(Toward) Scale-dependent weighting and localization for the NCEP GFS hybrid 4DEnVar Scheme

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Outline

- Overview of hybrid 4DEnVar scheme for NCEP GFS
- Short-term plans (things already tested)
- Toward improving localization
- Extension to scale-dependent weighting within hybrid
  - Experiments with toy model

Hybrid 4DEnVar

$$J(\mathbf{x}'_c,\mathbf{a}) = b_c \frac{1}{2}(\mathbf{x}'_c)^T \mathbf{B}_c^{-1}(\mathbf{x}'_c) + b_e \frac{1}{2}\mathbf{a}^T \mathbf{L}^{-1}\mathbf{a} + \frac{1}{2}\sum_{k=1}^{K}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}'_k)^T \mathbf{R}_k^{-1}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}')$$

$$\mathbf{z} = \mathbf{B}^{-1}\mathbf{x}'_c \qquad \mathbf{v} = \mathbf{L}^{-1}\mathbf{a}$$

Jo term divided into observation "bins" as in 4DVAR

Where the 4D increment is prescribed through linear combinations of the 4D ensemble perturbations plus static contribution, i.e. it is not itself a model trajectory

$$\mathbf{x}'_{(t)k} = \mathbf{C}_k\left[\mathbf{x}'_c + \sum_{m=1}^{M}(\alpha^m \circ (\mathbf{x}_e)_k^m)\right]$$

Here, ***static contribution is time invariant***. **C** represents TLNMC balance operator. ***No TL/AD in Jo term*** (**M** and $\mathbf{M}^T$). Linear **H** used in cost function.

Hybrid GSI details

- **Localization**:
  - Horizontal: Spectral operator to apply Gaussian function. Localization distances function of model vertical level
  - Vertical: Recursive filter (separable from above)

- **Ensemble variables**: Can be different than standard control variable for **B**c (Default u, v, T, ps, q_{wv}, q_{oz}, q_{cw})

- **Dual Resolution**: If ensemble at lower resolution, interpolation (and adjoint) between ensemble/analysis grids*

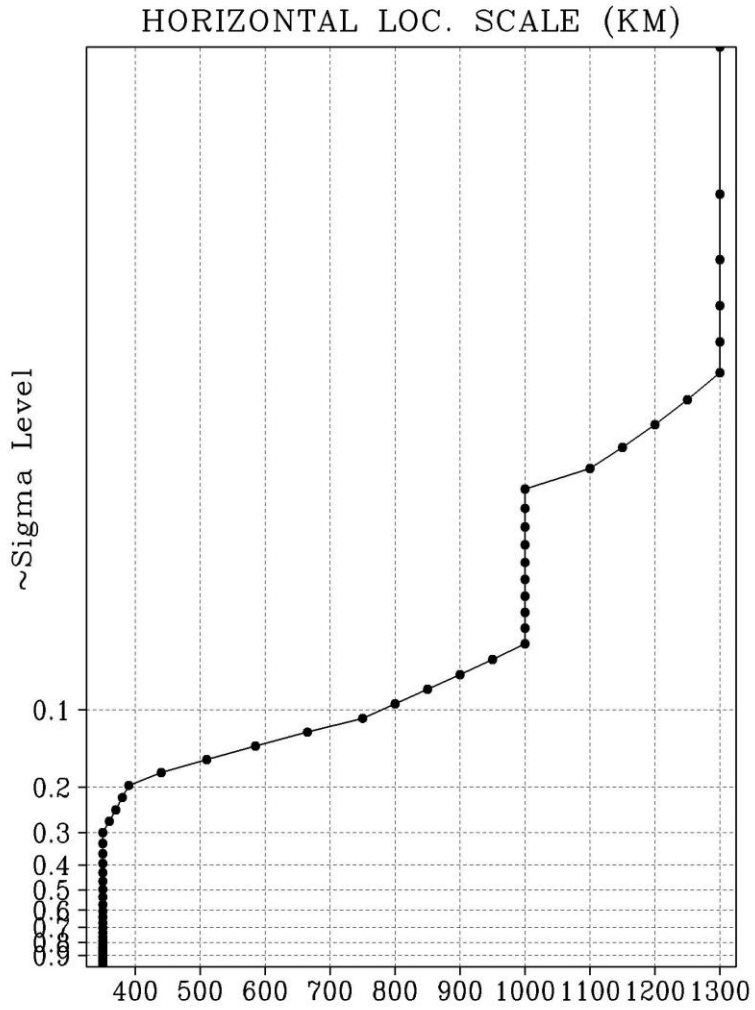
- **Initialization**: Option for Tangent Linear Normal Mode Constraint

$$\mathbf{x}'_{\mathrm{t}} = \mathbf{C}\left[\mathbf{x}'_{\mathrm{f}} + \mathbf{T}\sum_{m=1}^{M}(\alpha^{m} \circ \mathbf{x}_{\mathrm{e}}^{m})\right]$$

