

Modeling the variability of renewable generation and electrical demand in RTOs and cities using reanalyzed winds, insolation and temperature

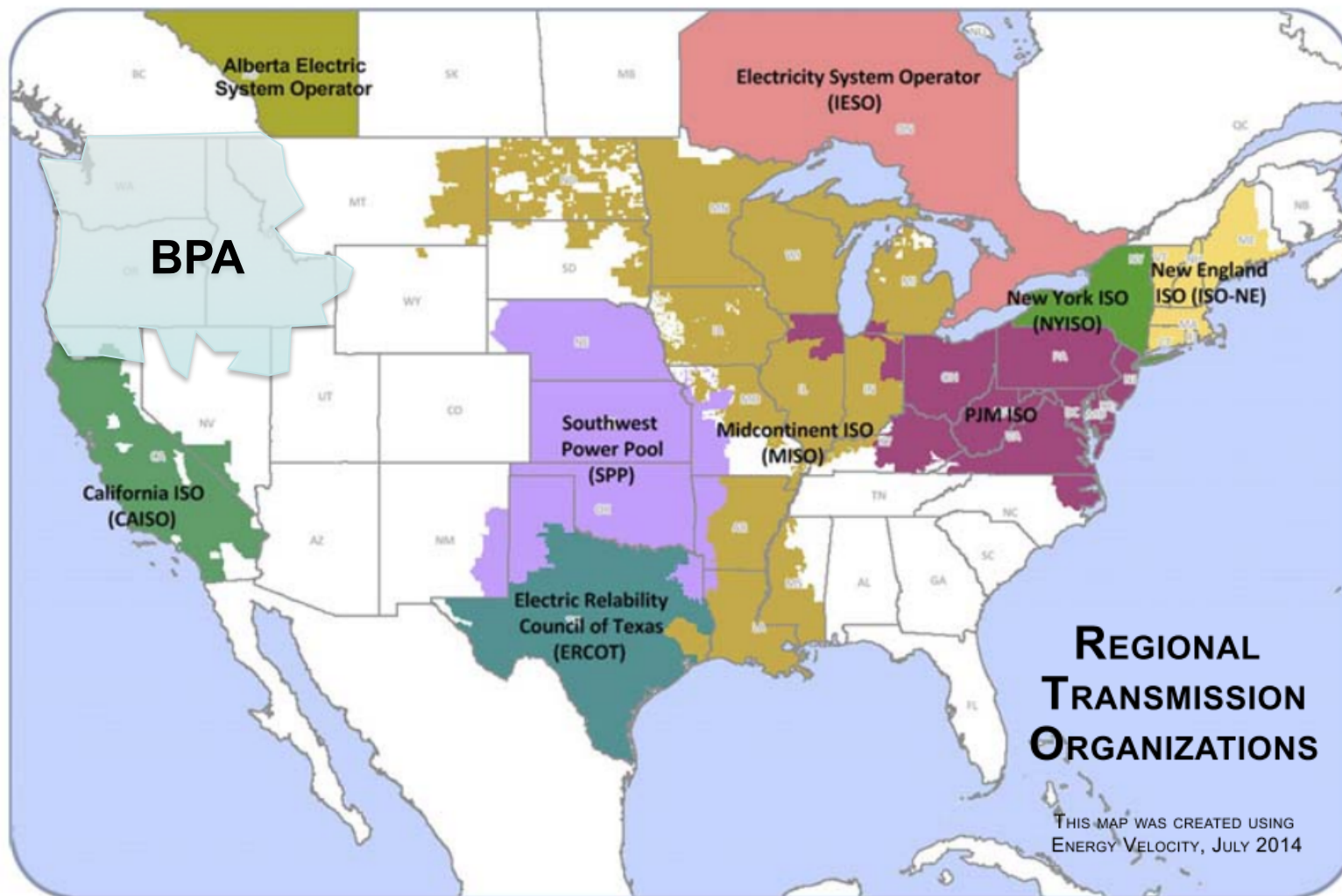
[1_Kirk-Davidoff_et al.pptx](#)

Daniel Kirk-Davidoff^{1,2},
Stephen Jascourt¹,
Chris Cassidy¹

¹MDA Information Systems LLC
²AOSC, University of Maryland

Photo by Bob Henson (UCAR)

US and Canadian RTO/ISO regions



Wind Farms in the US

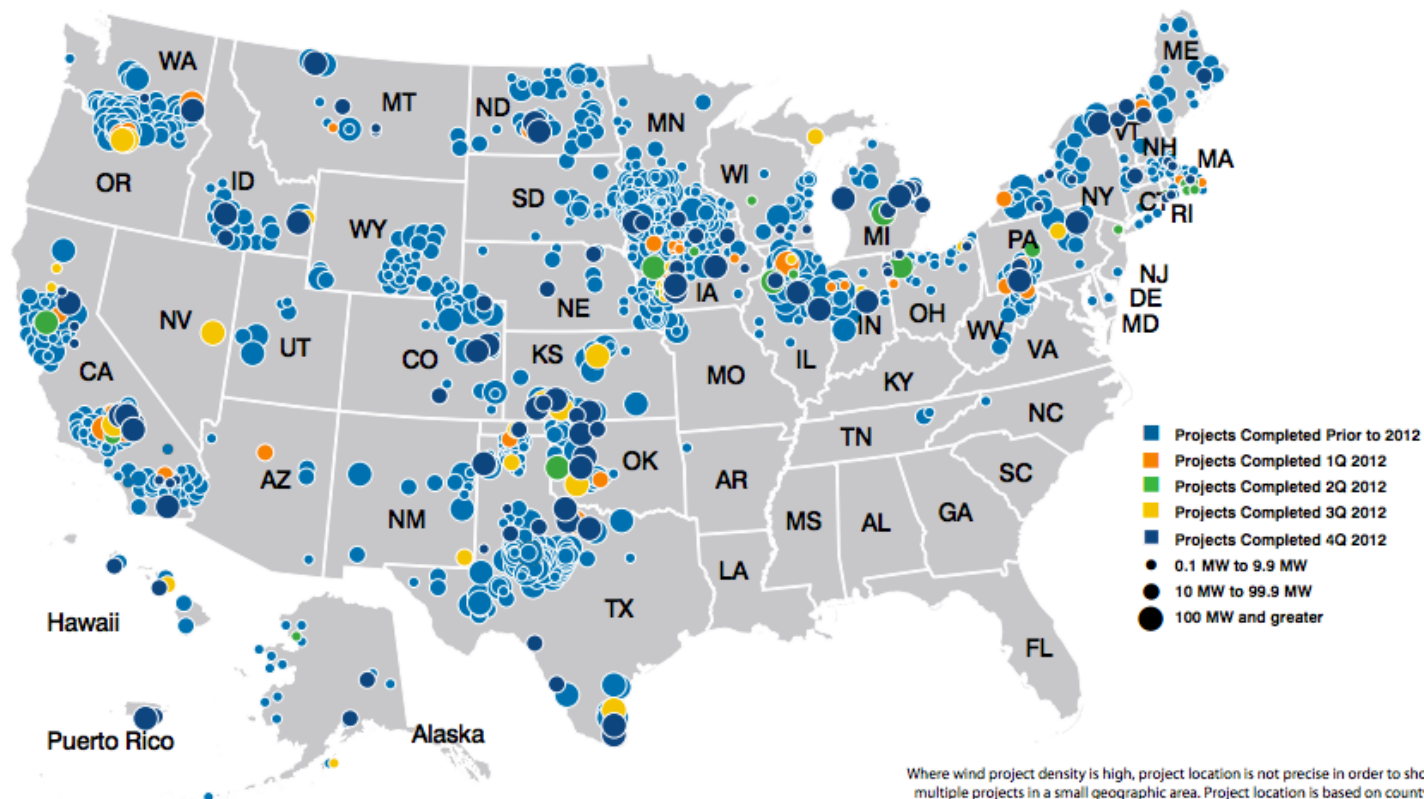
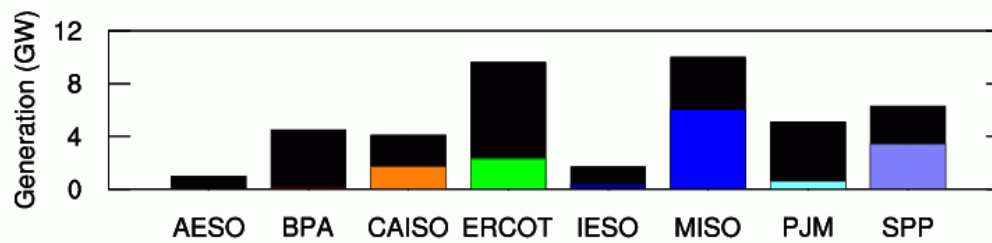
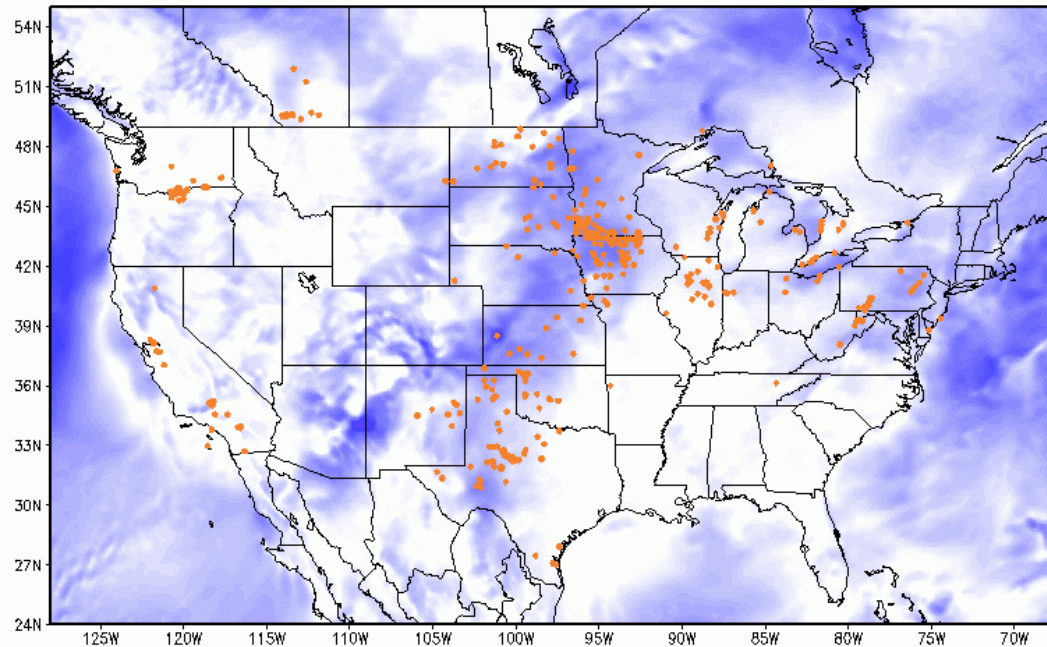


Image courtesy of AWEA

National Scale Wind Generation in near-real time

Wind Speed Valid 2015-06-06 at 17 UTC



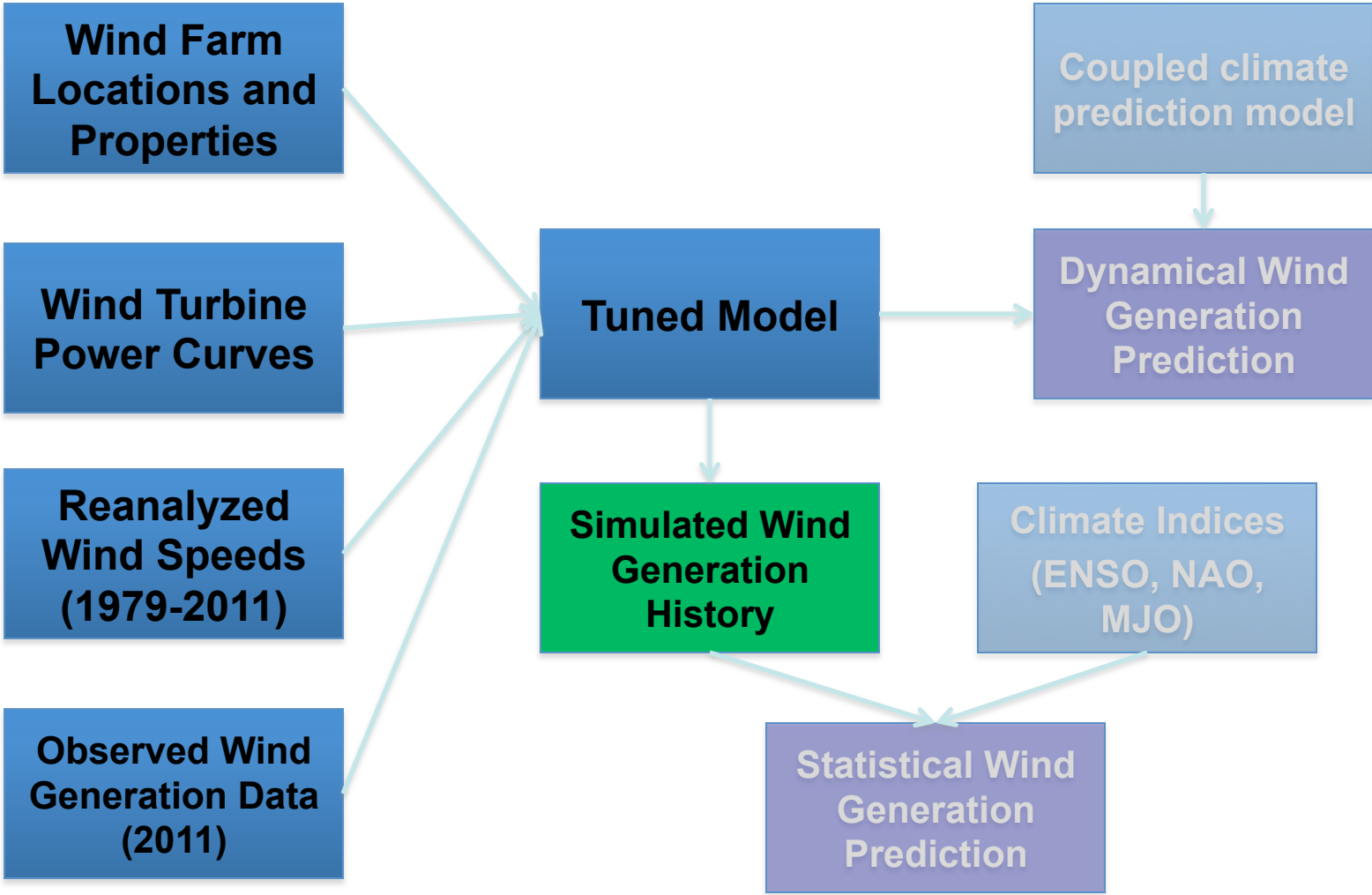
Generating an historical renewable generation index

The need: Energy traders and other electrical market participants need a consistent measure of wind generation in real electrical markets that represents the variability in electrical generation associated with weather fluctuations, and not changes in wind generation infrastructure. Such an index allows accurate assessment of the probability distribution of generation over the coming year, month, or week.

