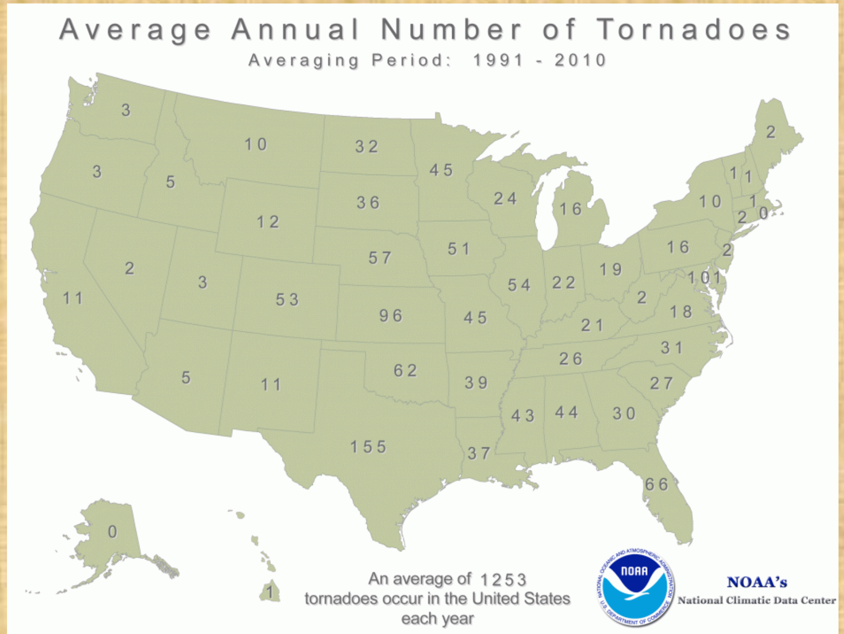
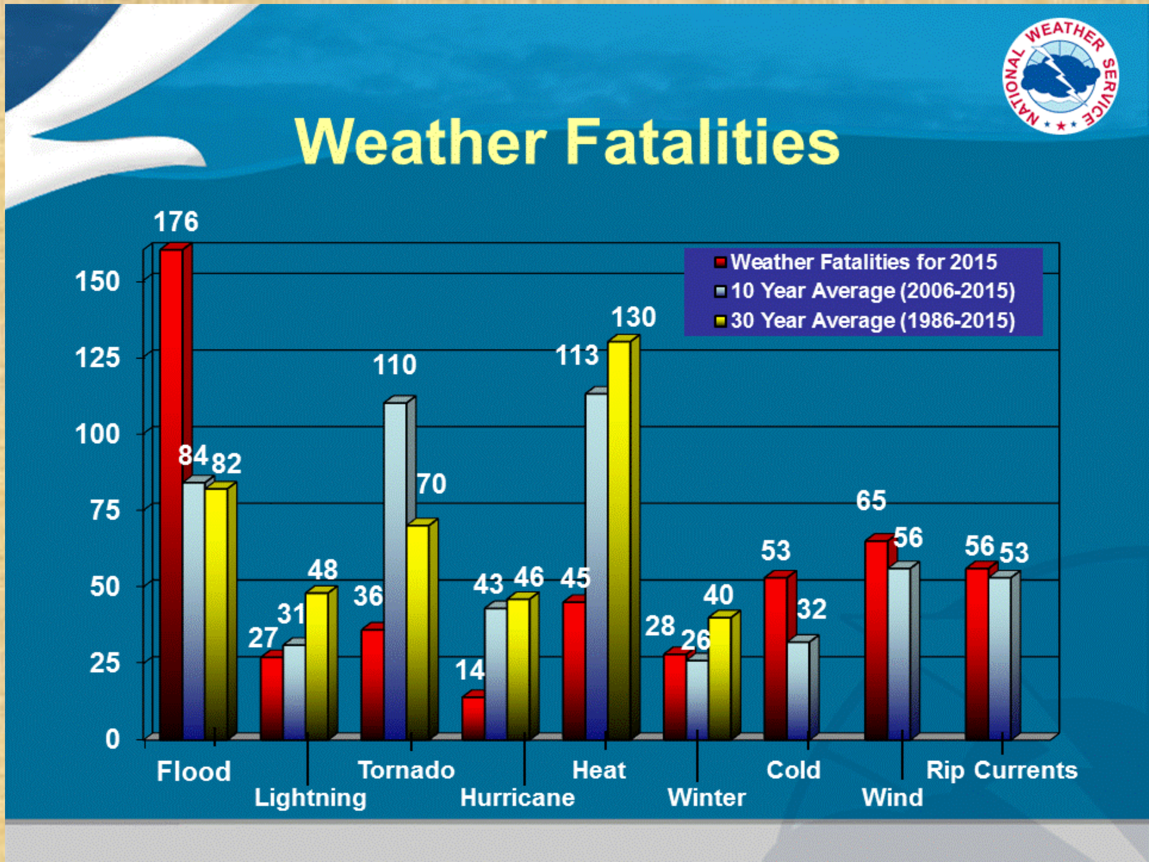
The Impacts of Hydrometeor Centrifuging on Tornado Dynamics

Ron Stenz

Why Study Tornadoes?

- Since 2011 three separate tornadoes each caused in excess of 2 billion dollars in damage
- ~1250 tornadoes per year
- ~70 fatalities from tornadoes per year





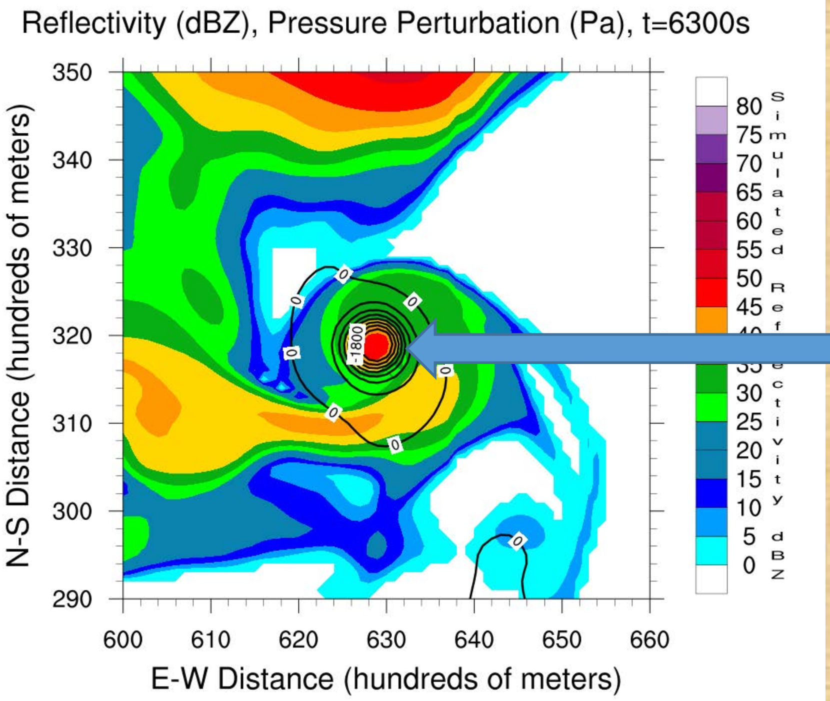
Introduction

- Numerical simulations are widely used to study supercells and tornadoes
- Cloud Model 1 (CM1) (Br
- Created by George Bryar
- Designed for idealized st
atmospheric phenomena
- Allows us to investigate
and determine environme
impacting their strength

Introduction

- Simulated tornadoes have an unrealistic buildup of precipitation in their centers

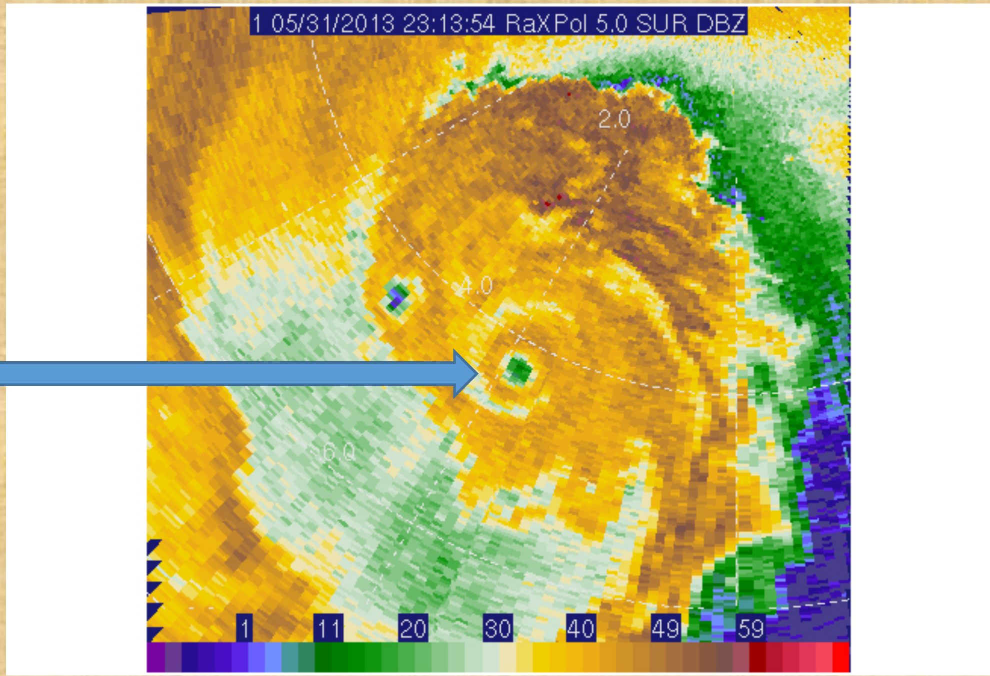
SIMULATED



Reflectivity Maximum (Left)

Reflectivity Minimum (Right)

OBSERVED



El Reno tornado reflectivity (OU Raxpol)

Past Observational Studies

- Dowell et al. 2005
- Observations of a tornado in Spencer SD, and an idealized 1D model
- Tornado core and immediate surroundings are associated with a minimum in reflectivity
- Maximum in tangential object speed occurs outside the maximum in tangential air motion

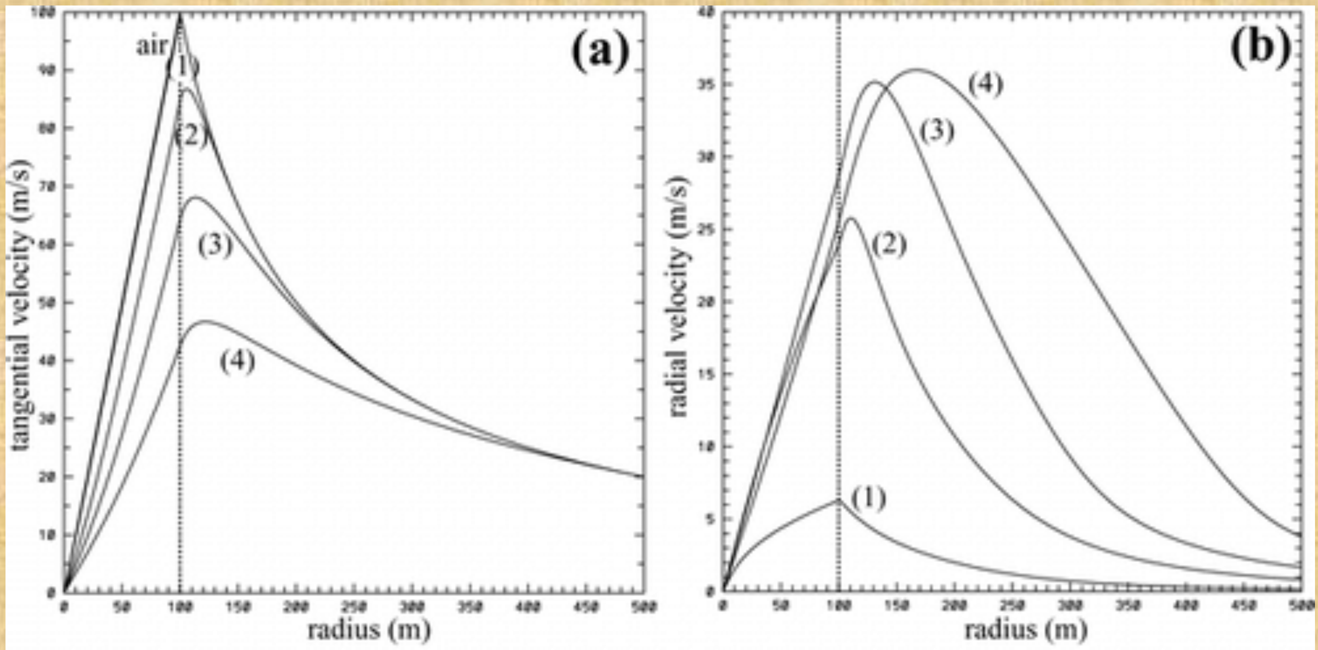


Fig. 3 Dowell et al. 2005

Why is Centrifuging Needed?

