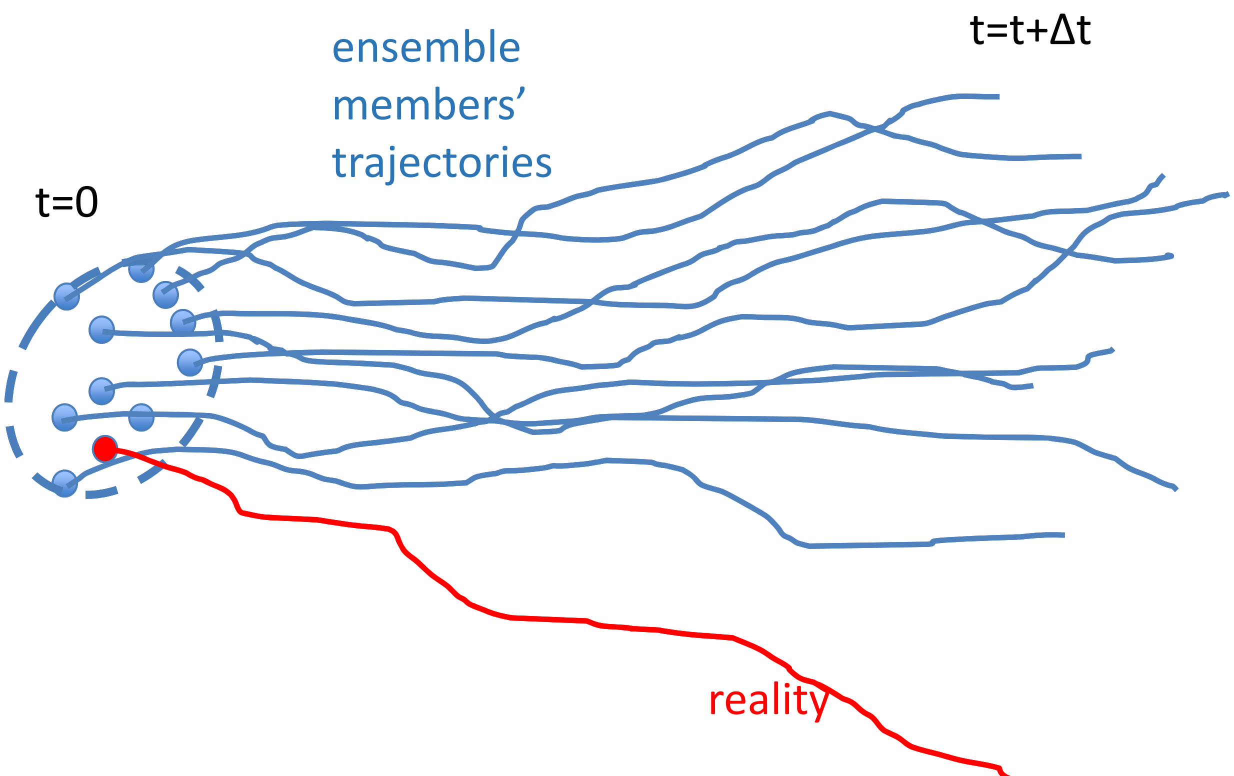
Tests of various schemes for representing model uncertainty in the GFS



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(with help from Dingchen Hou)

Test hypothesis

- Via a new suite of model uncertainty parameterizations (ECMWF’s SPPT, ECMWF/Met Office’s SKEB, home-grown stochastically perturbed boundary layer RH), we hypothesize that:
  - short and medium-range ensemble forecast spread can be increased to be more consistent with RMS error, improving probabilistic forecasts.
  - additive noise that is currently used to simulate model uncertainty in data assimilation can be replaced with model uncertainty parameterizations.

NCEP operational scheme (STTP)

Stochastic Total Tendency Perturbation

Scheme (*Hou, Toth and Zhu, 2006*)

NCEP operation – Feb. 2010

Formulation:

$$\frac{\partial X_i}{\partial t} = T_i(X_i;t) + \gamma \sum_{j=1,\ldots,N} w_{i,j} T_j(X_j;t)$$

Simplification: Use finite difference form for the stochastic term

Modify the model state every 6 hours:

$$X_i' = X_i + \gamma \sum_{j=1}^{N} w_{i,j}(t)\{[(X_j)_t - (X_j)_{t-6h}] - [(X_0)_t - (X_0)_{t-6h}]\}$$

Where w is an evolving combination matrix, and γ is a rescaling factor.

random linear combinations of ensemble tend
perturbations added to state every 6-h
(entire ensemble must be run concurrently).

this method tends to add spread preferentially where spread already is large.

Also, ensemble members are slaved together into one executable, which could mean that the whole ensemble could fail when one CPU fails.

New schemes tested: a combination of:

- Stochastically-perturbed **physics** tendencies (SPPT) – operational ECMWF scheme.
- Stochastic kinetic energy backscatter.
- Vorticity confinement (only for data assimilation experiment here)
- Stochastically-perturbed boundary-layer humidity (SHUM).

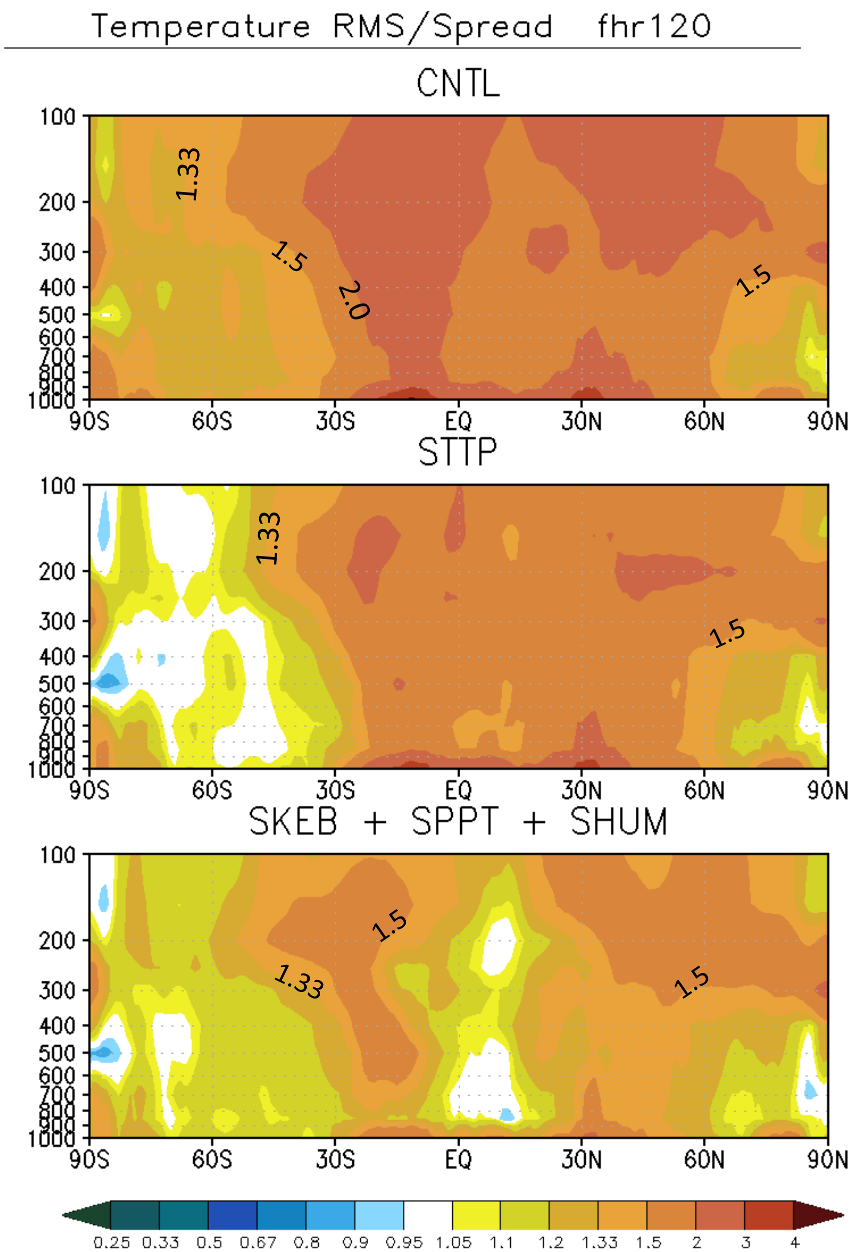
(some details in supplementary slides)

Test methodology

- T574L64 GEFS, using new semi-Lagrangian advection.
- Daily, August 1, 2013 to September 1, 2013
- 20-member ensembles.
- Initialized off operational hybrid GSI/EnKF control and operational ETR perturbations.
- Precipitation: used 1-degree CCPA analysis as verification.
- Used blended ECMWF/NCEP analysis for validation
- For comparison:
  – CONTROL (no model uncertainty)
  – STTP (operational model uncertainty method)

