NOAA Earth System
Research Laboratory

NOAA's 2nd-generation reforecast data set for the NCEP Global Ensemble Forecast System

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Reforecast background

- 1st-gen reforecast and CFSR have demonstrated utility of reforecasts for weather-climate applications (see previous GMB talks).
- A GEFS reforecast would be a nice complement to CFSR, especially to help with shorter-lead forecasts.
- Were such a data set available, it would have other uses:
  - Spur research in hydrologic prediction, calibration, statistical post-processing methods.
  - Facilitate labs and universities to work with GEFS, improving R2O to EMC.
  - Help diagnose GEFS model error characteristics, especially for low-frequency phenomena, possibly feeding back into GFS development.
  - Help EMC decide on its long-term strategy for reforecasting. How many members, how often?

GEFS reforecast v2 details

- Seeks to mimic GEFS operational configuration as of February 2012.
- Each 00Z, 11-member forecast, 1 control + 10 perturbed.\
- Reforecasts produced every day, for 1984120100 to current (actually, working on 2011 and 2012 now).
- CFSR initial conditions (GSI) + ETR perturbations (cycled with 10 perturbed members). After ~ 22 May 2012, initial conditions from hybrid EnKF/GSI.
- 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.
- Web interfaces to each coming soon. Links from TIGGE download pages?

Status

- 00Z reforecasts 1985-2010 completed.
- 2011-12 reforecasts mostly computed, but not yet downloaded to ESRL/PSD and reprocessed.
- Dick Wobus has submitted change request to NCO to save extra GEFS data so we can start archiving real-time data stream.
- We are a few weeks away from opening our ftp/web sites to public access for 1985-2010:
  – NOAA/ESRL site: fast access, limited data (99 fields).
  – US Department of Energy: slow access, but full data set

Data to be 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

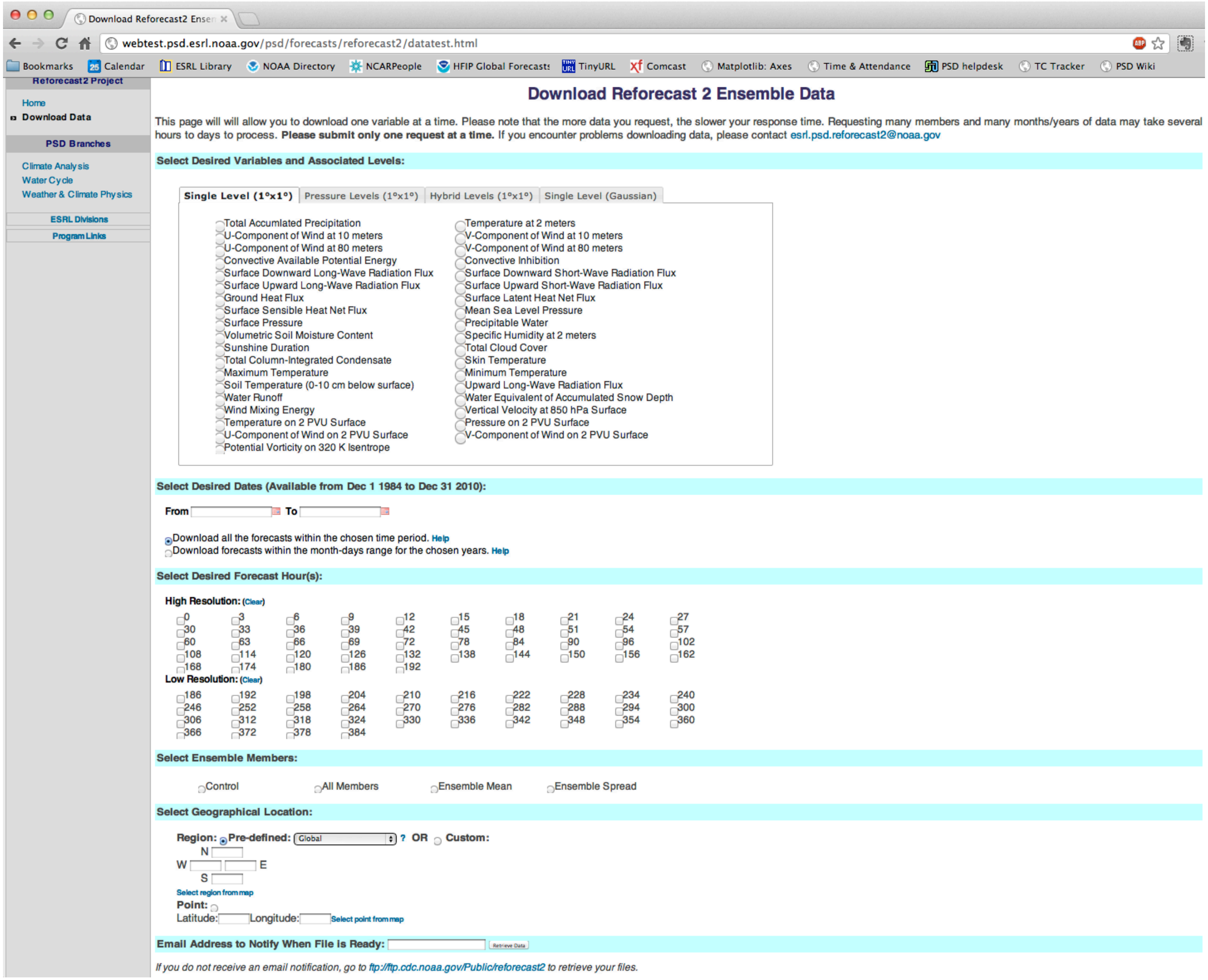
Also: hurricane track files

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

Prototype of our web form (creates netCDF4)



Download Reforecast 2 Ensemble Data

This page will will allow you to download one variable at a time. Please note that the more data you request, the slower your response time. Requesting many members and many months/years of data may take several hours to days to process. **Please submit only one request at a time.** If you encounter problems downloading data, please contact esrl.psd.reforecast2@noaa.gov

Select Desired Variables and Associated Levels:

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

◯ Total Accumlated 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
◯ Sunshine Duration	◯ 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 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: (**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: (**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						

Select Ensemble Members:

( ) Control   ( ) All Members   ( ) Ensemble Mean   ( ) Ensemble Spread

Select Geographical Location:

Region: (•) **Pre-defined:** [Global] **?** **OR** ( ) **Custom:**

N [ ]

W [ ] [ ] E

S [ ]

Select region from map

Point: ( )

Latitude:[ ]Longitude:[ ] **Select point from map**

Email Address to Notify When File is Ready: [ ] [Retrieve Data]

If you do not receive an email notification, go to ftp://ftp.cdc.noaa.gov/Public/reforecast2 to retrieve your files.

Download Reforecast 2 Ensemble Data

This page will will allow you to download one variable at a time. Please note that the more data you request, the slower your response time. Requesting many members and many months/years of data may take several hours to days to process. **Please submit only one request at a time.** If you encounter problems downloading data, please contact esrl.psd.reforecast2@noaa.gov

Select Desired Variables and Associated Levels:

Single Level (1°x1°) | **Pressure Levels (1°x1°)** | Hybrid Levels (1°x1°) | Single Level (Gaussian)

Variable

- Geopotential Height
- Temperature
- U-Component of Wind
- V-Component of Wind
- Specific Humidity

Levels (hPa)

1000	925	850	700	500	300	250	200	100	50	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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):

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☐ 0	☐ 3	☐ 6	☐ 9	☐ 12	☐ 15	☐ 18	☐ 21	☐ 24	☐ 27
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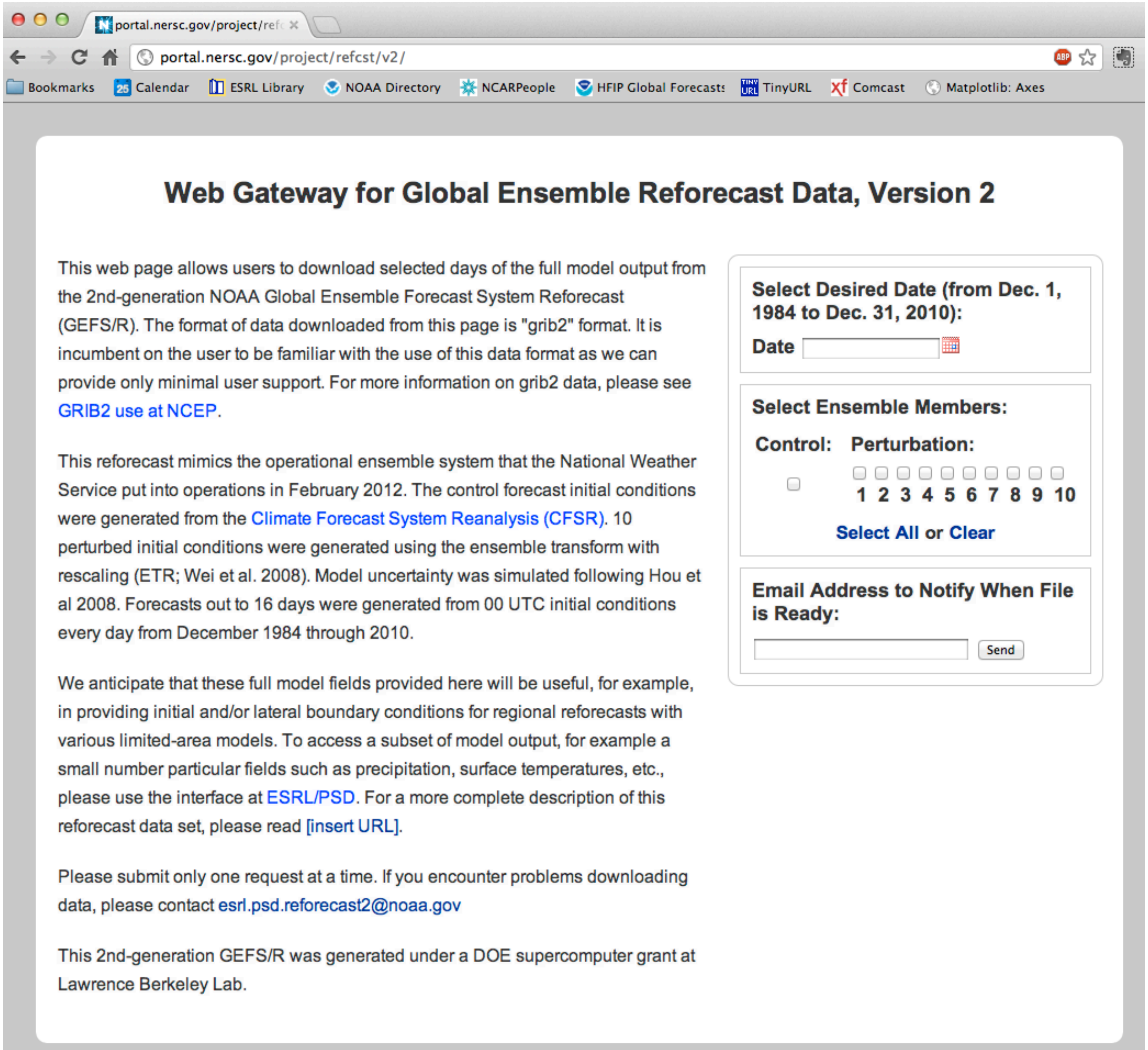
Select Ensemble Members:

○ Control ○ All Members ○ Ensemble Mean ○ Ensemble Spread

Other ways of accessing reforecast data

- ftp or gftp into our ftp.cdc.noaa.gov server (if you want lots of the original grib files). [soon]
- Pending Zeus grant, we intend to copy grib fields on Zeus mass store. [MDL plans to use]
- Data written out on external disk here within PSD for special customers (EMC/CPC, OHD), shipped back to them.
- DOE portal to get full dump of single day's grib data (next page).

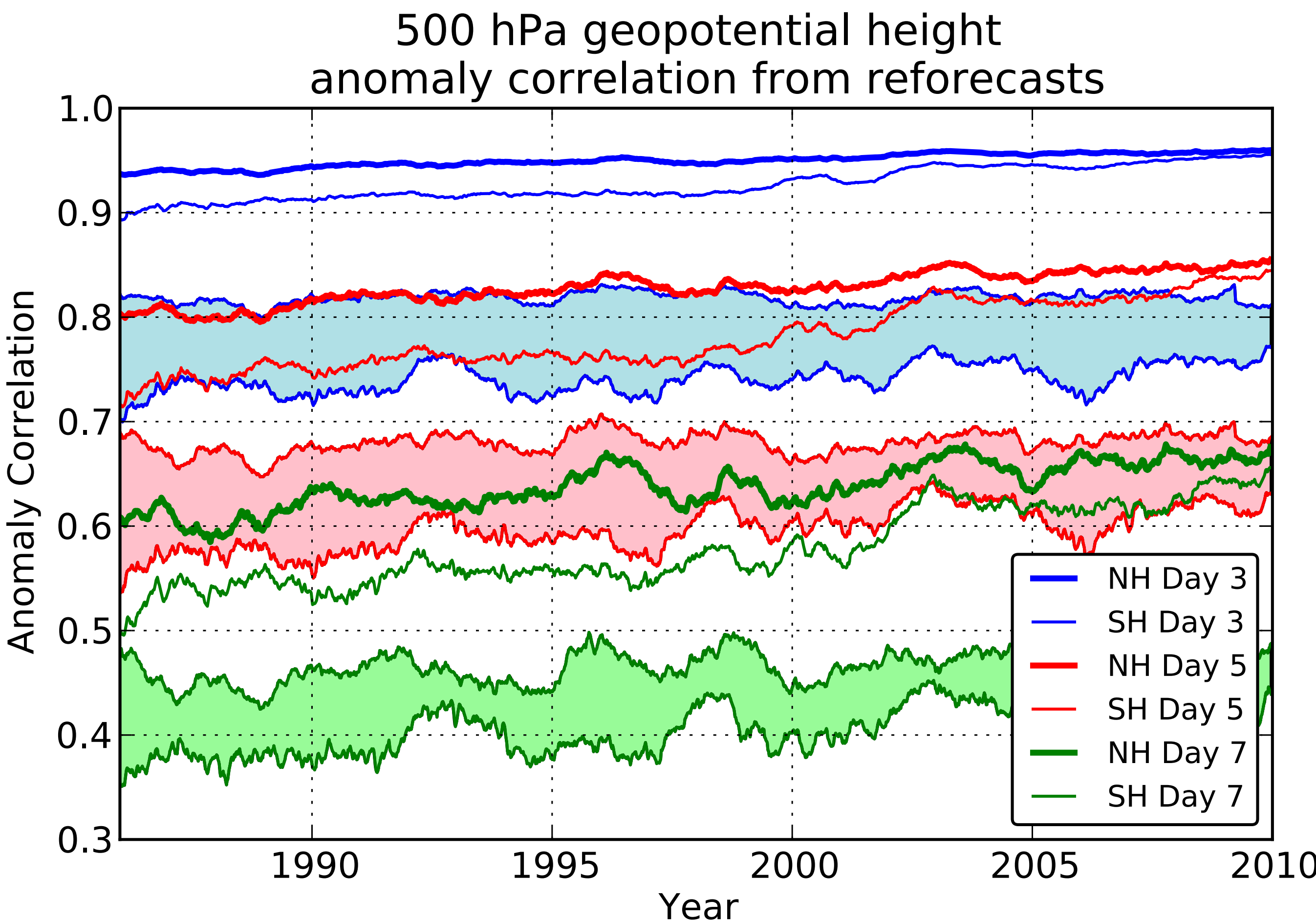


This DOE site will be ready for use in a few weeks for access to tape storage of full data (slower).

Use this to access full model state.

Later in this presentation we will show a regional WRF reforecast initialized from GEFS reforecast.

500 hPa Z anomaly correlation
(from deterministic control)



Lines w/o filled colors for second–generation reforecast (2010, T254)

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

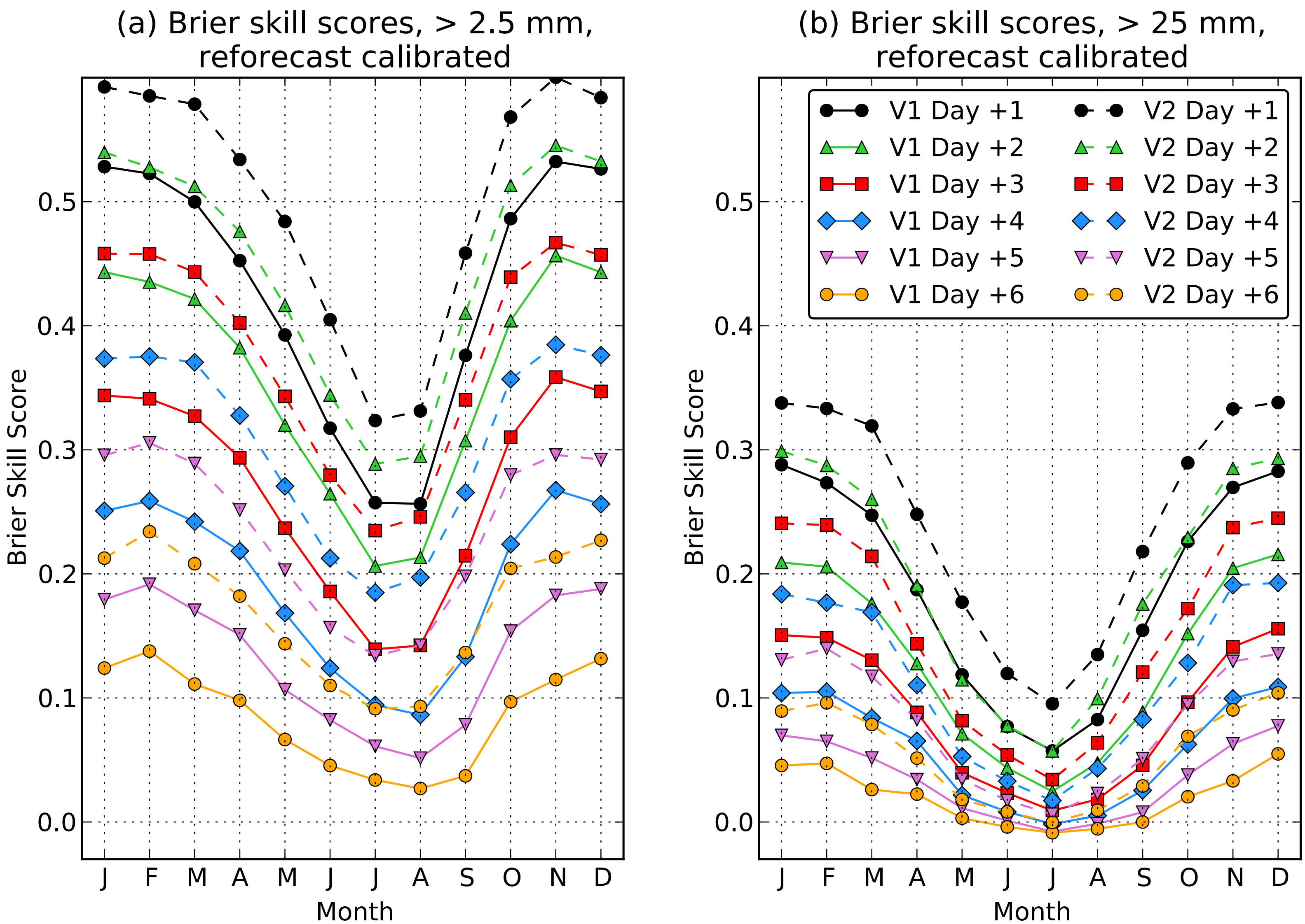
Perhaps a 1.5-2.5 day improvement.

How does the skill of post-processed forecasts change from reforecast v1 to v2?

- Let's look at post-processed 24-h precipitation forecast guidance.

- Will use a "rank analog" approach for post-processing (description in supplementary slides)

Skill of calibrated precipitation forecasts
(over US, 1985-2009, "rank analog" calibration method)



