The effects of low-level shear on simulated supercells

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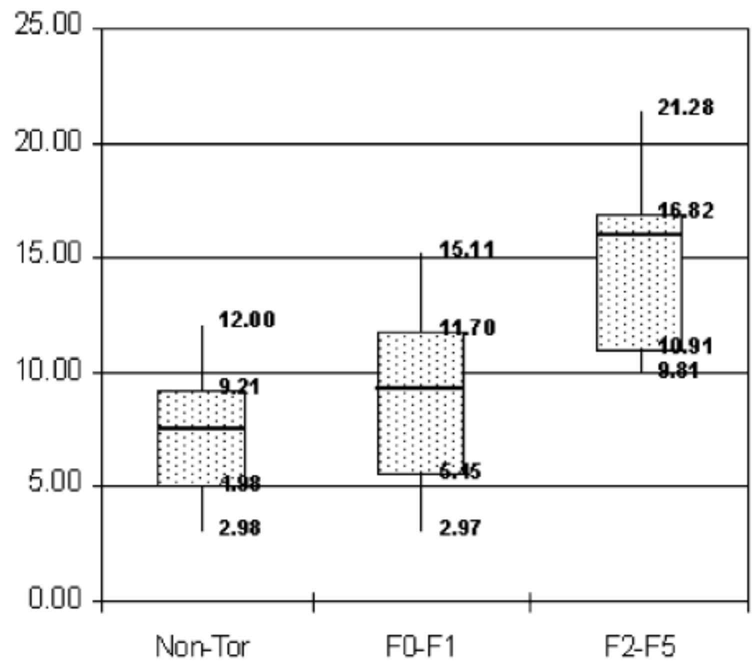
Motivation

- Several observations-based studies have found a correlation between significant tornadoes and low-level vertical wind shear:

0-1 km wind-vector difference (Δu) (m/s):



Doswell and Evans (2003, Atmos Res)

Hodograph shape in low levels: a "bend," or "kink," or "sickle shape," or "L-shape" is often seen in low levels (200 – 1000 m AGL)

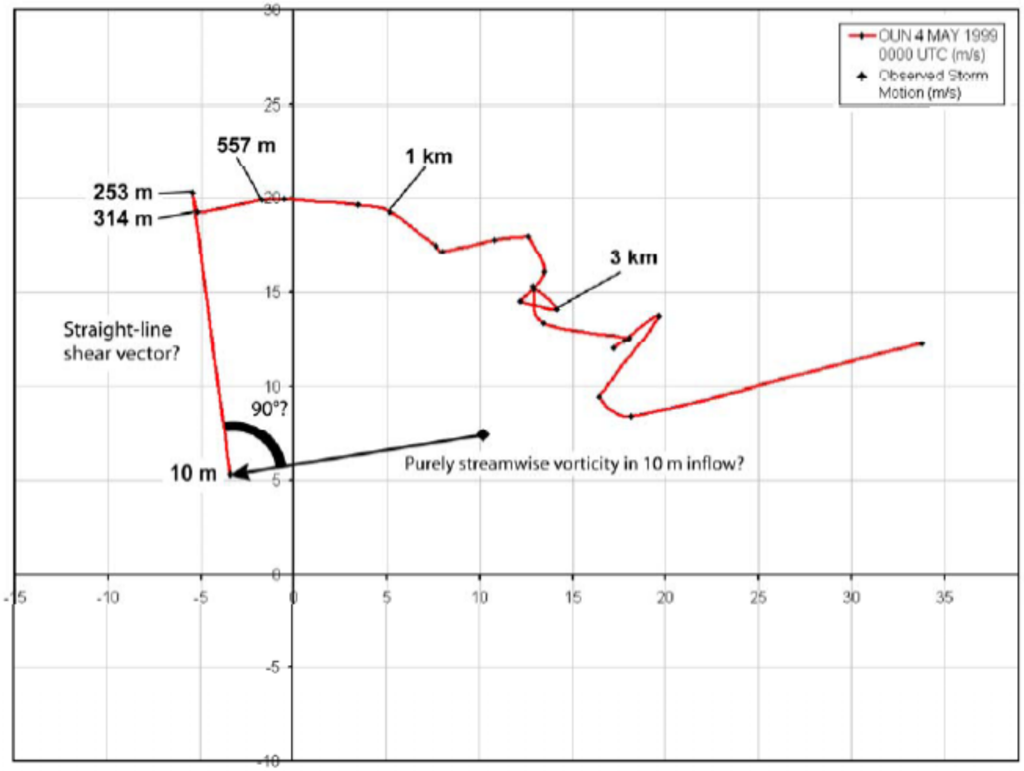


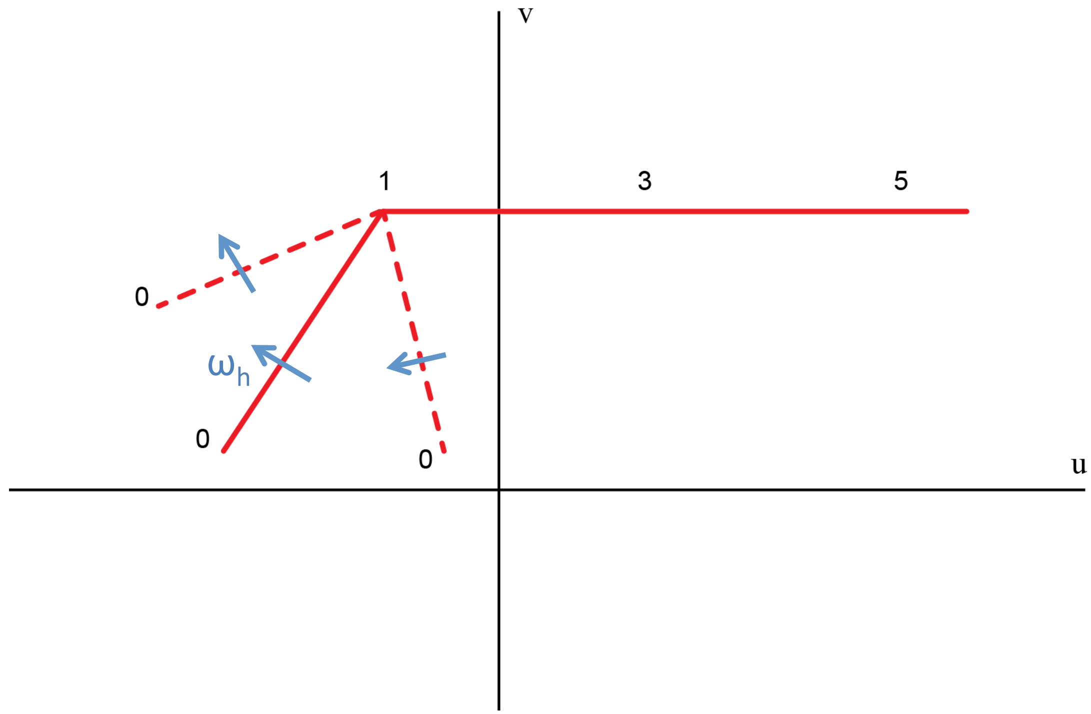
Figure 1: KOUN 0000 UTC 4 May 1999 hodograph. Axis units are in m s^{-1}.

Esterheld and Giuliano (2008, EJSSM)

See also: Wicker (1996, SLS Conf., 3.3)
Miller (2006, SLS Conf., 3.1)
Kis and Straka (2010, SLS Conf., P6.9)

Motivation

- Use idealized simulations to understand effects of low-level shear on supercells
- A simple hodograph:
  - Two straight-line segments (ω_h = constant)
  - Specified angle between low-level and upper-level segments



Methodology

- Numerical model: CM1 (http://www.mmm.ucar.edu/people/bryan/cm1)
- Δx, Δy = 500 m
- Δz varies from 20 m near surface to 500 m at z = 20 km
- Standard idealized model configuration:
  - Horizontally homogeneous environment
  - Warm thermal initialization
- No surface fluxes, no surface drag, no radiation
  - (ensures the specified environment does not change)
- Morrison (2009) double-moment microphysics scheme
  - increased threshold in raindrop breakup parameterization
  - see Morrison and Milbrandt (April 2011, MWR)
  - yields larger raindrops, less evaporation
  - estimated reflectivity obtained by integration of drop size distributions, assuming 10-cm wavelength radar (Bryan and Morrison, 2011, MWR in press)