- Unrealistic buildup of precipitation in tornado center increases negative buoyancy of air

Tilting Term

$$\frac{d\zeta}{dt} = \omega_H \cdot \nabla_H w + \zeta \frac{\partial w}{\partial z}, \qquad (3)$$

Stretching Term

(Naylor and Gilmore 2014)

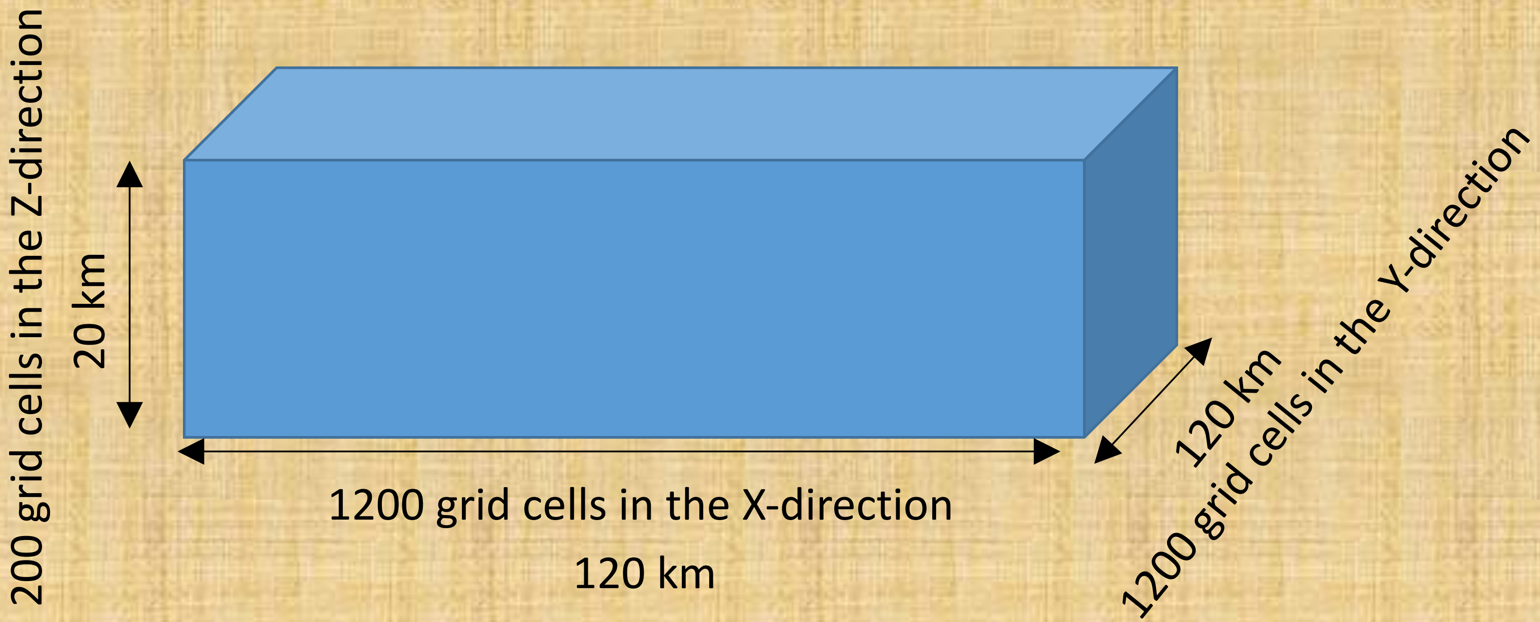
- What impact will this have on the simulated tornado?
- Hypothesis: Increase in stretching of vorticity with centrifuging, leading to stronger simulated tornadoes

Why Blue Waters?

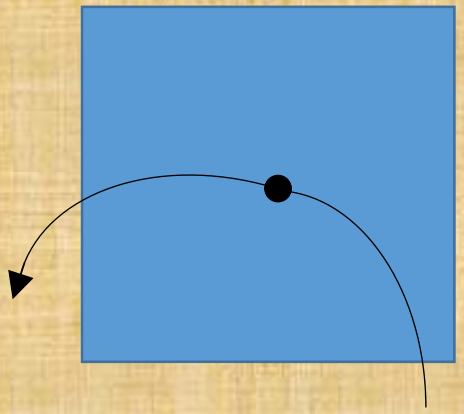
- Large computational demands
- Need for thousands of processors for each simulation
- Large output dataset
- Visualization support
- Blue Waters meets all of these research requirements

What Are the Computational Demands?

- Numerical simulation of a supercell that produces a tornado…
- Addition of centrifuging
  - Need to calculate curvature wherever there is precipitation
  - Must use trajectories at least every model time step



Calculate curvature for every grid cell with precipitation



Use centrifuging algorithm based on Gilmore et al. 2004 to calculate outward movement of precipitation

Why Blue Waters?

- 100m resolution simulation using 576 cores requires ~6-12 hours
- Large amount of output data
  - Data output for each timestep are ~10GB (Need frequent output for analysis)
  - Restart files are ~20GB
  - Project total… ~50-100TB
- Visualization Support
  - Coming Soon!

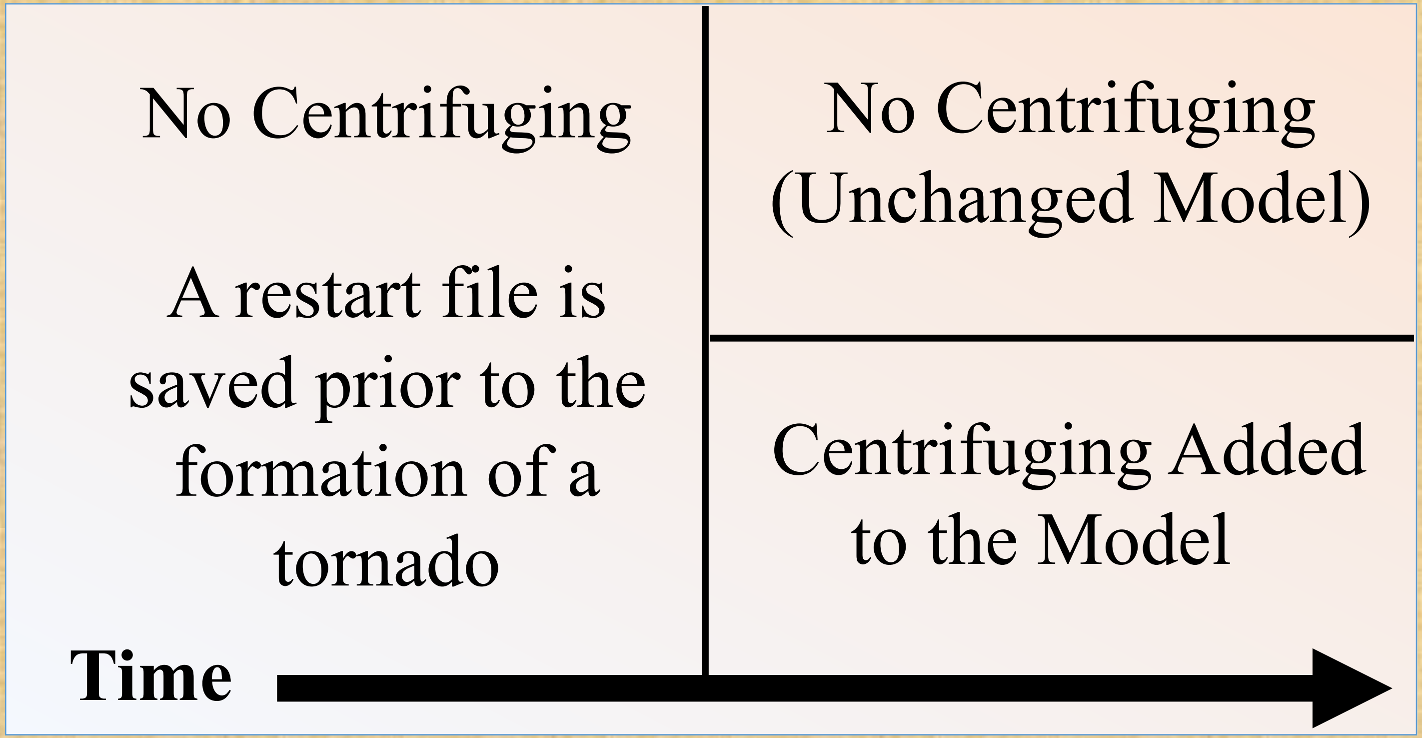
Experimental Design

- Convection is initiated in CM1 using w-forcing (Naylor and Gilmore 2012a)

$$w_{mag} = \begin{cases} w_{max} \cos^2\left(\frac{\pi}{2}\beta\right), & \text{if } 0 \le \beta \le 1 \\ 0, & \text{if } \beta > 1 \end{cases}$$

- Soundings used in CM1 come from an archive of real soundings taken in environments that produced supercell storms (Thompson et al. 2003)
- A subset of those soundings will be used for this study (soundings that have produced tornadoes in our past simulations on Stampede and Comet)

Experimental Design



- A "tornado" is defined by (Naylor and Gilmore 2012b)

(1) The pressure drop from the center of the vortex to the radius of maximum winds was - 4.5 hPa or less

(2) The horizontal wind speed at the radius of maximum winds was at least 30 m/s, and

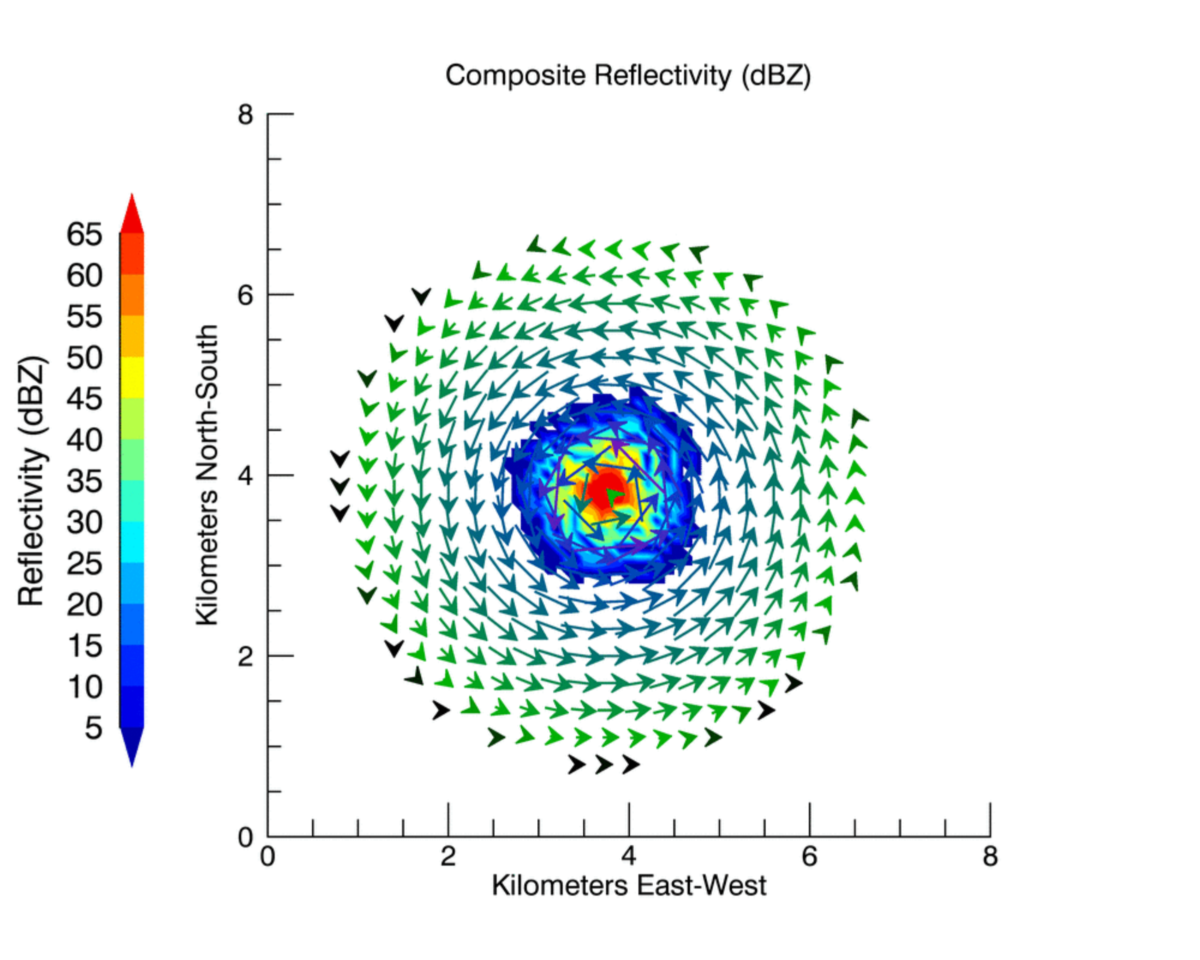
(3) Vertical vorticity in the center of the vortex was at least 0.1 s-1

