Environmental Sensitivity of Tropical Cyclone Outflow

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LONG-TERM GOALS

The overarching goal is to advance the understanding of sensitivities of tropical cyclone outflow to environmental conditions. This goal ties in with the primary objectives of the ONR Directed Research Initiative on Tropical Cyclone Intensity (TCI). Benefits to the Navy would include improved understanding and predictive skill of changes in the structure and intensity of tropical cyclones.

OBJECTIVES

The main objective of the study is to test the hypothesis that “the predictability of the outflow (and thereby TC structure change) is largely modulated by the environment, and in particular the amplitude and phase of upper-level troughs upstream and downstream.”

Several sub-hypotheses are also proposed:

(i) The development of poleward outflow channels is sensitive to small perturbations in the mid-latitude jet, and specifically the coupling between the outflow and the jet.
(ii) The relative phase between the TC and environmental features is critical in the establishment of outflow channels and thereby intensity change.

(iii) Modifications to the dynamic and thermal structure of the outflow influence both the radial TC structure (size; eyewall slope) and environmental features such as the mid-latitude jet.

(iv) Dynamic and thermodynamic perturbations to the outflow and sensitive environmental features are crucial in creating sufficient diversity in mesoscale ensemble predictions.

**APPROACH**

Throughout the project, testing of the hypotheses will be performed using a combination of observations and numerical models, including the Navy’s COAMPS-TC model.

Our initial approach in Year 1 has been to use real-time ensemble forecasts from the European Centre for Medium-Range Forecasts (ECMWF, with special permission) to produce novel ensemble products to investigate predictions related to outflow and assist with the ONR TCI and NASA Hurricane Sentinel 3 (HS3) field campaigns during August-October 2014.

A parallel approach has been to start investigating the structure of outflow as depicted in vertical wind profiles from dropwindsondes released from the NASA Global Hawk aircraft during the 2014 field campaigns.

**WORK COMPLETED**

Daily products from the 0000 UTC ECMWF ensembles were produced in real-time from July-October 2014, on the website [http://www.rsmas.miami.edu/personal/smajumdar/tci/](http://www.rsmas.miami.edu/personal/smajumdar/tci/)

Products include spaghetti contours of lower-tropospheric circulation (Fig. 1a) and local 200-850 hPa thickness anomaly, the probability that lower-tropospheric relative humidity exceeds 70% (Fig. 1b), and the probability that deep-layer wind shear exceeds 15 m/s. The 4-day ensemble predictions initialized on 10 October 2014, initialized nearly 3 days prior to the genesis of a cyclone that ultimately developed into Hurricane Gonzalo, give a 30% probability that the circulation, thickness anomaly and minimum sea level pressure will meet threshold criteria for a tropical cyclone (these criteria were introduced in Majumdar and Torn 2014). This information was used during forecast briefings to assist with the mission planning process.

A new ensemble product under development is related to the outflow (Fig. 1c). For a 2-day forecast of Hurricane Gonzalo initialized on 14 October 2014, the probability of winds at 200 hPa exceeding 10 m/s in the vicinity of Gonzalo is highest to the northeast, suggesting the highest likelihood of strong outflow in this area. A secondary area to the southwest of Gonzalo exhibits a lower probability of 200 hPa winds exceeding 10 m/s, suggesting a potentially weaker outflow channel to the southwest.
FIGURE 1. (a) 4-day, 50-member ECMWF ensemble predictions of circulation, initialized on 0000 UTC 10 October 2014. Circulation is defined as area-averaged relative vorticity within a disk of radius 200 km, averaged between the 700 hPa and 850 hPa levels. Purple contours correspond to values of $8 \times 10^{-5} \, \text{s}^{-1}$, which is often of comparable strength to a tropical cyclone. (b) Shading: probability that the corresponding 4-day prediction of 700 hPa relative humidity exceeds 70%. Red shading refers to a probability exceeding 90%, with other shades in intervals of 20% probability. Contour: ECMWF control forecast of 700 hPa relative humidity. (c) 2-day, 50-member ECMWF ensemble predictions of 200 hPa winds initialized on 0000 UTC 14 October 2014, associated with Hurricane Gonzalo. Shading: probability that 200 hPa wind speed exceeds 10 m s$^{-1}$, overlaid on ECMWF control forecast of 200 hPa streamlines (grey). Blue contours: ECMWF control forecast of mean sea level pressure.

RESULTS

The new Ph.D. student funded on this grant, Yi Dai, has begun to investigate vertical wind profile data from the dropwindsondes released over Hurricane Edouard in September 2014. The dropwindsonde data have been compared qualitatively against the hourly Atmospheric Motion Vectors (AMV) produced by CIMSS / University of Wisconsin. A preliminary investigation suggests that there is generally a good agreement between the AMVs in tropospheric layers (Fig. 2a) and the corresponding layer-averaged wind vectors in the dropwindsonde data (Fig. 2b). Furthermore, based on an analysis of several transects, the outflow layer is often readily apparent in the dropwindsonde data (Fig. 2b). In the middle of the outflow layer, there is often a strong central jet, e.g. 50 kt winds in dropwindsonde #40 between 175-200 hPa. The next step is to map the horizontal and vertical structure of the outflow...
through the evolution of Edouard, and to interpret the dynamic and thermodynamic structure in the context of the existing literature. Attention will focus particularly on changes to the outflow structure due to environmental interactions.

**FIGURE 2.** (a) Upper tropospheric Atmospheric Motion Vectors produced by CIMSS / University of Wisconsin-Madison, on 1100 UTC 12 September 2014. Dropwindsonde locations from a Global Hawk transect across Hurricane Edouard between 0953-1142 UTC on the same day are indicated by the red dots. (b) Vertical wind profiles from the corresponding ten dropwindsondes. Red lines indicate an estimation of the outflow depth determined from the dropwindsondes to the east and north of Edouard. (The green shading is an artefact of the graphics and can be ignored.)

**IMPACT/APPLICATIONS**

Novel ensemble forecast products have been developed during the 2014 field campaign, which may influence the way Navy ensemble forecasts are used and interpreted. The unprecedented array of full, high-resolution vertical wind profiles collected during Edouard is expected to reveal new insights into the structure and evolution of outflow.

**RELATED PROJECTS**

This project is related to the DRI grant entitled “Importance of the Coupling of Tropical Cyclone Outflow Vents with the Environment: Observational and Model Sensitivity Studies” (PI Chris Velden and Co-PI Brett Hoover), on which Majumdar is a Collaborator. The main early interactions have been the provision by CIMSS of satellite AMVs. This project is also related to projects conducted at NRL Monterey. The paperwork for an Educational Agreement is in progress, in order for the U. Miami team to use the COAMPS-TC model.
REFERENCES


HONORS/AWARDS/PRIZES

In Summer 2014, PI Majumdar was one of 15 faculty and staff university-wide selected into the Provost’s ‘Leadership U’ academy at the University of Miami, a new program focused on academic leadership.