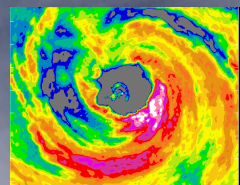
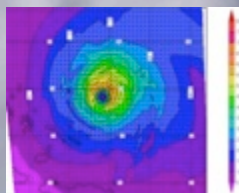
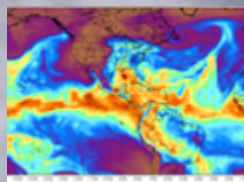
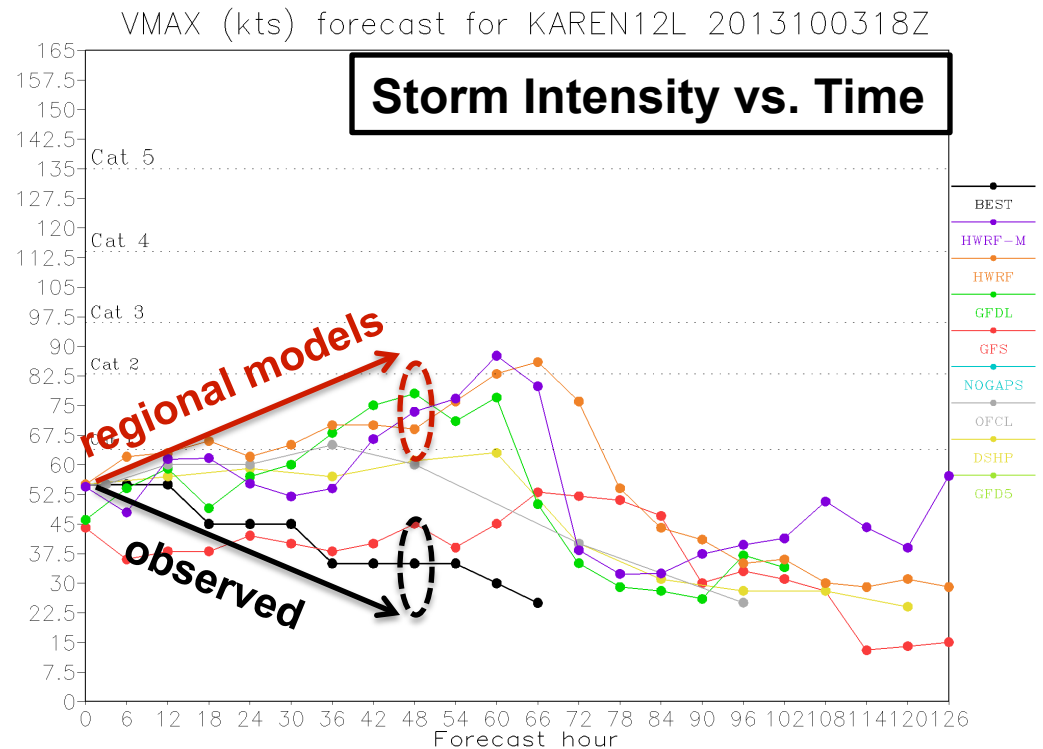
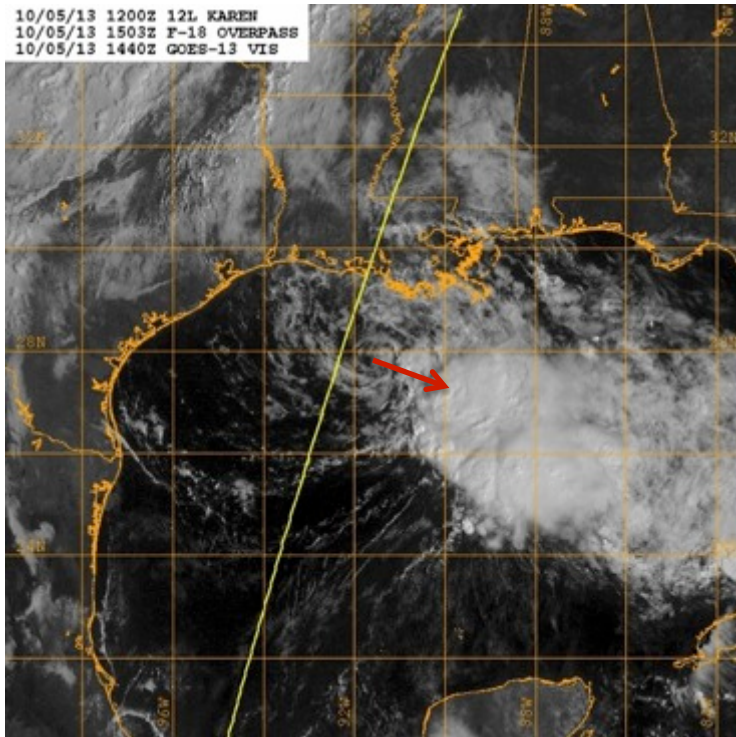


Tropical Cyclone Dynamics and Interactions with Storm Environment



Motivation

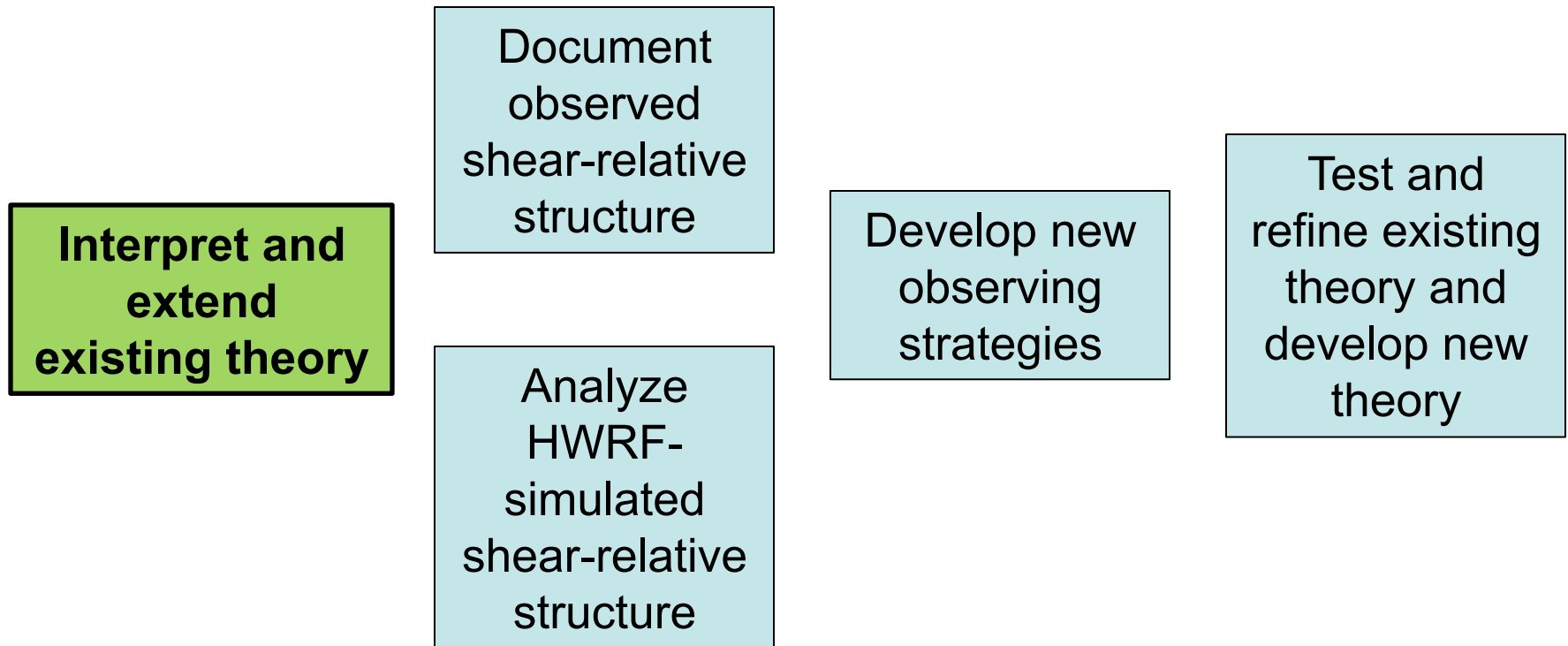
Accurate prediction of tropical cyclone (TC) intensity in vertically sheared flow is a major operational challenge.



