# Assimilation/Ensembles/Stoch Physics

Jeff Whitaker, Phil Pegion, Tom Hamill, Lili Lei

*NOAA/OAR/ESRL/PSD and University of Colorado/CIRES*

Rahul Mahajan and Walter Kolczynski

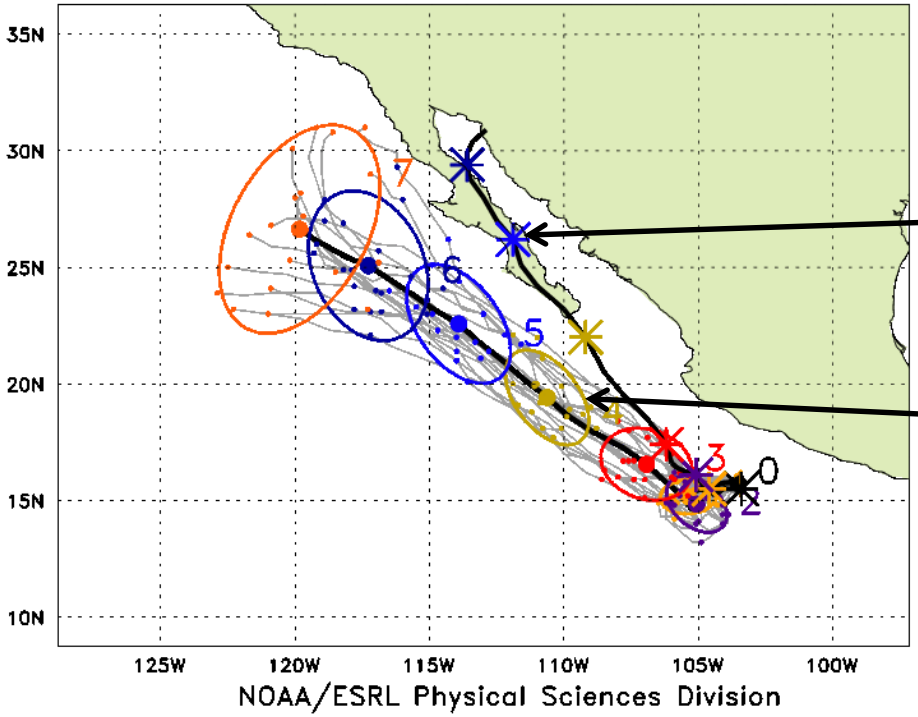
*NCEP*

# Projects

- Accounting for model uncertainty in NCEP GFS
  - 1st gen schemes developed and tested under HIWPP, anticipate implementation in GEFS v12
- Development of a operational hybrid 4D ensemble-var DA system for the GFS
  - Testing and implementation accelerated with HIWPP support.
  - Scheduled for implementation this spring.

# The need to account for model uncertainty in weather prediction

Hurricane Odile: Initialized Sept. 11, 2014 at 00Z
GEFS operational ensemble




Observed track

Ensemble Forecast tracks

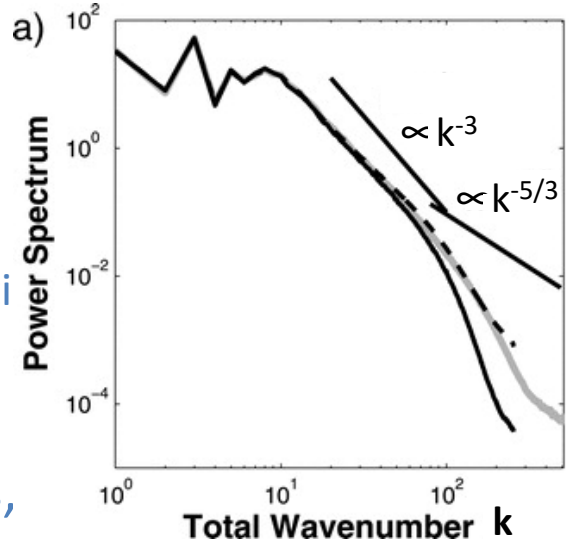
GFS ensemble was confident that the hurricane would stay off shore.

# How we currently account for model uncertainty in the GFS

- **Dynamics**: Due to the model's finite resolution, energy at unresolved scales cannot cascade to larger scales.
  - Approach: Estimate energy lost each time step, and inject this energy in the resolved scales. a.k.a stochasti energy backscatter (SKEB; Berner et al. 2009)

- **Physics**: Subgrid variability in physical processes, along with structural errors in the parameterizations result in model uncertainty
  - Approach: perturb the results from the physical parameterizations (Palmer et al. 2009), and boundary layer humidity (Tompkins and Berner 2008).

Kinetic Energy Spectrum




Berner et al. (2009)

# Initial Expts: Experiment Design

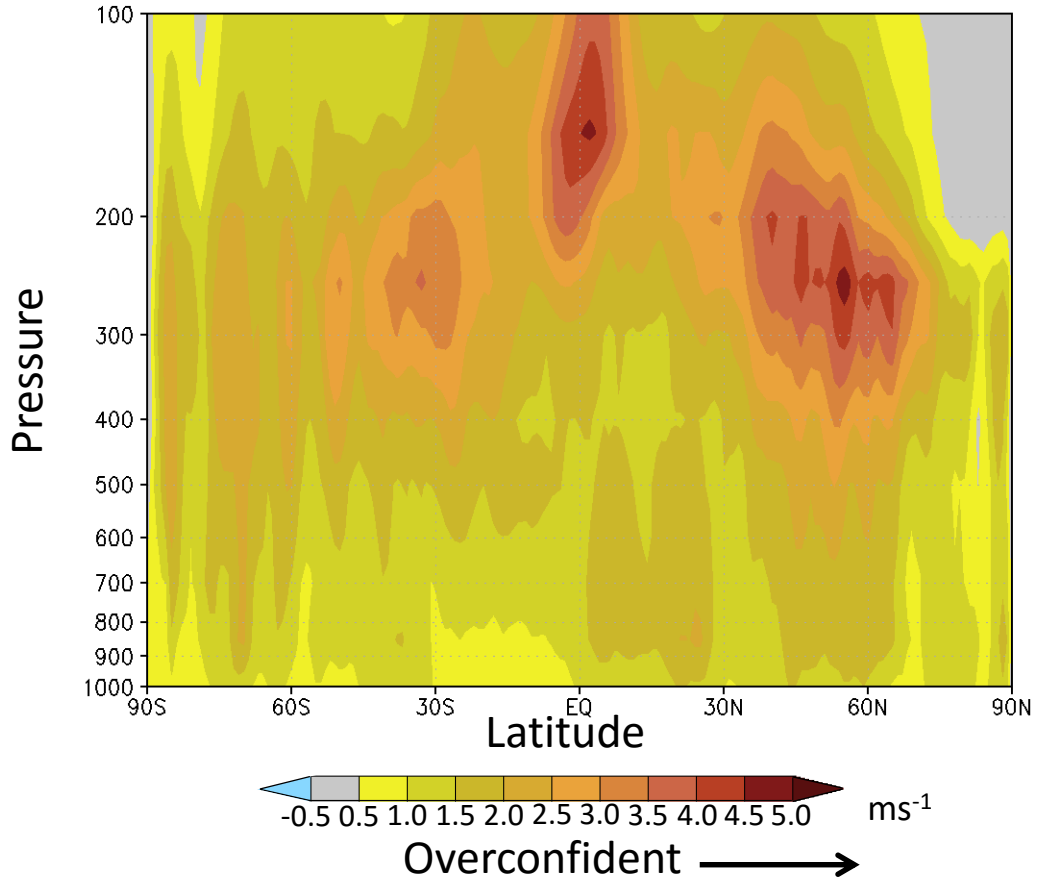
- NCEP GFS, T574-L64 – 20 member ensemble
- 5-day forecasts initialized every day at 00z for August 2012
- Verified against the consensus analysis
- CNTL: 20-member ensemble with only initial condition perturbations

# 5-day forecast Zonal Wind RMS error – Spread

zonal average from 1 month of forecasts: August 2012

**RMS error**: ensemble mean error with respect to verifying analyses

**Spread**: standard deviation among ensemble members

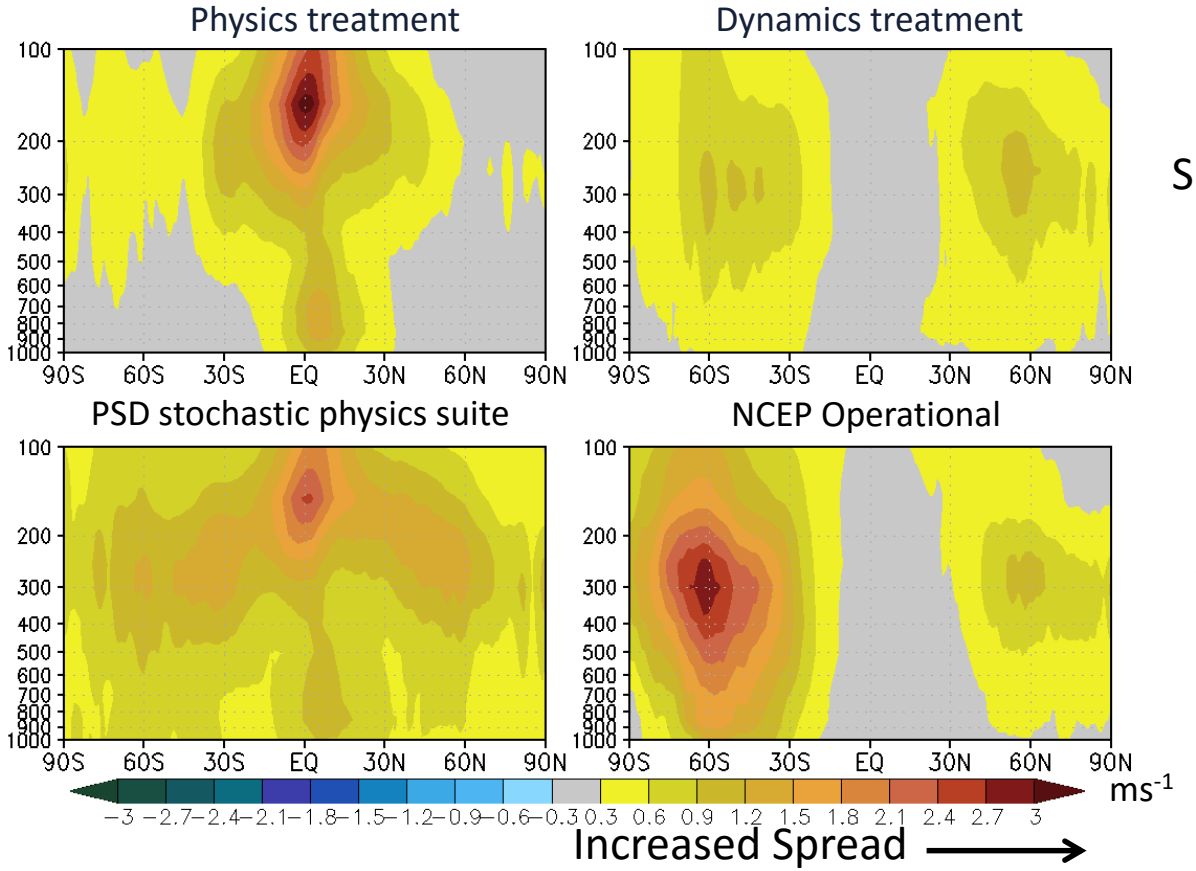



GFS ensemble, no treatment for model error “baseline”

# Change in Ensemble Spread

zonal average from 1 month of forecasts (Aug 2012)

