2018 NOAA/AOML/HRD Hurricane Field Program - IFEX

INSTRUMENT DESCRIPTIONS

The following are descriptions of instruments being flown on the P-3 and the G-IV aircraft during the season.

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

The P-3 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 exact functioning of the TDR for the hurricane season is still being developed. It is expected the single pulse repetition frequency will be about 3000/sec, and a long compressed pulse will be used to produce sensitivity on the order of -10 dBZ at 10 km. A short pulse will be 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 degrees.

The G-IV tail Doppler radar system has two transceivers that use traveling wave tube amplification. They transmit simultaneously through the fore and aft antennas. The antennas are canted approximate 20 degrees fore or aft of the plane normal to the fuselage of the aircraft. The single pulse repetition frequency will be about 3000/sec and a long compressed pulse provides sensitivity on the order of -10 dBZ at 10 km. There is no short pulse, so there are no data recorded within 3 km range of the radar. The frequency of the radar is in the x-band, with a wavelength of approximately 3 cm. The beam width is approximately 2.7 degree.

3. Lower Fuselage (LF) Radar [P-3]

TBD

4. Stepped Frequency Microwave Radiometer (SFMR) [P-3 and G-IV]

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 4.6 and 7.2 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 (using a geophysical model function, GMF, and inversion algorithm) to retrieve surface wind estimates along the flight track

(Uhlhorn et al. 2007). Recently, 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.

This season a dedicated SFMR experiment will utilize a second SFMR mounted on the P-3 to collect data at high-incidence roll angles. The operational SFMR will be collecting off-nadir data at horizontal polarization and the second SFMR will collect off-nadir data at vertical polarization, which simulates data that the SFMR would collect when the aircraft pitches. The goal is to develop corrections in the SFMR algorithm to obtain measurements of wind speed when the aircraft pitch and roll angle exceeds ±5°, which are currently not reported. A second objective in the SFMR experiment is to verify measurements from the SFMR on the G-IV against those from the operational SFMR on the P-3.

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5. GPS Dropwindsonde [P-3 and G-IV] and Ocean Profilers [P-3]

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.

Possible ocean profiling probes (to measure ocean temperature and salinity profiles) that could be used this season include: AXBTs (Airborne Expendable BathyThermograph), AXCPs (Airborne Expendable Current Profilers), and AXCTDs (Airborne Expendable Conductivity, Temperature, and Depth).

6. Cloud Microphysics [P-3]

The P-3 is equipped with cloud microphysics probes that image cloud and precipitation particles and produce particle size distributions. The probes flown include the 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}), Precipitation Imaging Probe (PIP) (for hydrometeor sizes between 100 µm and 6.2 mm), and the Cloud and Aerosol Spectrometer (CAS) (for aerosol and cloud hydrometeor size between 0.5 and 50 µm).

7. Doppler Wind LIDAR (DWL) [P-3]

7.1 Techincal Details

Due to operational instrument limitations, only limited continuous high-resolution wind observations exist in the TC boundary layer and in regions of low or no precipitation. A coherent-detection Doppler wind profile (P3DWL) system will be installed on the NOAA P-3 for the season and can collect wind profiles through the detection of aerosol scatters motion in areas of optically thin or broken clouds or where aerosols are ~1 micron or larger. In addition to potential improvement due to assimilation into numerical weather models, these measurements may shed light on physical processes in data sparse regions such as in the hurricane boundary layer, Saharan Air Layer (SAL), regions in-between rainbands, and in the ambient tropical environment around the TC.

The DWL is capable of performing a variety of scanning patterns, both above and below the aircraft. Depending on the scanning pattern, the vertical resolution of the wind proifiles is 25-50 m and the horizontal resolution is 1-2 km. Below the aircraft, the instrument can observe winds at or near the surface (~25 m). When sampling above the aircraft, it can observe as high as ~14 km (in the presence of high cirrus). However, in the presence of optically thick convection or within ~400 m of the instrument, the DWL is unable to collect measurements.

The DWL was used in the West Pacific field campaign THORPEX in 2008 where data collected in the near-TC environment improved both track and intensity forecasts. DWL has successfully retrieved continuous observations in high-wind regimes where few measurements are typically collected. Measurements obtained in the boundary layer provide a means of evaluating near-surface momentum field where surface energy exchange is an important process for hurricane evolution. The DWL provides observations that allow for axisymmetric wind field coverage due to its complementary relationship to TDR. This distribution of measurements is theorized to improve hurricane prediction by capturing asymmetries in the vortex.

