GLOBAL SOLUTIONS

IN ENGINEERING

Applications of Remote Sensing for Wind Power Development: Best Practices

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OUTLINE

- How remote sensing works
- Advantages and disadvantages of remote sensing
- Price comparison
- Deployment Best Practices
- Applications of remote sensing
  - Wind resource assessment (reduction of uncertainty)
    - Shear Validation
    - Wind Flow Modelling
  - Climate Suitability
  - Facility Operations
  - Supplementary tool for power performance testing

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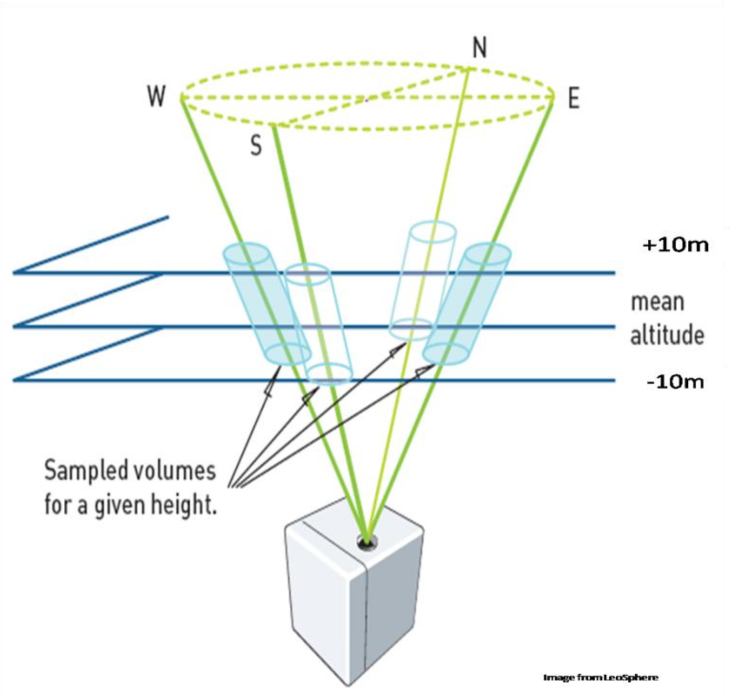
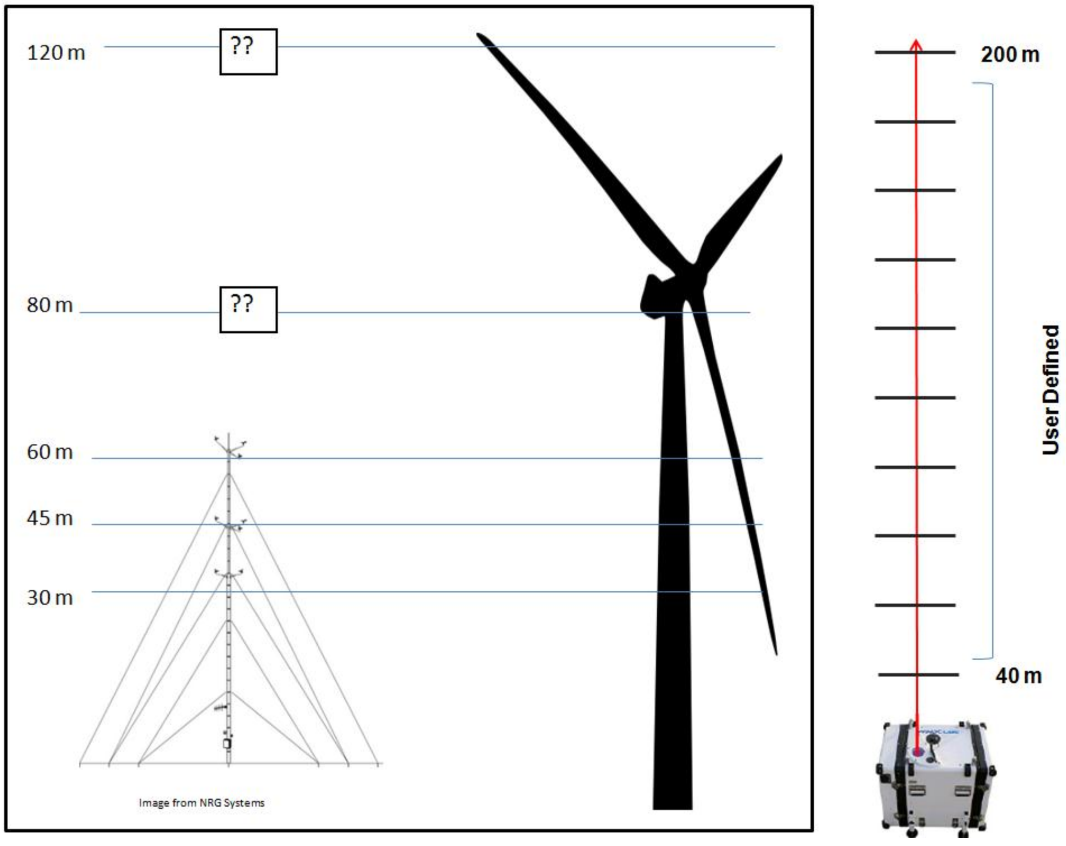
How Remote Sensing Works

