# MATURE STAGE EXPERIMENT
*Science Description*

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**Experiment/Module:** NESDIS Ocean Winds

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**Requirements:** Categories 2–5

**Mature Stage Science Objective(s) Addressed:**

1) Develop and refine measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment [*IFEX Goal 2*]

**Motivation:** This effort aims to improve our understanding of microwave scatterometer retrievals of the ocean surface wind field and to evaluate new remote sensing techniques/technologies. The NOAA/NESDIS/Center for Satellite Applications and Research in conjunction with the University of Massachusetts (UMASS) Microwave Remote Sensing Laboratory, the NOAA/AOML/Hurricane Research Division, and the NOAA/OMAO/Aircraft Operations Center have been conducting flight experiments during hurricane season for the past several years. The Ocean Winds experiment is part of an ongoing field program whose goal is to further our understanding of microwave scatterometer and radiometer retrievals of the ocean surface winds in high wind speed conditions and in the presence of rain for all wind speeds. This knowledge is used to help improve and interpret operational wind retrievals from current and future satellite-based sensors. The hurricane environment provides the adverse atmospheric and ocean surface conditions required.

The Imaging Wind and Rain Airborne Profiler (IWRAP), which is also known as the Advanced Wind and Rain Airborne Profiler (AWRAP), was designed and built by the University of Massachusetts and is the critical sensor for these experiments. IWRAP/AWRAP consists of two dual-polarized, dual-incidence angle radar profilers operating at Ku-band and at C-band, which measure profiles of volume reflectivity and Doppler velocity of precipitation in addition to the ocean surface backscatter. Currently the C-band portion of IWRAP has been installed with the prototype antenna for EUMETSAT's ASCAT follow-on satellite sensor that will be launched on EPS-SG. This antenna, on loan from ESA, is a dual-polarized slotted waveguide antenna which allows us to measure the cross-polarized response of the ocean surface, which is a new capability being implemented for the ASCAT follow-on sensor. The Stepped-Frequency Microwave Radiometer (SFMR) and GPS dropsonde system are also essential instrumentation on the NOAA-P3 aircraft for this effort. The NASA GORE (GNSS reflection) system has also been utilized to collect measurements to support the NASA CYGNSS mission, but future plans call for utilizing an improved GNSS-R receiver being developed by the CYGNSS project at the University of Michigan. A Ka-band radar system is being currently developed to enable finer resolution measurements at the air-sea boundary to help decouple what is happening at the interface in the storm environment.

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**Background:** The Ocean Winds P-3 flight experiment program has several objectives:

- Calibration and validation of satellite-based ocean surface vector wind (OSVW) sensors such as ASCAT, ScatSat, OceanSat-3 and the new CYGNSS mission that uses GNSS-R techniques to infer the ocean wind speed.
- Product improvement and development for current and planned satellite-based sensors (ASCAT, ScatSat, OceanSat-3, CYGNSS and SCA)
- Testing of new remote sensing technologies for possible future satellite missions (risk reduction) such as the dual-frequency scatterometer concept. A key objective for this year will be the collection of cross-polarized data at C-band to support ESA and EUMETSAT studies for the ASCAT follow-on (SCA), which will be part of their EPS-SG satellite series.
- Advancing our understanding of broader scientific questions such as:
    - Rain processes in tropical cyclones and severe ocean storms: the coincident dual-polarized, dual-frequency, dual-incidence angle measurements would enable us to improve our understanding of precipitation processes in these moderate to extreme rainfall rate events.
    - Atmospheric boundary layer (ABL) wind fields: the conical scanning sampling geometry and the Doppler capabilities of this system provide a unique source of measurements from which the ABL winds can be derived. The advanced digital receivers and data acquisition system recently implemented will enable to potentially retrieve the wind and reflectivity profiles essentially to the surface.
    - Analysis of boundary layer rolls: linearly organized coherent structures are prevalent in tropical cyclone boundary layers, consisting of an overturning “roll” circulation in the plane roughly perpendicular to the mean flow direction. IWRAP has been shown to resolve the kilometer-scale roll features, and the vast quantity of data this instrument has already collected offers a unique opportunity to study them.
    - Drag coefficient, Cd: extending the range of wind speeds for which the drag coefficient is known is of paramount importance to further our understanding of the coupling between the wind and surface waves under strong wind forcing, and has many important implications for hurricane and climate modeling. The advanced digital receivers and data acquisition capability allows us to retrieve wind and reflectivity profiles closer to the ocean surface, which can also be exploited to derive drag coefficients by extrapolating the derived wind profiles down to 0 m altitude.

