Diagnosing the rapid intensification of Hurricane Patricia (2015) from observations

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Overview

Hurricane Patricia (2015) set several global records, the most noteworthy being its maximum intensity of 185 knots (~ 215 mph) and rapid intensification rate of 105 knots (120 mph) in 24 hours. Patricia was heavily sampled by the National Atmospheric and Oceanic Administration (NOAA) WP-3D and National Aeronautics and Space Administration (NASA) WB-57 aircraft as a joint effort during the NOAA Intensity Forecasting Experiment (IFEX; Rogers et al. 2013) and Office of Naval Research Tropical Cyclone Intensity Experiment (TCI; Doyle et al. 2017). Novel observations gathered in Patricia during three intensive observing periods (IOPs) reveal new insights into the structure of a rapidly intensifying tropical cyclone.

Observational Instruments

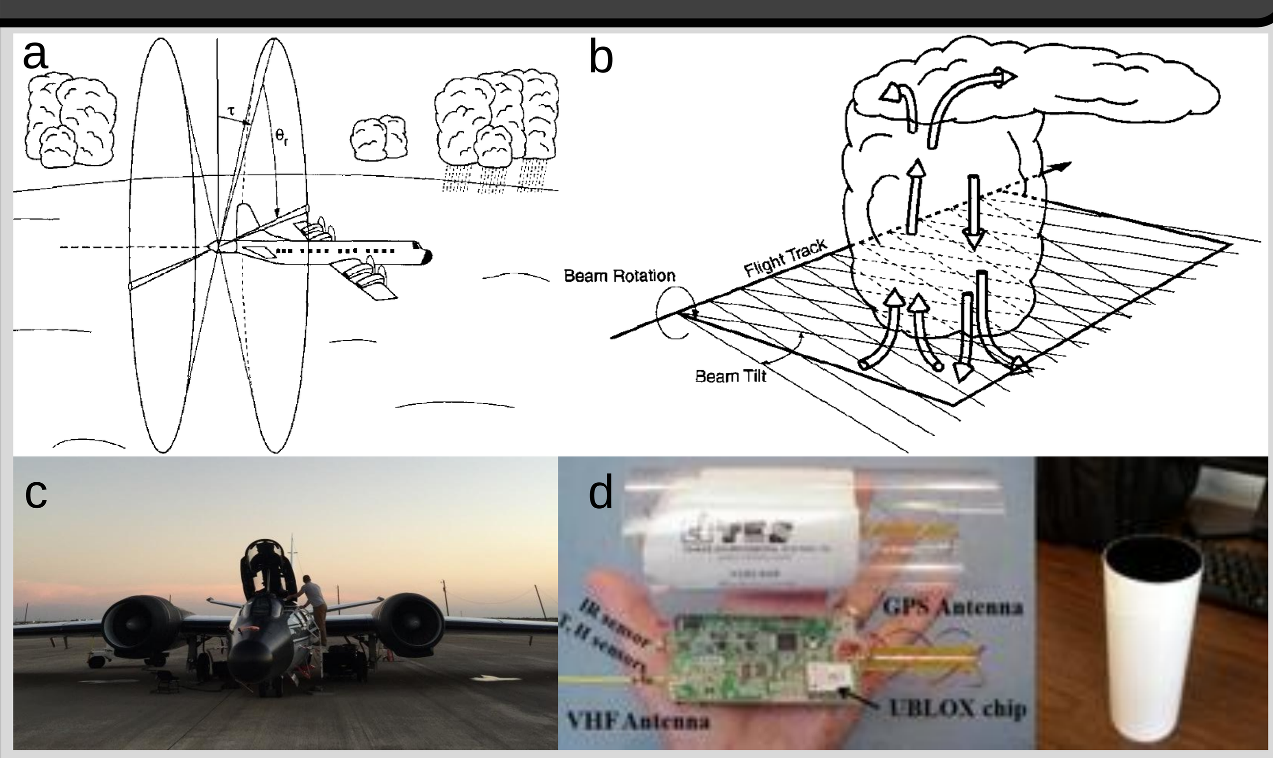

Fig. 1. (a) NOAA WP-3D tail Doppler radar scanning technique. (b) Schematic demonstrating how the tail Doppler radar samples a weather system. Cross hatching denotes the overlapping fore and aft beams of the radar (Hildebrand et al. 1996). (c) NASA WB-57 aircraft and (d) Expendable Digital Dropsondes (XDDs) released into Hurricane Patricia by the WB-57 from ~18 km altitude (courtesy Mark Beaubin).