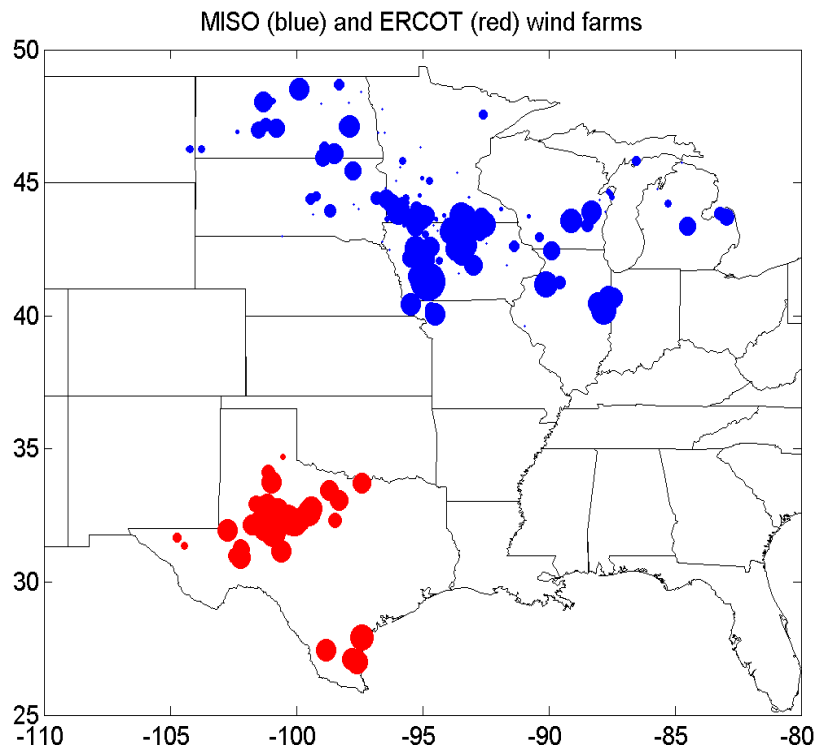
The solution: a procedure to generate a virtual history of wind generation for each electrical interconnection for past 30 years using an up-to-date, frozen wind generation infrastructure.

Each year, we can regenerate the 35+ year climatology of wind generation that would have resulted from the real wind variations over that period acting on the wind generation infrastructure of the present day.

Generating an historical renewable generation index



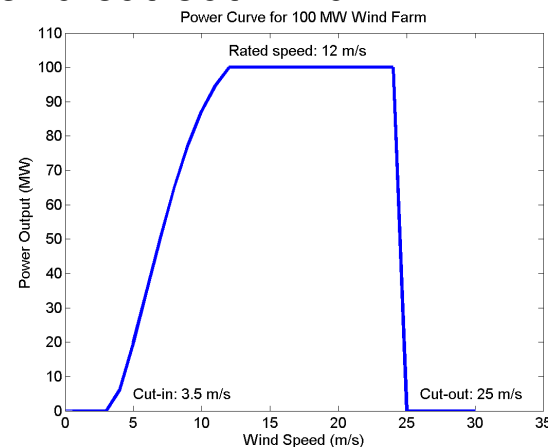
Wind Farm Locations & Properties



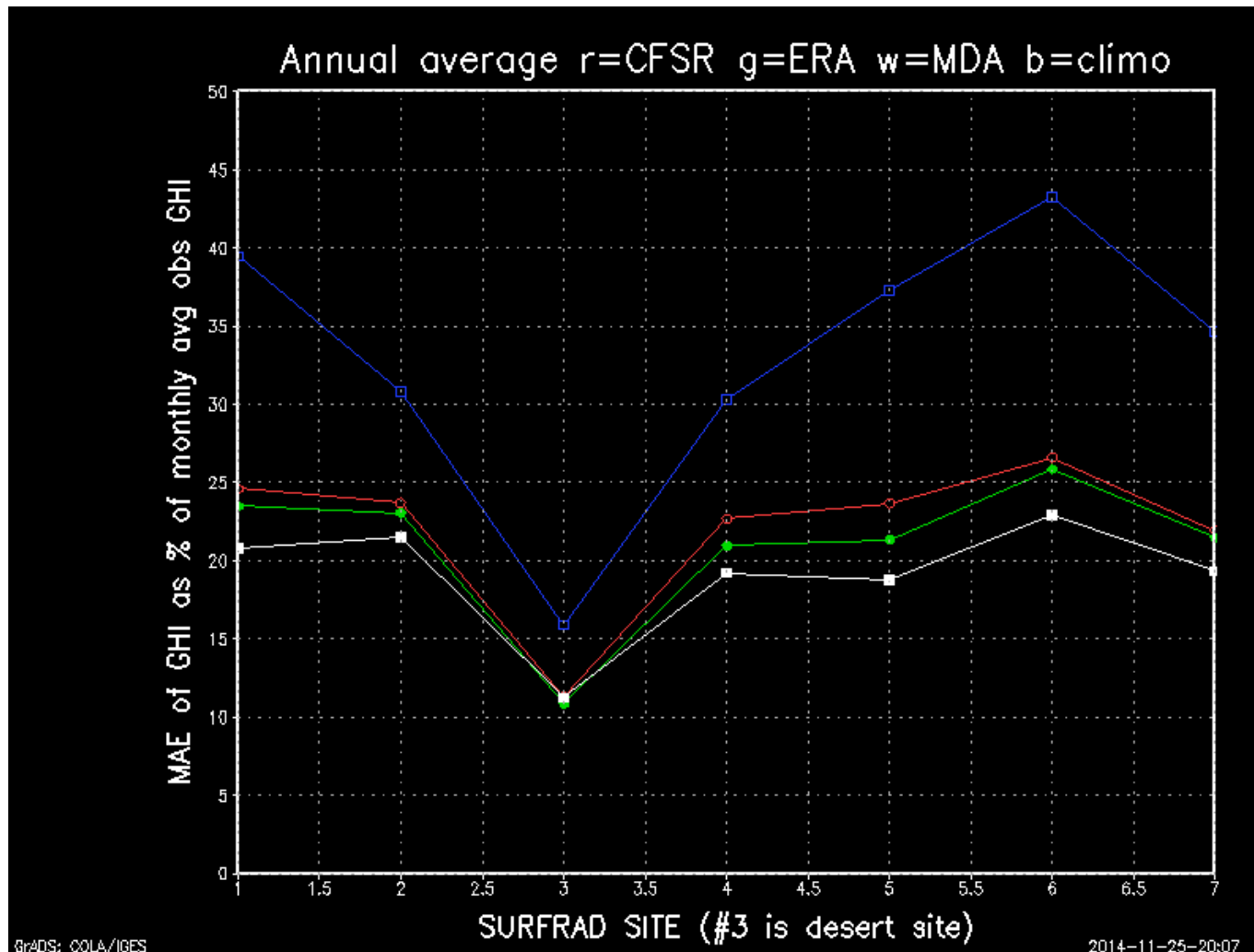
Farm locations and generation capacity are indicated by dots, scaled by size (largest is 444 MW). Total capacities are 13 GW in ERCOT, 15 GW in MISO

In this study, we will generate simulated historical wind and solar power generation for the AESO and IESO ISOs in Canada, and for the BPA, CAISO, ERCOT, MISO, PJM and SPP transmission organizations in the US.

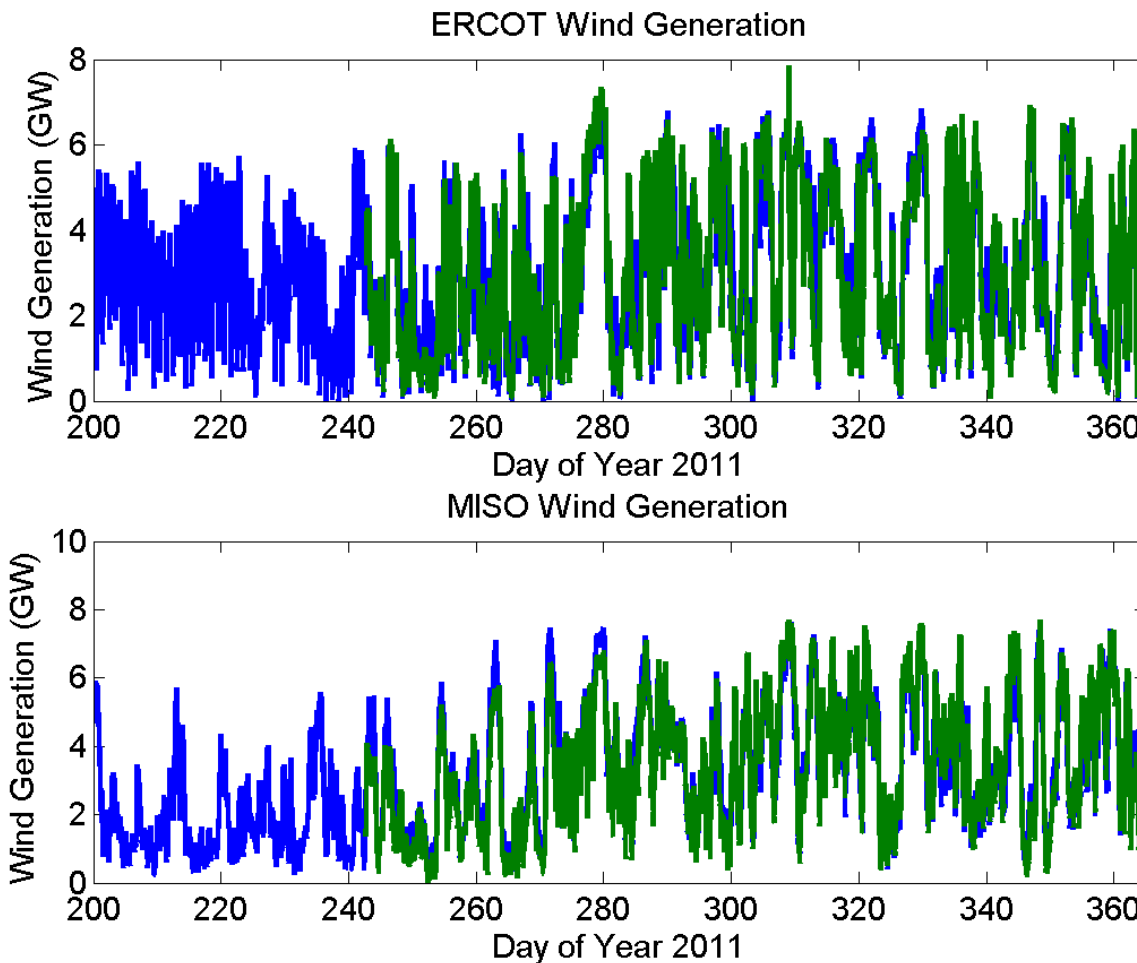
We use a parametric power curve that allows for arbitrary values of the cut-in, rated and cut-out wind speeds.



