INSTRUMENT DESCRIPTIONS

The following are descriptions of instruments being flown on the P-3 and the G-IV aircraft and ocean observing platforms and aircraft-deployed expendables planned for deployment before and during the 2025 Atlantic hurricane season include:

1. Flight-level Measurements [P-3s and G-IV]

Data from flight-level measurements are provided at 40 Hz (FAST) and 1 Hz and include: positional information, true air and ground speed, radar and pressure altitude, static and dynamic air pressure, air temperature, dew point temperature, d-value, horizontal and vertical wind, water vapor mixing ratio, and extrapolated surface pressure.

2. Tail Doppler Radar (TDR) [P-3s and G-IV]

The P-3 and G-IV tail Doppler radar (TDR) systems have two solid-state transceivers that simultaneously transmit through the fore and aft antennas. The antennas are canted approximately 20 degrees fore or aft of the plane normal to the fuselage of the aircraft. The pulse repetition frequency is about 3000 Hz, and a long compressed pulse is used to produce sensitivity on the order of -10 dBZ at 10 km. For the P-3 TDR, a short pulse is added to provide data in the first 3 km from the aircraft. The frequency of the radar is in the X-band, with a wavelength of approximately 3 cm, and the beam width is approximately 2 (2.7) degrees for the P-3 (G-IV).

3. Multi-Model Radar (MMR) [P-3s]

The Multi-Mode Radar (MMR) is an X-band, horizontally-scanning pulse Doppler radar system with a range up to 200 n mi, that has multiple operational modes available to the radar operator. Most relevant to hurricane operations is the Hurricane Weather mode (HWX) with turbulence identification. HWX mode shows nine colors referenced to reflectivity (dBZ) on the aircraft display, with the ninth color (white) being designated for turbulence detection when the range is set to less than or equal to 40 n mi. The pulse repetition frequency is about 1000 Hz, but varies according to maximum recording range, and the horizontal and vertical beam widths are 1.4 and 5 degrees, respectively.

4. Stepped-Frequency Microwave Radiometer (SFMR) [P-3s]

SFMR is an airborne microwave radiometer that offers retrieved surface wind speed and rain rate by measuring the surface brightness temperature at nadir at six C-band frequencies between 4.7 and 7.1 GHz. The apparent brightness temperature of the ocean surface is sensitive to the sea surface temperature (SST) and surface foam coverage due to wave breaking; as the surface wind speed increases, so does the coverage of sea foam and, subsequently, the brightness temperature (Nordberg et al. 1971; Rosenkranz and Staelin 1972; Klotz and Uhlhorn 2014). Therefore, brightness temperature increases with surface wind speed for a given SST. A retrieval algorithm uses the relationship between the surface emissivity and wind speed, as well as the relationship between rain emissivity and frequency (using a geophysical model function, GMF, and inversion algorithm) to retrieve surface wind and rain rate estimates along the flight track (Uhlhorn et al. 2007). Klotz and Uhlhorn (2014) corrected a deficiency in the SFMR surface wind speed algorithm for an overestimation of wind speed in weak wind and heavy rain conditions by revising the GMF coefficients for both the rain absorption and wind-induced surface emissivity models. The result was a significantly reduced bias at wind speeds less than hurricane force, and more accurate retrieved rain rates.

During the 2024 hurricane season, comparisons of the SFMR with the Imaging Wind and Rain Airborne Profiler (IWRAP) indicated there were instabilities in the performance of the various SFMR units owned by NOAA. Further investigation led to the discovery of several deficiencies in the computation of the brightness temperatures and variability in the performance of the units with changing temperatures. Therefore, the decision was made in late September 2024 to cease transmission of the SFMR data from the NOAA P-3s until these issues can be corrected.

5. GPS Dropsondes [P-3s and G-IV] and Ocean Platforms & Expendables [P-3s]

The GPS dropwindsonde (dropsonde) is part of the National Center for Atmospheric Research (NCAR) / Earth Observing Laboratory (EOL) AVAPS (Airborne Vertical Atmospheric Profiling System) Dropsonde system that measures vertical profiles of atmospheric temperature, pressure, humidity, and wind speed as it falls from the aircraft to the surface.

