



The NASA Aerosol Wind Profiler Doppler Wind Lidar, Part II: Airborne Flight Demonstration

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Abstract

The NASA Aerosol Wind Profiler (AWP) instrument, described in Part I of this paper, was flown aboard a NASA Gulfstream-III aircraft during its first two airborne science campaigns based in Hampton, Virginia and central California in September-November 2024. These campaigns were focused on demonstrating how a coherent-detection Doppler wind lidar could address NOAA wind observation requirements, and to observe planetary boundary layer processes to address NASA and U.S. Naval Research Laboratory science objectives in conjunction with High Altitude Lidar Observatory (HALO) differential absorption lidar (DIAL) water vapor and high spectral resolution lidar (HSRL) aerosol profiling. AWP observed a wide variety of weather regimes and phenomena with high detail (66-133 m vertical and 0.6-4 km spatial resolution, scan pattern dependent) and precision (.1 m/s bias, 0.89 m/s uncertainty) over nearly 100 hours of data collection. This is Part II of the AWP instrument description and airborne demonstration paper series that highlights wind profile measurements from Fall 2024 campaign flights and quantifies measurement performance with co-located Airborne Vertical Atmospheric Profiling System (AVAPS) dropsonde and NOAA Global Forecast System (GFS) wind profiles.

1. Introduction

Part I of this paper described the Aerosol Wind Profiler (AWP) instrument, its 3-D wind profile retrieval method, and examples of AWP data from two flights (Bedka et al. 2026). AWP is a pulsed coherent-detection Doppler wind lidar (CDWL), developed through a collaboration between NASA's Langley Research Center (LaRC) and Beyond Photonics, LLC and sponsored by the NASA Earth Science Technology Office (ESTO). AWP generates laser pulses at a 2.053 μm wavelength with a 200 Hz repetition rate and ~ 40 mJ/pulse. AWP uses optical heterodyning with a continuous-wave local oscillator reference laser to detect the intensity of laser light backscattered from aerosol and cloud, and the frequency shift to the backscatter from their motion. AWP directs laser light into two beam expanding telescopes mounted in parallel, one of which directs the light into a prism scanning mechanism that deflects the beam 30° off-nadir for vertical profiling of horizontal wind vectors, while the other beam is directed nadir with respect to the instrument orientation (mounted at a slight angle to compensate for typical aircraft angle of attack) for profiling of vertical wind speed. Horizontal wind profiles measured at $\pm 45^\circ$ azimuths intersect the ground several kilometers away from the aircraft but are merged with the vertical wind measurements to derive 3-D wind profiles. Retrieval processing settings and scanning/sampling settings used at the time of data collection enables profiling of relative aerosol backscatter, via signal-to-noise ratio (SNR), and wind vectors at 66-133 m vertical spacing with variable



horizontal spacing depending on operator-selected dwell time per line of sight (LOS) and aircraft speed.

NASA LaRC was funded under the 2022 “Measuring the Atmospheric Wind profile (3-D Winds): Call for Studies and Field Measurement Campaigns for NOAA/NESDIS” Broad Agency Announcement (BAA, NOAA NESDIS 2022) to demonstrate how a CDWL could meet NOAA wind observation requirements. This project was managed by the NOAA NESDIS Joint Venture program that is designed to work with the private sector, academia, and other federal agencies to explore the feasibility and capability of emerging technologies, spacecraft, and other mission-specific tools to meet NOAA’s mission requirements. In Fall 2024, AWP was flown along with the High Altitude Lidar Observatory (HALO) aboard the LaRC Gulfstream-III aircraft (G-3) in two phases for this demonstration. The first phase, based in Hampton, Virginia from 18 September to 16 October, is referred to here as the NOAA Joint Venture 3-D Wind Demonstration (“Demo”) project. The second phase, based in Santa Maria and Moffet Field, California from 27 October to 15 November, were flights within the NASA Westcoast & Heartland Hyperspectral Microwave Sensor Intensive Experiment (WH²yMSIE) – Active Passive PBL profiling Experiment (APEX). AWP collected data for nearly 100 hours combined across the two phases, sampling a diverse range of atmospheric regimes and environmental conditions. This paper describes 3-D wind profile datasets from the Fall 2024 G-3 flights, validation with Airborne Vertical Atmospheric Profiling System (AVAPS) dropsondes (NSF NCAR, 1993) and comparisons with NOAA Global Forecast System (GFS) model data.

2. Flight Campaign Descriptions

Objectives of the NOAA 3-D Wind Demo project were to demonstrate: 1) AWP wind and aerosol backscatter observations resulting from varied aerosol, cloud, and weather conditions over and offshore of the U.S., 2) the strengths/weaknesses of AWP and how it compares with dropsondes, GOES-16/18 AMVs, and NWP model prediction data, and 3) the estimated space-based performance of a CDWL with AWP-like capabilities (Bedka et al. 2025). Additionally, NOAA project partners demonstrated the positive impact of AWP data assimilation on Weather Research and Forecasting (WRF) model analyses and forecasts (Locke et al. 2026).

Objectives of WH²yMSIE are described by NASA GSFC (2024), and the objectives of the APEX component of WH²yMSIE include: 1) evaluation/validation of passive hyperspectral microwave sounder technology aboard the NASA ER-2 aircraft, 2) creation of a benchmark dataset for active lidar / passive infrared and microwave sounder retrievals of temperature and moisture for the NASA Decadal Survey PBL Incubation program (Texiera et al 2021), and 3) PBL science studies leveraging a combination of HALO and AWP data in conjunction with U.S. Naval Postgraduate School Twin Otter aircraft measurements.

AWP was positioned on the forward of two viewing ports on the G-3, while the HALO instrument was on the aft port. HALO features a four-wavelength differential absorption lidar (DIAL) transmitting near 935 nm for water vapor profiling (Caroll et al. 2022), and a 1064 nm backscatter and 532 nm high-spectral-resolution lidar (HSRL, Hair et al. 2008) for aerosol and cloud profiling. An AVAPS dropsonde system was also installed aboard the aircraft.

A list of flights and their sampling objectives are shown in Table 1. Maps of G-3 flight tracks are shown in Figure 1. NOAA 3-D Wind Demo flight days were chosen based on weather conditions within the ~6-hour endurance of the G-3, as well as aircraft and instrument operator availability. Objectives for two flight days (26 September and 31



October) required an aircraft refuel to extend the sampling duration. Dropsonde operations were limited to flight segments over ocean. WH²MSIE/APEX flight days were based on a variety of factors including ER-2 aircraft availability and weather conditions at Edwards Air Force Base where the ER-2 was based, availability of the G-3 and Twin Otter, and regional weather conditions reachable by the G-3 and ER-2. ER-2 underflights were intended to be absent of high cloud cover to allow IR and microwave sounders aboard the ER-2 to collect the best possible data, as well as to avoid clouds at the G-3 flight altitude that could attenuate the AWP/HALO lidar beams. When clouds were encountered at flight level, G-3 pilots were directed to fly slightly beneath the cloud base.

As described by Bedka et al. (2026), wind retrievals from most Fall 2024 flights incorporate all pulses per at each off-nadir LOS (45° to left and right of the aircraft orientation) with one LOS re-used in the next wind vector retrieval. One second per scan sequence was devoted to vertical motion measurement during these flights, while a variable time duration exceeding one second was used for off-nadir horizontal wind profiling. This decision causes horizontal wind retrievals to have a greater fraction of successful wind retrievals per profile than vertical wind retrieval. For selected flights, namely 8 and 31 October, and 7, 8, 9, 12, and 14 November, half the pulses per off-nadir LOS are used to generate independent wind vector retrievals (i.e. no re-use of an LOS wind profile) to study PBL processes.

Flight Date	Sampling Objective (* Indicates HALO Operations)	Number of AVAPS Dropsondes Released	AWP Dwell Time Per Off-Nadir LOS (seconds)	Duration of AWP Operation (hours)
2024-09-18	Instrument Engineering Check Flight *	1	4-6	2.8
2024-09-20	Airmass transitions across the southeast U.S. and Atlantic Ocean *	4	6	5.0
2024-09-24	Upper tropospheric trough over Nebraska and a severe thunderstorm environment over Kentucky and western Virginia *	0	6	5.0
2024-09-26	Hurricane Helene near-storm environment and steering flow. Two flights, with a refuel in Stennis, Mississippi *	3	6	7.6
2024-10-01	Airmass transition from mid-latitude to subtropical over the Atlantic *	6	6	4.2
2024-10-03	Wildfire smoke plume over New York and Ontario, polar jet stream over Quebec	5	6	3.8
2024-10-08	Airmasses over southeastern Virginia and northeast U.S. major metropolitan areas, overflight of the NOAA Wind Forecast Improvement Project – 3 (WFIP-3) domain	5	3-6	5.1
2024-10-15	Jet stream and upper-tropospheric trough over the northeast U.S.	6	6	4.9
2024-10-16	High pressure system over the midwest and southeast U.S. *	0	6	4.9
2024-10-27	Transit flight from Hampton, VA to Santa Maria, CA *	0	6	5.3
2024-10-30	Stratocumulus cloud morphology transitions over the Pacific west of Baja California, with ER-2 aircraft and ESA EarthCare satellite underflights *	10	6	4.1
2024-10-31	PBL evolution monitoring over Arizona. Two flights, with a refuel in Phoenix. Two flight segments with an ER-2 underflight *	0	3-6	6.1



2024-11-04	Oceanic airmass monitoring, overflight of San Francisco, the Sierra Nevada, and the Nevada Railroad Valley region, with ER-2 and ESA Arctic Weather Satellite underflights *	10	6	4.6
2024-11-07	Oceanic airmass monitoring, Ventura County, CA Mountain Fire smoke plume sampling, with NOAA-21 and ER-2 underflights *	14	2-6	5.2
2024-11-08	Coastal central CA wind, water vapor, and aerosol evolution within the PBL, coordination with the Navy Twin Otter *	0	2-4	5.1
2024-11-09	Coastal central CA wind, water vapor, cloud, and aerosol evolution within the PBL, coordination with the Navy Twin Otter *	0	1.5-4	5.5
2024-11-12	Coastal central CA wind, water vapor, cloud, and aerosol evolution within the PBL *	0	2-4	5.4
2024-11-13	Pre- and post-frontal airmass monitoring over the Pacific west of California, with ER-2, NOAA-21, and ESA EarthCare underflights *	7	6-15	5.6
2024-11-14	Coastal central CA wind, water vapor, cloud, and aerosol evolution within the PBL, coordination with the Navy Twin Otter *	2	1.5-4	5.4
2024-11-15	Transit flight from Moffett Field, CA to Hampton, VA *	0	15	4.1

Table 1: A list of G-3 flight dates, AWP observation duration, flight sampling objectives, dropsonde counts, and AWP dwell time per LOS. Asterisks at the end of the Sampling Objectives indicate that HALO operated during the flight.

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 91
 92

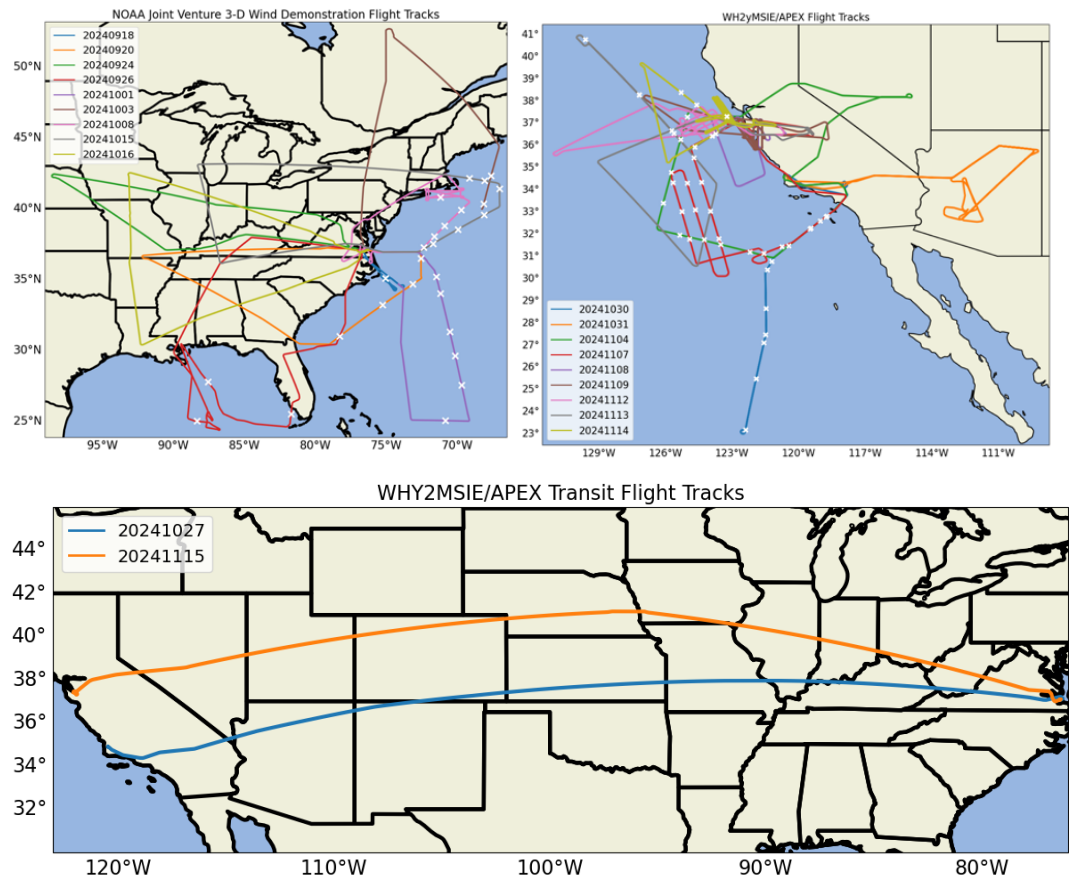


Figure 1: NASA Gulfstream-III (G-3) flight tracks for the NOAA 3-D Wind Demo (left), and the WH²yMSIE/APEX (right) campaigns. Dropsonde locations are shown with white X symbols. Cross-country transit flight tracks for WH²yMSIE/APEX are shown in the bottom panel.

3. AWP Flight Data Examples

Data from four flights are shown in the sections below to highlight novel observations of various weather phenomena and processes. Data from the remaining Fall 2024 campaign flights are shown and briefly described in Appendix A.

3.1. 13 November 2024

The objective of this flight was to coordinate G-3 and ER-2 sampling to the north and south of a decaying cold front over the Pacific, where differing airmasses and wind conditions were present. A corridor of southwesterly lower-to mid-tropospheric moisture transport was just offshore of the San Francisco Bay region and northern California along and to the south the front. The GFS depicted a 250 hPa jet stream north of the front with speed exceeding 70 m/s (Figure 2). A surface low-pressure system was located offshore of British Columbia, resulting in a pressure gradient along flight track and enhanced lower tropospheric wind speeds as the flight progressed northwestward. Wind vectors were retrieved at 7 second intervals (~1.6 km spacing assuming 225 m/s aircraft speed) from 1855-2243 UTC, and 16 second intervals (~3.6 km spacing) during the rest of the flight, incorporating 1 second for the AWP nadir



111 beam vertical motion measurement. AWP aerosol and wind patterns mirror each other from 2000-2100 and 2100-
 112 2200 UTC because the aircraft flew on the same track.

113 The flight departed from Moffet Field, CA and headed eastward over the California Central Valley at an ~8.5 km
 114 flight altitude (Figure 3). The flight then headed westward over ocean and overpassed multi-layered cloud along the
 115 front. AWP was able to penetrate through the upper-cloud layer into aerosol and cloud below. The flight then headed
 116 northwest into a cooler, post-frontal airmass. Near surface wind speed steadily increased as the flight progressed
 117 toward the low pressure system, reaching ~20 m/s after 2040 UTC. SNR was quite high (≥ 200 or 23 dB) beneath 3
 118 km, likely enhanced by sea spray from the strong winds (Figures 4 and 6-right). The wind speed increase occurred in
 119 conjunction with a deeper aerosol layer, deeper convective cells, and increased turbulence in the vertical wind
 120 component, supporting upward aerosol transport.