- Sodar (**SO**nic **D**etection **A**nd **R**anging), Lidar (**LI**ght **D**etection **A**nd **R**anging)
- Lidar measures doppler shift of light reflected from moving particles in the atmosphere
- Sodar measures doppler shift of sound reflected from eddies and turbulence in the atmosphere



Advantages to Remote Sensing

- Measurements at multiple heights
- Measurement throughout entire rotor swept area
- Highly mobile and flexible
- No permitting necessary
- Measures variables such as
  - Vertical Wind Speed
  - Wind Inclination angle
  - Turbulence Intensity
  - Wind Veer



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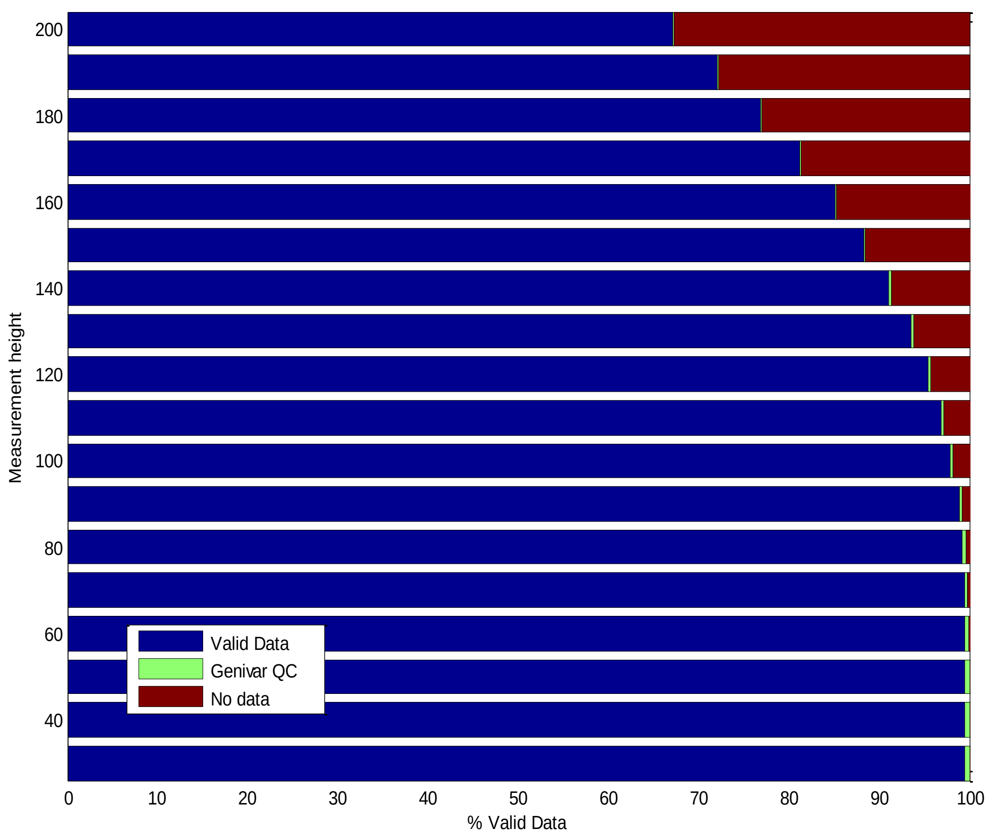
Disadvantages to Remote Sensing

- Reliability and data quality issues can be weather dependent
- Can be expensive
- Require a calibration using a conventional meteorological met mast
- Significant power requirements
- Volume averaging and vector measurements result in discrepancy from anemometer measurements
- Power curves are based upon anemometer measurements
- Results may vary in complex terrain
- Requires intensive data monitoring



