Ensemble prediction review for WGNE, 2010

Tom Hamill[1] and Pedro de Silva-Dias[2]

[1]NOAA/ESRL
[2]Laboratório Nacional de Computação Científica

tom.hamill@noaa.gov

1

Sources of improvement in probabilistic forecasts

- Make the model better
- Improve methods of generating initial conditions
- Treat model uncertainties in physically realistic fashion
  - stochastic effects
  - post-processing
- Better use of ensembles
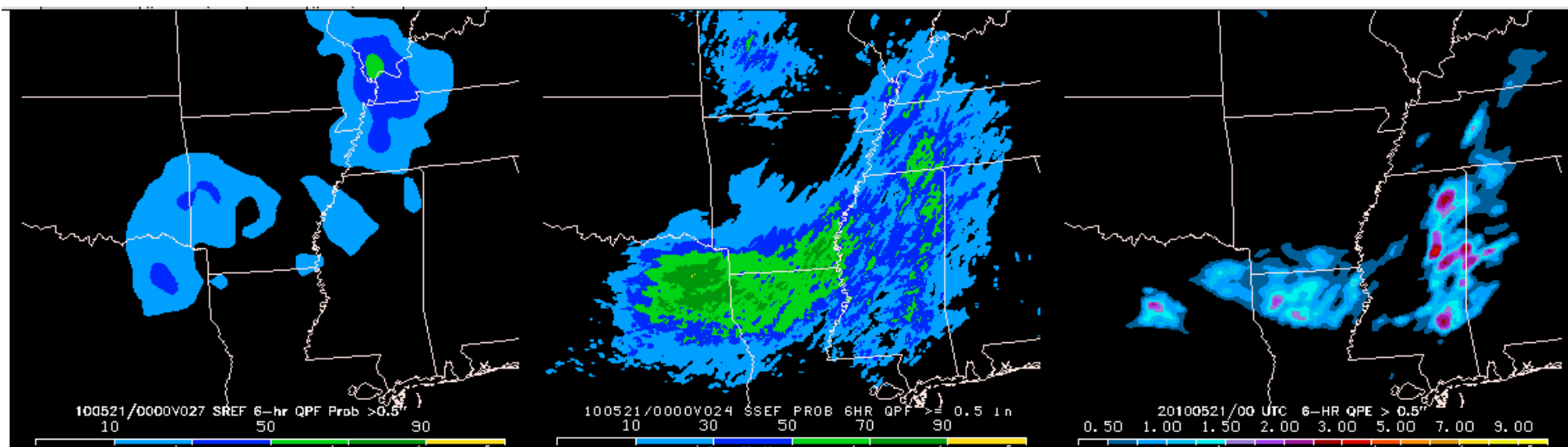
Making the model better

An example from NSSL-SPC Hazardous Weather Test Bed, forecast initialized 20 May 2010

http://tinyurl.com/2ftbvgs

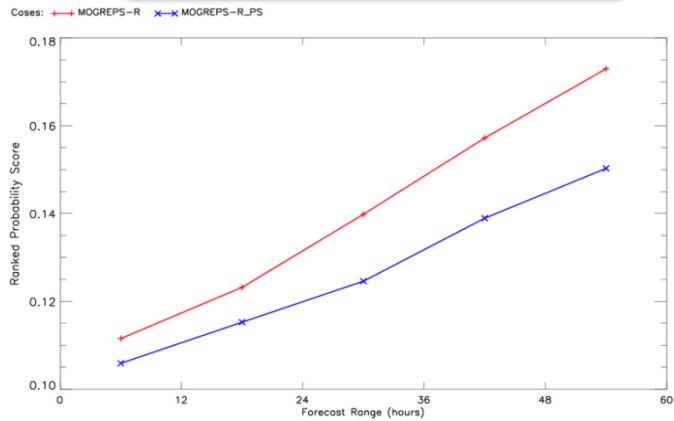30-km SREF P > 0.5"   4-km SSEF P > 0.5 "   Verification

With warm-season QPF, coarse resolution and parameterized convection of SREF clearly inferior to the 4-km, resolved convection in SSEF.
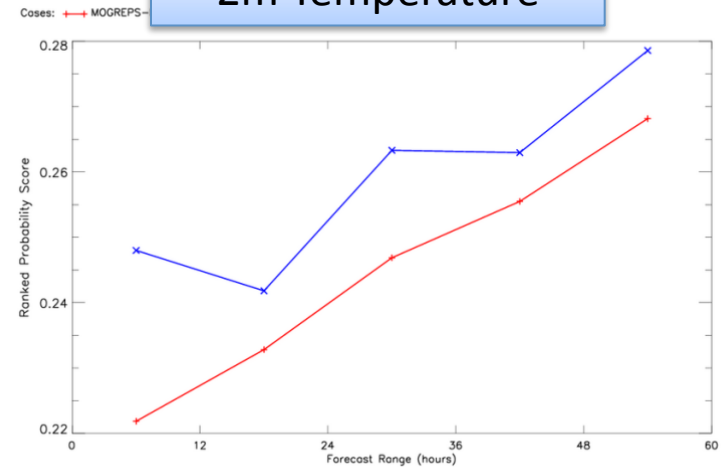
Example: UK Met Office's MOGREPS-R upgrade to 70 levels
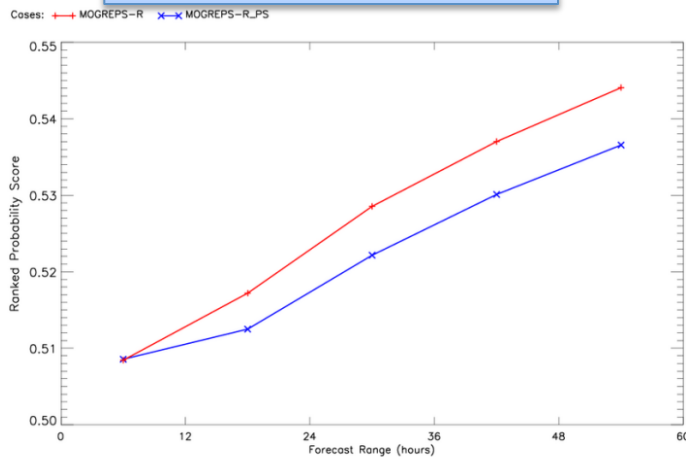
Ranked Probability Score
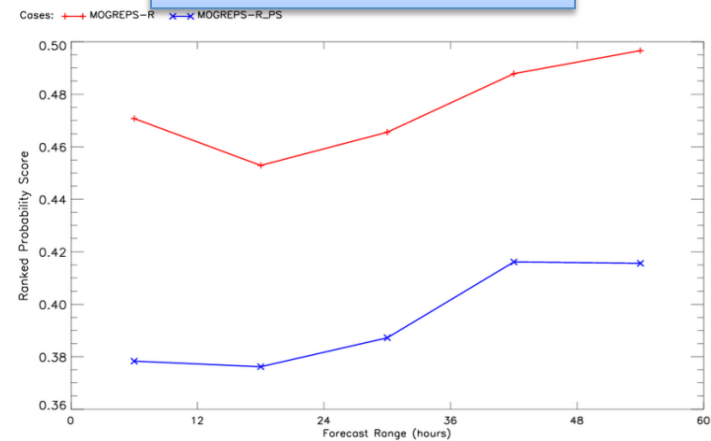*Area: Full NAE domain*

850hPa Temperature

2m Temperature

10m wind speed

6hrly Precipitation


c/o Richard Swinbank, UK Met Office.

Improve initial conditions for ensembles

- ECMWF: replacing evolved singular vectors with "ensemble data assimilations"

- Ensemble Kalman Filter (EnKF) progress

- Hybridizations of EnKF and Var.
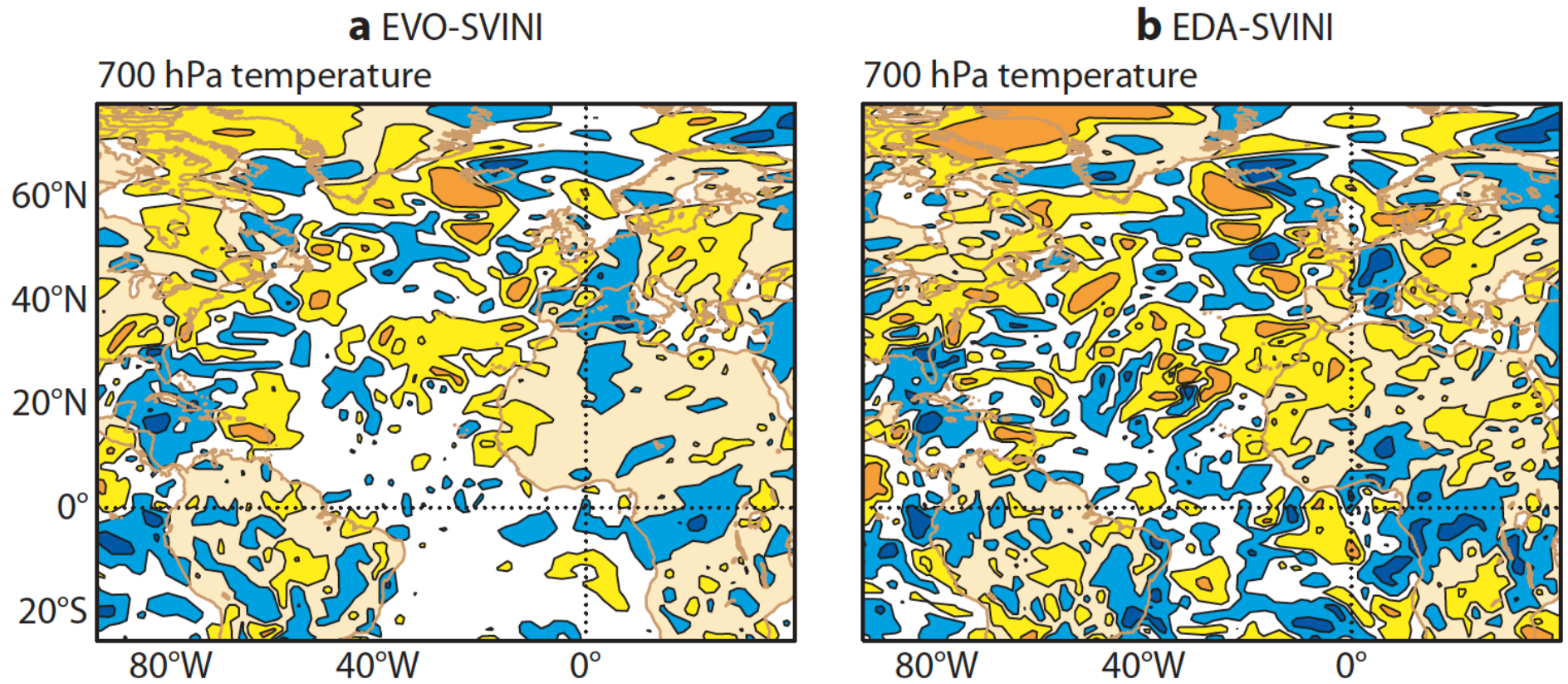
ECMWF's ensembles of data assimilation (EDA)

