Analyzing the Effects of Temporal Wind Patterns on the Value of Wind-Generated Electricity at Different Sites in California and the Northwest

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Research Questions

Focusing on California and the Northwest:

- How large of an effect can the temporal variation of wind power have on the value of wind in different wind resource areas?
- Which locations are affected most positively or negatively by the seasonal and diurnal timing of wind speeds?
- How compatible are wind resources in the Pacific Northwest and California with wholesale power prices and loads in either region?
- Can modeled/estimated wind data from AWS TrueWind help answer such questions?

Outline of Report

1) Introduction
2) Data Series Used for the Analysis
3) Effects of Wind Timing on the Value of Wind Power, Using TrueWind Data
4) Comparison of Results for TrueWind, Anemometer, and Production Data
5) Effects of Monthly and Diurnal Timing on the Value of Wind Power
6) Conclusions
7) Appendix: Validation of TrueWind Temporal Wind Speed Estimates

Methods Summary

Wind Speed Data

- TrueWind modeled wind-speed estimates (main emphasis)
- Anemometer measurements (secondary emphasis)
- Actual wind power production data (tertiary emphasis)

Wind Value Metrics

- Capacity factor during top 10% of historic (2000-04) peak load hours
- Historic wholesale market value (historic PX prices [1998-99] and Mid-C hub prices [2002-05])
- Forecast wholesale market value (avg. 2006-13, CEC forecast from 2003; avg. 2006-25, NWPPC forecast from 2005)

Summary of Key Findings (1)

Temporal patterns of wind production have a moderate impact on the wholesale market value of wind power and a larger impact on the capacity factor during peak load hours

- **Wholesale Prices:** Depending on the wind site, wholesale market values range from 11 percent below to 4 percent above the average wholesale-market spot price
- **Peak Load Hours:** Depending on the wind site, power production during peak demand hours ranges from about 50 percent below to about 40 percent above the average during the year

Value of wind power in wholesale spot markets in California and the Northwest is not *substantially* different from a flat block of power, and varies from one site to the next by at most ~15%; variation in expected production during the top 10% of peak load hours is substantially greater

Summary of Key Findings (2)

Northwestern loads appear well served by Northwestern wind and poorly served by California wind; results are unclear for CA loads

- Both the TrueWind and anemometer data indicate that Northwestern markets and loads would be well served by Northwestern wind sites and poorly served by most California resource areas
- TrueWind data indicate that California's markets and loads are relatively poorly matched by most California and Northwestern wind sites, but the anemometer data suggest that they would be well matched by many of the same sites

California's major wind passes are spring-summer peaking, but the strong diurnal profile is less attractive in matching California's summer-afternoon peaking demand/prices

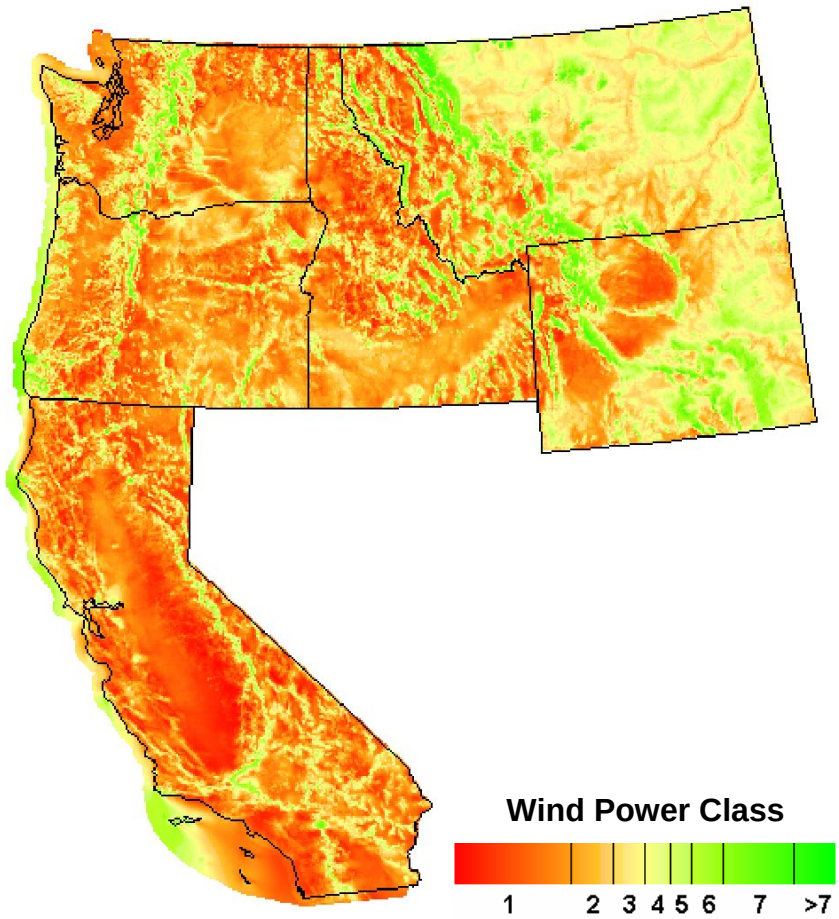
Northwestern wind sites have a more variable wind profile, with some spring-summer peaking resources, and other fall-winter-spring peaking resources that are a good match to the Northwest's winter peaking load/prices; diurnal profiles in Northwest are less pronounced, in general, than in California

Summary of Key Findings (3)

TrueWind and anemometer data generally agree about temporal wind speeds in most times and places, but disagree about California's summer afternoon wind speeds

- The TrueWind data indicate that wind speeds in California's coastal mountains and some Northwestern locations dip deeper and longer during summer days, as compared to anemometer data
- Disagreement is significant, and results in a poorer match between expected wind production and load/prices using the TrueWind data than when using the anemometer data
- Further tall-tower anemometer data, or more actual wind production data, are needed to determine which of the two datasets is more accurate

