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is sponsored by the National Science Foundation (NSF)

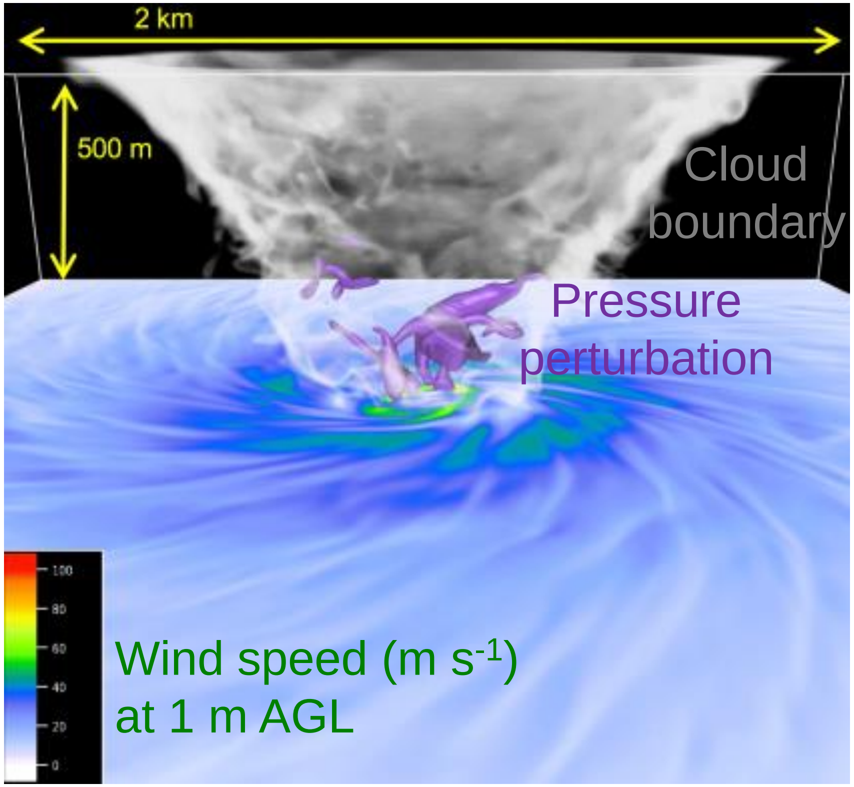
The stratiform region of squall lines and its representation in convection-allowing numerical models

George Bryan
National Center for Atmospheric Research (NCAR)

