Organized Convection and Mesoscale Vortices: Observations from BAMEX (2003)

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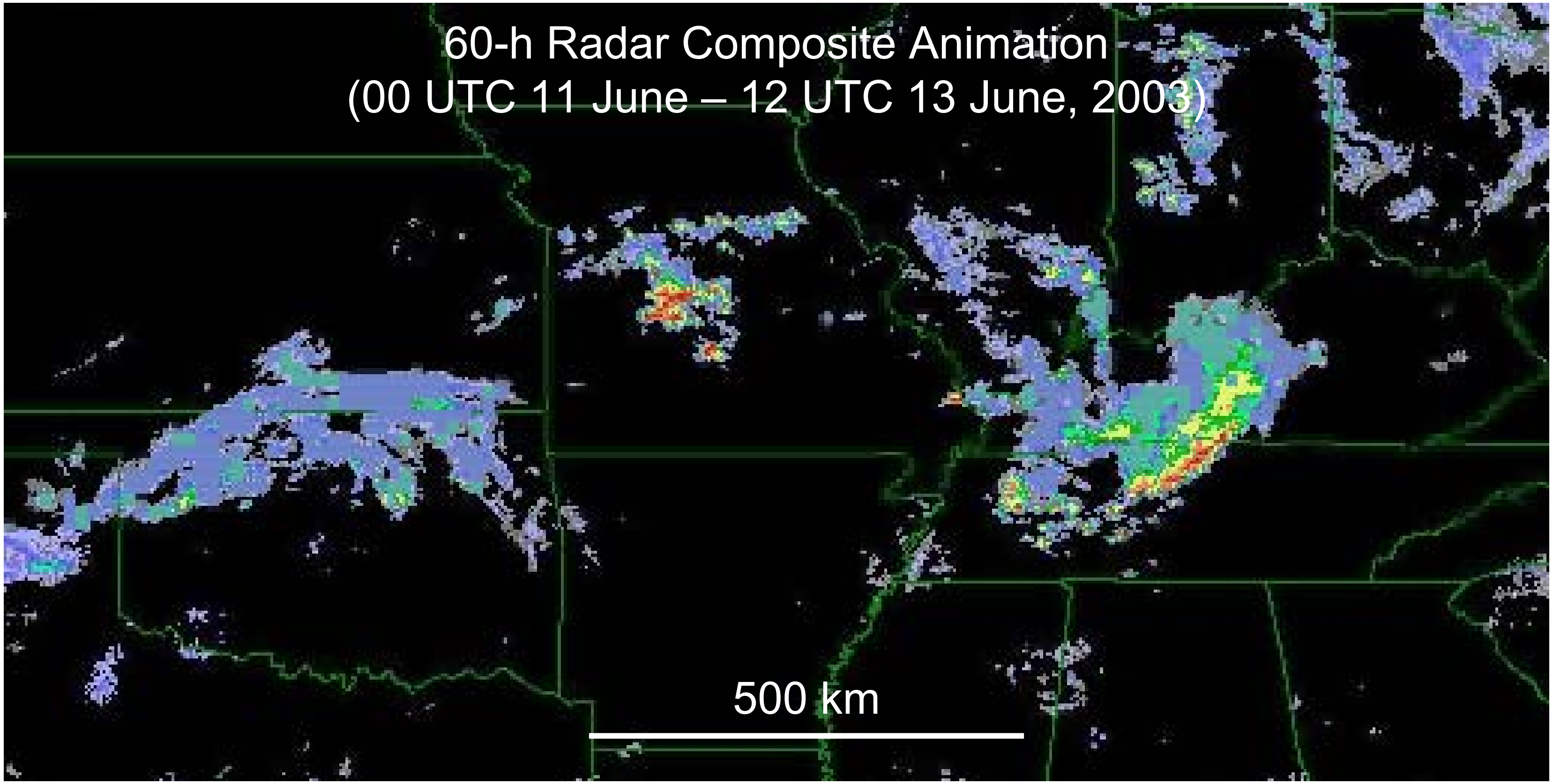
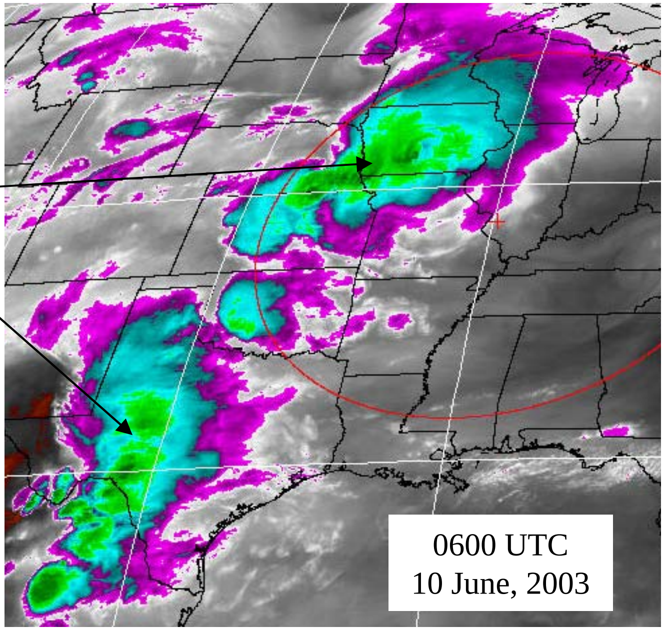


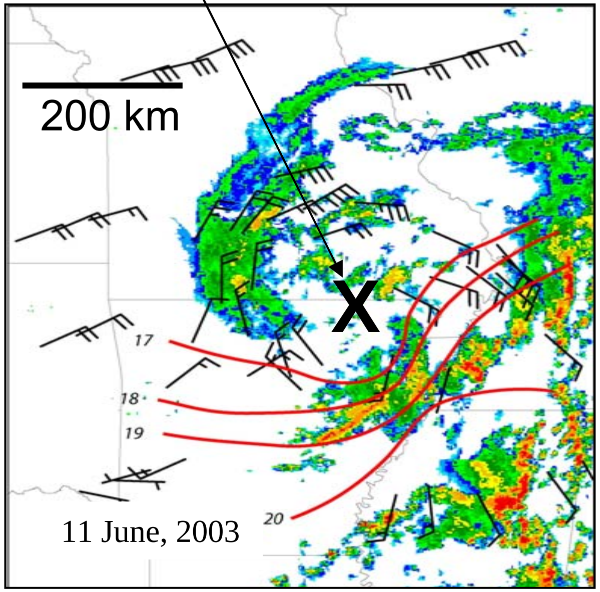
Background and Definitions

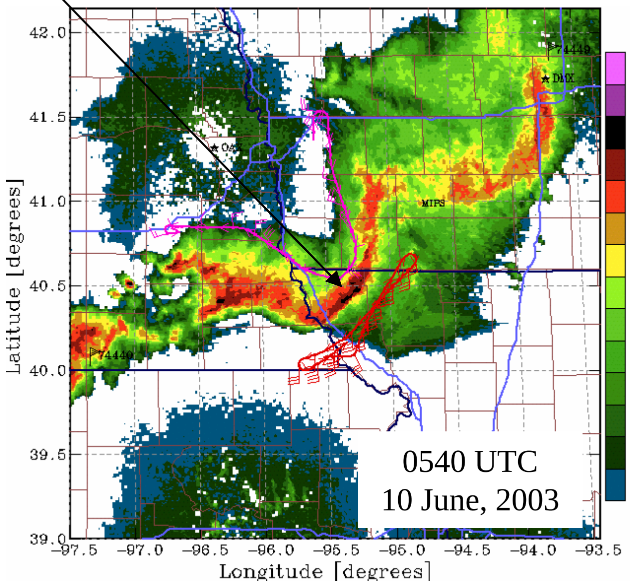
Mesoscale Convective System (MCS): an isolated, nearly contiguous region of thunderstorms, sometimes surrounded by an extensive region of moderate rainfall. Total size is usually 100-300 km across.

Bow-echo: a bow-shaped line of thunderstorms often containing strong surface winds.

Mesoscale Convective Vortex: a lower-mid-tropospheric horizontal wind circulation derived from an area of convection (often an MCS).

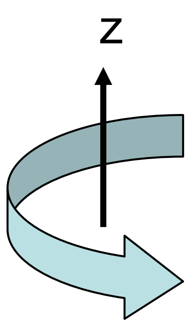






Rotation in MCSs on Different Scales

- Deformation Radius (~1000 km; mid-latitude)
- MCV (~100 km, 12 h)
- Line-end vortex (book-end vortex) (~30 km, 3 h)
- Mesovortex (~10 km, 1 h)
- Mesocyclone (~1 km, < 1 h)
- Tornado (100 m, 10 min)



Time Scales for MCVs

- Inertial: $2\pi/f \sim 18$ h
- Diurnal heating cycle ~ 24 h
- Rotation: $2\pi R/V \sim 18$ h *(for R=100 km, V=10 m/s)*
- Vertical Shear: $2R/(H^*dU/dz) = 2R/\Delta U \sim 6$ h *(for ΔU=10 m/s)*
- Diabatic Heating: $H/w \sim 6$ h *(for w=0.25 m/s, H=5 km)*

=> *Competing Time Scales*

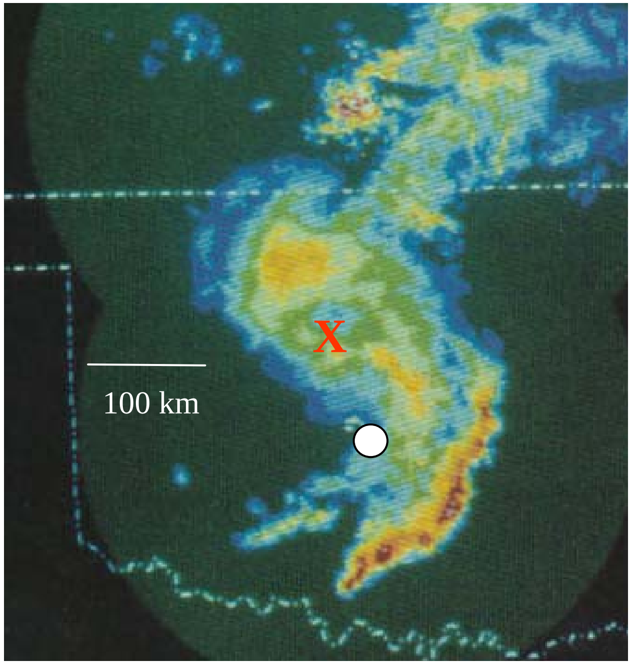
Why do we want to study Mesoscale Convective Vortices (MCVs)?

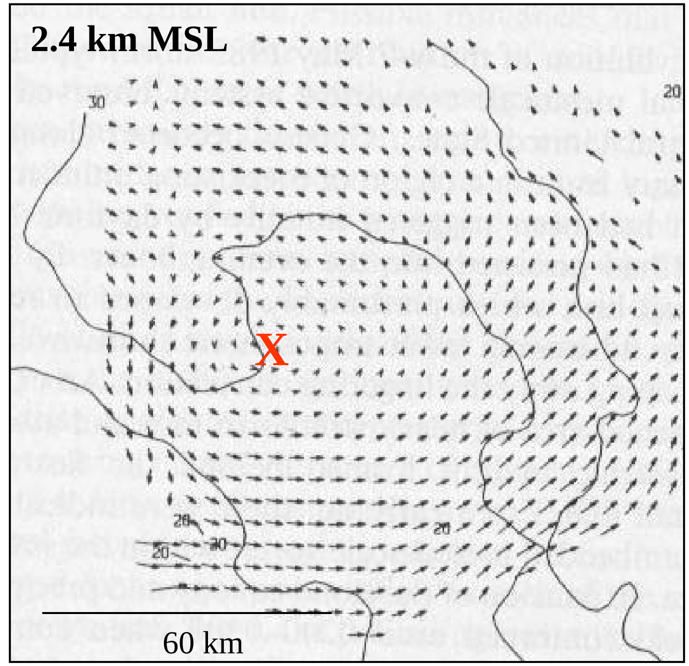
- Understand and quantify "upscale" growth (emergence of balanced modes)

- Understand the linkage between successive convective systems
  - *Convection initiation*
  - *Feedback to vortex*

- Verify and improve dynamical models used for mesoscale prediction and processes
  - *Quantitative Precipitation Forecasting*
  - *Representation of diabatic processes (PV redistribution)*

- Understand "downward" penetration of vorticity to boundary layer *(relevant to tropical cyclone formation)*





May 7 1985, 0500 UTC (Brandes, 1990, MWR)

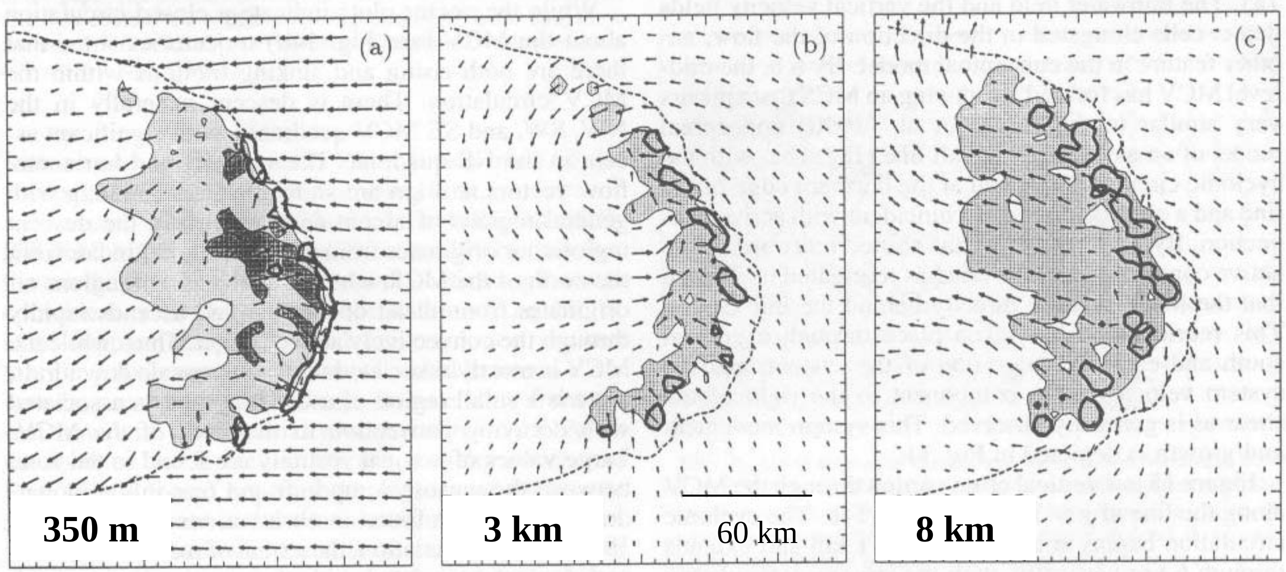
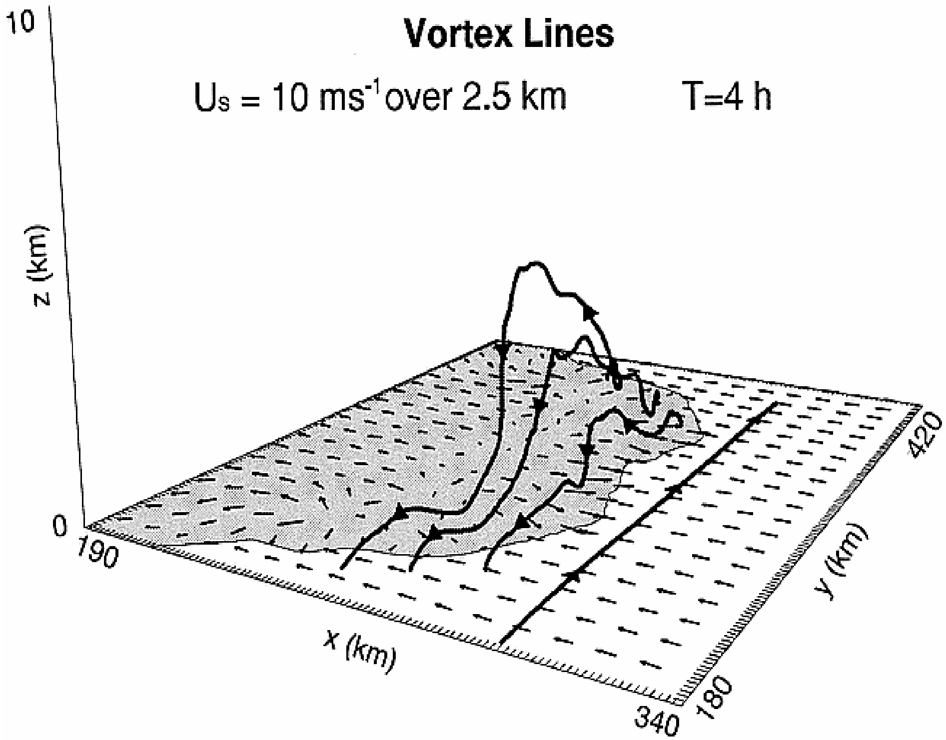
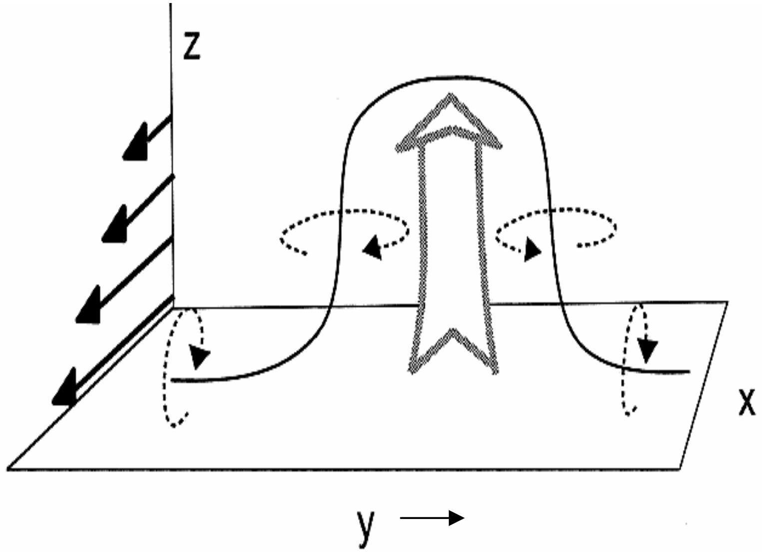


FIG. 13. The Coriolis simulation at 6 h, depicted as in Fig. 5.

Idealized Simulation (Skamarock et al., 1994, MWR)

