JP2.27 SHIPBOARD MULTI-SENSOR WIND PROFILES FROM NEAQS 2004: RADAR WIND PROFILER, HIGH RESOLUTION DOPPLER LIDAR, GPS RAWINSONDE

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1. INTRODUCTION

During the summer of 2004 a unique set of instrumentation was deployed on board the NOAA research vessel Ronald H. Brown (RHB) as part of the New England Air Quality Study (NEAQS). NEAQS is a regional portion of the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) planned by groups in North America and Europe to develop a better understanding of the factors that shape air quality in their respective regions and the remote North Atlantic. The Ronald H. Brown was only one of a number of platforms, including land sites and aircraft, tasked with monitoring the emissions of aerosol and ozone precursors and the atmosphere in which they reside.

This paper will discuss three primary sensors, two remote sensors and one in-situ sensor, used to measure wind profiles. Rawinsondes using Global Positioning System (GPS) wind tracking were launched 4-6 times daily providing a detailed profile of winds. A radar wind profiler (RWP) permanently deployed on the ship and corrected in real-time for ship motion, provided continuous hourly profiles at 60 and 100-m vertical resolutions. A High Resolution Doppler LIDAR (HRDL) with a 30-m along-beam resolution was operated during the experiment by NOAA's Environmental Technology Laboratory (ETL). Each instrument has its own pros and cons. This paper will compare the various methods and the unique opportunity of combining all the data into a single profile that is a much more useful representation of the winds.

Initial results show that the rawinsonde, RWP and HDRL data compare very well. Limitations with the minimum range of the RWP and possible sea- clutter contamination in the lower 0.5 km can be overcome by using the HDRL to fill in the lowest levels. In a like fashion, limited height coverage by HRDL can be compensated for by the RWP. Both the RWP and HDRL provided continuous wind profiles while the rawinsonde provides full thermodynamic and wind atmospheric profiles.

2. SYSTEM DESCRIPTIONS

Figure 1 shows the RWP antenna, with the turtle-shell like protective cover, mounted aft portside. The RHB system (Law et. al. 2002) is a low power 915-MHz RWP designed to gather atmospheric data to altitudes of 3-5 km nominally. If precipitating clouds are present, reflections from the water droplets make it possible to obtain data at higher altitudes. This system is composed of three major components: the 90-element phased-array antenna, the motion control and monitoring system (MCM), and the signal processing system (SPS). The electronically stabilized antenna has the capability of compensating for ship motion (roll, pitch, yaw) at 10 Hz through monitoring the ship's motion and computerized control of each element in the phased array antenna Real time displays of motion-corrected winds are available to the scientists on-board through a separate user computer. For NEAQS, standard output was 60-min averaged winds.

Fig. 1. Electronically stabilized phased-array 915-MHz antenna: R/V Ronald H. Brown (arrow).

The RWP system on board the ship employs ETL's advanced multi-peak picking signal processing system that provides meteorological products from averaged-Doppler spectra (Wolfe et. al. 2001; Weber and Wuertz 1991). It differs

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from the traditional “consensus” signal processing in recognizing that averaged Doppler spectra may contain multiple spectral peaks, where the atmospheric signal may not be the strongest peak. Also incorporated into the signal processing is real-time motion compensation.

The High Resolution Doppler Solid State Lidar (HRDL) system (Grund 1995; Grund et al. 2001) developed at ETL, obtained unique high -temporal and -spatial resolution wind measurements aboard RHB during the NEAQS 2004 field campaign. This Doppler lidar (Fig. 2), an active remote sensing system with hemispheric scanning capability, is similar in many respects to the more familiar Doppler weather radar, except it transmits near infrared (2.02 µm) instead of radio-frequency waves. The scattering targets for shorter-wavelength lidar are atmospheric dust and/or aerosol particles, which are ubiquitous in the lower troposphere and allow the lidar to obtain signal in cloud- and precipitation-free air. Data from the lidar can include aerosol *backscatter,* which is related in a complex way to aerosol concentration (and other aerosol properties), and *frequency*, from which the Doppler velocity component is calculated.

During NEAQS, HRDL operated in a continuous measurement mode from July 9 through August 12, 2004 with only occasional interruptions occurring during heavy rain and dense fog events. This lidar is able to provide accurate wind velocity measurements (on the order of 0.1 ms^{-1}) from a moving platform with the implementation of a motion-compensation (MC) system. By employing real-time MC, the ship-oriented scanner coordinates are transformed to a “world” coordinate system by ingesting continuous high-rep rate GPS data to adjust the pointing angles as the scanner is in motion and measurements are being obtained.

