2019 NOAA/AOML/HRD Hurricane Field Program - IFEX

END STAGE EXPERIMENT
Science Description

Experiment/Module: Tropical Cyclones at Landfall

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Requirements: TC making landfall, undergoing rapid weakening, or extratropical transition

End Stage Science Objective(s) Addressed:

1) Collect observations targeted at better understanding changes TCs undergo at landfall. Objectives include validation of surface wind speed estimates and model forecasts, understanding factors that modulate intensity changes near and after landfall, and to understand processes that lead to tornadoes in outer rainbands [*IFEX Goals 1, 3]*

2) Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in landfalling TCs. These measurements include improved three-dimensional representation of the TC wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds [*IFEX Goal 2*].

Motivation: The TC lifecycle often ends when it makes landfall and decays as it moves inland. During a landfall threat in the US, an average of 300 n mi (550 km) of coastline is placed under a hurricane warning, which costs approximately $1 million per n mi. The size of the warned area depends on the forecast track, extent of hurricane- and tropical storm-force winds, and evacuation lead-times. Research has helped reduce uncertainties in track forecasts, so the goal here is to improve the accuracy of the surface wind analyses and forecasts near and after landfall to allow for optimization of warning areas and reduction in preparations costs. In addition, forecasts of decay after landfall and of severe weather in the TC are required to adequately warn populations away from the coastline. Forecasts of severe weather, particularly tornadoes, embedded within a landfalling TC is particularly difficult.

Background: Dropwindsonde data have shown remarkable variations of the wind with height. A common feature is a wind-speed maximum at 300–500 m altitude. Theoretical and numerical modeling of the TC boundary layer suggests that the low-level jets are common features. The height of the jet varies by storm quadrant, and modeling indicates that this variation can be enhanced as a TC crosses land. Many TCs produce over-land wind gusts that exceed values expected based upon gust factor relationships determined in previous studies (Tyner et al. 2015). This module seeks to collect data that can be employed to investigate what physical mechanisms might govern the magnitudes of the gust factors that are observed for a given storm. The decay of the wind over land is another important factor that has forecast implications and thus we propose to collect data both during and shortly after landfall should to help refine both operational statistical (such as the Kaplan/DeMaria decay model) and numerical models (e.g., HWRF).

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Uncertainties in surface wind-speed estimates derived from flight-level and SFMR data collected near the coast continue to exist. This may be due to changes in bathymetry near the coastline which could alter the breaking-wave field thereby changing the roughness length and microwave emissions at high wind speeds. Evaluation of these effects on a tropical cyclone approaching the coastline may lead to adjustments to the operational SFMR-derived surface wind-speed algorithms.

Severe weather, including tornadoes, is often associated with landfalling TCs. The basic dynamic and thermodynamic structures found in TC supercells are not well-understood. While some studies have found that TC tornadoes can be similar to Great Plains tornadoes, some key differences exist, such as the height and amplitude of the vortices. Most TC tornadoes occur in the front-right quadrant of the TC primarily from 12 h prior to 48 h after landfall (Schultz and Cecil 2009). Additionally, the most damaging TC tornadoes occur in rainbands. While TC tornadoes are typically weaker than their Great Plains counterparts, they account for at least 10% of all tornadoes from Louisiana to Maryland (Schultz and Cecil 2009). Unlike Great Plains tornadoes, TC tornadoes are typically associated with relatively small values of CAPE, relying instead on friction-induced convergence that accompanies landfalling TCs. The sudden deceleration of the wind as it encounters the rough land surface helps drive vertical motion, which promotes embedded mesovortices and severe weather.

Hypotheses:

1. It is possible to improve real-time surface wind-speed estimates for landfalling TCs by obtaining in-situ aircraft data.
2. The above datasets can be used to validate statistical and numerical-model landfall sustained and gust wind-speed forecasts.
3. The understanding and ability to forecast changes in the structure and intensity of landfalling TCs can be enhanced utilizing the high-resolution kinematic and thermodynamic data sets collected during the aforementioned landfall research missions.
4. Traditional environmental parameters (e.g., CAPE, vertical shear, helicity) will distinguish sectors of the storm that are most supportive of supercell development. Thus, the areal coverage of Storm Prediction Center issued severe weather watches may be optimized and numerical-model output can be validated.

