Flow curvature correction

- Commercially offered solutions
  - Leosphere: Flow Complexity Recognition
  - ZephIR: Meteodyn CFD-based bias correction
  - Vaisala: WindSim CFD-based bias correction
  - Others
- Many independent studies

Improving Remote Sensor Accuracy in Complex Terrain using CFD simulations

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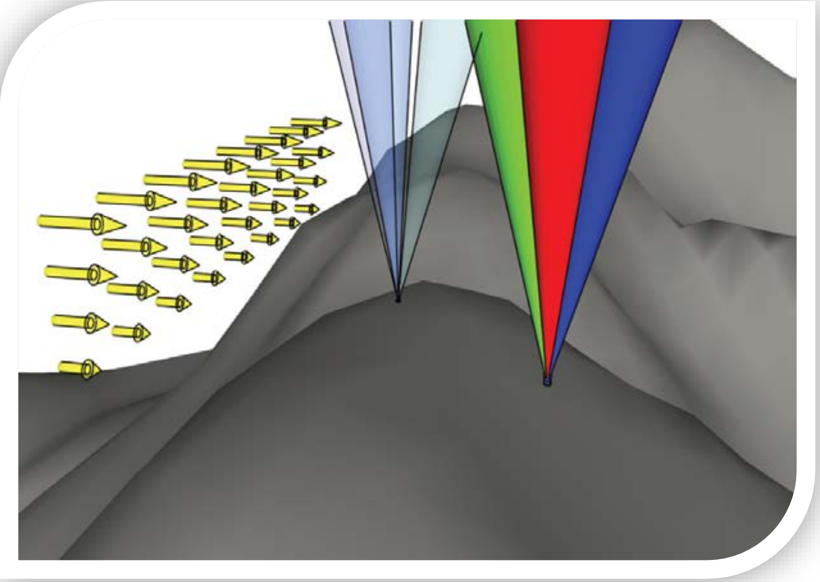
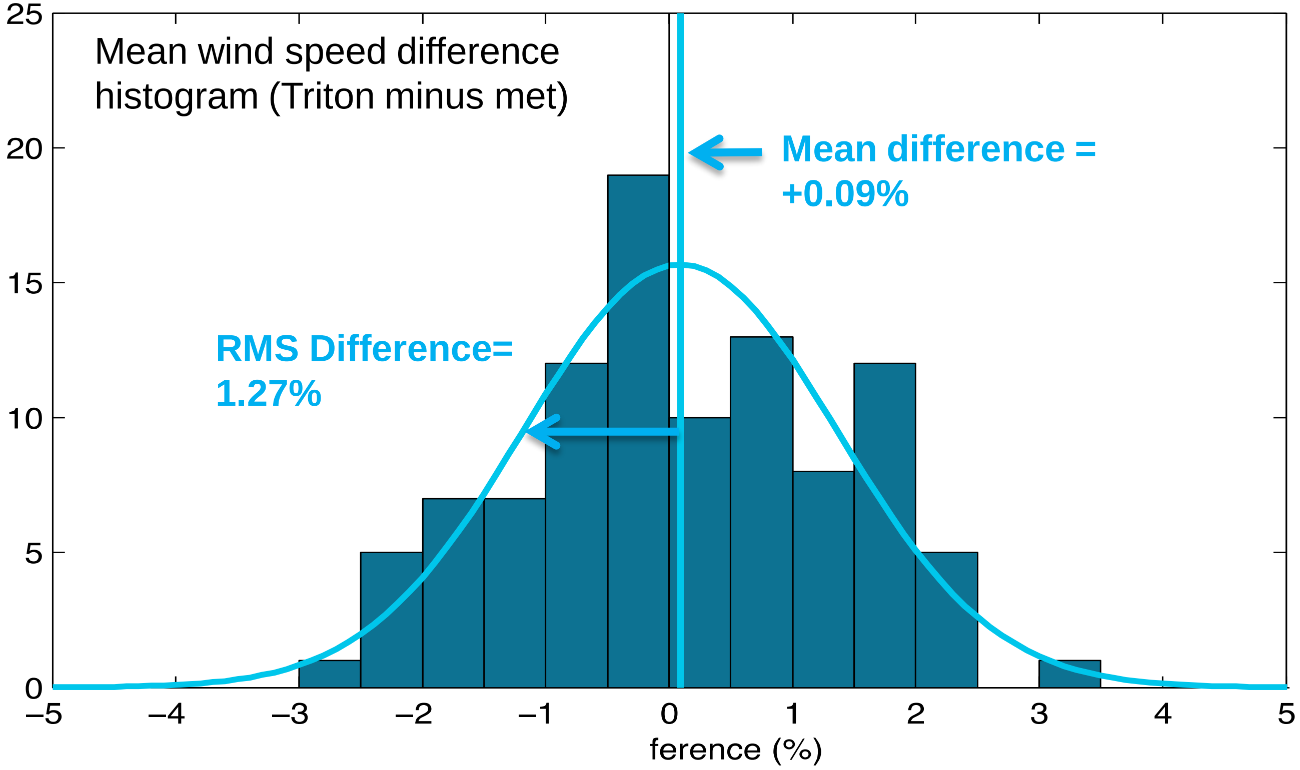
VAISALA