TrueWind Data



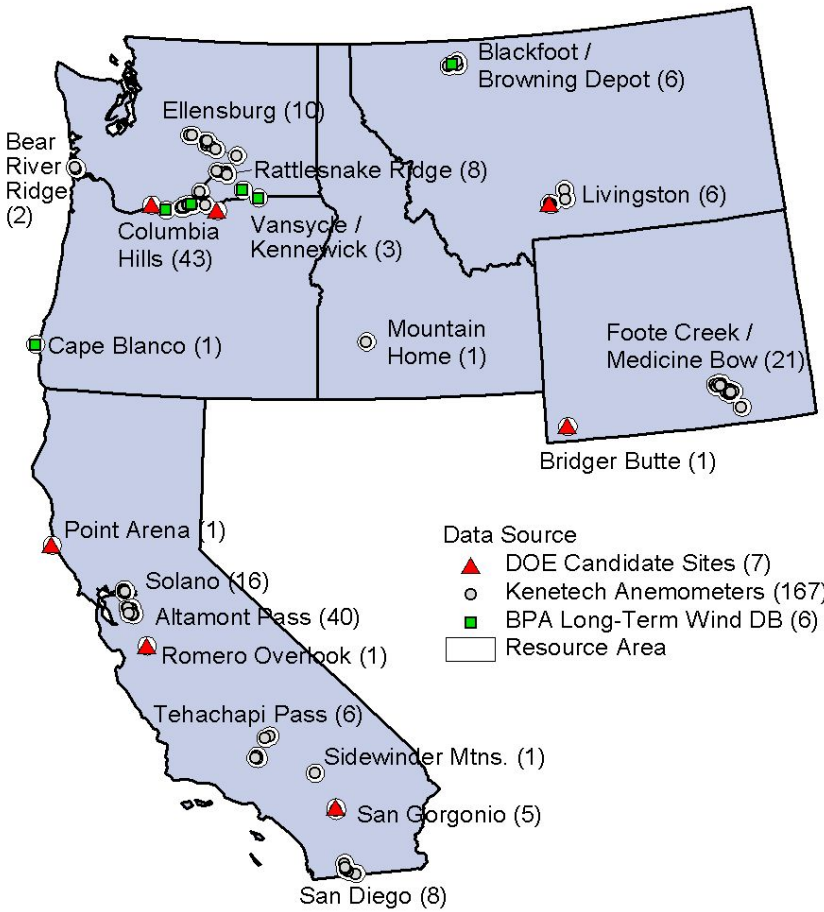
Wind speeds were modeled for 365 days, sampled from a 15-year period.

Annual average wind speeds for every cell on a 400-meter grid in the Northwest and a 200-m grid in California.

Time-varying speeds for every season-hour combination in the Northwest and month-hour combination in California, using an 8-10 km grid.

50-m elevation in the Northwest and 70-m elevation in California.

Anemometer Data



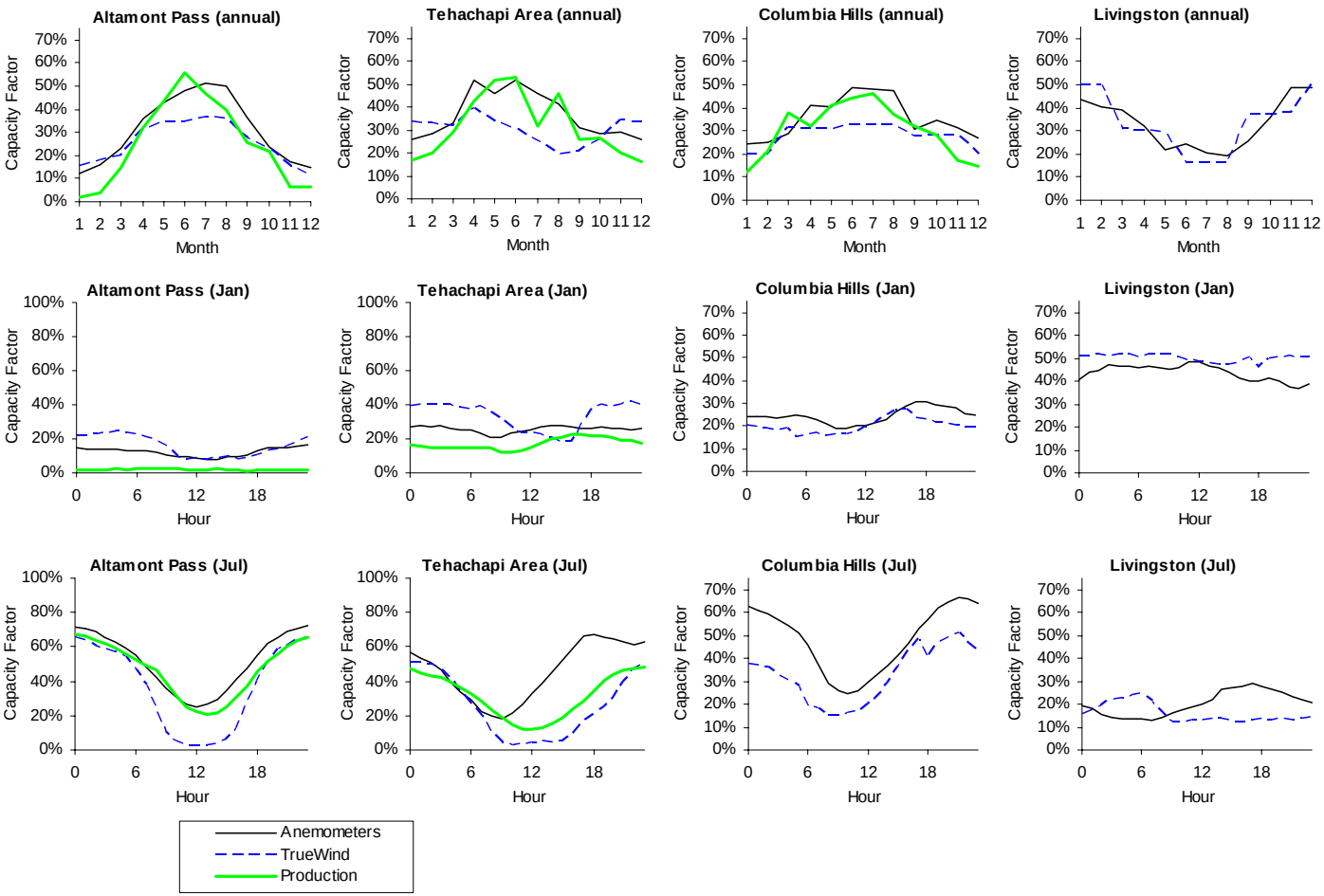
Anemometer data came from the DOE Candidate Site Program, Kenetech Windpower and the BPA Long-Term Wind Database.

Anemometers were grouped into separate “resource areas,” approximately 20 km across.

Each anemometer typically had 2-3 years of hourly wind speed data.

Most wind speeds were measured around 20-meter elevation.

Sample Wind Power Profiles



TrueWind shows deeper, longer dips in wind speed on summer afternoons in California coastal passes.

This may be due to different wind speeds at the 70-m TrueWind elevation and 20-m anemometer elevation, or may be due to modeling errors.

