EVALUATION OF WIND LIDAR INSTRUMENTS AT THE HOWARD UNIVERSITY BELTSVILLE RESEARCH SITE

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ABSTRACT

An analysis of wind measurements made by rawinsonde, lidars, profilers and other standard methods made at the Howard University Beltsville Campus is reported. In particular, three wind lidars that use different techniques for processing wind profile measurements are compared against each other and against other traditional wind sensing instruments. The lidars compared well with each other and with, with radiosonde data, a 915 MHz wind profiler and data from the Aircraft Communications Addressing and Reporting System (ACARS), as transmitted by NOAA's the Meteorological Assimilation Data Ingest System (MADIS) database. Application of the data to atmospheric dynamics and satellite-based profiling is made and will be reported.

1. INTRODUCTION

Wind profile information is one of the main meteorological variables that are crucial to accurate forecasting of weather. Yet, remote measurements of wind from satellite platforms have not been realized despite its importance. A substantial effort is currently underway to realize remote sensing of 3D wind profiling from space. One technique that has received a focused and intensive study is lidar-based Doppler wind profiling. Despite the importance of lidar profiling of winds, there exists very small database of measurements from which to evaluate performance of future space instruments and algorithms.

We have been involved with evaluating and studying the errors associated with ground-based lidar profiling. In the following, we briefly highlight a wind lidar intercomparison experiment that was hosted at the Howard University Beltsville Research Campus in February-March of 2009 and data from a continuous measurement of wind at the same site.

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2. SITE DESCRIPTION

The Howard University Beltsville Research Campus (HUBRC) is located between the major metropolitan cities of Washington D.C. and Baltimore, Maryland in Beltsville, at 39.054°N, -76.877°E. The site has access to a suite of remote and in-situ wind sensing instrumentation. The wind sensors include a 915 MHz wind profiler (operated by the Maryland Department of the Environment, MDE), several sonic and cup anemometers, radio-sounding based GPS sensors, the semi-permanent NASA Goddard Laboratory for Winds (GLOW), visiting lidars (e.g. Leosphere, NASA Langley Validation Lidar (VALIDAR), and other experimental wind lidars. In addition, several other standard atmospheric and soil instrumentation exist. Among these are the Vaisala CT25K ceilometer and a Micro-Pulse lidar; a 30 meter tower instrument with temperature, pressure, relative humidity and sonic anemometer(s); two continuous water vapor, temperature, and cloud-base temperature profiling microwave radiometers and a two-channel integrated water vapor and liquid water passive microwave radiometer; a NOAA network GPS; several passive long and short wave energy monitors; soil moisture sensors and several types of precipitation monitors are operational. The Howard University Raman Lidar (HURL), with its NIST-traceable lamp calibration, is located at this site and operates frequently to collect highly resolved profiles of water vapor and aerosol information. The site has hosted numerous field observation campaigns and serves as a co-laboratory for many of the universities, private industry, state and federal agencies.

3. DATA SOURCE

Data collected from more than three years of coincident operation of the GLOW and radiosonde at HUBRC will be used for the GLOW-Sonde intercomparison. Lidar-lidar wind intercomparisons will be made from updated data collected during the lidar wind profiling experiment in 2009. Three lidars: the NASA Goddard Laboratory for winds (GLOW), NASA Langley Validation Lidar (VALIDAR), and the Leosphere©, (www.leosphere.com; WLS 70 a commercial lidar) were operated at HUBRC under a NASA funded grant for demonstration of the 3D-doppler winds experiment described in the Decadal-Survey. A brief statement on three of these lidars is given below. In addition to the lidar wind data, all wind-measuring capable sensors were used in the comparison, whever possible. These include the 915 MHz wind profiler, several types of radio sounding sensors and data from the Aircraft Communications Addressing and Reporting System (ACARS), as transmitted by NOAA's the Meteorological Assimilation Data Ingest System (MADIS) database.

3.1 GLOW-SONDE COMPARISON

We start with a comparison of the GLOW lidar and rawinsonde for we have a larger data set of coordinated data. GLOW is a field deployable Doppler lidar system transmitting short (20 nsec) laser pulses into the atmosphere using Nd:YAG 355nm laser. The light backscattered by molecules and aerosols from the atmosphere is collected by a telescope and processed by the so-called double-edge technique. This technique utilizes two high spectral resolution optical filters located symmetrically about the outgoing laser frequency to measure the Doppler frequency shift. An extensive discussion of the edge technique can be found in [1][2][3][4]. Note that, although GLOW is designed for efficient operation in the clear air regions of the free troposphere and lower stratosphere, it can and has been adapted to operate in the boundary layer.