Patricia's track and intensity

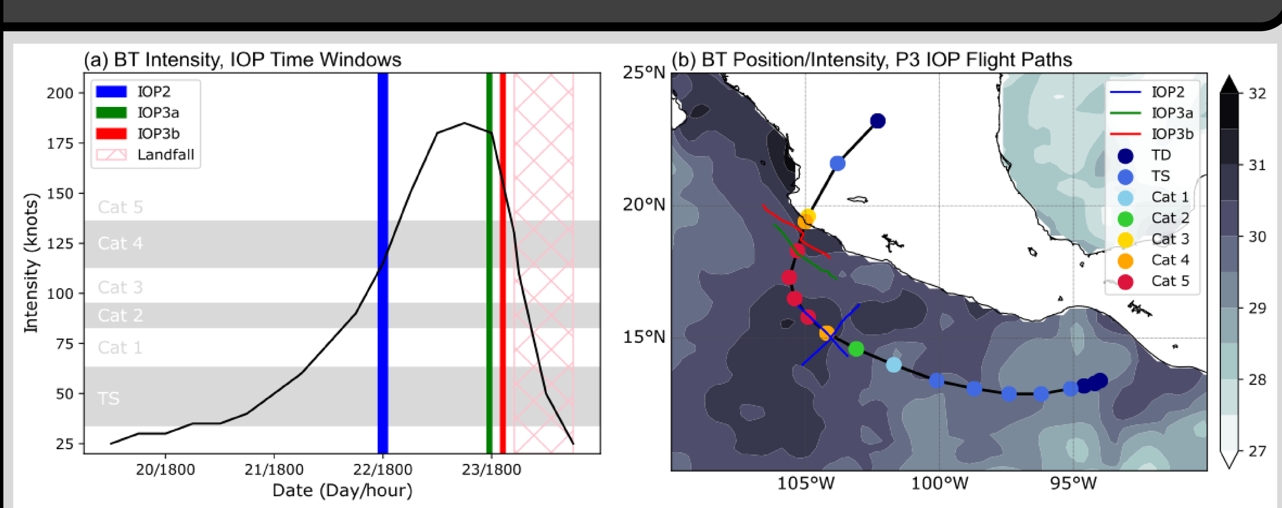

Fig. 2. (a) National Hurricane Center (NHC) Best Track (BT) intensity (knots) for Hurricane Patricia (2015). Colored lines denote the time windows for each intensive observing period (IOP) as follows: IOP2: 1715–1915 UTC 22 October, IOP3a: 1710–1800 UTC 23 October, and IOP3b: 2015–2100 UTC 23 October. IOP1 not shown. (b) BT position (black curve) and Saffir-Simpson scale intensity (colored dots) throughout Patricia's life cycle overlaid on the sea-surface temperatures valid 19 October from the Optimum Interpolation Sea Surface Temperature (OISST) database (Banzon et al. 2016).