Comparison of Technologies

- 60 m meteorological tower ~ $40k to $50 k
- 80 m meteorological tower $80 k to $150 k
- Sodar ~$40 k for unit + (deployment, decommissioning, data processing)
- Lidar $200 k to $250 k + (deployment, decommissioning, data processing)

Deployment Best Practices: General Commentary

- Bad data with insufficient period of records may be more harm than good
- Anemometer versus remote sensing measurements
  - Calibration via co-location with meteorological tower (vector measurement, volume averaging, air density correction)
- Technologies are still changing
- Deployment location can dramatically alter data quality
  - Echo, obstacles, complex flow in complex terrain and roughness

Deployment Best Practices: Obstacles

- Sodar:
  - 20 m greater than highest measurement height
  - Beam should not be oriented towards solid objects (20 m extra)
  - Ambient noise should be avoided
  - Wind noise from instrument configuration should be avoided
- Lidar:
  - 45 degree clearance is required

Deployment Best Practices: Complex Flow

- Complex flow conditions should be avoided
  - Downwind of terrain features in predominant wind directions is preferred
- Changes in the wind flow conditions within the measurement volume

Deployment Best Practices: Validation

- Co-locating the remote sensing unit in the initial deployment for calibration
  - Within **6 months** of stand-alone deployment for sodar, **annually** for lidar
  - Calibration required after configuration change or sensor replacement
  - Similar terrain, roughness and flow conditions of stand-alone deployment
  - Accurate anemometers
  - Sodar within 60 m to 150 m of tower, considering echo
  - Lidar immediately adjacent to tower
  - Similar elevation
  - Multiple tower monitoring heights
- An onsite meteorological tower is required for stand-alone operation
  - data quality control, outlier detection, filling and extending data

Data Requirements

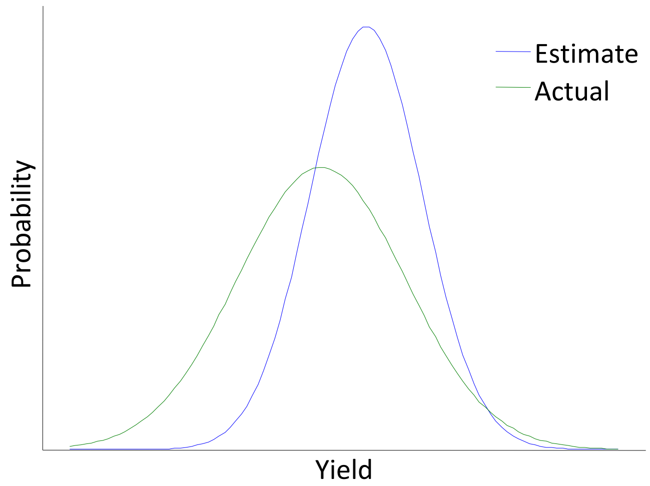
- Calibration:
  - Data collected for at least one month, three months preferred
  - At least 48 hours of valid data is required for each predominant wind direction
  - Both high and low wind speeds should be represented
  - Standard error should be less than 2% of the slope of any linear correlation with a meteorological tower
- Data for 6 months is recommended for stand-alone deployments, one year is desirable
- Seasonal sampling is acceptable (returned to a site for a 2 month period 3 times a year for example)

Applications of Remote Sensing

- Wind resource assessment: minimizing **uncertainty and bias**
  - **What are the most cost effective ways to reduce uncertainty?**
- Measurement of wind conditions for climate suitability
- Turbine operational monitoring
- Power performance testing

Uncertainty in Wind Resource Assessment

- An indicator of the total project uncertainty is the difference between the P50 and P90. A consequence of bias is an error in the P50.