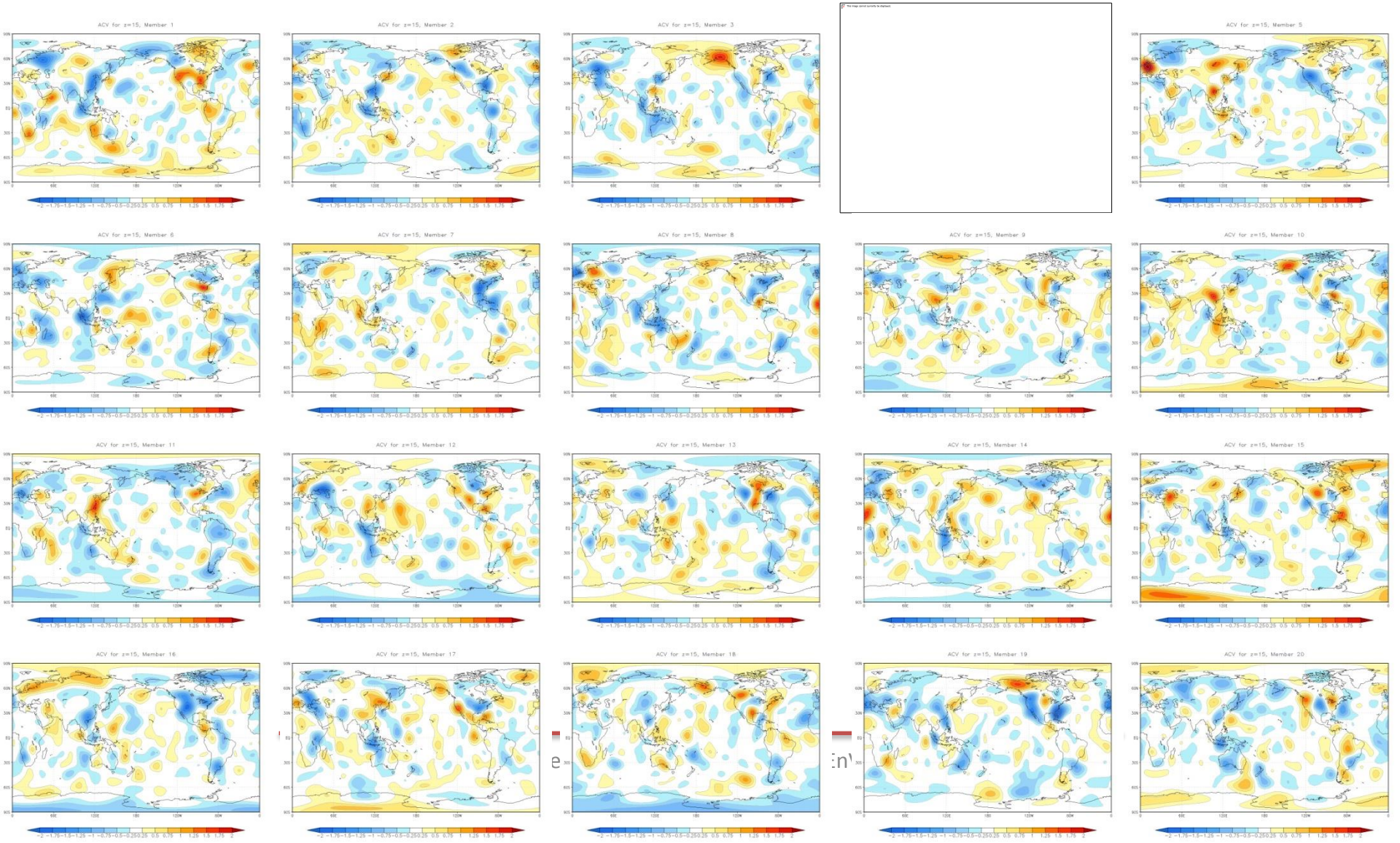
$$\mathbf{x}'_{\mathrm{t}} = \mathbf{C}\mathbf{x}'_{\mathrm{f}} + \mathbf{T}\sum_{m=1}^{M}(\alpha^{m} \circ \mathbf{x}_{\mathrm{e}}^{m})$$

Hybrid 4DEnVar Operational Configuration Implemented: May 2016

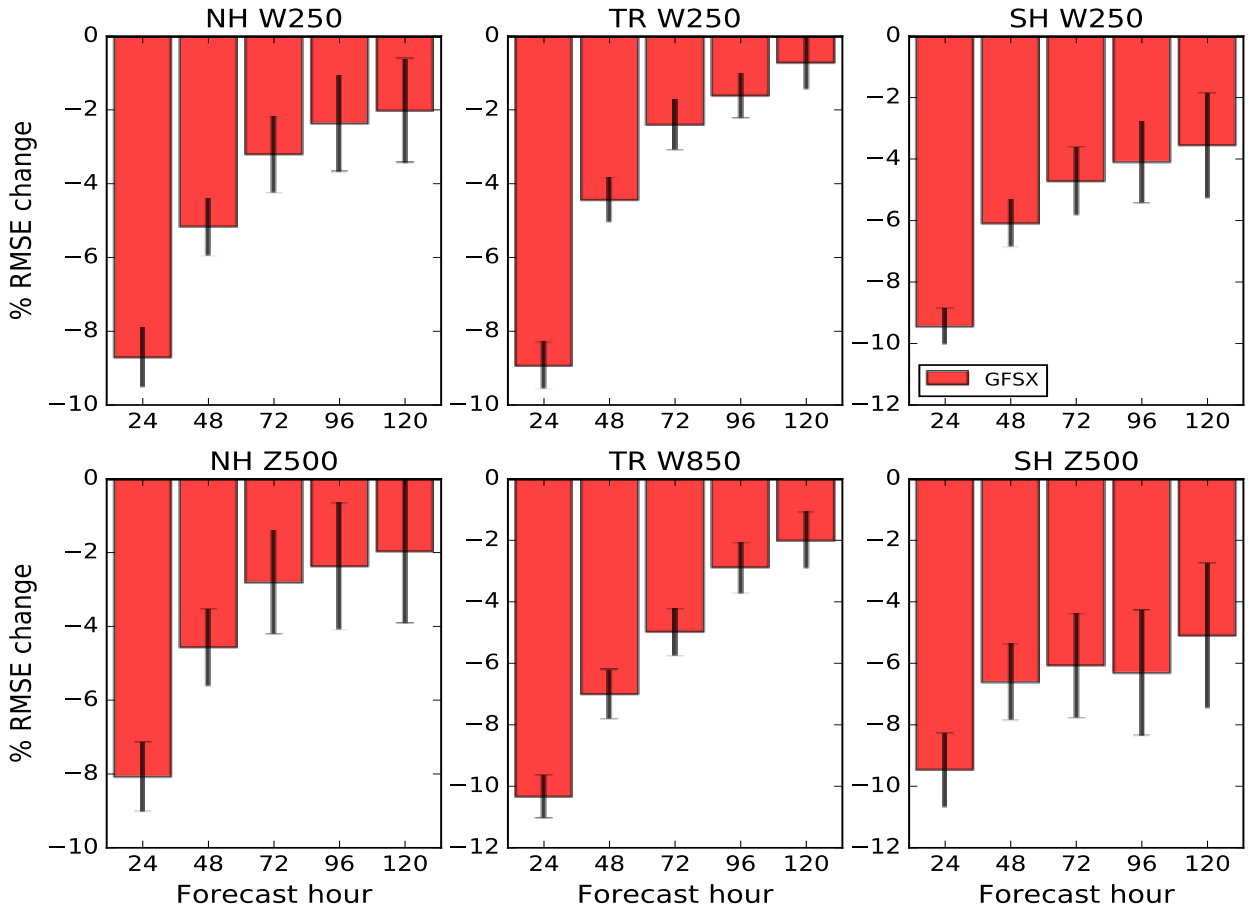
- T1534L64 Deterministic (SL dynamics)
- T574L64 EnSRF, 80 members, Stoch. Physics, Hourly Output
- 87.5% ensemble, 12.5% climatological for hybrid increment
- Level dependent horizontal localization (divide by 0.38 to convert to GC zero distance)
- 0.5 scale heights in vertical