How does the interaction of a TC with vertically sheared flow contribute to intensity change?

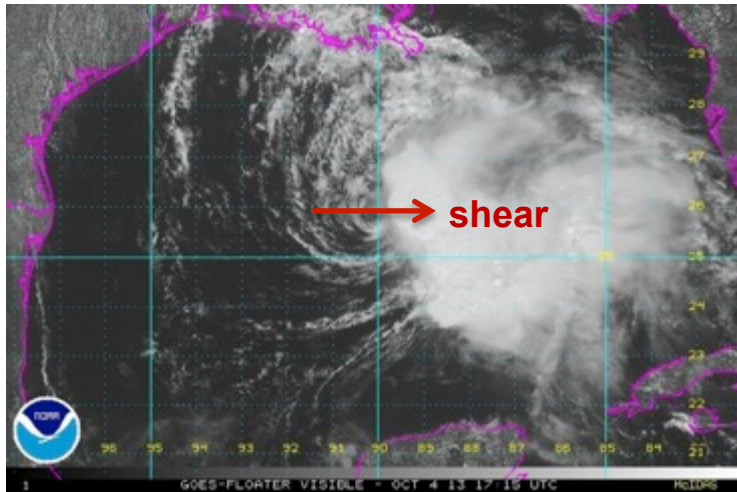
Motivation

- **HRD is uniquely positioned to advance understanding and prediction of TC intensity in shear.**

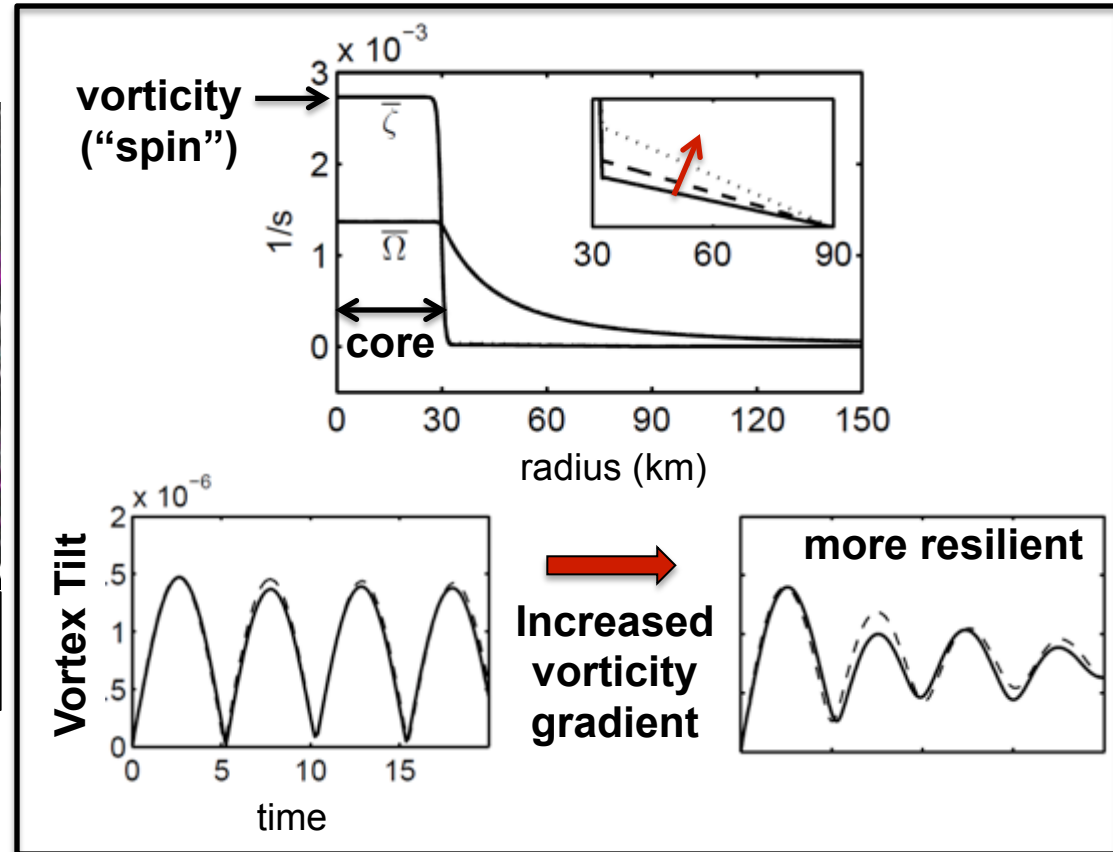


Theory

How do sheared TCs remain vertically resilient?



