Assimilation/Ensembles/Stoch Physics

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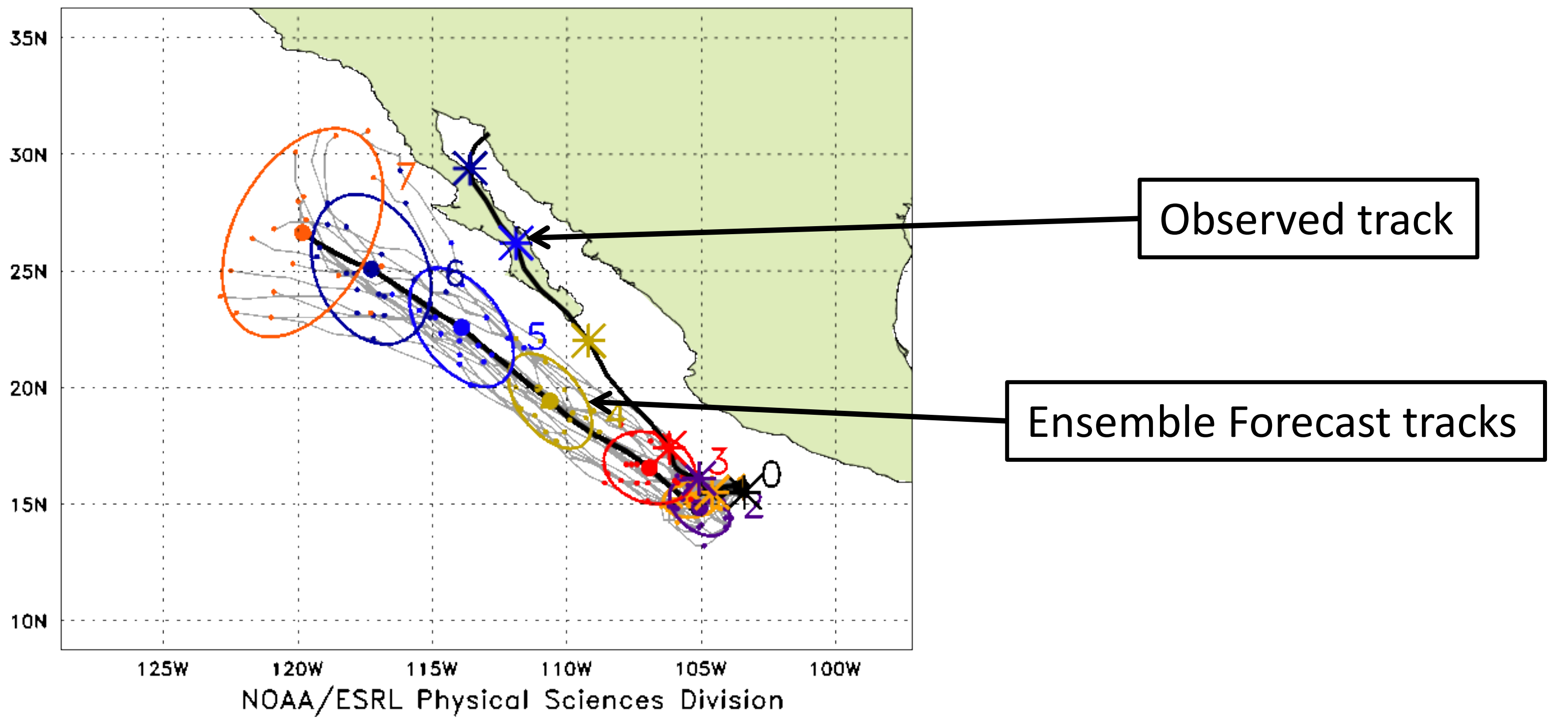
NCEP

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

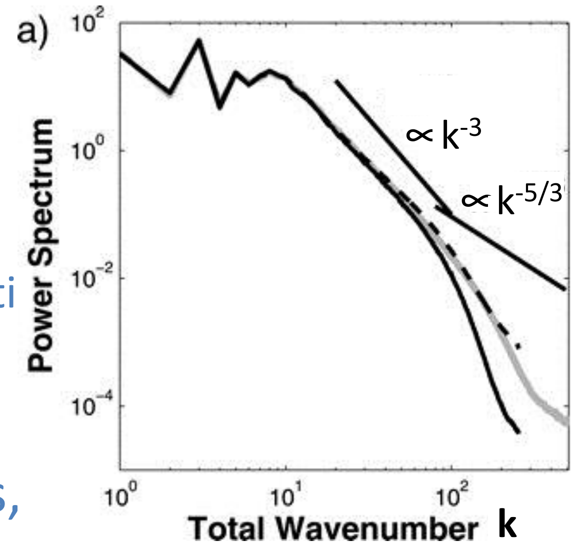


GFS ensemble was confident that the hurricane would stay off shore.

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)

Kinetic Energy Spectrum



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).

Initial Expts: Experiment Design

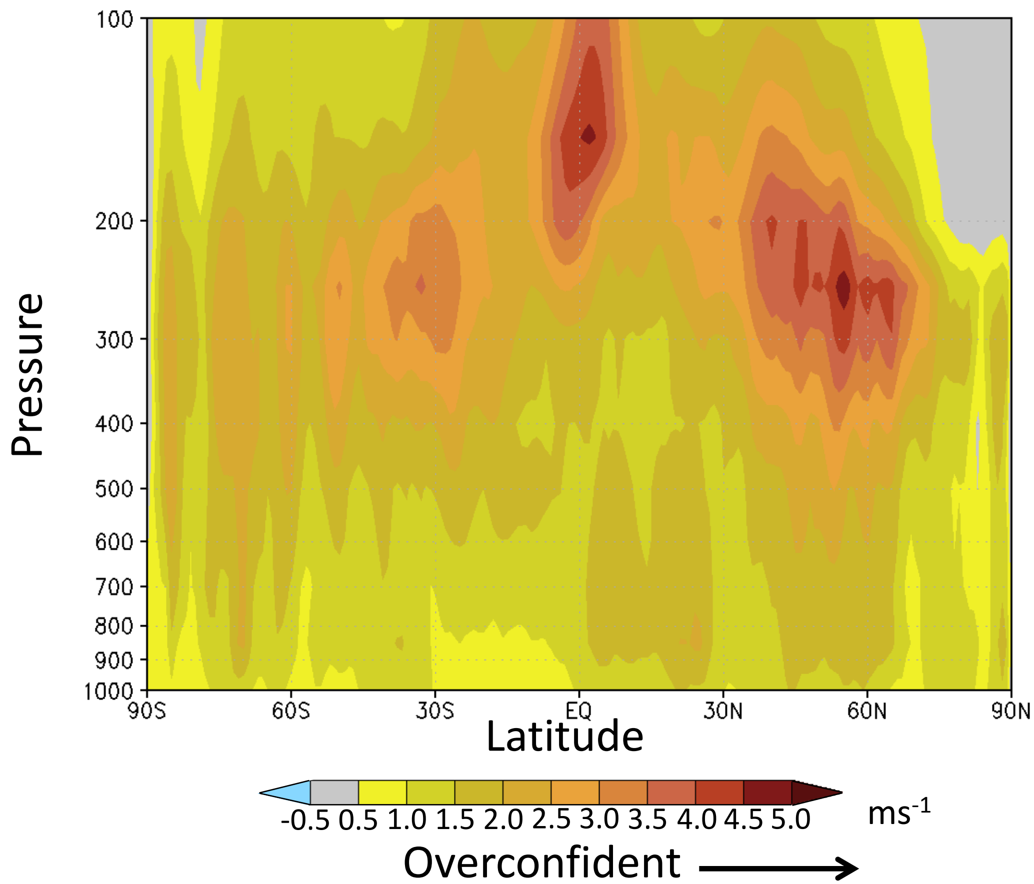
- NCEP GFS, T574-L64 – 20 member ensemble
- 5-day forecasts initialized every day at 00z for August 2012
- Verified against the consensus analysis
- CNTL: 20-member ensemble with only initial condition perturbations

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

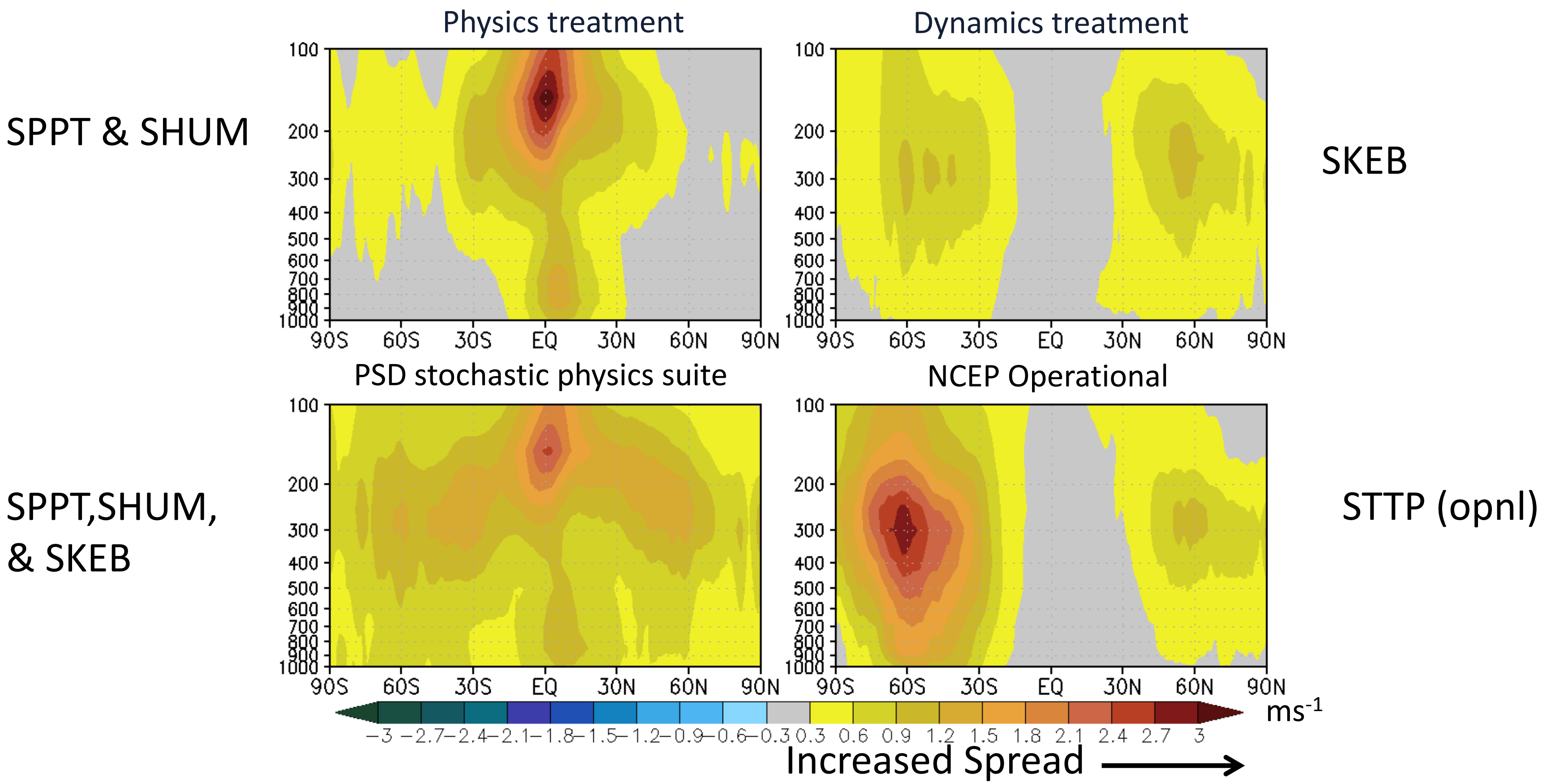


GFS ensemble, no treatment for model error "baseline"