- Want to better quantify analysis uncertainty.

- 10 independent, lower-res 4D-Vars (T255 outer, T95/159 inner loops) with perturbed obs, perturbed SSTs, perturbed model tendencies comprise the EDA.

- Not sure how the 10 are combined with the 50 initial-time SVs...

Perturbed initial condition, old technique of evolved singular vectors vs. new EDA
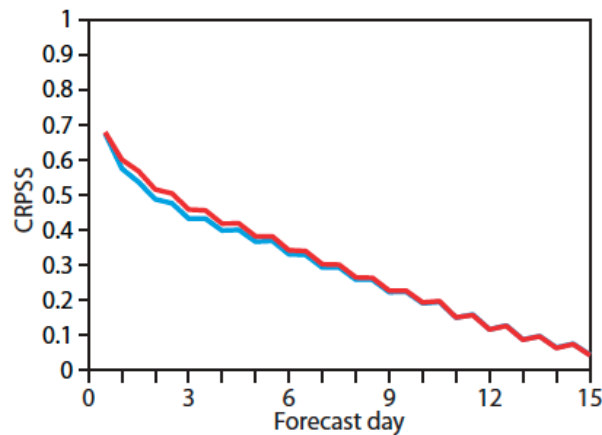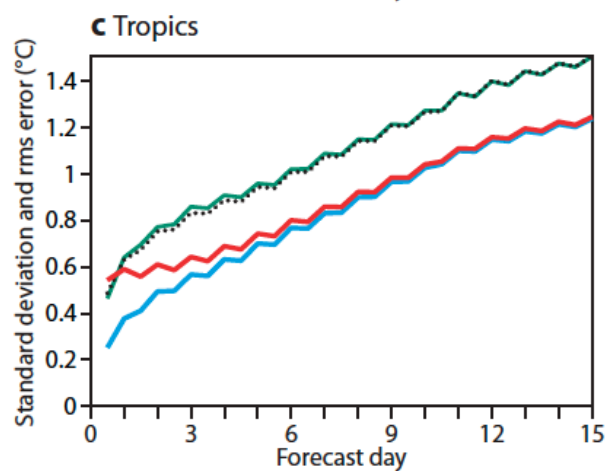

a EVO-SVINI
700 hPa temperature

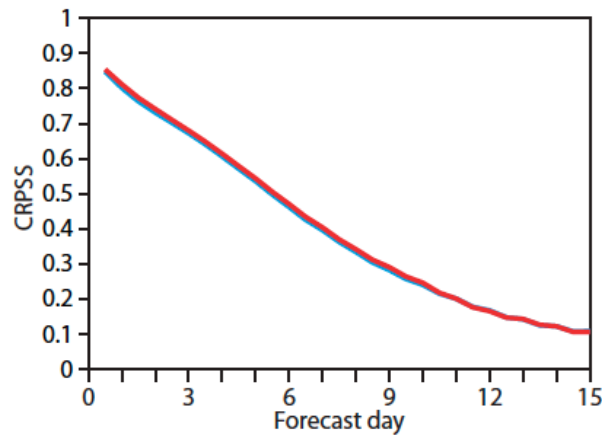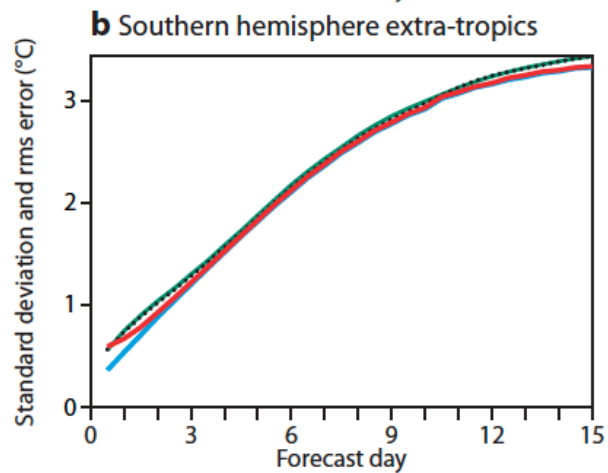**b** EDA-SVINI
700 hPa temperature
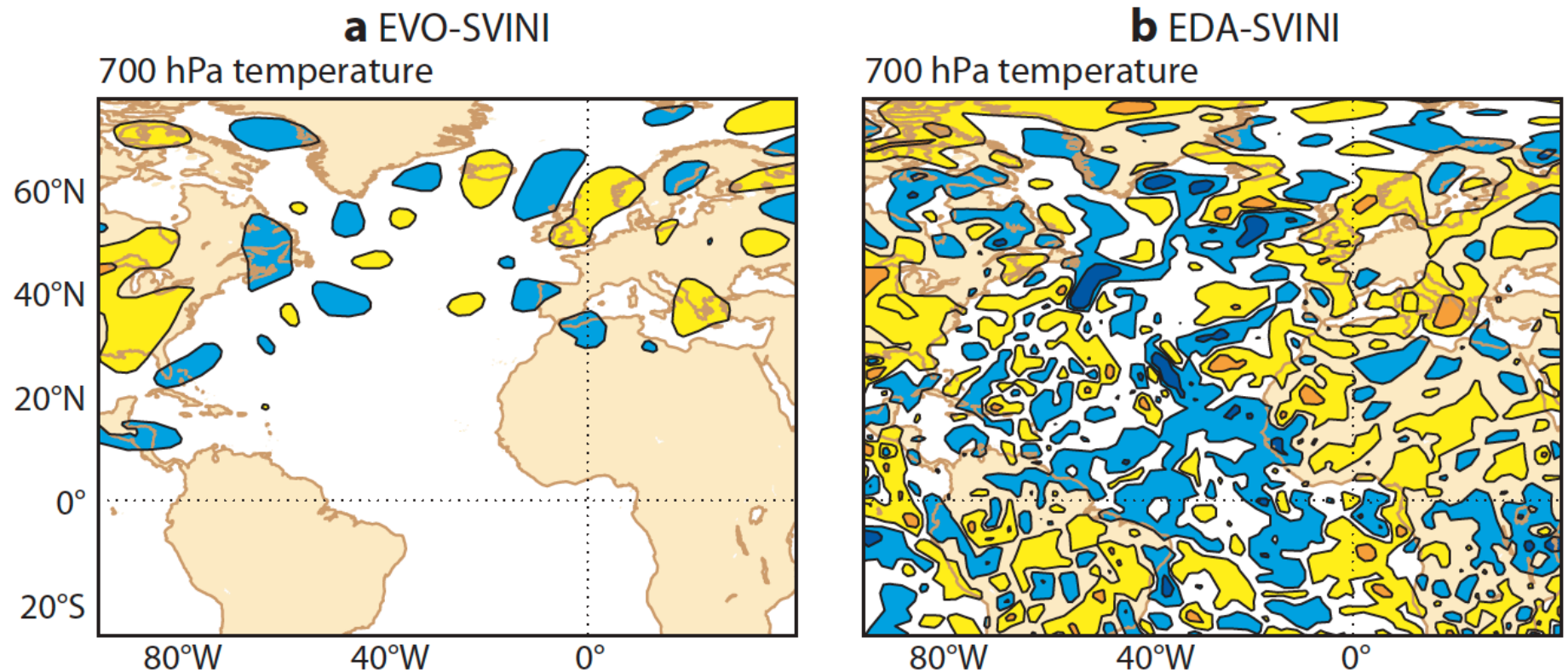
Analysis error of course not just confined to the storm track, so perturbations shouldn't, either.

Ref: ECMWF Newsletter 123

Perturbed forecast, 24 h later…

a EVO-SVINI
700 hPa temperature

b EDA-SVINI
700 hPa temperature

At 24-h lead, the EVO-SVINI perturbation have spread out, but there are still many regions with effectively no differences (i.e., forecast uncertainty is estimated to be negligible).

