SIMULATED AZIMUTHAL STRUCTURE OF THE HURRICANE BOUNDARY LAYER IN HURRICANES IRMA ('17) AND EARL ('10) DURING INTENSITY CHANGE

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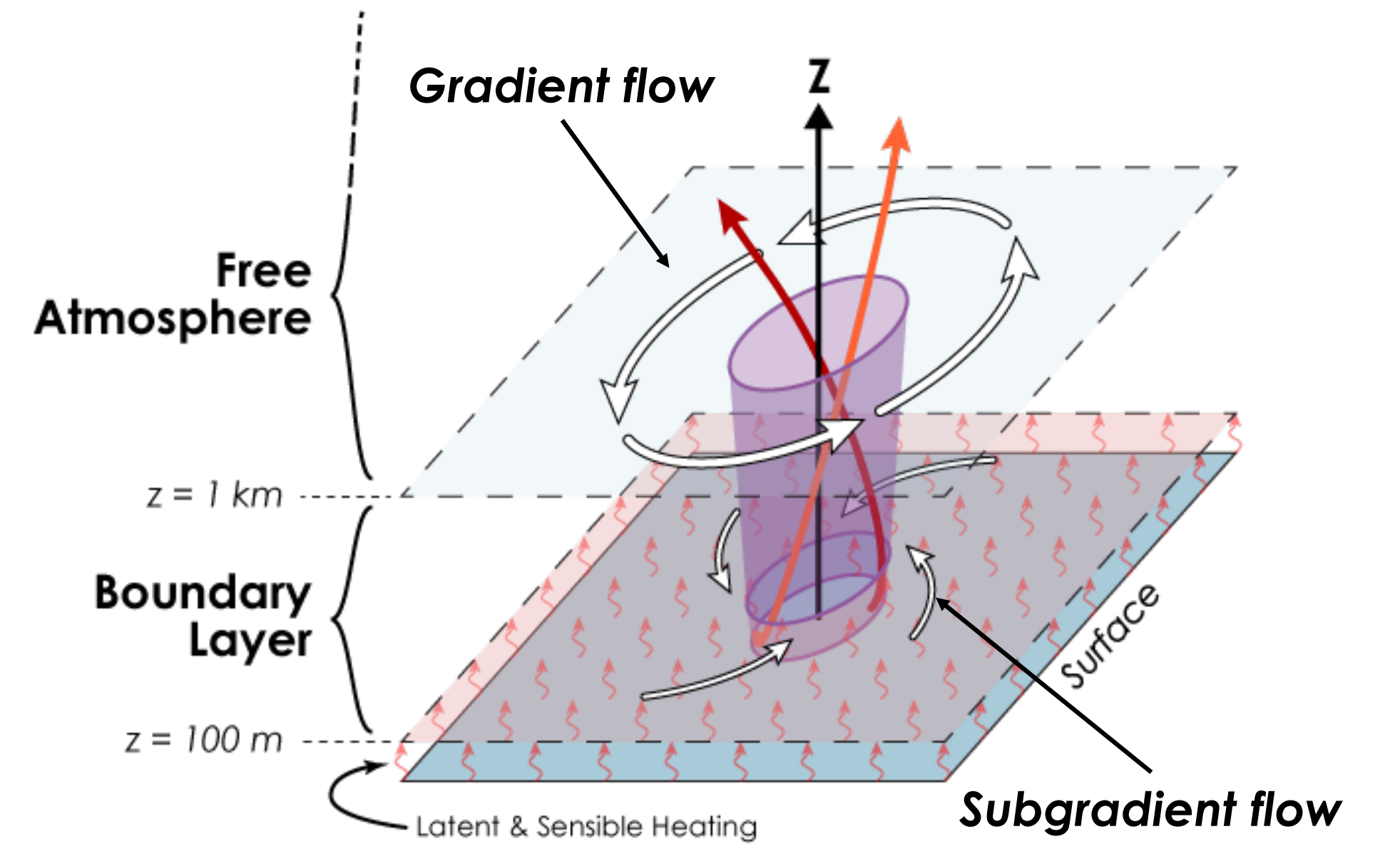
Introduction

The hurricane boundary layer (BL), constituting the lowest 1–2 km of the atmosphere, represents a key component of a hurricane's "heat engine." Friction promotes inflow in the hurricane BL[1], which draws heat and moisture sourced from the warm ocean toward the center of a hurricane[2].

*Entropy-rich air in the BL can **converge and ascend** in inner-core **convection**.*



In the free atmosphere ...

$$\frac{1}{\rho}\frac{\partial p}{\partial r} \approx fv + \frac{v^2}{r}$$

In the hurricane BL ...

$$\frac{1}{\rho}\frac{\partial p}{\partial r} \neq fv + \frac{v^2}{r}$$

*At least to this effect, **the BL plays a key role in storm intensity**.*

Observed **azimuthal-mean BL inflow** has been shown to **differ** between hurricanes that intensify and hurricanes that do not intensify[3], implying differences in **BL convergence** and possibly **convection**.

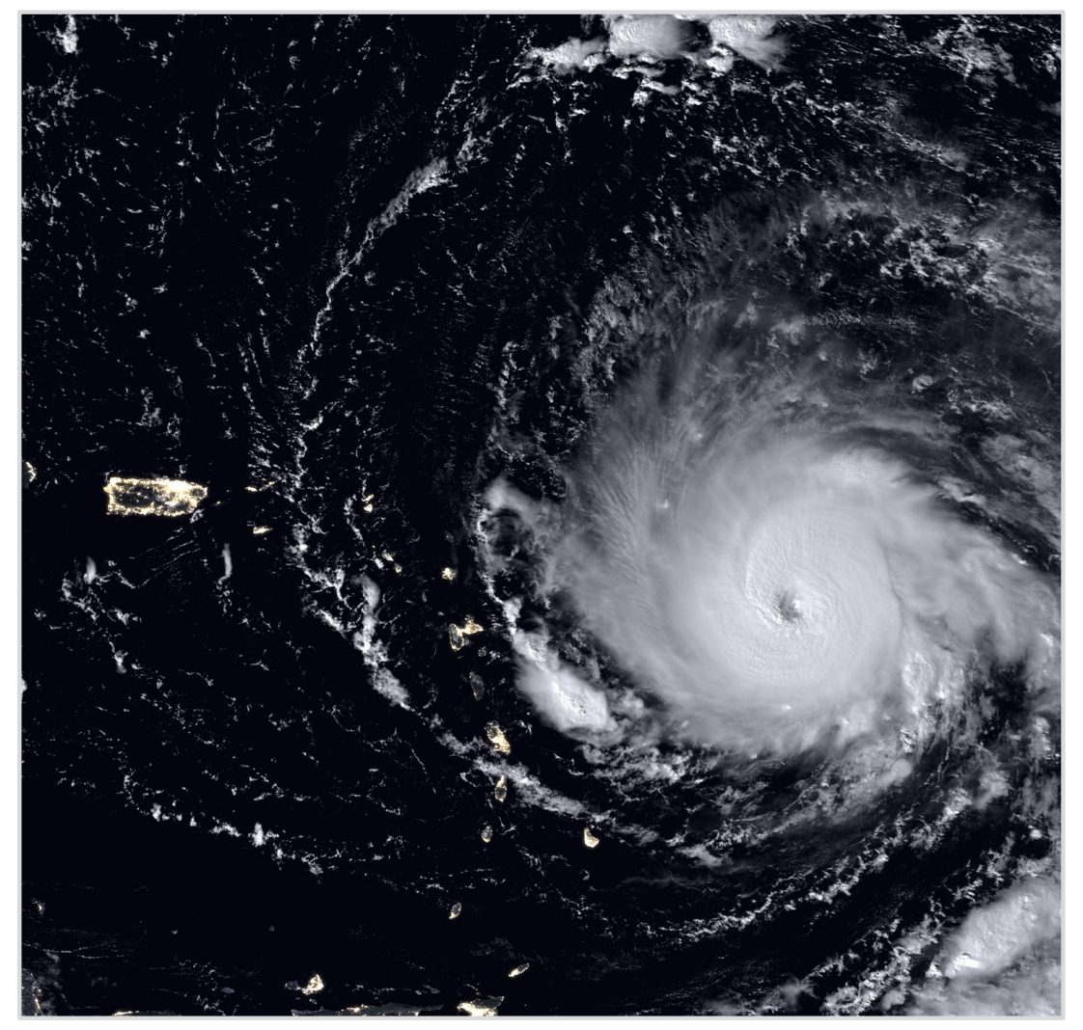
Radial inflow can also be **asymmetric**, with inflow depth and/or magnitude **enhanced downstream** of **storm motion** and **vertical wind shear**[4,5].

