Ensemble Application for Extreme Weather/Climate Detection

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Highlights

- Introduction
- Definition of extreme
- Applications
  - Anomaly Forecast and Extreme Forecast Index
  - Comparison
  - Evaluations
- Conclusion and future plan

Introduction

- Extreme weather events
  - Unusual, Unexpected, rare weather events
  - Cost: loss of lives, properties, equipment and etc.
  - Forecast: may be difficulty, may be not
  - Alarms to users (such as Watch, Warning and etc…)
  - Early decision and early protection
  - Widely social impacts
  - Always use updated forecast information

- Deterministic and probabilistic forecast
  - Easy missing extreme event from deterministic forecast
  - Using ensemble based forecast
  - Forecast in terms of probability or possibility
  - Wide coverage of the weather events from probabilistic sense, include extreme weather events.
  - Consider multi-variables (temperature, precipitation, wind and etc…)

Definition of Extreme Events

- Climatological extremes
  - Based on climatological distributions.
  - The tails (5% or less) of climatological distribution.
  - Considering a particular meteorological variable.
  - Considering a specific time and place.

- Forecast extremes
  - similar to climatological extremes
  - Different range and values of distribution.
  - Narrow band than climatology.
  - Conditional climatological sense.

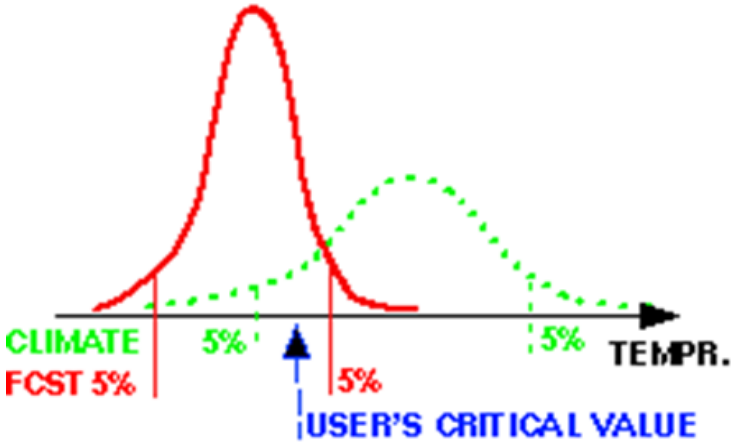


Fig. 1. Schematic indicating climatological (continuous), forecast (dotted) and user specific (dashed) extreme events.

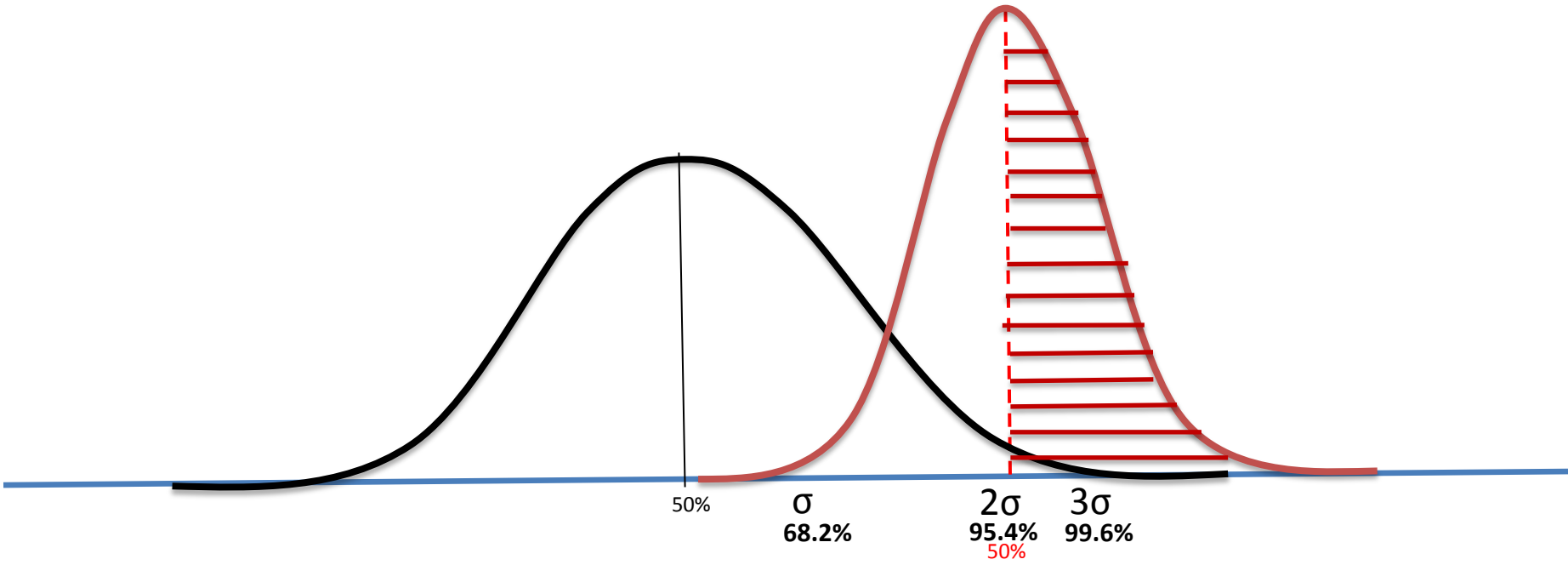
- User specific extremes
  - User defined extreme (not climatology, not forecasting).
  - For particular user, in particular area and time period
  - Sensitivity to particular area and in time period
  - Sensitivity to particular meteorological element.
  - The combination of the temporal/spatial.

Extreme Weather Forecasts

- Methods
  - Anomaly Forecast
  - Extreme Forecast Index

- Input data
  - model climatology/raw ensemble forecast
  - analysis climatology/bias-corrected forecast

Anomaly Forecast
One of GEFS/NAEFS applications



Schematics diagram for anomaly forecast (PDF)

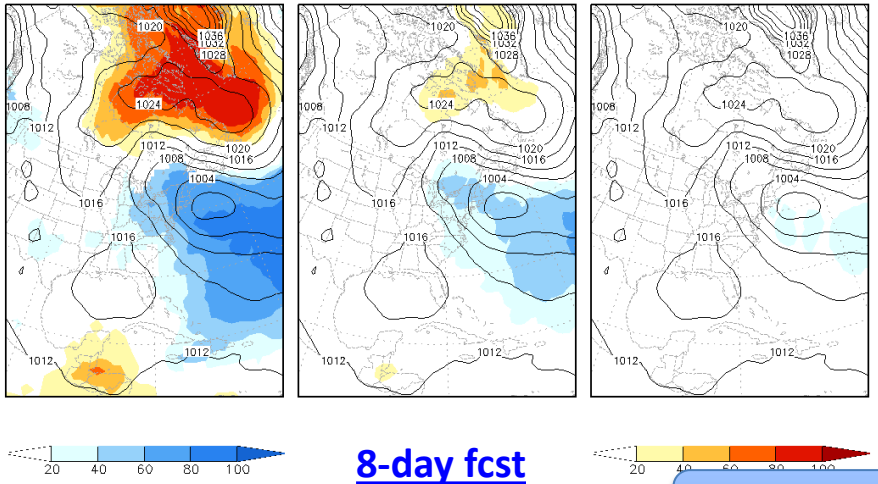
Definitions for Anomaly Forecast

ANF: Percentage of ensemble forecast (shaded area) which exceeds climate threshold (for example: 2σ) (NCEP/ NAFES product)

Anomaly forecast

Sea Level Pressure (PRMSL), 192-hour forecast
Ini. time:2012102300 Valid time:2012103100
Contour-mean forecast; Shaded-forecast anomalies

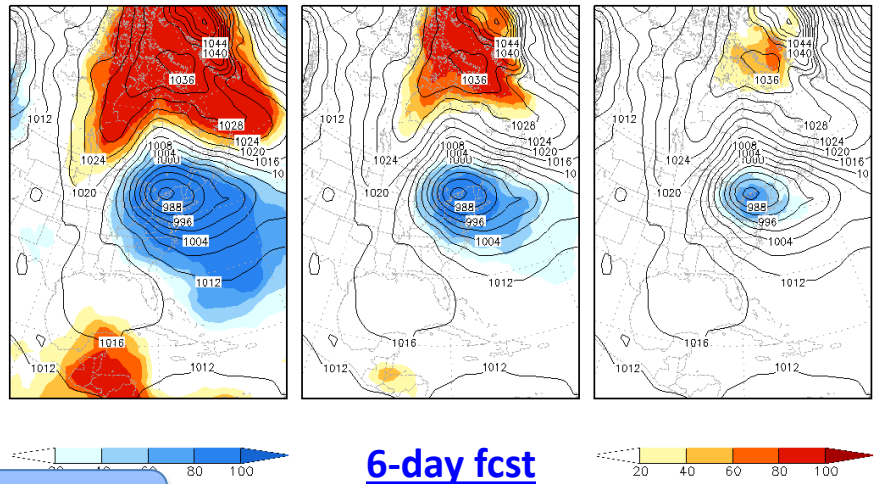
σ 2σ 3σ



8-day fcst

Sea Level Pressure (PRMSL), 144-hour forecast
Ini. time:2012102500 Valid time:2012103100
Contour-mean forecast; Shaded-forecast anomalies

one stdv two stdv three stdv



6-day fcst

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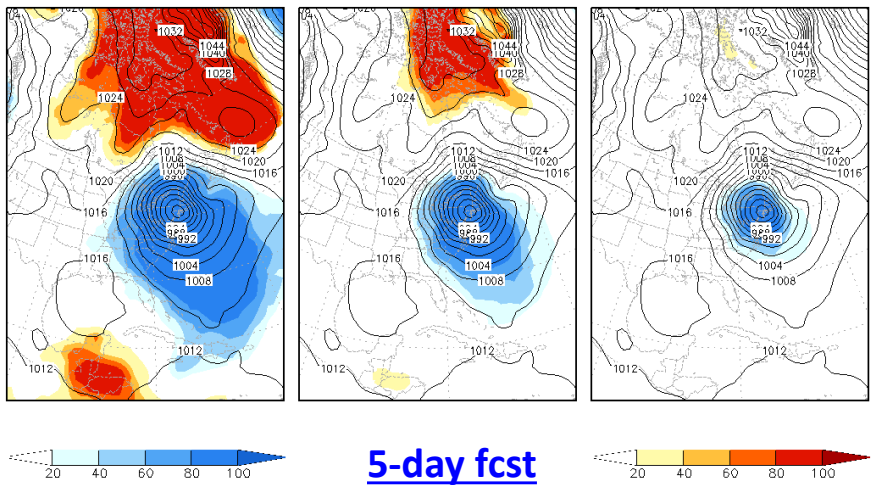
Hurricane Sandy

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

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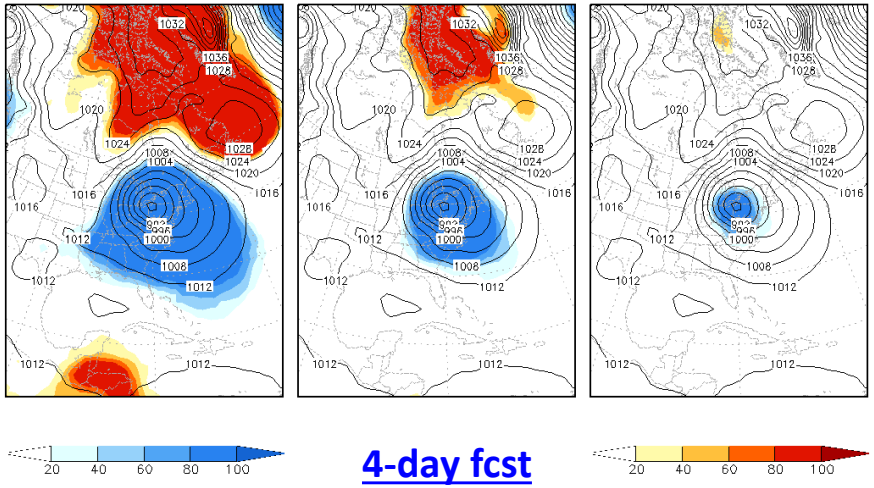
Sea Level Pressure (PRMSL), 96-hour forecast
Ini. time:2012102700 Valid time:2012103100
Contour-mean forecast; Shaded-forecast anomalies

