

# Anomaly Forecast and Extreme Forecast Index

Hong Guan and Yuejian Zhu

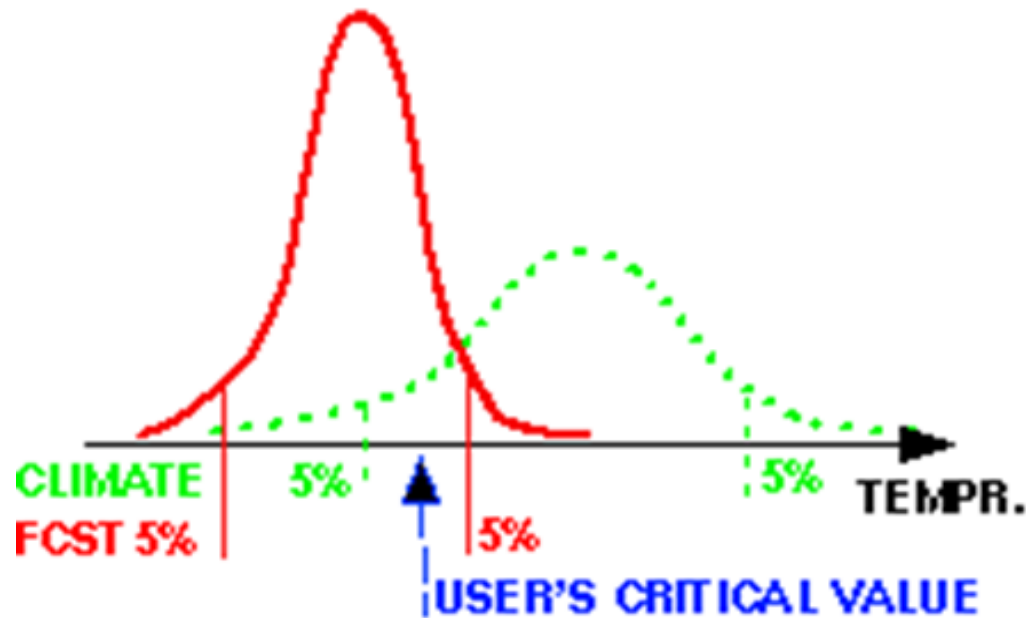
EMC/NCEP

June 29, 2017

# Highlights

- Definitions of extreme
- Common extreme weather forecast products
  - Anomaly Forecast (ANF) and Extreme Forecast Index (EFI)
- Developments of verification methodology
  - ANF and EFI comparison
  - Verification of extreme cold event forecasts
  - Verification of extreme heavy precipitation forecasts
- Real-time Parallel “ANF” and “EFI” products
  - June 13, 2017 Heatwave over the Northeast Conus
- Reference:
  - Guan, H. and Y. Zhu, 2017: "Development of verification methodology for extreme weather forecasts" *Weather and Forecasting*, Vol. 32, 470-491

# Definition of Extreme Events



*Fig. 1. Schematic indicating climatological (continuous), forecast (dotted) and user specific (dashed) extreme events.*

Climatological (forecast) extreme is the tails of corresponding distribution for a particular variable, time, and place.

# Extreme Weather Forecast Methods

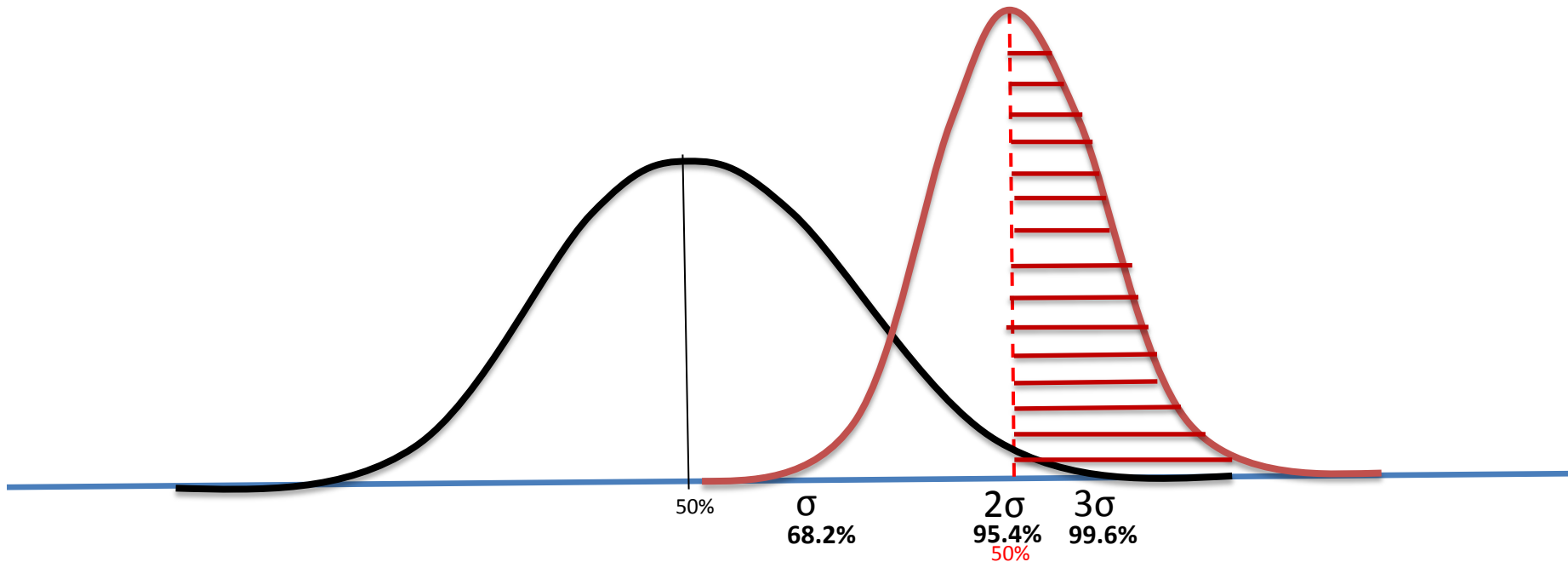
- Anomaly Forecast (**ANF**)

EMC/NOAA since 2006

- Extreme Forecast Index (**EFI**)

CMC, ECMWF, and ESRL/NOAA

# Anomaly Forecast (ANF)



Schematics diagram for anomaly forecast (PDF)

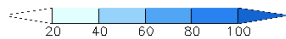
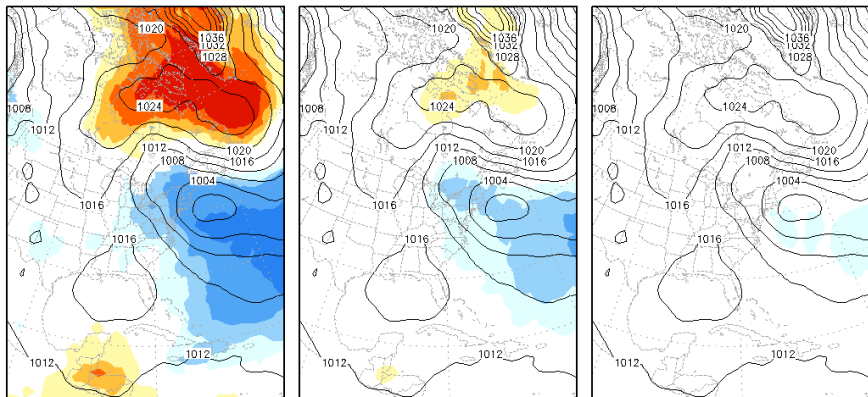
## Definitions for Anomaly Forecast

Percentage of ensemble forecast (shaded area) which exceeds climate threshold for example: exceeding  $2\sigma$  of ensemble mean or exceeding  $3\sigma$  of 20% ensemble forecast

Sea Level Pressure (PRMSL), 192-hour forecast  
 Ini. time:2012102300 Valid time:2012103100

Contour—mean forecast; Shaded—forecast anomalies

$\sigma$        $2\sigma$        $3\sigma$



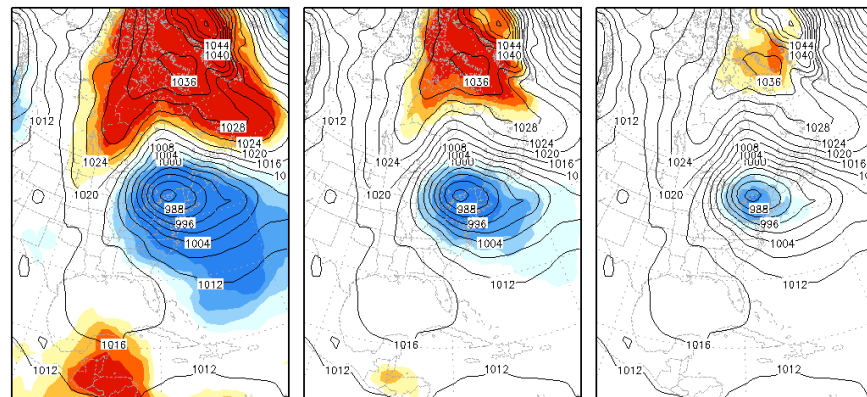
**8-day fcst**

Sea Level Pressure (PRMSL), 144-hour forecast  
 Ini. time:2012102500 Valid time:2012103100

Contour—mean forecast; Shaded—forecast anomalies

**Anomaly forecast**

one stdv      two stdv      three stdv



**6-day fcst**

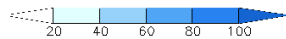
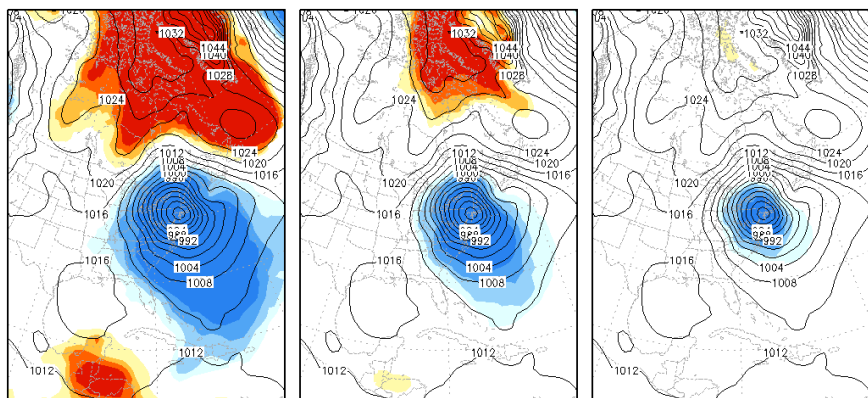
**Hurricane Sandy**

YUEJIAN ZHU, GCWMB/EMC/NCEP/NOAA

Sea Level Pressure (PRMSL), 120-hour forecast  
 Ini. time:2012102600 Valid time:2012103100

Contour—mean forecast; Shaded—forecast anomalies

one stdv      two stdv      three stdv

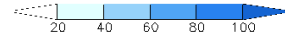
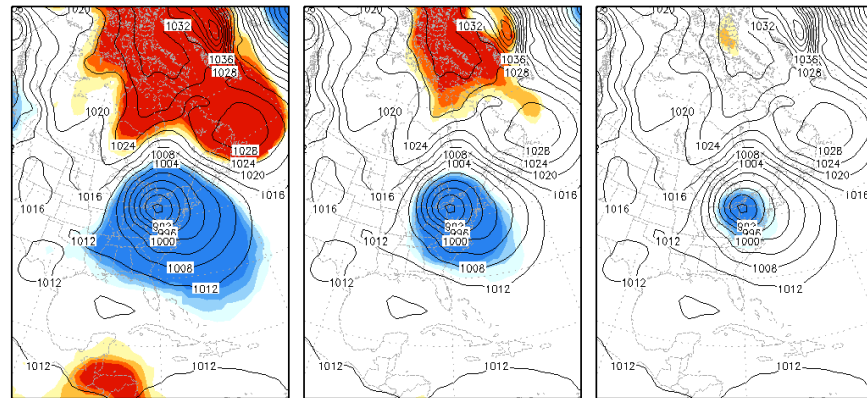


**5-day fcst**

Sea Level Pressure (PRMSL), 96-hour forecast  
 Ini. time:2012102700 Valid time:2012103100