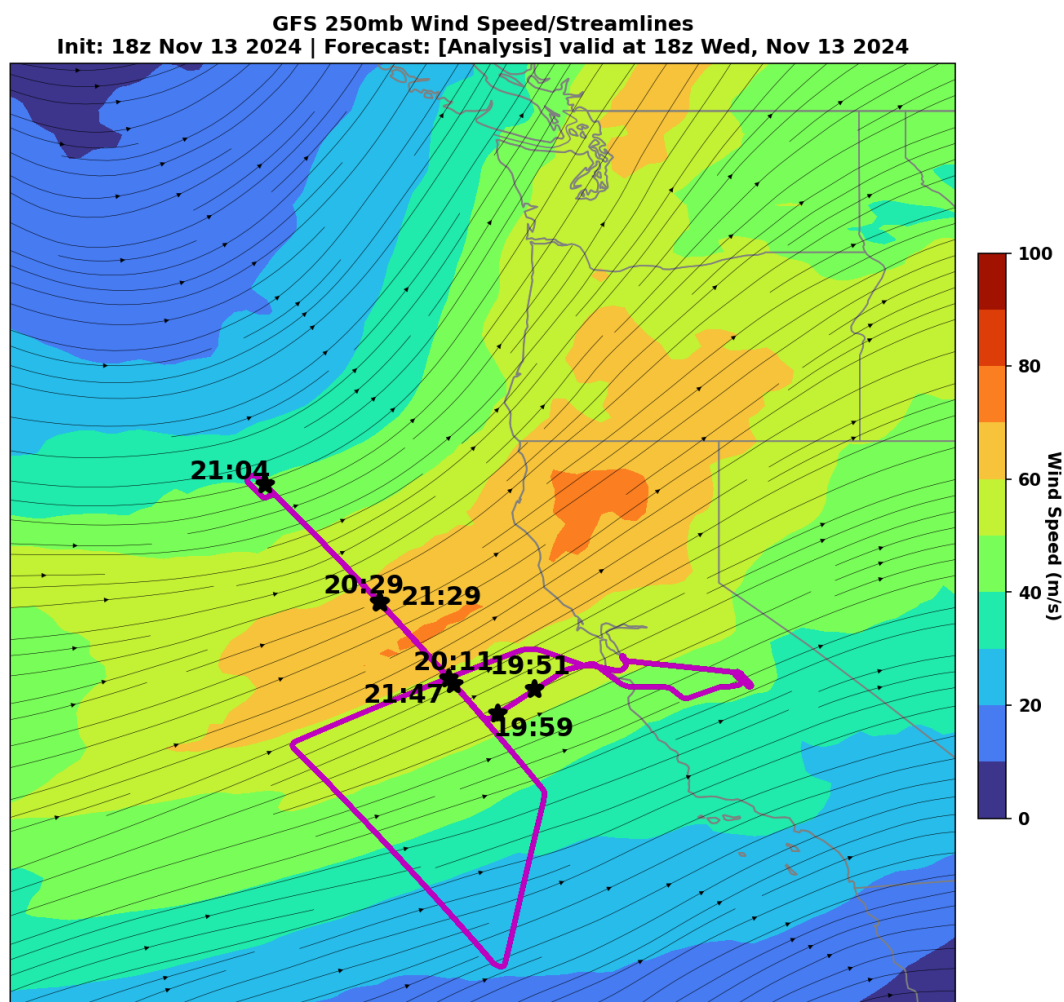
121 A shallow layer of ≥ 65 m/s wind speed sloped downward to 9 km altitude. The 18 UTC GFS tropopause analysis
 122 revealed that this layer resided about 2 km below the tropopause. The greatest AWP SNR observed above a 3 km
 123 altitude was present around 21 UTC, located in the stratosphere, similar to the 15 October flight highlighted in Part I
 124 and the 24 September flight described below in Section 3.2. Layered wind speed and direction patterns are evident
 125 above the downward sloping jet maximum, with speed perturbations exceeding 5 m/s between the layers (Figure 6-
 126 left). Wave-like undulations are evident in the horizontal wind data but are not visible in the SNR data. Such layers
 127 and undulations are unlikely be resolved by any other wind profiling technology other than a lidar. Vertical wind
 128 speed data measured every 6 seconds is dominated by vertically aligned patterns of upward and downward motions
 129 reminiscent of gravity waves that show some correlation with the undulations. As discussed by Bedka et al. (2026),
 130 gaps in successful vertical wind retrieval are caused by reduced signal return from 1-sec integration, compared with
 131 the 6 secs devoted to the horizontal wind measurement. Three comparisons between AWP and AVAPS (Figure 5)
 132 shows that the wind maximum was accurately measured as the flight progressed westward, and later north-westward.
 133 Further discussion of AWP validation with AVAPS is provided in Section 4.1.

134 After crossing the cold frontal cloud band at 2210 UTC, SNR reduced throughout the column, indicative of an
 135 airmass transition. The aircraft headed southwest along an ESA EarthCare satellite track over an opaque stratocumulus
 136 deck. The stratocumulus top height and PBL depth inferred from the sharp vertical SNR gradient was notably lower
 137 than the previously sampled post-frontal airmass, indicative of a change in thermodynamic conditions in the pre-
 138 frontal region. HYSPLIT back-trajectory analysis from a parcel initialized at the very thin 3 km altitude aerosol plume
 139 at 2250 UTC suggests that this airmass resided over the open Pacific Ocean 7 days prior (Figure 7-left), and near
 140 Japan 10 days prior (not shown). The very long-duration transport from Asia could be a source of the thin aerosol
 141 detected by AWP, but dispersion along the 10-day transport also explains the generally clean air in the pre-frontal
 142 airmass.

143 After a turn to the northwest and another traverse across the front, a deep aerosol layer appeared that was thicker
 144 than that observed earlier in the flight. HYSPLIT back-trajectories at 6 km within this plume at 2340 UTC suggests
 145 that it was rapidly transported from the northeastern China and Japan region 5 days earlier and across the Pacific
 146 (Figure 7-right). The jet stream measured earlier in the flight re-emerged shortly before final descent and landing.
 147 Throughout the flight, AWP SNR patterns show excellent agreement with HALO 532 nm aerosol backscatter (Figure



- 148 8). In some cases, AWP detected the presence of aerosol layers with backscatter near to or beyond the minimum
 149 backscatter threshold required for HALO quantitative aerosol intensive property retrieval.



150
 151 **Figure 2: NOAA GFS 250 hPa wind analysis valid at 18 UTC on 13 November 2024, overlaid with the G-3 flight track**
 152 **(magenta) which occurred 1-6 hours after the time of this GFS analysis and dropsonde release locations/times (black**
 153 **stars/text).**
 154

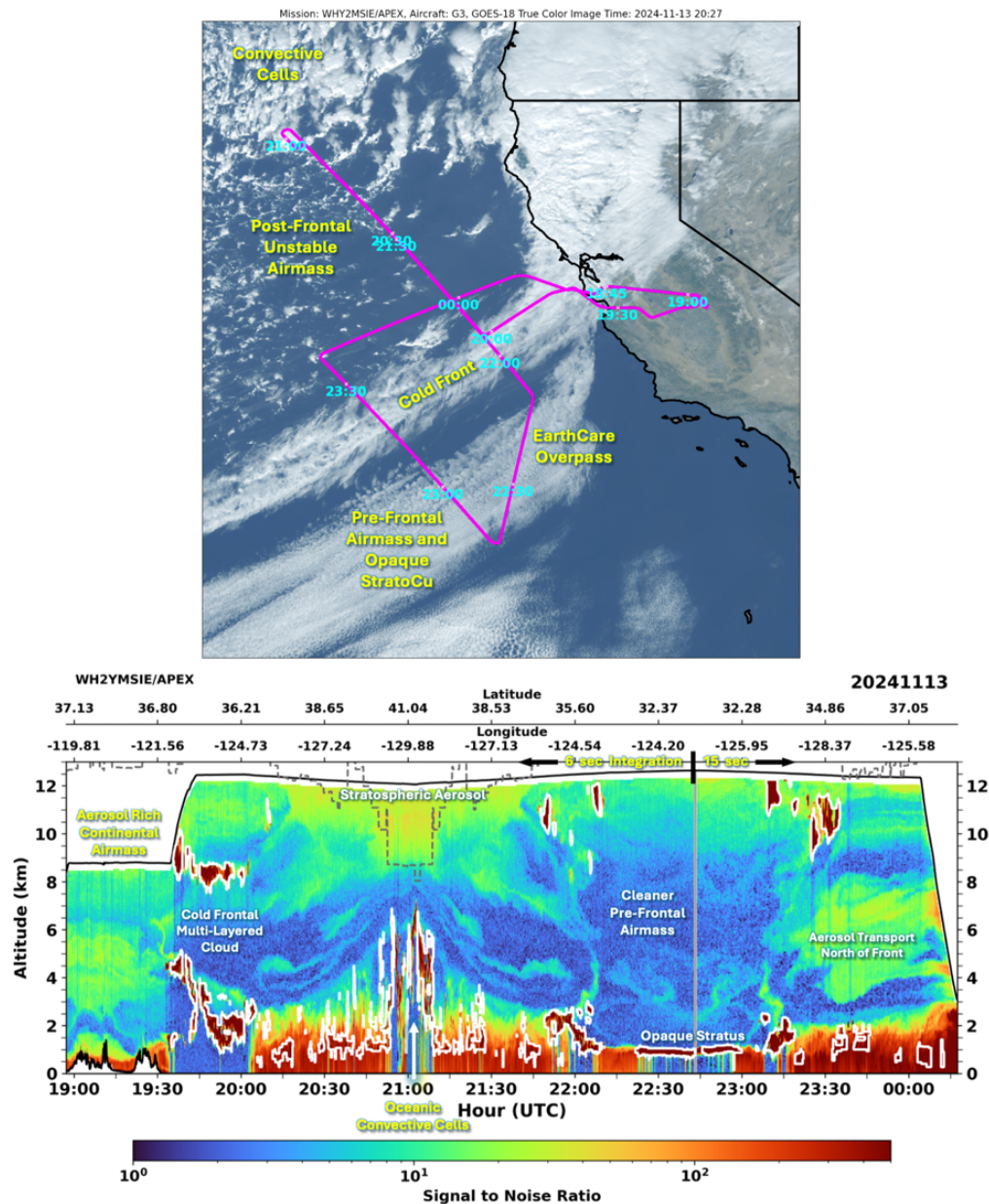


Figure 3: (top) GOES-16 True Color RGB composite on 13 November 2024 at 2027 UTC, overlaid with the G-3 flight track (magenta) and flight time in UTC (cyan). (bottom) AWP signal to noise ratio (SNR). Grey columns in the curtains indicate aircraft turns where wind profiles are invalid or instrument downtime. The grey dashed line indicates the tropopause height from the 18 UTC GFS model analysis. White contours indicate AWP cloud detection. Annotations in both panels indicate various features discussed in the text.

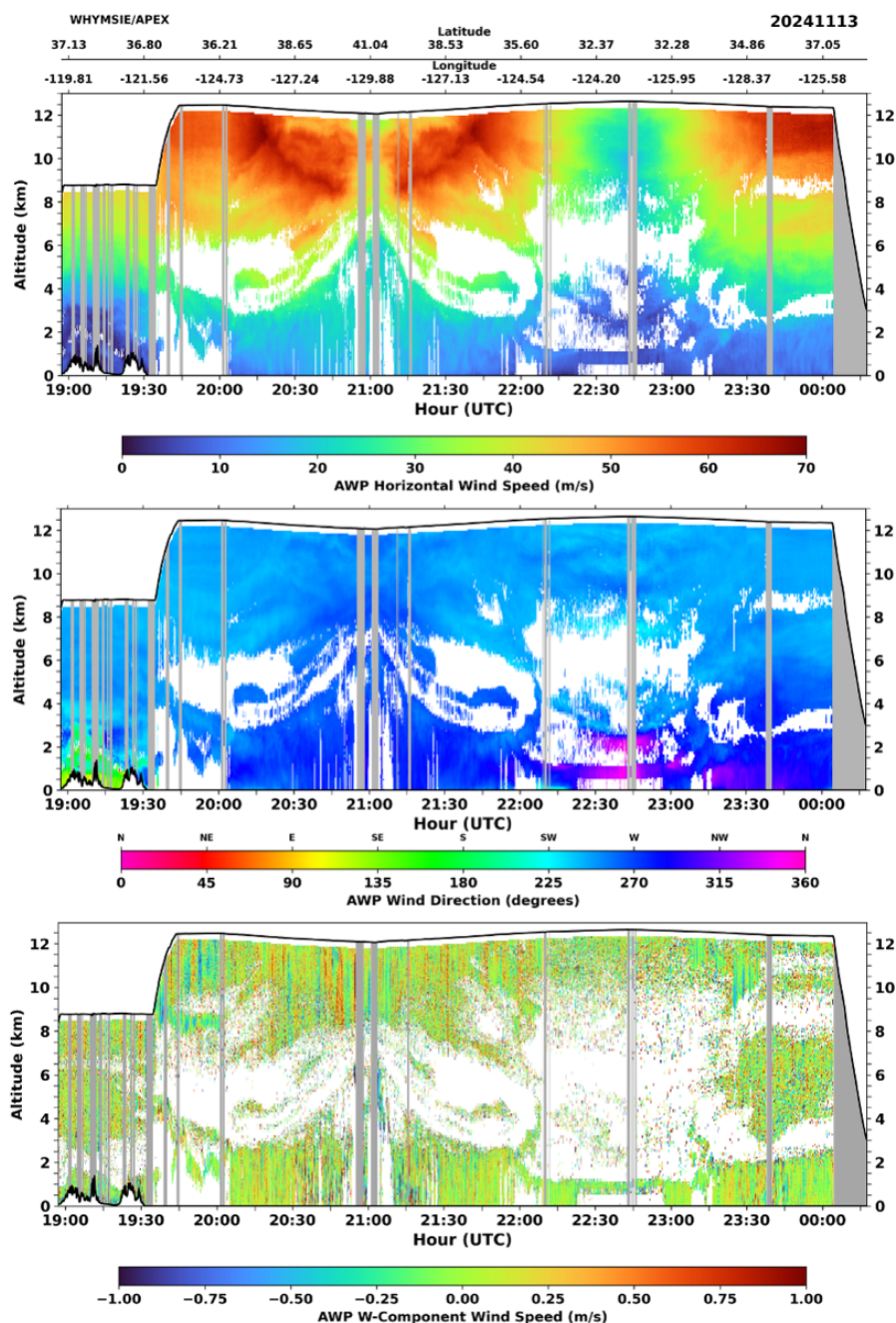


Figure 4: AWP horizontal wind speed, direction (top, middle) and vertical motion (bottom) on 13 November 2024. Grey columns in the curtains indicate aircraft turns or sharp aircraft pitch where wind profiles are invalid. White regions indicate regions beneath opaque cloud or where aerosol backscatter was insufficient for a wind retrieval.

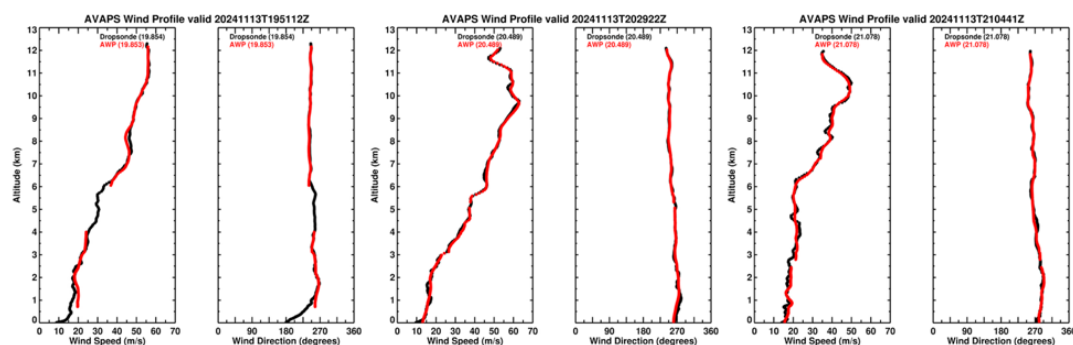


Figure 5: Co-located AWP (red) and AVAPS (black) dropsonde wind speed and direction profiles for sondes released at 1951 (left), 2029 (middle), and 2104 UTC (right).

