The use of "stochastic physics" in operational global data assimilation with NGGPS-FV3GFS

Daryl Kleist[1], **Rahul Mahajan[1,2], Catherine Thomas[1,2], Jeff Whitaker[3], Phil Pegion[3,4]**

[1]NOAA/NWS/NCEP/EMC
[2]IMSG
[3]NOAA/ESRL/PSD
[4]CIRES

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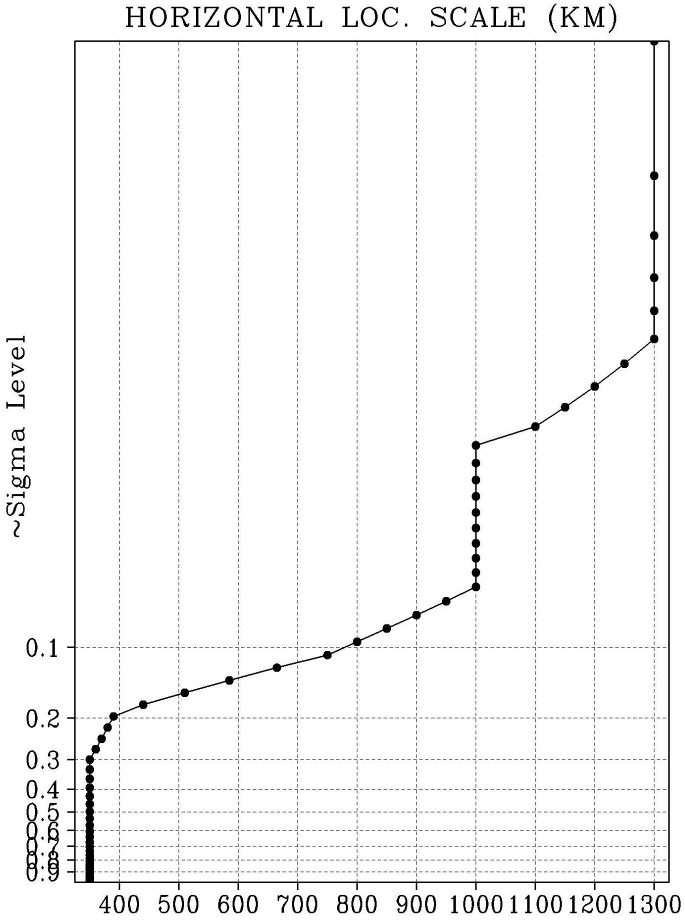
Current Operational GDAS Configuration Hybrid 4DEnVar (May 2016)

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

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

- ***T1534L64*** Semi-Lagrangian GFS (GSM)
  - 80 member ***T574L64*** EnSRF for data assimilation
  - Level-dependent localization
  - **Stochastic physics to represent model uncertainty (SPPT, SKEB, SHUM) – Since January 2015**
  - Analysis increment at ensemble resolution
  - Ensemble perturbations centered about hybrid analysis
    - Ensemble mean state estimate replaced

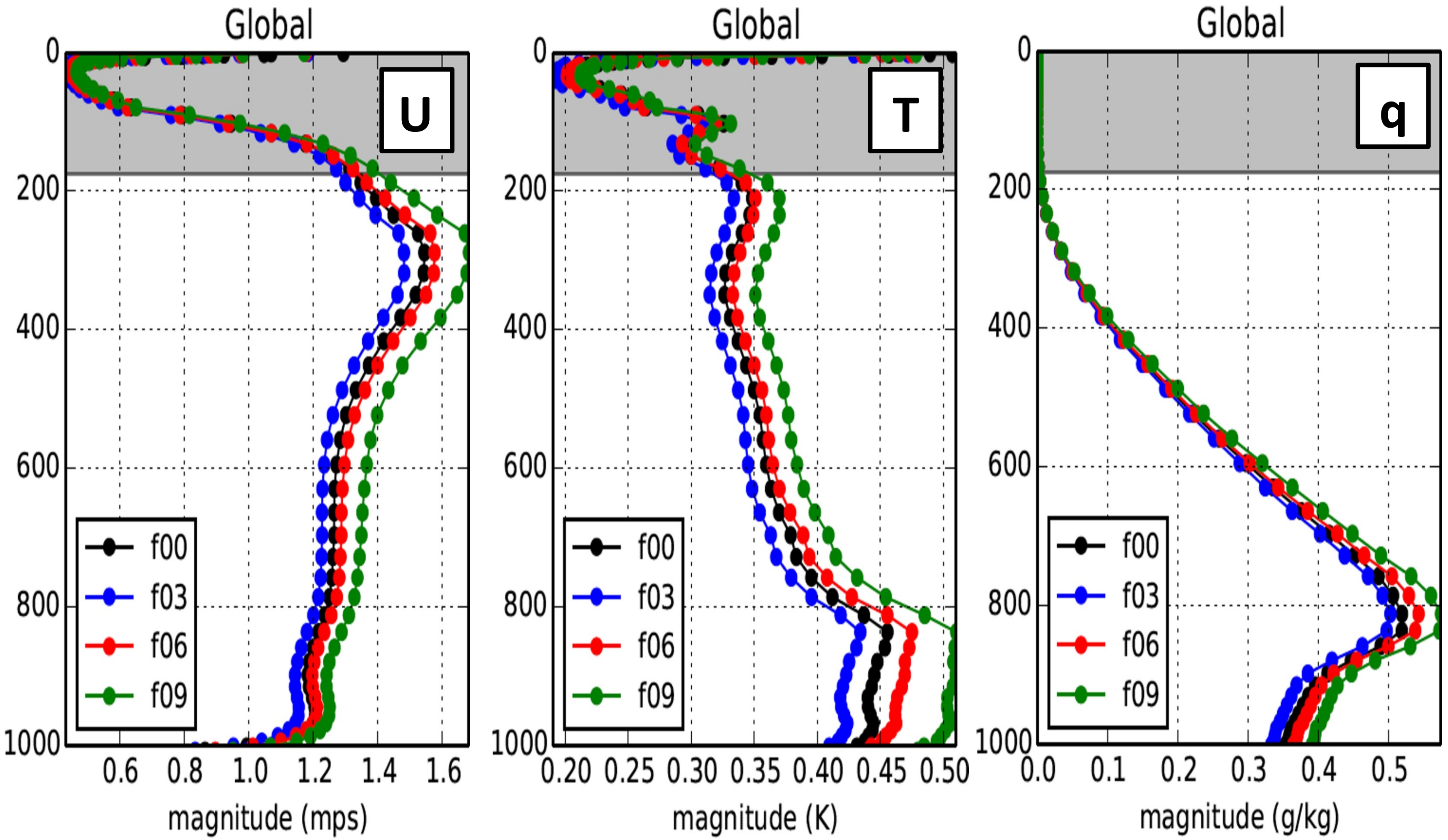


Posterior Inflation (Whitaker and Hamill 2012)

- Hybrid DA implemented at NCEP for GDAS/GFS in May 2012
  - 80 Member, EnKF-based ensemble
  - Deterministic 3x resolution compared to ensemble
  - Hybrid (25% static) 3DEnVar

- Ensemble included:
  - Multiplicative inflation (Relaxation to Prior Spread)
  - **Additive inflation using database of lagged forecast pairs (48h-24h valid at the same time)**
    - **Other approaches available such as random draws of B**
  - Recentering the ensemble perturbations
    - Accounts for differences in resolution, assimilation systems, etc.

