# Comparison of WAsP, MS-Micro/3, CFD, NWP, and Analytical Methods for Estimating Site-Wide Wind Speeds

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# Background

- Estimating turbine wind speeds continues to be one of the largest contributors to pre-construction energy estimate uncertainty.
- Currently there is no industry standard for estimating wind speeds used in energy estimates.
- It is still common practice to use simple wind flow models; however, several more computationally expensive modeling techniques are now available.
- Is one of the available wind flow models a “Silver Bullet”?

# Methodology (1)

- Select 5 sites that meet selection criteria.
  - Multiple met towers (50 or 60 meters tall)
  - Sufficient pre- and post-operation met tower and production data
  - Diversity of topography and regions
- Quality control and analyze meteorological and turbine production data from each project.
- Run wind flow models for each site.
  - DNV-GEC conducted all modeling except the NWP and Jack Kline modeling.

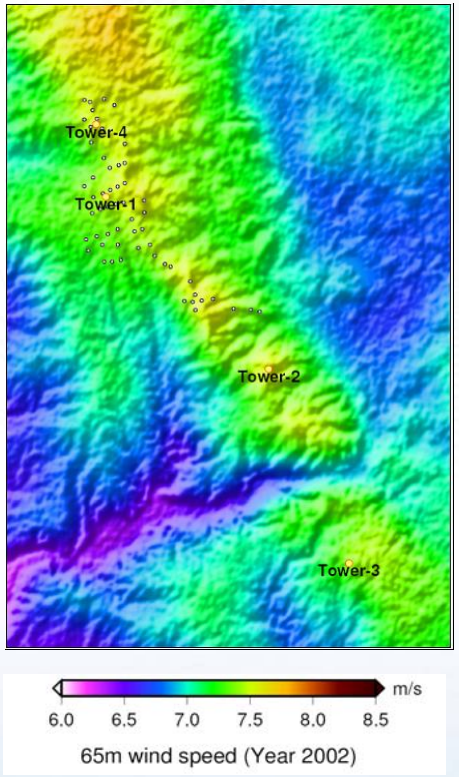
# Methodology (2)

- Post-processing of wind flow model estimates
  - All numerical flow models evaluated only take into account one met tower at time.
  - Post-processing is required to combine wind flow model results from multiple met towers (inverse distance squared weighting used).
  - To make comparisons to production data, wind speed estimates were crossed with manufacturer power curves.
- Evaluate uncertainty of results, RMS Error

# Uncertainty of Wind Speed Estimates

Model performance was assessed by analyzing results from two types of comparisons:

1. Accuracy of met tower wind speed predictions
2. Accuracy of turbine capacity factor estimates (wake free turbines, 9 m/s, 20º sector)

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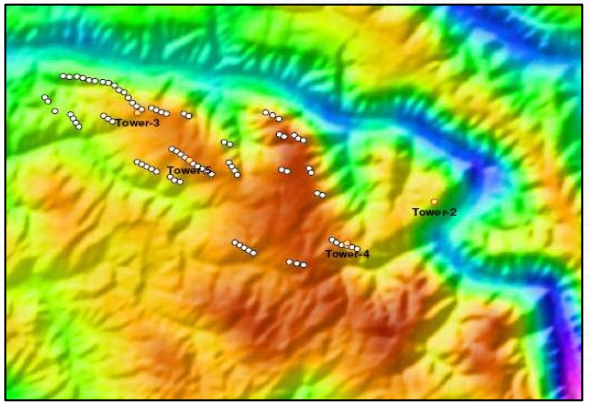
# Wind Estimating Methods Tested

- **Analytical** –Nearest Tower, Inverse Distance Weighted
- **Empirical** –Jack Kline Exposure Model, 3 of the 5 sites
- **WAsP**, Risø National Laboratory – linear model
- **MS-Micro/3**, Atmospheric Environment Service of Environment Canada – linear model
- **WindSim**, WindSim AS – non-linear CFD model, solves the Reynolds Averaged Navier-Stokes (RANS) equations
- **WRF**, Numerical Weather Prediction (NWP) – 3TIER, 2 of the 5 sites




MOS-corrected NWP results for Rolling Hills

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# Sites Studied

- Five projects in North America
  - 1-2 MW turbine architectures
  - At least 1 year of operational data
  - At least 3 pre-construction met towers
- Different geographic regions
- Range of terrain types, simple→complex
  - Upper Prairie
  - Open Ridge
  - Rolling Hills
  - Mountain Side
  - Eastern Mountain

