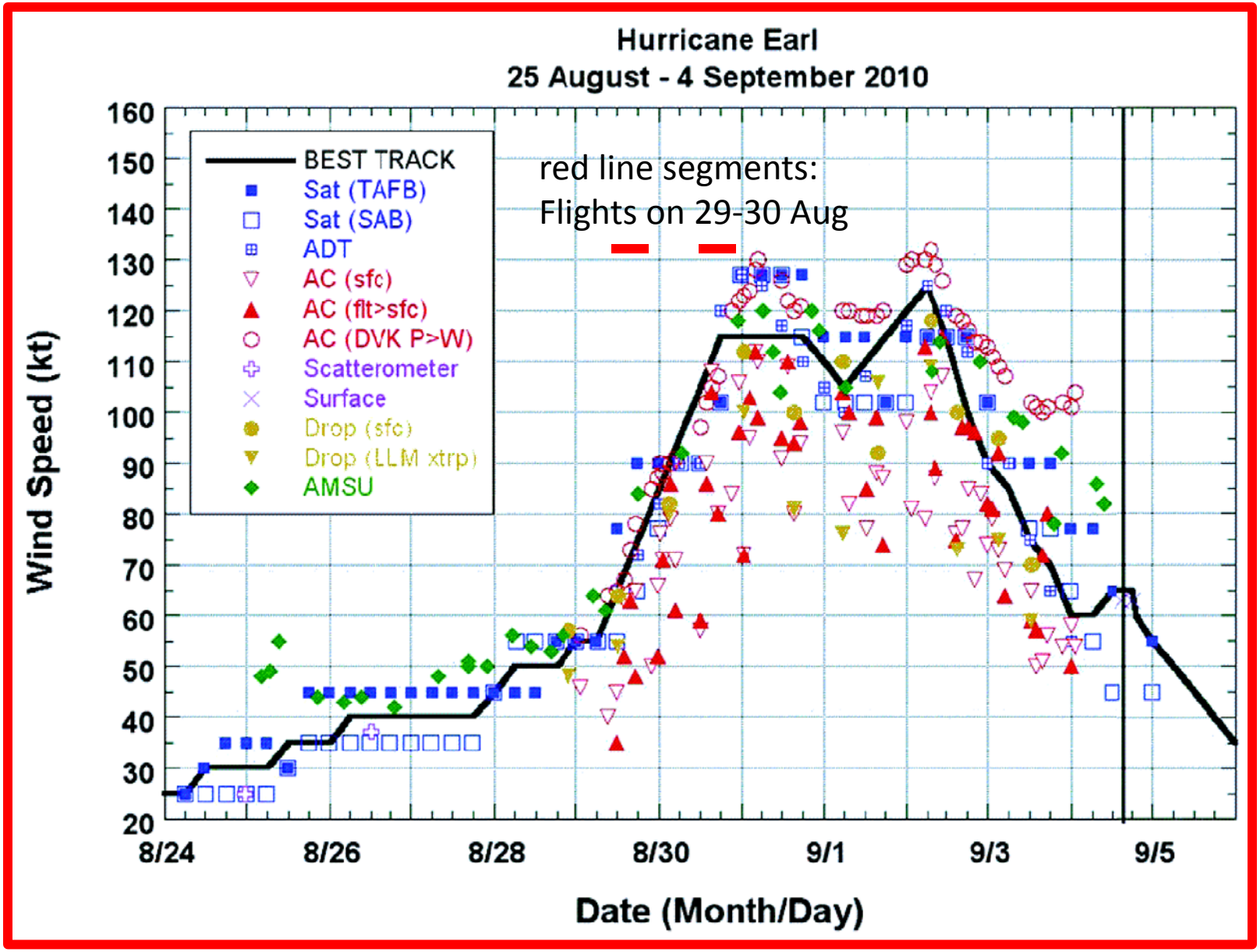
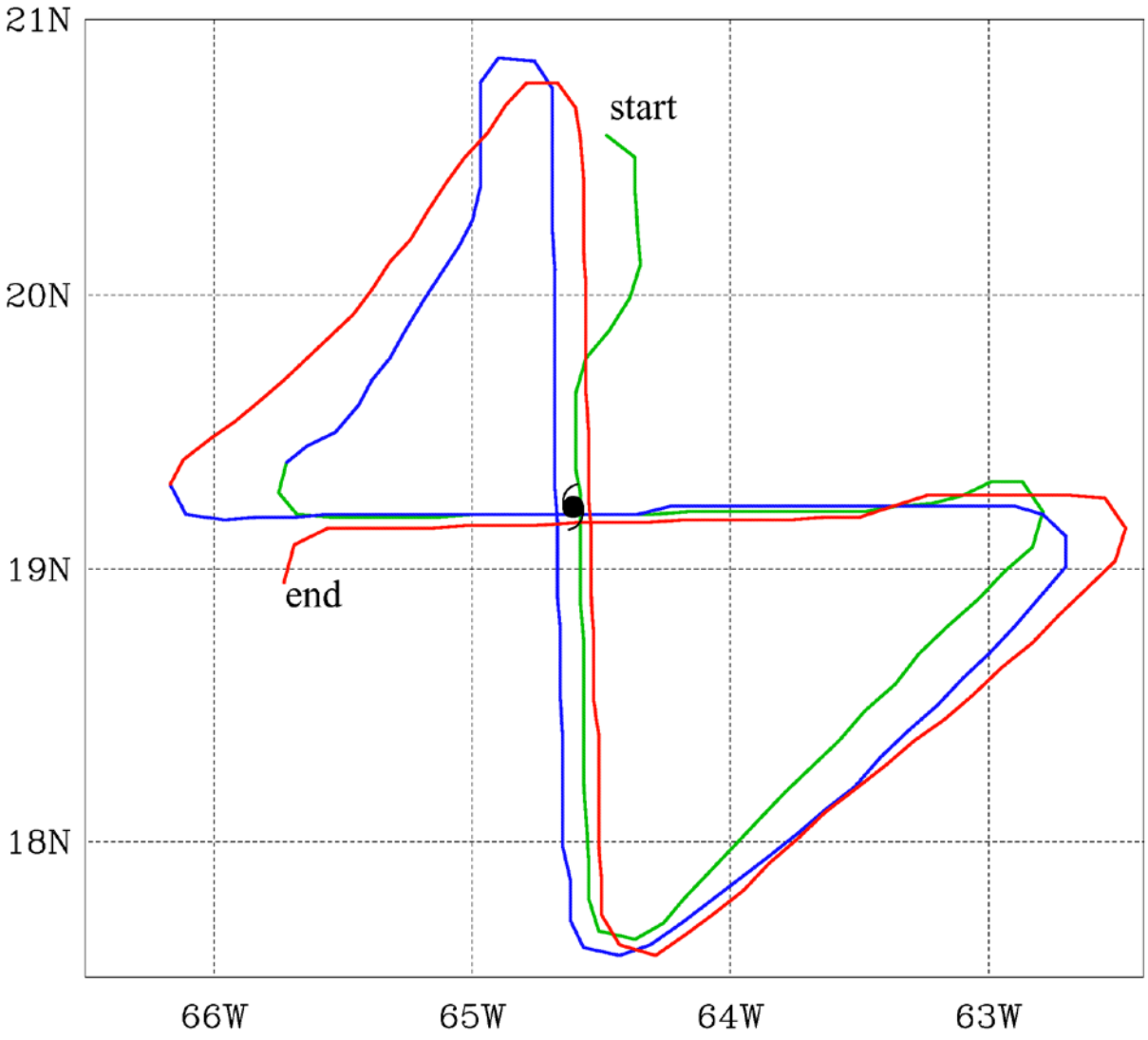
Evolution of Hurricane Earl During Rapid Intensification

