Customized Daily to Seasonal Predictions for the Energy Sector Using ECMWF Forecasts

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Who Is CFAN?
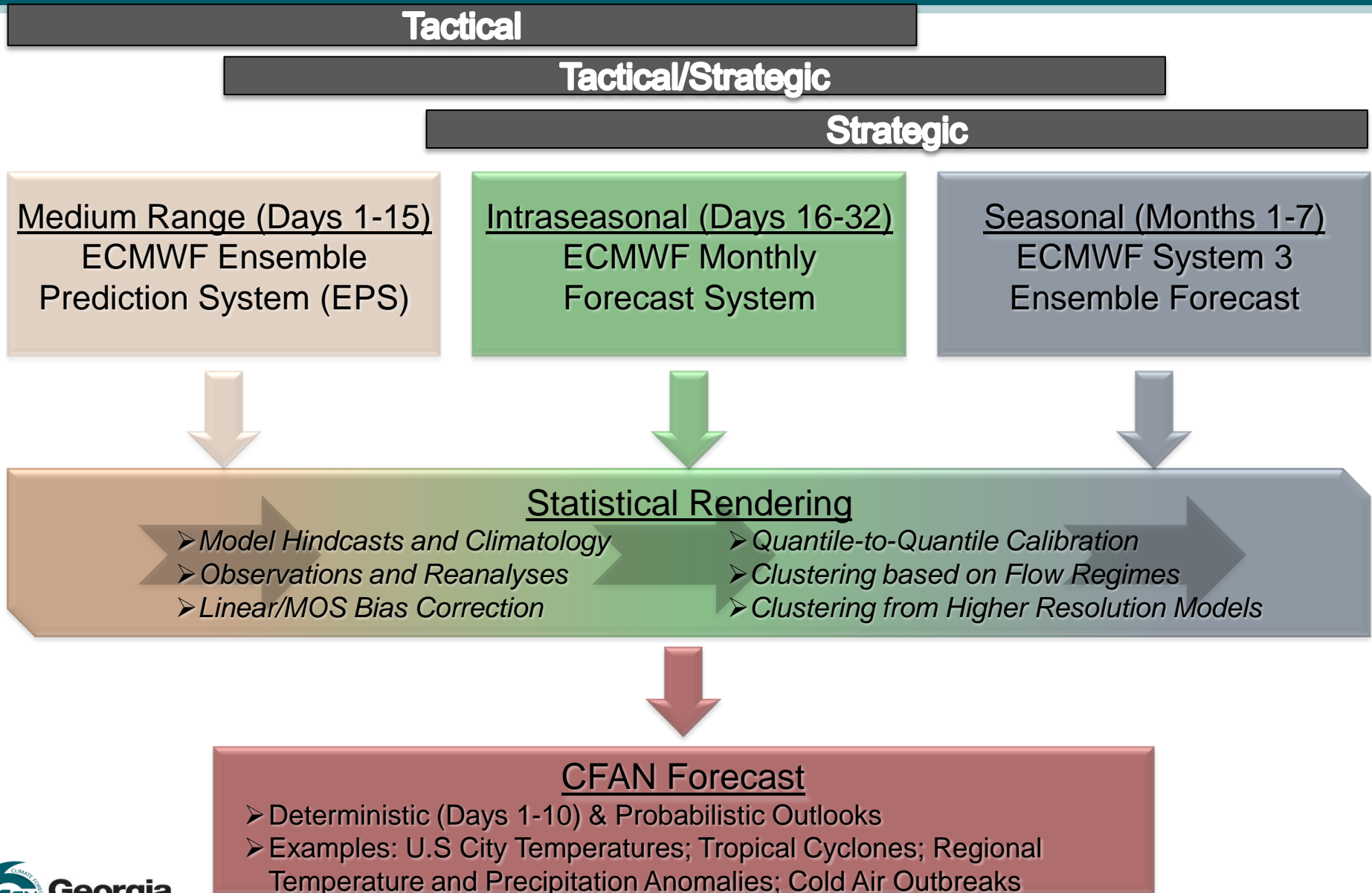
> **MISSION**
>
> *Apply Georgia Tech's cutting-edge weather and climate research to provide forecasting and decision support for risk management*
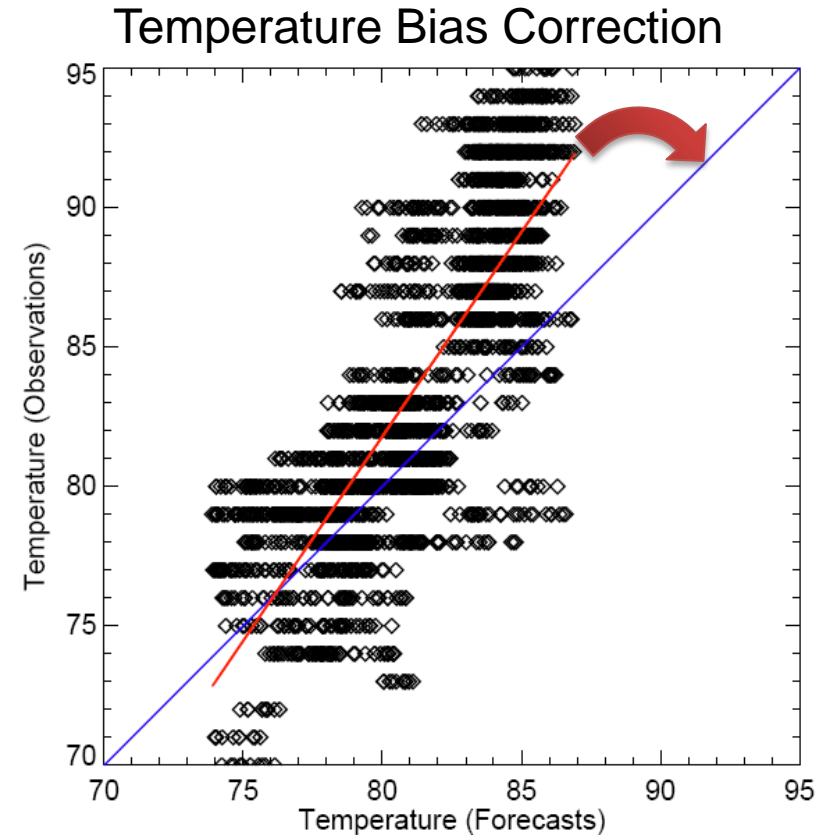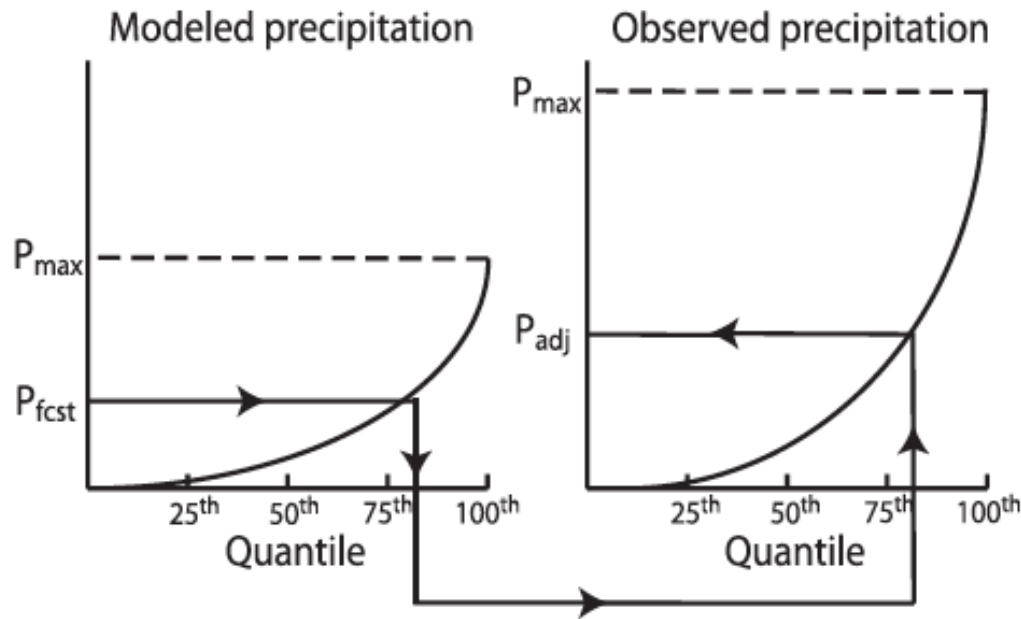
- GT Enterprise Innovation Institute VentureLab Company

- Our Products and Services
  - ➤ Forecasting high impact extreme events on daily to seasonal time scales to support decision making
  - ➤ Variables include temperature, wind, tropical cyclones, floods, precipitation, hydrology, snowpack
  - ➤ Support energy trading, economic development, risk management, disaster mitigation, regional stability, long-range asset planning

Would not be possible without ECMWF's forecast and hindcast products!

# CFAN's Hierarchical Forecasting Philosophy

Tactical

Tactical/Strategic

Strategic

Medium Range (Days 1-15)
ECMWF Ensemble
Prediction System (EPS)

Intraseasonal (Days 16-32)
ECMWF Monthly
Forecast System

Seasonal (Months 1-7)
ECMWF System 3
Ensemble Forecast

Statistical Rendering
➢ *Model Hindcasts and Climatology*
➢ *Observations and Reanalyses*
➢ *Linear/MOS Bias Correction*

➢ *Quantile-to-Quantile Calibration*
➢ *Clustering based on Flow Regimes*
➢ *Clustering from Higher Resolution Models*

CFAN Forecast
➢ Deterministic (Days 1-10) & Probabilistic Outlooks
➢ Examples: U.S City Temperatures; Tropical Cyclones; Regional
Temperature and Precipitation Anomalies; Cold Air Outbreaks

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Statistical Rendering: Quantile-to-Quantile Correction

