NOAA Earth System Research Laboratory

NOAA's multi-decadal global ensemble reforecast data set

Tom Hamill

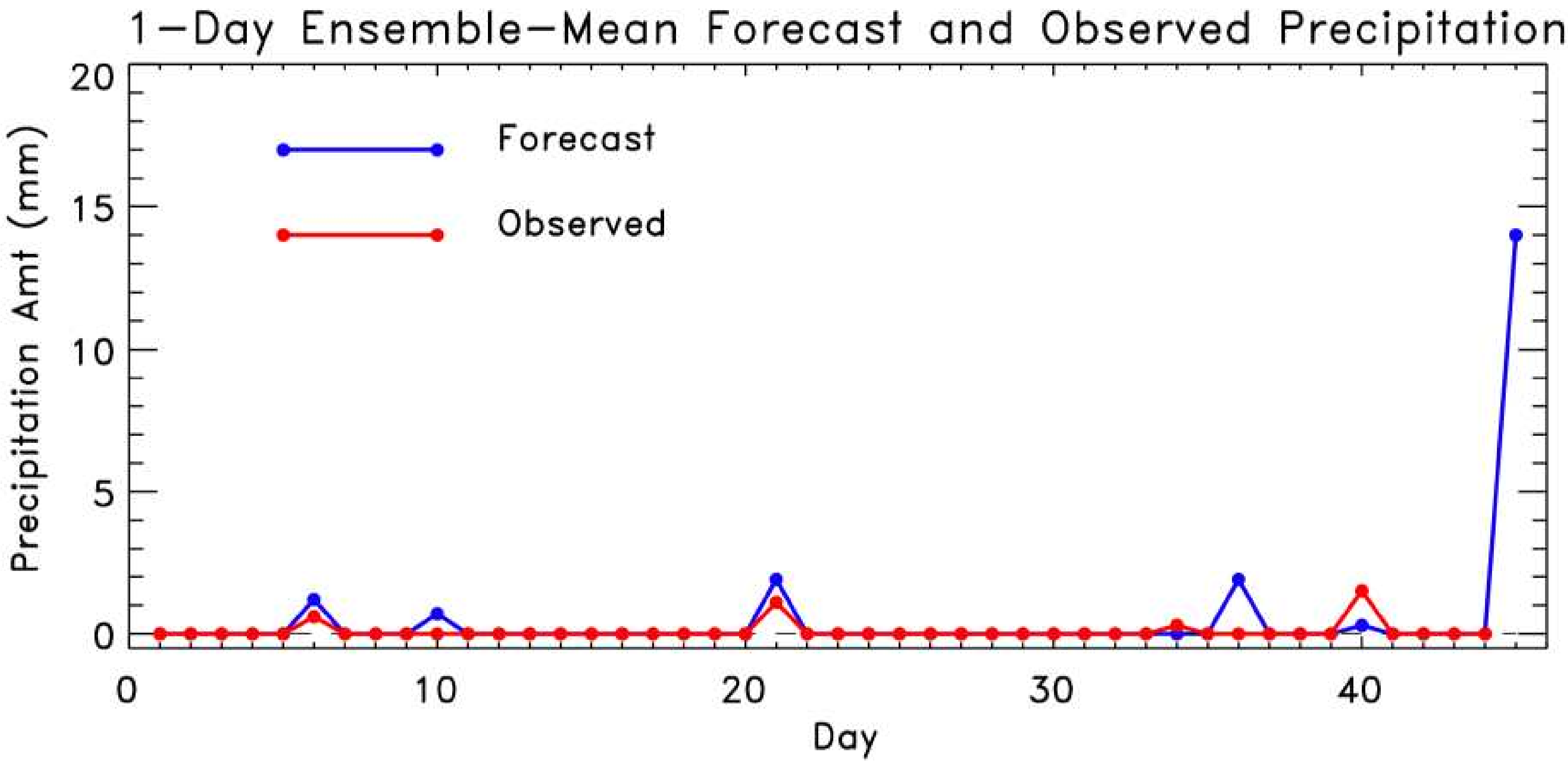
NOAA ESRL, Physical Sciences Division

tom.hamill@noaa.gov

also: Jeff Whitaker, Gary Bates, Don Murray, Francisco Alvarez, Mike Fiorino, Tom Galarneau

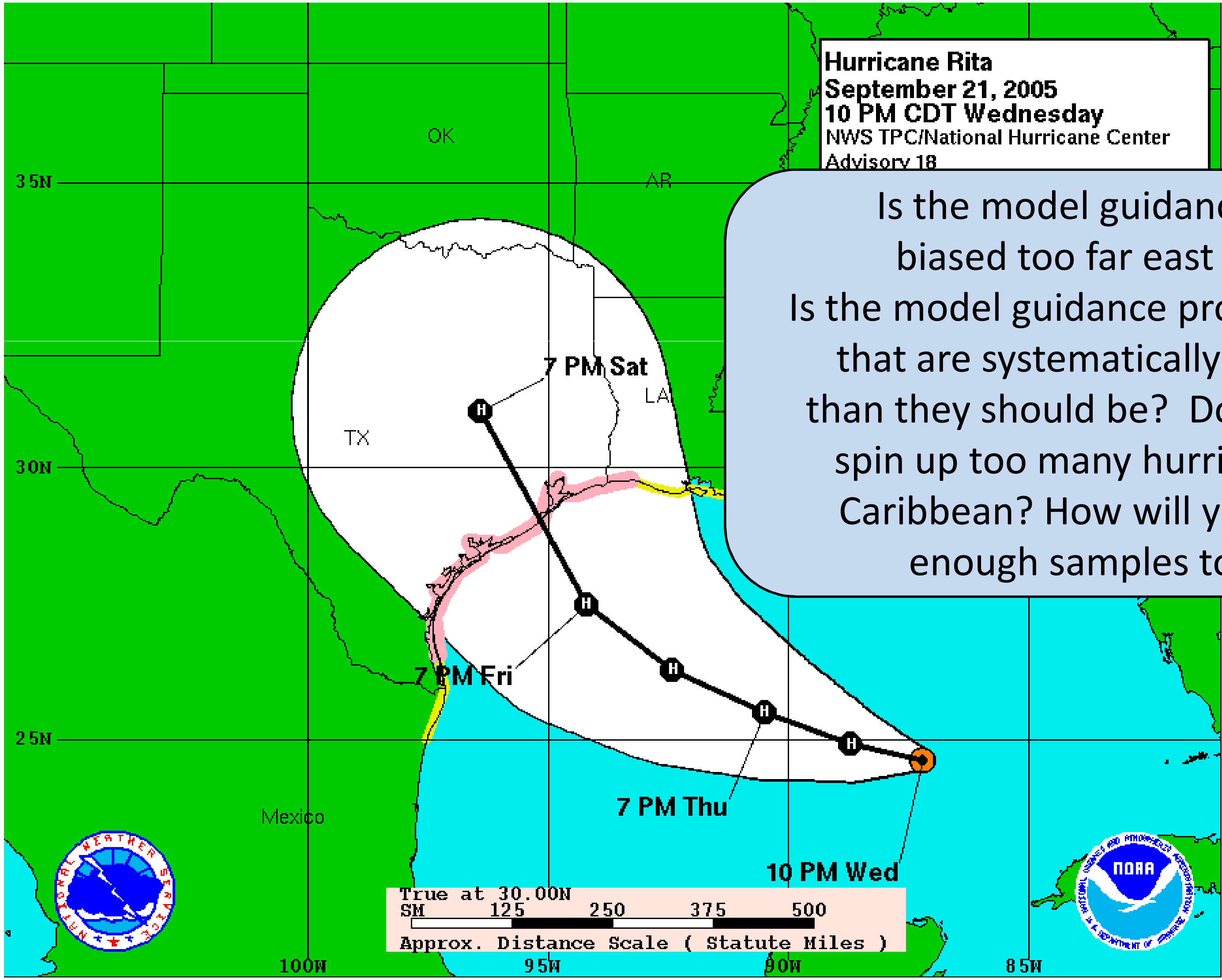
Presentation to ensembles in geophysics conference, Toulouse, Nov 2012

Statistical post-processing for rare events is challenging without a large training sample



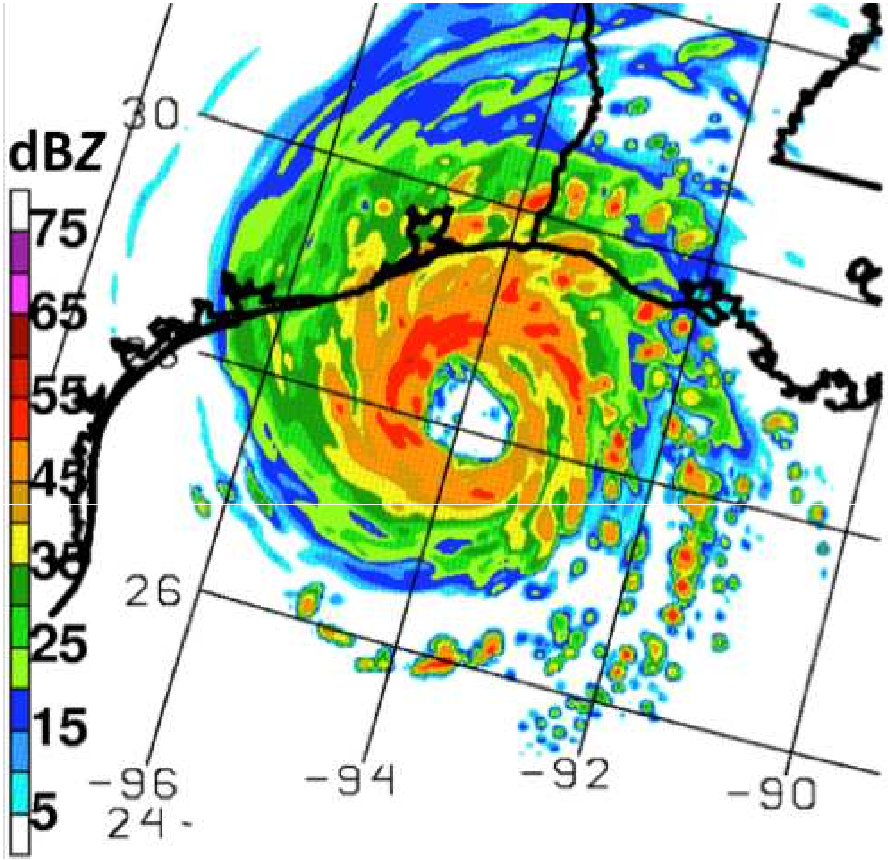
Say you want to statistically post-process your model precipitation forecast to improve it. Heavy precipitation events like the one today are the ones you care about the most. How do you calibrate today's forecast given past short sample of forecasts and observations?

2005 Rita official forecast (Houston, TX evacuated)



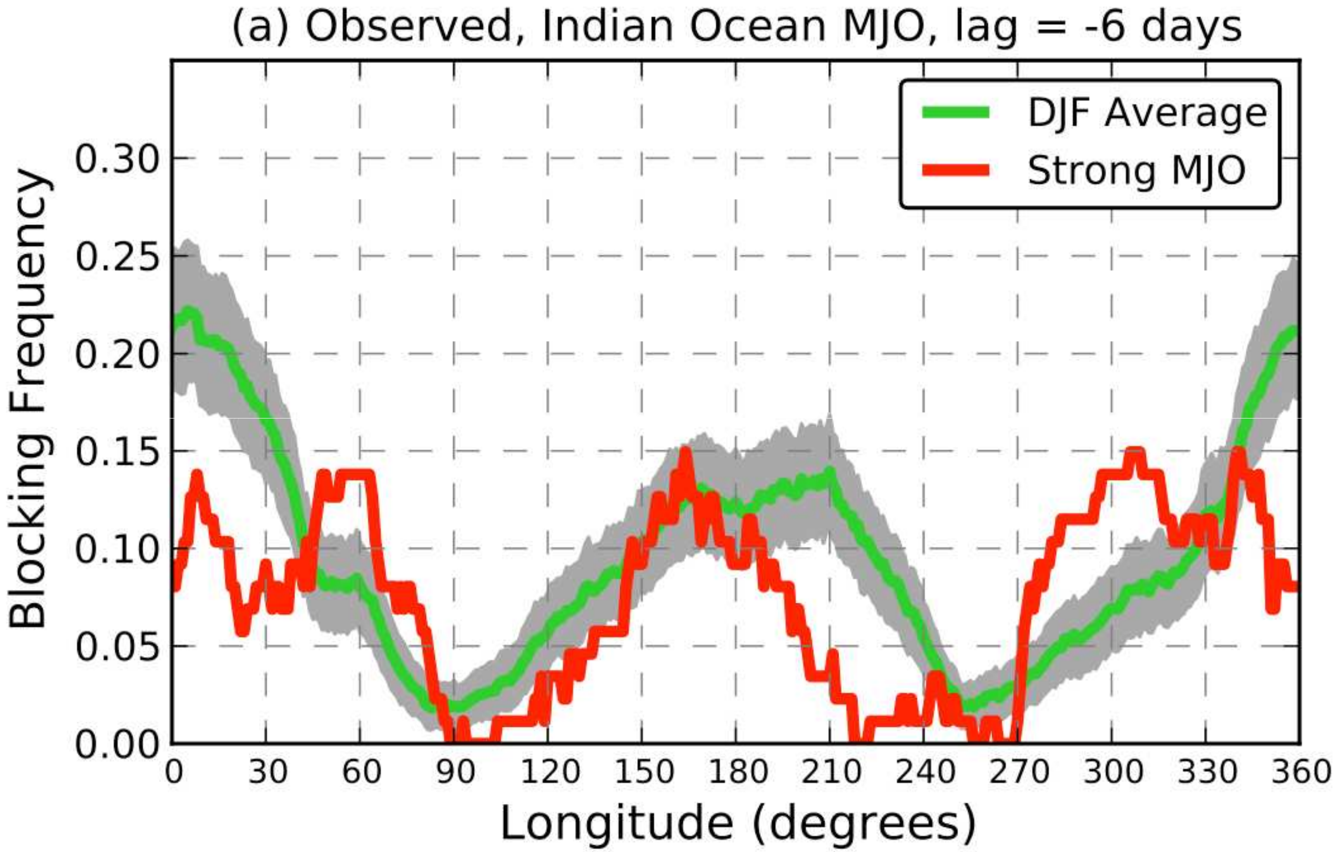
Is the model guidance for Rita biased too far east or west? Is the model guidance producing storms that are systematically less intense than they should be? Does the model spin up too many hurricanes in the Caribbean? How will you generate enough samples to know?

