Observations from VORTEX2: The pretornadic phase of the Goshen County, Wyoming, supercell (5 June 2009)

Paul Markowski, Yvette Richardson, & Jim Marquis
Pennsylvania State University

Bob Davies-Jones
Emeritus, NOAA NSSL

Erik Rasmussen
Rasmussen Systems

David Dowell
NOAA ESRL

Josh Wurman, Karen Kosiba, & Paul Robinson
Center for Severe Weather Research

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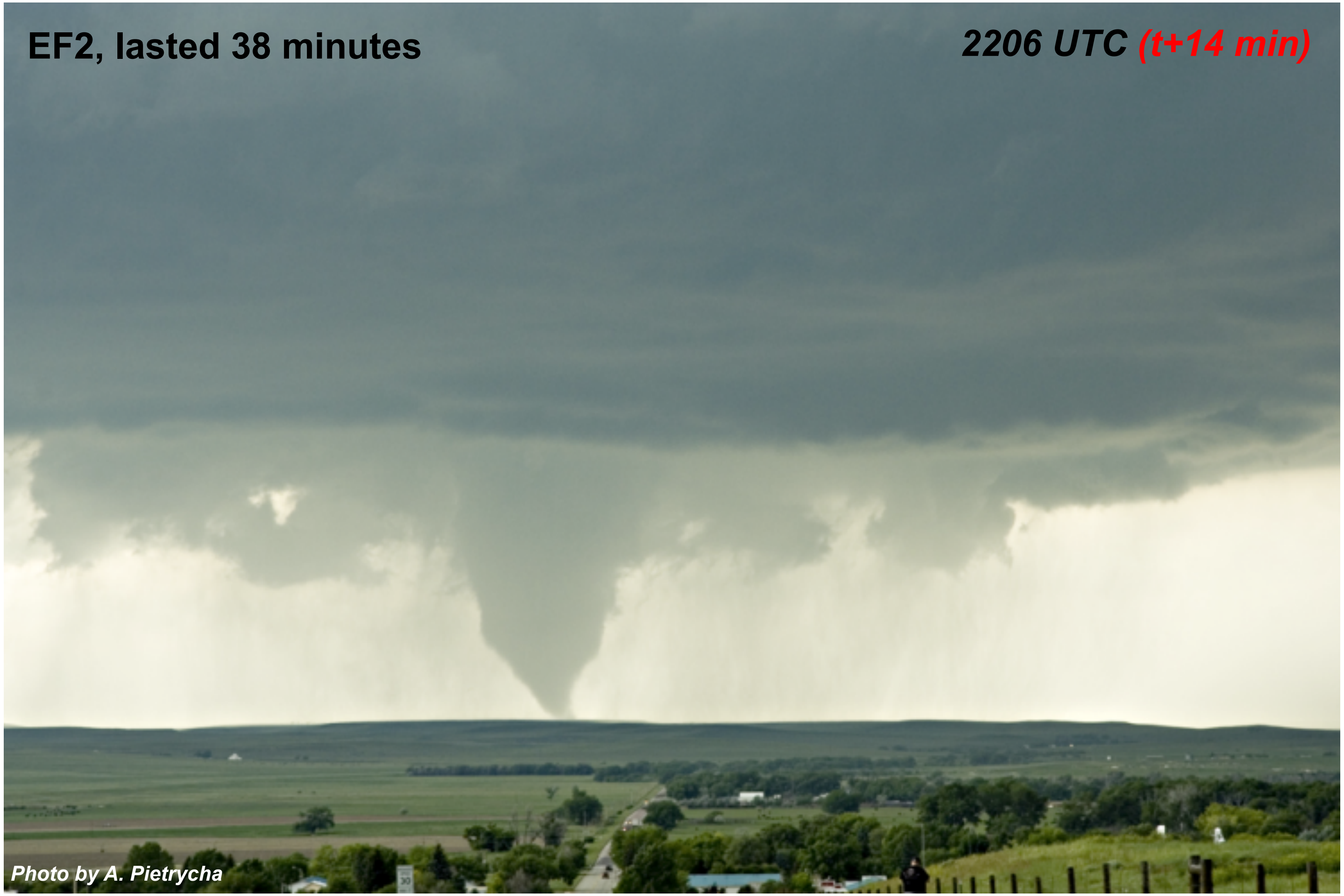
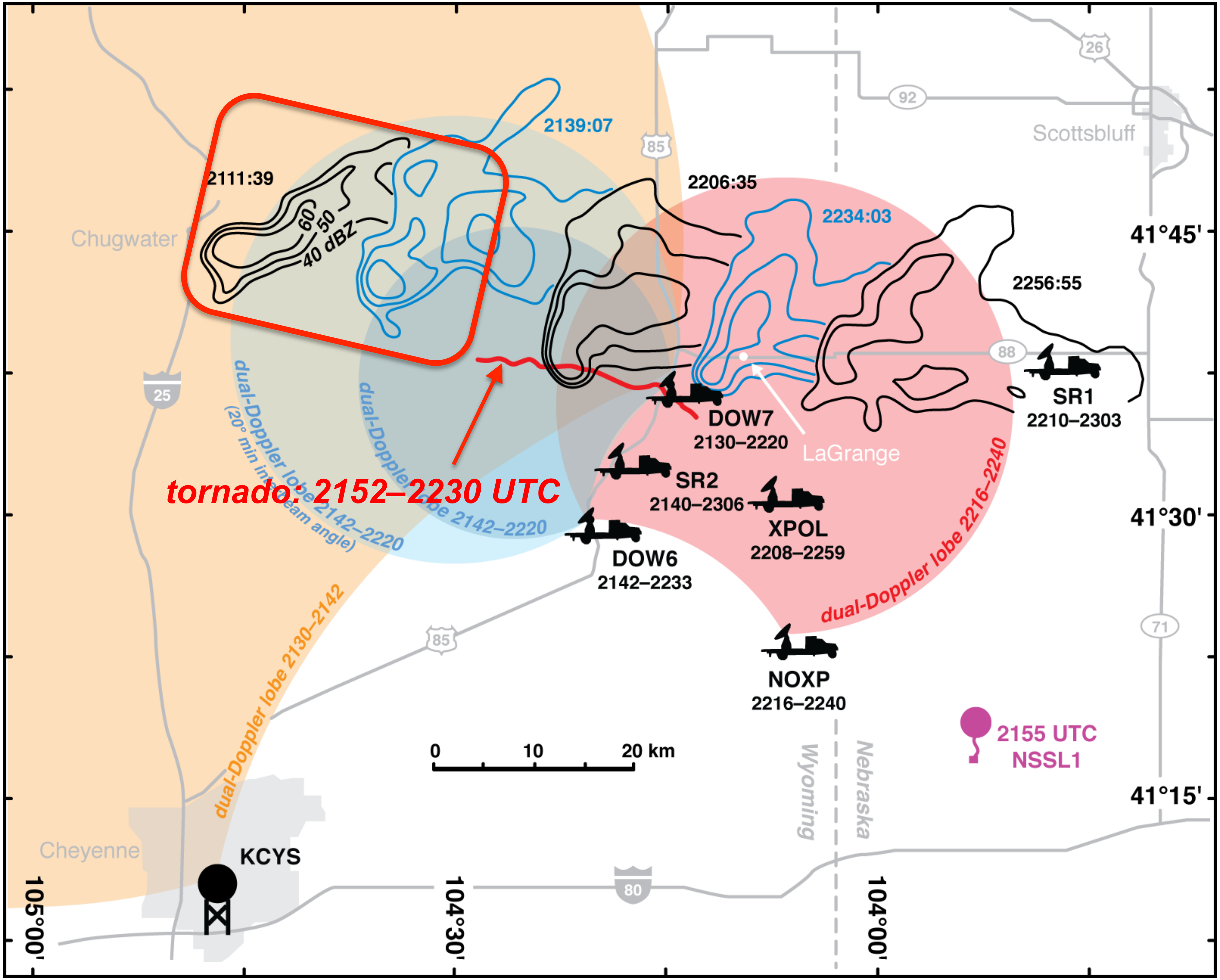
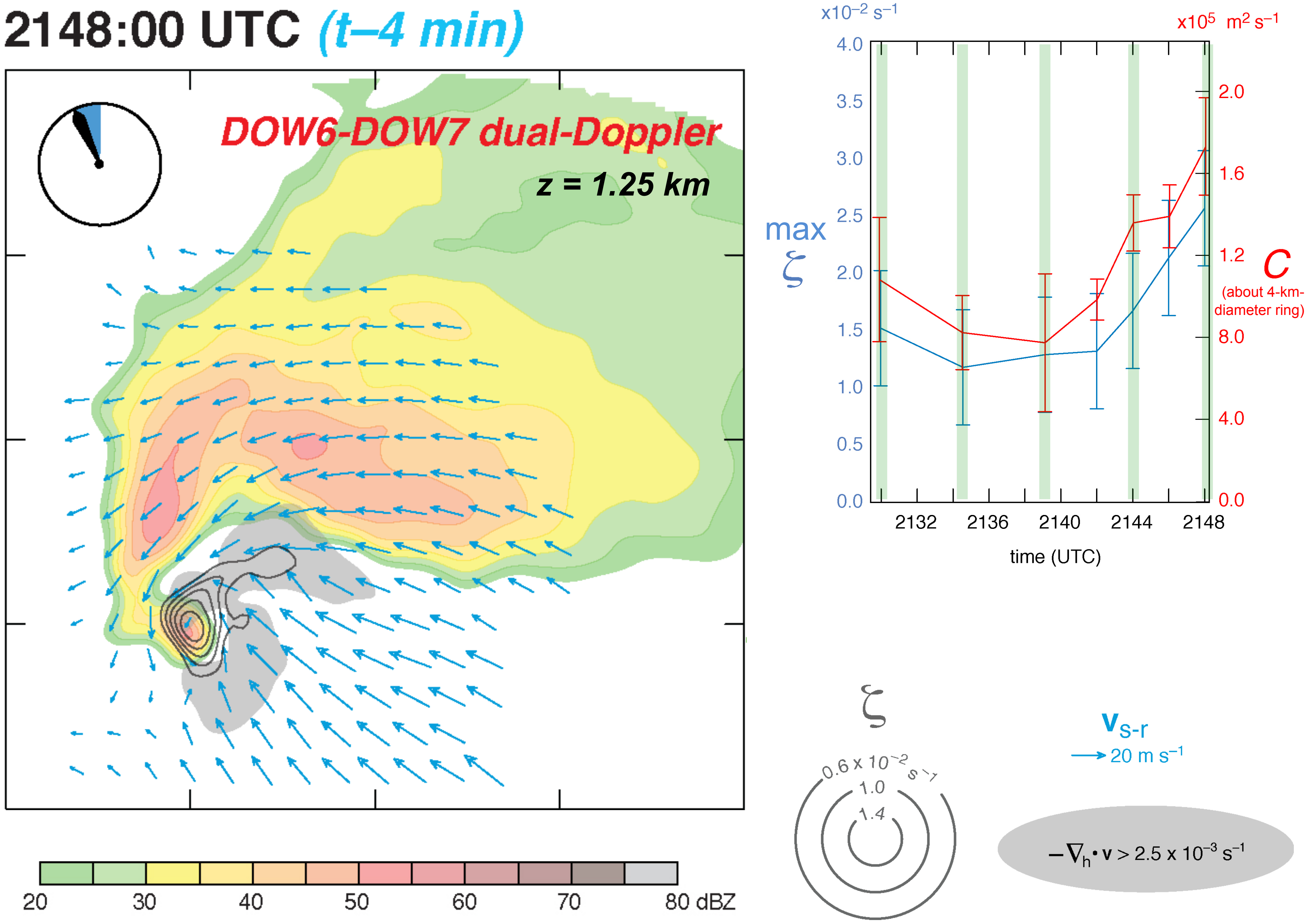
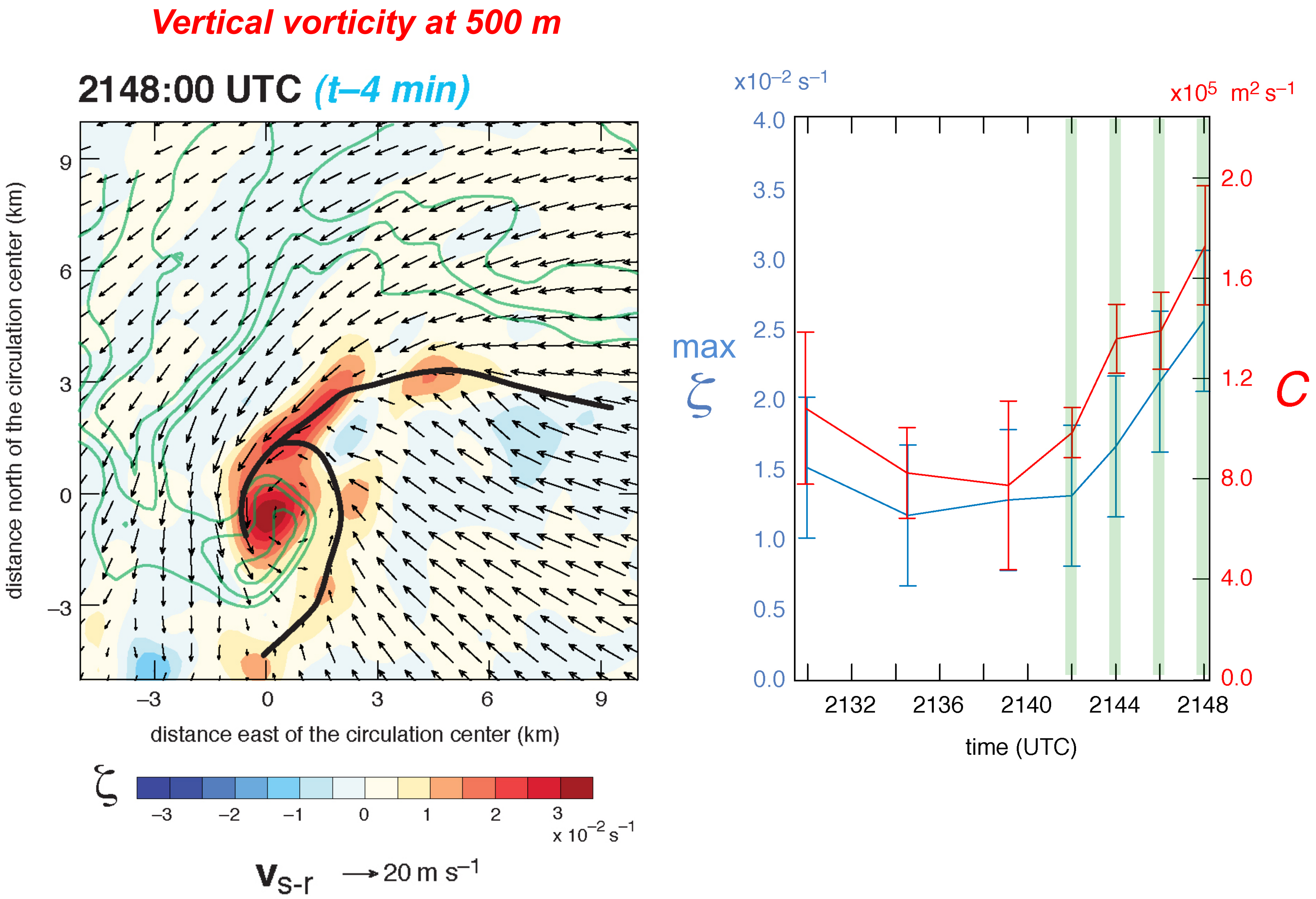