Mechanism for Lind-end Vortices

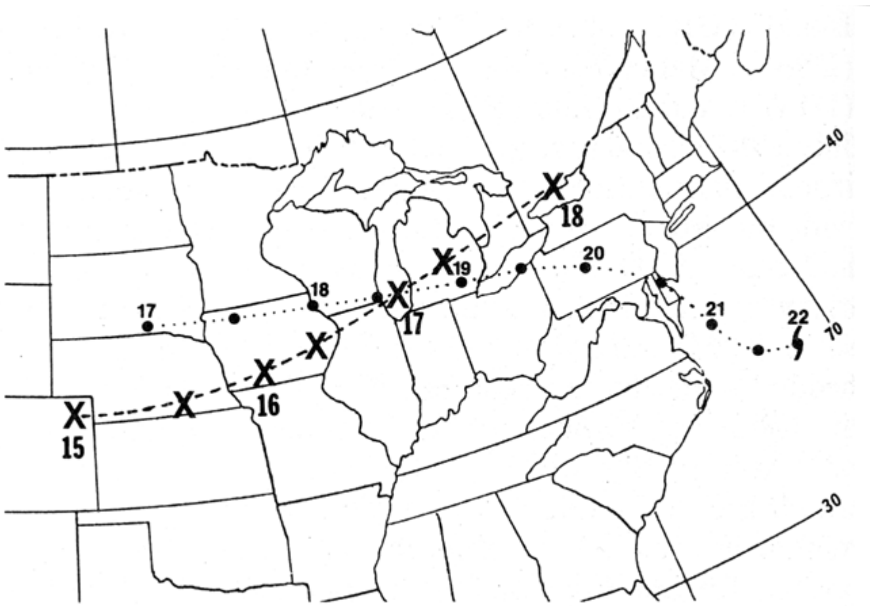


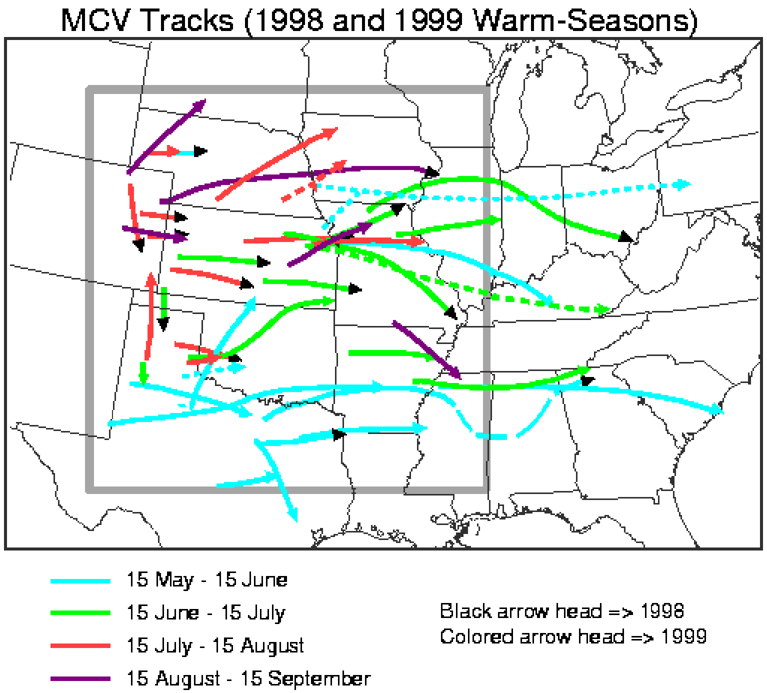


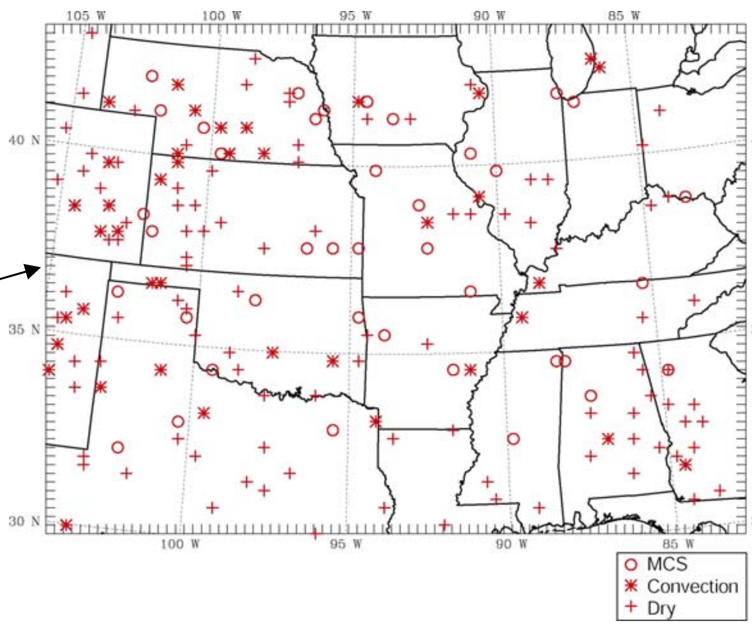
=> Tilting followed by stretching

MCV Tracks and Occurrence

Major Serial Cases

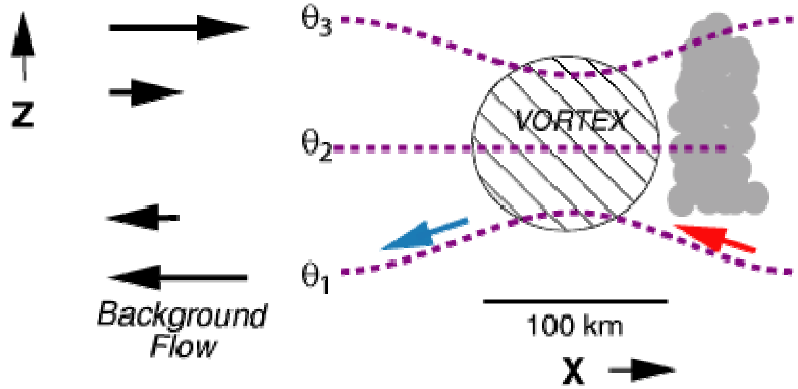




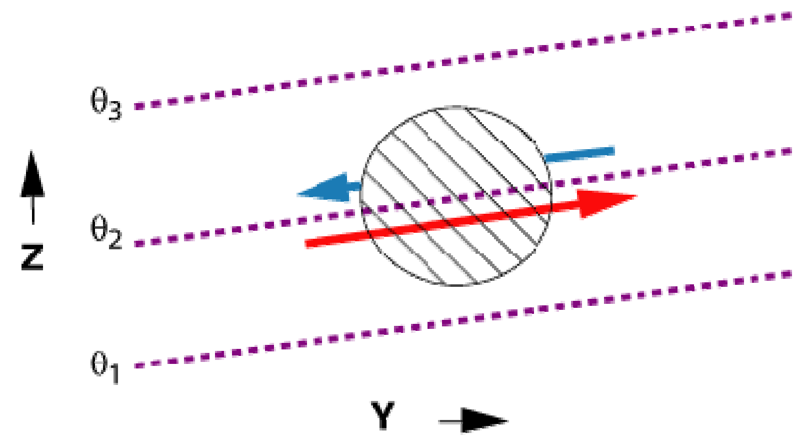


MCV Locations at Maximum Intensity (RUC-2 based, 1999)

Raymond and Jiang (JAS 1990) Conceptual Model of Isentropic Lifting within a Steady Balanced Vortex (e.g., MCV)

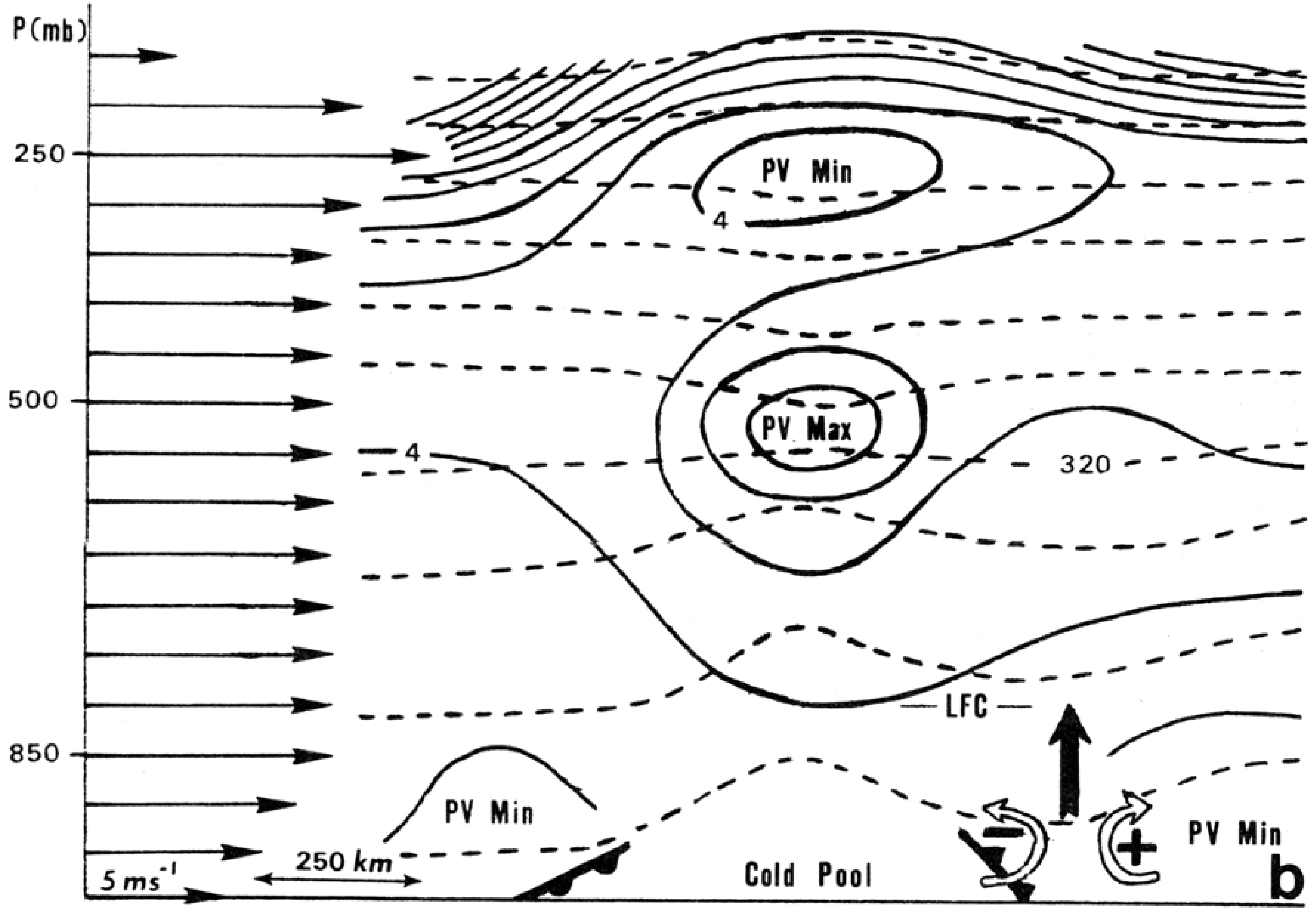


(a) Background shear-induced isentropic motion within baroclinic zone associated with balanced vortex



(b) Vortex-induced isentropic motion within background baroclinic zone

MCV Induced Lifting and Destabilization

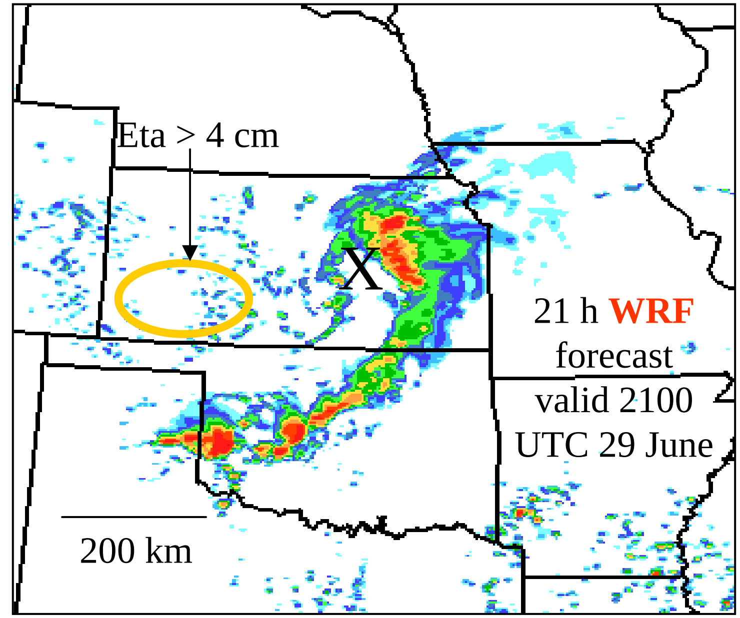


Fritcsh et al. 1994, MWR

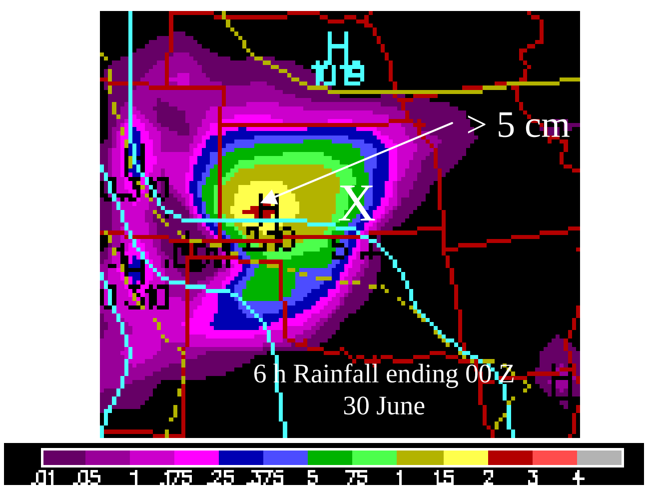
Precipitation Forecasts and MCVs:

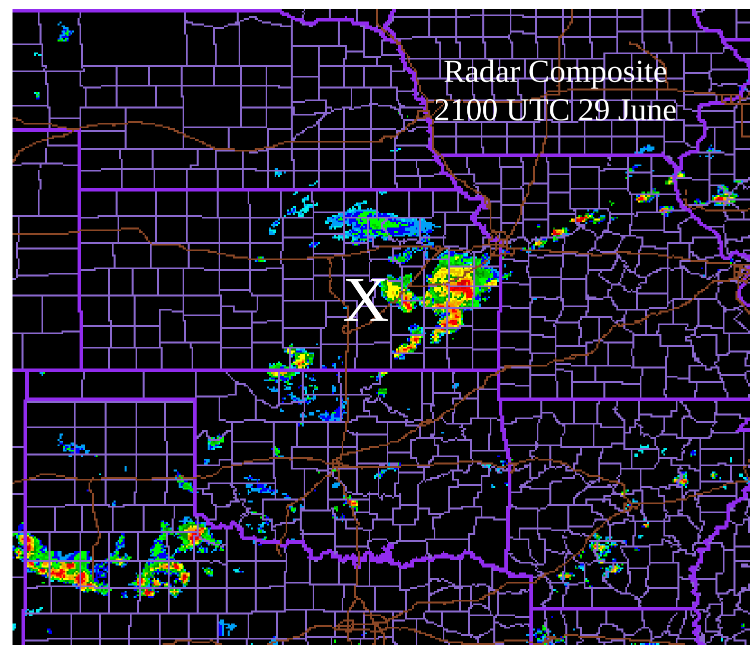
Comparison of the Weather Research and Forecast (WRF) model and the NCEP Eta model

- Eta poorly predicts MCV; subsequent rainfall in wrong place
- WRF has a much better prediction, related mostly to a better MCV prediction.



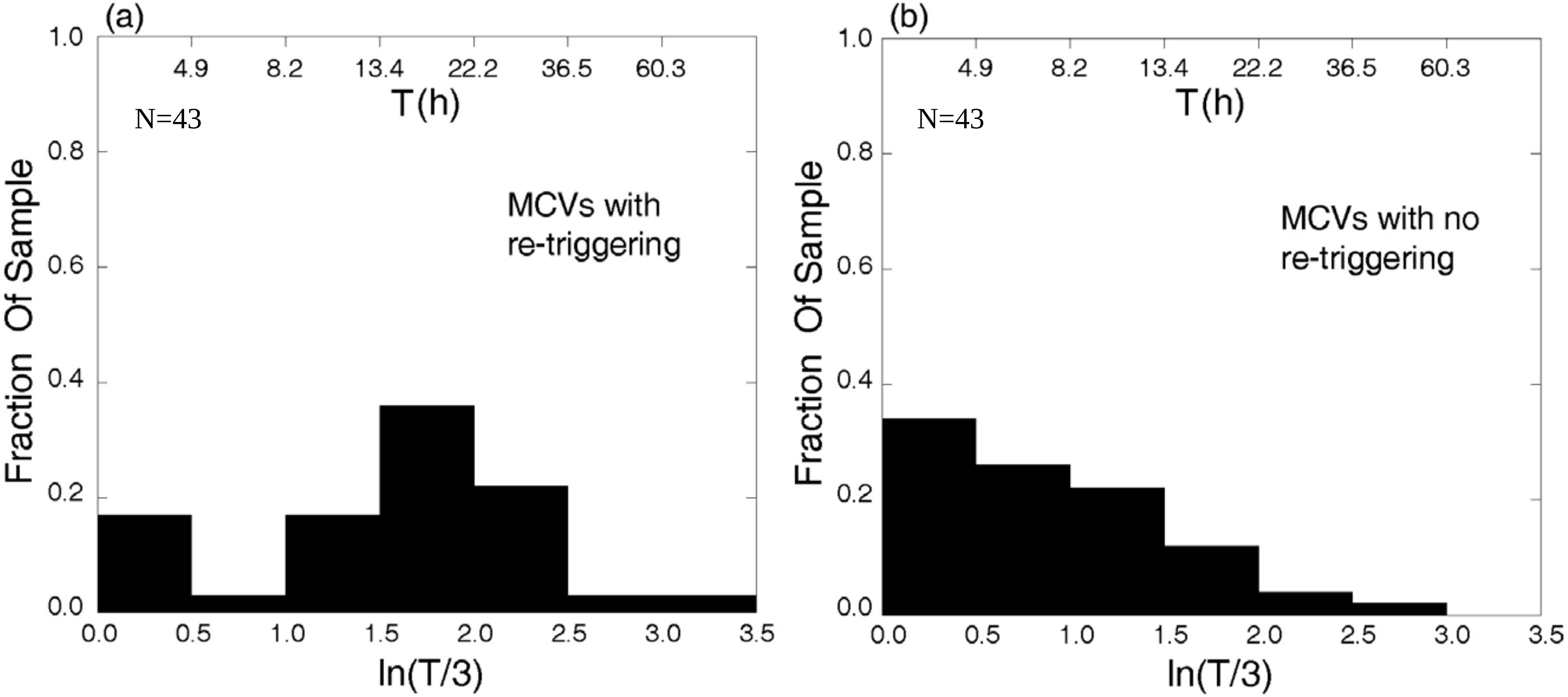
24 h Forecast from NCEP Eta





Longevity of MCVs

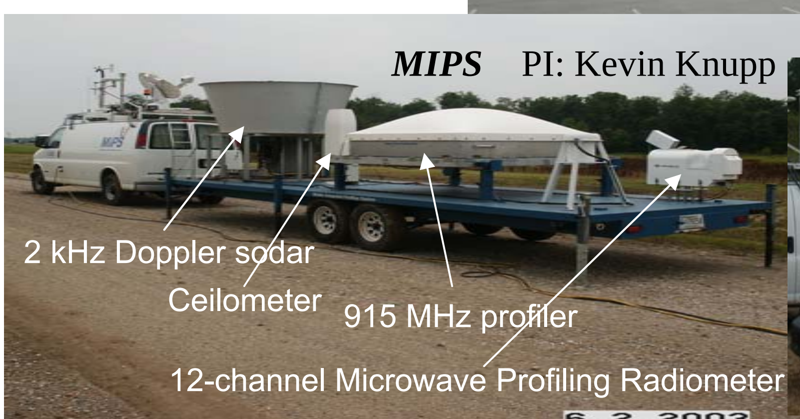
(based on 40-km RUC-2 analyses during JJA 1999)

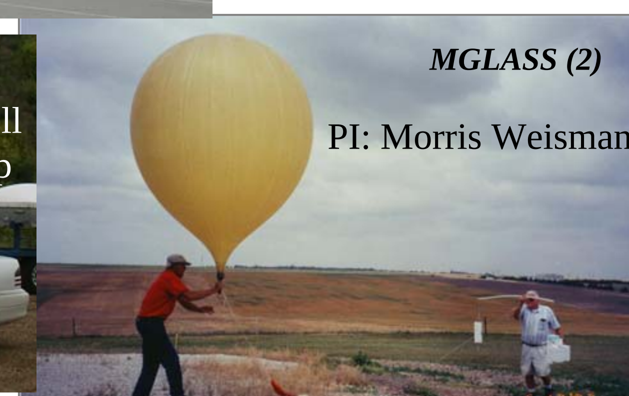


Davis et al. 2002, MWR

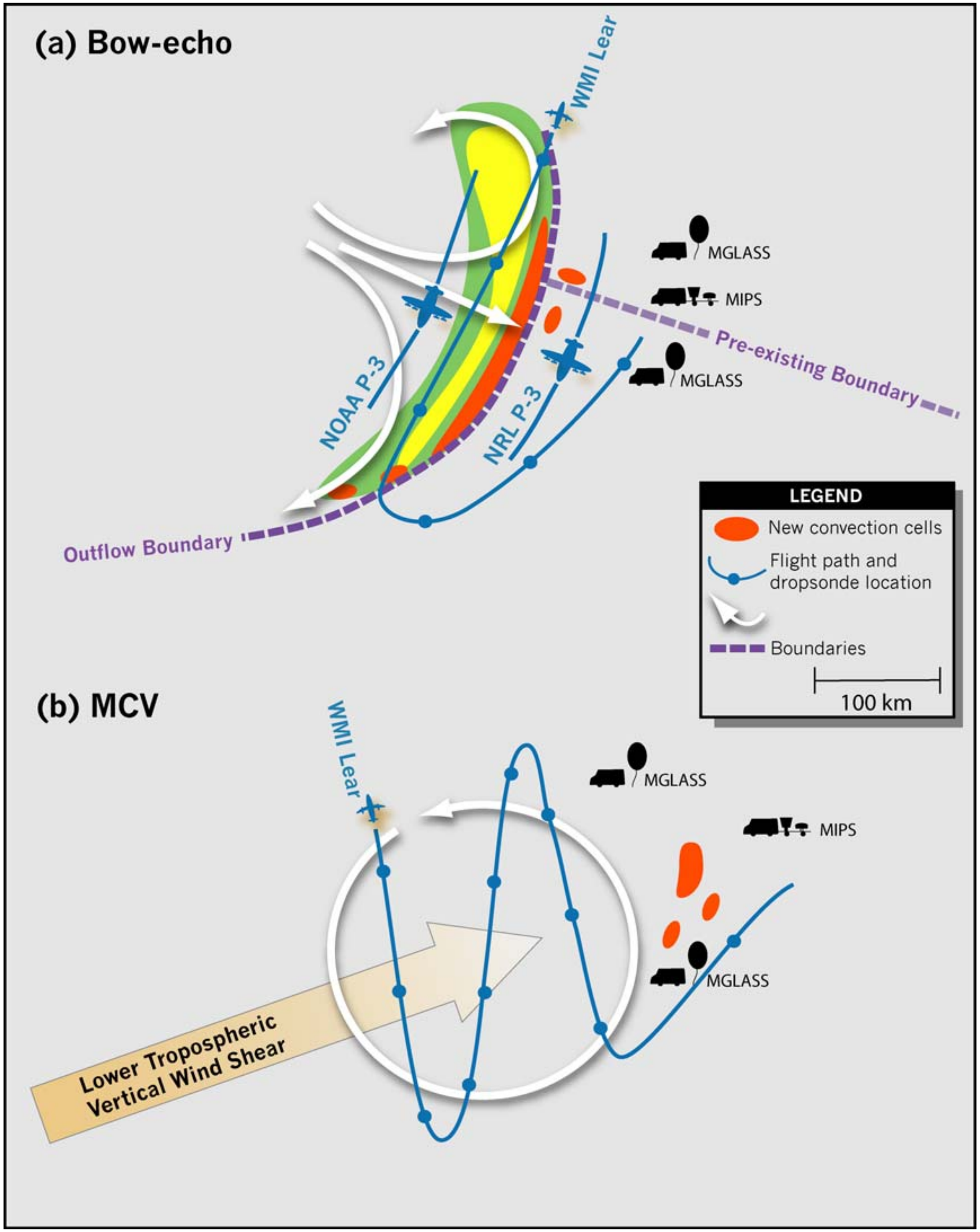
Bow Echo and MCV Experiment (BAMEX)

