Radar and Satellite-Based Tools for Predicting Locations of Mesovortex Formation within QLCSs

Edward Wolff,
Robert Trapp, and Stephen Nesbitt
University of Illinois Urbana-Champaign

PERiLS Science Meeting | November 17, 2023

Shallow Vortices

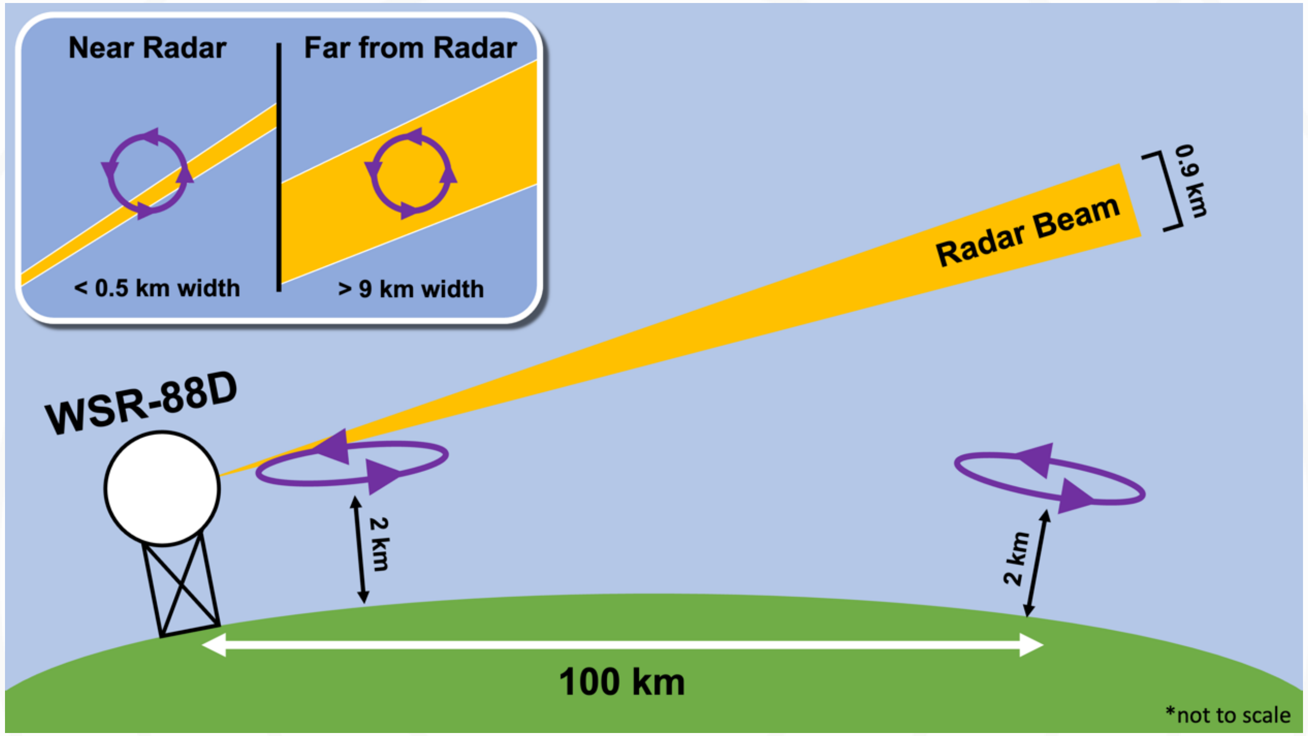


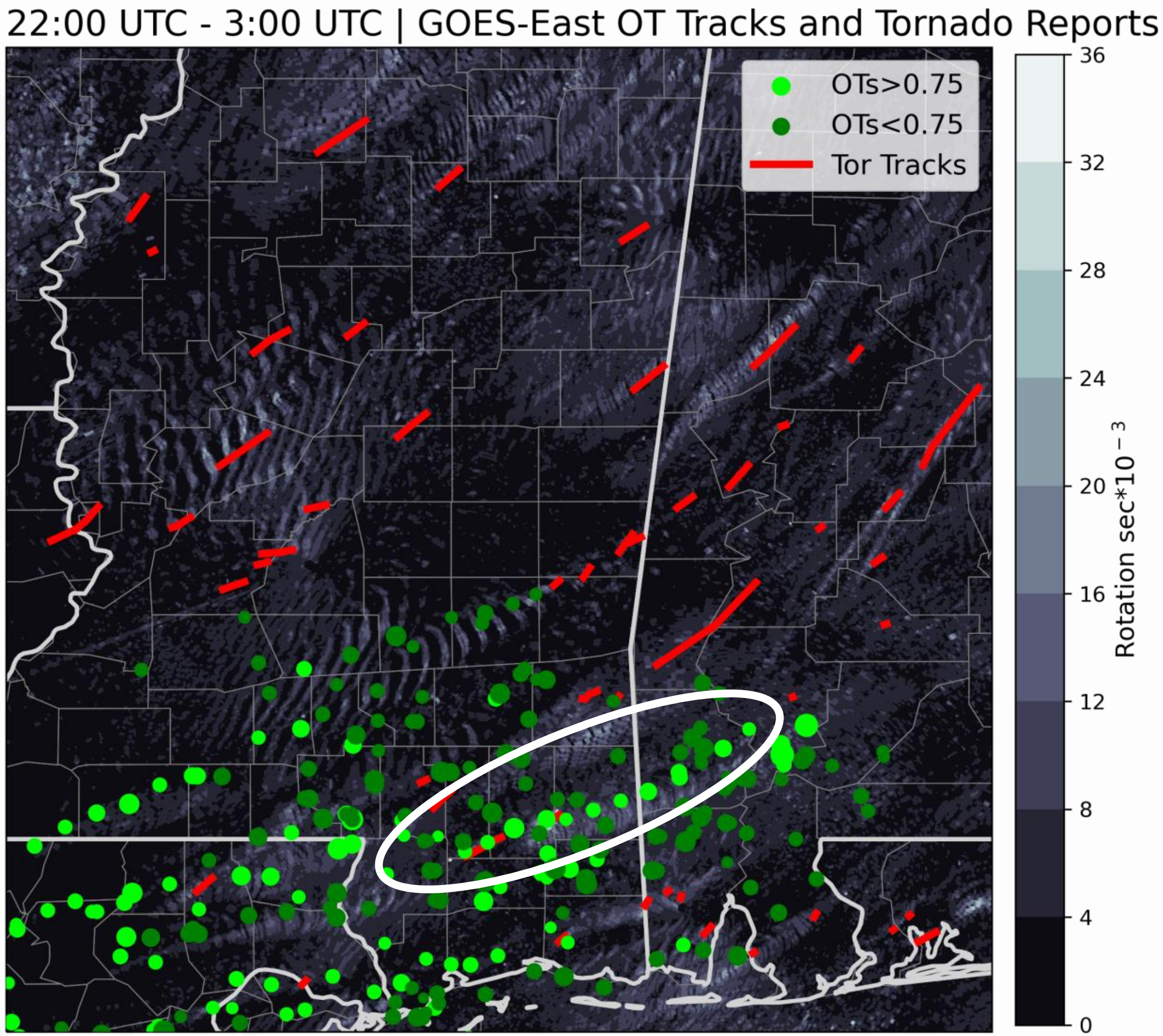
Illustration of radar beam height/width and QLCS vortex depth as distance from the radar increases

- QLCS vortices can be **shallow** and thus can **appear quickly** on radar
  - Developing below the lowest radar scans and between sweeps
- Significant drop in POD farther from radar sites (Brotzge et al. 2013)
  - Beam is higher above the surface and data is less detailed (Davis & Parker 2014)
- However, deep convection still important
  - Updrafts and downdrafts vital for vorticity generation (tilting/stretching)

Updrafts Shown By OTs

- Past work has shown links between updrafts and mesovortices or mesocyclones
  - Updrafts observed using overshooting tops (OTs)
- **Idea**: Identifying deep updrafts could reveal regions of the QLCS conducive for genesis and maintenance of vortices

