Airborne Doppler lidar surface returns: data products other than tropospheric winds

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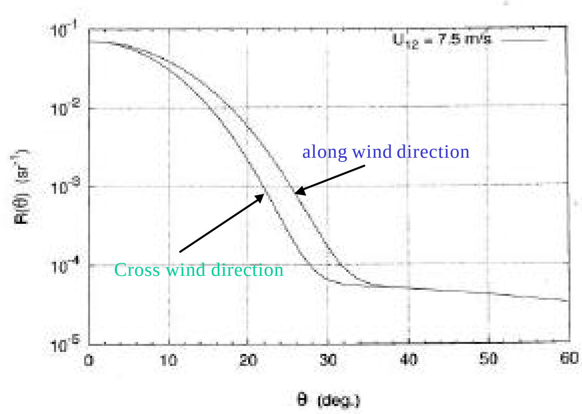
ABSTRACT

Space-based global wind observations are a potential application of Doppler lidars. While the use of Doppler lidars to measure winds has existed for several decades, the availability of airborne systems is relatively recent. Ground based Doppler wind lidars (DWL) have provided much experience in interpreting return signals and validating performance models. However, space-based operations present a very different perspective on the atmosphere. For that reason, airborne lidars are critical in the development of signal processing algorithms and performance model validation for both future space-based as well as sub-orbital instruments. As a component of a program to develop a calibration/validation strategy for all space-based wind observing systems, an airborne coherent 2 micron DWL was flown early in 2002. The primary purpose of those flights was to investigate the surface returns from water. This paper summarizes those missions and offers several examples of the findings.

1.0 BACKGROUND

The issue of Doppler lidar (infrared) returns from water surfaces has been argued for many years. The two basic questions are: 1) How does the wind speed alter the reflectance from open water bodies at typical lidar wavelengths? and 2) How does the reflectance from water bodies vary as a function of incidence angle. There have been efforts made using a backscatter lidar suspended from a bridge (Petri (1977)), backscatter lidars on aircraft (Bufton et al (1983); Hoge et al (1984)), and some Doppler lidar equipped aircraft (Tratt and Menzies, 1996). Menzies (et al., 1998) describe water surface returns during experiments with the Space Shuttle at nadir angle between +- 30 degrees.



Modeled reflectance from ocean surface
for a wind speed of 7.5m/s (Tratt, 2002)

Figure 1

Simple water reflectance theory does not provide much support for very useful signal strengths for nadir angles beyond 10-20 degrees over water. However, work by Tratt and Menzies (1996) has taken the pure water assumptions and added the effects of foam and wave slopes to the lidar signal model (Figure 1). The major feature of that response curve is the plateau reached at some angle near 20-30 degrees, depending upon the sea state. Since most of the concepts for future space-based DWLs involve nadir angles between 30 and 50 degrees, these model results have provided some measure of hope. The experiments reported here were designed, in part, to verify the form of the signal function shown in Figure 1.

To our knowledge, there have been no experiments designed to study the angular dependence of backscatter at 2um from a variety of water surfaces using a Doppler lidar. Given that one of the candidate technologies for space-based wind profiling is coherent detection at 2um, this issue has become the subject of a series of laboratory (Jarzembski and Srivastava, 1998), paper (Emmitt, 1994) and field campaigns. The Integrated Program Office (IPO) of NPOESS and the Navy's Center for Interdisciplinary Remotely-piloted Aircraft Studies (CIRPAS) co-funded the installation and engineering checkout flights of a Doppler Wind Lidar (DWL) on a Navy Twin Otter aircraft. (Figure 2). This instrument configuration is referred to as TODWL (Twin Otter Doppler Wind Lidar). The primary purpose of the first series of flights was to investigate the DWL returns from water surfaces. In the advent of a space-based deployment of a DWL, surface returns will be needed for final corrections of Line of Sight (LOS) velocities to insure the full accounting for satellite motion. For this reason the first series of flights in the spring of 2002 were devoted to over-flights of various water bodies that included ocean, rivers, lakes, canals and wetlands.