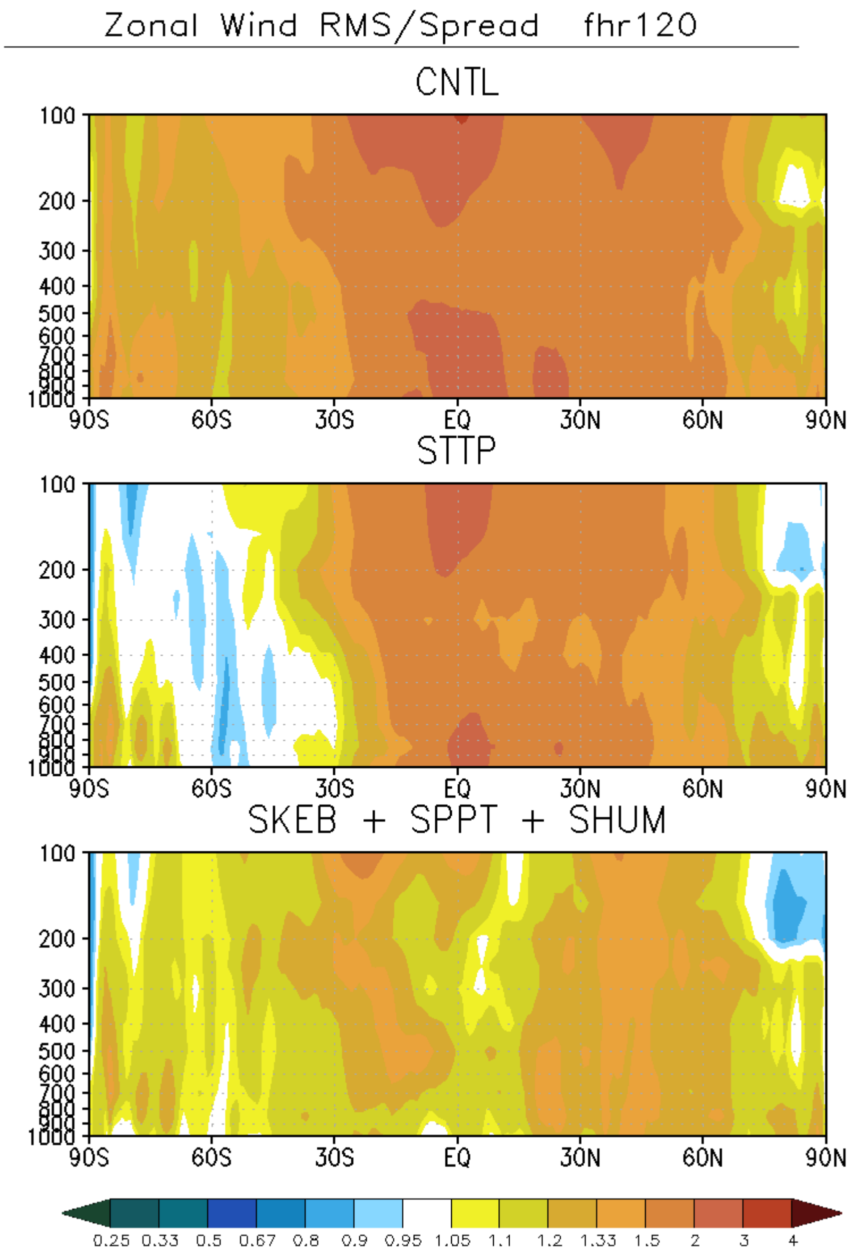
Medium-range forecast results

Day +5 RMS error / spread, temperature

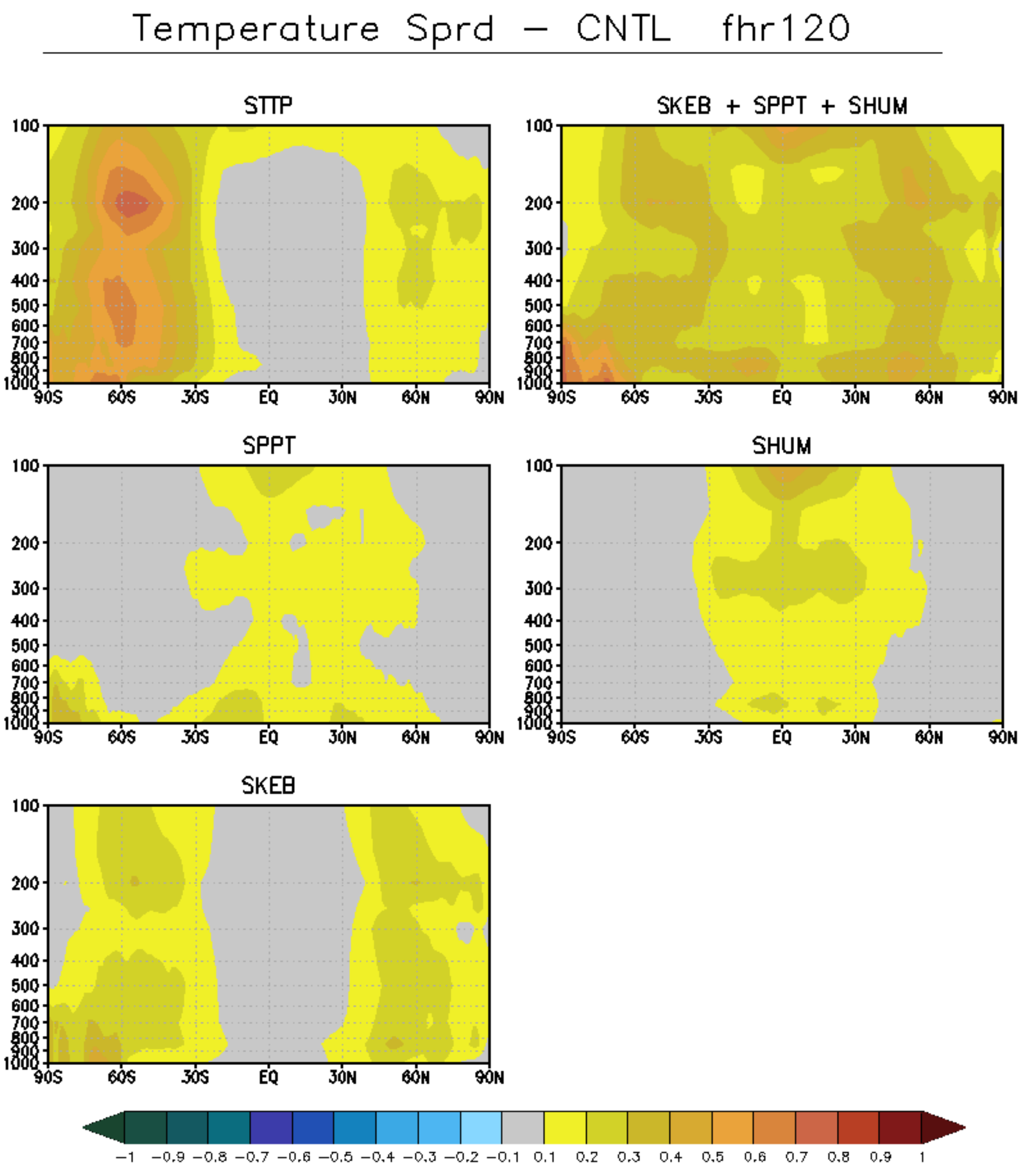


This ratio should be equal to 1.0, ideally. Where > 1.0, indicates a lack of spread