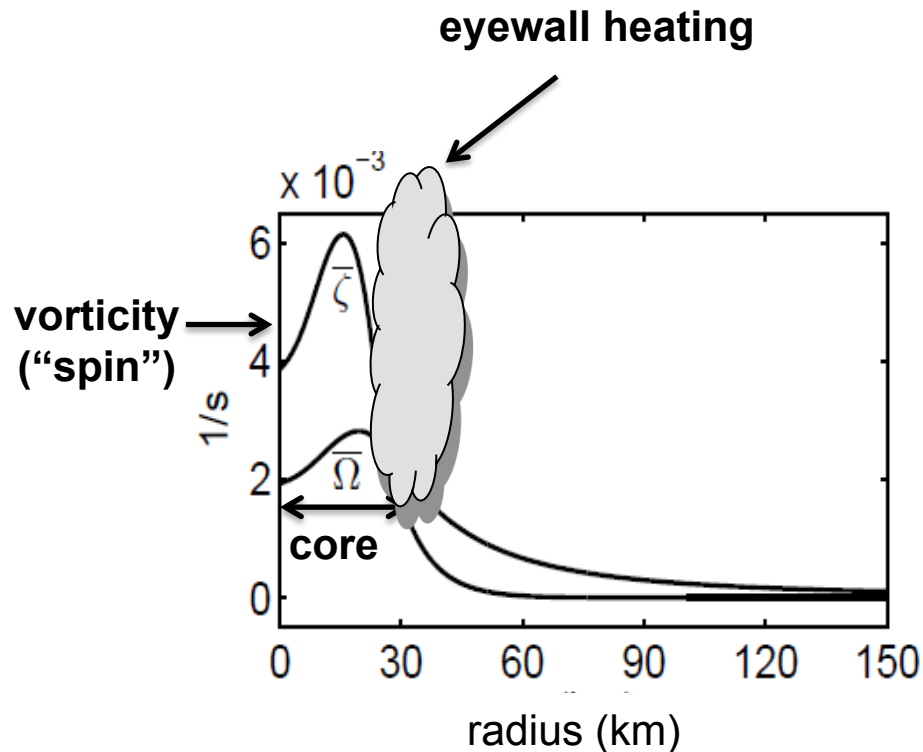
Exposed low-level center hints at vertical tilting of the circulation.



In the absence of convective heating, vertical resilience is dependent on the vortex profile outside the core in a readily understood way...

Theory

How do sheared TCs remain vertically resilient?



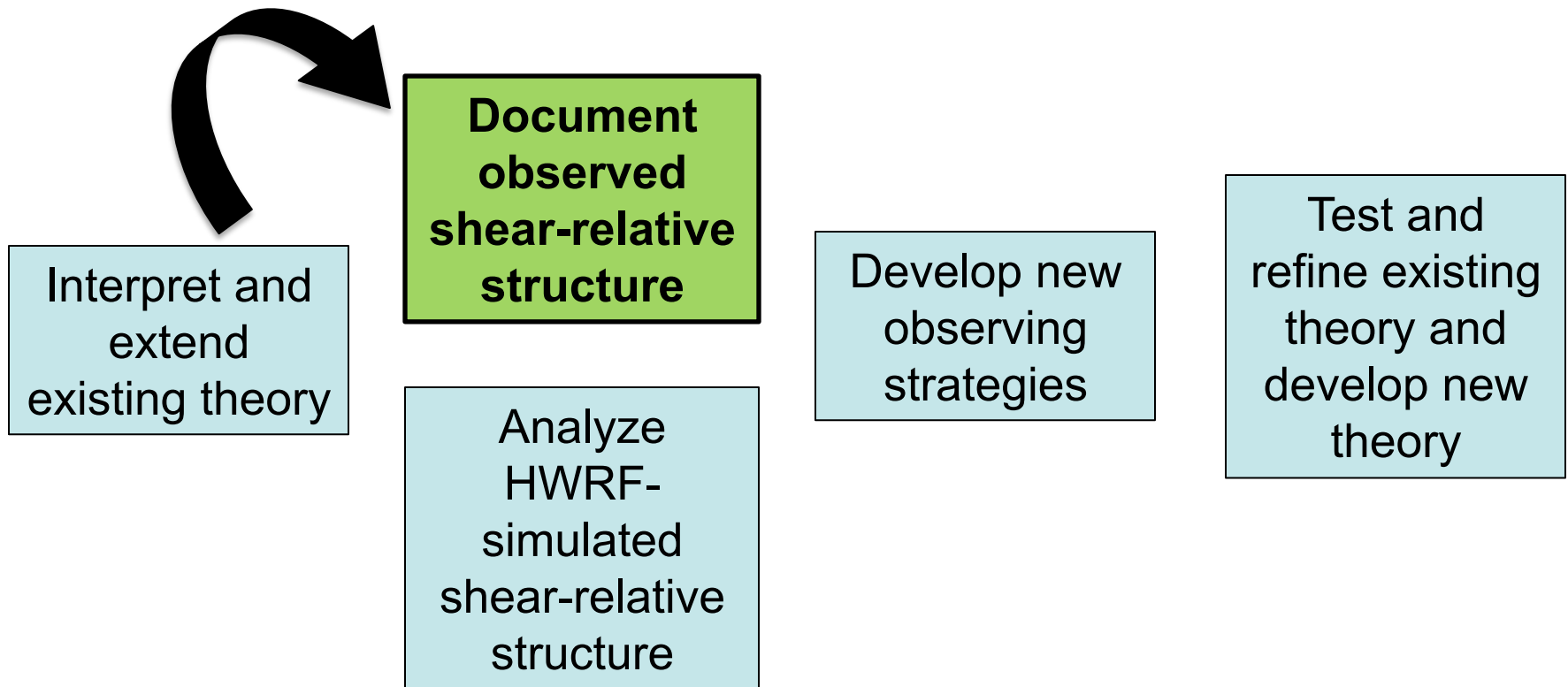
...but in nature it may not be so simple.

- Heating can alter, in a non-trivial way, the vortex resilience mechanism.

- The intensity response of a TC to vertical shear forcing may depend on how vortex tilt develops.

Motivation

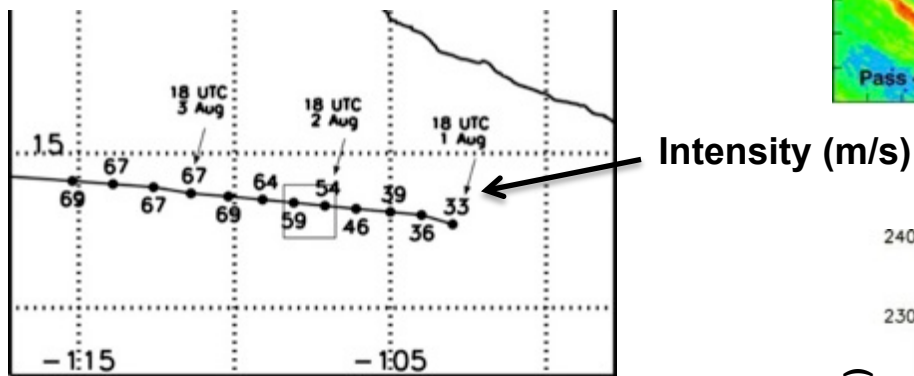
- **HRD is uniquely positioned to advance understanding and prediction of TC intensity in shear.**



Observations

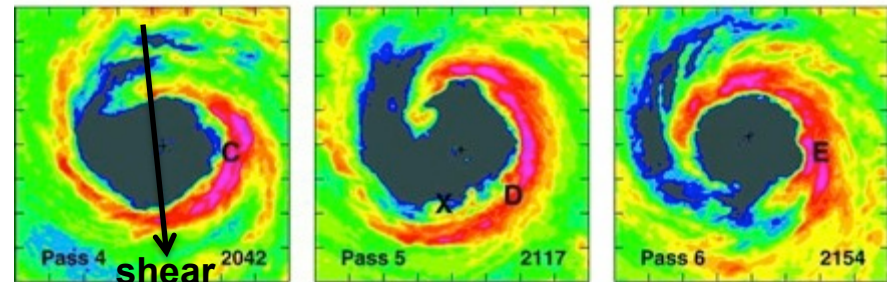
How do TCs intensify under external forcing by vertical wind shear?

