High-Resolution Weather Products to Enhance Energy Load Forecasting

NOAA Alternative Climate Normals Workshop

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NASA APPLIED SCIENCES PROJECT

Recent project explored applications of NASA products to meet the needs of energy companies for both short- and long-term planning

Short-term forecasting: Compared energy utility load forecast results with and without NASA satellite weather data. Conducted operational real-time testing, fine tuned results, and documented the benefits.

Climate Change Investigation: Assessed NASA climate data, model products, and projections to identify those of potential value to utilities for long-term (seasonal to 40 years) planning.

LONGER-TERM PLANNING

- Changes in climate could alter key parameters:
  - Base Planning Temperature
    - Will the coldest winter day be similar to decades past?
    - Will summer temperatures exceed records?
    - Will daily temperature profiles change?
  - Maintenance and installation of infrastructure
    - Equipment may be running warmer all year
    - Corrosion and decay accelerated by warmer or wetter conditions
    - Increased storm damage
    - Pipeline issues (temperatures, extreme events, permafrost)
    - Gas storage impacts
  - Renewables
    - Changes in seasonal volume/timing of hydropower resources
    - Changes in solar and wind
    - Policies are expected to require a greater percentage of renewables – and therefore improved forecasting
  - Behavior and population shifts

NASA PRODUCTS

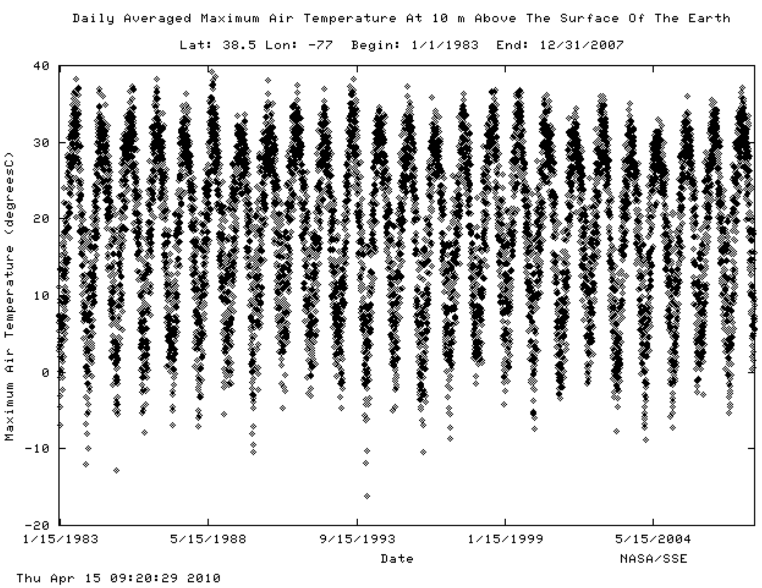
- NASA, directly and through partners, makes data available on many weather and climate related topics:
  - Climate model outputs, predicting future changes in climate based upon historical data and current observations
  - Observations of weather and hydrological parameters on a finer grid than ground-based data:
    - Temperature
    - Precipitation
    - Wind direction and speed
    - Solar strength
    - Snowpack
  - Many parameters available historically (to 25 years), near-real-time, and as forecasts

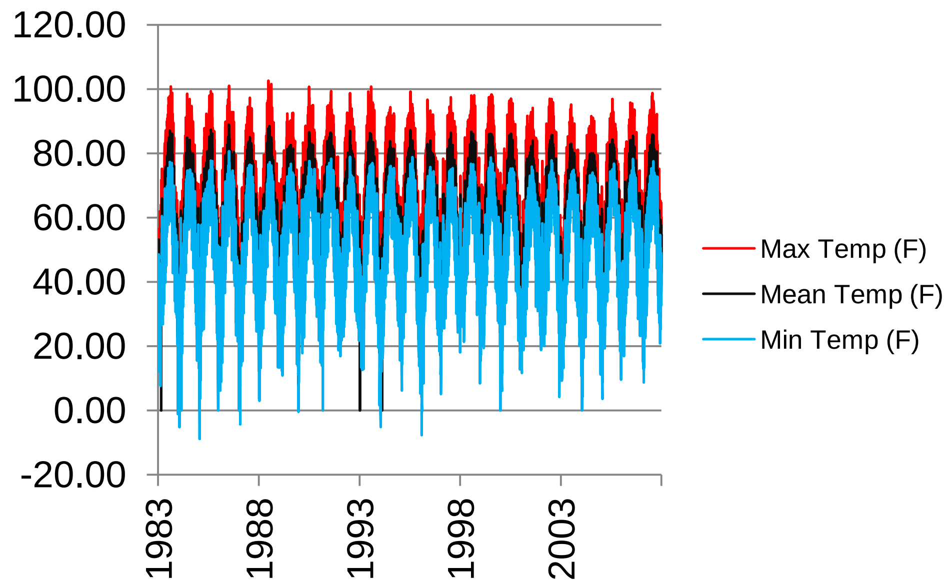
LONGER-TERM PLANNING

- Interviewed representatives of 10 energy companies around the U.S. about the way climate change may impact them, considering:
  - **Energy demand**
  - **Operation/infrastructure**
  - **Regulatory changes**
- Developed three example case studies for discussion
  - **Temperature**
  - **Groundwater**
  - **Snowpack**