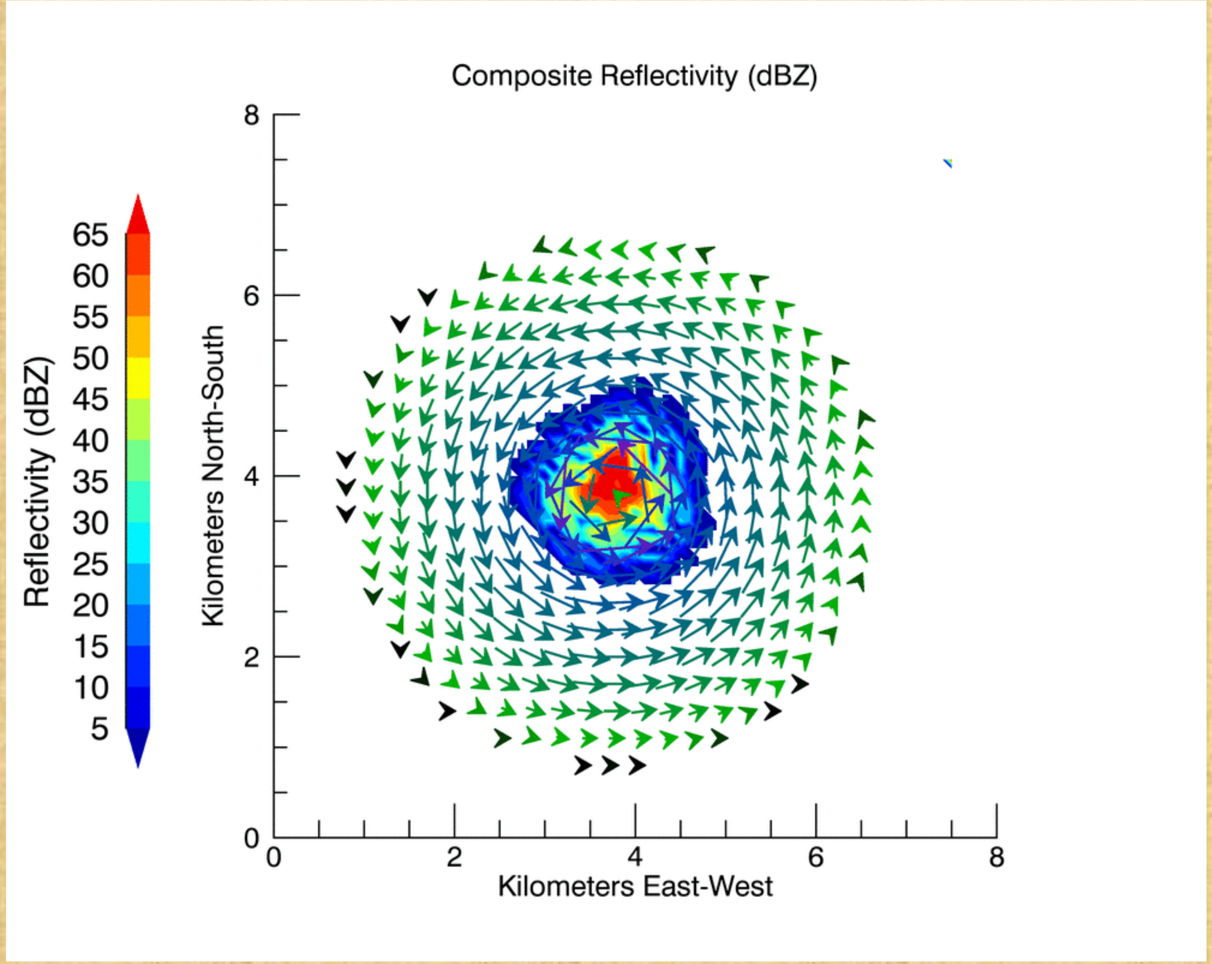
Idealized Vortex vs Supercell-Spawned Simulated Tornado

- Idealized Vortex
  - Rankine vortex
  - Can be run on 1 node (even 1 core)
  - Easy to control, sensitivity testing
- Supercell-Spawned Simulated Tornadoes
  - Hundreds to thousands of processors
  - More physically realistic
  - Gives insight into the processes within a tornado

Preliminary Results (Ideal Vortex)

Tornado Strength Vortex (55 m/s Maximum Winds)





Preliminary Results (Ideal Vortex)

