Hybrid Data Assimilation without Ensemble Filtering

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Contributions from: D. Kleist, D. Parrish, R. Treadon, and J. Whitaker

Similar to presentations given recently at Meteo-France and NCEP

Outline

Variational Formulations

FGAT 3dVar-ensemble Hybrid:

$$J(\delta\mathbf{x}) = \frac{1}{2}\,\delta\mathbf{x}^T\mathbf{B}_h{}^{-1}\delta\mathbf{x} + \frac{1}{2}\sum_{k=1}^{K}[\mathbf{H}_k\delta\mathbf{x} - \mathbf{d}_k]^T\mathbf{R}_k^{-1}[\mathbf{H}_k\delta\mathbf{x} - \mathbf{d}_k] + J_x$$

where

- $\mathbf{B}_h = \beta\mathbf{B} + (1-\beta)\mathbf{B}_e \circ \mathbf{C}$ is a *hybrid* of static and ensemble-based error covariances, $\mathbf{B}$ and $\mathbf{B}_e$ respectively;
- $\mathbf{C}$ is a localization error covariance of compact support;
- the incremental solution becomes $\delta\mathbf{x} = \delta\mathbf{x}_0 + \sum_m^M \delta\mathbf{x}_m^e \circ \alpha_m$, for an ensemble with a total of M members, $\delta\mathbf{x}_m^e$;
- NCEP and GMAO get $\delta\mathbf{x}_m^e$ by using the EnKF analyses plus inflation.
- NCEP and GMAO recenter EnKF analyses about hybrid analysis.

Problem Statement

- Hybrid DA includes: re-centering plus inflation
- Evaluations in GEOS DAS suggest:
  - Hybrid approach provides noticeable improvements only when using additive inflation, i.e., EnKF alone doesn't do it
  - Forecasts from EnKF analyses plus additive inflation result in mild spread within the background time window
  - It seems that much of the initial (analysis) spread can be simulated with additive inflation alone
  - Appreciable background spread is obtained in the latter case

Question: how does hybrid-DA perform when the ensemble filter is dropped and an ensemble of analyses is created from simply additively inflating the central analysis?

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Reasoning behind the filter-free approach

Hybrid implementations of ensemble-based analysis have a member increment be:

$$\delta \mathbf{x}_i^a = \delta \mathbf{x}_i^o + \delta \mathbf{x}^r + \delta \mathbf{e}_i$$

where:
- $\delta \mathbf{x}_i^o$ - increment due to observations, e.g., EnKF increment
- $\delta \mathbf{x}^r$ - increment due to re-centering
- $\delta \mathbf{e}_i$ - random additive perturbation to boost model error

Remarks:

1. $\delta \mathbf{e}_i$ does not represent model error and is redundant wrt $\delta \mathbf{x}_i^o$
2. in a dual-resolution context $\delta \mathbf{x}^r$ might as large as $\delta \mathbf{x}_i^o$
3. when magnitude of $\delta \mathbf{e}_i$ is comparable to that of $\delta \mathbf{x}_i^o$ the role of ensemble analyses is downplayed
4. if (2) and (3) hold, re-centering and inflation might be all that's needed

The present work evaluates the case when $\delta \mathbf{x}_i^0$ is ignored; that is, the ensemble is generated from randomly-inflated, $\delta \mathbf{e}_i$, central analysis.

Atmospheric GCM

- Fully ESMF-based
- Cubed-sphere hydrostatic dynamical core
- RAS-Bacmeister convective physics
- Chou-Suarez radiation scheme
- Koster et al. catchment land-surface model
- Lock et al. turbulence physics
- Interactive ozone
- Interactive GOCART aerosols
- OSTIA-prescribed SST

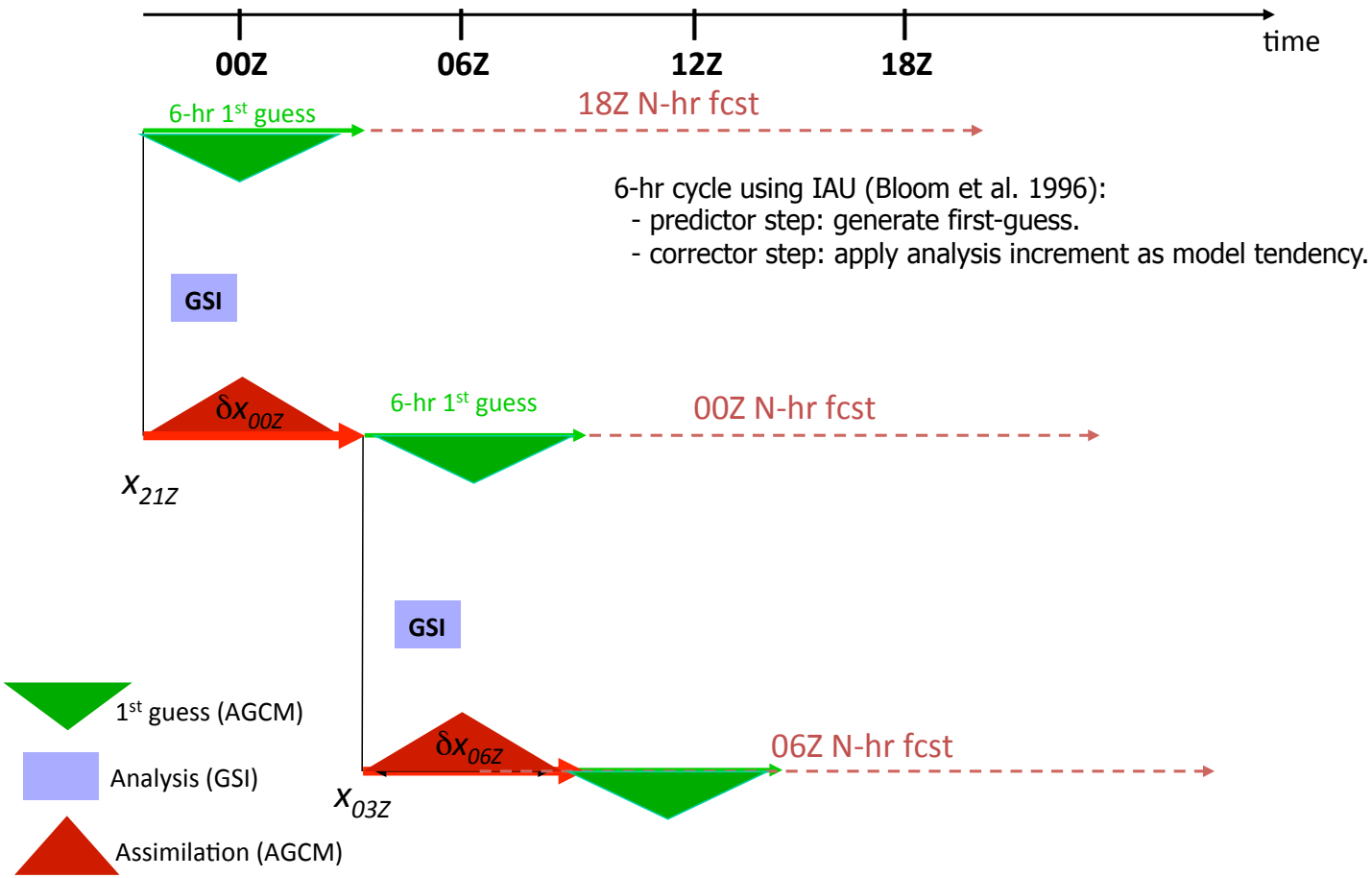
Analysis: GSI

- FGAT 3D-Var
- IAU-based assimilation
- TLNMC balance
- JCSDA CRTM
- Double-PCG minimization

