A New and Objective Empirical Model of Wind Flow Over Terrain

Jack Kline
RAM Associates
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Resource Assessment & Micrositing

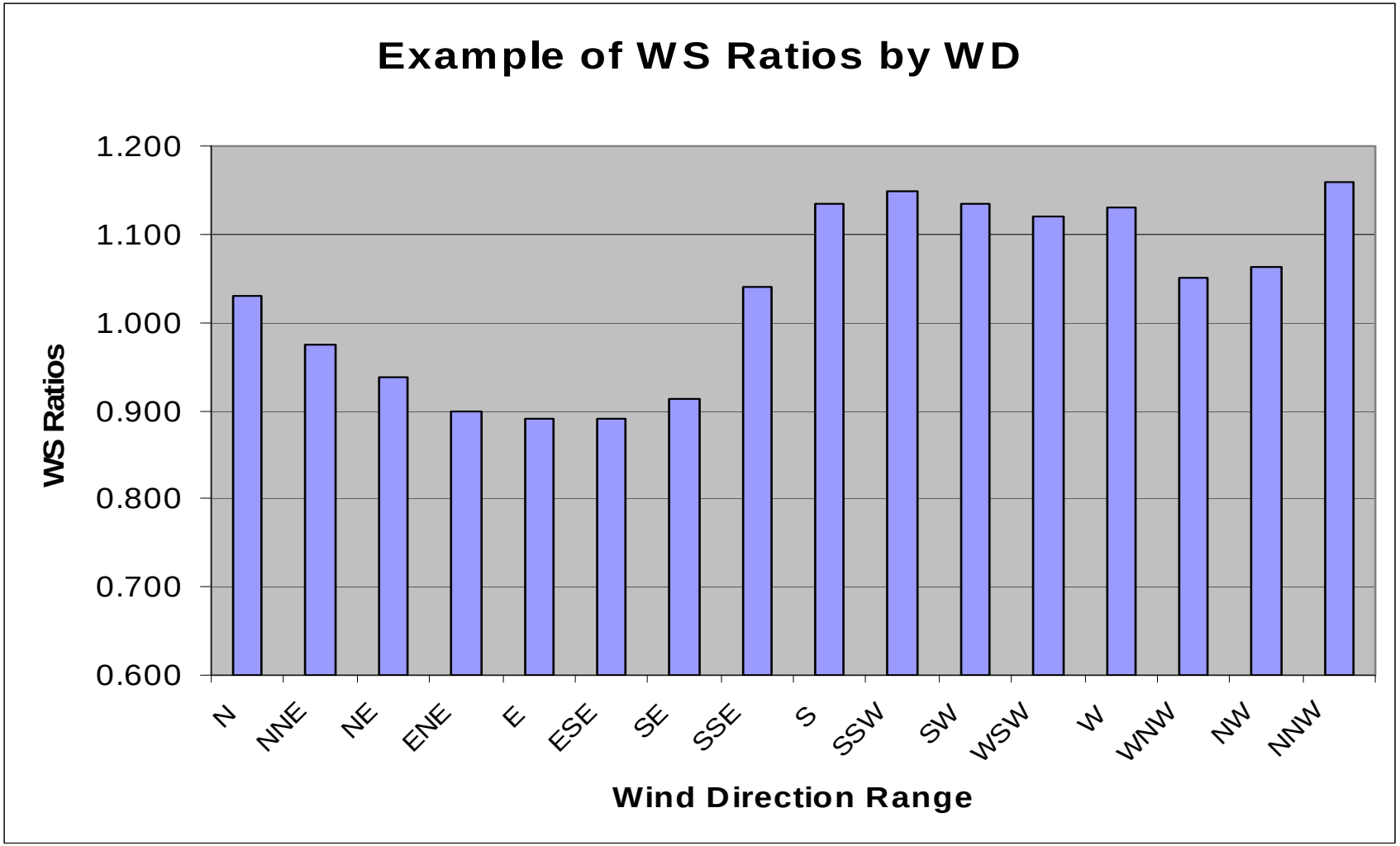
Why an Empirical Model?

- Fluid flow calculations exceedingly complex – CFD challenges
- WAsP - difficulty in complex terrain, potential bias
- The wind data will reveal terrain / wind flow relationships
- Ensemble approach – use all valid sites
- Careful data screening / QA required (WS - tower FX, failures; WD – boom orient.)

Why does the wind speed vary?