TEMPERATURE EXAMPLE

- Global mean temperatures are expected to rise 2-11.5 °F by 2100 (compared to 1980-1990)
  - North America is expected to warm MORE than average
  - Weather patterns are expected to be increasingly variable
- NASA temperature data are available from 1983 to present
  - Daily max, min, and average back to 1983 (Hourly for recent years)
  - Resolution of at least one degree (lat x lon, or ~100km) or finer

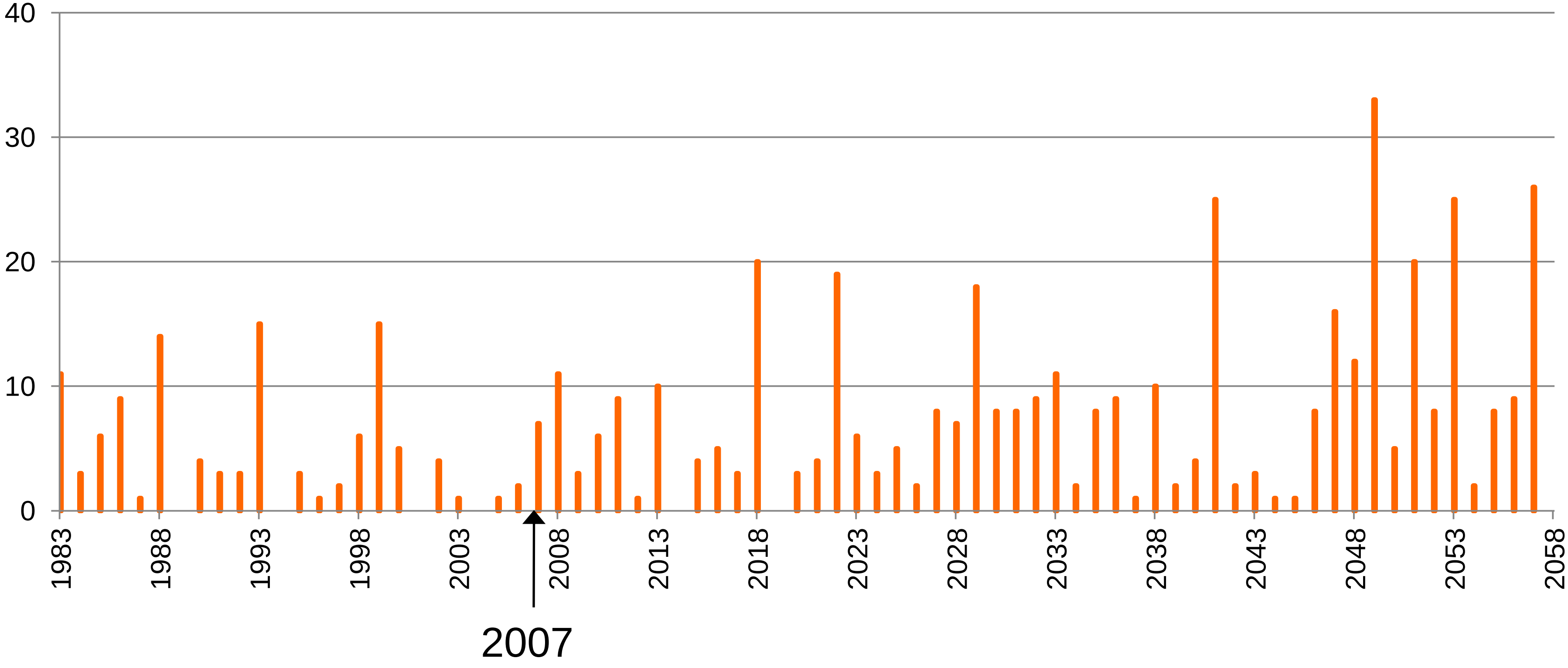




TEMPERATURE EXAMPLE

- Detailed NASA temperature records can be combined with climate models to project temperature trends into the future

Number of Days per Year with a Predicted Maximum Temperature Above 95 F (post-2007 points are modeled)



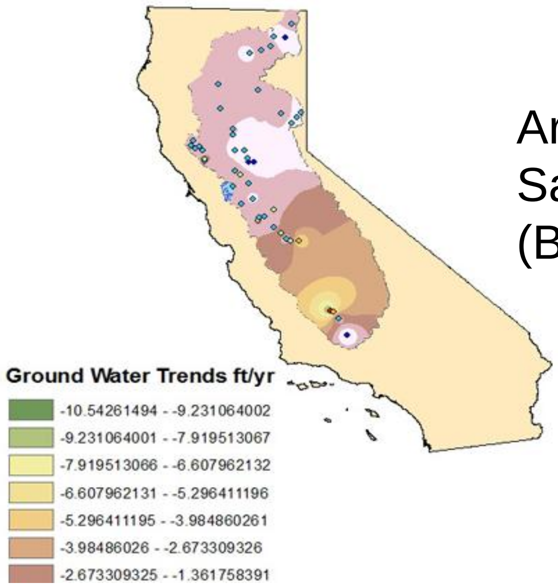
GROUNDWATER EXAMPLE

- Water resources are essential for some energy production technologies like Concentrating Solar Power (CSP)
- CSP is difficult to site because it requires:
  - Strong solar resources
  - Adequate water supply
- Many sites that are attractive for solar lack adequate surface waters, but may have available groundwater