Regional simulations of past weather



Say you'd like to run a realistic, regional simulation of hurricane Rita at high resolution and not get the false skill that you will get if you force it with observed lateral boundary conditions. Where can you get lateral boundary conditions from a current-generation larger-scale forecast?

Change in blocking frequency under strong Indian Ocean MJO



The atmosphere suppresses blocking subsequent to an active Indian-Ocean Madden-Julian Oscillation (MJO) during the Northern Hemisphere winter. Does the forecast model suppress blocking as well? How can one detect that with only a season or so of past forecasts and with both blocking and strong MJOs happening infrequently?

GEFS reforecast version 2 details

- Past forecasts using the currently operational GEFS, NOAA's global ensemble forecast system.
- Each 00Z, 11-member forecast, 1 control + 10 perturbed.
- Reforecasts produced every day, for 1984120100 to current (actually, working on finishing late 2012 now).
- CFSR (NCEP's Climate Forecast System Reanalysis) initial conditions (3D-Var) + ETR perturbations (cycled with 10 perturbed members). After ~ 22 May 2012, initial conditions from hybrid EnKF/3D-Var.
- Resolution: T254L42 to day 8, T190L42 from days 7.5 to day 16.
- Fast data archive at ESRL of 99 variables, 28 of which stored at original ~1/2-degree resolution during week 1. All stored at 1 degree. Also: mean and spread to be stored.
- Full archive at DOE/Lawrence Berkeley Lab, where data set was created under DOE grant.

Status

- 00Z reforecasts 1985-Sep 2012 completed and publicly available.
- Within a month or two, we will be pulling real-time GEFS data over from NCEP and putting it in our archive (hopefully within 12 h).
- Web sites are open to you now:
  – NOAA/ESRL site: fast access, limited data (99 fields).
  – US Department of Energy: slow access, but full data set
- Soon: experimental probabilistic precipitation forecast graphics over the US in real time.

Data that is readily available from ESRL

Table 1: Reforecast variables available for selected mandatory and other vertical levels. Φ indicates geopotential height, and an X indicates that this variable is available from the reforecast data set at 1-degree resolution; a Y indicates that the variable is available at the native ~0.5 degree resolution. AGL indicates "above ground level."

Vertical Level	U	V	T	Φ	q	Wind Power
10 hPa	X	X	X	X		
50 hPa	X	X	X	X		
100 hPa	X	X	X	X		
200 hPa	X	X	X	X		
250 hPa	X	X	X	X		
300 hPa	X	X	X	X	X	
500 hPa	X	X	X	X	X	
700 hPa	X	X	X	X	X	
850 hPa	X	X	X	X	X	
925 hPa	X	X	X	X	X	
1000 hPa	X	X	X	X	X	
$\sigma \cong 0.996$	X	X		X		
$\sigma \cong 0.987$	X	X		X		
$\sigma \cong 0.977$	X	X		X		
$\sigma \cong 0.965$	X	X		X		
80m AGL	X,Y	X,Y				X,Y

Also: hurricane track files

Data to be readily available from ESRL

Table 2: Single-level reforecast variables archived (and their units). Where an [Y] is displayed, this indicates that this variable is available at the native ~0.5-degree resolution as well as the 1-degree resolution.

Variable (units)
Mean sea-level pressure (Pa) [Y]
Skin temperature (K) [Y]
Soil temperature, 0.0 to 0.1 m depth (K) [Y]
Volumetric soil moisture content 0.0 to 0.1 m depth (fraction between wilting and saturation) [Y]
Water equivalent of accumulated snow depth (kg m^{-2}, i.e., mm) [Y]
2-meter temperature (K) [Y]
2-meter specific humidity (kg kg^{-1} dry air) [Y]
Maximum temperature (K) [Y]
Minimum temperature (K) [Y]
10-m u wind component (ms^{-1}) [Y]
10-m v wind component (ms^{-1}) [Y]
Total precipitation (kg m^{-2}, i.e., mm) [Y]
Water runoff (kg m^{-2}, i.e., mm) [Y]
Average surface latent heat net flux (W m^{-2}) [Y]
Average sensible heat net flux (W m^{-2}) [Y]
Average ground heat net flux (W m^{-2}) [Y]
Sunshine
Convective available potential energy (J kg^{-1}) [Y]
Convective inhibition (J kg^{-1}) [Y]
Precipitable water (kg m^{-2}, i.e., mm) [Y]
Total-column integrated condensate (kg m^{-2}, i.e., mm) [Y]
Total cloud cover (%)
Downward short-wave radiation flux at the surface (W m^{-2}) [Y]
Downward long-wave radiation flux at the surface (W m^{-2}) [Y]
Upward short-wave radiation flux at the surface (W m^{-2}) [Y]
Upward long-wave radiation flux at the surface (W m^{-2}) [Y]
Potential vorticity on θ = 320K isentropic surface (K m^2 kg^{-1} s^{-1})
U component on 2 PVU (1 PVU = 1 K m^2 kg^{-1} s^{-1}) isentropic surface (ms^{-1})
V component on 2 PVU isentropic surface (ms^{-1})
Temperature on 2 PVU isentropic surface
Pressure on 2 PVU isentropic surface

esrl.noaa.gov/psd/forecasts/reforecast2/download.html

Select Desired Variables and Associated Levels:

Single Level (1°x1°) | Pressure Levels (1°x1°) | Hybrid Levels (1°x1°) | Single Level (Gaussian ~.5°)

Total Accumulated Precipitation	Temperature at 2 meters
U-Component of Wind at 10 meters	V-Component of Wind at 10 meters
U-Component of Wind at 80 meters	V-Component of Wind at 80 meters
Convective Available Potential Energy	Convective Inhibition
Surface Downward Long-Wave Radiation Flux	Surface Downward Short-Wave Radiation Flux
Surface Upward Long-Wave Radiation Flux	Surface Upward Short-Wave Radiation Flux
Ground Heat Flux	Surface Latent Heat Net Flux
Surface Sensible Heat Net Flux	Mean Sea Level Pressure
Surface Pressure	Precipitable Water
Volumetric Soil Moisture Content	Specific Humidity at 2 meters
Total Cloud Cover	Total Column-Integrated Condensate
Skin Temperature	Maximum Temperature
Minimum Temperature	Soil Temperature (0-10 cm below surface)
Upward Long-Wave Radiation Flux	Water Runoff
Water Equivalent of Accumulated Snow Depth	Wind Mixing Energy
Vertical Velocity at 850 hPa Surface	Temperature on 2 PVU Surface
Pressure on 2 PVU Surface	U-Component of Wind on 2 PVU Surface
V-Component of Wind on 2 PVU Surface	Potential Vorticity on 320 K Isentrope

Select Desired Dates (Available from Dec 1 1984 to Dec 31 2010):

From: **To:**

- Download all the forecasts within the chosen time period. Help
- Download forecasts within the month-days range for the chosen years. Help

Select Desired Forecast Hour(s):

High Resolution: (Select All or Clear)

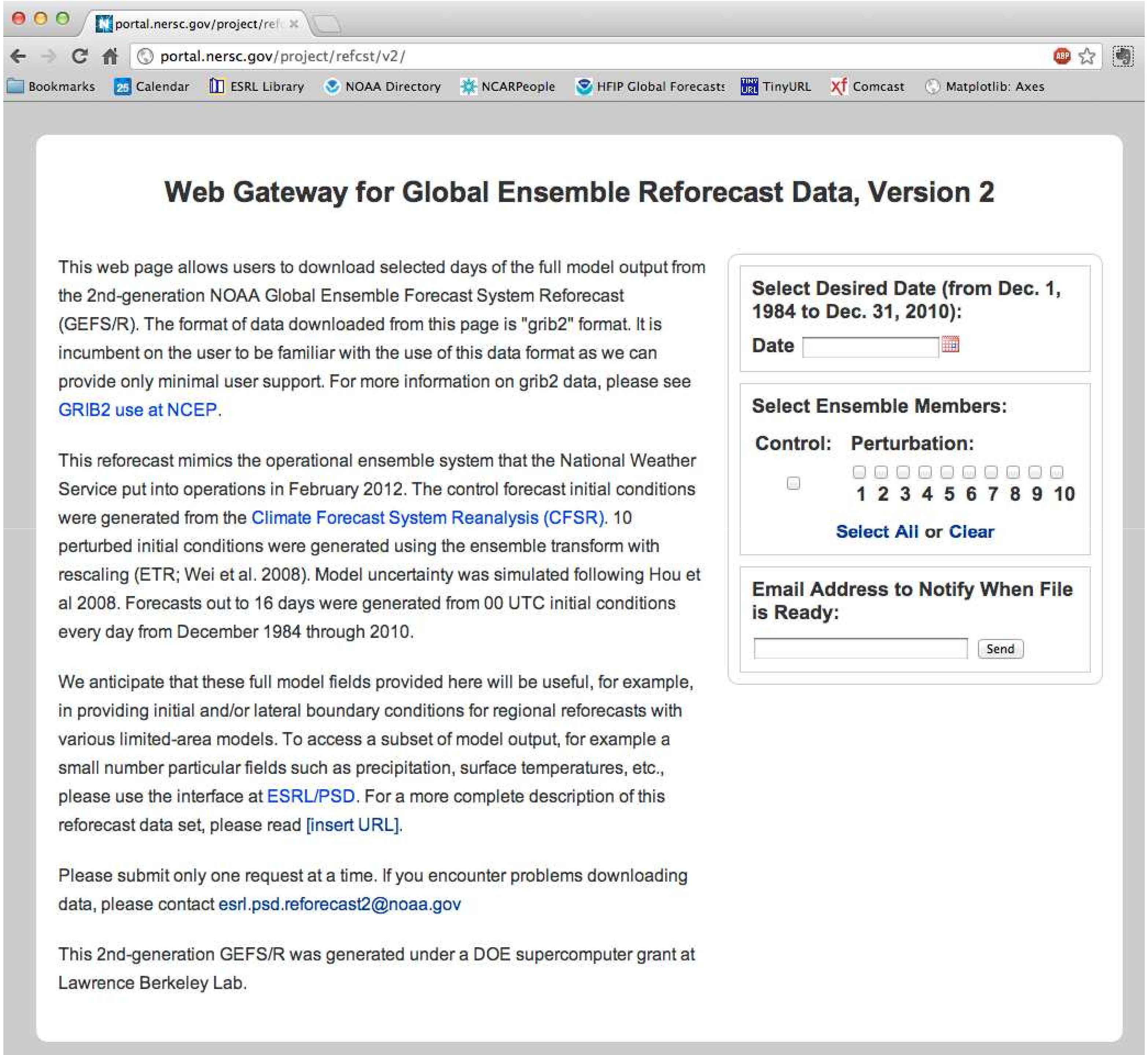
0	3	6	9	12	15	18	21	24	27
30	33	36	39	42	45	48	51	54	57
60	63	66	69	72	78	84	90	96	102
108	114	120	126	132	138	144	150	156	162
168	174	180	186	192					

Low Resolution: (Select All or Clear)

186	192	198	204	210	216	222	228	234	240
246	252	258	264	270	276	282	288	294	300
306	312	318	324	330	336	342	348	354	360
366	372	378	384						

Produces netCDF files.

Also: direct ftp access to allow you to read the raw grib files.



portal.nersc.gov/project/refcst/v2/

Bookmarks · Calendar · ESRL Library · NOAA Directory · NCARPeople · HFIP Global Forecasts · TinyURL · Comcast · Matplotlib: Axes

Web Gateway for Global Ensemble Reforecast Data, Version 2

This web page allows users to download selected days of the full model output from the 2nd-generation NOAA Global Ensemble Forecast System Reforecast (GEFS/R). The format of data downloaded from this page is "grib2" format. It is incumbent on the user to be familiar with the use of this data format as we can provide only minimal user support. For more information on grib2 data, please see GRIB2 use at NCEP.

This reforecast mimics the operational ensemble system that the National Weather Service put into operations in February 2012. The control forecast initial conditions were generated from the Climate Forecast System Reanalysis (CFSR). 10 perturbed initial conditions were generated using the ensemble transform with rescaling (ETR; Wei et al. 2008). Model uncertainty was simulated following Hou et al 2008. Forecasts out to 16 days were generated from 00 UTC initial conditions every day from December 1984 through 2010.

We anticipate that these full model fields provided here will be useful, for example, in providing initial and/or lateral boundary conditions for regional reforecasts with various limited-area models. To access a subset of model output, for example a small number particular fields such as precipitation, surface temperatures, etc., please use the interface at ESRL/PSD. For a more complete description of this reforecast data set, please read [insert URL].

Please submit only one request at a time. If you encounter problems downloading data, please contact esrl.psd.reforecast2@noaa.gov

This 2nd-generation GEFS/R was generated under a DOE supercomputer grant at Lawrence Berkeley Lab.