Control Variable Example
(2012012212, z=15, 20 members) [Using Old Localization Distances]
*Note in 4D, we assume this is valid for whole window



4DHybrid Trial Summary Plot (v. Op GFS) 20141201-20150330



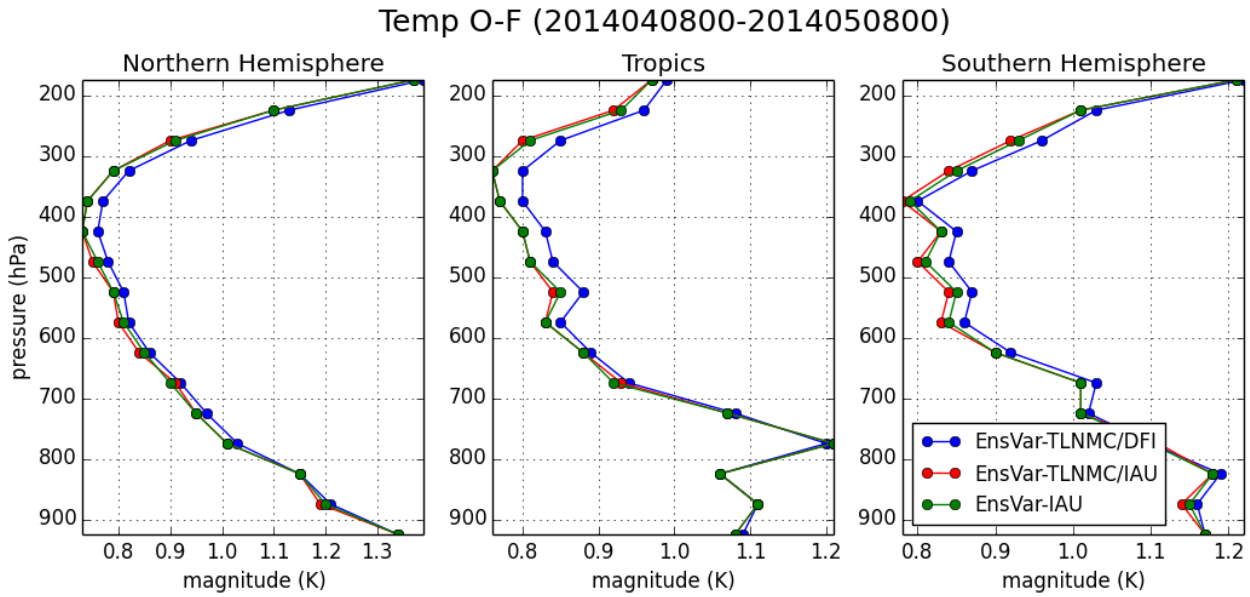
Incremental Analysis Update

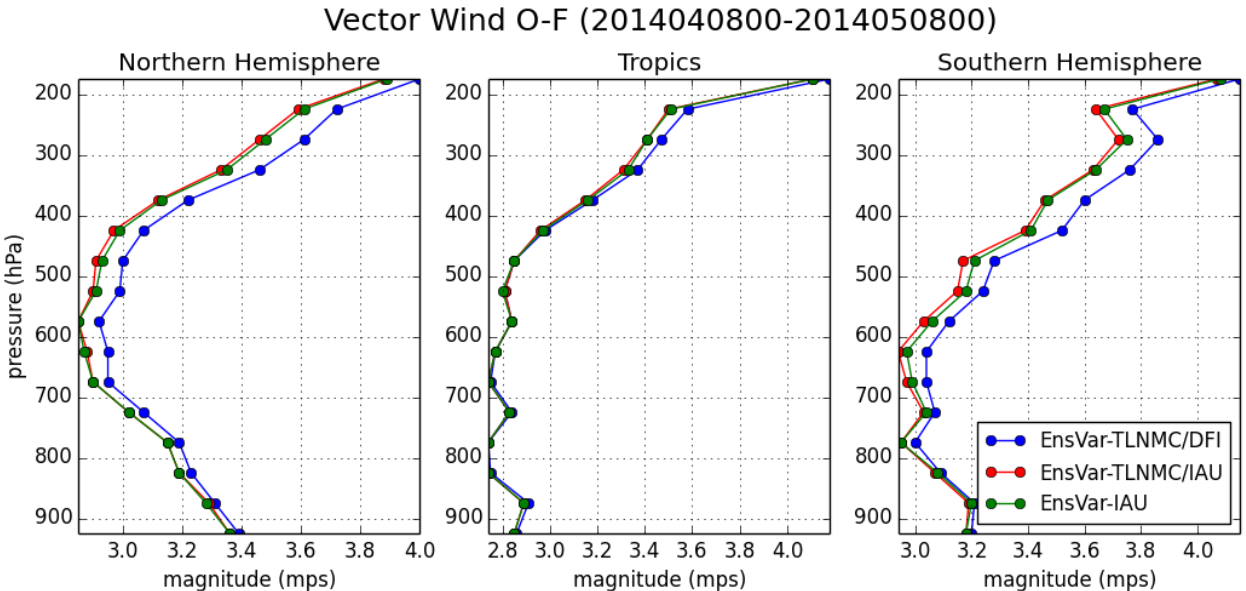
- The current configuration utilizes a combination of TLNMC Digital Filter

- Incremental Analysis Update (Bloom, 1996) helps by using model to distribute a (single) increment over a time window with constant weights (we call this 3DIAU).
  - Propagation of increment neglected, might be significant for fast-moving weather systems.
  - May help spin up unobserved/non-updated state variables

- 4D version of IAU has been proposed by UK Met Office and implemented into Env. Canada System