Contour—mean forecast; Shaded—forecast anomalies

one stdv      two stdv      three stdv



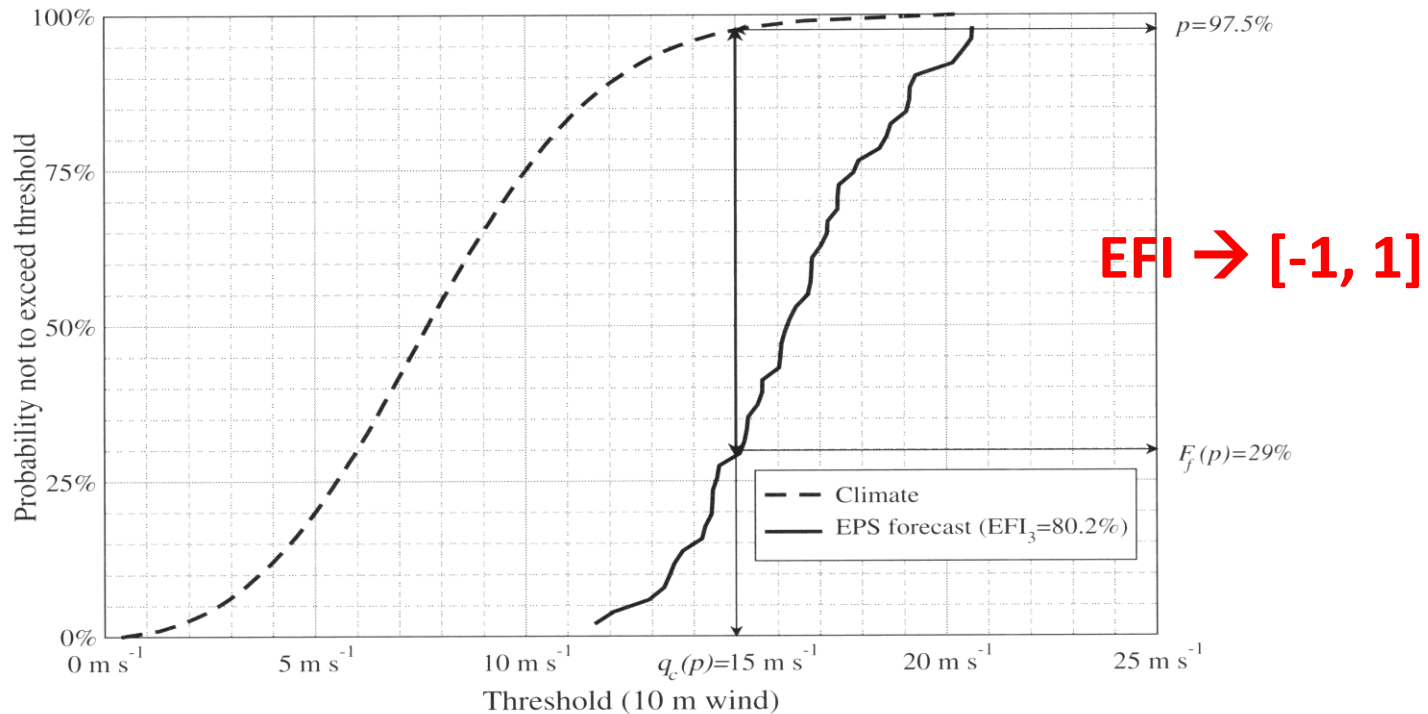
**4-day fcst**

YUEJIAN ZHU, GCWMB/EMC/NCEP/NOAA

YUEJIAN ZHU, GCWMB/EMC/NCEP/NOAA

# Extreme Forecast Index (EFI)

(Lalauette, 2003)



The EFI is a measure of the difference between the model climatological forecast distribution and the current ensemble forecast distribution.

CDF: cumulative distribution function

**Modified Equation**  
(Zsoter 2006)

$$EFI = \frac{2}{\pi} \int_0^1 \frac{p - F_f(p)}{\sqrt{p(1-p)}} dp$$

# Anomaly Forecast and Extreme Forecast Index

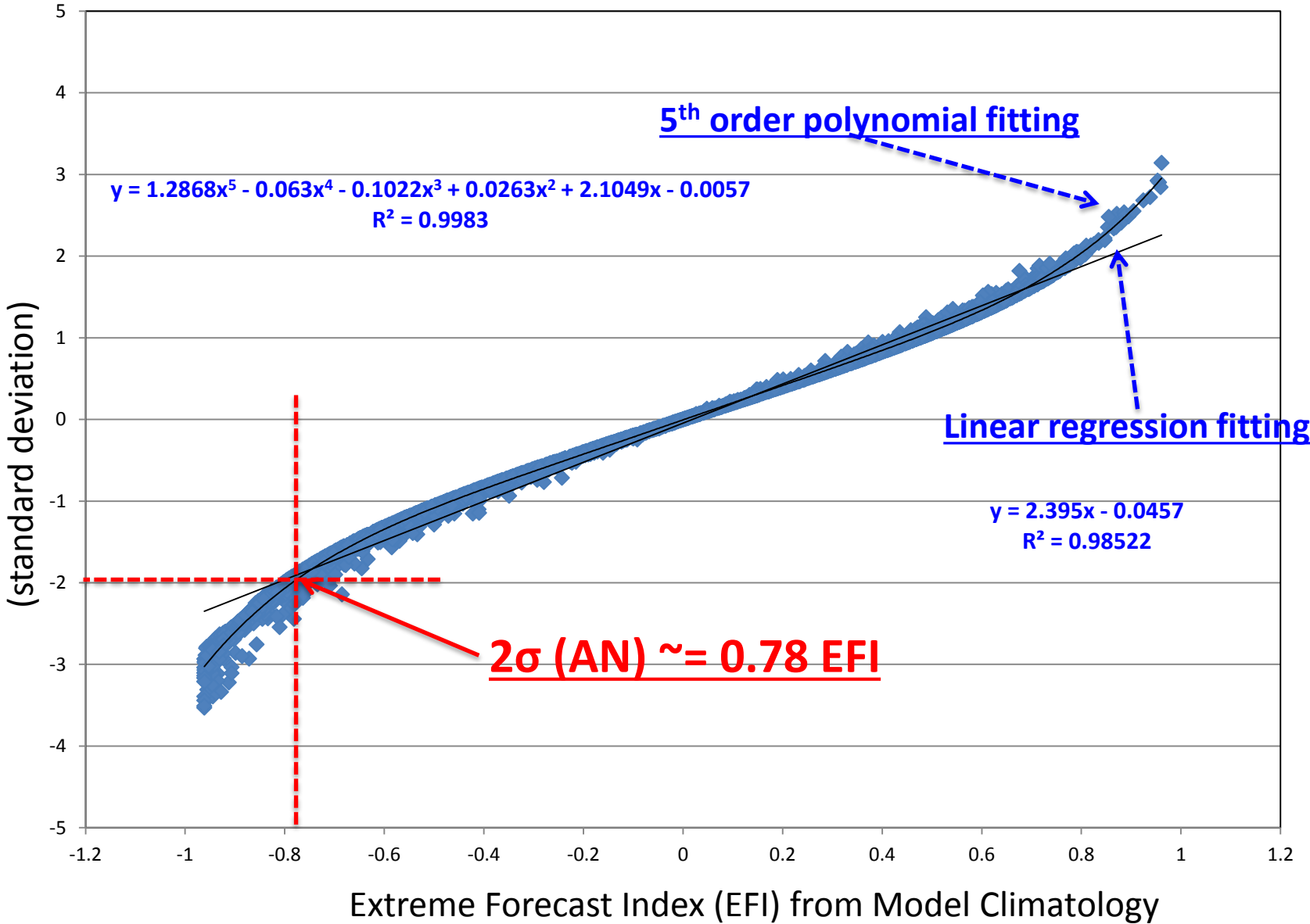
## Challenges?

- How to verify extreme forecast?
- How to compare these two measures?
- Relatively, what EFI value is equivalent to standard deviation (e.g.  $2\sigma$ ) anomaly of ensemble mean (as an example)?



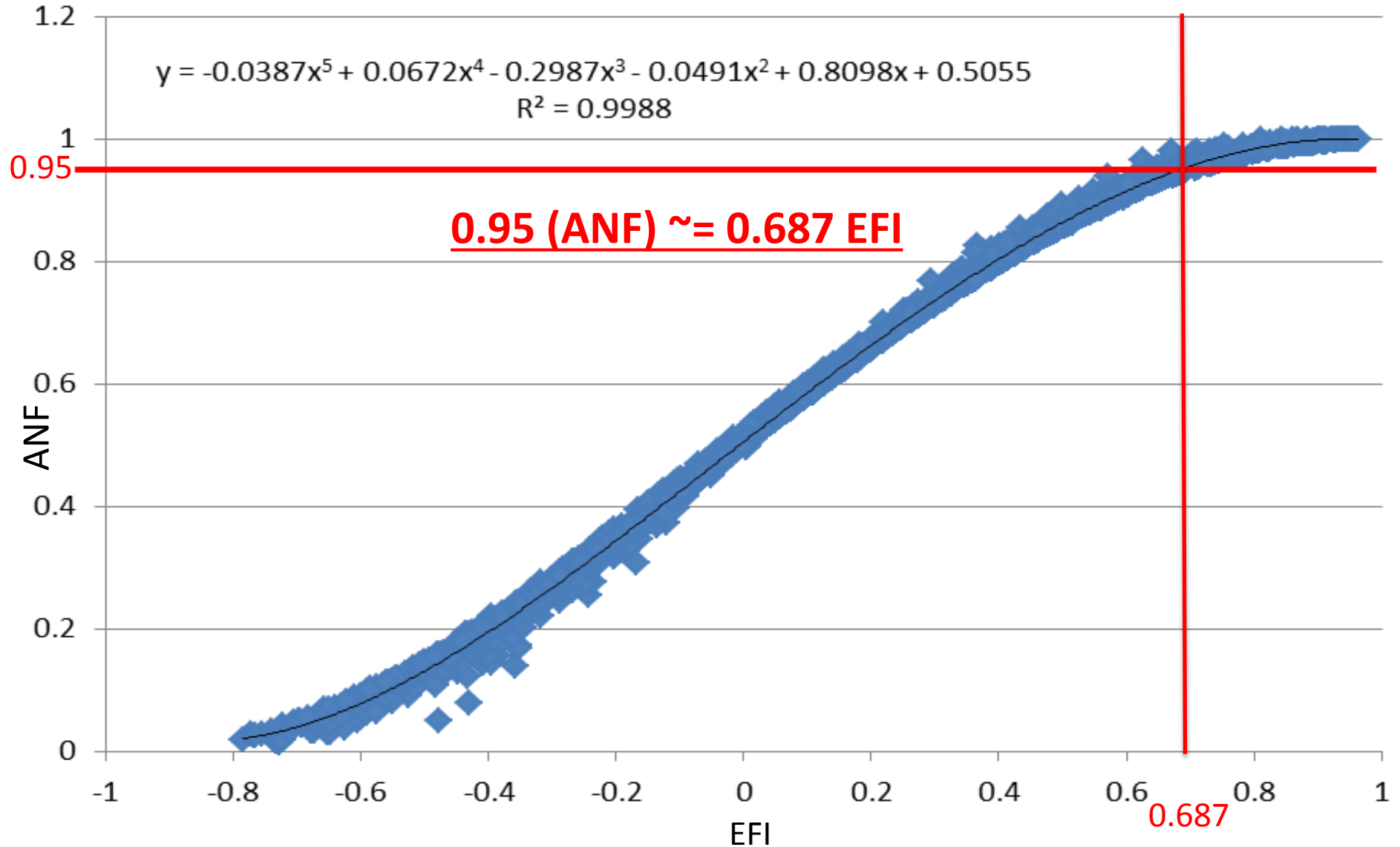
# Relationship between ANF and EFI for 2-m temperature valid 2015030100 (96-hour forecast) – GEFS V11

Ensemble Mean Anomaly Forecast (AN) from Model Climatology



# Relationship between ANF and EFI for Precipitation

Valid 2014010600UTC (96-hour forecast)- GEFS V11



# How can we measure the performance?

## Thresholds for Extreme Cold Events and Heavy Precipitation

Variable	analysis	ANF	EFI
Extreme cold event	$-2\sigma$	$-2\sigma$	-0.78
Extreme Precipitation	0.95	0.95	0.687

## Apply 2\*2 contingency table from selected threshold

Hit Rate (**HR**)

False Alarm Rate (**FAR**)

Frequency Bias (**FBI**)

Equivalent Threat Scores (**ETS**)

Performance diagram

# **Extreme cold event forecasts and verification**

# Experiments for extreme cold event forecasts and verifications

To estimate the relative performance of **different methods, model versions, references, and forecasts**

- Raw GEFS v11 forecast vs. M-climate (18y control-only reforecast)
- Bias-corrected GEFS v10 forecast vs. analysis climatology (30-year CFSR)
- Bias-corrected GEFS v11 forecast vs. analysis climatology (30-year CFSR)
- Bias-corrected GEFS v11 forecast vs. analysis climatology (40-year reanalysis)

