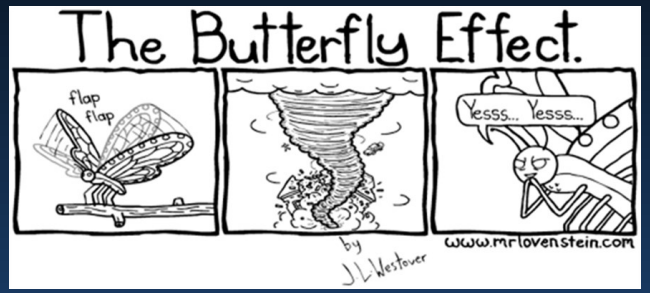
Ensembles, Anomalies, and Analogs

Michael Buchanan
Science and Operations Officer
National Weather Service Corpus Christi

Quick NWP refresher

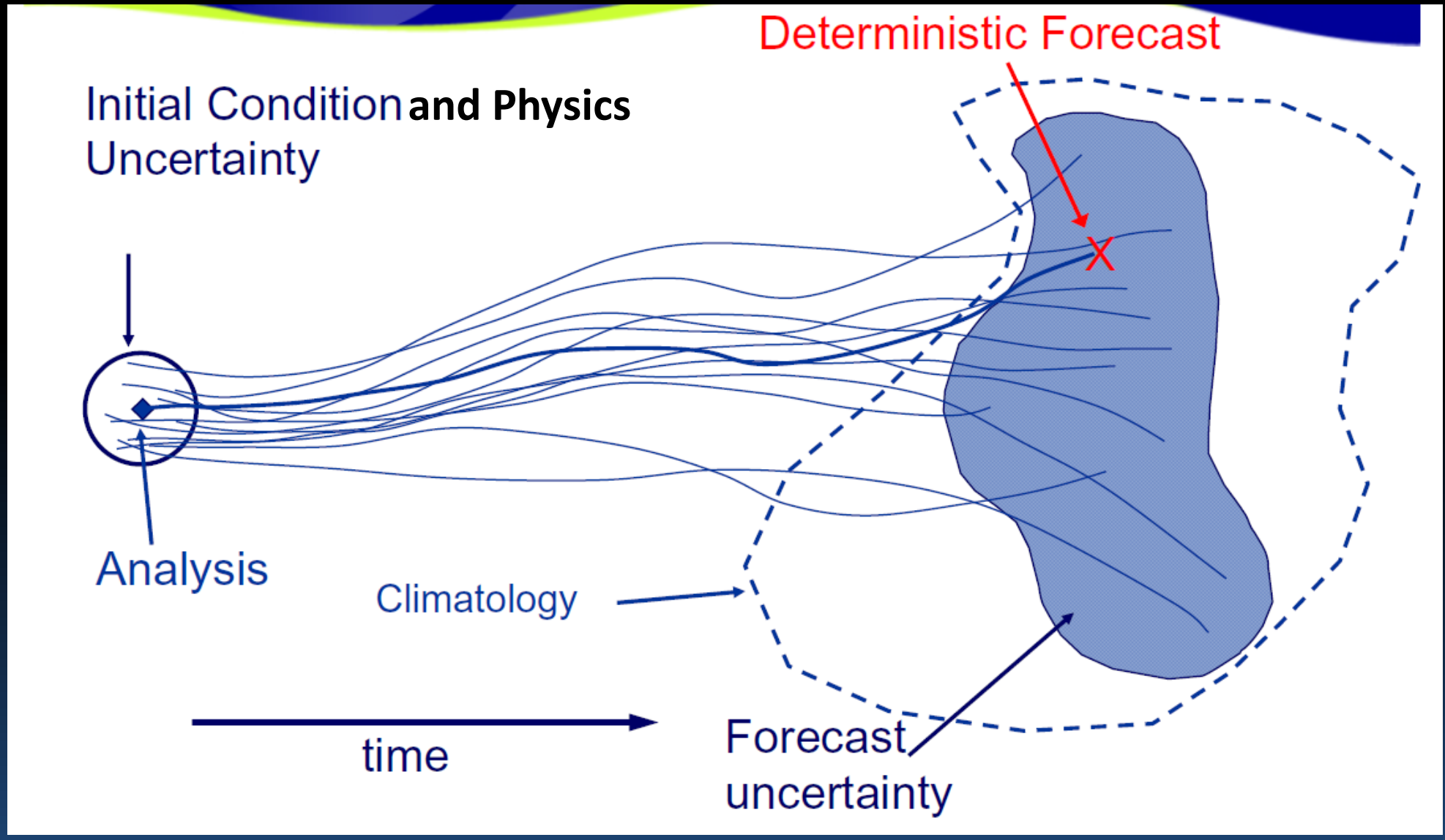
- Exact initial state of the atmosphere is NOT known!
  - Approximated through data assimilation.
- Errors can then grow with time.
- "Sensitive dependence on initial conditions" (Lorenz).
  - Chaos Theory
- Limits of predictability.



Range/Probability of “possible” outcomes

- Perturbed initial conditions will lead to a range of outcomes.
- Can also perturb the physics of the model.

Basic concept of Ensembles



Ensemble Advantages

- Attempts to cover the range of forecast possibilities.
  - Estimate the predictability for an event.
- Good agreement among members usually implies high predictability.
- Regardless of errors in initial conditions or varying physics, you can still get a similar forecast.

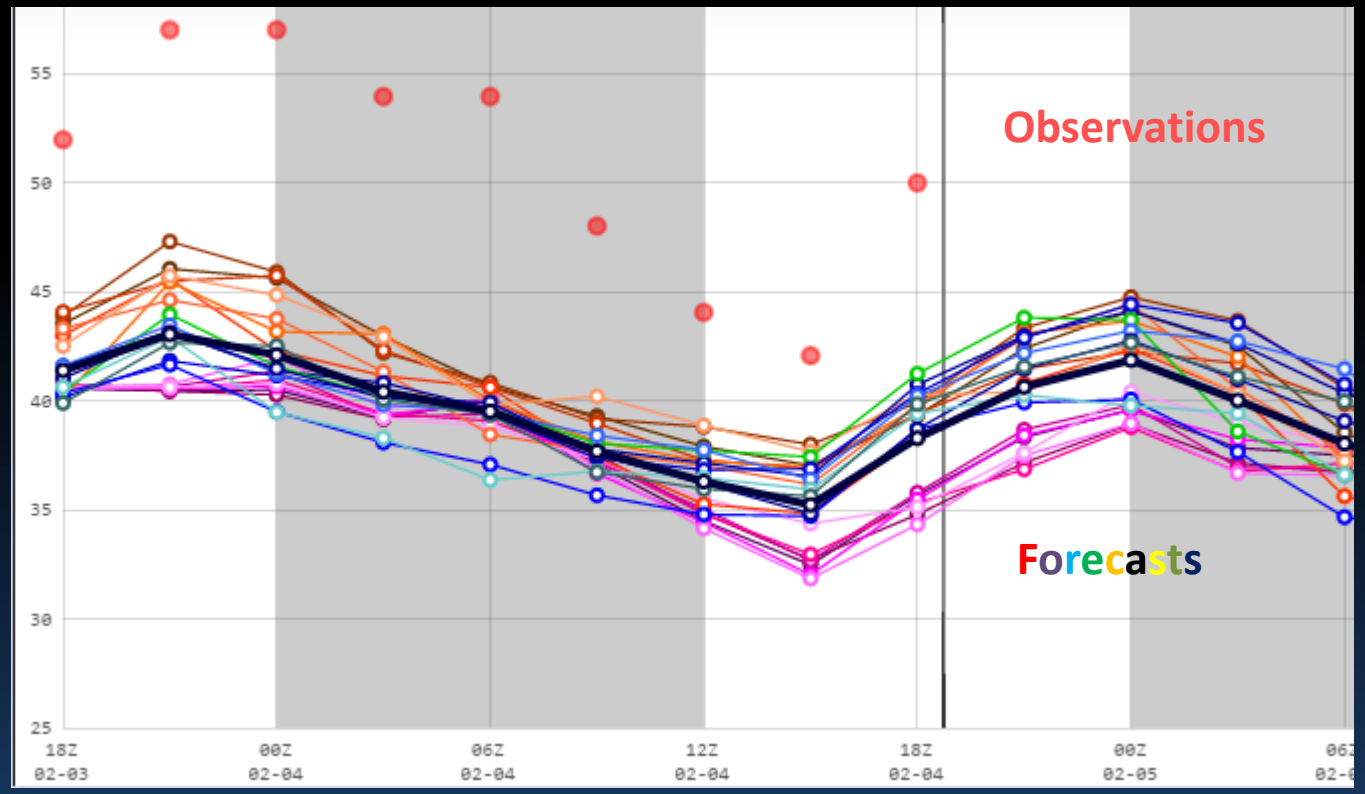
Ensemble Challenges

- Bias:
  - Perturb the initial conditions or physics all you want, but sometimes the model is just systematically too cold or too wet.

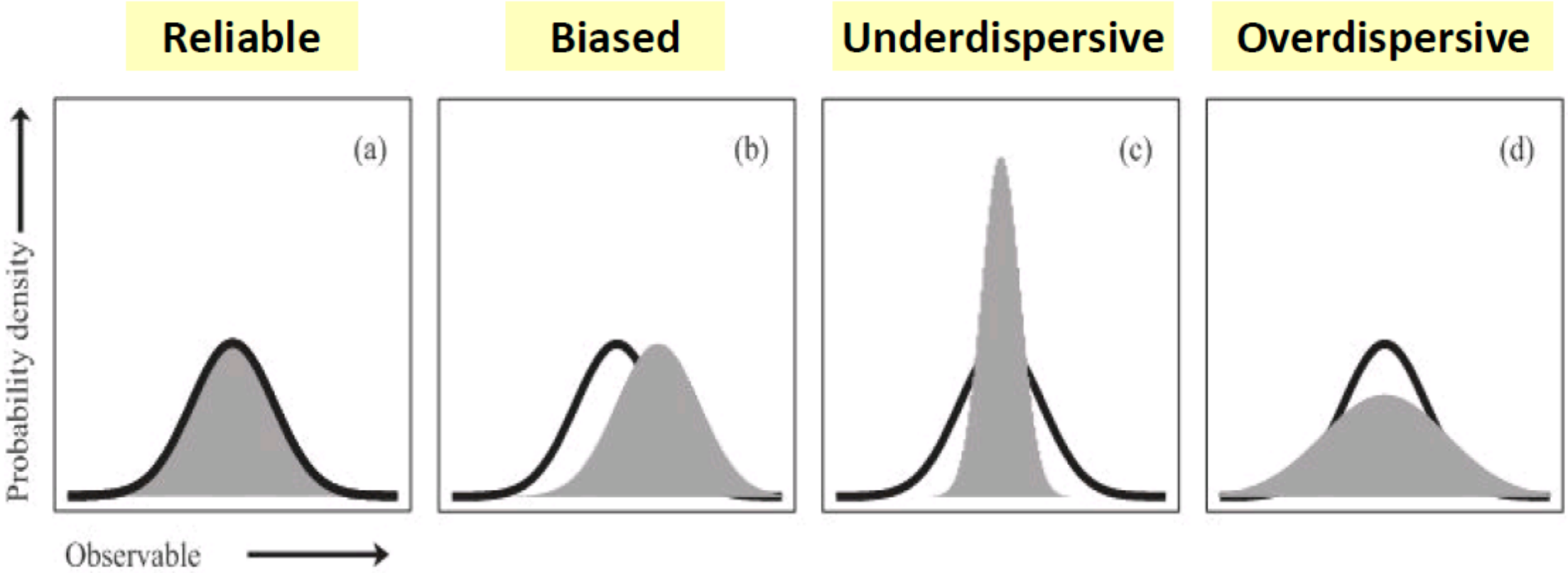
- Underdispersion:
  - Estimates of initial condition errors tend to be too small, and the real atmosphere may behave in ways completely outside the realm of our physics equations.
  - Result: **Ensemble doesn't have enough spread**.

Bias/Underdispersion

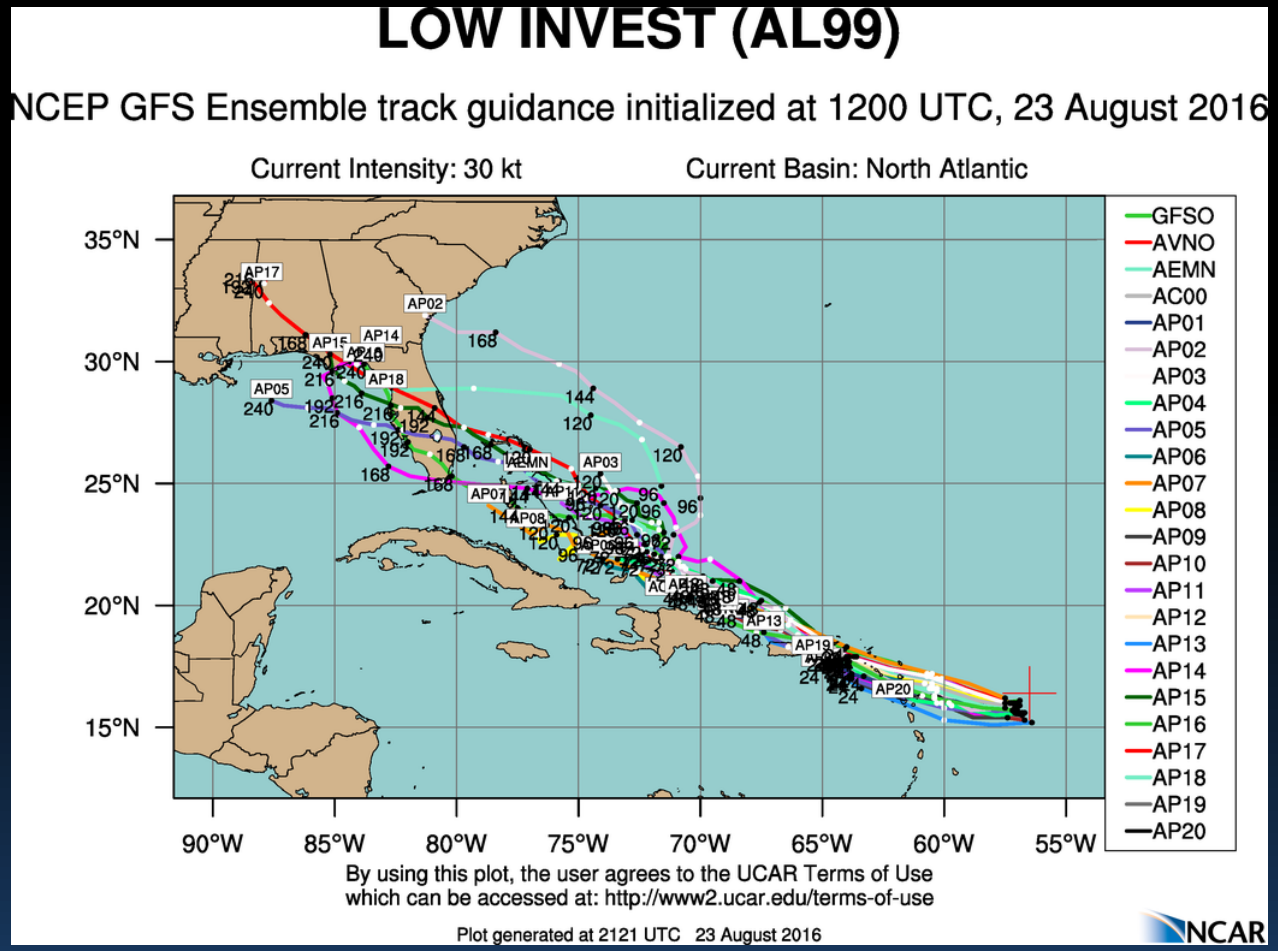
15 UTC 3 Feb 2015 Short-Range Ensemble Forecast
2-m temperature (F) at Salt Lake City, UT

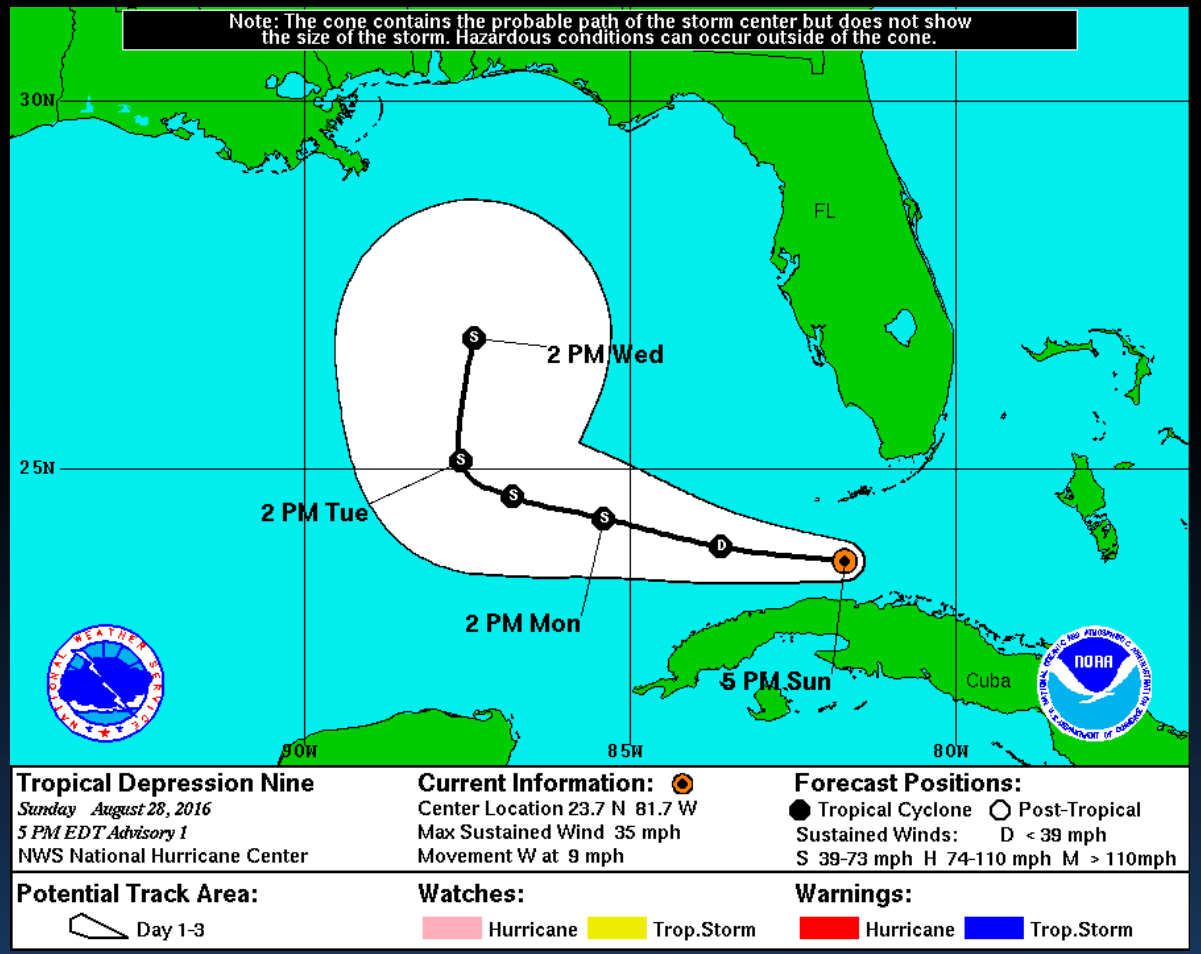


Forecast (Gray) vs. Observation (Black)

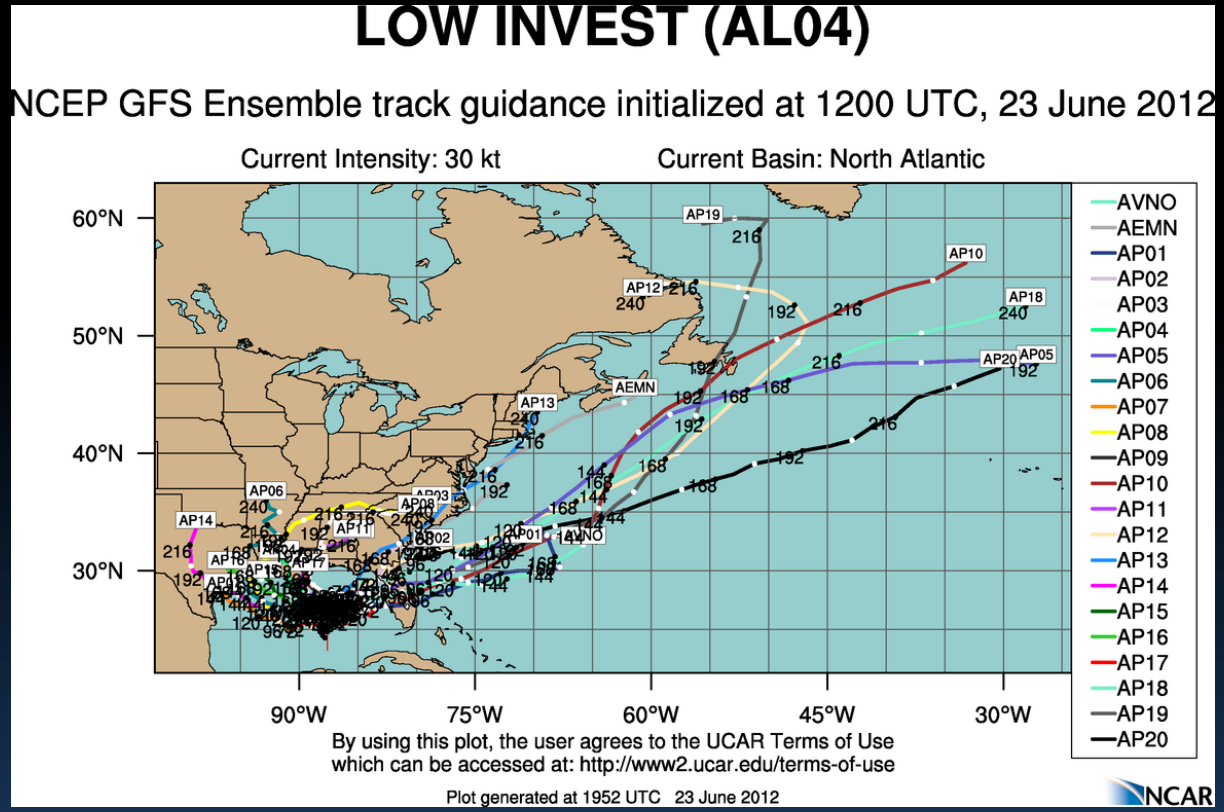


Underdispersive – INVEST 99L (2016)





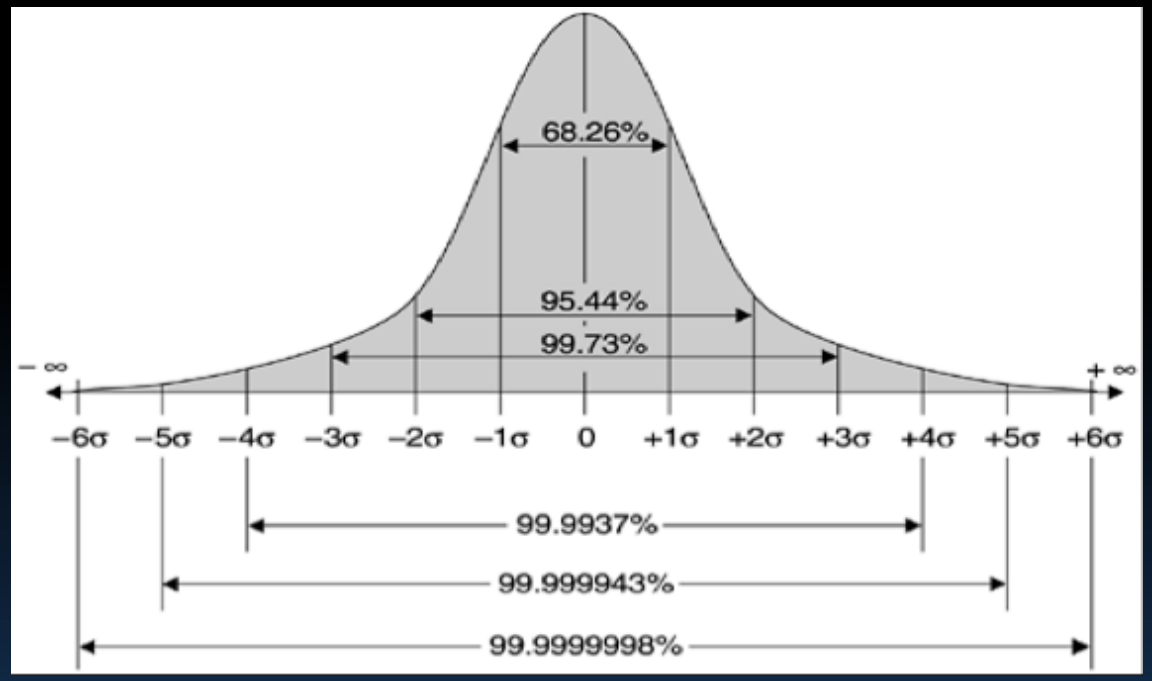
Overdispersive – Tropical Storm Debby (2012)



Types of Ensemble Forecast Systems (EFS)

- Same model but with different initial conditions.
- Same model but with different physics.
- A collection or “blend” of various models.

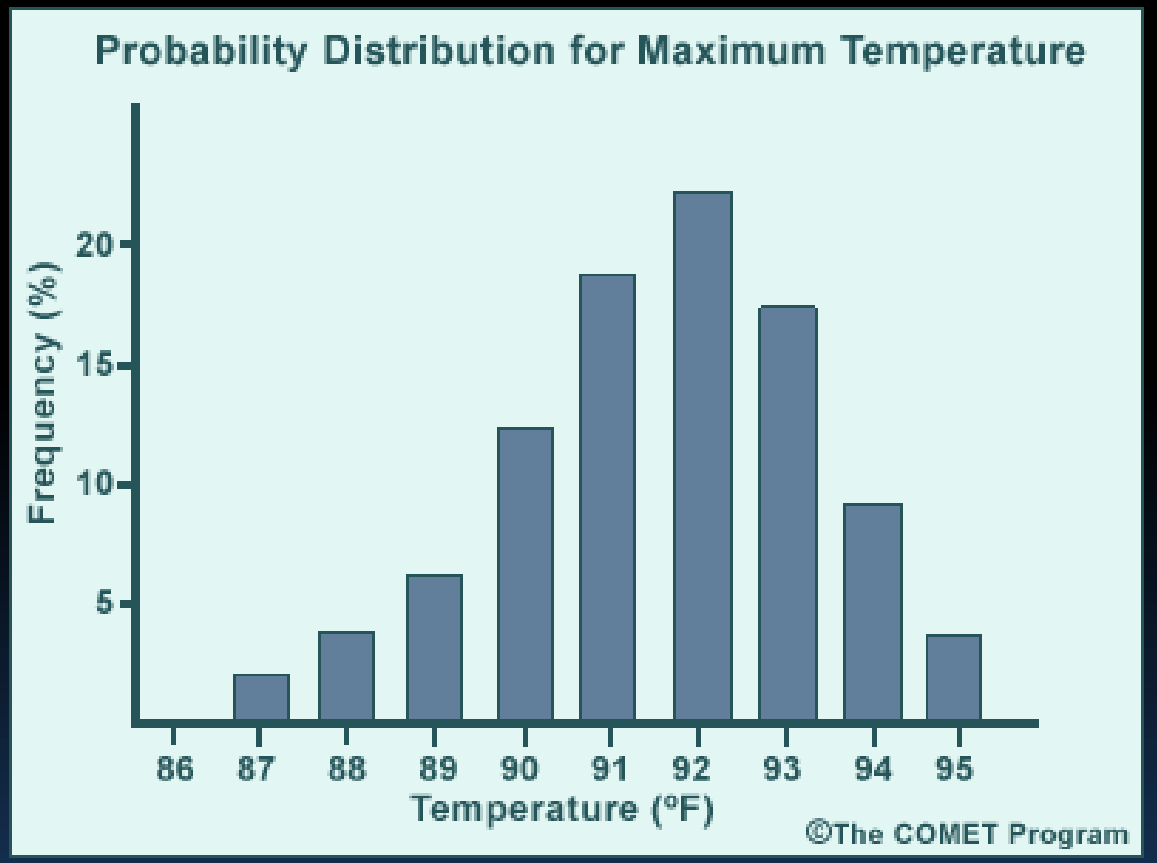
Statistics Refresher



- Normal (Gaussian) Distribution.
- Standard deviation is a common measure of variability (dispersion).
  - Lower SD = closer to the mean.
  - Higher SD = further from the mean.
- Range is another measure of variability.
  - Difference between max and min value.

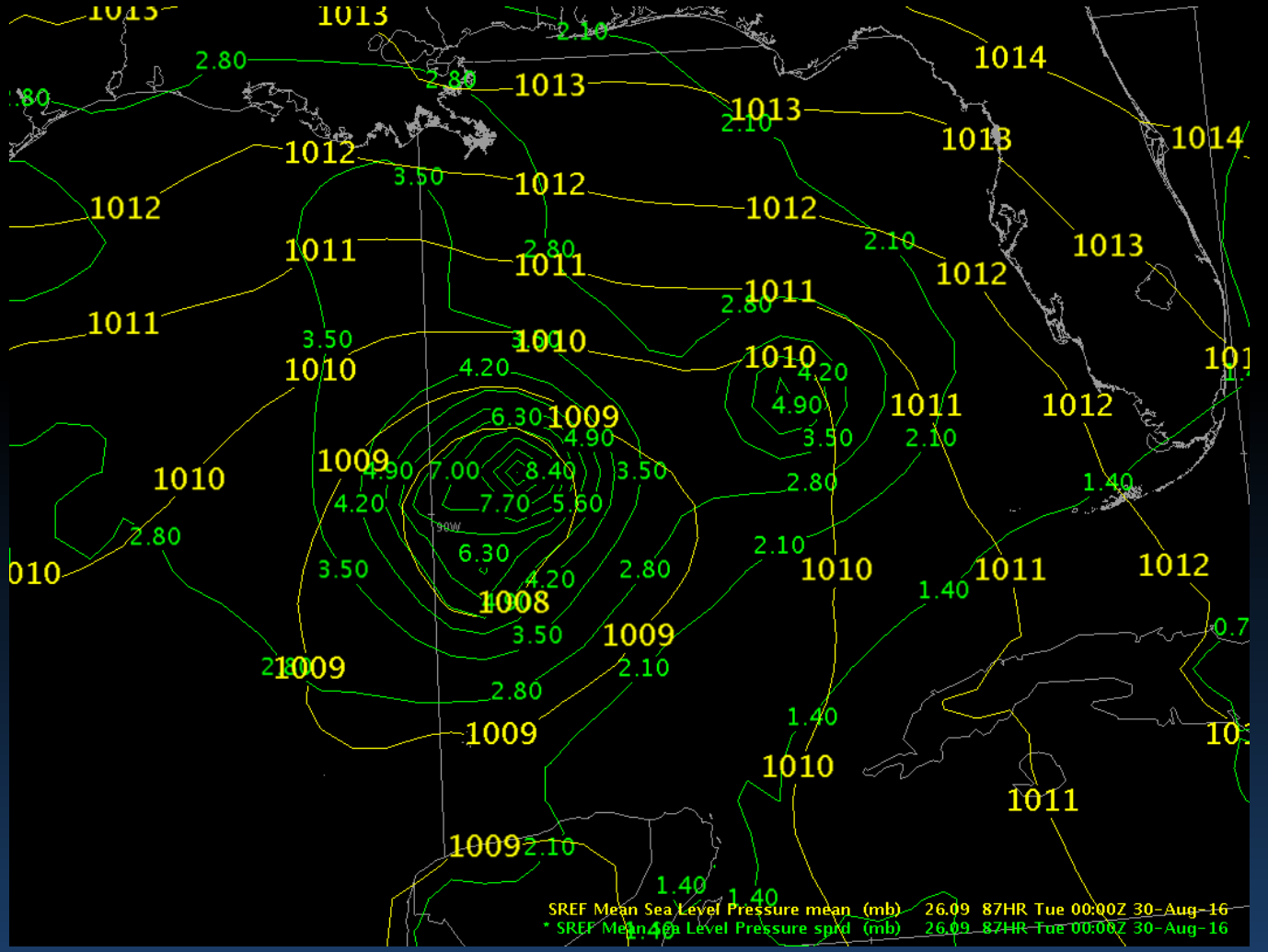
Probability Density (Distribution) Function (PDF)

- From a PDF, a measure of variability can be determined.
  - **Spread** (i.e., Range)
  - **Standard Deviation**
  - **Percentile**
  - Probabilities of Exceedance



Ensemble Mean and Spread

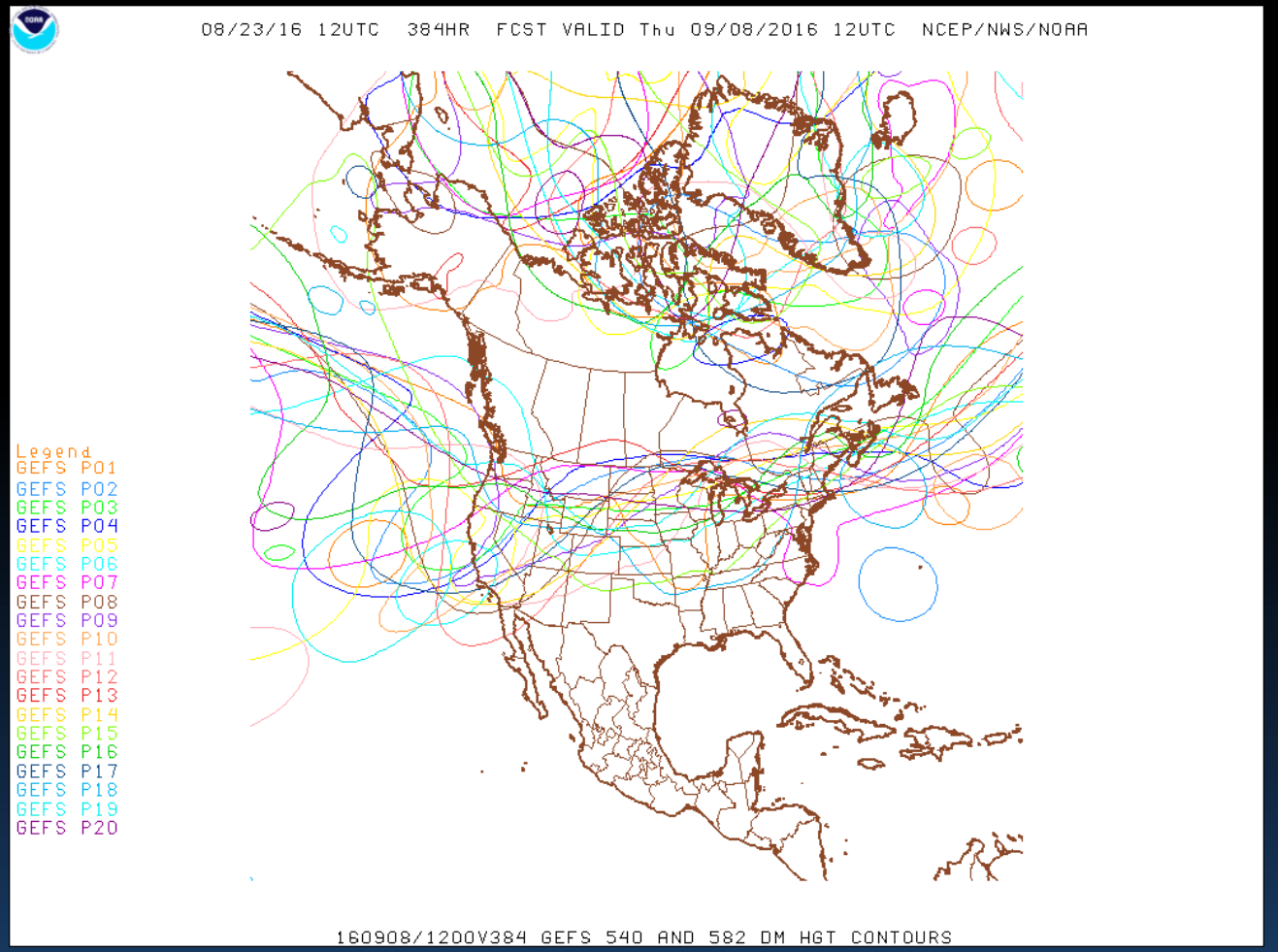
- **Mean** is the average of all members.
- **Spread** is the difference between the high and low member.
- “Normalized” spread also takes into account recent forecasts.



Synoptic Scale EPS/EFS
(Climate ensembles NOT covered)

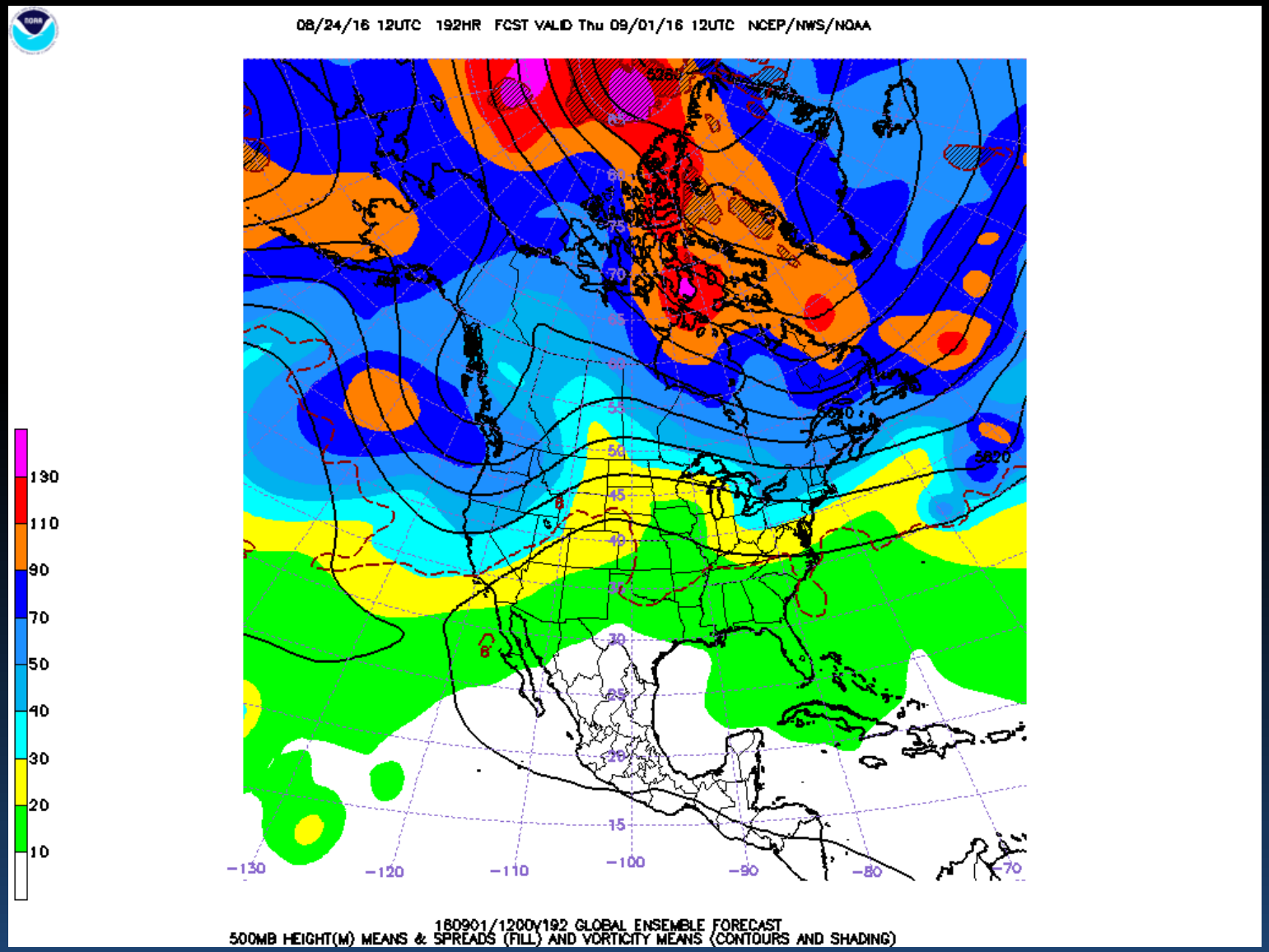
Global Ensemble Forecast System **(GEFS)**

- GFS is the core model.
  - Run every 6 hours out to 16 days.
  - ~34 km 0-192 hours
  - ~55 km 192-384 hours
- 20 “perturbed” initial conditions result in 20 members.
- 1 control run uses the same initial conditions as GFS.