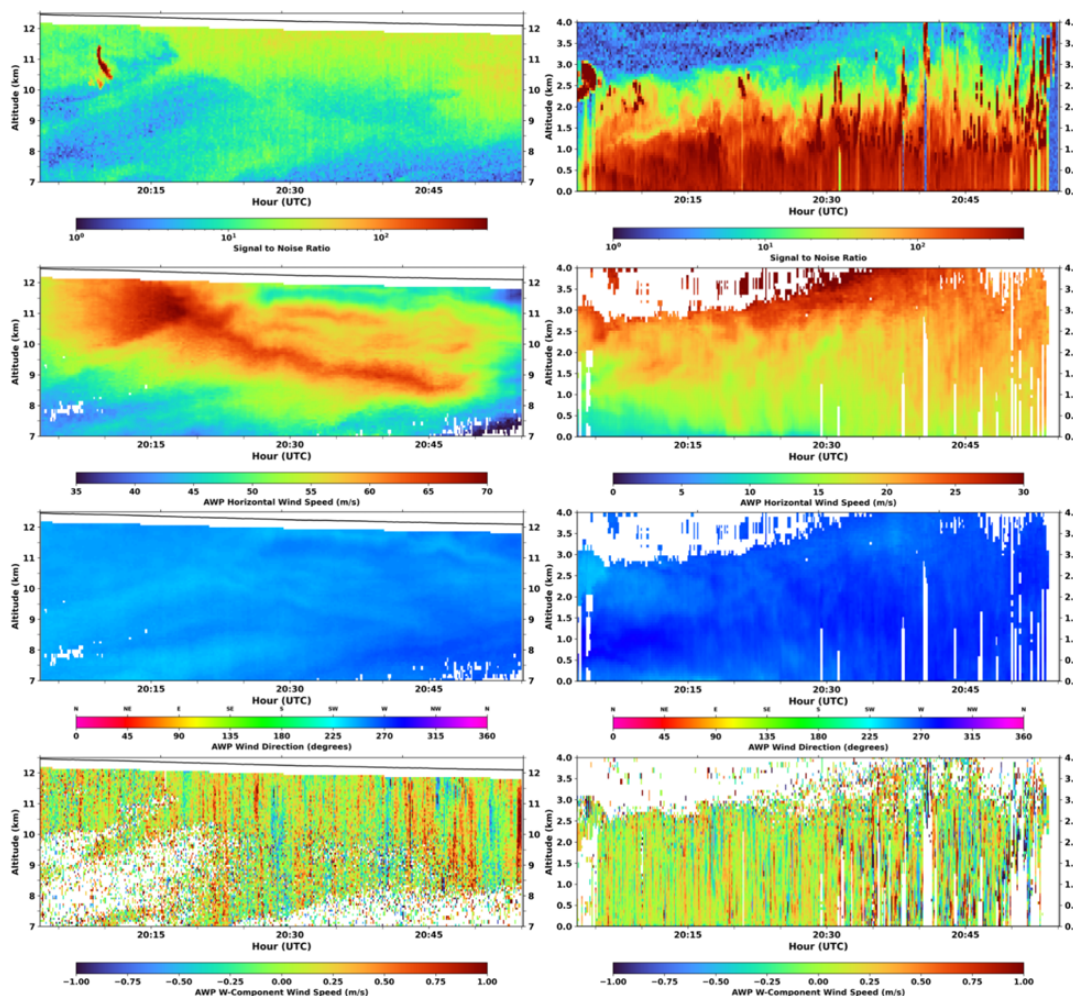


Figure 6: A view of AWP data in the upper-troposphere and lower stratosphere (left) and lower-troposphere / PBL (right) from 2003-2055 UTC. The wind speed color scales are compressed to better highlight features discussed in the text.

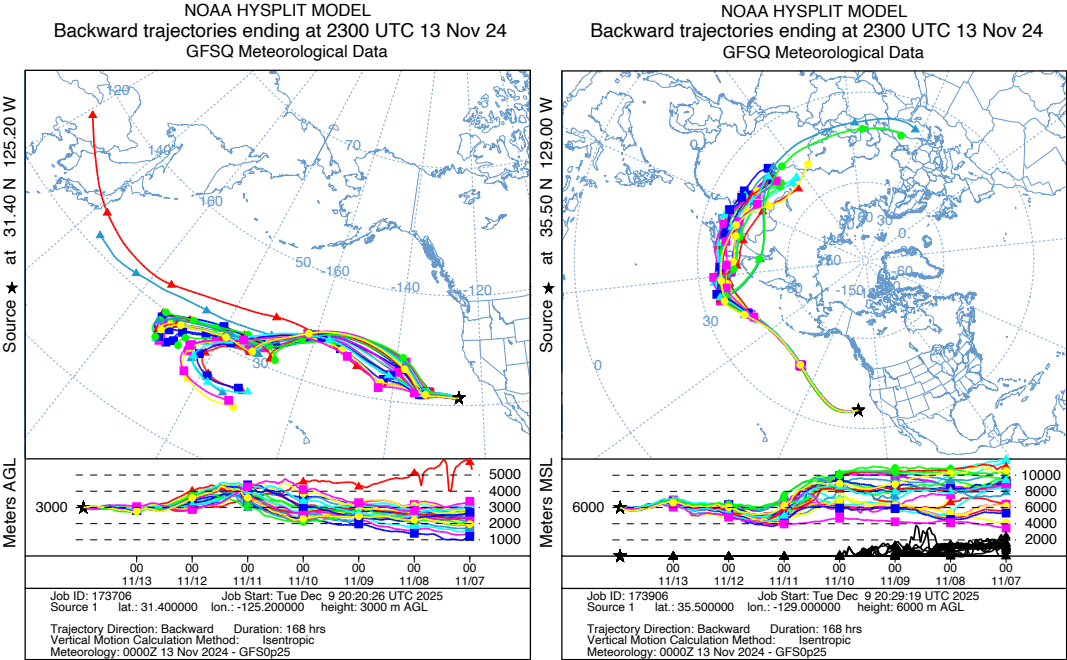


Figure 7: NOAA HYSPLIT 7-day back trajectory model runs for an ensemble of air parcels initialized from a thin aerosol plume observed at 3 km altitude at 2250 UTC (left) and a thick aerosol plume observed at 6 km altitude at 2340 UTC (right) on 13 November 2024. HYSPLIT runs were based on 0.25° NOAA GFS model meteorological fields and isentropic vertical transport.

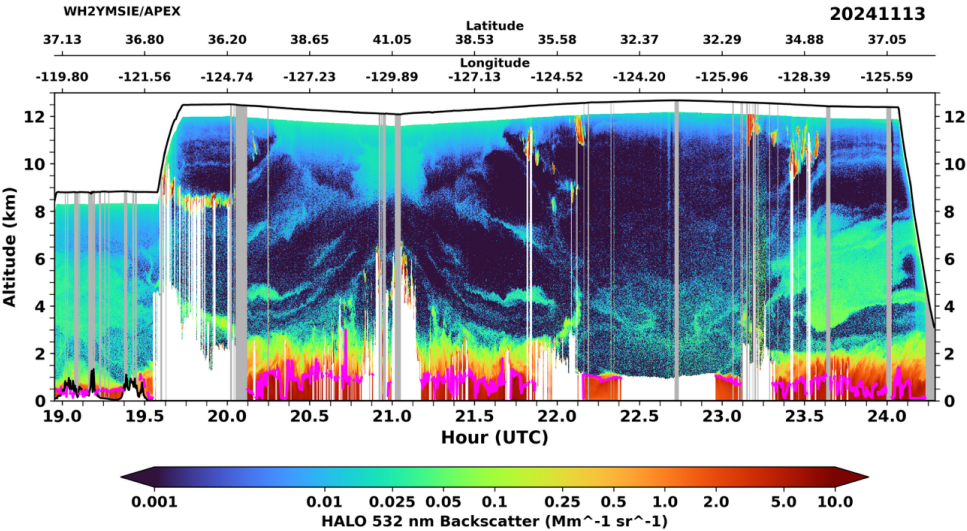


Figure 8: HALO cloud-screened 532 nm aerosol backscatter ($\text{Mm}^{-1} \text{sr}^{-1}$) for the 13 November 2024 flight, overlaid with a retrieval of mixed layer height (magenta) – a lidar-observed proxy for the height of the planetary boundary layer.



3.2. 24 September 2024

The objective of this flight was to sample a developing upper-tropospheric low-pressure system over Nebraska and a convective boundary layer associated with a warm, humid airmass over the central Appalachian region. This low was forecast to move southeastward and serve as the primary mechanism that steered the intense Hurricane Helene northward into the Florida Gulf of Mexico coast two days later. The geographic extent and sampling pattern for the flight was limited by the ~6-hour maximum G-3 endurance. The flight transected a trough axis located in Iowa and northwest Missouri (Figure 9). 250 hPa (~10.5 km altitude) jet streaks were located to the east and west of the trough which were sampled by AWP. Severe storms developed over Kentucky during the flight which caused the G-3 to have to divert northward from the planned track to avoid active storm cells. Mid- to high-altitude cloud cover was present throughout much of the flight (Figure 10-top). The AWP SNR curtain showed cirrus cloud tops above 10 km which had enough transparency to enable lidar penetration over 4 km deep into the cloud in some instances (Figure 10-bottom). The SNR curtain also shows an optically thick aerosol layer above cirrus tops, with lower SNR and differing spatial structure than the cirrus from 1648-1730 UTC and 1830-1906 UTC. The GFS identified a downward sloping tropopause that was aligned above the downward sloping cirrus tops from 1700-1730 UTC and beneath the thick aerosol layer, indicating that the aerosol likely resided in the lower stratosphere. A HYSPLIT backtrajectory analysis (Stein et al. 2015) suggested that the aerosol layer was located across northeastern China and Siberia 3-4 days prior to the AWP observation (not shown).

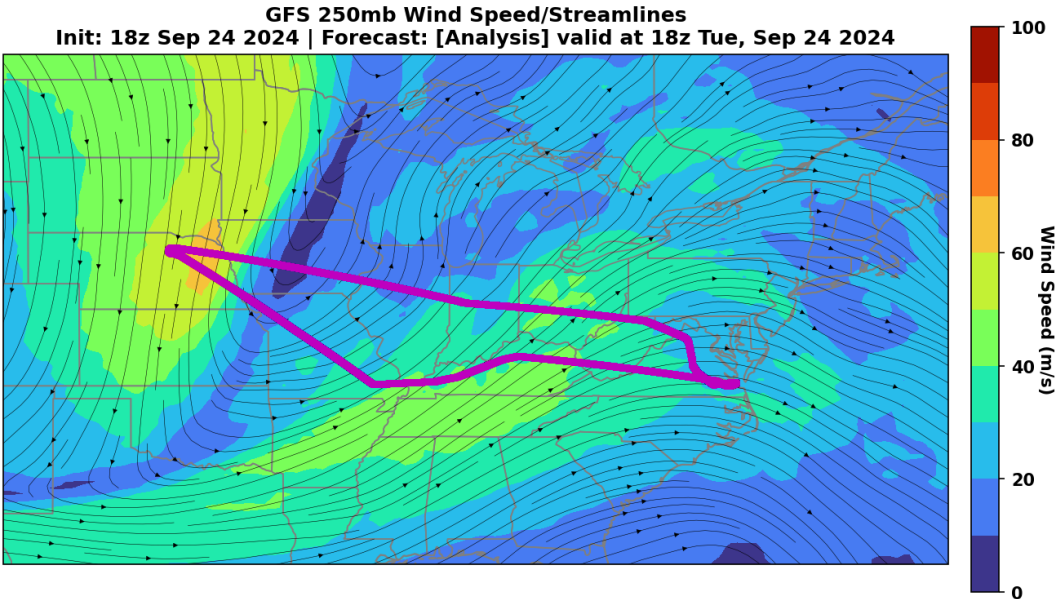
AWP observations within the trough reveal interesting dynamical features. Southwesterly to southerly winds were observed by AWP throughout much of the mid- to upper-troposphere on the eastern side of the trough prior to 1730 UTC (Figure 11). A jet streak was evident across Ohio from 1600-1630 UTC with speeds reaching ~45 m/s. Cirrus clouds present from 1700-1730 UTC were dominated by downward motion, consistent with observations from the 15 October flight discussed in Part 1 as well as other observations of cirrus from the EarthCARE Cloud Profiling Radar (Kim et al. 2025). The 1730 UTC timeframe marked the G-3 transect across the trough axis. A relative wind speed minimum signified the trough axis in AWP data which sloped downward from 12 to 7 km as the flight progressed westward (Figure 9). Layered wind speed variations were evident within and west of the trough axis, best seen in the AWP curtains focused on the 1700-1755 UTC timeframe (Figure 11). Wind direction transitioned to northerly on the western side of the trough with speeds exceeding 60 m/s. A filament of enhanced SNR / aerosol backscatter is evident on the leading edge of the jet from 8-11.5 km around 1740 UTC. The maximum wind speed layer between 10.5 and 11 km corresponded with a significant SNR reduction which extended westward throughout the jet streak. Beneath the jet streak, strong solar heating enhanced turbulence that reached up to 2.5 km altitude (Figure 11-lower left).

The aircraft did not have the endurance to fully transect the jet streak, and a turn to the southeast was made. The data curtains along this segment generally mirrored the appearance of the previous jet transect, though the wind speed minimum within the trough axis was not as pronounced as the prior transect, a characteristic also depicted by the GFS. Enhanced aerosol backscatter remained evident above the cirrus after 1830 UTC.

After progressing across Missouri, the flight crossed a cold front in western Kentucky, marking a transition between a drier continental airmass to a moister convectively unstable airmass. The NOAA Storm Prediction Center



220 indicated a “Slight Risk” of severe thunderstorms across eastern Kentucky where the G-3 flew (NOAA SPC, 2024).
221 After passing over thick cirrus, the near-surface wind direction shifted to southwesterly, and later southerly by 1930
222 UTC before the aircraft flew over cirrus outflow from an adjacent convective cell which inhibited the lidar from
223 profiling down to the surface. Strong upward motion (> 2 m/s) was observed within a convective cell at 6 km and
224 1922 UTC. A pronounced aerosol layer was present from 1855 to 1930 UTC, which featured wavelike structures at
225 8.5-9.0 km located along the base of the jet streak. Wind speed increased to 20-35 m/s in the 4-8 km layer across
226 Kentucky and western Virginia which enhanced vertical wind shear and contributed to the convective storm
227 organization and severity. The middle to upper regions of the AWP curtain show reduced aerosol backscatter from
228 1930-2000 UTC. Deep convection had passed through eastern Kentucky and West Virginia about 4 hours prior to the
229 flight, which may have scavenged aerosol aloft, though backscatter remained relatively strong in the lowest 4 km of
230 the profile at 1945 UTC.



231
232 **Figure 9: NOAA Global Forecast System (GFS) 250 hPa wind analysis valid at 18 UTC on 24 September 2024, overlaid**
233 **with the G-3 flight track (magenta) which was coincident in time with this GFS analysis.**

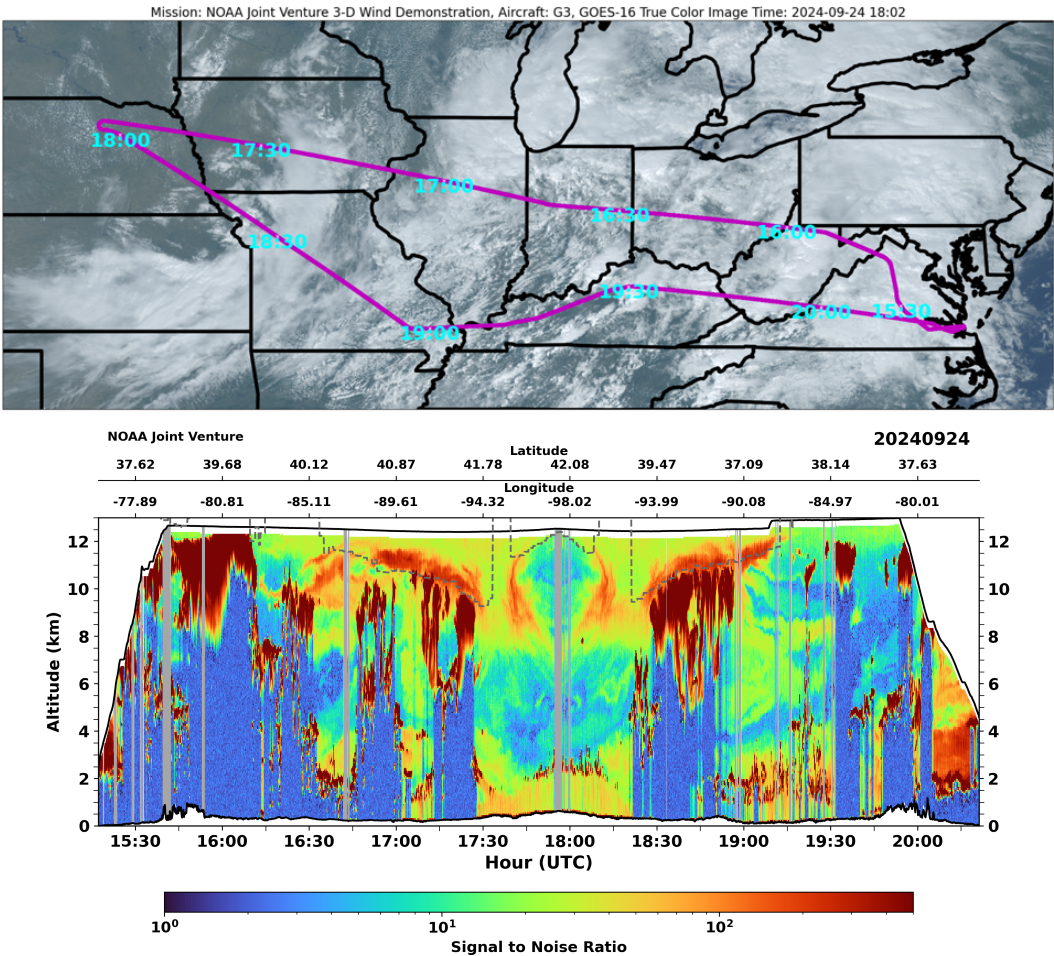


Figure 10: (top) GOES-16 True Color RGB composite on 24 September 2024 at 1802 UTC, overlaid with the G-3 flight track (magenta) and flight time in UTC (cyan). (bottom) AWP signal to noise ratio (SNR). Grey columns in the curtains indicate aircraft turns where wind profiles are invalid. White regions indicate data bins that are below ground level. The grey dashed line indicates the tropopause height from the 18 UTC GFS model analysis.