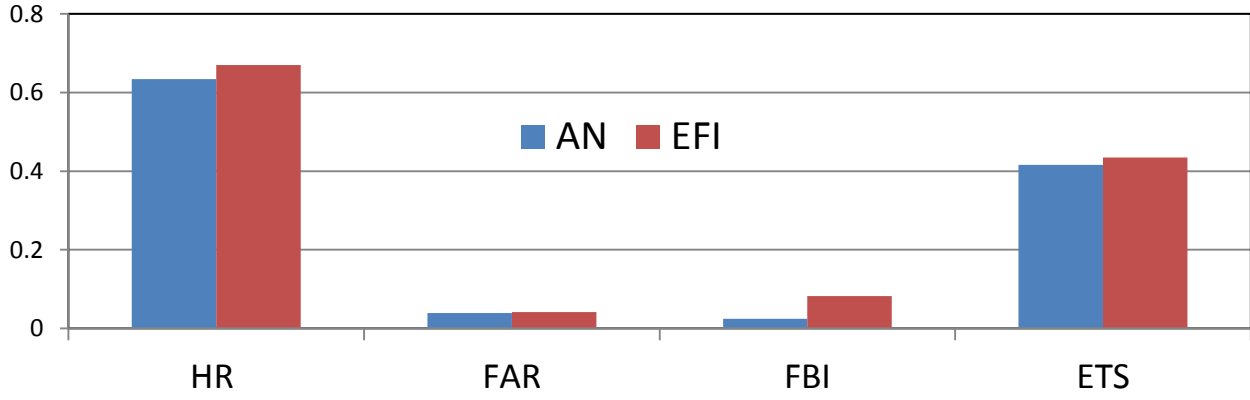
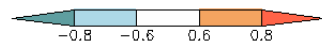
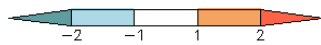
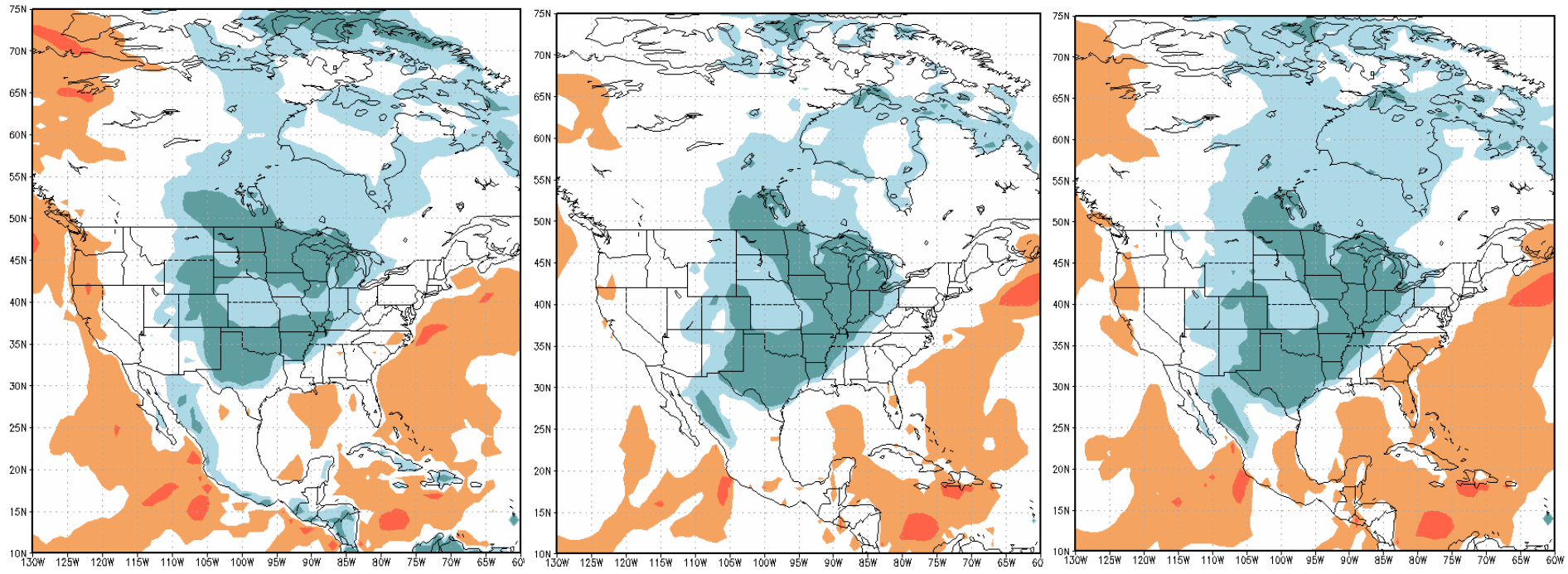
# Example of extreme cold weather event (Valid: 2015030500)

## Comparison between the two methods

Observed anomaly (analysis)

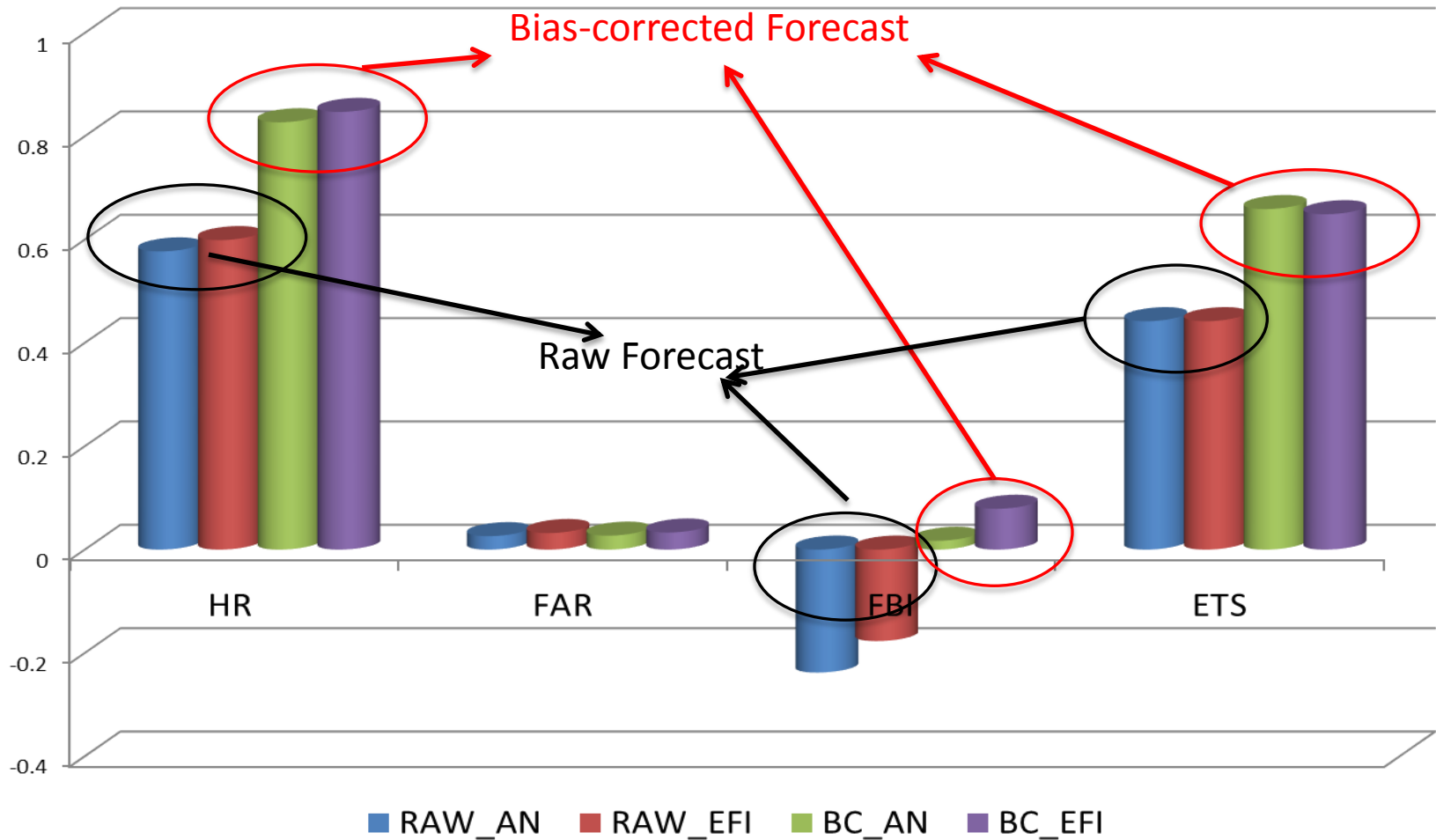
Extreme Forecast Index (EFI)

Anomaly Forecast (AN)