Select Desired Date (from Dec. 1, 1984 to Dec. 31, 2010):

Date

Select Ensemble Members:

Control: **Perturbation:**

1 2 3 4 5 6 7 8 9 10

Select All or Clear

Email Address to Notify When File is Ready:

Send

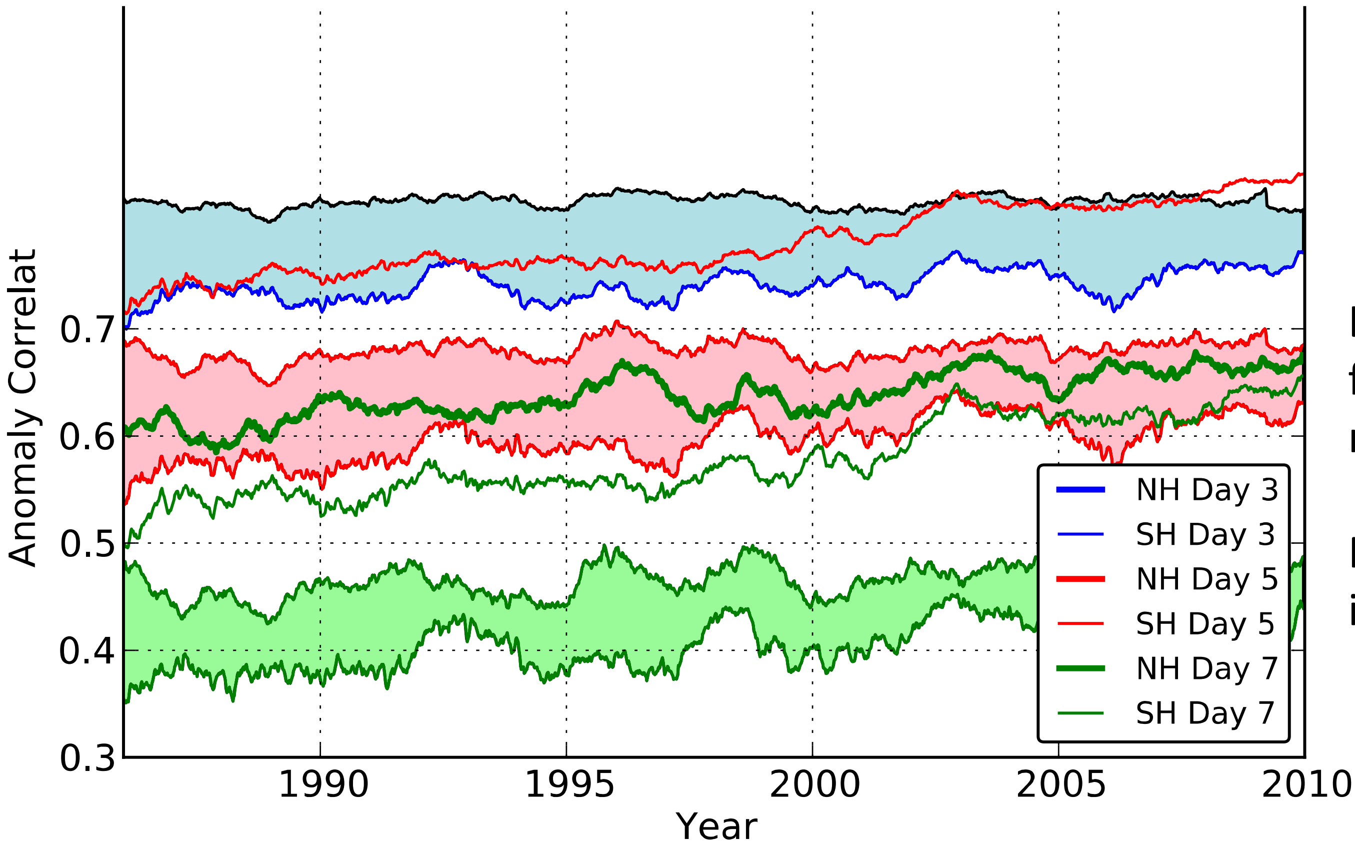
This DOE site will be ready for access to tape storage of full data (slower).

Use this to access full model state.

Characteristics of the unprocessed GEFS reforecasts.

How stationary are the errors?

500 hPa Z anomaly correlation
(from deterministic control)

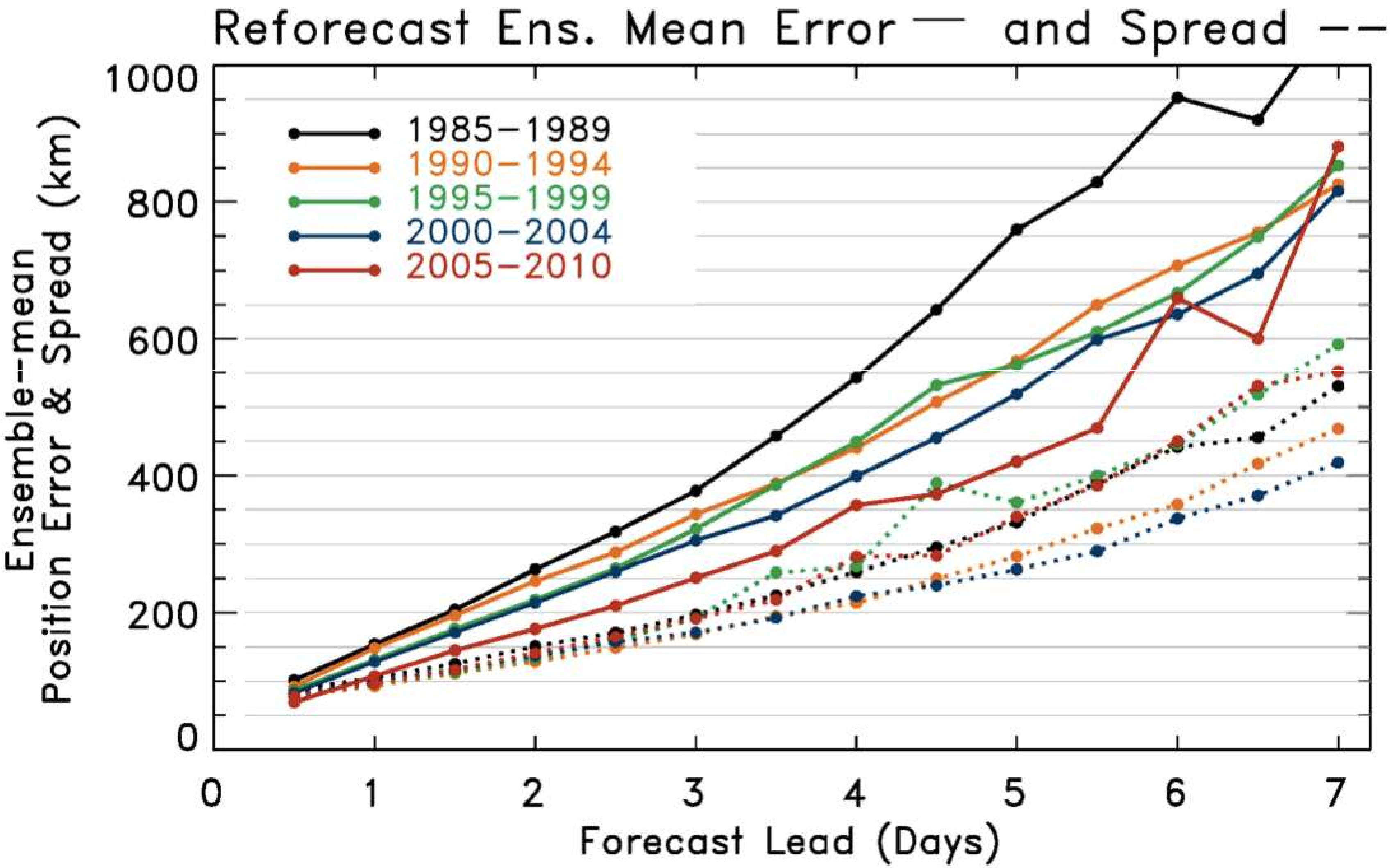


.ines w/o filled colors 'or second–generation 'eforecast (2012, T254)

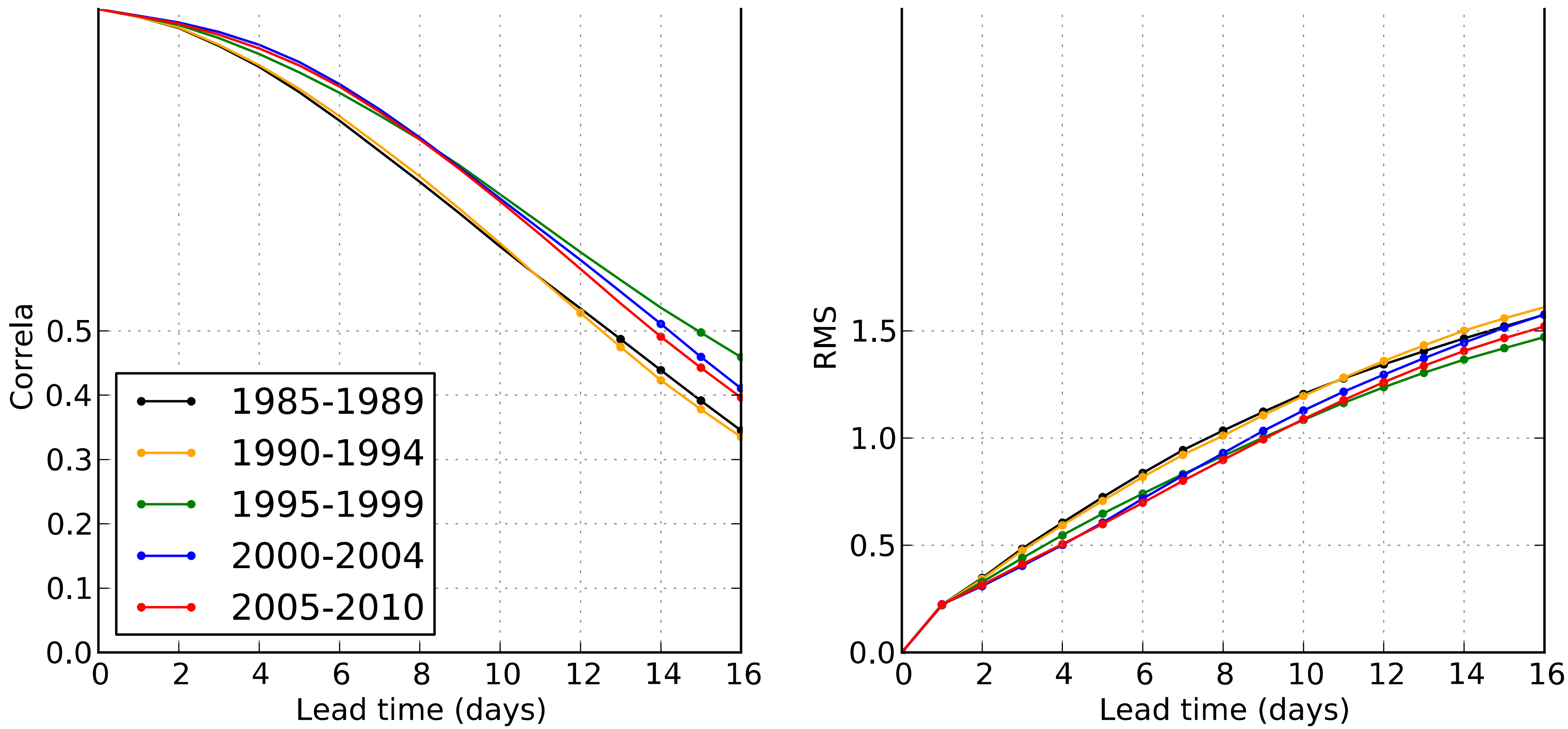
Lines with filled colors for first-generation reforecast (1998, T62).

Perhaps a 1.5-2.5 day improvement.