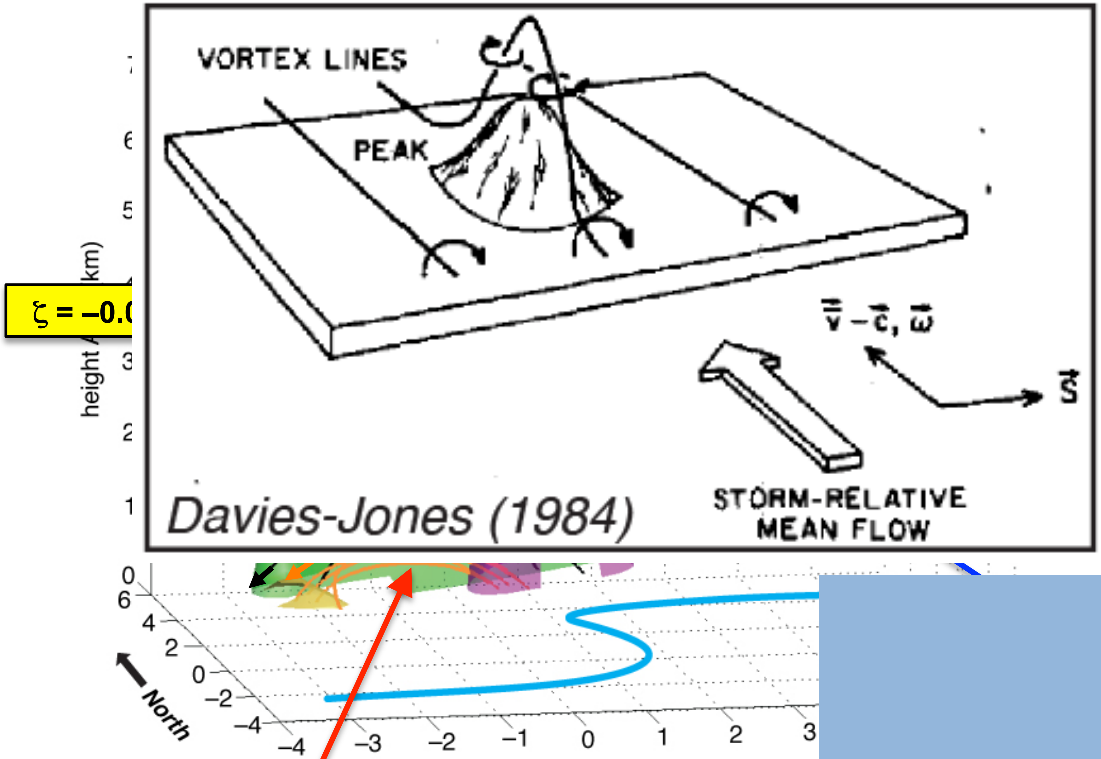
tornado: 2152–2230 UTC
2111:39
2139:07
2206:35
2234:03
2256:55
60
50
40 dBZ
Chugwater
Scottsbluff
LaGrange
Cheyenne
KCYS
DOW7
2130–2220
SR2
2140–2306
DOW6
2142–2233
XPOL
2208–2259
NOXP
2216–2240
SR1
2210–2303
2155 UTC
NSSL1
dual-Doppler lobe 2142–2220
(20° min inter-beam angle)
dual-Doppler lobe 2142–2220
dual-Doppler lobe 2216–2240
dual-Doppler lobe 2130–2142
Wyoming
Nebraska
0
10
20 km
41°45'
41°30'
41°15'
105°00'
104°30'
104°00'
25
85
85
80
26
92
88
71

