Minimizing Portfolio Uncertainty

Targeted Diversification of Projects

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Outline

1. Portfolio theory
2. Wind resource correlation via re-analysis data
3. Production data from active wind farms
4. Portfolio uncertainty North American case studies
5. Merchant market case study

Modern Portfolio Theory

→ **Lower overall risk by combining individual wind farms**

→ **Assumes normal distribution**

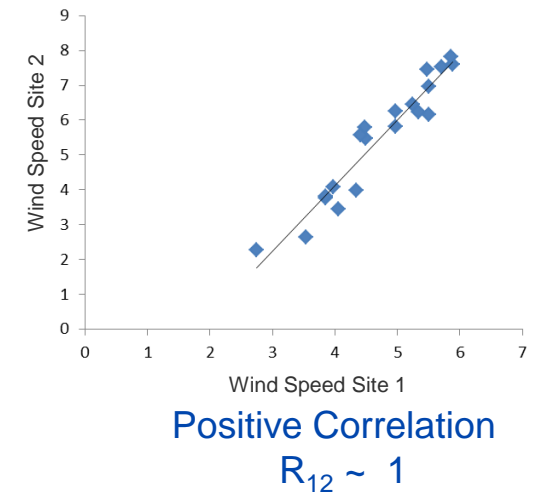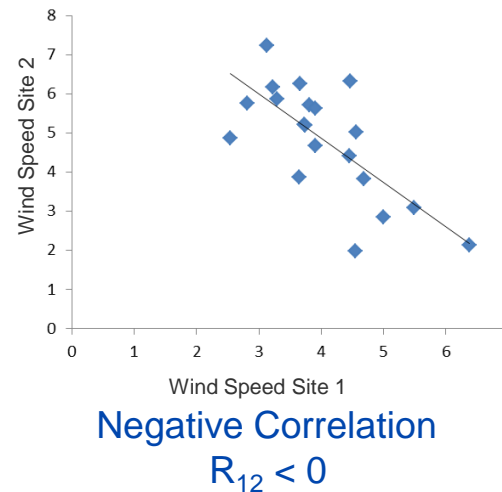→ **The portfolio risk can be separated into two components**

$$\sigma^2_{portfolio} = \sum_{i=1}^{N} \sigma_i^2 + \sum_{i=1}^{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} \sigma_i \cdot \sigma_j \cdot R_{ij}$$

