2 μm Doppler lidar returns from water surfaces and the overlying aerosols

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ABSTRACT

As Doppler lidars designed for environmental remote sensing move from ground-based platforms to airborne and space-based platforms, issues related to processing surface and near-surface returns are of increasing interest. In the case of Doppler wind lidars, the surface returns can be useful in calibrating the velocity estimates along the associated lines-of-sight, assuming the surface is not moving relative the Earth's frame of reference. This assumption may not hold for water surfaces and in that case, the Doppler signal might be useful in estimating surface currents (rivers and oceans). Whether the water returns are used for calibrating wind lidars or making water current measurements, the confounders of accurate observations include waves and the independent motions of overlying aerosols in the layer adjacent to the surface (LAS).

As part of a program to develop calibration/validation techniques for space-based Doppler wind lidars, a series of laboratory and airborne experiments are being executed. At NASA/MSFC a water slide has been constructed and used with a 2 μm coherent lidar to study the signal from water surfaces having varying velocities, roughnesses and turbidities. The angle of the water slide to the lidar beam can also be varied to test the theoretical function of signal return vs. angle of incidence. Results of those experiments have provided input to the design and execution of a set of airborne 2 μm coherent lidar experiments conducted in February and March 2002 out of Monterey, CA. The airborne system (funded by the US Navy and the Integrated Program Office of the NPOESS) collected data to be used to develop signal processing algorithms that can discriminate between the water surface motions and the velocity of the wind blown aerosols that are combined in the signal from just one range gate. This paper will report on both sets of experiments.

1. RESEARCH OBJECTIVES

Lasers in space represent a new frontier for remote sensing of the Earth's atmosphere and surface. Lidars are being developed that can be used for altimetry, ozone profiles, water vapor profiles, CO_2 profiles, winds and surface water motion. Soon IceSat will be launched to use a lidar altimeter to map ice coverage to within a few centimeters. In the future, Doppler lidars to measure the tropospheric winds may be launched. Any application of lidars that requires accurate pointing and ranging will involve the use and interpretation of returns from the surface, both terrestrial and water.

The Integrated Program Office of the NPOESS has been developing a calibration and validation plan for use with space-based observing systems used to measure winds. These systems include future scatterometers (e.g. Windsat), geosynchronous profilers (e.g. GIFTS) and possible Doppler wind lidars (e.g. GTWS). A major issue related to lidar wind observations is the use of surface returns to correct for residual pointing errors. This issue is the focus of both laboratory and airborne experiments since there is little experience with a space-based perspective of the Earth's surface. One would like to assume that the surface motion is zero for individual laser shots. Over land such an assumption would be violated by swaying trees, blowing sand, or dense smoke near the ground; over the water, the confounders include wave motion, both vertical and horizontal, as well as surface currents and dense sprays. Modeling efforts have estimated that waves and currents can introduce errors of several meters per second if a zero velocity assumption is invoked.

To address this gap in knowledge regarding surface returns, in particular at the 2μm wavelength currently envisioned for a wind lidar, a Doppler lidar was installed on a Twin Otter (Twin Otter Doppler Wind Lidar: TODWL) and flown in a series of engineering checkout flights during February and March, 2002. In addition to the airborne system, an experimental facility was built to conduct controlled experiments in a laboratory setting. The objectives of both initiatives were:

- To document the signal returns from water surfaces in various states of disturbance and from various viewing angles
- To develop signal processing techniques to discriminate between the water motions and the air /spray motions just above the surface (the LAS)
- To determine the lidar requirements for obtaining water surface returns adequate for estimating ocean and river surface currents

2. EXPERIMENT DESCRIPTIONS

2.1 Water slide

In response to some questions posed regarding the use of coherent Doppler lidar to measure the surface currents of rivers, NASA/MSFC decided to conduct a series of experiments on the Tennessee River using both a pulsed 2μm coherent Doppler lidar and a CW CO_2 Doppler lidar. After four deployments to the river, the conclusions were:

- It was not physically possible to view the river surface from angles greater than 20 degrees to the horizontal (need 45- 90 degrees)
- Even at the grazing angles, however, there were suggestions of water returns
- A means to tip a water surface up to the required incidence angles was needed

A water slide was designed and built that would allow experiments to be run at various incidence angles and for water with different surface roughnesses. (Figure 1). The slide produces a thin (~ 2mm) layer of water moving at speeds up to a few m/s, depending upon the angle and head of water in the reservoir. The slide is positioned ~ 300m from the lidar to allow for ~ 130m of air return in front of the water slide.

