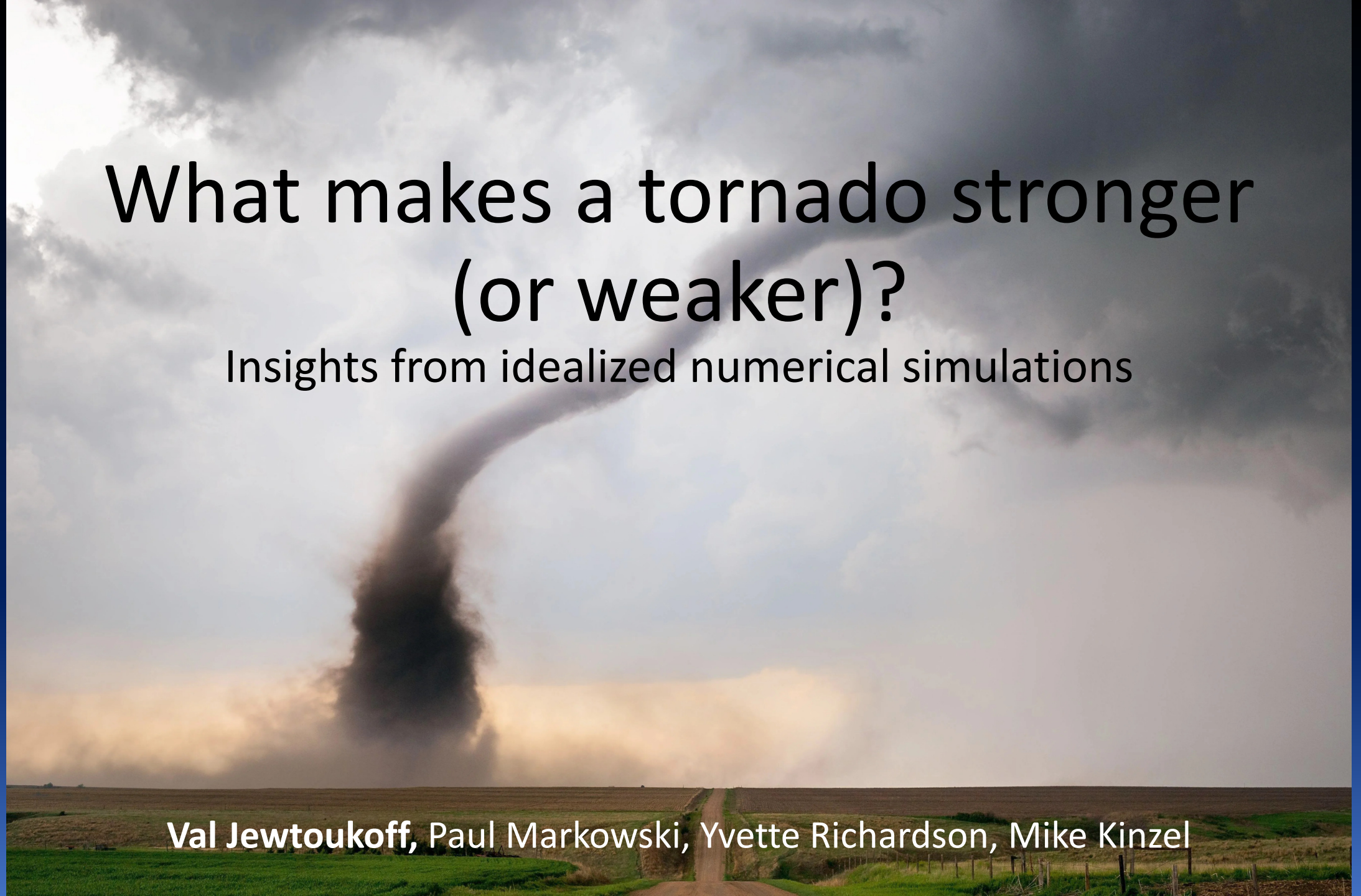


What makes a tornado stronger (or weaker)?

Insights from idealized numerical simulations

Val Jewtoukoff, Paul Markowski, Yvette Richardson, Mike Kinzel

Outline

1. Some of the things we know about tornadoes and their parent clouds

2. What makes a tornado stronger (or weaker)?

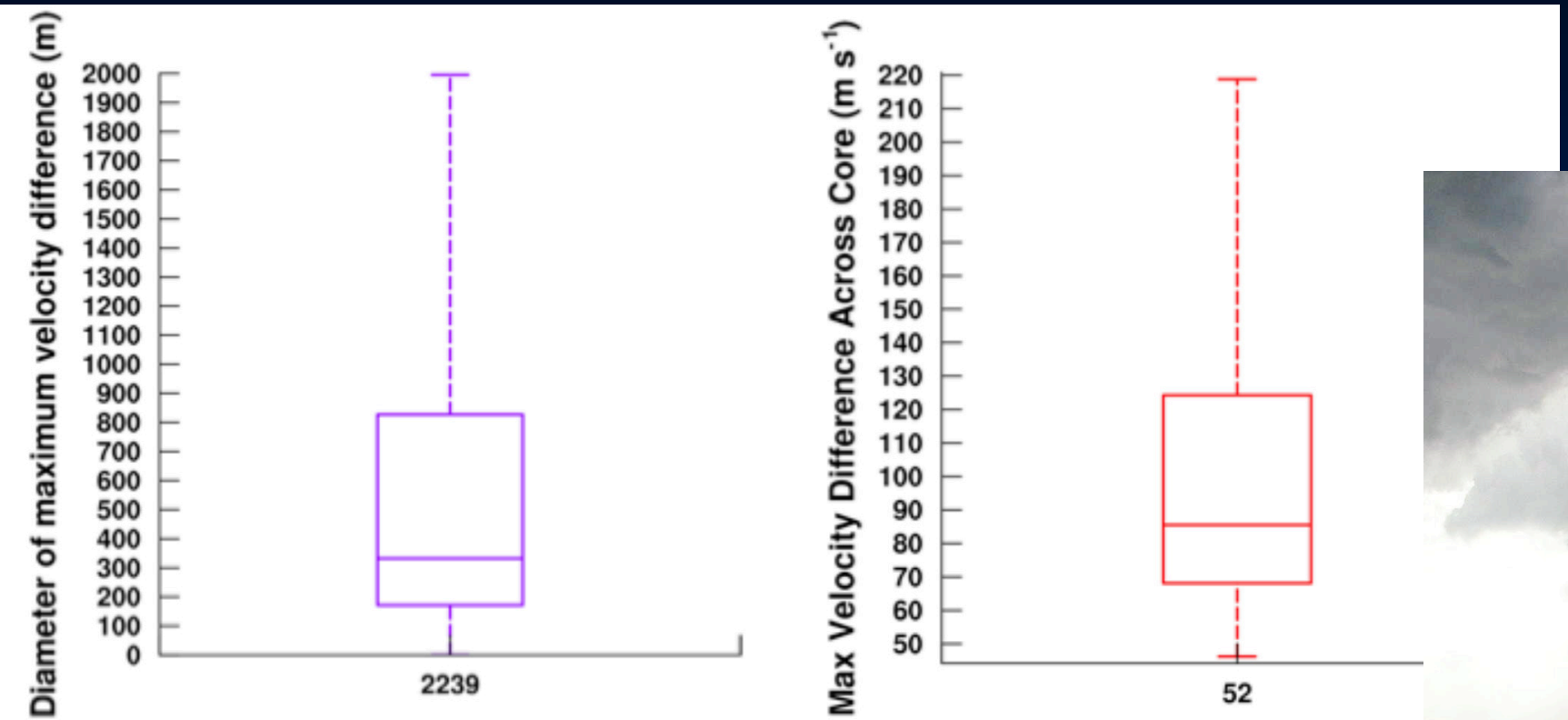
3. Perspectives and challenges

What is a tornado?

"a rapidly rotating column of air that occurs in association with a cumuliform cloud"
— Rotunno (2013)

… connected with the ground

Observed characteristics



Alexander & Wurman (2008)

Courtesy *CSWR*

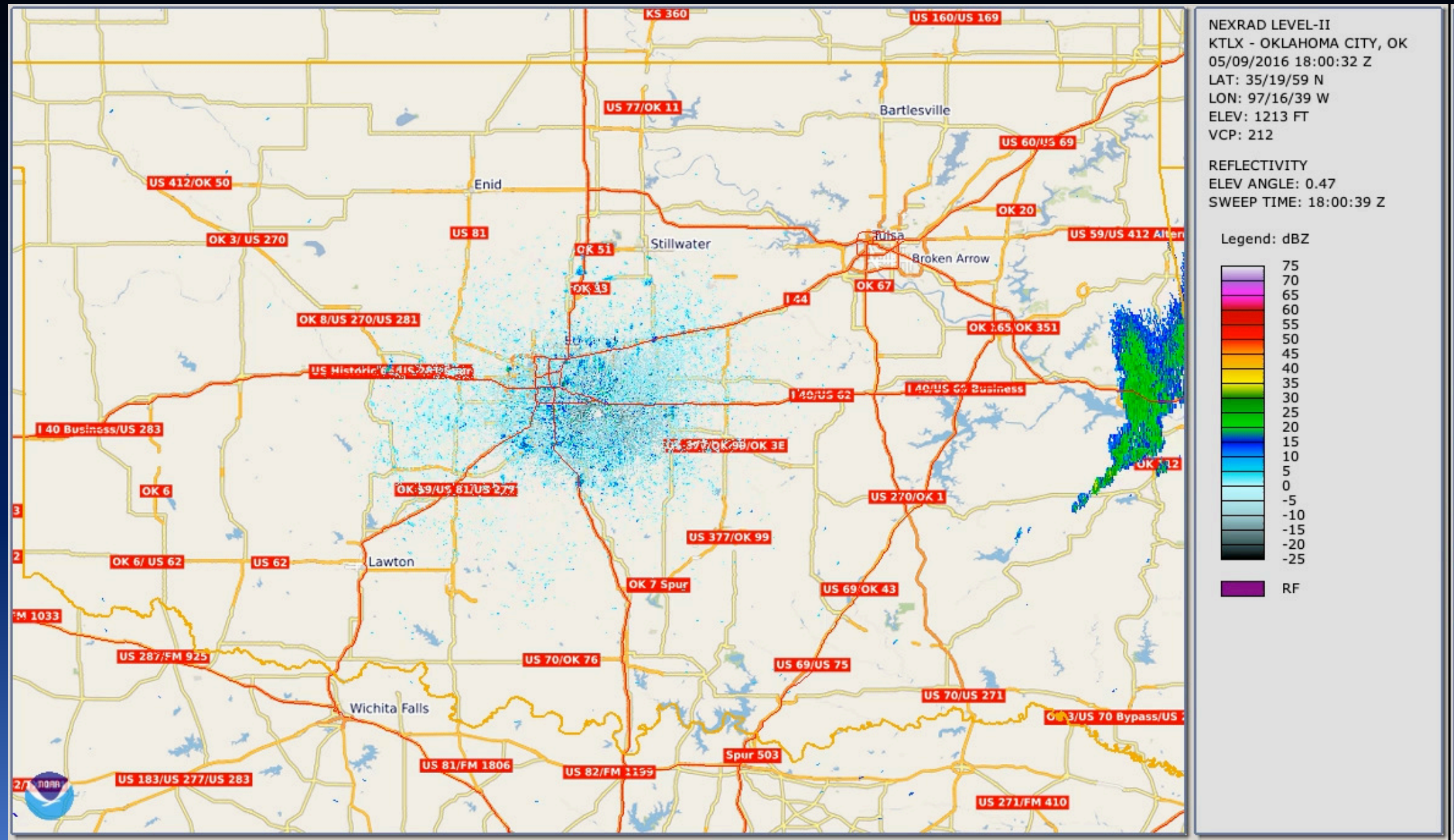
Why do tornadoes even matter?