- TCs can intensify, even rapidly, in sheared environments.

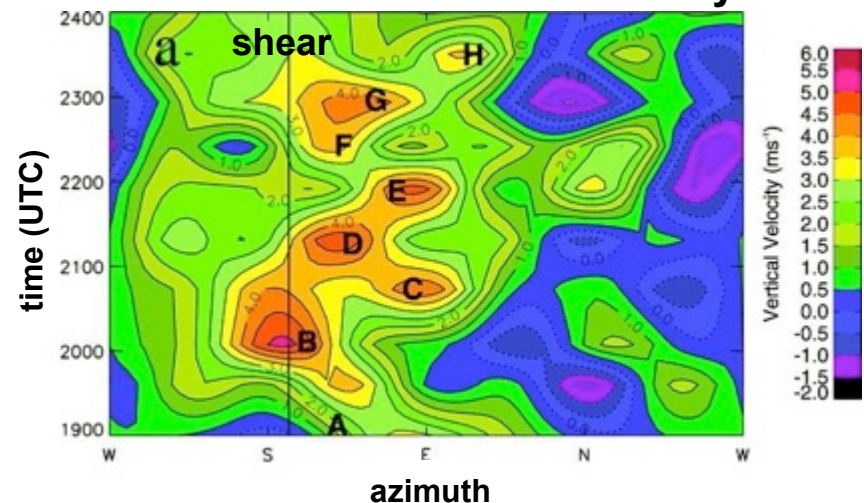


- “Axisymmetry” not a necessary condition for rapid intensification
- Intensification coincides with repeated downshear deep convective events

Radar reflectivity



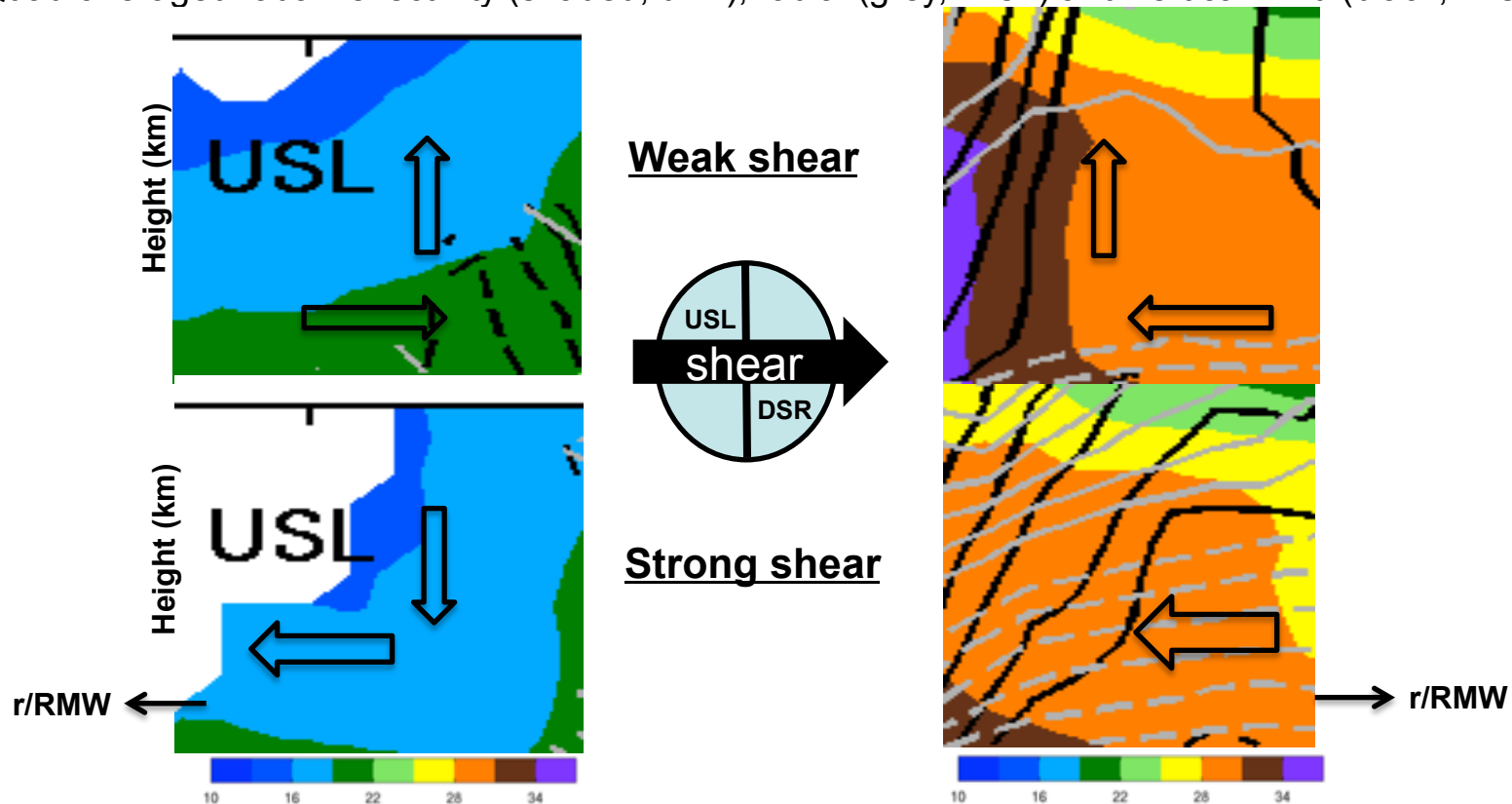
Radar-derived vertical velocity



Observations

What are the **typical** structural characteristics of sheared hurricanes?

