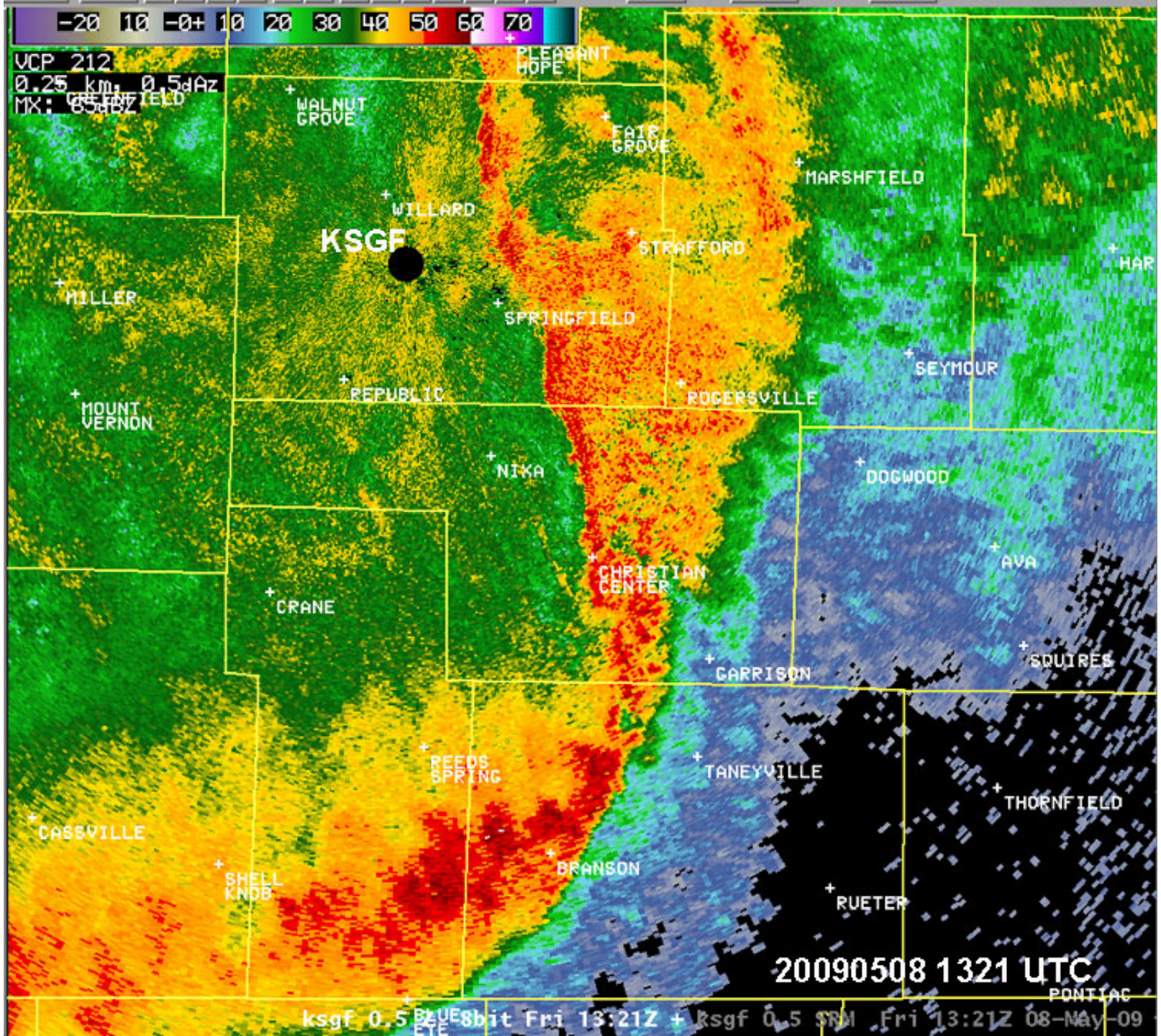
Bow echo mesovortices

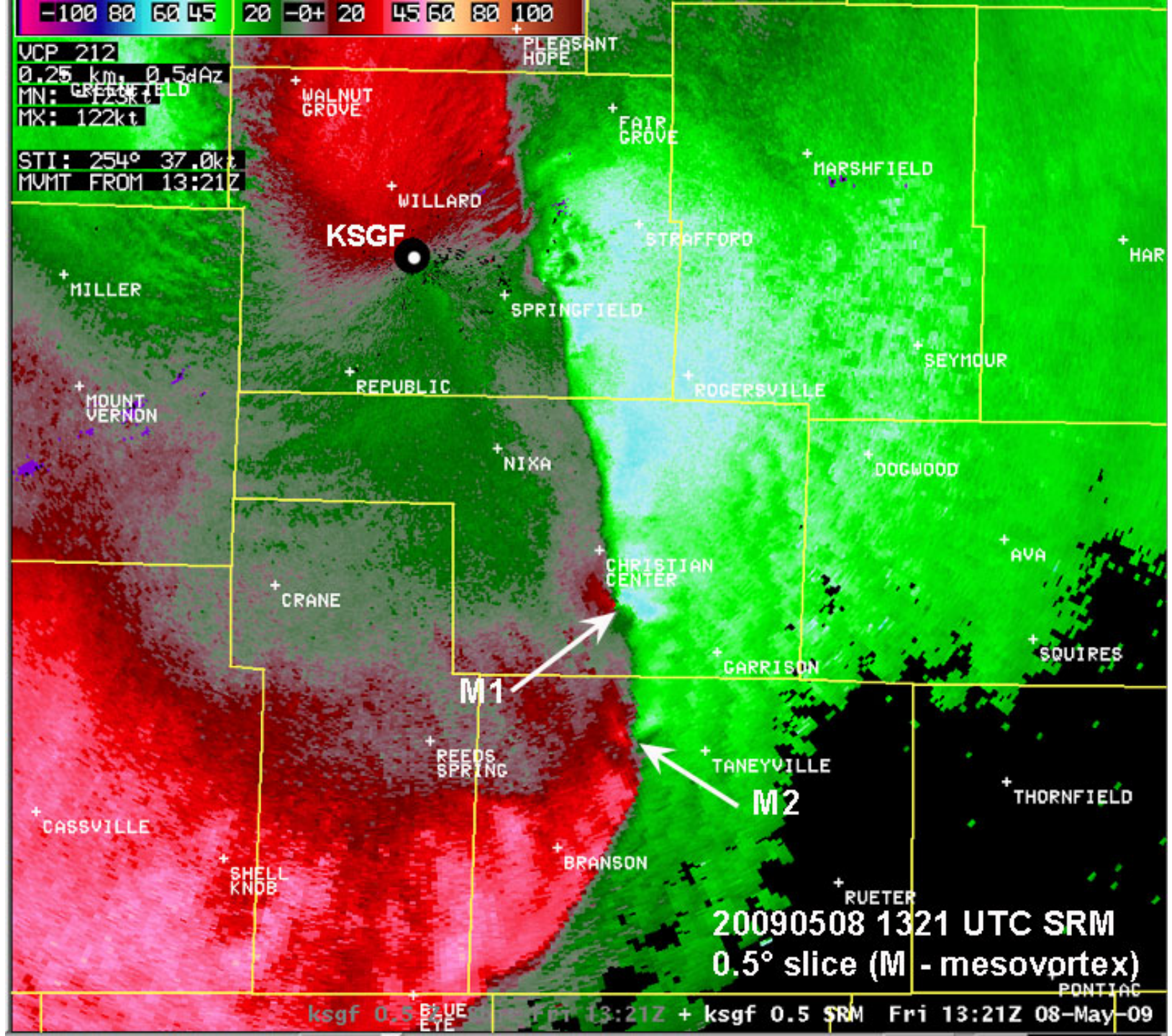
Often, small-scale vortices develop along the leading edge of a bow echo or QLCS.

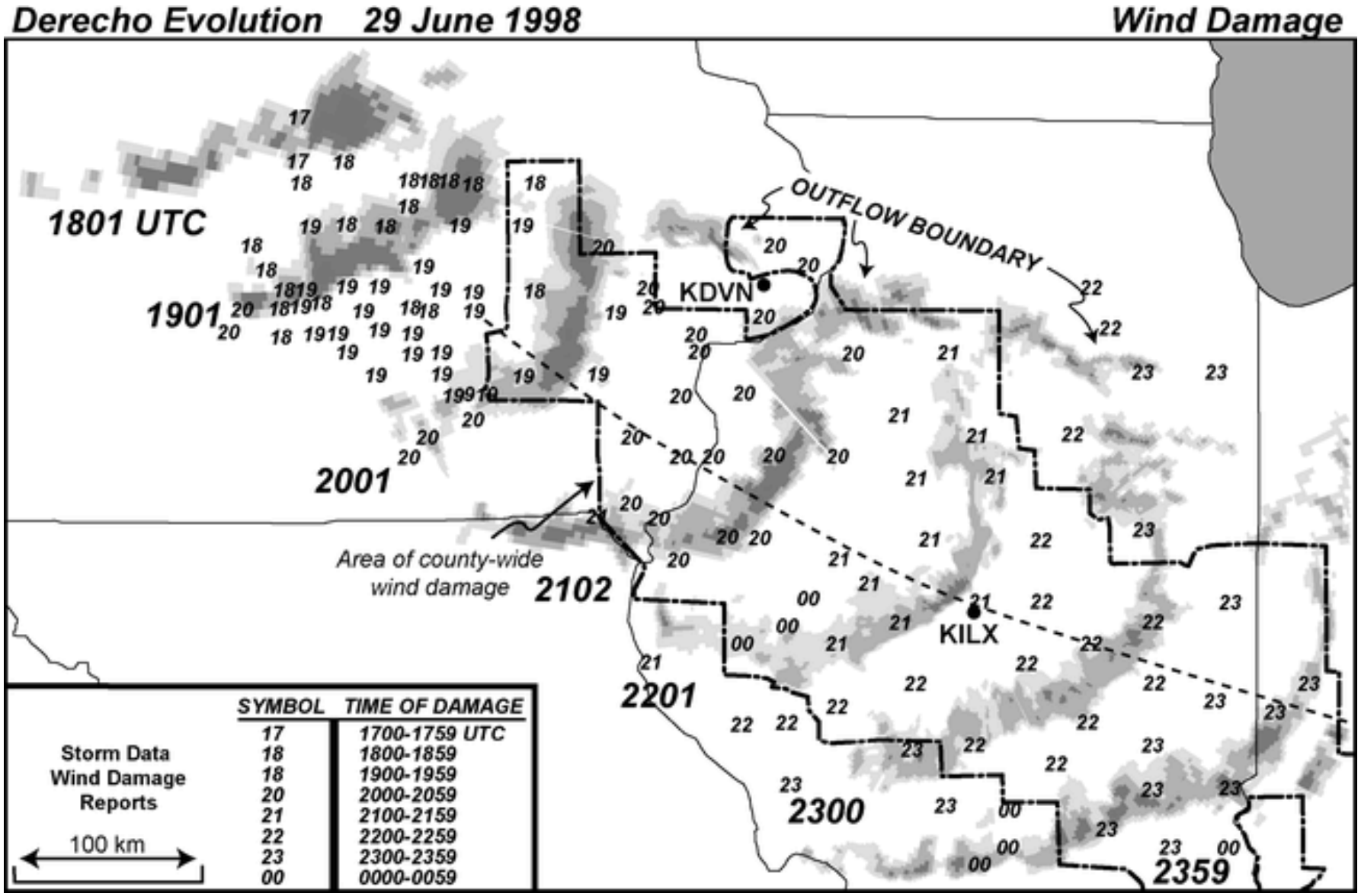
These are referred to as ***mesovortices*** (Przybylinski 1995).

Vertical vorticity in mesovortices present at **low-levels**, and may not contain appreciable mid-level rotation.

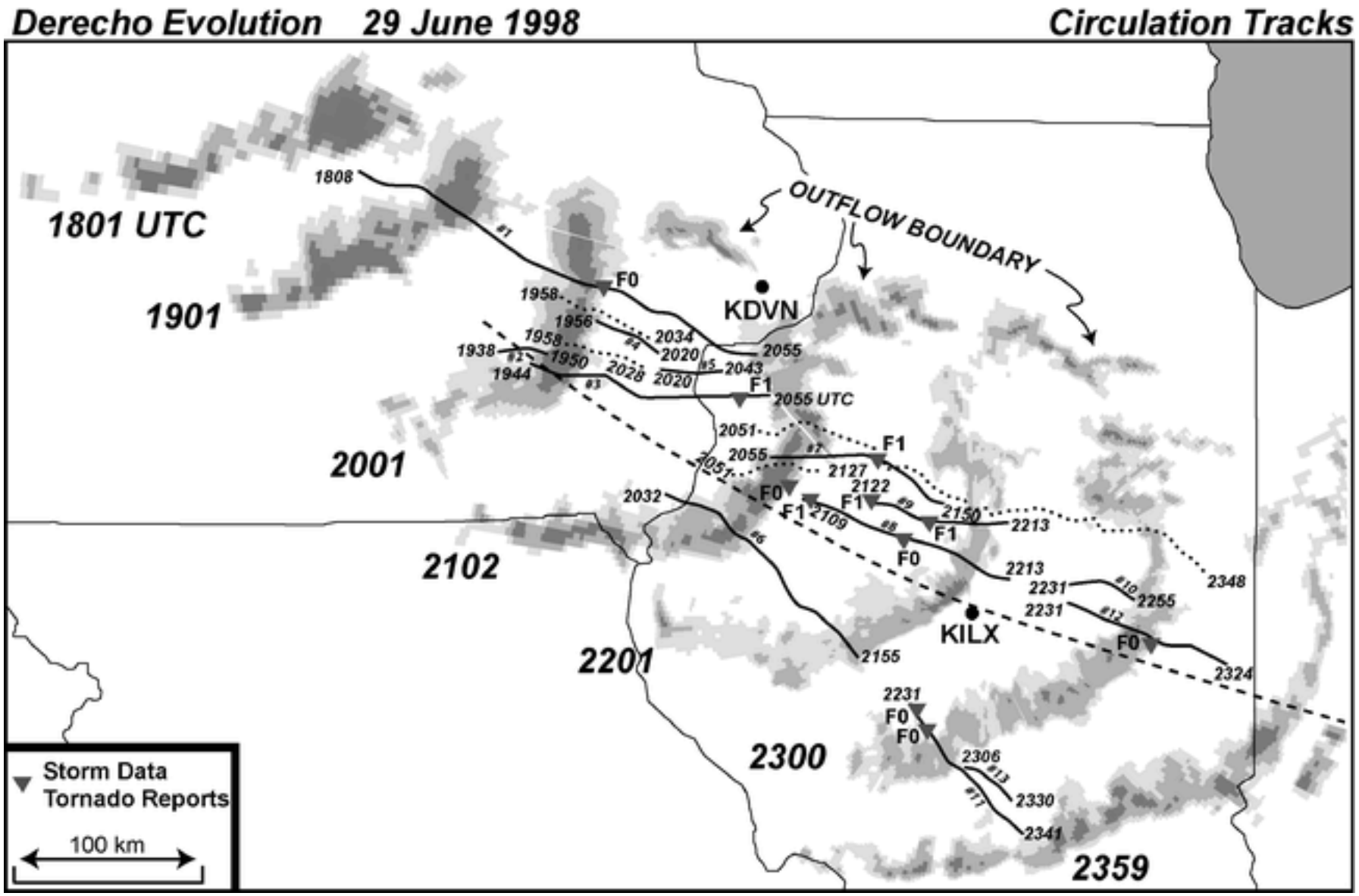
Mesovortices are often associated with the most intense surface winds in bow echoes and can occasionally produce tornadoes.


-20 10 -0+ 10 20 30 40 50 60 70
VCP 212
0.25 km, 0.5dAz
PLEASANT HOPE
WALNUT GROVE
FAIR GROVE
MARSHFIELD
WILLARD
KSGF
STRAFFORD
MILLER
SPRINGFIELD
SEYMOUR
REPUBLIC
ROGERSVILLE
MOUNT VERNON
NIXA
DOGWOOD
AVA
CHRISTIAN CENTER
CRANE
SQUIRES
GARRISON
REEDS SPRING
TANEYVILLE
THORNFIELD
CASSVILLE
BRANSON
SHELL KNOB
RUETER
20090508 1321 UTC
PONTIAC
ksgf 0.5 8bit Fri 13:21Z + ksgf 0.5 SRM Fri 13:21Z 08-May-09


-100 80 60 45 20 -0+ 20 45 60 80 100
VCP 212
0.25 km, 0.5dAz
MN: 12kt
MX: 122kt
STI: 254° 37.0kt
MVMT FROM 13:21Z
PLEASANT HOPE
WALNUT GROVE
FAIR GROVE
MARSHFIELD
WILLARD
KSGF
STRAFFORD
HAR
MILLER
SPRINGFIELD
SEYMOUR
REPUBLIC
ROGERSVILLE
MOUNT VERNON
NIXA
DOGWOOD
AVA
CHRISTIAN CENTER
CRANE
SQUIRES
GARRISON
M1
REEDS SPRING
TANEYVILLE
M2
THORNFIELD
CASSVILLE
BRANSON
SHELL KNOB
RUETER
20090508 1321 UTC SRM
0.5° slice (M - mesovortex)
PONTIAC
BLUE EYE
ksgf 0.5 SRM Fri 13:21Z + ksgf 0.5 SRM Fri 13:21Z 08-May-09

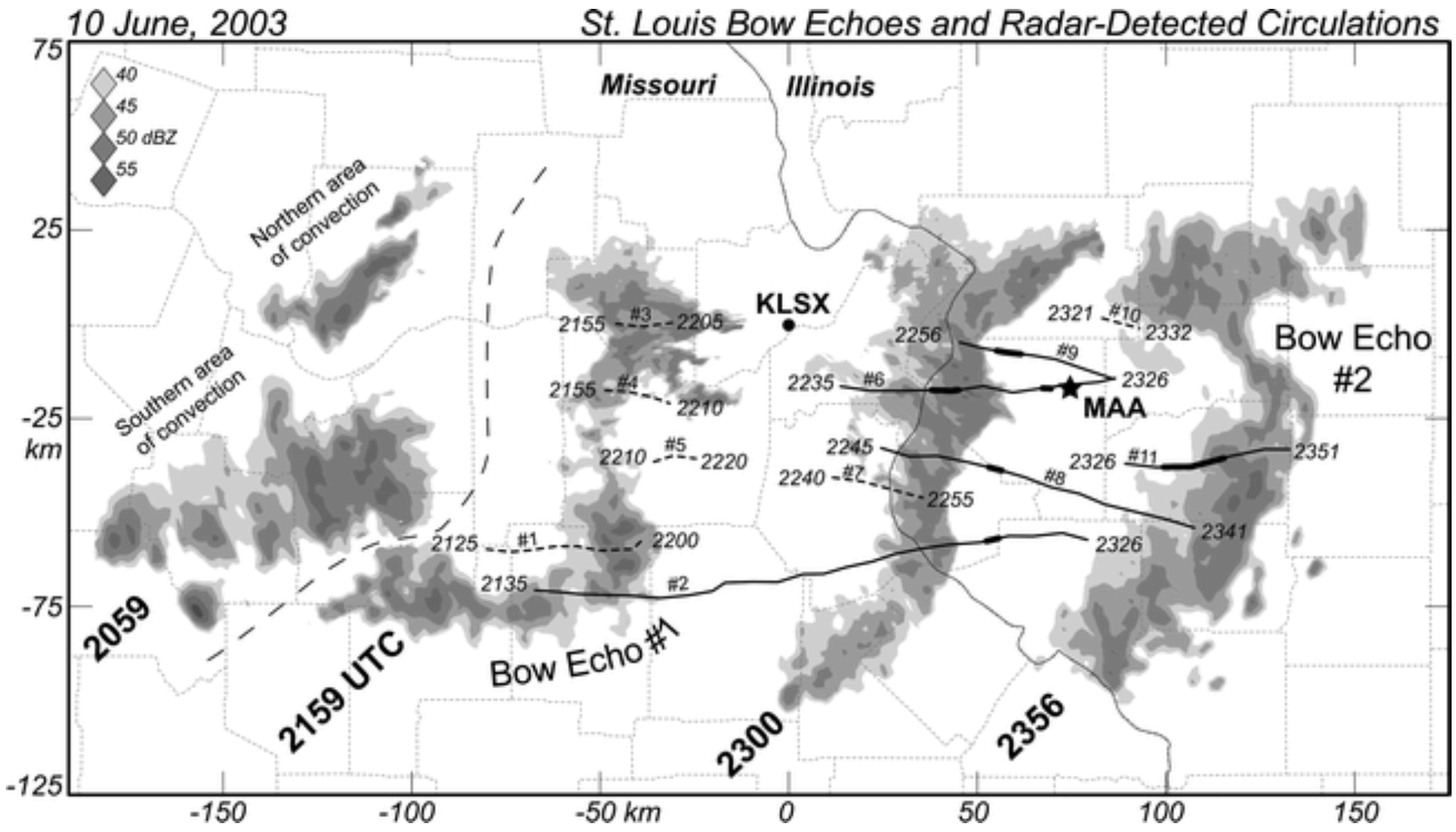


Observations: Atkins et al. (2004)



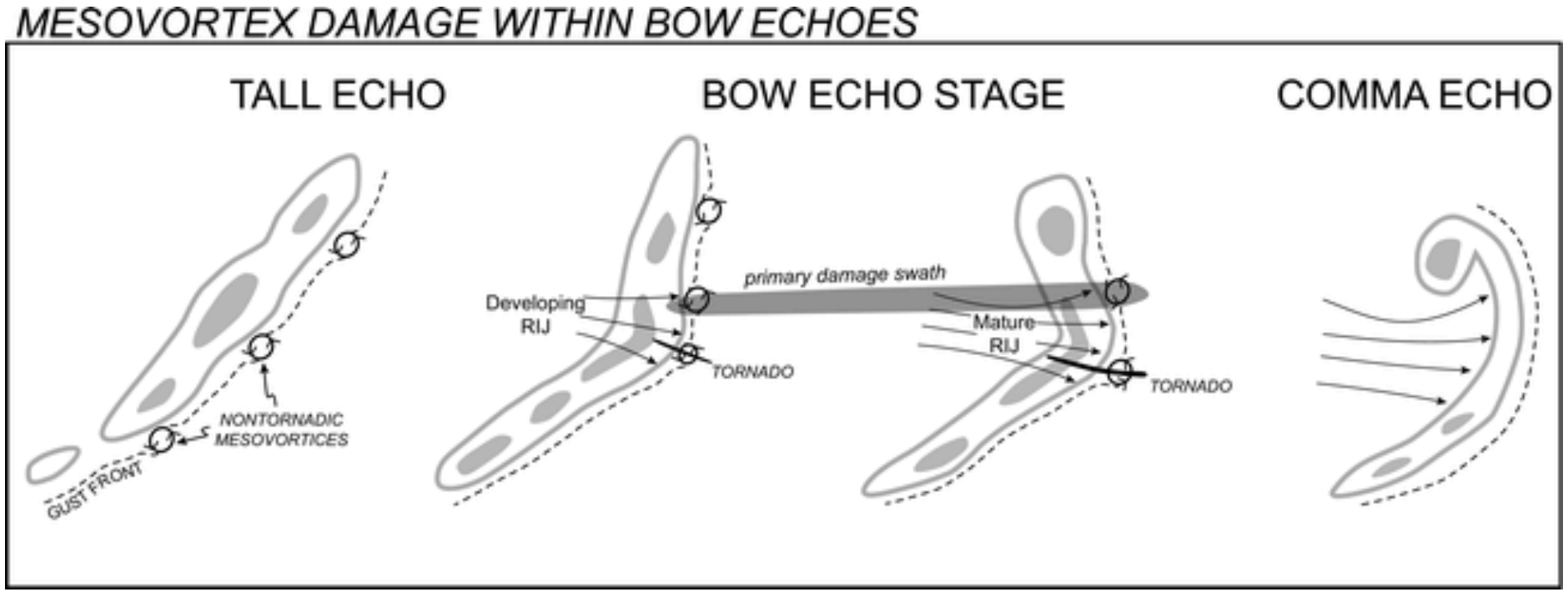
Observations:
Atkins et al. (2004)

Tornadic mesovortices had longer lifespan and stronger low-level rotation than non-tornadic mesovortices.