Independent Component

Correlated Component

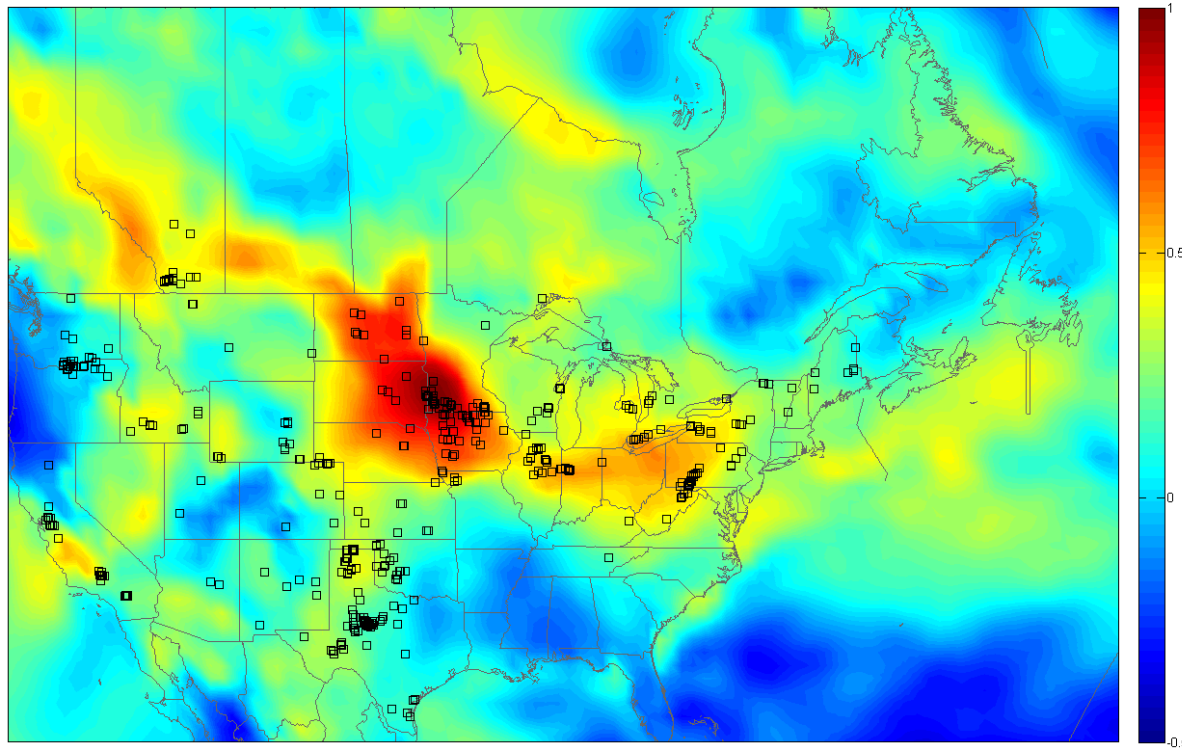→ R_{ij} = Correlation between projects

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Correlation of Wind Resource

→ Different components of uncertainty may be correlated
- Losses
- Turbine performance
- **Wind resource**

→ Focus on correlation of wind resource
- Typically main driver of 1-year uncertainty

→ ERA re-analysis data (20 years)
- Correlation of annual wind speed data calculated across North America

$$\sigma^2_{portfolio} = \sum_{i=1}^{N} \sigma_i^2 + \sum_{i=1}^{N}\sum_{\substack{j=1 \\ j \neq i}}^{N} \sigma_i \cdot \sigma_j \cdot R_{ij}$$

Negative Correlation
$R_{12} < 0$

Positive Correlation
$R_{12} \sim 1$

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Correlation of Wind Resource

Annual Wind Speed
Correlation (R) Map
- Great Plains

→ Correlation map shows strength of correlation to specific location
  - Strong correlation (red areas)
  - Negative correlation (blue areas)
→ Distinct wind speed patterns along geographic lines
  - E.g., Rocky Mountains
→ Stronger correlation North/South than East/West

Production Data

→ Monthly Production Data
- EIA (USA)
- IESO (Ontario)
- AESO (Alberta)

→ Filter by:
- Period longer than 48 months
- Location and name plate capacity is (NPC) known
- NPC > 9 MW