NREL.GOV

GROUNDWATER EXAMPLE

- The Gravity Recovery and Climate Experiment (GRACE) satellite detects the presence and volume of groundwater through variations in Earth's gravity
- Ground-based groundwater measurements are limited
- GRACE data can supplement ground-based data to better assess groundwater locations, volumes, and trends
  - GRACE provides improved spatial and temporal resolution



Areas of Groundwater Decline in the Sacramento-San Joaquin River Basins (Buis, 2008)

SNOWPACK EXAMPLE

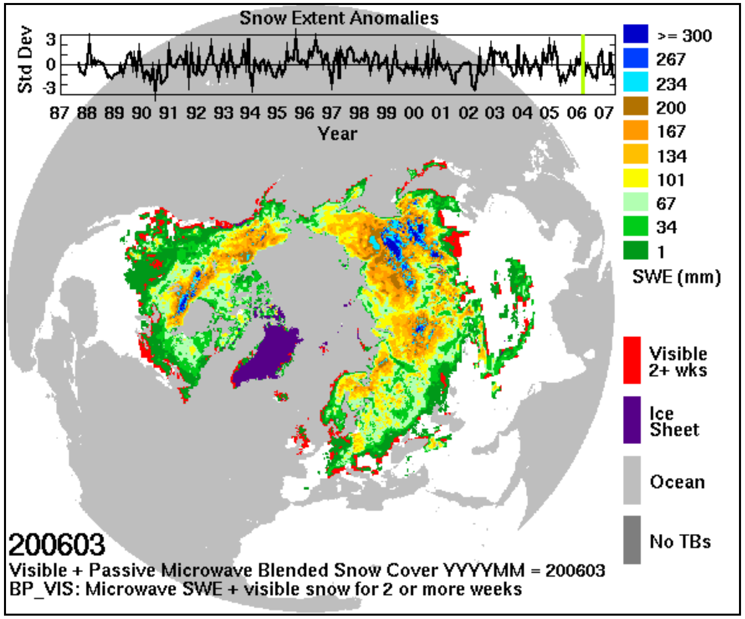
- Seasonal snowpack is an important factor in planning hydropower resources in many regions
- Expected changes in climate may cause changes in
  - Snow accumulation
  - Timing of runoff
  - And therefore, volume and timing of hydro resources

IMAGE: NASA

SNOWPACK EXAMPLE

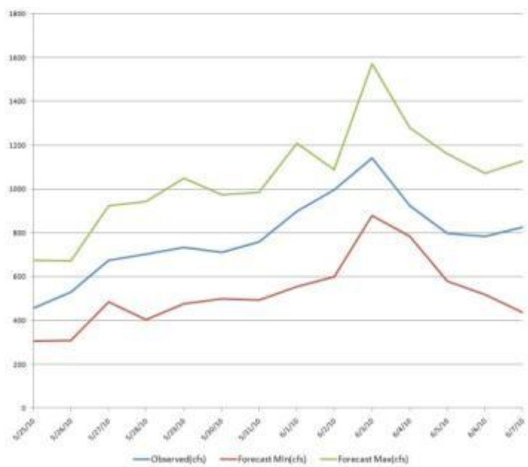
- NASA supports a number of projects related to
  - Observation of seasonal snow cover
  - Evaluation of snow water equivalent (water available assuming sudden melt)
  - Prediction of runoff volumes and timing

- Data sets include:
  - Daily (near real-time) maps of snow cover from satellite observations
  - Gridded historic data sets (daily, 1km x 1km, including satellite and ground-based observations) for:
    - Precipitation (liquid and solid)
    - Snow depth
    - Snowpack temperature
    - Snowmelt
    - Sublimation (snowpack, blowing snow)
    - Air temperature



SNOWPACK EXAMPLE

- Models and forecast examples include:
  - The Regional Hydro-Ecological Simulation System (RHESSys) model uses NASA satellite data to forecast snowpack behavior and regional watershed dynamics.
  - Snowpack forecasting models that incorporate decadal weather patterns, wind, air temp, storm frequency, atmospheric moisture, and soil moisture before the first snowfall.
  - Watershed-specific river flow forecasting models that incorporate historic information and NASA parameters.



Dungeness River model performance

Forecast max. flow
Actual flow
Forecast min. flow

IMAGE: http://pcnasa.ctc.edu/
North Olympic Peninsula Solutions Network

RESULTS

- Energy Companies suggested needs for the following products:

Parameter	Real-Time	Projected	Notes	Region
Temperature	Y	Y	20-30 years projected	ALL
Temp: Peak Summer High	n/a	Y	To assess current methods	NW, NE
Temp: Peak Winter Low	n/a	Y	To assess current methods	NE
Avg Rainfall	n/a	Y	Also need Variability	MW, NE
Groundwater	Y	Y	Increasingly important	SW, SE
Snowpack	Y	Y	SW impacted indirectly	NW, SW
River and Stream Temp	Y	Y	For compliance with fish regulations	NW
Glacier Monitoring	Y	Y	To help plan future hydro resources	NW

KEY POINTS

- The certainty of model projections would need to be "very high" (one company said 90% confidence) in order for energy companies to rely upon them.
- Projections need to be locally relevant (not global).
- Tools that allow investigation of multiple scenarios may be more useful than static projections.