- Over a wind farm area meteorological forcing not an issue for long-term WS variance (with certain exceptions)
- Surface roughness effects
- Temporal variance (seasonal, T-O-D, stability)
- Terrain effects – variance with site exposure

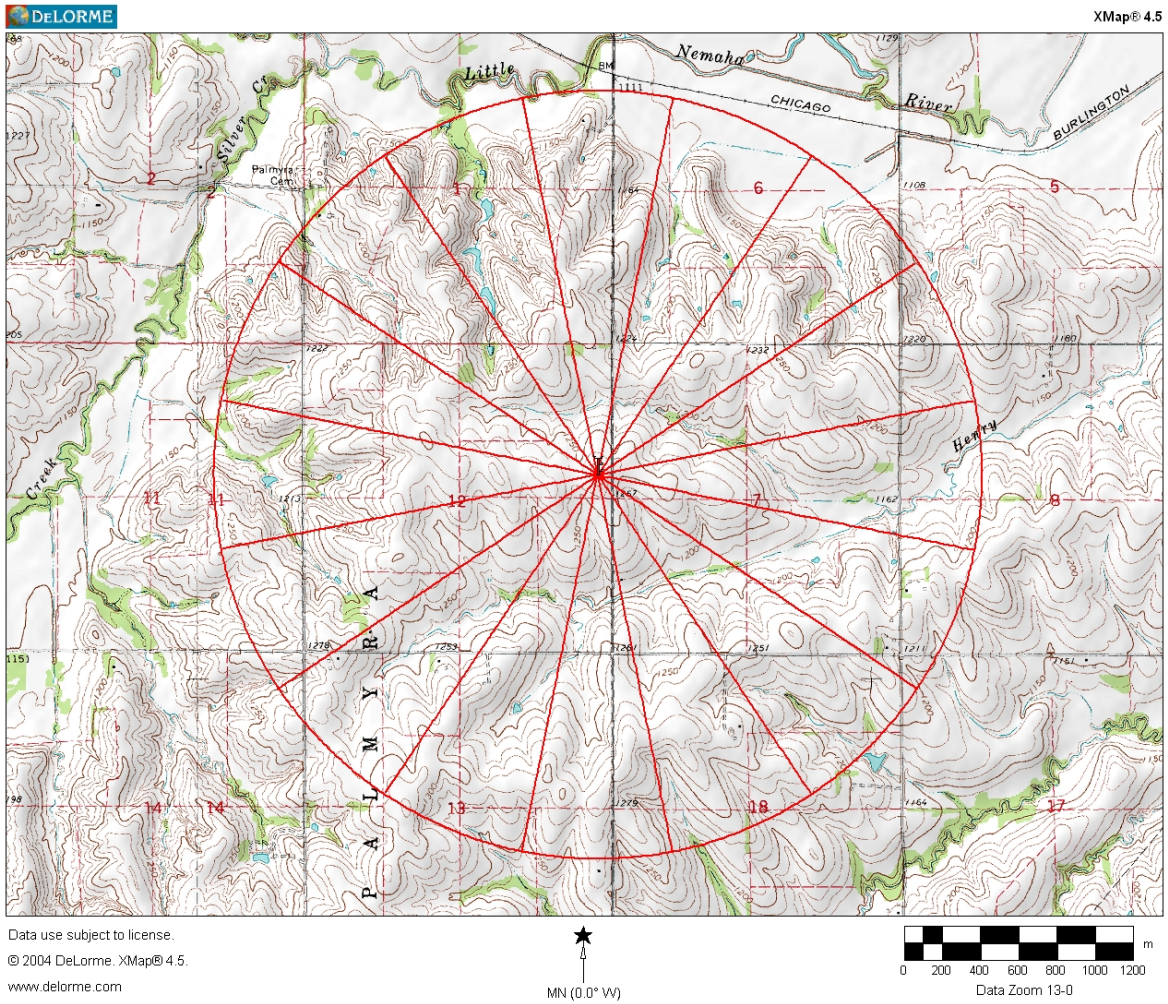
Variance of WS with WD



Basic Concept of Analysis

- The wind speed variation between met sites can be described by comparing exposures
- Obtain digital elevation models
- Calculate terrain exposures at met sites
- Experiment with calculation of exposures (radius of influence, weighting schemes)
- Analyze in context of WS ratios.
- What works for met sites works for turbines