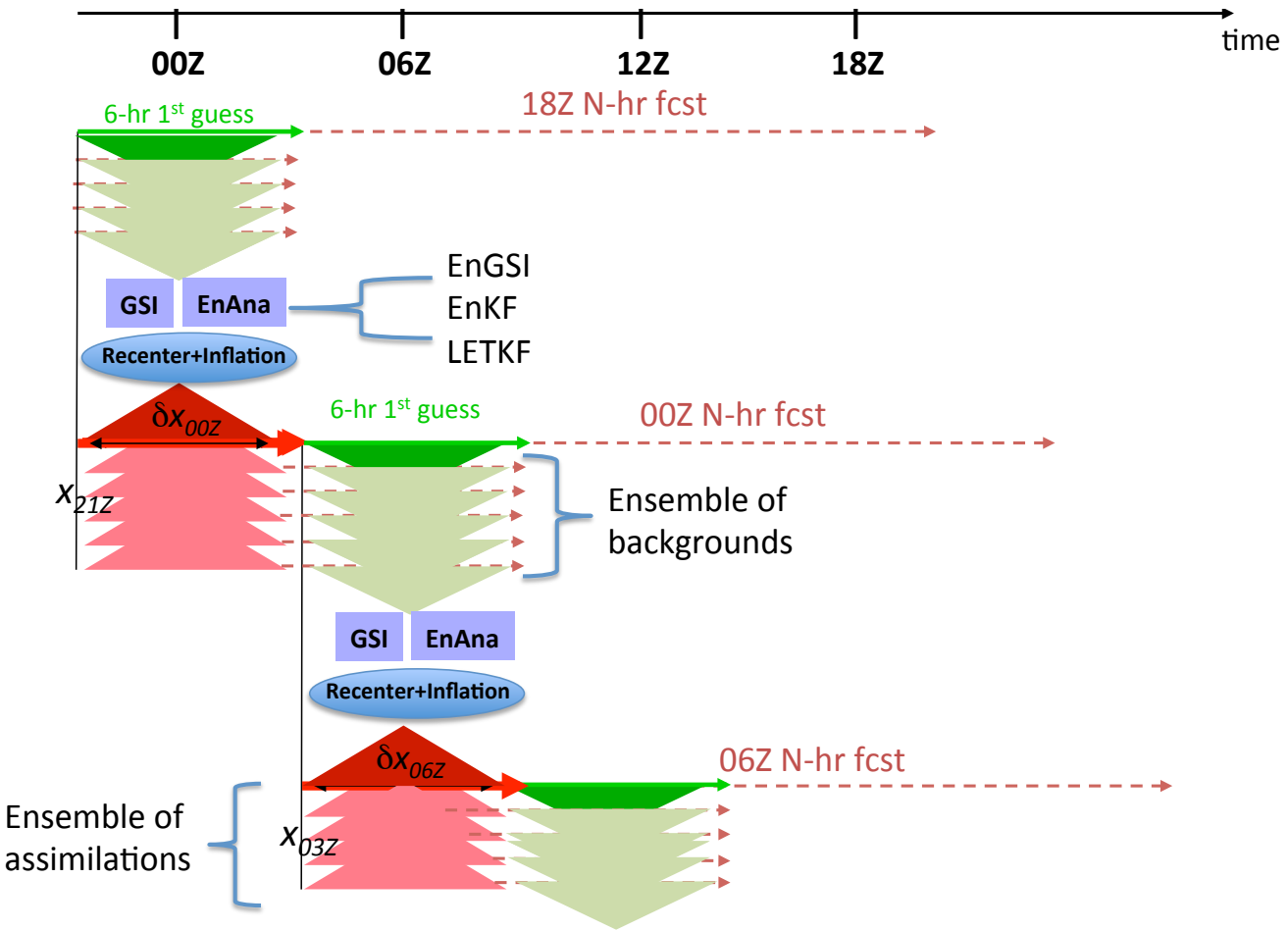
Ensemble filter

- ESRL-NCEP EnKF
- Full obs but ozone and precip

Schematic of GEOS IAU-based 3dVar



Schematic of IAU-based Hybrid 3dVar



Hybrid Experimental Setting

- Central DAS: 0.5^o outer and inner loops; 72-levels
- 32 Ensemble Forecasts: 1.0^o; 72-levels
- GSI Hybrid/Static **B**: 50% / 50%
- TLNMC applied to both static & hybrid covariances
- Vertical & horizontal localizations applied to ensemble **B**
- Add/ve perturbations scaled from NMC-like 48-24hr forecasts
- Experiment period (after spin up): April 2012

EnKF

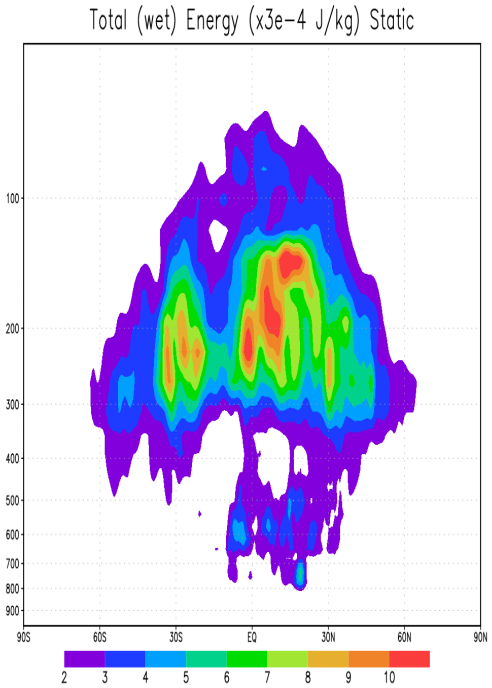
- Additive perturbation: 0.25
- EnKF

Filter-Free

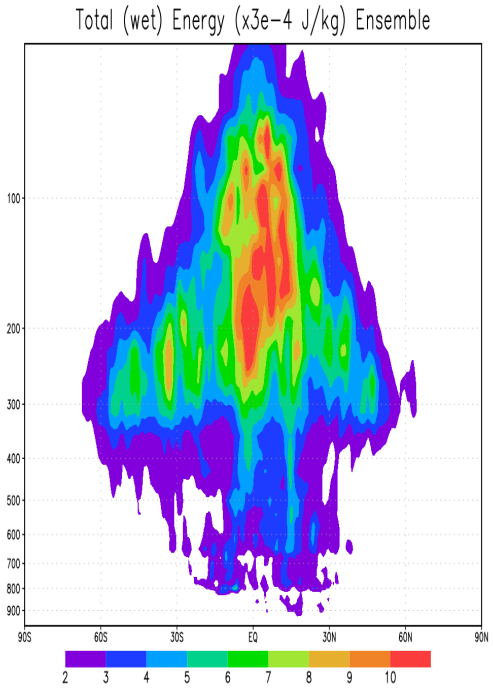
- Additive perturbation: 0.6
- No Ensemble Filtering

Analysis Increment as Total Energy for 00 UTC on 1 Jun 2012

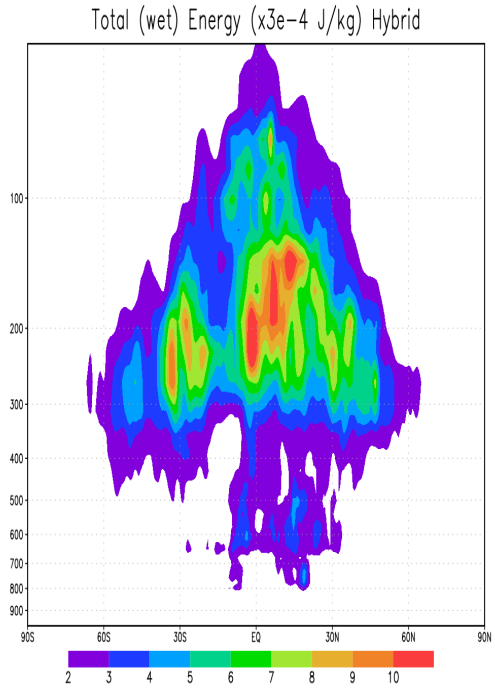
Static-Only



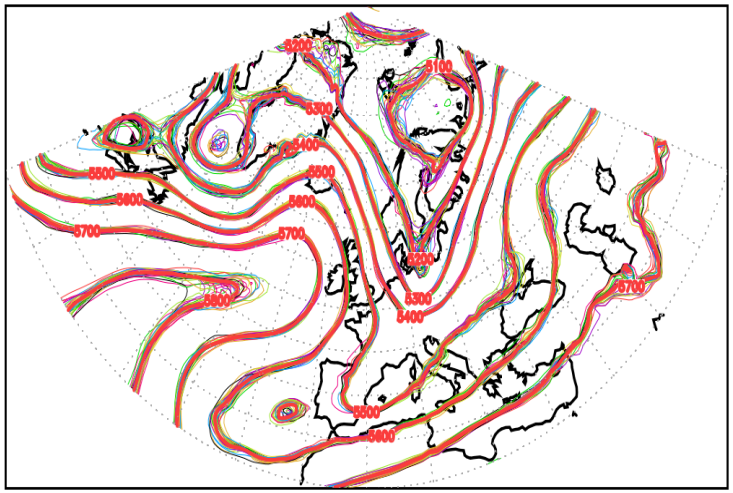
32-mem Ens-Only



Hybrid (50%/50%)



H 500 mb 12 UTC 20120407



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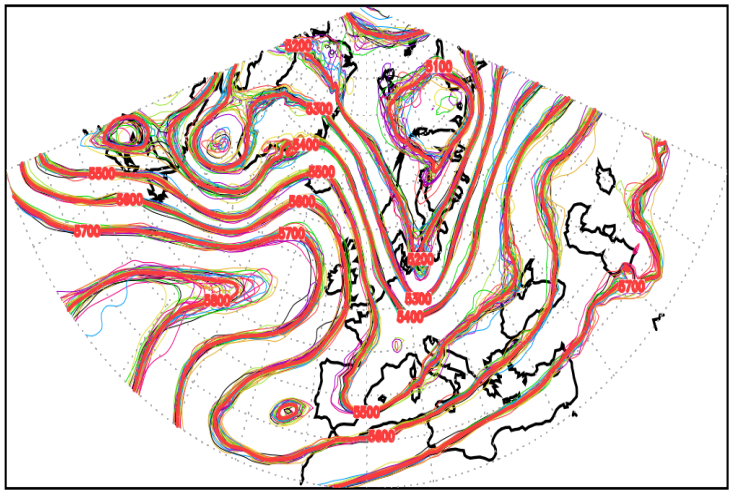