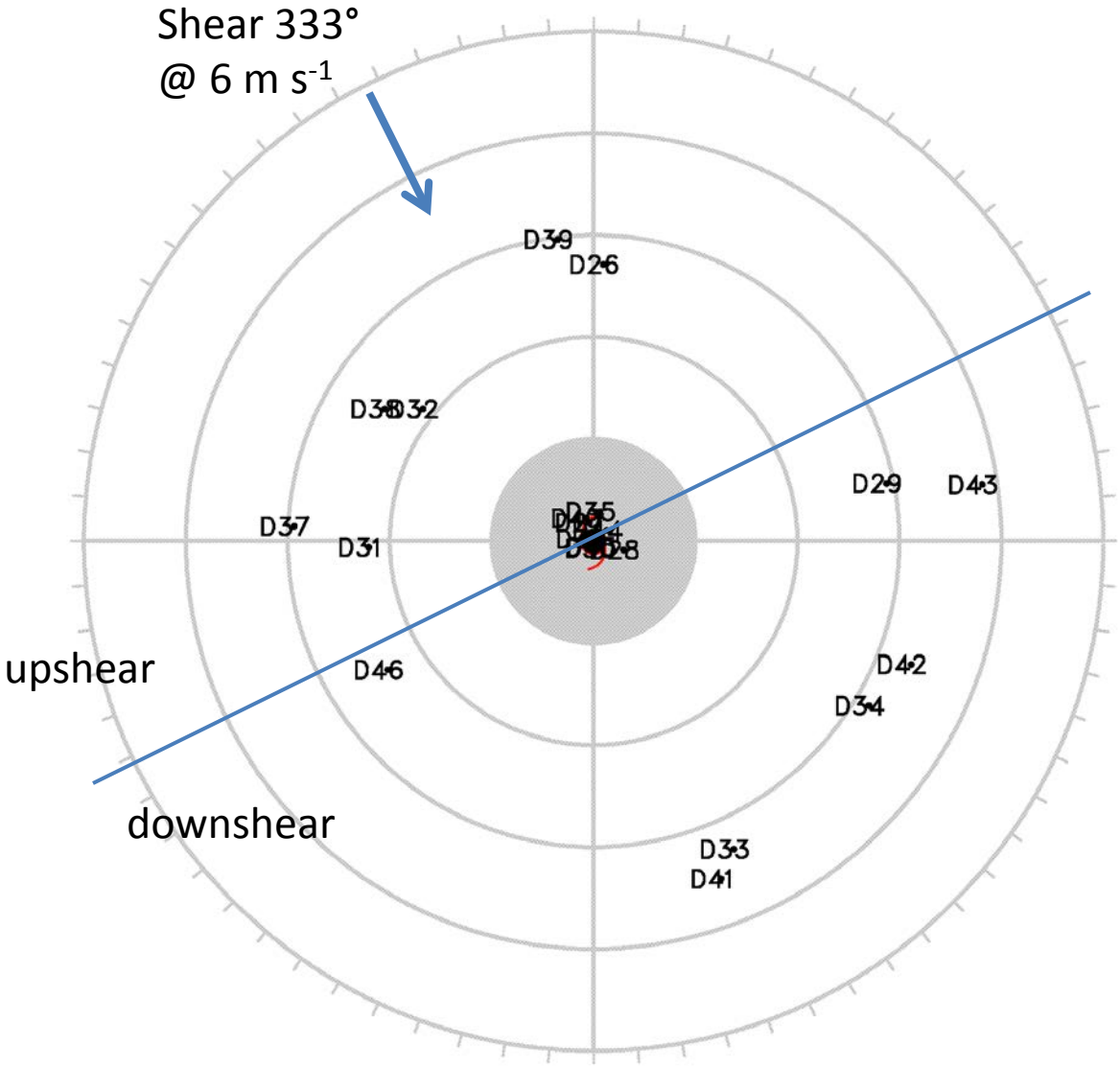
John Molinari, Scott Braun, and David Vollaro