Ensemble Spread Behavior – Additive Inflation



80 member ensemble initialized at 2014042400.

Replacement for additive inflation

- Following the lead of ECMWF, pursued the use of "stochastic physics"
  - SPPT: Stochastically Perturbed Physics Tendencies
  - SKEB: Stochastic Kinetic Energy Backscatter
  - SHUM: Stochastically perturbed boundary layer HUMidity
- All use stochastic random pattern generators to create spatially and temporally correlated noise.

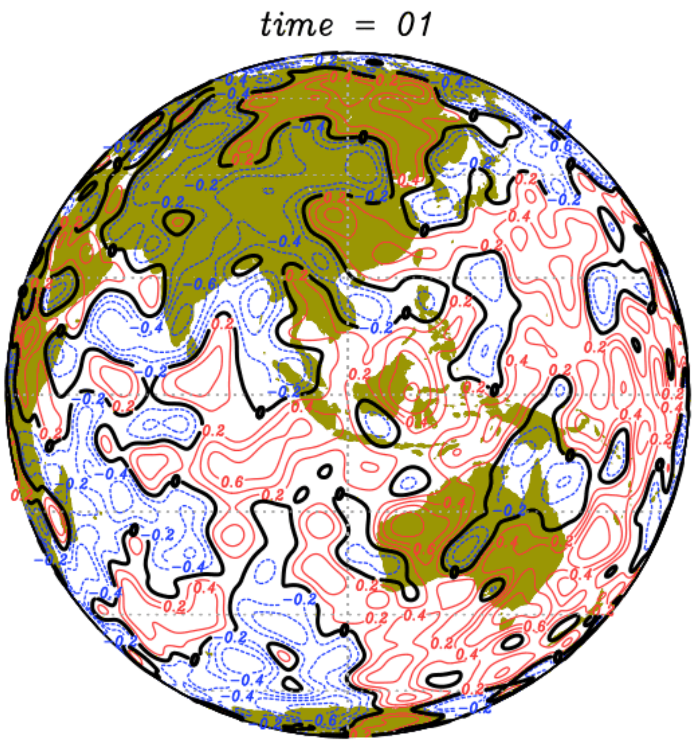
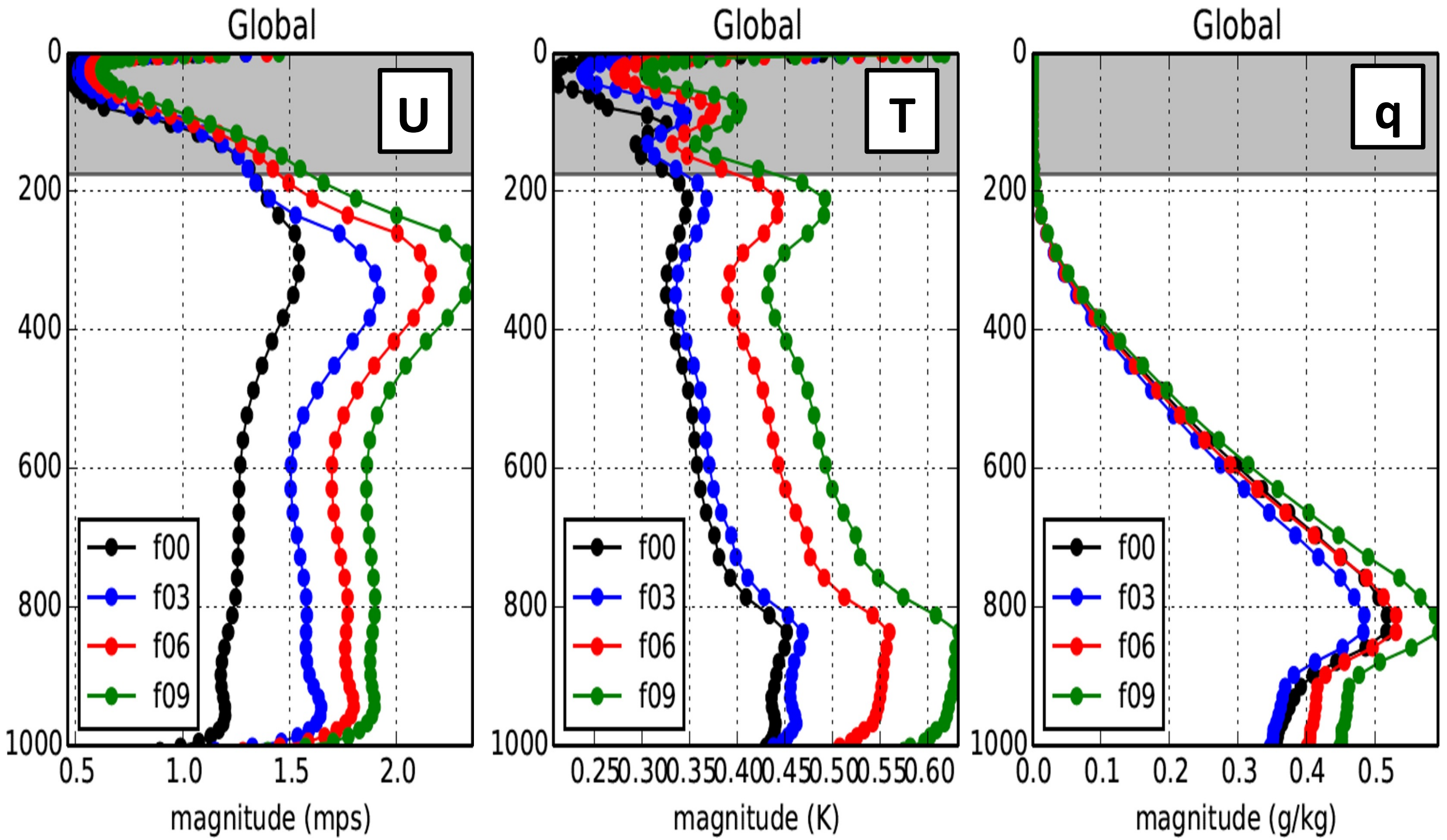


