# Characterizing Wind Turbine Inflow and Wakes Through Comparison of SODAR and Met Tower Observations

## A Part of TWICS: The Turbine Wake Inflow Characterization Study


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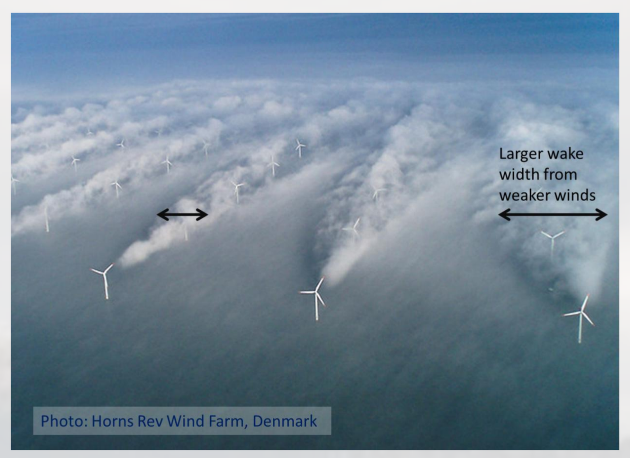
(4) University of Colorado—Boulder, USA (5) National Renewable Energy Laboratory, Golden, Colorado, USA

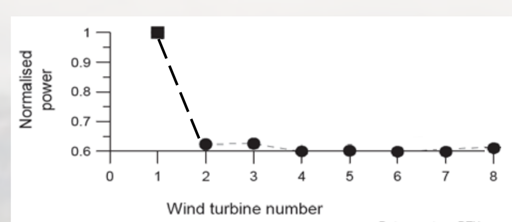

## Wind Energy: Turbine Wakes & Inflow

- Wind turbines generate electricity by harnessing the wind's kinetic energy
- Turbines create wakes (waves) of wind speed deficits




Above photo owned by Vattenfall. Photographer Christian Steiness; Annotation Neil Kelley NREL

- Wake characteristics depend on the atmospheric inflow
- Inflow varies based on meteorological phenomena, topography and land use
- These wakes can reduce production to 60% in downstream turbines




Right: Bathelmie et al, 2010: Quantifying the Impact of Wind Turbine Wakes on Power Output at Offshore Wind Farms (Data Courtesy of DTU- Technical University of Denmark)

## Increasing Efficiency of Wind Energy Generation

### Why are wakes & Inflow important to understand?

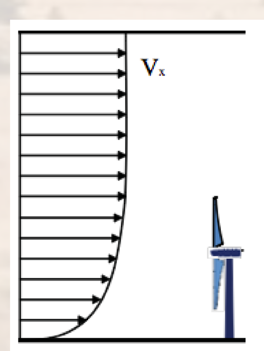
- Improve meso-scale model performance for turbulence in complex terrain
- Help engineers improve turbine design
- Maximize energy efficiency
- Pinpoint best wind farm sites
- Increase turbine lifetime
- $$ Reduce cost of energy $$

### Why is this research needed?

- Modern wind turbines penetrate a complex region of the atmosphere
  - Hub heights range from 80-120m
  - Blade diameters range from 60-120 meters

20% Wind Energy by 2030

U.S. Department of Energy



## TWICS: Turbine Wake Inflow and Characterization Study

### Field Campaign:

**April - May 2011**

The National Renewable Energy Laboratory's (NREL)

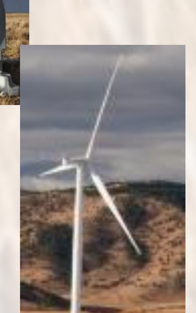
National Wind Technology Center (NWTC) south of Boulder, Colorado

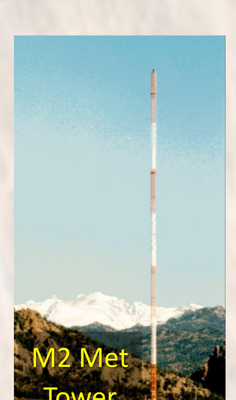
### TWICS Goals:

1. Assess structure and variability of inflow in complex terrain
2. Assess characteristics of resulting wakes
3. Improve Mesoscale Models

### Instruments Employed

- **NREL's M2 Meteorological Tower**
- **Second Wind's Triton Sodar**
- NOAA's high resolution dopplar lidar
- University of Colorado's Windcube Lidar