The lidars scanning strategy during NEAQS included sweeps along both constant azimuth and elevation angles to provide a variety of high resolution boundary layer information. Azimuth scanning produces cones of data that at the lowest elevation angles can provide surface wind data, and elevation scanning, which at the highest angles produce vertical slices of atmospheric features. The 360° azimuth scans, usually completed in 2 min or less, were processed to produce vertical profiles of the horizontal wind using the velocity-azimuth display (VAD) technique (Browning and Wexler 1968). Employing the VAD method from low to high angle sweeps, lidar-derived wind speed and direction profile information can be obtained on the order of ~ 5 m resolution in the boundary layer.

Fig. 2. High Resolution Doppler Solid State Lidar (HRDL) system.

The balloon sounding system used GPS wind finding digital rawinsondes. Launches were made every 4-6 hours and for special events such as an aircraft fly-over. Standard 5 ms^{-1} average ascent rates produced 10 m vertical resolution thermodynamic and wind profiles. The new digital sonde made it possible to obtain accurate wind profiles immediately above the release point.

3. RWP, HDRL AND RAWINSONDE COMPARISONS

The NEAQS cruise took place in July and August of 2004 and monitored the boundary layer within the Gulf of Maine in support of ICARTT and regional air pollution interests. One hundred and twenty-three rawinsonde launches were made during the project. Balloon soundings were compared to both RWP and HDRL average winds. Rawinsonde launch times were matched to the nearest 60-min averaged RWP data. Data not within a +/-15 min window of launch times and cases where there were problems with one of the two measurement systems were removed from this comparison. In a similar fashion, rawinsonde launch times were matched to the nearest 15-min averaged HDRL data. Data not within a +/-7 min window of launch times and cases where there were problems with one of the two measurement systems were removed from this comparison. Rawinsonde, RWP, and HDRL wind speed and direction data were converted to U and V components. Rawinsonde data were then linearly interpolated to the same wind levels measured by the RWP and HRDL respectively to provided both temporal and spatial consistency between all three measurements.

Scatter plots for the rawinsonde and RWP horizontal U and V wind components appear in Fig. 3 for the 100-m vertical resolution mode. Differences between RWP and rawinsonde winds are consistent with previous comparisons (Weber and Wuertz, 1990). Results from the 60 m mode (not shown) are consistent with Fig. 3 although there is slightly more scatter and reduced height coverage as might be expected due to lower transmitted power and therefore return signal in this mode. Only data between 0.5 and 3.0 km were used in the comparison in an attempt to eliminate any outliers in the lowest range gates where sea clutter occurs and in the higher gates where signal strength is near its lowest threshold. It is believed that a portion of the remaining scatter can be attributed to the fact that the quality control method used on these data could not handle a 5-beam configuration and was therefore modified to re-configure two of the four oblique beams to mimic a 3 beam configuration. More analysis is needed using ship motion and sea state information to help sort out possible interference periods.

Scatter plots for the rawinsonde and HDRL horizontal U and V wind components appear in Fig. 4. Strong correlation and minimal scatter are consistent with a reported velocity accuracy of 0.1 ms^{-1} for HDRL and also seen when comparing wind profiles. Even though time-series of HDRL wind barb profiles show a fair amount of temporal and spatial variability, both the balloon and HRDL consistently capture nearly identical wind profiles. Normal operation range of HRDL was up to 1.0 km reaching a maximum height of 1.5 km.

Figures 5 and 6 show comparison profiles of all three measurement techniques. Note that the title above the wind speed profiles is the date and time of the balloon launch while the title above the wind direction profiles is the end date and time for the RWP hourly averaged data. In Fig. 5 is an example where all three measurements depict a speed shear in the lowest 0.2 km. During this period HDRL is able to reach a maximum altitude of ~1.4 km. Figure 6 shows a period where HDRL only reaches ~ 0.4 km at which point the RWP data start and continue to follow the balloon. Finally in Fig. 7 is an example of an elevated direction shear depicted by both the balloon and RWP data. HDRL data again very nicely captures the lowest 1.0 km wind structure.

4. CONCLUSIONS

This analysis has provided insight into the performance and operational characteristics of the RHB radar wind profiler and a High-Resolution Doppler Lidar deployed during NEAQS. These results confirm that the electronically stabilized RWP, even in a high-clutter environment, and the motion compensated HDRL can measure and produce accurate real time winds. Also shown is the ability of the HDRL to monitor low-level winds below the minimum range gate of the RWP.