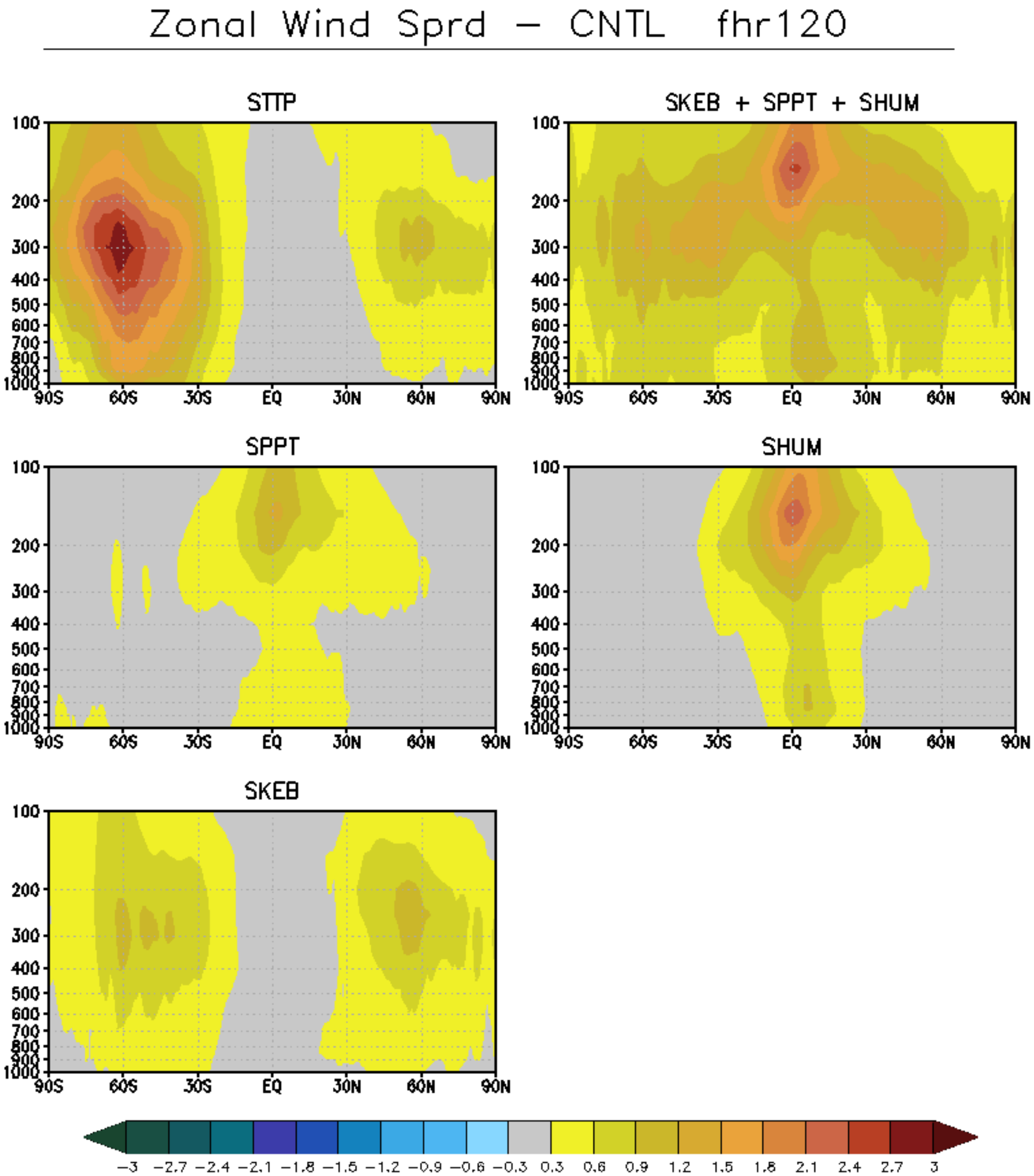
Day +5 RMS error / spread, zonal wind



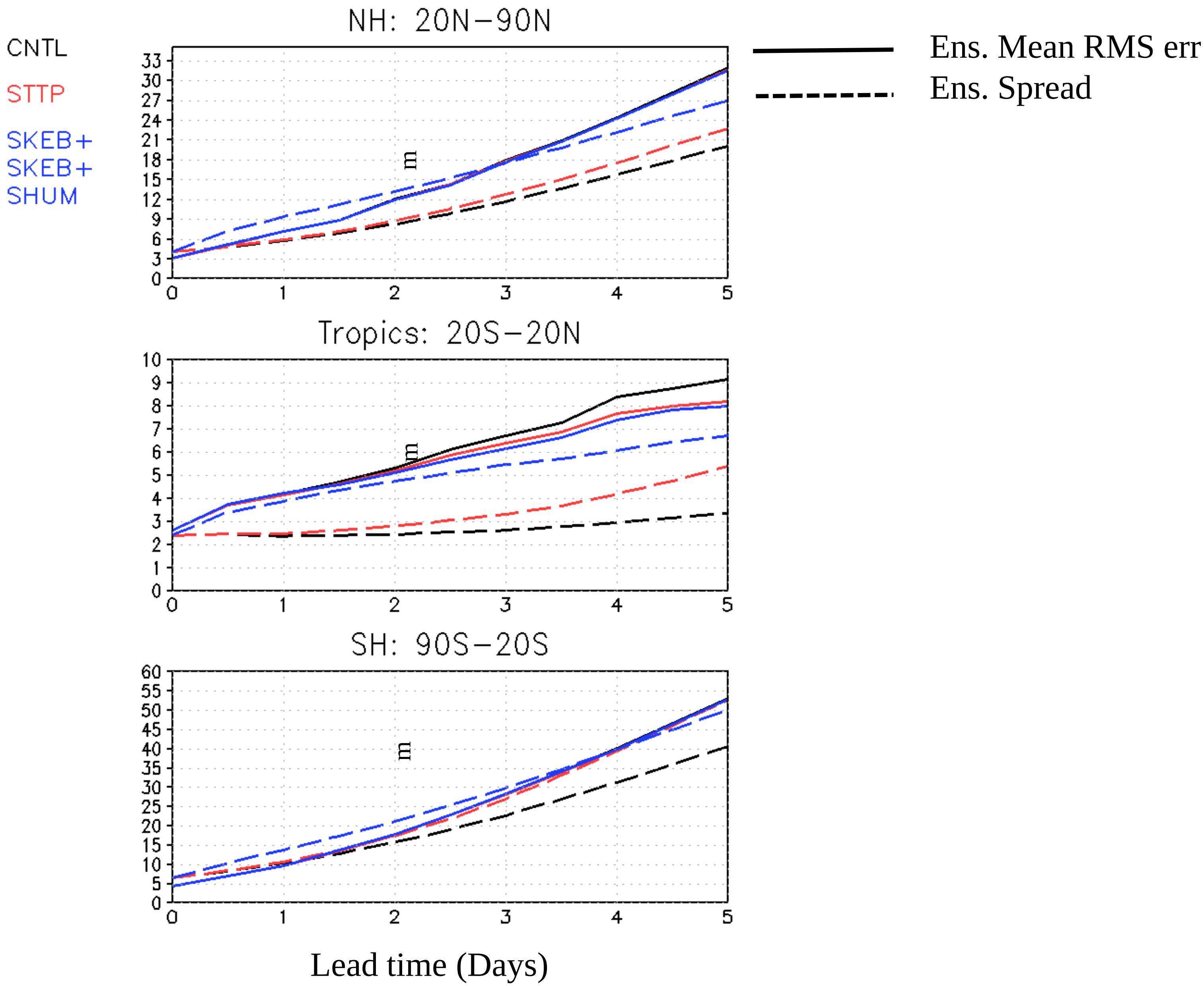
Day +5, spread increase from control



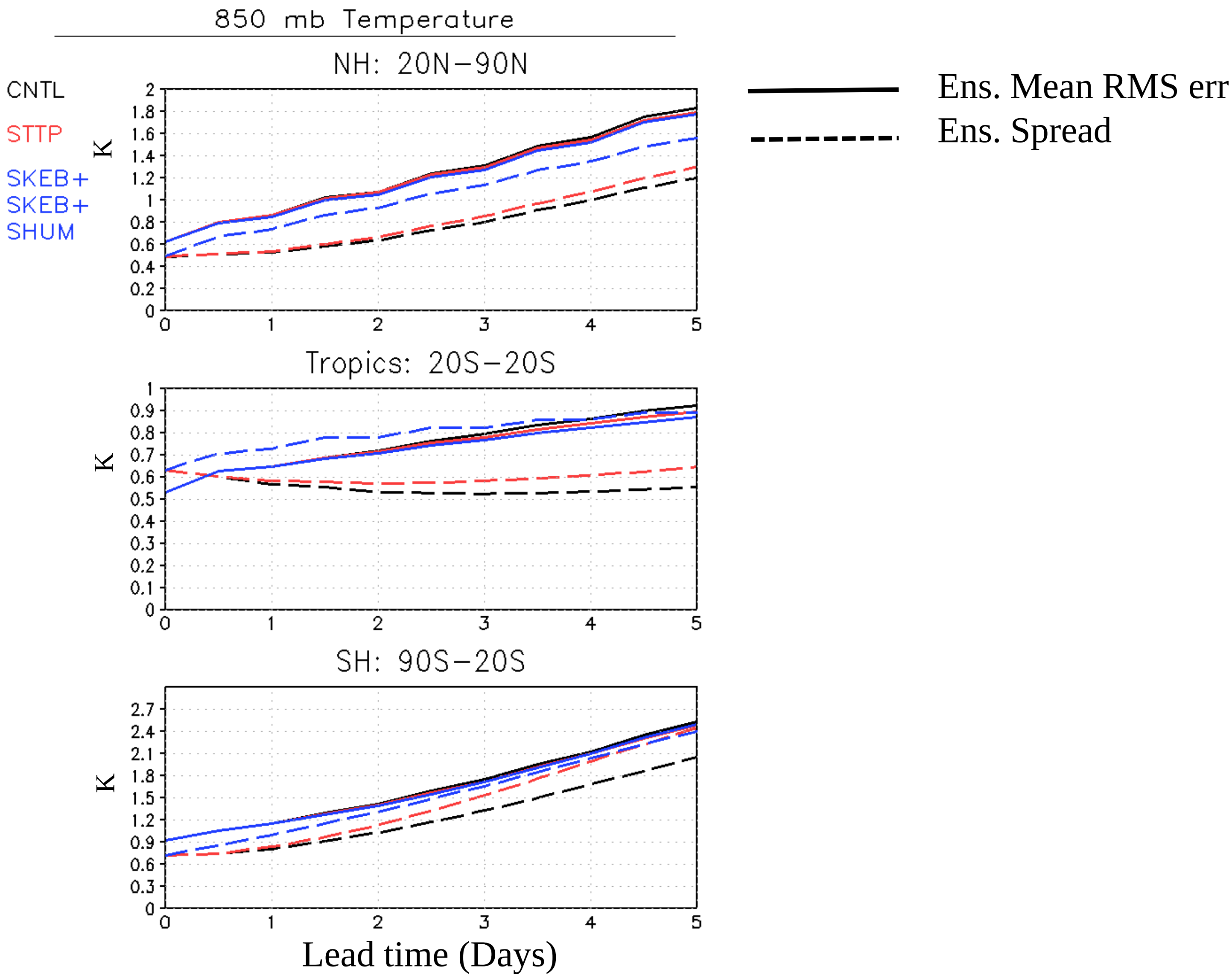
