Lidar Measurements of Wind, and Cloud and Aerosol Structures Using HARLIE at the WVIOP, September/October 2000

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Introduction

A new scanning lidar called Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) (Schwemmer 1998) was deployed on the ground in an upward-looking mode during the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) Water Vapor Intensive Operational Period (WVIOP) from September to October 2000. Using HARLIE, we made over 110 hours of measurements of aerosol and cloud backscatter and derived the horizontal wind speed and direction at cloud height over the ARM SGP site between September 17 and October 6, 2000.

HARLIE is an experimental technology demonstration using a holographic scanning telescope and operates at the 1064 nm wavelength of an Nd:YAG laser. It scans in a 90-degree (full angle) cone, usually with the scan axis vertical so that the elevation angle is a constant 45 degrees. Rotating continuously in azimuth at rates as high as 30 rpm, the scanning data provides a pseudo-3D (three-dimensional) visualization of aerosol backscatter. Principal data products include aerosol backscatter profiles, cloud bottom and top heights, boundary layer heights, and entrainment zone thickness. In addition, we placed particular emphasis during the IOP on developing a new data product: Horizontal wind vector profiles based on the motions of cloud and aerosol structures across the lidar scan. These are visualized along with shear, waves, and other dynamic behavior by observing videos of the backscatter data on rectangular and polar coordinates or pseudo-3D images played back at high speed.

For ground-based operation, HARLIE was integrated into a 4.4-m-long trailer (Figure 1). The beam exits a window on the roof of the trailer. A wide-angle sky camera (SKYCAM) is used in conjunction with HARLIE, video recording daytime-visible images of clouds within HARLIE's scan volume.

Figure 1. Photograph of the HARLIE trailer and SKYCAM deployed at the ARM SGP Cloud and Radiation Testbed (CART) site during the recent Water Vapor IOP.

Measurements

360-degree scans having spatial resolutions of 20 meters in the vertical and 1 degree in azimuth were obtained every 36 seconds during daily operating periods. The data products are placed on our workspace on the ARM r1 server, and are available to all ARM participants at http://r1.sgp.arm.gov/~dmiller/

For the purpose of illustrating the wind vector profiling capability of HARLIE, we focus our attention to the night of October 4th to 5th, a period abundant in aerosol and cloud structures over a wide range of altitudes. During this period a slowly advancing occluded front from the northwest brought a line of thunderstorms through the region. Referring to Figure 2, the observations began with a deck of cirrus clouds extending from 5.5 to 7 km altitude (Figure 3). Fifteen minutes before midnight Universal Time Coordinates a stratus layer arrives at 5 km and gradually drops in altitude. By 0400 cirrus appear ~14 km, probably blow-off from the advancing thunderstorms. By 0604 the T-storms are visible to the north and west. At 0630 a layer of dense clouds at 1 km appears and in 10 minutes obscured everything above them before raining over the site.

The wind vector derivations incorporate a new algorithm that uses a novel technique for detecting and measuring the bulk motion of structures in the backscatter field as they progress across the conical scan surface. Sroga et al. (1980) developed a similar scanning lidar technique for deriving wind vectors and turbulence from structure motion using a Fast Fourier analysis technique over a 2° azimuth scan. HARLIE's 360° scan utilizes information from a much larger volume of atmosphere and will be less sensitive to sub-kilometer-scale turbulence effects. The method consists of plotting the backscatter data at any given altitude as a function of azimuth angle on the Y-axis and time, or scan number on the X-axis. Edges of scattering features that move straight across the scan circle will appear as cosine structures in this "wave" image diagram (Figure 4). The amplitude, and hence the slope on the linear portion of the cosine curves, will be proportional to the wind speed. The phase of the cosines will indicate the direction. An interactive computer routine has been developed to facilitate the analysis of winds from HARLIE data files in this manner.