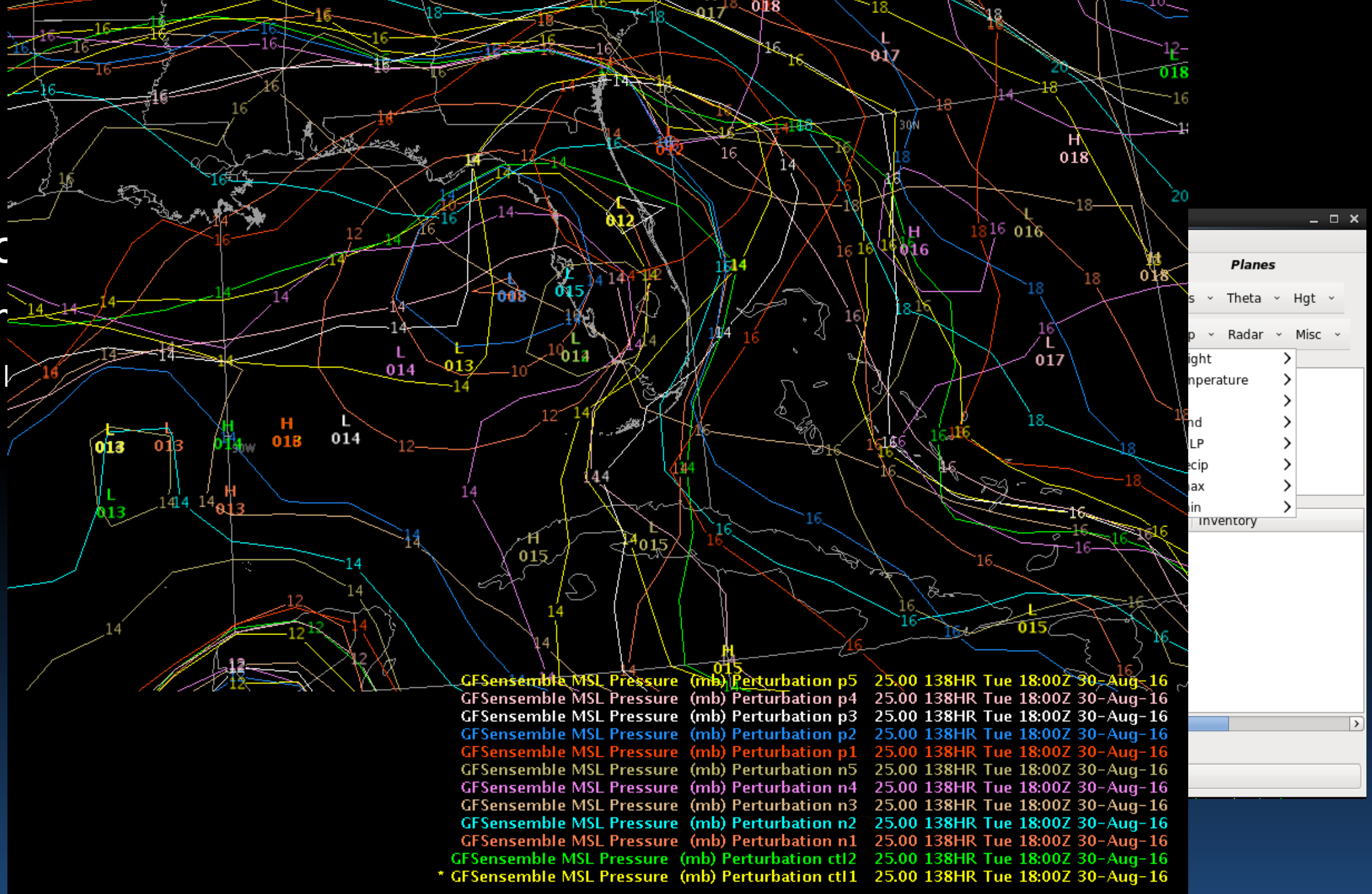


“Spaghetti” Plot

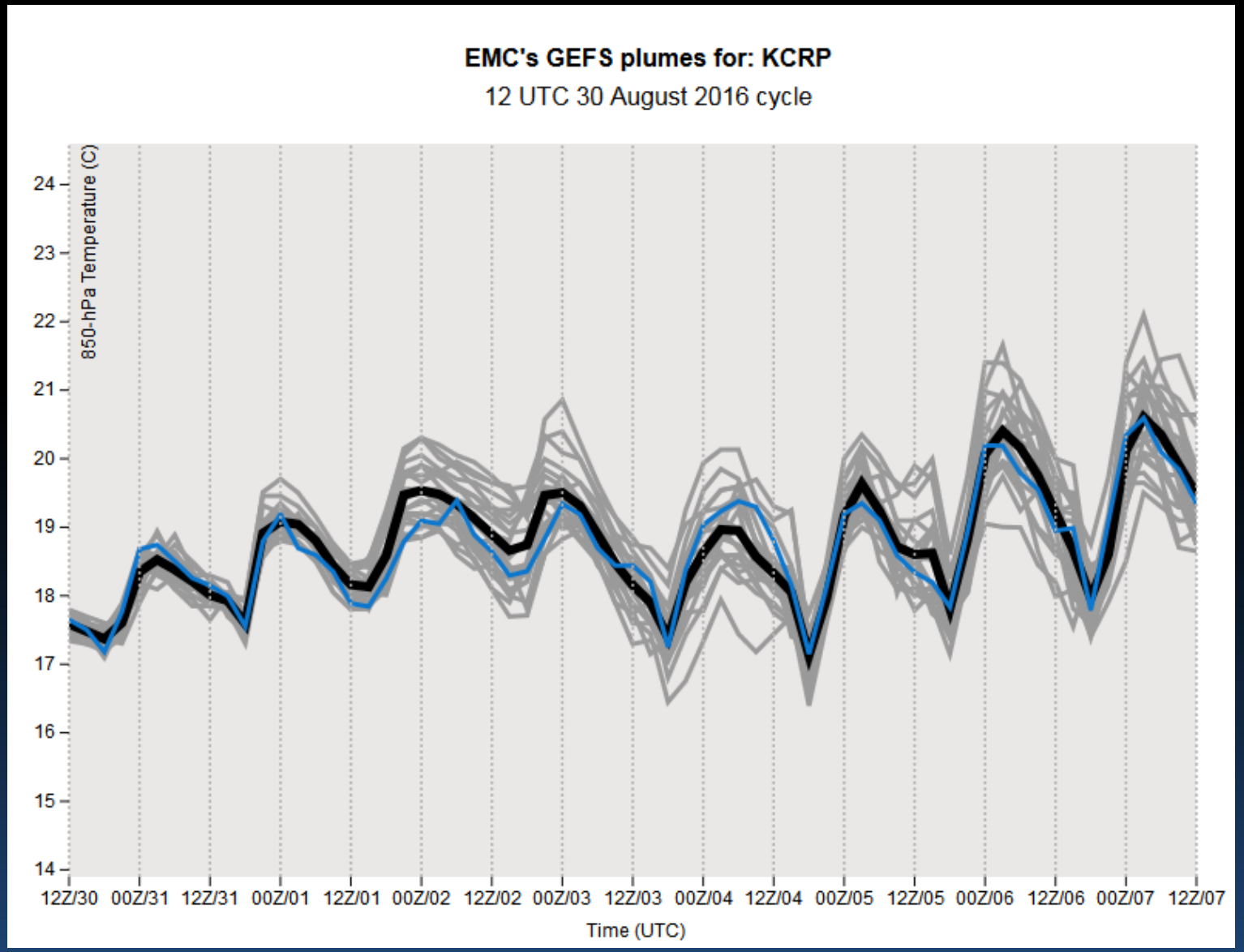
GEFS 500 mb Mean & Spread



- Majc
  - Or
    ca


Planes
Theta
Hgt
Radar
Misc
Inventory
GFSensemble MSL Pressure (mb) Perturbation p5 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation p4 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation p3 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation p2 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation p1 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation n5 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation n4 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation n3 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation n2 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation n1 25.00 138HR Tue 18:00Z 30-Aug-16
GFSensemble MSL Pressure (mb) Perturbation ctl2 25.00 138HR Tue 18:00Z 30-Aug-16
* GFSensemble MSL Pressure (mb) Perturbation ctl1 25.00 138HR Tue 18:00Z 30-Aug-16

850 mb Temp GEFS Plumes for KCRP



QPF

3-h QPF

2-m T

2-m Td

10-m wind

850-hPa T

PW

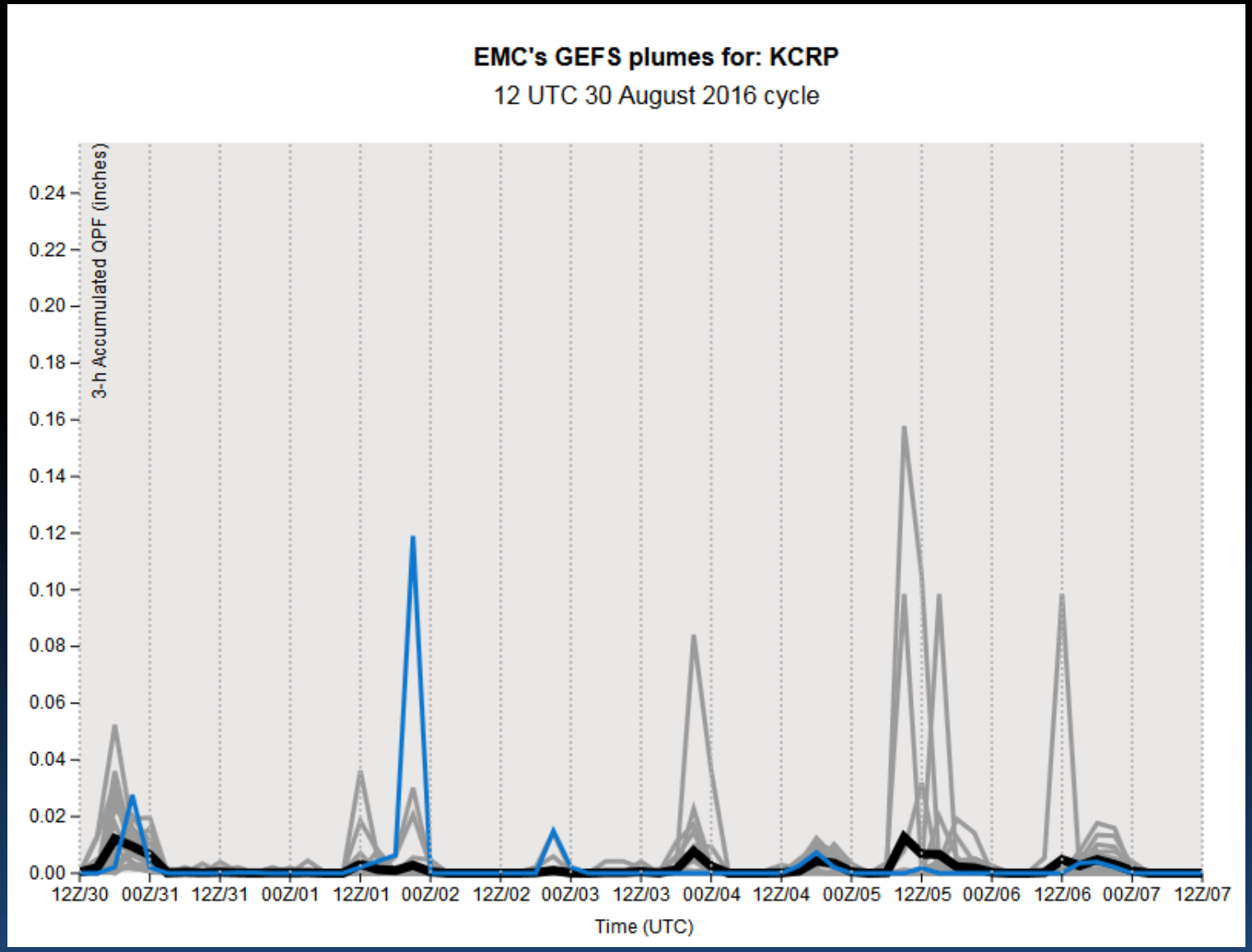
CAPE

Shear

P-type

Snow

3-hr QPF GEFS Plumes for KCRP



QPF

3-h QPF

2-m T

2-m Td

10-m wind

850-hPa T

PW

CAPE

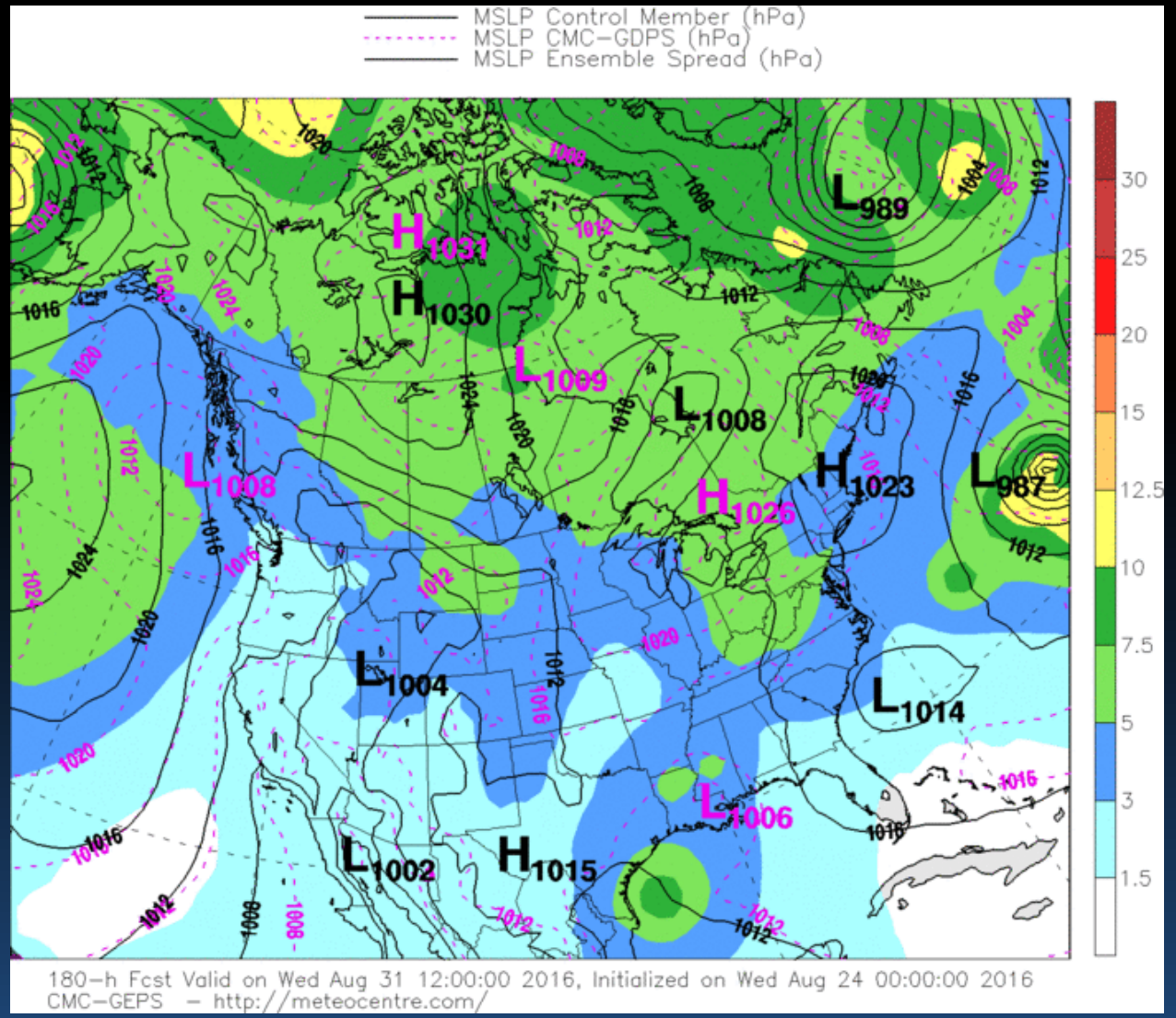
Shear

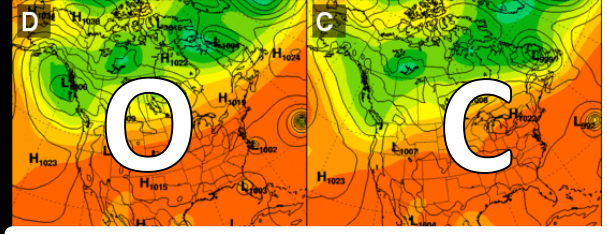
P-type

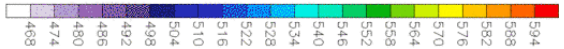
Snow

Canada's Global Ensemble Prediction System **(GEPS)**

- Global Environmental Multiscale (GEM) model is the core model.
- Run twice a day out to 16 days.
  - ~50 km resolution
- 20 "perturbed" initial conditions & physics result in 20 members.
- 1 control run.

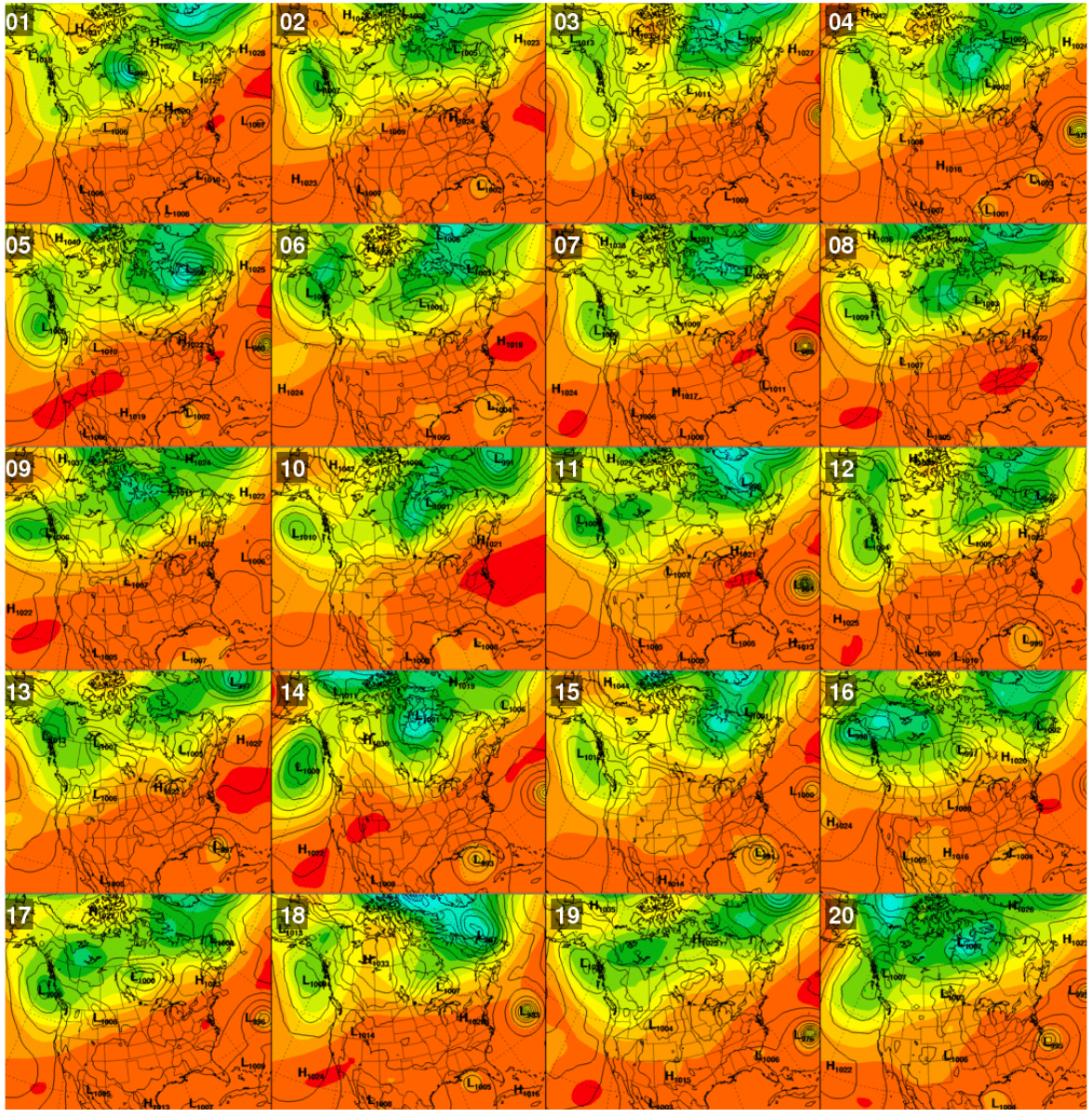






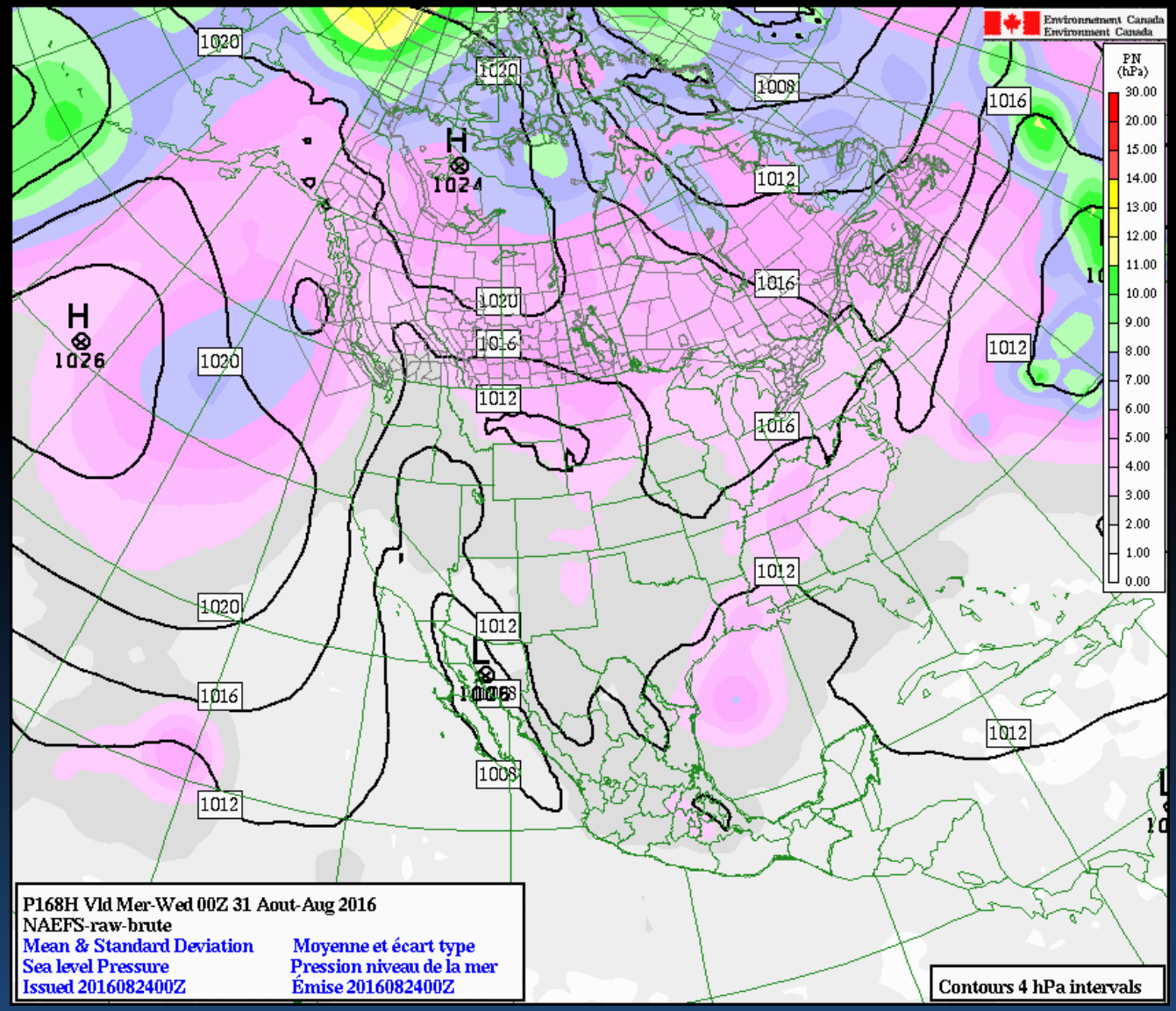
Mean Sea Level Pressure (hPa; black lines) and 500-hPa Height (dam; colors)

120-h Fcst Valid on Tue Aug 30 00:00Z 2016, Initialized on Thu Aug 25 00:00Z 2016
CMC-GDPS (D) & CMC-GEPS (C & 01-20) 00z http://meteocentre.com/

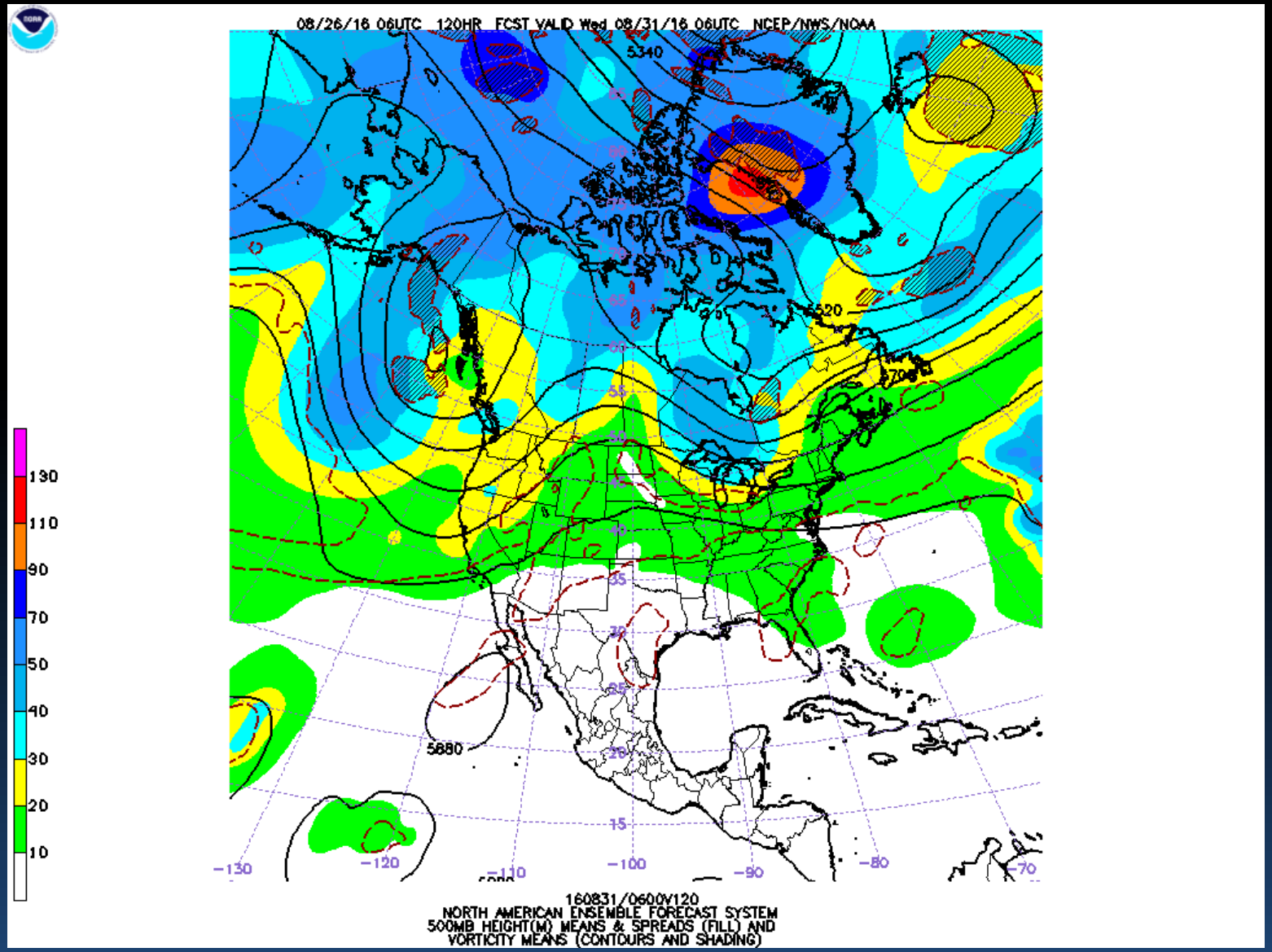


North American Ensemble Forecast System **(NAEFS)**

- GEFS and GEPS combined.
- 42 total members including 1 control run from each EPS.
- Run every 6 hours out to 16 days.
  - Resolution 1° x 1° (lat/lon).

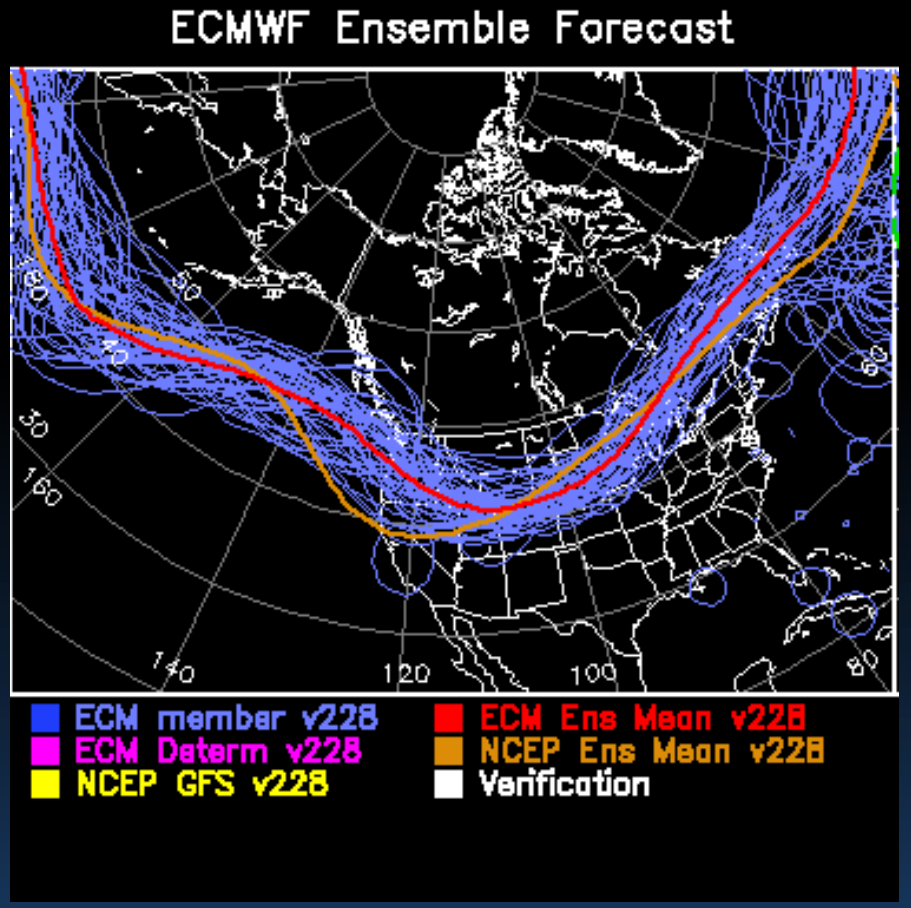


NAEFS 500 mb Mean & Spread

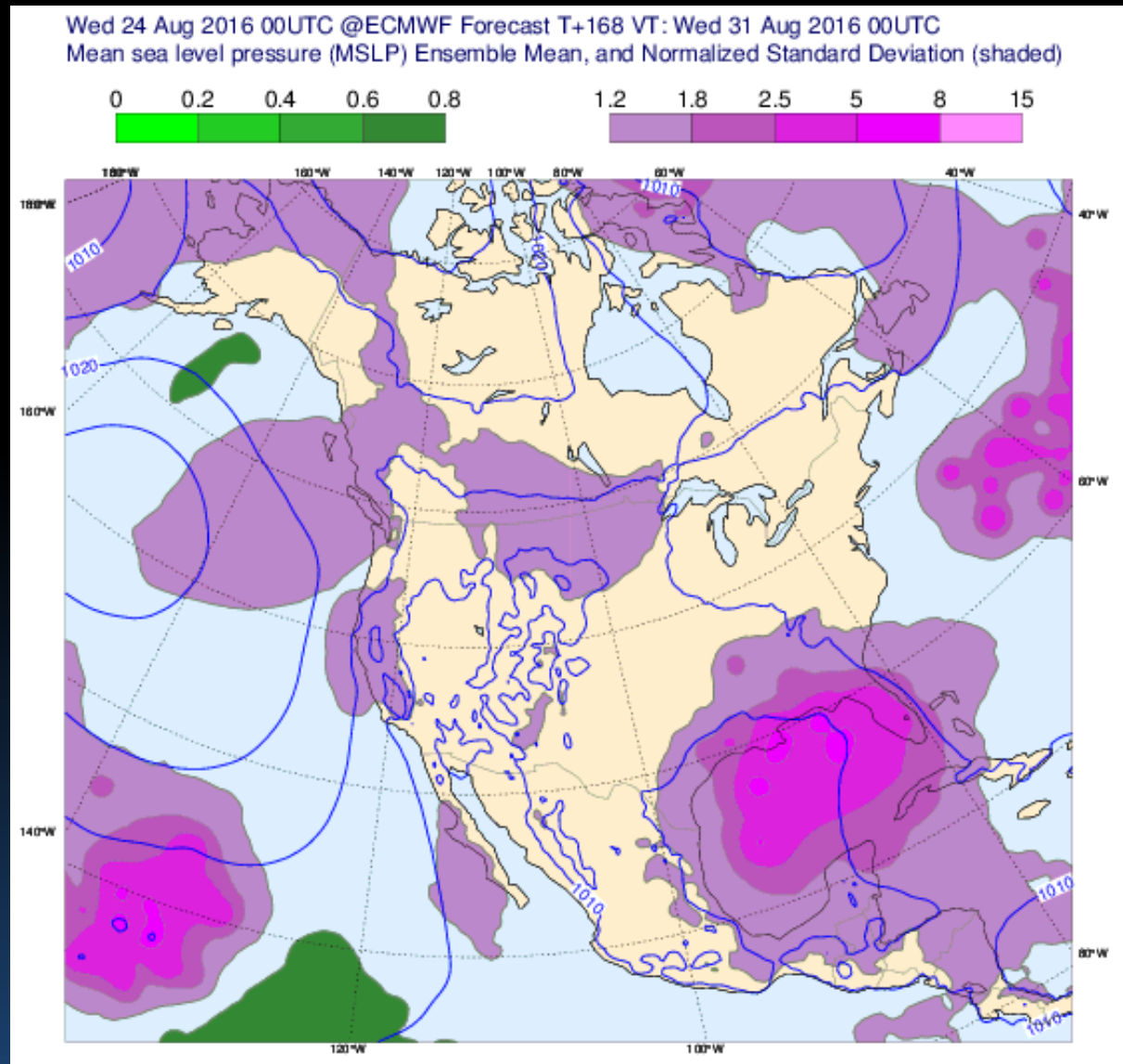


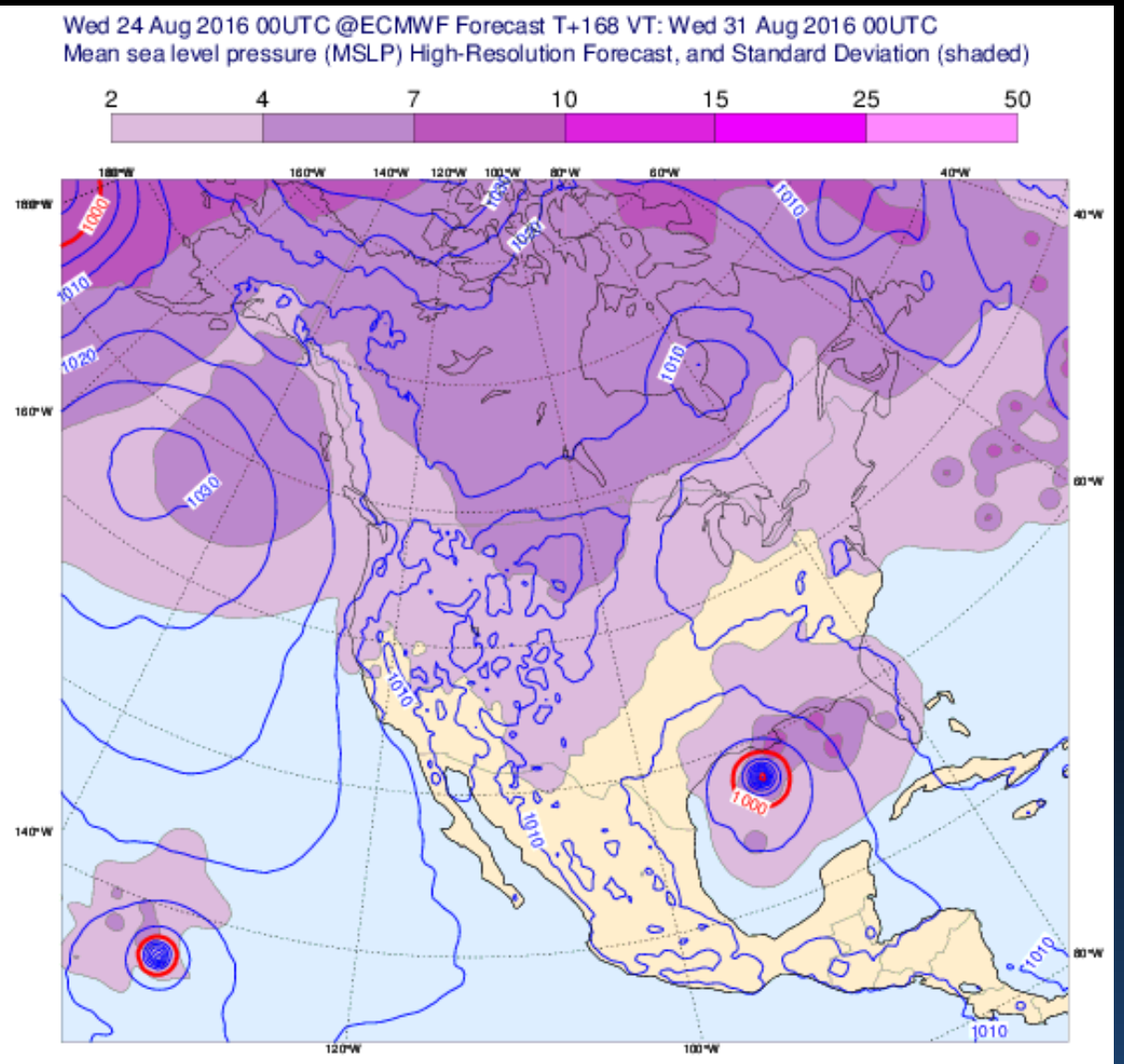
ECMWF Ensemble

- Run twice a day through 15 days.
  - ~18 km resolution.
- 50 perturbed initial conditions & physics result in 50 members.
- 1 control run.
- 1 high-resolution (HRES ~9 km) run through 10 days.



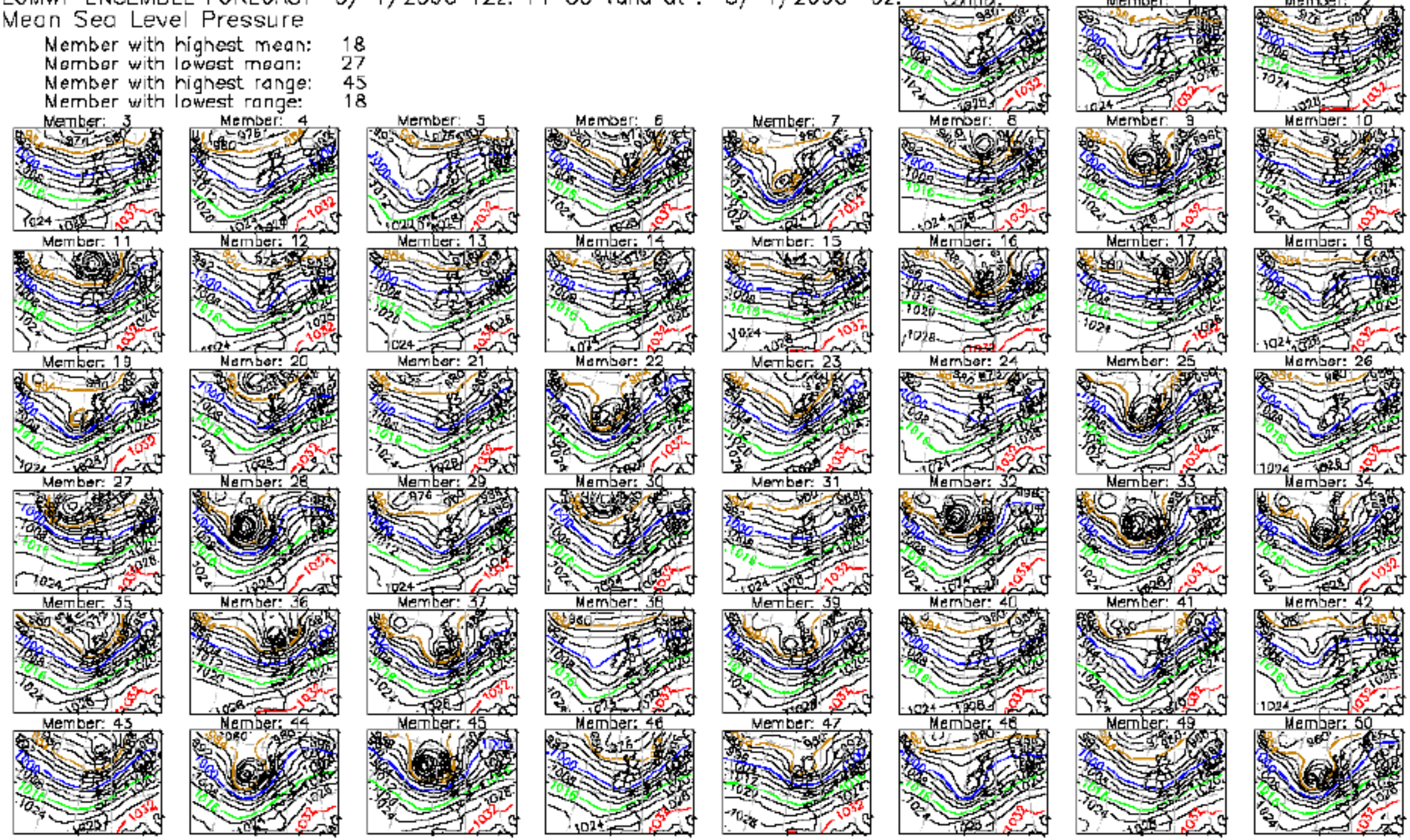
ECMWF Ensemble MSLP (Mean and High-Res)





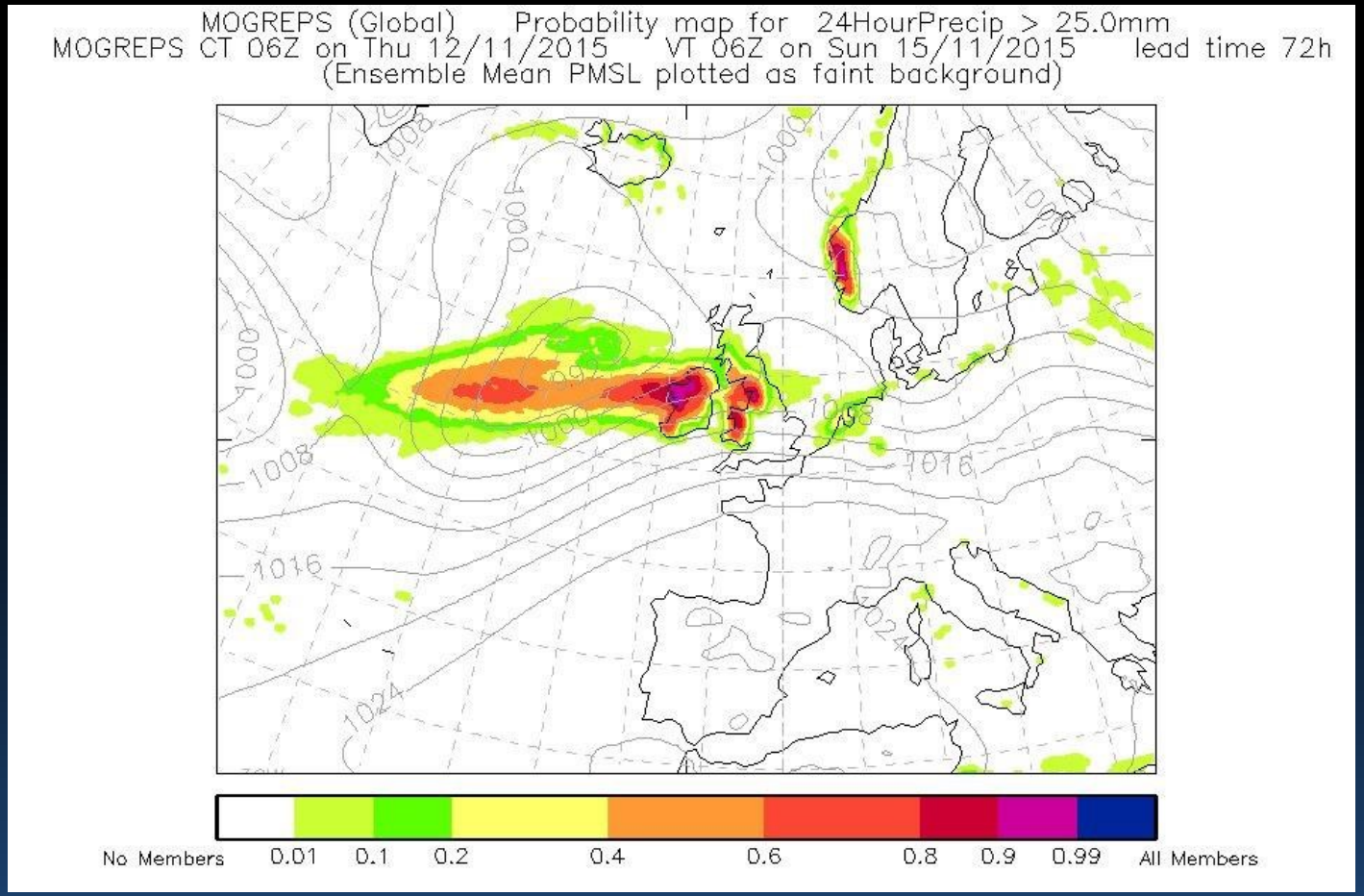
ECMWF ENSEMBLE FORECAST 6/ 1/2005 12z. T+ 36 Valid at : 8/ 1/2005 0z.
Mean Sea Level Pressure

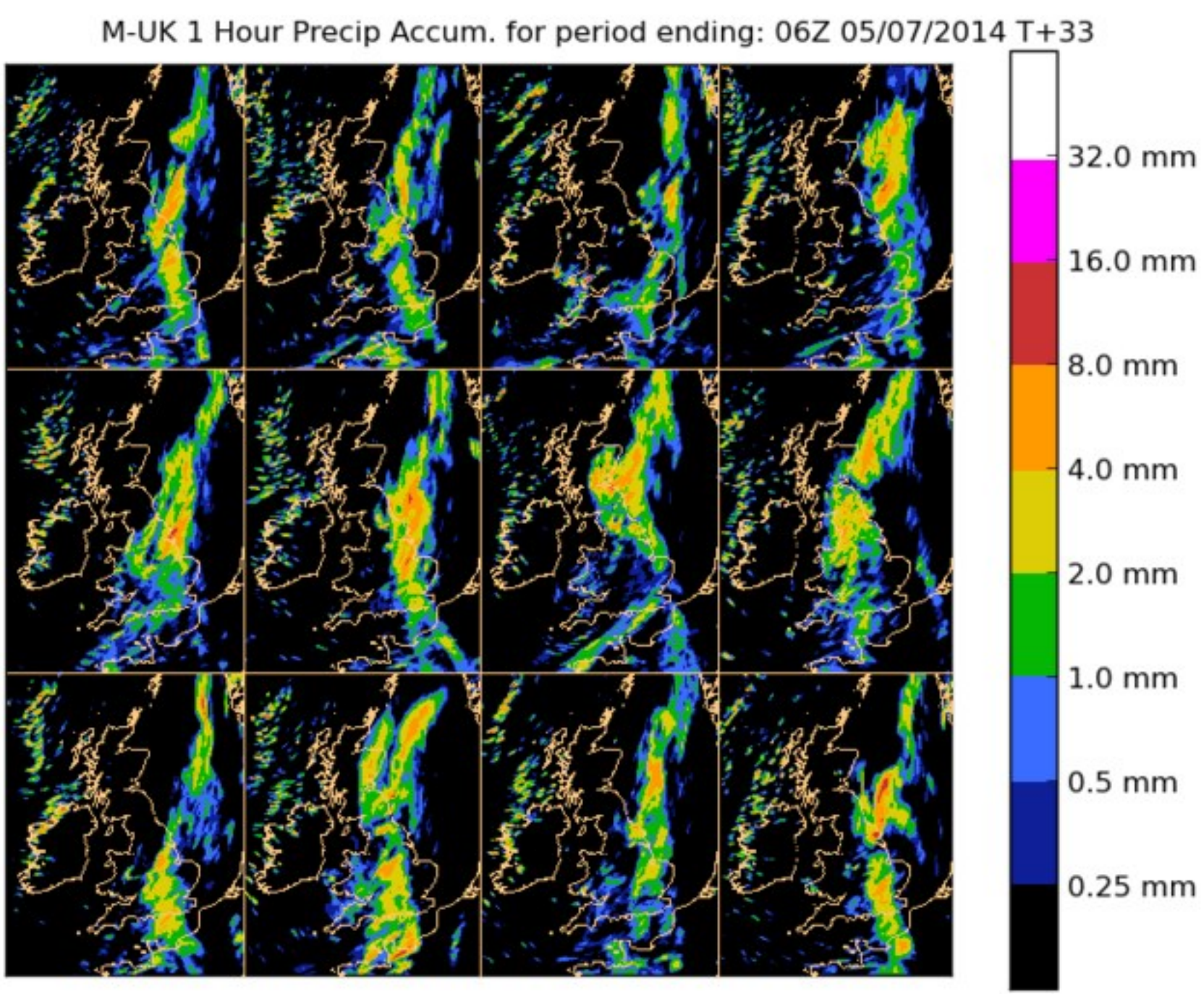
Member with highest mean: 18
Member with lowest mean: 27
Member with highest range: 45
Member with lowest range: 18



