Long-term Wind Speed Estimates from Short-term Data: So Many Ways to Get it Wrong!

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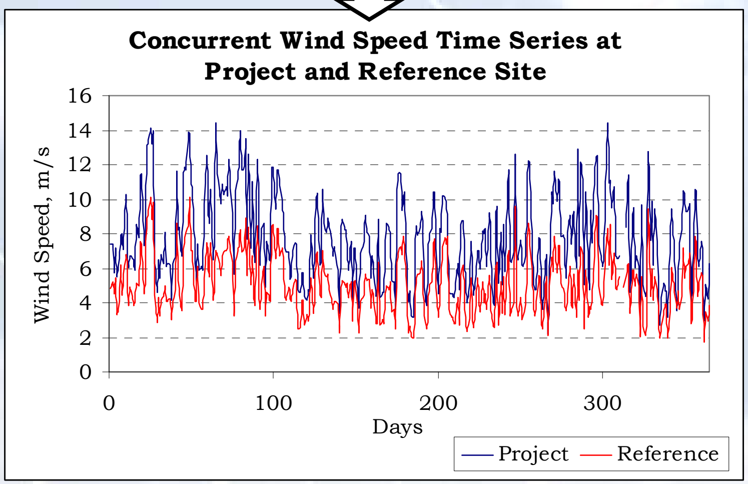
Objectives

- To better understand which parameters most significantly affect the accuracy of long-term wind speed estimates based on surface stations as reference.
- To test the relative accuracy of various MCP (Measure-Correlate-Predict) techniques.

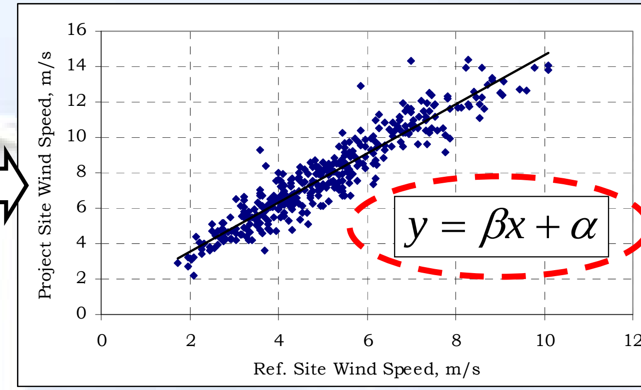
Overview of MCP and Various Techniques

- MCP (Measure-Correlate-Predict) is a technique used to estimate long-term wind speeds at a project site based on near-by long-term reference data.

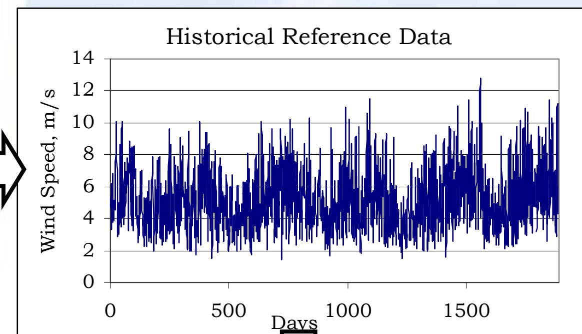
Measure concurrent data at project and reference site.



Determine a relationship (i.e. ***correlate***) between the project and reference sites.



Use the defined relationship and historical data from reference site to ***predict*** the long-term mean wind speed at project site.



Long-term Project Wind Speed Estimate

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Overview of MCP and Various Techniques: Ratio of Means and Regression Analyses

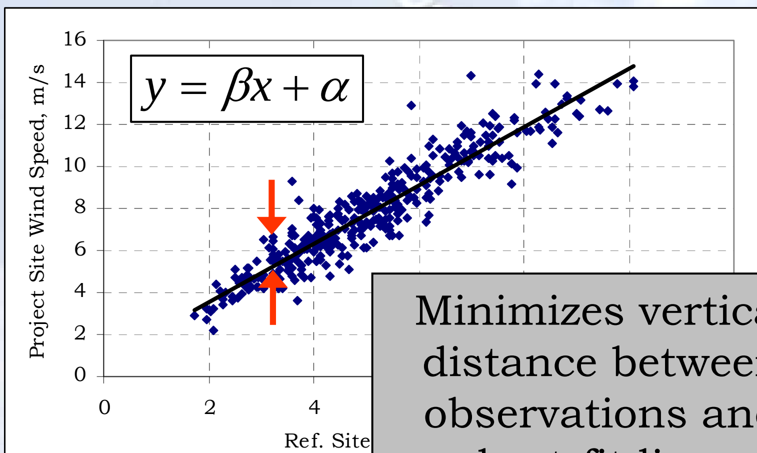
- Ratio of Means:
  - Analyzed by wind direction sector

$$\overline{U}_{hist\ \ project} = \frac{\overline{U}_{conc\ \ project}}{\overline{U}_{conc\ \ reference}} \overline{U}_{hist\ \ reference}$$

- Linear Regression:
  - Standard or Orthogonal

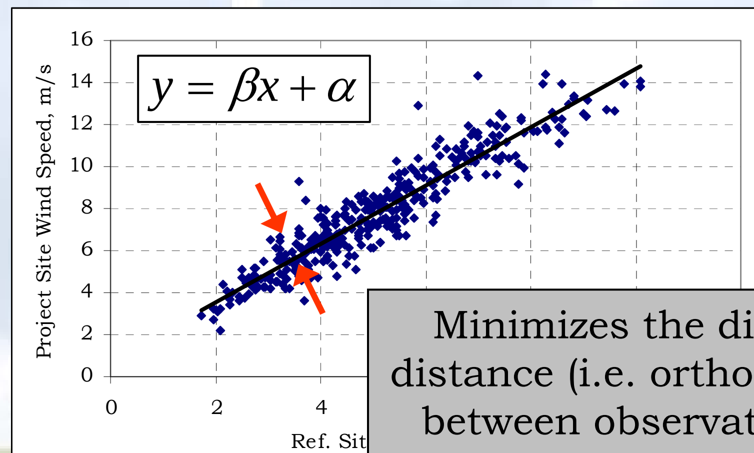
$$\overline{U}_{hist\ \ project} = \beta \times \overline{U}_{hist\ \ reference} + \alpha$$

- Standard Least Squares:



Minimizes vertical distance between observations and best-fit line.