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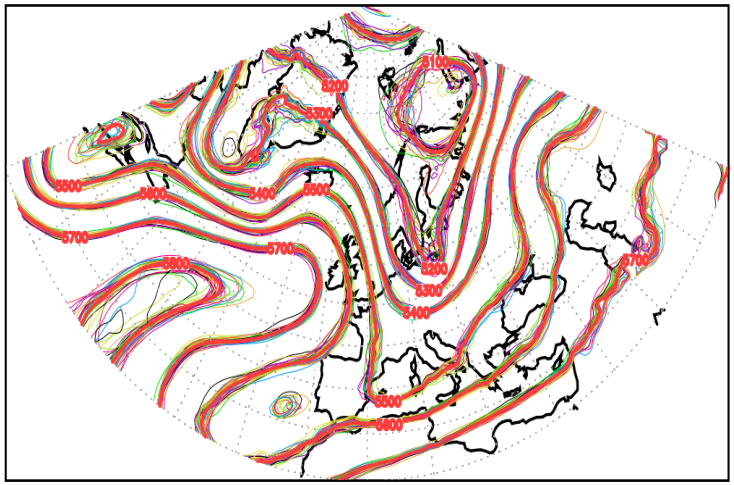
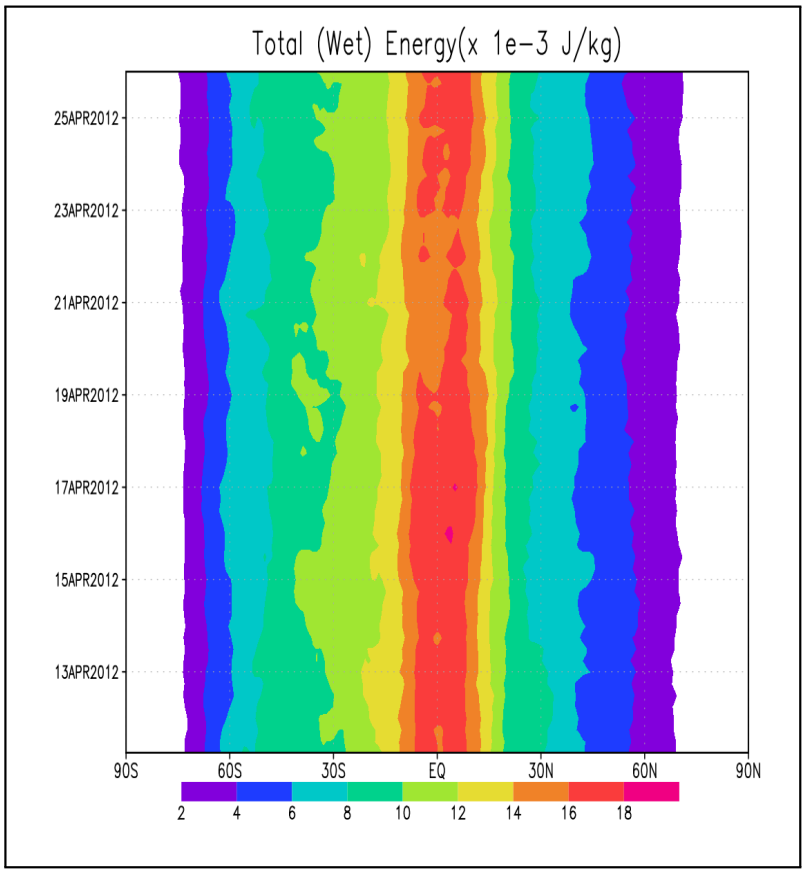
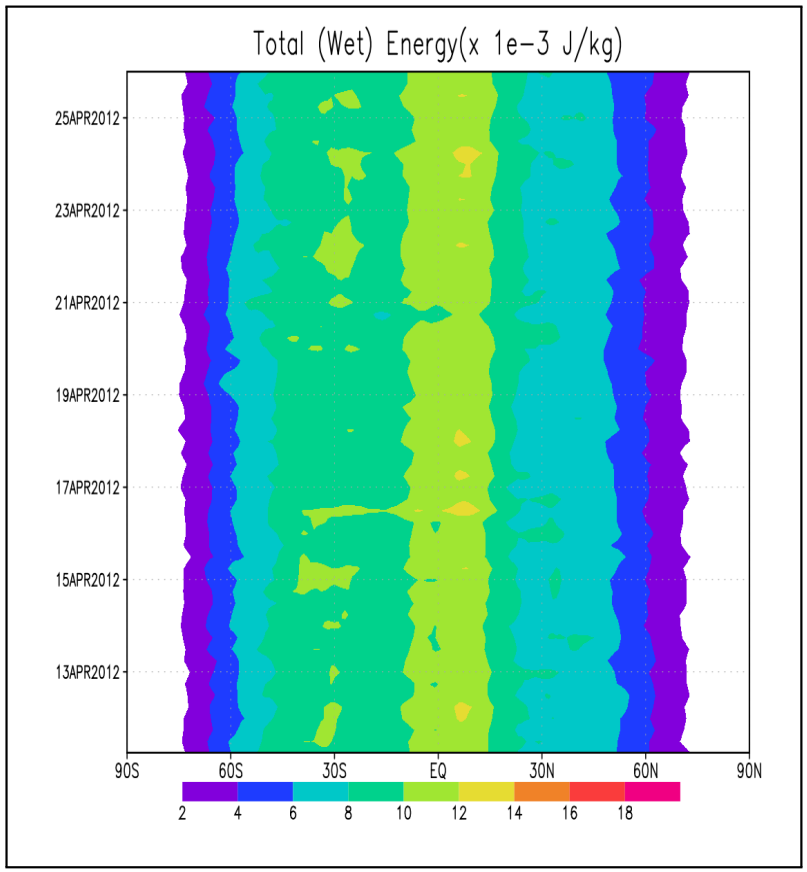