Day +5 spread increase from control



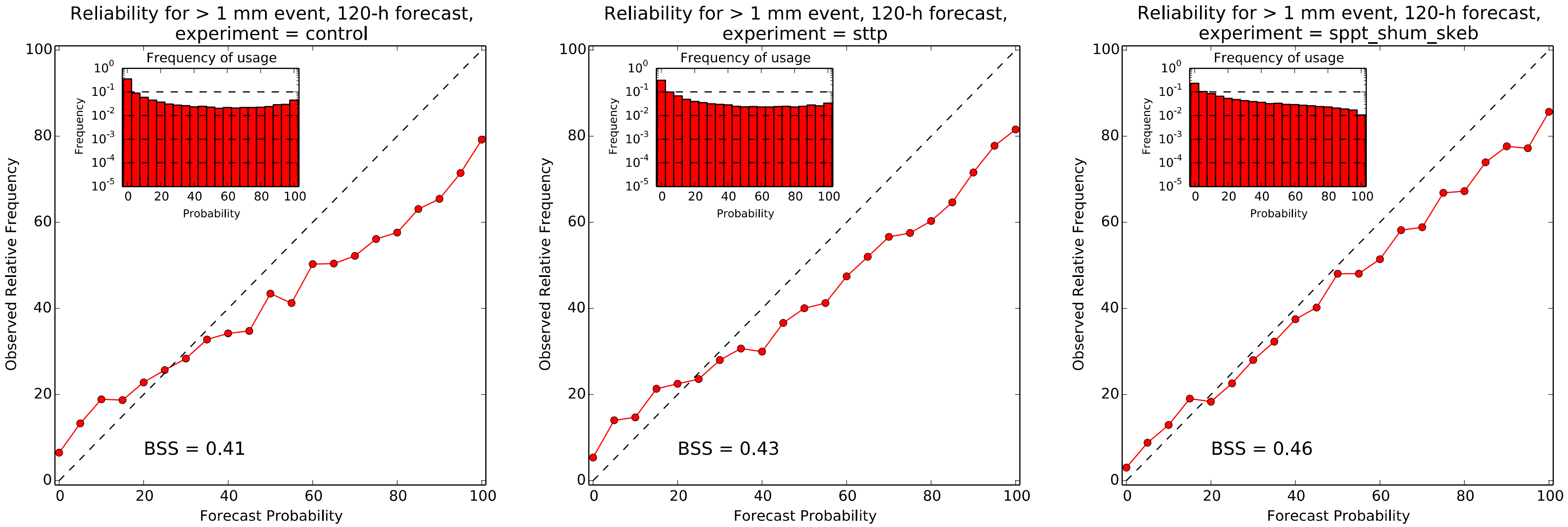
500 hPa height, spread and RMS error



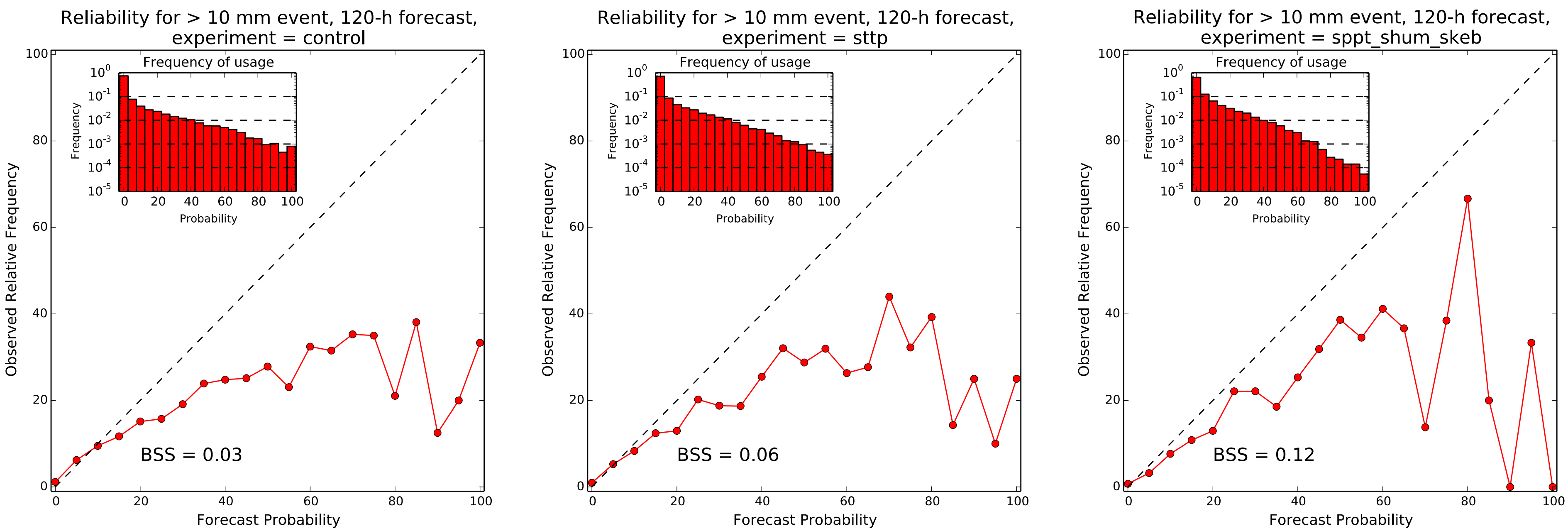
850 hPa temperature, spread and RMS error