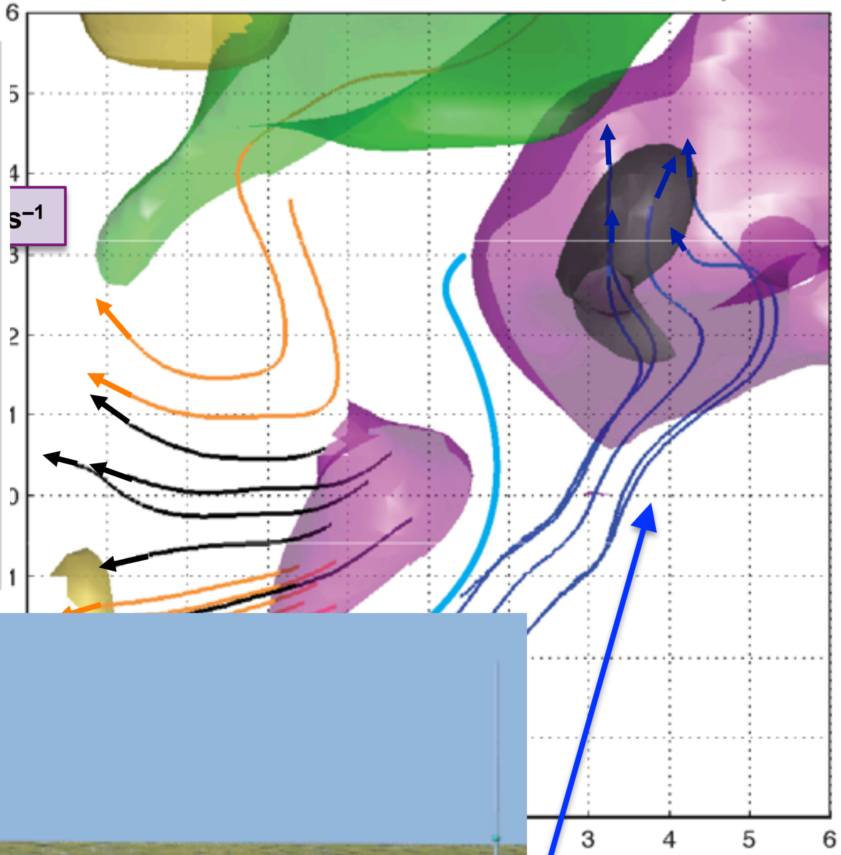

2148:00 UTC (t–4 min)
DOW6-DOW7 dual-Doppler
z = 1.25 km
20
30
40
50
60
70
80 dBZ
x10−2 s−1
x105 m2 s−1
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2.0
1.6
1.2
8.0
4.0
0.0
max ζ
C
(about 4-km-diameter ring)
2132
2136
2140
2144
2148
time (UTC)
ζ
0.6 x 10−2 s−1
1.0
1.4
vs-r
20 m s−1
−∇h • v > 2.5 x 10−3 s−1