NOAA STI Modeling Seminar
14 June 2017

Some of my recent work

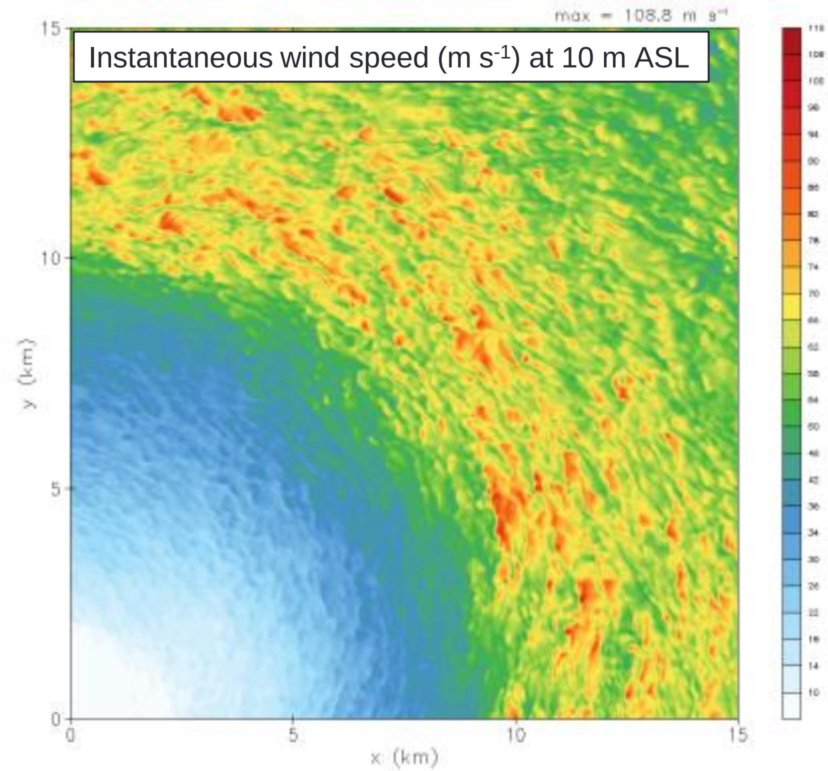
Tornado simulation



Δx = 5 m

Bryan et al, 2017, MWR
Dahl et al, 2017, MWR

Category 5 hurricane simulation



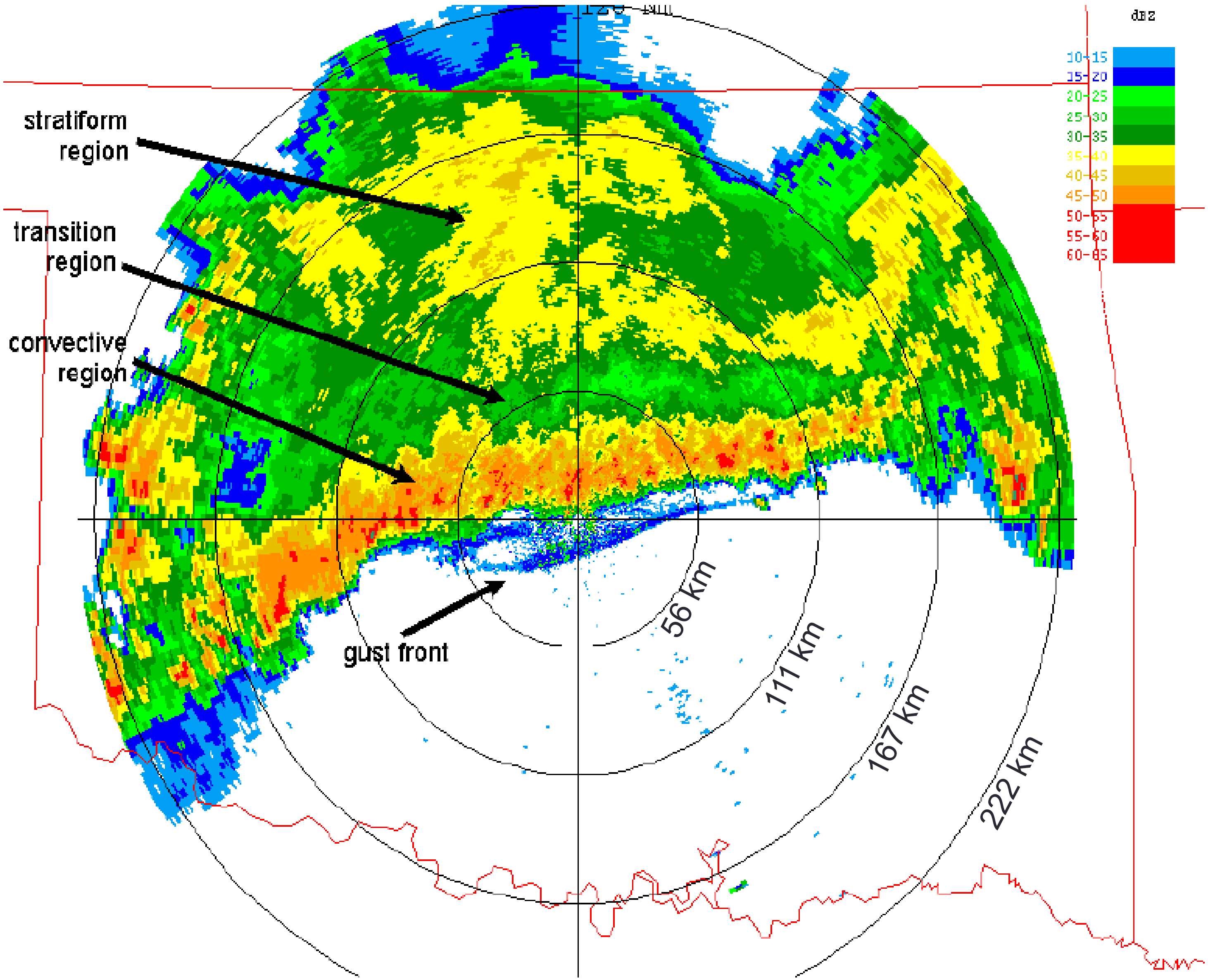
Δx = 32 m

Bryan et al, 2017, BLM
Worsnop et al, 2017, GRL

For more info: http://www2.mmm.ucar.edu/people/bryan/

Squall line (aka, MCS) with

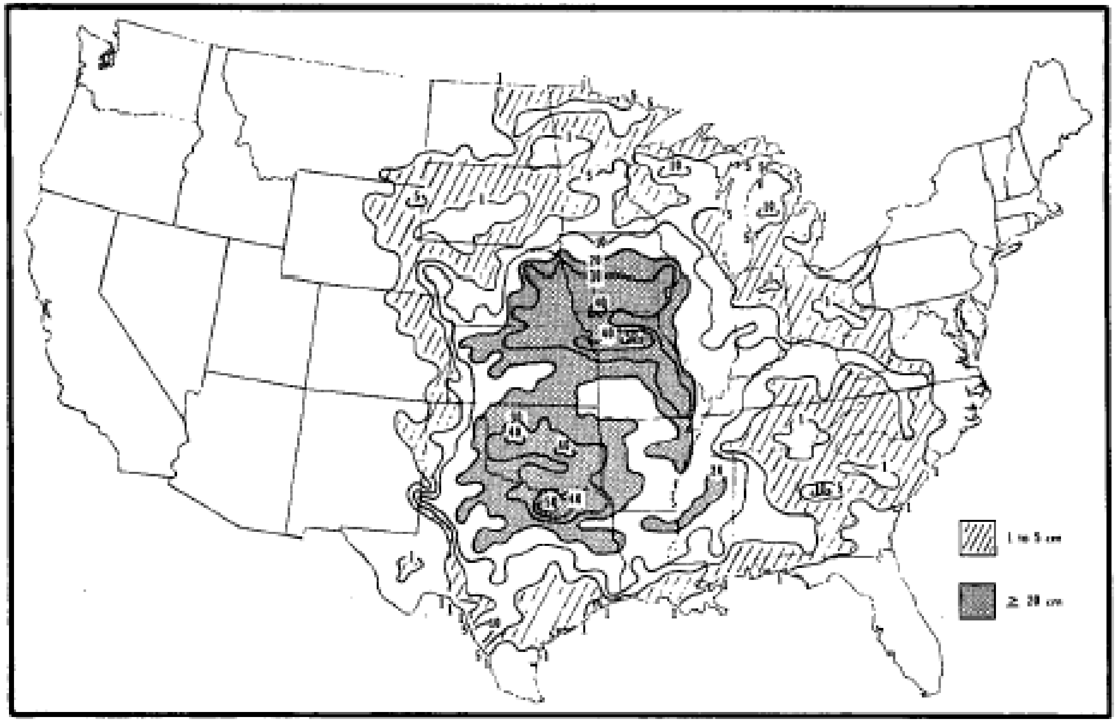
Leading-Line / Trailing-Stratiform structure



Bryan (2002)

Effects of MCSs

accumulated precipitation (cm) from 60 MCSs in 1982



dark shading:
≥ 20 cm

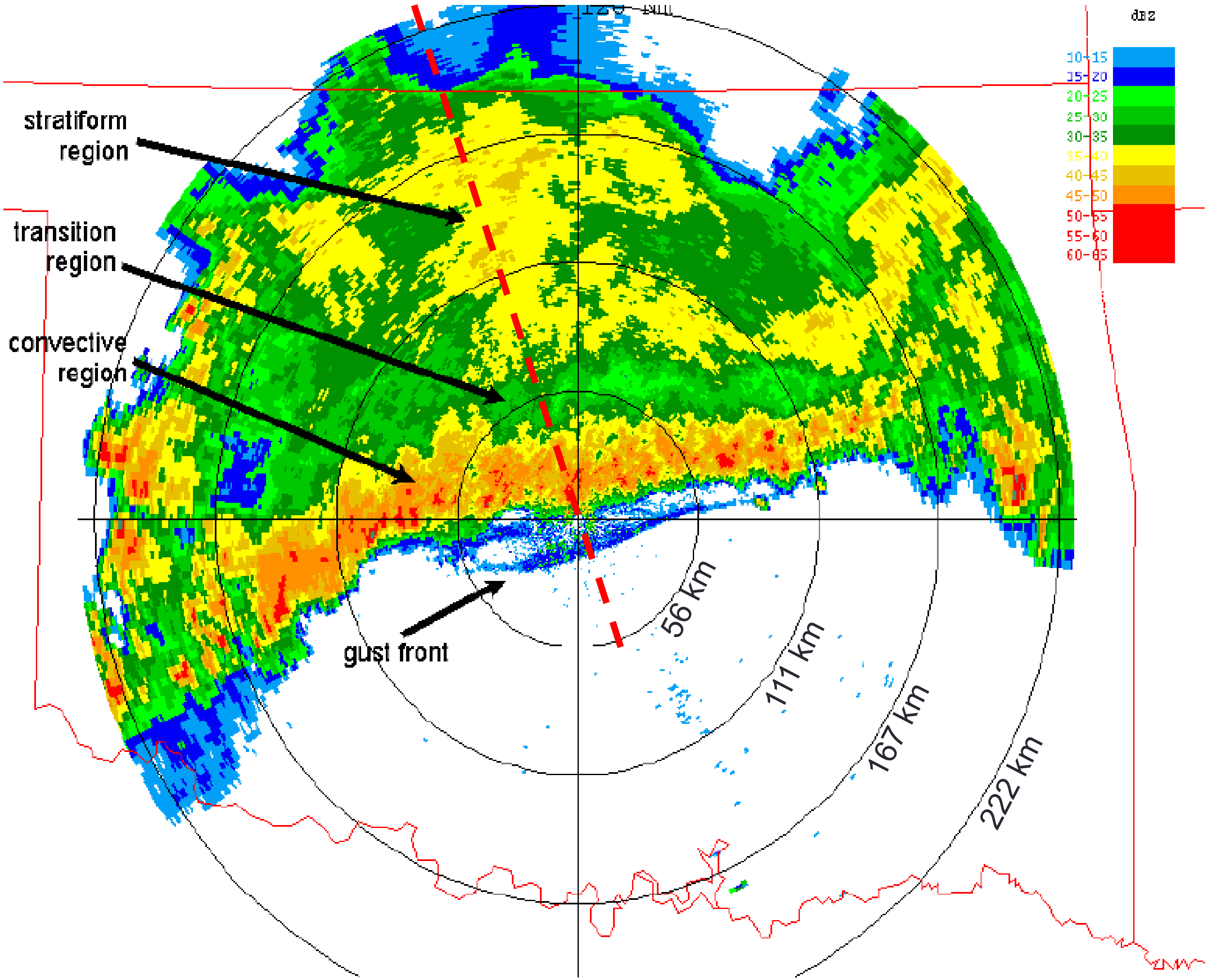
Fritsch et al. (1986)

- Fritsch et al. (1986): MCSs account for 30-70% of warm-season precipitation in the central USA

- Carbone and Tuttle (2008): about 60% of warm-season precipitation

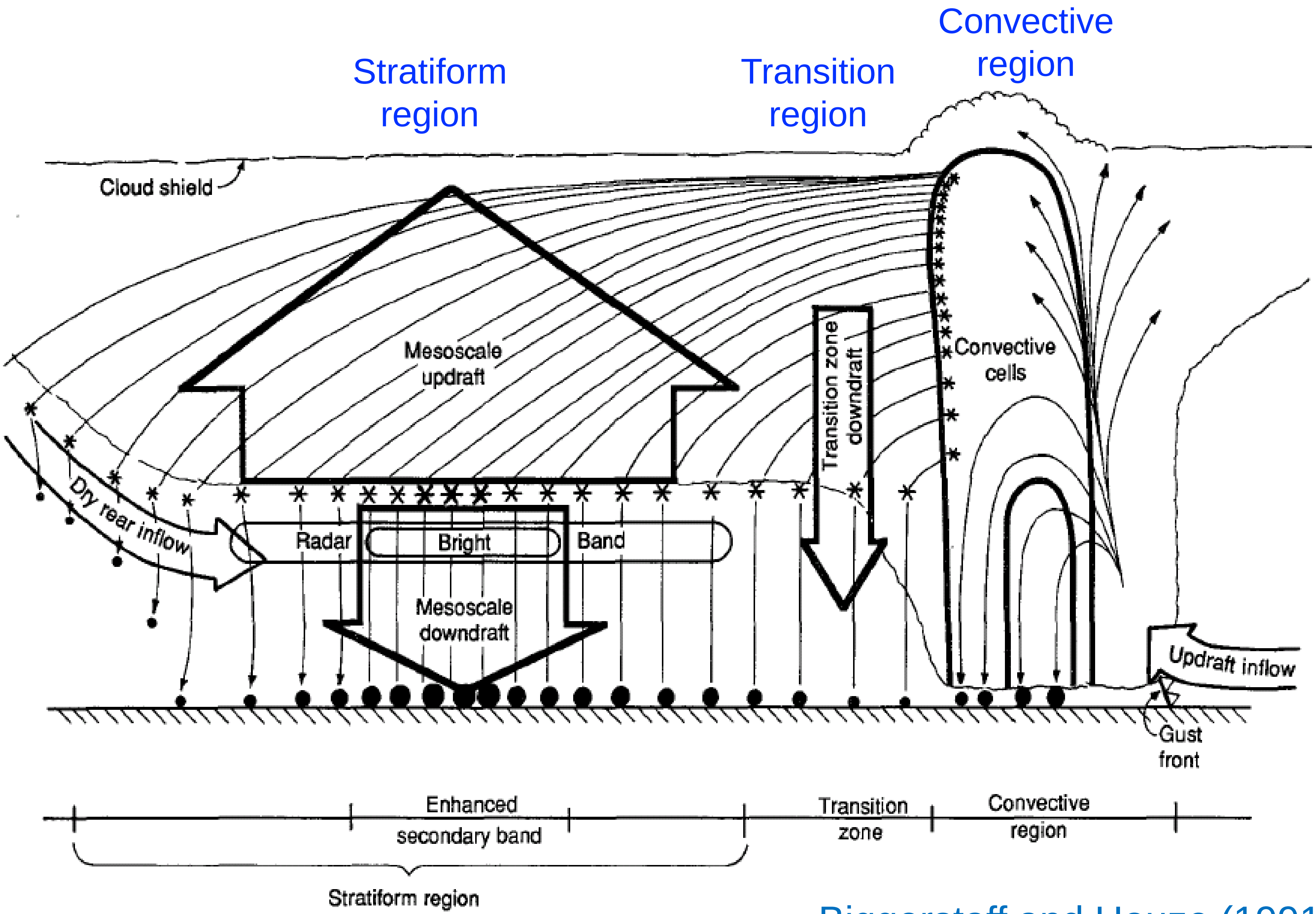
Squall line (aka, MCS) with

Leading-Line / Trailing-Stratiform structure



Bryan (2002)