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

Targets for this experiment include TCs either making landfall or approaching the coastline.

P-3 Pattern 1 (Offshore Intense Convection): A break-away/non-standard pattern in which the P-3 crosses the target rain band 10-15 n mi (20–25 km) downwind of intense convective cells and then proceeds to about 15 n mi (25 km) outside the rain band axis. The aircraft turns upwind and proceeds along a straight track parallel to the band axis. When the P-3 is ~10-15 n mi (20–25 km) upwind of the target cells, the aircraft turns and proceeds along a track orthogonal to the band axis until the P-3 is 15 n mi (25 km) inside the rain band then turns downwind and flies parallel to the rain band axis.

P-3 Pattern 2 (Coastal Survey): A break-away/non-standard pattern in which the P-3 flies parallel, but ~ 5-8 n mi (10–15 km) offshore so that the SFMR footprint is out of the surf zone. The second pass should be parallel and as close to the coast as safety permits. Finally, a short leg would be flown from the coast spiraling towards the storm center.

P-3 Pattern 3 (Real-time): A break-away/non-standard pattern in which the P-3 descends at the initial point and begins a low-level Figure-4 pattern, possibly modifying the legs to fly over buoy or C-MAN sites if possible. If time permits, the P-3 would make one more pass through the eye and then fly the Dual-Doppler option.

P-3 Pattern 4 (SFMR Coastal): A break-away/non-standard pattern in which the P-3 flies perpendicular to the coastline, across the bathymetry gradient, in a region with near constant surface winds. After flying away from the coast for about 27 n mi (50 km), the P-3 would turn downwind and then back towards the coast repeating a similar line as the first leg.

Links to Other End Stage Experiments/Modules: The TCs at Landfall Experiment can be flown in conjunction with following *End Stage* experiments and modules: NESDIS JPSS Satellite Validation Experiment and ADM-Aeolus Satellite Validation Module.

Analysis Strategy:
P-3 Pattern 1 (Offshore Intense Convection): Three-dimensional wind-field analyses and vertical profiles will be made from Doppler datasets. Dropwindsonde and flight-level data will be analyzed and combined with any available rawinsonde and surface (e.g. buoys, CMAN, etc.) observations to establish the kinematic and thermodynamic environment of targeted cells. Any available land-based radar will be used to augment airborne observations of cell evolution. Observations of TC supercells will be used to validate numerical models, to assess the ability to predict signatures of tornadic activity, and to compare TC tornadoes with those from mid-latitude supercells.

P-3 Pattern 2 (Coastal Survey): Three-dimensional wind-field analyses and vertical profiles will be compared with dropwindsonde, SFMR, IWRAP, and/or LIDAR data to characterize the differences between the onshore and offshore flow.

P-3 Pattern 3 (Real-time): Data transmitted from the aircraft in real time will be available for assimilation into numerical models and to validate forecasts of sustained wind speed, wind gusts, and thermodynamic fields such temperature, moisture, and rainfall.

P-3 Pattern 4 (SFMR Coastal): By flying this module in a region of nearly constant winds, with the wind speed measured by a dropwindsonde, the effects of bathymetry on SFMR measurements can be identified by comparing the brightness temperature measurements for each frequency along

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the leg. If the winds are not constant, but multiple dropwindsonde measurements are available along the leg, then any wind-speed change can be accounted for in the comparison. Flying one leg towards the coast and one away will also allow for the impact of wave-breaking direction to be evaluated.

Note: As part of the data collection and analysis procedures for each of the above flight modules, all P-3 flight-level and Doppler wind data will be made available at the AOC ftp site shortly after the conclusion of each mission while dropwindsonde data will be transmitted in real-time via the GTS. In addition, Doppler-data will also be transmitted in real-time to NCEP to aid in the initialization of the operational HWRF hurricane model.

References:

Schultz, L. A., and D. J. Cecil, 2009: Tropical cyclone tornadoes, 1950–2007. *Mon. Wea. Rev.*, **137**, 3471–3484.

Tyner, B., A. Aiyyer, J. Blaes, and D. R. Hawkins, 2015: An examination of wind decay, sustained wind speed forecasts, and gust factors for recent landfalling tropical cyclones in the Mid-Atlantic Region of the United States. *Wea. Forecasting***, 30**, 153-176.