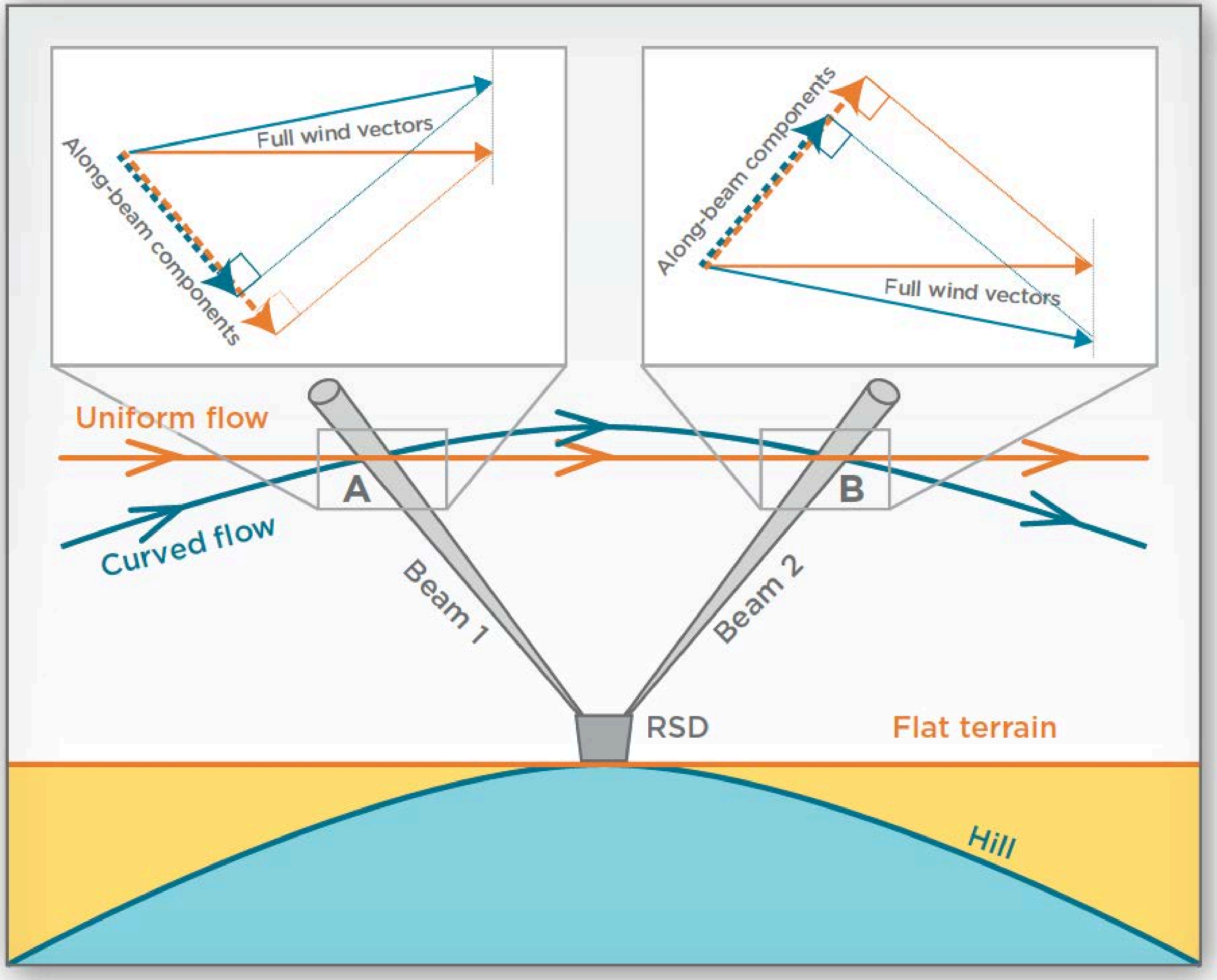
For reference: Flat-terrain validation study