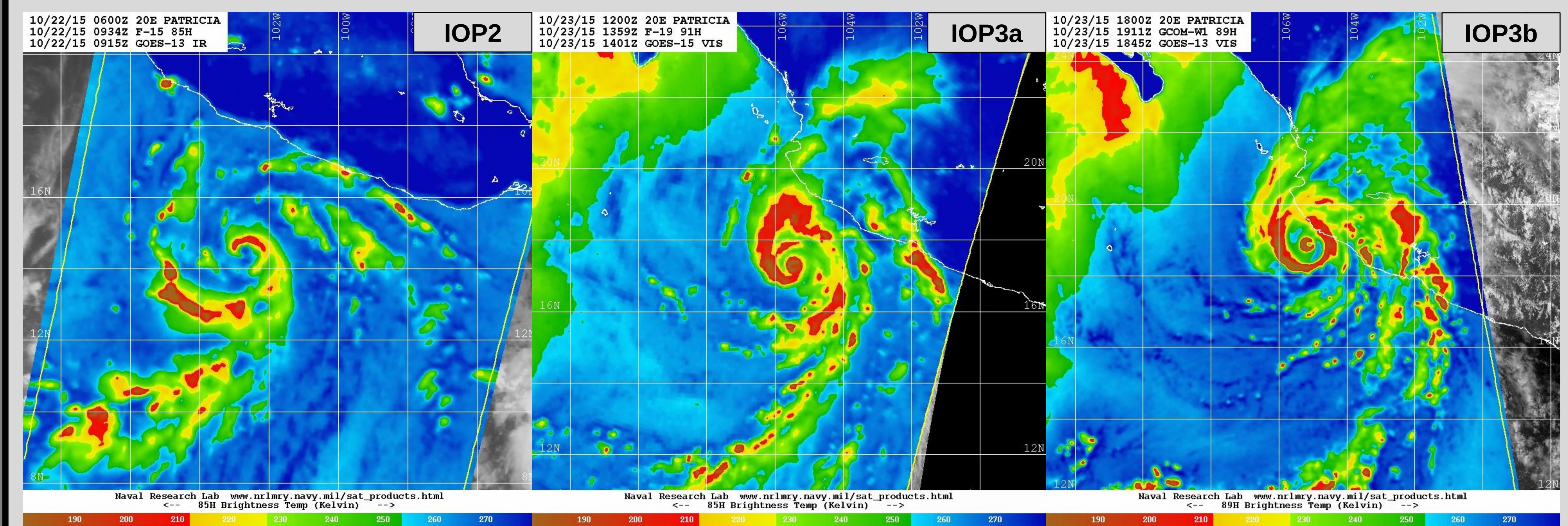

Fig. 3. Horizontal-polarized microwave (89–91 GHz) derived brightness temperature structure of Hurricane Patricia from 22 to 23 October as viewed by microwave imaging instruments aboard polar orbiting satellites. Time is shown in the upper-left corner and the closest corresponding IOP is shown in the upper-right corner. Courtesy of Naval Research Lab.

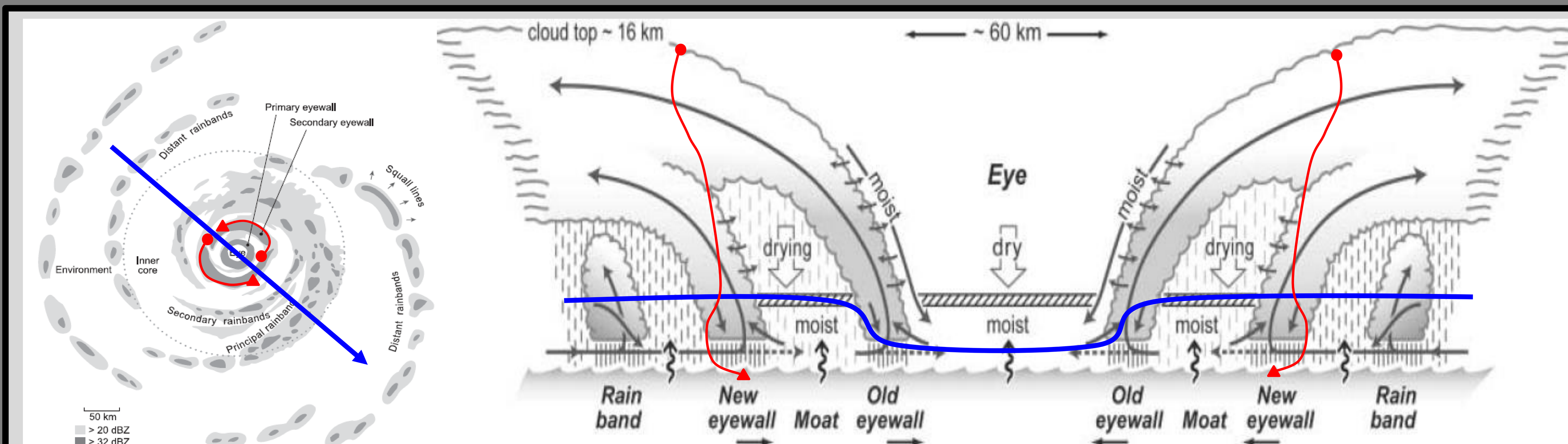

Fig. 4. (Left) Idealized top-down schematic of a tropical cyclone. The blue line denotes an example flight path of the NOAA WP-3D aircraft and the red lines denote example dropsonde trajectories released by the WB-57 from start (circle) to end (triangle). (Right) Idealized radius-height cross-section through a tropical cyclone showing the same examples. Adapted from Houze (2010) and Houze et al. (2007), respectively.

