Fall 2020 Meeting of the Working Group on Space-based Lidar Winds
November 17-19, 2020
Online Meeting Hosted by NOAA/NESDIS

Meeting Summary

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Overview

- The Working Group on Space-based Lidar Winds met virtually November 17-19, 2020
- The meeting, which is the latest in a series of meetings dating back to the 1990s, was hosted by NOAA/NESDIS and organized by co-chairs representing NOAA and NASA
- 128 Participants registered for and attended the meeting.
- The meeting included six science/technical sessions, each of which included presentations and discussion
- A total of 30 Science Talks, plus introductory/welcome talks from Vanessa Griffin and Karen St. Germain, were presented (Full Agenda in Appendix B)
- Primary points made in the talks and discussion for each session are summarized below.

Meeting Goals

- Exchange information on recent and planned activities relating to space-based wind observations, with a focus on lidar activities, among government, academia, and industry.
- Review scientific needs and anticipated impact of space-based wind observations to address those needs.
- Investigate concepts for future wind satellite missions.
- Examine the role of wind lidar in future global observing systems.
- Report on latest advancements in technology and retrievals relating to mainly lidar space-based wind observing systems.
- Educate the community on agency plans and programs relating to space-based wind observations and allow community input on those plans.
- Stimulate international collaborations on space-based wind lidar development and implementation.

Welcome talks

- Vanessa Griffin (Director, NOAA/NESDIS Office of Systems Architecture and Advanced Planning) and Karen St. Germain (Director, NASA/Science Directorate, Earth Science Division) presented welcoming talks from the two Working Group sponsoring agencies.
- Ms. Griffin discussed the importance of wind measurements to NOAA, and described the process being followed to develop the next generation earth observation architecture in the 2030-time frame. She noted the importance of cooperation between NOAA, NASA, industry and data users in defining the requirements and shaping the process.
- Dr. St Germain Summary described the NASA Earth Science program status, pointing out the link between current and future NASA priorities and the 2017 Decadal Survey on Earth Science and Applications from Space.

Session 1: Future Science Needs and Applications Motivating Space-based Wind Observations

- Presentations from NOAA/NCEP and NASA/GMAO focused on the need for wind profile observations to fill data gaps in numerical weather prediction (NWP). Previous studies have illustrated the value of current wind (2D) information and impact on NWP, and the potential value of wind profiles from active or passive sources. Trades and benefits from active/passive 3D winds were also discussed, as well their complementarity.
- ECMWF has demonstrated the value of individual classes of satellite sensors on medium range NWP, including the impact of conventional observations, atmospheric motion vectors (AMVs), radio occultation (RO), and infrared (IR) and microwave (MW) sounder data on regional forecast skills in the northern hemisphere, tropics and southern hemisphere. The Forecast Sensitivity – Observation Impact (FSOI) metric was also presented for the current observations assimilated at ECMWF, with focus on sources of wind information including Aeolus. On a per observation basis the impact of winds is generally high.
- NASA GMAO is analyzing the impact of spaceborne global winds from both forecast and science perspective. Studies investigating the forecast impact of Aeolus data show most impact is in the middle troposphere. GMAO is also investigating the impact of AMVs from both sounders and imagers from low earth orbiting and geostationary platforms. Passive approaches are likely complementary to active approaches by improving the horizontal coverage of wind measurements.
- New Observing System Simulation Experiments (OSSE) capabilities, which will be used to address potential impacts of passive and active 3D winds, are under development. Important needs in the OSSE context are good nature run data (realistic aerosol and clouds with adequate temporal resolution/spatial resolution), and accurate forward modeling including error modeling to simulate realistic observations from both lidar-based and passive winds.
- During the panel discussion, the consensus was that a single high-quality/high-cost DWL would in general be preferable to multiple 1 lower quality/lower cost DWLs.

- Additionally, the panel did not see an option where the current global satellite observing system could be degraded to accommodate a DWL; with the sense that DWL woud not gain back loss of forecast skill generally, and that in fact there would be more value complimenting existing sensors with DWL observations.

Session 2: Current Efforts, Concepts and Plans for Wind Measurements

- NOAA has established a Systems performance Assessment Team (SAT) to support NESDIS formulation activities for the next-generation environmental remote sensing programs. The SAT assesses pros and cons of different approaches to measuring key atmospheric variables, including 3-D wind. Both moisture-tracking constellations of sounders and lidar techniques are being investigated for providing the wind product. The process incorporates an advanced systems performance evaluation tool (ASPEN) designed to enable quantitative, detailed, comprehensive, traceable assessment of different options.