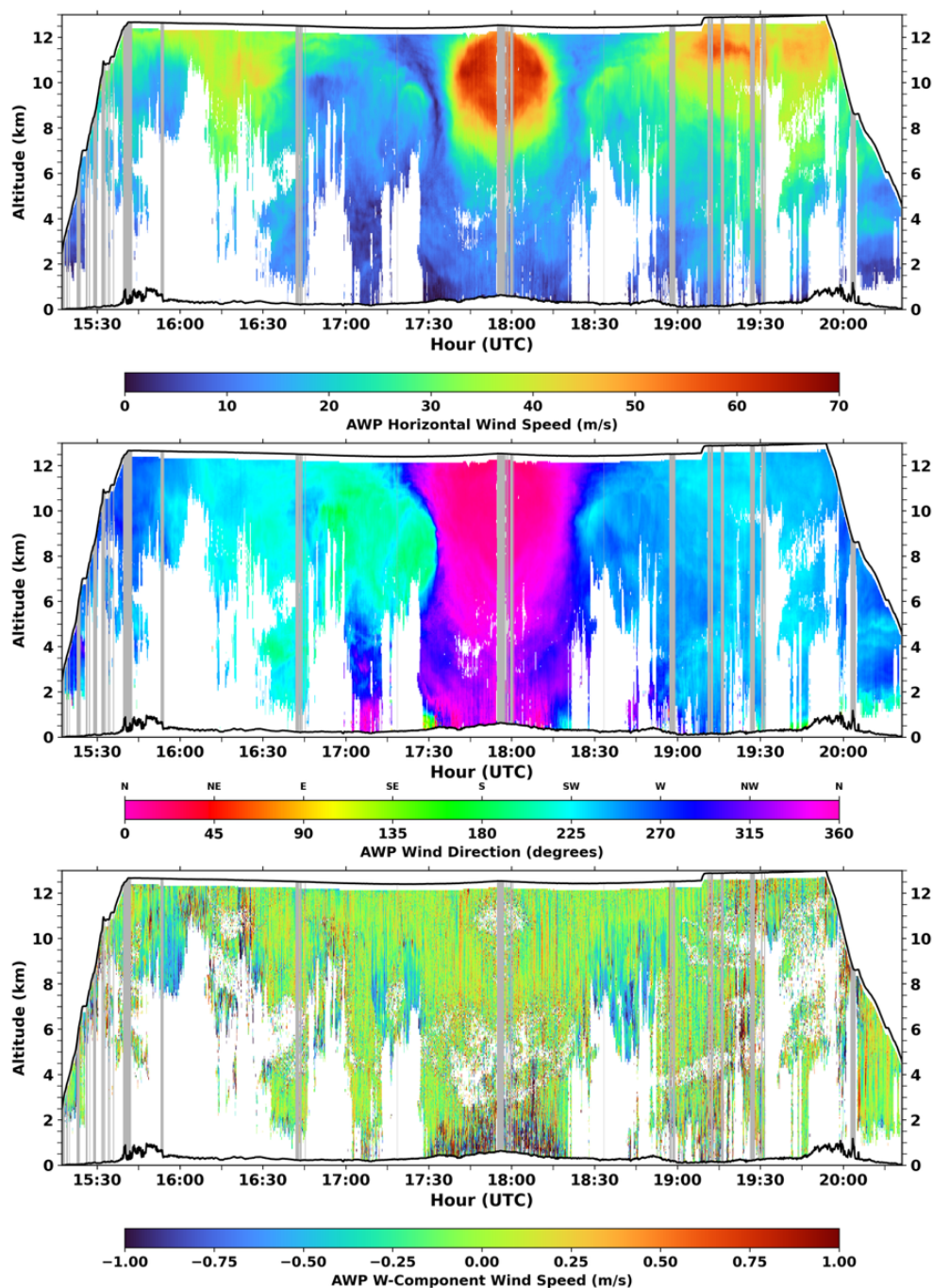


Figure 11: AWP wind speed (top) and wind direction curtains (bottom) on 24 September 2024. Grey columns in the curtains indicate aircraft turns where wind profiles are invalid. White regions indicate regions beneath opaque cloud, where aerosol backscatter was insufficient for a wind retrieval, or where data bins are below ground level.

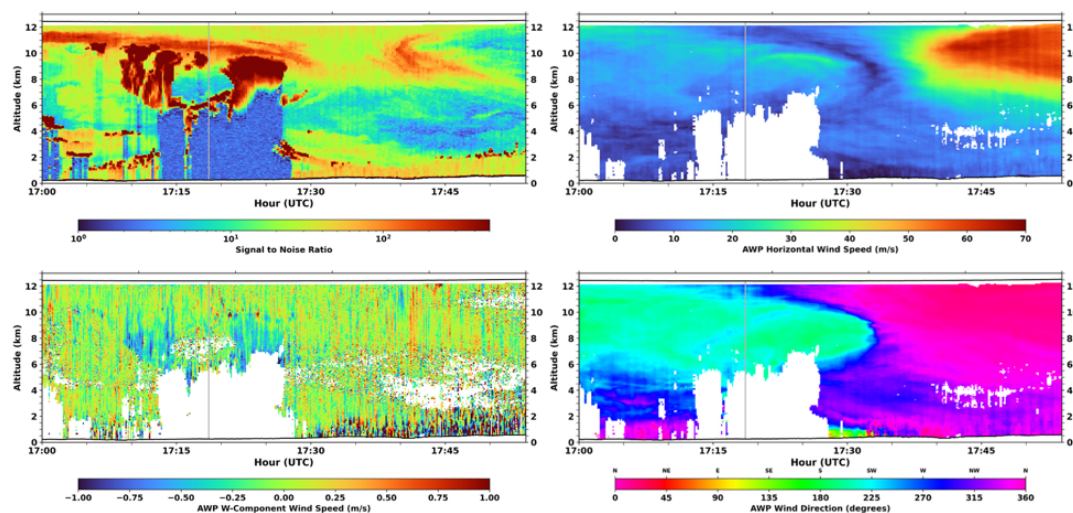


Figure 12: AWP SNR (upper-left), wind speed (upper-right), vertical wind speed (lower-left), and horizontal wind direction curtains (lower-right) on 24 September 2024 from 1700-1753 UTC, a period when the G-3 transected a mid- to upper-tropospheric trough over Iowa.

3.3. 31 October 2024

The objective of this flight was to coordinate measurements with the ER-2 while it was heading to/from sampling over central Oklahoma, as well as to observe changes in aerosol, wind and water vapor (WV) profiles throughout the day across Arizona. GOES-18 6.9 μm WV absorption channel imagery (Figure 13) shows mountain wave patterns across southern California and northern Arizona, that became more pronounced as the day progressed and cirrus across northern Arizona dissipated. The cirrus was located around 10 km altitude, so the G-3 flew beneath 9 km to avoid it and to improve lidar sensitivity within the PBL. The mission duration extended beyond the G-3 endurance, so a refuel was done in the Phoenix, Arizona area from 1910-2045 UTC. Horizontal wind vector and vertical wind speed profiles were retrieved at 4 second intervals throughout the flight (~ 0.9 km spacing).

The G-3 aligned with the ER-2 flight track near 1700 UTC and headed eastward across California and into Arizona. Throughout the flight, the AWP SNR curtain shows complex vertical layering of aerosols perturbed by mountain waves (Figure 14-left). Discontinuities in horizontal wind velocity, and to a lesser extent wind direction, are evident in association with the waves that extend throughout much of the column. Vertical motion exceeded 1 m/s within the waves (Figure 14-left, rows 4-5). Greater SNR and aerosol backscatter was evident from the surface to 1.5 km from 1830-1850 UTC during flight across the valley region near Phoenix.

After a refuel in Phoenix, the flight sampled nearly the same northern Arizona region as the first flight leg. During the second and third overpasses over this region, SNR and horizontal wind perturbations by the waves were more pronounced than previously observed. Vertical motions exceeded 2 m/s at times above 3 km altitude, compared to weaker motions during the morning overpass (Figure 14, rows 4-5). The mountain wave-induced vertical motions were superimposed onto PBL turbulence that extended ~ 1 km above the surface and had differing wavelength than the wave structures. Cirrus cloud cover retreated to the north and revealed more prominent wave signatures in the 2152 UTC GOES-18 image, consistent with the AWP depictions of increased wave amplitude. Enhanced aerosol

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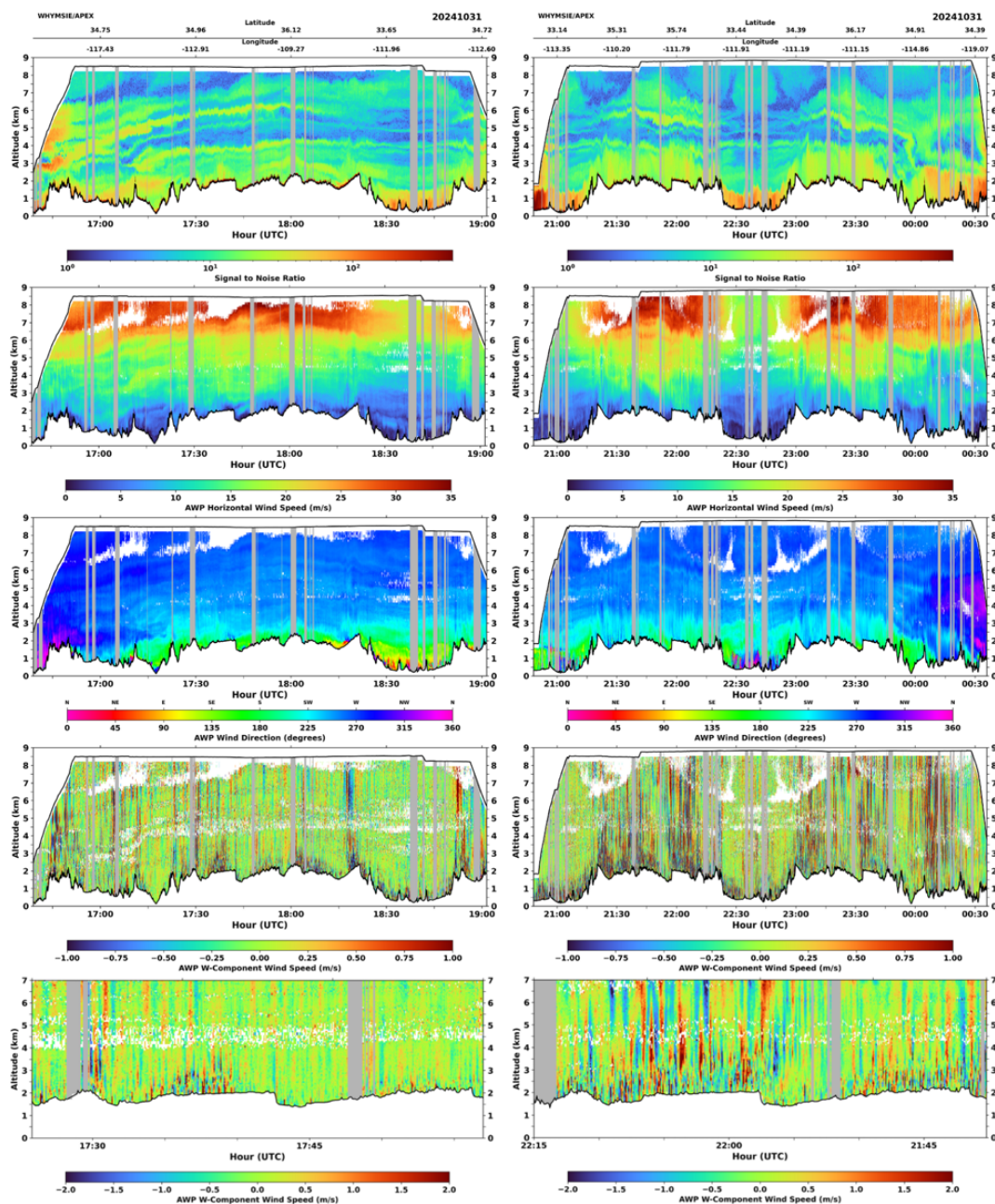


Figure 14: AWP SNR (1st row), wind speed (2nd row), wind direction (3rd row), and vertical wind speed (4th row) curtains from the first (left) and second (right) G-3 research flights on 31 October 2024. A focused comparison of vertical motion sampled in the morning and afternoon over the same region is shown in the 5th row with an expanded range in the color scale to better depict the strong vertical motions present in the afternoon. The horizontal wind speed color scale range is reduced (0–35 m/s) relative to other flights (0–70 m/s) to emphasize details.



294 **3.4. 9 November 2024**

295 The objective of the 9 November flight was to study the PBL and its evolution over the mountainous terrain of
 296 coastal central California, across Monterey Bay, and the offshore Pacific Ocean. This region was previously studied
 297 with an airborne wind lidar by De Wekker et al. (2012) who revealed complex wind flows caused by the highly
 298 variable terrain to the south and east of Monterey, CA. The flight began by heading eastward across the Sierra Nevada
 299 to climb to cruise altitude near 12.75 km for an east-to-west transect of Monterey Bay and a survey flight of wind,
 300 aerosol, cloud, and water vapor conditions several hundred kilometers offshore (Figure 1, brown line). 3-D wind
 301 vector profiles were retrieved at 5 second intervals during segments 1-4 of the flight over land and far offshore (~1.2
 302 km spacing, Figures 15-16). The mid-troposphere had weak aerosol loading which, combined with attenuation from
 303 clouds and shorter integration periods than some other Fall 2024 flights, inhibit wind retrieval in the 2.5-7 km layer.
 304 Like the 24 September flight, cirrus from 16.25-17.75 UTC provided strong backscatter over layers several kilometers
 305 deep and were dominated by downward motion. Aside from the regions within cloud, vertical wind conditions were
 306 much more quiescent than other previously discussed flights.

307 Upon descent to 7 km altitude around 17.75 UTC to fly beneath cirrus as well as to improve lidar sensitivity
 308 within the PBL, AWP scan rate was changed to enable 3-D wind retrieval at 2.5 sec intervals (~0.6 km spacing). This
 309 is the fastest scan rate employed during the Fall 2024 campaigns that was intended to resolve fine-scale wind variations
 310 which could be smoothed out with longer integrations. The complex flight track during this timeframe is overlaid on
 311 GOES-18 satellite data and annotated with numbers for each flight segment (Figure 15) to facilitate the discussion.

312 The G-3 executed repeated looping flight patterns over and immediately offshore of the coast for the remaining
 313 3.5 hours of the flight. Segments over land and Monterey Bay (6-10, 17) had differing backscatter and wind patterns
 314 throughout the column compared to the over water segments (11-16, 19), but wind speeds were relatively low (≤ 15
 315 m/s) overall. A focused example of wind and aerosol patterns over flight segments 5-11 is provided in Figure 17-left,
 316 with the wind speed color range compressed to better depict variations in these low-speed conditions. From the surface
 317 to 1.5 km, the mountainous terrain impacted wind direction quite notably, causing wind direction shifts over relatively
 318 short distances compared to the 1.5-2.25 km layer where winds were generally westerly. Subtle horizontal wind speed
 319 perturbations of ≥ 3 m/s in some instances are evident near the highest peaks, accompanied by vertical motions ≥ 1
 320 m/s. The curtain focused on segment 9 (Figure 17-right) shows that the strongest vertical motions were adjacent to
 321 and above the highest peak observed by AWP within the Santa Cruz mountain range. A local wind speed maximum
 322 near the surface with an embedded ~8 m/s area was located offshore of Point Sur, California at the southern end of
 323 segments 7, 9, and 11. From the surface to 0.2 km, wind direction shifted from northerly (magenta, red) over the
 324 southern half of Monterey Bay to west-northwesterly (blue) and southwesterly (cyan) over the northern half, likely
 325 driven by wind interaction with the Santa Cruz mountains. A shallow layer of high SNR near the ocean surface was
 326 caused by fog that dissipated during the flight. Lower tropospheric wind patterns were more persistent over offshore
 327 flight segments 11-16, likely due to reduced influence of the complex coastal California terrain (Figure 16).
 328 Diagnosing the mechanisms behind these complex wind flows will require high resolution numerical model runs,
 329 which is an excellent opportunity for future work. This flight demonstration highlights the need for rapid Doppler
 330 wind lidar sampling to resolve mesoscale coastal atmospheric dynamics for which AWP is well suited.

