SATELLITE VALIDATION EXPERIMENT
Science Description

Experiment/Module: **S**ynthetic **A**perture **R**adar **W**ind **I**nspection with **N**OAA-P3 **D**ata (SARWIND) Module

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Requirements: No requirements: flown at any stage of the tropical cyclone (TC) lifecycle including Pre-genesis

Plain Language Description: This experiment seeks to use aircraft observations to better validate high-resolution surface wind speed measurements becoming more frequently available with Synthetic Aperture Radar (SAR) polar orbiting passes. This will be accomplished by coordinating NOAA P-3 flights to occur simultaneously with an orbiting SAR pass near a TC or other ocean environments deemed research relevant to sample the wind and wave interface near the surface.

Satellite Validation Science Objective(s) Addressed:

The overarching objective is to better validate SAR data swaths with other well validated wind field sources on board the NOAA-P3 aircraft at a multitude of TC stages (from Pre-genesis to Major Hurricane intensity).

1. To test and validate new (or improved) satellite technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in TCs. These measurements include improved 2-d surface wind field representation of the hurricane wind field at high horizontal resolution (500-m to 3-km) [*APHEX Goal 2*]

Motivation:
In the last several years there has been a marked increase in high horizontal resolution (500-m) surface wind speed retrieval data available from SAR over Tropical Cyclones. Prior to 2023, SAR wind data was only available for TCs on a limited basis, supported mainly by existing SAR instruments on board of the European's Sentinel-1 and RadarSat2 polar-orbiting satellites. However, in the past year, a slew of SAR satellites have begun to be scheduled on a regular basis by the Canadian Space Agency (CSA) for their Radarsat Constellation Mission (RCM), which provides three additional satellites for capturing SAR-based wind retrievals of the ocean surface. With this increased coverage, many tropical cyclones are being captured by SAR passes as often as 2-3 times per day and could provide more consistent high-resolution and increased temporal coverage of the surface TC wind fields in addition to understanding structural changes in the TC inner core.

While there have been several SAR validation studies using existing data obtained from Sentinel-1 and RadarSat-2 (Shao et al. 2017, Mouche et al. 2019, Knaff et al. 2021), these studies have either focused on a limited number of TCs at various intensities with limited sample size, or just a single case study. In addition, most validation methods have focused on how SAR winds compare to only Stepped Frequency Microwave Radiometer (SFMR) and to better understand how well these remote sensing wind speed observations verify, as it is prudent to compare their values against a multitude of different wind based validation datasets. Moreover, it is also important to validate how well SAR-based derived surface winds also sample lower wind speed environments, where contamination from convection or shoaling effects near islands or other land masses could bias the brightness of the ocean surface retrieved from the instrument.

Background:
Synthetic Aperture Radar onboard polar orbiting satellites use radar reflectivity from normalized radar cross sections (NRCS) to determine surface roughness of the ocean. Waves on the ocean surface produce radar backscatter that, through a Geophysical Model Function (GMF), a wind speed retrieval can be obtained. In typical ocean conditions, winds generate small capillary waves that are optimally picked up by C-band radar wavelengths on many SAR capable satellites. The primary advantage of SAR is how imagery is created by using consecutive time steps along the satellite azimuth, which creates a 'synthetic' antenna with a ~3 km length, emulating the signal beam intensity far more powerful than the real antenna length. Thus, the NRCS backscatter imagery produced by this method is of much higher resolution (~500 m) than traditional scatterometer-based wind retrieval data (~12-25 km) while still maintaining a fairly large horizontal swath length (~500 km).

Recently, a new GMF was developed by NOAA-STAR to help obtain SAR wind-retrievals from the Radarsat Constellation Mission (RCM), a Canadian Space Agency (CSA) run campaign. Adapting the new GMF to this mission helped to provide 3 additional SAR satellites in addition to RadarSat2 and Sentinel-1, vastly increasing the temporal coverage for SAR available imagery in TC events. Additional SAR instruments from Sentinel-1C and NISAR are expected to become available later this year, likely further increasing the quantity of high resolution wind data from these instruments. Thus, 2024 is an opportune time to develop additional methods to cross-validate these wind data among both in-situ and aircraft-based wind data sources.