The spot size of the lidar beam on the slide is ~ 10 cm in diameter. A typical experimental run involved filling the reservoir and then coordinating the data collection with the release of the water regulated by a bar valve at the bottom of the tank. The flow could be considered steady state until the tank was almost empty. Some experimental results from this setup are presented in Section 3.

2.2 Airborne Doppler lidar

As part of its research program, CIRPAS (US Navy's Center for Interdisciplinary Remotely-piloted Aircraft Studies) added a 2μm coherent Doppler lidar to its Twin Otter, which carries a full array of particle probes (Figure 2). The laser produces 5mJ pulses at 80Hz. The Gaussian pulse FWHM is ~ 90m. The lidar, which has been designated TODWL, is unique in that its scanner is mounted in a side door (Figure 3) and allows the beam to be pointed with two degrees of freedom. In this way, vertical soundings of the wind profile can be obtained from above and below the aircraft. By pointing the beam forward, winds and aerosol signals can be correlated with the data from the particle probes. By dwelling at fixed nadir angles looking down, long time series of surface returns at fixed angles can be collected.

The aircraft is unpressurized and has an airspeed between 100 and 150kts below 12000 feet. In addition to the particle probes, the Twin Otter is equipped with two GPS systems, temperature and humidity probes, a dropsonde system and other aircraft position, attitude and motion sensors. During February and March of 2002, the TODWL collected 15 hours of data during flights over Monterey Bay; San Joaquin River; and the San Luis Reservoir in California and over various wind sounders near Boulder, Colorado. In the next section some examples of the data collected are presented.

3. Preliminary Results

3.1 Water slide

Several sets of experiments were conducted using the water slide shown in Figure 1. The baseline for the water experiments was a set of observations taken with the slide tilted to 45 degrees with no water flow. The dry signal can be seen in Figure 4. The 50mJ, 2μm lidar achieves a return signal of nearly 25 dB from the sanded Plexiglas surface. The return from the air just in front of the target is about 20 dB weaker.

Lessons are being learned as experiments are conducted and thus the current set of experiments must be considered exploratory. An example of returns from water flowing at 45 degrees to the lidar beam is presented in Figure 5. At 45 degrees, the signal from the water is now ~ 8dB above that from the air. What is of more interest in this case is that both the air and water motions (components along the LOS) can be discriminated according to their velocities, with the signal strength being a secondary factor. This velocity discrimination is the basis for algorithms being developed and used with the airborne data.

While a full set of experiments at angles between 0 and 75 degrees of incidence are still to be done, Figure 6 shows some results for a 60 degree incidence angle. In this case the two velocity peaks are tracked as a function of time with the water return more steady than that of the airflow.

3.2 Twin Otter Doppler wind lidar

The TODWL system flew over a variety of surface targets, which, in addition to many vegetated cases, included open ocean, rivers, lakes, wetlands and coastal surf zones. There were two primary sampling strategies used over water. One was to step the scanner in azimuth by ~ 30 degrees while looking down 30 degrees off nadir and to dwell at each step position for 2-5 seconds. This scan provided a wind profile above the water and data from the water surface at a variety of look angles. The second scan pattern was a series of long stares (5-30 seconds), straight ahead of the aircraft, at various angles off nadir ranging from –30 (backwards) to + 50.