Further detailed analysis of these data is planned to study the overall performance of the RWP and HDRL. This includes re-averaging both the RWP and HDRL data to evaluate the detailed temporal measurements both systems provide.

4. REFERENCES

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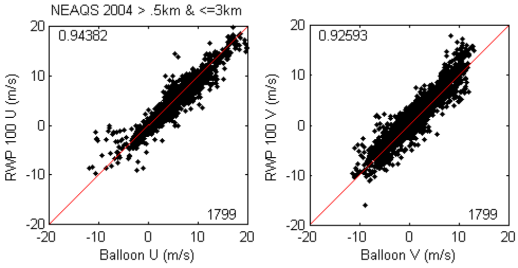

Fig. 3 U/V horizontal wind component scatter plots from NEAQS 2004. Radar wind profiler vs. rawinsonde: 100 m mode, for heights between 0.5-3.0 km.

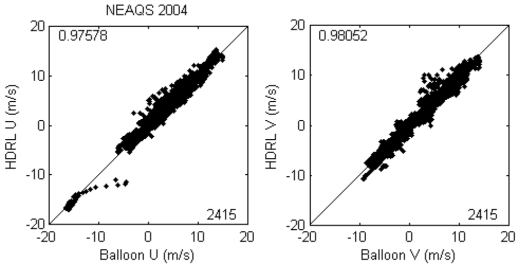

Fig. 4 U/V horizontal wind component scatter plots from NEAQS 2004. High Resolution Doppler Lidar vs. rawinsonde: for all heights.

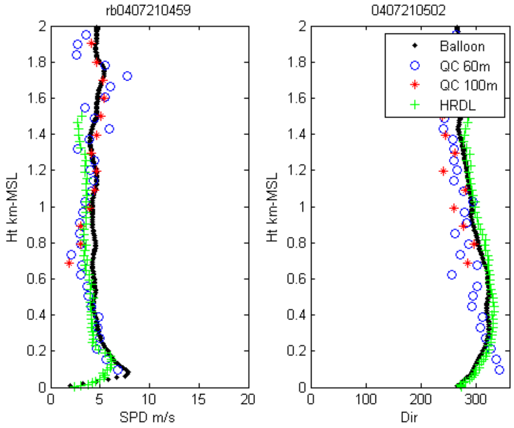

Fig. 5 Wind profiles on July 21, 2004 at 0459 UTC. Balloon, Radar Wind Profiler (60m and 100m), High Resolution Doppler Lidar.

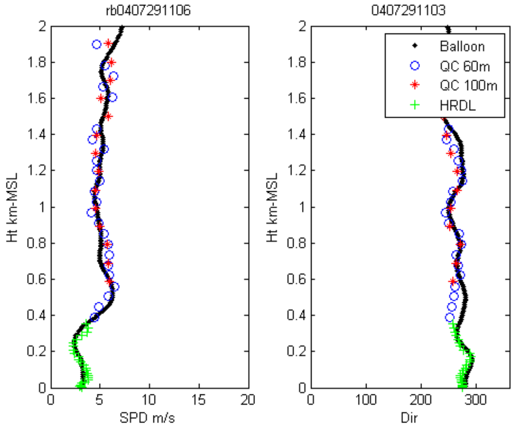

Fig. 6 Wind profiles on July 29, 2004 at 1106 UTC. Balloon, Radar Wind Profiler (60 m and 100 m), High Resolution Doppler Lidar.

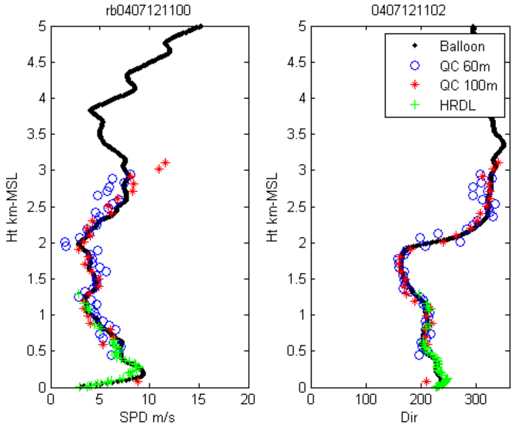

Fig. 7 Wind profiles on July 12, 2004 at 1100 UTC. Balloon, Radar Wind Profiler (60 m and 100 m), High Resolution Doppler Lidar.