# Airborne Radar Observations of Rainband Structure in Hurricane Ophelia (2005)

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## Hurricane Structure

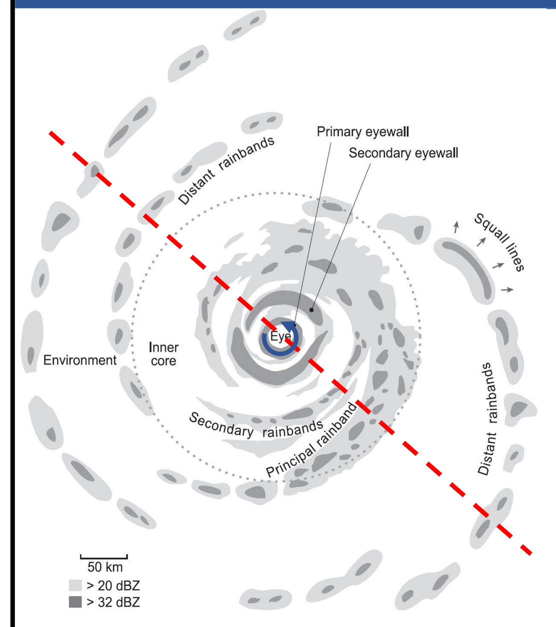
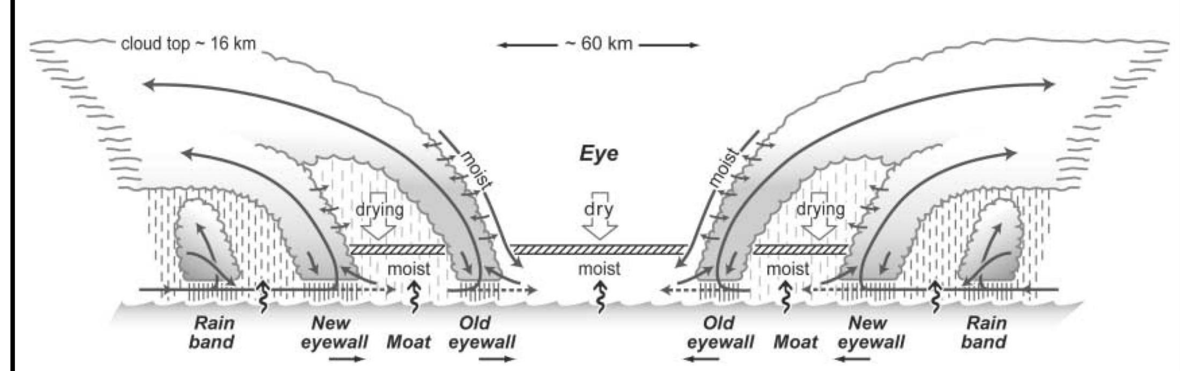


**Figure 1, Left.** An idealized top-down view of rainfall in a hurricane from Houze (2010). Blue arrow indicates the typical location of the maximum cyclonic wind speed and the direction of the primary (cyclonic) circulation in the Northern Hemisphere.

**Figure 1, Bottom.** An idealized cross-section view of a hurricane from Houze et al. (2007). The arrows indicate the secondary circulation (in-up-out). One can assume that the cross-section is taken along the dashed red line in the left figure.