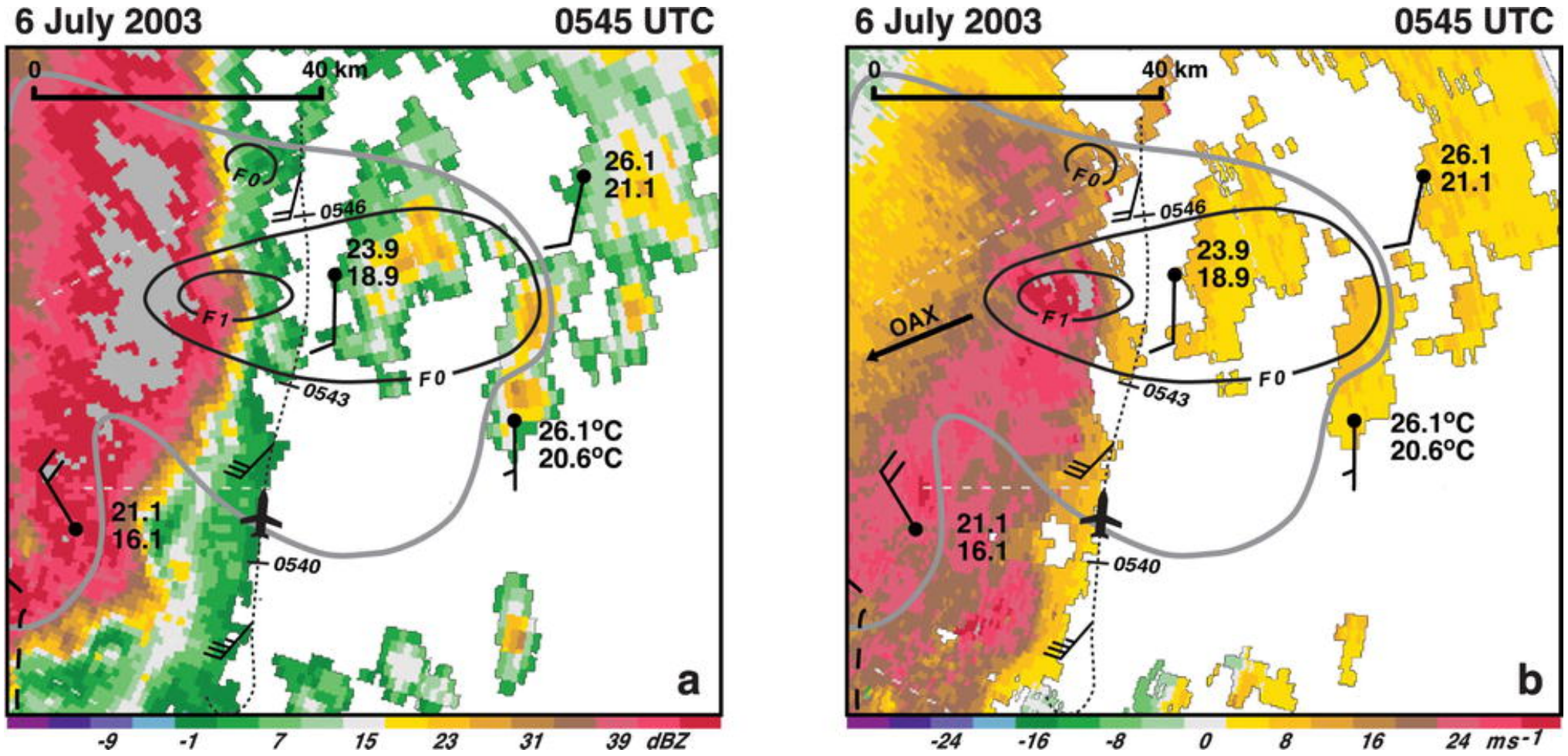


Observations:
Atkins et al. (2005)

Mesovortices coincident with most damaging wind reports, more likely to be tornadic if closer to RIJ.

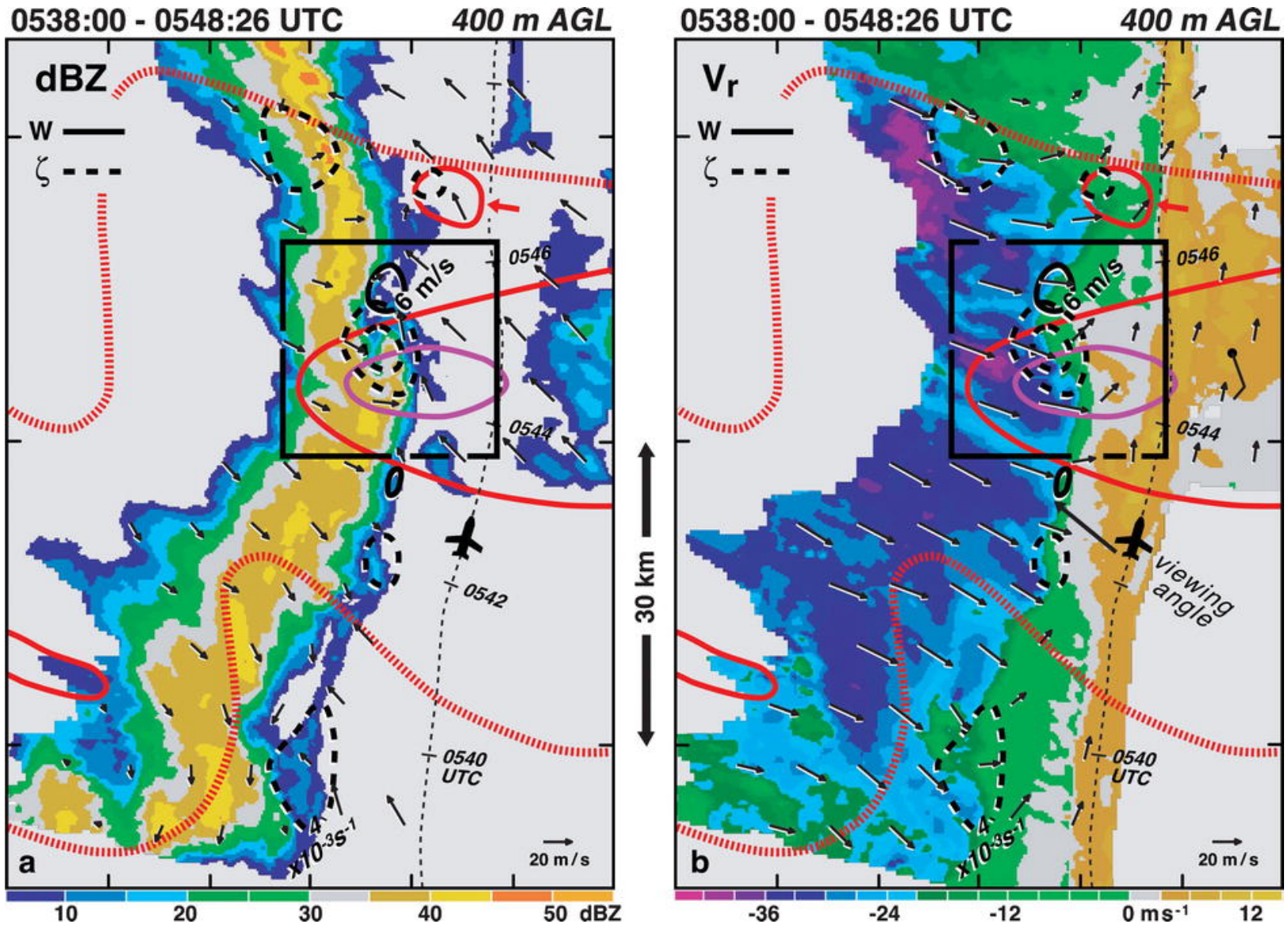


Observations:
Atkins et al. (2005)

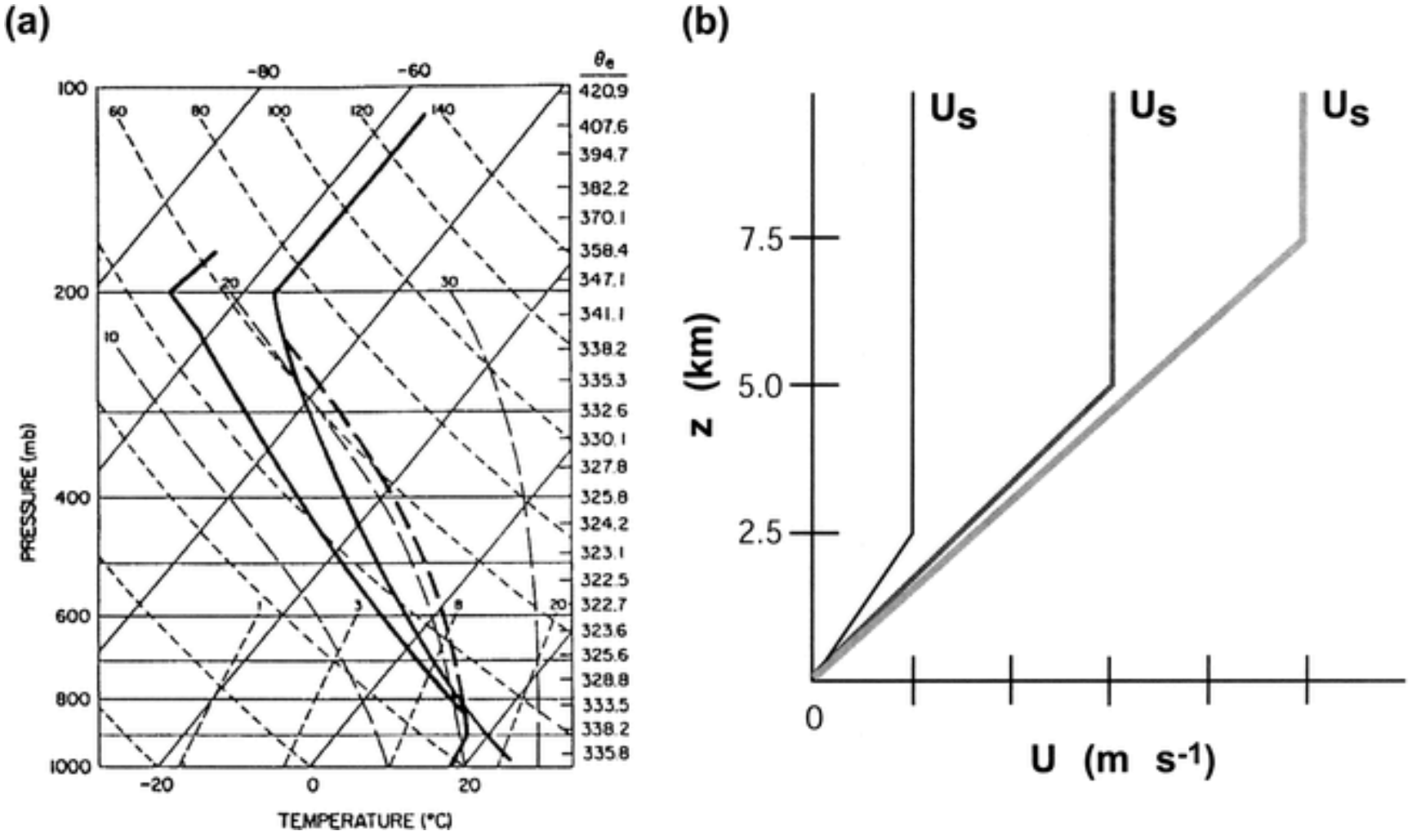


Observations:
Wakimoto et al. (2006)

Damaging winds in this case a result of superposition of mesovortex and RIJ (on south side).



Observations:
Wakimoto et al. (2006)

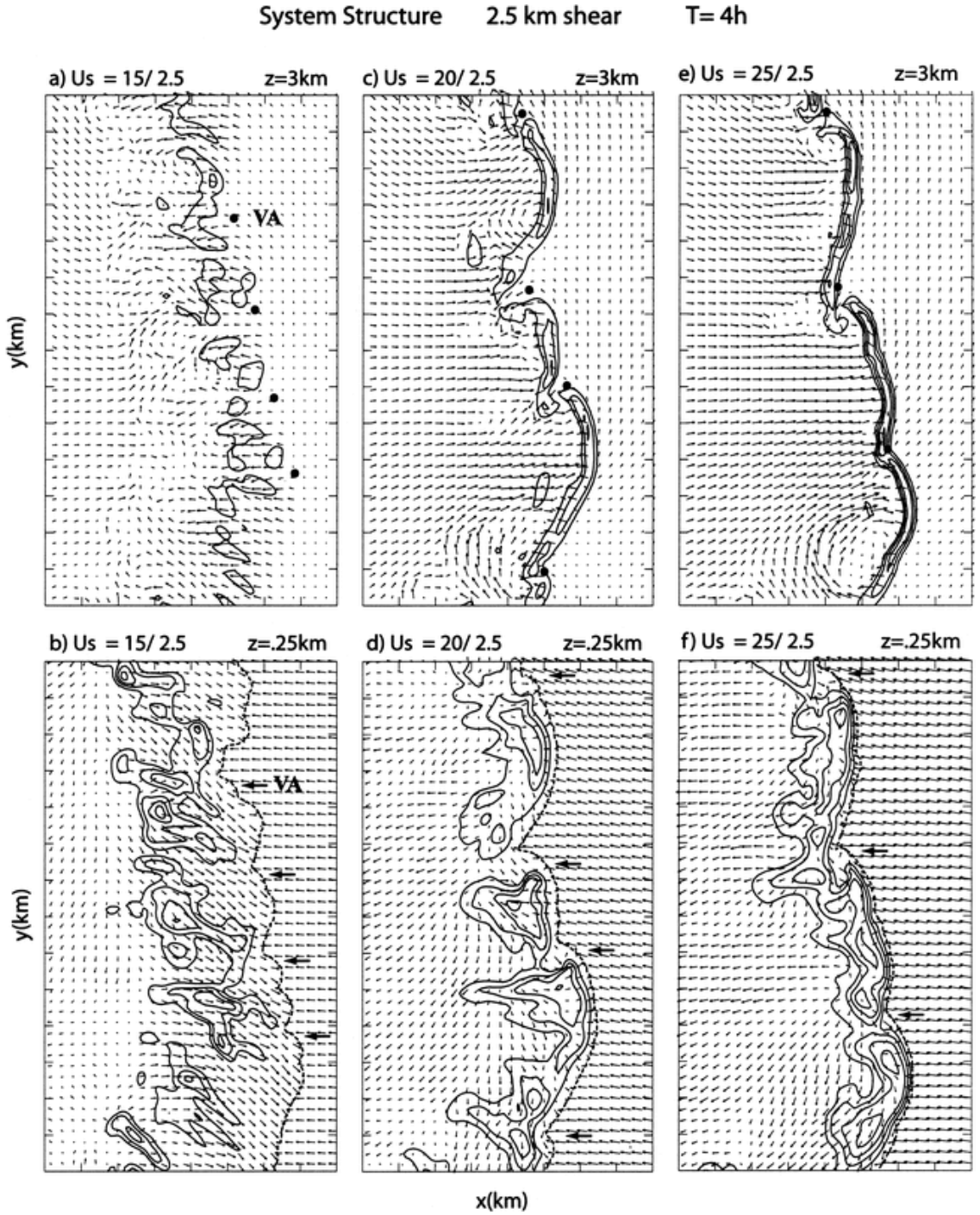


Modeling: Weisman and Trapp (2003)

Modeling: Trapp and Weisman (2003)

Coriolis
2.5 km shear
T=4h

Strongest mesovortices occurred in environments of strong low-level shear.



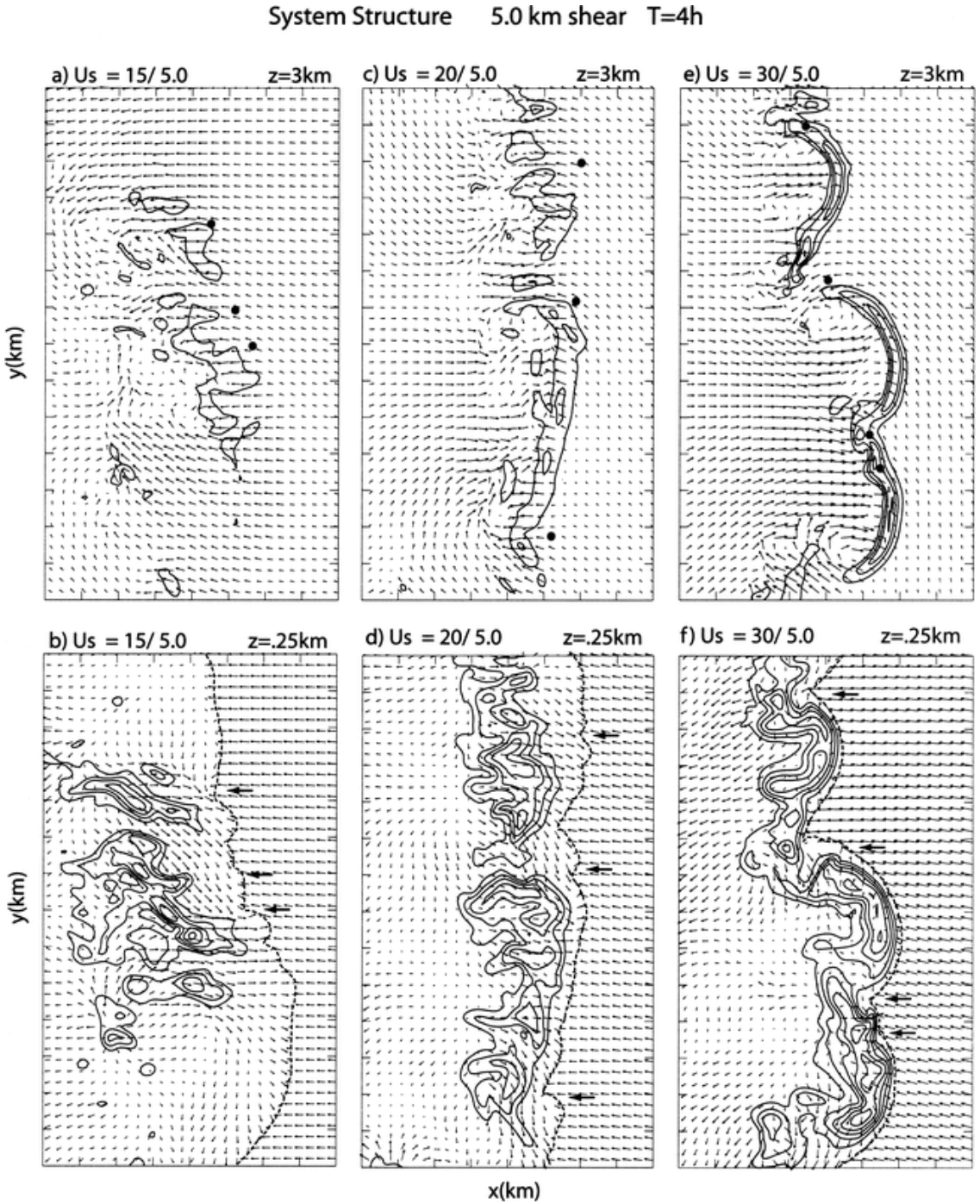
z=3 km

z=.25 km

Modeling: Trapp and Weisman (2003)

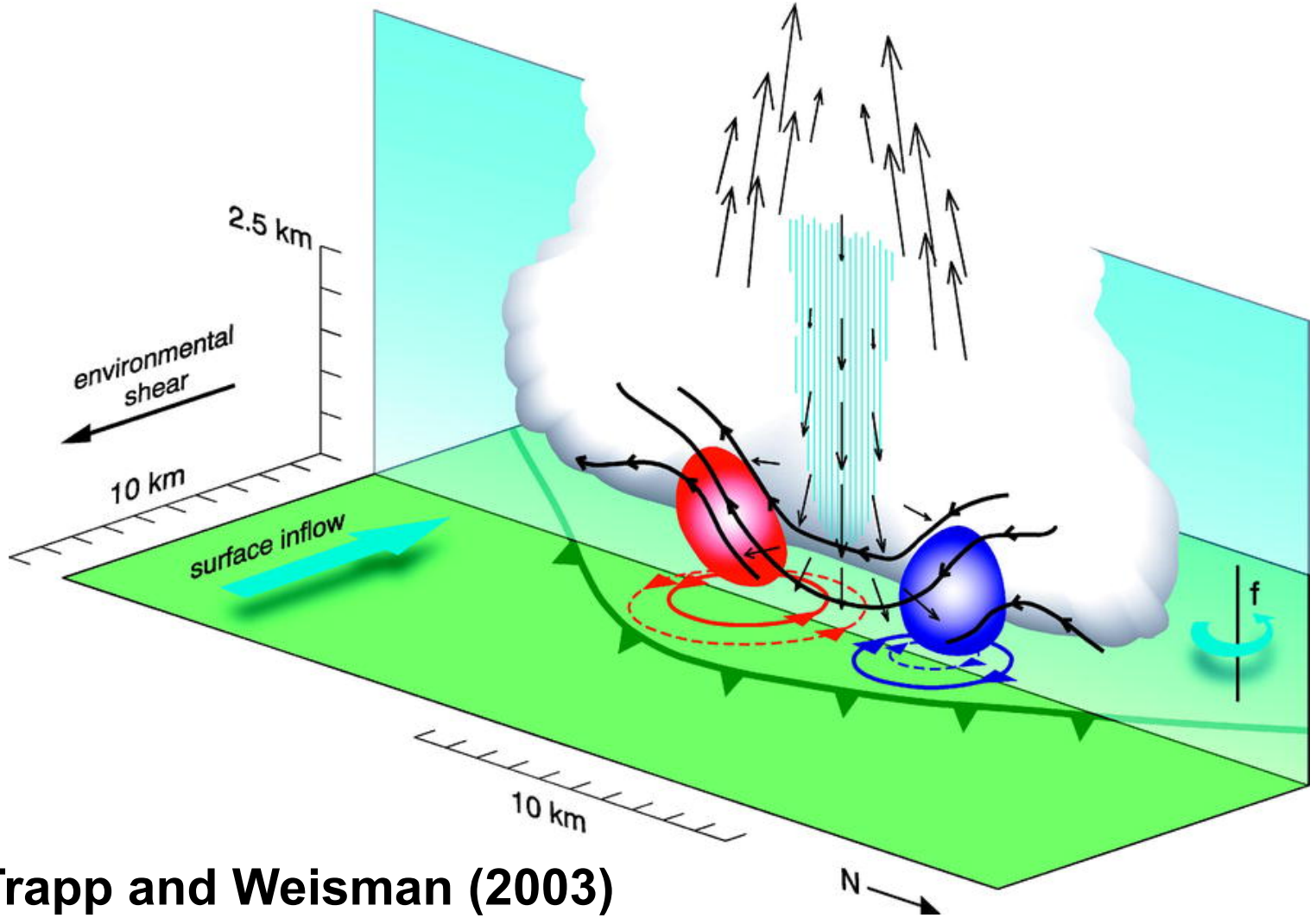
Coriolis
5 km shear
t=4h

Strongest mesovortices occurred in environments of strong low-level shear.