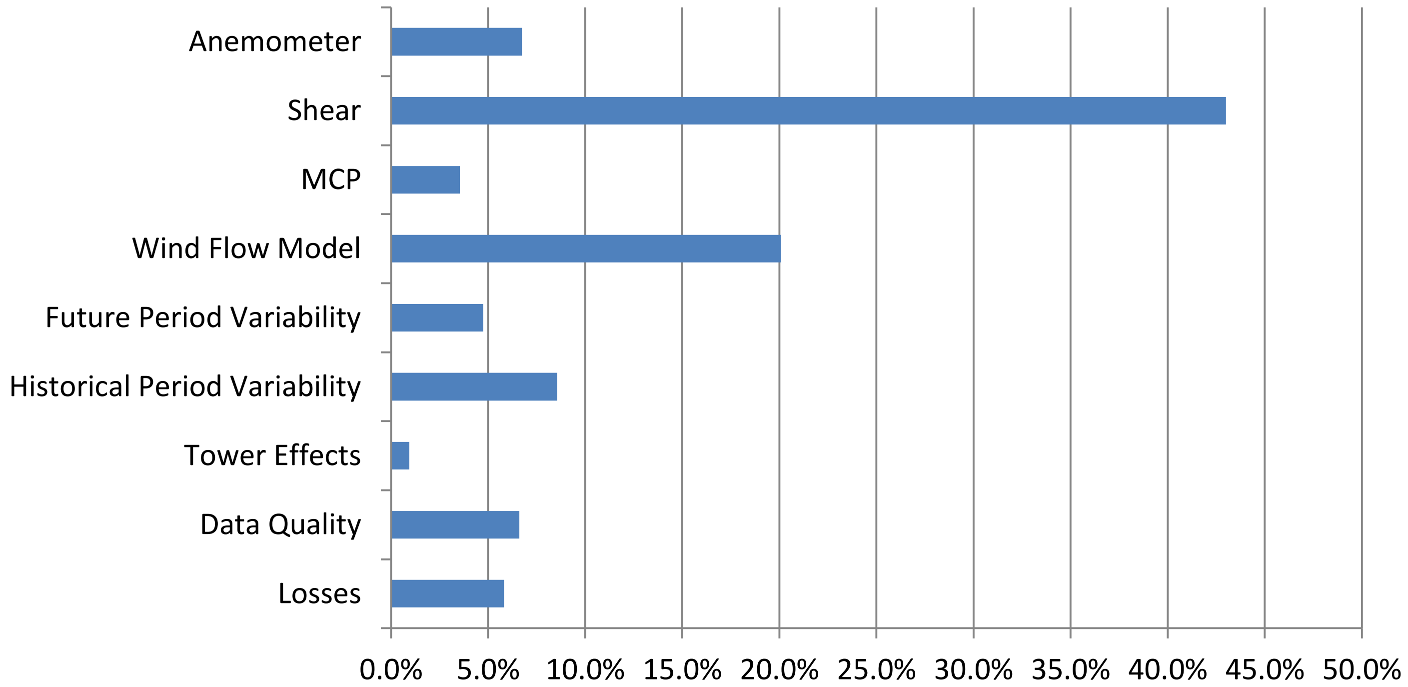
- Uncertainty is inevitable in wind resource assessment; however, the goal should be for it to **minimized**.
- In contrast to uncertainty, bias in yield assessment is **avoidable**. A goal of wind resource assessment is to eliminate sources of bias.

Example Sources of Uncertainty

Source	Standard Uncertainty
Anemometer	0.1 m/s
Shear	0.25 m/s
MCP	1.0% of wind speed
Wind Flow Model	5.0% production
Future Period Variability	1.1% wind speed
Historical Period Variability	1.5% wind speed
Tower Effects	0.5% wind speed
Data Quality	0.1 m/s
Losses	2.7% production

Relative Contribution of Uncertainty Components

- Remote sensing is commonly used to reduce **shear** and **wind flow modelling** uncertainty



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Circumstances for Remote Sensing Deployment: Shear Validation

- Identifying possible bias and high uncertainty in the shear extrapolation calculation at meteorological towers is key
  - Large distance between top measurement height and hub height
  - Inconsistencies between surface roughness and shear
  - Complex terrain/roughness
  - Inconsistent shear between monitoring heights (irregular shear profiles)
  - Inconsistent shear between meteorological towers
  - Inadequate meteorological tower instrumentation and configuration
  - Temporal trends
  - Possible sensor errors
  - Irregularities in thermal stability

Example 1: Surface Roughness

- Shear exponent should be approximately consistent surface roughness
  - $\alpha = 1/\ln(10/z)$ where α is the shear exponent and z is surface roughness (m)

Surface Roughness (m)	Equivalent Shear Exponent	Description
0.001	0.11	Water
0.03	0.17	Flat Prairie- low grass
0.1	0.22	Farmland
0.3	0.29	Light Forest
0.7	0.38	Tall dense forest

Example2: Irregular shear profiles

- Inconsistent shear profiles across meteorological tower heights and irregular thermal stability patterns