- An unbiased forecast will follow closer to the blue line
- The quantile-to-quantile method has the advantage of **removing the model bias while keeping the shape of the distribution** (no linear assumptions are made)
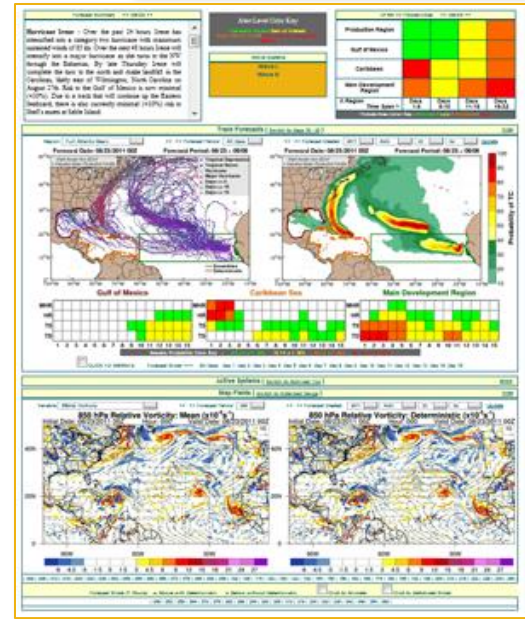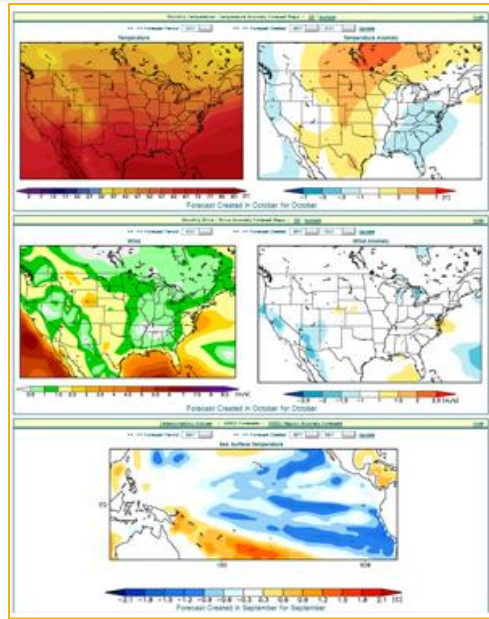
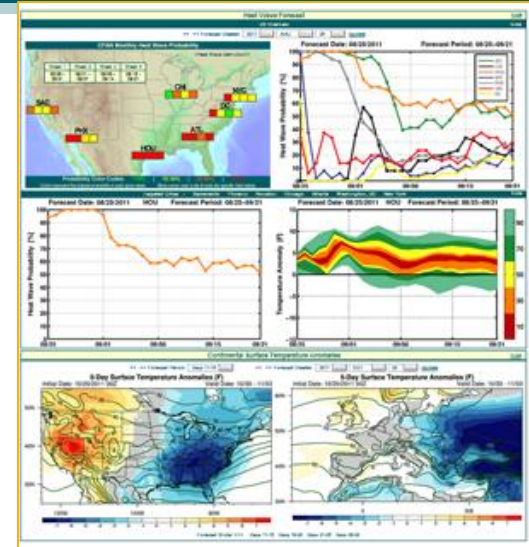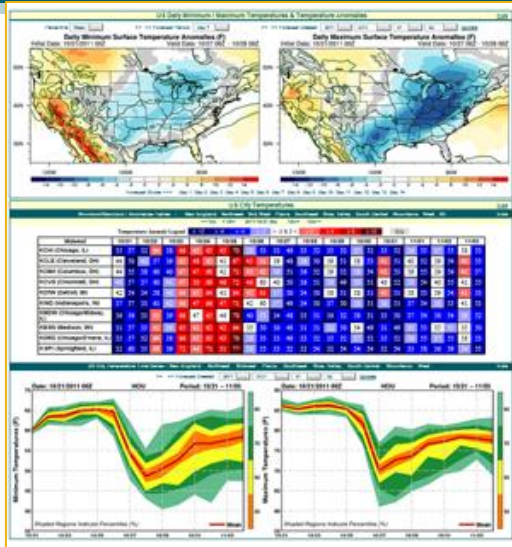# Ensemble Interpretation: Clustering Examples
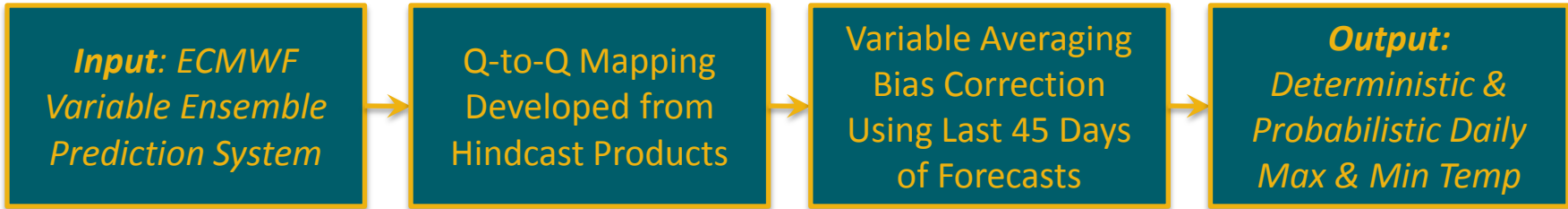
Tropical Cyclones: Major Hurricane Ophelia
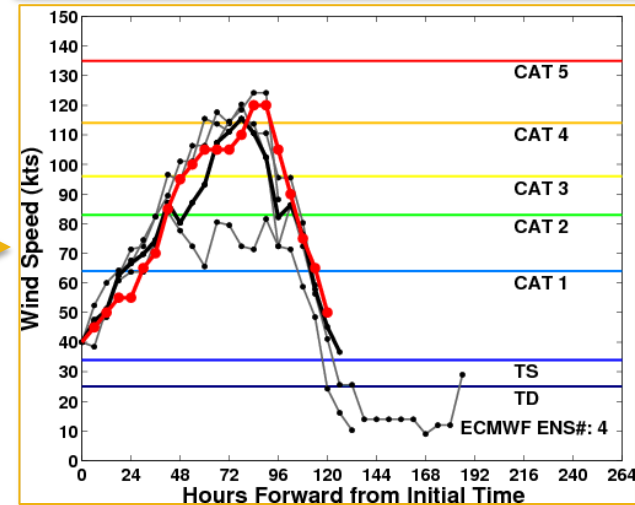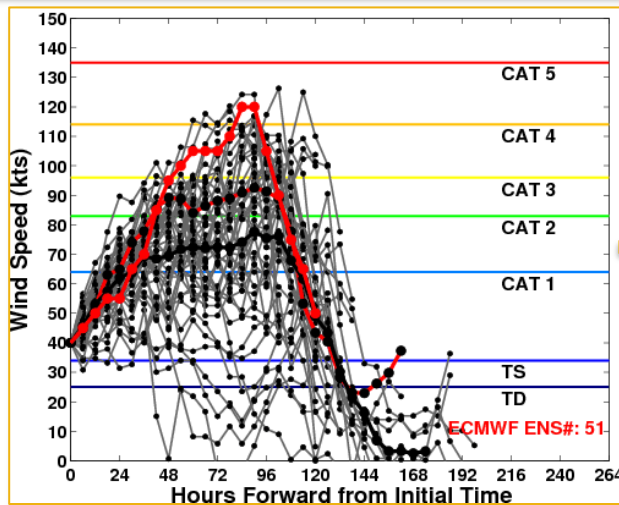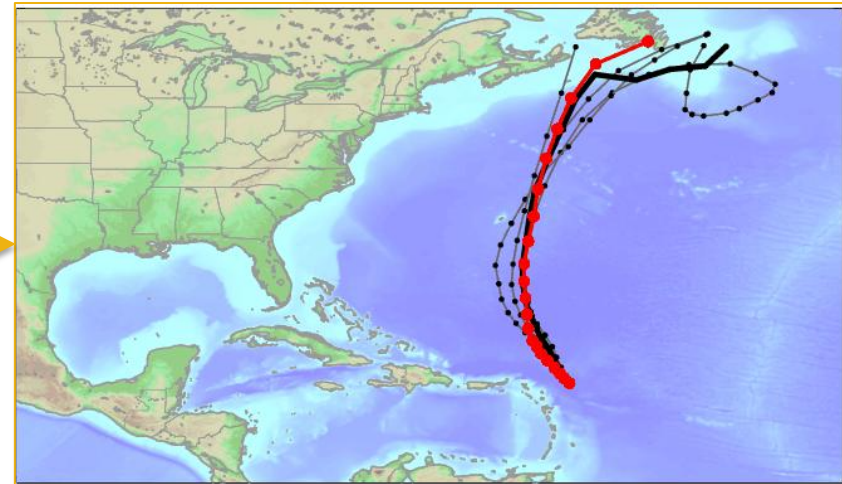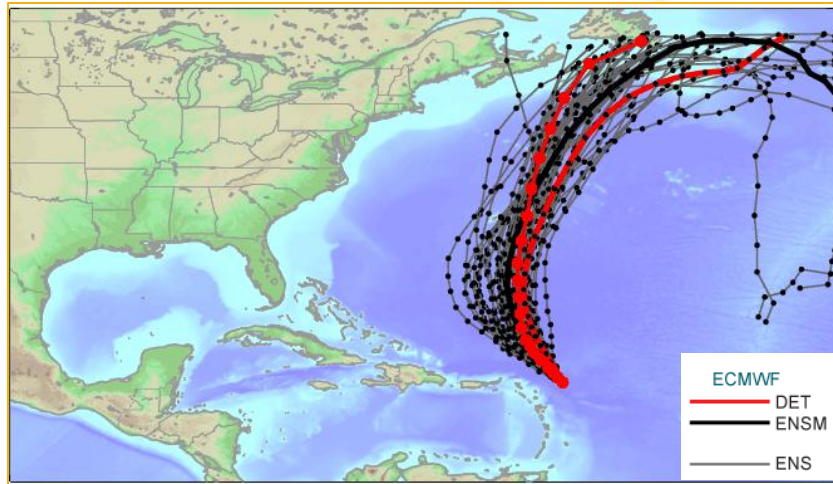
Clustering provides a more resolved forecast that ensemble mean when uncertainty (ensemble spread) is large

The CFAN Forecast Suite

15 Day

Tropical Cyclones

Monthly

Seasonal

U.S. Daily Temperature Forecasts

Input: ECMWF Variable Ensemble Prediction System → Q-to-Q Mapping Developed from Hindcast Products → Variable Averaging Bias Correction Using Last 45 Days of Forecasts → **Output:** Deterministic & Probabilistic Daily Max & Min Temp

Deterministic:

Daily Max/Min Temperature Forecasts for 105 U.S. Cities Based on Energy Trading Regions

Probabilistic:

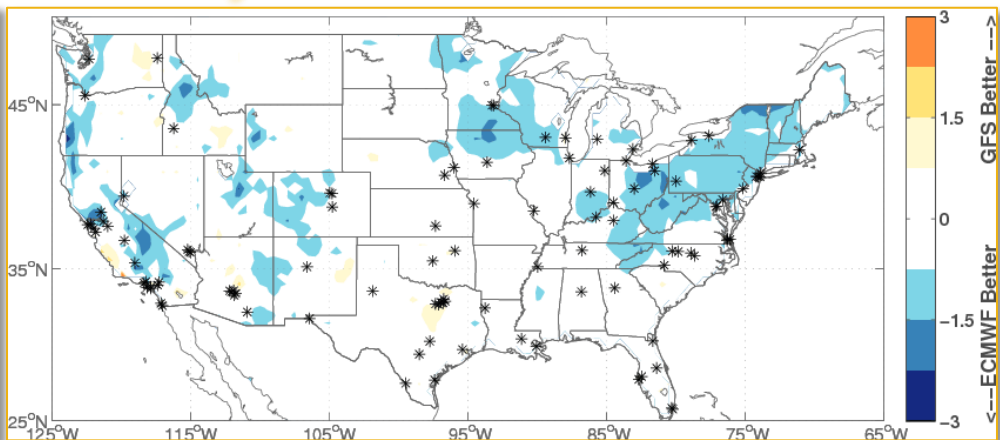Daily Max/Min Temperature Interpercentile Plumes for Each City

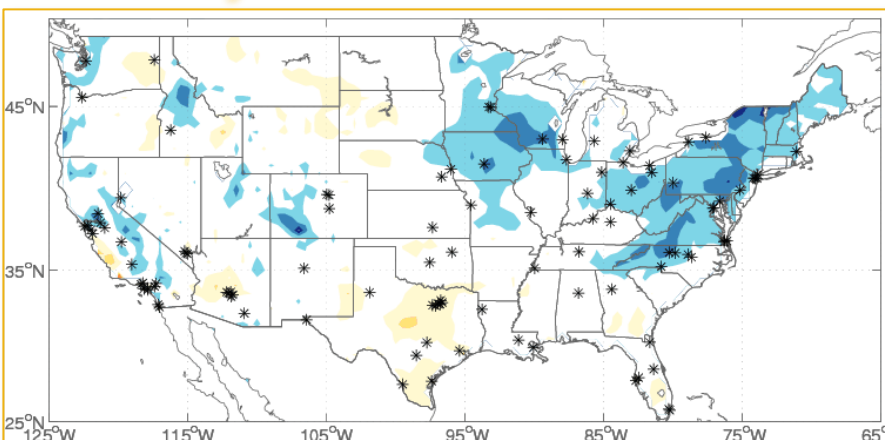# 15 Day: Comparison of ECMWF/GFS Temperatures