## Eyewall Replacement Cycle (ERC)

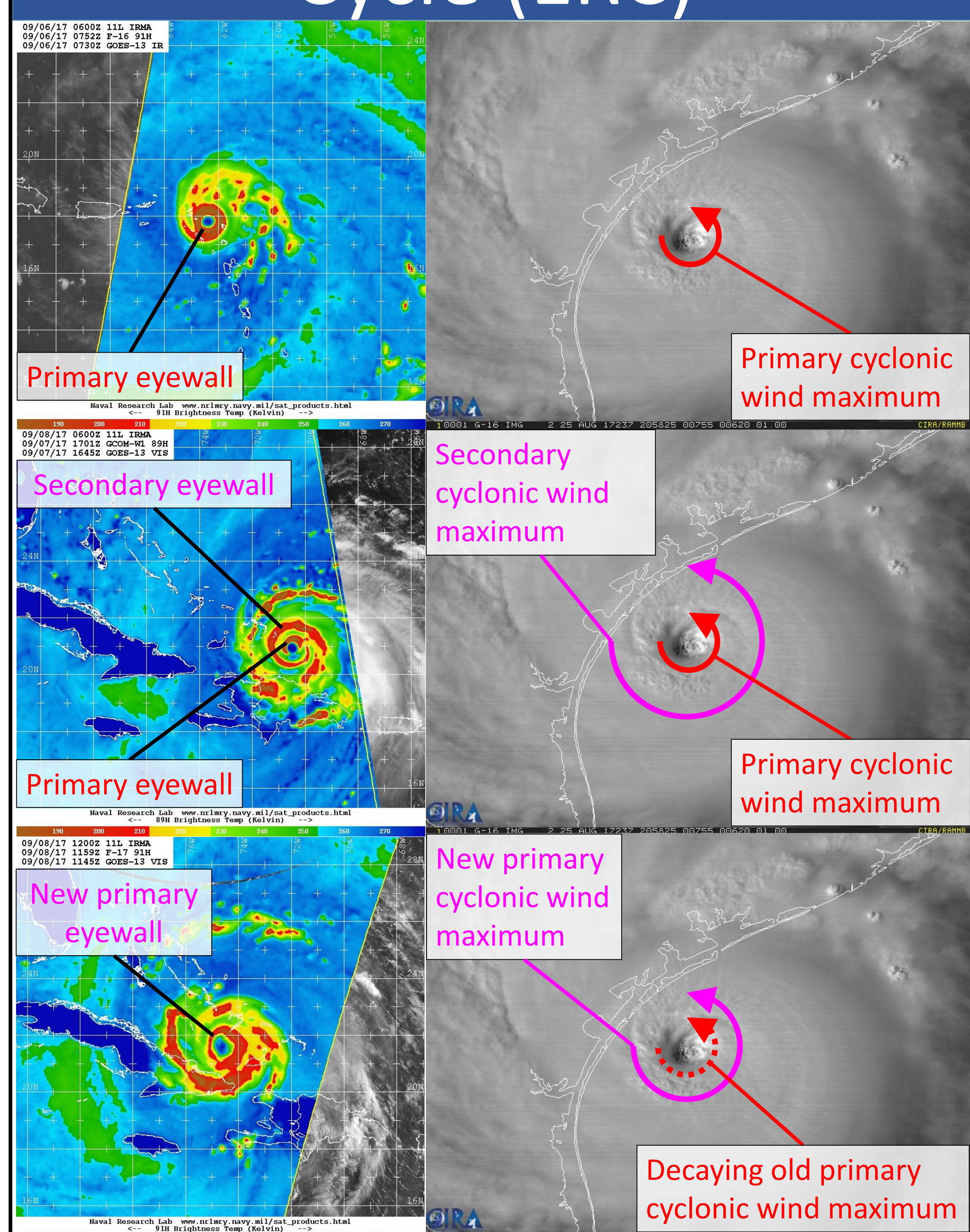