Solar Generation



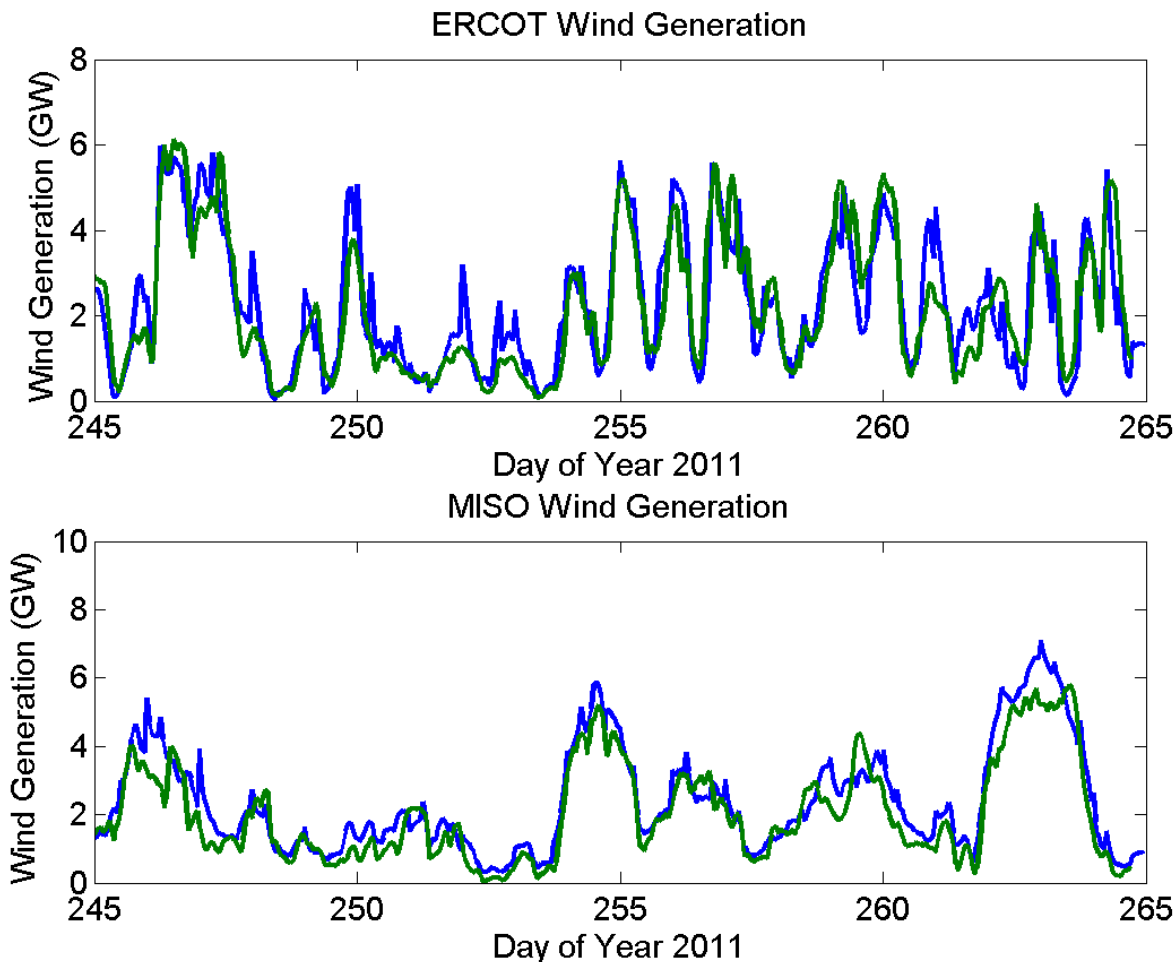
Simulated Wind Generation History



These plots show hourly wind generation for the ERCOT and MISO interconnections. Blue shows the simulated wind generation, green shows the actual generation. The agreement is quite good: correlation coefficients are 0.91 and 0.94 for ERCOT and MISO respectively.

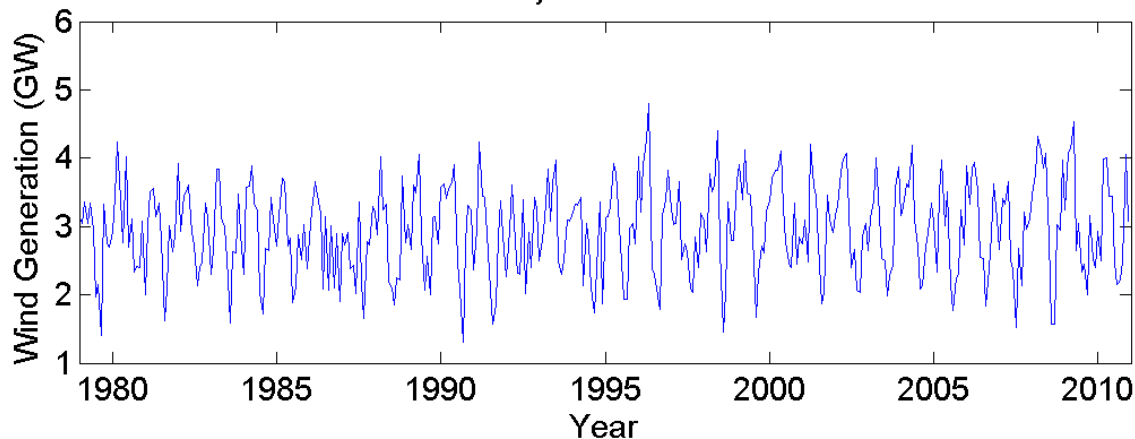
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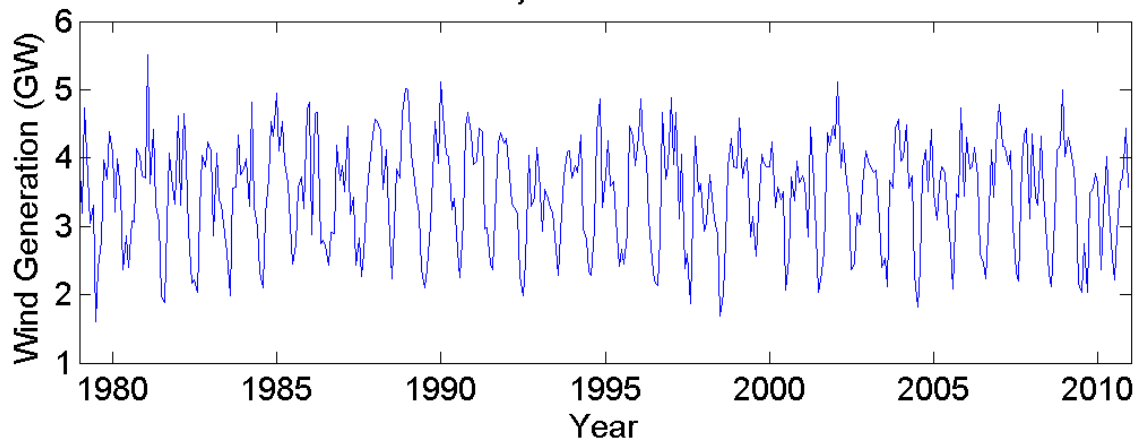


Simulated Wind Generation History

ERCOT Monthly Mean Wind Generation

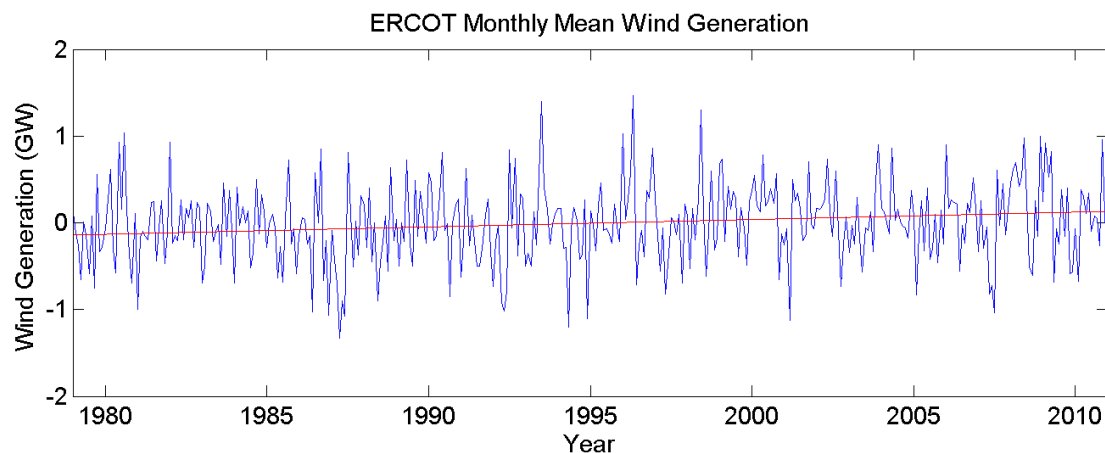


MISO Monthly Mean Wind Generation

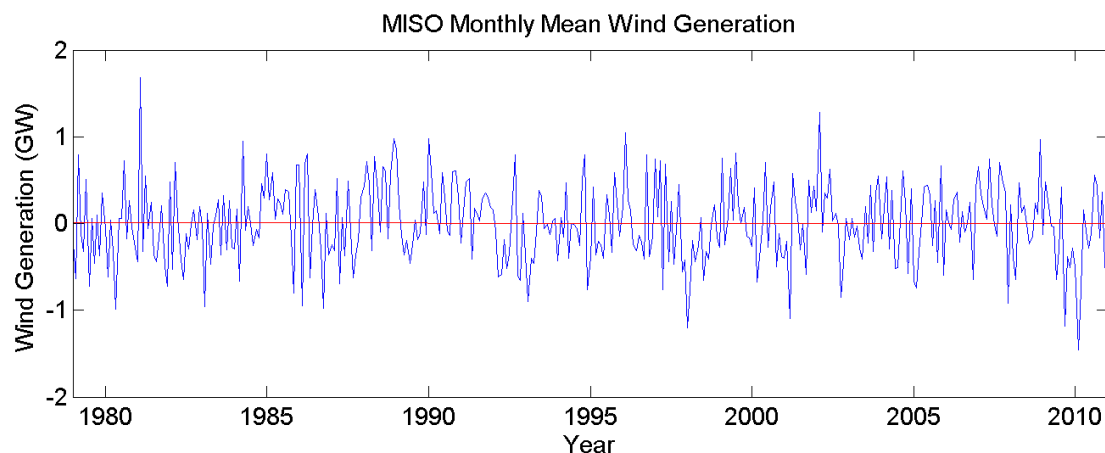


Here are the full 30 year histories, smoothed to monthly means for clarity.

Simulated Wind Generation History



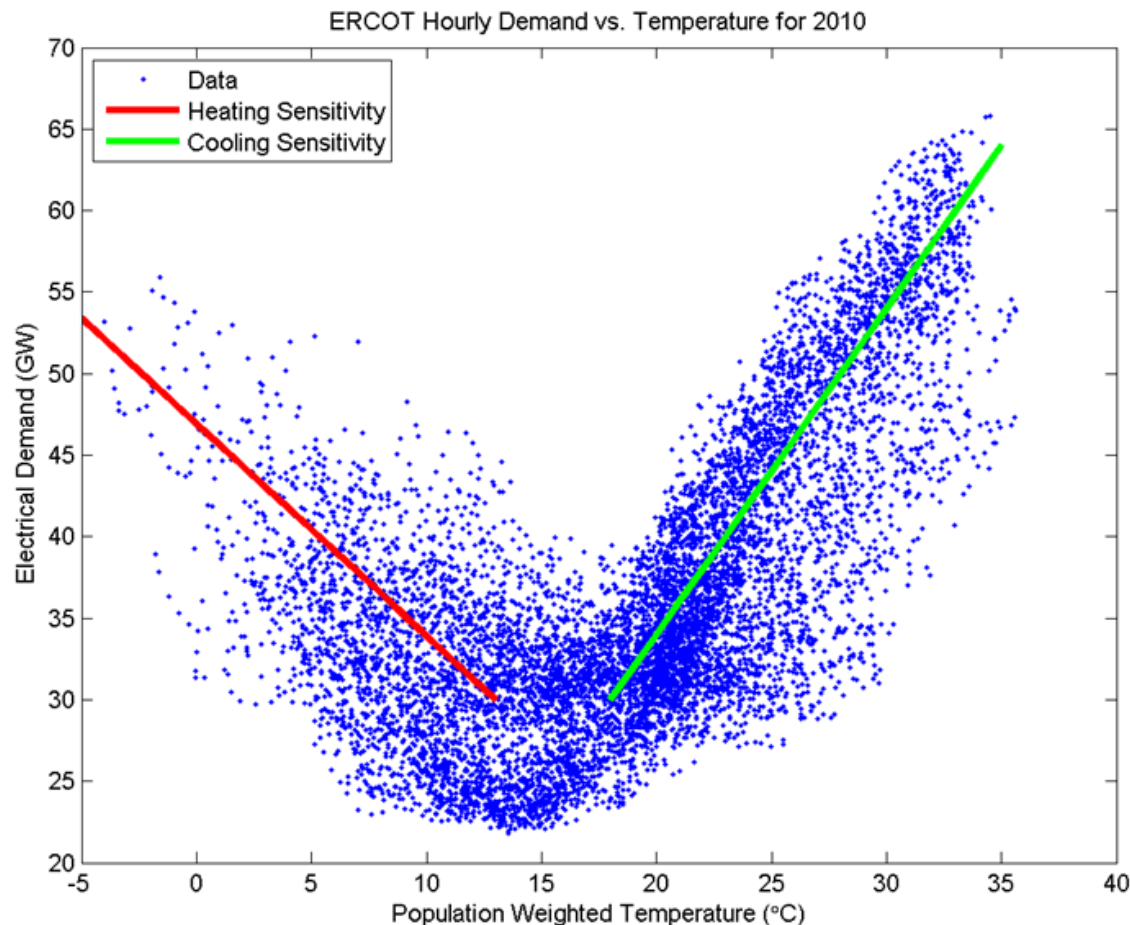
In these plots the annual cycle has been removed, to show the anomalous monthly mean generation in each interconnection.



A small, but significant trend of 85 MW/decade is evident in the ERCOT history, while the MISO history shows no significant trend.

