Outflow Layer Dynamics and Thermodynamics and Tropical Cyclone Intensity Change

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LONG-TERM GOALS

To understand the influences of the tropical cyclone outflow layer in storm formation and intensity change.

OBJECTIVES

Specifically, we are examining two aspects of the tropical cyclone outflow layer: the processes by which the dynamics and thermodynamics of the cirrus canopy create symmetric instability and turbulence; and the impact of the extended outflow layer (trough interactions and outflow jets) on the intensification of storms.

APPROACH

We are making use of HDSS and Global Hawk (hereafter GH) dropsondes. Because these are still in limited supply, we have also taken advantage of dropsondes from the NOAA G-IV and of rawinsondes released within 1000 km of tropical cyclones. Our calculations using these latter sources of data should make it possible for us to smoothly transition to HDSS and GH sondes. We have processed thousands of sondes and have written two papers.

The work is being done by PhD student Patrick Duran, Senior Scientific Programmer David Vollaro, and PI Molinari. PhD student Sarah Ditchek has contributed as well (see Research section), but is not supported on the grant.

WORK COMPLETED

a. Field Program participation

Molinari served for one month (July 15 – August 16, 2015), the last two weeks as Mission Scientist. Vollaro developed and implemented a process for displaying dropsonde soundings on visible and
infrared satellite images immediately after the flights for use in planning future flights. This has been tested and is functioning well. Duran served several weeks as a forecaster in the field program.

**b. Research**

Our first paper (Molinari and Vollaro 2014) identified symmetric instability in major Hurricane Ivan using G-IV sondes. Our second paper (Duran and Molinari 2015, submitted) investigated the influence of tropical cyclone intensity on the frequency of low Richardson number within the cirrus canopy, as well as tropical cyclone structure in the vicinity of the tropopause. This second paper also identified a diurnal cycle. PhD student Duran is now writing his PhD prospectus. He plans to investigate stability and shear variations within the tropical cyclone cirrus canopy using HDSS and GH sondes. PhD student Sarah Ditchek is studying the dynamics of the outflow layer using ERA-Interim analyses that extend to the 2000 km radius. Sarah is supported on a National Defense Science and Engineering graduate fellowship, but her work is directly relevant to the grant.

**RESULTS**

Molinari and Vollaro (2014) proposed that cirrus canopy physics can create symmetric instability in the outflow layer. In particular, radiative warming in the cirrus canopy and radiative cooling outside would act to steepen isentropes in a region where absolute momentum surfaces were flat. This state is by definition symmetrically unstable. In related numerical modelling work, the instability was found to develop after the storm intensified. In addition, the removal of this instability was associated with the end of intensification. Thus, symmetric instability seemed to play a critical role in determining the length of intensification periods.

Two figures display this instability. Fig. 1 (end of the document) shows radial-vertical cross-sections of relative humidity and absolute momentum in Hurricane Ivan. The cirrus canopy shows clearly in the extended high relative humidity in the outflow layer. The stippled red box shows the region where inertial instability is present. The “boxiness” of the unstable region reflects the 100-km radial resolution. Fig. 2 shows a similar structure from the numerical model of Nolan et al. (2013). The region of instability occurred at a similar height and radius. Over the following 8 hours, this instability was removed (i.e., the absolute momentum and equivalent potential temperature contours became parallel), and the storm ceased intensifying.

Duran and Molinari (2015) found that layers with Richardson number below 0.25, an indication of potential turbulence, occurred much more frequently in hurricane-strength disturbances than in tropical depressions and storms. This arose primarily because the upper troposphere of hurricanes has extremely low stability associated with an elevated tropopause as well as a stronger warm core (as a result of balanced dynamics in the stronger storms). Duran and Molinari also found evidence of a diurnal cycle in turbulence that was consistent with the work of Dunion et al. (2014): maximum low Richardson number frequency appeared to follow the “diurnal pulse” of high cloudiness found by Dunion et al.

Figure 3 from Duran and Molinari (2015) shows (left panel) the track of a G-IV flight on a satellite picture, and (right panel) the evolution of aircraft vertical acceleration (a direct measure of turbulence) along the track. It is apparent that the tropical cyclone cirrus canopy contains larger turbulence than the region outside. In his thesis Patrick is investigating physical processes within the cirrus canopy that might be responsible.
IMPACT/APPLICATIONS

The outflow layer represents a dramatically underexamined aspect of tropical cyclones. Our results thus far have provided some potentially new insights into cirrus canopy physics. These are not just of academic interest, but seem to relate to intensity changes and the diurnal cycle in tropical cyclones. The increasing numbers of HDSS and GH sondes will allow us to expand on previous work, with the goal of understanding the many roles of the tropical cyclone outflow layer.

RELATED PROJECTS

NONE

PUBLICATIONS


FIGURES

*Figure 1. Radial-vertical cross-section of mean absolute angular momentum (contoured), plotted over mean relative humidity (per cent; shaded). Red stippling indicates the region where absolute angular momentum decreases outward. From Molinari and Vollaro (2014).*
Figure 2. Azimuthally averaged absolute angular momentum (dark black contours; increment $10^5 \text{ m}^2 \text{s}^{-1}$) and equivalent potential temperature ($\theta_e$; shaded) from the hurricane nature run of Nolan et al. (2013), valid at 1500 UTC 3 August. The blue stippling indicates the region of inertial instability, which is nearly identical to that for moist symmetric instability. From Molinari and Vollaro (2014).

Figure 3. (a) The NOAA Gulfstream-IV (G-IV) flight track into Hurricane Ivan on 15 September 2005 between 0530 and 1310 UTC overlaid on an infrared satellite image valid at 0915 UTC. (b) Time series of aircraft vertical acceleration observed by the G-IV inertial navigation system. The initial time for both plots is indicated by the black asterisk in (a), and the color changes in the flight track correspond to the color changes in (b). All data plotted here were collected while the G-IV was at an altitude of 12 km or greater. From Duran and Molinari (2015).