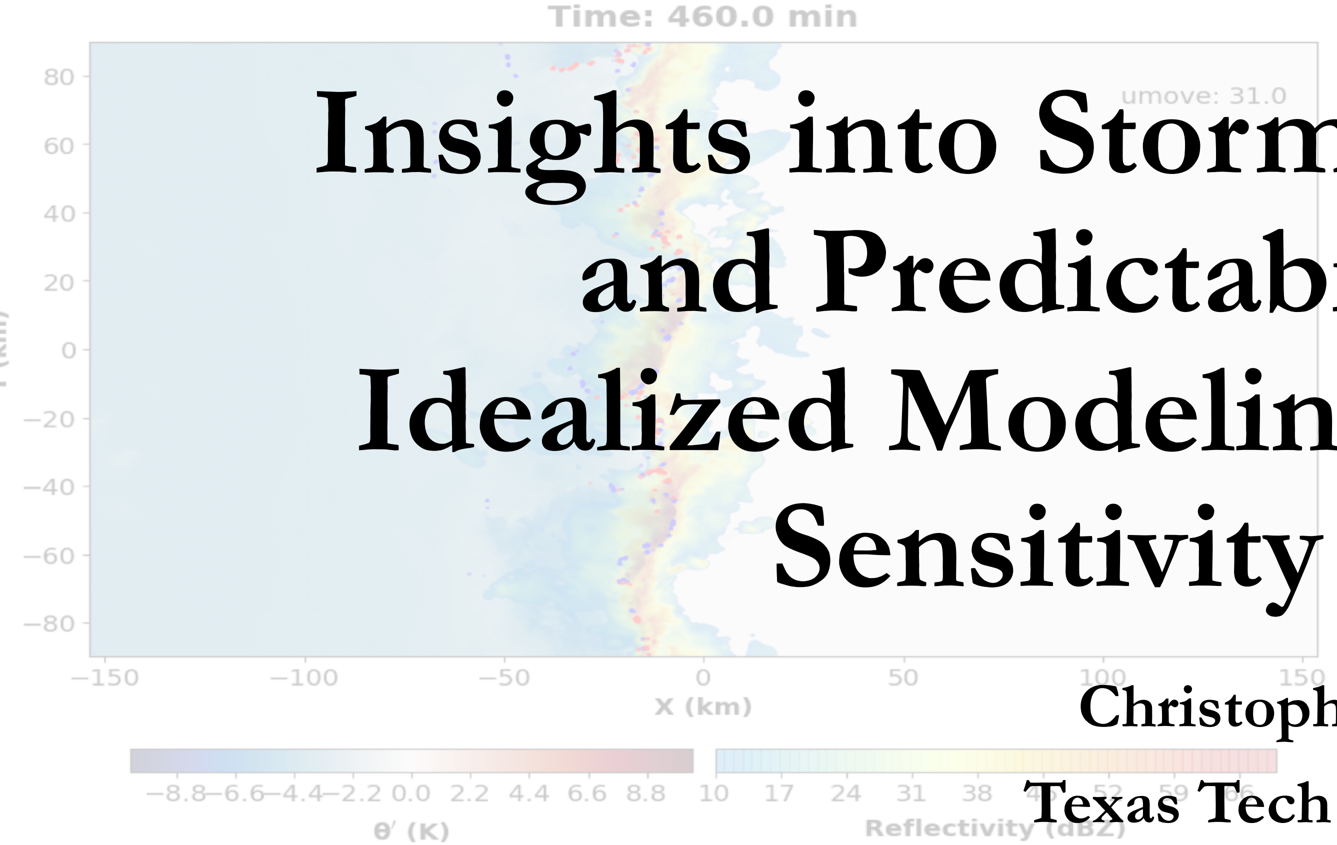
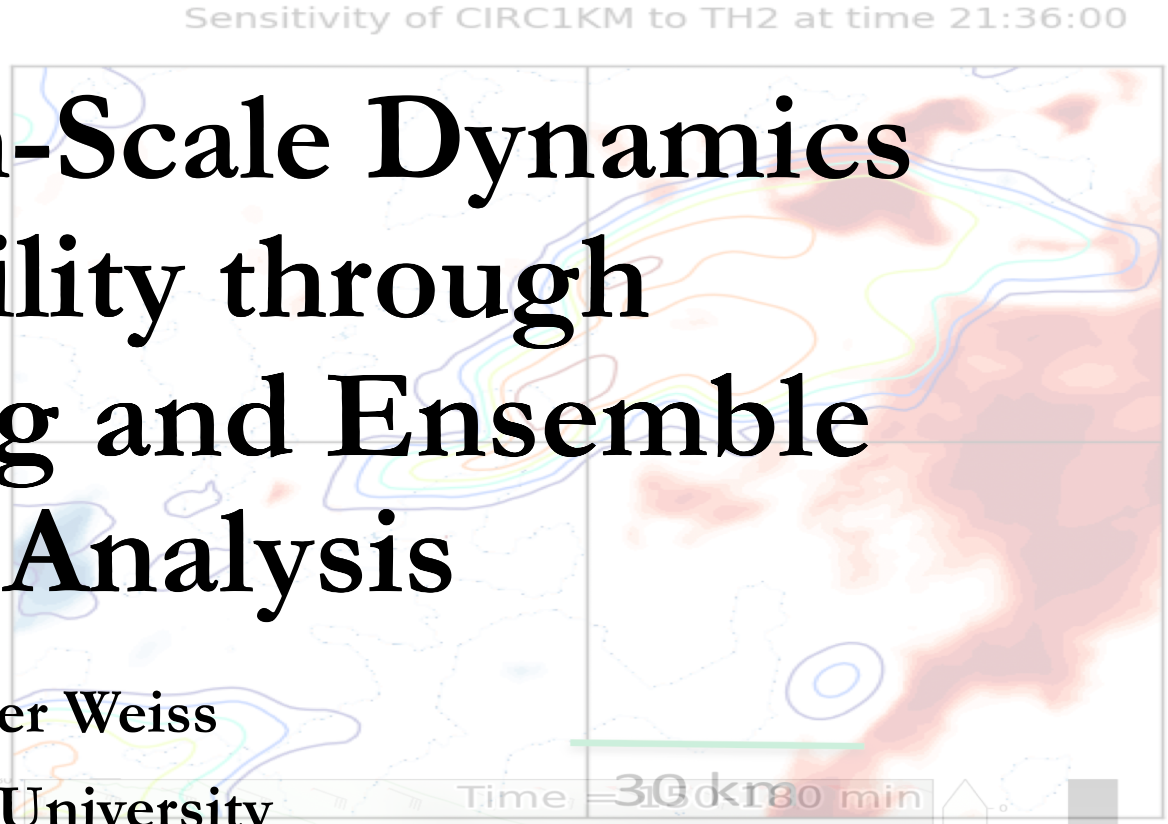
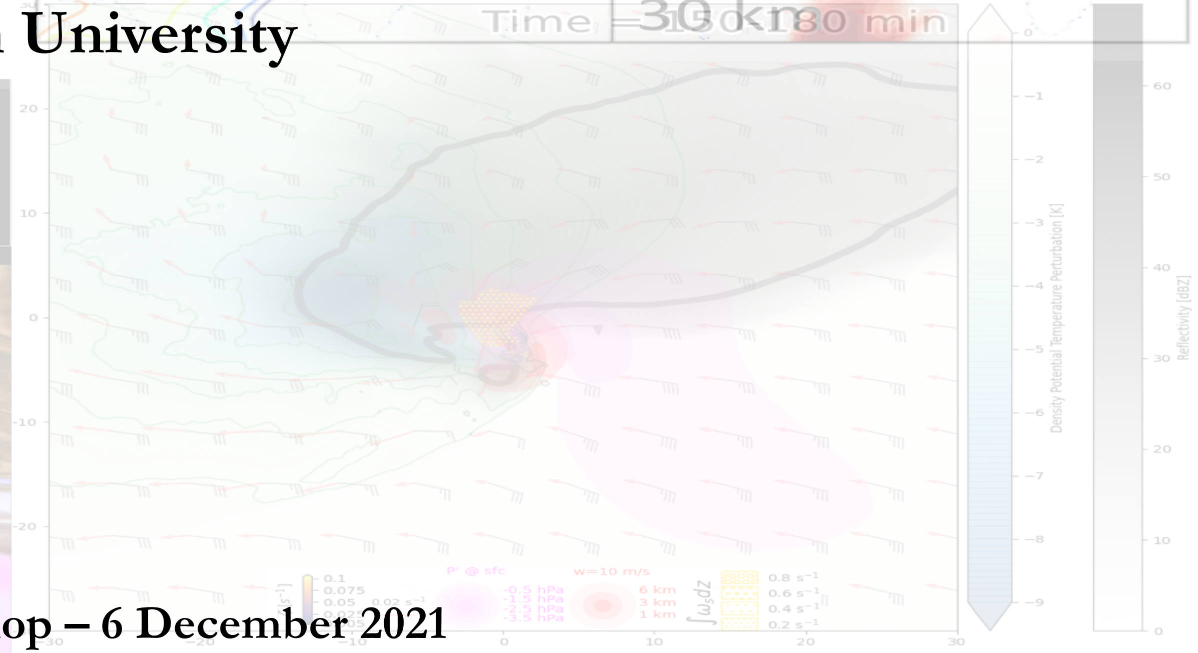




Insights into Storm-Scale Dynamics and Predictability through Idealized Modeling and Ensemble Sensitivity Analysis

Christopher Weiss

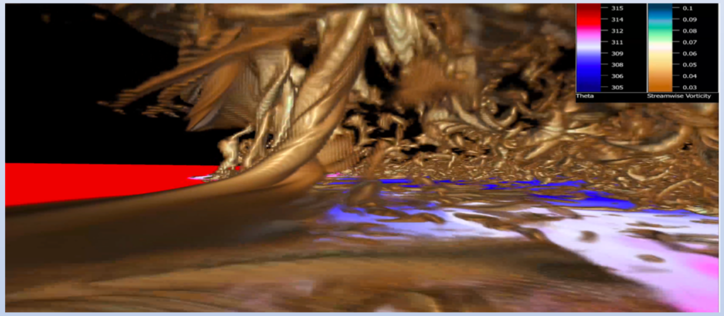
Texas Tech University



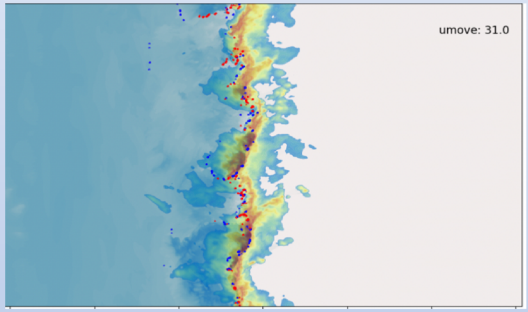
CIRWO Theme 2 Workshop – 6 December 2021