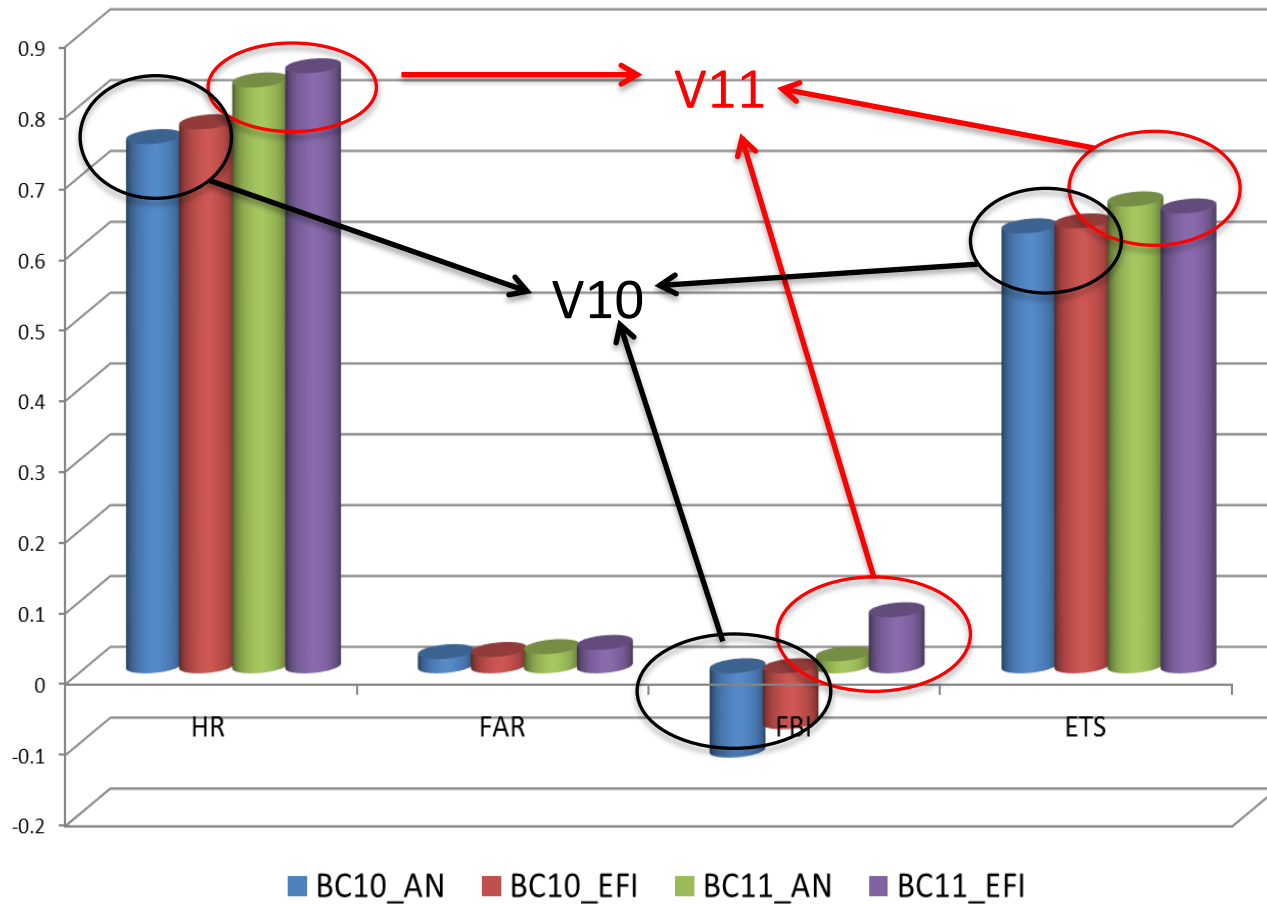


GEFS V11 Raw T2m  
Against  
Model climatology

# Statistics for extreme cold weather event (11 cases) for 13-14 winter (Raw and bias-corrected forecast (V11))

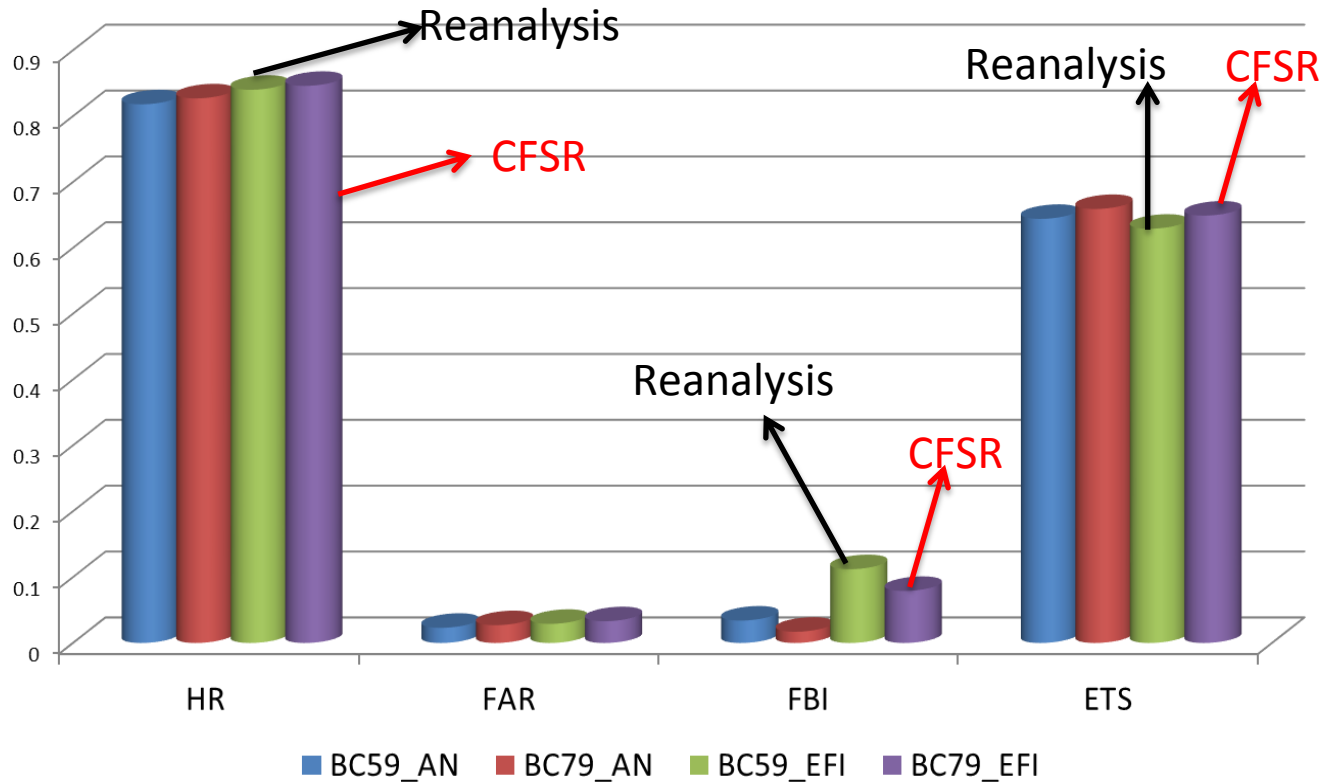


# Statistics for extreme cold weather event (11 cases) for 13-14 winter (V10 and V11 bias-corrected forecast)

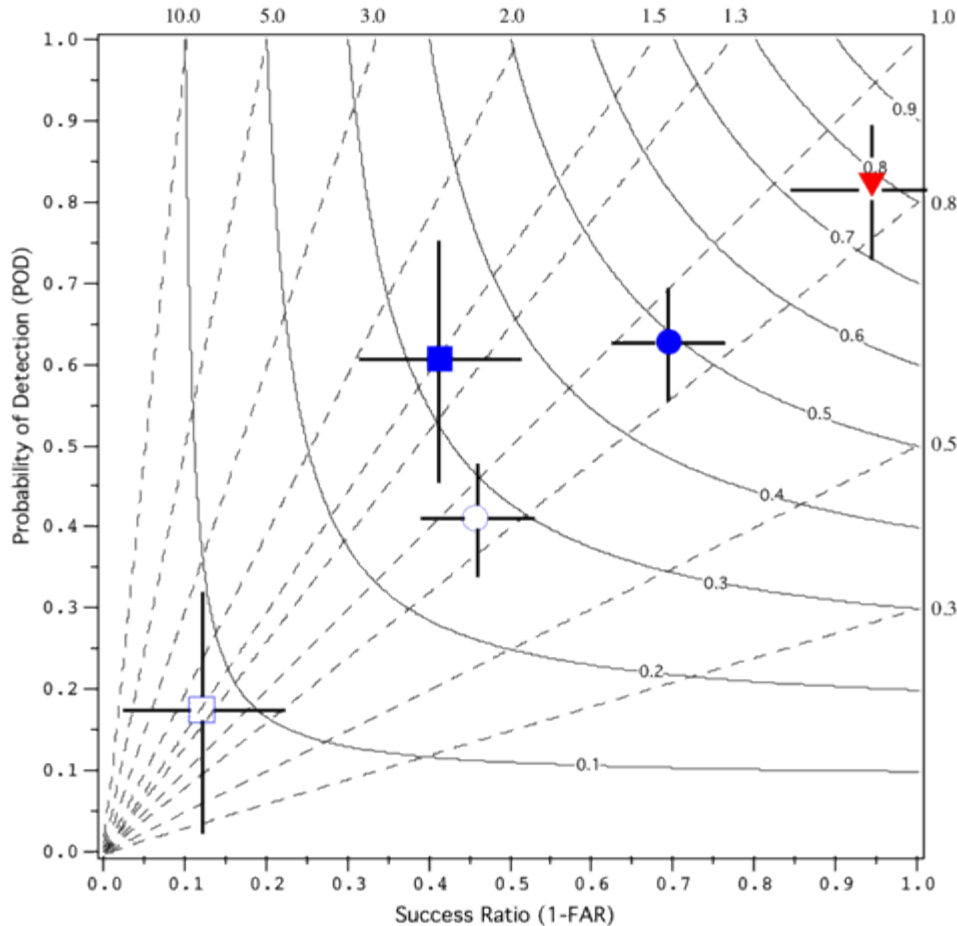




# Statistics for extreme cold weather event (11 cases) for 13-14 winter – bias-corrected V11 forecast for 40yrs reanalysis (from 1959) and 30yrs CFSR (from 1979)



# Performance Diagram ([Roebber, 2009](#))

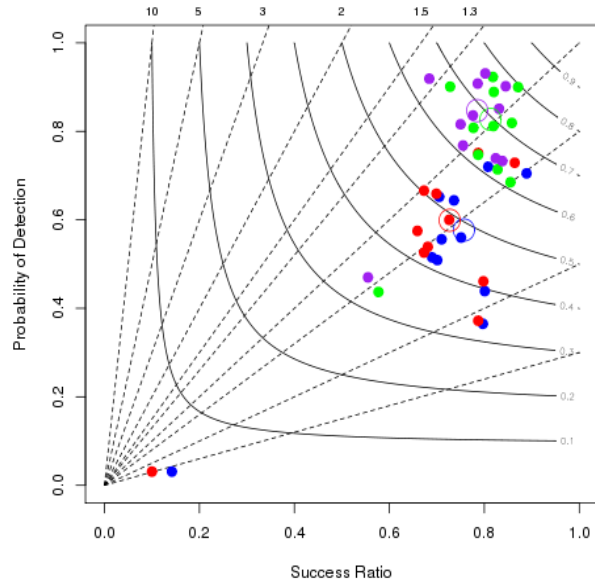


Exploiting the geometric relationship between four measures of dichotomous forecast performance: probability of detection (POD), false alarm ratio or its opposite, the success ratio (SR), bias and critical success index (CSI; also known as the threat score).

# Performance Diagram for Extreme Cold Events

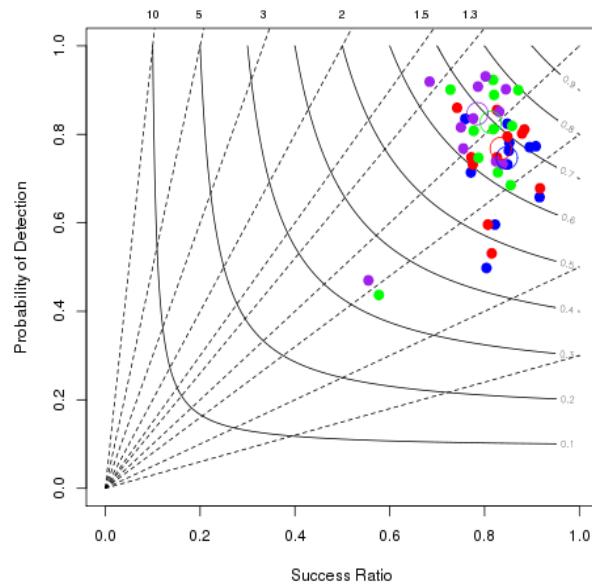
## Raw vs. bias-corrected forecasts

Performance Diagram: B=RAW\_AN, R=RAW\_EFI, G=BC\_AN, P=BC\_EFI



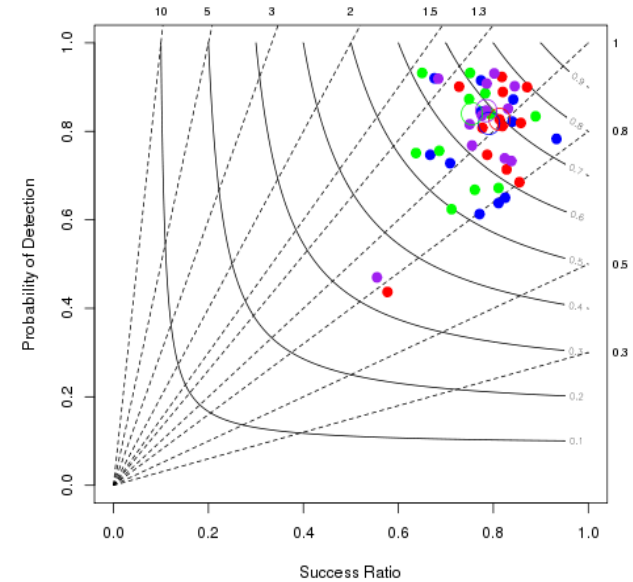
## v10 vs. v11 forecasts

Performance Diagram: B=BC10\_AN, R=BC10\_EFI, G=BC11\_AN, P=BC11\_EFI



## Reanalysis vs. CFSR

Performance Diagram: B=BC59\_AN, R=BC79\_AN, G=BC59\_EFI, P=BC79\_EFI



# **Extreme precipitation forecasts and verification**

# Experiment for extreme precipitation forecasts and verification

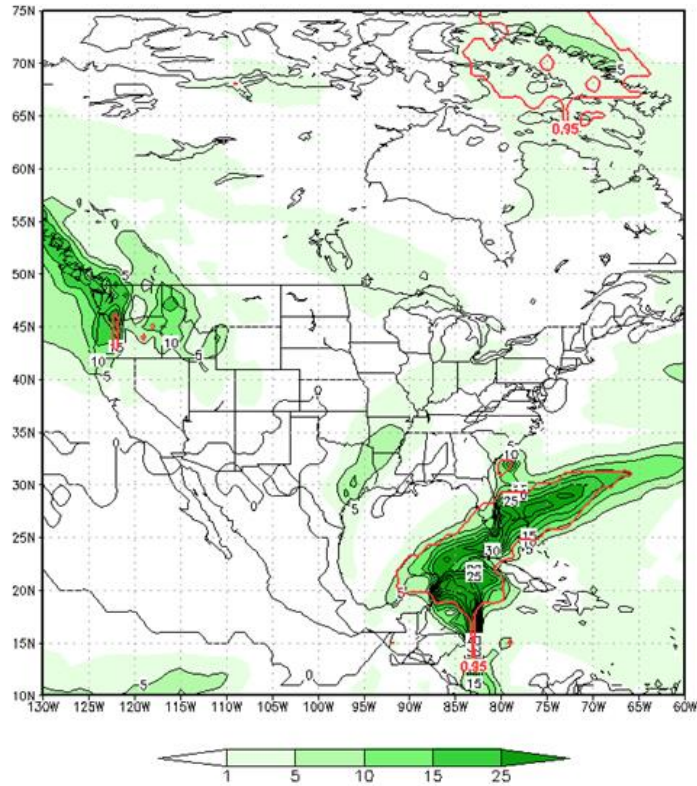
To estimate the relative performance of ANF and EFI:

- Raw GEFS v11 forecast vs. M-climate (18y control-only reforecast)