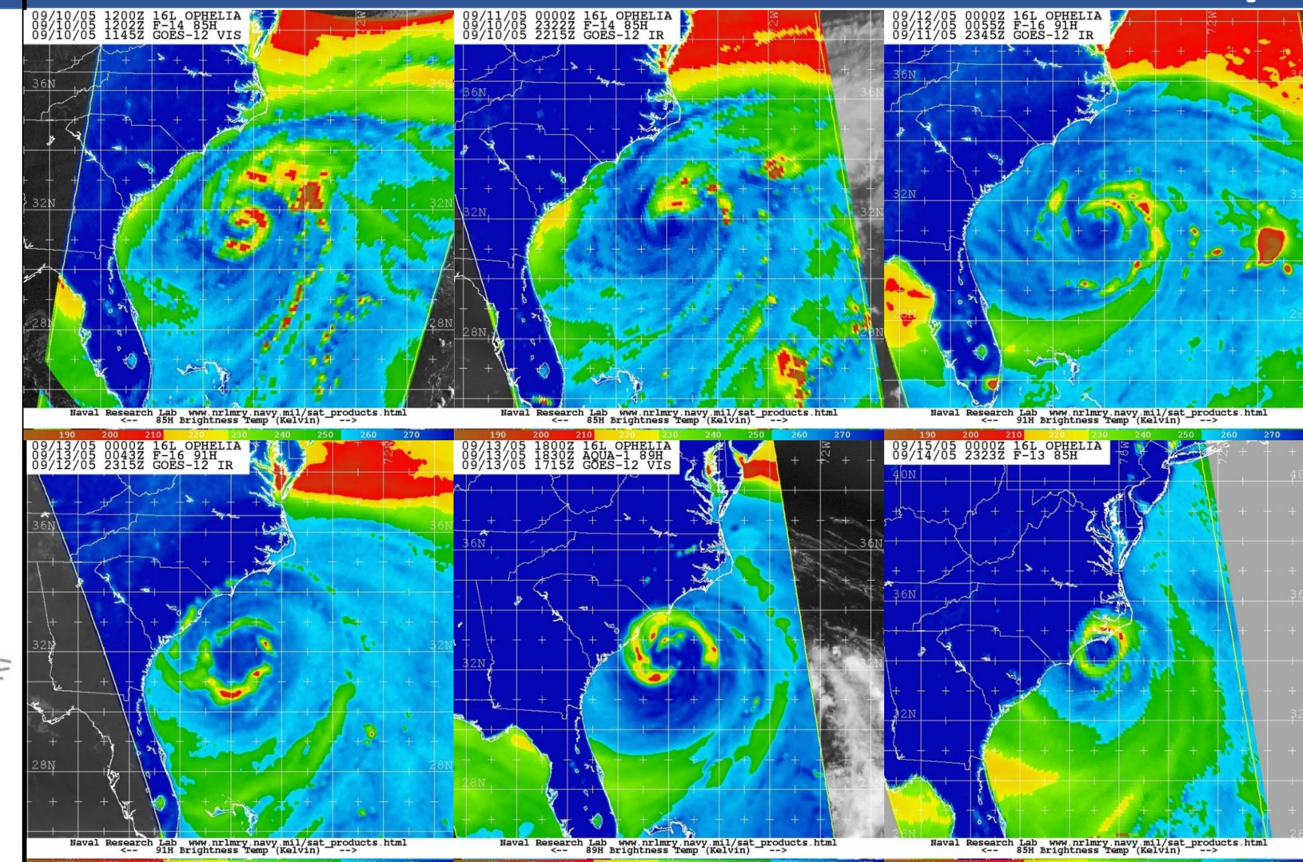