one stdv two stdv three stdv



4-day fcst

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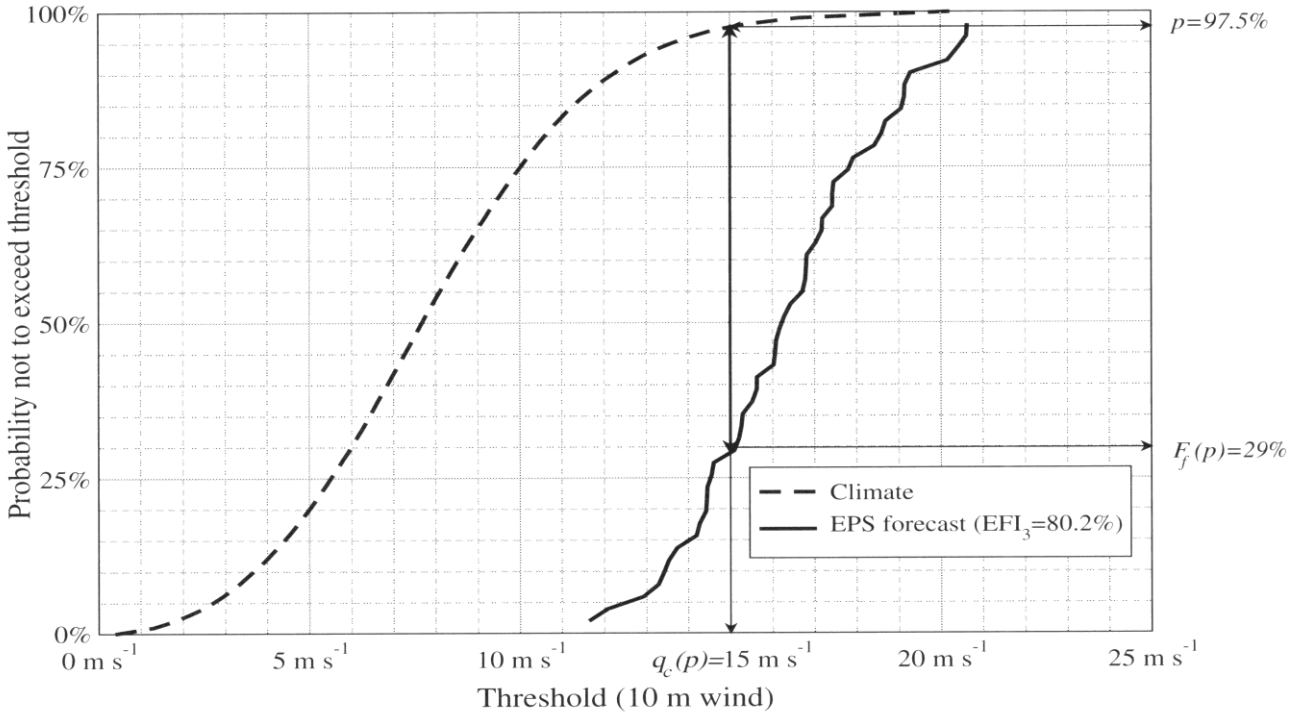
Extreme Forecast Index (Lalaurette, 2003)



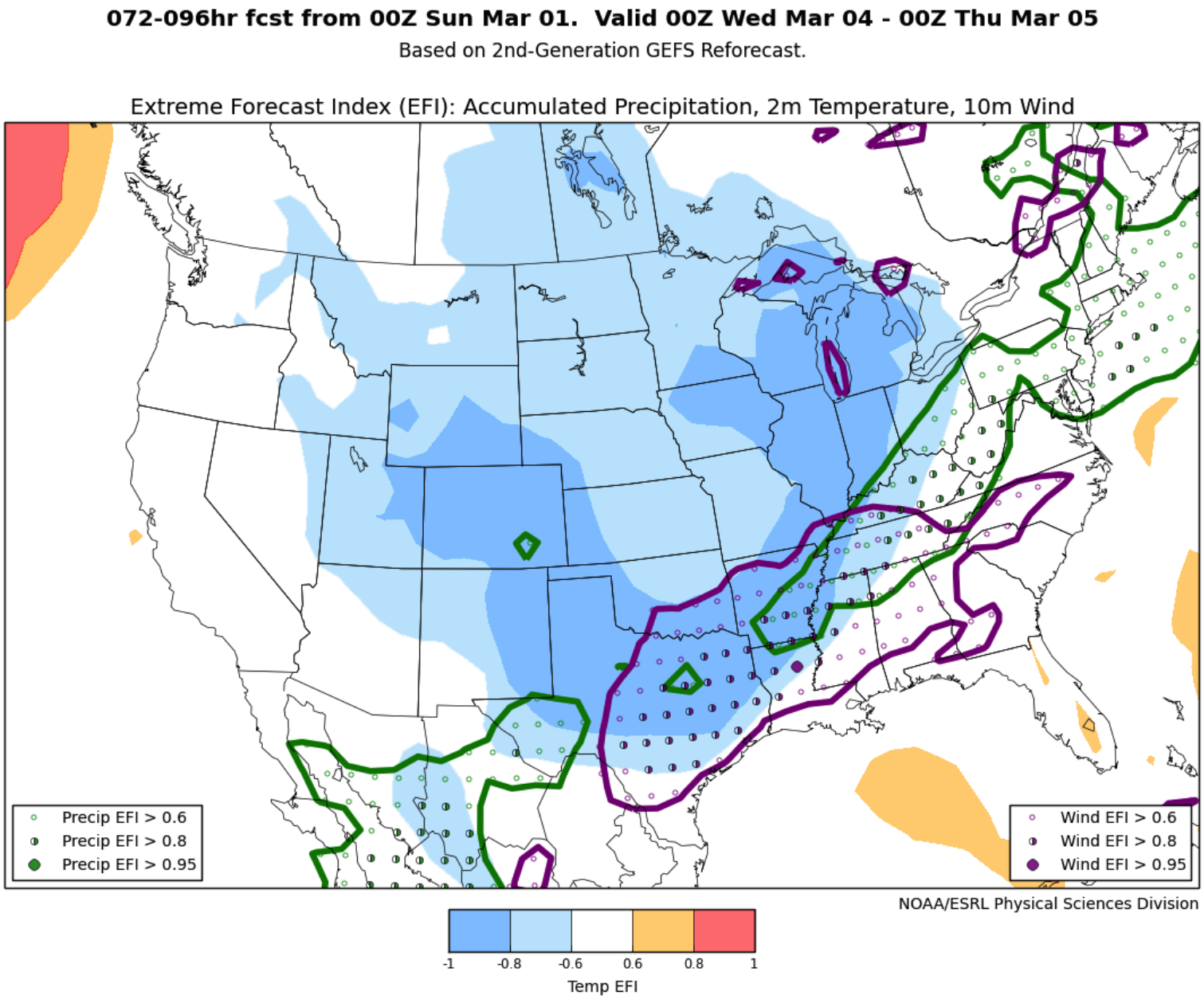
The EFI is a measure of the difference between the model climatological forecast distribution and the current ensemble forecast distribution.

CDF: cumulative distribution function

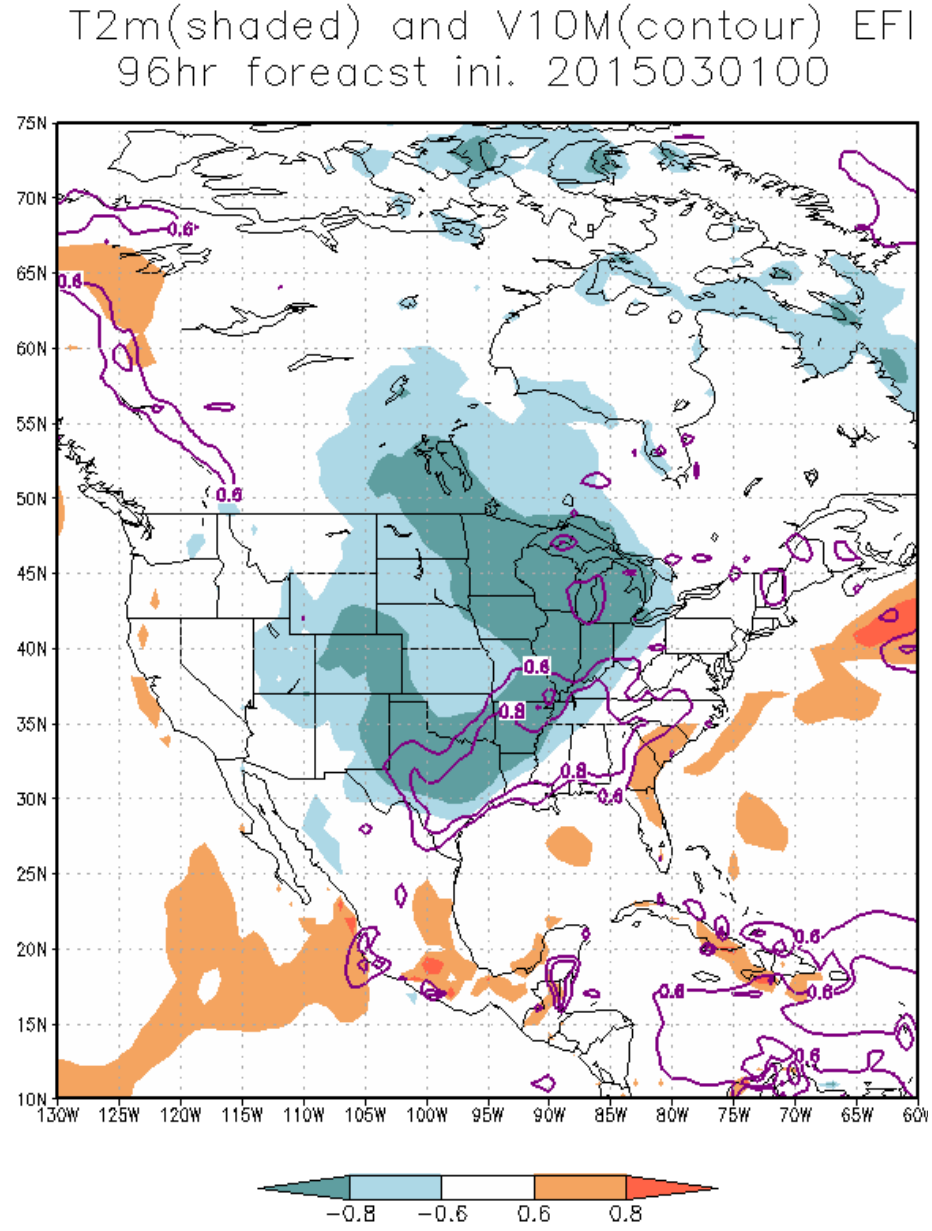
Modified Equation
(Zsooter 2006)

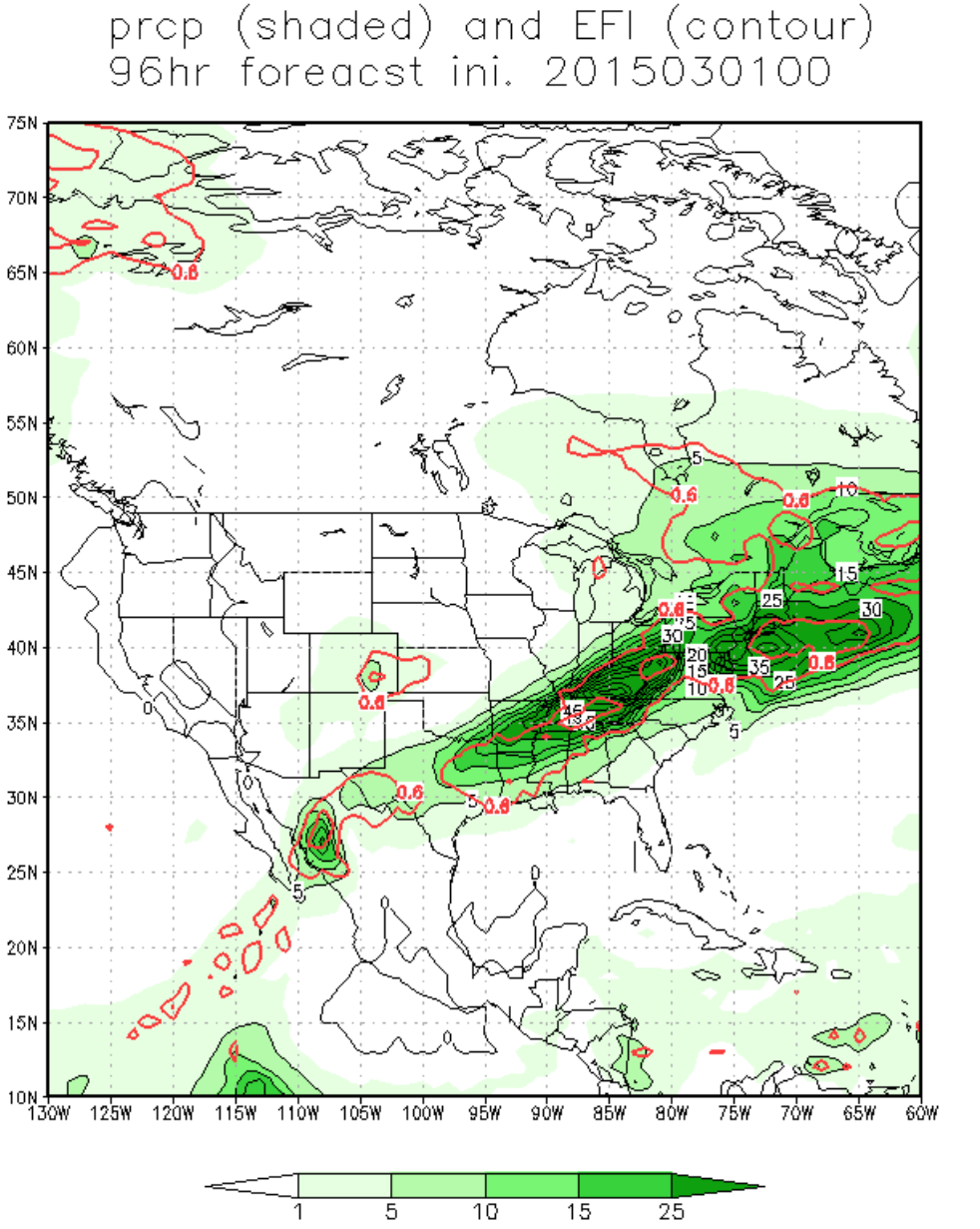
$$EFI = \frac{2}{\pi}\int_0^1 \frac{p - F_f(p)}{\sqrt{p(1-p)}}\,dp$$