Change in Ensemble Spread

zonal average from 1 month of forecasts (Aug 2012)

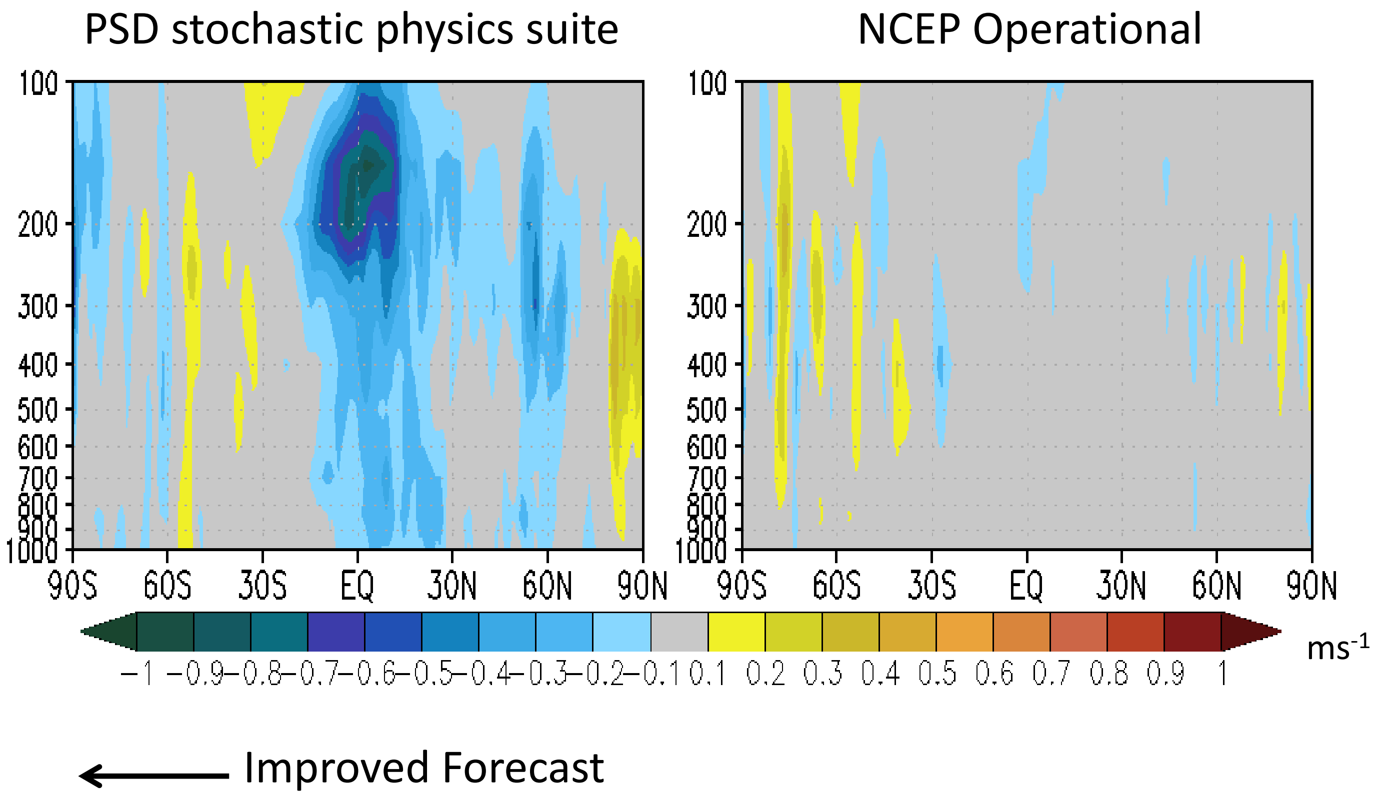
120 hr zonal wind spread difference compared to baseline



Change in Forecast Error

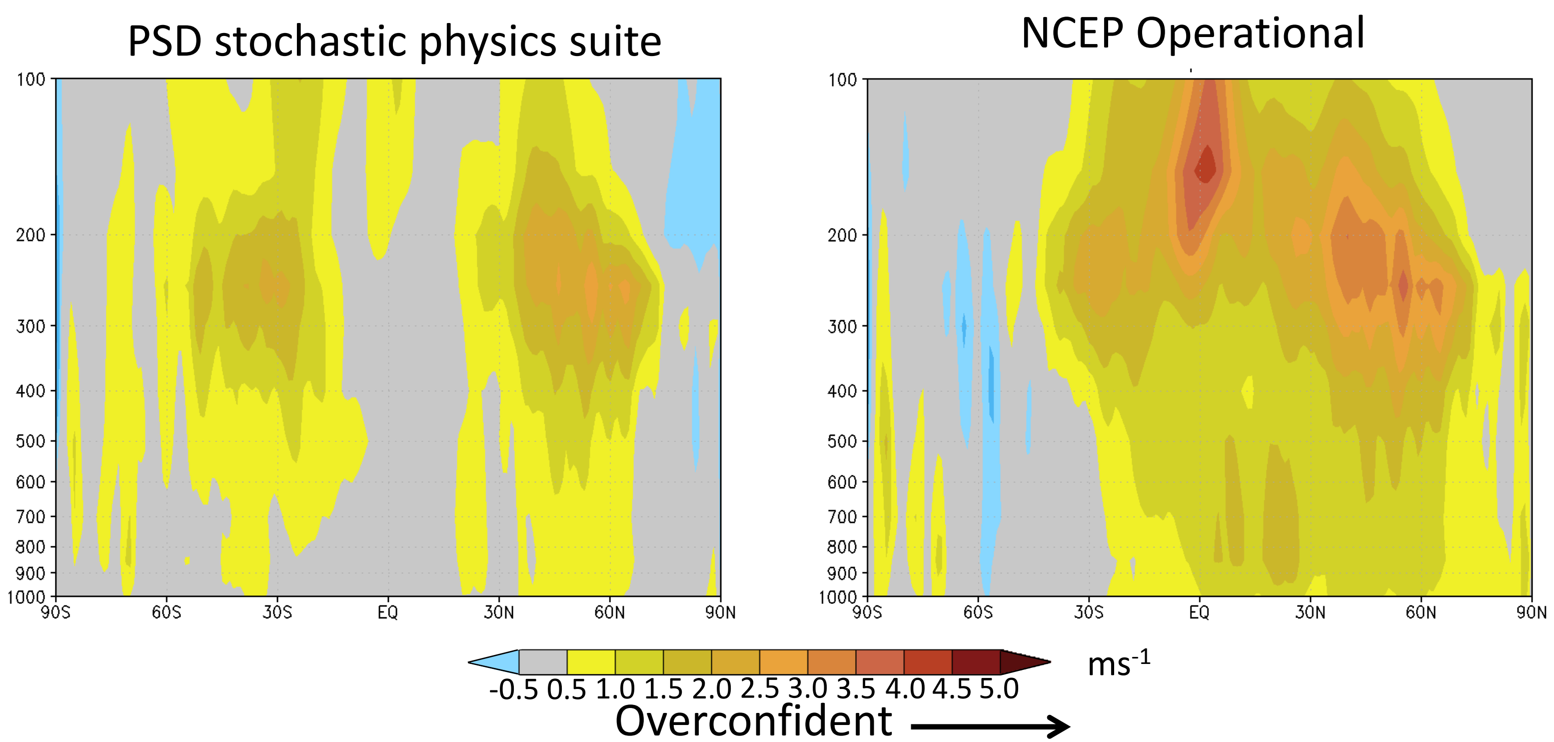
zonal average from 1 month of forecasts(Aug 2012)

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)

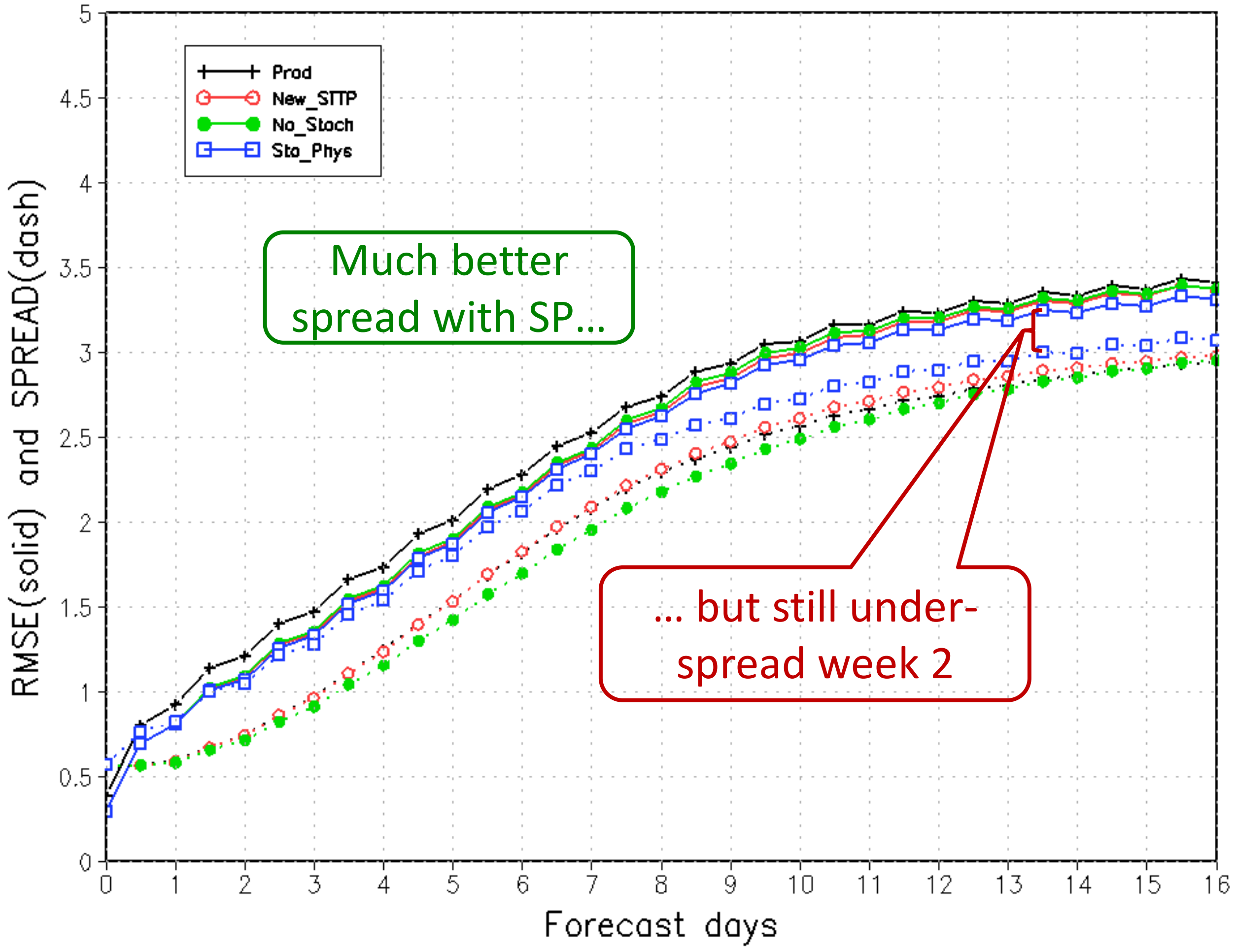
Four experiments:

- 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)



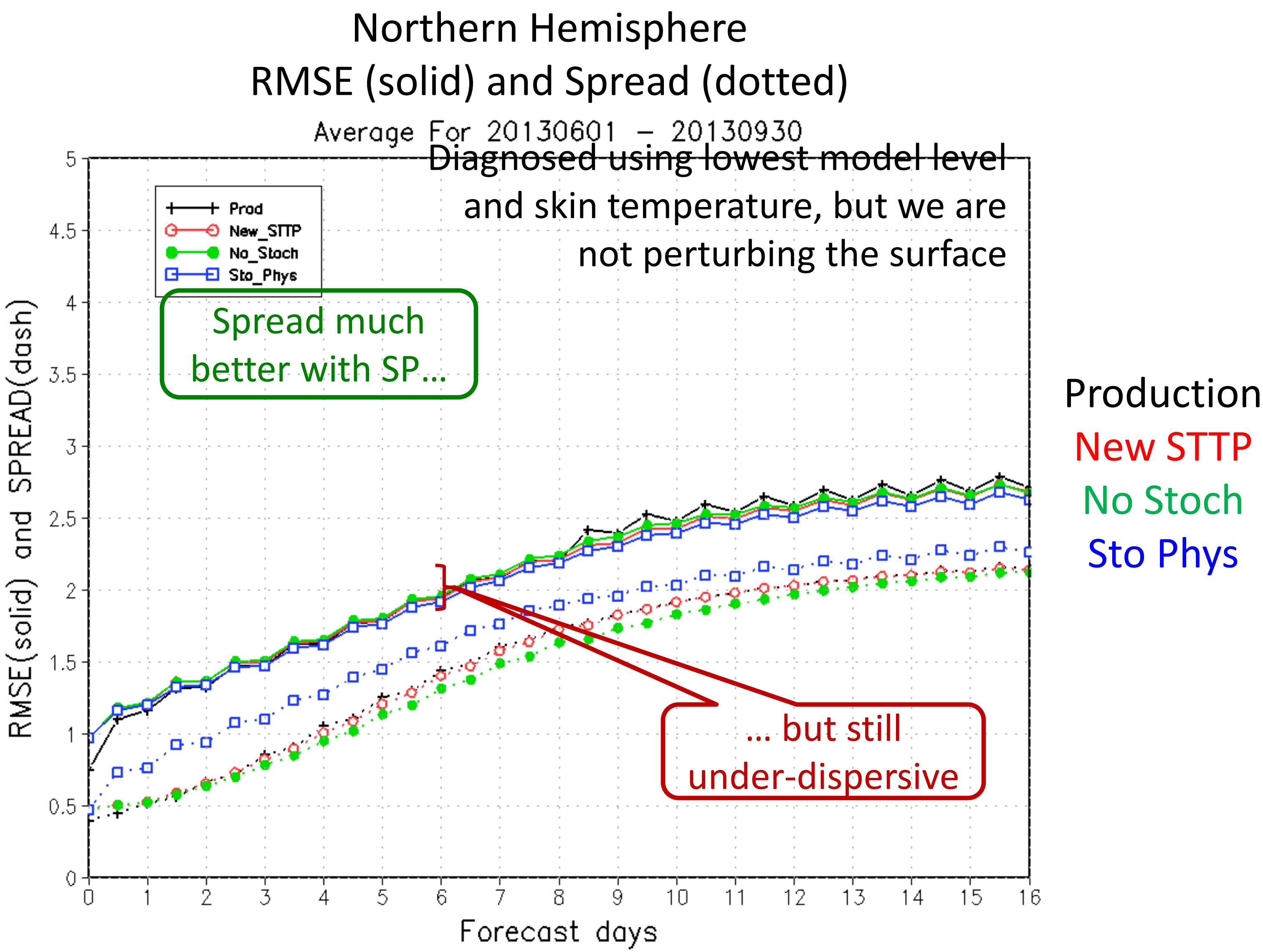
Production

New STTP

No Stoch

Sto Phys

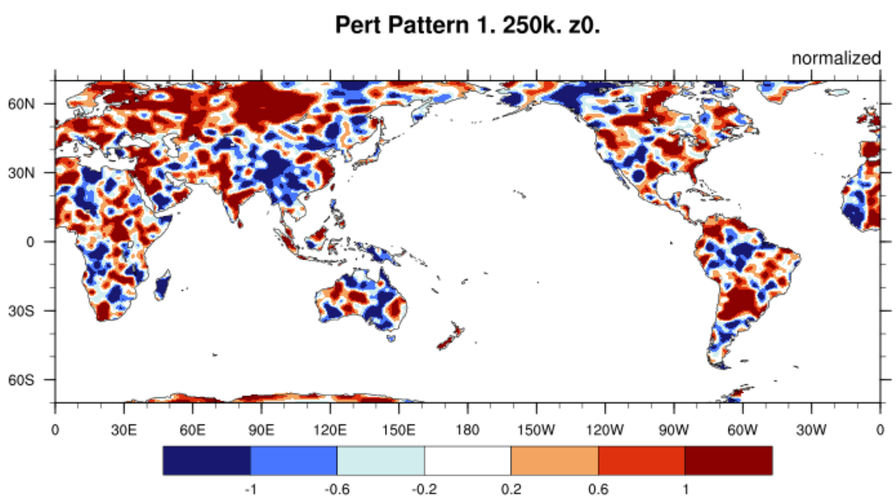
Summer Results — 2-m Temperature



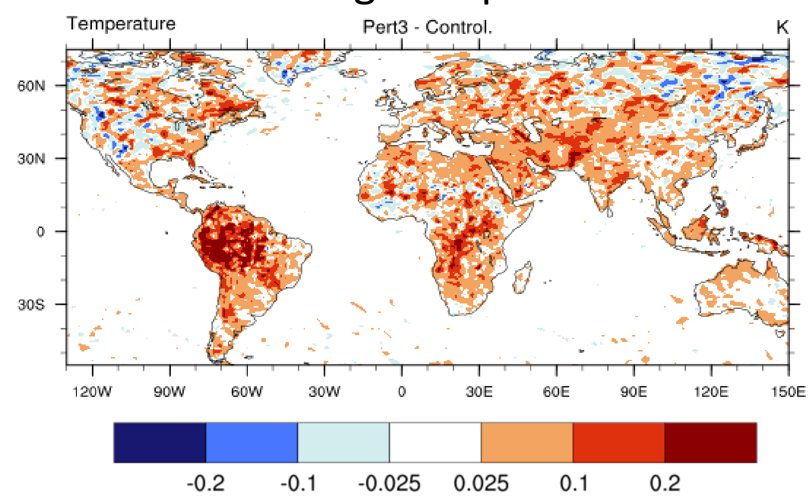
Surface Perturbations

- 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)



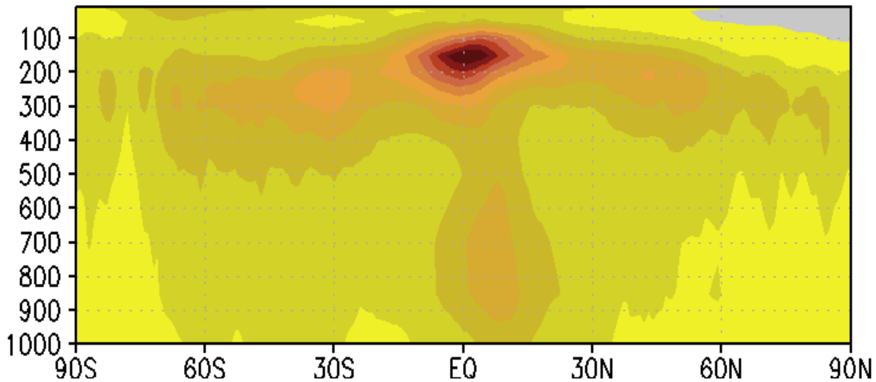
change of spread



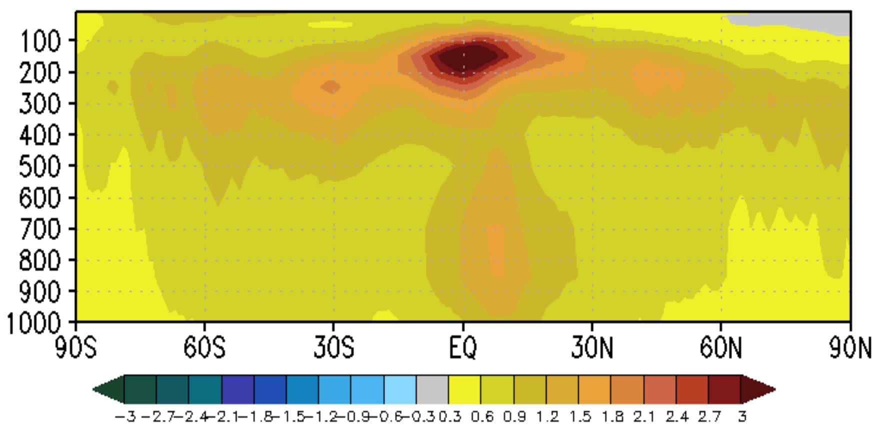
Change in Ensemble Spread (Temperature)

zonal average from 1 month of forecasts (August 2014)

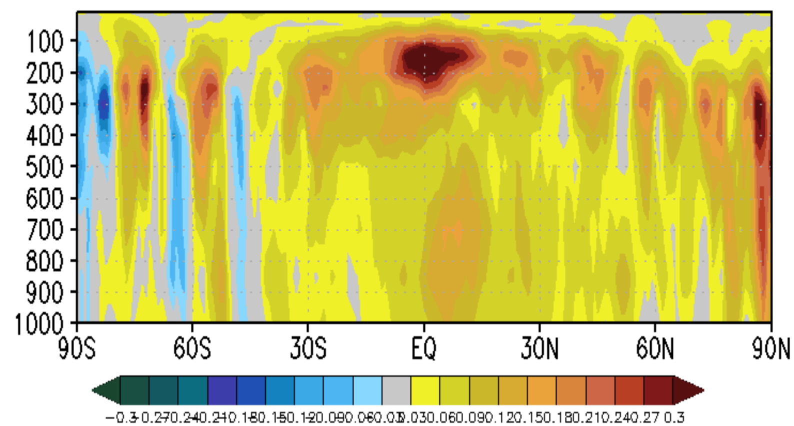
Atmosphere only stochastic parameterizations



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 1st 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