- Alternative concepts for an Aeolus follo-on mission have been investigated. More satellites, as well as observations at other times of day, would be beneficial. The current specifications for an Aeolus follow-on mission suggest a similar mission concept with enhanced horizontal and vertical resolution and better observation of aerosol properties.

- The 2017 Earth Science Decadal Survey notes the "transformative" importance of space-borne wind profiles for weather and air quality forecasting, and also identifies areas where wind information is critical for a better understanding of processes and model parameterizations. Winds need to be measured with higher precision, resolution and temporal frequency than previously available. New OSSE studies can be employed to assess impact under more realistic conditions. Suborbital campaigns retain value as comparison sources and to investigate processes and parameterizations.

- Atmospheric Motion Vector (AMV) winds derived from passive sounders are potentially complementary to lidar observations. Simulated measurements employing a nature run are being used to assess AMVs obtained by tracking water vapor and radiances. A potential IR sounder constellation directly tracking radiances utilizing a convolutional neural network is being assessed. A GMAO OSSE showed high impact for both a constellation of IR sounders and a geostationary microwave sounder.

- In Japan, a feasibility study of the performance and impact of an infrared coherent Doppler lidar system on a super low altitude satellite is under investigation. The initial study estimated percentage of coverage of the simulated system throughout the troposphere. A second phase is now utilizing an OSSE to assess the impact of the proposed system.

Session 3: Aeolus Status, Science, and Follow-on

- The Aeolus wind observations have demonstrated significant positive impact in NWP, which has led to operational assimilation at several European Met Centers. This is a great achievement, particularly considering the degraded performance of ALADIN, the first Doppler Wind Lidar in space, with respect to the pre-launch expectations

- The difference in performance levels of Aeolus between laser A and B, and variations with time, provide a good test bed for estimating the necessary performance of future systems to ensure significant NWP impact

- For future Doppler Wind Lidars (DWLs), additional spin-off products such as ocean surface winds and aerosol and cloud products should be considered for use in NWP and air quality forecast models and applications
- Regarding use of Aeolus products in models and analysis
    - Special attention should be paid to error inflation due to observation representativeness versus actual observation errors. Observation error correlations for all observations are important to assess and consider – and are typically low for DWLs
    - It was mentioned that for the Aeolus data analysis, it is important to use re-processed data and apply the recommended quality control (QC) (from ECMWF and available on Aeolus CAL/VAL site). Increased solar background noise in polar summer should be noted, particularly when comparing Aeolus to polar AMV observations.
- Several key results related to Aeolus impact were presented and discussed
    - Aeolus impact on TC track and intensity forecasts is mainly from the adjustment of the synoptic scale flow and increments on top of the storm
    - Model impact is seen above the Aeolus measurement levels due to improved representation of gravity waves
    - Aeolus impact persists into the medium forecast range, in contrast to shorter range AMV impact.
    - Aeolus impact on the temperature and humidity field prediction is also significant.
- AIRS (high resolution hyperspectral IR sounder) motion vector winds provide observations through the troposphere in the arctic (only available at high latitudes due to the orbit geometry). Coverage depends on humidity and ozone levels and their gradients. DWL & IR-sounders are highly complementary.

Session 4: Airborne Campaigns in support of Space-based Winds

- Two wind lidars on the DLR Falcon research aircraft were used in three campaigns during 2018-2019 to perform calibration and validation of Aeolus. Different types of Cal/Val were accomplished and statistical comparison results between the airborne lidars and Aeolus computed.
- Three coherent-detection wind lidars that fly on the Twin Otter, P3, and DC-8 aircraft have been used for research Airborne wind lidars can contribute significantly to the different phases and characteristics of a wind lidar space mission, and also have value for marine atmospheric boundary layer science.

- Scientific objectives and NASA DC-8 instrumental payload for the CPEX-AW campaign planned in July/Aug 2021 from Cape Verde as an US contribution to the Aeolus validation were presented. Examples of virtual flights through models from an international dry run for the campaign were discussed
- Assimilation of airborne Doppler wind lidar observations in the numerical model (HWRF) from observations of a Tropical Cyclone Lane in 2018 were presented. Coverage and impact from both wind lidar vs. the airborne tail Doppler radar showed that the wind lidar provides beneficial additional observations in the boundary layer.
- During the panel discussion the benefit of assimilation of airborne Doppler wind lidar in numerical models as a preparation for future space-borne mission was addressed. In addition, the upscaling of the instrument performance from airborne demonstrations to space-borne lidars was discussed, and the uncertainty in the modelling of the aerosol backscatter profiles as input to performance models and OSSES was addressed.