- Orthogonal Regression:



Minimizes the direct distance (i.e. orthogonal) between observations and best-fit line.

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Overview of MCP and Various Techniques: R^2 Adjustment to Regression Analyses

- Predicted project wind speed is adjusted using R^2 (coefficient of determination).

$$\overline{U}_{R^2\ Adj} = \overline{U}_{\substack{Conc.\\Proj.}}\left(1 + R^2\left(\frac{\overline{U}_{Lin.Reg.Est.}}{\overline{U}_{Conc.Proj.}} - 1\right)\right)$$

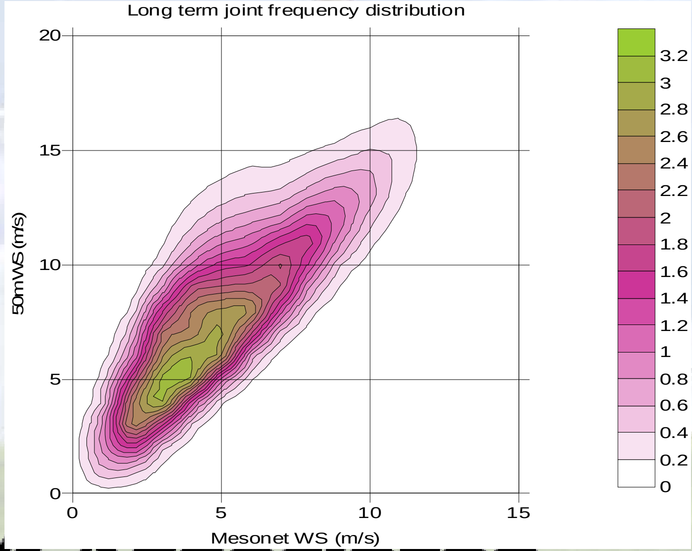
LT Estimate found from linear regression

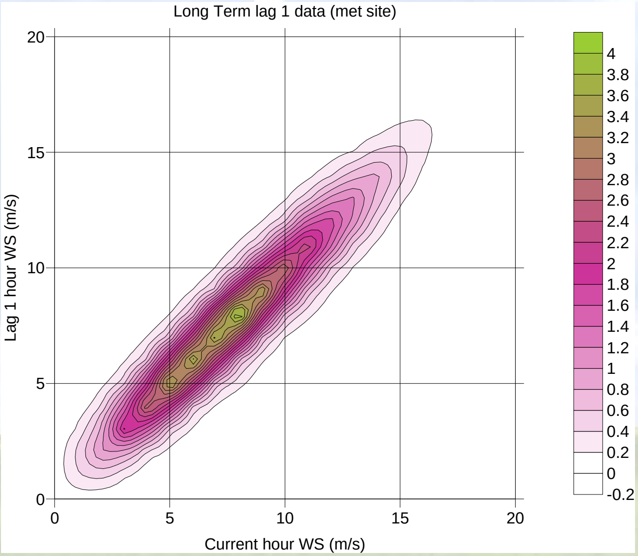
Mean project wind speed measured during concurrent period

Coefficient of Determination

Overview of MCP and Various Techniques: Matrix – Lag1

- Create two joint probability distributions:
  1. Reference vs. Project wind speeds
  2. Project wind speeds vs. Project wind speeds lag 1 hour
- Develop diurnal relationship between reference and project sites
- Using historical reference data, for every hourly data point:
  - Draw random number and use reference – project wind speed JPD to determine project wind speed.
  - Draw 2nd random number and use project – project lag 1 JPD to determine project wind speed.
  - Combine the two estimated project wind speeds (weighted or unweighted).
  - Use observed diurnal relationship to shape final product wind speed estimate.





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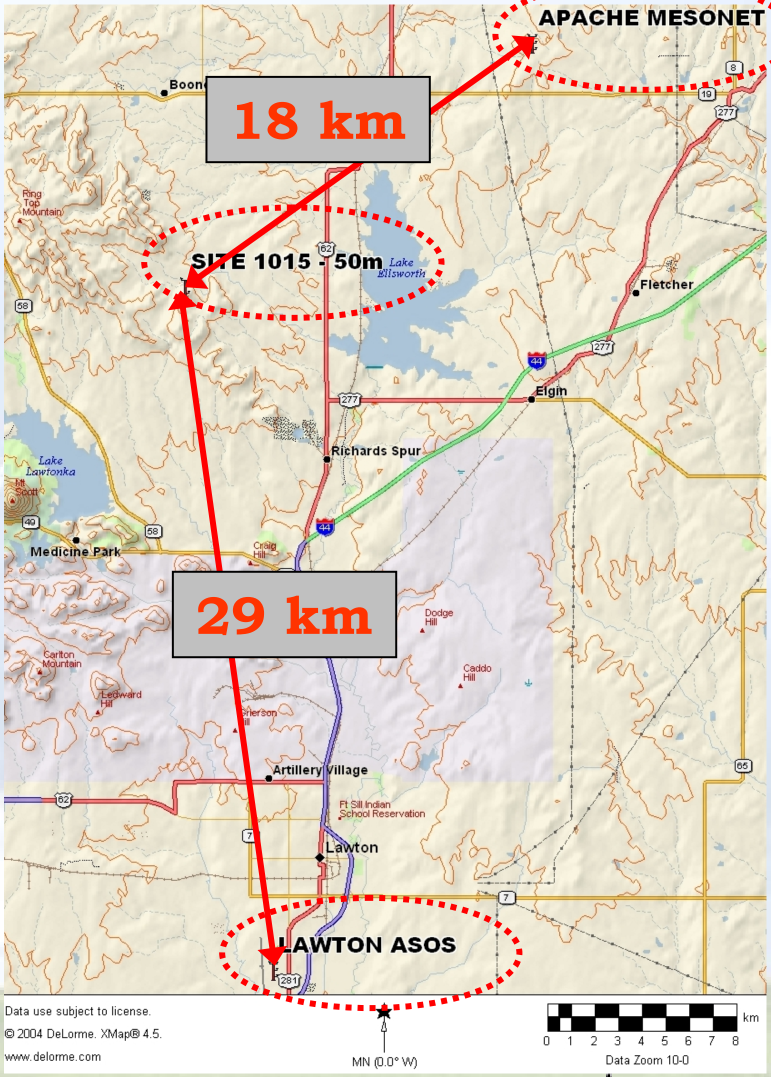
Planar or 2x Regression