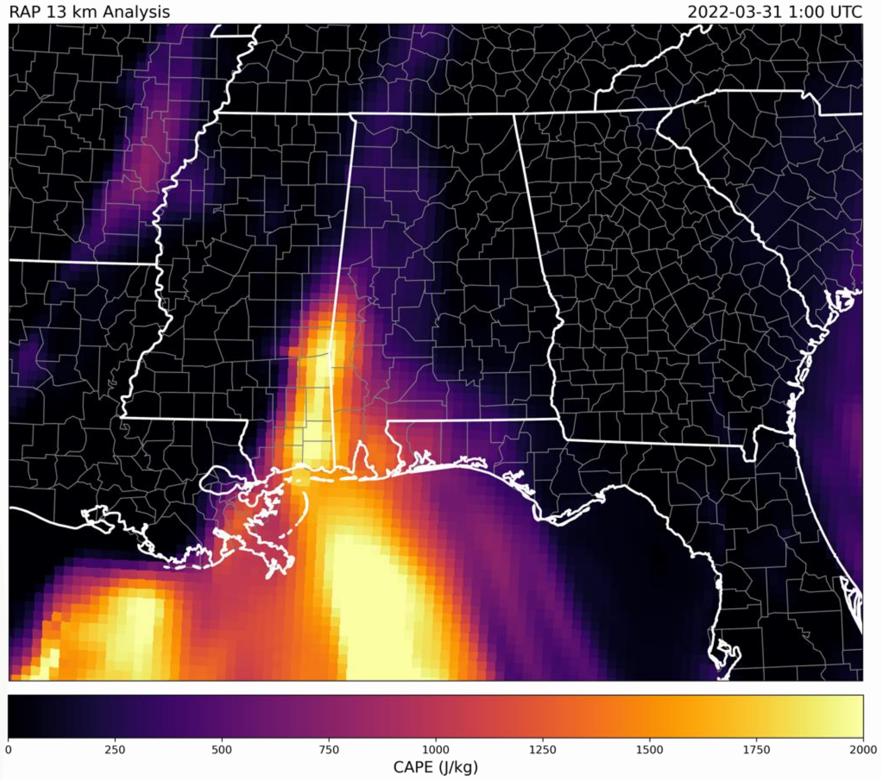
- **Case Study: PERiLS 2022 IOP 2**
- OTs line up well with tornado tracks (where OTs occur)
- No OTs detected north of approximately 32° N
- Why?



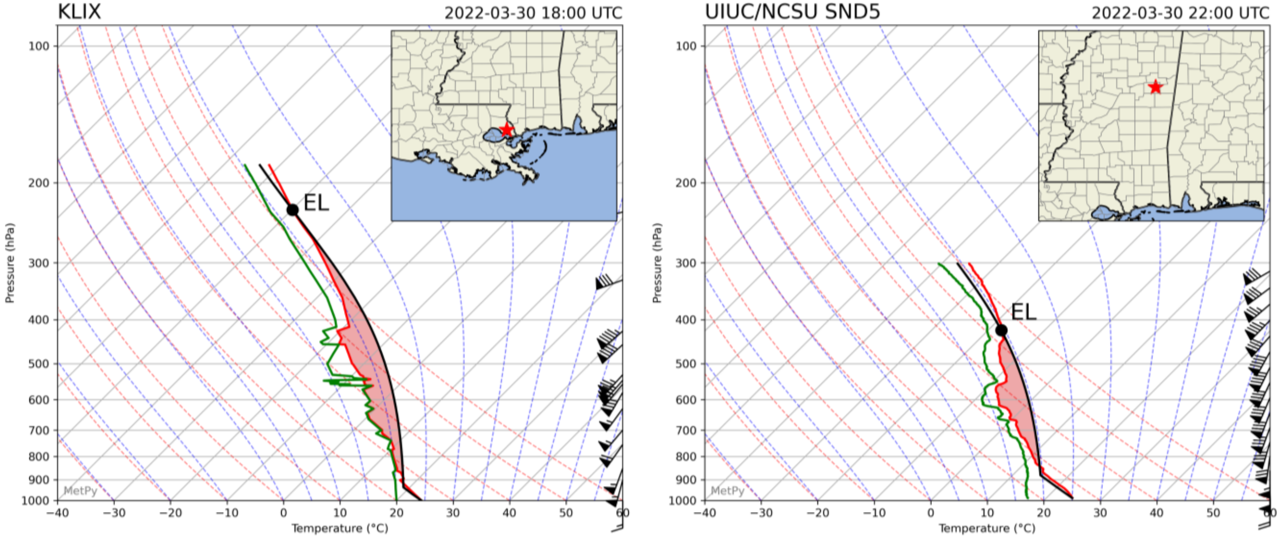
Tracked OTs, NCEI tornado tracks, and MRMS rotation swaths. Color denotes OT probability

Limitations to OTs

- Found that OT development is dependent on CAPE
    - Especially the vertical extent of positive buoyancy
    - Lower equilibrium levels and less CAPE result in shallower, weaker updrafts that do not reach the tropopause
        - This is what is seen in the northern portion of the QLCS

