Ground-based Remote Sensing:
Multi-technology Validation and Advancing Acceptance – Initial Results

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Abstract

The potential value of sodar and lidar has been demonstrated in numerous forums and has manifested through the increasing use of these technologies in resource and operational assessment. While these devices can provide valuable measurement of the 3D flow field across a turbine's rotor plane, their acceptance has been limited by a perceived lack of performance validation. Advancement of sodar and lidar acceptance – conceivably to the point of bankable stand-alone use – requires additional performance studies and an agreed-upon framework of requirements. This work addresses both of these needs through robust multi-unit field studies and a draft roadmap for remote sensing acceptance.

This study presents the results of multi-unit sodar and lidar deployments across North America. The measurements cover a variety of operating environments and terrain conditions. In all cases, the remote sensing data sets are compared with measurements from existing meteorological masts. The performance of both commercial and near-production lidar units are evaluated and compared with standard wind resource assessment equipment. Qualitative and quantitative assessments of performance are presented and potential sources of error and bias are identified. From these results and analyses, a conceptual roadmap to sodar and lidar acceptance is developed for resource and operational assessment.

Objectives

The focus areas of this presentation are:

- inter-comparison of field data from multiple Lidar and Sodar units at established wind monitoring sites
- quantitative estimates of potential sources of error and biases
- proposed framework for advancing the acceptance of Sodar and Lidar in wind resource and project energy assessment

Participants will benefit from a robust examination of the performance of sodar and lidar in a variety of environments. The industry will also benefit from an opened dialogue on the advancement of remote sensing acceptance.

The content of this poster introduces the program's approach, instrumentation, and provides an overview of each of the two field deployment phases. Initial lidar results from both phases are presented and preliminary findings on the devices' performance are discussed. Subsequent work areas are also defined.

Method

Approach

The field evaluation was conducted in two phases. Each phase was a minimum of four weeks in duration and was conducted at an active wind resource assessment site. Concurrent data were collected at the sites by multiple remote sensing devices as well as a pre-existing meteorological tower. The met towers, which serve as reference measurements, were equipped with industry-standard cup anemometers. Prior to testing of the remote sensing units, each tower was serviced and the primary anemometers replaced with calibrated sensors. Practical performance of the units was evaluated and output from each of the devices was compared with the tower data in time series, wind speed correlations, and wind rose output.

Instrumentation

Several models of commercially available and prototype remote sensing devices were examined. The lidar devices examined were the Natural Power ZephIR, the Leosphere / NRG Windcube, and the Catch the Wind Vindicator. The lidar devices are shown in Figures 1 and 2. The sodar devices examined were the ART VT-1, and the Scintec SFAS. The sodar devices are shown in Figures 3 and 4. The anemometers employed for primary comparison were calibrated NRG #40's.

Figure 1: Leosphere / NRG Windcube (left) and Natural Power ZephIR lidars, commercial units

Figure 2: Fixed-focus Catch the Wind Vindicator lidar, prototype

Figure 3: ART VT-1 trailerized sodar, commercial unit

Figure 4: Scintec SFAS flat array sodar, commercial unit

Phase 1

Phase 1 was conducted at an active upstate New York wind development site from early-December, 2008 through mid-January, 2009. Site characteristics are summarized below.

Reference tower:

50 m NRG tube, 3 monitoring levels (30, 40, & 49 m AGL)

Redundant NRG #40 at each level; Primary anemometers not affected by vibratory degradation

Test Equipment:

ZephIR 0148, Windcube 0020, Vindicator & VT-1 108

Site:

Rolling Farmland; N to S slope on site; ZephIR and Windcube sited about 125 m NNE of tower, ART sited about 120 m NNW; Vindicator sited about 60 m WNW

Figure 5: Topographical layout of Phase 1 site, upstate NY

Phase 2

Phase 2 was conducted at a wind resource research station in northern Iowa from mid-February through late-March, 2009. Site characteristics are summarized below.

Reference tower:

200 m lattice comm. tower; 4 monitoring levels (53, 102, 157, & 193 m AGL)

Calibrated NRG #40 primary sensors (post-December 2008 units); Calibrated NRG IceFree III redundant sensors

Equipment:

ZephIR 0145, Windcube 0020, & SFAS 0021

Site:

Nearly flat farm land, no crops; All devices located 140 m SW from tower; No elevation difference

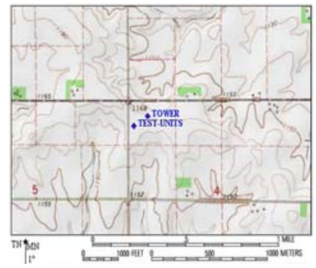

Figure 6: Topographical layout of Phase 2 site, northern Iowa

Results

Phase 1

A severe ice storm occurred during the Phase 1 evaluation. The storm resulted significant ice accumulation on the equipment and a loss of grid power at the monitoring site for several days. This event necessitated screening to treat suspect measurements during data analysis. Initial lidar results of Phase 1 are presented in the following figures.