Session 5: Space-based Wind Measurement Technology

- NASA ESTO investment in Lidar technology was reviewed, and the possibility of a combined active and passive mission for 3-D winds was introduced.
- A free flyer concept from Ball, advancing toward both aerosol and molecular winds was presented. A possible lidar and IR sounder combined mission was also discussed.
- A potential design for a wind Space Pathfinder mission was introduced. A prototype system is scheduled for testing on a NOAA P-3 on a path for an eventual space mission. NASA has supported a number of SBIR awards associated with coherent lidar technology advancements.
- A concept for an affordable constellation of coherent wind lidars was discussed.
- Progress on laser design, specifically the ESTO-funded HEUVD transmitter at Fibertek, was updated.
- Concepts for MISTiC Winds: Mid-wave sounder for temperature & humidity in troposphere, LISTiC: Long-wave sounder for temperature in the troposphere and stratosphere were presented. Leo vs Geo tradeoffs, along with the idea for a combined mission with microwave sounder that could give winds in all weather conditions were discussed.
- Winds derived from stereo viewing (Geo/Geo, Leo/Geo) from visible, IR, Shortwave IR, Longwave IR have been applied for several meteorological applications including studies of hurricanes, stratocumulus in PBL.
- Aeolus has definitively answered the question on feasibility of deploying high energy UV lasers in space, according to technologists in Europe and the U. S.

- Potential implementations of Doppler wind lidars on Smallsats are realistically achievable and is not a significant technology challenge.
- A coherent lidar winds mission would likely provide some benefit for larger-scale numerical weather prediction and/or atmospheric science, particularly at low altitudes and perhaps into the PBL.

Session 6: Moving Forward

- NOAA is looking at how satellites and sensors can be packaged in the most affordable and sustainable way. A number of sensors to meet NOAA requirements, as each sensor type has its strengths and limitations. NOAA is monitoring the status of Aeolus and is learning from the use of the data, in addition to anticipating launch of the EUMETSAT geostationary hyperspectral infrared sounder. NOAA has been and will continue to do OSSEs to determine the most impactful measurements on weather models. Improving the performance of both global-scale (i.e. GFS) and higher resolution mesoscale models (WRF, HRRR) is important, which may require wind measurements with differing resolution and precision in order to be impactful. In its planning for future observing systems, NOAA also needs to consider how models will look in 2030: will we have different models to handle different spatio-temporal scales and domains, or will NOAA be using one unified model? NOAA is and will be working with NASA to augment NASA technology related calls to mature key technologies. NOAA has also augmented the recent Earth Venture Mission-3 call with some funding, and is exploring available technologies from industry via Broad Agency Announcement calls.
- The Decadal Survey is driving NASA's near term research goals. NASA is focused on flexible, science-driven, partner-enabled Earth observing systems to advance 3-D wind science questions from the Decadal Survey. NASA provides a number of funding opportunities to address 3-D winds. The Earth Venture program provides opportunities to test and mature instruments via suborbital and orbital platforms. ESTO Instrument Incubator Program and Advanced Component Technology programs can aid technology development and the Advanced Information Systems Technology program can aid data exploitation. The importance of considering what activities need to be done to fit into an Earth System Explorer mission was stated, such as technology maturation, post-launch data assimilation, retrieval products, and process studies. NASA and NOAA have differences in measurement needs and techniques, and therefore differences must be addressed to effectively plan for a future space-based wind observing system. NASA is willing to discuss partnerships with other agencies, industry, and international partners to advance a 3-D wind mission.
- The EUMETSAT Council has expressed interest in a future operational DWL mission, and have tasked ESA with preparing a roadmap for such a mission. ESA is exploring transmitter, detector, and mirror developments to address current performance and anomalies with Aeolus. An operational mission requires increased robustness, longevity, and interoperability. NWP impact linearly scales with instrument performance, so improved performance for a follow-on Aeolus mission is important.

Increasing Aeolus performance for the follow-on mission will also improve PBL coverage and horizontal/vertical resolution capabilities. ESA is seeking to improve the number of vertical layers and spatial resolution per guidance from the Aeolus Science Advisory Group. The Roadmap study team kicked off in May 2020 and will conduct a final review in February 2022. The goal is to launch an Aeolus follow-on by the end of 2029.

