Development of a Compact, Pulsed, 2-Micron, Coherent-Detection, Doppler Wind Lidar Transceiver; and Plans for Flights on NASA's DC-8 and WB-57 Aircraft

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Abstract
We present results of a recently completed effort to design, fabricate, and demonstrate a compact lidar transceiver for coherent-detection lidar profiling of winds. The novel high-energy, 2-micron, Ho:Tm:LuLiF laser technology developed at NASA Langley was employed to permit study of the laser technology currently envisioned by NASA for global coherent Doppler lidar measurement of winds in the future. The 250 mJ, 10 Hz compact transceiver was also designed for future aircraft flight. Ground-based wind profiles made with this transceiver will be presented. NASA Langley is currently funded to build complete Doppler lidar systems using this transceiver for the DC-8 and WB-57 aircraft. The WB-57 flights will present a more severe environment and will require autonomous operation of the lidar system. The DC-8 lidar system is a likely component of future NASA hurricane research. It will include real-time data processing and display, as well as full data archiving. We will attempt to co-fly on both aircraft with a direct-detection Doppler wind lidar system being prepared by NASA Goddard Space Flight Center.

1 Motivation

The global measurement of horizontal wind profiles from space has been strongly endorsed by the National Oceanic and Atmospheric Administration (NOAA), the Integrated Program Office-National Polar-orbiting Operational Environmental Satellite Systems (IPO-NPOESS), the United States Air Force (USAF), and the National Aeronautics and Space Administration (NASA). Recently, the National Research Council (NRC) included the wind mission as one of fifteen missions recommended for NASA implementation in their earth science decadal survey (DS)[1].

After much study, NOAA, NASA, IPO, and the NRC agree that the sensor for the wind mission should be a hybrid Doppler wind lidar (HDWL) comprising a pulsed coherent-detection Doppler wind lidar (CDWL) at 2 microns and a pulsed direct-detection Doppler wind lidar (DDWL) at 0.355 microns. Within NASA this laser and lidar technology is being develop at Langley Research Center (LaRC) and Goddard Space Flight Center (GSFC), respectively[2].

2 Space-Based Wind Measurement Requirements

NOAA and NASA scientists have worked together with academia to develop wind measurement requirements for the two missions endorsed by the NRC DS: the science demonstration mission, and the operational mission. NASA and NOAA lidar technologists participated in the process to eliminate uncertainties in the meaning of the requirements. These comprehensive requirements are published in a NASA report[3].

3 Computer Simulation of Space-Based Wind Measurement

The linkage between the wind measurement requirements and the lidar hardware is a collection of computer simulations at LaRC, GSFC, and Simpson Weather Associates (SWA)[4]. In particular the SWA simulation has a sophisticated model of the atmosphere. It has been used to determine coherent and direct Doppler lidar parameters for the two NRC DS wind missions. Some of the coherent lidar parameters for the first space winds mission are 0.25 J pulse energy, 5 Hz pulse repetition frequency (PRF), and 0.5 m receiver diameter.

4 Coherent Doppler Wind Lidar Technology Development at LaRC

NASA LaRC has been developing coherent Doppler wind lidar technology continuously since the 1980s. The major portion of this effort has been the pulsed, 2-micron, long-pulse transmitter laser. Since 2002 this work has been performed under the Laser Risk Reduction Program (LRRP), a joint program at LaRC and GSFC. The LaRC 2-micron laser development under LRRP has been comprised of advancing pulse energy, pulse repetition frequency, beam quality, electrical efficiency, conductive cooling, compactness, and lifetime. Successes include partially conductively cooled pulse energy of 1.2 J[5], fully conductively cooled pulse energy of 0.4 J[6], pump laser diode array advancement, and demonstration of ground-based wind measurement[7].

5 The DAWN 2-Micron Pulsed Coherent Doppler Wind Lidar Transceiver

The Doppler Aerosol WiNd lidar (DAWN) project at LaRC sought to place the state-of-the-art pulsed 2-micron laser technology into a compact, engineered package for later aircraft flights. DAWN packaged the transceiver portion of the Doppler lidar system using conductively cooled pump laser diode arrays and a liquid cooled laser rod (partially conductively cooled). The transceiver of a lidar system comprises all transmit and receive optics except for the telescope and scanner. (see Figure 1 below) The completed DAWN transceiver, shown in Figure 2 below, is approximately 15 x 29 x 67 cm, and has a mass of 34 kg. It currently produces 0.25 J pulse energy at 5 Hz PRF. It will soon be capable of 10 Hz.