Schematic: microphysical perspective

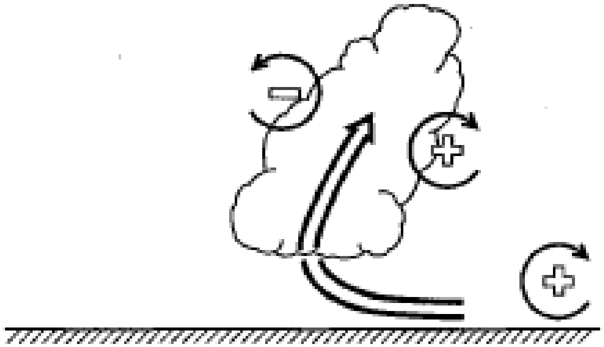


Biggerstaff and Houze (1991)

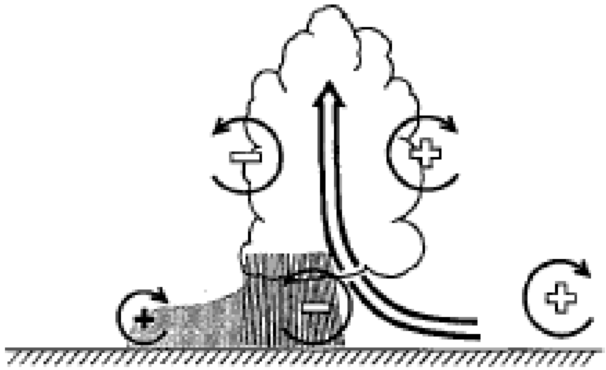
Schematic: thermodynamic perspective

Environmental shear vector

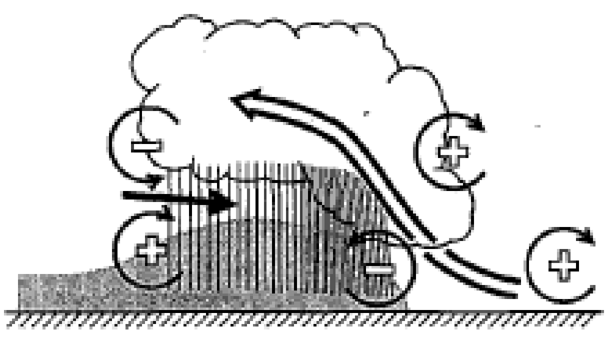
No cold pool:



Weak cold pool:



Strong cold pool:

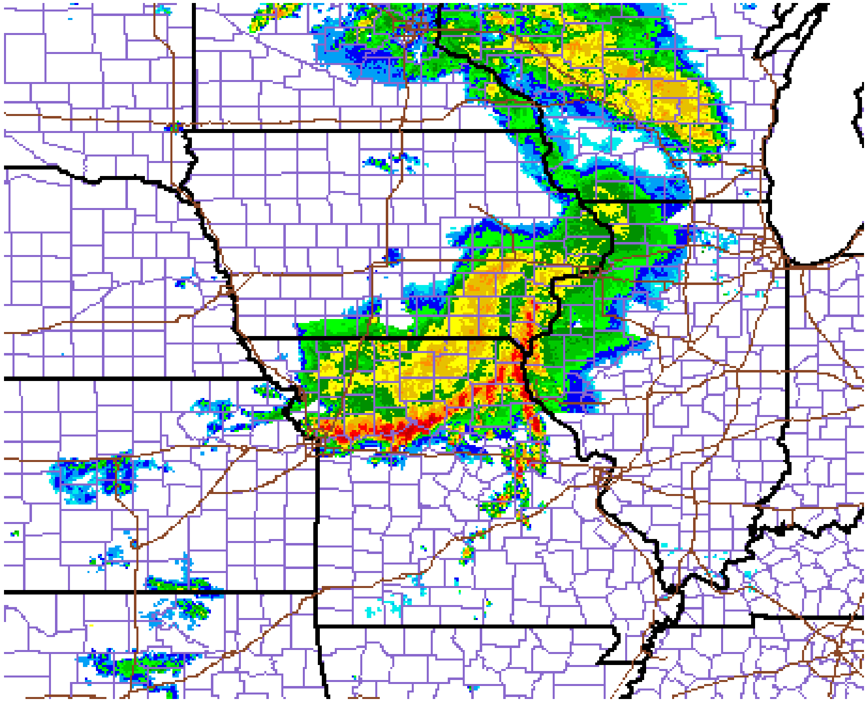


Weisman (1992)

Bow echo / squall line during BAMEX: 10 June 2003

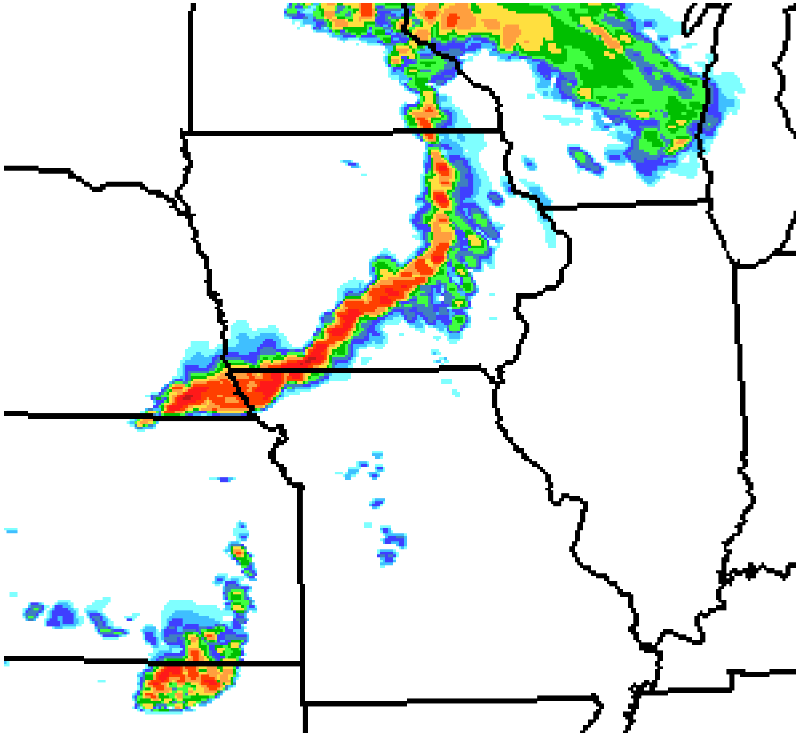
Observed radar image

<u>09 UTC</u>



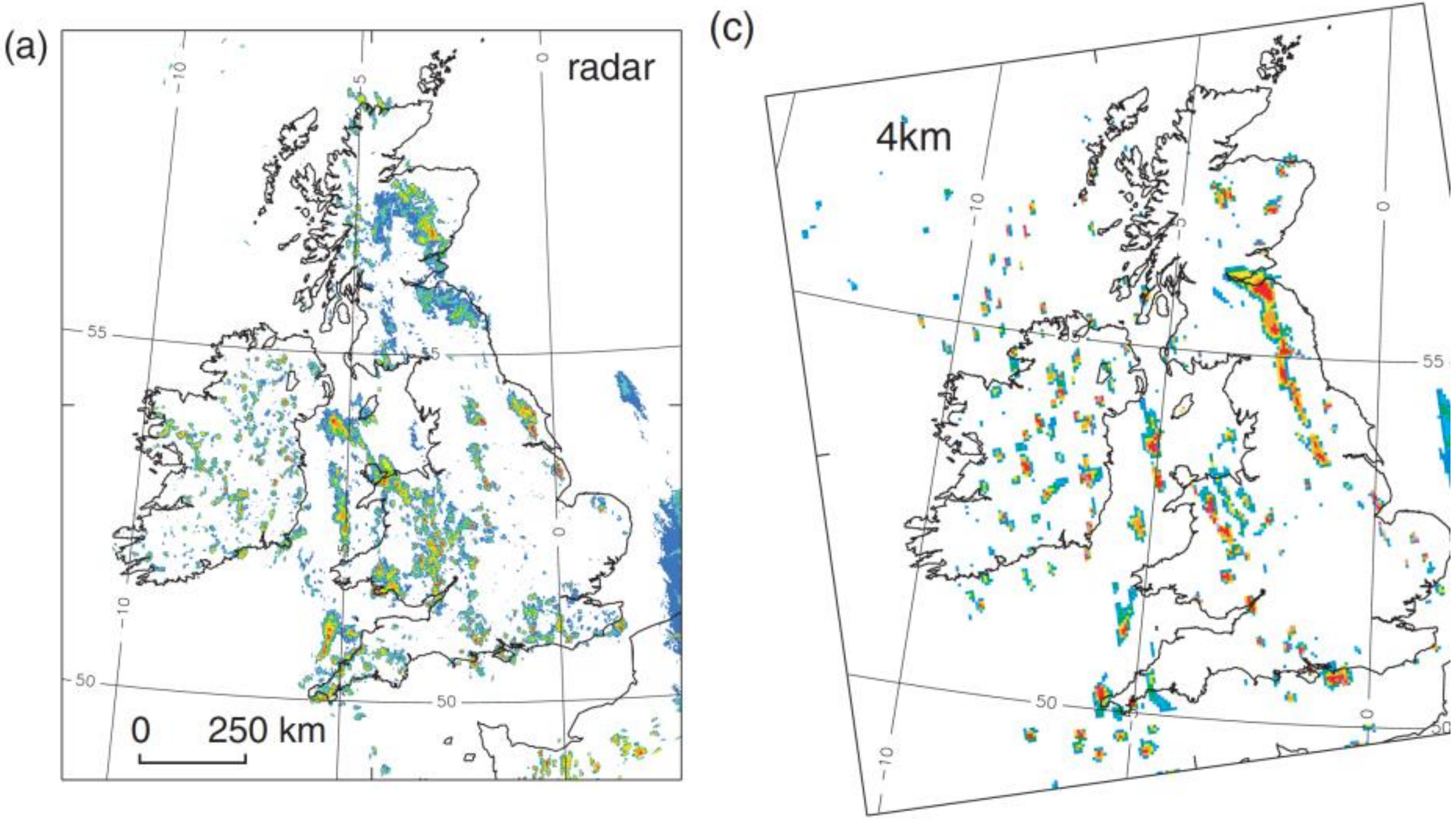
WRF-ARW forecast (Δx = 4 km)