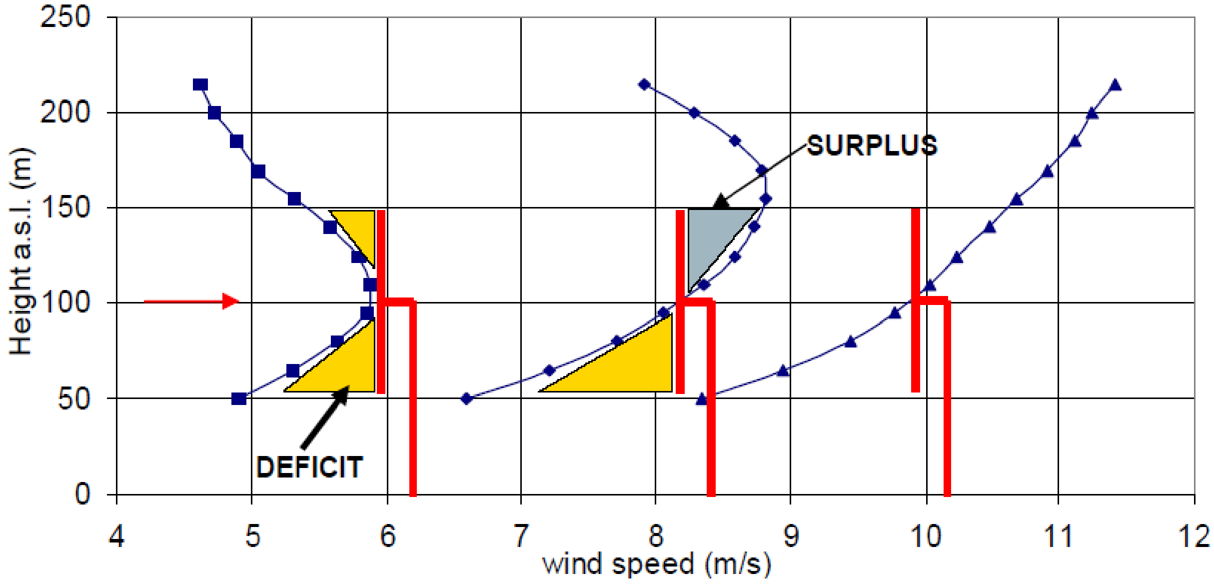

Figure citation: I. Antoniou, et. al, Uncertainty in Power Curve Measurements Caused by Wind Shear, Siemens, AWEA Workshop, Minneapolis 2009.

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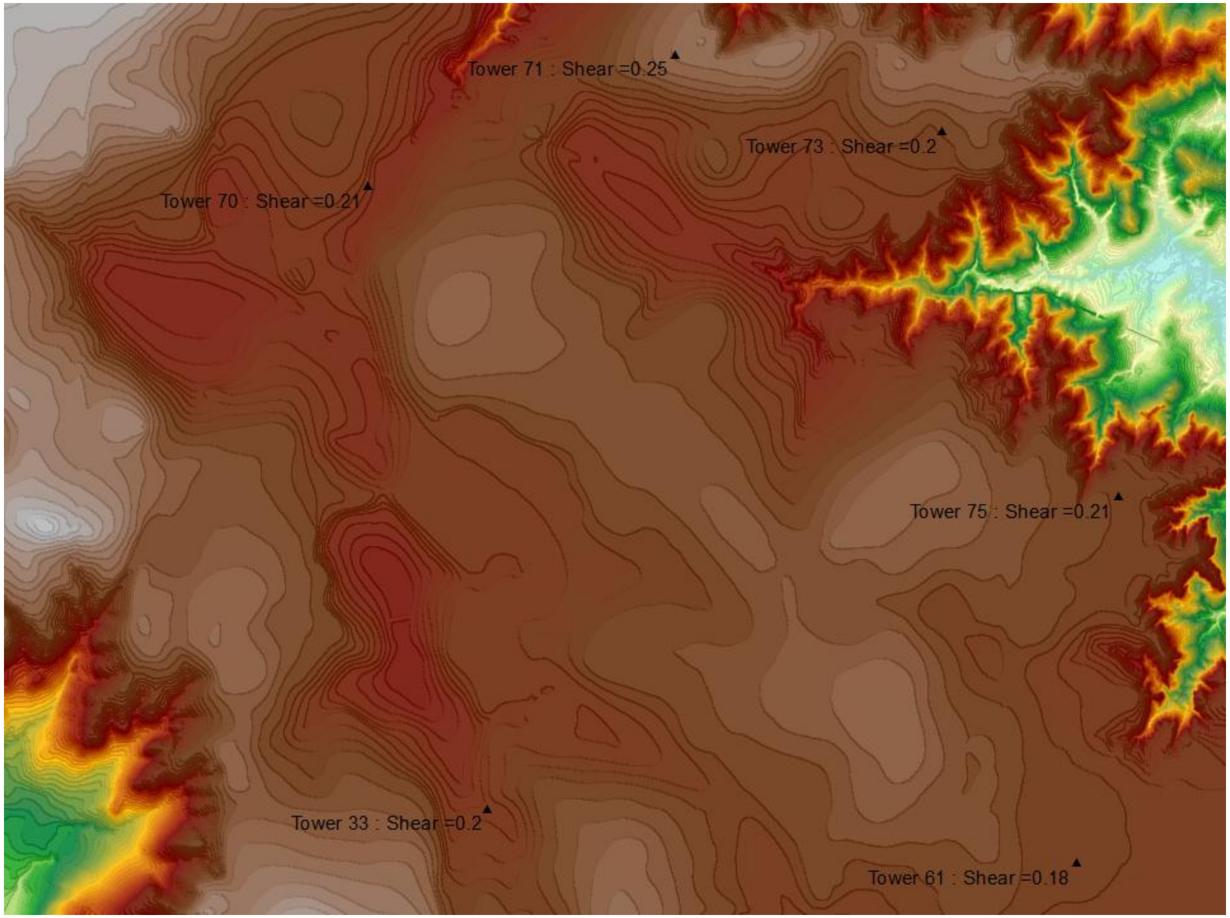
Example 3: Inconsistent Shear Across the Site