*How does **azimuthal** BL structure differ between hurricanes that intensify and those that do not? How do these differences compare from **case to case**?*

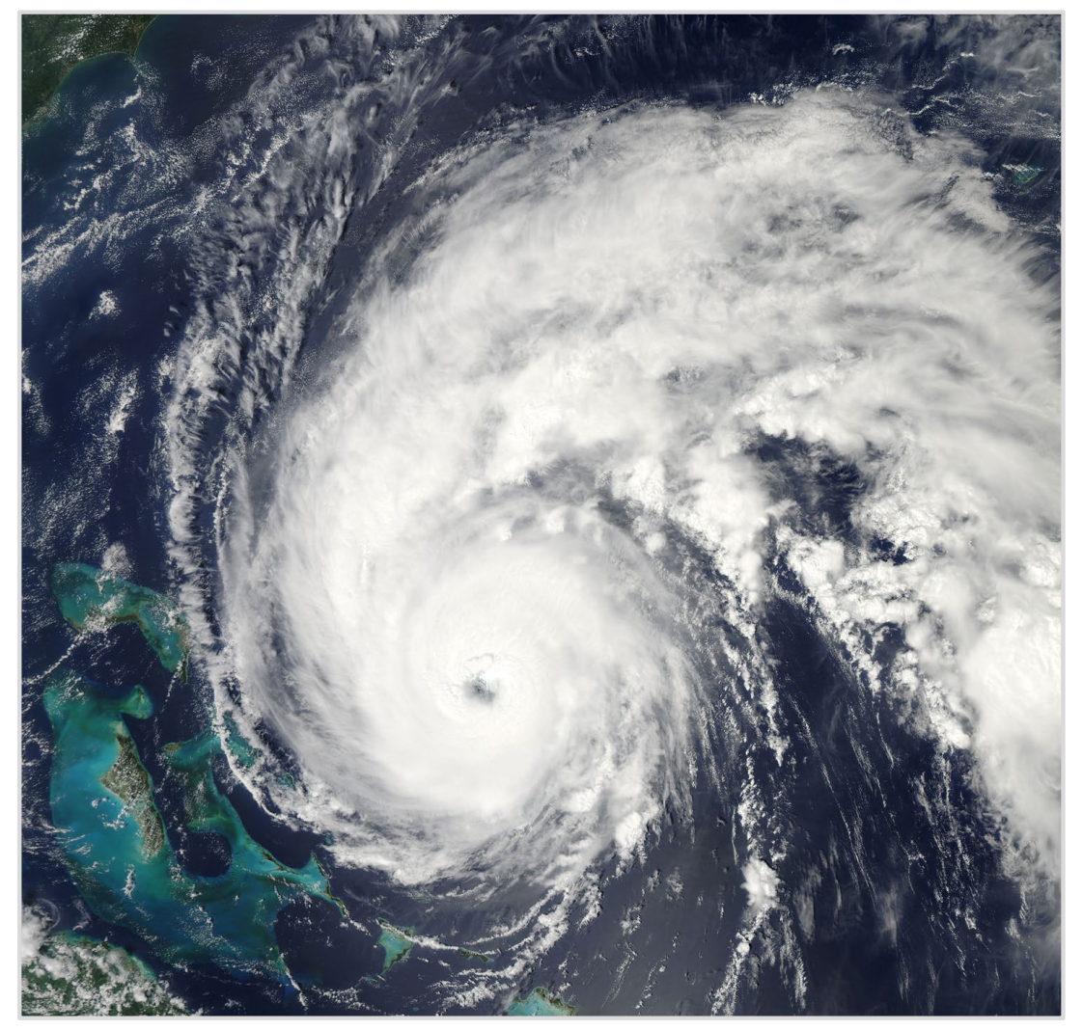
Case Subjects

High-resolution WRF-ARW[6] simulations were run for **Hurricanes Irma (2017) and Earl (2010).** These cases were chosen for their differing environmental shear and comparable intensities.

Hurricane Irma
Weak/moderate shear



Hurricane Earl
Moderate/strong shear



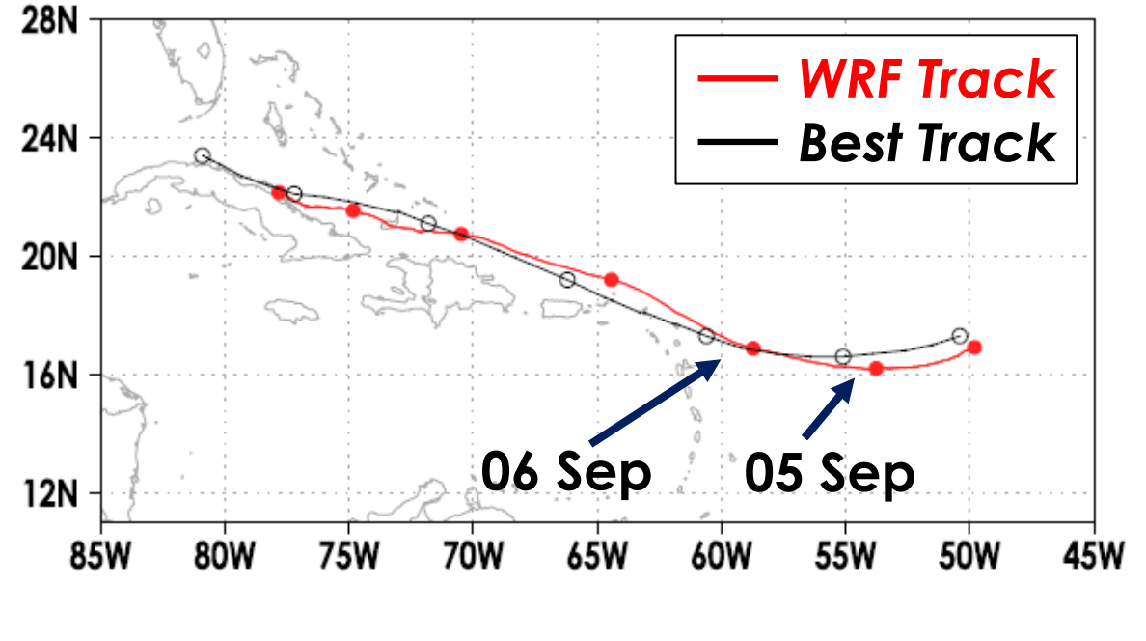
Satellite imagery taken from http://earthobservatory.nasa.gov