Quad-averaged radar reflectivity (shaded, dBZ), radial (grey, m s^{-1}) and vertical wind (black, m s^{-1})

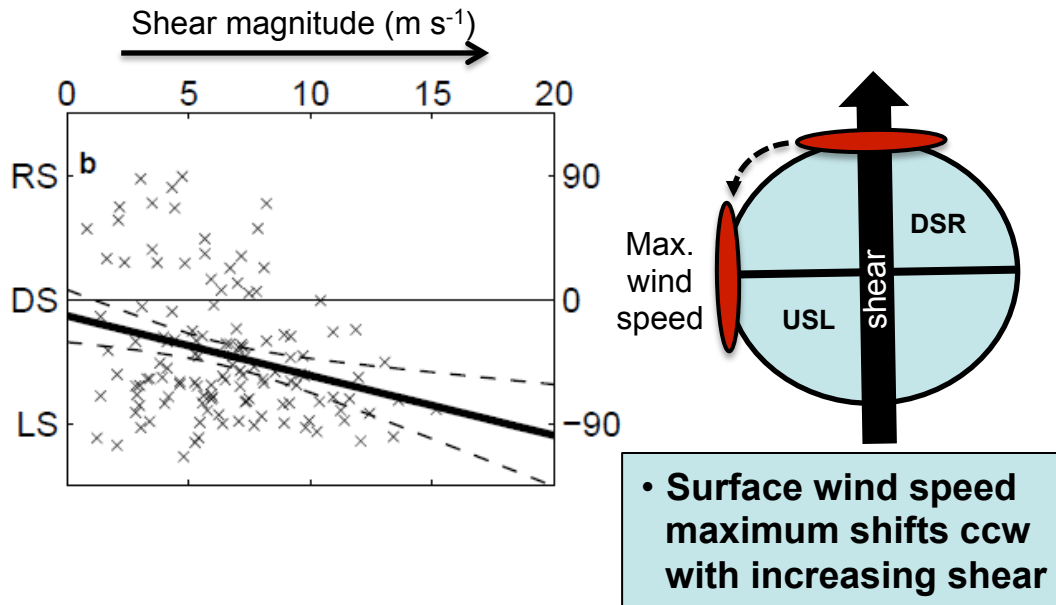


- The **strong-shear composite** shows stronger, deeper inflow downshear right; low-level outflow and eyewall subsidence upshear left

Observations

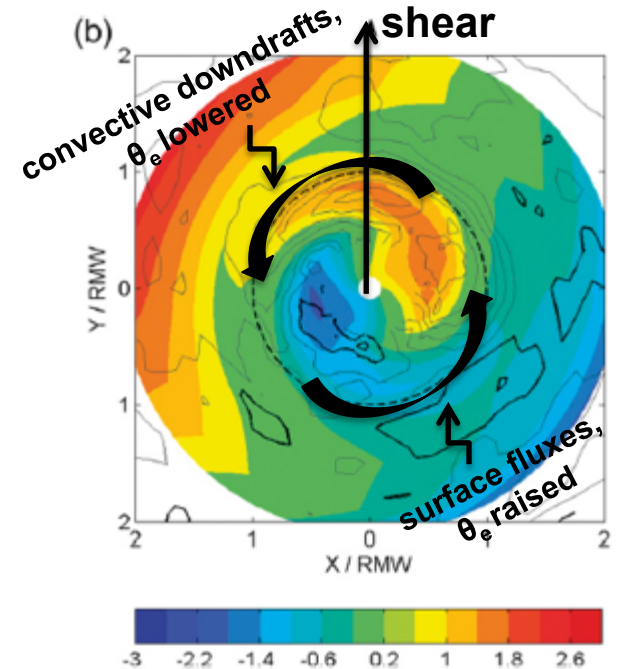
...and in the boundary layer?

SFMR Surface Wind Speed



GPS Dropsonde θ_e (50 m)

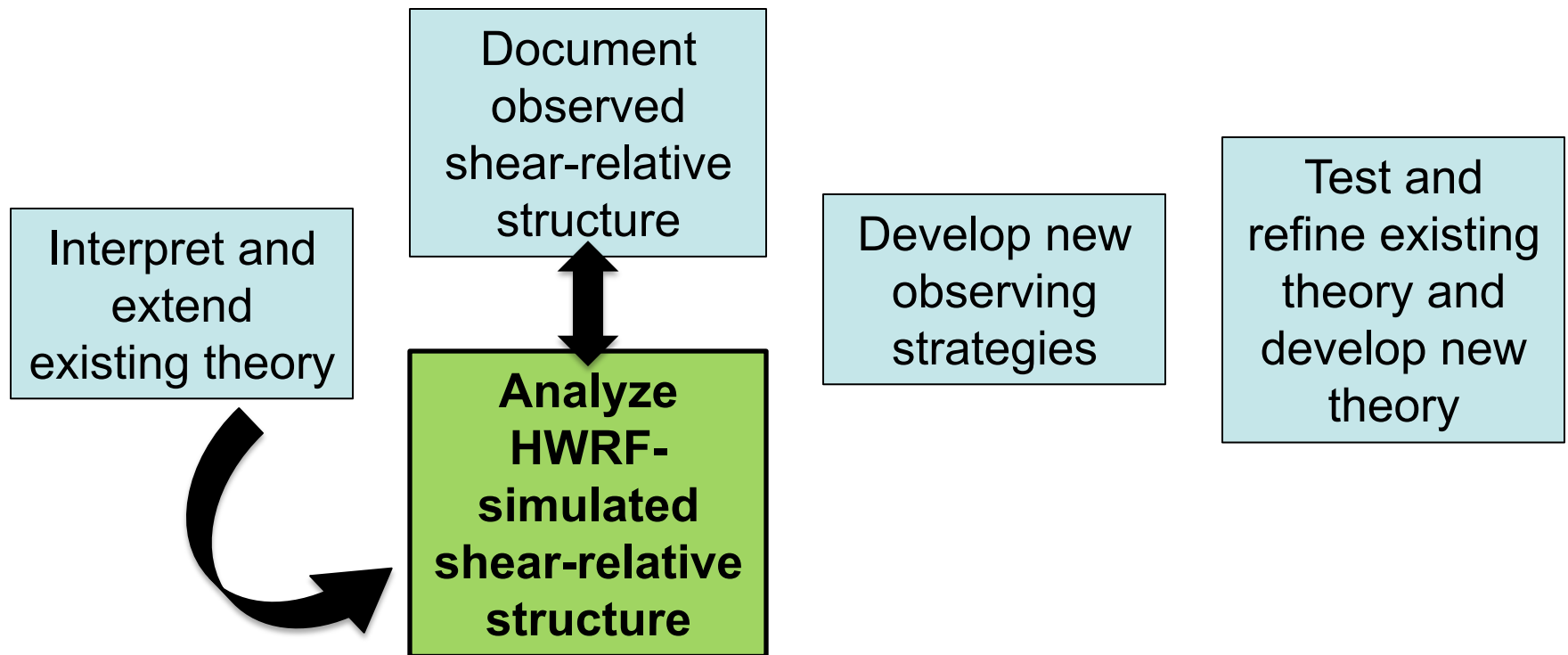
(Warmer, moister \rightarrow higher θ_e)



- Multi-case analyses show how boundary layer wind and thermodynamic structure are also impacted by vertical wind shear.