- Use two reference stations in planar regression.
- Two independent input variables, *x* and *y;* solve for two slopes*, m* and *n,* and one intercept*, b,* to predict one output variable, *z.*

$$z = mx + ny + b$$

Experimental Set-Up

- 2 Reference stations:
  - Apache Mesonet
  - Lawton ASOS
- Project site 1015:
  - 50 m met tower equipped with NRG #40 cup anemometer (some DFW correction)
  - Redundant sensors at two upper levels
- Length of concurrent data sets: March 2004 – April 2009
- Valid data recovery = ~99%
- Distance between reference and project sites:
  - Mesonet to Project site = 18 km
  - ASOS to Project site = 29 km



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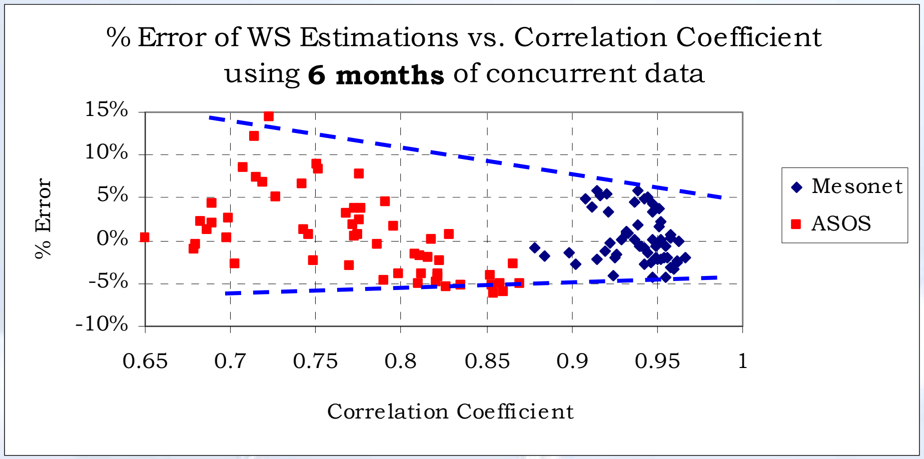
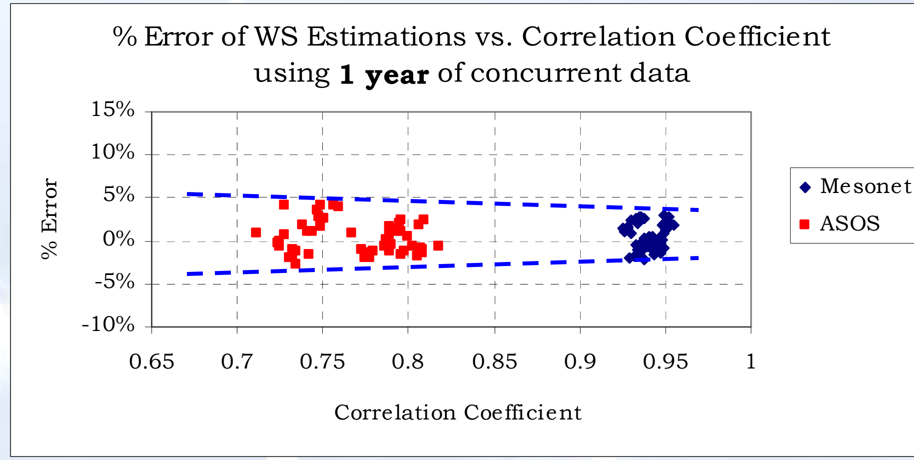
Methodology

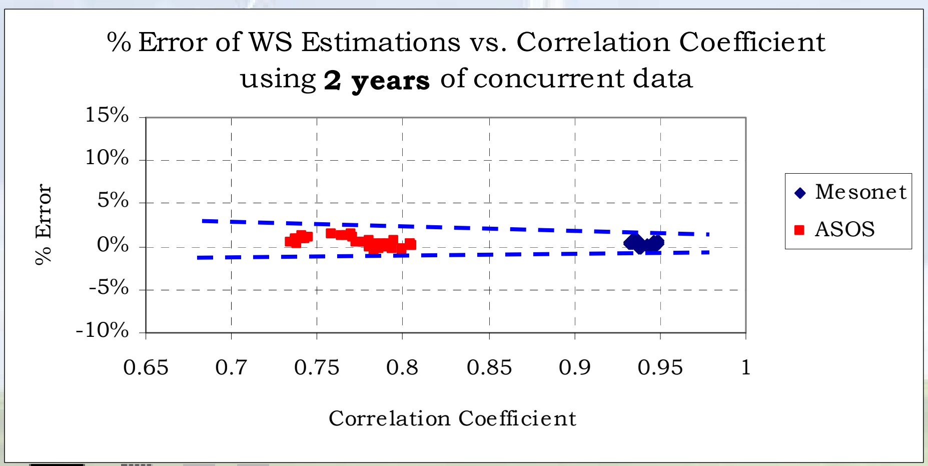
- Conducted MCP analyses using various techniques based on:
  - ASOS and Mesonet as reference
  - 6 months, 1 year and 2 years of concurrent data (with moving concurrent sub-sets in 1- month increments)
- Compared predicted LT wind speed to actual LT (i.e. 5 year) wind speed.
  - Calculated mean absolute error and standard deviation of errors
- Examined the sensitivity of long-term wind estimates to:
  - Correlation coefficient between reference and project sites
  - Deviation of reference wind speed to its mean
  - R^2 adjustment
  - Length of concurrent data set
  - Type of MCP technique

Sensitivity of Long-term Estimates to Correlation Coefficient

(Orthogonal regression, using daily avg. WS)







- Higher corr. coeffs. lead to a more accurate result when dealing with shorter concurrent data sets.
- With data sets longer than 1 year, higher corr. coeff. had small effect on accuracy.