UK Met Office Global and Regional Ensemble Prediction System **(MOGREPS)**

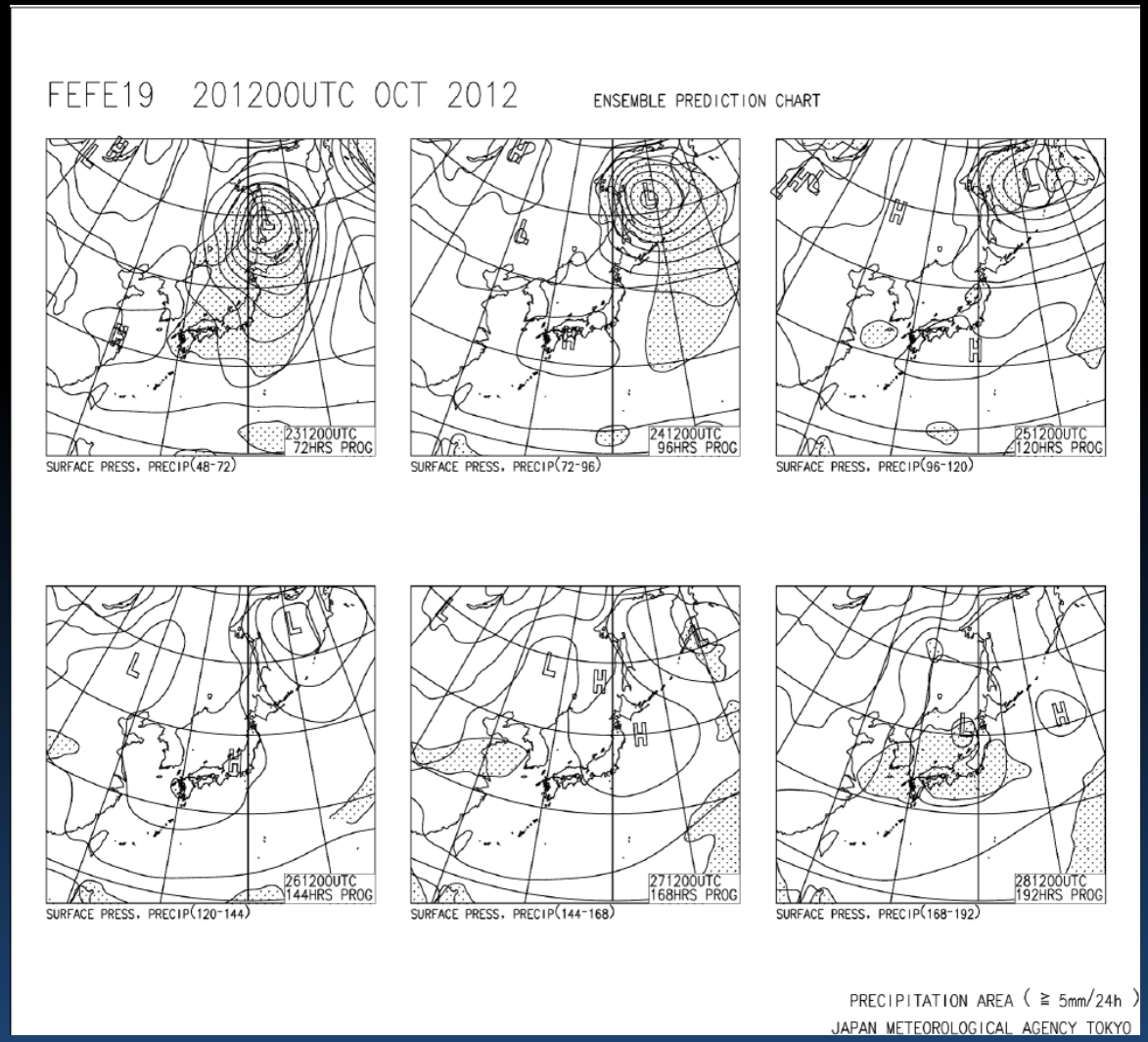
- 12 members per EPS.
  - 33 km resolution for Global
  - 2.2 km resolution for Regional (UK)
- Run every 6 hours.
  - Through 7 days for Global
  - Through 36 hours for Regional




M-UK 1 Hour Precip Accum. for period ending: 06Z 05/07/2014 T+33
32.0 mm
16.0 mm
8.0 mm
4.0 mm
2.0 mm
1.0 mm
0.5 mm
0.25 mm

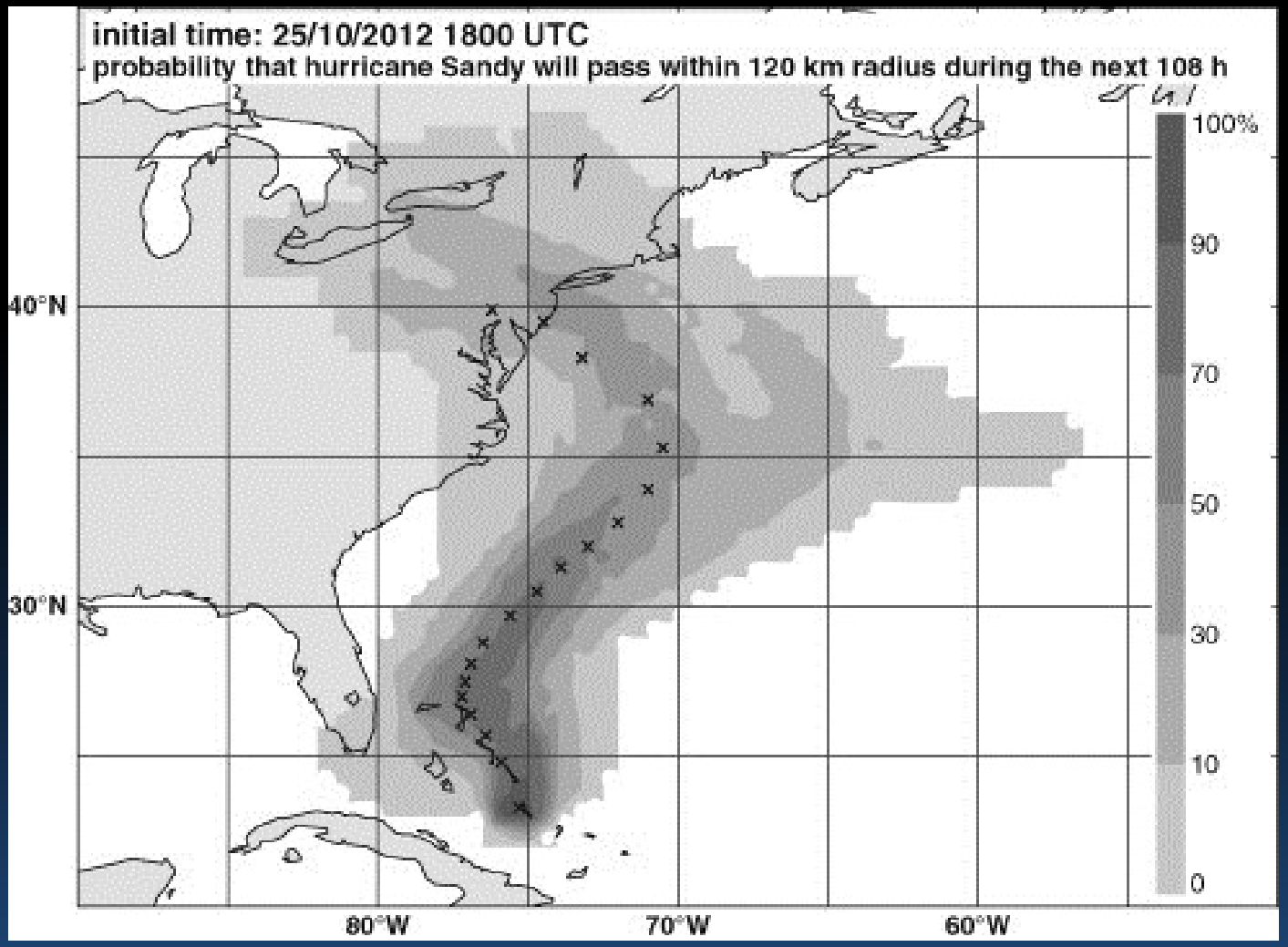
Japan Meteorological Agency
Ensemble Prediction System

- 27 members.
- Run at 00Z/12Z through 11 days.
- Resolution 0.375°.

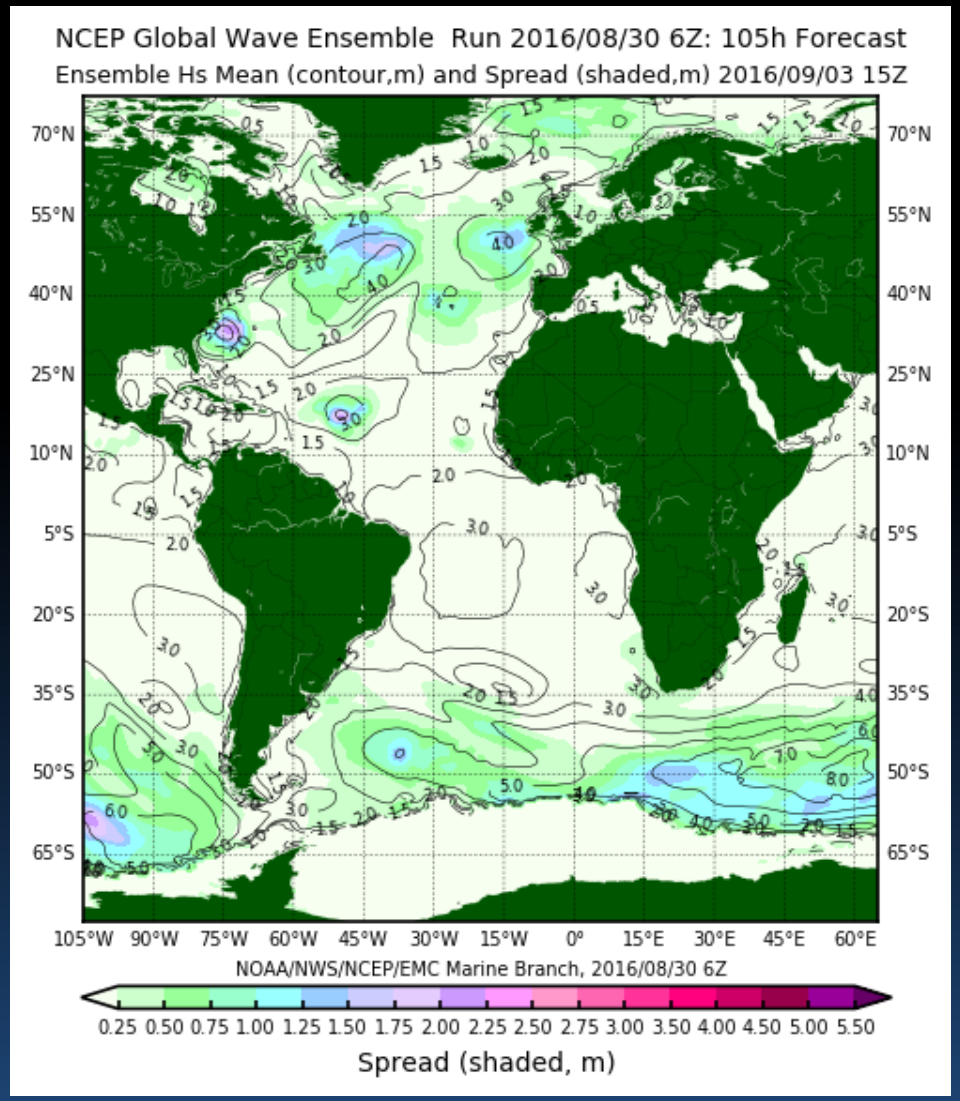


Meteo-France Prevision d'Ensemble ARPEGE **(PEARP)**

- 35 members.
- Run twice a day through 4 ½ days.
- Resolution 10-60 km.

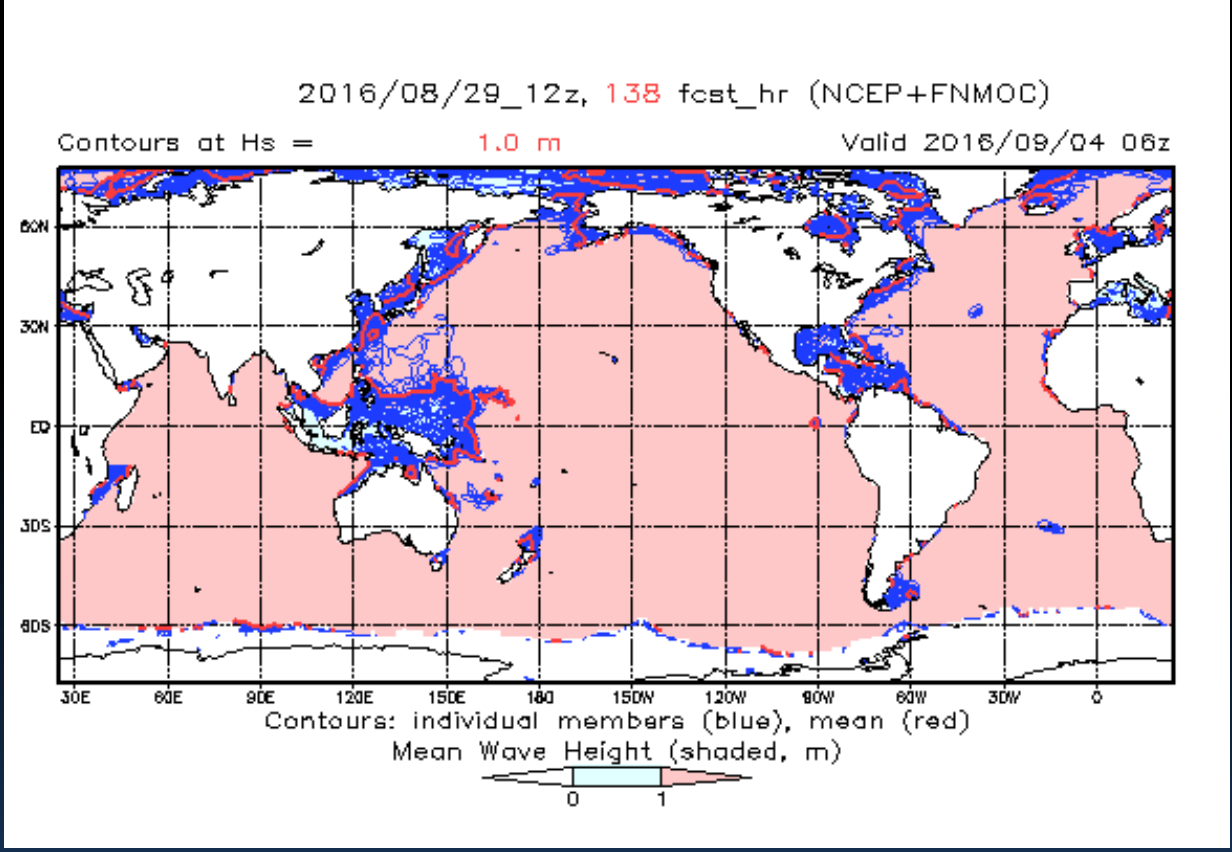


Global Ensemble Ocean Wave Forecast System (GEOWaFS)



- Uses the winds from the 21 members of GEFS.
- WaveWatch III is the core model.
- Run 4 times a day through 10 days.
- 0.1° x 0.1° resolution.

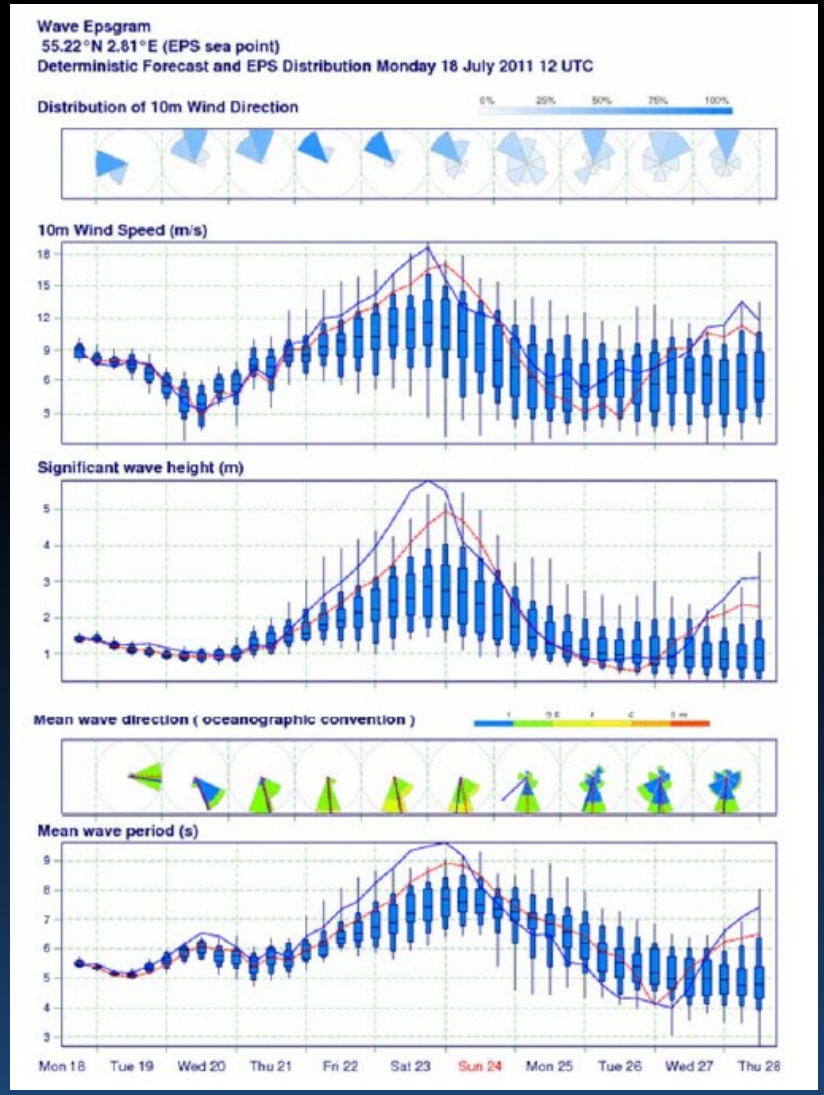
NCEP/FNMOC Wave Ensembles **(NFCENS)**



- 41 total wave ensembles from GEFS and FNMOC.
- Run 4 times a day through 10 days.
- 0.1° x 0.1° resolution.

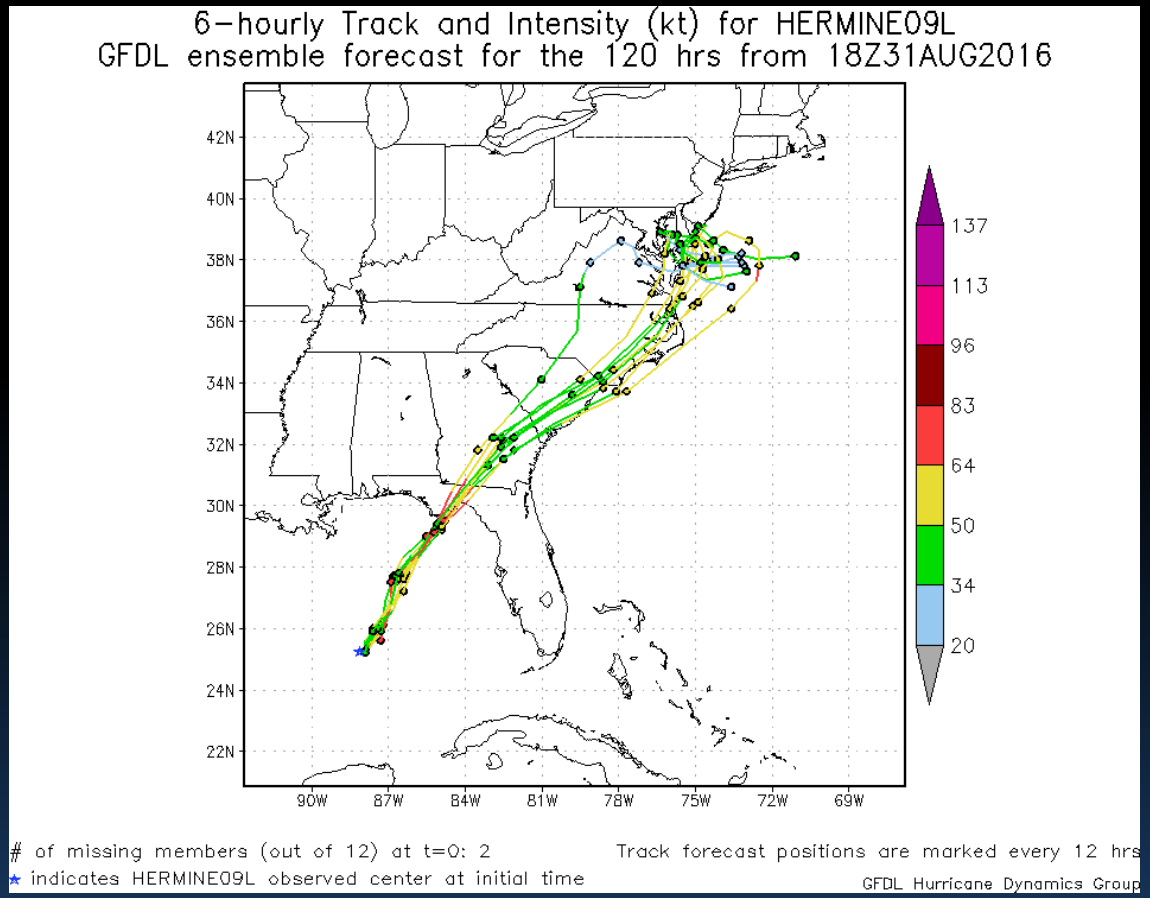
ECMWF Wave Ensemble (ENS-WAM)

- 51 members.
- Run at 00Z/12Z through 15 days.
- 0.25° x 0.25° resolution.



GFDL Hurricane Model Ensemble

- GFDL model is the core.
- 12 members based on initial and boundary conditions from GFS.
- ~55 km (parent), ~18 km, and ~6 km nest resolutions.
- 42 vertical levels.

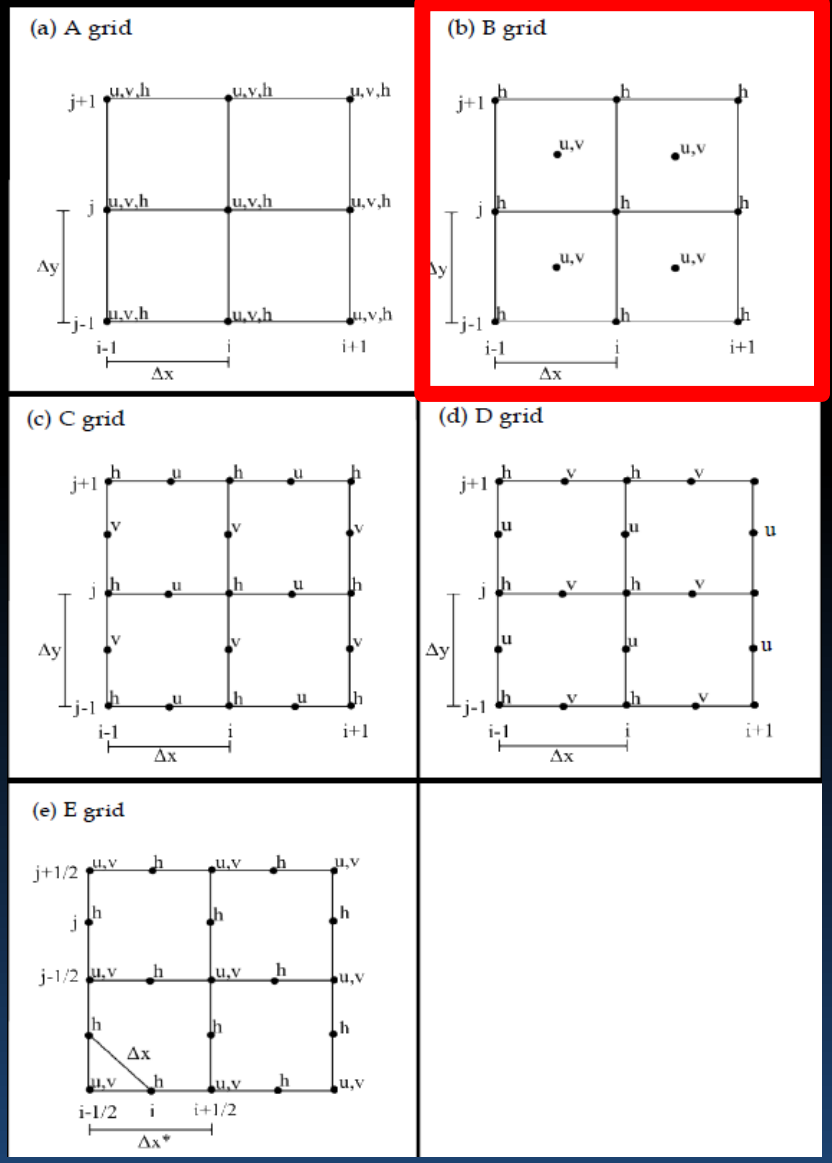


Short-Range EPS/EFS

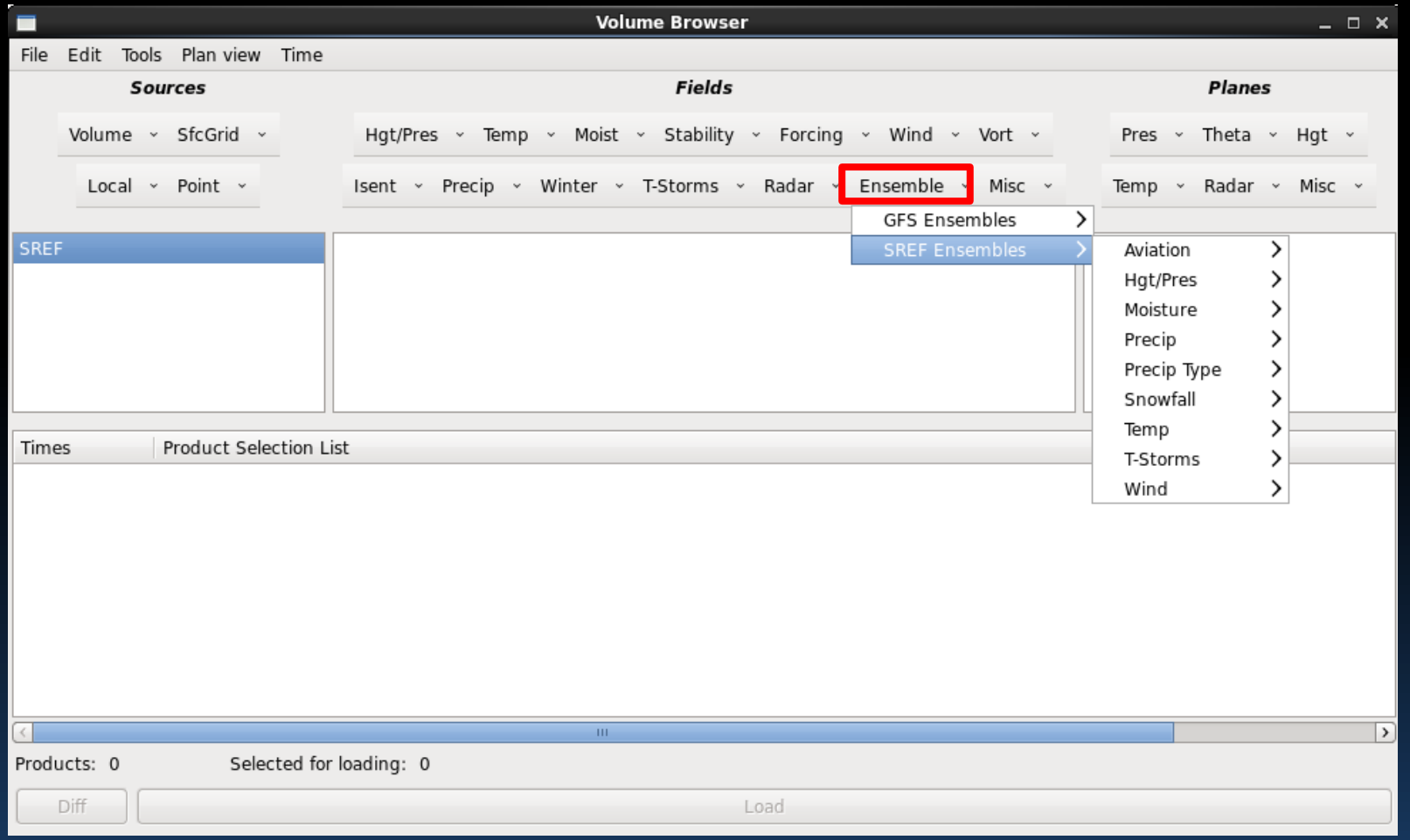
Short-Range Ensemble Forecast **(SREF)**

- 2 model cores used.
  - Nonhydrostatic Multiscale Model on B-grid **(NMM-B)**
  - Advanced Research WRF **(ARW)**
- 26 members produced from “perturbed” initial conditions & physics.
  - 13 members per core.
- Run at 03Z, 09Z, 15Z, and 21Z through 87 hours.
  - Hourly through 36 hours for derived aviation output (SREF website).
- Horizontal resolution 16 km.
- Vertical resolution 40 layers.

Arakawa Grids

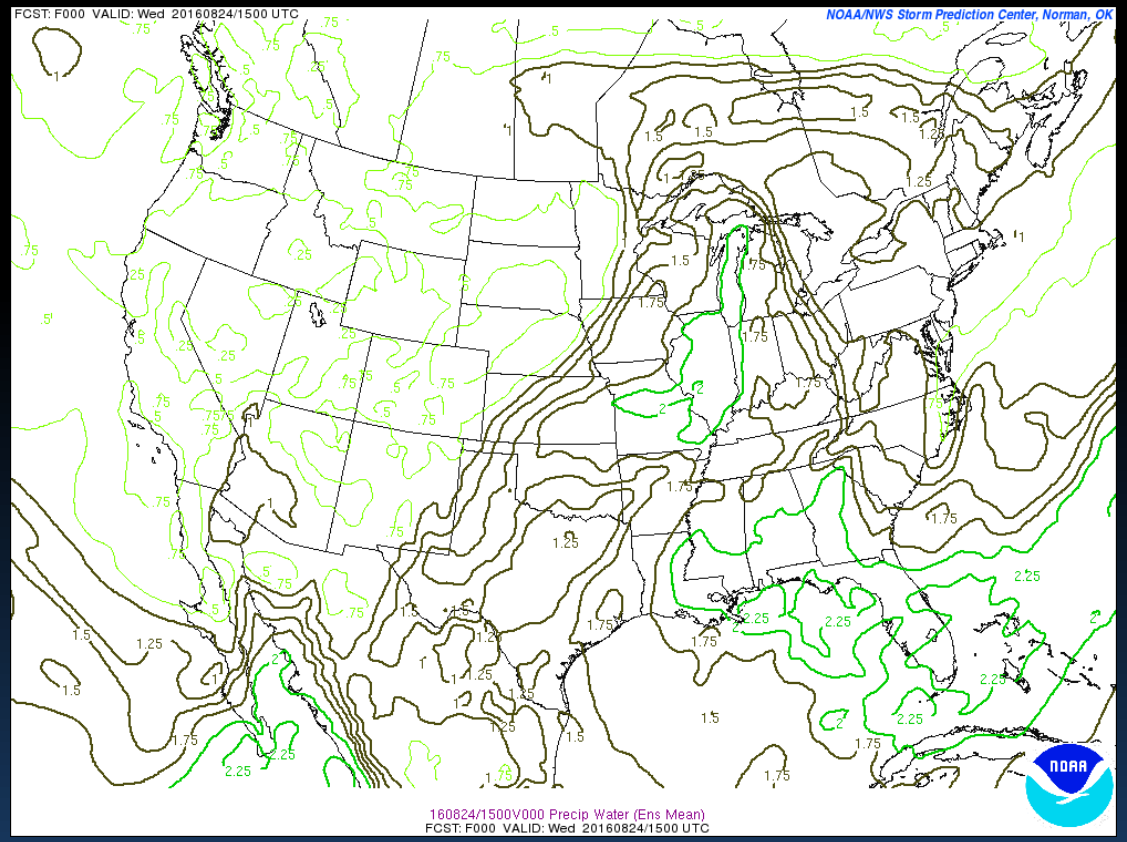


SREF in AWIPS

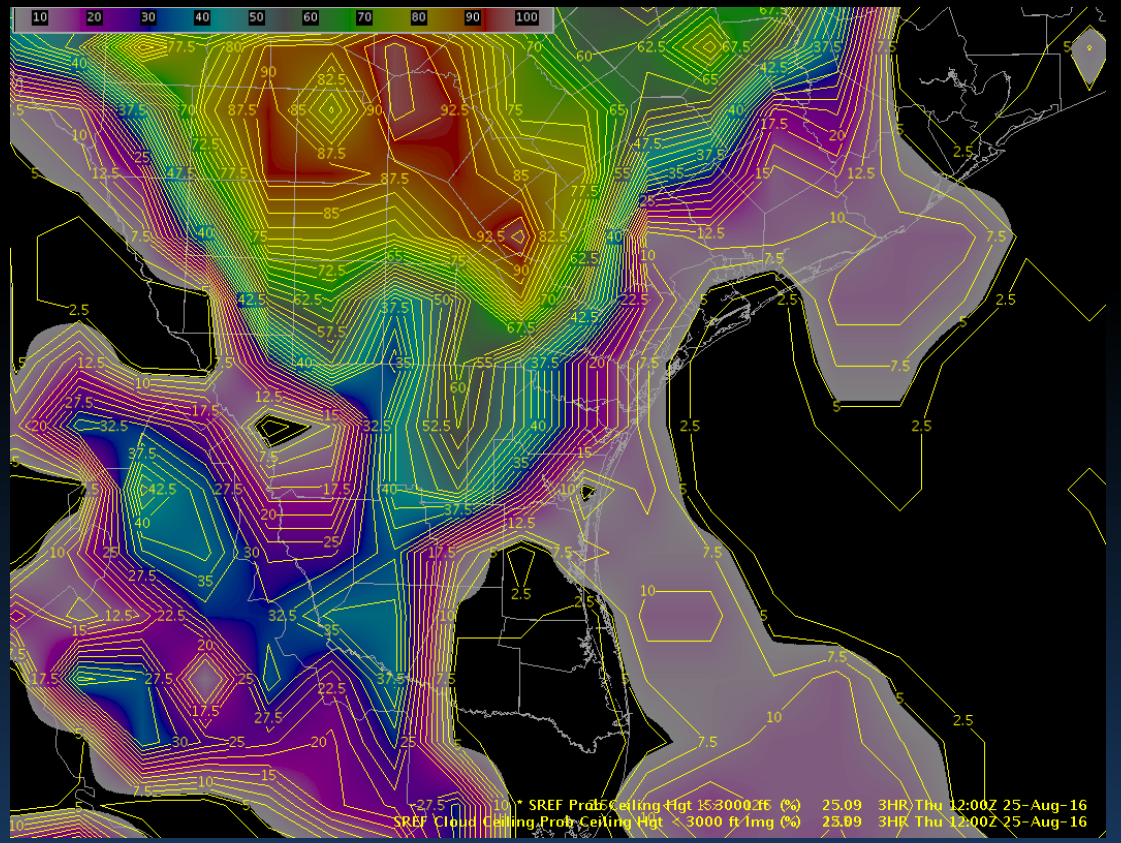


SREF Output

Mean PWAT

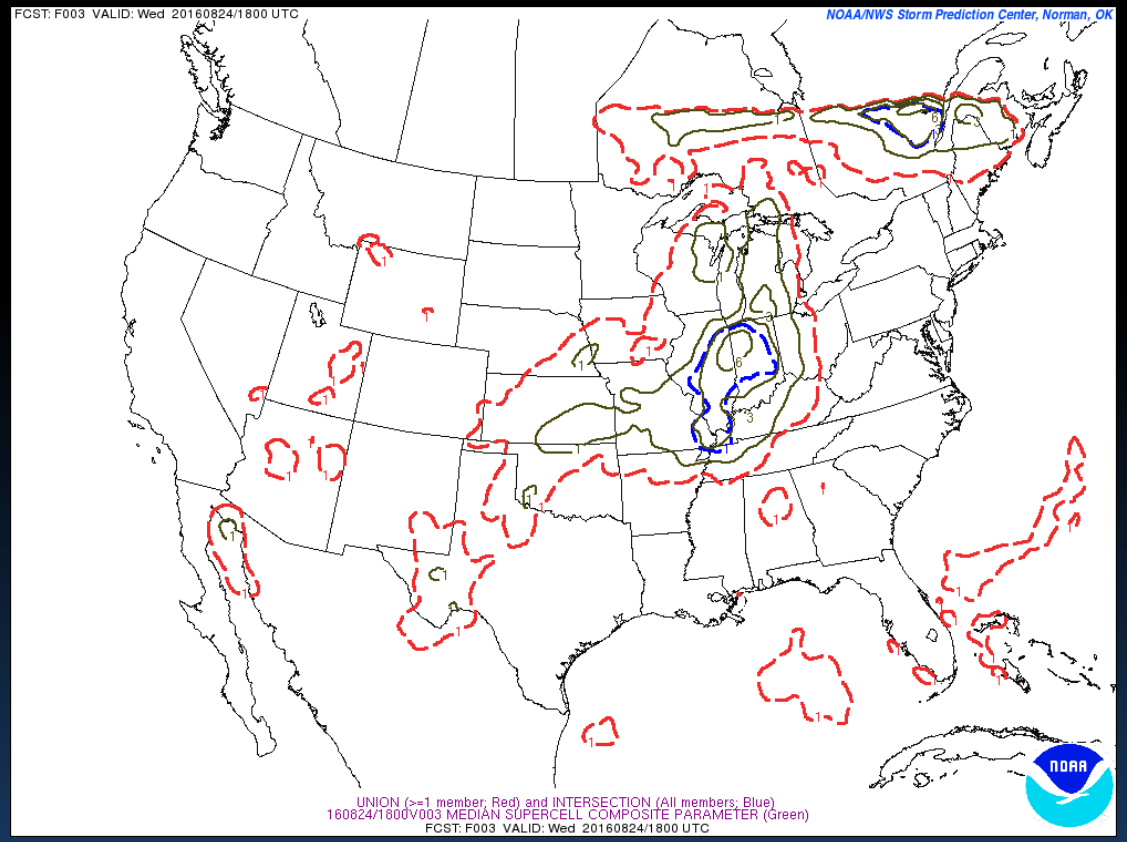


Probability of CIGs < 3k ft

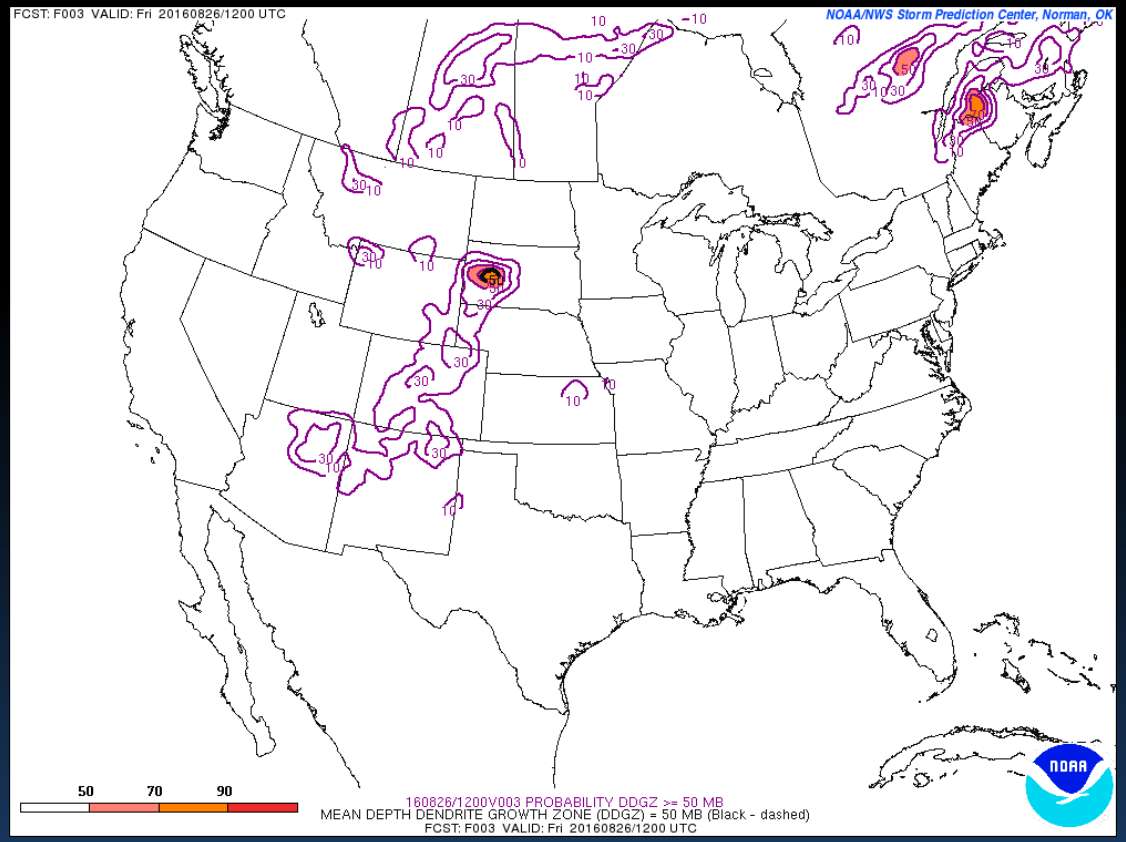


SREF Output from SPC

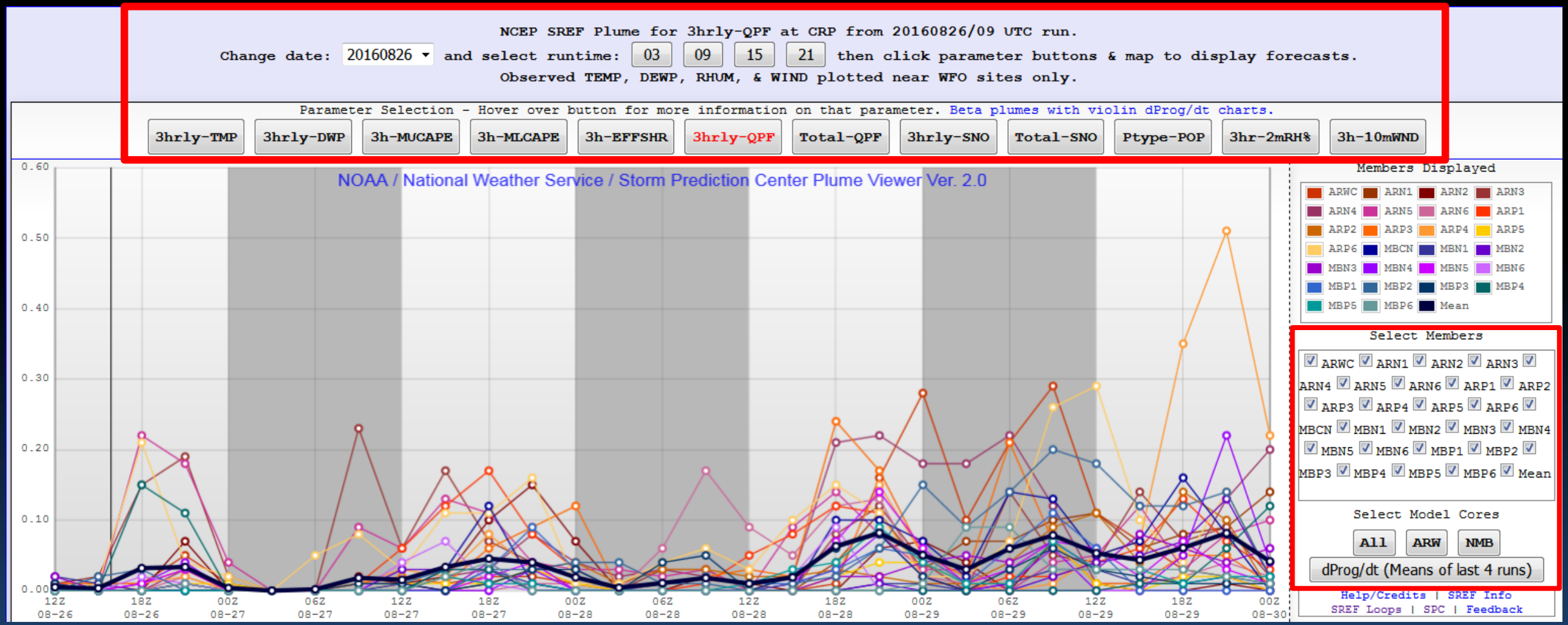
Supercell Composite Parameter



Prob of Dendritic Growth Zone >= 50 mb

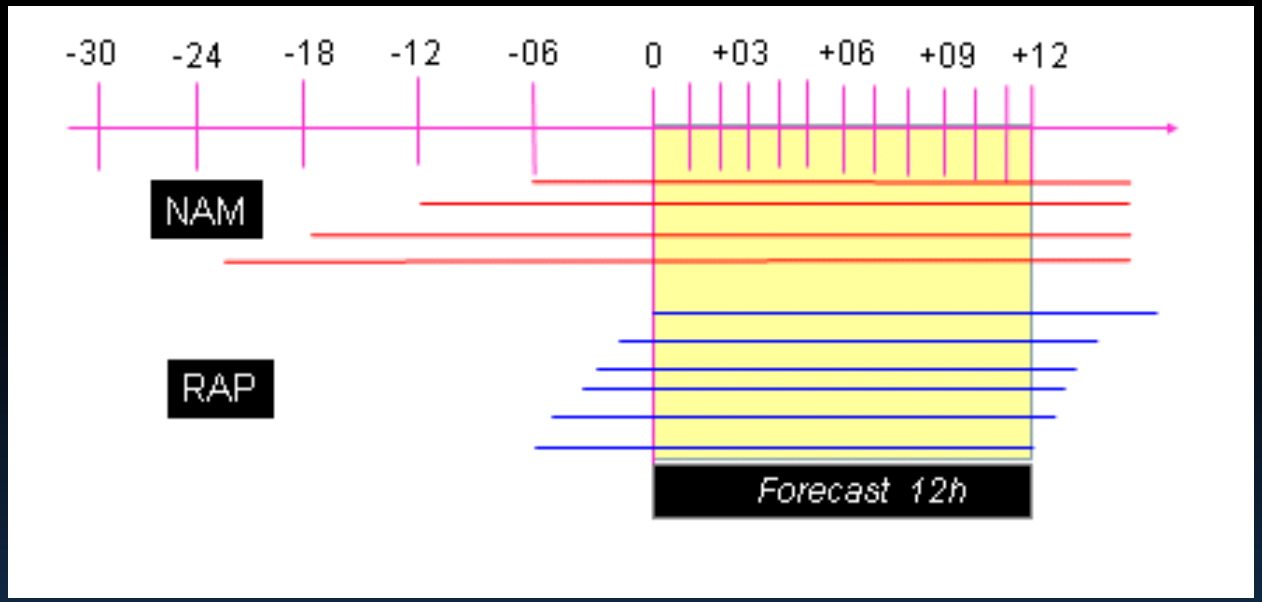


SREF Plume for CRP depicting 3-hour QPF from SPC



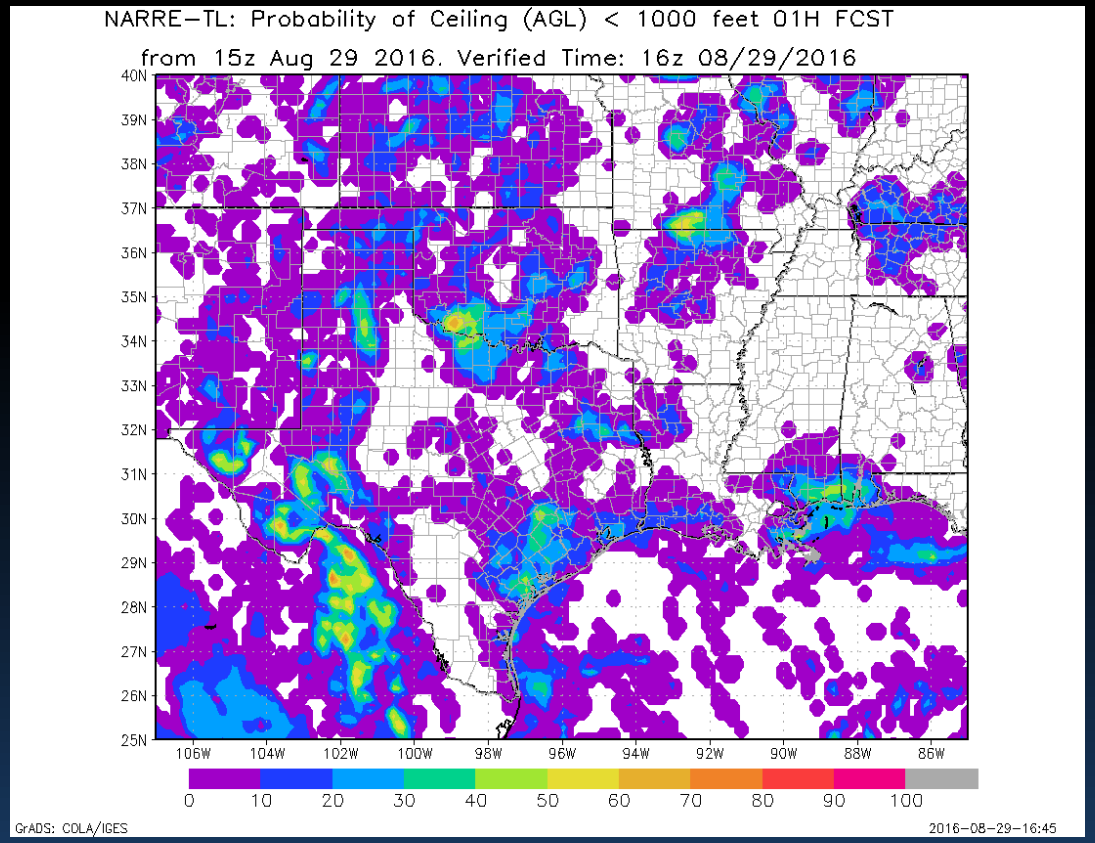
Time-Lagged North American Rapid Refresh Ensemble (NARRE-TL)

- Composed of NAM and RAP models.
- 10 total members.
  - 6 RAP members
  - 4 NAM members
- Run hourly out to 12 hours.
- ~12 km resolution.
- Time-lagging.
  - Use prior forecasts valid at same time.
  - Greatest weight on most recent forecast.