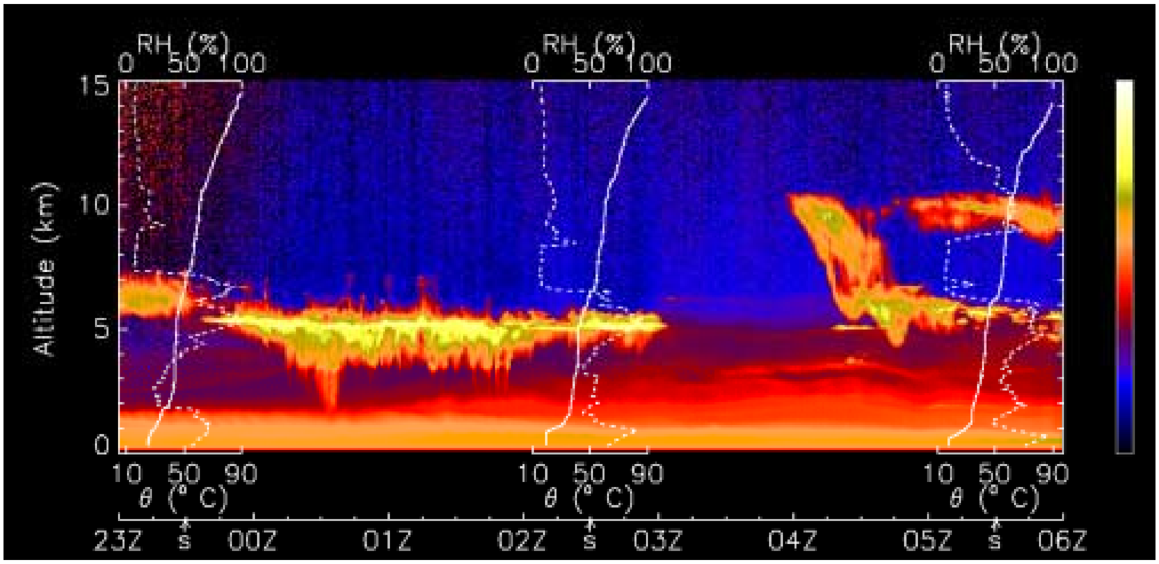

Figure 2. Lidar backscatter (scan-integrated) profiles versus time for the period from 2300 October 4 through 0600 October 5. Note the striking correlation between aerosol profiles and relative humidity and potential temperature profiles retrieved from rawinsondes.

Figure 3. A frame of SKYCAM video of cloud activity over the region covered by the HARLIE scans, made just prior to the first sonde launch in Figure 2.

Whenever possible, these measurements were compared with Loran-C winds as measured by the routine launches of Vaisala rawinsonde balloons scheduled by the ARM project. Figure 5 is a single comparison of HARLIE-measured winds with the nearest rawinsonde data. Taken overall, the agreement between these two types of observation is excellent, which could be taken merely as a validation of the relatively new HARLIE technique. However, the detailed comparison for a given sonde launch clearly requires that out of the HARLIE data, which are taken all the time at all altitudes, one must select those segments that match the altitude-time trajectory of the sonde. Moreover, the conical HARLIE scan at a

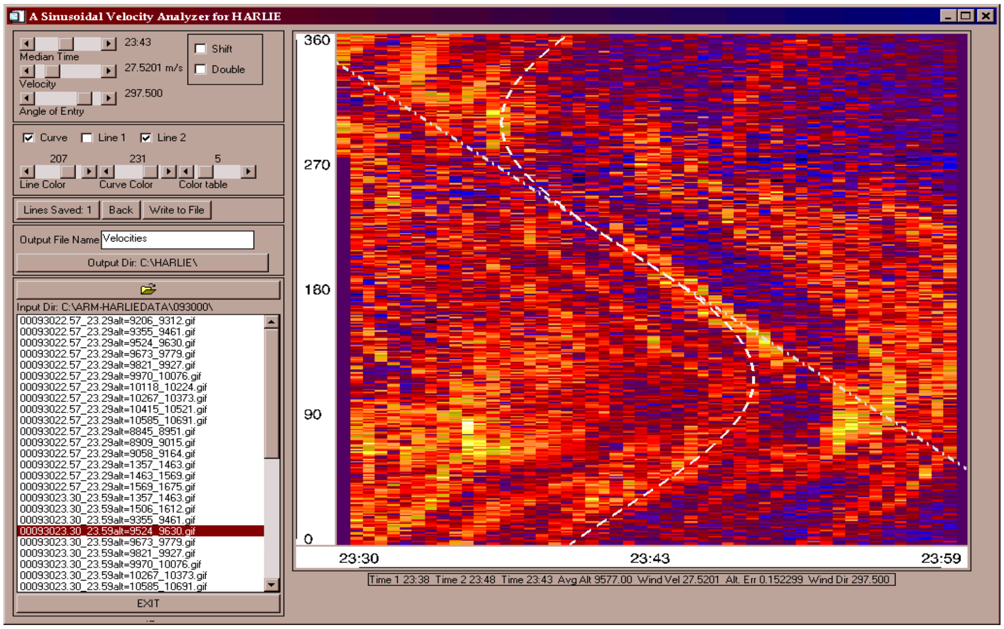

Figure 4. Example of a HARLIE “wave” image, backscatter at one altitude plotted versus azimuth angle on the Y-axis and time or scan number or the X-axis, used to retrieve wind vectors.