One Day Lead-Time
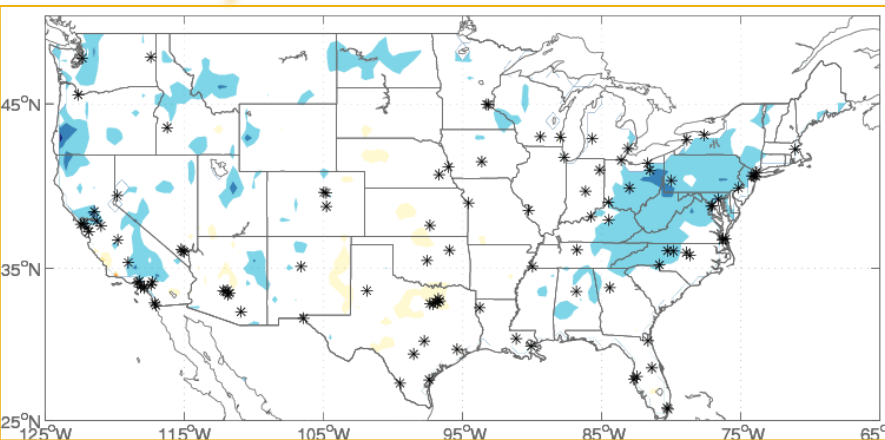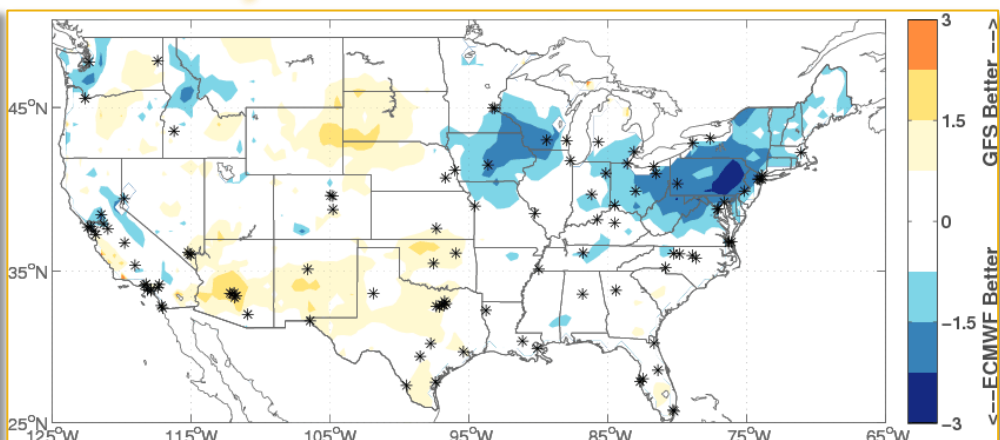
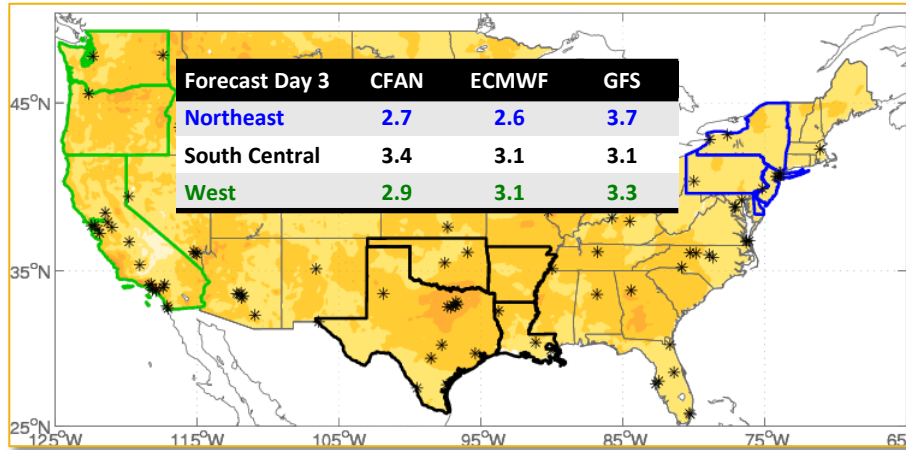**Three Day Lead-Time**

Five Day Lead-Time

Seven Day Lead-Time

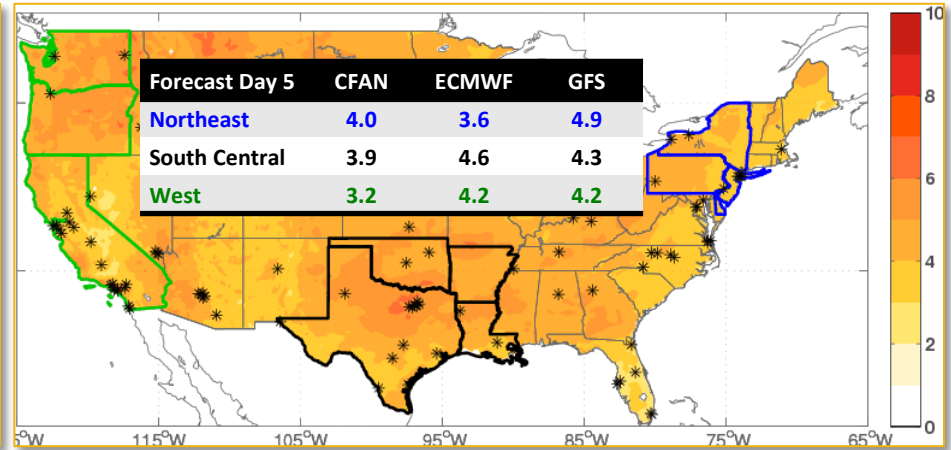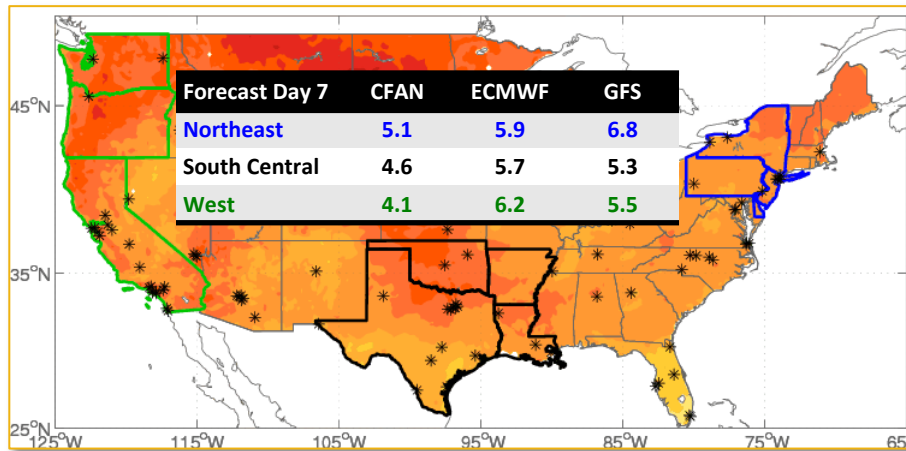*ECMWF shows better performance than GFS in regions with largest population*

Verification Period: 07/18 – 10/13/2011

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11/01/11

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CFAN 15 Day: MOS Performance

ECMWF Temperature Error Day 3

Forecast Day 3	CFAN	ECMWF	GFS
Northeast	2.7	2.6	3.7
South Central	3.4	3.1	3.1
West	2.9	3.1	3.3

ECMWF Temperature Error Day 5

Forecast Day 5	CFAN	ECMWF	GFS
Northeast	4.0	3.6	4.9
South Central	3.9	4.6	4.3
West	3.2	4.2	4.2

ECMWF Temperature Error Day 7

Forecast Day 7	CFAN	ECMWF	GFS
Northeast	5.1	5.9	6.8
South Central	4.6	5.7	5.3
West	4.1	6.2	5.5

ECMWF Temperature Error Day 10

Fore. Day 10	CFAN	ECMWF	GFS
Northeast	5.9	9.2	N/A
South Central	5.0	7.6	N/A
West	5.3	7.8	N/A
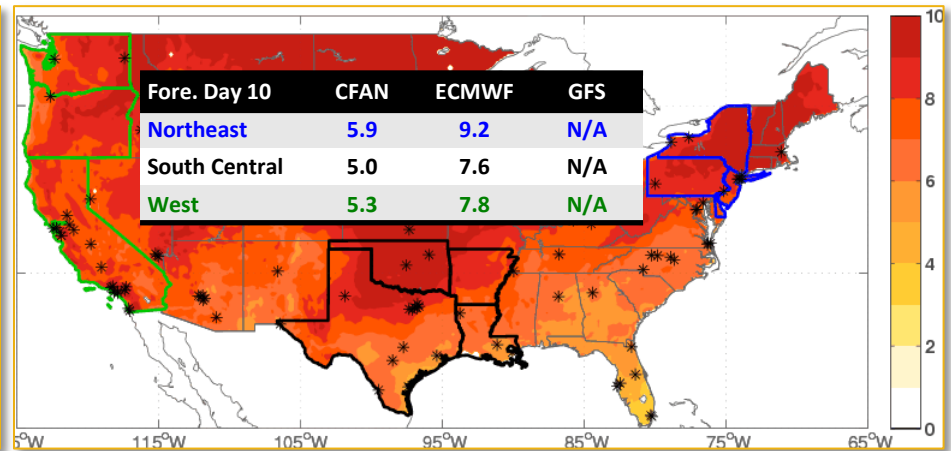
CFAN's MOS forecasts *outperform raw ECMWF and GFS forecasts*

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Regional CFAN MOS Root Mean Square Error (F) --> Average of all cities within a region

11/01/11

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CFAN Forecasts: 15 Day – Trading Decisions

CFAN MOS forecast caught the timing and severity of the NYC vicinity heat wave and it did it **over a week in advance**

LaGuardia Station MOS Forecast

	Days in Advance>	8	7	6	5	4	3	2	1
	˅Model								
7/21 Forecast	CFAN MOS (ECMWF)	97	95	97	95	97	99	98	99
	GFS Extended		91	91	94	93	92	93	95
	GFS						88	90	91
	NAM						88	91	88
7/22 Forecast	CFAN MOS (ECMWF)	97	98	99	103	105	104	104	104
	GFS Extended		94	96	96	98	97	98	98
	GFS						93	95	93
	NAM						96	97	96

Actual Temps

July 21st	
NYC	97
LGA	96
EWR	103

July 22nd	
NYC	104
LGA	104
EWR	108

"Although natural gas prices fell at most points across the country, likely as a result of a general lessening of the previous week's heat dome, the **Northeast saw significant price spikes during the week**."
*EIA Natural Gas Weekly Update*