Activities Relevant to CIWRO Theme 2

- Idealized Storm-scale Modeling

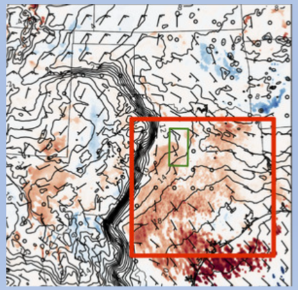


Supercell (e.g., SVC)

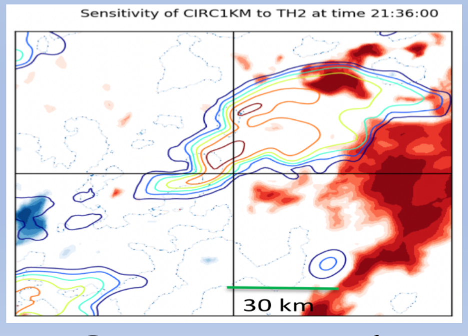


QLCS

- Ensemble Sensitivity Analysis



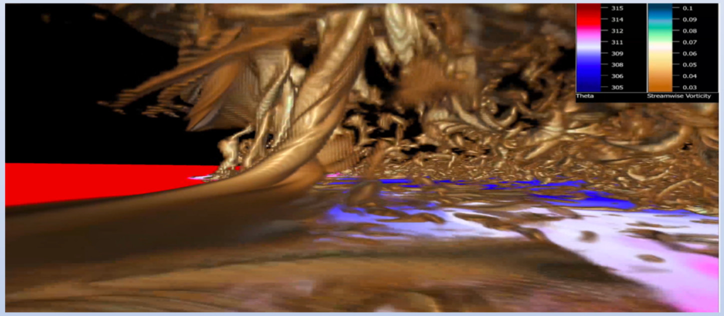
Mesoscale



Storm-scale

Activities Relevant to CIWRO Theme 2

- Idealized Storm-scale Modeling



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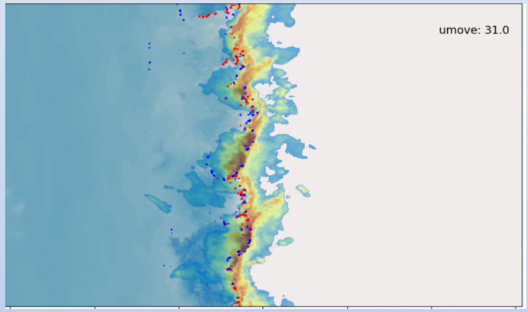

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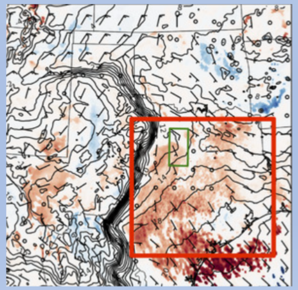

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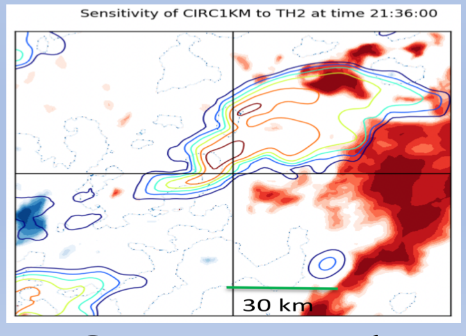
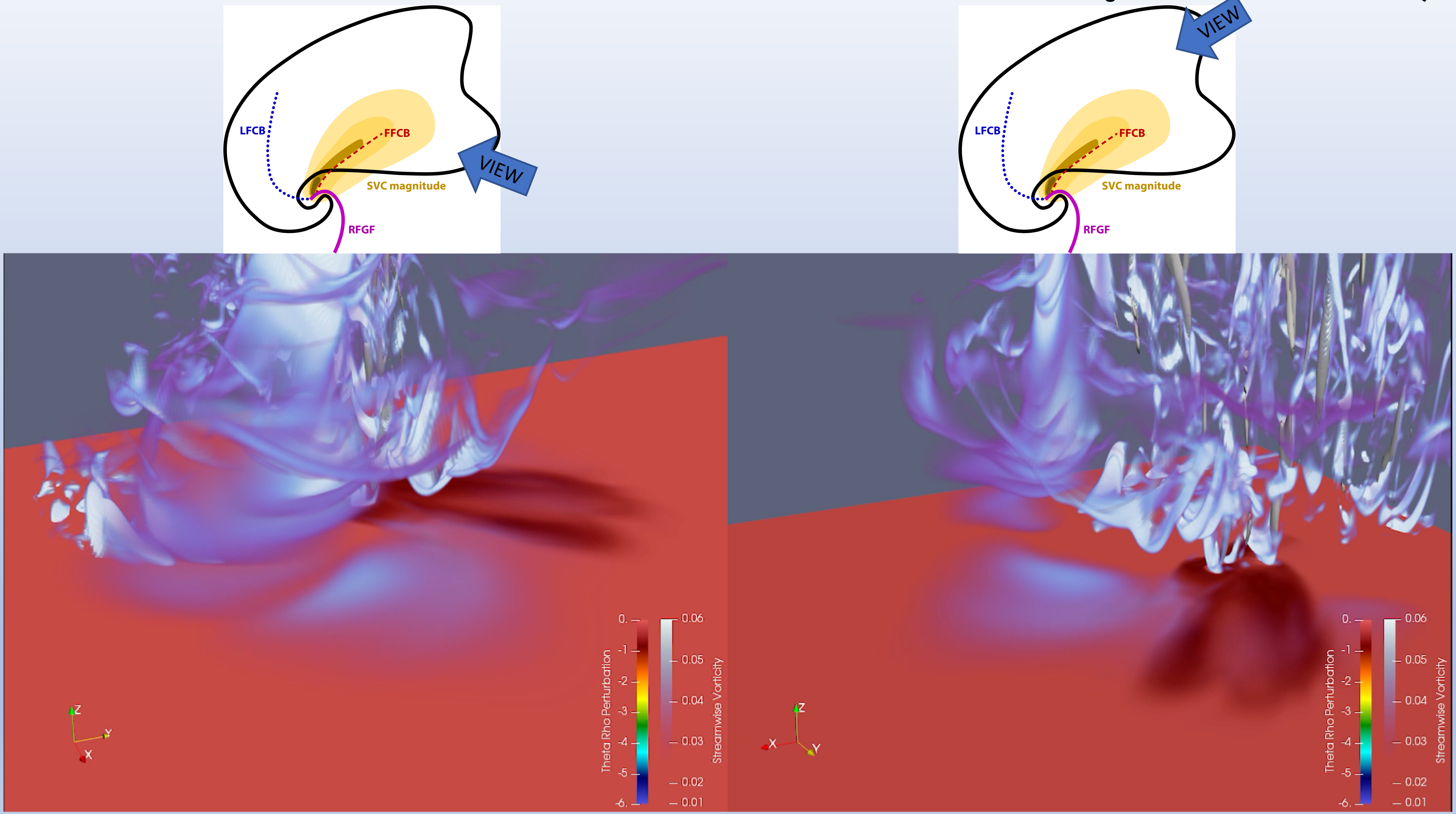


Storm-scale

Simulations of the Streamwise Vorticity Current (SVC)



Streamwise vorticity (white shade) and θ_ρ' (colored) [A. Schueth, Texas Tech]

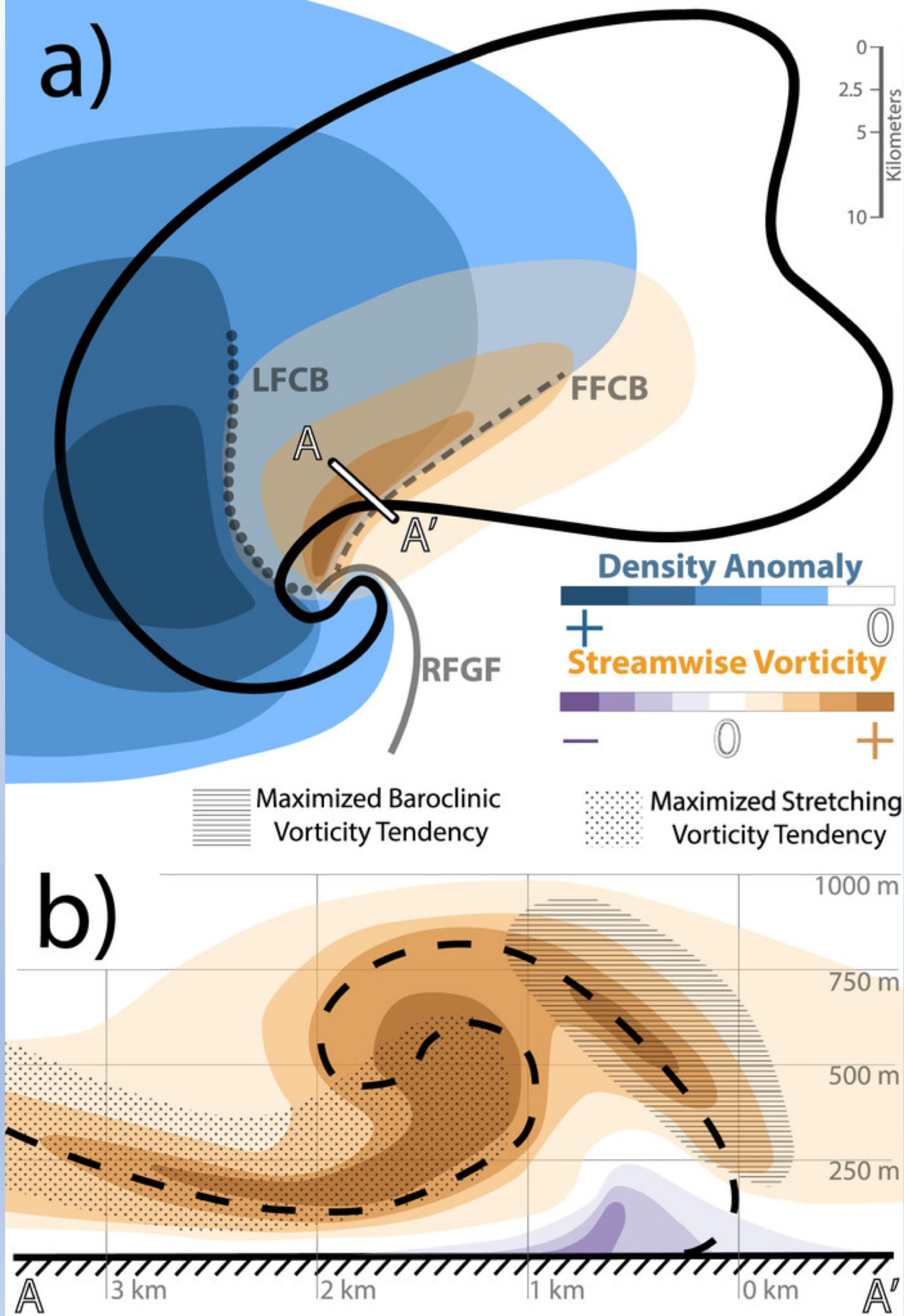
Simulating the SVC in CM1 - Past

Previous work (Schueth et al. 2021) took an in-depth look at the dynamics driving the SVC