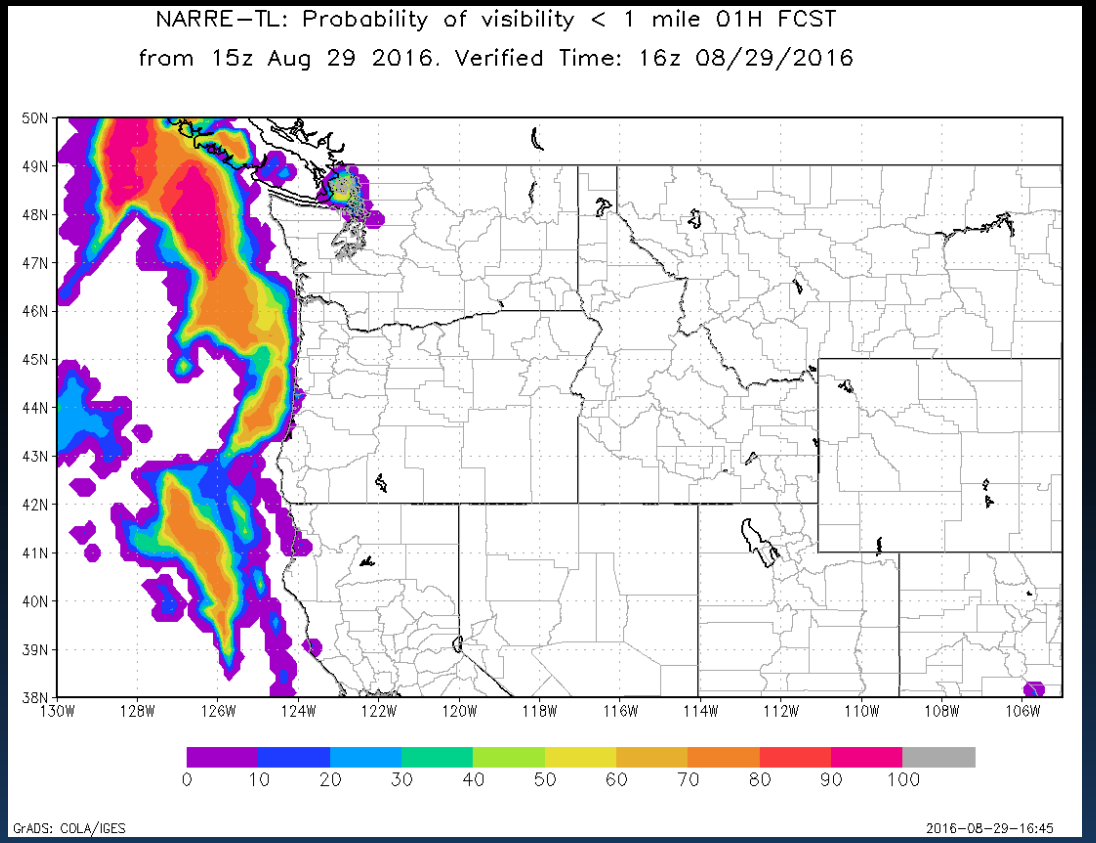


NARRE-TL Output

Prob of Cloud Base < 1k ft

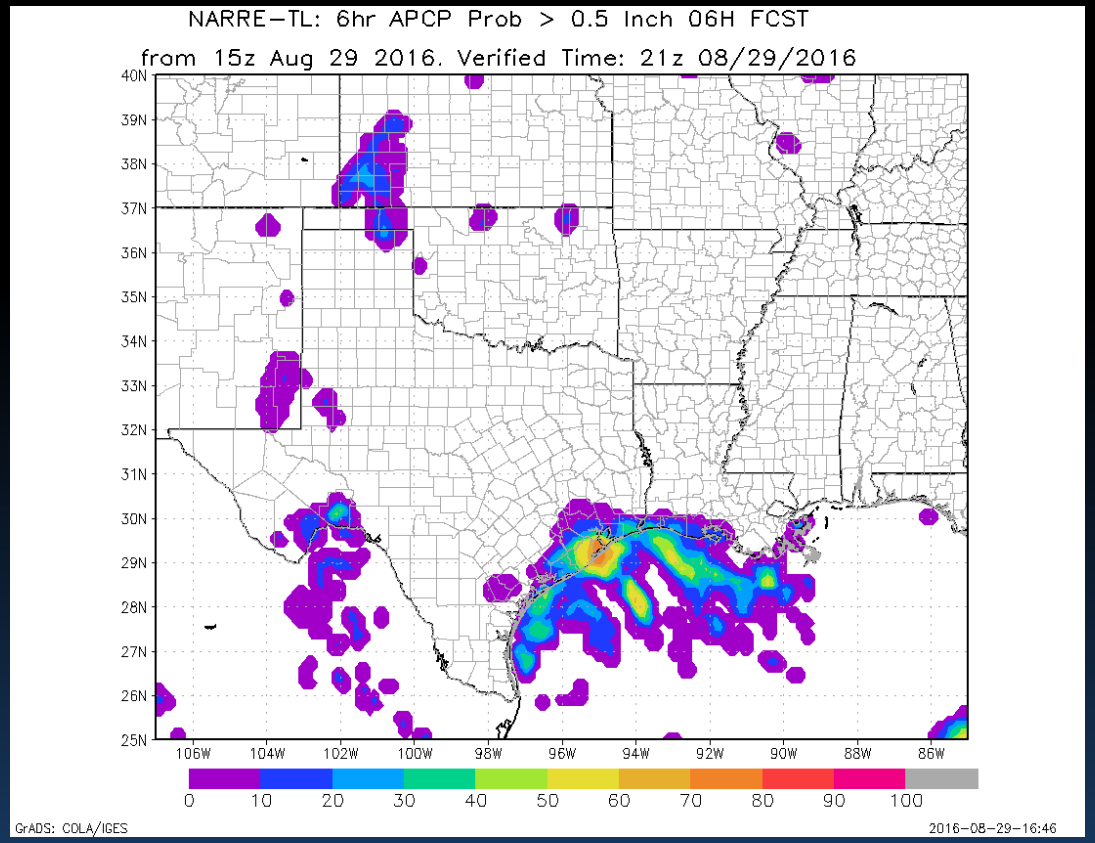


Prob of Visibility < 1 mile

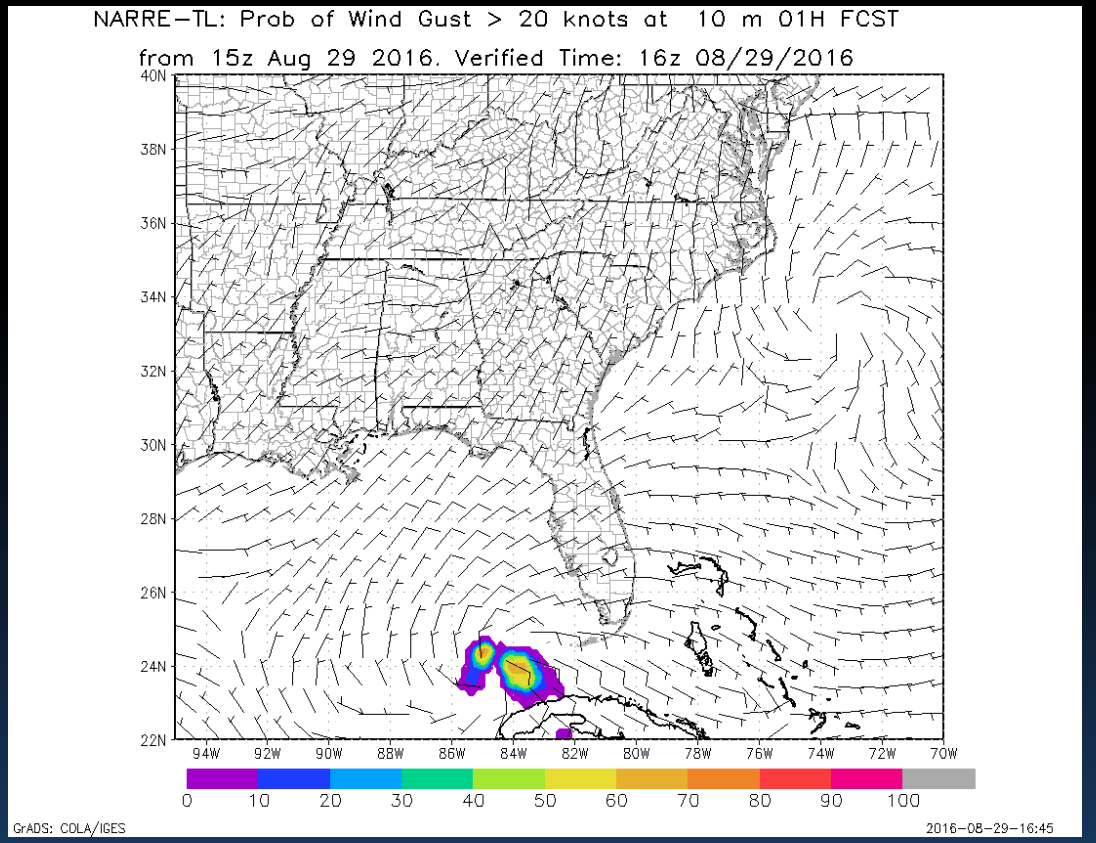


NARRE-TL Output

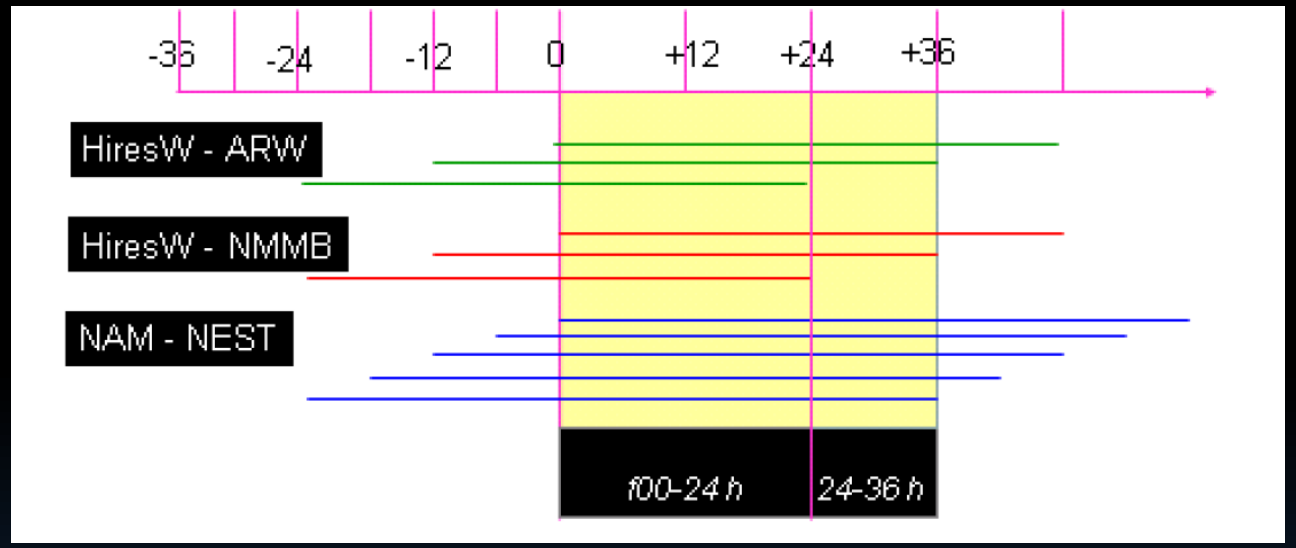
Prob of QPF > 0.5”



Prob of Wind Gust > 20 kt



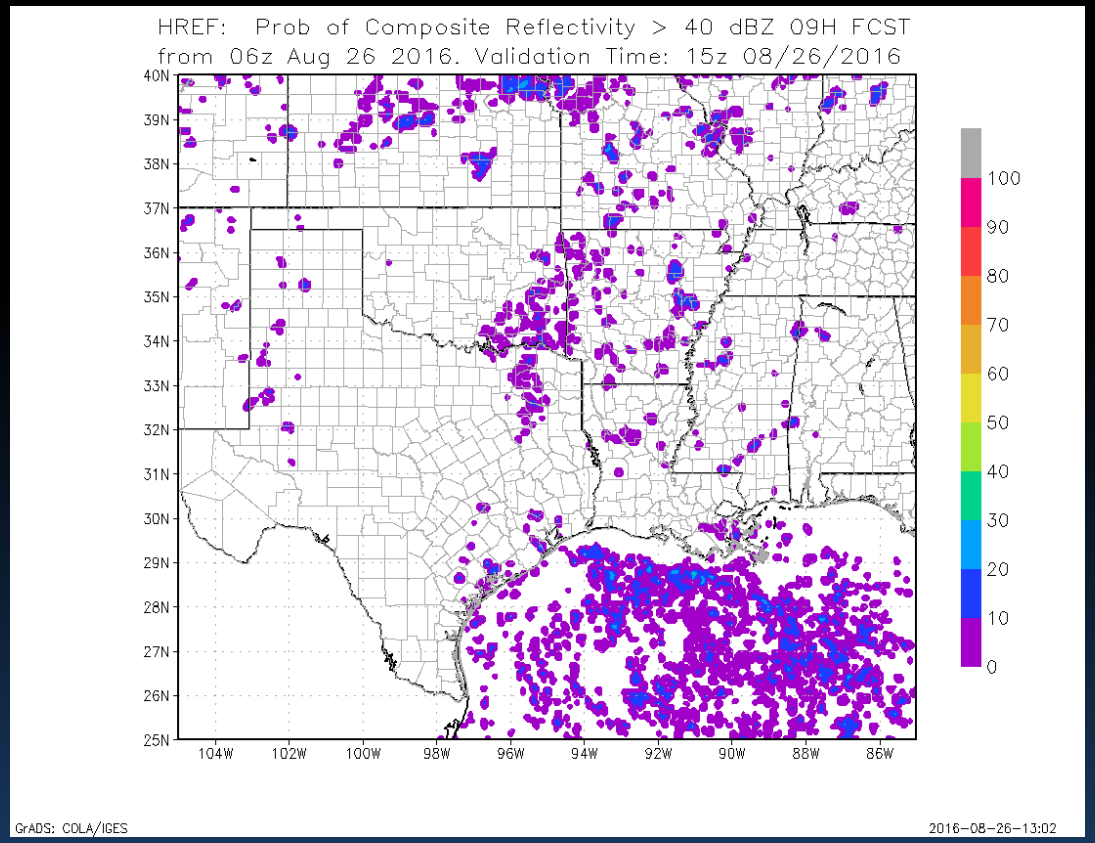
Time-lagged High Resolution Ensemble Forecast **(HREF)**



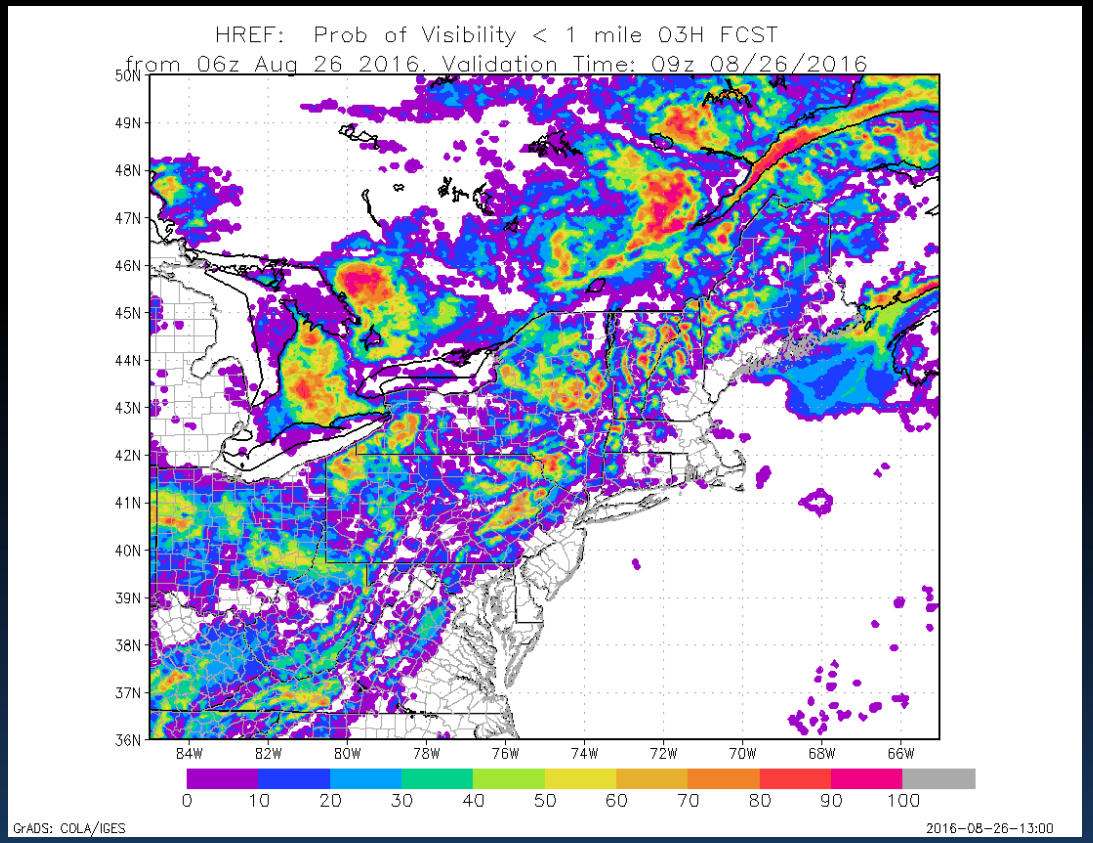
- HiResW-ARW, HiResW-NMMB, NAM-NEST models.
- 9-11 members.
- Run every 6 hours through 36 hours.
- ~4 km resolution.

HREF Output

Prob of Composite Reflectivity > 40 dBZ

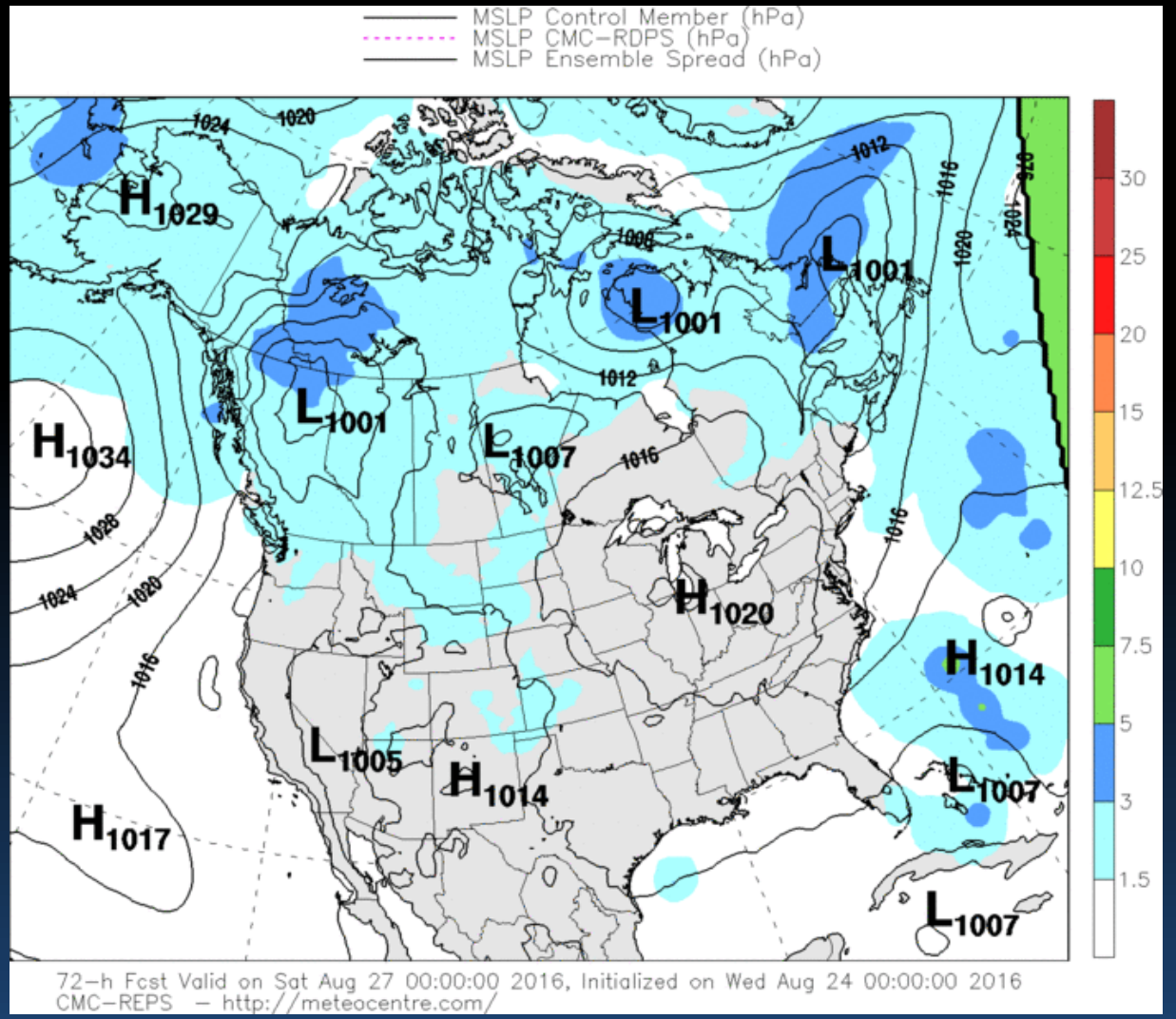


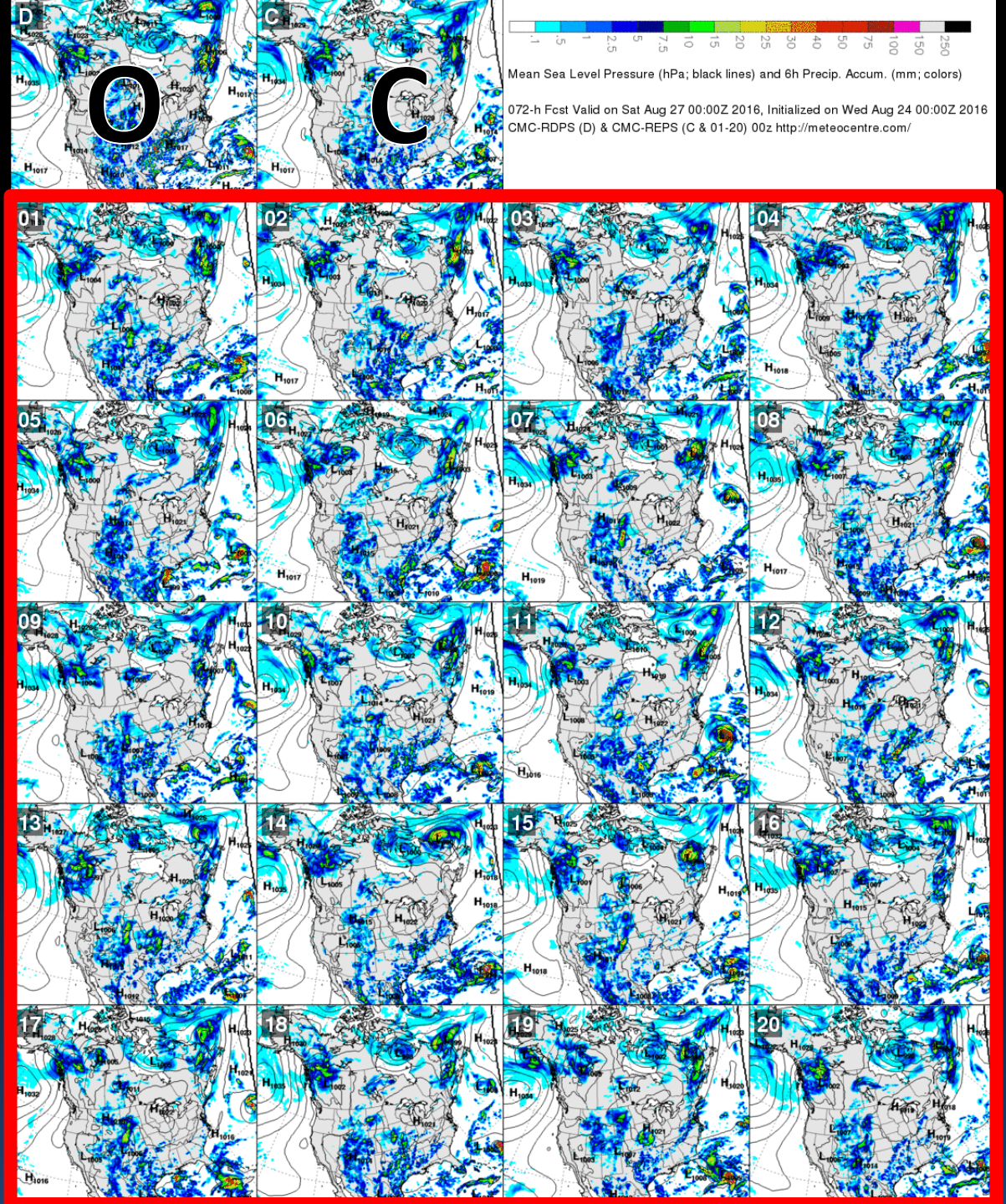
Prob of Visibility < 1 mile



CMC Regional Ensemble Prediction System **(REPS)**

- Initial conditions from GEPS.
- Physics “perturbations” result in 20 members.
  - 1 unperturbed control run.
- Run at 00Z/12Z through 72 hours.
- ~15 km horizontal resolution.
- 48 vertical levels.

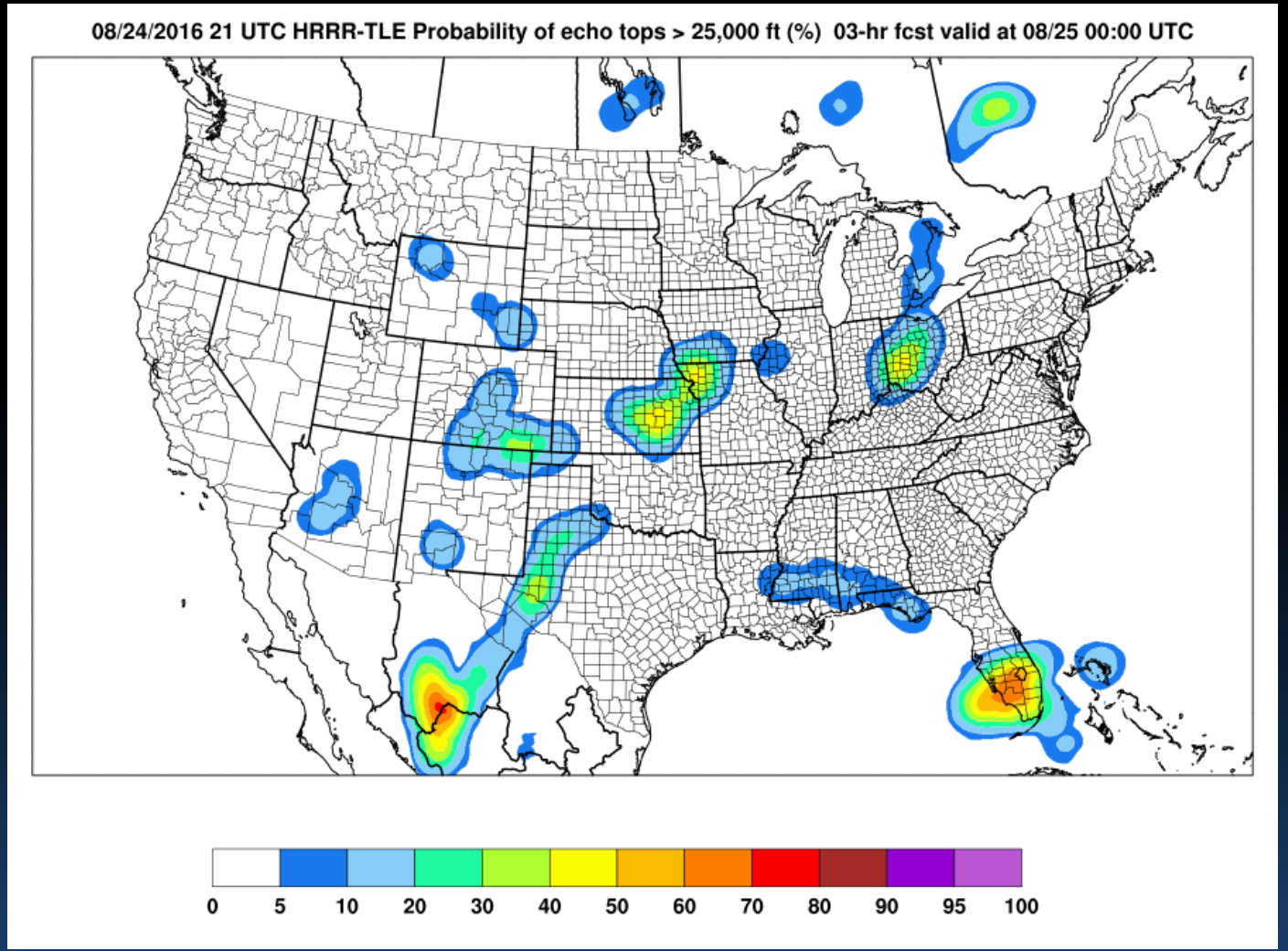



D
C
O
C
.1
.5
1
2.5
5
7.5
10
15
20
25
30
40
50
75
100
150
250
Mean Sea Level Pressure (hPa; black lines) and 6h Precip. Accum. (mm; colors)
072-h Fcst Valid on Sat Aug 27 00:00Z 2016, Initialized on Wed Aug 24 00:00Z 2016
CMC-RDPS (D) & CMC-REPS (C & 01-20) 00z http://meteocentre.com/
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20

Storm Scale EPS/EFS

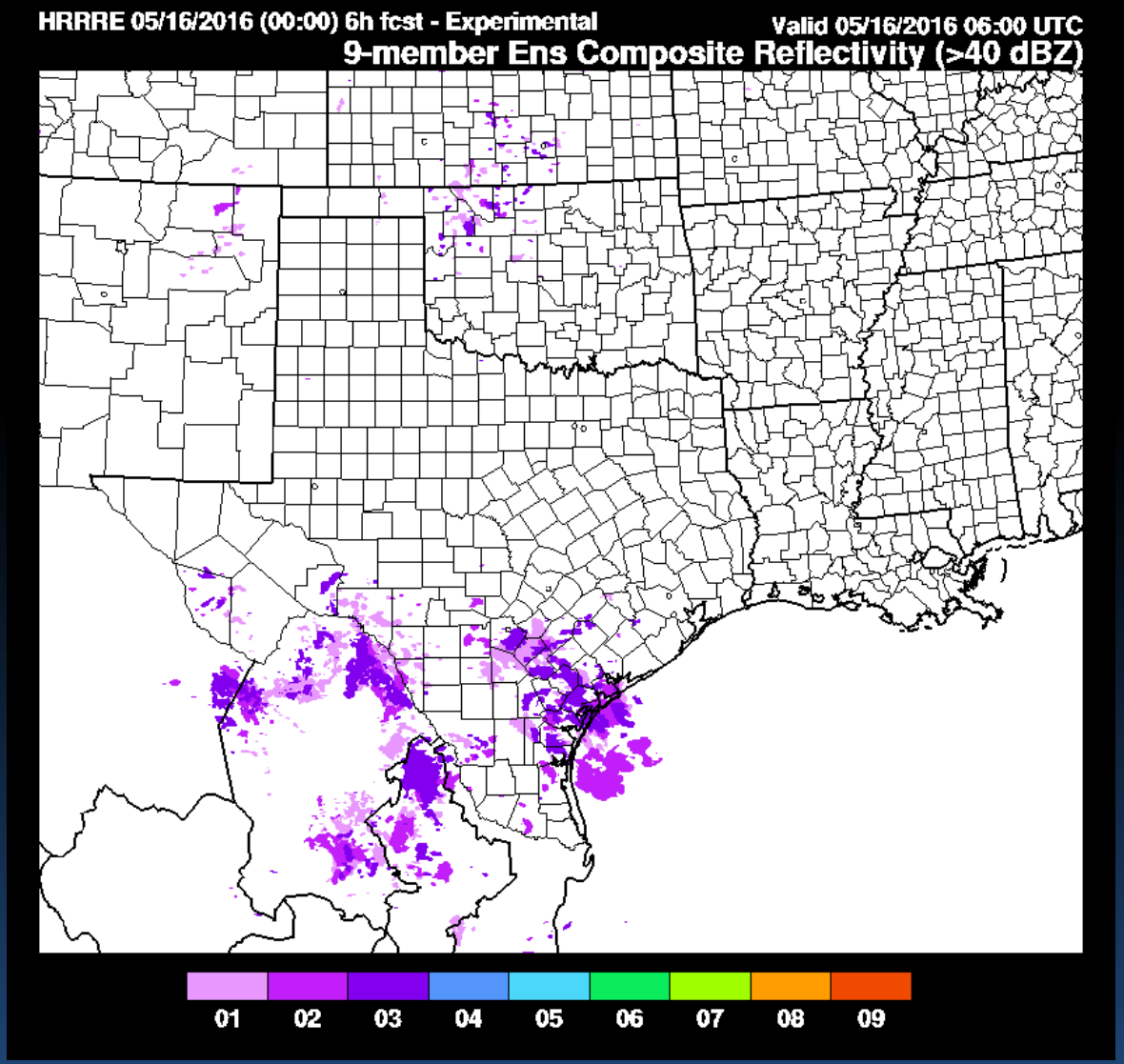
HRRR Time-Lagged Ensemble **(HRRR-TLE)**

- Experimental.
- 3 members.
  - Most recent HRRR run.
  - 2 previous HRRR runs.
- Run through 24 hours.
- 3 km resolution.
- Neighborhood probabilities.
- Severe wx, flash flood, and aviation applications.

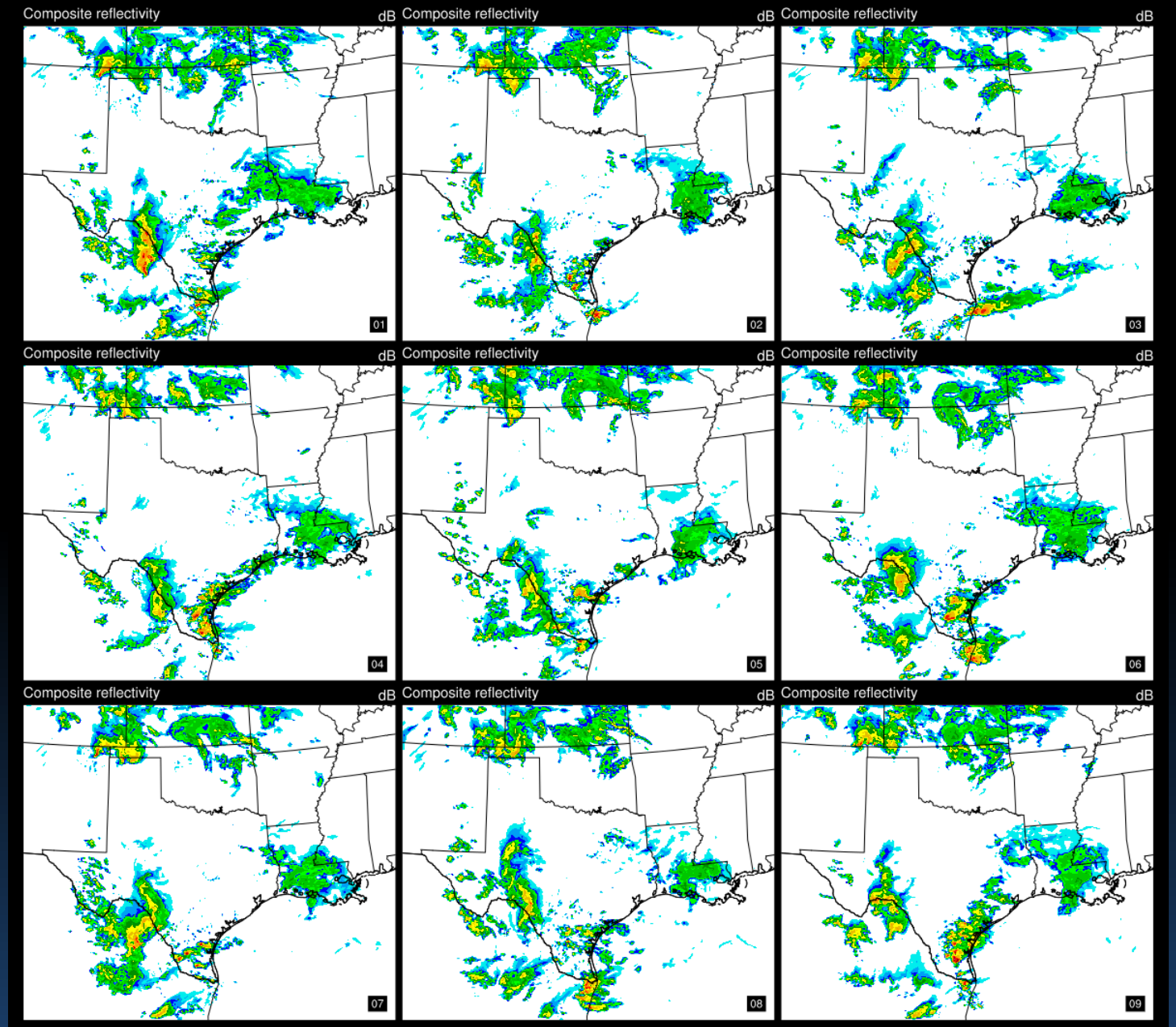


HRRR Ensemble **(HRRRE)**

- Experimental.
- 3-18 members.
  - Uses 40 HRRR members for data assimilation.
- 3 km resolution.
- Smaller domain than HRRR.
- Perturbations from GEFS.