Motivation

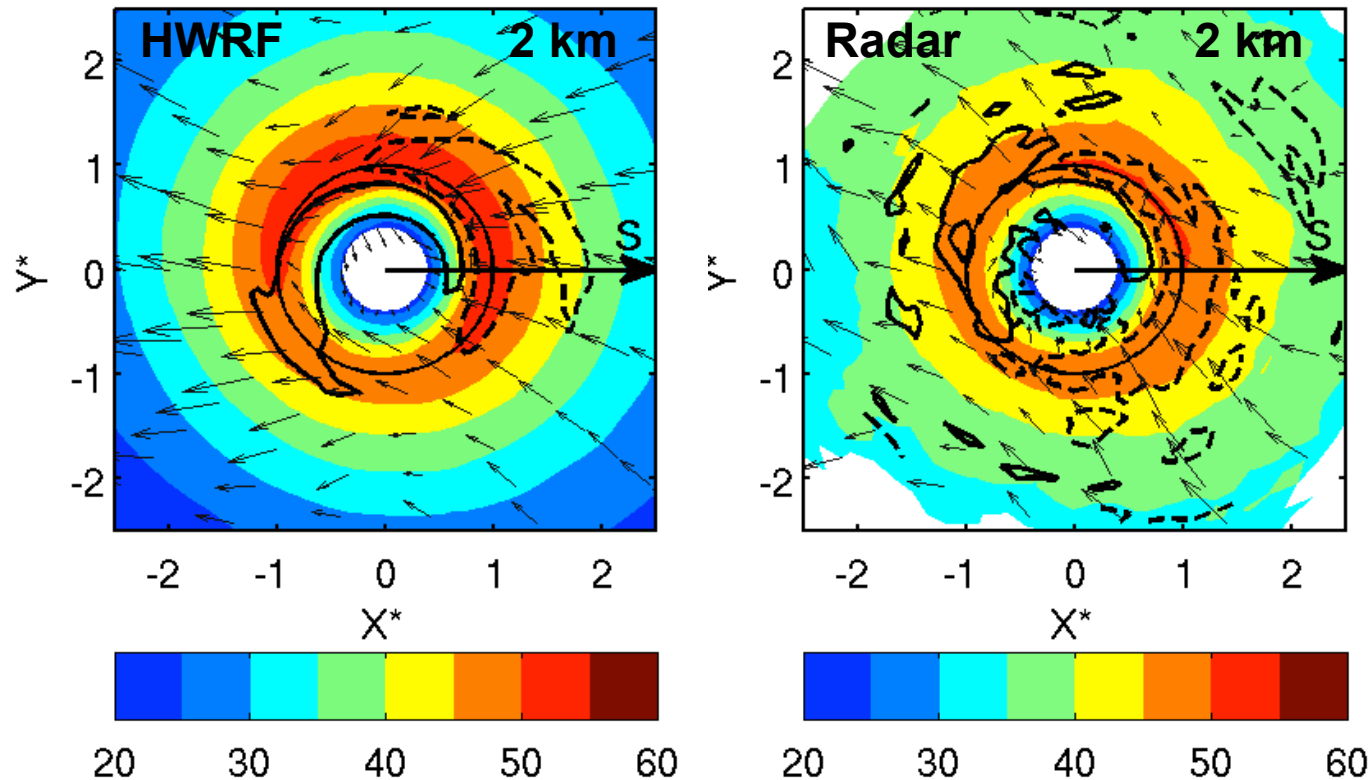
- HRD is uniquely positioned to advance understanding and prediction of TC intensity in shear.



Models

What are the **typical** structural characteristics of sheared hurricanes?

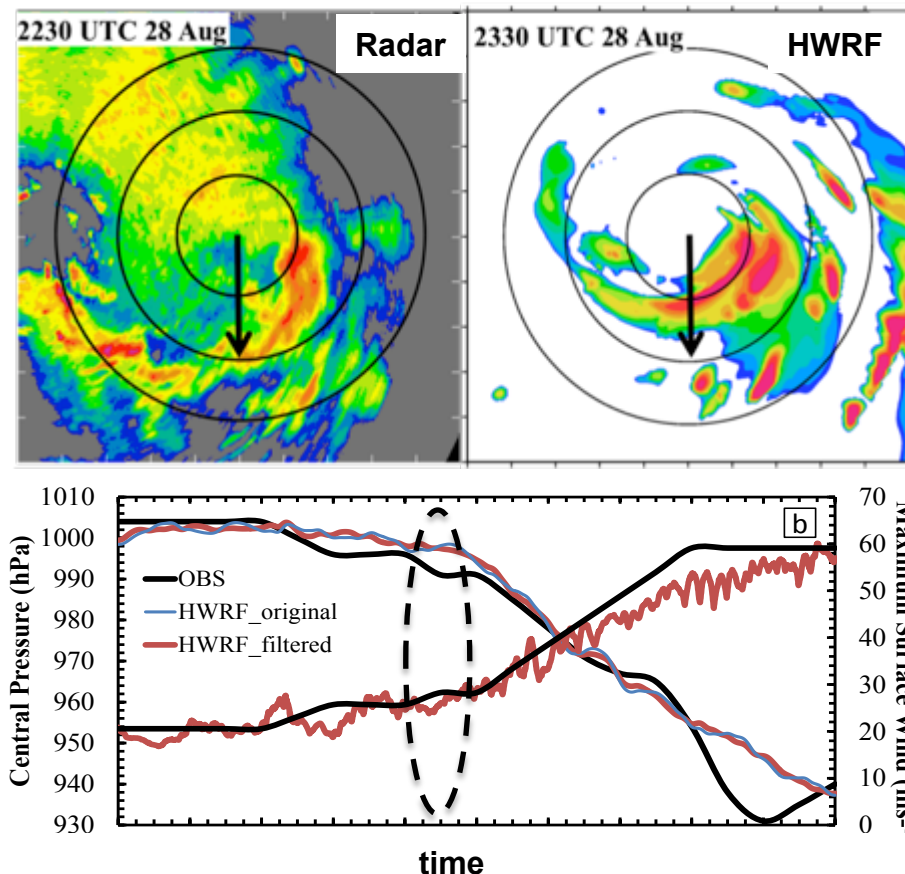
Storm-relative wind speed (shaded, m s^{-1}), divergence (s^{-1}) and asymmetric flow