Courtesy
Dick McGowan

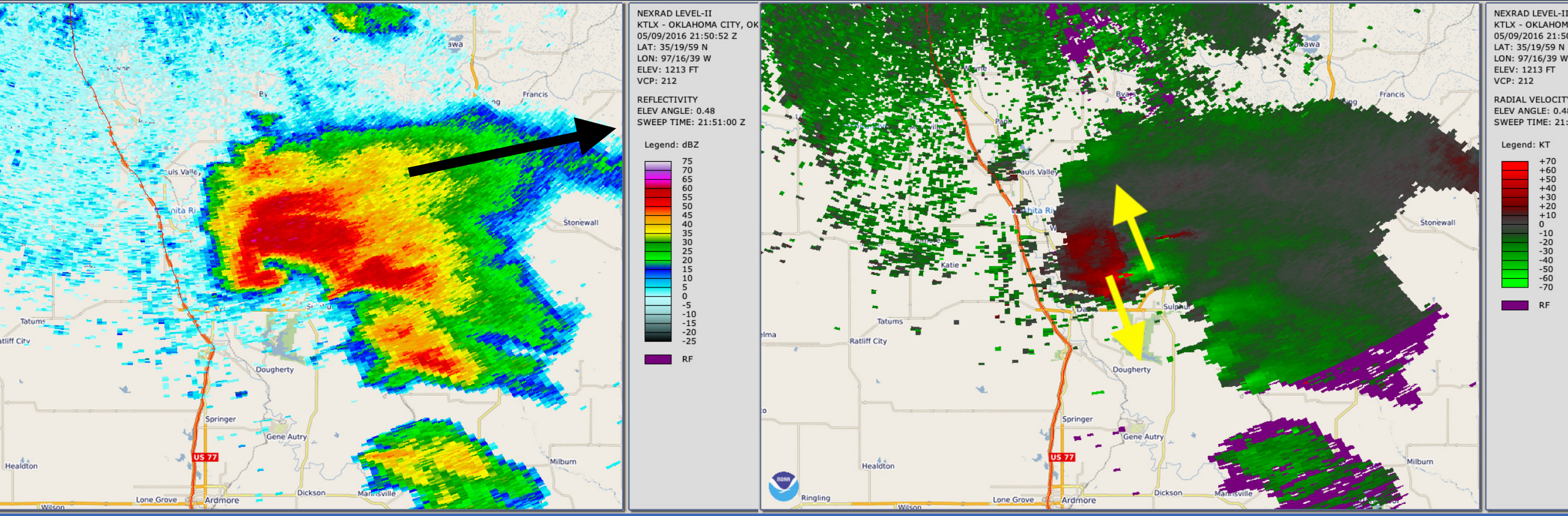
Tornado damage

Courtesy *Storm Prediction Center*

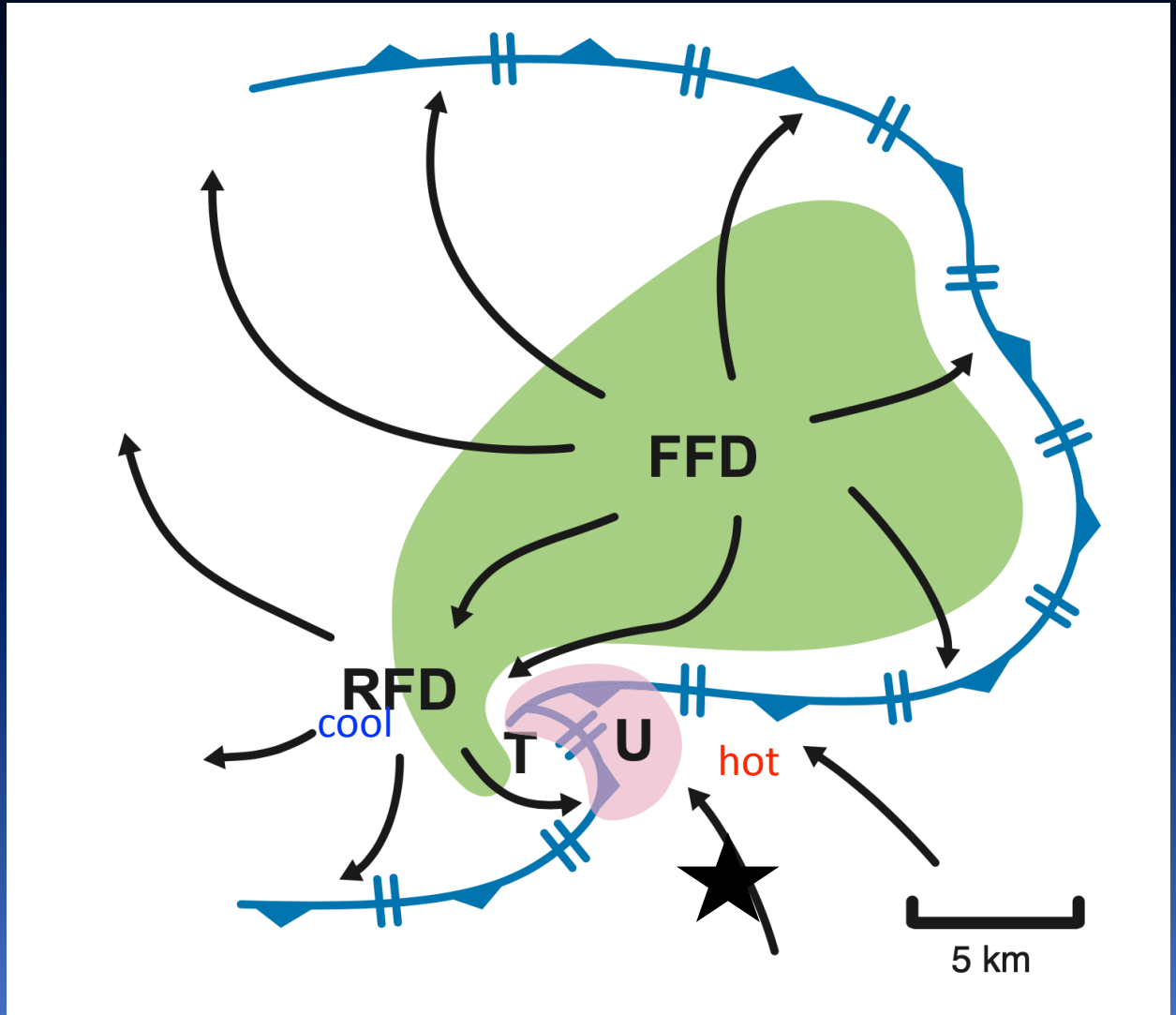
Radar observations



Supercell


NEXRAD LEVEL-II
KTLX - OKLAHOMA CITY, OK
05/09/2016 21:50:52 Z
LAT: 35/19/59 N
LON: 97/16/39 W
ELEV: 1213 FT
VCP: 212
REFLECTIVITY
ELEV ANGLE: 0.48
SWEEP TIME: 21:51:00 Z
Legend: dBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
RF
NEXRAD LEVEL-II
KTLX - OKLAHOM
05/09/2016 21:5
LAT: 35/19/59 N
LON: 97/16/39 W
ELEV: 1213 FT
VCP: 212
RADIAL VELOCIT
ELEV ANGLE: 0.4
SWEEP TIME: 21:
Legend: KT
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
RF
Francis
Stonewall
Tatums
Ratliff City
Dougherty
Springer
Gene Autry
Healdton
US 77
Milburn
Lone Grove
Ardmore
Dickson
Marietta
Wilson
Katie
Sulphur
Ringling

Features



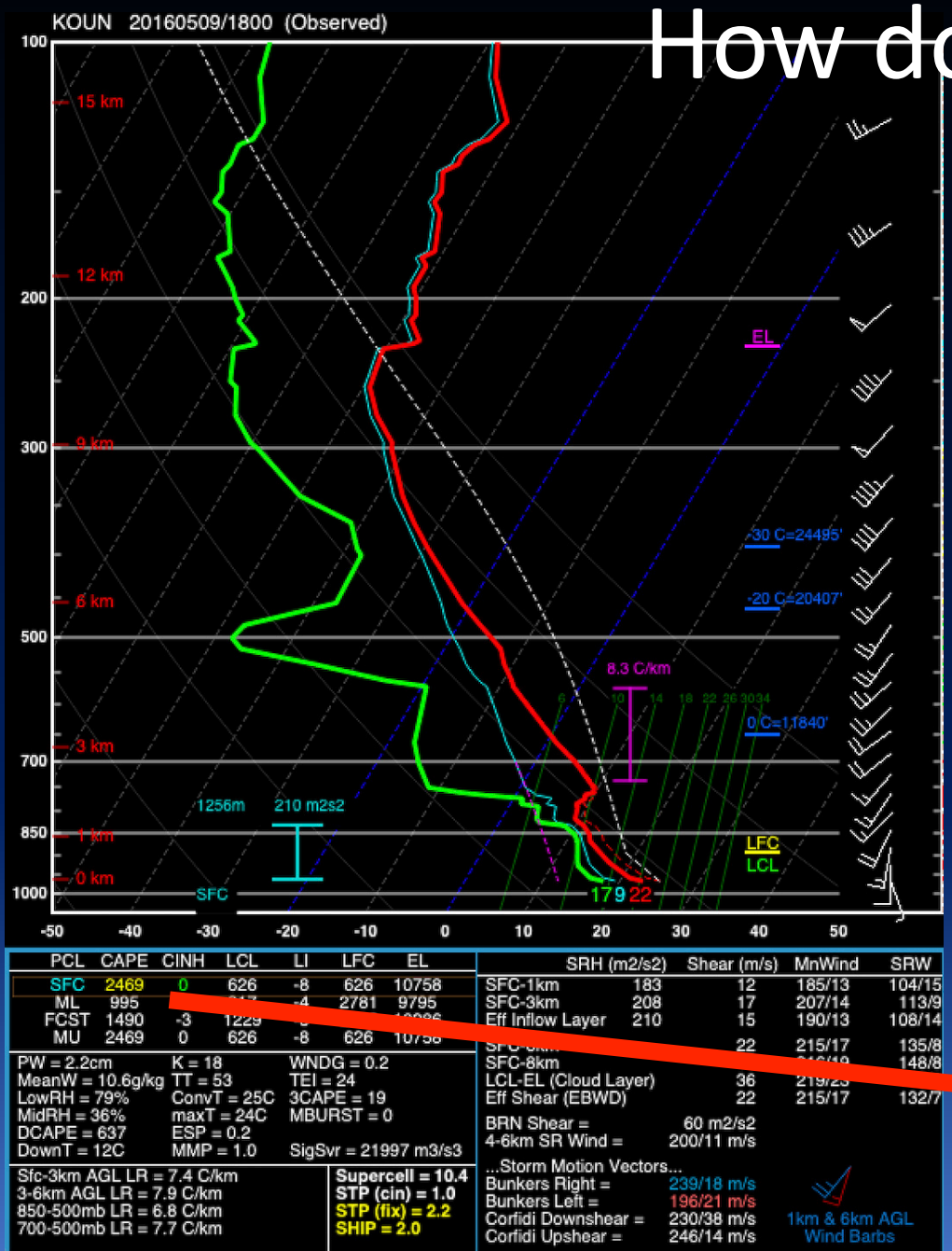
Adapted from *Markowski & Richardson (2010)*

Italy tornadic supercell
19 September 2021

Timelapse

Courtesy *Estremi di Meteo4*

How do supercells form?



- Source of instability (same ingredients as for “classic” convection) — resulting in high CAPE
- Lifting mechanism