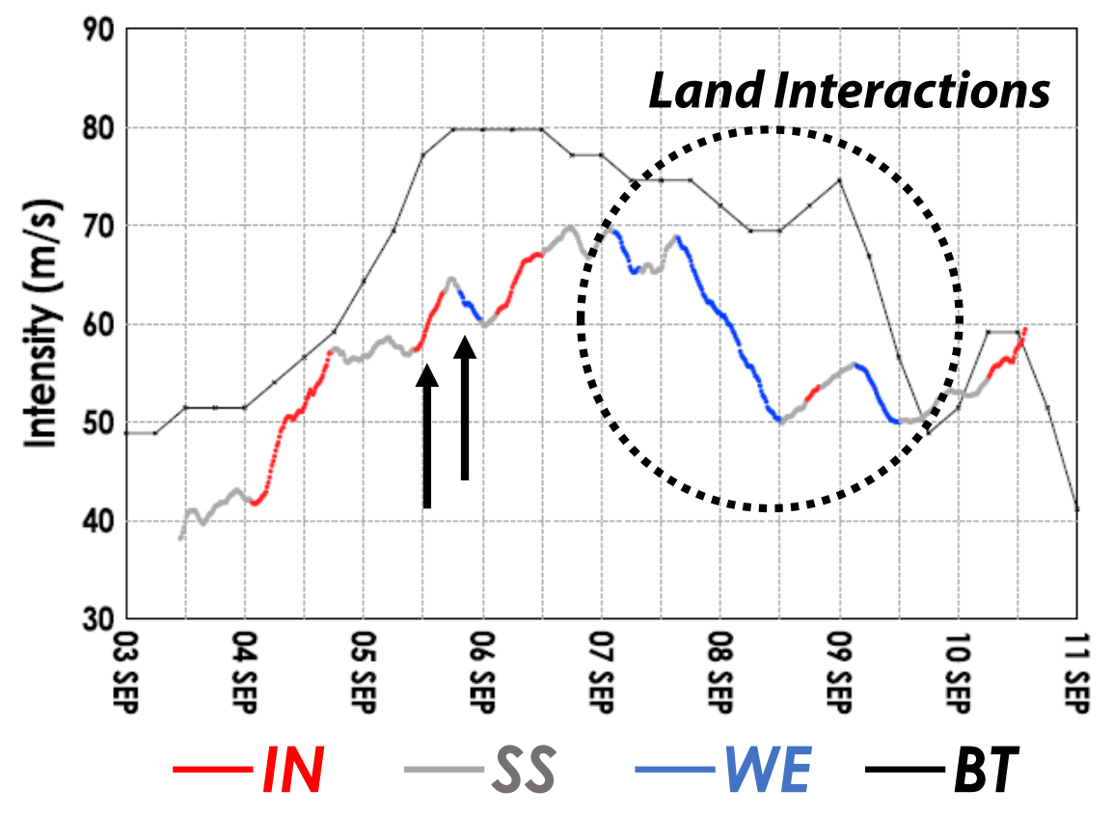
Hurricane Irma

For this case, we focus on two periods on 05 September: one intensifying, and one weakening. Irma tracked WNW at ~11 kt, while northerly shear increased from ~15 kt to ~20 kt just prior to weakening. Shear decreased to ~15 kt near the end of the weakening period.

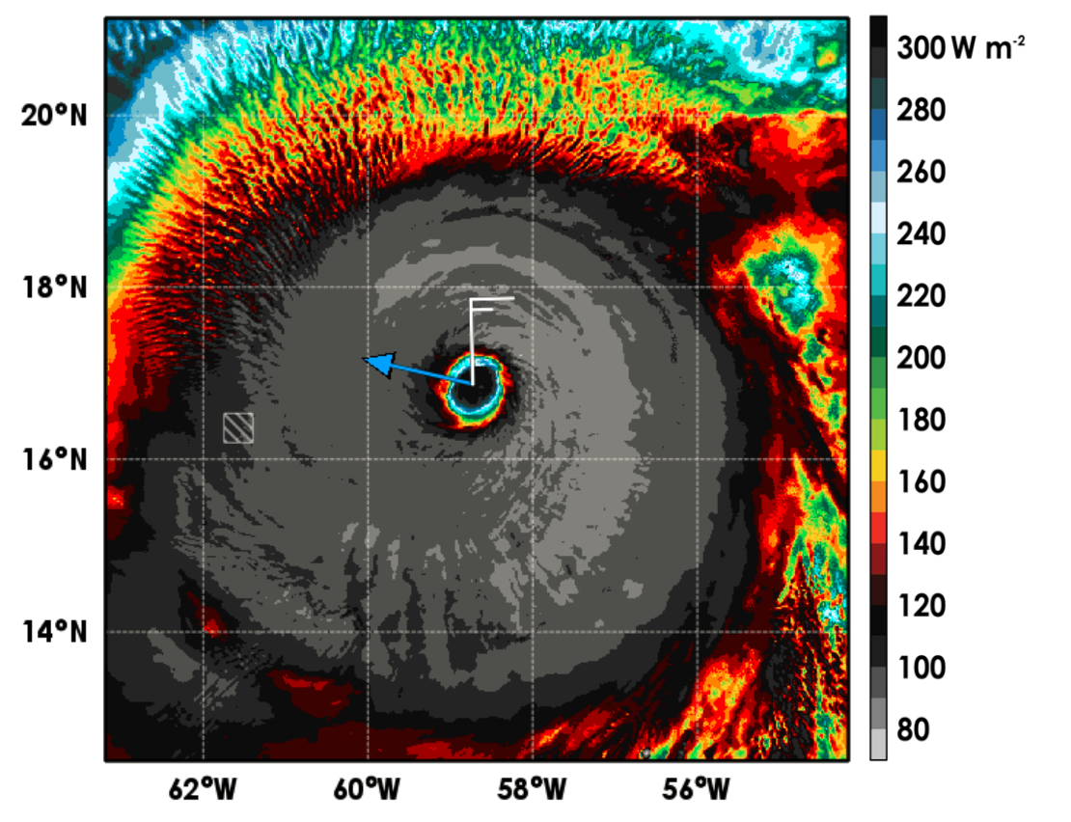
Irma's track and intensity are depicted below, with relevant points of time highlighted by arrows. On the right, we show a snapshot of Irma's simulated IR, with motion and shear drawn as a vector and a wind barb, respectively.

