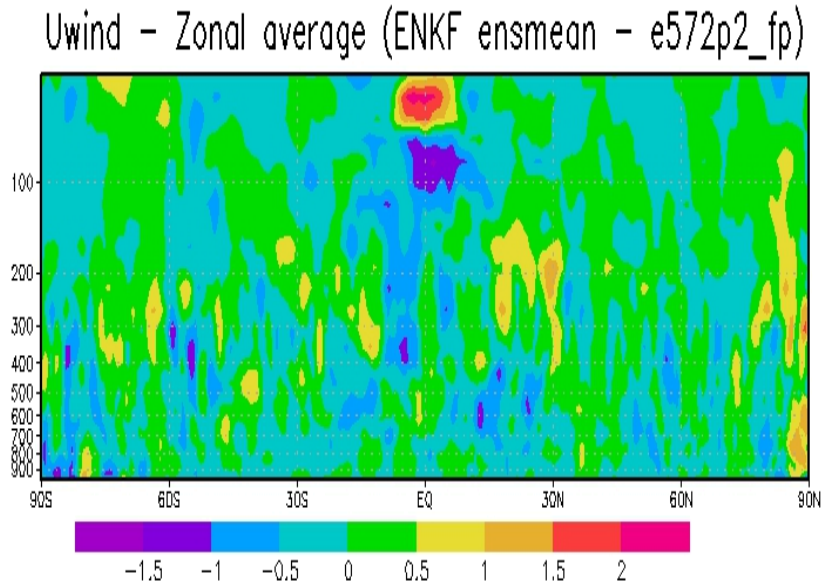


Ensemble-mean, Control analysis Vs Ops

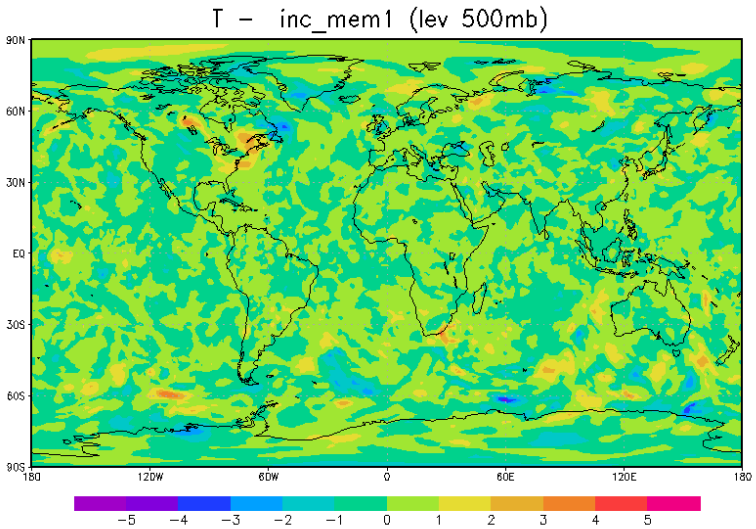


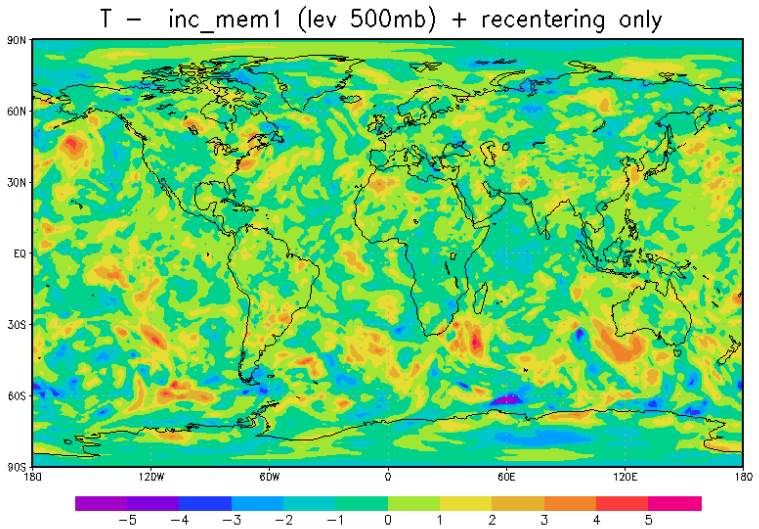


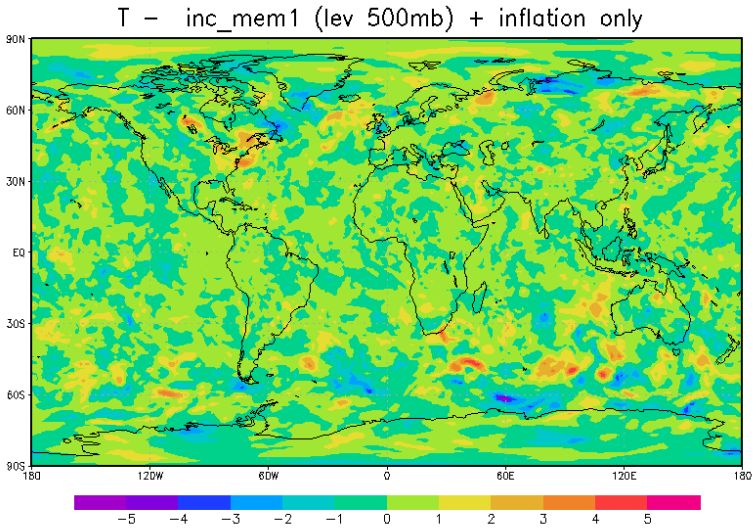


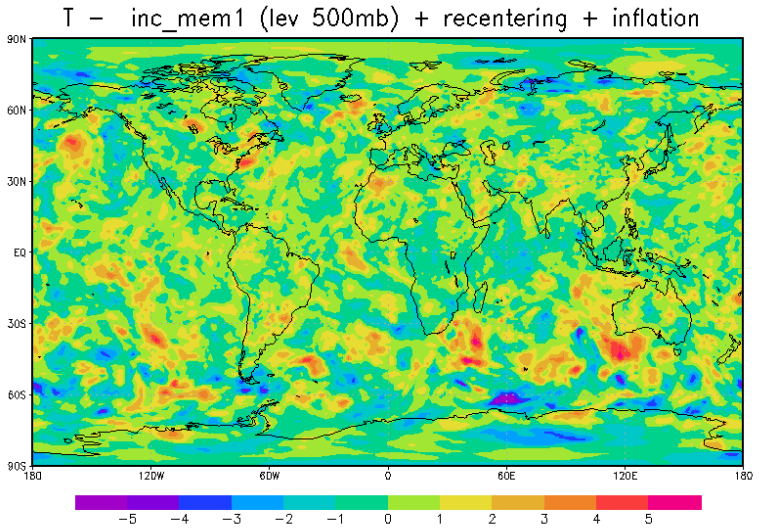


Low-res ens: inflation + re-centering

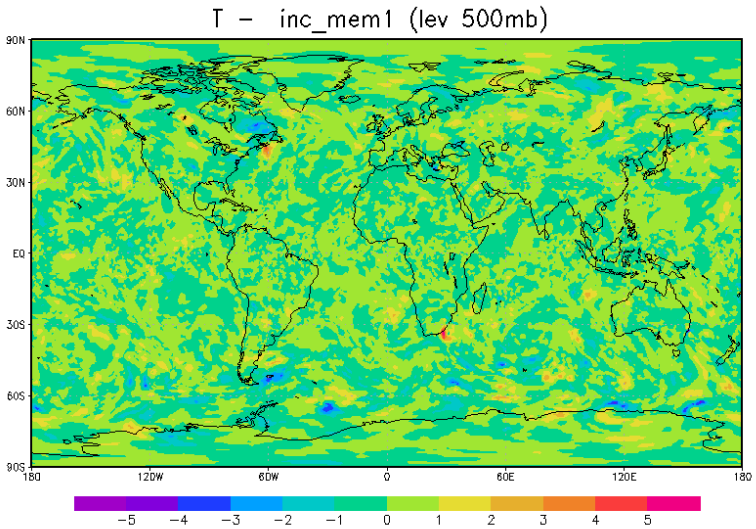


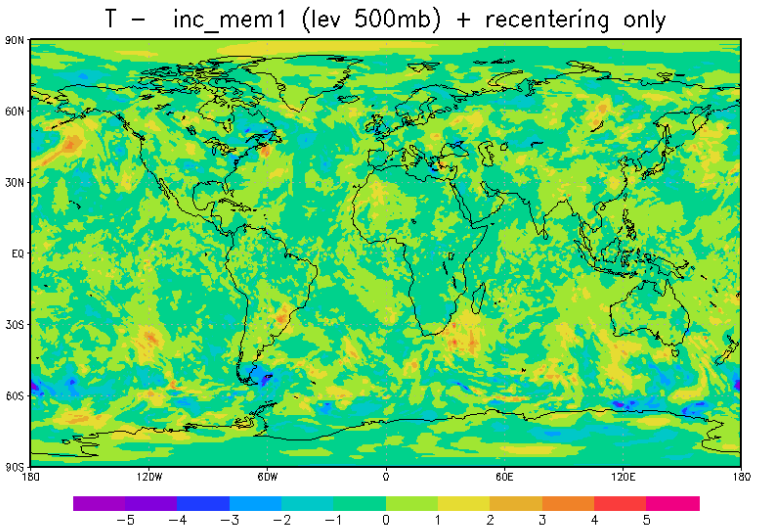