120 hr zonal wind spread difference compared to baseline




SPPT & SHUM

SKEB

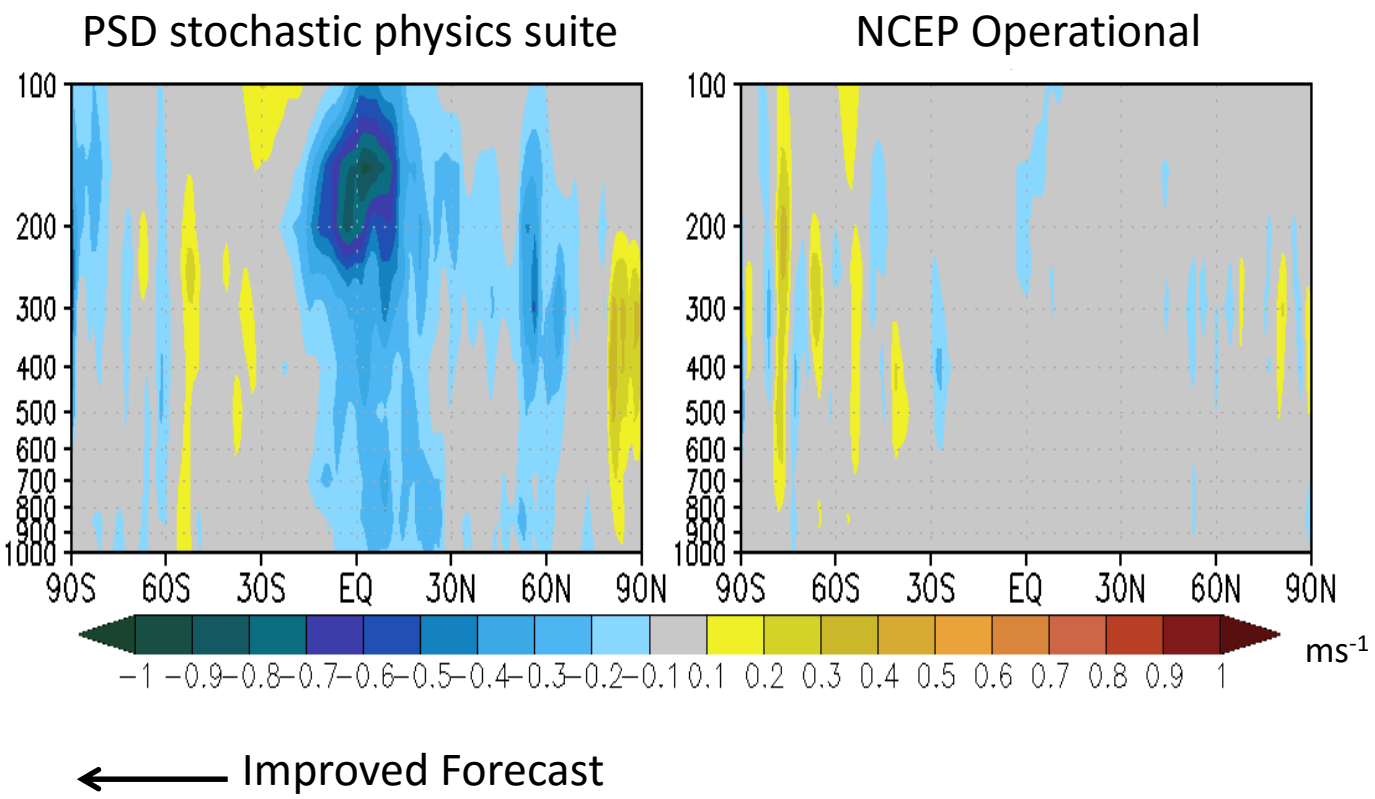
SPPT,SHUM, & SKEB

STTP (opnl)

# Change in Forecast Error

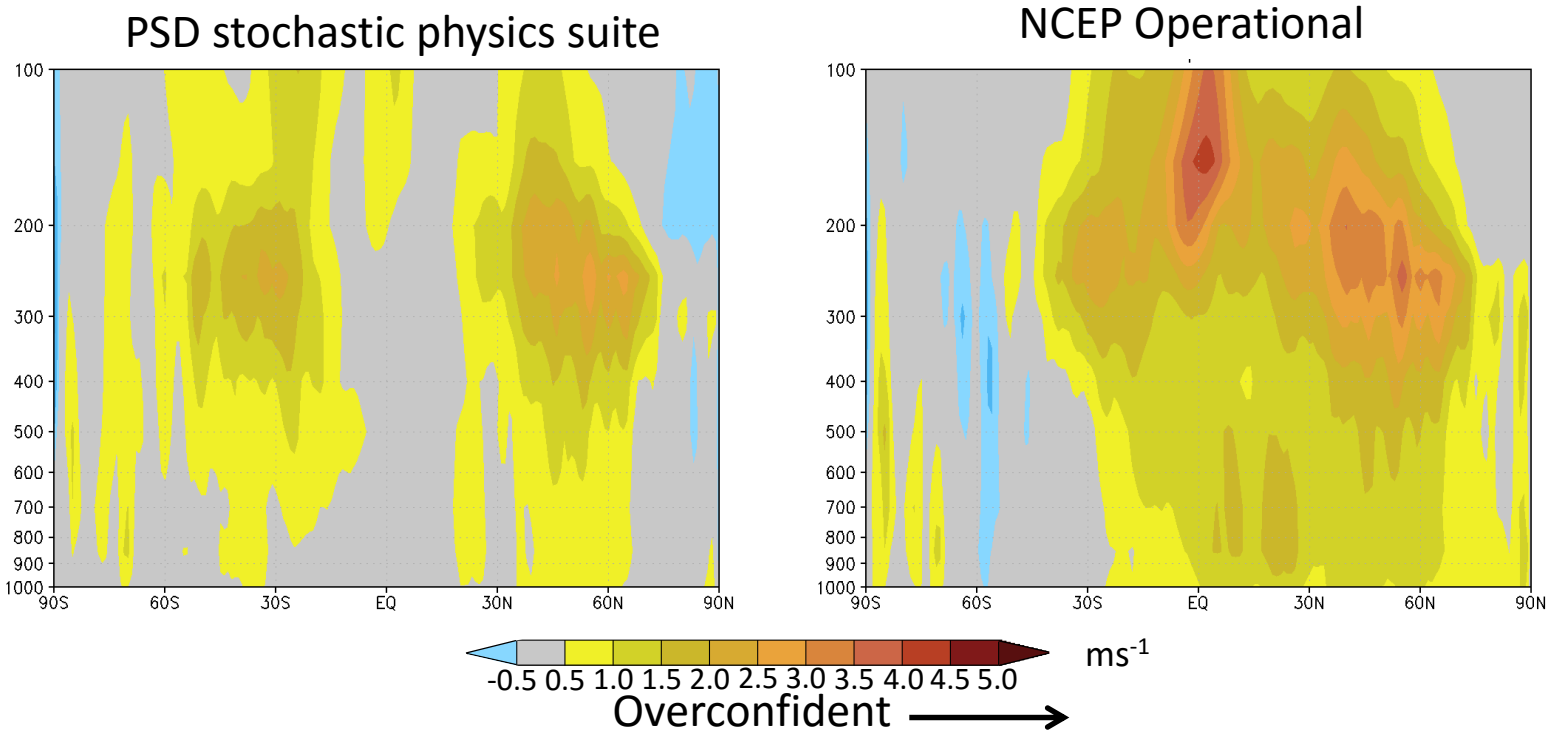
zonal average from 1 month of forecasts(Aug 2012)

120 hr zonal wind ensemble mean error compared to baseline



# Zonal Wind RMS error – Spread including treatment for model uncertainty

zonal average from 1 month of forecasts (Aug 2012)




1st gen stochastic physics package improves the spread/error relationship in the medium range forecast, but is still deficient in the jet stream regions, and in surface quantities which are not shown.

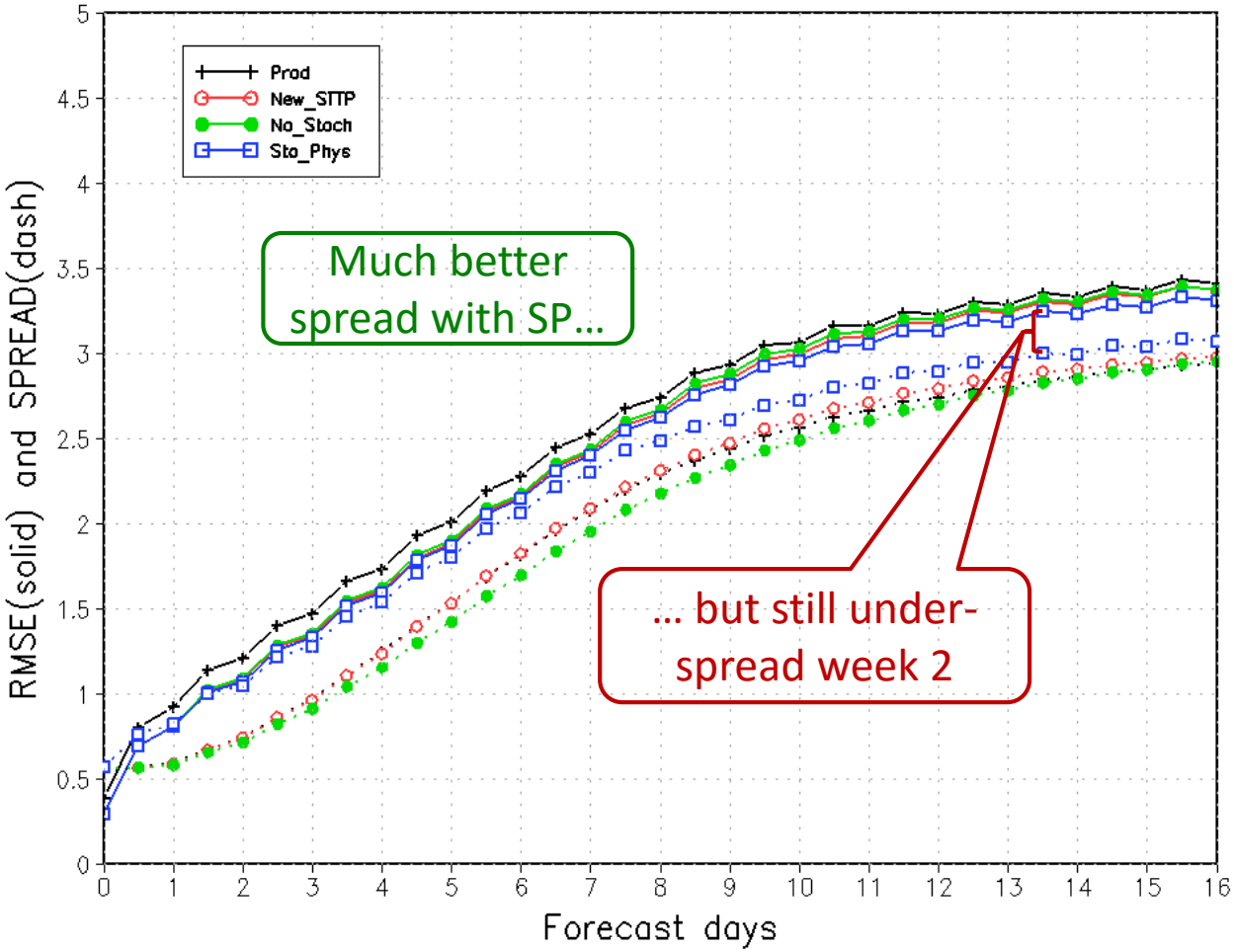
# Further testing at NCEP (Walter Kolczynski)

Four experiments:

- Prod: (Previous) Opnl Production forecast
  - Eulerian T254/190L42
  - BV-ETR initial conditions
- New STTP: Q1FY16 configuration
  - Semi-Lagrangian T574/382L64
  - EnKF initial conditions
  - Additional STTP tuning
- No Stoch: New configuration, but without any stochastic perturbation
- Sto Phys: New configuration with SPPT/SHUM/SKEB turned on