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Sensitivity of Long-term Estimates to Correlation Coefficient

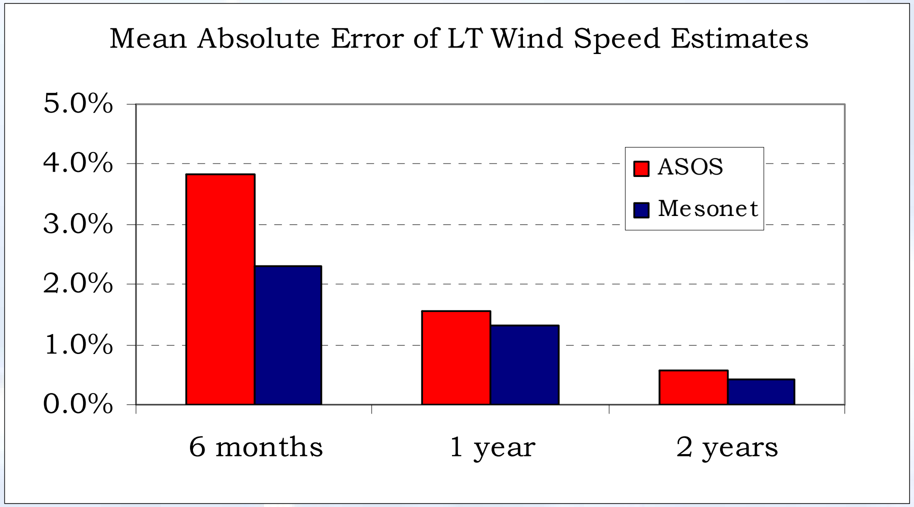
- Mean absolute error and standard deviation of the errors decreased for all data lengths.
- $R_{ASOS} = 0.77$; $R_{MESONET} = 0.94$

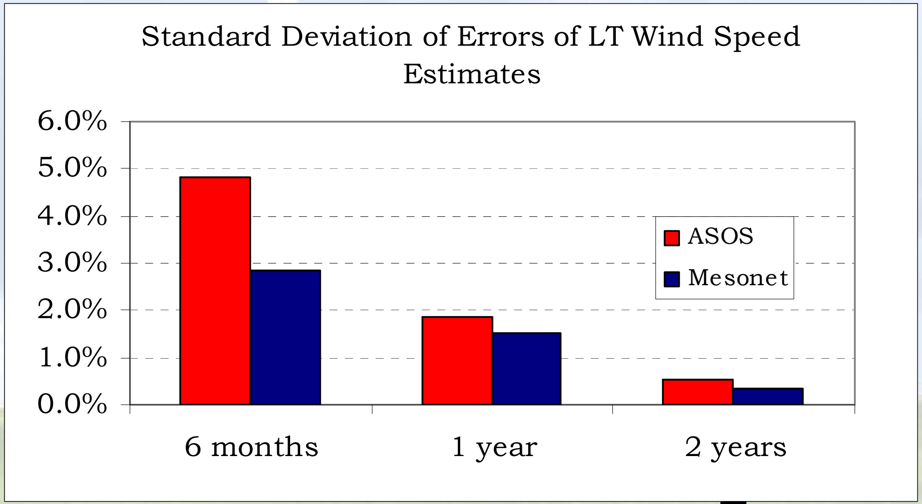
Mean Absolute Error

	ASOS	Mesonet
6 months	3.8%	2.3%
1 year	1.6%	1.3%
2 years	0.6%	0.4%

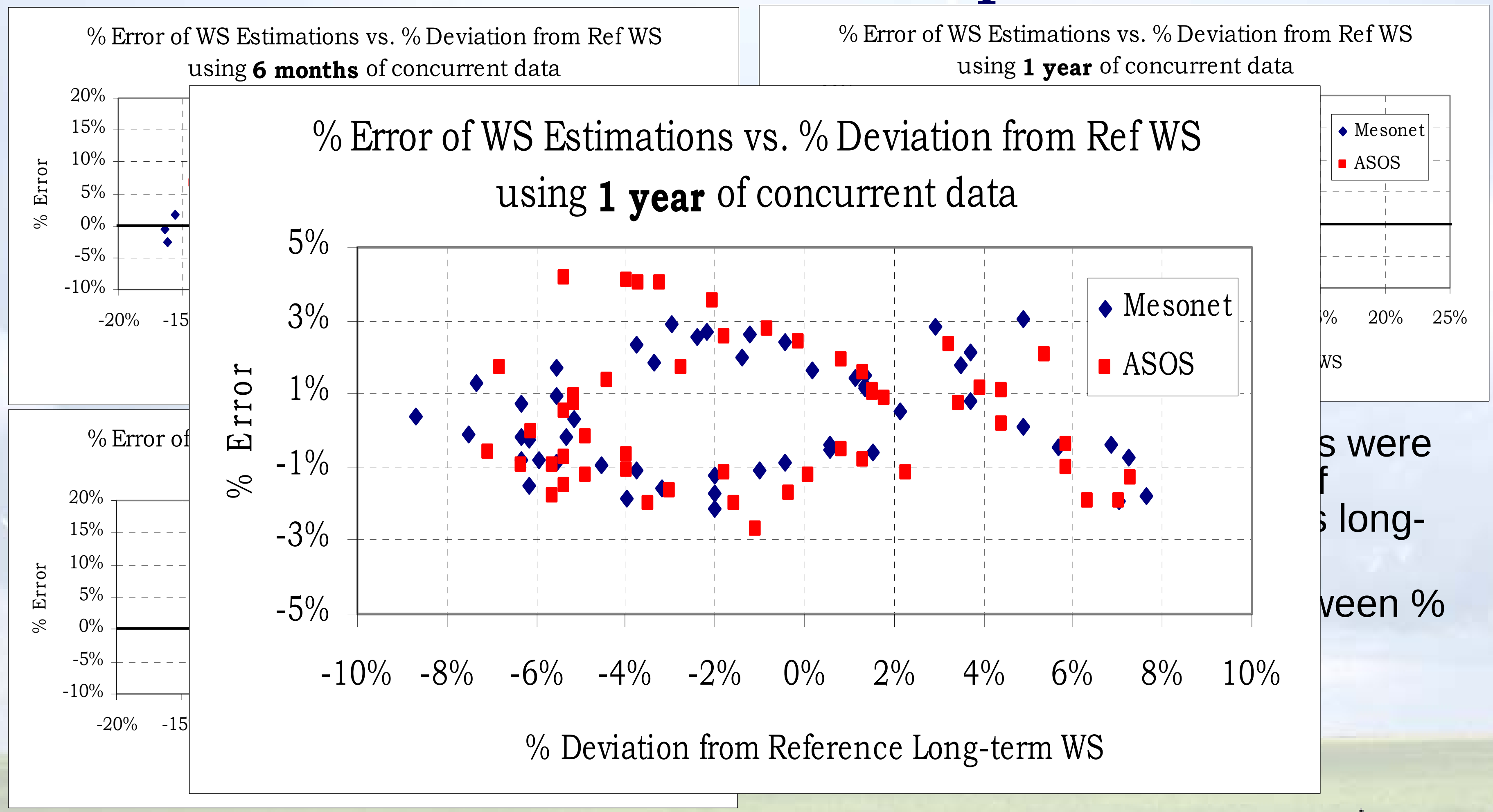
Standard Deviation of Errors

	ASOS	Mesonet
6 months	4.8%	2.9%
1 year	1.9%	1.5%
2 years	0.5%	0.3%





Sensitivity of Long-term Estimates to Reference Wind Speed



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Sensitivity of Long-term Estimates to R^2 Adjustments

