Workshop on Space-based Measurements of 3-Dimensional Winds
February 19-20, 2025, College Park, MD
Summary of Material Presented

Overview

NOAA and NASA hosted the Workshop on Space-based Measurements of 3-Dimensional Winds on February 19-20, 2025. The meeting marked a continuation of the series of meetings of the NOAA/NASA Working Group on Space-based Lidar Winds, renamed for this and future meetings to indicate that the scope of the Working Group has been expanded to include passive as well as active wind measurement communities. Because this was the first meeting of the Working Group in more than 3 years, the workshop was intended to provide an opportunity for the space-based winds community to reassemble and exchange information on recent developments relating to space-based winds measurements. Goals of the workshop were to update the space-based winds community on recent advancements and current status, and to explore future directions for both active and passive space-based 3-dimensional wind measurements from space.

More than 120 attendees registered for and participated in the workshop, which included presentations and discussion on major topics associated with space-based winds. Below we provide a very abbreviated synopsis of material presented at different sessions during the meeting. Presentations along with the meeting agenda can be viewed at https://cires1.colorado.edu/events/lidarworkshop/LWG/.

Current status of a potential US space-based winds mission

In this session, NOAA and NASA representatives provided updates and perspectives on current activities within the two agencies for improving space-based winds.

- Better space-based measurements of 3D Winds remain a high priority within NOAA for improving NWP. However, under current budget restraints and competing priorities, NOAA needs to articulate an exceptionally strong case to justify a winds mission based solely on NWP benefits.
- In NASA, a strong science case to go along with the demonstrated impact on NWP is needed to justify a 3D winds mission needs to be strong. Although better winds measurements would improve the science output for many NASA science goals, a winds-focused mission is not possible without demonstration of a significant scientific return along with strong support across the science and NWP communities. Previous proposed 3D winds missions, which were not selected, focused primarily on NWP benefits but did not demonstrate the necessary science

impact needed to justify funding from NASA. The upcoming Decadal Survey offers an opportunity to strengthen and articulate a broad-based case for a 3D winds mission.

- One potential next step toward a winds mission could be for NOAA to support a mission incubation team to strengthen and broaden support from NOAA NWP as well as articulate a high-impact winds-based science mission that could be carried-out from a space-based platform.

International space-based winds efforts

Given the complexity and potential expense of future atmospheric winds missions, international collaboration on future winds missions would likely provide a higher impact product to the global winds community than that produced by agencies acting independently This session focused on the success of the Aeolus mission and on potential collaboration among Europe, Japan, and the United States.

- The more-than-four-year ESA Aeolus mission was a qualified success, showing measurable positive impact on NWP despite relatively sparse data set and instrument performance below that specified. During the July 2019 – October 2020 best performance period period Aeolus provided slightly more impact than scatterometers and slightly less impact than radiosondes. The Aeolus 1 data were used operationally for daily forecasts by a number of European prediction centers. Aeolus 1 demonstrated that laser and lidar technology could function over a multi-year mission. End-of-life was determined by satellite fuel and solar activity, not by the instrument. Reprocessing of Aeolus 1 data sets is ongoing and has demonstrated that impact could be increased by improving instrument performance and data processing.
- A consistent positive effect of the Aeolus HLOS wind profiles across the range of operational NWP models suggests a significant gap in our current picture of the tropical UTLS flows. According to results from the University of Hamburg, the gap is associated with the underestimation of the vertical shear of the zonal wind in the mean state and wave amplitudes, in particular within the TTL.
- An operational Aeolus 2 mission, to be launched in the 2034 timeframe, is under development to provide 10 years of wind observations. Aeolus 2 will improve performance by addressing primary issues that arose during the Aeolus 1 mission. Aeolus technology development, performance, and lessons learned during the 4-year mission shaped the Aeolus-2 instrumentation and mission designs. The Aeolus 2 design currently includes addition of a cross-polarization aerosol channel for improved aerosol characterization.

- Japan is studying a coherent Doppler Wind lidar mission, assessing different laser technologies at 1.5 and 2 μm. The Japanese cabinet office has revised its basic plan on space policy.

Applications and performance studies for improved 3D winds

In this session, articulation of needs for space-based winds and studies of potential methodologies and instruments to address the needs were presented.

- EUMETSAT is investigating IASI and IASI next generation wind products, anticipating that these products will have good synergy with Aeolus lidar measurements.
- Because winds are gases on the move, a potentially broad, high impact science application of 3D wind data that merits further exploration would be application in computing horizontal transport and fluxes of greenhouse gases, pollutants, aerosols, as well as for mass balance calculations and PBL characterization.
- Improved 3D wind data would be of value to the NOAA Ocean Prediction Center to better understand translation of jets to the surface, identify circulations, and improved calculations of vorticity, temperature, and moisture advection.
- NASA advanced air mobility research, investigating observational requirements for control of 3D airspace, anticipates need for better wind products to improve airspace management for advanced mobility
- A BAE space-based comparison study of the Aeolus 1 direct detection instrument, a notional quadrature Mach -Zehnder Interferometer (QMZI) direct detection system, and a heterodyne system instrument based on a system currently under development, was developed from a NASA GMAO GEOS5 nature run. The simulation included aerosol backscatter coefficients computed from the nature run as well as system performance detriments to performance such as speckle, background light, lack of field widening, alignment and aberration effects, and beam divergence issues. The results indicated that, as expected based on the Aeolus results, the notional direct detection instruments generally could provide good coverage throughout the troposphere, albeit with the need for a large (1.5 m) telescope. The results indicated both advantages and challenges for heterodyne space-based 3D winds measurements, due mainly to issues regarding sensitivity in low aerosol regions and optics/laser technology questions that need to be addressed.
- A JPL study showed that lidar wind measurements (infrequent, unbiased, high vertical resolution) can be exploited to remove biases from AMV measurements. Machine learning appears to have application for applying lidar data for bias correction of AMVs.