- Vaisala's 2015 Validation Study of Triton Wind Profilers in Flat Terrain
  - 30 collocated RSD / met tower pairs
    → Real-world, customer-provided data!
  - 24 separate units from 11 different customers across the globe
- Results
  - Root mean-squared difference (Triton minus met) in mean wind speed of 1.27%



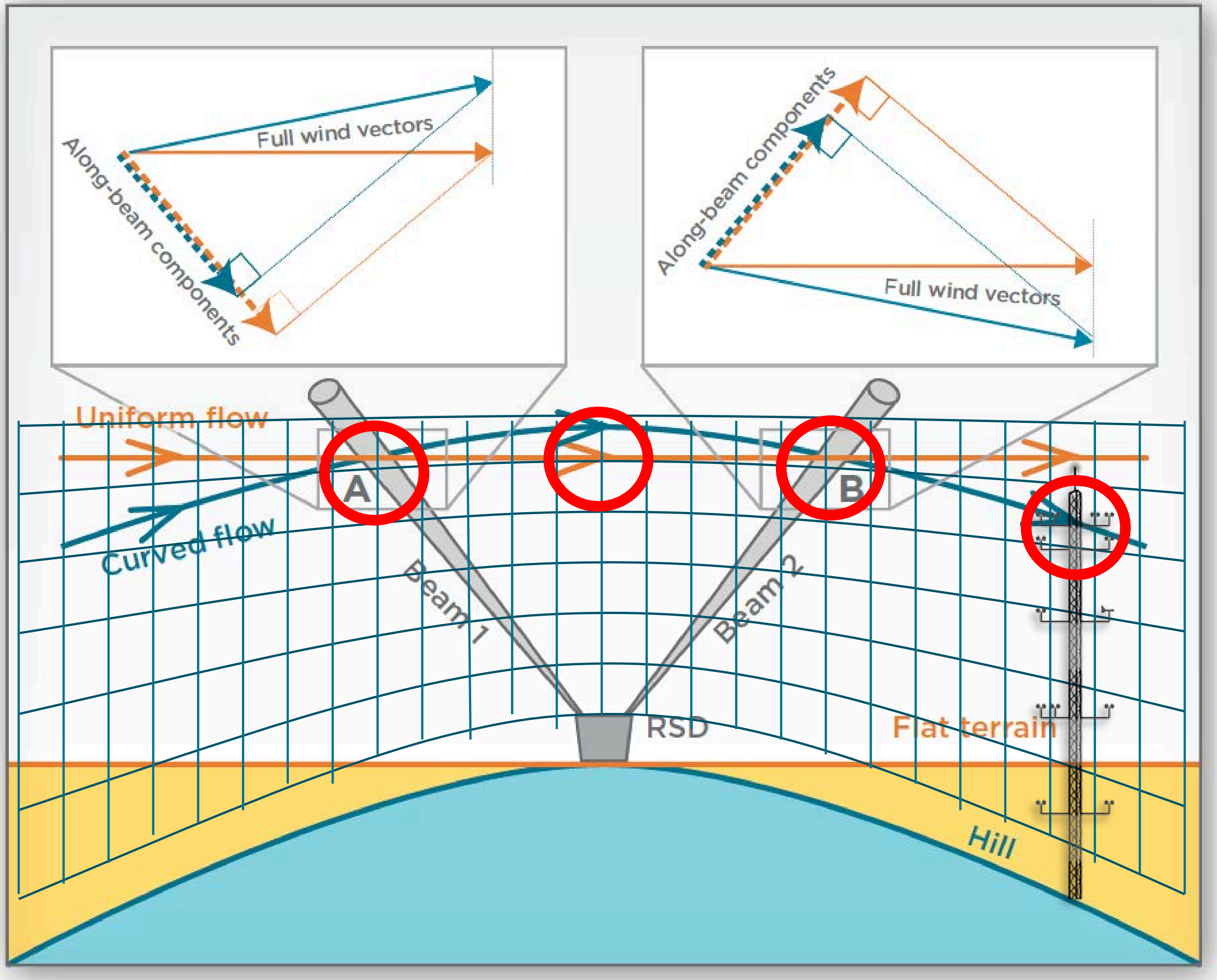
→ Triton and met each have uncertainty of ~1%.