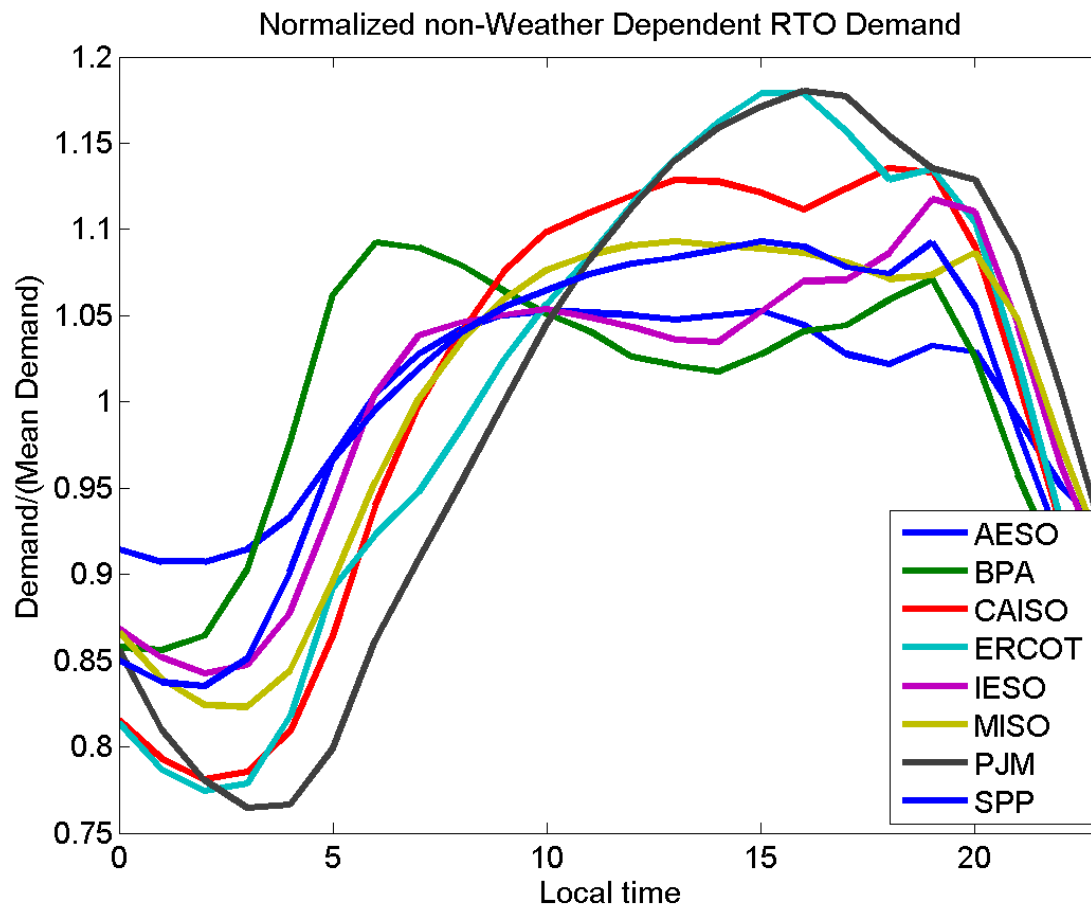
Electrical Demand Simulation

We can also simulate the weather-dependent part of electrical demand using reanalysis temperature data (weighted by population) and actual demand data. Of course we could just use actual demand data as well, but we want to isolate the contribution of weather variability here.

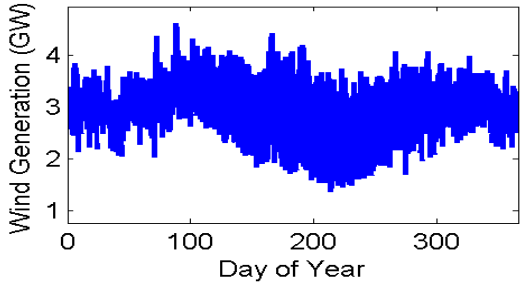
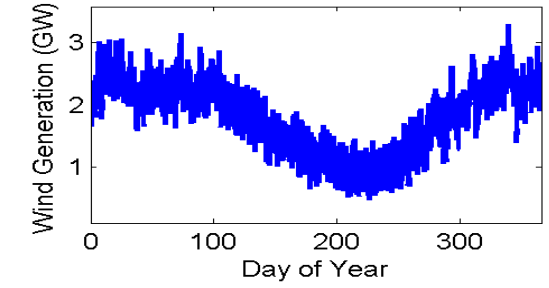
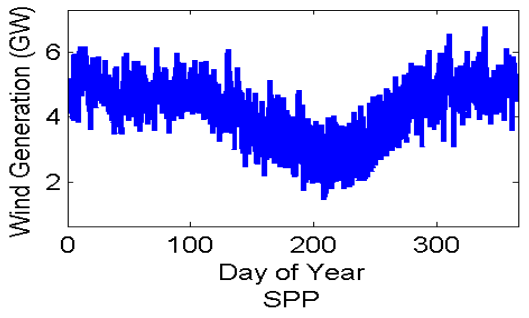
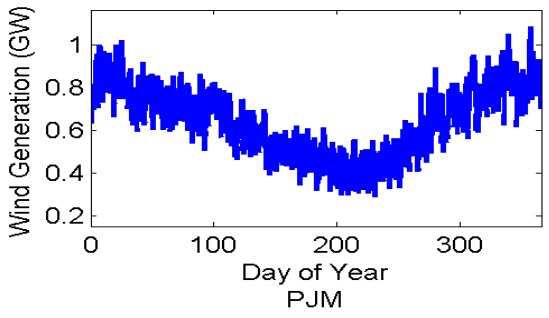
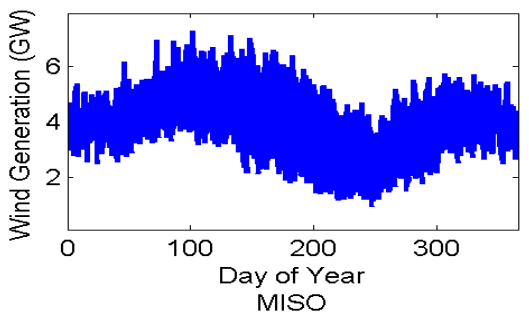
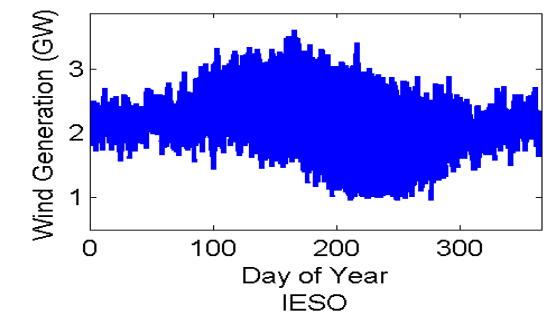
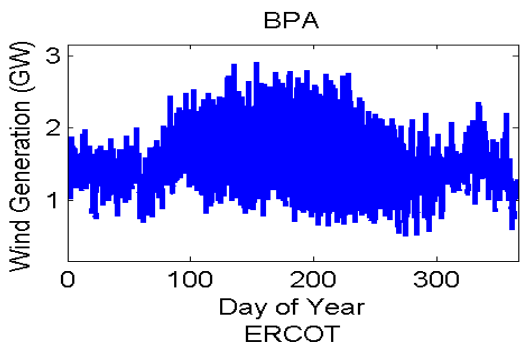
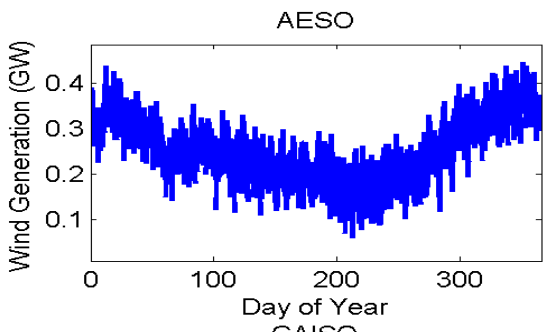


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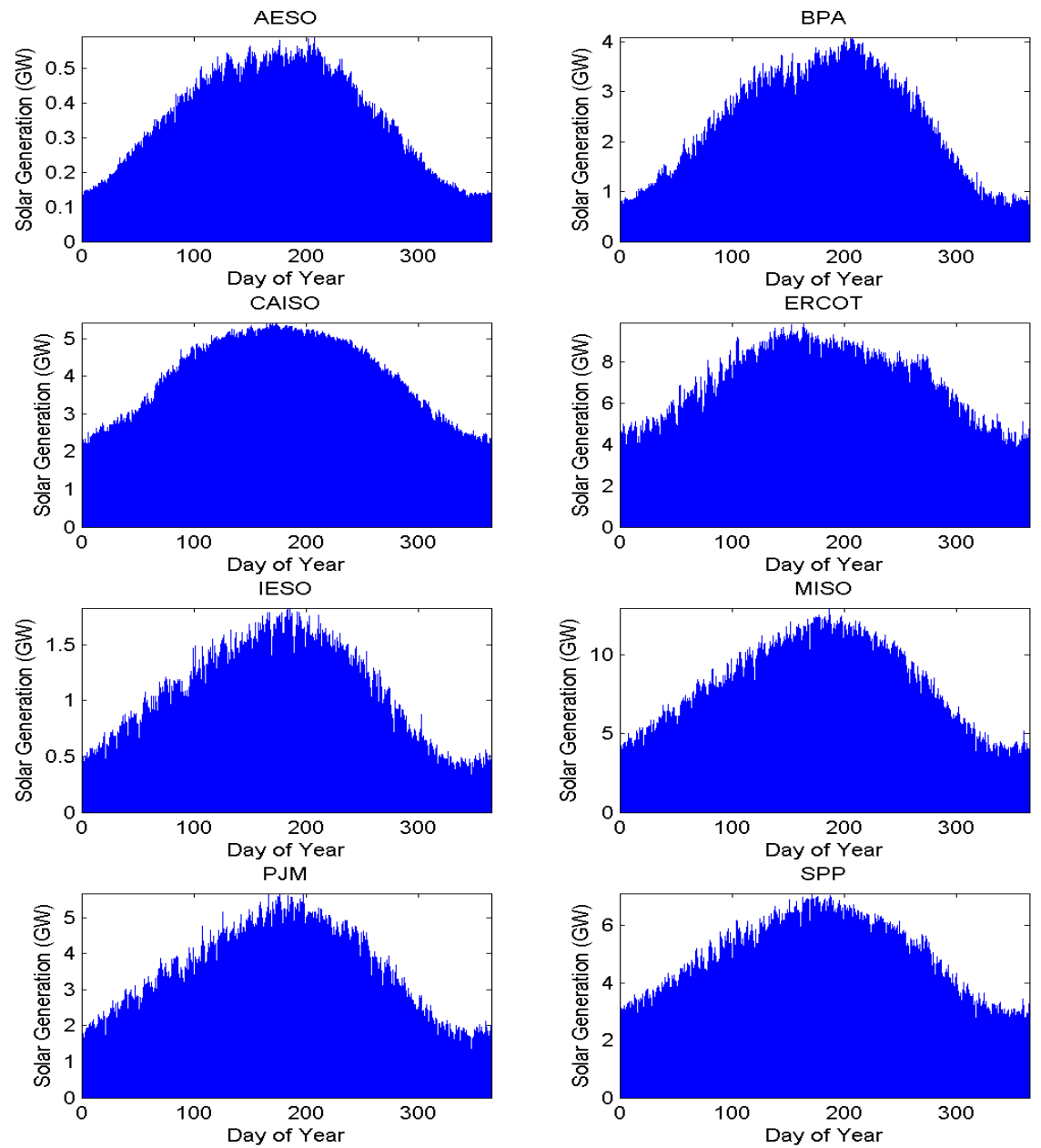
Simulated Wind Generation History



Here we show the average of 32 years of simulated wind generation history, by hour of year.

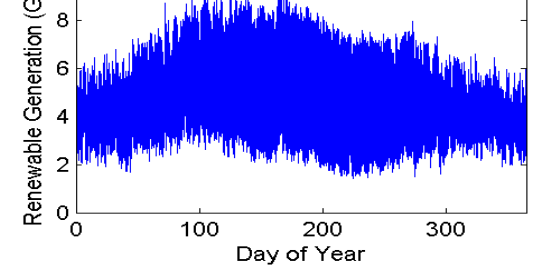
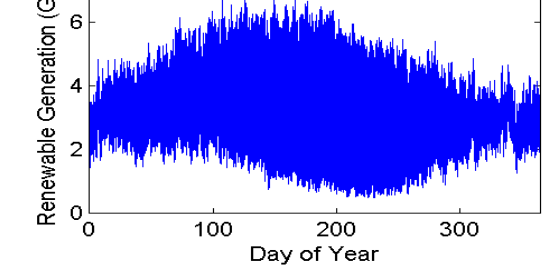
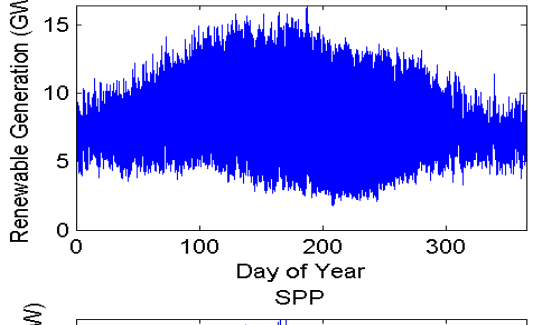
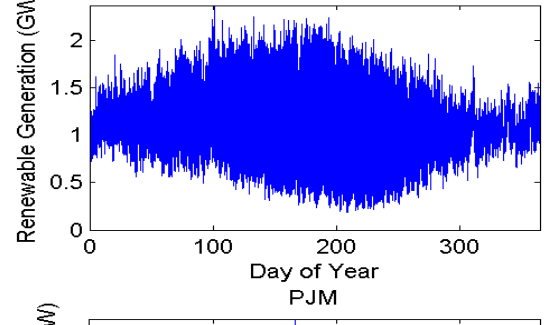
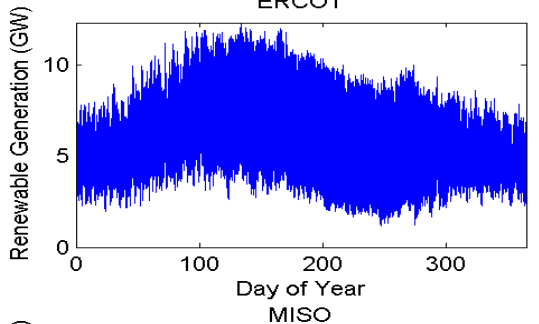
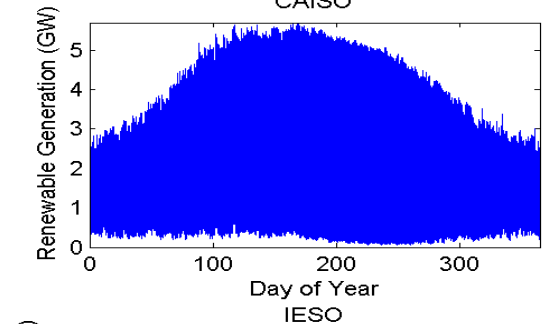
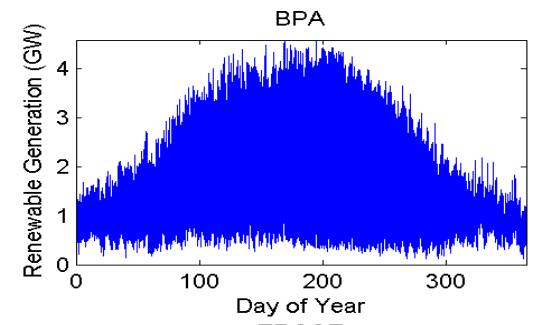
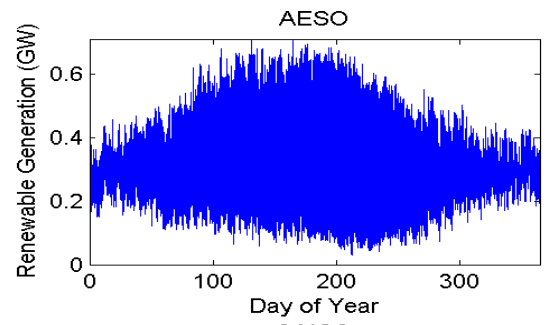
This shows well the change in the amplitude of the diurnal cycle, as well as the change in daily mean generation through the seasonal cycle.