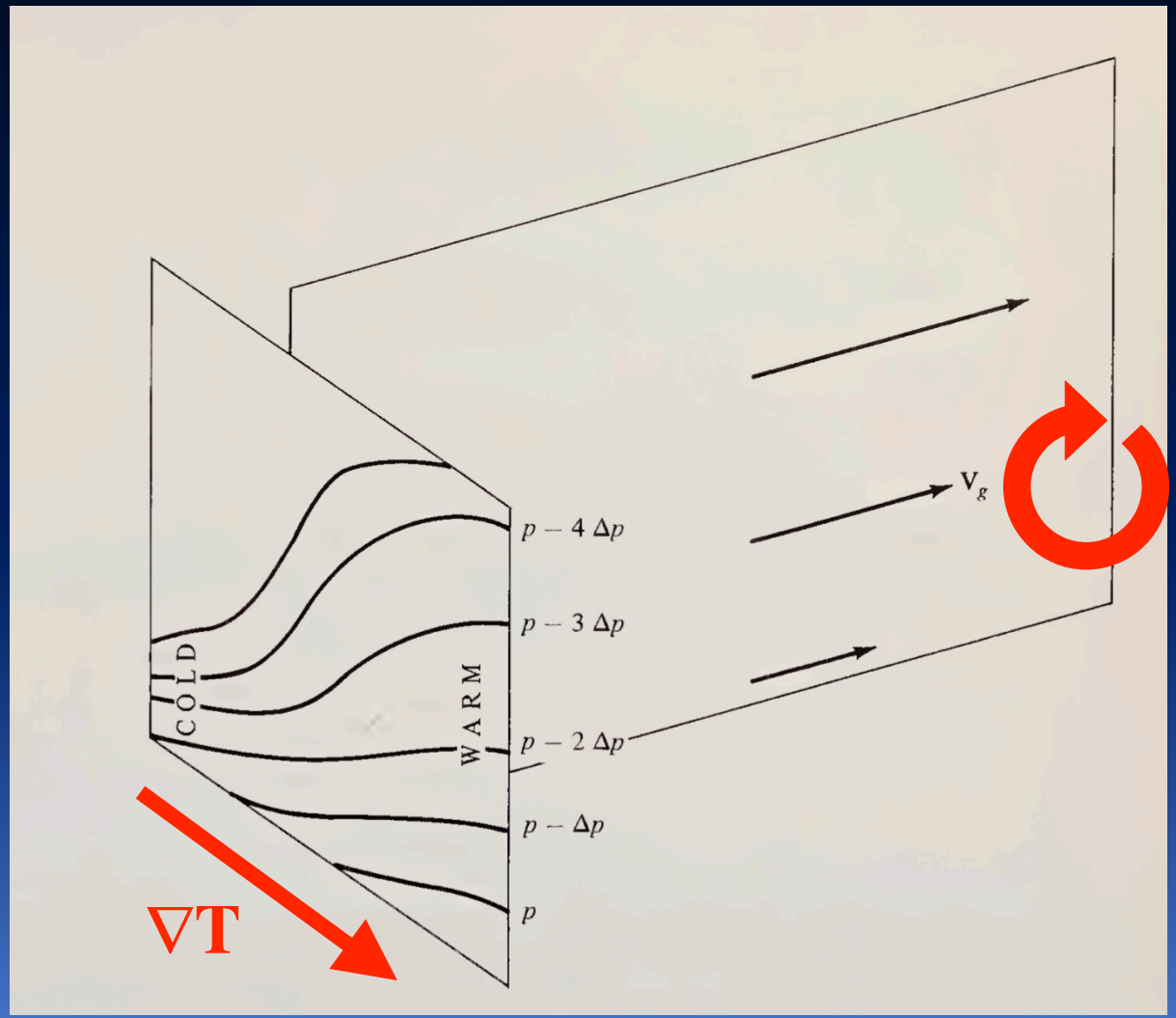
+

- the “right” type of vertical wind-shear

PCL	CAPE
SFC	2469
ML	995
FCST	1490
MU	2469

Production of nearly horizontal vorticity at the synoptic scale

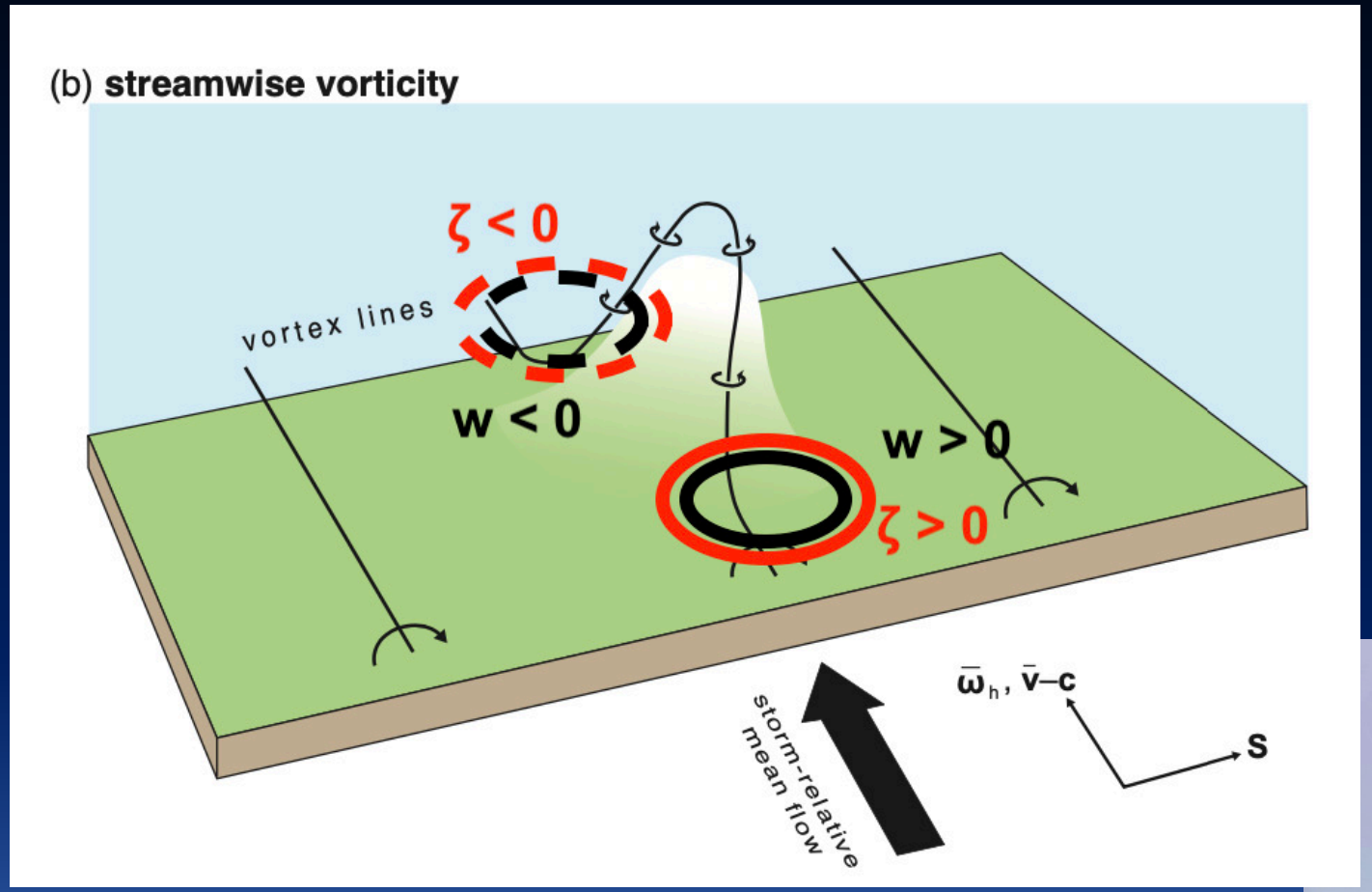
thermal wind



Adapted *from Dutton (1976)*

Origin of mid-level rotation

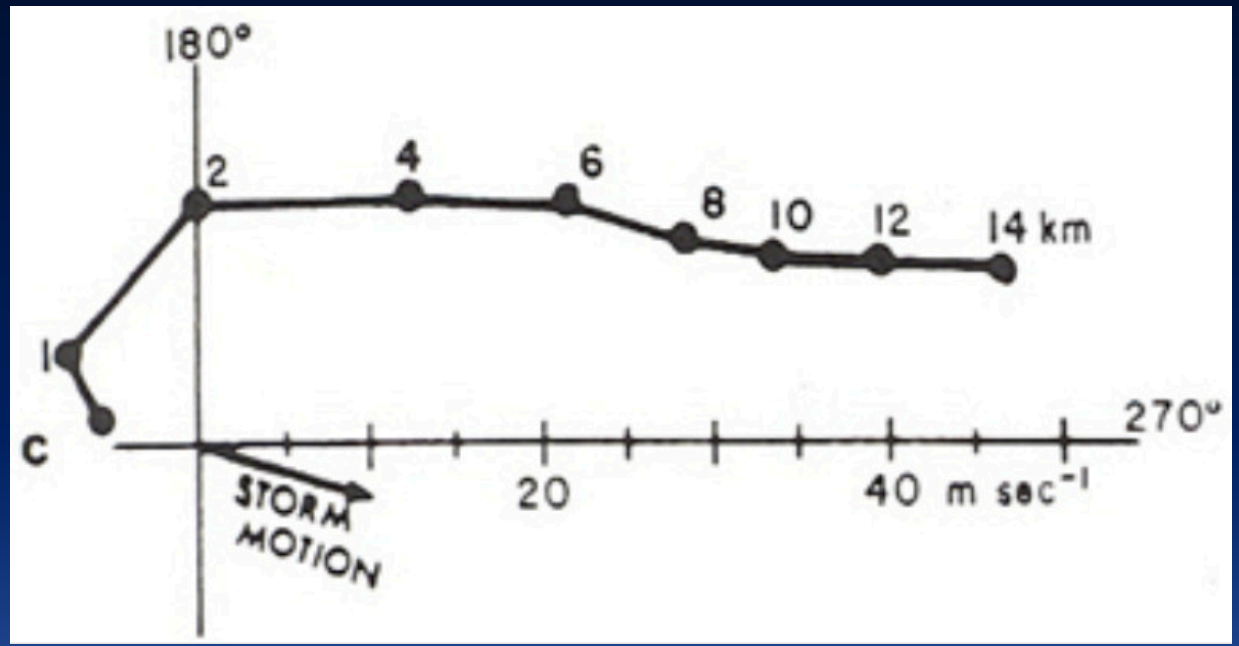
- S



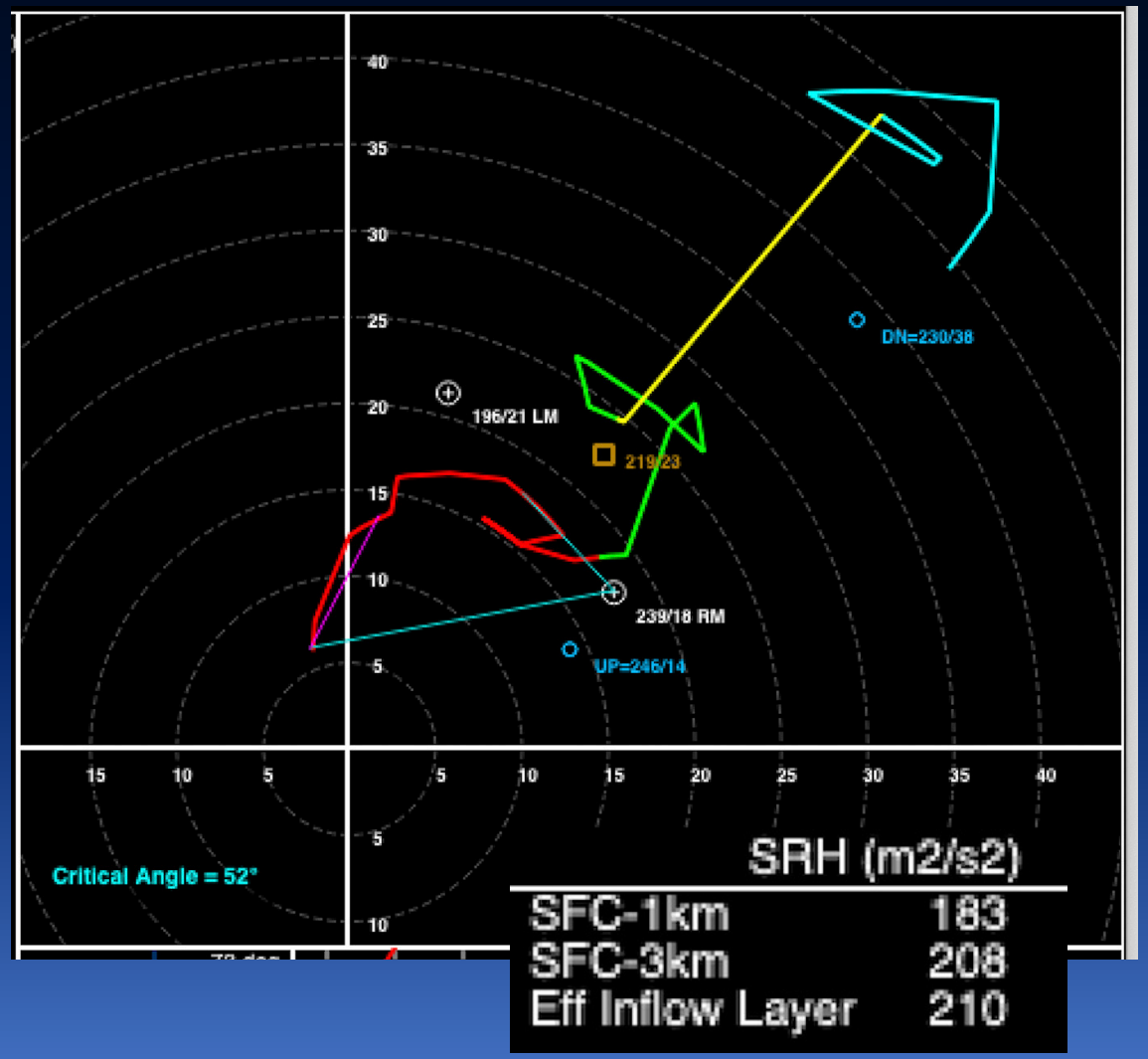
streamwise vorticity

Adapted from
Markowski & Richardson (2010)

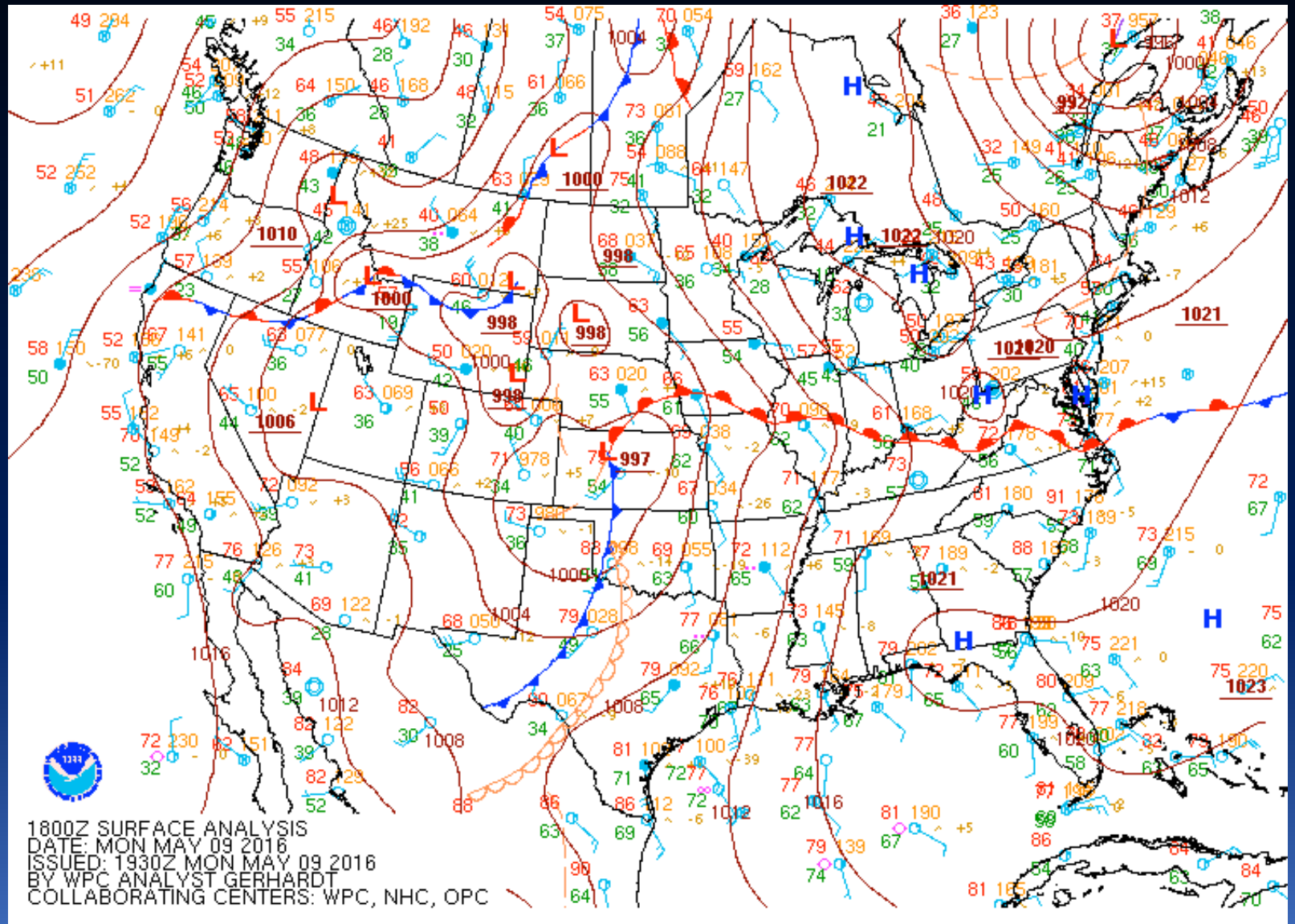
Environment with streamwise vorticity: the clockwise-turning hodograph



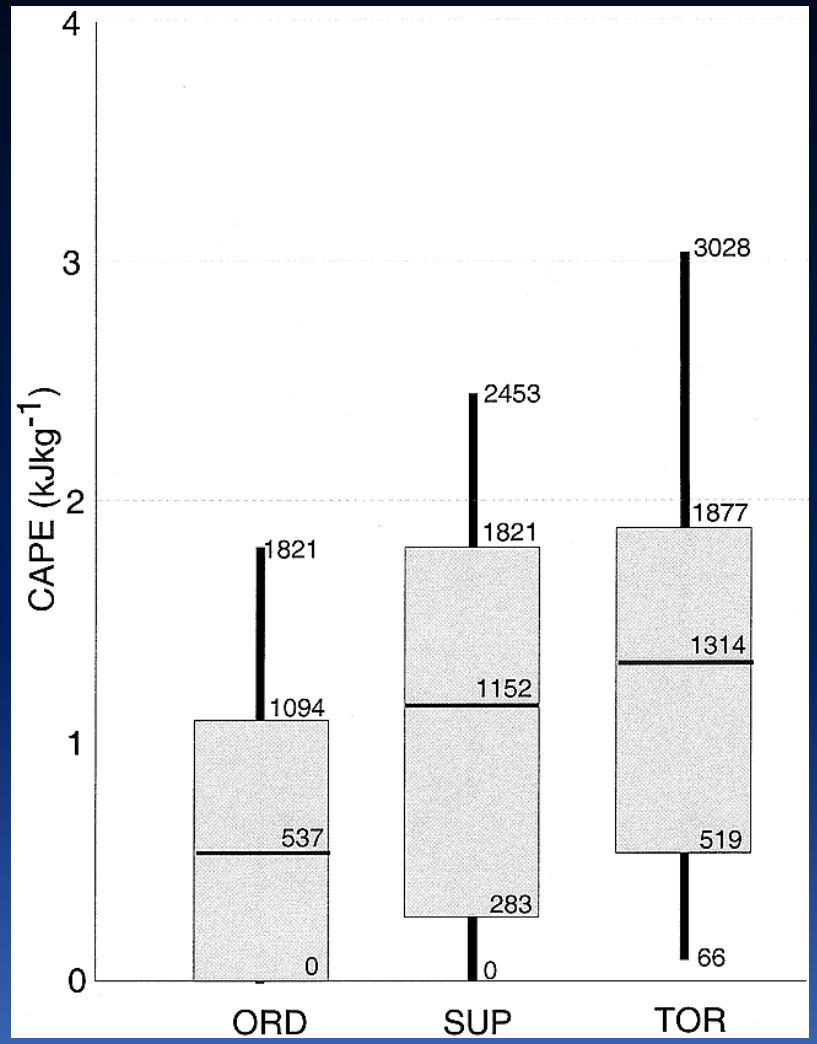
Chisholm & Renick (1972)