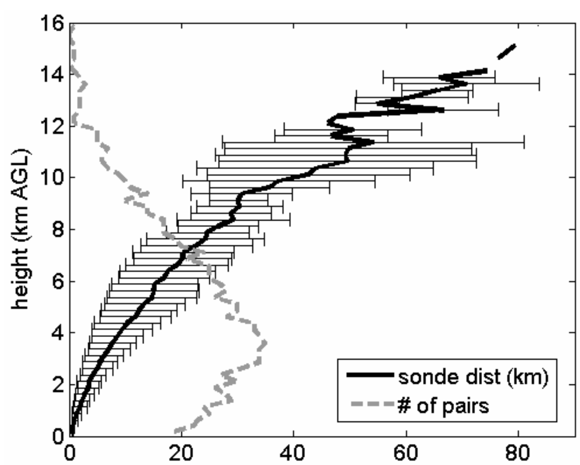

Figure 1. Number of GLOW-RS92 pairs and the average distance of the rawinsonde from the HUBRC at each GLOW height level. Note that error bars are of length one standard deviation and x-axis is for both distance and #.

Time-height matched GLOW and rawinsode data pairs were first created using an archive of data at the HUBRC. Matched pairs are then interpolated to a common height grid – used as the GLOW heights. This processes is important in that it ensures the comparison to be of samples from the same time and height. However, the rawinsonde wanders from the launching point and may be up to 80-100km away above 10km altitude. Thus, a record was kept as to how many matched-pairs and how far from the GLOW location were these rawinsonde points located. This ensures that whatever conclusions are derived from this comparison, a perspective of distance is included and merged with what the atmospheric variability may have been. Figure-1 is such a plot – no of GLOW-Sonde pairs versus altitude and the distance of the rawinsonde points in the pairing with their standard deviation. As can be seen from the plot, all the data considered for the statistics are within an 80km radius from Beltsville. As reported in [5], a spatial variability of wind speed between 2.5 – 3.5 m/sec is to be expected at such distance.

Figure 2 is a difference plot of the GLOW-rawinsonde matched pairs. As can be seen in the figure, the average wind speed difference varies with altitude from about 1m/sec near the ground to about of -3 m/sec at altitudes above 10km. The observed trend in speed seems to be correlated to the distance from GLOW, but the values are similar or lower than what would be expected following work by [5]. In addition to the atmospheric variability that this non-collocation introduces, the handling of the high resolution rawinsonde data by the sonde-company software will also introduce some small variability. For example, the smoothing choice of the rawinsonde high frequency data may add to the observed difference and its variability.

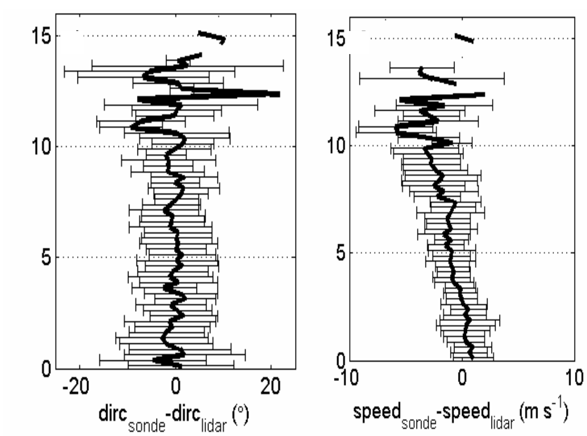

Figure 2. Wind speed and direction difference (m/s) between GLOW and rawinsonde measurement pairs plotted versus height (km). One-standard deviation of the differences at each height and the average (dark line) are shown.

3.2 VALIDAR-SONDE COMPARISONS

The NASA/Langley LIDAR, called VALIDAR, uses a novel high-energy, 2-micron, Ho:Tm:LuLiF laser technology developed at NASA Langley and employed to study laser technology currently envisioned by NASA for future global coherent Doppler lidar winds measurement. This system is sensitive to aerosol and provides data in most of the lower troposphere, where most of the aerosol and clouds reside. For details of VALIDAR see [6][7].

For this comparison, there were not as many rawinsonde-VALIDAR data as there were for GLOW. Of the limited data archive we have similar data handling, as done for GLOW and described above, was also performed on the rawinsonde and VALIDAR data sets. A total of 250 points from surface to about 10km were found.

A scatter plot of this data points is shown in Figure 3. A good correlation for both components of the wind vector is found. Similar limitations discussed above for lidar-sonde measurement platforms also hold in this case.

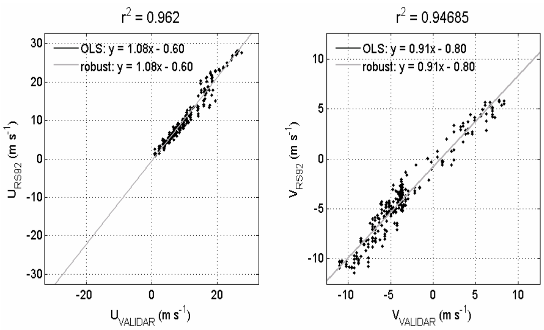

Figure 3. Scatter plot the resolved components of VALIDAR against rawinsonde values.

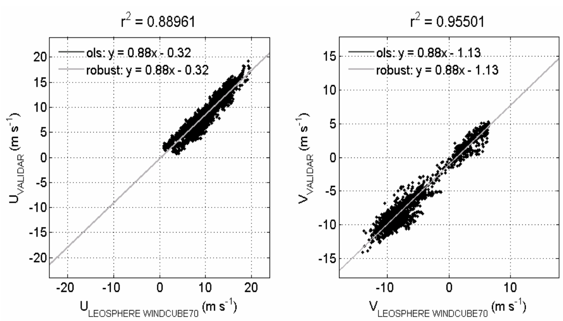

Figure 4. Scatter plot of the resolved components of VALIDAR and WLS70.