- Horizontal inflow acceleration was the largest contributor to SVC vorticity
- Baroclinic vorticity was a close second in vorticity generation

Unanswered questions:

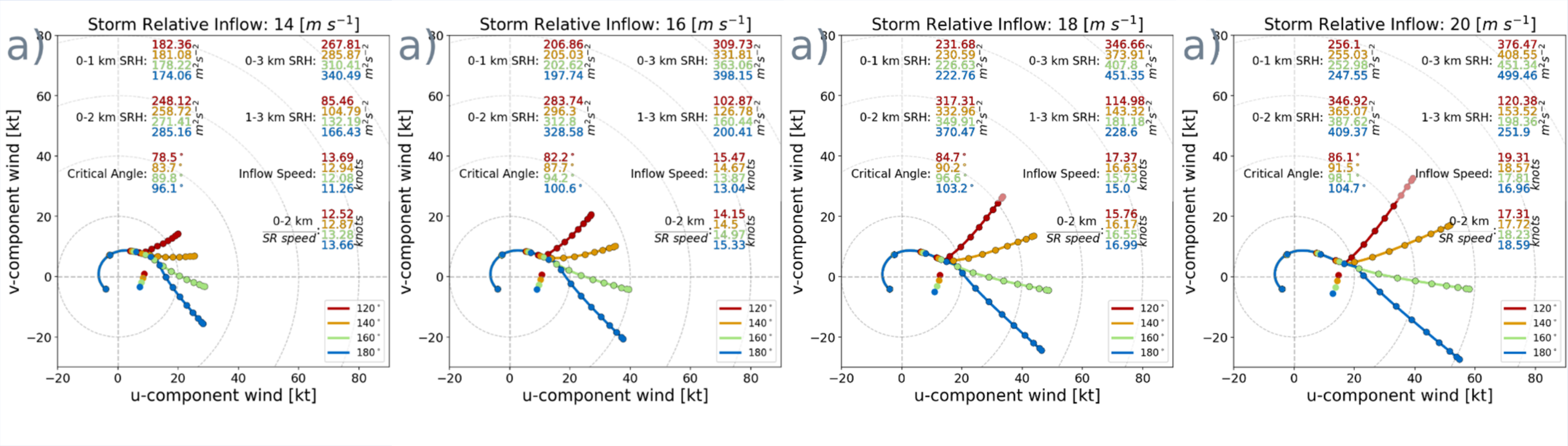
- How does the SVC affect the parent storm?
- Does the orientation of the SVC/FFCB change the magnitude of the SVC or downstream effects?
- Are there environmental conditions that better support SVCs?



Simulating the SVC in CM1 - Present

16 simulations exploring a wind shear parameter space to simulate different conditions for the SVC

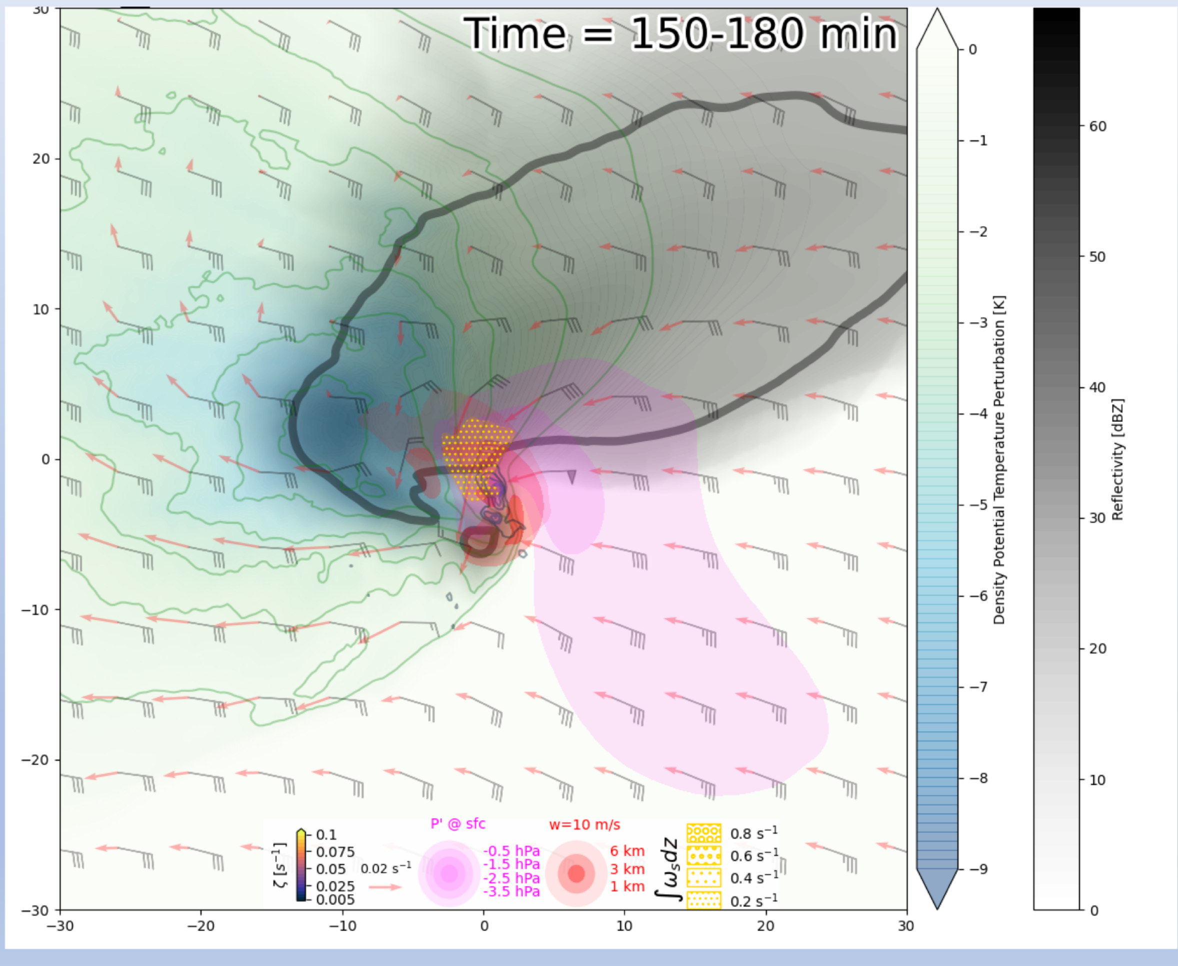
- 4 magnitudes of storm-relative inflow > different updraft strengths and inflow accelerations
- 4 angles of upper-level venting > different cold pool placements and boundary orientations



Simulating the SVC in CM1 - Future

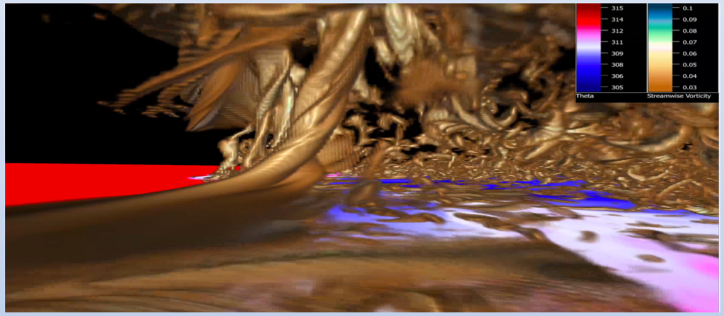
Solving the effects of the SVC

- Quantifying the effects hodograph structure has on cold pool placement and boundary location
- Backward parcel trajectories to quantify how much air is originating in the SVC
- Forward parcel trajectories to quantify where SVC air ends up
- Pressure decomposition to further illuminate the SVCs role in low-level VPPGF
- Determine temporal linkage between updraft intensification, tornado formation, and SVC strength



Activities Relevant to CIWRO Theme 2

- Idealized Storm-scale Modeling



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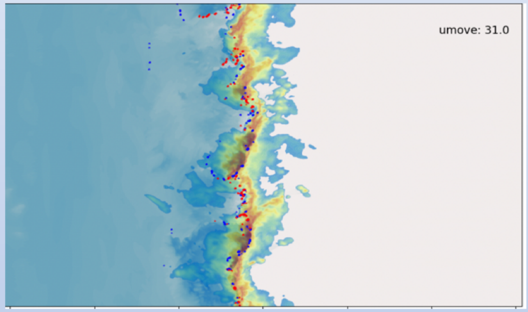
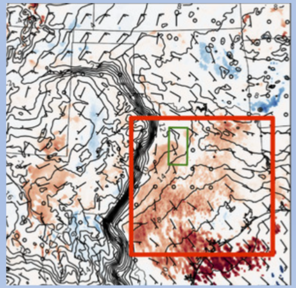
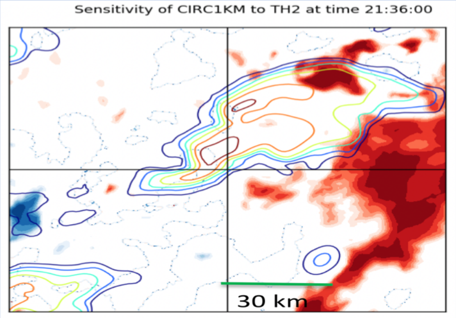


QLCS

- Ensemble Sensitivity Analysis



Mesoscale

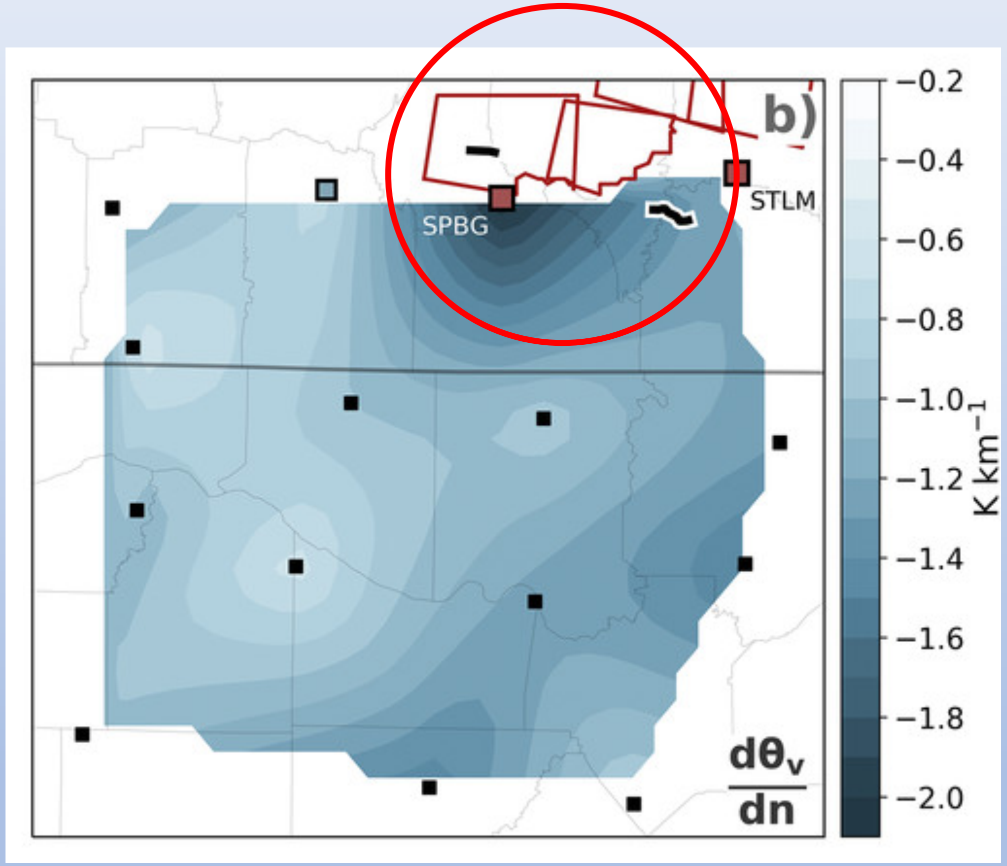


Storm-scale

Simulations of HSLC Quasi-Linear Convective Systems

Past Research

- McDonald and Weiss (2021) found stronger θ_v gradients near a tornado in a HSLC QLCS, implications for baroclinic vort generation and low-level updraft magnitude
    - **How important are cold pool characteristics for mesovortex development in HSLC QLCS events?**