Huge local market spike in New York around heat wave

Spot Prices ($ per MMBtu)	Thu. 14-Jul	Fri. 15-Jul	Mon. 18-Jul	Tue. 19-Jul	Wed. 20-Jul	Thu. 21-Jul	Fri. 22-Jul	Mon. 25-Jul
Henry Hub	4.42	4.49	4.60	4.60	4.64	4.58	4.46	4.45
New York	4.75	4.82	5.45	6.73	9.13	13.41	6.39	5.00

EIA Natural Gas Weekly Update
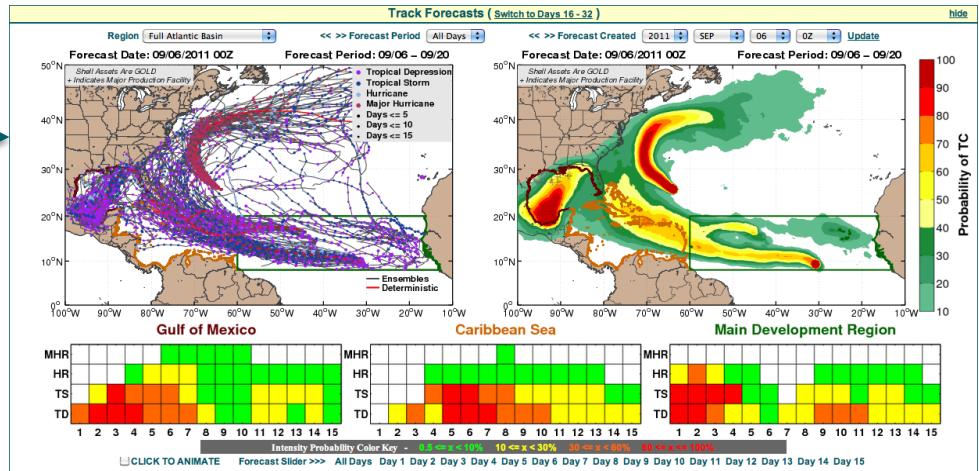
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Tropical Cyclones: 15-Day Forecasts

Forecast Summary and Regional Tropical Cyclone Risk Outlook
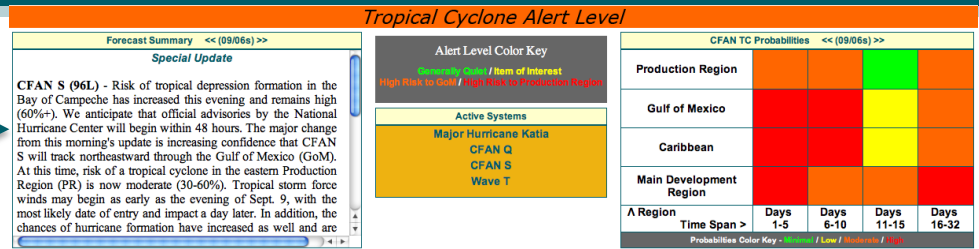
**Basin Wide ECMWF Ensemble Track and Intensity Forecasts**

Probabilistic guidance uses: ECMWF ensembles + Monte Carlo Resampling from ECMWF Hindcast TC Tracks

System Track and Intensity Model Guidance

Track forecasts corrected for initial position errors + mean along-track and cross-track bias

Intensity forecasts adjusted using initial intensity error + q-to-q mapping

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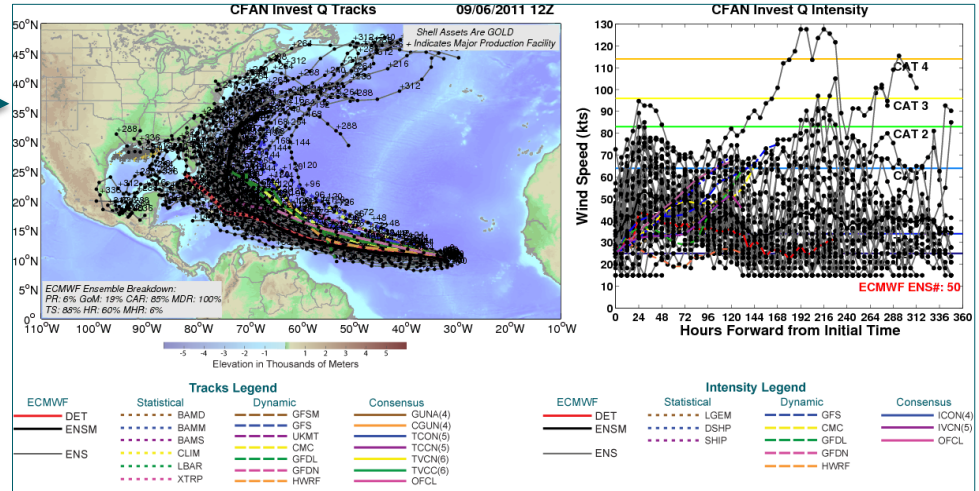
Tropical Cyclones: Forecast Skill of Regional Outlooks

Brier Skill Scores 2008-2011

Regions	Days 1-5	Days 6-10	Days 11-15
Production Region	**0.45 (0.47)**	**0.27 (0.14)**	0.08 (0.05)
Gulf of Mexico	**0.56 (0.39)**	**0.19 (0.19)**	-0.06 (0.03)
Caribbean	**0.55 (0.42)**	**0.25 (0.21)**	-0.10 (-0.09)
Main Develop. Region	**0.52 (0.38)**	**0.14 (0.22**)	-0.20 (-0.12)
All Regions	**0.52 (0.42)**	**0.21 (0.19)**	-0.07 (0.03)

Format: CFAN (ECMWF); **Statistically Significant Values at 90% level**
Note: Values > 0 Forecast Skillful Relative to Climatology

- CFAN has *outperformed ECMWF and climatology during the past four years for a majority of regions during Days 1-10*.

- CFAN performance relative to ECMWF is attributed to appropriately identifying periods of higher (lower) than normal predictability while accounting for systematic model tendencies/errors

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Tropical Cyclones: Genesis Forecasting

Large-Scale Environment (*Predict: Days 1-15+*)(e.g. low wind shear, high humidity, easterly waves, thermodynamic instability)

Internal Dynamics (*Predict: Days <2*) (e.g. vortical hot towers, MCV merger, convective processes)

Tropical Cyclone Genesis Prediction

- Satellite: Dvorak T-Numbers (Days < 2)
- Model forecast guidance for large-scale environment and easterly waves (Days 2+)

Initial Date: 08/28/2011 12Z   Hour: 012   Valid Date: 08/29/2011 00Z

Matthew (PGI46L)

Forecast Date: 08/28/2011 12Z   Forecast Period: 08/28 – 09/11

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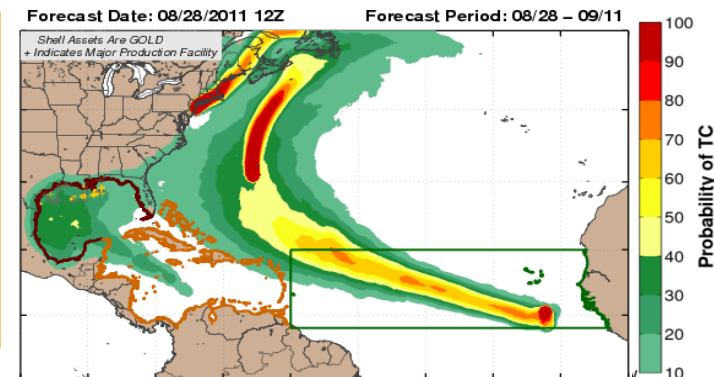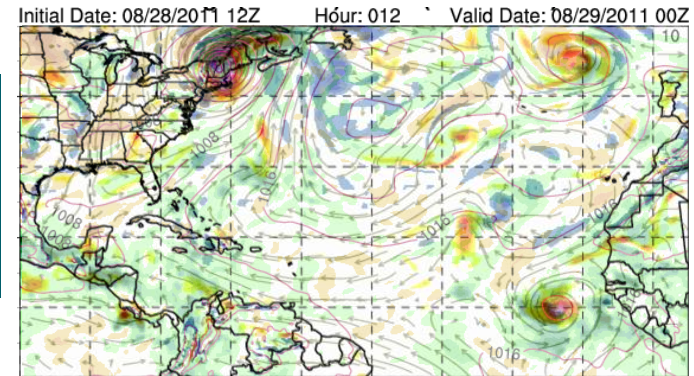
Tropical Cyclones: Genesis Forecast Performance

Tropical Cyclones	CFAN (in days) 30% (60%)	NHC (in days) 30% (60%)
TS Arlene	5.5 (0.5)	1.3 (0.3)
TS Bret	0.9 (0)	0.1 (0)
TS Don	9.4 (0.9)	4.9 (0.4)
TS Emily	5.5 (3.5)	3.5 (2.7)
TS Harvey	13.6 (6.6)	1.6 (0.6)
MHR Irene	6.2 (4.5)	1.5 (0.2)
TD 10*	7.9 (0)	0.9 (0)
MHR Katia	5.9 (2.9)	0.9 (0.9)
TS Lee	6.5 (3.0)	1.0 (0.5)
TS Maria	8.4 (1.4)	0.4 (0.4)
TS Nate	4.4 (1.4)	0.9 (0.4)
MHR Ophelia	8.6 (1.6)	2.1 (1.9)
HR Philippe	0.6 (0)	0.6 (0)
TS Rina	3.8 (2.8)	2.8 (0.6)

Table provides the number of days in advance
*Improper designation by NHC

Current: 2011	CFAN 30% (60%)	NHC 30% (60%)
All TCs	6.2 (2.1)	1.6 (0.6)

- TC genesis has been more predictable in 2011 compared to 2010

CFAN False Alarm Ratio

- 42% using moderate (30-60%) risk
- 13% using high (60%+) risk

Previous: 2010	CFAN 30% (60%)	NHC 30% (60%)
All TCs	4.1 (1.8)	1.6 (0.8)

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Tropical Cyclones: Forecast Performance