Ref: ECMWF Newsletter 123

**a** Northern hemisphere extra-tropics

EDA-SVINI standard deviation
EDA-SVINI rmse eror
EVO-SVINI standard deviation
EVO-SVINI rms error

EDA-SVINI
EVO-SVINI

b Southern hemisphere extra-tropics
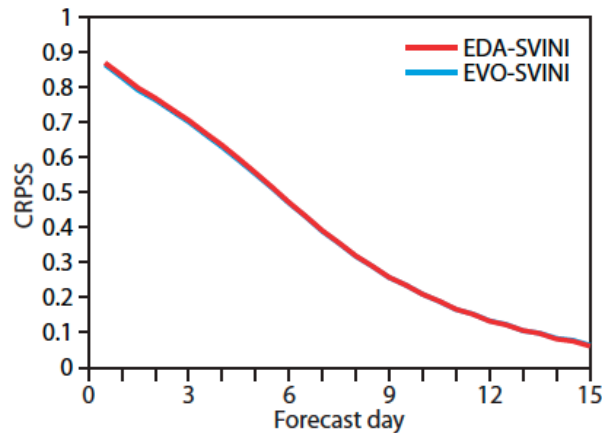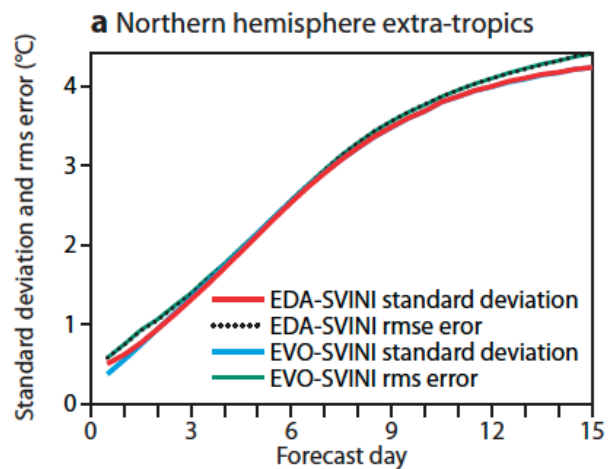
c Tropics

ECMWF: impact of EDA vs. old evolved singular vectors, T850

Ref: ibid

9

Use in data assimilation:
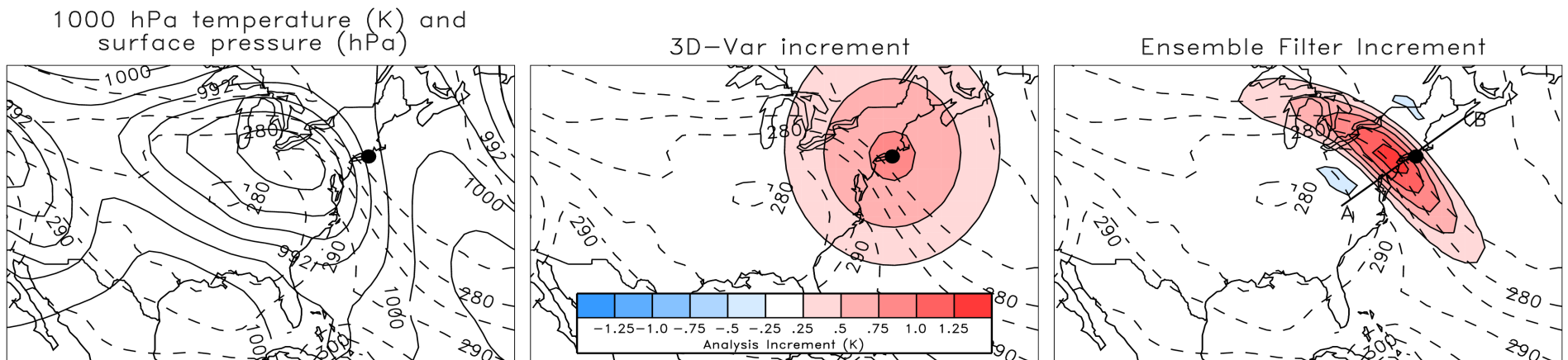# ECMWF's T850 wind background-error estimate, old and EDA

a Operational method

b EDA, 10 members, T255 outer loop, T95/T159 inner loop
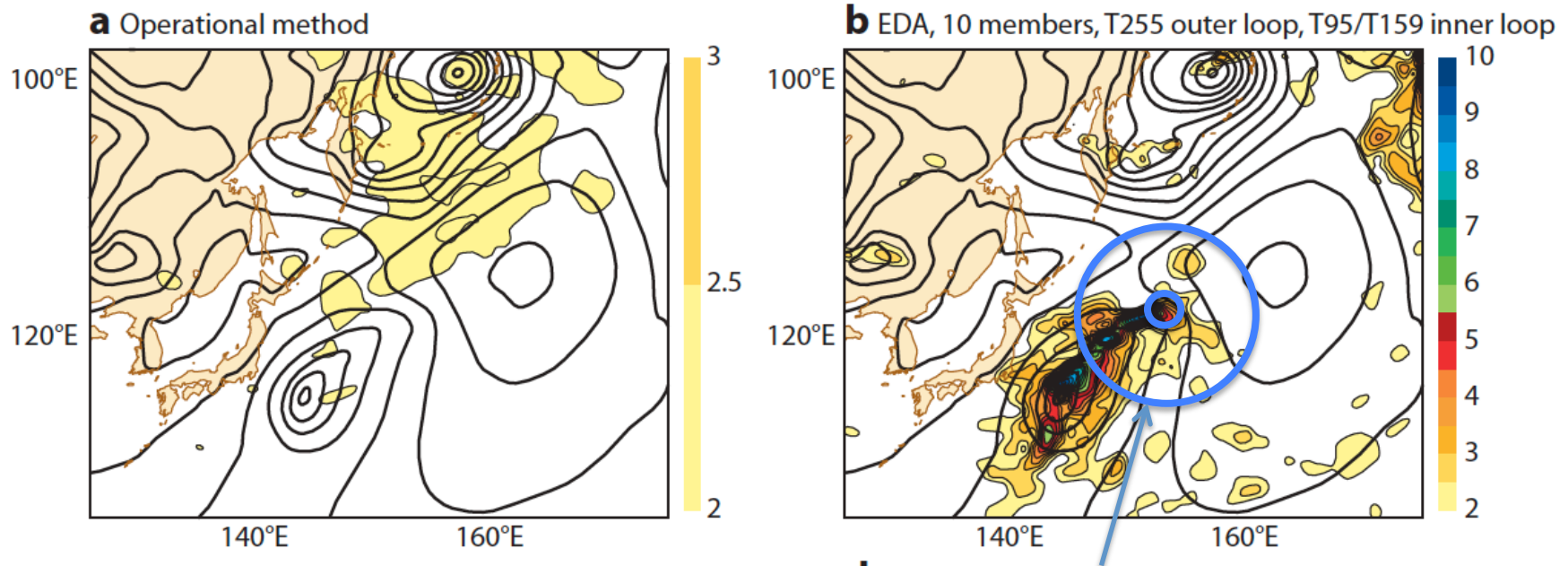
Still isotropic background-error **covariances**, at least at beginning of assimilation window.

Ref: ibid

# EnKF in comparison, uses ensemble to estimate covariance structure, too.

update to an observation 1K greater than mean background at dot.

1000 hPa temperature (K) and surface pressure (hPa)

3D-Var increment

Ensemble Filter Increment

Analysis Increment (K)
−1.25 −1.0 −.75 −.5 −.25 .25 .5 .75 1.0 1.25

Other practical advantages of EnKF are that (1) it's comparatively easy to code and maintain, and (2) it parallelizes rather easily. Main computational expense is propagating the n forecasts forward to the next analysis time; with M processors available, use M/n for each forecast. For the update, there are algorithms that load-balance and achieve very good scaling.

Global statistics, GFS/EnKF vs. ECMWF

(ensemble statistics, 5 June to 21 Sep 2010; all basins together)

