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Lidar Observations of Thermal

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Doppler Lidar Observations of an Atmospheric Thermal Providing Lift to Soaring Ospreys

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Abstract

Vertical wind measurements are presented of an atmospheric thermal in which ospreys (*Pandion haliaetus*) were soaring. These observations were made with a Doppler lidar, allowing high spatial and high temporal resolution wind profiles in clear air. The thermal was generated at the onset of a cloud bank, producing a rolling eddy upon which ospreys were seen to be riding. A determination is made on the size and shape of the thermal, wind speeds involved, and the altitude to which the birds could have ridden the thermal.

1. Introduction

Raptors in soaring flight take advantage of upward drafts of air to maintain altitude with minimal flapping. One source of updraft, called a thermal, is generated by differential heating of the ground. A circular eddy results of warm air flowing upwards and cool air flowing downwards. In the atmospheric condition described here, the differential heating is associated with the abrupt transition from a clear sky to a partly cloudy sky. At this interface of clear sky to cloudy a thermal was generated on which ospreys were observed to be riding.

Understanding the structure of a thermal can provide insight into how birds exploit these features for soaring, the maximum height to which the thermal may be ridden, and on the strength of wind speeds involved. The characteristics of the thermal may also be of interest to glider pilots and designers of light aircraft such as unmanned aerial vehicles. Previous studies on bird flight and thermals has involved radar analysis of the bird's motion and by aircraft chasing the birds.[1,2] Structure of thermals has typically been inferred in these studies by atmospheric models. The result presented here with a Doppler lidar show a direct observation of much of a thermal's structure.

2. Doppler Lidar

Doppler lidar is an instrument in which pulses of light from a laser are transmitted to the atmosphere to be reflected from aerosols suspended in the atmosphere. This weakly reflected signal is collected by a telescope. The distance from which the reflection occurs is calculated by relating the speed of light to the timing of the transmitted and received pulses. Since the reflection of the light pulses comes from small particles entrained in the wind, the Doppler shift from these particles provides a tracer for the wind field. Doppler lidar is analogous to Doppler radar with the main distinction being the wavelength of the probing pulses—radar operates at long radio wavelengths while lidar operates at short infrared wavelength. An important difference between radar and lidar is that radar is effective for larger targets such as rain drops or a bird, while lidar is effective for very small targets such as micrometer-sized aerosol particles. The use of Doppler lidar for meteorological applications has been under development since its invention in the 1960s, but has not yet found widespread use because of its expense and complexity. Recent innovations in solid-state laser materials has improved the reliability and promoted more use of Doppler lidars.

A unique capability of the lidar reported here is its high output energy for operation to farther ranges.[3] NASA is developing high energy lidar systems for a future installation on an orbiting satellite to provide global-scale wind profiles. The current lack of such global-scale wind measurements is a primary obstacle to improving weather forecasting. As new technologies are developed toward this goal, tests are performed of the lidar's operation by making wind measurements. It was during one of these tests that the measurements described here were coincident.

A key feature in the lidar's design has been to make the output beam safe for ocular viewing. A high level of eye safety is allowed by the wavelength of the laser used at 2050 nm, an infrared wavelength not noticed by the eye. The configuration reported here has an energy density two orders of magnitude lower that the American National Standards Institute's indication of maximum permissible exposure for this wavelength.[4] Furthermore, the narrow beam of the laser is unlikely to be encountered by a bird, and if did occur would be for a very short extent of time as the bird is in motion.

3. Measurement Scenario and Observational Results

The campus of NASA Langley Research Center in Hampton, Virginia USA and the surrounding suburban community is bordered by marshland and tributaries that flow into the lower Chesapeake Bay. Ospreys are often seen in flight as they travel to and from these waters, and the undeveloped acres within the campus are likely habitats for their nests. The Doppler lidar is installed in a mobile trailer that is typically stationed at a site overlooking a marsh in order to stay clear of tall trees that would interfere with the lidar beam.

As shown in Figure 1, the lidar beam was pointed straight up. The beam can be scanned in a hemisphere to build up component profiles to measure the horizontal wind vector, but in this case the beam was fixed at a zenith-looking orientation to only measure the vertical component of the wind. In this configuration the vertical wind component is probed as the horizontal wind advects aerosols and clouds across the lidar beam. A wind data product is produced every 4 seconds with a sample of wind given in increments of 75 m. Due to the reflection of the outgoing laser pulse from optics within the lidar causing the detection electronics to saturate, the lidar is blind within 200 m from the lidar. Hence, the minimum height at which wind can be measured is 200 m.