7.2 Pattern/Module Requirements

DWL scanning pattern criteria are as follows:

- Weak or asymmetric TCs: Four scans down 20 with a 5 second nadir followed by one scan up 20 with 5 second vertical. If signal strength in the up scan is very weak, only scan down.
- Boundary layer/SEF measurements: DN 20 mode (12 point stepstare) with 5 second vertical stare between 360 degree scans.
- SAL: Two scans at down 20 with a 5 second nadir followed by one scan up 20 with 5 second vertical. If signal strength in the up scan is very weak, change to 4 scans down, one scan up. If no signal upward, only scan down.

7.3 Analysis Strategy

An analysis of TC structure will be performed by evaluating boundary layer height, inflow characteristics (layer depth, strength of the peak, angle), and gradient wind in secondary eyewall. An analysis of SAL includes capturing the details of the easterly jet. To evaluate the impact of DWL observations on hurricane forecasts, OSE's will be performed using both line-of-sight and post-processed vector wind data. Observations collected from the DWL in conjunction with other observing platforms will be used to evaluate the model representation of different aspects of a TC, such as the boundary layer, SAL intrusions, and sheared TCs. Multiple modeling frameworks are expected to be used.

8. Compact rotational Raman LIDAR (CRL) [P-3]

8.1 Technical Details

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. As illustrated in Fig. CRL-1, the CRL integrated telescope, laser, and receiving system fits into a box of 13x20x26 inches weighing approximately 100 lbs. 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 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).

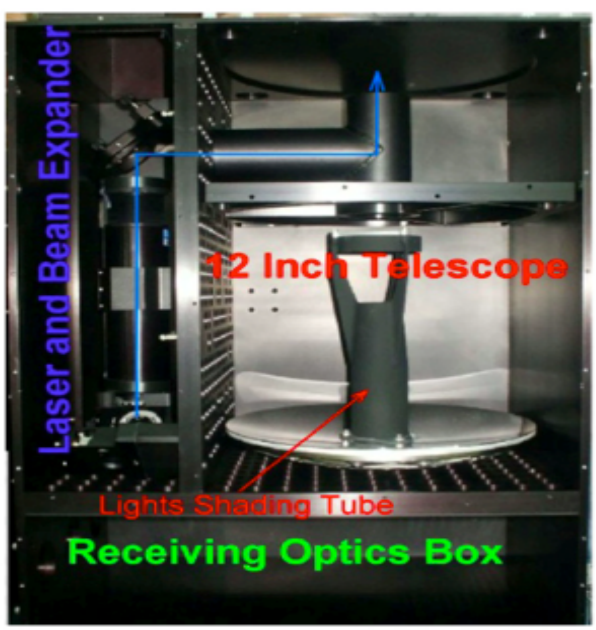

Figure CRL-1. *Photograph of CRL inner structure. Different parts of lidar system are highlighted.*

Although the 50-mJ laser limits water vapor measurement 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. The CRL was deployed onboard the UWKA from 1 June to 15 July 2015 over the Great Plains during the recent Multi-Agency PECAN (Plains Elevated Convection At Night) deployment. The CRL operated reliably and collected 120-hrs of excellent data around convective clouds. Fig. CRL-2 shows aerosol, water vapor, and temperature measurements obtained by the CRL on 1 July 2015. The co-varying of aerosol, water vapor, and temperature are clearly illustrated by over 4 hours of measurements around a Mesoscale Convective System (MCS). The first hour of data shows gradual variations of temperature, water vapor, and aerosol when the UWKA flew from the base station to the storm. The UWKA then flew a tight racetrack pattern to approach the storm, resulting in symmetric water vapor mixing ratio (WVMR), aerosol lidar scattering ratio (LSR) patterns. Around the storm, the spatial variations of WVMR and LSR are much sharper. From 0700–0800 UTC, the UWKA flew across the boundary of the cold pools, which had over 3°C temperature drop at the flight level, three times. Resolving such fine-scale 2-D variations of aerosol, water vapor, and temperature is only possible with airborne Raman lidar measurements.