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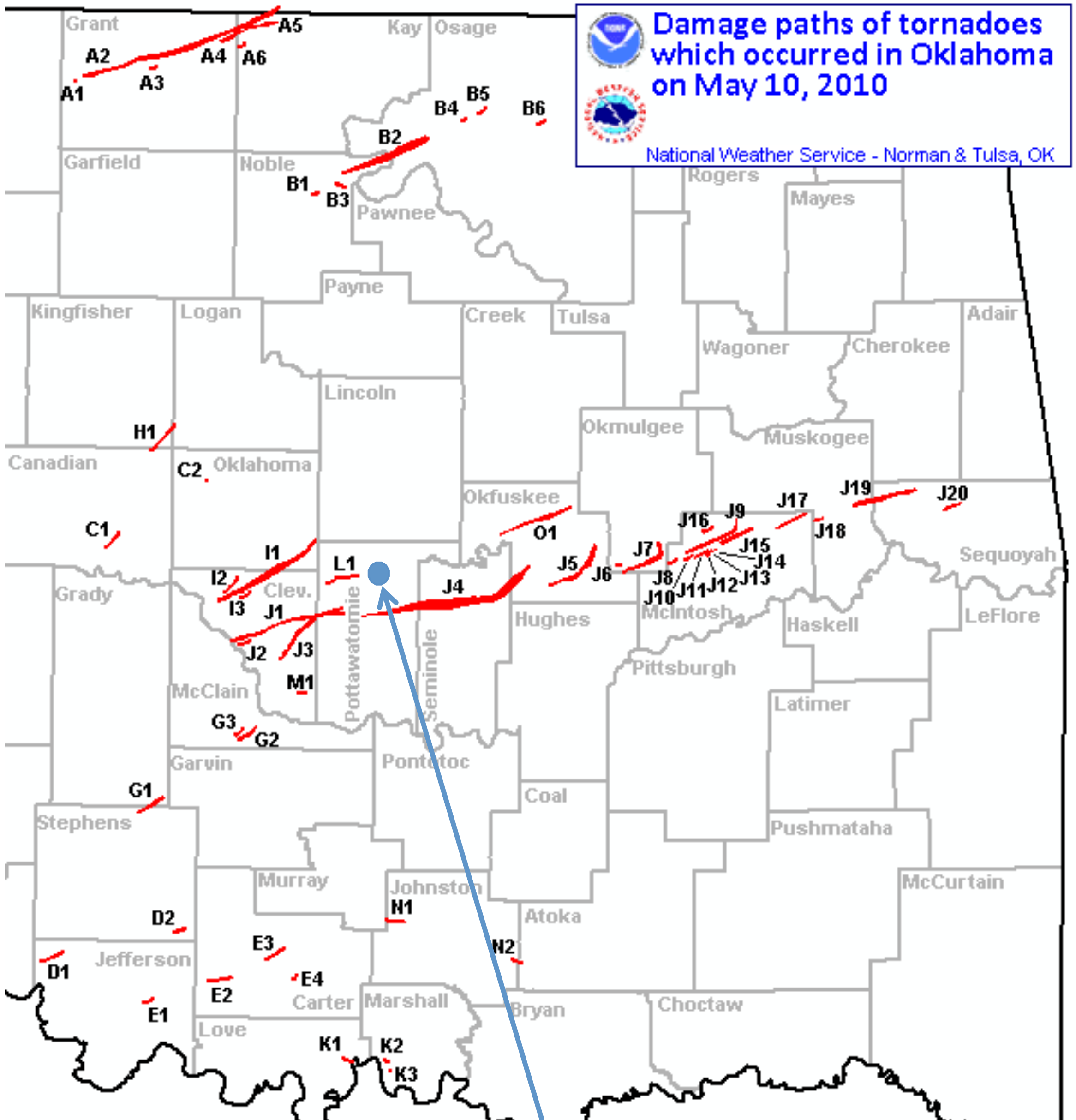
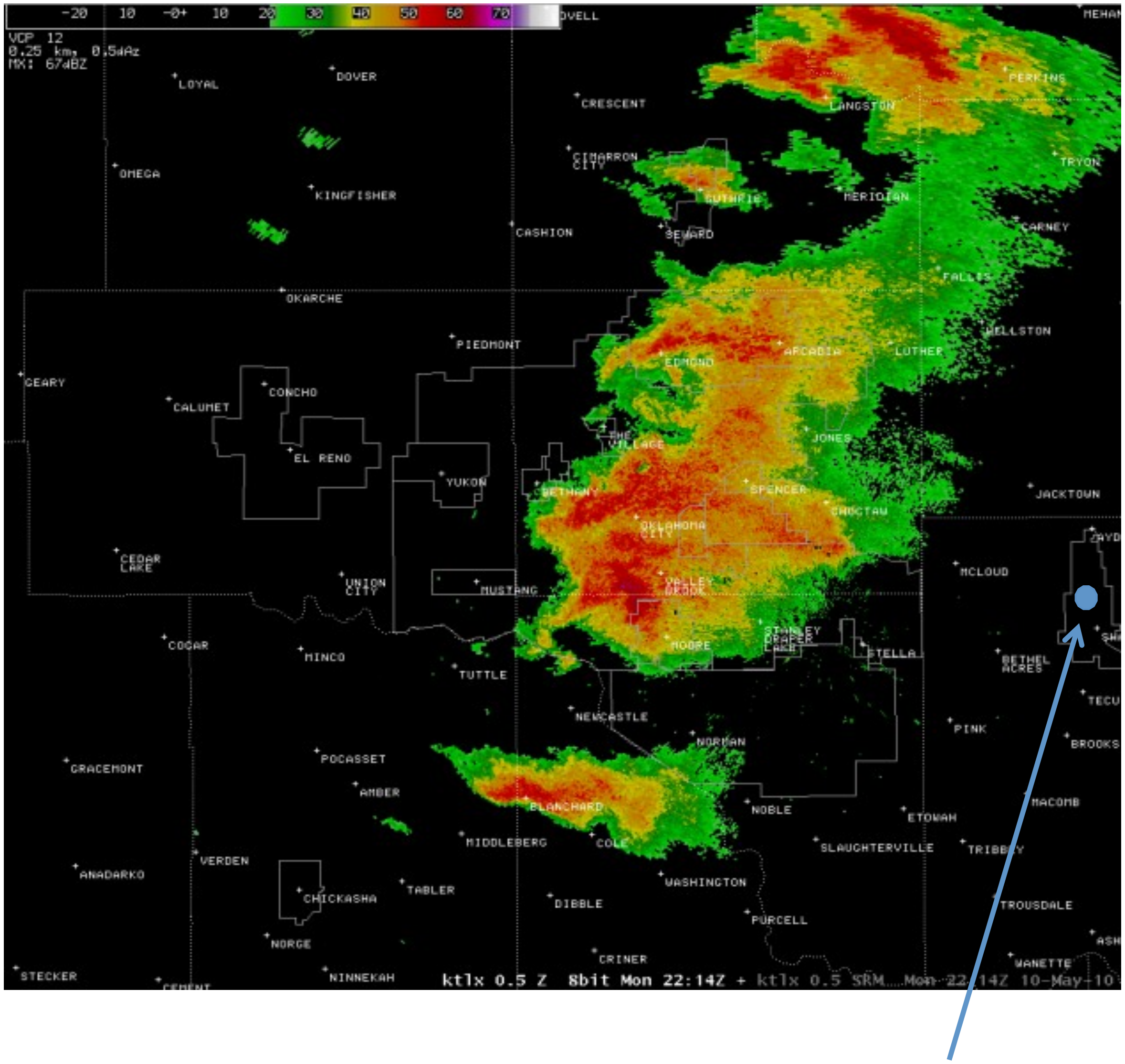


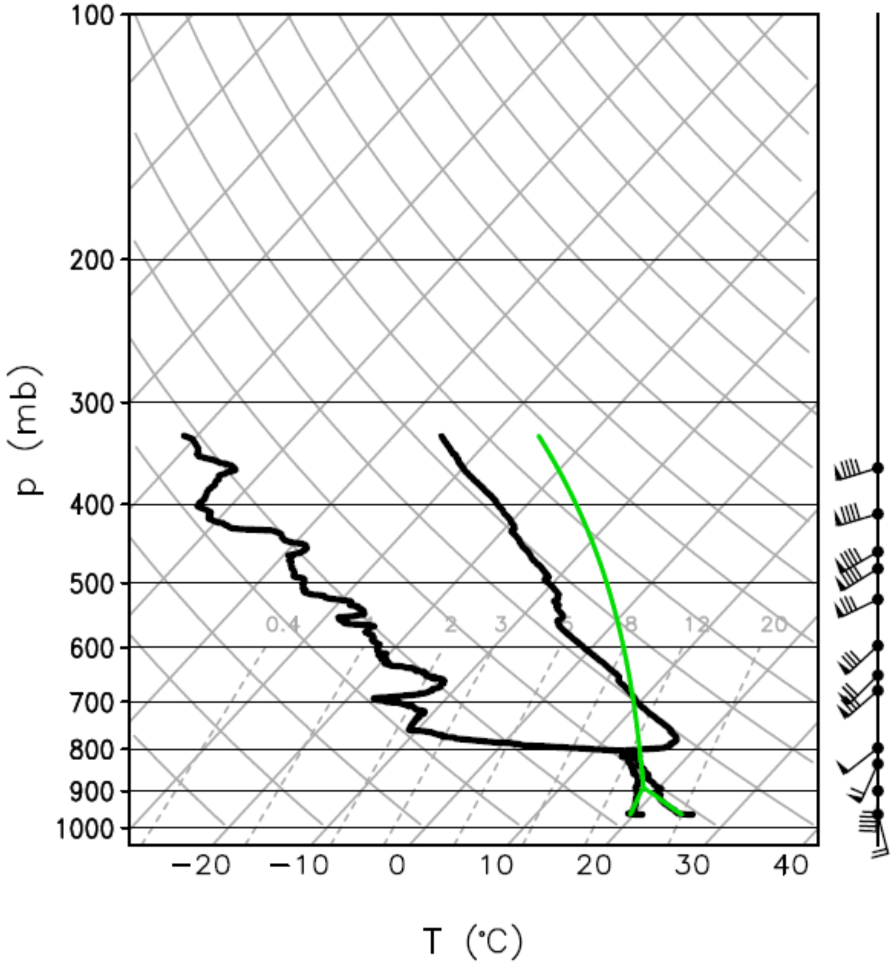
Hourly soundings from Shawnee before storms arrived

Radar image 15 minutes after last sounding launch from Shawnee, OK
(45 minutes before tornado)



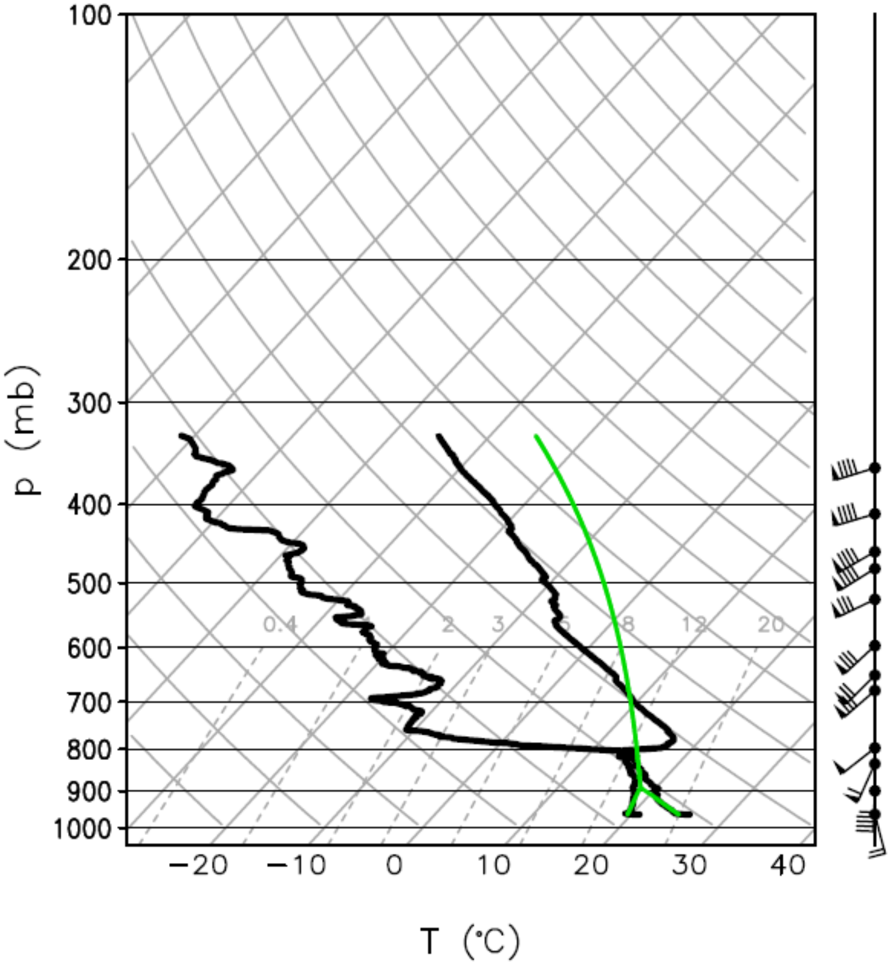
sounding site

Shawnee, OK: 2100 UTC
(2 hours before tornado)