ECMWF Hindcast Tropical Cyclone Forecasts
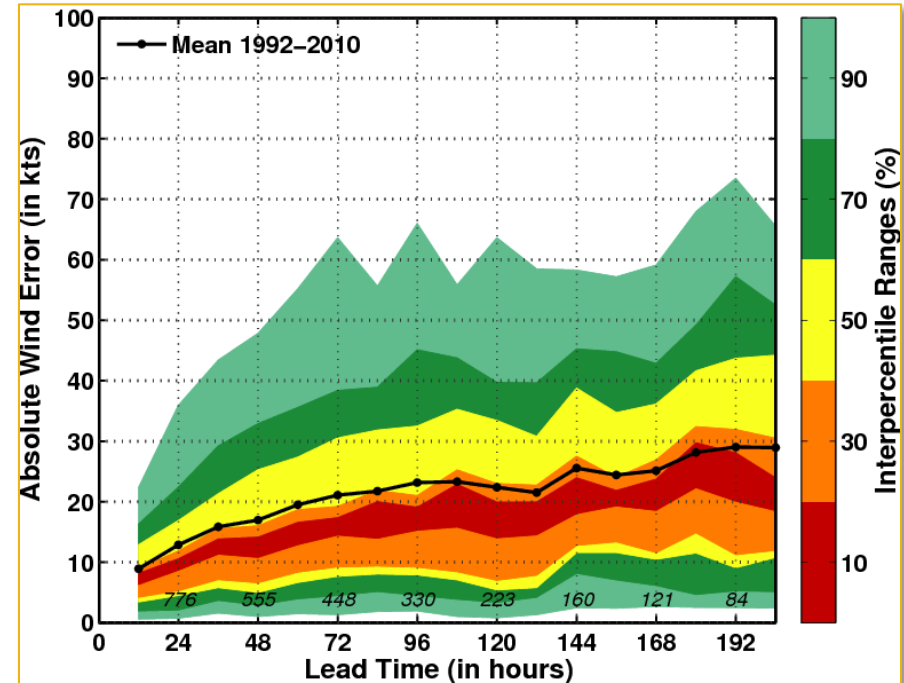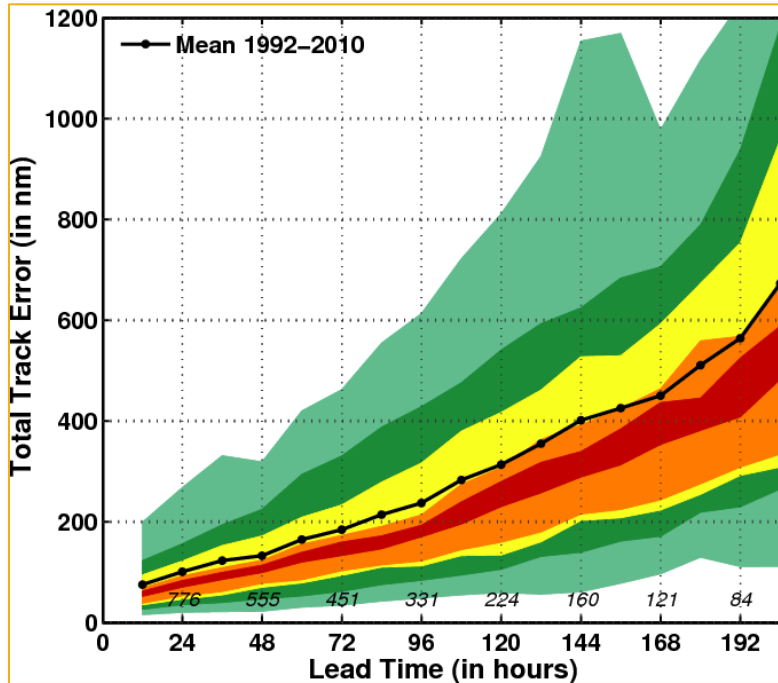
- ## Track errors become increasingly non-Gaussian at longer lead-times
  - ➢ Motivation to use all ensembles (maximum likelihood) versus ensemble mean

- ## Intensity errors grow rapidly during the first 72 hrs but level off around 20-25 kts
  - ➢ Similar performance to National Hurricane Center's intensity forecasts

Tropical Cyclones: Monthly Outlooks

Input: ECMWF Monthly Forecast and Hindcasts	Determine prob. bias-correction from model and obs. climate	Bias-track adjustment for TCs forming in the eastern Atlantic	**Output:** Bias-corrected track density probabilities and anomalies
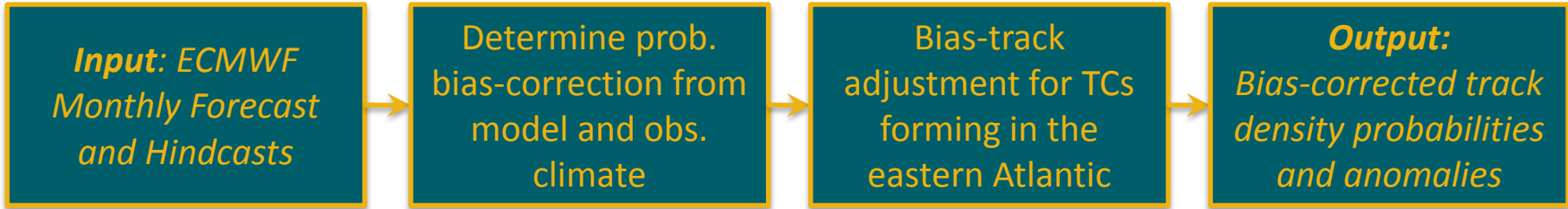
ECMWF Forecast - Climatology
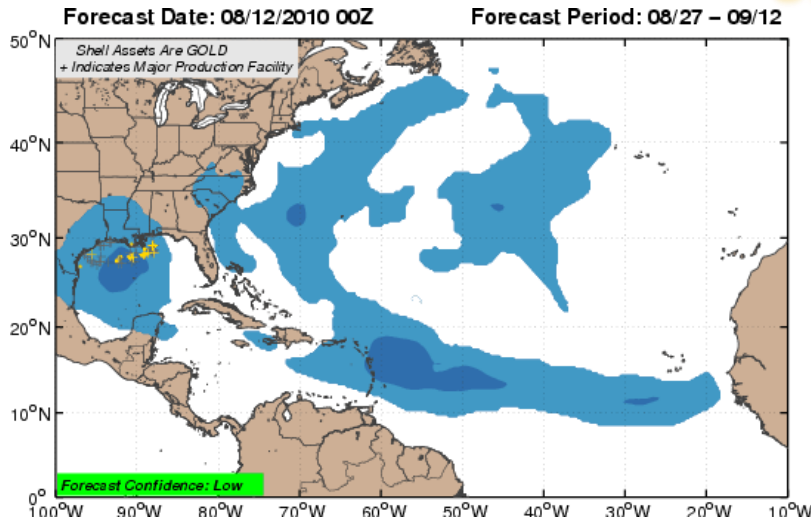
Hindcast-Calibrated Forecast
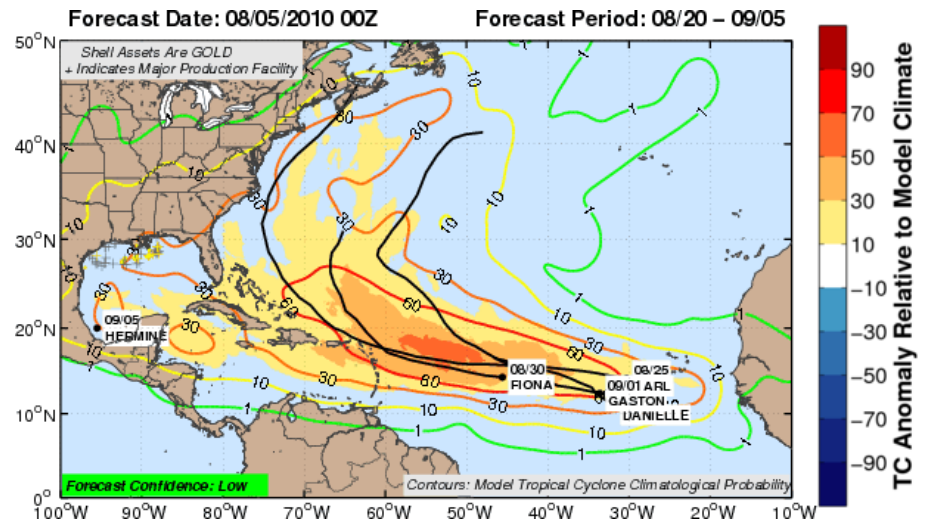
Observed Tropical Cyclones in Black

Forecast confidence assigned based on phase and amplitude of the Madden-Julian Oscillation

U.S. Heat Wave Monthly Forecasts

Input: *ECMWF Monthly Forecast and Hindcasts* → Theoretical Extreme Value Distribution from Hindcast Products → **Output:** *Probabilistic Extreme Temperature and Heat Wave Forecast*

Heat Wave Probability:

- Weekly forecast for each City
- Daily estimates for each city
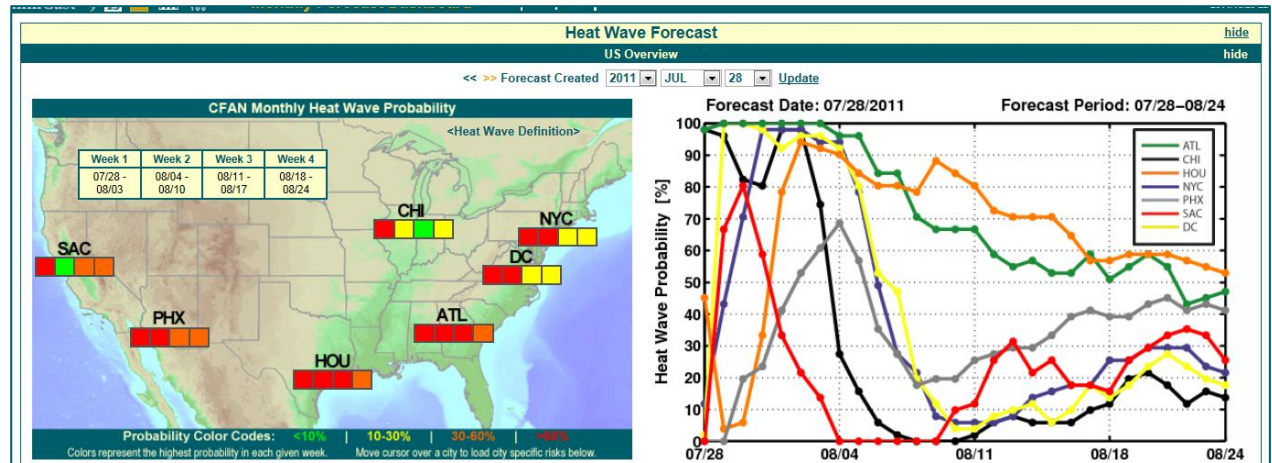
Daily Anomalous Temperature:

 - Interpercentile plumes for each city
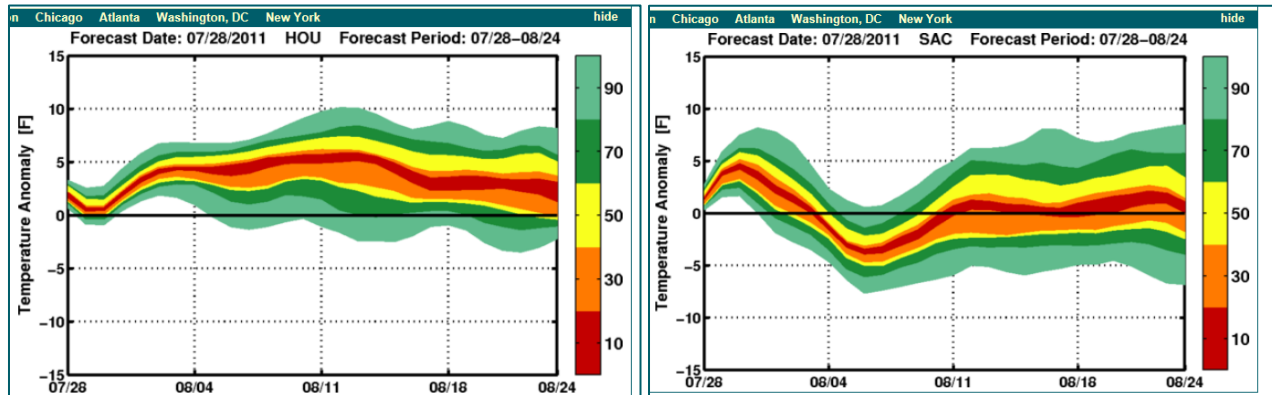
Heat Wave Forecast Performance: Summer 2011