Skill of calibrated precipitation forecasts
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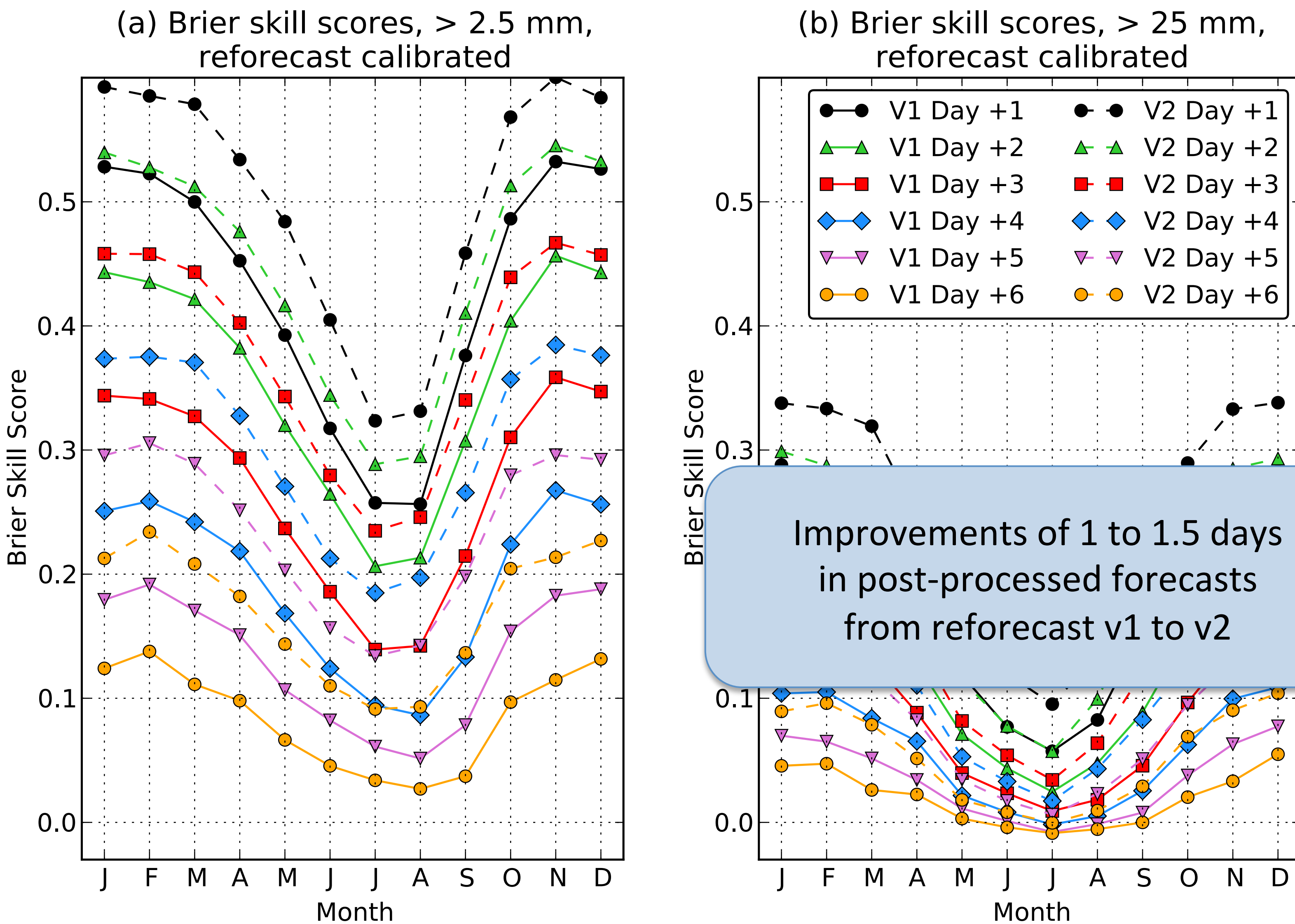
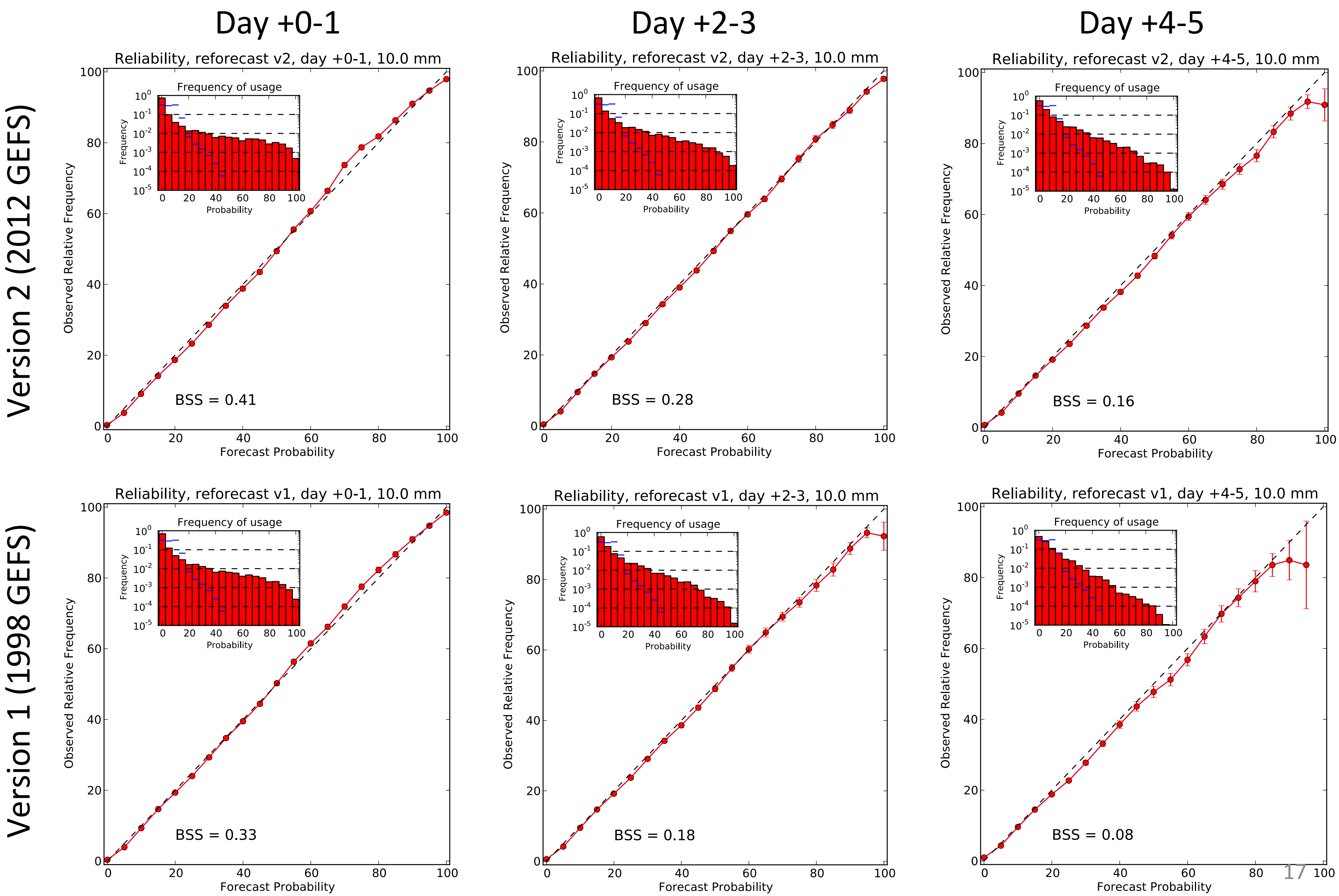
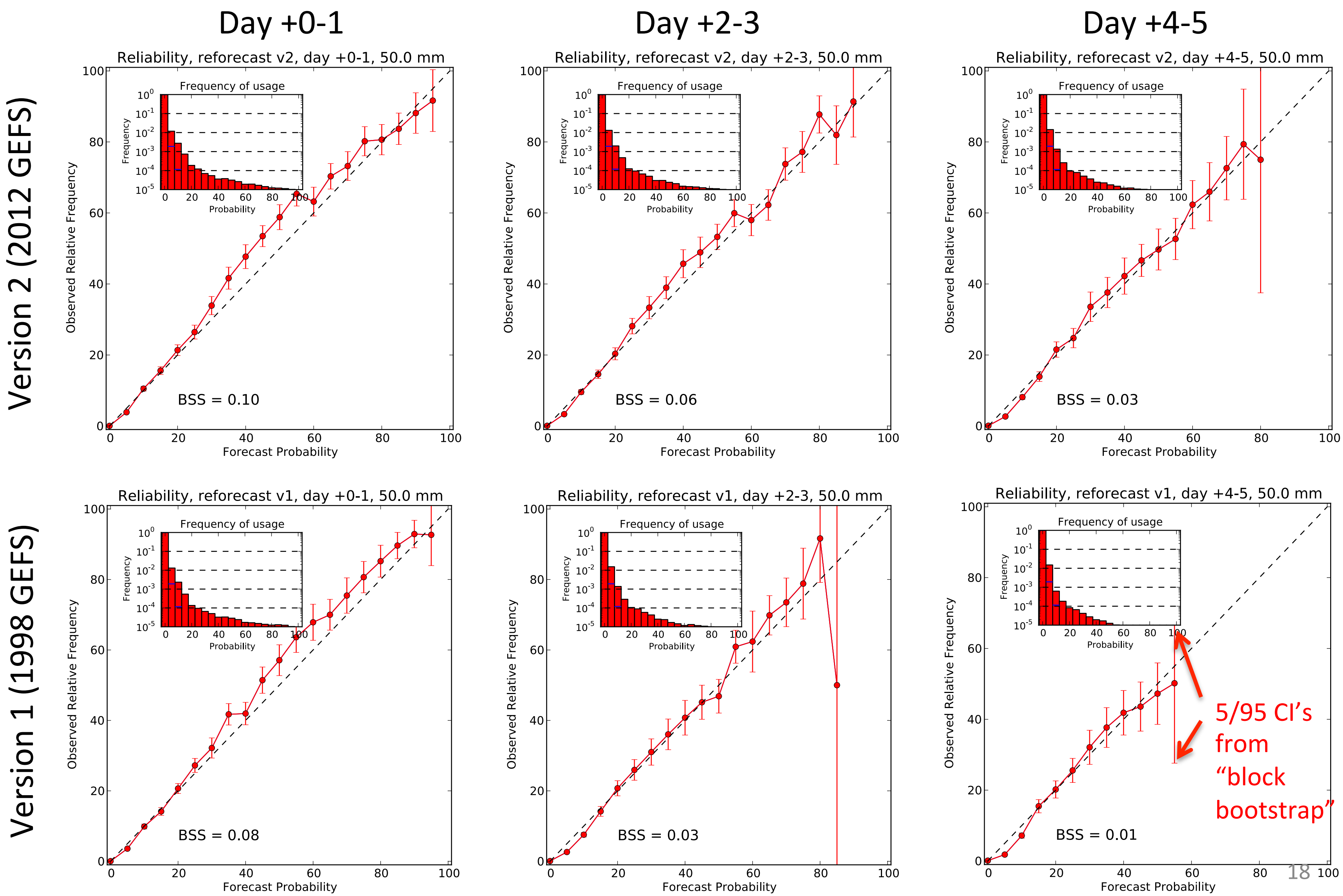


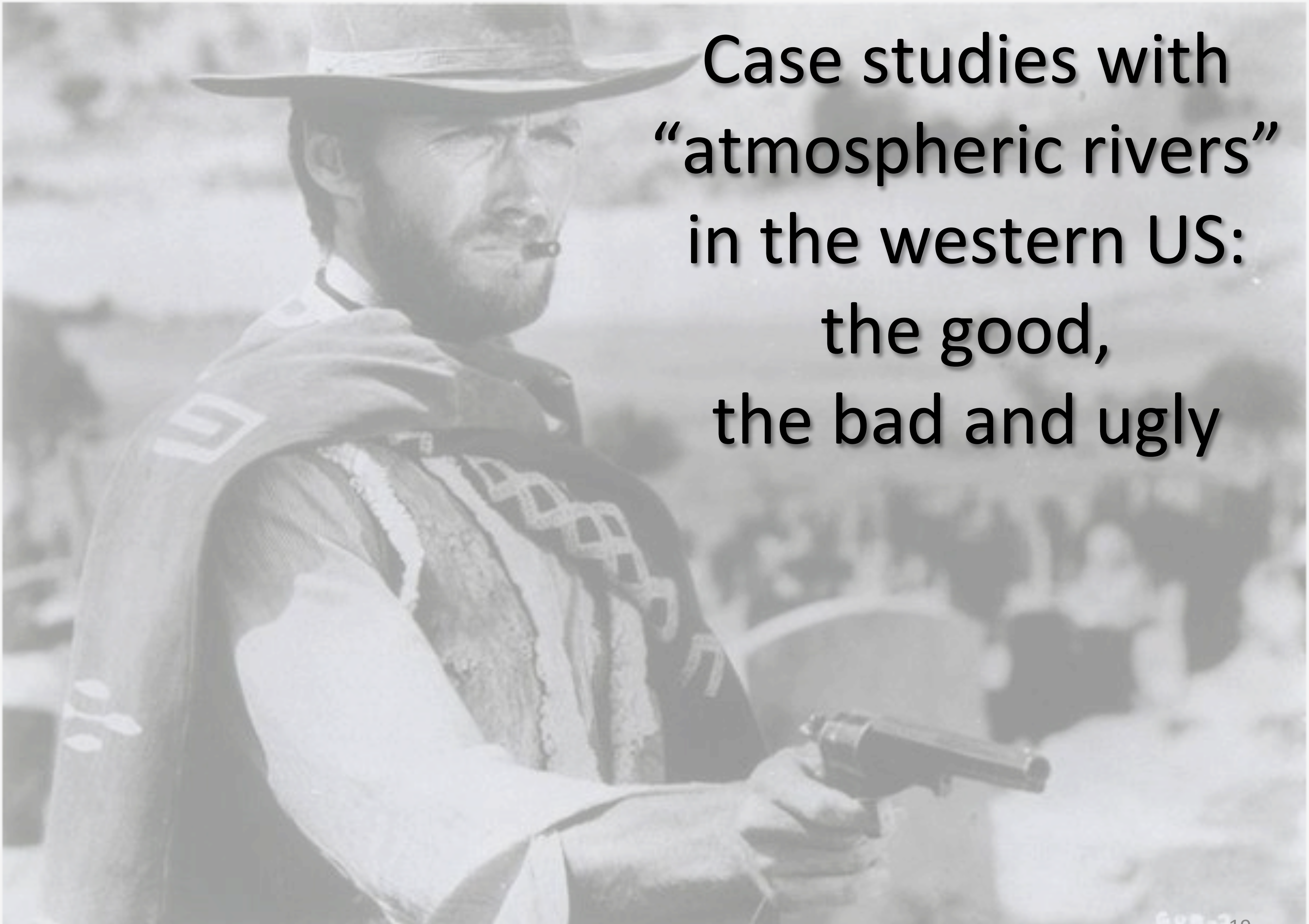
Improvements of 1 to 1.5 days
in post-processed forecasts
from reforecast v1 to v2

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



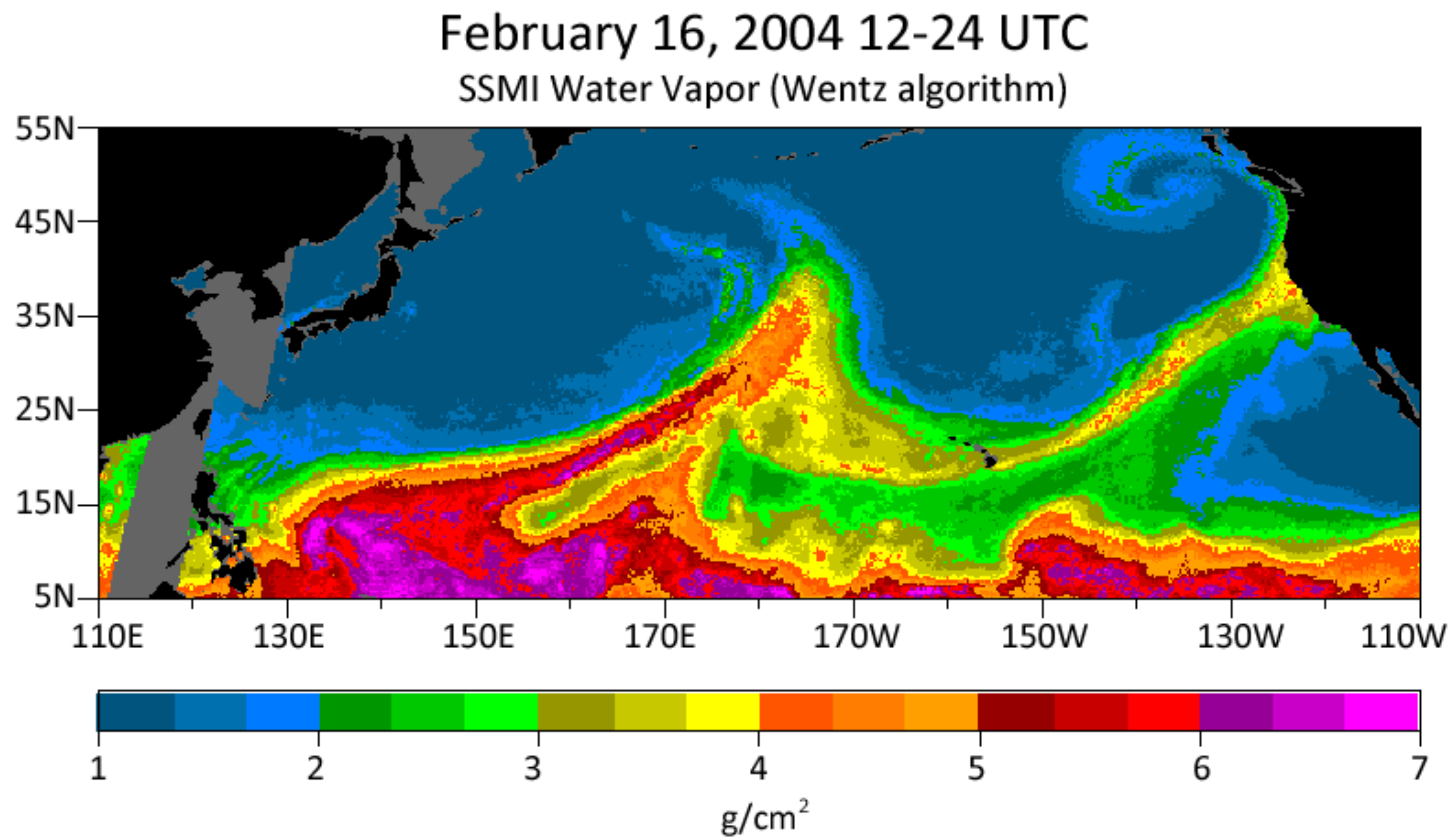
Reliability, > 50 mm precipitation 24 h^{-1}





Case studies with “atmospheric rivers” in the western US: the good, the bad and ugly

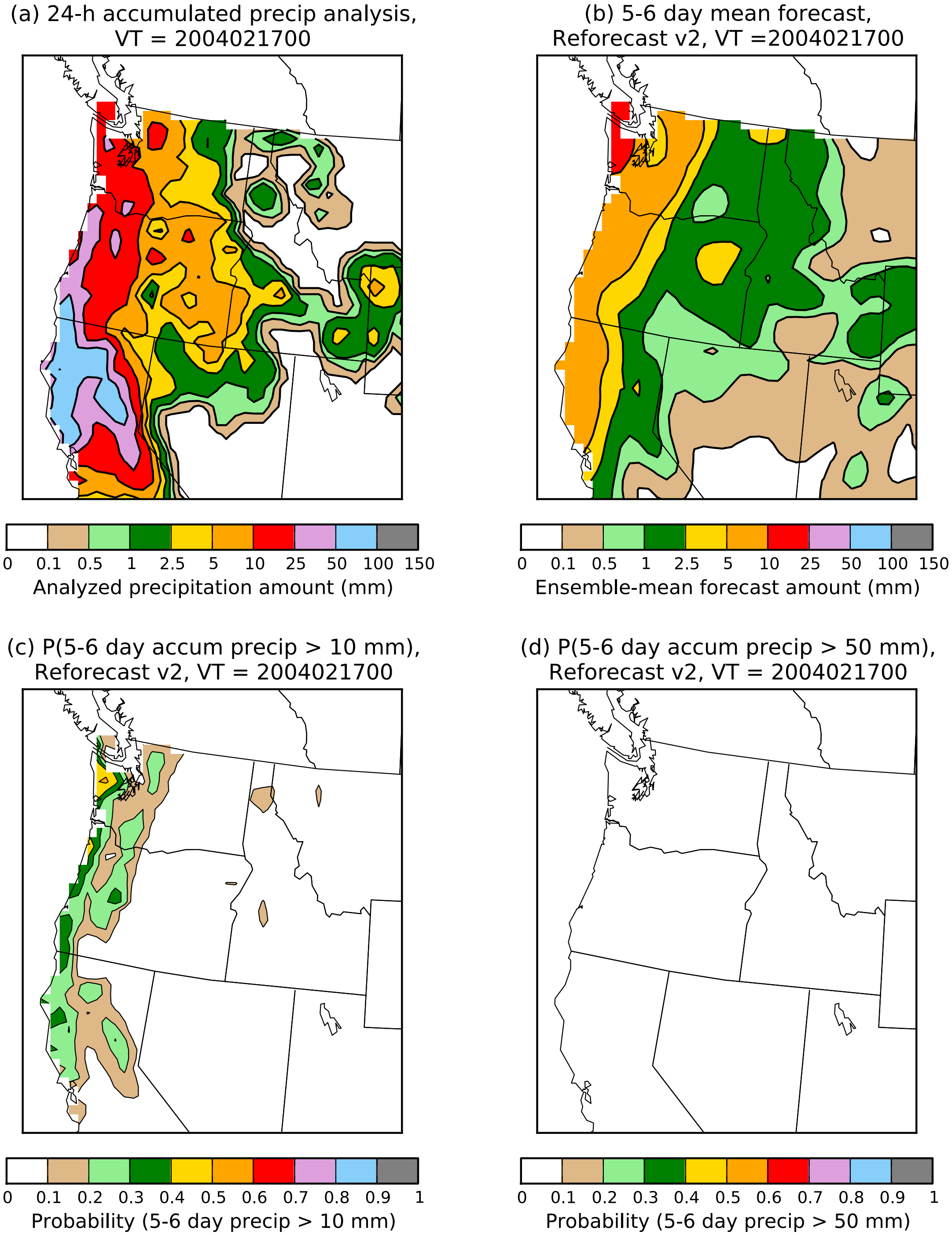
The bad and ugly atmospheric rivers case study

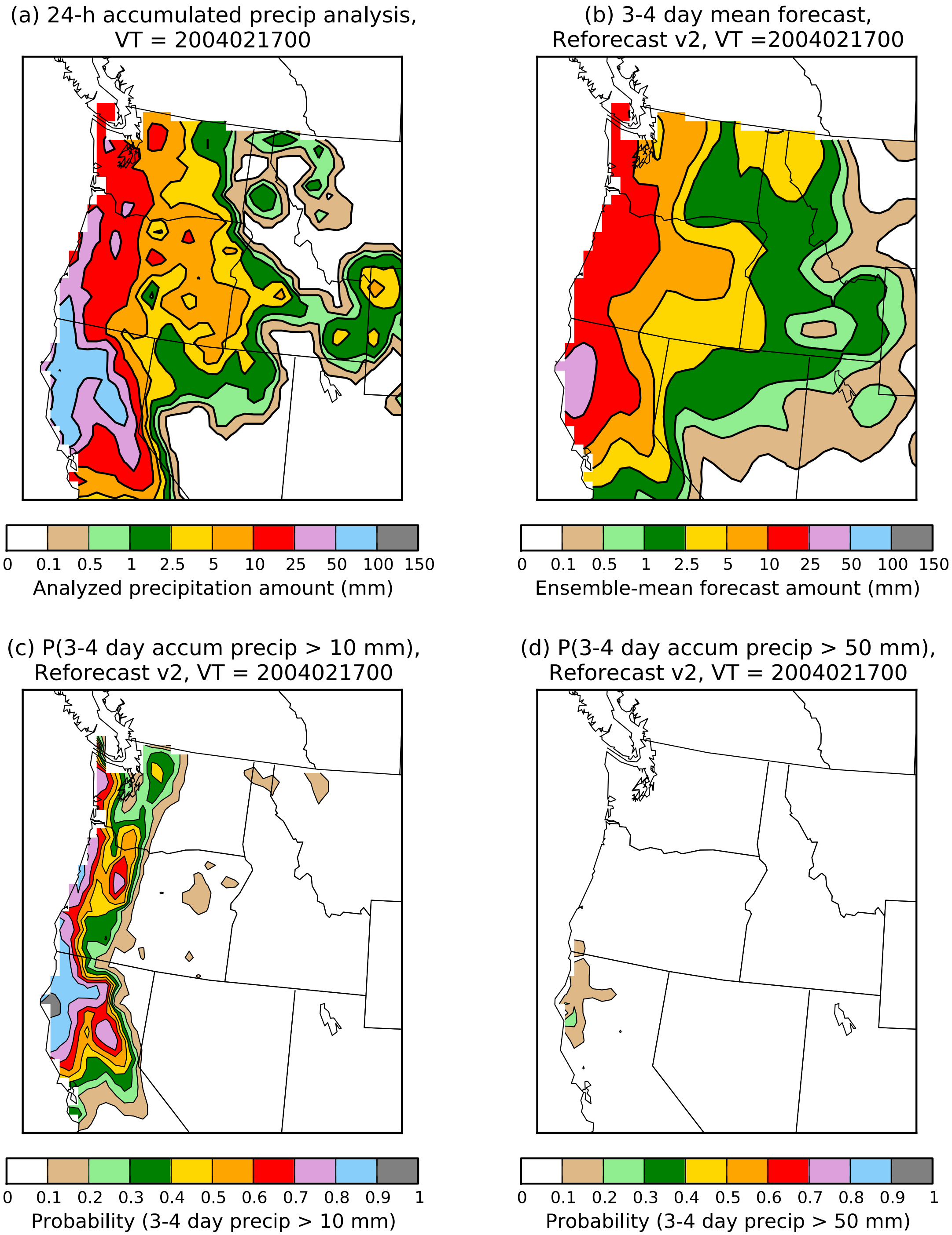


- ➢ 10" rain in the coastal mountains, 4-7" in Russian River watershed. Streamflows in top 0.2% of historical observations.