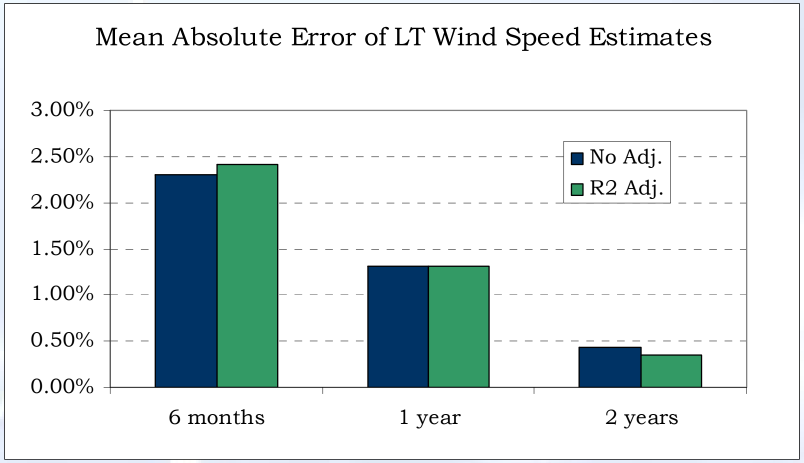
- Used orthogonal regression with Mesonet reference data and applied R^2 adjustment.
- Results showed no improvement in accuracy when adjustment made.

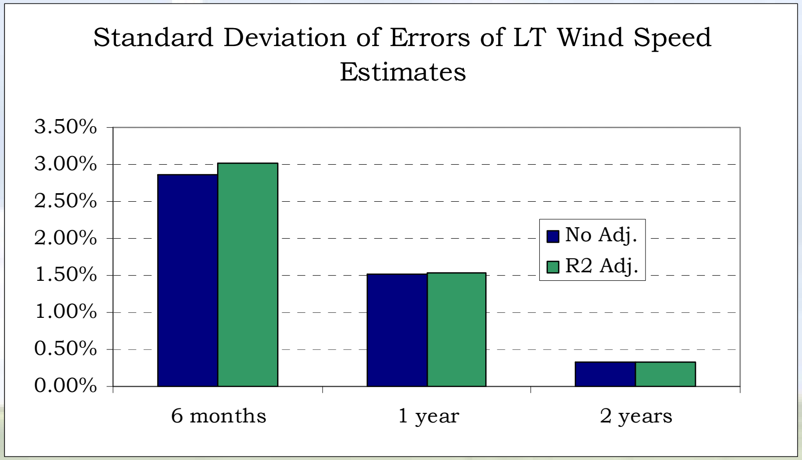
Mean Absolute Error

	No Adj.	R^2 Adj.
6 months	2.30%	2.42%
1 year	1.31%	1.32%
2 years	0.43%	0.35%

Standard Deviation of Errors

	No Adj.	R^2 Adj.
6 months	2.87%	3.02%
1 year	1.51%	1.53%
2 years	0.33%	0.33%





How can accuracy worsen when R^2 adjustment is made?

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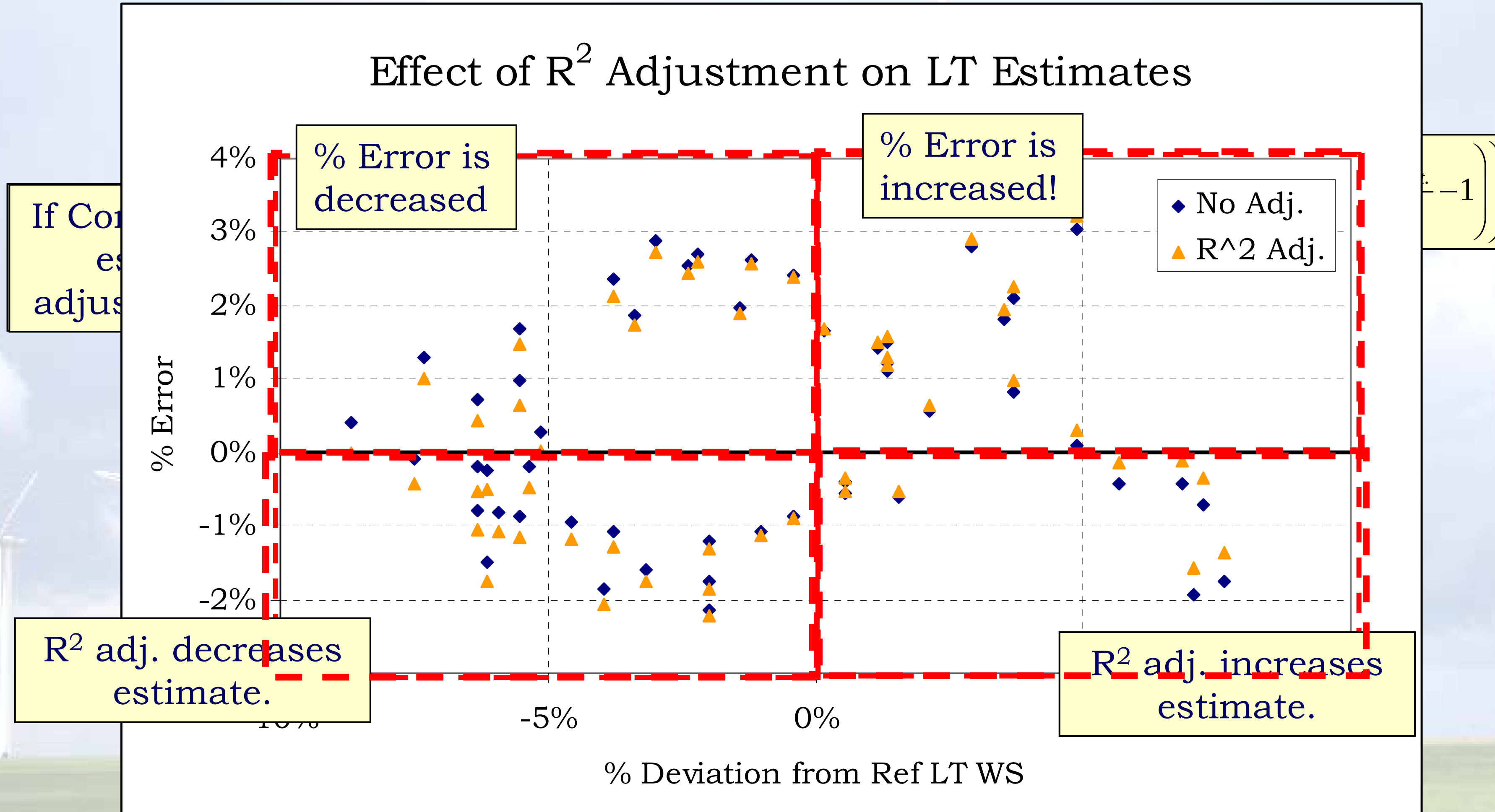