9 h valid <u>09 UTC</u>



from M. Weisman

UK Met Office model, 8 July 2014



Clark et al (2016, Meteor. Appl.)

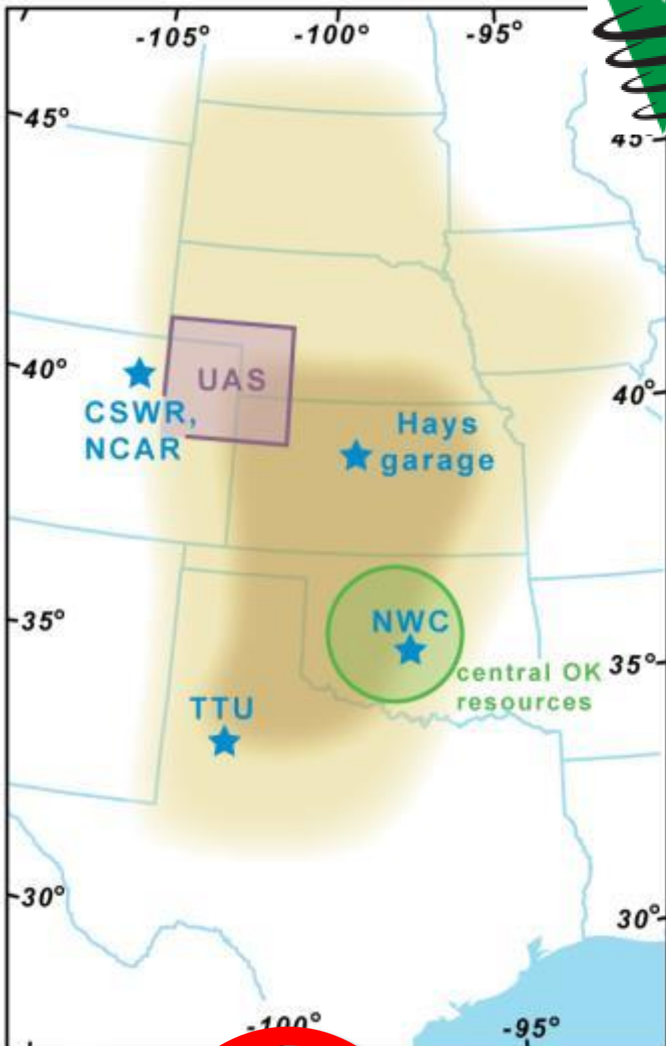
Outline

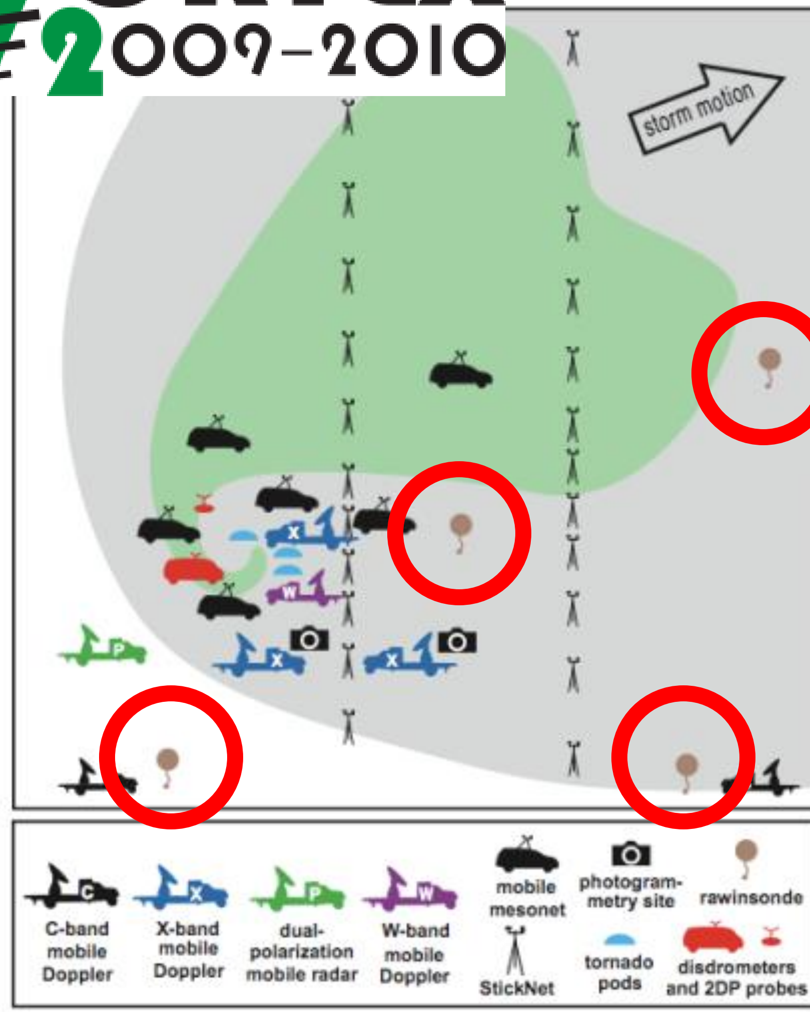
- Goal:
  - Determine how/why a trailing-stratiform region forms
  - (using obs. & simulations)

- Observations:
  - VORTEX2 (Wurman et al. 2012, BAMS)
  - Squall line case: Bryan and Parker (2010, MWR)

- Numerical modeling:
  - Following Bryan and Morrison (2012, MWR): Δx = 4 km, 1 km, and 250 m
  - Compare simulations with/without trailing-stratiform region
  - New diagnostics (e.g., parcel trajectories)

VORTEX 2 2009–2010





storm-scale radars (C-band)


SR1


SR2

mesocyclone-scale radars (X-band, two dual-pol)


DOW6


DOW7


UMASS XPOL

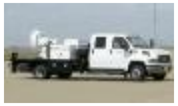

NOAA XP

tornado-scale radars (W-, Ka-, X-band)


RapidScan DOW


UMASS W-band


CIRPAS MWR-05XP (phased array)


TTU Ka-band

in situ tornado probes (12)

rawinsondes (4)

StickNet (24)

mobile mesonet (8-10)