# Example of Extreme Precipitation Forecast

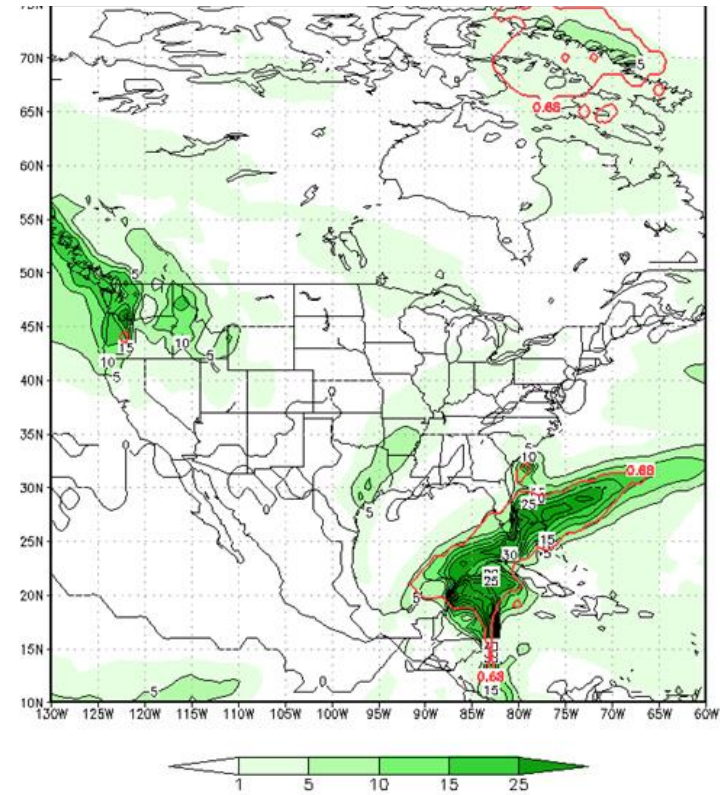
ANF

a. acpr (shaded) and ANOMF=0.95 (contour)  
96hr forecast ini. 2014010600



EFI

b. acpr (shaded) and EFI=0.687 (contour)  
96hr forecast ini. 2014010600

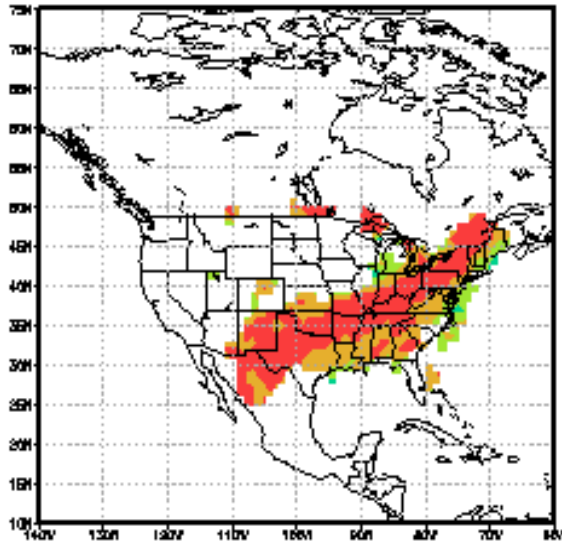


The dependence of the extreme precipitation on the geographic location

# Example of Extreme Precipitation Forecast and Verification

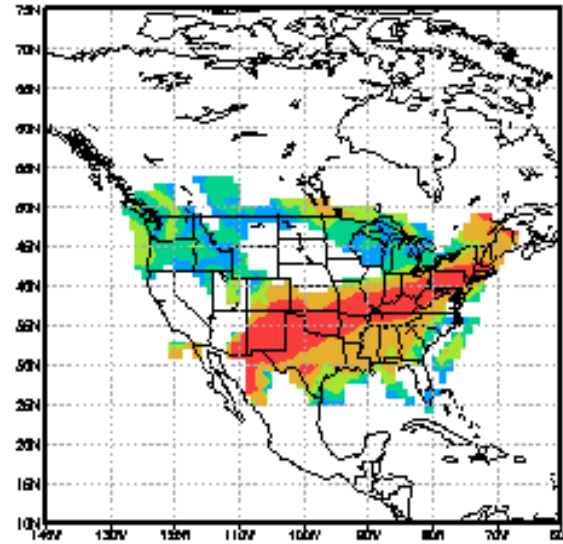
CCPA

a) ANOMA, analysis 2013120612



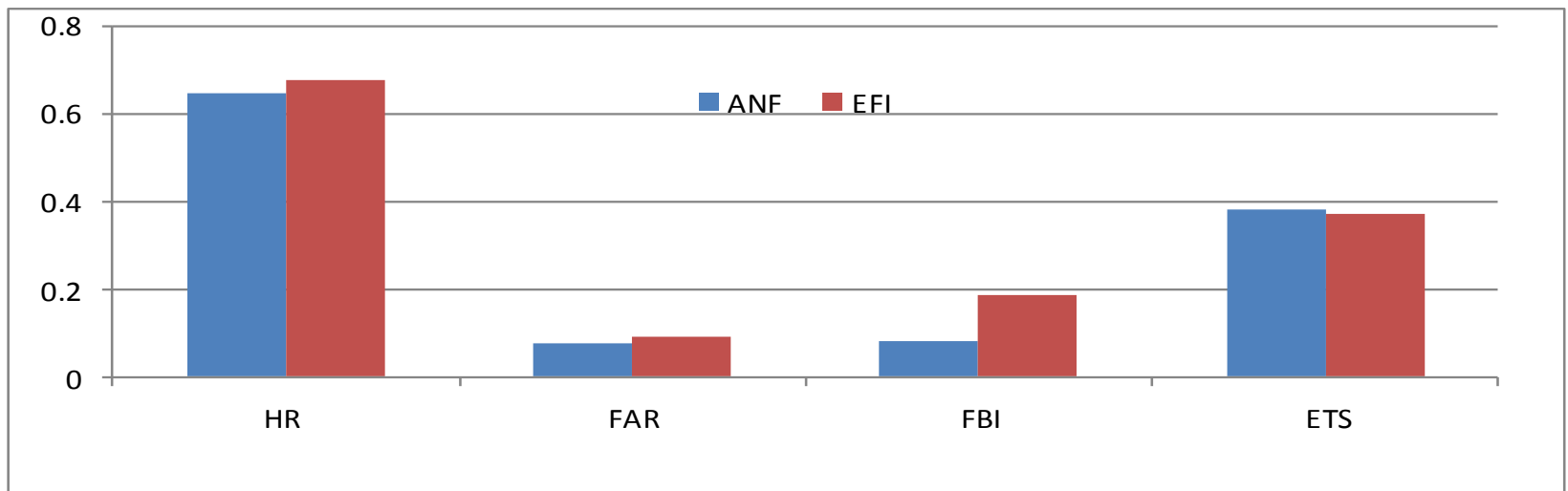
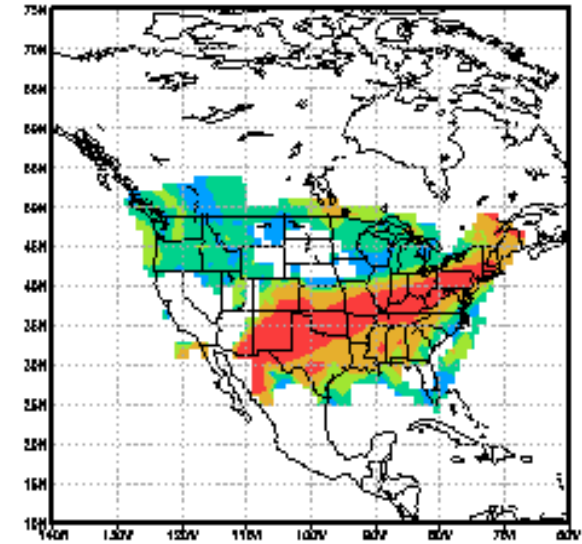
ANF

b) ANOMF, F84hr ini. 2013120300



EFI

c) EFI, F84hr ini. 2013120300



# EMC Real-time Parallel “ANF” and “EFI” Products

Bias corrected forecast .vs  
analysis climatology



# EMC real-time parallel experiments

<http://www.emc.ncep.noaa.gov/gmb/wd20hg/html/EFIANF.html>

Running once per day

4 variables:

Precipitation

Surface temperature

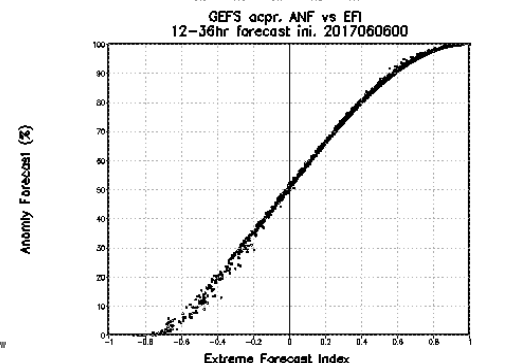
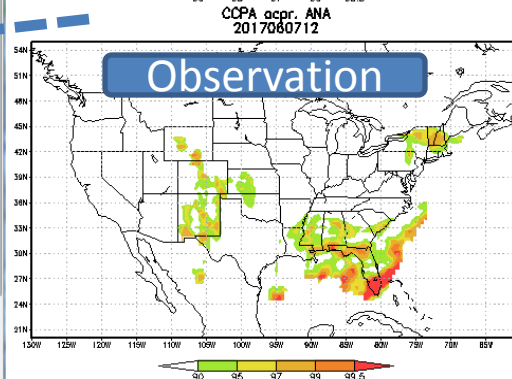
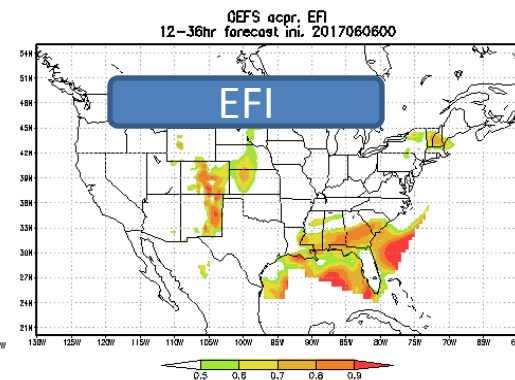
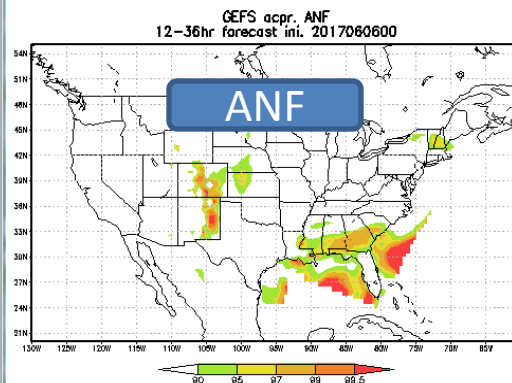
Surface wind speed

Sea surface pressure

## GEFS EFI and Ensemble-Mean ANF products (update once per day)

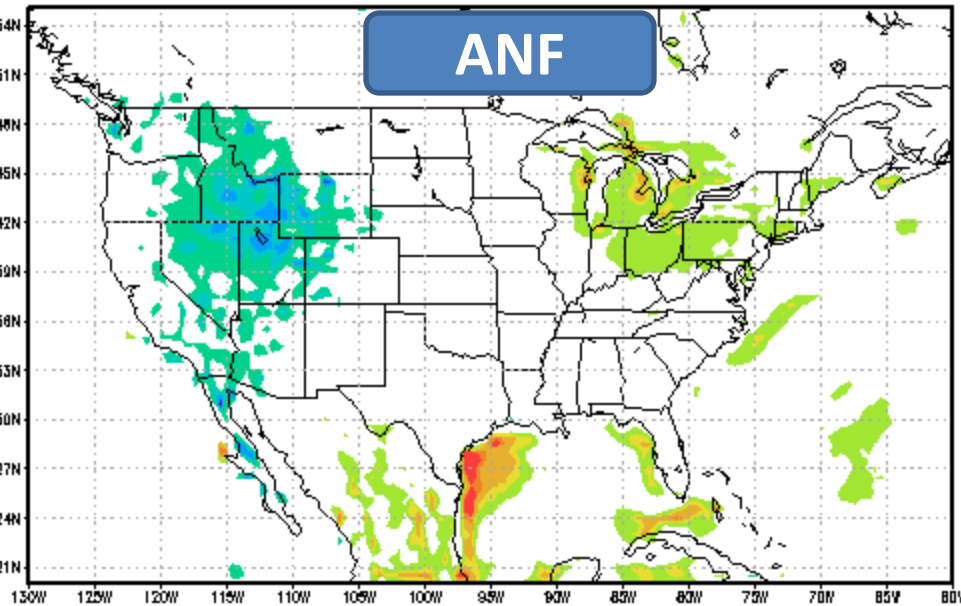
This web-site displays ensemble based EFI and ANF products, at 0.5\*0.5 degree resolution, once per day (00UTC), every 24-hour, out to 16 days. For precipitation: each map includes three different products which are 1). Ensemble-Medium Anomaly Forecast (ANF) 2). Extreme Forecast Index (EFI) 3). Analysis (ccpa) Anomaly (ANA). For T2m, w10m, and SLP, there are only ANF and EFI. ANA is not included.

Date	QPF	T2M	W10M	SLP
20170615	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170614	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170613	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170612	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170611	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170610	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170609	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170608	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170607	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170606	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170605	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170604	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170603	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170602	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>
20170601	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>	<a href="#">T00Z</a>