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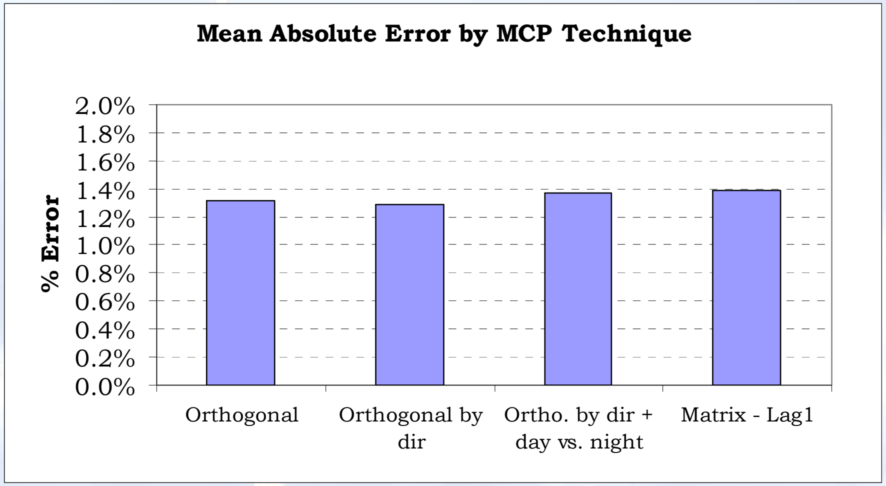
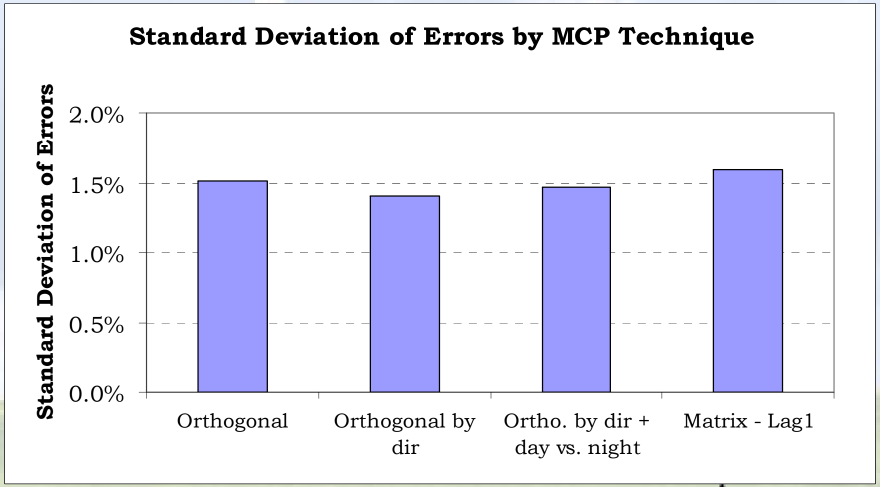
Sensitivity of Long-term Estimates to MCP technique

- Using 1-year of Mesonet data, conducted MCP methods:
  - Orthogonal regression (daily avg. wind speeds)
  - Orthogonal regression by wind direction sector (hourly)
  - Orthogonal by wind direction and day vs. nighttime (hourly)
  - Matrix - Lag1 (hourly)

MCP Technique	Mean Abs. Error	Std. Dev. Of Errors
Orthogonal	1.31%	1.51%
Orthogonal by dir	1.28%	1.40%
Orthogonal by dir + day vs. night	1.37%	1.47%
Matrix - Lag1	1.39%	1.59%