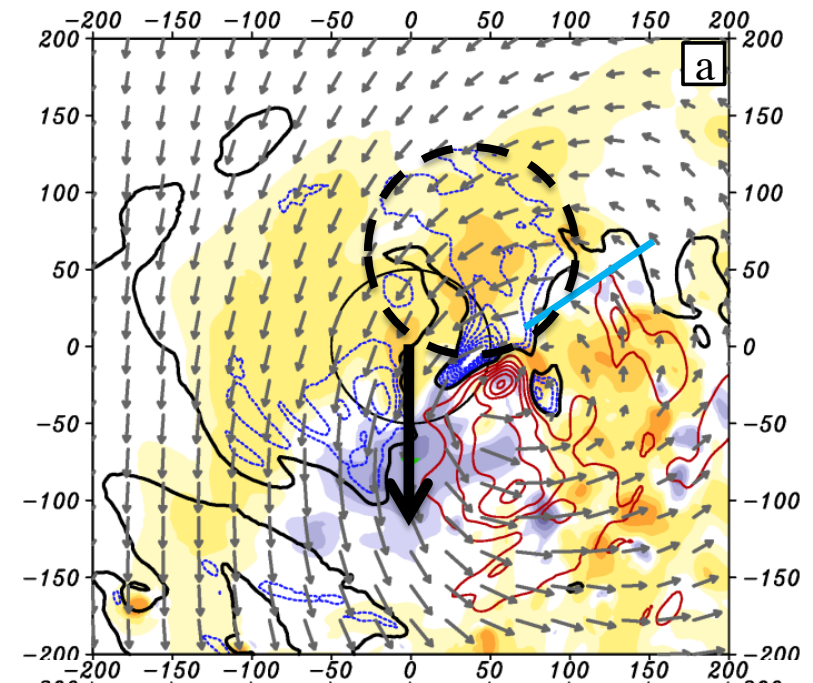
- Composites of observed data are used to evaluate typical simulated shear-relative hurricane structure

Models

How do TCs intensify under external forcing by vertical wind shear?



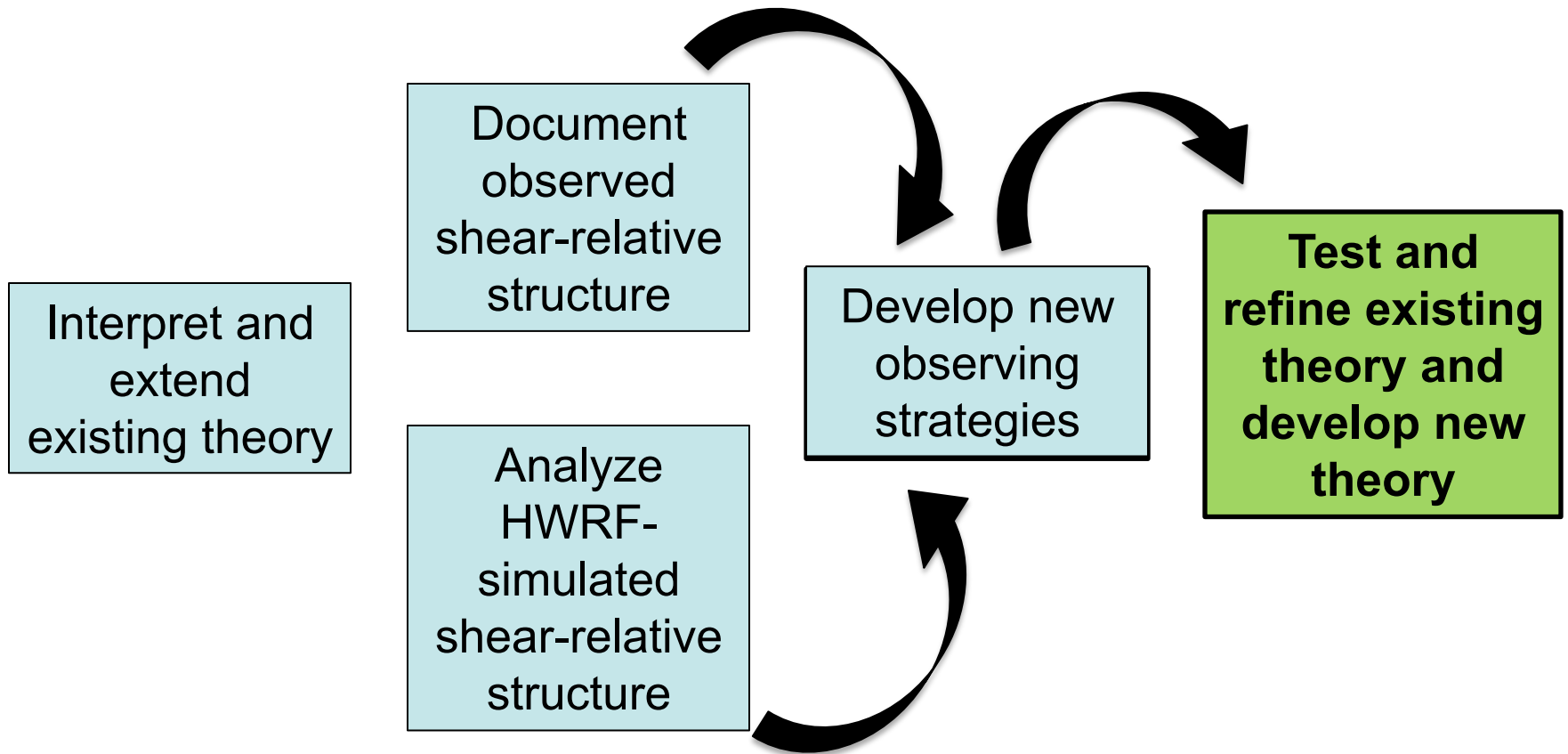
Temp. change (shaded), vertical wind (contour)



- **Hi-res HWRf is starting to correctly simulate convective asymmetry. This is critical for intensity prediction. Analyses are used to gain insight into observed evolution.**

Motivation

- **HRD is uniquely positioned to advance understanding and prediction of TC intensity in shear.**