20 May- 6 July, 2003

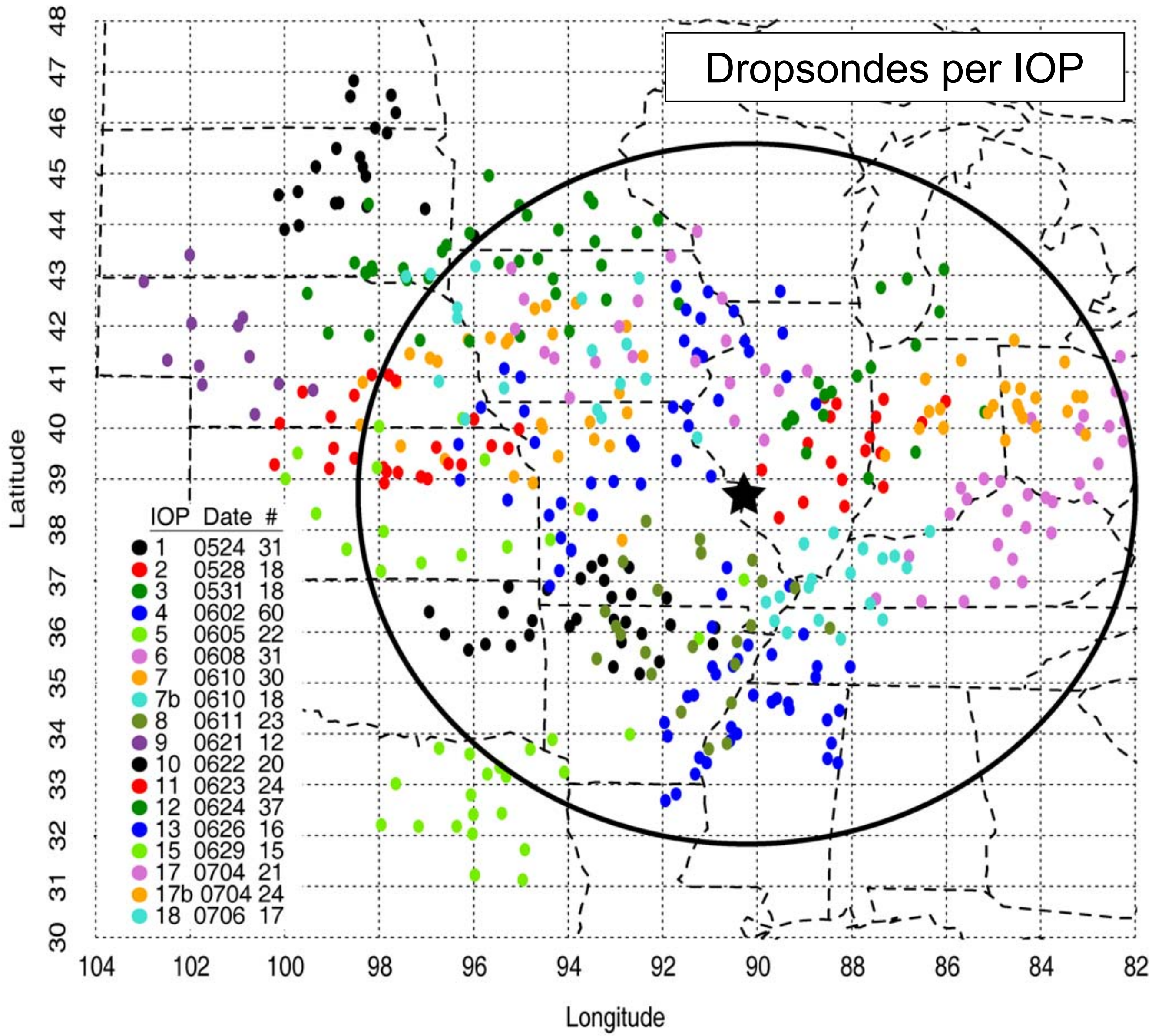




BAMEX Facility Deployment Strategy



BAMEX Domain

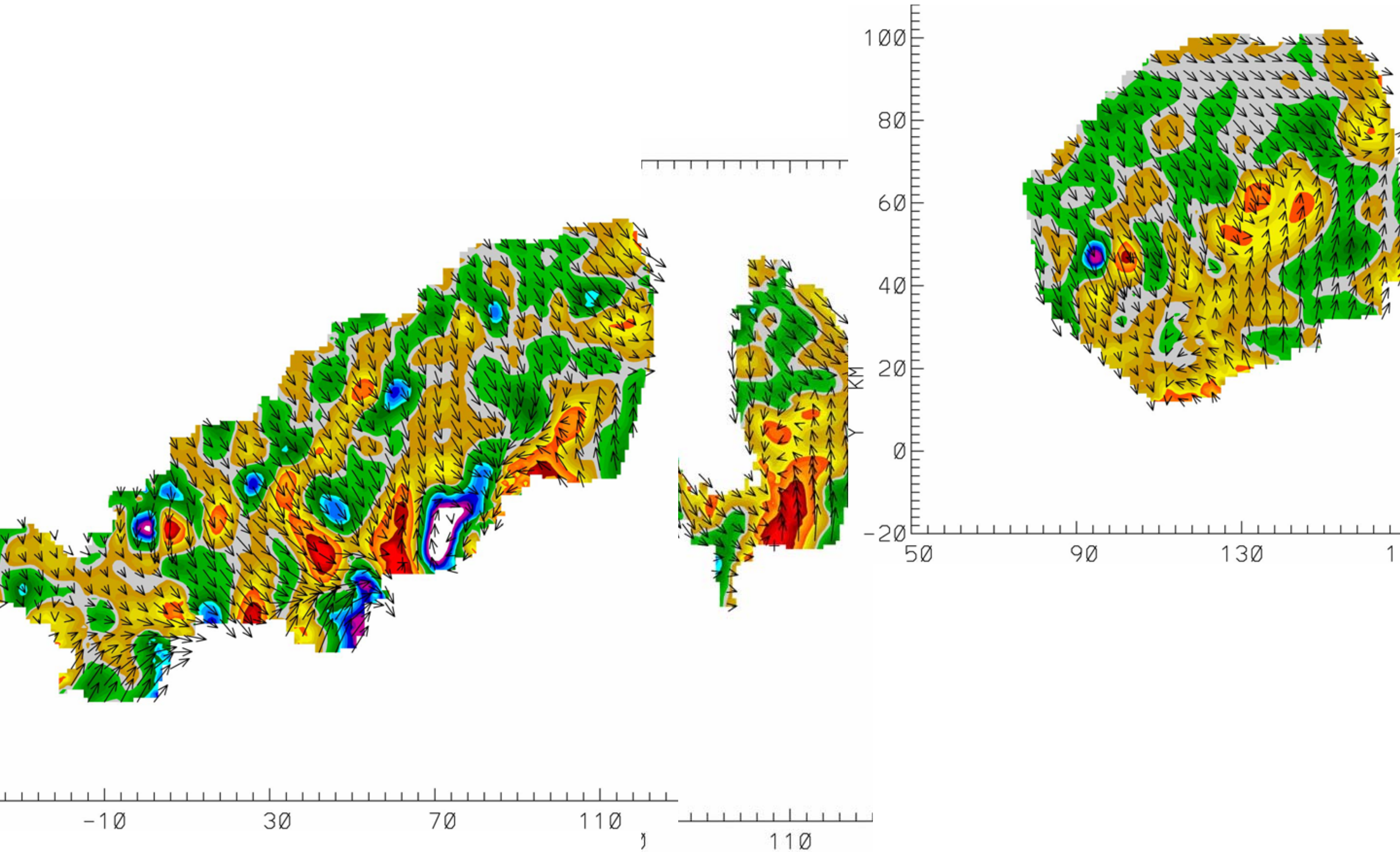


Courtesy Junhong Wang, ATD

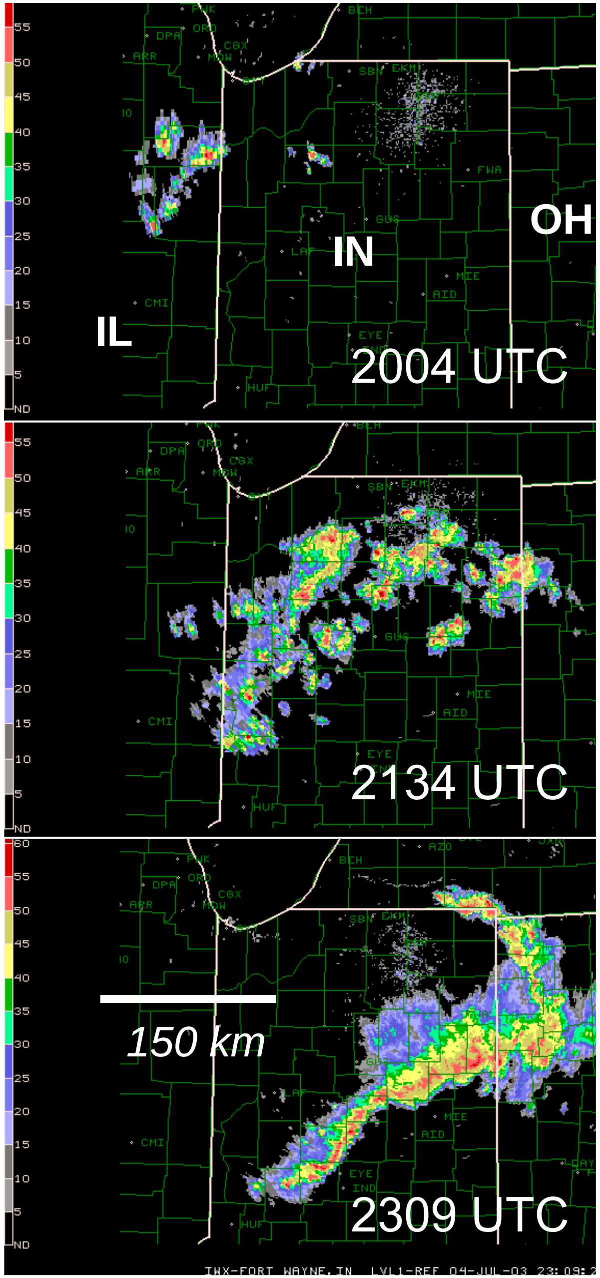
Developing MCVs

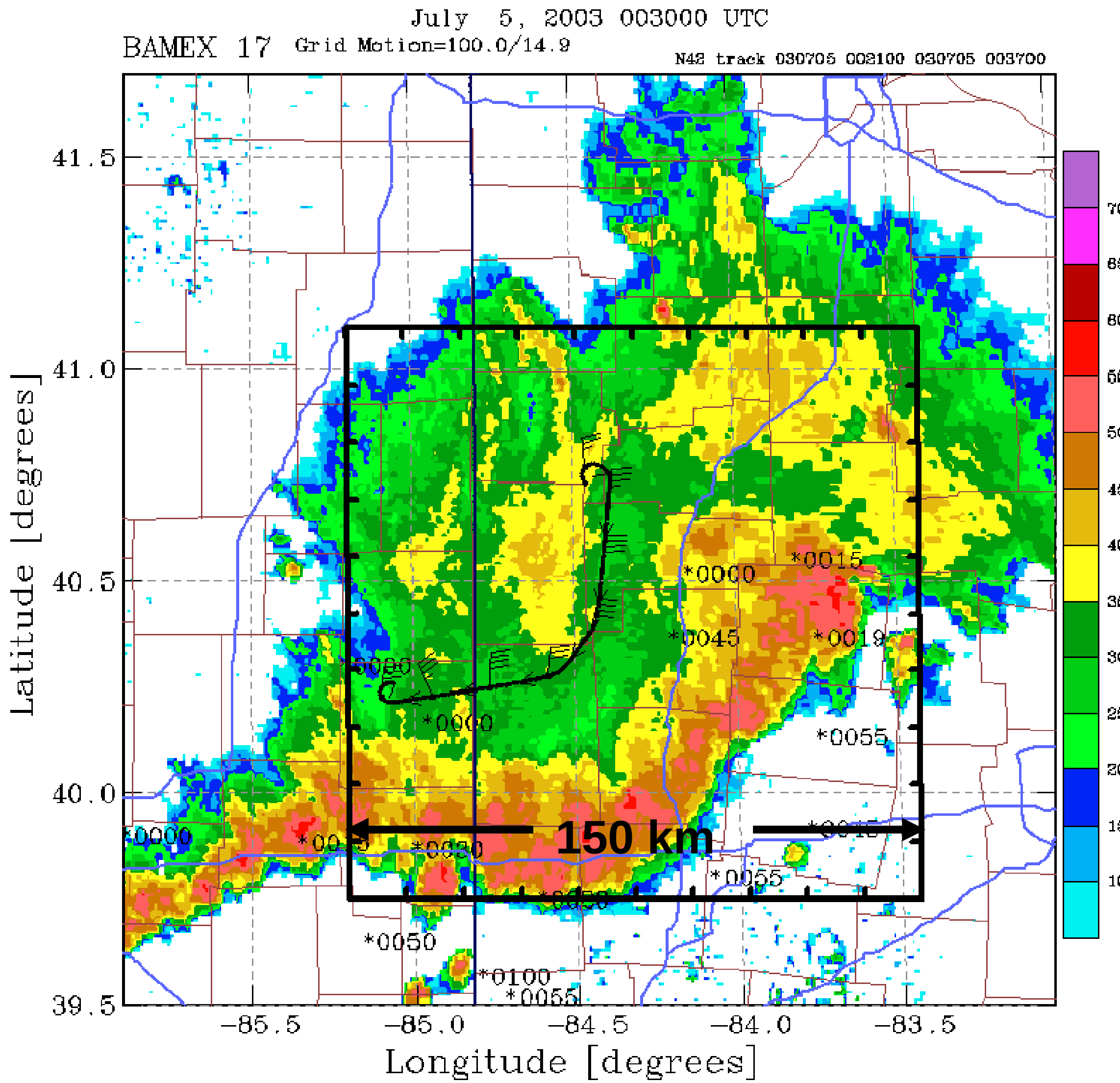
- July 4-5: Severe Bow Echo
  - NOAA P-3
  - Lear
- July 6: Severe Bow Echo
  - NOAA P-3
  - NRL P-3 (ELDORA)
  - Lear

IOP 16 (3 July, 2003)

