COMPACT, ENGINEERED, 2-MICRON COHERENT DOPPLER WIND LIDAR TRANSCEIVER

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Abstract

A new project, selected in 2005 by NASA's Science Mission Directorate (SMD) under the Instrument Incubator Program (IIP), will be described. The 3-year effort is intended to design, fabricate, and demonstrate a packaged, rugged, compact, space-qualifiable coherent Doppler wind lidar (DWL) transceiver capable of future validation in an aircraft and/or Unmanned Aerial Vehicle (UAV). The packaged DWL will utilize the numerous advances in pulsed, solid-state, 2-micron laser technology at NASA's Langley Research Center (LaRC) in such areas as crystal composition, architecture, pump diode laser array light coupling, efficiency, cooling techniques, pulse energy, and beam quality. The packaged transceiver will be as close to an envisioned space-based DWL system as the resources and technology readiness allow. Also as resources allow, we will consider a future upgrade to the coherent lidar transceiver to permit simultaneous wind and CO_2 concentration profile measurements. Since aerosol and dust concentration is also available from the lidar signal, and since CO_2 measurement on Mars is the same as air density measurement, there is future potential for a triple measurement lidar system for both Earth and Mars remote sensing from orbit. A key follow-on step after the IIP will be to add a telescope, scanner, and software for aircraft validation. This IIP should also put us in a position to begin a parallel formulation study in the 2006-2007 timeframe for a space-based DWL demonstration mission early next decade.

The Need for Tropospheric Winds

The science and operational communities of the United States (US) and other countries greatly need global profiles of wind velocity for many applications; especially improved weather prediction, greater understanding of climate issues, and mitigation of weather hazards to the population and to commerce. The high value of winds to improved weather prediction is highlighted by the fact that it is ranked as the highest priority unmet measurement by the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO), which is a joint office representing the US Department of Defense (DOD), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA)[1]. A strong case for tropospheric wind profiling from space has been made in the scientific literature[2-6]. Wind measurements have been shown to have a very positive economic benefit to the country[7-8]. NASA has confirmed this priority in its 2006 Strategic Plan[9]. In the Plan, Sub-goal 3A calls for NASA "to improve prediction of climate, weather, and natural hazards," and to provide services to the Nation including "weather forecasting; climate prediction; natural hazard assessment, prediction, and response; and environmental management, including air quality forecasting and land use assessment." Sub-goal 3A also states "NASA also is working to advance radar, laser, and light detection and ranging technologies to enable monitoring of such key Earth system parameters as land surface, oceans, ice sheet topography, and global tropospheric winds that could lead to advances in weather and severe storm prediction."

The Wind Requirements

The wind measurement requirements, in order for the wind observations to be useful through assimilation into computer models, were defined in 2001 by a scientific panel led by NASA and NOAA[10-13]. "Threshold" and "Objective" requirements were listed and were stated to provide a "noticeable" and "significant" improvement, respectively. Recently a NASA convened Laser/Lidar Technology Requirements Working Group has worked to correct errata and to confirm the 2001 requirements and has added a third category of "Demonstration" requirements to guide a demonstration Doppler wind lidar space mission. All three sets of requirements require scanning of the laser beam in order to obtain effective "vector horizontal" wind information. The NASA Science Mission Directorate (SMD) has adopted the expanded requirements. A report from the Working Group should be issued during 2006. Meeting the NASA-NOAA wind measurement requirements from Earth orbit, especially the coverage, resolution, velocity error, and number of simultaneous tracks of horizontal vector wind, is a challenge. These requirements will not all be met simultaneously by any existing or currently planned sensing systems[12].

