README file for Goddard Lidar Observatory for Wind (GLOW) IHOP Wind Profiles. Version 1.0

TITLE: GLOW IHOP wind speed and direction profiles. Analysis Version1.0

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1.0 DATA SET OVERVIEW

Introduction:

The Goddard Lidar Observatory for Winds (GLOW) is a mobile direct detection Doppler lidar system. GLOW uses an optical interferometric technique to measure the Doppler shift of the laser signal backscattered by air molecules. The lidar operates at a wavelength of 355 nm and is designed to profile 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 H2O Project (IHOP_2002). GLOW was located at the Homestead profiling site in the Oklahoma panhandle about 15 km east of the SPOL radar. Several other lidars (SRL and HARLIE), radars (MAPR and UMass FM-CW) and passive instruments (Aeribago) were permanently operated from the Homestead site 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.

The first version of the GLOW IHOP data set consists of wind speed and direction profiles determined from the combination of four directions (N,S, E, W. The data have been averaged in altitude and temporally to a common format. Two formats are included in this version: 1) 30 minute averaged winds at 100 meter vertical resolution and 2) 10 minute averaged winds with 100 meter vertical resolution for altitudes below 3 km and 200 meters vertical resolution for altitudes above 3 km. More details on the data acquisition and processing are given in Section 3.0 below. Contact the PI with requests for alternative spatial and temporal processing of the GLOW data for specific days.

Time period covered by the data:
GLOW was operational 13 May through 25 June, 2002. The lidar was operated in coordination with the IHOP science experiment plan. Continuous sampling intervals range from 1 hour to >23 hour in duration.

Physical location (including lat/lon/elev) of the measurement or platform: Homestead Profiling Site. Latitude: 36.558N; Longitiude: 100.606W; Elevation: 862 m

Any World Wide Web address references (i.e. additional documentation such as Project WWW site): http://glow.gsfc.nasa.gov

2.0 INSTRUMENT DESCRIPTION

GLOW is a mobile direct detection Doppler lidar system designed to profile winds in clear air from the surface into the stratosphere. The GLOW lidar is used as a field deployable system for studying atmospheric dynamics and transport and also as a testbed to evaluate instrument technologies and to validate performance models used to develop future systems. Direct detection Doppler lidar is a relatively new technique which has many similarities to Dopper radar or the more commonly known coherent (or heterodyne) Doppler lidar. As with other Doppler systems the fundamental measured parameter is the frequency shift induced by the motion of the scatterering target. The component of the wind along the line of sight of the beam (radial wind speed) is determined from the measured Doppler shift. A unique feature of a direct detection Doppler lidar is that either aerosols or molecules can be used as primary scattering target. The GLOW receiver employed in IHOP_2002 is optimized for the molecular Doppler measurement. The lidar operates in the ultraviolet at a wavelength of 355 nm to maximize the signal return and for eyesafty. The Doppler lidar receiver in the GLOW lidar system is based on the double edge technique1,2. The double edge method utilizes two high spectral resolution optical filters located symmetrically about the outgoing laser frequency to measure the Doppler shift.

The GLOW lidar system is integrated in the cargo compartment of a modified delivery van. The laser, telescope and beam pointing optics are mounted on an optical bench that is bolted to the truck frame. A 45 cm aperture azimuth-over-elevation scanner is mounted on the roof to allow access to the atmosphere. The scanner provides full hemi-spherical pointing using motor driven azimuth and elevation mirrors. The matching 45 cm telescope is mounted below the scanner to collect the laser signal backscattered from the atmosphere. The collected light is coupled to a fiber optic cable that delivers the signal to the Doppler receiver.

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 photomultiplier tube detectors 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. 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 in IHOP means that some averaging (spatial and/or temporal) is required in post processing to obtain good performance above the boundary layer.

The details of the GLOW lidar system design and performance characteristics have been described elsewhere (refs). Operating parameters for GLOW during the IHOP_2002 experiment are summarized in the Instrument Table 1.