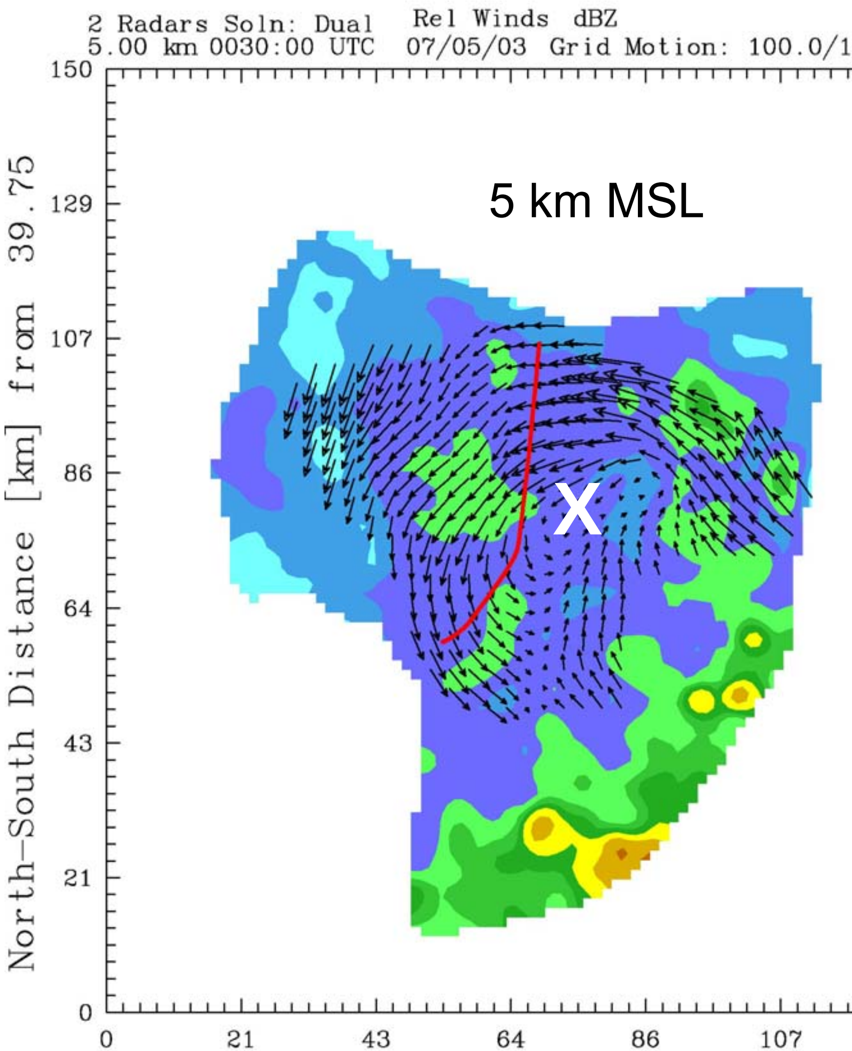


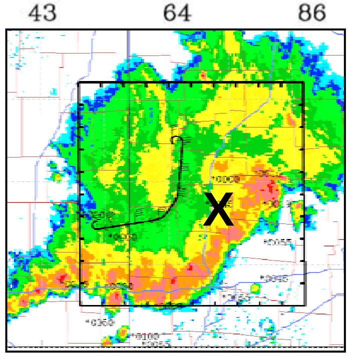
IOP 17: July 4-5

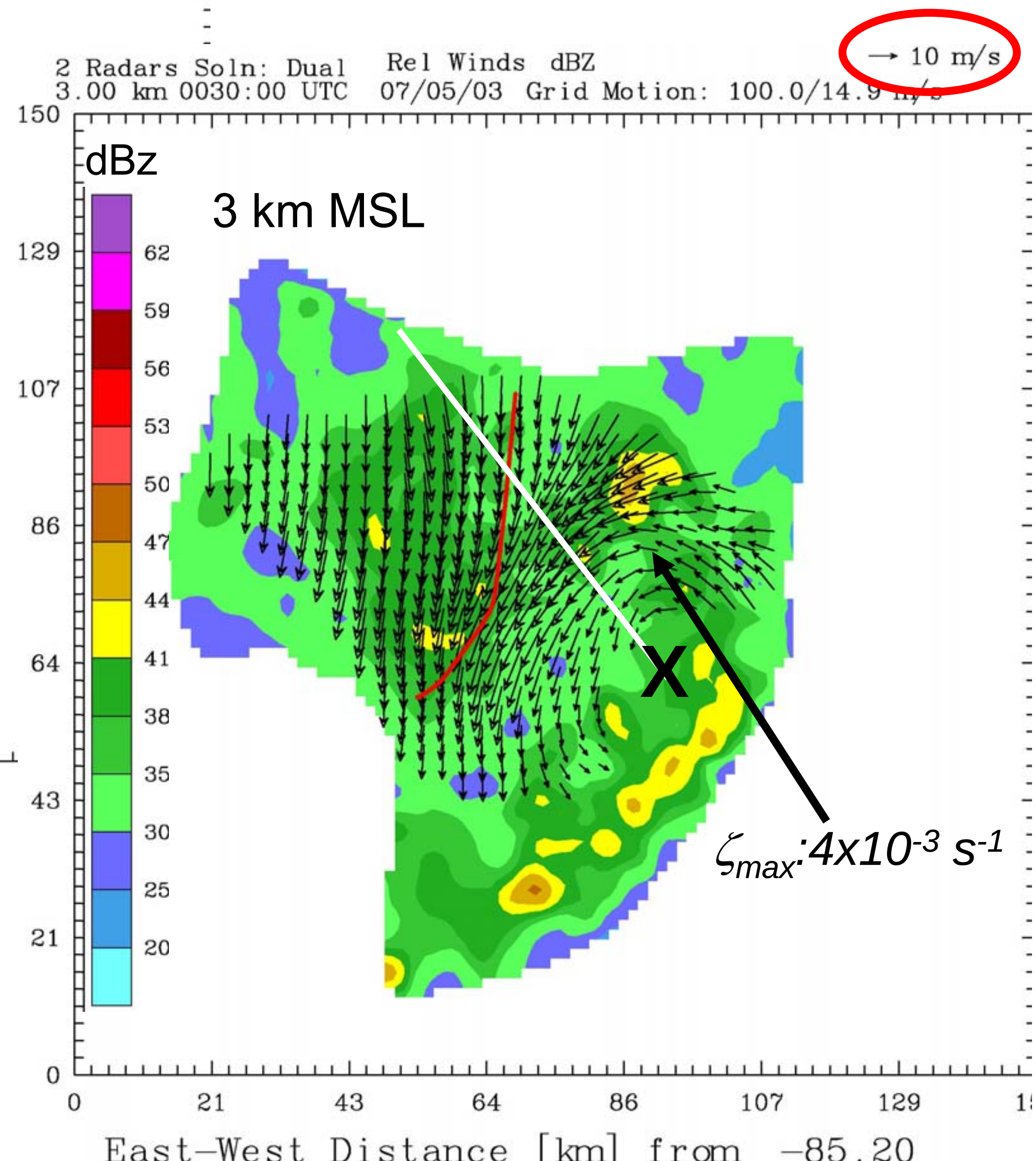




Mesoscale Vortex

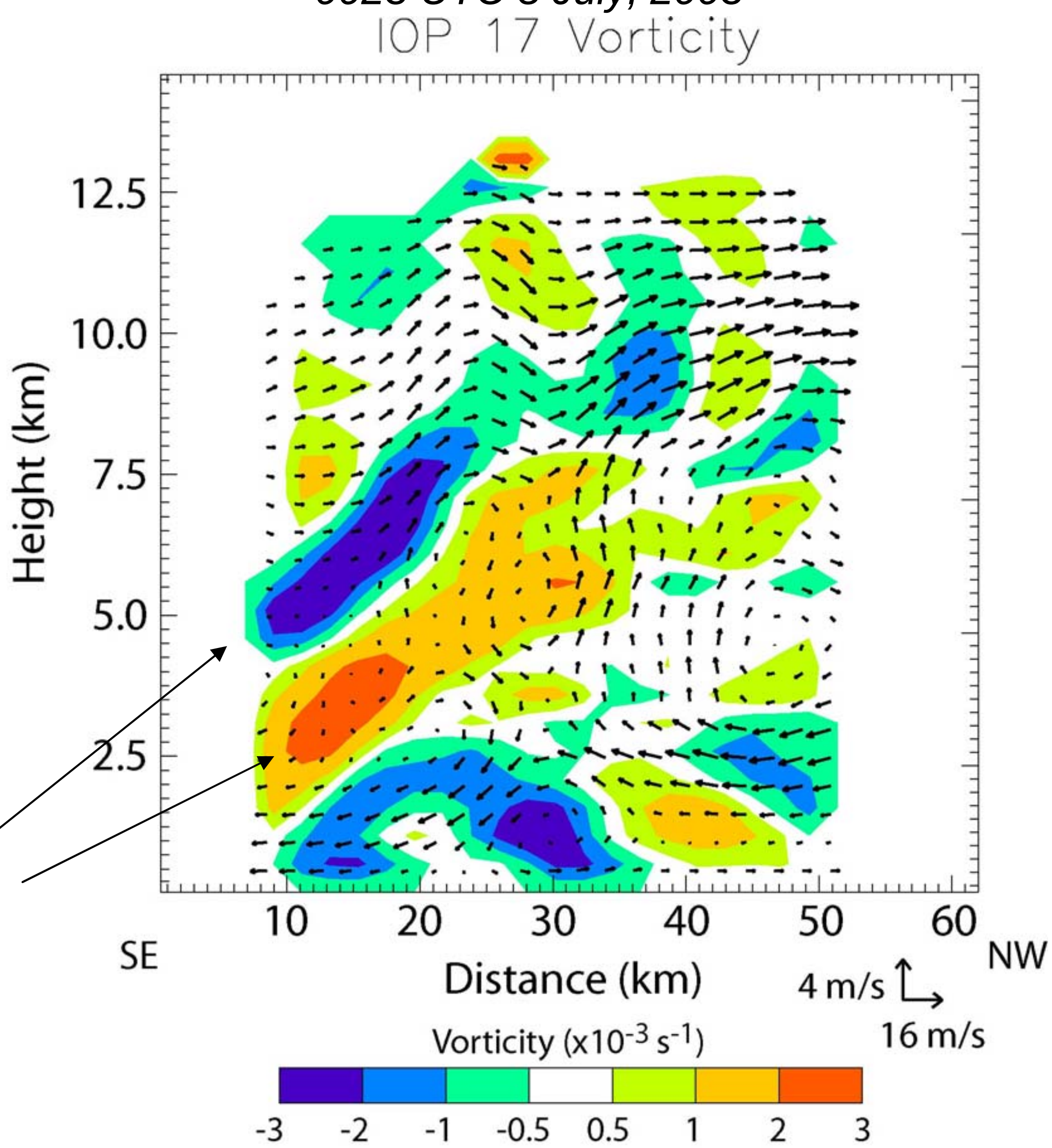






Vertical Cross Section of Relative Vorticity

0023 UTC 5 July, 2003



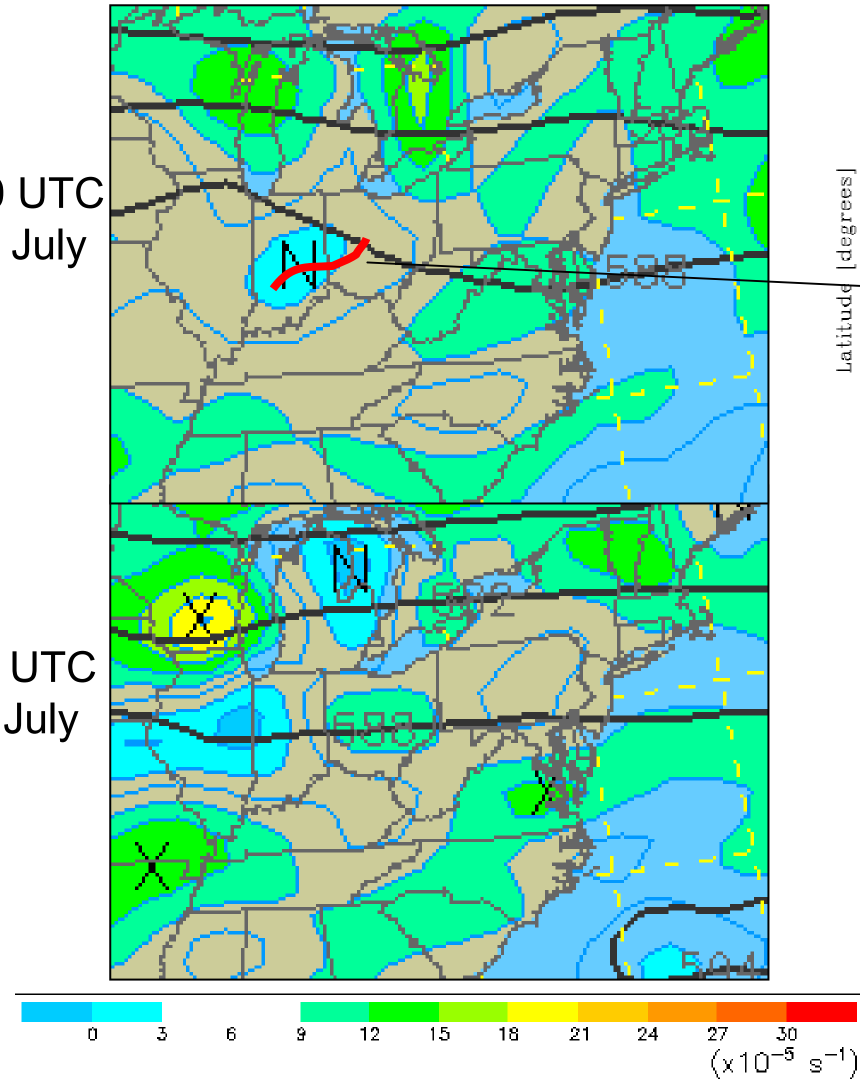
Tilted structures noted by Zhang 1992

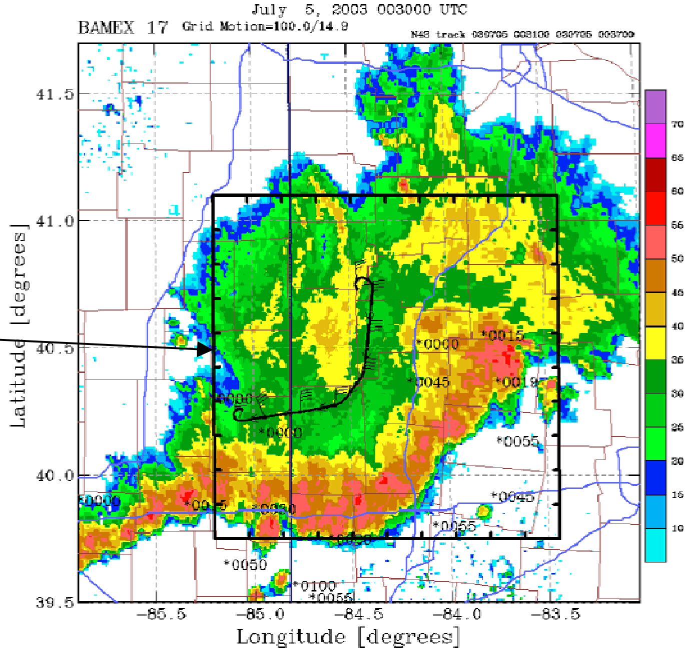
Mid-tropospheric Vorticity

500 hPa η and Φ (Eta Analysis)

00 UTC
5 July

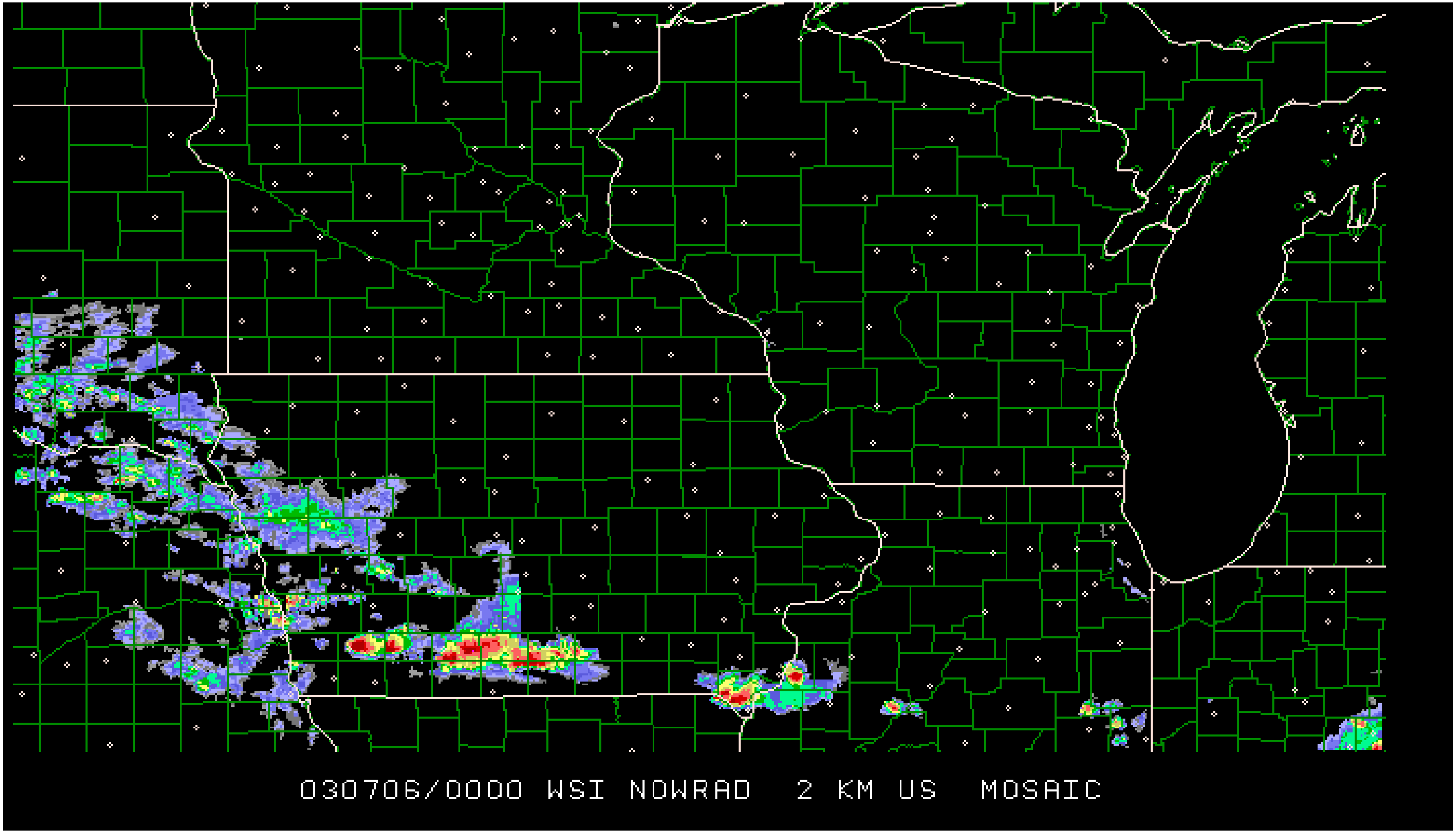
12 UTC
5 July



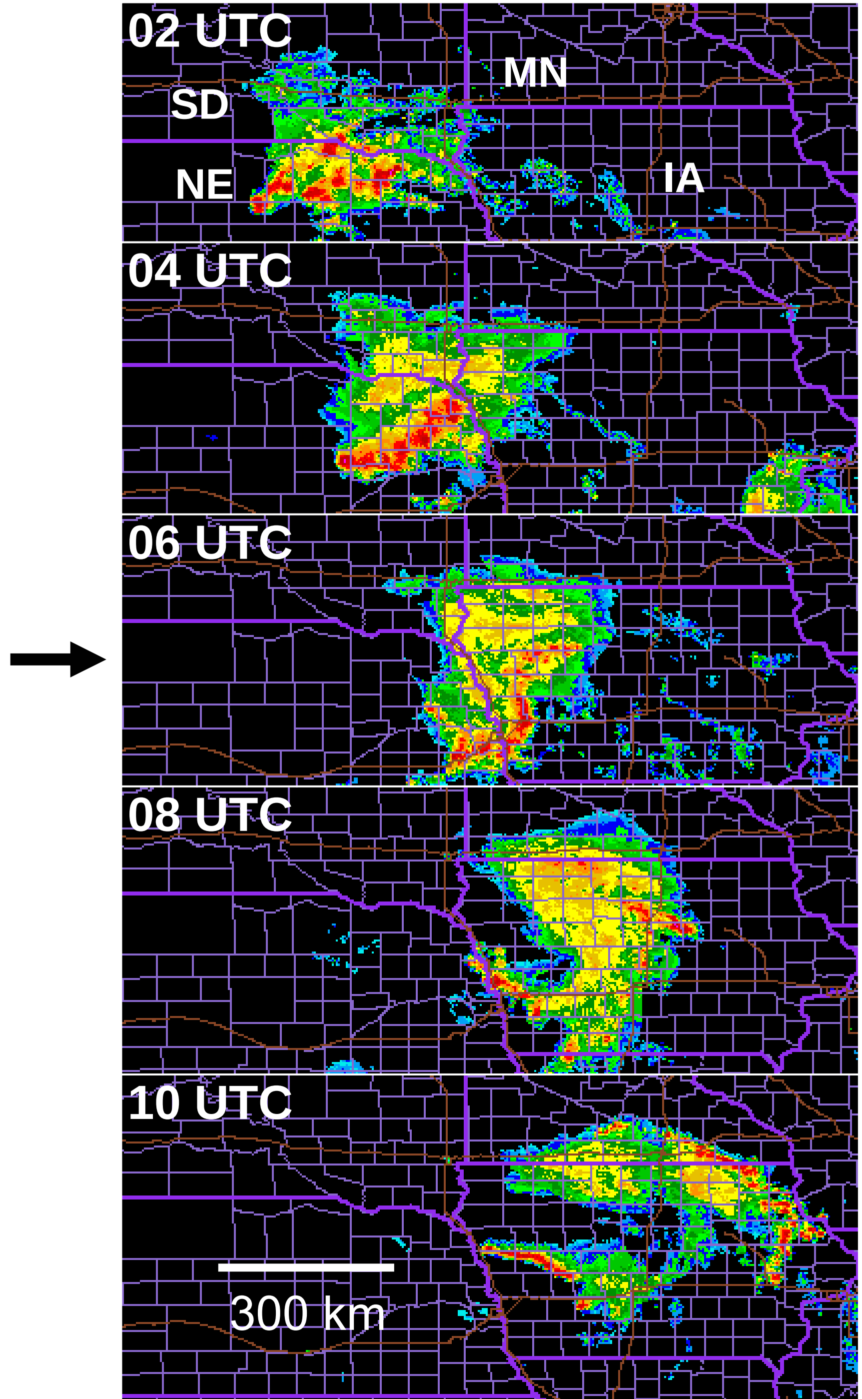


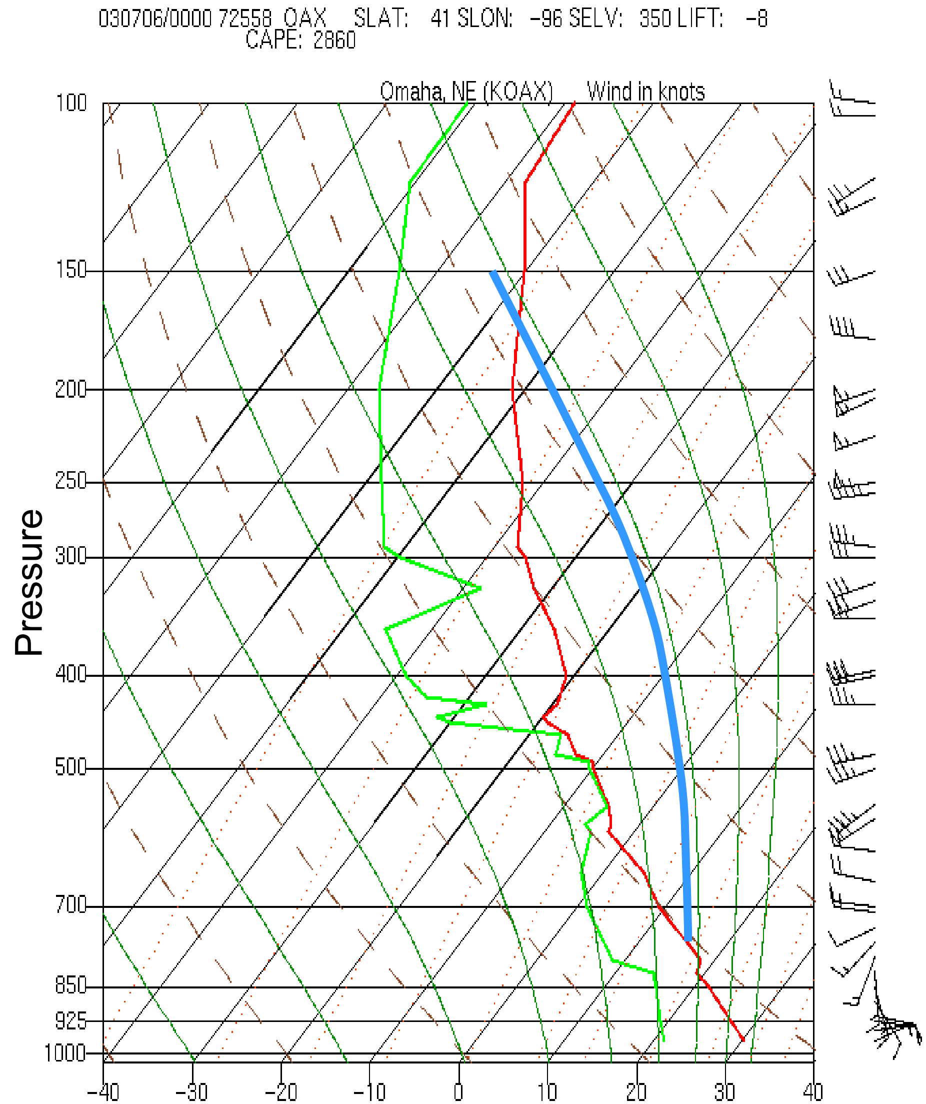
Initial vorticity negative: no mid-tropospheric vortex in analysis at 12 UTC.

Reflectivity Animation: 6 July

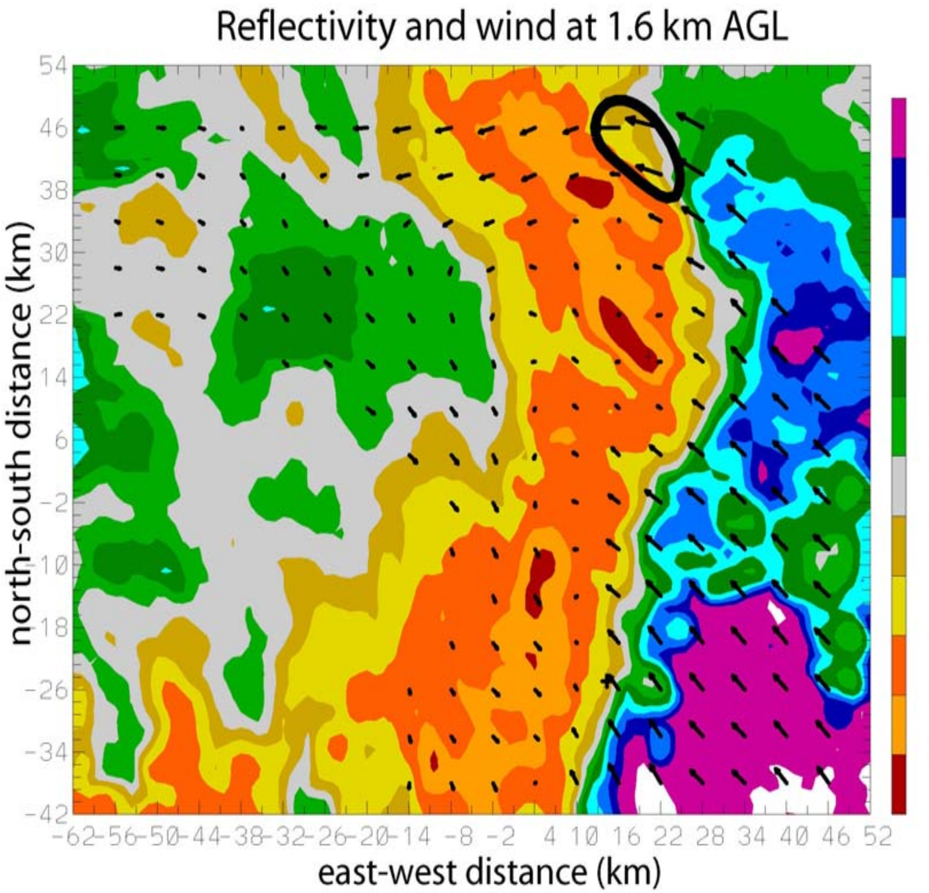


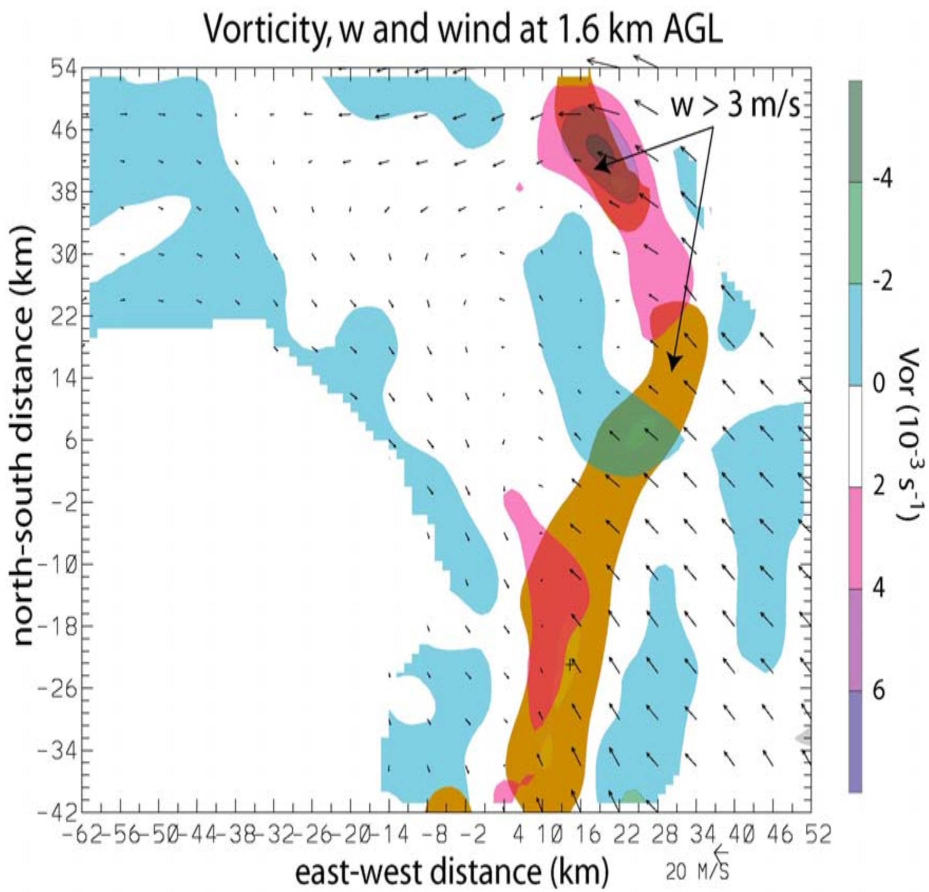
IOP 18 (6 July)