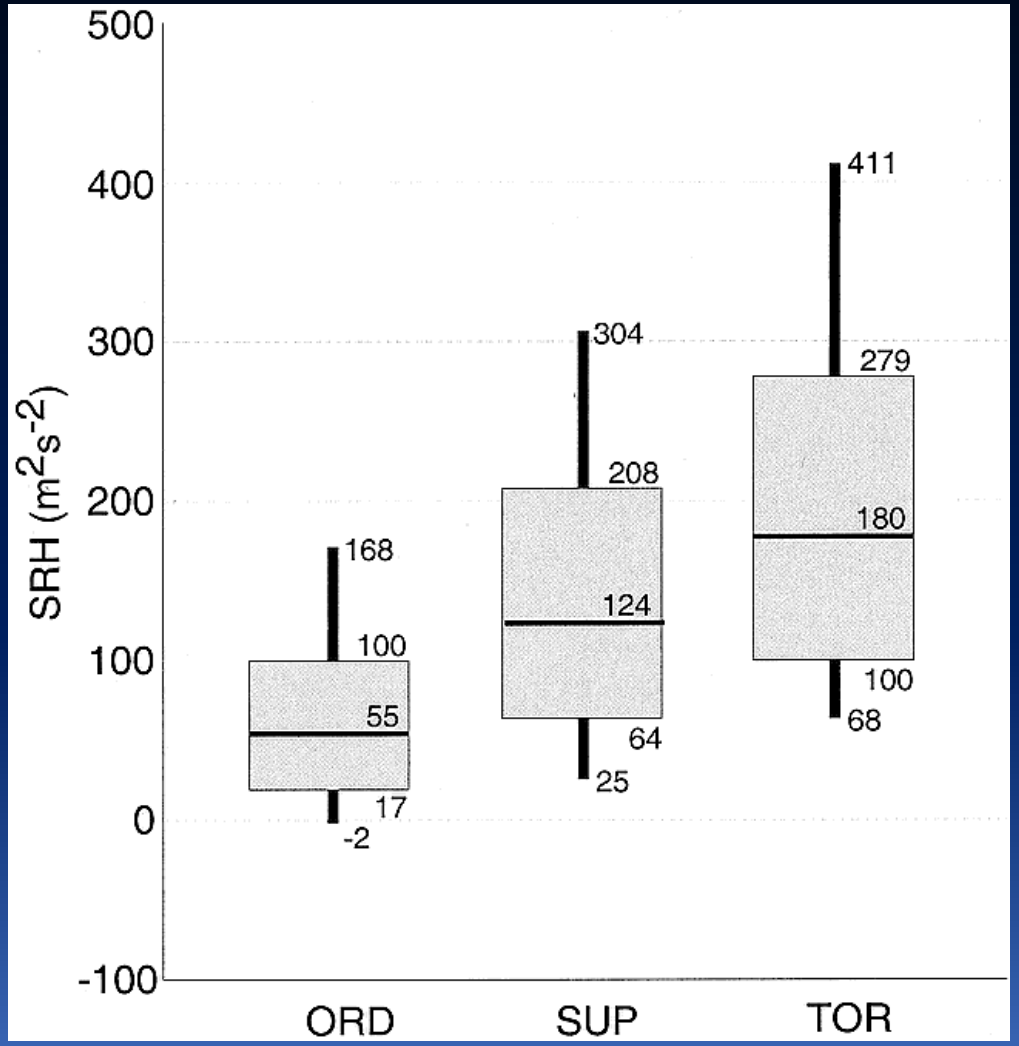


What causes veering of the wind with height: warm advection



CAPE-shear climatology

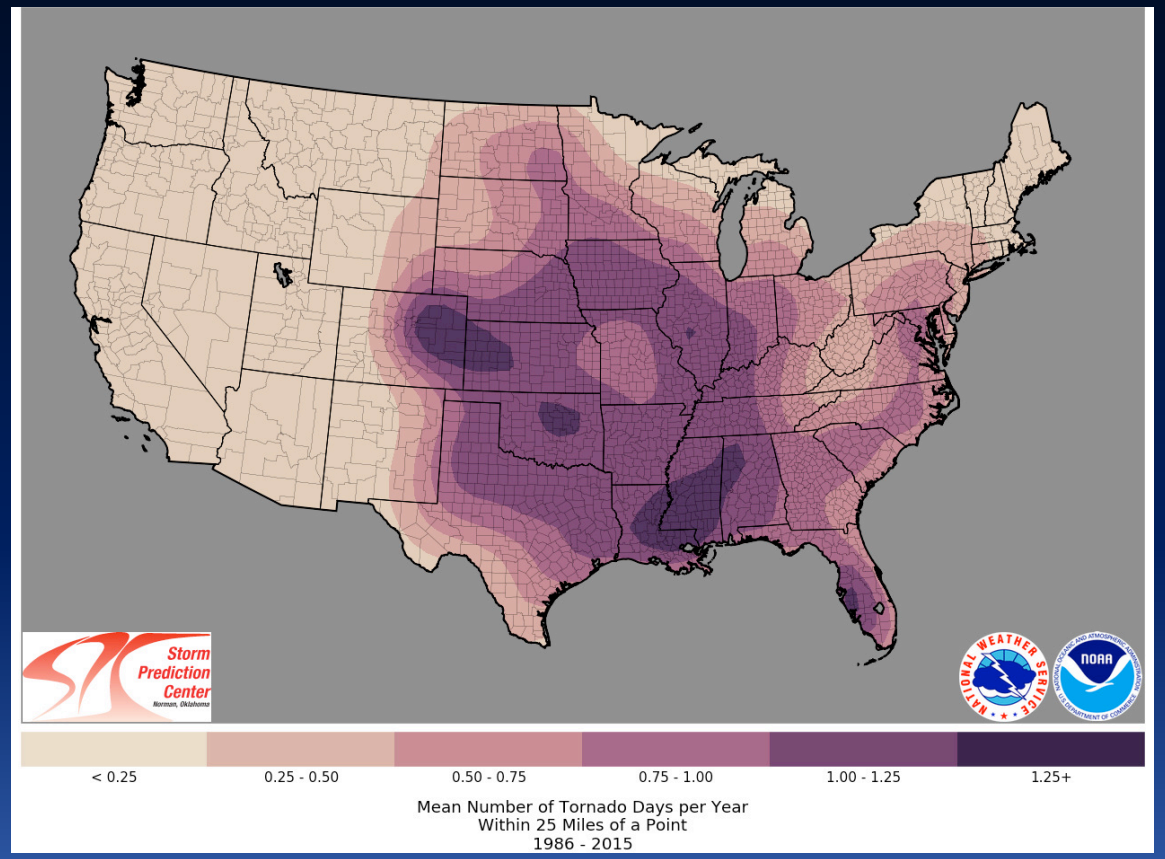




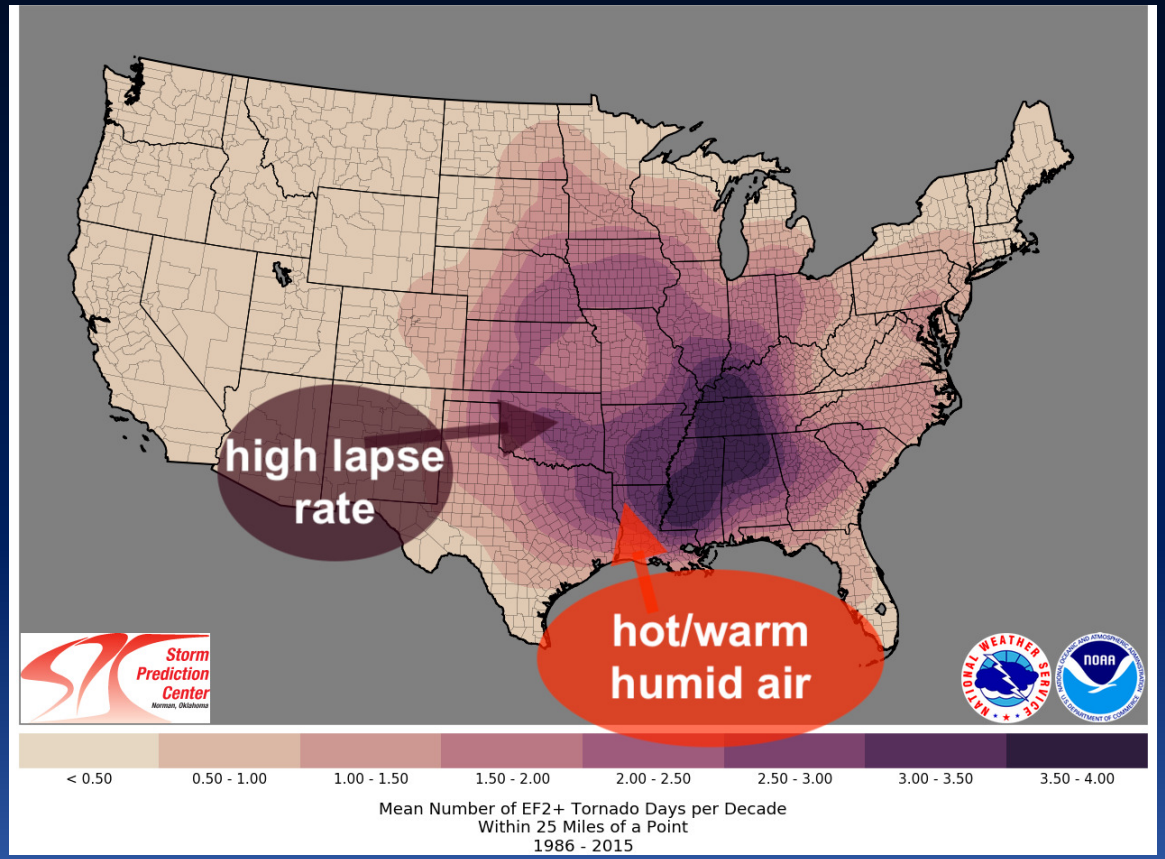
Weisman & Blanchard (1998)