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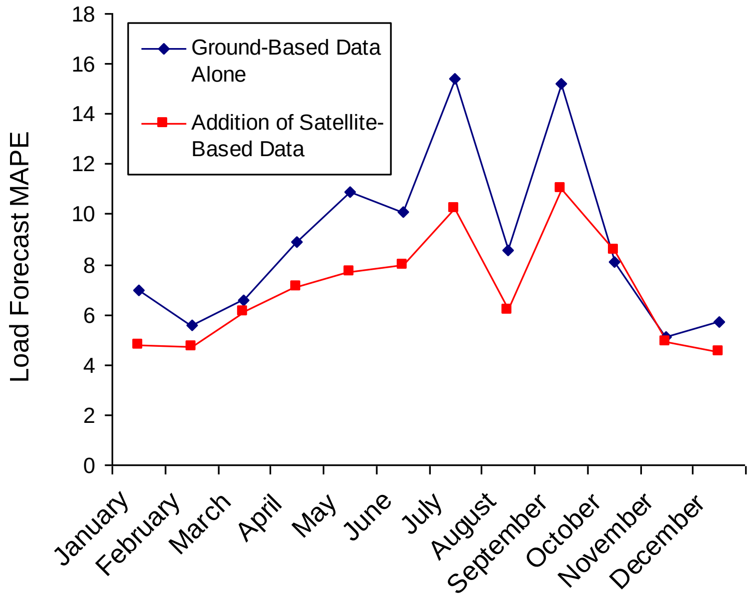
SHORT-TERM LOAD FORECASTING

WEATHER IN ENERGY LOAD MODELS

Problem – surface reporting stations and forecast sites are limited

- few and usually far apart
- not in representative areas because of terrain, or influenced by local effects

Preliminary study showed that the use of more data improves load forecasts

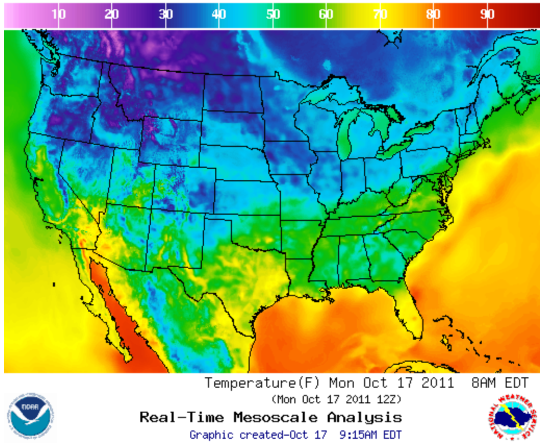


Weather data needs to be:

- Available in real-time (observations)
- Forecast at 1-3 hour intervals
- Forecast 1-10 days in future
- Parameters include Temperature (also daily max / min), Relative Humidity, Wind (speed/direction), Precipitation, Cloud cover, Solar energy, etc.