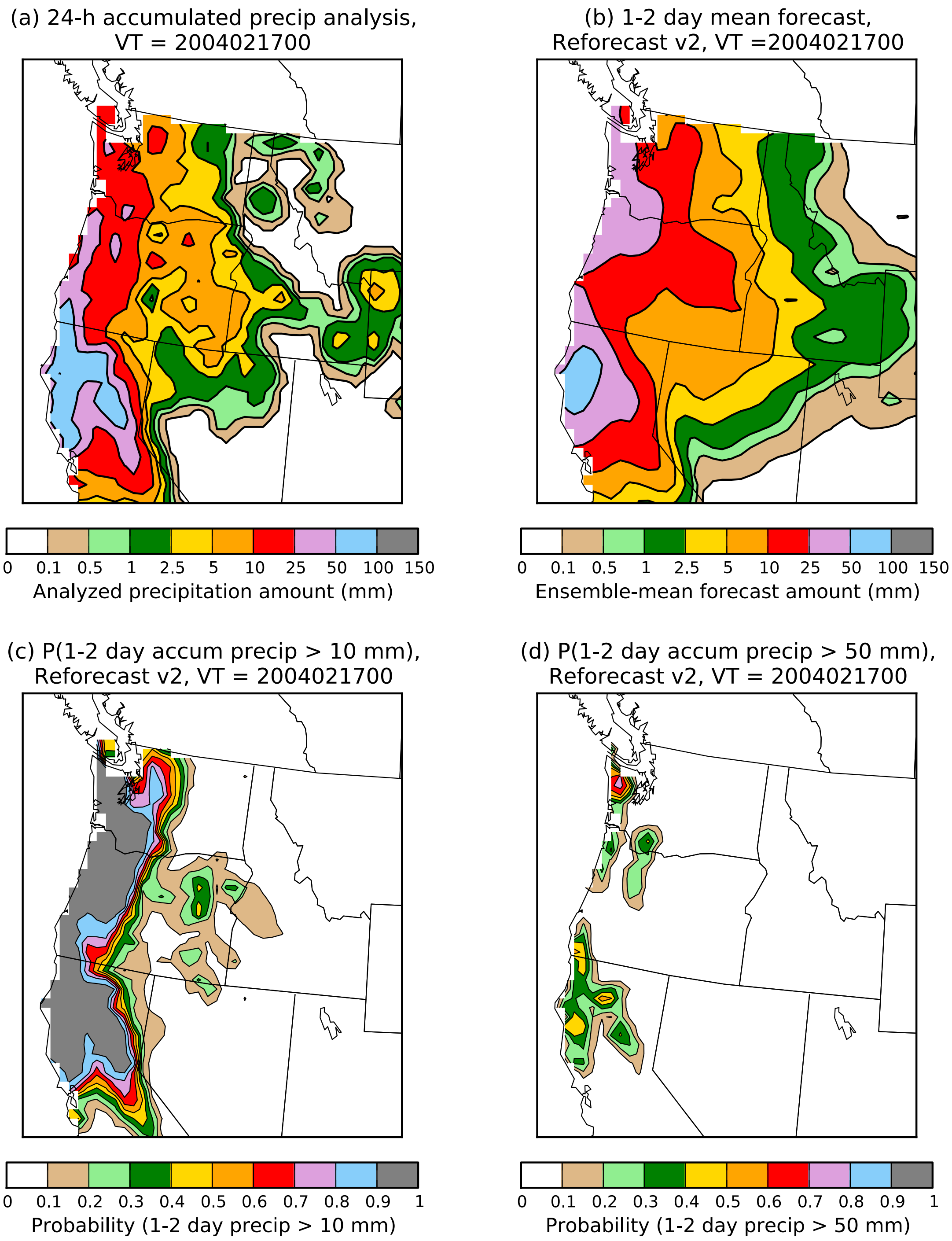
Source: http://www.esrl.noaa.gov/psd/atmrivers/events/

6-day forecast

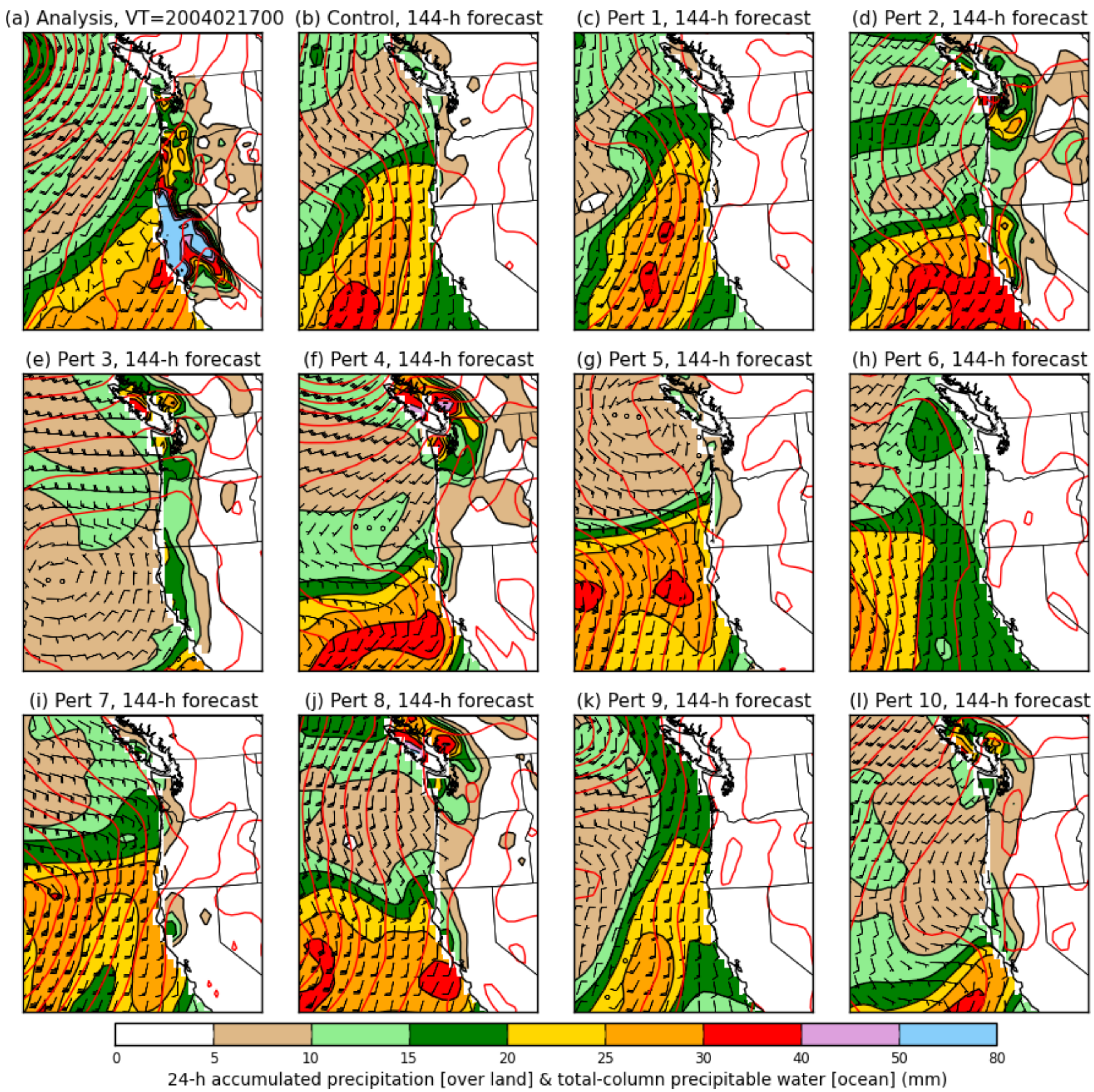




4-day forecast



2-day forecast

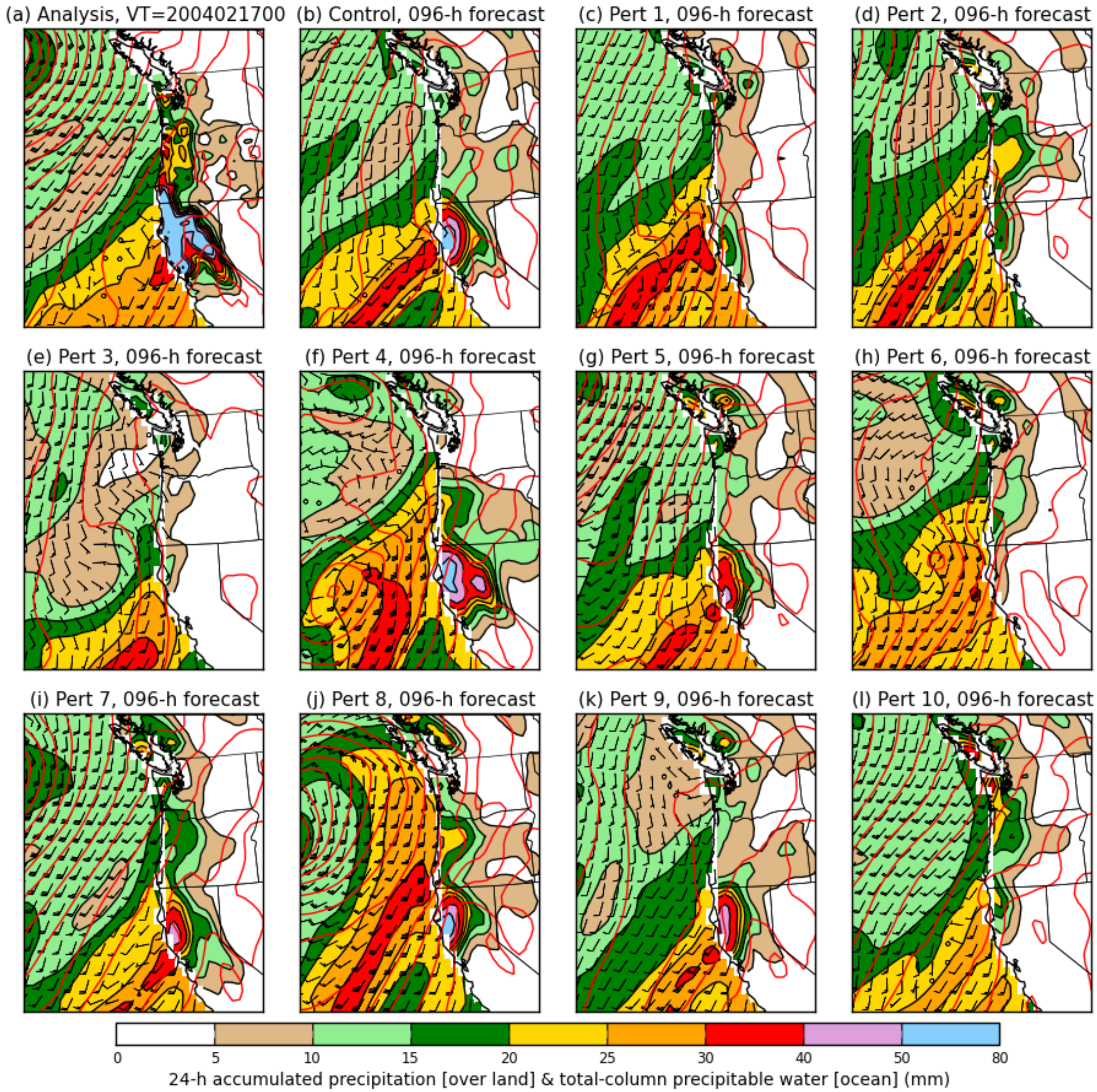


6-day forecast

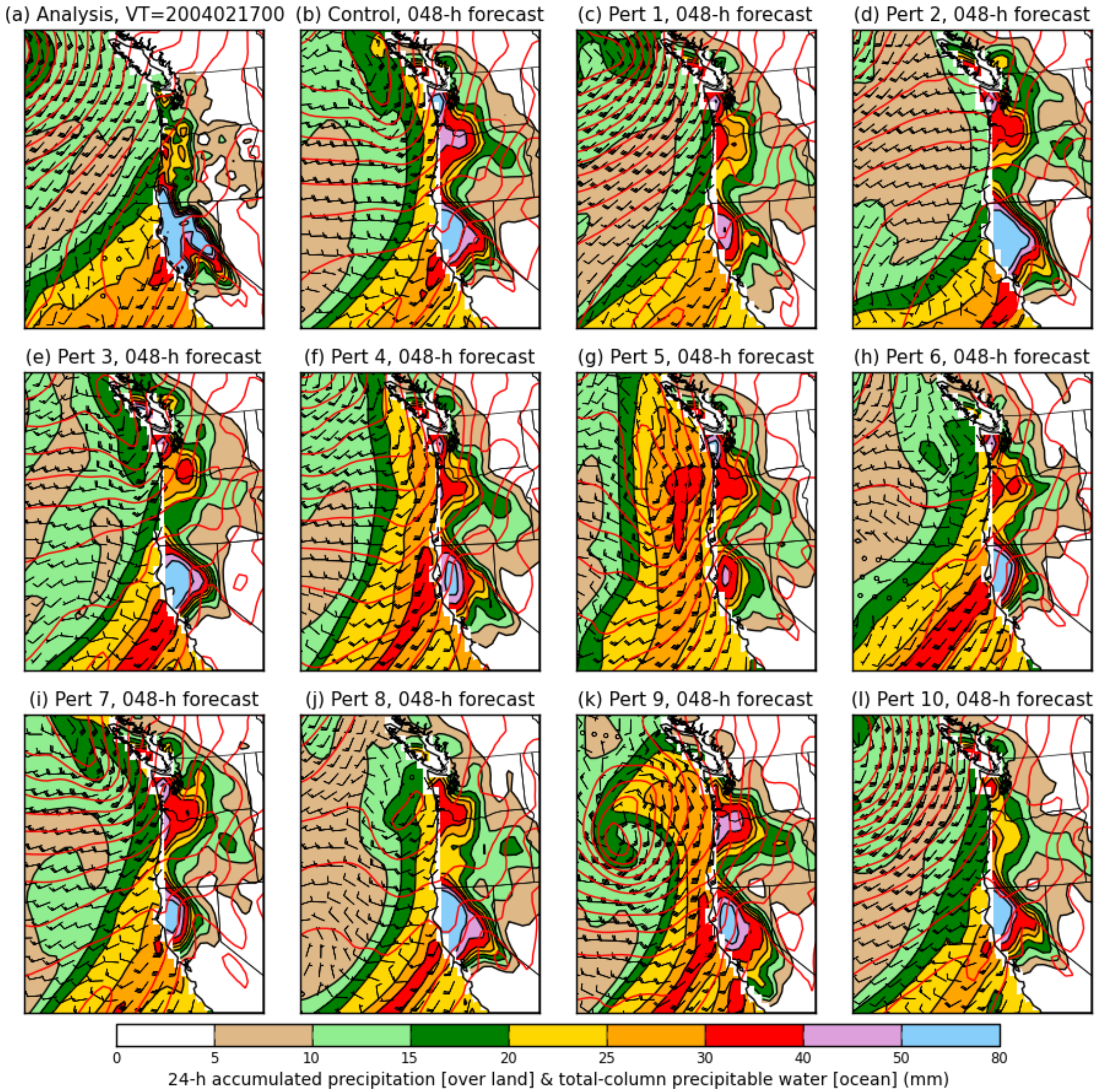
Colors: over the ocean, the total-column precipitable water. Over land, the 24-h accum. precipitation.

Wind barbs for the 925 hPa level.

Red contours: mean sea-level pressure.



4-day forecast

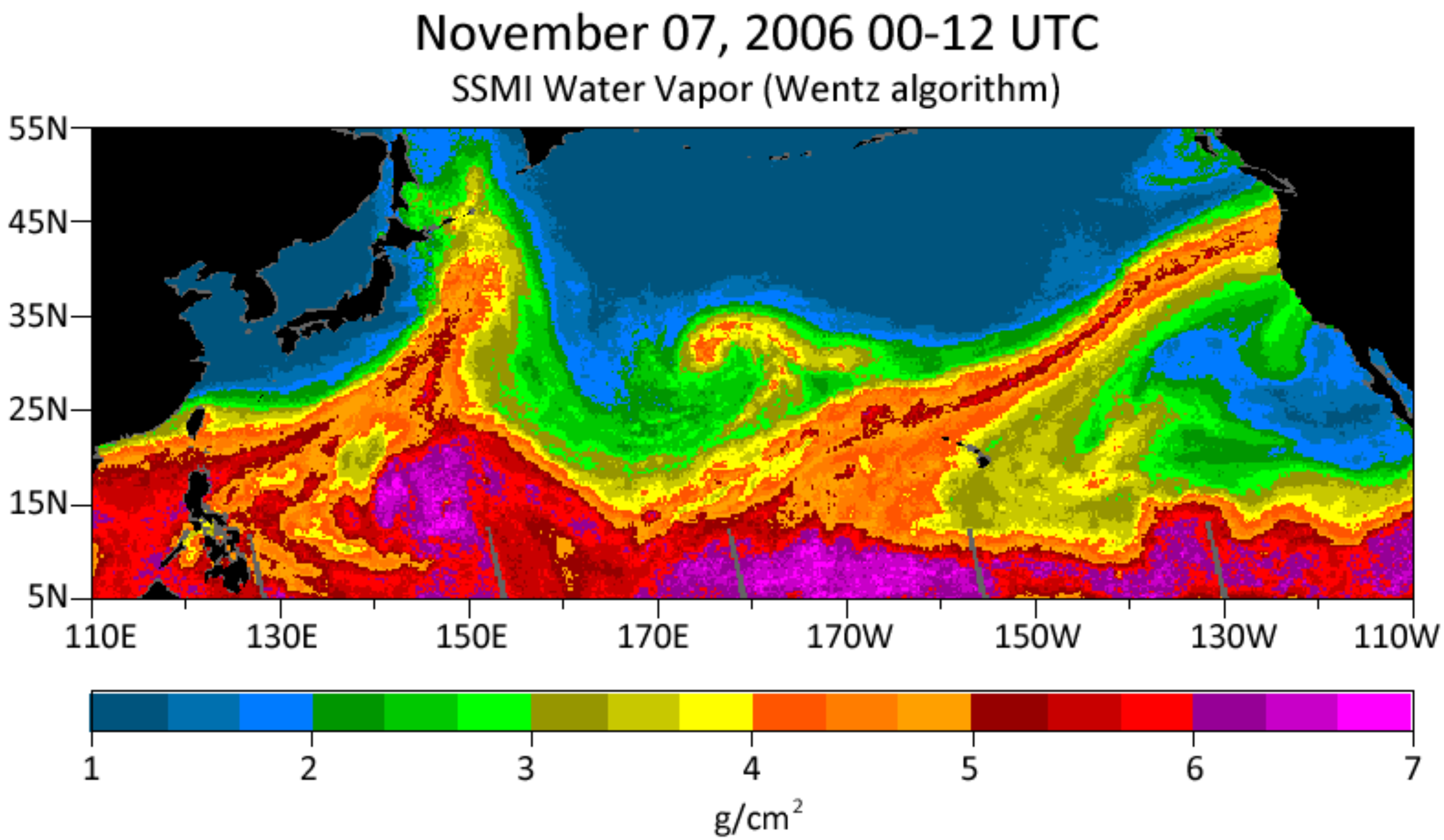


2-day forecast

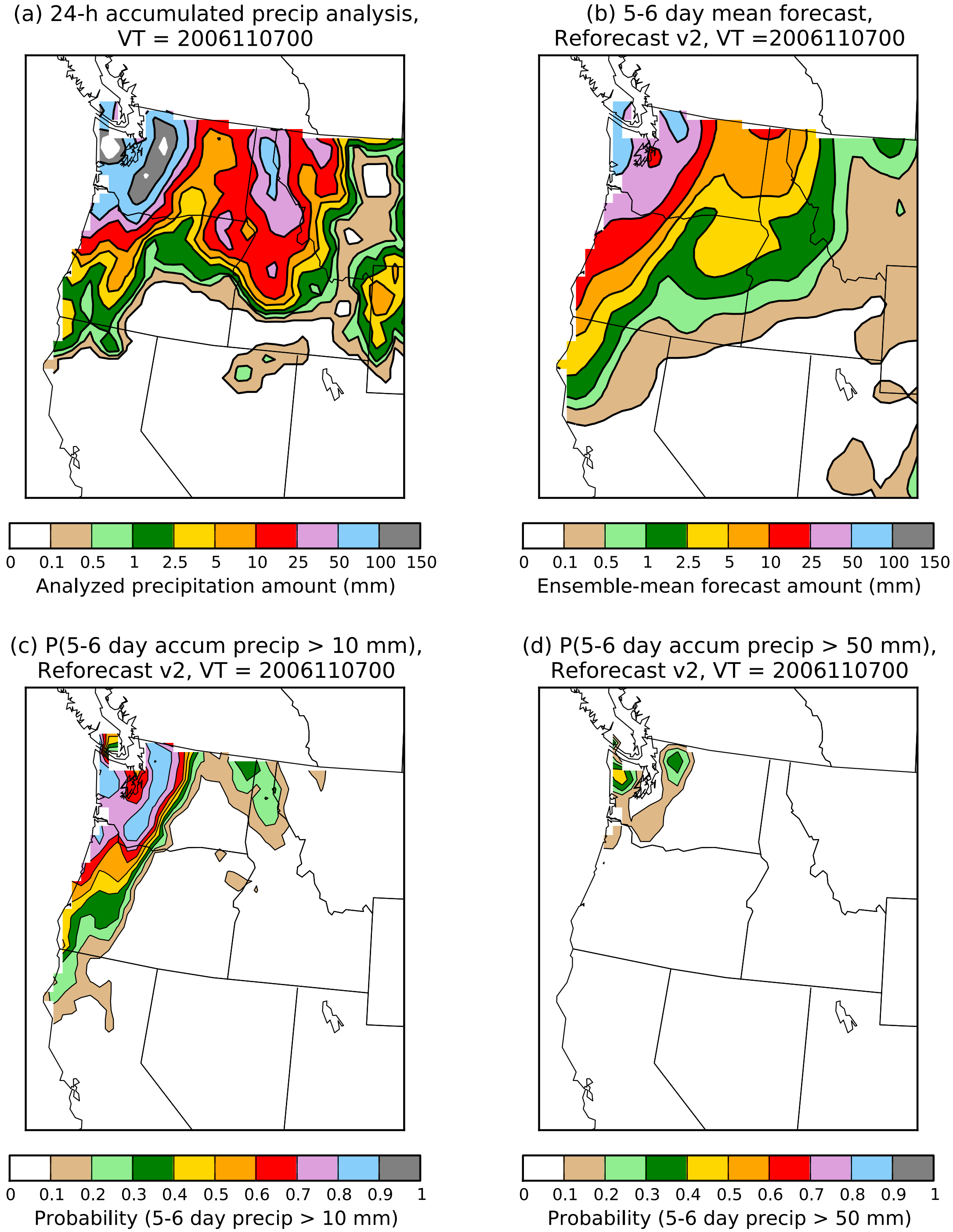
Case study, tentative conclusions

- Statistical post-processing will not be able to correct for everything. In this case, the synoptic-scale predictability was apparently quite low.
- Improvements to post-processed probabilistic forecasts in such a case will require improved ensemble guidance.