Evolution of 6-hr Background Spread

EnKF-based hybrid

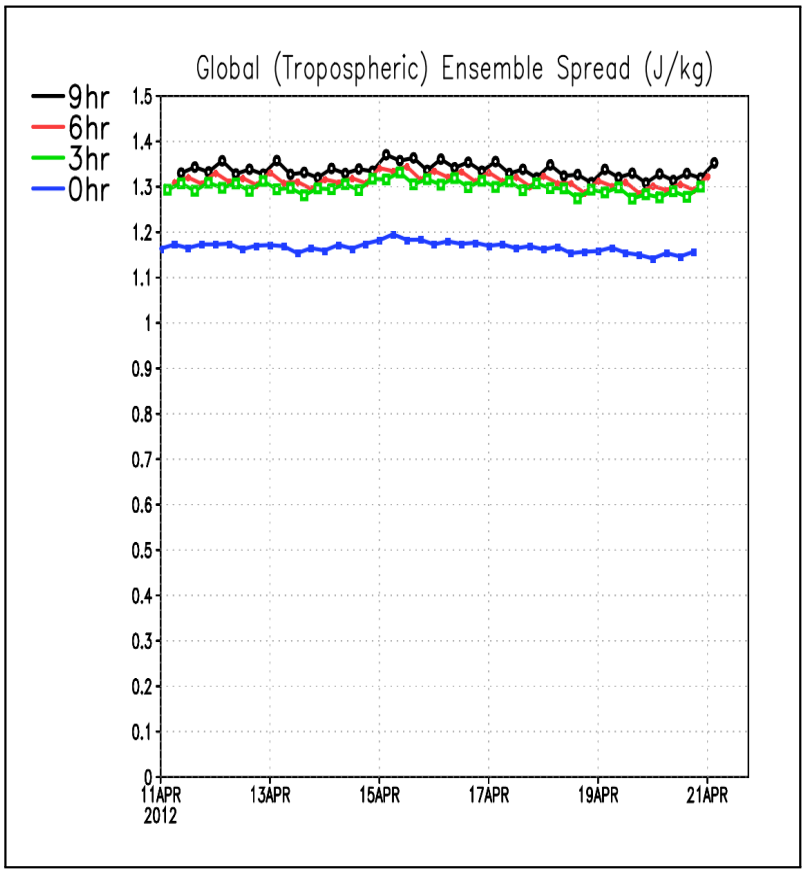


Filter-Free hybrid

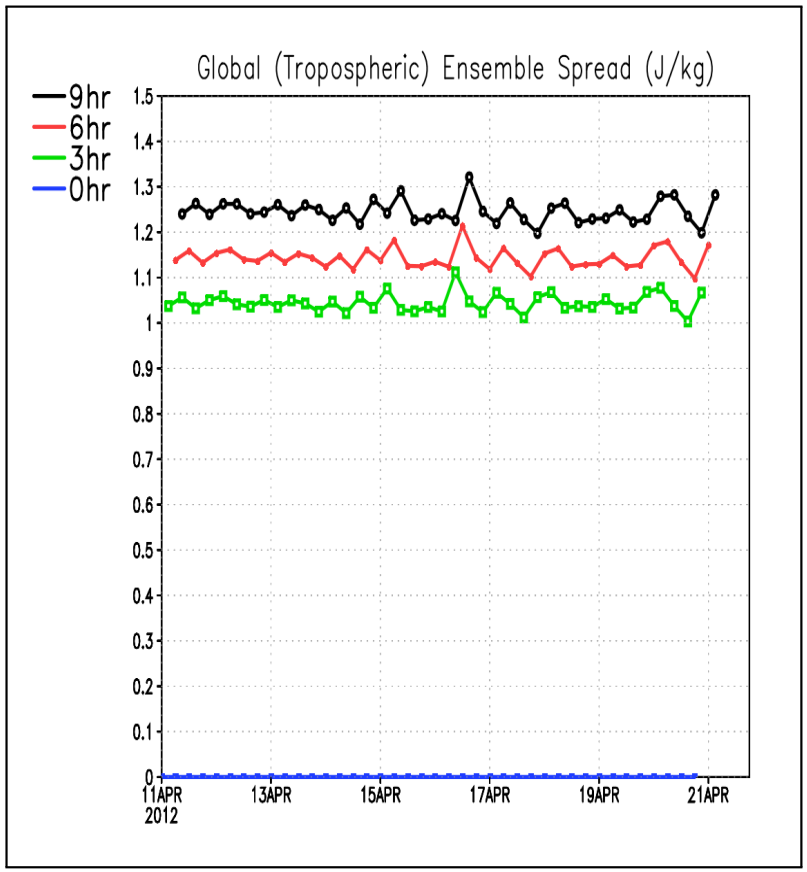


Spread within 9-hr Background Period

EnKF-based hybrid

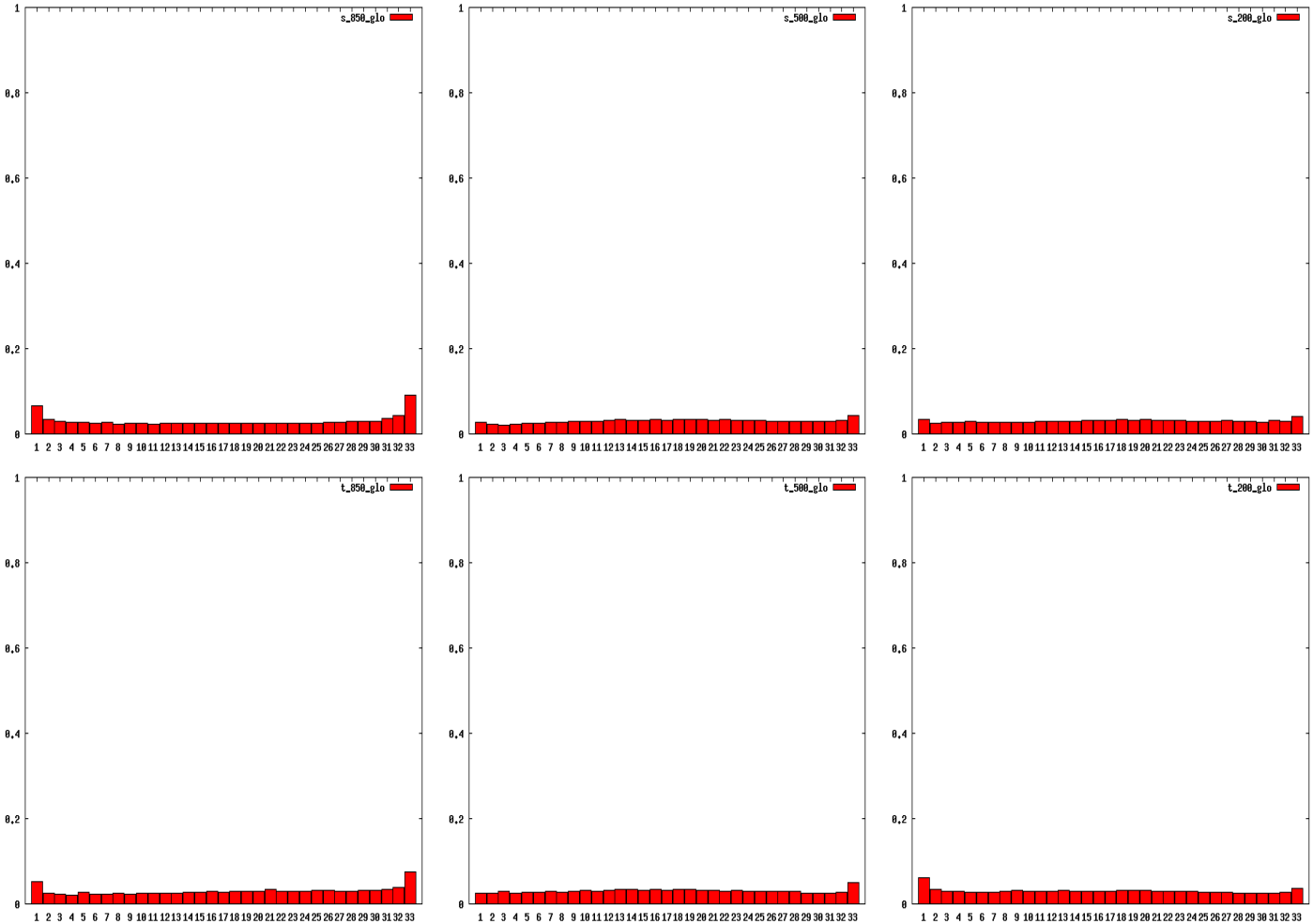


Filter-Free hybrid



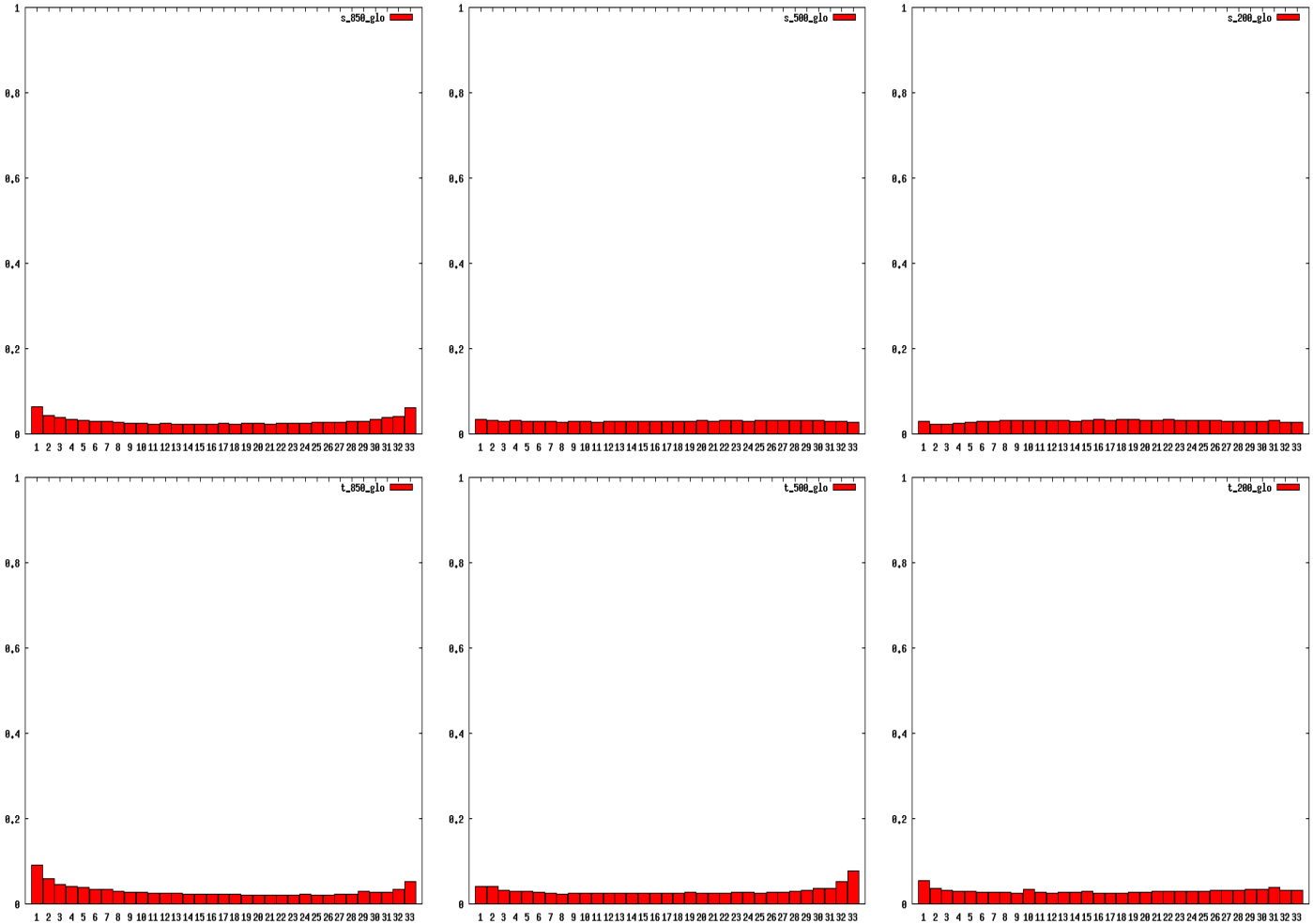
Rank-histograms, EnKF: speed (top) and temperature (bottom)

850 hPa 500 hPa 200 hPa



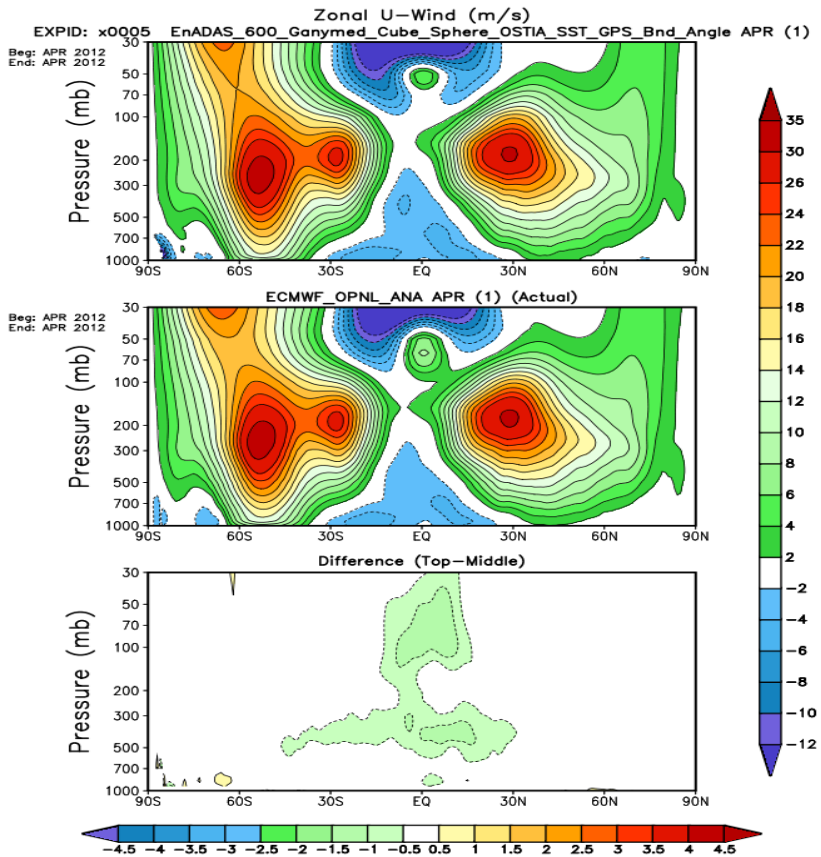
Rank-histograms, Filter-free later tuning: speed (top) and temperature (bottom)