3.3 VALIDAR-LEOSPHERE WLS 70

The WindCube™-WLS70 (from LEOSPHERE©) detailed in [8] was also operated in the wind lidar experiment in 2009. The operation is similar to that of the VALIDAR – in that it uses aerosol-based wind derivation. Note that WLS70 operates with a laser that is almost three orders of magnitude lower in power than VALIDAR and thus is limited in its reach in height. A time resolution of 30s per profile and a range resolution of 50m from (100m to 2000m), and a velocity resolution (0.2m/s) is quoted but not always achieved.

A comparison of these two aerosol-based wind sensors shows a very good correlation based on 1798 pairs of data similarly processed as described above. A case study analysis, advantages and disadvantages as well as performance against rawinsondes will be discussed at the presentation.

4. VALIDAR-GLOW: *THE HYBRID CONCEPT*

A central goal of the HUBRC wind activity was demonstration of the future NASA Decadal survey 3D-Wind lidar concept demonstration. A combination of the molecular-based direct detection for the upper troposphere and the coherent method for the lower troposphere is a leading candidate for future NASA 3D wind lidar mission, as described in the NASA Decadal Survey. A preliminary demonstration of this concept is attempted in Figure 5. It shows, albeit for a single case, a combined operation of the molecular-based (GLOW) and the aerosol-based (VALIDAR) system would be capable of profiling the entire depth of the troposphere. It reveals that the correlation coefficient between these two lidar systems has a maximum between the altitudes of 3.7 to 5km. This may be explained by fact that the sensitivity of the two methods (aerosol sensitive systems and molecular-sensitive system) peaks at different altitudes from the ground. This is expected to lead to an overlapping optimum region for wind retrieval using the two techniques and a good region for data merge when creating a combined profile of wind properties.

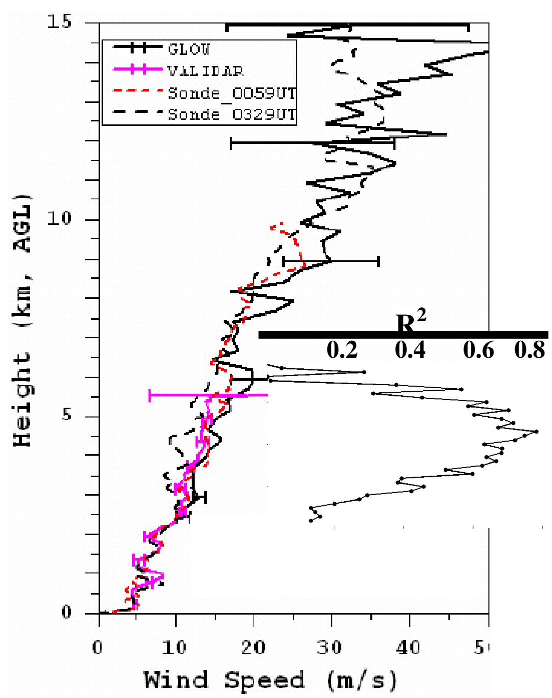

Figure 5. A composite plot GLOW, VALIDAR, and rawinsonde data with inset graph of the variation of the GLOW-VALIDAR correlation coefficient

4. LIDAR AND STANDARD SENSORS

An extended discussion and comparison of GLOW with the profiler and a summary of the biases of each instrument will be respect to several of the wind-measuring instruments have been completed and will be presented at the conference.

8. SUMMARY

Valuable lessons on how to combine the systems, algorithm development toward understanding the data strengths and error characteristics of the two lidar systems/techniques have been achieved by this experiment. Further, extended operation of the GLOW lidar at HUBRC has allowed us to gain valuable knowledge in the performance of the molecular system during thin cirrus conditions, use of the system for aerosol and cloud variability studies as well as its comparison with profiles. These increased understanding of the system has allowed for better algorithm development in the sub-orbital version of the molecular wind lidar (TWILITE system; see Gentry et al…) that has been demonstrated with successful engineering flight from the NASA ER-2 aircraft. Ground based performance of these candidate technologies demonstrates increased progress and maturation of the technology and algorithm needed for NASA's Future 3-D Winds Measurement from Space.

Lidar-based measurements of the global wind need to be able to resolve long term trends in the wind profile and capture the variations in the jet stream. A discussion of the archived wind measurements and implications for future satellite based wind sensing resolutions will be discussed.

Further, a comparison of the ACARS, a discussion on the processing of the gps-wind by rawinsonde manufacturers and its implication for instrument comparisons will be discussed using archived lidar and sonde measurements. A comparison of the lidar measured winds with ACARS measurements [9] revealed that lidar winds have a smaller variability by comparison. Quantitative comparisons with ACARS and the many other instruments and a discussion of the performance of GLOW within thin cirrus conditions [10] will be presented during the presentation.

9. ACKNOWLEDGMENTS

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