Data and Analysis Limitations

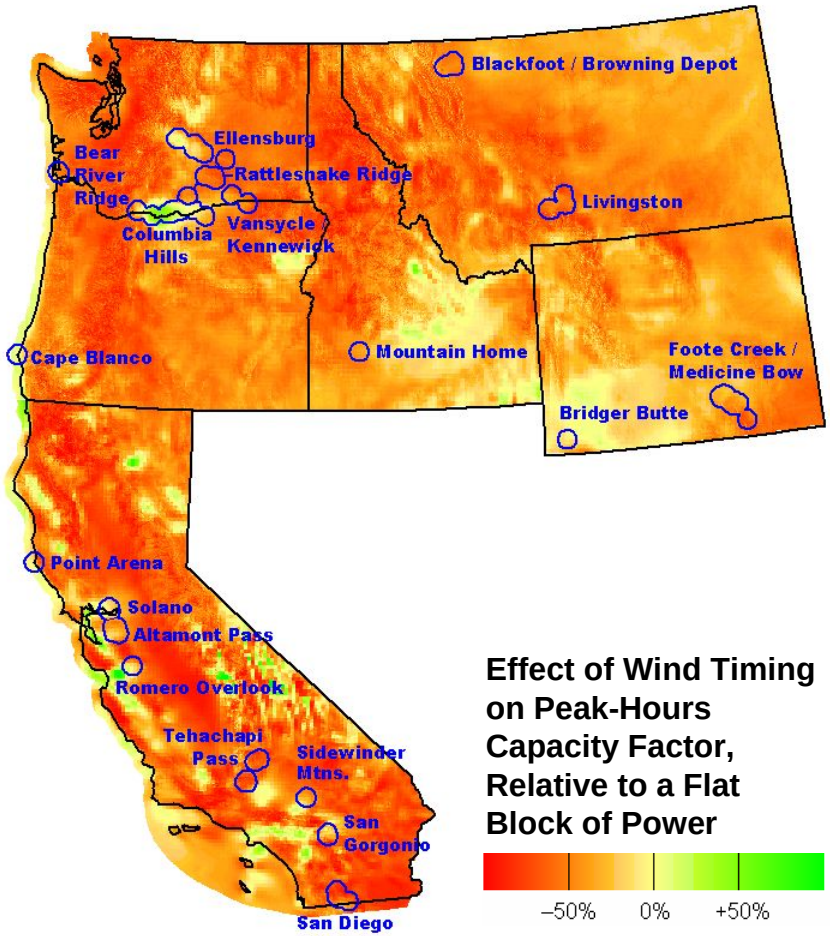
Several factors may cause the TrueWind, anemometer and production datasets to disagree, and make it difficult to say which is more accurate, including:

- **Wind Shear**
  - We estimated wind speeds at a 70 m hub height from anemometer measurements taken at lower elevations
- **Limitations of Historical Data**
  - The TrueWind, anemometer and production data generally come from different historical periods
- **Anemometer Location**
  - The locations of anemometers may be incorrect by a few kilometers in some cases, causing them to be compared to the wrong TrueWind cell
- **Spatial Resolution**
  - TrueWind's main weather model had a resolution of around 2.5 km, which is too coarse to fully resolve the geographic features in some areas
- **Modeling Uncertainty**
  - TrueWind's weather model uses limited mathematical detail, and is initialized and tuned with a limited set of real-world data

Wind Value Metrics

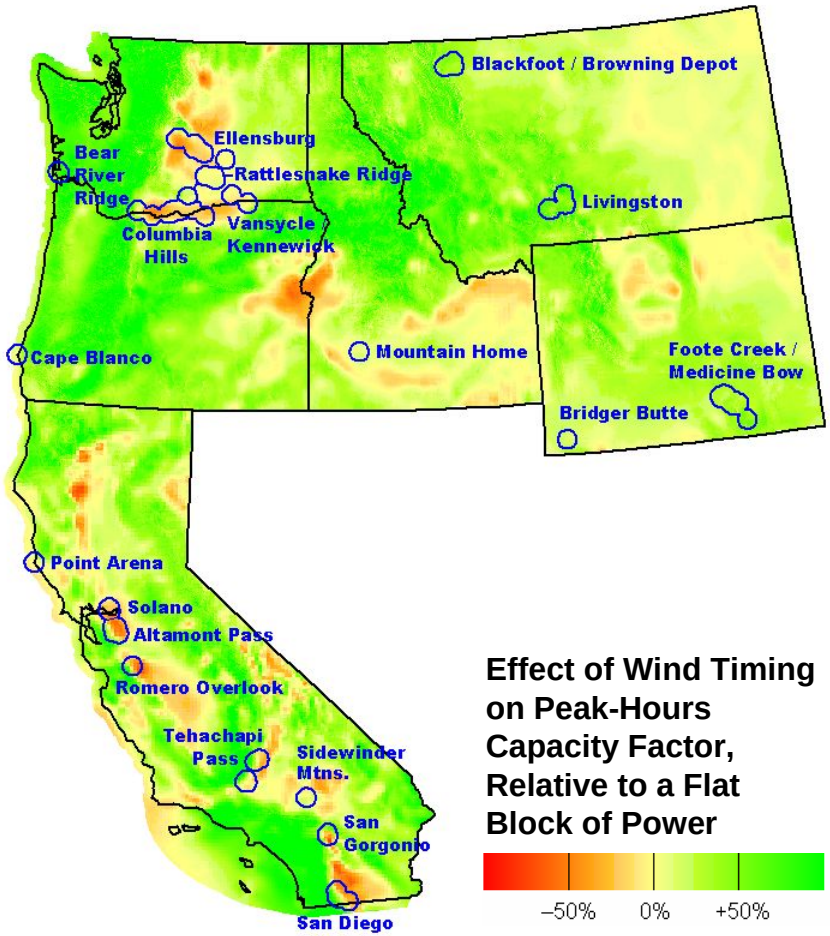
- Capacity factor during top 10 percent of load hours
  - summer afternoons in California, winter nights in the Northwest
  - reported as the percent difference relative to the annual capacity factor at the same location
- Wholesale market value of wind power
  - percent difference relative to the same amount of power delivered as a flat block in wholesale spot market, using historical and forecast wholesale power prices for California and the Northwest
- For reference
  - Class 5 site compared to Class 4: +11% in wholesale market value
  - Class 3 site compared to Class 4: -14% in wholesale market value

Effect of Wind Timing on Capacity Factor During Top 10% of California Load Hours



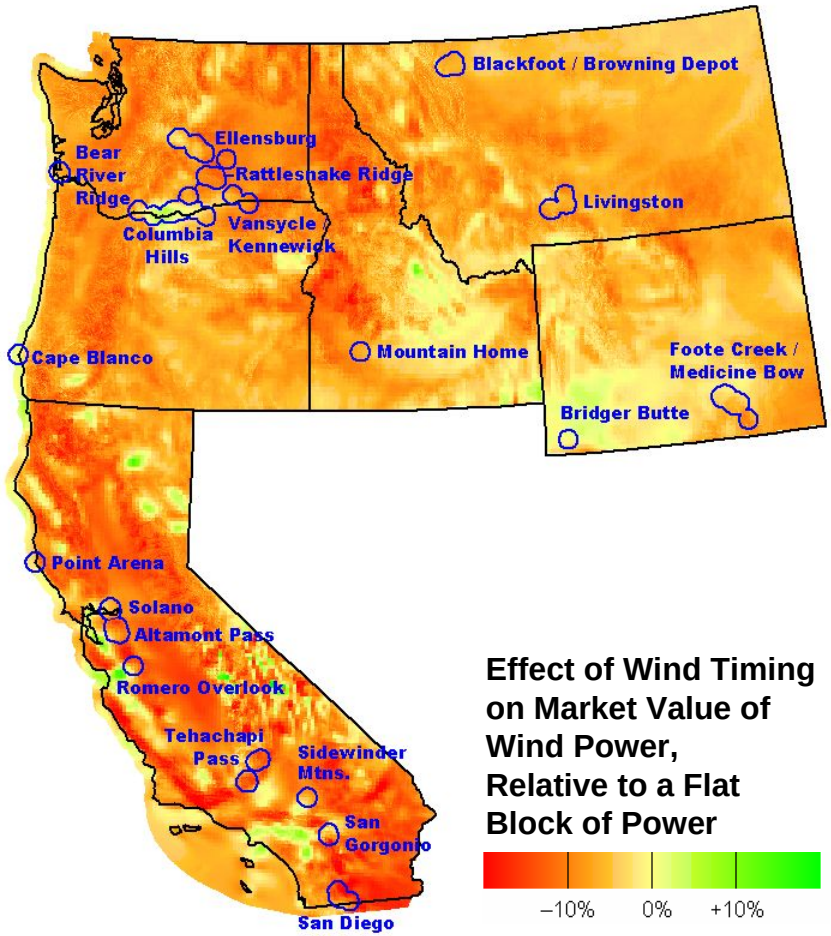
- TrueWind wind data
- Historical ***California*** loads
- Wind power production in most areas is lower than the annual average during California's peak demand hours
- Columbia Hills sites appear well-matched to California's peak loads