McDonald and Weiss 2021

Current Research

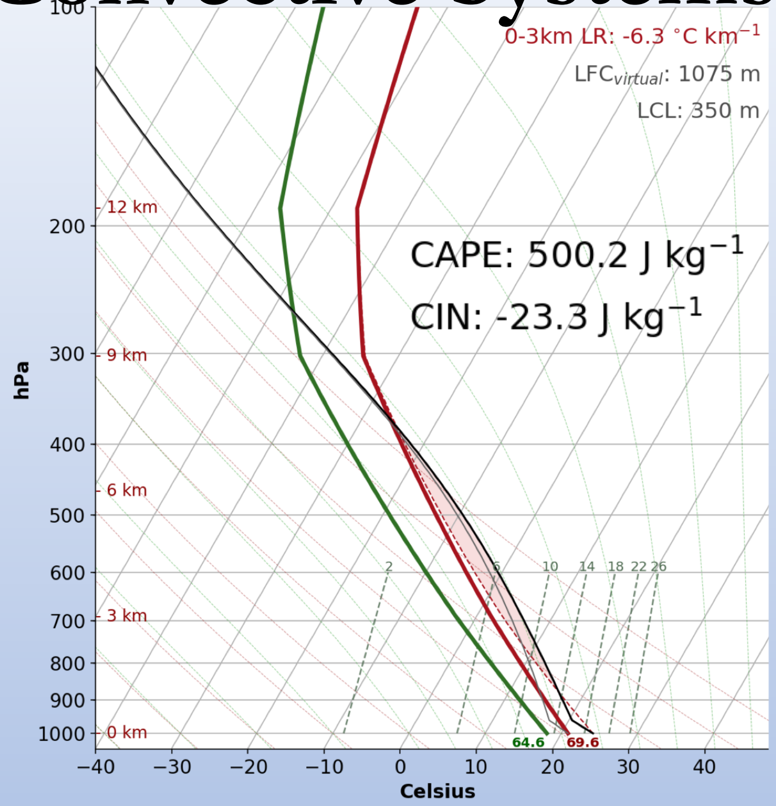
- Simulate HSLC QLCSs in CM1 and explore effects of cold pool characteristics on MV and TLV generation and maintenance

- Look at effects of modifying 3-6 km shear vector magnitude
    - Increased shear -> decreased cold pool temperatures (Coniglio et al. 2006)
        - Impacts on baroclinic vorticity generation?
        - Impacts on low-level updrafts (via convergence and/or RKW concepts)?

Simulations of HSLC Quasi-Linear Convective Systems

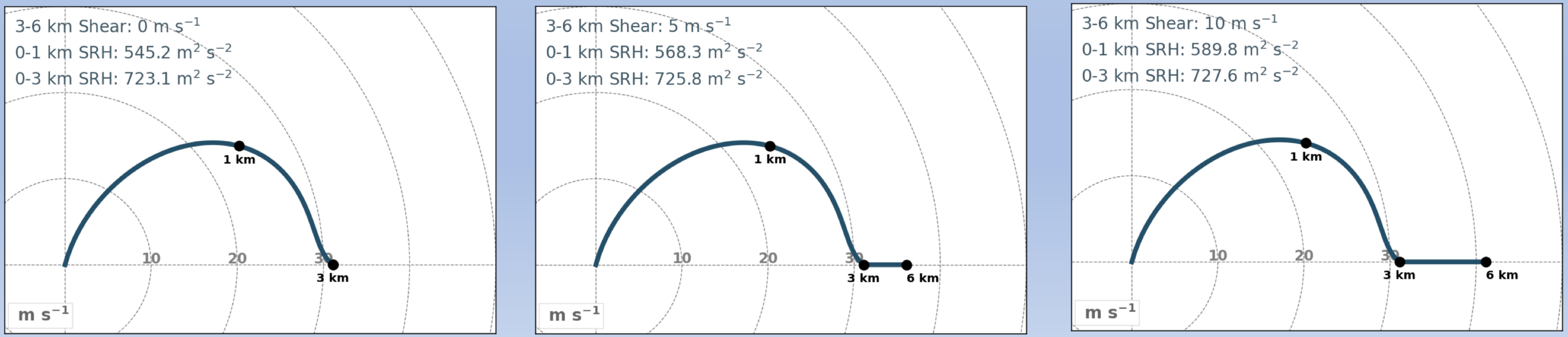
Model Set Up

- Input sounding with 500 J kg^{-1} SBCAPE (based on Sherburn and Parker 2019)
- Very strong low-level shear hodographs, with 0-, 5-, and 10-m s^{-1} 3-6 km shear
- 6-km deep pseudo cold front as CI mechanism (Sherburn and Parker 2019)
  - Heat sink (-0.001 K s^{-1} if cold pool warmer than -2.5 K)
- Periodic N/S boundaries, 250 m dx (10 m dz, stretched to 250 m at ~10 km)



Simulations

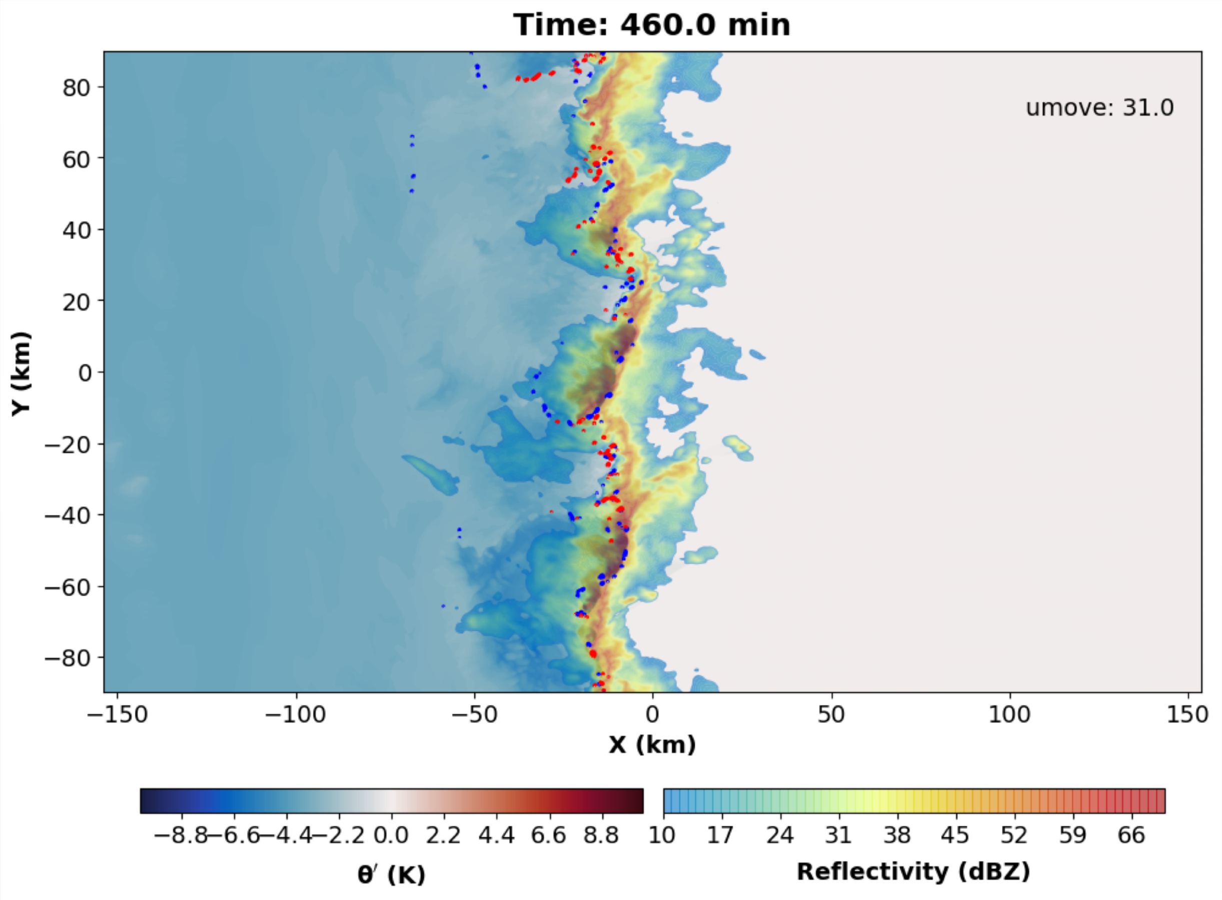
- 12-hour simulation of each hodograph for both free slip and semi-slip lower BC