96-120 h reliability, > 1 mm / 24h



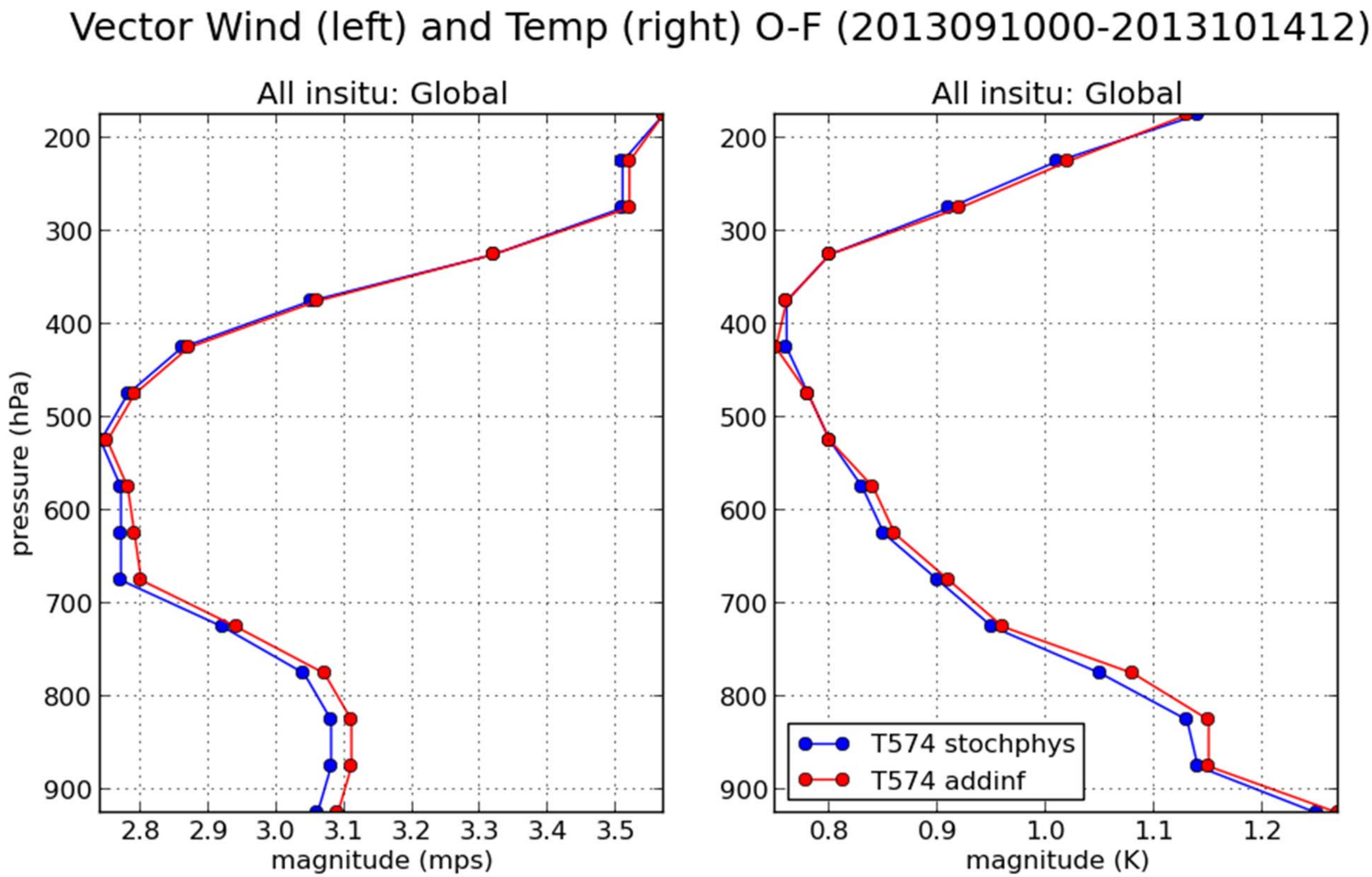
96-120 h reliability, > 10 mm / 24h



Data assimilation experiment

- Control:
  - As in NCEP ops (using additive inflation).
- Expt:
  - Replace additive inflation with combination of SPPT, SHUM, SKEB and VC. Spatial/temporal scales of 250km / 6 hrs for each (except 1000 km/6 hrs for VC). Stochastic VC. Amplitudes set to roughly match additive inflation spread. Multiplicative inflation as in NCEP ops.
- Period: Sept 1 to Oct 15 2013, after 7 day spinup.

Impact of O-F for control forecast



Conclusions

- Combination of SPPT, SKEB, and SHUM improves medium-range forecast guidance substantially.
- Also useful for improving treatment of model uncertainty in data assimilation.
- We will work with EMC to get this implemented.

ECMWF method (SPPT)

Stochastically Perturbed Physics Tendency

- Perturbed Physics tendencies

$$X_p = (1 + r\mu)X_c$$

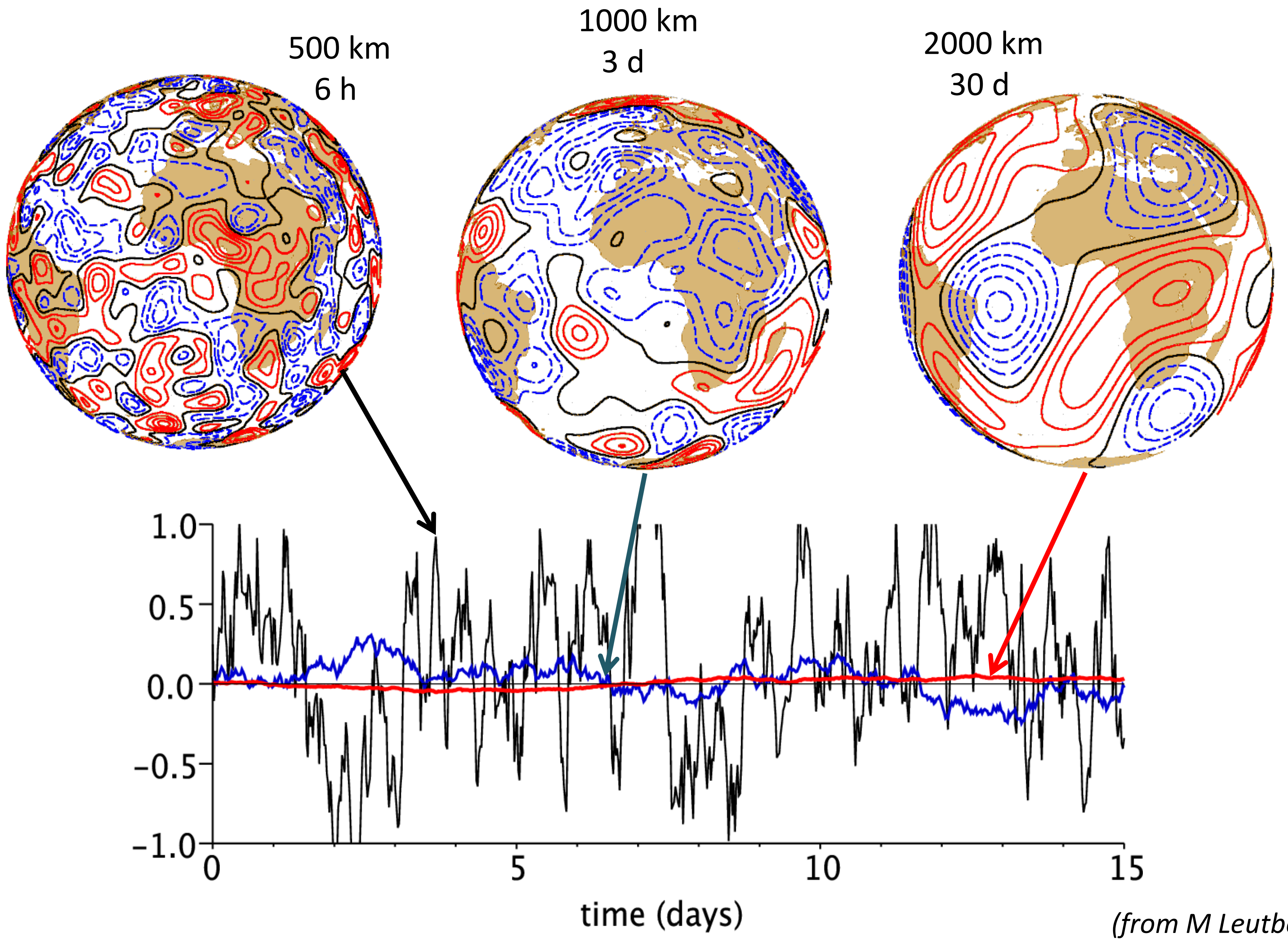
Original tendencies from gbphys

μ- vertical weight: 1.0 between surface and 100 hPa, decays to zero between 100 hPa and 50 hPa.

r- horizontal weights: ranges from -1.0 to 1.0, a red noise process with a

- Temporal timescale of 6 hours
- e-folding spatial scale of 500 km

Examples of stochastic patterns



(from M Leutbecher)

Vorticity confinement

(Sanches, Williams and Shutts, 2012 QJR doi 10.1002)

$$\frac{D\mathbf{V_H}}{Dt} + f\mathbf{k} \times \mathbf{V}_H + \nabla\phi = \mu\nabla^2\mathbf{V}_H + \epsilon\hat{\mathbf{n}} \times |\zeta|\,\widehat{\mathbf{k}}$$

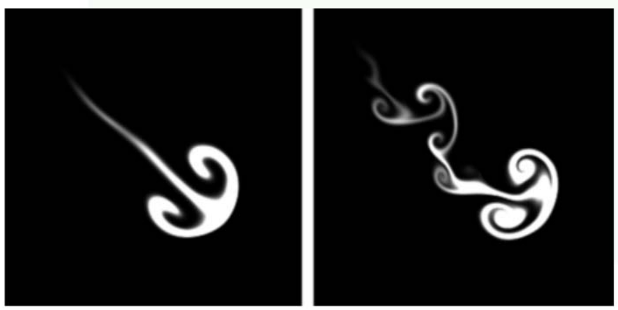
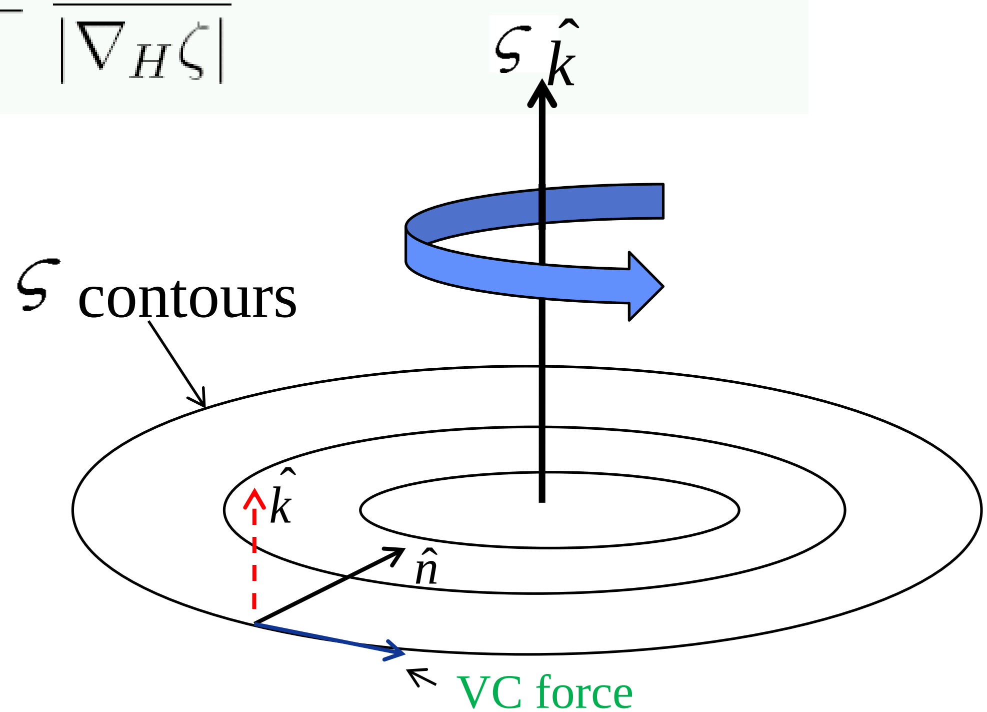