CIRPAS Twin Otter Spring 2002

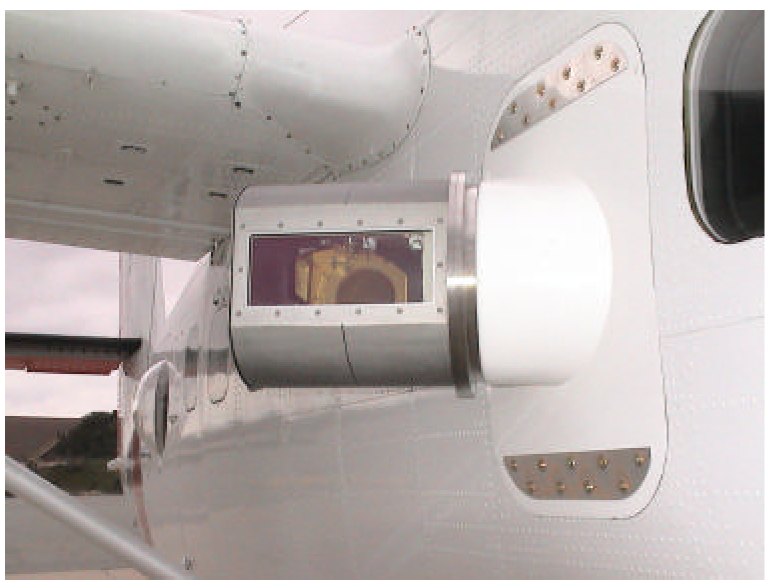
Figure 2

2.0 EXPERIMENTS

The TODWL instrument is described in Table 1. The one feature that distinguishes this airborne Doppler lidar from most others is the side mounted two-axis scanner (Figure 3). This configuration allows for conical scans above, ahead and below the aircraft. In most instances, a complete 8 point step-stare conical scan takes approximately 15 seconds. At the nominal cruise speed of 50 m/s (IAS), a wind profile is obtained every 750-800meters. The scanner can also be pointed directly nadir (adjusted for aircraft pitch and roll). In the nadir setup, vertical motions of the surface and atmosphere can be observed to within 20 cm/sec accuracy. The range resolution depends upon the backscatter structure. Using a sliding range gate in the processing we are able to achieve 10-20 meter vertical resolution. In the case of the water or earth surface, the height resolution is better than 10 meters.

Table 1 TODWL System Description

Wavelength	2 microns
Energy per pulse	5-7 mJ
Pulse repetition rate	80
Pulse length (FWHM)	90 meters
Telescope diameter	10 cm
Scanner	2 axis forward (240 deg.) and starboard (60 deg.)



TODWL 2-axis scanner

Figure 3

The first series of experiments were conducted over and near the Monterey Bay in California during February, 2002. A brief summary of the experiments is given in Table 2. The wind conditions favored waves of a meter or so in height during all flights. The goal of the experiments was to collect DWL data from different nadir angles ranging from 0 to 50 degrees. Flight paths were executed that allowed sampling in both the cross and along wind directions. The scan patterns were primarily of three types: conical (from which the complete wind profile could be derived), step/stare at different nadir angles along the flight path, and near nadir dwells or dithers. Long flight legs allowed for the acquisition of statistically meaningful observations.

Table 2 Summary of experiments (11-15 February, 2002)

Target	Types of scans
Ocean with white caps	RHI (-5 to +10); RHI (-5 to +30); RHI (-10 to + 50)
	VADS (10 and 30 degree nadirs); Nadir find (±5)
Ocean no white caps	RHI (-5 to +10); RHI (-5 to +30); RHI (-10 to + 50)
River (San Joaquin)	± 5 degree left/right at 0,10,20,30 degrees forward off nadir; 40 scans during 6 overflights
Lake (San Luis)	RHI(-5 to +20)
Canals	± 5 degree left/right at 20degrees forward off nadir
Land	VADS, RHI’s and fixed
Cloud tops	VADS and RHI (-5 to 30)
Dropsondes	2 over buoy
Aerosol Backscatter experiments	Fixed angles at various altitudes

A second series of overflights were conducted over a segment of the San Joaquin River located to the east of San Francisco. The river offered a water surface that was weakly disturbed (optical reflectance wise) and was moving with a fairly constant (in time) surface speed. The challenge in the river case was to fly the river in a manner that allowed the side to side scan to be centered on the river. A ground spotter observed the aircrafts alignment as well as obtained data on winds and surface currents. The surface speed was measured with in situ flow gages spaced several meters across the river. Eight passes were made over the same segment of river.