US tornado climatology

Courtesy
Storm Prediction Center

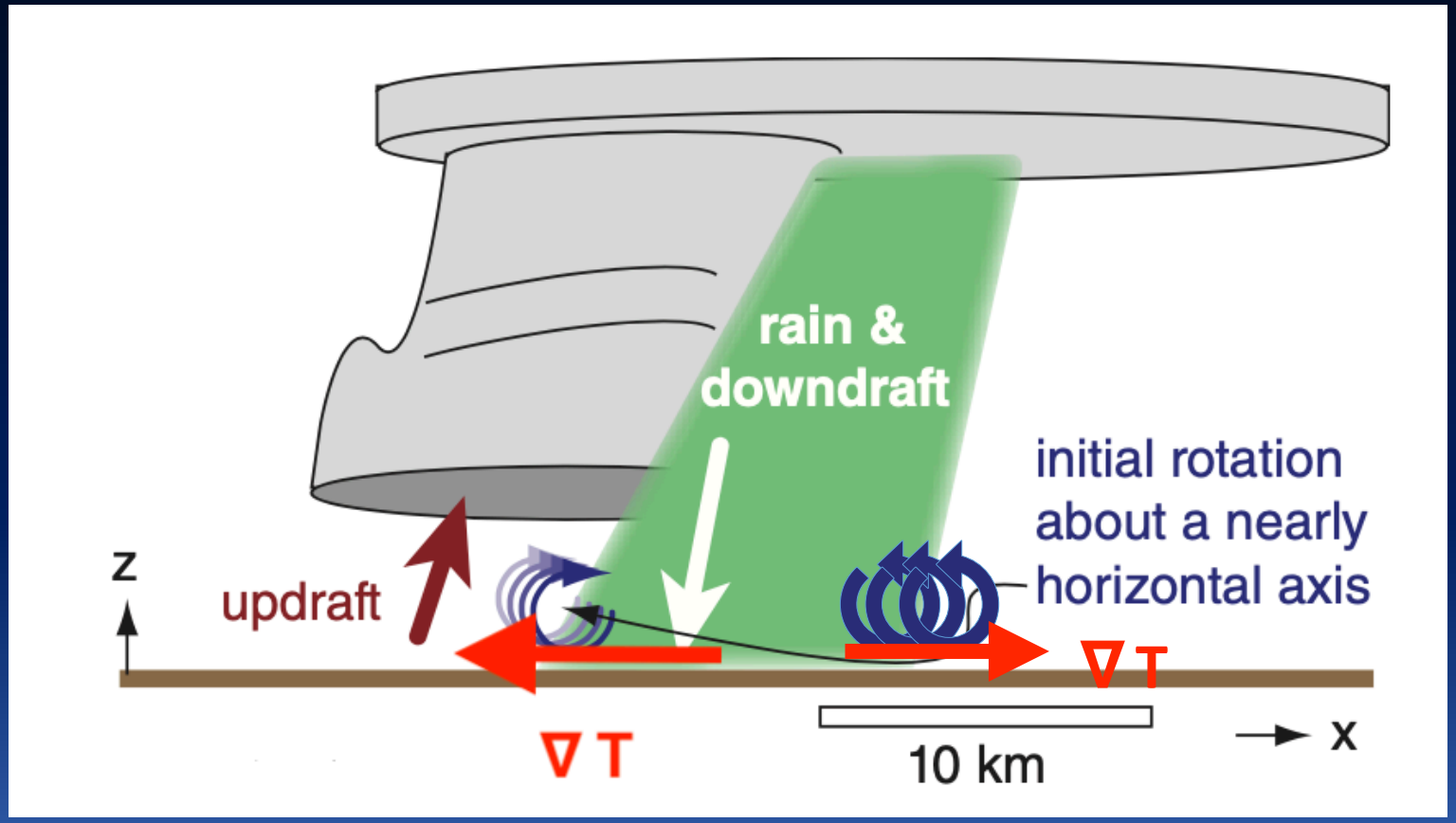


all



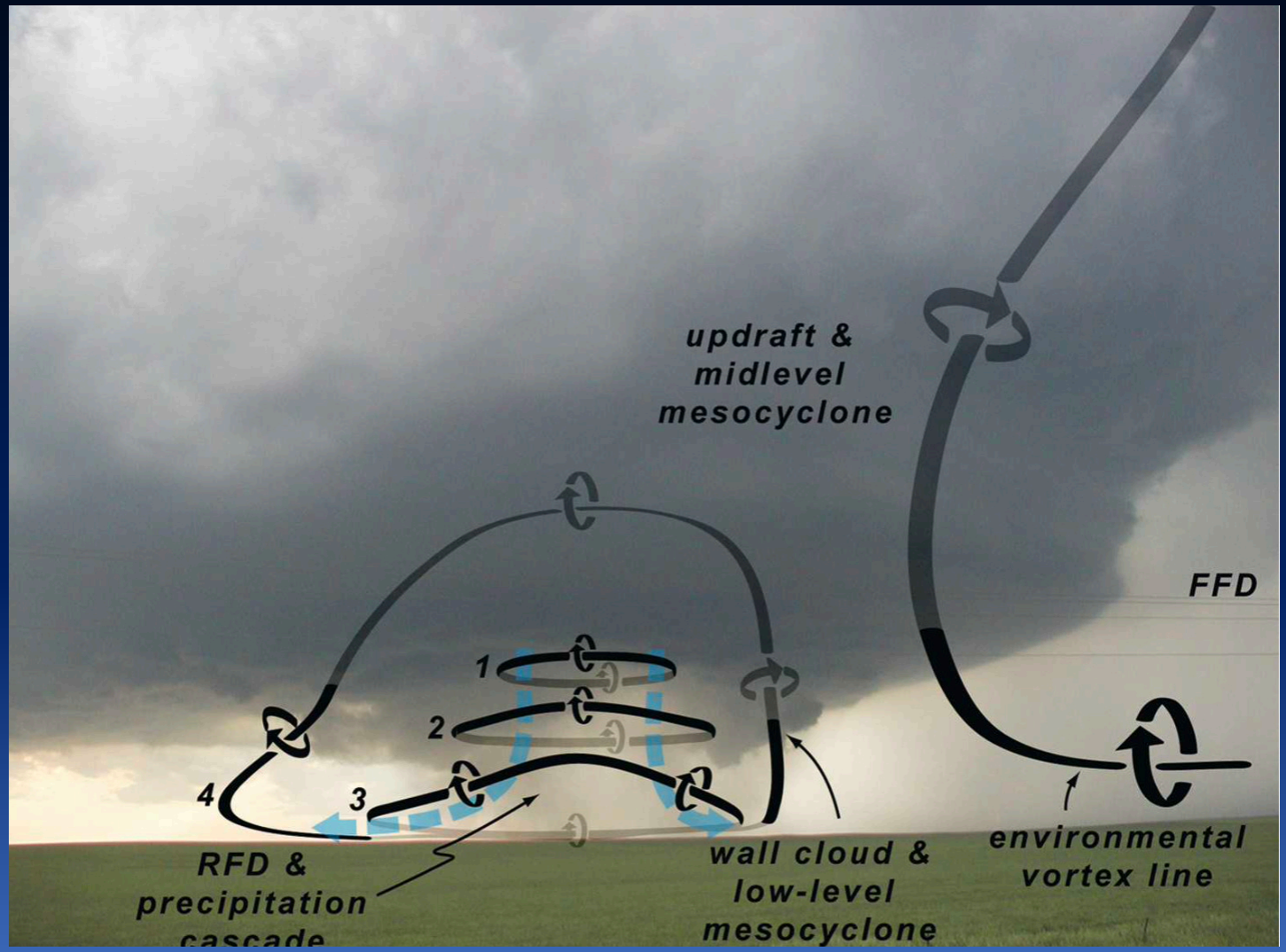
EF2+

Baroclinic generation of vorticity along a downdraft



Adapted from *Stull (2017)*

Vortex lines

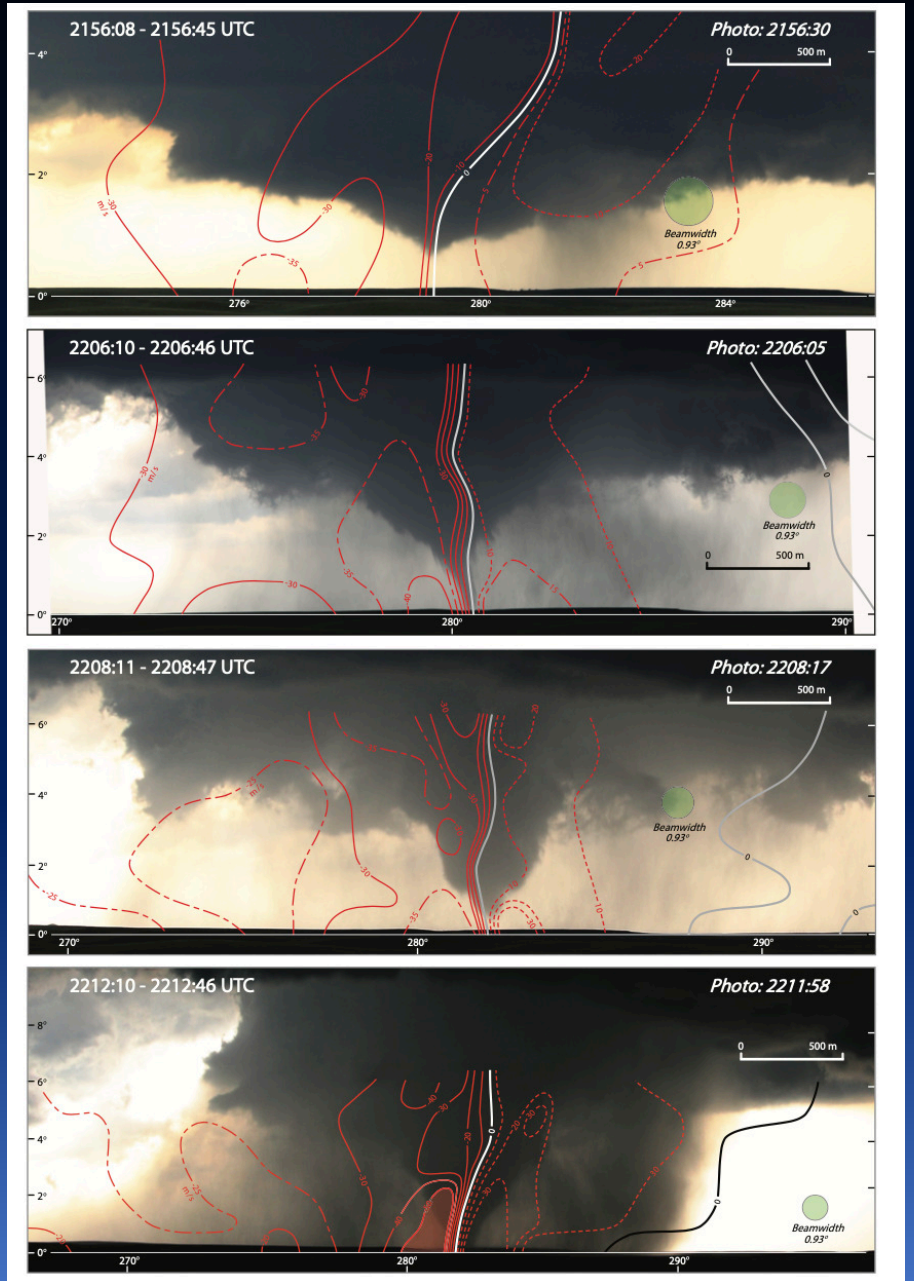


Markowski et al. (2008)

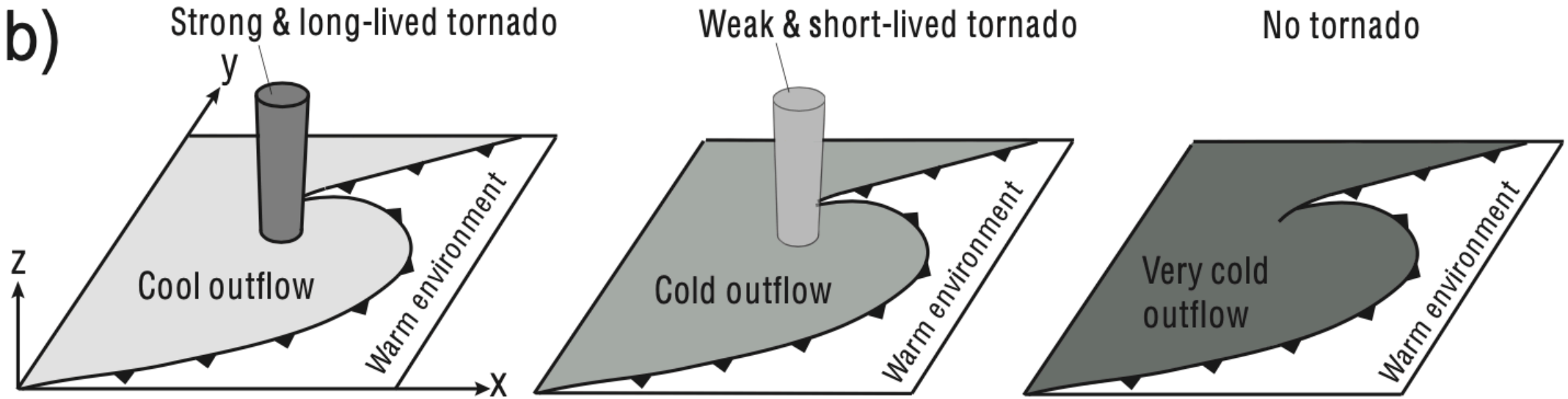
Tornadogenesis

Lagrange tornado, WY
5 June 2009

Wakimoto et al. (2011)

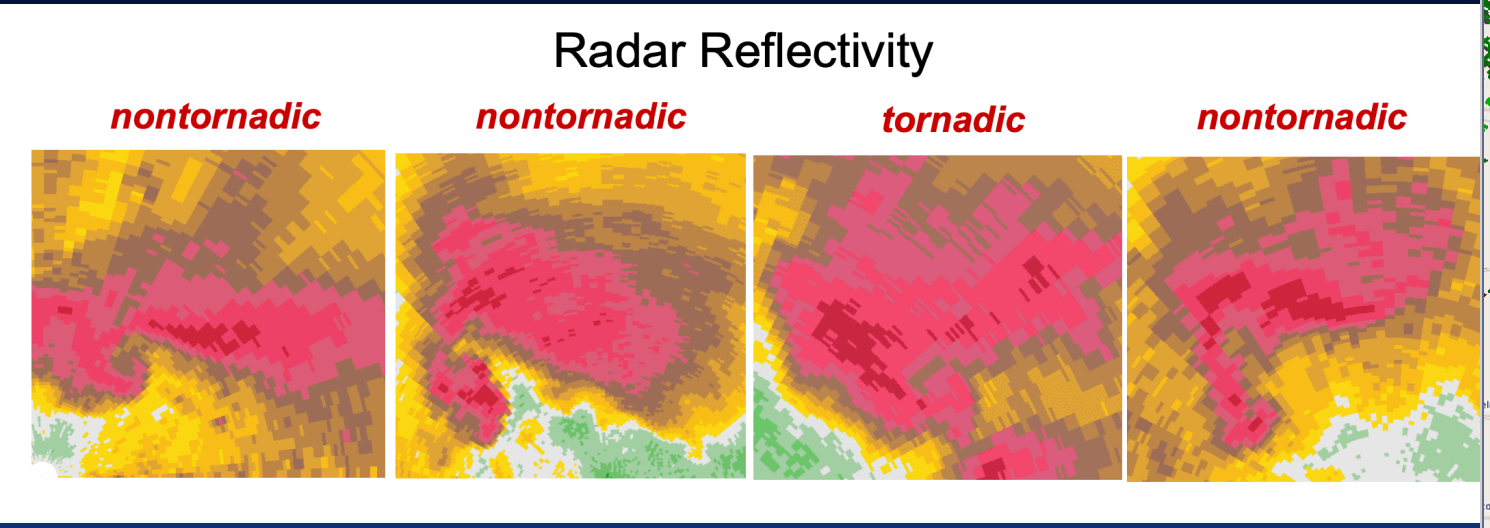


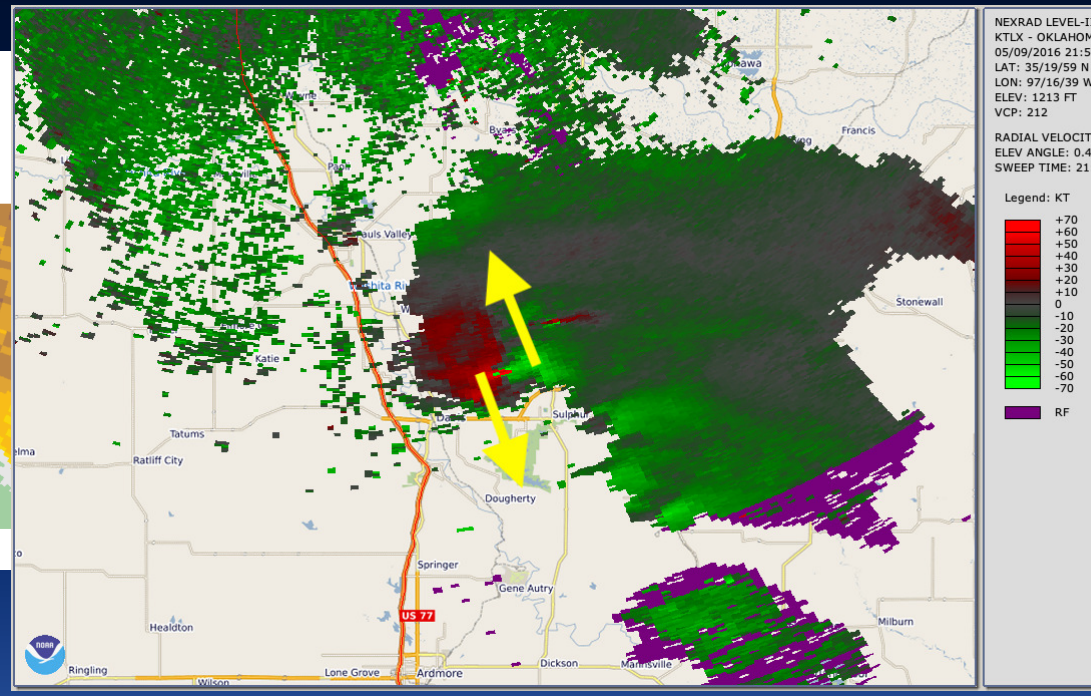
Importance of the cool outflow



Adapted from Marquis et al. (2012)

Other challenges





Courtesy *Rich Rotunno*

Tornado vortex

Litchfield, MN
11 July 2016

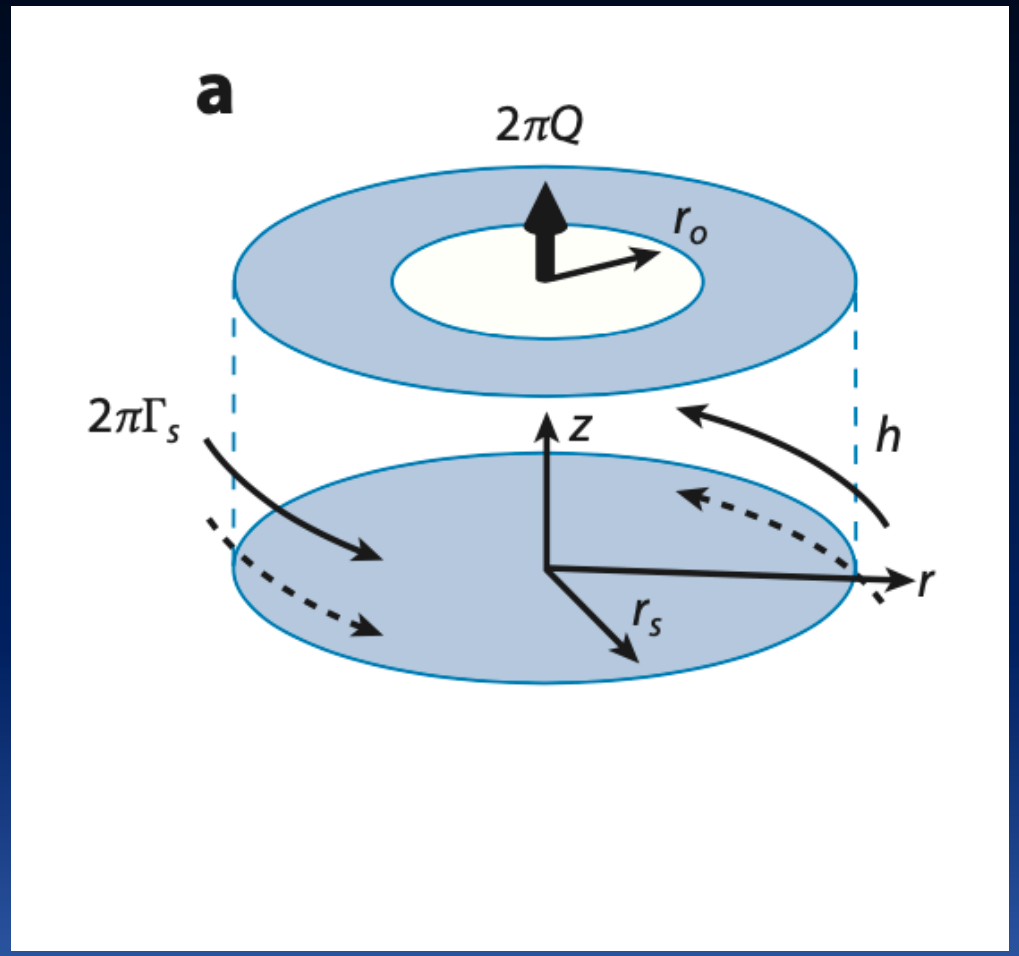
Manitou, OK
7 November 2011

Rochelle, IL
9 April 2009

Rotunno (2013)