Figure 6: Two frames of animation from two mpeg movies created using `flowanim` and `mpeg2encode`. Both frames depict the 60th frame of the movie. The left animation is created without vorticity confinement, the one on the right with vorticity confinement and a *relatively* high force factor

$$\hat{\mathbf{n}} = \frac{\nabla_H\zeta}{|\nabla_H\zeta|}$$



acts as an advective velocity

ε=0.6 in our experiments

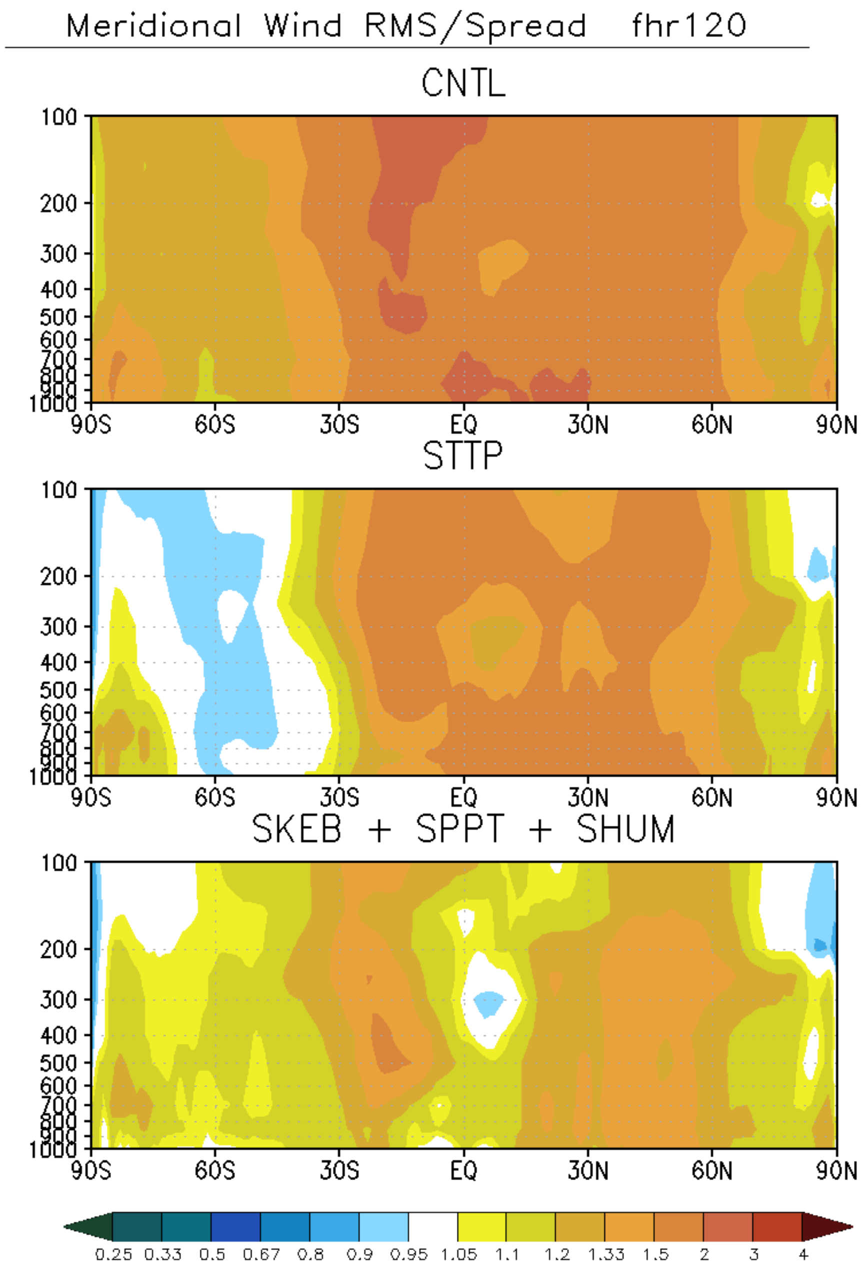
Stochastic boundary-layer humidity

- SPPT only modulates existing physics tendency (cannot change sign, trigger new convection).
- Triggers in convection schemes very sensitive to BL humidity.

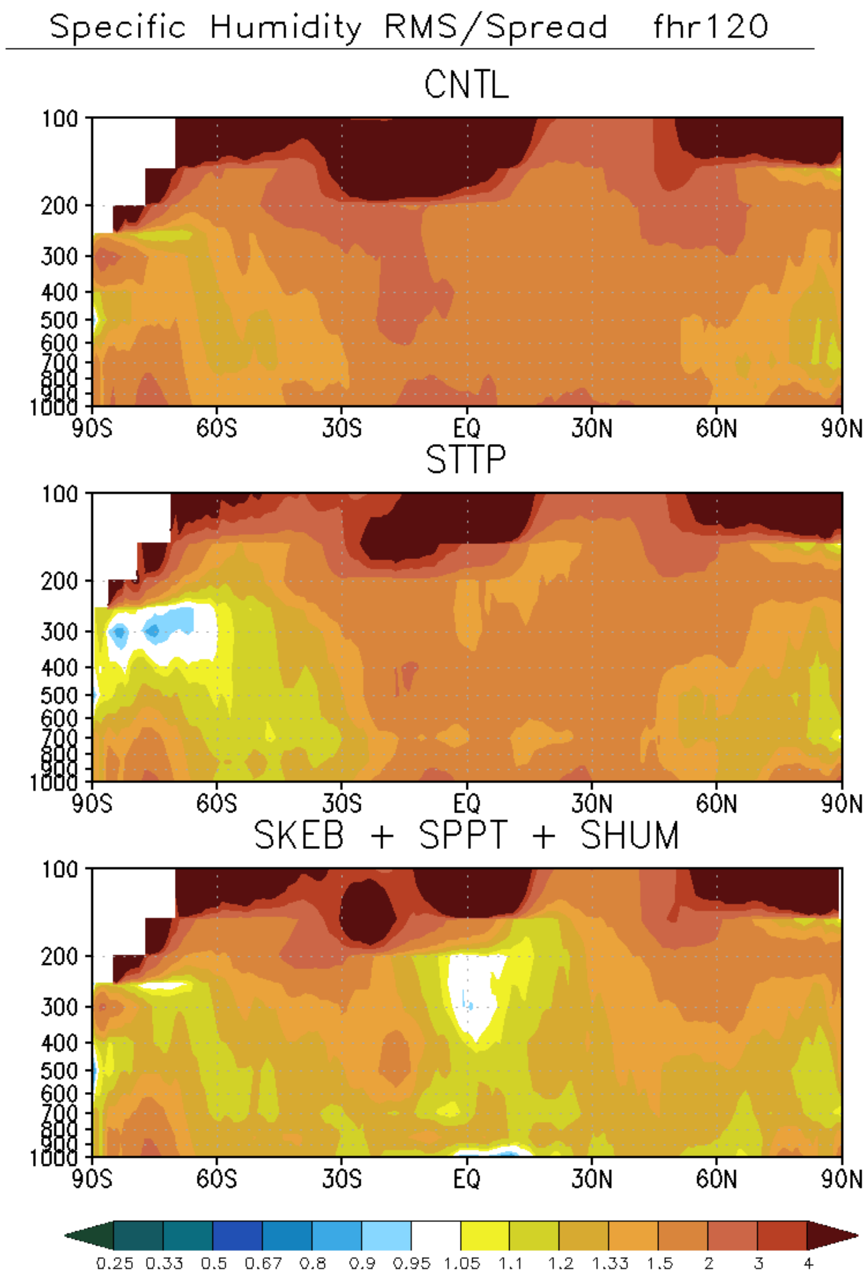
$$q_{perturbed} = (1 + r\mu)q$$

- Vertical weight **r** decays exponentially from surface. Added every time step after physics applied. Random pattern **μ** has a (very small) amplitude of 0.00375, horizontal/vertical scales (250 km, 3-h).