850 hPa | 500 hPa | 200 hPa

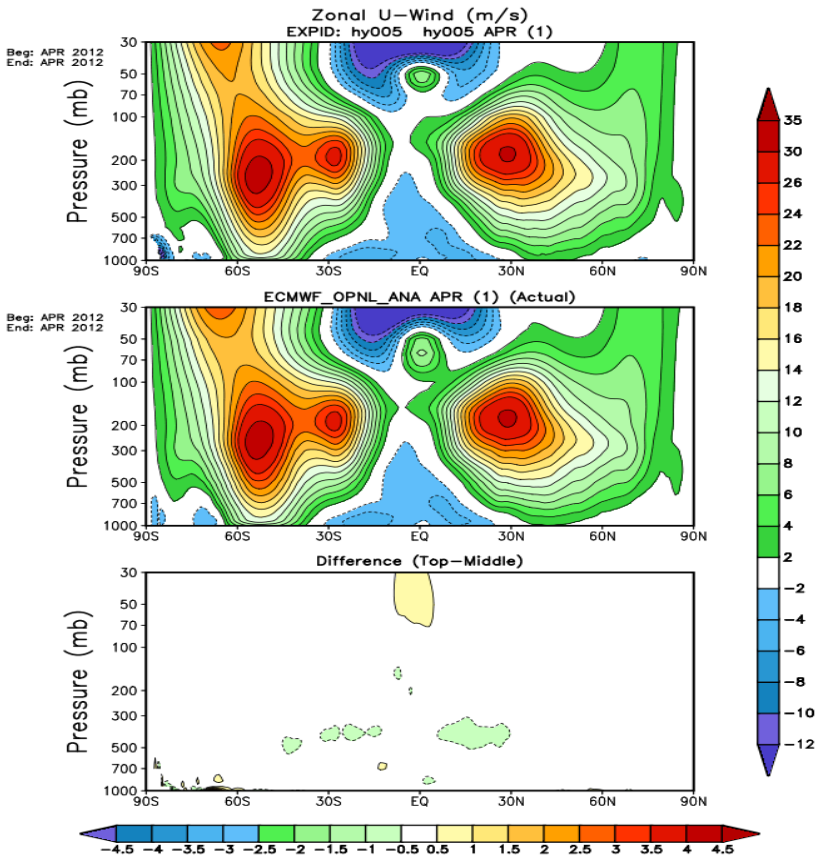


Comparison w/ ECMWF: Zonally-Averaged Monthly Mean U-Wind

Control 3d-Var



EnKF-based hybrid



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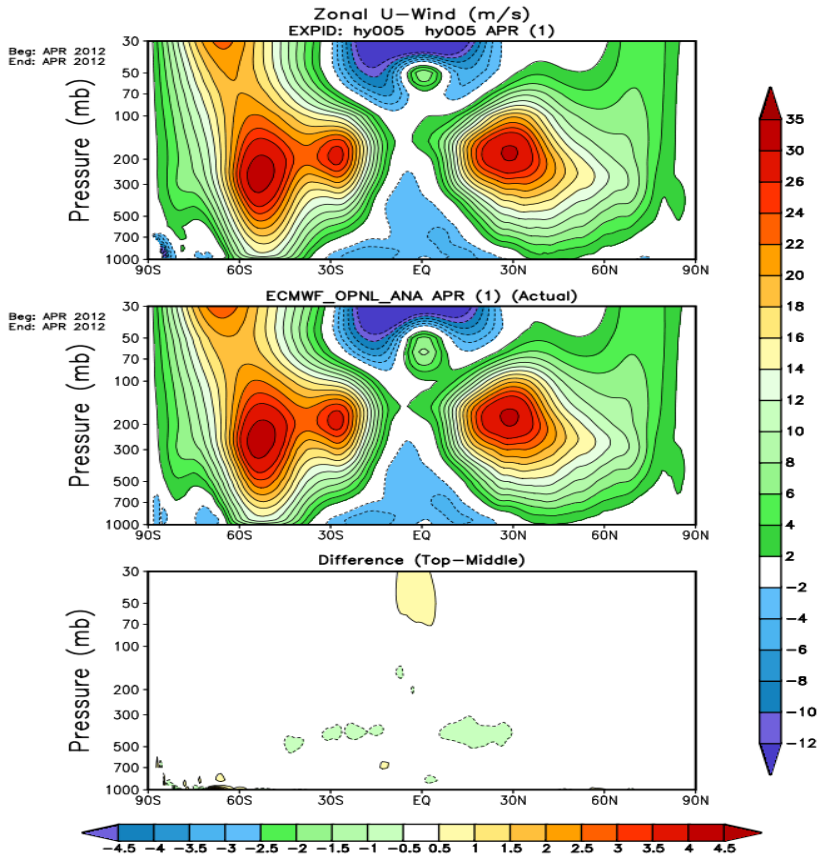
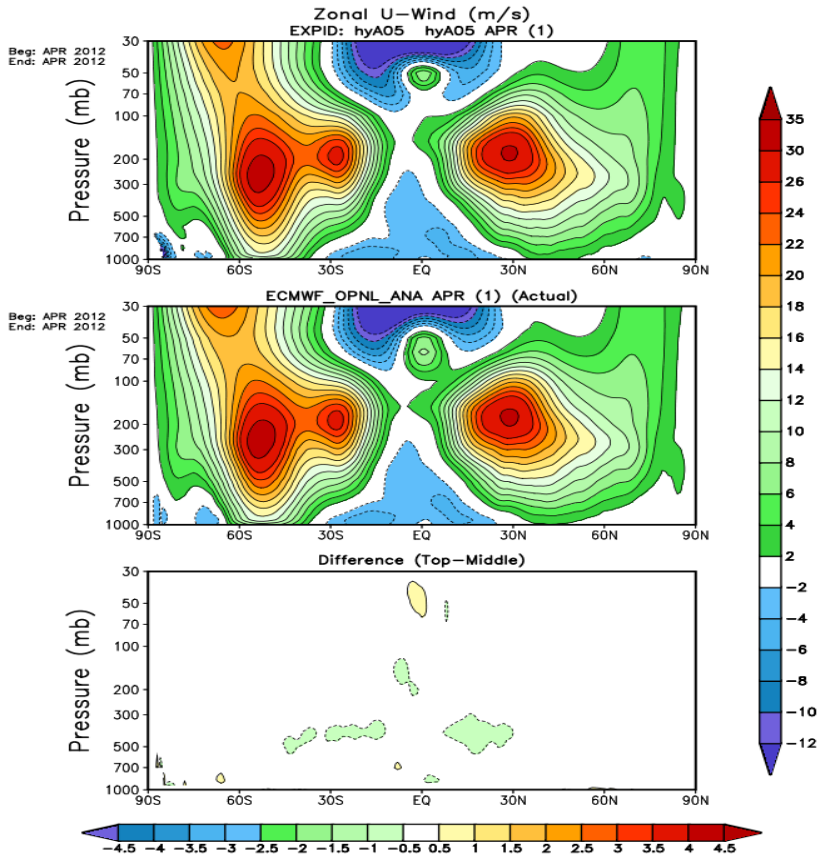
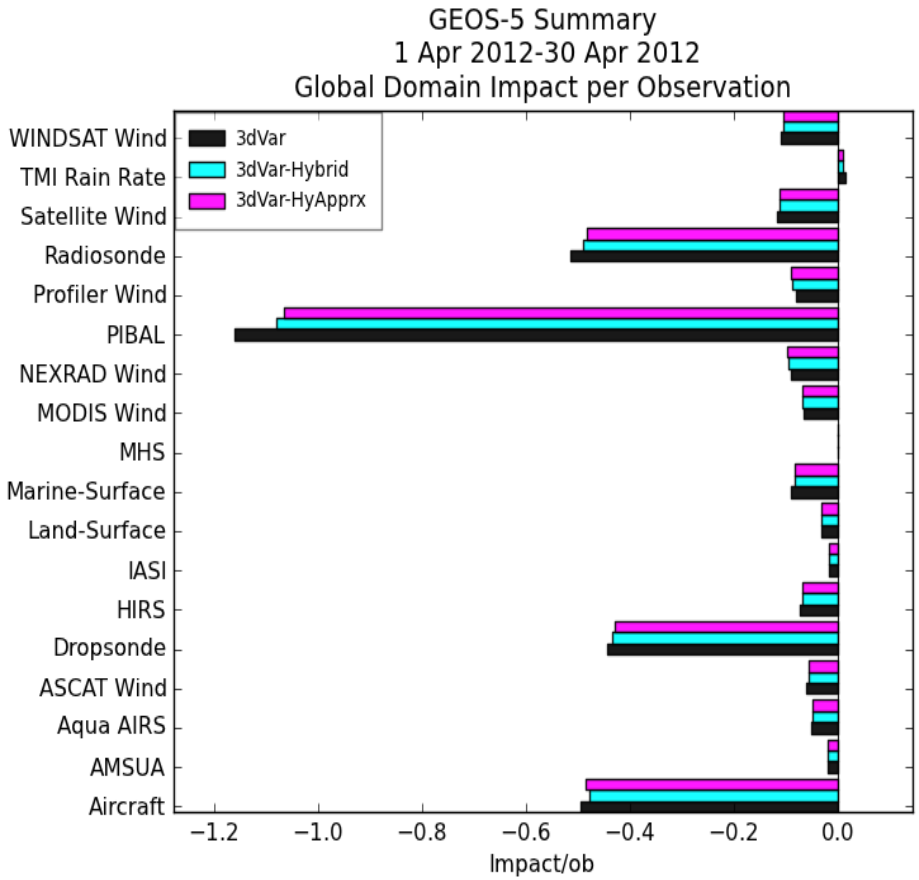


Filter-Free hybrid



Observation Impact on Analysis: April 2012 (Imp/ob)



Note: GPS removed on purpose since data identifier (KX) is messed in diagnostic file for control