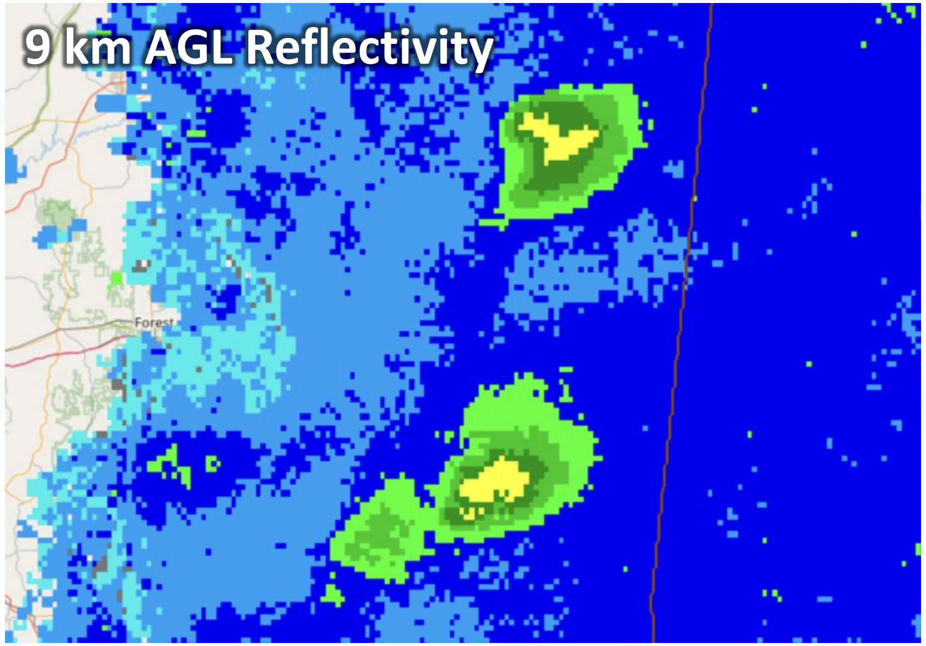


RAP 13 km analysis surface-based CAPE



Soundings from KILX (left) and a PERiLS team farther north along the QLCS (right)