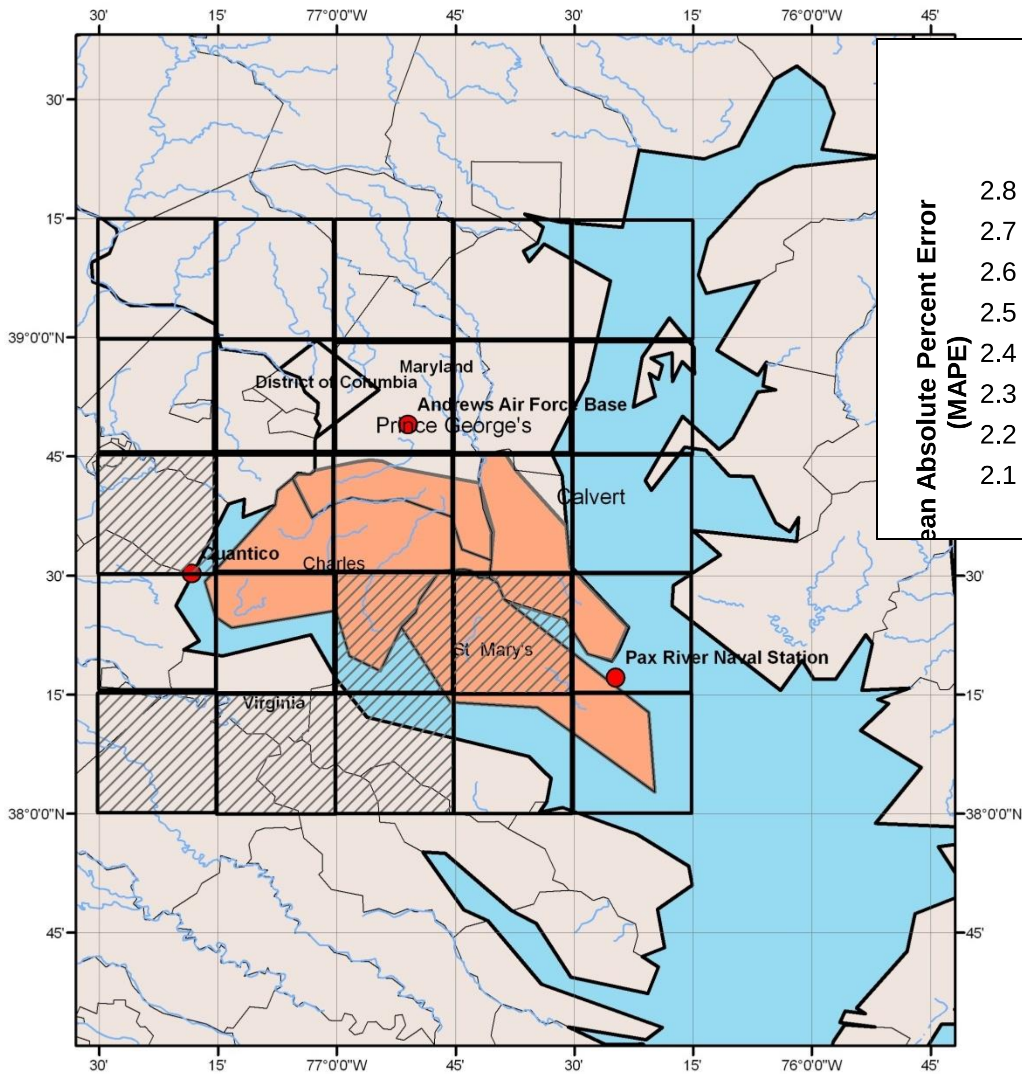
NASA and NDFD PRODUCTS

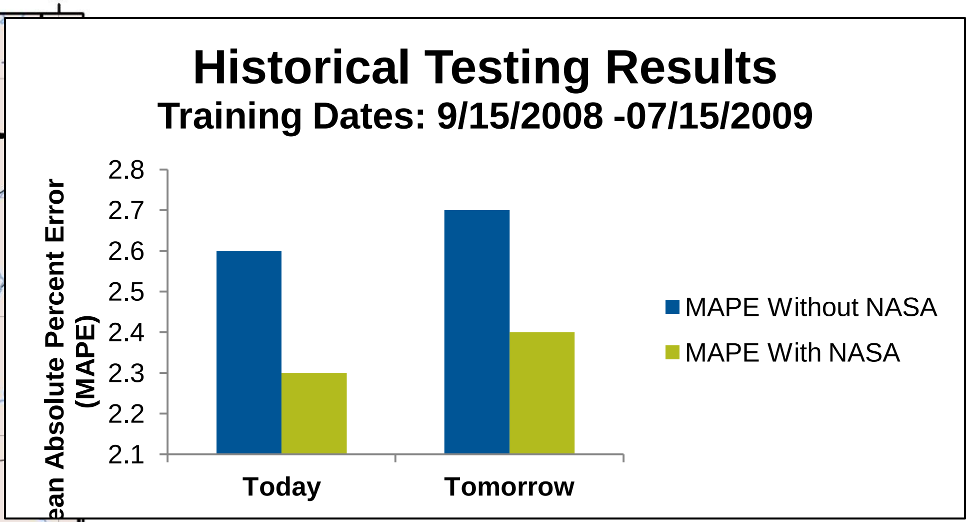
- NASA POWER project provided historical weather
- NASA SPoRT Center provided high-resolution (5km) hourly weather forecasts from 0-36 hours
- NWS National Digital Forecast Database (hourly to 3 hourly, 5km) was added out to 7 days
  - Available in the Continental U.S.
  - Available directly from NOAA/NWS and through third-party providers