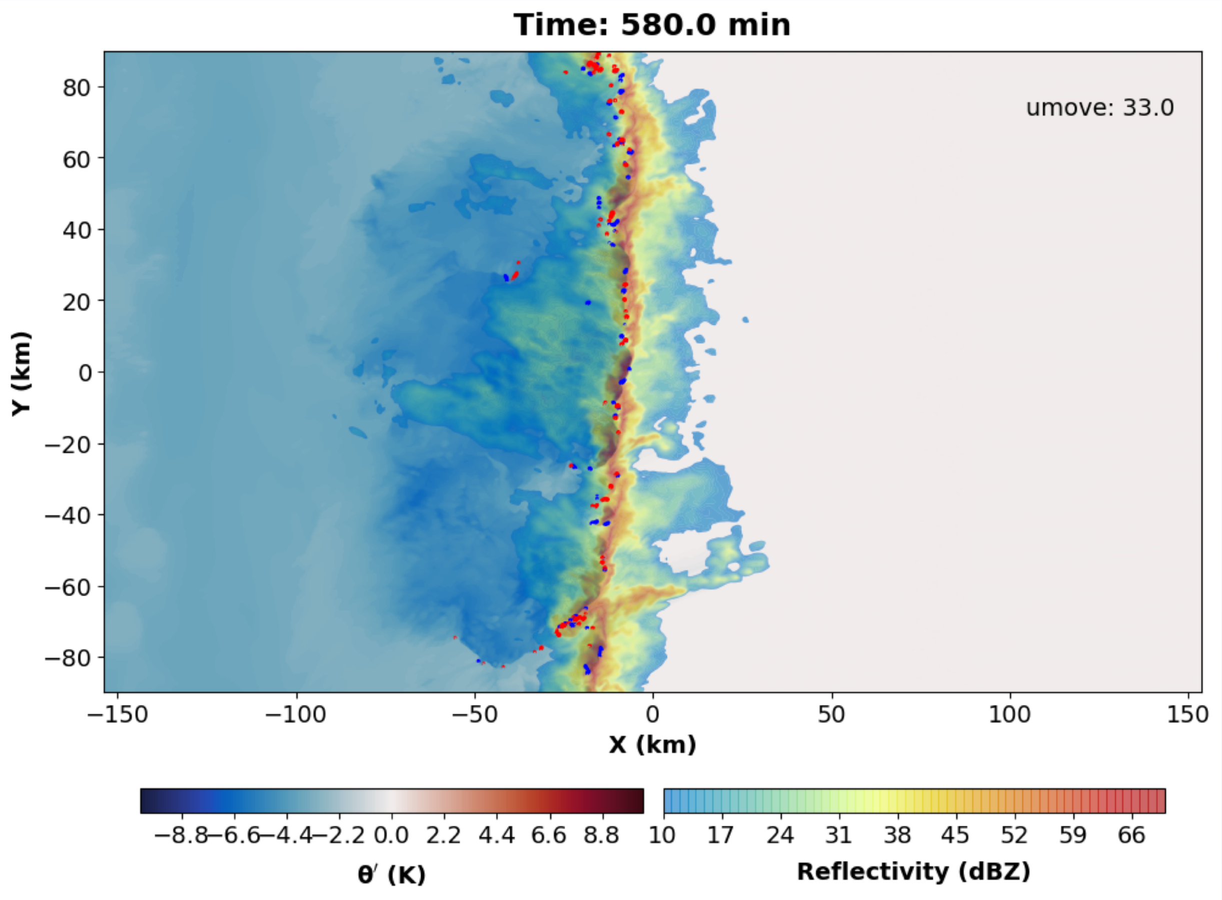


Simulations of HSLC Quasi-Linear Convective Systems

- Example images from 10-m s^{-1} 3-6 km shear (free slip) run

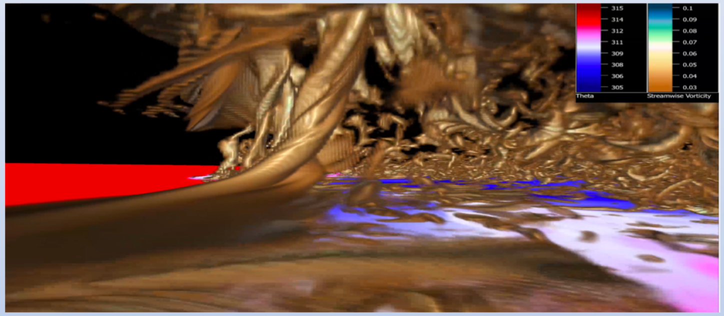
Red: $\zeta > 0.02\ s^{-1}$
Blue: $\zeta < 0.02\ s^{-1}$





Activities Relevant to CIWRO Theme 2

- Idealized Storm-scale Modeling



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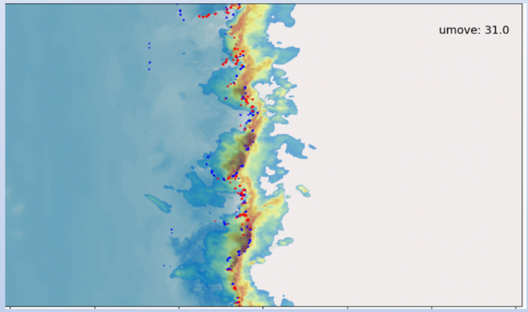

QLCS

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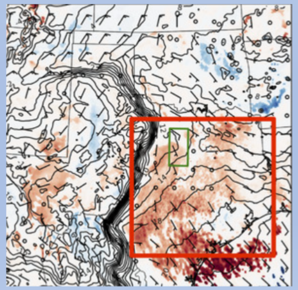
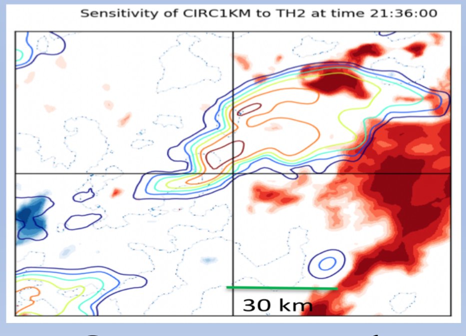


Mesoscale



Storm-scale

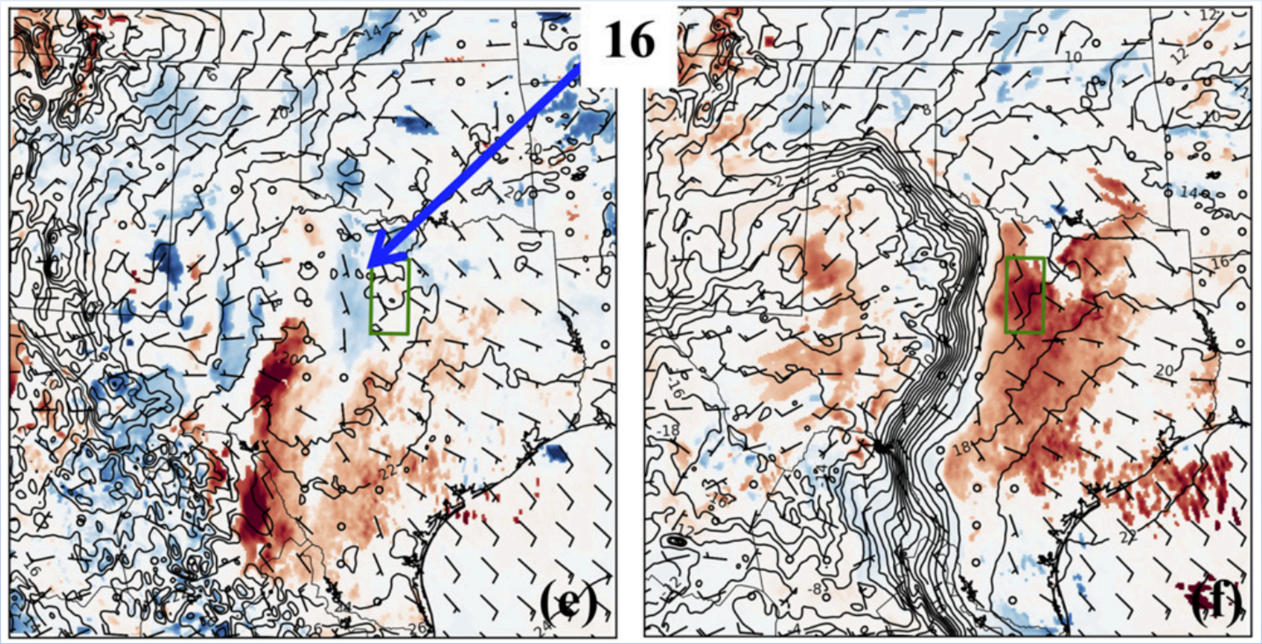
Ensemble Sensitivity Analysis (ESA)

- Linear regression between scalar response variable (R) and initial state variable (x_t) over suite of ensemble members

- How does prior atmospheric state influence a specified outcome?

- Sensitivity formulation:

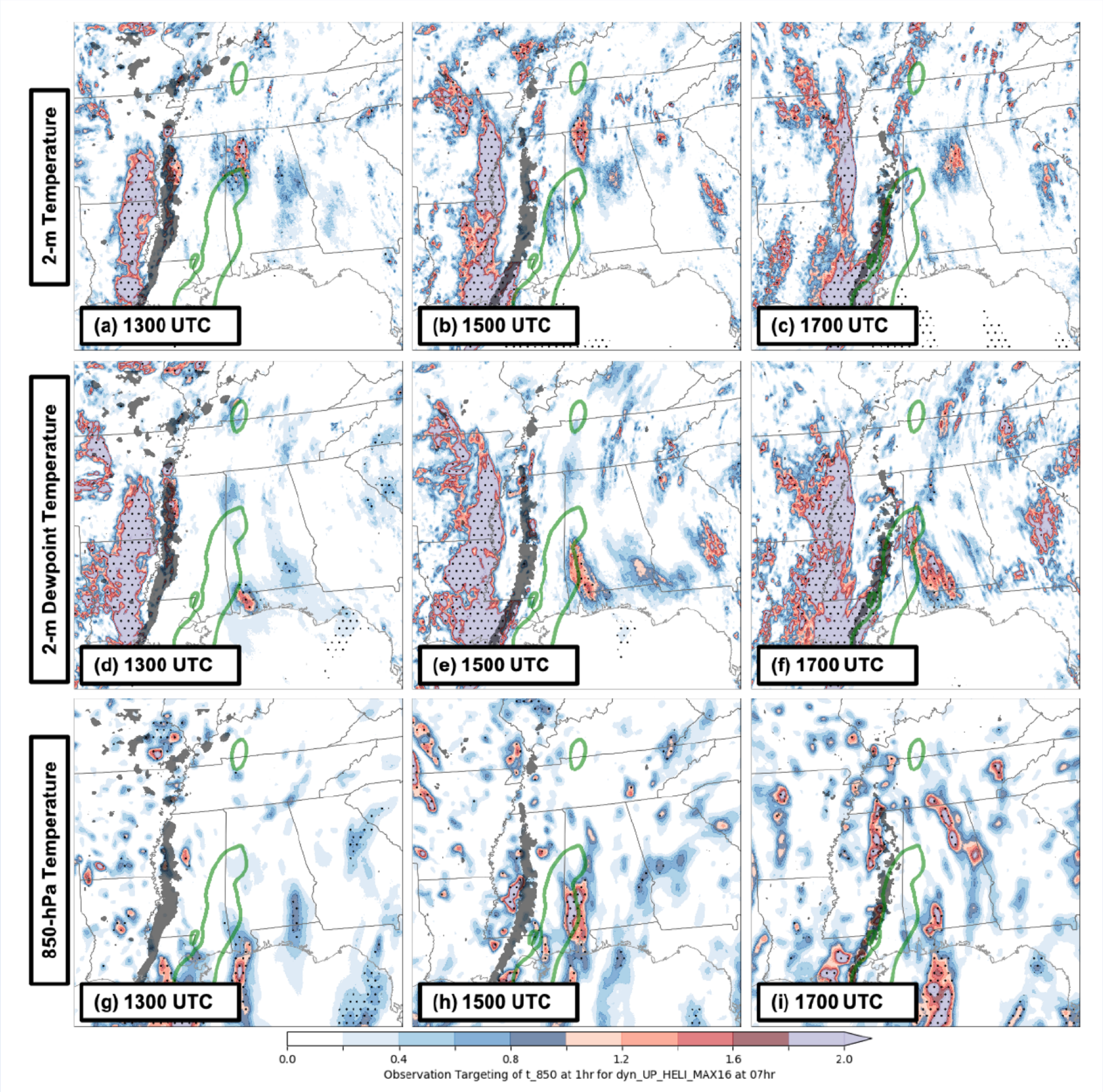
$$\frac{\partial \vec{R}}{\partial \vec{x}_t} = \frac{\delta \vec{R} \delta \vec{x}_t^T}{\delta \vec{x}_t \delta \vec{x}_t^T} \qquad \delta R = R - \bar{R}$$