In one case, a TODWL sounding from the surface to 6 km (Figure 7) was obtained in close proximity to a sounding taken with the microwave sounder at Fort Ord, CA. This sounding was taken during a series of step stare scans over Monterey Bay that revealed easily detectable water surface returns out to ~45 degrees off nadir (Figure 8). While it is too early in the analyses to draw firm conclusions, other experiment runs confirm the water surface returns beyond 30 degrees. As can be seen in Figure 9, the air and water speeds can be discriminated. This is most apparent when using a sliding range gate technique which shifts the time series (100MHz digitization) by one sample between FFTs (Figure 10).

4. SUMMARY

Both laboratory and airborne experiments have been conducted using 2µm coherent Doppler lidars to study returns from water surfaces. A water slide was constructed and used to conduct a set of experiments at 45 and 60 degrees incidence angles to the lidar beam. Given the short range (~350 meters) from the lidar to the target, returns from the water in the slide were very obvious, even at these high incidence angles. Results confirm assumptions made in the interpretation of lidar data obtained from an airborne system flying over various water bodies in California.

A preliminary conclusion is that using the velocity information, water surface returns can be discriminated from those of the air just above the surface. Most noteworthy is the ability to identify the water return from the Doppler signal long after the intensity of the water return becomes equal to or much less that that from the overlying air.

The ability to detect and measure the water surface velocity may enable the estimation of ocean and river surface motions from a space-based Doppler lidar in the future.

4. ACKNOWLEDGEMENTS

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Water slide

Permits generation of water flows at angles to the horizontal ranging from 75 to 10 degrees