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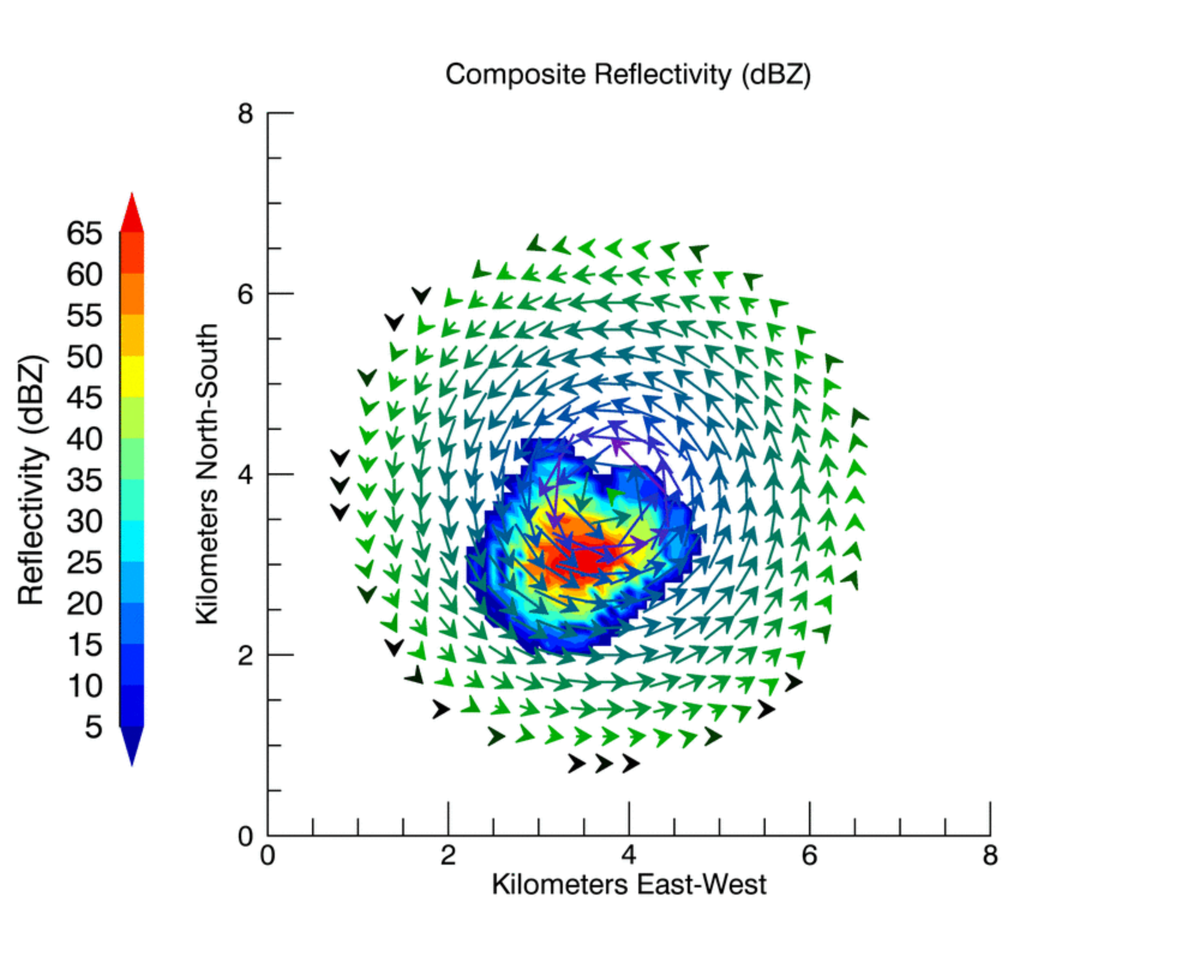
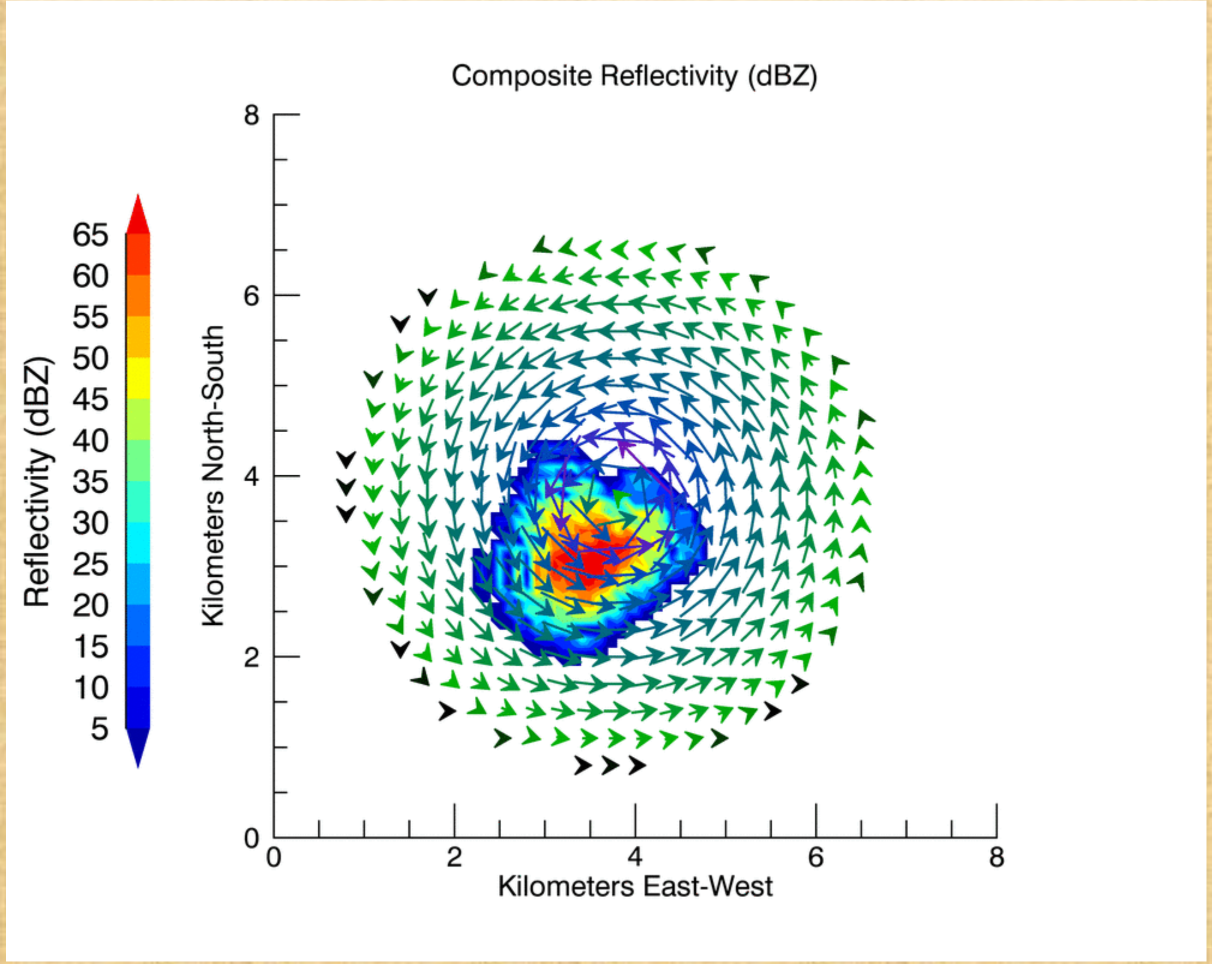
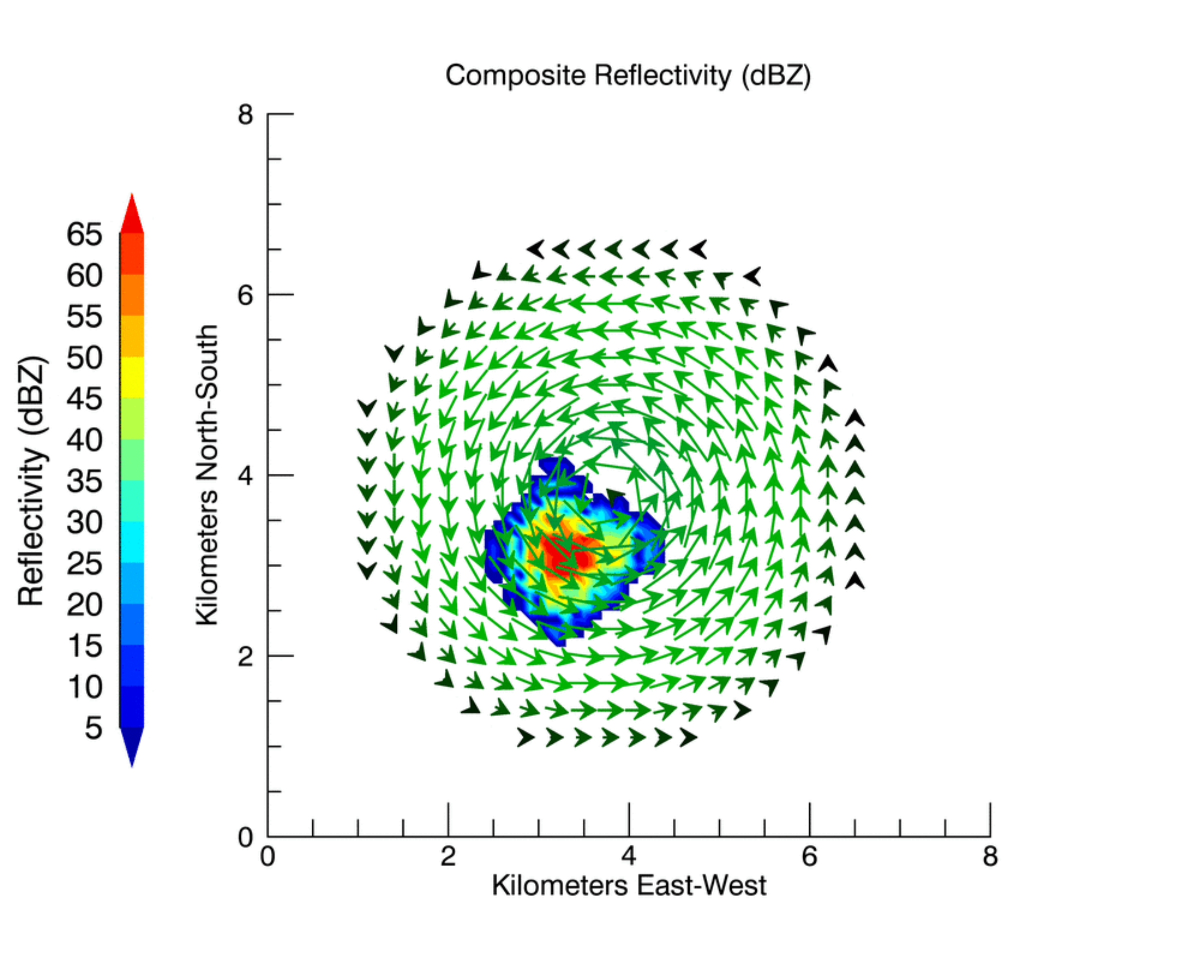
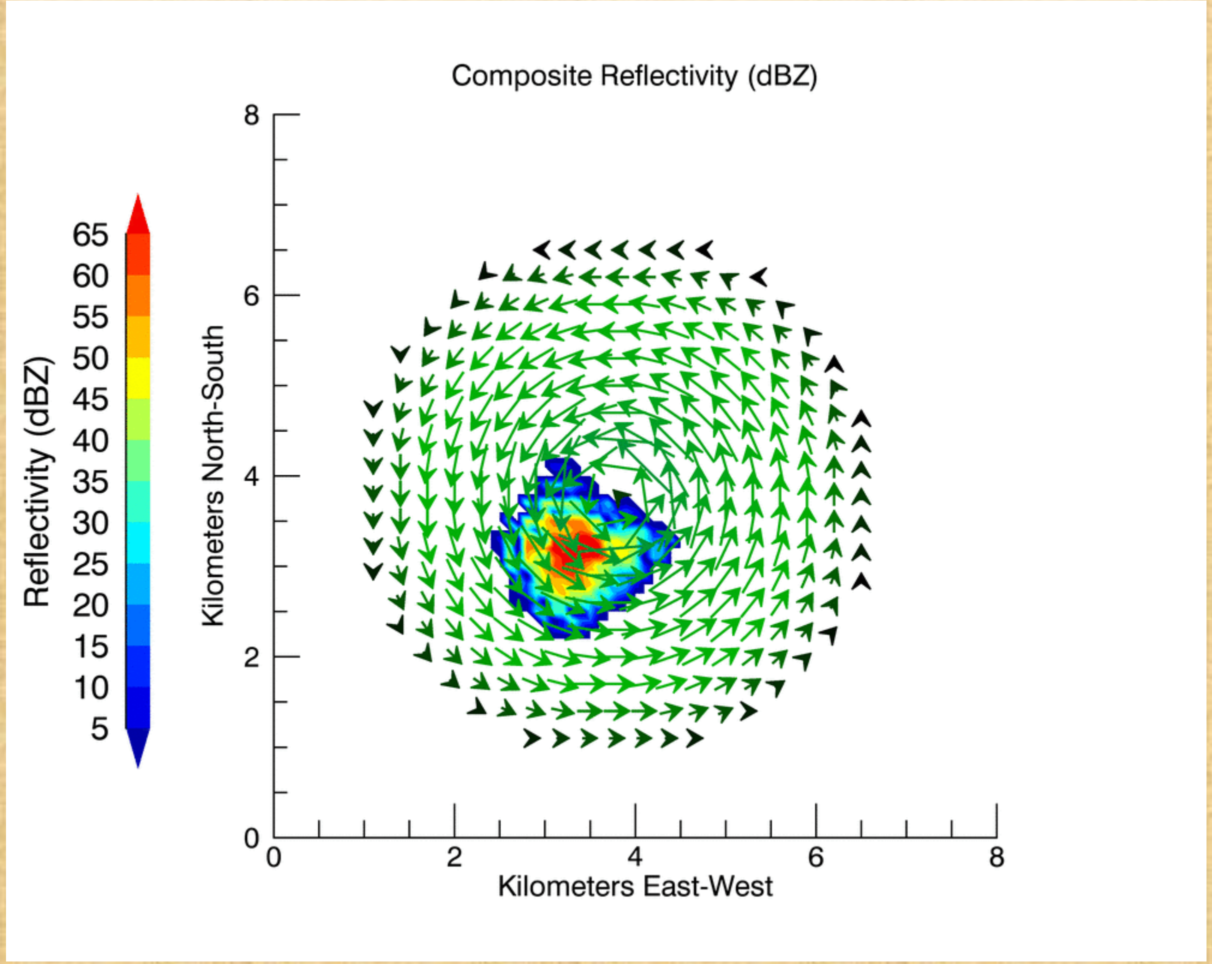




Preliminary Results (Ideal Vortex)

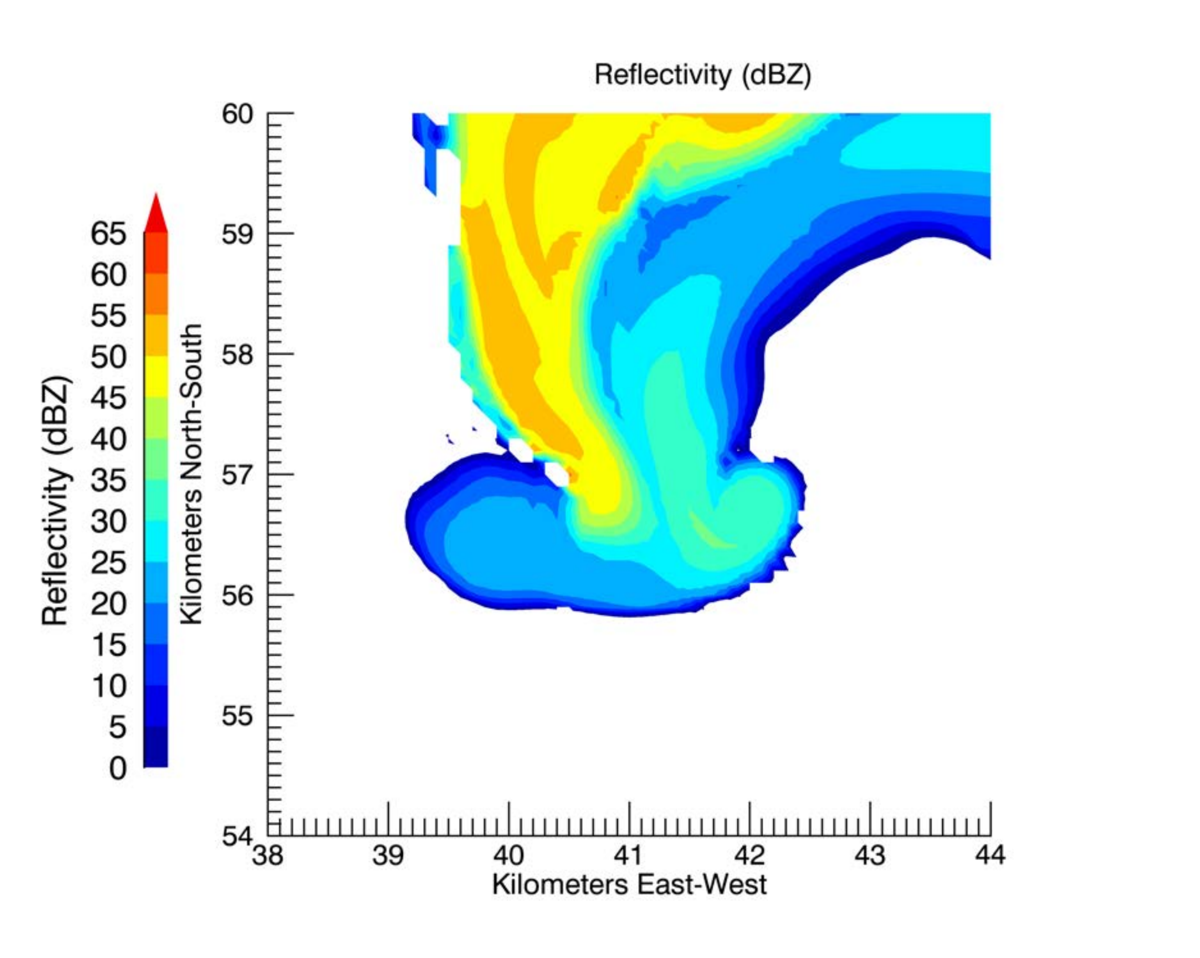
Weak Vortex (20 m/s Maximum Winds)