Operational GEFS based EFI (ref: 25 years refcst – ESRL)



Parallel GEFS based EFI (ref: 18 years refcst – EMC)





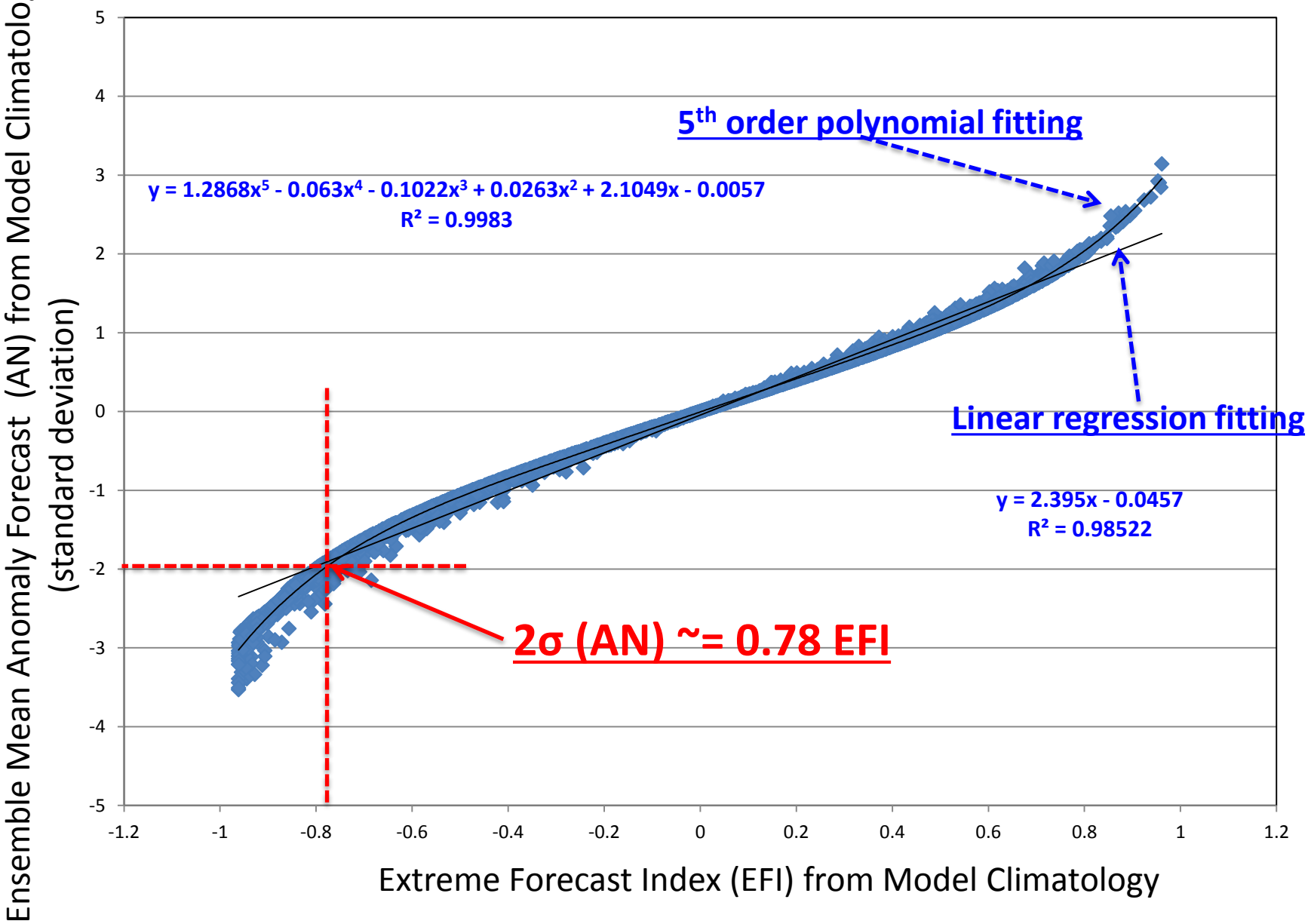
Anomaly Forecast and Extreme Forecast Index

How to compare these two measures?

What EFI value is equivalent to 2σ anomaly?

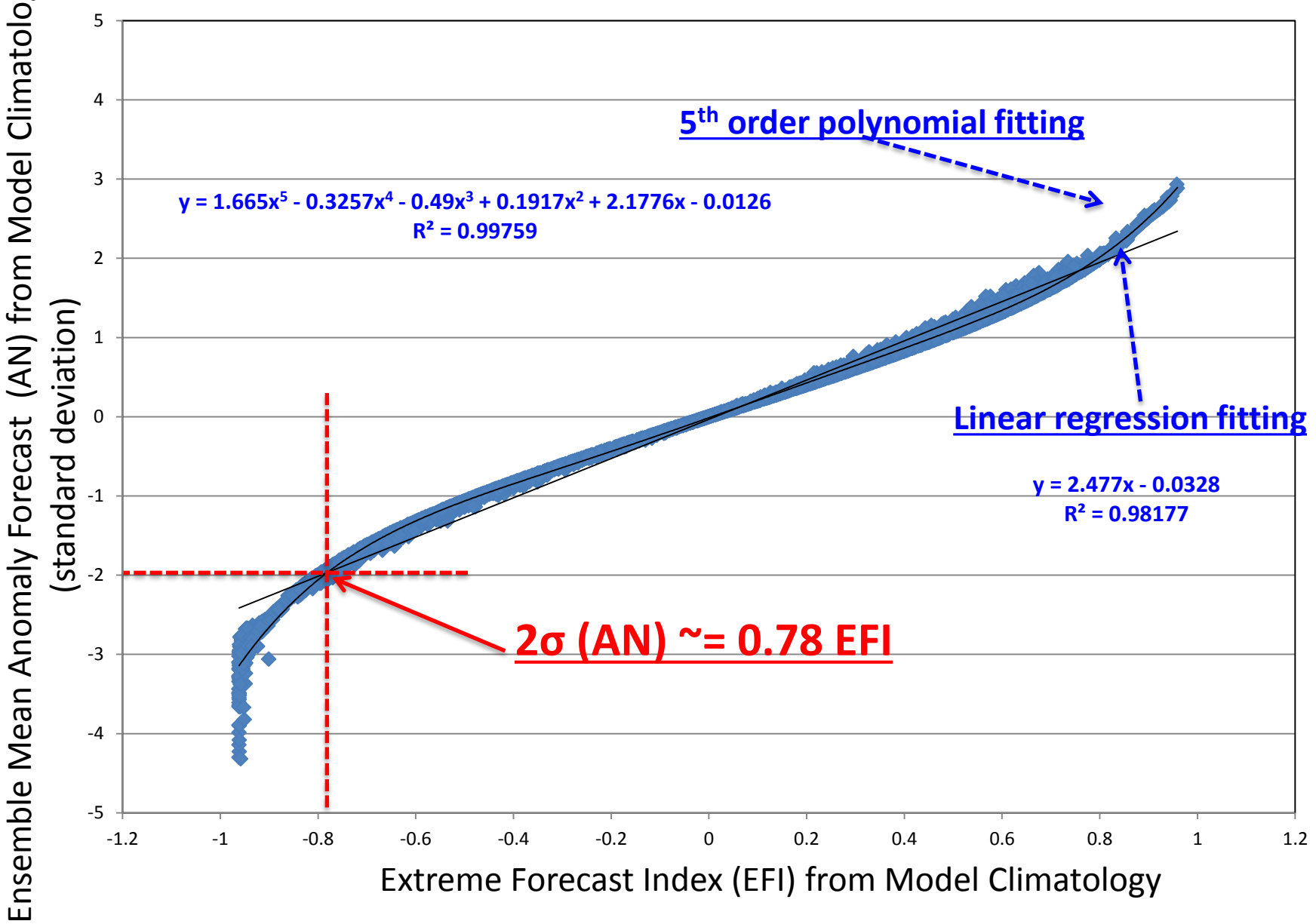
Raw Global Ensemble Forecast Distribution to Model Climatological Distribution

Surface Temperature (20150301 00UTC - 96 hours forecast) – GEFS V11.0



Raw Global Ensemble Forecast Distribution to Model Climatological Distribution

Surface Temperature (20150223 00UTC - 96 hours forecast) – GEFS V11.0



Evaluation for extreme cold weather forecasts

- How can we measure the performance?

  define a threshold for analysis extreme event (2σ), ANF-based (2σ), and EFI-based (0.78) extreme event, then we create contingency table and calculate

  - Hit and False alarm rate (HR and FAR):
  - Frequency Bias (FBI)
  - True Skill Score (TSS)
  - Equivalent Threat Scores (ETS)
  - Receiver Operating Characteristic (ROC) skill score

    HR and FAR for different forecast

    ANF: using 0%, 5%, 10%, 15%, 20%,……100% ensemble forecasts

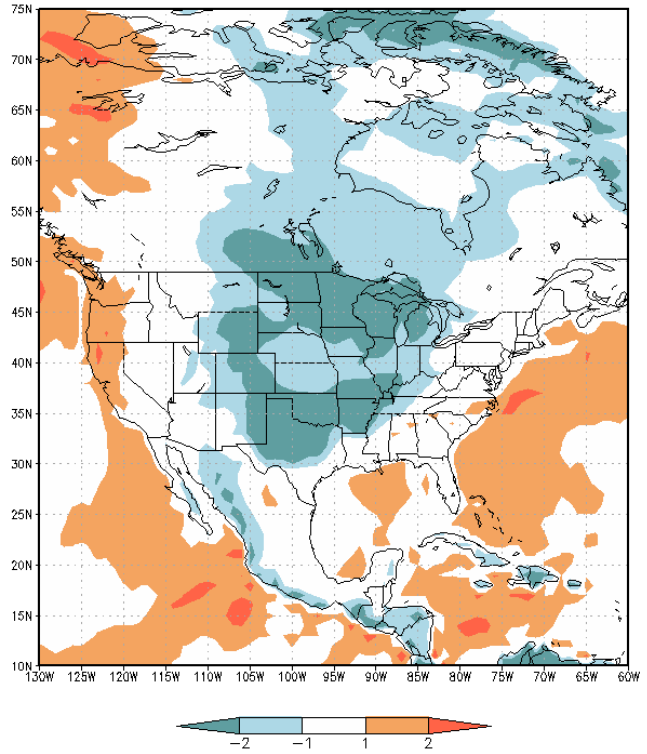
    EFI: using -0.03σ, -0.08σ, -013σ, ……. -1.030σ

- Which one is relatively better?
  - For raw ensemble forecast/model climatology or bias corrected forecast/analysis climatology
  - For operational (v10) or parallel (v11)
  - For using 40-year reanalysis or 30-year CFSR as a reference