→ Filtered to:
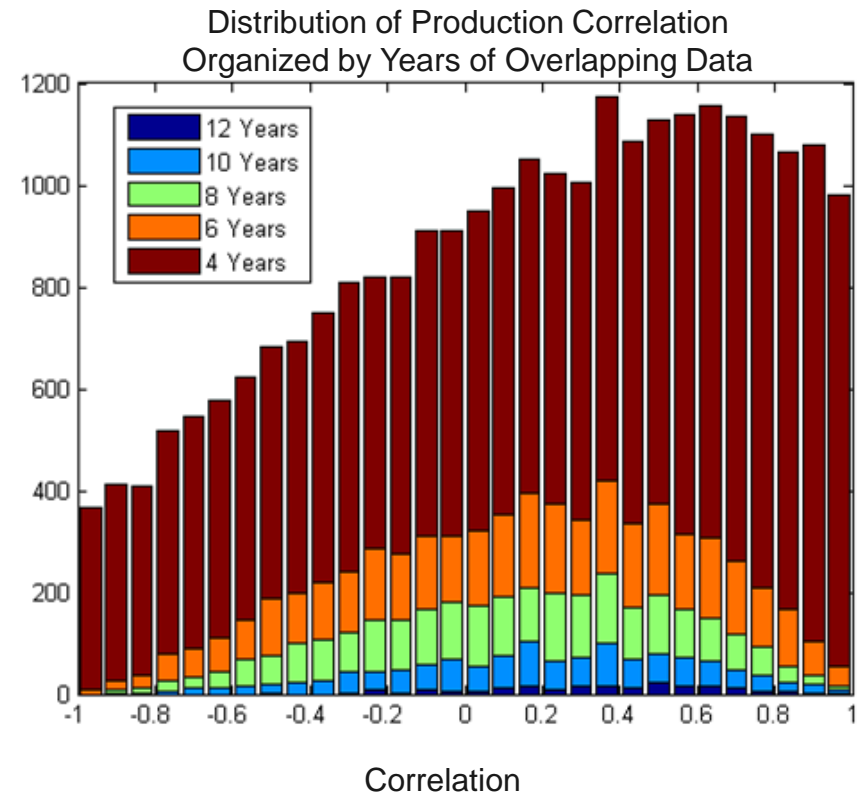- 313 Wind Farms
- NPC 27.4 GW
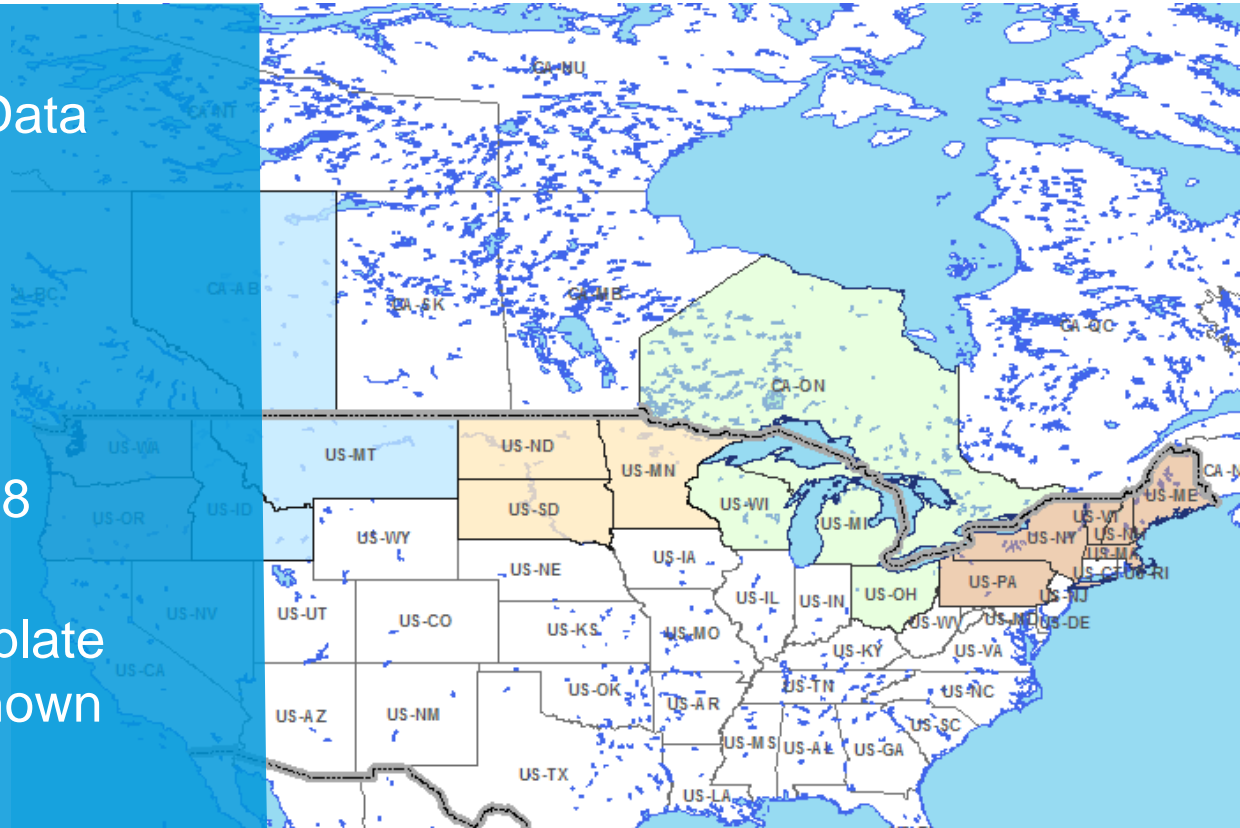