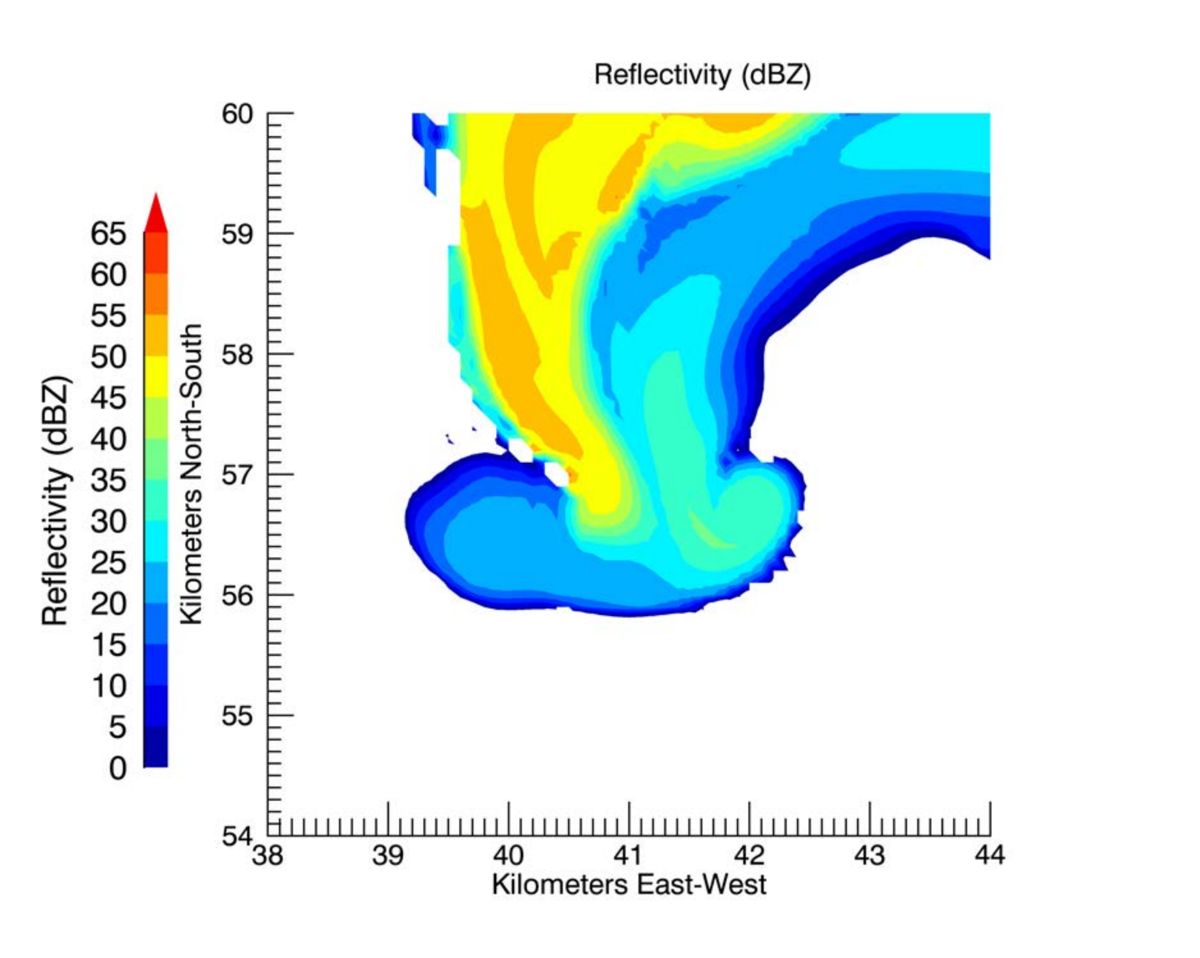




Preliminary Results (Full Simulation)

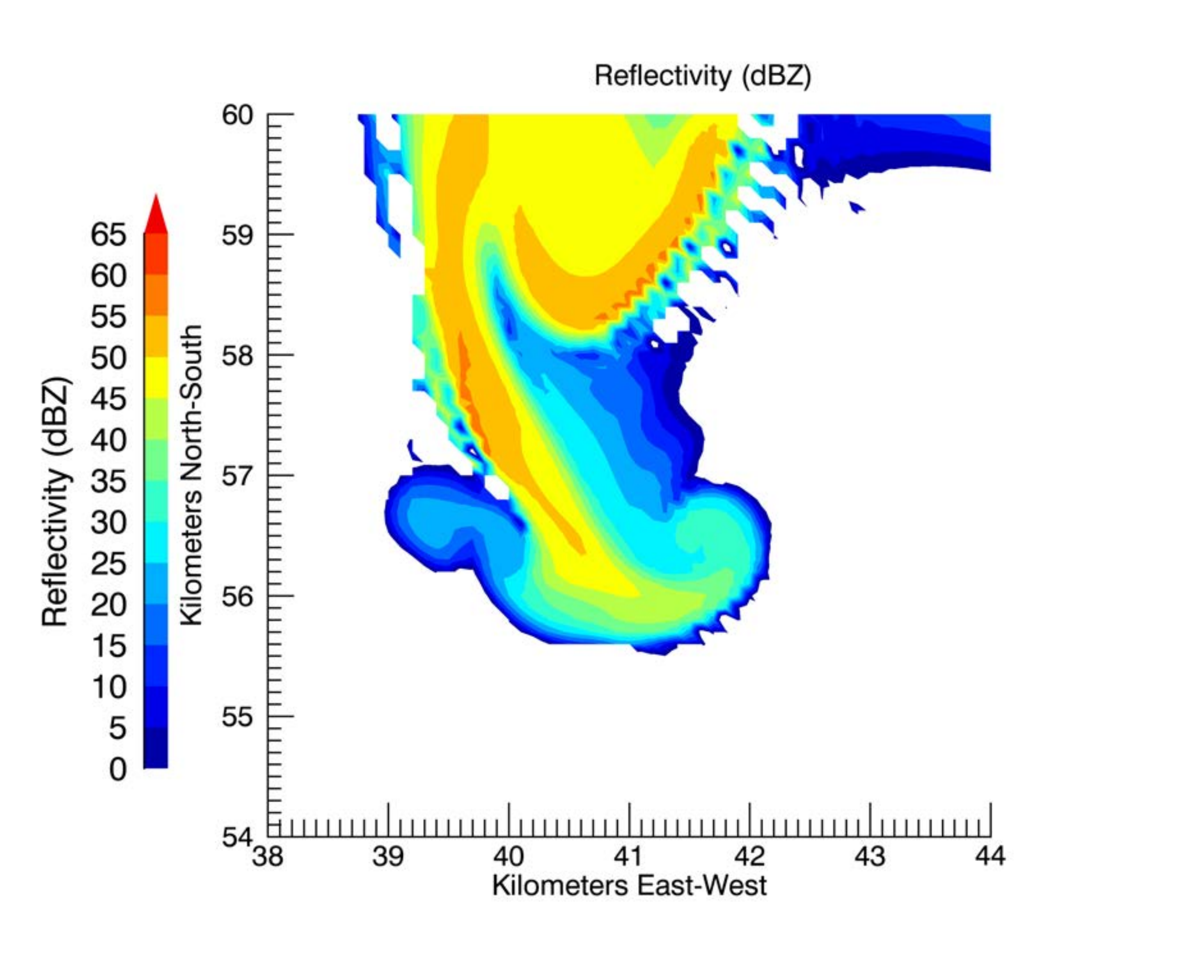
Time = 6000s

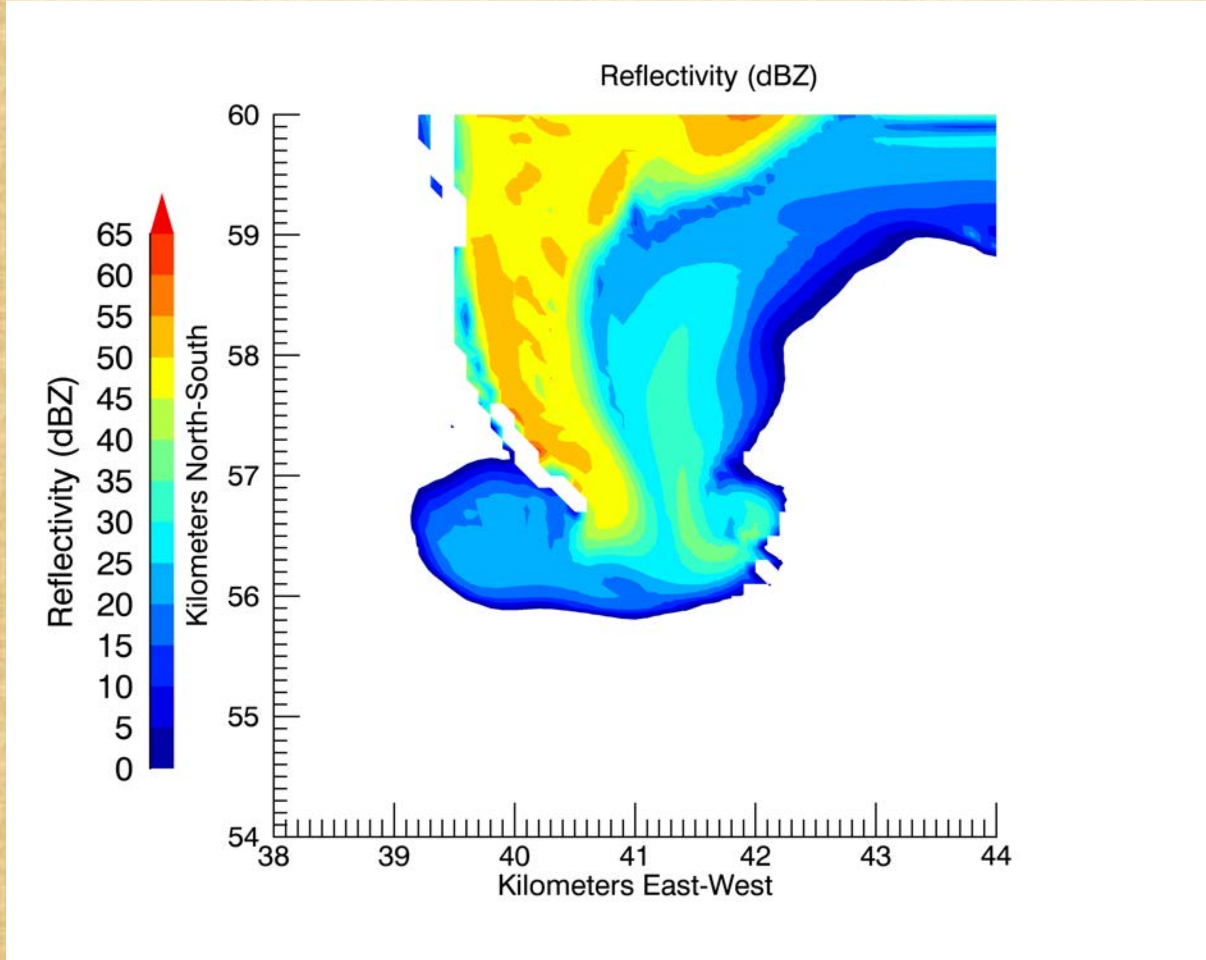




Preliminary Results (Full Simulation)