# Summer Results — 850-hPa

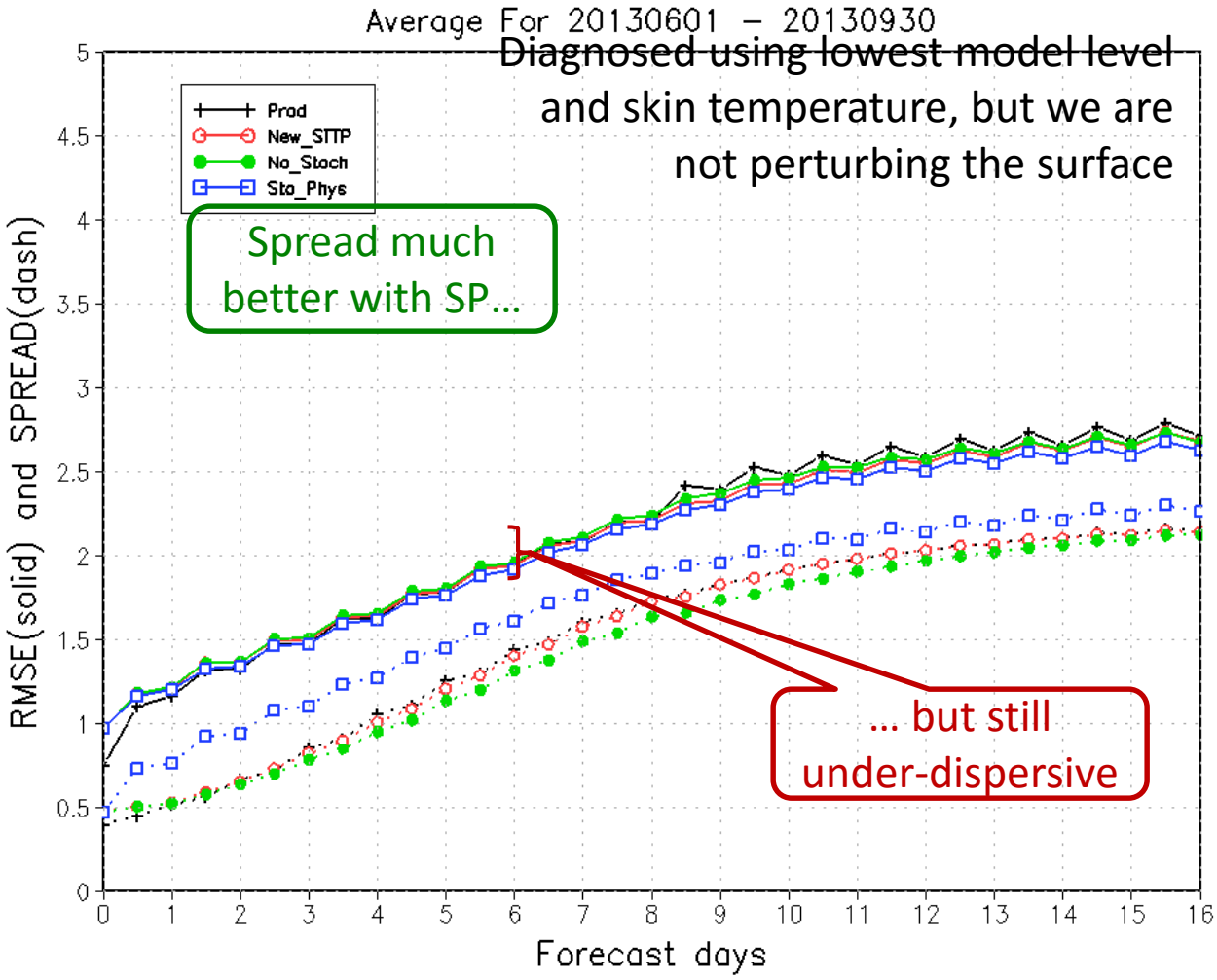
Northern Hemisphere
RMSE (solid) and Spread (dotted)




Production
New STTP
No Stoch
Sto Phys

# Summer Results — 2-m Temperature

Northern Hemisphere
RMSE (solid) and Spread (dotted)

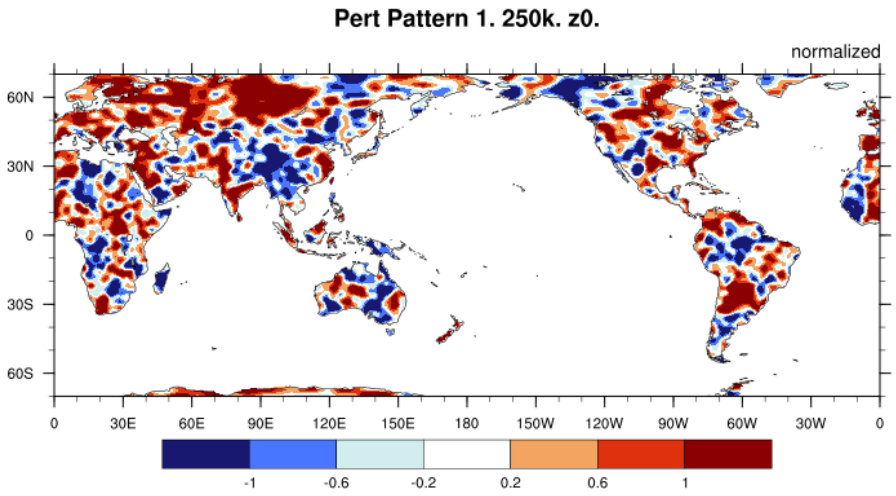



Production
New STTP
No Stoch
Sto Phys

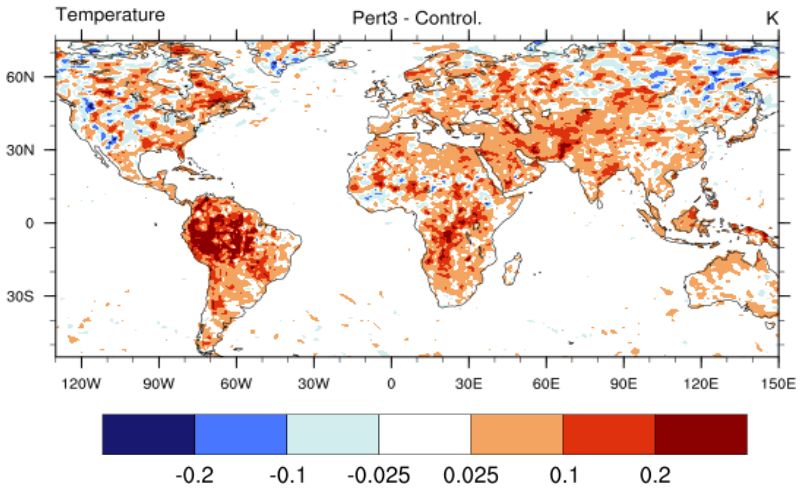
# Surface Perturbations

- There are errors associated with the lower boundary conditions
  - in atmosphere only runs (GFS), SST anomalies are damped toward climatology during the forecast.
  - Errors associated with land surface model and initial conditions (not addressed here)

- Methods
  - Perturb SST with random pattern
  - Perturb surface momentum roughness length (Z0),thermal roughness length (zt) and soil hydraulic conductivity (SHC), and leaf area index (LAI)



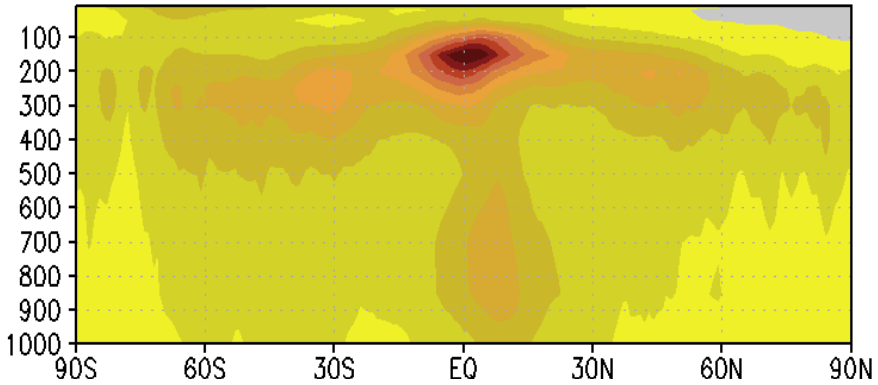

change of spread



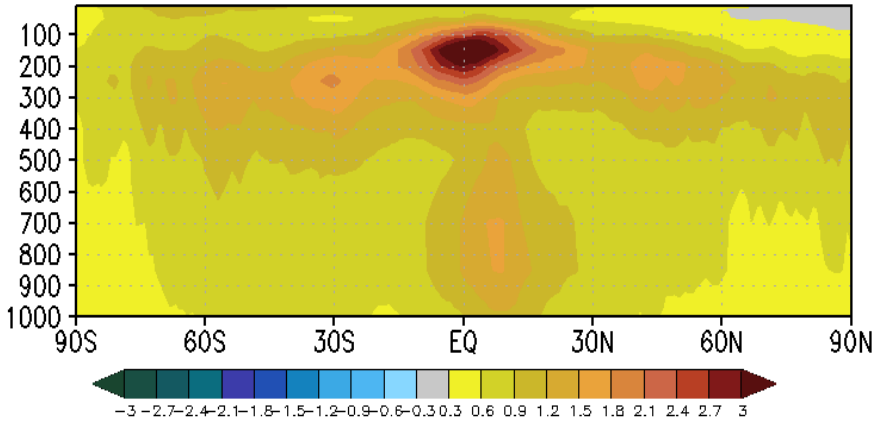
# Change in Ensemble Spread (Temperature)

zonal average from 1 month of forecasts (August 2014)

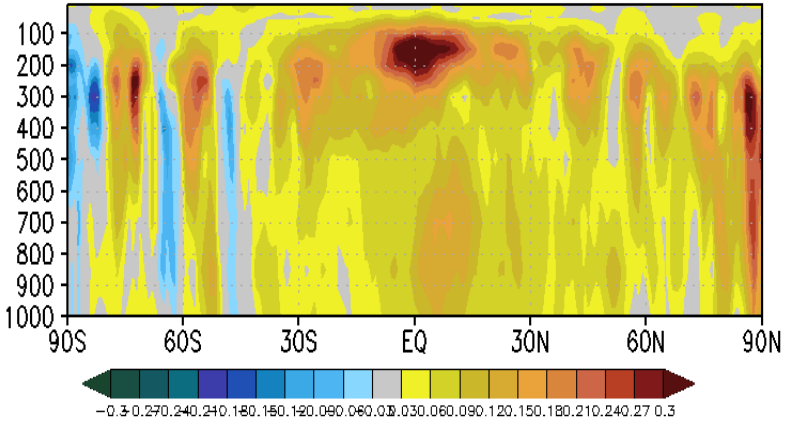
Atmosphere only stochastic parameterizations




Atmosphere & land stochastic parameterizations




Impact from surface perturbations




The addition of the surface (SST and land) perturbations provides a small increase in spread.

# Issues

- Ensemble spread still too small in jet regions, and near surface.
- There is ongoing work to address the initial condition uncertainty of the land state through forcing the land model with different precipitation estimates
- Next step is to develop physically based (process level) stochastic paramterizations to replace these 1$^{st}$ gen (somewhat ad-hoc) methods.

# Hybrid 4D-EnVar development

- NCEP developed code for using 4D ensemble covariances in GSI
- ESRL developed and testing extensions to EnKF code to improve efficiency, calculate 4D increments.
  - Added code to GFS to implement 4D incremental analysis update (IAU).
- ESRL/NCEP jointly tested and tuned prototype hybrid 4DEnVar system.

# Ensemble-Variational methods: *nomenclature*

- ***En-Var:*** background error covariance ($\mathbf{P^b}$, updated using EnKF and propagated through an ensemble, for e.g.) is used in the variational solver.

- ***3D-EnVar***: $\mathbf{P^b}$ is assumed to be constant through the assimilation window (current NCEP implementation).

- ***4D-EnVar***: $\mathbf{P^b}$ at every time in the assimilation window comes from ensemble estimate (no TLM needed).

- ***En-4DVar***: static $\mathbf{P^b}$ is replaced with ensemble estimate (or hybrid) at the beginning of the assimilation window, but propagated with tangent linear model (and its adjoint) within the window.