Theoretical Extreme Value Distribution from Hindcast Products

Heat Wave

75th Quantile

Heat Wave Probabilistic Forecast
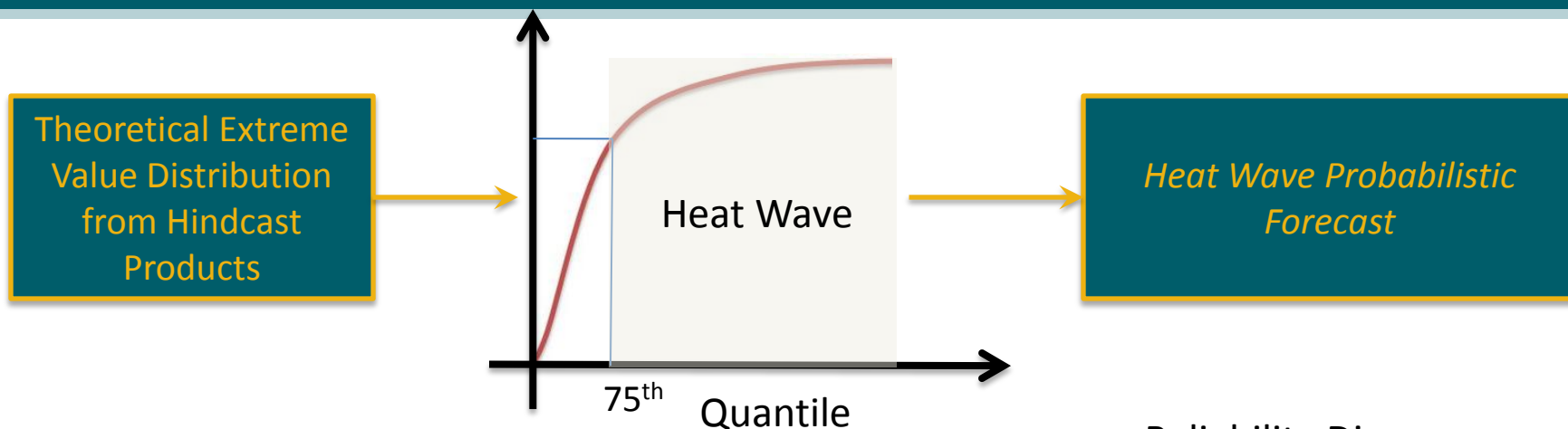
Heat Wave Probability:

- Verification Period: June – Oct. 2011
- For both lead periods, CFAN underforecasts the observed heat wave occurrence
- Extreme events forecasts are generally more reliable

Reliability Diagram

- 1–14 Days
- 15–28 Days

Observation Frequency

Forecast Probability

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Forecast Product:

- ACC > 0.3 - statistically significant at 95% confidence level

- Temperature error levels off to 5-7F after the first 2 weeks
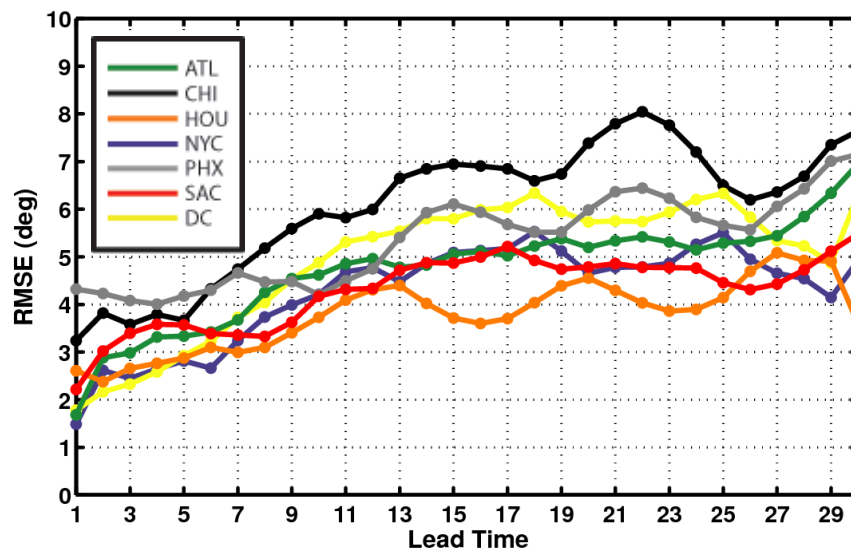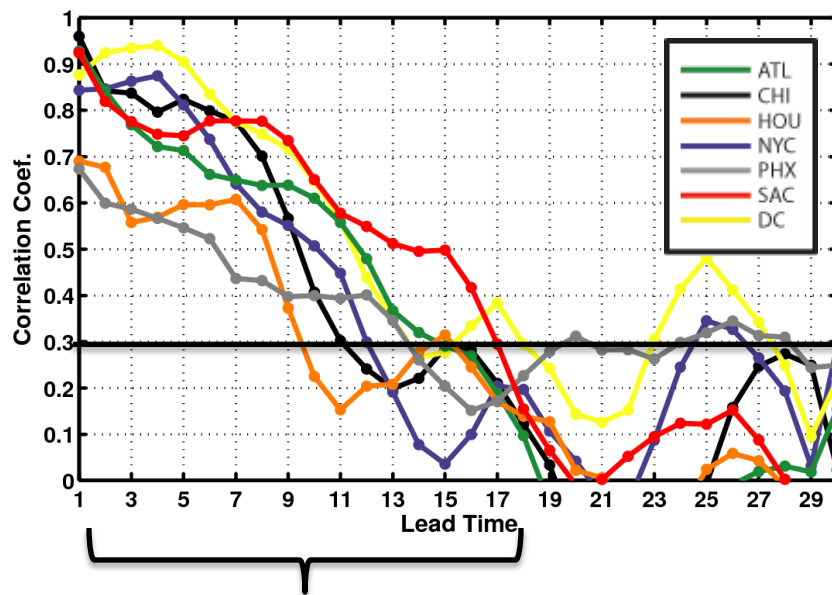
Monthly Temperature Forecast: Summer 2011
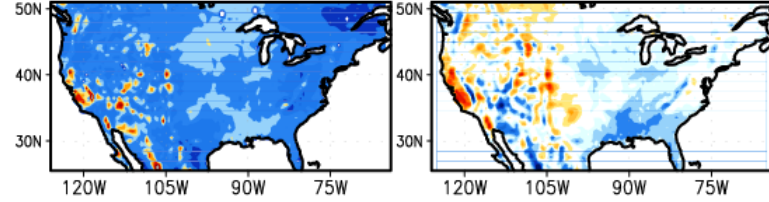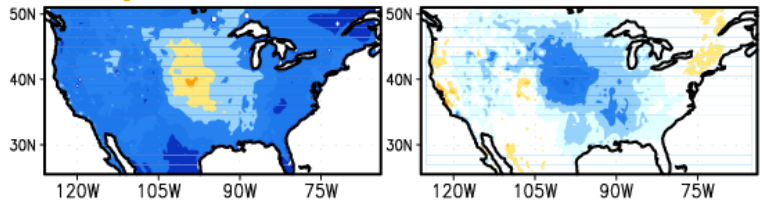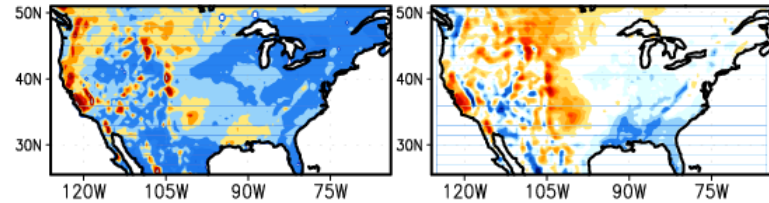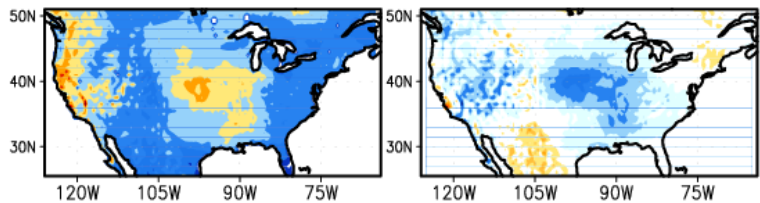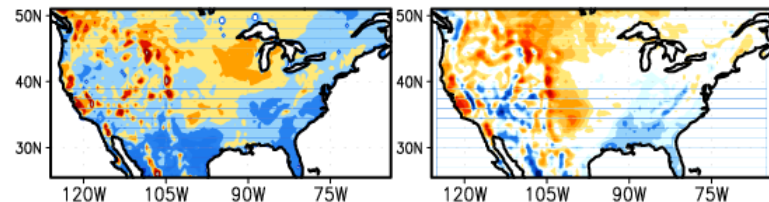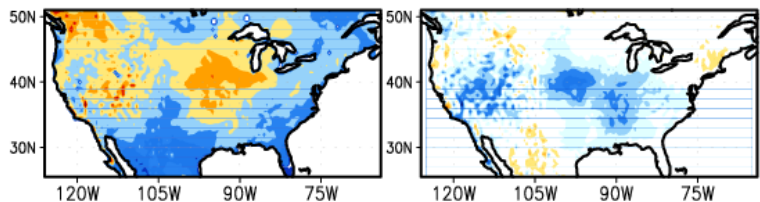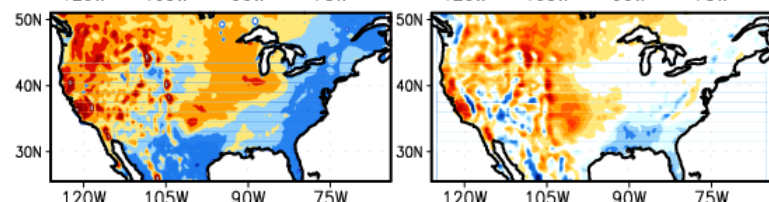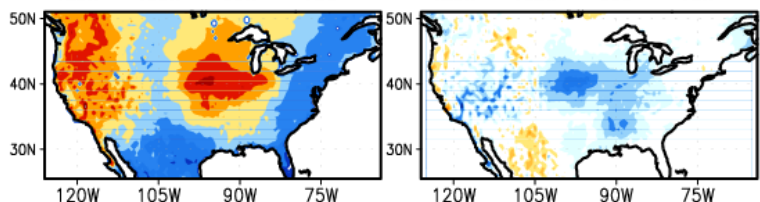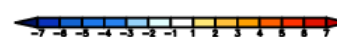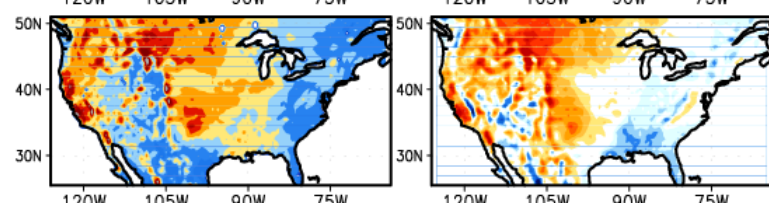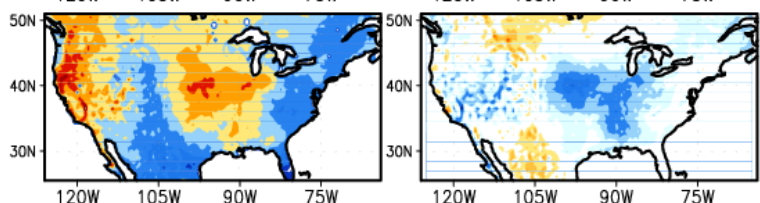
07/07 7am CDT