NDFD Website:
http://www.nws.noaa.gov/ndfd

HISTORICAL TESTING

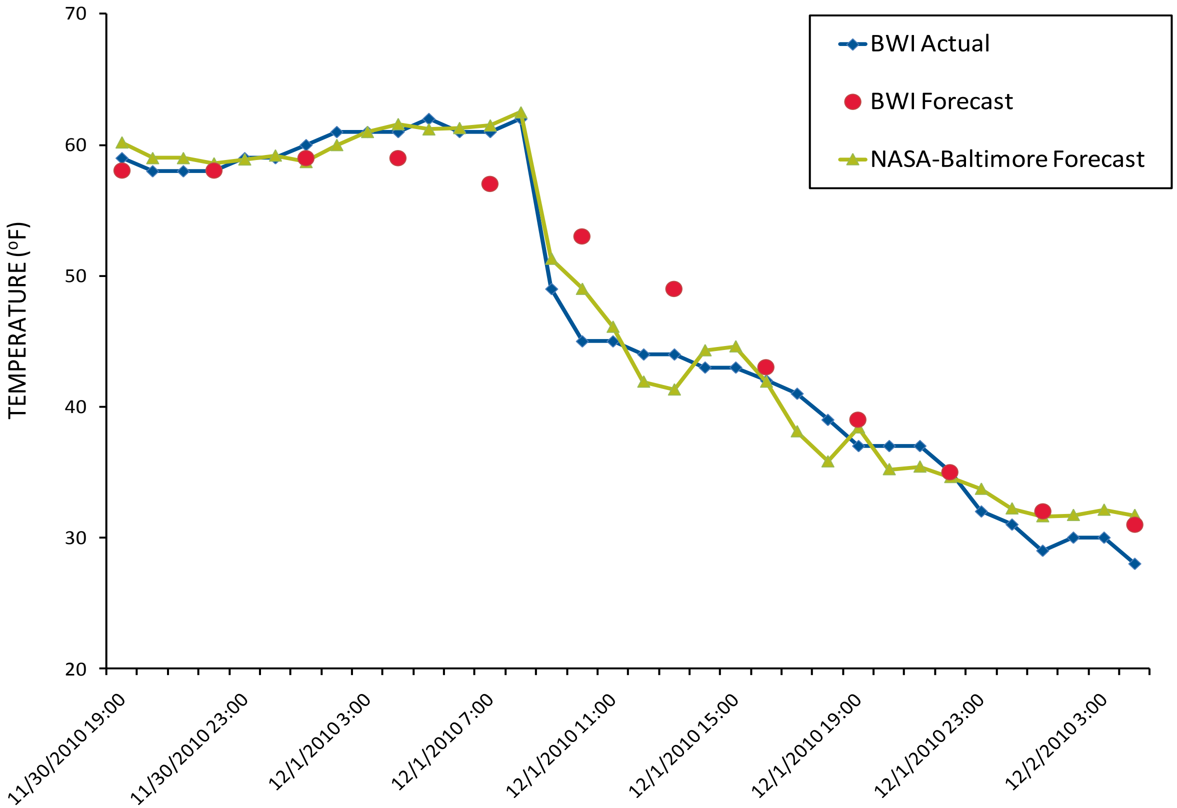




- Inclusion of high-resolution NASA/NDFD weather forecasts reduced error in energy load forecasts

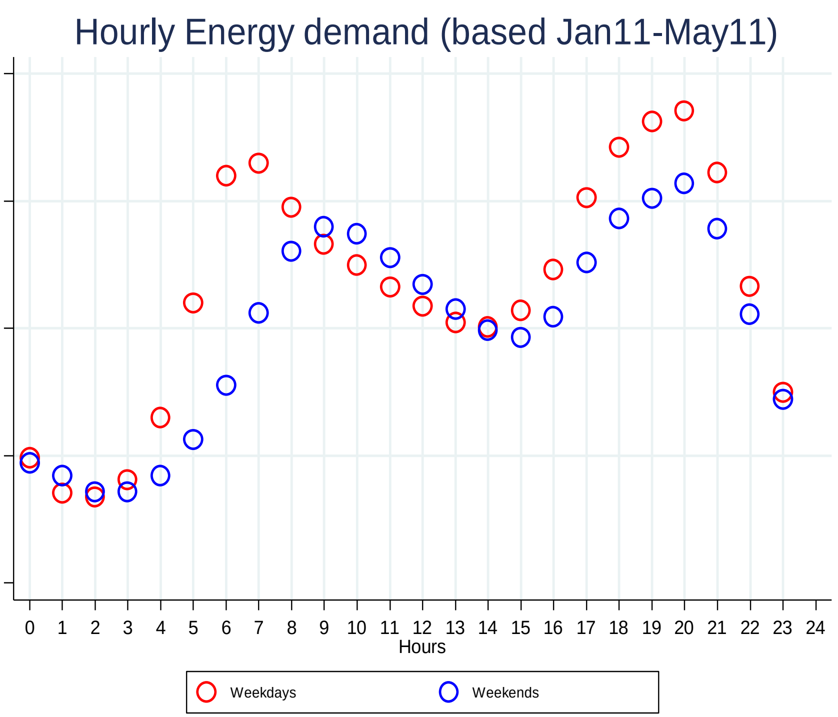
NASA and NDFD Forecasts

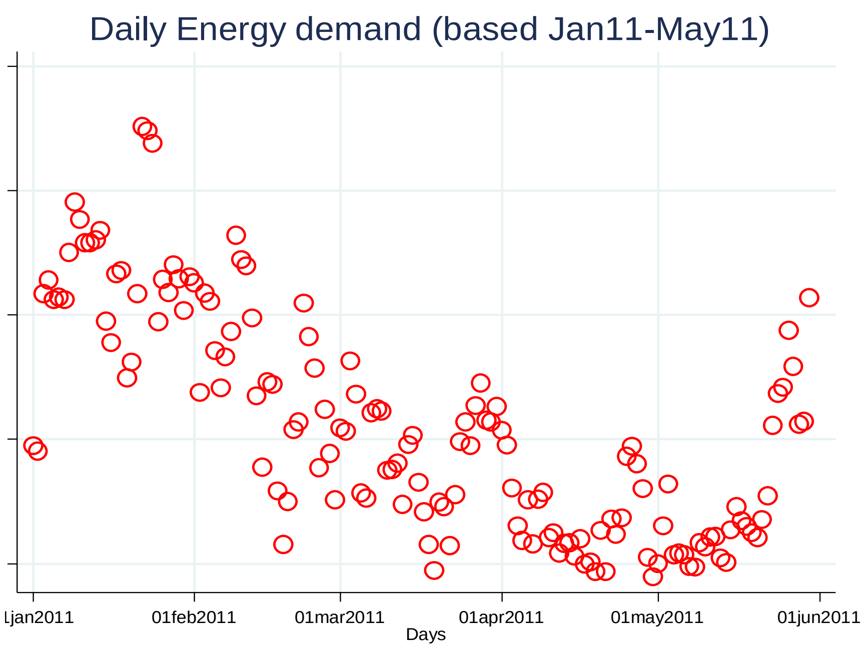
NASA weather forecasts captured some fast temperature changes far better than the ground-based forecast



Pattern in Demand

- Energy patterns have distinct daily and seasonal patterns.
- Utilities can inspect weather-adjusted model results to understand When and Which additional weather forecast points may be useful.
- If certain conditions have consistently greater error, the selection of forecast points can be focused on improving performance at those times.