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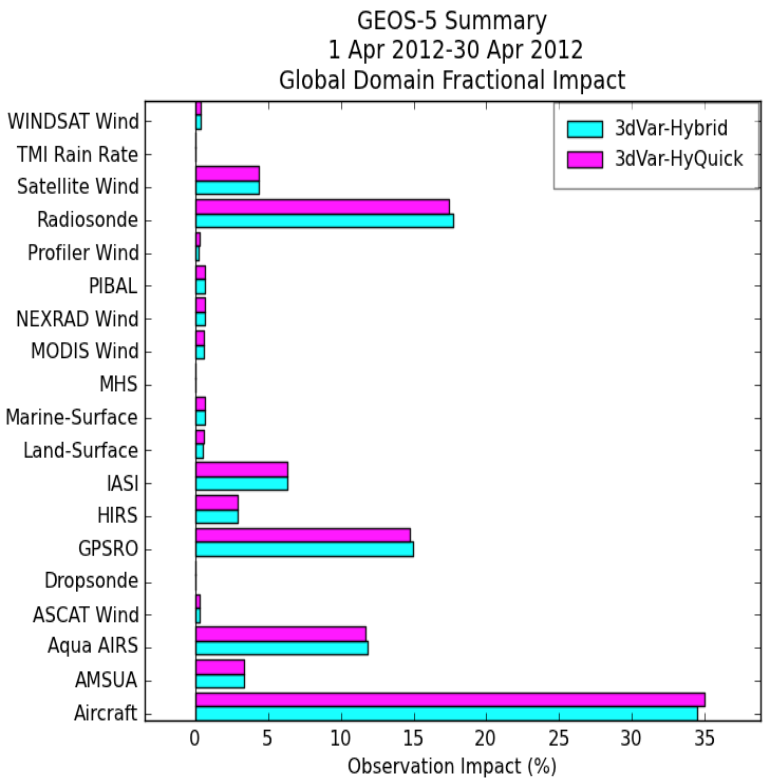
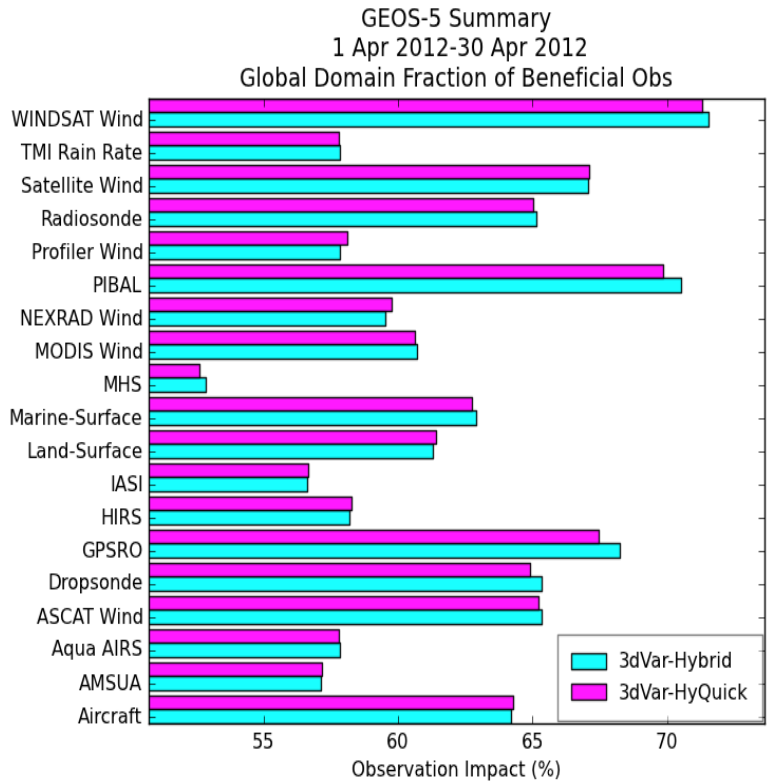


Fractional

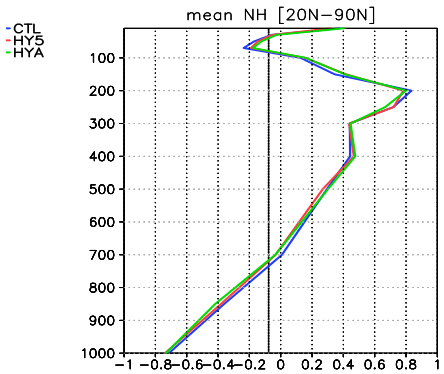


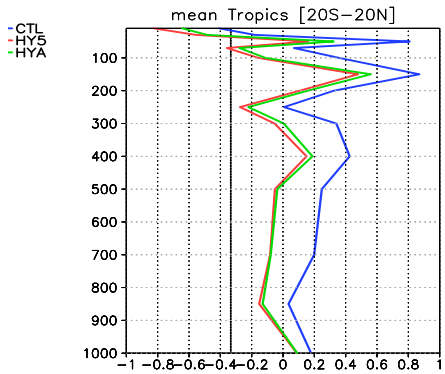
Beneficial

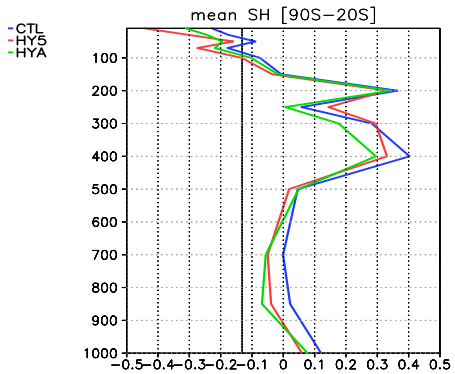
RAOB fits to background: Bias

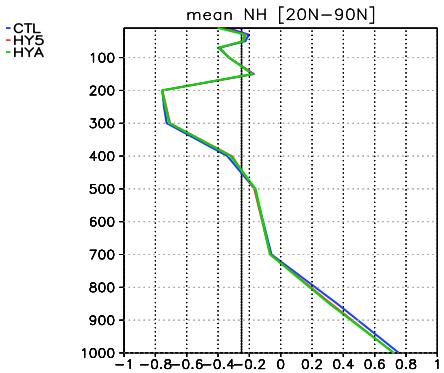
Zonal Winds (top); Temperature (bottom)