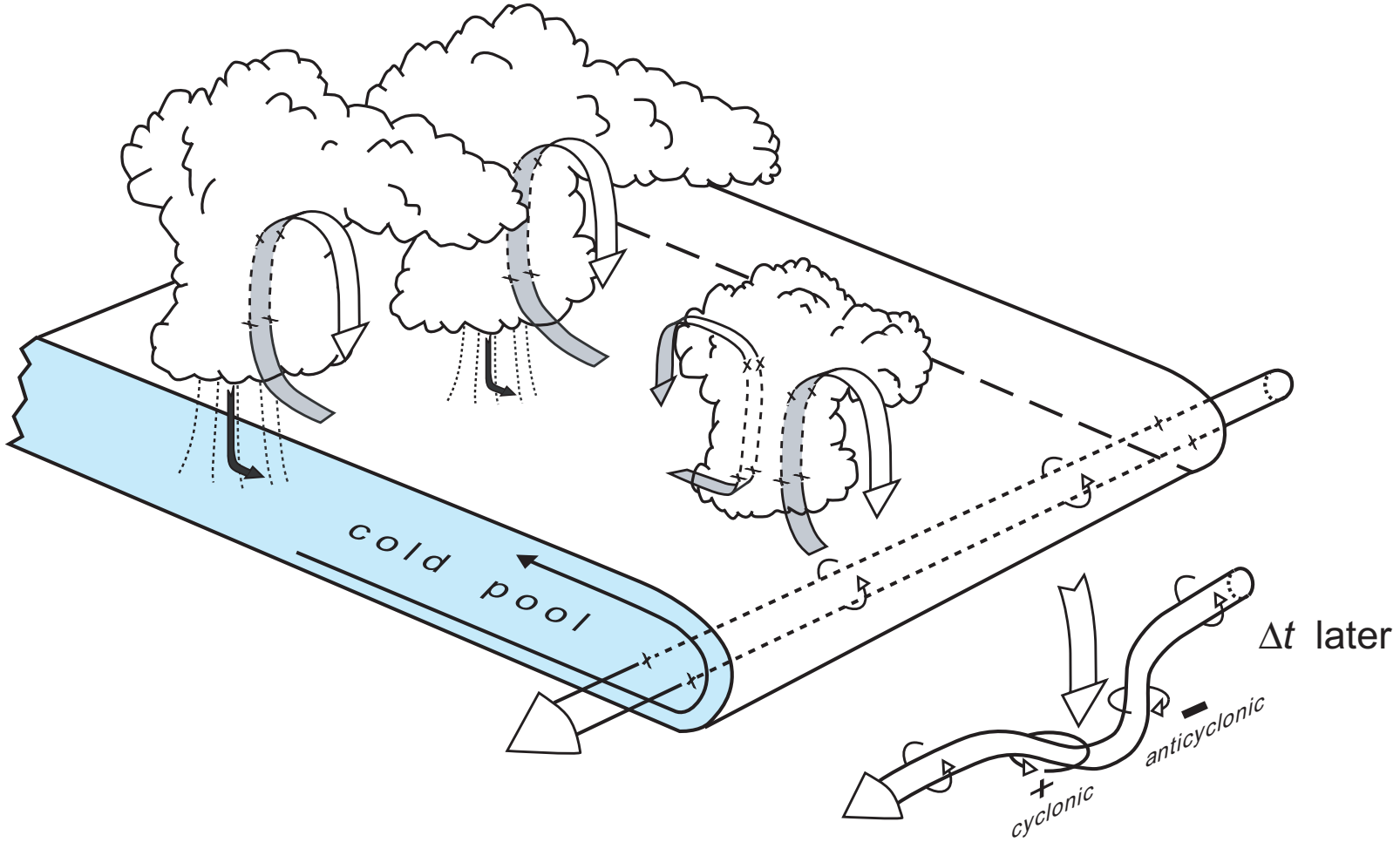
z=3 km

z=.25 km



Modeling: Trapp and Weisman (2003)

Vortex generation driven by tilting of *crosswise* vorticity by rainy downdraft. Cyclonic vortex favored due to impacts of Coriolis. In mature phase, horizontal vorticity can be due to RIJ.

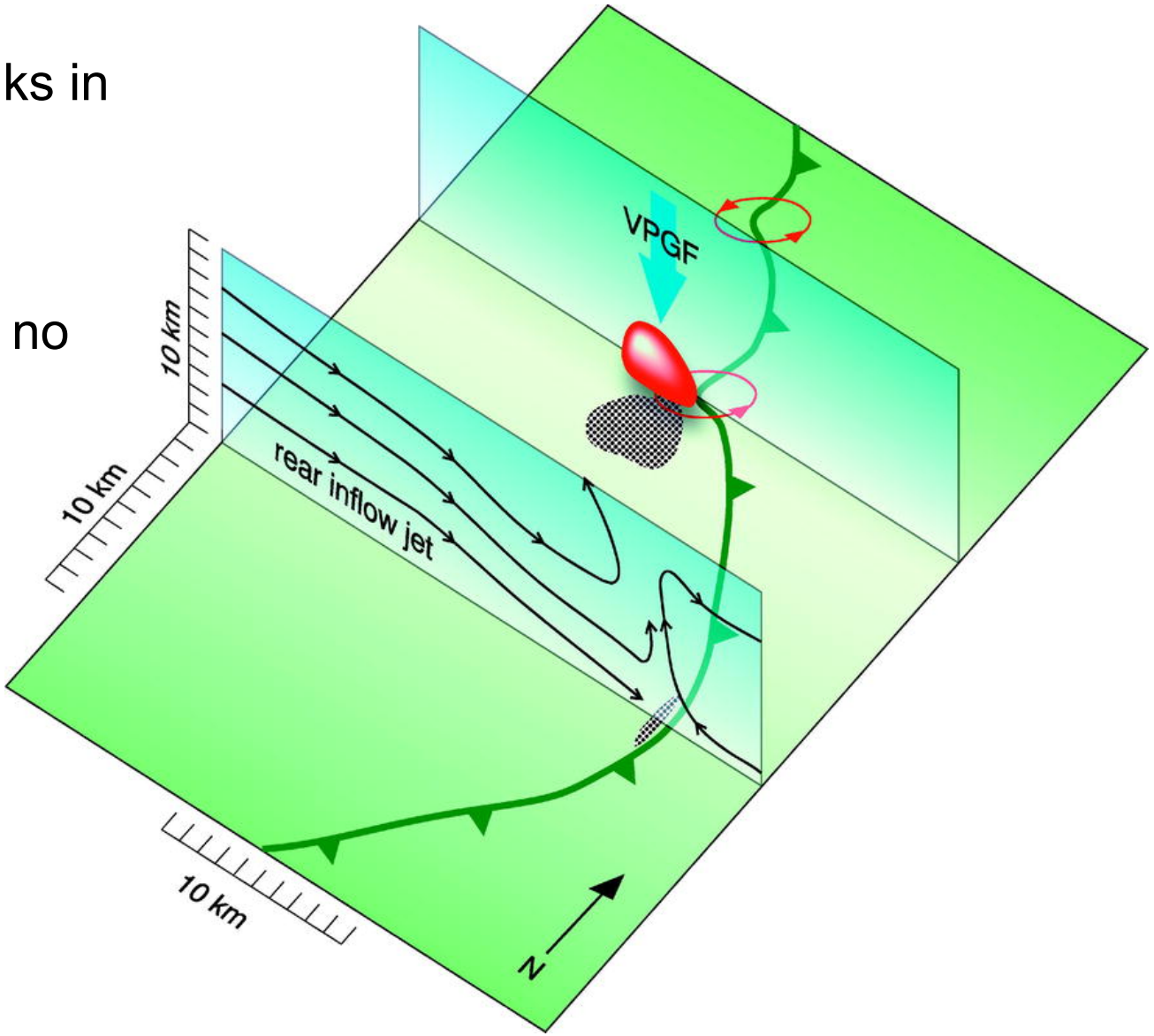


Similar mechanism identified in Wakimoto et al. (2006) based on observations, but in that case they determined that downdraft was “mechanically forced” along edge of updrafts (i.e., compensating downdrafts).

Modeling: Trapp and Weisman (2003)

VPPGF due to mesovortex produced kinks in QLCS.

No deviant propagation as in supercells, no upward dynamic VPPGF. Streamwise vorticity/SRH thinking not useful.

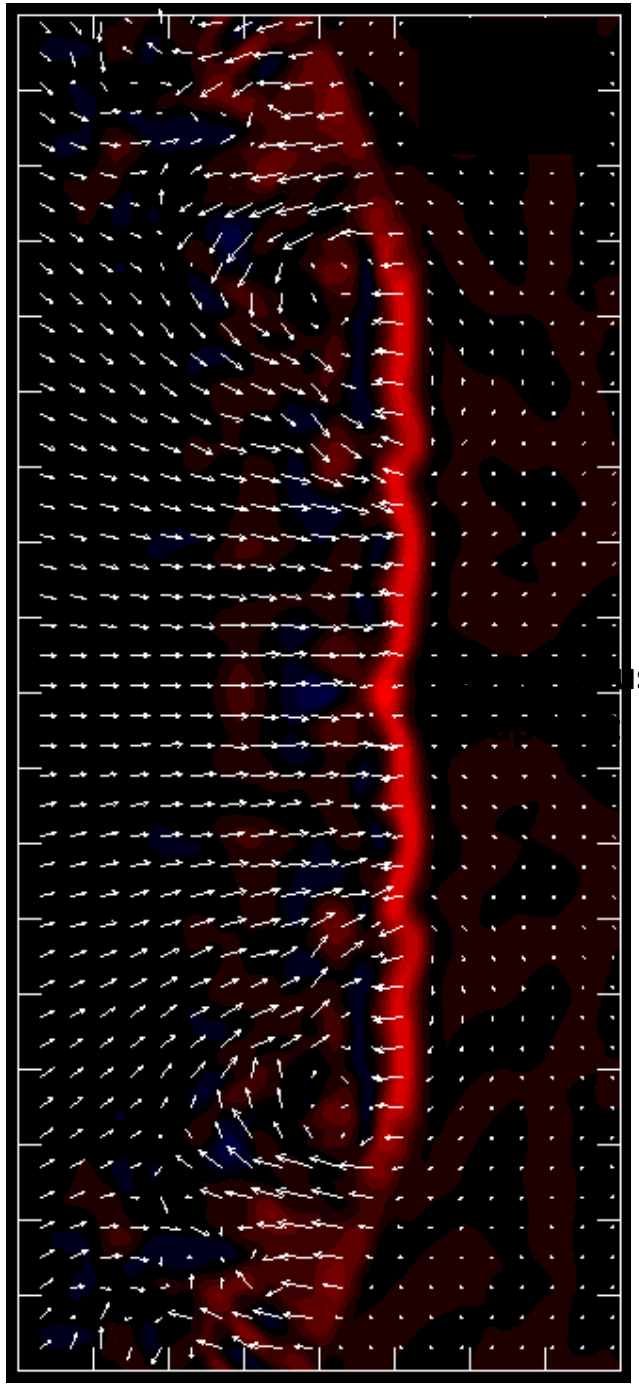


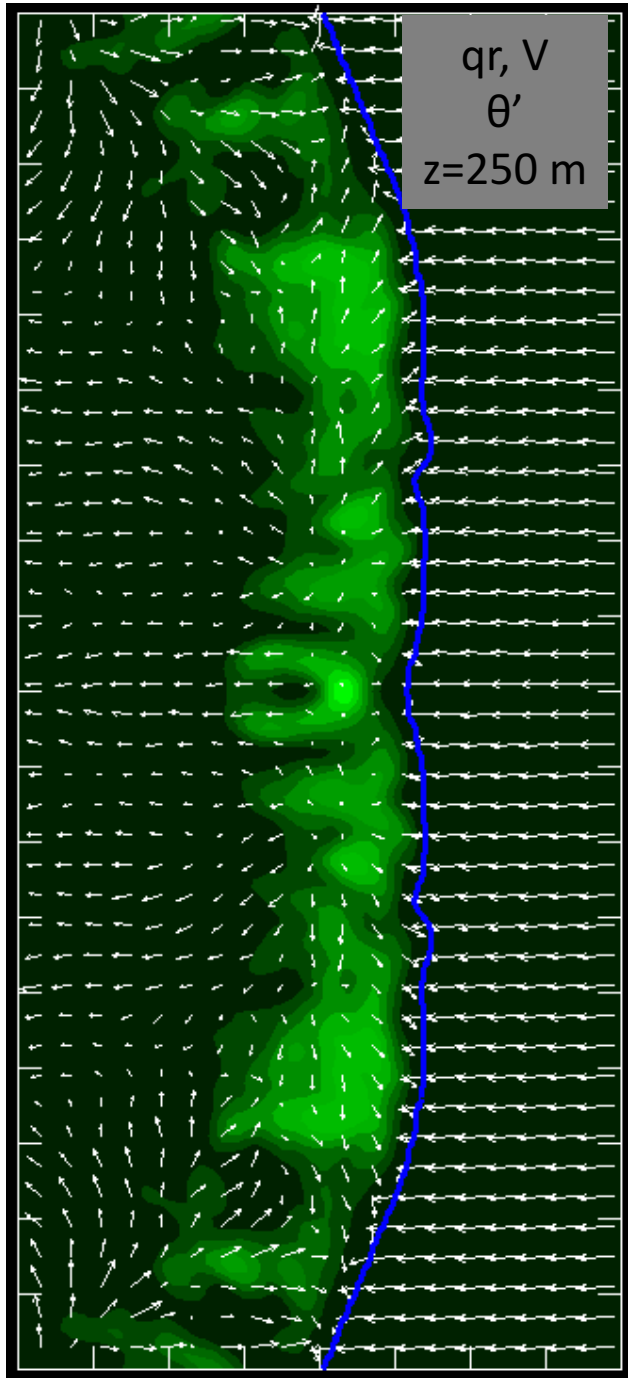
No Coriolis!

U_S = 20/2.5

f=0

t = 4 hr





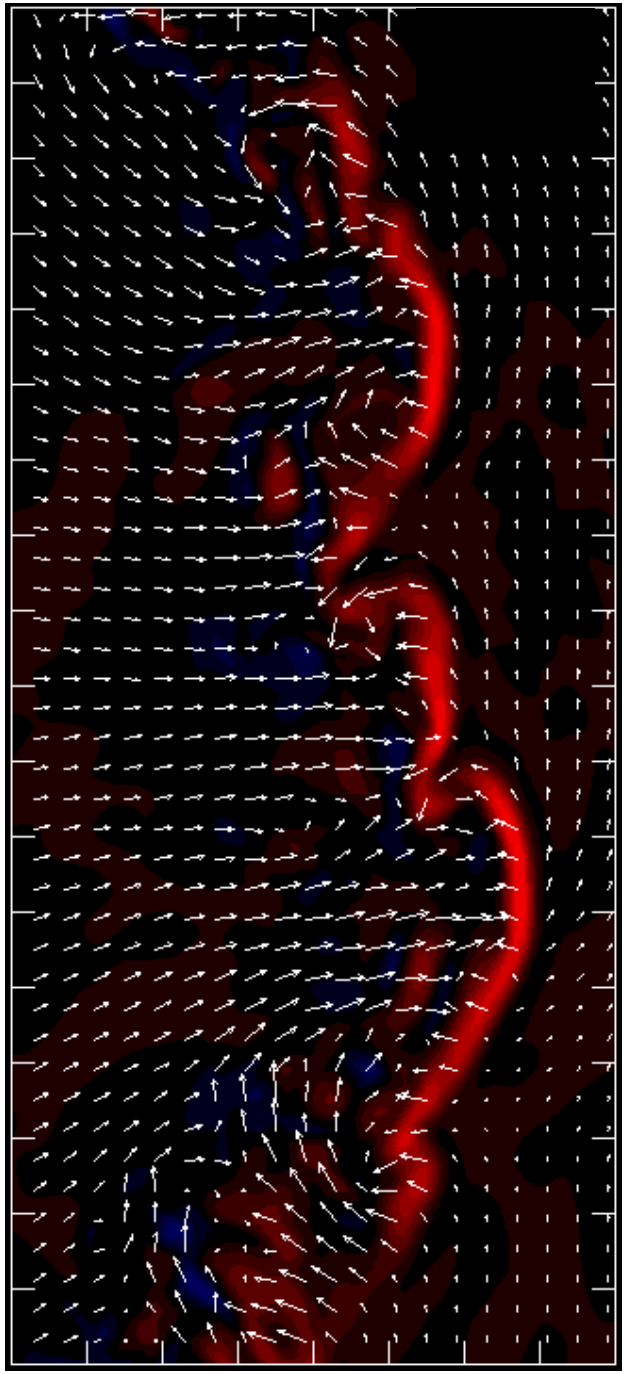
no meso-vortices!

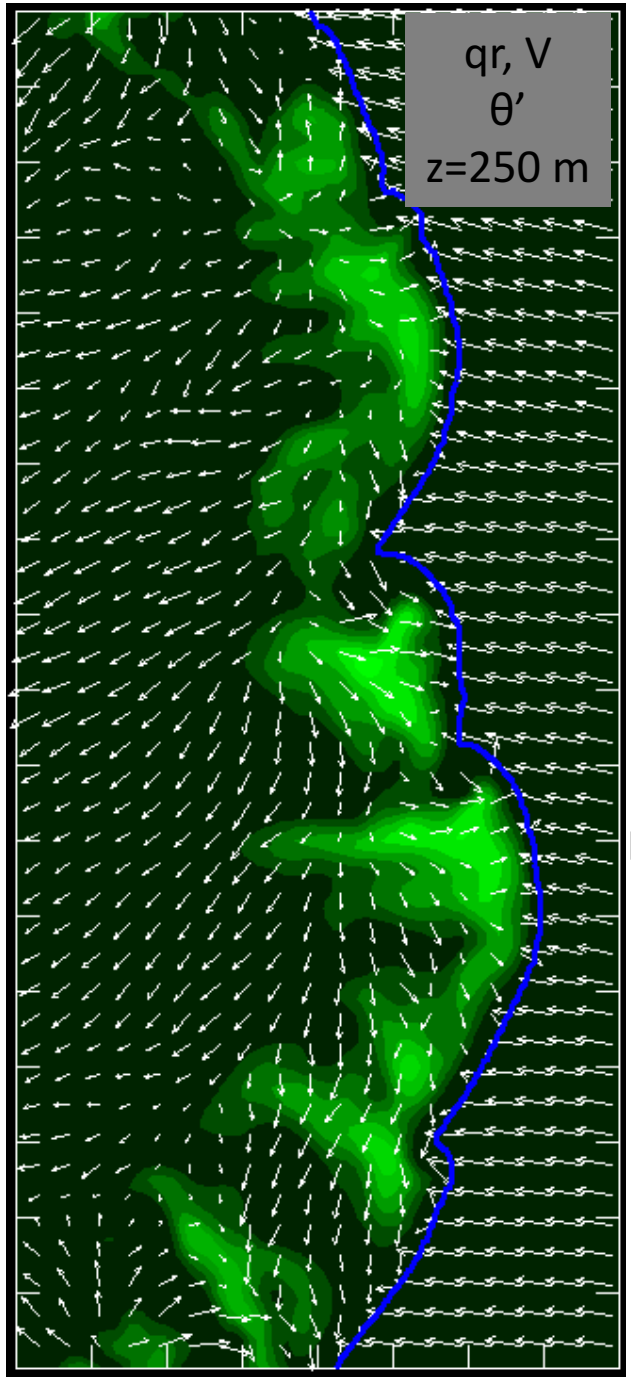
50 km

Coriolis!