Figure 1 Water slide used to simulate lidar returns from river surfaces

Figure 2 CIRPAS Twin Otter Spring 2002

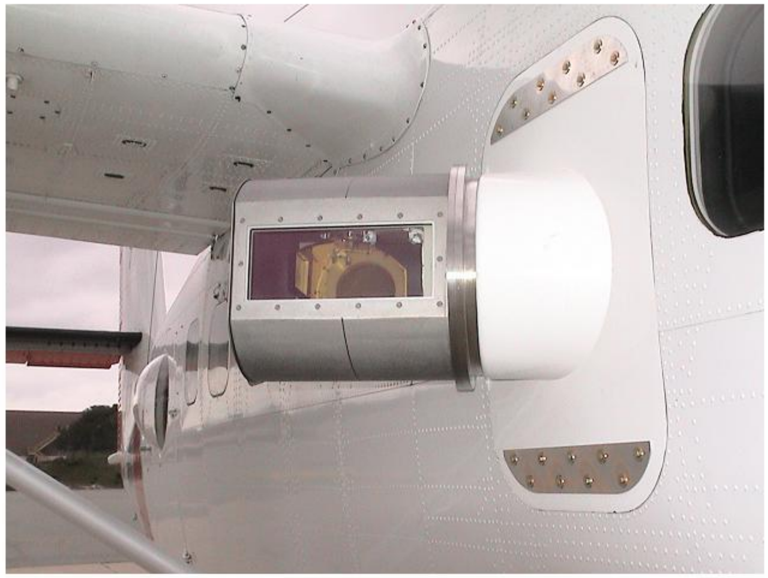

Figure 3 TODWL 2-axis lidar scanner

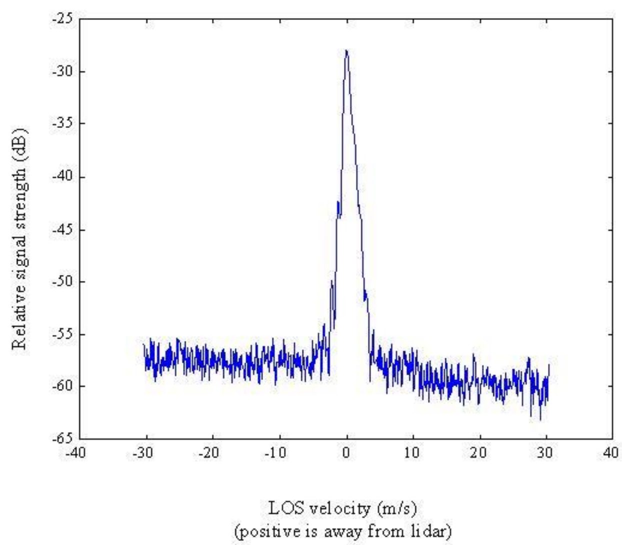

Figure 4 Return from water slide before water flow

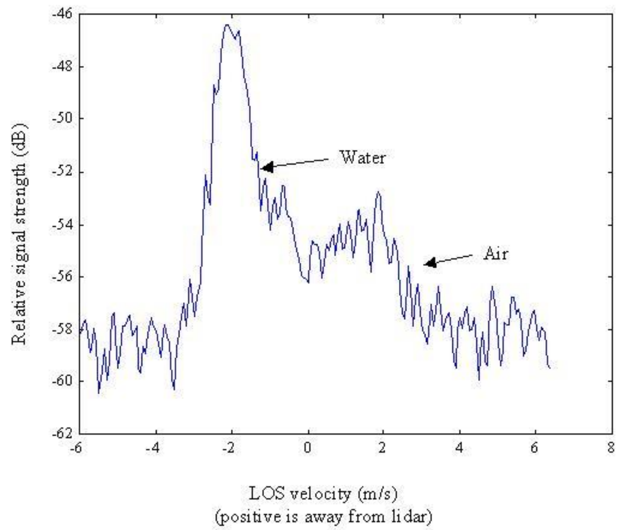

Figure 5 Water flow return at 45 degrees