Simulated Solar Generation History



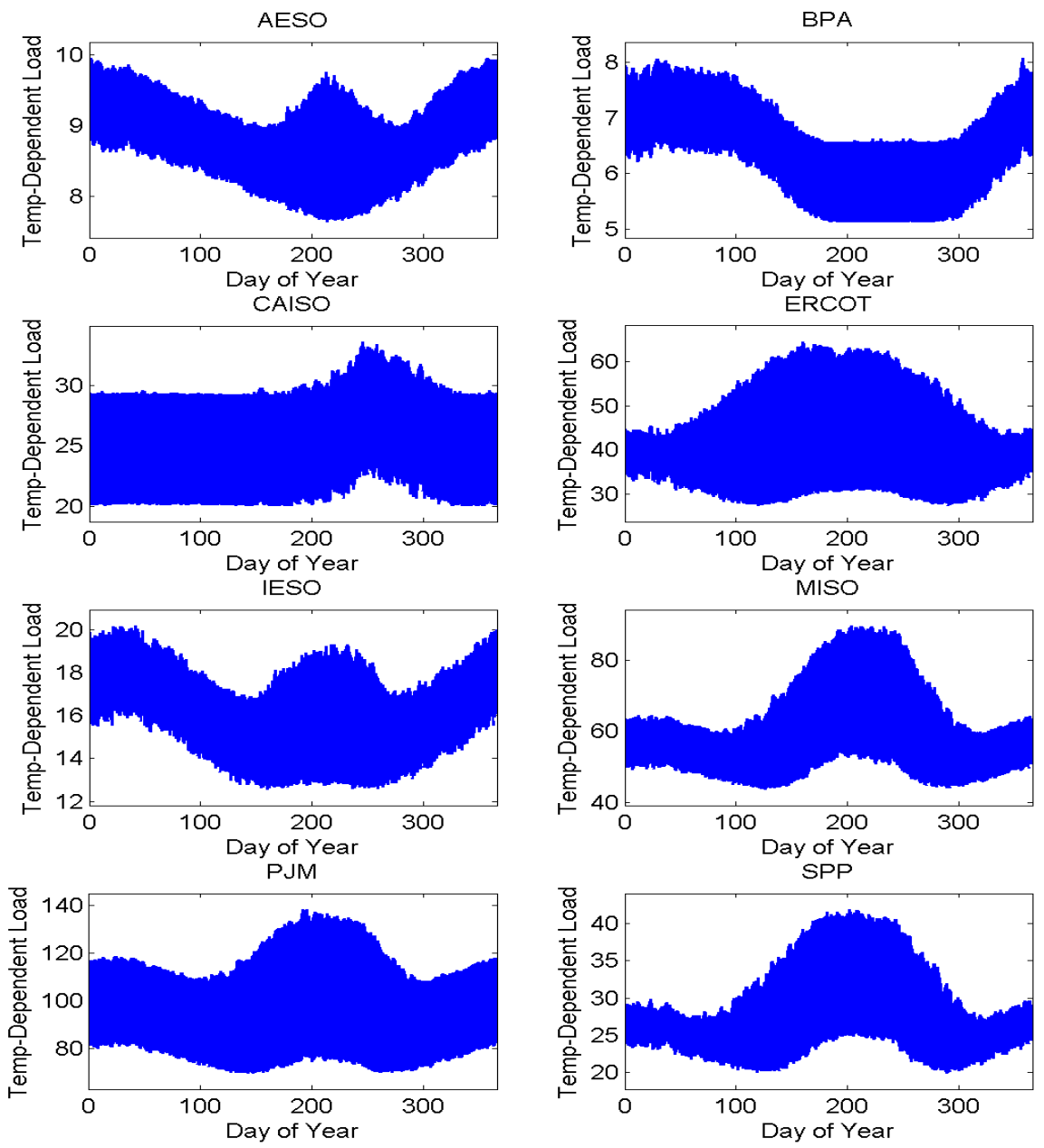
Here we show the average of 32 years of simulated solar generation history, by hour of year.

Simulated Renewable Generation History



Here we show the average of 32 years of simulated total renewable (solar + wind) generation history, by hour of year.

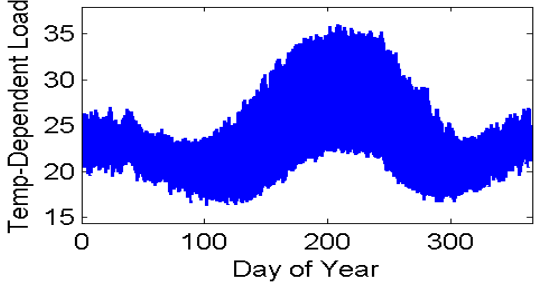
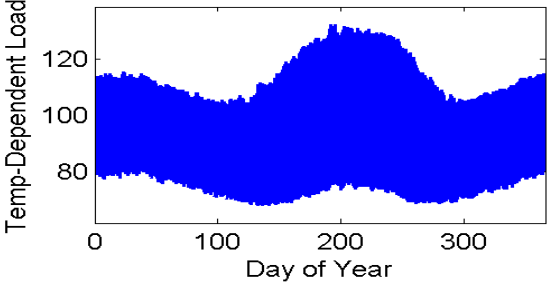
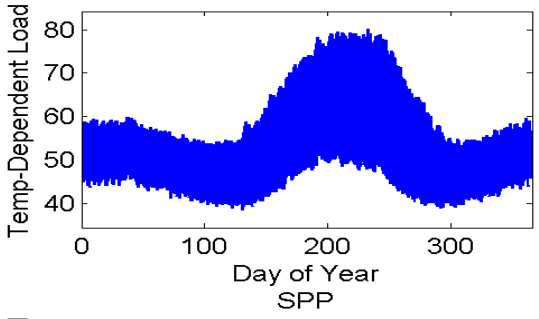
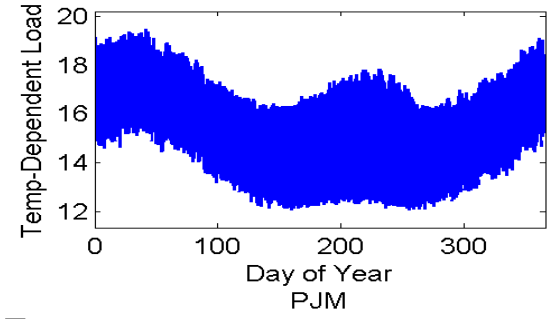
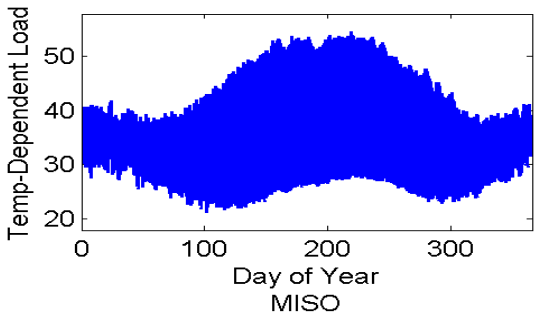
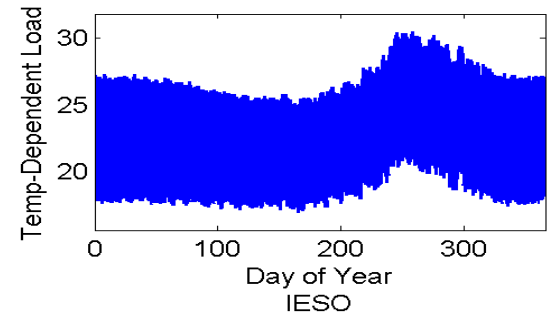
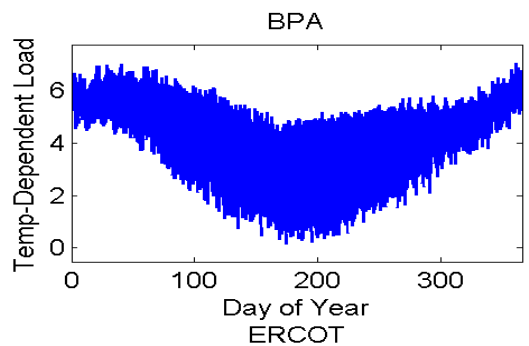
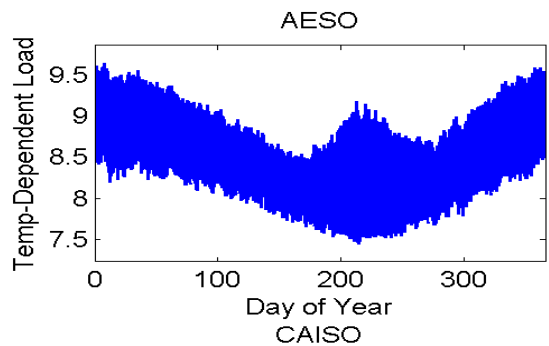
Simulated Electrical Demand History



Here we show the average of 32 years of simulated temperature-dependent electrical demand, by hour of year.

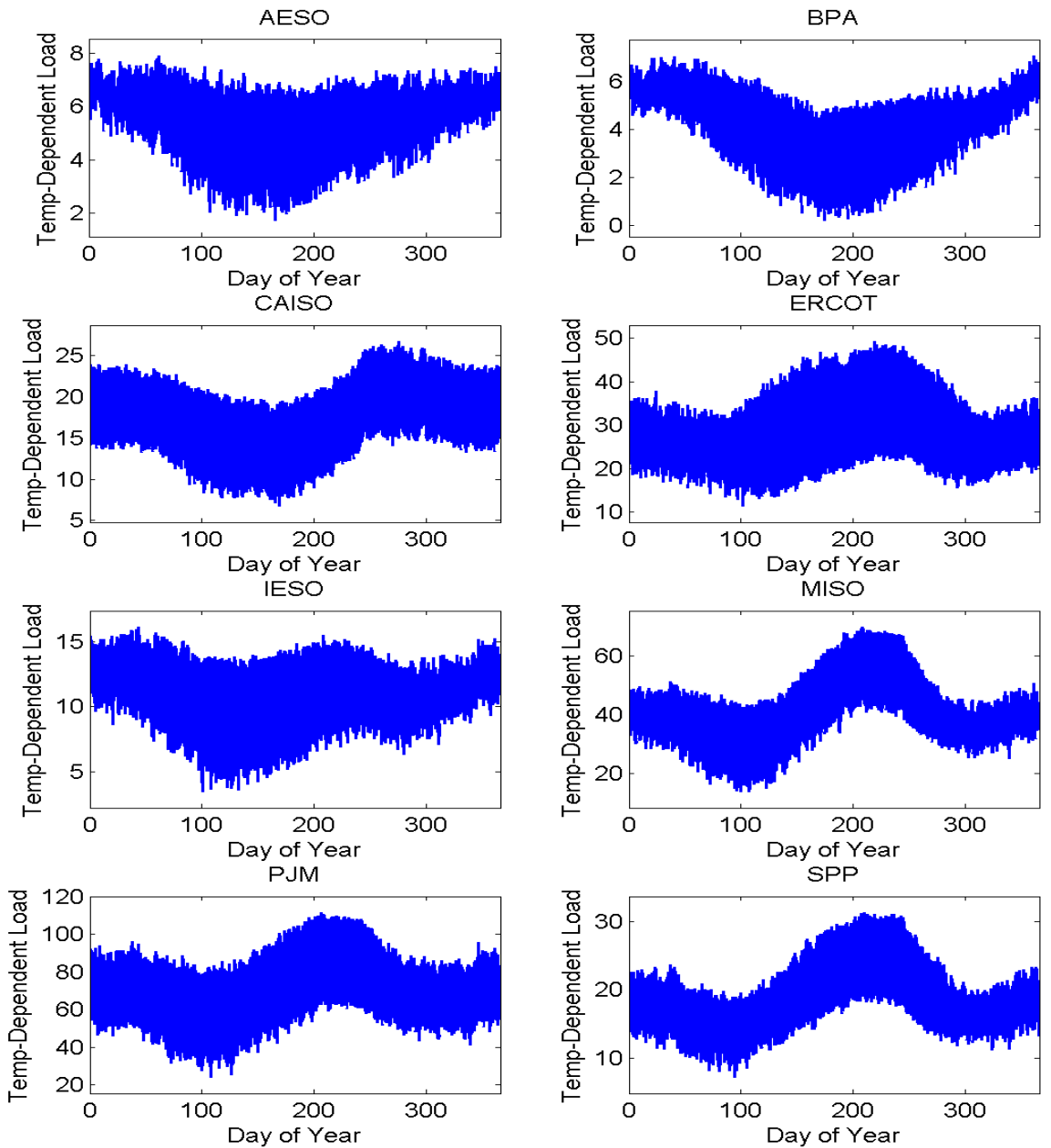
This shows well the change in the amplitude of the diurnal cycle, as well as the change in daily mean generation through the seasonal cycle.