U_S = 20/2.5

t = 4 hr





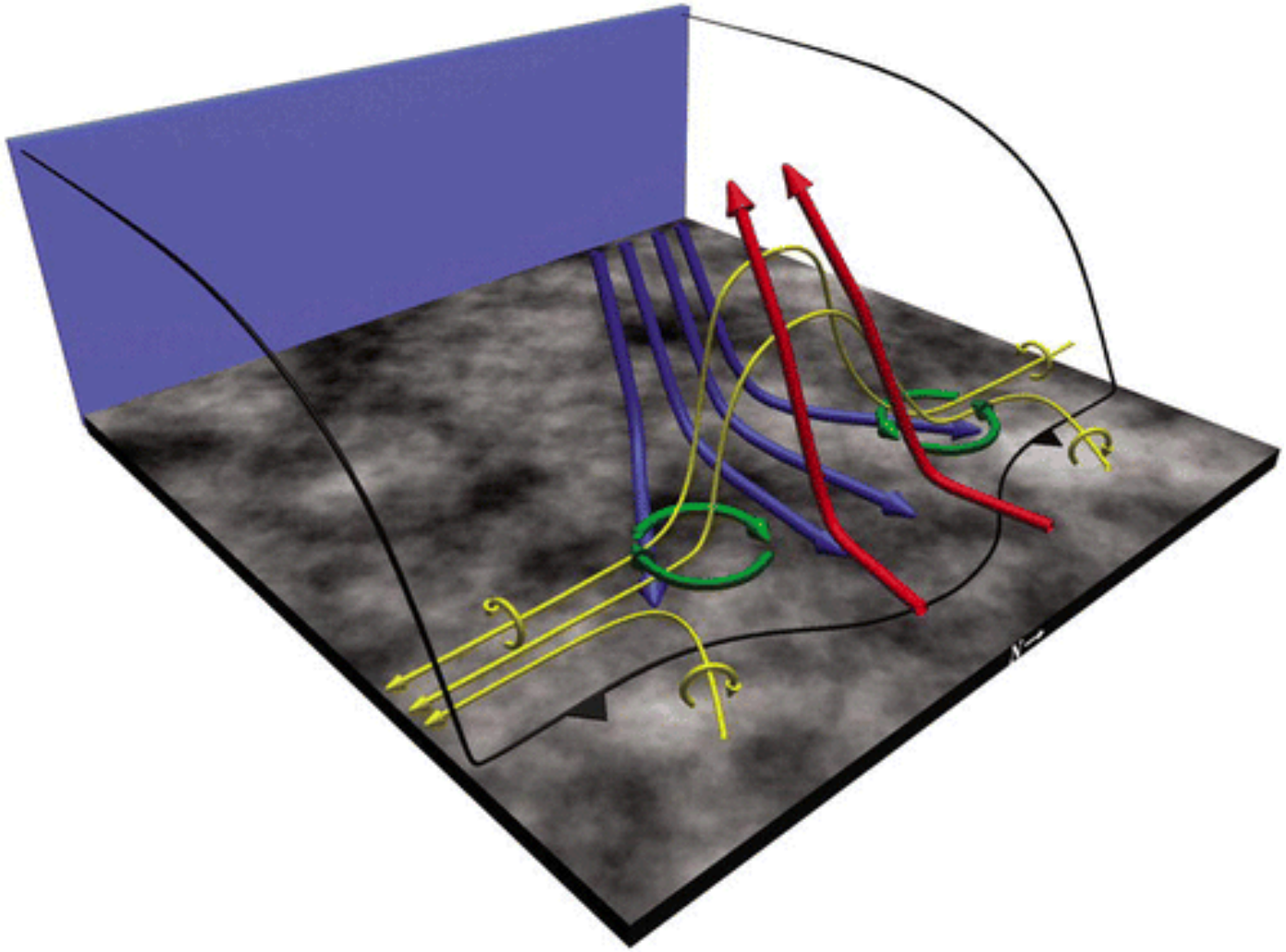
50 km

locational bias

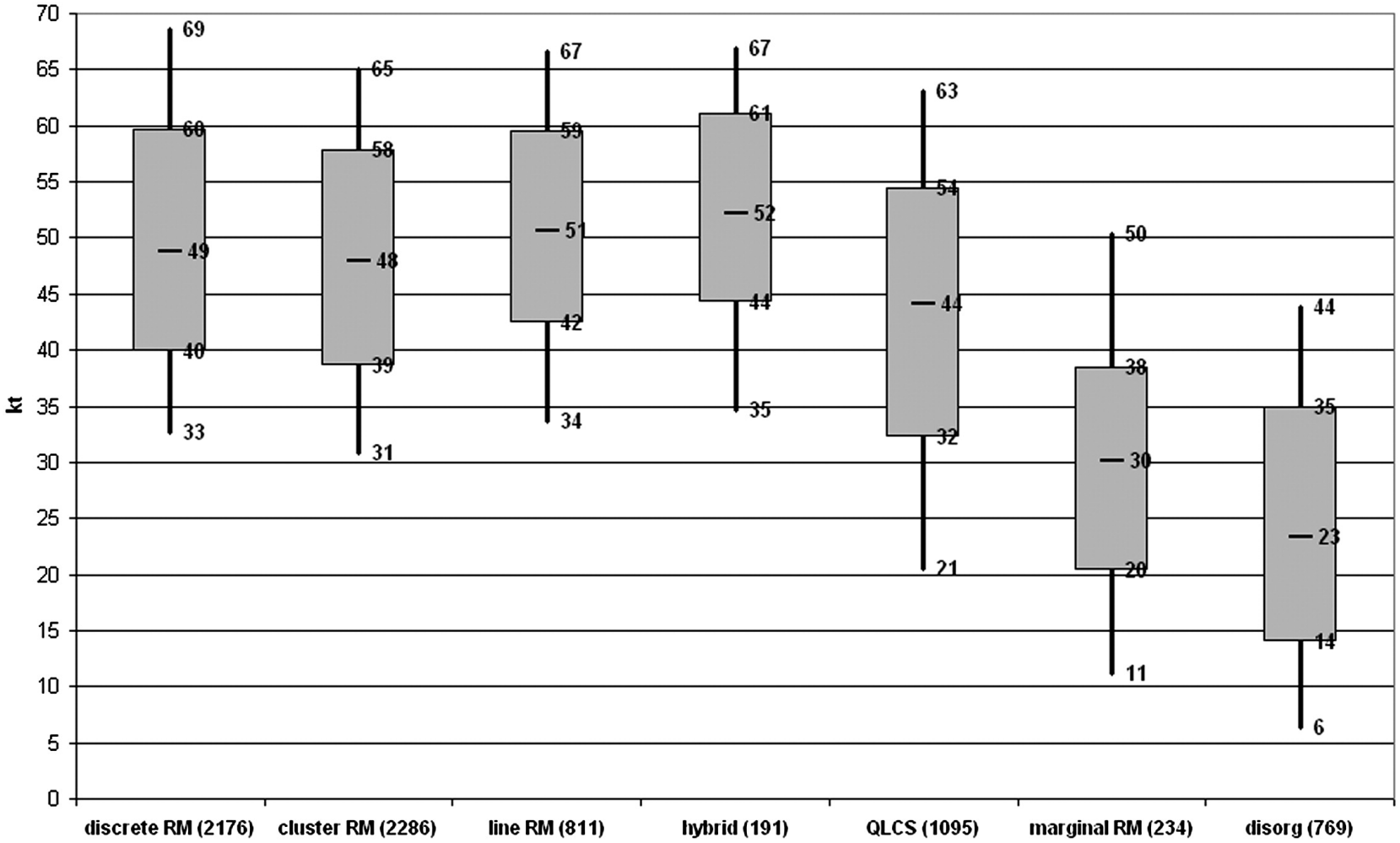
Modeling: Atkins and Laurent (2009)

Other mechanisms have been identified that lead to mesovortices, including the ***upward*** tilting of horizontal vorticity by a localized strong updraft associated with an outflow surge.

Cyclonic member of pair favored while anti-cyclonic member of pair weakened (simulations were run with Coriolis forcing).



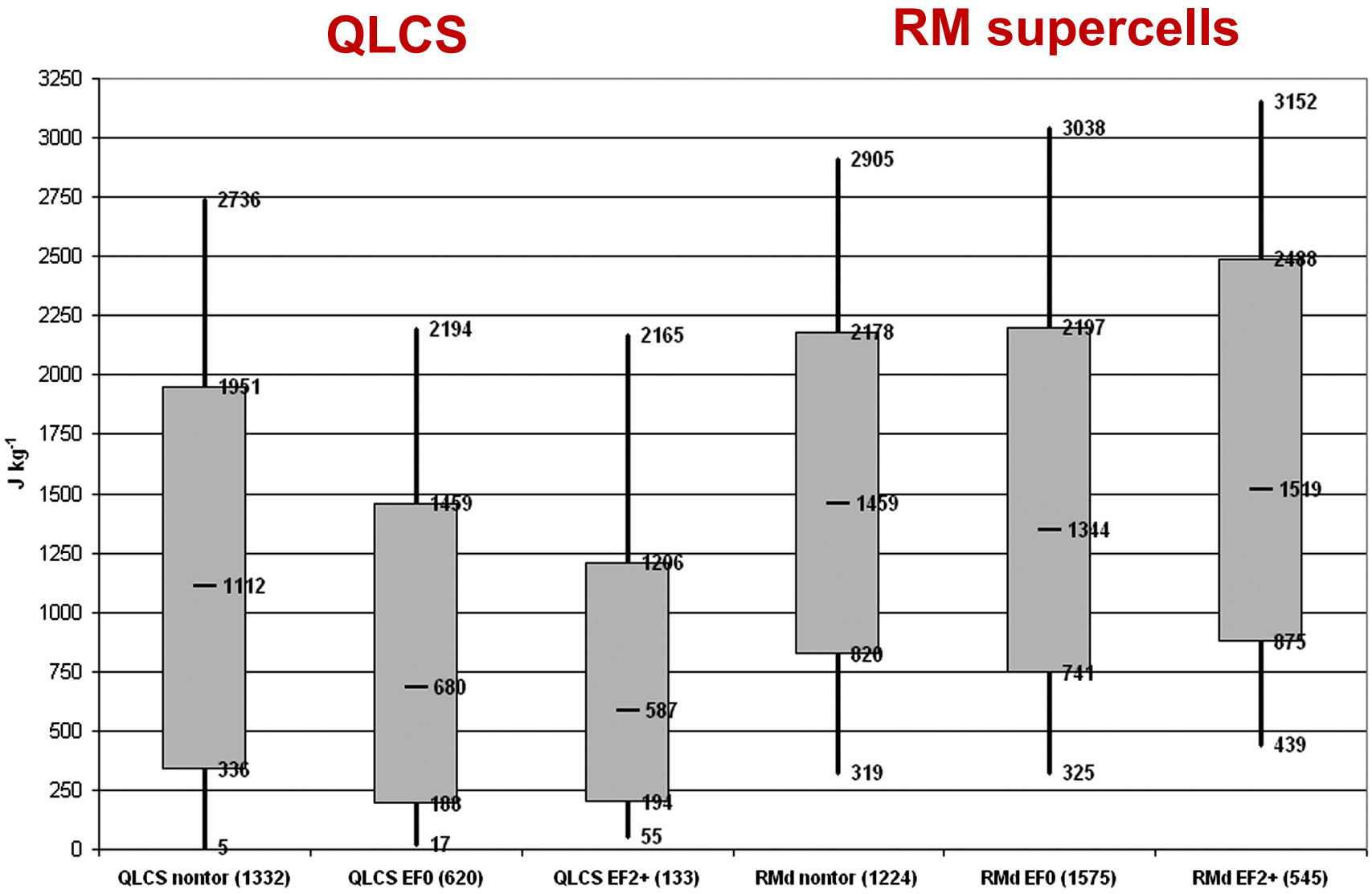
Environments of tornadic QLCS and supercells



Thompson et al. (2012)

Effective BWD (EBWD)

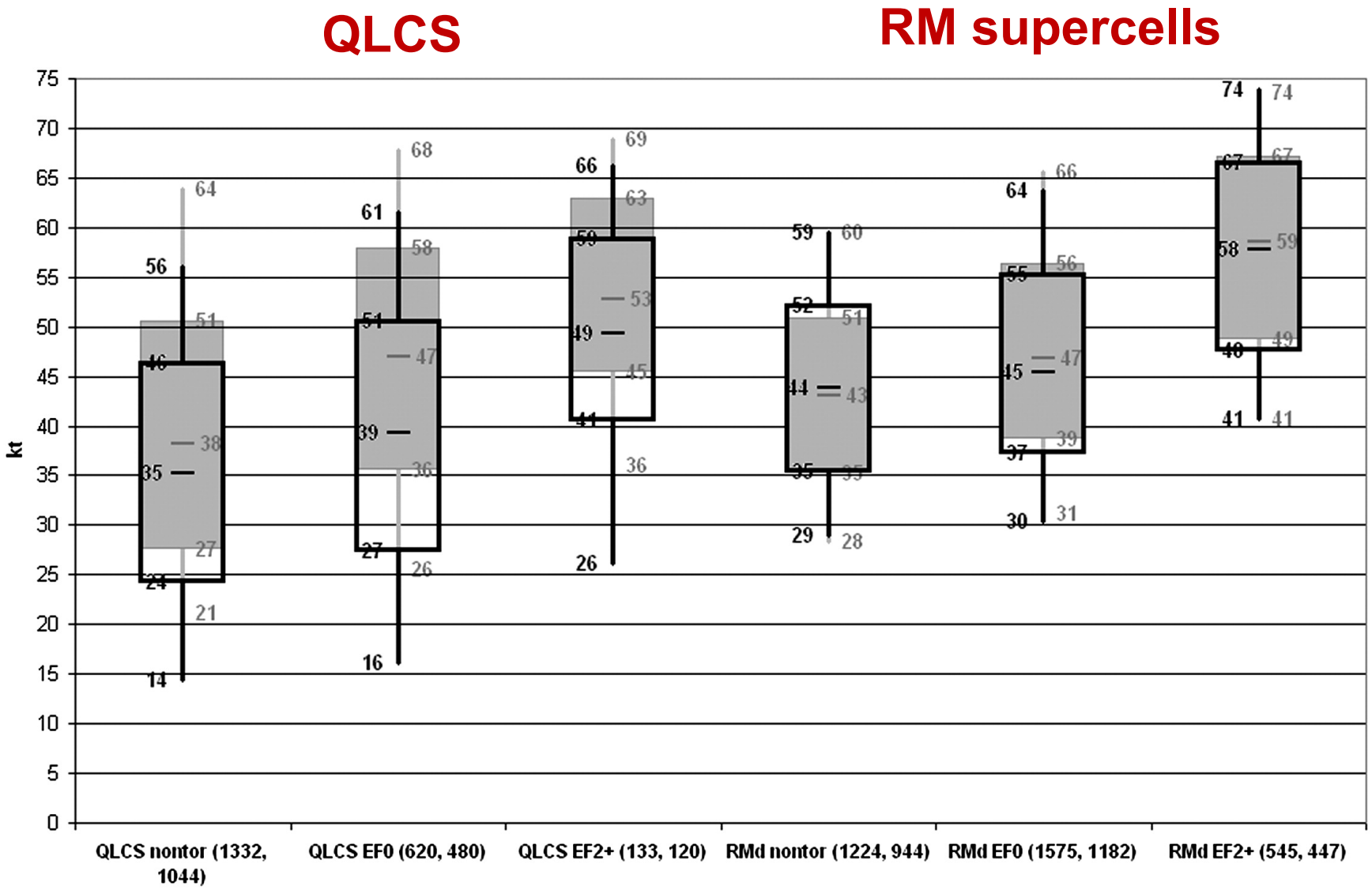
Environments of tornadic QLCS and supercells



Thompson et al. (2012)

MLCAPE

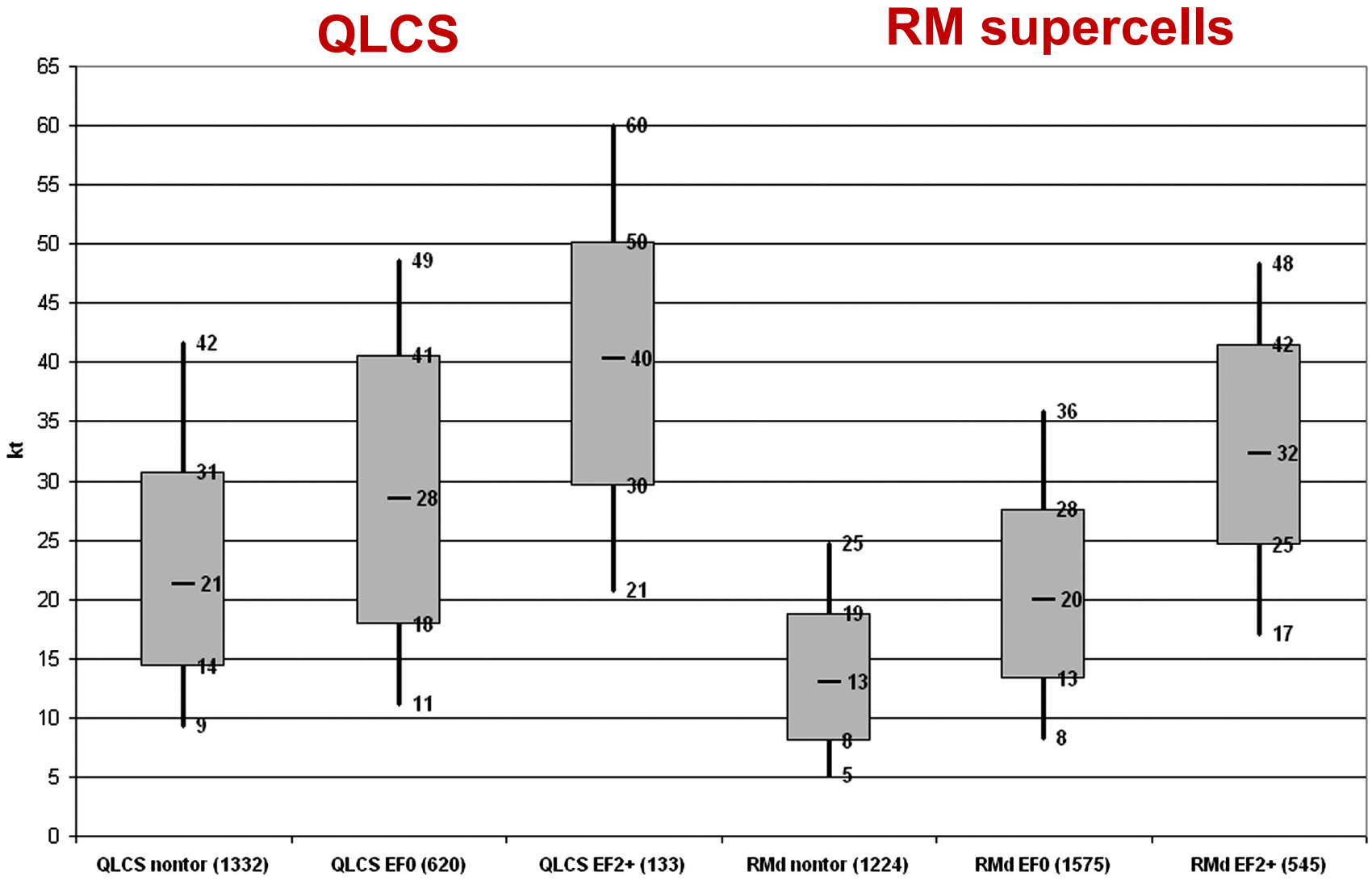
Environments of tornadic QLCS and supercells



Thompson et al. (2012)

0-6 km BWD/EBWD (bulk wind difference)

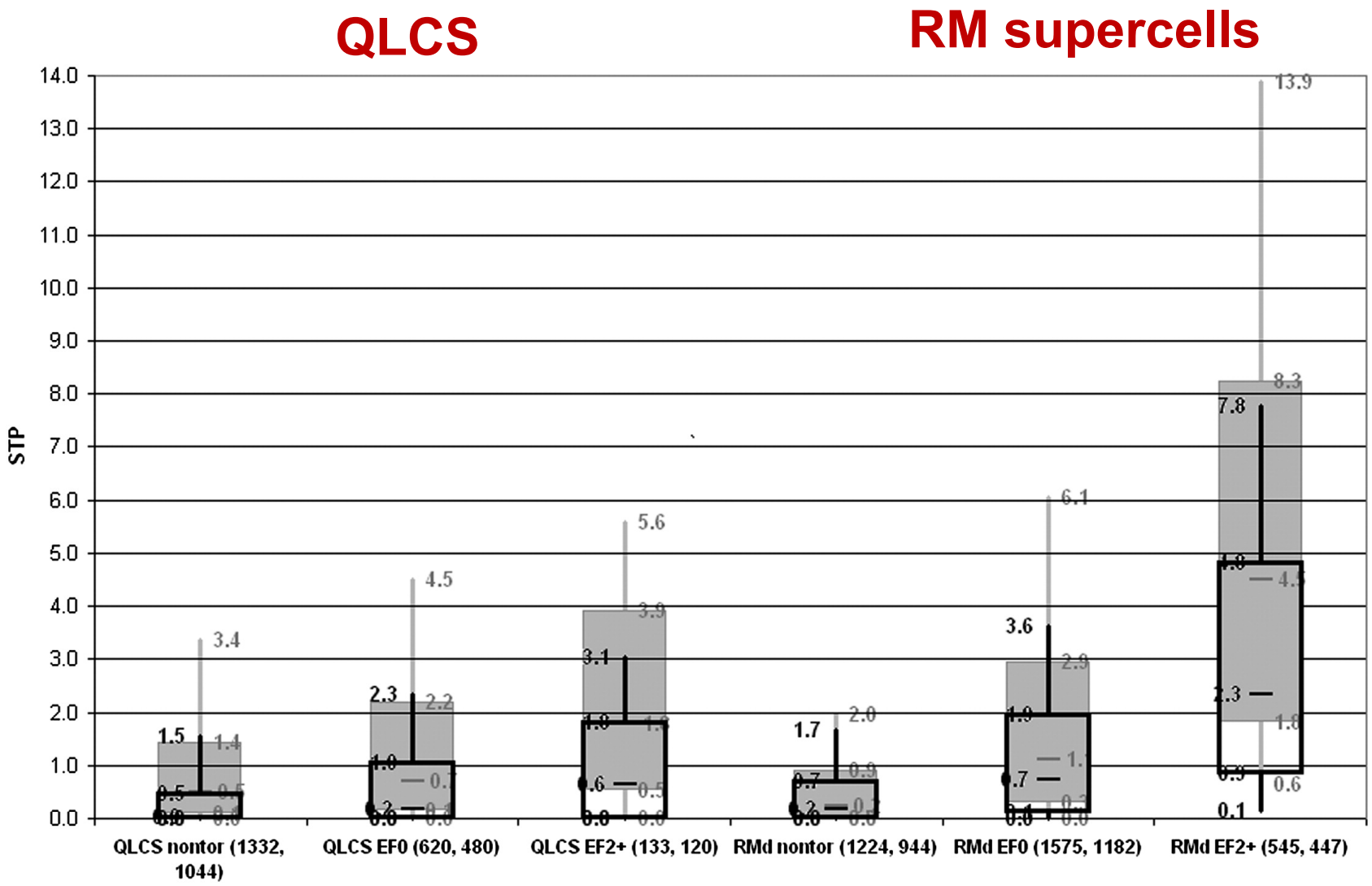
Environments of tornadic QLCS and supercells



Thompson et al. (2012)

0-1 km BWD (bulk wind difference)

Environments of tornadic QLCS and supercells



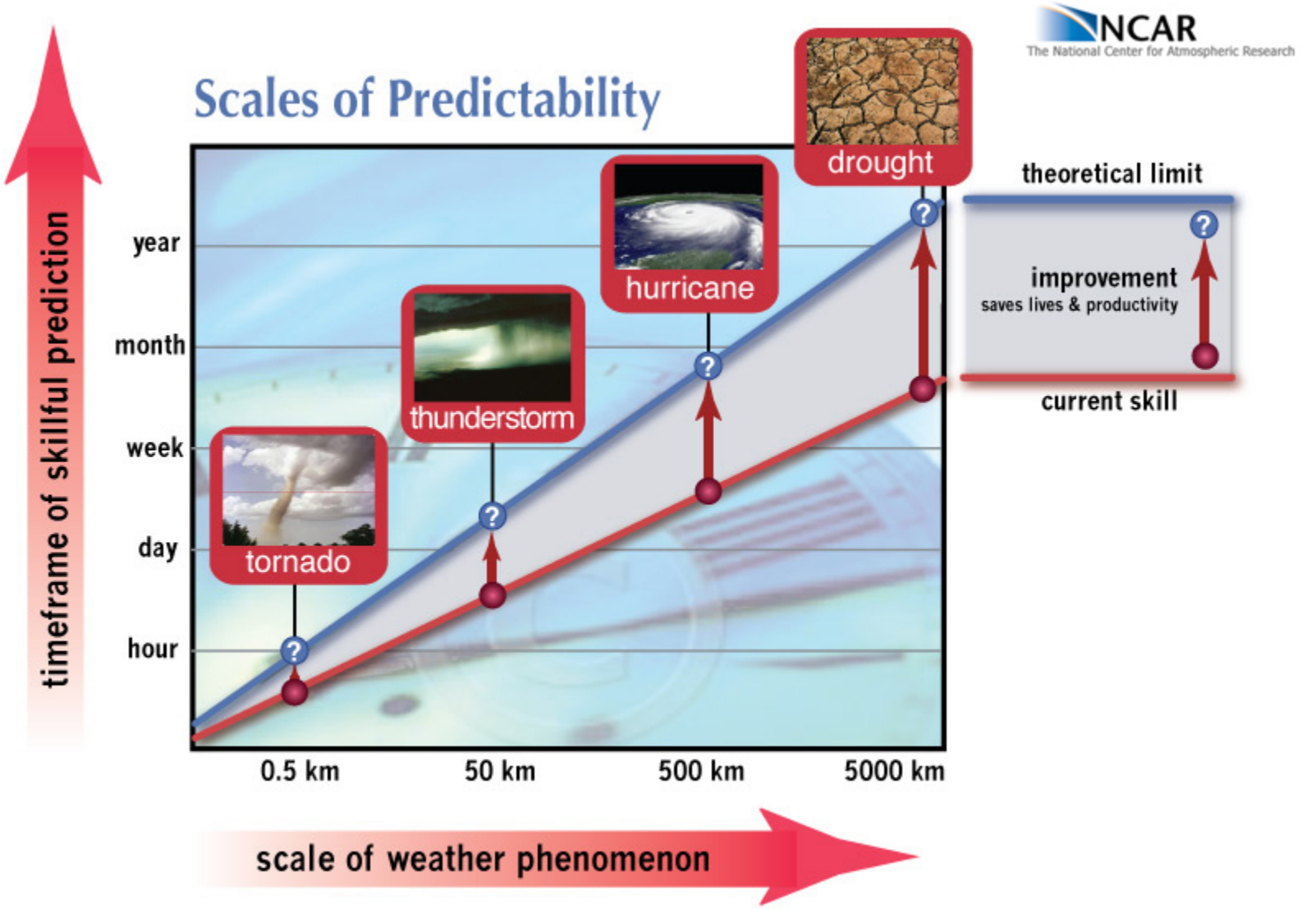
STP/ESTP

Thompson et al. (2012)

”…environmental differences between the supercells and linear modes were relatively small, indicating that point measures of buoyancy and vertical wind shear alone are not able to clearly discriminate between storm modes in a practical sense. Thus, convective mode forecasts must necessarily rely on factors such as shear vector and mean wind orientation to the storm initiation focus [i.e., a surface dryline or cold front, after Dial et al. (2010)], the magnitude of the ascent along the initiating boundary, as well as initial storm spacing and potential storm interactions (Bluestein and Weisman 2000).”