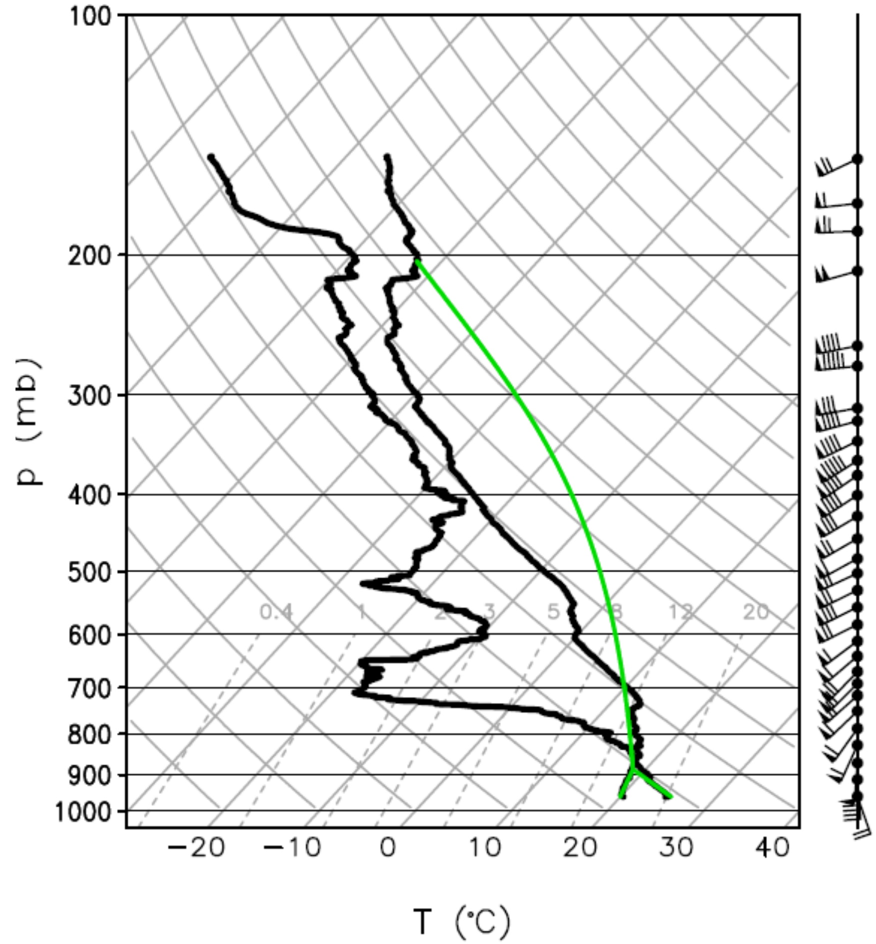
CIN: 60 J kg^{-1}

Shawnee, OK: 2100 UTC
(2 hours before tornado)



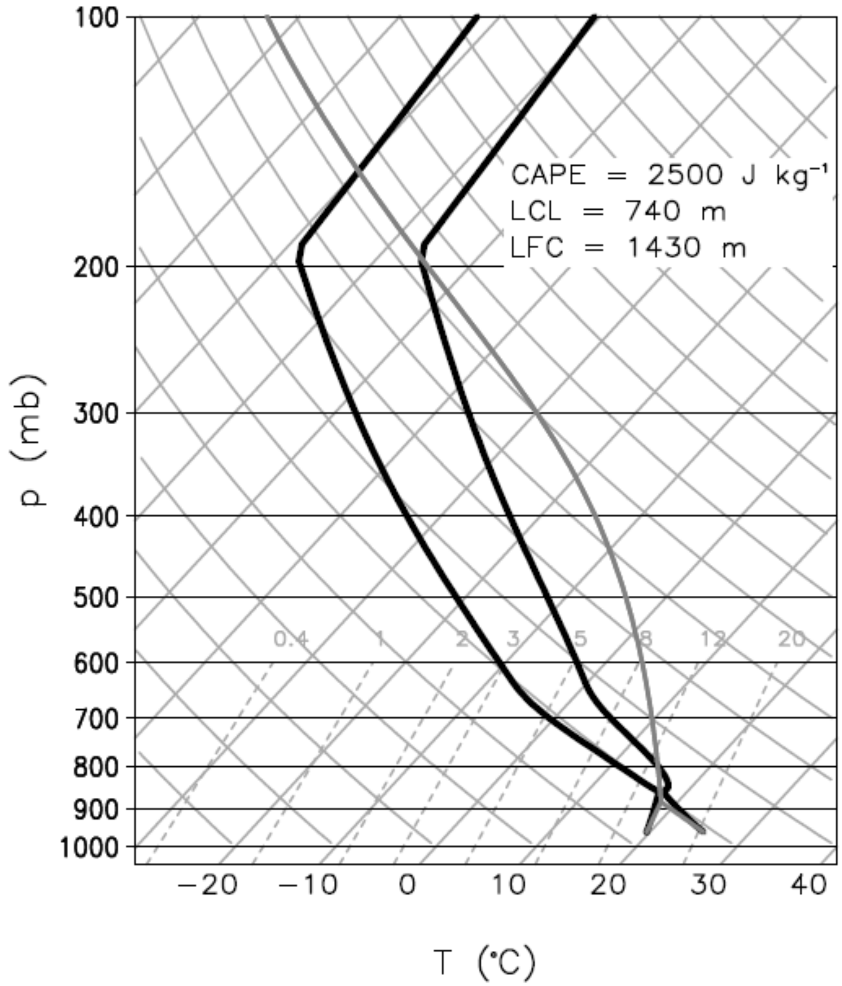
CIN: 60 J kg^{-1}

Shawnee, OK: 2200 UTC
(1 hour before tornado)

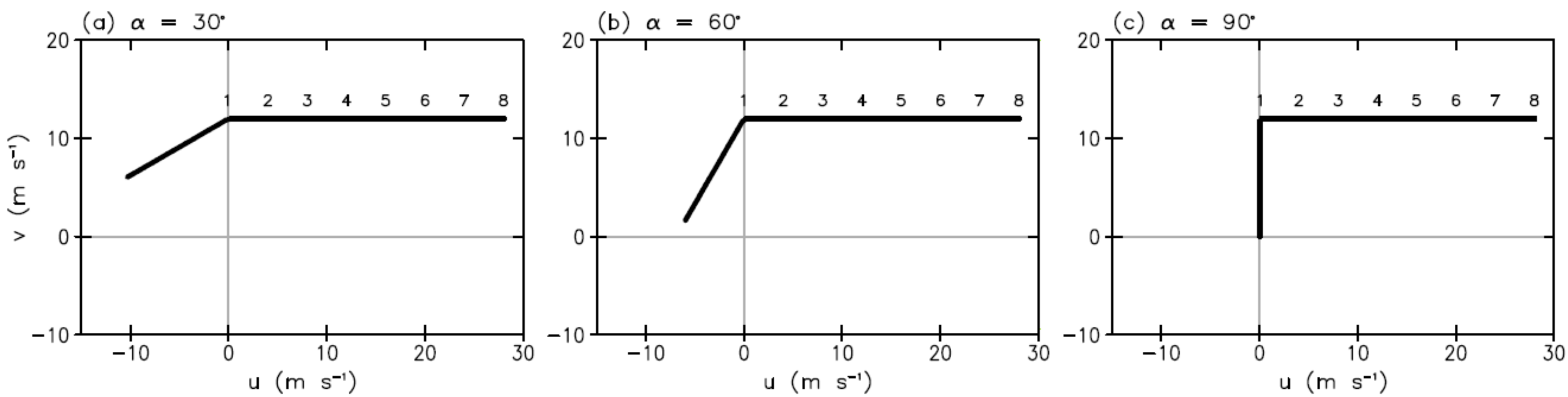


CIN: 3 J kg^{-1}

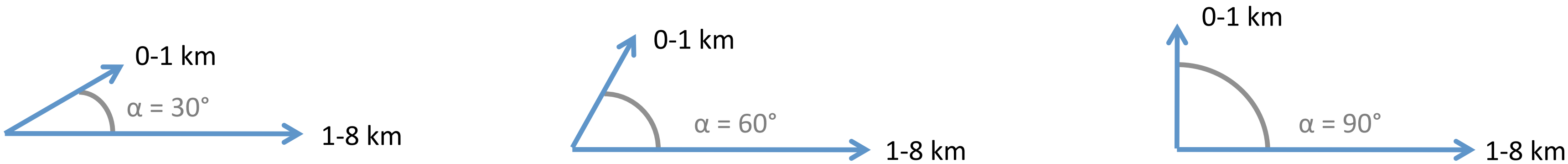
Initial conditions for idealized model simulations:



Initial Wind Profiles:

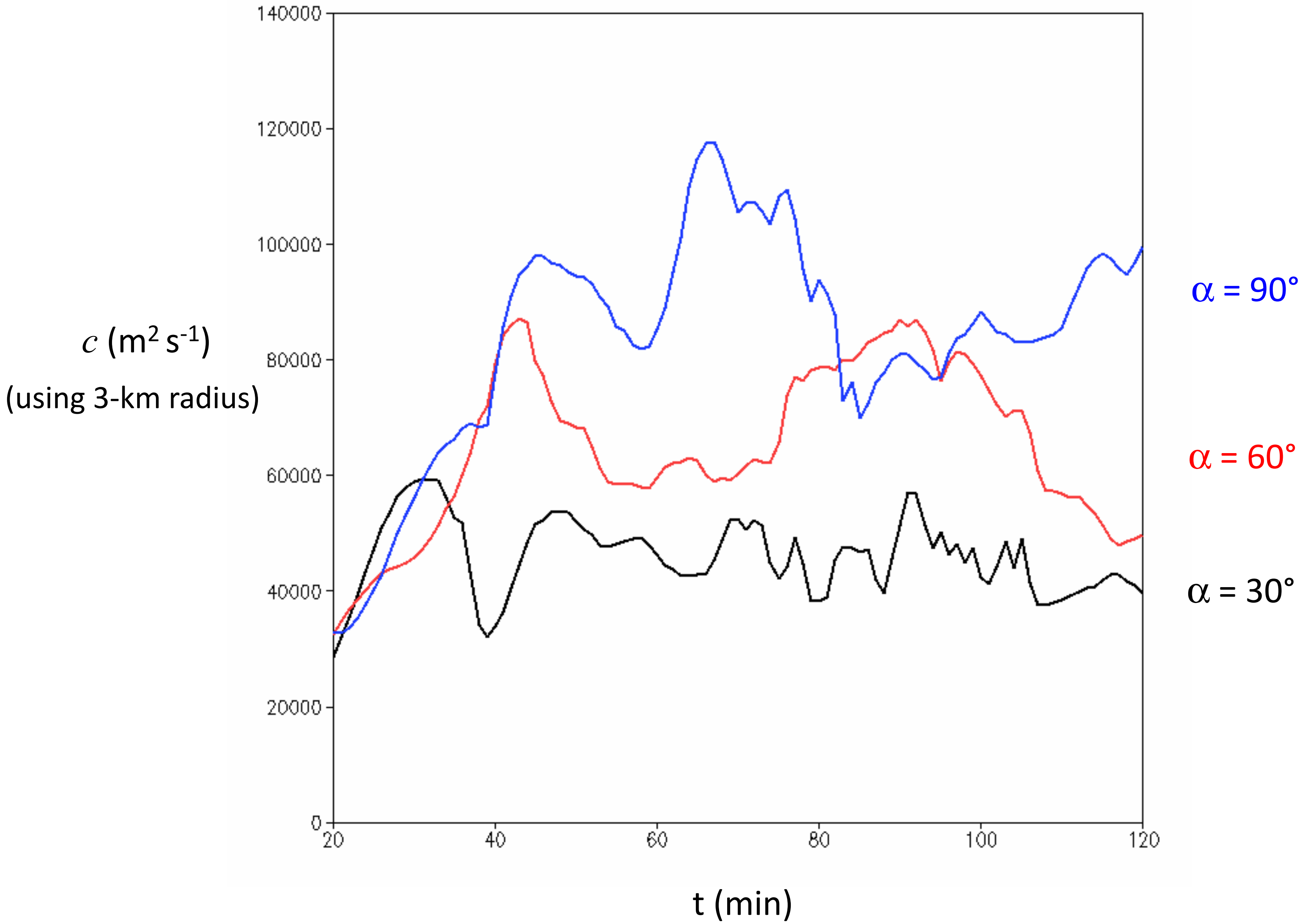


α is the angle between 0-1 and 1-8 km shear vectors:

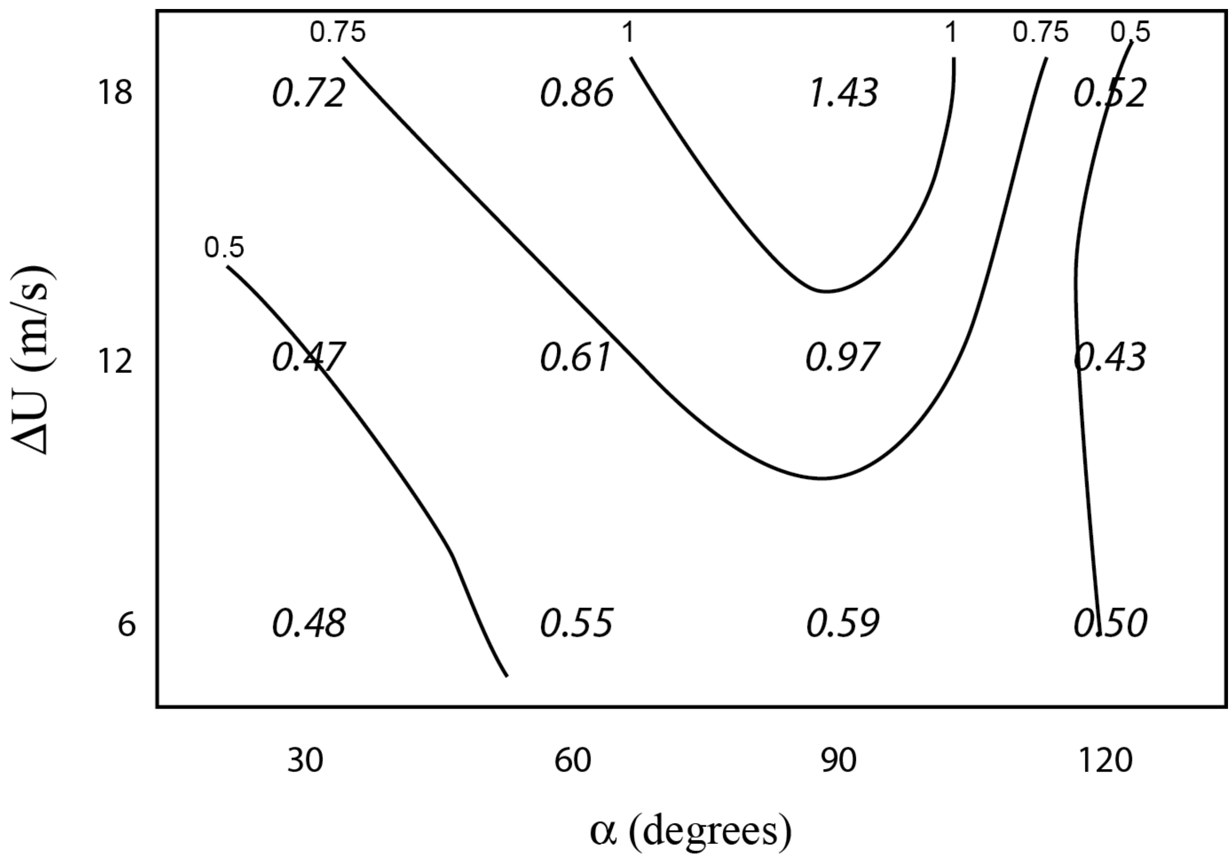


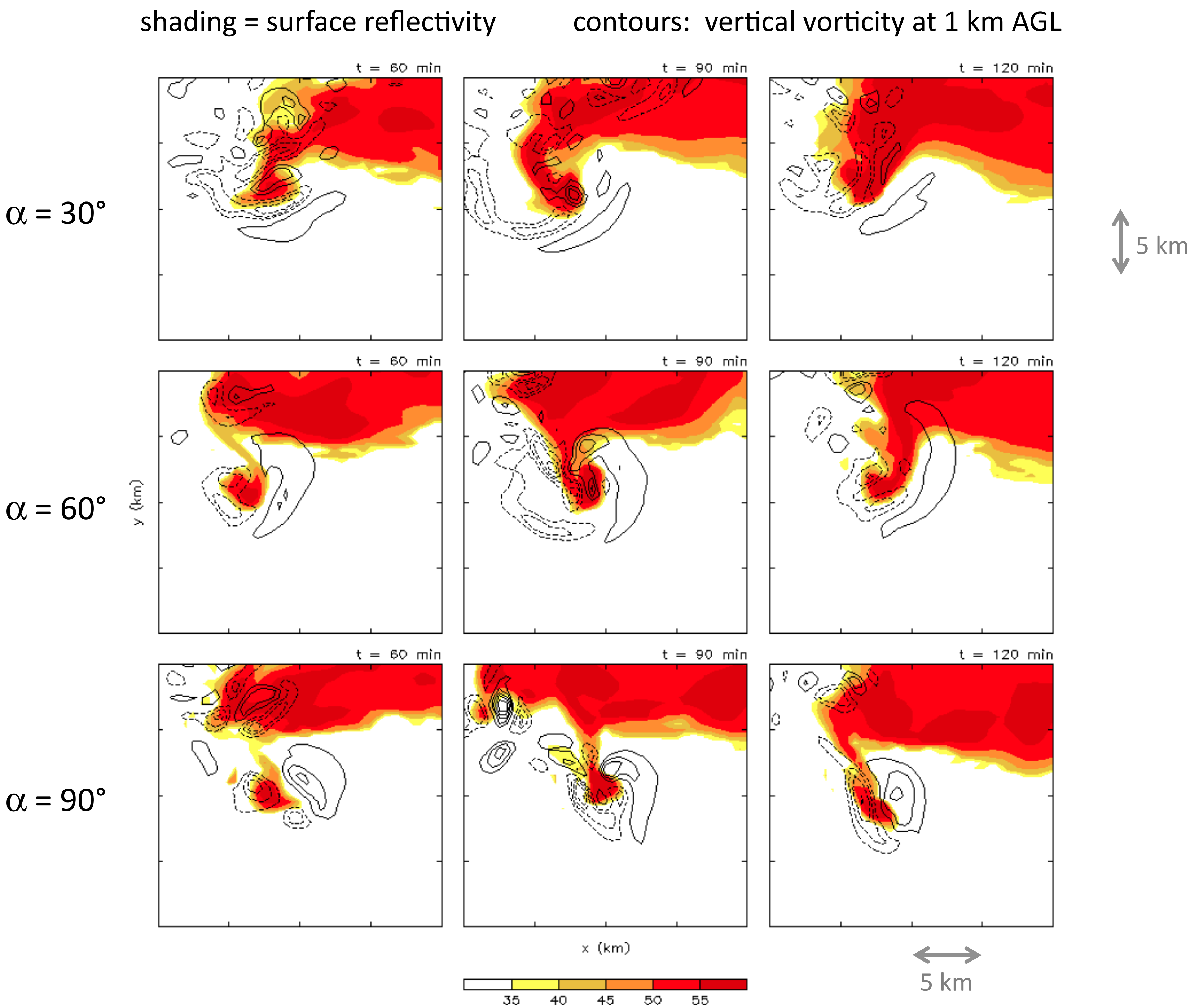
Maximum Circulation (c) at 1 km AGL

$$c = \oint v \bullet dl$$



Maximum Circulation at z = 1 km (60-90 min average)

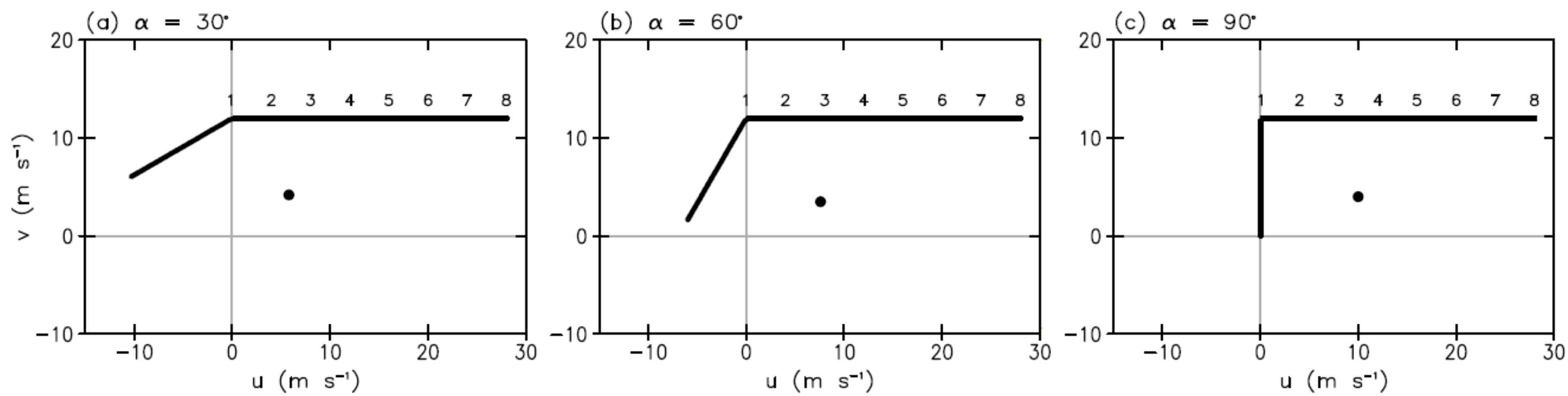




shading = surface reflectivity
contours: vertical vorticity at 1 km AGL
t = 60 min
t = 90 min
t = 120 min
α = 30°
α = 60°
α = 90°
5 km
y (km)
x (km)
35
40
45
50
55
5 km