Examination of Terrain Exposure



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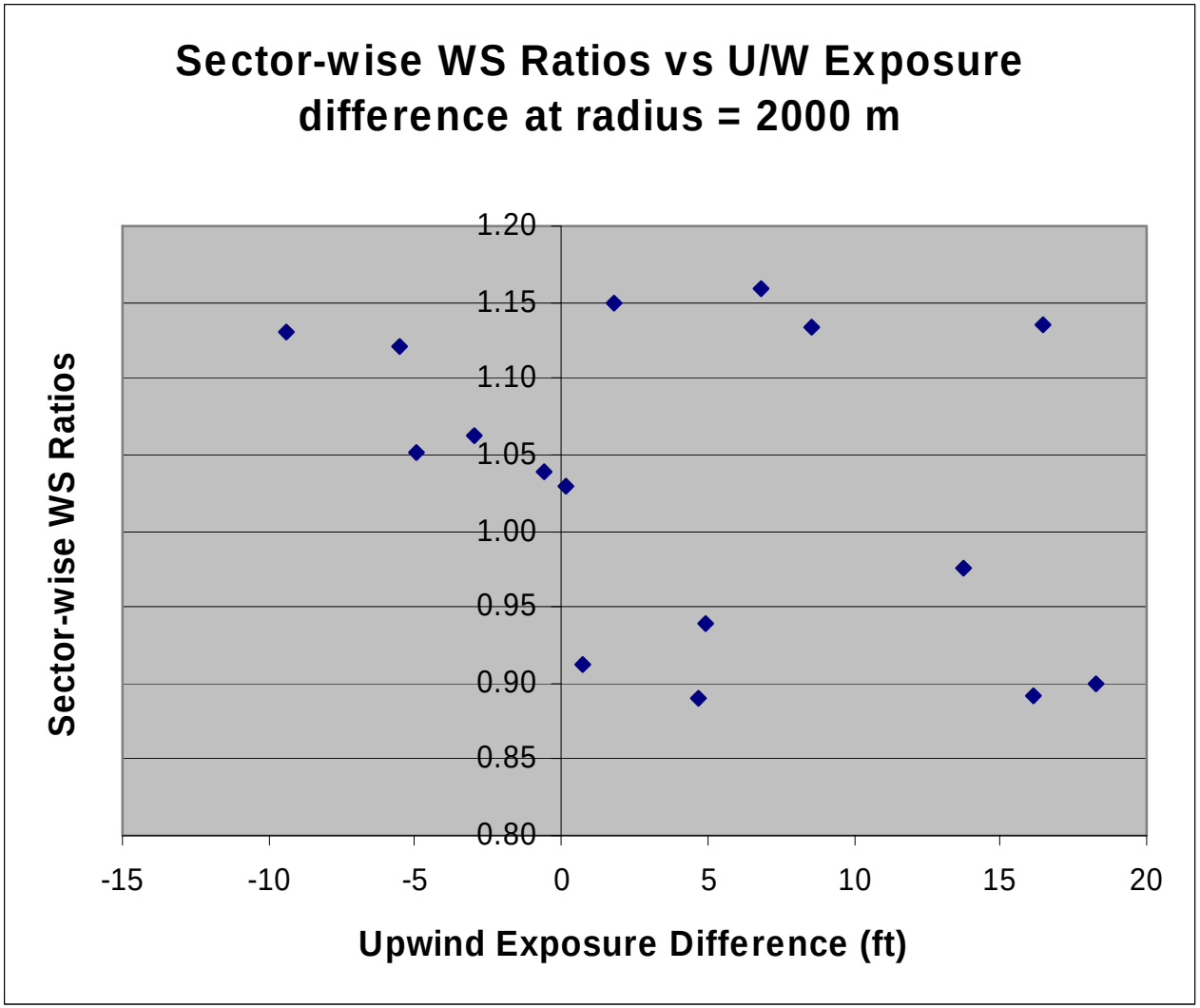