Effect of Wind Timing on Capacity Factor During Top 10% of Northwestern Load Hours



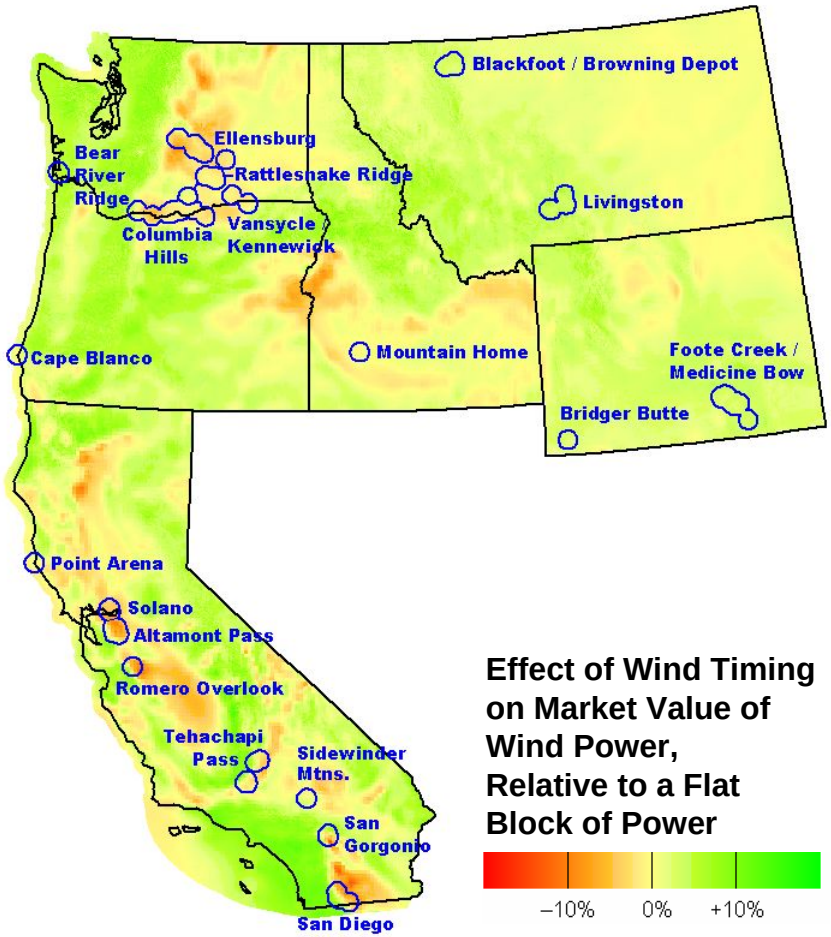
- TrueWind wind data
- Historical ***Northwest*** loads
- Wind power production in most areas is above the annual average during the Northwest's peak demand hours
- However, winds in a number of the known resource areas are neutrally or poorly matched to peak Northwest loads

Effect of Wind Timing on Market Value in California, Relative to a Flat Block of Power



- TrueWind wind data
- Historical ***California*** Prices
- Wind timing has a similar but smaller effect on market value of power, compared to peak-hours capacity factor
- Most areas are poorly matched to California's power markets, according to the TrueWind data

Effect of Wind Timing on Market Value in the Northwest, Relative to a Flat Block of Power