To observe → **2.3 MegaWatt Wind Turbine**

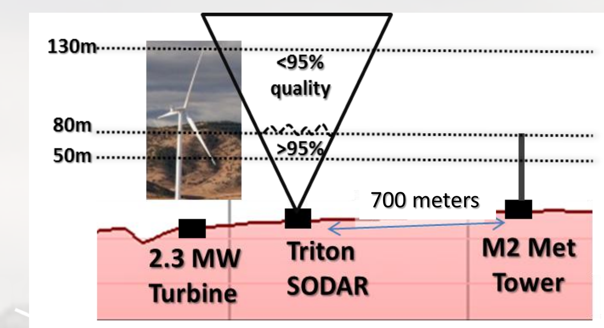
- 80m hub height; 50m blades

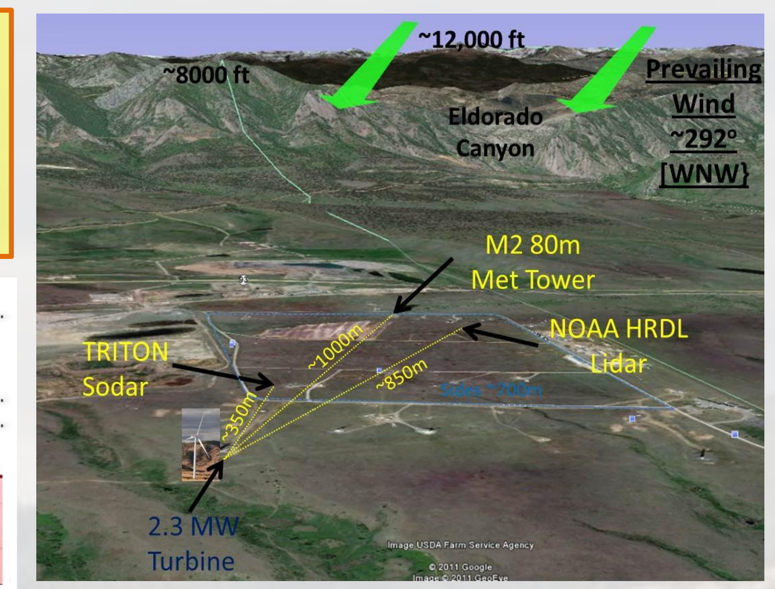
## Project Goals & The National Wind Technology Center Site

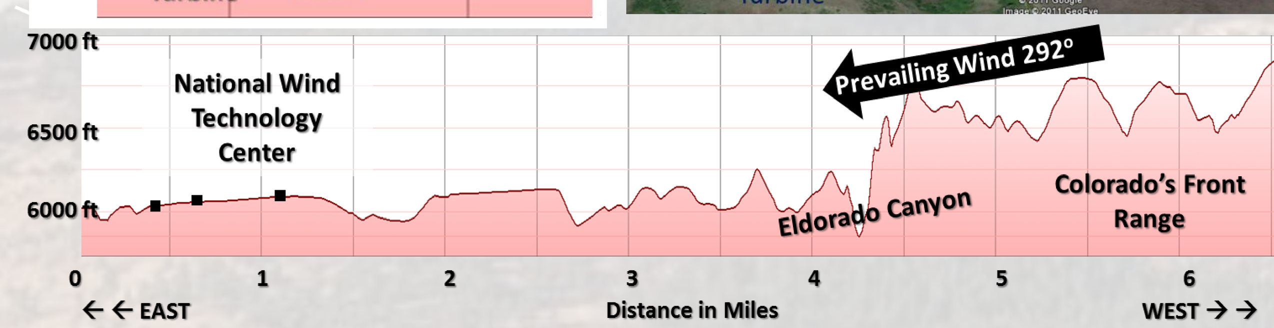
### Summer Project Goals

Use SODAR and Met Tower Obs. to:

1. Validate SODAR data from M2
2. Characterize Turbine Inflow



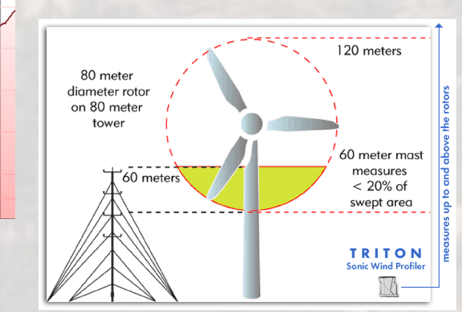

- The NWTC site is located downwind of Colorado's Front Range
- The Prevailing Wind is at ~292 degrees; ~ the angle instruments in line

**Long Term Trends:**

April 1 – May 7, 2011

**Intensive Observing Periods (IOPs):**

1) April 15
2) April 22
3) April 27 – 28




- Utility size turbines being built higher and larger
- Sodar's have the potential to 'see' just as high, or higher than some met towers are built.