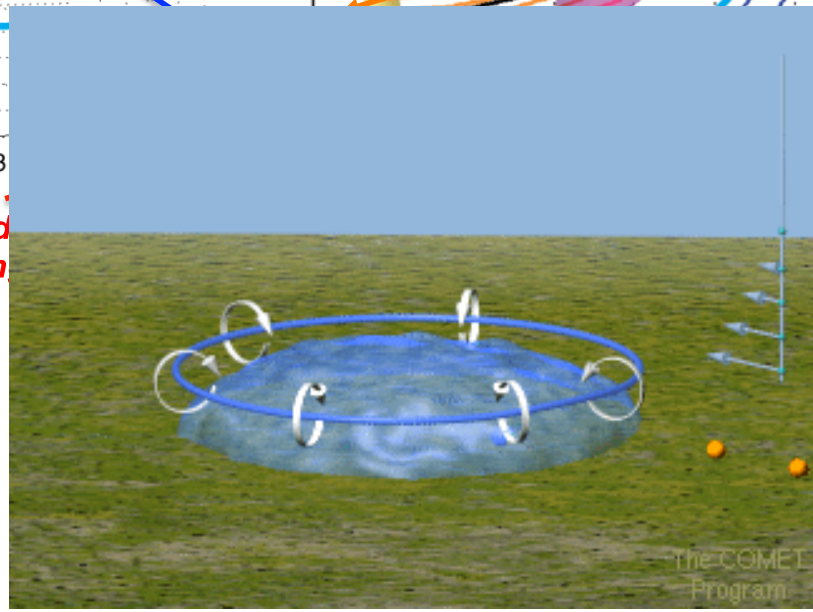
2142–2148 UTC



2129:58 UTC *(t–22 min)*

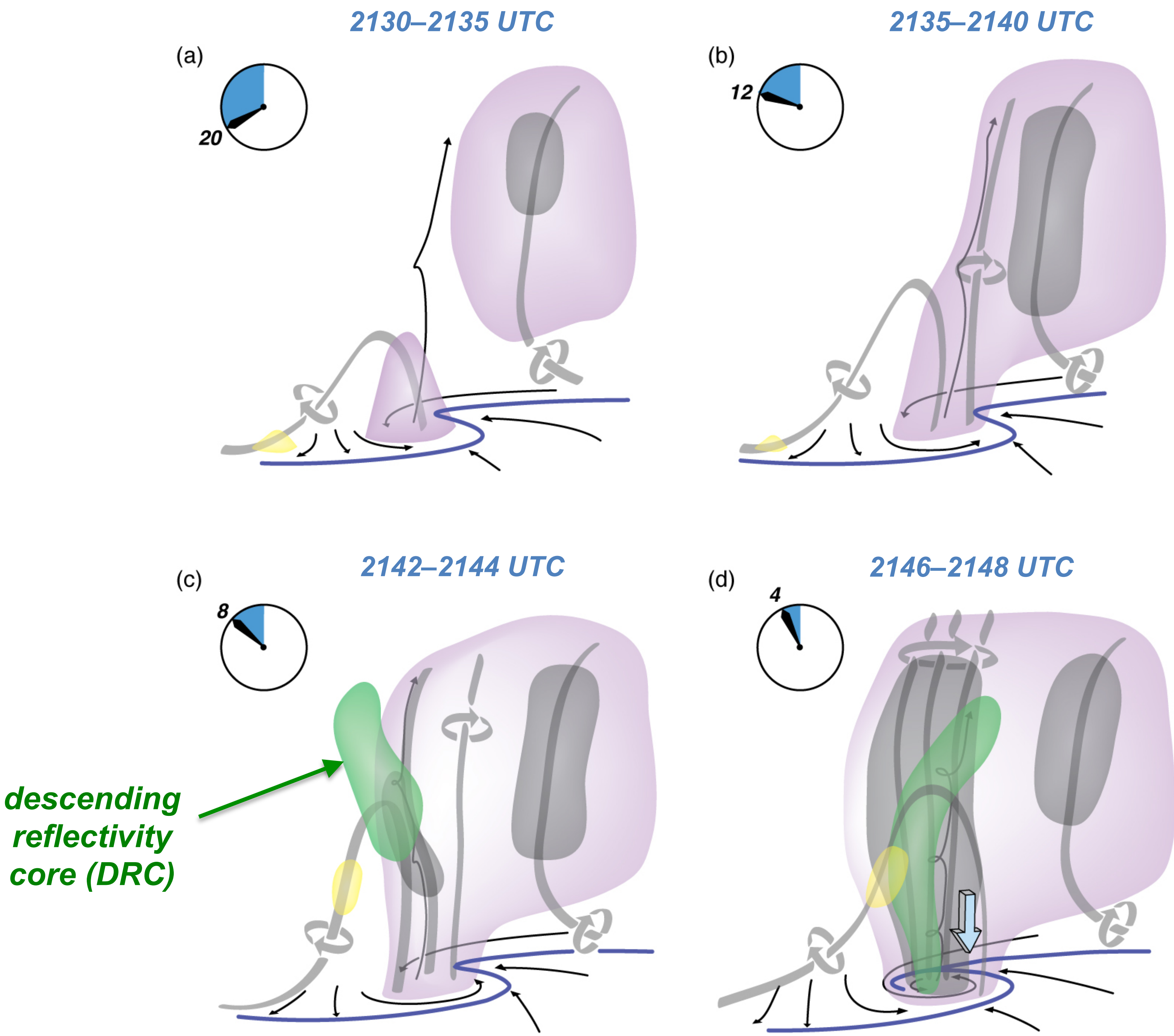






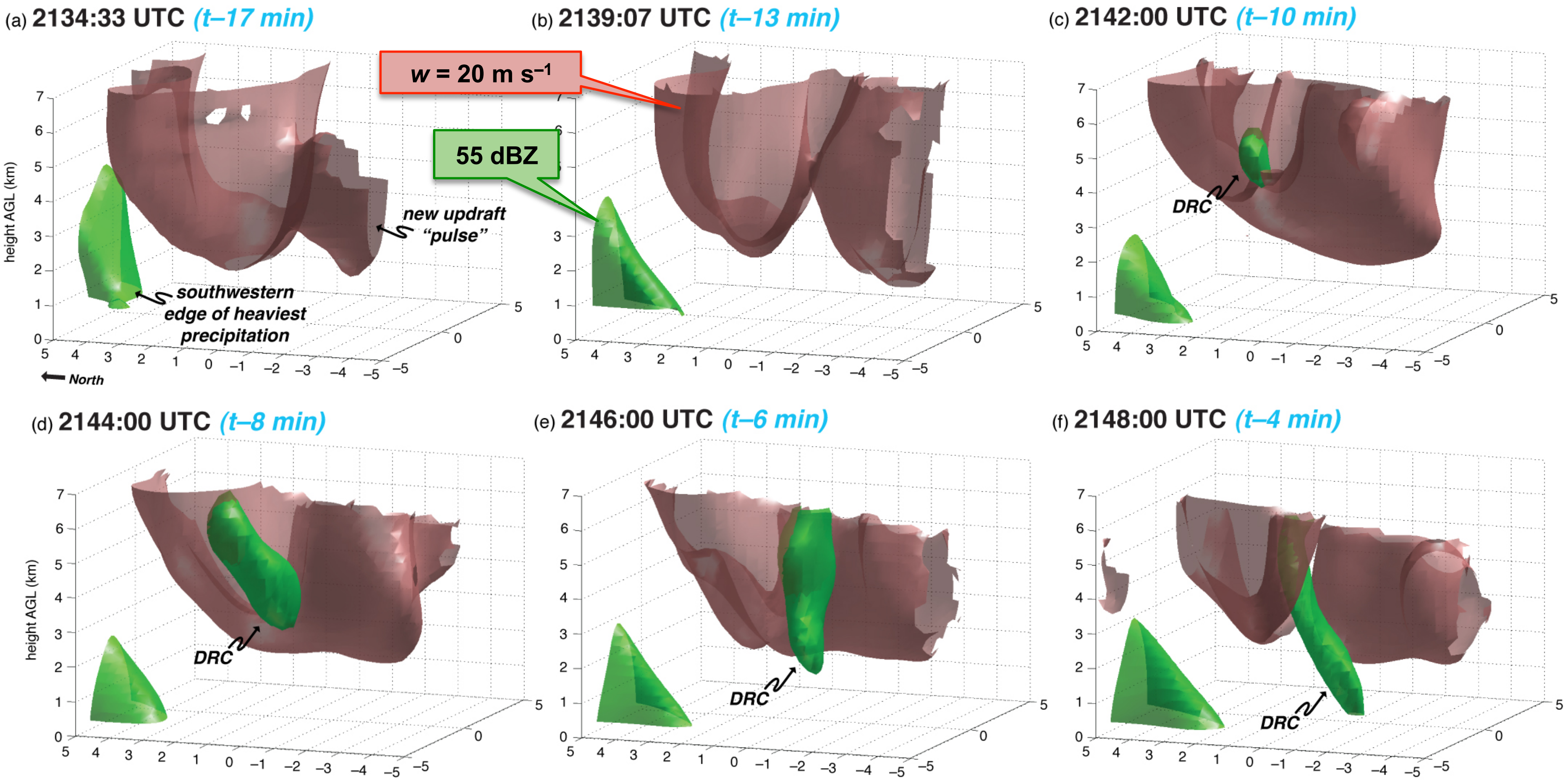
arches—strongly suggest baroclinically generated vorticity within the cold pool and subsequent liftin the vortex lines

vortex lines

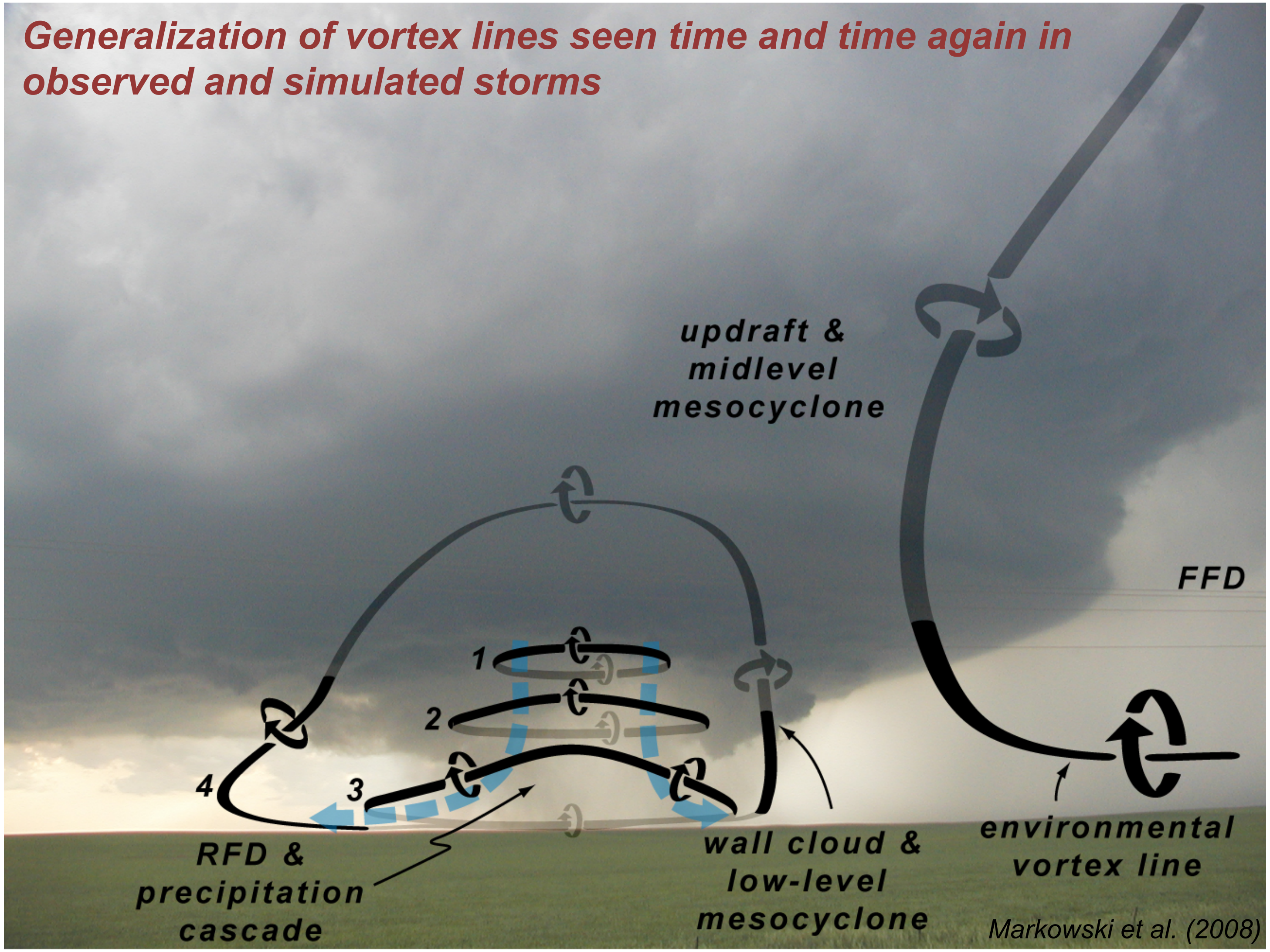


2130–2135 UTC
(a)
20
2135–2140 UTC
(b)
12
2142–2144 UTC
(c)
8
descending reflectivity core (DRC)
2146–2148 UTC
(d)
4

Descending Reflectivity Core (DRC):
2134–2148



What are the relative roles of environmental vorticity versus storm-generated vorticity?

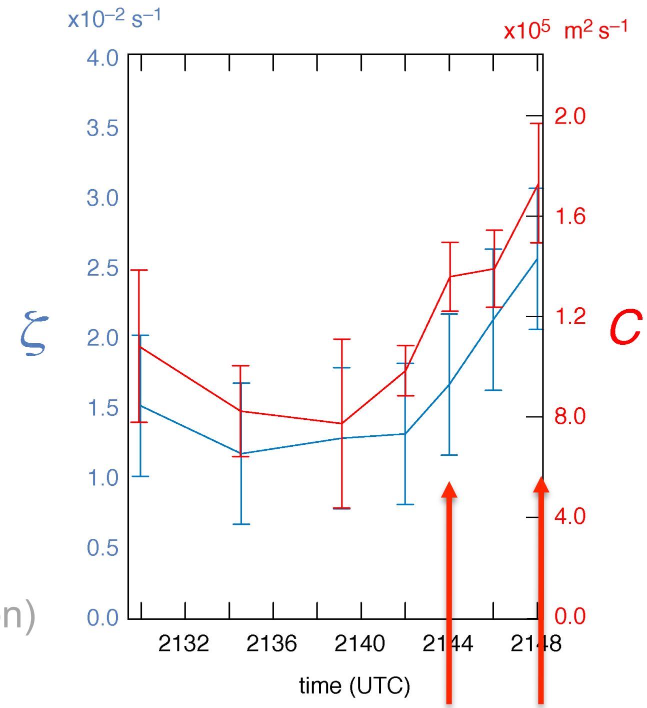


Both are important (e.g., we cannot get a supercell without strong environmental vorticity, and simulations/ theory show that we cannot get rotation at the surface without downdrafts and baroclinity).

What is less obvious is how their relative importance might vary from storm to storm (and perhaps determine the likelihood of tornadogenesis).

Material circuit approach

- Circuits strategically encircle the low-level mesocyclone
  - Circuits have a diameter of 3 km and are centered on the circulation at z = 0.75 km at 2148 UTC (Circuit A) and 2144 UTC (Circuit B)



- Circulation can change only as a result of the solenoidal effect—

$$\oint \mathbf{v} \cdot \mathbf{dl} \quad \frac{DC}{Dt} = \oint B\mathbf{k} \cdot \mathbf{dl} = \oint B\, dz$$

(Boussinesq, inviscid assumption)

therefore, we can learn something about the **bulk contribution to the mesocyclone's circulation from baroclinic vorticity generation**.