Maximum surface wind speed in Hurricane Earl, from the National Hurricane Center.



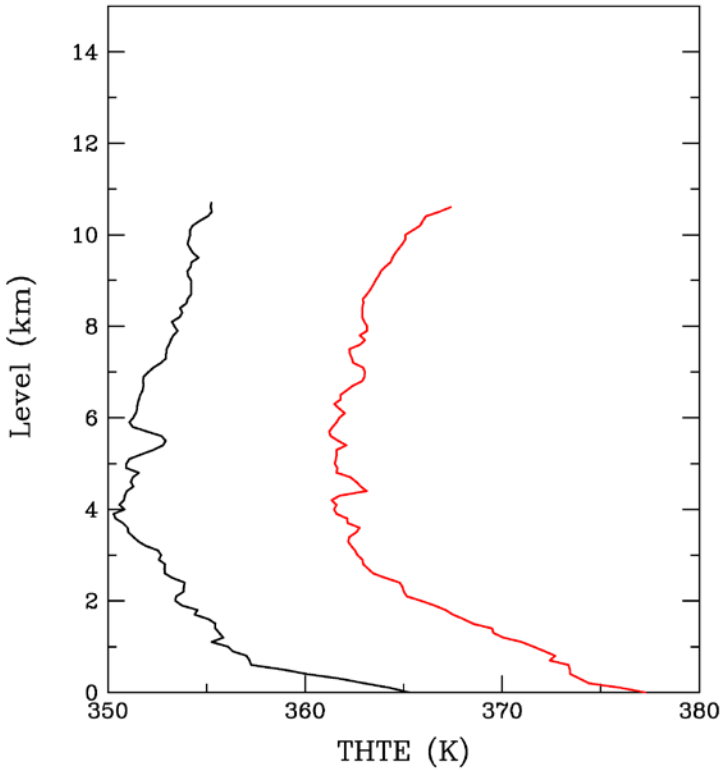
Flight tracks of the DC-8 with respect to the center of Hurricane Earl. The center is defined using NHC Best Track values.



Sonde splashdown locations on 30 August 2010. Range rings are at 50 km increments.

To address mechanisms for intensity change, consider the key role played by eyewall moist static energy (we will represent using θ_e). Using Emanuel's theory, reducing eyewall θ_e directly reduces intensity by reducing work done in the Carnot cycle.