*Courtesy: Jeff Whitaker*

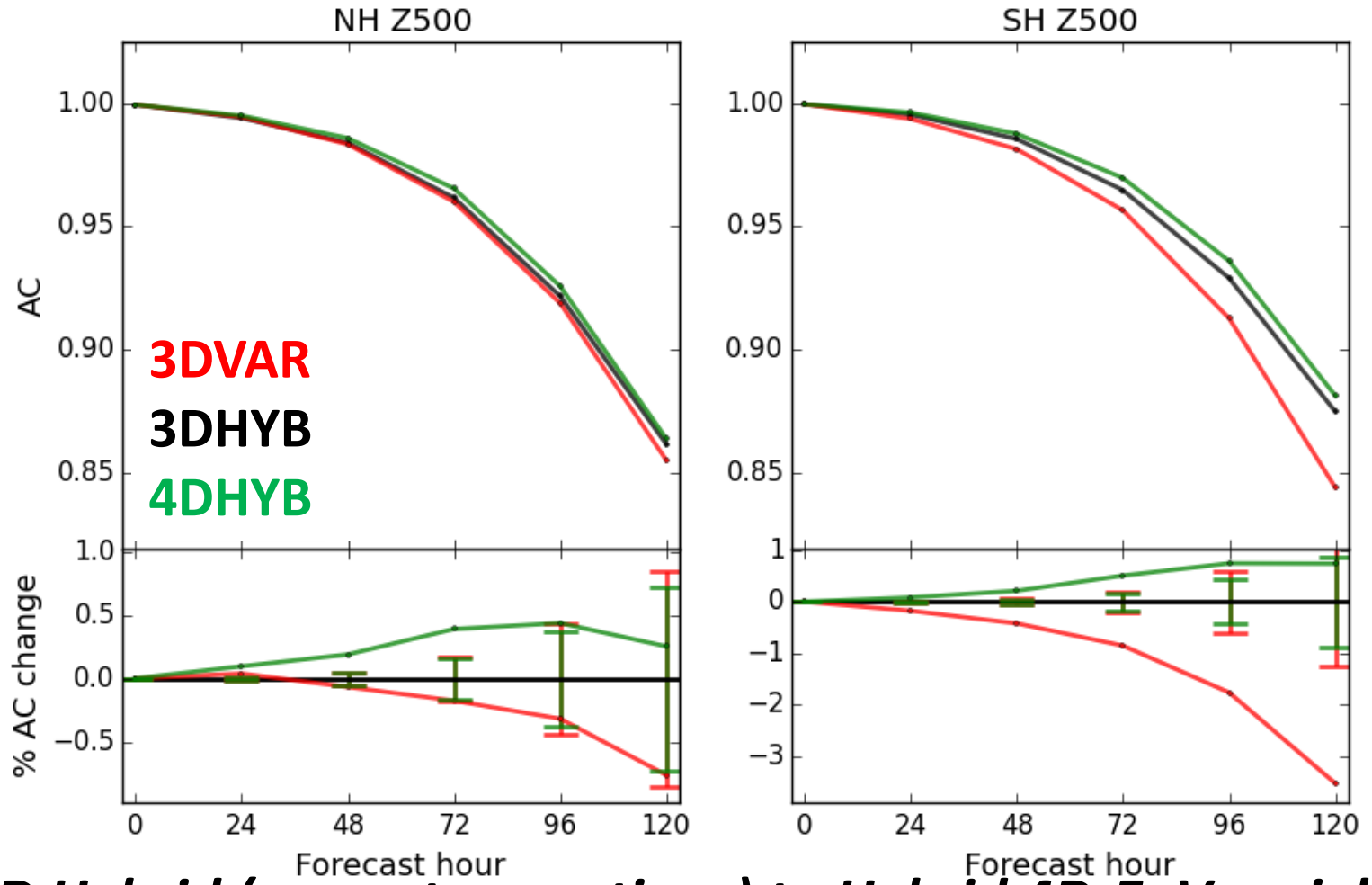
# 4DHybrid details

| | Current 3DHybrid | Proposed 4DHybrid |
|---|---|---|
| Static / Ensemble Weights | 25% static ; 75% ensemble | 12.5% static; 87.5% ensemble |
| Additive Inflation | 5% | 0% |
| Tropospheric localization length scales | | ½ of current 3D Hybrid |

**Test Configuration**

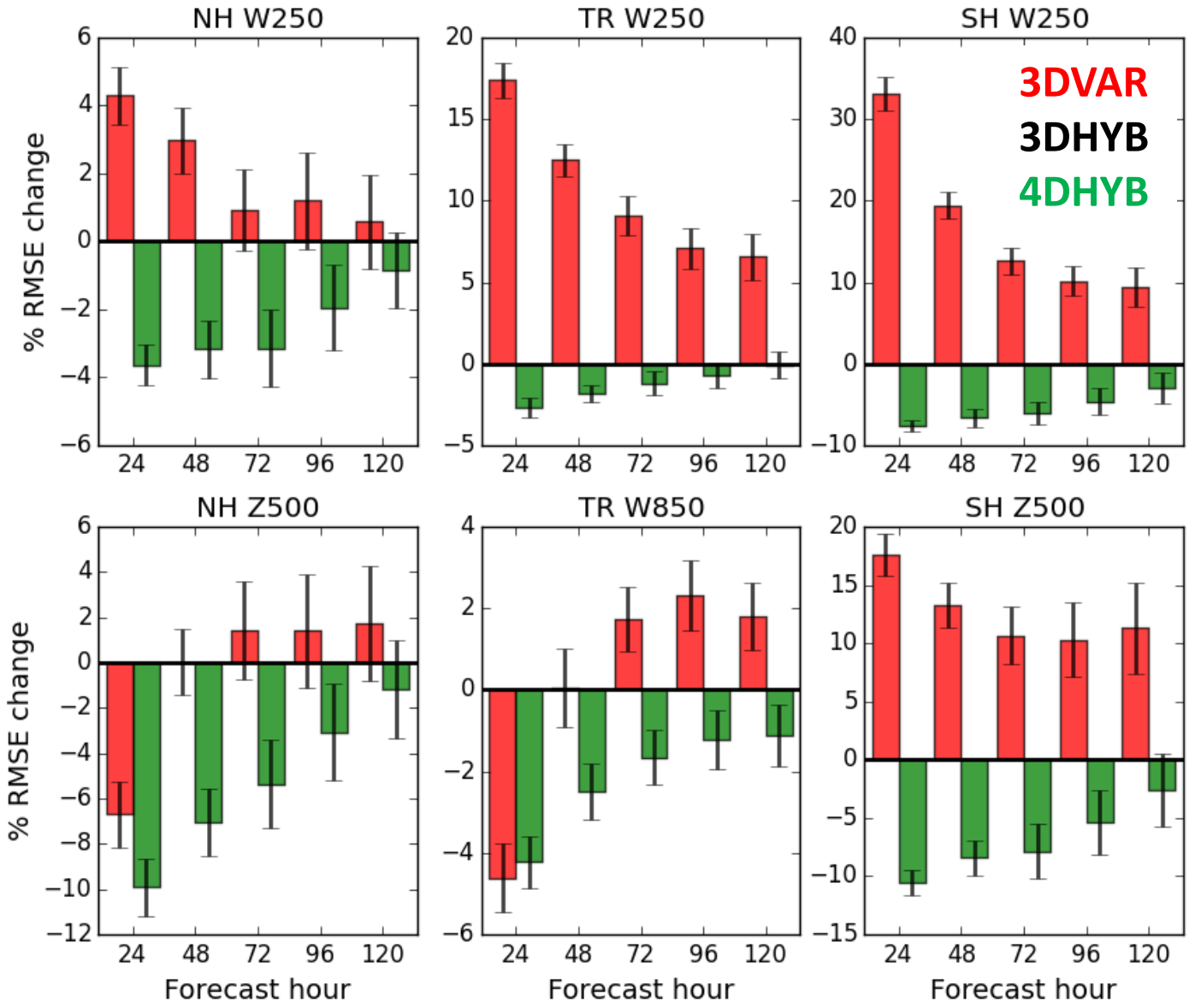
- T670L64 deterministic GFS with 80 member T254L64 ensemble with fully coupled (two-way) EnKF
- Incremental normal mode initialization (TLNMC) on total increment
- Multiplicative inflation and stochastic physics for EnKF perturbations
- Full field digital filter

# 500 hPa Die Off Curves (low res tests)

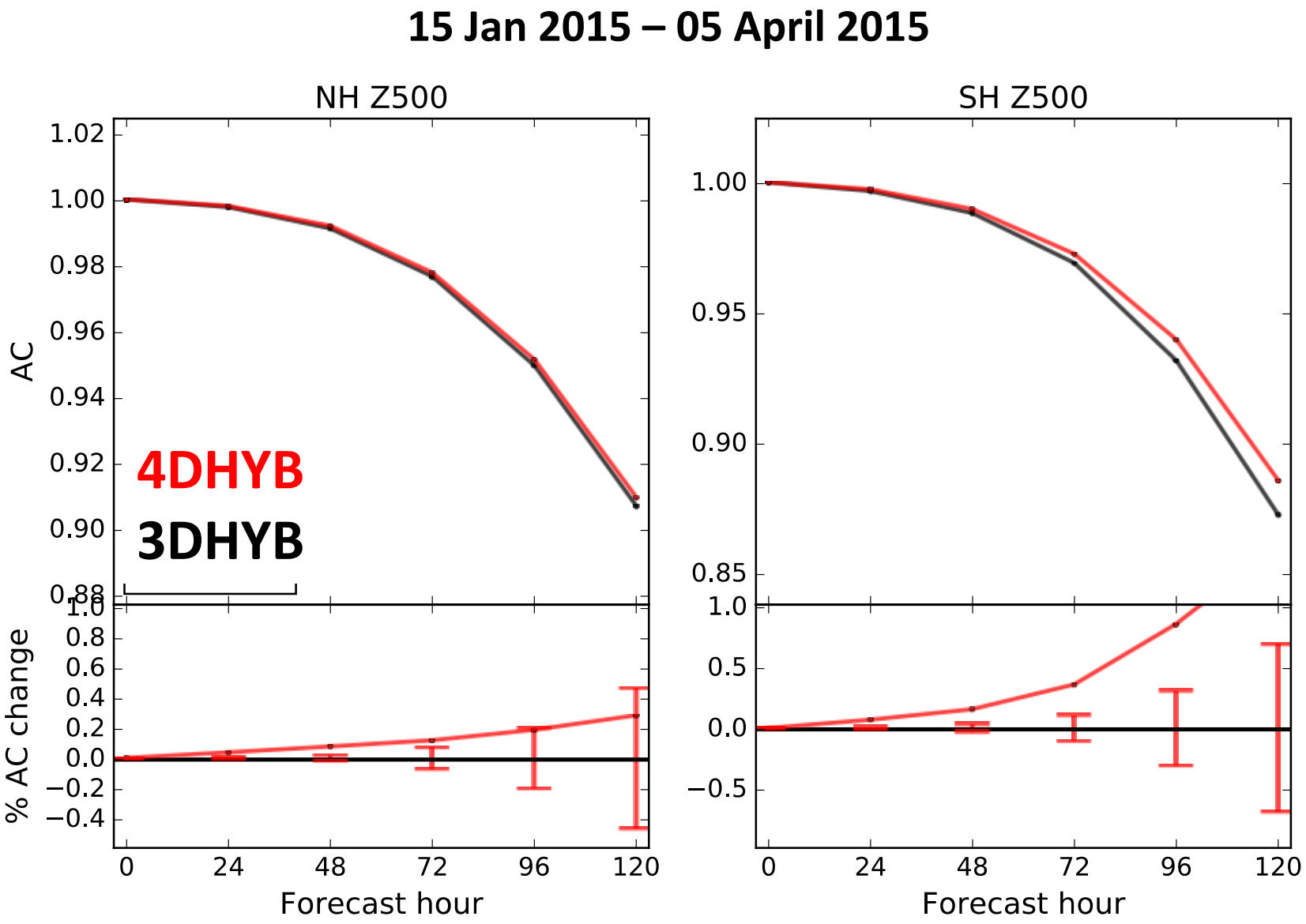



***3D Hybrid (current operations) to Hybrid 4D-EnVar yields improvement that is about 75% in amplitude in comparison from going from 3DVar to 3D Hybrid***