- $\oint \mathbf{v} \cdot \mathbf{dl}$ is a much less volatile calculation than the forcing terms in the vorticity equation

On the Rotation and Propagation of Simulated Supercell Thunderstorms

RICHARD ROTUNNO AND JOSEPH KLEMP

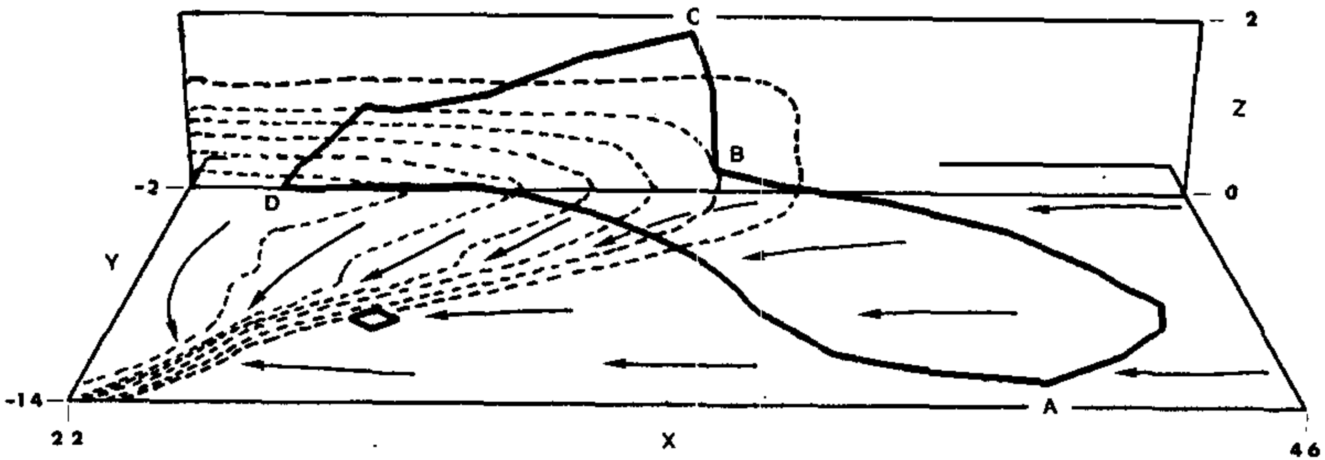
National Center for Atmospheric Research,[1] *Boulder, CO 80307*

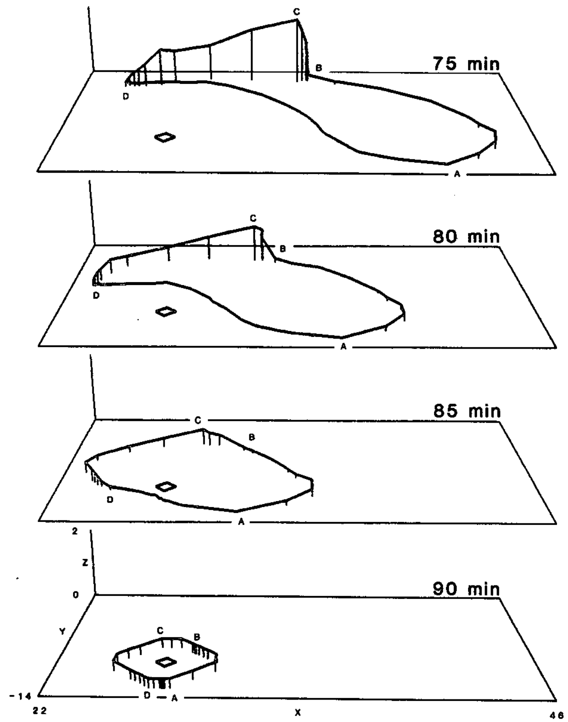
(Manuscript received 14 June 1984, in final form 18 October 1984)

ABSTRACT

We examine the rotation and propagation of the supercell-like convection produced by our three-dimensional cloud model. The rotation in the supercell is studied in terms of the conservation of equivalent potential vorticity and V. Bjerknes' first circulation theorem; neither of these have been used previously in this connection, and we find that they significantly contribute to the current level of understanding in this area. Using these we amplify the findings of our previous work in which we found that the source of midlevel rotation is the horizontally oriented vorticity associated with the environmental shear, while the low-level rotation derives from the baroclinic generation of horizontally oriented vorticity along the low-level cold-air boundary. We further demonstrate that these same processes that amplify the low-level rotation also produce the distinctive cloud feature known as the "wall cloud."

We find that the thunderstorm propagates rightward primarily because of the favorable dynamic vertical pressure gradient that, owing to storm rotation, is always present on the right flank of the updraft. Simulations without precipitation physics demonstrate that this rightward propagation occurs even in the absence of a cold outflow and gust front near the surface.