Fits to Obs for Initialization Trials
Courtesy Lili Lei



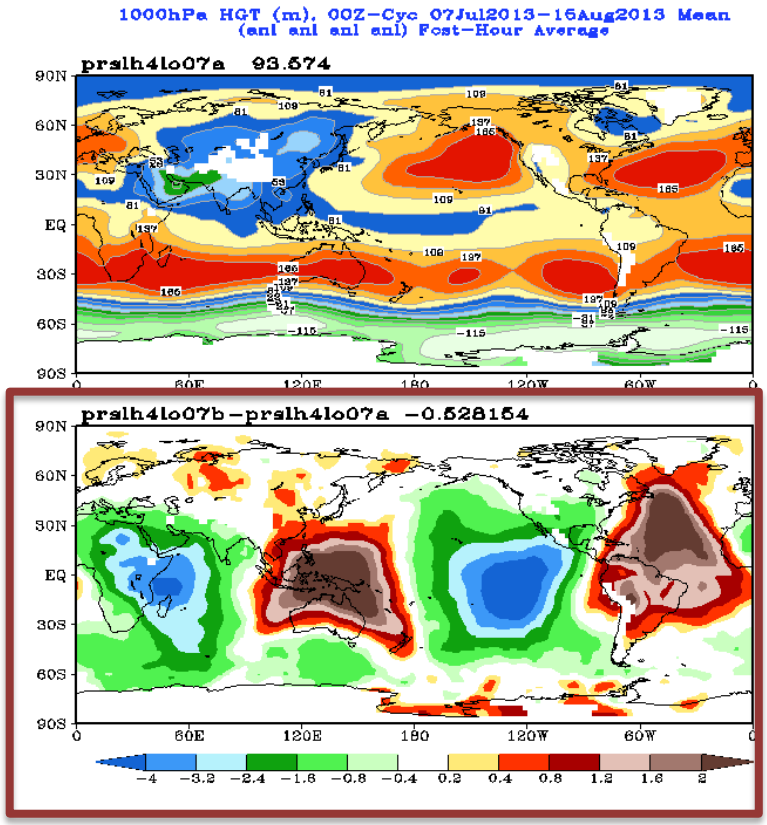


DFI worst performing

TLNMC + 4DIAU best performing

Additional result presented on poster 29 (yesterday)

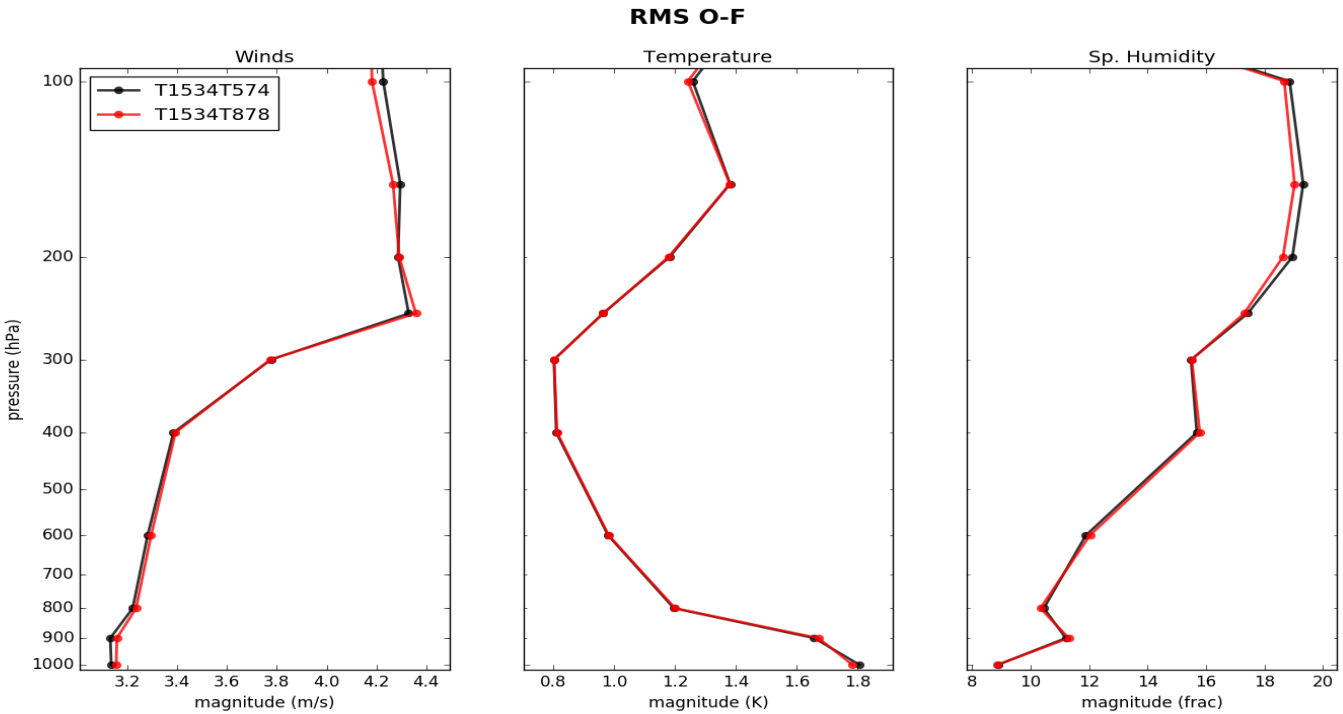
Impacts of IAU-DFI



GFS 4D Hybrid IAU-DFI at 00 UTC

Buehner et al. (2015)