Sensitivity of maximum reflectivity of dryline convection to 2-m (left) temperature and (right) dewpoint. (Hill et al. 2016)

MOTIVATION:
- Improved dynamical understanding of phenomena
- Targeted observations to improve forecasts

Mesoscale Application of ESA



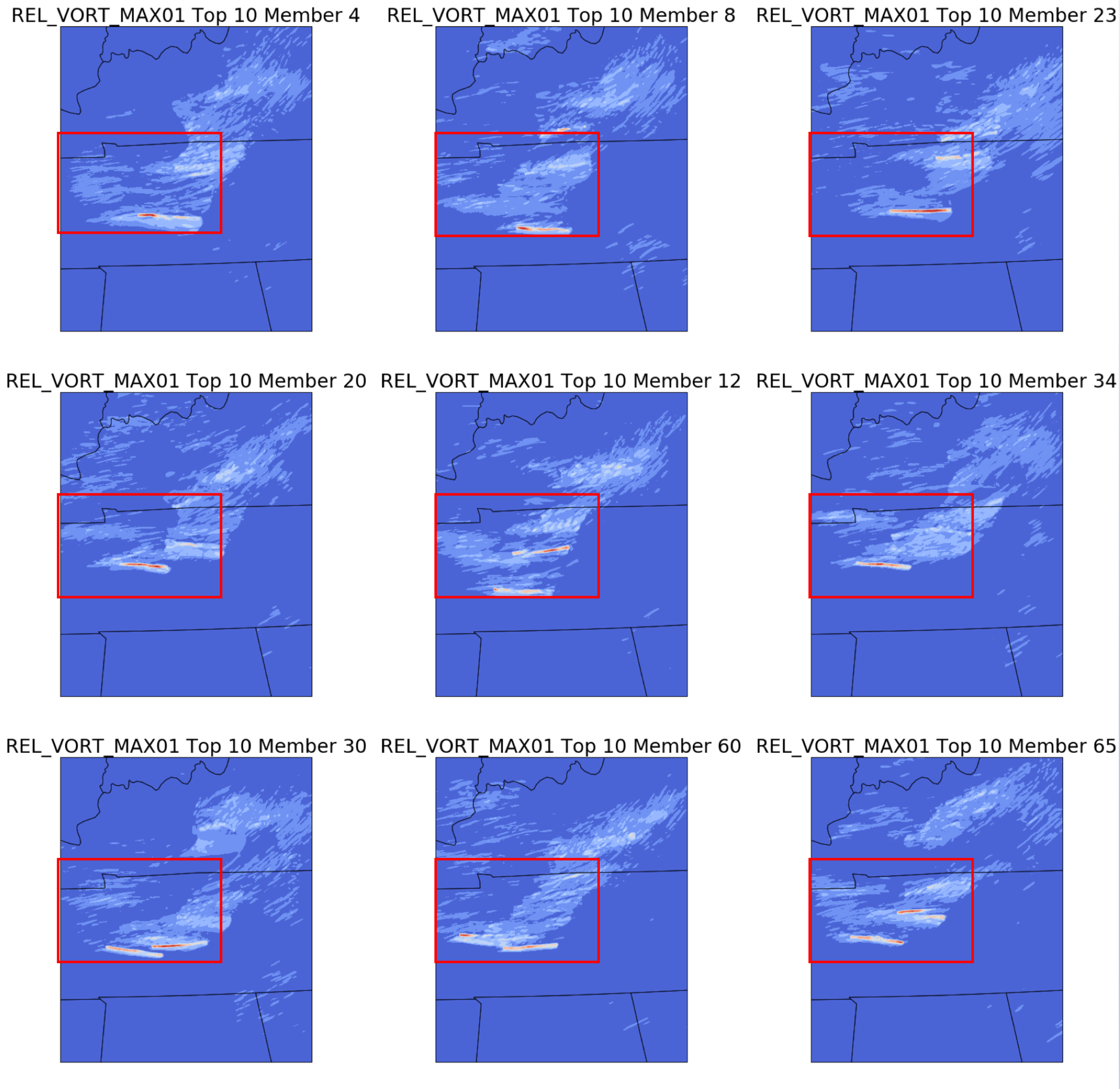
Hill et al. 2021

- Hill et al. (2021) examine how ESA-derived targeting fields (color shaded) distribute relative to a severe QLCS from VORTEX-SE 2017.
- Most significant sensitivity identified for near-surface thermo of cold pool
- Widely distributed areas of sensitivity to surface thermo and 850 mb temperature in inflow sector

Application of ESA to 3 Mar 2020 Nashville, TN Event

Downtown Nashville approx. 0600 UTC 3 Mar 2020

- 80 HRRRE 1-km simulations of the event are being used for ESA
- 0100 UTC HRRRE initialization
- Initial results focus on maximum $\zeta_{0\text{-}1\ \mathrm{km}}$ for a large response box



Top 9 Members, Response: Max 1-hr $\zeta_{0\text{-}1\ \mathrm{km}}$ 0500-0600 UTC