Updrafts Shown By Radar

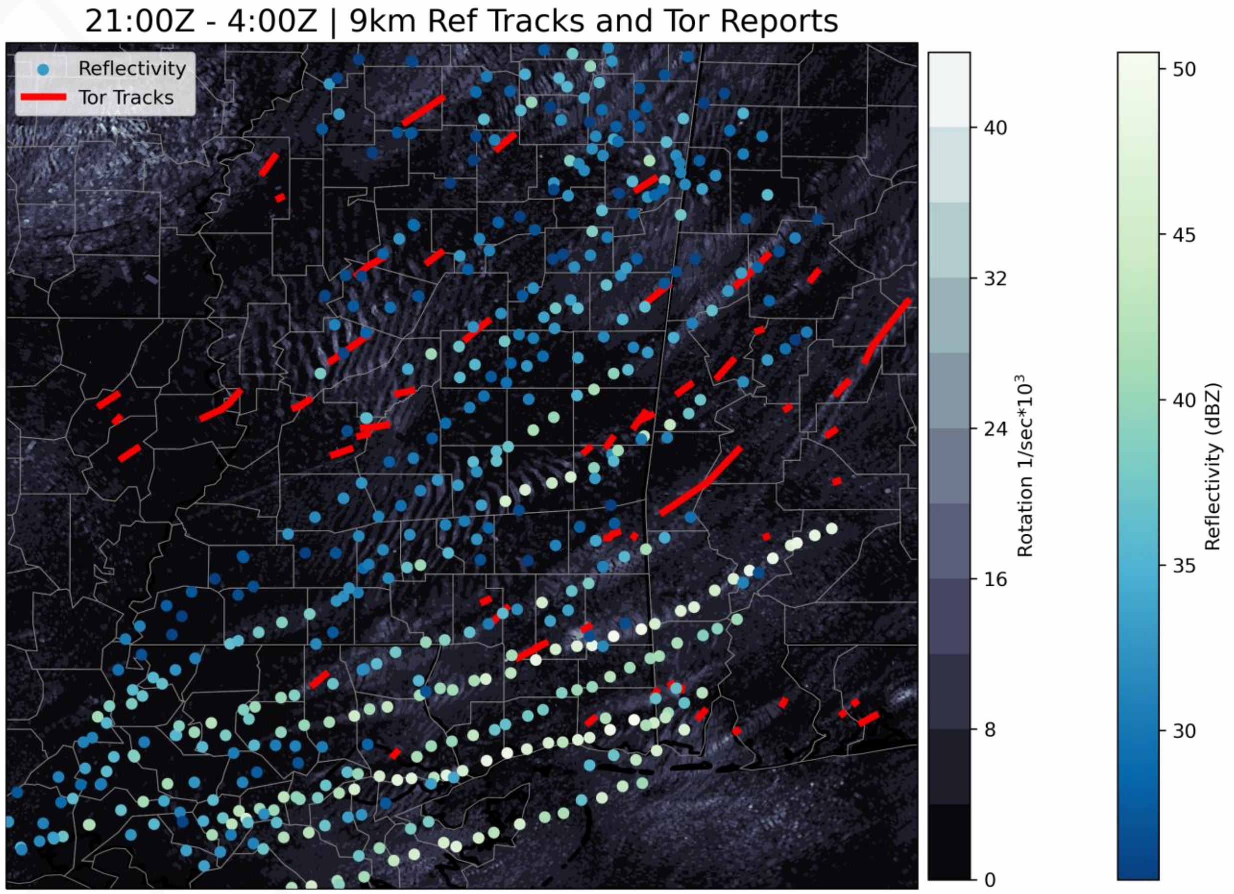


9 km AGL composite reflectivity shown in the NSSL MRMS data viewer

- Composite radar data were obtained using the NSSL's Multi-Radar Multi-Sensor viewer
- Specifically:
  - **9 km AGL constant height reflectivity**
    - This level was chosen as it was just below the equilibrium level on the nearest NWS sounding (theoretically the top of any deep updrafts)
    - Reflectivity cores are defined as areas of reflectivity greater than 25 dBZ
    - Only cores associated with the QLCS are recorded