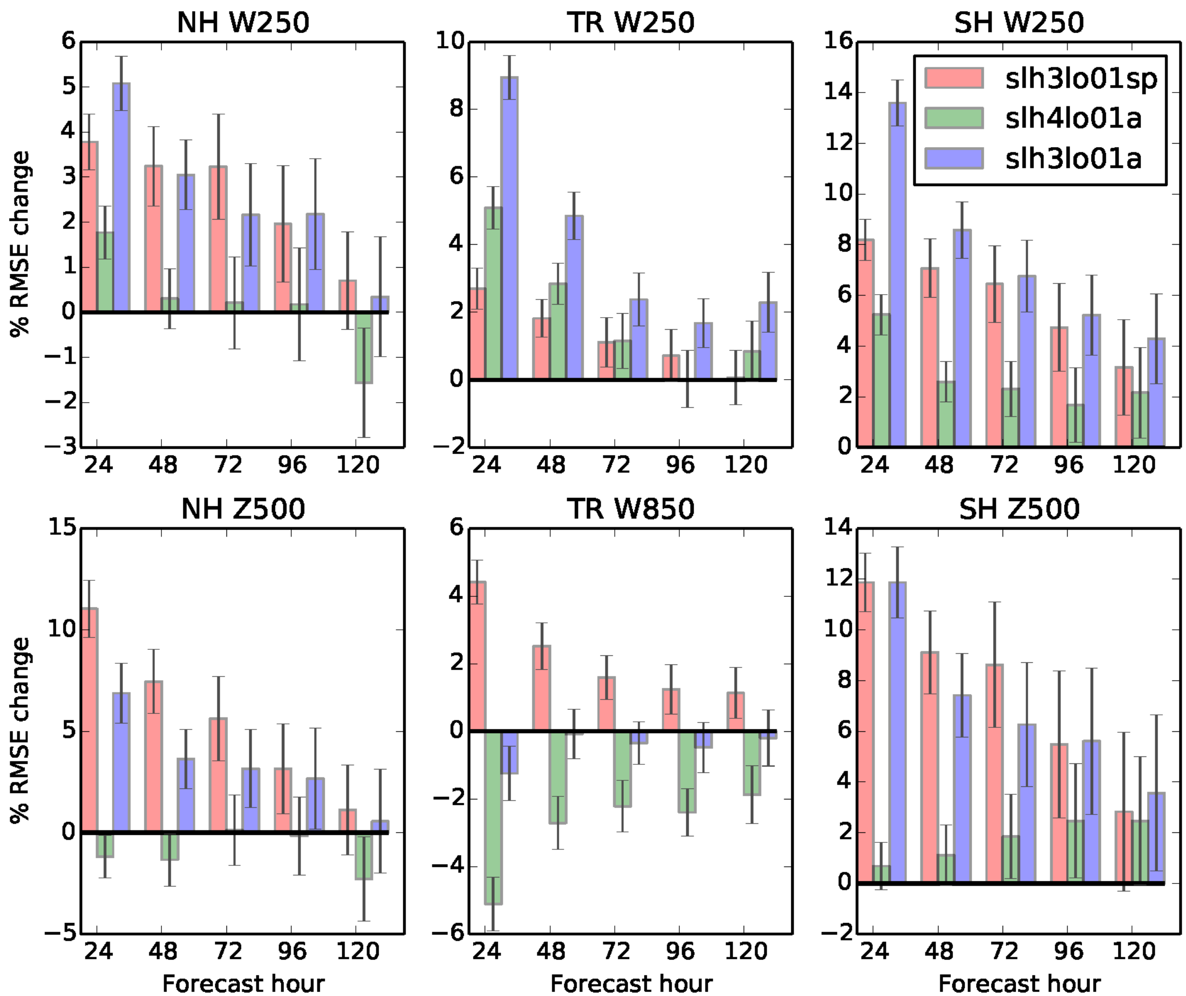
Figure courtesy of Chien-Han Tseng and Deng-Shun Chen

Ensemble Spread Behavior – Stochastic Physics (Replaces Additive Inflation)



80 member ensemble initialized at 2014042400.

Impact of "Stochastic Physics" (SP) on DA Cycling T670/T254 Hybrid with GFS Spectral



SP shows improvement for most lead times and metrics in both 3D and 4D

Some degradation from SP, particularly in low level tropics (retuning has since improved)

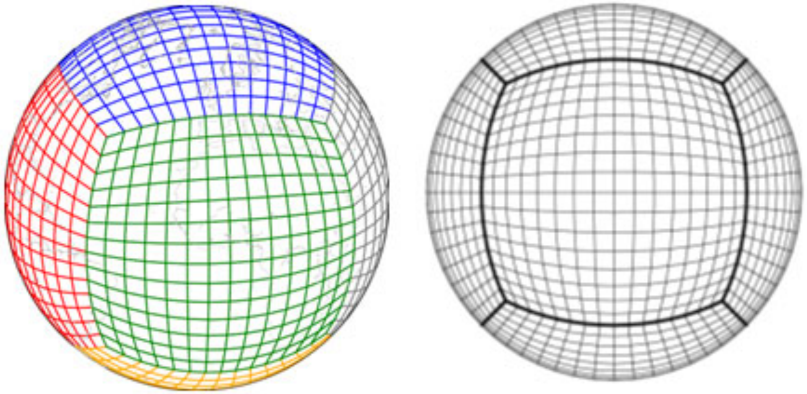
% change RMSE for period covering July-October 2013. Baseline (0) is 4DEnVar with stochastic physics experiment.

Next Generation Global Prediction System (NGGPS)

- Design/Develop/Implement "next generation" global prediction model
  - Nonhydrostatic, scalable dynamics
  - Accelerate physics development
    - Significant leveraging of "community"
- Toward Advanced Data Assimilation
  - Significant investment in Joint Effort for Data Assimilation Integration (JEDI) project
- Position NWS for next generation HPC
- Basis for "Unified Forecast System" across scales
  - From convection allowing ensembles to coupled seasonal prediction

NGGPS/FV3-GFS

- NOAA GFDL FV3 selected for dynamic core component of NGGPS
  - Using Non-hydrostatic option
  - Initial prototyping with (mostly) GFS physics (new: GFDL MP)
  - Initial work uses C768 (~13km) L64 (55km top)



Courtesy: GFDL

- Data Assimilation
  - Adaptation of current hybrid 4DEnVar scheme
    - 80 member ensemble (C384), EnKF update, Stochastic Physics
  - Regridding to accommodate current DA infrastructure
  - Target for 2019 implementation is 127L with 80km top

NGGPS: FV3 Timeline

FY17				FY18				FY19				FY20			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

Evaluate, prepare and document FV3 dycore for GFS

Implement FV3 dycore in NEMS@

Couple FV3 to GFS physics (NUOPC physics driver) perform forecast-only experiments, tuning and

Develop DA techniques % (physics grid; New data)

Cycled experiments, benchmarking, efficiency and optimization

Real-time parallel FV3GFS forecasts to the field

Pre- and post-processing, verification & downstream

3-year retrospective + real-time parallels, EMC and Community Evaluation

Experimental (beta) implementation of FV3GFS*

NCO Parallel

NEMS/FV3GFS in operations

Further advancements of FV3GFS with inputs from NGGPS and community contributions & Global-Meso unification

* Q3FY18 FV3GFS will be very similar to operational GFS being implemented in May 2017

'@ Q3FY19 FV3GFS target resolution is ~10km grid with 127 layers, extends up to 80 km.

'& Advanced physics: Scale-aware convection, SHOC PBL, Double-moment microphysics, Unified convective and orographic gravity wave drag etc

'% DA system will be 25km 127 levels using 4d-Hybrid EnVAR

Adaptation of Stochastic Physics to FV3 (Phil Pegion – ESRL)

- Code for ‘stochastically perturbed physics tendencies’ (SPPT), ’perturbed boundary layer specific humidity’ (SHUM), and ‘stochastic kinetic energy backscatter’ (SKEB) ported to FV3.