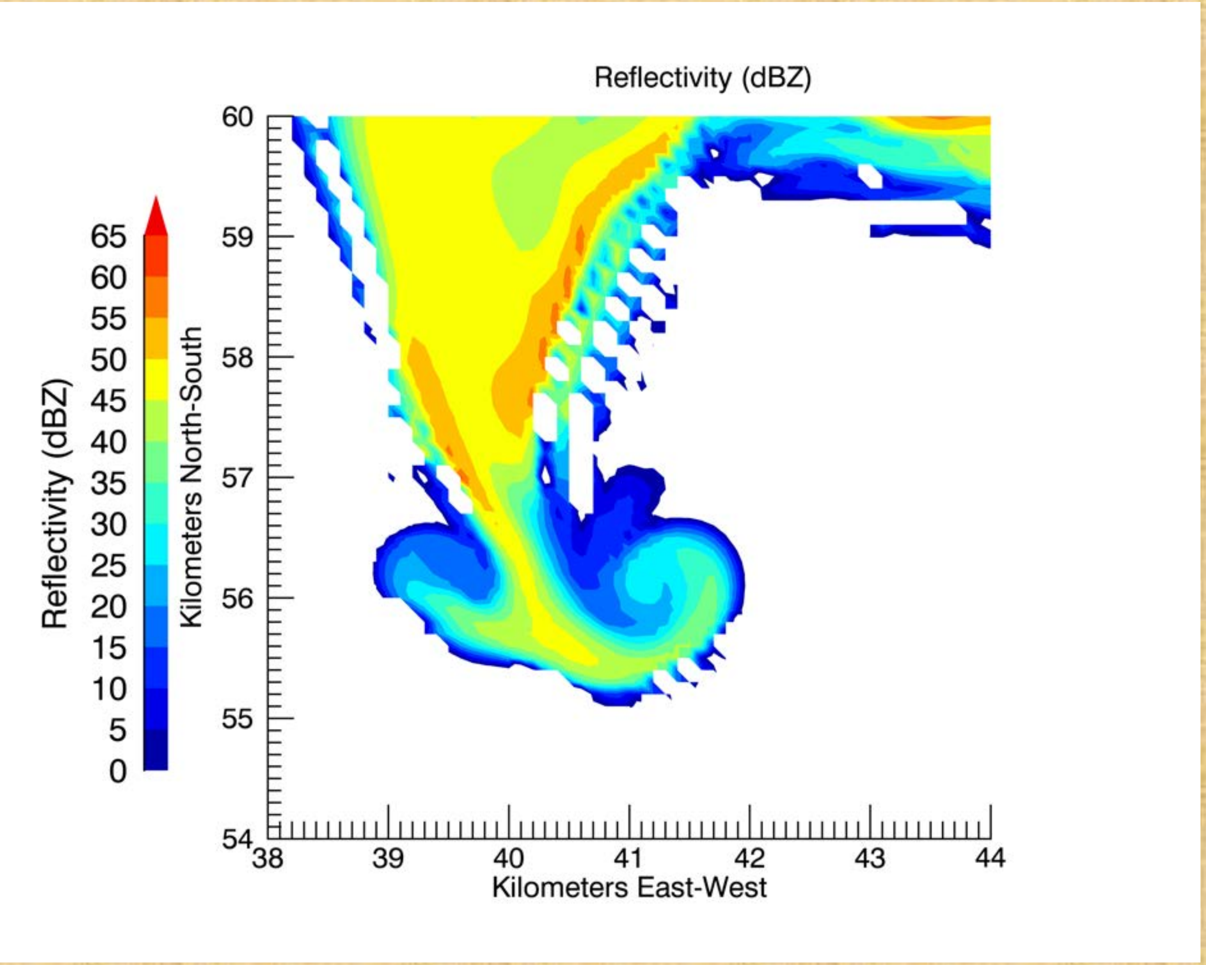
Time = 6100s

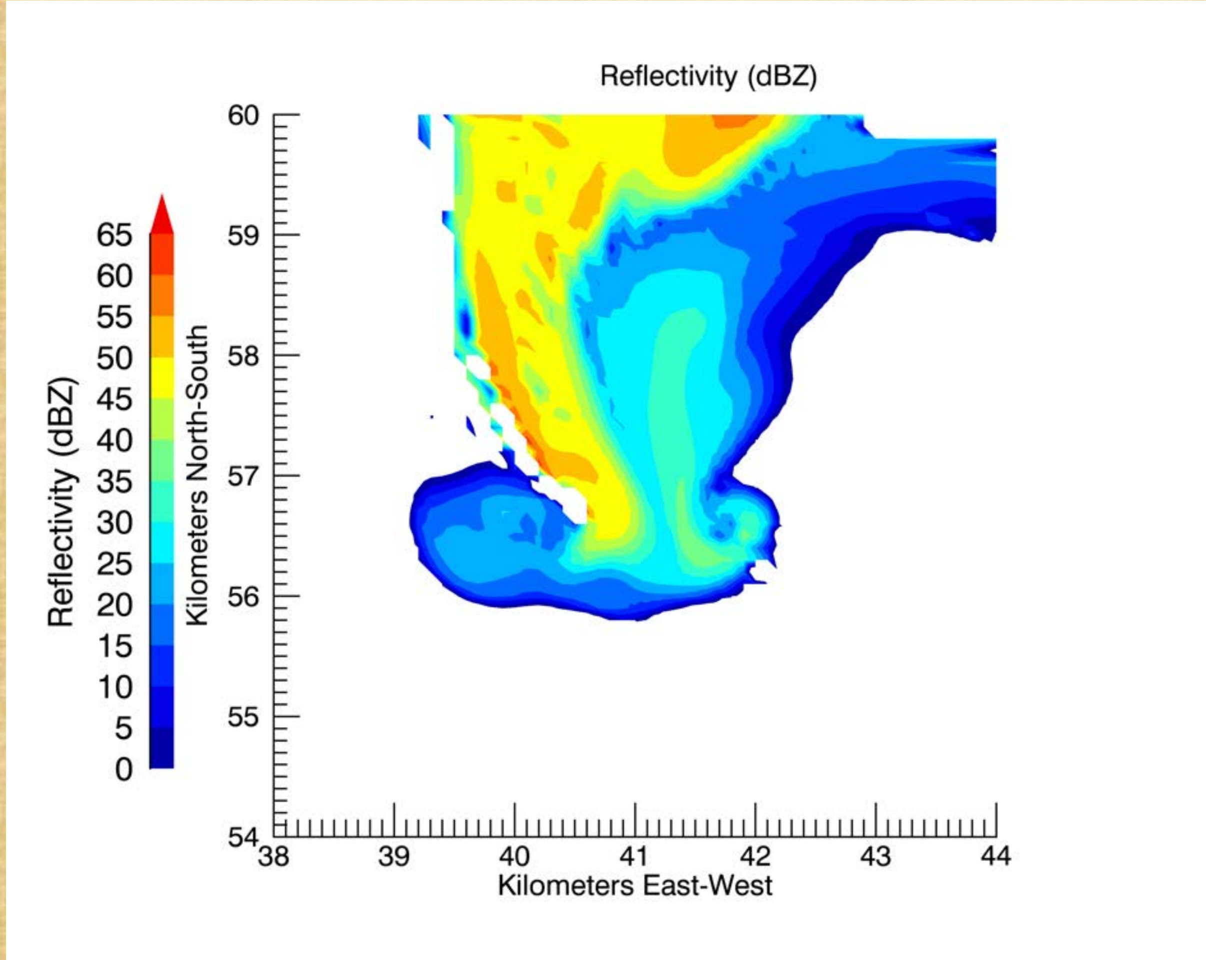




Preliminary Results (Full Simulation)