- All values and locations manually recorded from the NSSL viewer

Updrafts Shown By Radar

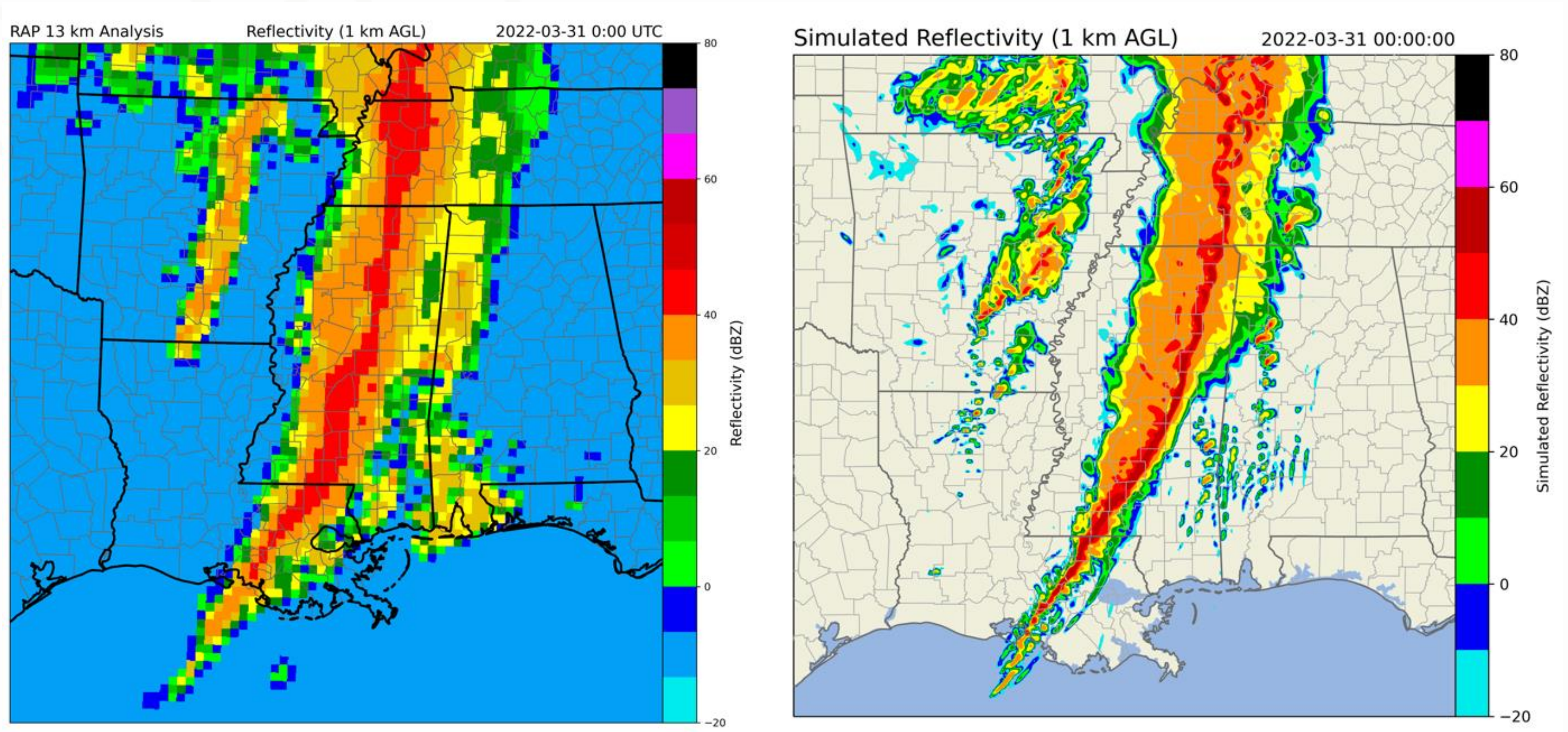
- Similar to OTs, **501 reflectivity cores** (obtained at 10 minute intervals) are plotted alongside tornado tracks
- Spacing and orientation very similar to tornado tracks
- Unlike OTs, reflectivity cores appear as far north as the northernmost tornado tracks
- Nearly every QLCS tornado track is **spatially correlated** to a series of reflectivity cores
- Reflectivity cores are often visible well before tornadoes occur