Simulated Electrical Demand History



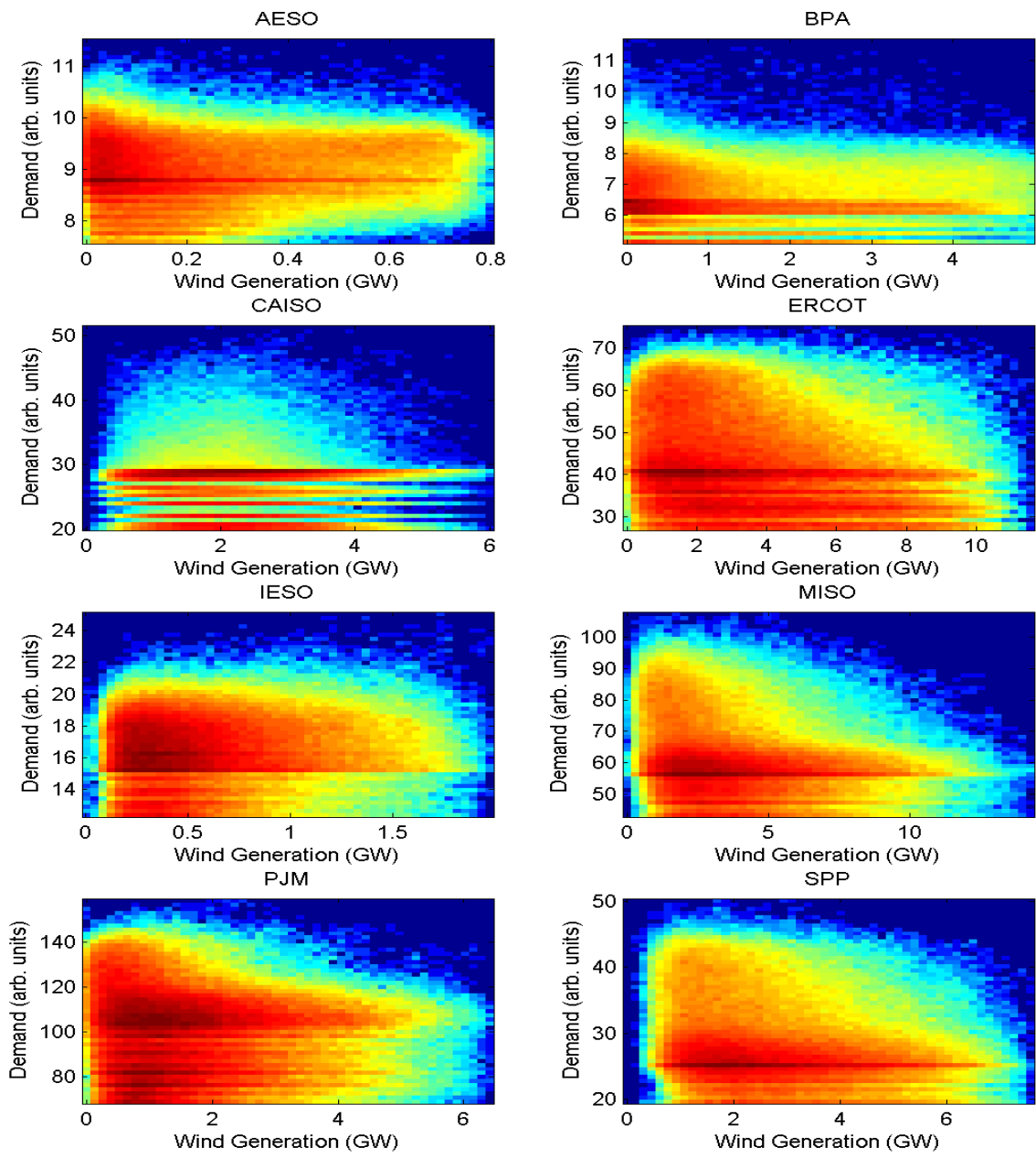
These figures show demand with renewable generation subtracted.

Simulated Electrical Demand History

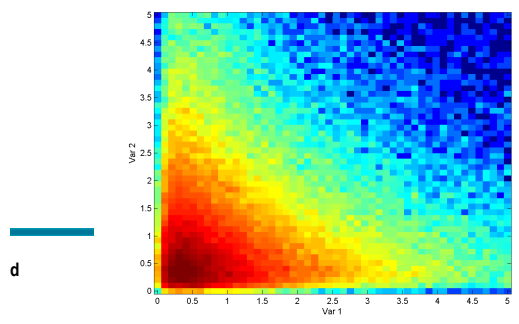


These show demand minus renewable generation for 35% renewable penetration in each RTO/ISO.

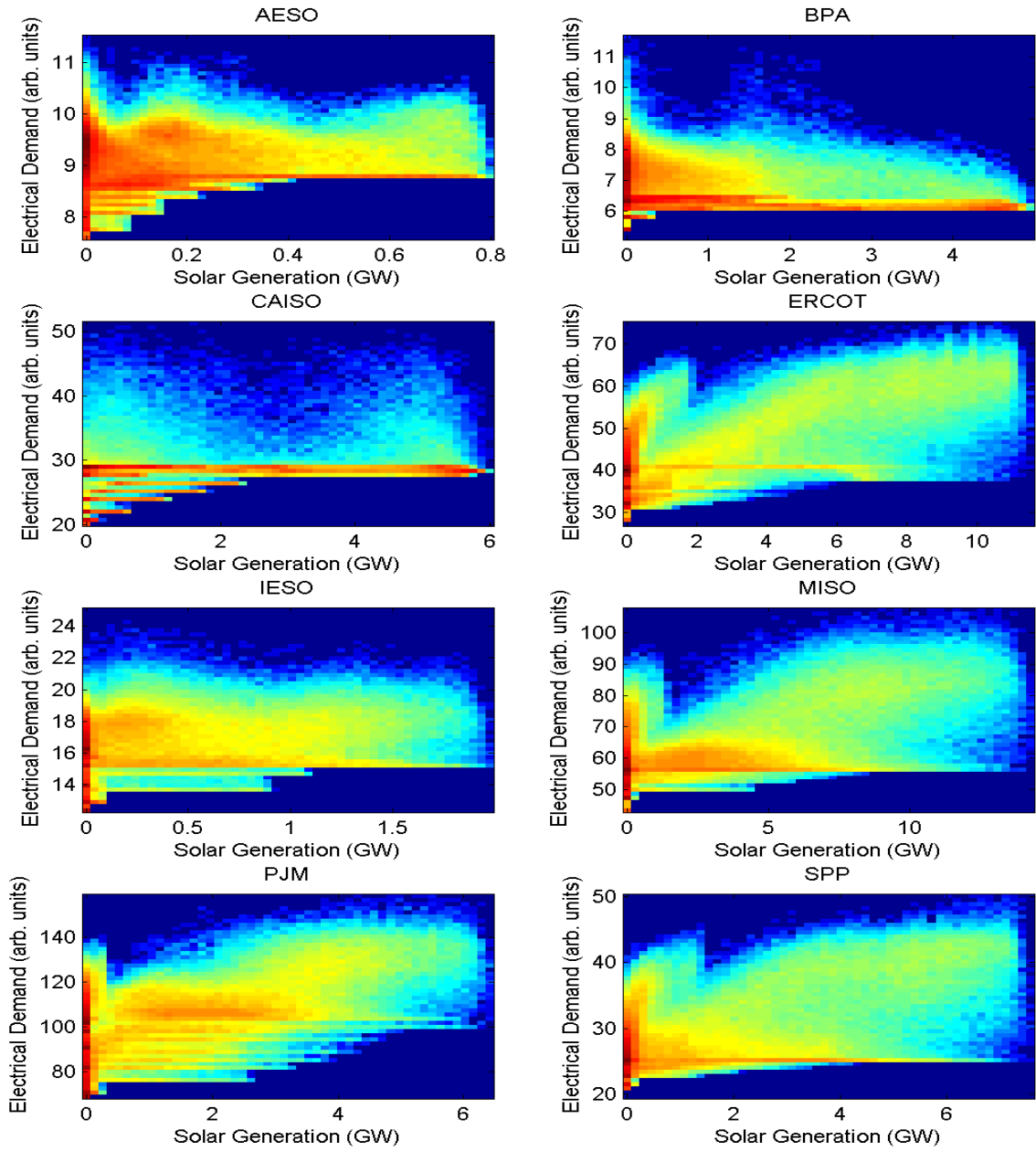
Correlation of Wind and Demand



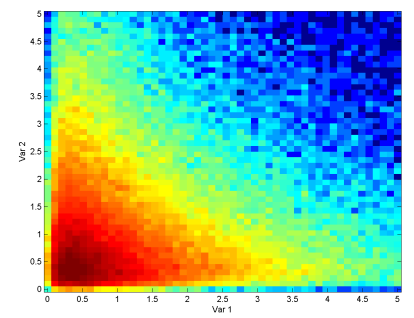
Here we show two-dimensional histograms of wind generation (horizontal axis) and temperature-dependent electrical demand (vertical axis). For reference, the same map for two log-normally distributed random variables is shown below. Some of the relationships (MISO) are “worse” than random, in the sense of preferentially low generation during times of high demand and vice versa, while others are “better” (AESO, PJM).



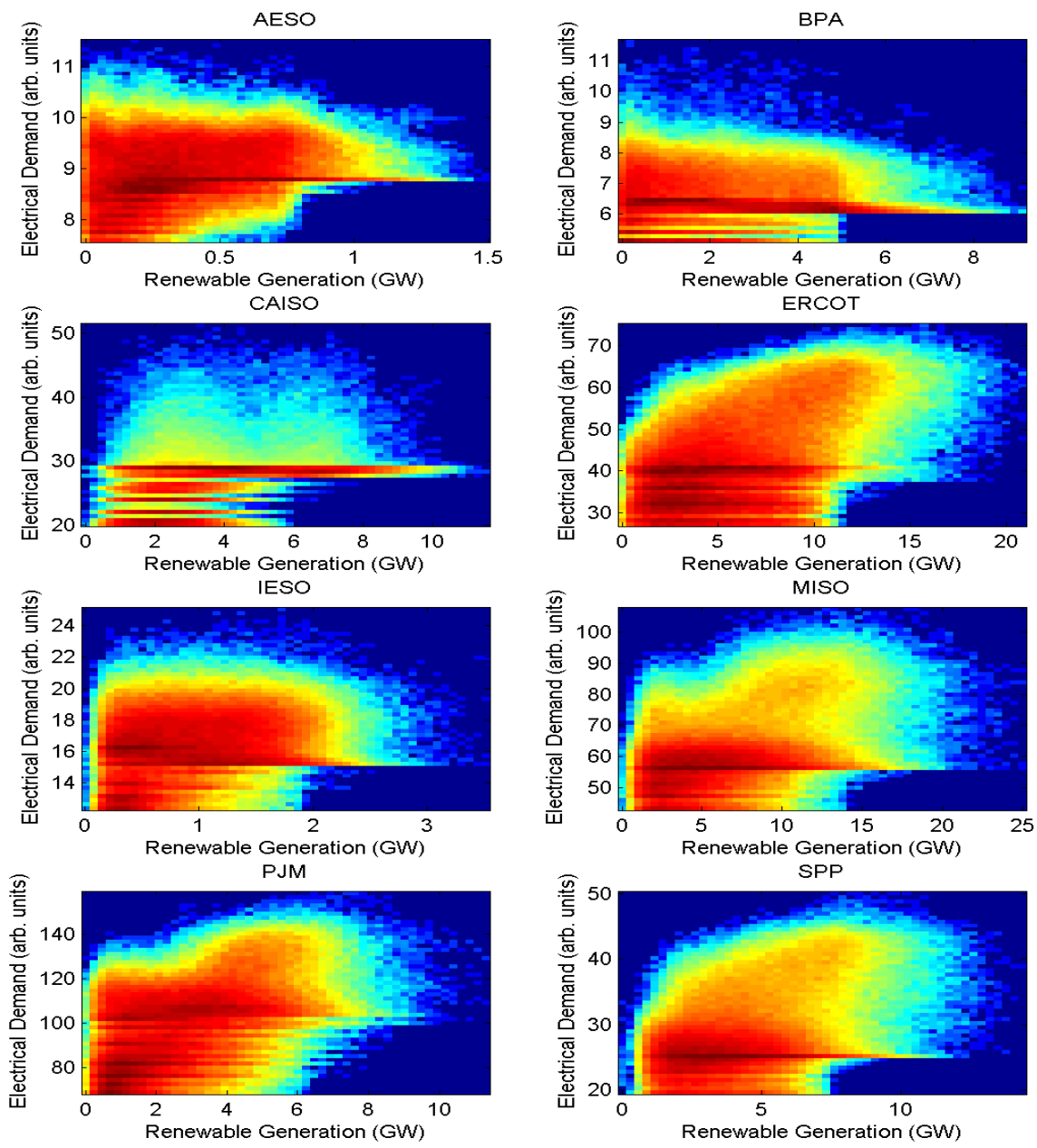
Correlation of Solar and Demand



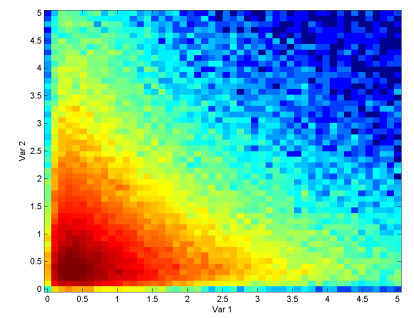
Here we show two-dimensional histograms of solar generation (horizontal axis) and electrical demand (vertical axis). Correlations range from 0.03 in BPA to 0.72 in ERCOT.