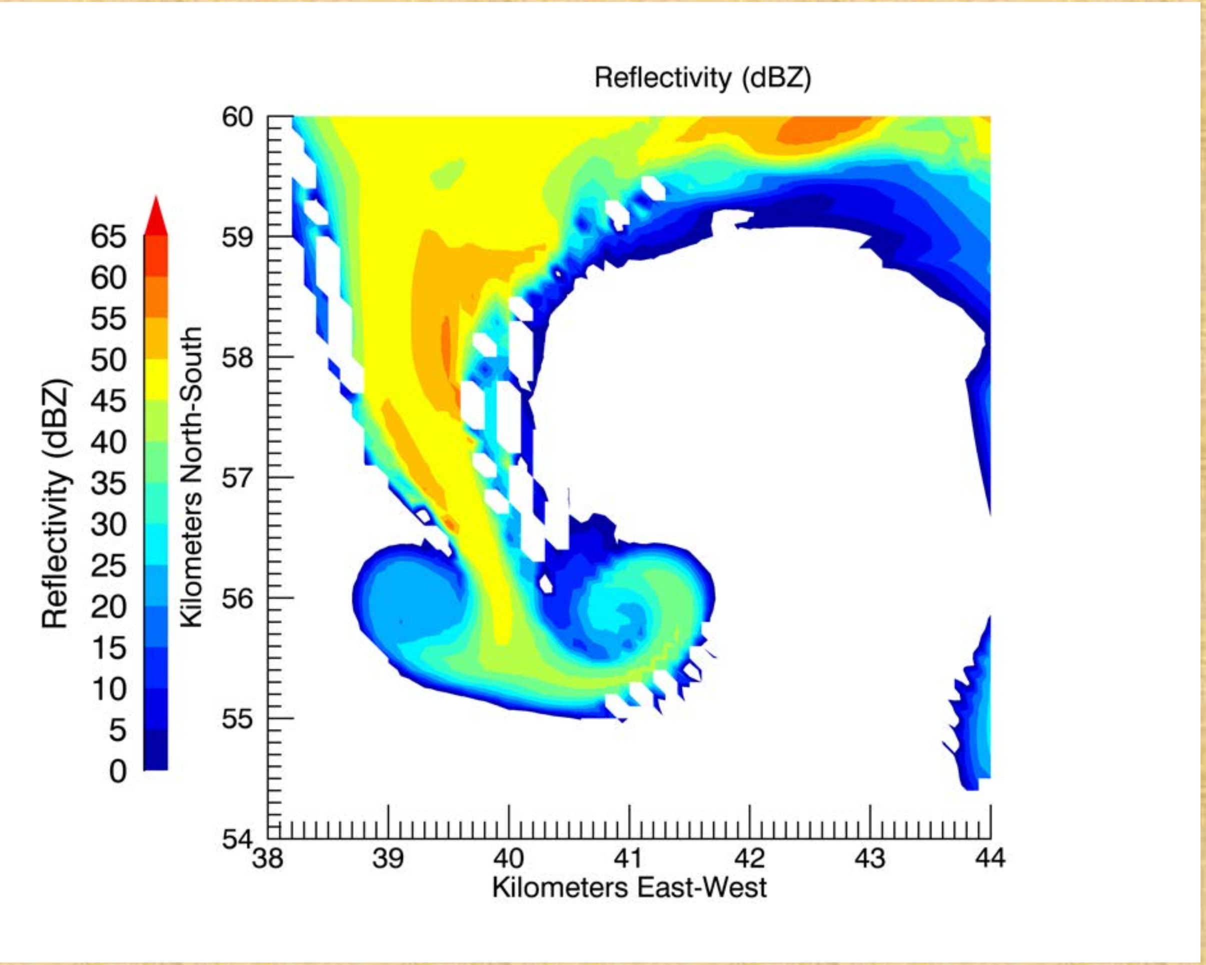
Time = 6200s

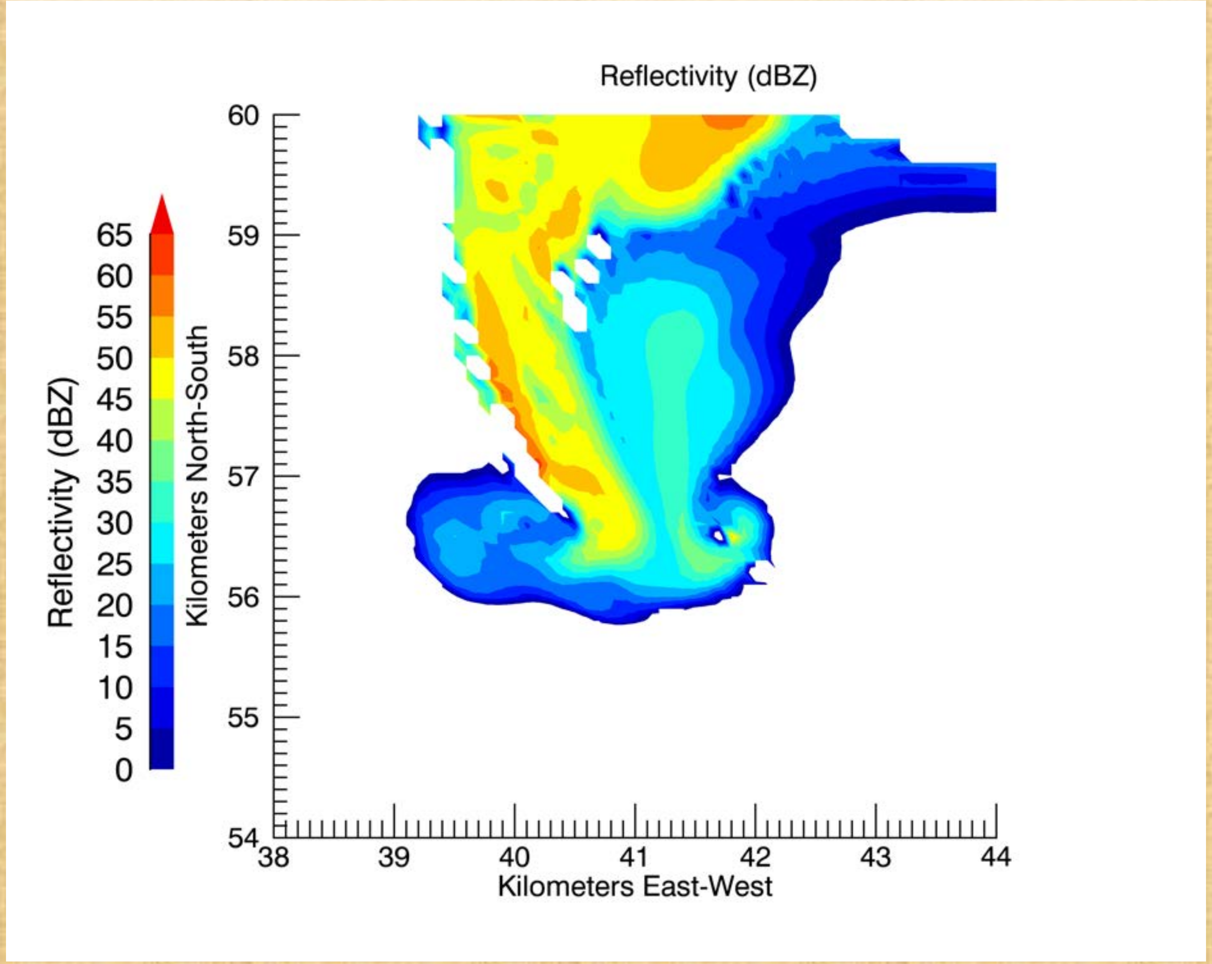




Preliminary Results (Full Simulation)

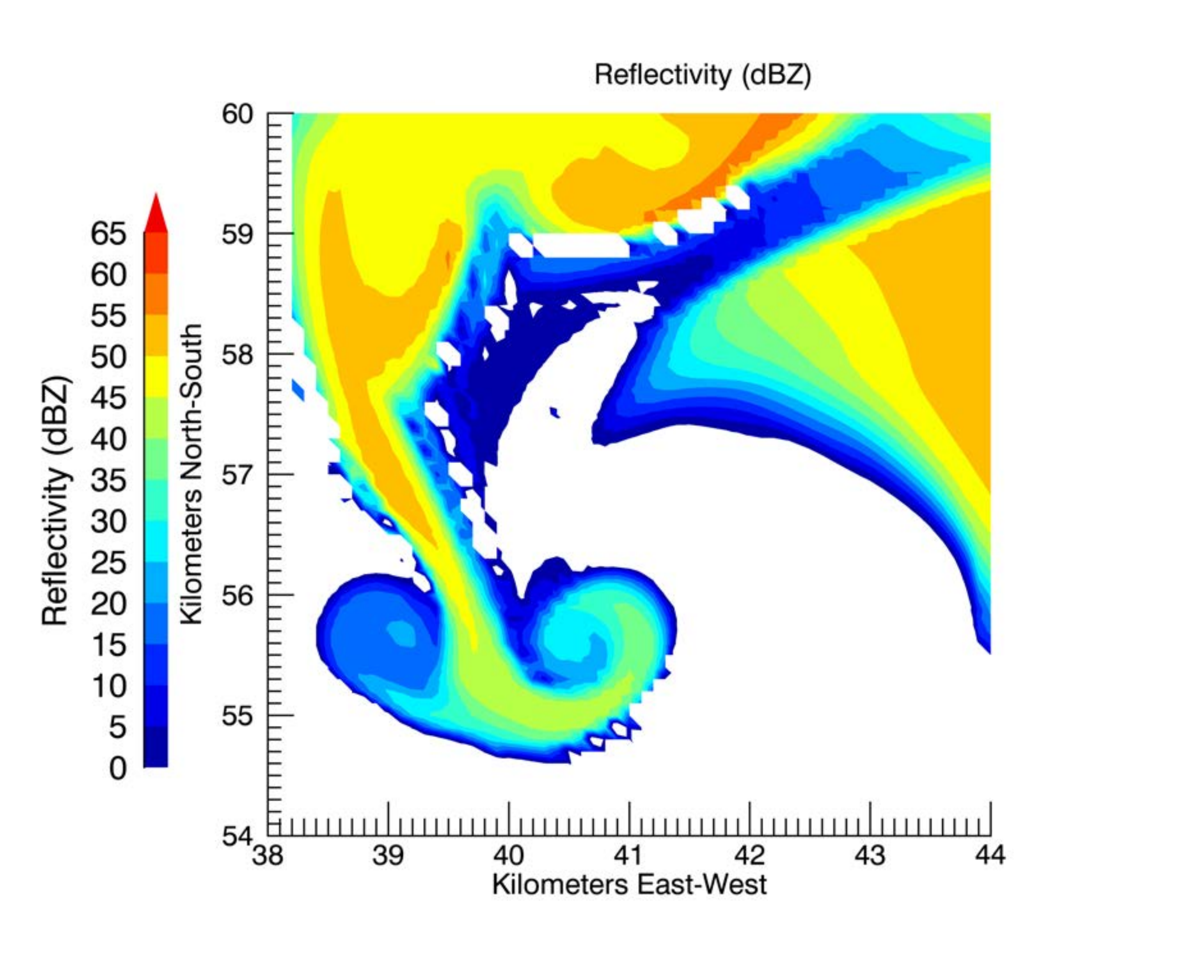
Time = 6300s

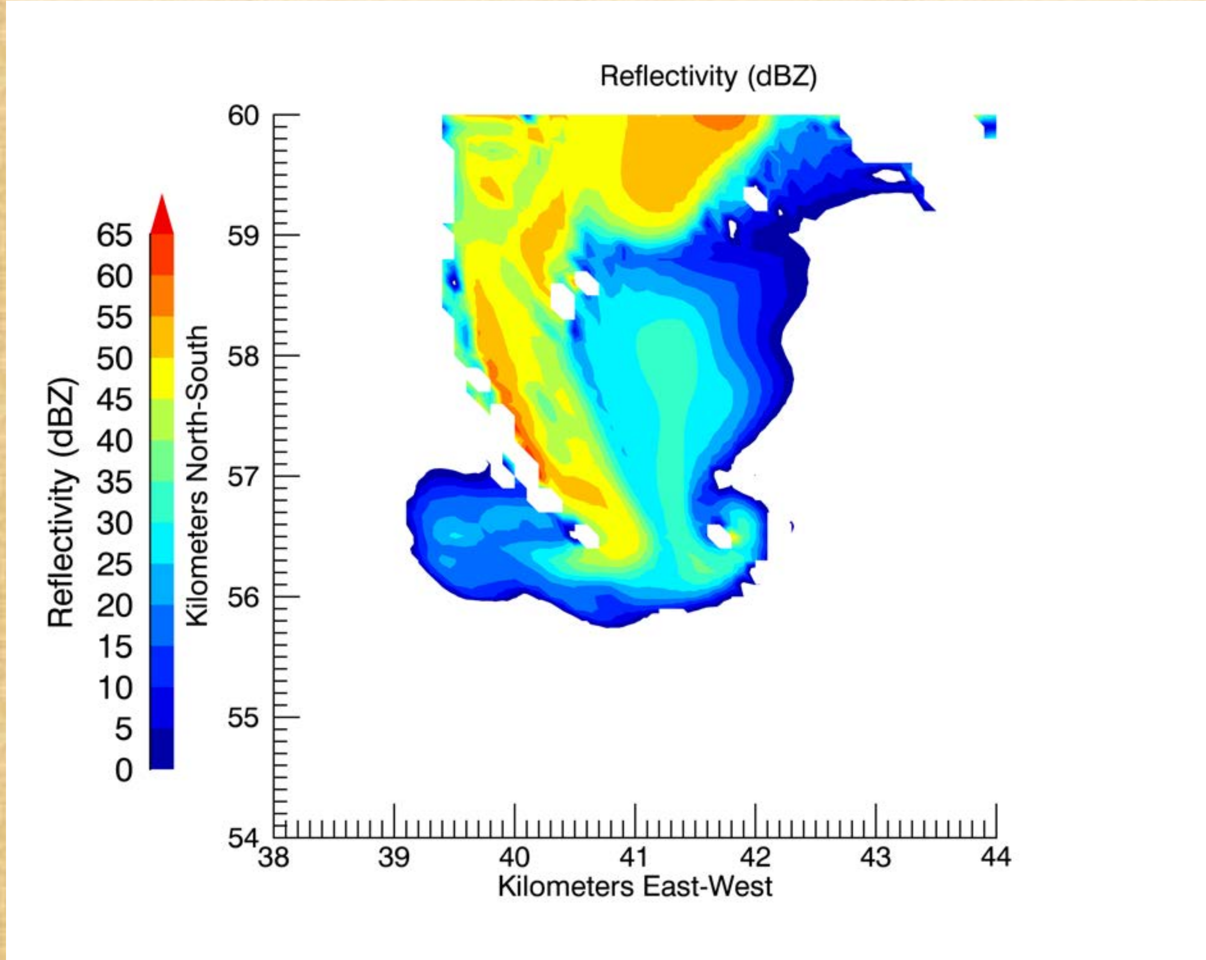




Preliminary Results (Full Simulation)