Thompson et al., (2012)

Predictability: What can we hope to do?



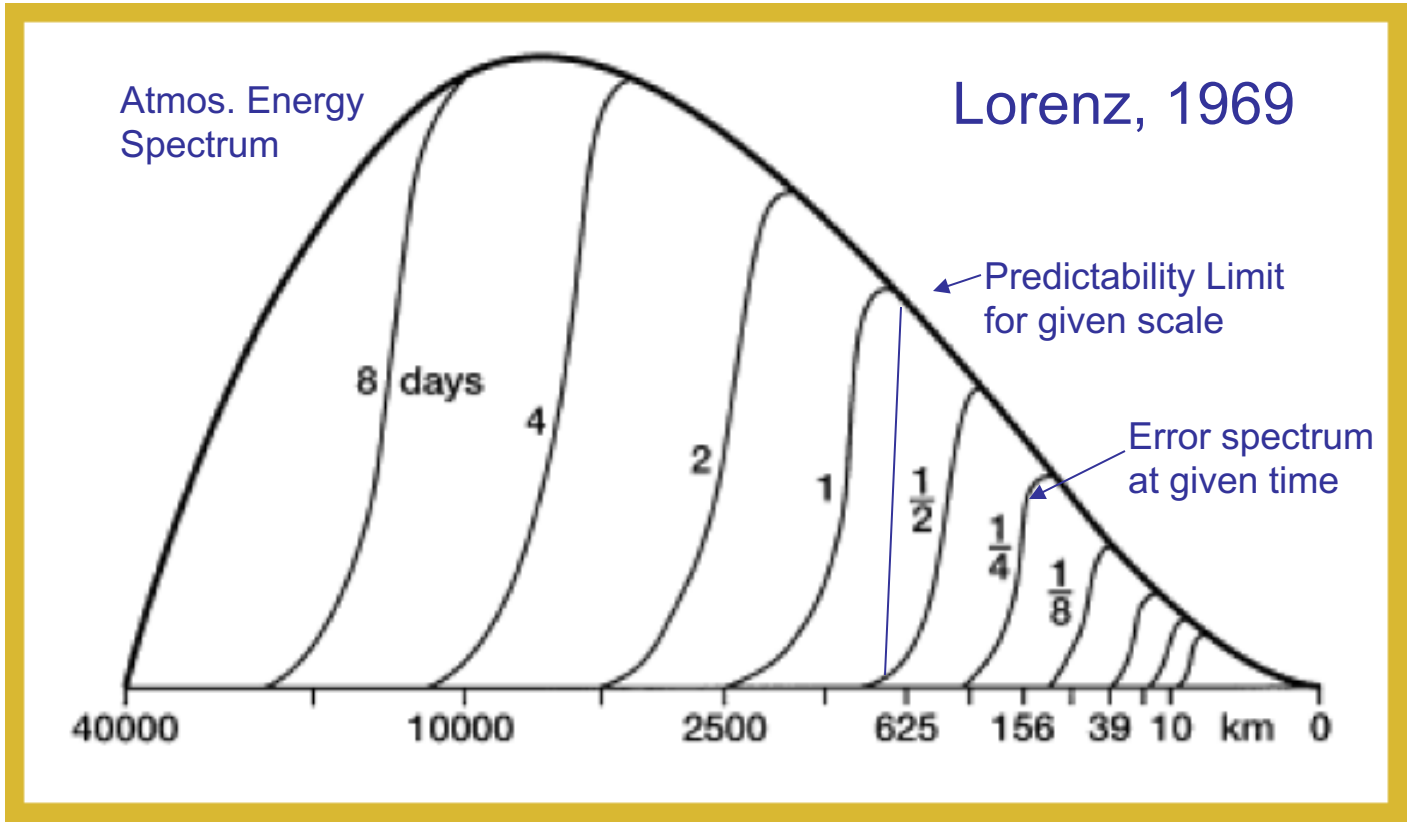
Practical predictability – the ability to predict based with current state of the art prediction systems

Controlled by deficiencies in ICs, forecast models, grid spacing, data assimilation methodologies, domain sizes, computing limitations, etc.

Intrinsic predictability – the extent to which prediction is possible if an ideal procedure is used

Controlled by chaotic nature of atmosphere; rapid error growth in convection.

Intrinsic Predictability Limits??



Scale (km)

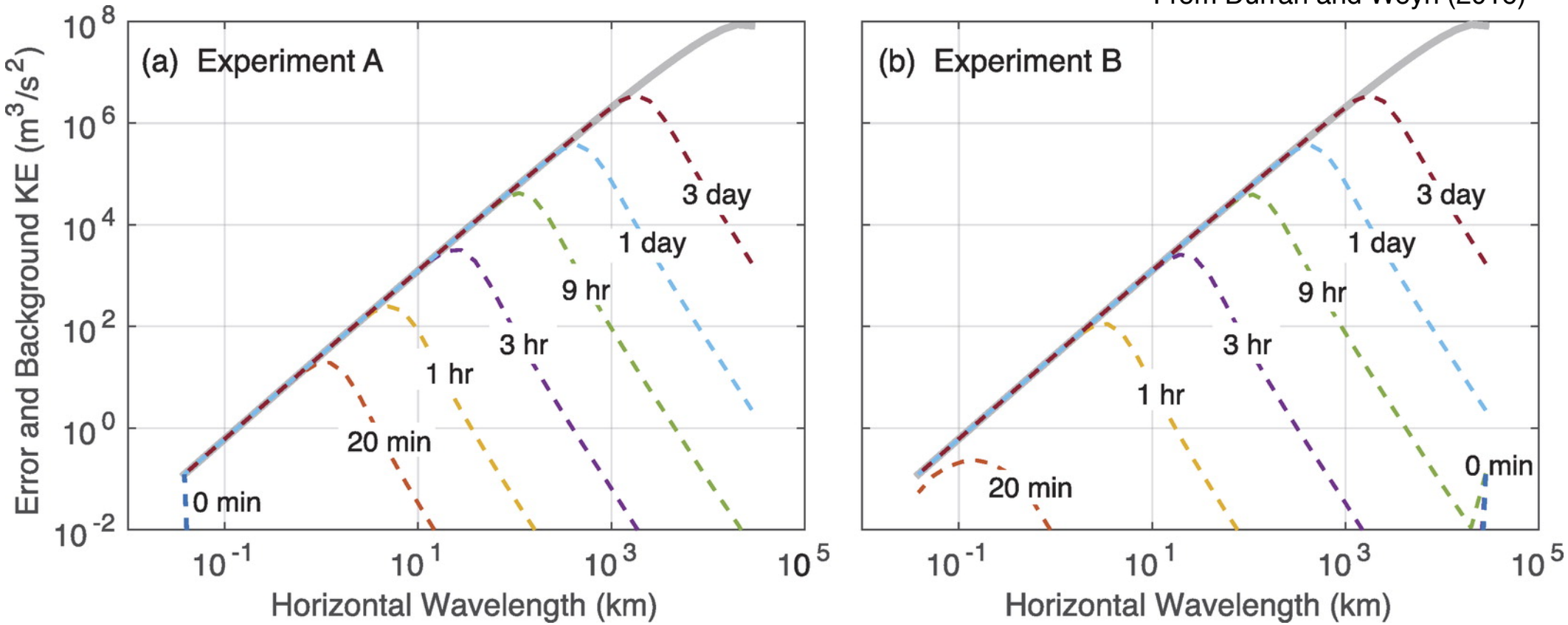
Subsynoptic waves (~1200 km): ~1.5 days

Convective Systems (~300 km): ~12 h

Thunderstorms (~10 km): ~ 1h

Intrinsic Predictability Limits??

From Durran and Weyn (2016)

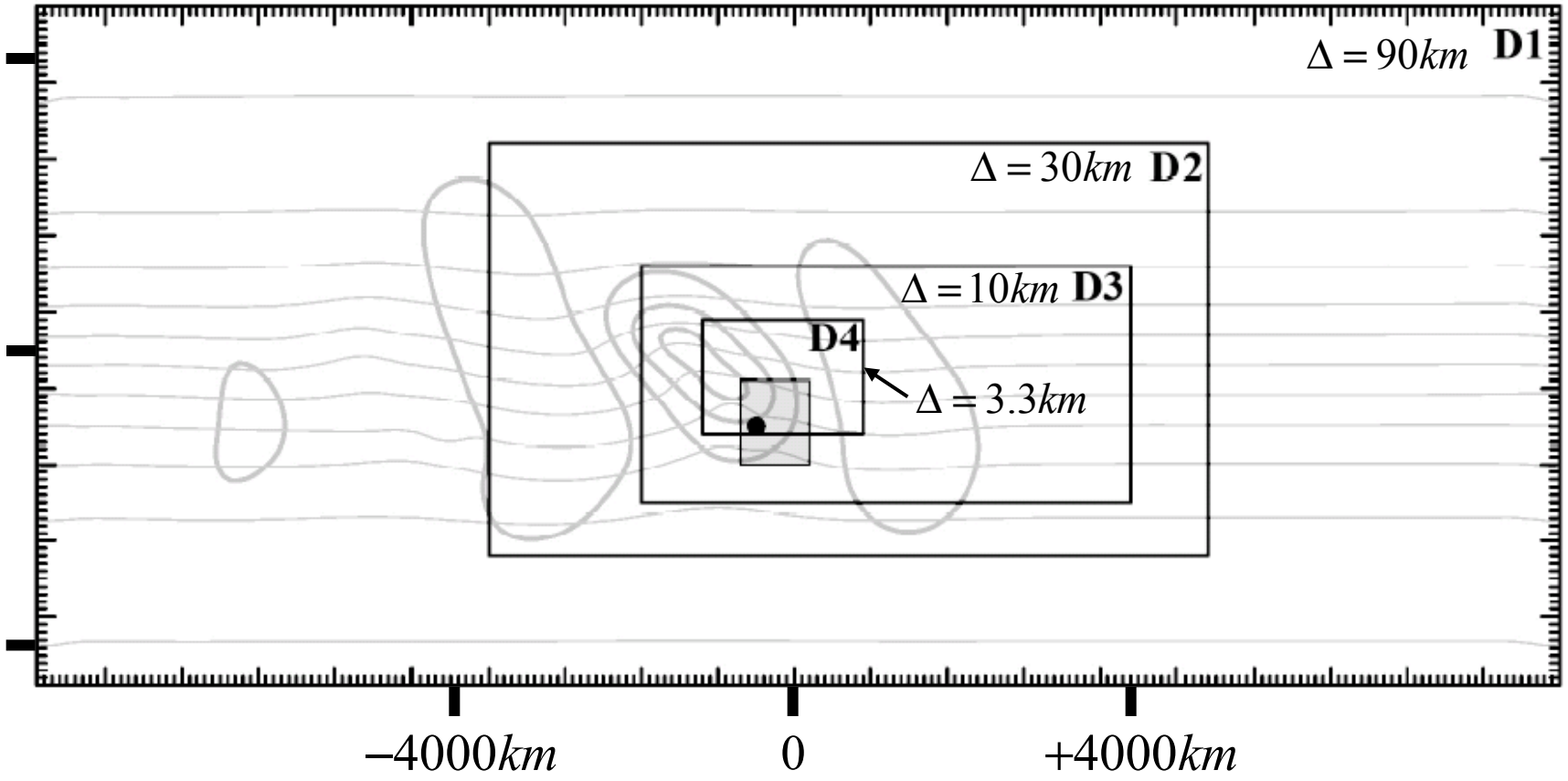


Small-scale initial error (38 m)
Large relative error to background KE

Large-scale initial error (28,000 km)
Small relative error to background KE

Errors grow upscale and become “saturated”

Baroclinic Waves / Moist Convection

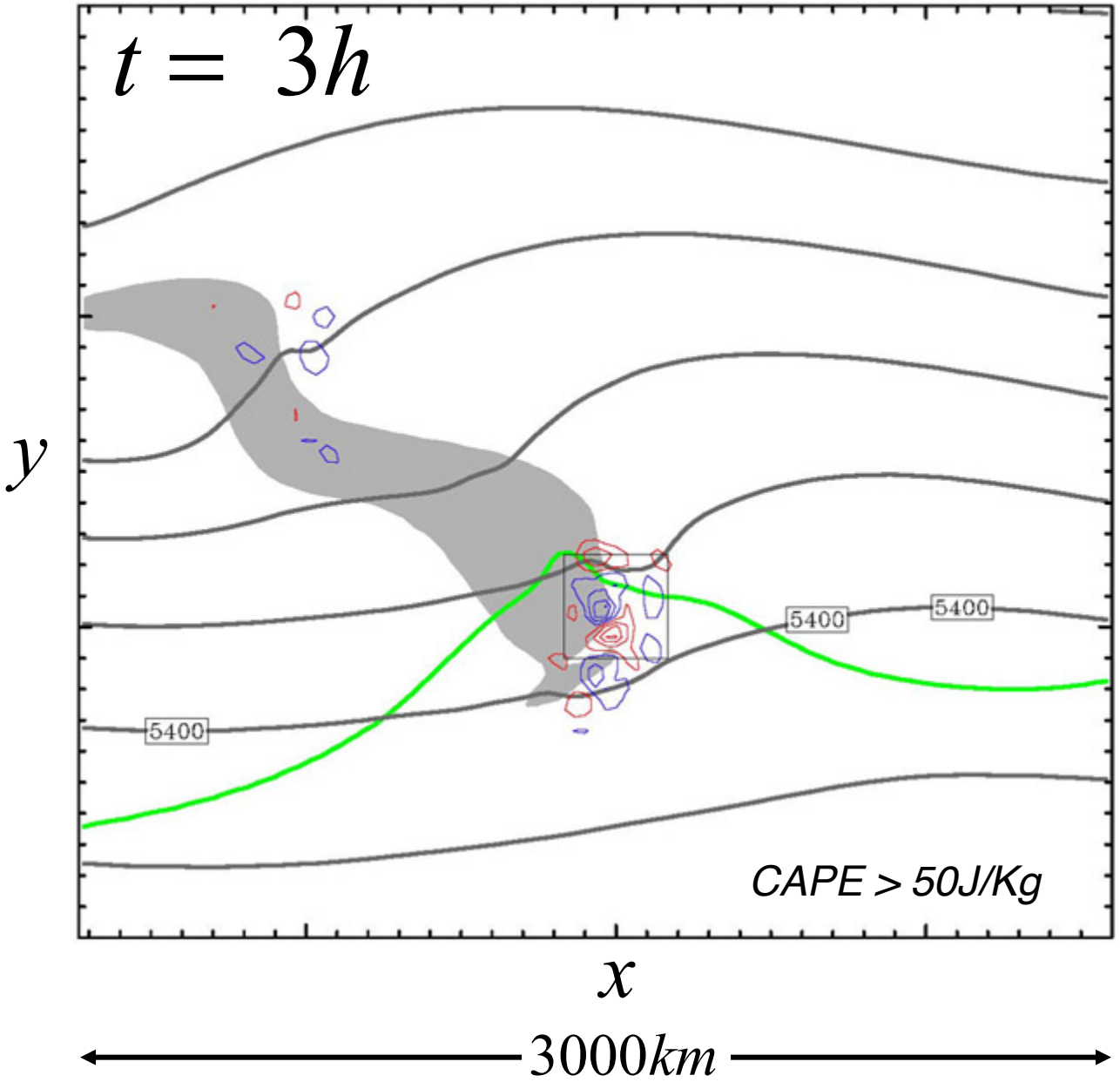


white noise $T_{max}' = \pm 0.2^{\circ}C$ added to D2 at t = 36h

Zhang et al. (2007)

Evolution of Difference Field

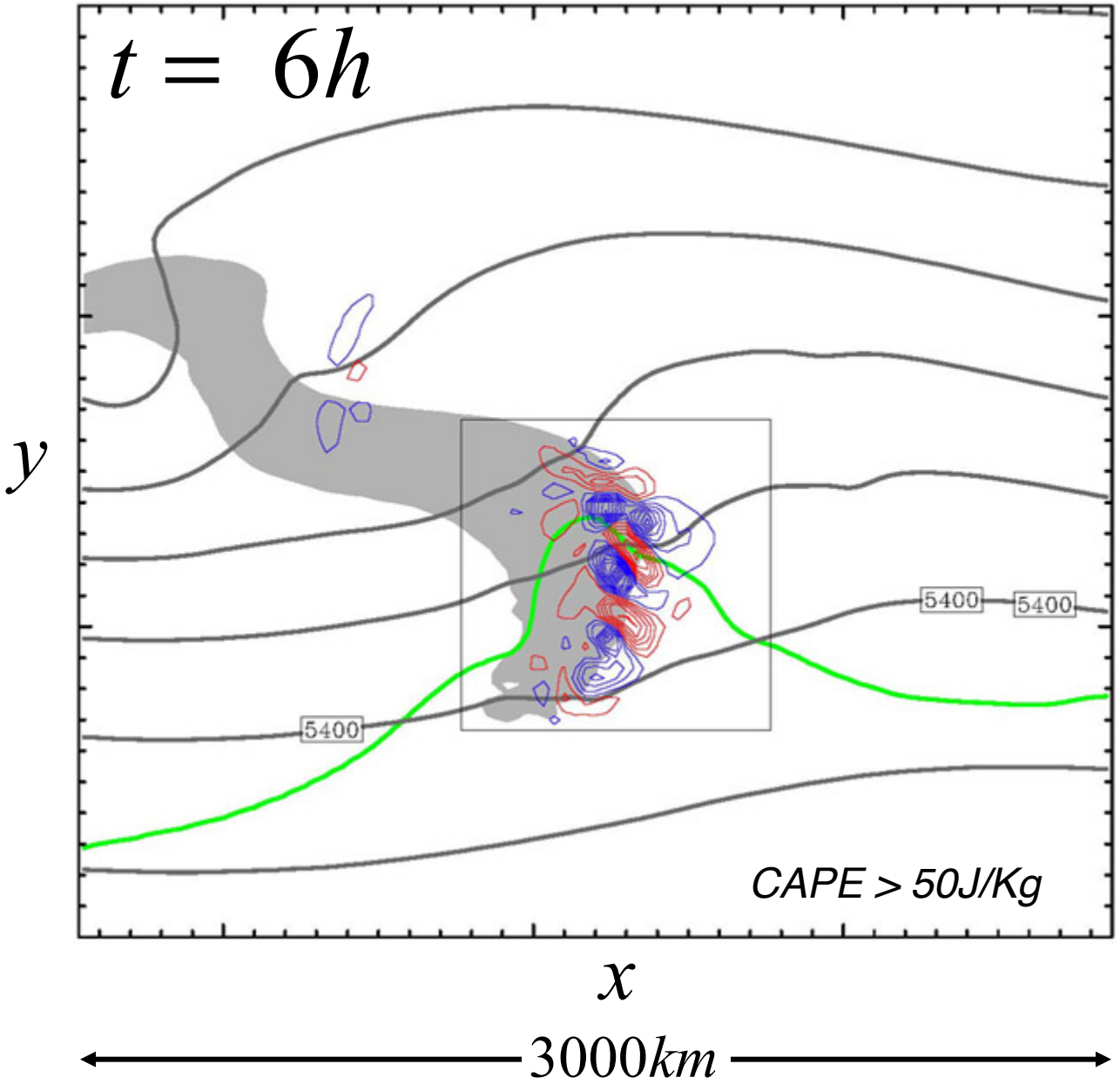
500 hPa height (solid), *v' (color, c.i.=2m/s), 3h precip (shaded > 3mm)*



Zhang et al. (2007)

Evolution of Difference Field

500 hPa height (solid), *v' (color, c.i.=2m/s), 3h precip (shaded > 3mm)*



Zhang et al. (2007)

Evolution of Difference Field

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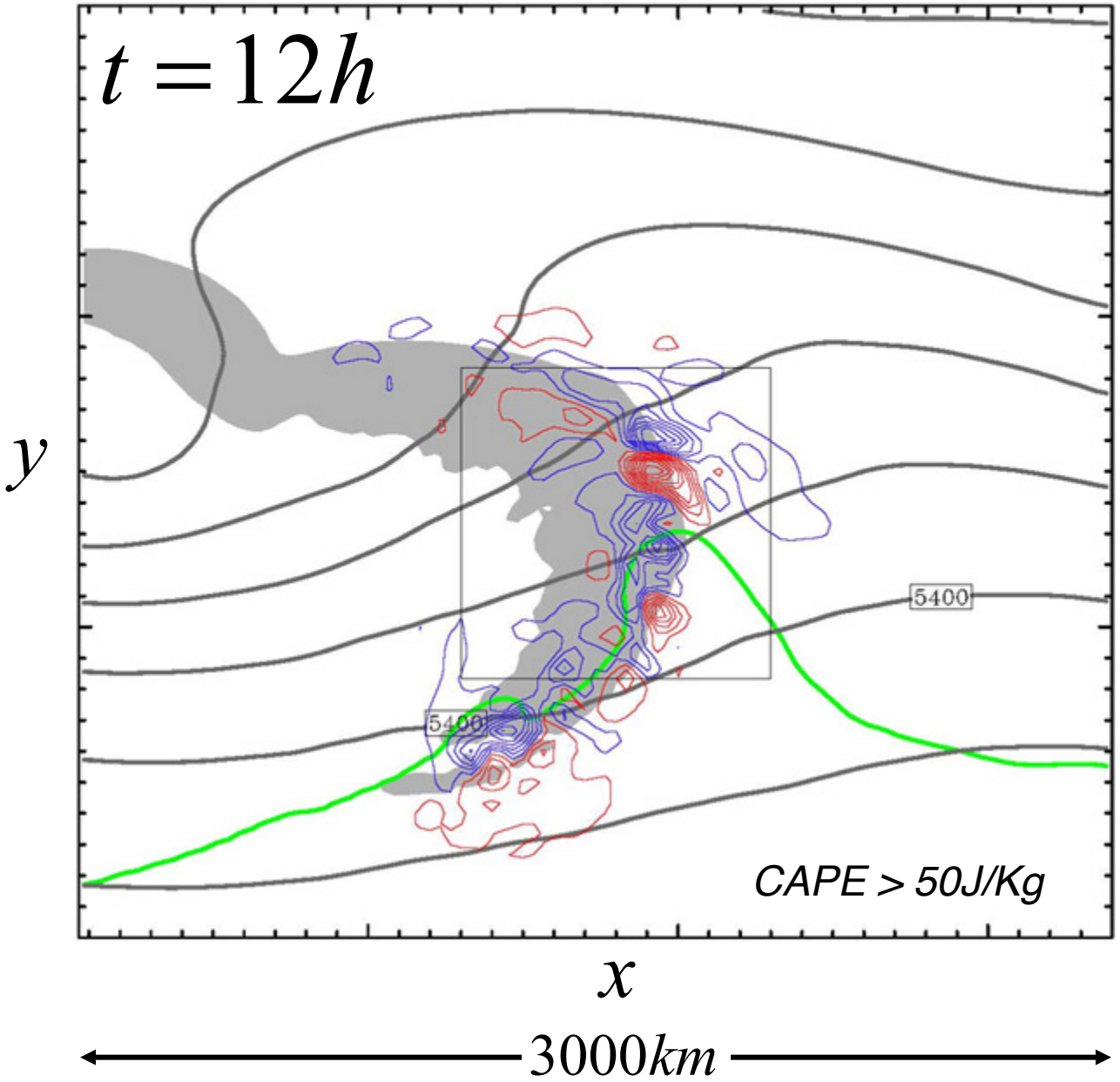