**Figure 2, Left Column.** Satellite microwave imagery of Hurricane Irma (2017) as it was undergoing an eyewall replacement cycle, courtesy of the Naval Research Laboratory (NRL). Reds indicate the presence of active thunderstorms.

**Figure 2, Right Column.** Satellite visible imagery of Hurricane Harvey (2017) at a single time, courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA). The arrows represent an idealized evolution of the cyclonic wind maxima associated with an eyewall replacement cycle, and are not related to Hurricane Harvey.

## Hurricane Ophelia (2005)



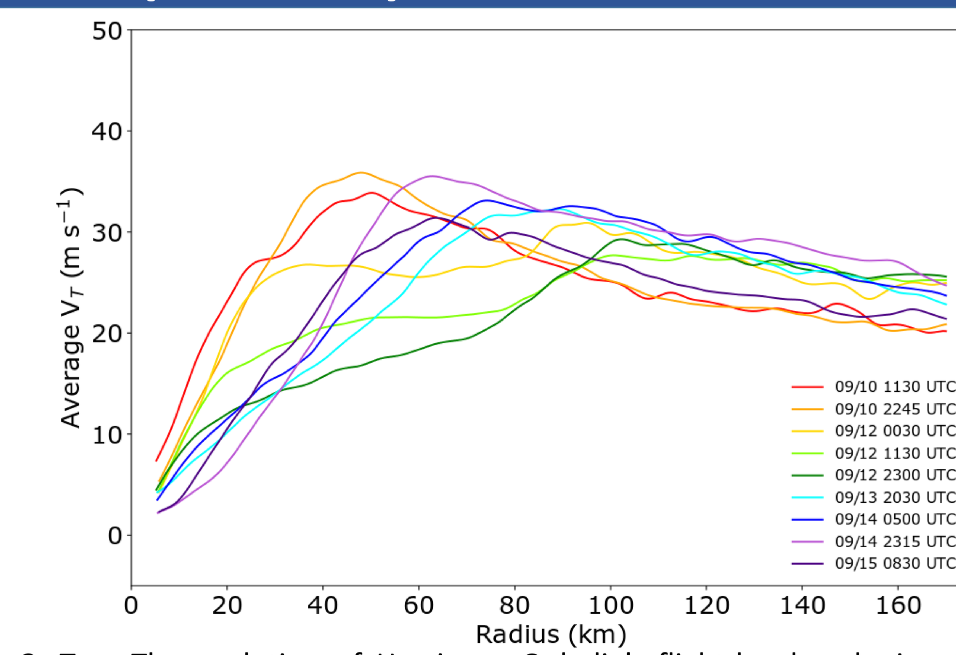



**Figure 3, Top.** The evolution of Hurricane Ophelia's flight-level cyclonic wind speed averaged around the storm. Observations were obtained from the United States Air Force Hurricane Reconnaissance mission.

**Figure 3, Left.** Satellite microwave imagery showing the location of active thunderstorms (or lack thereof) in Hurricane Ophelia (2005). Images courtesy of the Naval Research Laboratory (NRL).

- Aircraft reconnaissance flights into Hurricane Ophelia (2005) detected cyclonic wind evolution associated with an eyewall replacement cycle.
- Hurricane Ophelia (2005) underwent an eyewall replacement cycle in the absence of widespread active thunderstorms.