The DAWN transceiver was transported to the LaRC VALIDAR (VALIDation LIDAR) and aligned with the existing 15 cm off-axis, reflecting telescope and full hemispheric scanner. With no internal alignment needed, it measured winds in Hampton, Virginia to greater heights than previously seen. As part of a separate NASA project, DAWN and VALIDAR were transported to Beltsville, Maryland for intercomparisons of wind measurements with GSFC's Doppler lidar and with other sensors. The DAWN transceiver did not need any re-alignment after the highway trip. It performed very well and could be left unattended for long periods of time. Figure 3 shows both horizontal and vertical wind profiles vs. altitude for an unattended 14 hour period on March 11-12, 2009. The abscissa is time and the ordinate is altitude from 0 to 7500 m for all 4 data panels. From top to bottom the data panels are horizontal wind speed, horizontal wind direction, vertical wind speed, and vertical signal power. The horizontal wind profile is measured using two orthogonal azimuth angles and a 45 degree elevation angle. The vertical wind profile is measured with a third zenith direction. The wind data are plotted with 3-minute shot integration times to obtain a profile. The 14 hours of data contain about 280 of these wind profiles.

LaRC is currently busy developing lidar systems using DAWN for the DC-8 and WB-57 aircraft. Co-flights with GSFC's direct detection Doppler lidar are planned.