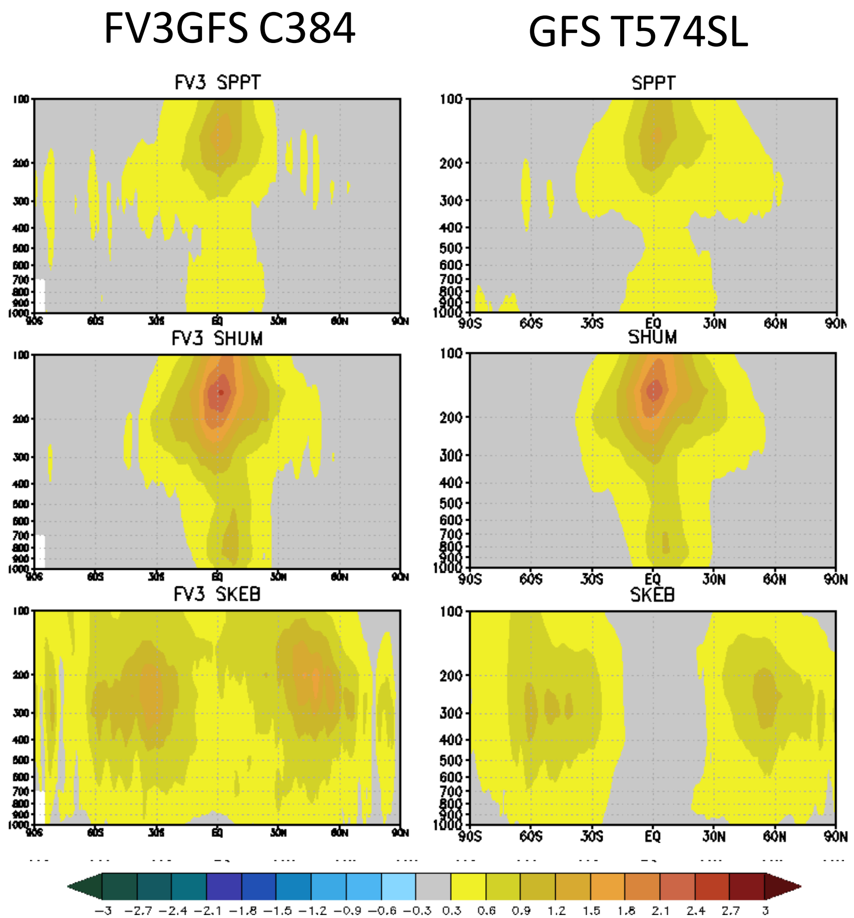
- Some stability issues with SPPT in FV3 – workaround built into system.

- Dissipation estimate for SKEB modified from GSM

- Random patterns generated in spectral space, interpolated to cubed sphere
    - *Plans to develop a native cubed sphere grid version.*

FV3 version reproduces essential features of spectral model implementation

Bottom line result: 5-day forecast of zonal wind

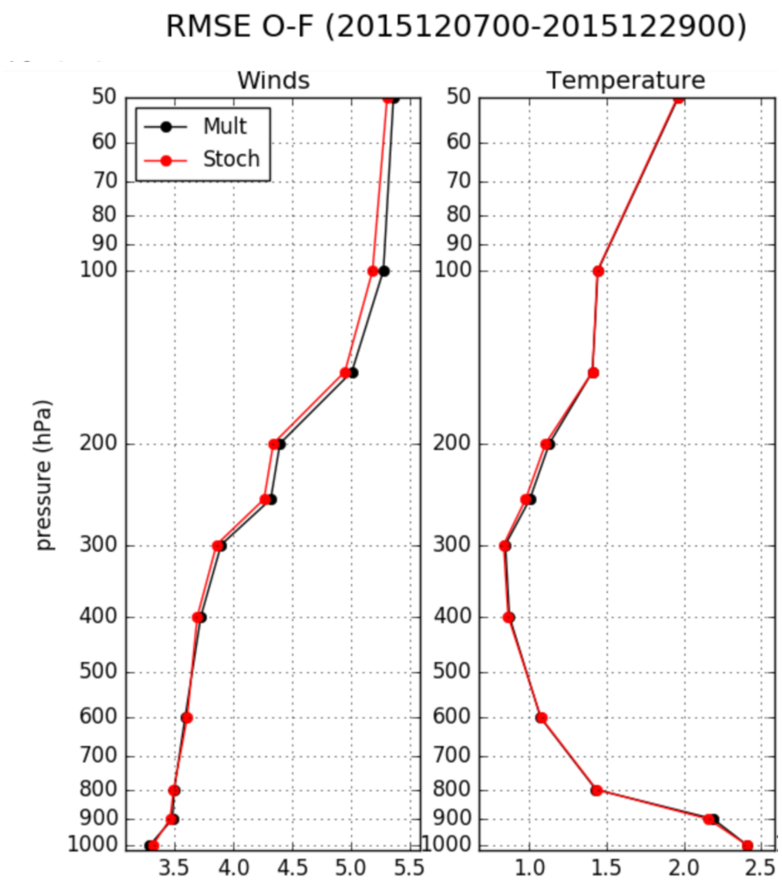


Result courtesy Jeff Whitaker and Phil Pegion (ESRL)

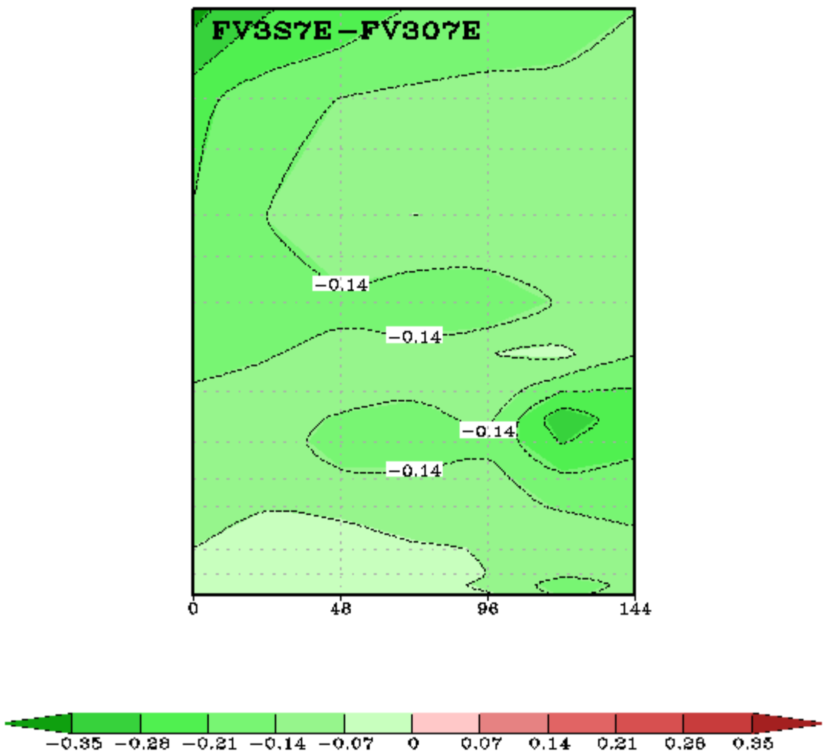
Change in ensemble spread relative to a control ensemble with only initial condition perturbations. GSM is initialized every day at 00Z for August 2014. FV3GFS is only initialized every 5th day starting at 00Z August 1,2014.