The "good" atmospheric rivers case study: Nov 2006 Oregon-Washington floods

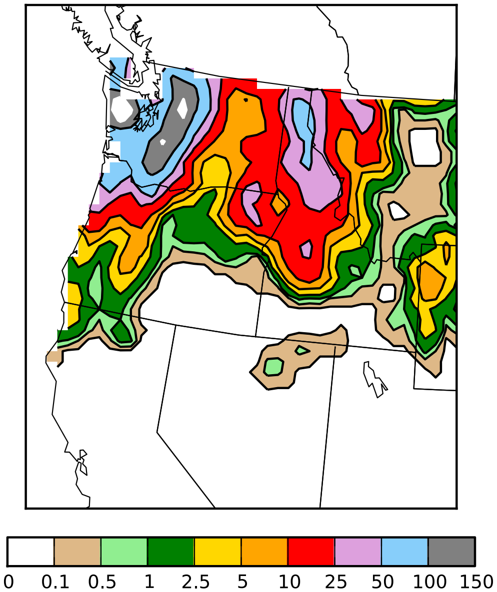


8-20 inches of rain in Cascades; flooded rivers; extensive damage to Mt. Rainier NP.



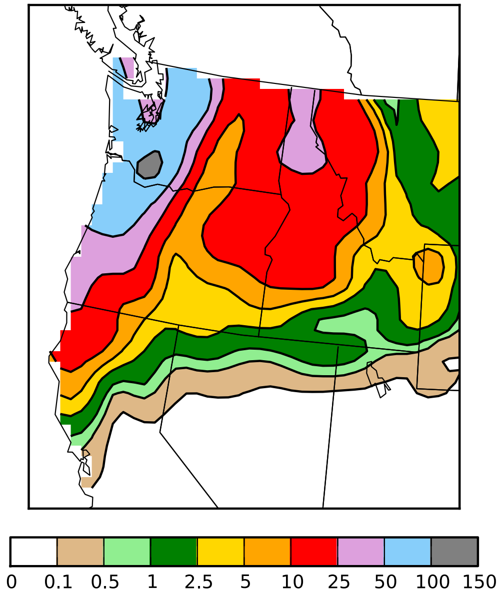
6-day forecast

(a) 24-h accumulated precip analysis,
VT = 2006110700



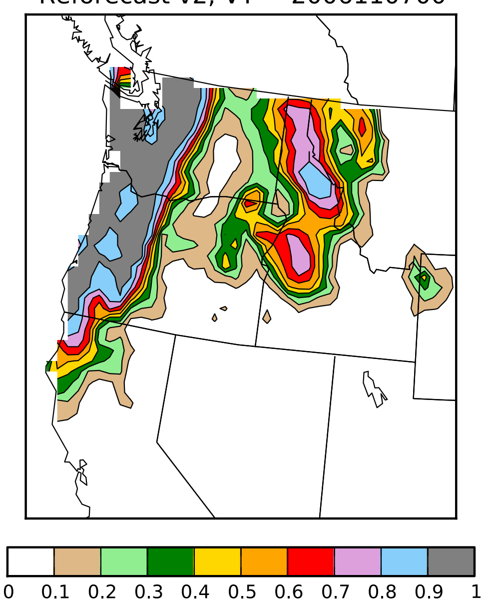
Analyzed precipitation amount (mm)

(b) 3-4 day mean forecast,
Reforecast v2, VT =2006110700



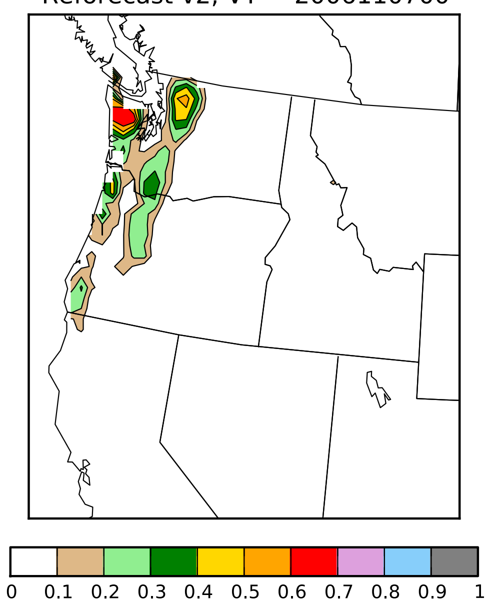
Ensemble-mean forecast amount (mm)

(c) P(3-4 day accum precip > 10 mm),
Reforecast v2, VT = 2006110700



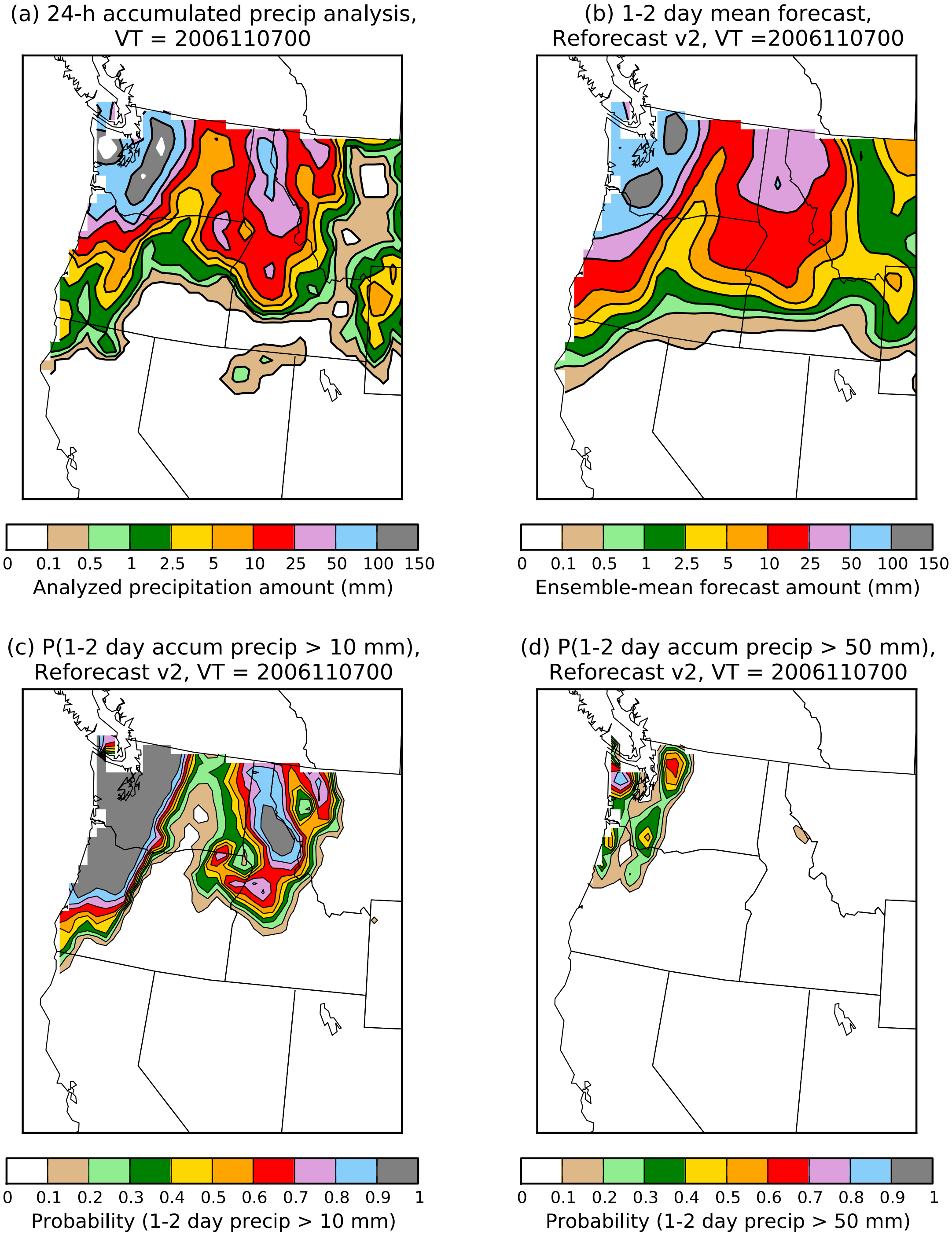
Probability (3-4 day precip > 10 mm)

(d) P(3-4 day accum precip > 50 mm),
Reforecast v2, VT = 2006110700

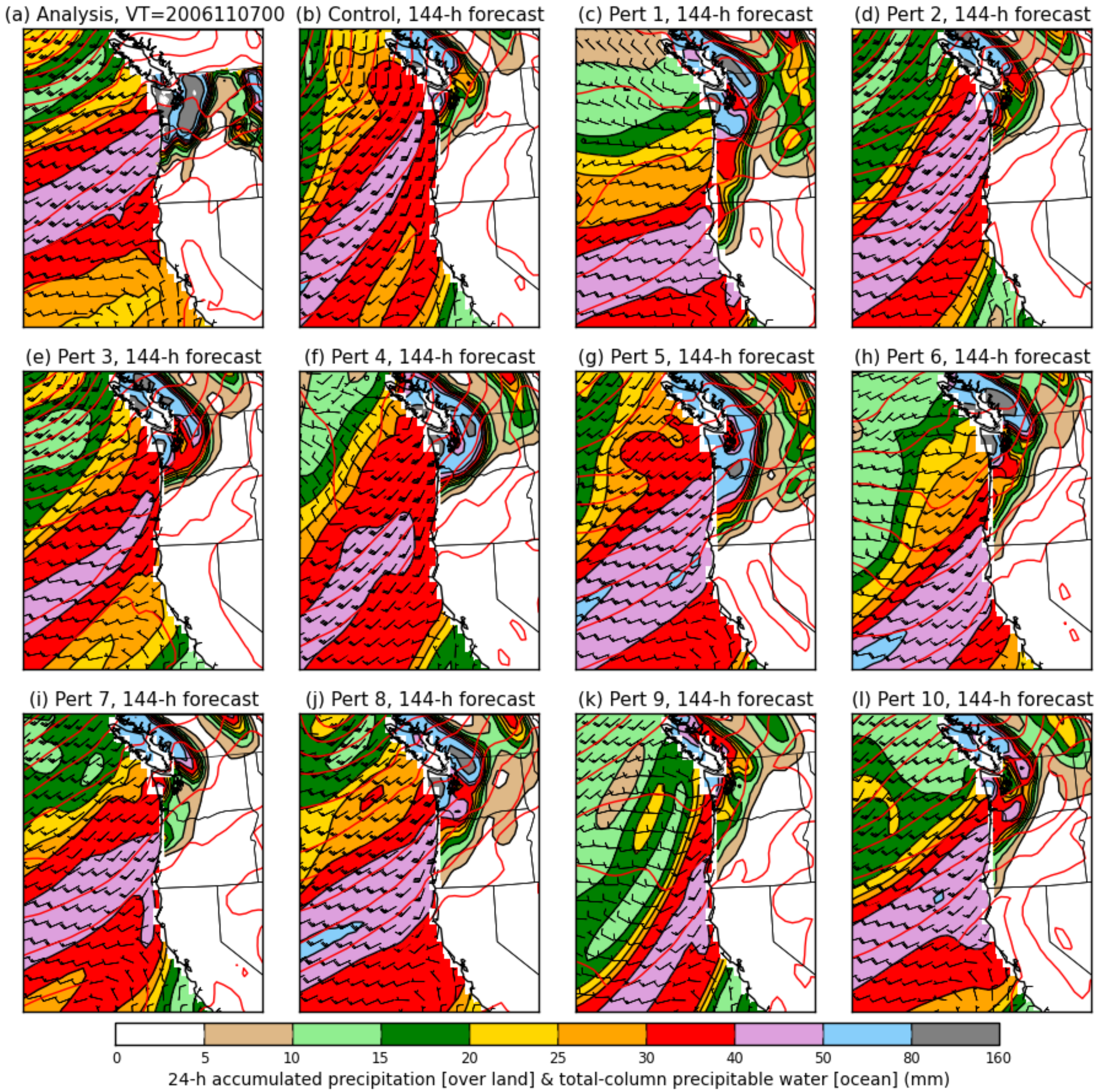


Probability (3-4 day precip > 50 mm)

4-day forecast



2-day forecast

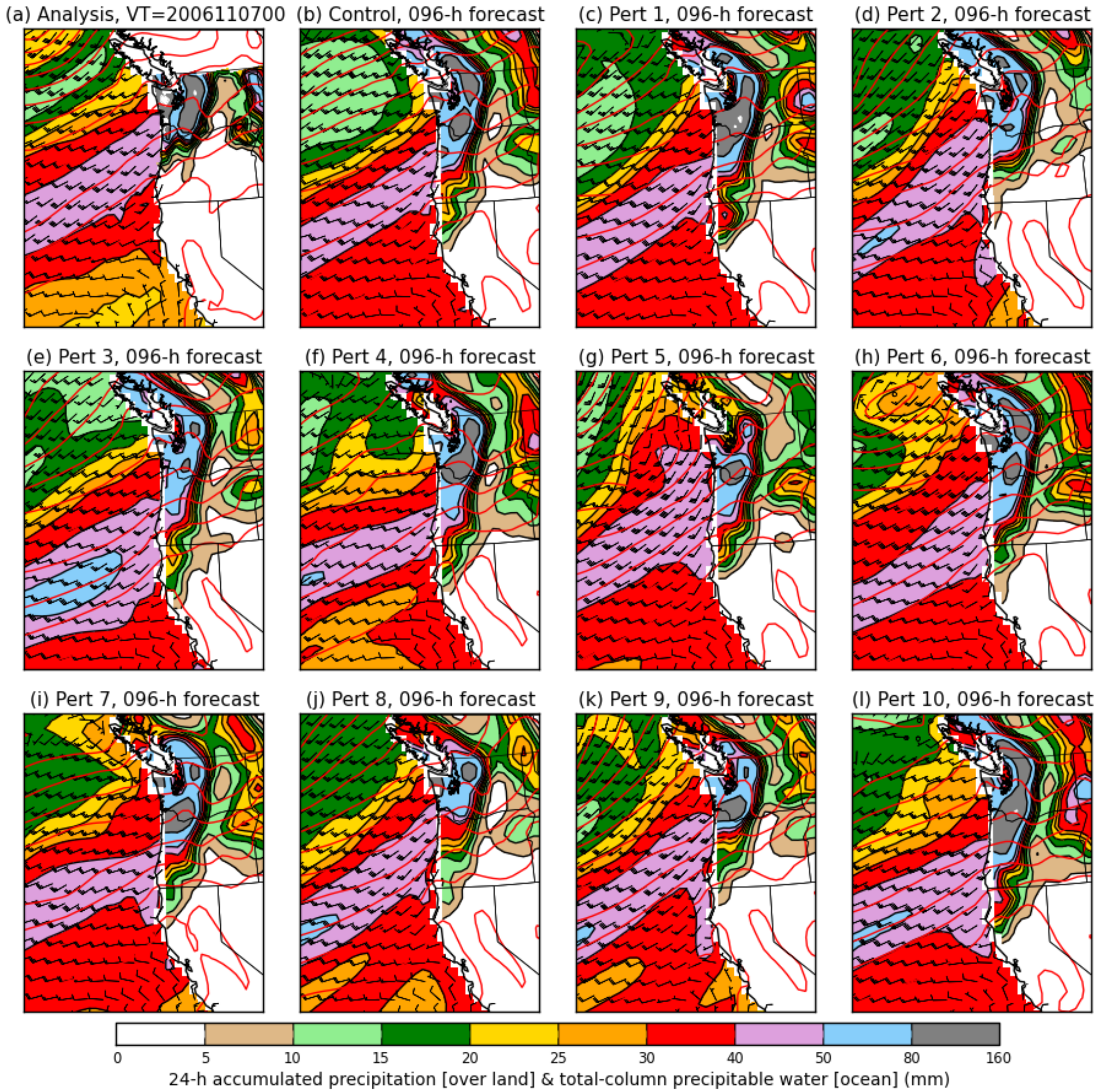


6-day forecast

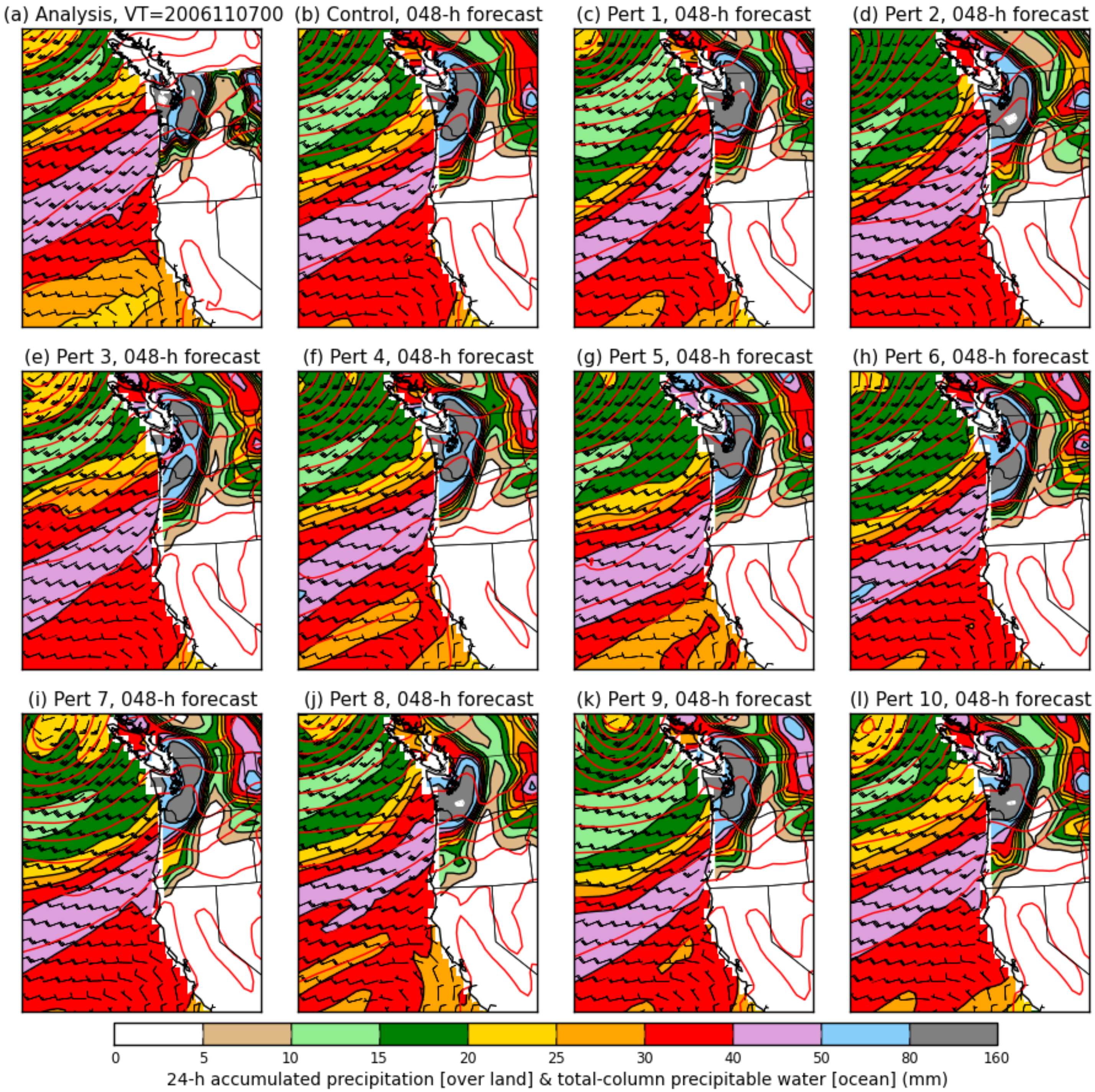
Colors: over the ocean, the total-column precipitable water. Over land, the 24-h accum. precipitation.

Wind barbs for the 925 hPa level.

Red contours: mean sea-level pressure.



