2018 NOAA/AOML/HRD Hurricane Field Program - IFEX

END STAGE EXPERIMENT
Science Description

Investigator(s): Sim Aberson, John Kaplan (Co-PIs), Peter Dodge, Ghassan Alaka, Heather Holbach, Jun Zhang, and Jason Dunion (Co-Is)

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

Science Objectives:

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) Collect observations targeted at better understanding changes TCs undergo while rapidly weakening over the open ocean or undergo extratropical transition. [*IFEX Goals 1, 3*]

Description of Science Objectives:

SCIENCE OBJECTIVE #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.*
[Landfall]

Motivation and Background: 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.

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.

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 observed maximum sustained wind speeds. In addition, uncertainties in deriving surface wind-speed estimates from flight-level and SFMR data collected near the coast remain. Changing bathymetry could alter the breaking-wave field, which could change the roughness length and microwave emissions at high wind speeds. Evaluation of these effects may lead to adjustments to the operational SFMR-derived surface wind-speed algorithms.

Decay over land is also important, and data collected during and shortly after landfall should help refine both operational statistical models (such as the Kaplan/DeMaria decay model) and numerical models.

Objectives:

- Collect Doppler, flight-level, and SFMR surface wind-speed data both within the core and near storm environment (within about 240 n mi of the TC center) to help improve and validate real-time and post-storm surface wind-speed estimates.
- Document the thermodynamic and kinematic changes in TC structure during and after landfall and improve understanding of the factors that modulate changes in TC intensity near the time of landfall.
- Collect observations to evaluate numerical model forecasts of the three-dimensional structure of TCs during and after landfall.
- Collect kinematic and thermodynamic data in rainbands that have the potential to produce tornadoes.

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 surface 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:

P-3 Module #1: Landfall (Offshore Intense Convection)

A break-away/non-standard pattern in which the P-3 crosses the target rain band 20–25 km downwind of intense convective cells and then proceeds to about 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 ~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 25 km inside the rain band then turns downwind and flies parallel to the rain band axis.

P-3 Module #2: Landfall (Coastal Survey)

A break-away/non-standard pattern in which the P-3 flies parallel, but ~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 Module #3: Landfall (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 Module #4: Landfall (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 50 km, the P-3 would turn downwind and then back towards the coast repeating a similar line as the first leg.

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Analysis Strategy:

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.

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.

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.

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 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.

References:

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

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SCIENCE OBJECTIVE #2: *Collect observations targeted at better understanding changes TCs undergo while rapidly weakening over the open ocean or undergo extratropical transition.* [Weakening/Extratropical Transition (ET)]

Motivation and Background: The poleward movement of a TC initiates complex interactions with the midlatitude environment frequently leading to sharp declines in hemispheric predictive skill. In the Atlantic basin, such interactions frequently result in upstream cyclone development leading to high-impact weather events in the U. S. and Canada, as well as downstream ridge development associated with the TC outflow and the excitation of Rossby waves leading to downstream cyclone development. Such events have been shown to be precursors to extreme events in Europe, the Middle East, and may have led to subsequent TC development in the Pacific and Atlantic basins as the waves progress downstream. During this time, the TC structure begins changing rapidly: the symmetric distributions of winds, clouds, and precipitation concentrated about a mature TC circulation center develop asymmetries that expand. Frontal systems frequently develop, leading to heavy precipitation events, especially along the warm front well ahead of the TC. The asymmetric expansion of areas of high wind speeds and heavy precipitation may cause severe impacts over land without the TC center making landfall. The poleward movement of a TC also may produce large surface wave fields due to the high wind speeds and increased translation speed of the TC that results in a trapped-fetch phenomenon.

During this phase of development, hereafter referred to as extratropical transition (ET), the TC encounters increasing vertical wind shear and decreasing sea surface temperatures, factors that usually lead to weakening of the system. However, transitioning cyclones sometimes undergo explosive cyclogenesis as extratropical cyclones, though this process is poorly forecast. The small scale of the TC and the complex physical processes that occur during the interactions between the TC and the midlatitude environment make it very difficult to forecast the evolution of track, winds, waves, precipitation, and the environment. Due to sparse observations and the inability of numerical models to resolve the structure of the TC undergoing ET, diagnoses of the changes involved in the interaction are often inconclusive without direct observations. Observations obtained during this experiment will be used to assess to what extent improvements to TC structure analyses and the interaction with the midlatitude flow improve numerical forecasts and to develop techniques for forecasting these interactions. Improved understanding of the changes associated with ET will contribute to the development of conceptual and numerical models that will lead to improved warnings associated with these dangerous systems.

Questions for study:

- How is the TC vortex maintained in regions of vertical wind shear exceeding 30 m s^{-1}?

- How is the warm core maintained long after the TC encounters vertical wind shear exceeding 30 m s^{-1}?
- How does vertical shear exceeding 30 m s^{-1} alter the distribution of latent heating and rainfall?
- Does vortex resilience depend upon diabatic processes? On subsequent formation of new vortex centers, or by enlisting baroclinic cyclogenesis?
- Does the vertical mass flux increase during ET, as has been shown in numerical simulations?
- Is downstream error growth related to errors in TC structure during ET?
  Is ET sensitive to the sea-surface temperatures?

Hypotheses: ET depends upon the survival of the TC as it penetrates into midlatitudes in regions of increasing vertical wind shear.

Aircraft Pattern/Module Descriptions:

P-3 Pattern #1: Weakening/ET
G-IV Pattern #1: Weakening/ET

Two specific targets are to be sampled during each mission, the TC itself, and the interface between the TC and the environmental flow. The systems will be sampled every 12 h from the time it begins the transition to an extratropical cyclone to the time it is out of range of the aircraft, or the system dissipates.

Analysis Strategy: Data analysis will occur after the final mission, mainly via case studies based on incorporating the data in a sophisticated data assimilation/model system.

References:

Evans, C., K. M. Wood, S. D. Aberson, H. M. Archambault, S. M. Milrad, L. F. Bosart, K. L. Corbosiero, C. A. Davis, J. R. Dias Pinto, J. Doyle, C. Fogarty, T. J. Galarneau, Jr., C. M. Grams, K. S. Griffin, J. Gyakum, R. E. Hart, N. Kitabatake, J. S. Lentink, R. McTaggart-Cowan, W. Perrie, J. F. D. Quinting, C. A. Reynolds, J. Riemer, E. Ritchie, Y. Sun, and F. Zhang, 2017: The Extratropical Transition of Tropical Cyclones. Part I: Cyclone Evolution and Direct Impacts. *Mon. Wea. Rev.*, accepted for publication.