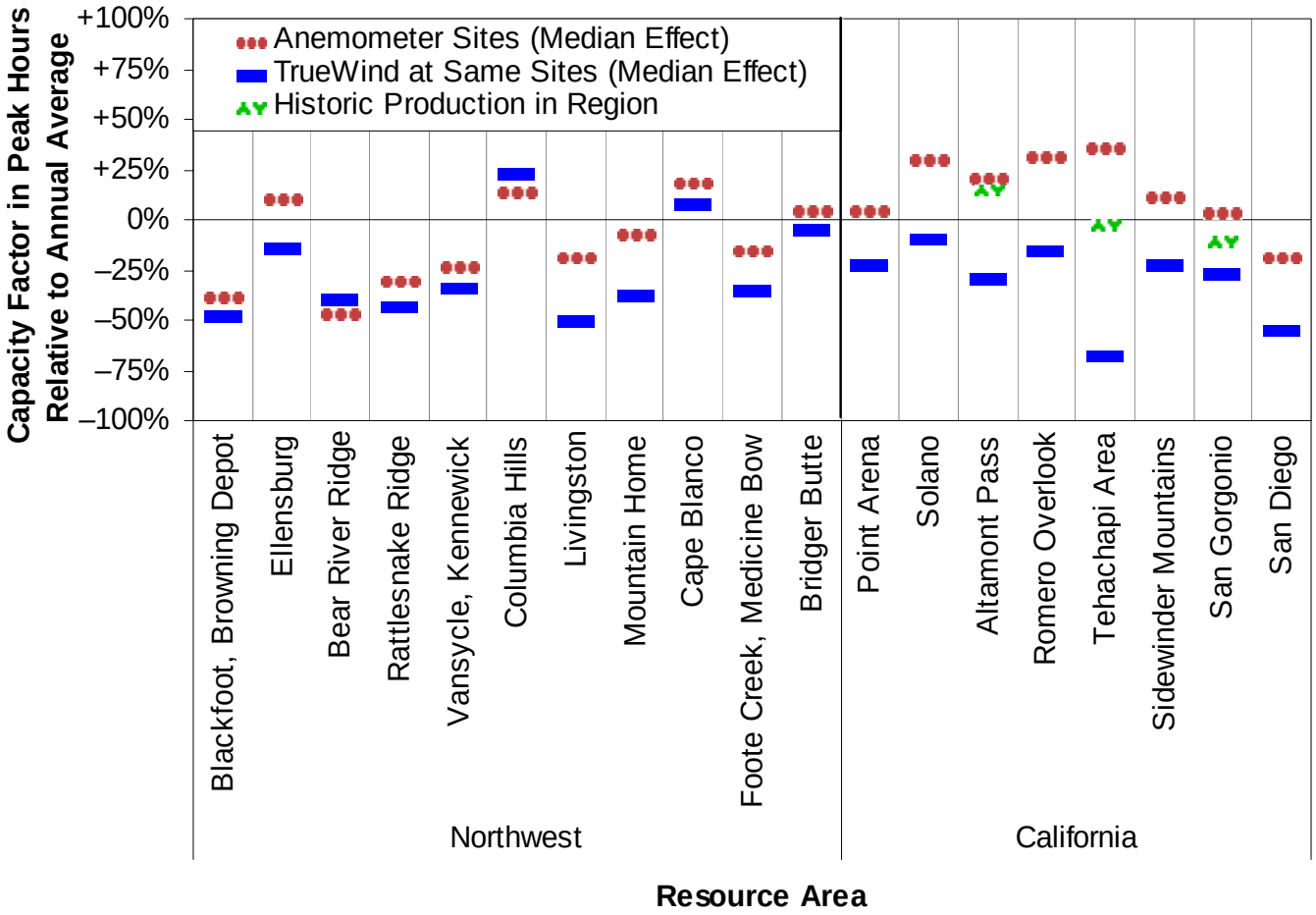


- TrueWind wind data
- Historical ***Northwest*** Prices
- Similar to effect on peak-hours capacity factor
- A number of known resource areas are neutrally or poorly matched to Northwestern markets
- Other land area is well matched to Northwestern markets

Comparative Results Between TrueWind and Anemometer Data

- In California, TrueWind data are more pessimistic than anemometers on summer afternoons
  - TrueWind data yield lower peak-hours capacity factors and lower market value for California sites
- TrueWind and anemometer data mostly agree at other times and locations, and also generally agree on the difference between the best and worst locations in California or the Northwest
- Difference between the best and worst resource areas according to TrueWind:
  - Peak-hours capacity factor: ~75%
  - Annual market value of power: ~15%
- Difference between the 10th and 90th percentile of all anemometer towers:
  - Peak-hours capacity factor: 50-70%
  - Annual market value of power: 5-10%

Effect of Timing on Peak-Hours Capacity Factor, with Historical California Loads

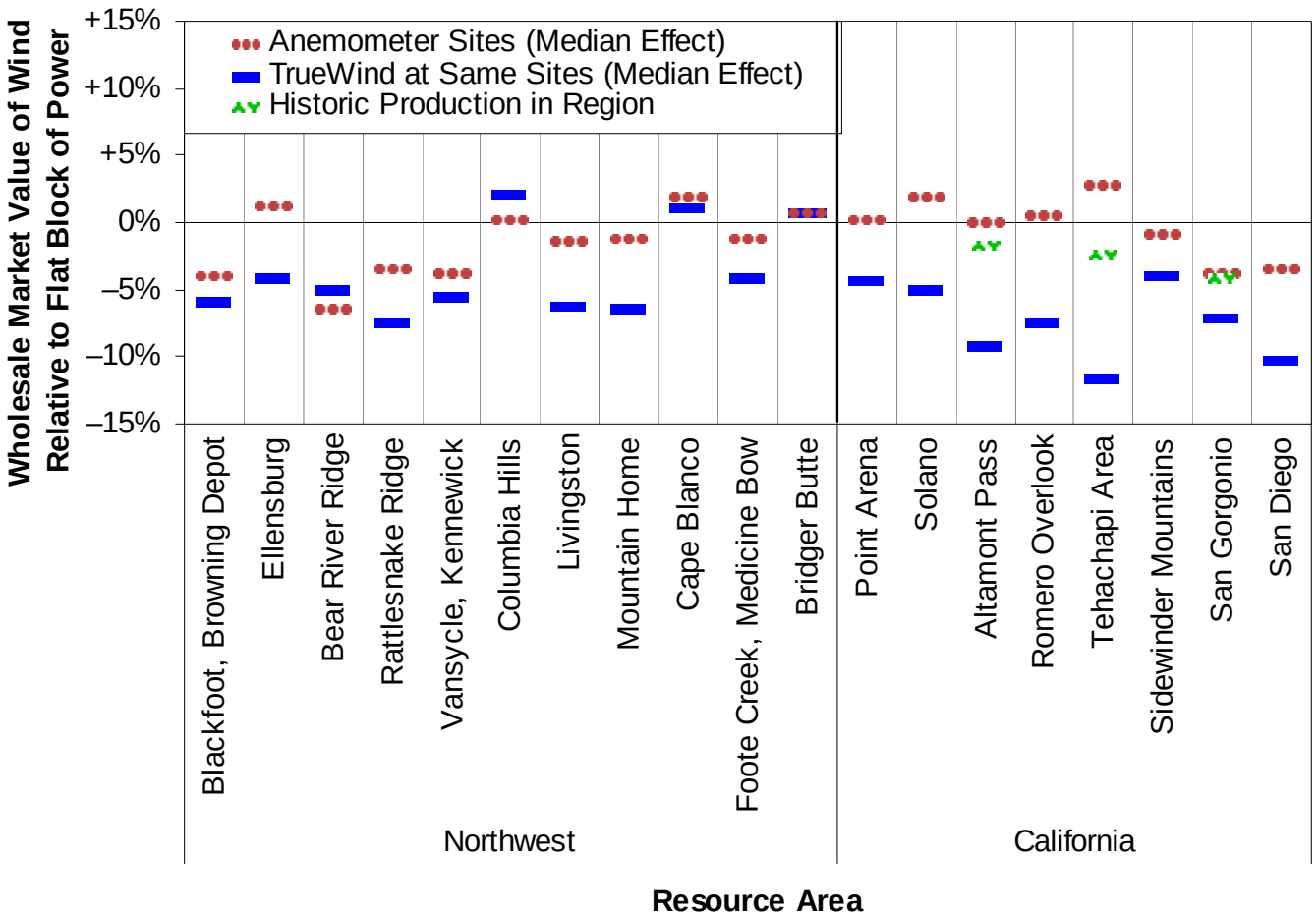


Effects in this chart depend mostly on summer afternoon wind speeds.

Moderate agreement between datasets in the Northwest, poor agreement in California.

Datasets agree on difference between best and worst sites.