- An industry perspective pointed out what we know at the present time regarding a future winds mission: 1) NOAA wants to field a 3-D wind mission by 2030, 2) DWL technology is mature and ready for space, and builds upon previous investments, and 3) a space DWL will not be a $1 billion mission. Developing an operational wind lidar mission should be a "team sport" between the public and private sectors. The Explorer class Decadal Survey mission has many candidates for observables, including winds, and only one will be selected by 2030. Supporting the NOAA 3-D winds effort should be a near-term priority since they are defining their next-generation space architecture. Because 2030 is not far from now, how do we optimize the technology pieces of a wind mission so that it is ready by 2030.

Final Discussion on Moving Forward.

A lively discussion followed the presentations in the Moving Forward session. The main points presented focused on the current status of lidar winds and steps the space-based lidar winds community should consider in moving forward on a U. S. mission. The discussion was organized around several key questions, with input from the presenters and wind community attendees summarized below:

What steps are required to advance a wind lidar mission aimed at improving NWP?

- We've yet to see the requirement part really flushed out for a mission aimed at NWP. Advocating/asking that this should be the top priority right now.
- If we really want to do this and get this job done, we need to start now.
- It is critical to advocate to Congress whatever needs to get done and make it happen.
- If we're going to satisfy a requirement in 10-12 years from now, we need to ask, where do we need to be in 5 years, in 3 years, in 1 year to accomplish this goal. Timeframe requires delivered approach. "We will do X by date Y to achieve goal Z."
- It is important to establish what we need in the technology and science areas. Will OSSE studies provide information in the correct time frame to make decisions on Wind Lidar, AMVs, etc.? Do we look at this as a significant milestone where output will drive the process? What other activities should be in parallel?
    - For Aeolus, we need the science studies to convince Aeolus follow-on decision makers to continue on.
    - More needs to be done. We should have a predicted performance that can be assessed by NWP centers. Then a buy-in from their side which would go to EUMETSAT.

    - Running an OSSE to demonstrate this impact is more convincing.
        - NOAA OSSE study is quite important. It aims to look at impacts of lidar, AMVs, and explore different aspects of that. Output of this study provides a basis for making the case for these next-generation instruments.
        - It is a first step, but we probably need to look at something more comprehensive when we talk about OSSEs. We're limited by type of Nature Run, etc.
    - It's about documenting the science questions, including NWP, in the sense of what we want to accomplish.
- If this group came up with activities that could be funded by BAAs, would that be appropriate to consider funding?
    - NOAA response: they would be considered.
- NOAA is in the middle of programming for their next-generation architecture. In next few years they'll be requesting budgets for joint ventures (where wind systems would fit). Is there any benefit to this group helping with the roadmap and giving an assessment of potential costs of getting to an operational system based on a set of requirements from NOAA?
    - Joint Venture is separate; it's used to make decisions and work with partnerships. Developing LEO missions (where lidar would be), we're trying to look at product-centric position. First step in LEO is with sounding. We are considering our next steps in LEO or GEO or space weather. 3D winds will likely be a LEO-type mission, with the exception of a hyperspectral IR sounder in GEO. The two orbits could be complimentary.
    - Now is the time to put together the benefits to a particular 3D wind mission, how it would affect the overall NOAA mission (not just atmosphere but ocean, land, etc). this group could do this.
- We need a visionary statement for 3D winds. We will need a map to get there, a gap-closure plan.
    - This is an important action item for the group.

What steps are needed to develop a process-study oriented wind lidar mission?

- How does the WG team up to prepare a winning proposal for NASA 3D winds? What sort of a proposal would likely be funded as an explorer mission in the NASA framework?

  - How can we get this team to work together for a winning proposal? OSSE studies, looking at what NOAA's planning for 2030s. Not sure how to answer this now, after hearing the discussions.
  - NASA framework would be the path forward for a winds mission. Is this the only opportunity NASA could provide, via the Explorer class? Yes, for now.
  - It is possible for an Earth Venture mission as well. Would be shocked if there wasn't an IR sounder/AMV/3D winds proposal that was not submitted to EVM.
    - There is no money on the Explorer wedge right now. EVM has money.
  - Let's keep asking this question.

If there were some funding available to investigate needed activities related to 2030 wind system, what activities would be necessary to be supported?