A third set of data was collected during the overflight of the San Luis Reservoir. On this occasion the surface appeared to be quite smooth with very little evidence of wind disturbances.

3.0 FINDINGS

While the experiments described above were conducted in the interest of understanding surface returns for use in obtaining reliable wind observations from a moving platform, there were several “non-wind” findings that generated interest from TODWL investigators: wave spectra, wave and aerosol backscatter correlations, and surface horizontal motions (river currents). In this paper, we will address the ocean wave and LAS (Layer Adjacent to the Surface) aerosol findings. At this time we can report that the river motion could be estimated from nadir angles less than 10 degrees. However, improved corrections for the aircraft motion are still being developed.

In the nadir view, the vertical wave motion can be sensed. The reflectance of the water surface changes with location relative to wave crests and troughs. However, the velocity measurement accuracy with a coherent DWL remains independent of the signal strength until the signal gets close to the threshold sensitivity of the instrument. At 80 Hz repetition rate and a ground speed of ~ 50 m/s, the TODWL was able to make single shot velocity measurements spaced approximately .5 meters. In regions where the single shot return signal was near or below threshold strength, several shots were accumulated before processing for LOS observations.

The issue of discriminating the water surface returns from those associated with the aerosols in the LAS was addressed with two processing tools. First, the TODWL had a frequency chirp which produced a very clear velocity signature with time for "hard" targets. Second, by using a sliding range gate to process the LOS data stream, we were able to isolate the water surface returns from the LAS returns. In Figure 4, an example of this process is shown.

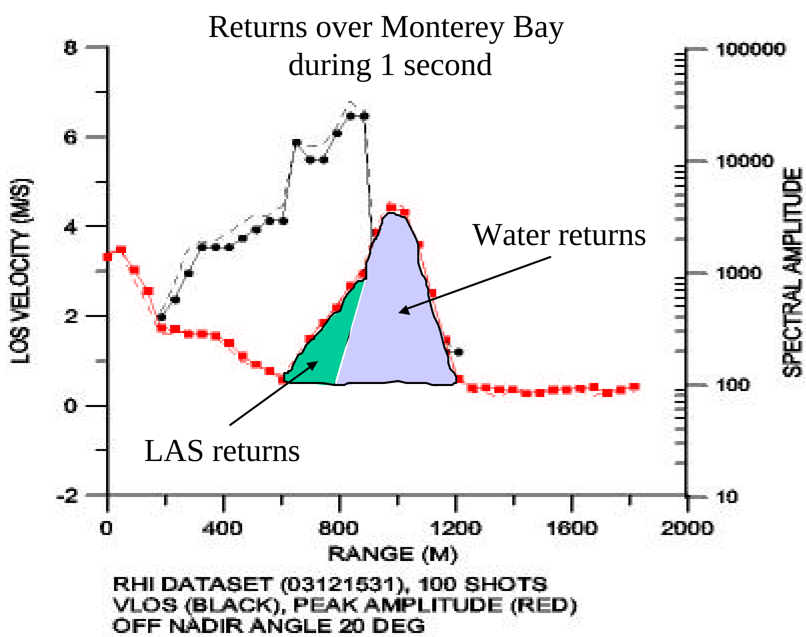
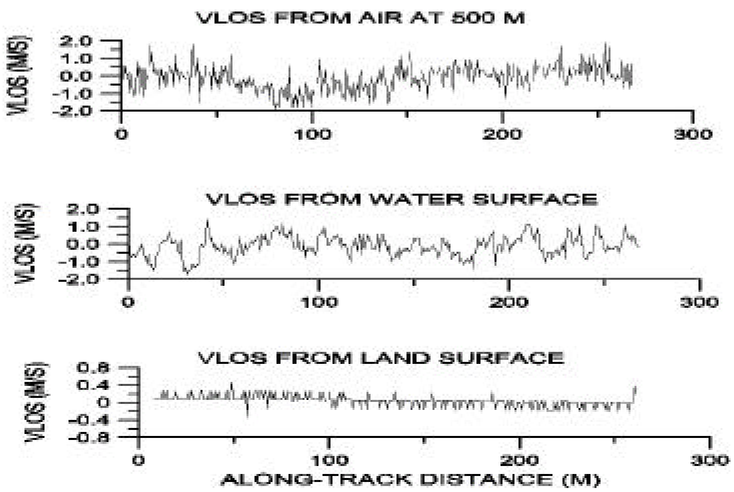