4-day forecast

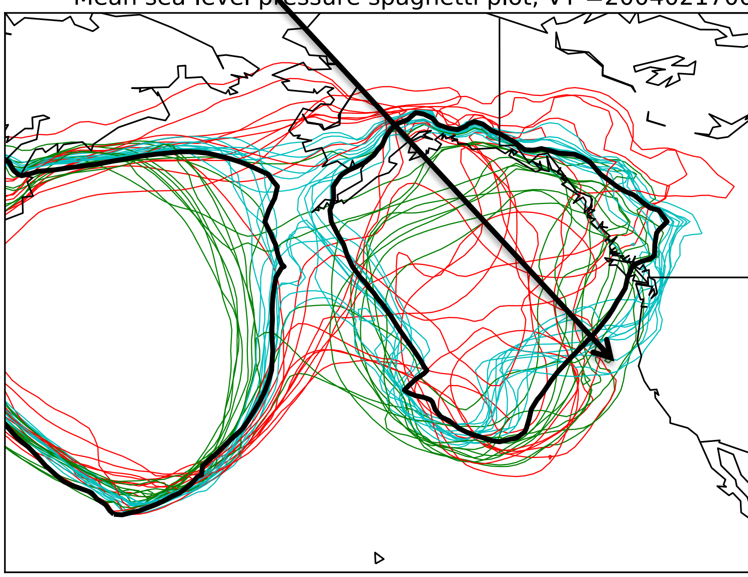


2-day forecast

Spaghetti Westerns

Inconsistent forecasts of orientation of isobars and hence wind direction

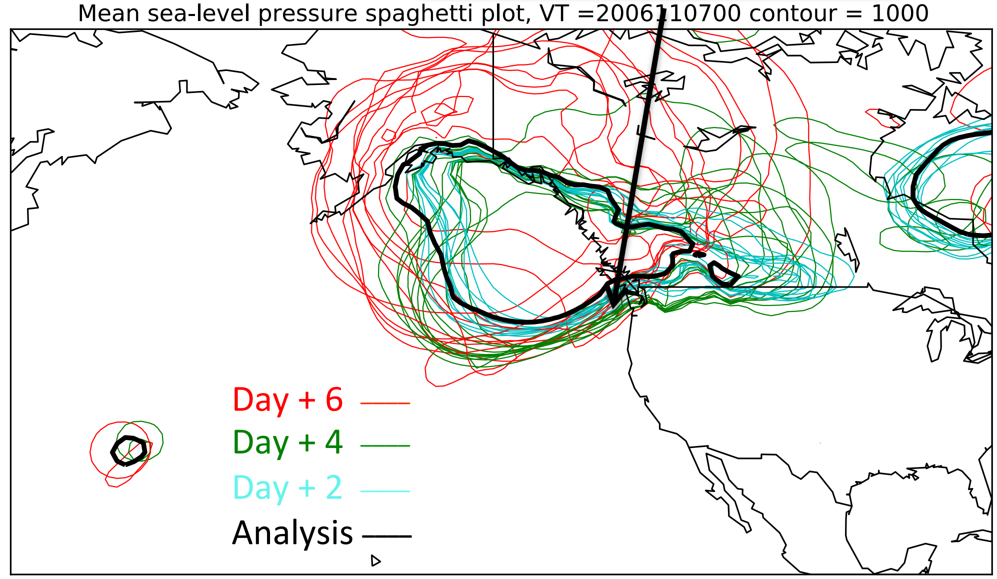
Mean sea-level pressure spaghetti plot, VT =2004021700 contour = 1004



The bad and the ugly

Consistent forecasts of orientation of isobars and hence wind direction

Mean sea-level pressure spaghetti plot, VT =2006110700 contour = 1000



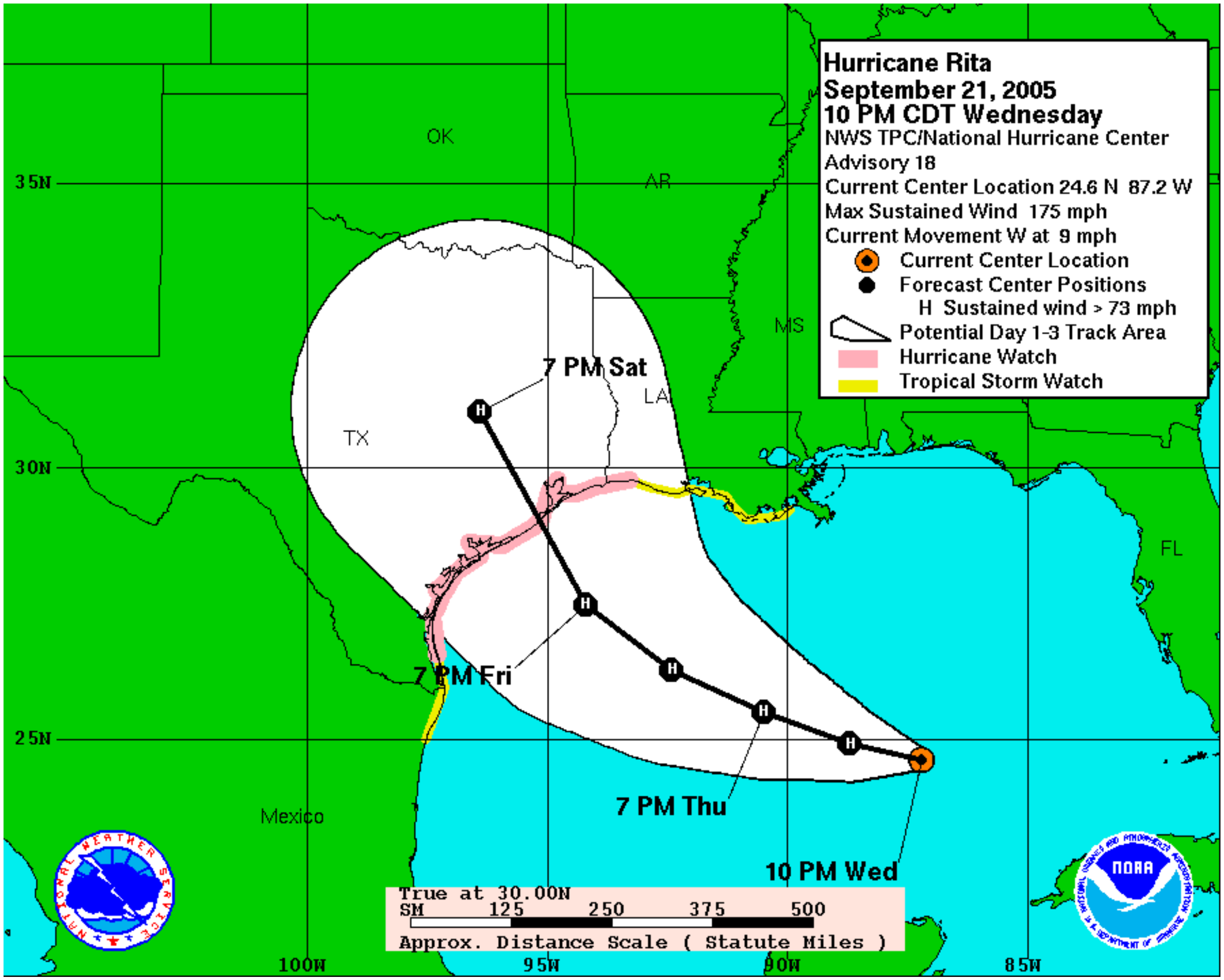
The good

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 & HFIP grant (pending)

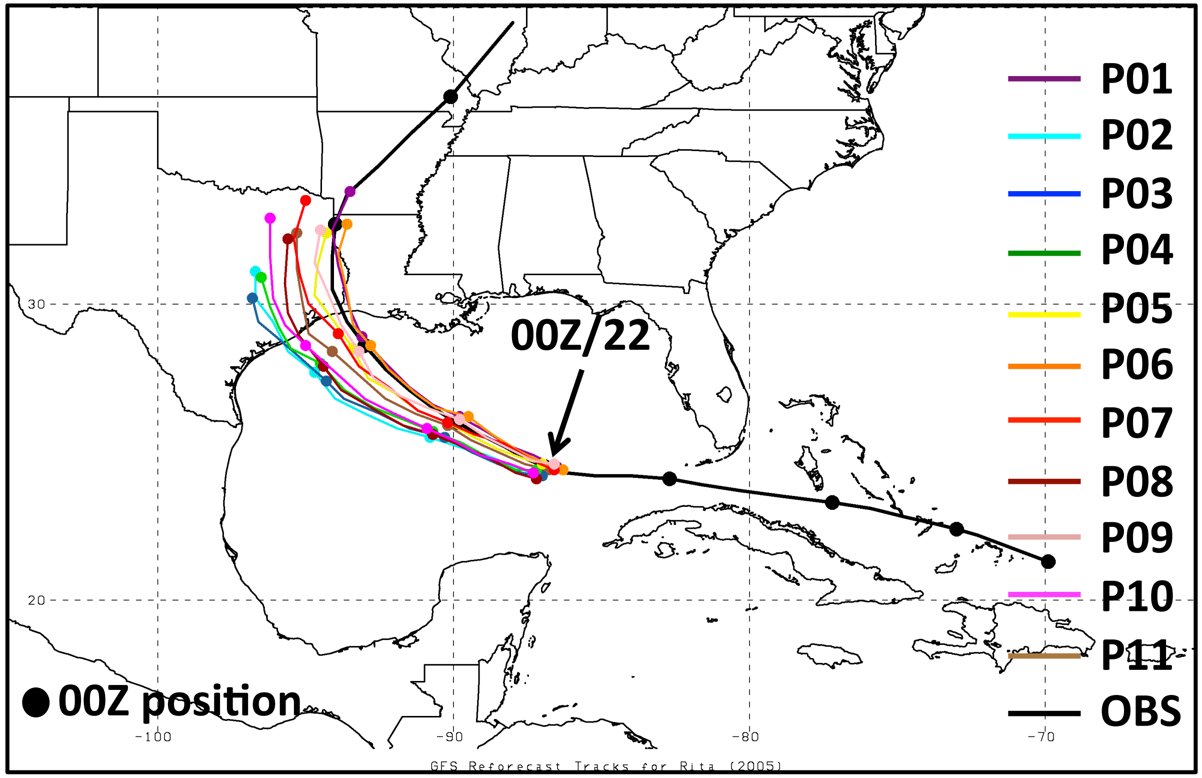
2005 Rita official forecast (Houston, TX evacuated)

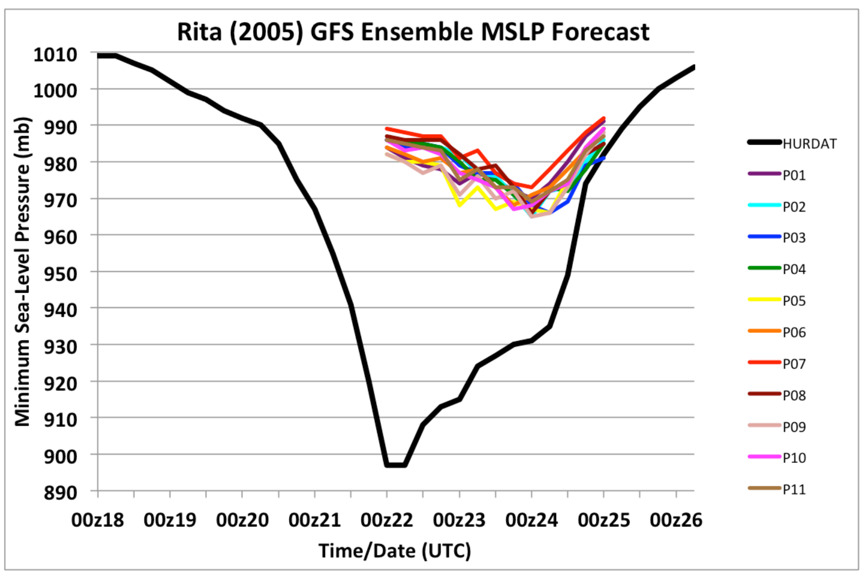


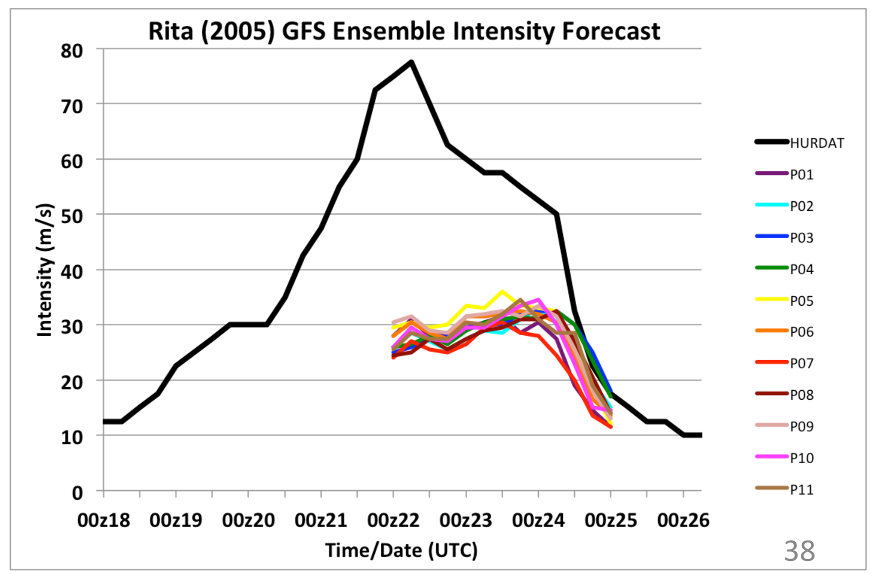
TC Rita (2005)

GFS reforecast ensemble

72-h forecast initialized at 00Z 22 Sept



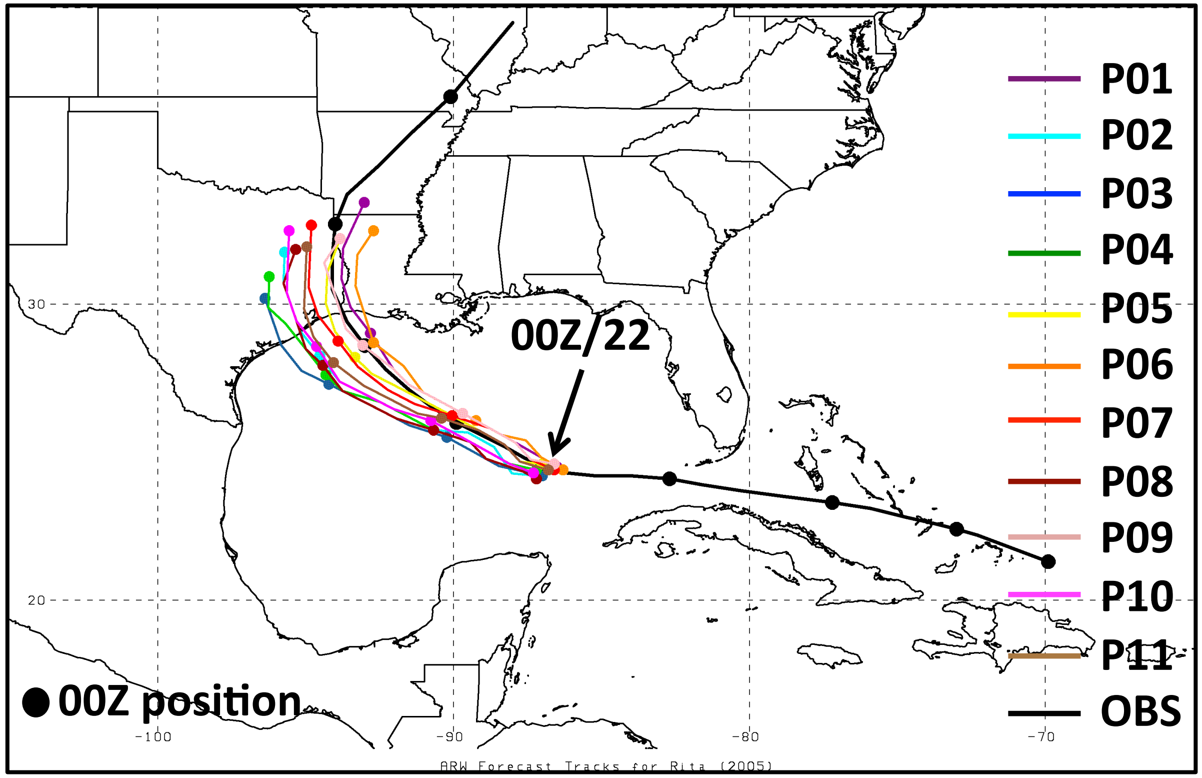


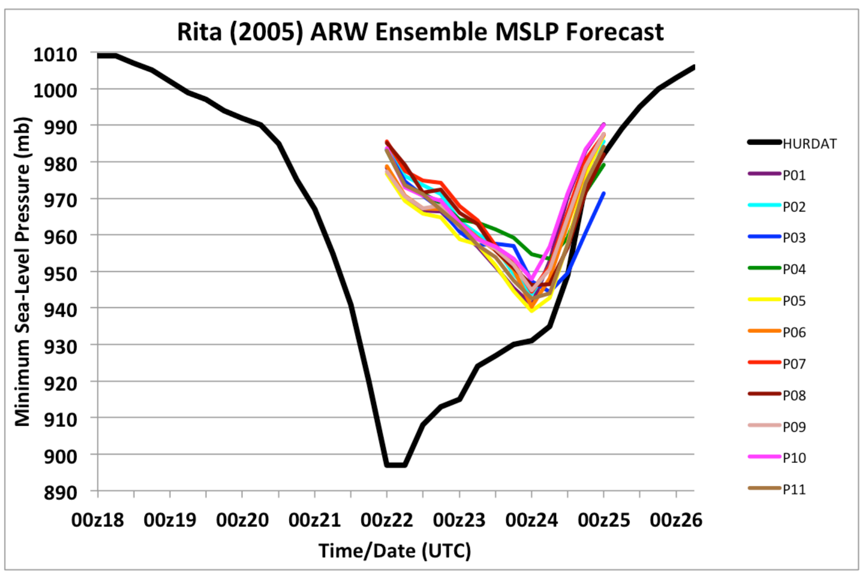


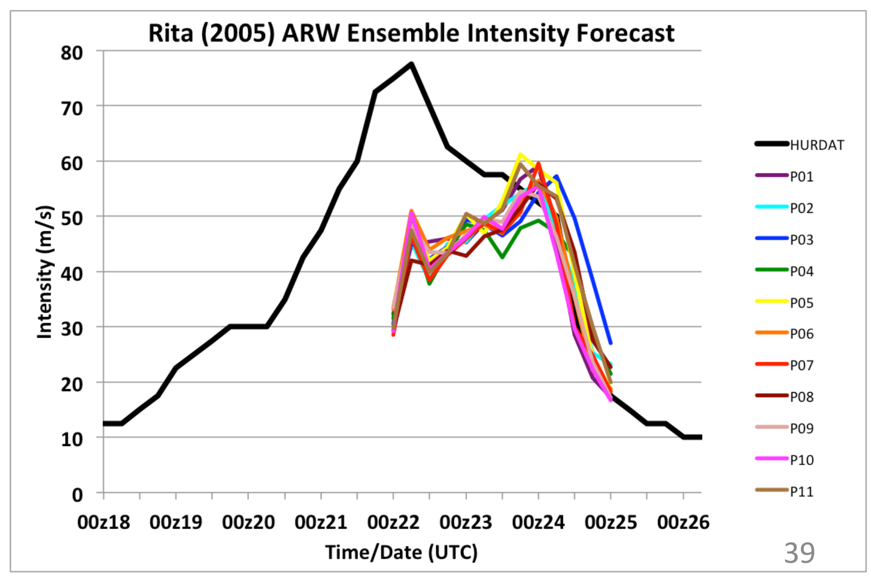
TC Rita (2005)

ARW ensemble with GFS reforecast ensemble as boundary and initial conditions

72-h forecast initialized at 00Z 22 Sept

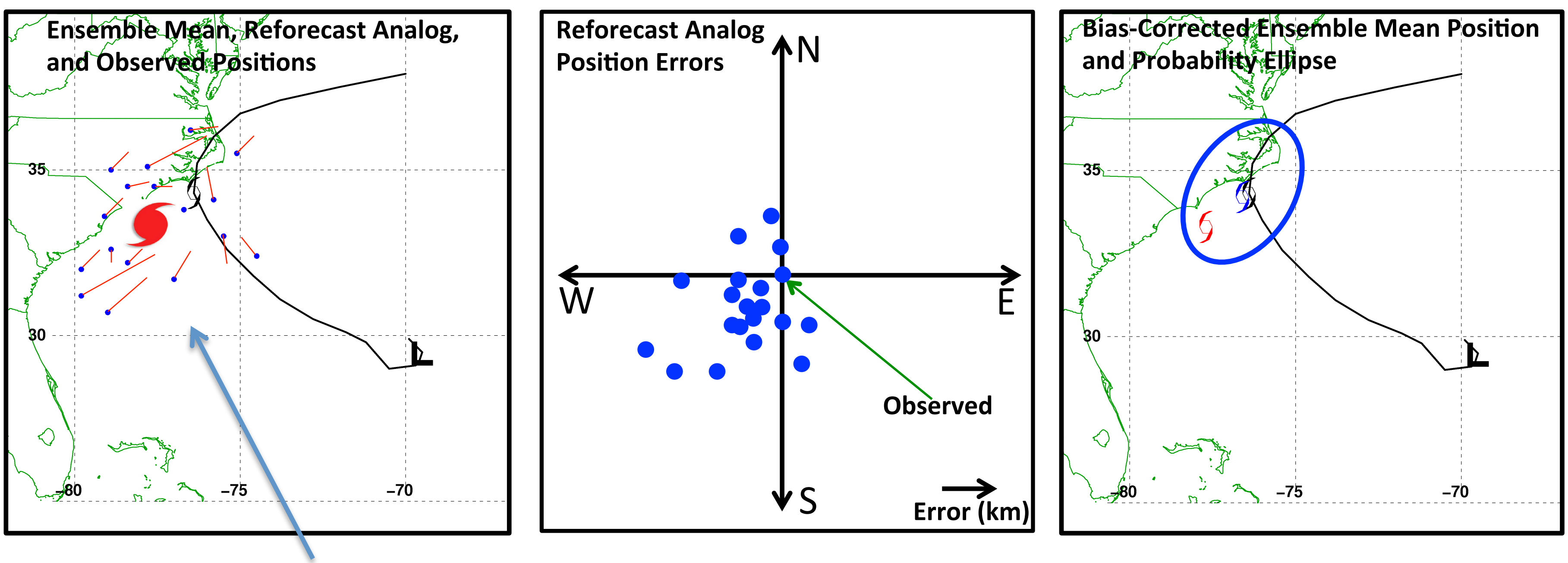






A synthetic example of using reforecasts to make track error bias corrections

72-h Forecast Verifying 1200 UTC 9 September

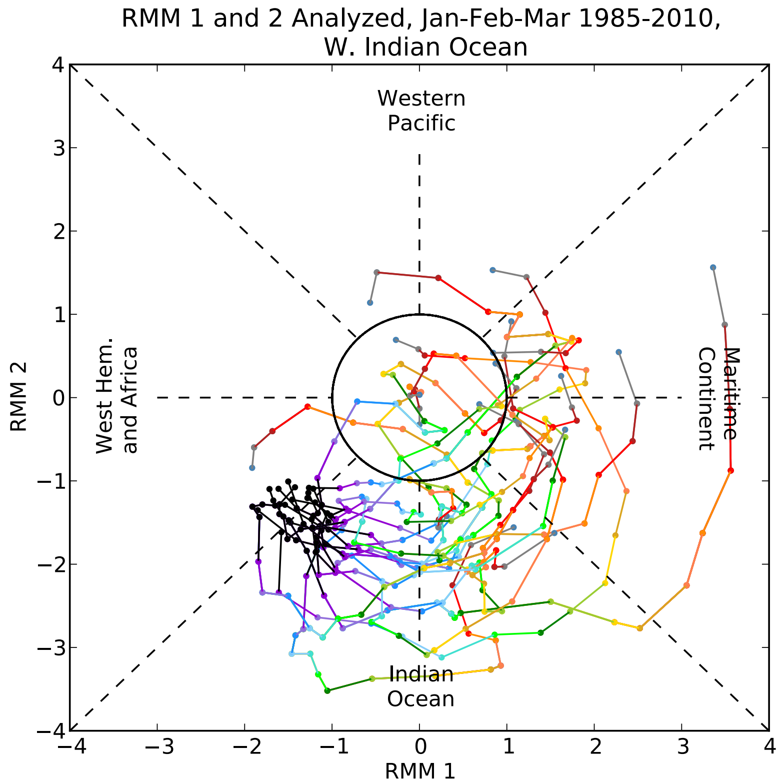


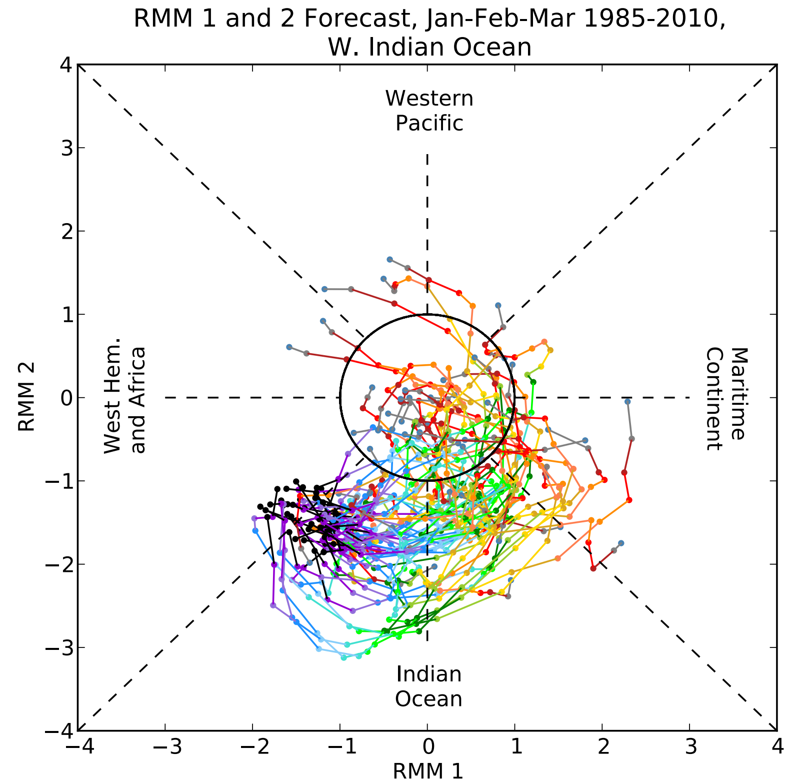
Red : mean forecast position

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

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

Application: diagnosis of MJO





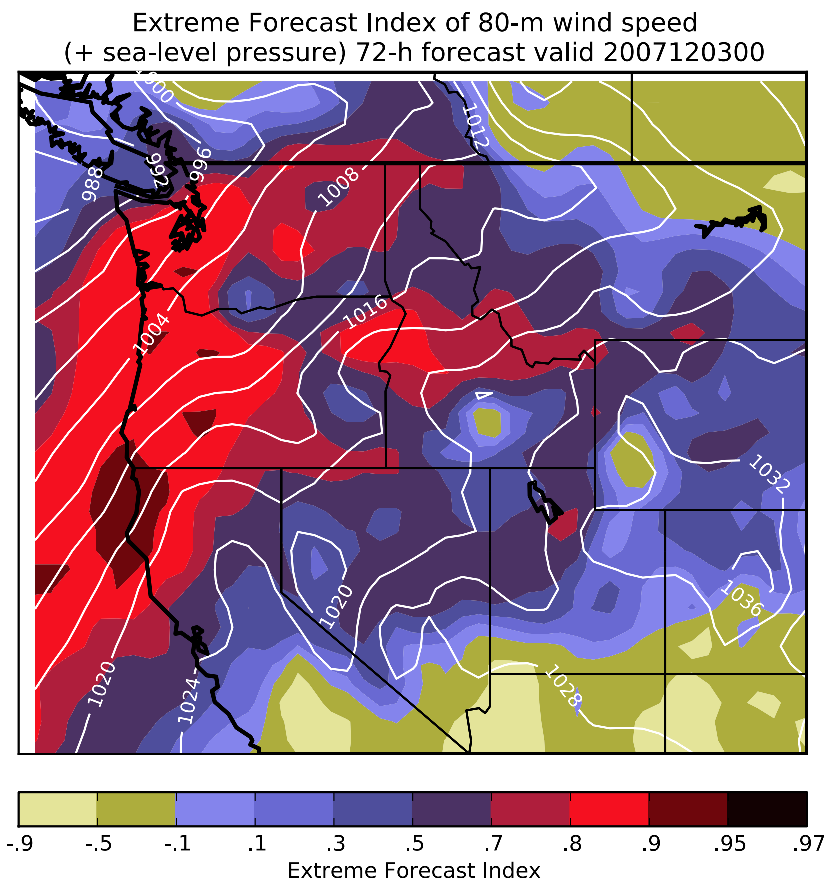
Let's examine subset of cases that start off with initial conditions that project onto relatively strong MJO emerging from African continent.

