END STAGE EXPERIMENT
Science Description

Experiment/Module: Extratropical Transition

Investigator(s): Sim Aberson

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

Plain Language Description: Tropical cyclones can either decay (spin down) or transform into powerful extratropical cyclones when they encounter cold water below or high wind shear in the atmosphere. The mechanisms by which tropical cyclones become extratropical is not well forecast by numerical models leading to large errors, especially in impacts downstream of the actual transitioning cyclone. This experiment aims to improve forecasts of these systems.

End Stage Science Objective(s) Addressed:

1) Collect observations targeted at better understanding changes TCs undergo while rapidly weakening over the open ocean or undergo extratropical transition [*APHEX 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, 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 [*APHEX Goal 2*]

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.

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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: 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.

Links to Other End Stage Experiments/Modules: None

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., and co-authors., 2017: The extratropical transition of tropical cyclones. Part I: Cyclone evolution and direct impacts. *Mon. Wea. Rev.,* **145**, 24317-4344.

Keller, J. H., and co-authors, 2019: The extratropical transition of tropical cyclones. Part II: Interaction with the midlatitude flow, downstream impacts, and implications for predictability. *Mon. Wea. Rev.*, **147**, 1077-1106.