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# Project Locations


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# Results (I)

## RMS Error of Met Tower Wind Speed Estimates

| | Method | Upper Prairie | Open Ridge | Rolling Hills | Mountain Side | Eastern Mountain | Overall |
|---|---|---|---|---|---|---|---|
| | | 2 Towers | 3 Towers | 3 Towers | 3 Towers | 2 Towers | |
| Analytical Model | Distance Weighted | 3% | 5% | 2% | 9% | 12% | **6%** |
| Empirical Model | Jack Kline Exposure* | - | 0% | 10% | 6% | - | **N/A** |
| Numerical Models | WindSim | 6% | 2% | 8% | 8% | 13% | **7%** |
| | WAsP | 5% | 2% | 7% | 8% | 16% | **7%** |
| | MS-Micro/3 | 4% | 1% | 6% | 8% | 16% | **7%** |
| | NWP | 4% | - | 8% | - | - | **N/A** |

- Generally uncertainty increased as a function of increasing terrain complexity for all modeling methods
- No single model consistently produced more accurate met tower wind speed estimates

* Results for Jack Kline Model based on fewer met tower combinations than other model results

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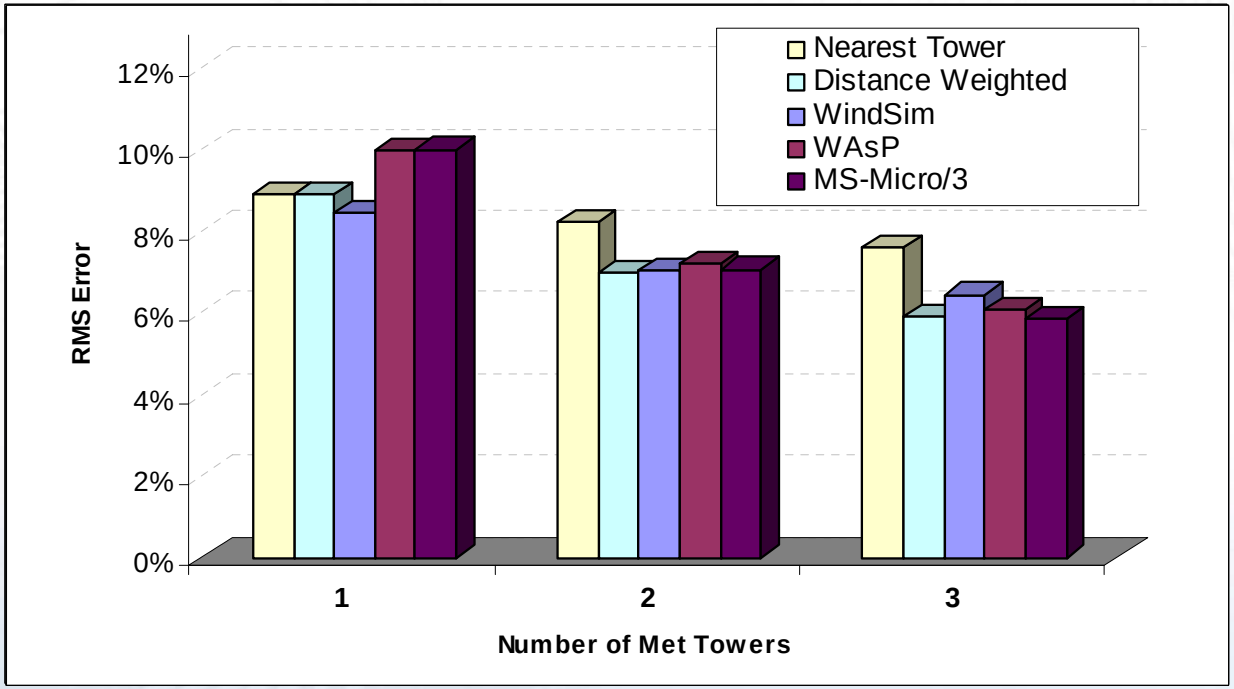
# Results (II)

Uncertainty as a Function of Number of Met Towers, all sites combined

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# Results (III)

RMS Error of Turbine Wind Speed Estimates

| | Method | Upper Prairie | Open Ridge | Rolling Hills | Mountain Side | **Overall** |
|---|---|---|---|---|---|---|
| Analytical Model | Distance Weighted | 5% | 7% | 6% | 18% | **9%** |
| Numerical Models | WindSim | 3% | 8% | 15% | 14% | **10%** |
| | WAsP | 3% | 5% | 12% | 14% | **8%** |
| | NWP | 6% | - | 7% | - | **N/A** |
| | NWP-MOS | 6% | - | 4% | - | **N/A** |