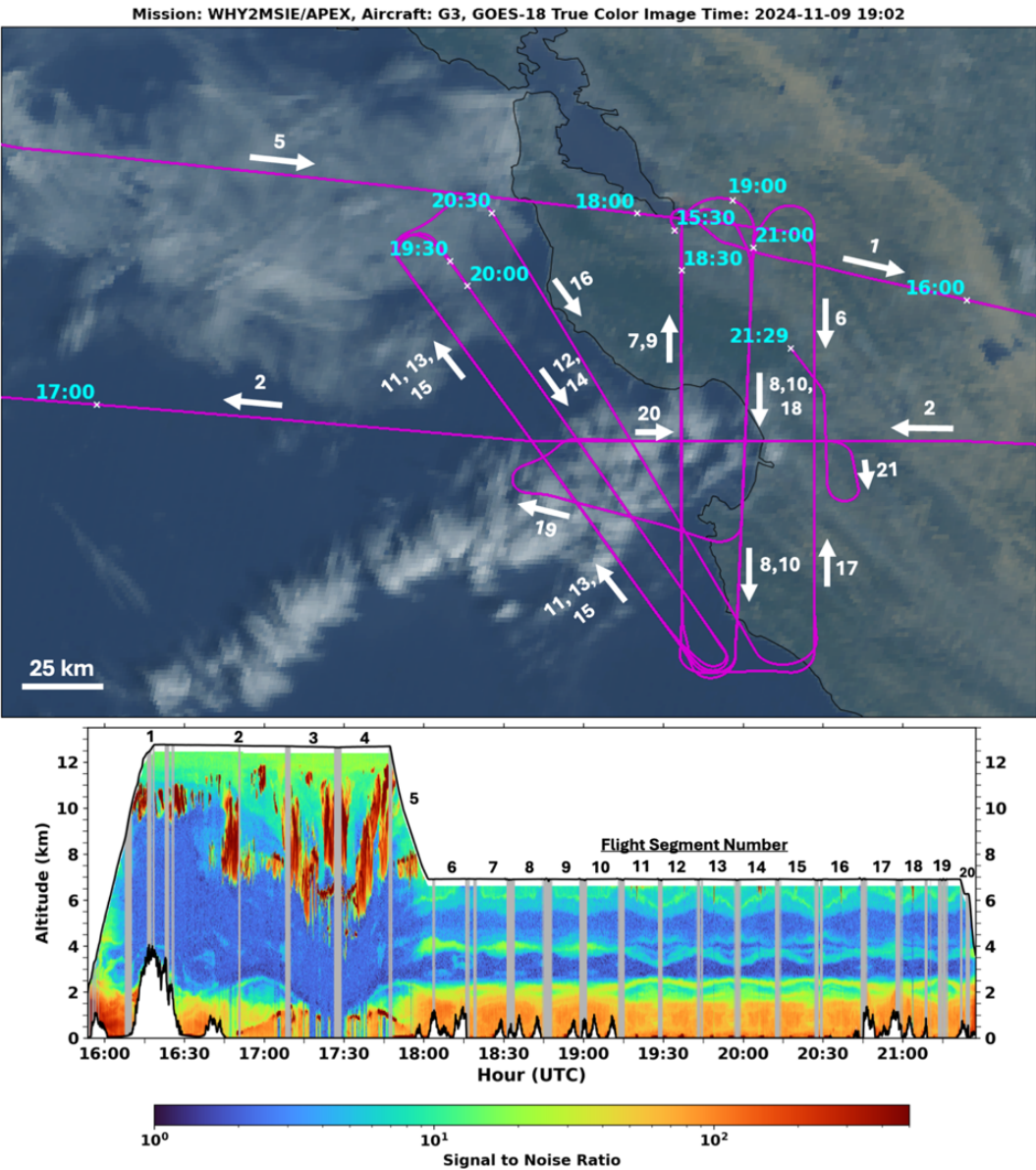


Figure 15: (top) GOES-16 True Color RGB composite on 9 November 2024 at 1902 UTC, overlaid with the G-3 flight track (magenta) and flight time in UTC (cyan). Flight segments are numbered and annotated with arrows showing the direction of flight. (bottom) AWP SNR curtain annotated with flight segment numbers for the 9 November flight.

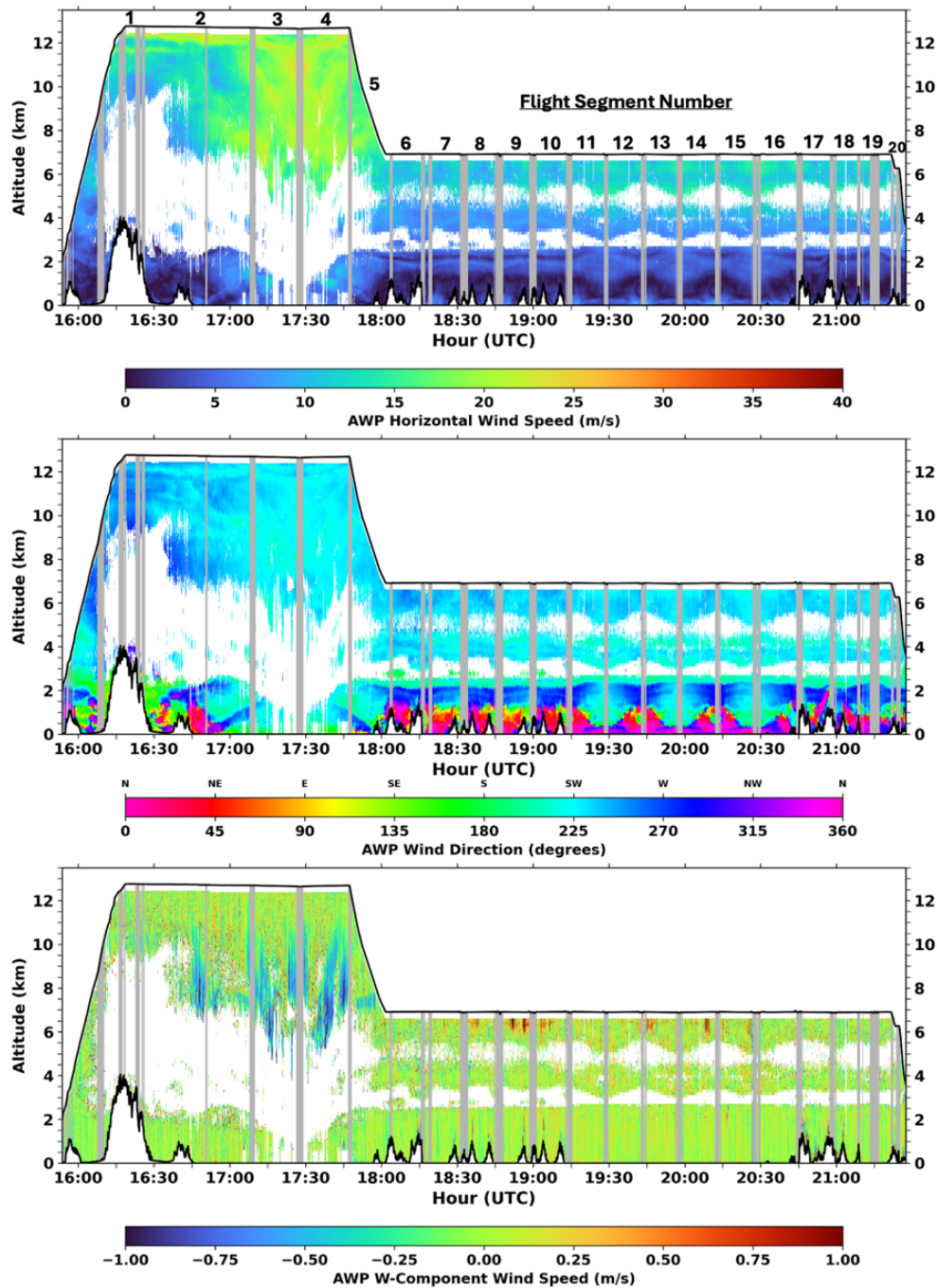


Figure 16: Horizontal wind speed (top), direction (middle), and vertical wind speed curtains (bottom) on 9 November 2024. Curtains are annotated with the flight segment numbers identified in Figure 15.

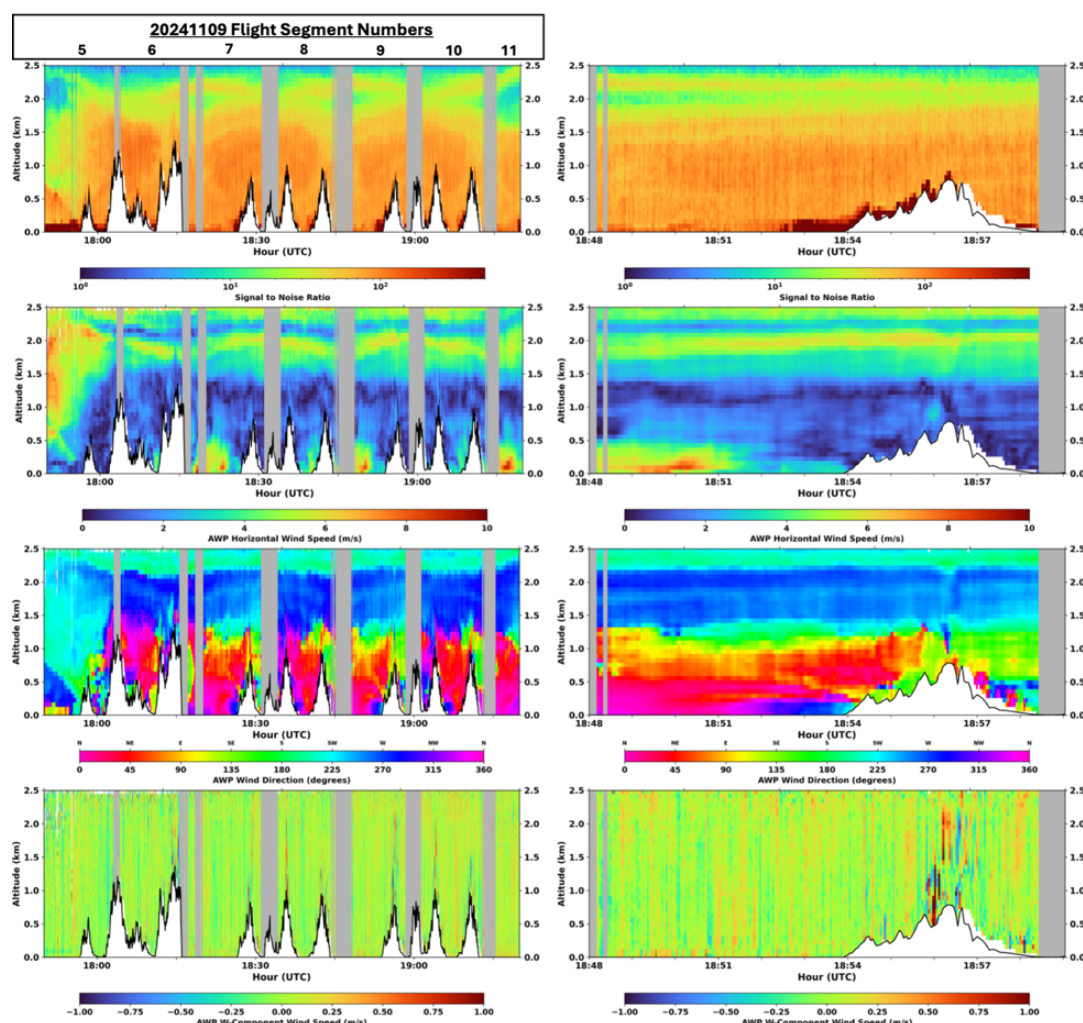


Figure 17: Zoomed AWP SNR (top), wind speed (middle) and wind direction curtains (bottom) on 9 November 2024 in the 0–2.5 km altitude range, over a period from 1750–1920 UTC (left) and over segment 9 from 1848–1959 UTC. Curtains are annotated with the flight segment numbers identified in Figure 15. Note that the wind speed color range is reduced from 0–70 m/s shown in Figure 16 to 0–10 m/s to better depict fine-scale wind variations. White area to the right of the mountain range in the right panels is caused by beam blockage of one of the AWP beams by topographic variations.

3.5. Vertical Coverage of Successful AWP Wind Retrieval

Successful and accurate AWP wind profile retrieval requires sufficient SNR. SNR is modulated by aerosol concentration and atmospheric turbulence in a measurement volume, as well as instrument- and algorithm-related parameters such as laser pulse energy, telescope area, heterodyne mixing efficiency, detector quantum efficiency, the number of laser pulses integrated within the retrieval, the magnitude of various other noise sources, and laser pulse attenuation by cloud cover. An SNR of 2.8 (3.0) is required to achieve a successful off-nadir (nadir) retrieval (Bedka et al. 2026). Lower SNR values can be used to successfully retrieve accurate winds, but with increased random noise that is difficult to filter away.



353 The wind retrieval success rate as a function of height is a key metric for data users. The fraction of successful
354 wind retrievals is derived from data from all flight segments above a 6 km aircraft altitude during the Fall 2024 flight
355 campaigns. Rather than relying on a fixed empirical SNR threshold, clouds are identified using a multi-step spatial
356 coherence algorithm applied to the AWP SNR profiles. This method applies altitude-dependent SNR thresholds,
357 vertical running means to refine cloud boundaries, and morphological filtering to isolate contiguous, spatially coherent
358 cloud layers. 6 km was selected to capture all flight segments while the aircraft was at a stable cruise altitude. The
359 lidar pulse is considered to have reached the surface if an SNR above the instrument noise level was recorded in the
360 vertical bin immediately above the surface elevation, defined by the ETOPO dataset (NOAA NCEI 2022). Cloud free
361 profiles or segments above cloud (green) and segments beneath the upper-most cloud top (red) are analyzed separately
362 (Figure 18). An example of the AWP cloud mask is provided in Figure 3 for the 13 November flight. AWP achieved
363 a 60-99% success frequency from cloud-free profiles. The 3-8 km altitude layer typically had the lowest aerosol
364 concentration and weakest signal return, leading to a 60-75% success frequency. Backscatter was especially prominent
365 within the lowest 2.5 km, within and near to the PBL, where success was ~85-95%. Success decreased to as low as
366 35% at 3.5 km for profiles beneath attenuating cloud cover but still was in the ~50-60% range in the PBL region due
367 to greater aerosol loading. As shown in Part I, longer signal integration could be achieved by combining data from
368 multiple AWP scans would improve success rate, a capability that will be achieved with future retrieval algorithm
369 development.

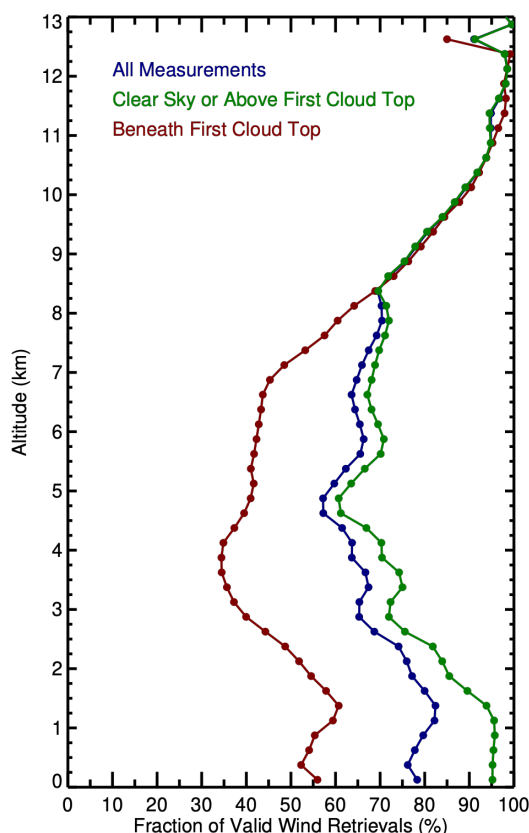


Figure 18: The fraction of successful wind retrieval, derived from all flight segments with aircraft altitude above 6 km and excluding large aircraft roll and pitch segments, during the Fall 2024 flight campaigns. This success rate is separated by whether the profile intersected a cloud, identified using a multi-step spatial coherence algorithm applied to the AWP SNR profiles

4. AWP Validation and Comparison with Numerical Weather Prediction

4.1. Validation with AVAPS Dropsonde

68 AVAPS dropsondes were co-located with AWP data during the Fall 2024 flights. Sonde releases sampled features such as atmospheric wind, water vapor, and temperature gradients, localized wind speed or water vapor maxima/minima, and gaps in cloud cover. AVAPS data are quality-controlled with a human-supervised automated algorithm within the ASPEN software package (Martin and Suhr 2021; Vömel et al. 2023). AVAPS collect data with 2 Hz frequency and 5–8 m spacing between vertical levels which are averaged to the 66 m AWP bin spacing in these comparisons. AVAPS wind profiles have previously been compared with in-situ wind observations from a NASA research aircraft during the Aerosol Cloud meteorology Interactions over the western Atlantic Experiment (ACTIVATE) campaign, showing a 0.21 m/s bias and 1.68 m/s uncertainty (Namdari et al. 2025). Of the three wind speed categories analyzed by Namdari et al., the greatest bias (0.41 m/s) was found for the slowest speeds (< 5.8 m/s), suggesting that there may be greater overall AVAPS uncertainty in low-speed conditions.