Impact of Stochastic Physics
C384 L64 cycled DA tests (3DHybrid)

- Similar to tests from GFS/GSM, use of stochastic physics (SPPT/SHUM) show modest improvement in DA
  - GFS/GSM also uses SKEB, work ongoing within FV3



Wind RMSE Difference, Global (EXP-SP minus Control)

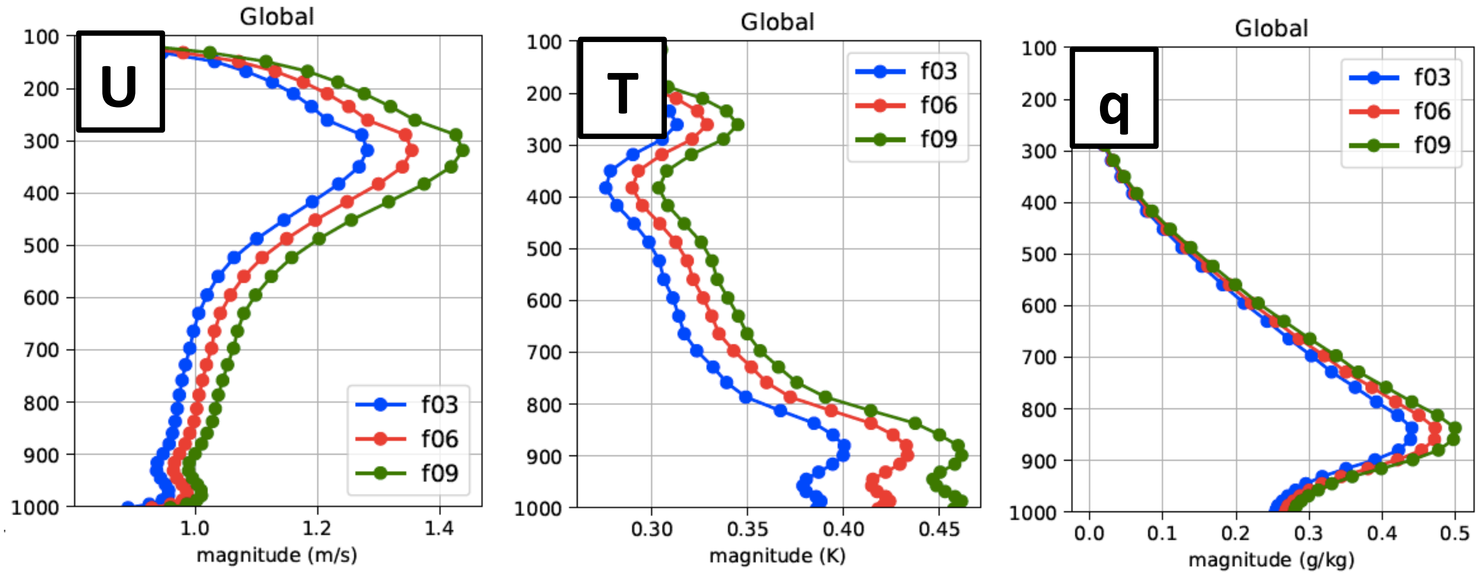


FV3GFS Beta and Implementation

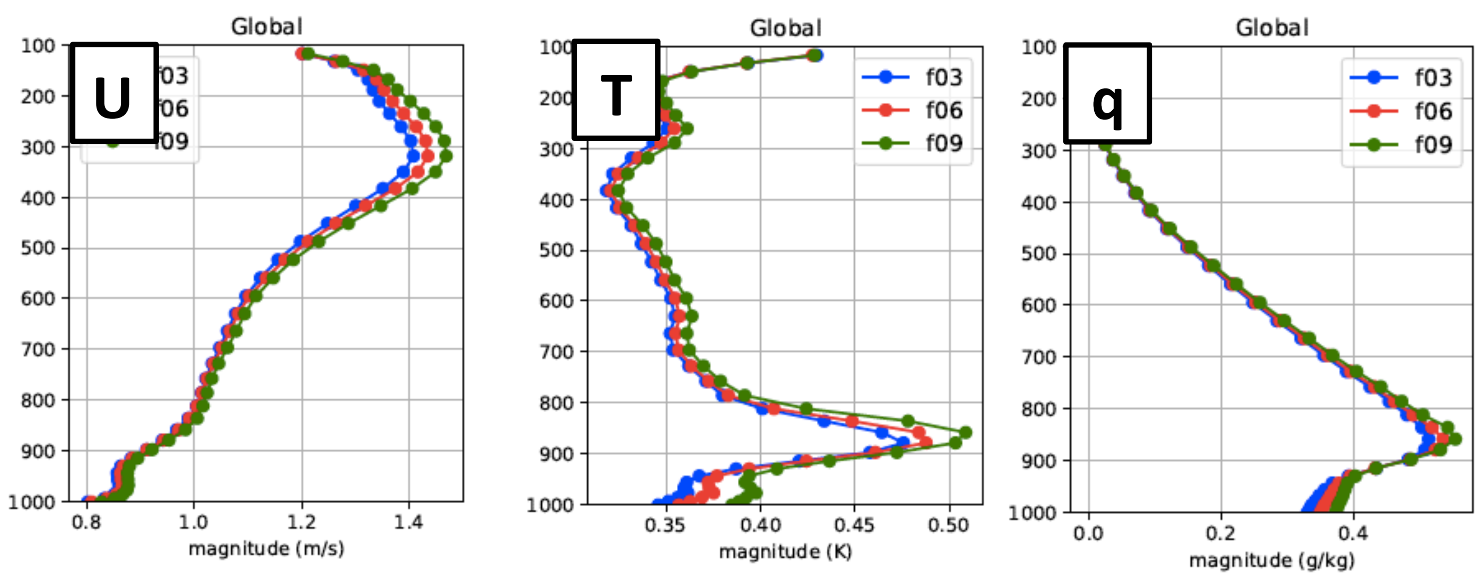
- Stochastic physics integral part of beta version and 2019 FV3-GFS testing and implementation.
  - ***Cathy Thomas (talk): Advances in cloud and water vapor analysis within NGGPS-FV3GFS (Tuesday 11:40 a.m.)***
  - ***Rahul Mahajan (poster): 10.2 – Adopting NCEP's Hybrid 4DEnVar Data Assimilation System to the FV3GFS***