Track for 00Z 04 – 10 Sep



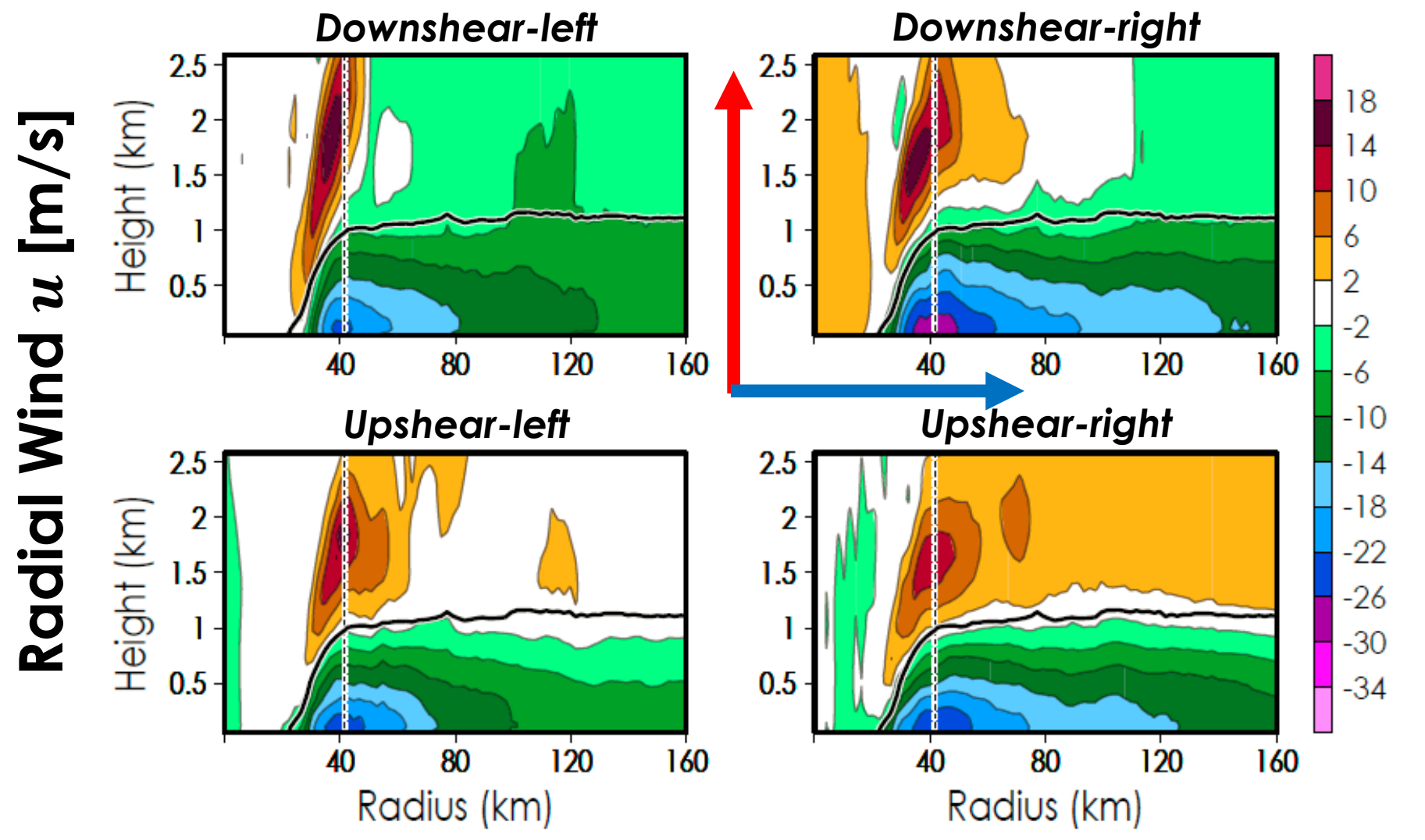


00Z 06 September

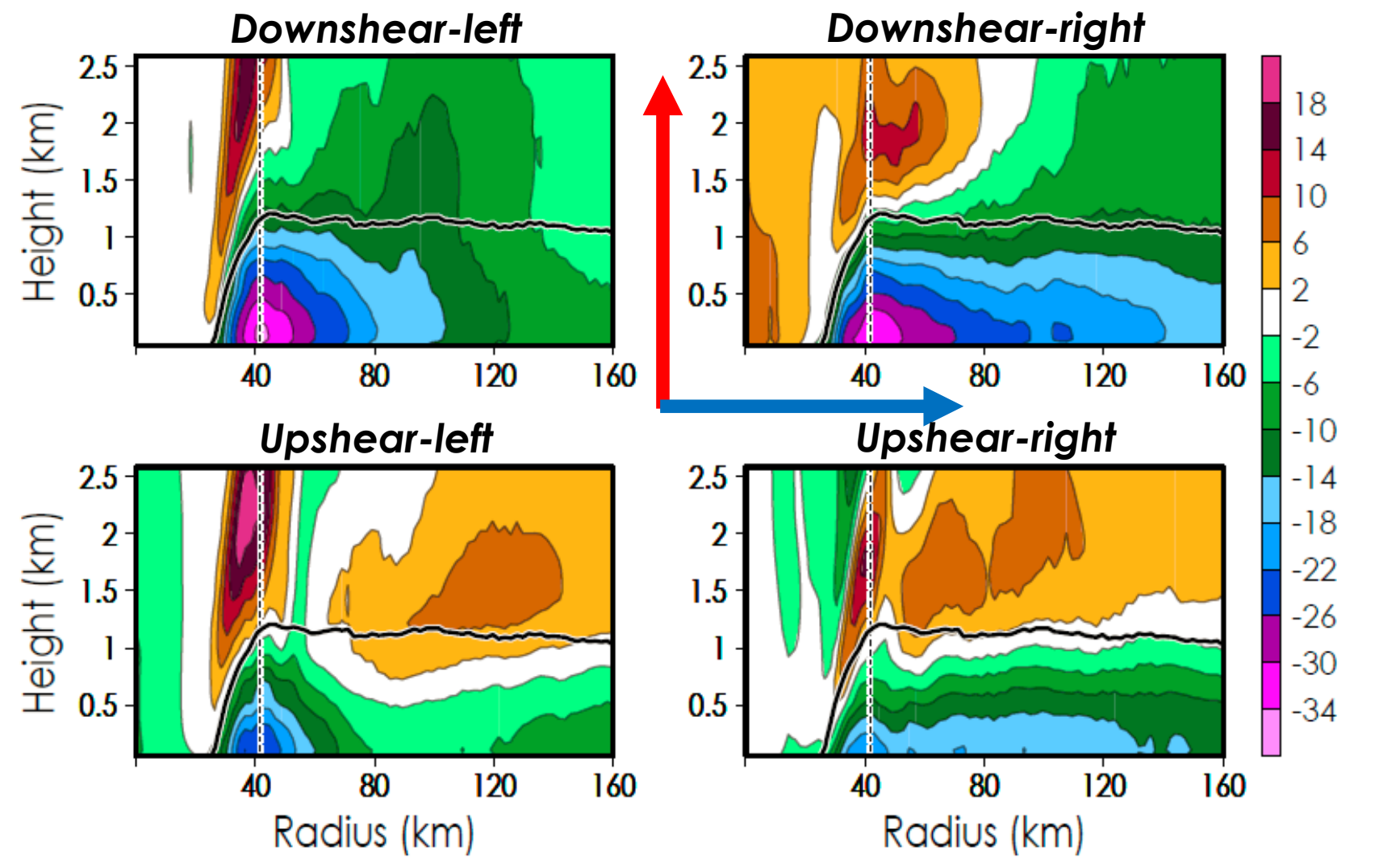


Below are radius-height cross sections of radial wind from each shear-relative quadrant during intensification (left) and weakening (right) on 05 September. The solid black line is the azimuth-mean inflow layer top, and the dotted line is the RMW. Red and blue vectors respectively denote the shear and storm motion directions.