T254 GFS/EnKF vs. T639 ECMWF operational
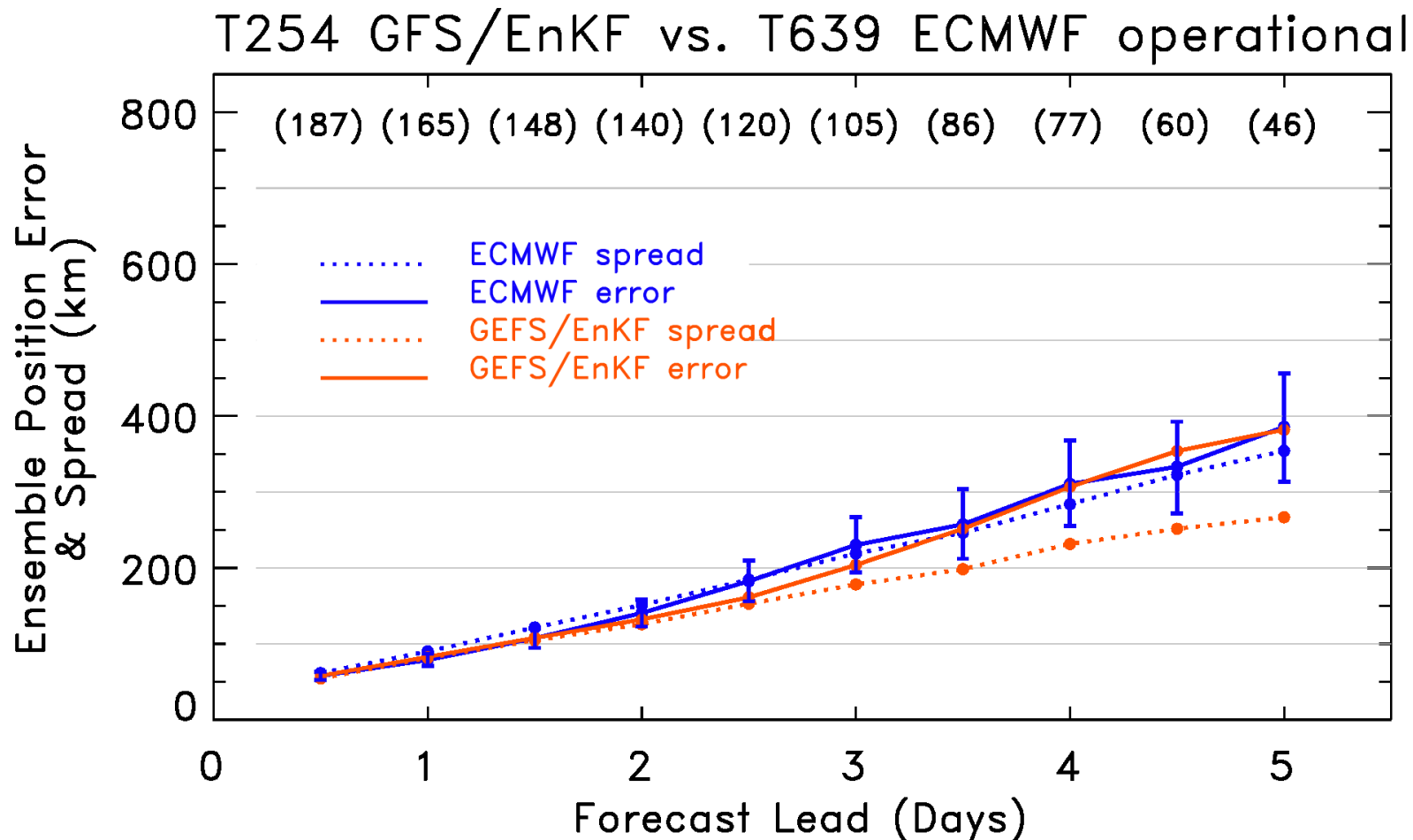
GFS/EnKF competitive despite lower resolution (T254 vs. ECMWF's T639). GFS/EnKF has less spread than error this year, more similar last year. Is this due to this year's T254 vs. last year's T382?

12

Global statistics, GFS/EnKF vs. NCEP


T254 GFS/EnKF vs. T190 NCEP Operational
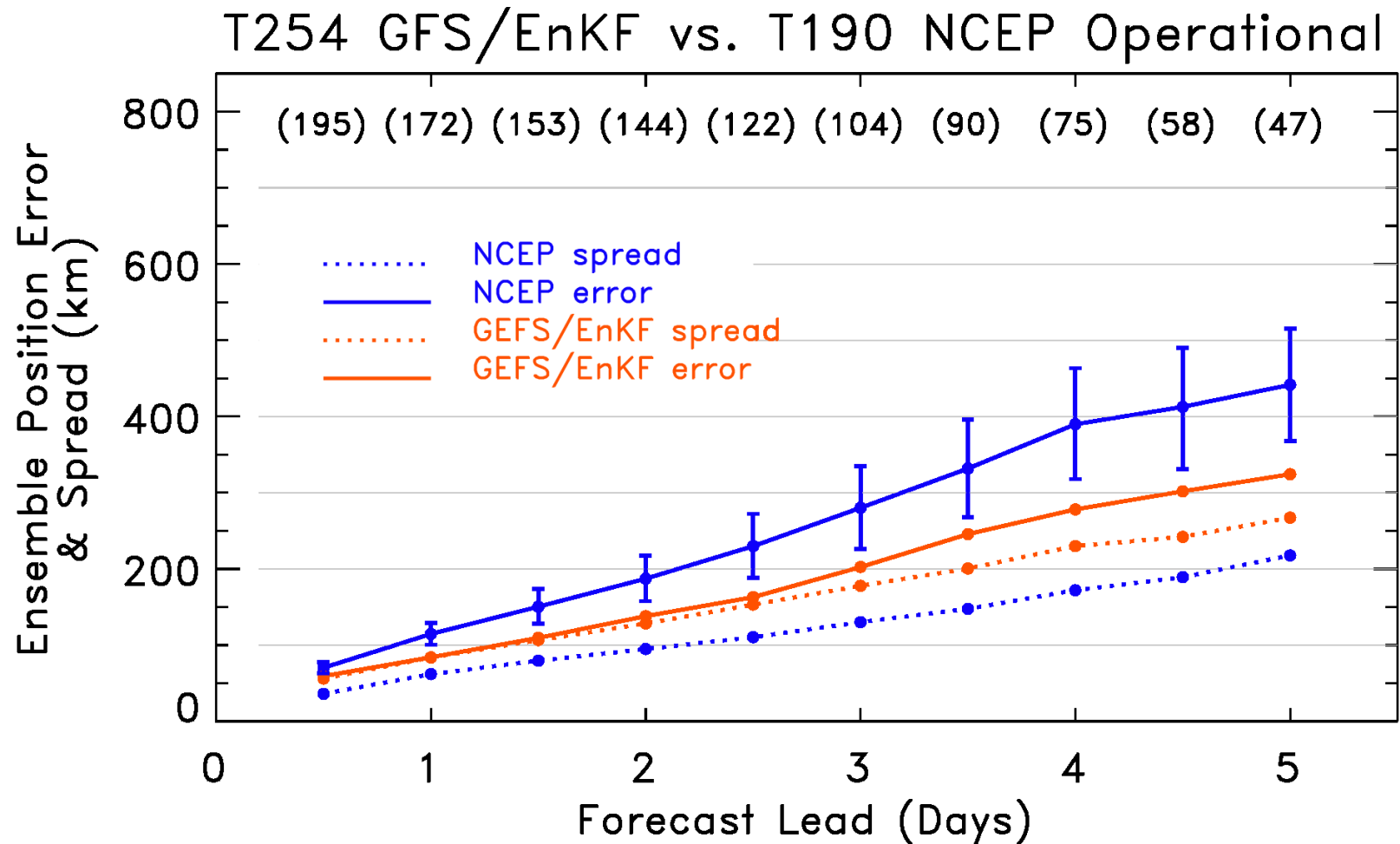
At most every lead, GFS/EnKF is statistically significantly better than NCEP operational ens., which uses (a) older GFS model, lower resolution; (b) ETR perturbations around GSI control, and (c) vortex relocation.

EnKF being used for climate reanalysis also (particularly advantageous with sparse data)

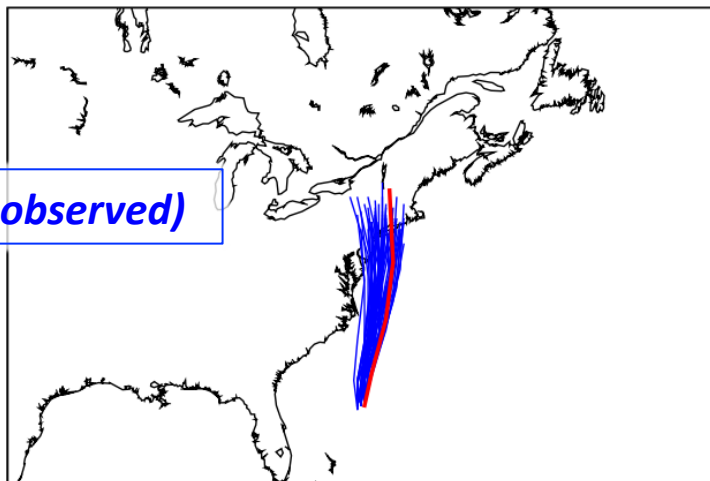Reanalysis of the 1938 New England Hurricane using only p_s obs
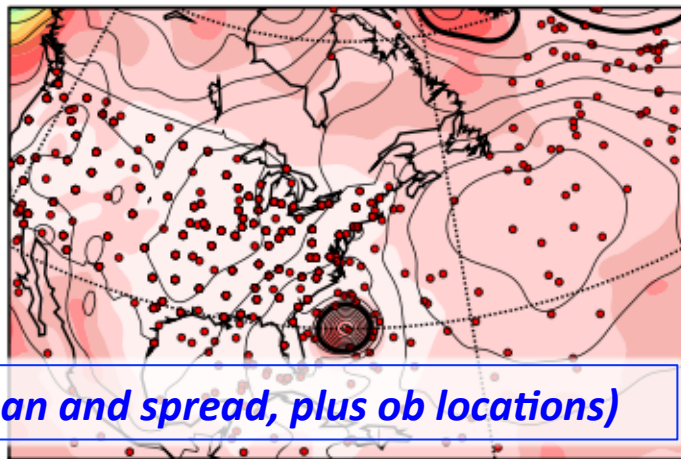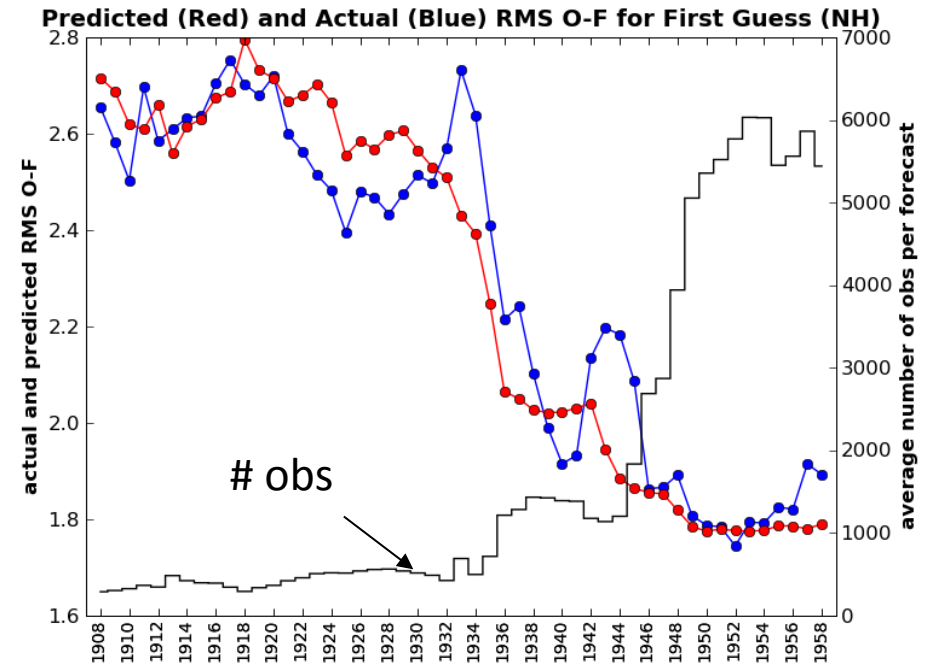