Flow curvature bias in complex terrain



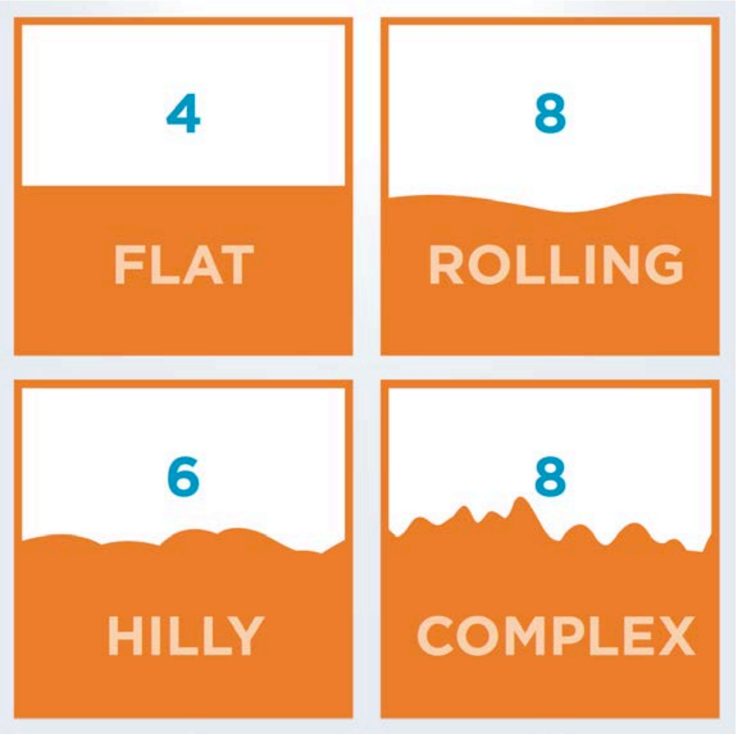
- Hill/ridge: RSD has low flow curvature bias.
- Bowl/valley: RSD has high flow curvature bias
- Uniform slope: RSD has no flow curvature bias