Example: consider mean eye/eyewall θ_e in Earl on 29 and 30 August using means from dropsondes (uses all DC-8 sondes within the radius of maximum winds):



What might have caused RI to end? [These are likely not mutually exclusive!]

a. Vertical wind shear increased

b. The storm reached its maximum potential intensity (MPI)

c. Unstable eyewall breakdown and mixing of vorticity

d. A secondary eyewall cycle began

e. Decrease in SST under the storm due to upwelling

Most of these do not provide an explicit mechanism

How might an increase in vertical wind shear weaken the storm?

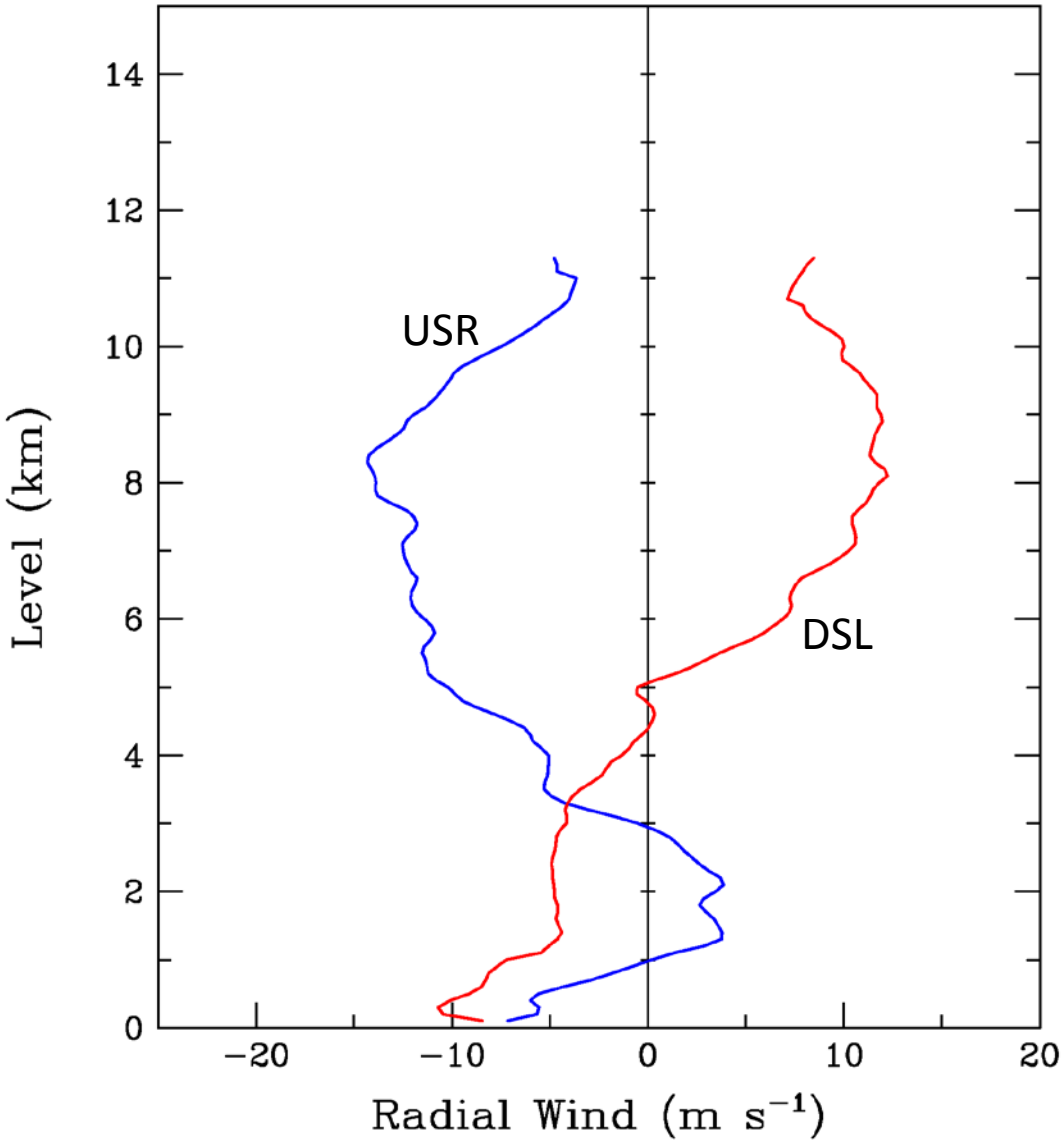
a. Low θ_e air reaches the boundary layer via convective downdrafts and is carried to the eyewall (Riemer et al. 2010), reducing the eyewall θ_e and thus reducing work done in the Carnot cycle (Tang and Emanuel 2010).

b. Low θ_e air is mixed into the eyewall above the surface by eddies (Tang and Emanuel 2010), most likely vortex Rossby waves (Montgomery and Kallenbach 1997).