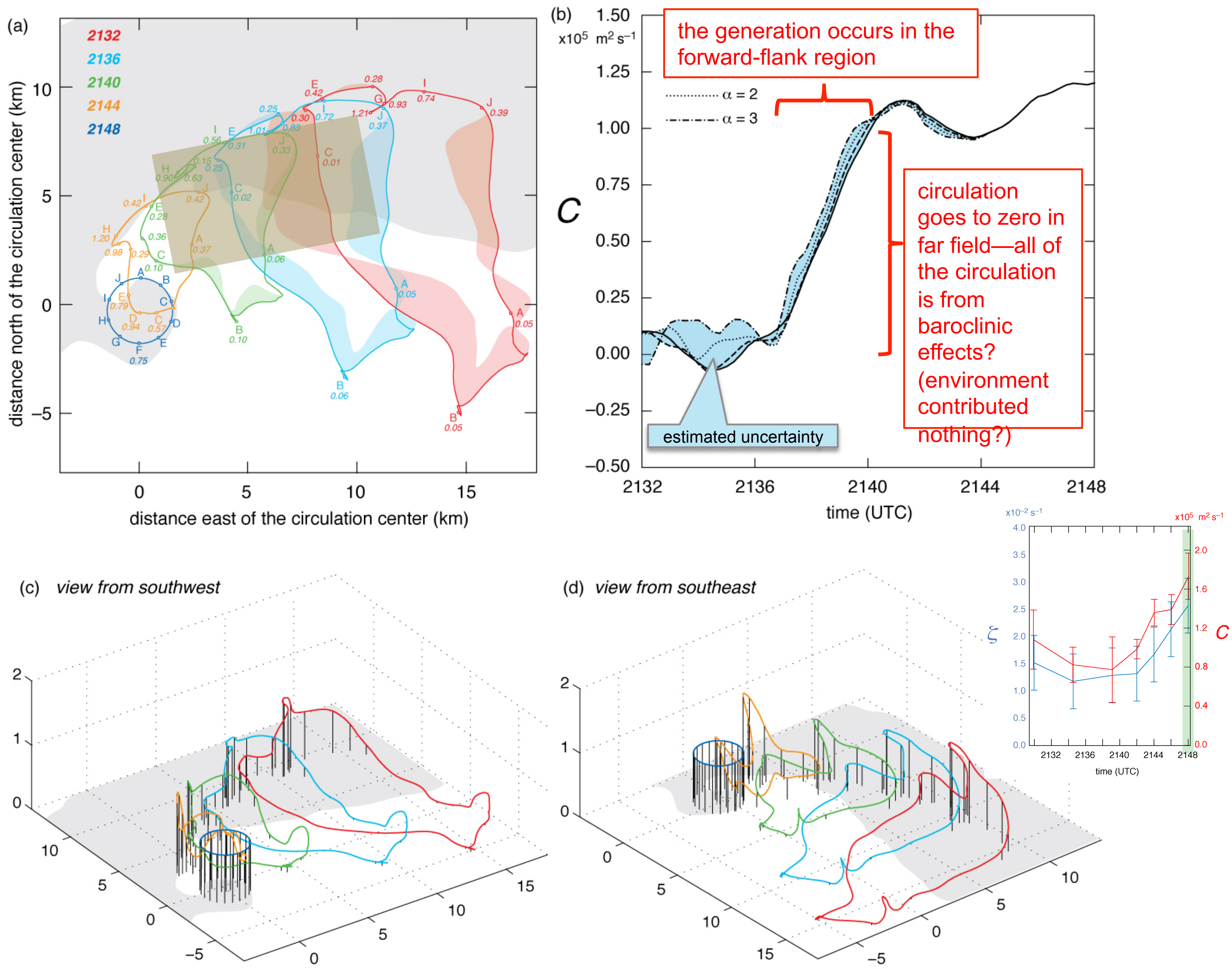


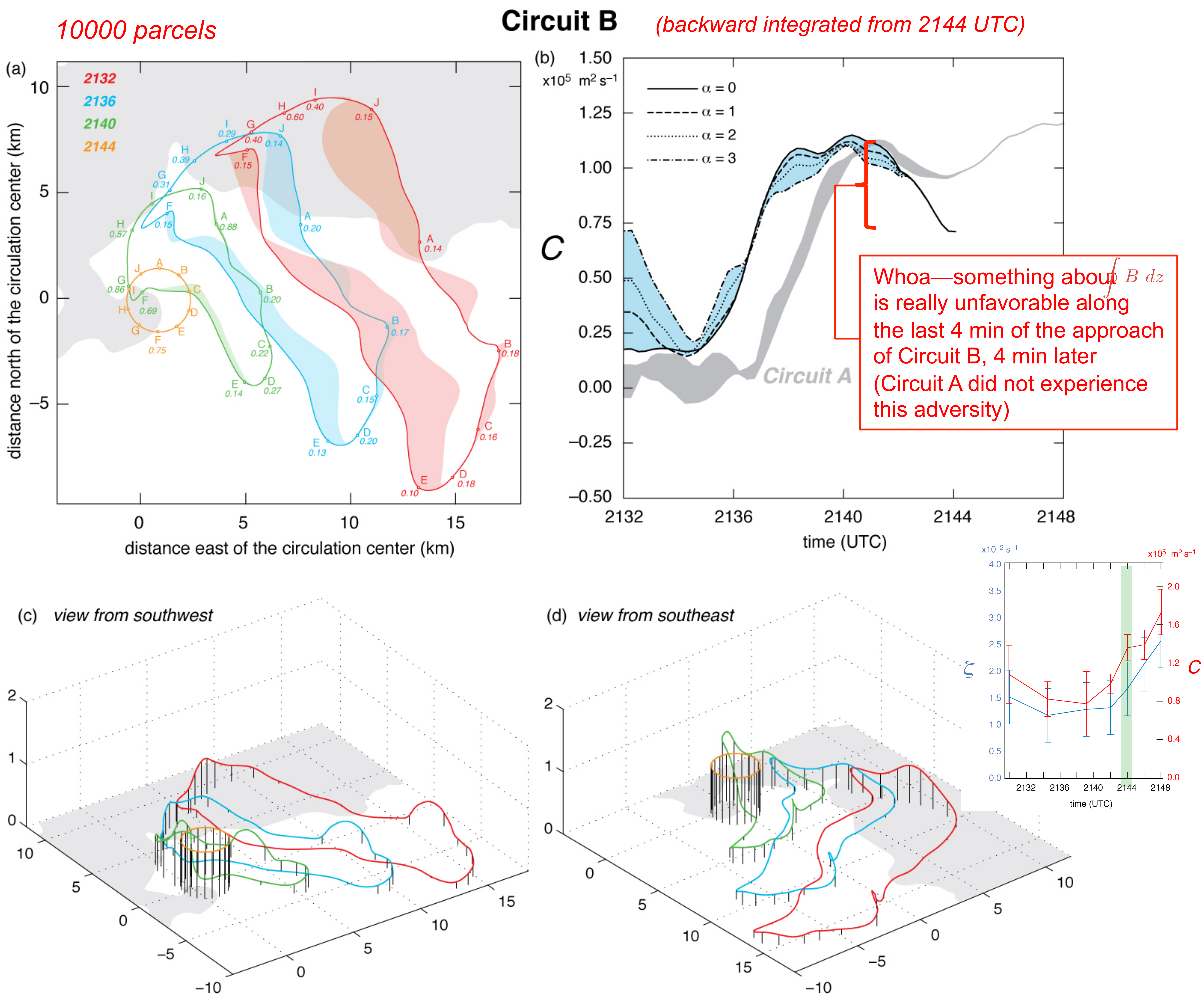


10000 parcels

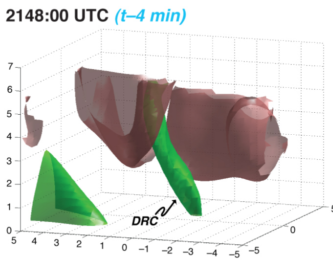
Circuit A

(backward integrated from 2148 UTC)

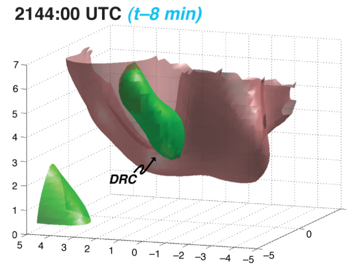


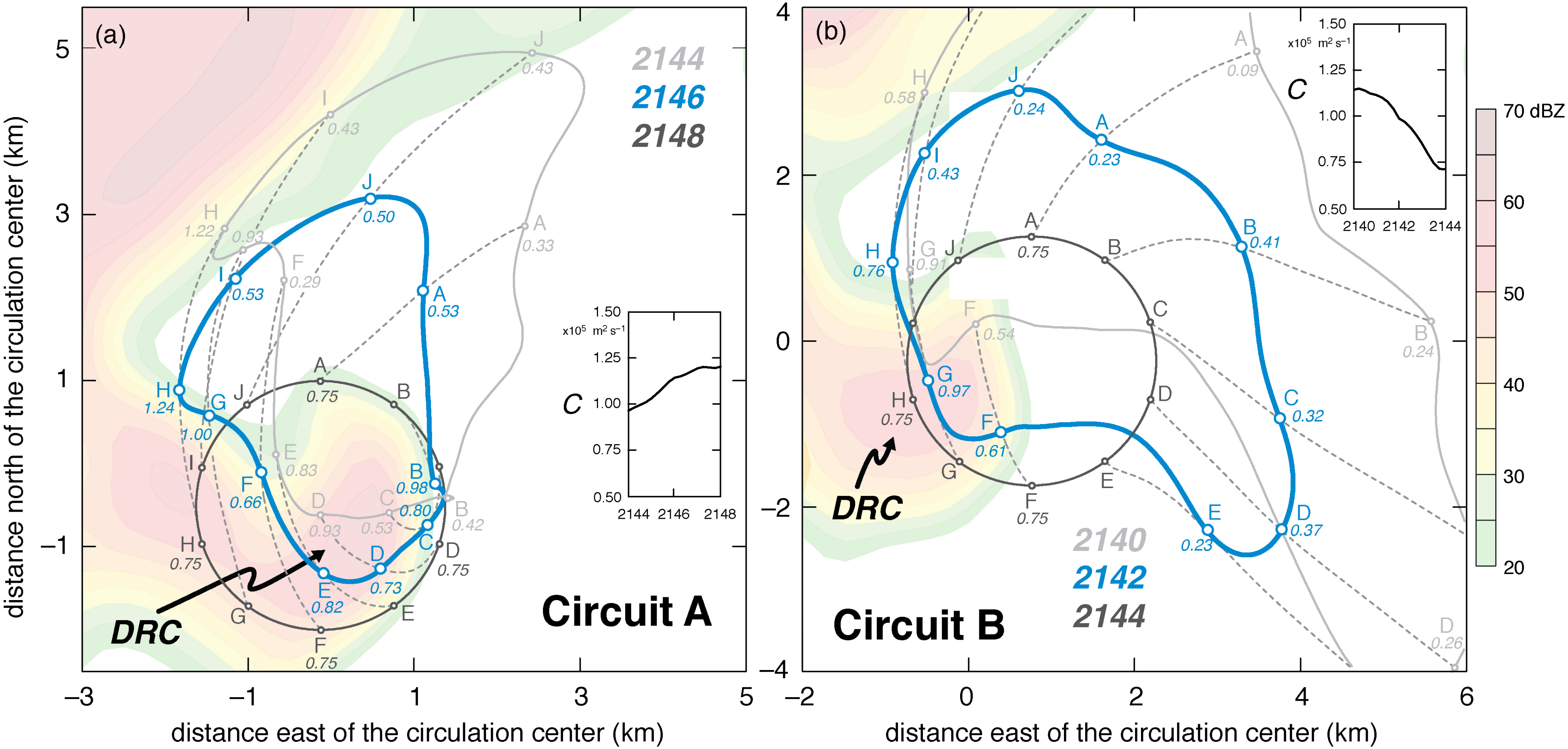


10000 parcels
Circuit B
(backward integrated from 2144 UTC)
(a)
2132
2136
2140
2144
distance north of the circulation center (km)
distance east of the circulation center (km)
(b)
x10^5 m^2 s^-1
α = 0
α = 1
α = 2
α = 3
C
Circuit A
time (UTC)
Whoa—something about ∫B dz is really unfavorable along the last 4 min of the approach of Circuit B, 4 min later (Circuit A did not experience this adversity)
(c) view from southwest
(d) view from southeast
x10^-2 s^-1
x10^5 m^2 s^-1
ζ
C
time (UTC)



$$\frac{DC}{Dt} = \oint B\mathbf{k}\cdot\mathbf{dl} = \oint B\,dz$$





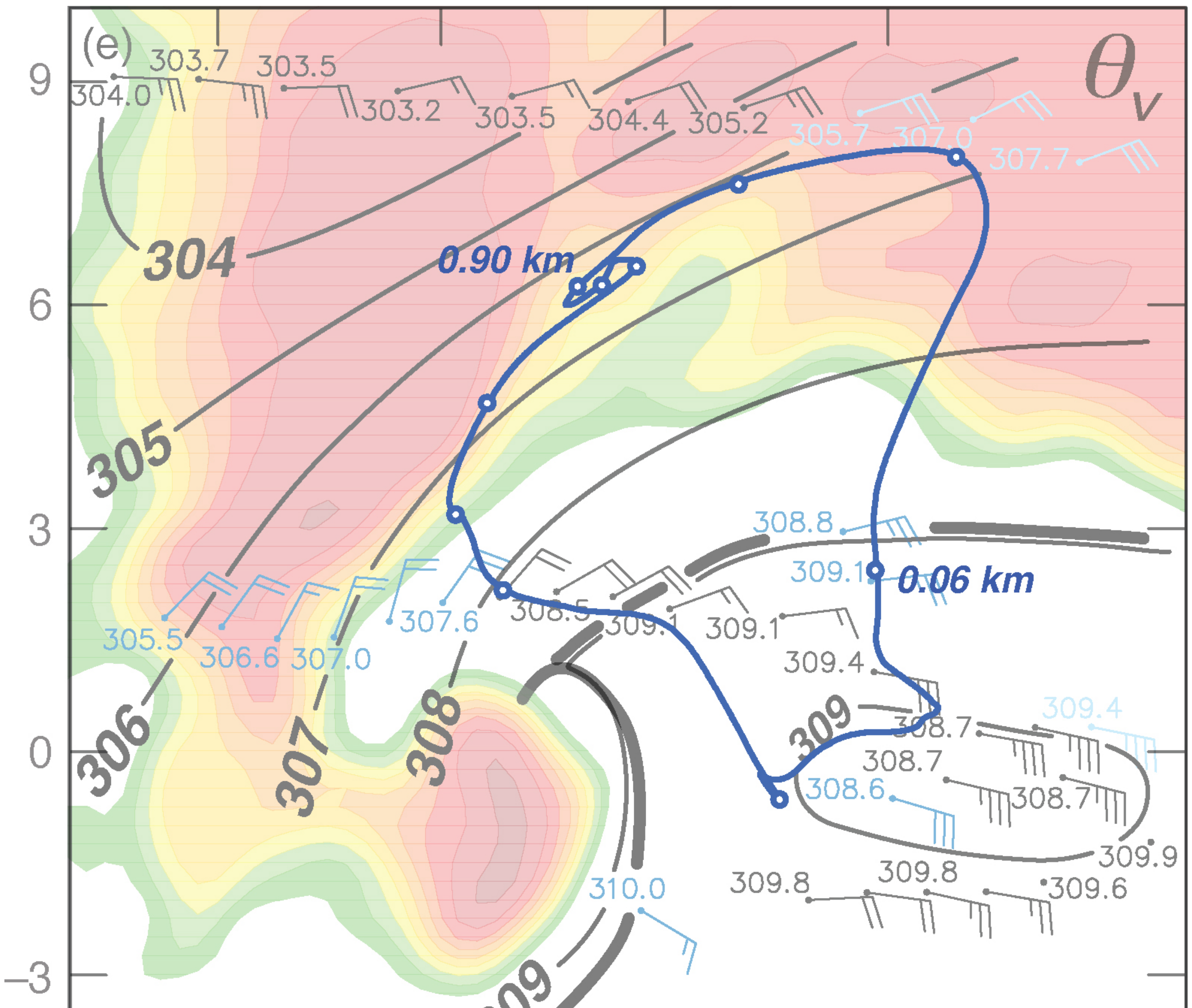
Circuit A: **DRC alters buoyancy field and/or promotes occlusion (end result is DC/Dt >> 0)**