Operational (SPPT/SHUM/SKEB) versus FV3GFS (SPPT/SHUM) 2018030300

OPS

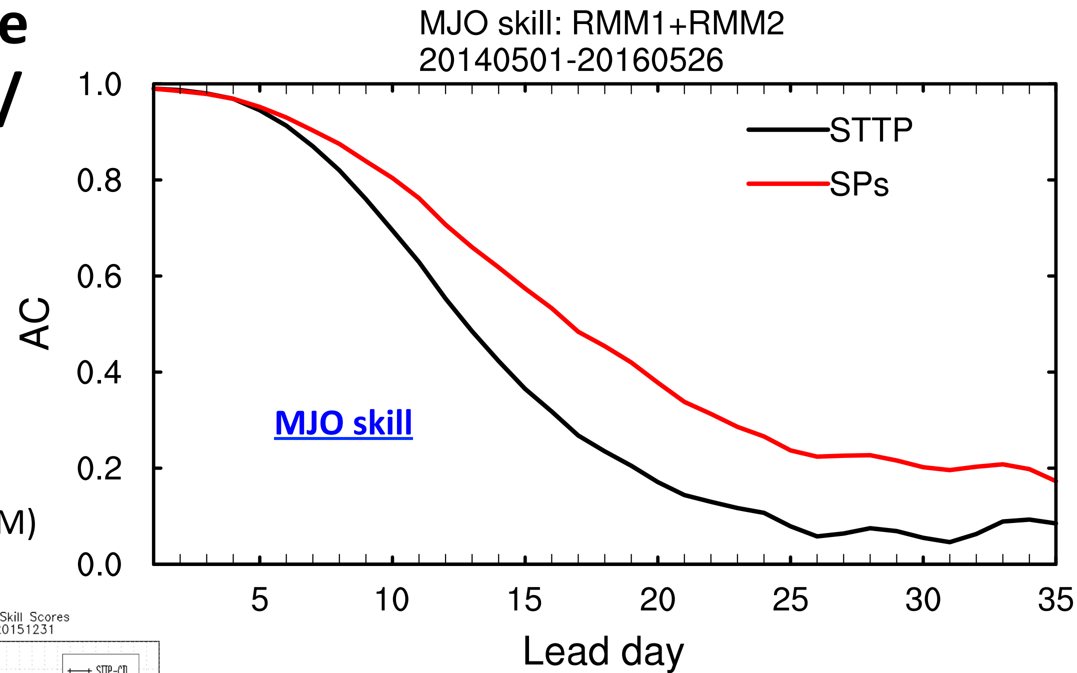


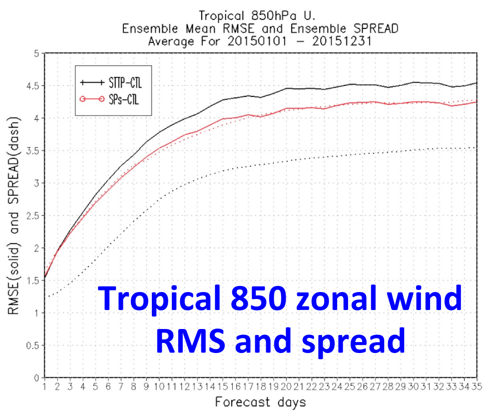
FV3

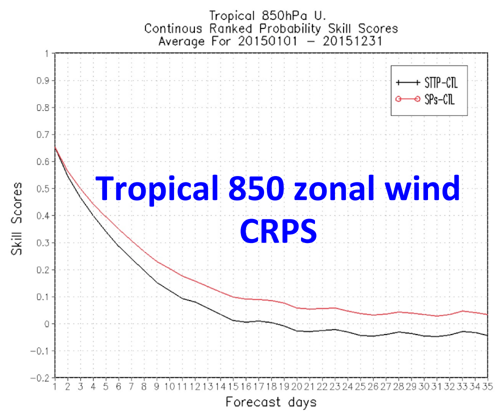


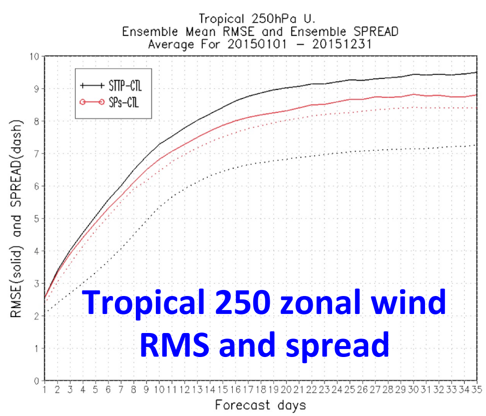
"SubX" experiments: Use of same schemes in EPS/ DA (From EPS Team) Courtesy Y. Zhu

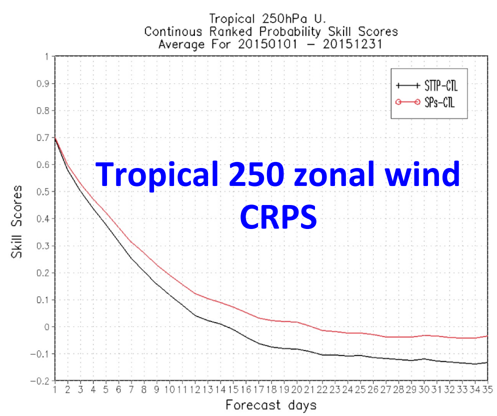
- NCEP GEFSv11 – current operation
- TL574L64 (0-8 days)
- TL382L64 (8-35 days)
- STTP (control) .vs SPs (SKEB+SPPT+SHUM)
- Period: May 2014 – May 2016

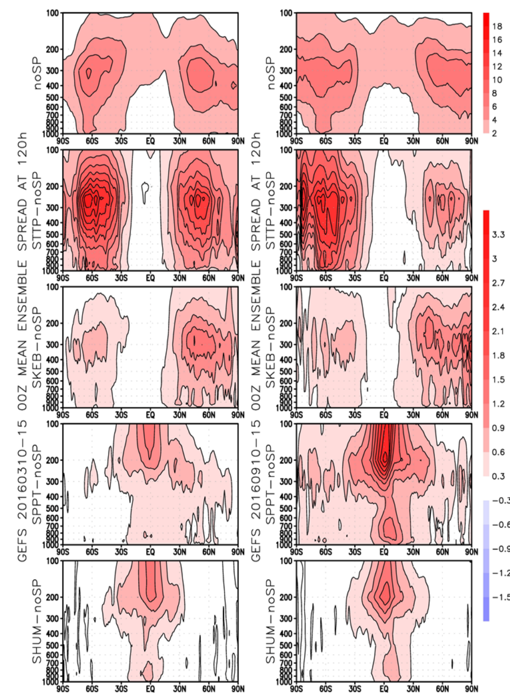












Impact of stochastic schemes: 5 cases F120 – 5 days

Top down

No SPs (ctl)
STTP
SKEB
SPPT
SHUM

Stochastic Advection as Possible Alternative to SKEB (Whitaker)

- Upscale energy transfers (turbulent cascade).
  - Addressed with ‘backscatter’ schemes (Berner et al 2009, *http://dx.doi.org/10.1175/2008JAS2677.1*)
  - ***Stochastic Kinetic Energy Backscatter (SKEB):*** random PV forcing scaled by diffusion magnitude – injects energy where it is being dissipated to simulate missing upscale energy transfer.
  - Designed to represent the effect of nonlinear interactions between unresolved waves.