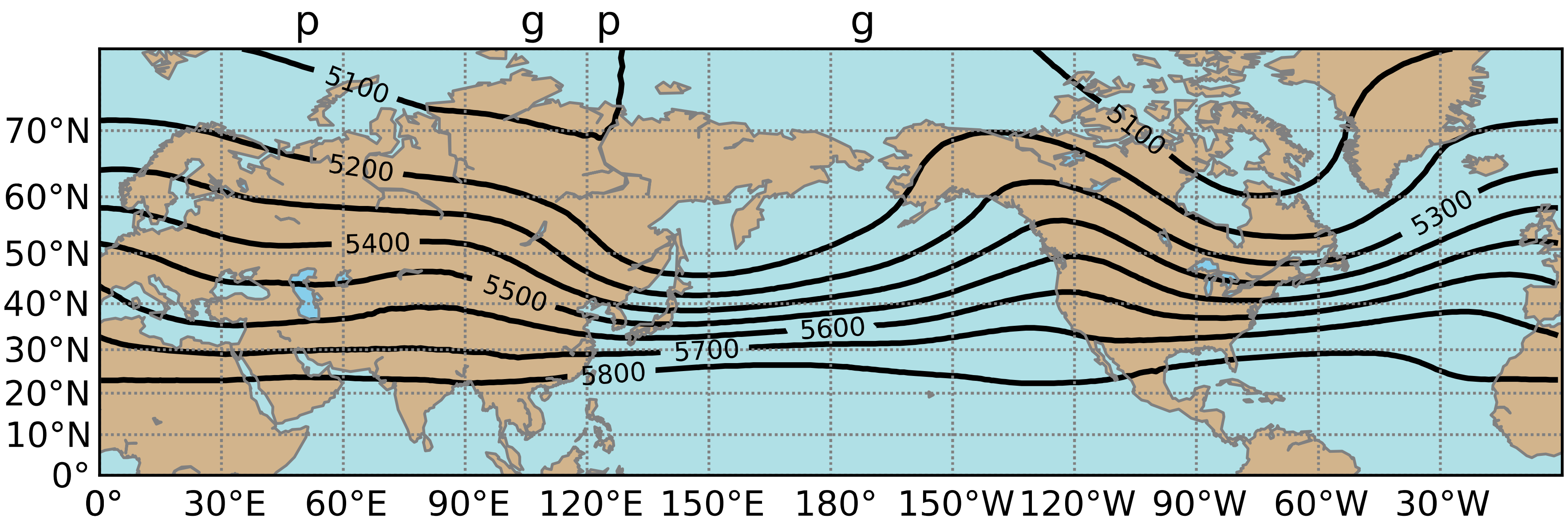
Tropical cyclone track error and spread



Bi-variate MJO RMM1 and RMM2 correlation and RMSE by half decade



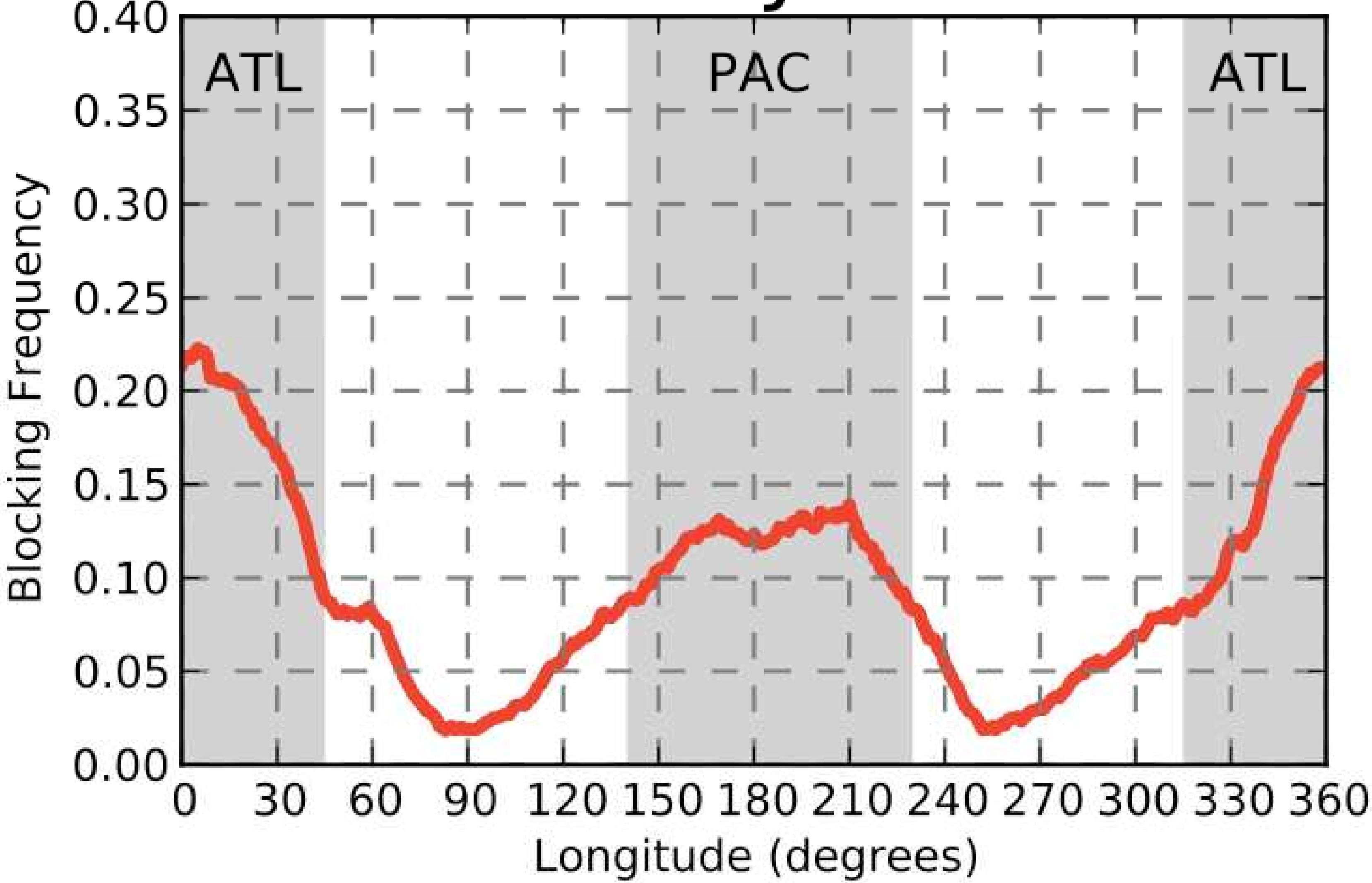
The first 10 years are much less skillful than the subsequent 16.



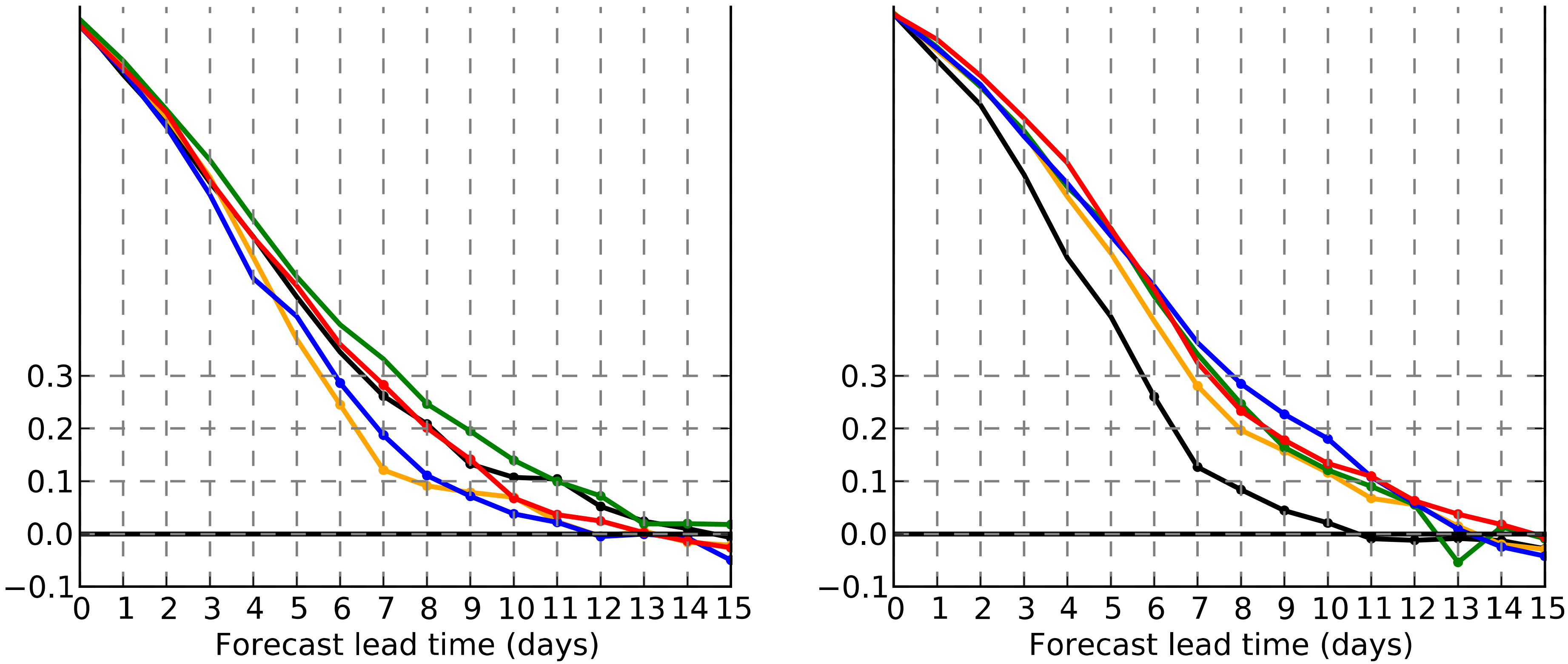
Dec-Jan-Feb 1985-2010 CFSR data. Blocks defined here by Tibaldi/Molteni algorithm.

Blocking frequency

Dec-Jan-Feb



GEFS blocking skill by half decade

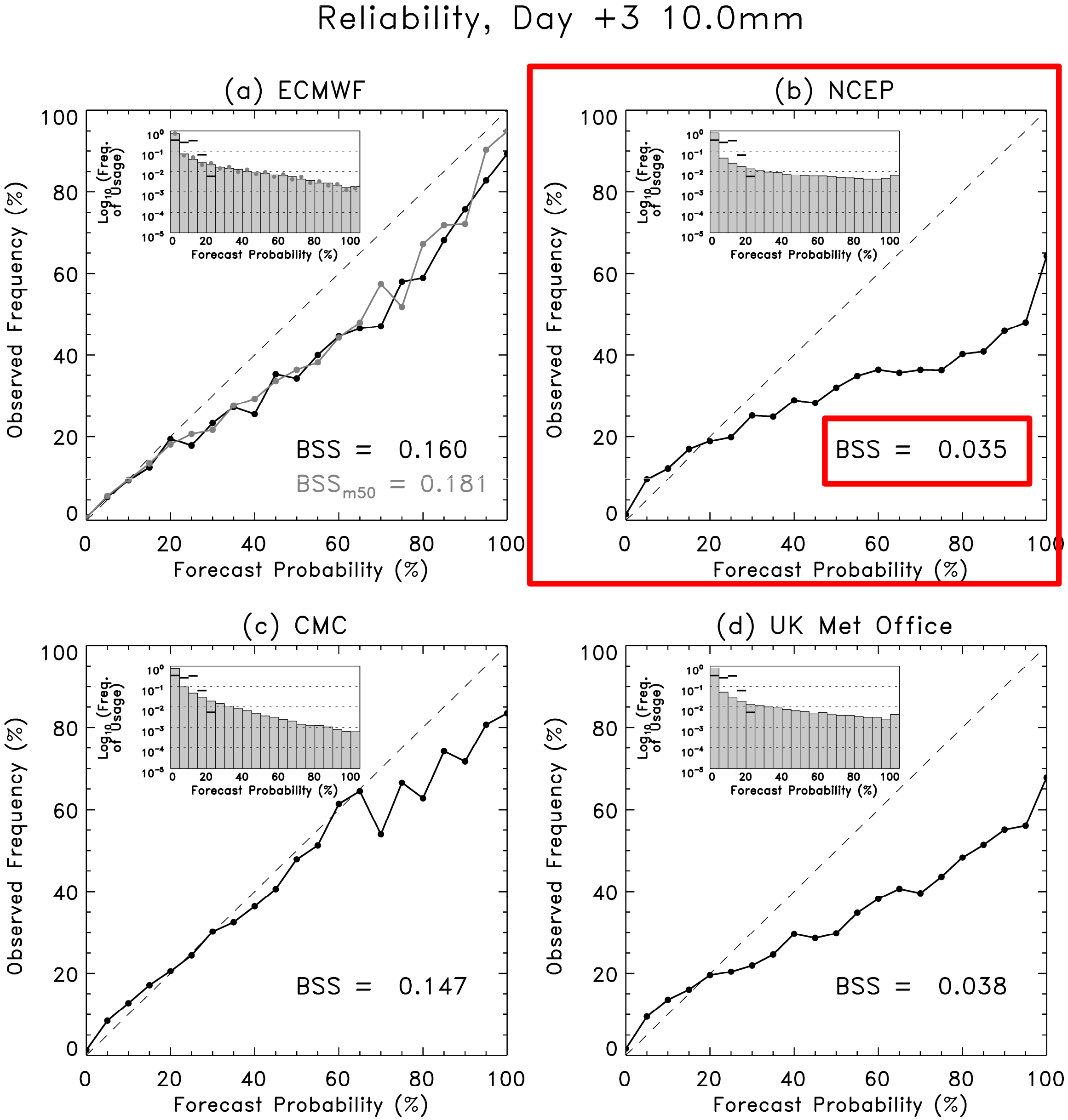


Blocking is evaluated using Tibaldi-Molteni algorithm for every longitude, every day. Skill of the ensemble in predicting blocking for each longitude is then evaluated.

Decreased Atlantic sector skill in 1985-1989 period stands out.

Statistical post-processing using reforecasts

Statistical post-processing of precipitation forecasts

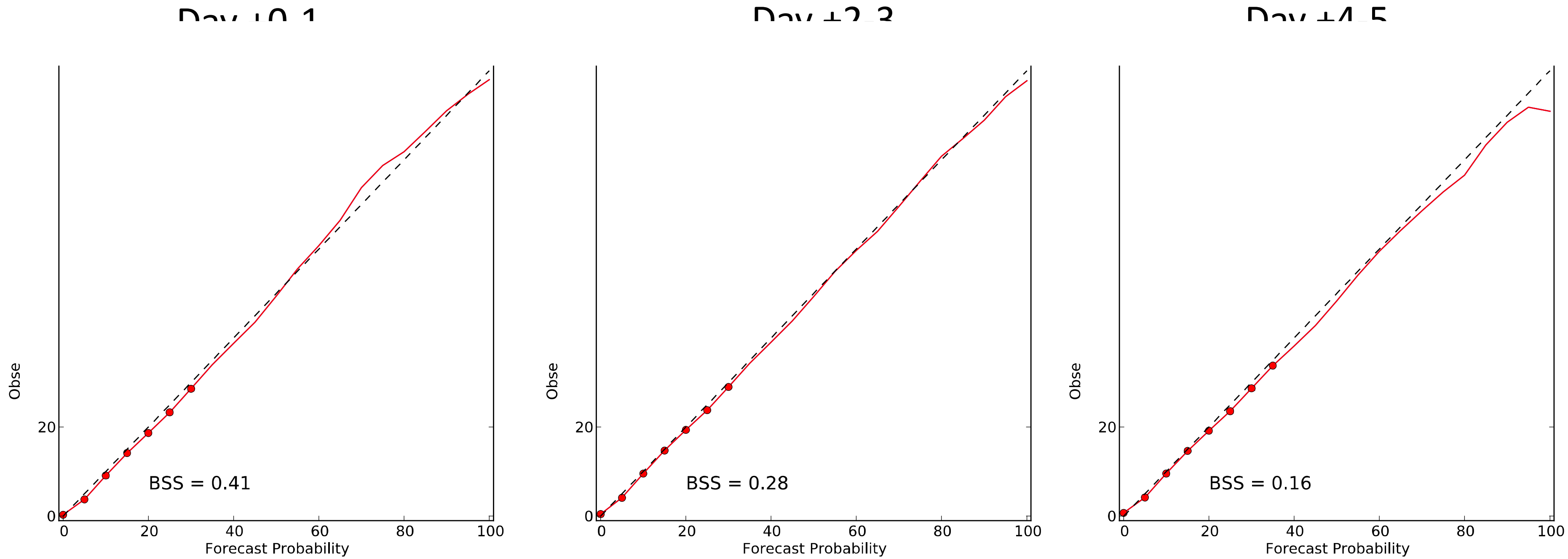


This is data from Jul-Oct 2010, when the GEFS was T190.