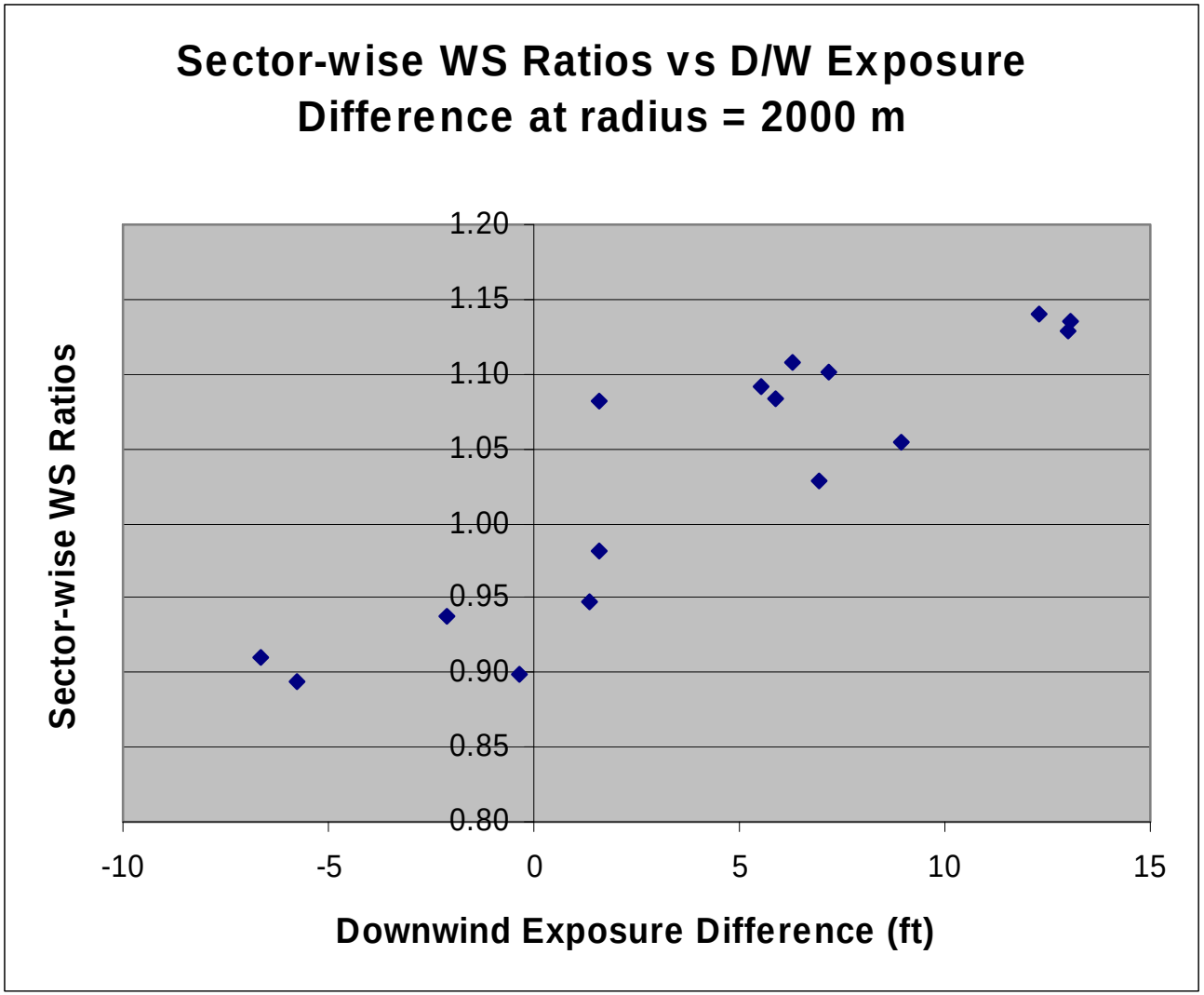
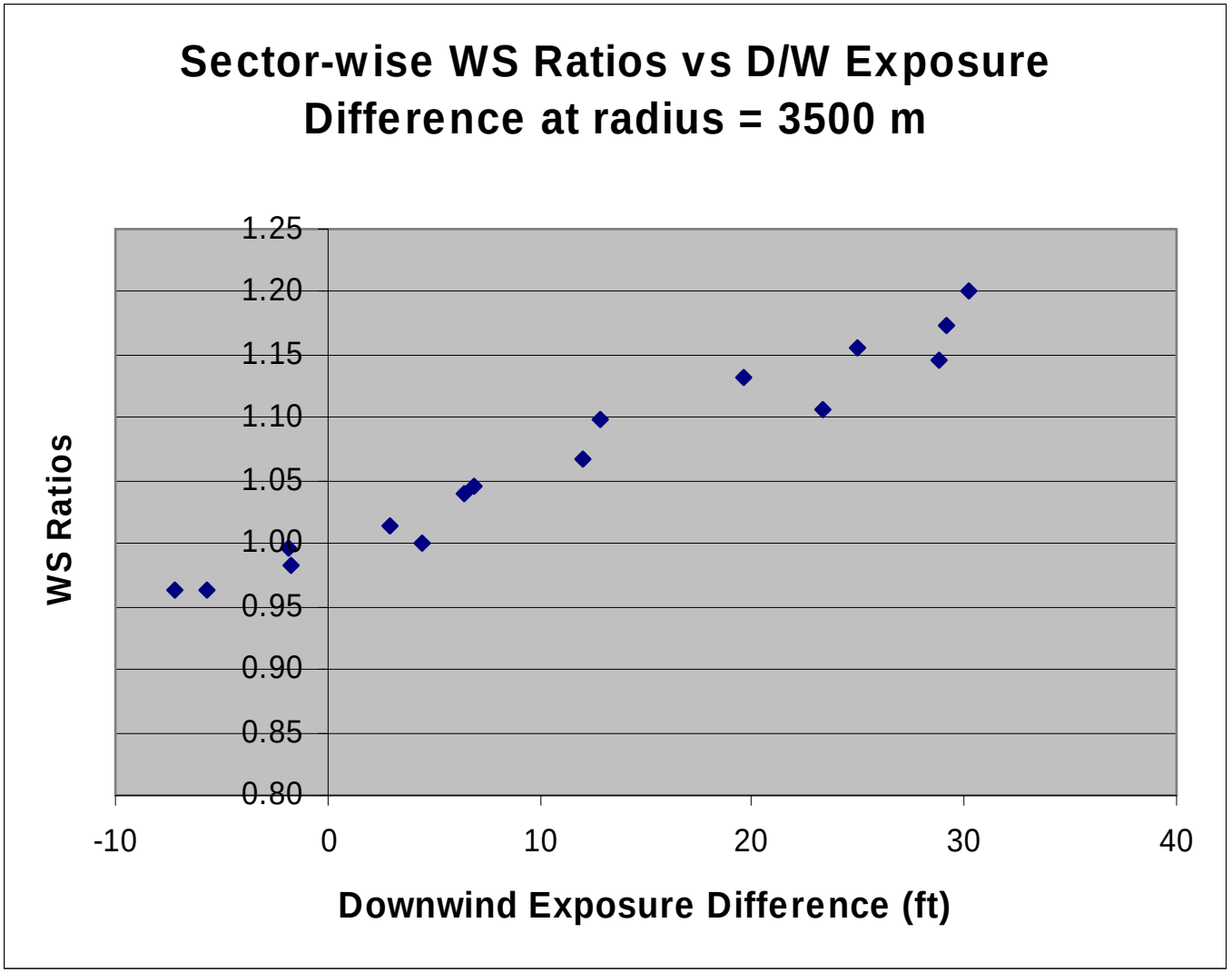
First Application - upwind