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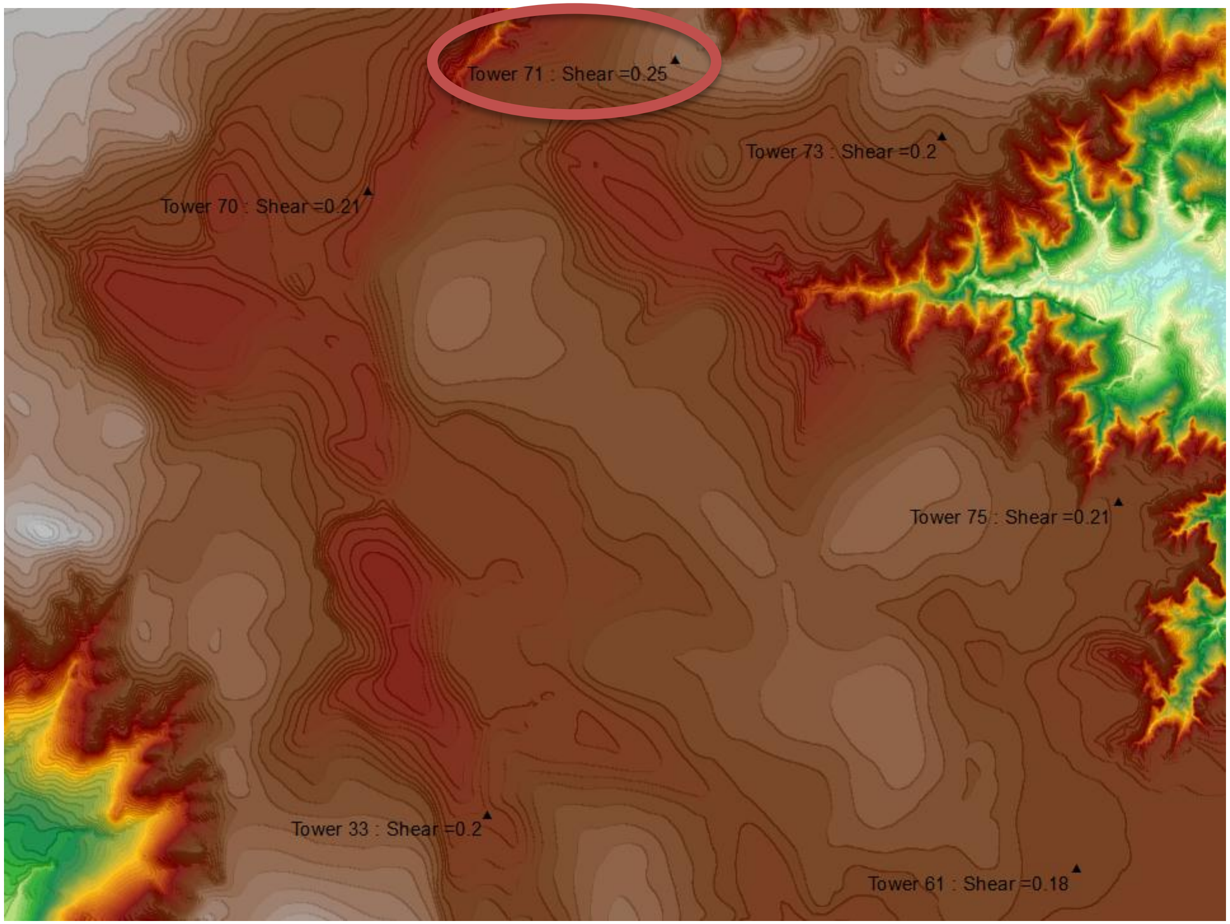
Example 3: Inconsistent Shear Across the Site