CFAN Monthly Forecast captures major heat wave due 7/17-7/21 over vast area of US

5-Day Surface Temperature Anomalies (F)
Initial Date: 07/07/2011 00Z   Valid Date: 07/17 - 07/21

Forecast Date: 07/07/2011   HOU   Forecast Period: 07/07–08/03
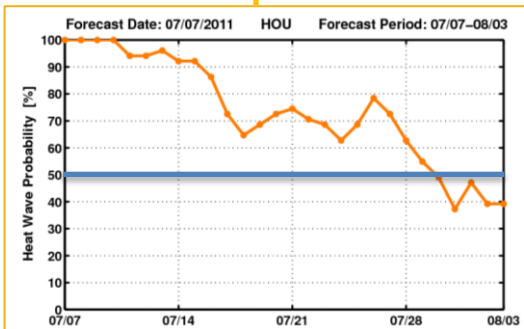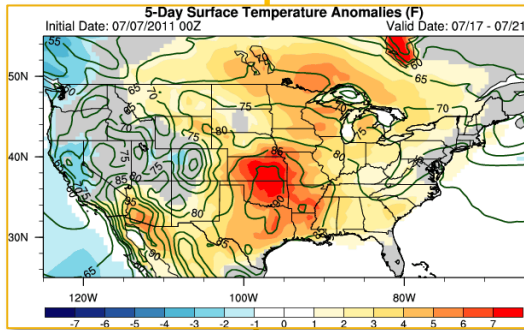
Natural Gas August Futures   7/7 - 7/22 (Daily Average)

Market rises due to forecast heat wave

"…Natural gas prices responded as a "heat dome" spread across much of the United States, bringing temperatures into the triple digits in many areas.…" *EIA Natural Gas Weekly Update*
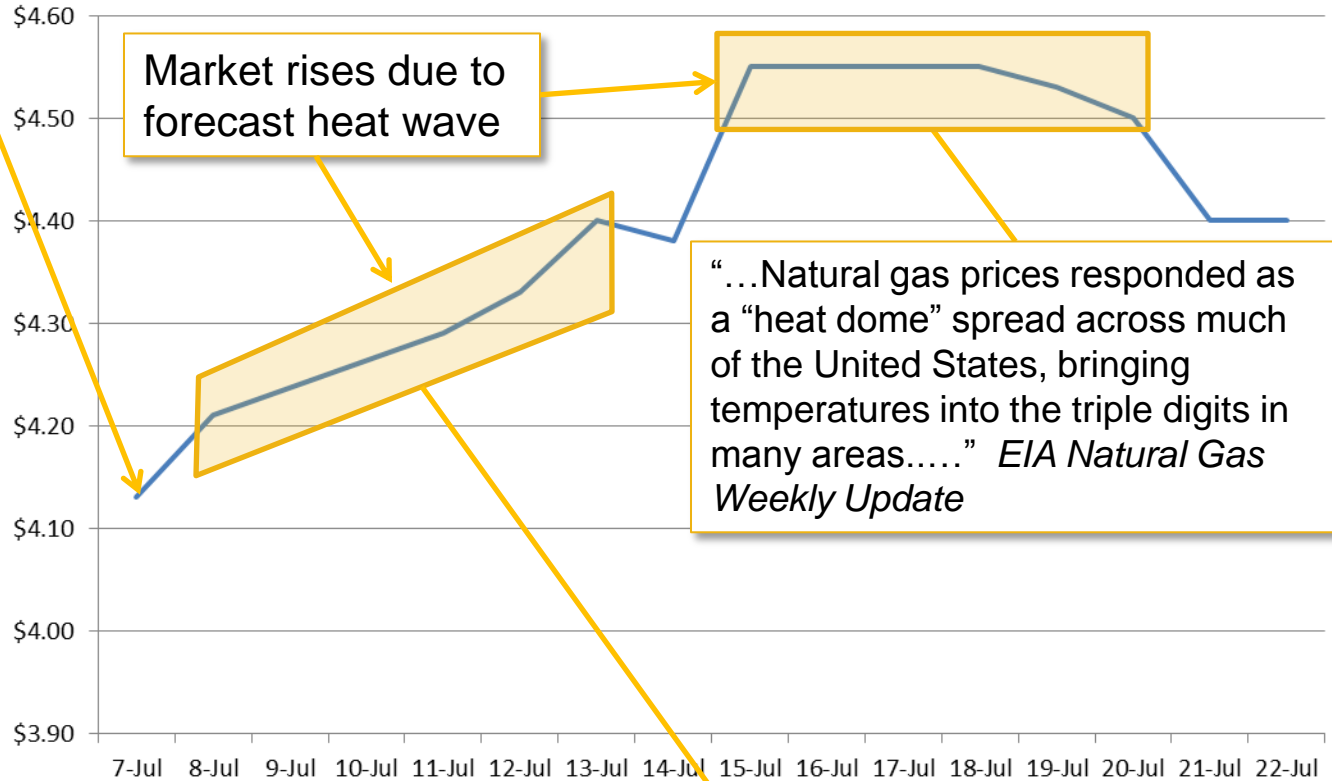
"Since last Thursday, expectations of higher temperatures with rising cooling load has likely been the chief catalyst propelling futures to a string of four consecutive days of price gains accounting for the bulk of the week's price increase." *EIA Natural Gas Weekly Update*

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Seasonal Forecast: Clustering Examples

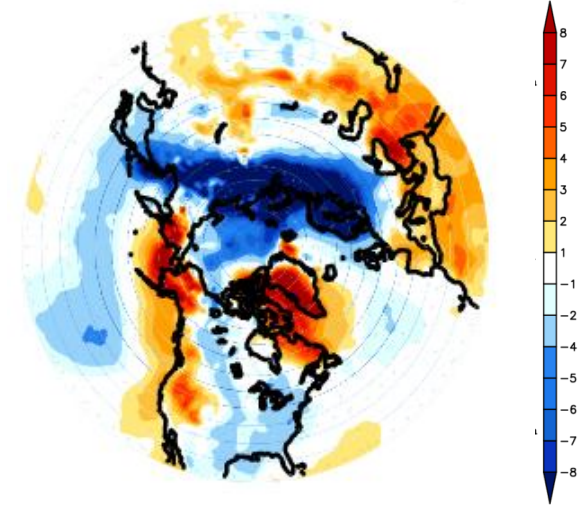**Clustering analysis based on Northern Hemisphere 500 hPa geopotential height**
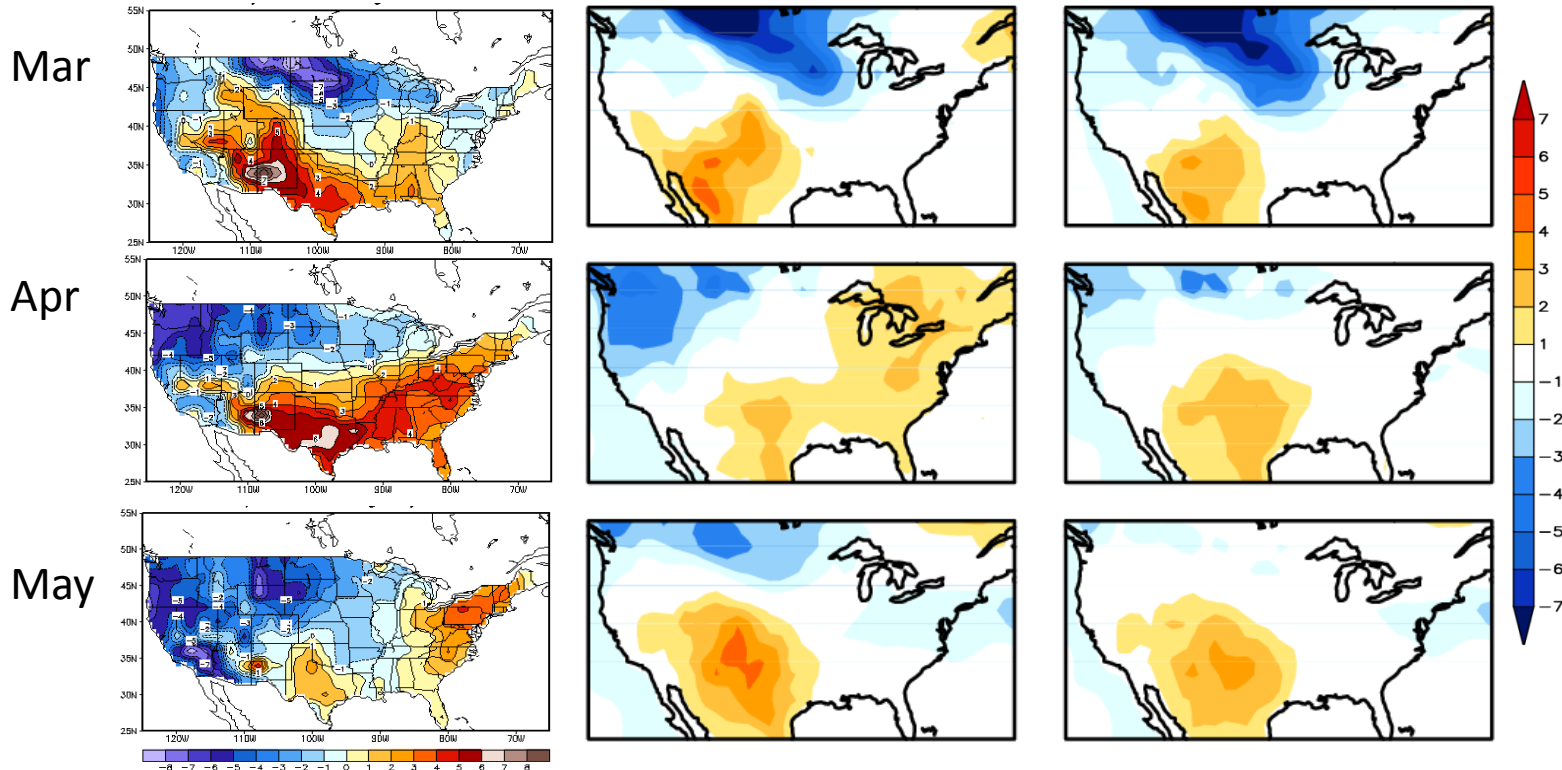
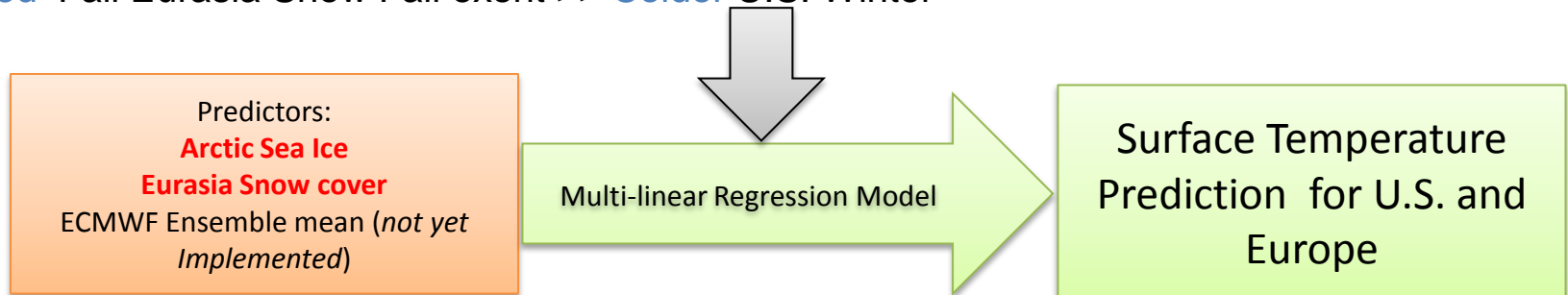# Seasonal: Improving Winter Forecast Skill

**Winter Temperature regressed on
Fall Arctic Sea Ice**
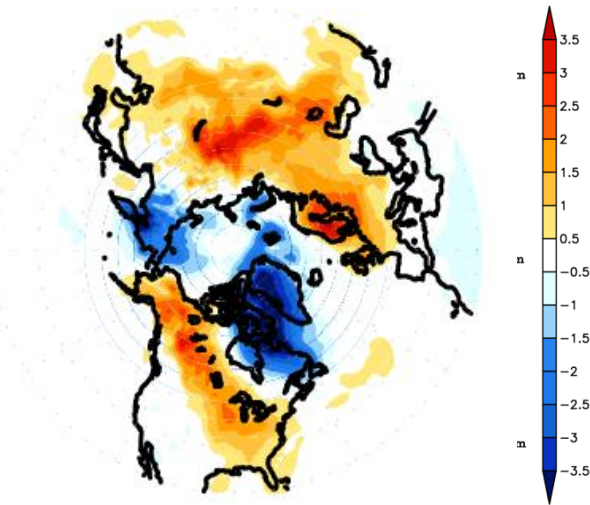
**Winter Temperature regressed on
Fall Eurasia Snow Cover**

- Arctic sea Ice extent and snow cover impact mid-latitudes surface temperatures [Liu & Curry, 2011, Cohen & Saito, 2003, etc.]