Tracked MRMS 9 km reflectivity cores, NCEI tornado tracks, and MRMS rotation swaths. Color indicates max reflectivity of the core at 9 km

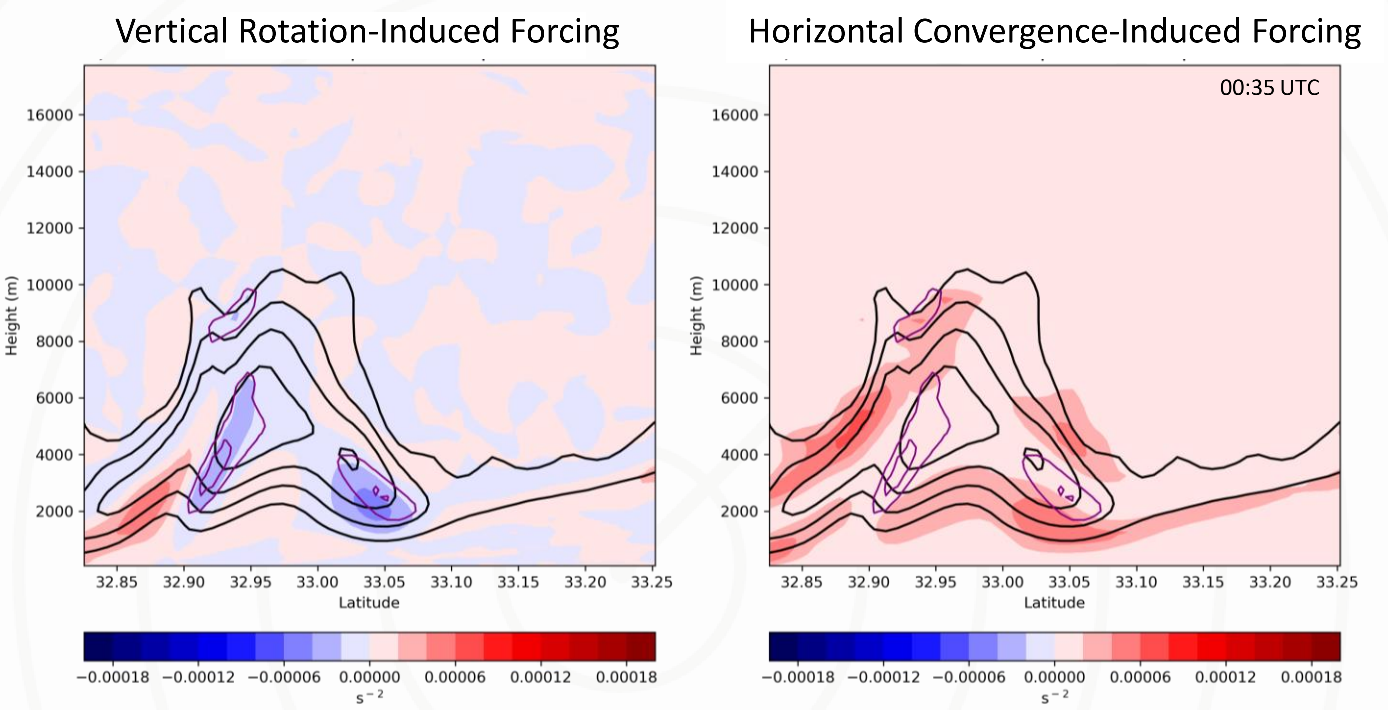
WRF Modeling

- Wanted to understand the physical link between these updrafts and the co-located vortices
- Ran a 3 km grid spacing WRF simulation with a 1 km nested grid
- Produced a QLCS similar to the observed system