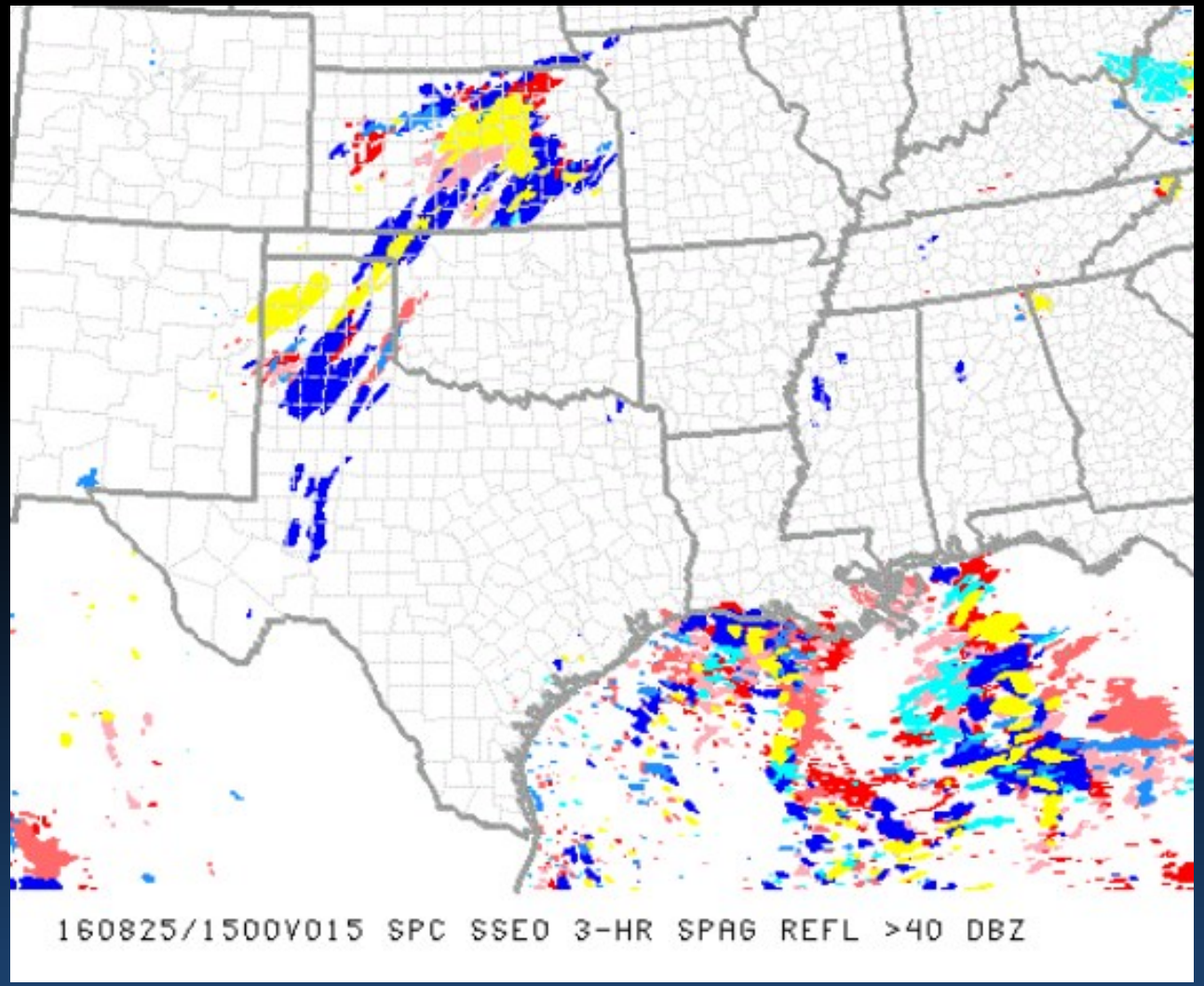
HRRRE 05/15/2016 (18:00) 12h fcst - Experimental Valid 05/16/2016 06:00 UTC



SPC's Storm-Scale Ensemble of Opportunity **(SSEO)**

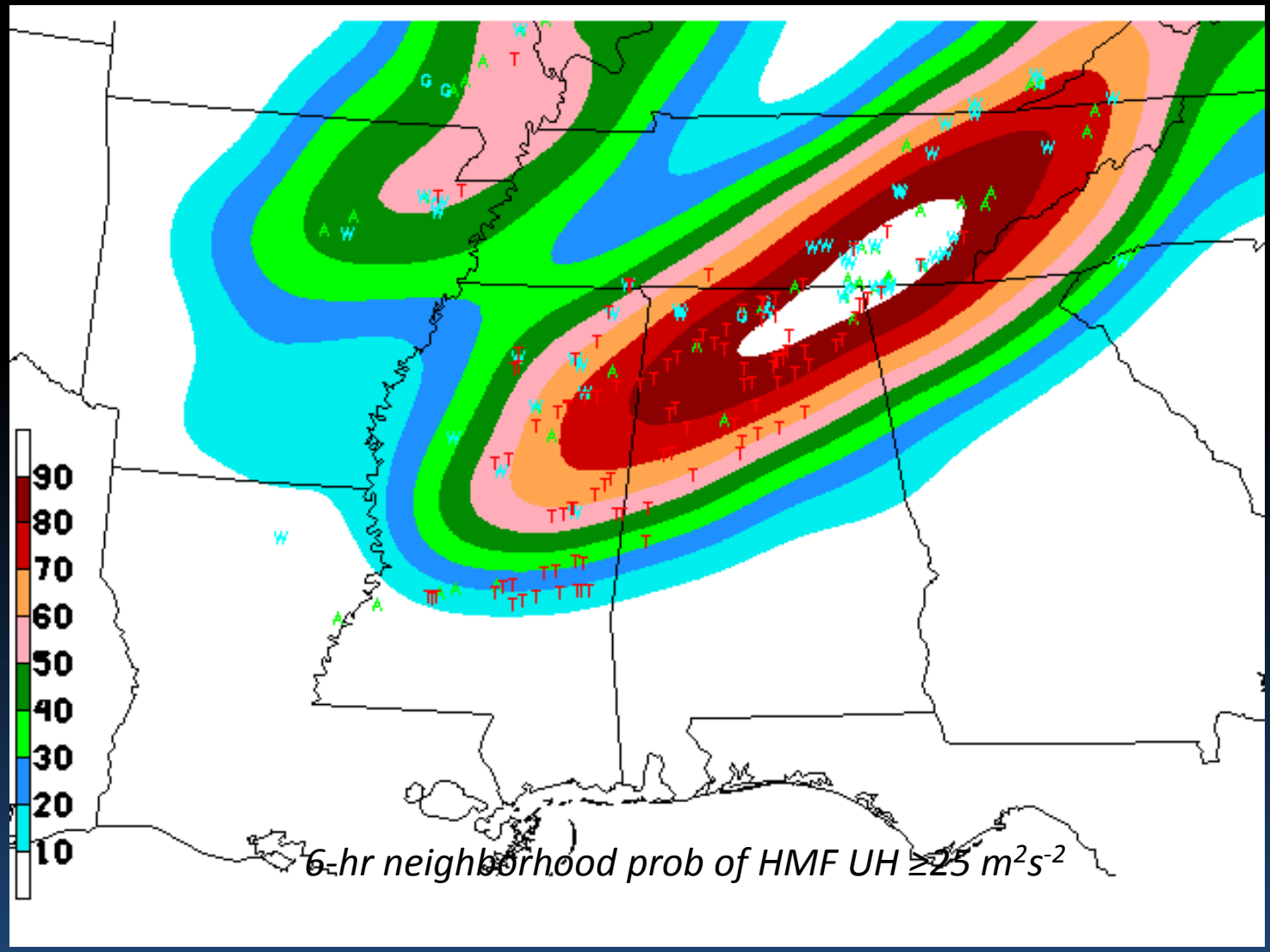
1) NSSL ARW
2) HRW ARW
3) HRW ARW -12 h
4) CONUS WRF-NMM
5) HRW NMMB
6) HRW NMMB -12 h
7) NAM CONUS Nest

- Processed in N-AWIPS and GEMPAK by SPC.
- Run at 00Z/12Z thru 36 hours.
- ~4 km resolution.



SSEO Verification

27 April 2011 (18-00Z)

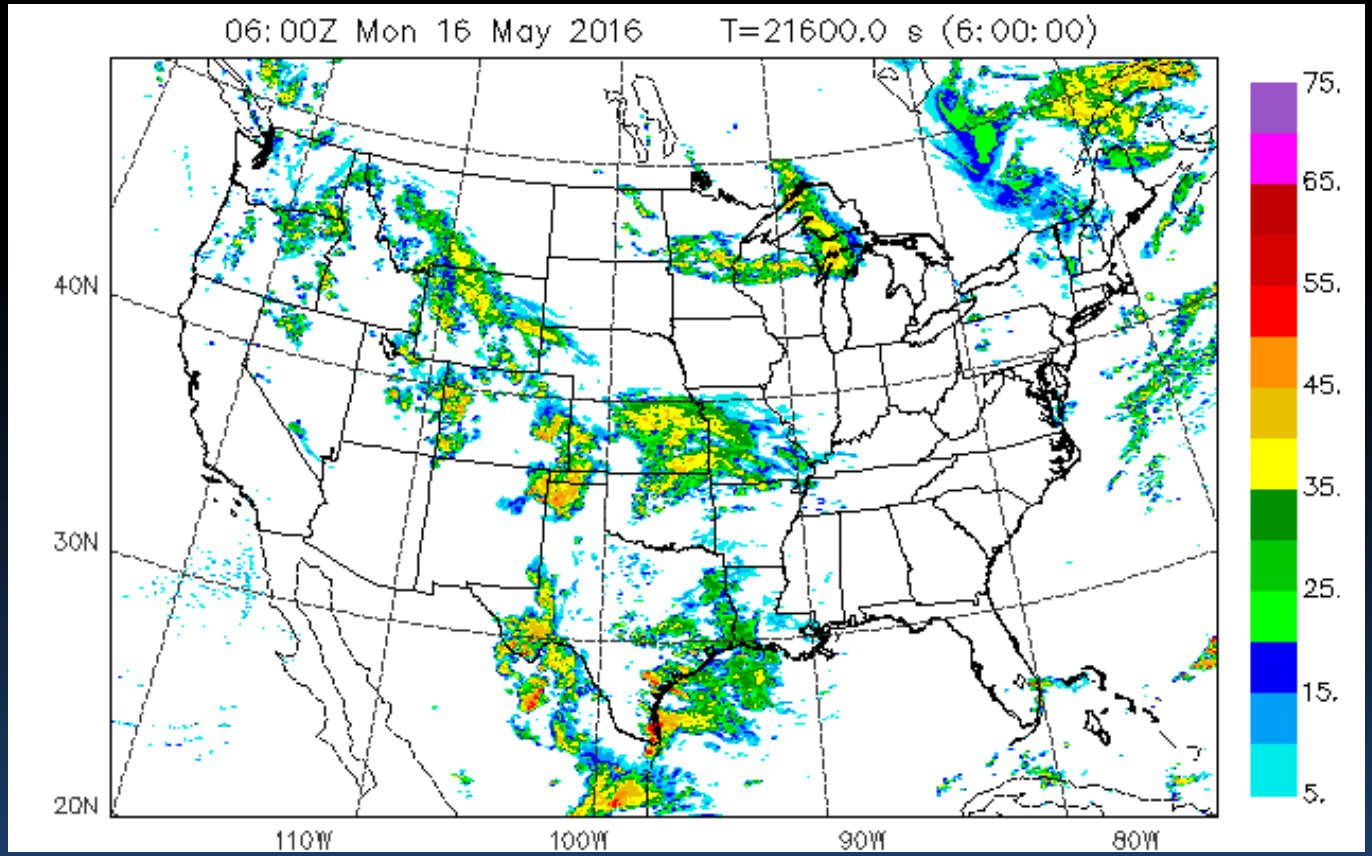


6-hr neighborhood prob of HMF UH ≥25 m^2s^{-2}

Credit: Steve Weiss, Branch Chief, Science Support Branch, SPC

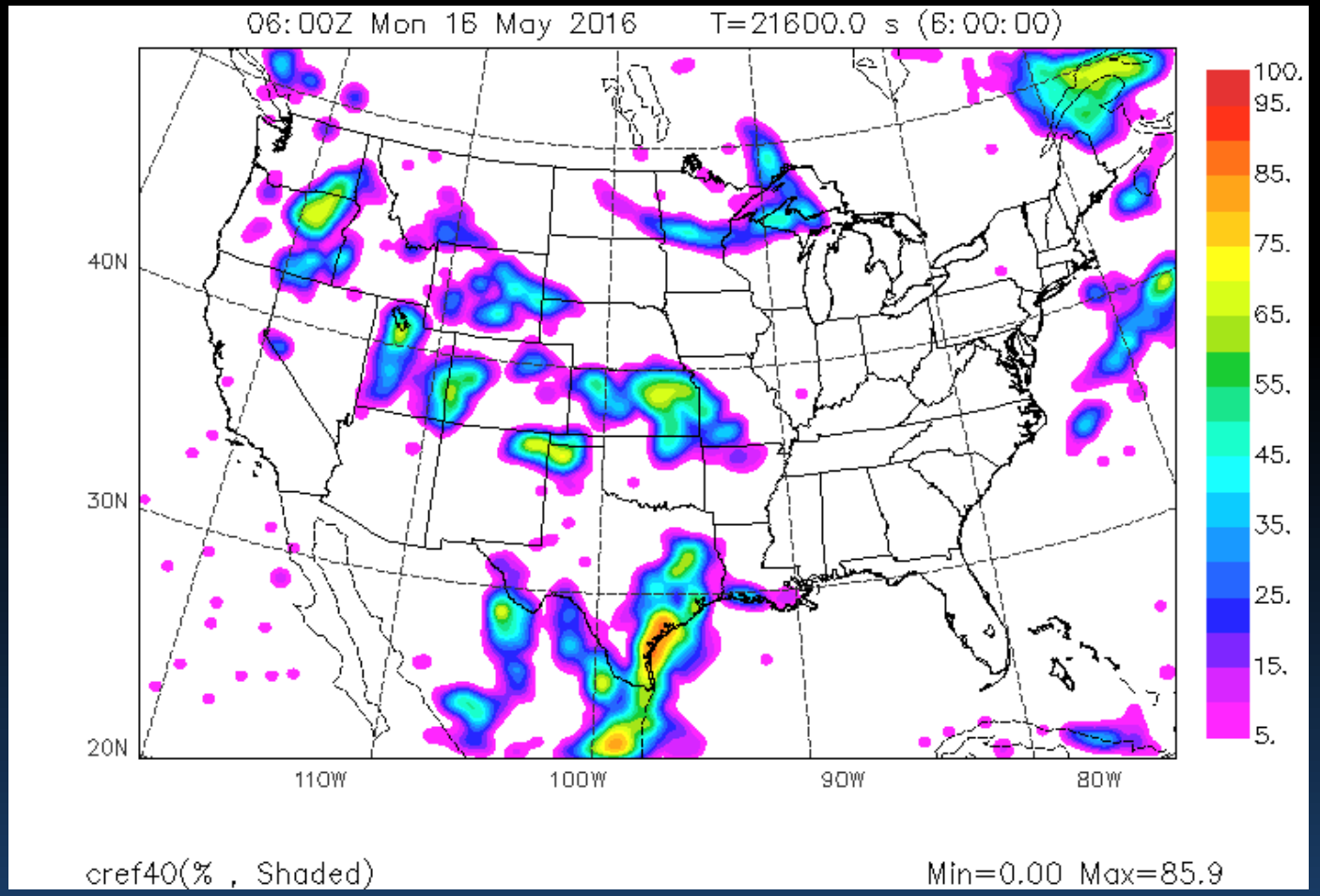
Storm Scale Ensemble Forecast **(SSEF)**
3DVAR-based

- 19 WRF-ARW & 6 NMM-B members.
- Run at 00Z through 60 hours.
- 3 km resolution.
- Available only in the Spring.



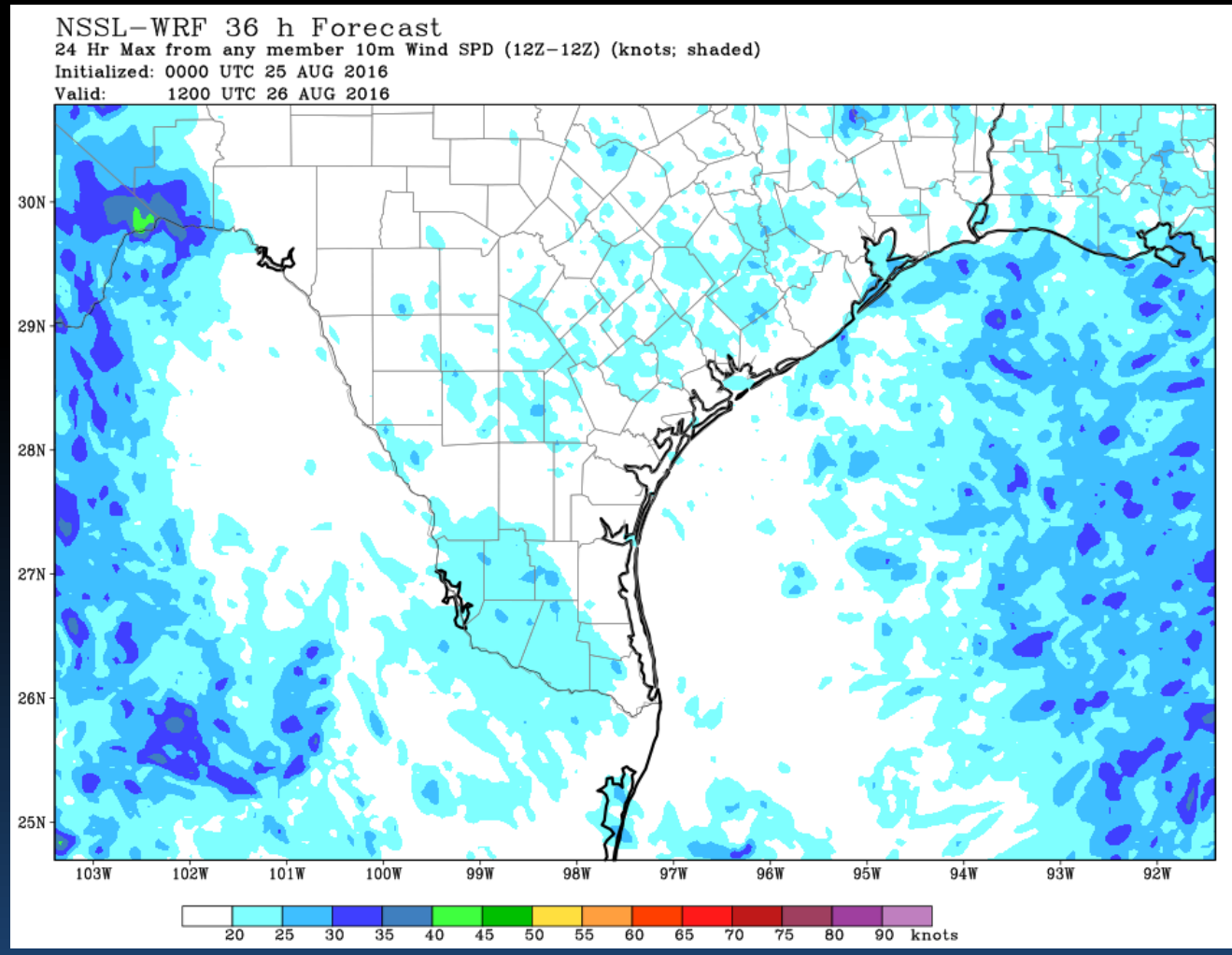
Storm Scale Ensemble Forecast **(SSEF)**
GSI+EnKF-based

- 40 input members.
- 12 forecast members.
- Run at 00Z through 60 hours.
- 3 km resolution.
- Available only in the Spring.



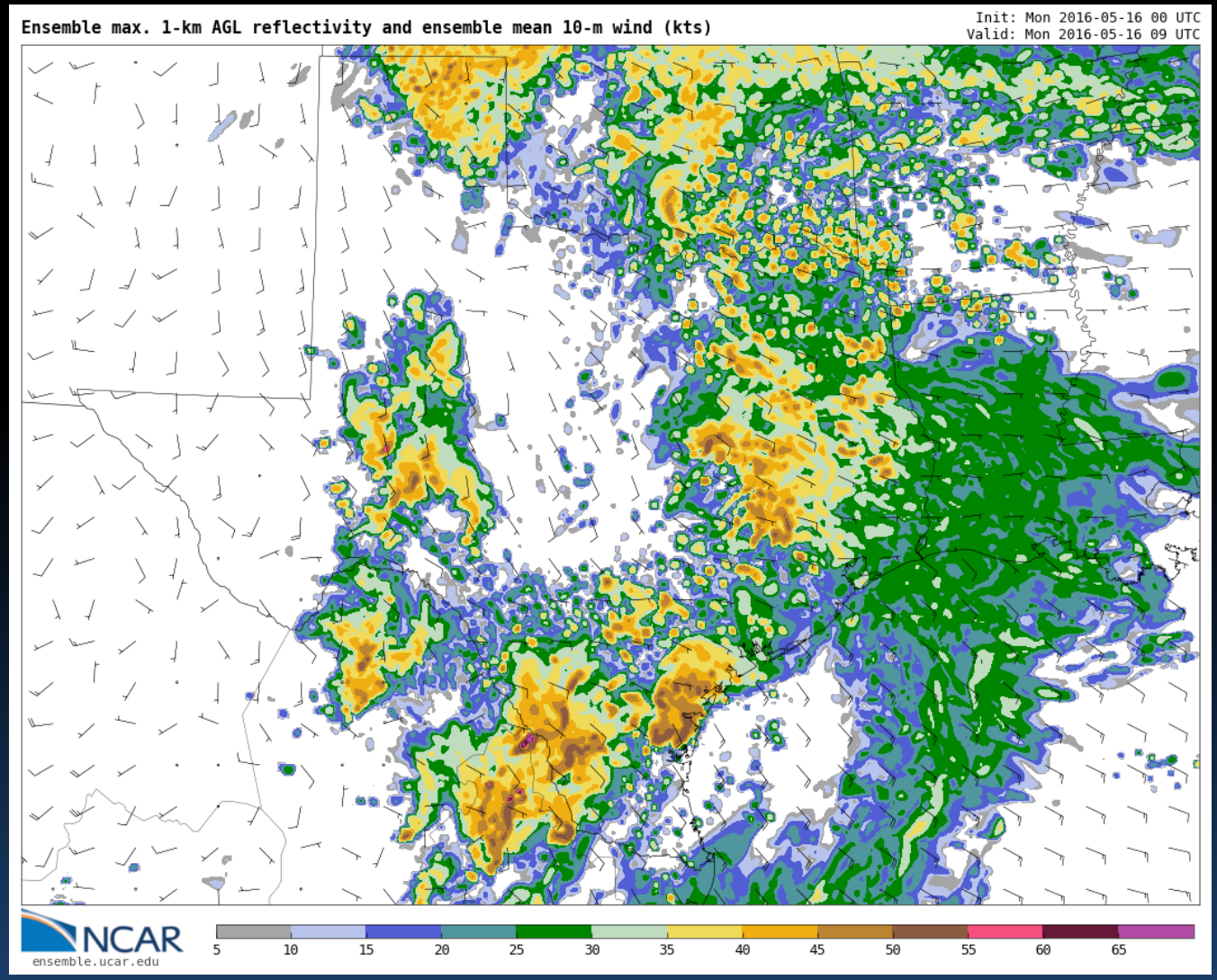
NSSL WRF Ensemble

- 9 members.
  - NSSL WRF
  - SREF members
- Run at 00Z through 36 hours.
- 4 km resolution.
- Severe Wx/Flood applications.



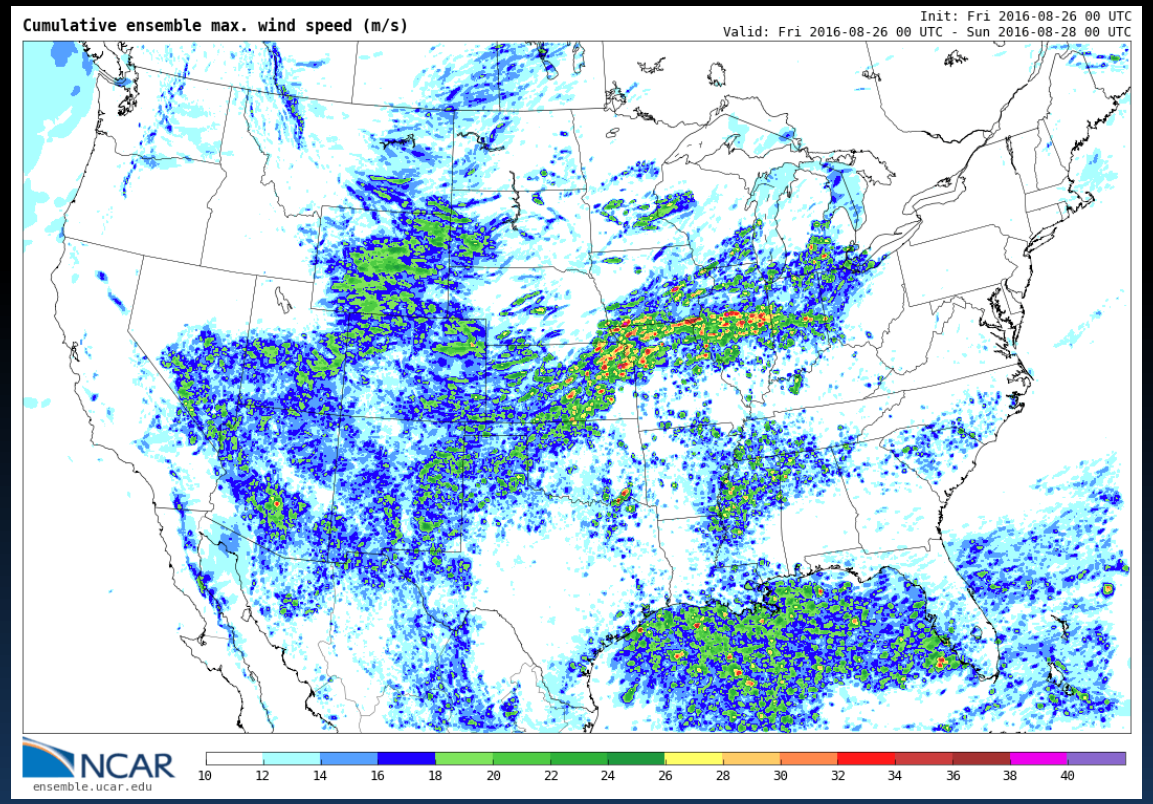
NCAR Ensemble

- WRF-ARW.
- Run at 00Z through 48 hours.
- 10 members.
- 3 km resolution.
- Severe/Winter WX applications.

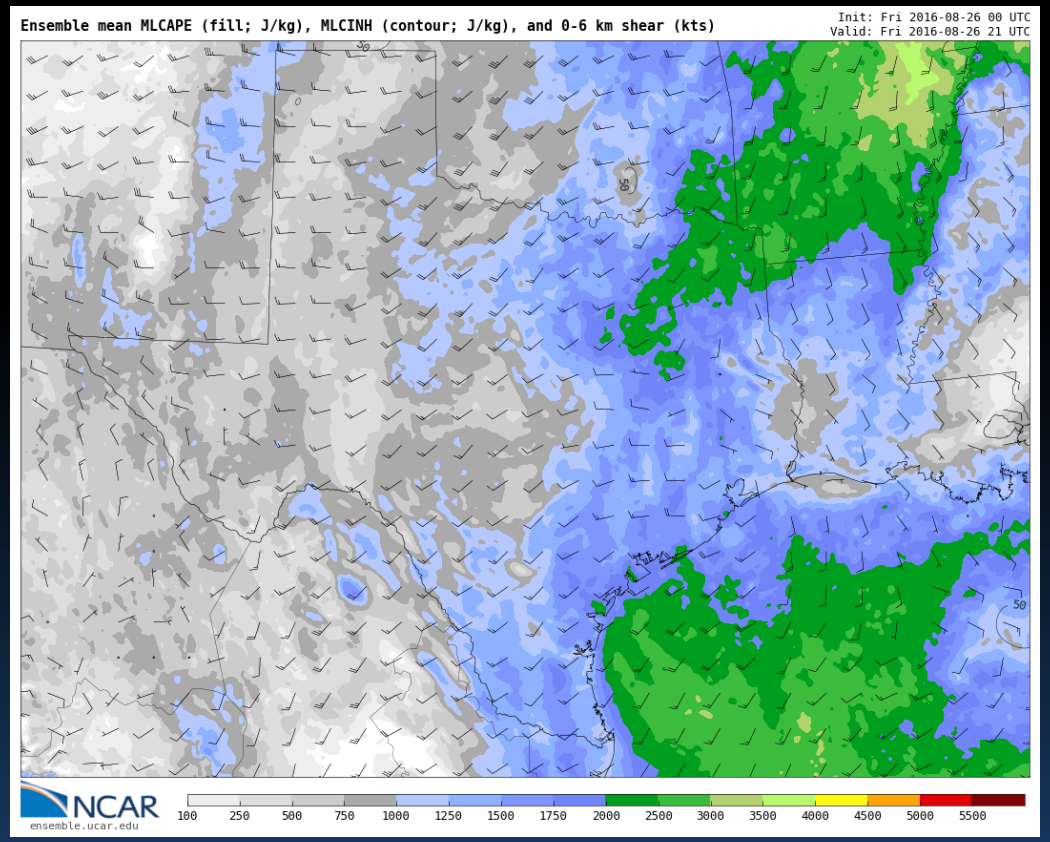


NCAR Ensemble Output

Cumulative Ensemble Max Wind Speed



Ensemble Mean MLCAPE/0-6 km Shear



Anomalies

Can an EPS tell us something about the historical significance of a weather event?

- Not really.
- An EPS does not place the forecast into historical context.
- “How does the current forecast compare to typical conditions at this time of year?”
- “How does the current forecast compare to past forecasts?”

Basic Climate Concepts

- **R-Climate**
  - Reanalysis or observed data-based climatology.
  - CFSR, ERA-Interim, MERRA-2, NARR, etc.
- **M-Climate**
  - Internal model or forecast system climatology.

Placing the Forecast in Context

- **R-Climate**
  - "You don't usually get a surface low pressure that strong across the Northwest Gulf of Mexico in April."

- **M-Climate**
  - "The GEFS rarely predicts this much precipitation, 5 days out."

R-Climate

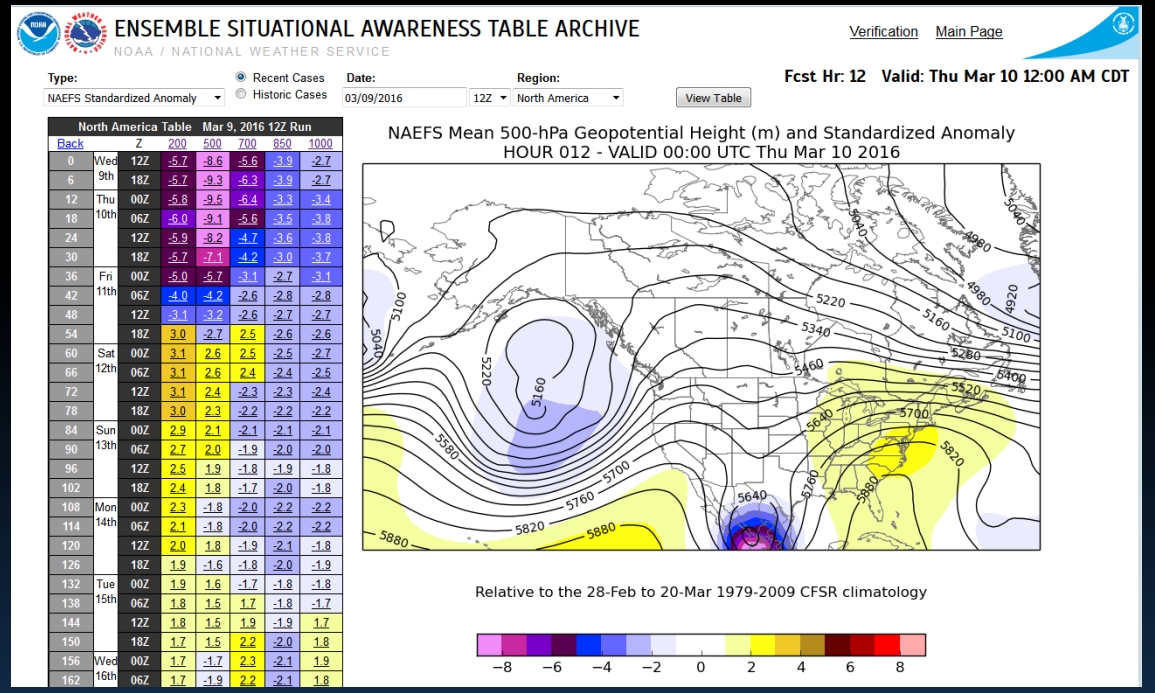
- Significant high-impact events **DO** have a strong signal!
- High DSS value.
  - Allows partners to make decisions in advance of an extreme event!
- Does **NOT** say anything about impacts!
  - Inferred?
  - Analogs will somewhat address impacts.

R-Climate Statistics

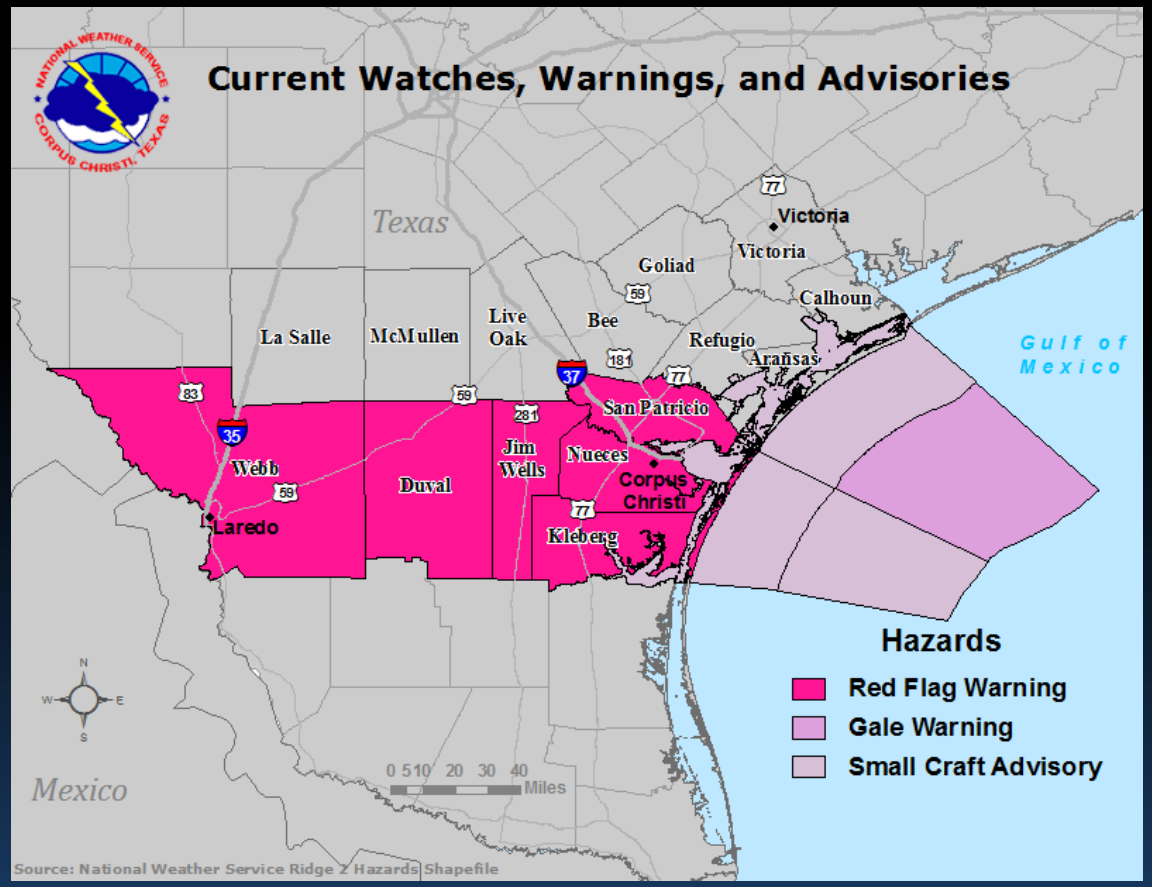
- **Standardized or normalized anomaly**
  - (Forecast – Climate Mean) / Climate Standard Deviation
  - Dispersion “issues” are usually solved.
  - Compare “apples to apples”.
- **Percentile**
  - “Where would the forecast fall with respect to climatology?”
- **Return Interval**
  - “How often do these forecast values show up in the climatology?”
- **Probabilities**
  - “How many members produce extreme values?”

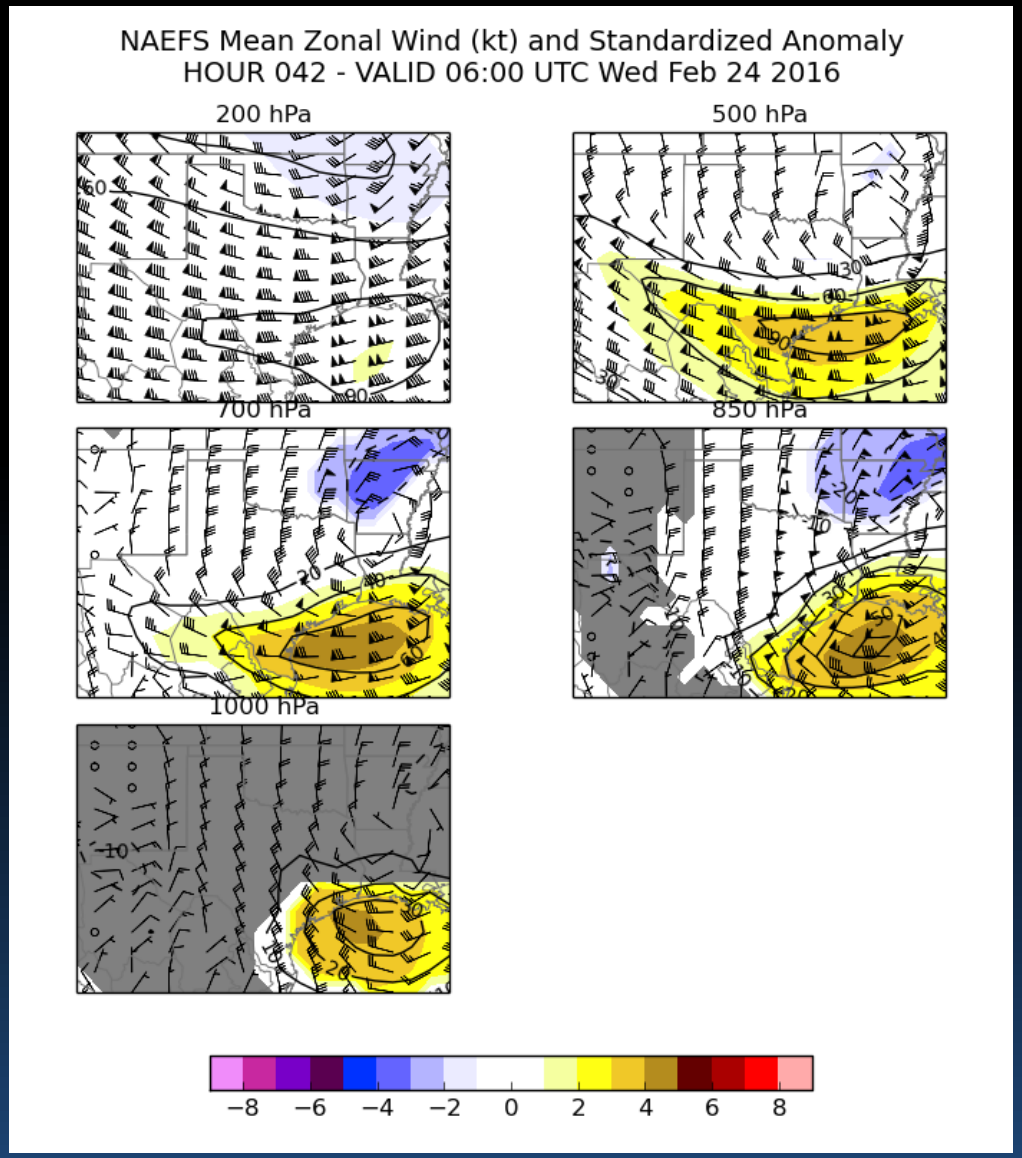
WRH Situational Awareness Table

- Use R-Climate to quickly identify where/when the forecast departs from climatology.
- Compares the NAEFS ensemble mean and CFSR (1979-2009).
- Strong “signal” implies most members depart from climo.
  - Extreme event detection likely.