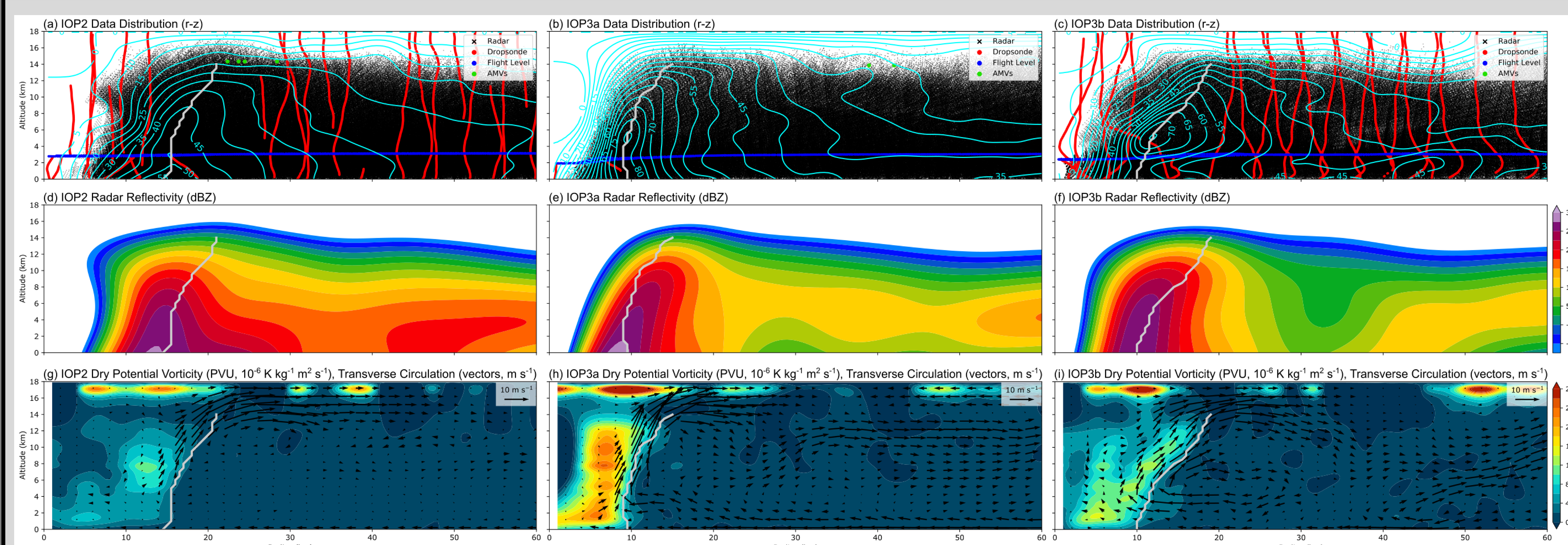

Fig. 5. Axisymmetric observational analyses created using the Spline Analysis at Mesoscale Utilizing Radar and Aircraft Instrumentation (SAMURAI; Bell et al. 2012) technique – a 2-D spline based variational technique that yields the most likely state of the atmosphere given a set of observations. (a), (c), (e) Storm-relative data distributions for IOP2, IOP3a, and IOP3b, respectively, in the radius-height (r-z) plane. Dropsonde trajectories are shown in red, in-situ measurements in blue, atmospheric motion vectors in green, and tail Doppler radar observation points in black. Tangential velocity is overlaid in cyan contours (every 5 m s^{-1}). (d), (e), (f) Radar reflectivity (dBZ) as observed by the P3 tail Doppler radar. (g), (h), (i) Dry Ertel's potential vorticity (shaded, PVU; 1 PVU = 10^{-6} K kg^{-1} m^2 s^{-1}) and transverse circulation vectors (m s^{-1}). The radius of maximum tangential winds (RMW) is shown in gray for each figure.