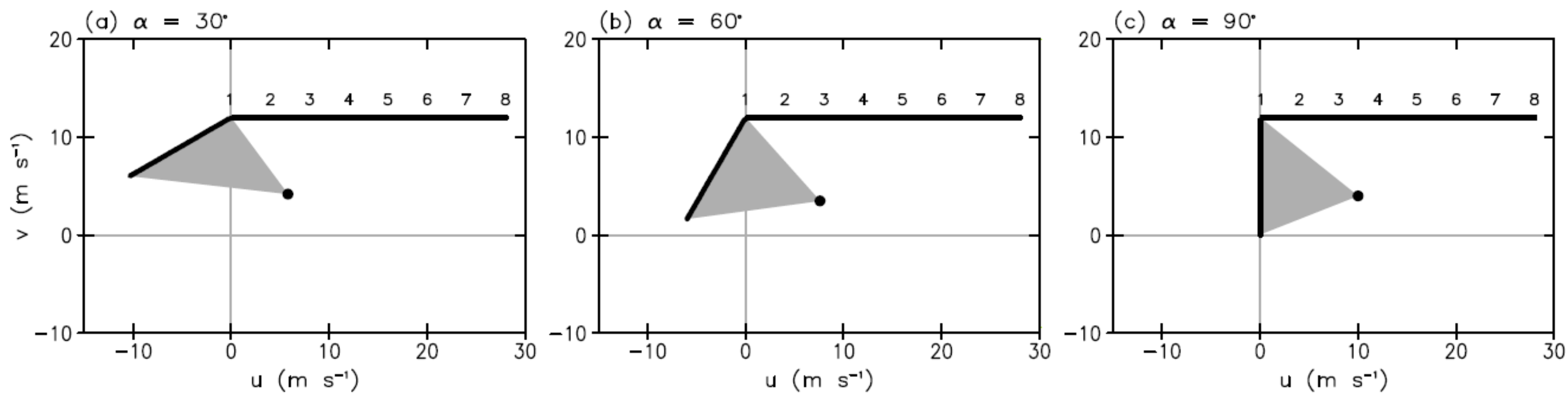
Initial Wind Profiles:

Storm motion from model simulations:



Initial Wind Profiles:

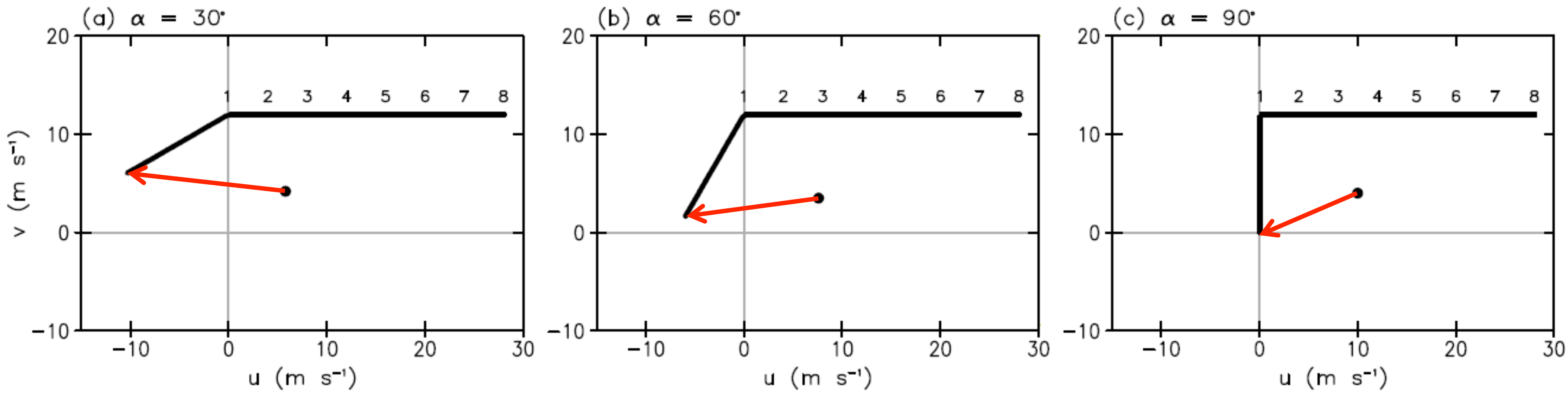
Using storm motion from model simulations:



0-1 km SRH = 112 $m^2 s^{-2}$ | 0-1 km SRH = 126 $m^2 s^{-2}$ | 0-1 km SRH = 116 $m^2 s^{-2}$

0-6 km ΔU = 31 $m s^{-1}$ | 0-6 km ΔU = 28 $m s^{-1}$ | 0-6 km ΔU = 24 $m s^{-1}$

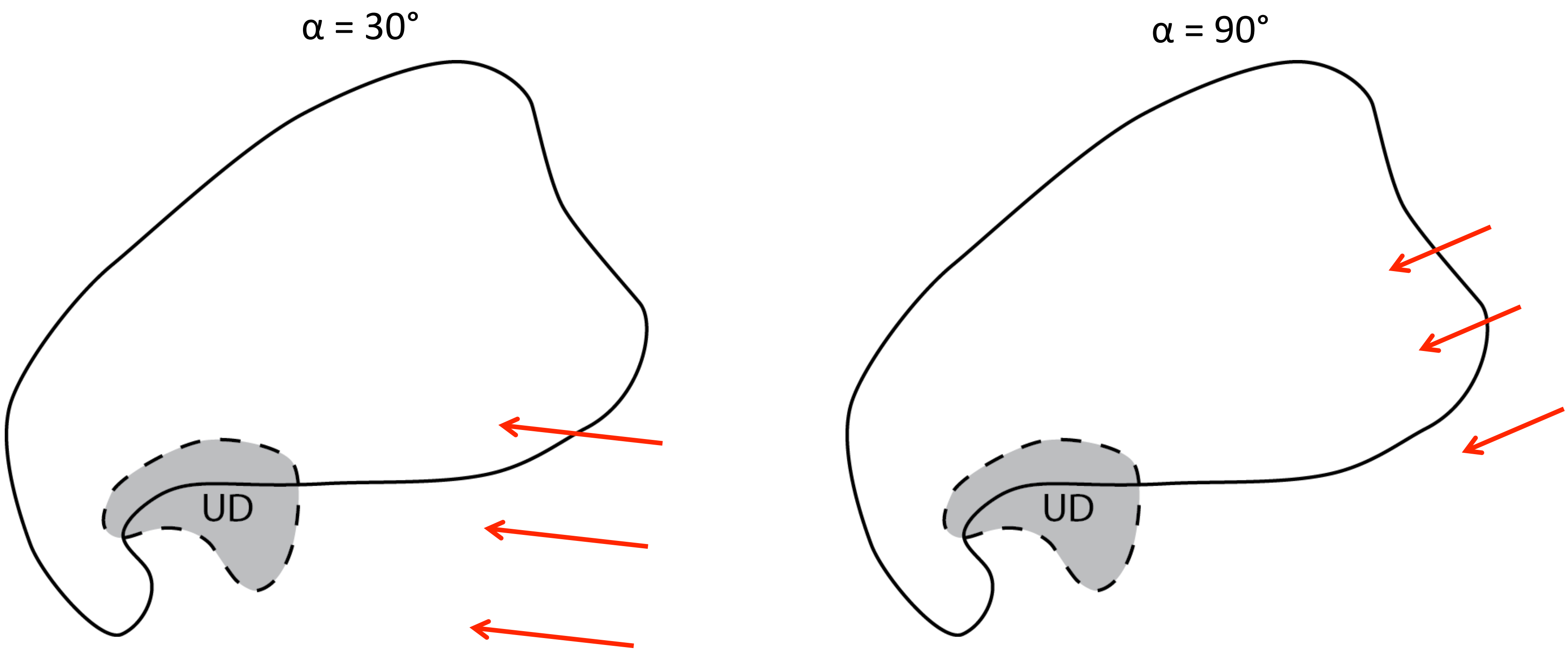
Storm-relative winds near surface:



Magnitude of storm-relative winds at surface:

16 m s^{-1} | 14 m s^{-1} | 11 m s^{-1}

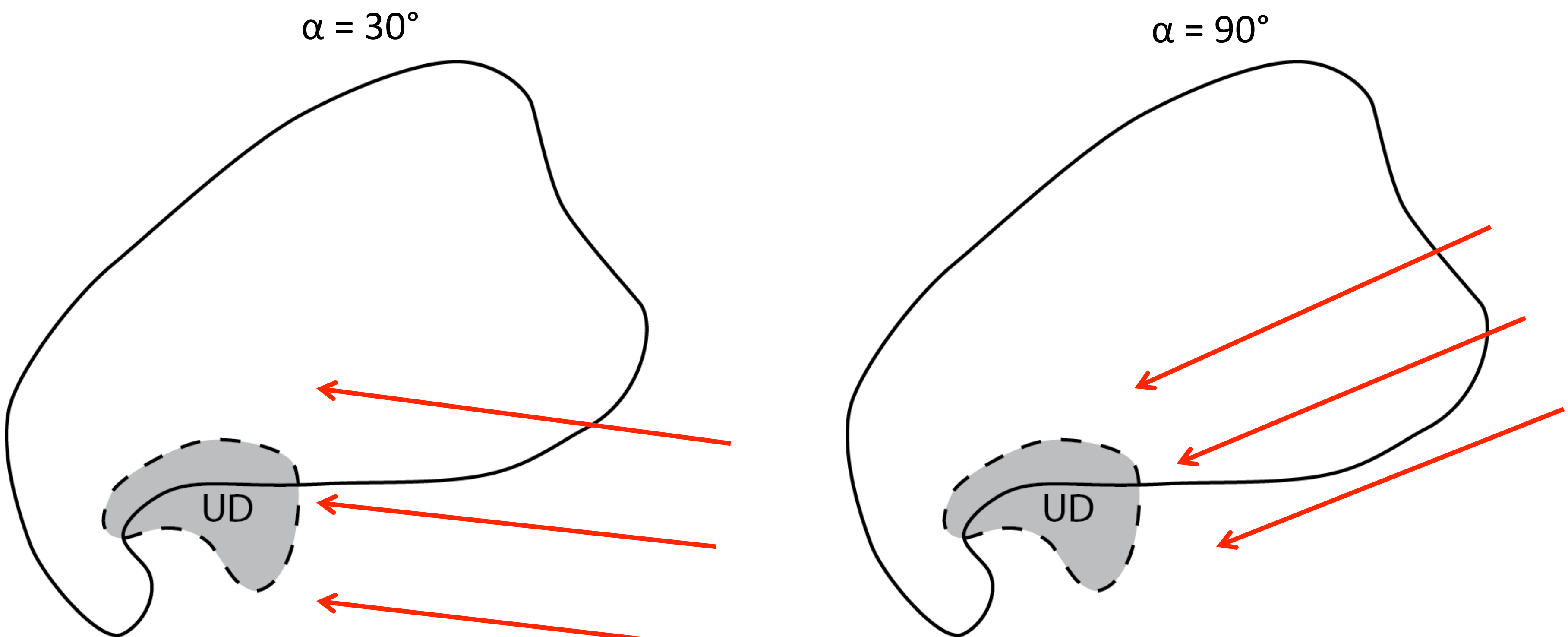
Storm-relative winds near surface:



For the “L-shaped” hodograph:

--> Parcels have more residence time along forward flank

Storm-relative winds near surface:

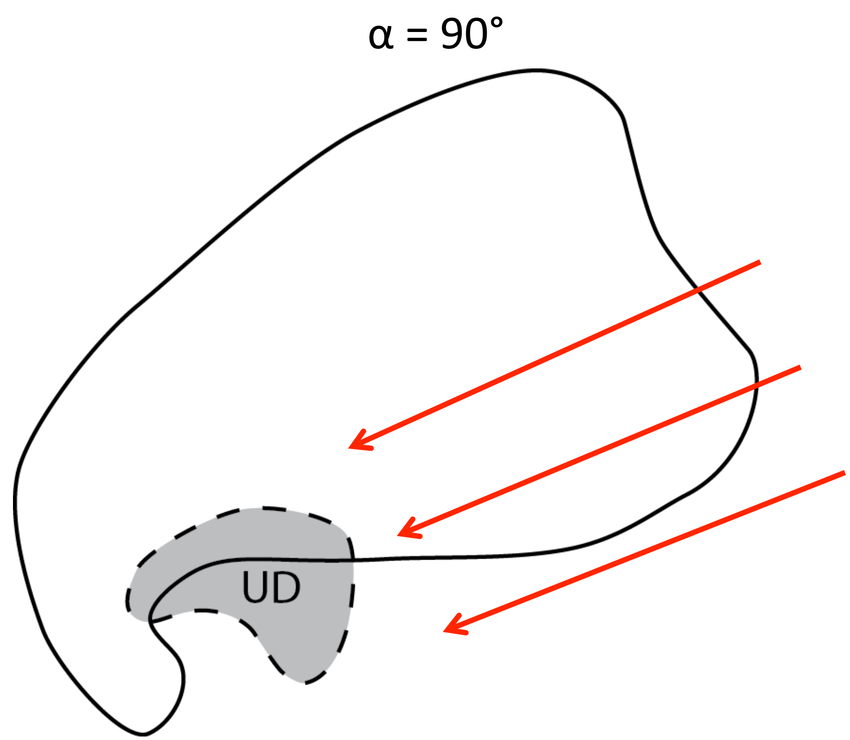


For the “L-shaped” hodograph:

--> Parcels have more residence time along forward flank

--> “traverse through more storm” (K. Kosiba, 4 October 2011)

Storm-relative winds near surface:



From horizontal vorticity equation
(Klemp and Rotunno 1983, JAS)

$$\Delta\omega_s \approx \frac{g}{\theta_0}\frac{\partial\theta}{\partial n}\frac{\Delta s}{v_s}$$

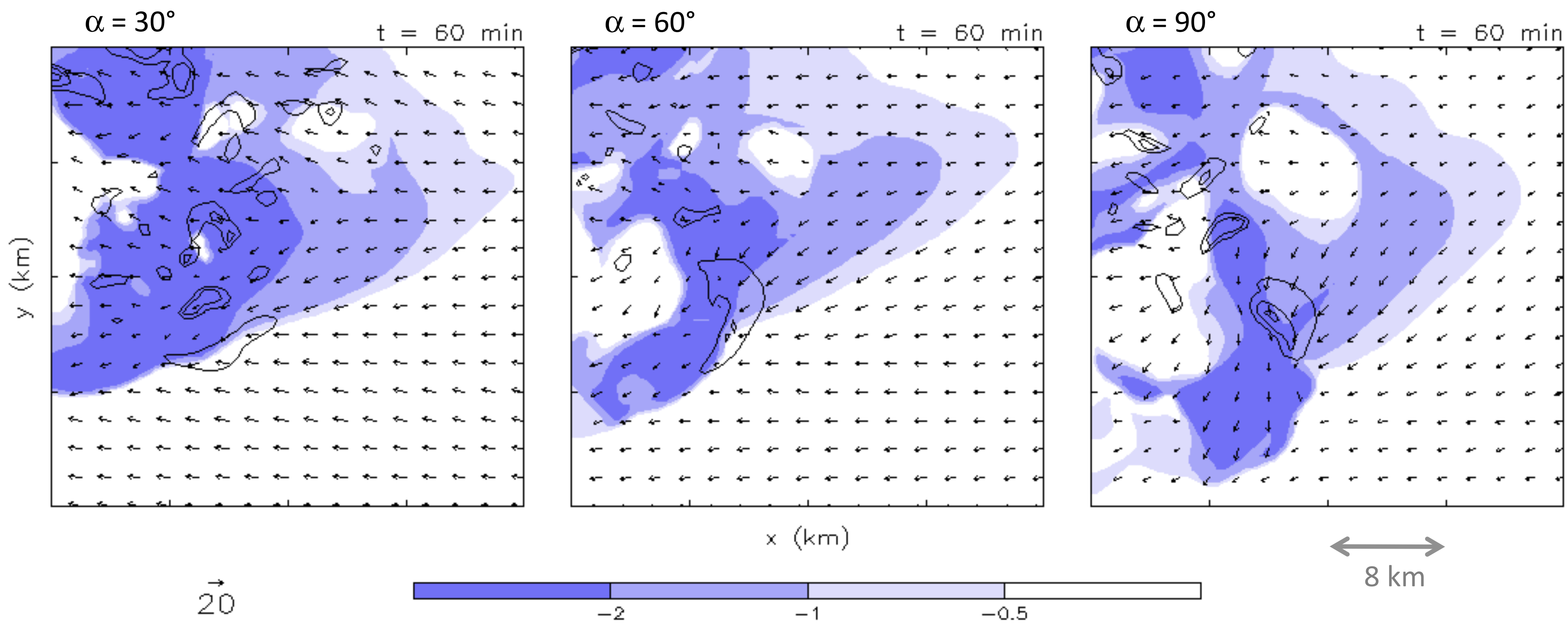
$\partial\theta/\partial n \approx 1$ K per 5 km
$\Delta s \approx 20$ km
$v_s = 10$ m s^{-1}

--> $\Delta\omega_s \approx 0.015$ s^{-1}

Shading: potential temperature perturbation (K) at z = 10 m

Vectors: storm-relative horizontal velocity at z = 10 m

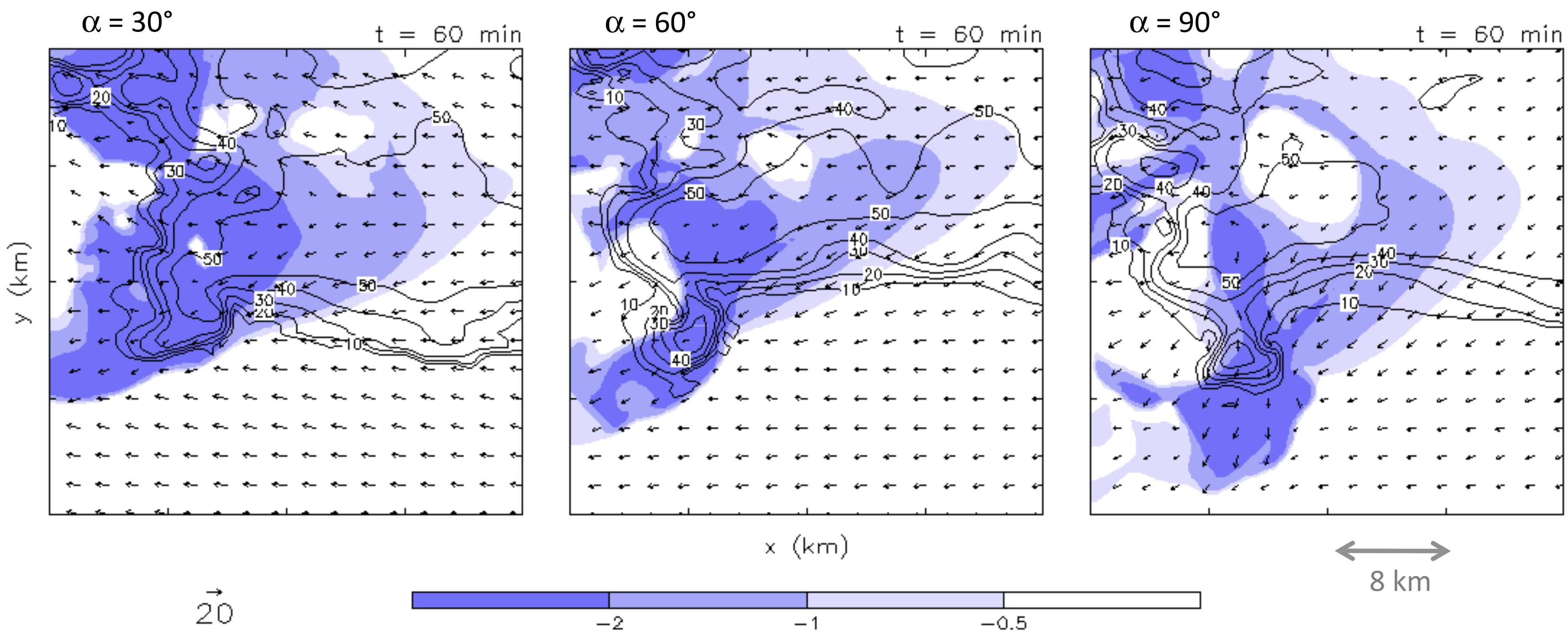
Contours: (positive) vertical vorticity (every 0.005 s^{-1}) at 1 km AGL