***Intensification**, 12Z 05 Sep*



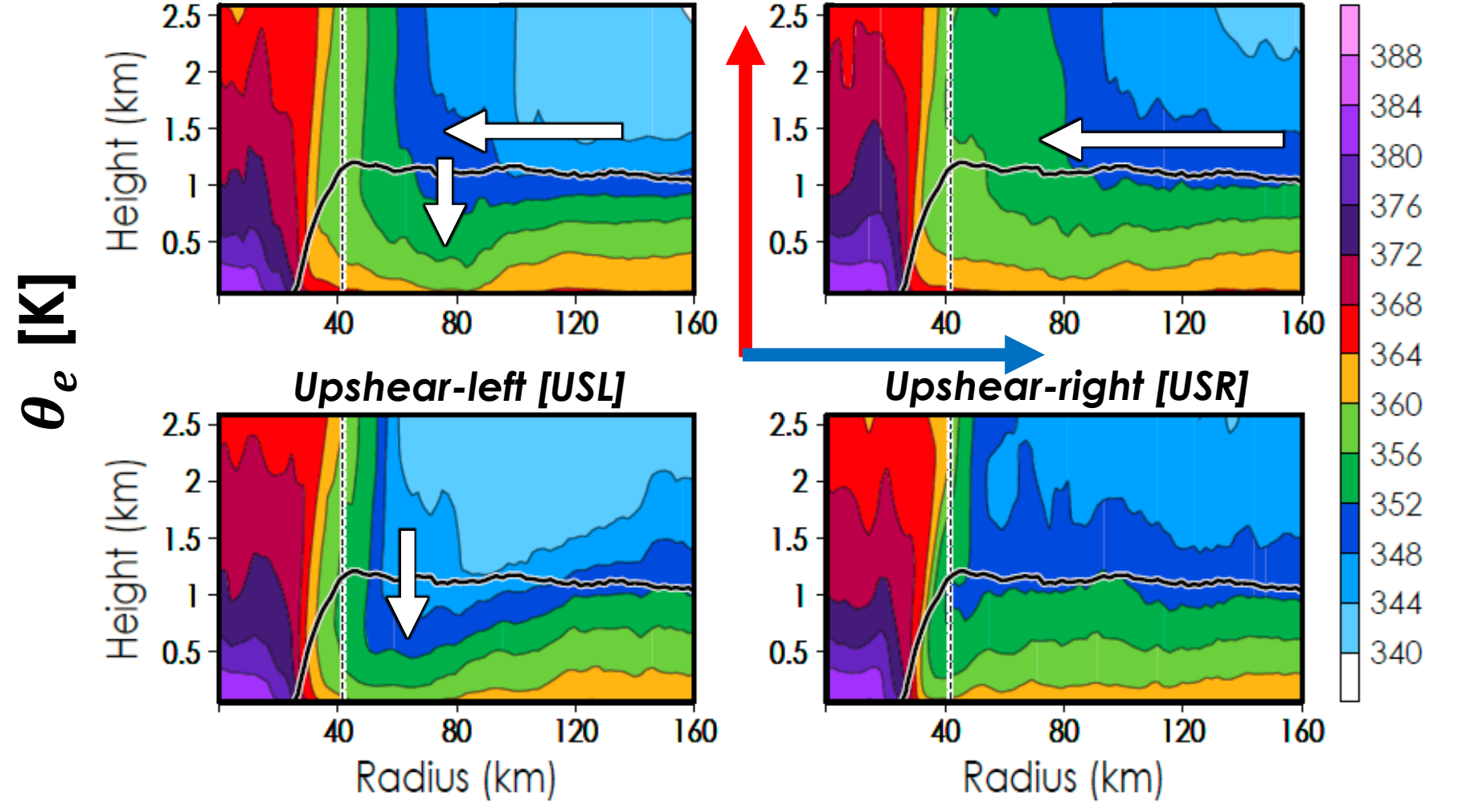
***Weakening**, 21Z 05 Sep*

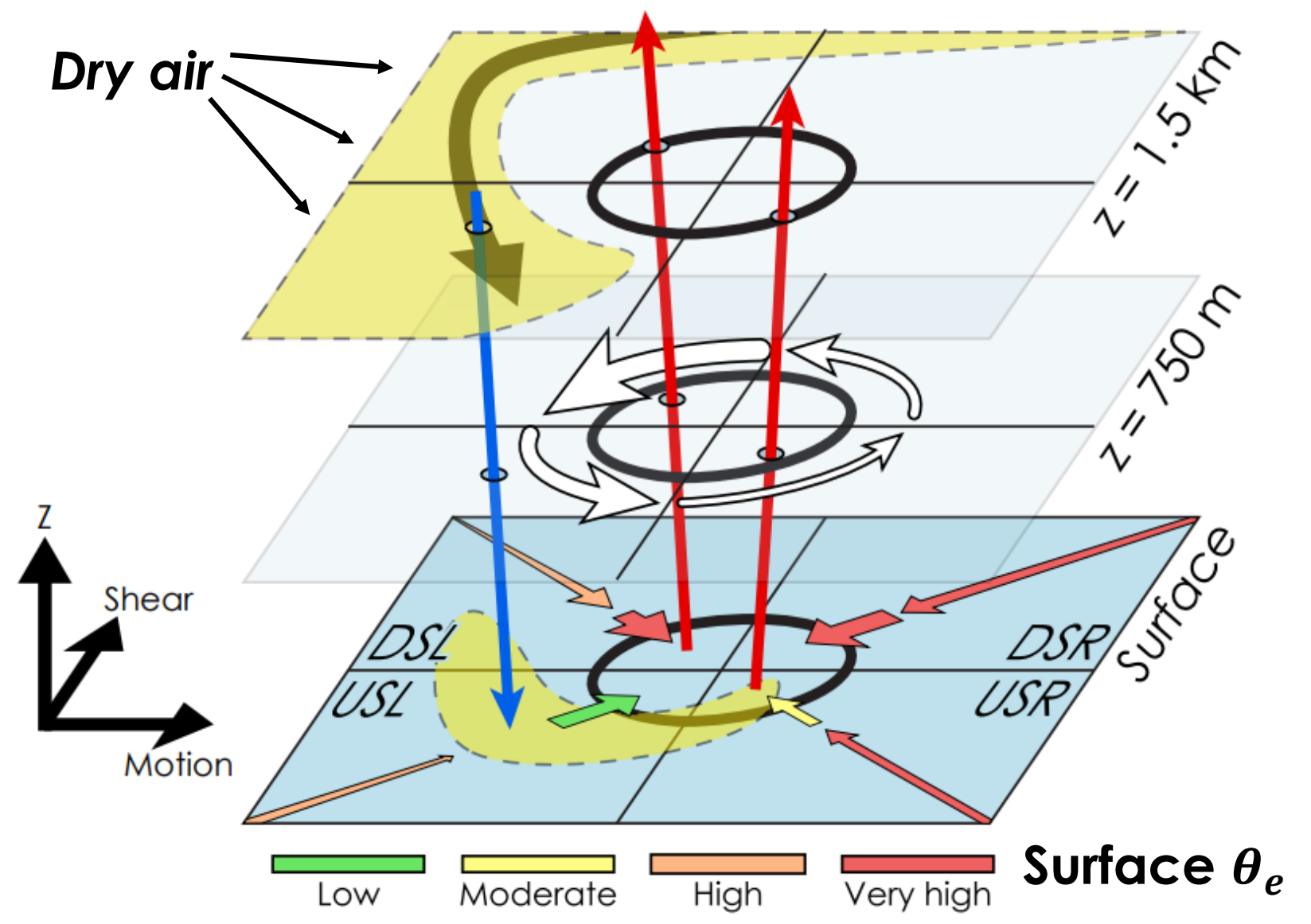


Asymmetry is amplified during weakening, with **ample BL divergence upshear-left**.