- How one model performs relative to another model is subject to the sample size and conditions the models are validated against

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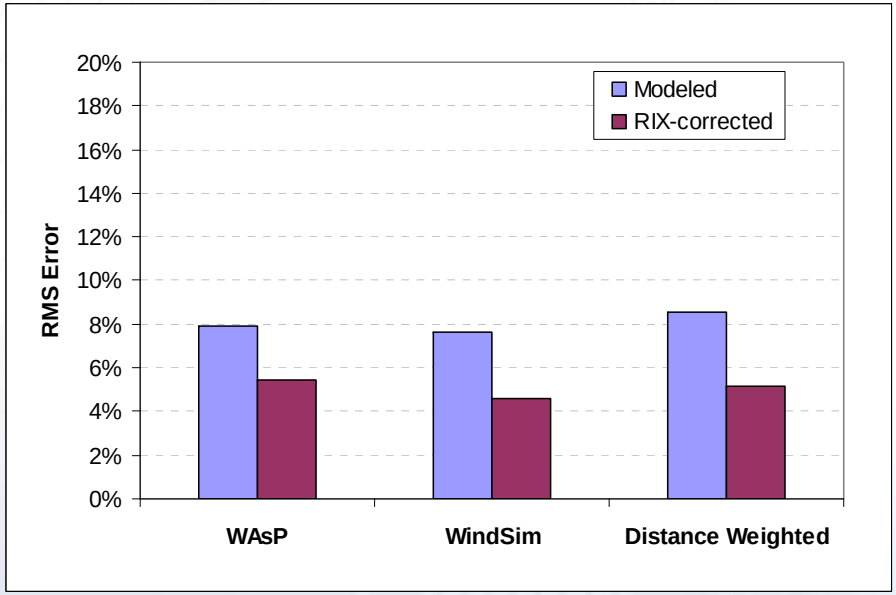
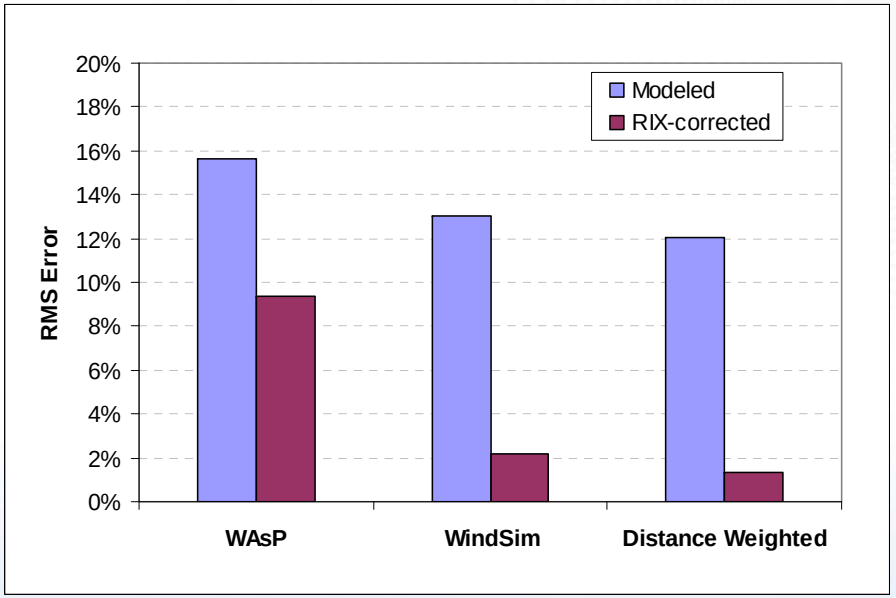
# Results (IV)

## -ΔRIX Corrected Met Tower Wind Speed Prediction Results

### Mountain Side




### Eastern Mountain

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# Conclusions

- Simple analytical models tested provide results with similar uncertainties to the numerical models investigated.
- Jack Kline model yielded promising results at 2 of the 3 sites modeled.
- WAsP and MS-Micro/3 performed equally.
- With all extrapolation methods, increasing the number of met towers that are used to model site-wide wind speeds decreases the uncertainty of the results.
- Uncertainty increased as terrain complexity increased for all models.
- RIX index corrections were found to decrease uncertainty for both analytical and numerical models.
- Careful consideration must be given when interpreting and using model results.

# Acknowledgements


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