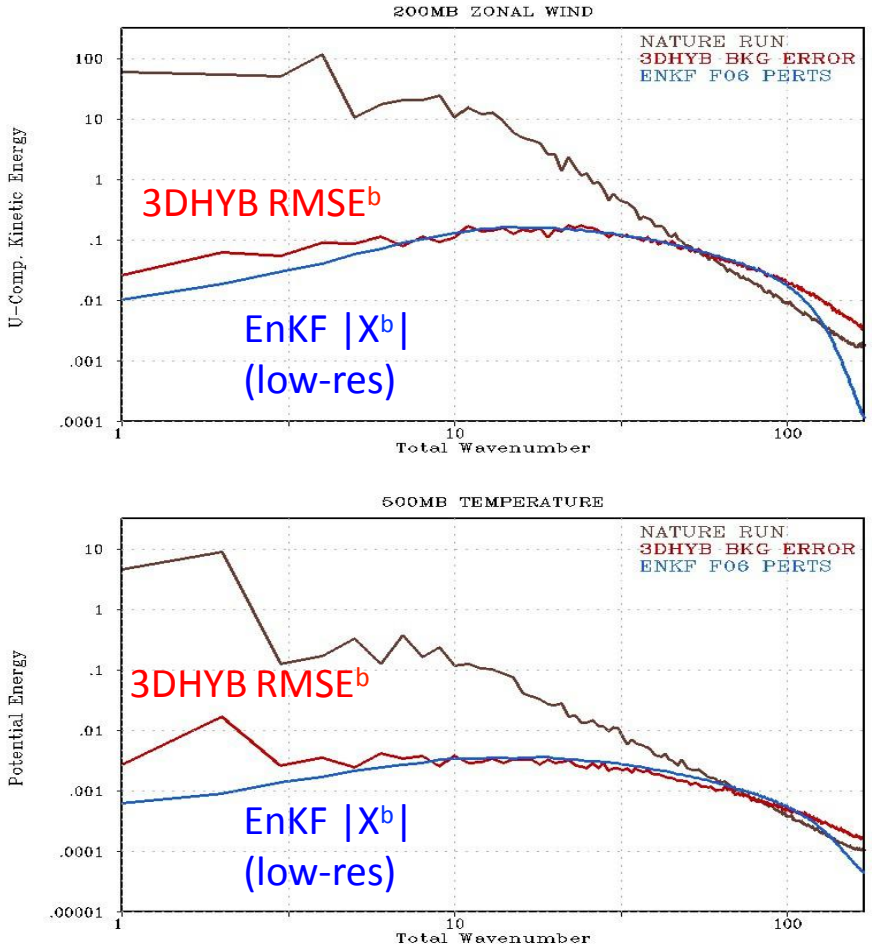
Experiments with higher ensemble resolution (Rahul Mahajan, 15 day sample)



- On new computing asset, test simply increasing resolution of ensemble from T574 to T878. Some model parameters tuned for 878 but everything else identical.
- This also results in higher resolution analysis increment (done at ensemble res.)

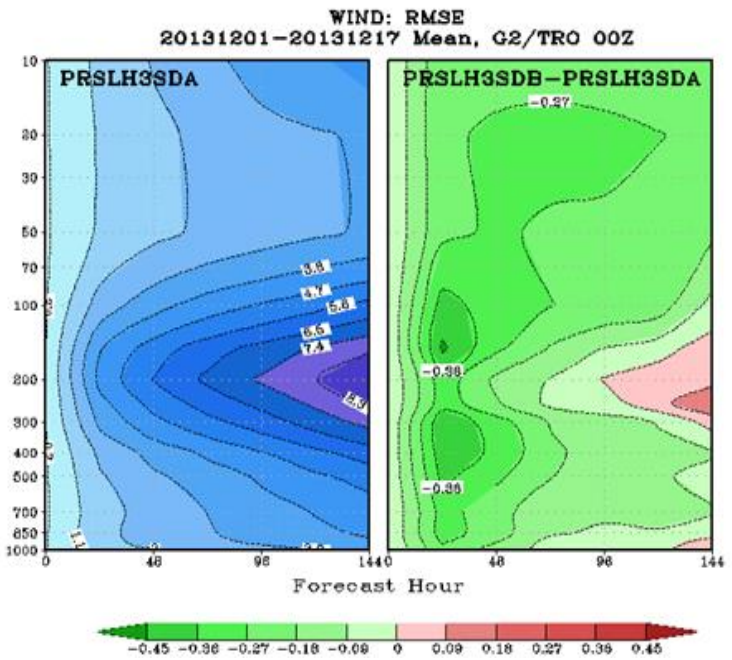
Hybrid DA System (OSSE-based): Scale-Dependence

- Dual-resolution hybrid
  - Mismatch in power spectra of ensemble and actual background error
- Potential remedies
  - ***Scale-dependent weights***
  - ***Scale-dependent localization***
  - Dynamic constraints
  - Scale-dependent inflation



Scale-Dependent hybrid weighting for GSI

- Software to apply ***scale dependent weights*** implemented and tested in OSSE setting
- Preliminary tests with GFS in OSSE and ***real data*** experiments have shown mixed results thus far
  - Improved winds, degraded heights
  - Quantitatively estimate scale-dependent weights?
- Scale-dependent (and waveband-based) localization has proven successful
  - Future work should aim to integrate scale dependent weighting and localization (already underway for GFS)
  - May be necessary to improve initialization of water vapor, clouds, etc.



Experiments with Lorenz (2005) Model III

$$\frac{dZ_n}{dt} = \left[X,X\right]_{K,n} + b^2\left[Y,Y\right]_{1,n} + c\left[Y,X\right]_{1,n} - X_n - bY_n + F$$

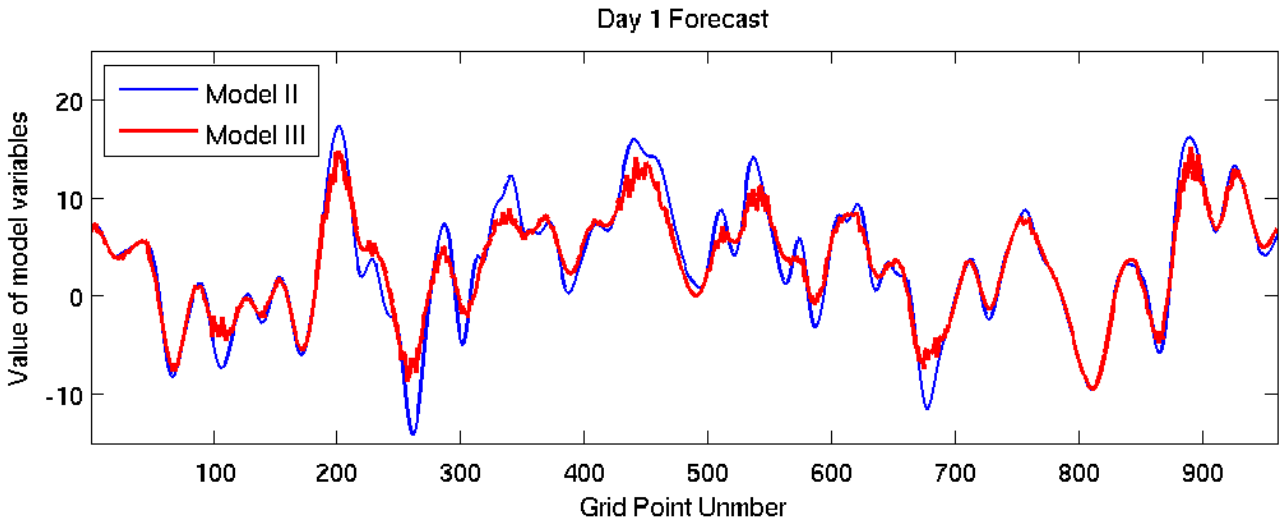
$$X_n = \sum_{j=-J}^{J} a\left(a - b|i|\right) Z_{n+1}$$

