Remotely Measuring Turbulent Coastal Atmospheres

W.P. Hooper,[1] G.M. Frick,[1] B.P. Michael,[2] and R.J. Lind[3]
[1]*Remote Sensing Division*
[2]*Command Support Division*
[3]*Naval Postgraduate School*

Introduction: In April and May 2006, personnel from the Remote Sensing Division conducted joint measurements with Naval Postgraduate School (NPS) personnel in testing the capabilities of a recently developed eye-safe lidar that tracks the movement of large aerosol structures (Fig. 5). The test was conducted at Point Sur, CA, a rugged coastal region 30 km south of Monterey, CA, noted for high winds. In coastal areas where winds and large shoaling waves make in situ measurements difficult, scanning lidars represent a powerful tool for remotely measuring the winds and visualizing the airflow.

Transmitter Design: Scanning lidars have been used since the 1970s to measure winds and map aerosol structures;[1] however, eye-safety issues severely limited the use of these early systems. Powerful optical pulses are required to generate detectable backscatter signals from atmospheric aerosols. Since these pulses can damage the eye's retina, measurements could not be made near airports and in urban areas. This problem has been solved in recent years with Optical Parametric Oscillators (OPO) or Raman methane gas cells, which can convert the optical pulses to safer wavelengths (in the 1.5 μm band) that are absorbed by the eye's humor and can not reach the retina. Now the transmit power is limited not by safety issues but by the conversion process since the highly focused beam required for the conversion process can damage OPO crystals or convert methane to soot.

To increase the output power density of the eye-safe lidars, the NRL system uses deuterium instead of methane or OPO. Unlike the methane cells that require recirculating fans and are multipass, the Raman deuterium cells have no moving parts and require only a single pass to generate a backward-scattered or phase-conjugated beam. When generated by comparable lasers, a phase-conjugated pulse is found to be half the length and one third the divergence of the forward-scattered pulses from OPO crystals or methane cells. Since the photodiode detectors in the 1.5 μm band are only 200 microns in diameter, using a highly collimated transmit beam is important, allowing efficient collection and focusing of backscattered light onto the detector.

Measurements: Airflow by the Point Sur area is often dominated by the turbulent eddies generated by the Point Sur rock, which is 500 m long and 100 m high (Fig. 6). The false-color image shows a horizontal lidar measurement made at the top of the rock. Approximately once a minute, the rock produces a large eddy that travels downwind and vertically mixes aerosols generated by surf zones — these large aerosol structures are not visible to the eye but are easily tracked by a scanning lidar[2].

Figure 7 shows wind observations for the first week of May when the winds changed from a 20 m/s flow from the North to a weak southerly flow and then changed back to a strong northerly flow. This oscillation is typical of airflow in the Big Sur area of the California coast. The false-color image in Fig. 7 shows another horizontal lidar scan. This scan was taken on May 5 when the winds accelerated. The conditions are very different from those shown in Fig. 6. In Fig. 7, the aerosol structures are dominated by kilometer-long roll structures that persist for about 6 hours.

Summary: The NRL scanning lidar is a powerful remote sensing tool for characterizing winds and airflow in maritime areas. During comparisons with the NPS measurements, lidar wind speeds and direction measurement errors were less than 1 m/s and 5 degrees, respectively. Since our system has been validated as eye-safe by the Navy's Laser Safety Review Board, the lidar can be used near airports and in urban areas. Field tests have already been conducted along the Chesapeake Bay and in Washington, DC. The deuterium Raman cells (designed, built, and tested at NRL) have been used for over a year and have not required any maintenance. A key future step of this research is to produce a compact, autonomous lidar system for remotely mapping wind fields from Navy ships.

[Sponsored by ONR]

References

[1] W.P. Hooper and E.W. Eloranta, "Lidar Measurements of the Wind in the Boundary Layer: the Method, Accuracy and Results from Joint Measurements with Radiosonde and Kytoon," *J. Cli. Appl. Meteor.* **25**, 990-1001 (1986).
[2] W.P. Hooper, J.E. James, and R.J. Lind, "Lidar Observations of Truculent Vortex Shedding by an Isolated Topographic Feature," *Boundary-Layer Meteorol.* **80**, 95-108 (1996).

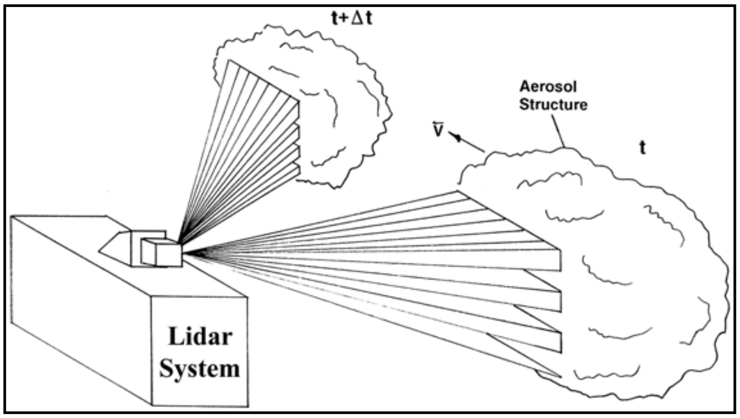

FIGURE 5
The lidar scans back and forth, mapping large aerosol structures (100 m to 1 km) and tracking their movement.