# RMSE Summary



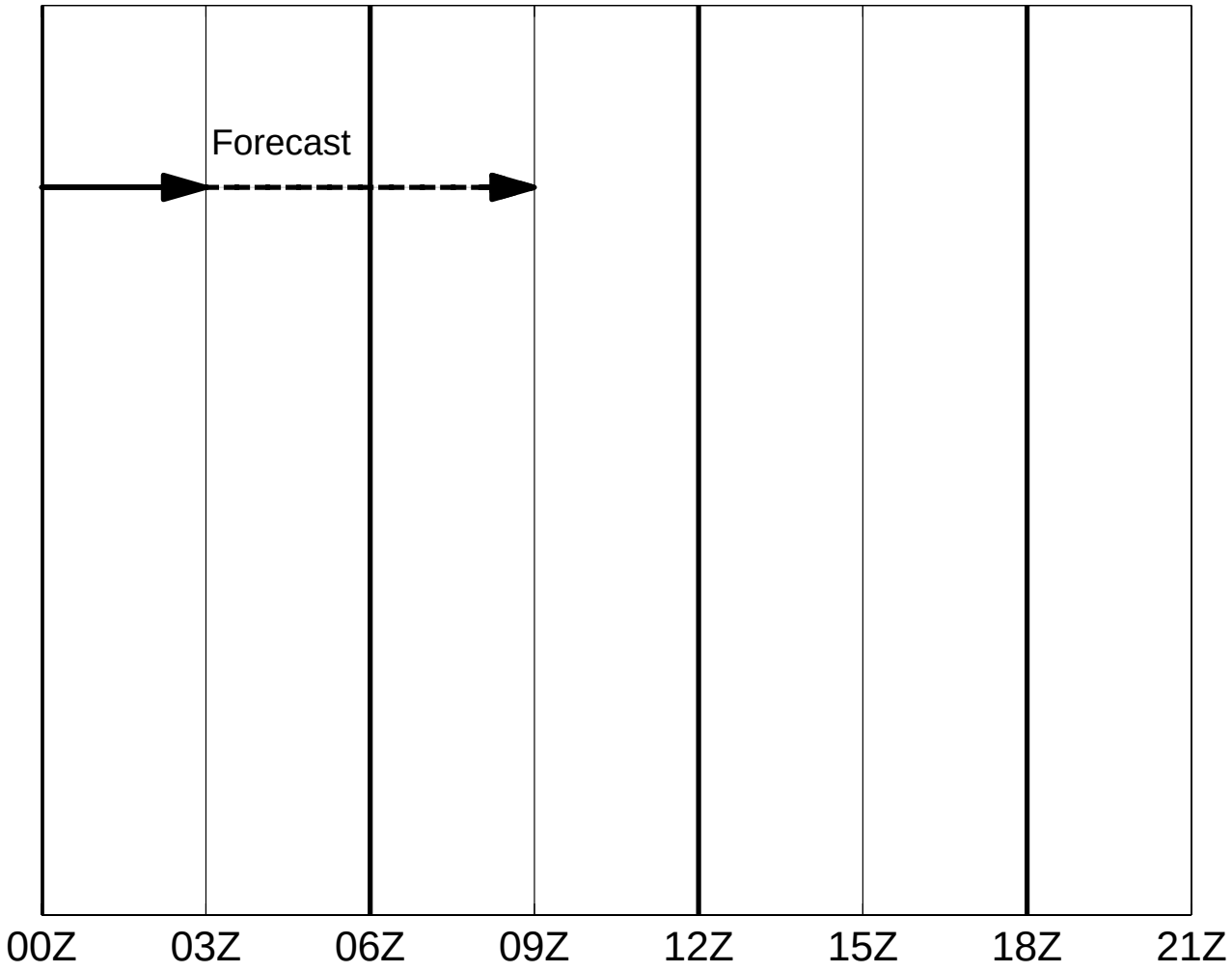
# 500 hPa Die Off Curves (full res parallel)



# 4D-IAU motivation

- The analyses produced by the ensemble Kalman filter (EnKF) may be dynamically inconsistent and contain unbalanced gravity waves that are absent in the real atmosphere.
- These imbalances can be generated by the discontinuous nature of the EnKF, and exacerbated by covariance localization and inflation.
- One strategy to combat the imbalance is the incremental analysis update (IAU), which uses the dynamic model to distribute the analyses increments over a time window.
- The traditional IAU (3DIAU) often computes the analysis increment once and assumes it to be constant for each assimilation window.
- The propagation of the analysis increment in the assimilation window is neglected, yet this propagation may be important, especially for moving weather systems.

# Schematic of the 4DIAU



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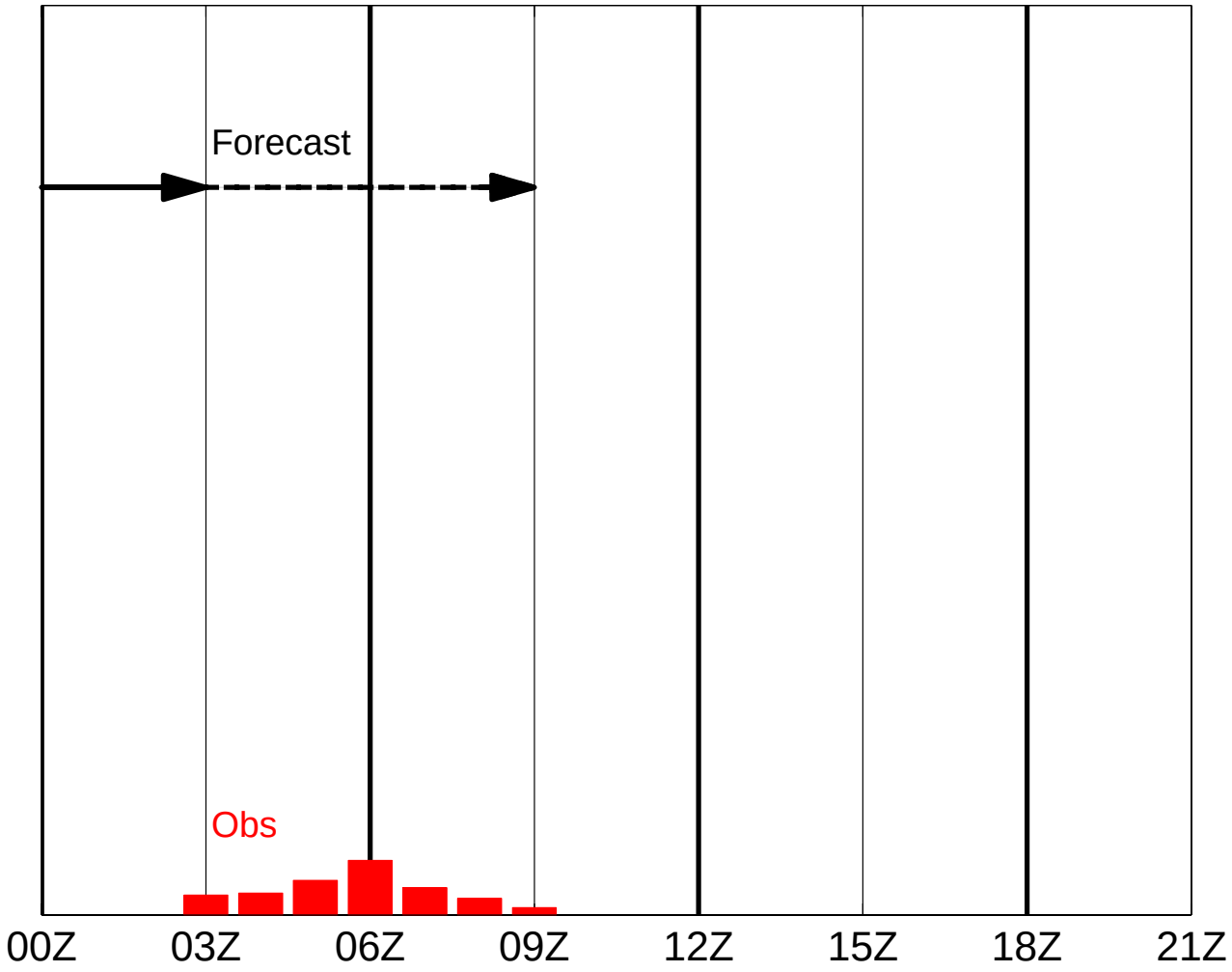

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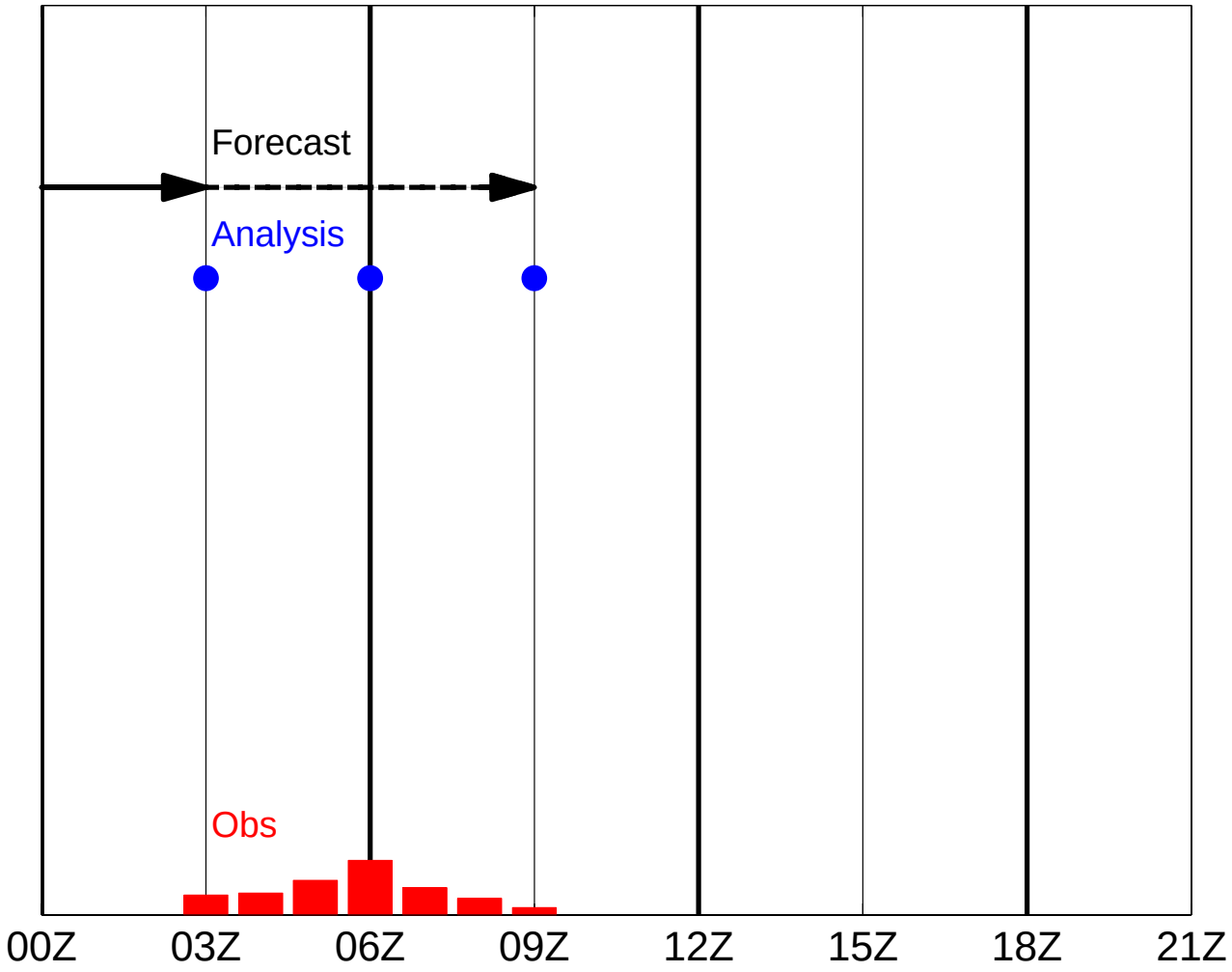