$$Y_n = Z_n - X_n$$

$$a = \frac{\left(3l^2+3\right)}{\left(2l^3+4l\right)}$$

$$b = \frac{\left(2l^2+1\right)}{\left(l^4+2l^2\right)}$$

N: Model resolution - 960
K: Smoothing Parameter (defined in weights for X in model II) - 32
F: Forcing - 15
I, b, c: Coupling parameters – 12, 10, 2.5



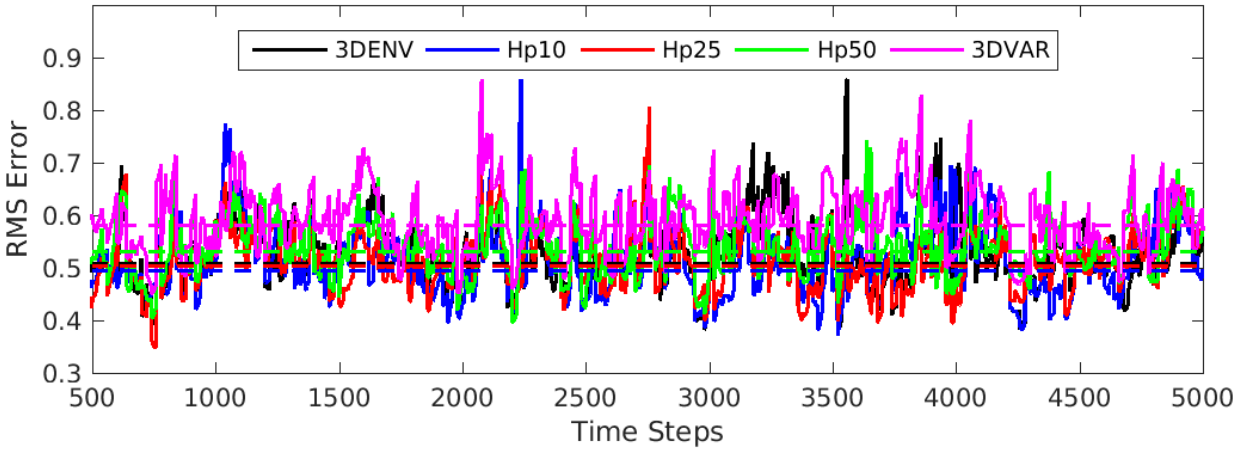
Experimental Settings

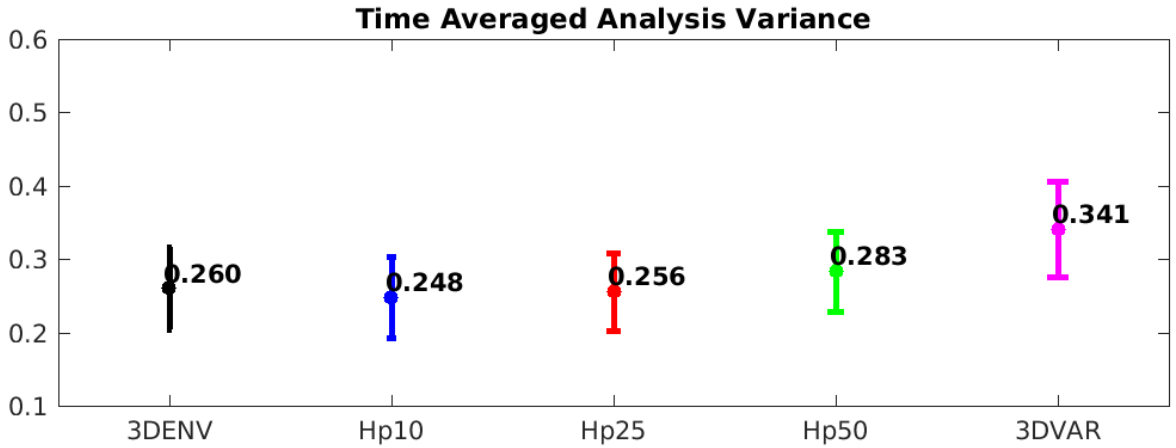
Lorenz 2005 model	Truth	Central	Ensemble
Model Type	Model III (Two-scale)	Model III (Two-scale)	Model III (Two-scale)
Resolution (N)	960 pts	960 pts	960 pts
Smoothing Parameter (K)	32	32	32
Forcing Constant (F)	15	14	14
Coupling Parameters (I)	12	12	12

Observation Network	
Observation Error	σ=1.0
Assimilation window	20 time steps
Observed at	Randomly selected (12.5% observation coverage)