Correlation of Production
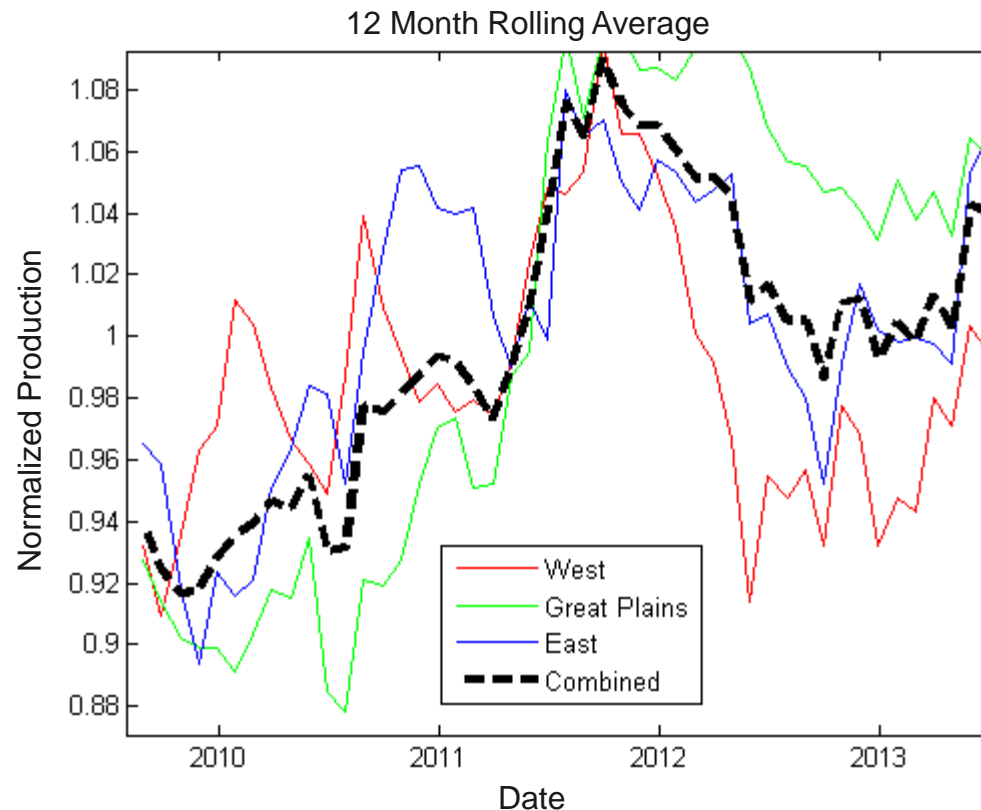
→ **EIA Annual Production Correlation**