Effect of Timing on Market Value of Power, with Historical California Prices



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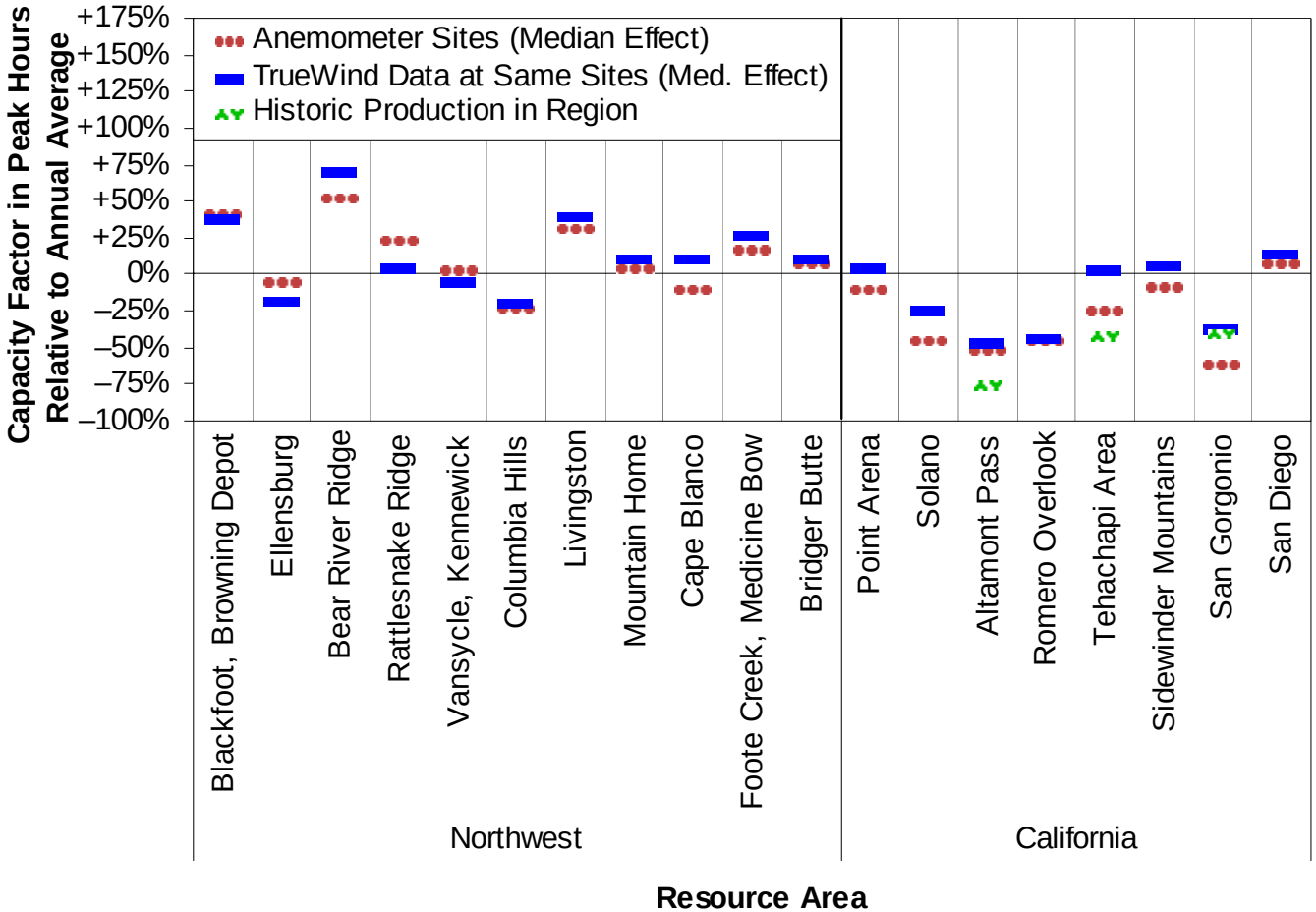
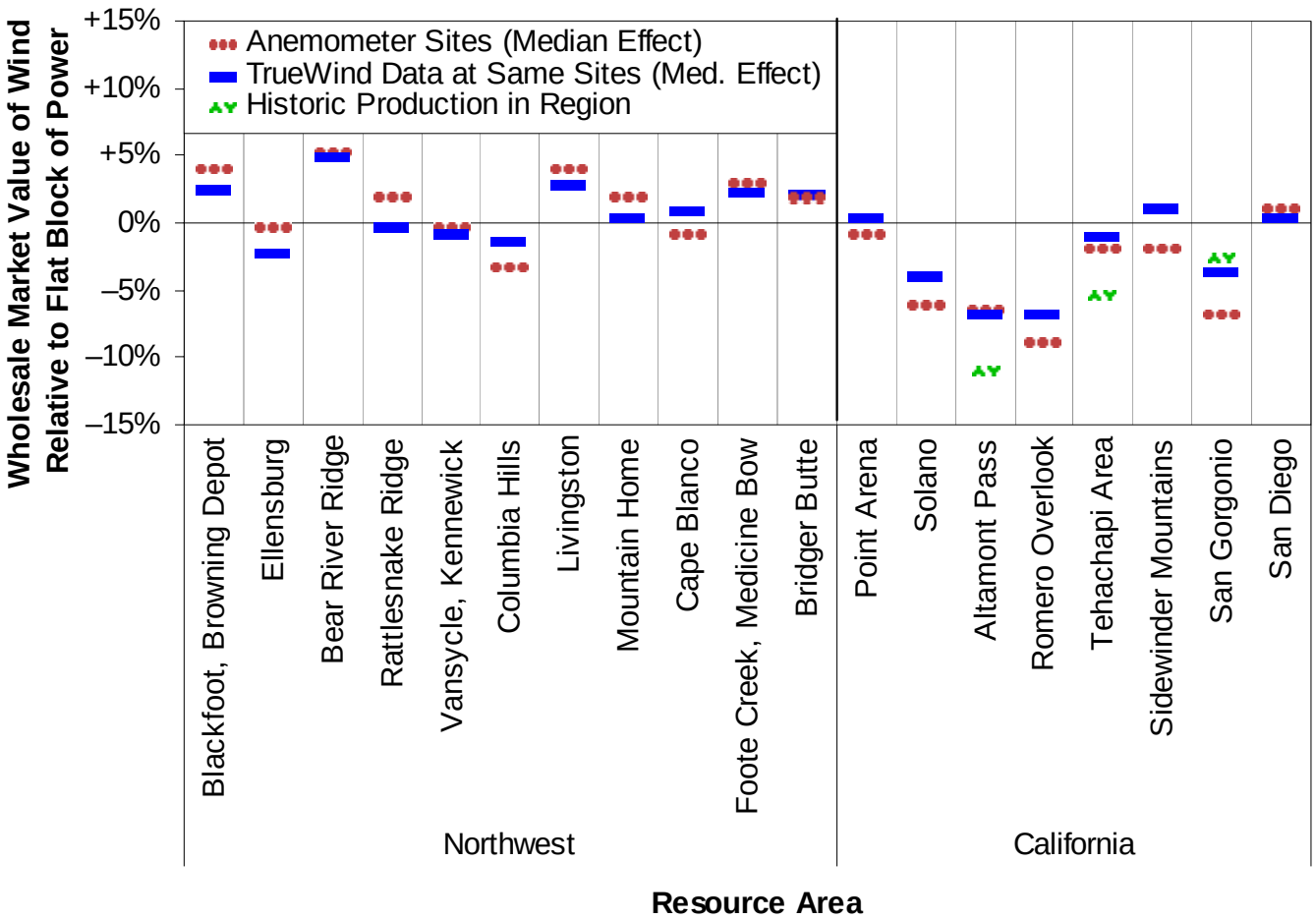
Effect of Timing on Peak-Hours Capacity Factor, with Historical Northwest Loads



Effects in this chart depend mostly on winter evening wind speeds.