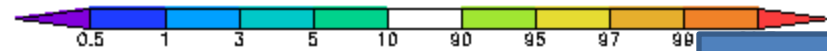


192hr forecast ini. 2017060500

**ANF**

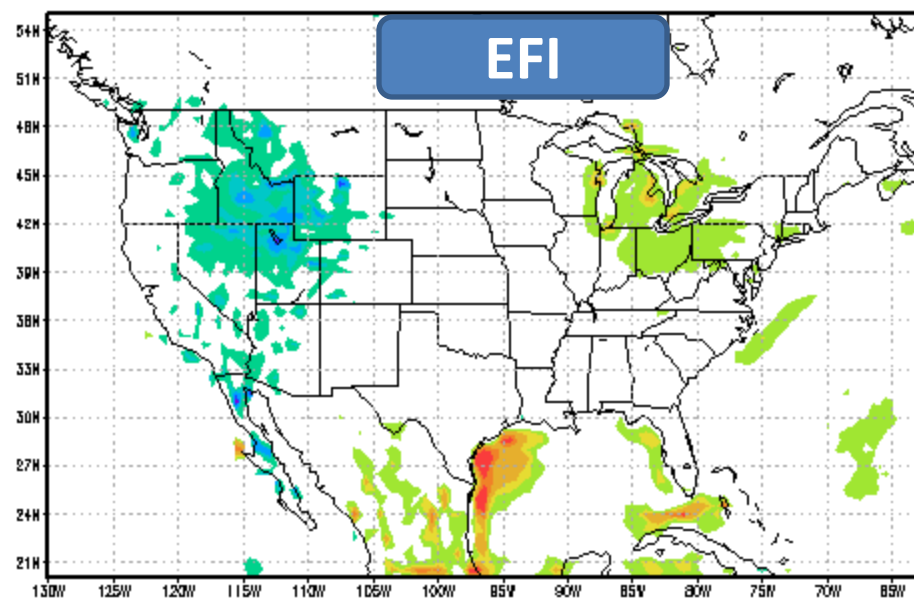


GEFS 12m Anomaly Analysis  
2017061300

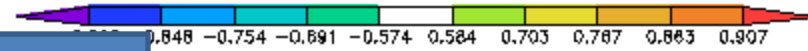


192hr forecast ini. 2017060500

**EFI**

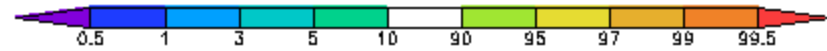
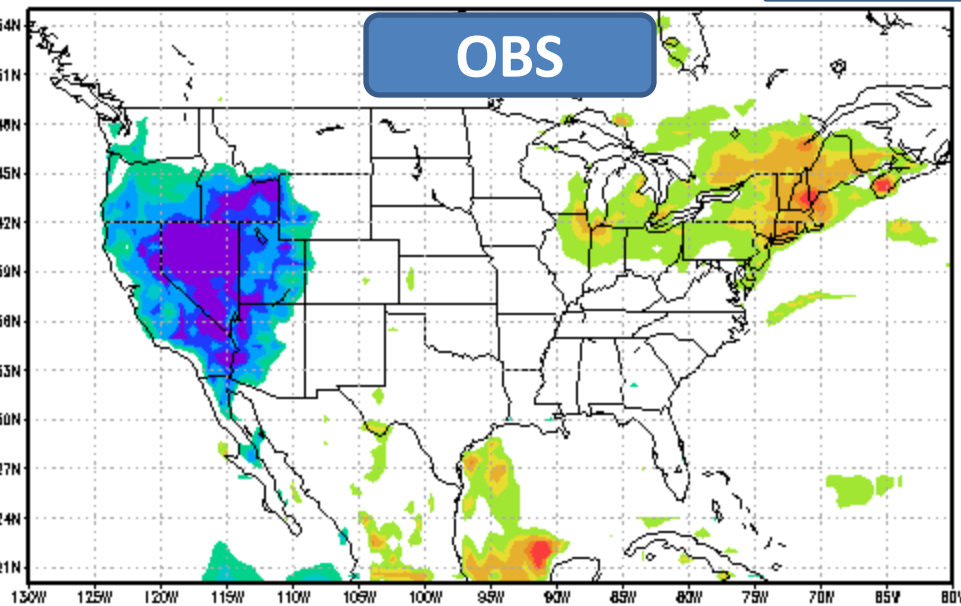


GEFS 12m ANF vs EFI  
192hr forecast ini. 2017060500

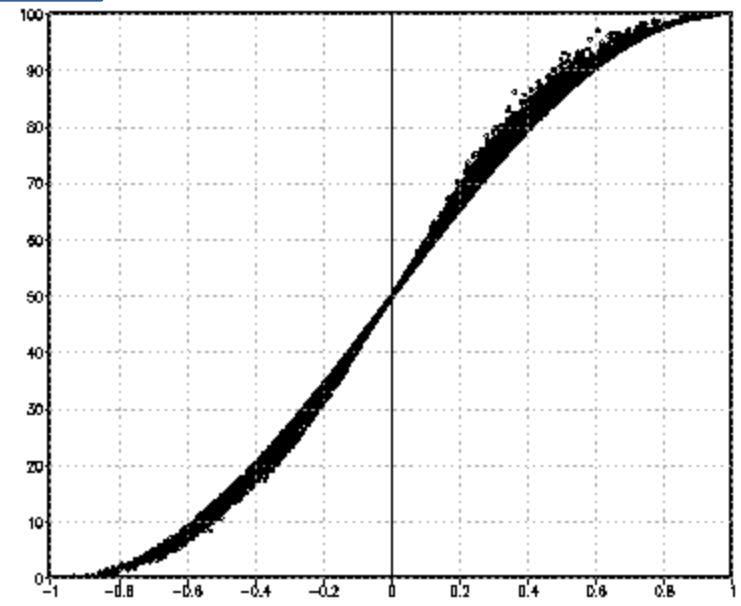


**192 hours**

**OBS**



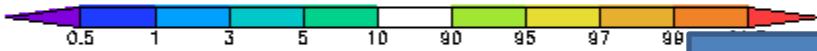
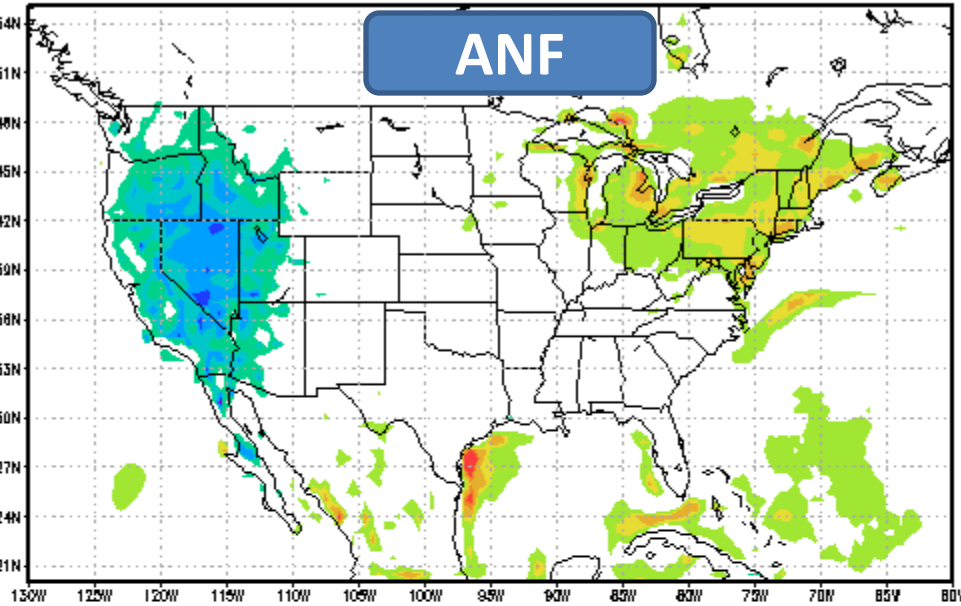
Anomaly Forecast (%)



Extreme Forecast Index

144hr forecast ini. 2017060700

**ANF**

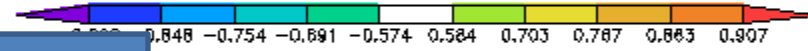
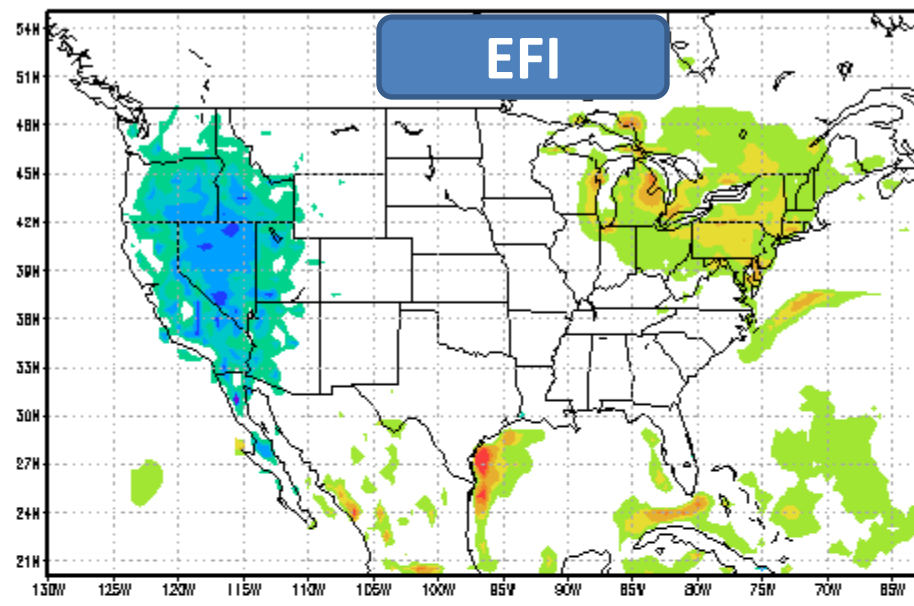


GEFS 12m Anomaly Analysis  
2017060700

**144 hours**

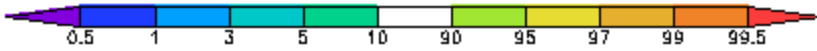
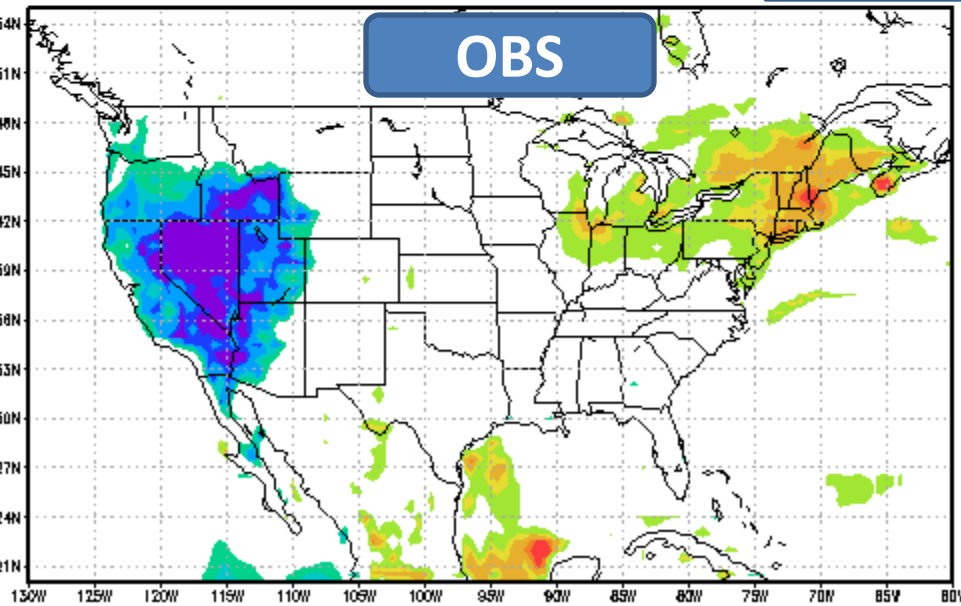
144hr forecast ini. 2017060700

**EFI**

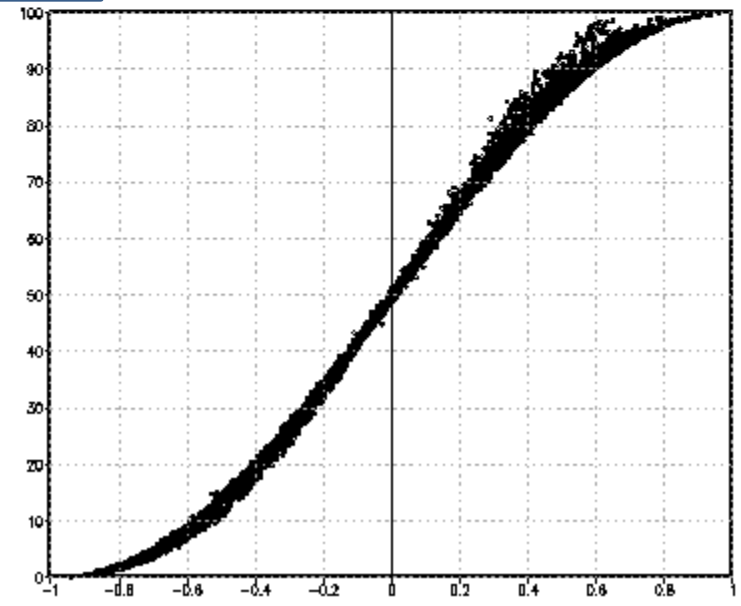


GEFS 12m ANF vs EFI  
144hr forecast ini. 2017060700

**OBS**



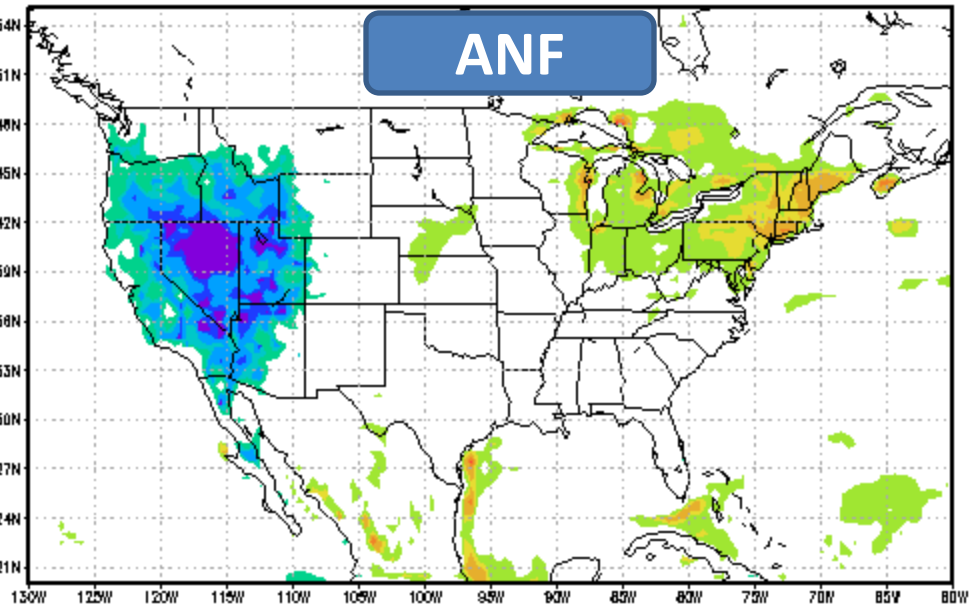
Anomaly Forecast (%)



