END STAGE EXPERIMENT
Science Description

Experiment/Module: Tropical Cyclones at Landfall

PIs/Investigator(s): John Kaplan, Peter Dodge, Ghassan Alaka, Heather Holbach, Jun Zhang, Frank Marks

University mobile observing team leaders: Michael Biggerstaff (University of Oklahoma), John Schroeder (Texas Tech University), Forrest Masters (University of Florida), Kevin Knupp (University of Alabama at Huntsville), David Nolan (University of Miami)

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

Plain Language Description: Landfalling tropical cyclones (TCs) can produce a variety of high impact weather conditions including damaging wind gusts and tornadoes for which there exists limited objective forecast guidance. Thus, our experiment seeks to utilize both aircraft and land-based platforms to obtain data in landfalling TCs with the overarching goal of improving both our understanding and capability to predict such dangerous phenomena that are typically associated with these landfalling systems.

End Stage Science Objectives 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*].

3) 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, rapidly weakening TCs, and TCs undergoing extratropical transition. 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: During a tropical cyclone landfall threat, the size of the warned area typically depends on such factors as the forecast track, extent of hurricane- and tropical storm-force winds, and the required evacuation lead-times. Since significant improvements in track forecasts have been observed in recent years, the overarching goal of our experiment is to improve the accuracy of the observed and forecast surface sustained and gust wind speeds at and after the time of landfall to enable forecasters to further optimize the warnings that they issue. Tornadoes spawned by landfalling TCs are also a dangerous hazard for those that reside along and near the path of those systems. Thus, improvements in the forecasting of each of the above phenomena (maximum wind, wind gusts, and TC spawned tornadoes) are required to achieve to aid with the protection of life and property.

END STAGE EXPERIMENT

Science Description

Background: 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.

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 in tropical cyclones approaching the coastline may lead to adjustments to the operational SFMR-derived surface wind-speed algorithms.

Although wind gusts produced by landfalling tropical cyclones can have a significant impact on both life and property, explicit numerical model forecasts of wind gust magnitudes are presently quite limited. Thus, forecasters have typically estimated tropical cyclone wind gusts in real-time by multiplying the mean wind by gust factors obtained in previous observational studies. Gust factors, typically defined as the ratio of the peak wind over some short time interval to that of the longer term mean, have been explicitly studied in tropical cyclones by a number of researchers (e.g., Durst 1960; Powell et al. 1991, 1996; Krayer and Marshall 1992; Harper et al. 2009; Masters et al. 2010;Tyner et al. 2015). Those studies suggest that gust factors vary as a function of such factors as roughness, convection, and mean wind speed. Notably however, each of the above studies has tended to recommend utilizing one particular gust factor for a given averaging period or wind speed despite results from those same studies indicating that significant variability in gust factor values can be seen even when those conditions (e.g. averaging time, sustained wind speed) are similar. The decay of the wind over land is another important factor that has forecast implications. Thus, this module seeks to collect data both during and shortly after landfall in an effort to better understand and predict the wind gust and maximum wind magnitude both at and after TC landfall.

Goal(s): This experiment is designed to employ the P-3 aircraft to collect thermodynamic and kinematic observations in landfalling tropical cyclones to aid in achieving three goals:

1. To better understand the mechanisms that modulate a TC’s potential for producing tornadoes.
2. To investigate the factors that control both the magnitude of the wind gusts and rate of decay of the sustained wind both at and after landfall.

3. To reduce the uncertainty in SFMR wind speed estimates in coastal regions. [IFEX Goal 2]

Hypotheses:

1. Airborne data collected can be used to compute traditional environmental parameters (e.g., CAPE, vertical shear, helicity) that will aid in distinguishing sectors of the storm that are most supportive of supercell development. These data will be helpful for optimizing the Storm Prediction Center issued severe weather watches and validating numerical-model output.
2. It is possible to improve real-time surface wind-speed estimates for landfalling TCs by obtaining in-situ aircraft data.
3. The collection of the proposed datasets can be used to better understand and predict both the sustained and gust wind-speeds produced by landfalling TCs.

Objectives:

1. Collect kinematic and thermodynamic data in rainbands that have the potential to produce tornadoes.
2. Collect Doppler, flight-level, and SFMR surface wind-speed data both within the core and near storm environment (within about 240 n mi/440 km of the TC center) to help improve and validate real-time and post-storm surface wind-speed estimates.
3. Collect observations that provide a measure of three-dimensional TC structure prior to and near the time of landfall to aid with the understanding and prediction of the mechanisms that modulate both sustained and gust wind speeds of landfalling TCs.

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

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.

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:

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. Additionally, these in-situ data will provide a database for potential development of new real-time forecasting algorithms for quantities such as wind gusts.

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.

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:

Durst, C.S., 1960: Wind speeds over short periods of time. *Meteor. Mag.*, **89,** 181-186.

Harper, B.A., J.D. Kepert, and J.D. Ginger, 2010: Guidelines for converting between various wind averaging periods in tropical cyclone conditions. *World Meteorological Organization Tech. Doc*., WMO/TD-1555, 54 pp.

Krayer, W. R. and R. D. Marshall, 1992: Gust factors applied to hurricane winds. *Bull. Amer. Meteor. Soc.,* **73,** 613-617.

Masters, F. J., P. J. Vickery, P. Bacon, and E. N. Rappaport, 2010: Toward objectives, standardized intensity estimates from surface wind speed observations. *Bull. Amer. Meteor. Soc.*, **91**, 1665–1681.

Powell, M.D., P. P. Dodge, and M.L. Black, 1991: The landfall of Hurricane Hugo in the Carolinas: Surface wind distribution. *Wea. Forecasting*, **6**, 379-399.

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.