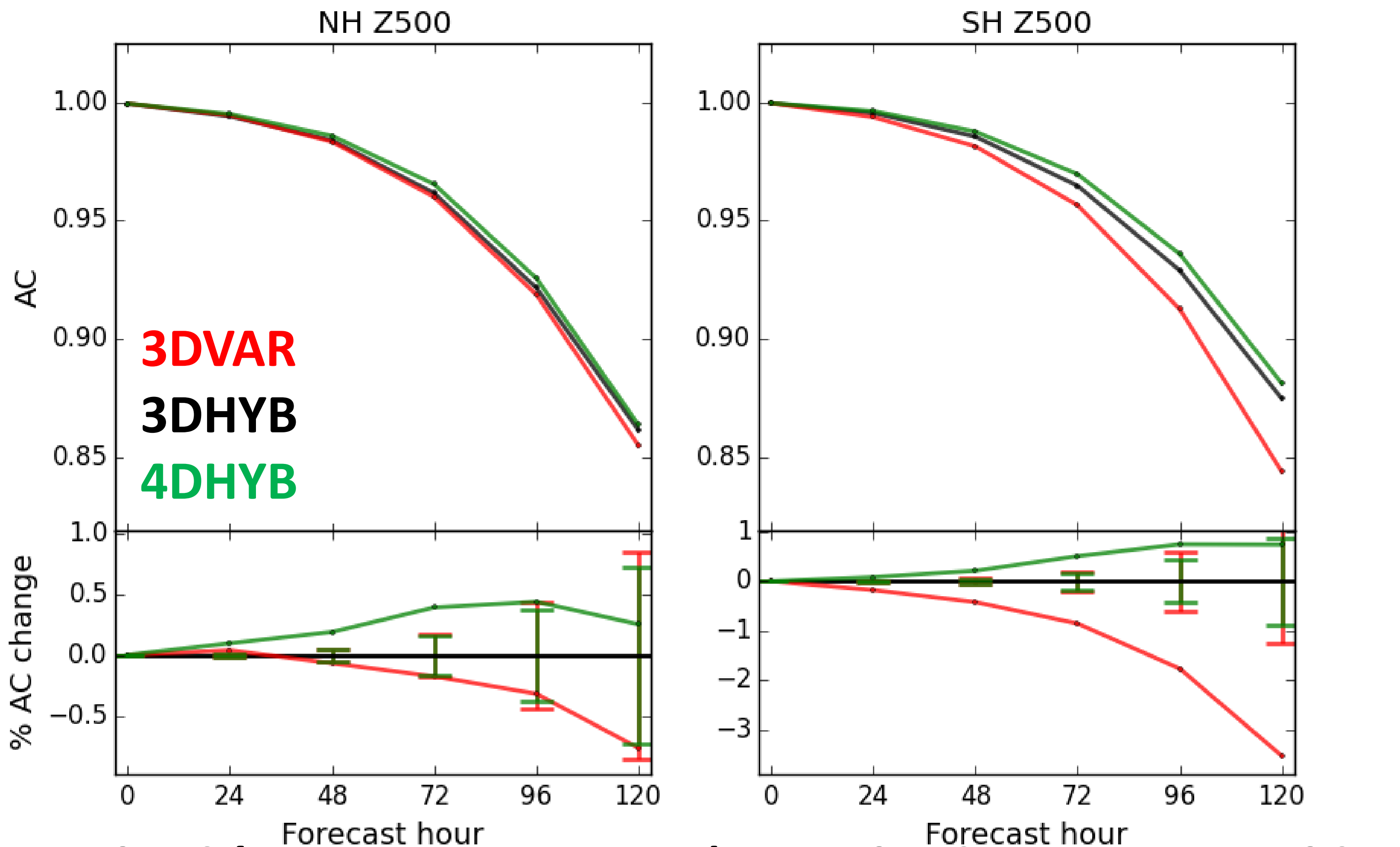
4DHybrid details

	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

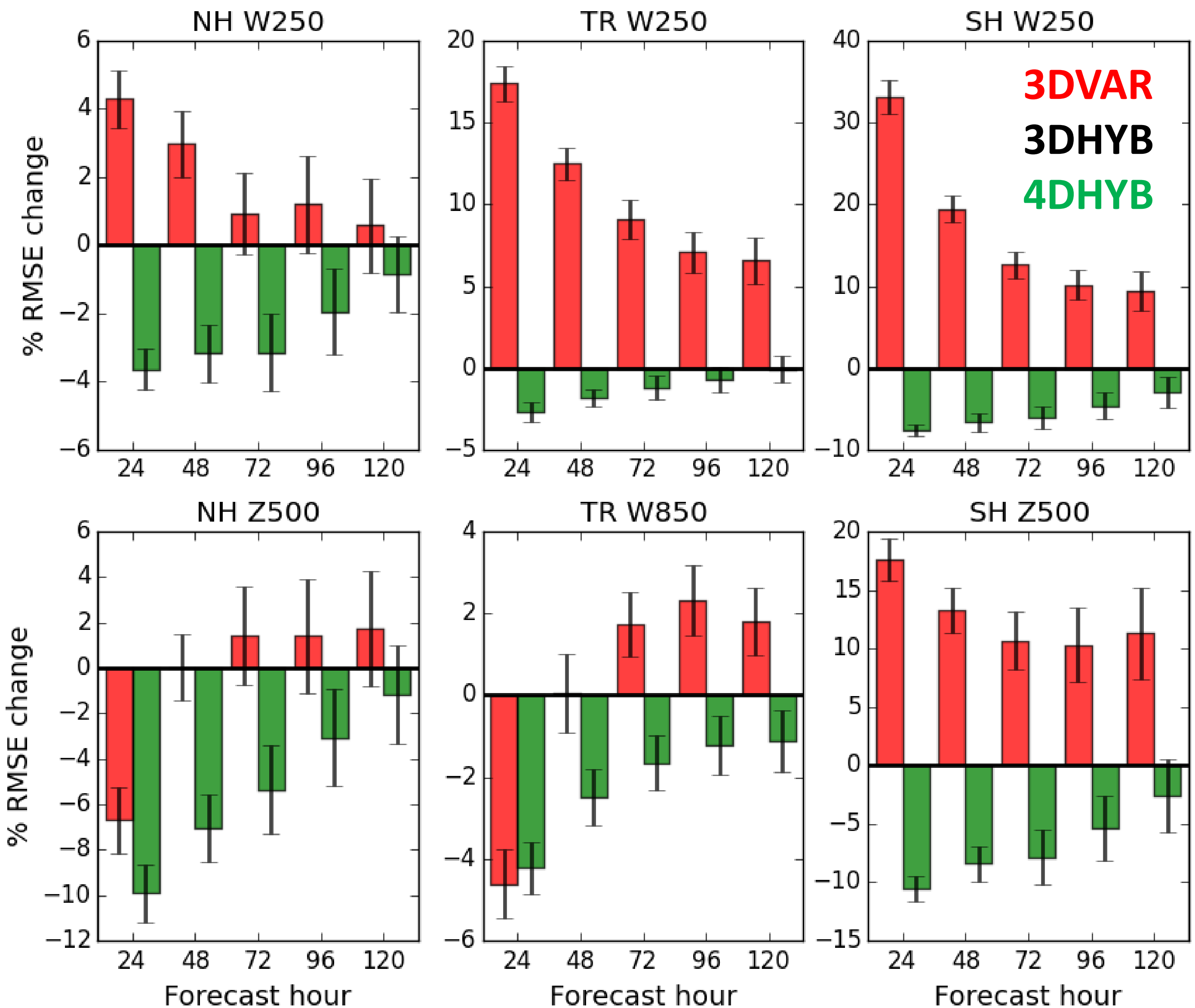
- T670L64 deterministic GFS with 80 member T254L64 ensemble with fully coupled (two-way) EnKF
- Incremental normal mode initialization (TLNMC) on total increment
- Multiplicative inflation and stochastic physics for EnKF perturbations
- Full field digital filter

500 hPa Die Off Curves (low res tests)



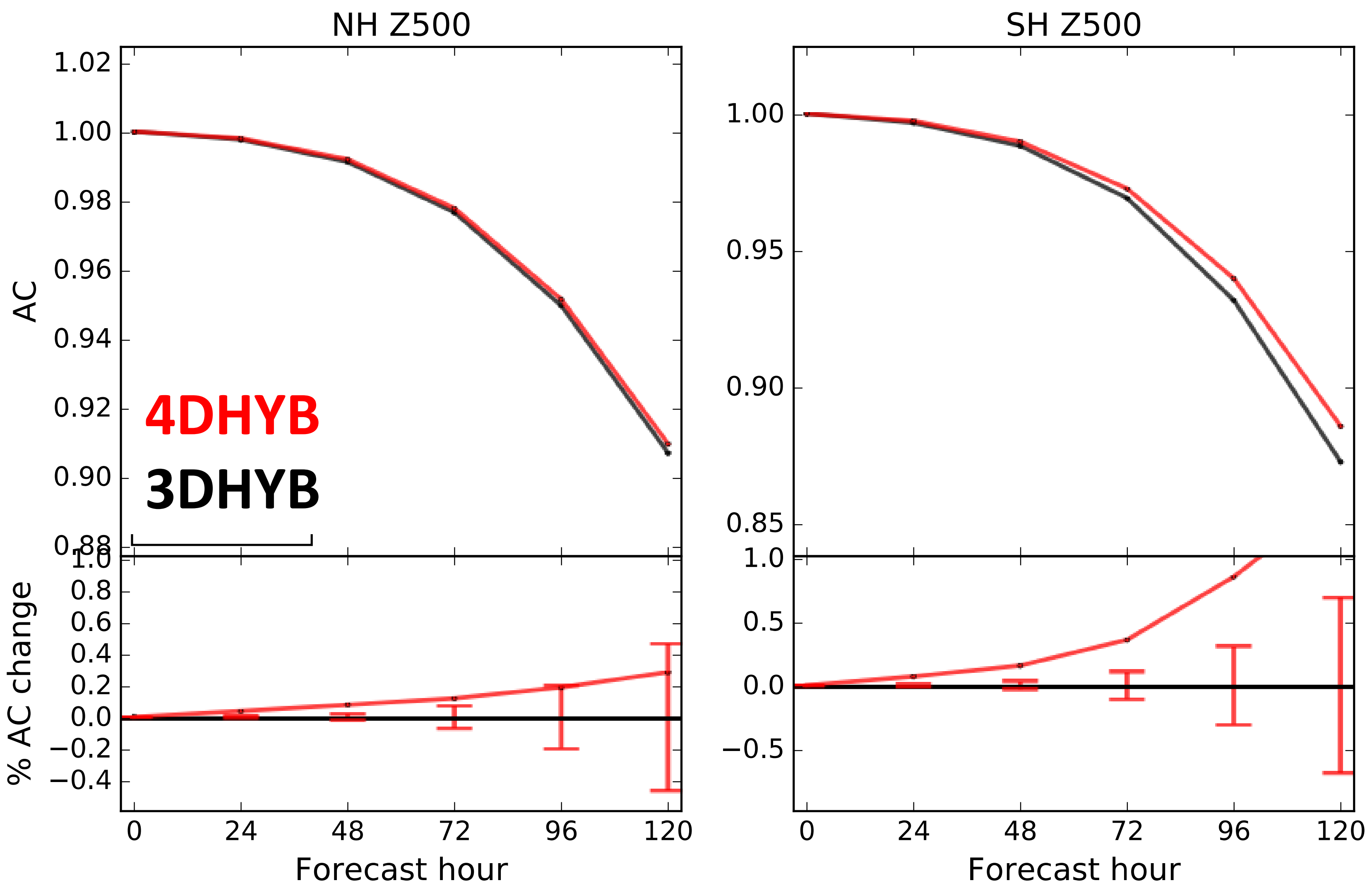
3D Hybrid (current operations) to Hybrid 4D-EnVar yields improvement that is about 75% in amplitude in comparison from going from 3DVar to 3D Hybrid

RMSE Summary



500 hPa Die Off Curves (full res parallel)