**Hypotheses:**

1. We don’t fully understand what is happening at the air-sea interface in extreme storm conditions, but it should be possible to characterize this with the proper instrumentation and data collection methodologies.

**Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information):**

**P-3 Pattern 1:** The sensitivity of the IWRAP/AWRAP system defines the preferred flight altitude to be below 10,000 ft to enable the system to still measure the ocean surface in the presence of rain conditions typical of tropical systems. With the Air Force Reserve typically flying at 10,000 ft pressure altitude, we have typically ended up with an operating altitude of 7,000 ft radar. Operating at a constant radar altitude is desired to minimize changes in range and thus measurement footprint on the ground. Higher altitudes would limit the ability of IWRAP/AWRAP to consistently see the surface during intense precipitation, but these altitudes would still provide useful data, such as measurements through the melting layer, to study some of the broader scientific questions.

*Maneuvers:* Straight and level flight with a nominal pitch offset unique to each P-3 is desired during most flight legs. Constant bank circles of 10–30 degrees have been recently implemented, as a method to obtain measurements at incidence angles greater than the current antenna was configured for. These would be inserted along flight legs where the desired environmental conditions were present. Generally, it would be a region of no rain and where we might expect the winds to be consistent over a range of about 6–10 miles, about the diameter of a circle. This would not be something we would want to do in a strong wind gradient region where the conditions would change significantly while circling.

*Patterns:* Typically, an ideal Ocean Winds flight pattern would include a survey pattern (Figure-4 or Butterfly) that extended about 50 n mi (95 km) from the storm center. The actual distance would be dictated by the storm size and safety of flight considerations. Dependent upon what was observed during the survey pattern radial legs in and out of different sectors of the storm focusing on different wind and/or rain conditions.

*Storm Types:* The ideal Ocean Winds storm would typically be in a hurricane (category 1 and above) where a large range of wind speeds and rain rates would be found. However, data collected within TDs and TSs would still provide useful observations of rain impacts on the surface observation.

**Links to Other Mature Stage Experiments/Modules**: NESDIS Ocean Winds can be flown in conjunction with following *Mature Stage* experiments and modules: Eye-Eyewall Mixing, Gravity Wave, SEF, and SFMR Modules, TC Diurnal Cycle Experiment, TC in Shear Experiment, TDR Experiment, Synoptic Flow Experiment, NESDIS JPSS Satellite Validation Experiment, and ADM-Aeolus Satellite Validation Module.

**Analysis Strategy:** The analysis depends on the scientific question under investigation, but it usually involves comparing the normalized radar cross-section (NRCS) measured by IWRAP to another sensor on a storm-relative grid. Instruments used in the past include SFMR, dropsondes, and satellite observations (Sapp et al. 2013, 2016b,a, 2018; Guimond et al. 2018). Improvements to satellite geophysical model functions have also been developed from SFMR wind speed collocation with satellite observations (Soisuvarn et al. 2013). High-resolution 3D wind field structures in the hurricane boundary layer is also included in the analysis (Guimond et al. 2018). The behavior of cross-polarized NRCS has been studied recently at C-band in extremely strong wind conditions (Sapp et al. 2018, 2016a) using SFMR, dropsondes, and a storm-relative gridding scheme. Cross-polarized NRCS at Ku-band at hurricane-force wind speeds have only been measured by IWRAP in the 2018 hurricane season, and that will continue. New elements will include: collocation of wave height measurements from an on-board Ka-band interferometric altimeter to analyze the dependence of NRCS on wave height and sea spray.

**References:**

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