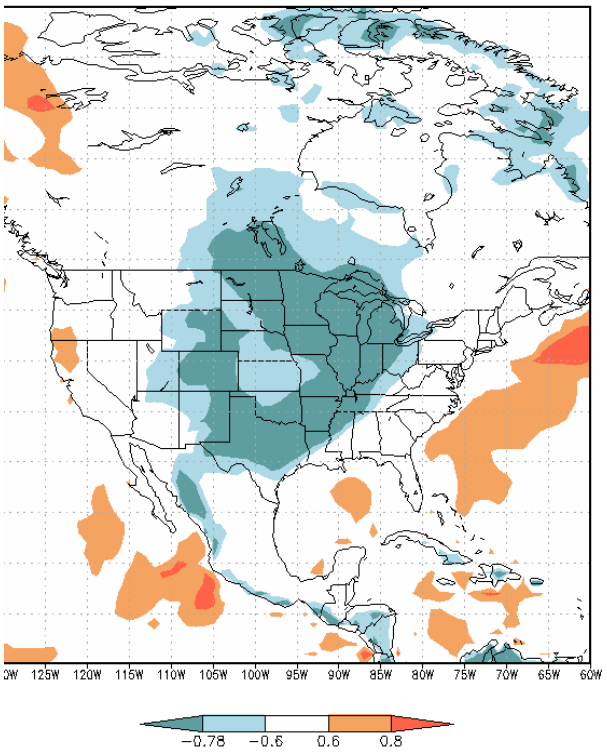
- How can the climatology impact the products?
  - Mainly the variance of climatology
  - Extreme events are in the tail of climatological distribution

Example of extreme cold weather event (Valid: 2015030500)

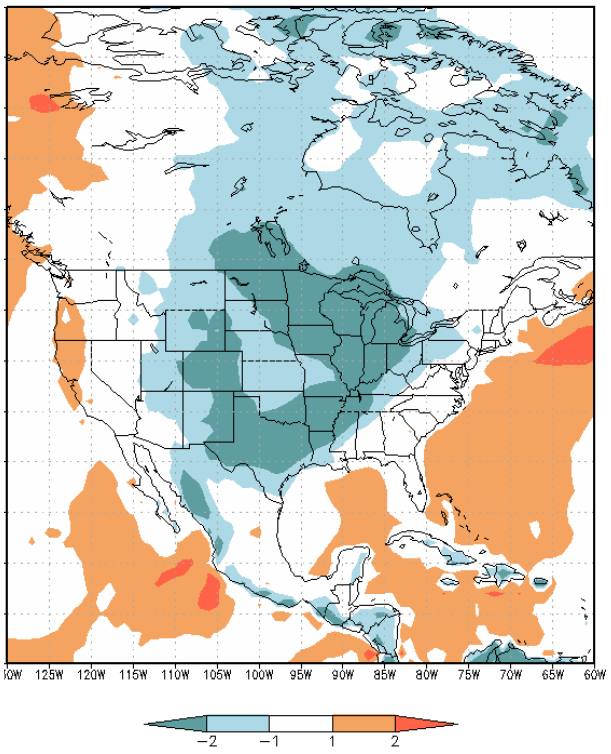
Observed anomaly (analysis)

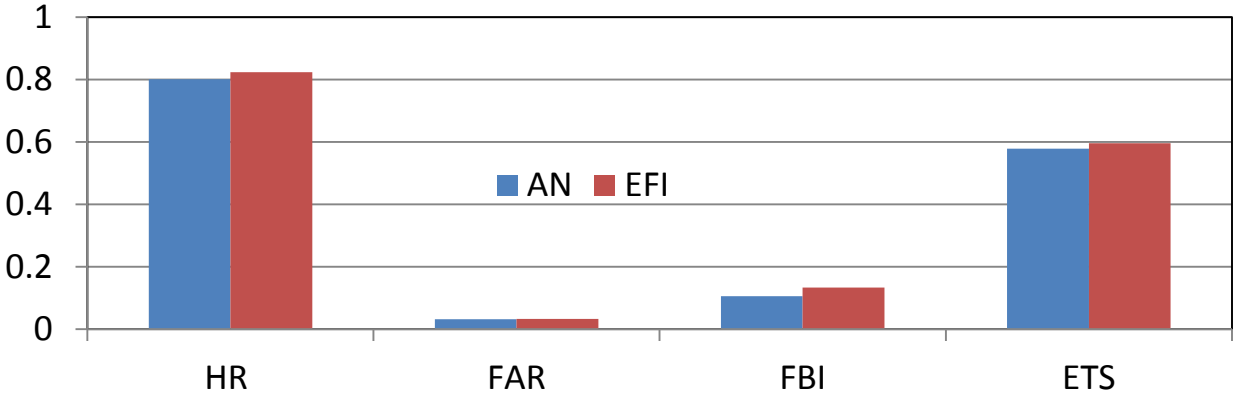


Extreme Forecast Index (EFI)



Anomaly Forecast (AN)

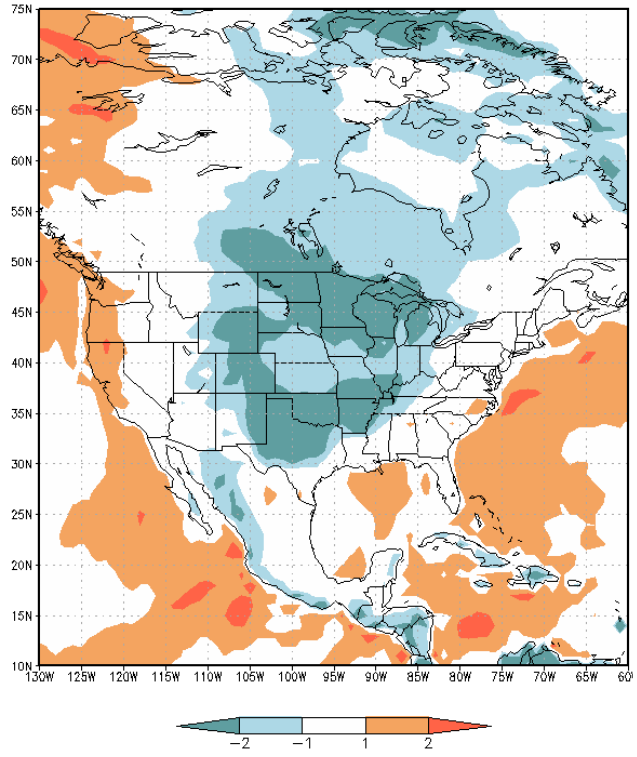




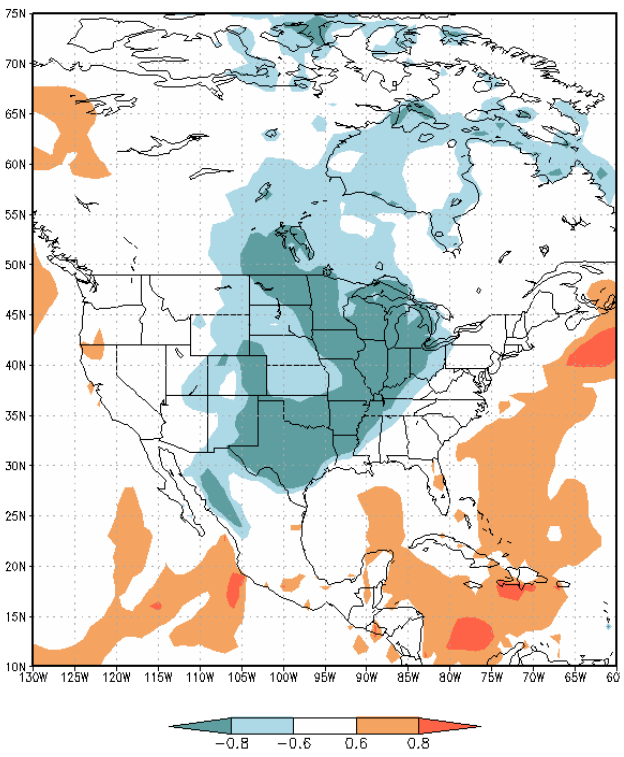
GEFS V10 bias corrected T2m
Against
Observed climatology

Example of extreme cold weather event (Valid: 2015030500)

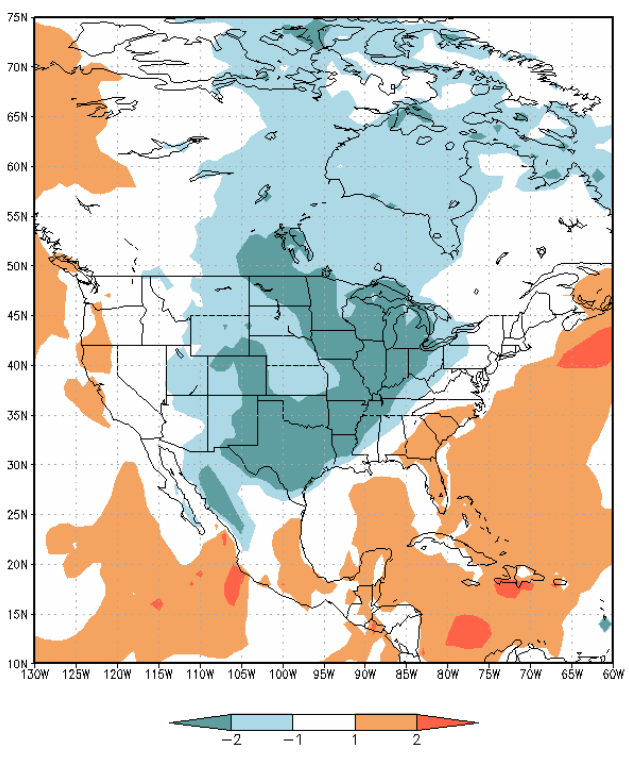
Observed anomaly (analysis)

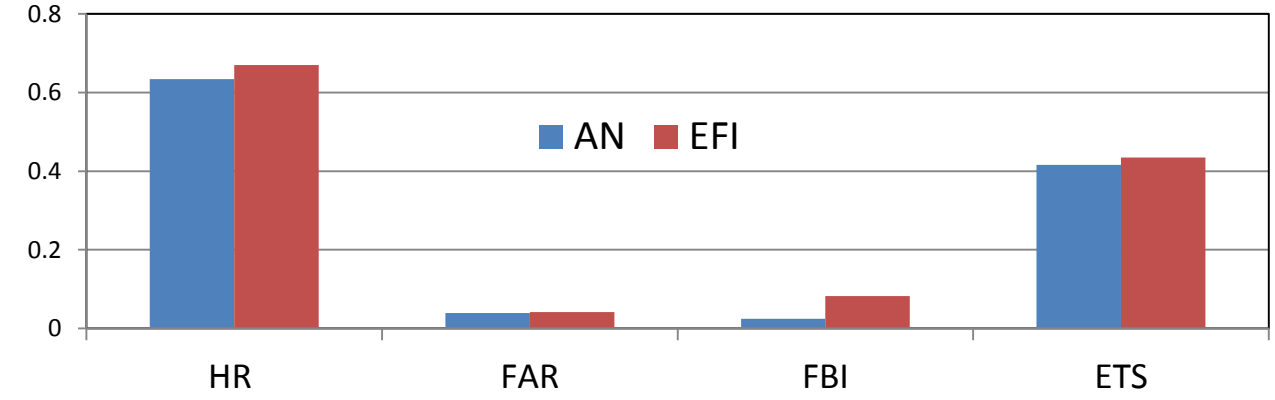


Extreme Forecast Index (EFI)



Anomaly Forecast (AN)

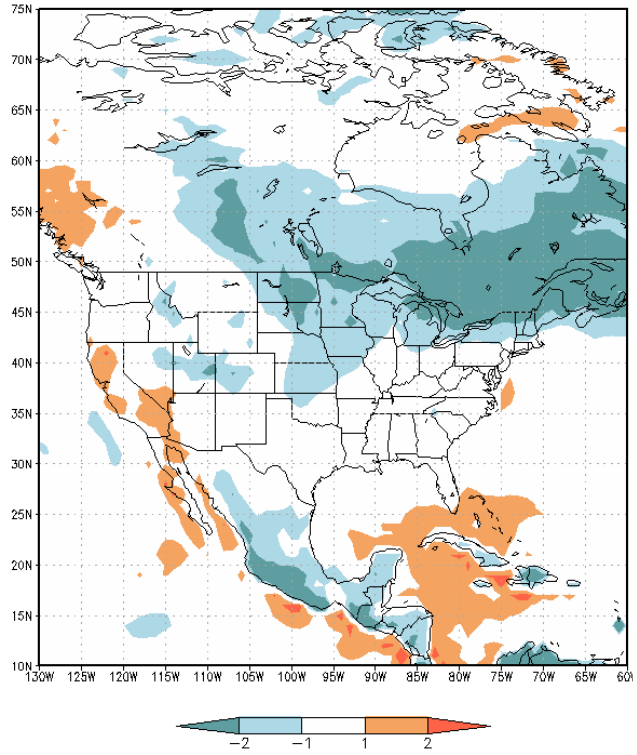




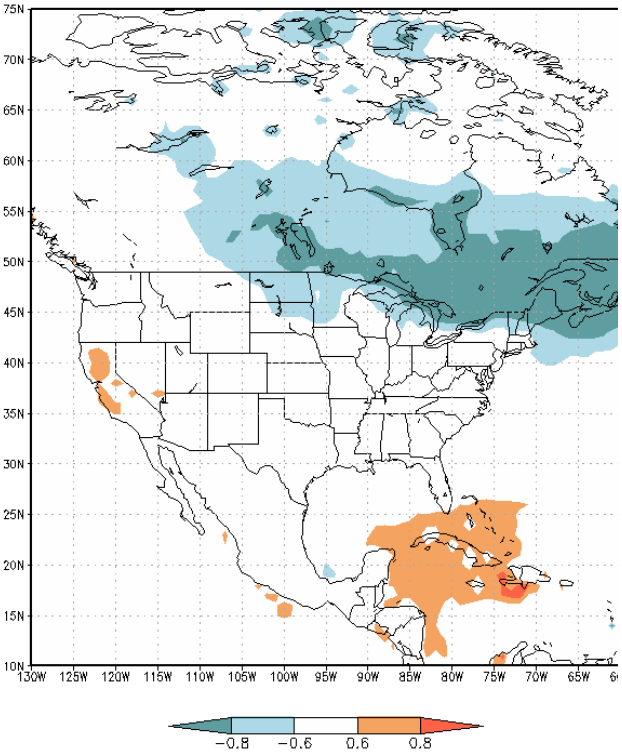
GEFS V11 Raw T2m
Against
Model climatology

