2018 NOAA/AOML/HRD Hurricane Field Program - IFEX

INTRODUCTION

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1. Description of Intensity Forecasting Experiment (IFEX)

One of the key aspects of NOAA's Mission is, "To understand and predict changes in the climate, weather, oceans, and coasts..." with a long-term goal of achieving a, "Weather-ready Nation," in which society is able to prepare for and respond to weather-related events. This objective specifies the need to improve the understanding and prediction of tropical cyclones (TCs). The NOAA/National Weather Service/National Hurricane Center (NHC) is responsible for forecasting TCs in the Atlantic and East Pacific basins, while NOAA/National Centers for Environmental Prediction (NCEP)/Environmental Modeling Center (EMC) provides numerical weather prediction (NWP) forecast guidance for the forecasters. Together they have made great strides in improving forecasts of TC track. With support from the research community, forecast errors of TC track have decreased by about 50% over the past 30 years. However, there has been much less improvement in forecasts of TC intensity, structure, and rainfall. This lack of improvement is largely the result of deficiencies in routinely collecting inner-core data and assimilating it into the modeling system, limitations in the numerical models themselves, and gaps in understanding of the physics of TCs and their interaction with the environment. Accurate forecasts will rely heavily on the use of improved numerical modeling systems, which in turn will rely on accurate observational datasets for assimilation and validation.

The operational Hurricane Weather Research and Forecasting (HWRF) model uses an assortment of physical parameterizations intended to represent subgrid-scale processes important in TC evolution. Such a modeling system holds the potential of improving understanding and forecasting of TC track, intensity, structure, and rainfall. In order to realize such improvements, however, new data assimilation techniques must be developed and refined, physical parameterizations must be improved and adapted for TC environments, and the models must be reliably evaluated against detailed observations from a variety of TCs and their surrounding environments.

To conduct the research necessary to address the issues raised above, since 2005 NOAA has been conducting an experiment designed to improve operational forecasts of TC intensity, called the Intensity Forecasting EXperiment (IFEX; Rogers et al., BAMS, 2006, 2013). The IFEX goals, developed through a partnership involving the NOAA/Atlantic Oceanographic and Meteorological Laboratory (AOML)'s Hurricane Research Division (HRD), NHC, and EMC, are to improve operational forecasts of TC intensity, structure, and rainfall by providing data to improve the operational numerical modeling system (i.e., HWRF) and by improving understanding of the relevant physical processes. These goals will be accomplished by satisfying a set of requirements and recommendations guiding the collection of the data:

- GOAL 1: Collect observations that span the TC life cycle in a variety of environments for model initialization and evaluation
- GOAL 2: Develop and refine measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment
- GOAL 3: Improve understanding of the physical processes important in intensity change for a TC at all stages of its life cycle

A unique, and critical, aspect of IFEX is the focus on providing measurements of TCs at all stages of their life cycle. While the focus of hurricane research flights during the past 30 years has been predominantly on mature storms, leading to a dataset biased toward these types of systems, IFEX now also places a focus on the genesis and early stages of storms. This emphasis will not only provide critical observations during a period in the storm life cycle when there is perhaps the greatest uncertainty in the track and intensity forecasts, but also fills an observing gap during the early stages of a storms development where case and composite studies have lacked.

2. Experiments Overview

This season, HFP-IFEX includes experiments for each stage of the TC life cycle: "Genesis", "Early", "Mature", and "End" of life cycle.

The *"Genesis Stage Experiment"* consists of objectives that require observations during the pre-Tropical Depression (TD), or "Invest" (designated by NHC) period of a developing (or non-developing) storm. Each of three objectives focus on progressively larger-scale aspects of a disturbance: one that evaluates the co-evolution of precipitation (such as convective bursts), and the response of the developing vortex at multiple levels to that precipitation, another that seeks to investigate the kinematic and thermodynamic characteristics of the "pouch" as it evolves towards a "self-sustaining entity" (i.e., a TC), and a third aimed at describing the evolving favorability of the large-scale environment surrounding a developing (or non-developing) disturbance.

The *"Early Stage Experiment"* will consist of objectives that require observations in TCs at TD, Tropical Storm (TS), or Category 1 hurricane intensity. The first objective is to identify processes responsible for the intensification (or non-intensification) during these early stages, including those that experience (rapid) intensification in moderately sheared environments. This objective emphasizes sampling in a shear-relative framework, particularly in the upshear quadrants where changes in the precipitation distribution is intimately linked to future intensity change. The second objective investigates the structure and impact of convective bursts cycling around the TC center on intensity change, while a third objective requires measurements across arc cloud boundaries emanating away from the TC center. These measurements will increase our understanding on the formation and evolution of arc clouds and their impacts on TC structure and intensity in the short-term.