Probabilities directly estimated from ensemble prediction systems are often unreliable.

Can we statistically post-process the current GEFS using reforecasts and improve reliability and skill?

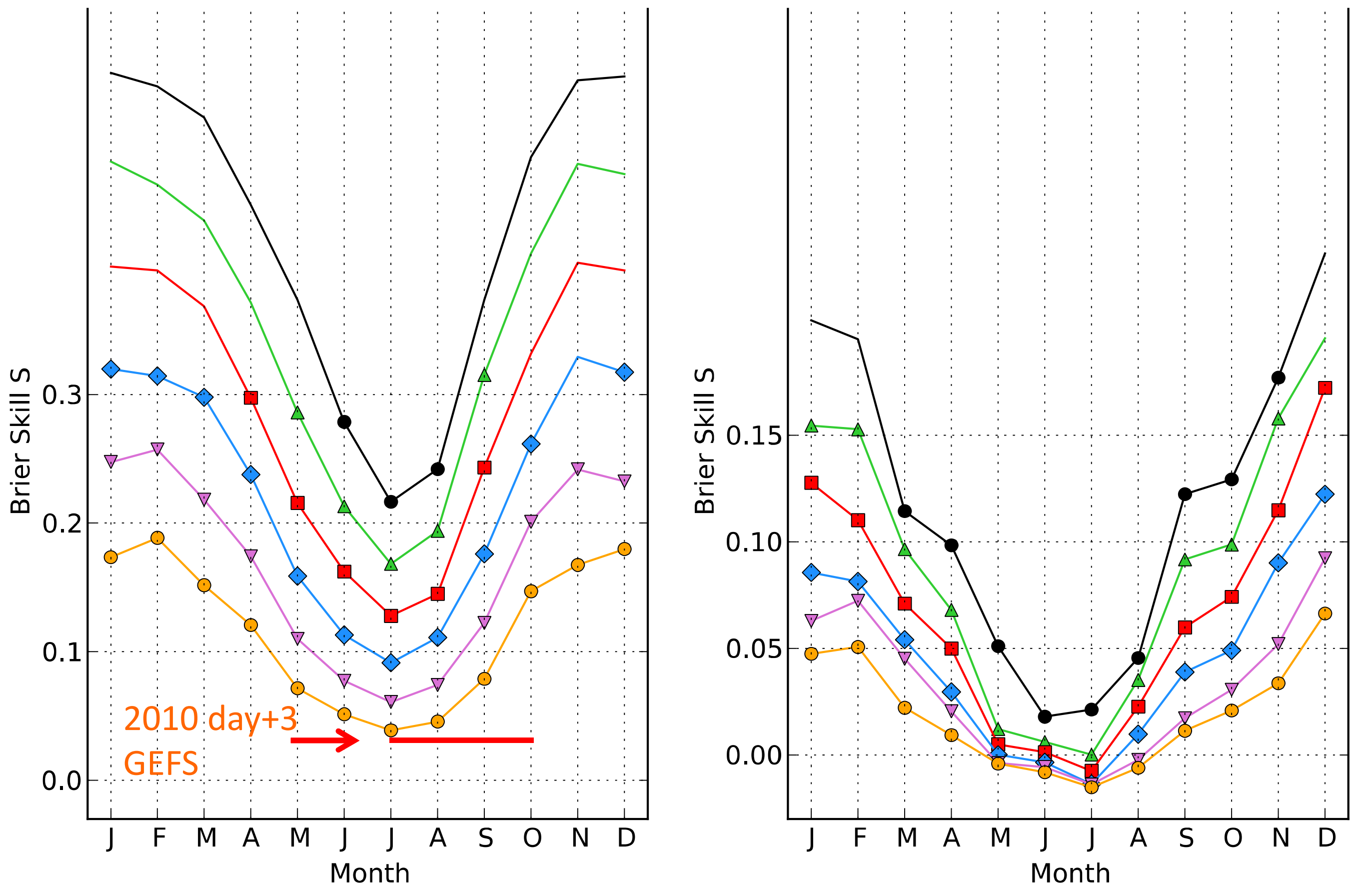
Reliability, > 10 mm precipitation 24 h^{-1}



Almost perfect reliability possible with very simple calibration algorithm.

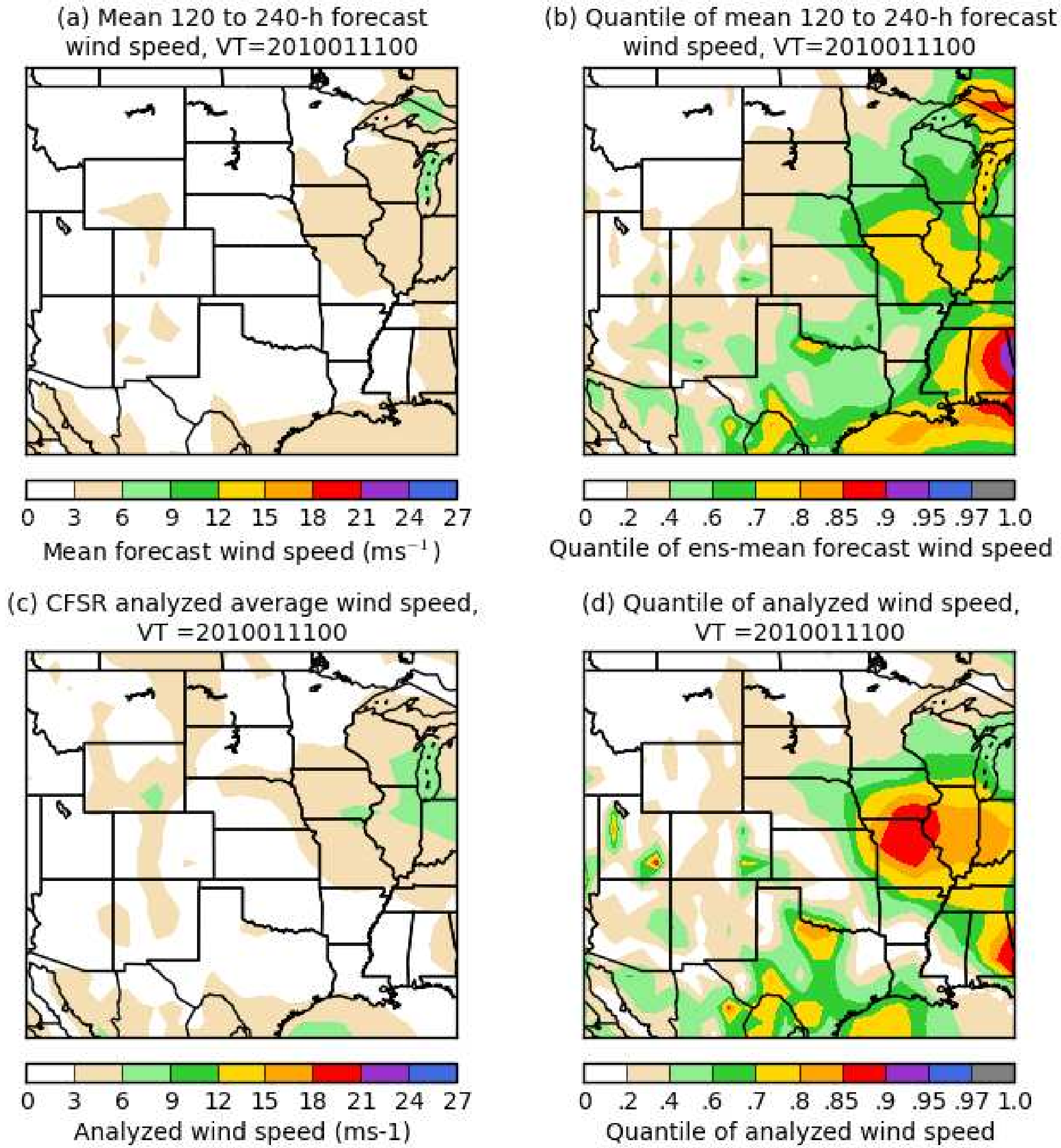
Statistical post-processing method used was “rank analog” technique discussed in Whitaker and Hamill (2006 MWR) and Hamill et al. (2012, BAMS, submitted).

Skill of calibrated precipitation forecasts
(over US, 1985-2010, “rank analog” calibration method)



Verification here against 32-km North American Regional Reanalysis (tougher).
Verification in previous plot against 1-degree NCEP precipitation analysis (easier).

Other statistical post-processing work in progress

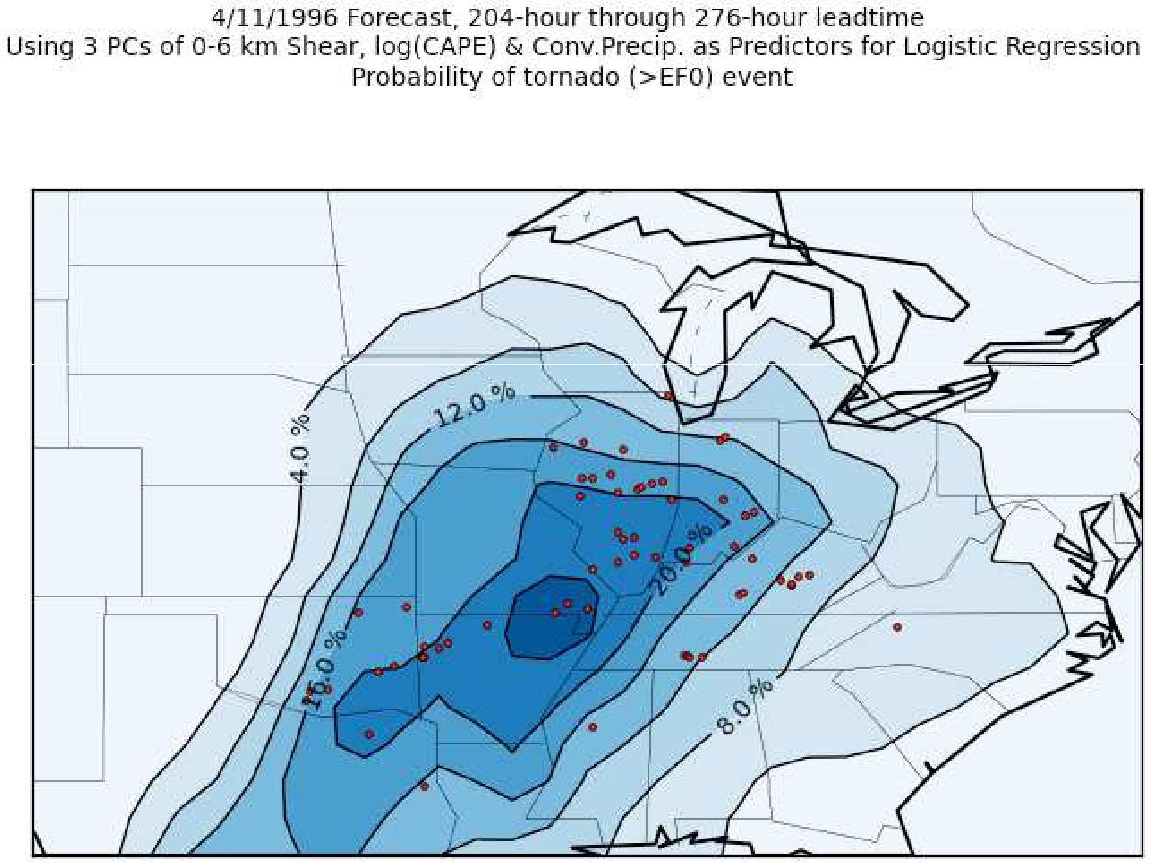


Say you don't have observational or analysis data widely available for statistical post-processing. How can you leverage reforecasts to tell you whether or not today's weather is unusual?

Here's an example quantifying how unusual the forecast wind speed is relative to past model forecasts of wind speed for a similar time of the year.

This might be useful for making decisions for wind energy, for example.