- Reduced Fall Sea Ice cover >> Colder U.S. Winter

- Increased Fall Eurasia Snow Fall exent >> Colder U.S. Winter

Predictors:
Arctic Sea Ice
Eurasia Snow cover
ECMWF Ensemble mean (*not yet Implemented*)

Multi-linear Regression Model

Surface Temperature Prediction for U.S. and Europe

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Regression Model Evaluation

Correlations between Observed and Forecasted Temperatures (1981-2010)
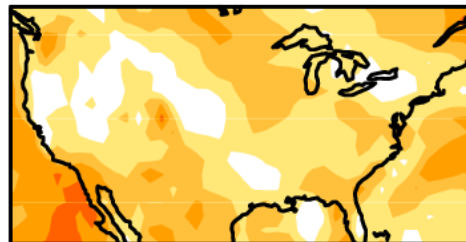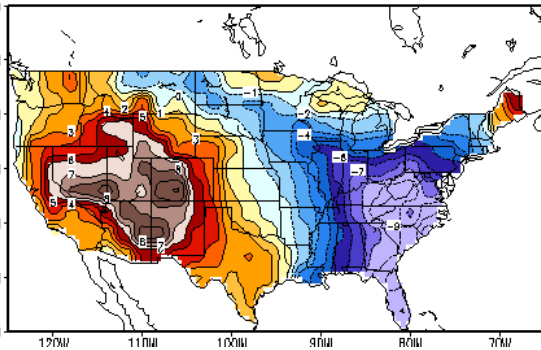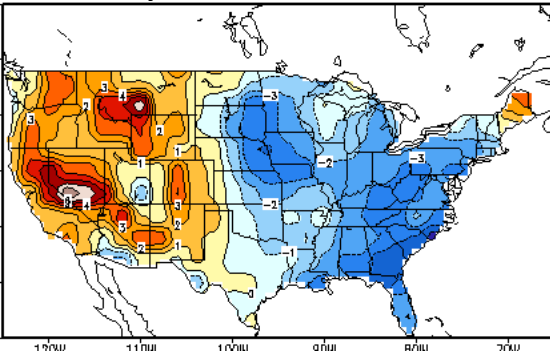
Seasonal: Winter 2010 Example

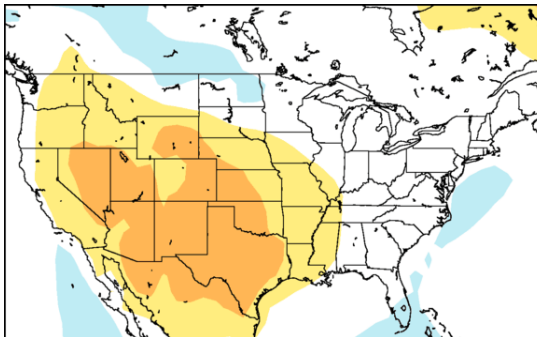Observations | ECMWF System 3 | Forecast using September 2010 Arctic Sea Ice and Snow Cover
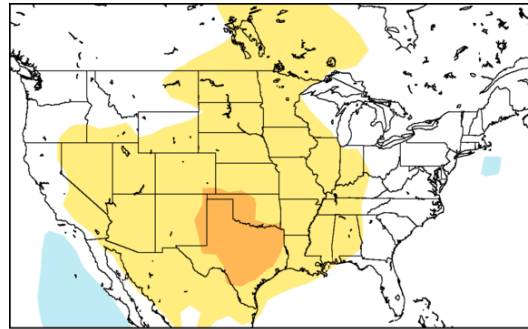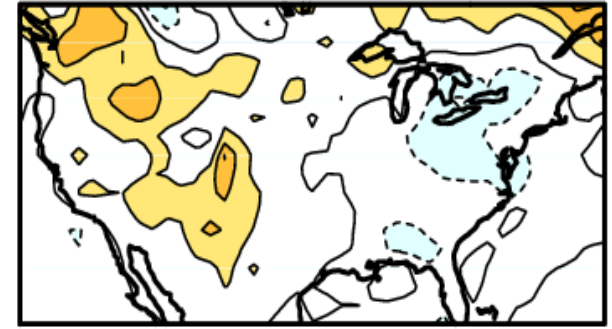
December · January | IC Nov 2010 Fcst for Dec · IC Dec 2010 Fcst for Jan | Fcst for Dec · Fcst for Jan
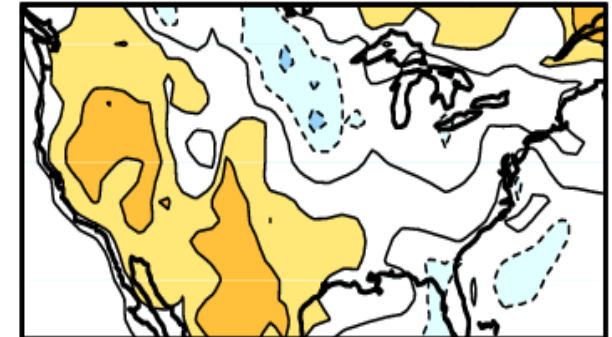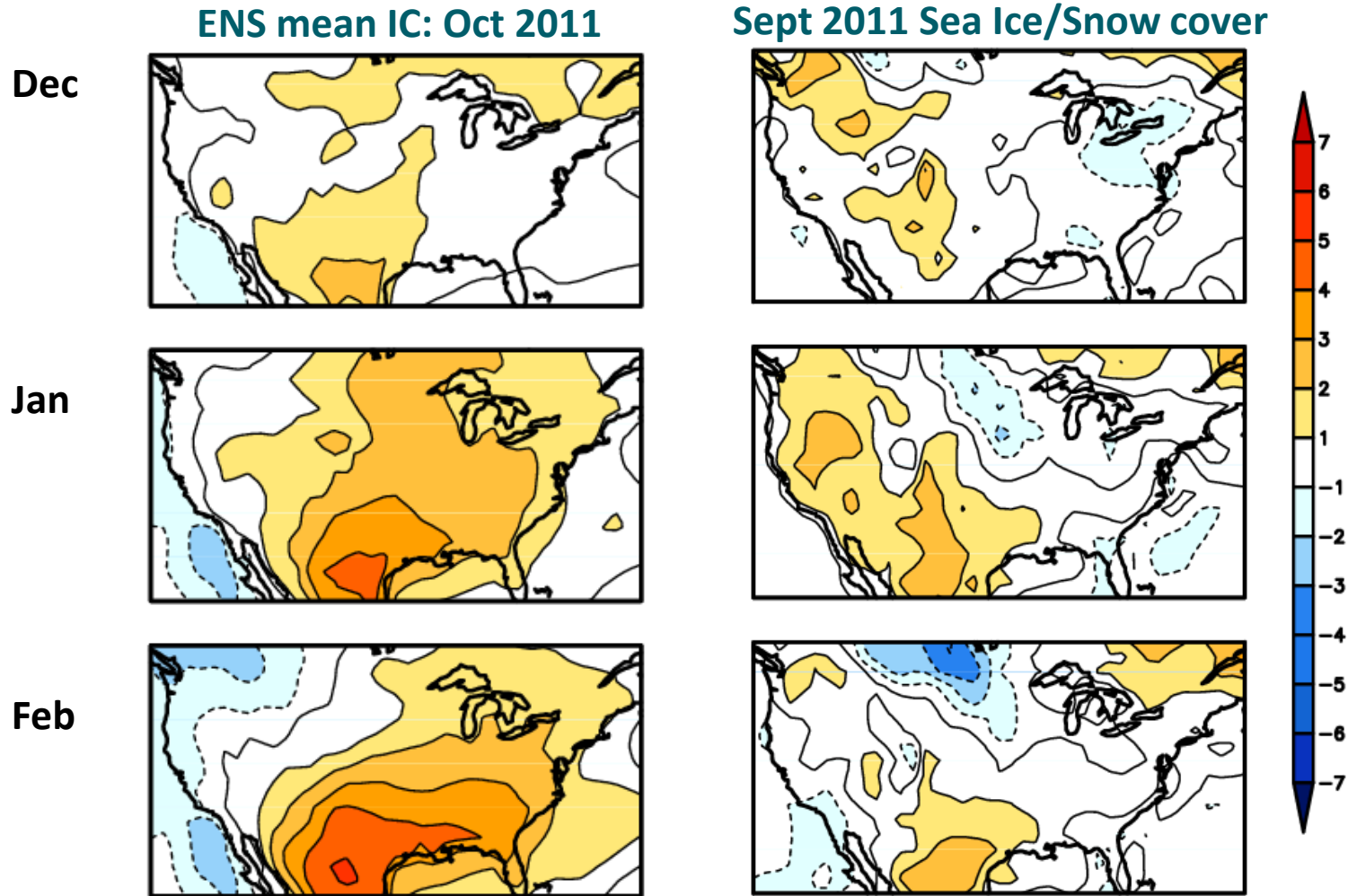
- **A combined statistical forecast (EC ens. mean/Arctic predictors) will improve model skill when the arctic patterns are dominant**

Seasonal: Winter 2011 Temperature Statistical Forecast

ENS mean IC: Oct 2011

Sept 2011 Sea Ice/Snow cover

Dec

Jan

Feb

- **For September 2011, both Arctic Sea Ice and Eurasia snow levels are <u>very close to 2010 levels</u>, resulting in a very similar surface temperature prediction**

Georgia Tech

Summary

- ECMWF forecasts are fundamental components to several CFAN products on daily to seasonal time scales

- Statistical rendering and ensemble interpretation is made possible through the use of ECMWF hindcast products
  - ➤ More frequent hindcast products or larger hindcast ensemble would be very beneficial

- Energy traders are well-equipped to use and interpret probabilistic forecast guidance
  - ➤ Forecast skill of ECMWF products relative to other model guidance provides market trading opportunities