Tornado vortex experiments

a swirl ratio S = v/w can be defined



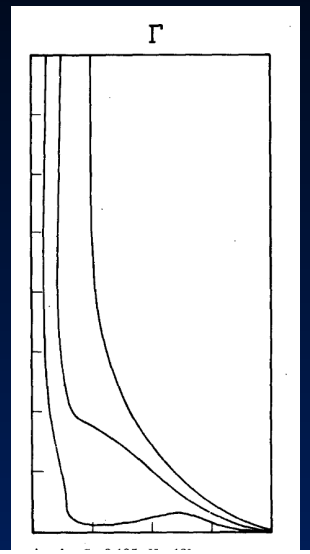
c

Ward chamber

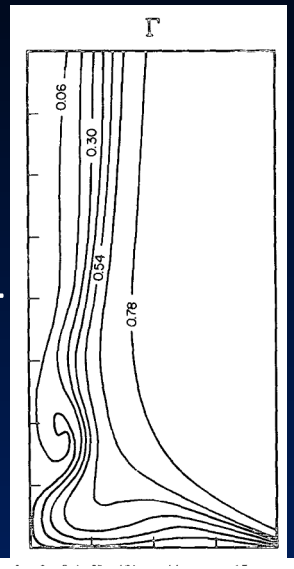
From single vortex to multi-vortex tornado

Rotunno (1979)

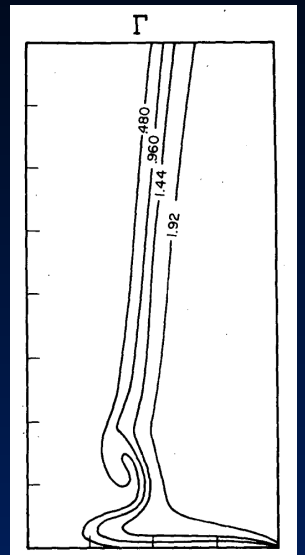
S = 0.15



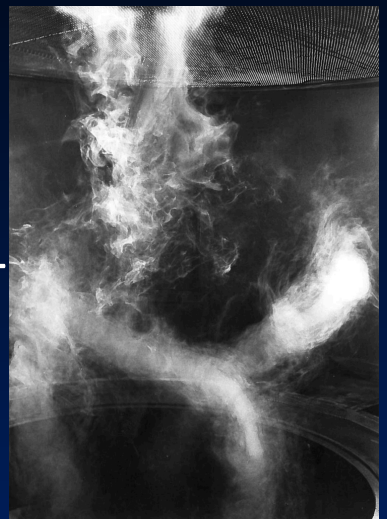
S = 0.4



S = 1

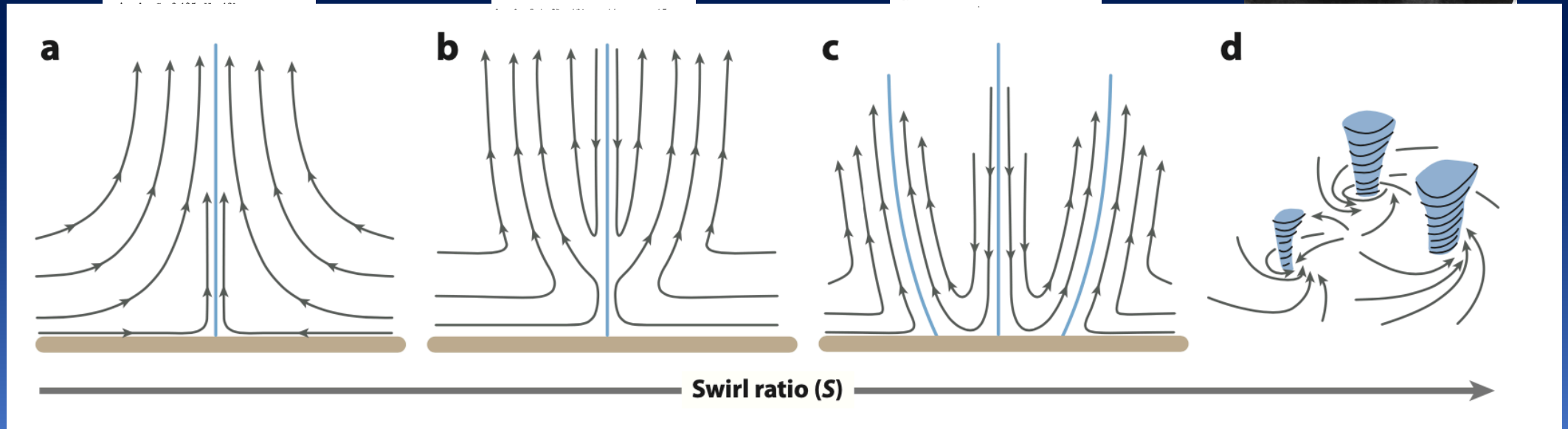


S > 1



Church et al. (1979)

Adapted from *Davies-Jones (1986)*



Outline

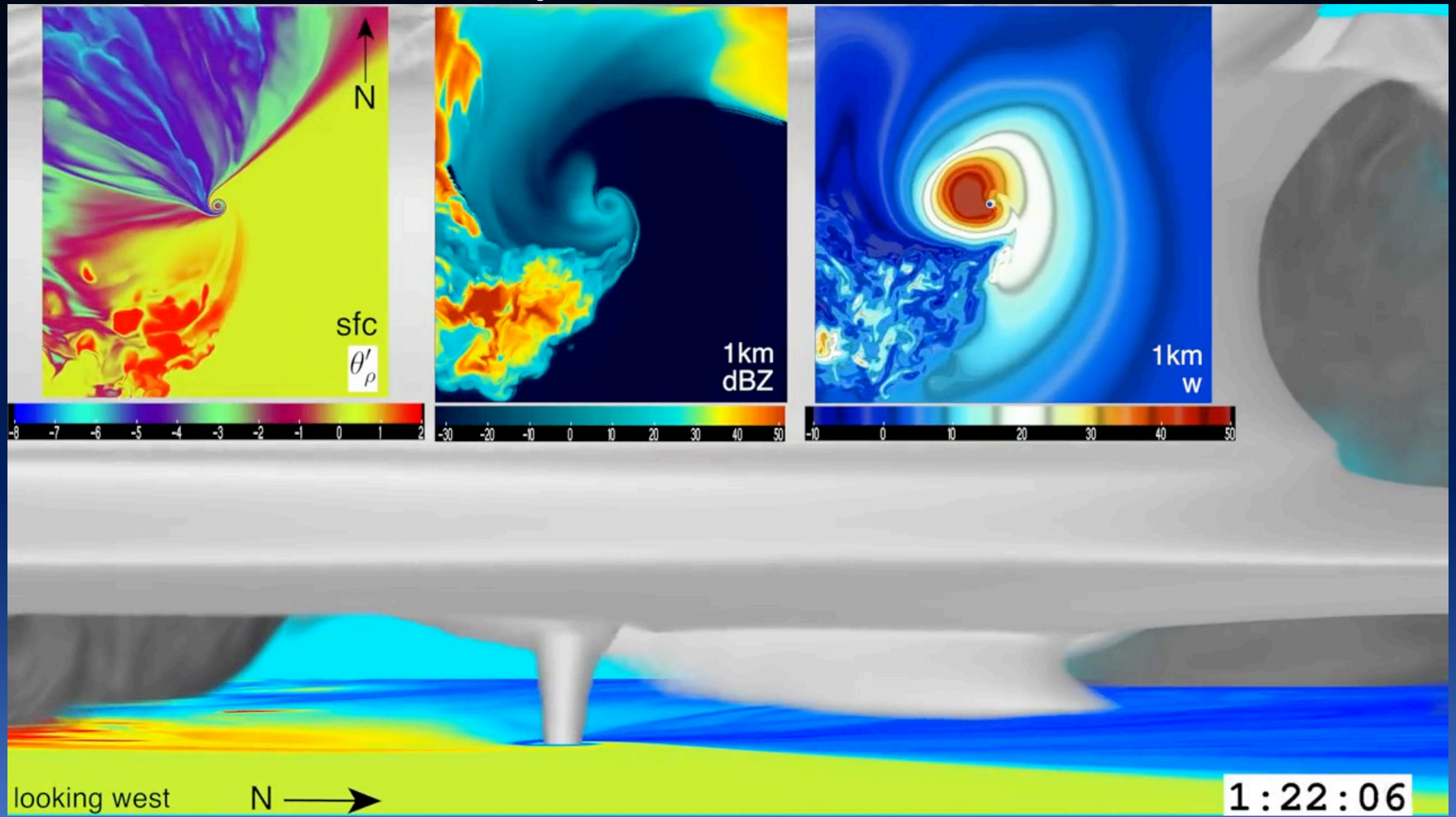
1. Some of the things we know about tornadoes and their parent clouds