02 UTC
MN
SD
NE
IA
04 UTC
06 UTC
08 UTC
10 UTC
300 km

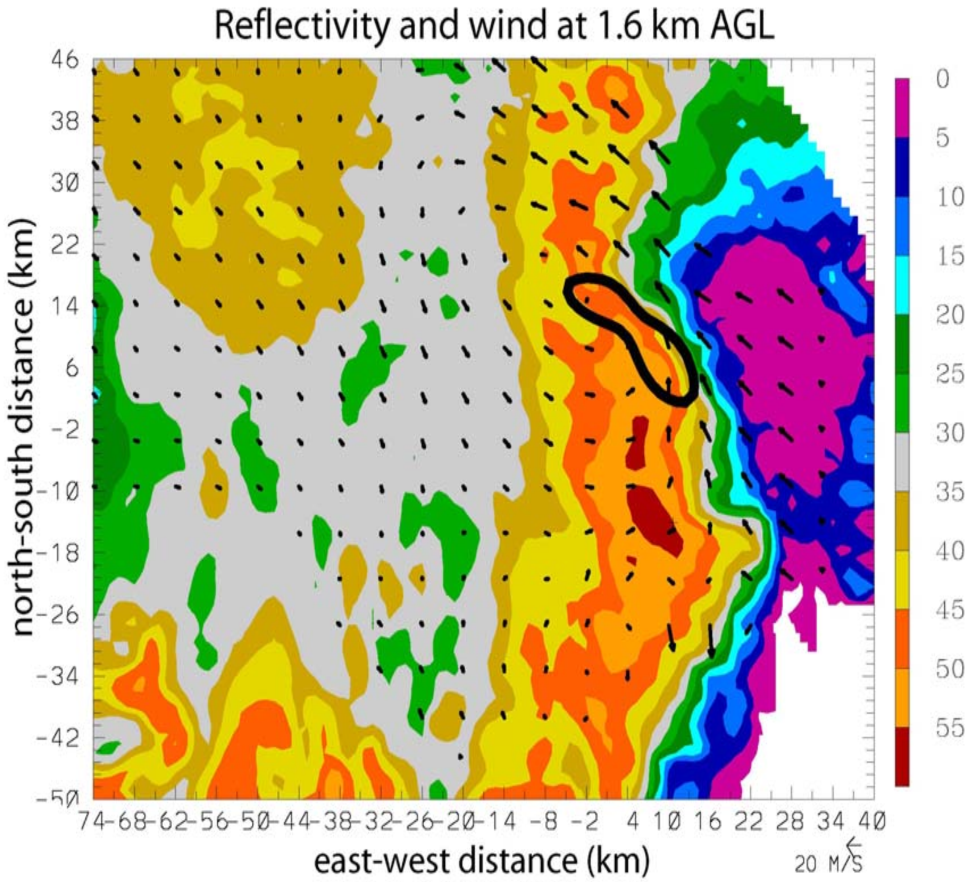

030706/0000 72558 OAX SLAT: 41 SLON: -96 SELV: 350 LIFT: -8
CAPE: 2860
Omaha, NE (KOAX) Wind in knots
Pressure
100
150
200
250
300
400
500
700
850
925
1000
-40 -30 -20 -10 0 10 20 30 40

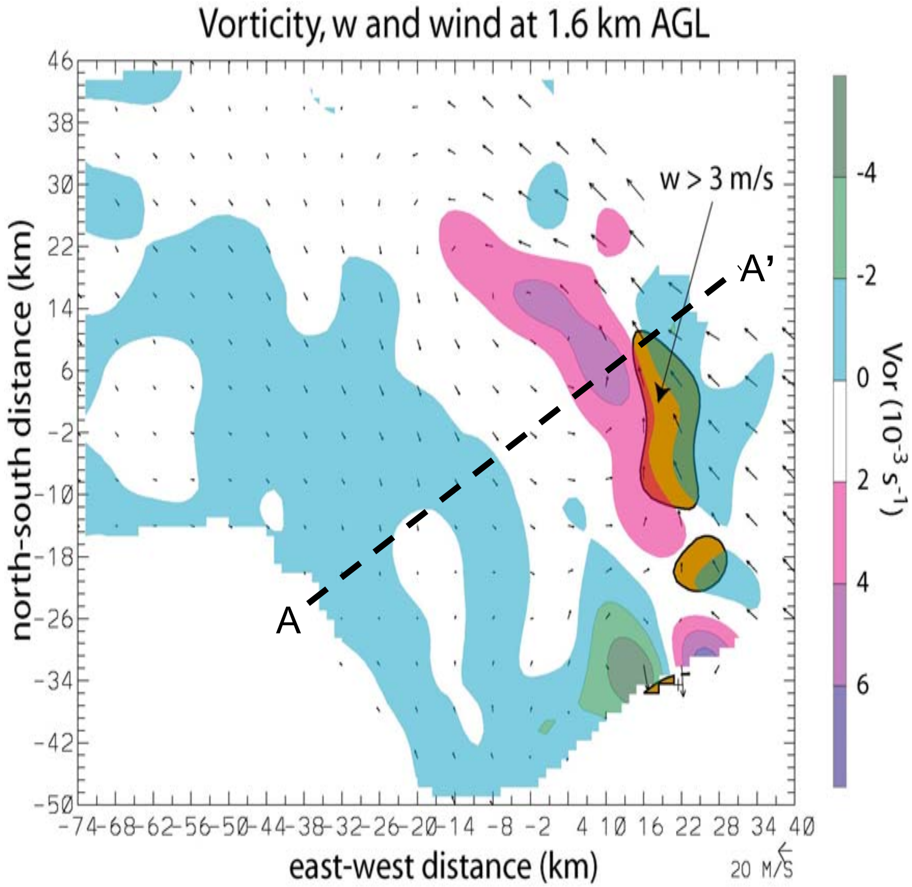
0517 UTC 6 July



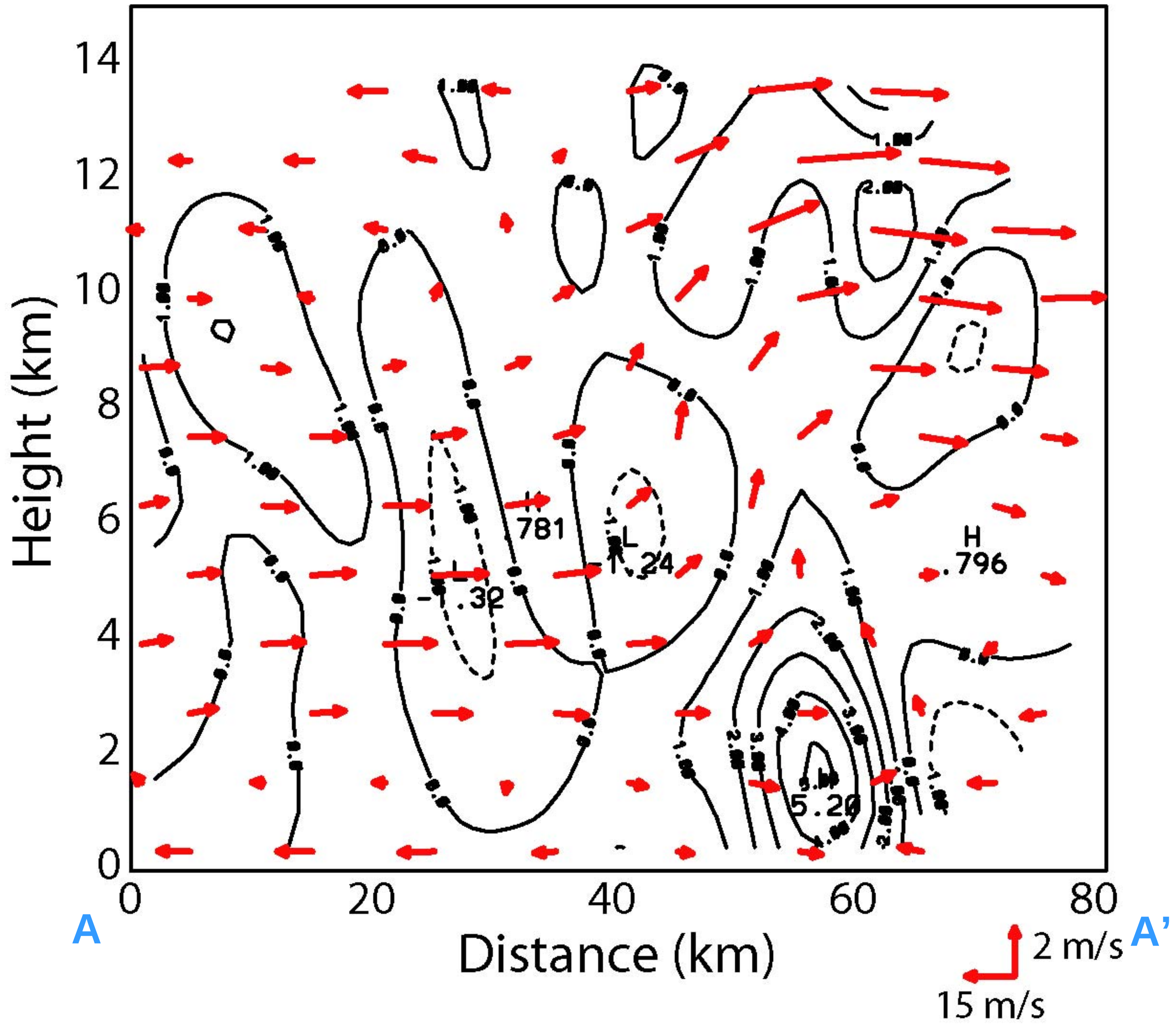


0550 UTC 6 July

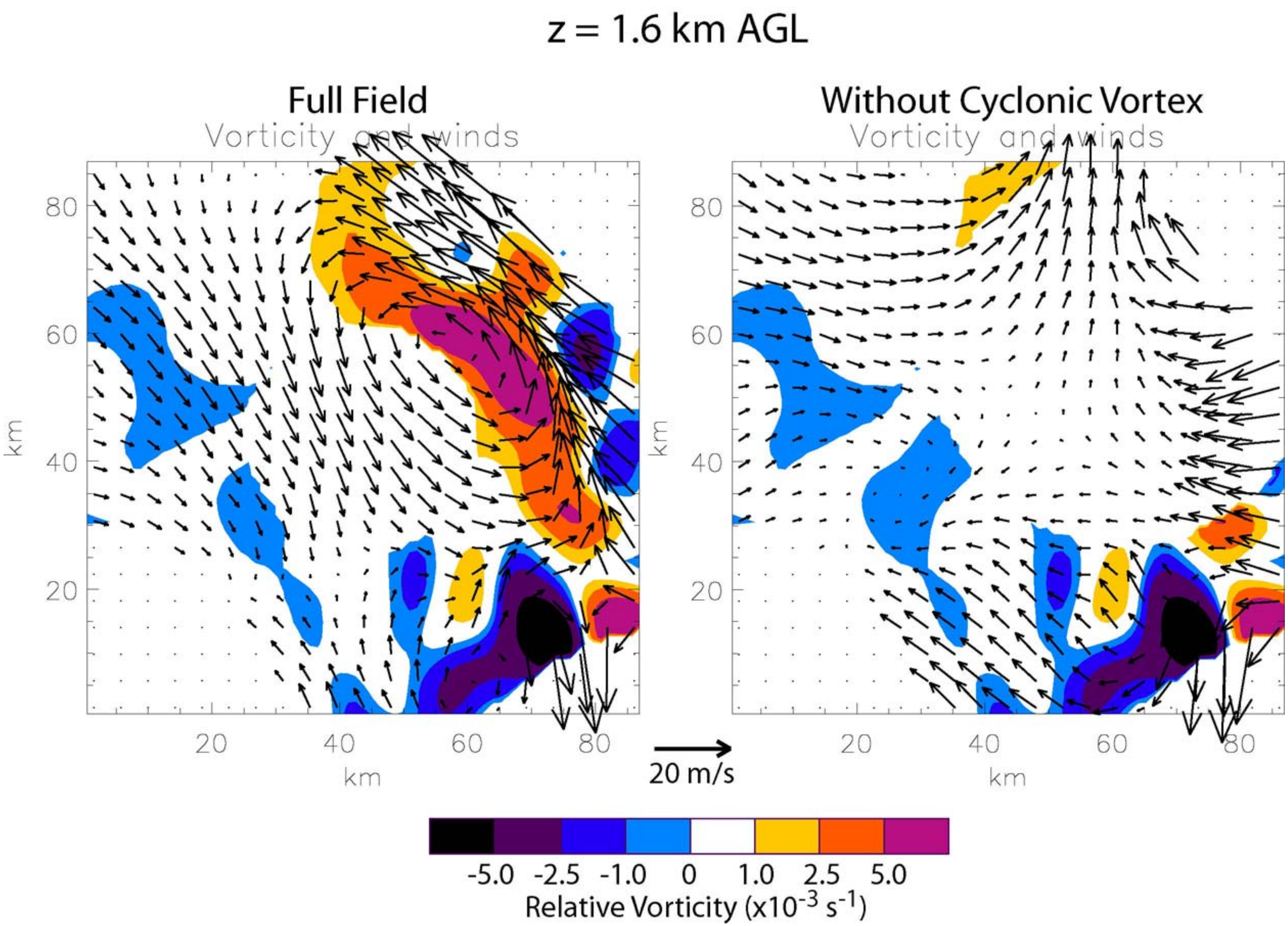




Vertical Cross Section Through Line-end Vortex



Developing MCV, July 6, 2003 (IOP 18)



Evolution of Mid-tropospheric Vortex

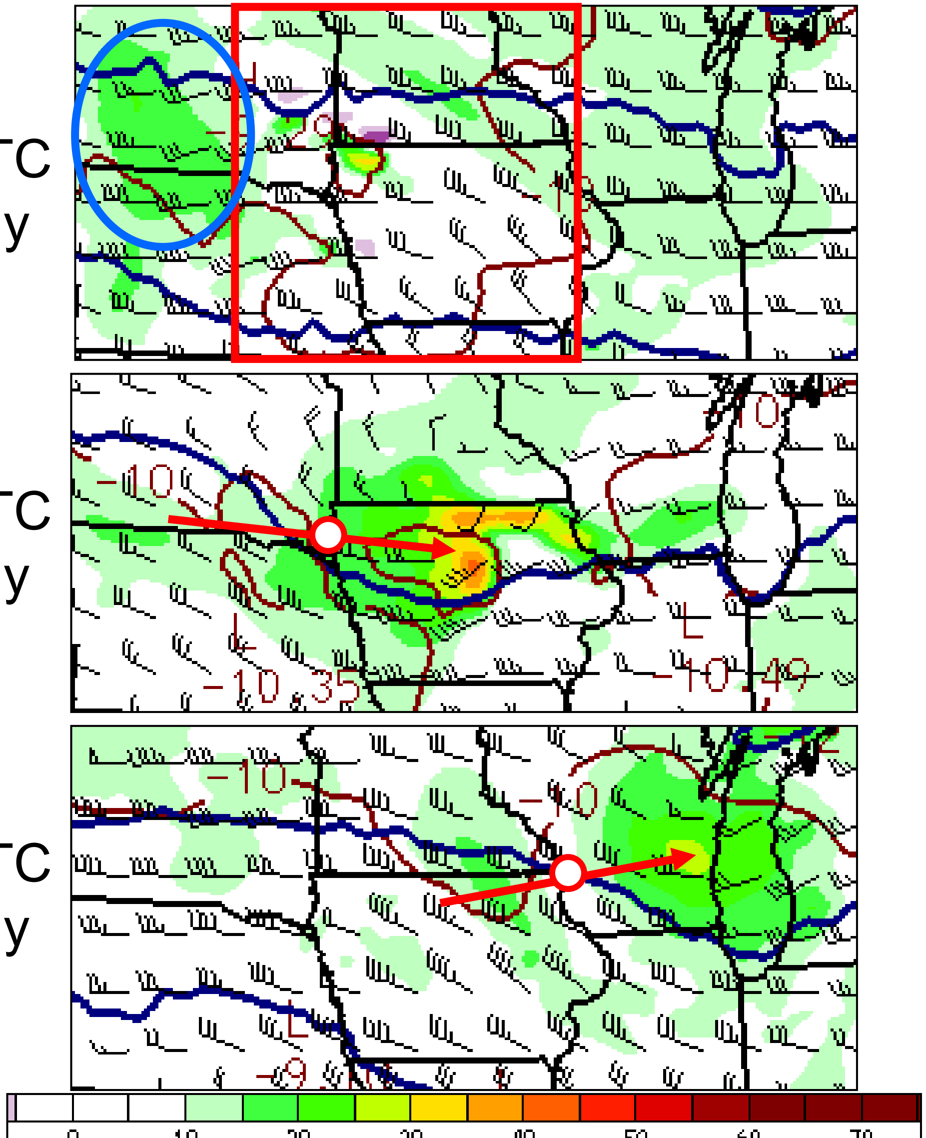
12 UTC 6 July

Eta 500 mb ζ, wind analysis

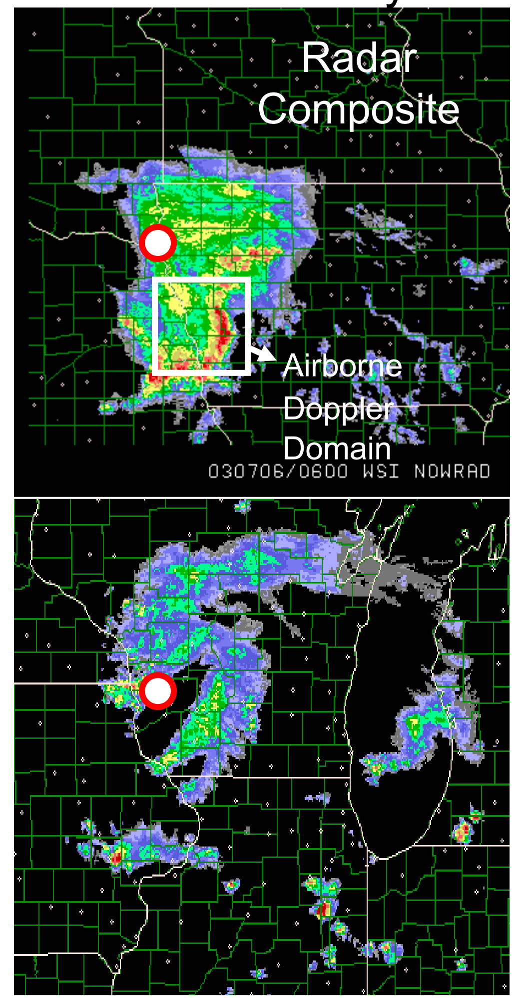
00 UTC 6 July

12 UTC 6 July

00 UTC 7 July

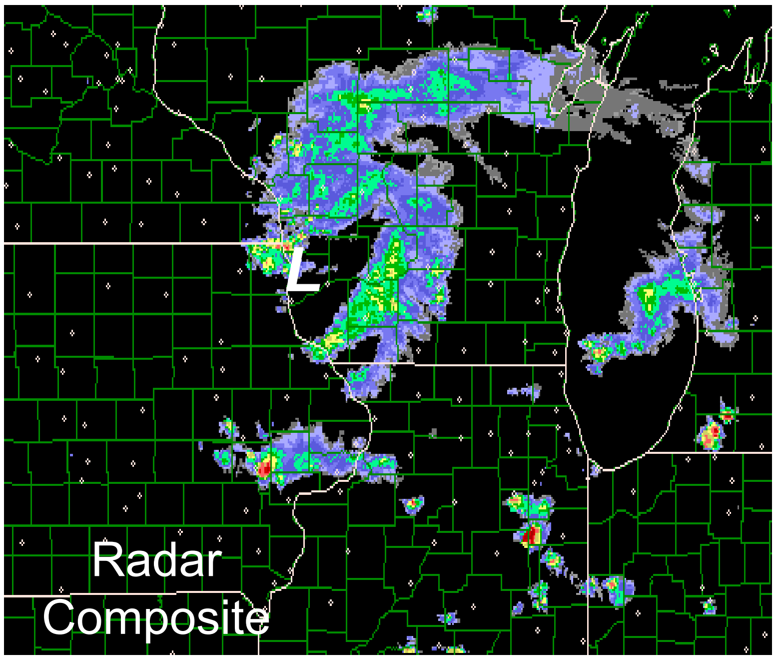


06 UTC 6 July

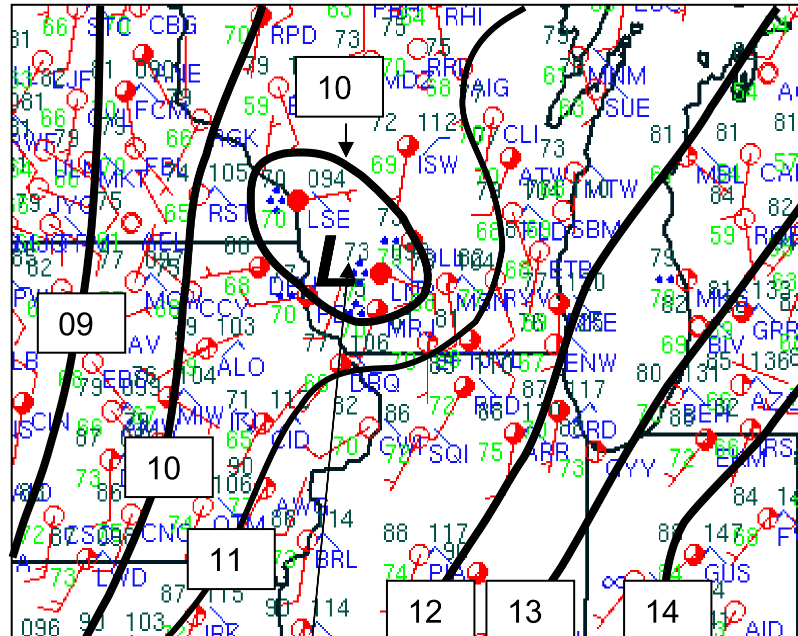


18 UTC 6 July

18 UTC 6 July



Sea-level Pressure (1 hPa interval)