- Do we need expanded OSSE studies, analysis of Aeolus, technology development, etc.?
- Can we really think about how to do this OSSE study? We should probably use the current observations, assess boundary layer bias in current models and how this would impact the OSSEs is key. This is an issue we haven't been able to address. Perhaps we can add some systematic design to address this boundary layer/surface layer bias in current system. This would be a good start.
- Mike Hardesty will solicit activities from participants here: high level recommendations. Cory Springer did a great job setting framework that's needed. What are the steps we need to move forward, with the goal of providing (a first iteration of) a next-generation observing system in 2030 timeframe?

Summary of key points and recommendations

- Missions focused on improving NWP for the most part have different measurement requirements than those aimed at improving understanding of atmospheric processes. It is probably best to consider these as separate missions for planning and purposes, although a mission aimed at, e.g., NWP will provide useful information for process studies and vice versa.
- It would be very helpful for planning and technology development if more information were available regarding a NWP measurement requirement and vision statement for 3-D winds from space. Upcoming OSSE studies could be focused on defining the requirements for a mission. A careful examination of the goals and specifications for a winds mission is a high priority.
- The Aeolus mission is providing valuable information for evaluation of the impact of future Doppler wind lidar observations and has enhanced US/European collaborations on lidar wind measurements and assimilation. For assessing impact of next generation missions, Aeolus instrument performance can be extrapolated to predict performance of notional wind lidar systems for evaluation in OSSE studies.

- The prospect of an Aeolus follow-on mission scheduled for ~2030 offers the opportunity for an international collaboration in improved 3-D winds observations. This time frame aligns well with NOAA planning horizons for next-generation measurement.
- Given the importance of 3-D winds, planning for a 2030 3-D winds mission needs to start now. Milestones and dates established as soon as possible are needed to outline the necessary steps leading to a mission in 2030. Ideally such a mission would be planned and closely coordinated with efforts in Europe and Japan. Establishment of a Science Traceability Matrix, flowing from the measurement requirements for a winds mission, would help define the needed technology development and performance demonstration to carry out the mission
- NOAA and NASA analysis and OSSE efforts can be helpful in providing the justification for an Aeolus follow-on mission, which would be of significant value to the US. A formal international collaboration would further enhance the likelihood of approval of the Aeolus follow-on
- Near-term funding is critical, through BAAs and other mechanisms, to support technology development and demonstration of wind measurement capability, in parallel with OSSE studies in order to provide space-based wind measurements in the 2030 time frame. Examples of BAA-supported activities that would directly advance the NSOSA 2030 need-date for 3-D winds are
    - Investigation of high-TRL solutions to meet the operational needs for "3D winds" (vertical profiles of horizontal winds) to support numerical weather prediction needs (there is not time for technical development!). A BAA study should describe high-TRL designs that could be launched NLT 2030 and also describe cost/performance options for a complete system (instrument, bus, launch, etc.) derived from this design.
    - Investigation of Missions/Constellations to understand the trades between mission cost (including path to TRL6) and performance in obtaining 3D-Wind observations, as already demonstrated on orbit, or scaled to space.
    - Investigation of technical readiness and performance to understand risks and opportunities for various space-based wind measurement approaches, with clear roadmaps, timelines for each type of technology to reach TRL6, and rough cost estimates for a demonstration mission.
- OSSE studies should investigate the impact of both lidar and sounder-based winds missions as well as the impact of observations from a mission combining both active and passive technology. The OSSE studies could also evaluate the impact of a nominal coherent winds mission for NWP. The OSSE collaboration with KNMI is excellent and should enhance international collaboration on global winds. However, time is of the essence to reach the goal of a winds mission by 2030.

- Government and industry technology groups should provide information on needed technology development and demonstration, as well as costs and milestones, to reach the 2030 mission target. It is important to encourage government industry dialogue to move forward cooperatively on technology development.
- The Working Group on Space-based Lidar Winds can provide a valuable contribution by serving as the focus for a 2030 3-D winds activity. Given the charter from NOAA and/or NASA, the Working Group could work with NOAA to define the requirements and develop a road map/gap closure plan for a space-based wind lidar mission aimed at NWP, and could also organize a team to develop a proposal aimed at a NASA Explorer of EVM mission focused on smaller-scale process studies.
- The Working Group could enlarge its scope to include passive wind measurements with the added goal to specifically look at complementarity and contrast between active and passive wind measurement techniques. Because the International Winds Working Group already has a heavy emphasis on passive AMV wind measurements, the WGSLW should be careful to concentrate on active/passive solutions to avoid duplications.