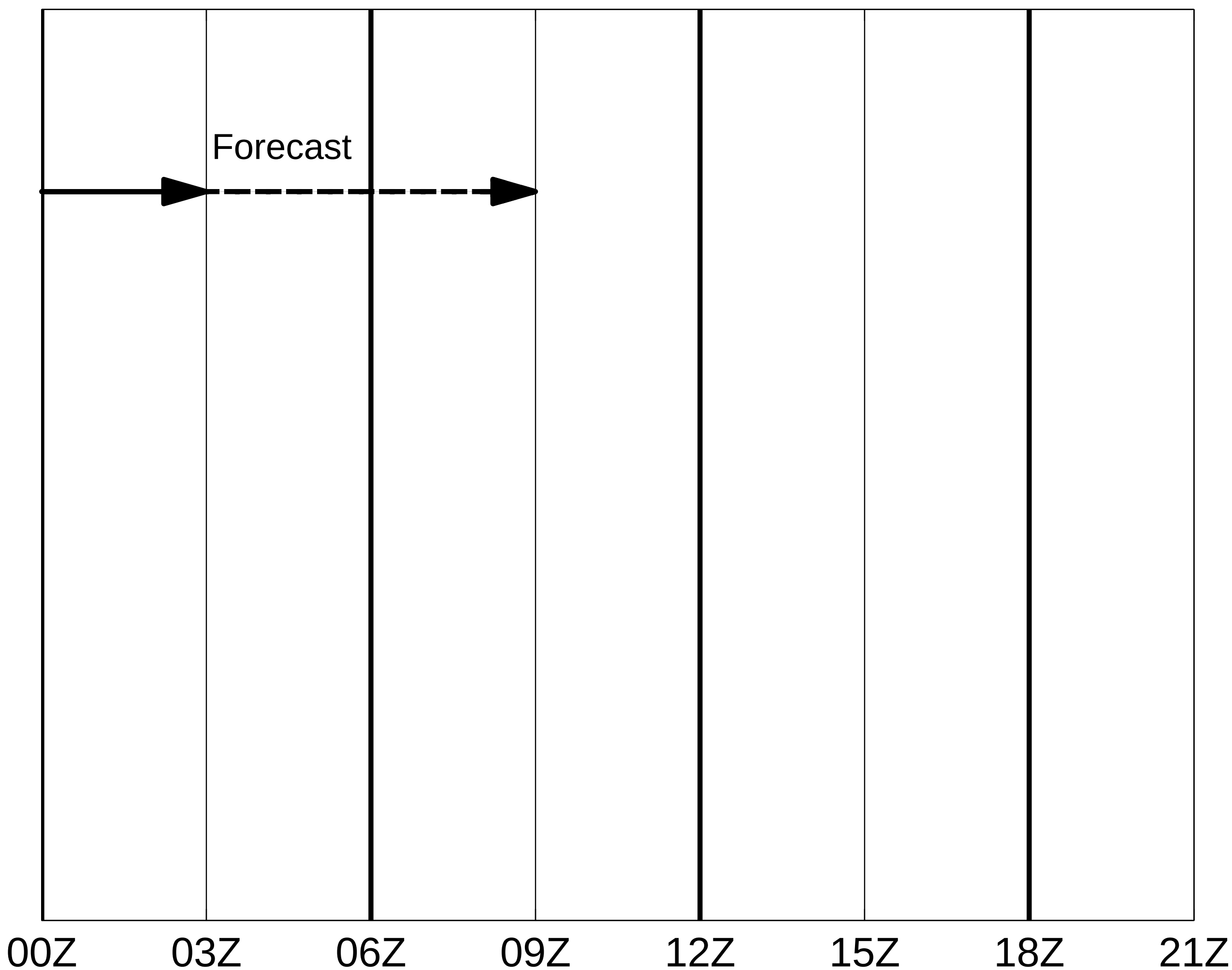
15 Jan 2015 – 05 April 2015



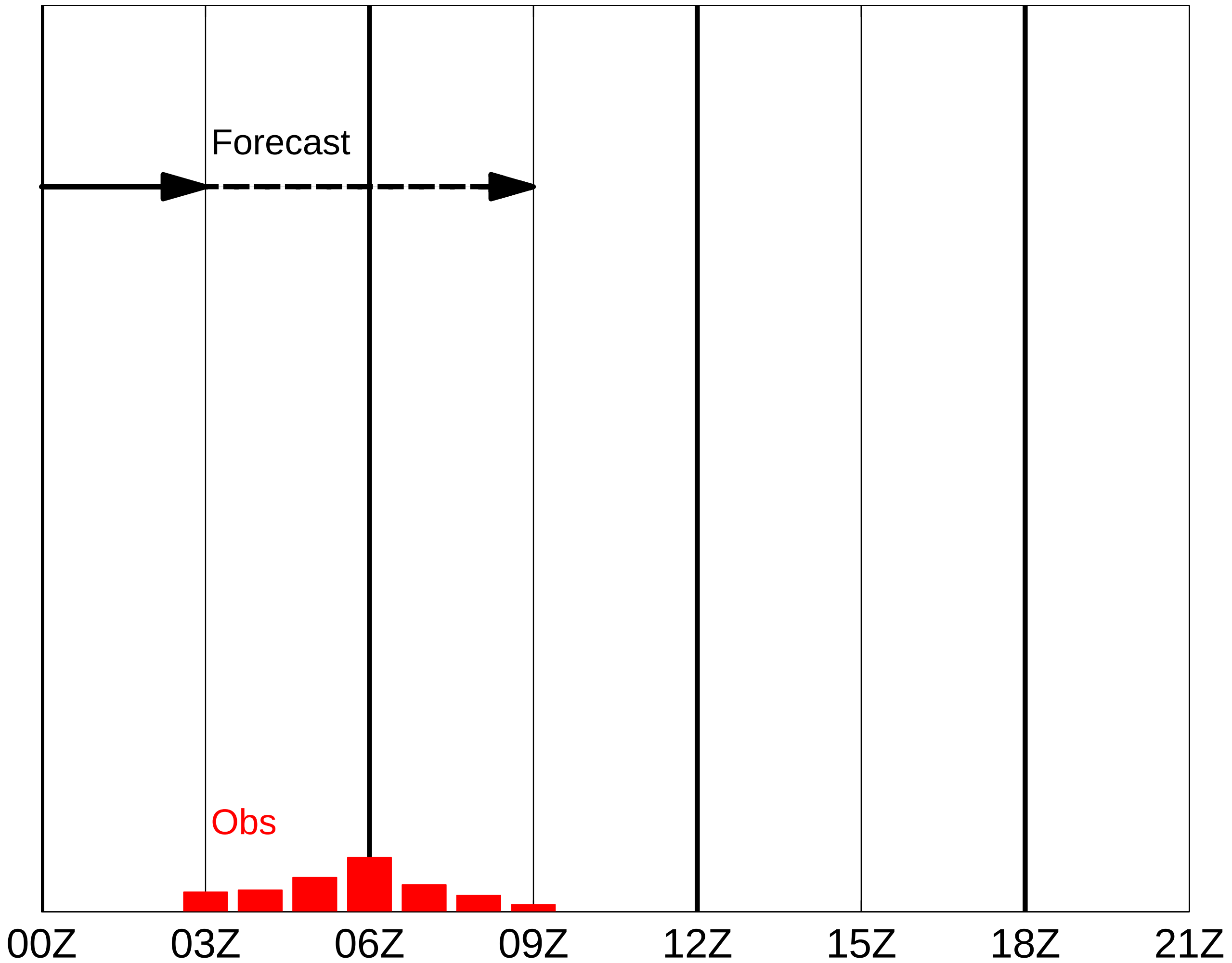
4D-IAU motivation

- 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.