MSLP (mean and spread, plus ob locations)
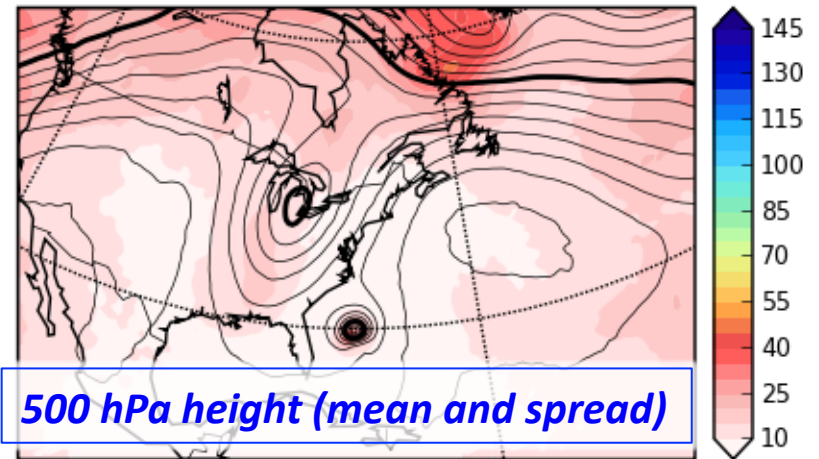
500 hPa height (mean and spread)
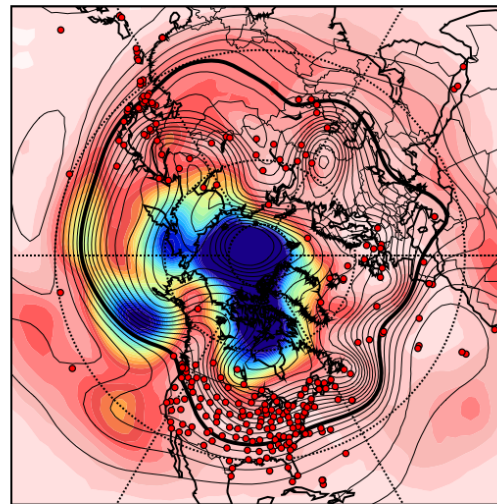
24-h track forecasts (red observed)

Estimating space and time-varying uncertainty in reanalyses

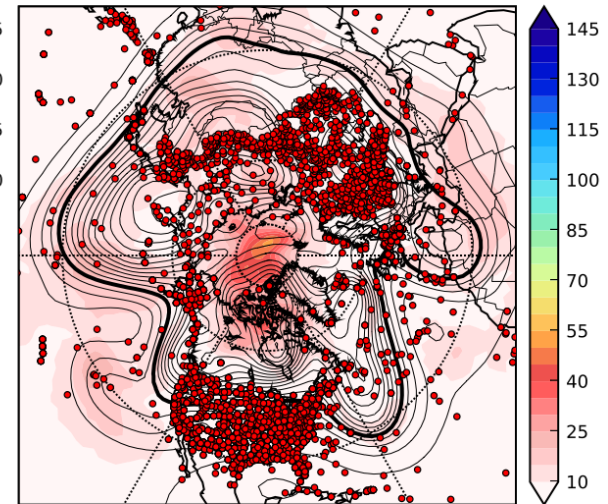*(20th Century Reanalysis Project, led by Gil Compo)*

EnKF accurately captures changing uncertainty as observing network changes.

Predicted (Red) and Actual (Blue) RMS O-F for First Guess (NH)

obs

(A) Ens Mean Z500 and Z500 spread (m) 1920010100

(B) Ens Mean Z500 and Z500 spread (m) 1950010100

15

www.esrl.noaa.gov/psd/data/20thC_Rean

FIG. 2. Impact on the verification scores of the 6-day forecasts from the EnKF experiment with respect to the 4D-Var-Bnmc experiment as a function of lead time and pressure. The plotted quantity is the difference in the standard deviations of the forecasts verified against radiosonde observations such that positive values correspond with a positive impact (i.e., a reduction in the standard deviation) for the EnKF experiment relative to the 4D-Var-Bnmc experiment. Positive (negative) values are denoted by solid (dashed) contours. The impact is shown for (top) *U*, (middle) *T*, and (bottom) GZ for (left) NH-X, (middle) TR, and (right) SH-X.

CMC's comparison of EnKF vs. 4D-Var with static covariances

Ref: Buehner et al., MWR, 2010

17
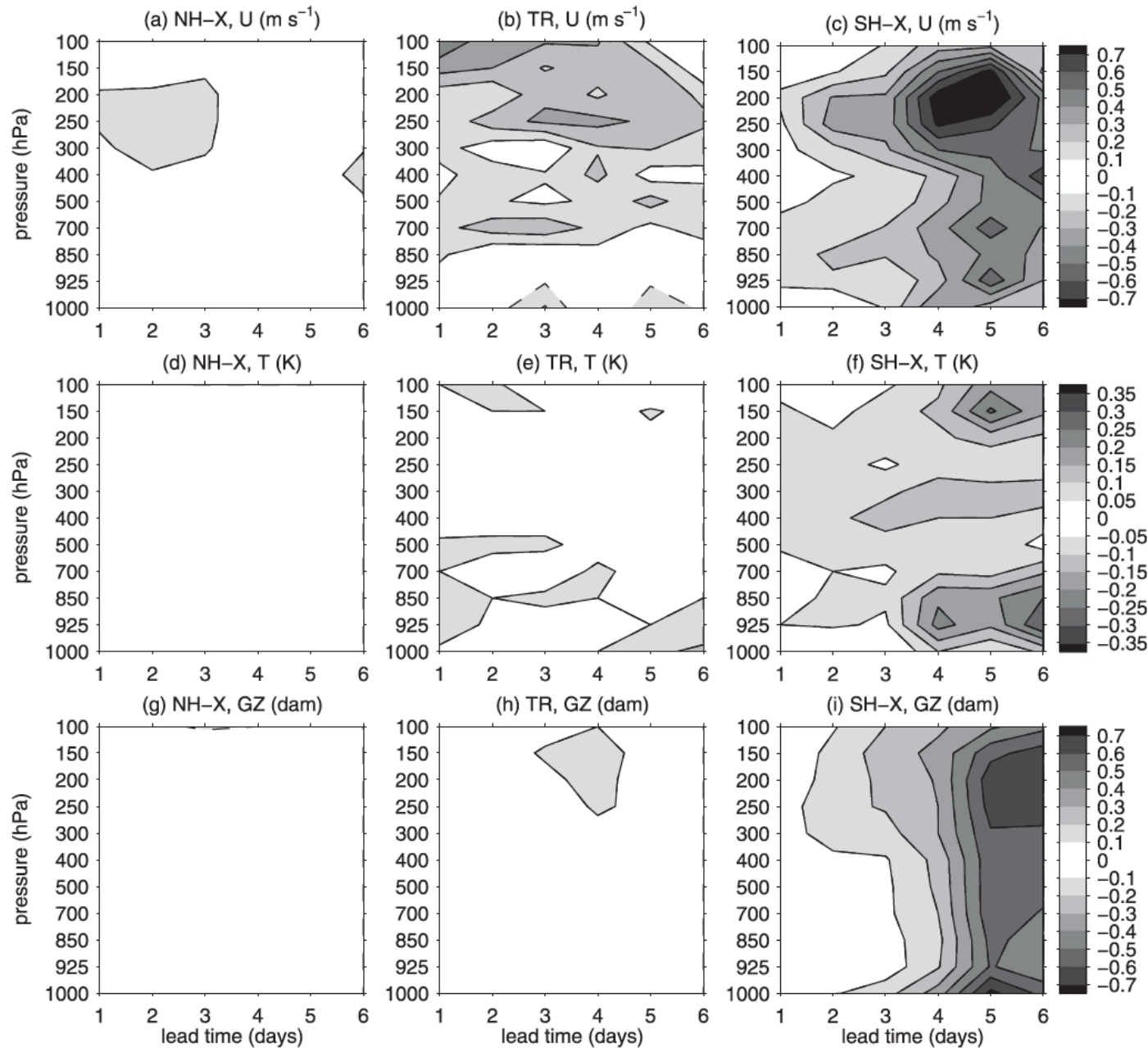
CMC's hybrid, with EnKF covariances used in 4D-Var

ref: Buehner et al., MWR, 2010

FIG. 4. As in Fig. 2, but showing the impact from the 4D-Var-Benkf experiment with respect to the 4D-Var-Bnmc experiment. Positive values (solid contours) correspond with a positive impact (i.e., a reduction in the standard deviation) for the 4D-Var-Benkf experiment relative to the 4D-Var-Bnmc experiment.