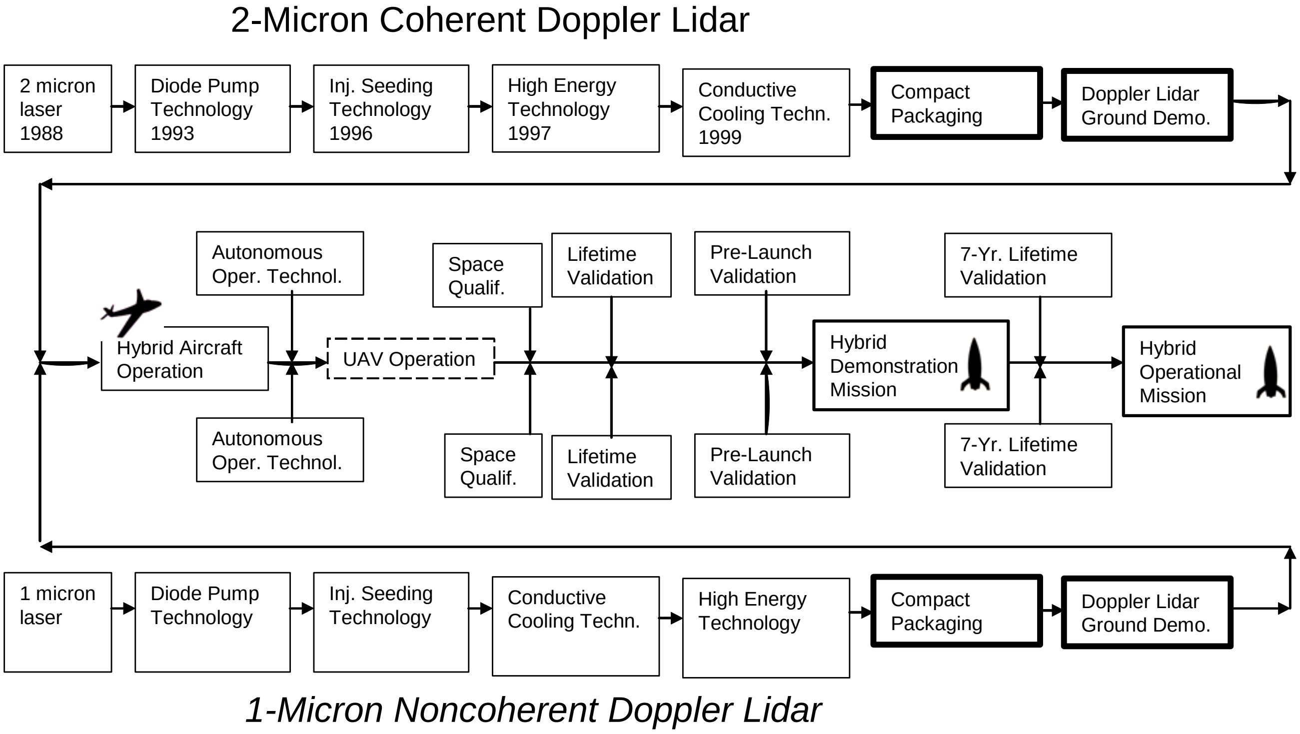
The Technology Solution

The consensus of NASA and NOAA is that the desired vector horizontal wind profile measurements can best be made by a hybrid, pulsed, DWL system; that is, a lidar system consisting of both a coherent (heterodyne) detection DWL system and a noncoherent (direct) detection DWL system working together in a complementary fashion[14]. The coherent DWL would make highly accurate wind profile measurements in atmospheric regions having an aerosol backscatter coefficient above a certain threshold, and in areas with clouds. The noncoherent DWL would make less accurate wind measurements, and would require a larger receiver mirror and higher pulsed laser optical power (pulse energy-pulse rate product), but would obtain data from molecular backscatter in the mid- and upper-troposphere where there are fewer aerosols. Both the coherent and noncoherent Doppler wind lidar technologies have been steadily advanced and demonstrated, and a key milestone would be a space demonstration of vector wind measurement in the near future.

The European Space Agency (ESA) is developing a space demonstration of a noncoherent DWL for launch in 2008, the Atmospheric Dynamics Mission (ADM)[15]. For reasons of cost, risk, and spacecraft accommodations, the DWL will not scan and will therefore not measure horizontal vector winds. Nevertheless, it will provide very valuable information about the performance of the noncoherent DWL technology, and about the atmosphere. Perhaps the information gained about the atmosphere will allow a relaxation of the wind measurement requirements, leading to more mission design options. For now, the US NASA/NOAA requirements require vector winds to be measured at multiple cross-track distances from the spacecraft ground track. This requirement mandates a step-stare lidar scanner that is at least capable of multiple look directions lying on the surface of a cone centered about the nadir direction. It would be prudent to demonstrate space-based, scanning, vector wind profile measurements with both coherent and noncoherent DWL's.

Roadmap to a Space Demonstration Mission

A possible roadmap to a Doppler wind lidar space demonstration mission, and beyond to an operational mission is shown in the figure. Two parallel paths are shown for the development of the coherent and noncoherent technologies and lidar systems. Many of the required steps shown have already been accomplished. Other critical work that has been done in the past, that enables this roadmap and is not shown in the figure, includes theoretical development; computer performance simulation; characterization of the atmosphere; observing system simulation experiments (OSSEs); lidar intercomparisons; aircraft flight campaigns (coherent); 1-micron space lidar altimetry missions (noncoherent); telescope, scanner, and receiver development; and pump laser diode array characterization, lifetime, and improvement efforts. The work to be performed under the recently awarded IIP project is indicated by the two thickly-outlined boxes in the coherent lidar path. Our IIP project will compactly package the LaRC pulsed 2-micron laser technology, and demonstrate the packaged, rugged transceiver through ground-based measurements. The corresponding thickly-outlined boxes in the noncoherent lidar path indicate a second awarded IIP project that will be performed at NASA's Goddard Space Flight Center (GSFC) using noncoherent DWL technology. These paths are shown to merge for the highly recommended step of flying in a high-altitude aircraft to mimic the downward view through clouds from space, to see how the two lidar technologies work together, and to gain experience with the interaction of the technologies in both DWL systems. The roadmap shows a possible UAV demonstration; an optional step indicated by a dashed box. Work should begin as soon as possible on autonomous operation of the DWL systems, lifetime validation, space qualification, and pre-launch validation of both photon sensitivity and Doppler shift calibration. Following this, a space-based demonstration of a scanning DWL collecting vector winds is recommended. Ideally, this would be a hybrid DWL demonstration, but it could also consist of



separate demonstrations of coherent and noncoherent DWL systems. The final goal is an operational mission employing a hybrid DWL. Due to range squared losses for all lidar remote sensing, the orbit height should be as low as possible, perhaps 400 km.

Additional Applications of the Technology

There have been two interesting developments recently that add more applications beyond wind measurement for the pulsed 2-micron laser technology. First, global measurement of CO_2 concentration has become very important for climate change understanding. In principle, using the differential absorption lidar (DIAL) technique, the 2-micron laser can simultaneously measure wind and CO_2 from earth orbit[16]. Furthermore, the laser can emit double pulses with one pulse of each DIAL wavelength, leading to higher concentration accuracy. This had been demonstrated by us on the ground[17-18]. Second, the US goal to explore Mars has led to a need for landing more mass on Mars surface with much greater location accuracy. This leads to a requirement for better characterization of the Mars atmosphere. The 2-micron laser technology is capable of providing wind, dust, and air density profiles from Mars orbit[16]. The air density would be derived from DIAL measurements of the CO_2 concentration, the primary component of the atmosphere (95%).

Conclusions and Acknowledgements

We appreciate the NASA/ESTO funding of this IIP project and we look forward to taking yet one more step towards the enabling of global wind measurement, both for Earth and for Mars.

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