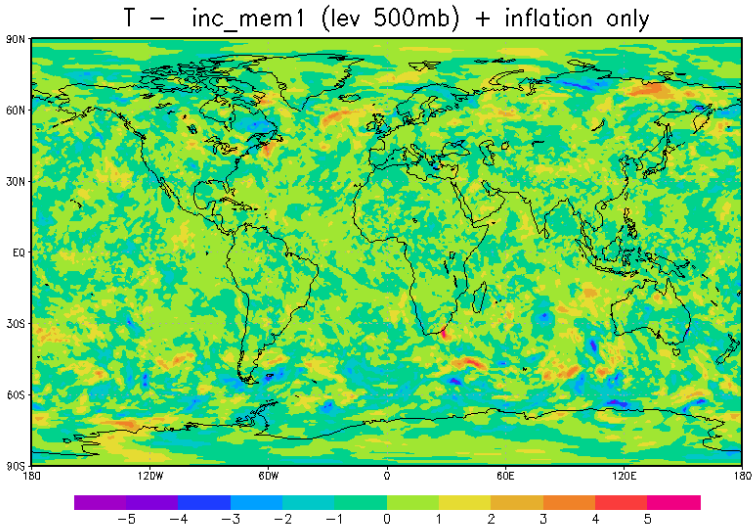


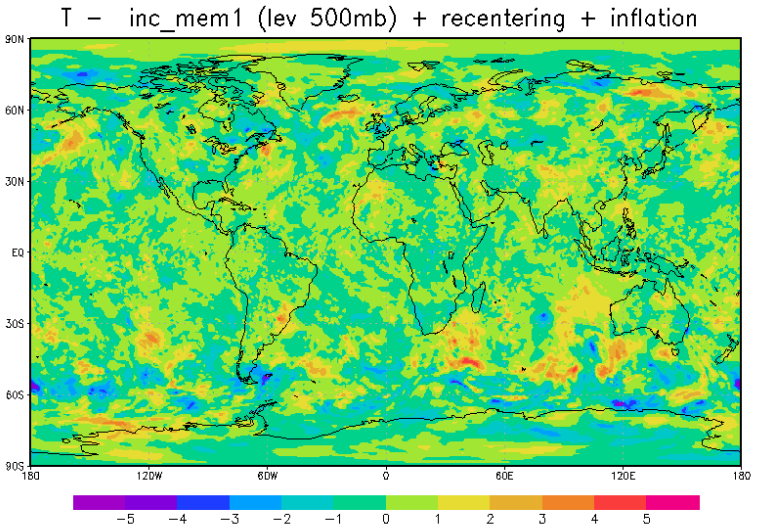


High-res ens: inflation + re-centering









Conclusion

- Additive inflation is essential to the performance of the ensemble.

  $\Rightarrow$ We need to try the hybrid with the 0.4 scaling factor.
- The resolution difference between the ensemble and the central is critical for the re-centering step.

  $\Rightarrow$ Re-evaluate the need for the re-centering in the "same-resolution" configuration.

What next?

- Extend the two-resolutions twin experiment for more robust results.
- The conditioning of the hybrid problem when the covariance weights are vertically varying.
- Assess how will the filter-free scheme perform when running same-resolution....stay tuned!