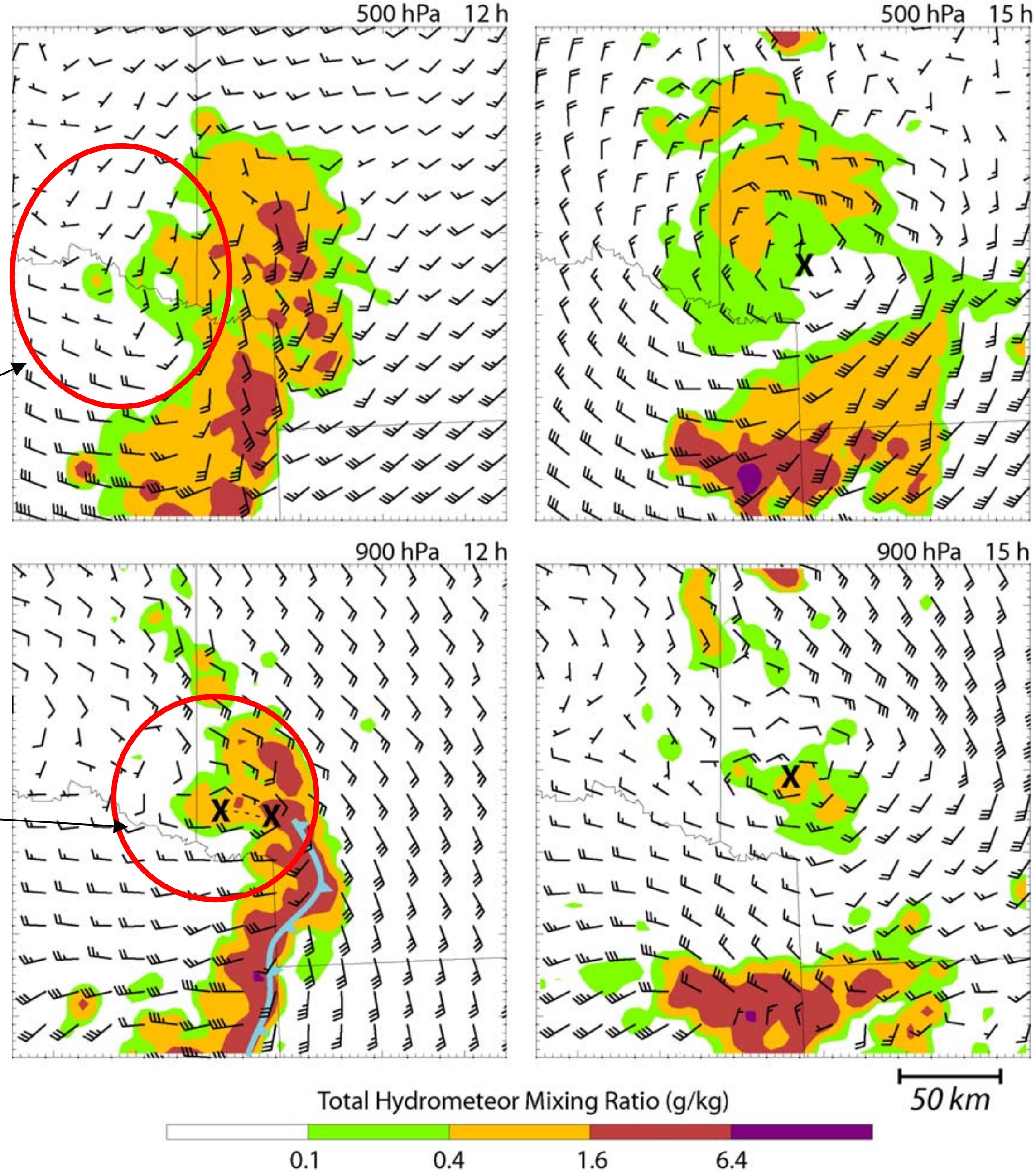
Vortex signature at surface

Coupling of Vortices at Two Levels

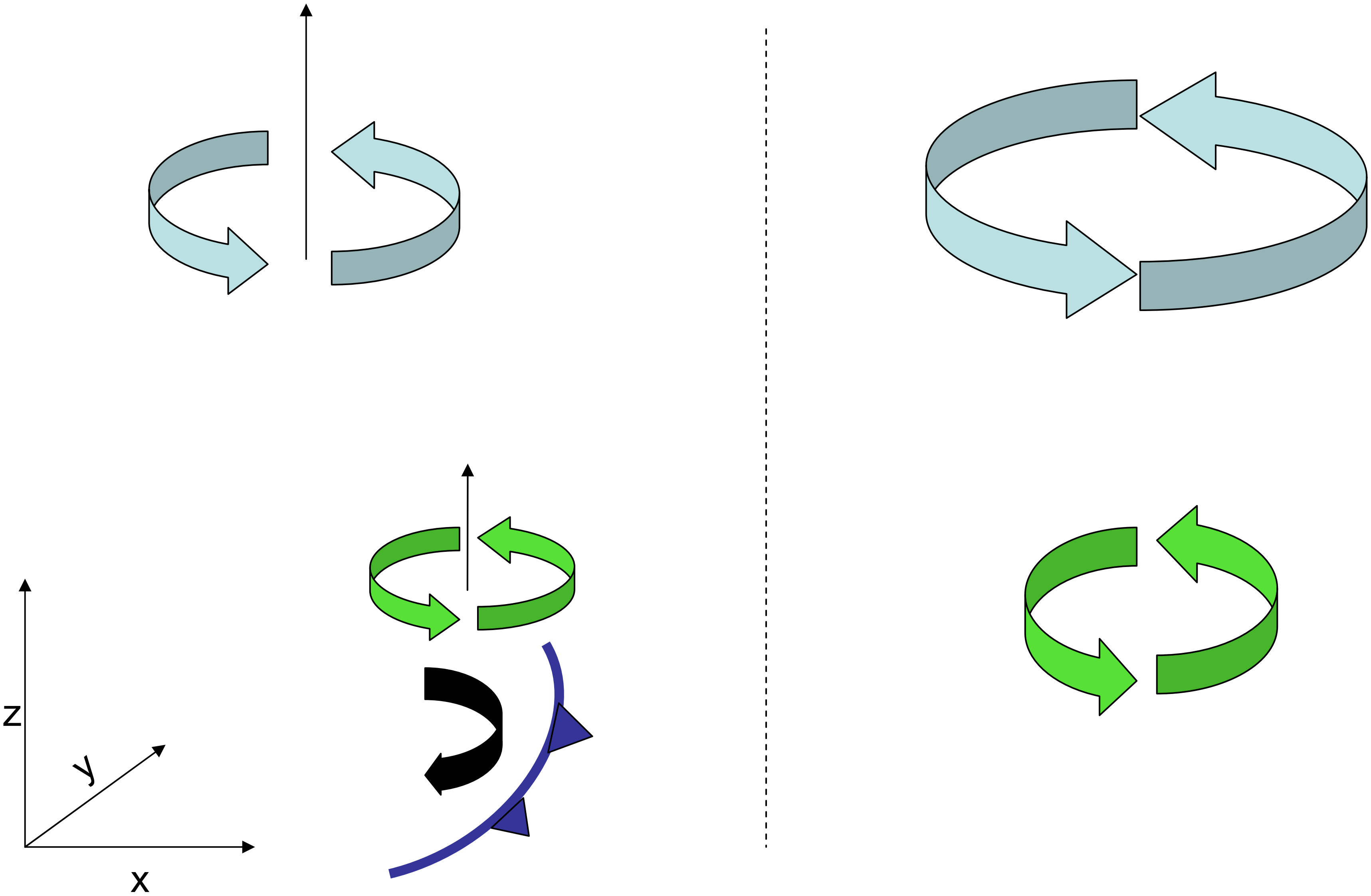
MM5 Simulation of 27-28 may, 1998 case, 1.5 km grid.

Remnant mid-tropospheric vorticity

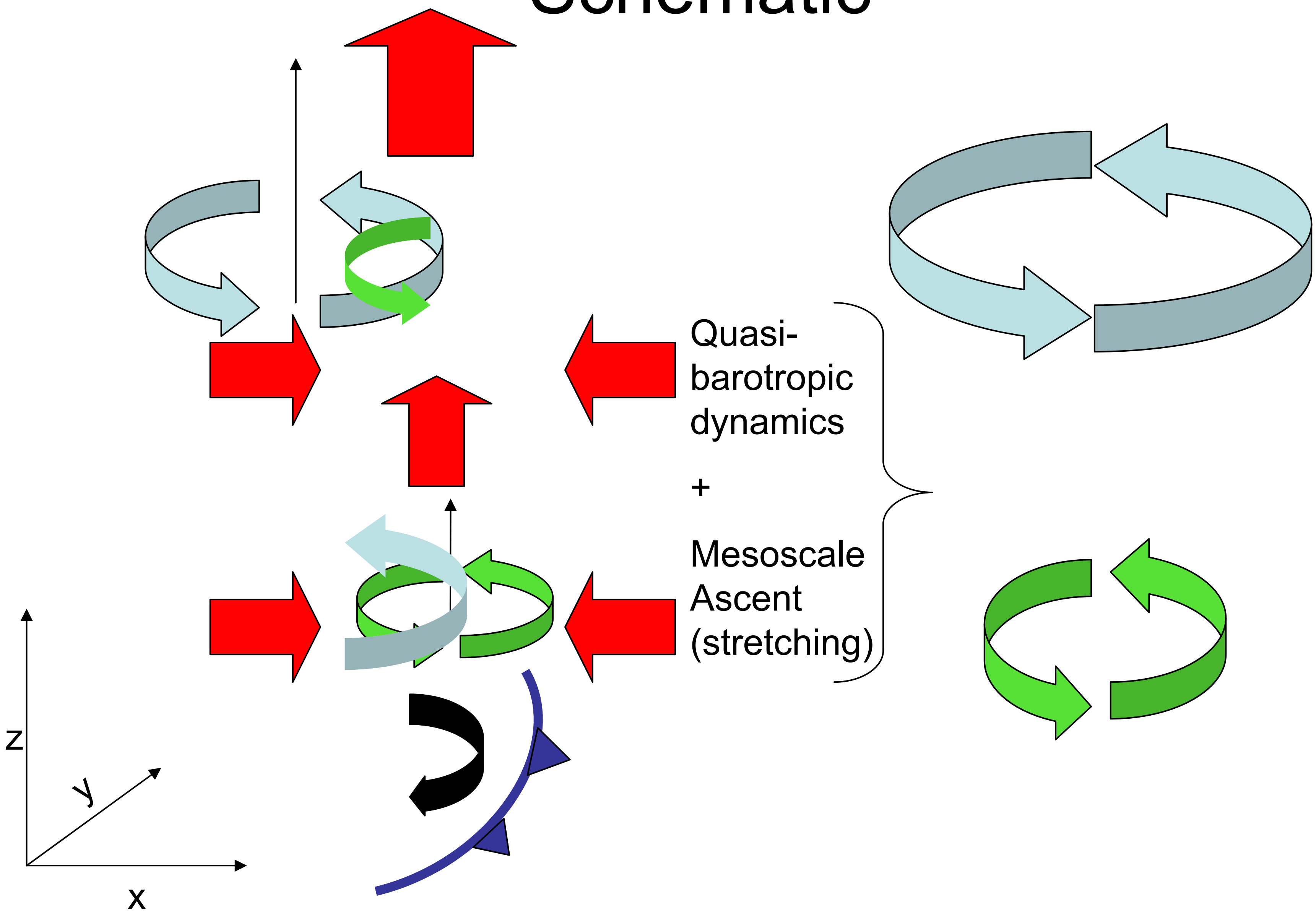
New Line-end Vortex at 900 mb



Schematic



Schematic



z
y
x
Quasi-
barotropic
dynamics
+
Mesoscale
Ascent
(stretching)

Key Points and Issues

- Line end most intense in the lower troposphere
- Circulation already ~ half mature MCV
- Most of storm-relative rear-inflow is rotational

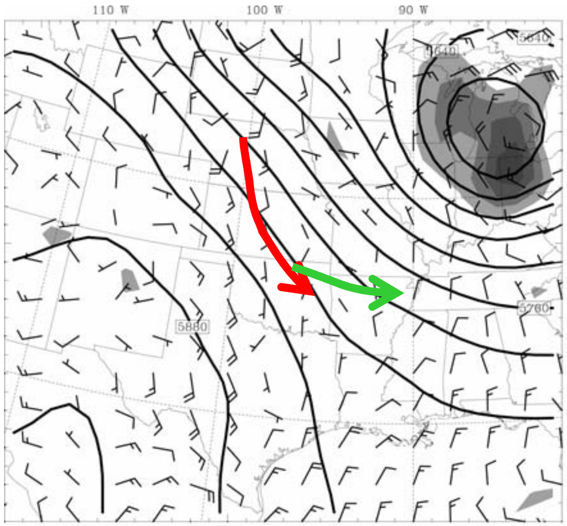
- What is relationship to mid-level MCVs?
  - In IOP 18, perhaps vortex merger
  - IOP 17: no long-lived MCV observed

Mature MCVs

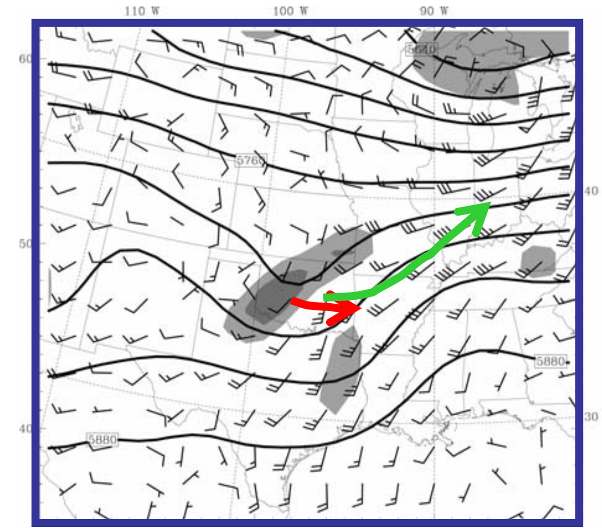
- May 24: remnant of severe bow echo
- June 2: hybrid with cyclone wave
- June 5: remnant of large MCS
- June 11: Multi-day MCS/MCV system, late became frontal cyclone
- June 24: MCV from multi-MCS complex

- Data: dropsondes, MGLASS, profilers (storm relative and time-space corrected)