- Calculated between all 313 wind farms

- Years with flagged data removed

- Annual production synchronized between all wind farms

- Correlation calculated for the overlapping period of record

→ **Significant amount of projects are moderately correlated**

- Correlation map can be used to find locations with weak correlation

Distribution of Production Correlation
Organized by Years of Overlapping Data

Legend:
- 12 Years
- 10 Years
- 8 Years
- 6 Years
- 4 Years

Correlation

Production Data

12 Month Rolling Average

- → Portfolio of 3 wind farms
  - – West, Great Plains, East
  - – 5 years of production data
  - – Distance = 4100 miles
- → Similar sized wind farms
  - – 100 MW Facility
- → Wind farms chosen based on the re-analysis correlation map
  - – Annual EIA production data also shows poor correlation between wind farms
  - – Reduced 1-year uncertainty may improve financing potential due to diversification of risk

North American Case Studies

Legend

☆	Wind Farm Location

IAV

Color	Range
	5.5 - 6.0%
	6.0 - 6.5%
	6.5 - 7.0%
	7.0 - 7.5%
	7.5 - 8.0%
	8.0 - 8.5%
	8.5 - 9.0%
	9.0 - 9.5%

→ The same 3 projects as previous production example
  - Project uncertainty based on calculated production inter-annual variation for each region
→ Overall uncertainty based on analysis correlation
  - $\sigma_{portfolio} = 5.2\%$ Vs. $\sigma_{portfolio} = 7.25\%$ assuming a strong correlation (R2 = 1)
  - P95 increases by 3.8% compared to a strong correlation case
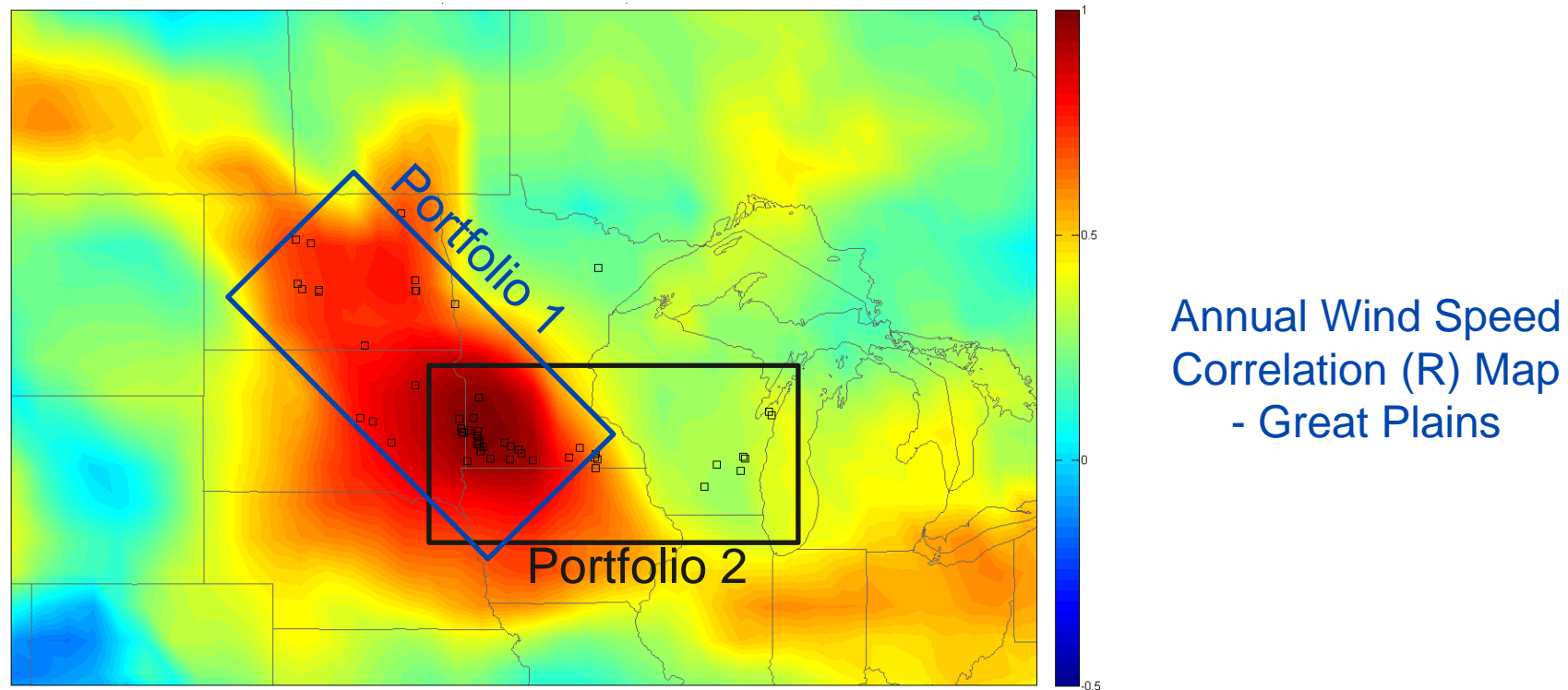→ Validated using EIA production correlation
  - $\sigma_{portfolio} = 5.7\%$

Re-analysis Annual Wind Speed Correlation - R

Wind Farm	West	Great Plains	East
West	-	0.1	0.2
Great Plains	0.1 (0.3)	-	0.5
East	0.2 (0.4)	0.5 (0.6)	-

() – Correlation based on EIA invoiced production

North American Case Studies

Annual Wind Speed
Correlation (R) Map
- Great Plains

→ **Portfolio 1**
- 3 x Great Plains (σ = 7.25%)
- Distance = 808 miles
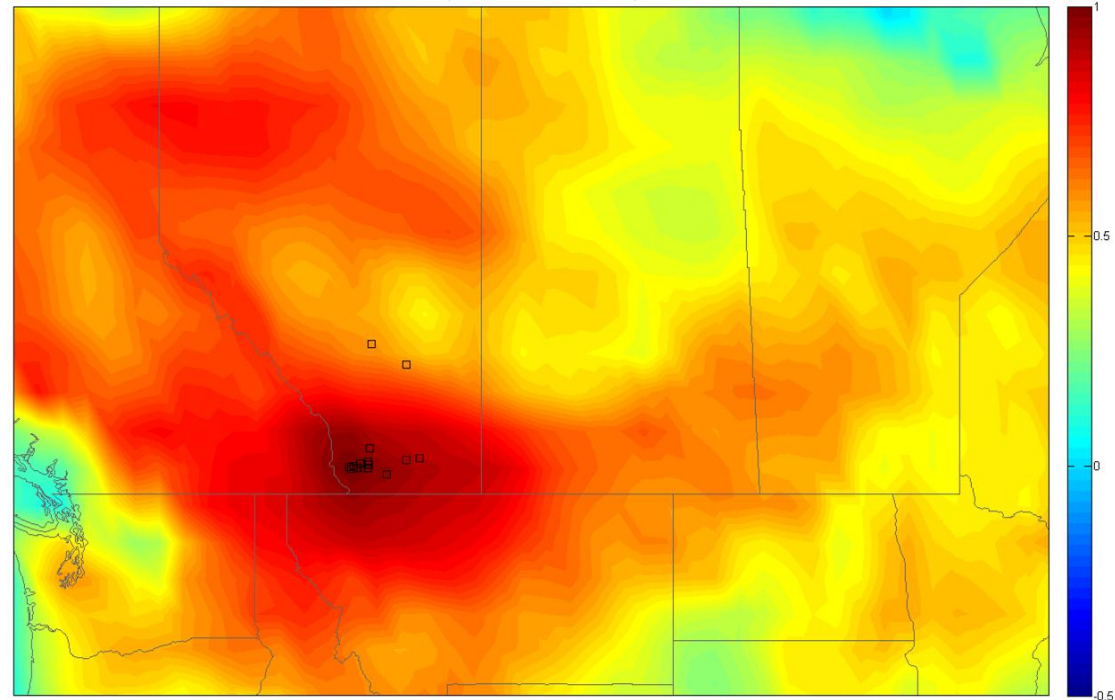- Average Correlation = 0.81
- 1-year $\sigma_{portfolio1}$ = 6.8%