Instrument:	GLOW Molecular Doppler Lidar
Measurement:	Tropospheric Wind Profiles, radial or processed to u,v components
Operated by:	NASA/GSFC
Contact:	Bruce Gentry Bruce.M.Gentry@nasa.gov
Platform:	Ground-based, mobile, truck based
Site:	Homestead Site
Transmitter Wavelength:	355 nm
Output/Pulse Energy:	<40 mJ
Average Power:	0.4 W
Pulse Repetition Frequency:	10 Hz
Pulse Length/Width:	15 ns
Beam Area (at exit point):	3.9 cm2
Transmitter Beam Divergence:	0.15 mrad
Eye safe:	NOHD: 0.27 km
Measurement Range (min & max):	0.1 to 10 km
Measurement Direction:	Full hemi-spherical scanning capability
Operations Mode:	Manual
Receiver Telescope Diameter:	25 cm eff. (Actual 45 cm stopped down to 25 cm effective diameter)
Receiver Field of View:	0.2 mrad
Resolution - Range: **(Daytime, Nighttime)**	Sampled at 45m in range; Typ averaged to 100 m to 1 km for wind profiles. Dependent on maximum range desired. Same day and night.
Resolution - Time: **(Daytime, Nighttime)**	Sampled at 10 sec; Typical average to 30s to 5 min per line of sight dependent on max range. Same day and night
Sampling Rate:	
Accuracy (incl. altitude, averaging and range):	<1 m/s (100m to 5000m; 200m vertical resolution ; 300 sec averaging/LOS); S/N dependent
Data	Hard drive

Table 1 - GLOW Instrument Table for IHOP_2002

3.0 DATA COLLECTION AND PROCESSING

Data Collection- 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 sec zenith pointing measurement is made before repeating the cycle. The total time to complete a 5-direction cycle, including the time required for the scanner to move to the next position, is approximately 3 minutes. The photon counting signals are binned in range (time) using a multi-channel scalar and 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). So for each 30 second line-of-sight measurement the raw signal levels (detected photocounts) are stored in three files each of 10 second duration. This allows considerable flexibility in averaging data during post processing. The typical azimuth angle sequence is 270°, 0°, 90°,180°. Elevation angles of 15°, 30° and 45° were used depending on conditions. The radial wind profiles along each of the azimuth directions can be derived and the horizontal wind speed and direction can be determined from the four line-of-sight profiles.

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.

Data Processing – The raw photon counting signal data from the two high spectral resolution edge filter channels are processed into profiles of wind speed and direction as described in references 3 and 5. Here is brief description of the steps in that processing

1) Prior to any averaging, the background level in each channel is subtracted
2) A correction for non-linear response ('dead time correction') of the PMT's is applied if necessary.
3) The data in each channel is re-binned to match the desired vertical resolution.
4) Temporal averaging is applied by summing the signals obtained in each detector channel from common directions in a fixed number of consecutive cycles of the scan pattern. For example to produce the 30 minute averaged wind data the signals from 9 cycles of the scan pattern (Vertical, West,North,East, South) are included in the average. All of the Northward pointing signals are combined to produce an averaged North profile, similarly for the South, West, and East directions.
5) The averaged data are processed for radial line of sight wind speed in each direction. (Note- This data is available on request with some disclaimers and will be released to the archive soon)
6) The North and South signals are processed to determine the v component and the East and West signals are processed to determine a u component. *In this version of the data analysis we are assuming spatial homogeneity of the horizontal wind field at any given altitude over the sampling region of the lidar and also assume the vertical wind is negligible(i.e. w=0).*
7) During the wind calculations (steps 5 and 6) several corrections are applied to account for atmospheric effects. There is a small dependence of the instrument spectral response on temperature because the spectral shape of the molecular backscattered signal is velocity broadened by the random thermal motion of the molecules. The width of that spectrum is proportional to $T^{1/2}$ (Boltzman velocity distribution). There is an effective increase in the Doppler sensitivity as the temperature decreases. There is also an inelastic scattering correction for Brillioun scattering which is a function of atmospheric density. The maximum value of this correction is about 9% at 1000 mb and falls to a few percent at 500 mb. For these corrections we use local values for temperature and pressure

profiles determined from the ISS sondes. We estimate the residual error from these effects to be 1-2 % in the reported velocity.