Circuit B: **converges upon ζ_{max} before DRC arrives at low levels (DC/Dt < 0 during circuit's final approach)**

Summary

- Despite significant environmental vorticity, environmental vortex lines do not appear to have contributed to the low-level circulation in a significant way
  - That leaves baroclinic vortex lines (Bjerknes' theorem)
- The total increase in circulation about the material circuits (~1.2 x 10^5 m^2 s^{-1}) was very similar to the increase in the simulated supercell analyzed by Rotunno and Klemp (1985), but occurred much faster, despite the fact that the observed cold pool was much weaker than the cold pool in Rotunno & Klemp's simulation

2144–2152 UTC mobile mesonet observations



$$\Delta C \sim \frac{g}{\theta_0}\Delta\theta_\rho \Delta z \Delta t$$

increase in circulation over Δt

typical difference in density potential temperature between the “up” part of the circuit and “down” part

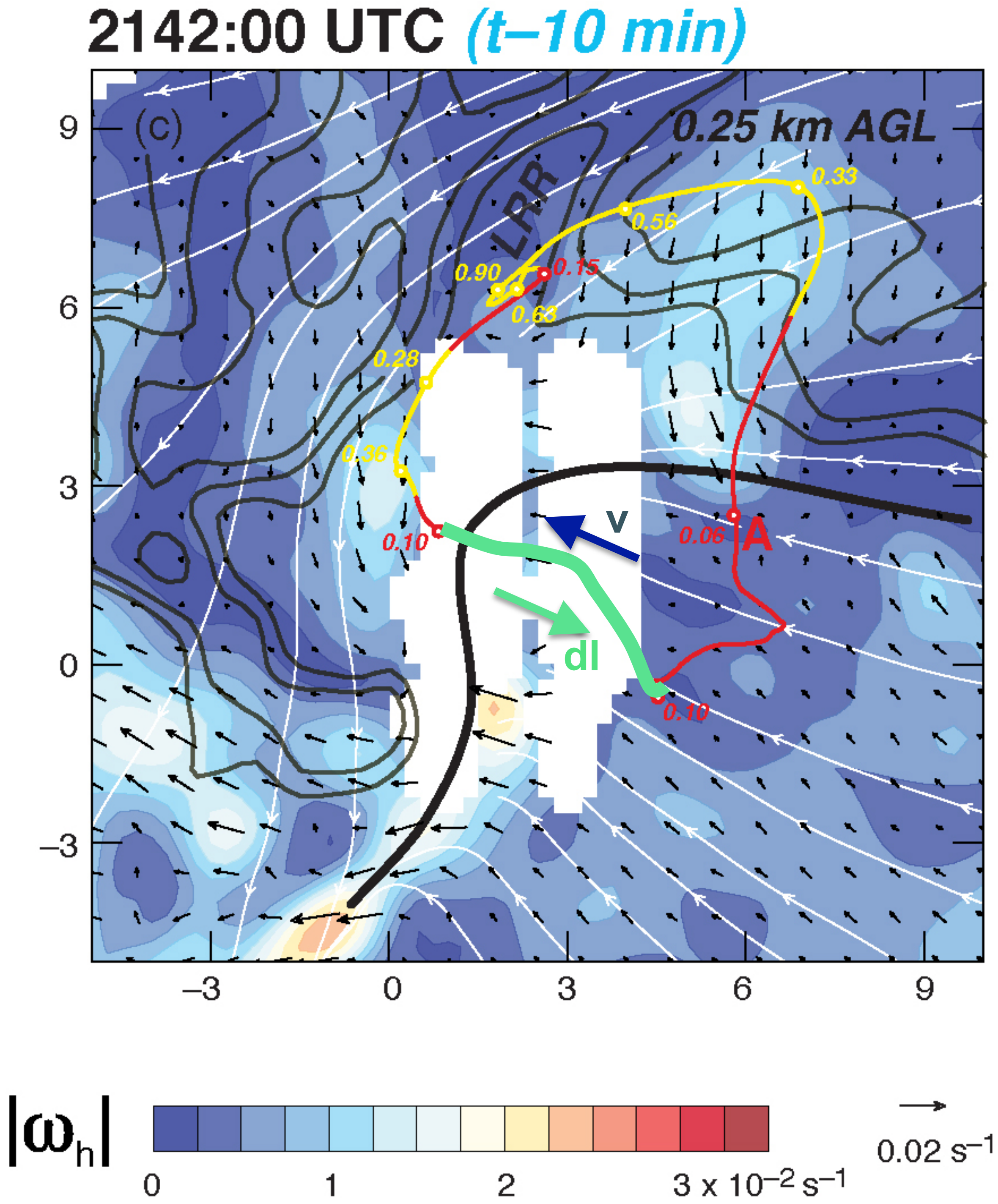
peak height difference on the circuit

For generous assumptions of Δz = 1000 m and $\Delta\theta_\rho$ = 10 K (this requires *doubling* the observed ~3-K $\Delta\theta_v$ and adding *another* 4 K to account for hydrometeors), $\Delta C = 0.8 \times 10^5$ m^2 s^{-1} (only 60% of the observed $\Delta C = 1.2 \times 10^5$ m^2 s^{-1}).

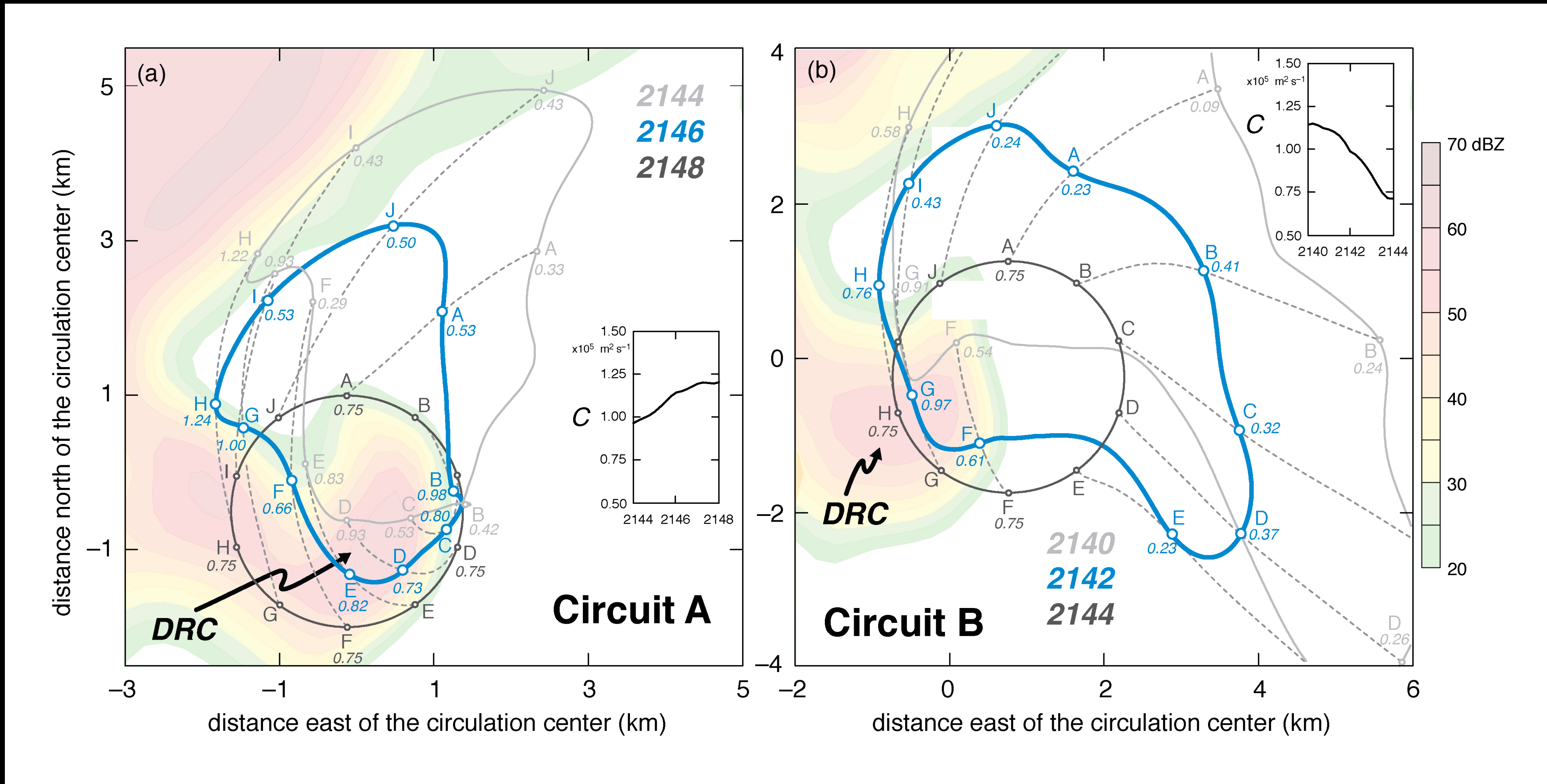
$$\frac{DC}{Dt} = \oint B\, dz + \boxed{\oint \mathbf{F} \cdot \mathbf{dl}}$$

We can't exclude the possibility that surface drag might have contributed positively to *DC/Dt*.