## Methods & Filters

### M2 Met Tower & Triton SODAR

- Data were 10 minute averages
- Comparing 50m and 80m Wind Speed & Direction Measurements
- Determine Correlations
  - 37-day averages
- Compare measurements at 50, 80m for Intensive Observing Periods

### Filters

**For All Plots:**

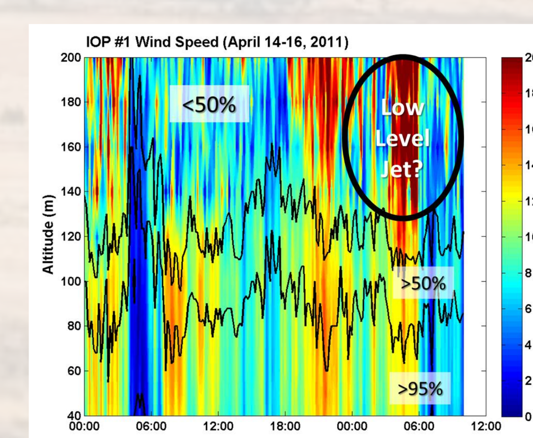
*Triton Quality of >95%

*M2 Wind Direction of 225 – 360

**Wind Direction Plot Filters:**

*M2 & Triton Wind Speeds of >3.5 meters per second(7.8 mph)

## Good Sodar Data Retrievals up to 80m

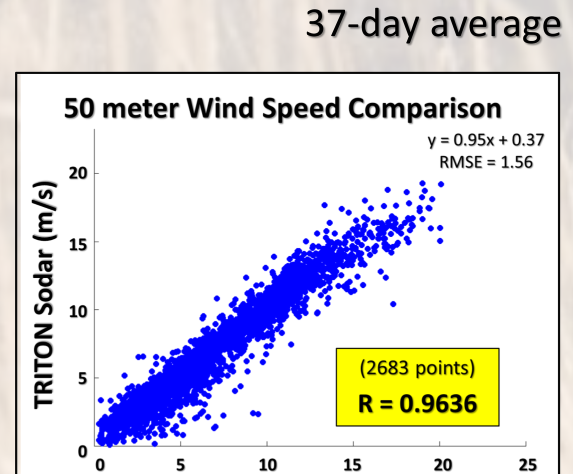


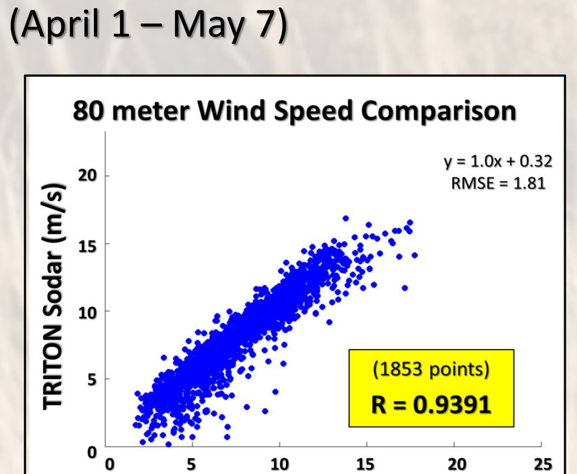

- Data quality is reduced above 80-100 meters
- Second Wind recommends 95% quality for all analysis
- Black lines indicate maximum height of 95% and 50% Triton quality. Quality factor based on Signal to Noise Ratio

## SODAR and Met Tower Have Strong Correlations for Wind Speed

### Strong Correlations for Wind Speed

37-day average (April 1 – May 7)

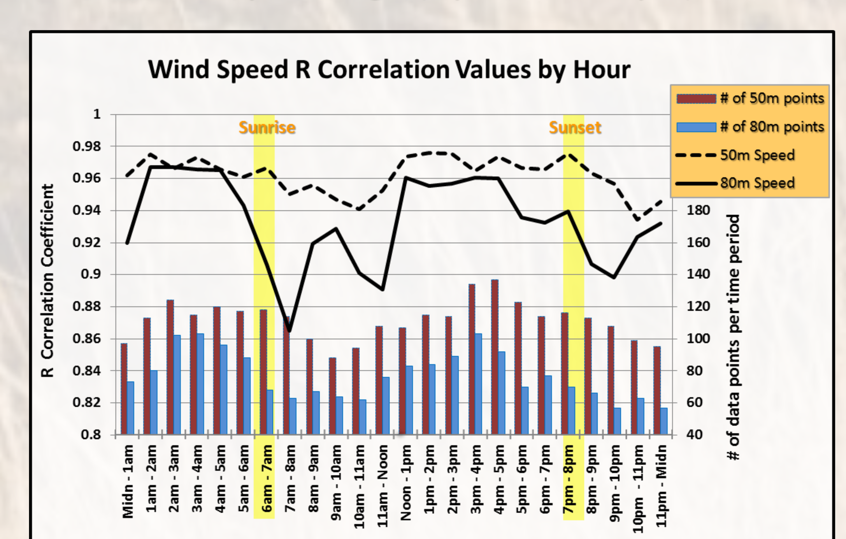



- Strong linear correlations of wind speed (R > 0.93) between M2 and Triton at 50m and 80m
- Flow usually homogeneous across NWTC, but occasionally inhomgeneous --> slightly lower correlations