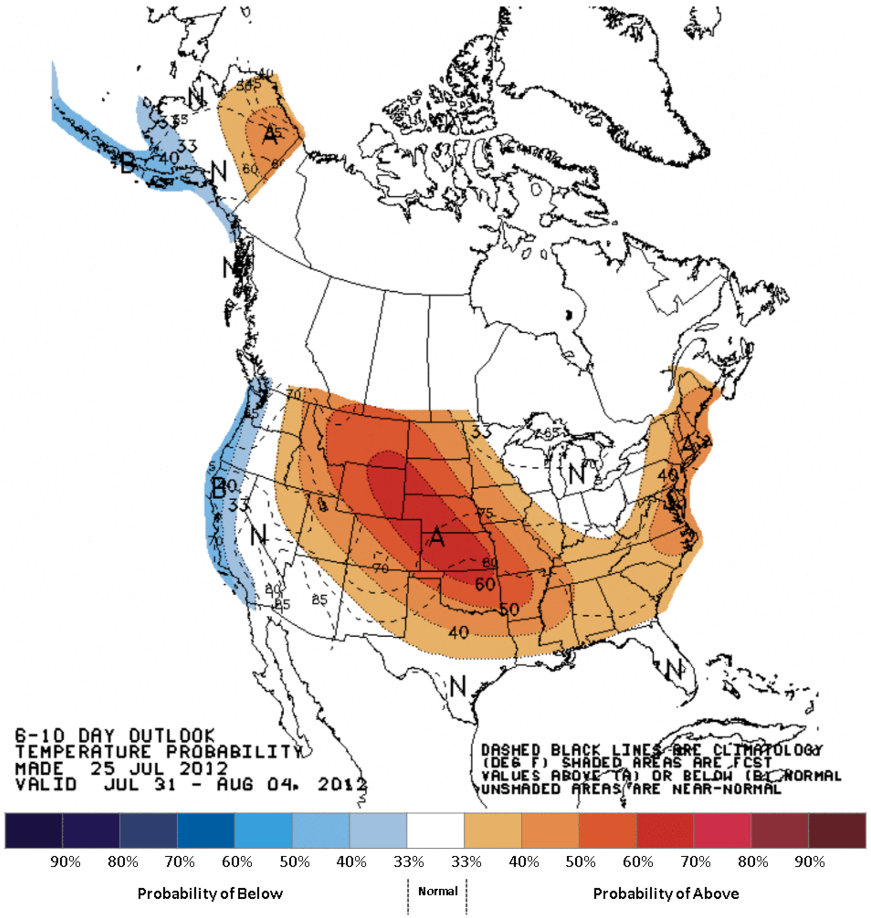
Application: extended-range tornado forecasting

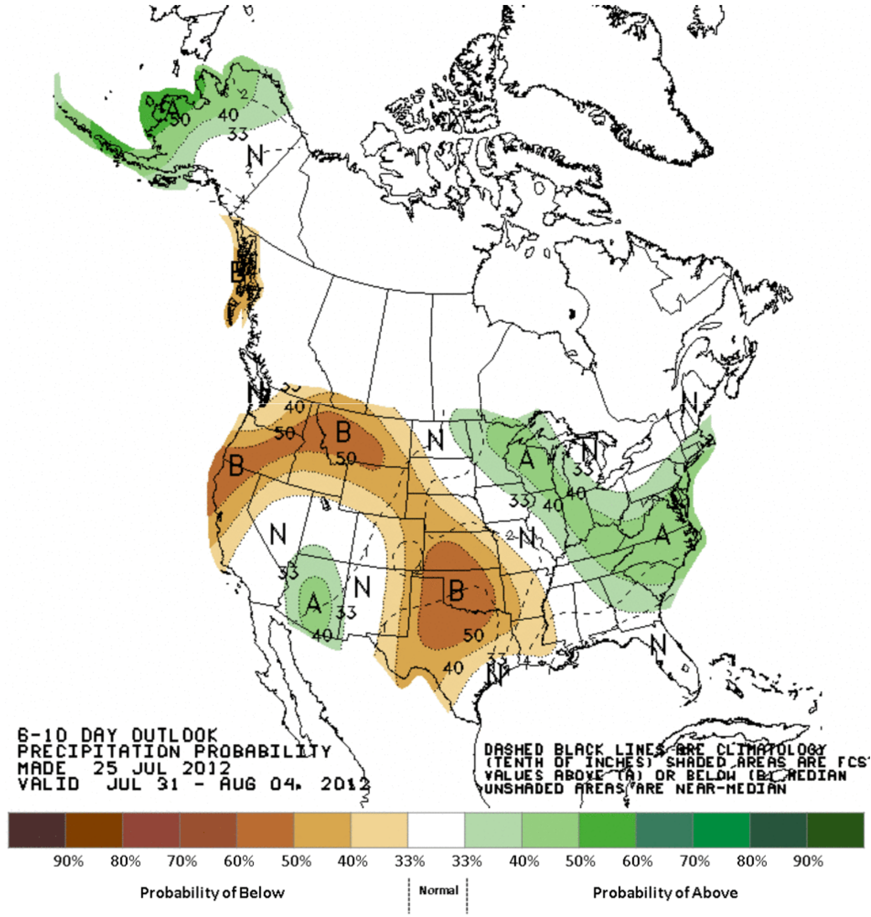


Francisco Alvarez,
St. Louis University,
is working with me
and others on using the
reforecasts to make
extended-range
predictions of
tornado probabilities.

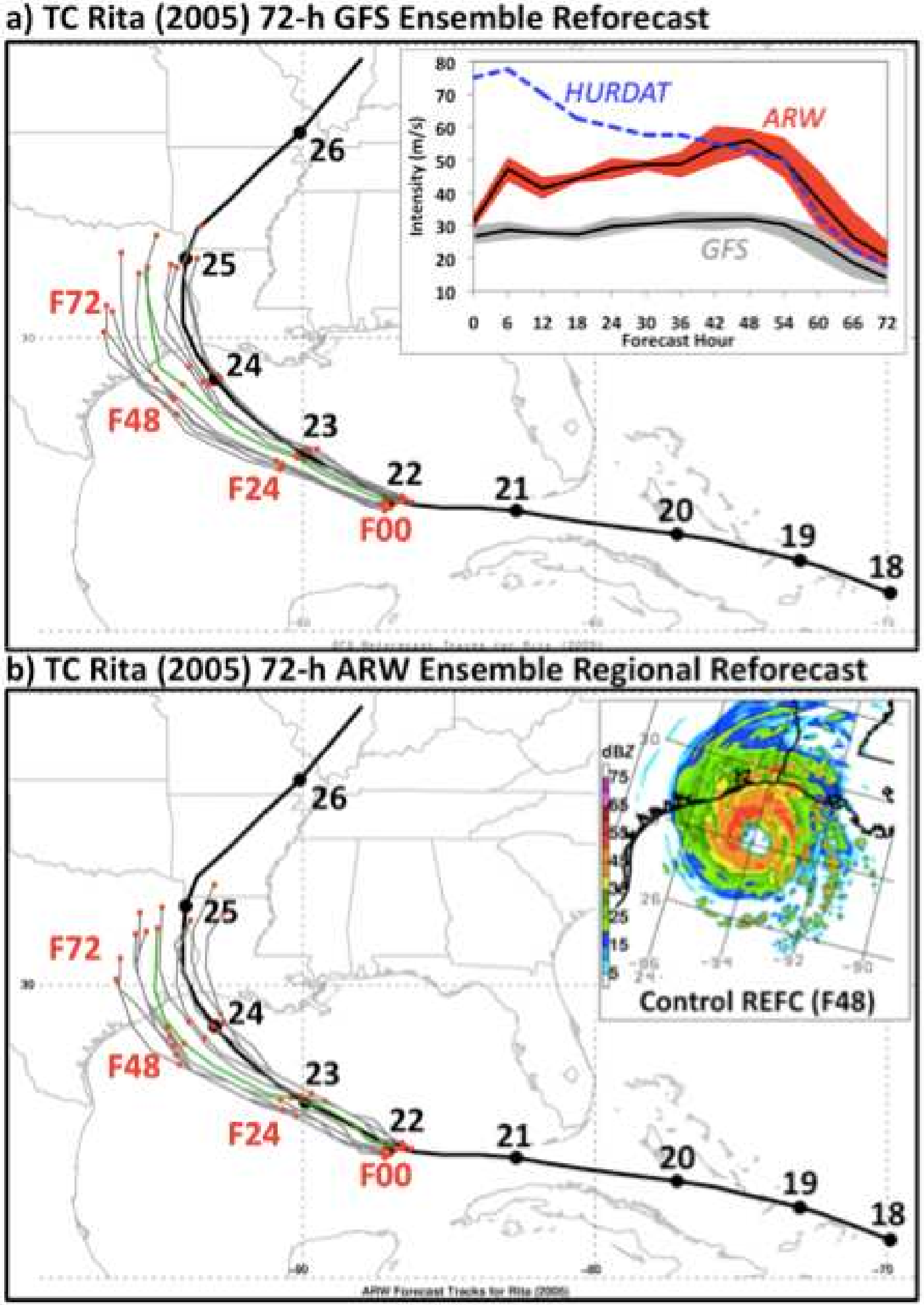
Ph.D. work,
in progress.

Application: Improved 6-10 day and week-2 forecast guidance





Dan Collins of NCEP Climate Prediction Center leading this effort.



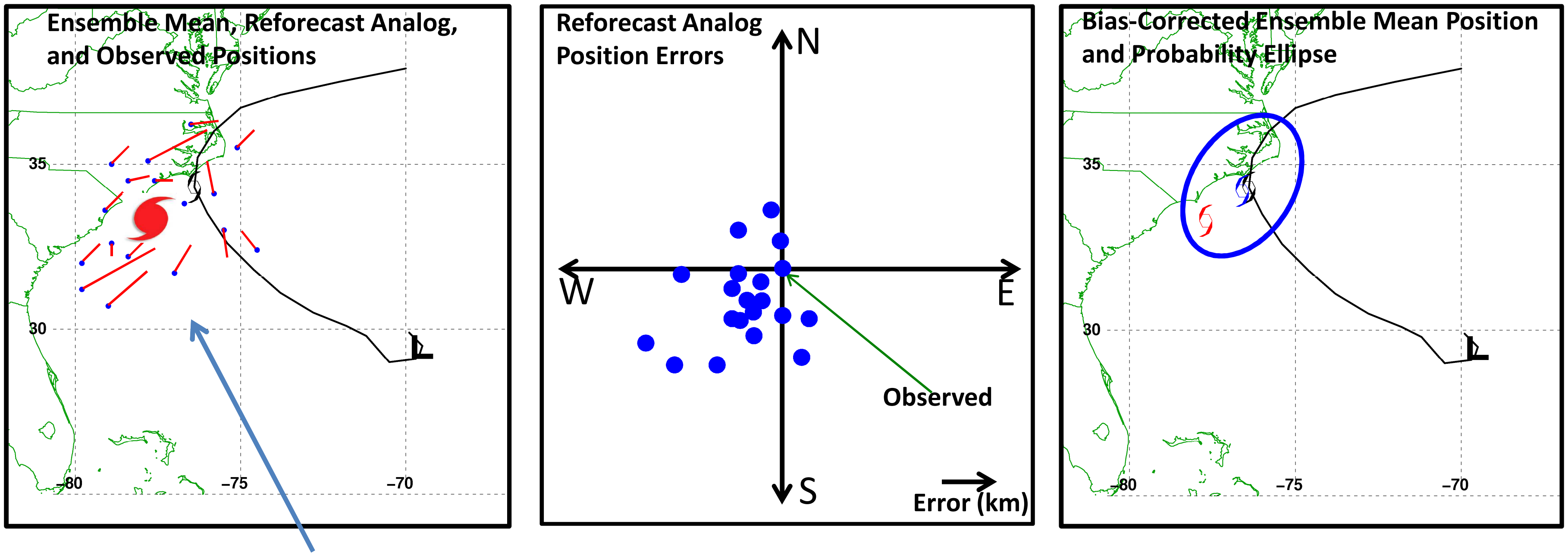
Regional reforecast initialization

Here, Hurricane WRF for Rita.

c/o Tom Galarneau

A synthetic example of using reforecasts to make track error bias corrections

72-h Forecast Verifying 1200 UTC 9 September



Red : mean forecast position

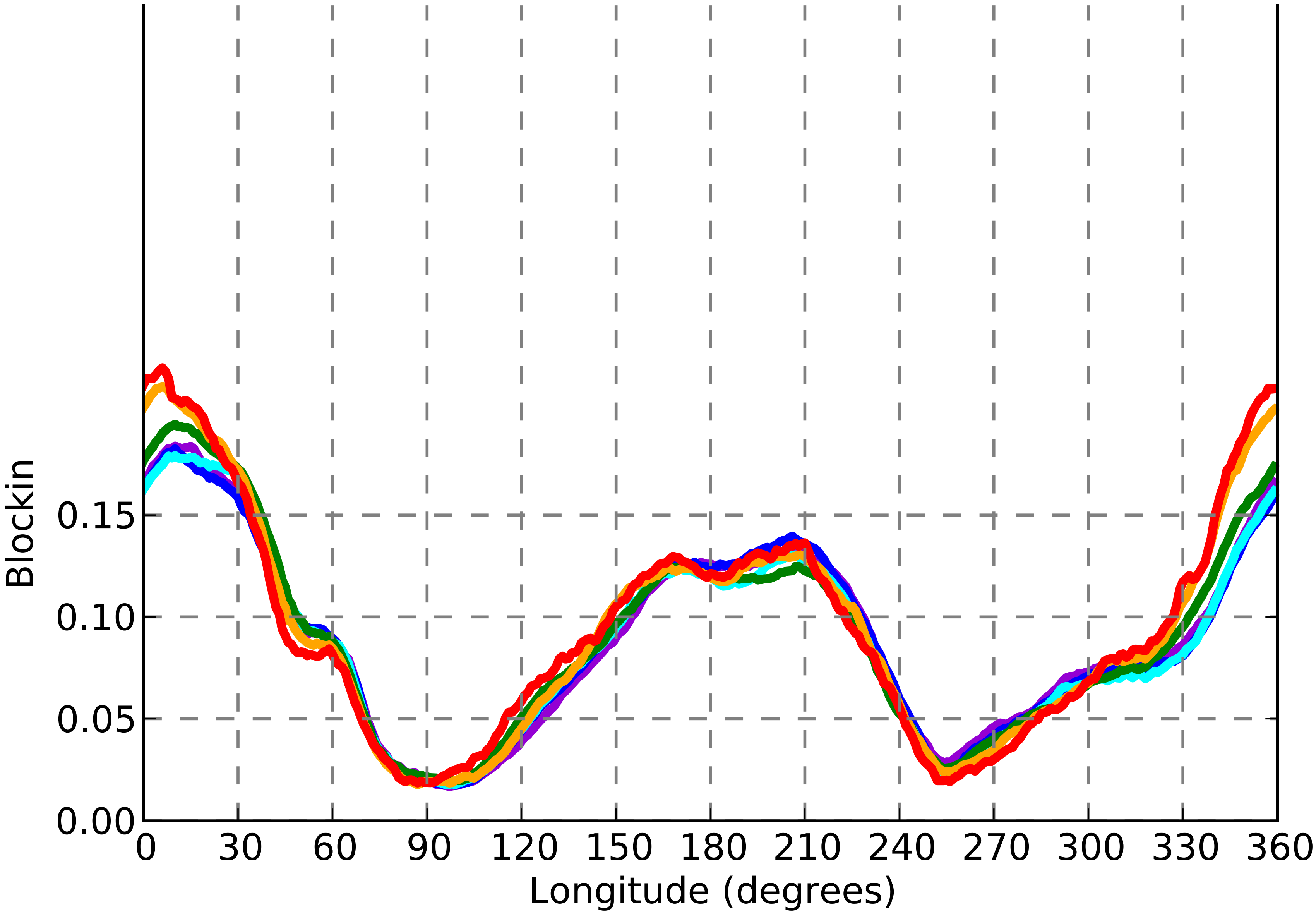
Blue dot: forecast positions of +72-h forecast analogs

End of red tail ___ : observed positions at +72 h

c/o Tom Galarneau, NCAR.