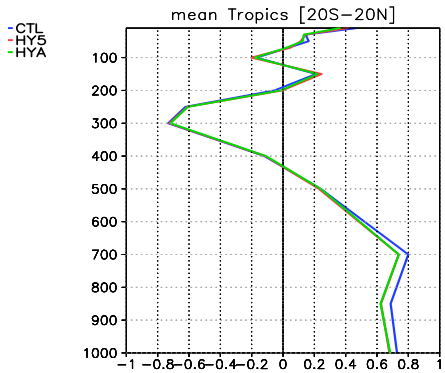
NH Tropics SH

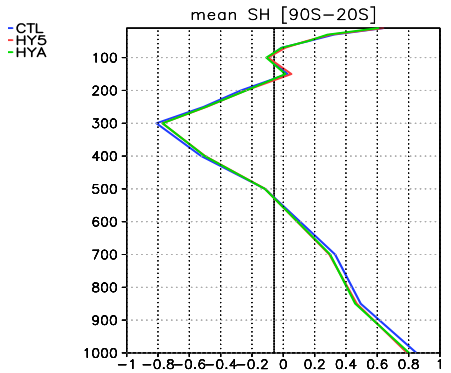






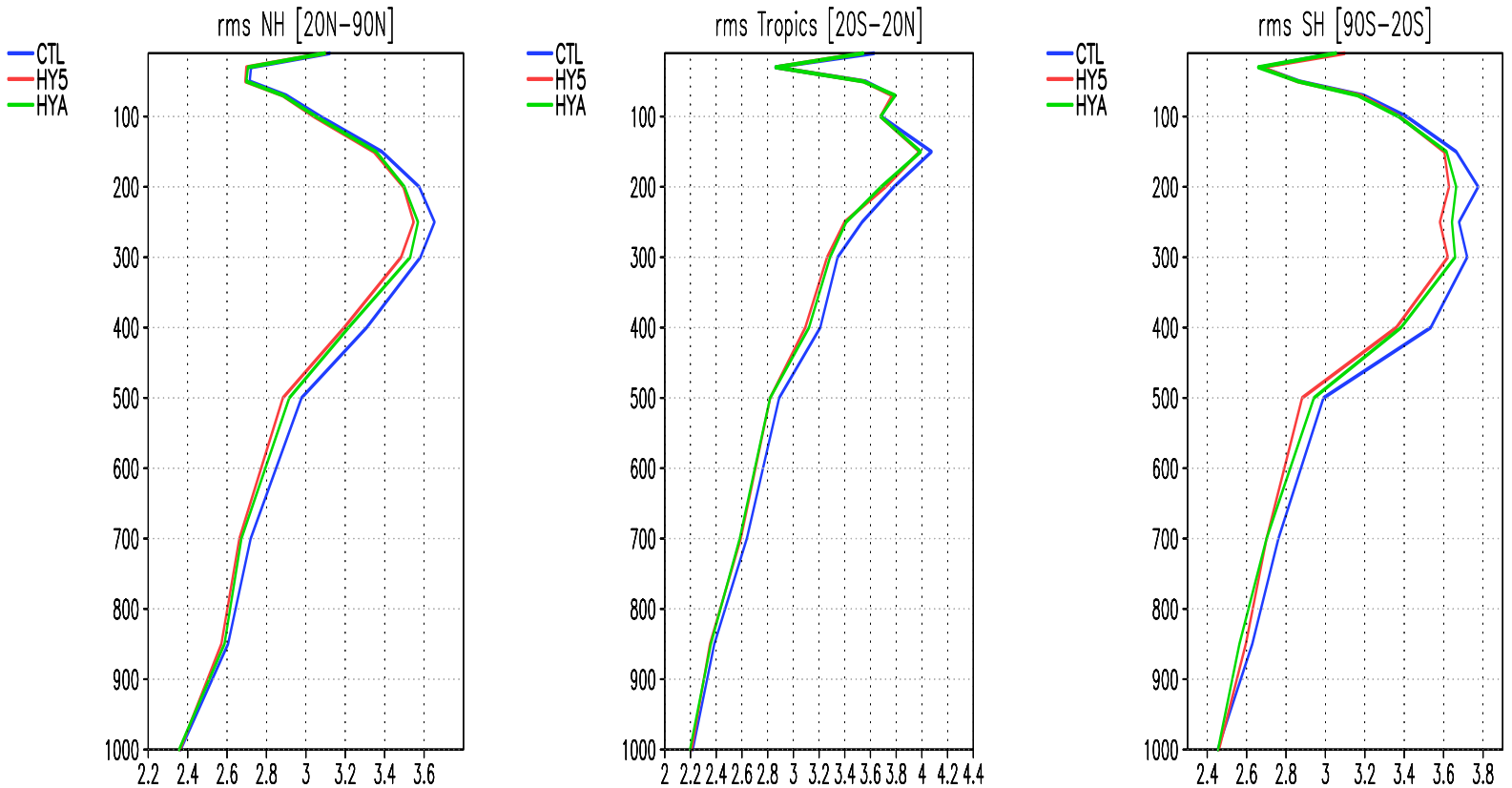






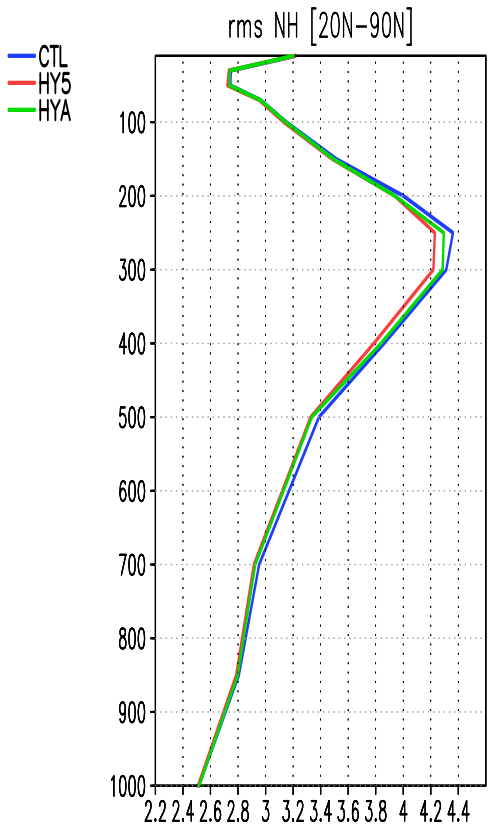
Zonal wind RAOB fits to background: RMS

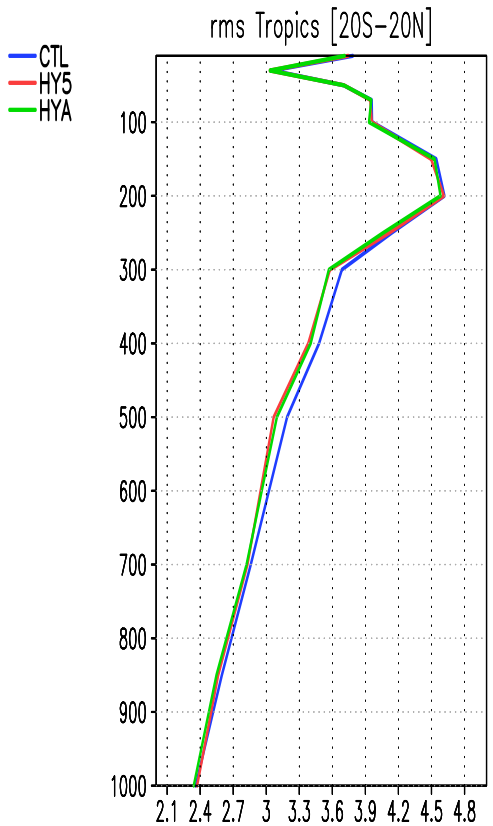
NH Tropics SH

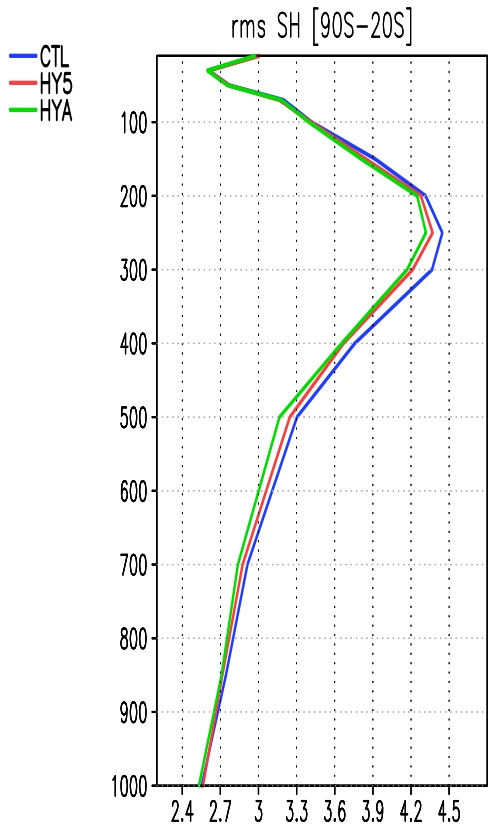


Zonal wind RAOB fits to 24-hour forecast: RMS

NH Tropics SH

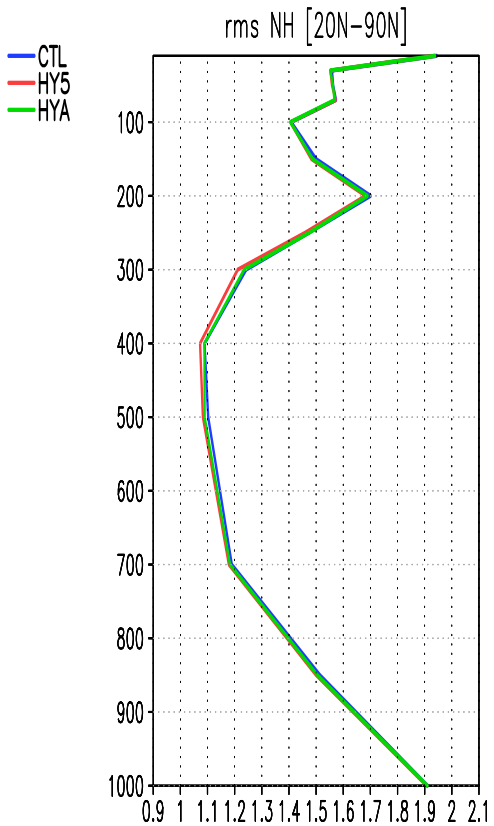


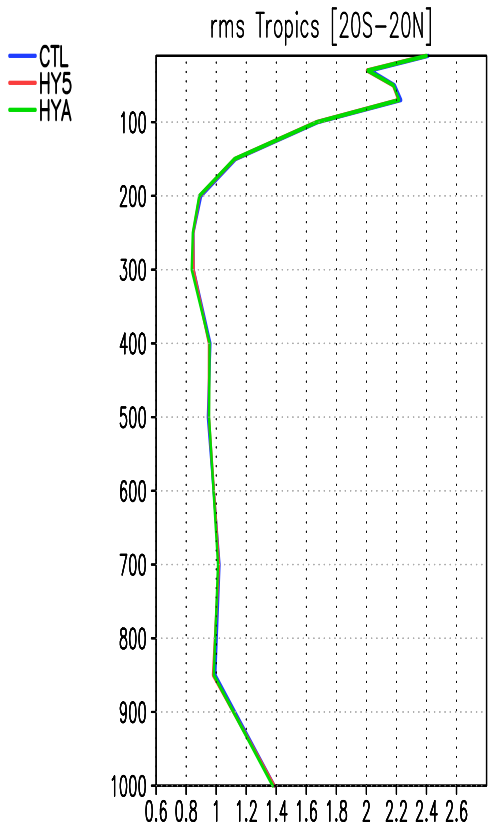


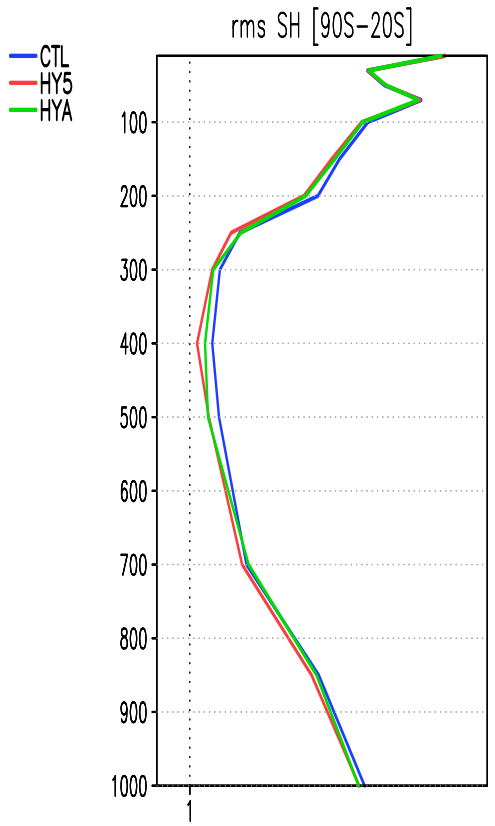


Temperature RAOB fits to 24-hour forecast: RMS

NH Tropics SH

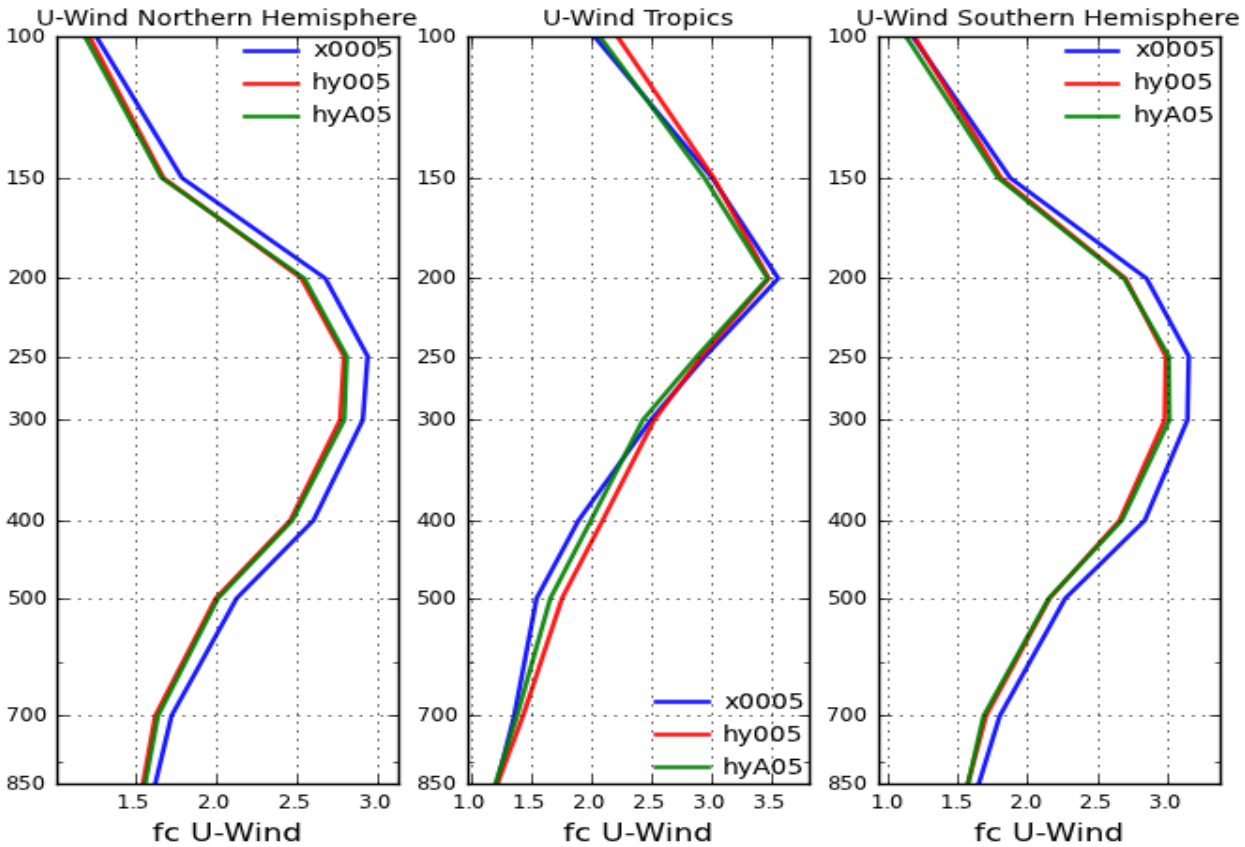






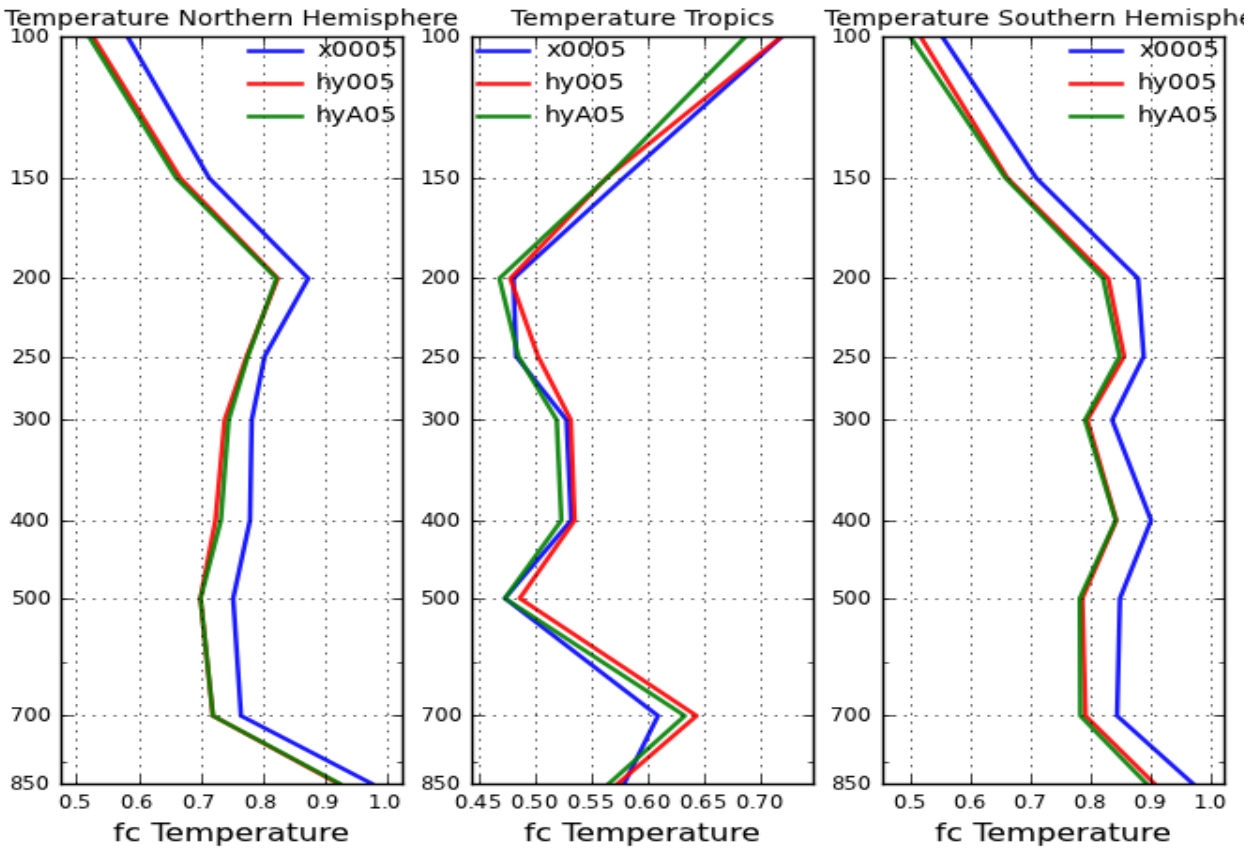
24-hour forecast vs analysis: Zonal Wind

NH Tropics SH



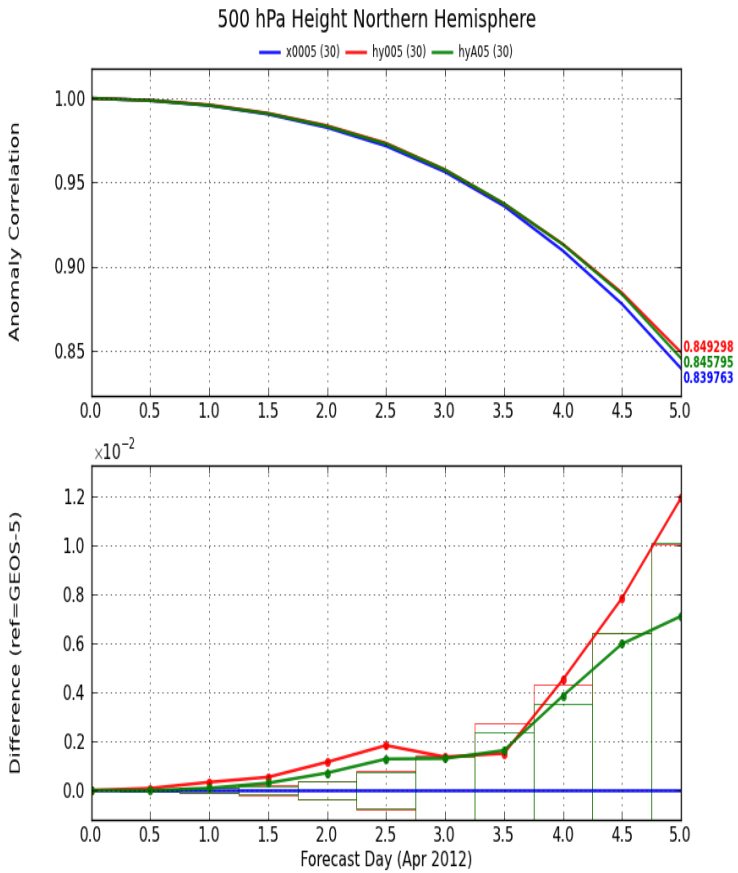