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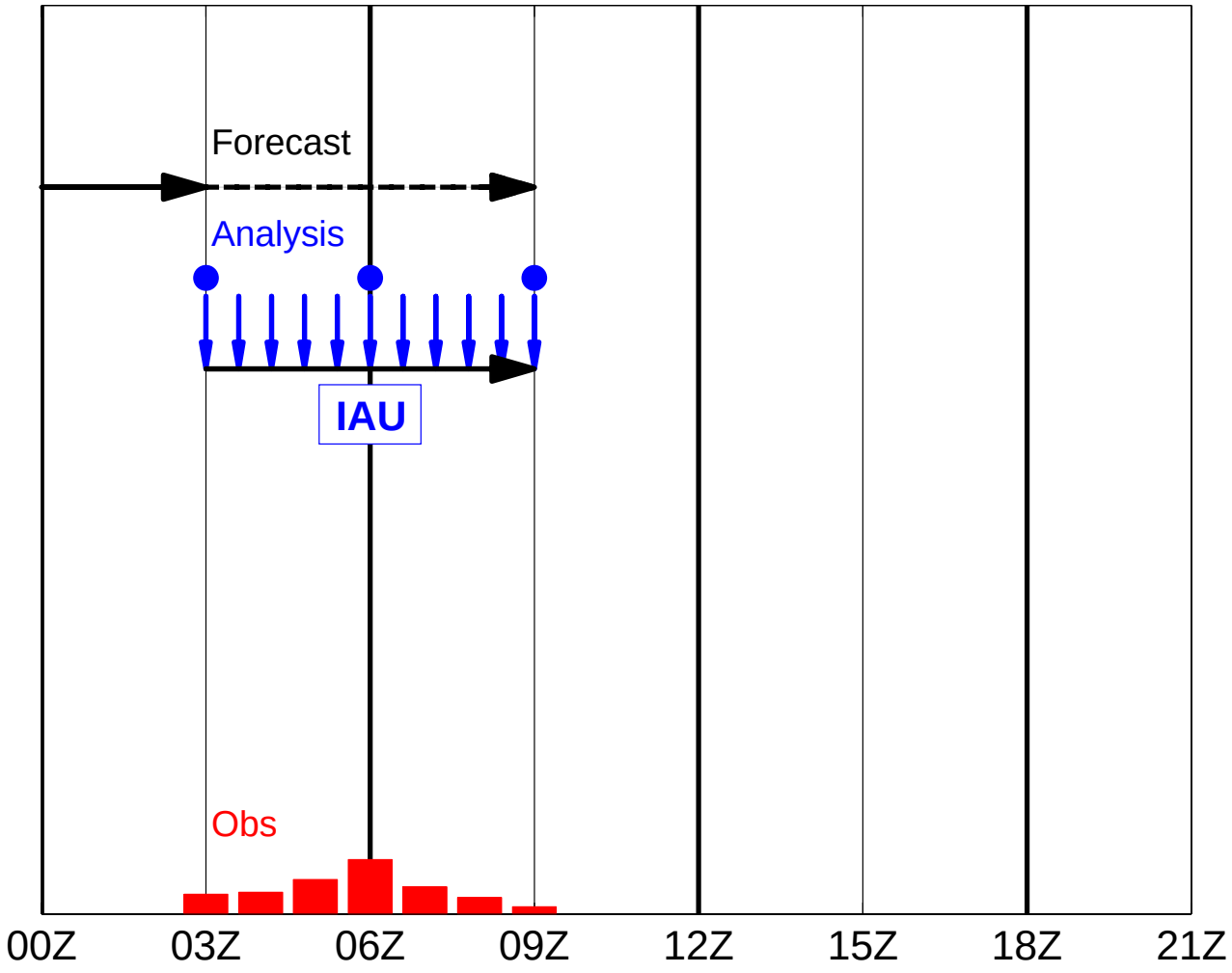

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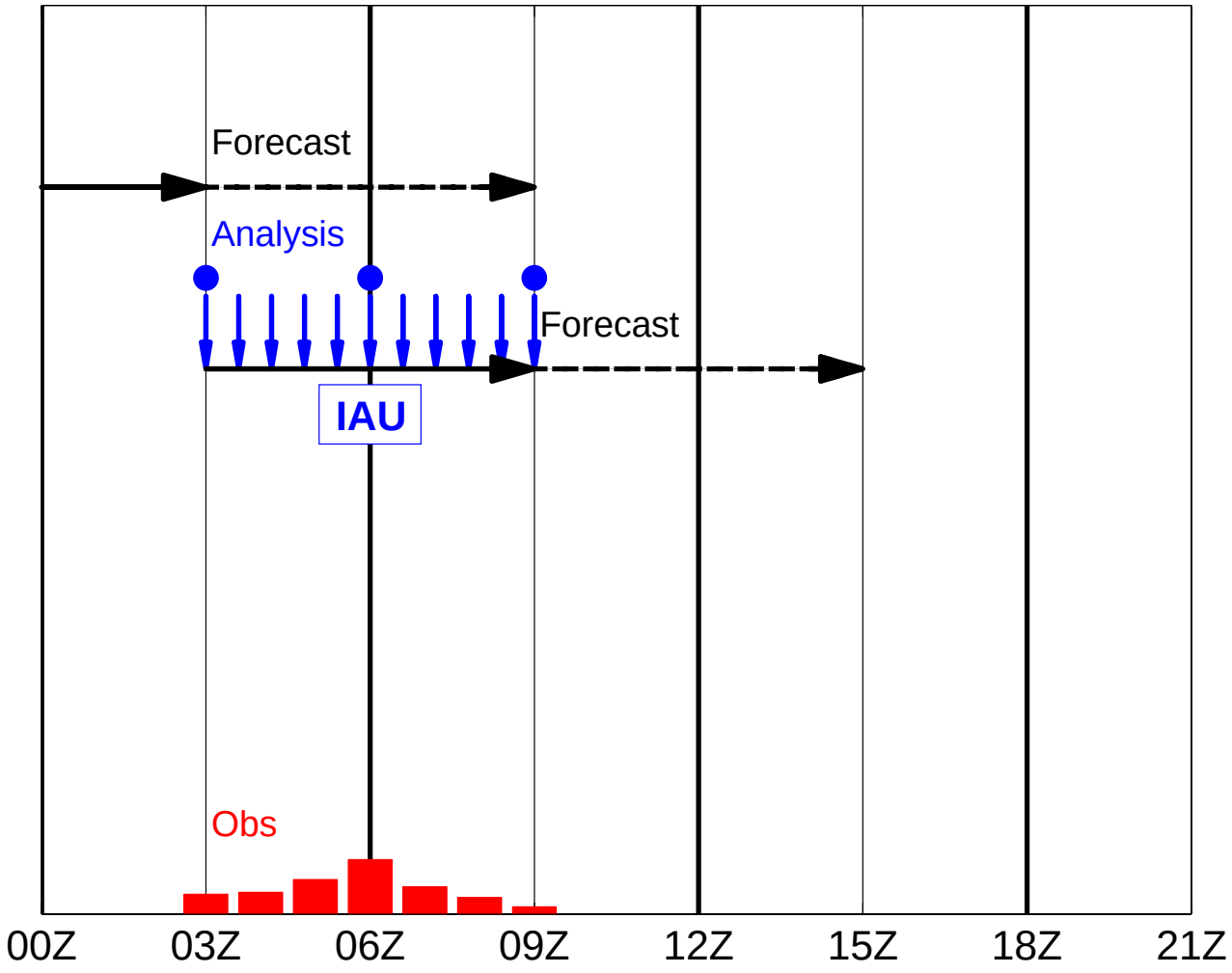

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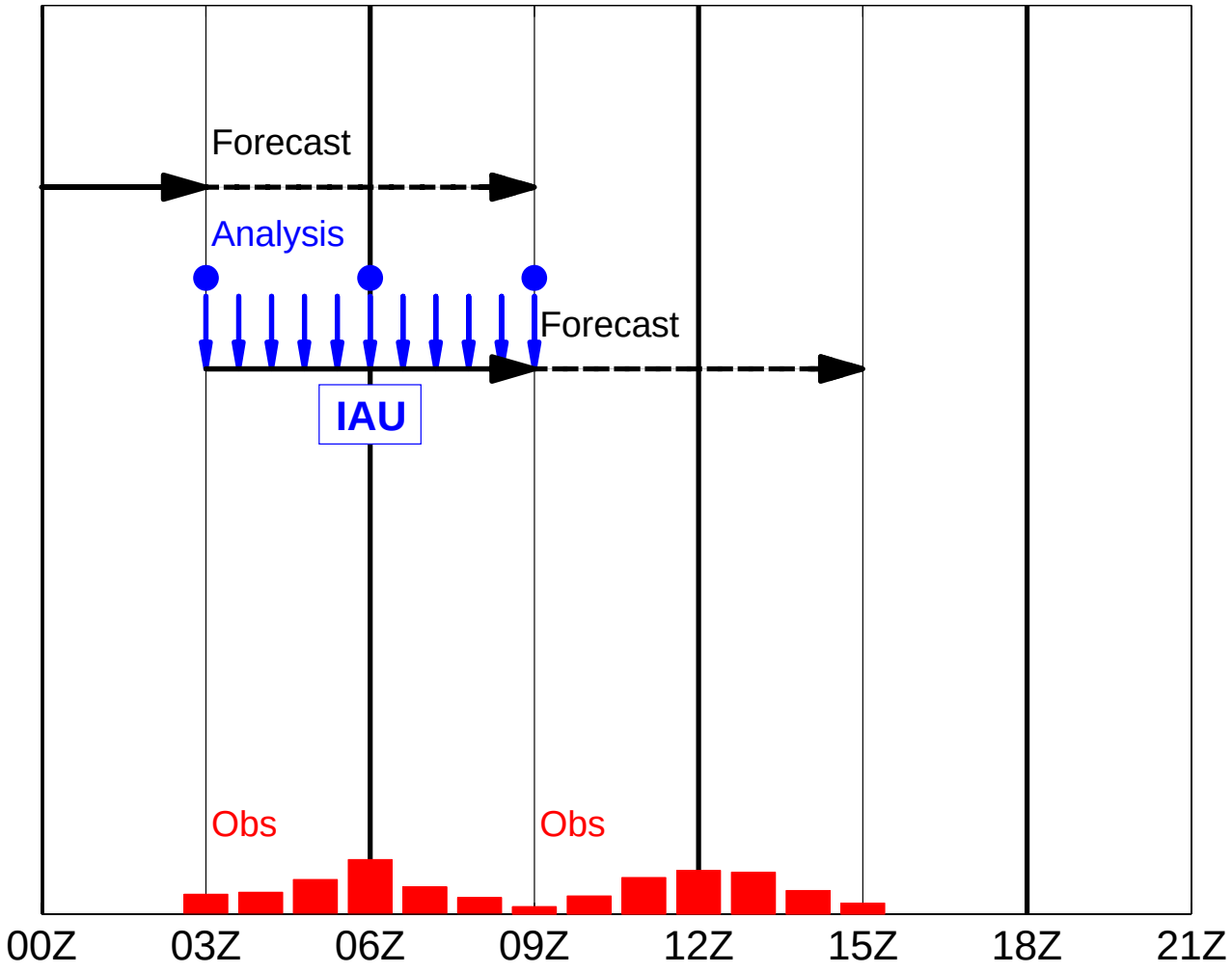