*During weakening, deep inflow downshear transports drier air above the BL inward. The **air then descends into the BL left of shear**, in coincidence with BL divergence there.*

***Weakening**, 21Z 05 Sep*



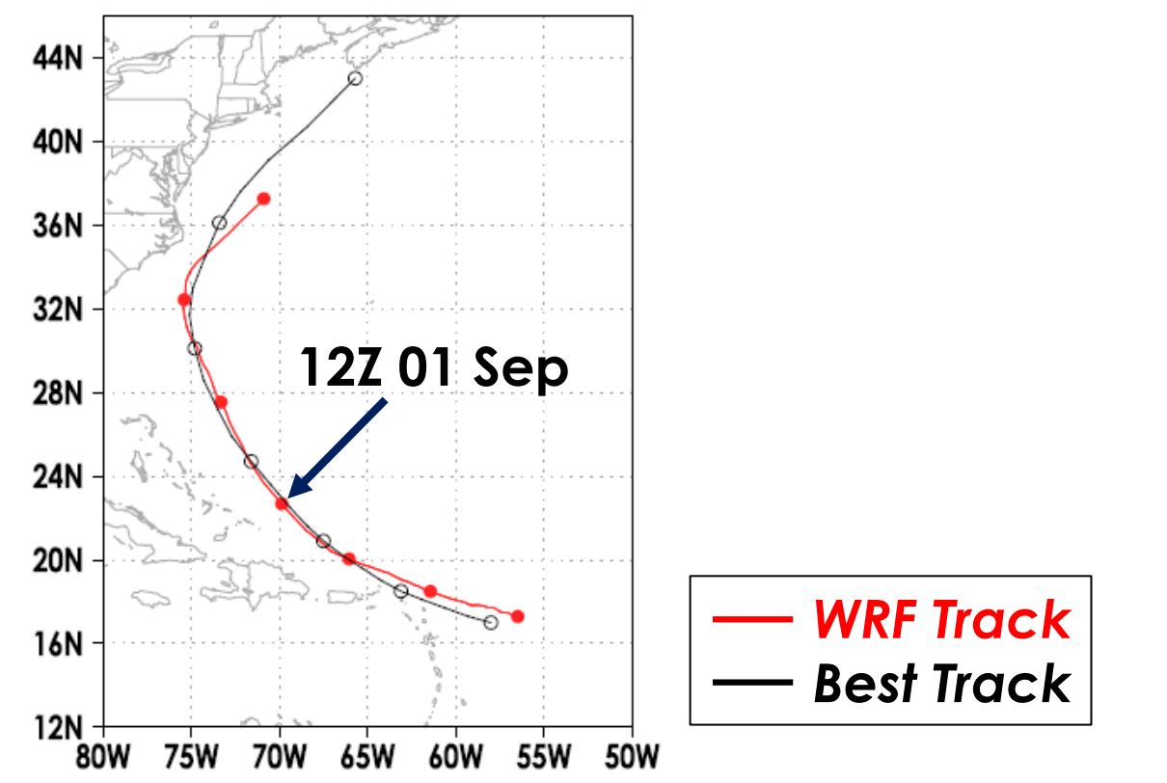


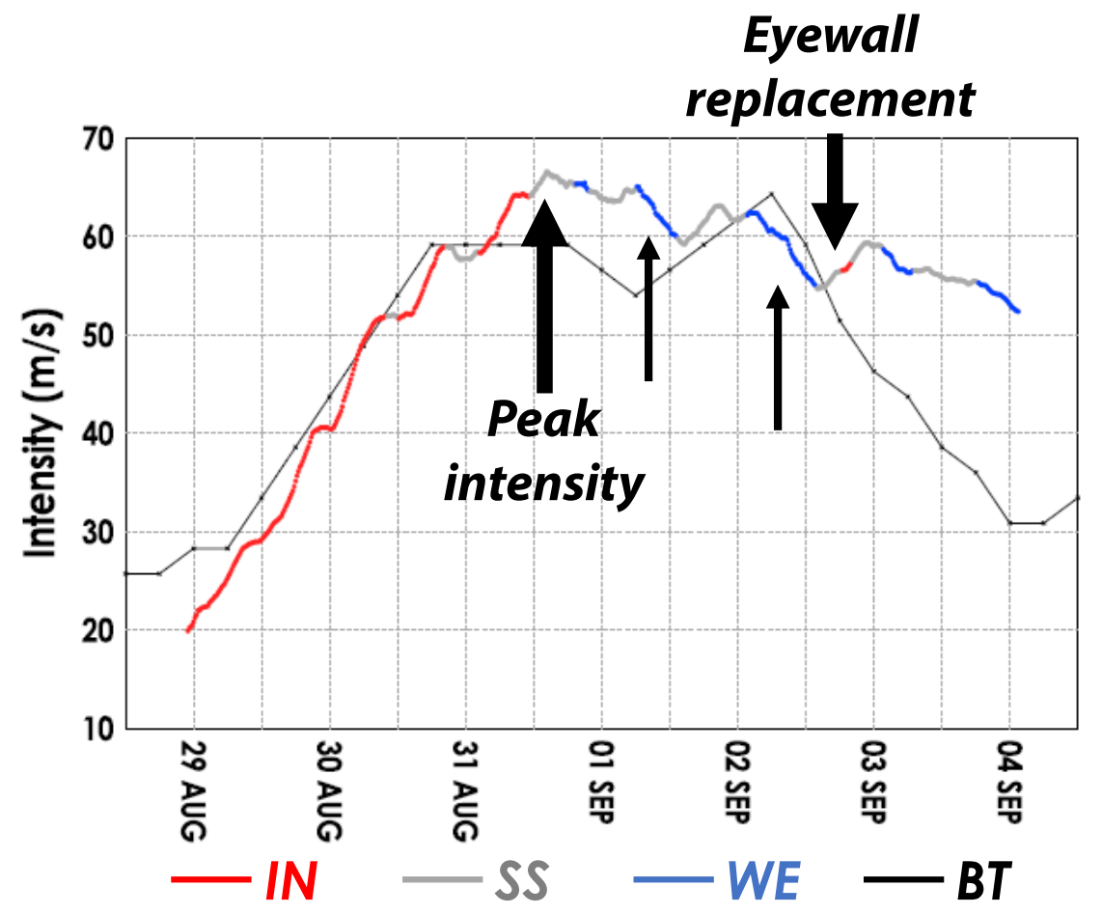
*As shown in the schematic on the right, the dry air that descends into the BL left of shear is then ingested by convection downwind, **likely reducing Irma's intensity.***