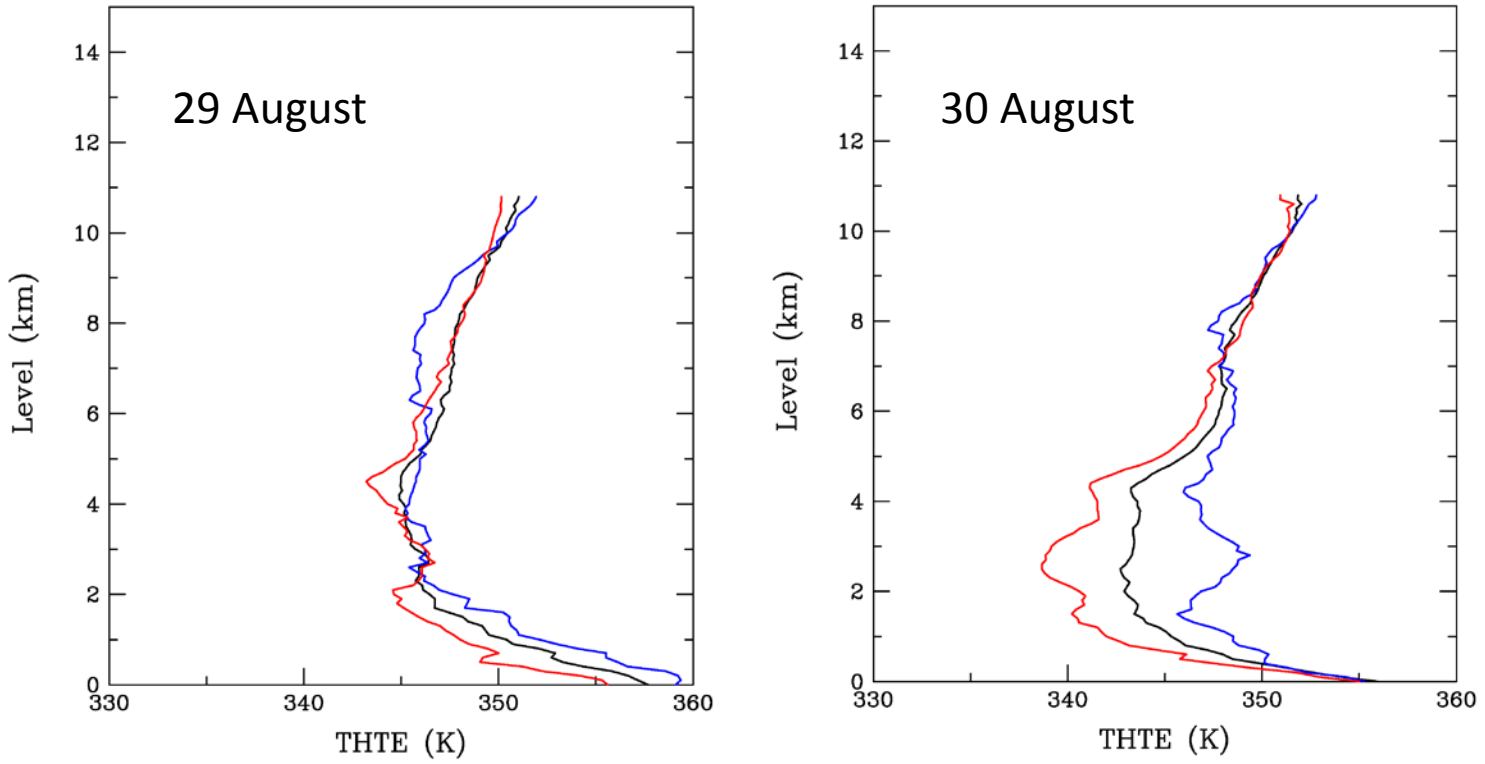
Does ambient vertical shear increase?

Evolution of ambient vertical wind shear in Hurricane Earl

	12 UTC 30th	15 UTC 30th	18 UTC 30th	21 UTC 30th	00 UTC 31st
SHIPS		337° 2 m/s		333° 6 m/s	
GFS	313° 3.2 m/s		349° 1.6 m/s		329° 7 m/s
ECMWF	002° 4.6 m/s		354° 4 m/s		290° 5 m/s



Mean storm-relative radial velocity for all downshear-left sondes (blue) and upshear-right sondes (red) for the flights on 30 August in Hurricane Earl.