Figure 4

Based upon nearby buoy data, we expected swell with a period of 11.1 seconds, length of ~200 meters and height of 2.4 meters; dominate wind waves with 3.7 seconds, length of 21 meters and height of 1 meter. The measured wind waves at the buoy were consistent with estimations based upon the wind speed at 10 meters. To compare with the aircraft data these wave lengths are adjusted by their phase speed resulting in 160 meters and 20 meters.

Using data from a .3 km segment of nadir viewing we obtained the results shown in Figure 5. Included is a sample of single shot data obtained from a portion of the same flight leg that occurred over land. It is clear from the land returns that the velocity accuracy is within the .2 m/s resolution used in this analysis. The time series of the water surface return suggests periods consistent with our expectations. The air returns from 500m above the water, indicate a higher frequency component as one would expect from the sheared profile in Figure 6.



Nadir view over water

Figure 5

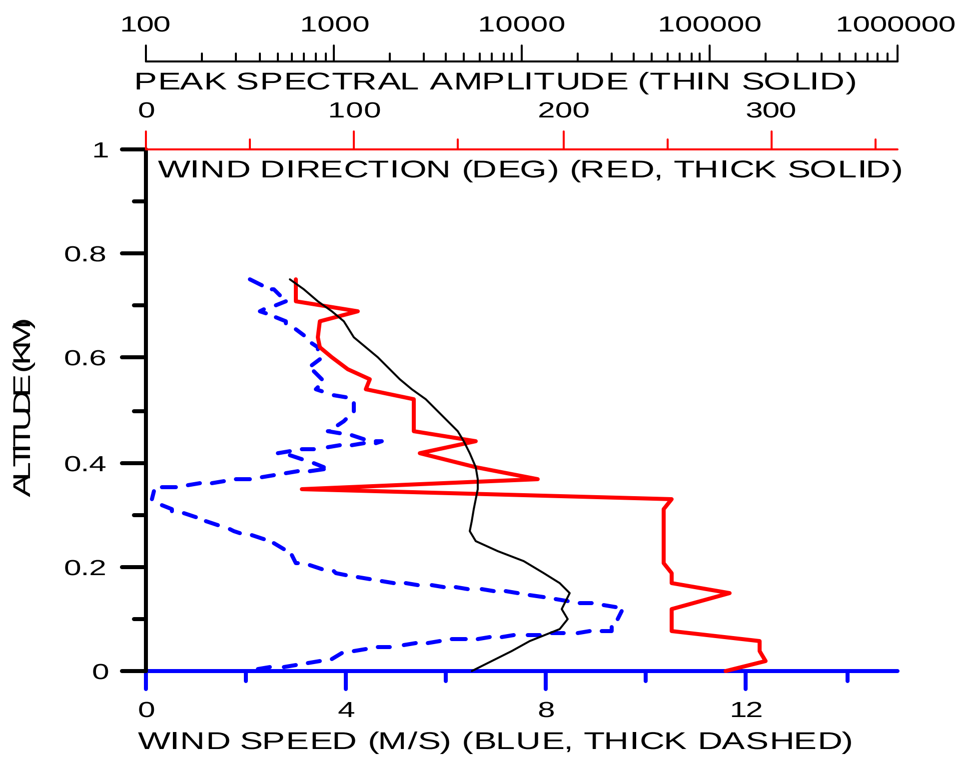
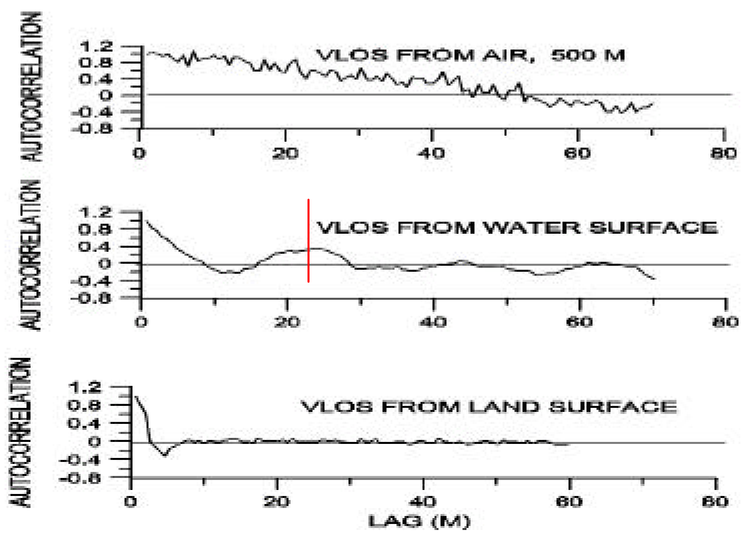