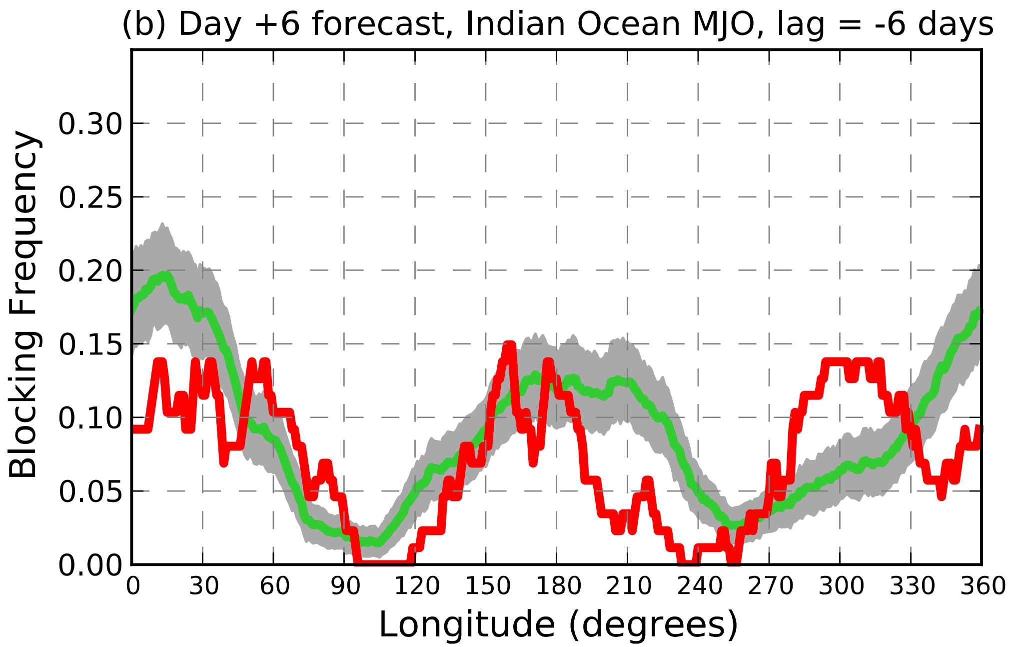
Diagnosis of model errors associated with infrequent phenomena

Example: atmospheric blocking, the Madden-Julian Oscillation, and their interaction



Under-forecasting of Atlantic block frequency after day +3

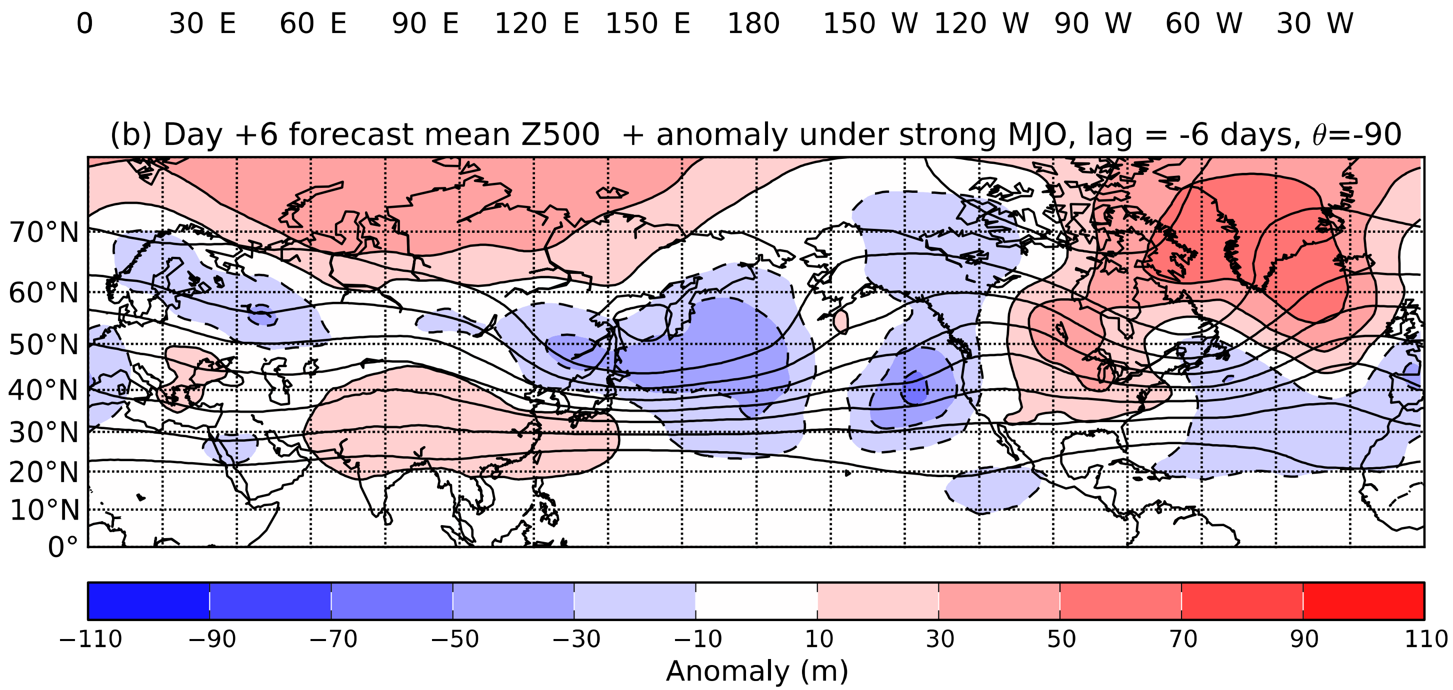
Change in blocking frequency under strong Indian Ocean MJO



Shaded areas are confidence 5/95% confidence intervals.

Suppression of blocking frequency in the east Pacific and Atlantic under strong MJO. Day +6 GEFS nicely replicates this suppression.

Z500 anomalies under strong (6-day lagged) Indian Ocean MJO



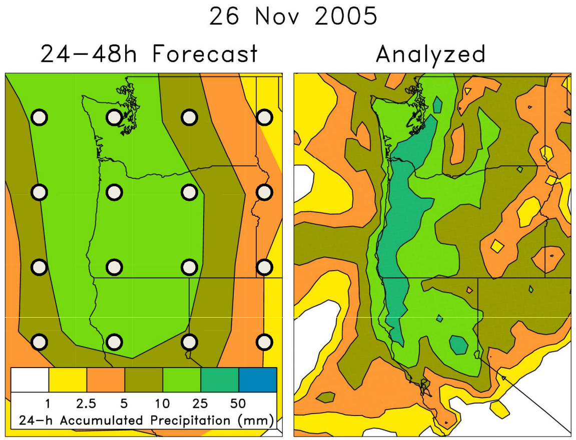
Conclusion

- GEFS reforecast data is now freely available for your use.
  - Fast archive of common variables.
  - Slower tape archive of full model state.
- We hope this will spur research in advanced statistical post-processing and facilitate understanding of GEFS model errors, facilitate regional reforecasts.

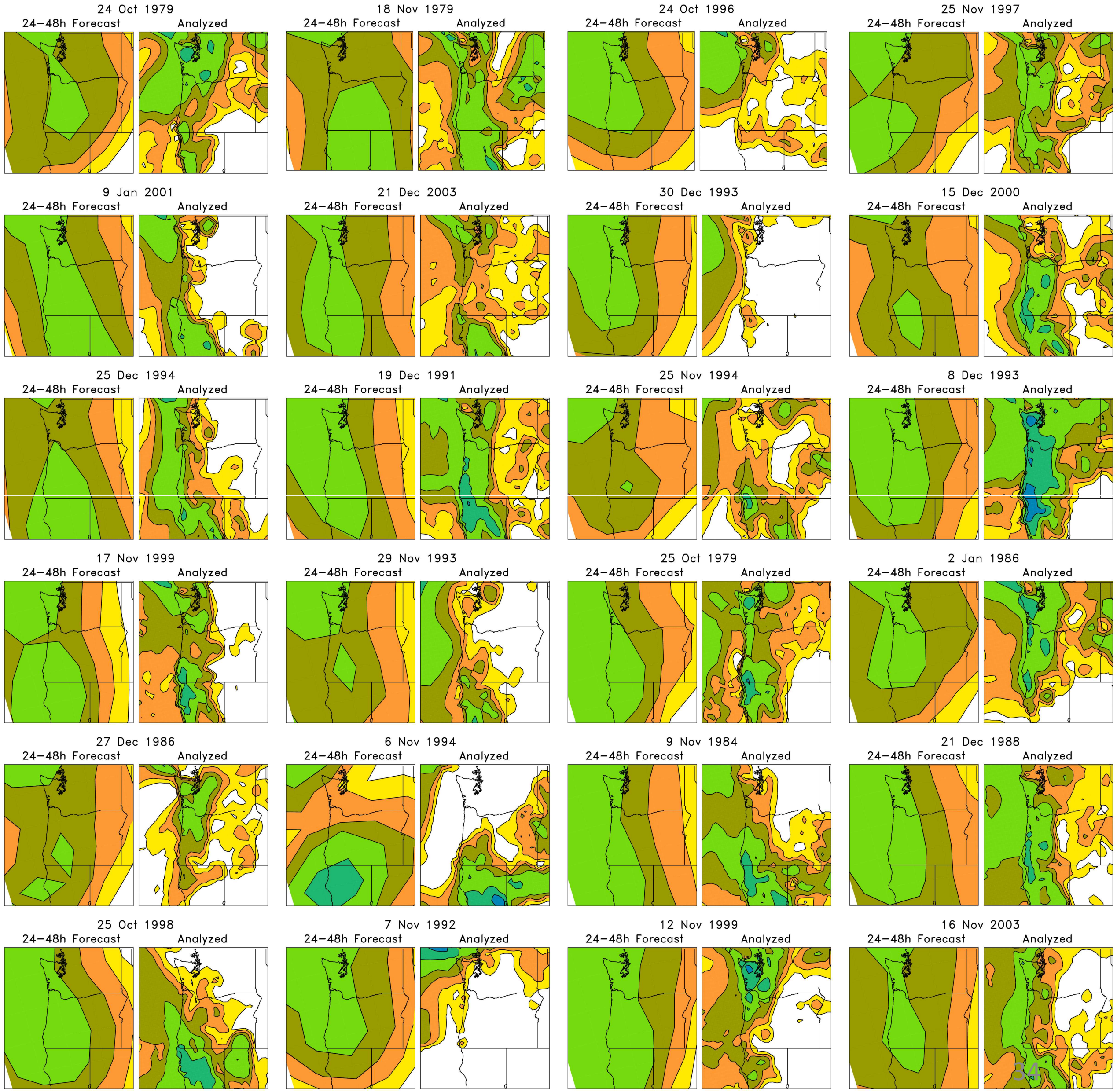
Supplementary slides

Basic analog technique for statistical downscaling (here, v1)

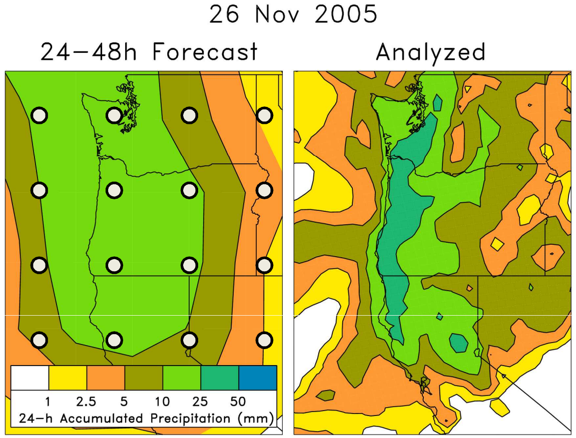
Today's ens. mean forecast + subsequent analyzed precipitation

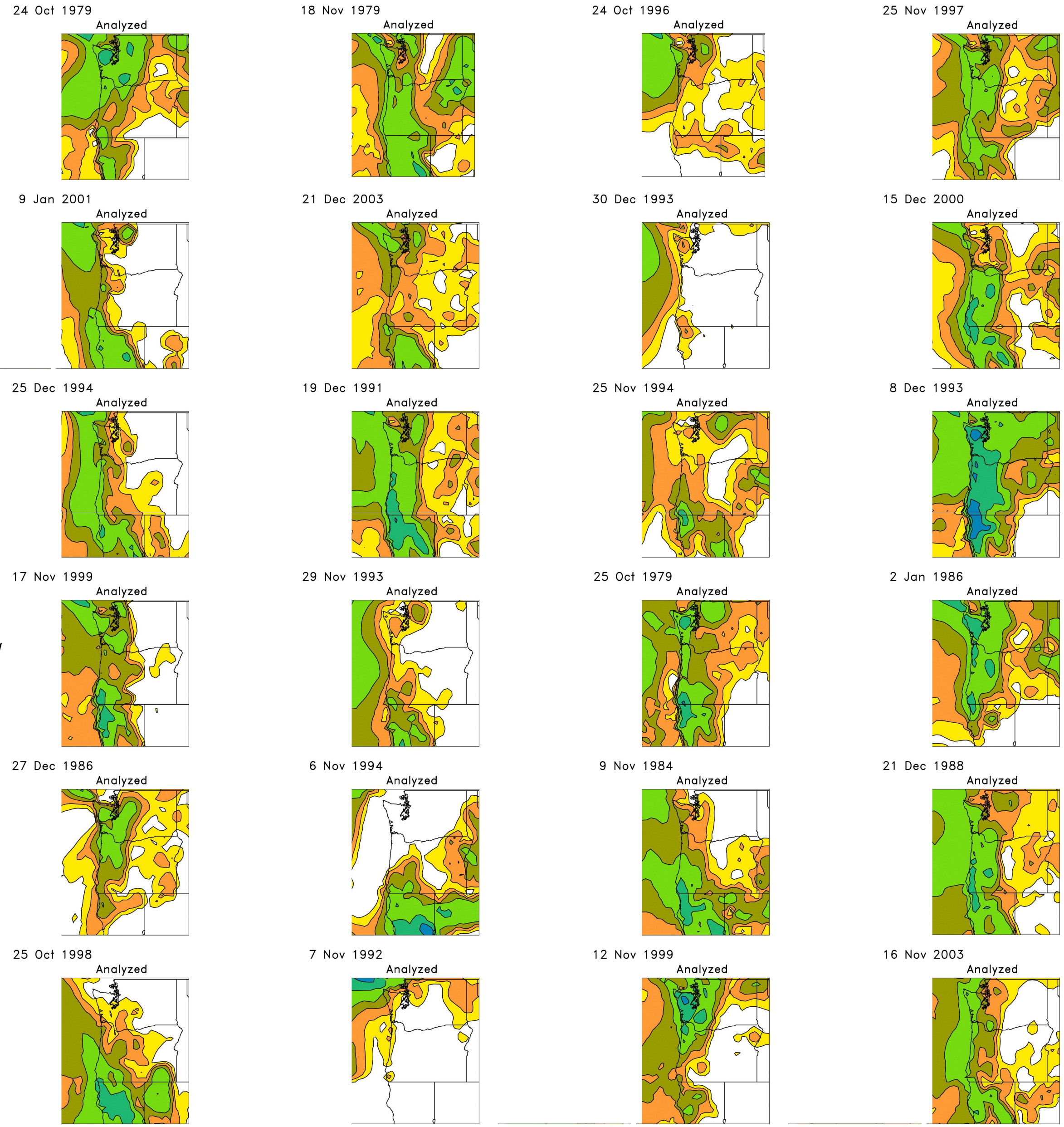


On the left are old forecasts similar to today's ensemble-mean forecast. For making probabilistic forecasts, form an ensemble from the accompanying analyzed weather on the right-hand side.