Zhang et al. (2007)

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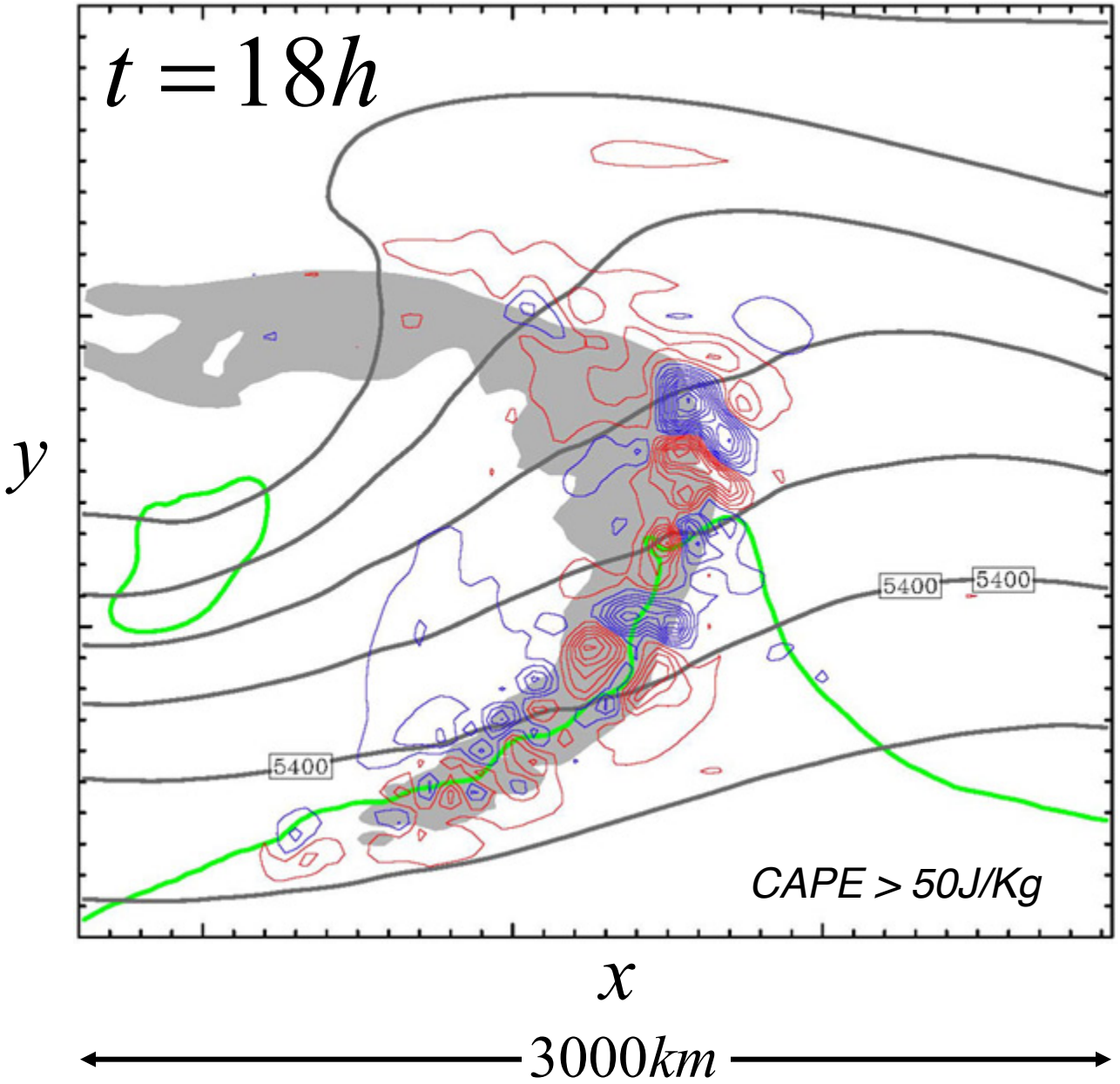
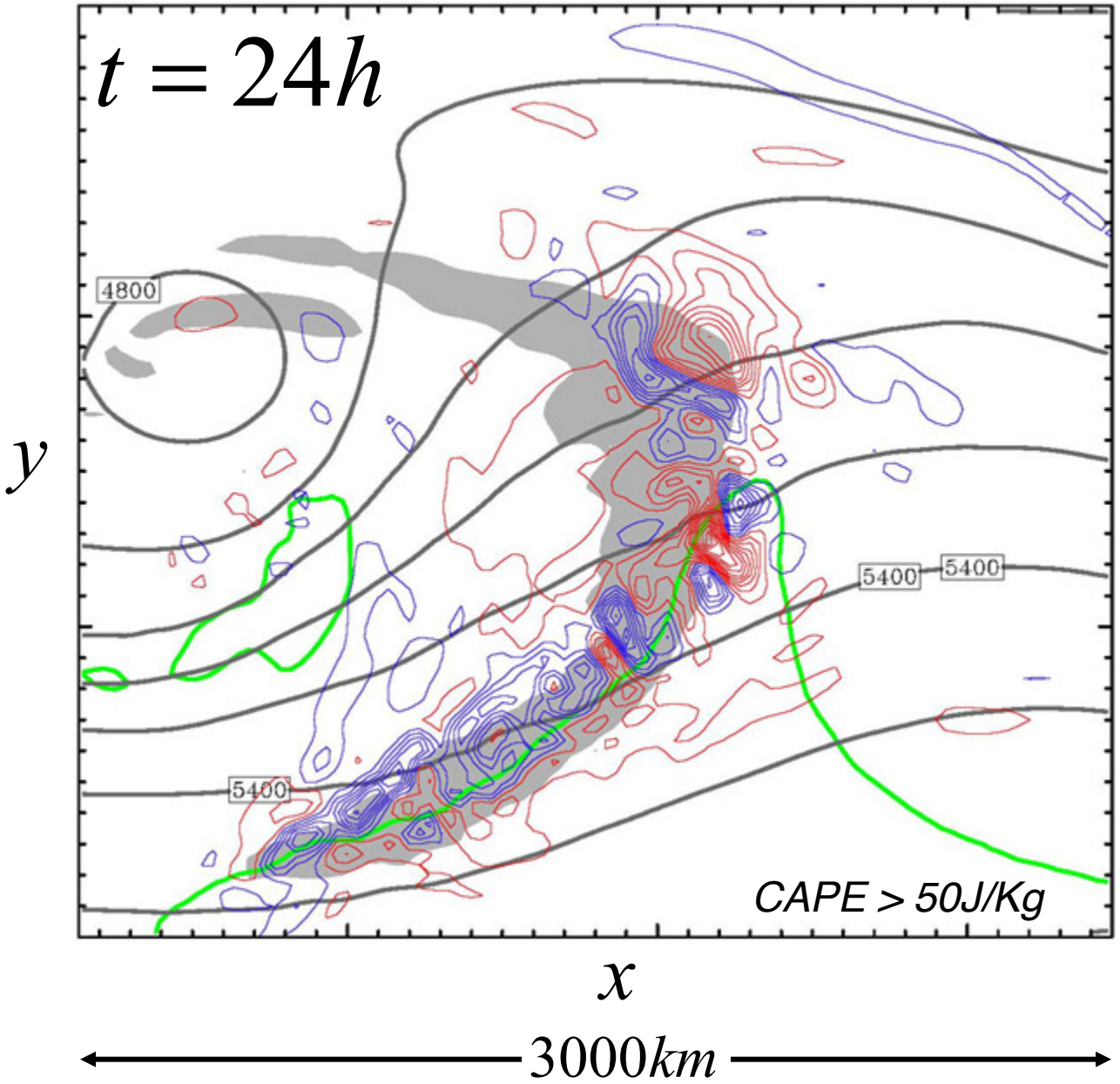


Zhang et al. (2007)

Evolution of Difference Field

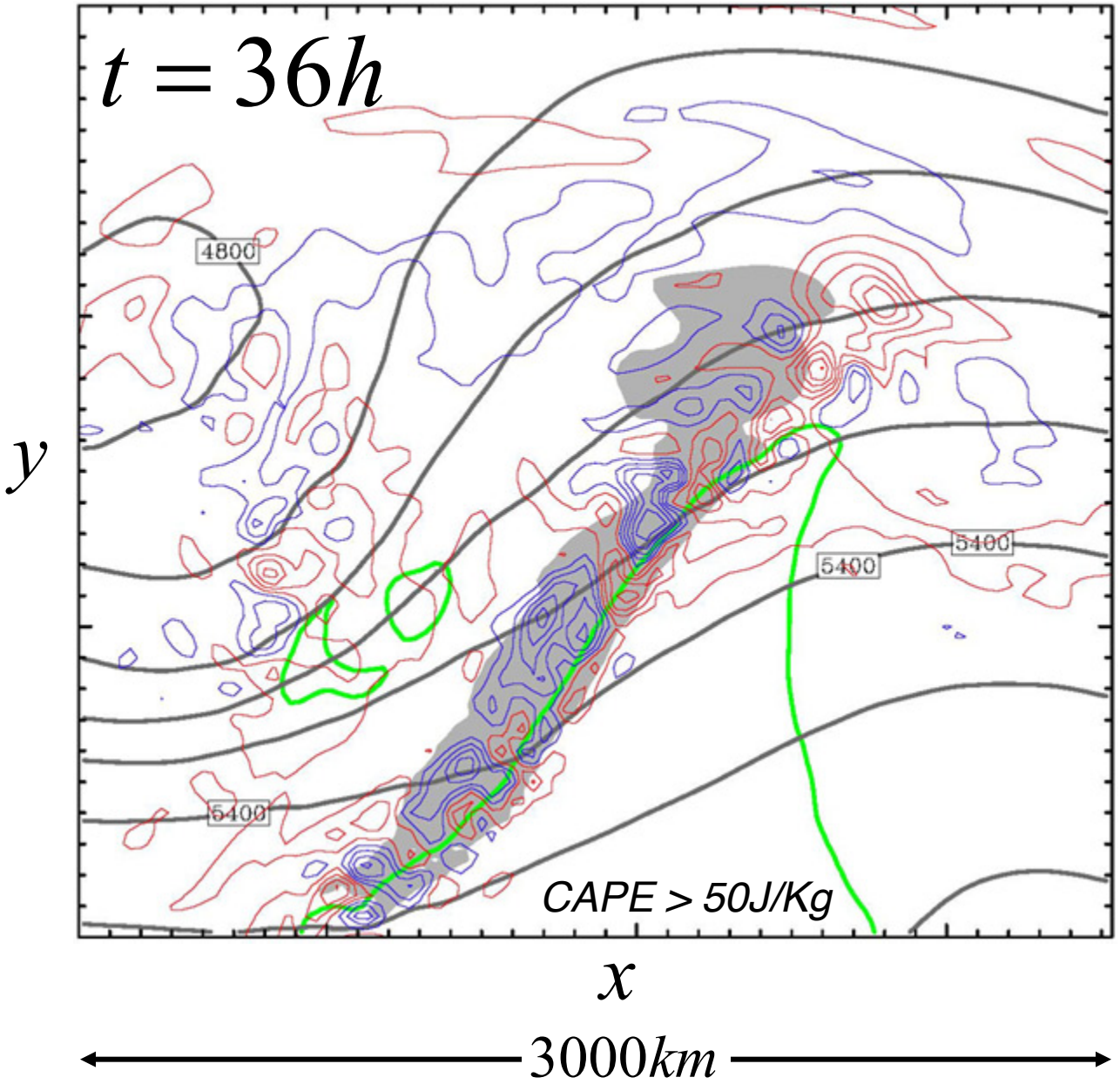
500 hPa height (solid), *v' (color, c.i.=2m/s), 3h precip (shaded > 3mm)*



Zhang et al. (2007)

Evolution of Difference Field

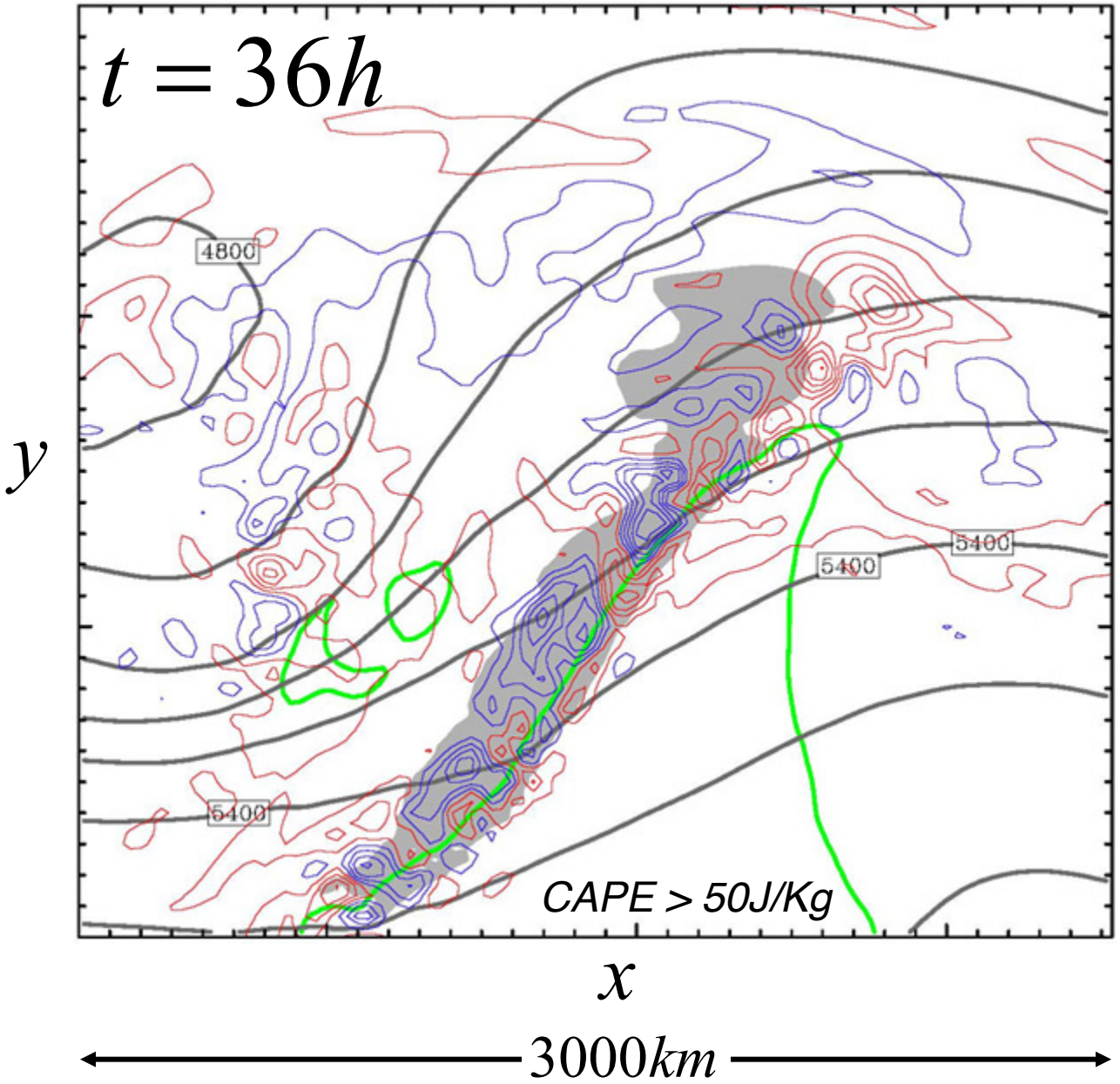
500 hPa height (solid), *v' (color, c.i.=2m/s), 3h precip (shaded > 3mm)*



Zhang et al. (2007)

Evolution of Difference Field

500 hPa height (solid), *v' (color, c.i.=2m/s), 3h precip (shaded > 3mm)*



Zhang et al. (2007)

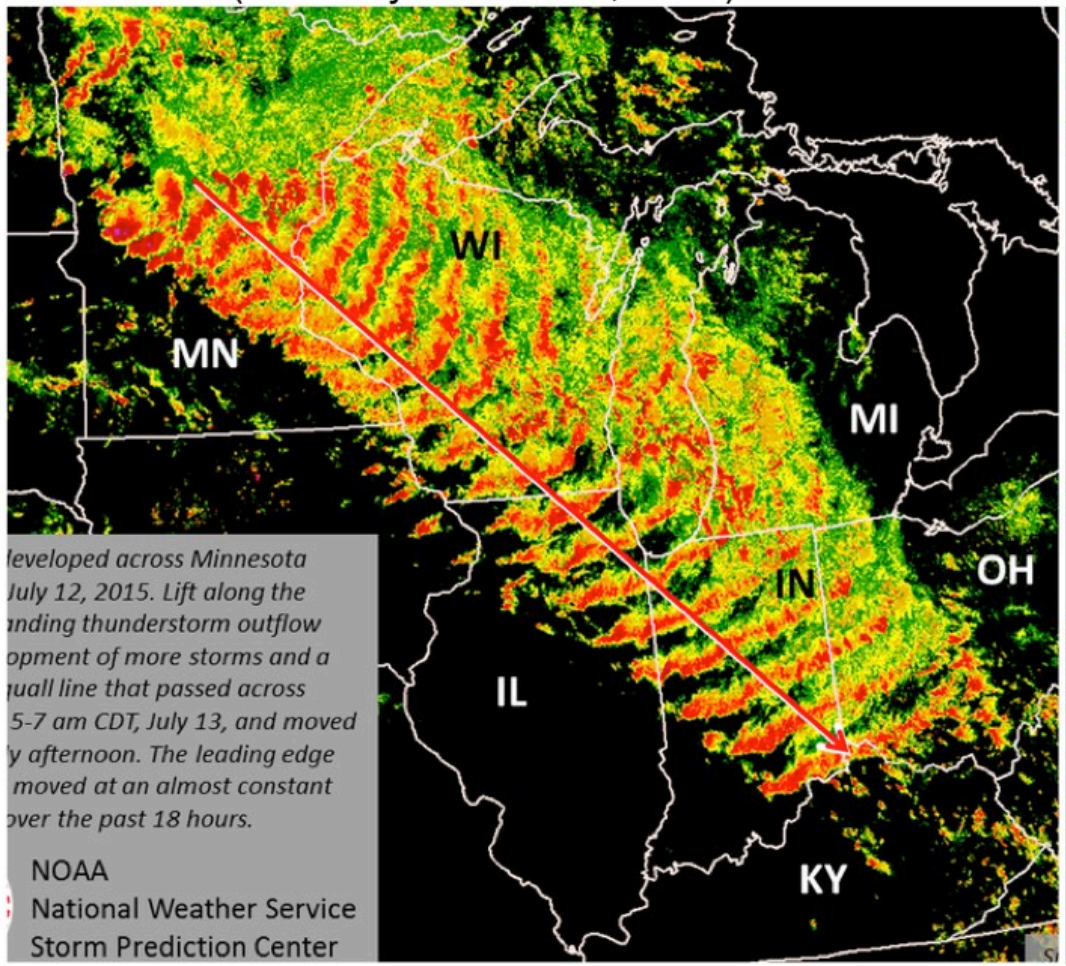
From Zhang et al. (2007):

"In the initial stage, the errors **first grow from small-scale convective instability** and then quickly saturate at the convective scales on time scales of O(1 h). The amplitude of saturation errors may be a function of CAPE and its areal coverage determined by large-scale flows. In the transitional stage, the **errors transform from convective-scale unbalanced motions to larger-scale balanced motions likely through geostrophic adjustment on the time scale of O(1/f).** Part of the errors due to difference in latent heating from convection may be retained in the balance fields while the others are radiating away in the form of gravity waves. In the final stage, **the balanced components of the errors in the larger-scale flow grow with the background baroclinic instability**."