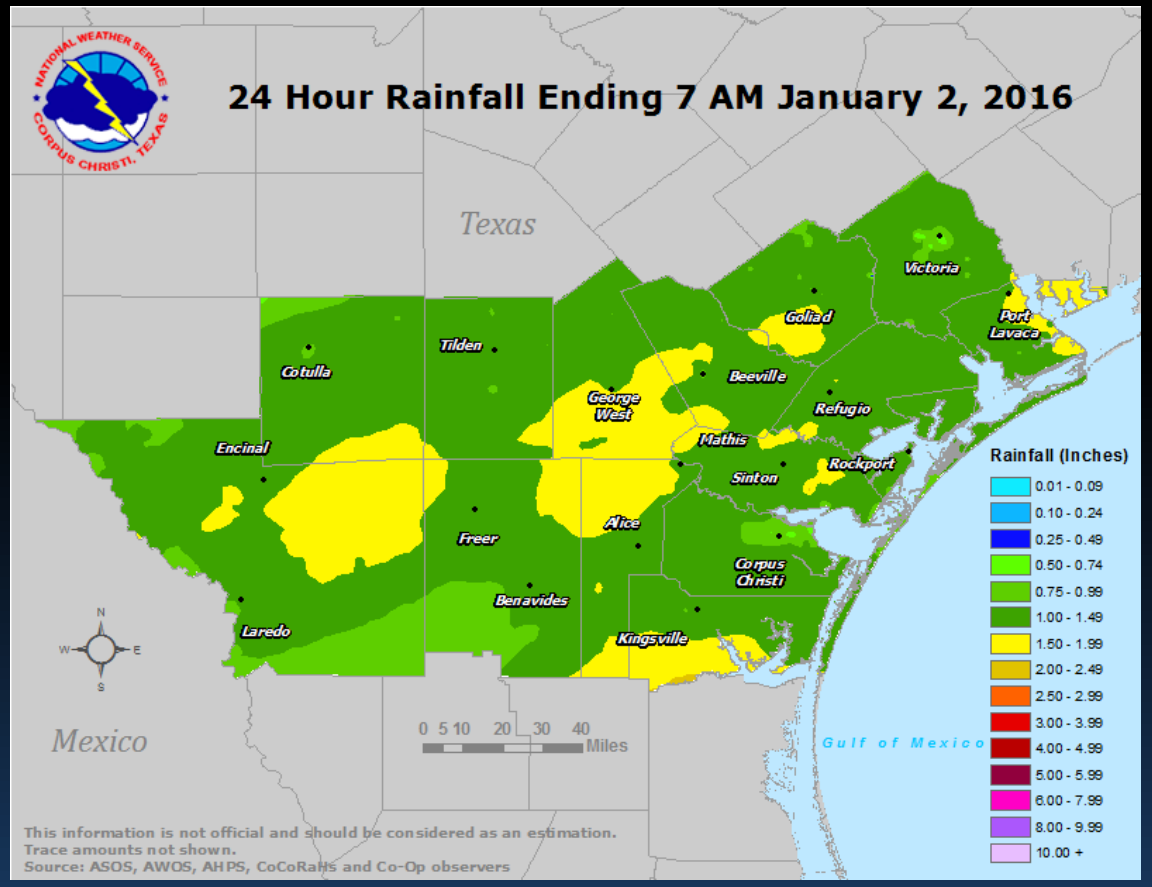


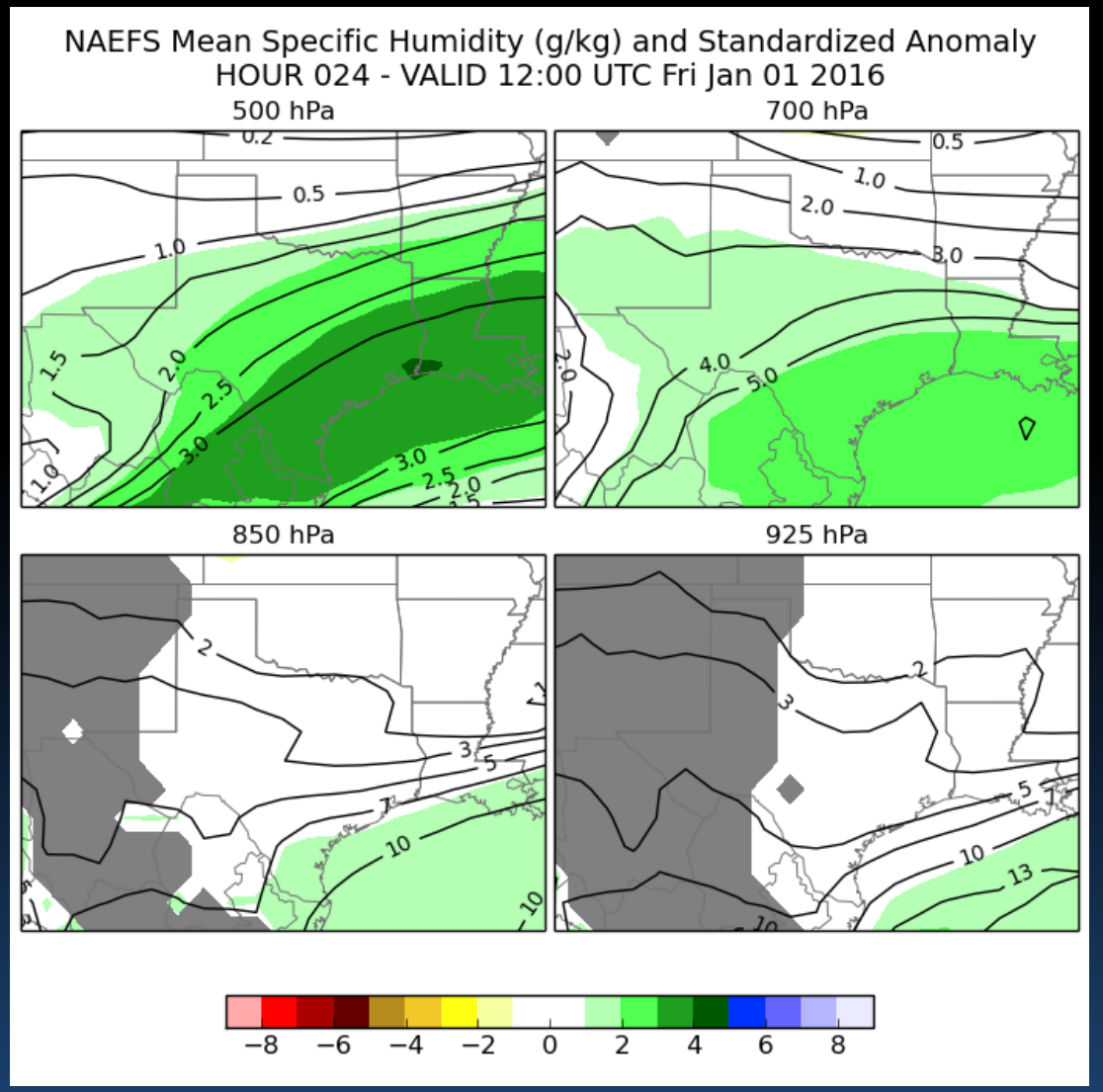
High Winds on 2/24/16





Heavy Rain on New Year's Day 2016





ENSEMBLE SITUATIONAL AWARENESS TABLE ARCHIVE

NOAA / NATIONAL WEATHER SERVICE

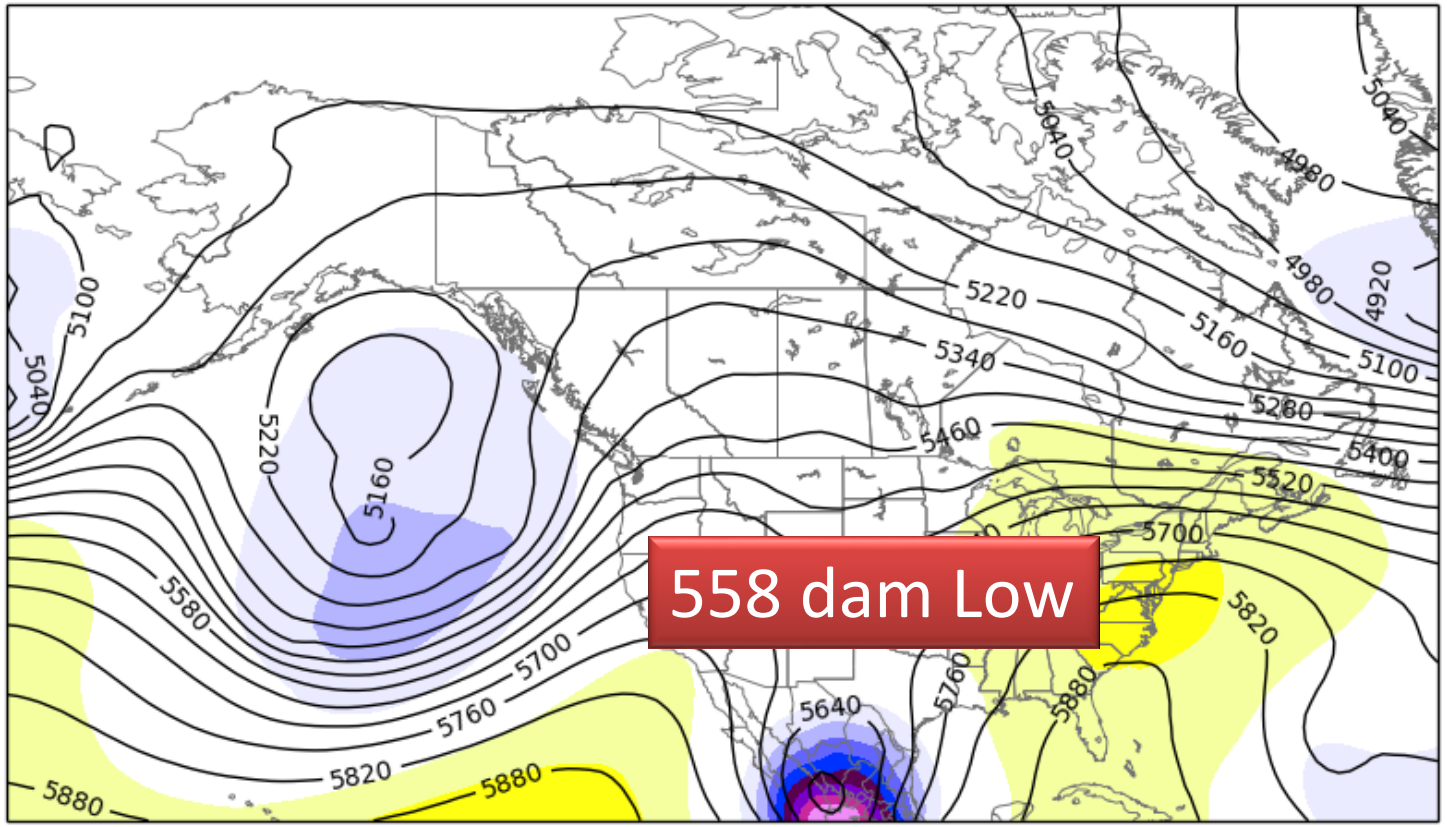
Type: NAEFS Standardized Anomaly | Recent Cases | Historic Cases | Date: 03/09/2016 | 12Z | Region: North America | View Table

Fcst Hr: 12 Valid: Thu Mar 10 12:00 AM CDT

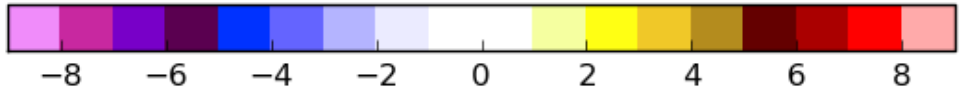
North America Table Mar 9, 2016 12Z Run

Back		Z	200	500	700	850	1000
0	Wed 9th	12Z	-5.7	-8.6	-6.6	-3.9	-2.7
6		18Z	-5.7	-9.3	-6.3	-3.9	-2.7
12	Thu 10th	00Z	-5.8	-9.5	-6.4	-3.3	-3.4
18		06Z	-6.0	-9.1	-5.6	-3.5	-3.8
24		12Z	-5.9	-8.2	-4.7	-3.6	-3.8
30		18Z	-5.7	-7.1	-4.2	-3.0	-3.7
36	Fri 11th	00Z	-5.0	-5.7	-3.1	-2.7	-3.1
42		06Z	-4.0	-4.2	-2.6	-2.8	-2.8
48		12Z	-3.1	-3.2	-2.6	-2.7	-2.7
54		18Z	3.0	-2.7	2.5	-2.6	-2.6
60	Sat 12th	00Z	3.1	2.6	2.5	-2.5	-2.7
66		06Z	3.1	2.6	2.4	-2.4	-2.5
72		12Z	3.1	2.4	-2.3	-2.3	-2.4
78		18Z	3.0	2.3	-2.2	-2.2	-2.2
84	Sun 13th	00Z	2.9	2.1	-2.1	-2.1	-2.1
90		06Z	2.7	2.0	-1.9	-2.0	-2.0
96		12Z	2.5	1.9	-1.8	-1.9	-1.8
102		18Z	2.4	1.8	-1.7	-2.0	-1.8
108	Mon 14th	00Z	2.3	-1.8	-2.0	-2.2	-2.2
114		06Z	2.1	-1.8	-2.0	-2.2	-2.2
120		12Z	2.0	1.8	-1.9	-2.1	-1.8
126		18Z	1.9	-1.6	-1.8	-2.0	-1.9
132	Tue 15th	00Z	1.9	1.6	-1.7	-1.8	-1.8
138		06Z	1.8	1.5	1.7	-1.8	-1.7
144		12Z	1.8	1.5	1.9	-1.9	1.7
150		18Z	1.7	1.5	2.2	-2.0	1.8
156	Wed 16th	00Z	1.7	-1.7	2.3	-2.1	1.9
162		06Z	1.7	-1.9	2.2	-2.1	1.8

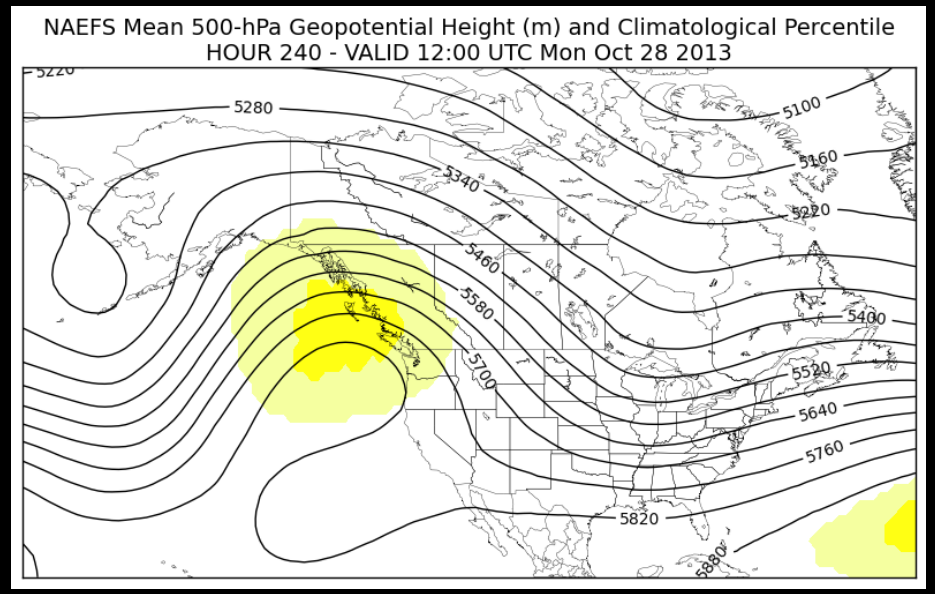
NAEFS Mean 500-hPa Geopotential Height (m) and Standardized Anomaly
HOUR 012 - VALID 00:00 UTC Thu Mar 10 2016



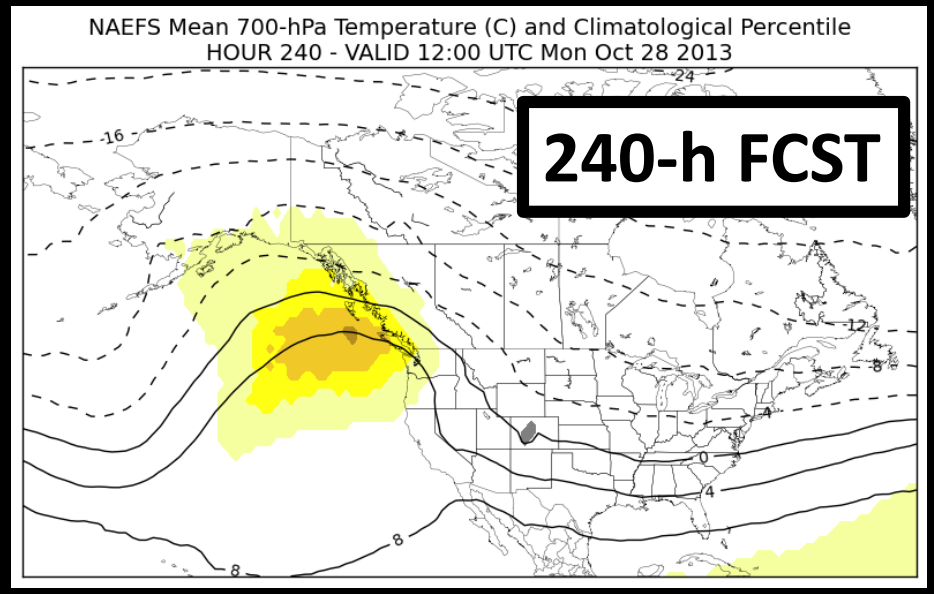
Relative to the 28-Feb to 20-Mar 1979-2009 CFSR climatology