8) The u,v components are combined to produce averaged profiles of wind speed and direction.
9) Errors in the wind speed and direction are calculated by propagating the detected signal shot noise through the wind algorithms. These are error estimates of the random error and have been shown to be well correlated with statistical estimations of the instrumental noise.
10) Data flags (value set to -999) are applied to data in which the velocity exceeds 100 m/s and when the total averaged signal in one PMT channel is below 200 photocounts. The last flagging procedure has the effect of excluding all wind estimates with an error exceeding about 10 m/s. This highlights a characteristic of a direct detection Doppler lidar: a gradual degradation in accuracy (proportional to the square root of the detected signal counts) is typically observed as the signal level decreases. *Data users should be aware of this gradual degradation and apply their own accuracy flags as the application warrants.*

4.0 DATA FORMAT

In this version of the analysis the wind speed and direction data been processed for two different averaging schemes. The first set of wind profiles are from 30 minute averaged data (9 scan cycles) with a vertical resolution of 100 m. The second set of profiles are 10 minute averaged winds (3 scan cycles) with vertical resolution of 100 m for altitudes below 3 km and 200 m above 3 km. It is possible to produce winds from a single scan cycle (3 minutes) with vertical resolution as high as 30 m. The effect of decreasing the averaging (vertical or temporal) is that the accuracy and the maximum range of the instrument will be reduced. There are likely to be cases when the higher spatial or temporal sampling will be important (e.g. the bore events of June 4, 14 and 20) and we will certainly accommodate requests to produce data sets at higher resolutions. Requests for special averaging schemes should be directed to the PI.

The data files are in ascii format and begin with 16 rows of header information identifying the instrument, experiment, location and processing parameters used in the analysis. This followed by a row identifying the column parameter as follows

Alt (m) = Altitude reported in meters above ground level

Ch1 (photocounts) = Total photocounts detected on PMT 1 during the sampling interval. This is derived by taking the average of the total signals from the 4 directions used in the measurement. It is intended as to give a representative signal intensity profile

Ch2 (photocounts) = Total photocounts detected on PMT 2 during the sampling interval. This is derived by taking the average of the total signals from the 4 directions used in the measurement. It is intended as to give a representative signal intensity profile for this reported wind profile.

UWind (m/s) = u component of the wind speed in m/s

VWind (m/s) = v component of the wind speed in m/s

Speed (m/s) = wind speed in m/s

Error(m/s) = estimate of random error in the wind speed
Direction(degrees) = wind direction in degrees
Error (degrees) = estimate of the random error in the wind direction

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SAMPLE DATA FILE
==========================================================================================