18

Preliminary EnKF-GSI hybrid results

Temp O-F (2009123012-2010013012)
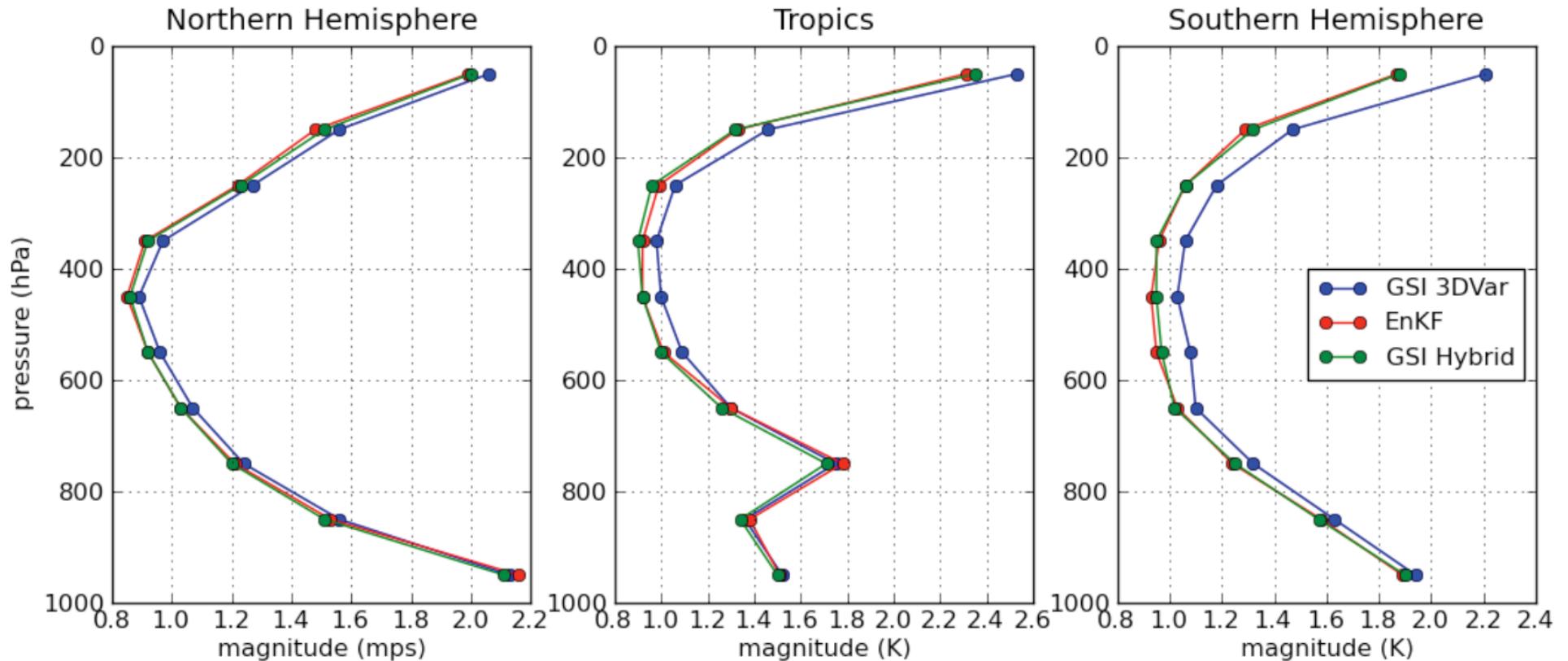
In **very early tests** with little tuning, for temperature, EnKF-GSI and EnKF comparable in error (50-50 split between GSI & EnKF covariances).

Preliminary EnKF-GSI hybrid results

Vector Wind O-F (2009123012-2010013012)
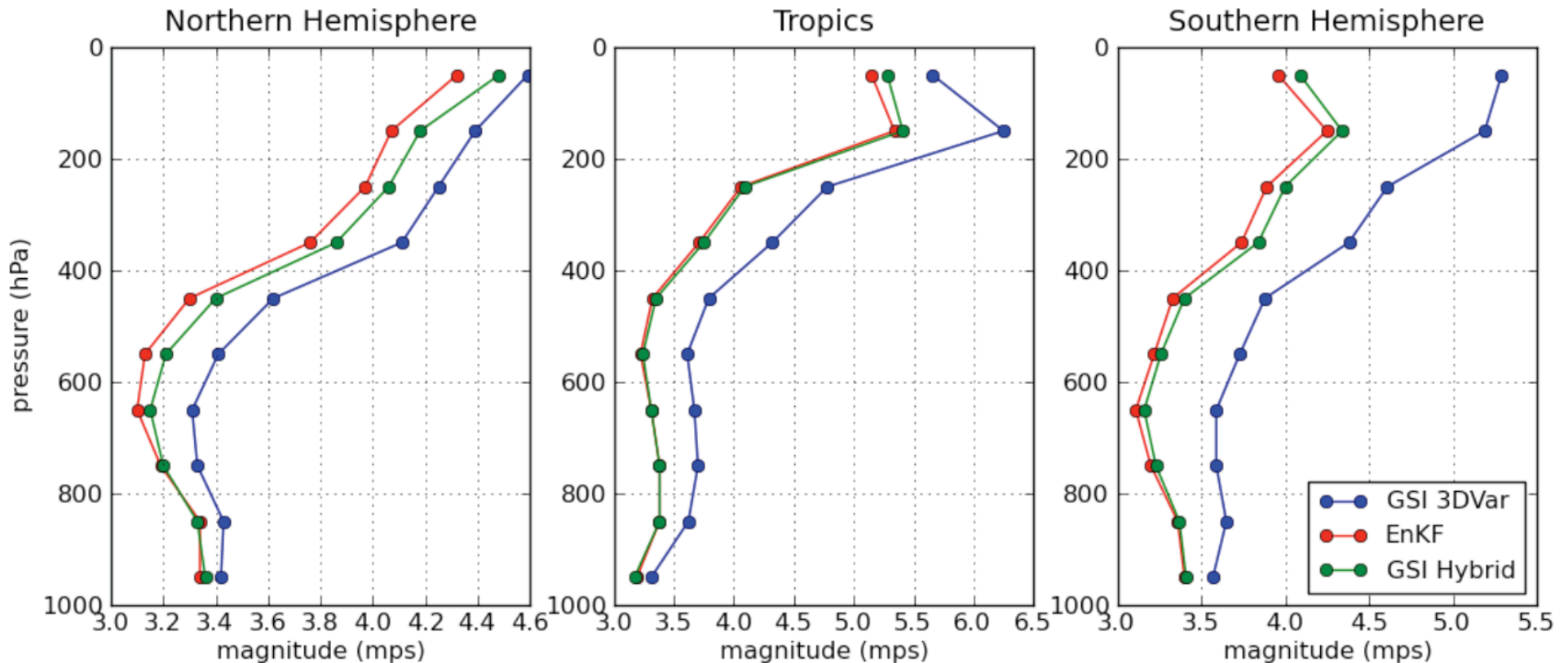
For winds, EnKF-GSI slightly higher than EnKF outside of tropics. Operating hypothesis
is that EnKF can assimilate data over time window, while current hybrid can only assimilate
synoptic observations. This will not be the case with a 4D-Var hybrid.   Also, room to
adjust how much to weight EnKF and XD-Var covariances. Hence, expect hybrid to improve.

Accounting for model uncertainty

- Forecast error grows not only because of chaos, but because of model imperfections
  - limited resolution
  - bugs
  - less than ideally formulated (and deterministic) parameterizations

- Remedies
  - multi-model ensembles
  - post-processing
  - stochastic elements introduced into forecast model.

BAMS article, August 2010

THE THORPEX INTERACTIVE GRAND GLOBAL ENSEMBLE

BY PHILIPPE BOUGEAULT , ZOLTAN TOTH, CRAIG BISHOP, BARBARA BROWN, DAVID BURRIDGE, DE HUI CHEN, BETH EBERT, MANUEL FUENTES, THOMAS M. HAMILL, KEN MYLNE, JEAN NICOLAU, TIZIANA PACCAGNELLA, YOUNG-YOUN PARK, DAVID PARSONS, BAUDOUIN RAOULT, DOUG SCHUSTER, PEDRO SILVA DIAS, RICHARD SWINBANK, YOSHIAKI TAKEUCHI, WARREN TENNANT, LAURENCE WILSON, AND STEVE WORLEY

Leading NWP centers have agreed to create a database of their operational ensemble forecasts and open access to researchers to accelerate the development of probabilistic forecasting of high-impact weather.