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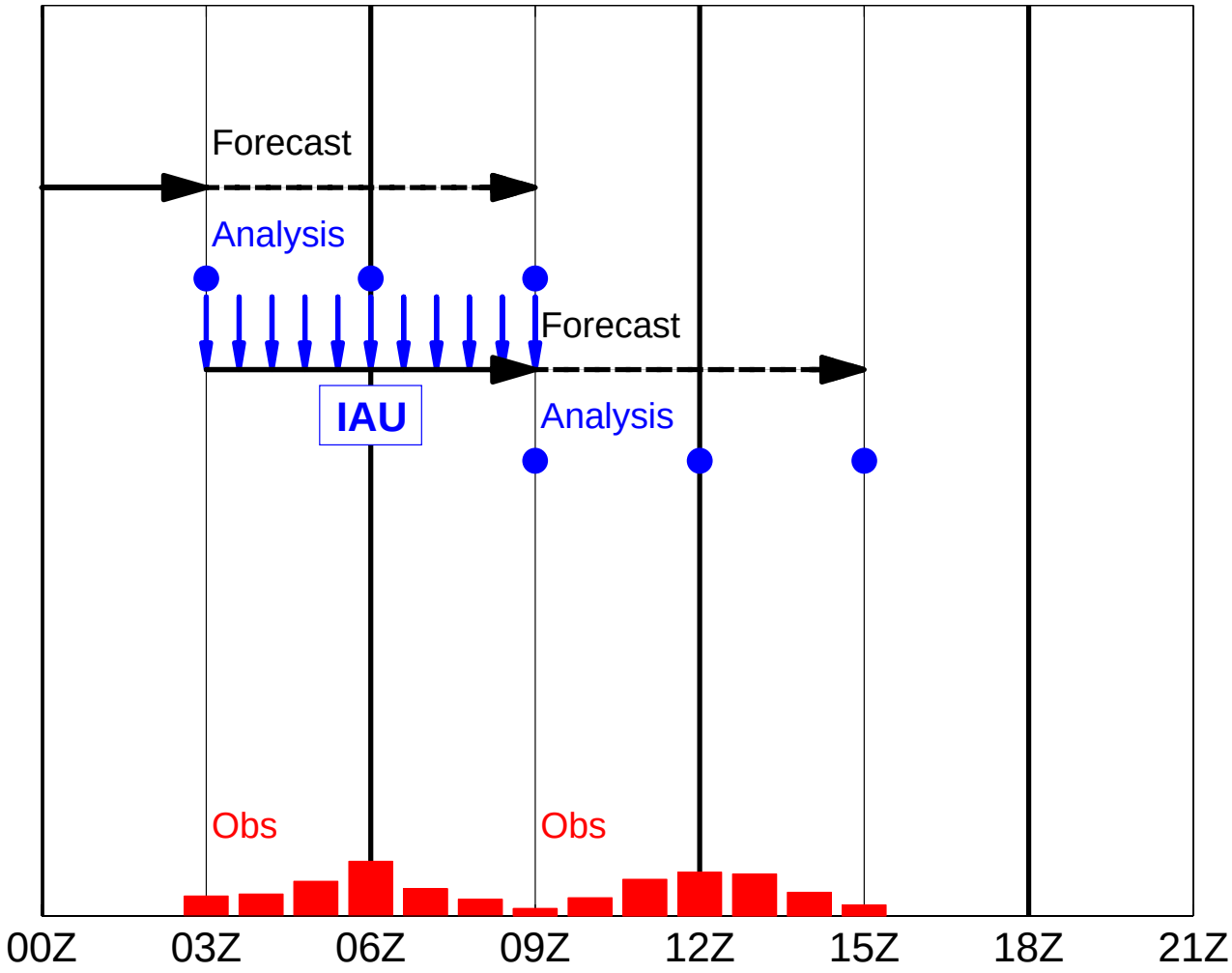

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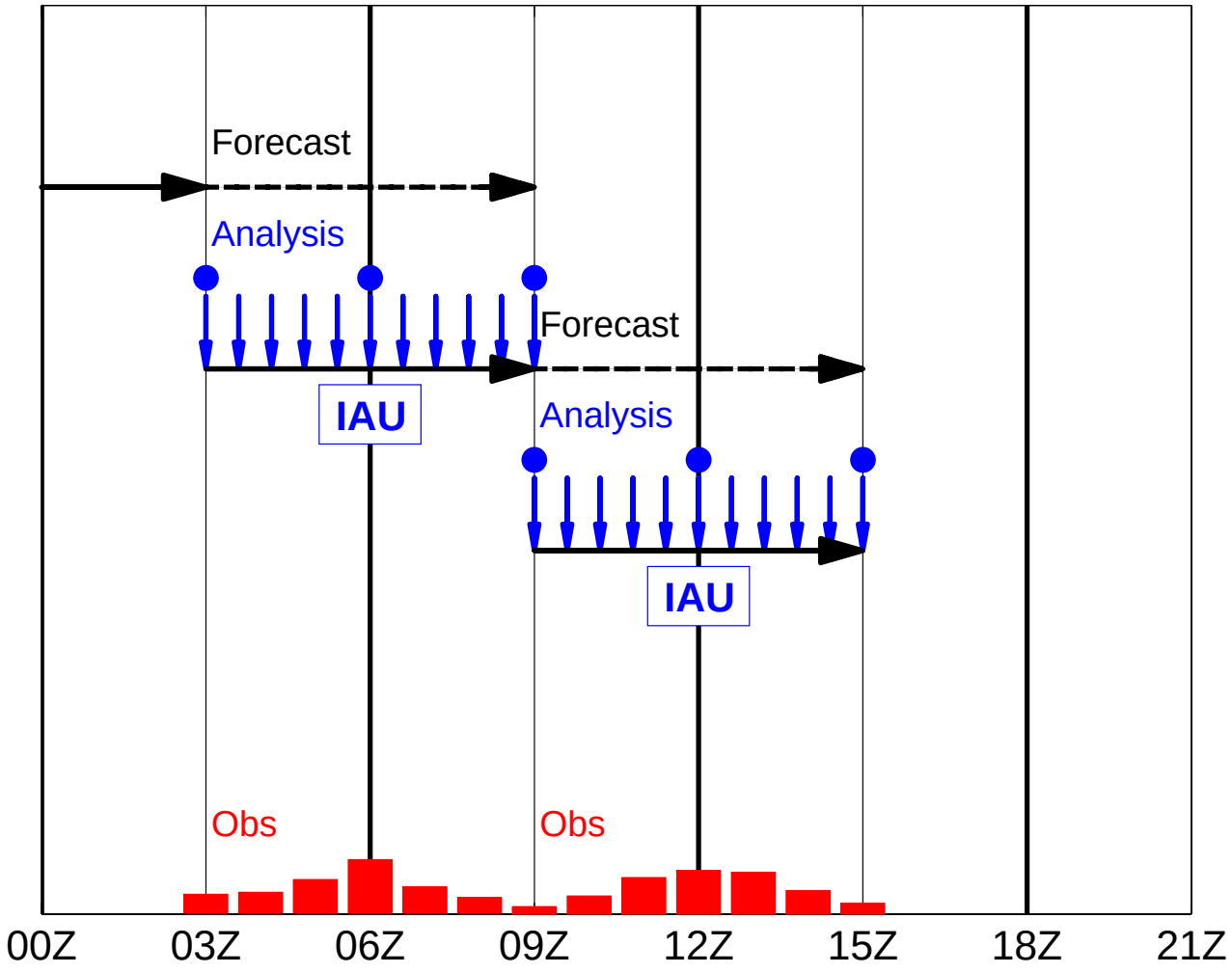

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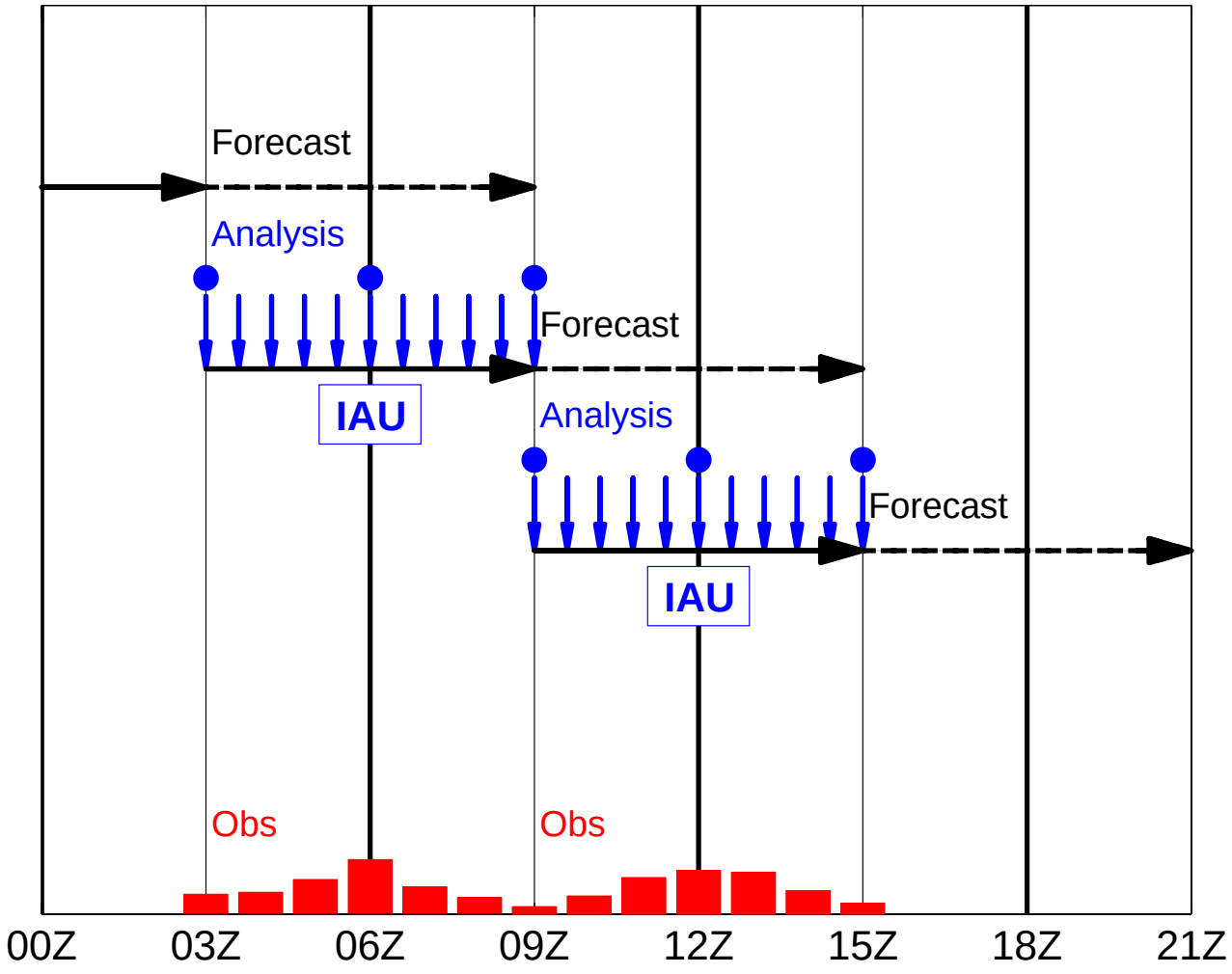
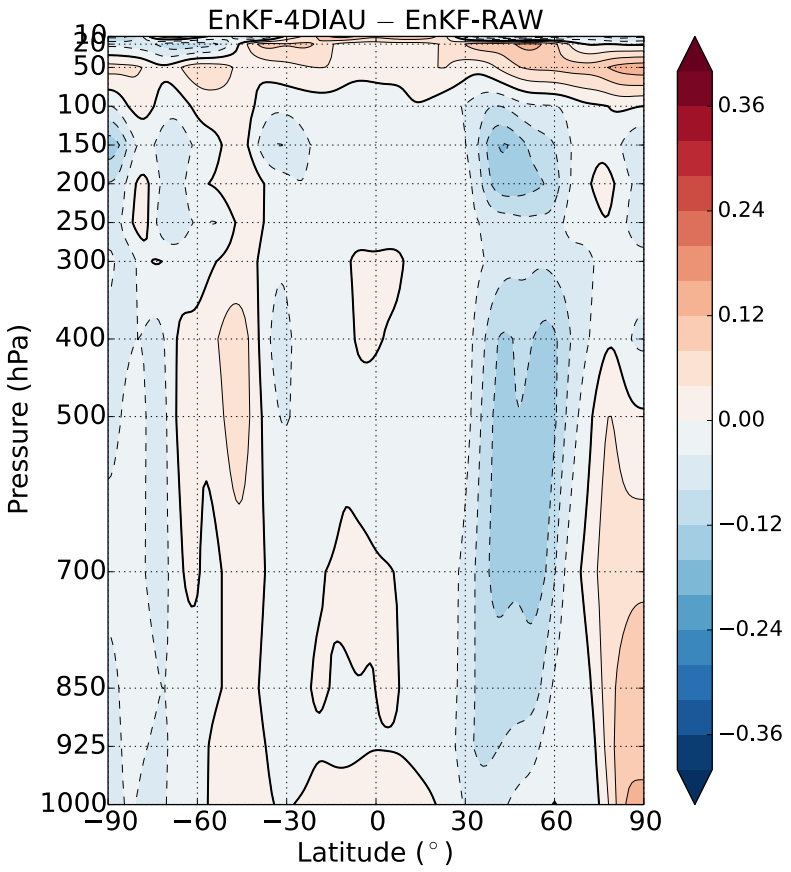