ZephIR Results

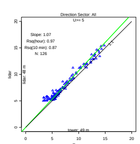

Figure 7: Hourly Speed Correlation at 48 m

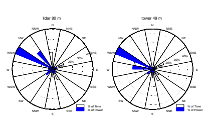

Figure 8: Wind Rose comparison

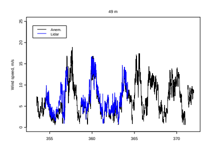

Figure 9: Time Series of 10-min Speed Measurements

Windcube Results

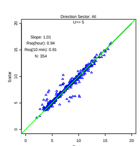

Figure 10: Hourly Speed Correlation at 48 m

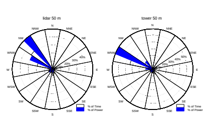

Figure 11: Wind Rose comparison

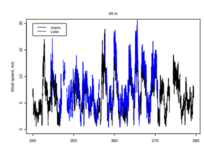

Figure 12: Time Series of 10-min Speed measurements

Vindicator Results

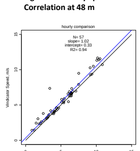

Figure 13: Hourly Speed Correlation at 48 m

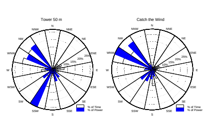

Figure 14: Wind Rose Comparison

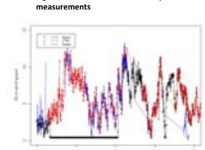

Figure 15: Time Series of 10-min Lidar, ART Sodar and Tower Measurements

Phase 2

Phase 2's tall reference mast, combined with the relatively flat terrain, provided an excellent opportunity to correlate the remote sensing measurements with anemometry at heights well above typical met masts.

Lidar results from the first half of the Phase 2 field campaign are presented in the following figures.

ZephIR Results

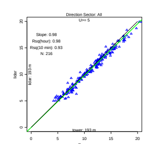

Figure 16: Hourly Speed Correlation at 193 m

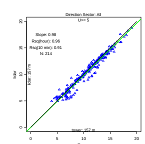

Figure 17: Hourly Speed Correlation at 157 m

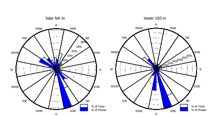

Figure 18: Wind Rose Comparison at 193 m

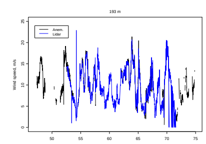

Figure 19: Time Series of 10-min Data 193 m

Windcube Results

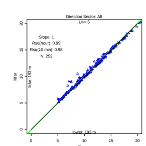

Figure 20: Hourly Speed Correlation at 193 m

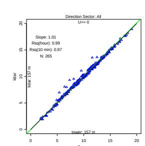

Figure 21: Hourly Speed Correlation at 157 m

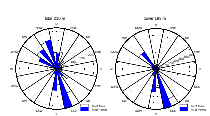

Figure 22: Wind Rose Comparison at 193 m

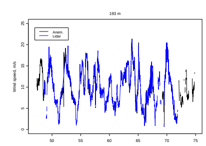

Figure 23: Time Series of 10-min data at 193 m

ZephIR Profiles

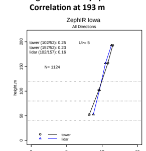

Figure 24: Wind Shear Profile Comparisonvs. NRG #40

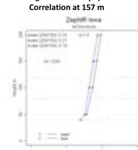

Figure 25: Wind Shear Profile Comparison – NRG IceFree III

Windcube Profiles

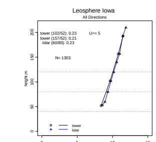

Figure 26: Wind Shear Profile Comparison – NRG #40

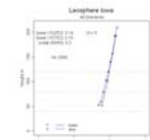

Figure 27: Wind Shear Profile Comparison – NRG IceFree III

Discussion

Performance Discussion

Brief observations on each lidar unit's performance in Phases 1 and 2 are presented below.

- While ZephIR experienced equipment issues during both Phases, unit 145 showed significantly improved correlations with reference anemometry in Phase 2.
- Weather and equipment issues affected portions of Windcube's Phase 1 data. In spite of this, overall performance of unit 0020 was generally good at both locations.
- The fixed-focus Vindicator was the only device to collect data continuously through out the Phase 1 ice storm. While a generator issue did cause a gap in the period of record, its overall performance was good.

Future Work

Continuing work on this topic includes the following efforts to reach the project's overall objectives:

- Additional detailed analysis of full field data sets from Phases 1 and 2. Efforts will include inter-comparison of remote sensing data sets and examination of weather- and terrain-induced effects.
- Quantitative estimates of potential sources of error and biases for each of the technologies tested.
- Drafting a framework for advancing the acceptance of Sodar and Lidar in wind resource and project energy assessment

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