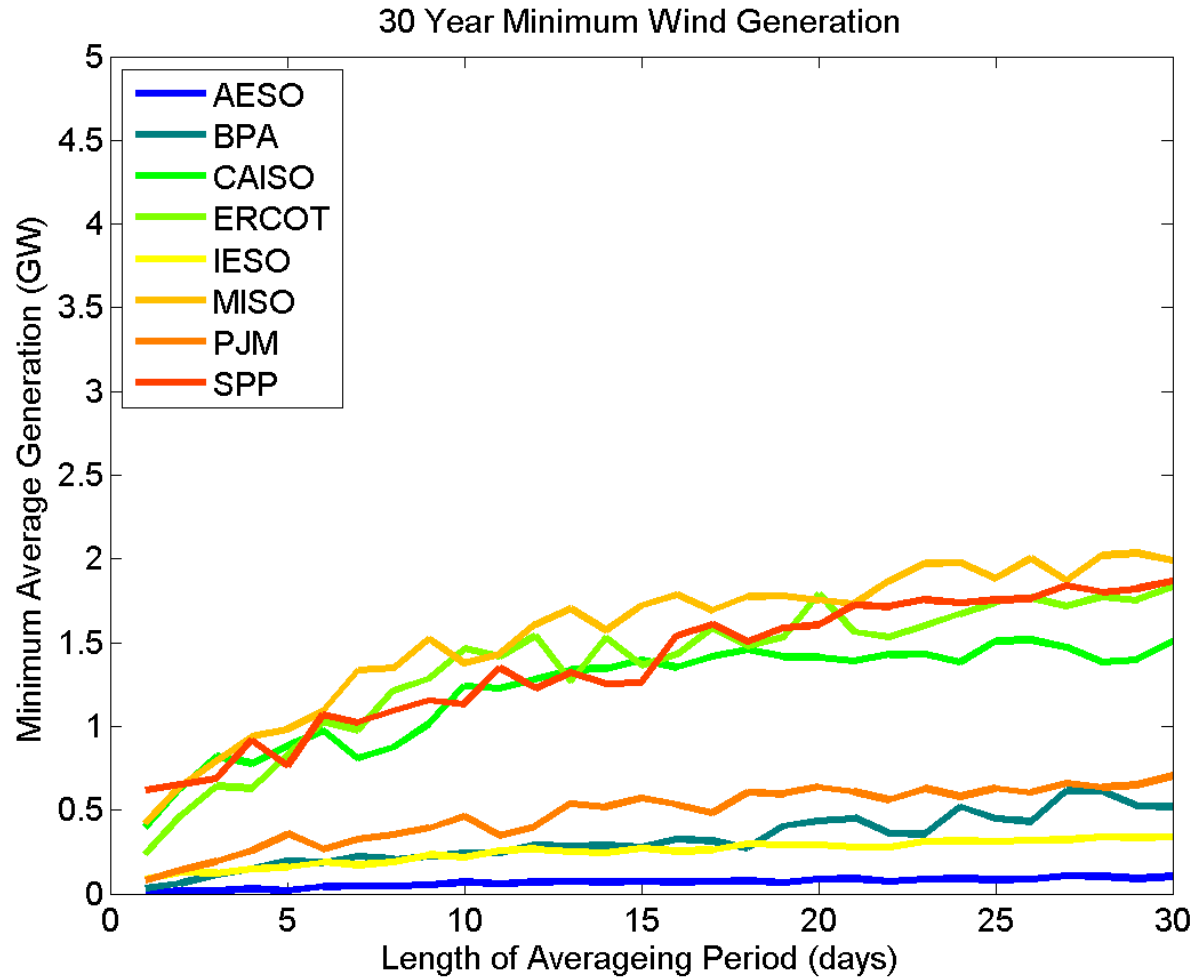
Correlation of Renewables and Demand



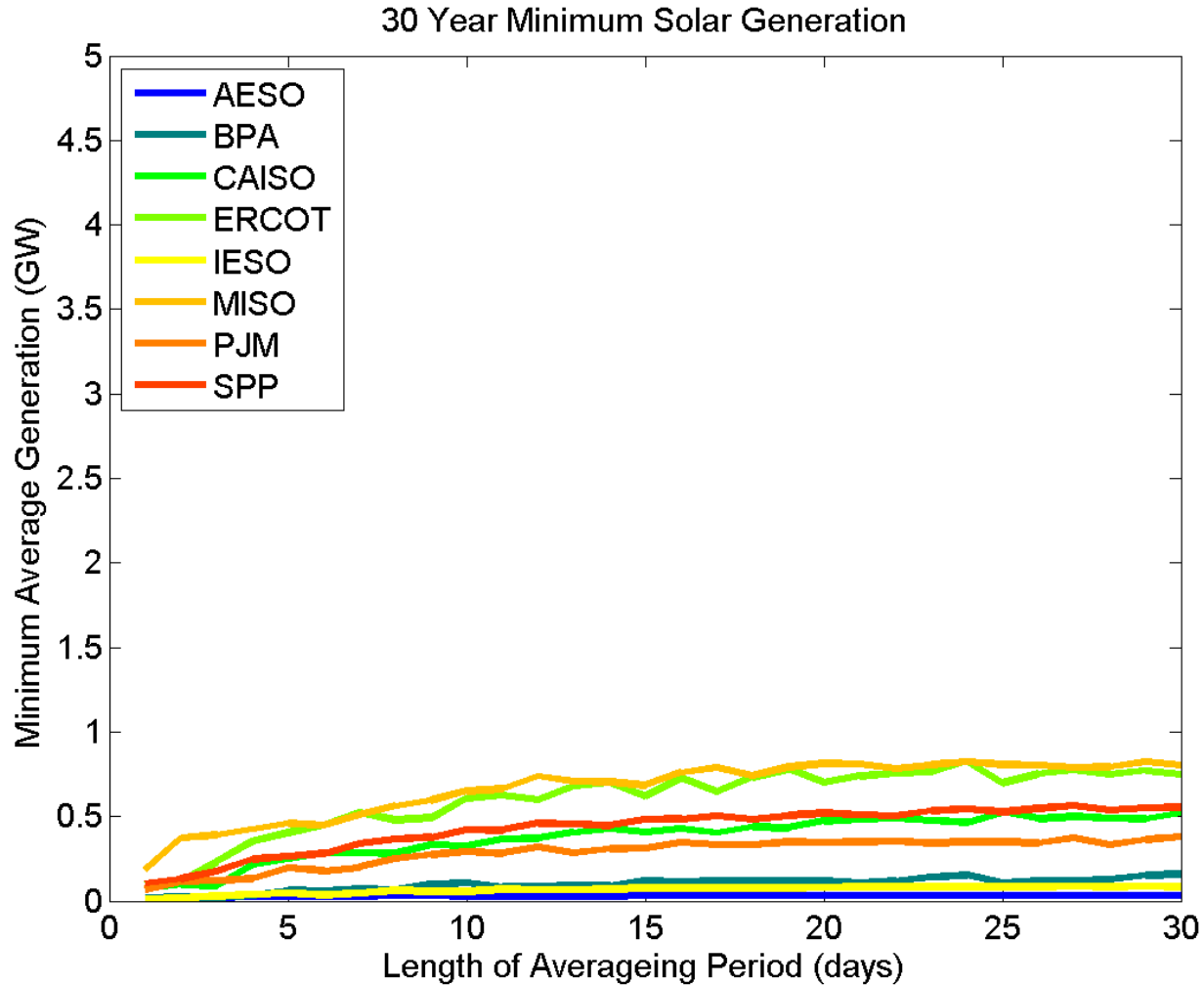
Here we show two-dimensional histograms of total renewable generation (wind + solar, horizontal axis) and electrical demand (vertical axis). Correlations range from 0.00 in BPA to 0.48 in ERCOT.



