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### DIRECT DETECTION DOPPLER LIDAR WIND MEASUREMENTS OBTAINED DURING THE 2002 INTERNATIONAL H<sub>2</sub>O PROJECT (IHOP)

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#### 1. Introduction

The Goddard Lidar Observatory for Winds (GLOW) is a mobile Doppler lidar system that uses direct detection techniques for profiling winds in the troposphere and lower stratosphere. In May and June of 2002 GLOW was deployed to the Southern Great Plains of the US to participate in the International H<sub>2</sub>O Project (IHOP). GLOW was located at the Homestead profiling site in the Oklahoma panhandle about 15 km east of the SPOL radar. Several other Goddard lidars, the Scanning Raman Lidar (SRL) and HARLIE, as well as radars and passive instruments were permanently operated from the Homestead site during the IHOP campaign providing a unique cluster of observations. During the IHOP observation period (May 14, 2002 to June 25, 2002) over 240 hours of wind profile measurements were obtained with GLOW. In this paper we will describe the GLOW instrument as it was configured for the IHOP campaign and we will present examples of wind profiles obtained.

#### 2. GLOW Description

The GLOW lidar is a field deployable system for studying atmospheric dynamics and transport. It also serves as a testbed to evaluate new lidar technologies and to validate instrument models used to develop future systems. Figure 1 shows GLOW deployed next to the Goddard Scanning Raman Lidar in Oklahoma during the IHOP\_2002 experiment.

The Doppler lidar receiver in the GLOW lidar system is based on the double edge technique<sup>1, 2</sup>. The double edge technique utilizes two high spectral resolution optical filters located symmetrically about the outgoing laser frequency to measure the Doppler shift. The details of the double edge method have been recently reported for lidar systems measuring the Doppler shift from either aerosol<sup>3,4</sup> or molecular<sup>1, 2</sup> backscattered signals. The double edge technique is an example of a class of direct detection Doppler methods that are related by the common technologies employed in the measurement.



**Figure 1 - GLOW Doppler lidar deployed in Oklahoma during IHOP\_2002**

The details of the GLOW lidar system design and performance characteristics have been described elsewhere<sup>1, 5</sup>. The laser is mounted on an optical bench along with the 45 cm aperture telescope

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which collects the backscattered signal. A matching 45 cm aperture scanner is mounted on the roof above the telescope. The azimuth and elevation mirrors are motor driven to allow full hemispherical pointing. The laser is a single frequency, flashlamp pumped Nd:YAG laser which has a 10 pps pulse repetition frequency. The laser output is frequency tripled to 355 nm for the molecular Doppler wind measurements. Table 1 lists the key system parameters. The maximum transmitted laser pulse energy is typically in the range of 70-80 mJ at 355 nm. The backscattered laser light is collected and coupled to a fiber optic cable that delivers the signal to the Doppler receiver. In the receiver, the beam is collimated and split into five channels. Three of these beams are directed along parallel paths through a tunable Fabry-Perot etalon which is used as the high spectral resolution edge filter.

	Typical / <i>IHOP</i>
Wavelength	355 nm
Telescope/Scanner Aperture	0.45 m / <b>0.25 m</b>
Laser Linewidth (FWHH)	80 MHz
Laser Energy/Pulse	70 mJ / <b>5 to 40 mJ</b>
Laser Repetition Frequency	10 pps
Etalon FSR	12 GHz
Etalon FWHH	1.7 GHz
Etalon Peak Transmission	>60 %
PMT Quantum Efficiency	15%

**Table 1 - GLOW lidar system parameters. Values optimized for IHOP are shown in bold**

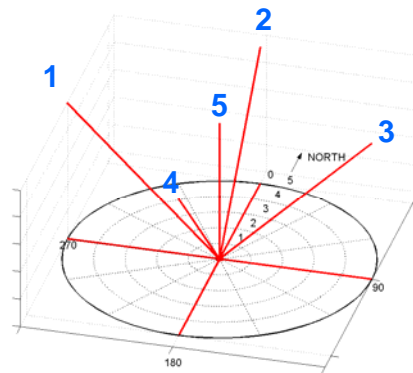
Two of these etalon channels (the ‘edge’ channels) have photo-multiplier tube (PMT) detectors operating in photon counting mode. These channels provide the information used in the Doppler shift measurement. The third etalon channel is used to sample the outgoing laser frequency as a reference. The other two channels serve as energy monitor channels used to provide intensity normalization of the respective etalon channels during calibration.

The GLOW molecular receiver has been designed for efficient operation in the clear air regions of the free troposphere and lower stratosphere. This provided some challenges for IHOP which was focused on convective activity in

the boundary layer and lower troposphere. The photon counting PMTs provide high detection sensitivity in the upper troposphere and stratosphere where the return signals are small. One side effect of this is that when the maximum laser pulse energy and the full telescope aperture are used the signals collected from ranges less than 5 km are too large and the response of the photon counting detectors is non-linear. For the IHOP experiment the most important altitudes for observations of convective activity and boundary layer evolution are from the surface to 5 km. To ensure coverage of the lowest 5 km the signal levels were optimized by reducing the pulse energy to between 5 mJ and 40 mJ depending on atmospheric conditions and the experimental objectives of the day. In addition, the effective telescope aperture was reduced from 45 cm to 25 cm. The low laser average power (0.05 W to 0.4 W) used means that some averaging (spatial and/or temporal) is required in post processing to obtain good performance above the boundary layer. The photon counting signals are binned in a multi-channel scalar, integrated for a selectable number of shots and stored. For the IHOP experiment the minimum range bins are 45 m (300 nsec) and the minimum integration time is 10 seconds (100 shots).