Figure 6



Autocorrelations at lags out to 70 meters for the time series in Figure 5

Figure 7

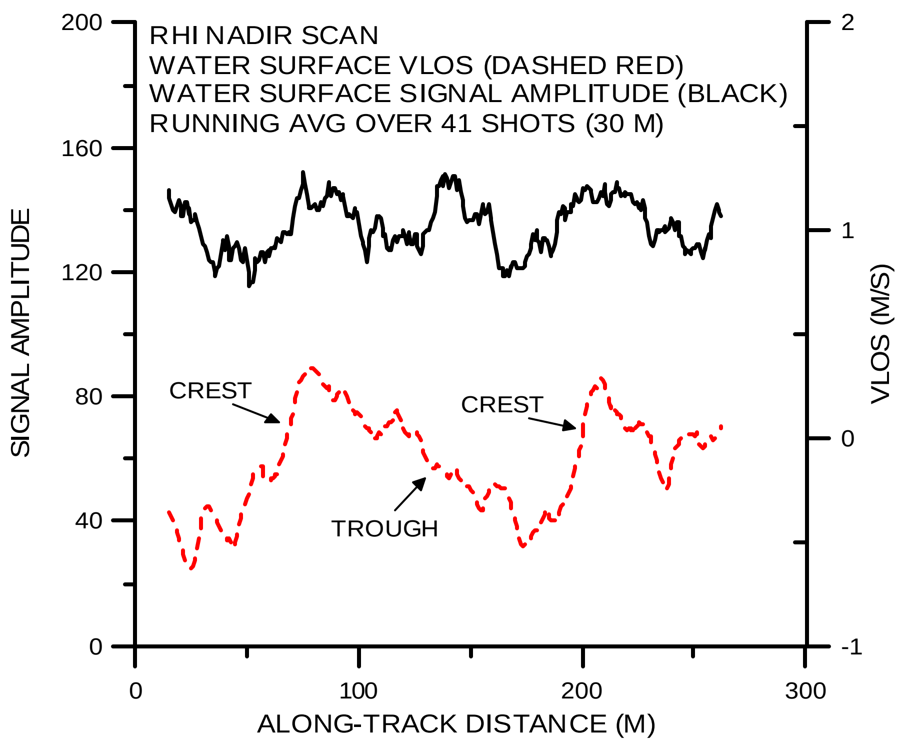


Figure 8

The generation of spray and foam by the wind and wave action is a confounder to the interpretation of the lidar returns and to the estimation of energy and momentum fluxes at the air/sea interface. The initial attempt to investigate the distribution of spray in the LAS relative to the wave geometry found a pattern consistent with the following: within a wave there are two areas responsible for the strongest signals, the bottom of the trough and the crests. Within the trough the probability of water facets that are very close to perpendicular to the lidar beam is high. Within the crests there is a high probability of foam and spray that would have a high reflectance. In Figure 8 we show an example of this relationship.

4.0 SUMMARY

In addition to horizontal and vertical winds, an airborne Doppler lidar can be used to study water surface motions and their correlations with aerosols. These correlations may have meaningful impacts on the interpretation of data obtained with a space-based wind lidar and also on the parameterization of fluxes over water surfaces at wind speeds above those that produce whitecaps. The authors are continuing to explore the Spring 2002 data for more information on these issues. It is their intent to use those finding to design a more comprehensive follow-on series of flights.

5.0 ACKNOWLEDGEMENTS

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