45° elevation angle covers a wide area that is more representative of the average wind conditions above the site than the isolated track of the sonde’s ascent. Atmospheric turbulence may account for some of the discrepancies between the sonde winds and the HARLIE winds.

Conclusions

We suggest that the HARLIE instrument offers a more general and improved representation of the horizontal wind profile whenever there is sufficient backscatter by clouds and aerosols for lidar operation. HARLIE is a rugged and compact lidar that operates from aircraft as well as from the ground and has been used in several meteorological campaigns. As a “direct detection” lidar, HARLIE does not require the complexity of a coherent detection system. The data reduction algorithms facilitate the rapid and accurate determination of wind speed and direction at all altitudes.

Acknowledgements

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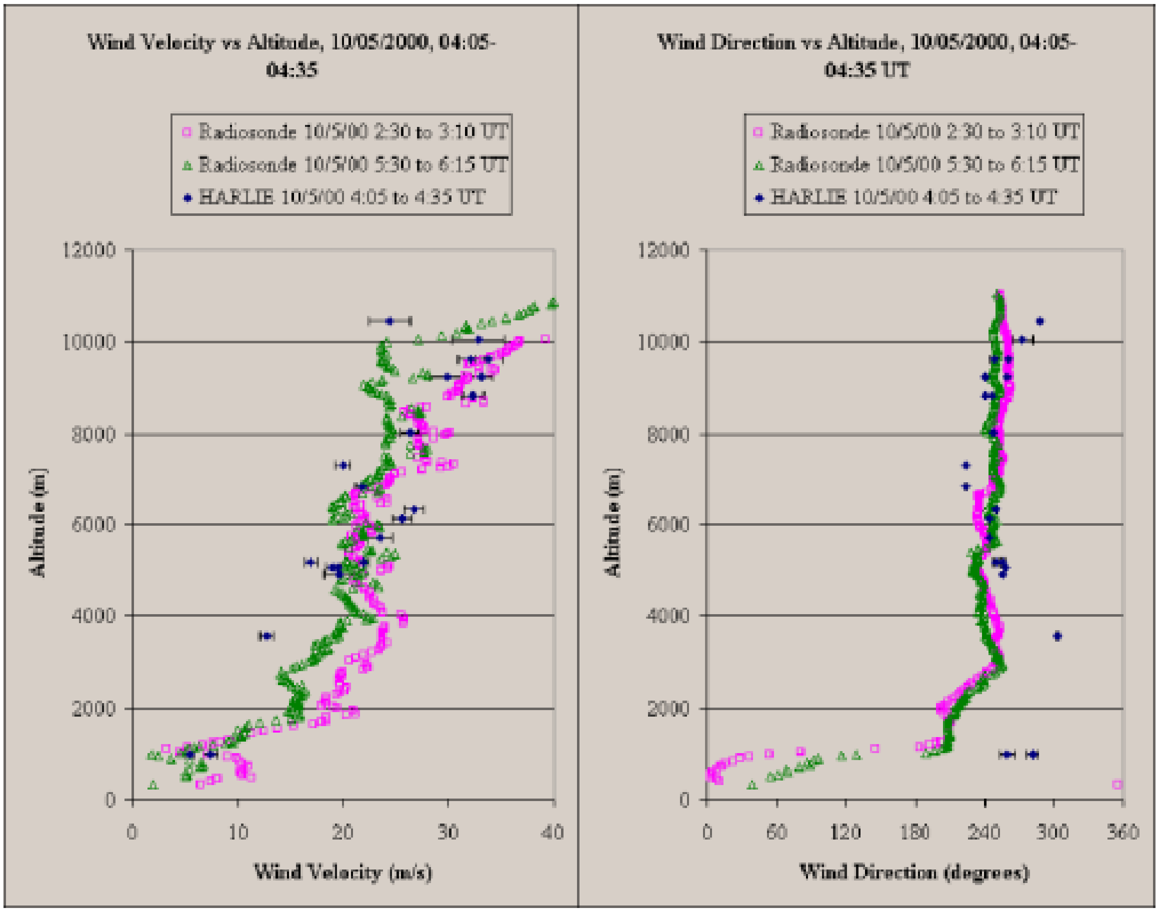

Figure 5. Plot of HARLIE wind speed (left) and direction (right) measurements (black dots), compared with rawinsonde-derived winds (green and pink symbols). The error bars represent the root mean square of several measurements taken close in time from a single wave image.

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