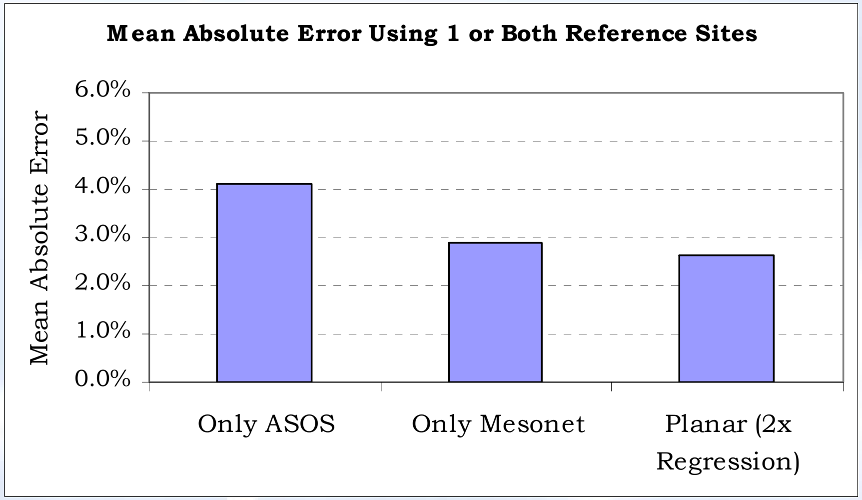


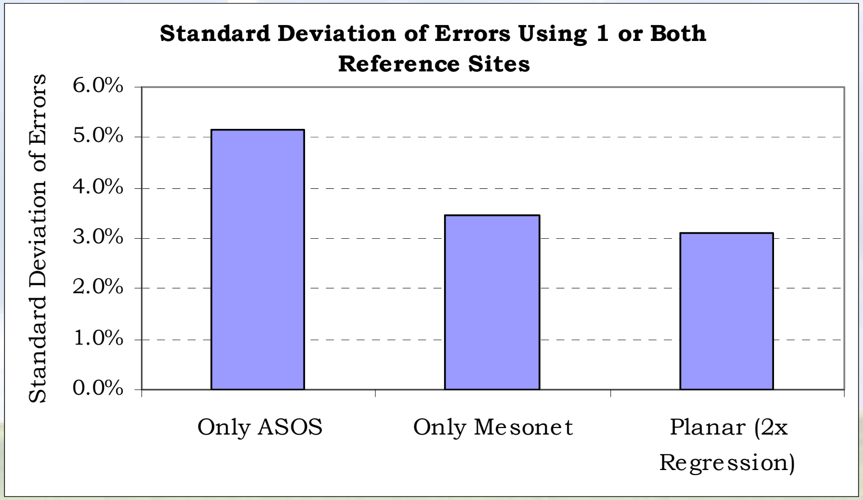


Planar or 2x Regression

- Use both reference sites to predict the project site wind speeds.
- Conducted analysis using 14 – 6-month long data sub-sets
- Mean absolute error and standard deviation of errors decreased when planar regression was used.

MCP Technique	Mean Abs. Error	Std. Dev. Of Errors
ASOS	4.13%	5.15%
Mesonet	2.87%	3.46%
Planar	2.61%	3.12%





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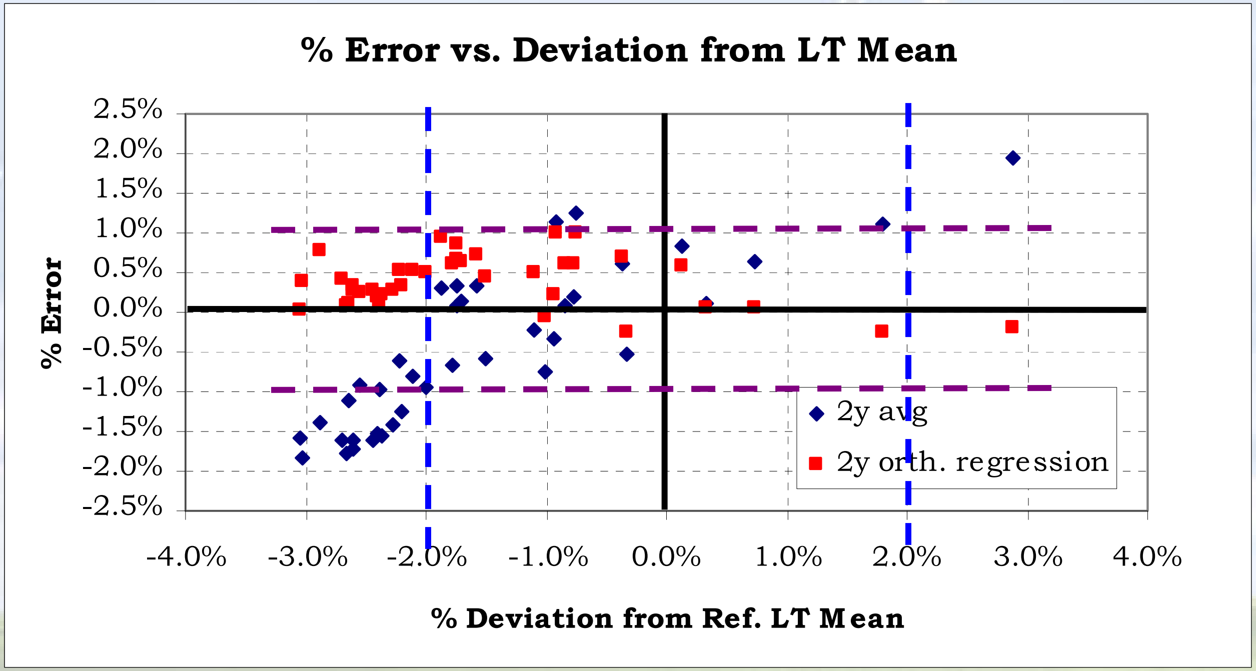
Is MCP always necessary/appropriate with 2-years of project site data?

- Compared moving 2 year average wind speeds and long-term MCP estimate (based on orthogonal regression) to actual long-term value.
- When reference mean deviates more than ~2% from long-term mean, the % error exceeds +/- 1%.



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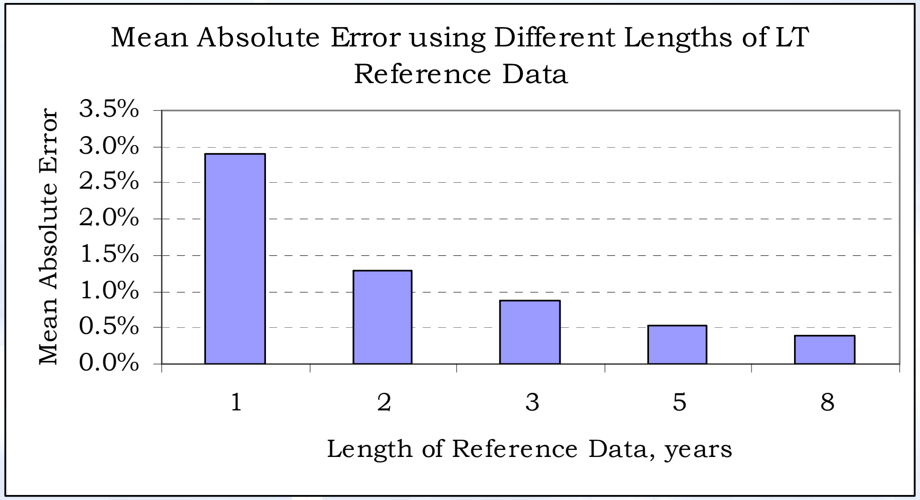
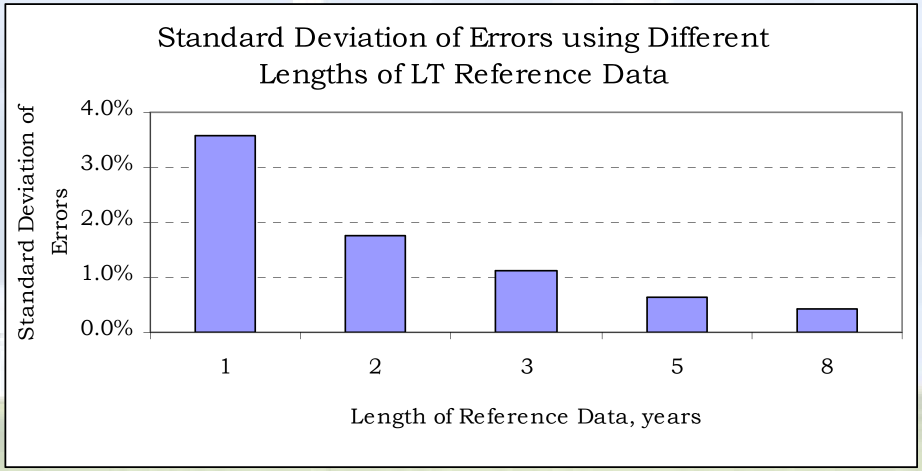
Error and Uncertainty associated with using 5-year data set as Long-term