Generally good agreement between the datasets.

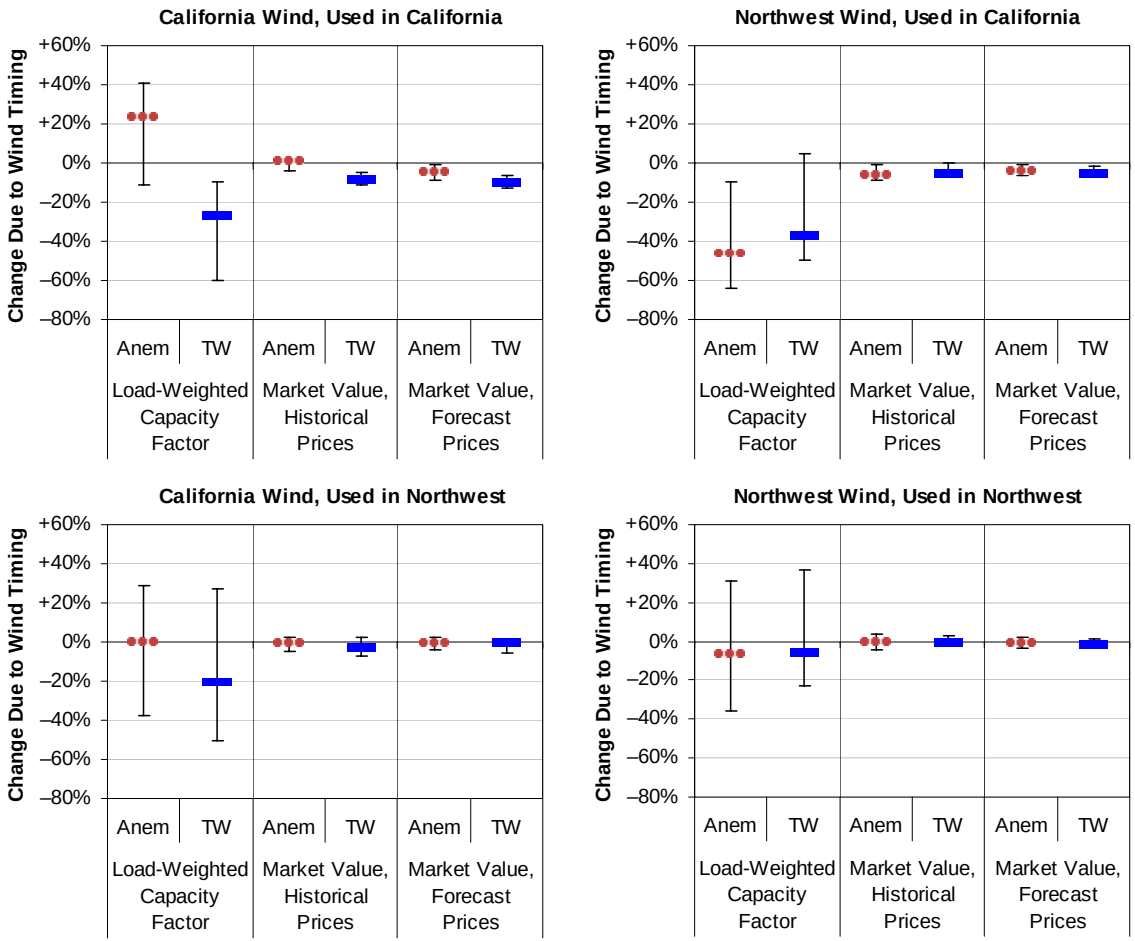
Effect of Timing on Market Value of Power, with Historical Northwest Prices



Effects in this chart depend mostly on winter evening wind speeds.

Generally good agreement between the datasets.

Effect of Wind Timing at All Anemometer Towers, Using Anemometer and TrueWind Data



Markers show median and range between 10th and 90th percentile, for all anemometer towers in each region.

Northwest wind appears better suited for Northwest markets.

California wind may be better suited for California, but results are ambiguous.

Anemometers and TrueWind disagree about the value when California wind is used in California.

Conclusions

- Temporal patterns of wind production in California and the Northwest have a relatively modest impact on the wholesale market value of wind *(even the worst sites have a wholesale market value of just 10% below a flat block of power)*
- Temporal patterns of wind production that vary from one site to the next have a larger impact on production during the top 10 percent of peak load hours
- California's major wind passes are spring/summer peaking, but the diurnal profile is less attractive in matching California's summer-afternoon peaking demand and prices; Northwestern wind sites have a more variable wind profile, with some spring/summer peaking resources, and many winter peaking resources
- TrueWind modeled data provides useful insight into temporal wind patterns, but additional validation with tall-tower anemometer data or actual wind production data is needed

For More Information...

Download the full report from:

http://eetd.lbl.gov/ea/ems/re-pubs.html

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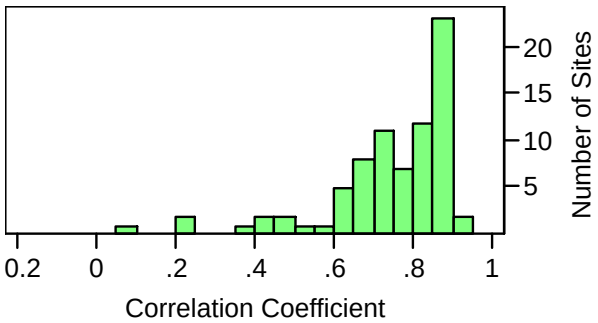
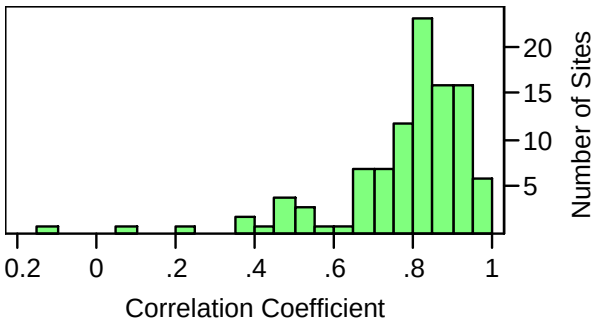
Validation Efforts: TrueWind Estimates vs. Anemometer Measurements

Correlation Between TrueWind and Anemometer Wind Speeds at Individual Towers

California Sites



Northwest Sites



Correlation coefficient shows how well the TrueWind and anemometer data match at each anemometer tower.