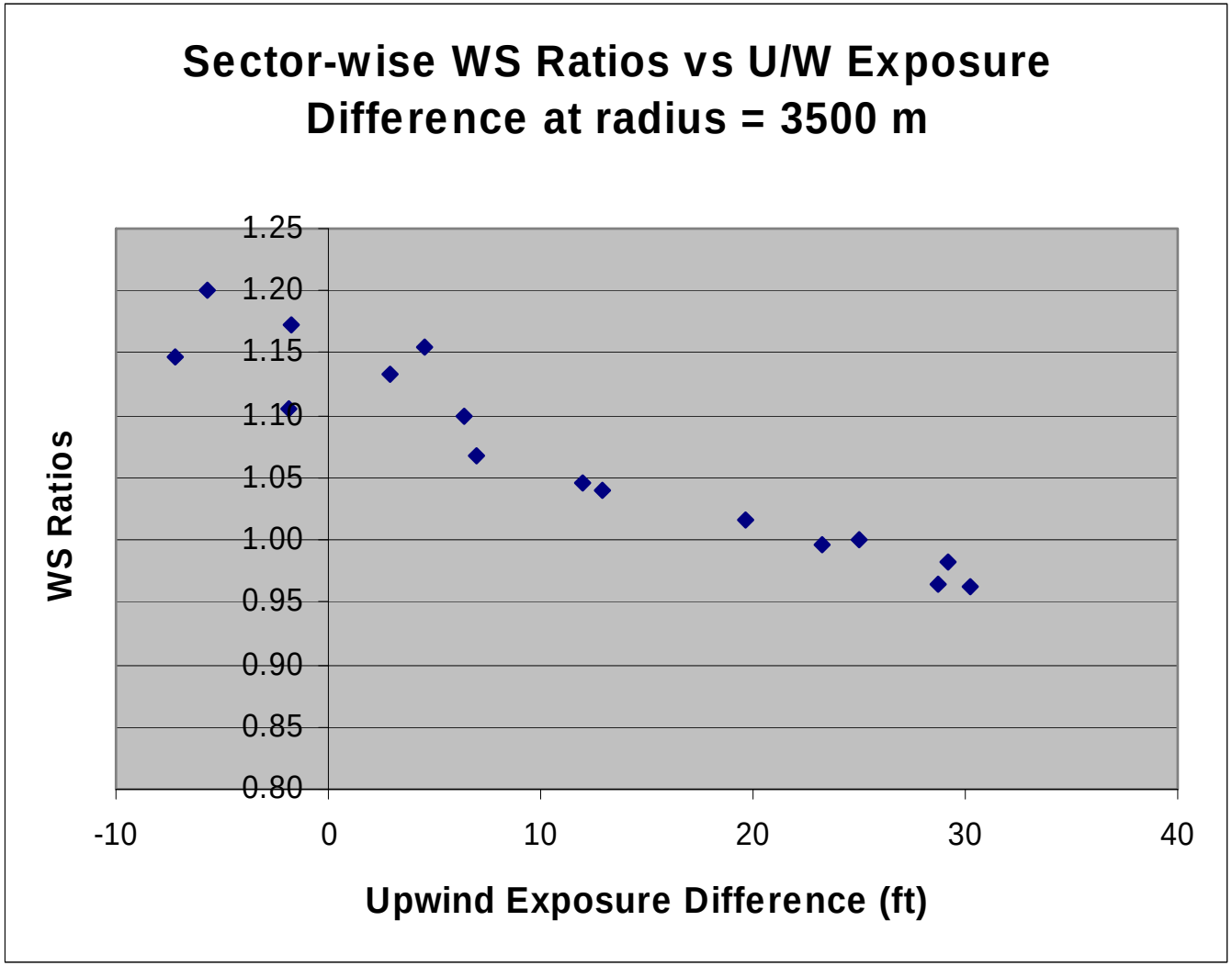
First Application – downwind



Application at another site



Same site – upwind difference



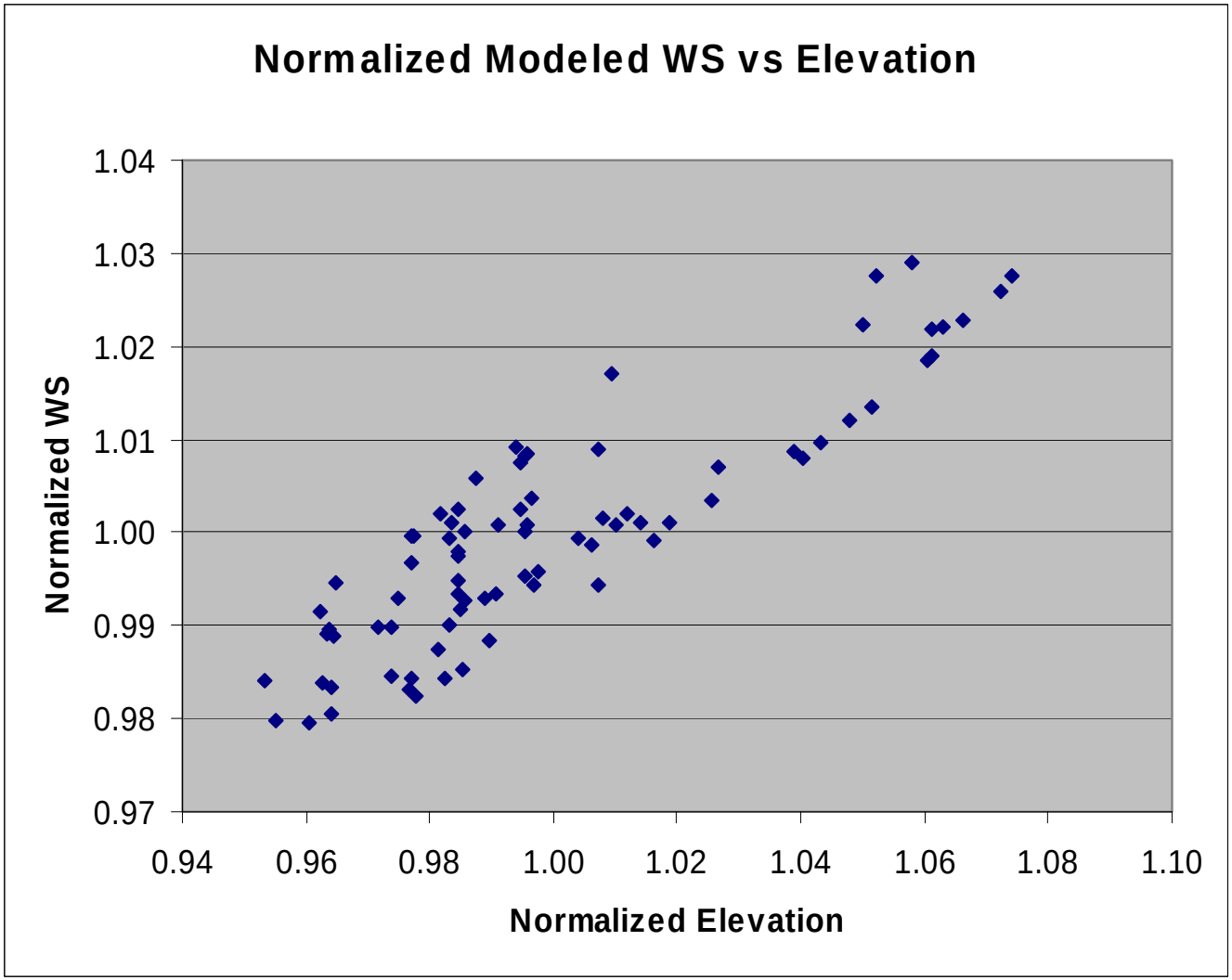
Observations on WS & Terrain

- Best results at radius = 3500 m
- Three-sector exposure smoothing improves results