- ’Location uncertainty’: unresolved motions advecting resolved features
  - Addressed with ‘randomized transport’ (Resseguier et al 2016, *https://arxiv.org/abs/1611.03041*)
  - ***Randomized transport (RANTRAN***): models location uncertainty by adding a random component to the velocity field used in advection.
  - Designed to represent ‘location uncertainty‘ from advection of resolved features by unresolved motions.

Tests with FV3 (Whitaker)

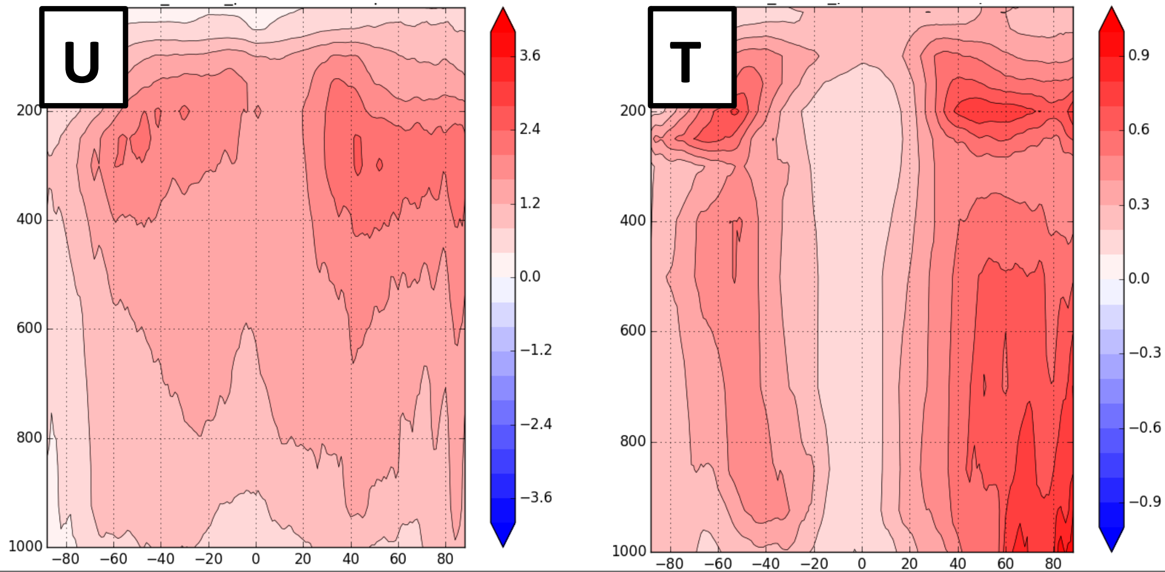
- Version of RANTRAN implemented into FV3

- 31 5-day 20 member forecasts run every 00UTC from 1 Jan to 31 Jan 2014 at ~50 km resolution using operational GFS EnKF initial conditions.

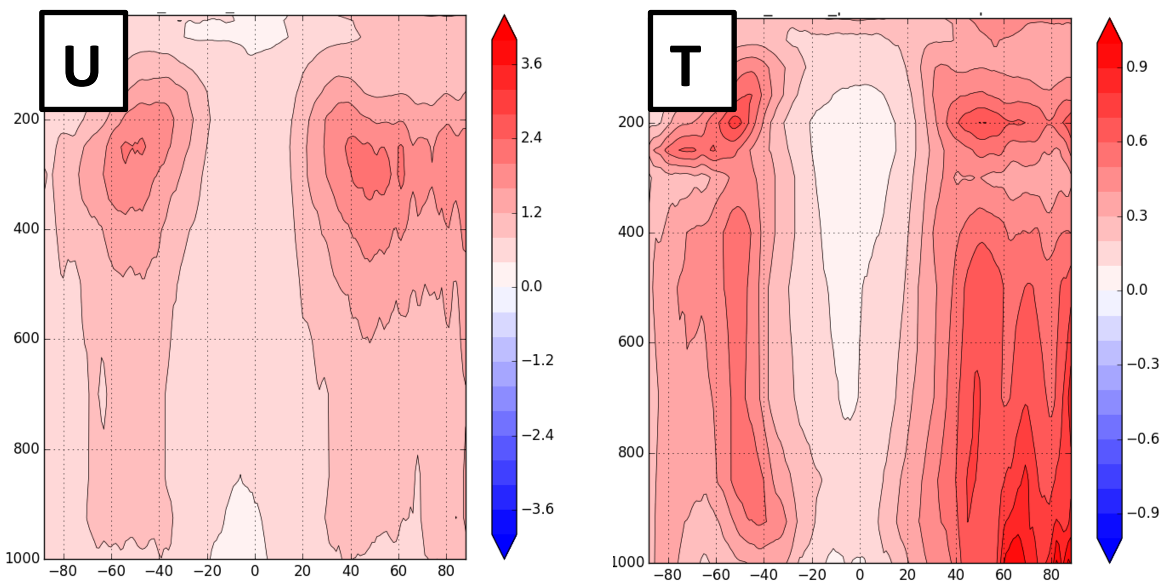
- 3 experiments:
  - Control (no stochastic component)
  - RANTRAN (randomized transport). 250 km/6-h correlation scales.
  - SKEB. 250 km/6-h correlation scales using smoothed kinetic energy numerical dissipation estimate.