Ocean observing platforms and aircraft-deployed expendables planned for deployment before and during the 2025 Atlantic hurricane season include:

1. AXBTs (Airborne Expendable BathyThermograph): measure ocean temperature from the surface to depths of 400 m (shallow water probes) and 800 m (deep water probes)
2. AXCPs (Airborne Expendable Current Profilers): measure ocean temperature and velocity versus depth
3. AXCTDs (Airborne Expendable Conductivity, Temperature, and Depth probes): measure ocean temperature and salinity versus depth
4. NOAA Hurricane Underwater Glider (autonomous underwater vehicle): profiles of temperature, salinity, and density structure from the near ocean surface to 1000 m
5. Saildrone (uncrewed surface vehicle): sea surface temperature and salinity, upper ocean (6-100 m) currents with 2 m resolution, surface air temperature & humidity (2 m), pressure (0.5 m), and wind direction & wind speed (3.2 m), wave height & wave period.
6. Surface drifting buoys [SVPB (https://gdp.ucsd.edu/ldl/svpb/ and DWSB (https://gdp.ucsd.edu/ldl/dwsbd/)]: measure sea surface temperature, pressure, directional wave spectra
7. MicroSWIFT expendable wave buoys: measure significant wave height, peak wave period, dominant wave direction, scalar wave energy spectrum, directional moments of the spectrum.

6. Cloud Microphysics [P-3]

The P-3s are equipped with cloud microphysics probes that image cloud and precipitation particles and produce particle size distributions. The probes flown will include:

1. Droplet Measurement Technologies, Inc. (DMT) (www.dropletmeasurement.com) **Cloud Combination Probe (CCP)** for aerosol and cloud hydrometeor size distributions from 2

to 50 µm, 2-D images and precipitation size distributions between 25 and 1550 µm, liquid water content from 0.05 to 3 g m^{-3}. The CCP includes 2 droplet instruments:

a. **Cloud Droplet Probe (CDP)** for hydrometeor sizes between 3 - 50 µm)

b. **Cloud Imaging Probe (CIP)** for hydrometeor sizes between 25 µm - 1.6 mm, including the **CIP Grayscale (CIP GS)** particle imaging module

2. **Precipitation Imaging Probe (PIP)** for hydrometeor sizes between 100 µm and 6.4 mm

3. **Cloud and Aerosol Spectrometer (CAS)** for aerosol and cloud hydrometeor size between 0.5 and 50 µm). The CAS forward resolution is 0.63 - 50 µm, while the backward resolution is 1.6 - 100 µm.

7. Imaging Wind and Rain Airborne Profiler (IWRAP) [P-3]

IWRAP, which is also known as the Advanced Wind and Rain Airborne Profile (AWRAP), consists of two dual-polarized, dual-incidence angle radar profilers operating at Ku- and C-bands, and measures profiles of volume reflectivity and Doppler velocity of precipitation, as well as ocean surface backscatter. For more information regarding the use of IWRAP during this year's HFP, please refer to the following three NESDIS Ocean Winds, Waves, and Precipitation Experiment documents in the Mature Stage Experiment: *Science Goals & Observational Applications*, *Science Description*, and *Flight Pattern Descriptions.*

8. Ka-band Interferometric Altimeter (KaIA) [P-3]

KaIA is a next generation centimetric radar altimeter that provides real-time observations of significant wave height (SWH) of the ocean surface. The instrument is nadir-looking and operates at Ka and Ku bands. KaIA also has the capability to retrieve mean squared slope (MSS), relative ocean height, and wind speed estimates at low wind speeds.

9. The Rain, Ocean and Atmosphere Radar System (ROARS) [P-3]

The ROARS instrument is an X-band and Ku-band electronically scanning radar system. The novel antenna can be electronically pointed from nadir to 60 degrees in elevation over the full azimuth angle range (0-360 degrees). ROARS is currently configured to perform conical and cross-track scans to record volume & surface backscatter and Doppler profiles from precipitation and the ocean surface. This includes wide bandwidth profiles at nadir for altimetry. From these measurements, the precipitation rate, three-dimensional atmospheric wind profiles within precipitation bands, ocean surface vector winds, and significant wave height can be retrieved and mapped.

10. Airborne Doppler Lidar (ADL) [P-3]

The Airborne Doppler Lidar (ADL) is an all-fiber compact Doppler lidar system that operates at a wavelength of 1.55 µm (eye-safe). The nadir-pointing ADL provides vertical air velocity and aerosol/precipitation vertical distributions below the aircraft flight-level. Like other optical instruments, liquid and mixed-phase clouds quickly attenuate ADL signals. ADL provides 200 range-gate measurements with gate sizes selectable from 15 to 60 m.

11. Compact rotational Raman Lidar (CRL) [P-3]

The CRL is powered by a Nd:YAG laser with 50 mJ pulse energy running at 30 Hz. The normal ocular hazard distance of CRL is less than 200 m, which allows eye-safe operation during aircraft normal operation away from airport. It uses a compact, lightweight transmitting- receiving system, which can be easily mounted to the P-3 nadir port. The CRL was initially developed to obtain 2-D distributions of water vapor, aerosols, and clouds and was first deployed on the University of Wyoming King Air (UWKA) in 2010 (Liu et al. 2014). The successful demonstration of CRL led to the development of MARLi. In early 2015, low-J and high-J pure rotational Raman channels (J is the rotational quantum number) were added to provide temperature measurements (Wu et al. 2016).