Example of extreme cold weather event (Valid: 2014010200)

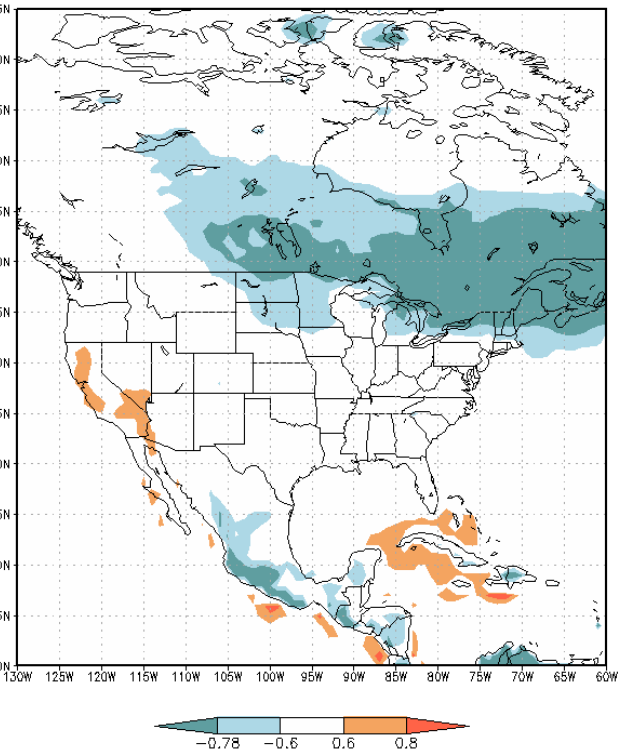
Observed anomaly (analysis)

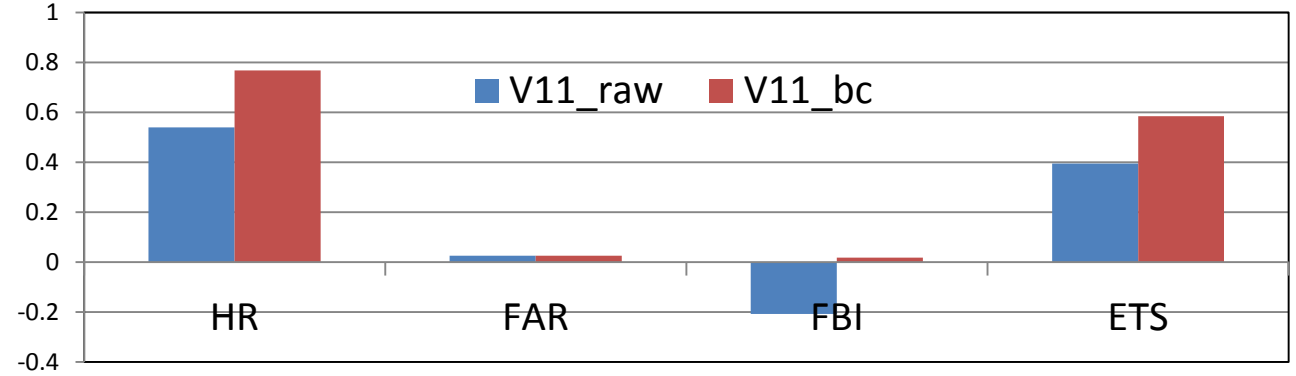


EFI (RAW)



EFI (Bias corrected)



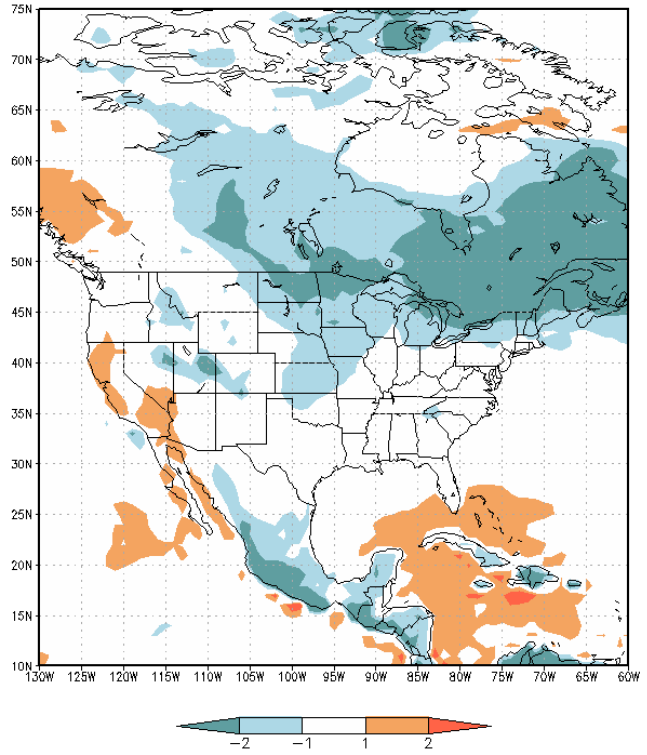


GEFS V11 Raw T2m
Against
Model climatology

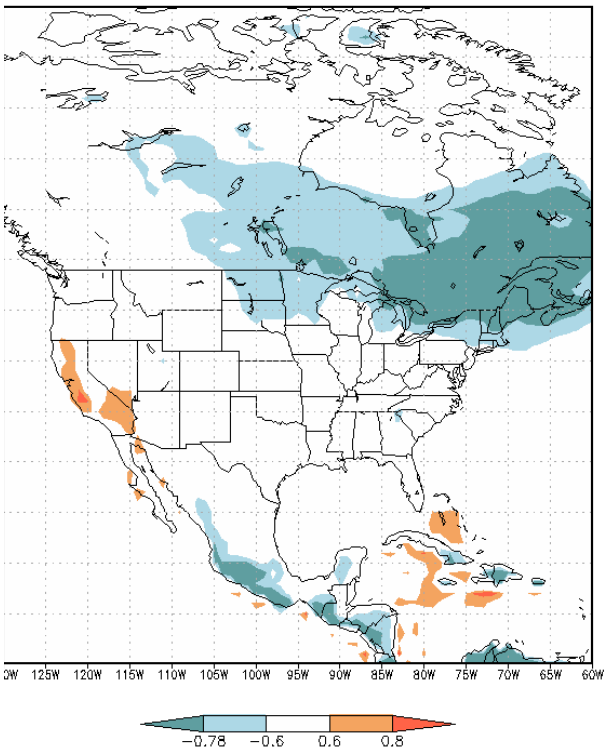
GEFS V11 BC T2m
Against
Observed climatology

Example of extreme cold weather event (Valid: 2014010200)

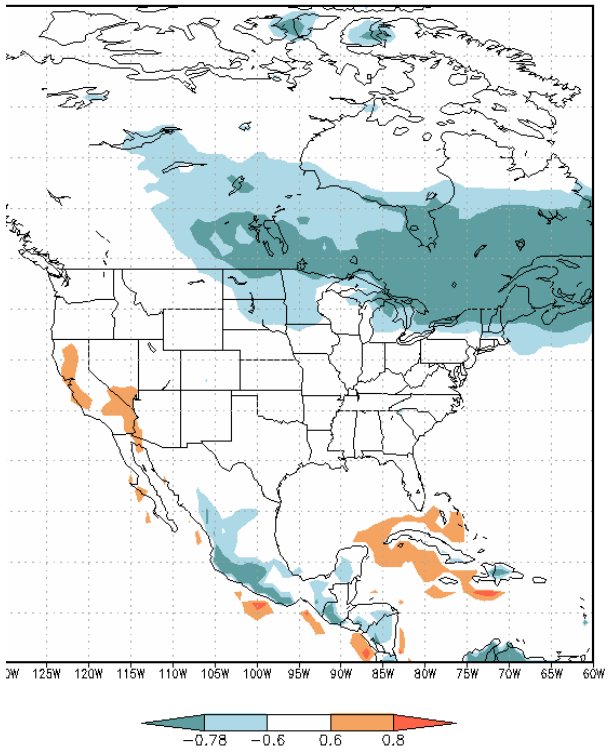
Observed anomaly (analysis)

