MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: NESDIS Ocean Winds

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Requirements: Invest– category 5

Plain Language Description: To improve our understanding of microwave retrievals of the ocean surface and atmospheric wind fields, and to evaluate new remote sensing techniques/technologies. To help validate satellite-based sensors of the ocean surface in extreme conditions and reduce risk for future satellite missions. To provide forecasters with near-real-time hurricane boundary layer profiles, where possible.

Mature Stage Science Objective(s) Addressed:

1) Collect observations targeted at better understanding internal processes contributing to tropical structure and intensity change [*APHEX Goals 1, 3*].
2) Collect observations targeted at better understanding the response of tropical to their changing environment, including changes in vertical wind shear, moisture and underlying oceanic conditions [*APHEX Goals 1, 3*].
3) Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in tropical cyclones. These measurements include improved three-dimensional representation of the tropical cyclone wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds and underlying oceanic conditions [*APHEX 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 Ocean Winds experiment is part of an ongoing field program for which the goal is to further our understanding of microwave scatterometer and radiometer retrievals of the atmospheric and 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.

Background: The NOAA/NESDIS/Center for Satellite Applications and Research in conjunction with the University of Massachusetts (UMASS) Microwave Remote Sensing Laboratory, Tomorrow.io (formerly Remote Sensing Solutions), the NOAA/AOML/Hurricane Research Division, and the NOAA/OMAO/Aircraft Operations Center have been conducting flight experiments during the hurricane season for the past several years. 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. IWRAP 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 with a 30m range resolution. Last hurricane season, we installed and operated the azimuthally scanning C-band antenna for the first time since 2014. The Stepped-Frequency Microwave Radiometer (SFMR) and GPS dropsonde system are also essential instrumentation on the NOAA-P3 aircraft for this effort. KaIA, a Ka- and Ku-band interferometric altimeter radar system, will be installed again to enable finer resolution measurements at the air-sea boundary to help decouple what is happening at the interface in the storm environment. The UMASS Simultaneous Frequency Microwave Radiometer (Vilardell Sanchez et al. 2021) is another instrument developed by UMASS to measure ocean surface wind speed and intervening rain rate in steep gradients. The lack of available instrument ports or a wing pod has prevented this instrument from being installed since 2019.

Goal(s): 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, AMSR-2, Oceansat-3, SMAP, SWOT and the 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, OceanSat-3, CYGNSS and SCA)
- Validation of Tomorrow.io's Pathfinder missions (Ka-band satellite radar system) including precipitation profiles and ocean surface altimetry observations (SWH, SSH)
- Participation in the GOMO's CHAOS experiment
- Testing of new remote sensing technologies for possible future satellite missions (risk reduction) such as the dual-frequency scatterometer concept.
- Testing of new real-time airborne remote sensing technologies and transmission to forecasters.
- Advancing our understanding of broader scientific questions such as:
    - Rain processes in tropical cyclones and severe ocean storms: the coincident 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 retrieval of 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. The instruments used by this team have been shown to resolve the kilometer-scale roll

features, and the vast quantity of data the IWRAP instrument has already collected offers a unique opportunity to study them.
- o 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: 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.

1. Stepped Frequency Microwave Radiometer brightness temperatures represent geophysical phenomena different from those sampled by the sources of ground truth used for developing the wind speed and rain rate retrieval processes (specifically, dropsondes and TDR). These differences are due to the significant location difference of the surface and atmospheric winds encountered by the SFMR and the dropsonde and the non-uniform distribution of wind and rain in a tropical cyclone.

2. The operational Stepped Frequency Microwave Radiometer wind speed retrievals are sensitive to rain drop-size distribution and rain rate. The errors in these retrievals are not captured by the current operational GMF.

Objectives:
1. Sample the atmosphere and ocean surface in tropical cyclone wind conditions with varying degrees of rain with IWRAP, KaIA, SFMR(s), and GPS dropsondes.
2. Perform near-real-time significant wave height (SWH) retrievals with KaIA in tropical cyclone conditions and transmit to the ground.
3. Perform near-real-time 3D (atmospheric) and ocean surface vector wind (OSVW) retrievals with IWRAP in hurricane conditions and transmit to the ground.

4. Validate Tomorrow.io's Pathfinder precipitation and altimetry radar mission within and around the tropical cyclone with coincident Ka-band precipitation profiles and altimetry measurements (KaIA) from the aircraft.

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information): This module uses the P-3s, primarily in three patterns: a predictable storm survey pattern (P-3 Pattern #1), a dynamic, weather-targeting pattern (P-3 Pattern #2), and a higher altitude pattern to sample more of the precipitation environment for comparisons with the Pathfinder mission (P-3 Pattern #3). The interest for both is in tropical cyclone winds and both rainy and rain-free environments. The sensitivity of the IWRAP system defines the preferred flight altitude to be below 10,000 ft radar altitude 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 prefer an operating altitude of 7,000 ft radar altitude. 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 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.

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, Rainband Complex Survey, RICO SUAVE, Surface Wind Speed and Significant Height Validation, CHAOS and TC Diurnal Cycle Experiment.

Analysis Strategy: The analysis depends on the scientific question under investigation, but it usually involves comparing the normalized radar cross-section (NRCS), Doppler-derived winds measured by IWRAP, SFMR retrievals, or dropsondes to another sensor on a storm-relative grid while accounting for storm motion. Therefore, we need a regular set of storm center estimates. Most of the presentation is done on the ground, so these storm center fixes are required to be available to the PI and co-investigators on the ground during the flight; vortex data messages (VDMs) seem to be reliable enough. Computing the NRCS involves compensating for the illuminated area on the surface, so keeping a consistent altitude from the ocean surface removes uncertainty associated with this calculation. 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. New elements will include: collocation of wave height measurements from the on-board Ka-band interferometric altimeter (Sapp et al. 2021) to analyze the dependence of NRCS on wave height and sea spray.

References:

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