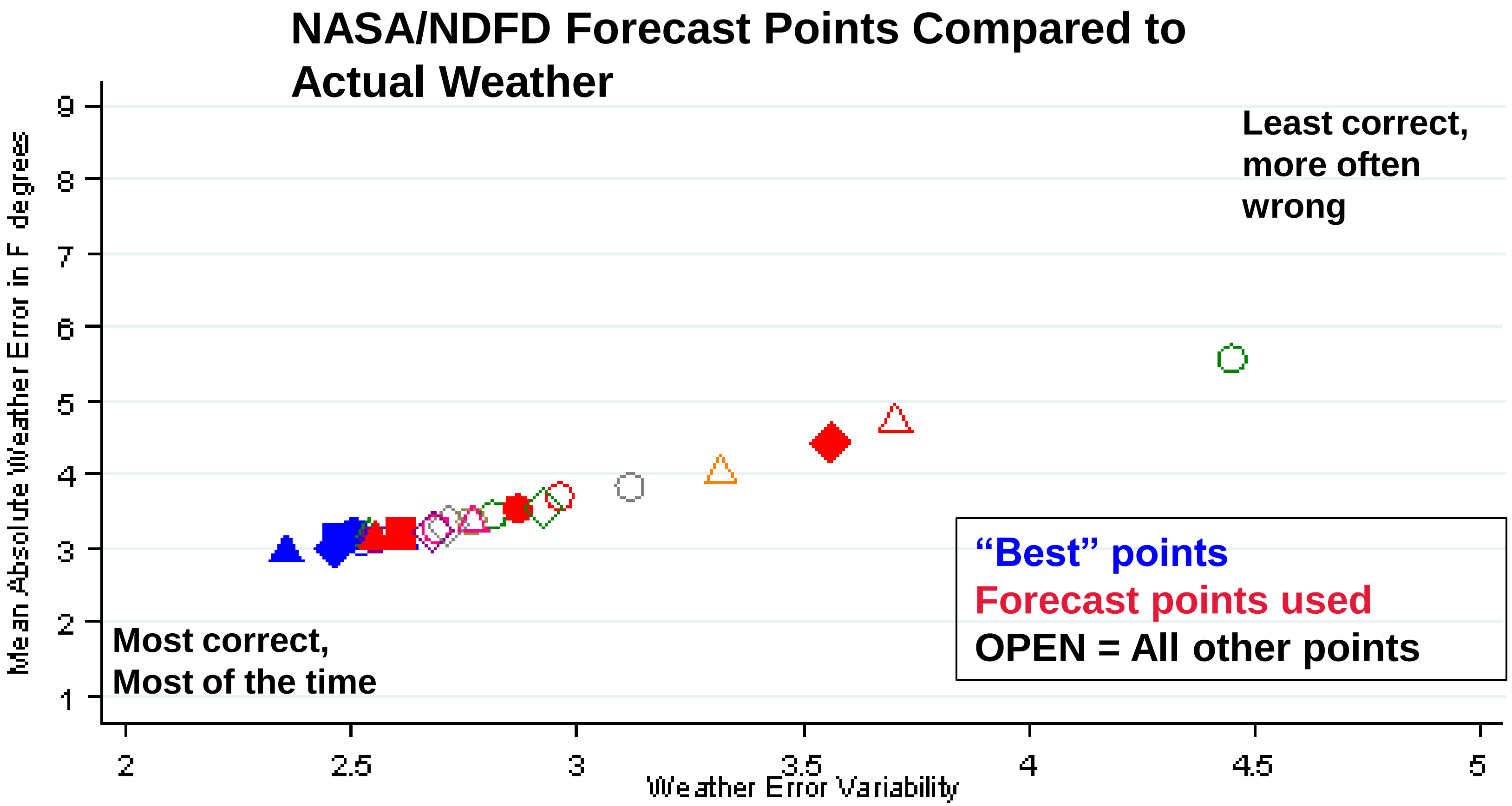


PATTERN IN DEMAND

- Patterns to investigate in choosing weather forecast points:
  - Seasons
  - Hottest days
  - Coldest days
  - Largest changes in 12 hours
  - Largest changes in 3 hours

MEAN vs. VARIABILITY

- NASA forecasts that are, on average, most similar to actual weather are not necessarily the best
- Comparing Mean Absolute Error and Standard Deviation lets us see how VARIABLE forecast points are compared to actual weather



CONCLUSIONS

- NASA/NDFD weather forecast points can be very useful to improve load forecasts
- Selection of a subset of available weather forecast points can balance optimization of model performance with need for forecast improvement in specific situations
- Seasons, times of day, and certain weather conditions (e.g., coldest or hottest days, rapid changes) should be investigated in choosing weather forecast points
- Means are important, but variability from actual points is more important in choosing weather points

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ADDITIONAL SLIDES

Operational Testing

- Three Utilities ran two models daily:
  - Standard model with ground-based weather forecasts
  - New model with ground-based weather forecasts PLUS:
    - NASA forecasts out to ~30 hours (36 hours GMT)
    - NDFD forecasts out to 7 days
- Results were mixed
  - Improvements were seen with NASA forecasts on some days, seasons, and locations, but improvement was not uniform
  - Fine-tuning the selected weather forecasts was needed
    - NASA/NDFD weather forecast points were initially chosen to represent a variety of local weather profiles, with the expectation that the neural network load forecasting tool would weight the different profiles appropriately
    - Selection of weather forecast points should instead focus on points that are most representative of actual weather in the service area