laser disdrometers and video particle probes

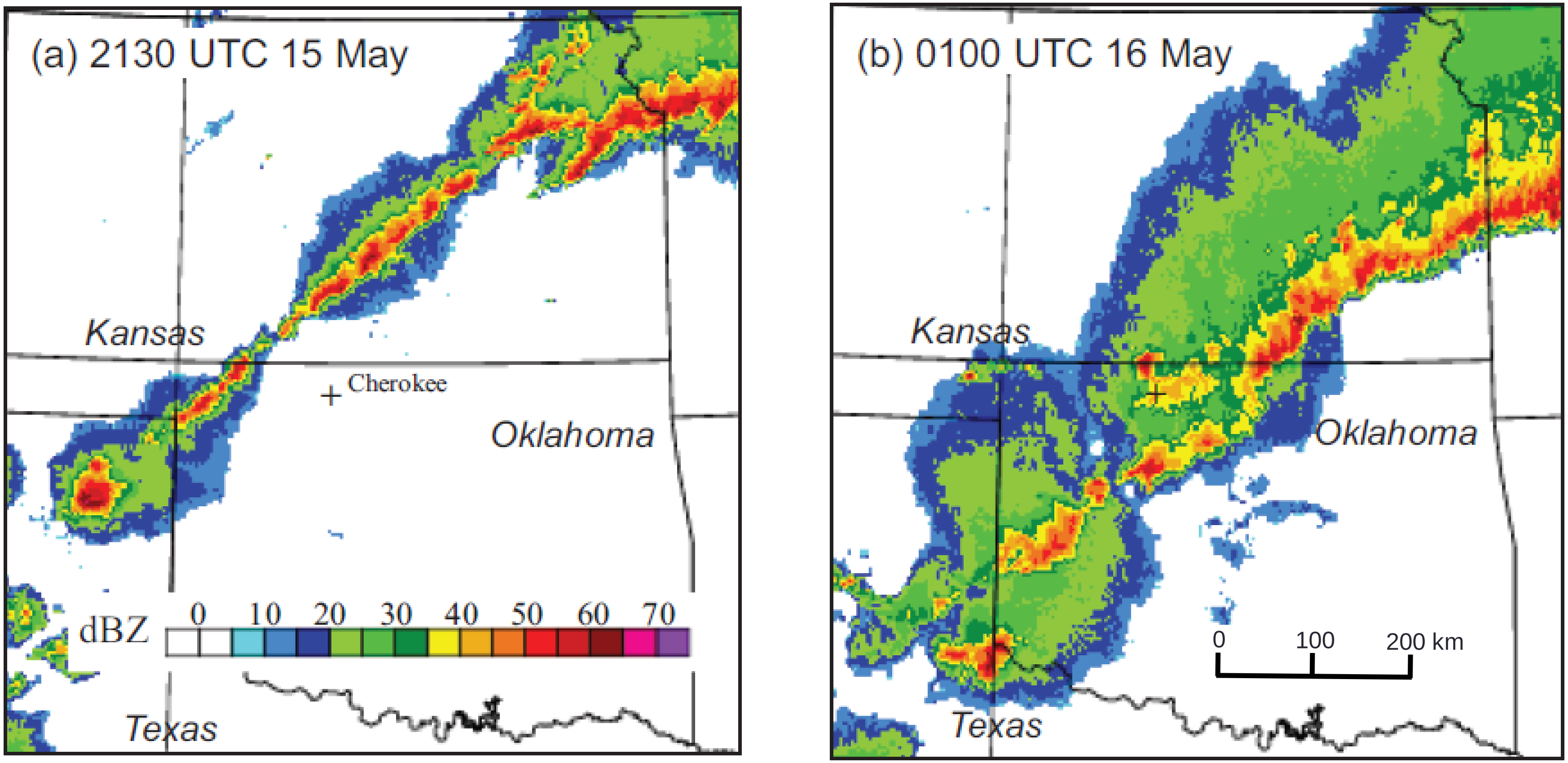
UAS

coordination vehicle

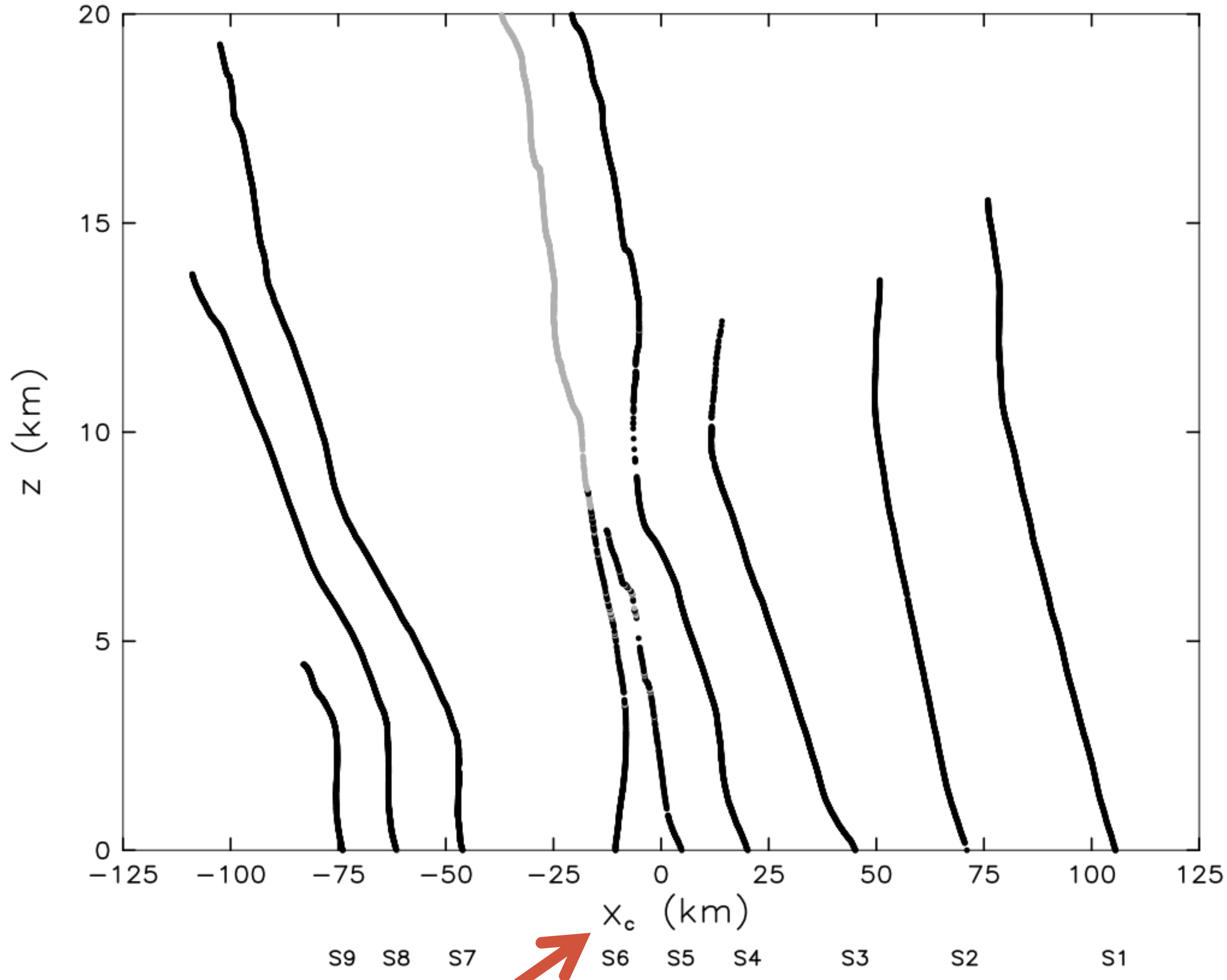
V2 Operations Center (VOC) in Norman, OK

15 May 2009 Squall Line during VORTEX2

at beginning of data collection: at end of data collection:

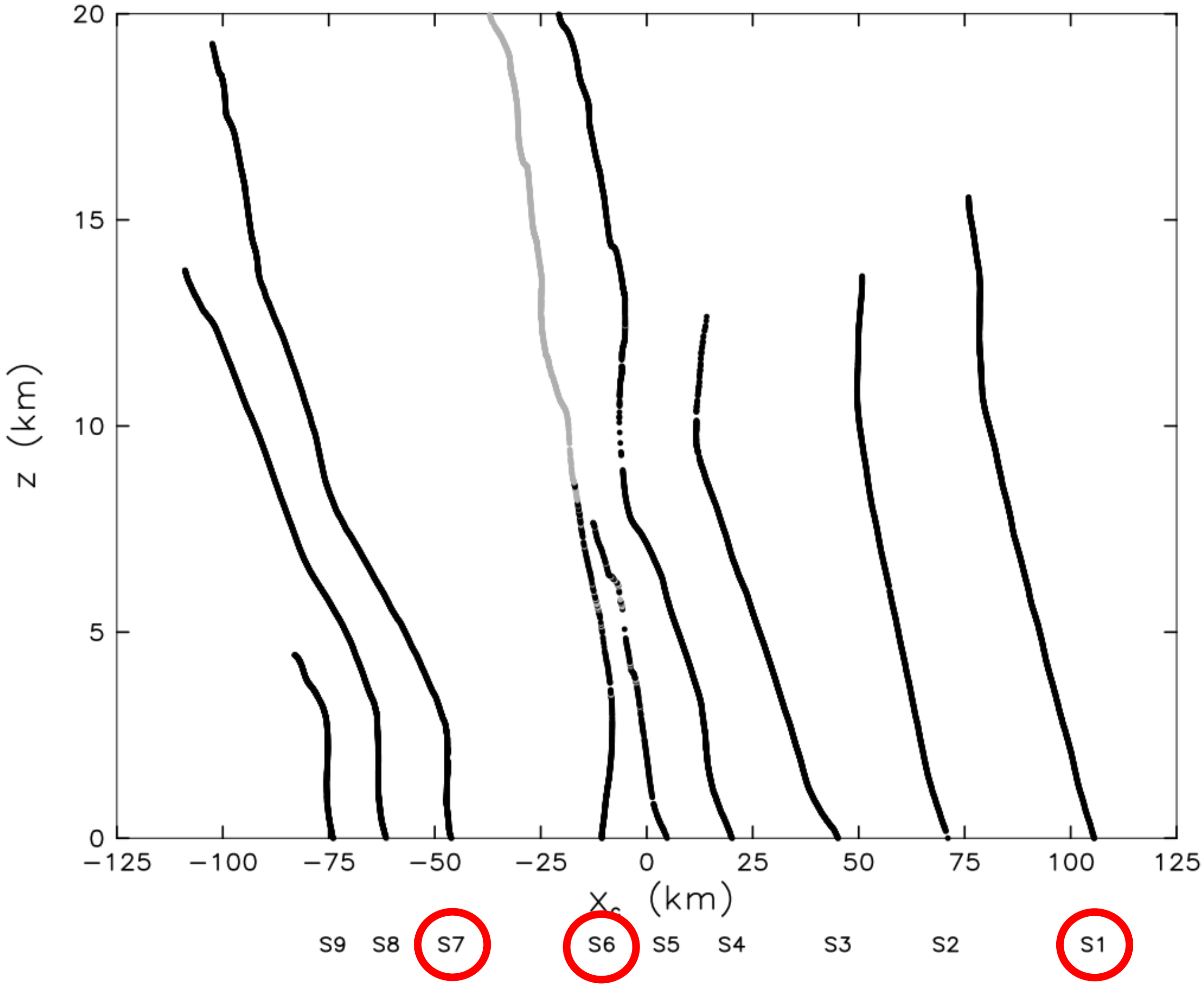


System-relative location of all sounding data

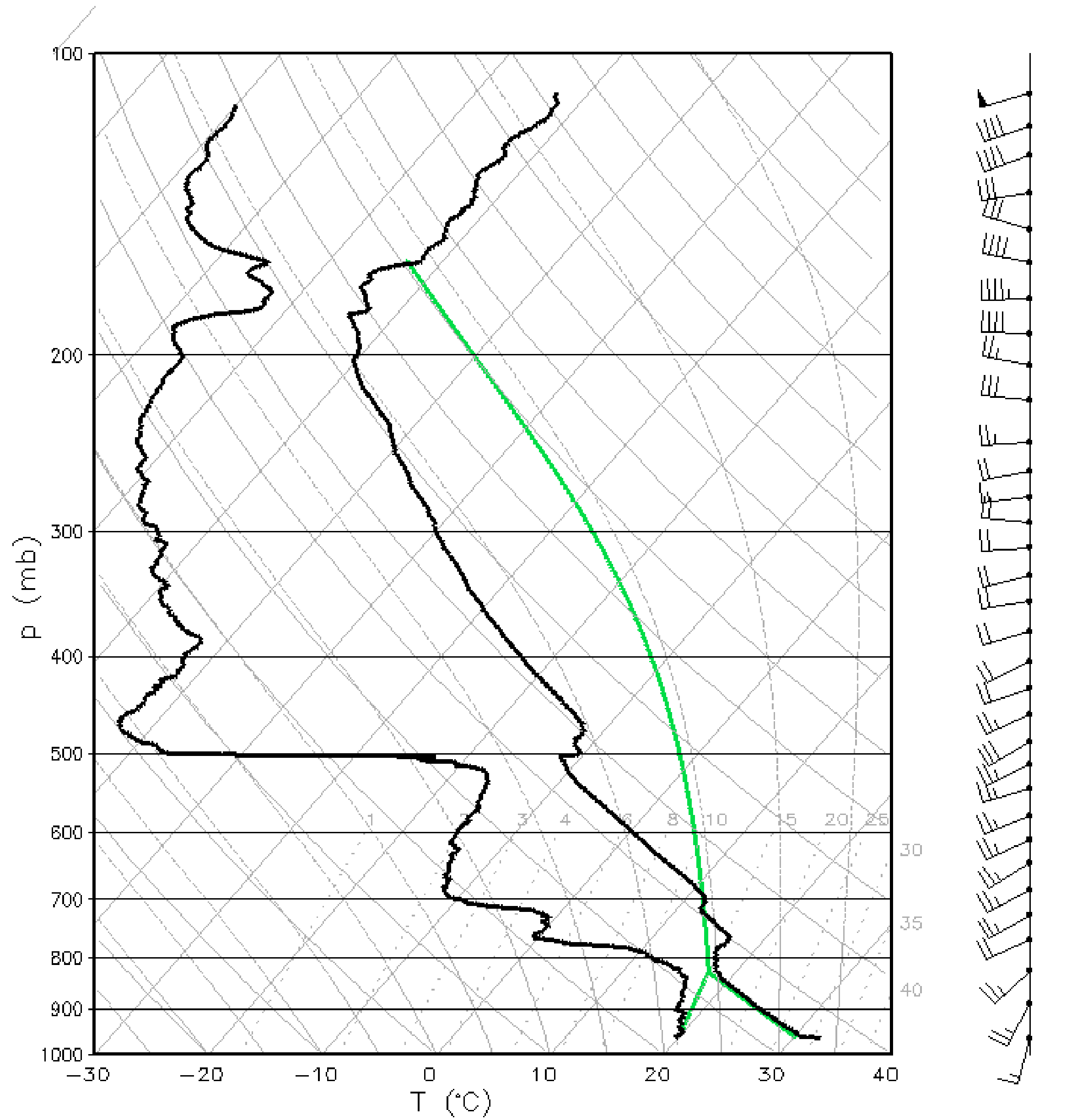


x_c is the line-normal distance to the surface gust front

System-relative location of all sounding data



S1 (first sounding): x_c = +106 km



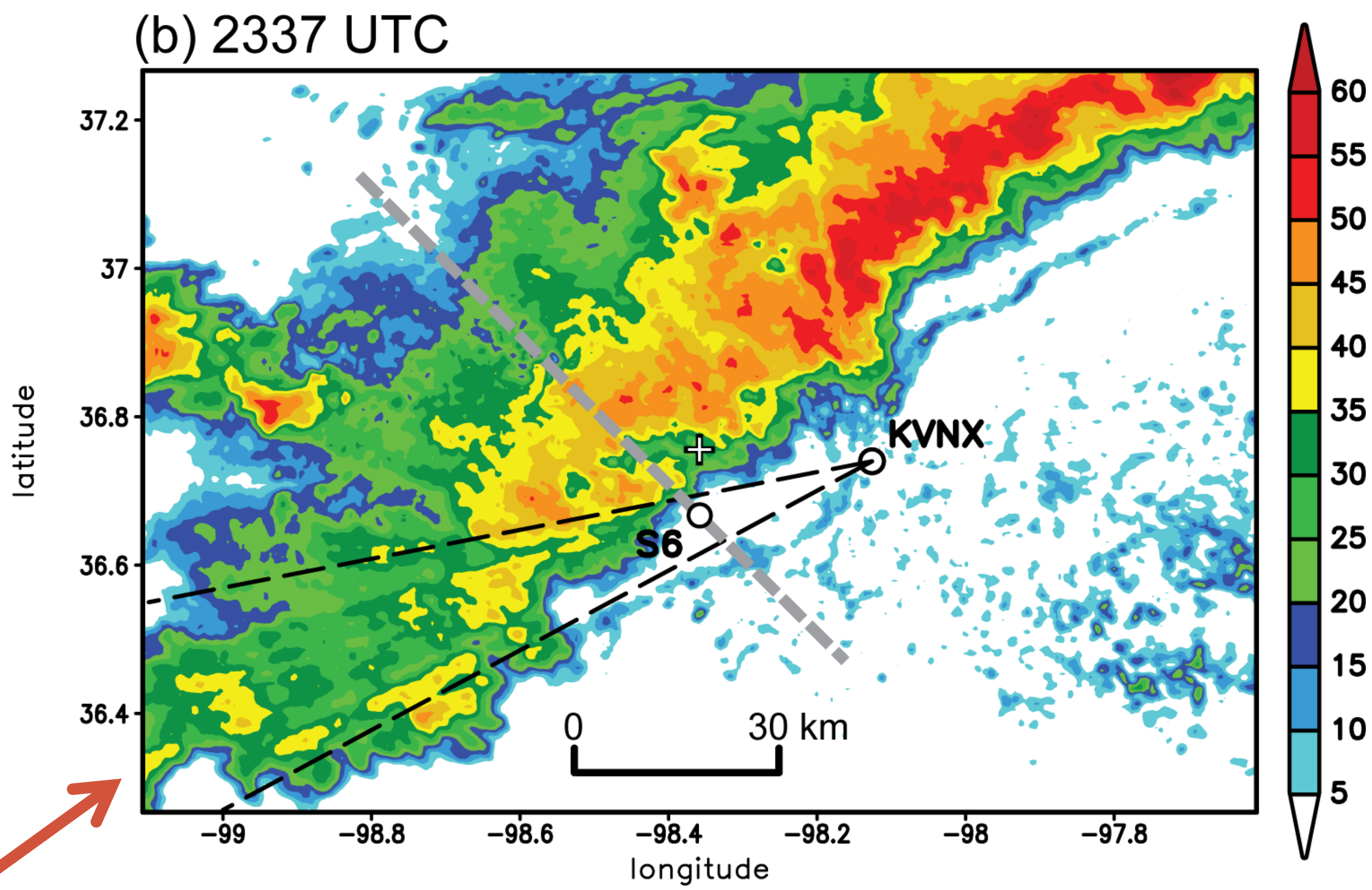
CAPE = 4200 J kg^{-1}

CIN = 8 J kg^{-1}

Δu (0.5 – 2 km) = 10 m s^{-1}

Δu (0.5 – 10 km) = 10 m s^{-1}

KVNX, lowest elevation (0.5°)