Modeling (and correcting) flow curvature bias

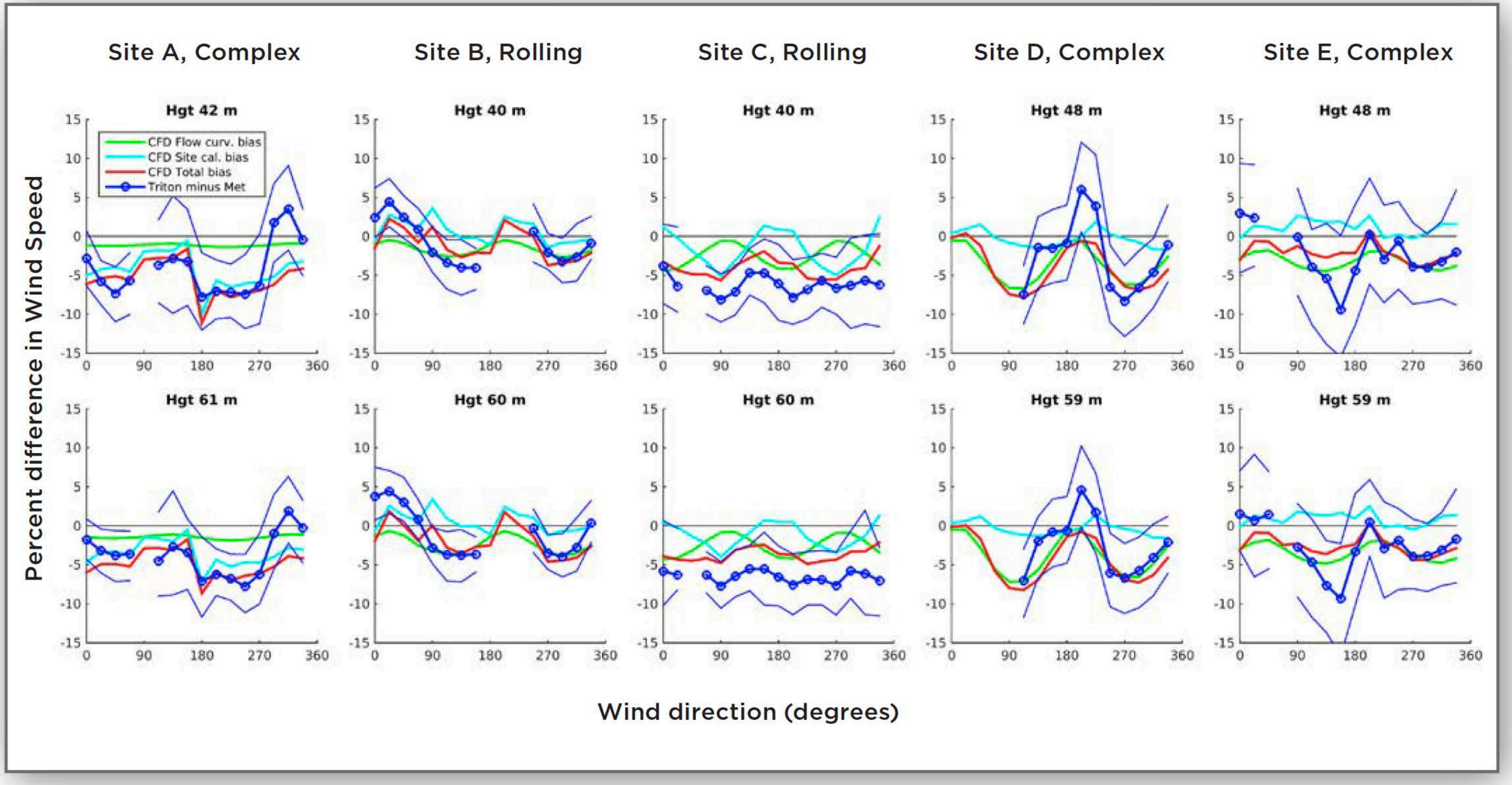


Validation study of WindSim CFD-based correction with Triton sodars

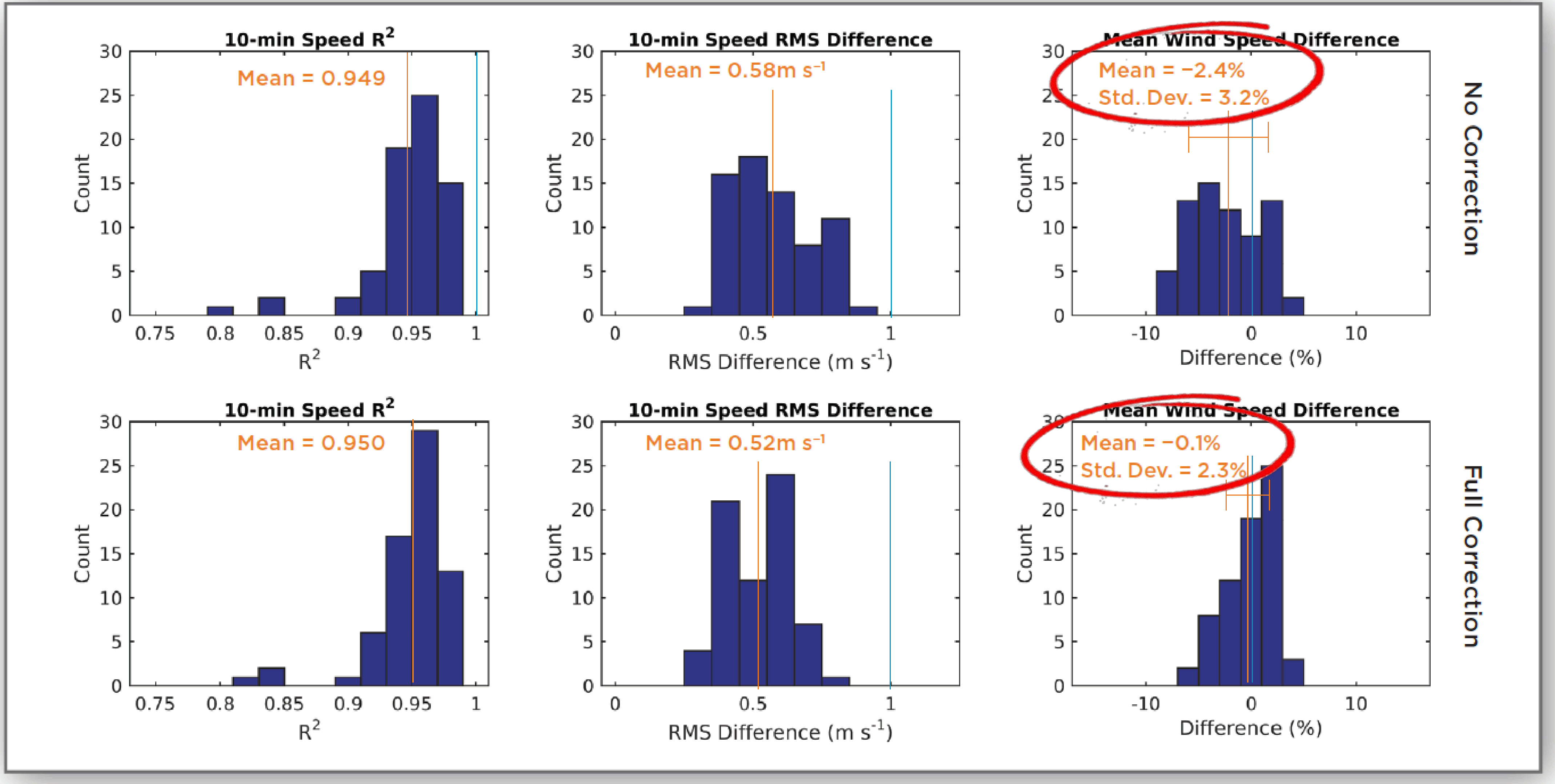