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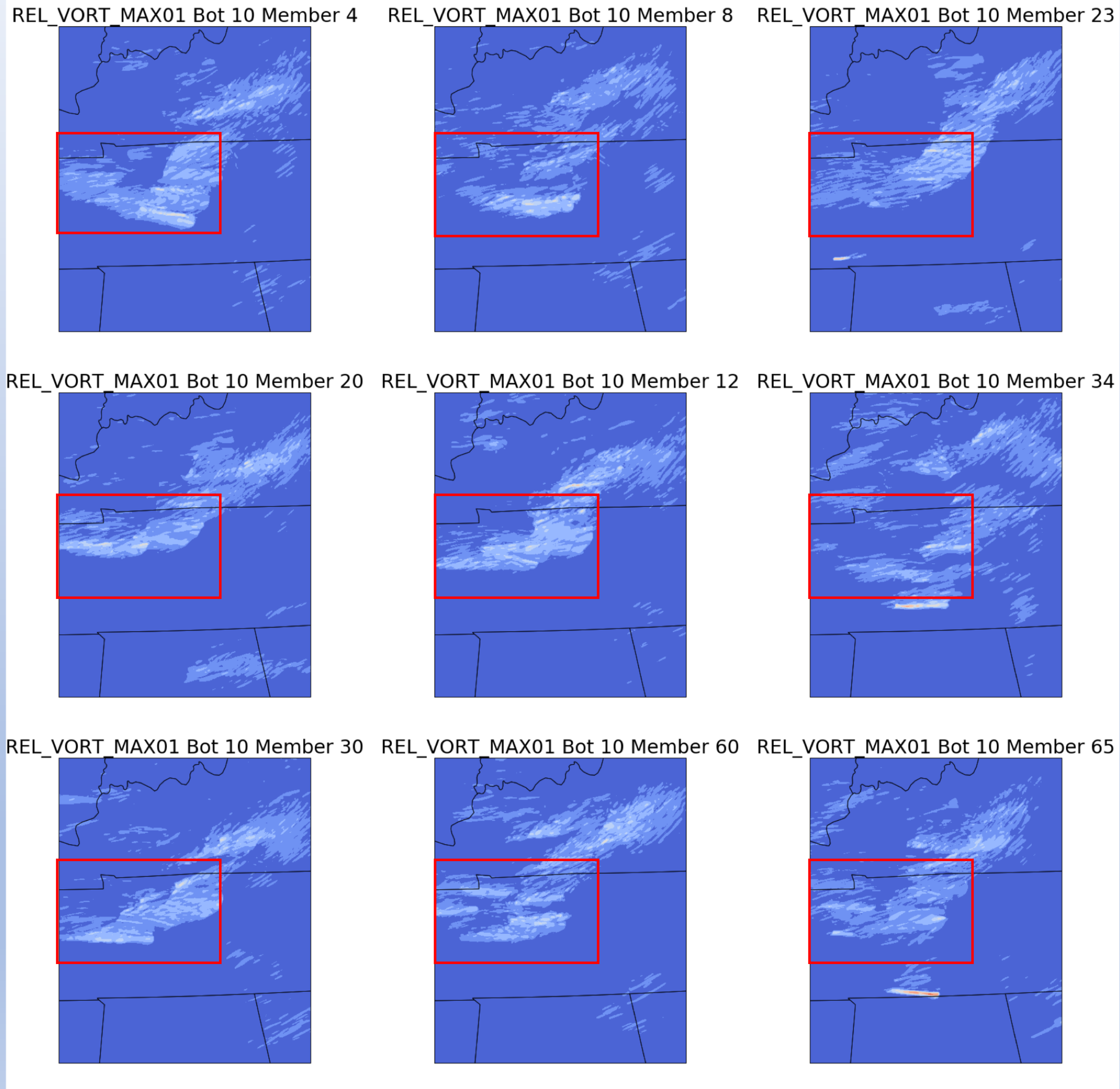
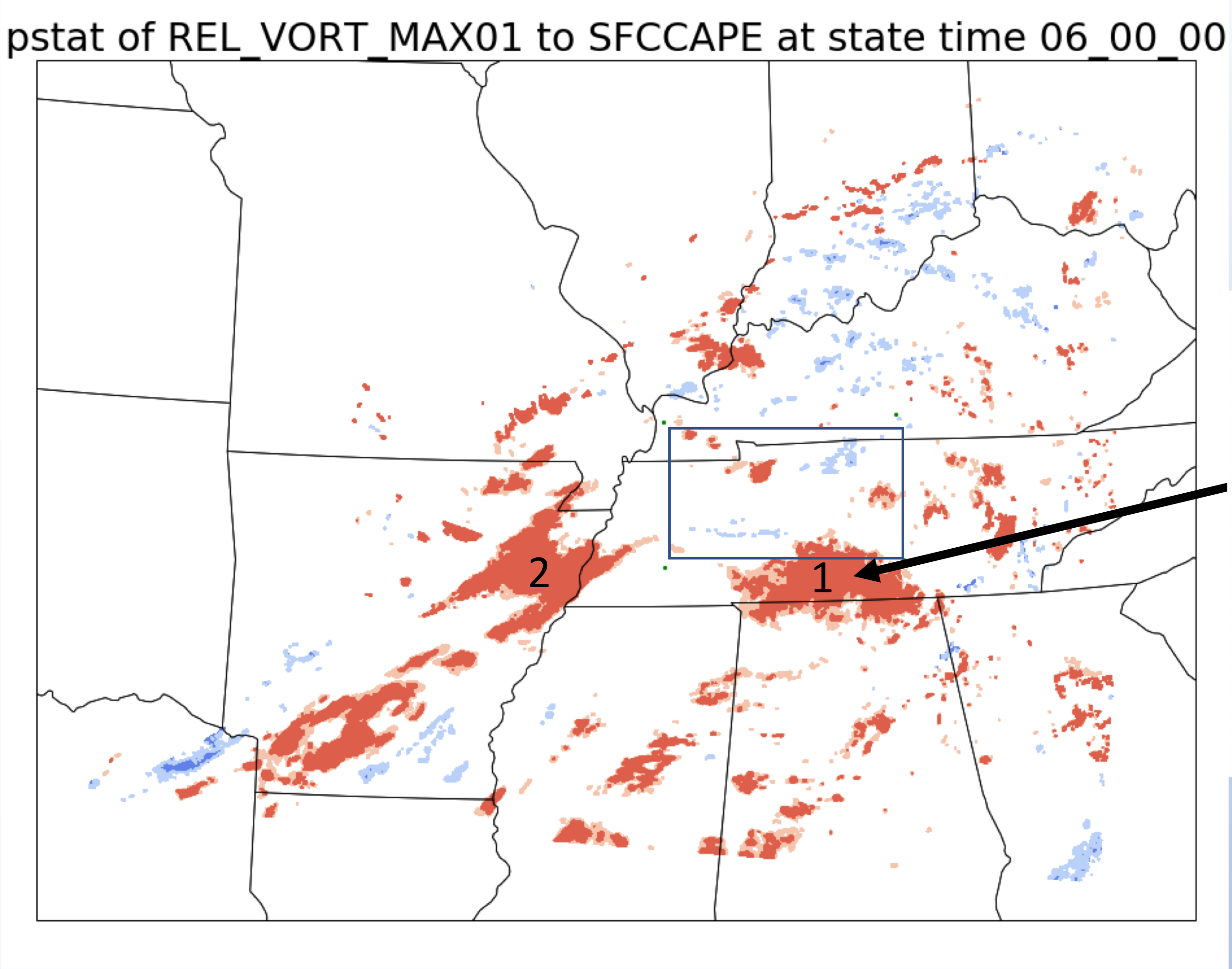
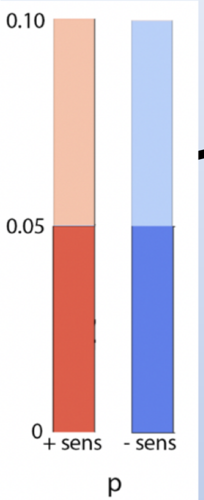
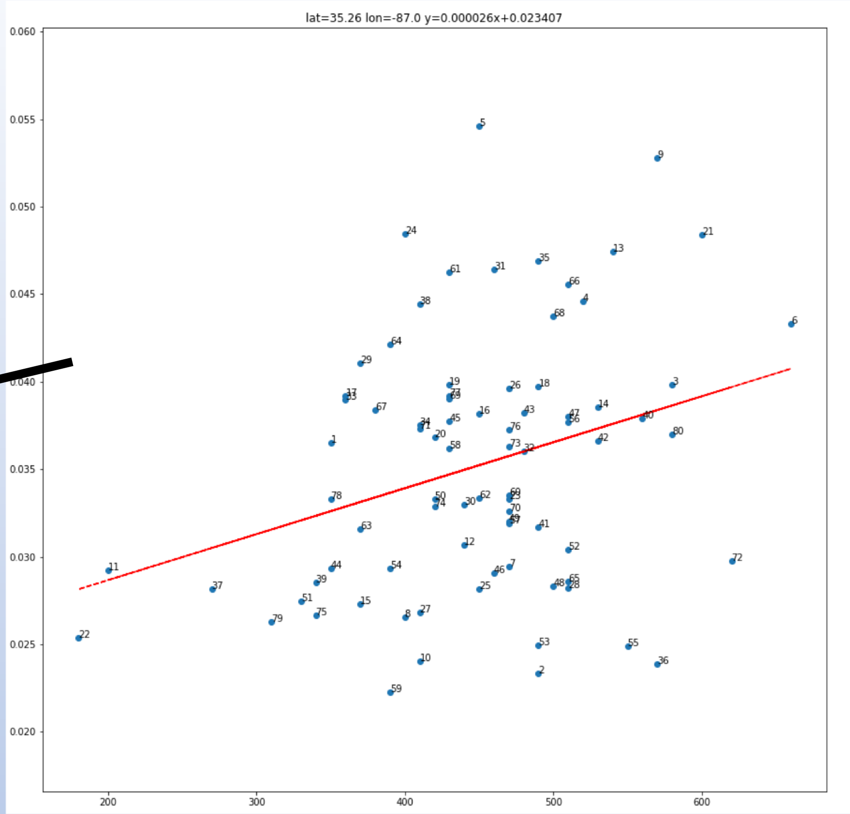


Bottom 9 Members, Response: Max 1-hr $\zeta_{0\text{-}1\ km}$ 0500-0600 UTC







$\zeta_{max,0\text{-}1\ km}$

SFCCAPE

p-statistic for $\zeta_{max,0\text{-}1\ km}$ (0700 UTC) and surface-based CAPE (0600 UTC)

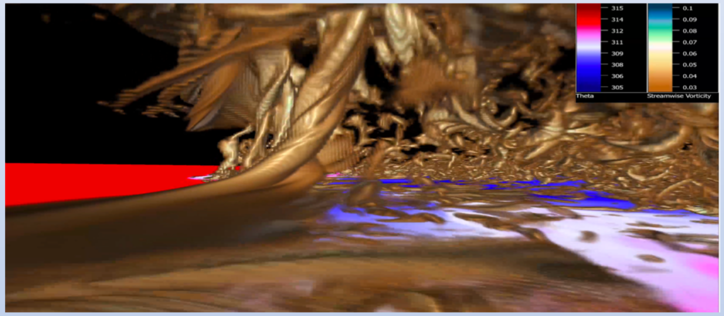
Two regimes:
1: (+) Inflow signal, strongest at 0600, but portions extend upstream into N MS/AL as far back as 0100.

2: (+) Signal in warm sector near front, related to front position and width/magnitude of CAPE axis ahead.

Scatter plot of 80 ensemble members showing relationship between surface-based CAPE (0600 UTC) and low-level vertical vorticity (0700 UTC) in a positively sensitive region (denoted by arrow).

Activities Relevant to CIWRO Theme 2

- Idealized Storm-scale Modeling



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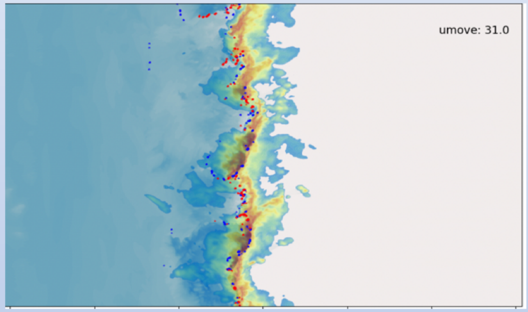

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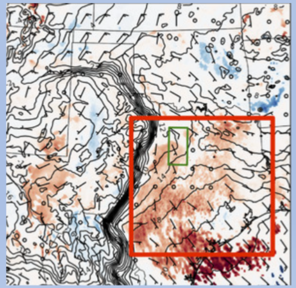
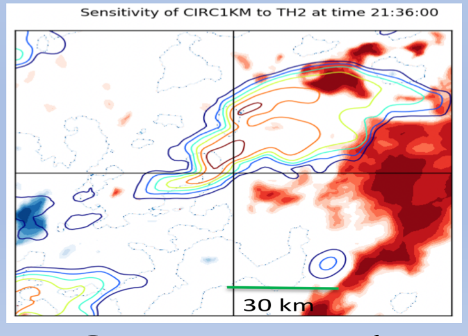
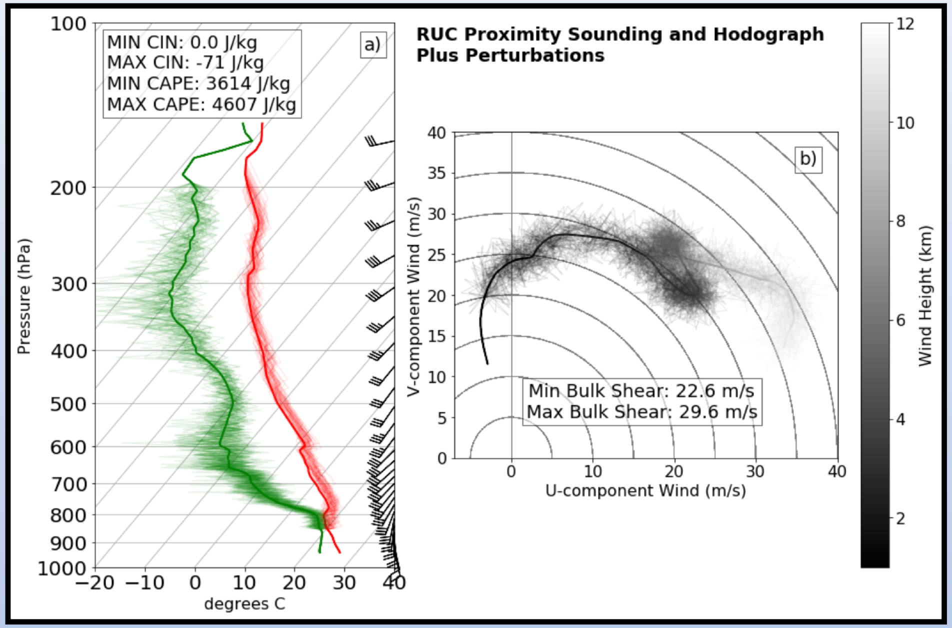


