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**
- Intraseasonal (Days 16-32)
  - ECMWF Monthly Forecast System

**Tactical/Strategic**
- Medium Range (Days 1-15)
  - ECMWF Ensemble Prediction System (EPS)
- Seasonal (Months 1-7)
  - ECMWF System 3 Ensemble Forecast

**Strategic**
- 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
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

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**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

ECMWF shows better performance than GFS in regions with largest population

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

11/01/11
CFAN’s MOS forecasts outperform raw ECMWF and GFS forecasts.

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

<table>
<thead>
<tr>
<th>Actual Temps</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 21st</td>
</tr>
<tr>
<td>NYC</td>
</tr>
<tr>
<td>LGA</td>
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<tr>
<td>EWR</td>
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<tr>
<td>July 22nd</td>
</tr>
<tr>
<td>NYC</td>
</tr>
<tr>
<td>LGA</td>
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<tr>
<td>EWR</td>
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<table>
<thead>
<tr>
<th>LaGuardia Station MOS Forecast</th>
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</thead>
<tbody>
<tr>
<td>Days in Advance&gt;</td>
</tr>
<tr>
<td>vModel</td>
</tr>
<tr>
<td>7/21 Forecast</td>
</tr>
<tr>
<td>CFAN MOS (ECMWF)</td>
</tr>
<tr>
<td>GFS Extended</td>
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<tr>
<td>GFS</td>
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<tr>
<td>NAM</td>
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<tr>
<td>7/22 Forecast</td>
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<tr>
<td>CFAN MOS (ECMWF)</td>
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<tr>
<td>GFS Extended</td>
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<td>GFS</td>
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<tr>
<td>NAM</td>
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<table>
<thead>
<tr>
<th>Spot Prices</th>
<th>Thu</th>
<th>Fri</th>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
<th>Fri</th>
<th>Mon</th>
</tr>
</thead>
<tbody>
<tr>
<td>($ per MMBtu)</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Henry Hub</td>
<td>4.42</td>
<td>4.49</td>
<td>4.60</td>
<td>4.60</td>
<td>4.64</td>
<td>4.58</td>
<td>4.46</td>
<td>4.45</td>
</tr>
<tr>
<td>New York</td>
<td>4.75</td>
<td>4.82</td>
<td>5.45</td>
<td>6.73</td>
<td><strong>9.13</strong></td>
<td><strong>13.41</strong></td>
<td>6.39</td>
<td>5.00</td>
</tr>
</tbody>
</table>

EIA Natural Gas Weekly Update
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
## Tropical Cyclones: Forecast Skill of Regional Outlooks

### Brier Skill Scores 2008-2011

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

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
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+)
### Tropical Cyclones: Genesis Forecast Performance

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

#### Current: 2011

<table>
<thead>
<tr>
<th>CFAN 30% (60%)</th>
<th>NHC 30% (60%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All TCs</td>
<td>6.2 (2.1)</td>
</tr>
</tbody>
</table>

#### Previous: 2010

<table>
<thead>
<tr>
<th>CFAN 30% (60%)</th>
<th>NHC 30% (60%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All TCs</td>
<td>4.1 (1.8)</td>
</tr>
</tbody>
</table>

- 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

*Table provides the number of days in advance

*Improper designation by NHC

11/01/11
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

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**ECMWF Forecast - Climatology**

*Forecast Date: 08/12/2010 00Z*

*Forecast Period: 08/27 – 09/12*

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**Hindcast-Calibrated Forecast**

*Forecast Date: 08/05/2010 00Z*

*Forecast Period: 08/20 – 09/05*

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Observed Tropical Cyclones in Black

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

11/01/11
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 Probability:
- Verification Period: June – Oct. 2011
- For both lead periods, CFAN underforecasts the observed heat wave occurrence
- Extreme events forecasts are generally more reliable
City Temperature Forecast Performance: Summer 2011

Forecast Product:

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

- Temperature error levels off to 5-7F after the first 2 weeks
CFAN Forecasts: Monthly – Trading Decisions

07/07 7am CDT
CFAN Monthly Forecast captures major heat wave due 7/17-7/21 over vast area of US

Natural Gas August Futures 7/7 - 7/22 (Daily Average)

Market rises due to forecast heat wave

"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

"…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
Cluster analysis based on Northern Hemisphere 500 hPa geopotential height

IC: March 2011

<table>
<thead>
<tr>
<th>Observation</th>
<th>High Predictability Cluster</th>
<th>Ens. mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td></td>
<td></td>
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<tr>
<td>May</td>
<td></td>
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</tbody>
</table>
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 extent >> **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
Regression Model Evaluation

Correlations between Observed and Forecasted Temperatures (1981-2010)

Forecast Using **September** Predictors

Forecast Using **October** Predictors

Forecast Using **November** Predictors

Dec

Jan

Feb
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

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