2. What makes a tornado stronger (or weaker)?

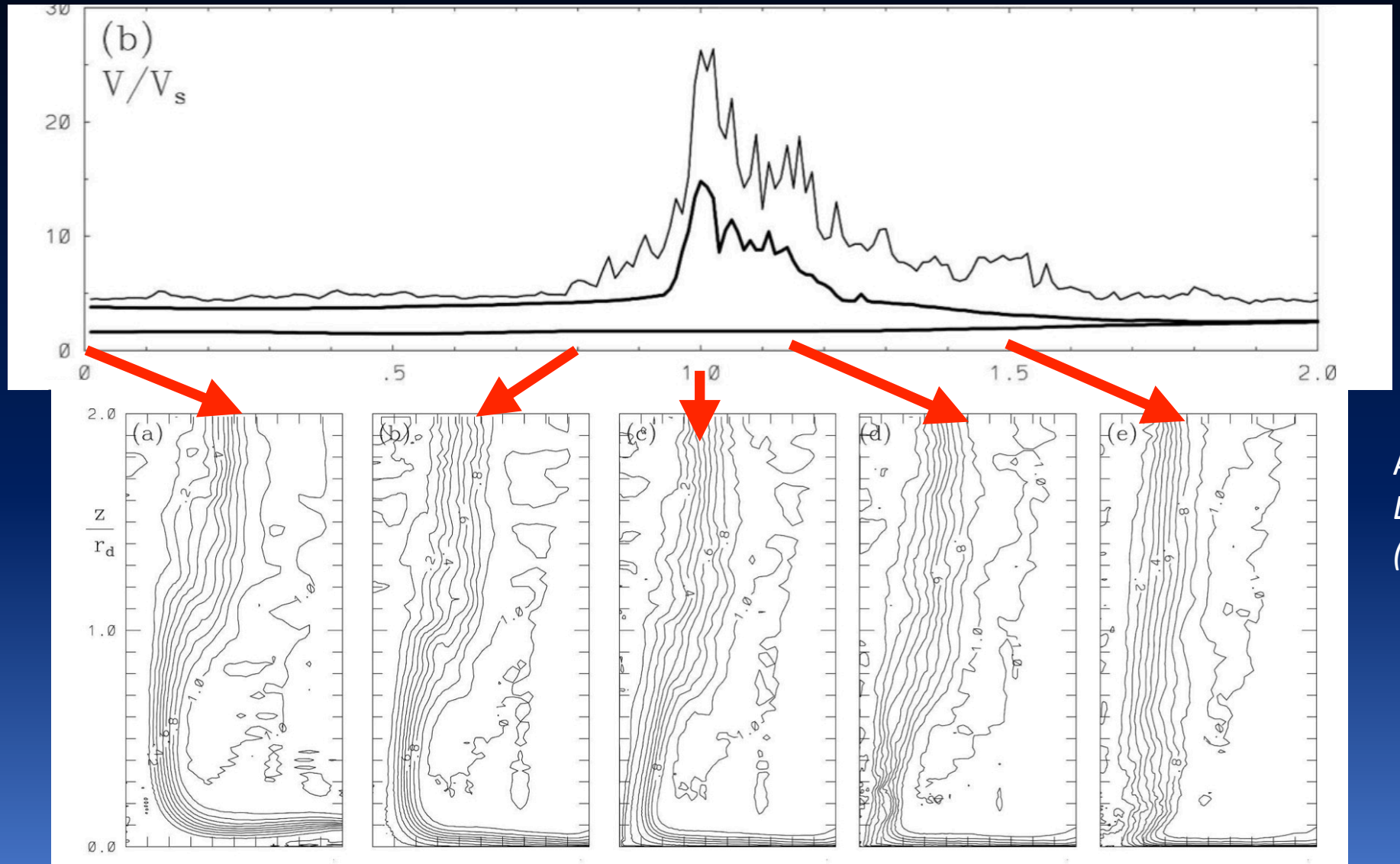
3. Perspectives and challenges

Outflow surges in tornado simulation with parent cloud

Courtesy
Leigh Orf

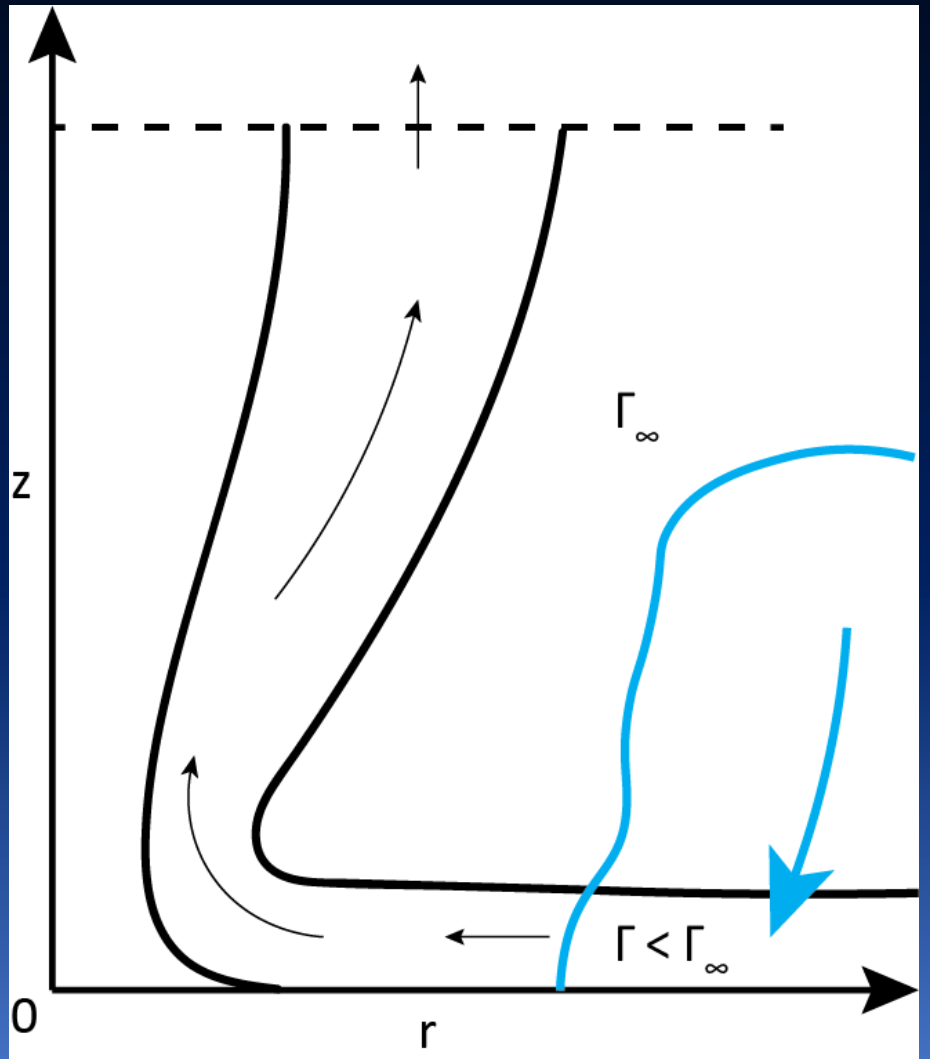


Intensification via perturbation of the inflow layer



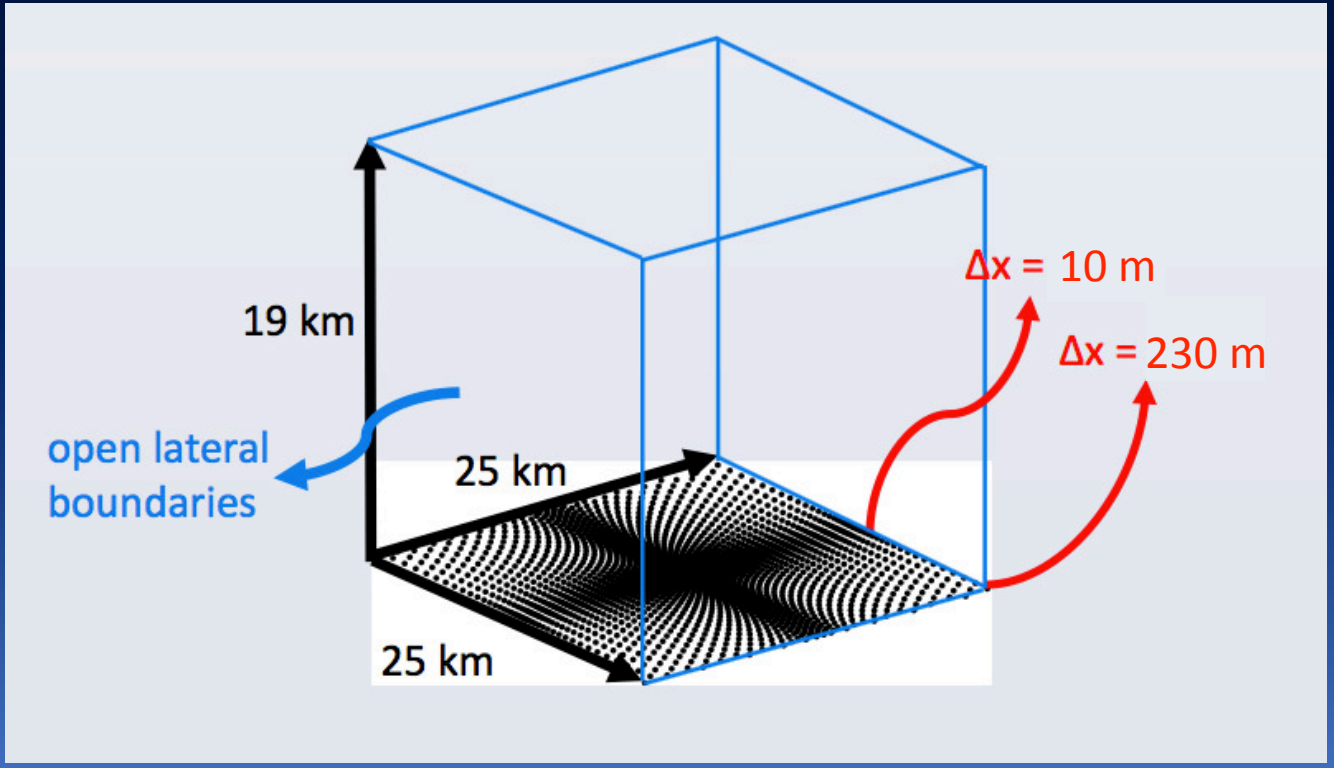
Adapted from *Lewellen & Lewellen (2007)*

Downward then radial inward transport of angular momentum



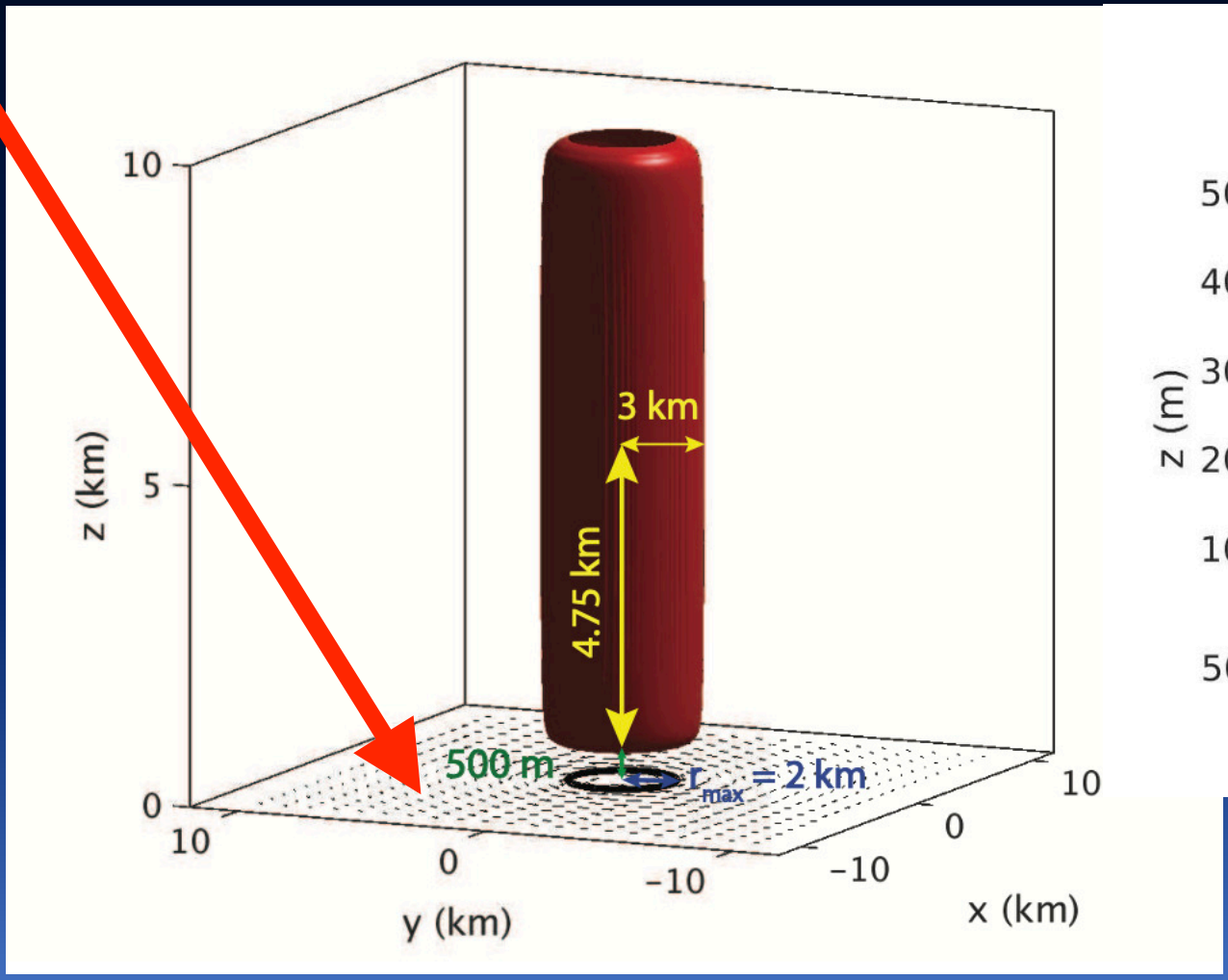
Methodology

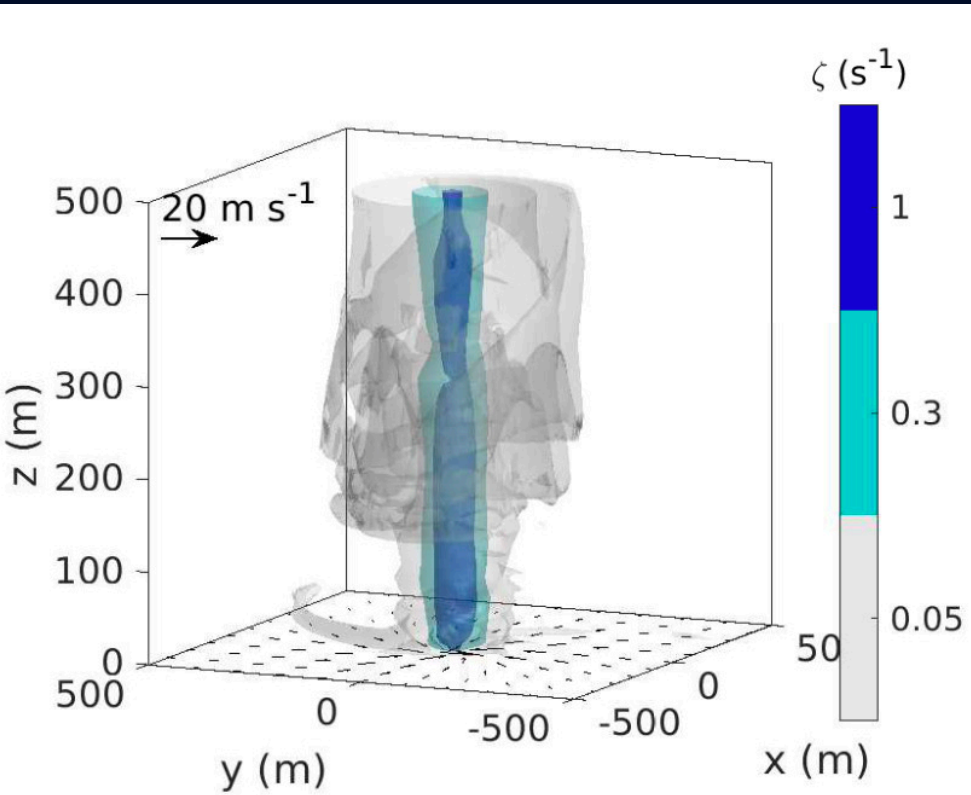
idealized LES simulations of tornado vortex with CM1 *(Bryan & Fritsch 2002)* with heat source and sink added *(Markowski & Richardson 2014)*