Mesoscale

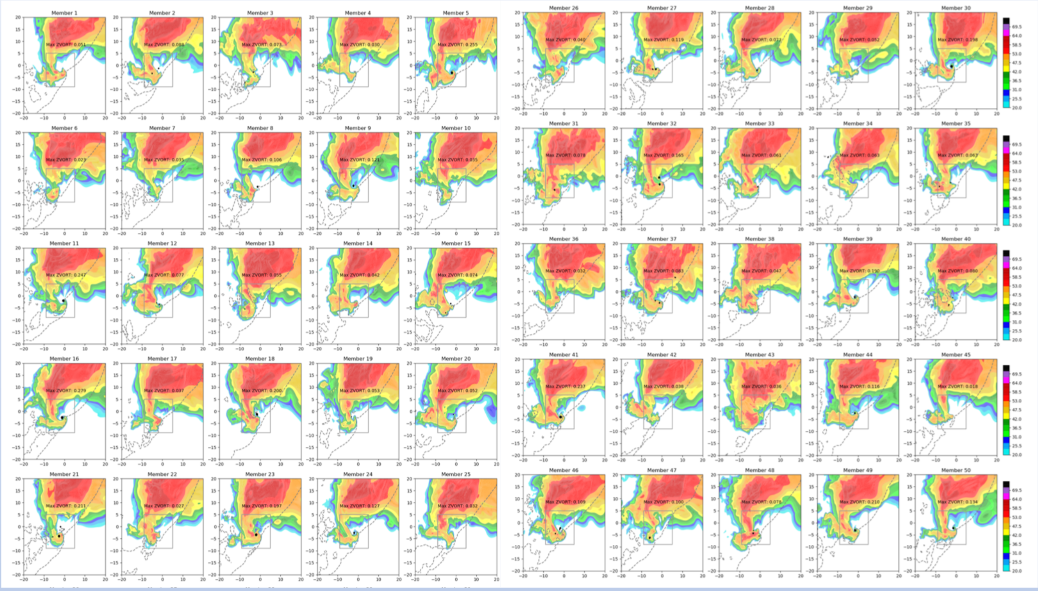


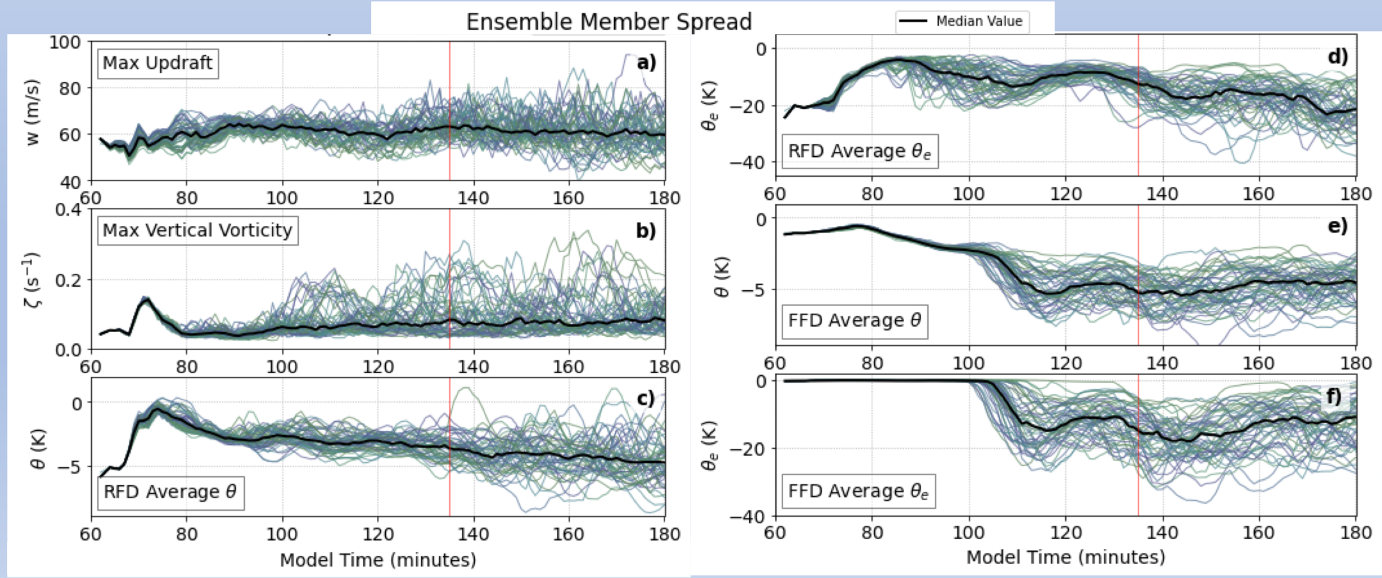
Storm-scale

Storm-scale ESA



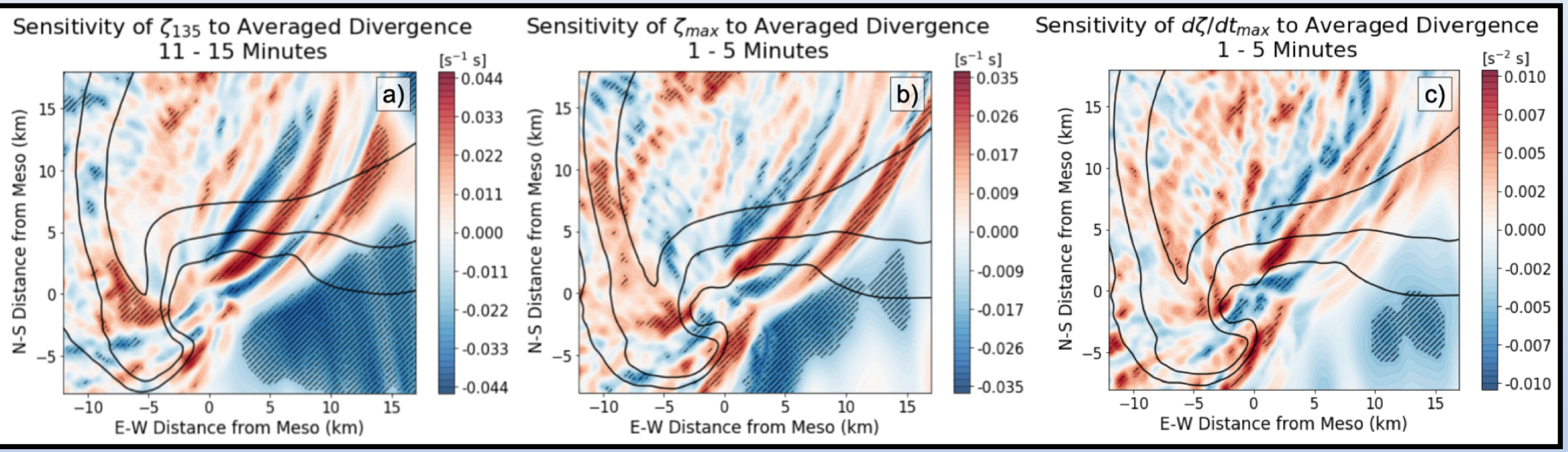
(Hutson and Weiss 2022, in prep)





- 50-member CM1 ensemble (250-m res)
- Gaussian errors added in T, RH, u and v aloft

Storm-scale ESA



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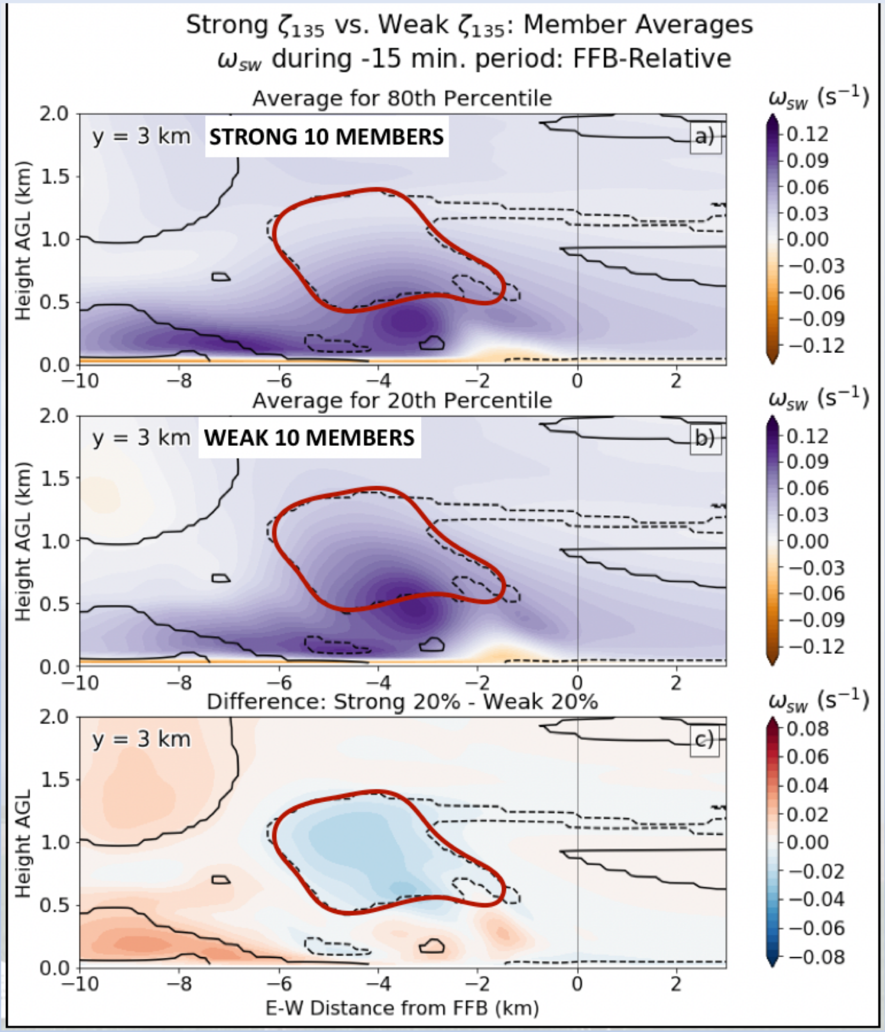

- All metrics of lowest level vertical vorticity (instantaneous value at specific integration time, max for integration period, maximum time rate of change) are sensitive to position of forward-flank boundary relative to the low-level mesocyclone.
- The altitude of streamwise vorticity near the FFB differs between ”strong” (i.e., more low-level vertical vorticity) and “weak” (i.e., less low-level vertical vorticity) members, stronger members featuring position closer to the surface.

Potential of ESA in WoFS

- ESA previously utilized at large scales to study atmospheric dynamics in hindsight
- Recently proven successful in a convective context
  - TLV formation in simulated supercells (Hutson and Weiss 2022, in prep)
  - Convective ensemble subsetting (Coleman and Ancell 2020)
- WoFS - unique opportunity to apply ESA in operational setting
  - Ensemble-derived probabilistic forecasts key to initiatives like TWIEP
  - Applicability of 36-member ensemble to uncover dynamical relationships
  - Ensemble subsetting: identify most skillful members, inexpensively improving forecast accuracy

(from Hutson 2021)

Going Forward:
Avenues of CIWRO Collaboration

- Activities that contribute to a Weather Ready Nation:
  - OAR Strategic Goal 3: Make forecasts and predictions better
  - OAR Strategic Goal 4: Drive innovative science
- Physical understanding derived from idealized modeling and ESA activities will benefit both goals
- ESA objectives, in particular, will inform the probabilistic hazard info produced as part of the Tornado Warning Improvement and Extension Program (TWIEP)
- Ultimately, we aim to help integrate ESA/subsetting methodology into operations (e.g., AWIPS) (more from Brian Ancell this afternoon)
- Interested in pursuing (high-risk, high-reward?) opportunities available in ESA-assisted storm-scale targeting