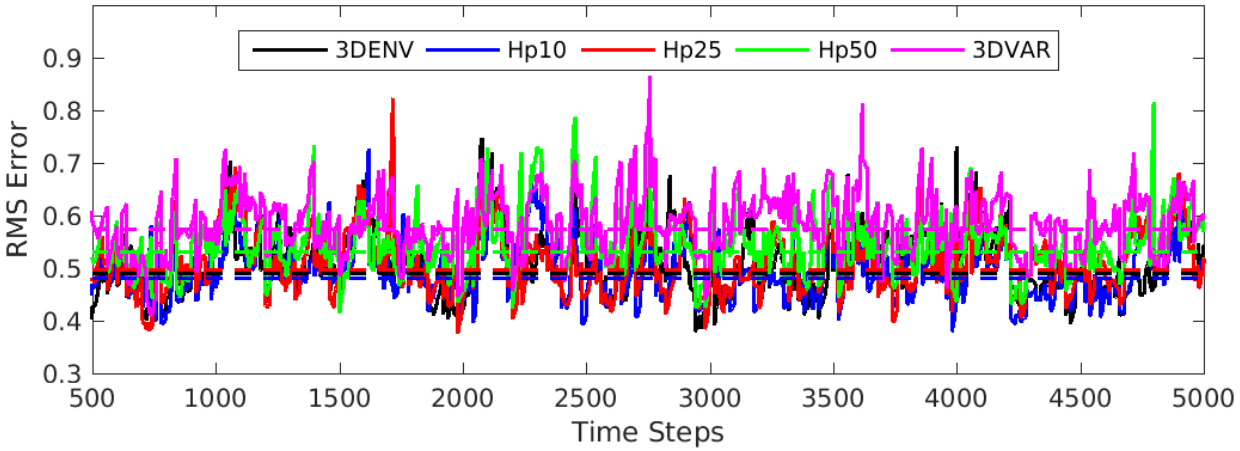
The Settings of LETKF	
Ensemble Size	20
Additive Inflation (RTPP)	0.75
Multiplicative Inflation	1.01
Localization Length (Grid)	15

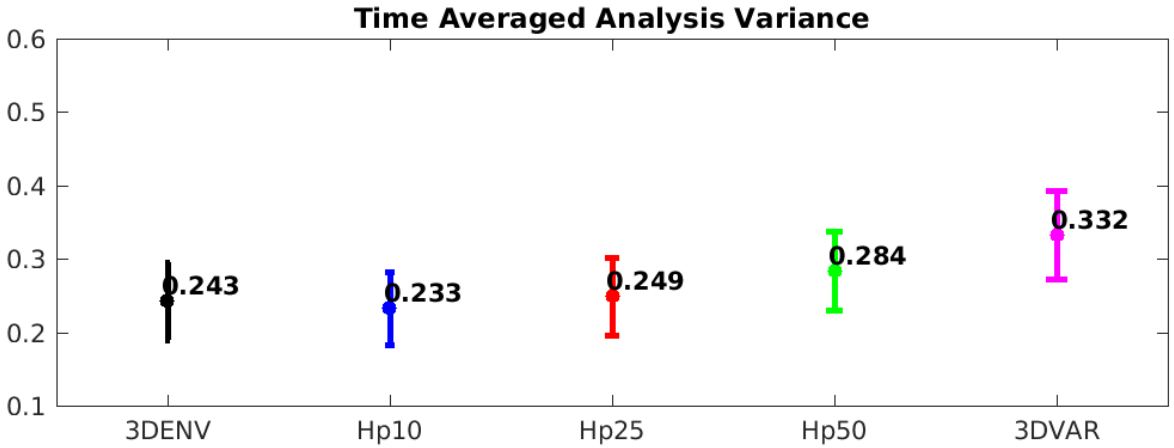
Single Resolution Impact
Sensitivity to Hybrid Weighting



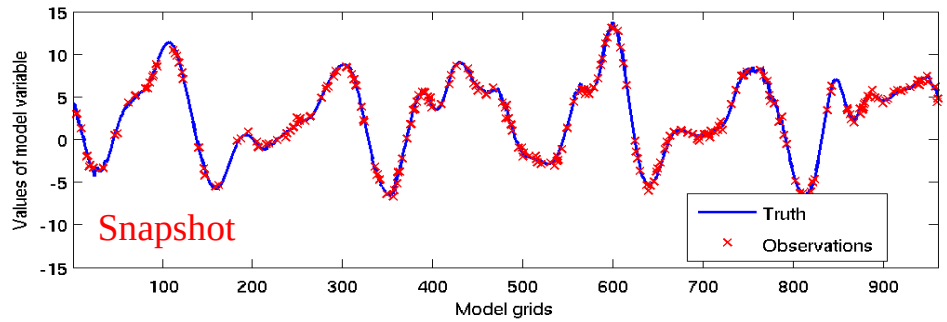


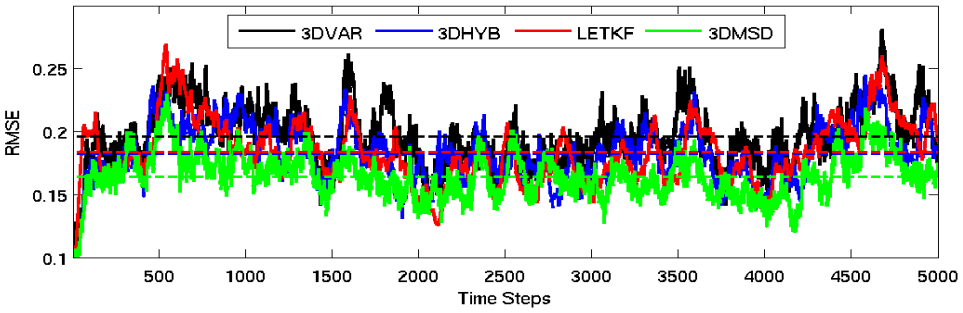
Single Resolution Impact
Hybrid plus (two band) waveband localization

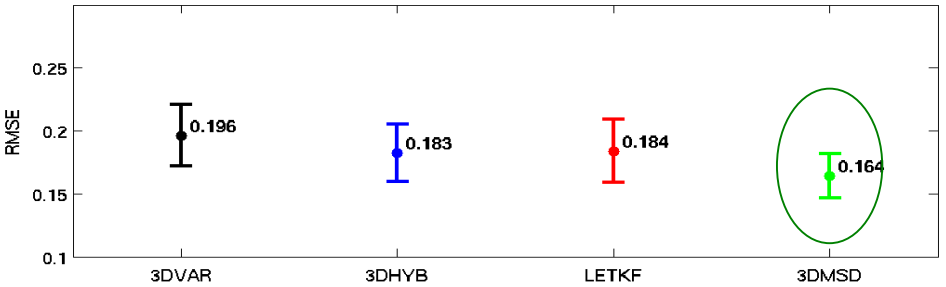




Dual-resolution Hybrid with Lorenz 2005 (Imperfect Toy Model)