(Left) RAP 13 km analysis of 1 km AGL reflectivity and (right) WRF 3 km parent domain simulation of 1 km AGL reflectivity; both at 1:00 UTC

Do Mesovortices Form Updrafts?

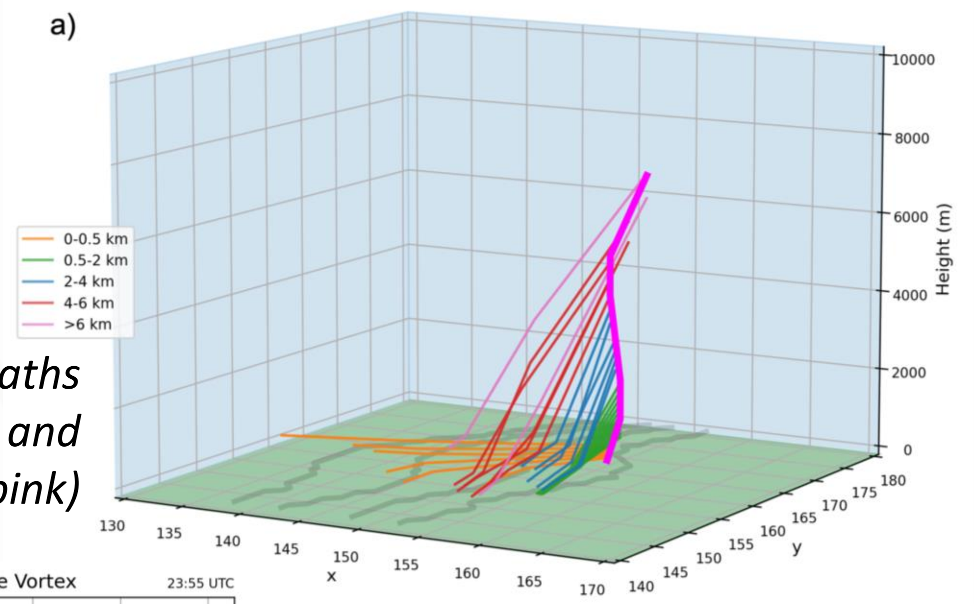


Cross sections at the vortex just prior to "tornadogenesis"; vertical velocity (black) and Okubo-Weiss parameter (magenta) are contoured

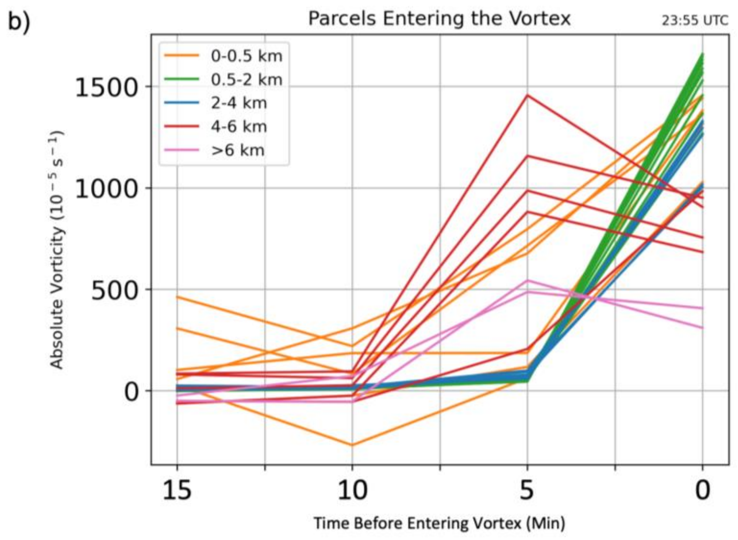
- First question: does a pre-existing vortex result in deep updrafts? (***No***)
- Evaluating updraft forcings shows that, prior to "tornadogenesis", the parent mesovortex has minimal impact on vertical motions
- Greater forcing occurs later after vortex intensifies
  - Could contribute to low-level intensification of vertical motions, would suppress deep updrafts

Do Updrafts Form Mesovortices?