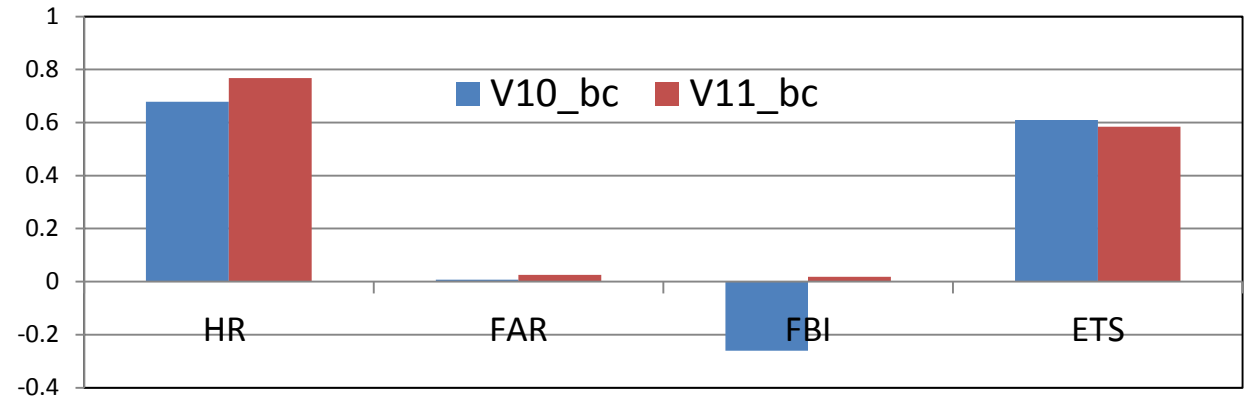


EFI (Bias corrected) – V10



EFI (Bias corrected) – V11

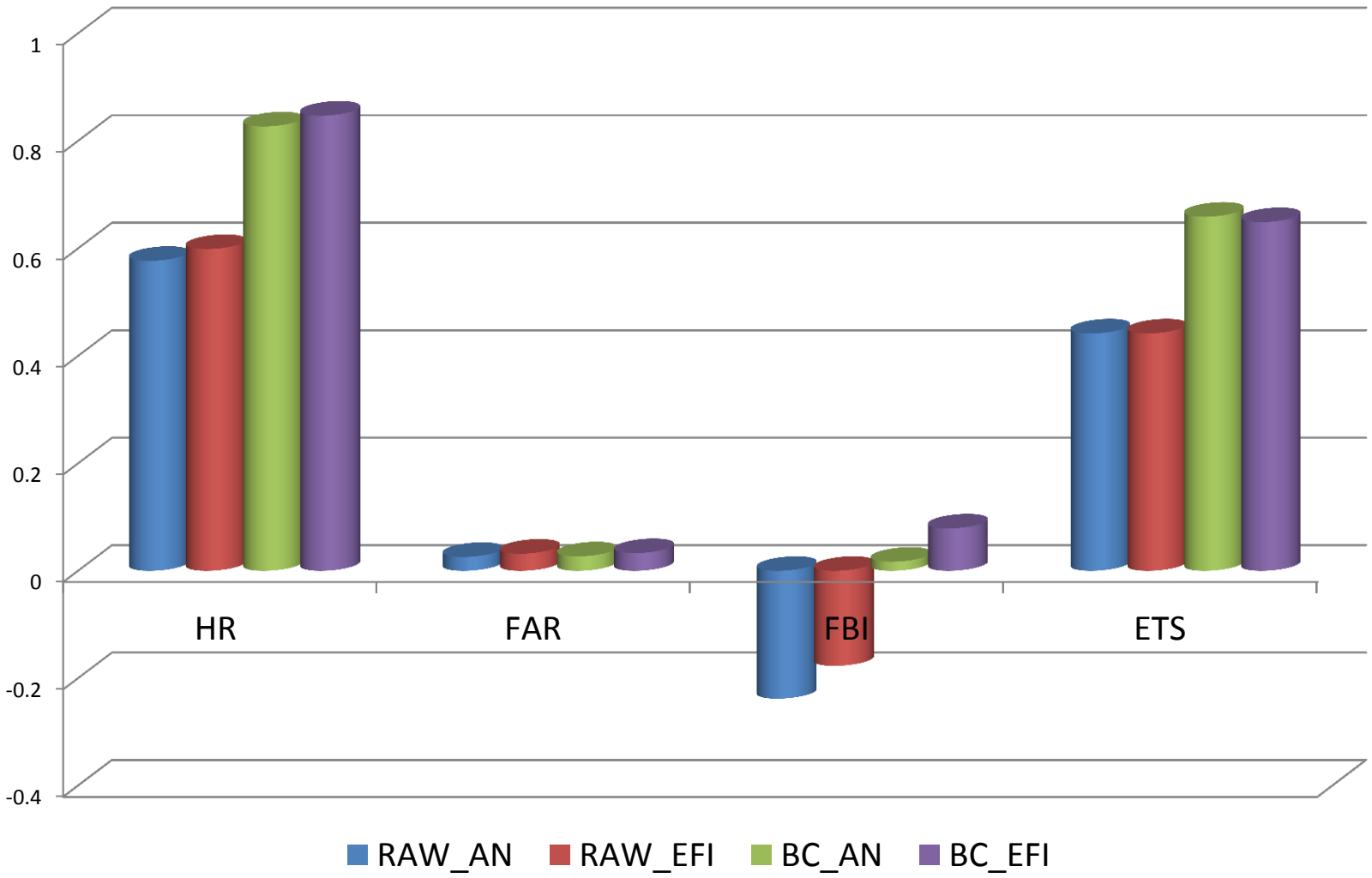




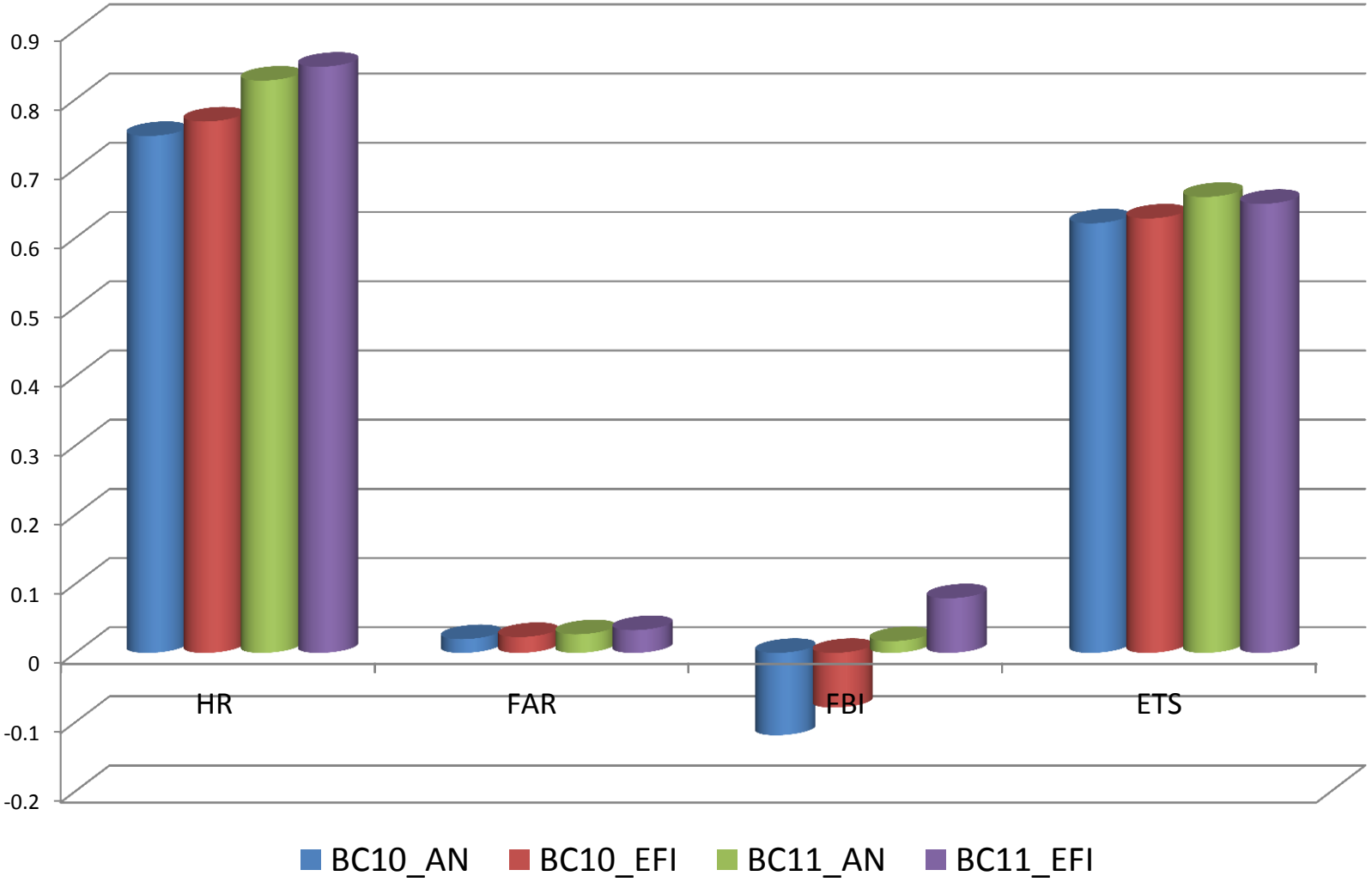
GEFS V10 BC T2m
Against
Observed climatology

GEFS V11 BC T2m
Against
Observed climatology

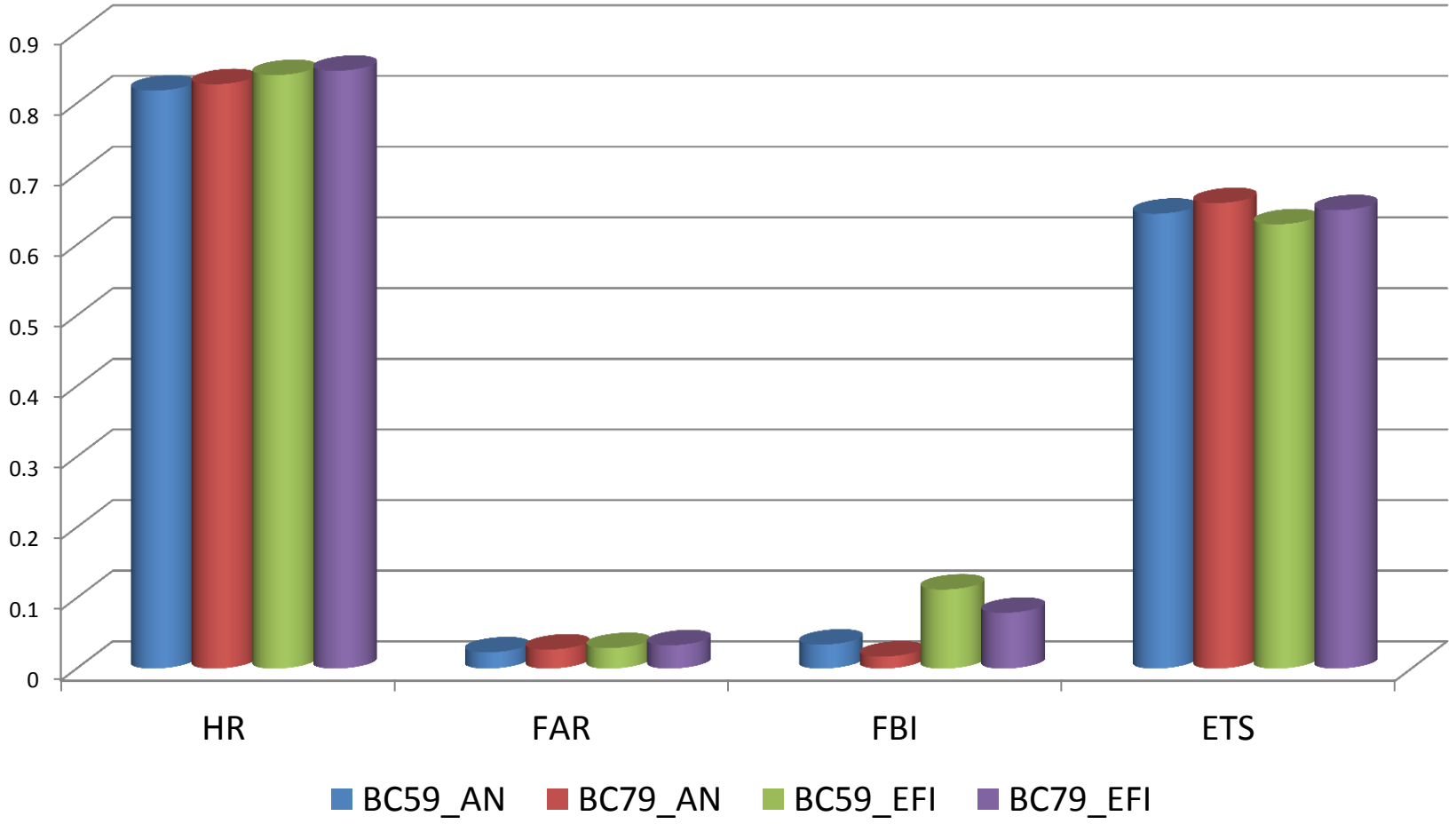
Statistics for extreme cold weather event (11 cases) for 13-14 winter – raw and bias-corrected forecast (V11)



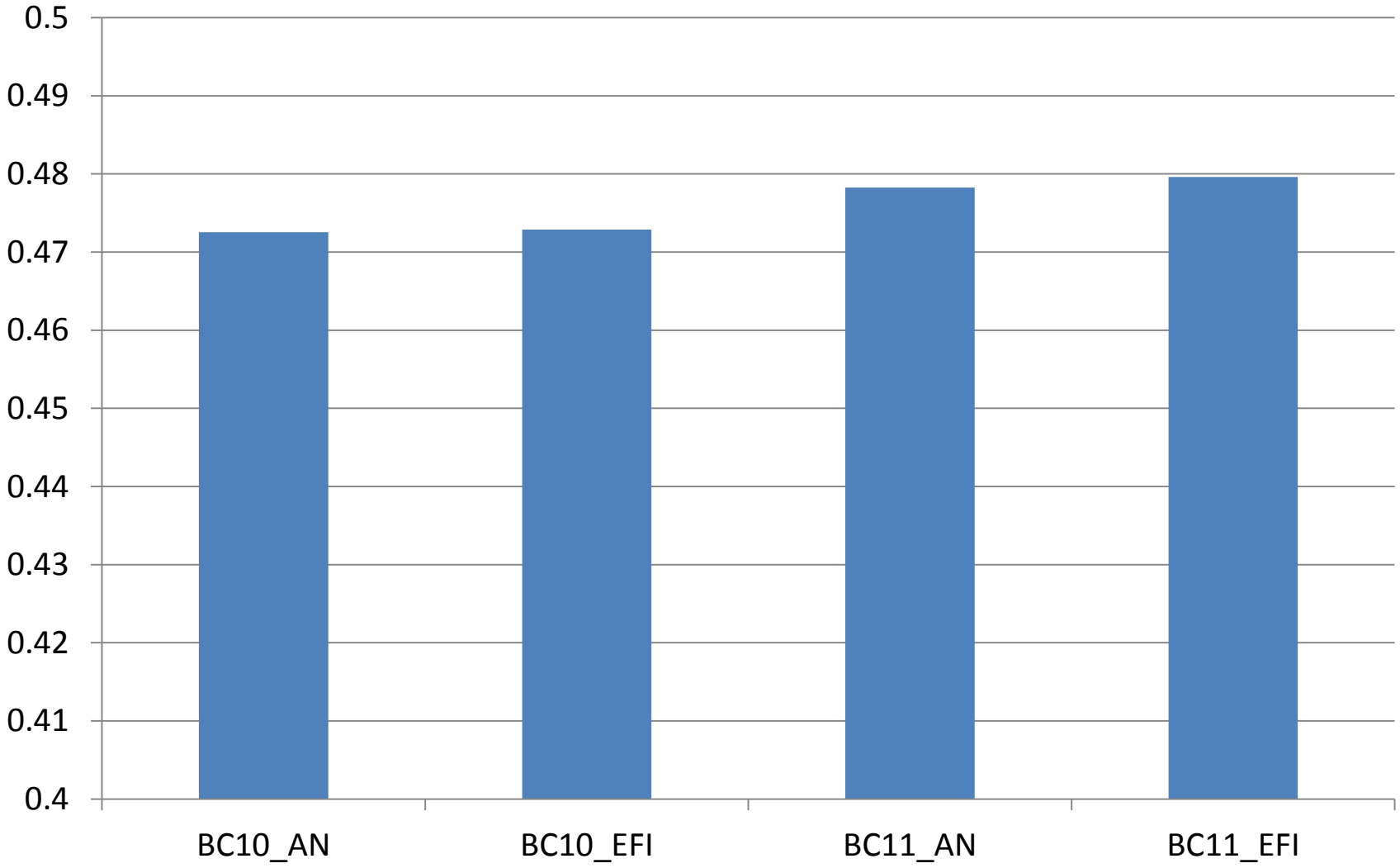
Statistics for extreme cold weather event (11 cases) for 13-14 winter – V10 and V11 bias-corrected forecast