### Diurnal Trend in Wind Speed Correlations

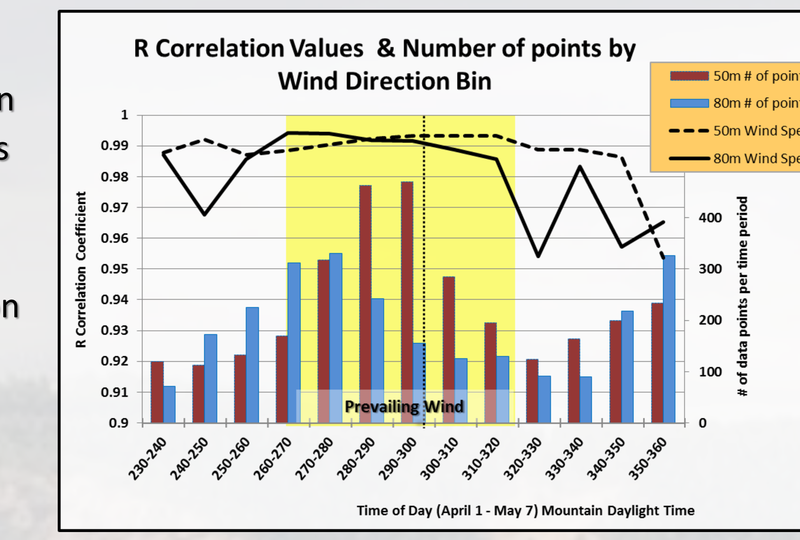
37-day average (April 1 – May 7)



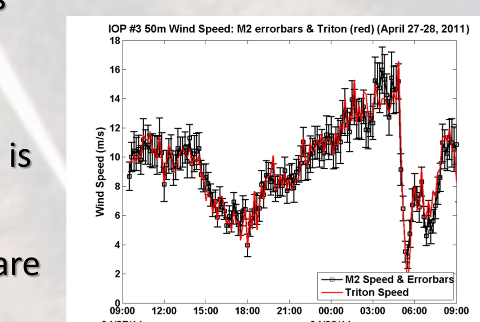

- Variation in # of data points due to data quality and filters
- Lower speed correlations in morning; highest before sunset
- M2 wind direction data may have had errors
- Smaller number of filtered data at 80m potentially behind lower R values

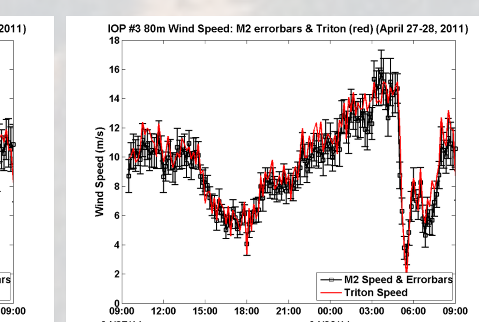
## Wind Direction Bin Correlations & IOP Lineplot

- Correlations highest from 270-320 degrees and when the sample size of points is highest
- Lower 80 meter R's could be from M2 errors or Triton instrument bias/ future quality control work




- At 50m Triton within M2 stdev error bars
- At 80m Triton has slightly higher measurements and is outside error-bars
- Note: instruments are 700 m apart.





## Conclusions & Next Steps

1. Triton data quality reduced above 80 meters
2. Strong linear correlations of wind speed (R>0.93) between M2 and Triton at 50 and 80m
3. Flow usually homogeneous across NWTC, but occasionally inhomogeneous --> slightly lower correlations --> terrain effects
4. Wind speed correlations vary with time of day (weaker in morning)
   - Different conditions at Triton sodar and tower site from localized heating and turbulent mixing
   - Changes in Triton performance with diurnal changes in atmospheric stability (decreased data quality → less data points

### Next Steps

**Results from this research will feed into future analysis of data collected during TWICS and help our understanding of turbine performance in the atmospheric boundary layer**

- Wind direction correlations are weak, require more quality control
- Examine larger data set (more time periods) to provide more robust correlation results: looking at time of day and wind direction bins
- Examine metrics such as turbulence intensity & atmospheric stability
- Compare Triton and M2 data with the lidars operated during TWICS

## Acknowledgements & Contact Information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