We have lots of cases of this afforded by multi-decadal reforecasts.

It appears that GEFS is too regular with its RMM1/RMM2 forecasts, while the analyzed evolution is more scattered with its trajectories.

Other work in progress

- Blocking diagnostics (w. Steve Colucci, Cornell U.)
- Development of forecast tools to support extended-range renewable-energy forecasts

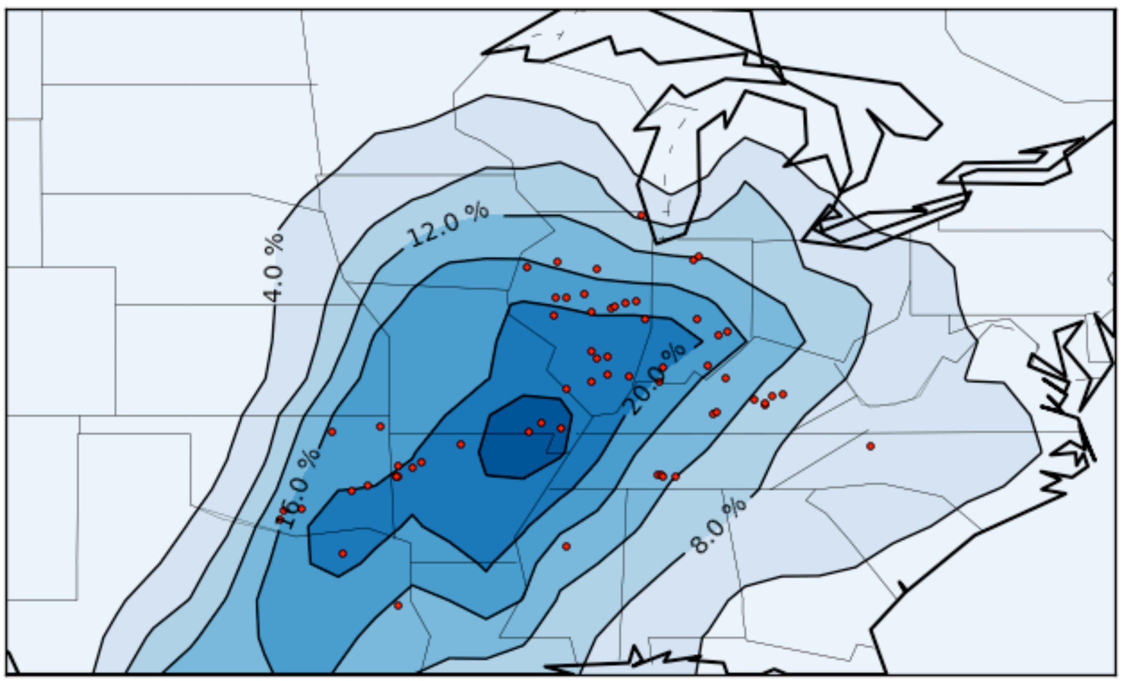


Example of ECMWF's Extreme Forecast Index, where the current ensemble guidance is compared to the model forecast climatology. Values near 1.0 indicate that ensemble forecasts are consistently higher than forecasts populating the climatology.

This can be useful especially in situations where there isn't observational data available for calibration.

Application: extended-range tornado forecasting

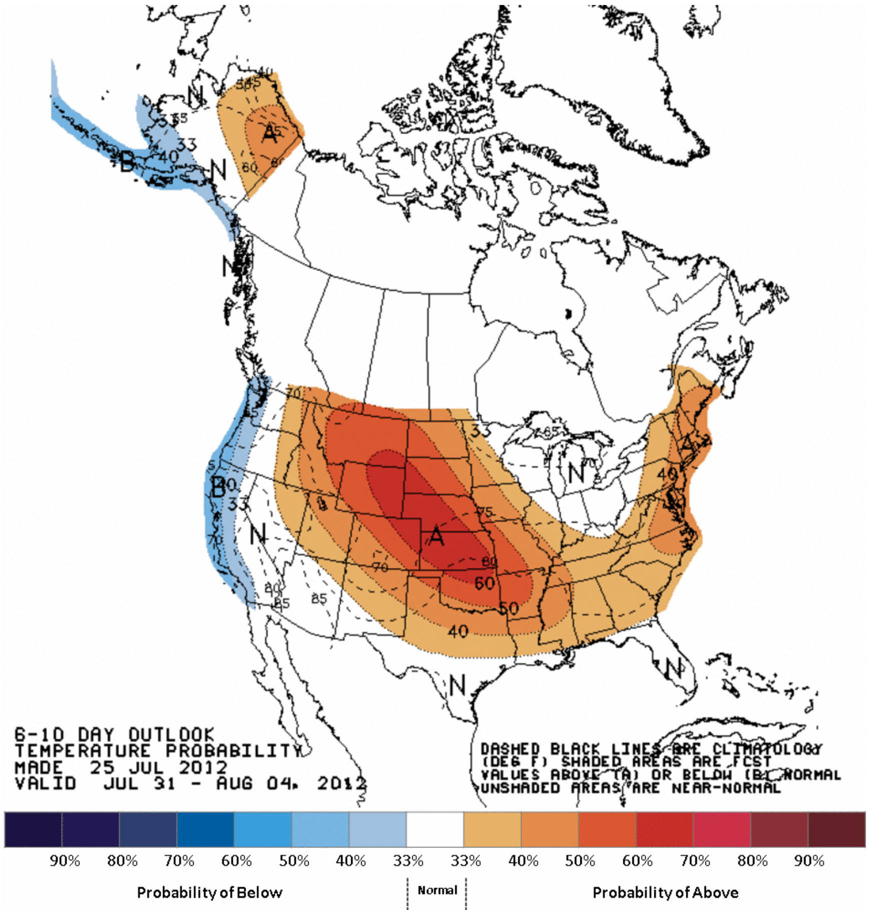
4/11/1996 Forecast, 204-hour through 276-hour leadtime
Using 3 PCs of 0-6 km Shear, log(CAPE) & Conv.Precip. as Predictors for Logistic Regression
Probability of tornado (>EF0) event

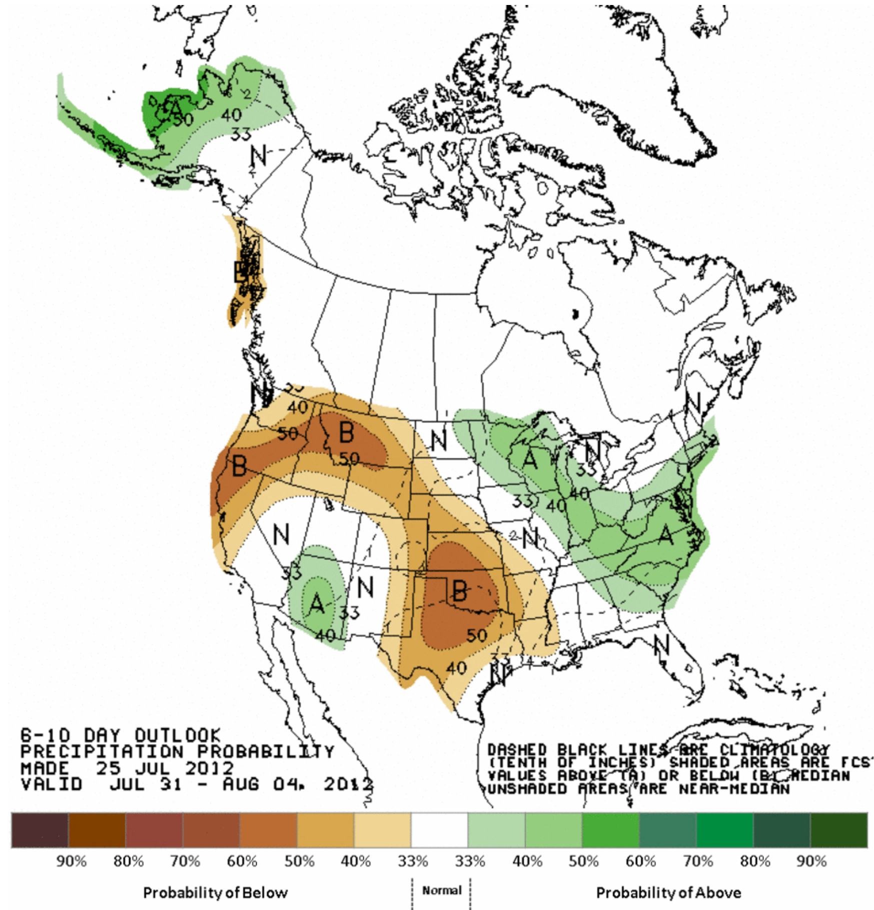


Francisco Alvarez, St. Louis University, is working with me and others on using the reforecasts to make extended-range predictions of tornado probabilities.

Ph.D. work, in progress.

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





Dan Collins, CPC leading this effort.

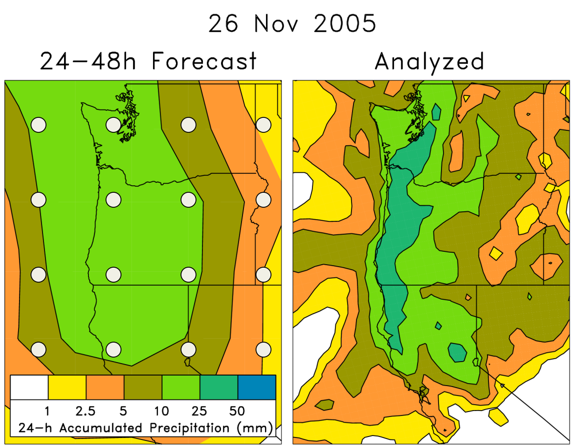
Conclusions

- Reforecast data set created for current operational NCEP GEFS.
- Reforecast data and real-time forecasts available shortly.
- Useful for statistical calibration.
- Helpful for determining how you may choose to configure real-time reforecasts in the future.

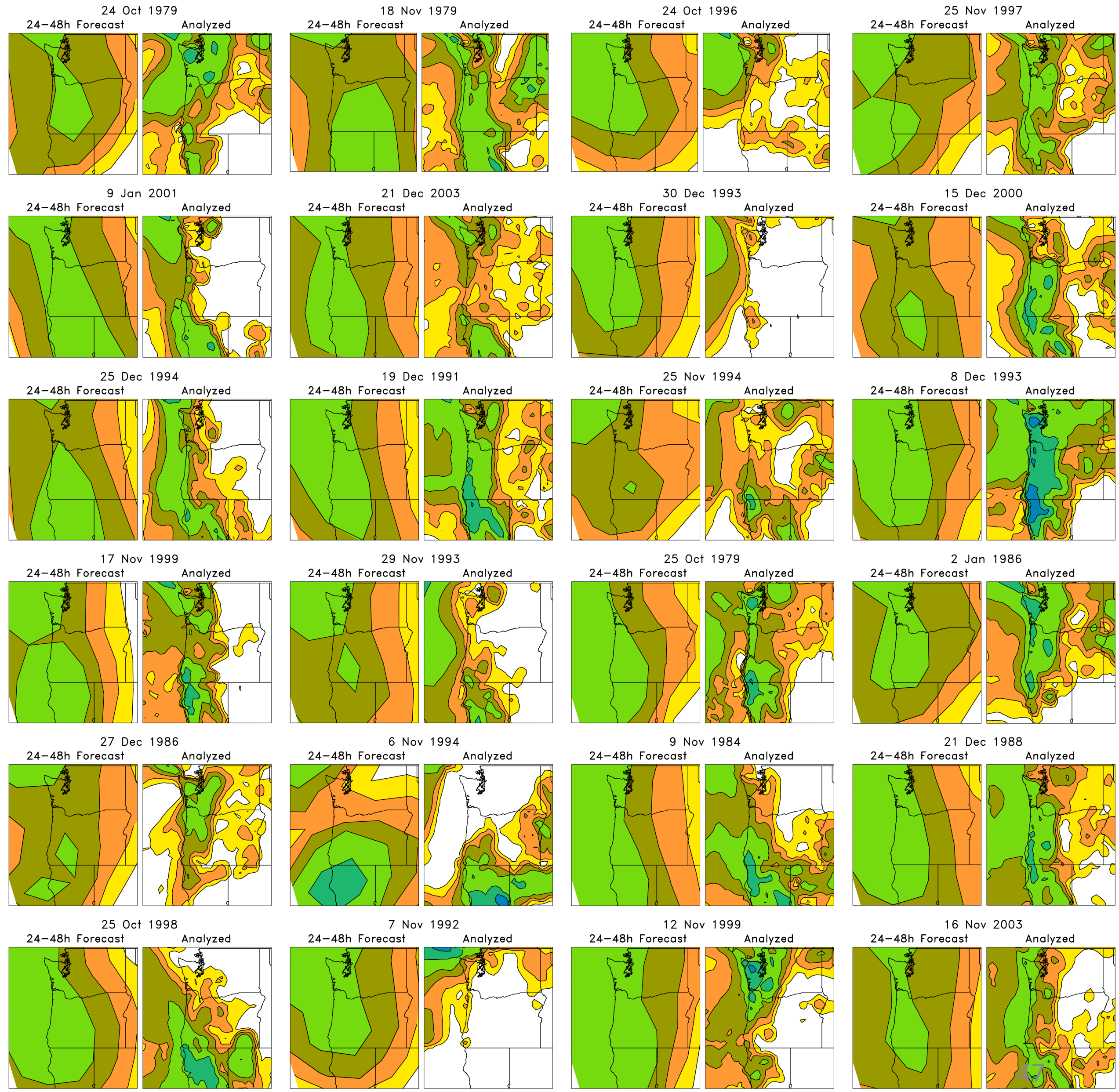
Supplementary slides

Basic analog technique for statistical downscaling (here, v1)

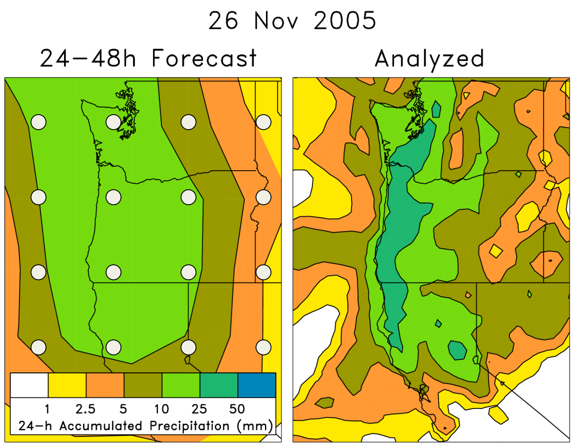
Today's ens. mean forecast + subsequent analyzed precipitation

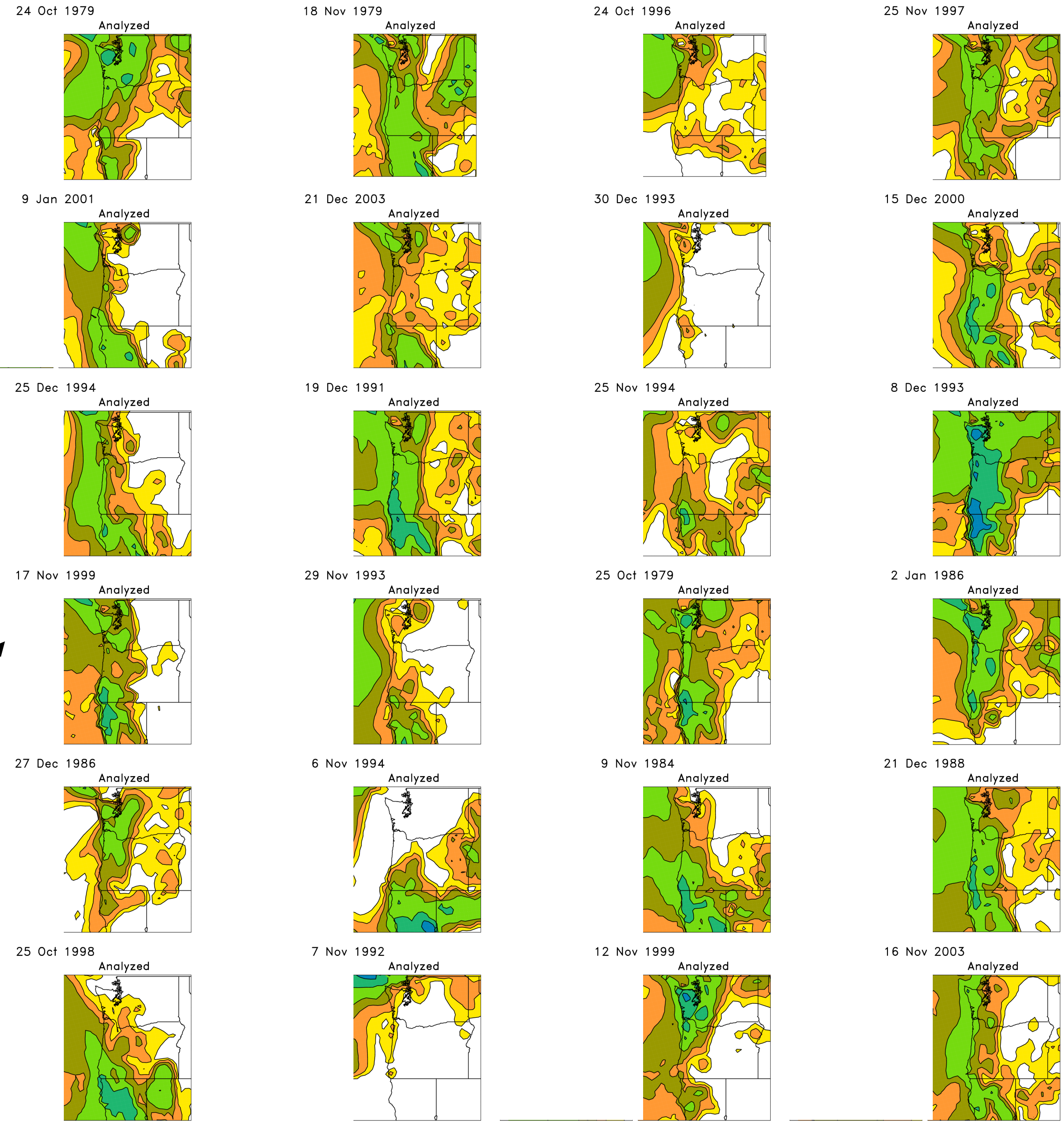


On the left are old forecasts similar to today's ensemble-mean forecast. For making probabilistic forecasts, form an ensemble from the accompanying analyzed weather on the right-hand side.



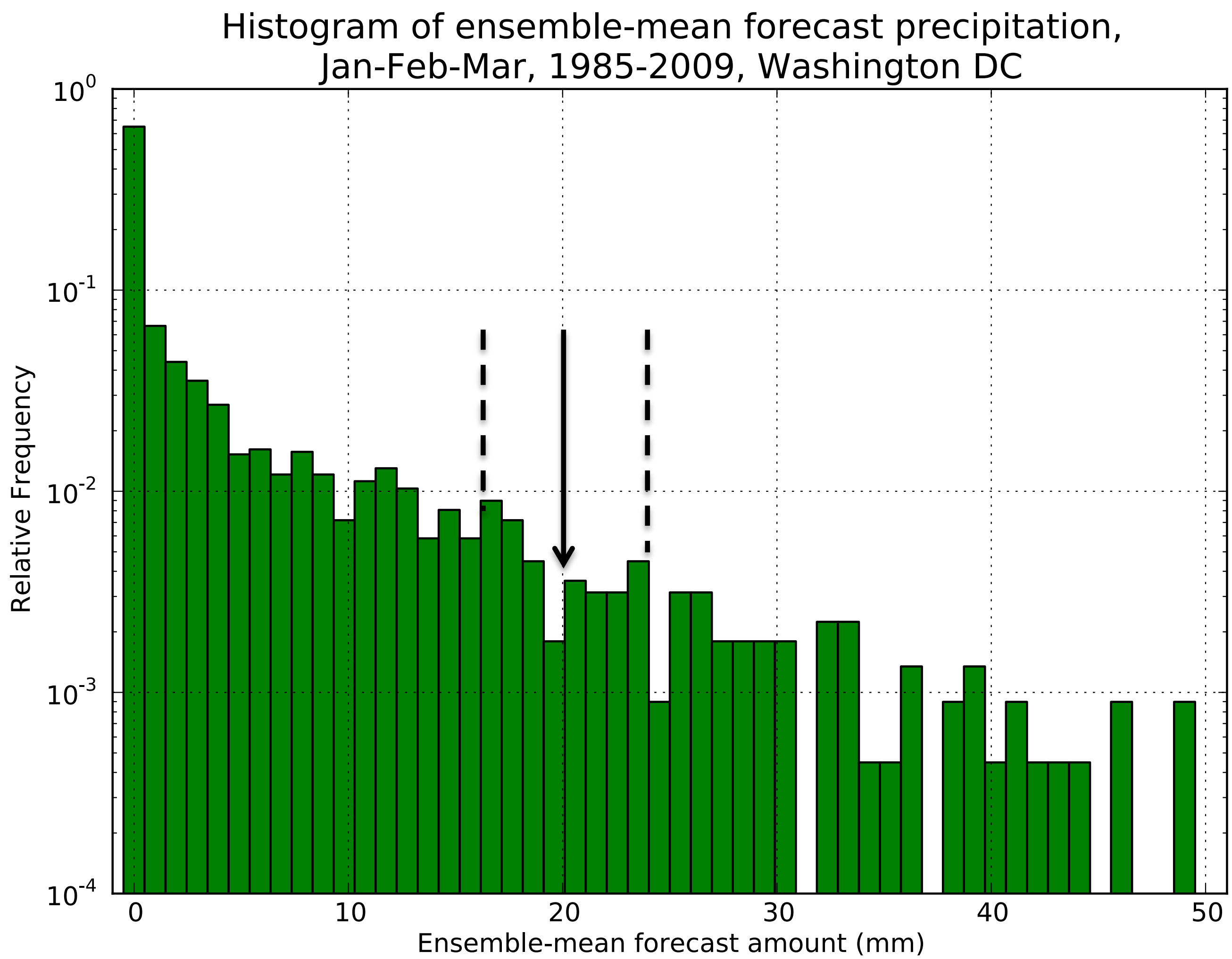
Analog technique for statistical downscaling





Form an ensemble from these

Problem with basic analog reforecast technique



Say today's forecast is for 20 mm. There are more forecasts slightly 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

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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

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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.