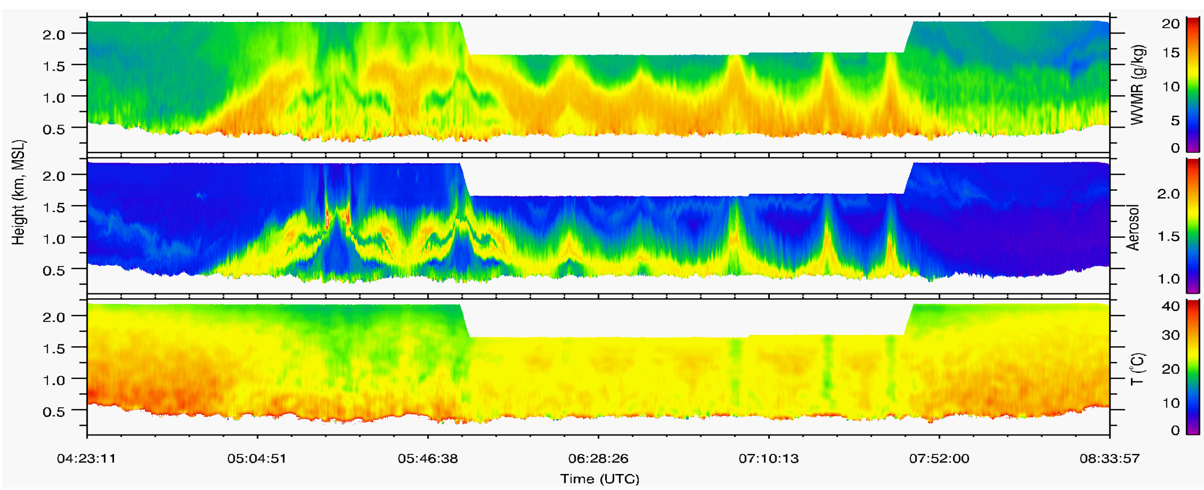

Figure CRL-2. *CRL measurements of WVMR (top), aerosol LSR (middle), and temperature (bottom) from repeated sampling of the inflow into a MCS on 1 July 2015. The white areas at the lower boundary of the image indicate the surface.*

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.

8.2 Motivation

Despite potential benefits with increasing model horizontal resolution, TC forecast models still face many challenges in intensity prediction (e.g., Bender et al. 2007; Davis et al. 2008; Tallapragada et al. 2014; Zhang et al. 2017). As the horizontal resolution of operational hurricane forecast models approaches 2 km (and eventually reaches 1 km), these models begin to resolve TC inner-core and boundary layer structures. However, TC atmospheric boundary layer (ABL) structures are challenging to observe. Since 1997, Global Positional System (GPS) dropsondes have been the main tool to provide ABL structure (e.g., Franklin et al. 2003). Nonetheless, dropsonde observations are limited by sample size and coarse horizontal resolution, such that previous ABL studies mainly used a composite approach (Barnes 2008; Zhang et al. 2011; 2013). High-resolution temperature and water vapor measurements are only available at the flight level, which is typically above the boundary layer. Although unmanned aircraft based observations will fill some gaps in the near future (Cione et al. 2016), fine-scale two-dimensional (2-D) thermodynamic structures of TC ABL are still lacking.

To transform our capabilities for characterizing the TC ABL thermodynamics, we propose to install the CRL, developed at the University of Wyoming, on a NOAA P-3 aircraft to simultaneously provide fine-scale temperature, water vapor, and aerosol profiles when P-3 is out of clouds. Due to small laser used for CRL, the measurement range may be limited to within 2-km below P-3. Measured ABL structures in TCs will improve our understanding of the physical processes in the TC ABL, which can be used to further upgrade model physics representations. The new observations also can be used to initialize model simulations and to evaluate model simulation results.

The main objectives of the first CRL deployment on the P-3 are:

1) Characterize the spatial variability of ABL water vapor, temperature, and aerosol vertical structures;
2) Survey environment variability of thermal structure in the lower free troposphere;
3) Characterize sea spray and ocean wave structure under different wind regimes.

8.3. Synergies with other P-3 Measurements

Dropsonde, UAS (Coyote) and CRL, together with P-3 in-situ measurements, will provide detailed measurements of the temperature and water vapor structure. Dropsonde measurements provide essential vertical thermodynamic profiles at a coarse horizontal resolution, while P-3 and UAS in-situ measurements provide high horizontally resolved measurements at discrete heights. CRL 2-D cross-sections of water vapor and temperature (as well as UAS in-situ measurements) could fill data gaps between dropsonde observations and in-situ observations. Combined DWL and CRL measurements also offer an opportunity for a more complete analysis of combined wind and thermodynamic measurements for more effective TC ABL characterization.