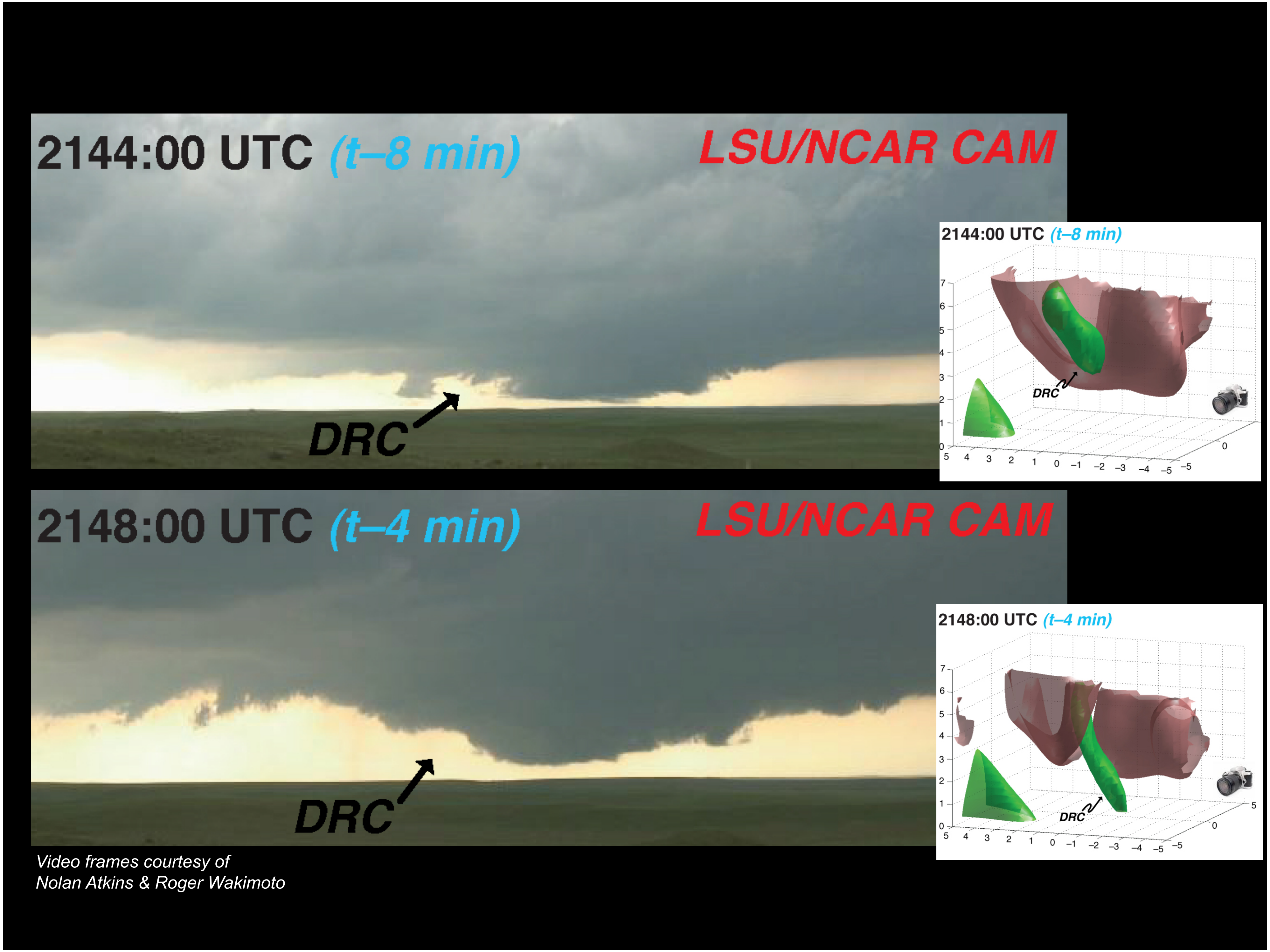
(Surface drag is well-known to be important for tornadogenesis by disrupting cyclostrophic balance, but its possible contribution to low-level mesocyclone rotation has not been considered previously.)



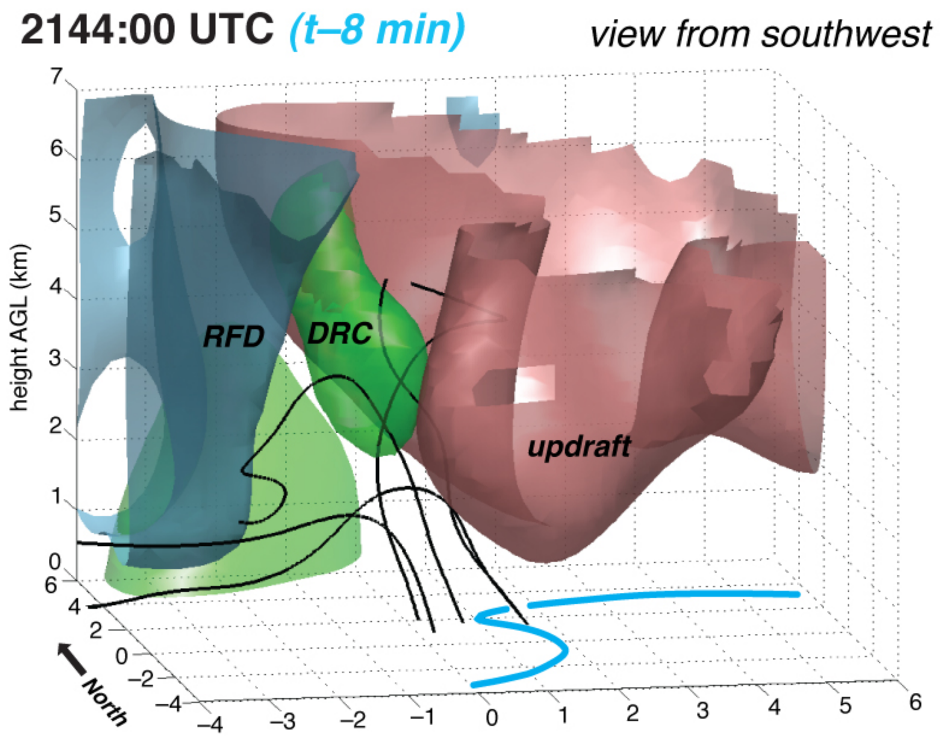
Summary

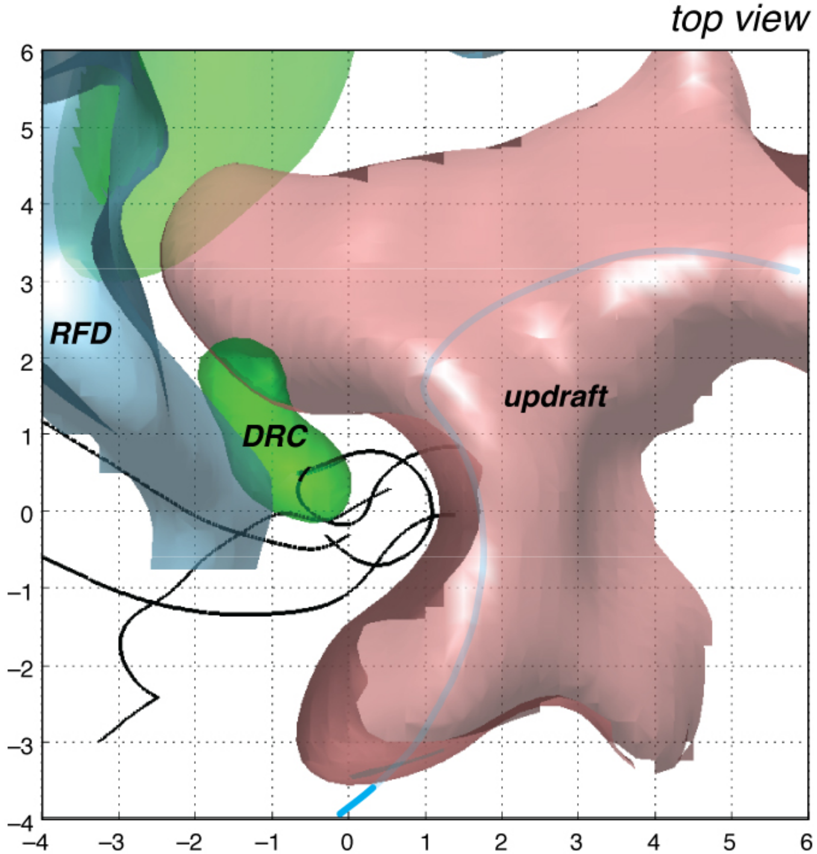


look like? (the DRC was optically transparent)


2144:00 UTC (t–8 min)
LSU/NCAR CAM
DRC
2144:00 UTC (t–8 min)
DRC
2148:00 UTC (t–4 min)
LSU/NCAR CAM
DRC
2148:00 UTC (t–4 min)
DRC
Video frames courtesy of
Nolan Atkins & Roger Wakimoto

- If the environmental vorticity did not directly contribute to the low-level circulation, then what was its role?





- Perhaps environmental vorticity is important, especially at low levels, **because its tilting establishes the base of the midlevel mesocyclone at fairly low elevations**.

- **This would give rise to a strong upward-directed perturbation PGF at low levels that could forcibly lift negatively buoyant air**
  (the upward-directed perturbation PGF must be strong enough to offset the negative buoyancy of the circulation-bearing outflow air).