# Testing EnKF-4DIAU with Real Data Experiments

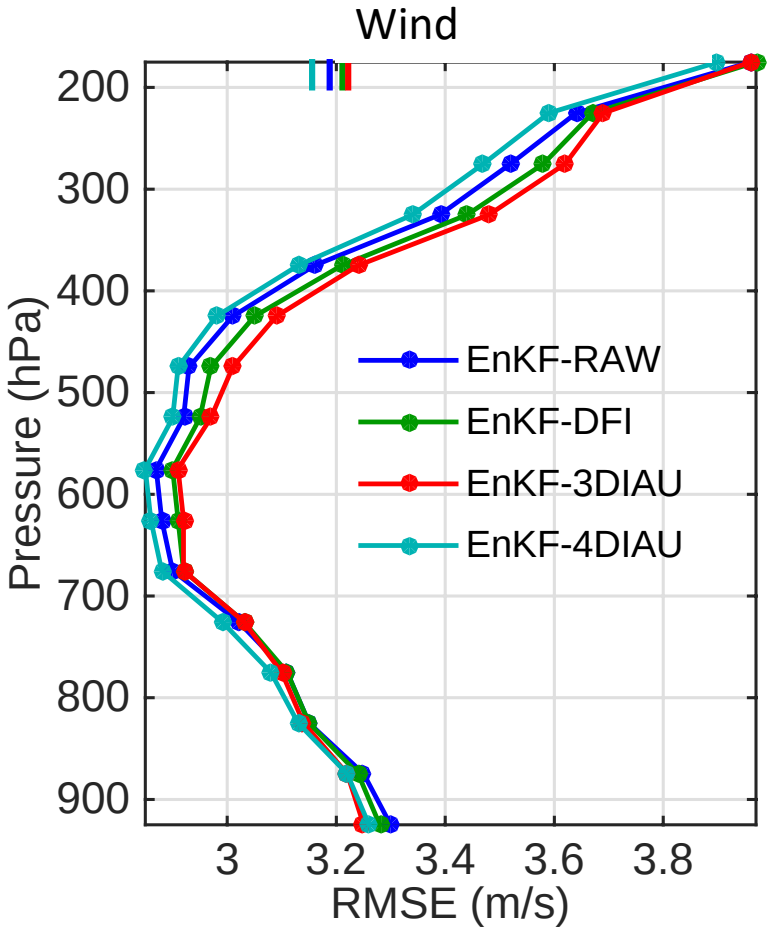
- The Global Forecast System (GFS) with 80 T574 (~30 km) members are used.
- 1250 km/1.0 scale height localization.
- Stochastic physics and multiplicative inflation (no additive inflation).
- Radiance bias correction comes from a separate GSI 3D Ensemble-Variational run.
- 6-hour cycling, 3-h forecast output (increments computed at the beginning/middle/end of assimilation window for IAU).
- Integration time 2014040100-2014050800; first 7 days are discarded for verification.

| Exp. Name | Exp. Description |
|---|---|
| EnKF-RAW | Pure EnKF |
| EnKF-DFI | EnKF with digital filter initialization (DFI) |
| EnKF-3DIAU | EnKF with 3DIAU, no DFI |
| EnKF-4DIAU | EnKF with 4DIAU, no DFI |

# 5-day forecast errors (temperature) – neg values means 4DIAU better




# 6-h wind forecasts vs in-situ obs




EnKF-DFI has slightly larger errors than EnKF-RAW.

EnKF-3DIAU produces the largest errors except below 800 hPa.

EnKF-4DIAU is noticeably better than the other experiments.

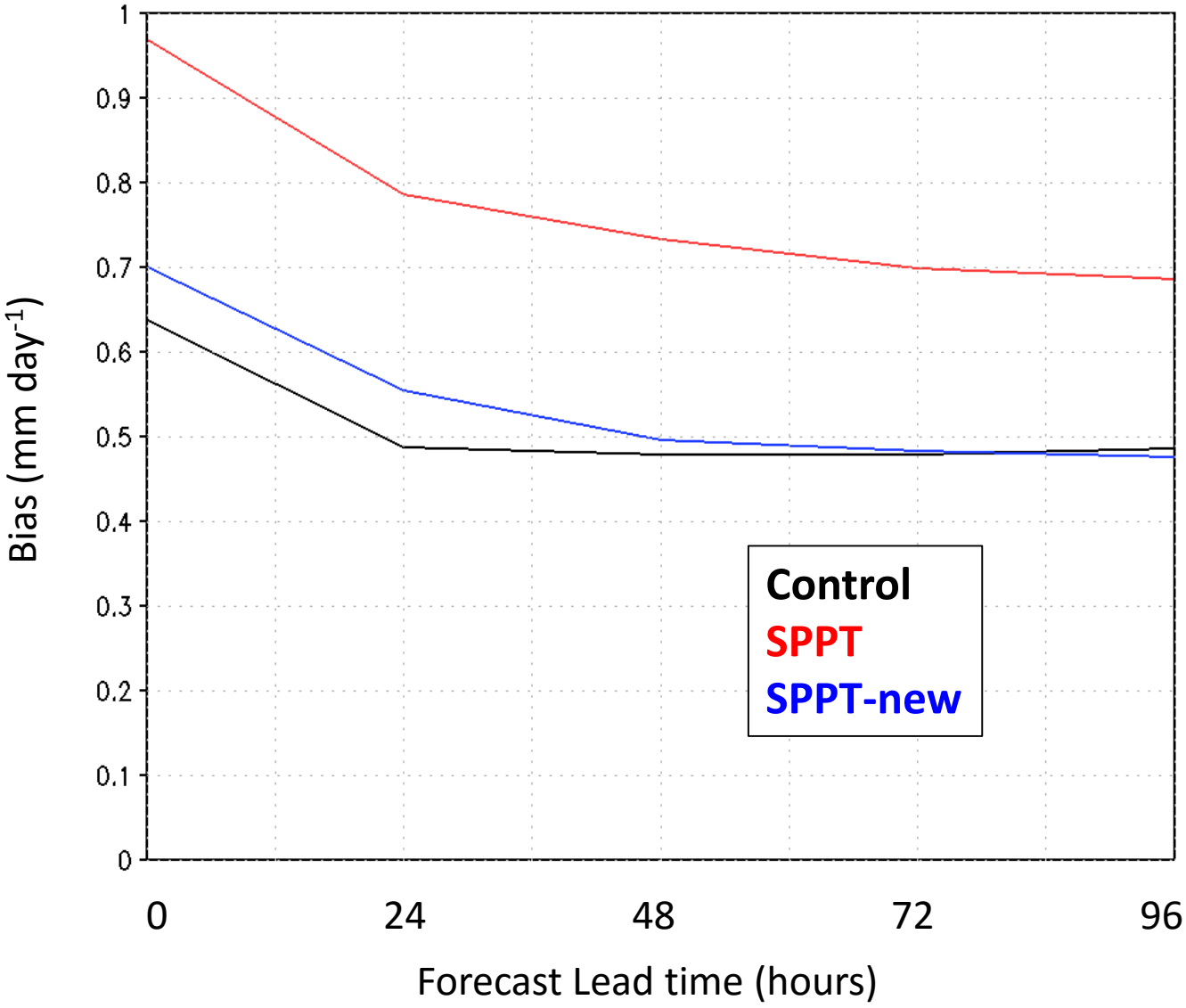
# Ongoing DA work

- 4DIAU to be implemented as part of first 4DEnVar upgrade (FY17).
- Improving the utilization of radiances in the EnKF (better vertical localization).

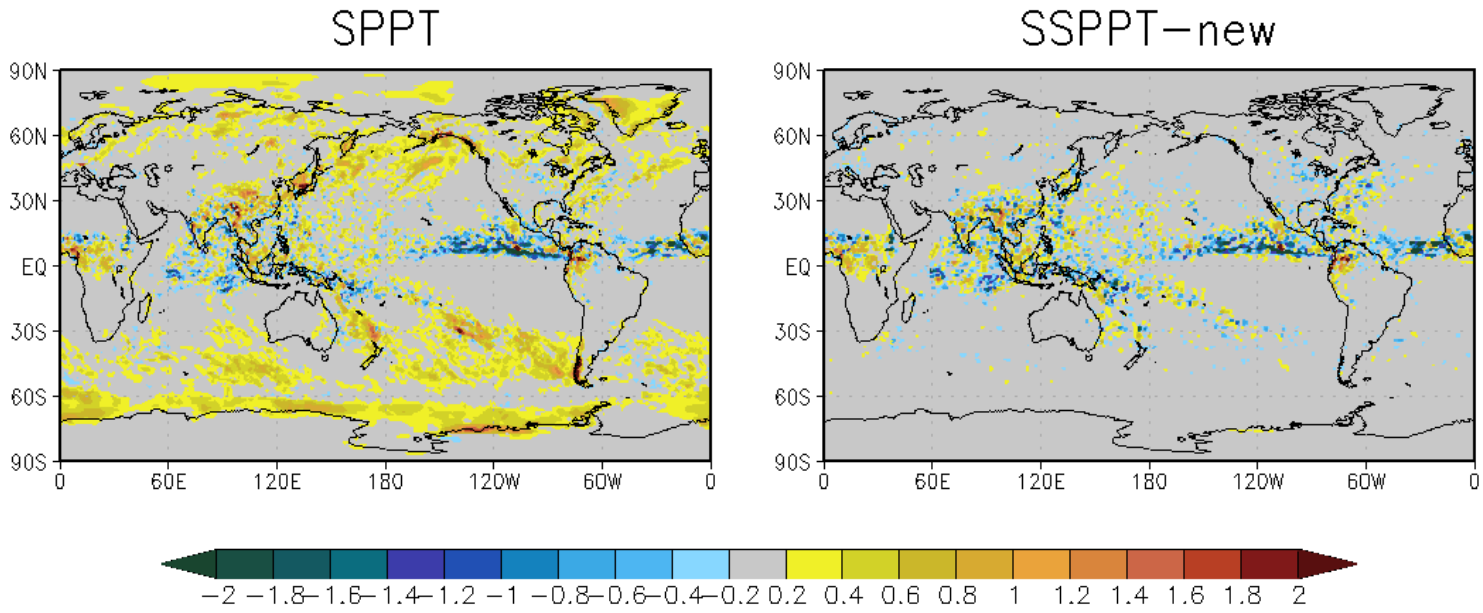
# Fix for SPPT

- SPPT perturbs the tendencies from physics before adding them back to the state.
- Other outputs from physics (precipitation) are not perturbed
  - This results in a mismatch between latent heating/moistening and precipitation accumulation
  - Due to non-linear interactions, the result is a global increase in precipitation
- Fix is to perturb precipitation the same amount as the tendencies

# Global Mean Precipitation Bias vs GPCP



# Ensemble mean forecast error compared to control forecasts
## 24-48 hour Precipitation




Perturbing the precipitation along with the tendencies removes the increase in error In the extra-tropical storm tracks.