IOP 1: 00 UTC 24 May



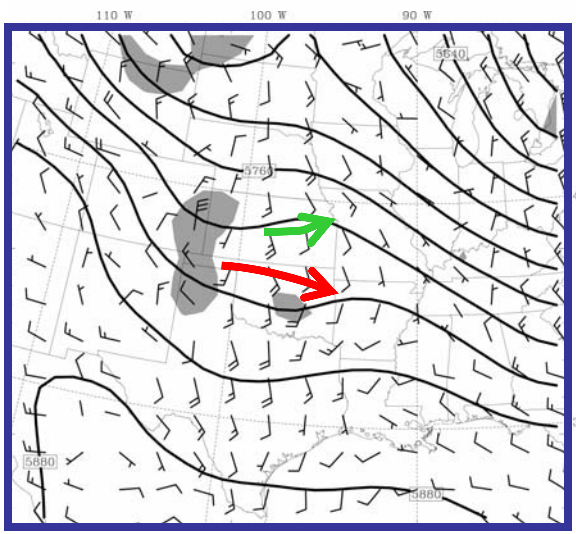
IOP 8: 00 UTC 11 June



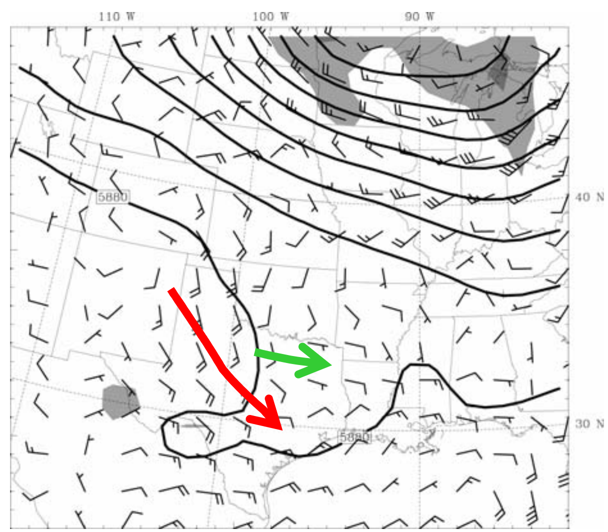
Precursor Conditions

500 hPa Φ, ζ
850 hPa wind

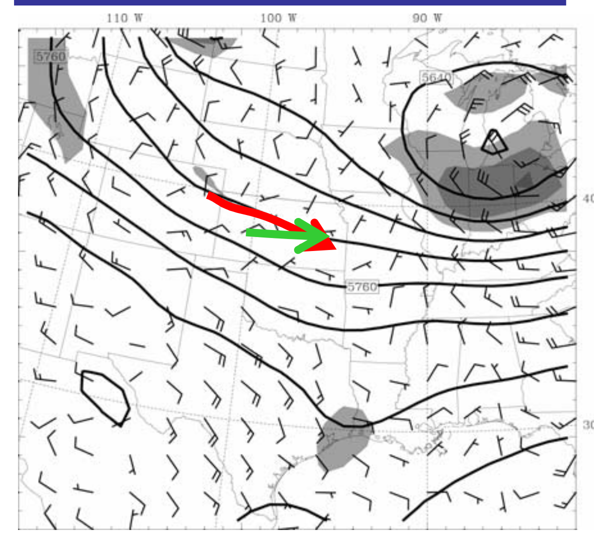
→ MCS → MCV



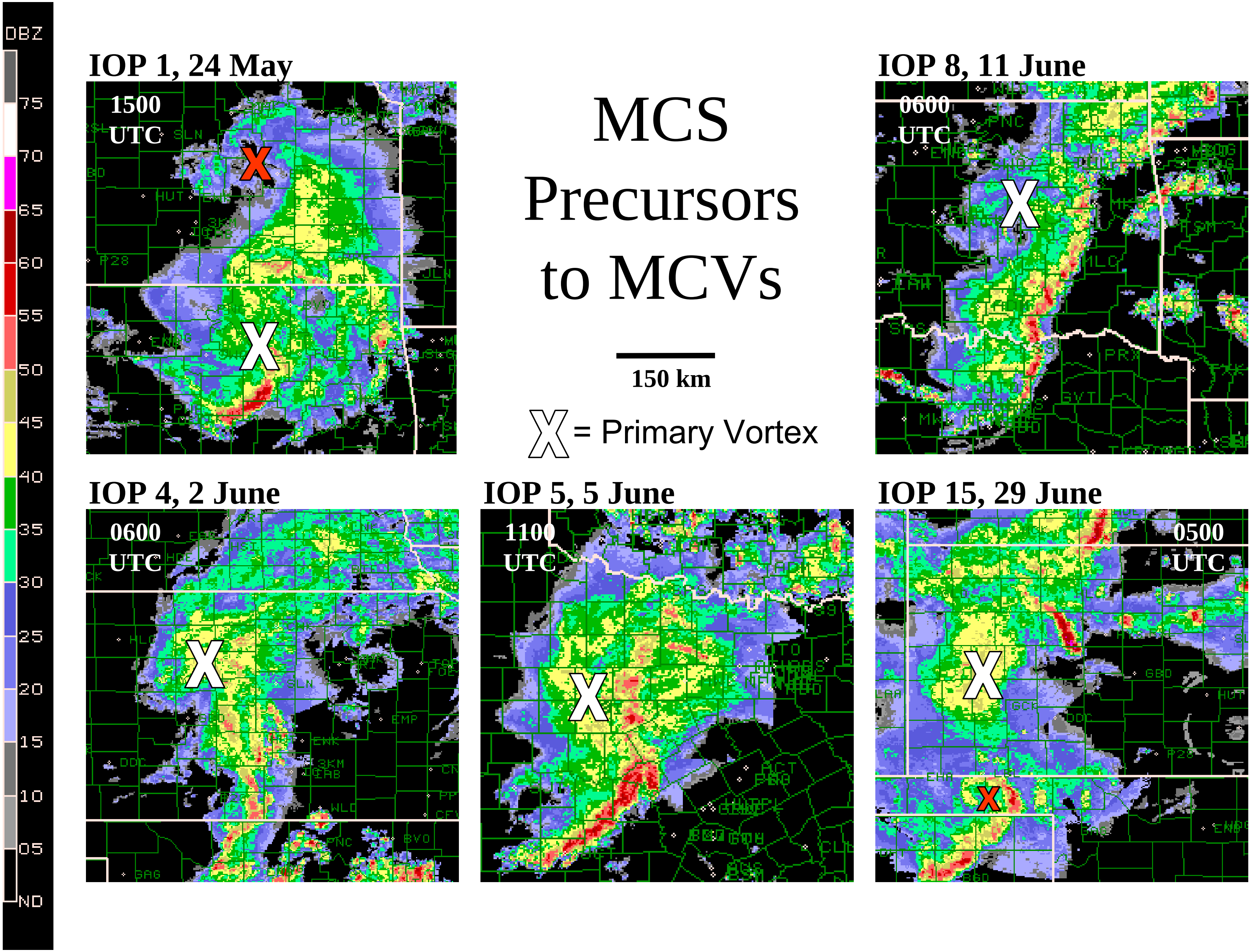
IOP 4: 00 UTC 2 June

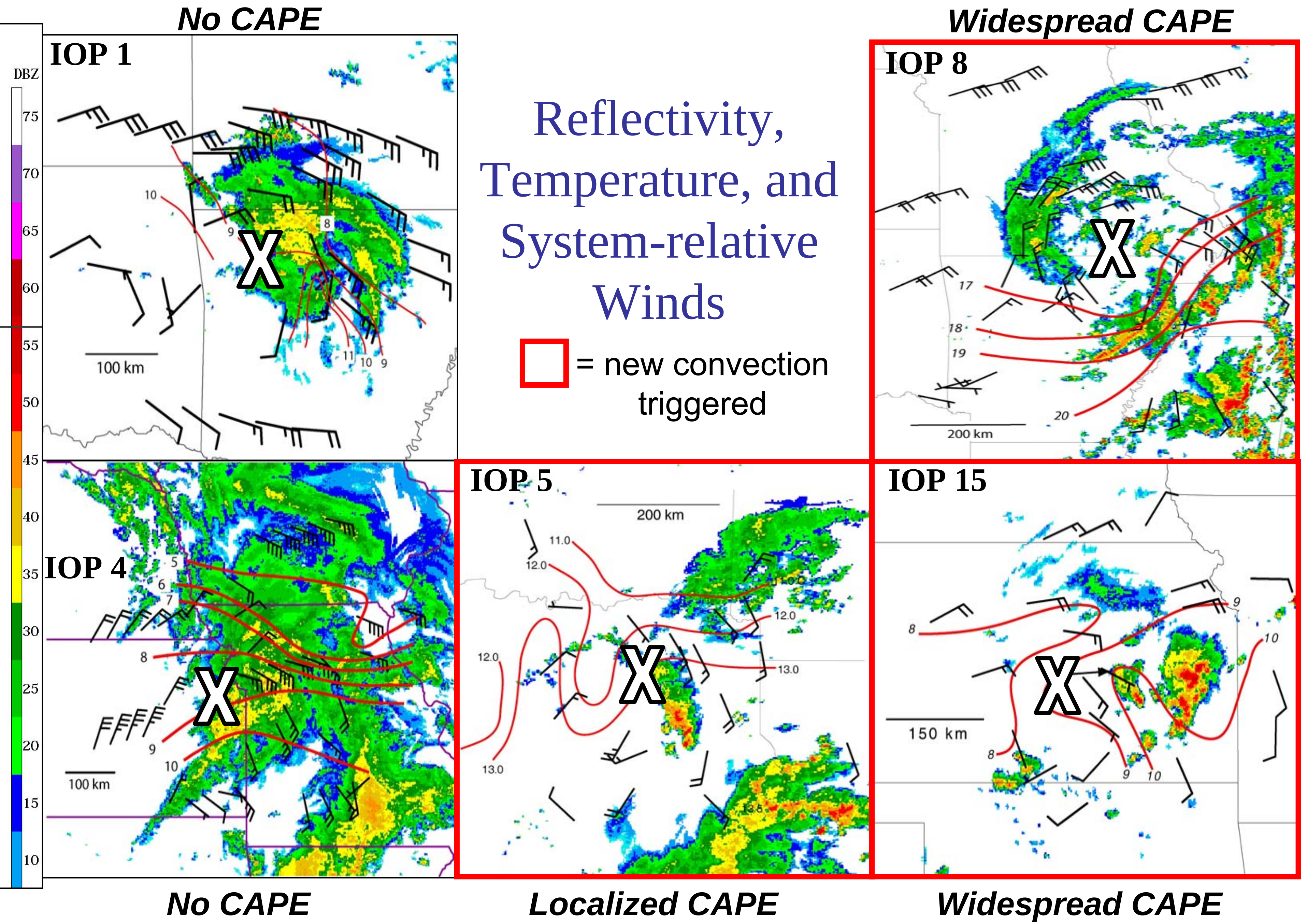


IOP 5: 00 UTC 5 June



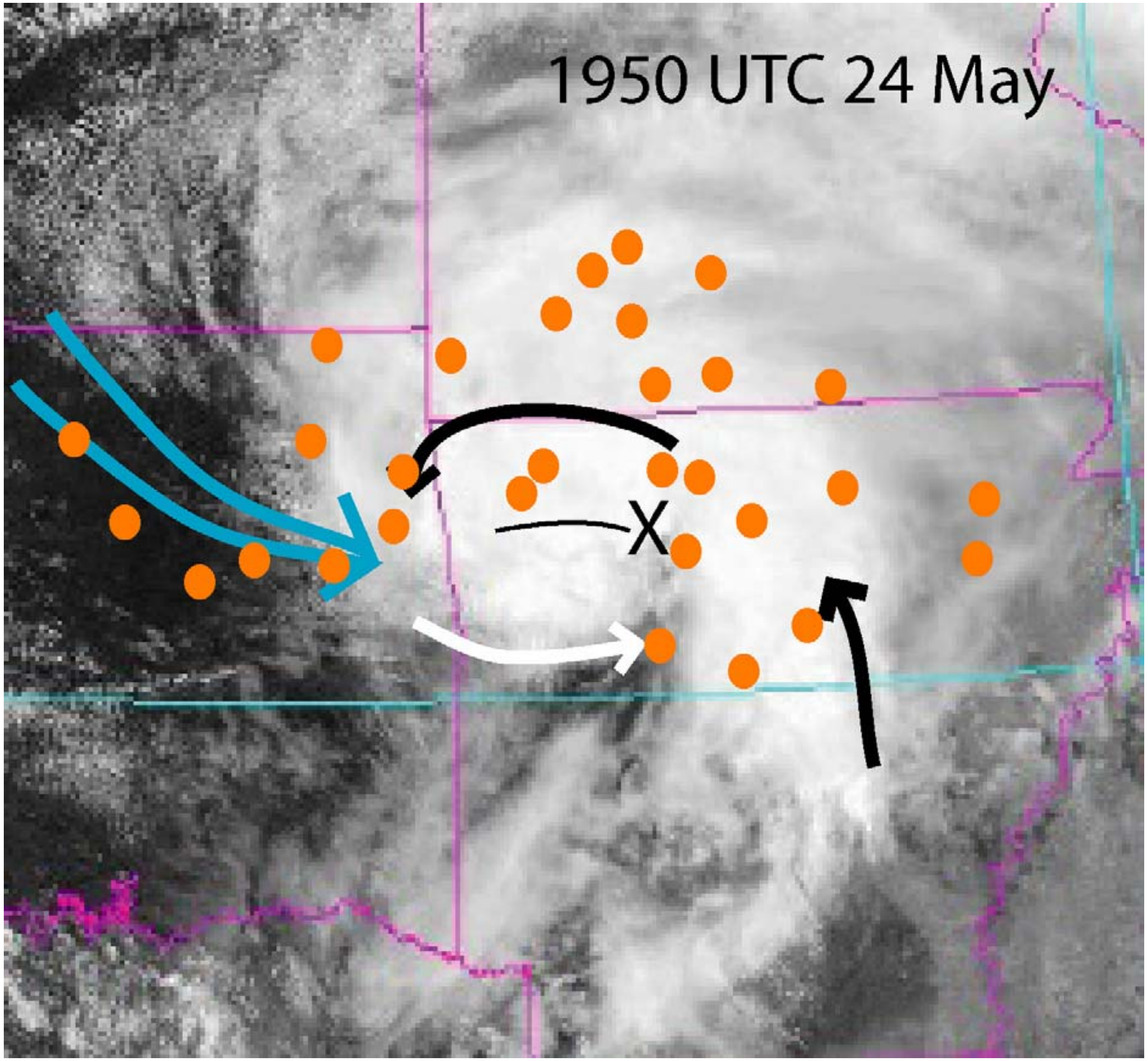
IOP 15: 00 UTC 29 June


MCS Precursors to MCVs
150 km
X = Primary Vortex
IOP 1, 24 May
1500 UTC
IOP 8, 11 June
0600 UTC
IOP 4, 2 June
0600 UTC
IOP 5, 5 June
1100 UTC
IOP 15, 29 June
0500 UTC
DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
05
ND



No CAPE
Widespread CAPE
Reflectivity, Temperature, and System-relative Winds
= new convection triggered
IOP 1
IOP 4
IOP 5
IOP 8
IOP 15
DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
100 km
200 km
150 km
X
No CAPE
Localized CAPE
Widespread CAPE

IOP 1



200 km

Analysis Method

- Dropsonde, profiler and MGLASS

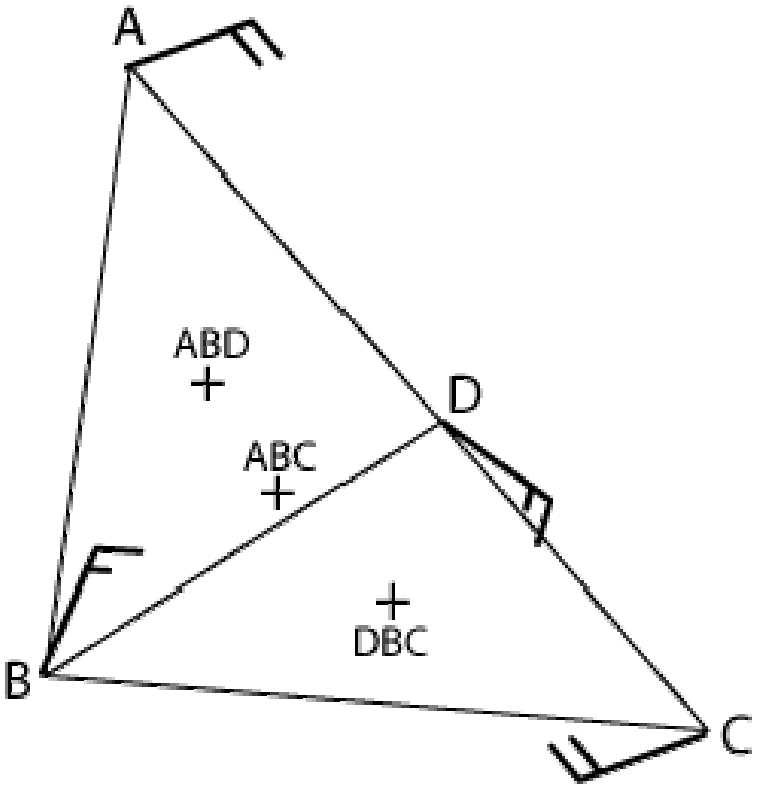
- Composited to common reference time (const MCV motion assumed)

- Divergence and vorticity analyzed assuming linear variation along sides

- Restrictions on minimum angle, area; maximum side length and area

- Overlapping triangles used to assess "confidence" (σ)

- 25-km analysis grid

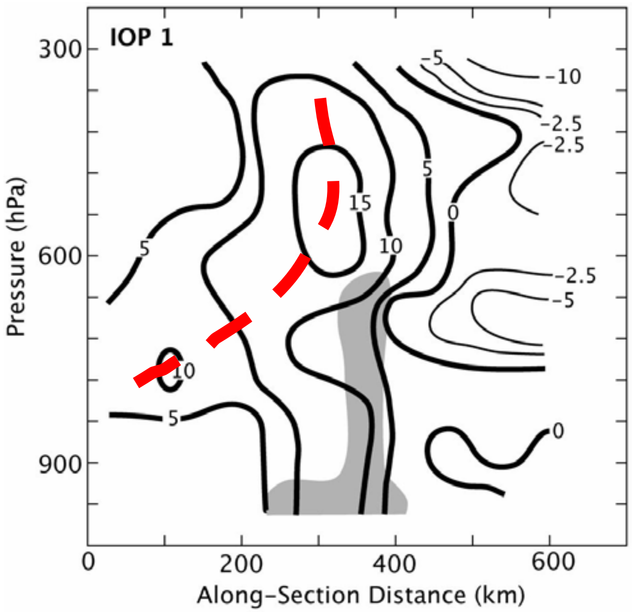


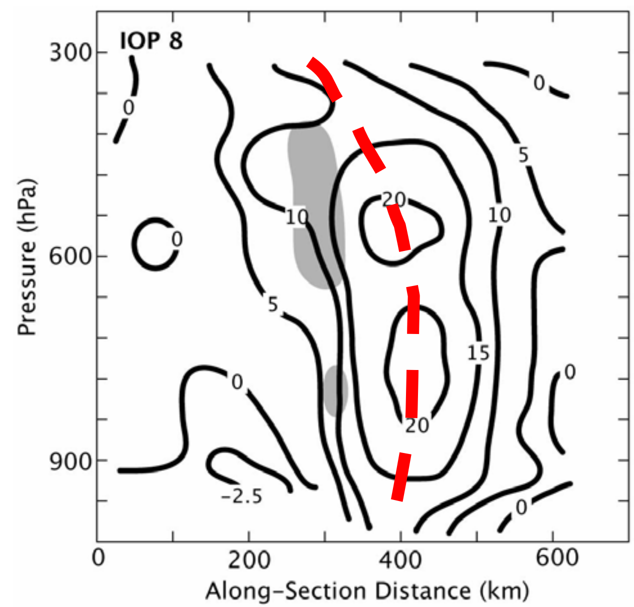
MCV Vertical Structure

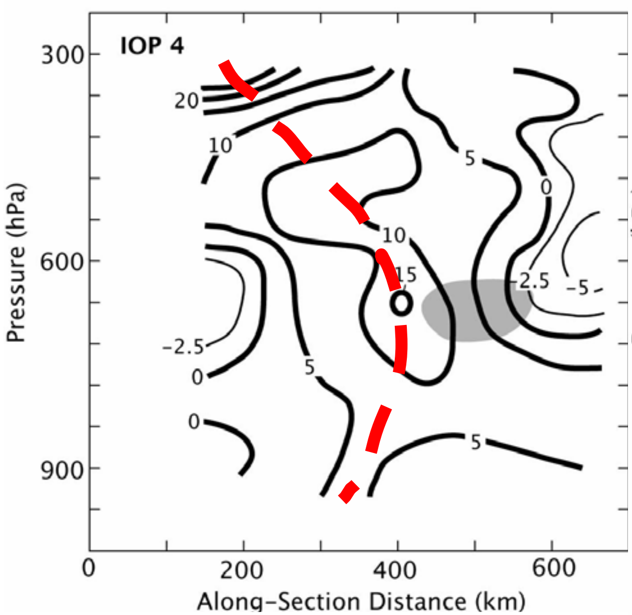
Shading=low confidence

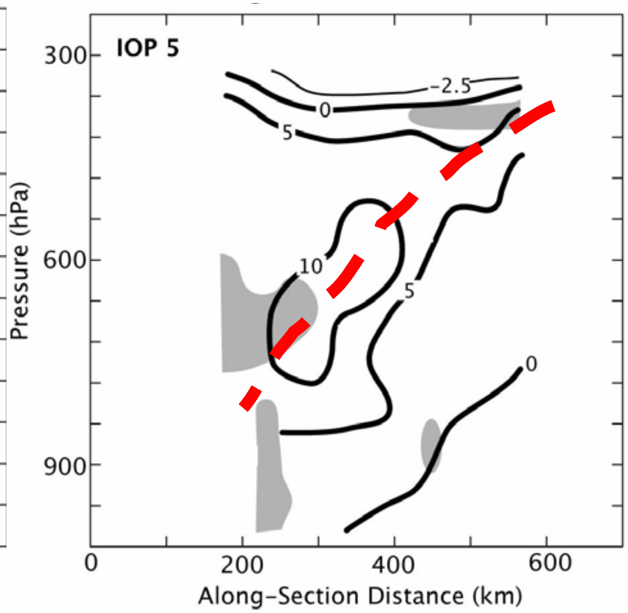
Red line=vortex axis

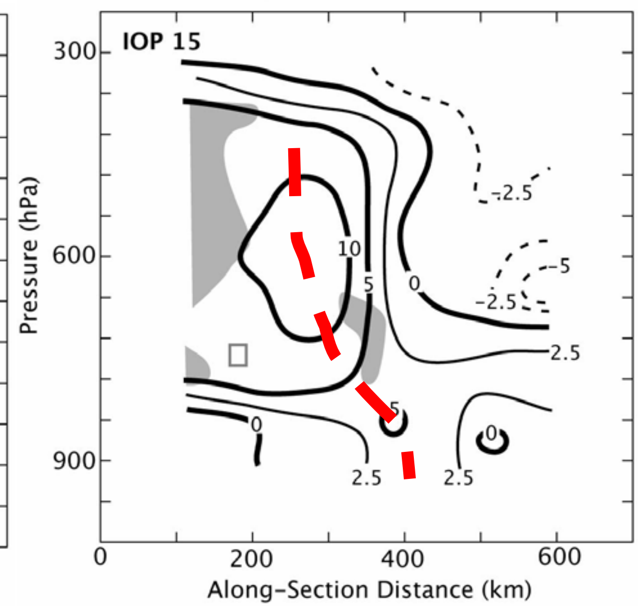
Contour: $5x10^{-5}$ s^{-1}



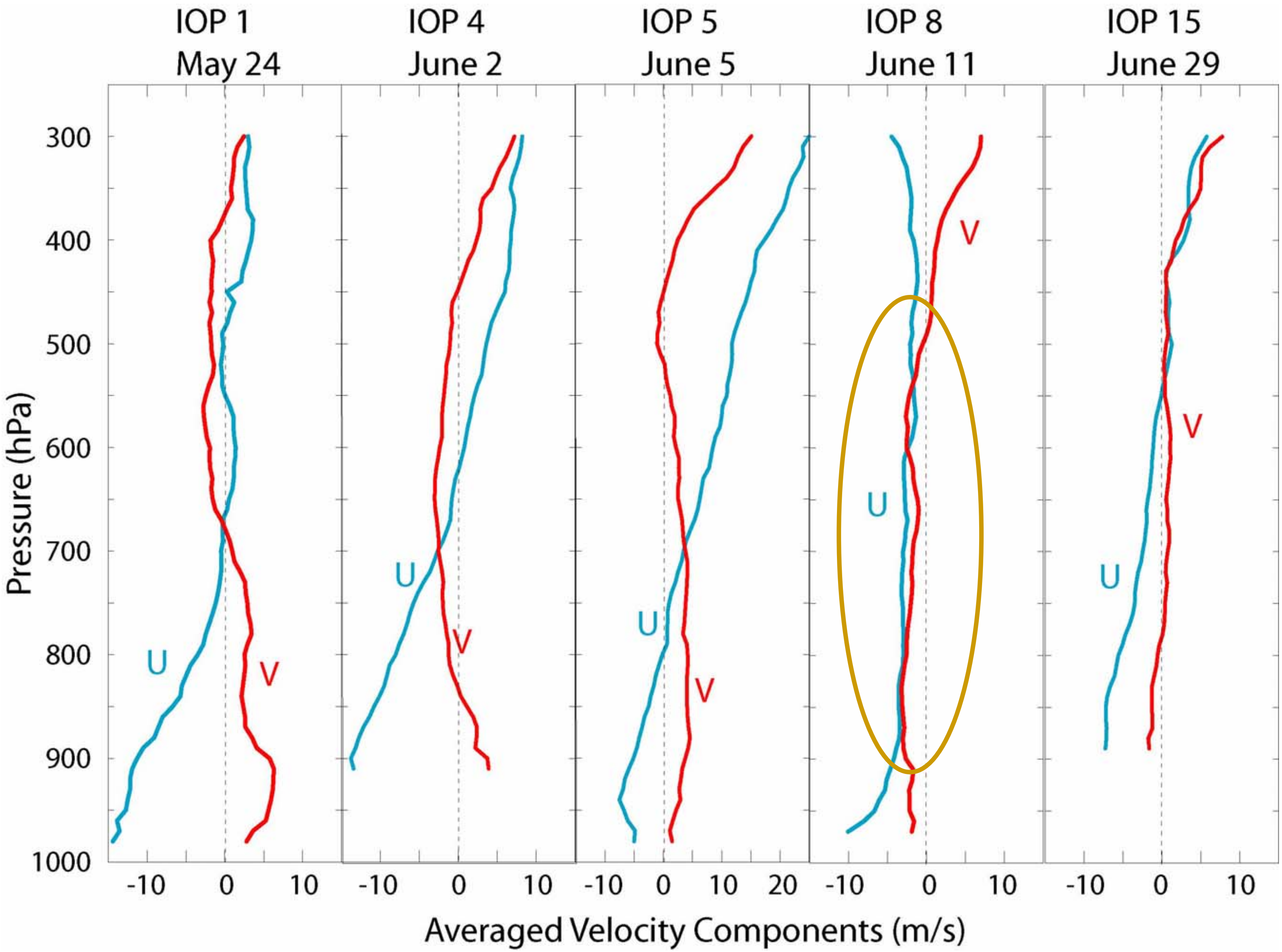




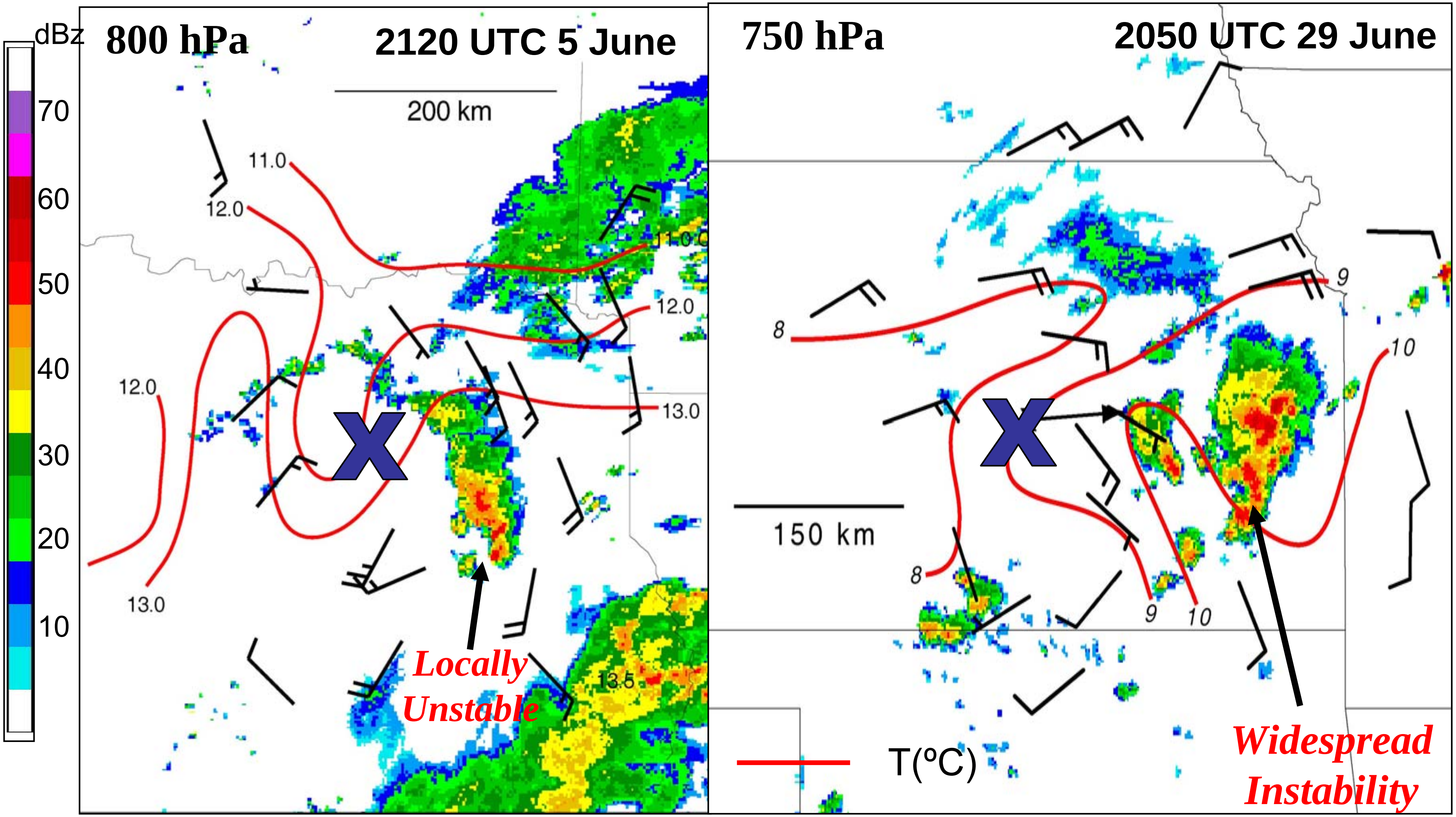




Wind Profiles (averages of quadrant means)