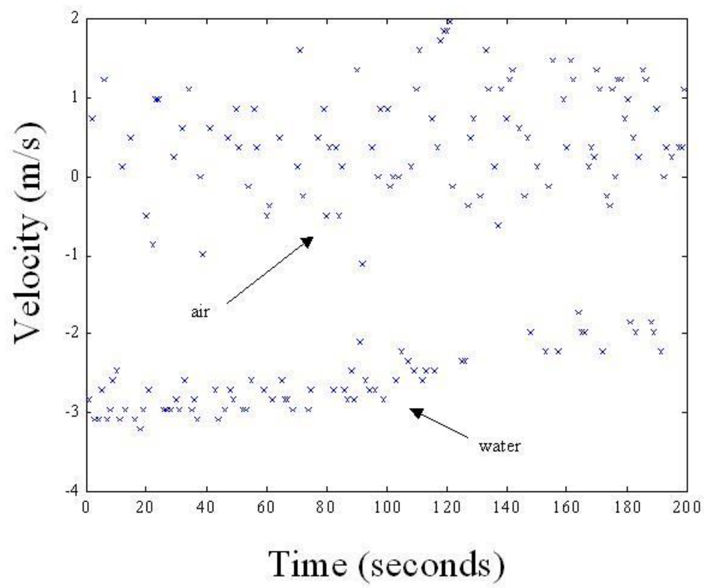

Figure 6 Time series of water and air LOS velocities for slide at 30 degrees

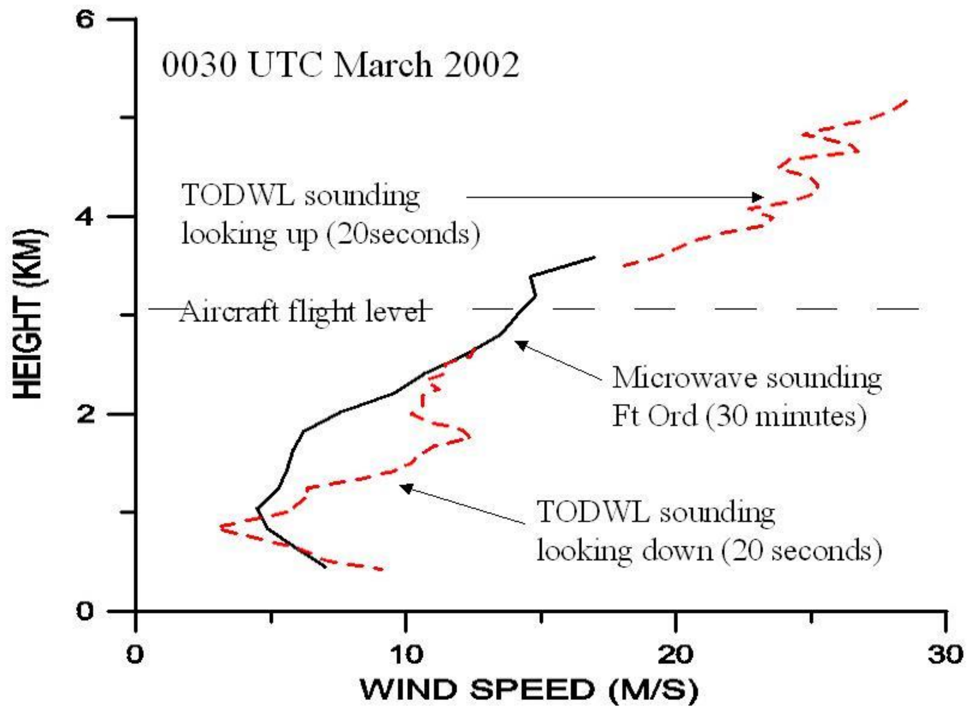

Figure 7 TODWL sounding near Monterey Bay, CA

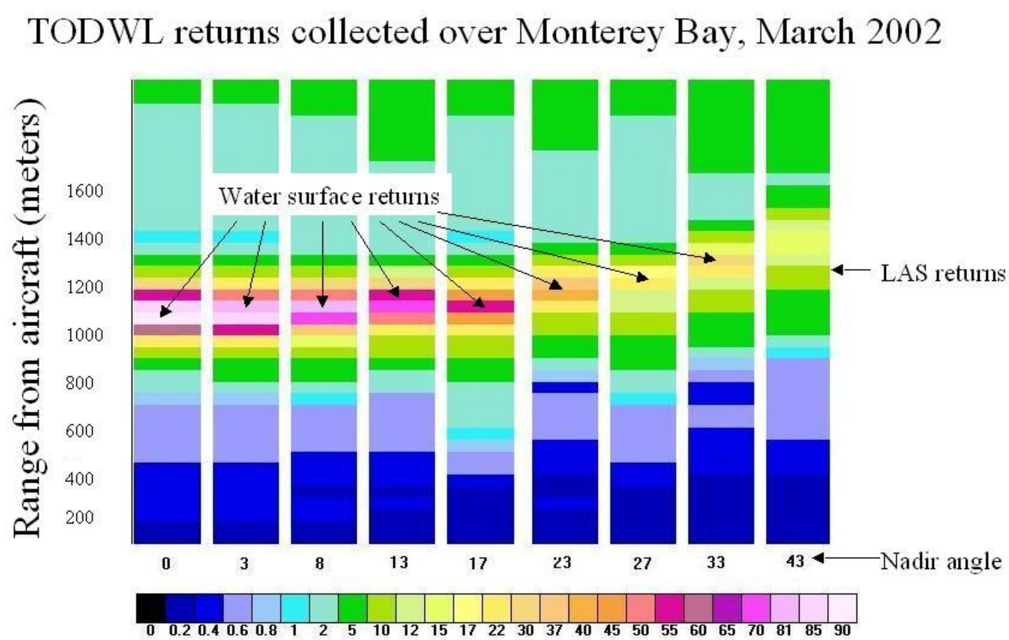

Figure 8 Relative signal amplitude

(range corrected with 400 shot integration)