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)



ROC area for extreme cold weather event (11 cases) for 13-14 winter – V10 and V11 bias-corrected forecast



Summary and Future Plan

- Both of anomaly forecast (ANF) and extreme forecast index (EFI) could predict extreme events.
- Verification Stats. for cold extreme events for 2013-2014 winter indicates
  - EFI forecasts more cold extreme events than ANF
  - ANF produces better ETS
  - The ROC area for EFI and ANF is very similar
  - Bias corrected forecast has higher scores than raw forecast
  - GEFSv11 performs better than GEFSv10
  - More reasonable climatology (CFSR) gives a slightly better performance than (reanalysis) .
- Will work on verifications for wind and precipitation.
- To have longer period to calculate the statistics

Background!!!

Abstract

- In 2006, the post-processing of NCEP Global Ensemble Forecast System (GEFS) and North American Ensemble Forecast System (NAEFS) has been implemented to enhance probabilistic forecast through anomaly forecast of various weather elements. Anomaly forecast is one of NAEFS products from bias corrected forecast and reanalysis based climatology. It is measuring the forecast departure (bias–free) from climatology (observation). Based on NCEP/NCAR 40-year reanalysis, daily climatological distribution (PDF) has been build up for 19 atmospheric variables, such as height, temperature, winds and etc. The uncertainty information for anomaly by comparing forecast PDF to climatological PDF allows users to identify the extreme weather event easily. There are many applications in past years for extreme heat waves, winter storms and etc.

- Later, a new daily climatology has been generated from latest Climate Forecast System (CFR) reanalysis. Apparently, CFSR has much improved analysis quality through various enhancements, such as the quality of observations, state-of-art model and assimilation system, and much higher spatial resolution. There will be a comparison of two climatological distributions in terms of their anomaly forecast for extreme weather/climate events. In the contrast, there is another way to build up anomaly forecast (or Extreme Forecast Index (EFI)) in the communities, that bases on raw ensemble forecast and model based climatology, such as ensemble reforecast (20 years). Therefore, a multi comparison of anomaly forecast for several extreme weather/climate events will be performance through out this study.

Nature of Extreme Events

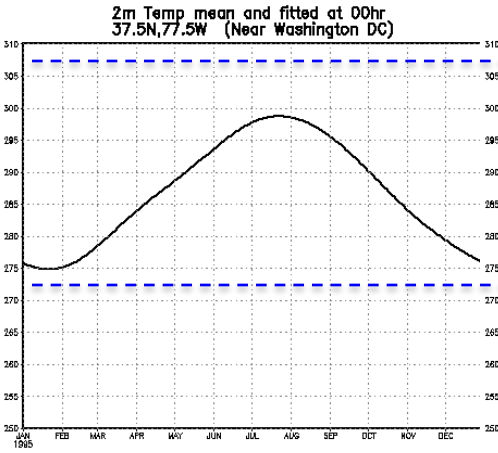
- Physical system.
  - The same for extreme and non-extreme events.
  - Different from phase space of system.
  - Near the edge of the distribution.
  - Small scale system in generally.

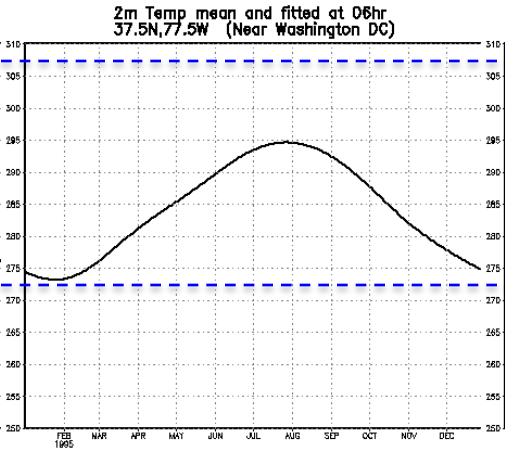
- Nonlinear process.
  - Play a crucial role to define the “edge”.
  - Creating additional uncertainty.
  - Model’s limitation to predict extreme by nonlinear process.

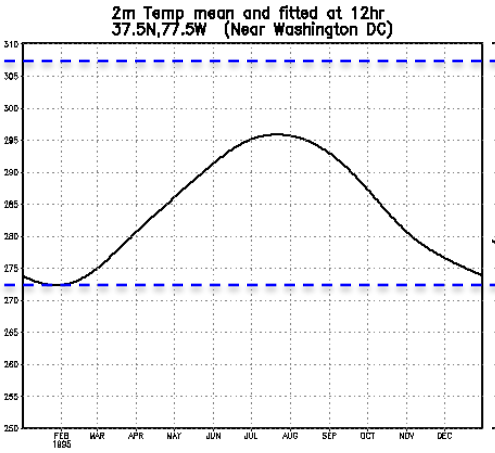
- Combination of many factors:
  - Snow covers, cloud covers.
  - Minimum temperature, and maximum temperature.
  - Combined high temperature and high humidity – heat index
  - Wind speed, combined cold temperature and wind sheer –wind chill
  - Precipitation amount and concentration.
  - Time, location and etc…

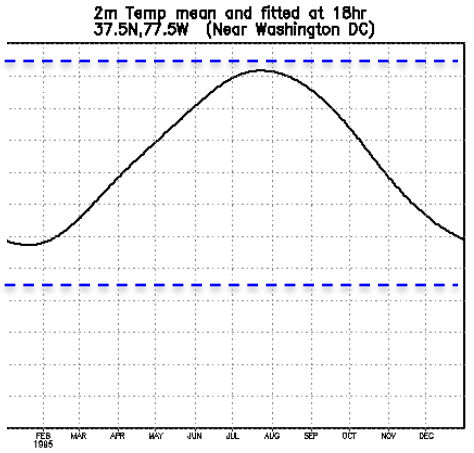
GEFS V11.0 Model Climatology (18 years)

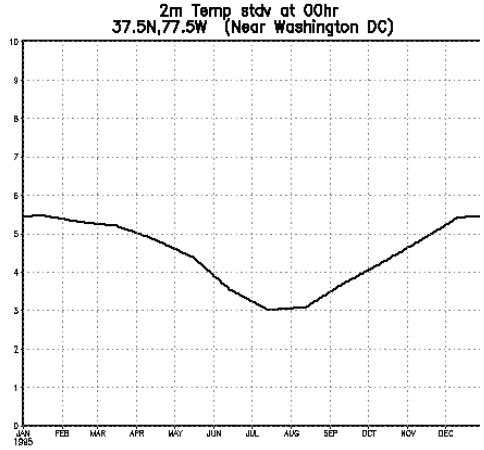
Demonstrate diurnal variation of surface temperature

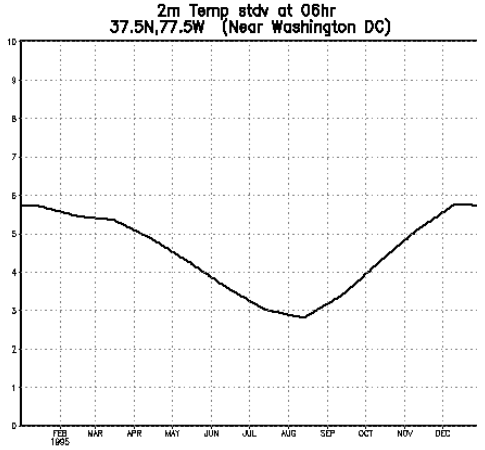


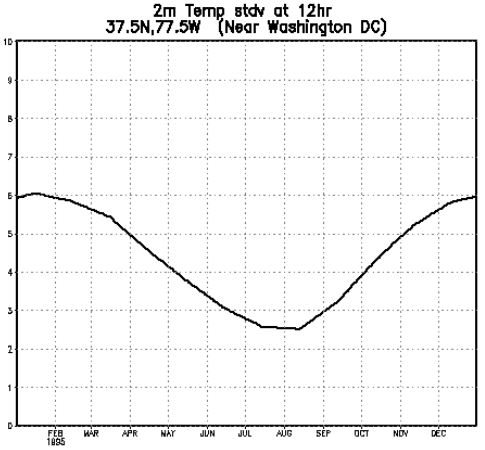


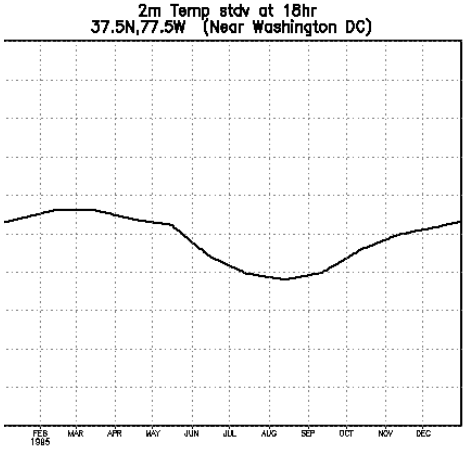






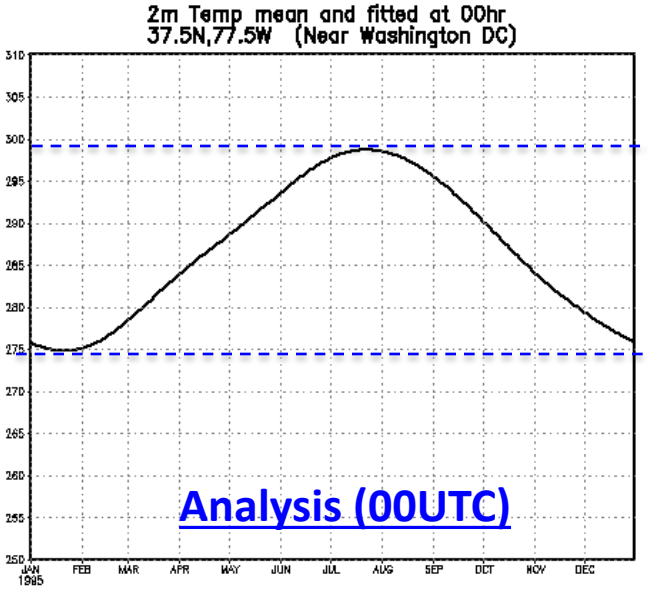




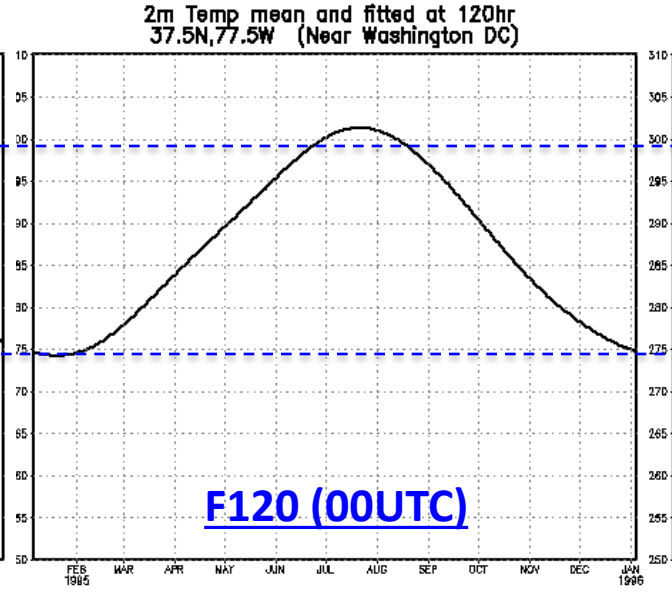


[Analysis (00UTC)](#) [F06 (06UTC)](#) [F12 (12UTC)](#) [F18 (18UTC)](#)