24-hour forecast vs analysis: Temperature

NH Tropics SH

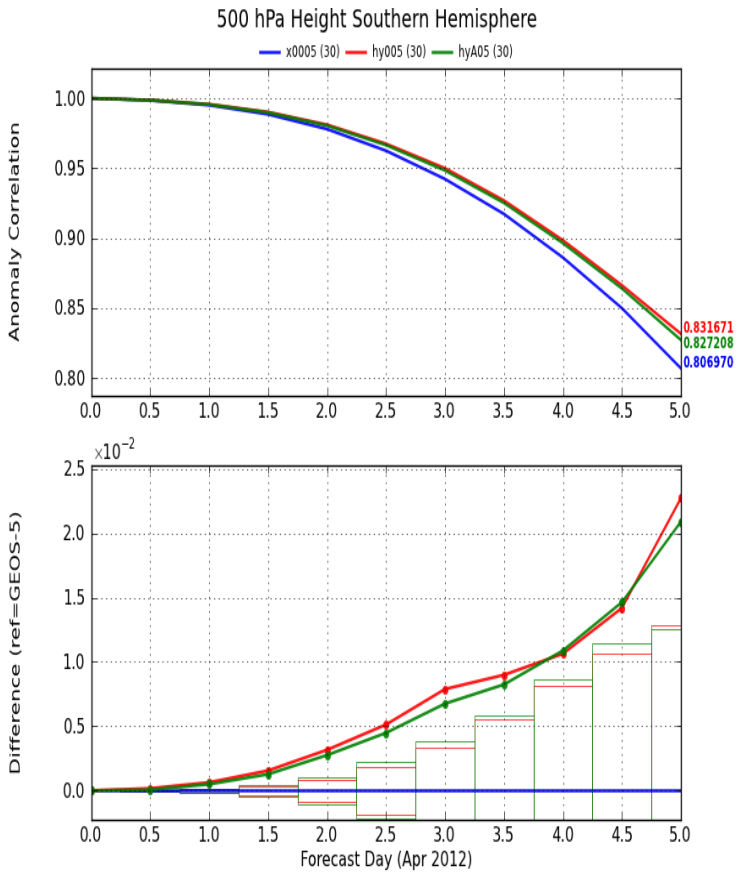


Anomaly Correlations: H500

Northern Hemisphere



Southern Hemisphere



Summary

Main Points

- Overall 3d-hybrid approach gives positive results in GEOS DAS with noticeable reduction of model biases and improved skill scores
- Filter-free scheme works just as well as EnKF in sustaining ensemble
- Would be nice to study skill of NMC-like perturbations in an EPS

Advantages of Filter-Free Hybrid

- Really inexpensive way of generating ensemble
- Avoids need to maintain two analysis systems
- Avoids contradictions when calculating adjoint-based obs impact

Still, could it be the EnKF is not properly tuned? See Amal's presentation