$\theta_e(z)$ outside the core (from r = 75 to 200 km) averaged over all sondes (black), downshear left only (red) and upshear right only (blue). Although the storm is stronger on the 30th, mean surface entropy is lower, and low θ_e air exists in the lower troposphere downshear left, the same quadrant where storm-relative inflow is occurring.

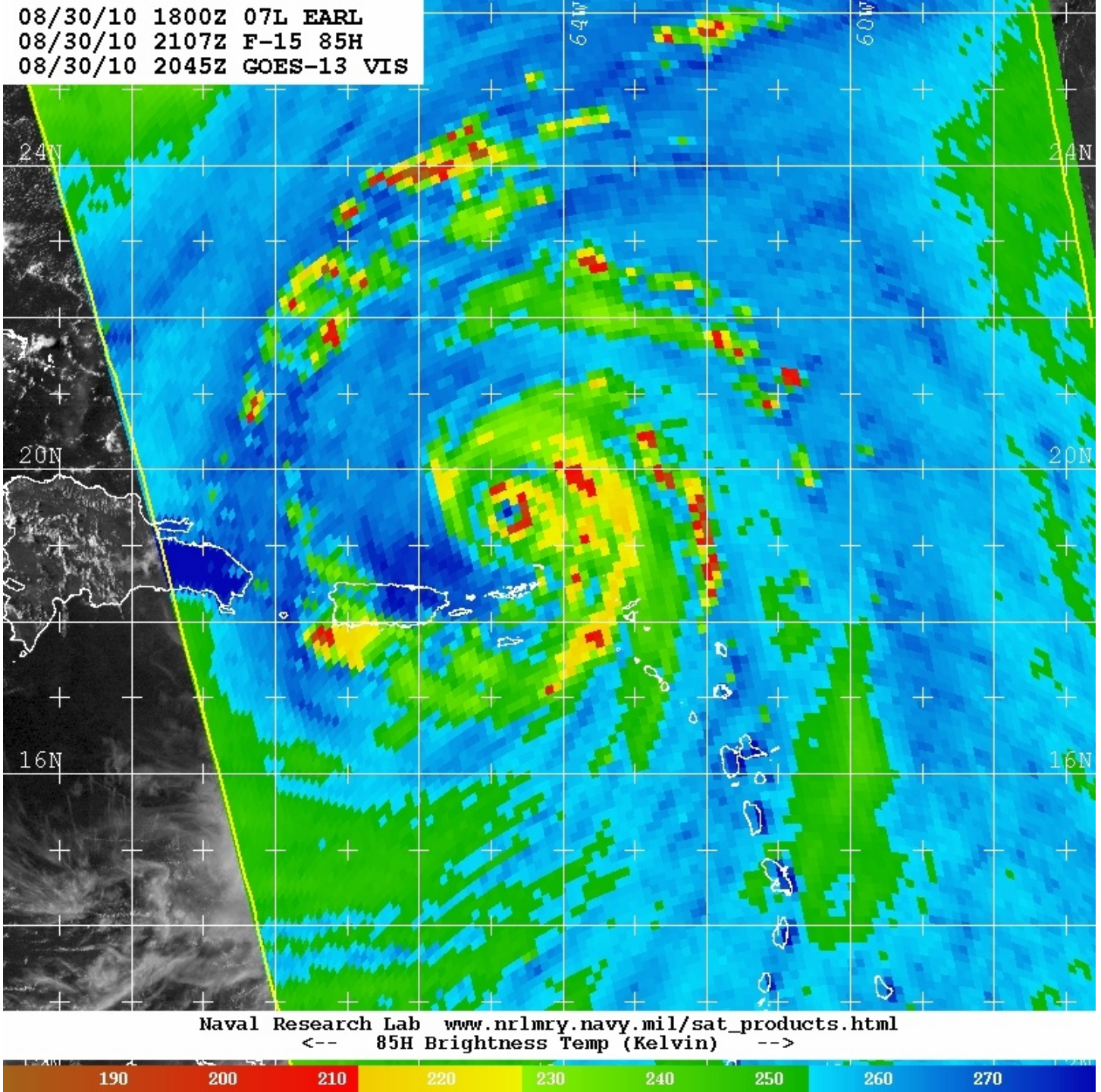
Mean pseudoadiabatic CAPE from 75-200 km radius

29th: 772 J kg^{-1}
30th: 409 J kg^{-1}

Mean CIN from 75-200 km radius

29th: 8 J kg^{-1}
30th: 20 J kg^{-1}

On the 30th, CIN is largest downshear left, where we earlier saw dry air in the lower troposphere. Riemer et al. (2010) saw low theta-e air approach the storm core in this quadrant.