- Next question: does a pre-existing updraft result in strong vortices? (***Yes***)
- Parcel trajectories terminating in the mesovortex originate largely in the environmental inflow
    - These parcels ascend as they reach the vortex/updraft
    - Only attain vorticity once ascent occurs
- Tilting/stretching by the updraft appears responsible for vorticity generation



Parcel trajectory paths colored by height and mesovortex location (pink)

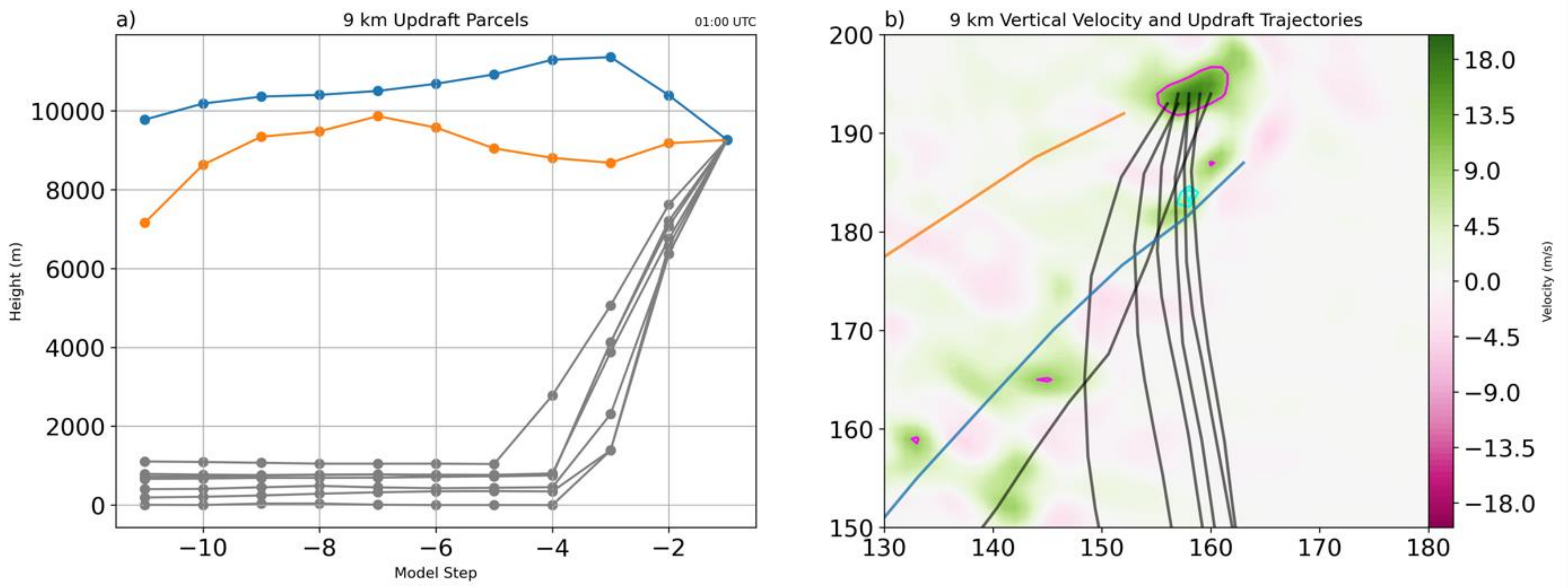


Heights (left) and absolute vorticity (right) for parcels entering the vortex

Conclusions

- Many QLCS updrafts are deep enough to be observed on upper-tropospheric radar sweeps
  - Data that is available for a much larger portion of the country than low levels
- Locations of these deep updrafts indicate where conditions are favorable for vortex formation
- *Deep updrafts appear to be an important precursor to vortex formation (necessary but insufficient condition)*

- **Main takeaway: QLCS research often focuses on low levels (with good reason), but evidence of surface processes are also apparent aloft**



Heights (left) and parcel paths (right) for parcels making up the updraft at 9 km (gray) and other 9 km parcels (orange/blue)

Future Work

- Future work will expand this analysis to a larger number of events and make use of idealized simulations
  - Are these signatures always apparent? If not, what constrains them?
  - Do signatures aloft vary based upon the mesovortex genesis mechanism?
  - What can the width, intensity, and longevity of reflectivity cores tell us?

Thank You!

Questions?

Funding provided by NSF AGS 2020462