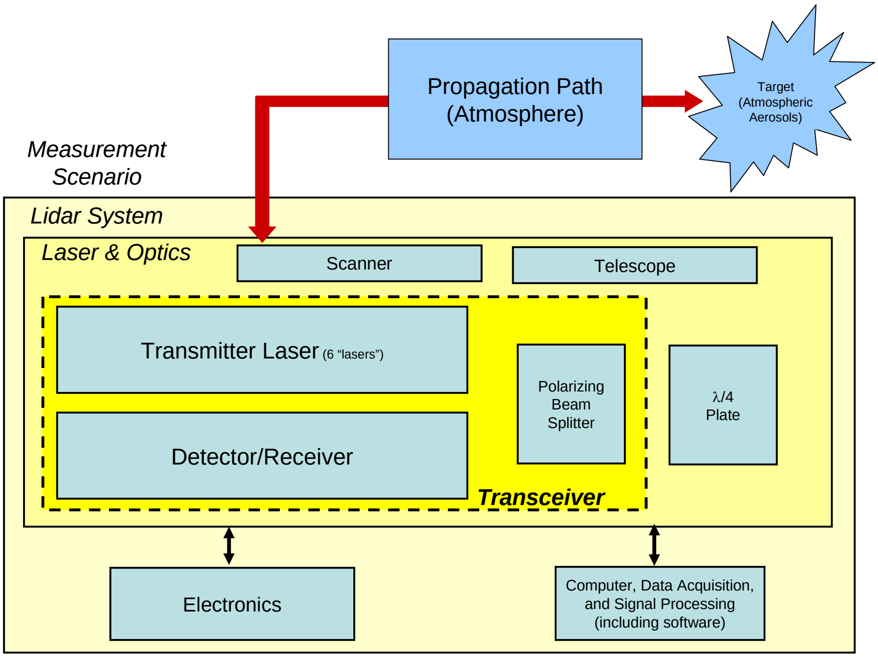

Figure 1. Diagram showing transceiver portion of lidar system addressed by DAWN

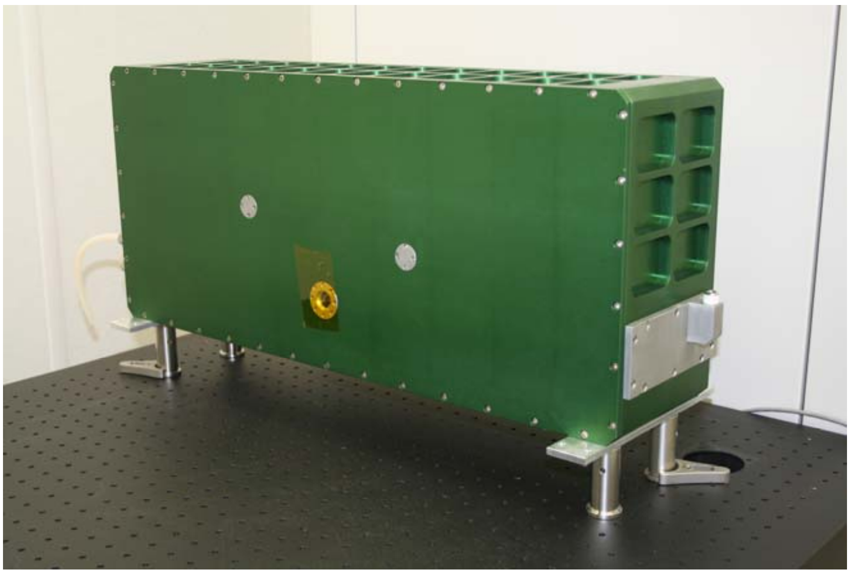

Figure 2. The DAWN pulsed, 2-micron, coherent Doppler wind lidar transceiver

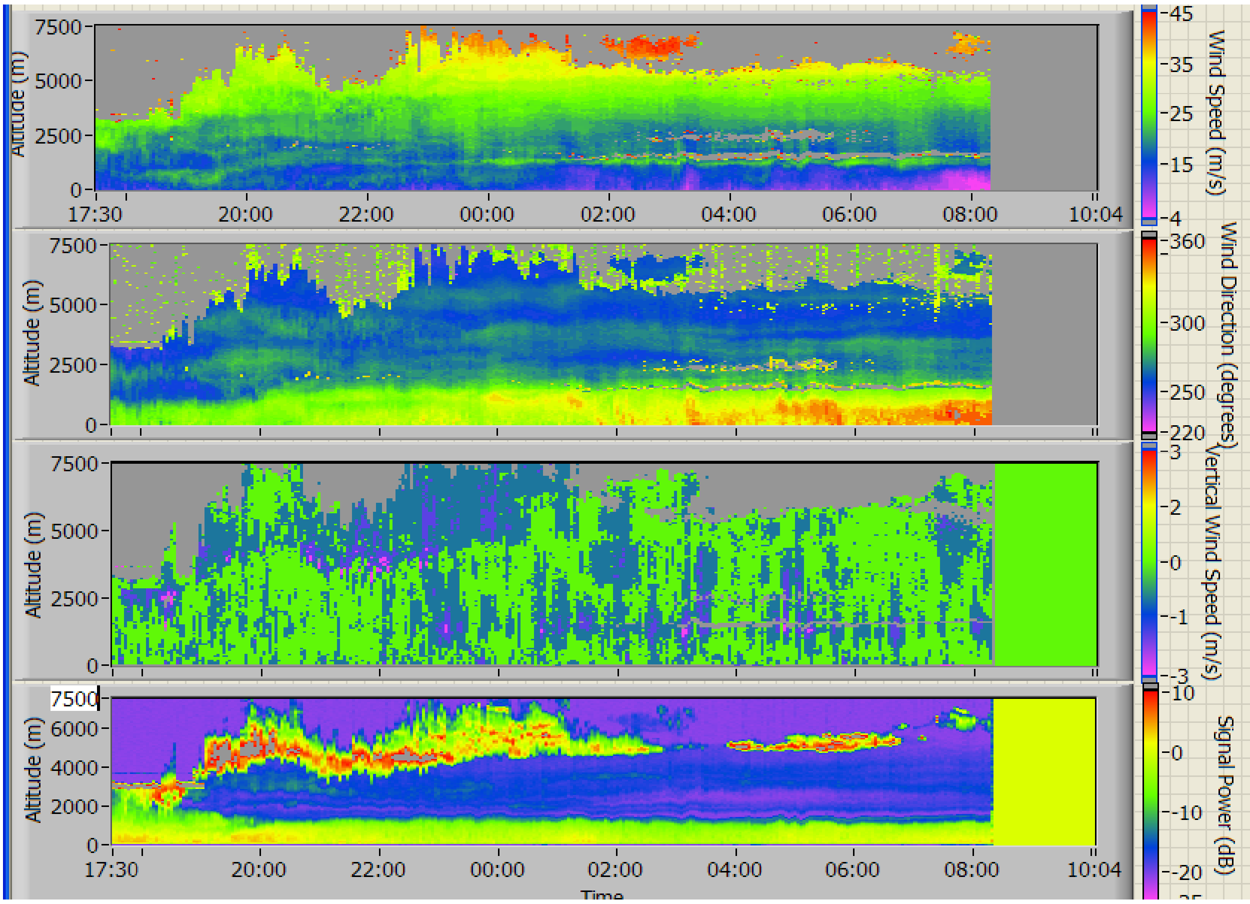

Figure 3. DAWN-VALIDAR horizontal and vertical wind data over 14 hours and with unattended operation

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