388 AVAPS (referred to as sondes hereafter) descend with a parachute making them susceptible to horizontal drift
 389 during their ~14 min descent from 13 km flight level to the surface. Strong winds perpendicular to the aircraft track
 390 caused some sondes to drift over 30 km from track which could incorporate notable spatial variability in AWP-sonde
 391 statistics. To address this, AWP data are weighted-averaged over a 150-second time window, encompassing a 34-39
 392 km distance assuming a 225-260 m/s ground speed, as well as over 5 AWP vertical bins. The profile at the center of
 393 the window is weighted highest, and the weighting linearly drops from 1 to 0 toward the window edge in the horizontal
 394 / temporal dimension, and from 1 to 0.75 in the vertical dimension.

395 Example AWP (red), AVAPS (black), GOES-16/18 atmospheric motion vectors (AMV, orange), NOAA GFS
 396 (magenta) and High-Resolution Rapid Refresh (HRRR, green) NWP model initial analysis profile (time interpolated
 397 to the AVAPS release) comparisons are shown in Figure 19. The close agreement between AWP (red) and sonde
 398 (black) curves, in addition to those from Figure 5 demonstrate the high vertical detail and precision offered by AWP.
 399 These profiles capture a variety of wind conditions and vertical wind shear. The GFS and HRRR model also agree
 400 well with sonde and AWP with the exception few outliers. A future paper will more thoroughly document relationships
 401 between AWP, several NWP models, reanalyses, and AMVs.

402 Co-locations between AWP and sonde vector wind speed, and U- and V-component speed from all flights are
 403 compiled in Figure 20. AWP had a negligible bias (< 0.1 m/s), high root-mean squared difference (0.89 m/s RMSD,
 404 also referred to as precision or random error), and high correlation (0.997) with AVAPS wind speed. Wind components
 405 showed similarly strong agreement. These statistics exceed the best precision achieved with the NASA LaRC Doppler
 406 Aerosol WiNd (DAWN) lidar, 1.22 m/s during the 2019 Aeolus Cal/Val Test Flight campaign (Bedka et al. 2021).
 407 Using the closest AWP profile in time to the sonde release, rather than the weighted average, increased disagreement
 408 by ~0.3 m/s (not shown), which we attribute to spatio-temporal wind variability. Greater AWP uncertainty is evident
 409 in the scatterplot at slower wind speeds, consistent with previous results from DAWN (Bedka et al. 2021). This could
 410 be attributed to greater AVAPS uncertainty described above, or sonde drift from the aircraft flight track. The impact
 411 of sonde drift is evident when comparisons are separated by distance between the sonde and aircraft. (Table 2), where
 412 wind vector difference increased by 77% for comparisons closest to the aircraft (0-5 km) versus the furthest distance
 413 bin (25+ km).

414 AWP accuracy is further demonstrated as a function of wind speed in Table 2. The greatest AWP-sonde
 415 disagreement relative to the measured wind speed occurred with the weakest wind conditions (0-2.5 m/s), where
 416 directional differences are most pronounced. These larger direction errors are expected, as small variations in the U-
 417 and V-wind components can lead to substantial changes in calculated wind direction at low speed. The best agreement
 418 occurs at the highest wind speeds (≥ 30 m/s), where the wind speed/direction bias is negligible and RMSD is 0.71 m/s
 419 and 1.38° . The highest wind speeds are typically at high altitudes and thus closest to the aircraft where AWP-sonde
 420 comparisons are more confident, which may contribute in part to the especially good agreement.

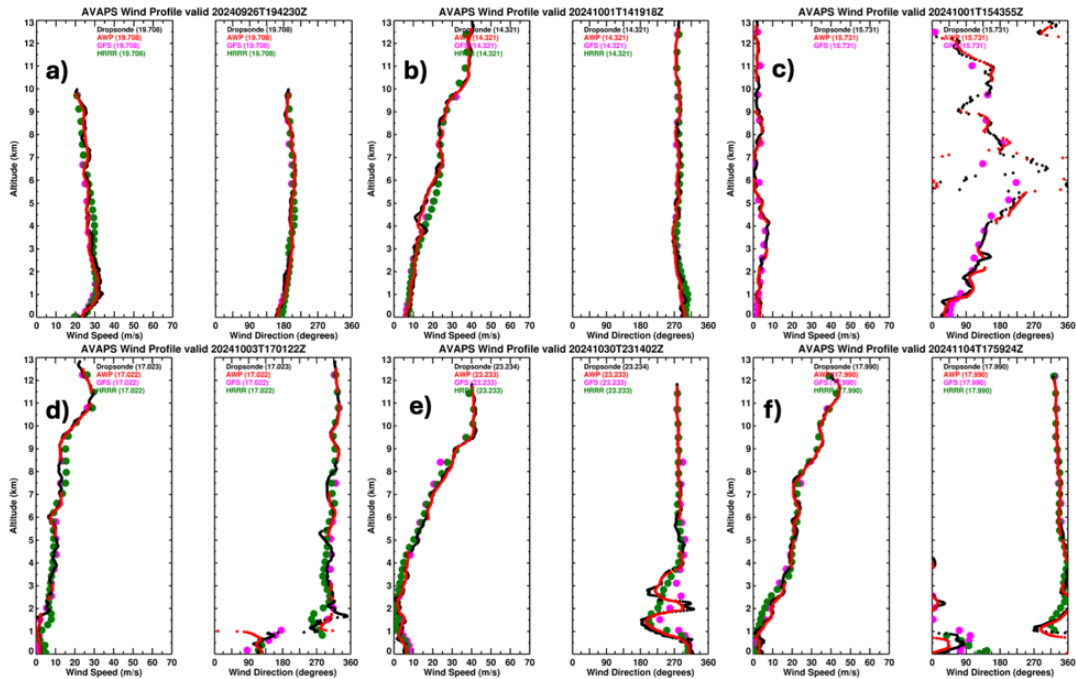


Figure 19: Six comparisons between AVAPS, AWP, NOAA GFS and HRRR model data, and GOES-16/18 AMVs across five Fall 2024 flights. The 1 October flight (upper-right panel) extended outside the HRRR model domain.

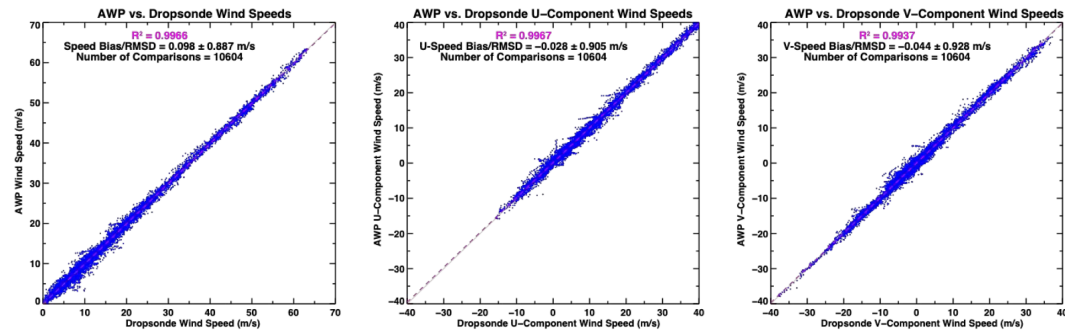


Figure 20: Comparison between AWP and AVAPS dropsonde wind speed (top), U-component (middle), and V-component speeds (right) from all 68 co-located profiles.



434

AVAPS Sonde Distance from Aircraft (km)	Speed Bias $\pm$ RMSD (m/s)	Direction Bias $\pm$ RMSD ($^{\circ}$)	Wind Vector RMSD (m/s)	Number of 66 m AWP Bins
0-5	0.07 ± 0.79	0.45 ± 10.53	1.13	4622
5-10	0.08 ± 0.80	0.10 ± 10.39	1.20	2727
10-15	0.14 ± 0.91	0.65 ± 4.74	1.36	1515
15-20	0.14 ± 1.11	1.4 ± 12.69	1.59	794
20-25	0.28 ± 1.05	0.55 ± 5.14	1.67	533
25+	0.02 ± 1.49	-0.91 ± 6.08	2.0	413
Wind Speed Range (m/s)				
0 - 2.5	-0.18 ± 0.69	6.46 ± 32.62	1.09	412
2.5 - 5	-0.06 ± 0.78	0.52 ± 14.85	1.21	1132
5 - 10	0.20 ± 1.01	-0.12 ± 8.71	1.43	2663
10 - 15	0.16 ± 0.99	-0.02 ± 4.48	1.33	1570
15 - 20	0.07 ± 1.02	0.47 ± 3.83	1.50	1222
20-25	0.00 ± 0.79	0.18 ± 2.12	1.13	896
25-30	0.11 ± 0.72	0.13 ± 1.57	1.03	628
30+	0.12 ± 0.71	0.31 ± 1.38	1.19	2081

Table 2: Comparison of AWP wind and co-located dropsonde wind observations, grouped by dropsonde wind speed. For each wind speed category, the bias and root-mean-square difference (RMSD) are provided for wind speed, u- and v-wind components, and wind direction.



4.2. Comparison with the NOAA Global Forecast System Data

As was described in Part I, AWP U- and V-component wind retrievals are averaged to each GFS grid box transected by the G-3 to enable an assessment of the accuracy of GFS wind analyses and forecasts. GFS grid boxes have variable vertical depth, with the shallowest depth near the surface and coarsest depth in the upper atmosphere near the aircraft. GFS data are analyzed from the initial analysis (0 hour) out to a 7-day (168 hours) forecast across all flights except for 8, 9, 12, and 14 November that were focused on repeated sampling over small regions. AWP and GFS curtains and the AWP-GFS difference for the 13 November and 24 September flights are shown for the initial analysis, 3-day, and 7-day forecast (Figures 21-24). There is generally good agreement for the initial analysis, but substantial differences emerge at 3 days that further increase at 7 days. For example, jet stream positions are generally well forecast through 72 hours but are poorly forecast 7 days prior to flight. The initial analysis (0 Hour) has the best statistical agreement with AWP, with 2.06 m/s wind analysis precision and a 0.36 m/s slow bias (Figure 25-left). The slow bias persists across all forecast intervals and increases with forecast lead time. AWP error is significantly better than the GFS initial analysis error, indicating that its data should have a positive impact when assimilated, which was confirmed with an AWP regional WRF model assimilation experiment (Locke et al. 2026). Precision degrades rapidly beyond 24 hours, peaking at 8.75 m/s at 144 hours (6 days), a factor of ~4.25 worse than the initial analysis. A significant contributor to the poorer precision for the 6-day forecast compared to 7 days is a particularly poor U-component forecast for Hurricane Helene on 26 September. V-component forecasts were generally less precise than those for the U-component. (Figure 25-middle and -right). HALO provided retrievals of mixed layer height a lidar-derived proxy for PBL height derived from aerosol backscatter profiles (Scarino et al. 2014), during WH²YMSIE/APEX flights (Figure 8). Wind speed forecasts are ~0.75 – 1.25 m/s poorer in the free troposphere relative to the mixed layer from the initial analysis to a 4-day lead time. The difference grows to 3 m/s by 7 days (not shown). Mixed layer wind speed forecasts, however, are actually poorer than free troposphere if quantified as a percent difference relative to the AWP observed wind speed. Improved lower-tropospheric wind profile observations like those from a wind lidar are needed to close this gap in forecast accuracy.

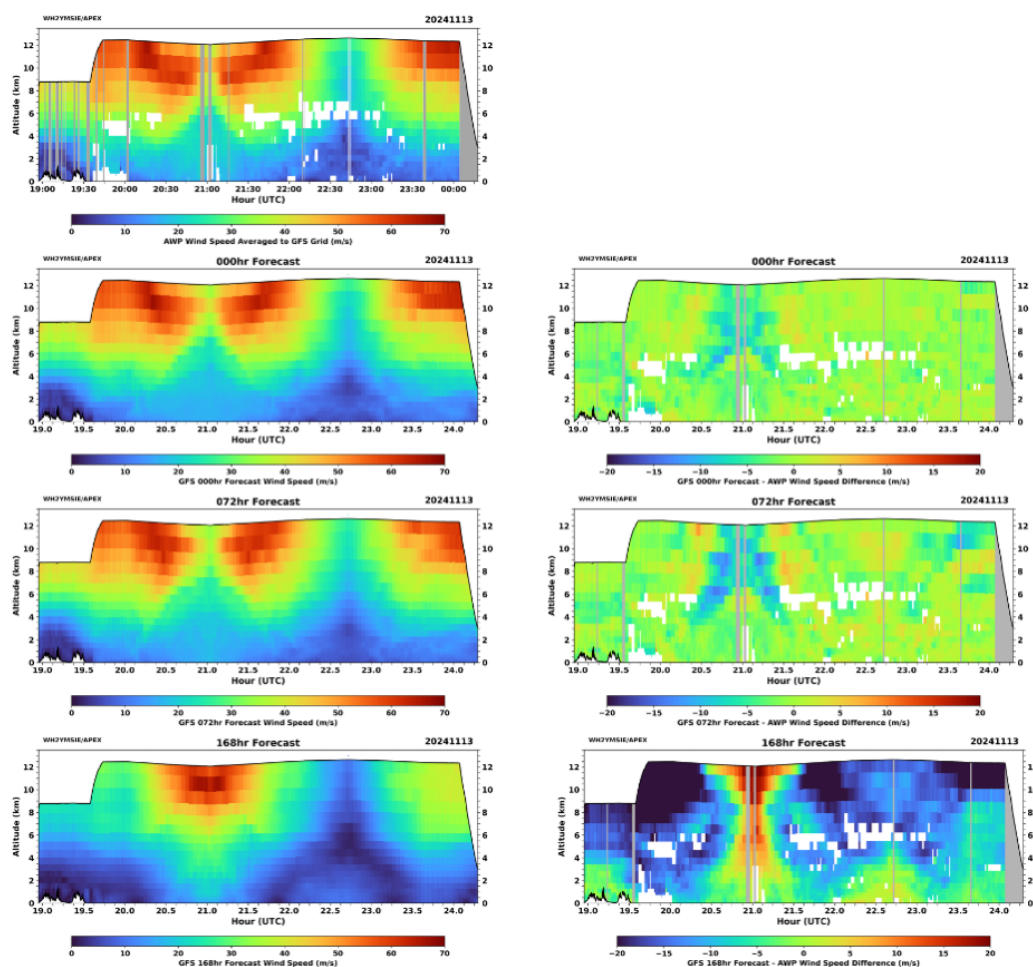


Figure 21: (top row) Observed AWP wind speed averaged to GFS grid cells intersected by the 13 November 2024 flight track). (Rows 2-4). GFS 00 hour, 72 hour, and 168 hour wind speed forecast (left column) and GFS-AWP wind speed difference (right column).

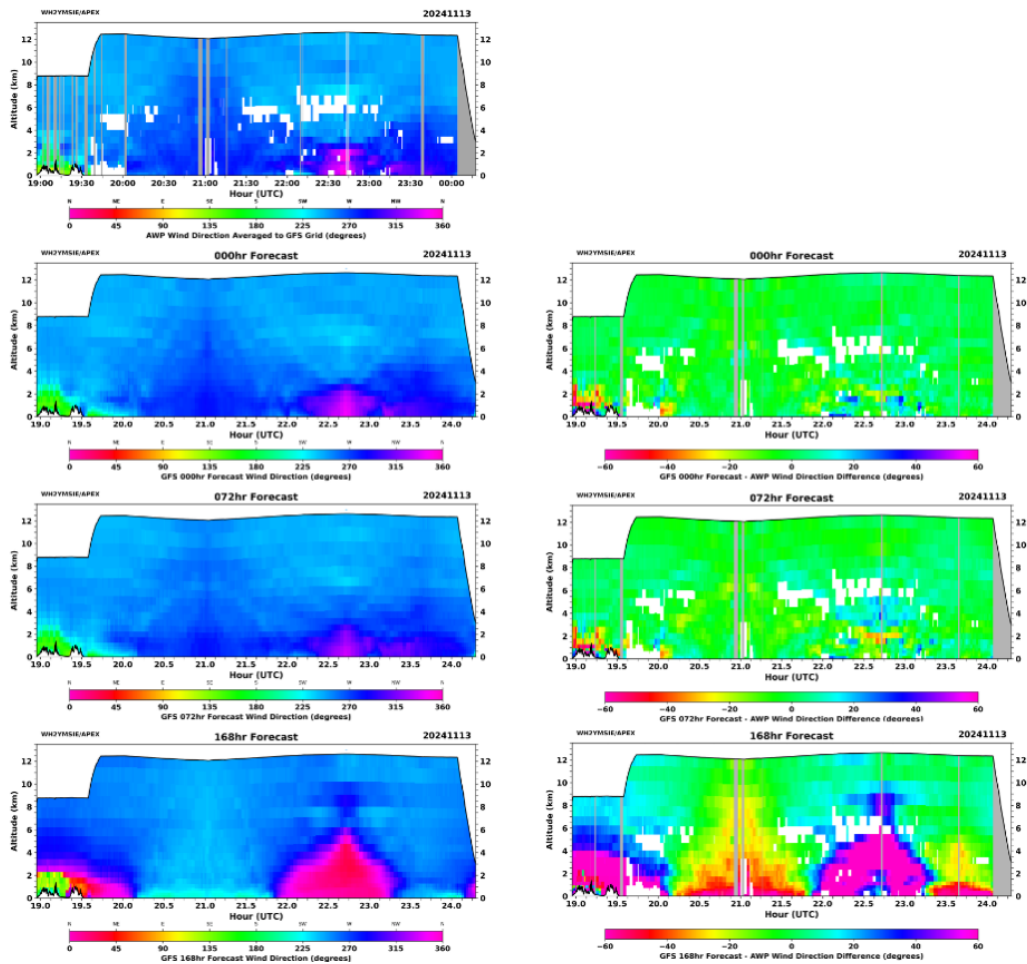


Figure 22: Same as Figure 21, but for 13 November 2024 wind direction.