Extreme Forecast Index

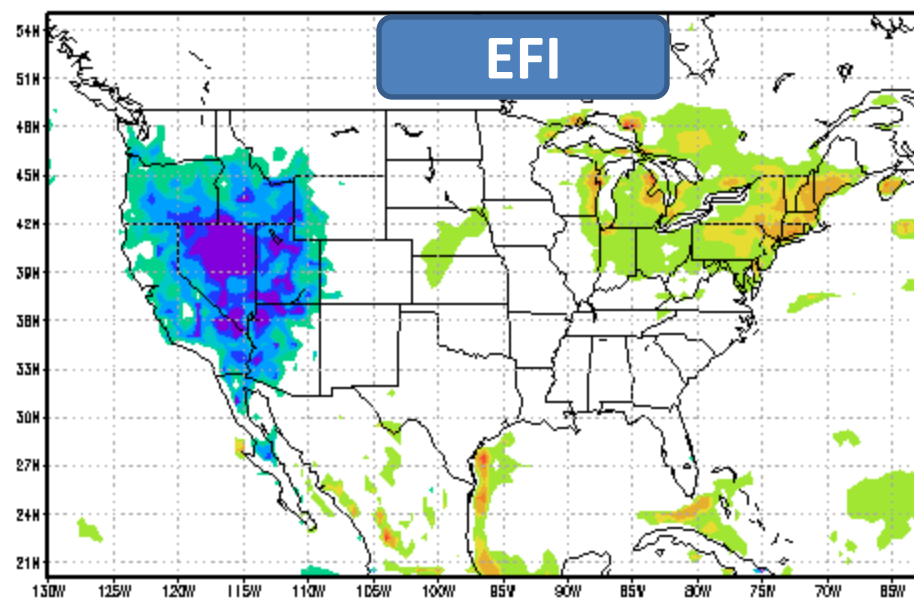
96hr forecast ini. 2017060900

**ANF**



96hr forecast ini. 2017060900

**EFI**

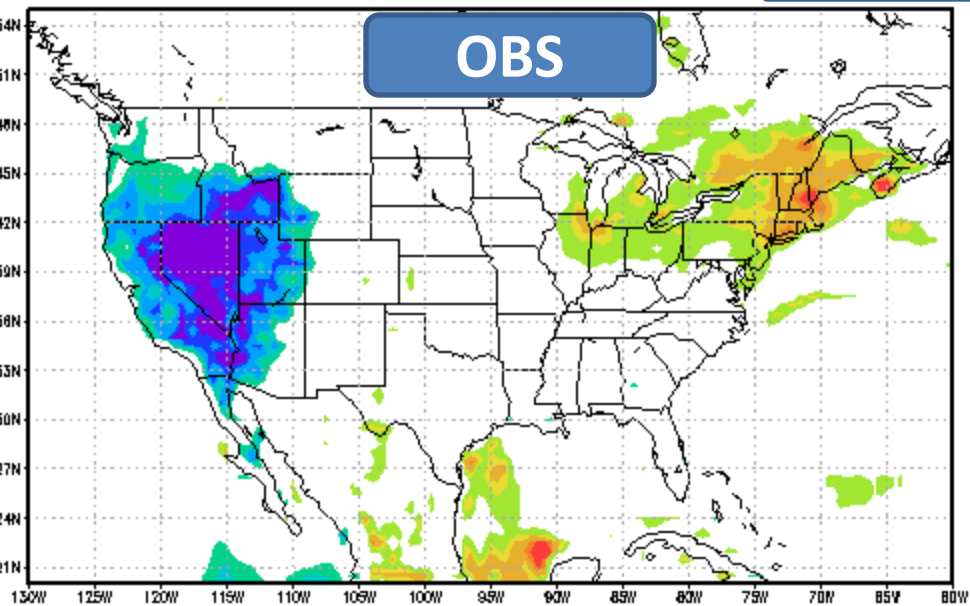


GEFS 12m Anomaly Analysis  
2017060900

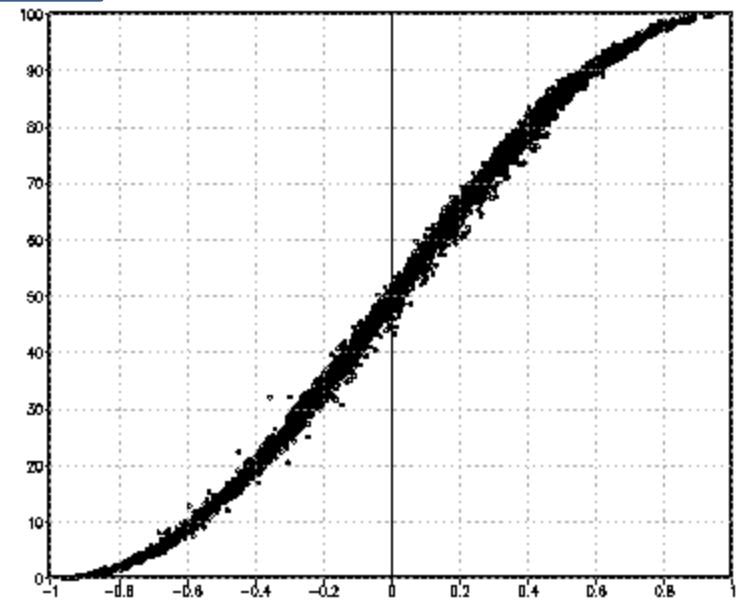
**96 hours**

GEFS 12m ANF vs EFI  
96hr forecast ini. 2017060900

**OBS**



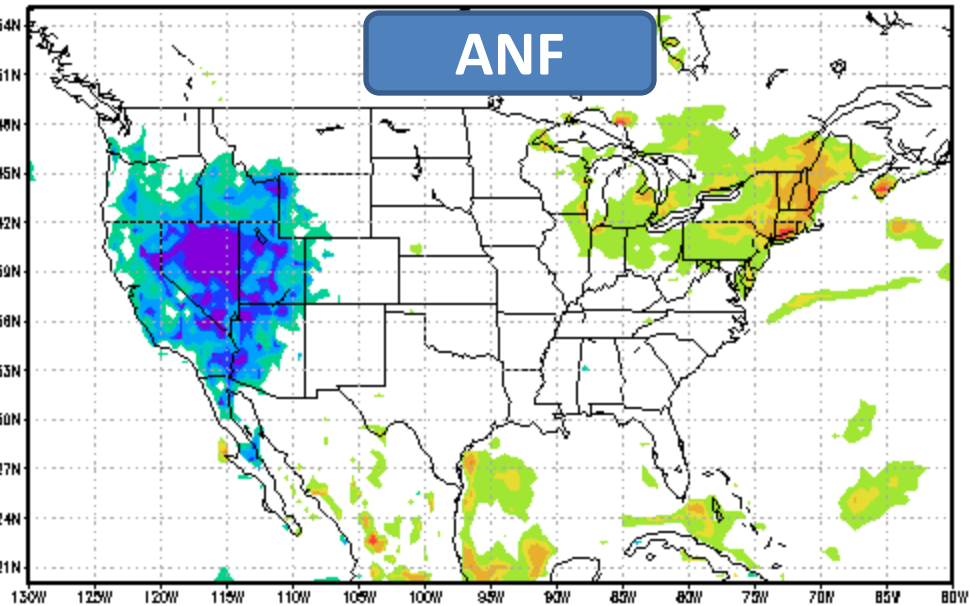
Anomaly Forecast (%)



Extreme Forecast Index

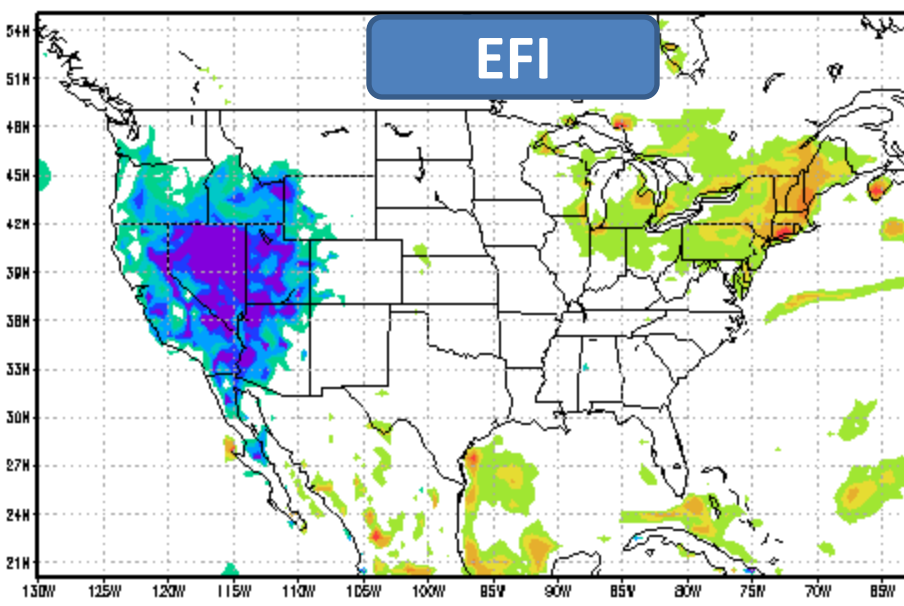
48hr forecast ini. 2017061100

ANF



48hr forecast ini. 2017061100

EFI

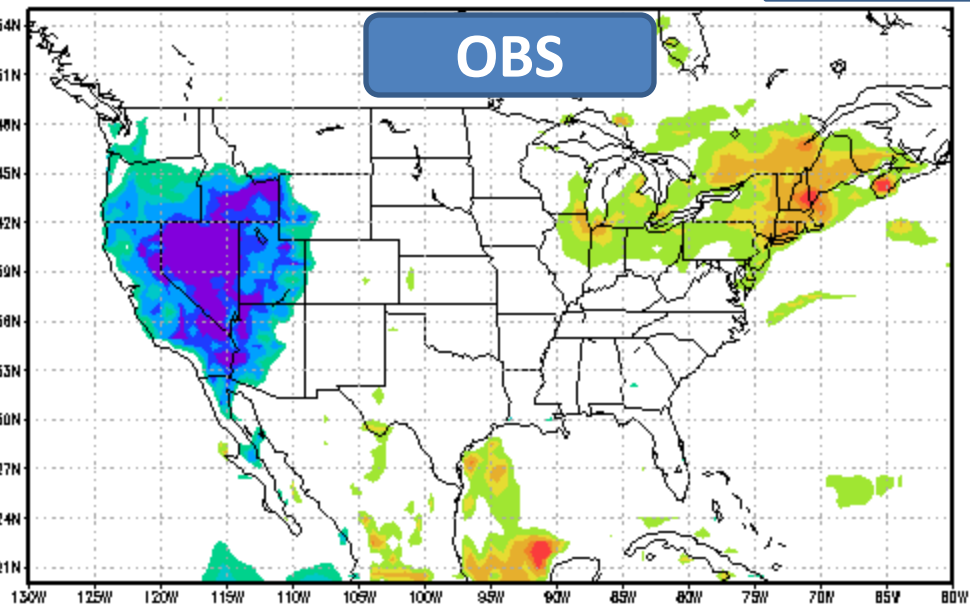


GEFS 12m Anomaly Analysis  
2017061100

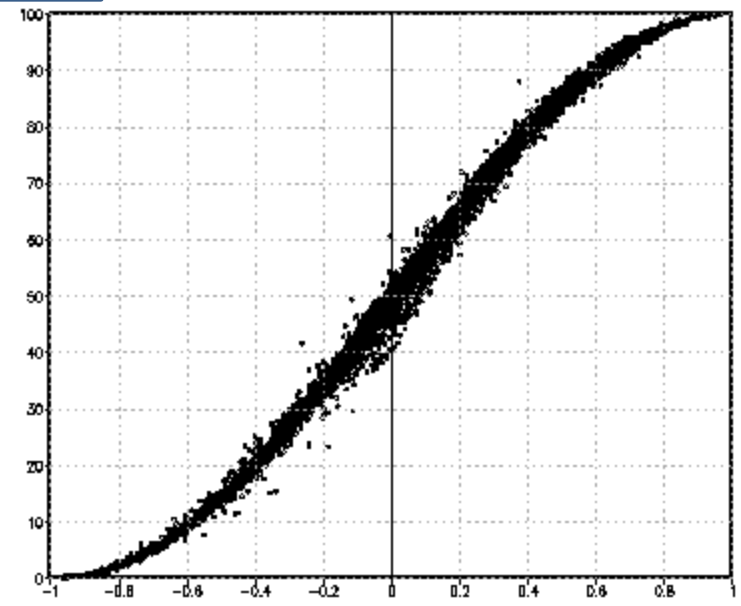
48 hours

GEFS 12m ANF vs EFI  
48hr forecast ini. 2017061100

OBS



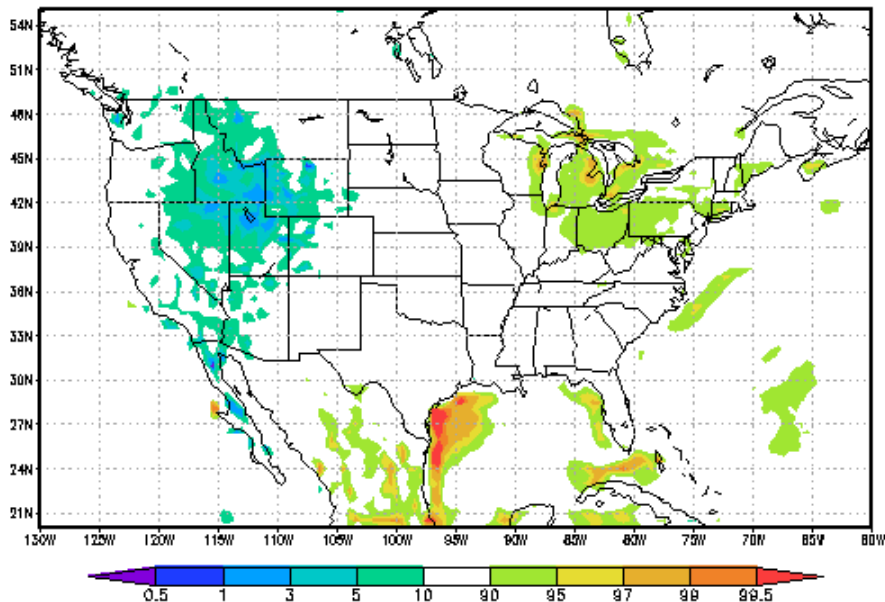
Anomaly Forecast (%)