- Downwind exposure differences dominant
- Upwind exposure differences typically have a negative relationship to WS ratios
- R^2 from 0.88 to 0.95 for D/W exposures
- In multiple regression (include U/W exposure) adds ~0.01 to R^2

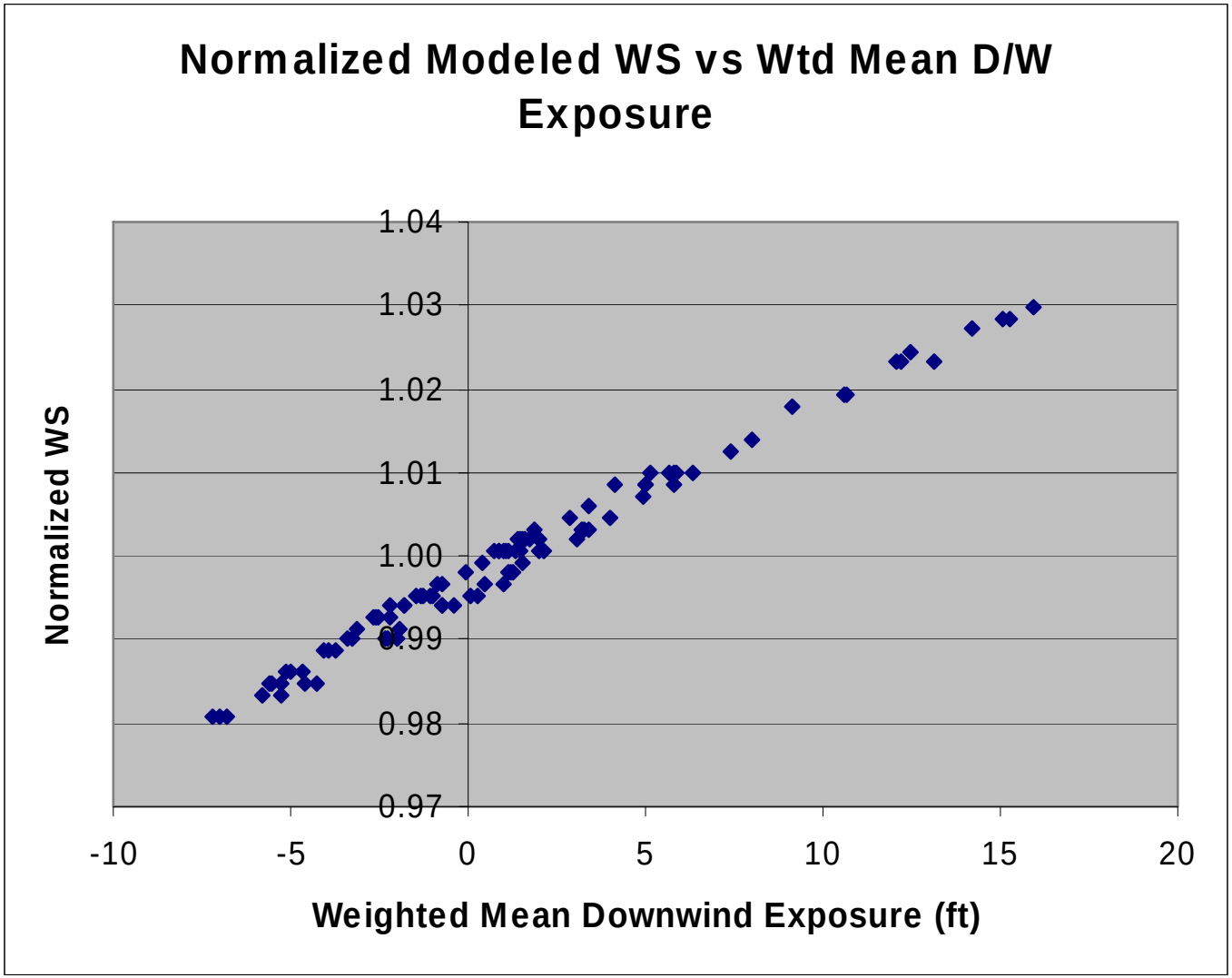
Model Overview

- Analyze WS data in context of terrain exposures – develop relationship that best fits all met towers' WS
- Calculate exposures at turbine sites and difference between turbine & reference site
- Use observed relationship to calculate WS ratios and WS in each sector at turbine sites
- Weight sector WS by D/W WD frequency
- Average & Normalize