- Compared reference site variability to its 15 year long-term average.
- Mean absolute error of 0.5% associated with 5-year long-term data set.

Reference Data Length	Mean Abs. Error	Std. Dev. Of Errors
1 year	2.9%	3.6%
2 years	1.3%	1.8%
3 years	0.9%	1.1%
5 years	0.5%	0.7%
8 years	0.4%	0.4%





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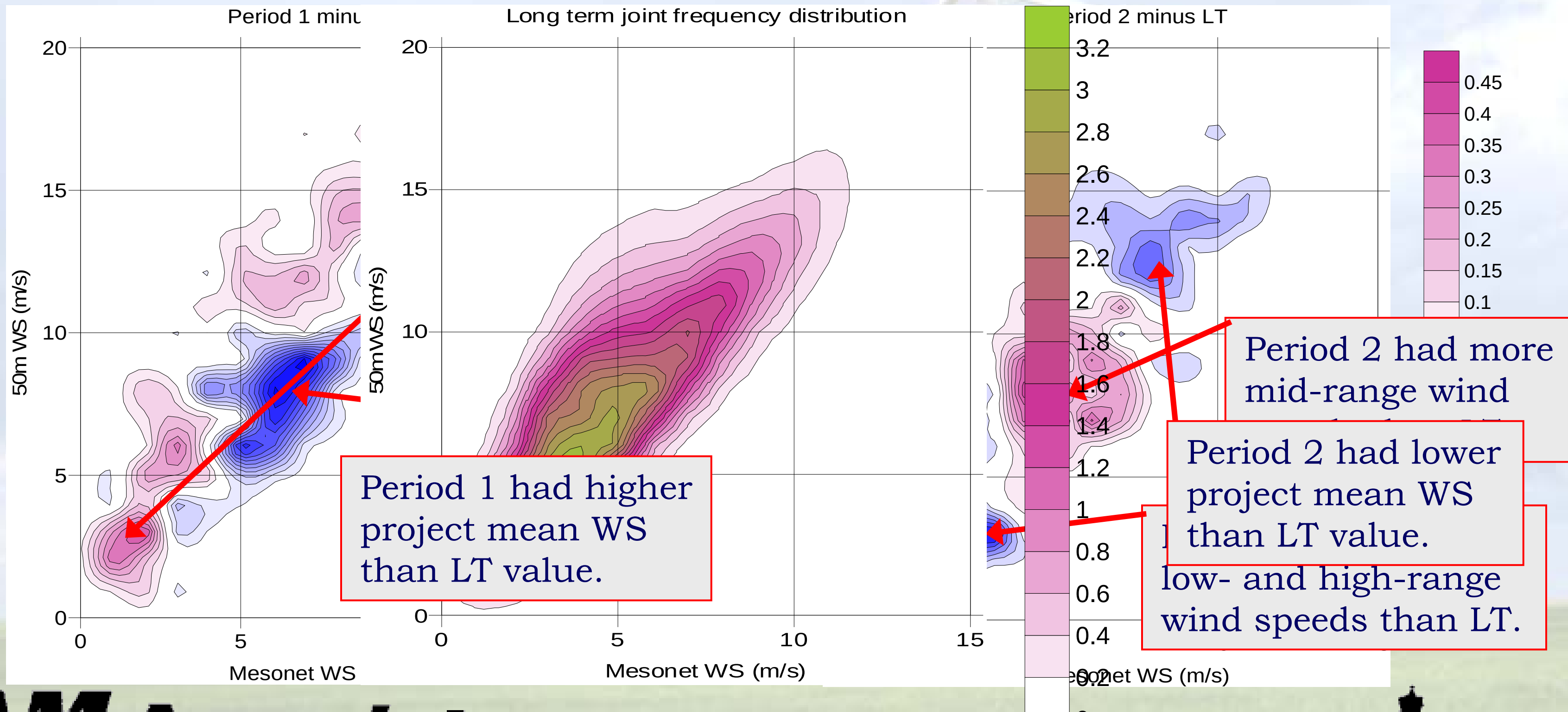
Variations in Relationship of Wind Speed Distribution

- Why is it so difficult to accurately estimate long-term wind speed?
  - The relationship between the reference and project site cannot be assumed to be constant!
- Looked at two 1-year periods at the reference site for which mean speeds were approximately equal to long-term mean.



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Observations and Recap

- Strength of correlation has a more significant impact on long-term wind speed estimate error for shorter data periods than for longer ones.
- No obvious relationship between % error in long-term estimate and % deviation from reference wind speed.
- Adjusting estimate based on R^2 reduces error under certain circumstances and increases it in others.
- MCP technique had small effect on error of wind speed estimate.
- Planar regression showed small improvement in accuracy of estimate based on short-term data periods.
- Length of data set had most significant impact on error of estimate.
- If project data length is 2 years, MCP may not be necessary if reference average is within ~2% of long-term mean.
- Relationship between reference and project site changes and cannot be assumed to be constant. Since consistency is an implicit assumption of MCP, errors are inevitable!

Future Work

- Chaos theory, strange attractors
- Wind shear extrapolation adds even more uncertainty