## Results

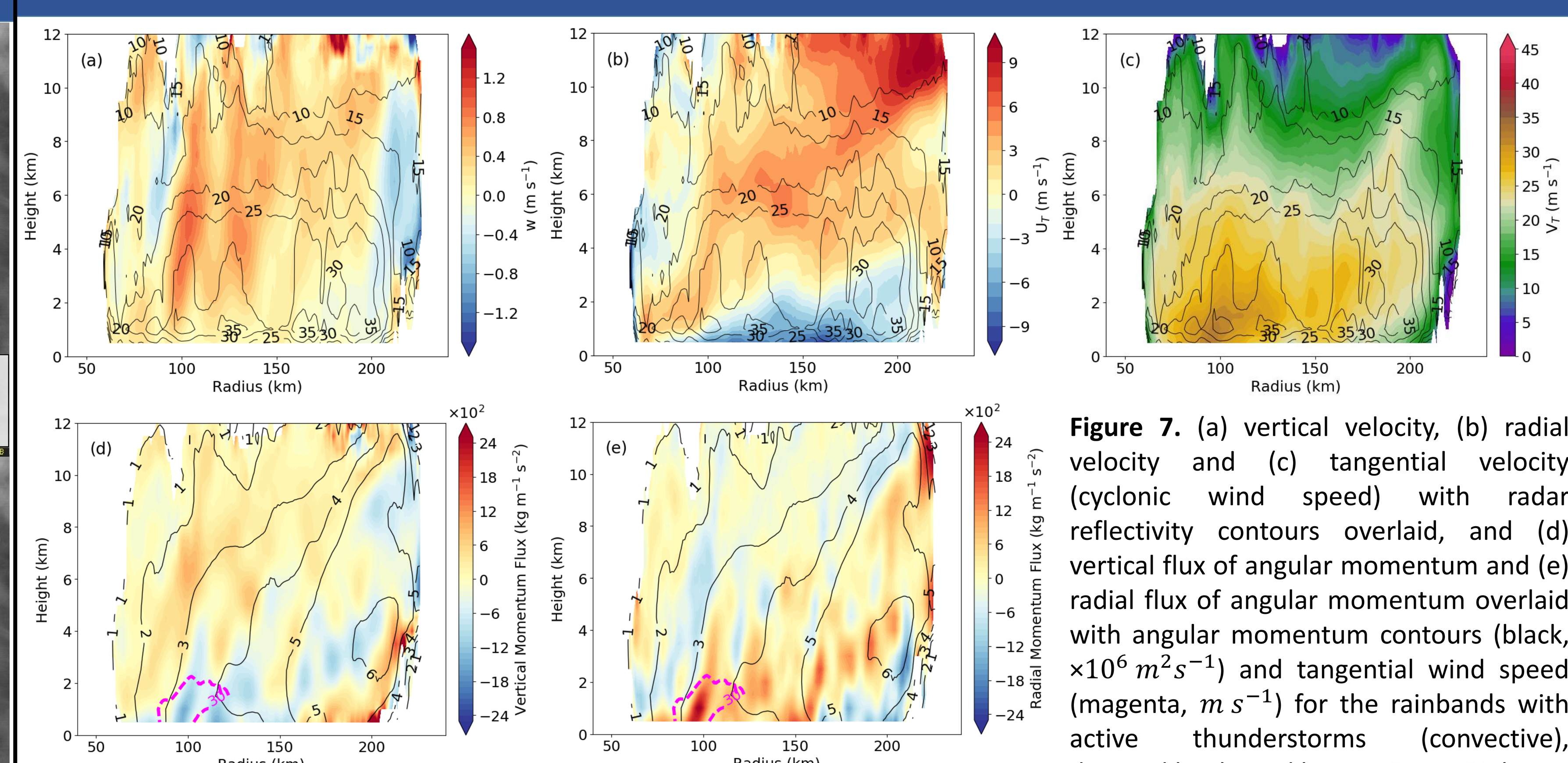


**Figure 7.** (a) vertical velocity, (b) radial velocity and (c) tangential velocity (cyclonic wind speed) with radar reflectivity contours overlaid, and (d) vertical flux of angular momentum and (e) radial flux of angular momentum overlaid with angular momentum contours (black, $\times 10^6\ m^2 s^{-1}$) and tangential wind speed (magenta, $m\ s^{-1}$) for the rainbands with active thunderstorms (convective), denoted by the red lines in Fig. 6, RIght.

- Rainbands with active thunderstorms have weaker cyclonic winds, with a maximum located in the lower levels associated with a low-level inward-flowing secondary circulation.
- However, active thunderstorms were not widespread throughout Hurricane Ophelia.