PI/DATA CONTACT= Gentry, Bruce (NASA/Goddard)
DATA COVERAGE = START: 0619221700.00; STOP: 0619224700.00 UTC
PROFILE TIME = 20020619223200.00
ELEVATION ANGLE = 45 deg
PLATFORM/SITE = Homestead
INSTRUMENT = Goddard Lidar Observatory for Wind (GLOW)
LOCATION = 36.558N, 100.606W
SITE ELEVATION = 862 meters
DATA VERSION = 1.0 (12 Sept 2003), PRELIMINARY
REMARKS = National Aeronautics and Space Administration, IHOP_2002
REMARKS = Temporal resolution is 30 minutes
REMARKS = Altitude resolution is 100 meters
REMARKS = Bad data = -999.0
REMARKS = Altitude is reported in meters above ground level
REMARKS = Data point time is midpoint of 30 minute average
REMARKS = Data point altitude is assigned to the midpoint of averaging interval
REMARKS = Data point Date/Time provided in UTC
     alt      Ch1      Ch2    UWind    VWind    Speed    Error  Direction   Error
     (m)     (cts)    (cts)   (m/s)    (m/s)    (m/s)    (m/s)    (deg)     (deg)
    50.0  24782.0  26375.9     -2.5     16.2     16.4      1.7    176.3       5.7
   150.0  21626.5  23680.1     -5.7     19.7     20.6      1.8    168.9       4.8
   250.0  28712.8  31576.3     -3.8     18.0     18.4      1.6    173.2       4.6
   350.0  38850.8  42819.0     -2.9     20.2     20.4      1.4    176.7       3.5
   450.0  54031.2  59586.1     -4.1     20.5     20.9      1.2    173.6       2.9
   550.0  73603.4  80891.1     -3.5     16.8     17.2      1.0    173.1       3.0
   650.0  94092.9 103188.0     -3.1     15.7     16.0      0.9    173.8       2.9
   750.0 109595.5 120102.7     -2.8     15.6     15.8      0.8    174.7       2.7
   850.0 116855.4 127767.9     -2.0     15.0     15.2      0.8    177.6       2.8
   950.0 117607.5 128711.6     -1.7     15.0     15.1      0.8    178.3       2.8
  1050.0 114101.5 125064.6     -1.5     15.8     15.9      0.8    179.6       2.7
  1150.0 107708.8 117825.0     -0.4     16.5     16.5      0.8    183.7       2.7
  1250.0  99892.0 109344.6      0.7     17.7     17.7      0.8    187.4       2.6
  1350.0  92163.5 100697.0      1.7     17.5     17.6      0.9    190.6       2.7
  1450.0  84512.3  92150.8      2.6     17.1     17.3      0.9    193.5       2.8
  1550.0  77032.3  84007.6      4.0     16.9     17.4      0.9    198.4       3.0
  1650.0  70484.4  76327.1      5.6     16.9     17.8      1.0    203.3       3.0
  1750.0  64363.7  69745.7      6.4     15.1     16.4      1.0    208.0       3.5
  1850.0  58759.2  63478.7      7.7     12.9     15.0      1.1    215.9       4.0
  1950.0  53659.5  58170.7      7.0     14.6     16.1      1.1    210.7       3.8
  2050.0  49274.5  53479.4      7.9     16.1     17.9      1.2    211.1       3.6
  2150.0  45324.6  49156.3      9.0     14.6     17.2      1.2    216.6       3.9
  2250.0  41866.8  45446.0      9.2     11.0     14.3      1.3    224.7       5.0
  2350.0  38573.6  41827.0      7.2     10.0     12.3      1.3    221.0       6.0
  2450.0  35502.0  38564.1      7.9     10.3     13.0      1.4    222.4       5.9
  2550.0  32702.4  35497.7      8.3      9.4     12.6      1.4    226.5       6.4
  2650.0  30096.4  32791.3      7.2      7.3     10.2      1.5    229.4       8.2
  2750.0  27847.1  30311.8      8.8      6.3     10.8      1.5    239.6       8.2
```

5.0 DATA REMARKS

The data have been quality checked by comparing sample profiles with ISS sondes launched from the Homestead site. Further comparisons with MAPR, profilers and sondes will continue. Results of those comparisons will be reported. The GLOW lidar is designed predominantly to measure winds from the molecular backscattered signal. At the operating wavelength of 355 nm the GLOW lidar also ‘sees’ photons scattered from aerosols which have a significantly different spectral signature from the molecular signal. The instrument is designed to be insensitive to the aerosol/molecular backscatter ratio.

However during the IHOP campaign, very high aerosol loading in the boundary layer was observed on some days and there may have some residual impact on the wind determination. We will be using available aerosol data from the HARLIE (1064 nm) lidar and the Scanning Raman Lidar (355 nm) to investigate this further.

6.0 REFERENCES

1. "The Edge Technique - Theory and application to the Lidar Measurement of Atmospheric Winds",C. L. Korb, B. Gentry, and C. Y. Weng, Applied Optics, 31, pp 4202-4212, 1992.
2. "Edge Technique for High Accuracy Doppler Velocimetry", B. Gentry and C. L. Korb, Applied Optics, 33, pp 5770-5777, 1994.
3. "Wind Measurements with a 355 nm Molecular Doppler Lidar", Bruce M. Gentry, Huailin Chen and Steven X. Li, Optics Letters, 25, 1231-1233, 2000.
4. "Profiling tropospheric winds with the Goddard Lidar Observatory for Winds (GLOW)", Bruce Gentry, Huailin Chen, , *Proceedings of the 21st International Laser Radar Conference,* Quebec City, Canada, July 8-12, 2002.
5. "Performance validation and error analysis for a direct detection molecular Doppler lidar", Bruce Gentry and Huailin Chen, Invited Paper, *SPIE Third International Asia-Pacific Environmental Remote Sensing Conference*, Hangzhou, Oct 23-27, 2002.

Additional references can be found at
http://glow.gsfc.nasa.gov/publications/index.htm