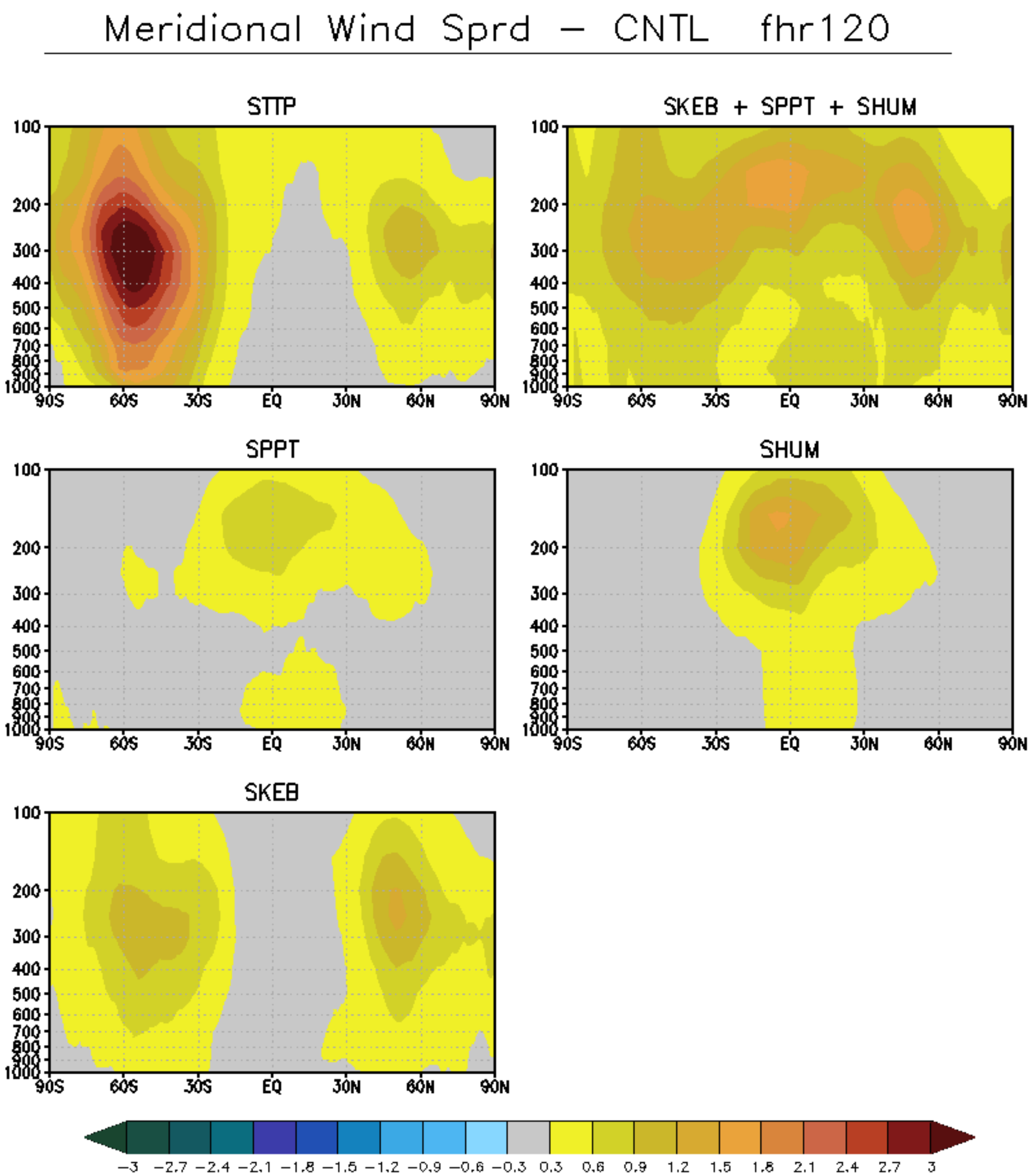
Day +5 RMS error / spread, meridional wind



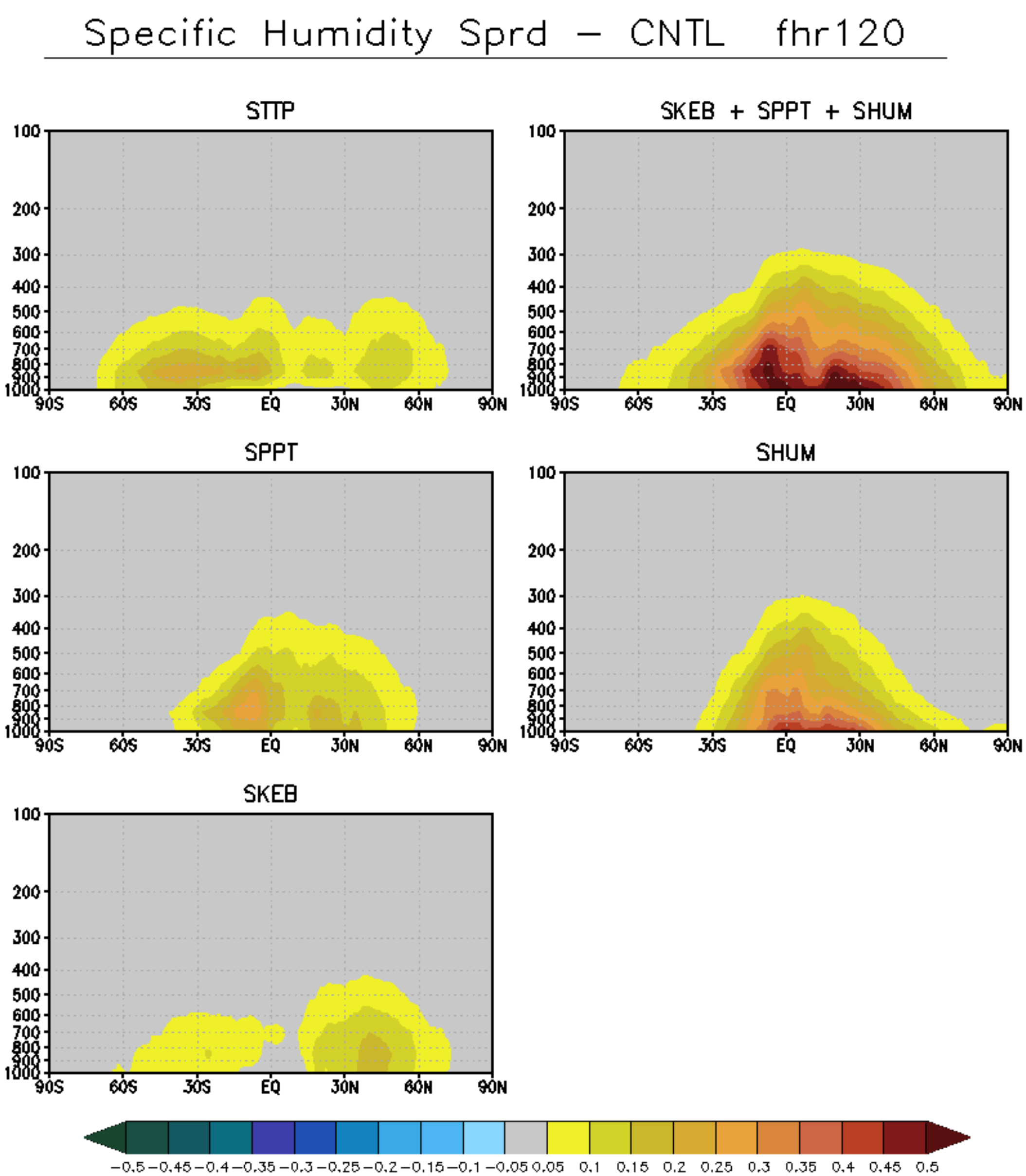
Day +5 RMS error / spread, specific humidity