→ **Portfolio 2**
- 3 x Great Plains (σ = 7.25%)
- Distance = 781 miles
- Average Correlation = 0.55
- 1-year $\sigma_{portfolio2}$ = 6.1%

$$\sigma_{portfolio2} \downarrow = P_{95} \uparrow 1.3\% \text{ Vs. } \sigma_{portfolio2}$$
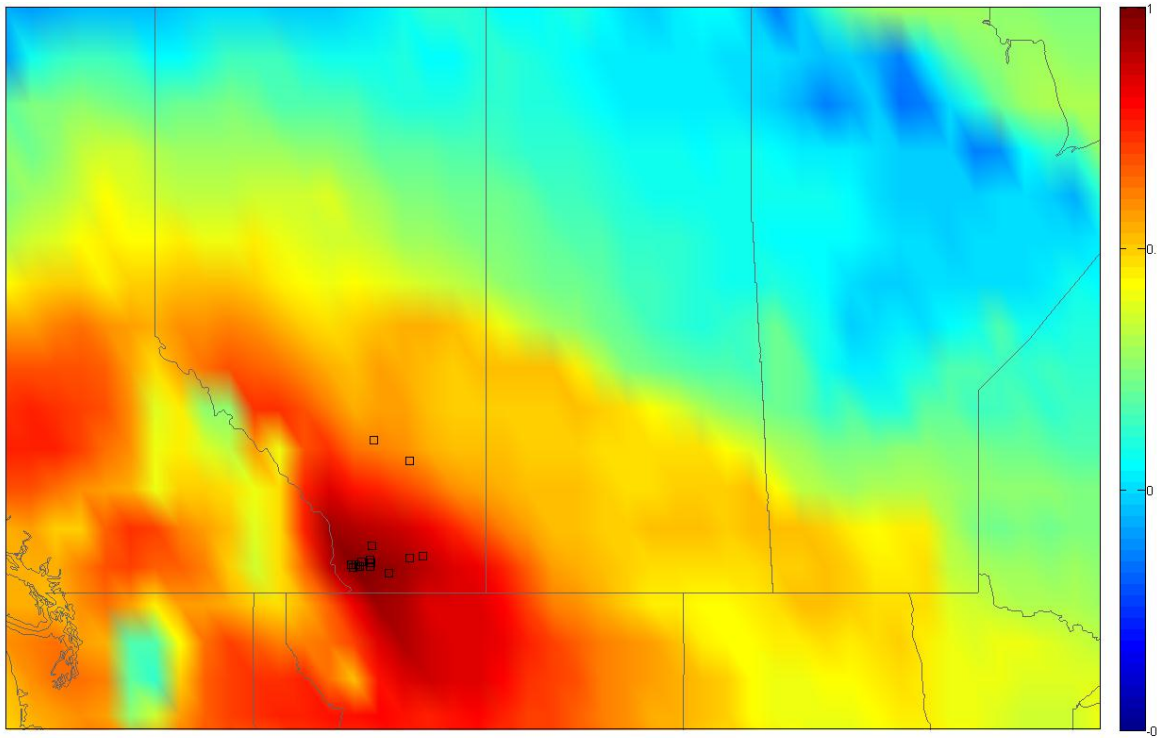
North American Case Studies