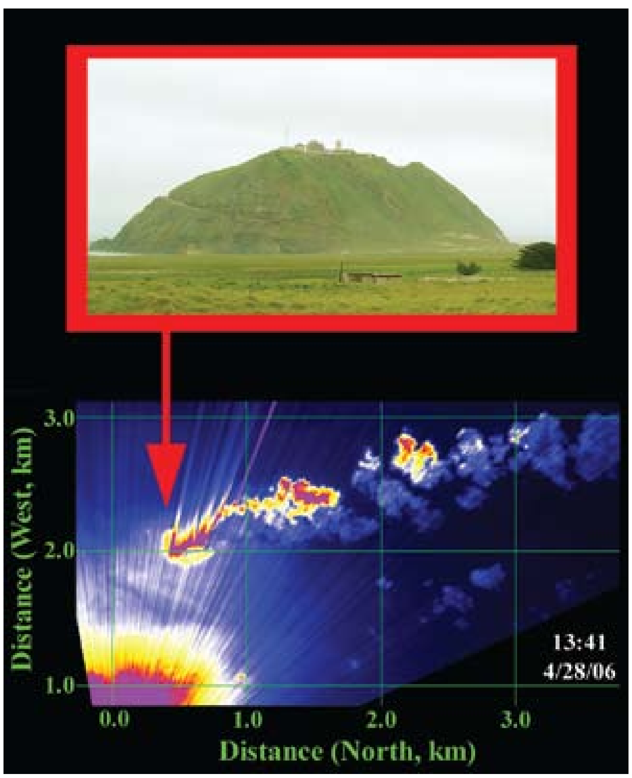

FIGURE 6
The upper image shows the Point Sur rock, and the lower image shows a horizontal lidar scan. The color is related to the aerosol backscatter. Purple and red are the strongest returns; blue is the weakest. The rock generates eddies that move towards the North (upper right). The rock location is denoted by the red arrow.

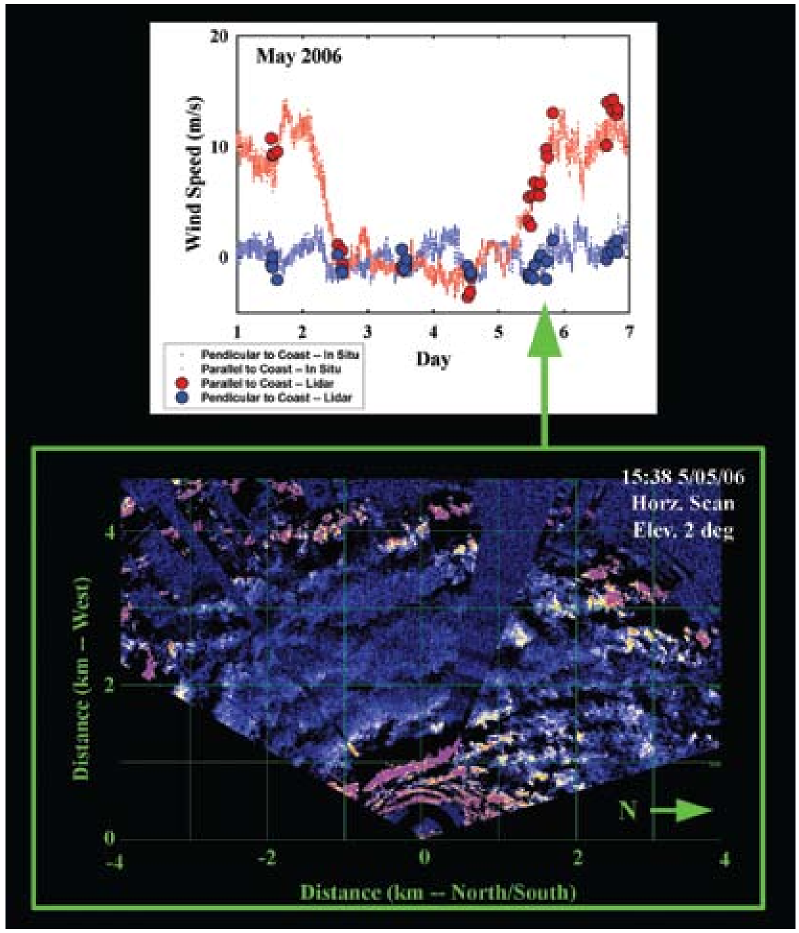

FIGURE 7
The upper plot shows lidar (large dots) and in situ wind measurements (small dots). The red shows the wind parallel to the coast and the blue wind perpendicular to the coast. During the first week of May, the winds decrease in speed and reverse (on May 2). Three days later, the winds reverse and increase in speed. The lower plot shows a false color image of the roll structures that are generated when the flow accelerates (the green arrow denotes the time in wind speed plot).