Impact on 5-day Spread

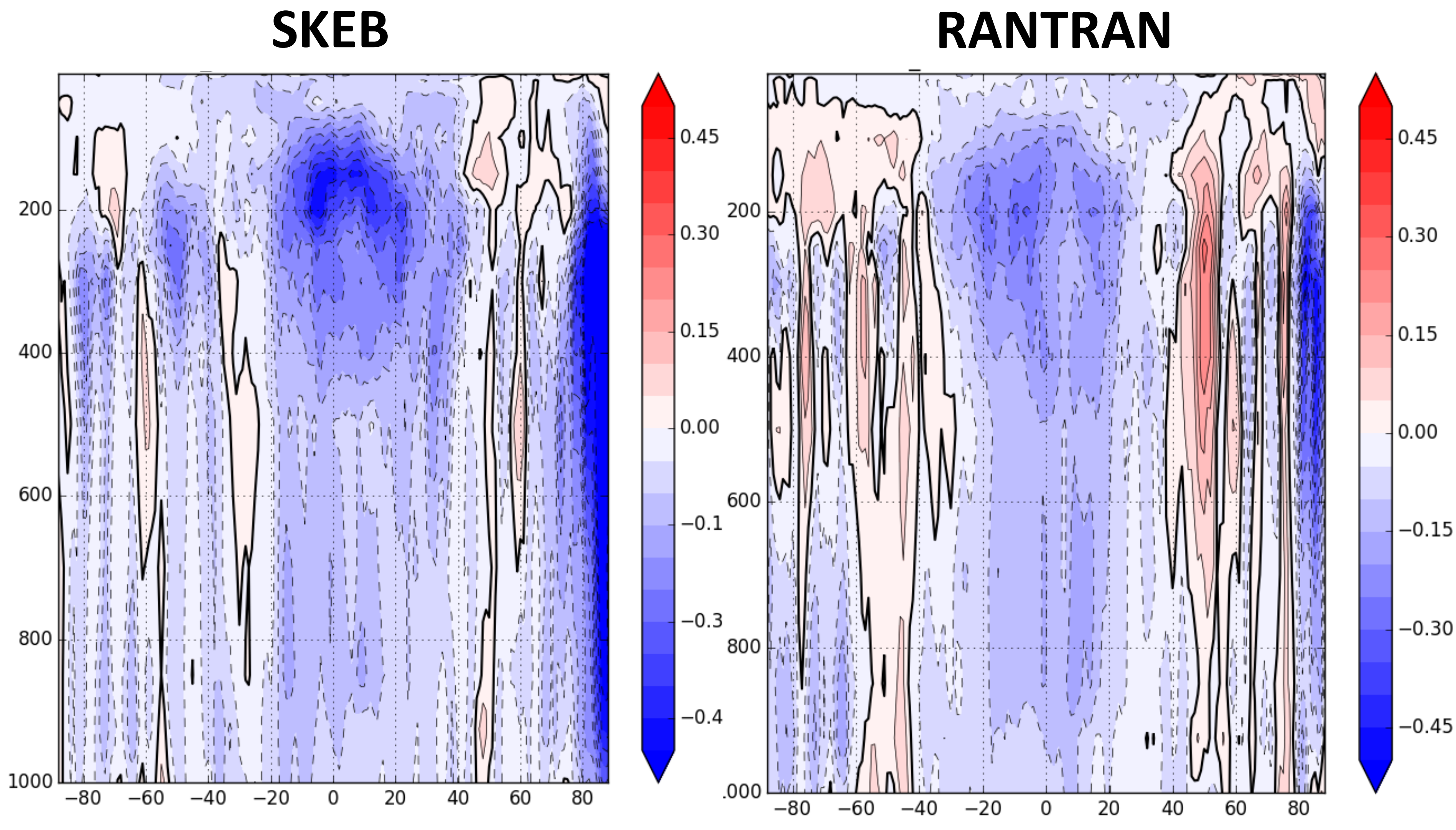
SKEB



RANTRAN



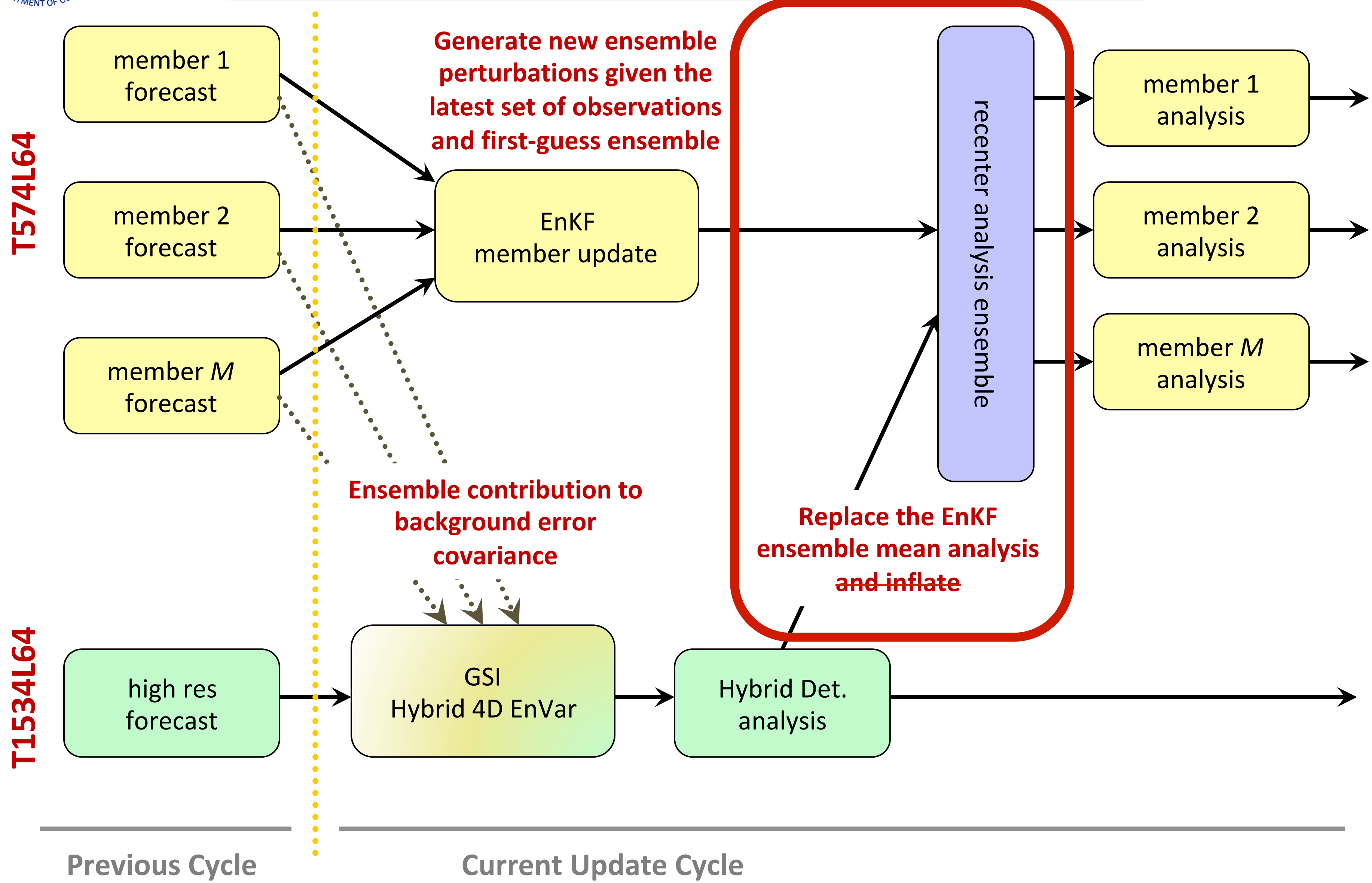
Ensemble Mean Vector Wind RMSE Difference (Relative to Control)



Summary

- Successfully replaced additive inflation with stochastic physics in data assimilation cycling
  - Working toward use of same stochastic physics in ensemble prediction system
- Ported stochastic schemes into FV3-GFS
  - SHUM & SPPT will be included in operational implementation (2019)
  - SKEB is still being considered/tested
- Exploring random transport scheme as supplement or replacement of SKEB

Current Operational Configuration
Hybrid 4DEnVar (May 2016)



- Version of RANTRAN implemented into FV3
  - Random non-divergent C-grid winds with specified correlation structure added added to interpolated C-grid winds when computing fluxes.
  - Fluxes of potential temperature, mass, humidity, vertical vorticity, hydrometeors and ozone are perturbed.
  - A single random pattern of streamfunction is used to generate random winds – no vertical structure. No smoothed dissipation estimate needed.