Goal(s): The overall goal of this experiment is to provide increased simultaneous sampling of Tropical Cyclones at the same time a SAR pass is scheduled overhead, aiming to provide high-quality and high-resolution verifying datasets that can evaluate the accuracy of SAR-based wind data in TCs. The aircraft data is aimed to help validate the SAR wind fields structure and intensity, which could provide critical data for the NHC operational and final best-track evaluation. SAR passes for pre-genesis cases are also considered, in addition to sampling the airflow around islands including low-level jets and wakes induced by island orography in accordance with MAGPIE objectives.

Hypotheses:

1. Surface wind speed measurements and estimates derived from aircraft observations can be used to evaluate the performance of the SAR GMF and characterize the retrieval errors for the SAR 500-m and 3 km data products available in all stages of the TC lifecycle. These retrieval errors can be used to provide location, intensity, and structural uncertainties.

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2. SAR derived wind values at native 500 m resolution may not be a good comparison to sustained 1-minute wind data typically used for the TC intensity best track, but is more representative of instantaneous wind speeds given the short SAR overpass time (several minutes) near a TC along its polar orbit. Additional post processing may be needed to convert peak winds retrieved from SAR to obtain a sustained wind more appropriate for determining TC intensity (using maximum sustained 1 minute wind) at the time of an overpass.

3. In addition to structural characteristics seen in TCs (eye, eyewall, rainbands), SAR wind-retrieval data can effectively resolve and observe atmospheric phenomena such as convective outflow boundaries, gap and barrier low-level jet flow around islands with modest and more pronounced topography, and wind induced maxima related to rain bands, but additional quality control tools may be needed to distinguish wind maxima from non-wind related phenomena such as intense ice scattering aloft.

Objectives:

1. Coordinate with the Canadian Space Agency (CSA) and NOAA-STAR SAR team to schedule additional SAR passes for relevant cases during MAGPIE and the Hurricane Field Program season in order to further increase the coverage of relevant cases to sample. Come up with a schedule that provides enough lead time to allow for proactive scheduling of a SARWIND NOAA P-3 Module.

2. Collect GPS dropsonde, SFMR, flight-level, aircraft TDR, and IWRAP (if available) data to validate SAR satellite-derived wind speeds in a variety of tropical environments.

3. Coordinate P-3 data collection with SAR overpass in time **(+/- 1-1.5 hours**), prioritizing the RMW and/or regions of deepest convection closest to the overpass time for TC-related targets.

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

P-3 Pattern #1: This pattern is a figure-4 (or rotated figure-4, time permitting) to maximize both the coverage of the surface wind field beneath the largest mesoscale convective burst and collect observation on the convective structure in a pre-TC disturbance concurrent with a SAR overpass. The flight path should center on (or near) the deepest convection and leg lengths can be shortened to remain within the area of precipitation associated with the MCS.

P-3 Pattern(s) #2: Any figure-4, butterfly, or rotated figure-4 within a strong tropical storm up through a major hurricane. Ideally, a transect through the storm's radius of maximum wind (RMW) will be concurrent with a SAR overpass. Additional dropsondes may be released within the RMW. A flight-level center fix should also be made on this particular transect. Within **+/- 1.5 h** of the SAR overpass, the leg length may be extended outward (up to **125 n mi**) in order to capture the maximum extent of the 34-kt wind radii in a particular quadrant. There may also be an option with this flight pattern to time a SAR overpass with the location of max TS radii extent to see if wind speed retrievals with SAR match the outer wind field of the TC in a similar fashion to the RMW.

Links to Other Experiments/Modules: SARWIND can be flown in conjunction with nearly all HFP Genesis, Early, and Mature Stage experiments. This Module will also coordinate closely with any MAGPIE related objectives that the SARWIND experiment could map on to easily.

Analysis Strategy: The general strategy for real-time data collection during TC-related flights is to target the deepest convection (Genesis and Early Stage) or the RMW (Mature Stage) during the time of the SAR overpass. Observations collected in the longer lead times (**more than 15 minutes from the overpass**), should focus on less convective regions.

Data analysis strategies will be instrument dependent and include comparisons to dropsonde, SFMR, reduced flight-level winds, TDR, and IWRAP measurements, if available. Aircraft fix locations will be compared to SAR fix locations to account for potential position (and structural) differences. Finally, to better understand SAR observations characteristics such as attenuation and effects of nadir angle, the TDR analyses will be used to identify convective regimes and evaluate and compare accuracy in different regions.

References:

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