8.4. Pattern/Module Requirements

To support studies on air-sea interaction and the ABL, P-3 flights within the ABL or near the altitude of the ABL top are required to provide fine-scale ABL temperature, water vapor, and aerosol structures with the CRL. Typically, to sample the full ABL structure the optimal flight altitude with the inner core is right below cloud base. Such flight pattern will allow us to resolve cold pool, roll structure, ABL top mixing, sea spray and near-surface water vapor and temperature structure. Together with flight-level wind and thermodynamic measurements, surface wind from SFMR, and storm-scale dynamics from radar, we will have a unique dataset to study air-sea interactions and ABL processes.

The data collection should continue during transits to/from storms to not only characterize storm scale inflow structure, but also to improve the initial state of the HWRF model and to validate the boundary layer structures represented in the model.

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).

8.5 Analysis Strategy

The CRL will provide an unprecedented fine-scale water vapor, temperature, and aerosol structures in and around a TC. Using the CRL data together with other measurements from the P-3, the following basic analyses will be produced to study:

1) The TC ABL structures across different scales: Key questions we seek to answer are:
    a. How does the ABL evolve from the outer rainbands to the inner core?
    b. Does deepening of the ABL coincide with TC intensification?
    c. What is the dominant scale of horizontal ABL inhomogeneity?

2) Ocean wave structure and sea spray under different wind regimes: The spectrum analyses of ocean wave heights will be performed to study the variations of transition wave scales between the energy injection spectrum and the inertial spectrum under different near surface wind speeds. Sea spray has been recognized as a key part of air-sea interactions under high wind conditions, but challenging to observe. CRL near surface aerosol structure will be used to study sea spray productions and their impacts on near-surface water vapor and temperature structures, which control sensible and latent heat fluxes from ocean.

3) The variations of environmental thermodynamic properties within the lower free troposphere under different TC conditions: The key initial analysis is to understand the interactions of the lower free troposphere and ABL. The vertical distributions of aerosol, water vapor and temperature will be used to determine ABL top heights and vertical mixing across them. Other than the entrainment/mixing processes across the

ABL top, the exchange of the free troposphere and ABL can occur through different scale circulations, especially around the convective rainband. The fine-scale 2-D structures of water vapor, temperature, and aerosol will allow us to identify such processes.

4) The observed fine-scale ABL structure and evaluate high-resolution hurricane model simulations against those observations (e.g., Zhang et al. 2015): The ultimate goal of improved TC ABL observations is to advance our understanding of ABL processes in the TC environment and to improve their simulations in weather forecast models. As the first step to achieve the goal, we will use observations to evaluate TC ABL structures simulated by high-resolution HWRF focusing on how HWRF capturing ABL structure variations between the inner core and the outer rainband and under different TC intensities.

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9. 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. See the NESDIS OCEAN WINDS portion of the New Observing Systems (NOS) (Science Objective #3) objective in the Mature Stage Experiment for the goals of use of IWRAP for this year's HFP.

10. Wide Swath Radar Altimeter (WSRA) [P-3]

The WSRA (developed by ProSensing: http://www.prosensing.com) is an instrument that provides for measurements of sea surface topography and rain rate. The WSRA measures the sea surface topography by determining the range to the sea surface in 80 narrow beams spread over ±30° in the cross-track direction (Walsh et al. 2014). Using measurements of sea surface topography and backscattered power, the WSRA offers real-time information on significant wave height, ocean directional wave spectra, the mean square slope of the ocean surface, and rain rate. The mean square slope (i.e., the sea surface small-scale roughness) responds to changes in wind speed, and can be determined by the variation of the radar-backscattered power with incidence angle. Data collected are transmitted to NHC for operational use.

References

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11. Coyote UAS

The Coyote is an electric-powered unmanned aircraft with 1-hour endurance and is built by the Raytheon Company (formerly Sensintel Corporation and British Aerospace Engineering [BAE]). In many ways, this unmanned aerial system (UAS) platform can be considered a 'smart GPS dropsonde system' since it is deployed in similar fashion and currently utilizes a comparable meteorological payload similar to systems currently used on the G-IV and P-3 dropsonde systems. The Coyote can be launched from a P-3 sonobuoy tube in flight, and collects in-situ measurements of temperature, relative humidity, pressure, and remotely senses sea surface temperature. The three-dimensional wind field can be determined using the aircraft's GPS changes in position. Unlike the GPS dropsonde, however, the Coyote UAS can be directed from the P-3 to specific areas within the storm circulation (both in the horizontal and in the vertical). Furthermore, Coyote observations are continuous in nature and give scientists an extended look into important small-scale thermodynamic and kinematic physical processes that regularly occur within the near-surface boundary layer environment. The Coyote, when operated within a hurricane environment, provides a unique observation platform from which the low-level atmospheric boundary layer environment can be diagnosed in great detail.