- A BAE comparison of Doppler lidar, multi-angle stereo AMVs, IR hyperspectral AMVs, and and Hyperspectral microwave AMVs for LEO indicated that a constellation of hyperspectral IR sounders met NOAA requirements for speed and resolution, and that impact could be enhanced in combination with Doppler lidar.
- Work at the University of Wisconsin demonstrated capability in comparison with dropsondes and Aeolus 1. Optical flow retrievals can be applicable for measuring 3D winds from geostationary sounder retrievals.
- A Simpson Weather Associates analysis indicates the appearance of some convergence on reconciling previous aerosol data bases and measurement campaign results with current model-based outputs from GEOS5. The HALO instrument flying together with the Aerosol Wind Profiler provided the opportunity to conduct backscatter sensitivity evaluations for AWP under a variety of atmospheric conditions. Availability of realistic aerosol backscatter estimates in the G5 nature run simulations enables a more realistic assessment of lidar instrument performance and impact for OSSE studies.

Advances in Space-based Winds Technology

New technology work presented in this session focused on laser development. Improved laser efficiency and stability benefits space-based winds measurements by potentially enabling smaller, lower-mass, higher efficiency instruments with improved sensitivity.

- New Heterodyne laser technology developed at Beyond Photonics for the NASA Langley Aerosol Wind Profiler (AWP) program and demonstrated includes an 11-w transmitter, highly stable seed and local oscillator lasers, efficient beam switching, auto-alignment, and low mass carbon-fiber structure. An improved transmitter under development generates 20 W of laser output with compact design. This transmitter could provide significant improved performance for space-based heterodyne wind system than previous designs studied. The Wind-SP/ AWP systems demonstrated several needed technologies for airborne and space based coherent lidars
- MITLL is also developing new laser transmitters. Cryogenic Ho:YLF offers a large step change in transmitter performance relative to current 2-μm transmitter technology by virtue of fundamentally better materials properties and provides a path to space-based transmitter with better average power scalability (>10X), better energy per pulse capability (lower E_{sat}), and higher electrical-to-optical efficiency (>2X, including power to the cryocooler. Ongoing developments in Tm-doped fibers for pumps and other front-end technology offer further improvements to transmitter technology in push to space. Next step in the development will be to implement

Tm-fiber-pumped cryogenic Ho:YLF laser for coherent Doppler wind lidar transmitter

Application of Airborne instruments in developing and implementing a space-based winds mission

In this session, the importance of aircraft-mounted instruments as a component of space-based missions to demonstrate performance, evaluate hardware, provide data sets for algorithm development, and study the characteristics of atmospheric phenomena at different scales and how they will be observed from space were presented.

- At Langley Research Center, the NASA Aerosol Wind Profiler (AWP) collected data across ~100 flight hours in a variety of geographic locations, wind/weather regimes, and aerosol/cloud conditions to demonstrate instrument performance during the NOAA Joint Venture 3-D Wind Demo and NASA WH^{2}yMSIE/APEX missions. After recent significant improvements to AWP telescopes, the instrument demonstrated the capability to measure aerosol/cloud backscatter and vector wind profiles with excellent reliability, and high precision, detail, and vertical coverage required for a range of weather process studies, especially those focused on the planetary boundary layer (PBL). AWP observations indicate that although aerosols are ubiquitous in the atmosphere, our ability to detect and retrieve winds from them depends on instrument performance and retrieval algorithm choices. Clear discrepancies exist between different model simulations of heterodyne wind lidar space-based performance that need to be understood before judgements can be made about the suitability of heterodyne technology in space. LaRC is building a copy of the AWP transceiver that will enable higher pulse energy (60 mJ at 200 Hz) for use in future airborne campaigns such as NURTURE aboard the NASA 777, while also supporting technology developments and design studies that would enable a path to space.
- Honeywell & NOAA have partnered to explore and investigate HALAS (355 nm lidar characterization of winds, extinction, density, pressure, temperature, water vapor) technology for future satellite applications. A ground base instrument was redesigned for airborne operation from an RQ-4 Global Hawk. A flight campaign is scheduled to begin in March 2025 to demonstrate capability of the instrument to measure atmospheric parameters from an airborne platform.
- The DLR Aeolus Airborne Demonstrator, along with a 2 μm coherent Doppler lidar participated in 4 airborne campaigns to validate Aeolus winds under different conditions. The campaigns were crucial for model-independent validation of

Aeolus winds. Success and impact of the airborne campaigns indicate a strong need to continue this program for Aeolus 2.

- The application of the GEOS-5 nature run to provide aerosol backscatter estimates and optical properties synchronized with weather parameters provides a global distribution of weather and optical properties well-suited to OSSE studies and for comparison with airborne lidar results.