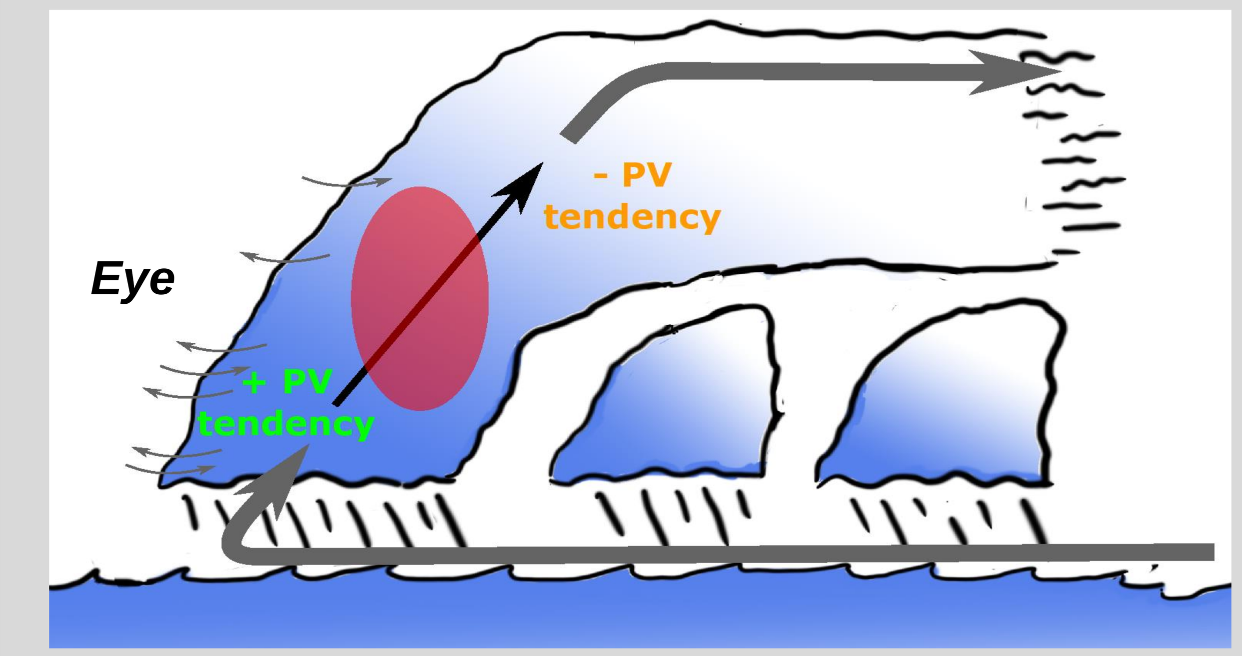

Fig. 6. Idealized radius-height cross section through a tropical cyclone. The large gray arrow denotes the transverse circulation, black arrow the absolute vorticity vector, red shading the diabatic heating, and small gray arrows the mixing at the eye-eyewall interface. Potential vorticity tendency from diabatic heating is shown in green/orange. Adapted from Hill and Lackmann (2009), courtesy of Alyss Ferrer.

Conclusions

Hurricane Patricia (2015) formed in a favorable environment characterized by high sea-surface temperatures (Fig. 2b). Its compact structure at early stages (Fig. 3) further enhanced its ability to undergo rapid intensity changes. A strong transverse circulation provided persistent forcing for the generation of a potential vorticity tower within a narrow annulus of ~10 km (Fig. 5). The mechanism sustaining the hollow tower of potential vorticity (Fig. 6) was ultimately impeded by the formation of a secondary eyewall, leading to a breakdown of the primary eyewall and mixing at the eye-eyewall interface (Figs. 5c, f, i). Future work will characterize potential vorticity asymmetries throughout Patricia's life cycle with 3-D observations, providing further insight into the dynamics involved in tropical cyclone rapid intensification.