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The *"Mature Stage Experiment"* will consist of objectives that require observations in stronger hurricanes (Category 2 intensity or greater). Science objectives during this stage are separated into those that will evaluate internal processes to the TC and those that will investigate the interaction of a TC with its environment. Observations are sought on a number of important internal processes that could result in structural and intensity changes in a TC; these include the diurnal cycle, gravity wave activity, secondary eyewall formation and eyewall replacement cycles, and the mixing that occurs between the eye and eyewall. The objective on environmental interaction encompasses sampling storms experiencing an evolving environmental vertical wind shear profile, and the influence of arc clouds as they emanate from away from the center into the surrounding environment. The third objective is consistent with IFEX GOAL #2 and is to evaluate the use of new observing systems to sample the hurricane structure, including the boundary layer (using the unmanned aerial system, Coyote) and its environment (e.g., the air-sea interface).

The *"End Stage Experiment"* consists of objectives that require observations during the weakening or extratropical transition period of storm, and/or during landfall. As with other stages, these experiments focus on the structural changes that occur in a TC. The landfall objective additionally focuses on the validation of surface wind speed estimates and forecasts, as well as rainbands and their potential to generate severe weather.

Other experiments included in the HFP Plan (HFPP) are the following:

- *"Ocean Survey"*: Ocean observations obtained from sonobouys (e.g., AXBTs, AXCTDs, and AXCPs) will be used to better understand a TC's interaction with the underlying ocean (such as enthalpy flux), and obtained at enough resolution to rigorously test coupled TC models.
- *"Synoptic Flow"*: This experiment will investigate new strategies for optimizing the use of aircraft observations to improve forecasts of TC track, intensity, and structure. It suggests targeting regions in and around the TC with aircraft where ensemble prediction systems suggest the most sensitivity of TC-related forecast metrics (position, intensity, and track).
- *"Tail Doppler Radar"*: The primary goal of this experiment is to gather wind measurements that will provide three-dimensional wind analyses of the TC that can also be used to create a more accurate initialization for HWRF.
- *"SFMR Experiment"*: The goals of this experiment are to improve surface wind speed algorithms when the instrument is looking at off-nadir (high, > ±5°) incidence angles, and to validate SFMR measurements from the G-IV by coordinating sampling with the P-3.

3. HFP Plan Organization

The HFP-IFEX missions presented in this document are separated into individual science experiments. Each experiment outlines Science Objectives that map onto to one or more IFEX GOAL listed in subsection (1). Science Objectives are described for each experiment in their, "Science Description" documents. The "Science Description" includes the motivation and background on the science behind each objective, relevant hypotheses, a description of the aircraft "Patterns" and "Modules" that will be flown for that objective, and the analysis strategy once data is collected. Accompanying each experiment are also, "Pattern and Module Descriptions," which provide a summary of details regarding the mission execution (timing, patterns, expendables, etc.). These provide the information needed for the PIs, [FIELD PROGRAM DIRECTOR], and aircraft crew to plan and execute a mission associated with an experiment.

Multiple "Patterns" and "Modules" are possible for each Science Objective in an experiment. Each "Pattern" and "Module" is numbered sequentially within an individual Science Objective, and labeled with a shorthand descriptor; for example, a pattern in the "Environment Interaction" objective of the *"Mature Stage Experiment"* is named, "**P-3 Pattern #1: Environment Interaction (TC in Shear)**". A second qualifier may be provided; in the previous example, "TC in Shear."

In most cases (unless otherwise noted), "Patterns" will be identified as one of the "standard" patterns, illustrated in APPENDIX A (e.g., Lawnmower, Square-spiral, Figure-4, Rotated Figure-4, Butterfly). Many of the "Patterns" outlined in the experiments are "standard" patterns that are subsequently modified to meet the sampling needs of the objective.

Within each experiment, reference is made to either "Patterns" or "Modules." "Patterns" refers to missions that require an entire dedicated mission (i.e., generally greater than 3 h of flight time). "Modules" refer to break-away (e.g., from the "standard" patterns described APPENDIX A), shorter flight segments that generally require less than 3 h or less of flight time for completion.

References

Rogers, R., and co-authors, 2006: The Intensity Forecast Experiment: A NOAA multiyear field program for improving tropical cyclone intensity forecasts. *Bull. Amer. Meteor. Soc.*, **87**, 1523–1537.

Rogers, R., and co-authors, 2013: NOAA's Hurricane Intensity Forecasting Experiment: A Progress Report. *Bull. Amer. Meteor. Soc.*, **94**, 859–882.