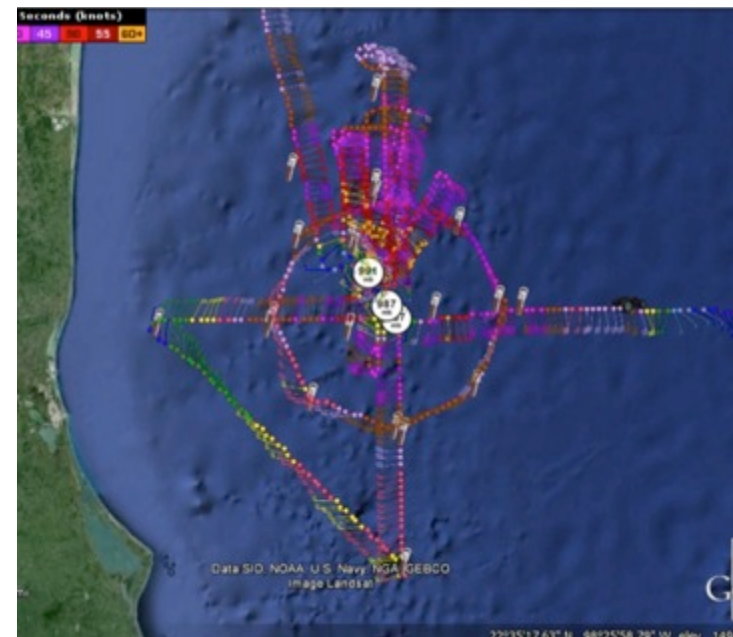
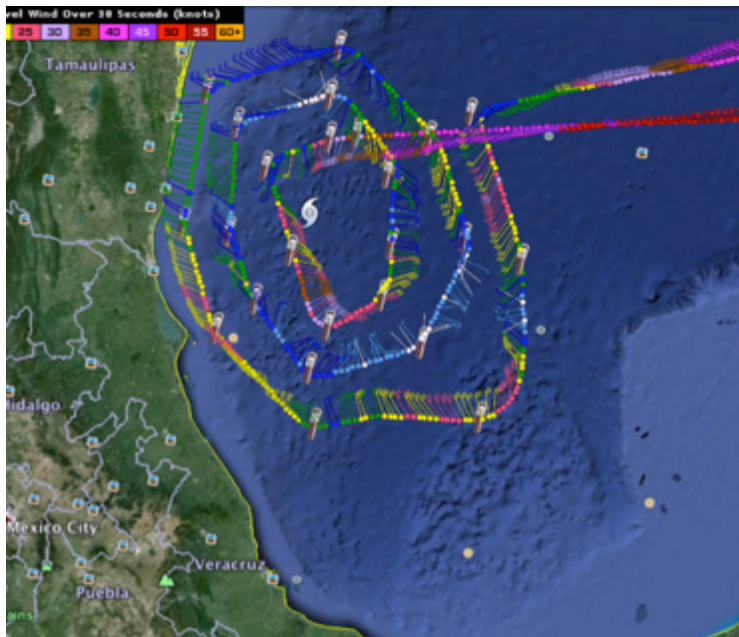
Observing Strategies

How is hurricane intensity limited by vertical wind shear?

G-IV Flight Pattern



P-3 Flight Pattern

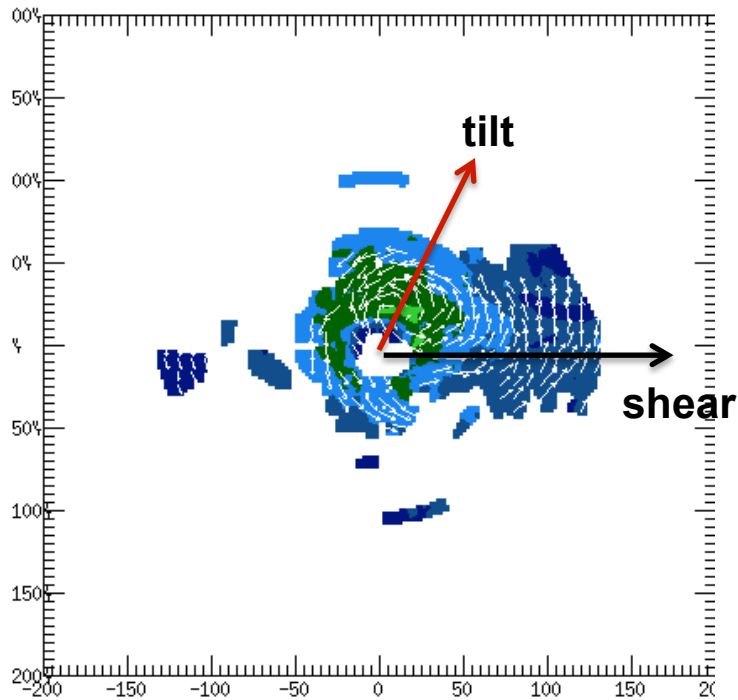


- **New observing strategies are developed to document structural changes in hurricanes resulting from interaction with sheared environmental flow.**

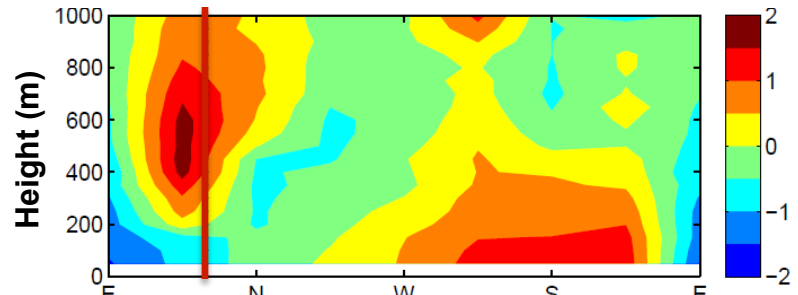
Testing Theory

How is hurricane intensity limited by vertical wind shear?

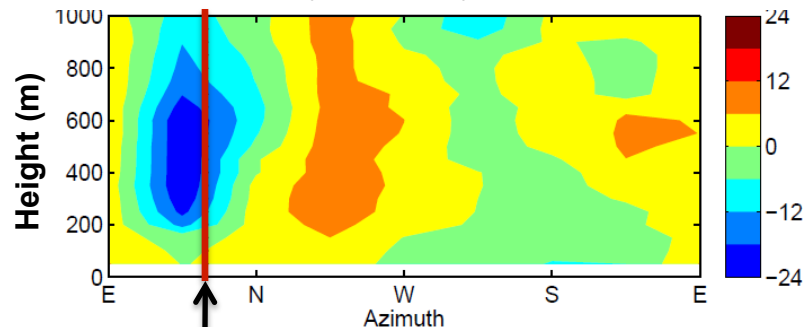
2 KM wind speed (shaded), 7 KM flow (vectors)



Azi. Temperature anomaly: $r = 2xRMW$



Azi. Humidity anomaly: $r = 2xRMW$



tilt

- Radar and dropsonde data from Ingrid (2013) are used to examine the relationship between shear, vortex tilt, boundary layer modification, and intensity change.

Summary

HRD is uniquely positioned to **advance** and **utilize** understanding of dynamical processes relevant to TCs.

- Advancement of understanding has come through
 - Development of theory
 - Examination of observed and simulated cases
 - Compositing based on observed and simulated data
- Utilization of understanding is evident in
 - Development of new observing strategies
 - Improvements in parameterizations impacting dynamical processes
 - Improvements in analysis systems

HRD's research on TC interaction with the storm environment has produced a set of tools and methodologies that will permit the impact of shear on **intensity change** to be addressed in a comprehensive manner in the years to come.

QUESTIONS?



References

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Reasor, P. D., R. Rogers, S. Lorsolo, 2013: Environmental Flow Impacts on Tropical Cyclone Structure Diagnosed from Airborne Doppler Radar Composites. *Mon. Wea. Rev.*, **141**, 2949–2969.

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