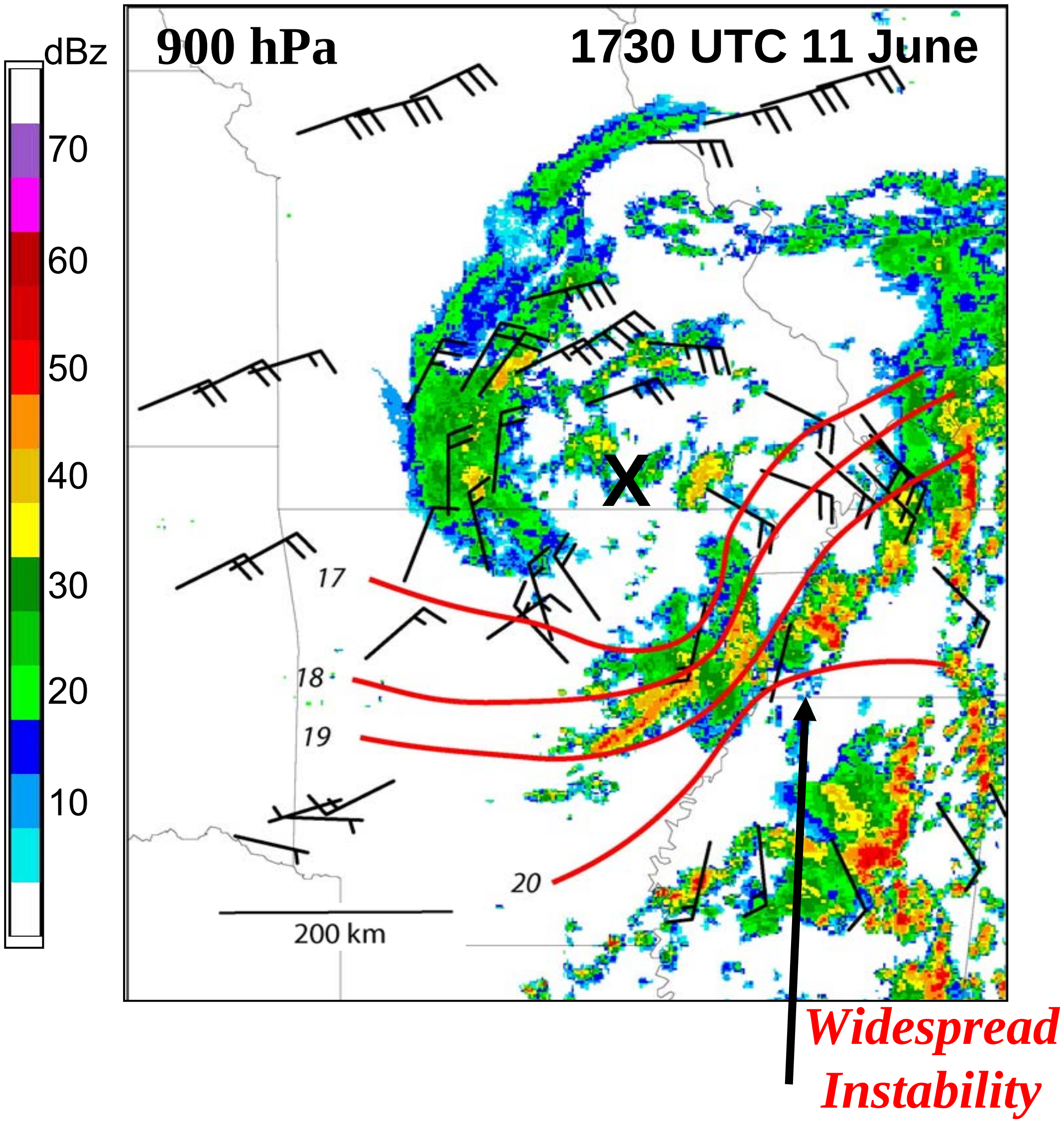


IOP 5 IOP 15

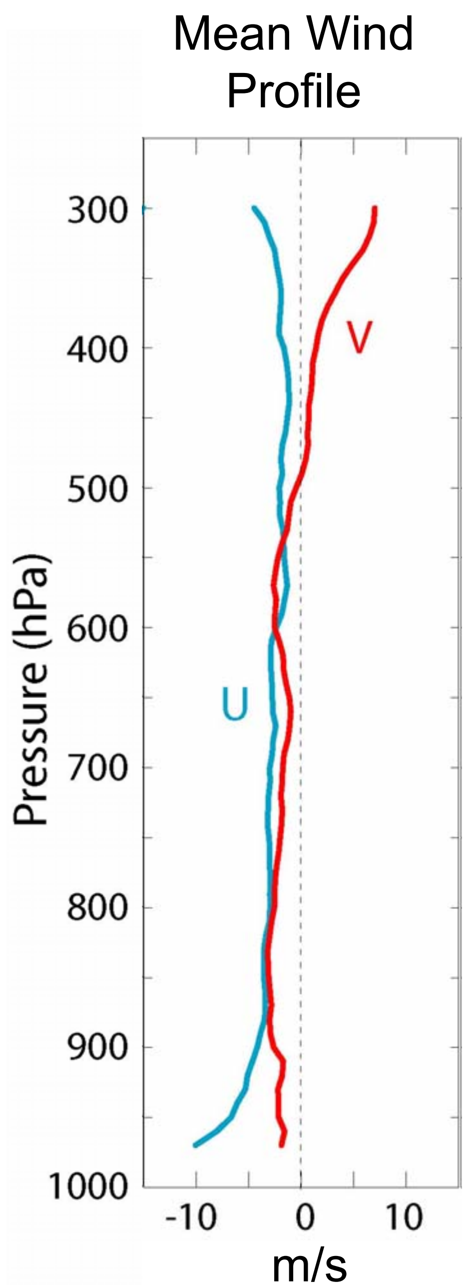


Convection Initiation Downshear from MCV

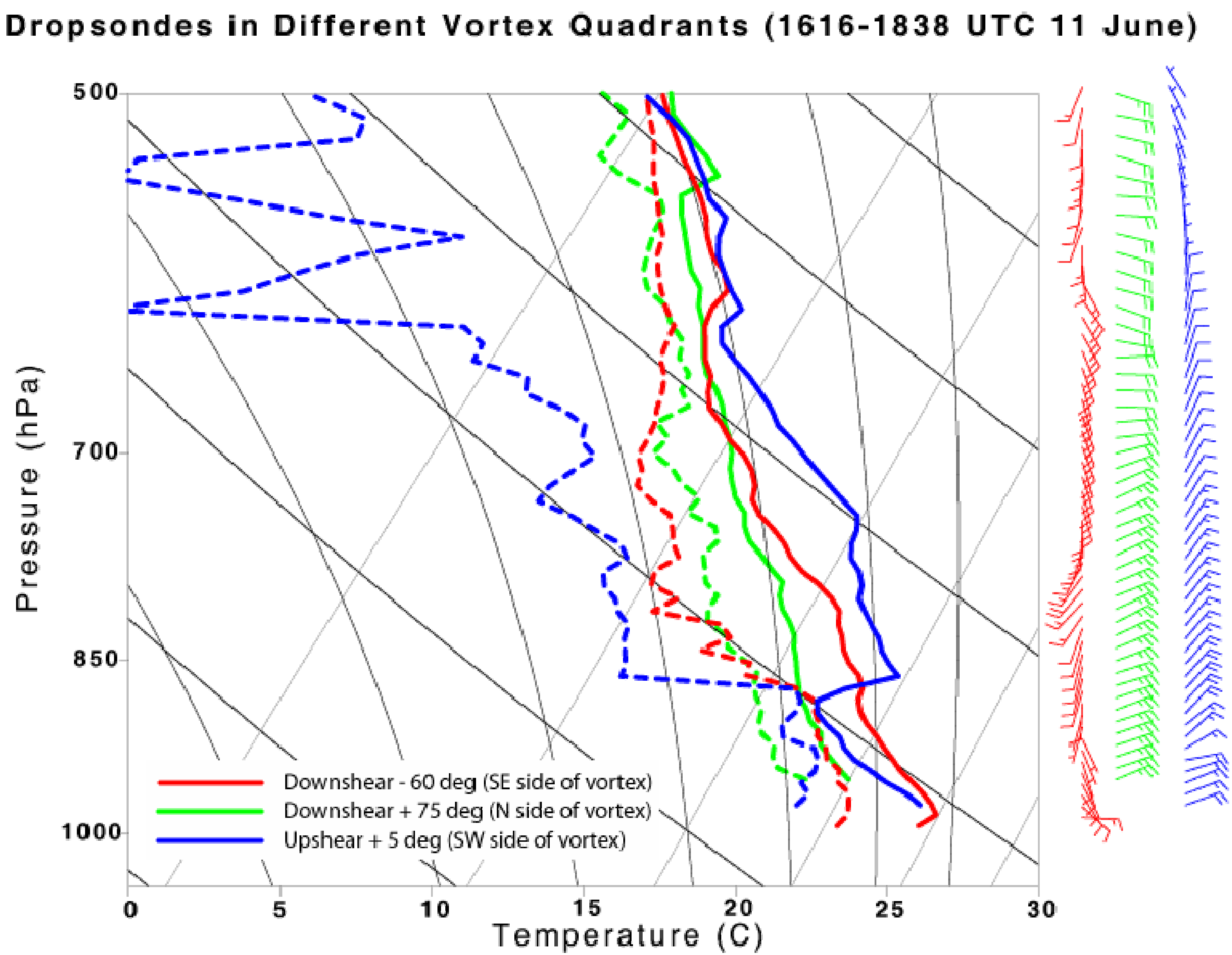
IOP 8



dBz
70
60
50
40
30
20
10
900 hPa
1730 UTC 11 June
X
17
18
19
20
200 km
Widespread Instability



Mean Wind Profile
Pressure (hPa)
300
400
500
600
700
800
900
1000
V
U
-10
0
10
m/s



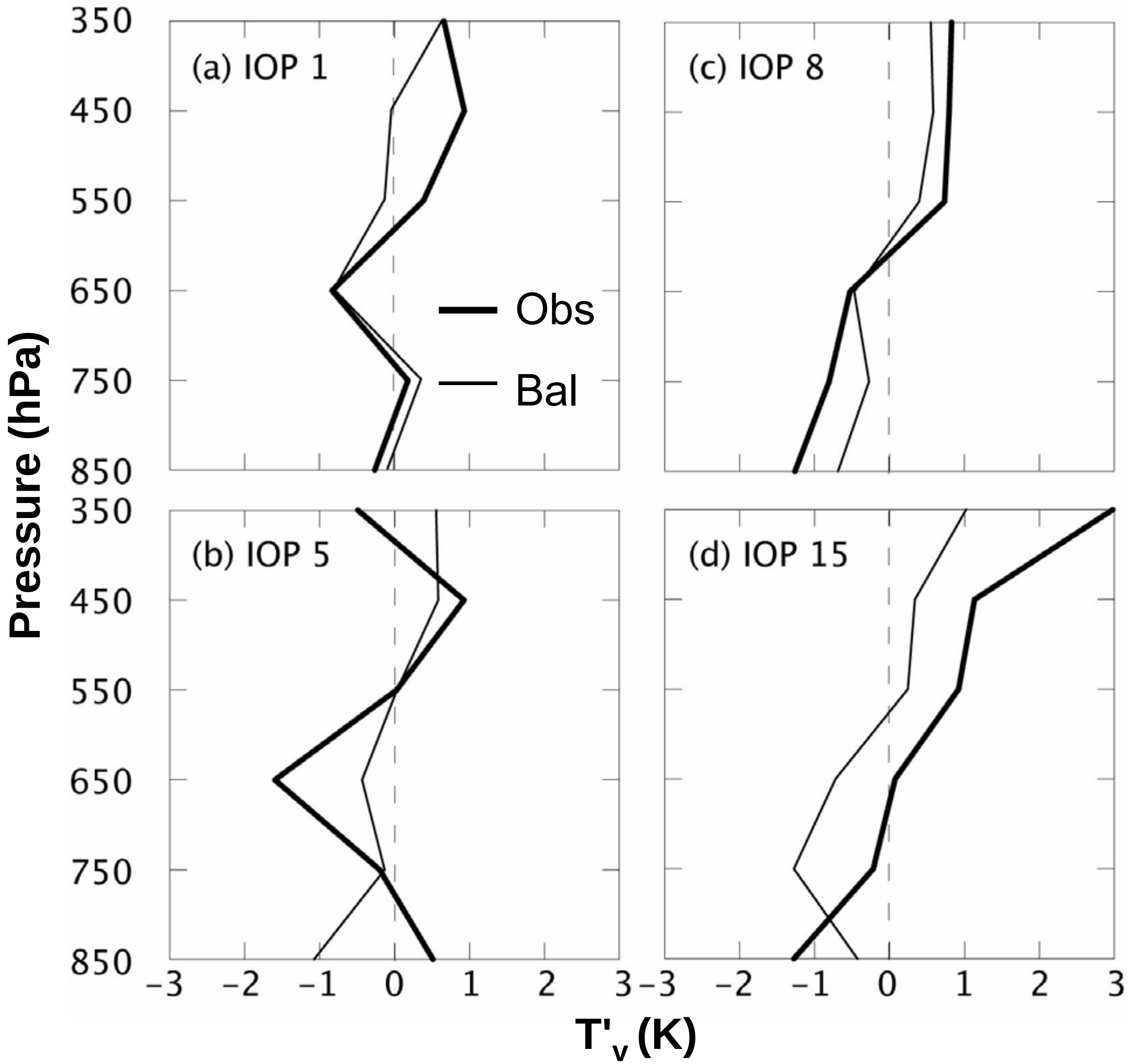
Dropsondes in Different Vortex Quadrants (1616-1838 UTC 11 June)
Pressure (hPa)
500
700
850
1000
Temperature (C)
0
5
10
15
20
25
30
Downshear - 60 deg (SE side of vortex)
Downshear + 75 deg (N side of vortex)
Upshear + 5 deg (SW side of vortex)

Balance within MCVs

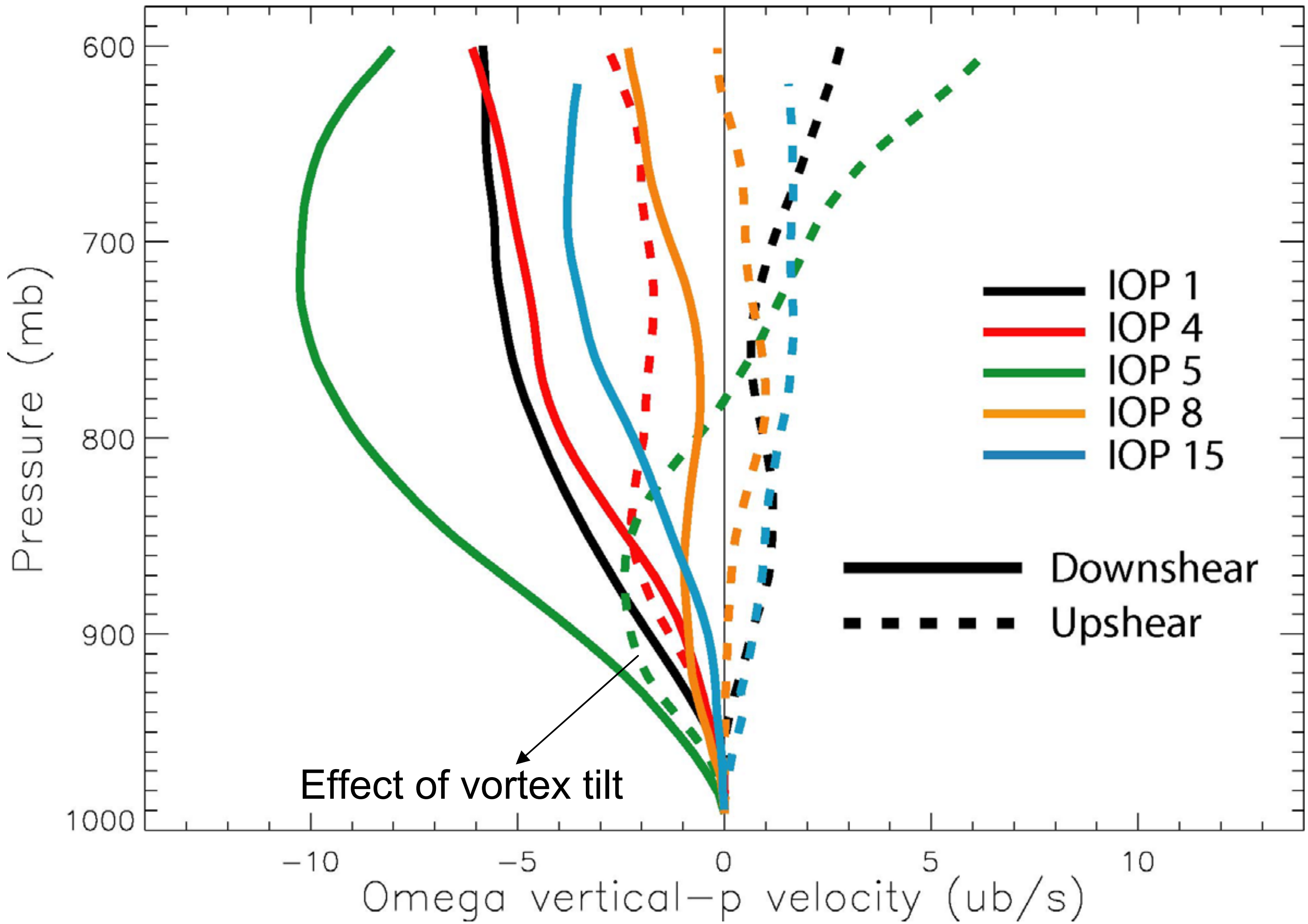
Procedure:

- ➢$\zeta \rightarrow \Psi \rightarrow \Phi$ via nonlinear balance
- ➢$\Phi \rightarrow T_v$ (hydrostatic)
- ➢T_v profile at sounding locations
- ➢Quadrant averages ($r<R_{max}$; $r \geq R_{max}$)
- ➢Subtract mean outer profile from inner profile: $\mathbf{T'_v}$

IOPs 1 and 8 have best data coverage



Vertical Motion Profiles



Summary

- Developing Vortices
  - Tied to convective line
  - Large fraction of circulation of mature MCV
  - Merger (at two levels) leads to deep vortex
- Mature MCVs
  - Structure responds to vertical shear
  - All maximize at 550-600 hPa.
  - Balanced
  - Weak surface signature except multi-day or short-wave cases
  - Modification of convection environment

Remaining Questions

- Vortex merger and symmetrization for incipient MCV? Do we understand the basic formation mechanism? *(analogy to TC mechanism of Montgomery et al.?)*
- Effect of developing MCV on MCS?
- Resistance of mature MCV to shear, adiabatic or diabatic?
- Is shear main limiting factor in vertical structure?
- What selects 550-600 hPa for maximum strength of mature MCV? Shear? Melting?