26 Sites with collocated Met Tower and Triton Wind Profiler



Examples of predicted bias versus observed mean wind speed difference



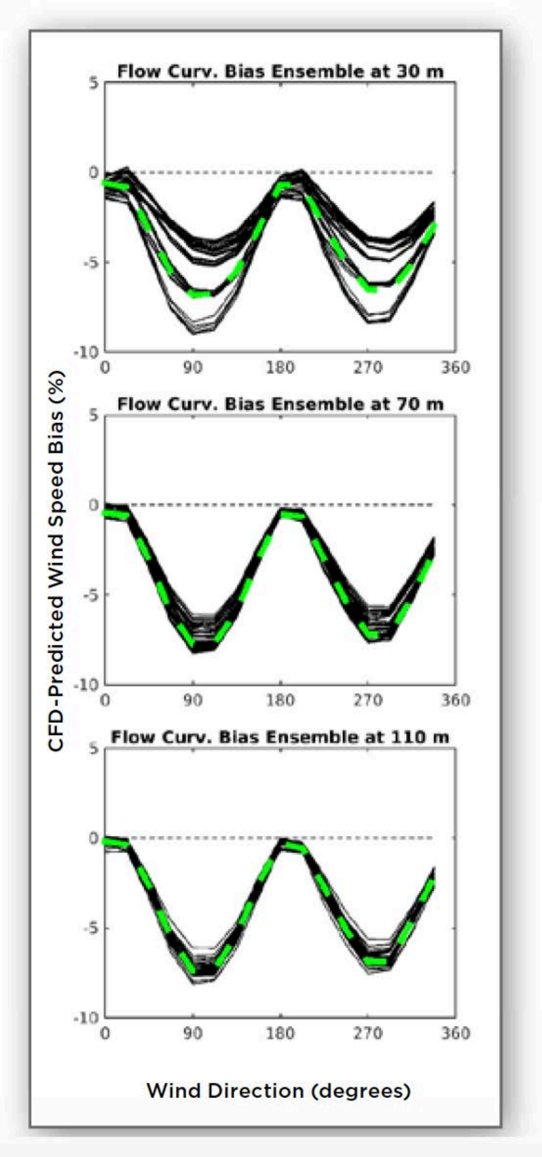
Wind speed difference histograms
(Triton minus met tower)