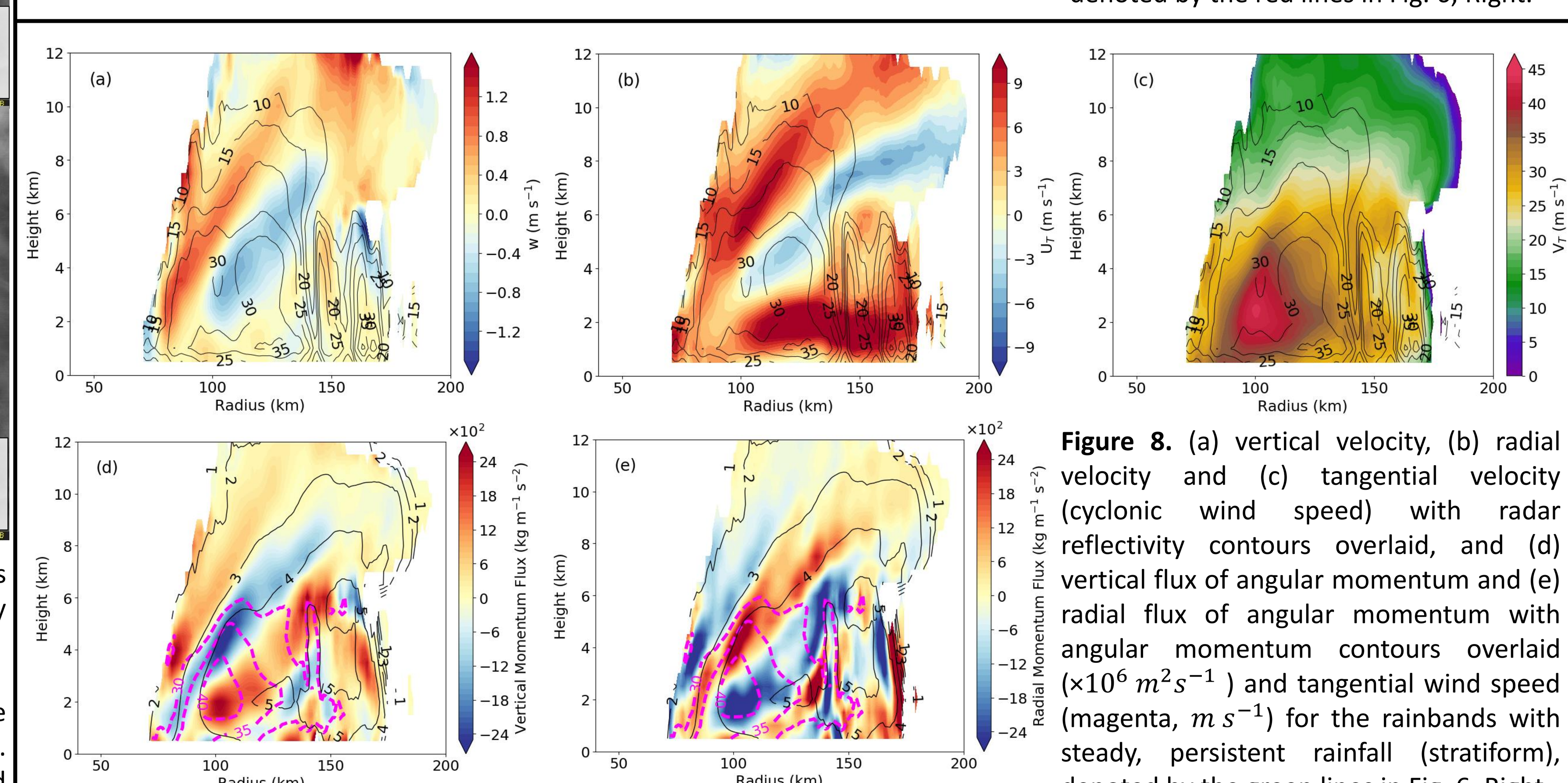


**Figure 8.** (a) vertical velocity, (b) radial velocity and (c) tangential velocity (cyclonic wind speed) with radar reflectivity contours overlaid, and (d) vertical flux of angular momentum and (e) radial flux of angular momentum with angular momentum contours overlaid ($\times 10^6\ m^2 s^{-1}$ ) and tangential wind speed (magenta, $m\ s^{-1}$) for the rainbands with steady, persistent rainfall (stratiform), denoted by the green lines in Fig. 6, Right.

- Rainbands with light, steady rainfall have stronger cyclonic winds, with a maximum in the mid-levels associated with mid-level inward-flowing secondary circulation.
- Strongest radial angular momentum convergence found in light, steady rainfall and may be responsible for cyclonic wind evolution of an eyewall replacement cycle in Hurricane Ophelia.