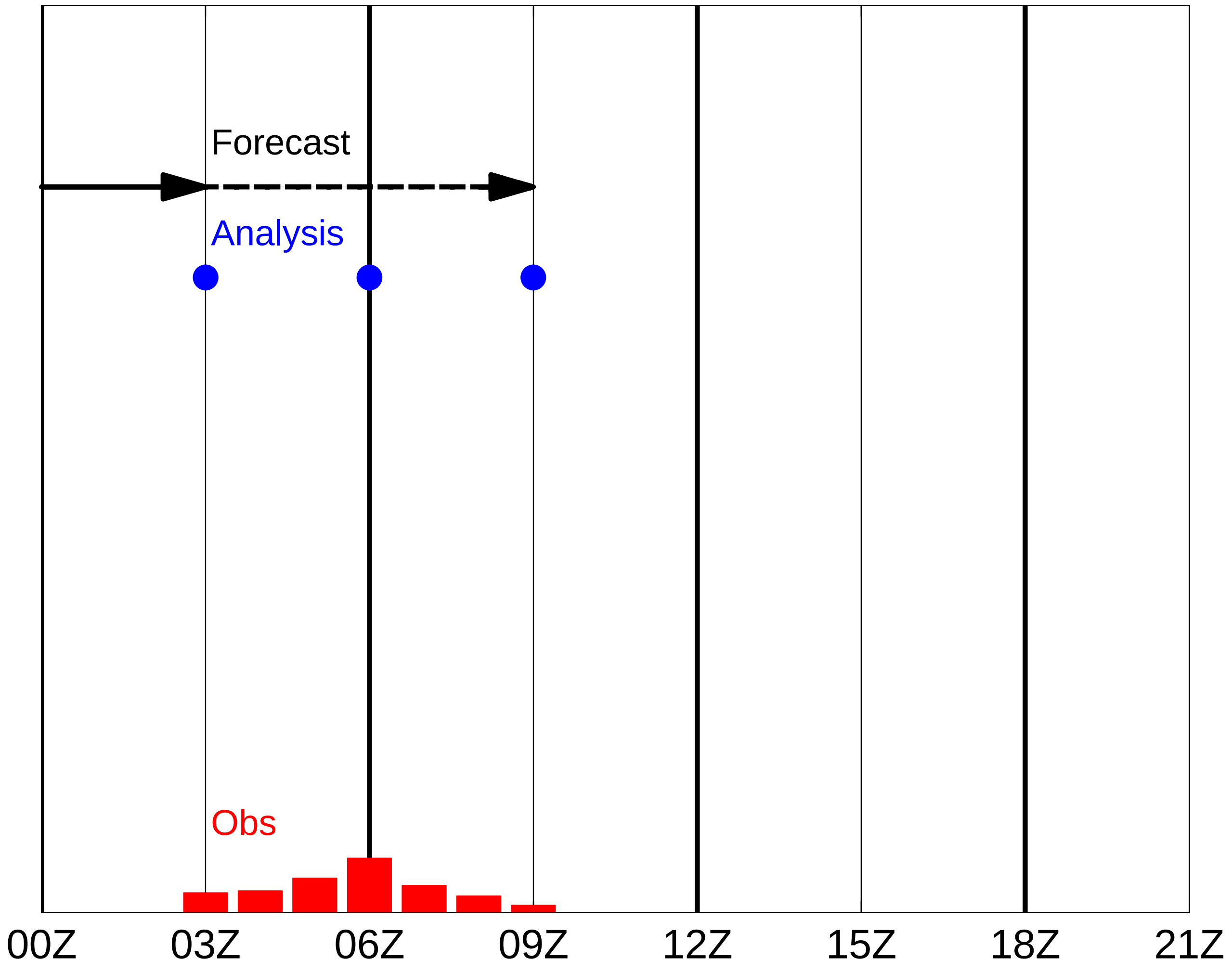
Schematic of the 4DIAU



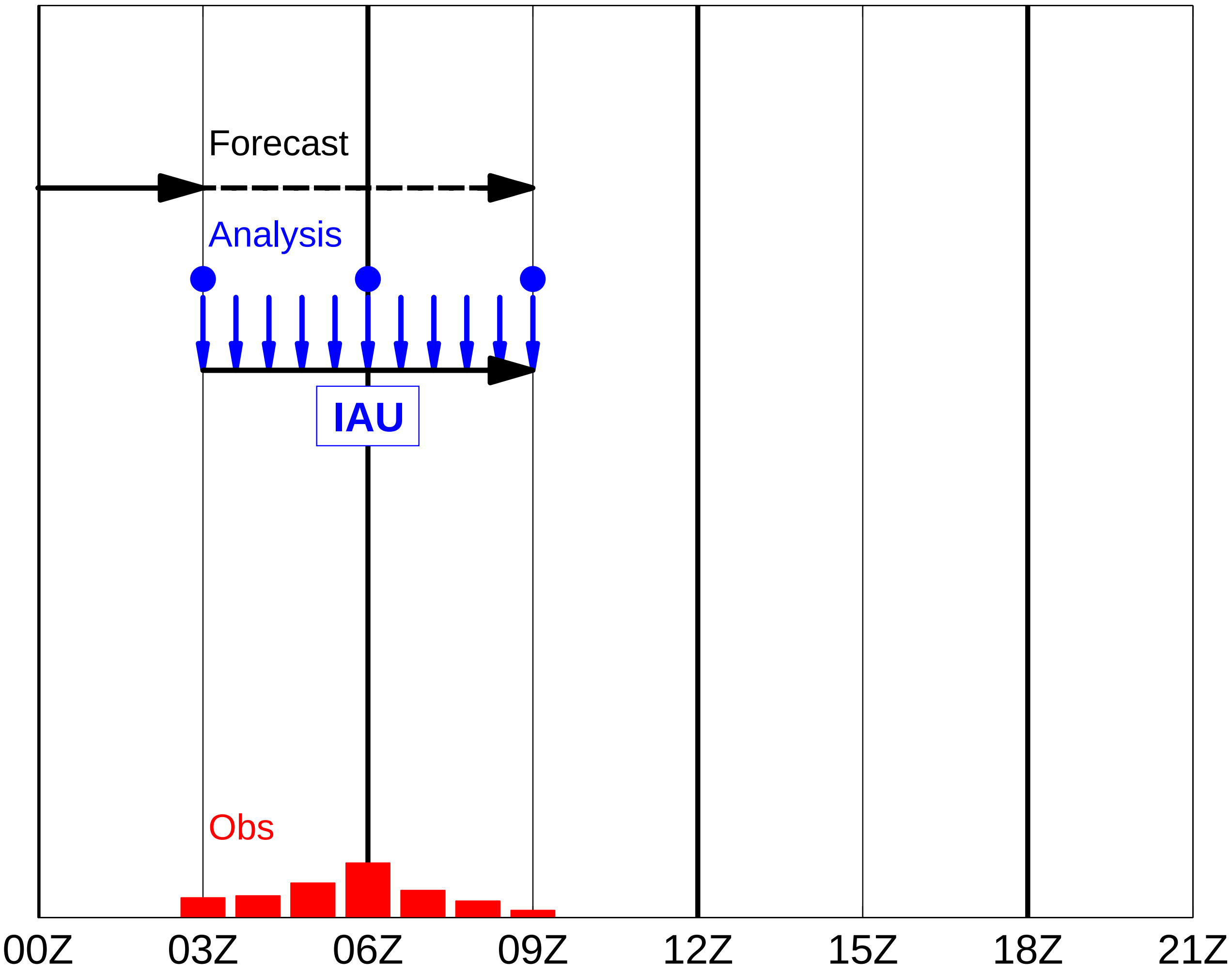
Schematic of the 4DIAU



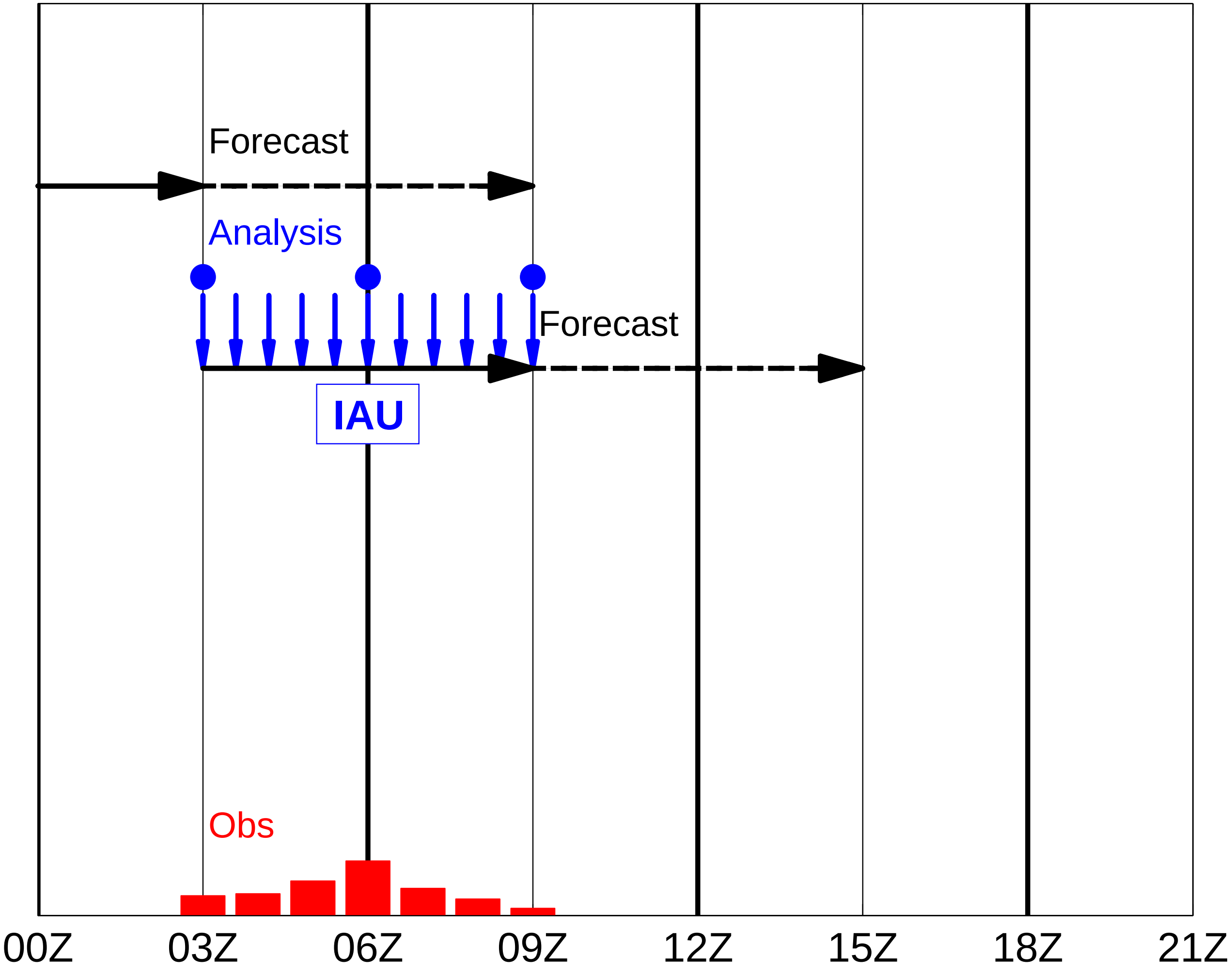
Schematic of the 4DIAU



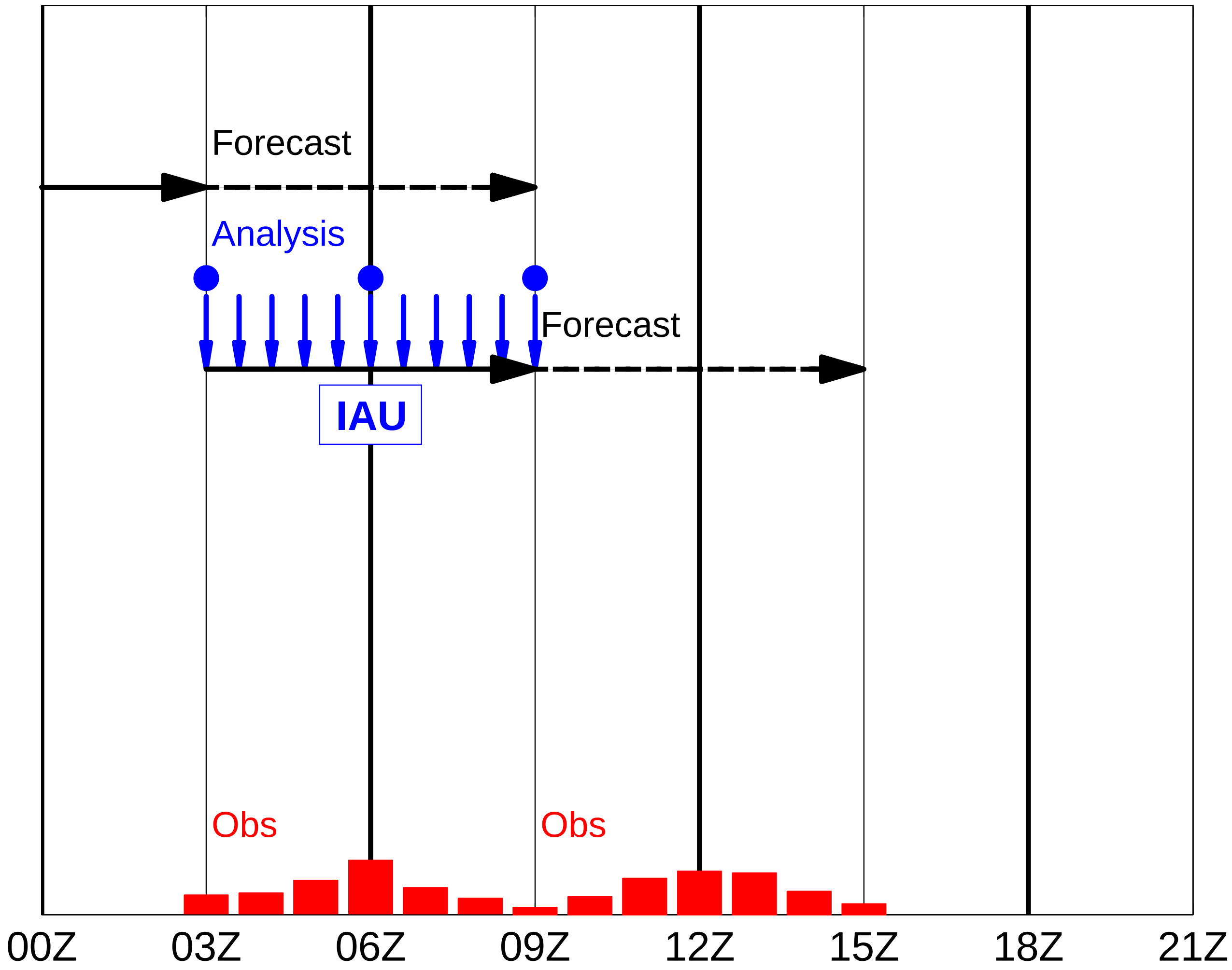
Schematic of the 4DIAU



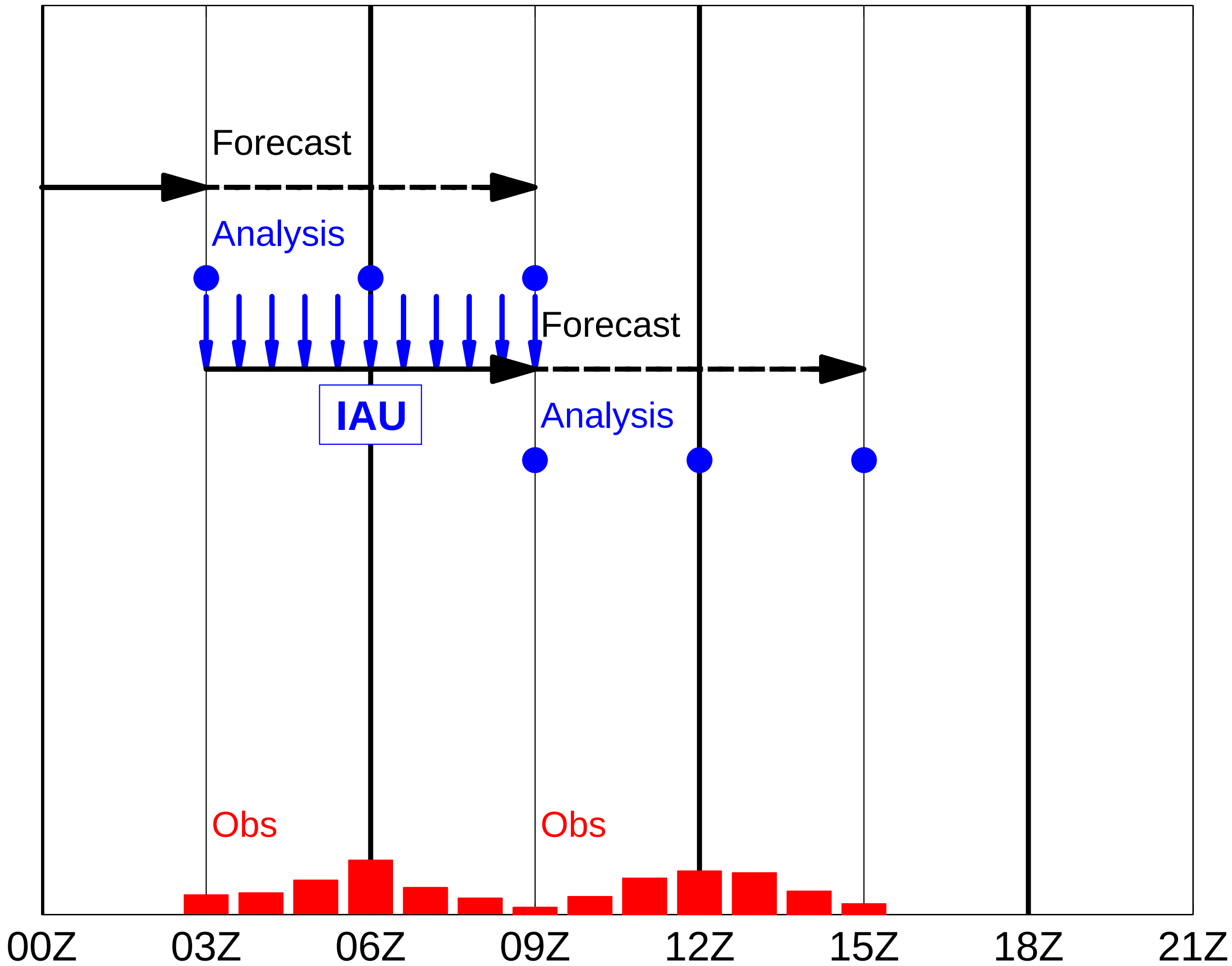
Schematic of the 4DIAU



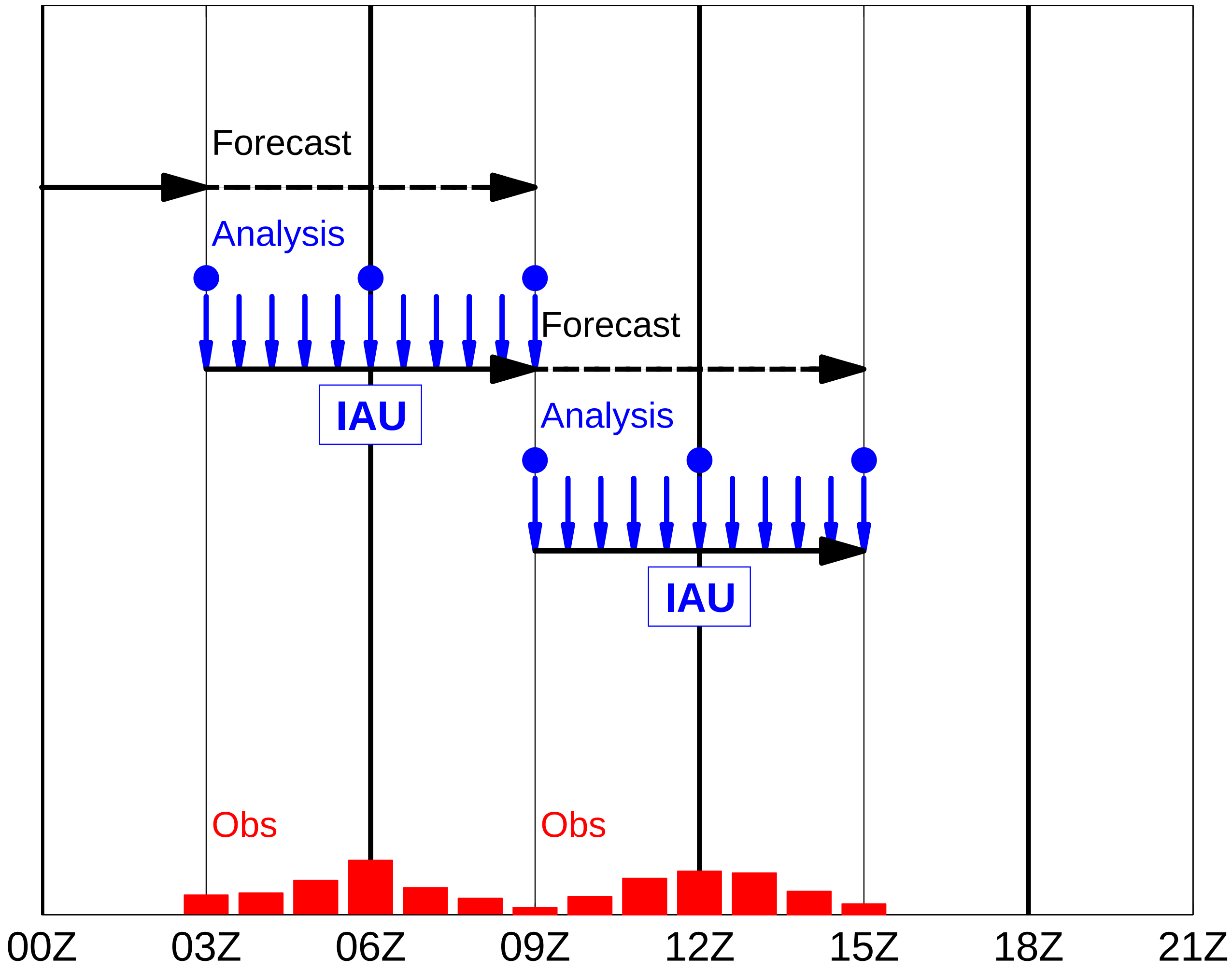
Schematic of the 4DIAU



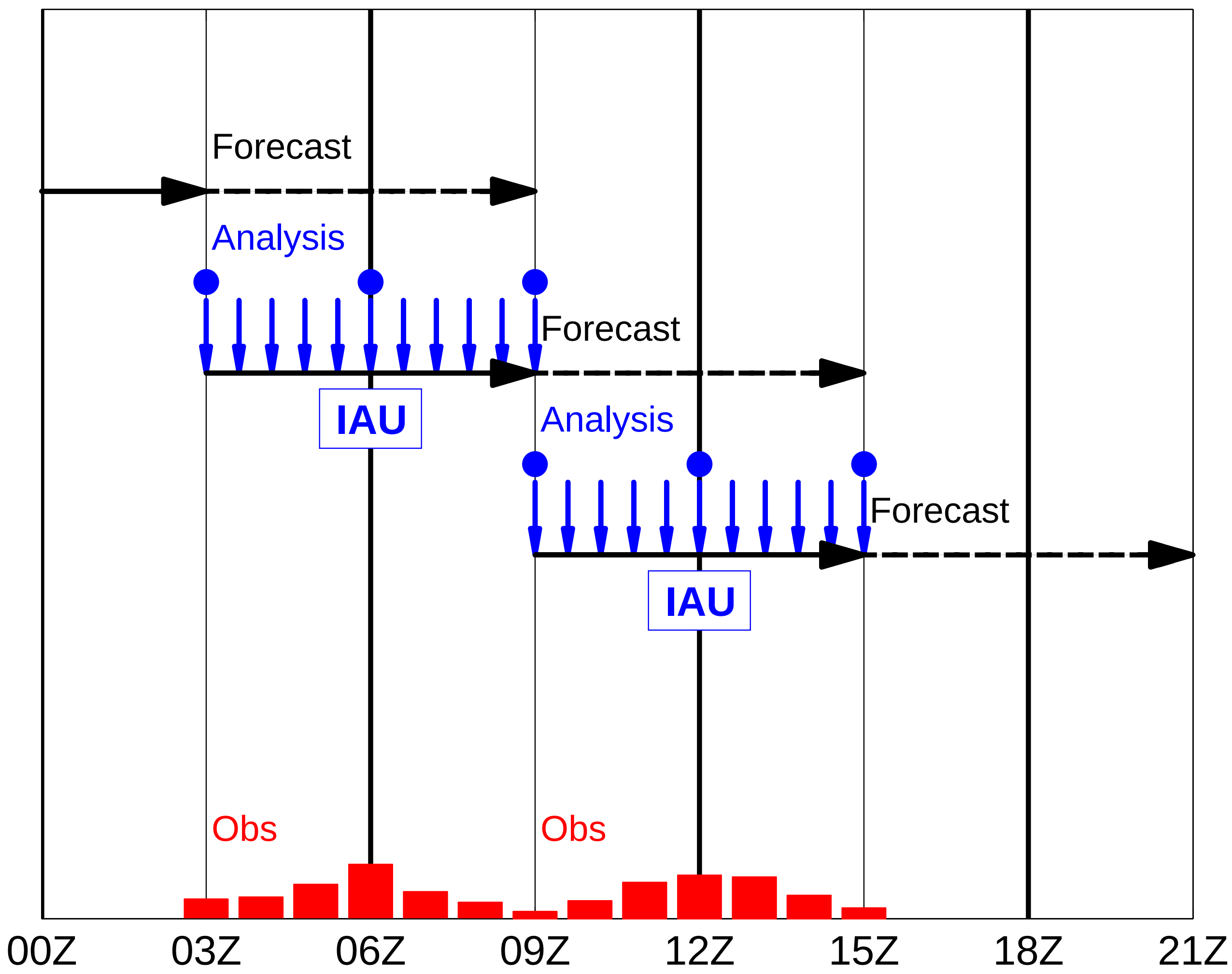
Schematic of the 4DIAU



Schematic of the 4DIAU



Schematic of the 4DIAU