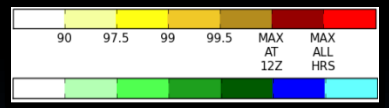


500-hPa Height

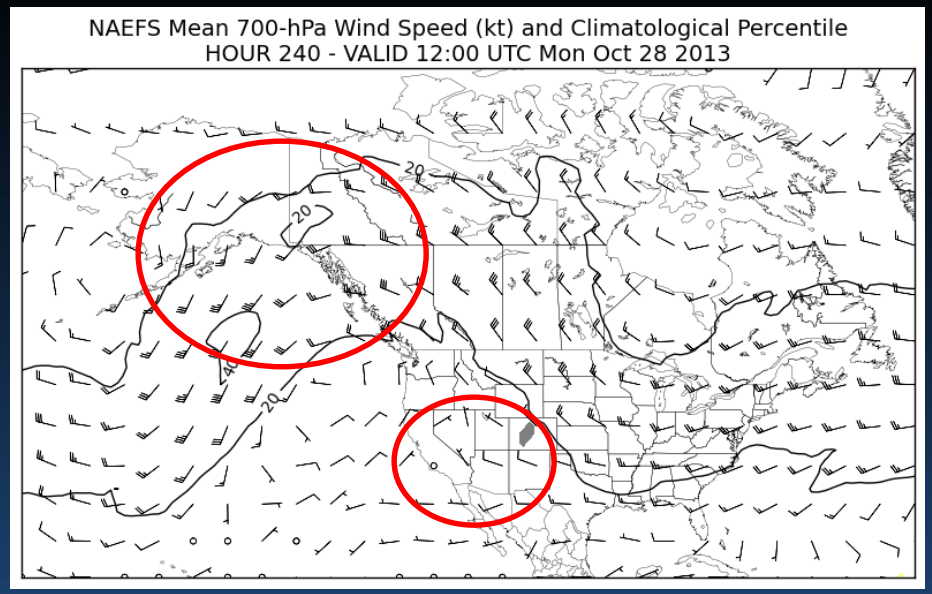


700-hPa Temperature

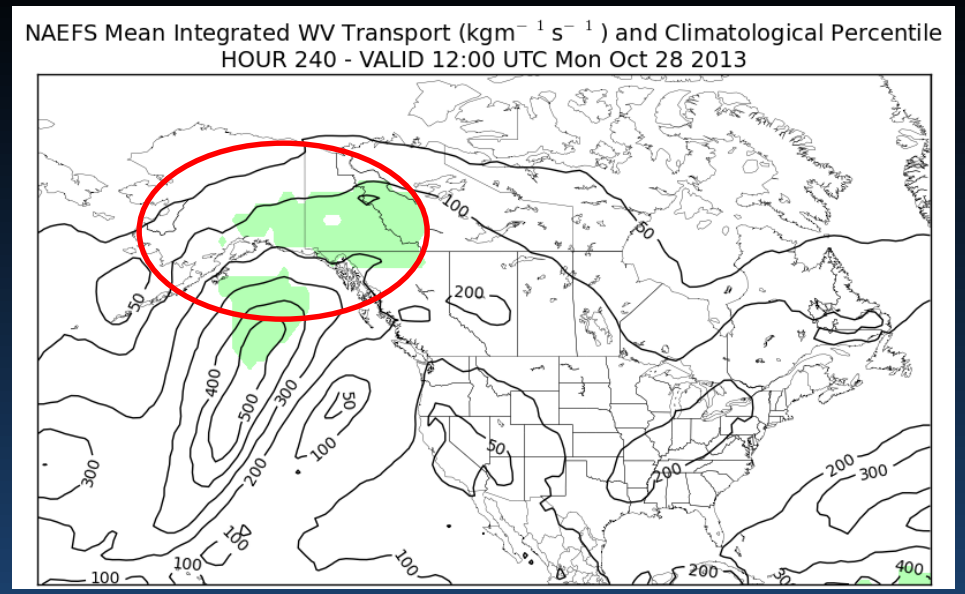




700-hPa Wind Speed

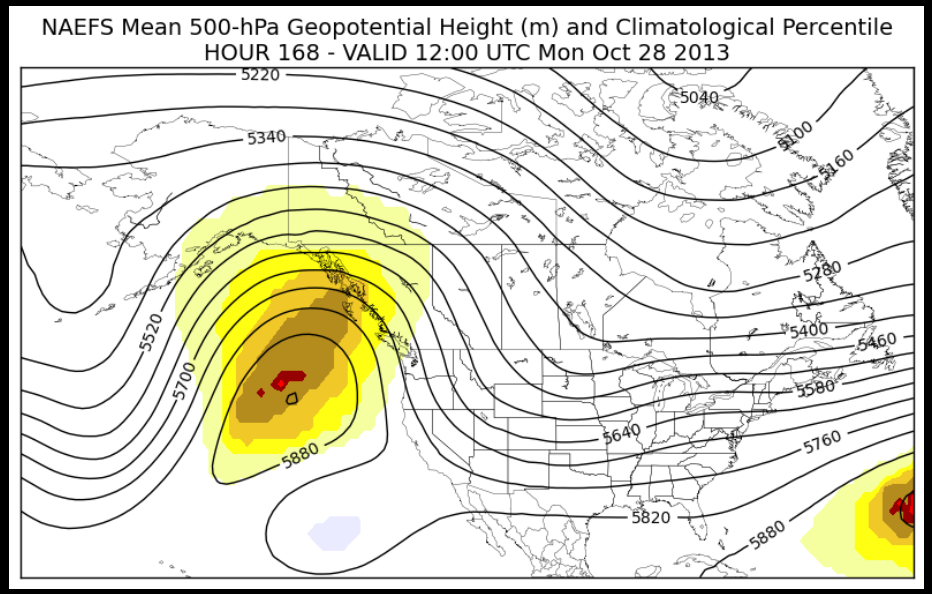


Integrated WV Transport

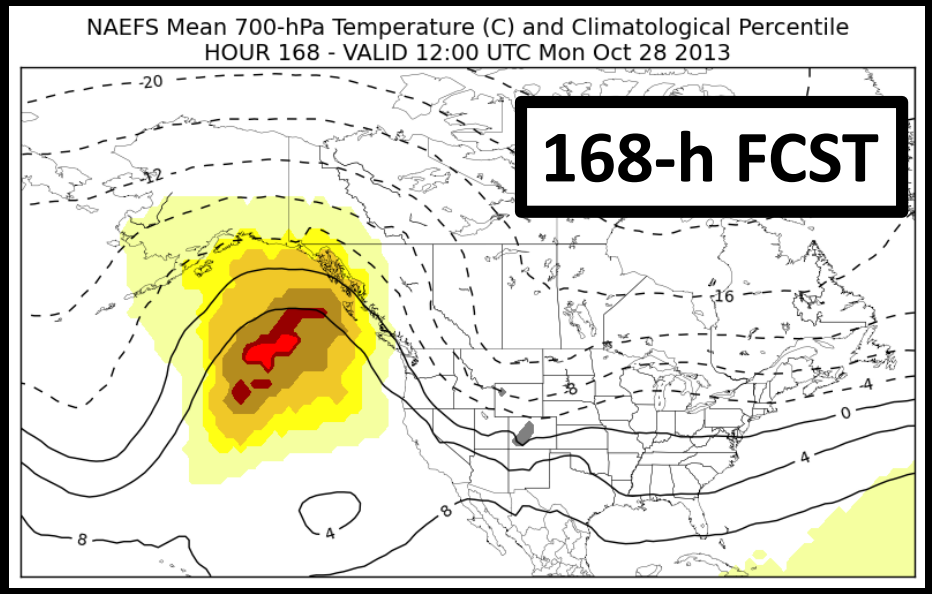


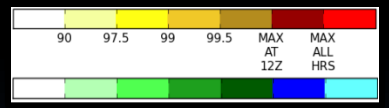
Credit:
Trevor Alcott
ESRL/GSD

500-hPa Height

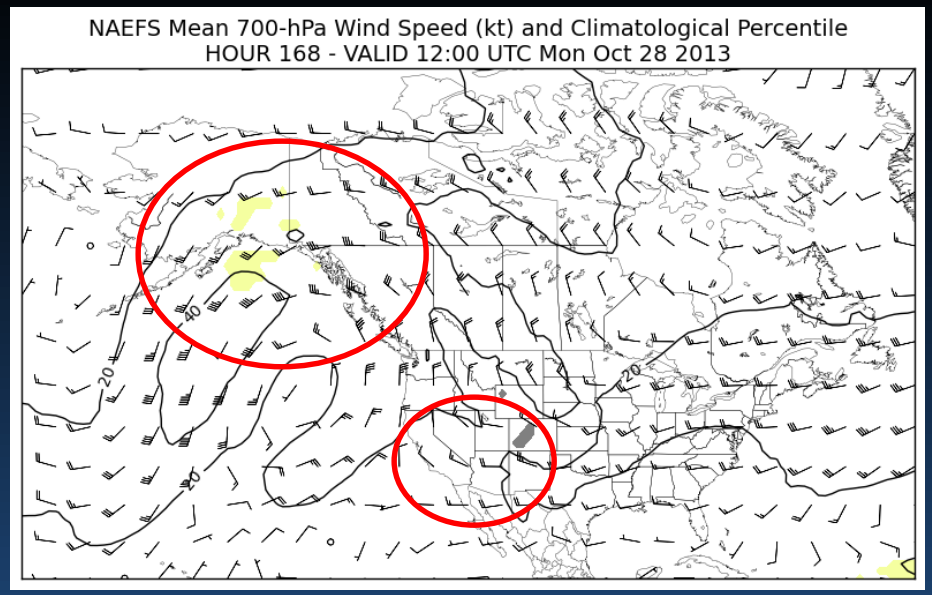


700-hPa Temperature

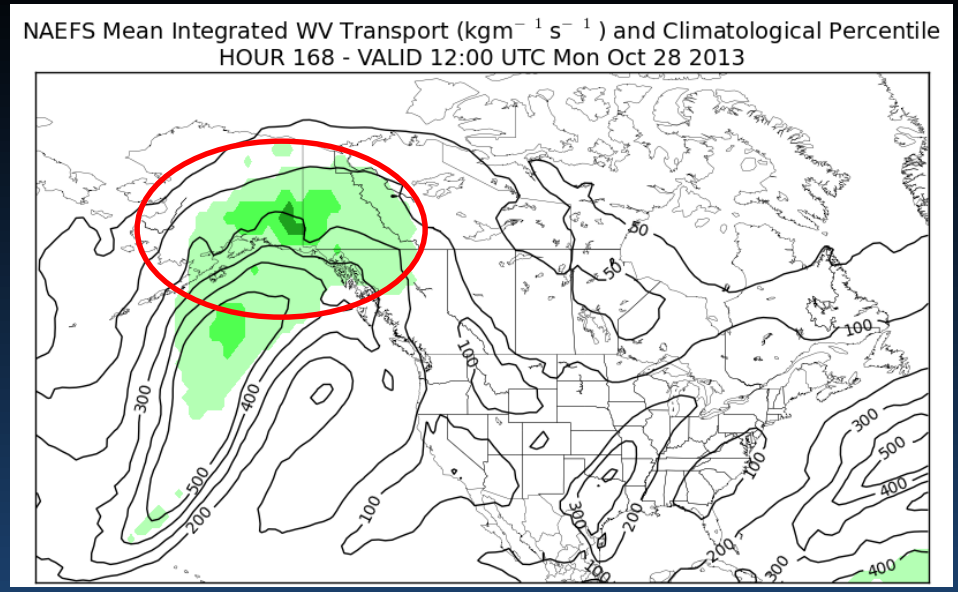




700-hPa Wind Speed

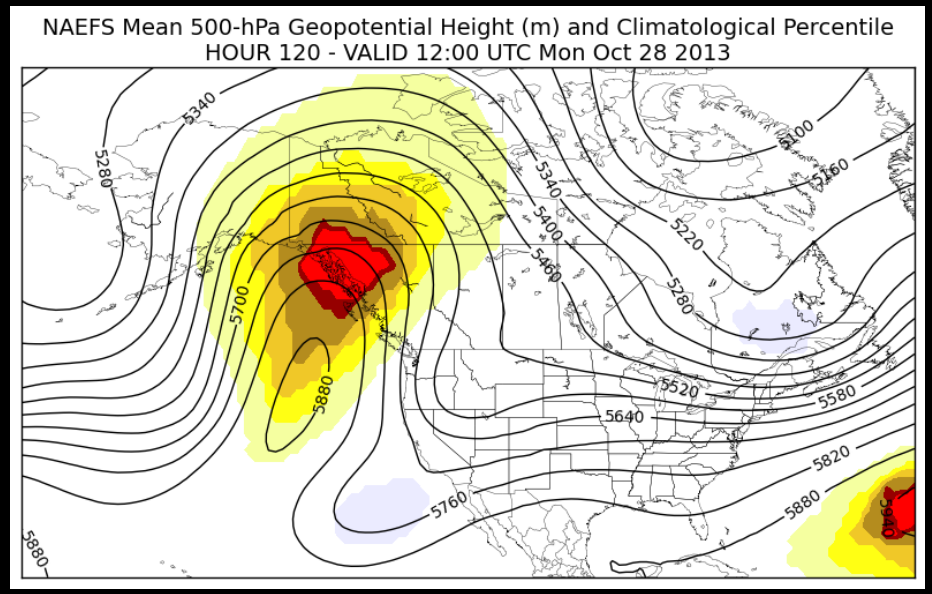


Integrated WV Transport

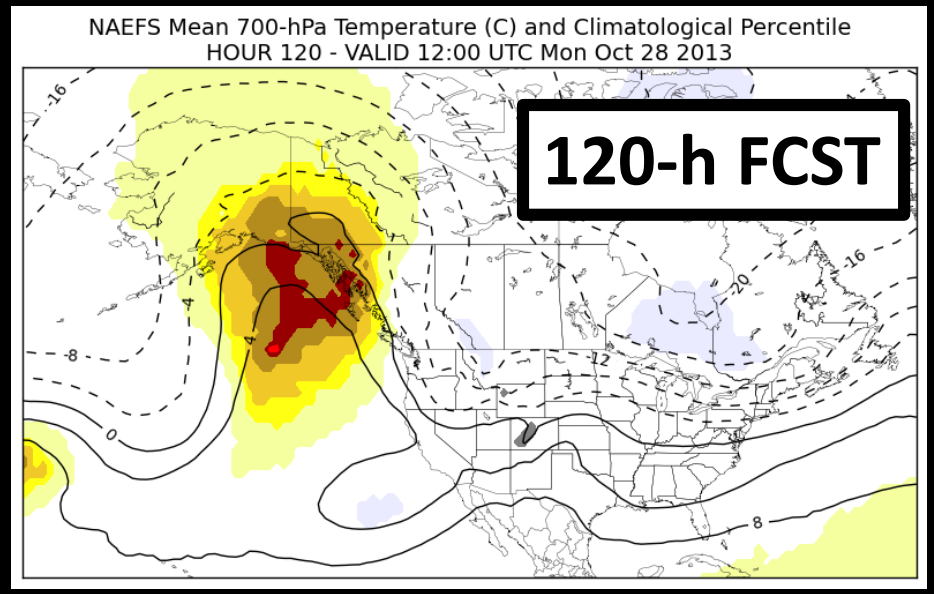


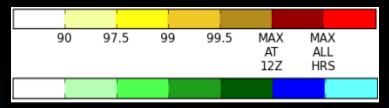
Credit:
Trevor Alcott
ESRL/GSD

500-hPa Height

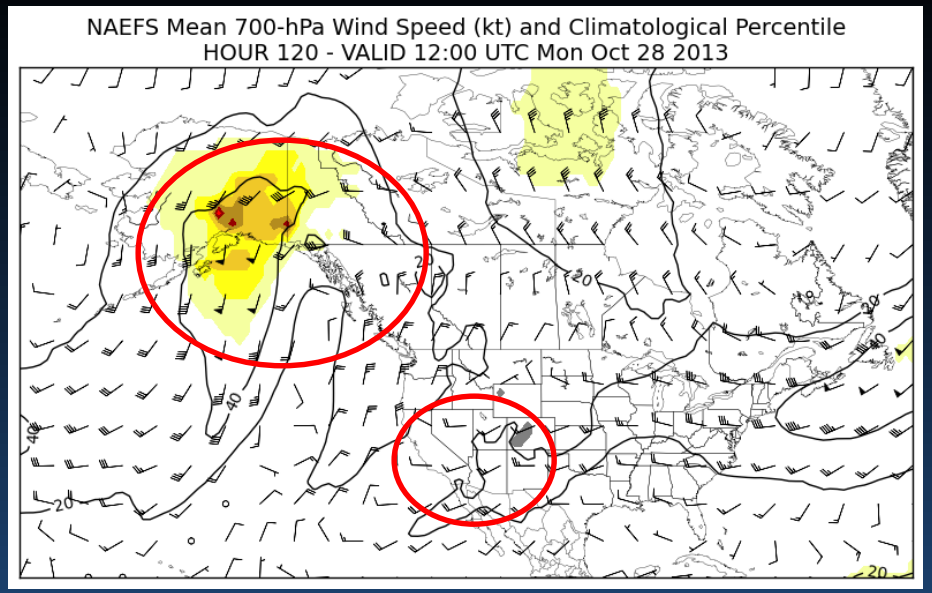


700-hPa Temperature

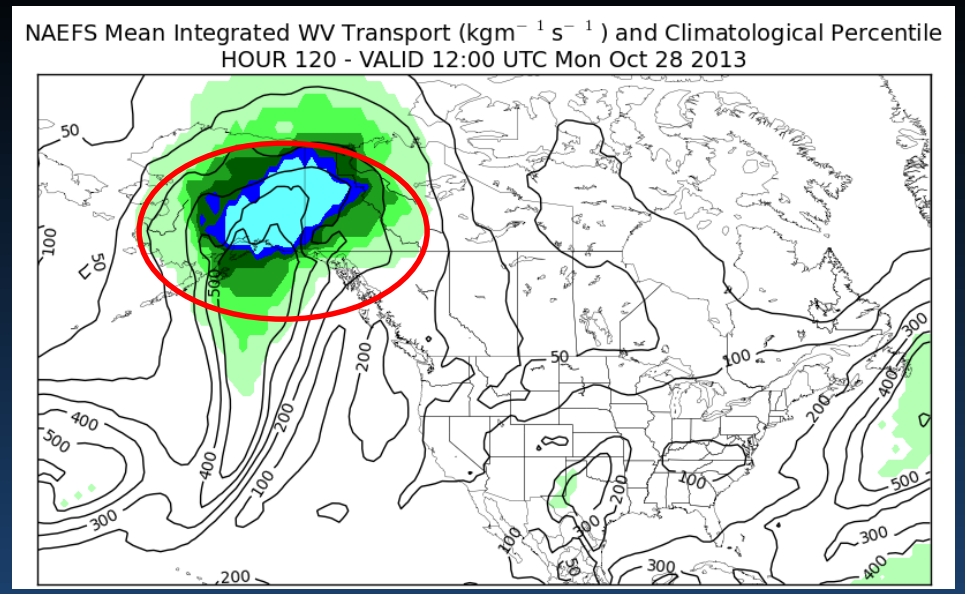




700-hPa Wind Speed

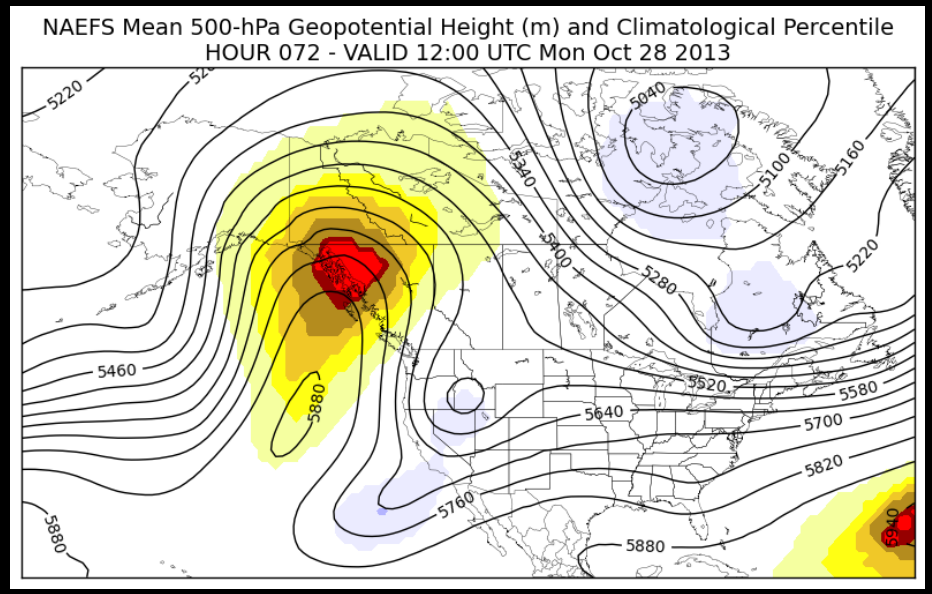


Integrated WV Transport

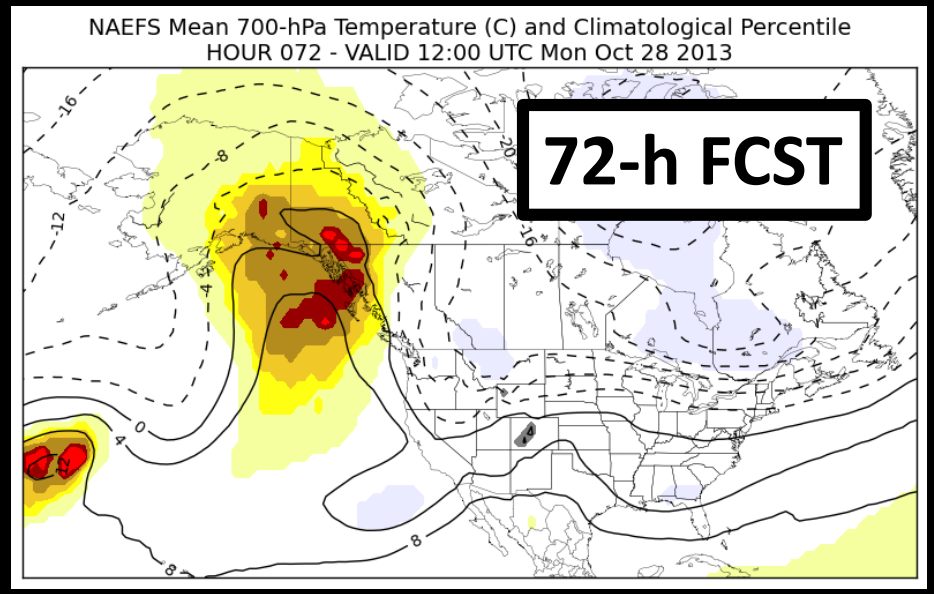


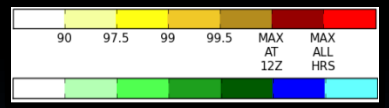
Credit:
Trevor Alcott
ESRL/GSD

500-hPa Height

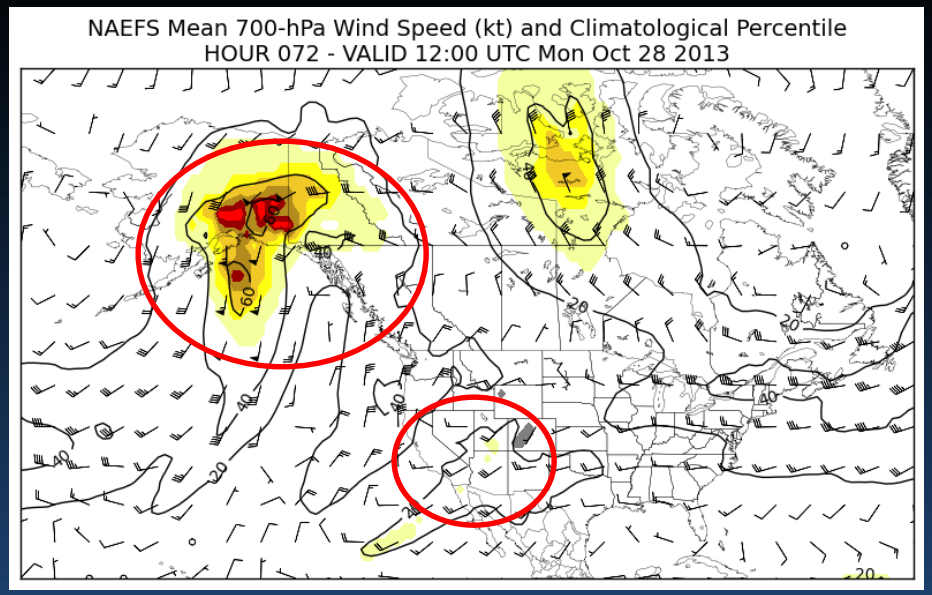


700-hPa Temperature

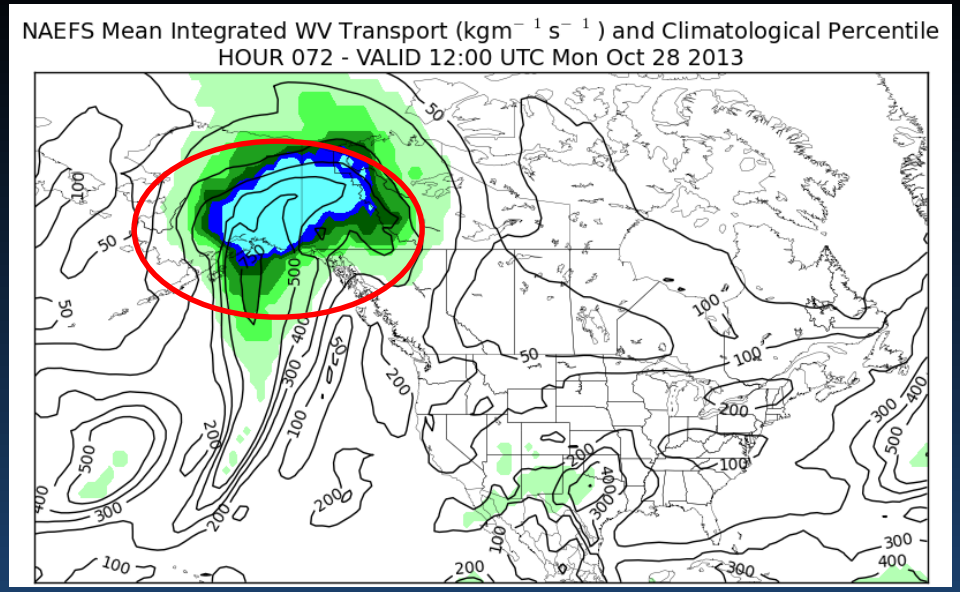




700-hPa Wind Speed

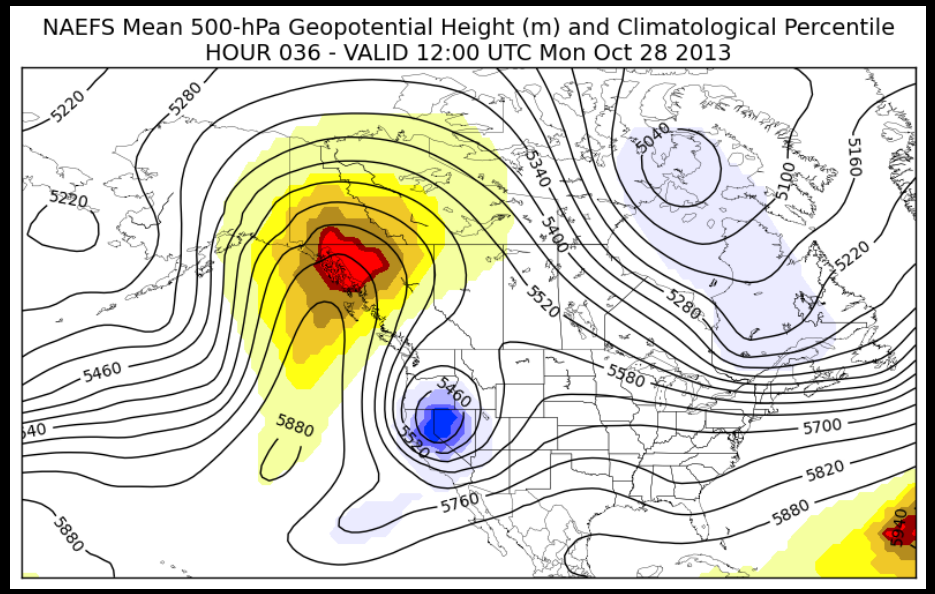


Integrated WV Transport

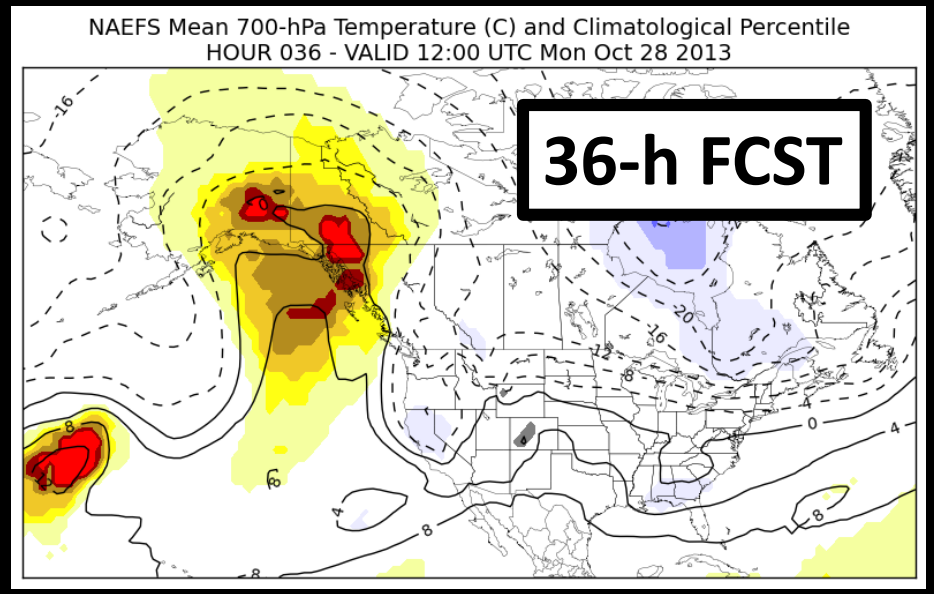


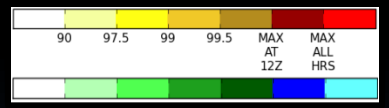
Credit:
Trevor Alcott
ESRL/GSD

500-hPa Height

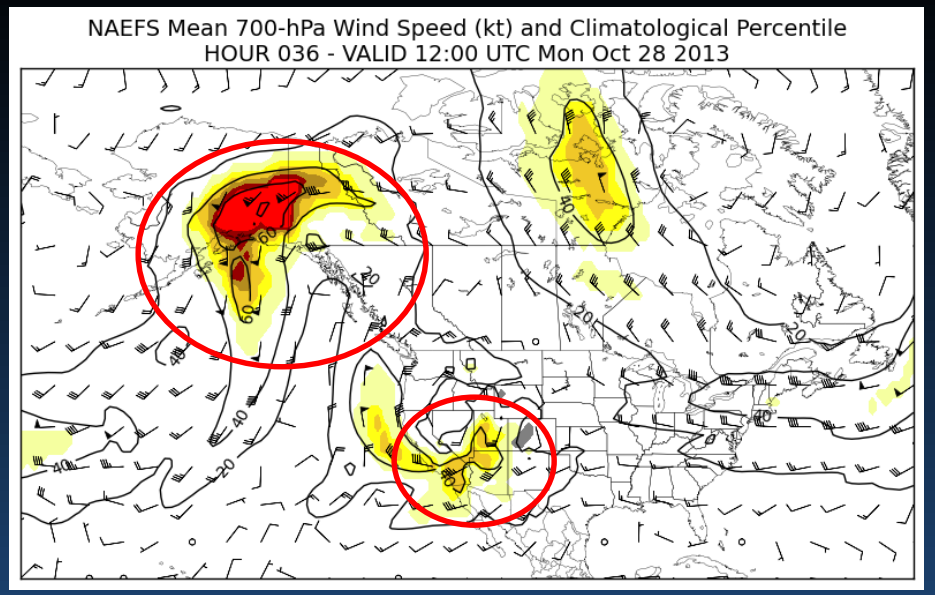


700-hPa Temperature

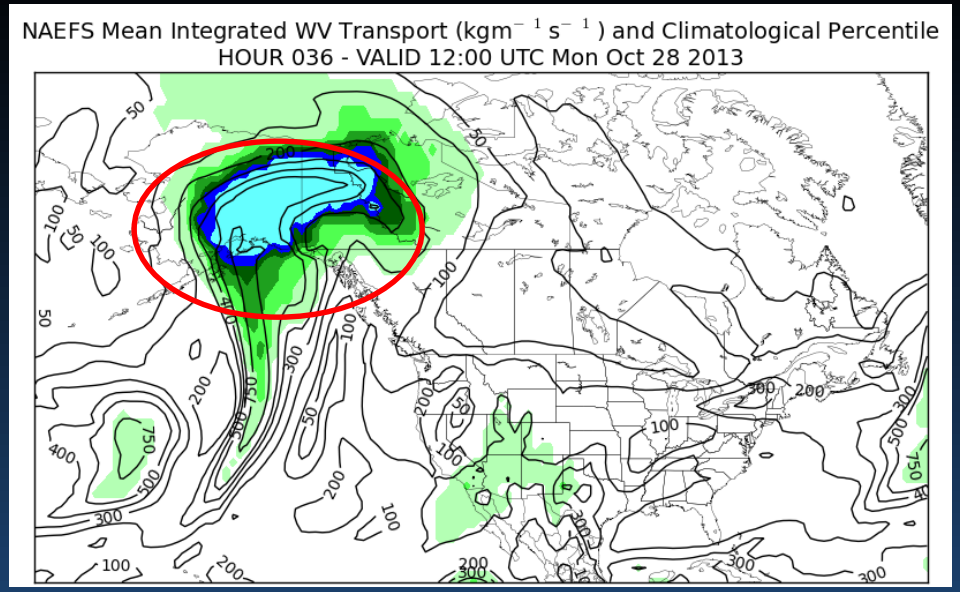




700-hPa Wind Speed

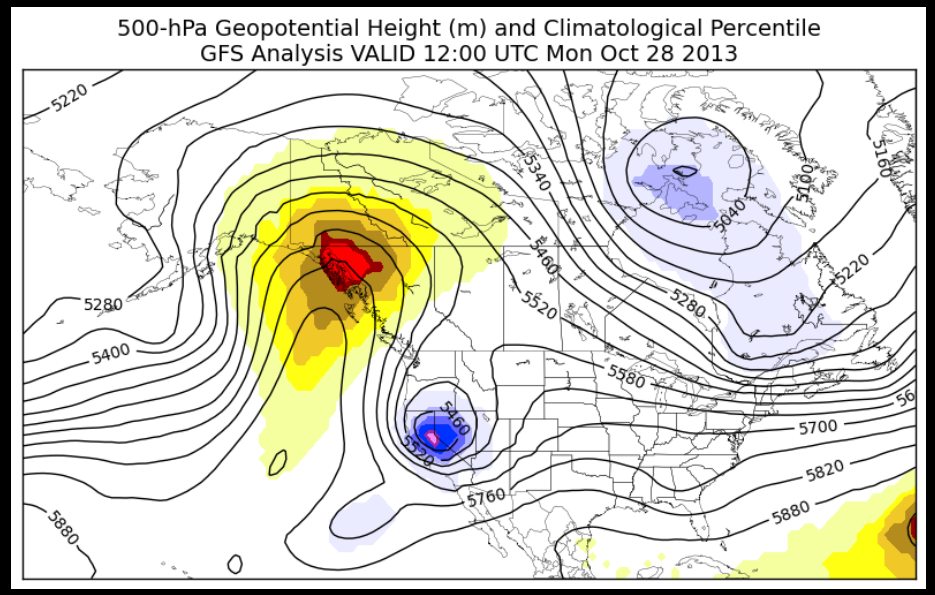


Integrated WV Transport

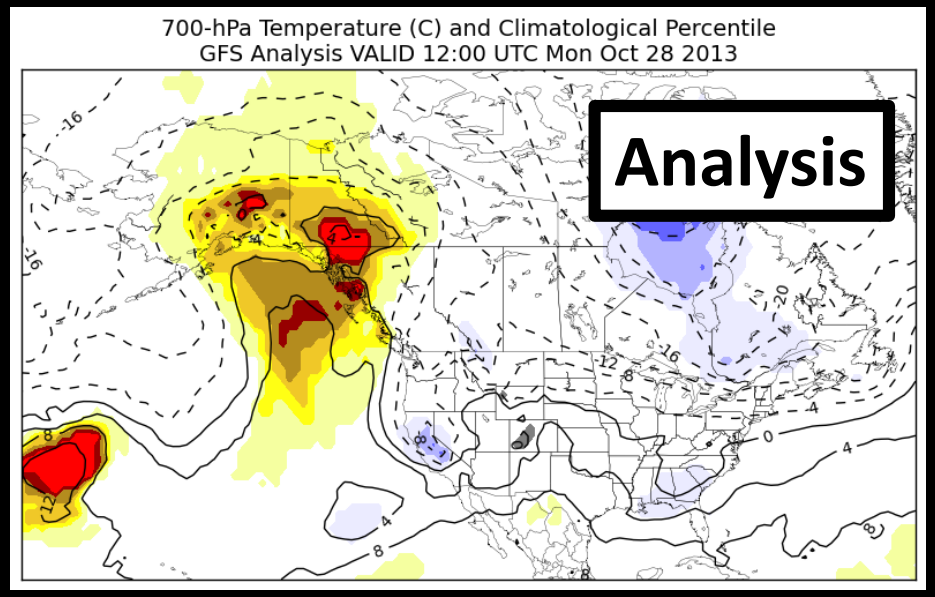


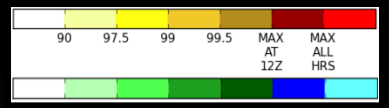
Credit:
Trevor Alcott
ESRL/GSD

500-hPa Height

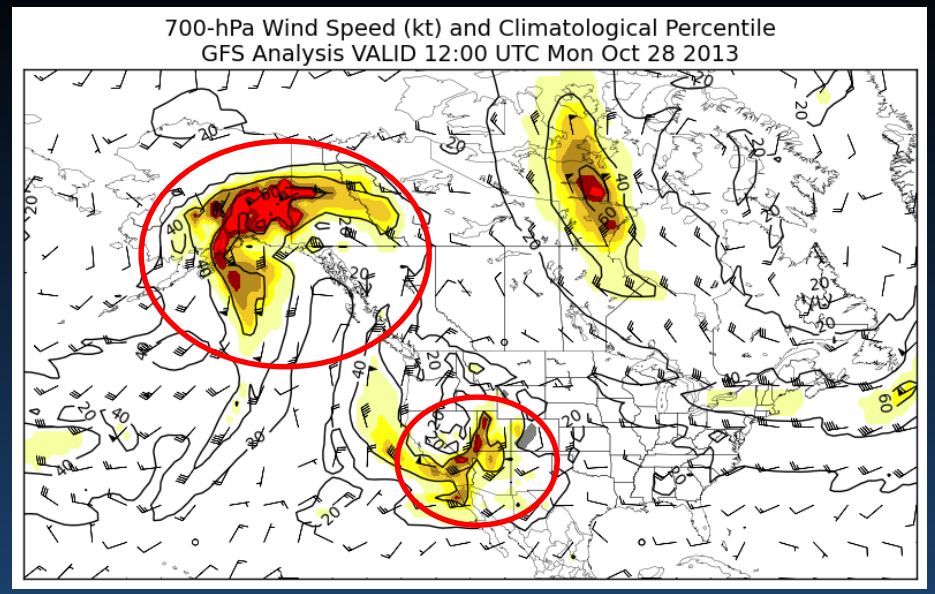


700-hPa Temperature

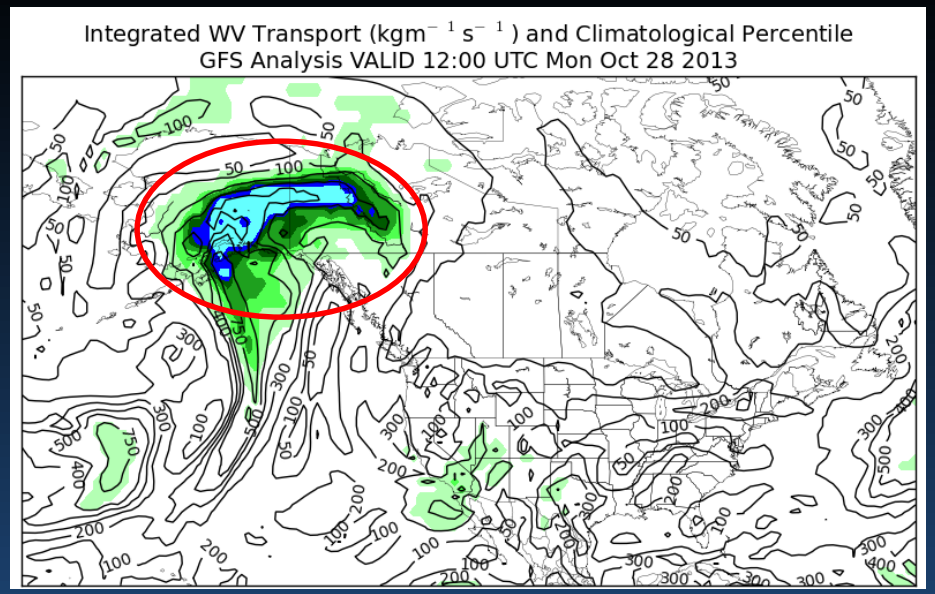




700-hPa Wind Speed

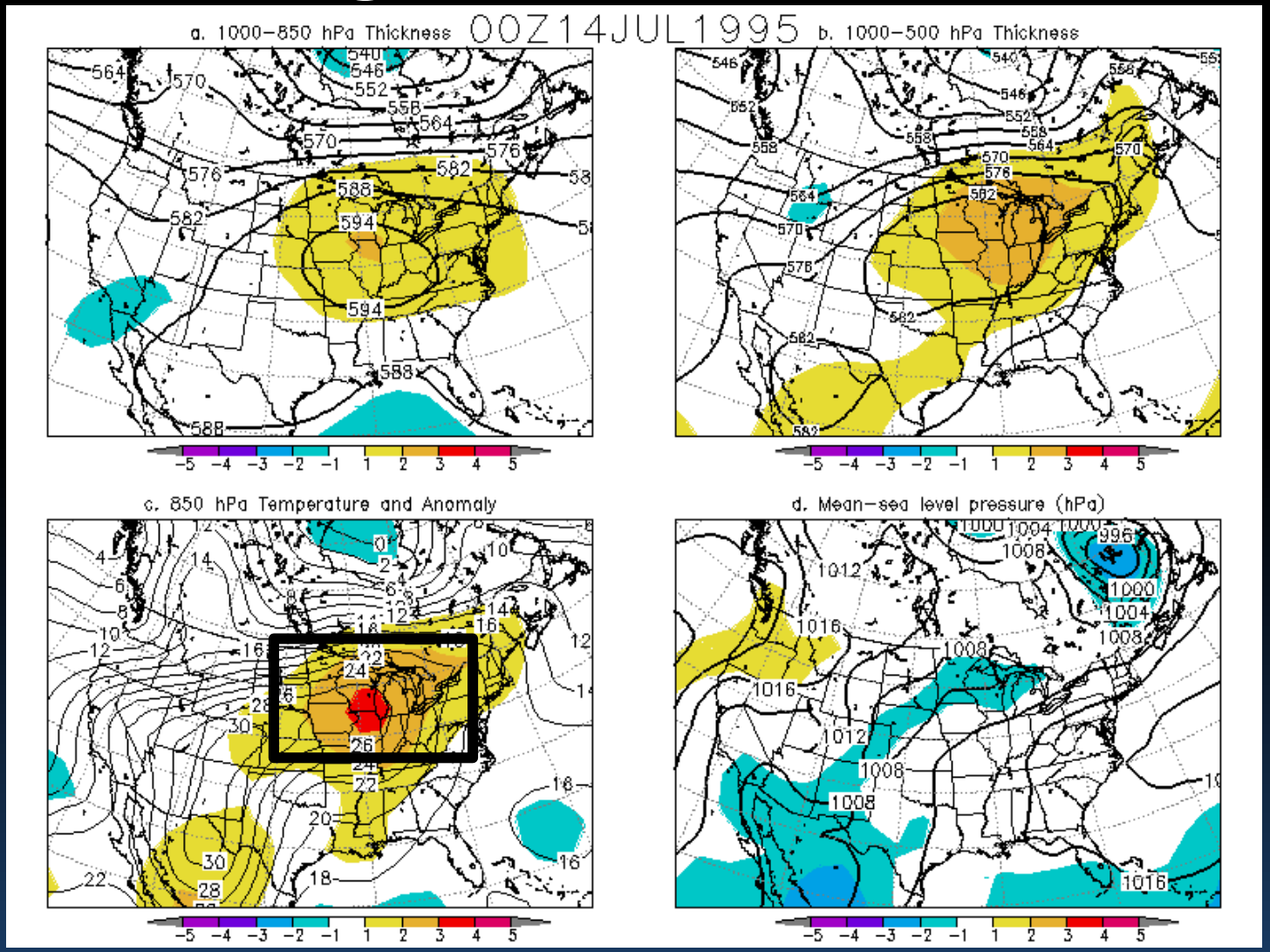


Integrated WV Transport



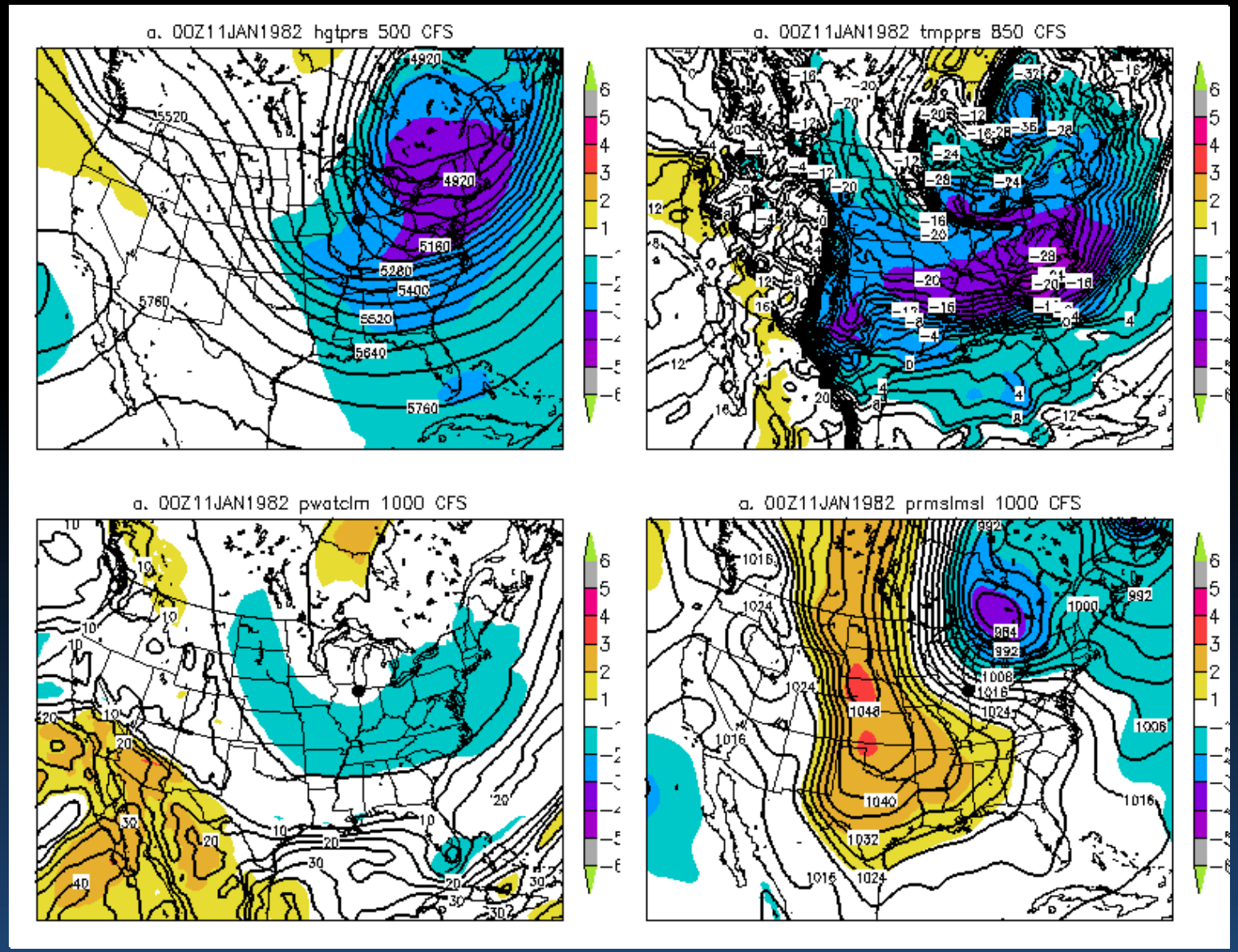
Credit:
Trevor Alcott
ESRL/GSD

Chicago Heat Wave 1995



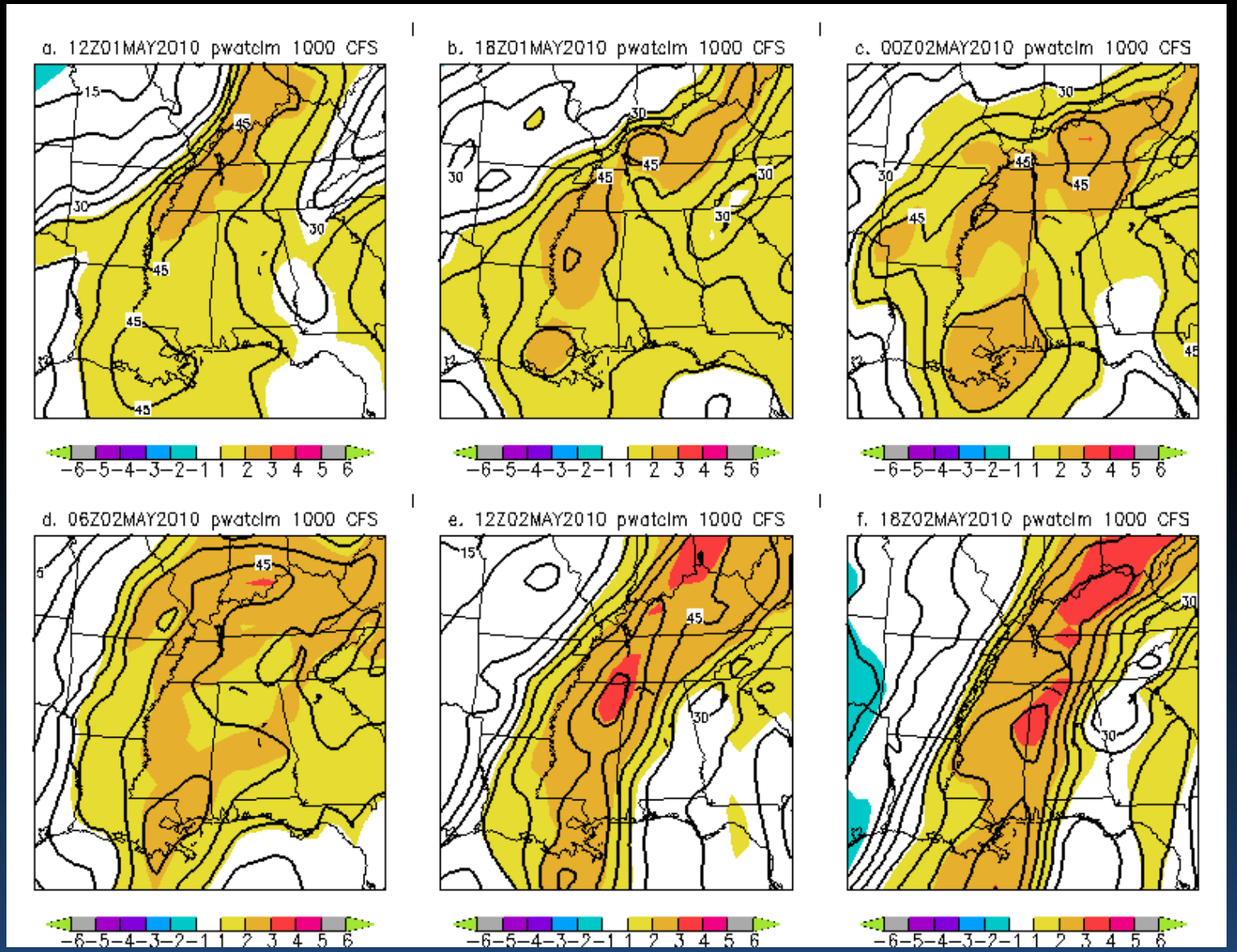
Credit: Rich Grumm, SOO, WFO State College

Jan 10-11, 1982



Credit: Rich Grumm, SOO, WFO State College

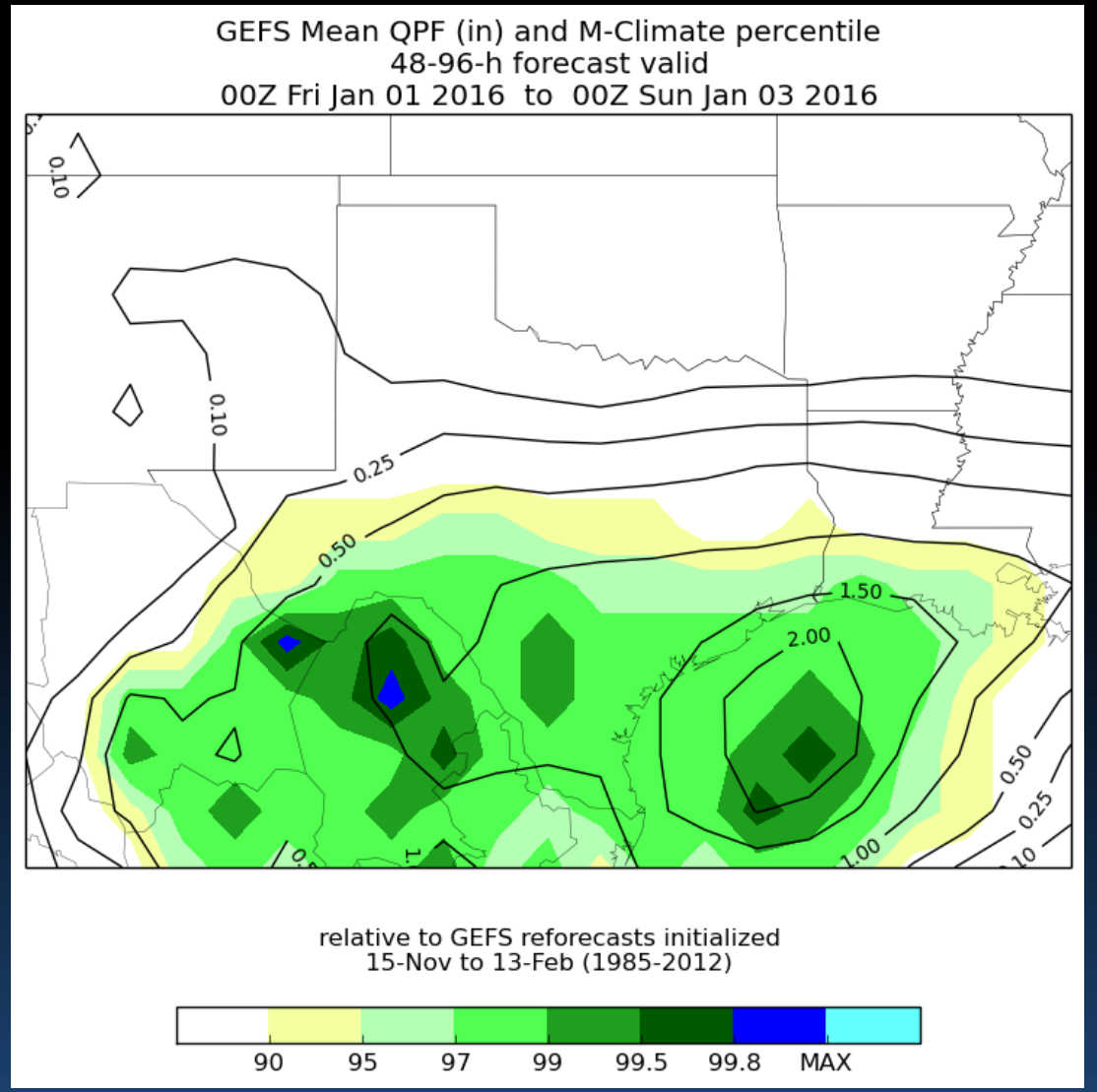
PW anomalies for the Nashville Flood May 1-2, 2010



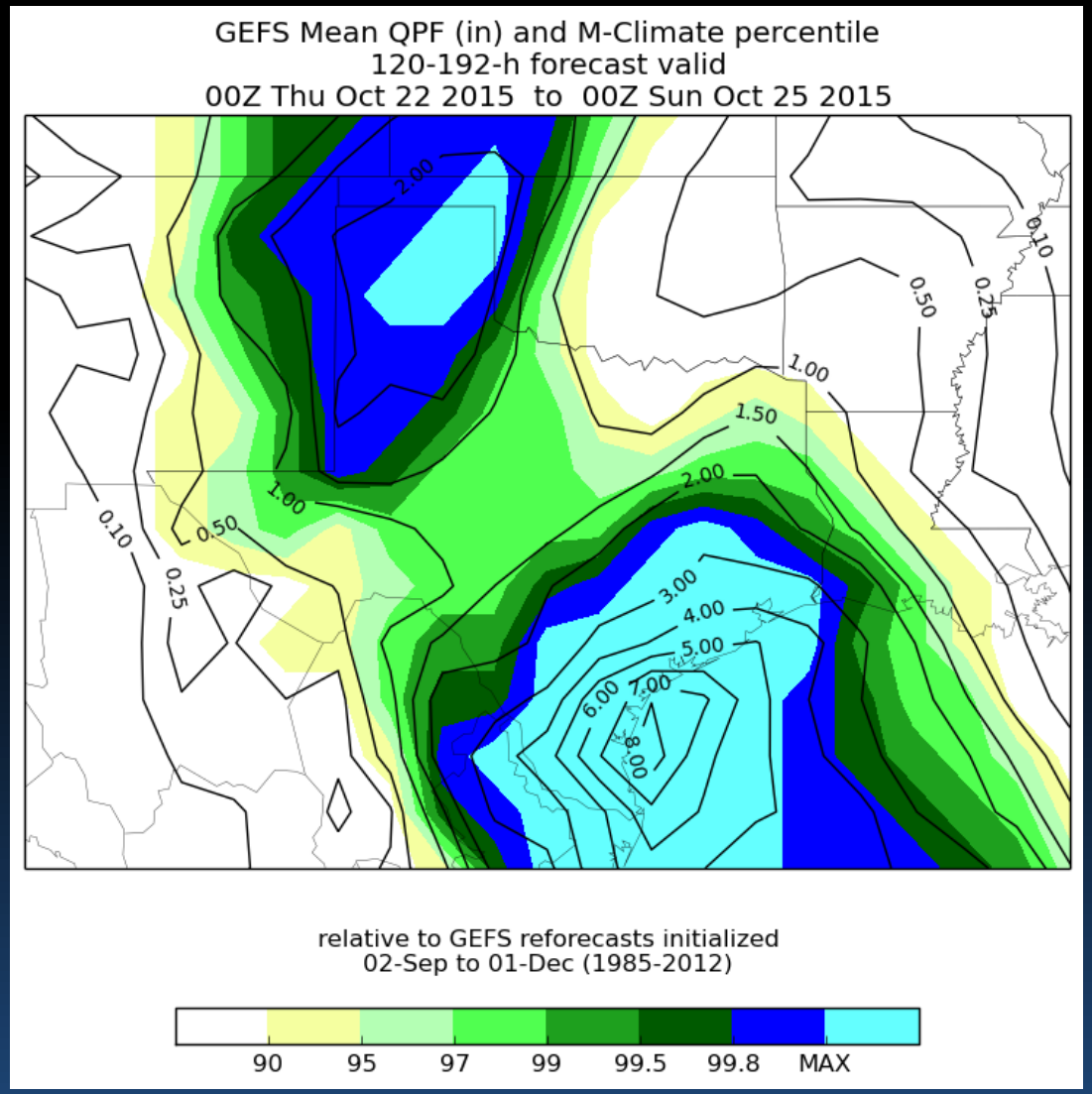
Credit: Rich Grumm, SOO, WFO State College

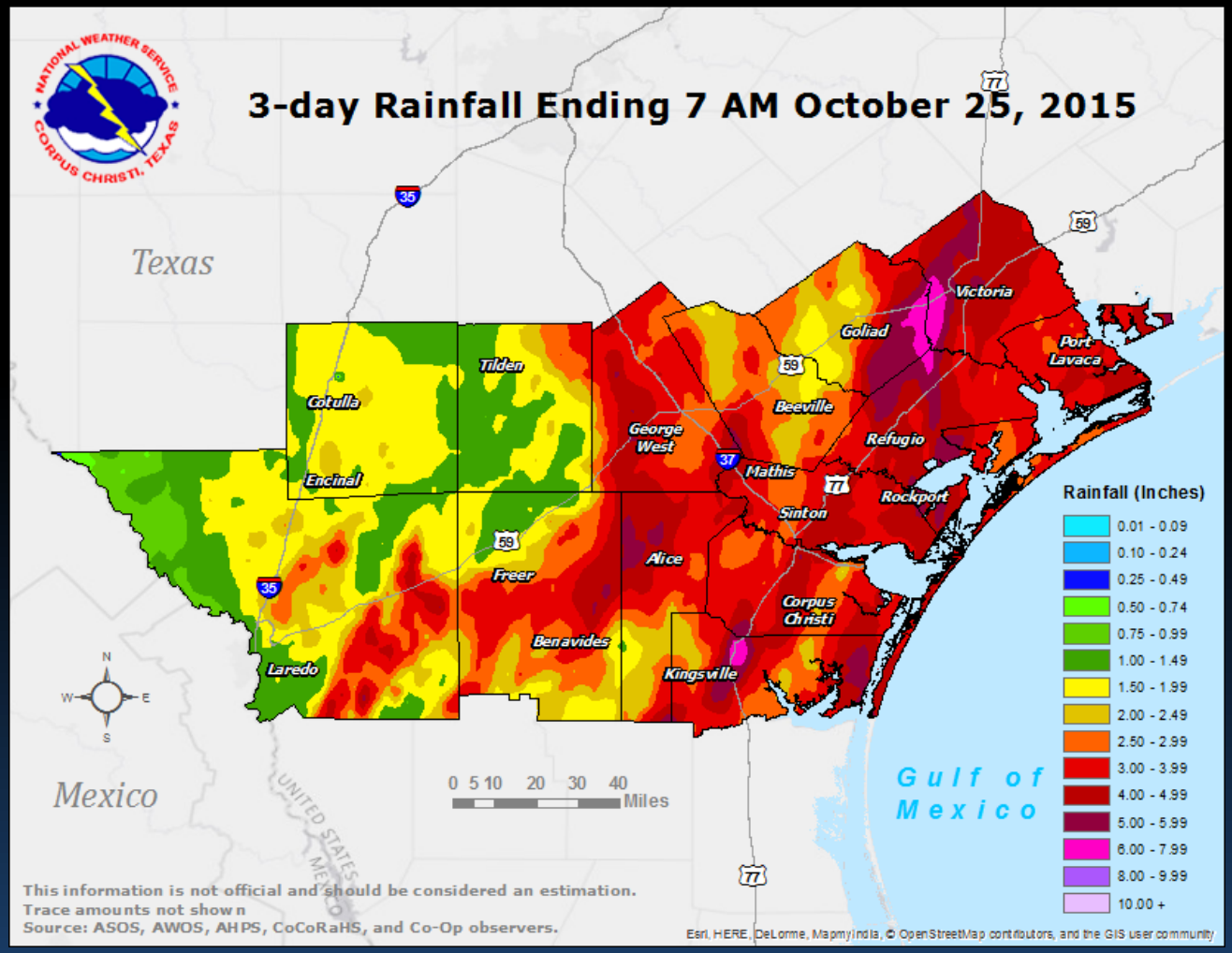
M-Climate

- How does the current forecast compare to past forecasts?
- Past forecast climatology is called a “reforecast”.
  - Time-consuming to produce.
- GEFS reforecasts go back 30 years.
  - Analyzed with reanalysis data (CFSR).

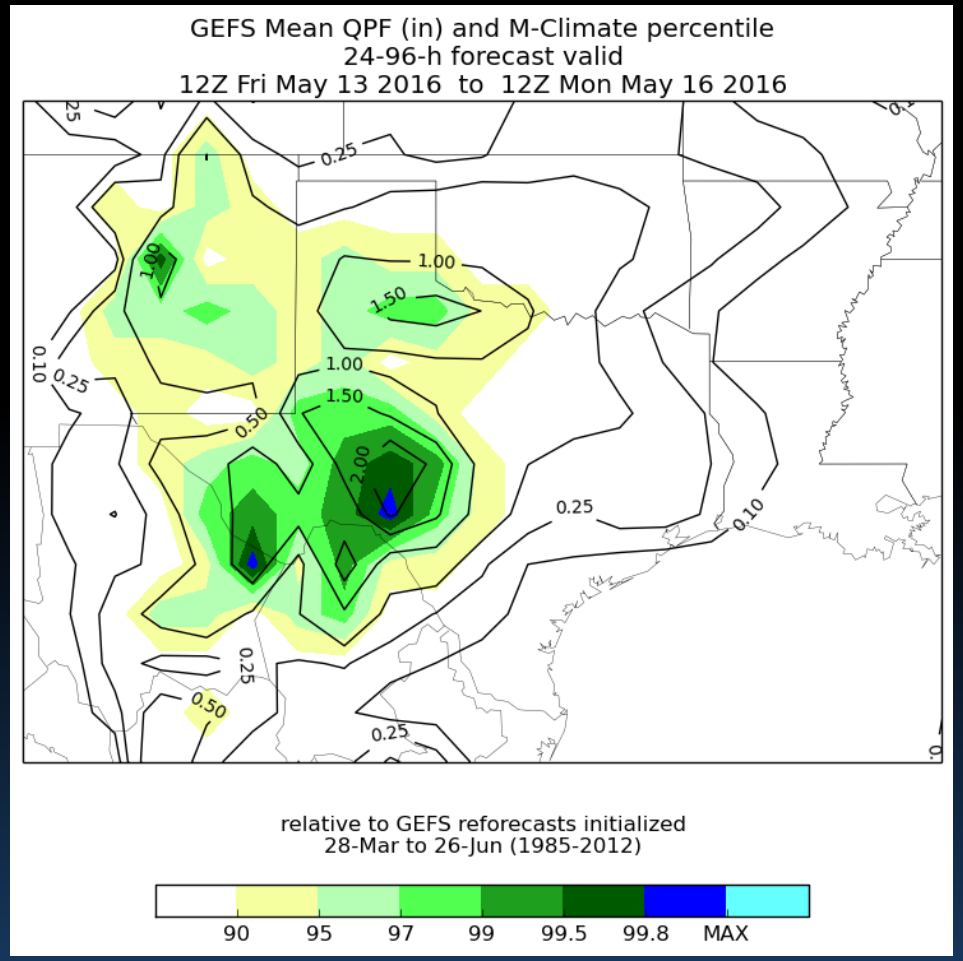


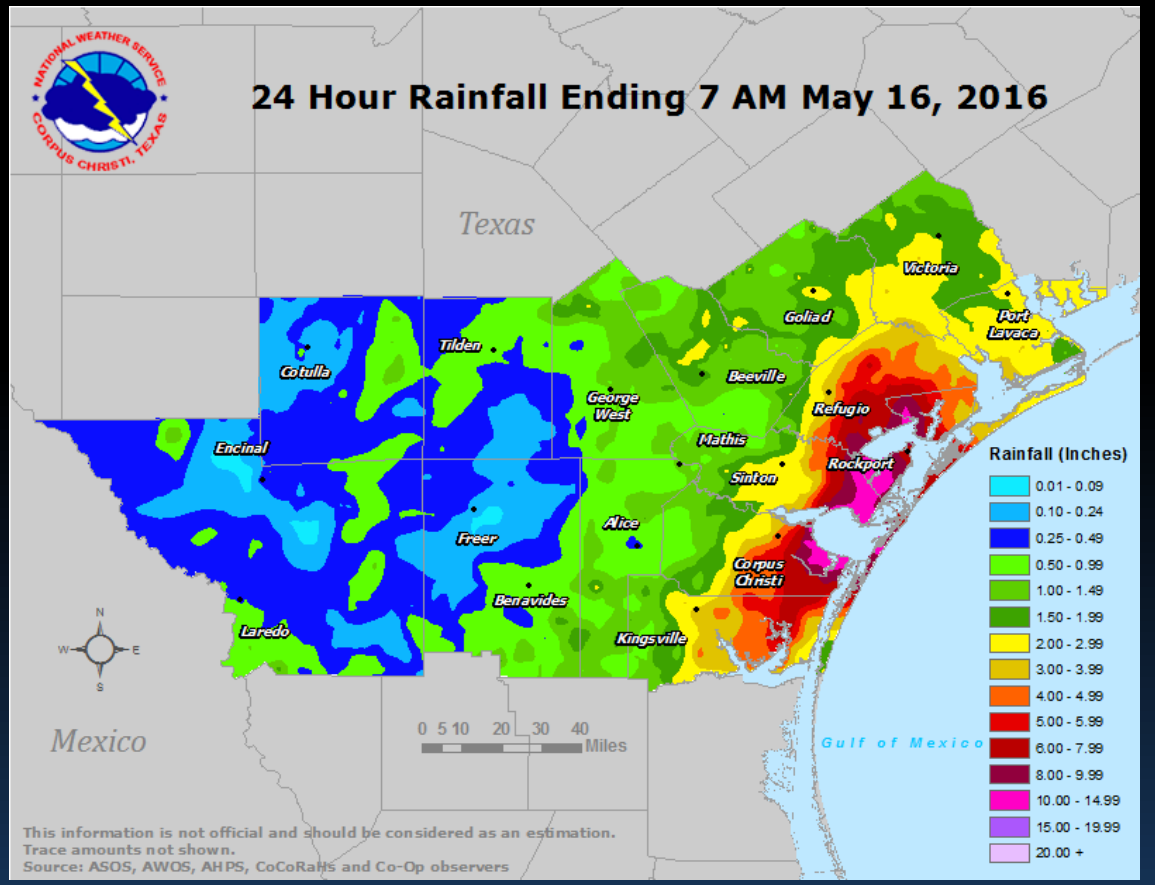
GEFS Mean QPF M-Climate Percentile
Oct 22-25, 2015





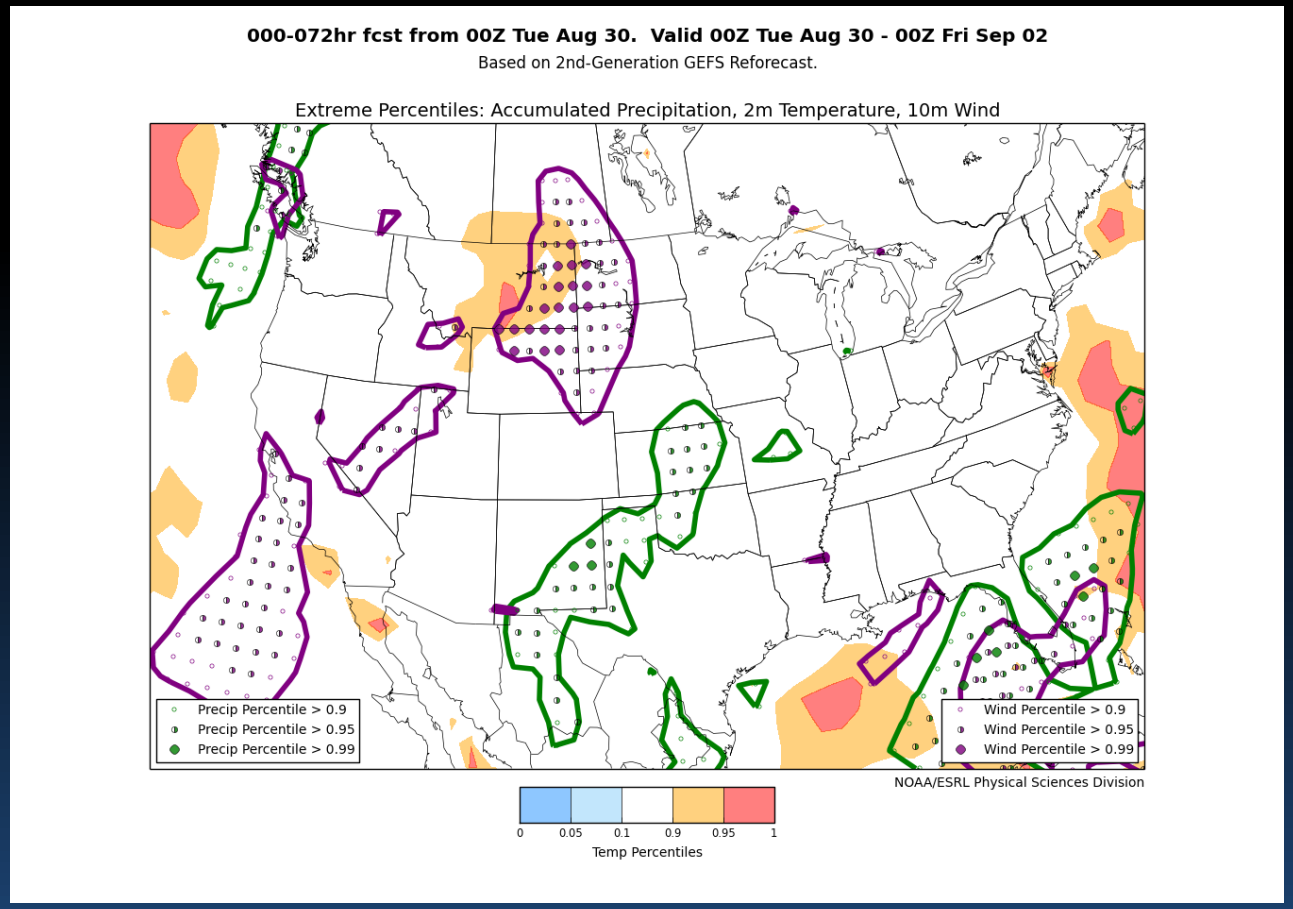
Anomalies can still miss significant events

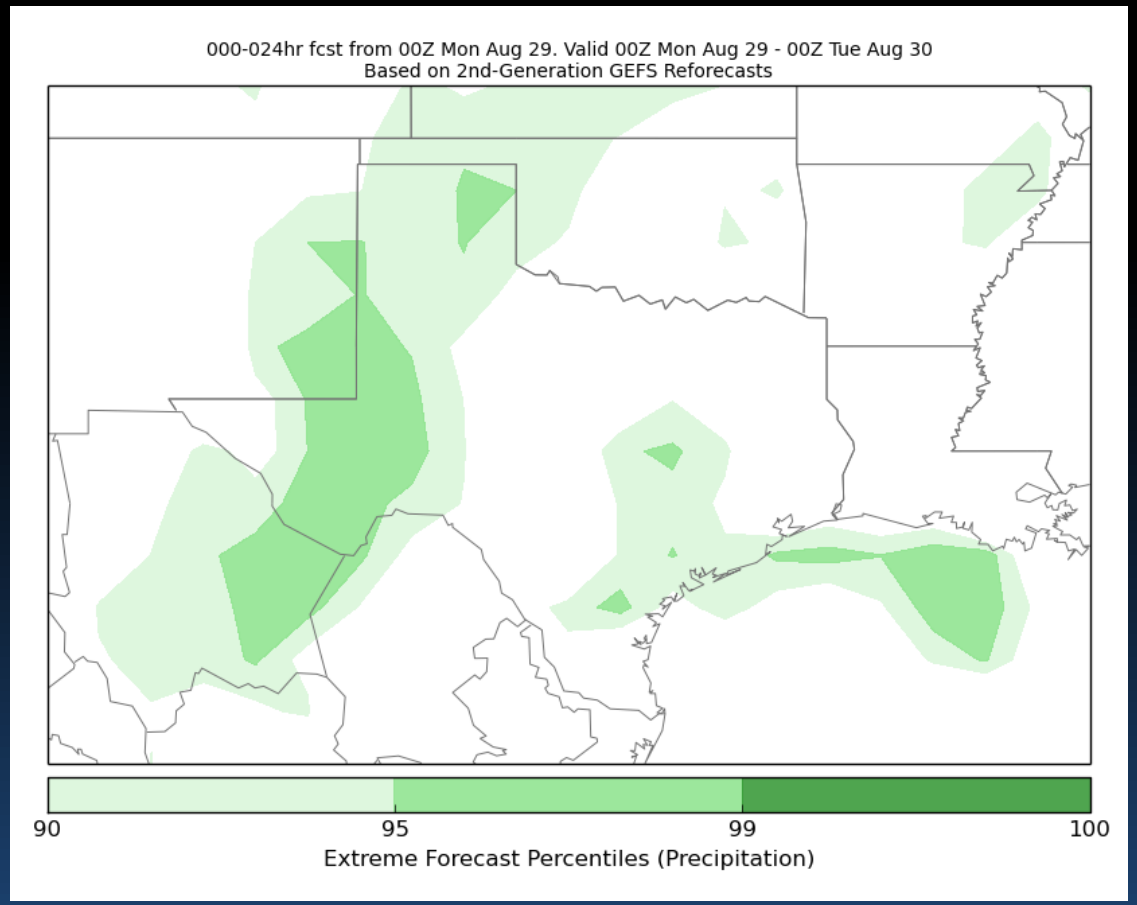




Extreme Forecast Index (EFI)

- Index used to identify an extreme event based on the M-Climate.