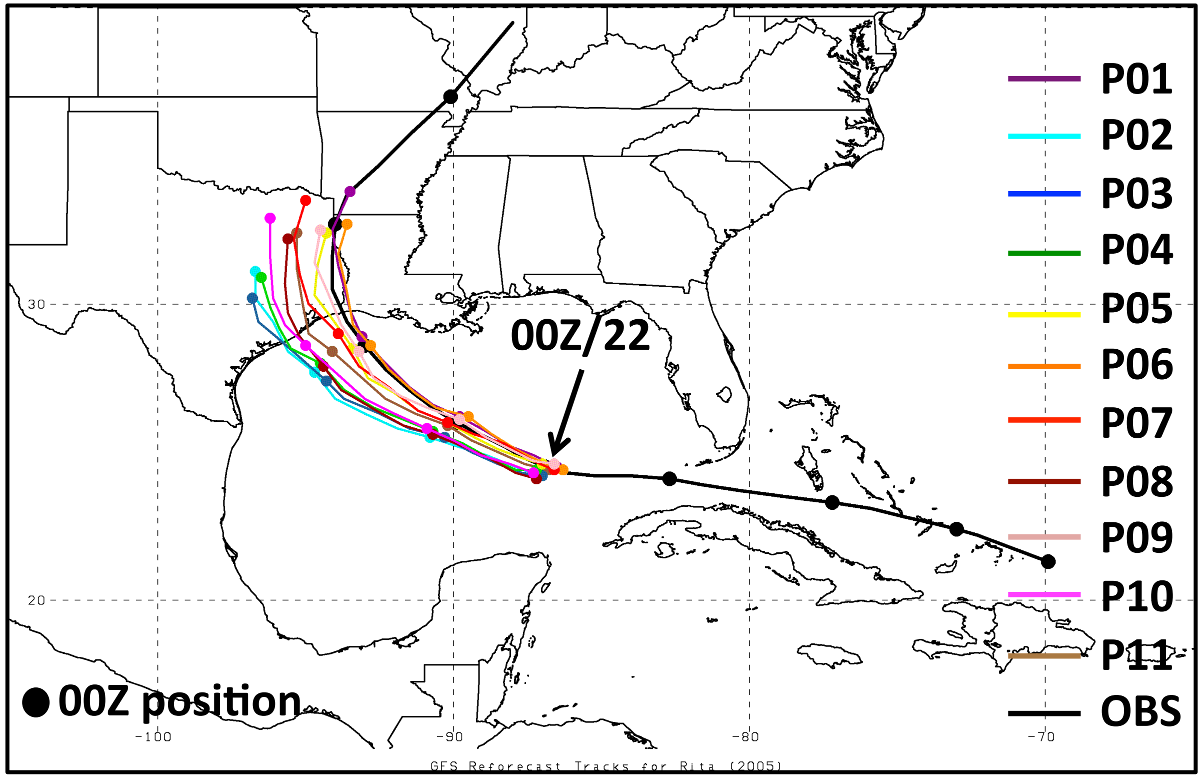
Regional Reforecast with ARW v3.4

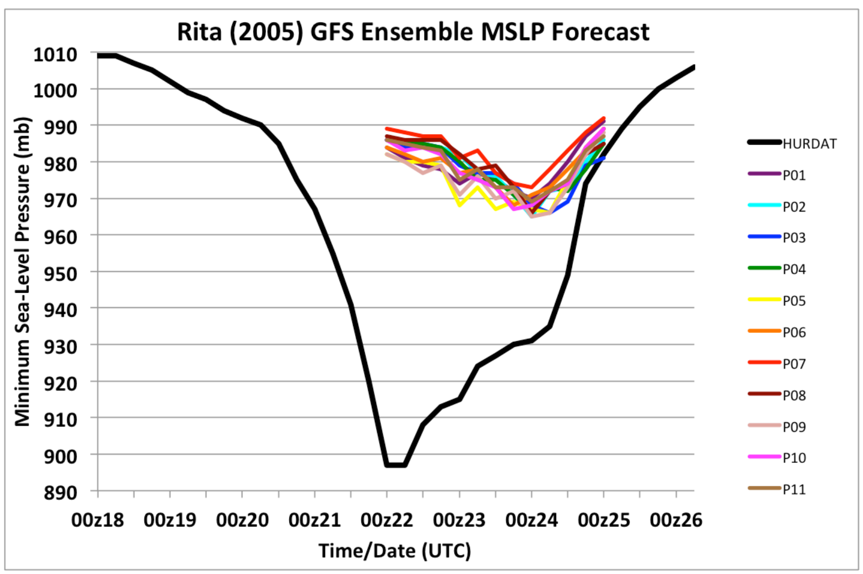
- 2-way nested simulation 36-, 12- and 4-km with 36 vertical levels
  - 12- and 4-km moving nests
- Time step: 180, 60, and 20 s
- Initial and boundary condition: GFS reforecast ensemble member
- Tiedtke cumulus scheme on 36 and 12 km; explicit on 4 km
- YSU PBL scheme
- HYCOM ocean analysis
- WSM6 microphysics
- 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

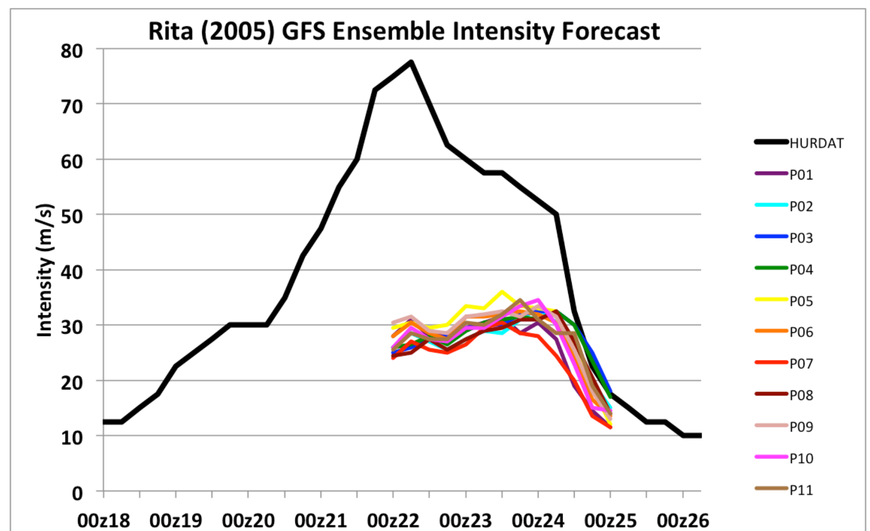
TC Rita (2005)

GFS reforecast ensemble

72-h forecast initialized at 00Z 22 Sept



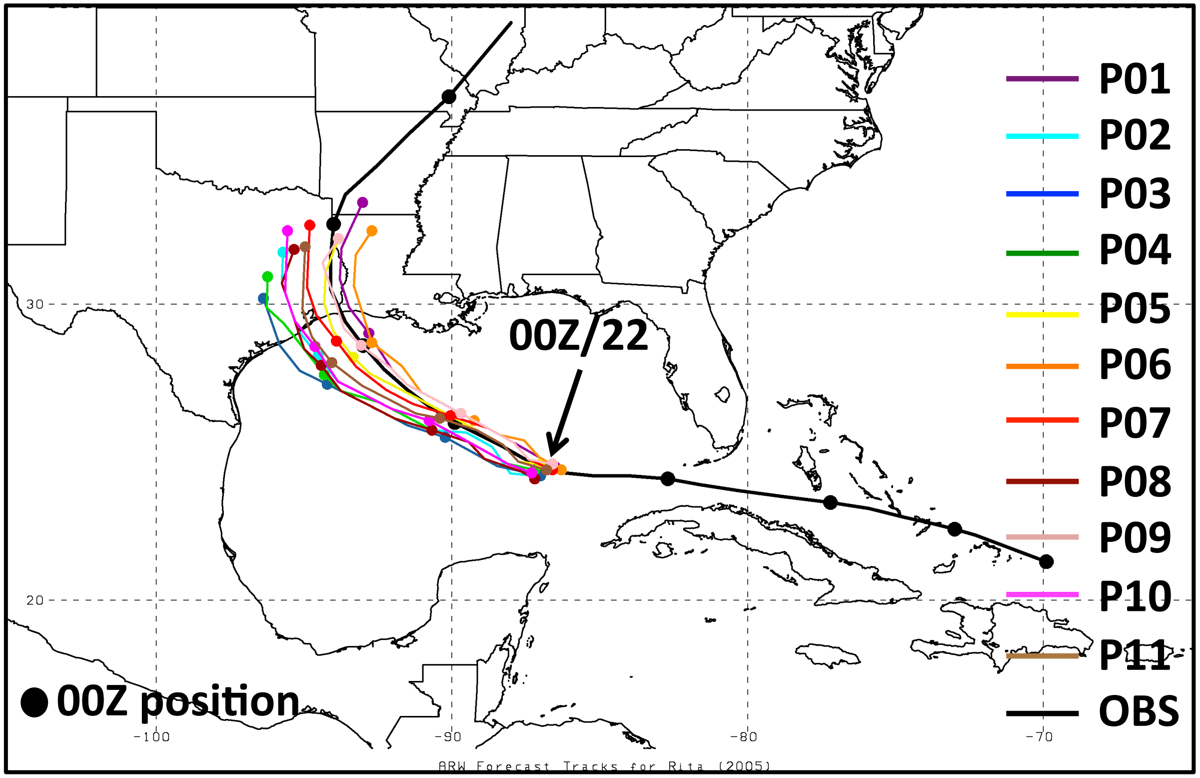


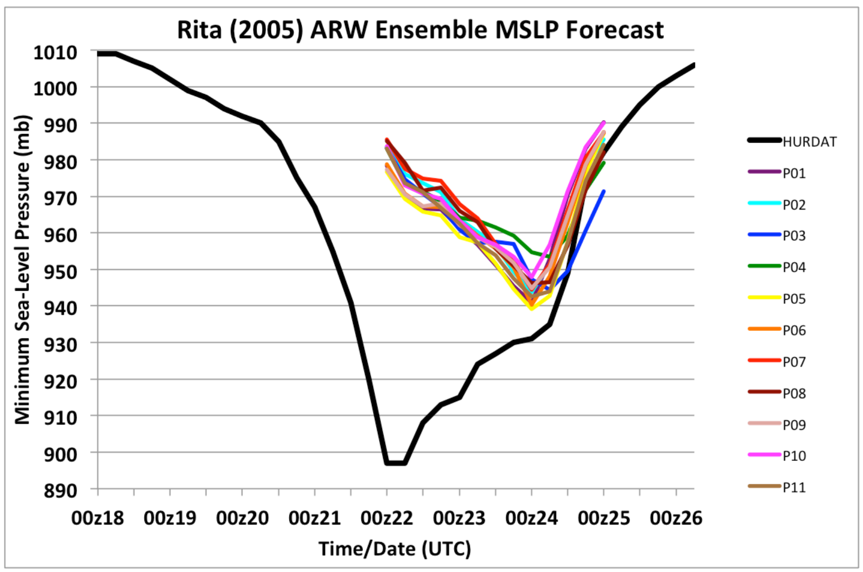


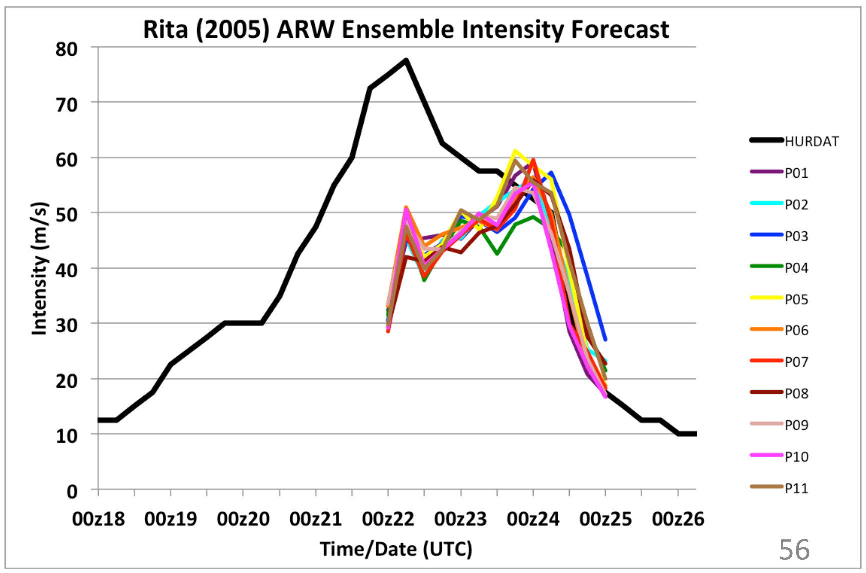
TC Rita (2005)

ARW ensemble with GFS reforecast ensemble as boundary and initial conditions

72-h forecast initialized at 00Z 22 Sept



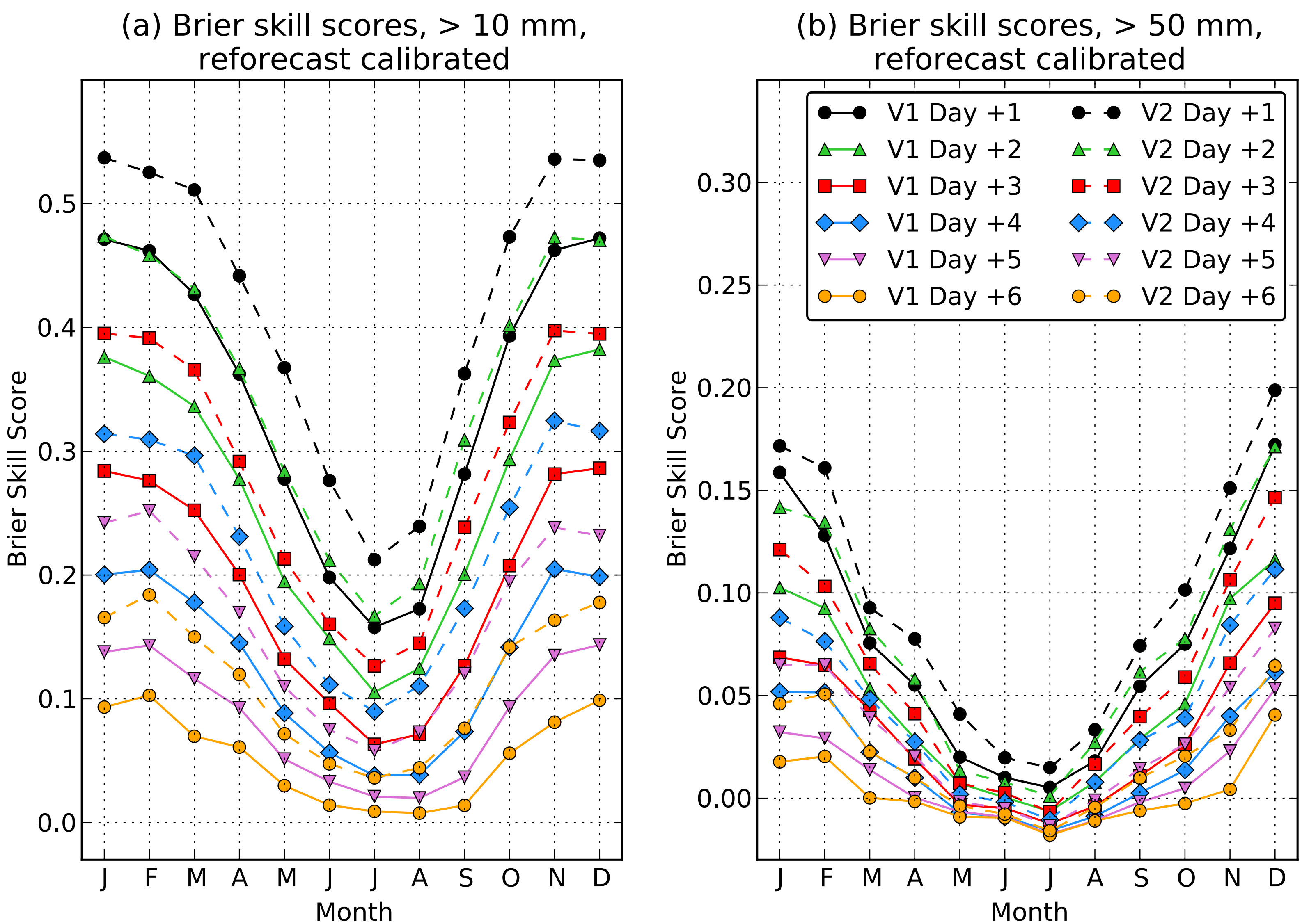




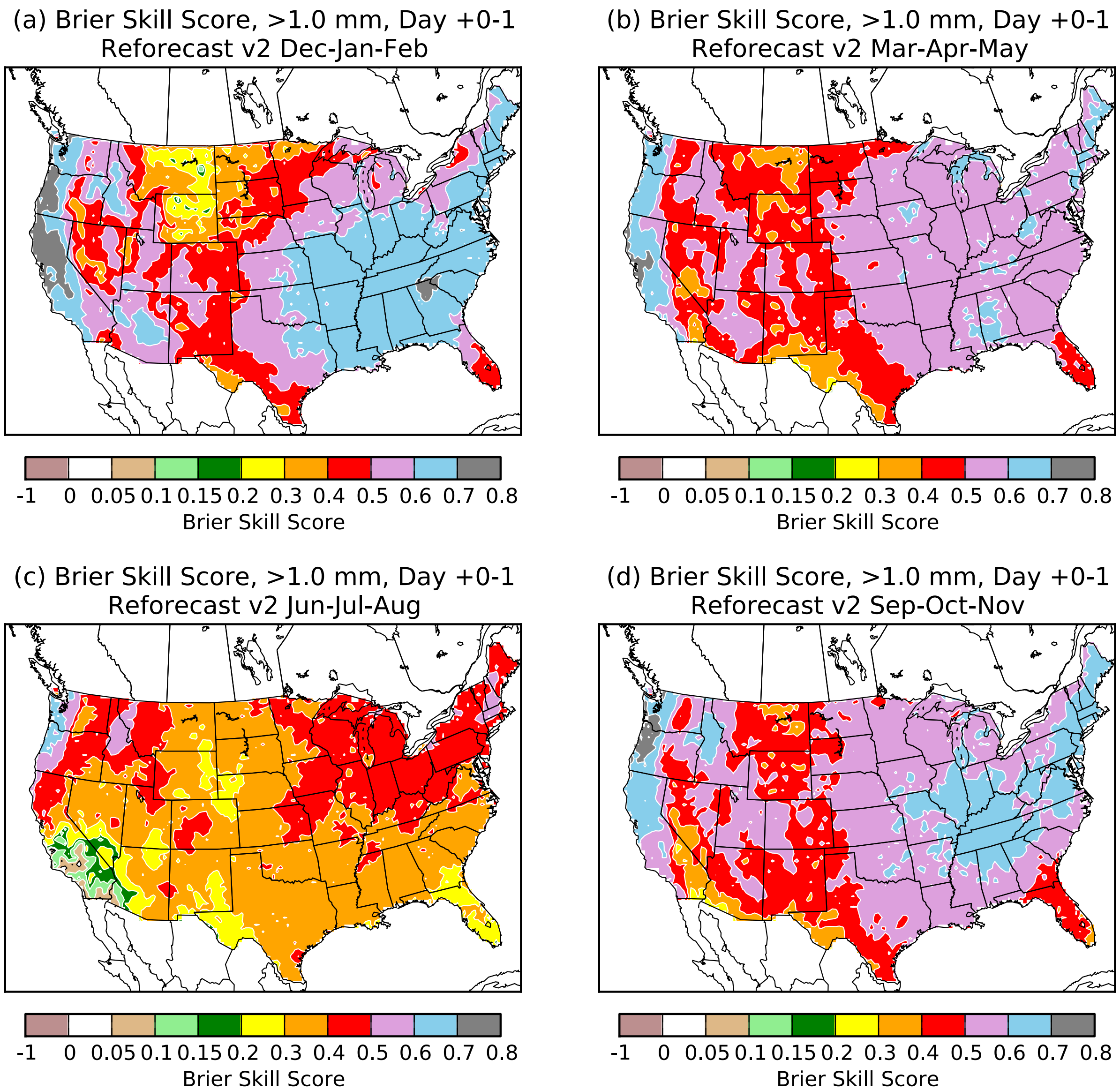
Some known applications in development

- Real-time web page of experimental PQPF forecasts (ESRL, in development to replace v1 web page)
- Development of experimental forecast products for renewable energy sector (Hamill, ESRL).
- 6-10 day and 8-14 day forecasts (Dan Collins, CPC).
- Detecting and correcting bias in hurricane track and intensity (Jiayi Peng, NCEP/EMC, Tom Galarneau, NCAR).
- Objective probabilities for severe weather several days to weeks hence (Francisco Alvarez, St. Louis Univ. + Hamill)
- Improving hydrologic predictions (Haksu Lee et al., NOAA/ NWS/OHD).
- Also: BAMS article once published will presumably spur wider usage.