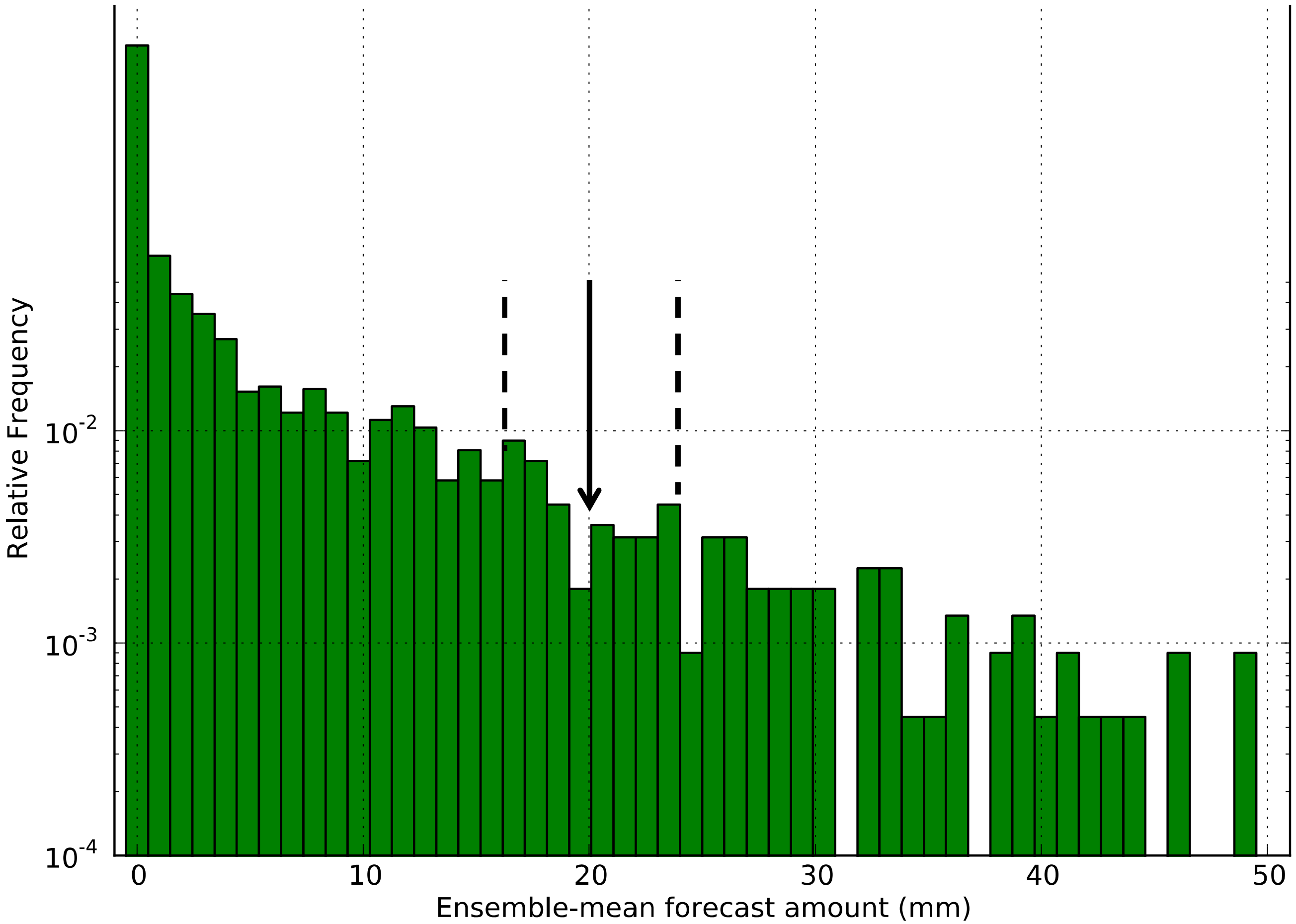
Analog technique for statistical downscaling





Form an ensemble from these

Problem with basic analog reforecast technique



ɔday's forecast is
) mm. There
ıore forecasts
:ly less than 20 mm
than slightly more than
20 mm.

Assuming correlation between forecast and observations, analogs will be biased toward lower precipitation amounts.

“Rank” analog procedure

- Convert precipitation forecast time series to ranks:

today’s

```
x    = [0,    0,     7, 15,   1,   3, 6, 4,    1, 2, 12, 5, 6, 8]

x(r)= [1.5, 1.5, 11, 14, 3.5,  6, 9, 7, 3.5, 5, 13, 8,10,12]
```

“Rank” analog procedure

- Convert precipitation forecast time series to ranks:

today’s

```
x    = [0,   0,    7, 15,   1,   3, 6, 4,   1, 2, 12, 5, 6, 8]

x(r)= [1.5, 1.5, 11, 14, 3.5,   6, 9, 7, 3.5, 5, 13, 8, 10, 12]
```

with standard analog, these would be the two forecasts with the closest values.

“Rank” analog procedure

- Convert precipitation forecast time series to ranks:

today’s

```
x    = [0,   0,    7, 15,   1,  3, 6, 4,   1, 2, 12, 5, 6, 8]

x(r)= [1.5, 1.5, 11, 14, 3.5,  6, 9, 7, 3.5, 5, 13, 8,10,12]
```

with rank analog, these would be the two forecasts with the closest ranks.

Rank analog calibration details

- 24-h accumulated precipitation, validated on NARR grid (~32 km) over CONUS, 1985-2009.
- Rank analog approach: at each grid point in CONUS, using that grid point and +/- 3 surrounding grid points in N-S, E-W direction, find dates of 75 past forecasts that are closest in average precipitation rank of ensemble mean forecast. Make probabilistic forecasts from analyzed NARR precipitation data on dates of those 75 analogs.
- (Conventionally calculated) Brier Skill Scores, reliability diagrams, etc. NARR again used for verification.

Define BSS for evaluating blocking skill

- The blocking Brier Skill score is calculated after summing forecast and climatological Brier scores over the relevant longitudes in either the Pacific or Atlantic basins, respectively, then averaged. For example (Pac):

$$BSS = 1.0 - \frac{BS_{forecast}}{BS_{climo}}$$

$$BS_{forecast} = \sum_{l_p=1}^{nlons} \sum_{i=1}^{ndates} \left(p_i^{forecast}\left(l_p\right) - o_i\left(l_p\right) \right)^2$$

$$BS_{climo} = \sum_{l_p=1}^{nlons} \sum_{i=1}^{ndates} \left(p_i^{climo}\left(l_p\right) - o_i\left(l_p\right) \right)^2$$

$$o_i\left(l_p\right) = \left\{ \begin{array}{cc} 1 & if\ blocked \\ 0 & if\ unblocked \end{array} \right\}$$

$$p_i^{forecast}\left(l_p\right) = ensemble-based\ probability\ of\ block\ for\ this\ longitude$$

$$p_i^{climo}\left(l_p\right) = climatological\ probability\ of\ block\ for\ this\ longitude$$

Computing the CRPSS of GEFS RMM1 and RMM2 forecasts

- CRPSS = 1 – CRPS(forecast) / CRPS(climatology)

$$CRPS(forecast) = \sum_{i=1}^{ndates} \sum_{j=1}^{ncats} \frac{1}{ncats} \left(\Phi_{forecast}\left(i, x(j)\right) - \Phi_{analyzed}\left(i, x(j)\right) \right)^2$$

$$CRPS(climo) = \sum_{i=1}^{ndates} \sum_{j=1}^{ncats} \frac{1}{ncats} \left(\Phi_{climo}\left(i, x(j)\right) - \Phi_{analyzed}\left(i, x(j)\right) \right)^2$$

$$x(1) = -5.0, \quad x(2) = -4.9, \quad \ldots, \quad x(ncats) = +5.0$$

$$\Phi(\,\cdot\,) = cumulative\ distribution\ function\ for\ either\ RMM1\ or\ RMM2$$

- $\Phi(\cdot)$ estimated from normal distribution fit to sample mean and standard deviation.

Blocking computation method: follows Tibaldi and Molteni, 1990 *Tellus*

(1950). The procedure we have applied is as follows: the 500 hPa field is firstly evaluated on a 4° by 4° regular latitude–longitude grid covering the Northern Hemisphere. Then the geopotential height gradients GHGS and GHGN (referring to middle and high latitudes respectively) are computed for each longitude point of the grid:

$$\mathrm{GHGS} = \frac{Z(\phi_o) - Z(\phi_s)}{(\phi_o - \phi_s)},$$

$$\mathrm{GHGN} = \frac{Z(\phi_n) - Z(\phi_o)}{(\phi_n - \phi_o)},$$

where

$\phi_n = 80°\,\mathrm{N} + \Delta,$
$\phi_o = 60°\,\mathrm{N} + \Delta,$
$\phi_s = 40°\,\mathrm{N} + \Delta,$
$\Delta\ = -4°, 0°$ or $4°$.

A given longitude is then defined as "blocked" at a specific instant in time if the following conditions are satisfied for at least one value of Δ:

(1) $\mathrm{GHGS} > 0,$

(2) $\mathrm{GHGN} < -10$ m/deg lat.

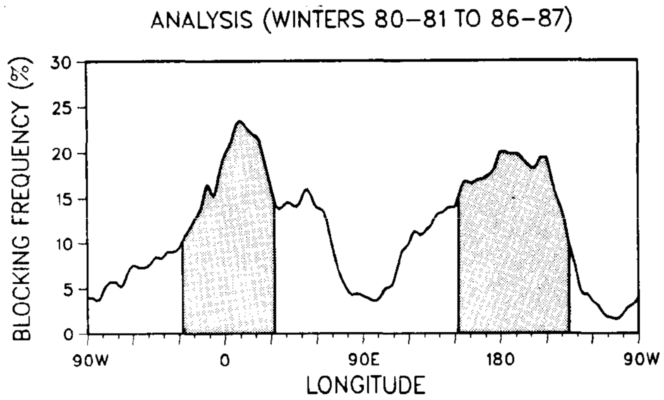


Fig. 1. Percentage frequency of blocking (objectively defined in Section 2) as a function of longitude and computed on all ECMWF daily objective analyses of our database.

There are alternatives, such as PV-based index by Pelly and Hoskins. While these may have some advantages, this old standard used hereafter.

MJO deterministic verification metrics

$$\mathrm{COR}(\tau) = \frac{\sum_{i=1}^{N}[a_{1i}(t)b_{1i}(t) + a_{2i}(t)b_{2i}(t)]}{\sqrt{\sum_{i=1}^{N}[a_{1i}^2(t) + a_{2i}^2(t)]}\sqrt{\sum_{i=1}^{N}[b_{1i}^2(t) + b_{2i}^2(t)]}},$$

where $a_{1i}(t)$ and $a_{2i}(t)$ are the observed RMM1 and RMM2 at day t, and $b_{1i}(t)$ and $b_{2i}(t)$ are their respective forecasts, for the ith forecast with a τ-day lead. Here, N is the number of forecasts.

COR(τ) measures the skill in forecasting the phase of the MJO, which is insensitive to amplitude errors. COR(τ) is equivalent to a spatial pattern correlation between the observations and the forecasts when they are expressed by the two leading combined EOFs.

$$\mathrm{RMSE}(\tau) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\{[a_{1i}(t) - b_{1i}(t)]^2 + [a_{2i}(t) - b_{2i}(t)]^2\}}.$$

from Lin et al., Nov 2008 *MWR*.

Demo: Regional reforecast with WRF ARW v3.4 using global reforecast for initial, boundary conditions

- 2-way nested simulation 36-, 12- and 4-km with 36 vertical levels
  - 12- and 4-km moving nests
- Time step: 180, 60, and 20 s
- Initial and boundary condition: GFS reforecast ensemble member
- Tiedtke cumulus scheme on 36 and 12 km; explicit on 4 km
- YSU PBL scheme
- HYCOM ocean analysis
- WSM6 microphysics
- Noah land surface
- 2D Smagorinsky turbulence scheme
- Goddard shortwave radiation
- RRTM longwave radiation
- Second order diffusion
- Positive definite scalar advection
- Donelan wind-dependent drag formulation
- Garratt wind-dependent enthalpy surface fluxes

c/o Tom Galarneau, NCAR & NOAA HFIP grant