## Hurricane Rainbands

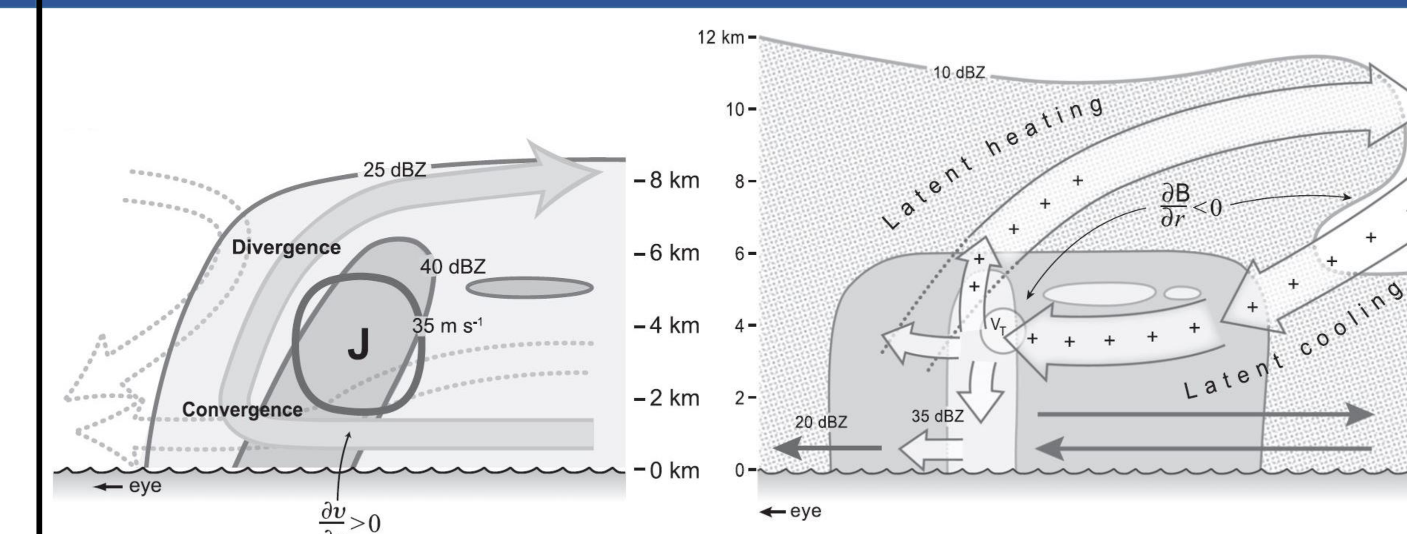



**Figure 4, Left.** Secondary circulation in rainbands dominated by active thunderstorms (convective). Schematic from Hence and Houze (2008).

**Figure 4, Right.** Secondary circulation in rainbands dominated by light, steady rainfall (stratiform). Schematic from Didlake and Houze (2013).