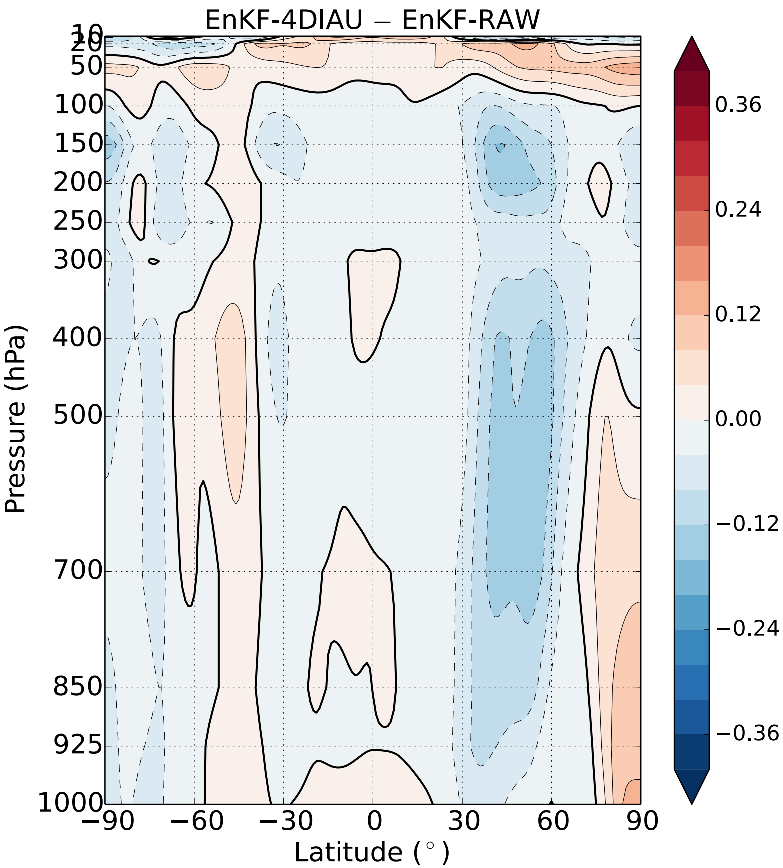


Testing EnKF-4DIAU with Real Data Experiments

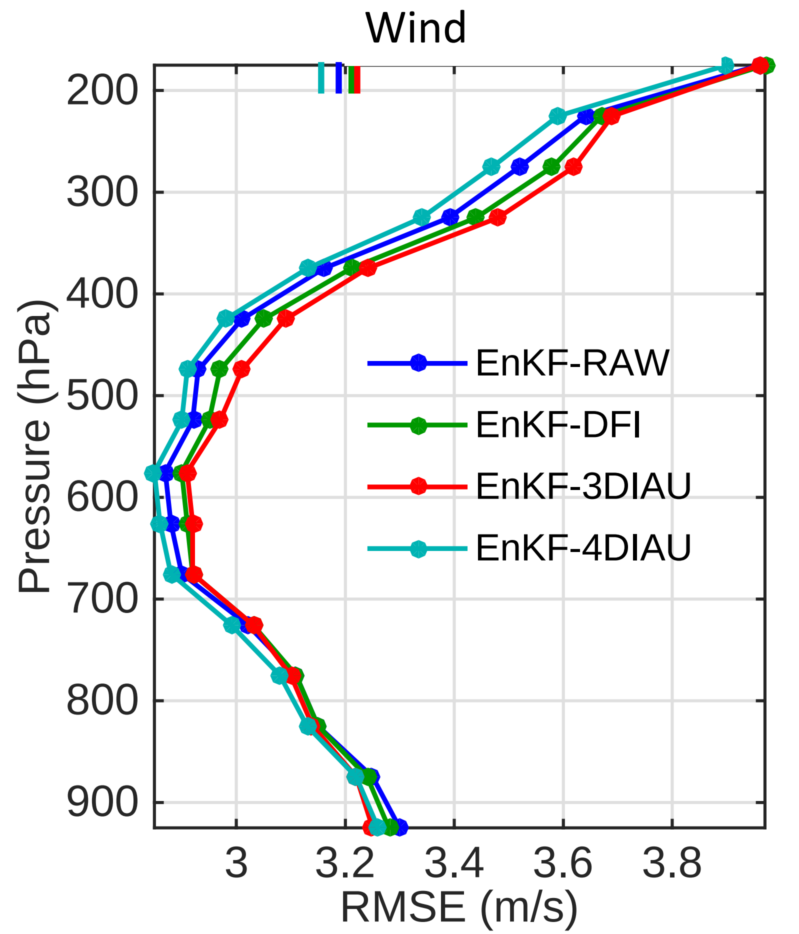
- The Global Forecast System (GFS) with 80 T574 (~30 km) members are used.
- 1250 km/1.0 scale height localization.
- Stochastic physics and multiplicative inflation (no additive inflation).
- Radiance bias correction comes from a separate GSI 3D Ensemble-Variational run.
- 6-hour cycling, 3-h forecast 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.