08/30/10 1800Z 07L EARL
08/30/10 2107Z F-15 85H
08/30/10 2045Z GOES-13 VIS
64W
60W
24N
20N
16N
Naval Research Lab www.nrlmry.navy.mil/sat_products.html
<-- 85H Brightness Temp (Kelvin) -->
190
200
210
220
230
240
250
260
270

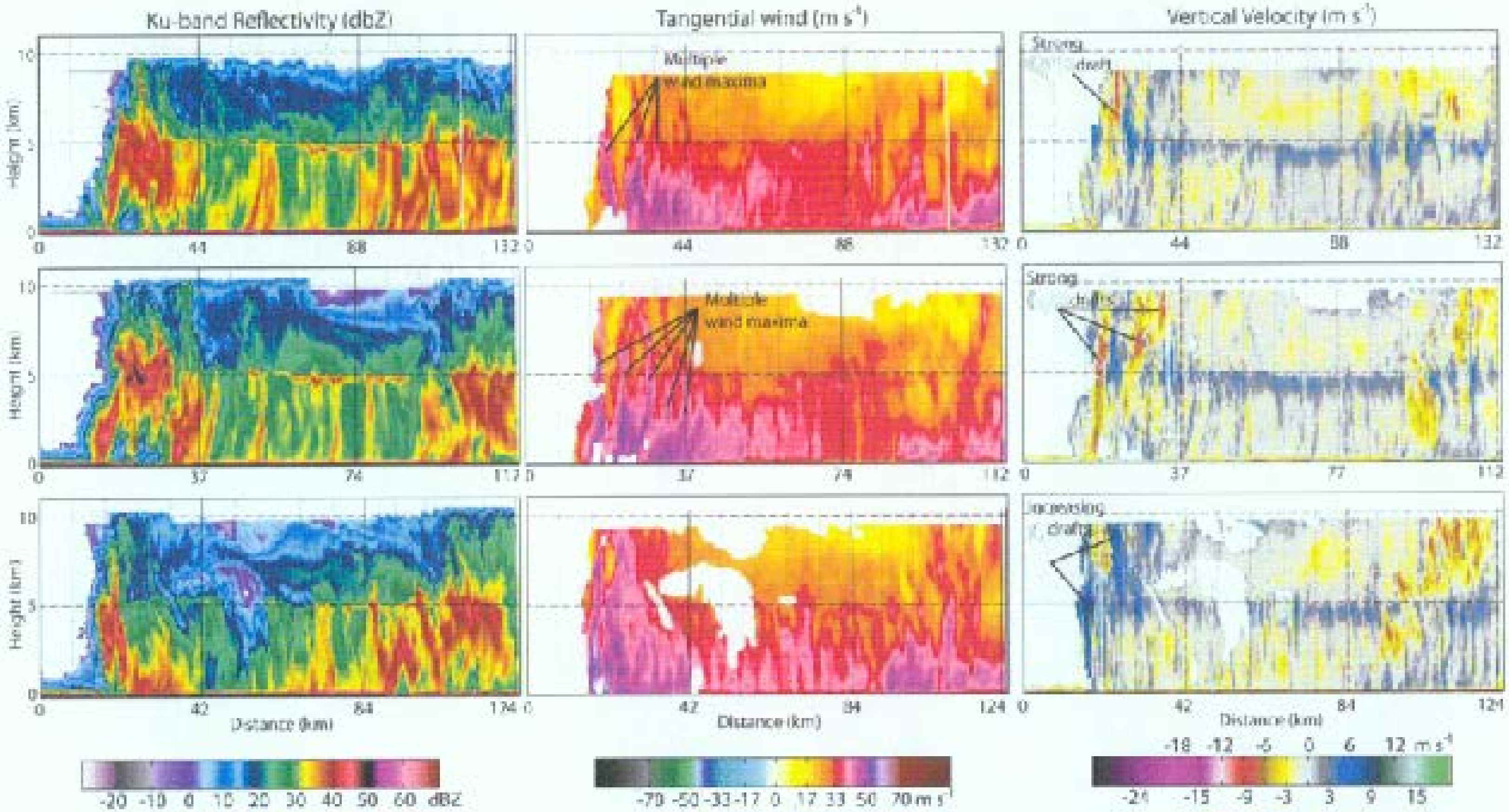
Evidence that vertical wind shear is affecting Hurricane Earl late on the 30th

- Increasing shear with time from global model estimates
- Strong cross-storm flow from dropsondes
- Clear shear signature in convection
- Dry air in the lower troposphere southeast of the center outside the 75 km radius, in the same location as strong storm-relative inflow
- Large CIN and small CAPE in the same region