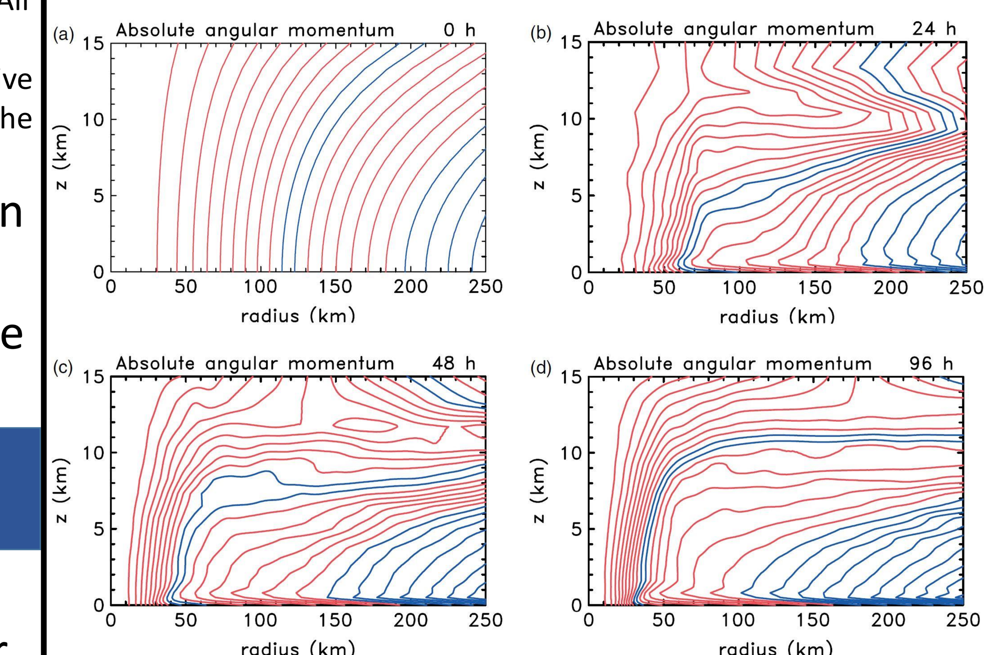


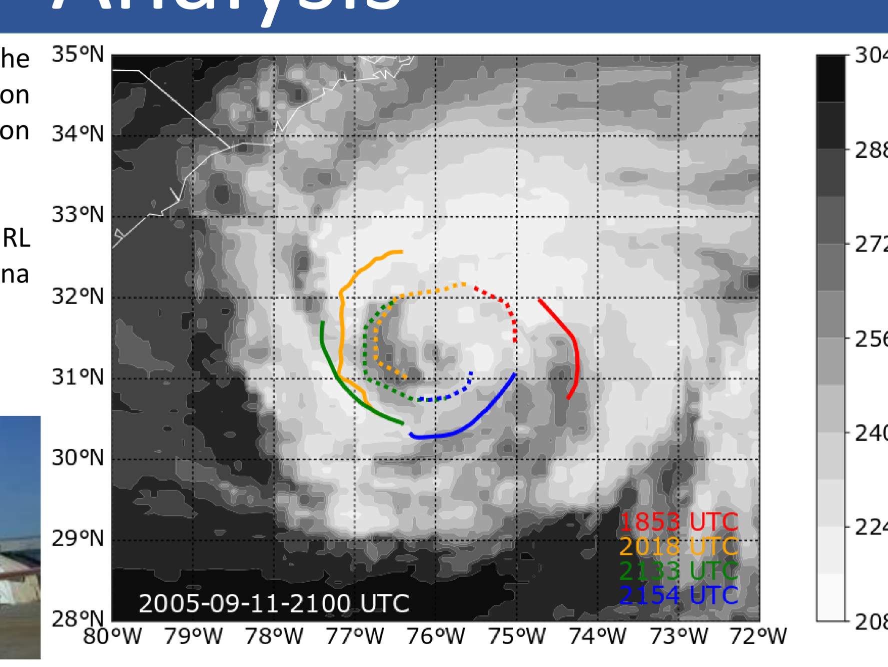

**Figure 5.** Results from an axisymmetric model of a hurricane from Smith et al. (2009). Contours show lines of absolute angular momentum.

**Hypothesis:** Secondary circulation in light, steady rainfall converge angular momentum in the absence of widespread active thunderstorms, leading to an eyewall replacement cycle.

## Analysis

**Figure 6, Right.** Flight track for the aircraft (NRL, solid; NOAA43, dashed) on September 11th 2005. The observation times are listed.

**Figure 6, Bottom.** A picture of the NRL aircraft with the radar antenna protruding from its back.




- Airborne radar observations (NOAA43 and NRL) of Hurricane Ophelia on Sept. 11th 2005 from the Hurricane Rainband and Intensity Change Experiment (RAINEX).
- Data analysis tool known as SAMURAI (Bell et al. 2012).

## References

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