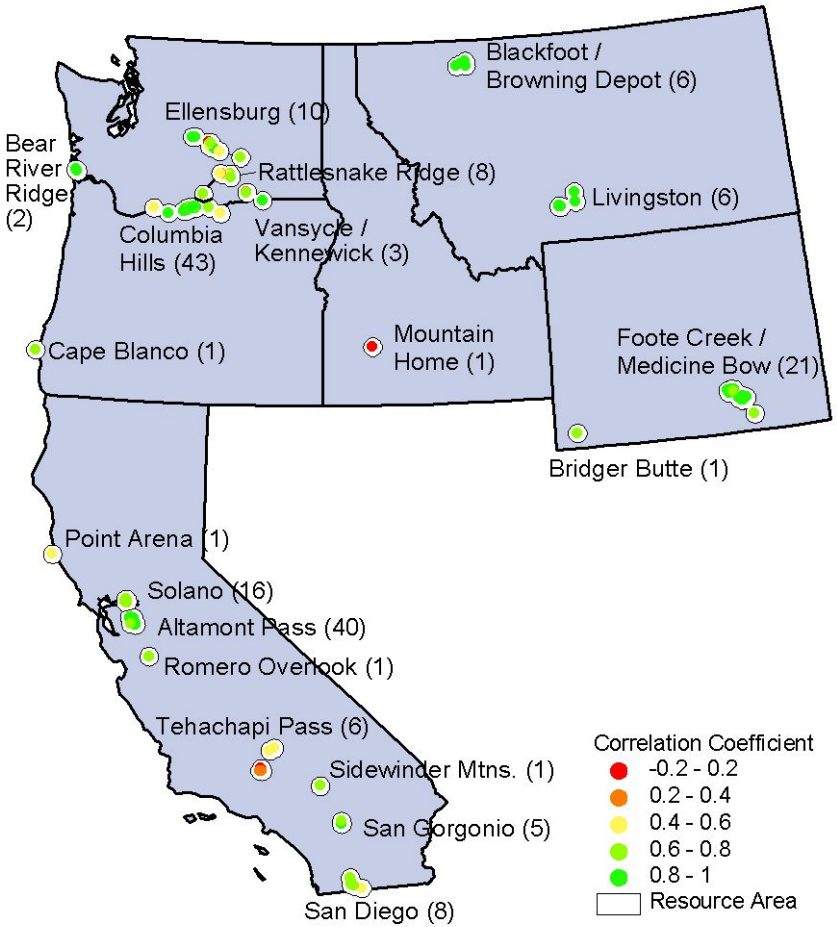
Median correlation coefficient in California: 0.786 (R^2=0.62)

Median correlation coefficient in the Northwest: 0.823 (R^2=0.68)

TrueWind data reflected about 62 percent of the variation in the anemometer data at a typical site in California, and about 68 percent of the variation in the Northwest.

Disagreements may be due to differences in wind speed between the anemometer height (20-30m) and the TrueWind height (50-70m), inaccuracy in the TrueWind model (e.g., inability to resolve terrain features below about 10km), or selection of different years for the TrueWind and anemometer data.

Correlation Between TrueWind and Anemometer Wind Speeds at Individual Towers

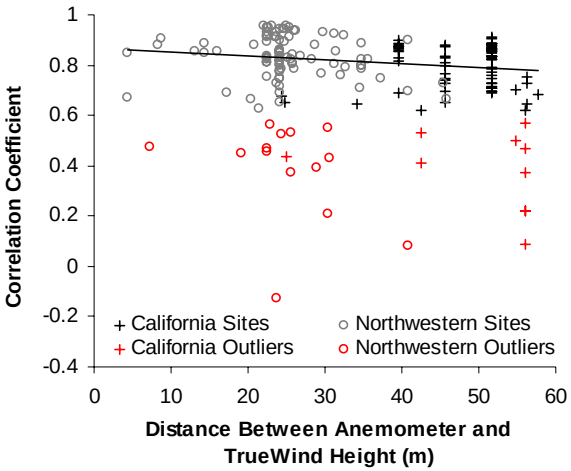


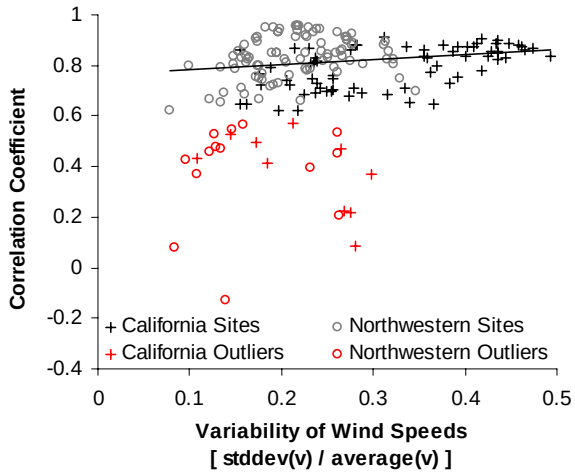
TrueWind and the anemometers matched poorly (R<0.5) in Tehachapi, Point Arena and Mountain Home.

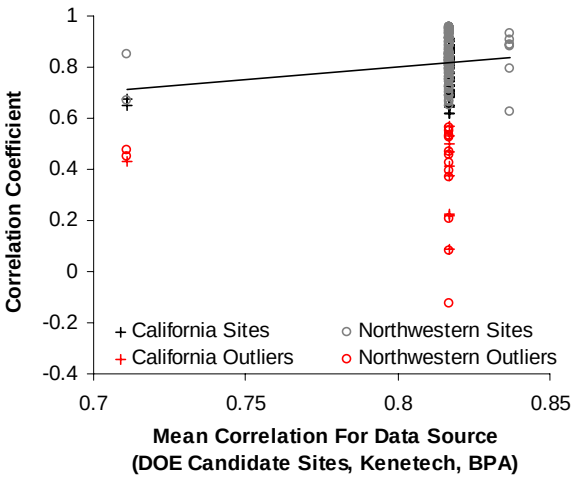
The datasets matched moderately well (0.5<R<0.7) in Romero, San Diego, Vansycle, Rattlesnake Ridge, and Ellensburg.

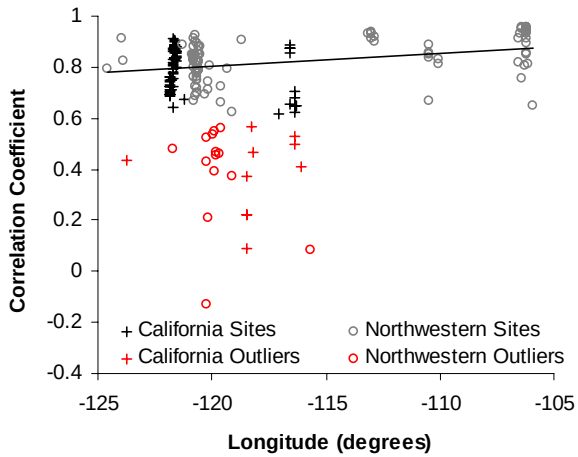
The datasets matched well (R>0.7) elsewhere.

Factors Affecting the Fit Between TrueWind and Anemometer Data









The quality of fit between TrueWind and anemometer data rises for anemometers closer to the TrueWind model height, sites with more variable wind speeds, Kenetech or BPA anemometers, and sites further inland.

The poorest-matched sites did not fit this pattern. These included all of the towers in the Tehachapi area and about half of the Rattlesnake Ridge, Ellensburg and San Diego towers. This may indicate a systematic problem in modeling these regions.