Hurricane Earl

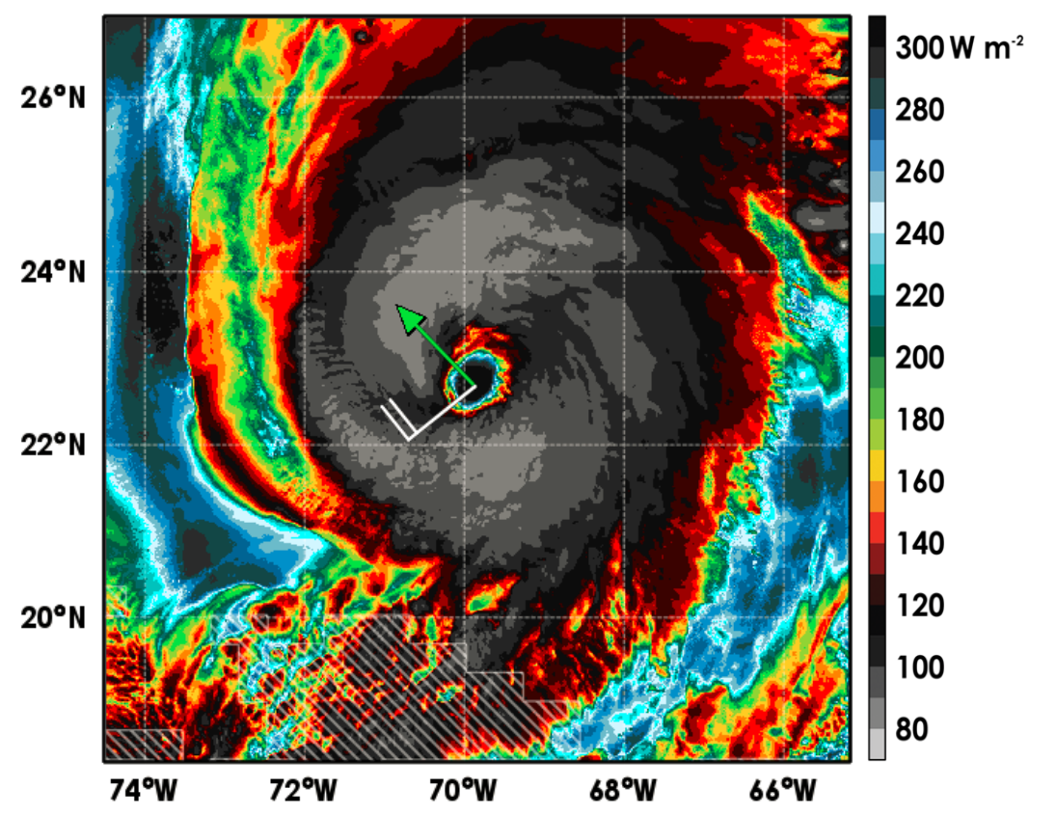
In this case, we highlight a period of prolonged weakening following peak intensity, which culminated in an eyewall replacement.

Track for 12Z 29 Aug – 04 Sep



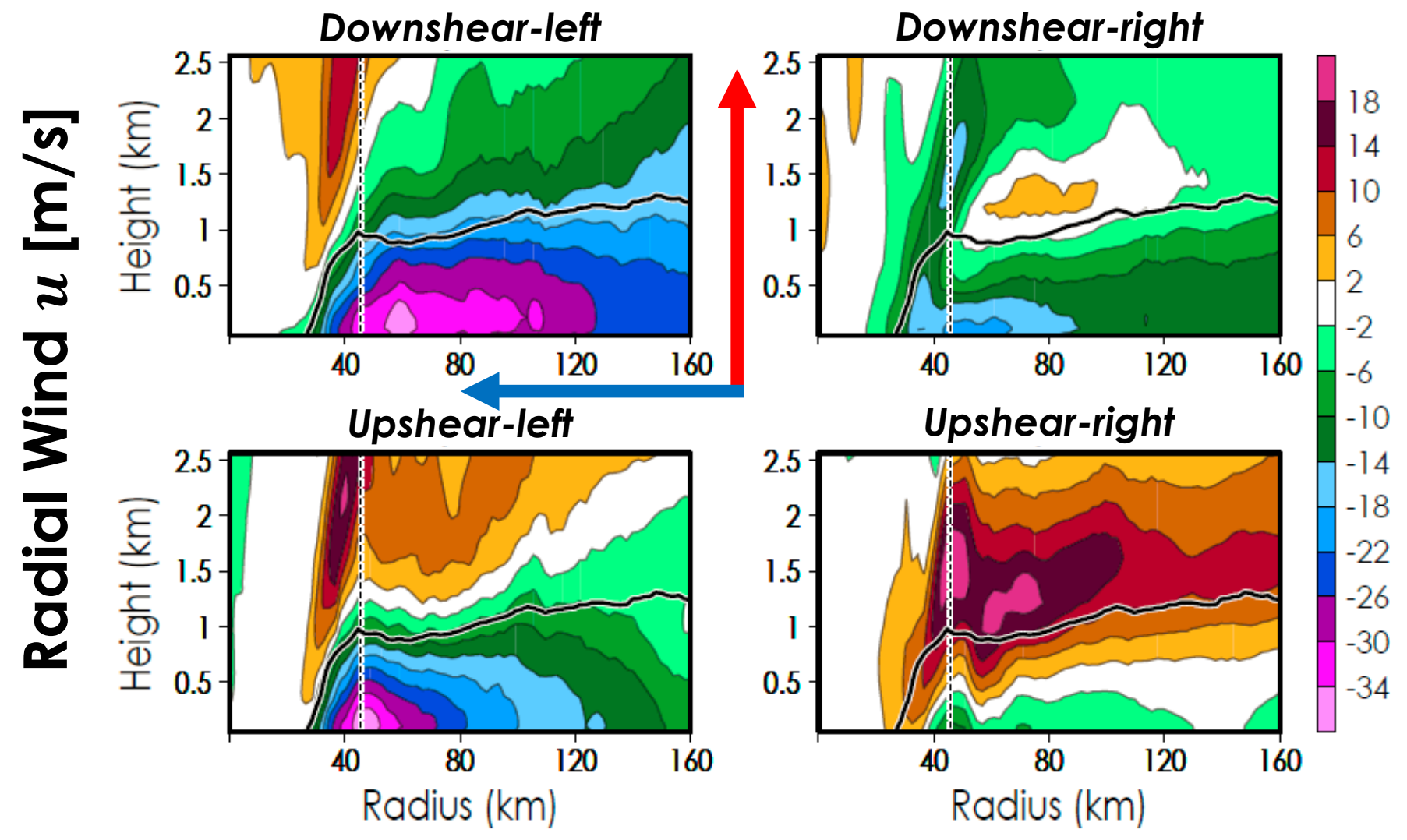


12Z 01 September



Following peak intensity, shear increased from ~15 kt to ~20 kt, and then became nearly orthogonal to the storm motion. Earl's BL exhibited strong asymmetry after 01 September.

***Weakening**, 09Z 01 Sep*



Unlike Irma, **Earl develops strong outflow in the USR quadrant**.