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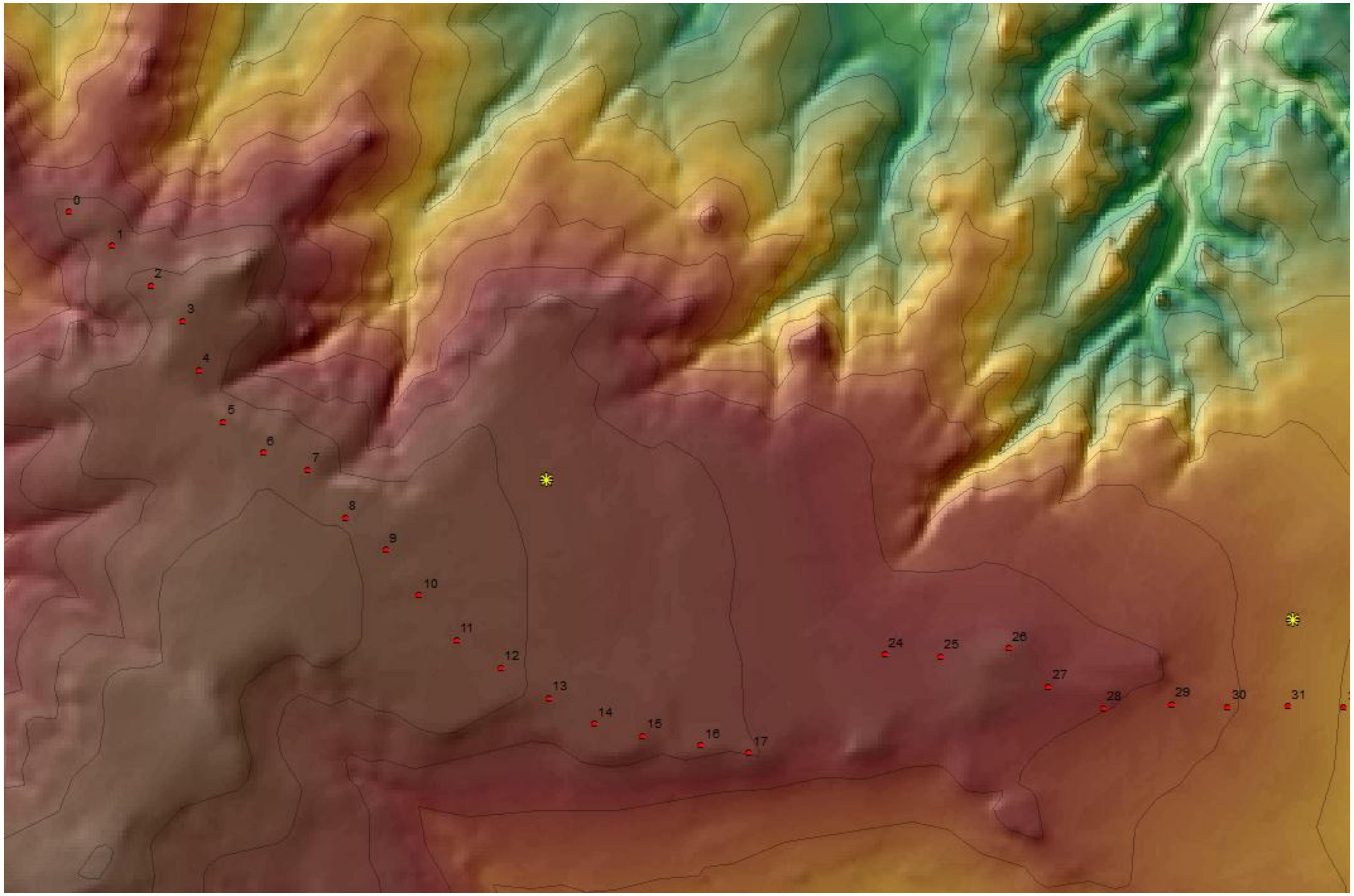
Circumstances for Remote Sensing Deployment: Wind Flow Modelling