A vertical wind profile spanning approximately 36 minutes from the afternoon of July 25, 2005 is shown in Figure 2. About ¼ of the way through this data set a band of clouds came through the view of the lidar beam in an abrupt transition from clear skies to partly cloudy skies. Along the interface of this cloud front a long horizontal thermal eddy occurred, through which the lidar cut a cross-sectional view. As this cloud front was visually observed to be approaching, generation of a thermal was anticipated and a 35-mm camera made ready for a record of birds that might take flight. A photograph of ospreys passing over the lidar is shown in Figure 3. The high altitude of these birds made identification of them by plumage or physiology difficult, but the prevalence of ospreys living in the area and the silhouette of the birds pictured here led to the conclusion that these birds were ospreys. Four ospreys were observed flying in the vicinity of the lidar, spread in line parallel to the cloud bank.

The velocity data of Figure 2 allows the determination of the physical dimensions of the thermal. The height of the thermal can be seen as 700 m, and the altitude at which the updraft terminates. Hence, the osprey could have conceivably ridden the updraft to as high as 700 m and maintained this altitude as the horizontal wind pushed the thermal along a northeasterly track (that is, the horizontal wind was from the southwest). The ospreys were observed to circle, but with the circle spiraling out toward the northwest. This direction of travel brought the birds from land to over water.

Determination of the horizontal dimension of the thermal must take into account the duration in time seen in Figure 2 in relation to the horizontal wind speed. The horizontal wind speed at the time the thermal was observed was measured at 4 m/s by a ground-based propeller anemometer. The horizontal dimension of the thermal can then be calculated to be 900 m, and the general shape of the thermal seen to be elliptical with updrafts in the first half and downdrafts in the second half. These dimensions, though, are only the cross-section of the thermal. The thermal is actually a long rolling eddy, with a length probably extending the distance of the cloud bank—many kilometers in this case.

The vertical wind speeds measured show a peak of 3 m/s in both the updraft and downdraft portions of the thermal. The downdraft coupled with the updraft poses the question of if the ospreys use the downdraft to advantage. While the updraft provides a ride for searching for prey, perhaps the downdraft is also used to accelerate descent when diving for prey. Immediately after the thermal seen to be carrying the ospreys, a counter-rotating eddy of smaller dimensions can be seen in Figure 2. More updrafts and downdrafts then follow, but lacking the organized structure of the first thermal. Only this first thermal was seen to be carrying birds.

4. Conclusions

A Doppler lidar has been used to cross-sectionally measure the wind fields of a thermal giving lift to soaring ospreys. The thermal was measured to be 900 m in horizontal extent, 700 m high, and involve wind speed peaking at 3 m/s. Aside from providing lift, the thermal gave lateral motion to the bird as the thermal advected along with a 4 m/s horizontal wind. In the configuration used here the vertical component of wind was probed from a fixed location. Work is underway to develop a version of the lidar that can be installed in an aircraft. From an airborne platform the thermal could be chased to study the propagation and evolution of the thermal.