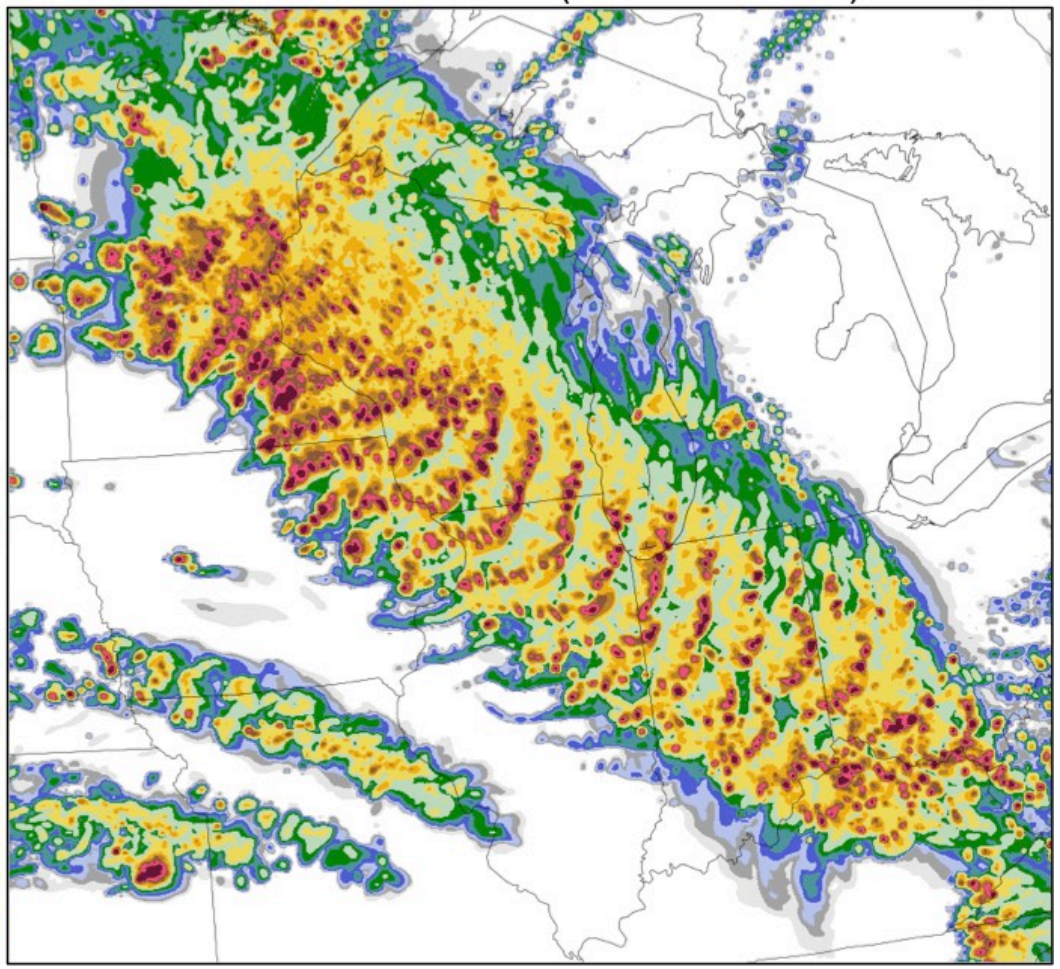
Upscale error growth only …. Neglects down-scale propagation of errors (Durran and Weyn 2016)

But often predictions of storms are made days in advance…

Observed (courtesy G. Carbin, SPC)

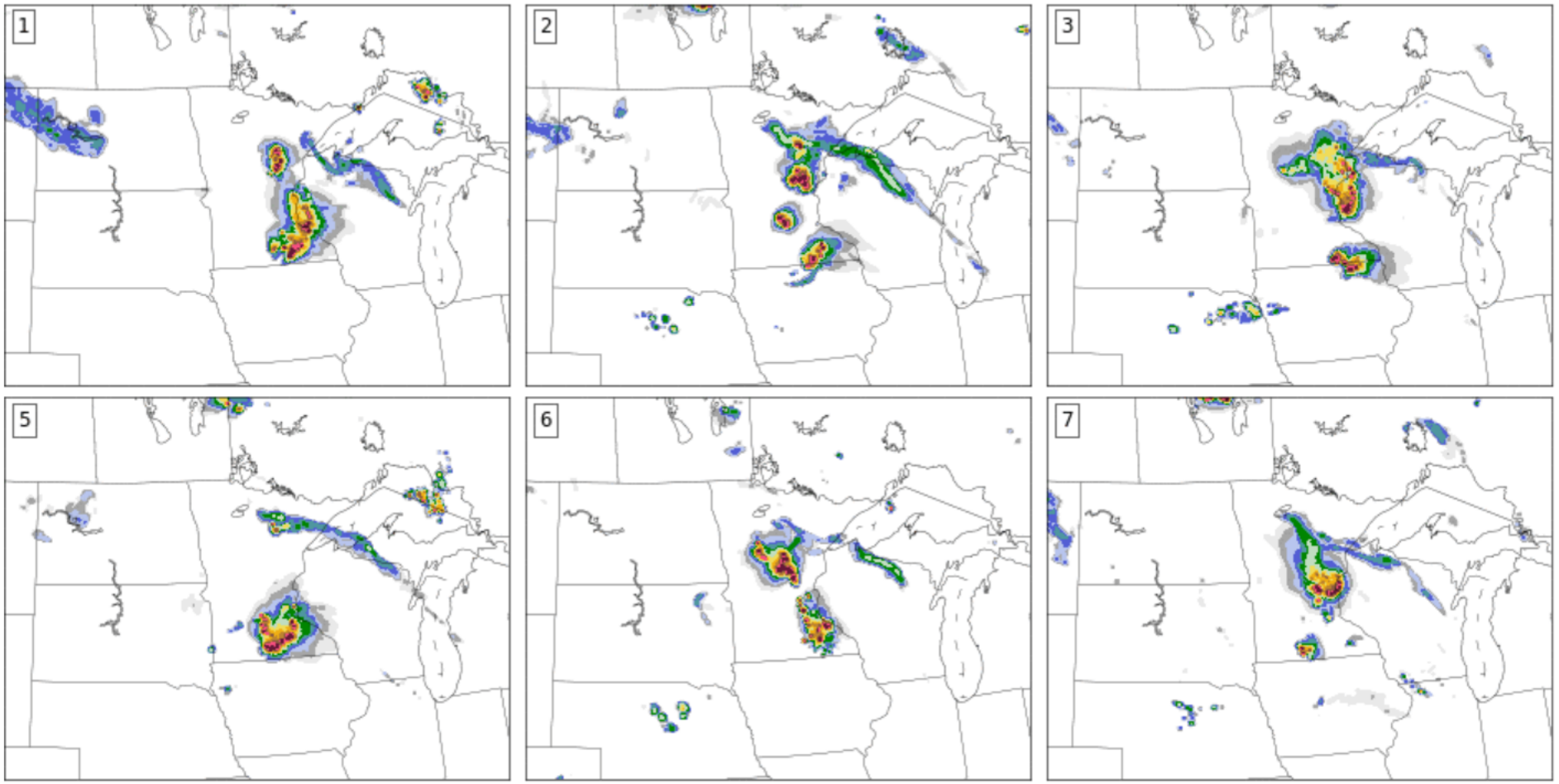


NCAR Ensemble Member (26 – 45 hr fcst)



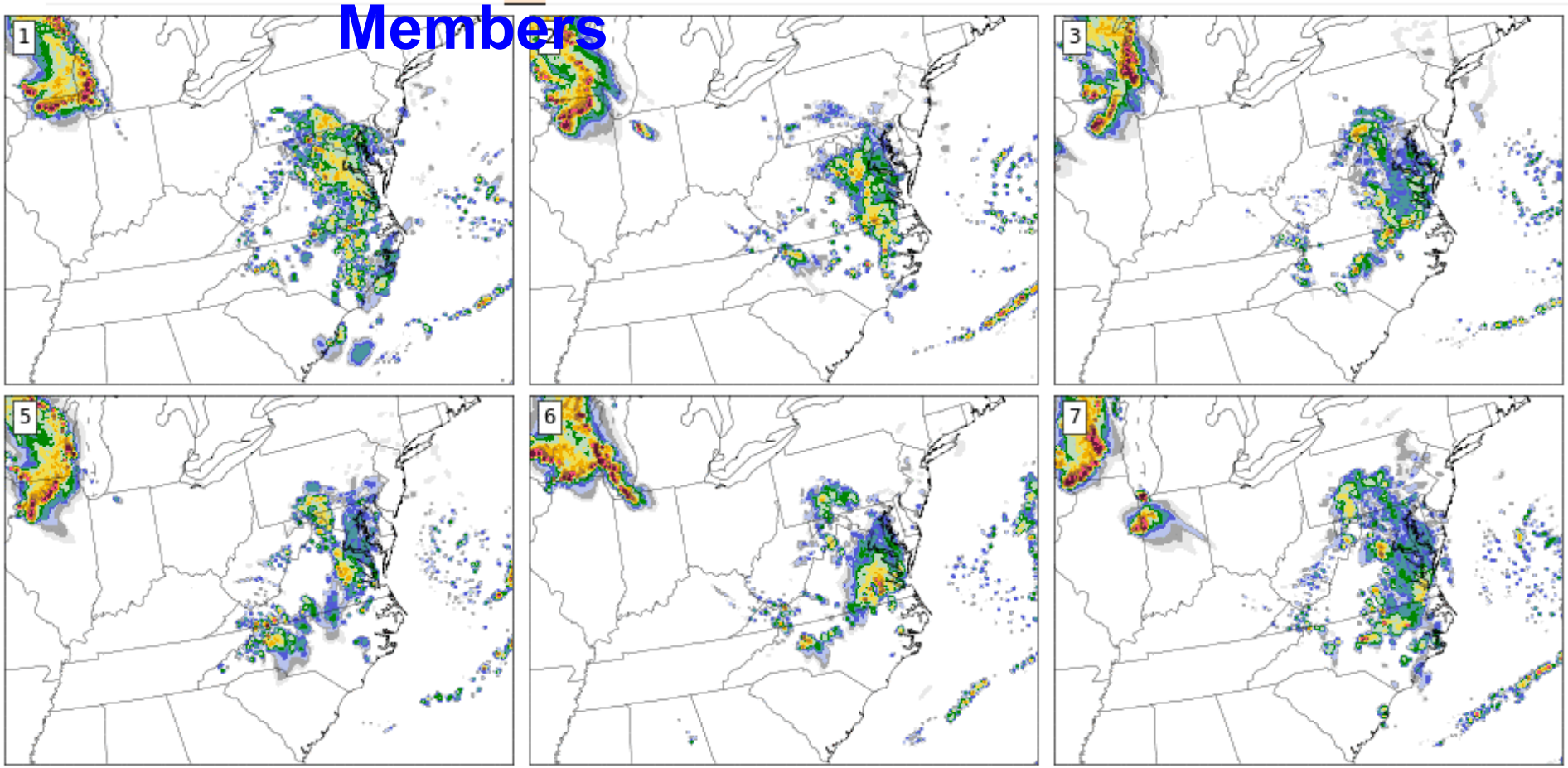
13 July 2015

06 h forecast 6 Ensemble



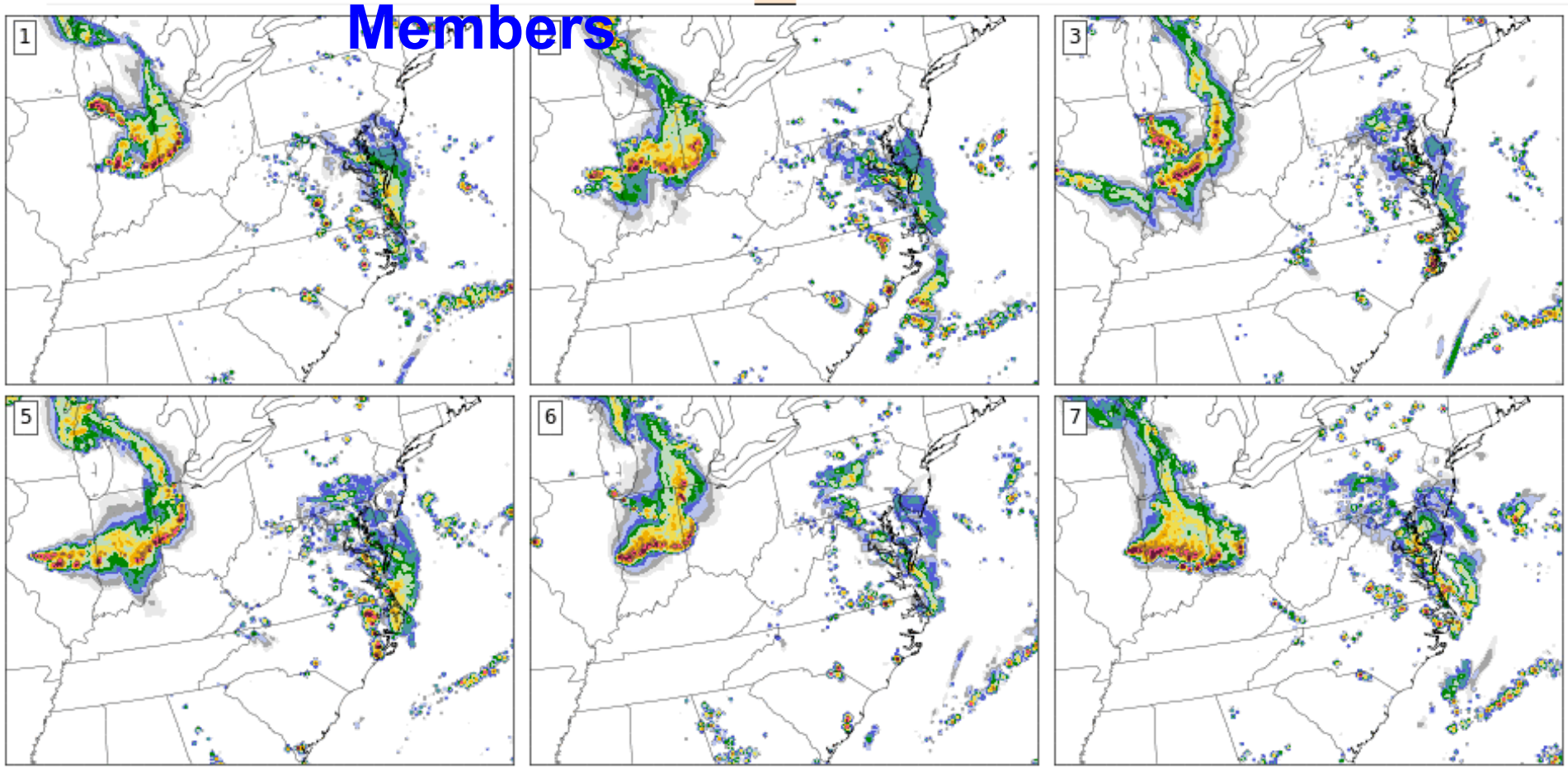
13 July 2015

12 h forecast 6 Ensemble Members



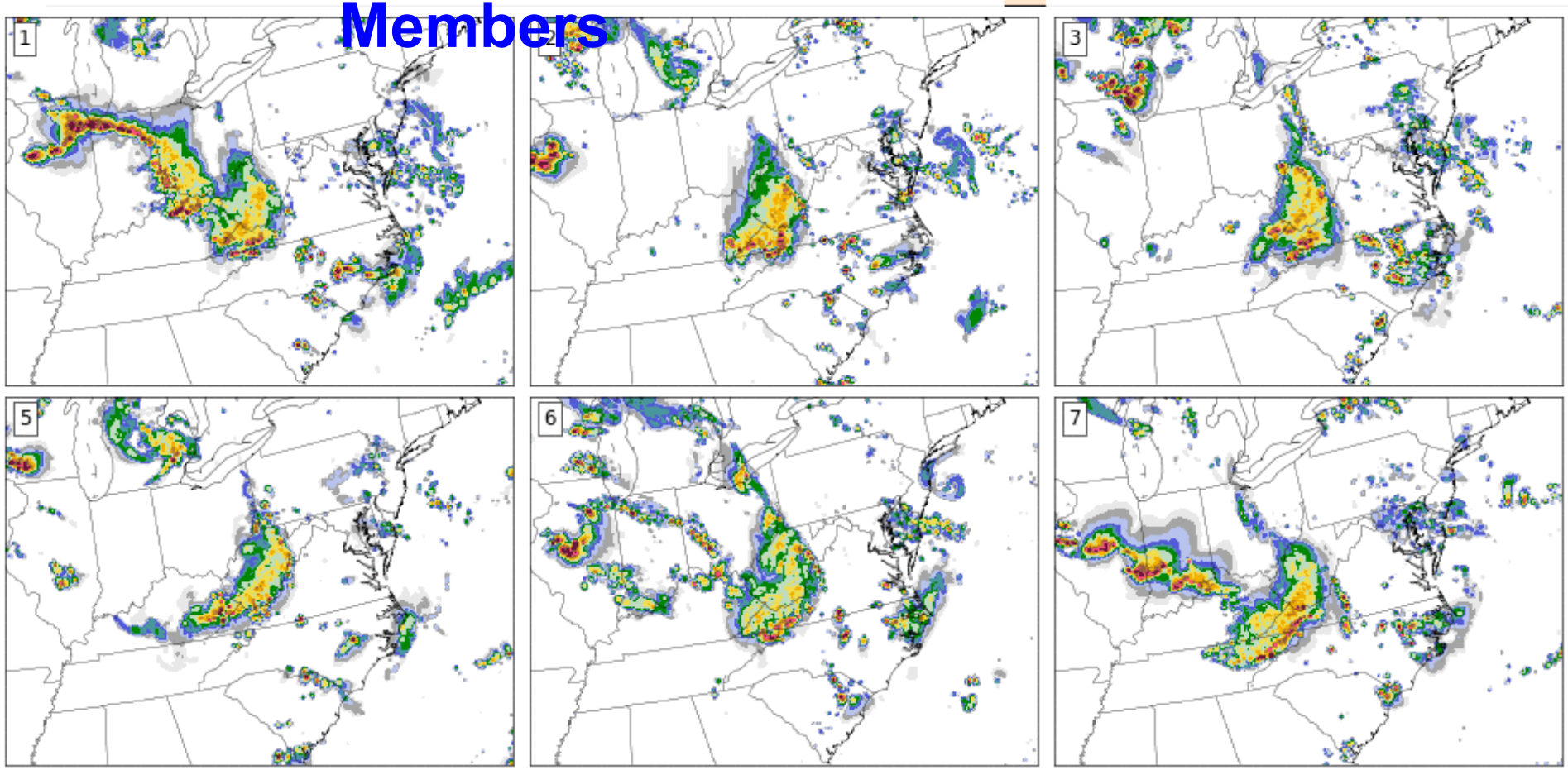
13 July 2015

18 h forecast 6 Ensemble Members



13 July 2015

24 h forecast 6 Ensemble Members

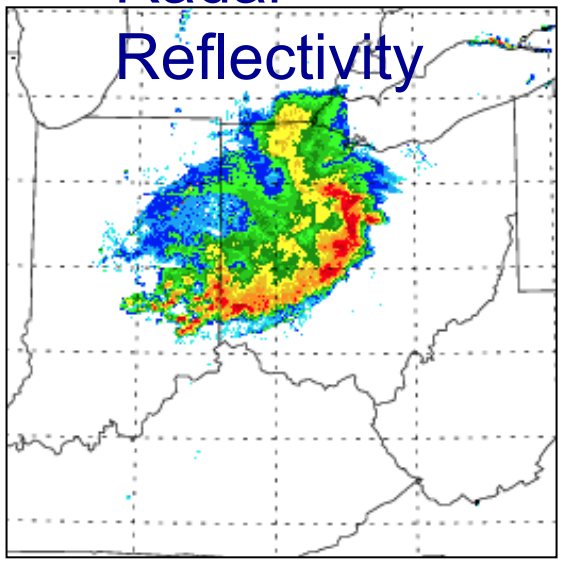


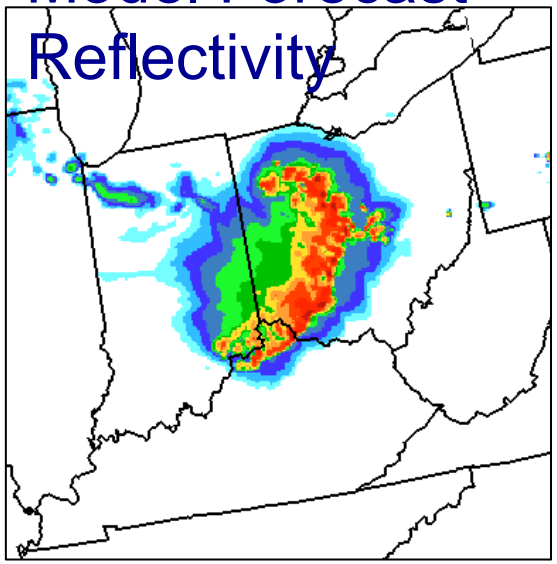
So, really, how predictable were these events??