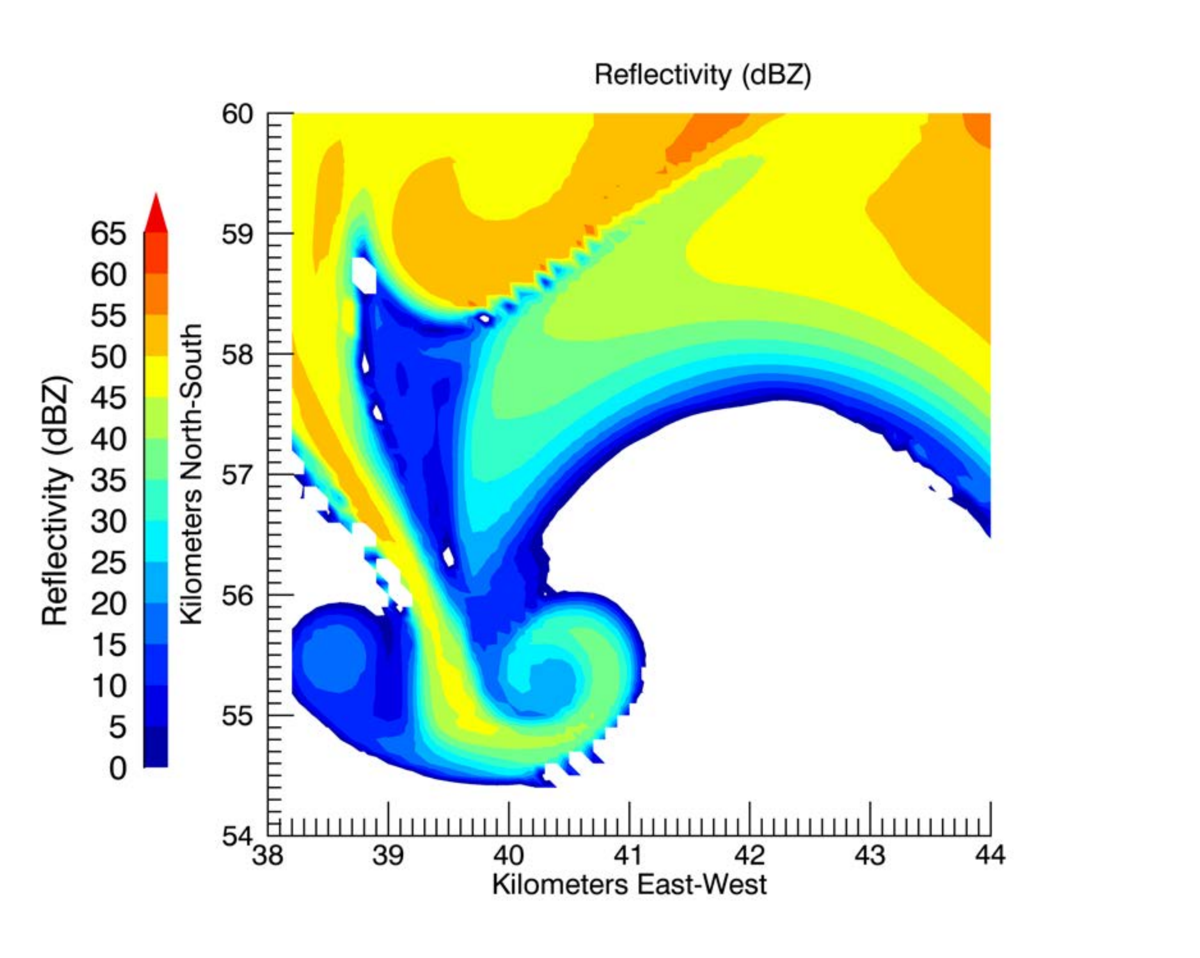
Time = 6400s

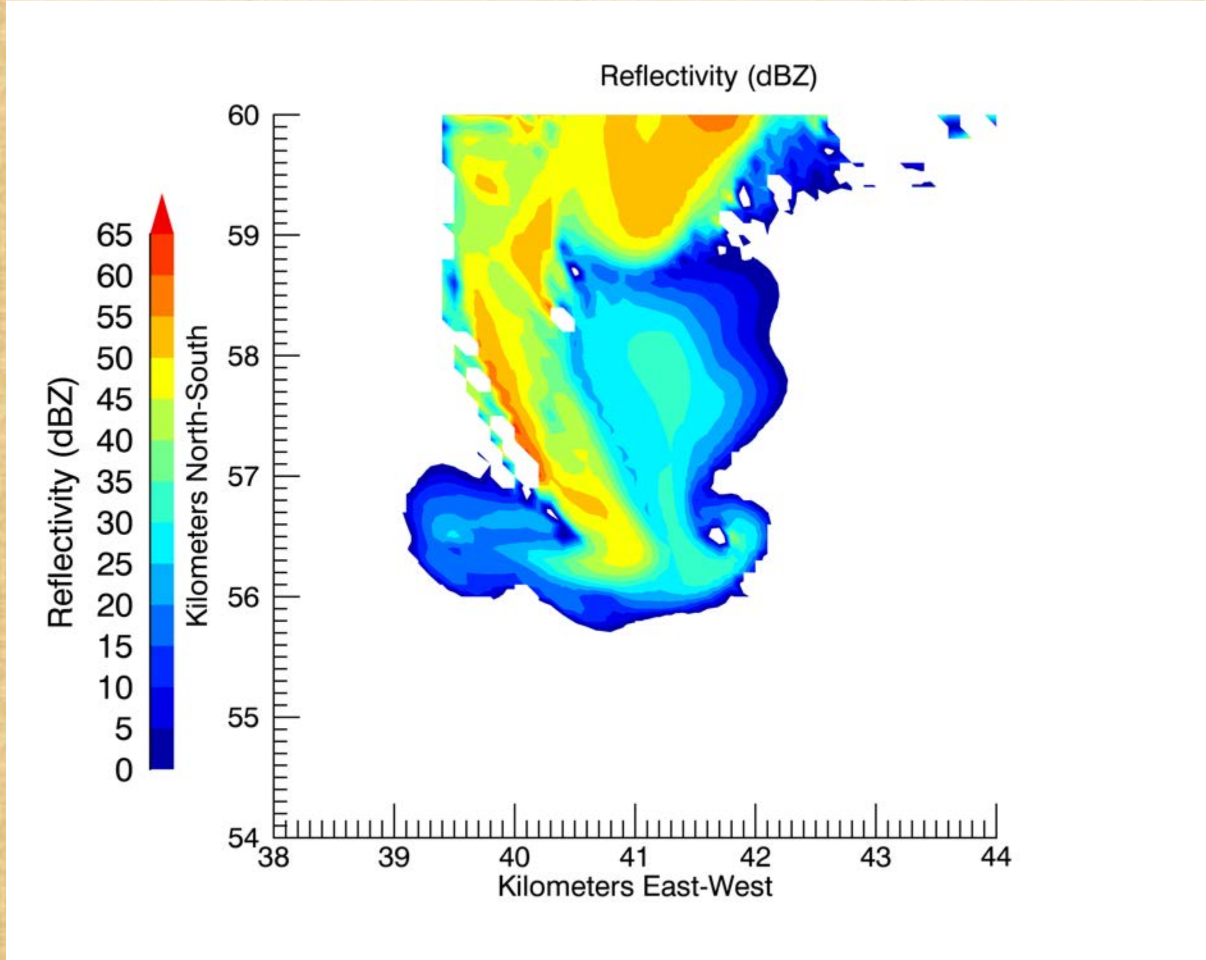




Preliminary Results (Full Simulation)

Time = 6500s

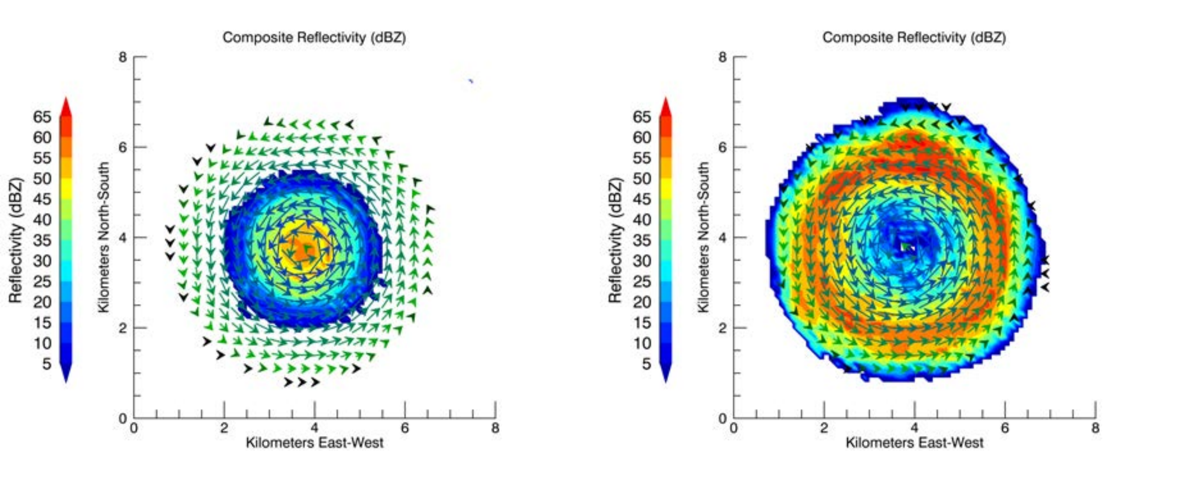




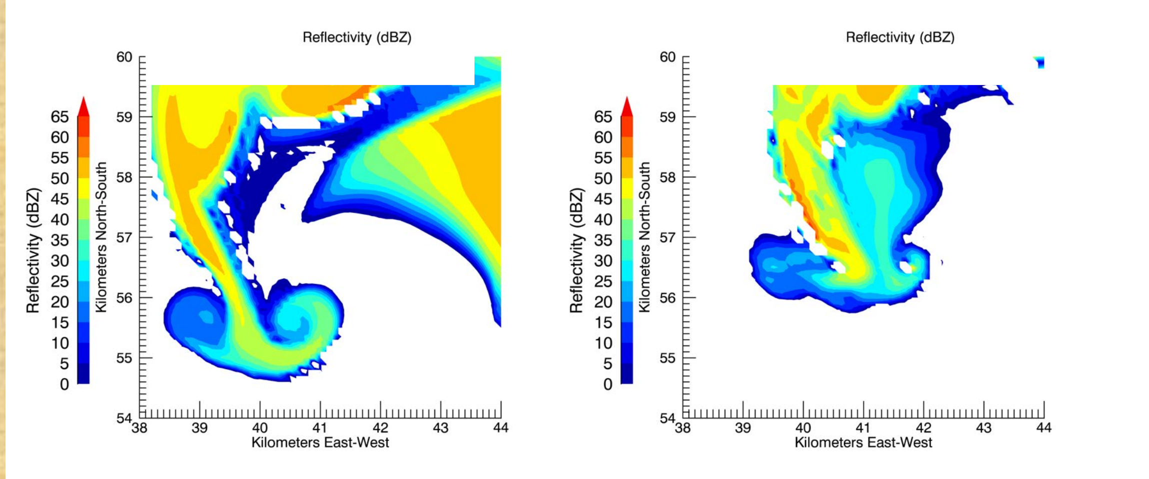
Summary of Findings So Far

- Removal of unrealistic buildup of precipitation in both idealized vortices and a supercell-spawned simulated tornado
- Only several minutes are needed to remove precipitation from the vortex center
- Centrifuging appears significant for weaker vortices and curvature values less than those found in tornadoes

Idealized Vortex

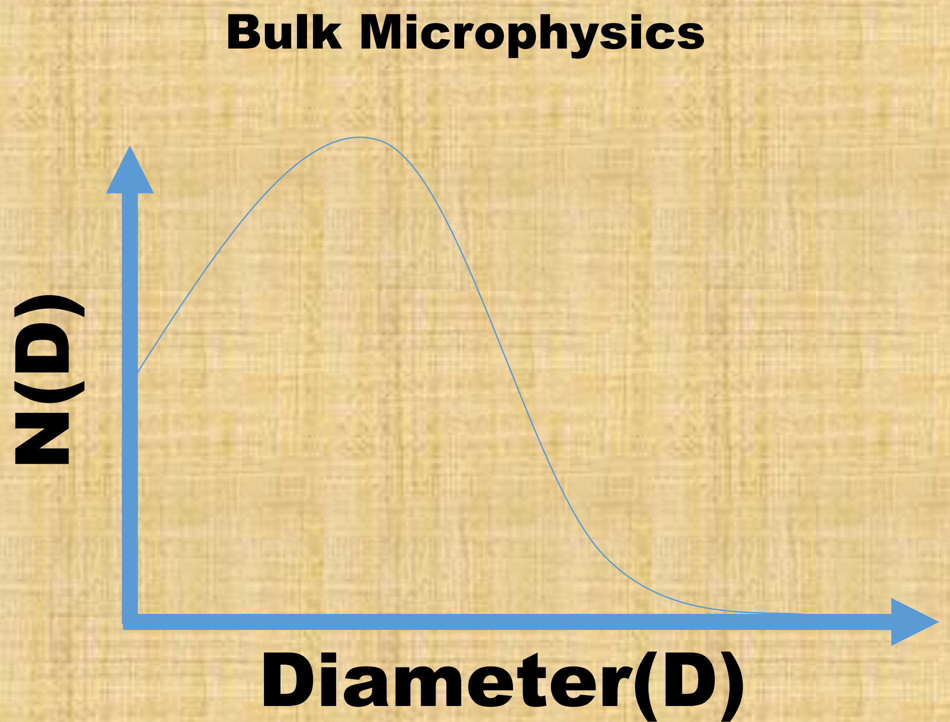


Supercell-Spawned Simulated Tornado



Remaining Challenges

- Address problem with mixing ratios getting too large
- Explore more sophisticated centrifuging parameterizations
  - Try hybrid bulk-bin?



Broader Impact

- More realistic tornado simulations
- Improved forecasting of tornadoes?

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Questions?

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