Shading: potential temperature perturbation (K) at z = 10 m

Vectors: storm-relative horizontal velocity at z = 10 m

--> Contours: reflectivity (dBZ) at z = 10 m

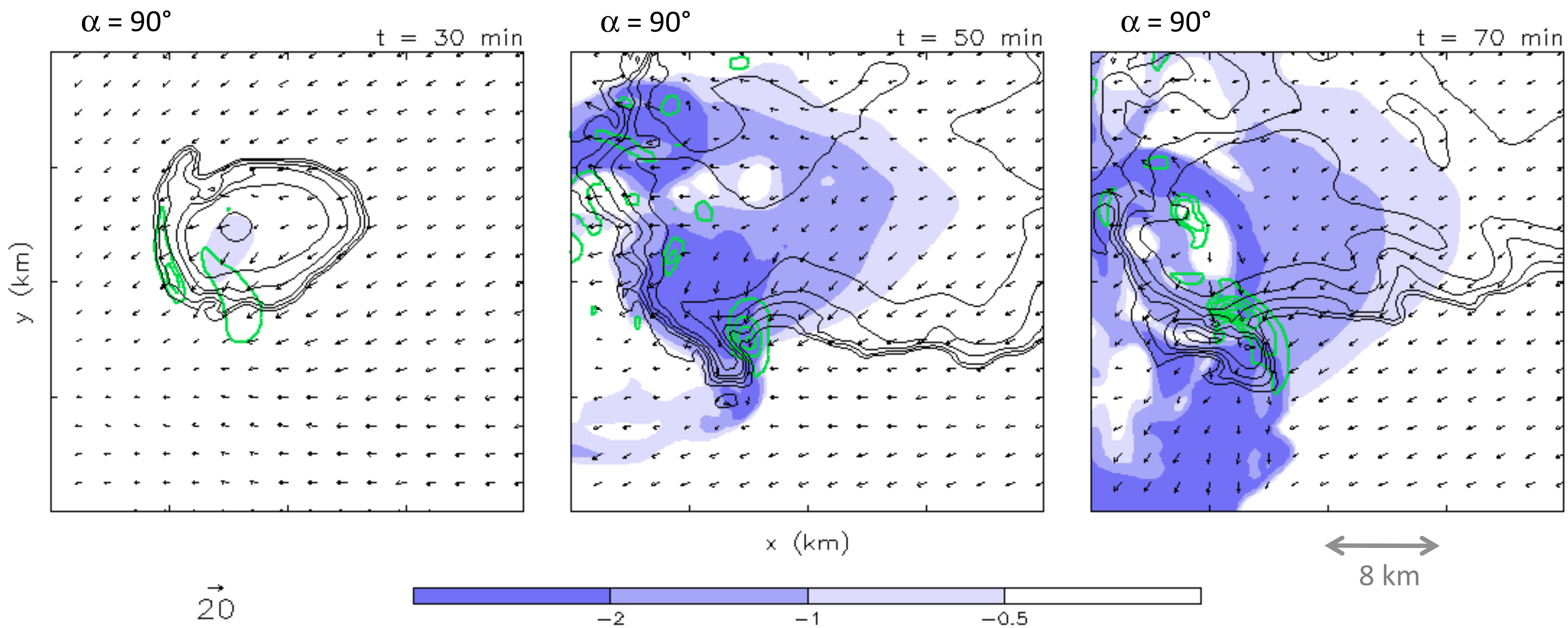


Shading: potential temperature perturbation (K) at z = 10 m

Vectors: storm-relative horizontal velocity at z = 10 m

Black Contours: reflectivity (dBZ) at z = 10 m

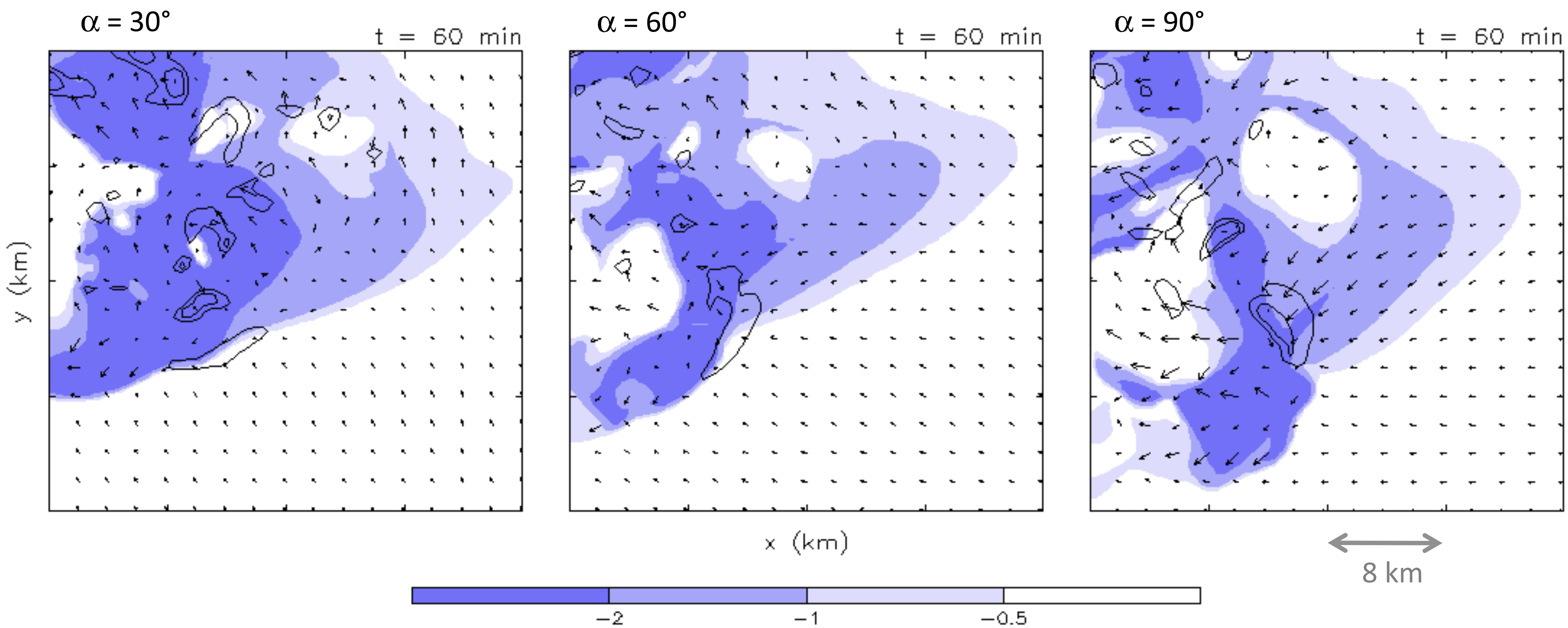
--> Green Contours: (positive) vertical vorticity (every 0.005 s^{-1}) at z = 1 km



Shading: potential temperature perturbation (K) at z = 10 m

--> Vectors: horizontal vorticity at z = 100 m

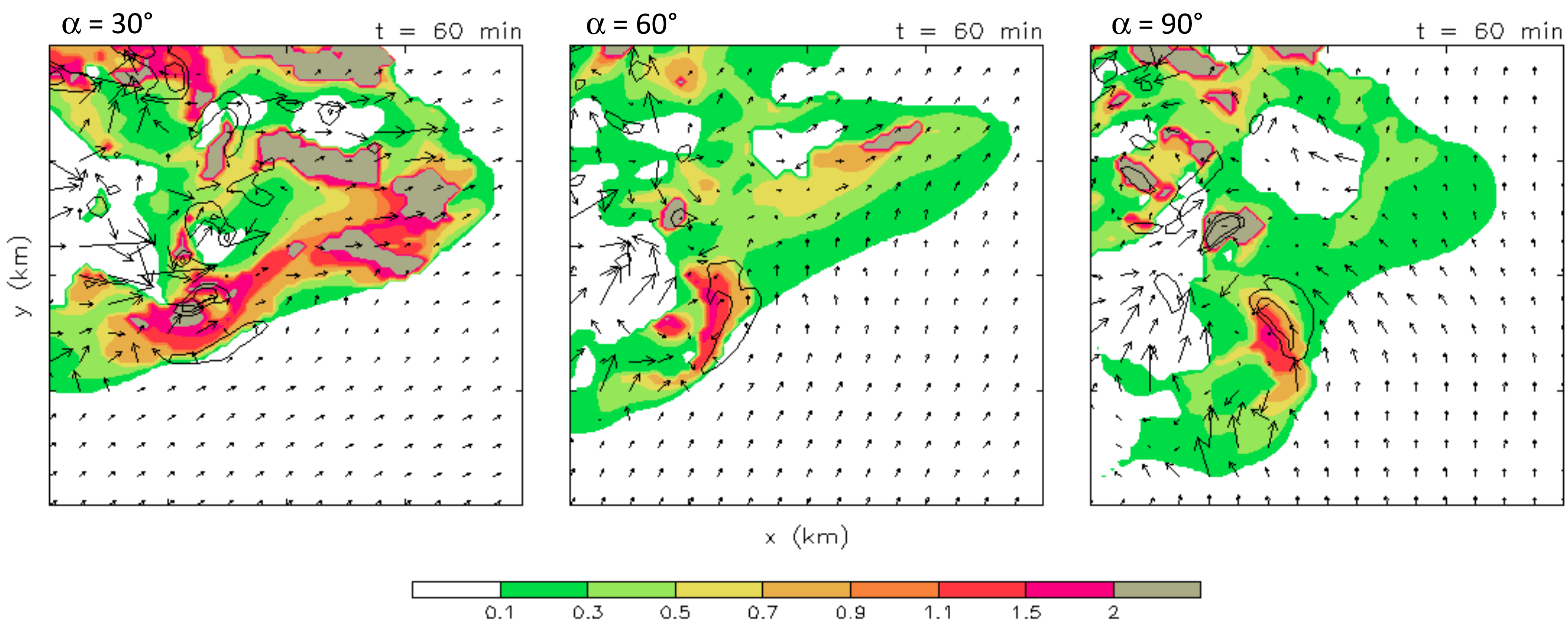
--> Contours: (positive) vertical vorticity (every 0.005 s^{-1}) at 1 km AGL