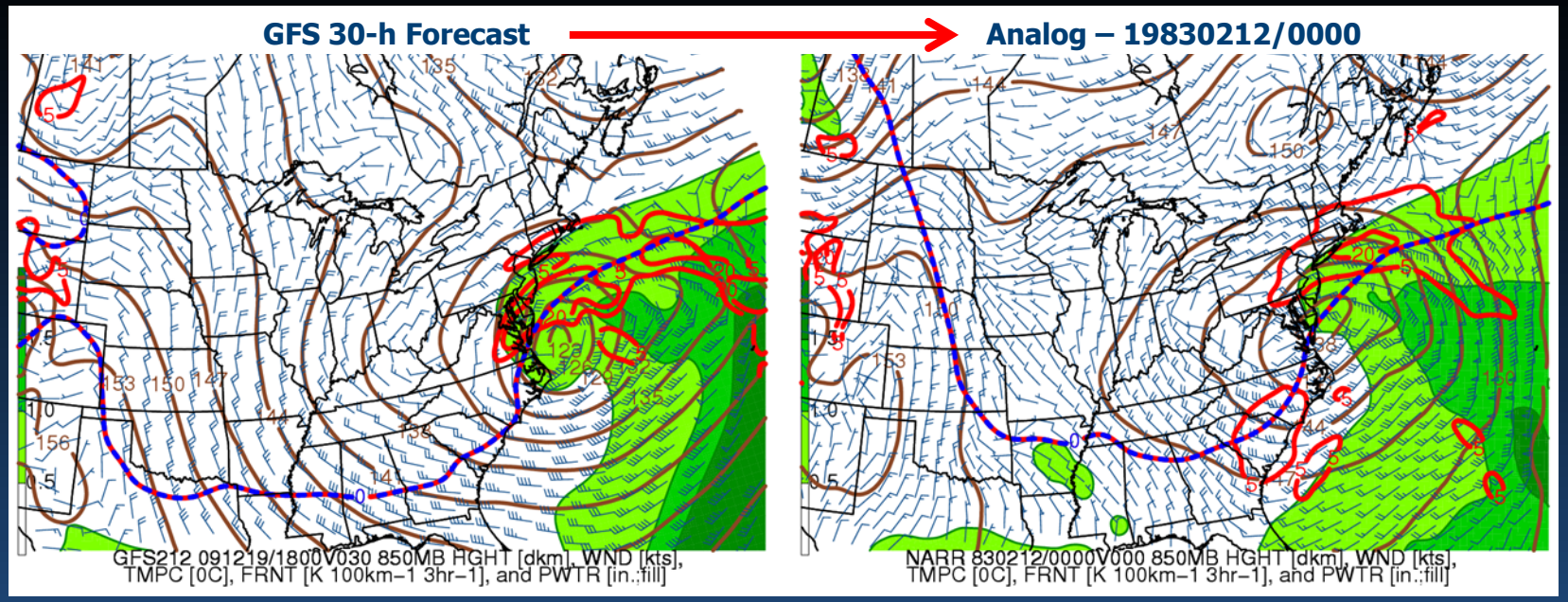


Analogs

What is an Analog?

- If the current state of the atmosphere resembles a previous state then the two are termed **analogs**.

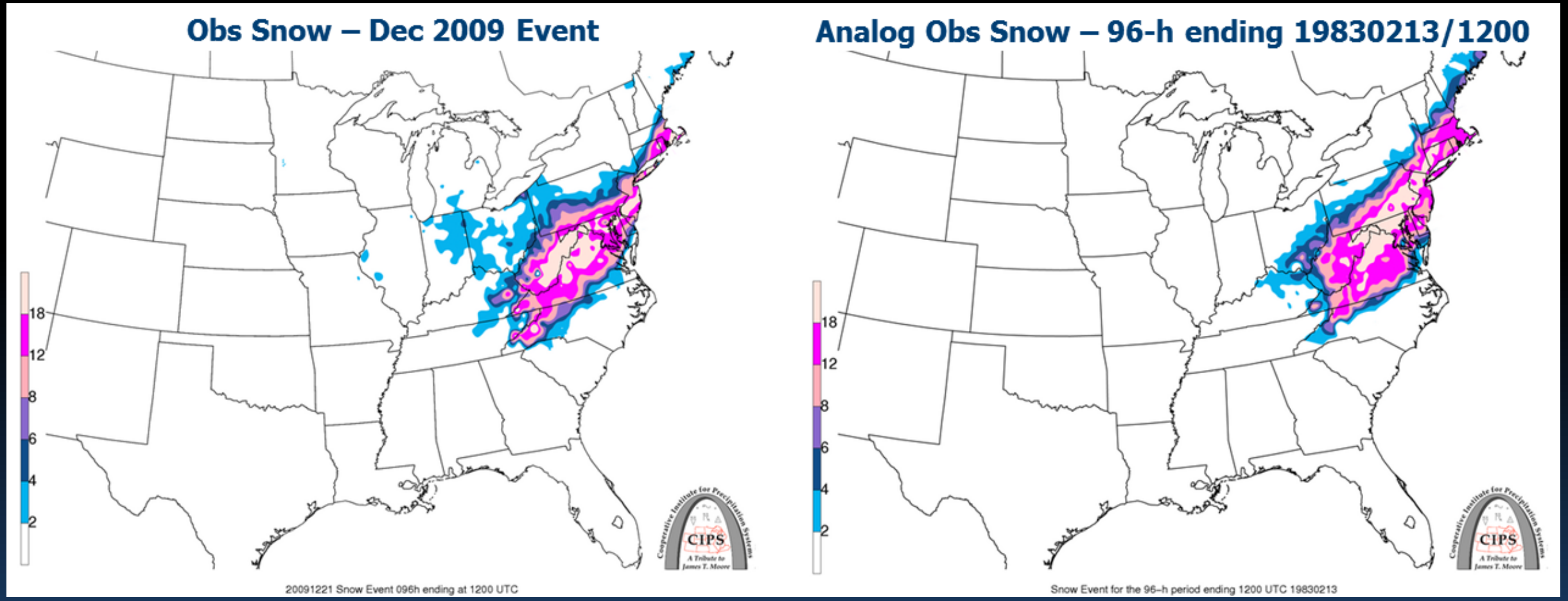
- "Pattern recognition".



Benefits of Analogs

- Assists forecasters in identifying high impact events.
  - "Anomalous" events.
- Awareness of potential impacts.
  - Similar past analogs may produce similar impacts.
- Increases situational awareness.

Analogs can be a useful forecast tool.



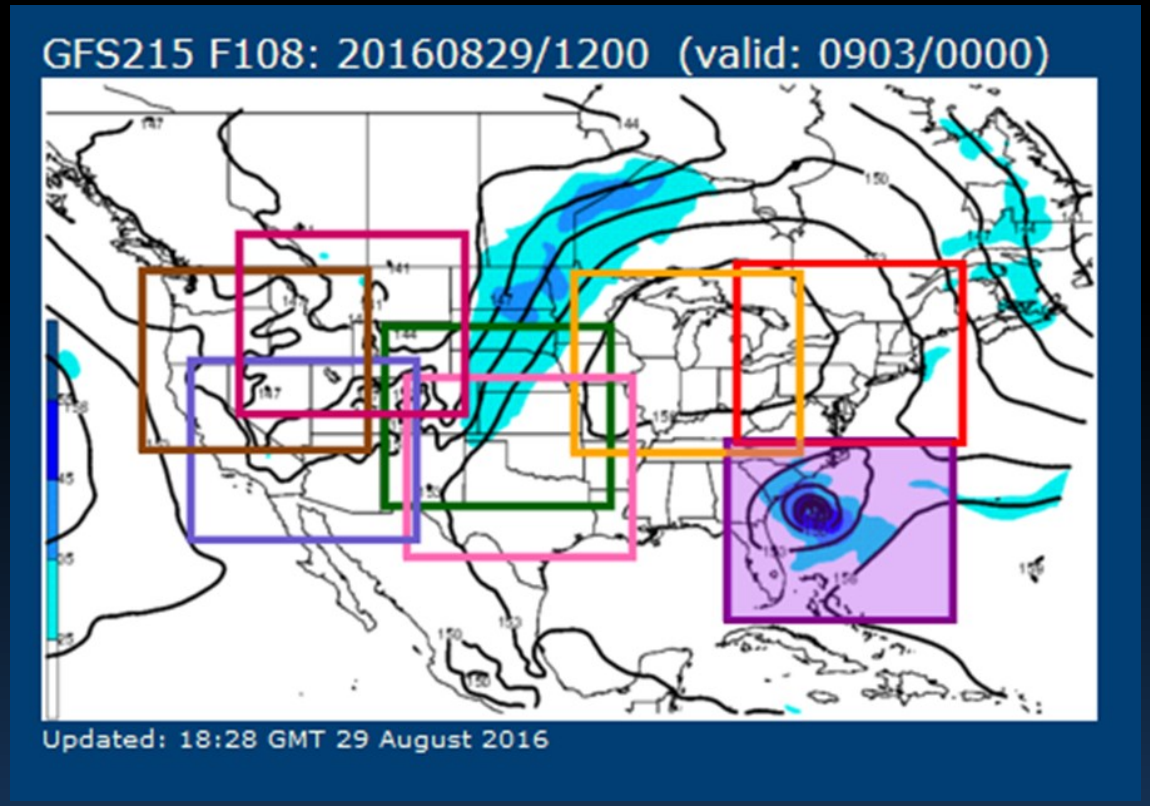
Limitations of Analogs

- Analogs depend upon the accuracy of the model.
- Analogs are NOT forecasts.
- A perfect analog match is usually NOT possible.
- Potential impacts are just that…potential.
  - Biases in reporting
  - Data converage

Cooperative Institute for Precipitation Systems

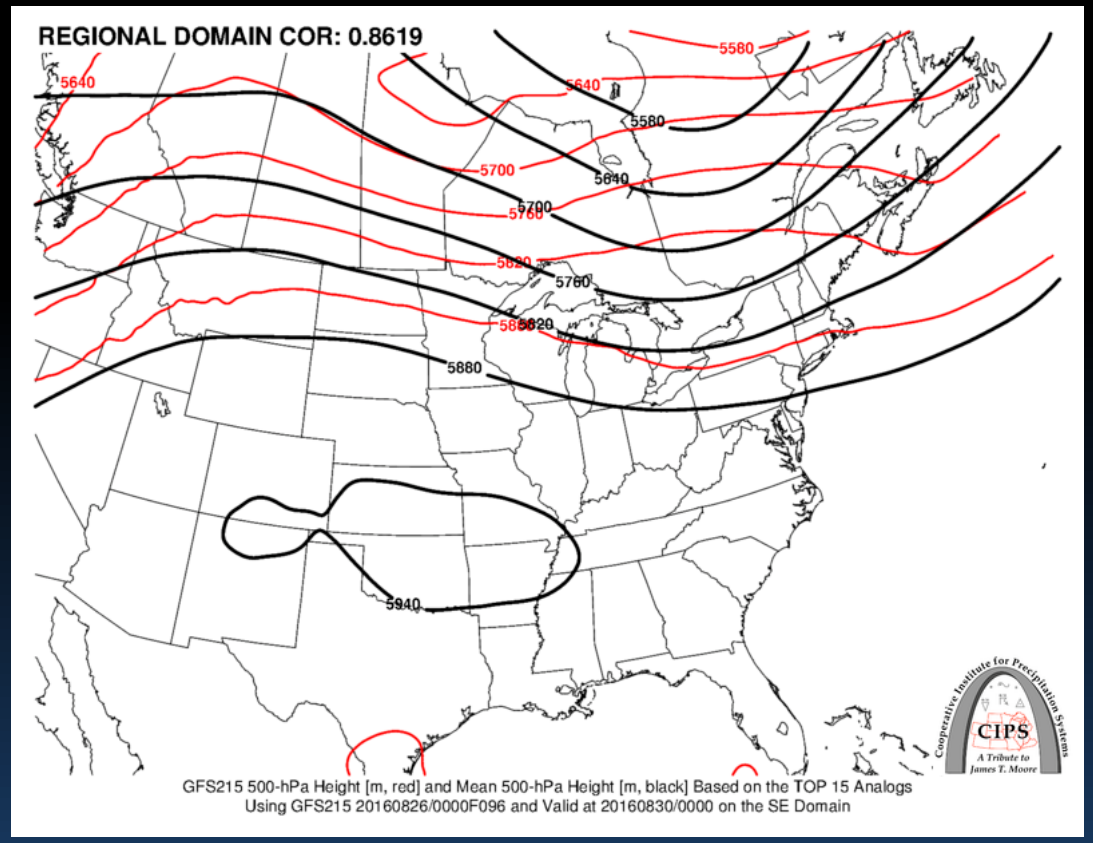
(CIPS) Analog Guidance

- Maintained by Dr. Charles Graves, St. Louis U.
- One of the best analog archives.
  - 10 day running archive.
  - Runs twice a day through 120-132 hours.
  - Different domains.
- Searches the NARR (1979-2014) against the NAM/GFS for potential analogs.
  - Top 15 best correlated analogs are found.

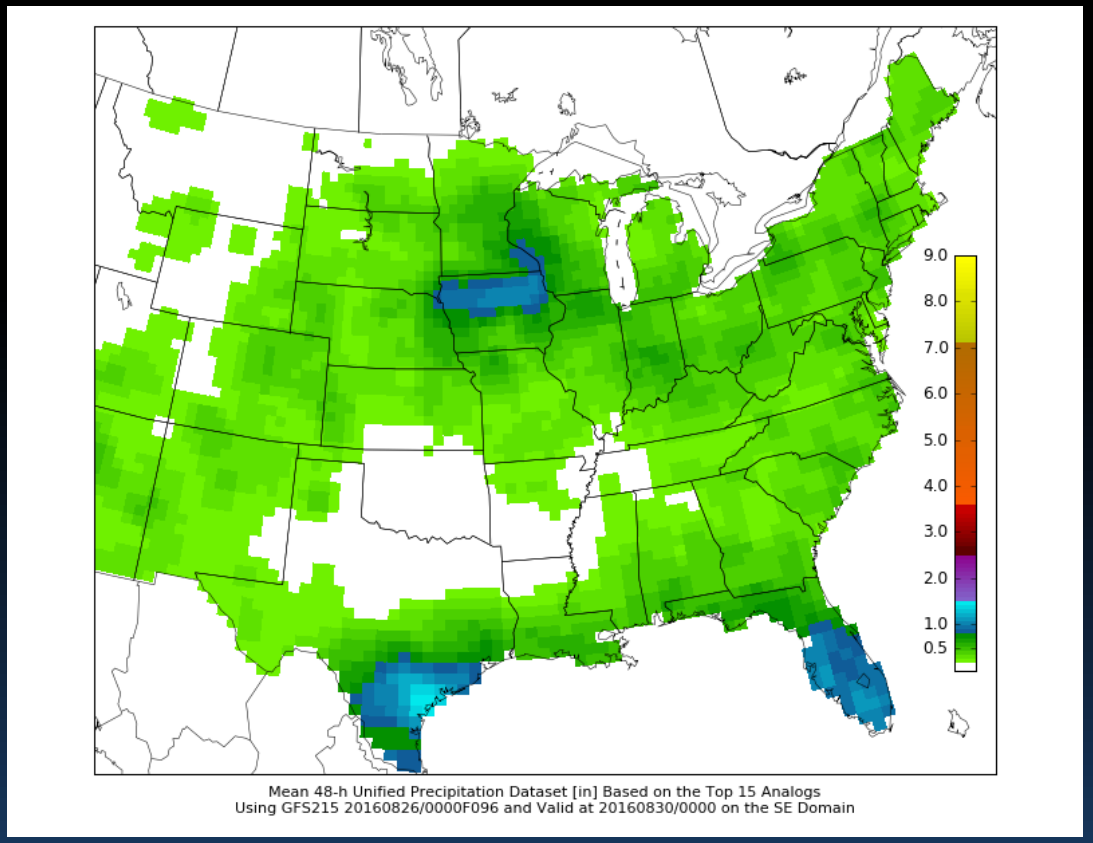


CIPS Short Range Analog Example valid at 08/30/16 00Z

500 mb Height

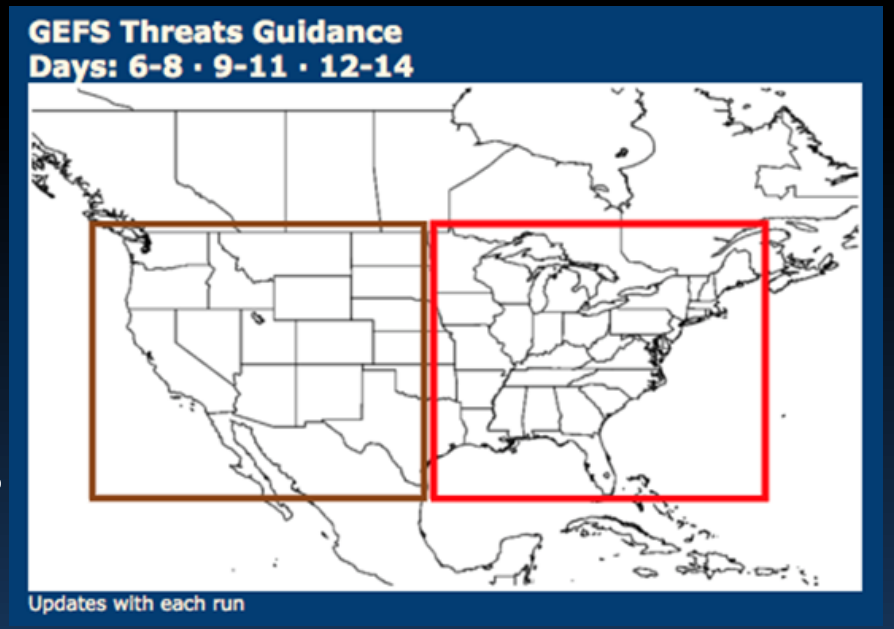


48-hour Pcpn



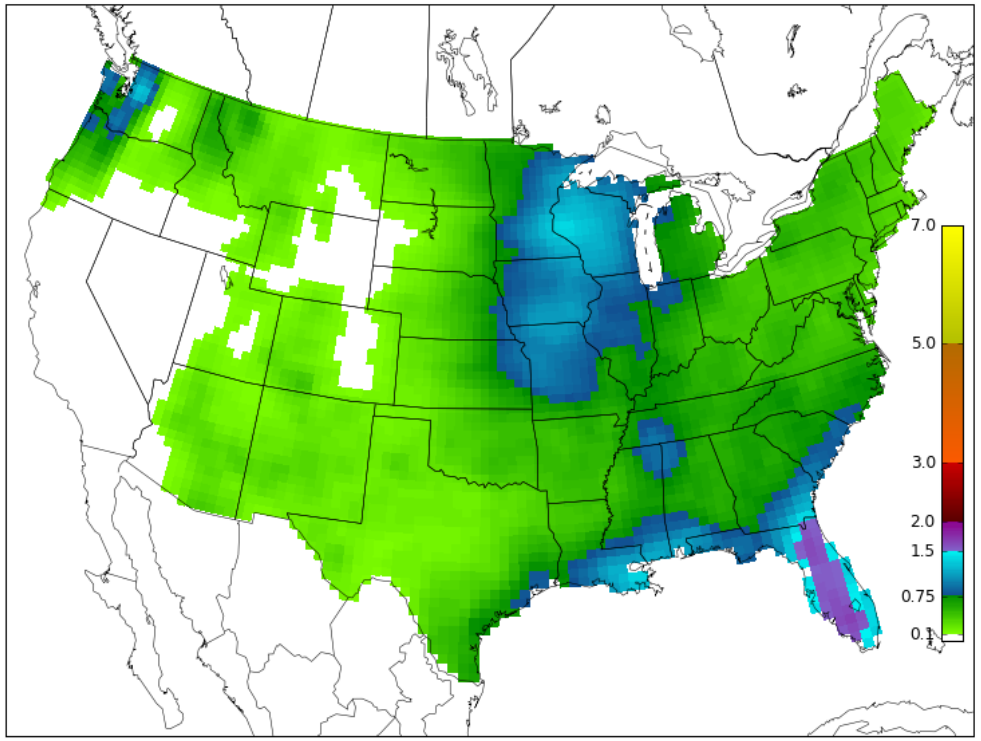
CIPS Extended Analog Guidance

- Three sets of extended analog guidance using the GEFS ensemble (6-8 day, 9-11 day, and 12-14 day) are run once a day (00Z) for 2 domains.
- Top 5 analogs from each GEFS member.
- Guidance is based off these 105 analogs.



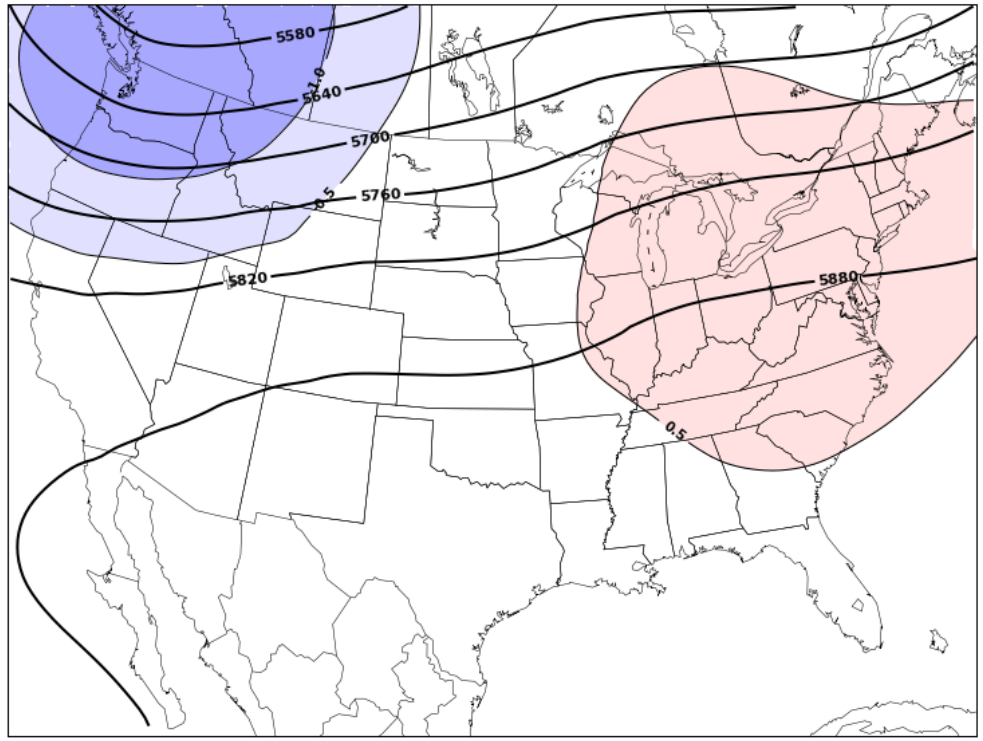
CIPS Extended Analog Example

72-hour Mean QPF



9-11 Day Mean 72-h Unified Precipitation Dataset [in] of 105 Analogs Based on the
Top 15 Analogs from each GEFS Member Centered on 20160829/0000F240 and Valid 20160908/0000

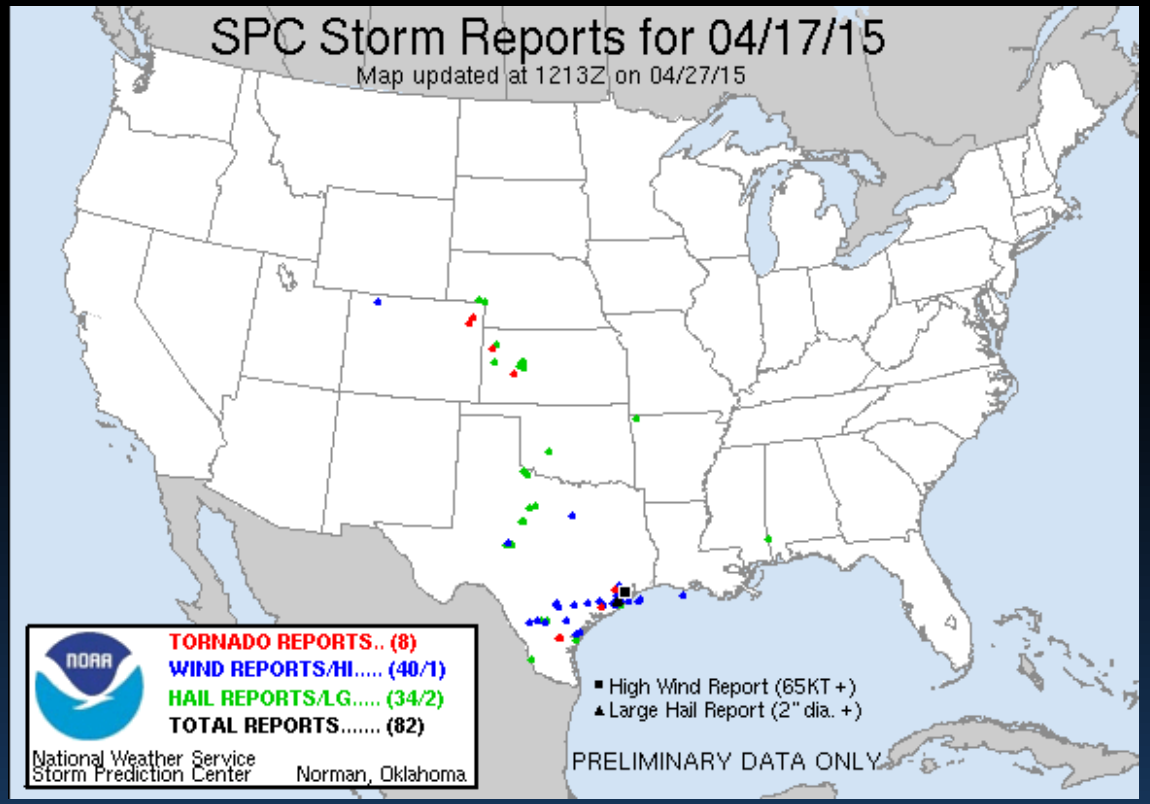
Mean 500 mb Height/Standard Anomaly



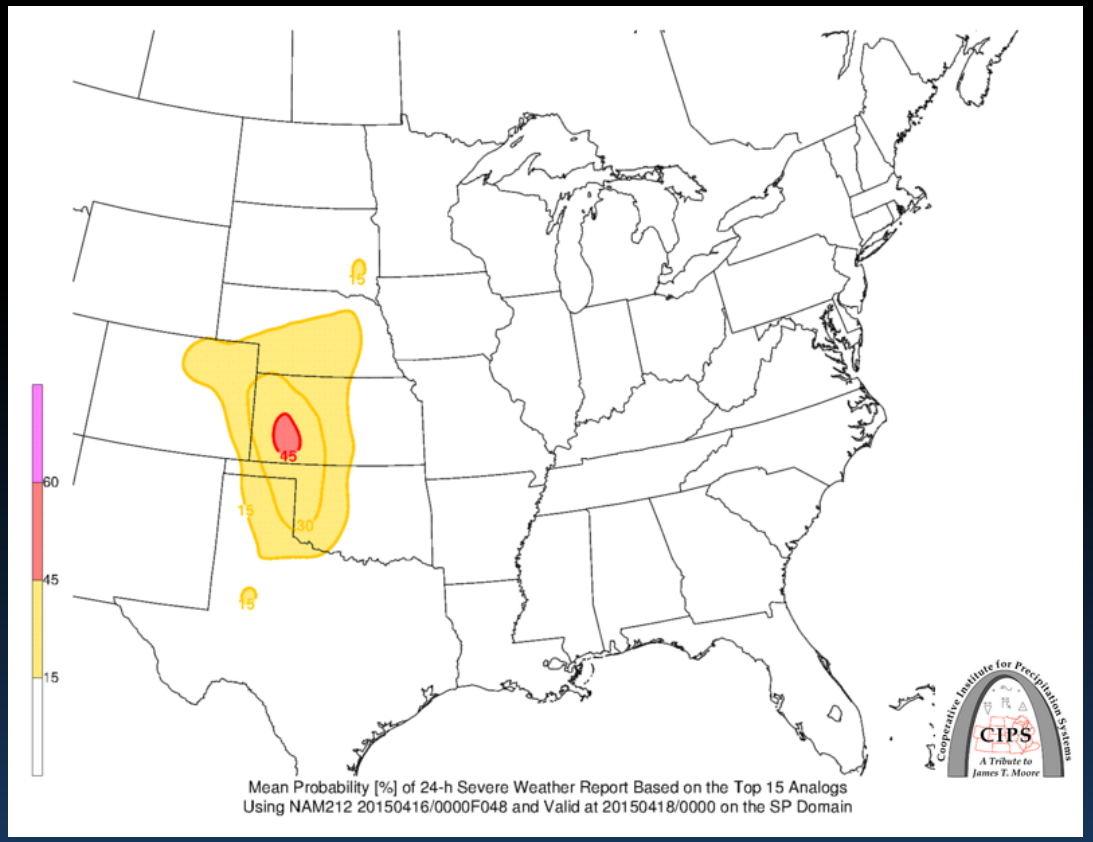
Mean 500-hPa Height [m] and Standard Anomaly [σ] of Top Analogs Based on
Top 5 Analogs from each GEFS member centered on 20160829/0000F240 and Valid at 20160908/0000

Analog Fail

Widespread Severe Wx across CRP CWA

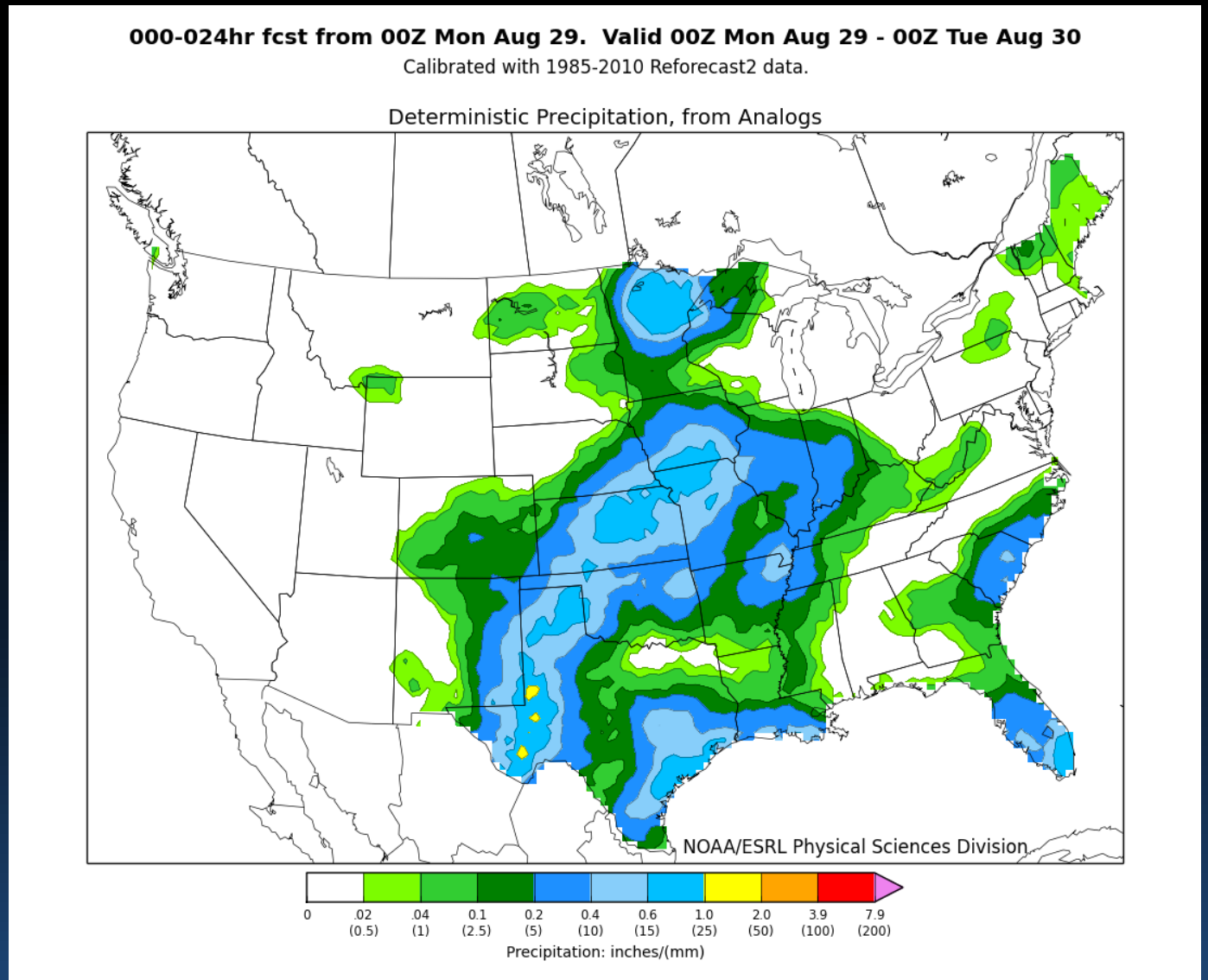


Mean Prob of SVR WX Reports was 0%



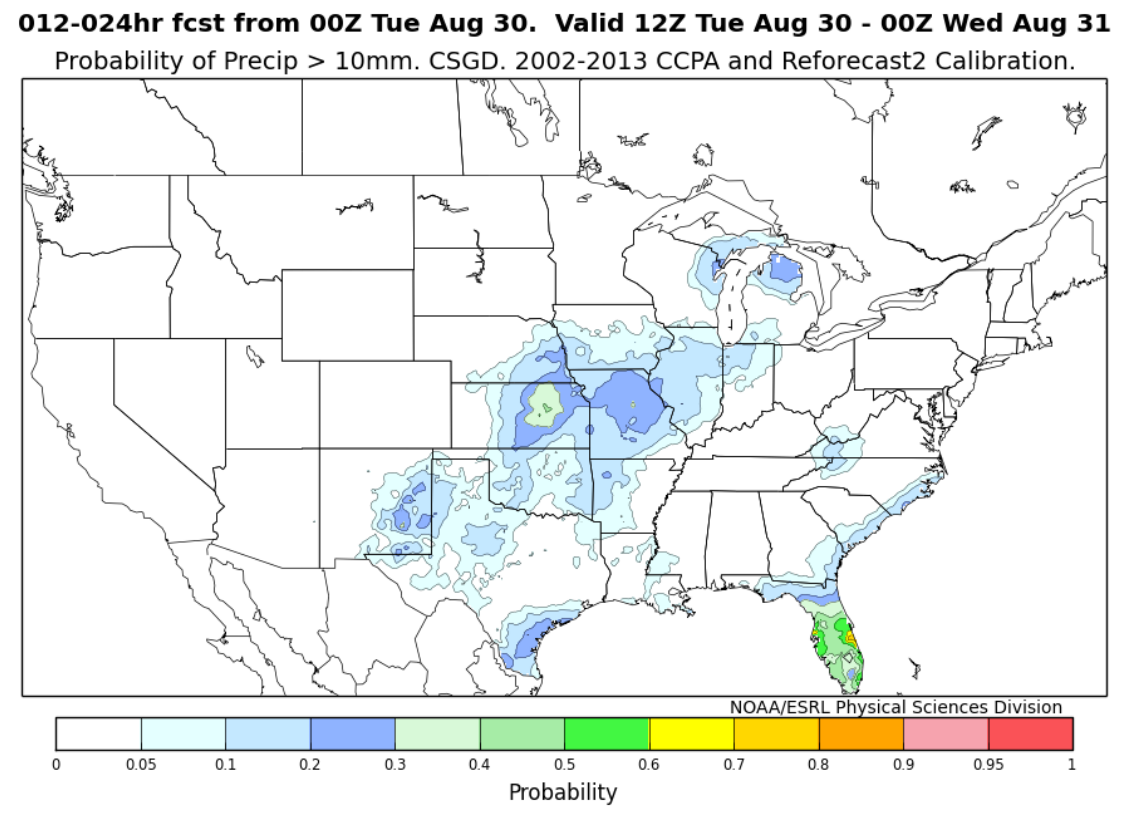
ESRL GEFS Reforecast Analogs

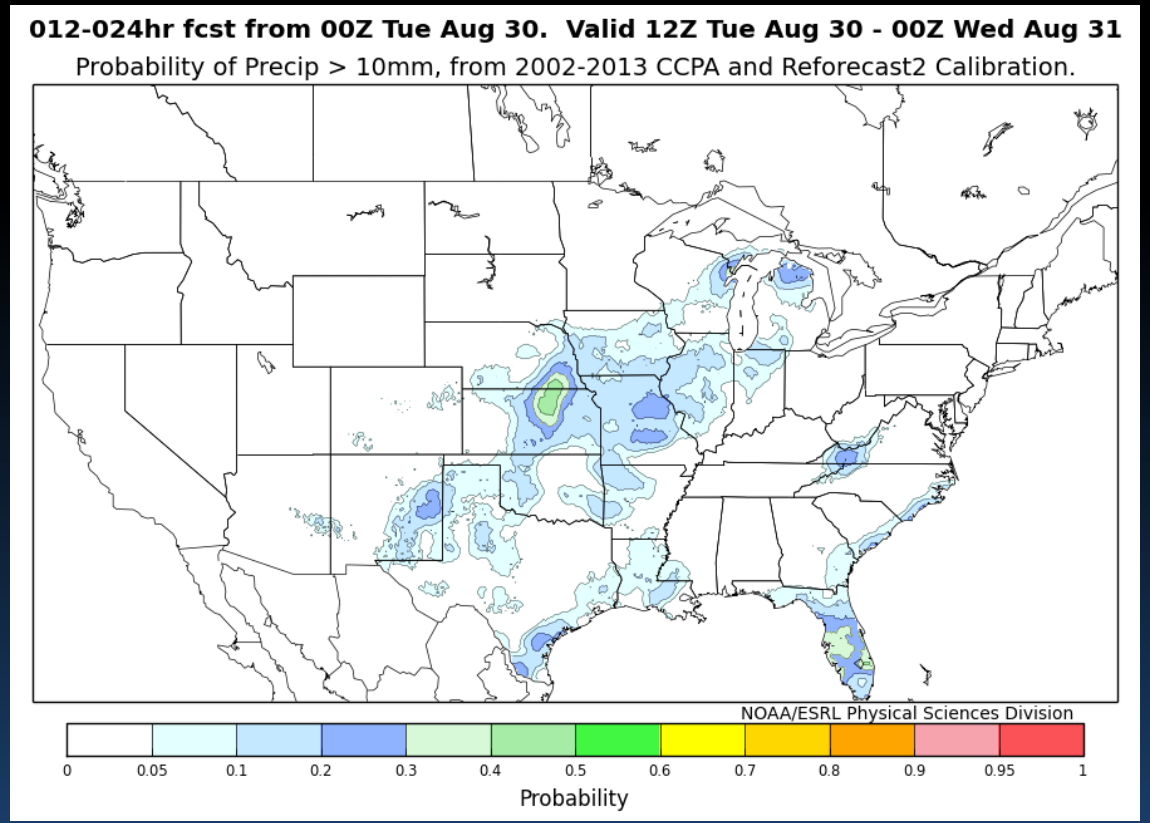
- Compares the current GEFS with past GEFS reforecasts to find analogs.
- From these analogs, probabilities are calculated based on NARR analysis.



ESRL High-Res GEFS Reforecast Pcpn Analogs

- GEFS Reforecasts & Climatology-Calibrated Precipitation Analysis.





Home | Forecast Aids | Models | Tropical | Research | Past Data | Dual-Pol | BOIVerify | National | Other Resources

http://www.srh.noaa.gov/crp/?n=soo

Mesoscale and Storm-Scale (Deterministic and Ensembles)

- High-Resolution Rapid Refresh (HRRR)
- SPC HRRR Browser
- HRRRX
- HRRR Time-Lagged Ensemble
- HRRRE (Ensemble)
- HRRR Aviation
- HRRR Smoke
- HRRR Soundings
- Rapid Refresh (RAP)
- NAM Rapid Refresh (NAMRR)
- NCEP High-Resolution Window WRF-NMMB
- NCEP High-Resolution Window WRF-ARW
- SPC 4 km WRF-NMM - 12Z Run
- SPC 4 km WRF-NMM - 00Z Run
- NSSL Deterministic and Ensemble WRF Forecasts (00Z run only)
- Texas Tech 3 km WRF
- Short-Range Ensemble Forecast (SREF) - MAG webpage
- SREF - EMC webpage
- SREF Aviation
- SPC SREF Page
- SPC SREF Plumes
- SPC Storm-Scale Ensemble of Opportunity
- High Resolution Ensemble Forecast Time Lagged (HREF-TL)
- North America Rapid Refresh Ensemble Time-Lagged (NARRE-TL)
- Storm-Scale Ensemble Forecasts (SSEF) - Only available during the HWT each Spring
- Canadian Model - RDPS

Synoptic

- GFS
- NAM
- NAM - HIRES
- ECMWF
- Canadian Model - GDPS
- UKMET-G
- NRL/FNMOC NAVGEM
- Japan Meteotorological Agency GSM
- MeteoFrance ARPEGE
- Deutscher Wetterdienst ICON (Germany)

Ensembles

- Ensemble Situational Awareness Table
- Ensemble Forecast Viewer (Penn State)
- WRH Ensemble Graphics
- Global Ensemble Forecast System (GEFS) Spaghetti Plots
- GEFS Mean and Spread
- GEFS Plumes
- Canadian Ensemble - GEPS
- Canadian Regional Ensemble - REPS
- North American Ensemble Forecast System (NAEFS) - MAG webpage
- NAEFS - Canadian webpage
- ECMWF and NCEP Ensemble Products
- ECMWF Ensemble
- NCAR Ensemble Forecasts
- ESRL GEFS Reforecasts

http://www.srh.noaa.gov/crp/?n=soo

Marine

- WFO Corpus Christi Nearshore Wave Prediction System (NWPS)
- WFO CRP NWPS 3-hour graphics of Waveheights, Period, Swell, Currents, Sea Surface Height, Wavelength, Winds, Depth, and Spectral Density
- Gerling-Hanson plot for Buoy 42019
- Wavewatch III - MAG webpage
- WaveWatch III - NCEP webpage
- HURWave (WW3 with a blend of GFS & HWRF winds)
- Global Ensemble Ocean Wave Forecast System
- Combined NCEP/FNMOC Wave Ensembles Product
- Global Real-Time Ocean Forecast System (RTOFS)
- Northern Gulf of Mexico Operational Forecast System (NGOFS)
- TAMUCC-CBI Artifical Neural Network Water Level Forecasts
- Extratropical Surge and Tide Operational Forecast System (ESTOFS) - Storm Surge
- ESTOFS - Total Water Level
- MDL's ExtraTropical Storm Surge Model (ETSS/ET-SURGE) - Storm Surge
- ETSS Point Output
- ETSS Port Aransas Graph Output
- Sea, Lake, and Overland Surges from Hurricanes Model (SLOSH)

Tropical Cyclone

- Tropical Cyclone Guidance - NCAR/UCAR
- Tropical Cyclone Guidance - Univeristy of Wisconsin at Milwaukee
- Hurricane WRF Model
- FSU Model Page
- Navy's COAMPS-TC Model
- Tropical Cyclone Guidance - SUNY Albany
- Tropical Cyclone Forecast Products from EPS (TCEPS)
- ESRL Experimental Tropical Cyclone Tracks
- GFDL Hurricane Model Ensemble
- Hurricane Model Summary

Other

- WR STID Forecast Confidence Toolkit
- SR STB Forecast Toolkit
- Weather Archive and Visualization Environment (WAVE)
- National Blend of Models (NBM) Viewer
- National Water Model
- Penn State E-WALL
- Tropical Tidbits Model webpage
- HYSPLIT (Email Username and Password Protected)
- Navy Aerosol Analysis and Prediction System (NAAPS)
- SPC MARS Forecast Loop
- Climate Forecast System (CFS) Severe Weather Dashboard
- NCEP CFS Plume Viewer
- Cooperative Institute for Precipitation Systems (CIPS) Historical Analog Guidance

Young grasshopper, you are now well on your way to becoming an NWP guru!

$$\frac{\partial u}{\partial t}+\dot{\sigma}\frac{\partial u}{\partial \sigma}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv-\frac{uv}{r}\tan\phi+g\frac{\partial z}{\partial x}+c_p\theta\frac{\partial \pi}{\partial x}+F_x=0$$

$$\frac{\partial v}{\partial t}+\dot{\sigma}\frac{\partial v}{\partial \sigma}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu+\frac{u^2}{r}\tan\phi+g\frac{\partial z}{\partial x}+c_p\theta\frac{\partial \pi}{\partial y}+F_y=0$$

$$\frac{\partial (gz)}{\partial \sigma}+c_p\theta\frac{\partial \pi}{\partial \sigma}=0,$$

$$\frac{\partial \theta}{\partial t}+\dot{\sigma}\frac{\partial \theta}{\partial \sigma}+u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}+H=0,$$

$$\frac{\partial p_\sigma}{\partial t}+\frac{\partial}{\partial \sigma}(\dot{\sigma}p_\sigma)+\frac{\partial}{\partial x}(up_\sigma)+\frac{\partial}{\partial y}(vp_\sigma)-\frac{vp_\sigma}{r}\tan\phi=0, \qquad \pi=\left(\frac{p}{P}\right)^\kappa.$$