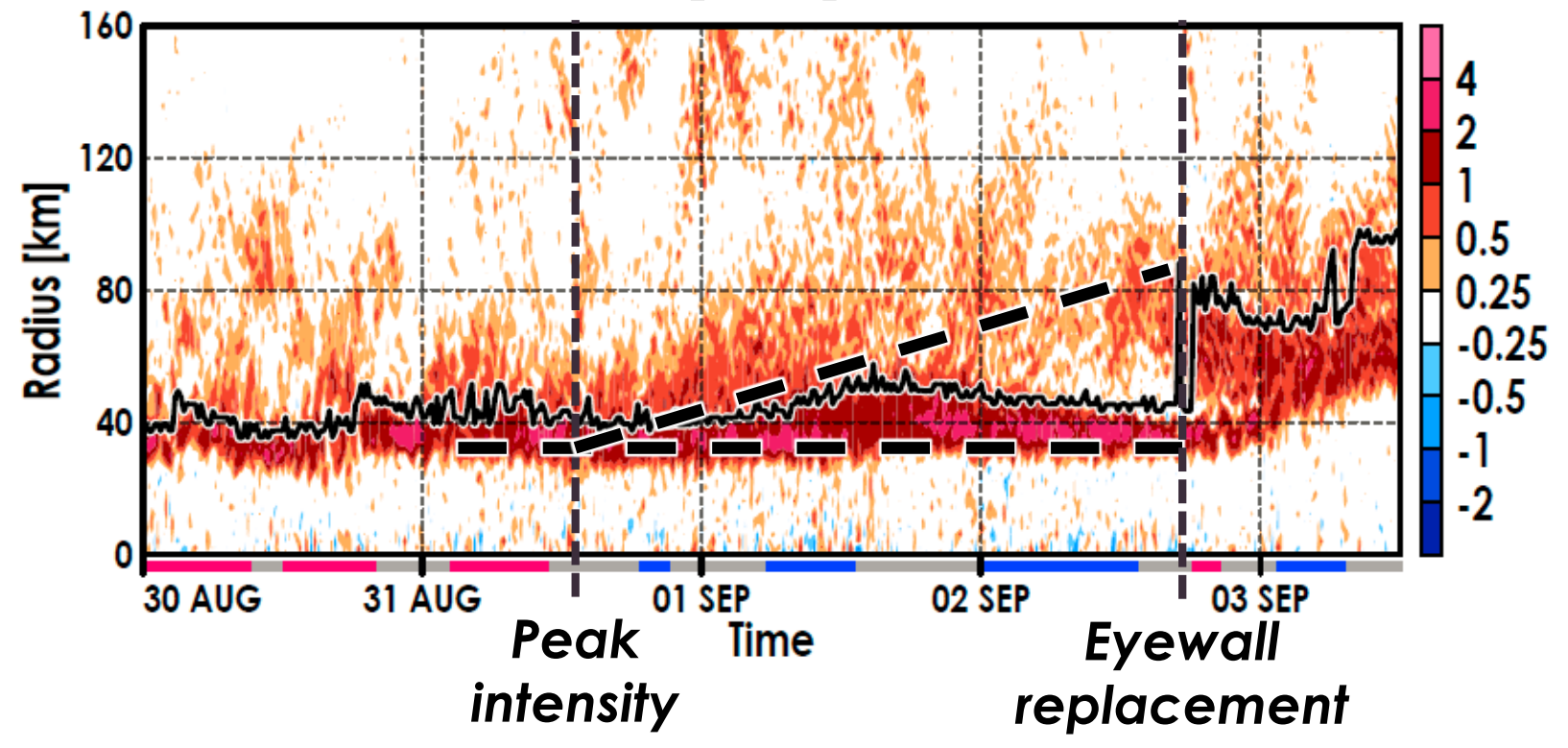
The outflow is linked to the intense inflow left of shear, which positively advects angular momentum inward . . .

$$M_a = rv + \frac{1}{2} f_o r^2$$

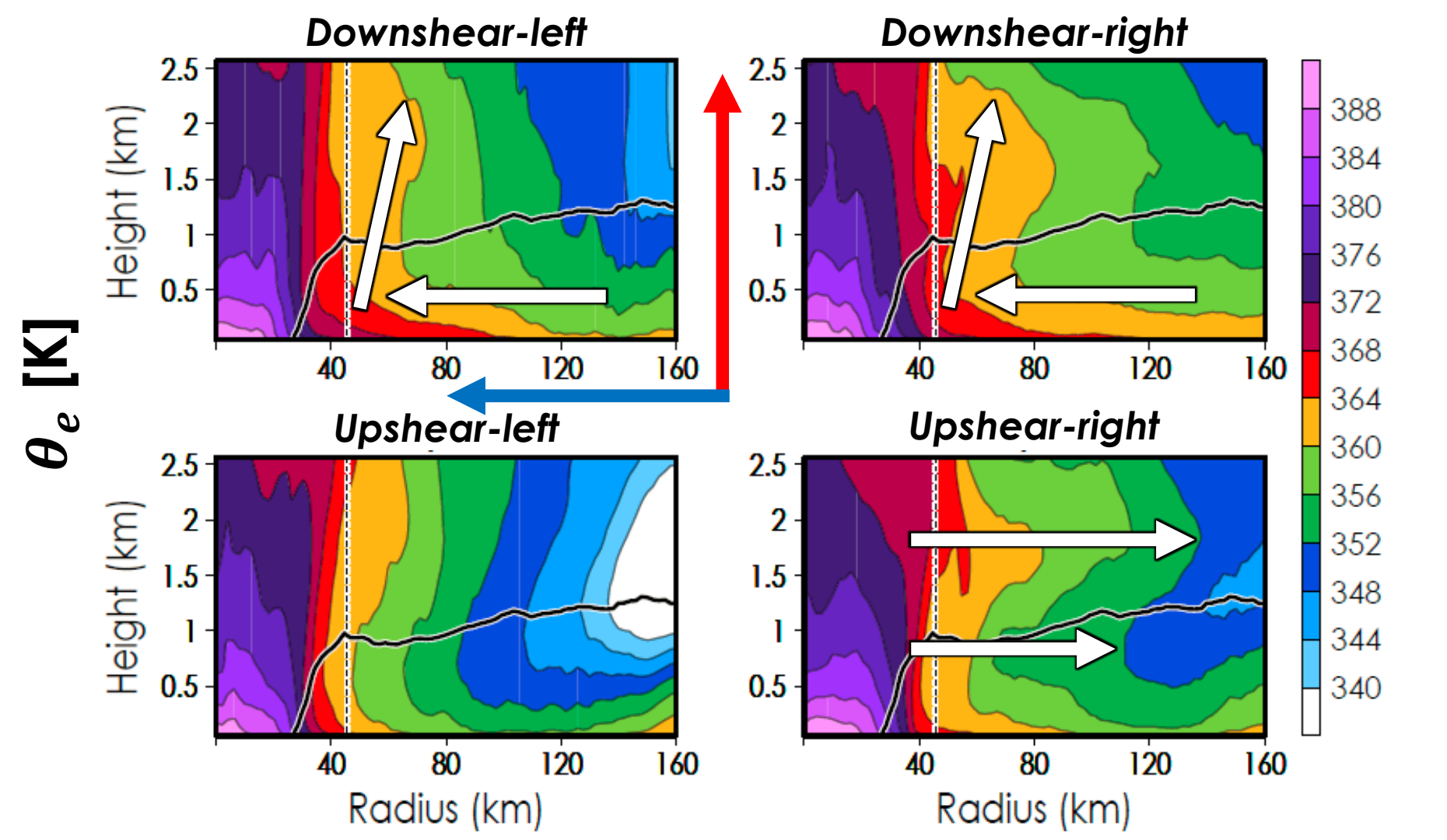
. . . and results in a local spin-up of v. This leads to strongly supergradient flow in the USL quadrant.

The supergradient flow is associated with an outward-directed agradient force. The USR outflow broadens the v-field, thereby increasing the inertial stability I^2 of the vortex outside of the RMW. The USR outflow also advects high-entropy air outward, which may recirculate via replenished BL inflow downshear.

Time evolution of azimuth-mean vertical wind [m/s] at $z \approx 1.2$ km



* In the above figure, the solid black line denotes the RMW. *



Earl's weakening is coincident with the emergence of an outer region of BL ascent. The outwardly exhausted high-θ_e air may recirculate into the outer region of ascent, possibly helping to form the roots of convection outside the RMW.

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