CM1

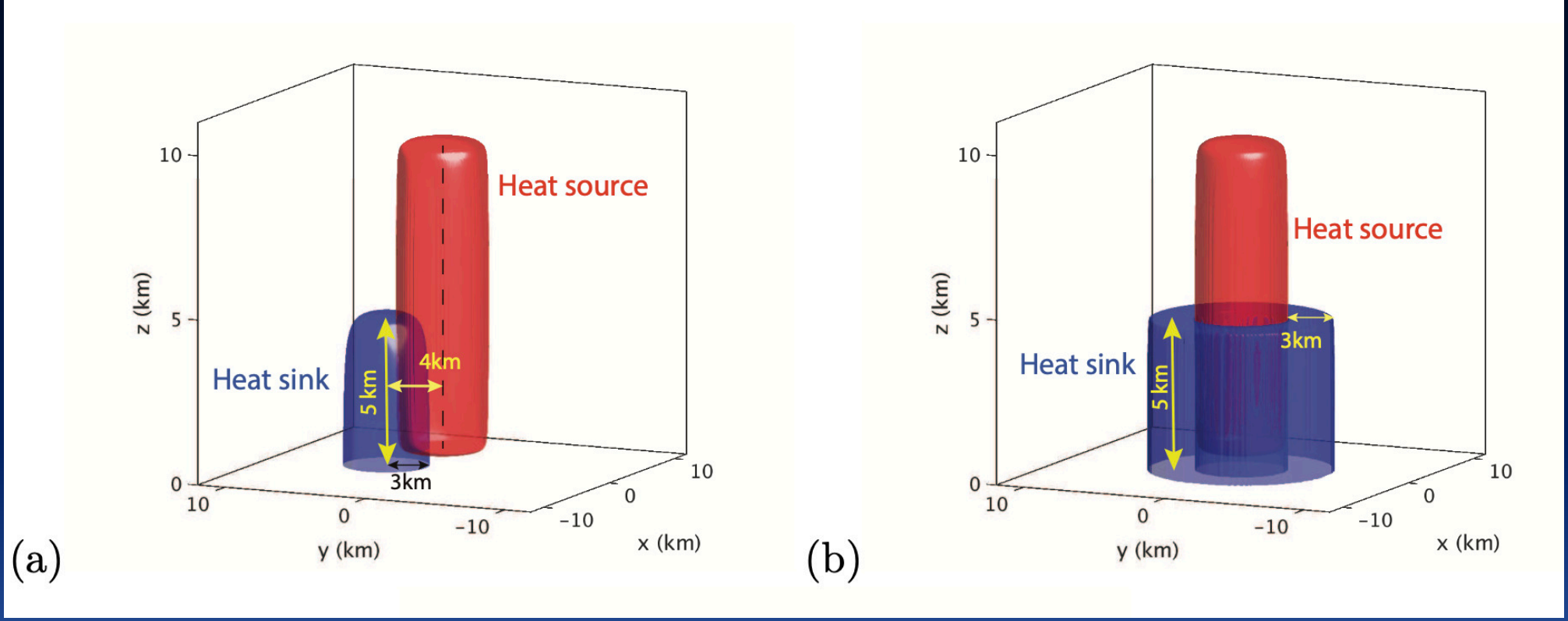
initial wind profile:
Rankine vortex





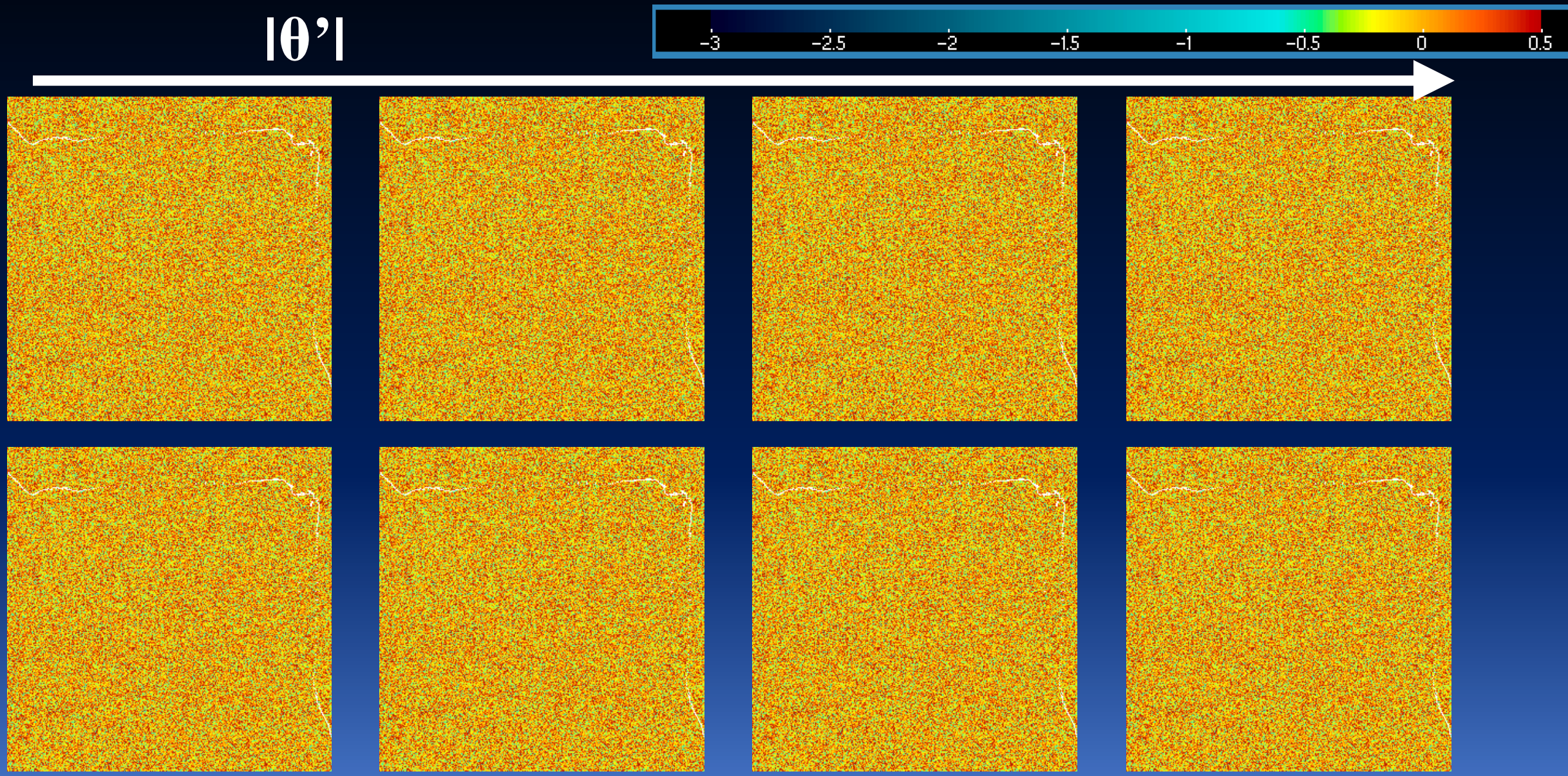
CTL simulation

Introducing outflow surges

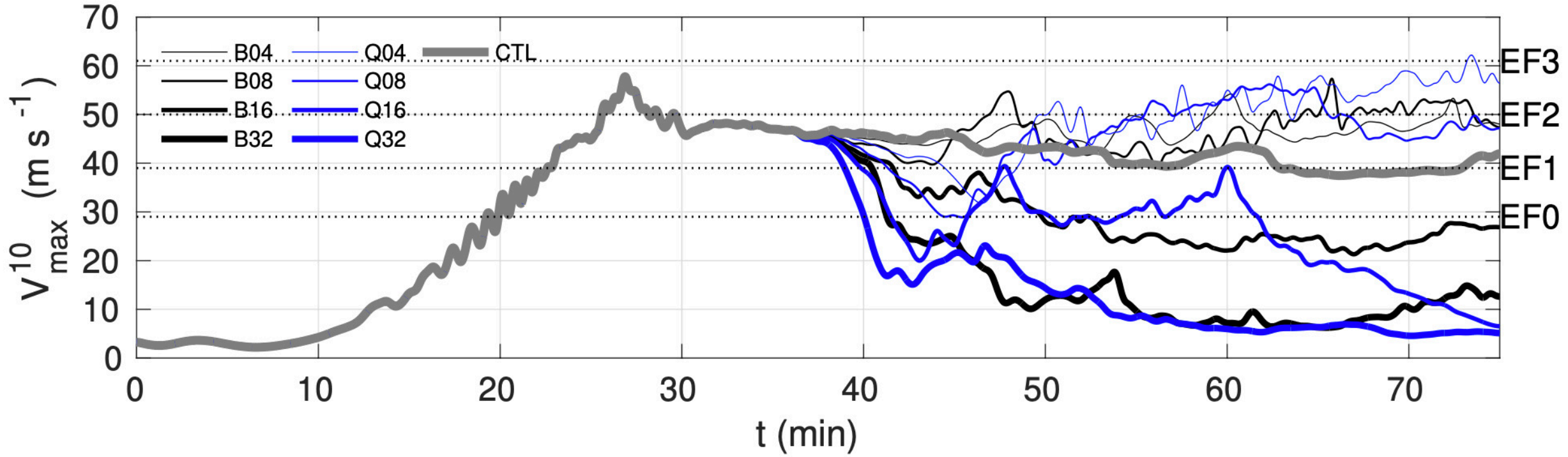


heat sinks with various magnitudes
activation between t = 35 and 37 min

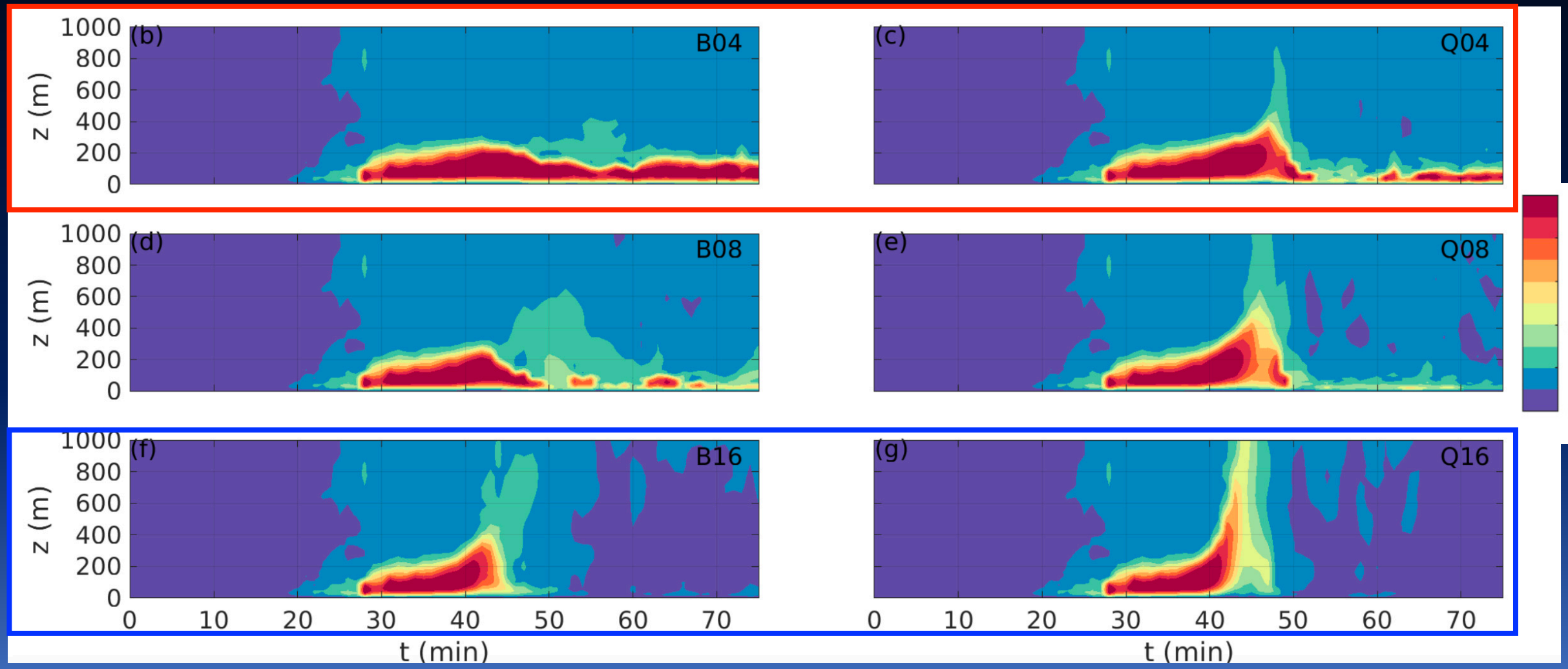
Outflow surges



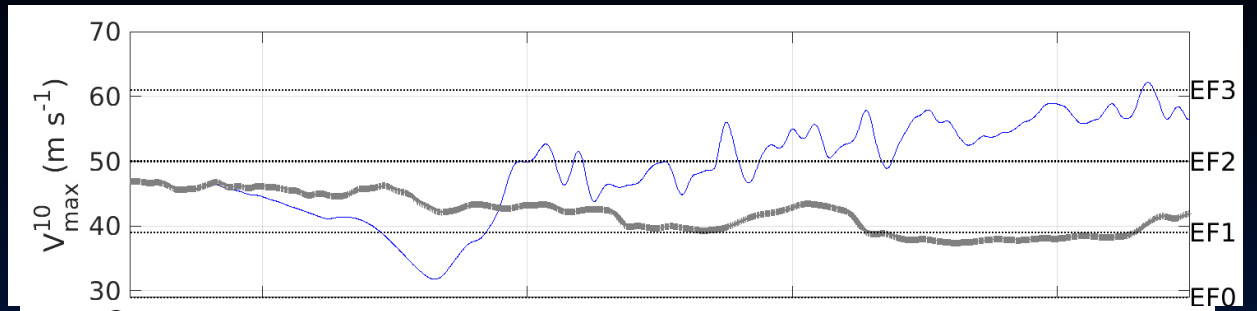
Maximum low-level winds

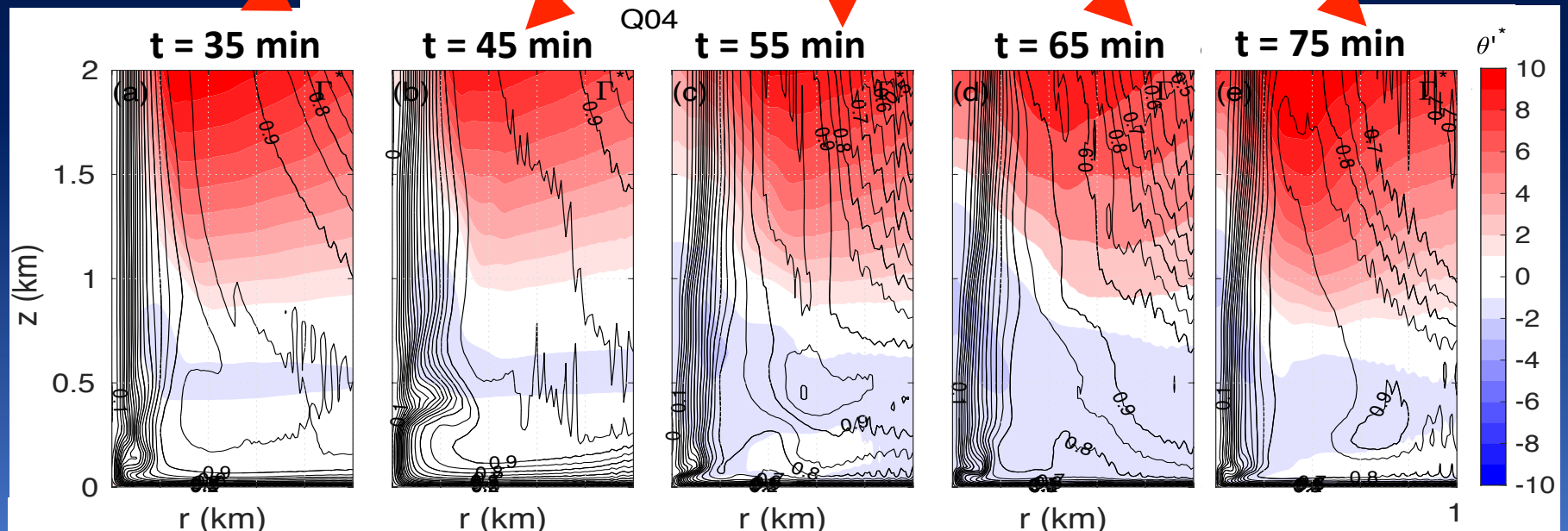


Modification of overlying updraft



Significant tornado intensification





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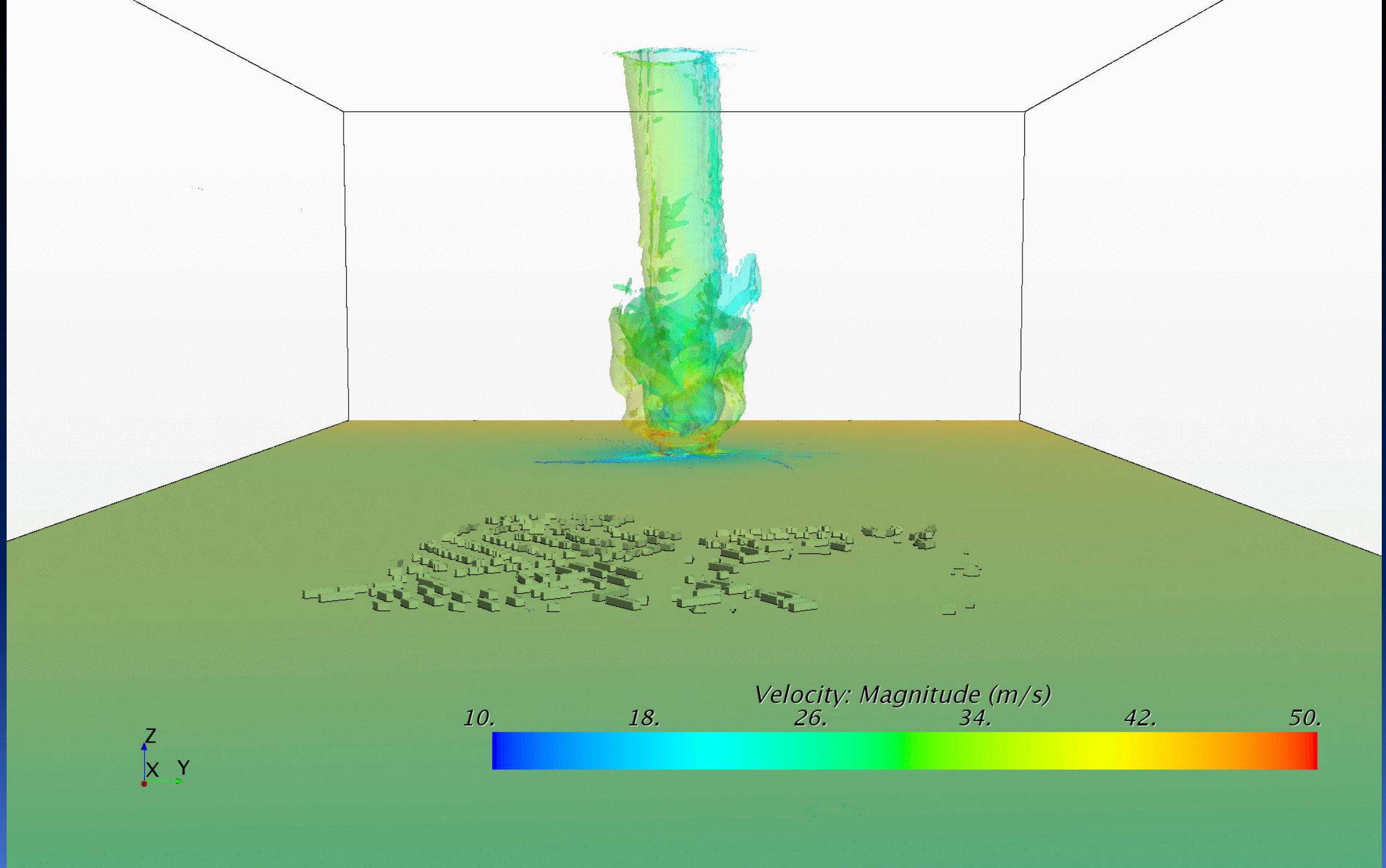
Velocity: Magnitude (m/s)
10.
18.
26.
34.
42.
50.
Z
X
Y


Thank you!
valerian.jewtoukoff@fuw.edu.pl