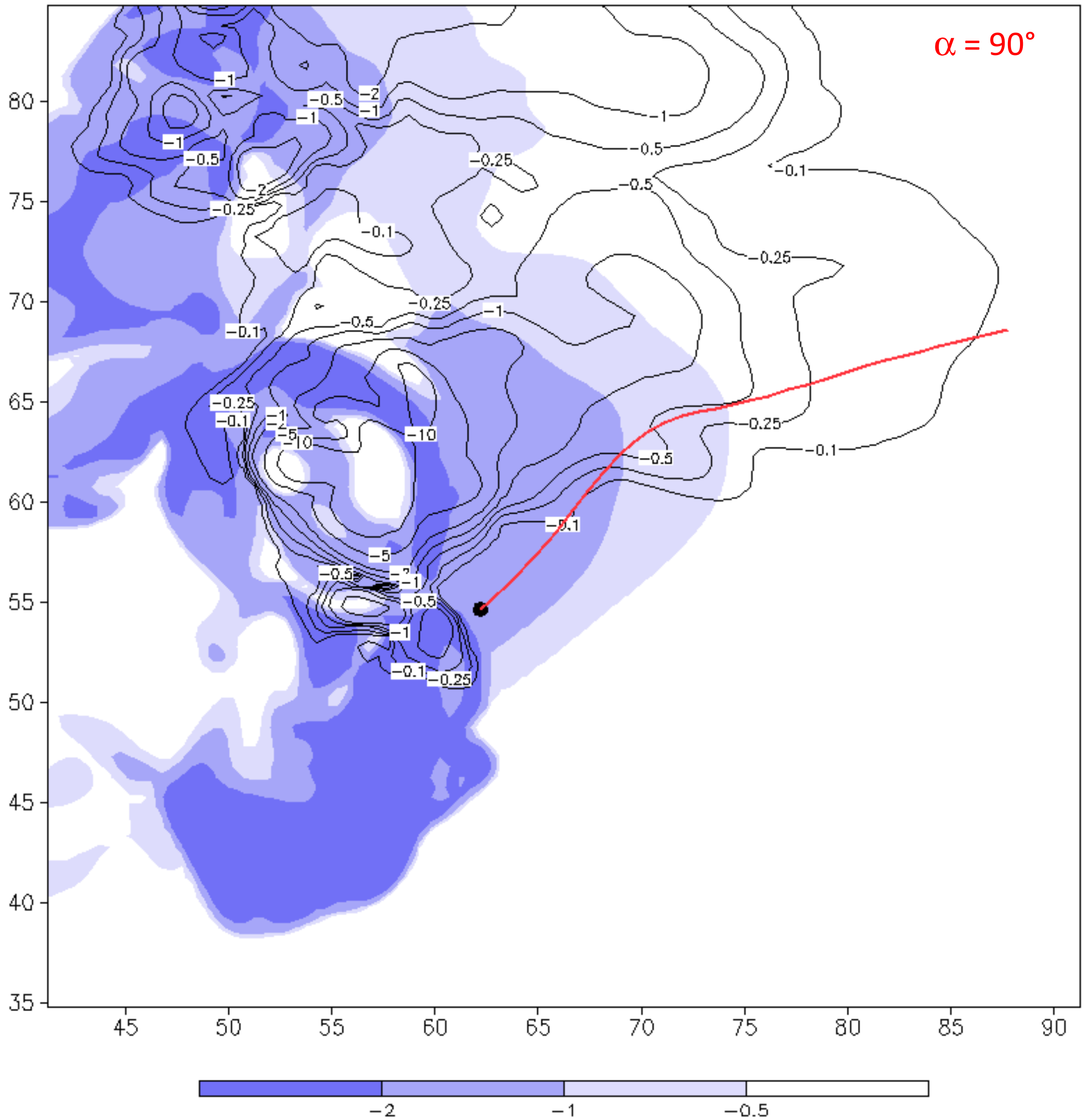
--> Shading: cold-pool depth (h) (km)

--> Vectors: 0-1km shear vectors

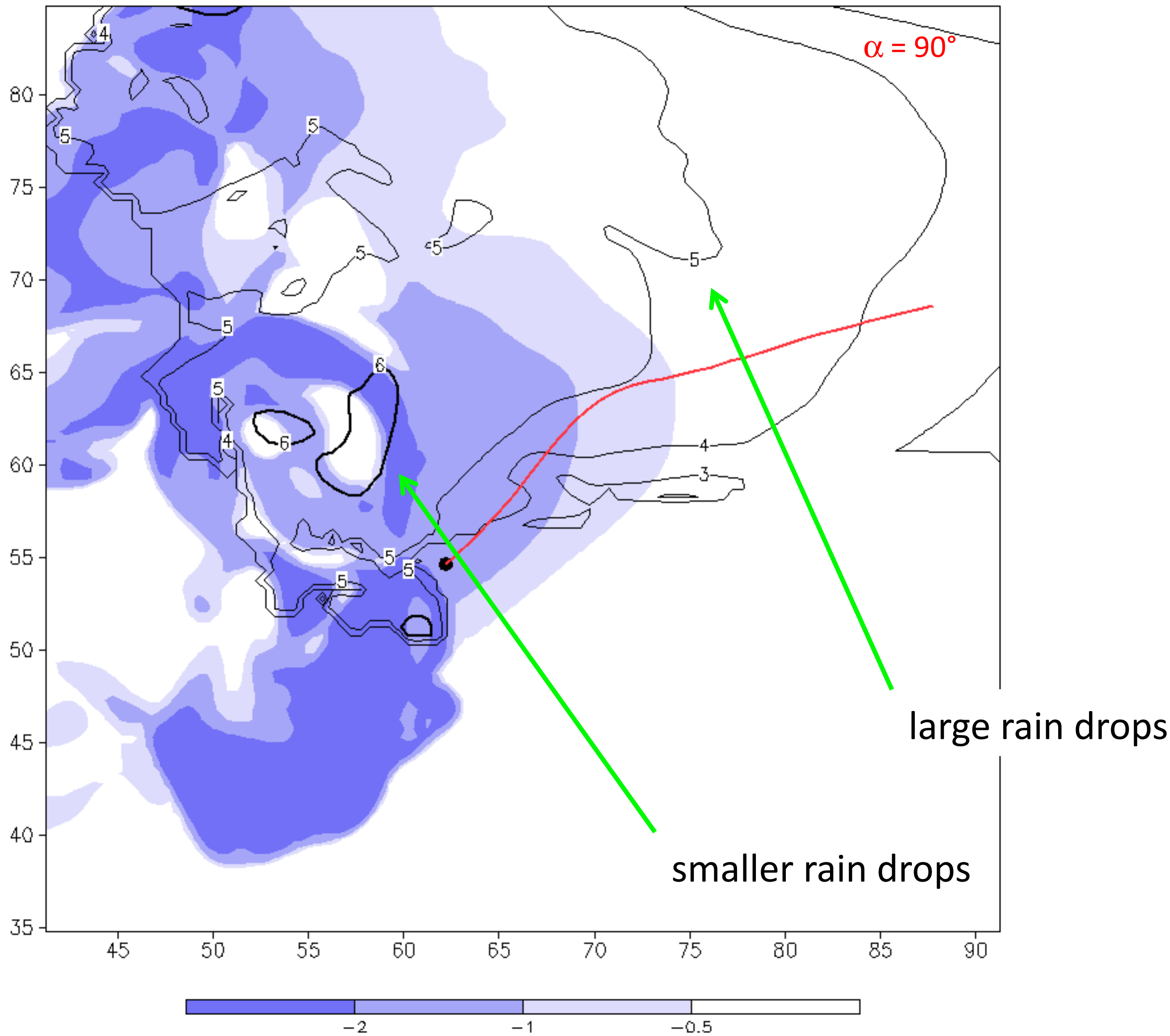
Contours: (positive) vertical vorticity (every 0.005 s^{-1}) at 1 km AGL



Contours: evaporation rate (g kg^{-1} h^{-1})



Contours: $\log_{10}(N_{0r})$ (intercept parameter in microphysics scheme)



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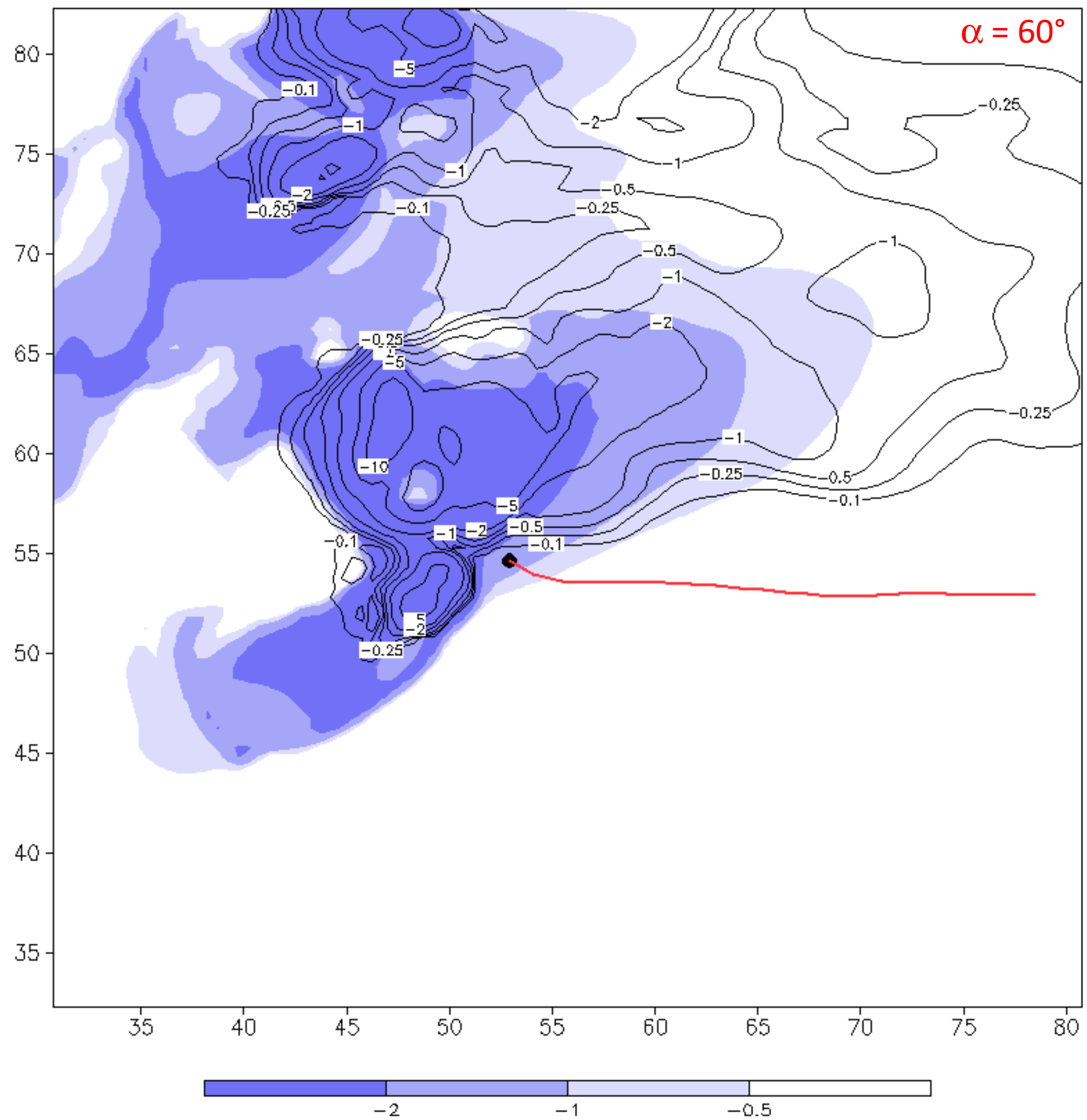

Summary

- Magnitude of low-level shear vector and angle of low-level shear vector (relative to mid-level shear vector) affects low-level rotation in simulated supercells
  - roughly 90° angle produces strongest low-level circulation

- Reason (preliminary):

  Low-level storm-relative flow is weaker

  --> longer residence time in forward-flank region

  --> greater net baroclinic generation of vorticity

- Other possible effects:
  - Shear/updraft and shear/downdraft interaction
  - Cold-pool/shear interaction