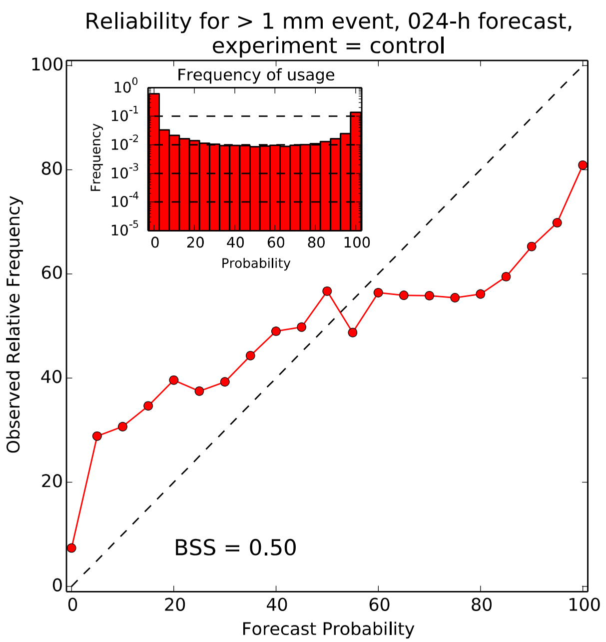
Day-5 Spread increase from Control

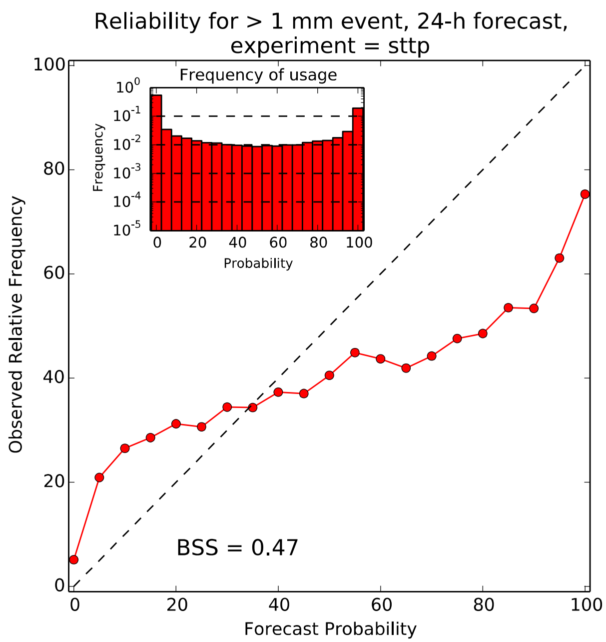


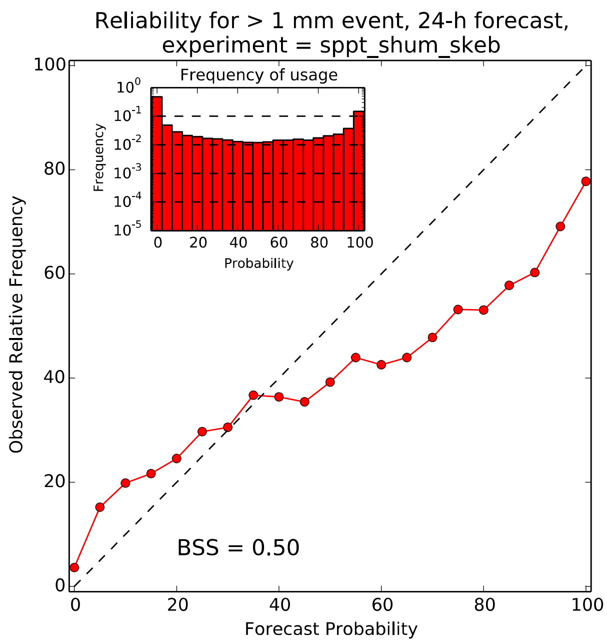
Day-5 Spread increase from Control



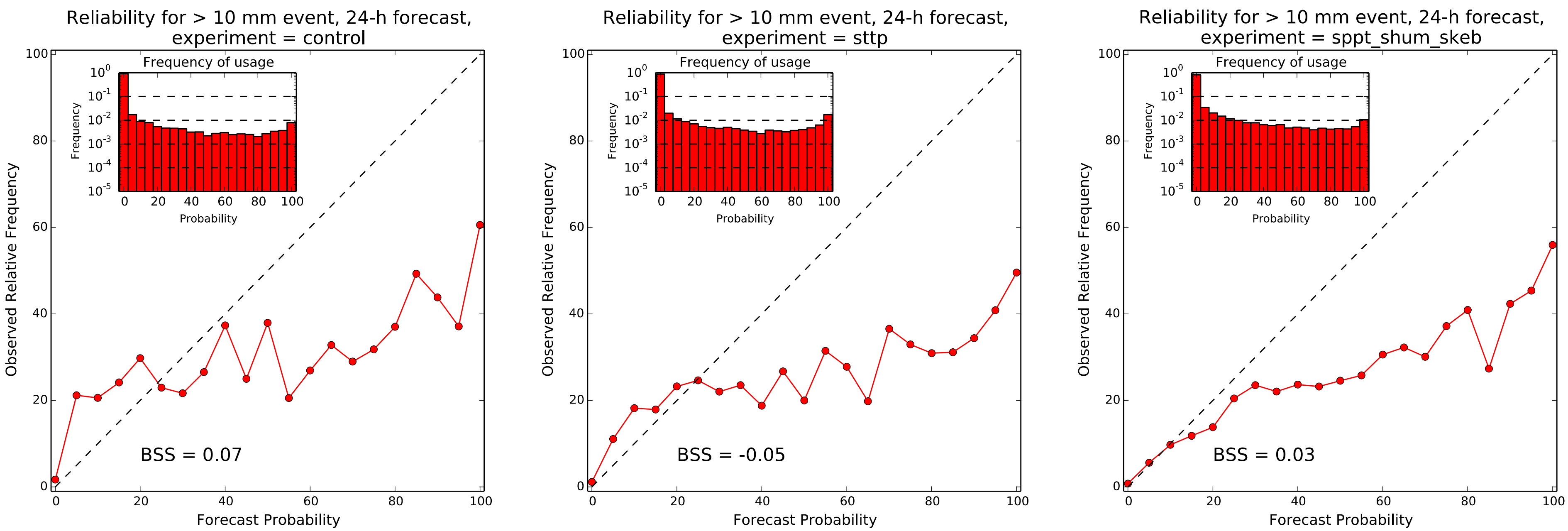
0-24 h reliability, > 1 mm / 24h



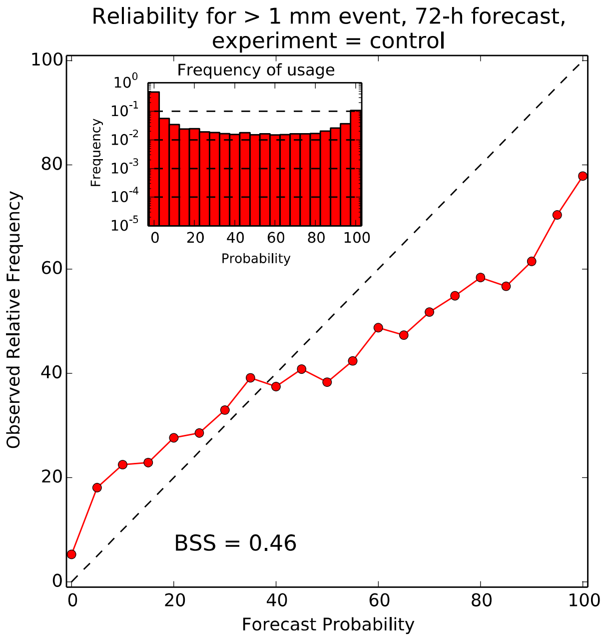


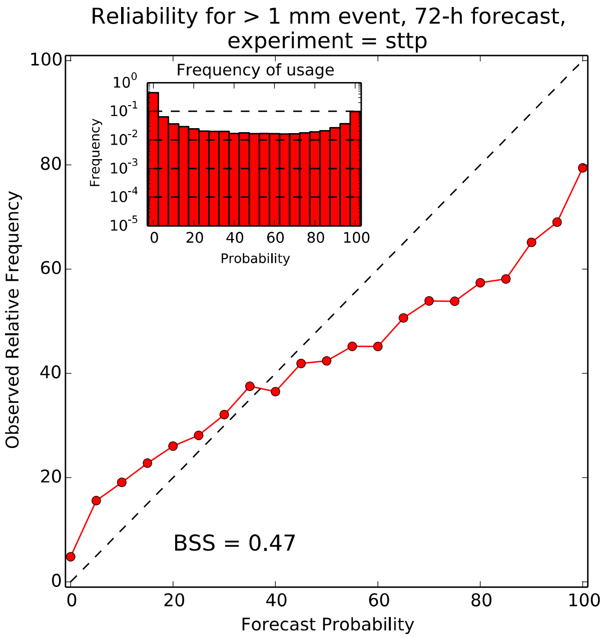


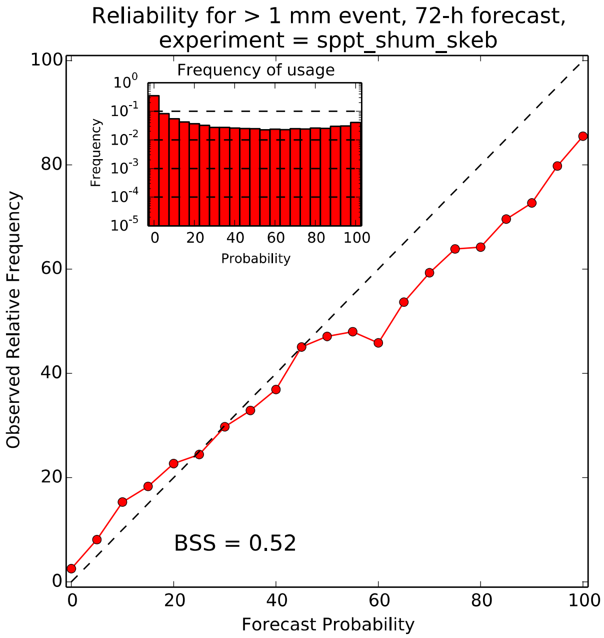
0-24 h reliability, > 10 mm / 24h



48-72 h reliability, > 1 mm / 24h







48-72 h reliability, > 10 mm / 24h