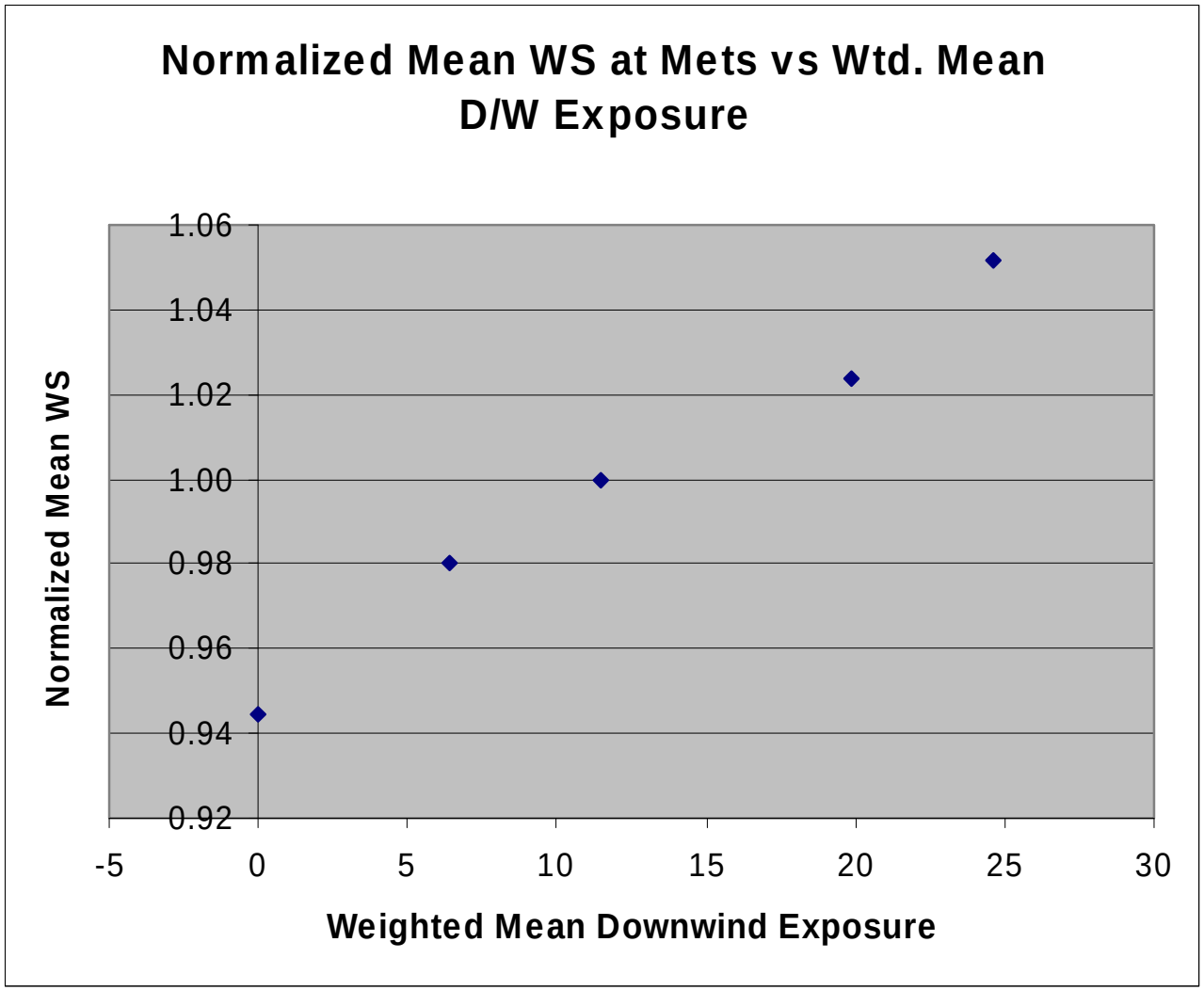
Modeled WS vs. Elevation



Modeled WS vs. Mean Exposure



Mean HH WS vs. Mean Exposure



Conclusions

- Data shows that terrain influence on WS is dominated by downwind exposure
- Radius of prime influence is ~3500 m
- Stability influence – stable conditions produce steeper slope in WS vs. exp. diff.
- Model approach may be most effective in complex terrain situations. Std err as low as 0.035 m/s.
- Can be adapted to a variety of terrain situations. No apparent bias.