Statistical Analysis

- This analysis had two primary objectives:
  - Identify possible changes that would improve a utility's NASA/NDFD load forecast
  - Identify and describe analyses that utilities can perform to most successfully apply NASA/NDFD weather forecasts

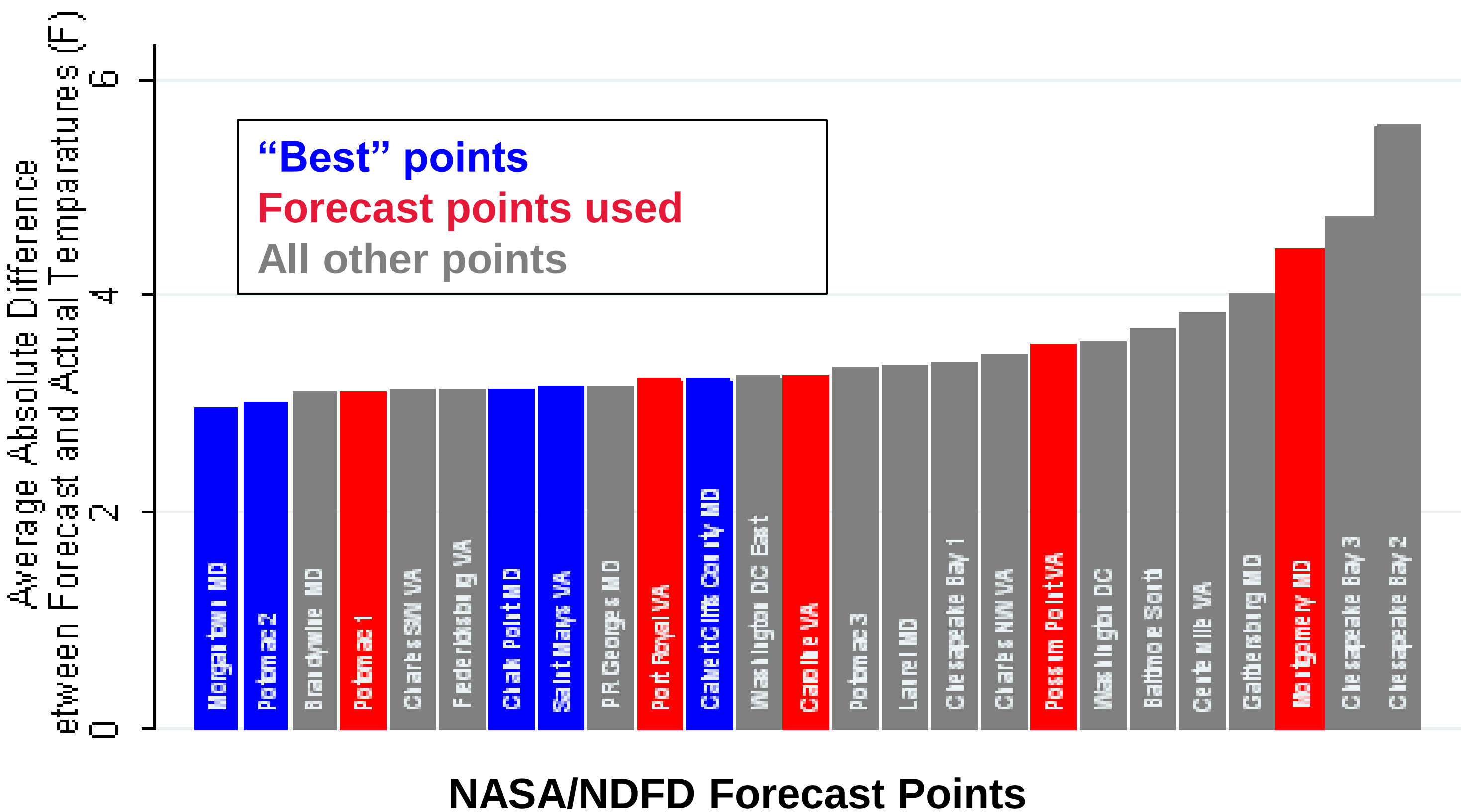
- Challenges:
  - Weather is only a portion of the error in load forecasts; energy demand is another source of error. Without re-training the model, it is not possible to directly link weather forecast error to energy demand error.
  - Actual weather observations are not available on the spatial scale of the NASA forecasts, so it is difficult to evaluate the forecast accuracy

Motivation

- Including a large number of inputs in load forecasting models can sacrifice model performance. The questions to be addressed by energy utilities in deciding whether, how, and which additional forecasts use include:
    1. Are the NASA/NDFD forecasts closer to actual weather than existing ground-based forecasts?
    2. Of the available forecast points, are there certain points which will always or sometimes improve the forecast?
    3. Will different subsets of forecast points improve the forecast in different situations, such as seasons or times of day?

“Best” forecast points

- Forecast points with lower variability are more often closer to the actual weather
- Blue bars are the “Best” points, and have some of the lowest Average Absolute Difference between actual and forecast



Weather patterns

- Some weather forecast points may be more useful in certain situations
  - One of the forecast points (1°x1°) used for a company was located over Lake Erie (red x)
  - For the next-day forecast, the Lake Erie point was very poor at predicting actual weather at either the Erie or Buffalo airport
  - However, the forecast for the Lake Erie point was the best predictor of actual weather 7 days out