### 3. Lidar Observations

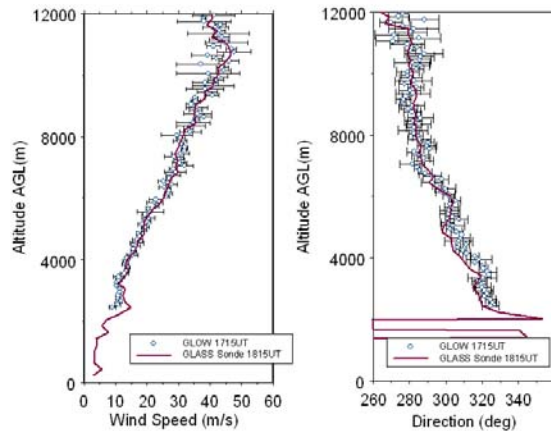
During the IHOP experiment GLOW was operated in several modes. The most common was a step stare scanning mode, in which the lidar ‘stares’ for 30 seconds at a fixed elevation angle along each of the four cardinal directions. A final 30 second zenith pointing measurement is made before repeating the cycle. The typical azimuth angle sequence is 270°, 0°, 90°, 180°. The five direction step-stare scan pattern is illustrated in Figure 2.



**Figure 2 - Five direction scan pattern used during IHOP**

Elevation angles of 15°, 30° and 45° were used depending on conditions.

The measured data product from the GLOW Doppler lidar is the radial wind speed along the line-of-sight of the laser in each of the each of the azimuth directions. By combining the line-of-sight data from the four directions height profiles of the u, v components of the wind field can be determined. Alternatively, profiles of the horizontal wind speed and direction can be displayed as shown in Figure 3. The lidar data,

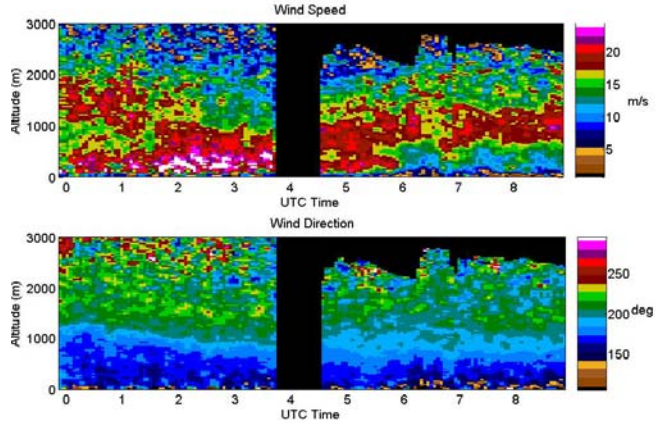


**Figure 3 – Lidar data from May 13, 2002. The mean and standard deviation of 3 consecutive lidar profiles of wind speed (right) and direction (left) are shown (blue diamonds) along with coincident radiosonde wind data (red line). The vertical resolution of the lidar data is 100 meters.**

shown as blue diamonds in Figure 3, are the mean and standard deviation of three consecutive profiles of wind speed and direction taken on the afternoon of May 13, 2002. The vertical resolution of the data is 100 m and the temporal resolution is 30 minutes. Wind profile data from a radiosonde launched from the NCAR Integrated Sounding System, co-located with GLOW at the Homestead Profiling site, is shown for comparison.

Continuous operation of the lidar can produce a time series of wind profile data to capture dynamics within the boundary layer. An example is shown in Figure 3 which shows 9 hours of wind data obtained during a low level jet experiment on the morning of June 20, 2002. The elevation angle for the first block of data extending from 2340 UT on June 19 to 0340 on the June, 20<sup>th</sup> was 45 degrees. The elevation angle was lowered to 30 degrees for the remaining portion

of the time period. The four direction radial wind profiles have been combined to derive the wind speed and direction. The lidar signals have been averaged to a vertical resolution of 100 meters and the temporal resolution is 3 minutes per profile. The maximum errors are around 3



**Figure 4 - Time series of lidar wind speed (top) and direction (bottom) profiles obtained on the morning of June 20, 2002. A low level jet maximum is observed at 0200 UT. In addition the arrival of a bore wave is observed as 3 oscillations beginning at 0600 UT.**

m/s, generally observed at the highest altitudes where the signal levels are decreasing. The low level jet is observed between 0140 and 0300 UTC. The maximum speed of 27.4 m/s is observed at a height of 450 meters at 0200 UT. Of particular interest is the notable drop in wind speed observed in the lowest kilometer beginning at 0600 UTC. This drop in wind speed is coincident with the arrival of a bore wave at the Homestead site. The bore is observed as an apparent drop in wind speed from a maximum of 24 m/s to a minimum of around 3 m/s. Three oscillations of the bore wave with a period of about 1 hour are observed in the lowest kilometer.

In addition to the five direction step-stare scanning mode described above, a number of other step-stare scan patterns were used for special cases. A total of 244 hours of lidar wind profiles were obtained in the IHOP experiment. Of this total, 211 hours are from the five direction scans and the remaining 33 hours form operation in other modes.

#### 4. Summary

The GLOW Doppler lidar completed an intensive field campaign in the spring of 2002 as one of many instruments operated in the IHOP\_2002 field experiment. Calibration and validation of the

GLOW wind profile data from IHOP has been completed and the data has been made available to the scientific community. A number of case studies of events (drylines, bores, low-level jets) have been identified for further study with members of the IHOP scientific community.

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