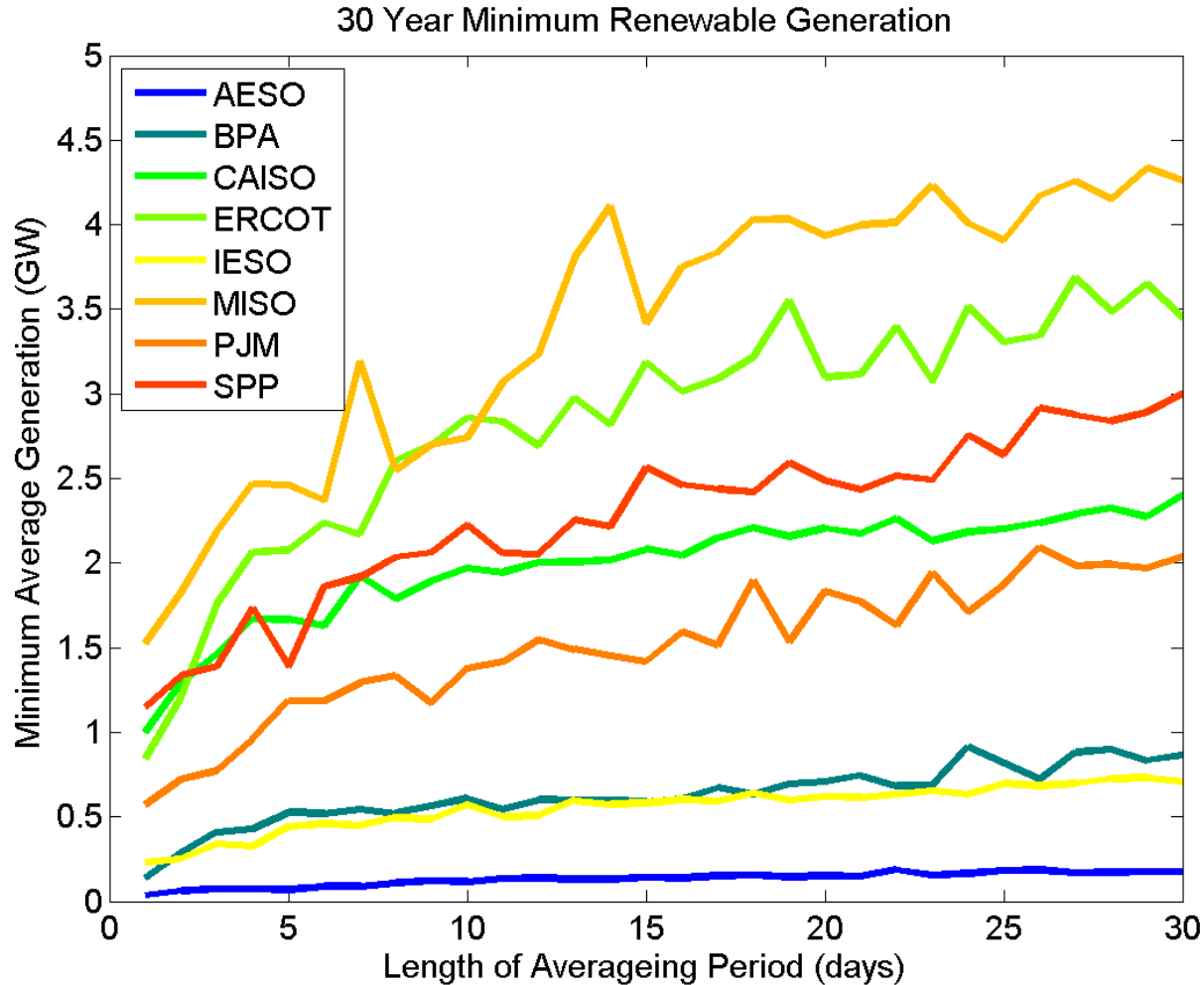
Generation Droughts



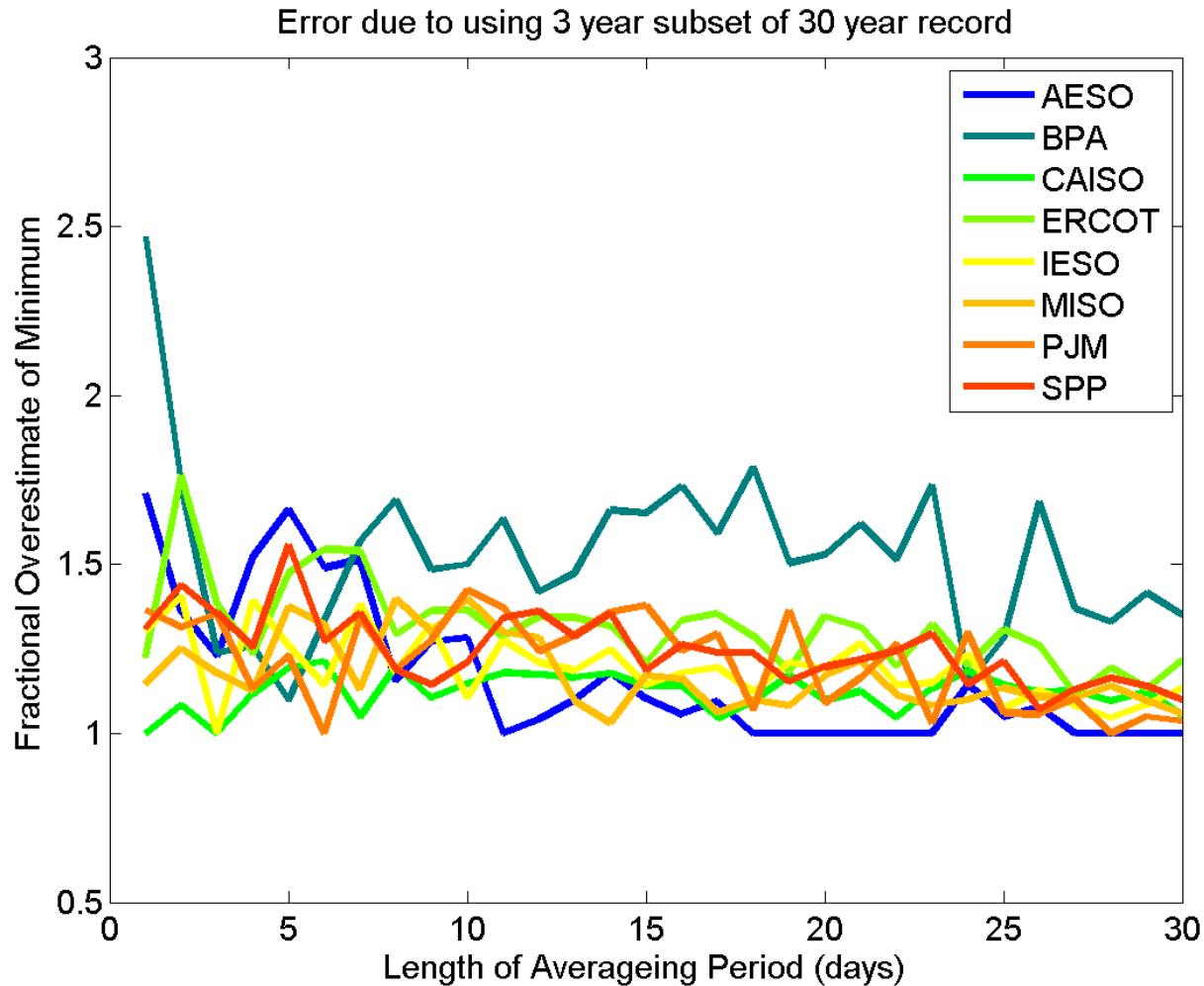
Generation Droughts



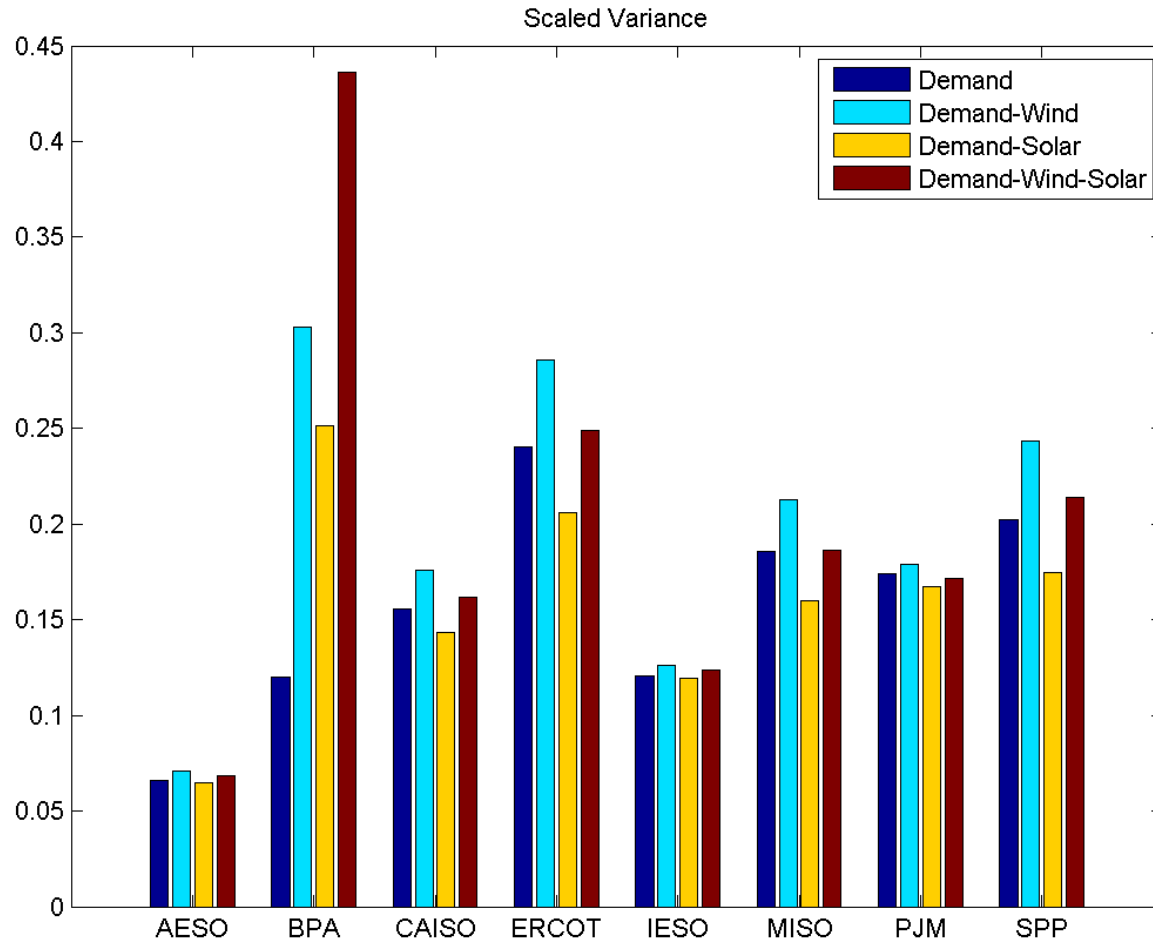
Generation Droughts



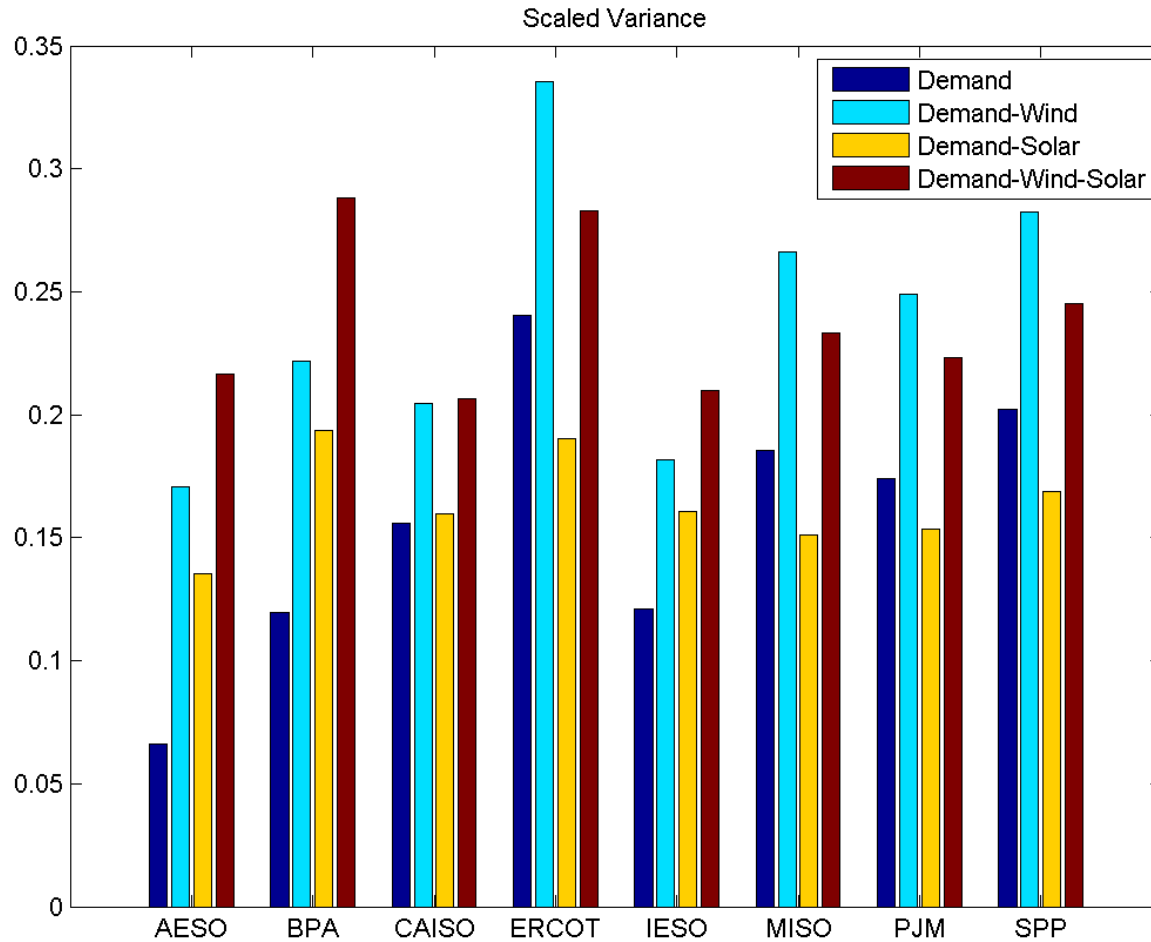
Generation Droughts



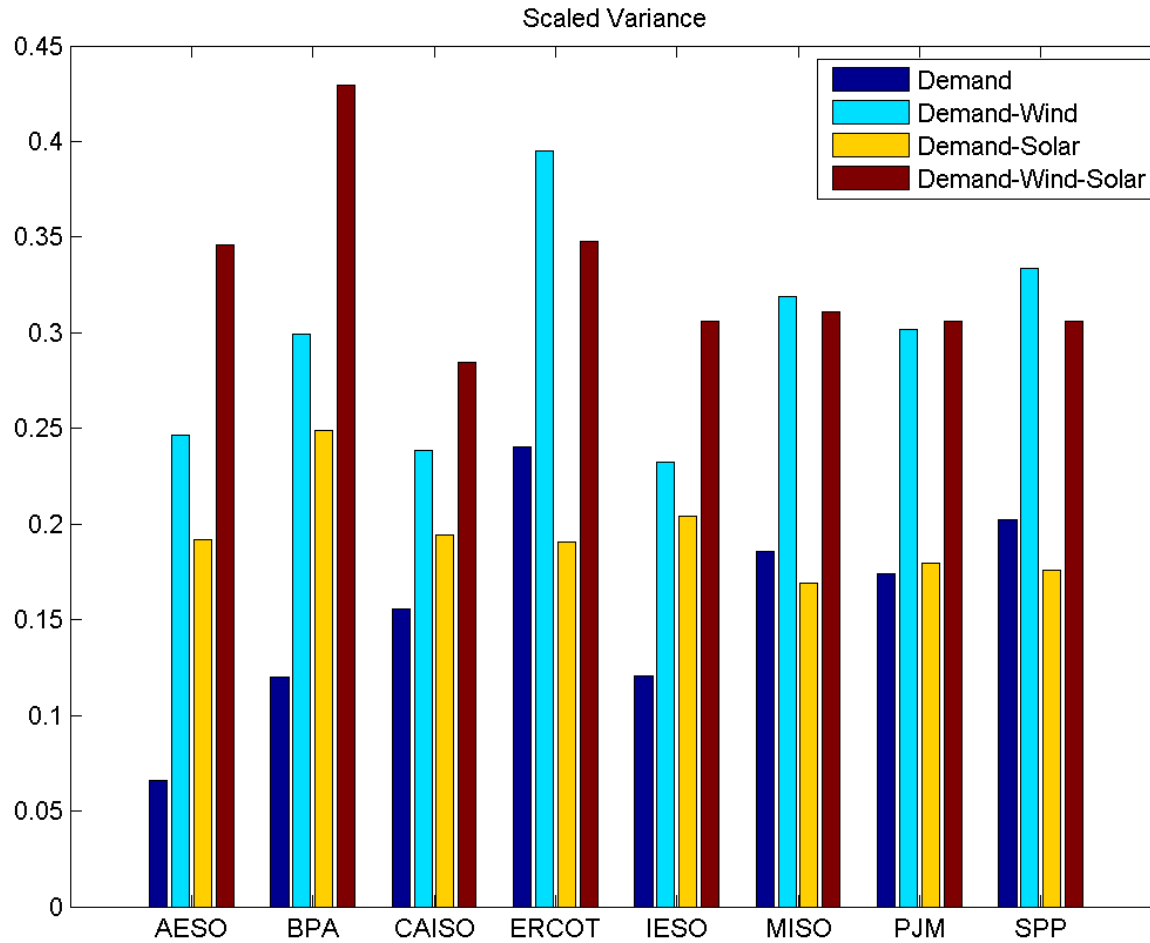
Over-all variance for present wind, scaled solar



Over-all variance for 25% renewable generation



Over-all variance for 35% renewable generation



Conclusions

- Renewable generation (solar, wind and combined) variability has very different characteristics in different regions.
- Reanalysis does a good job reproducing wind generation and demand variability. High resolution is probably not necessary, given our ample observed generation record.
- Determination of reanalysis's ability to reproduce subtler aspects of solar variability will have to wait for more installed capacity for validation.
- A thirty year record of simulated generation allows improved estimates of rare events vis-à-vis a shorter record, but the advantage isn't overwhelming