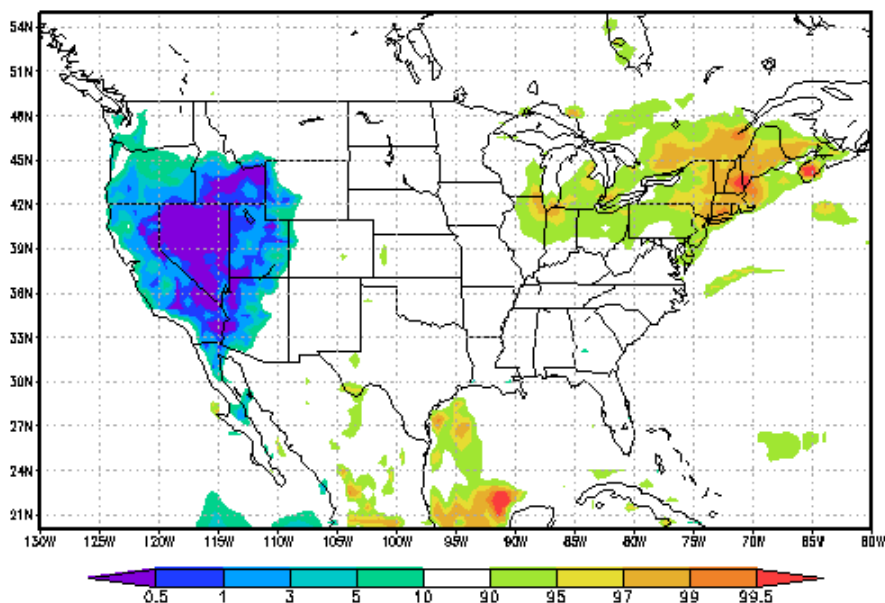
Extreme Forecast Index

# Demonstration of Animation (valid for 2017061300)

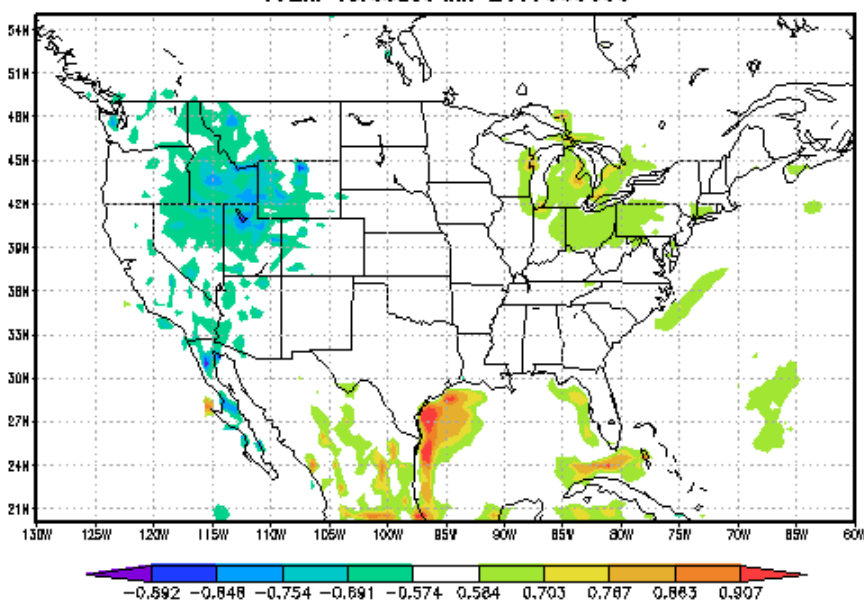
GEFS 12m Anomaly Forecast  
192hr forecast ini. 2017060500



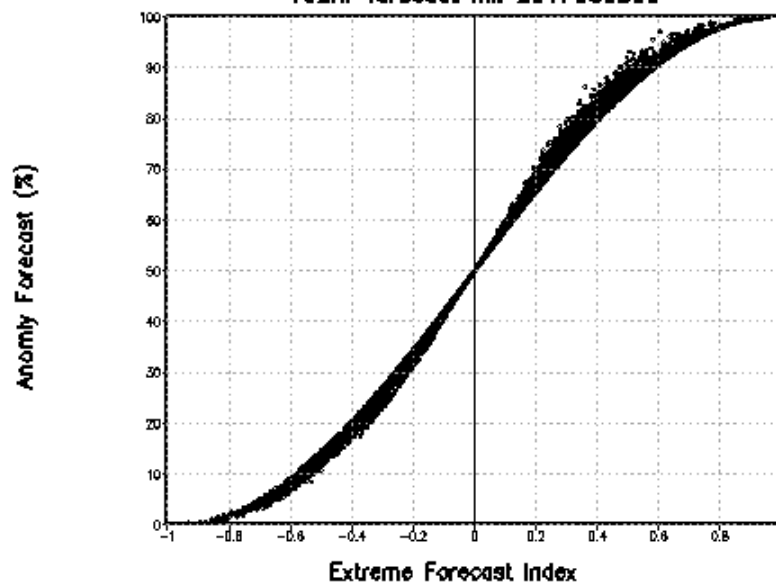
GEFS 12m Anomaly Analysis  
2017061300



GEFS 12m EFI  
192hr forecast ini. 2017060500



GEFS 12m ANF vs EFI  
192hr forecast ini. 2017060500




# Ensemble Situational Awareness Table (NWS WR/WPC)

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## ENSEMBLE SITUATIONAL AWARENESS TABLE

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**Model Run:** Jun 28, 2017 12Z | 
 **Table Region:** Western U.S. | 
 **Plot Region:** Western U.S. | 
 **Output:** NAEFS Standardized Anomaly | 
 [View Table](#)

**WFO Western U.S. Table Jun 28, 2017 12Z Run**

		Z	I	U	V	WSP	SLP	Q	PW	IVT	
0	Wed	12Z	-1.7	2.0	2.7	-2.2	2.7	-2.5	2.9	-1.9	2.3
6	28th	18Z	-1.7	1.9	2.9	-2.4	2.9	-2.5	2.6	-1.9	3.2
12	Thu	00Z	-1.6	1.9	2.6	-3.0	2.2	-2.4	2.4	-1.8	2.5
18		06Z	1.7	2.1	2.5	-2.6	2.4	-2.4	-1.9	-2.1	1.8
24	29th	12Z	2.0	2.0	2.5	-2.7	2.7	-2.0	2.4	-2.4	1.3
30		18Z	2.2	1.9	2.3	-2.4	2.0	-1.8	2.3	-2.2	1.6
36	Fri	00Z	2.3	2.2	2.4	-2.4	2.3	-1.8	-2.2	-1.8	1.2
42		06Z	2.4	2.7	2.4	-2.4	2.4	-1.7	2.0	-2.1	1.4
48	30th	12Z	2.2	2.7	2.3	-2.4	2.3	-1.8	-2.2	-1.9	1.5
54		18Z	2.0	-2.3	2.0	-2.6	2.0	-1.8	-2.1	-1.7	1.1
60	Sat	00Z	1.9	-2.0	1.8	-2.8	2.2	-1.6	2.4	-1.3	1.5
66		06Z	1.9	1.9	1.6	-2.6	2.7	-1.4	2.0	-1.3	0.7
72	1st	12Z	1.8	2.2	-2.2	-2.5	2.7	-1.7	2.1	-1.2	0.9
78		18Z	1.8	2.3	1.8	-2.4	2.6	-1.7	2.5	-1.1	1.0
84	Sun	00Z	-1.8	2.2	1.6	-2.2	2.3	-1.8	2.3	-1.2	1.0
90		06Z	1.7	2.2	1.8	-2.1	1.9	-1.9	1.6	-1.1	1.0
96	2nd	12Z	1.6	2.1	1.7	-2.1	1.9	-1.8	1.9	-1.1	1.0
102		18Z	-1.6	2.1	1.4	1.9	2.1	-1.6	2.5	-1.1	1.2
108	Mon	00Z	1.5	1.9	-1.4	-1.7	1.3	-1.5	2.7	-1.1	1.4
114		06Z	1.5	1.9	-1.4	-1.5	1.2	-1.3	2.1	1.1	1.1
120	3rd	12Z	1.3	1.8	1.5	-1.3	1.4	-1.3	2.5	-1.5	1.0
126		18Z	1.2	1.7	1.4	-1.3	1.5	-1.4	2.6	-1.4	0.6
132	Tue	00Z	1.1	1.7	1.4	-1.3	1.5	-1.5	2.4	-1.4	0.9
138		06Z	1.1	1.7	-1.1	-1.3	1.5	-1.3	1.9	-1.5	0.6
144	4th	12Z	1.0	1.7	1.1	-1.2	1.3	-1.1	2.1	-1.6	0.6
150		18Z	0.9	1.5	1.1	-1.1	1.2	-1.1	2.2	-1.6	0.6
156	Wed	00Z	0.9	1.6	1.0	-1.1	1.2	-1.2	2.1	-1.4	0.8
162		06Z	0.9	1.4	1.1	-1.1	1.2	-1.3	1.6	-1.4	0.6

**How to navigate:**

**On the main table:** Click a field (e.g., 'Z') to switch to a sub-table with data for that vertical level. Click a value (e.g., '2.8') to plot a multi-panel image for that time and field at that level.

**On a sub-table:** Click a value (e.g., '2.8') to plot an image for that field and level. Click a level (e.g., '500') to loop images for that field and level at all forecast hours.

**For a different table:** Select the desired Model Run, Table Region, and Output Type from the drop-down menus above, and click View Table.

**The NAEFS Ensemble:** A 42-member ensemble consisting of 21 GFS ensemble members and 21 Canadian (GEPS) members. Each set of 21 members includes a control run and 20 initial condition perturbations. Although the GFS and GEPS are run at relative resolutions of 55 and 66 km, respectively, the NAEFS is distributed on a 1-degree grid.

**NAEFS Standardized Anomaly:** How different is the model forecast from the climatological mean? Compares the NAEFS ensemble mean for a 3-week running mean and standard deviation derived from the 1979-2009 Climate Forecast System Reanalysis. Standardized anomaly =  $(NAEFS\_forecast - CFSR\_climatology\_mean) / CFSR\_climatology\_standard\_deviation$

**NAEFS Percentile (Recommended):** Where would the model forecast fall with respect to climatology? Example: MAX at 00Z indicates that values in the current NAEFS forecast are greater than all 00Z values in the CFSR climatology for a 3-week period centered on the valid day. Forecasters are encouraged to focus on "MAX" and "MIN" values, indicating that the ensemble is forecasting an event that would fall outside the 1979-2009 climatology for this time of year.

**NAEFS Return Interval:** How often do these forecast values show up in the climatology? Specifically, how often were the CFSR values (in a 3-week period centered on the valid time) more extreme than values in the NAEFS forecast. Example: a return interval of 5 on Feb 15th means that roughly every 5 years, there is a day in mid-February when values in the current forecast were met or exceeded. Another example: "outside CFSR climate" for temperature means that none of the mid-February reanalyses were this warm between 1979 and 2009.

**NAEFS Probabilities:** How many of the ensemble members produce "extreme" values? Indicates the fraction of NAEFS members with values either higher or lower than any CFSR reanalysis (in a 3-week period centered on the valid time). 80% probability of a min for MSLP on 00Z 15 Sept means

Example of another application

**Questions and Comments?**