- Supplemental point source of wind speed/direction data (stand-alone deployment)
- Identifying scenarios with high probability of modelling error/uncertainty
  - Features with large anticipated modelling error (hill bluffs, large changes in terrain/roughness)
  - Large distances between turbines and meteorological towers (> 2.5 km)
  - Large difference in elevation between turbine and meteorological towers (even when positioned within 2.5 km)
  - Terrain features not sampled by meteorological towers
  - Poor round-robin validation between meteorological towers

Example 1: UnsampledTerrain Features, Large Distances



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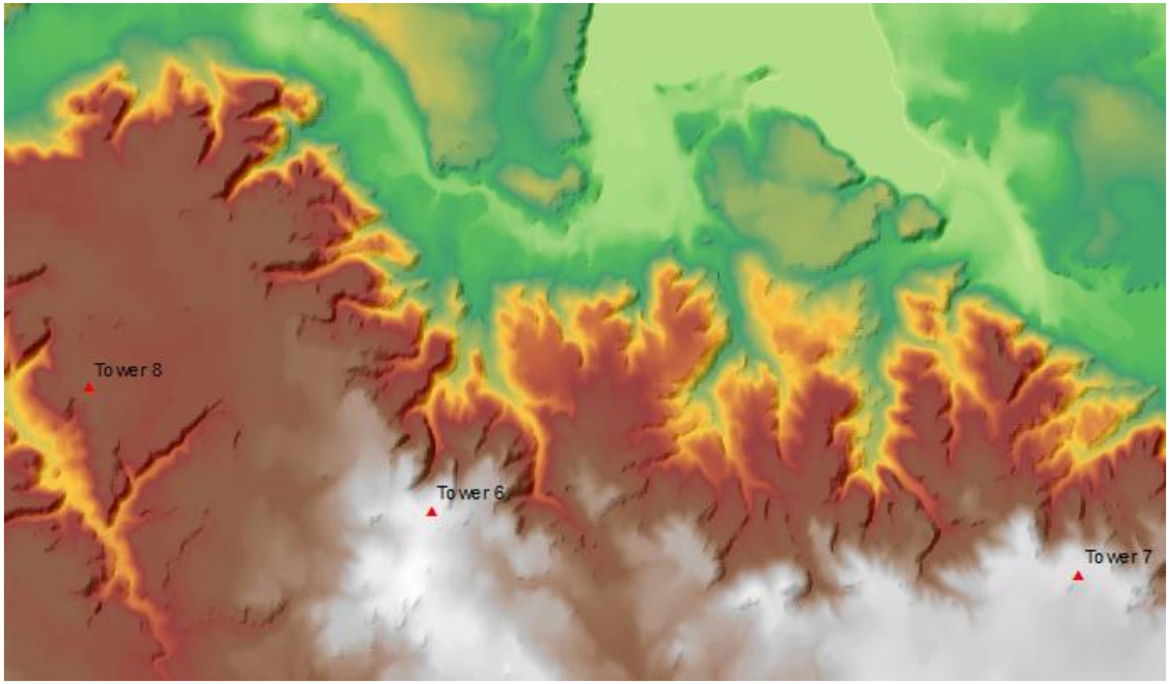
Example 2: Poor Model Validation



Model Seed	Modelled Results		
	Tower 6	Tower 7	Tower 8
Tower 6	-	2.08%	14.79%
Tower 7	-1.95%	-	12.35%
Tower 8	-12.26%	-10.90%	-

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Climate Suitabilty

- Remote sensing can be used to measure supplemental wind flow conditions
  - Inclination angle
  - Turbulence
  - Wind Veer
  - Shear
- Provides validation for modelling results
- Provides validation for meteorological tower measurements

Turbine Operational Monitoring

- Round robin measurement of wind speeds at turbine locations
- Preventative maintenance tool
- Identify turbine performance issues
  - Computer control
  - Blade pitch
  - Yaw angle
  - Extreme wind flow conditions
  - Blade soiling
  - Turbine underperformance

Power Performance Testing

- Supplemental data collection in addition to prescribed configuration in IEC 61400-12-1
- Measurement of shear in the upper rotor swept area
- Collection of data for filtering extreme wind flow conditions

Conclusions

- Remote sensing is a valuable tool for reducing uncertainty and bias in wind resource assessment
- Campaigns should be designed to target the most significant contributors to uncertainty
- Is an emerging technology and has limitations
- Special care must be taken to properly deploy instruments and analyse data
- Additional applications of remote sensing are:
  - Measurement of wind flow conditions for turbine climate suitability
  - Turbine operations monitoring tool
  - Measurement tool for data for extreme weather condition filtering in supplement to IEC 61400-12-1 for power performance testing

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