- Test with dual resolution configuration (ensemble at half resolution
- Slightly different parameters (more observations, lower observation error variance)
- Add in simple waveband dependent weighting
  - Large influence from ensemble at larger scales.
  - Larger influence from static B (with small correlation lengths) at small scales

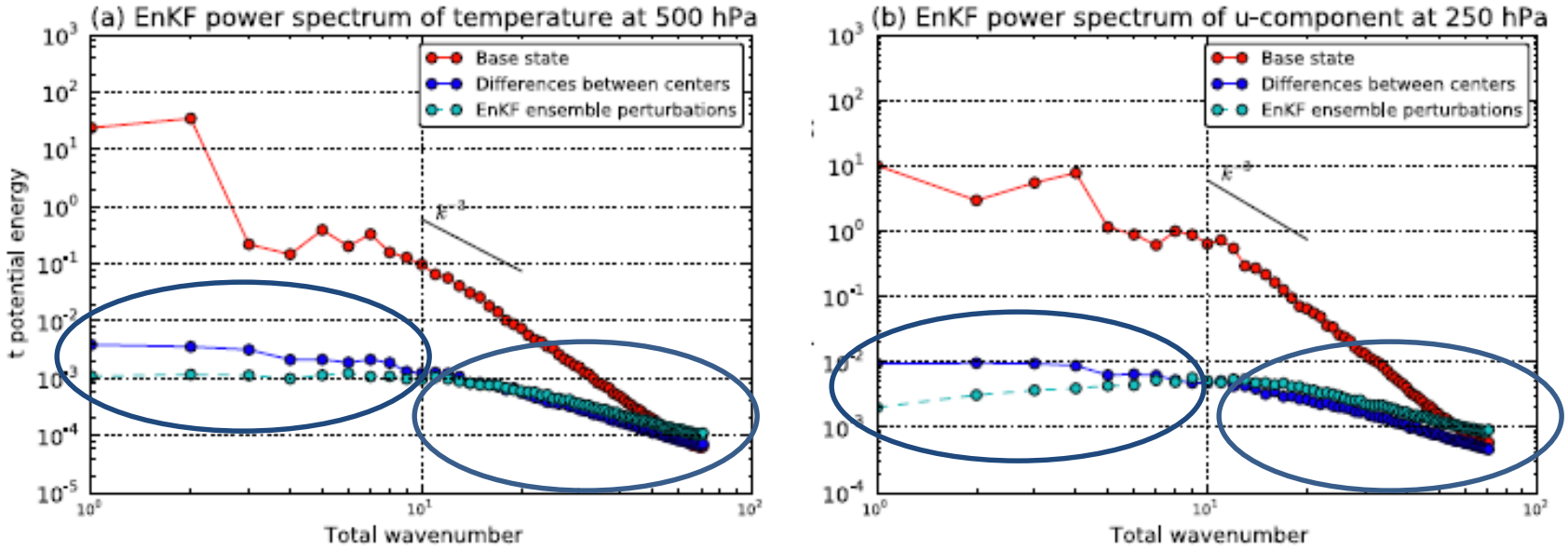
Next Steps

- Toy Model
  - Continue exploration of scale-dependent weighting and localization
  - Apply quantitative estimation of scales and weights (Menetrier and Auligne 2016)

- NCEP GFS
  - Follow lead of Buehner and implement waveband* (spectral/spatial) and scale dependent localization
  - Explore addition of waveband dependent weighting between static/ensemble in hybrid 4DEnVar

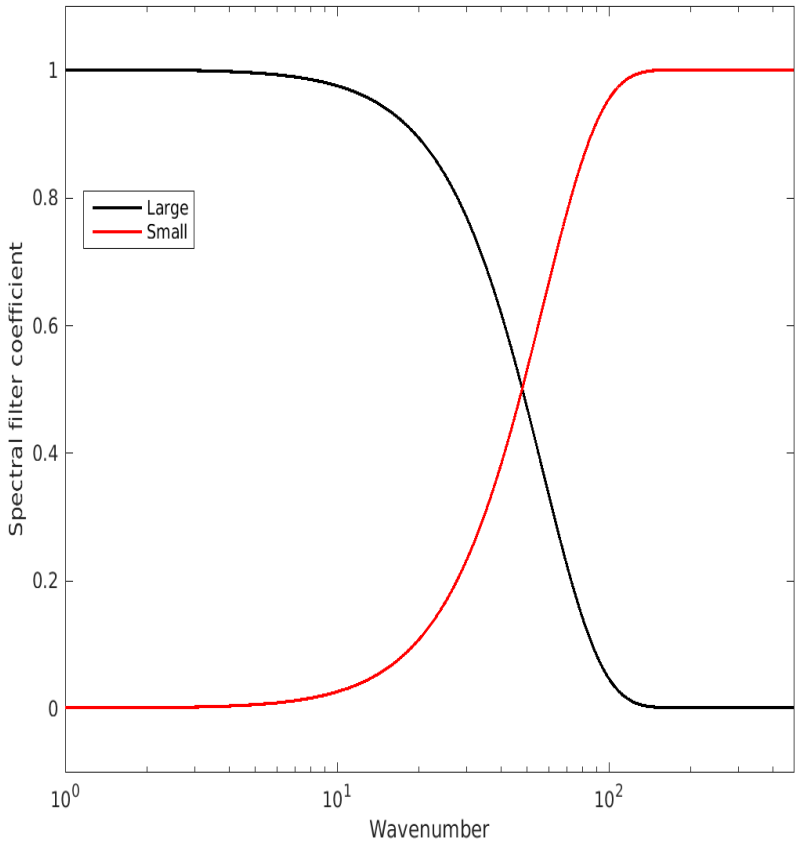
- Backup Slides

Scale-Dependence
(Courtesy: Tom Hamill)



(1) Generally more power at all wavenumbers relative to ETR.
(2) Overestimate of power (i.e., amplitude of perturbations) at small scales. Likely this is attributable to inappropriate analysis increments due to the use of smaller-than ideal ensemble size (n=80) in the EnKF, and still-crude methods (covariance localization) for filtering usable signal from sampling noise.

Two Wavebands



Ensemble Perturbation