OBJECTIVES AND CONCEPT. During the past decade, ensemble forecasting has undergone rapid

from different systems (the so-called superensemble). The hope is that multimodel ensembles will provide

Multi-model ensembles

- **Pros**: Equally skillful, independently developed models make better probabilistic forecasts than what each produces individually.

- **Cons**: what if talent and resources were pooled to develop one (or a few) really good models rather than disperse the effort? (as evidence, consider ECMWF vs. the rest of the TIGGE community).

http://ruc.noaa.gov/tracks/

Q▾ Google

Earth System Research Laboratory
Global Systems Division

NOAA ESRL Demo -- Tropical Cyclone Tracks from Ensemble Models   Help

Basin View: ○ Bay of Bengal ○ Western Pacific ○ Eastern Pacific ○ Atlantic ○ World ● Unrestricted (with Date/Model Selection)

2010 09 01 12Z

PREFERENCES:
☑ Best Track
☐ Intensity Plots ↺
☐ Information Markers ○
☐ Invest Storm Tracks
◯ Performance Hints

COMPARISON OF TRACKS:
☑ Multiple Ensembles at same time

ENSEMBLE MODEL TRACKS: #Memb
☑ GFS Enkf #21 ▮ (green)
☑ ECMWF #50 ▮ (yellow)
☐ UKMO #23 ▮ (white)
☑ CMC #20 ▮ (purple)
☑ NCEP GFS #20 ▮ (red)

☐ Best Track (Only)

LOAD BY DATE:
Date: Time:
2010 09 01   12
← →   ← →

Storm Id: Action:
Earl (AL07)   View

Lat Lon Lines:
Every 40 deg

☑ DESCRIPTION

  Avail at 00Z and 12Z:
  Observed Best Track (black)
  Ensemble GFS ENKF (green)
  Ensemble ECMWF (yellow)
  Ensemble UKMO (white)
  Ensemble CMC (plum)
  Ensemble NCEP GFS (crimson)
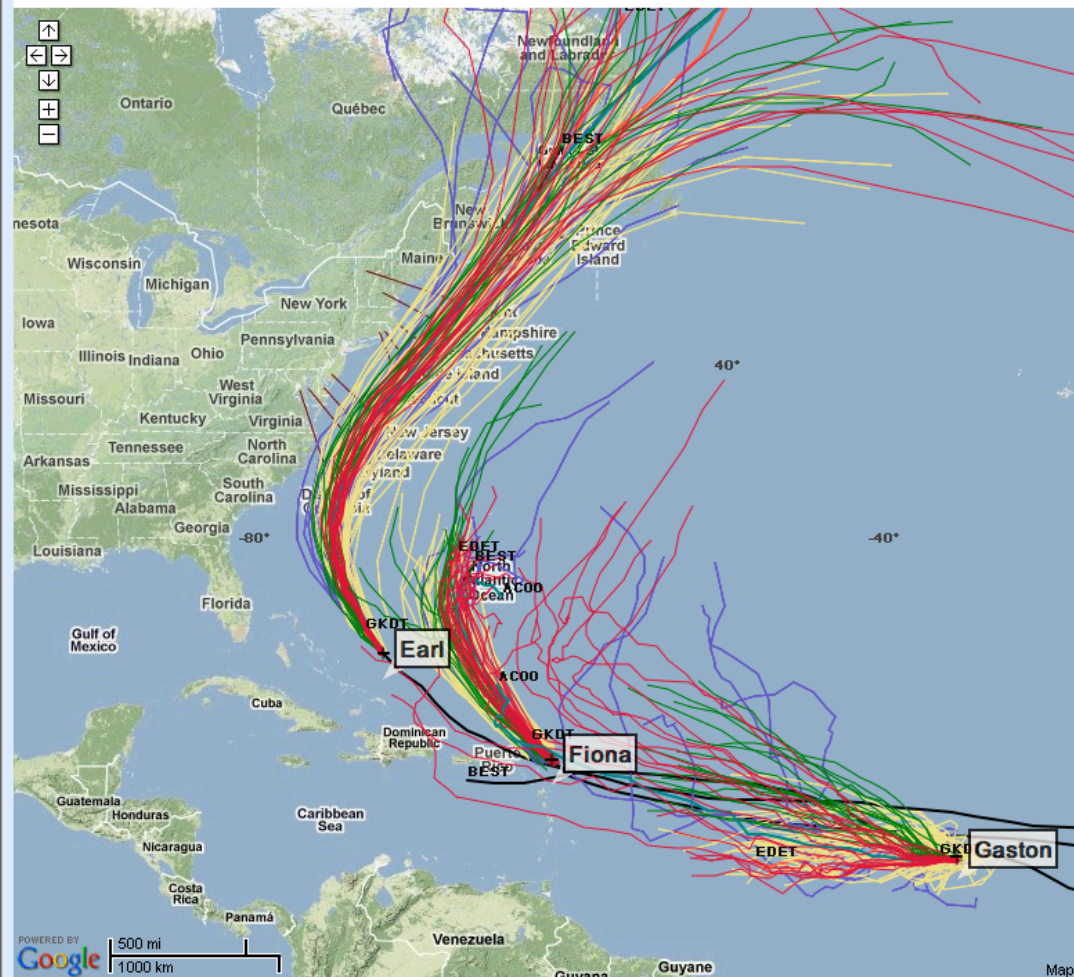
Mouse Lat Lon: 31.877558, -43.857422

24

Pro: Example of multi-model improvement from NAEFS

Northern Hemisphere 2 Meter Temp.
Continous Ranked Probability Skill Scores
Average For 20081201 – 20090228

Legend:
- Raw NCEP
- Statistically adjusted NCEP
- Adjusted NCEP + CMC
- Adjusted NCEP + CMC + Navy