Radar Reflectivity

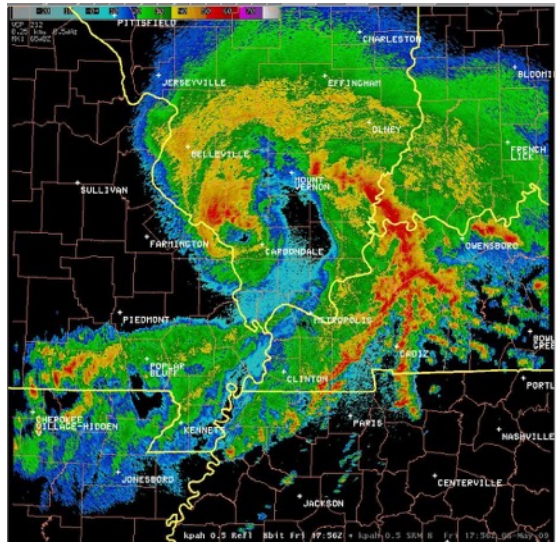
Model Forecast Reflectivity

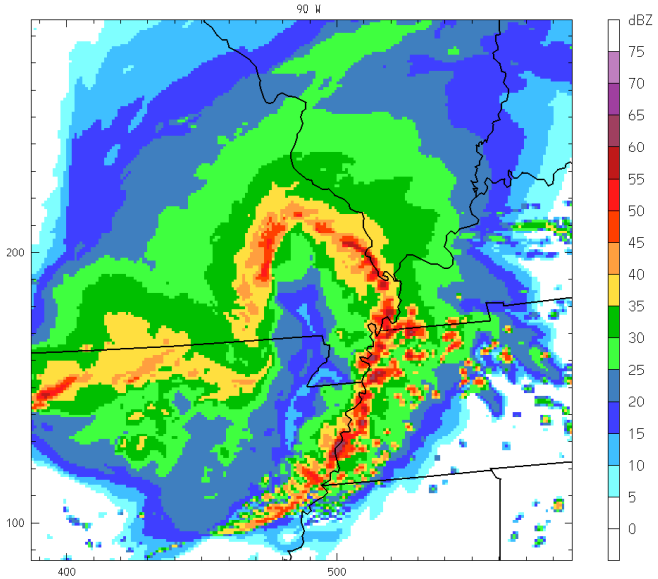
29 June 2012



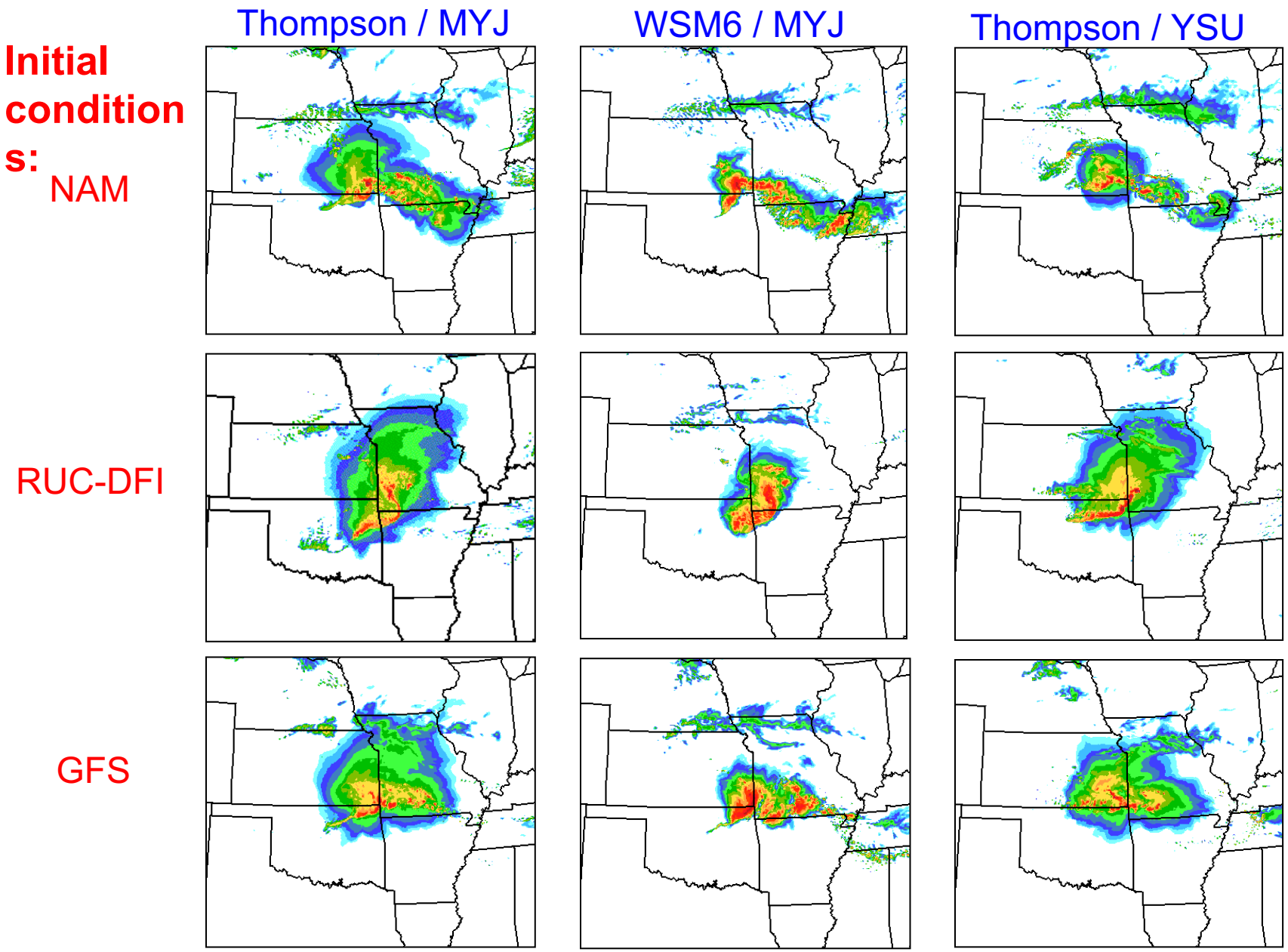


08 May 2009



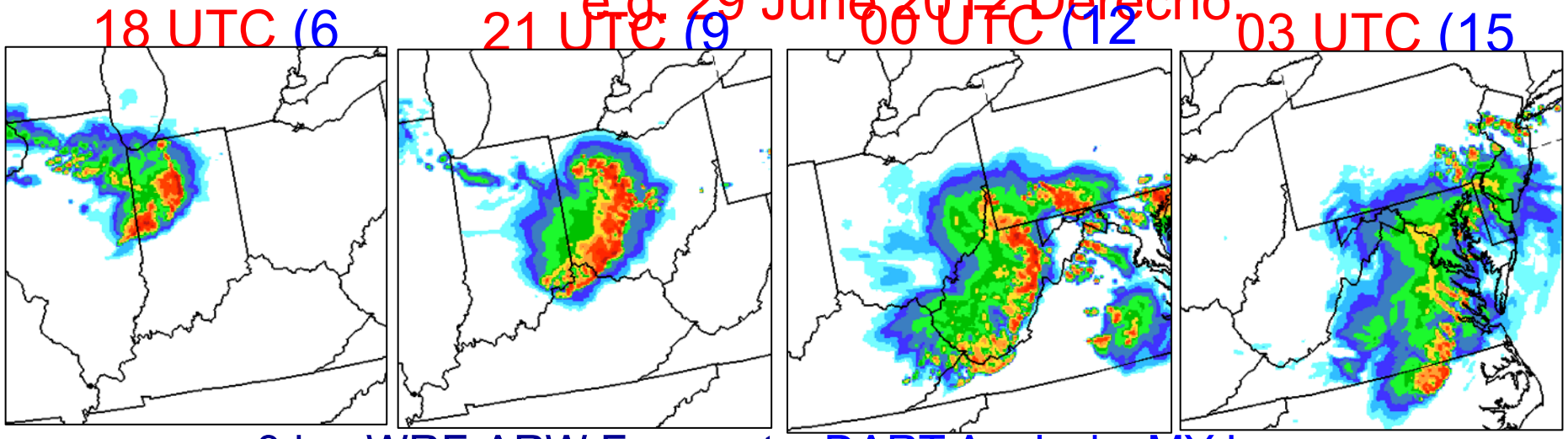


8 May 2009 Super-derecho 24 h Forecasts

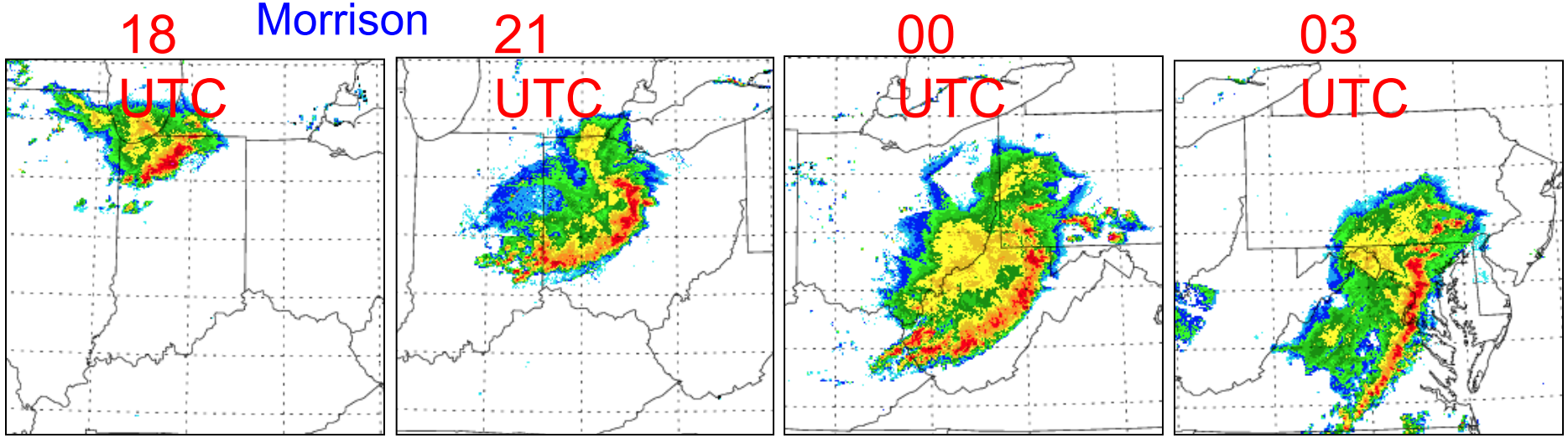


Convectively explicit (3 km) forecasts can be quite "good"

e.g. 29 June 2012 Derecho:



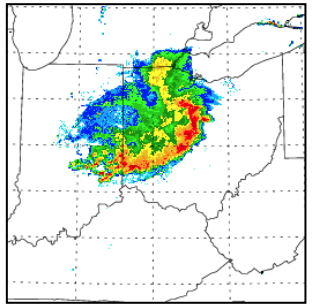
3 km WRF-ARW Forecast: DART Analysis, MYJ, Morrison



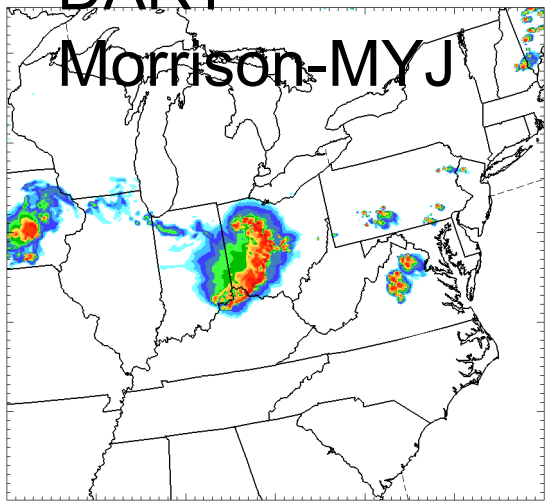
Composite Radar

…but are especially sensitive to the initial analysis!!

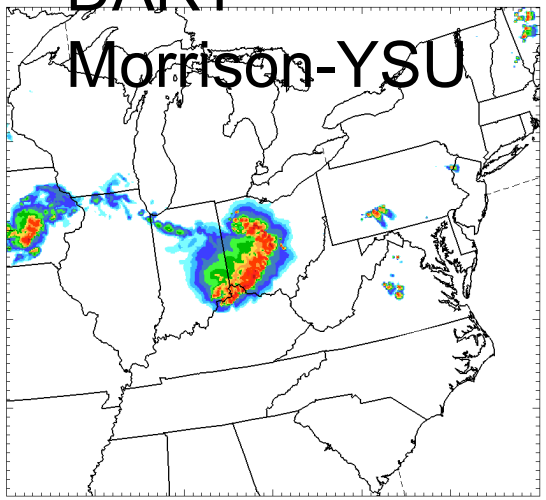
29 June 2012 Derecho



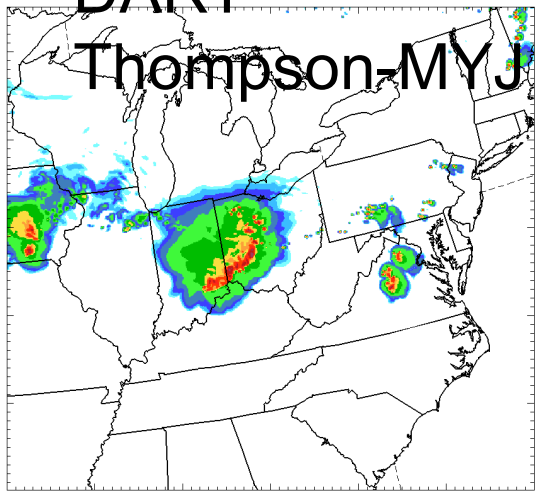
DART-Morrison-MYJ



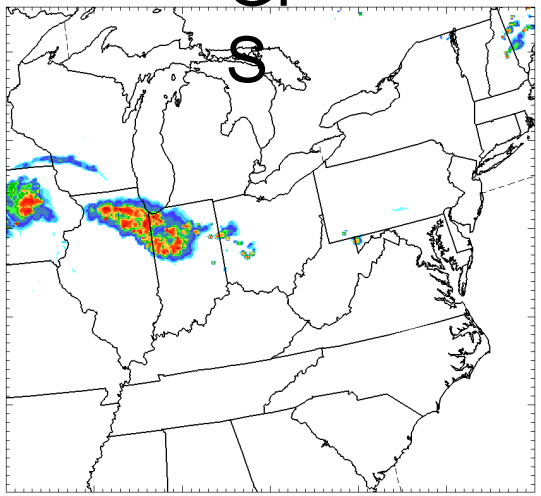
DART-Morrison-YSU



DART-Thompson-MYJ



GFS



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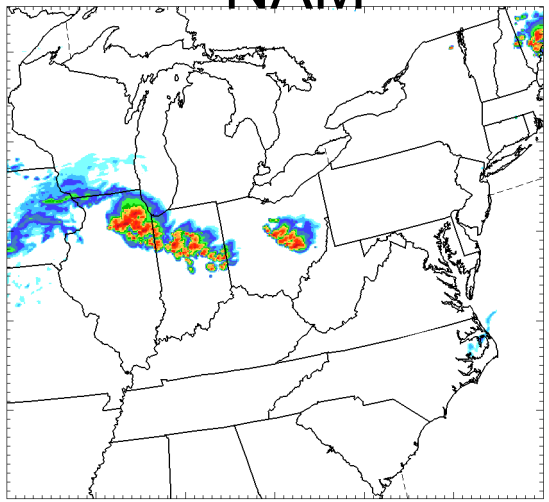
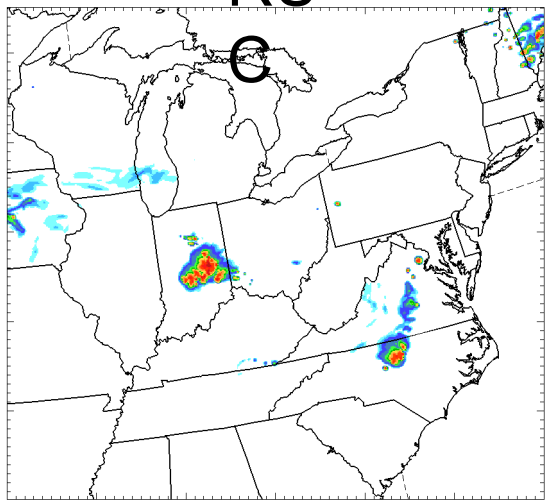
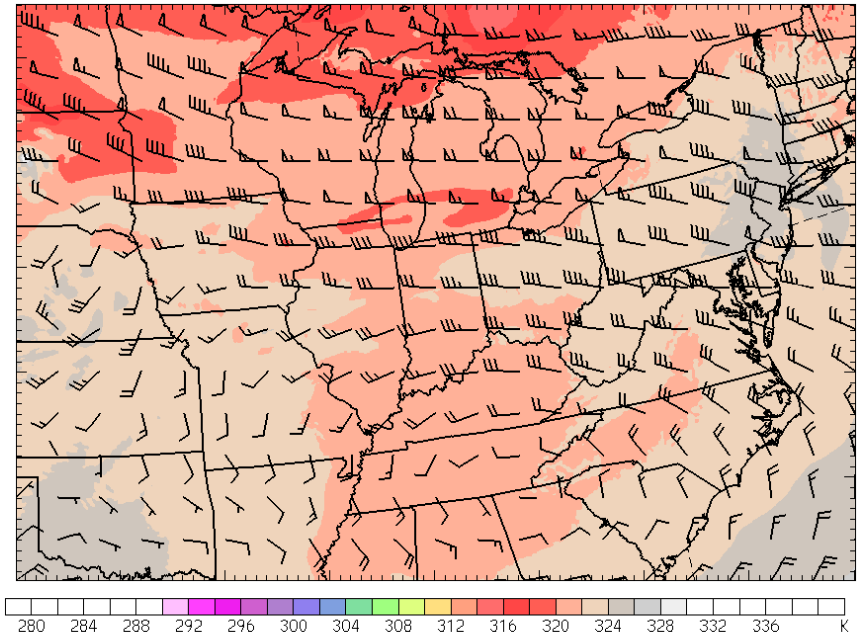


RUC

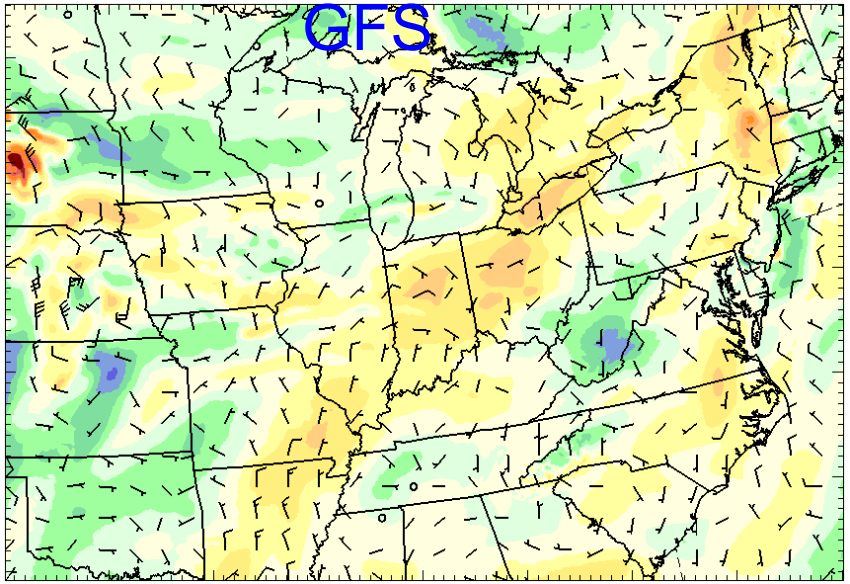


12 UTC Analysis Differences 500 hPa Theta

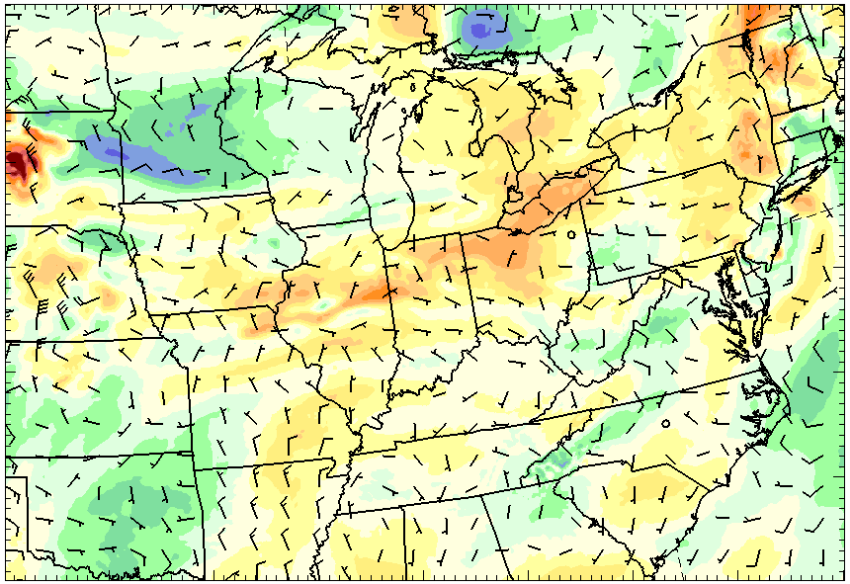
2K / 5 ms-1 Differences

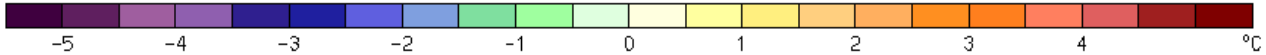


DART - GFS



DART - NAM



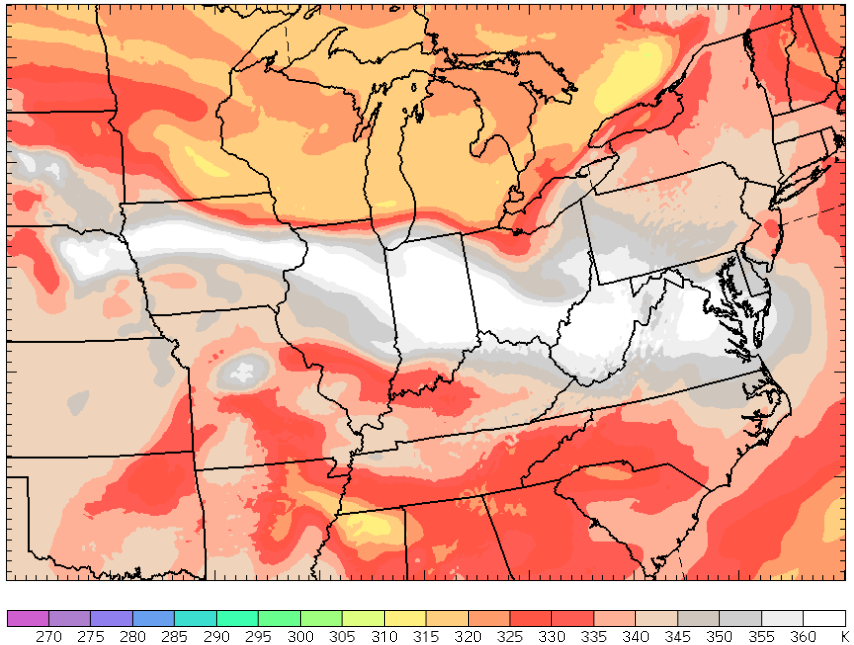


12 UTC Analysis Differences:

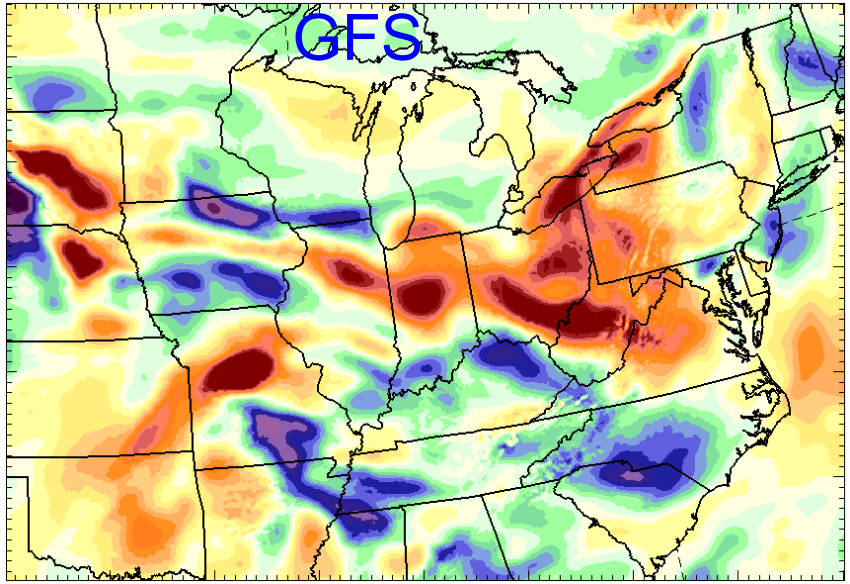
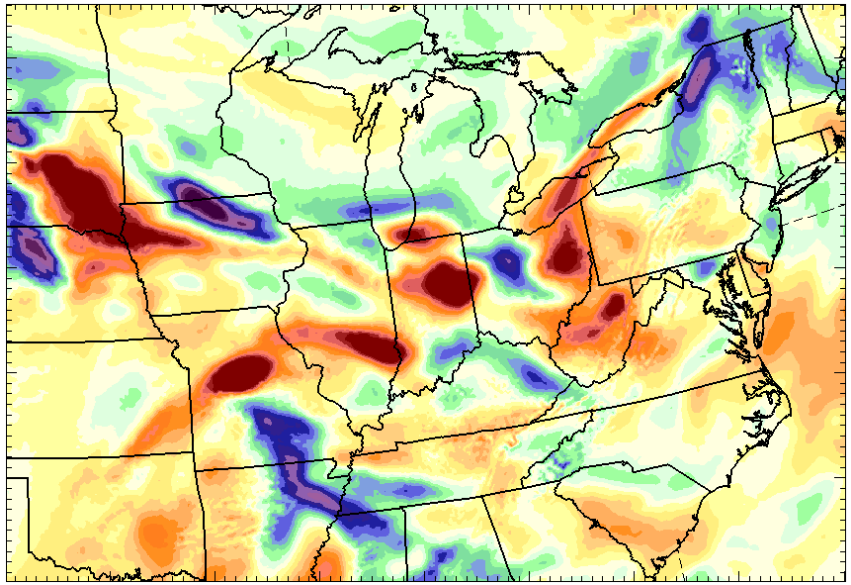
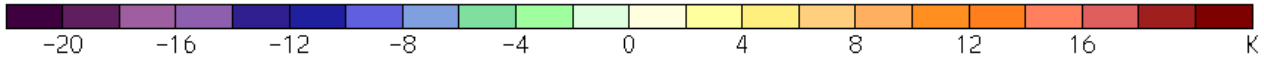
850 hPa Theta-E

20 K Differences

***low-mid tropospheric moisture!



DART - GFS



DART - NAM