Although the 50-mJ laser limits water vapor measurements to short range under high solar background conditions, the CRL still can provide excellent data for characterizing the spatial variability of aerosol, water vapor, and temperature during night or under normal solar background conditions. CRL signals are sampled with an A/D card at 250 MHz, which corresponds to a 0.6 m vertical resolution. The temporal/horizontal resolution will be set depending on the application. The data acquisition system is capable of saving individual profiles, which correspond to about 3.6 m horizontal resolution at a typical P-3 cruise speed of 108 m s^{-1}. The highest resolution data is important for studying ocean surface wave characteristics, fine-scale sea spray structure, and ABL height variation. Different post-averaging can be done to improve signal-to-noise ratio as necessary for different atmospheric features. CRL will collect data continuously during P-3 research and operational missions to provide real-time fine-scale environment variations in TC, which are hard to detect with satellite measurements or airborne passive sensors alone. With the current small laser, we expect CRL water vapor and temperature measurements to be limited within 2 km below aircraft altitude without extensive spatial averaging. The instrument can obtain surface aerosol measurements and surface wave structure when the P-3 flies within 3-4 km altitude and is clear of clouds. Such measurements are still valuable to characterize thermodynamics structure and aerosol variations within TC. For example, flights between the eyewall and rainbands can measure the inflow structure within the inner core. CRL also provides aerosol depolarization measurements, which can be used to effectively identify dust aerosols associated with the Saharan Air Layer (SAL).

12. Airborne Radio Occultation (ARO) System [P-3 & G-IV]

The Airborne Radio Occultation (ARO) observation system uses Global Navigation Satellite System (GNSS) signals, including the Global Positioning System (GPS), to retrieve refractivity profile observations continuously during flight, typically 30-45 profiles over a 7-8 hour flight. The ARO receiver and recorder use L-band 1.2-1.5 GHz signals from the existing Science GNSS antenna on the top of the fuselage used for AVAPS on the G-IV. The retrieved refractivity (or bending angle) can be assimilated directly into models, or moisture and temperature profiles can be retrieved subject to a first guess assumption. ARO provides slanted profiles with 400 m vertical resolution roughly 400 km to the side of the flight track to link dropsondes to mid-level features of the larger scale environment. Standard ARO profiles typically capture ~4 km above the surface to flight level, while research mode post-processing can retrieve data to the surface. The final aircraft antenna position and velocity accuracy are 30 cm and ~0.01 m/s, respectively, sampled at 1 Hz, or 10 Hz on request. The accuracy of the profile observations at mid-tropospheric levels is 1% refractivity, 1.5 K and 15-20% specific humidity (Haase et al., 2014). Delivery of the final ARO products after processing is dependent on sufficient staff resources, but the latency is: near-real-time standard ARO w/ 1 Hz positions assuming NOAA real-time data transmission - 1 hour latency. Standard ARO w/ 1 Hz positions assuming post-flight download - 1 day latency. Final post-processed ARO products (verified) - 2 week latency.

References

Klotz, B.W., and E.W. Uhlhorn, 2014: Improved Stepped Frequency Microwave Radiometer Tropical Cyclone Surface Winds in Heavy Precipitation. *J. Atmos. Oceanic Technol.*, **31**, 2392–2408.

Liu B., et al. 2014: Compact airborne Raman lidar for profiling aerosol, water vapor and clouds, *Opt. Express*, **22 (17)**, 20613–20621.

Nordberg, W. J., J. Conway, D. B. Ross, and T. Wilheit, 1971: Measurements of microwave emission from a foam-covered, wind-driven sea. *J. Atmos. Sci.*, **28**, 429–435.

Rosenkranz, P. W., and D. H. Staelin, 1972: Microwave emissivity of ocean foam and its effect on nadrial radiometric measurements. J. *Geophys. Res.*, **77**, 6528–6538.

Uhlhorn, E. W., P. G. Black, J. L. Franklin, M. Goodberlet, J. Carswell, and A. S. Goldstein, 2007: Hurricane Surface Wind Speed Measurements from an Operational Stepped Frequency Microwave Radiomater, *Mon. Wea. Rev.*, **135**, 3070–3085.

Walsh, E. J., I. PopStefanija, S. Y. Matrosov, E. Uhlhorn, and B. Klotz, 2014: Airborne Rain-rate Measurement with a Wide-Swath Radar Altimeter. *J. Atmos. Oceanic Tech.*, **31**, 860–875.

Wu, D., et al., 2016: Airborne compact rotational Raman lidar for temperature measurement, *Opt. Express*, **24**, A1210–A1223.