Y-axis: Skill Scores
X-axis: Forecast days
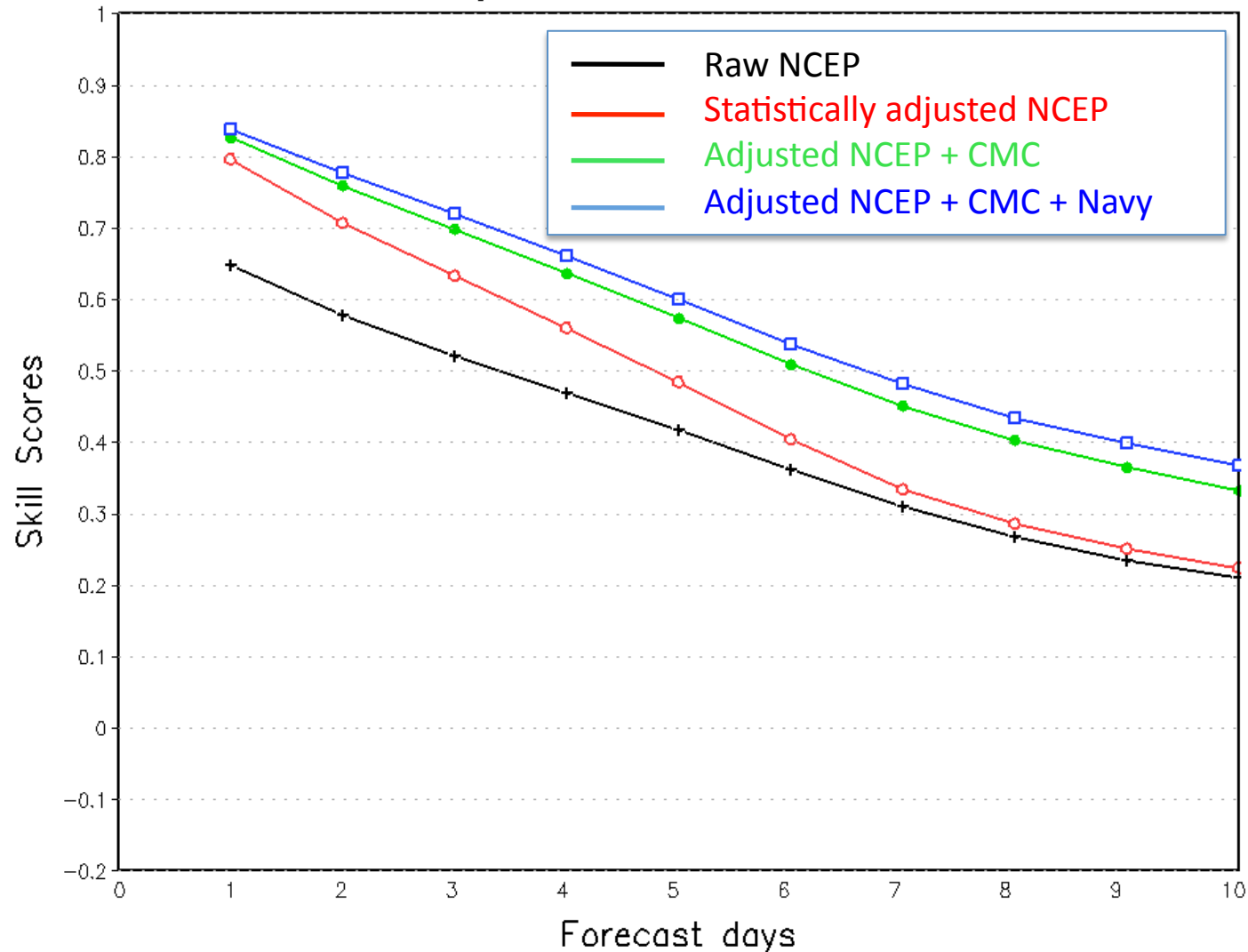
Con: T2m forecasts,
ECMWF-reforecast vs. multi-model
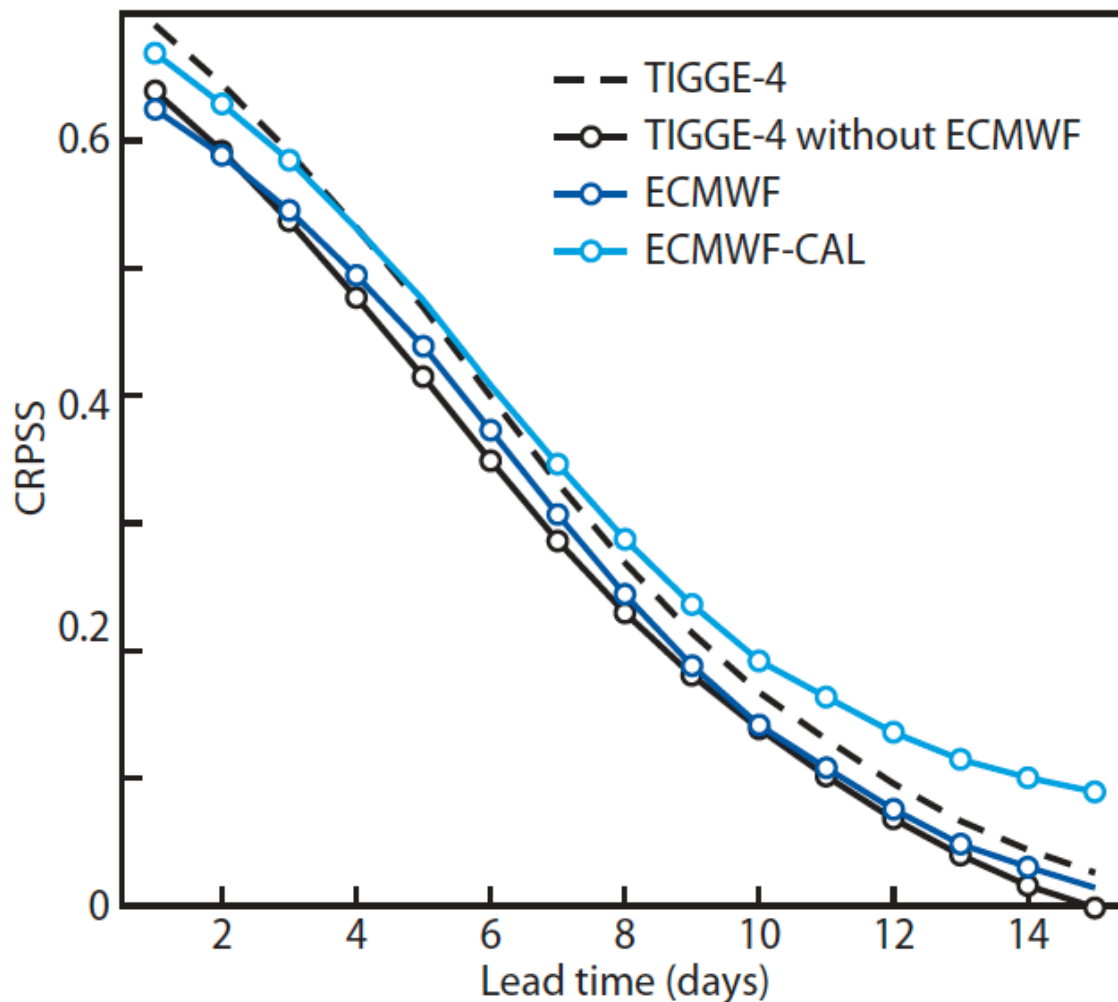
TIGGE-4: combination of ECMWF, CMC, NCEP, and UKMO 30-day bias corrected ensembles.

ECMWF-CAL: their forecasts, corrected using a combination of previous 30-day bias and 20-year reforecast using "nonhomogeneous Gaussian regression."

Here, ERA-Interim used for verification (controversial, since analyses have biases. However, verification against station obs similar).

Ref: Hagedorn et al. 2010, MWR, conditionally accepted.

Potential value of reforecast approach

(a) NARR Analyzed Precipitation

(b) Ensemble-mean Precipitation 1-day fcst, 0000 UTC 1997 01 01
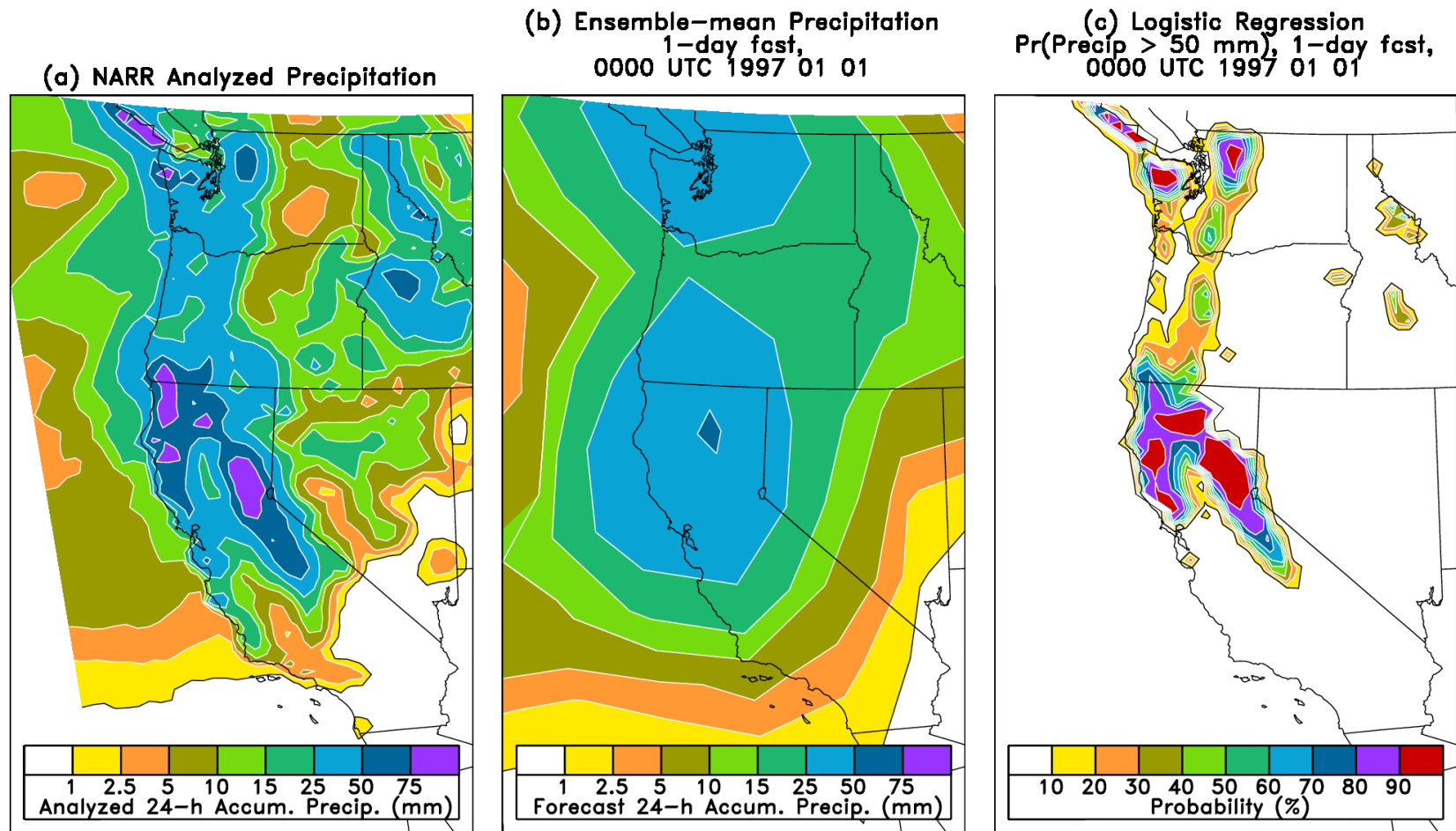
(c) Logistic Regression Pr(Precip > 50 mm), 1-day fcst, 0000 UTC 1997 01 01

Post-processing with large training data set can permit small-scale detail to be inferred from large-scale, coarse model fields. Large training data set especially helpful with rare events.

NOAA to generate new reforecast data set

- Will generate 11-member ensemble to 16 days lead using GFS every day over 30-year period.
- Data set to be freely available, hopefully by mid 2011.
- Common variables like those from TIGGE data set available on fast-access archive.
- Full model fields archived to tape.
- Will continue to run model in real time, somehow, somewhere (either at NOAA's EMC or ESRL)

Some recent work on stochastic parameterizations

- Stochastically perturbed physical tendencies (ECMWF).

- Stochastic backscatter (ECMWF, Met Office, CMC, others).

- Stochastic convective parameterization (universities, Met Office, NOAA/ESRL, US Navy, others)

- Field is in its relative infancy. WGNE/THORPEX Workshop at ECMWF planned, 11-14 June 2011.

Conclusions

- EnKF rapidly moving from exotic technology to being widely exploited for data assimilation and ensemble prediction.

- Statistical post-processing and multi-model techniques may be helpful.

- Physically plausible stochastic methods to treat model uncertainty the next frontier
  - discussion of June 2011 workshop later in WGNE