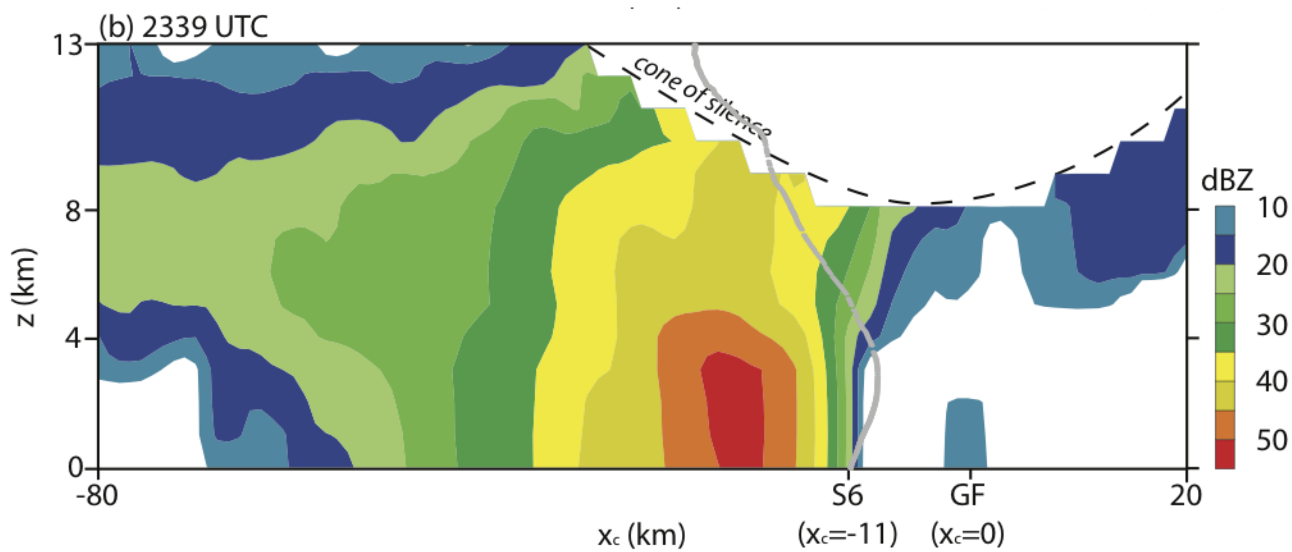


(region of partial beam blockage)

S6: “cold pool” sounding

Radar analysis
(normal to line)

Gray line is
sounding trajectory



S6: “cold pool” sounding

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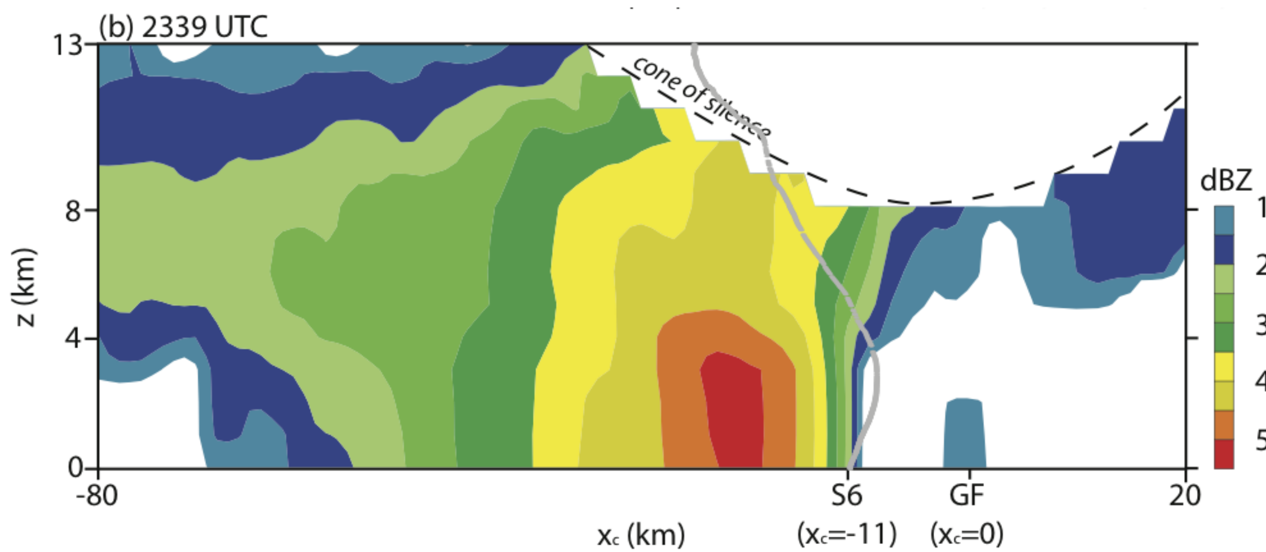
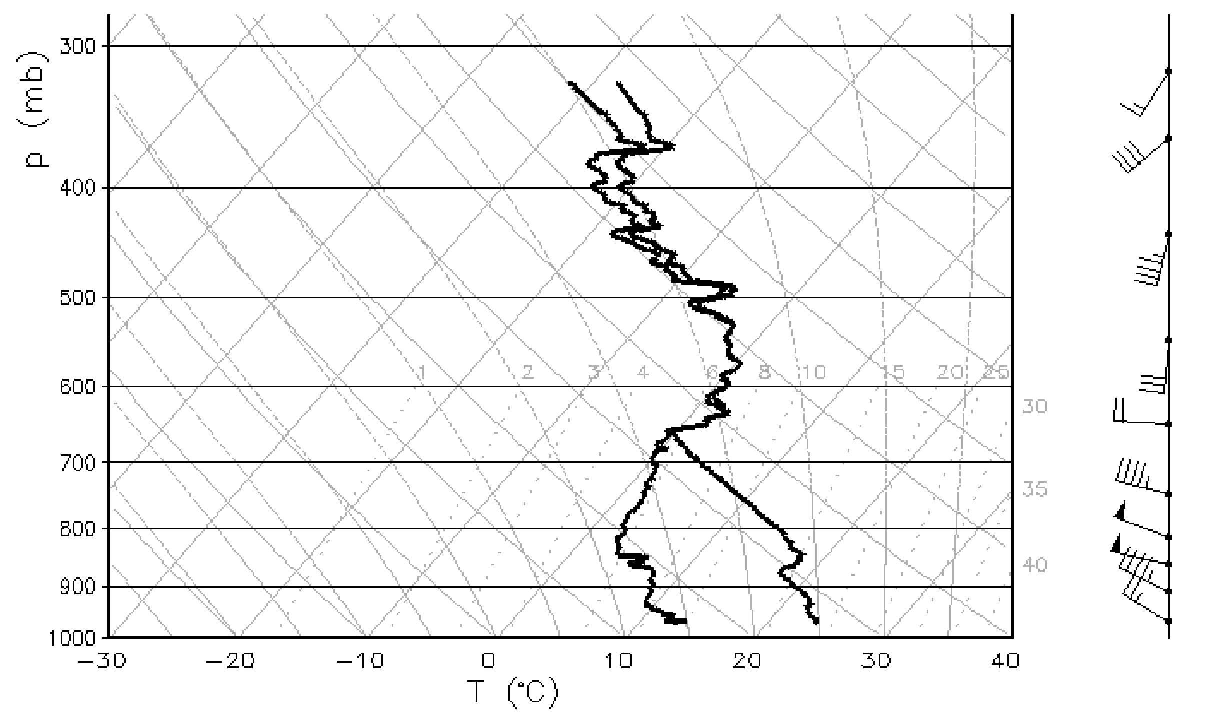
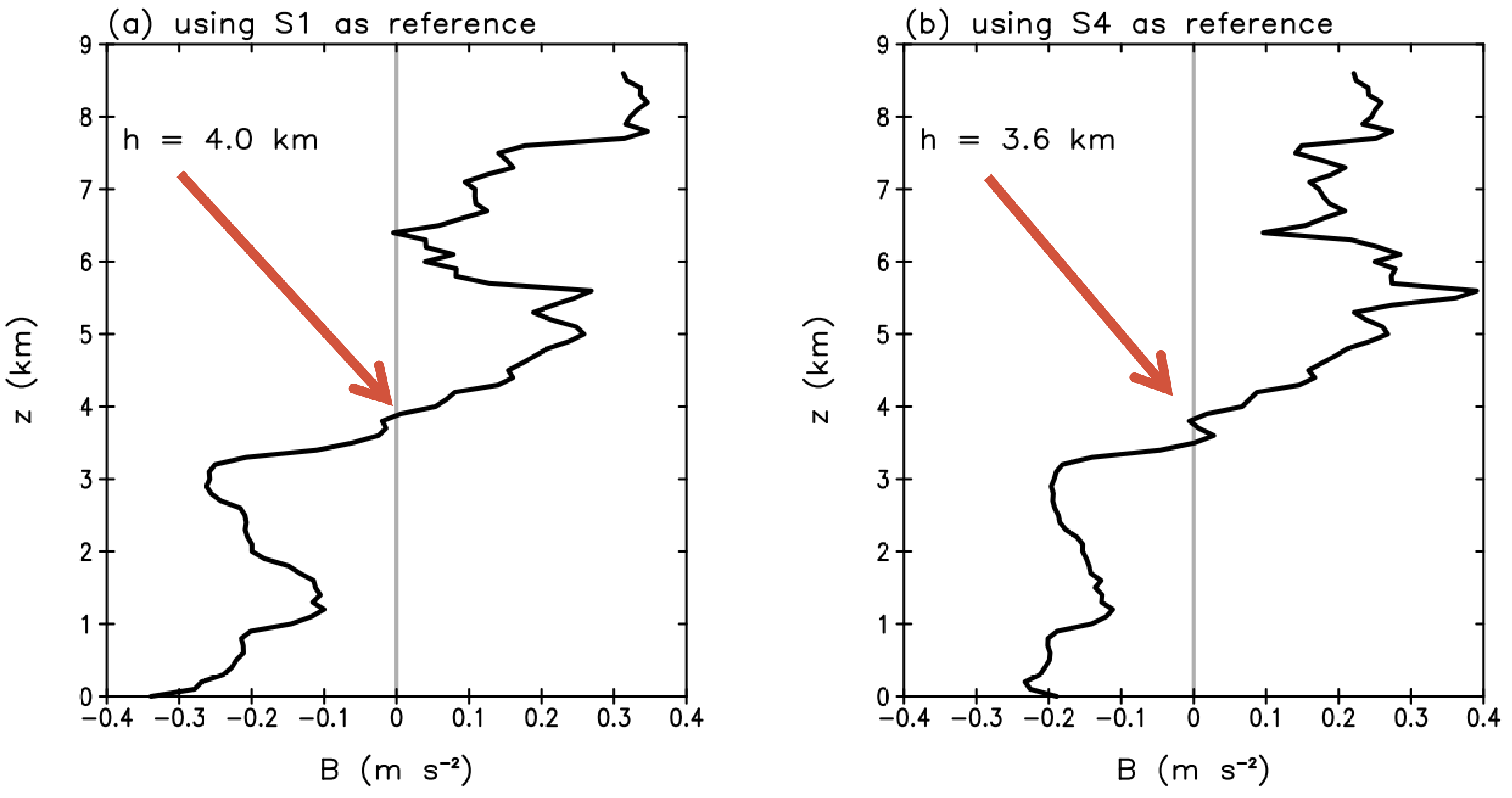