→ Alberta

→ Portfolio 1
- 2 x Central
- 1 x Southern

→ Portfolio 2
- 1 x Central
- 2 x Southern

→ Difference in uncertainty
- 8.1% vs. 8.3%

→ Strong correlation of annual wind speed throughout Alberta

→ Not a significant improvement to uncertainty but …

Annual Wind Speed Correlation (R) Map - Southern Alberta

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Correlation - Averaging Period

Monthly Wind Speed Correlation (R) Map - Southern Alberta

→ Correlation of monthly wind speed is not consistent across Alberta
- Central sites are less correlated to the southern portion

→ Alberta is a **merchant market** with high concentration of wind farms in the south.
- Wind energy is a price-taker

→ Power Pool Analysis of Alberta
- Based on actual production data and historical power pool prices

→ Difference to Average Pool Price
- Central Alberta – ~20%
- Southern Alberta – ~40%

Merchant Market
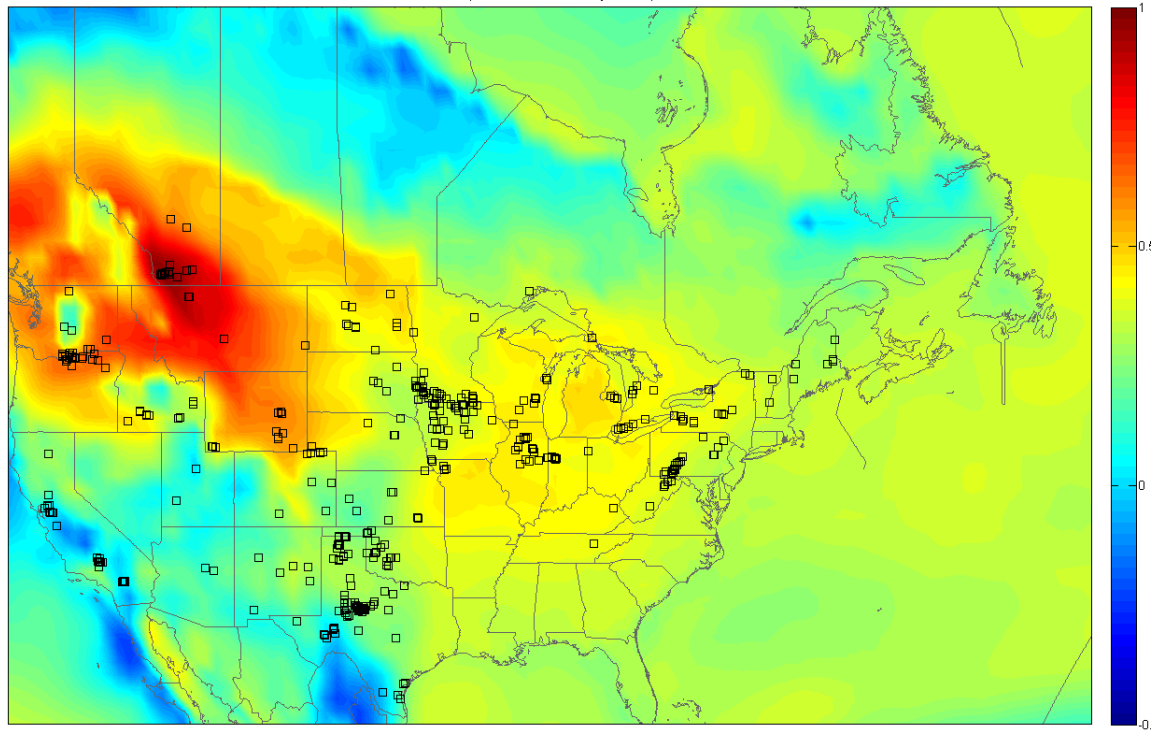
Monthly Wind Speed
Correlation (R) Map
- Southern Alberta

→ Correlation map of monthly data better suited for price analysis

→ Clustering of wind farms becoming more prevalent

→ Low correlation to the areas of high wind penetration is ideal

→ Correlation map can be used to find regions with low correlation to high penetration areas

  − Increased monthly revenue due to lower discount

→ Weak correlation of monthly production between portfolio wind farms can also smooth monthly revenue

THANK YOU

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