Uncertainty of Remotely Sensed Mean Wind Speed
(based on 26 Triton / Met Tower pairs in this study)

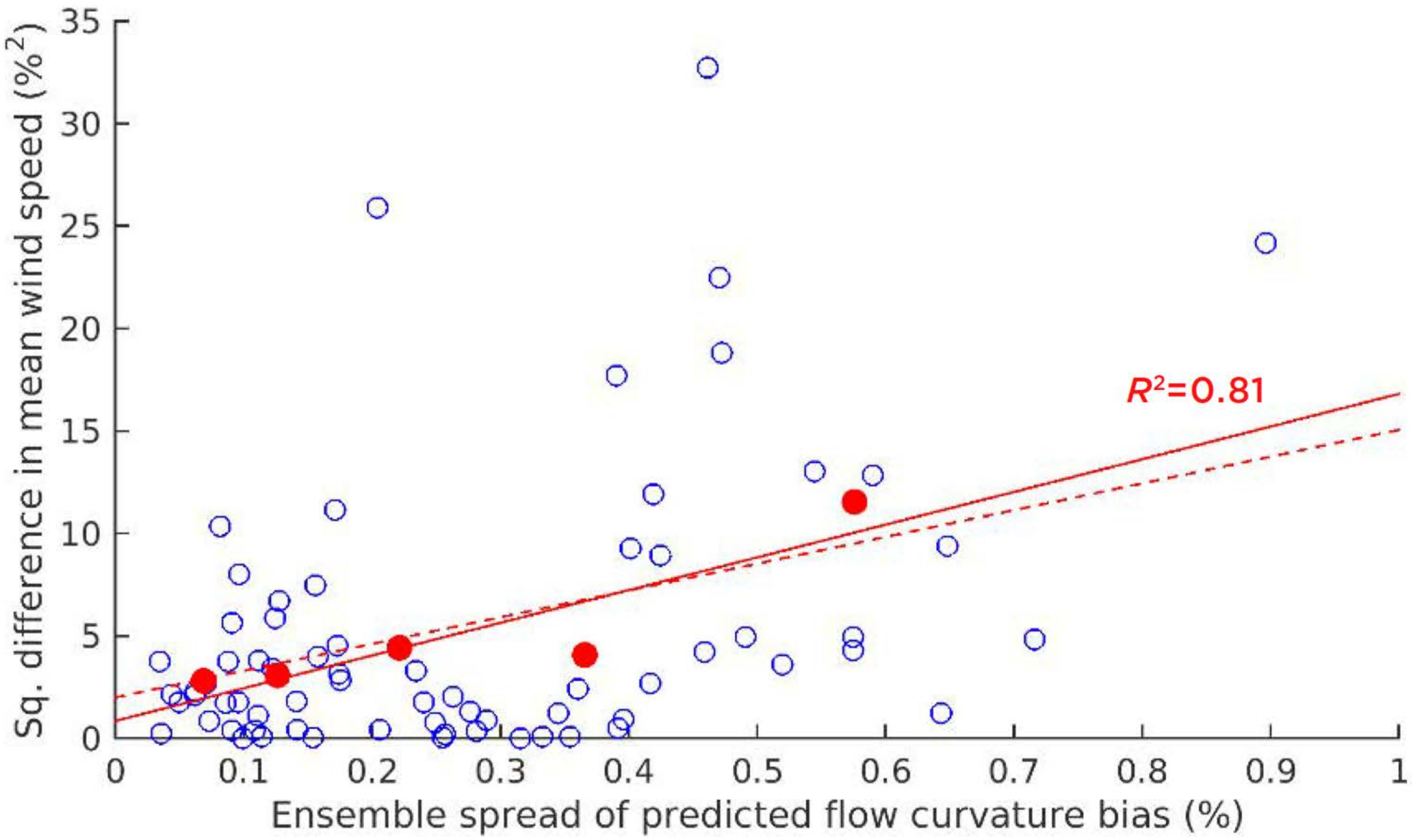
Source of Uncertainty on Mean Wind Speed	Triton Minus Met Uncertainty	Triton Uncertainty
Met Tower	1.0%	n/a
Triton (Flat Terrain Performamce)	1.0%	1.0%
Site Calibration Correction	0.8%	n/a
Flow Curvature Correction	1.8%	1.8%
Total	2.3%	2.0%
Flat terrain study:	1.3%	1.0%