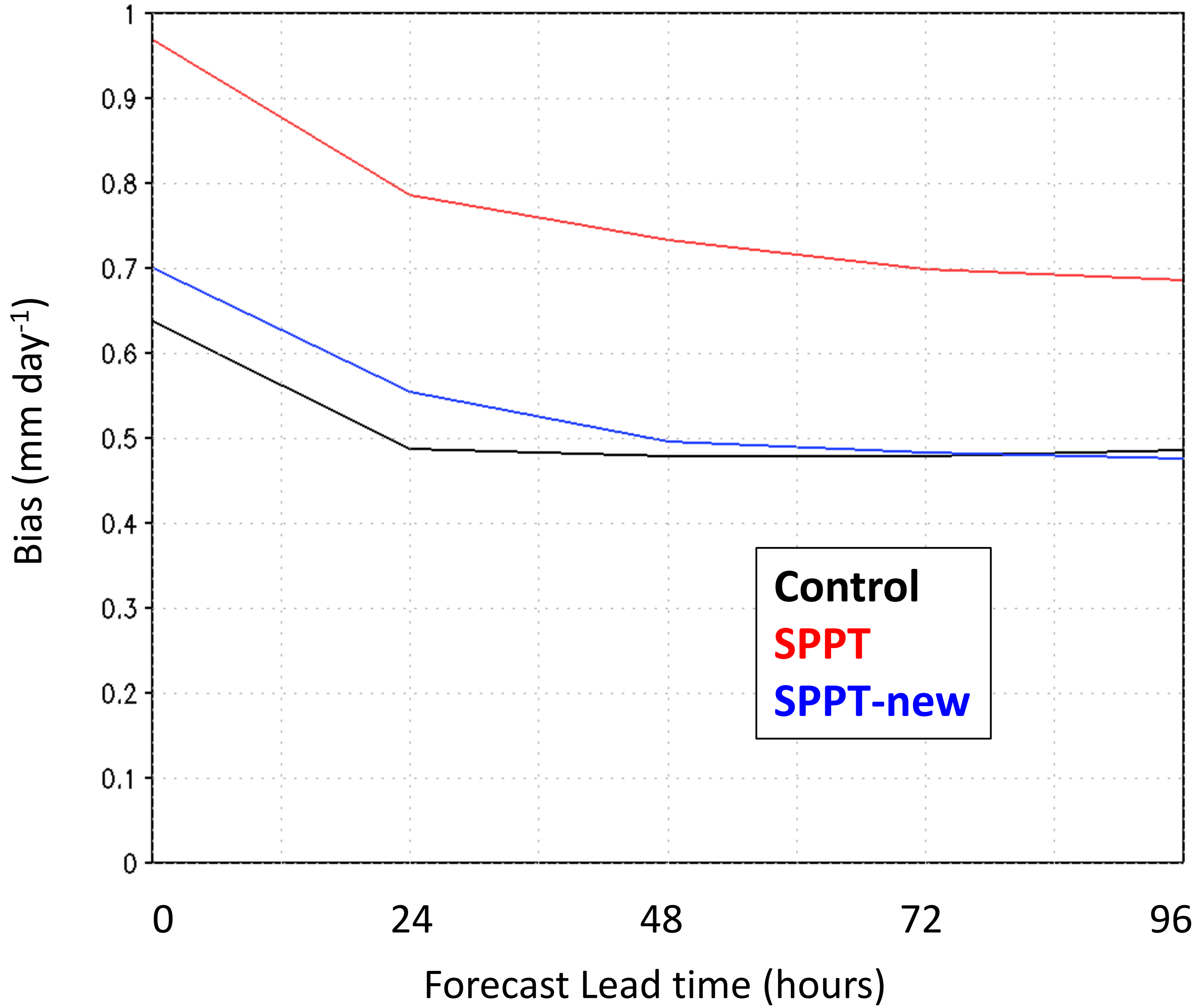
Ongoing DA work

- 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

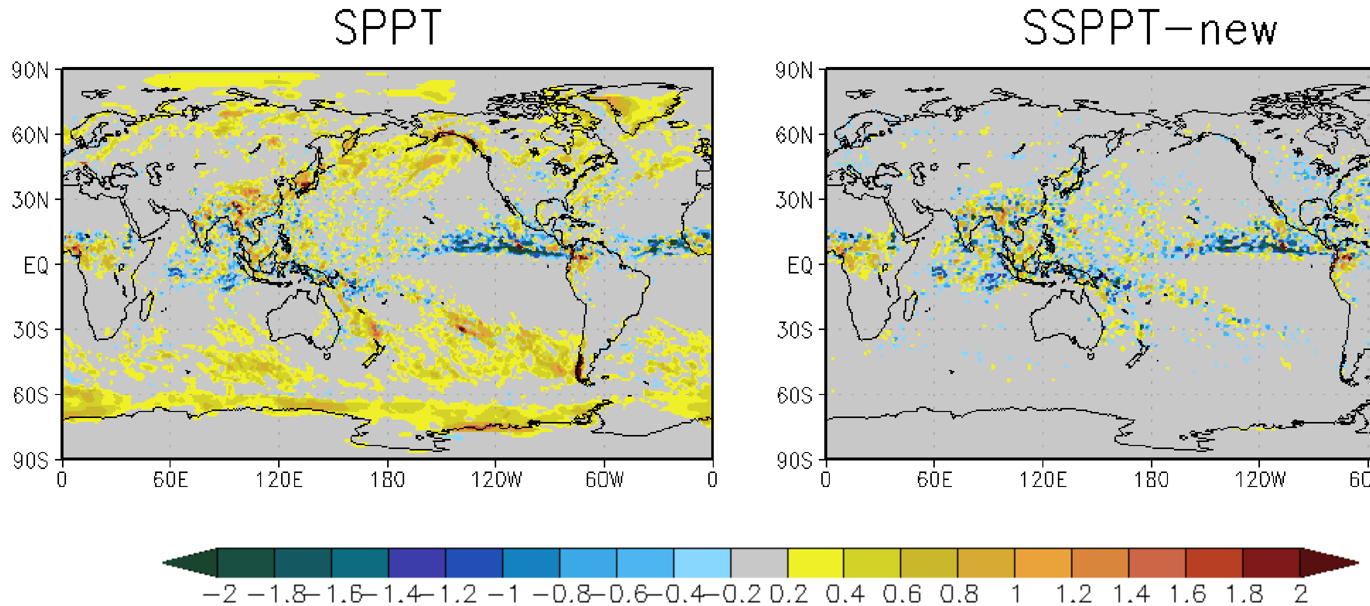
- SPPT perturbs the tendencies from physics before adding them back to the state.
- Other outputs from physics (precipitation) are not perturbed
  - This results in a mismatch between latent heating/moistening and precipitation accumulation
  - Due to non-linear interactions, the result is a global increase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