5. References

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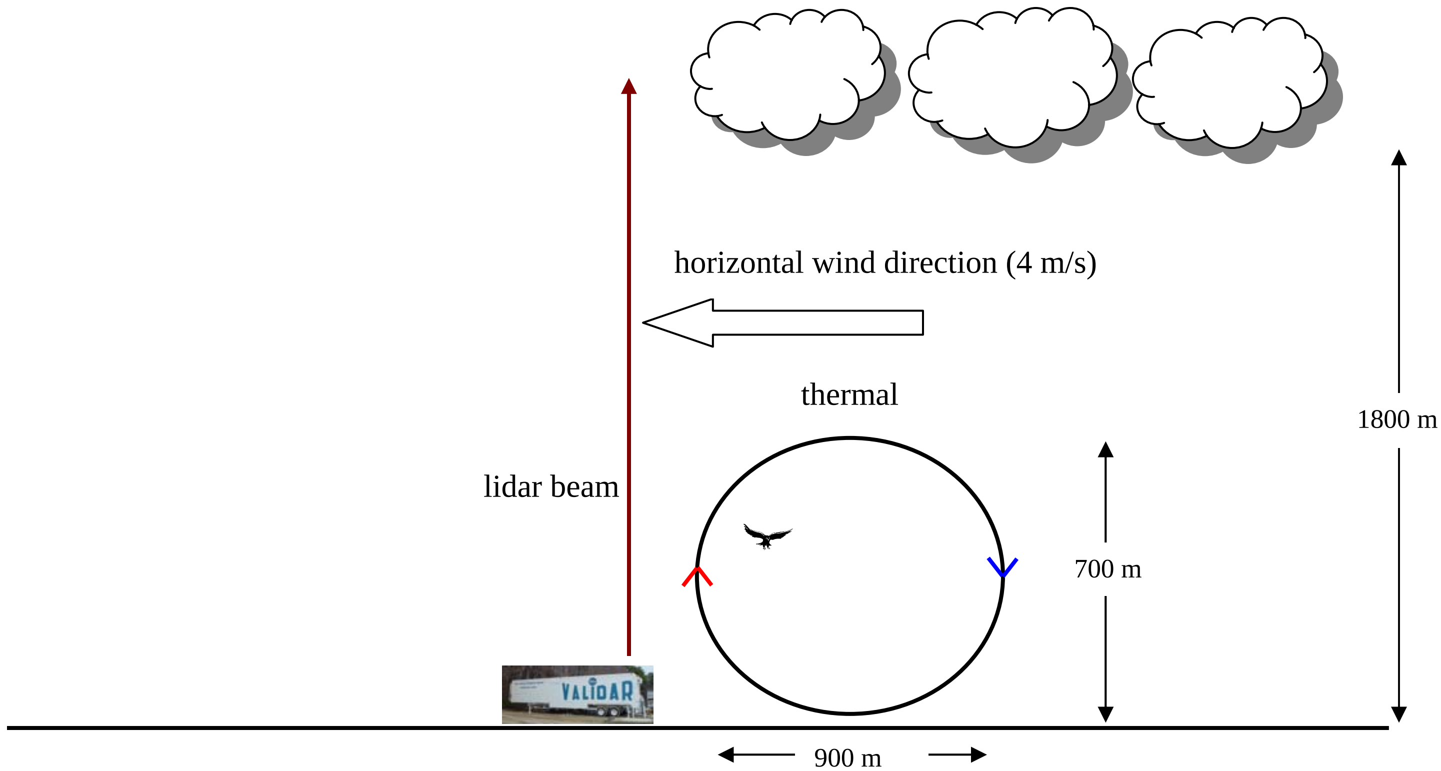

Figure 1: Sketch of measurement scenario. The thermal eddy is pushed along by the horizontal wind, bringing it over the field of view of the lidar. The labeled dimensions of the thermal are derived from the data of Figure 2.

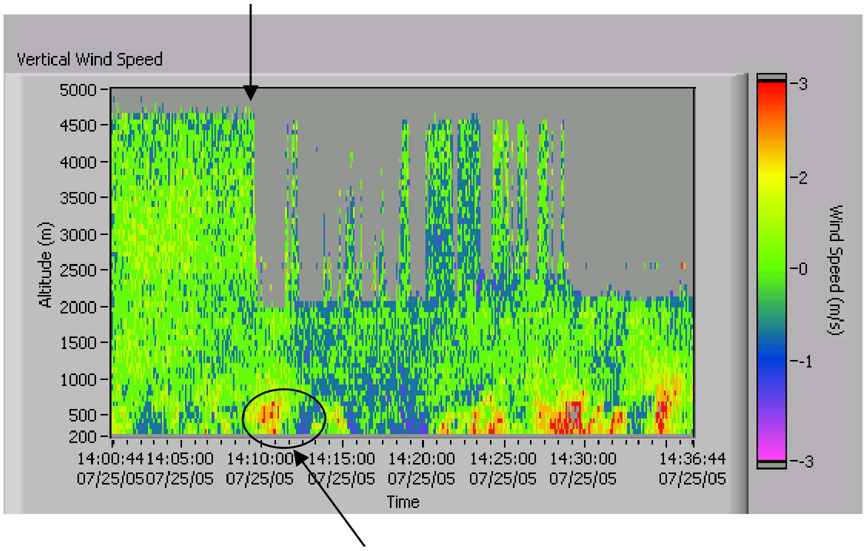

Figure 2: Vertical wind profiles measured with Doppler lidar. A change in cloud conditions occurred at 14:10 local time, creating a thermal eddy. A change in the turbulence at low altitudes can be seen before and after this transition.

Figure 3: Photograph of two ospreys circling in the vicinity of the lidar. Photograph was taken with 300 mm focal length lens, and the resulting small image of the birds even with such a zoom suggests their high altitude of flight of several hundred meters.