Site-specific uncertainty



“Ensemble” of CFD-predicted flow curvature bias

Mean wind speed differences vs. ”ensemble spread”



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Uncertainty of Remotely Sensed Mean Wind Speed
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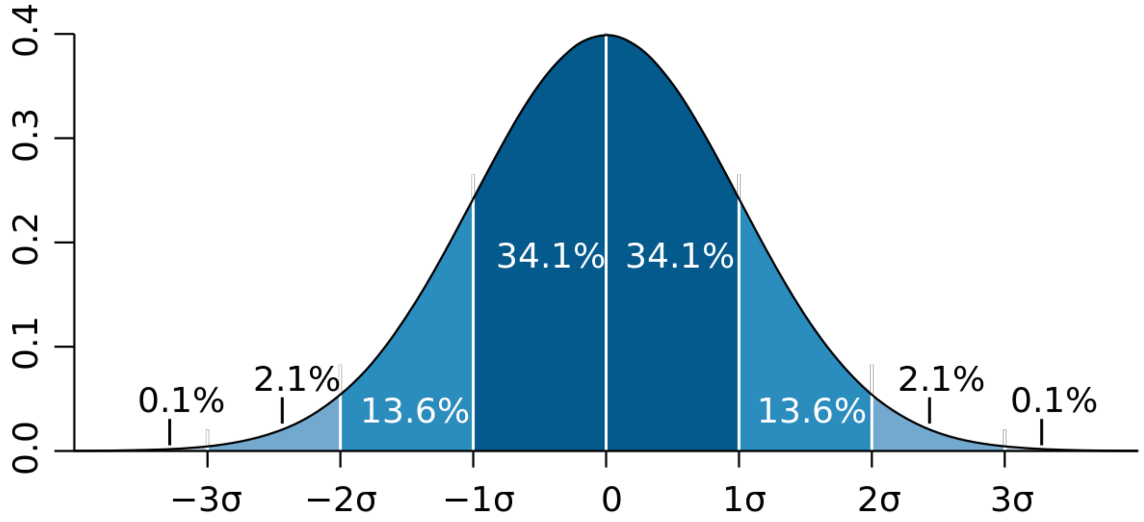
Type of Terrain	Average Triton Uncertainty
Flat	1.3%
Rolling	1.9%
Hilly	2.2%
Complex	2.2%
By Height	**Triton Uncertainty**
Low (median height = 43 m)	2.2%
Medium (median height = 60 m)	1.9%
High (median height = 89 m)	1.6%

Conclusions

- We tested at CFD-based flow curvature correction on 26 Triton Wind Profilers collocated with met towers at sites of diverse terrain complexity around the globe.
- Most of the sites were in “convex” curved flow (over hills and ridges) and exhibited, on average, a low bias in mean wind speed difference (Triton minus met tower) of -2.4%.
- When the CFD-based flow curvature correction was applied, this low bias was reduced to -0.1% on average. However, the correction leaves an additional uncertainty, increasing the uncertainty on Triton mean wind speed from 1% (found in the flat terrain validation study) to 2% when flow curvature correction is applied.
- A method was developed to estimate a site-specific uncertainty based on uncertainty in the flow curvature calculation (the “ensemble spread”). It showed:
  - More complex sites incur greater uncertainty, but still at a level that would help reduce overall uncertainty of a project.
  - Uncertainty decreases with height → good new for increasing hub heights.

A side note about comparing two uncertain measurements

- An uncertainty range is not an absolute limit. → normal distribution has “tails”



- When you subtract two uncertain measurements, the resulting uncertainty is larger.

Unc. Of each Measurement	Uncertainty of the difference	Fraction of Triton / met tower pairs where mean wind speed difference greater than	
		3%	5%
1.5%	2.1%	1 out of 6	1 out of 50