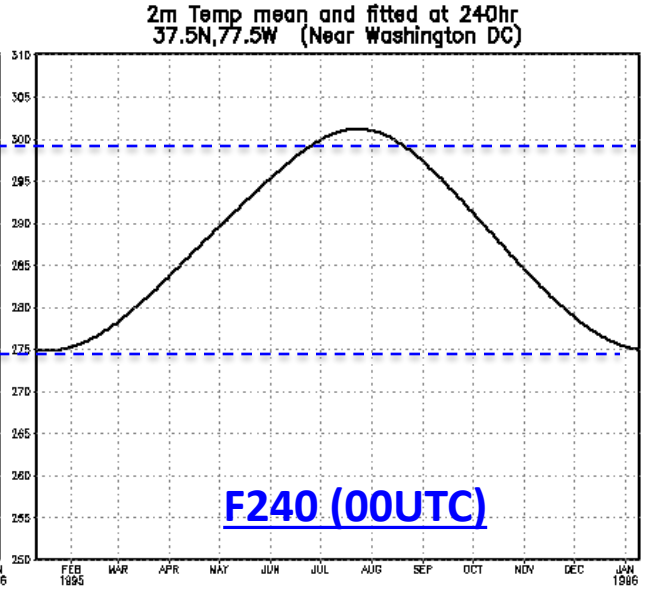
GEFS V11.0 Model Climatology (18 years)



Analysis (00UTC)



F120 (00UTC)



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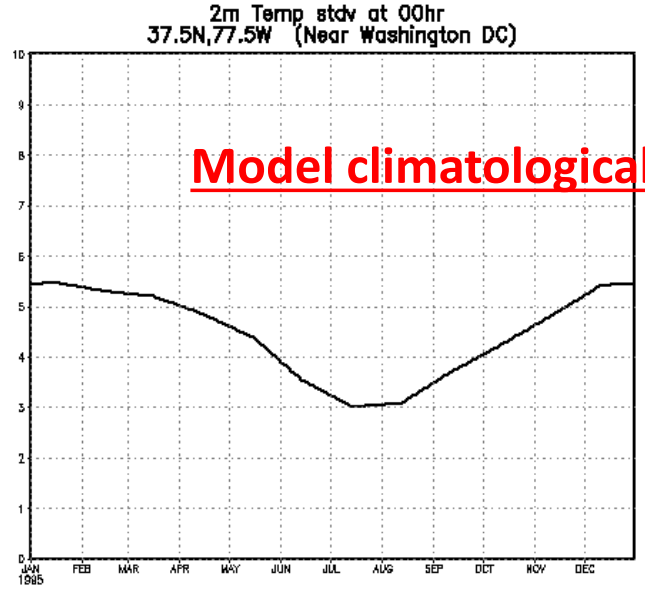
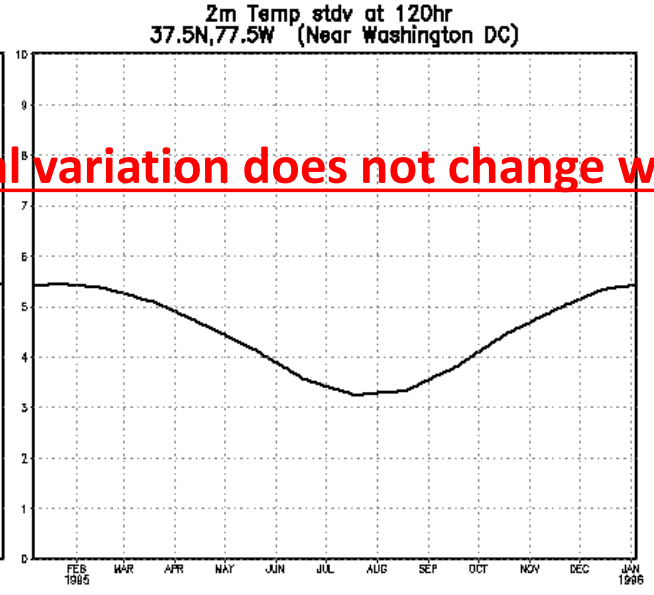
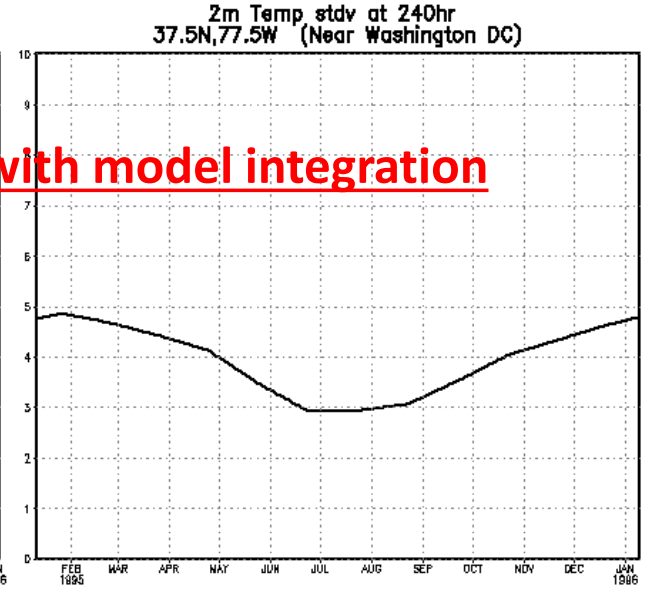


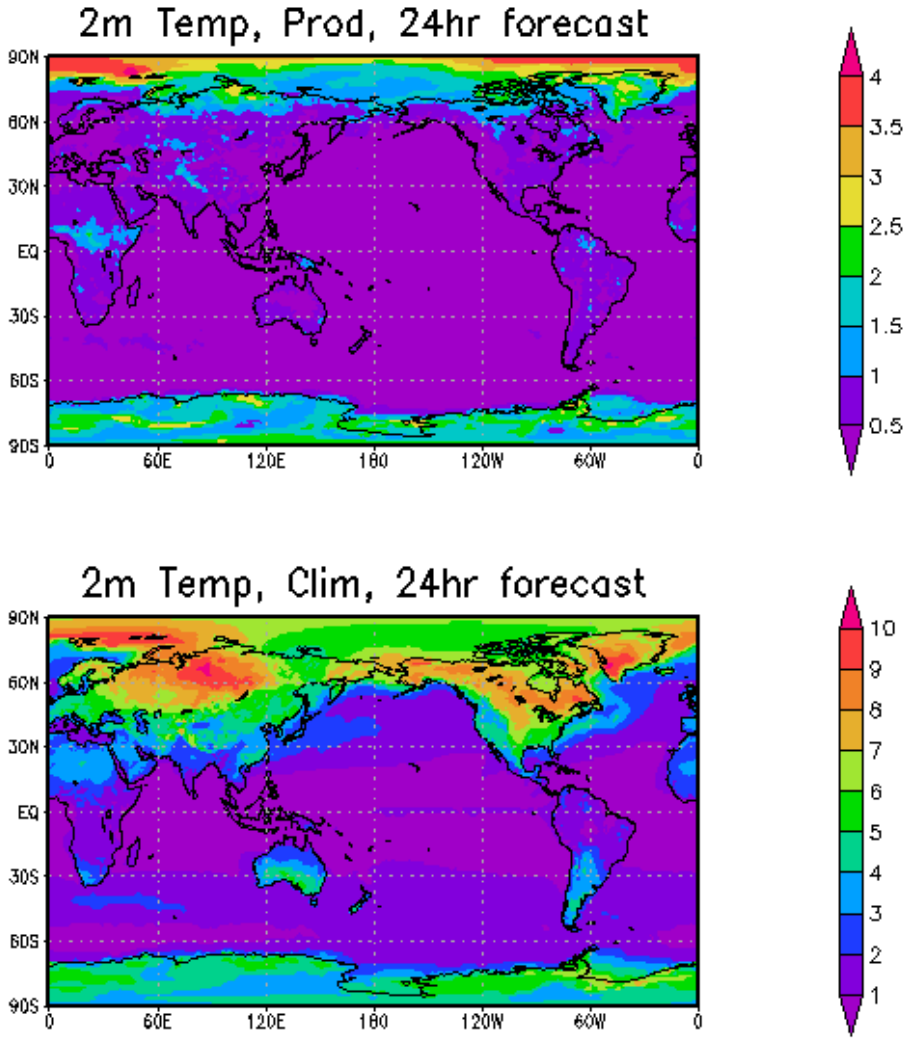


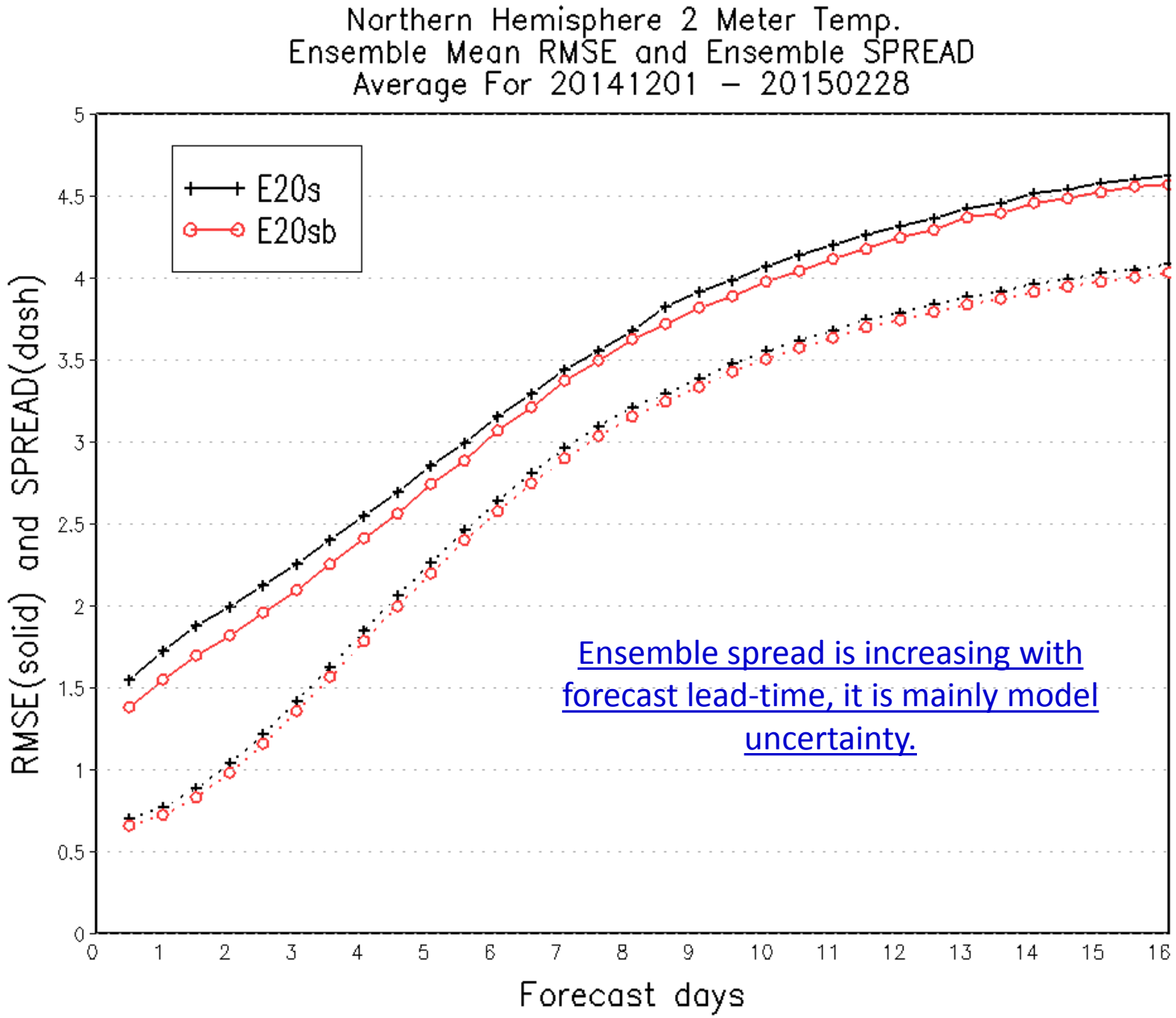


Model climatological variation does not change with model integration

Comparison of 15 days average ensemble spread and model climatological standard deviation

Center day – Feb 26 2015




Northern Hemisphere 2 Meter Temp.
Ensemble Mean RMSE and Ensemble SPREAD
Average For 20141201 – 20150228
E20s
E20sb
RMSE(solid) and SPREAD(dash)
Forecast days
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Ensemble spread is increasing with forecast lead-time, it is mainly model uncertainty.