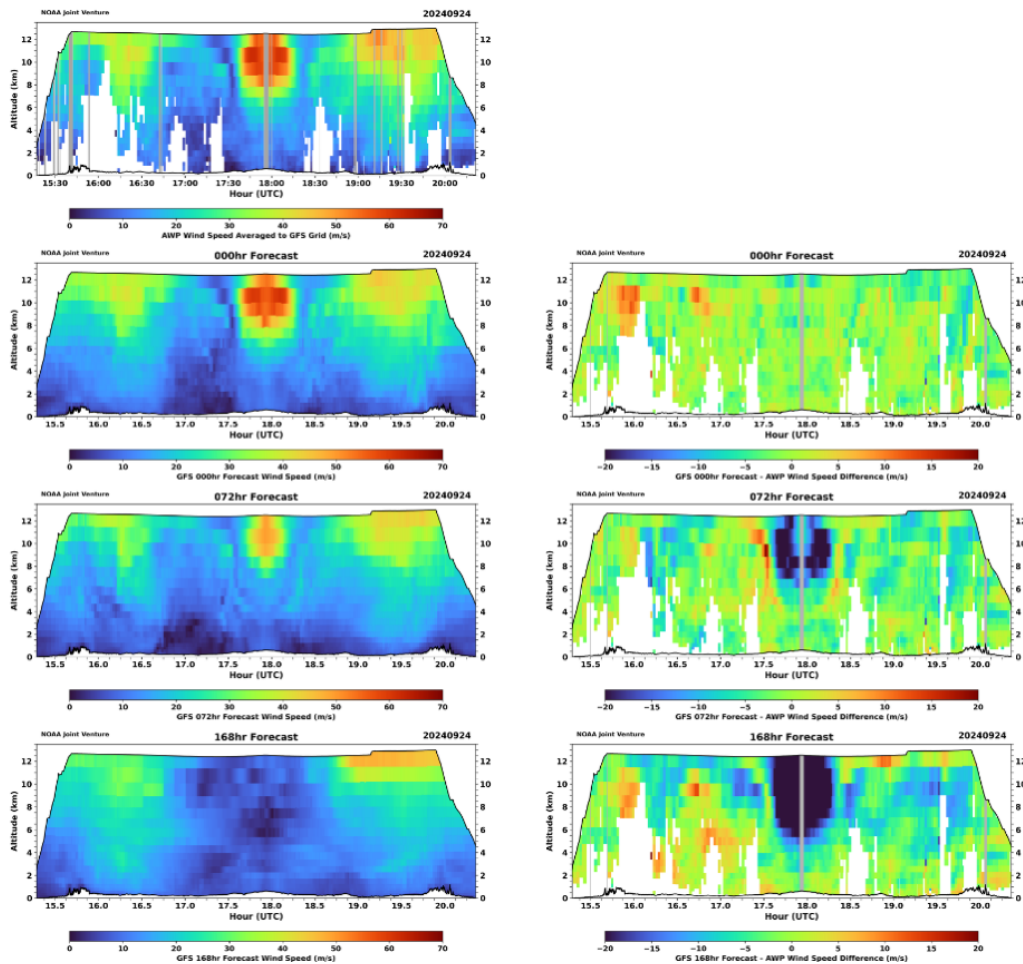


Figure 23: Same as Figure 21, but for wind speed from the 24 September 2024 flight.

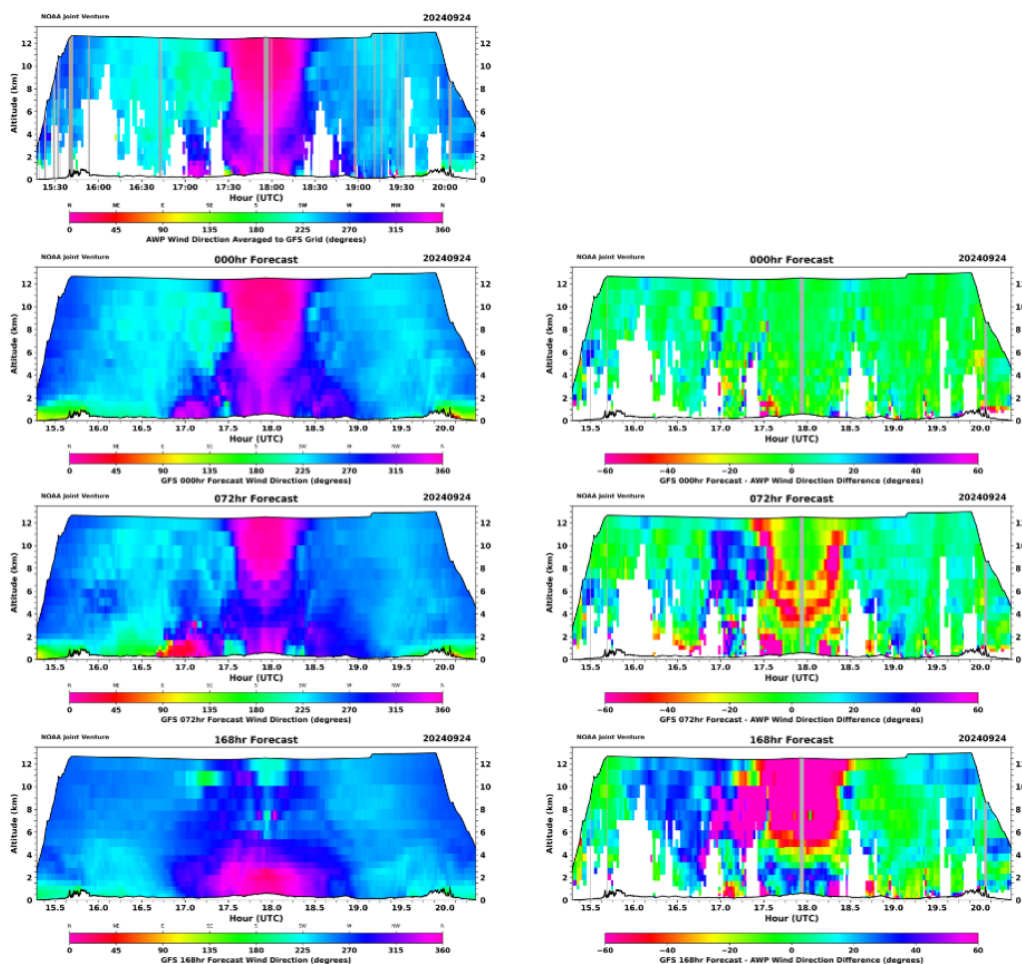


Figure 24: Same as Figure 22, but for wind direction from the 24 September 2024 flight.

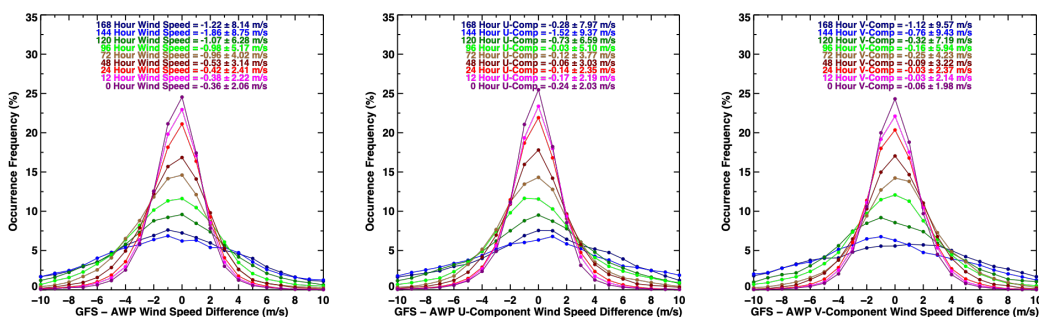


Figure 25: Histograms of GFS-AWP wind speed (left), U-component (middle), and V-component (right) differences as a function of forecast lead time, ranging from the initial analysis to 168-hour (7 day) lead time.



5. Summary

This paper describes the Aerosol Wind Profiler (AWP) CDWL and highlights aerosol/cloud backscatter and wind profile data collected during AWP's first two science campaigns that took place in Fall 2024, the NOAA Joint Venture 3-D Wind Demonstration and NASA WH²yMSIE/APEX. AWP observed a wide variety of weather regimes, weather phenomena, and wind conditions over the nearly 100 hours of instrument operation with high detail and precision. Wavelike wind structures in horizontal wind profiles were observed within a mid-latitude cyclone trough, in the stratosphere above a jet streak, and over mountainous terrain, while wind flows were shown to vary significantly over short distances over coastal central California especially within the PBL. Turbulence in the PBL, mountain waves, gravity waves, and descending motion within cirrus cloud featured prominently in the vertical motion data. Resolving these 3-D wind and aerosol structure requires rapid scanning, high aerosol backscatter sensitivity, high resolution and precision offered by AWP.

When flying at high altitude across many Fall 2024 flights, AWP success rate ranged from 60-99% in clear sky conditions, with the lowest success rate occurring near 5 km altitude. Cloud attenuation reduced success rate to as low as 35% in the mid-troposphere, but was in the ~50-60% range in the PBL region in cloudy conditions. AWP was able to penetrate and retrieve wind over 5 km into cirrus in some situations, demonstrating that clouds can also be a valuable backscatter target especially in clean aerosol conditions where wind retrieval may otherwise fail.

AWP exhibited excellent agreement relative to AVAPS dropsonde for individual profiles highlighted in both Parts I and II of this paper, and with minimal bias (< 0.1 m/s) and small uncertainty (0.89 m/s) from all co-located data. AVAPS comparisons highlight the robustness of AWP wind measurements across a range of wind speed regimes, especially for high wind speeds where bias and uncertainty were especially small (.71 m/s and 1.38°). AWP's excellent precision allows it to be used as a truth to evaluate GFS model analyses and forecast. GFS wind speed had relatively good agreement with AWP at the initial analysis time (0.36 m/s slow bias and 2.06 m/s precision), but worsening performance with increasing forecast lead time (1.22 m/s slow bias and 8.14 m/s precision at 7 days). V-component forecasts were less precise than U-component forecasts. Future work will investigate the performance of other NWP models and reanalyses, as well as other space-based wind measurements from atmospheric motion vectors and scatterometers.

AWP data collected during the Fall 2024 flight campaign has demonstrated AWP's high quality wind measurement capability, and its value for both weather process studies and understanding model performance. Though it is uncommon for a coherent-detection wind lidar like AWP to successfully measure a continuous wind profile throughout a column, the data is extremely precise and valuable where such measurements can be made. An initial data assimilation experiment has proven that AWP data improves model performance (Locke et al. 2026), which expands upon previous studies with the airborne DAWN wind lidar that routinely demonstrated positive impact (e.g. Feng et al. 2025; Hristova-Veleva et al. 2021). Future work will involve improving the wind retrieval algorithm to integrate across scan patterns to improve aerosol sensitivity and vertical coverage of wind profiles. Additionally, for future flight campaigns, AWP will integrate over longer durations in the nadir direction, compared to 1-sec employed during Fall 2024 flights, to improve aerosol sensitivity and spatial coherency of vertical wind speed measurements.

AWP is expected to be the NASA Earth Science Division's primary airborne wind profiling sensor over the



513 coming years and beyond. AWP will be flying aboard the NASA's Boeing 777 during its maiden airborne science
 514 campaign called the North American Upstream Feature-Resolving and Tropopause Uncertainty Reconnaissance
 515 Experiment (NURTURE) in January-February 2027 (NASA ESPO, 2025). NURTURE seeks to advance knowledge
 516 of the processes that lead to extreme high-impact weather events during the winter, such as severe cold air outbreaks,
 517 windstorms and hazardous seas, snow and ice storms, sea ice breakup, and extreme precipitation. Beyond NURTURE,
 518 we expect AWP to be especially relevant for campaigns focused on understanding and improving prediction of aerosol,
 519 dust, smoke, and pollution transport, cloud formation/evolution, PBL turbulence, dynamics, and fluxes, wildfire
 520 dynamics, cyclones, severe thunderstorms, and many other phenomena and processes.

521

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533

534 **Author Contributions**

535 Bedka is the science PI for AWP. He led instrument operations aboard the aircraft, and development of AWP retrievals
 536 and scientific analyses conducted by Khlopenkov and Cooney. Marketon is the engineering PI for AWP who led
 537 instrument development and aircraft integration. Applin led laser integration and optimization, in collaboration with
 538 Wilson and Traore. Wilson optimized telescope performance. Henderson led development development of several
 539 AWP laser modules, and he provided guidance on wind retrievals and lidar operations. Cross provided engineering
 540 support and served as the AVAPS operator and dropsonde data producer. Begay developed instrument control and
 541 data collection software modules, and served as an AWP operator during research flights.

542

543 **Competing Interest**

544 We have no competing interests.

545

546 **Data Availability Statement**

547 AWP data from the NOAA Joint Venture 3-D Wind Demonstration and WH²yMSIE/APEX, as well as the AVAPS
 548 data from WH²yMSIE/APEX are available at NASA LaRC: [https://www-air.larc.nasa.gov/cgi-](https://www-air.larc.nasa.gov/cgi-bin/ArcView/whymsie?G3=1)
 549 [bin/ArcView/whymsie?G3=1](https://www-air.larc.nasa.gov/cgi-bin/ArcView/whymsie?G3=1)



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Appendix A: AWP Data Examples from Other Flights

AWP curtains for other NOAA 3-D Wind Demo and WH²yMSIE/APEX flights not discussed in either Part 1 or 2 of the paper are shown in Figures A1-A4, illustrating the wide variety of aerosol backscatter and wind conditions sampled by the flights. The highest wind speeds were measured in Quebec, Canada on 3 October, where 80+ m/s speed was present in the jet stream. A thick wildfire smoke plume was also observed on this day between 2 and 5 km altitude from 1420-1510 UTC.

A flight on 26 September sampled the environment around Hurricane Helene as it was approaching landfall on the Florida Gulf Coast. The transit from Hampton, VA to the outer rain bands of the storm over the Gulf of Mexico (Flight 1) featured an aerosol rich environment and a nearly complete layer of successful wind retrievals. The region near the storm was quite cloudy, requiring many altitude changes to allow lidar pulse penetration to the surface.



625 Hurricane-force winds exceeding 35 m/s were measured above a 1 km altitude over the Florida peninsula on the
 626 eastern side of the storm circulation (Flight 2).

627 Several flights featured AWP rapid scanning with an emphasis on studying lower tropospheric and PBL dynamics.
 628 On 8 October, the G-3 overflew a region with nine active wind energy lease areas and ground-based PBL measurement
 629 sensors over southern New England within the NOAA-DOE Wind Forecast Improvement Project – 3 domain (WFIP-
 630 3), sampled by AWP with 1.5 sec/LOS. This flight also collected detailed PBL measurements over southeastern
 631 Virginia at end of the flight. Like the 9 November flight described above, the 8, 12, 14 November flights were PBL
 632 and cloud-process focused flights with repeated tracks over small domains offshore of central CA, where AWP
 633 measured 3-D wind vectors at up to 2.5 sec intervals. After 2215 UTC on 7 November, AWP measured wind vectors
 634 every 3 secs instead of every 7 secs like earlier in the flight to capture higher detail in a wildfire smoke plume from
 635 the Ventura County, California “Mountain Fire” which reduced SNR and successful retrieval throughout the column
 636 (L.A. Times, 2024).

637 On some flights such as 26 September Flight 1 and 27 October, clouds provided signal for wind retrieval over a
 638 layer several km deep. Wind speed varied by up to ~30 m/s throughout the cloud depth in some instances. Though
 639 opaque cloud limits wind measurement to near cloud top, semi-transparent cirrus can provide strong and deep signal
 640 return for Doppler wind lidar profiling.