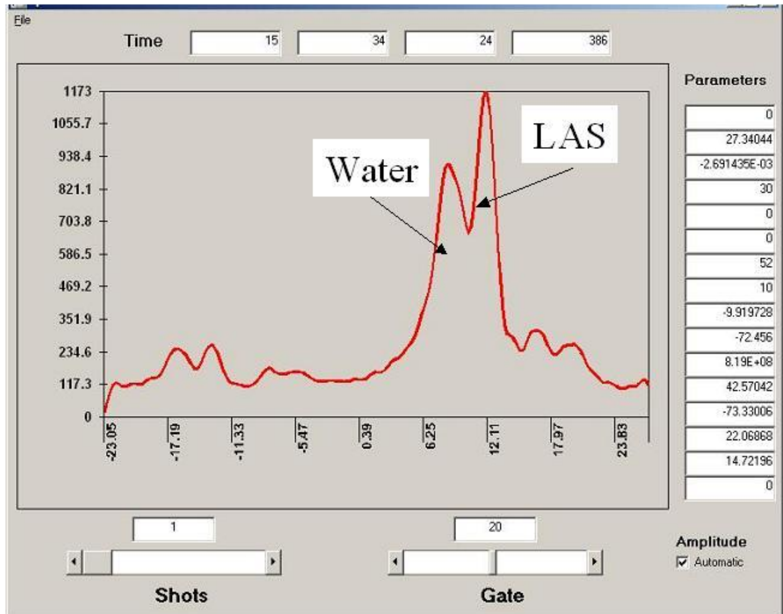

Figure 9 Spectrum for range gate 20 associated with the data shown in previous slide. The data has not been fully corrected for the aircraft forward motion

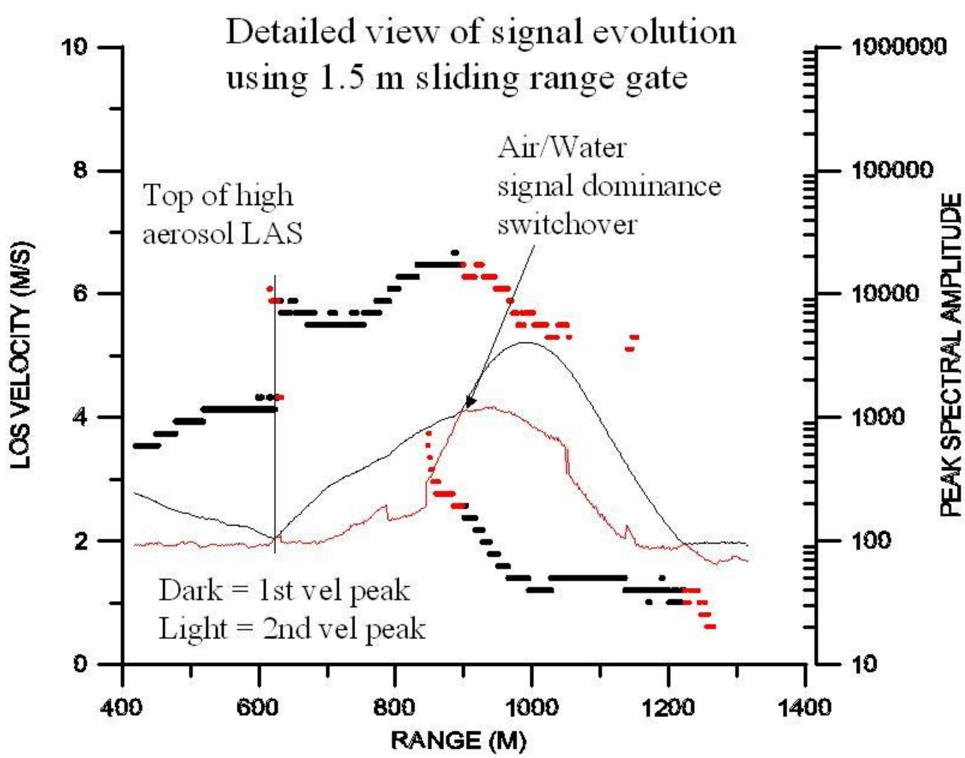

Figure 10 Signal evolution using 1.5 m sliding rangegate