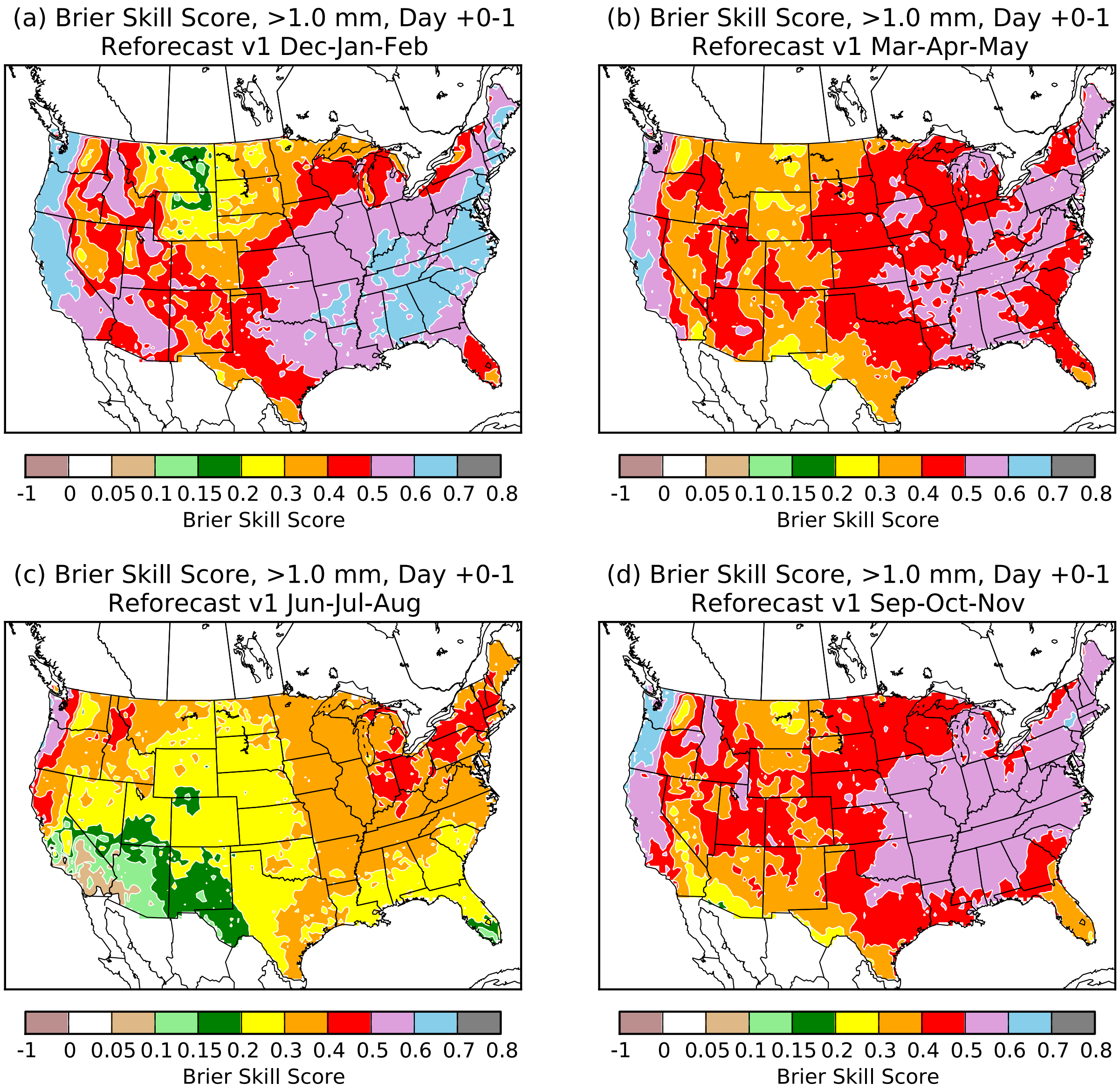
Scores, > 10 mm and > 50 mm



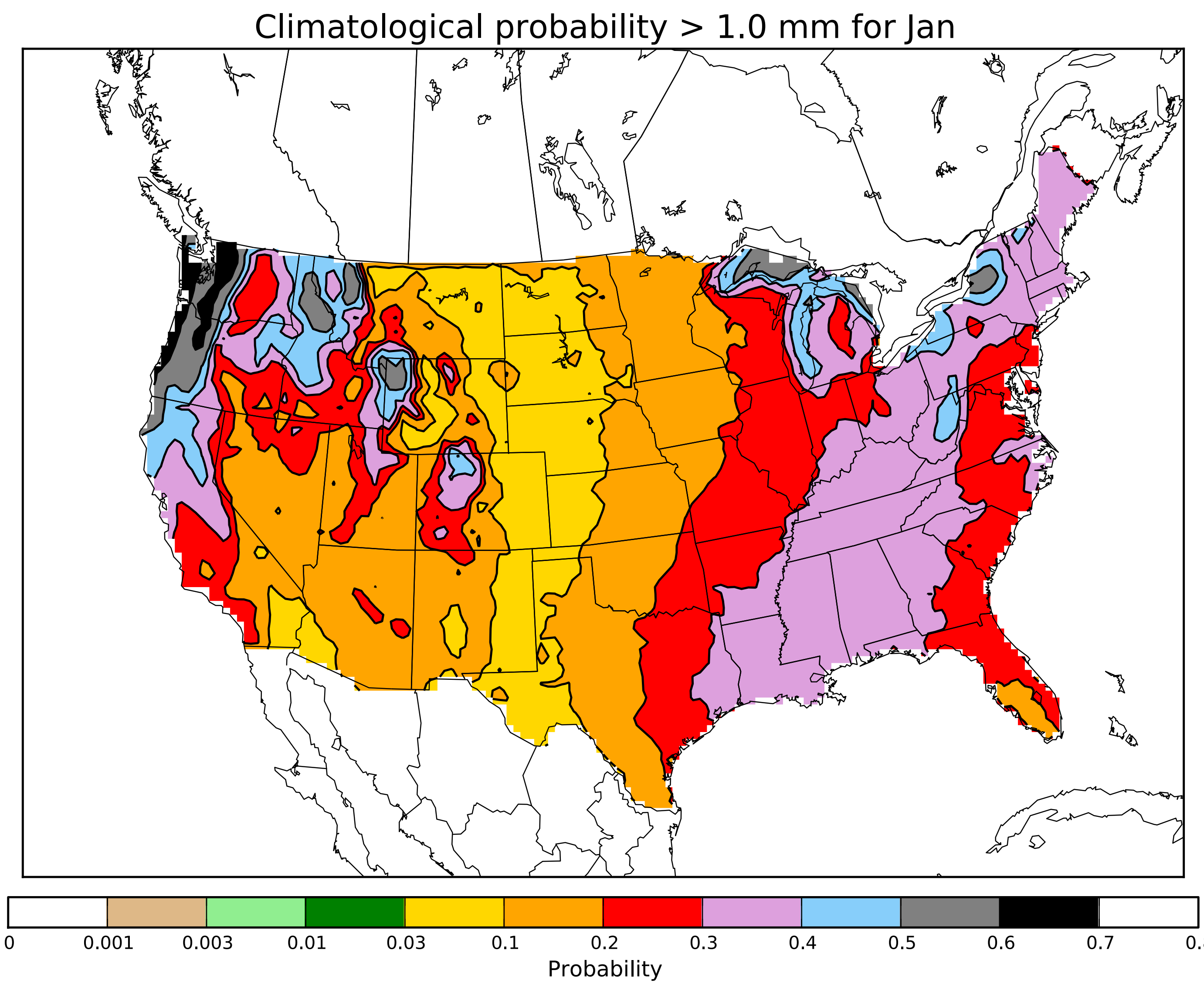
Brier Skill Scores, Day +0-1, 1.0 mm $24h^{-1}$ (reforecast version 2)



Brier Skill Scores, Day +0-1, 1.0 mm $24h^{-1}$ (reforecast version 1)



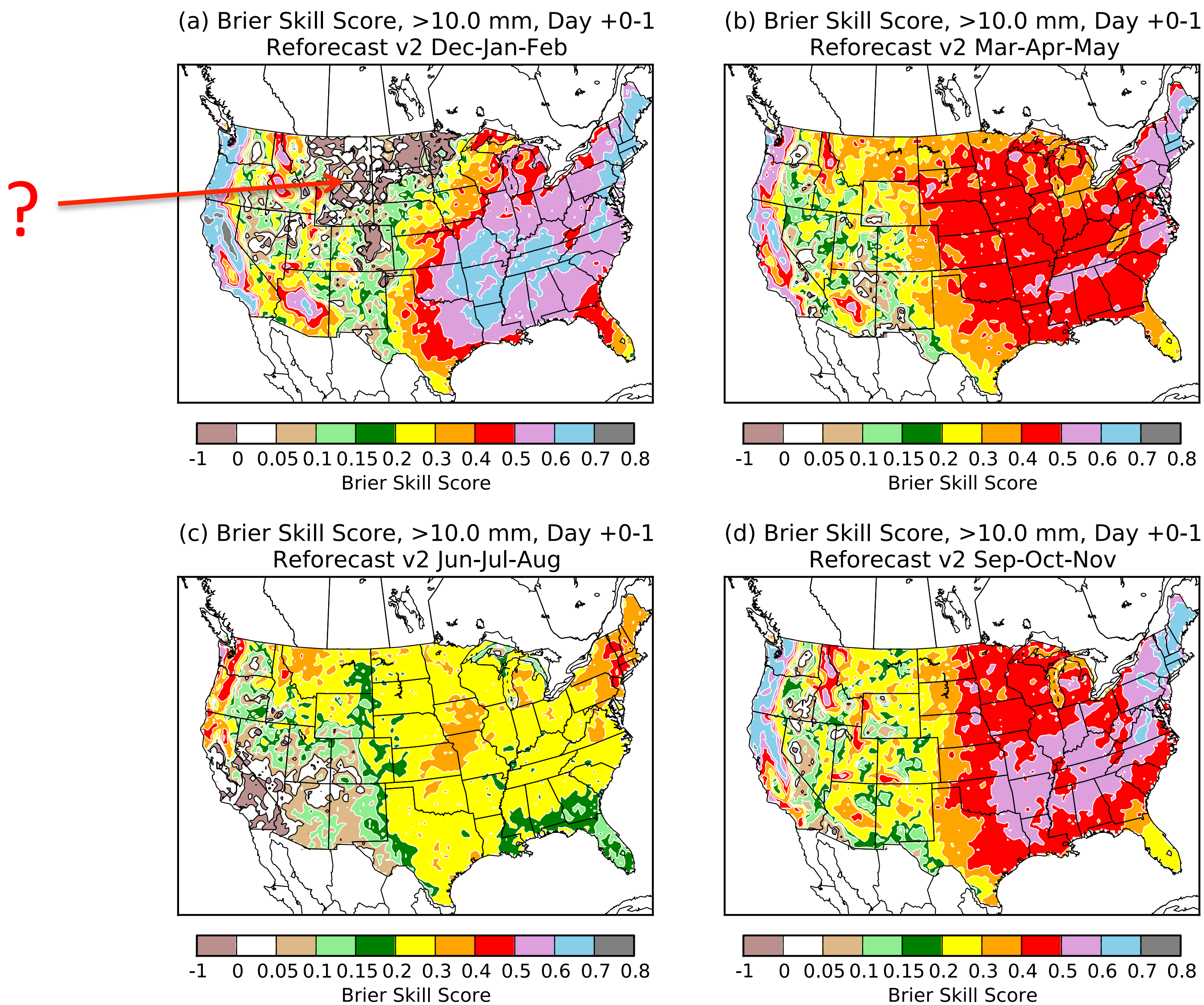
NARR climatology, > 1-mm 24 h^{-1}



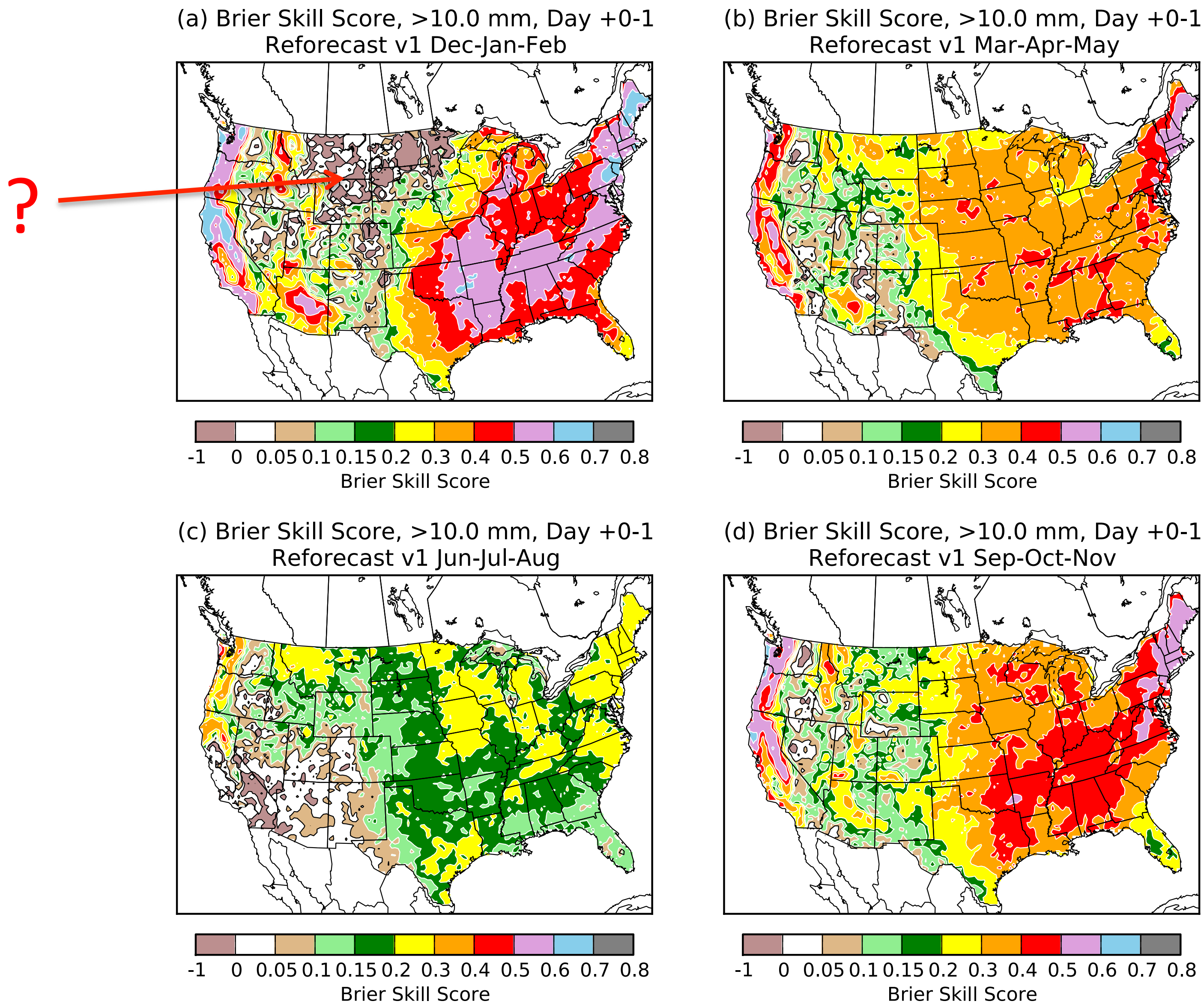
a modest relationship between where precipitation is common and the magnitude of skill.

Also, note relationship with terrain forcing.

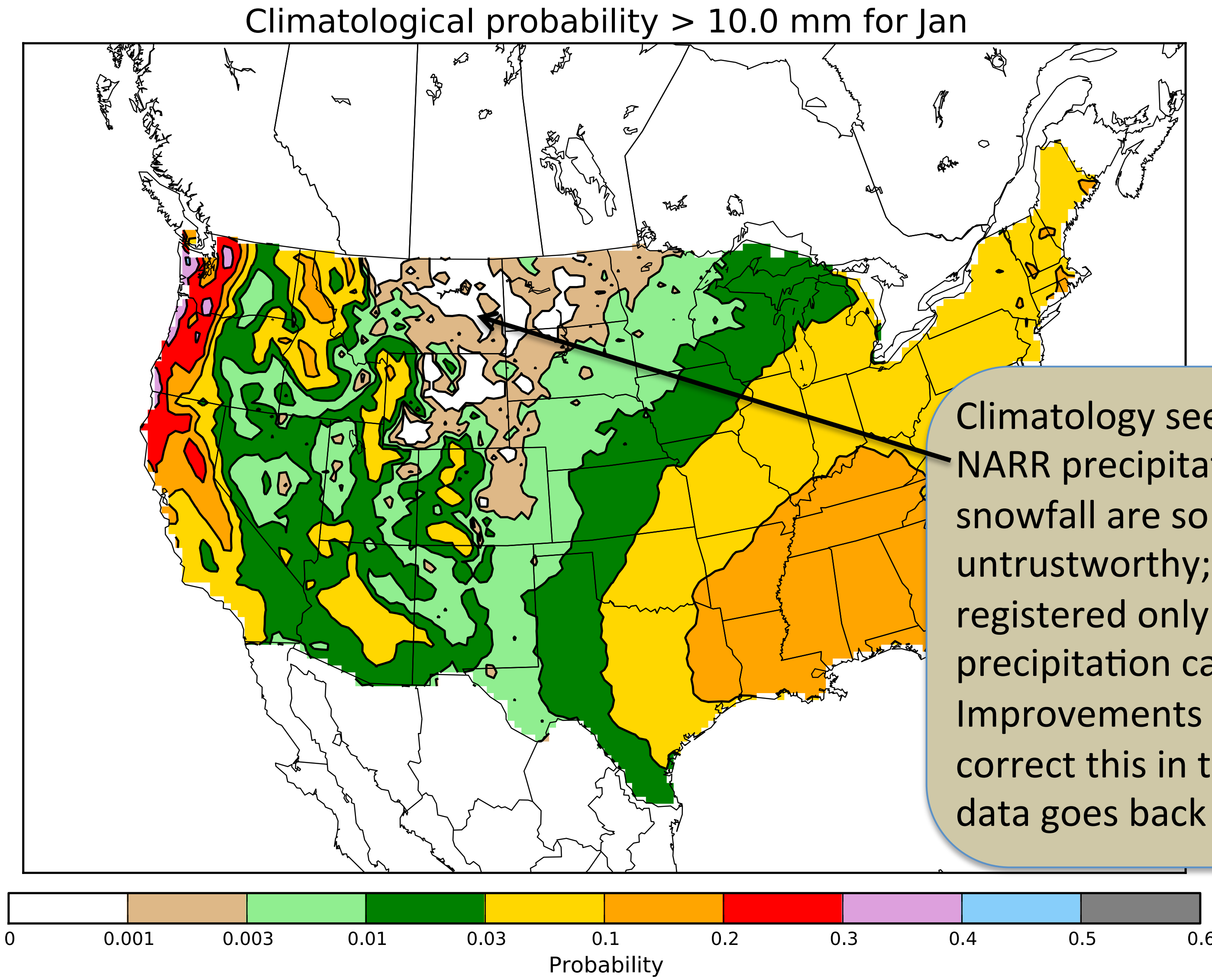
Brier Skill Scores, Day +0-1, 10.0 mm 24h^{-1} (reforecast version 2)



Brier Skill Scores, Day +0-1, 10.0 mm $24h^{-1}$ (reforecast version 1)



NARR climatology, > 10 mm 24 h^{-1}



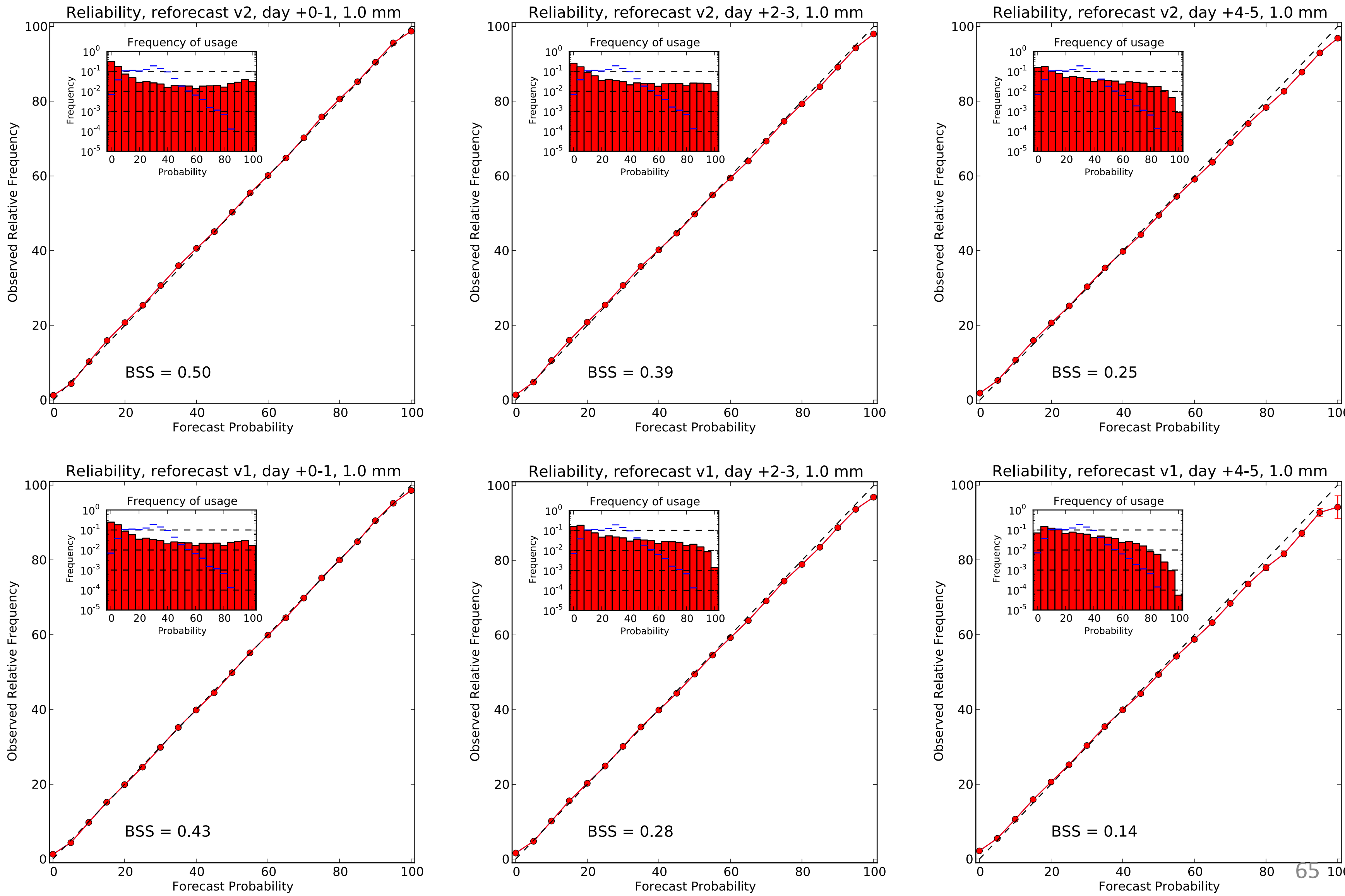
Climatology seems anomalously dry. NARR precipitation analyses after snowfall are somewhat untrustworthy; precipitation registered only as snow melts, so precipitation can be off by days. Improvements to Stage IV may correct this in the future, but this data goes back only to 2002.

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

Day +0-1 | Day +2-3 | Day +4-5

Version 2 (2012 GEFS)

Version 1 (1998 GEFS)



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