641 Many flights featured vertical coverage of successful wind retrievals exceeding 75% of the column (in the absence
 642 of cloud), while some others had notably reduced coverage. SNR regularly exceeded 100 (20 dB) in the PBL which
 643 is very strong signal relative to the minimum of 2.8 (4.47 dB) required for wind retrieval (Bedka et al. 2026). SNR
 644 decreased to levels between 1 and 100 above the PBL where aerosol concentrations were lower. Gaps in successful
 645 wind retrieval most often occurred in the 4-8 km layer which typically had the lowest aerosol concentration (Section
 646 5.5). Four flights on 1, 27, 30 October, and 7 November, featured environments with the weakest aerosol backscatter.
 647 As discussed in Section 3, pulse integration duration has significant impact on backscatter sensitivity, which modulates
 648 wind retrieval success. Experience with the 15 November flight data featured in Part I of this paper (Bedka et al. 2026)
 649 indicates that gaps in wind coverage from other flights could be partially filled with longer integration via merging
 650 multiple adjacent AWP scans. Nevertheless, “clean”, aerosol-free layers present the greatest challenge to a CDWL.
 651 HYSPLIT modeling of clean mid-tropospheric airmasses over the Pacific indicated that they typically spend several
 652 days lingering in the central Pacific where there are no local aerosol sources aside from sea spray or other oceanic
 653 biogenic aerosols (not shown). Aerosol rich airmasses were rapidly transported from Asia or traversed over North
 654 America.

655 The AWP INS/GPS unit malfunctioned at the end of the 3 October flight which forced instrument downtime and
 656 inhibited three AWP - sonde comparisons. INS/GPS uncertainty throughout the 3 and 16 October, and 20 September
 657 flights inhibited reliable vertical motion retrieval. Laser pulse energy was a little lower on the 27 October flight (~34
 658 mJ vs ~40 on other flights) while the AWP operator was doing some instrument experimentation which reduced SNR
 659 and the depth of successful wind retrieval.

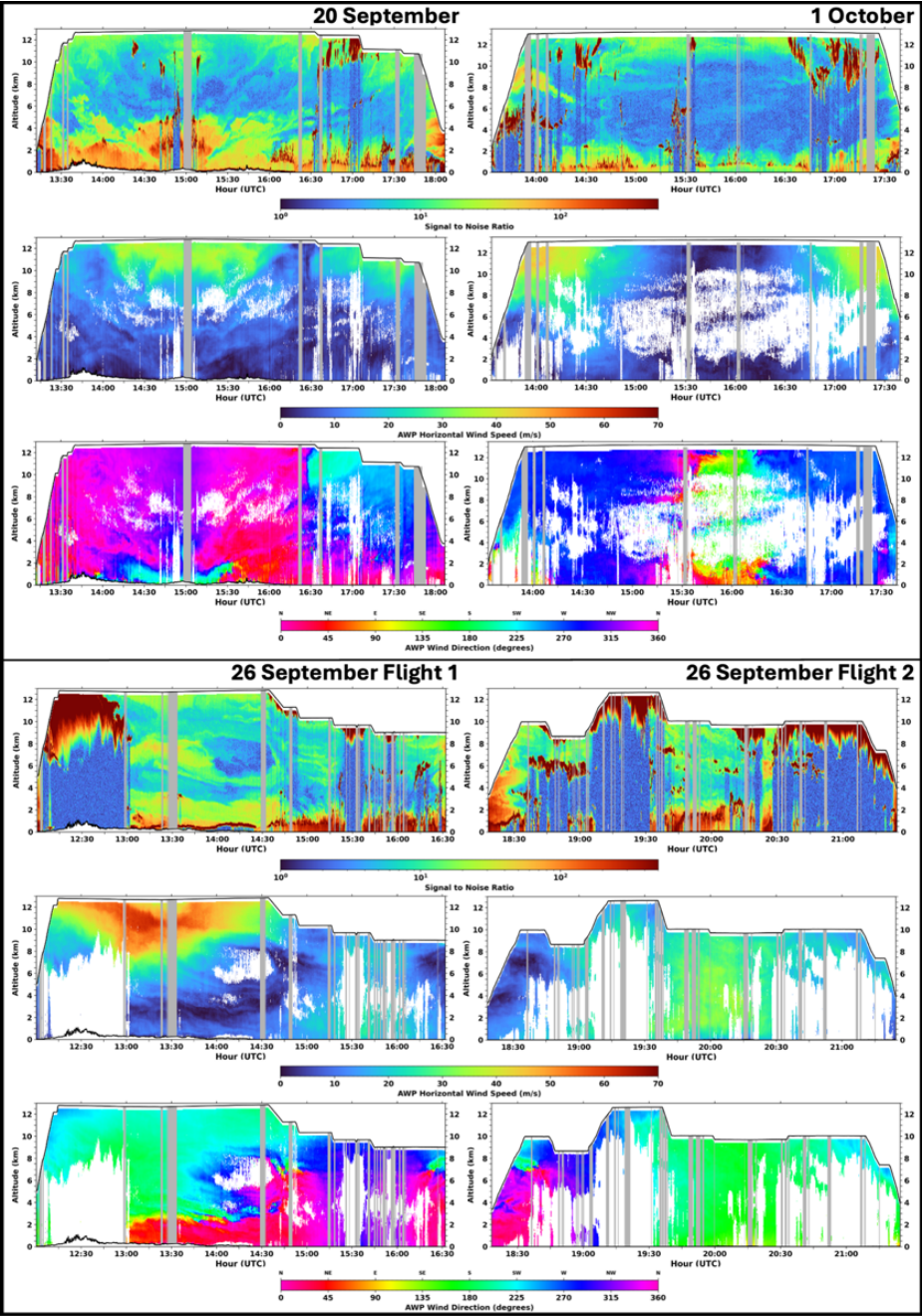


Figure A1: SNR, wind speed, and wind direction curtains from the remaining September 2024 NOAA 3-D Wind Demonstration flights based out of Hampton, VA. White columns indicate aircraft turns where wind profiles are invalid.

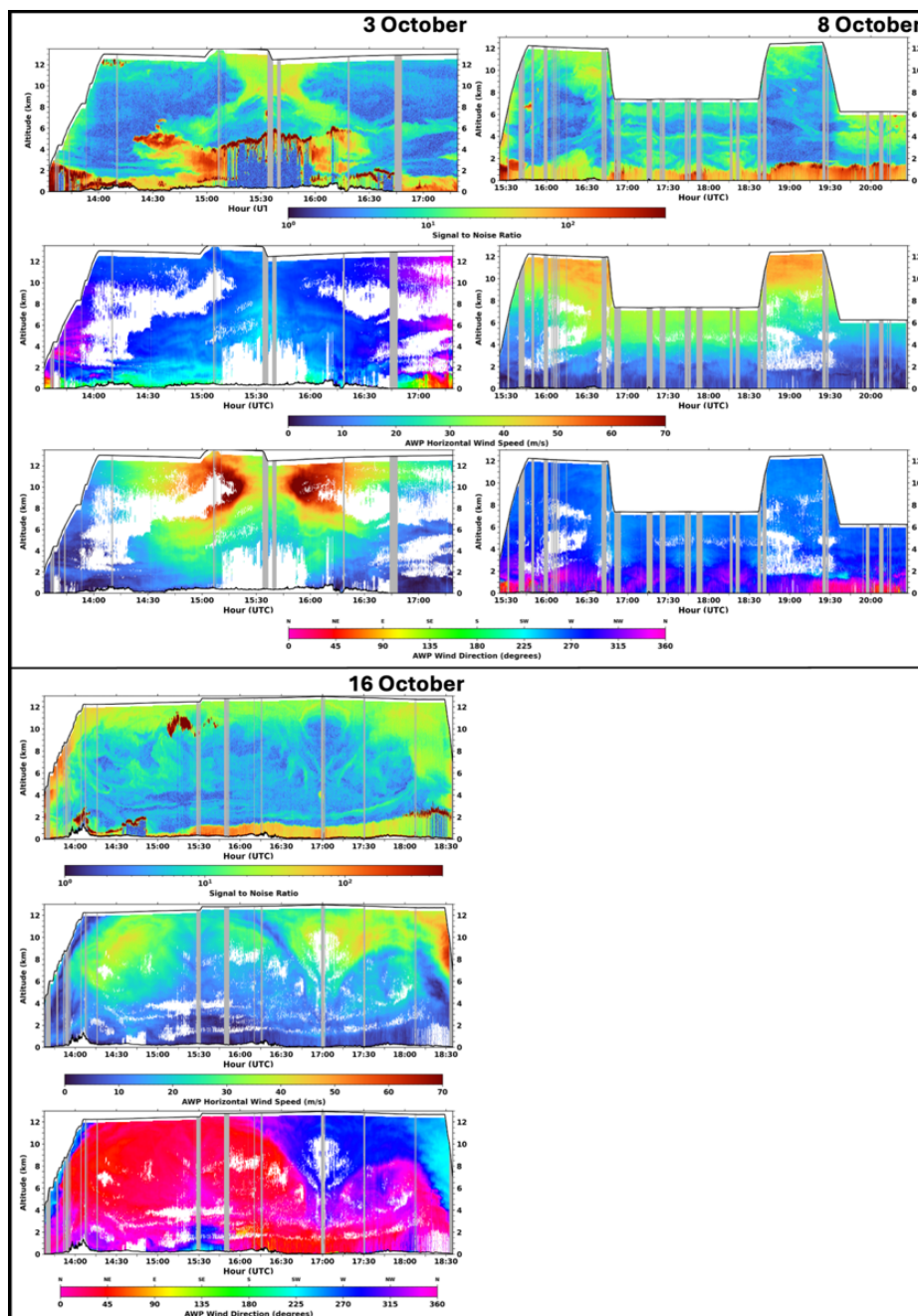


Figure A2: Same as Figure A1 but for the remaining October 2024 NOAA 3-D Wind Demonstration flights.

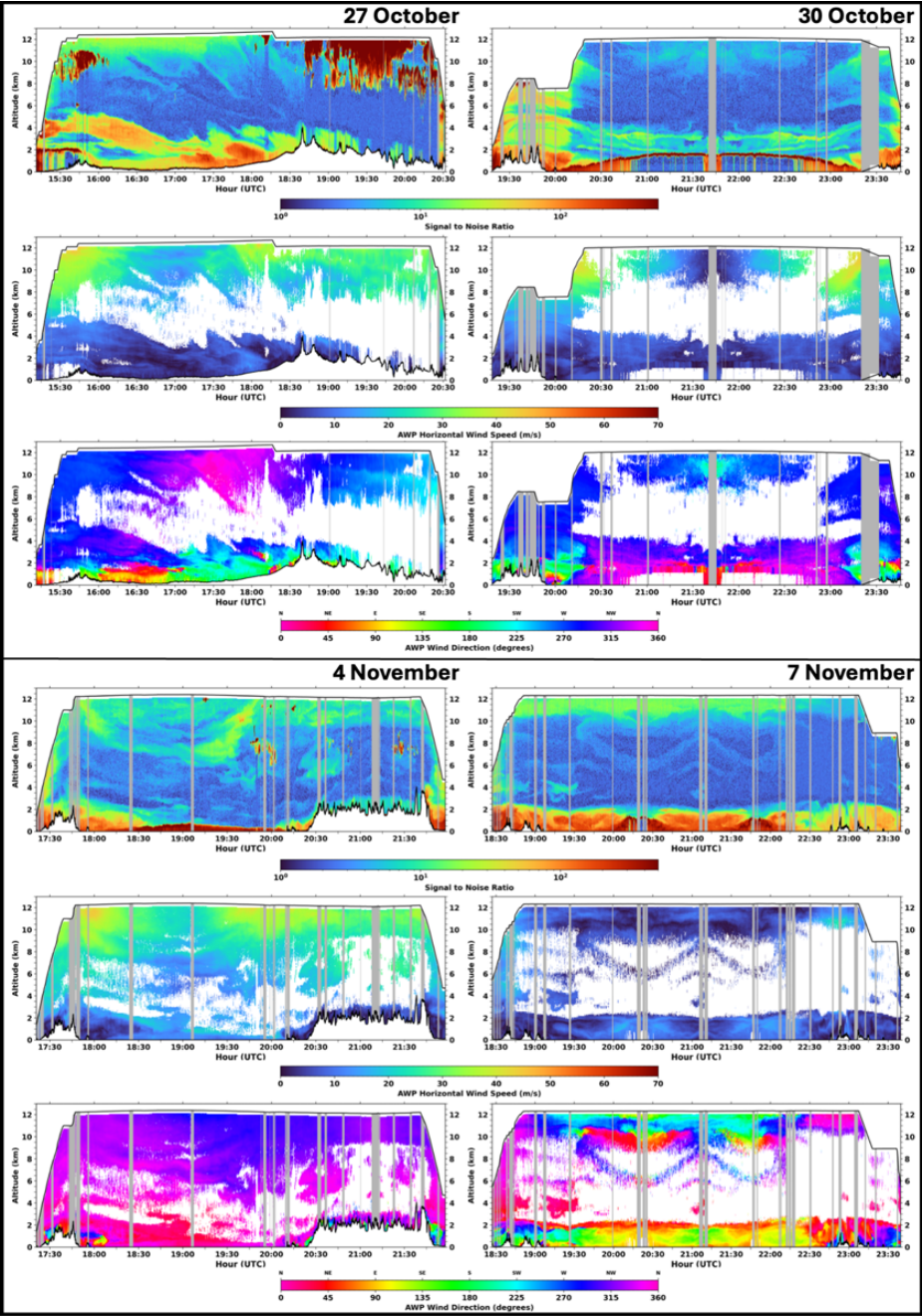


Figure A3: Same as Figure A1 but for four WH²yMSIE/APEX flights.

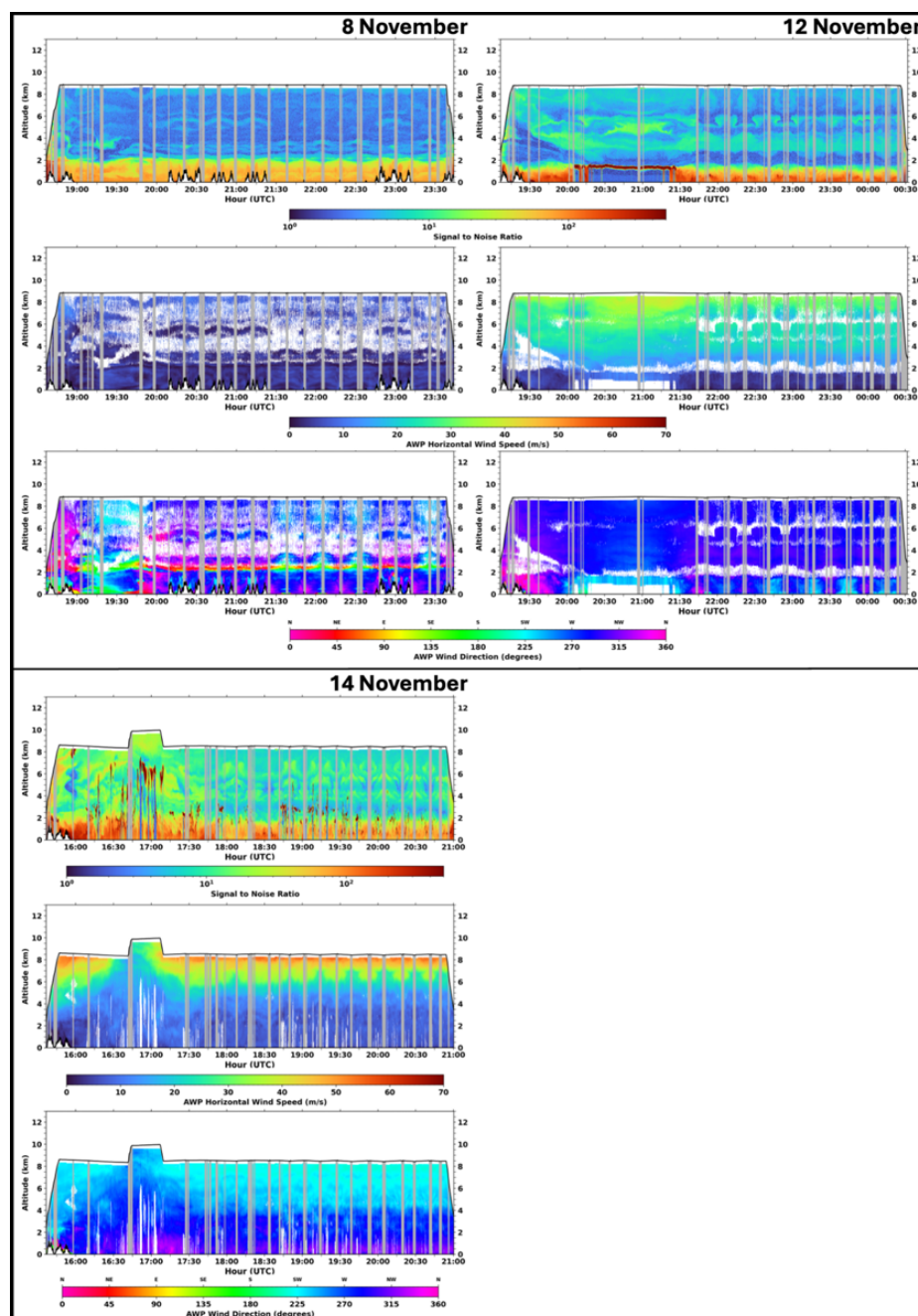


Figure A4: Same as Figure A1 but for four WH²yMSIE/APEX flights that were PBL and cloud-process focused, where AWP retrievals were generated with half the pulses per LOS to better depict wind flow detail.