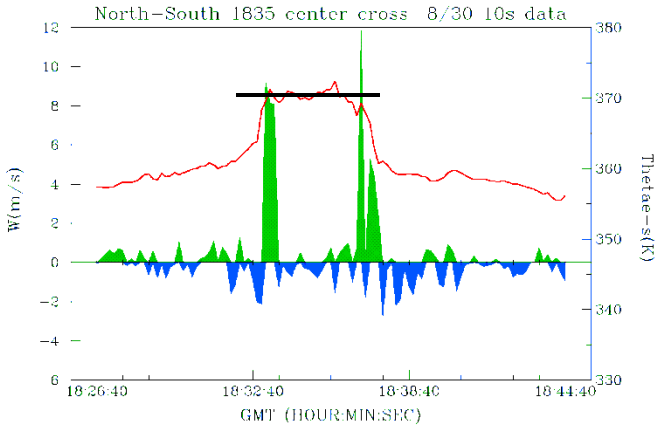
Evidence that vertical wind shear is affecting Hurricane Earl late on the 30th

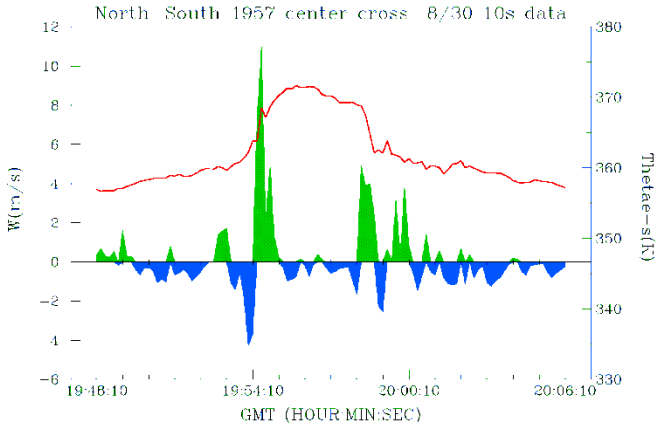
- Increasing shear with time from global model estimates
- Strong cross-storm flow from dropsondes
- Clear shear signature in convection
- Dry air in the lower troposphere southeast of the center outside the 75 km radius, in the same location as strong storm-relative inflow
- Large CIN and small CAPE in the same region

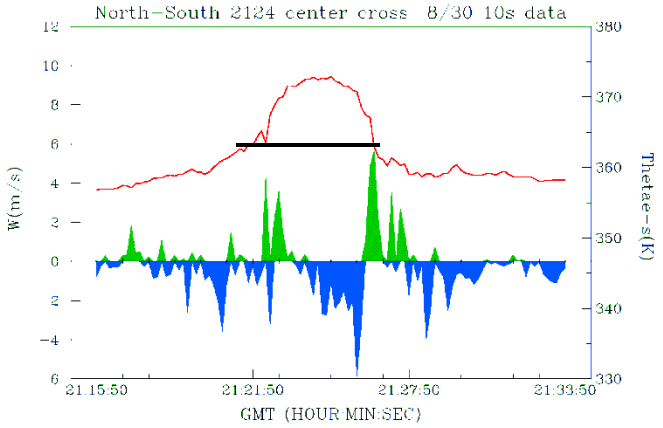
This is insufficient to indicate shear-induced ending of RI!
No clear evidence that downdrafts are occurring or that dry air is reaching the storm core



Ku-band Reflectivity (dbZ)
Tangential wind (m s-1)
Vertical Velocity (m s-1)
Height (km)
Distance (km)
Multiple wind maxima
Strong draft
Strong drafts
Increasing drafts
-20 -10 0 10 20 30 40 50 60 dBZ
-70 -50 -33 -17 0 17 33 50 70 m s-1
-18 -12 -6 0 6 12 m s-1
-24 -15 -9 -3 3 9 15







FLIGHT-LEVEL DATA

North-south cross-sections of saturated θ_e (red) and vertical motion (green is upward, blue downward). θ_{es} equals θ_e only when saturated, most likely when updrafts are strong.

Eyewall shows clearly in the updrafts at flight level.

Eyewall θ_e is similar to boundary layer θ_e at the first time, but decreases with time by more than 5 K. Evidence for lower θ_e reaching the eyewall in the boundary layer?

Next steps in this research

1. Full examination of all APR-2 cross-sections, quantification of azimuthally-averaged vertical velocity in the eyewall, which provides an indirect measure of eyewall buoyancy

2. Examination of multiple dropsondes from P-3 flights late on the 30th. At least a dozen are available, several of which are released between the eyewall radius and the 75-km radius, the region missing from the DC-8 sondes. We are looking for direct evidence of downdrafts to support Riemer et al.'s mechanism for shear-induced weakening

3. Goal: to find the cause of the end of RI in Hurricane Earl

Comment: APR-2 and HIWRAP provide outstanding data for this kind of study