S6 data on skew–T diagram:

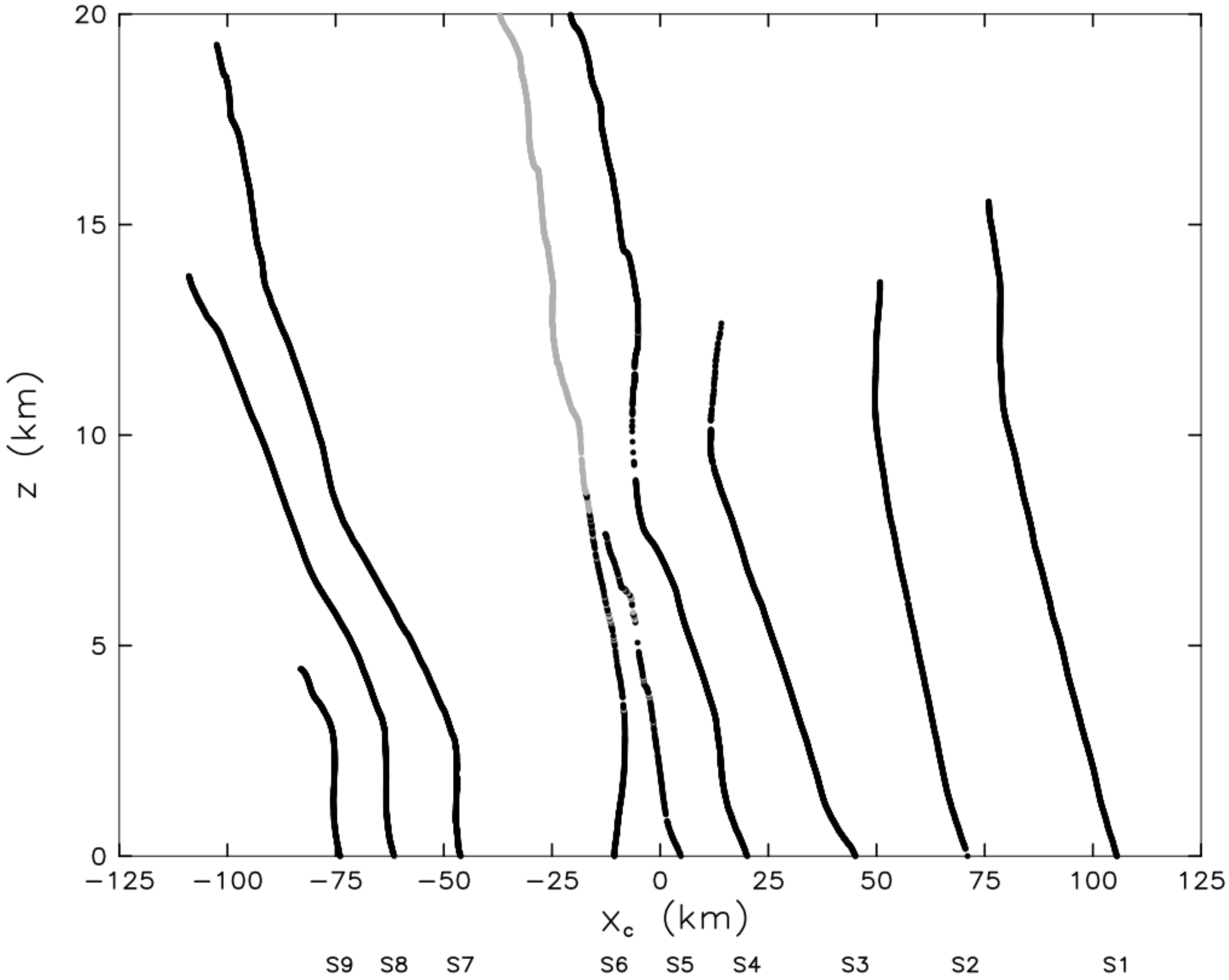


Vertical profiles of buoyancy (B) from S6:

$$B = g\frac{(\theta - \theta_0)}{\theta_0} + 0.61g(q_v - q_{v0})$$



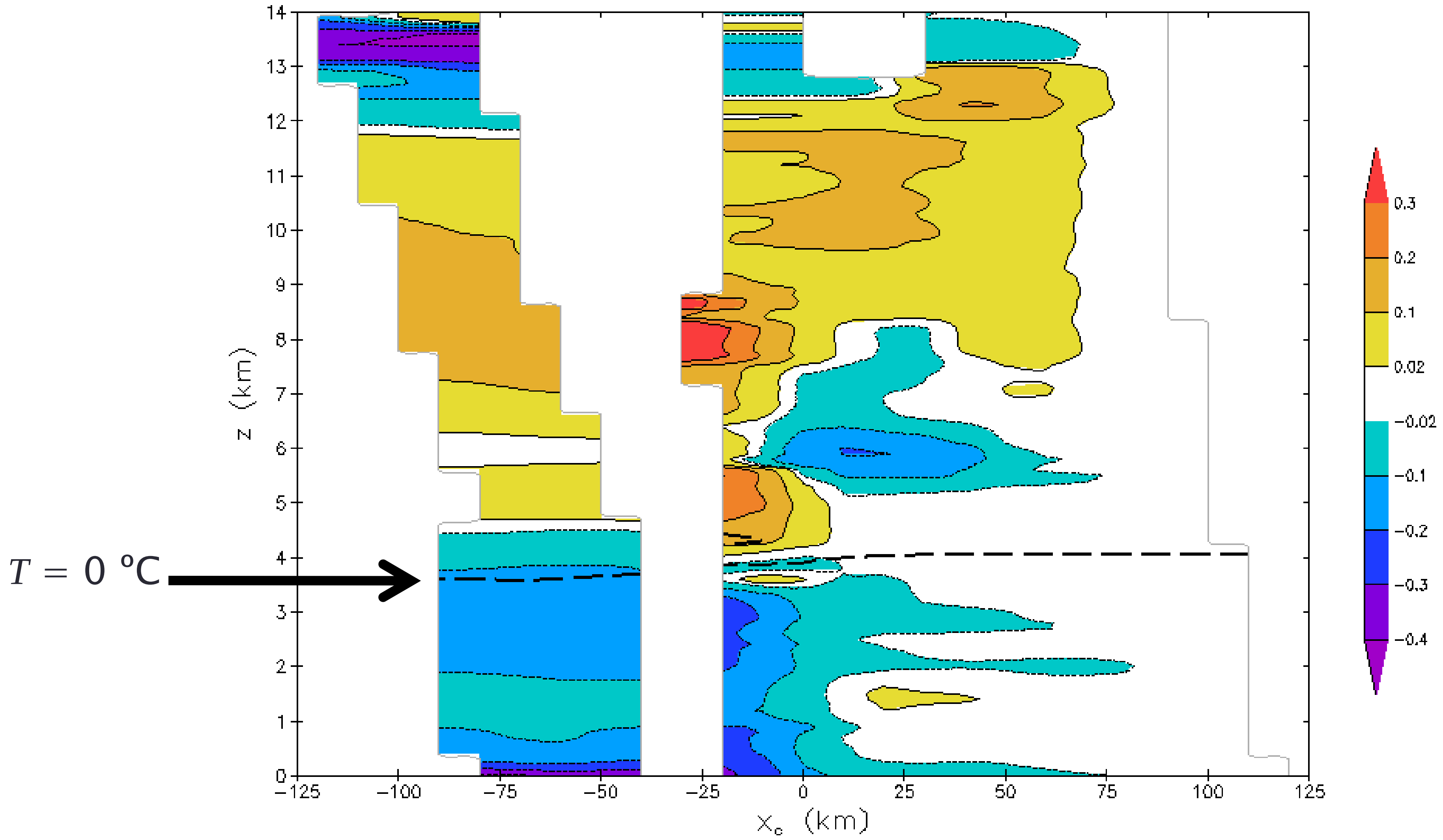
System-relative location of *all* sounding data



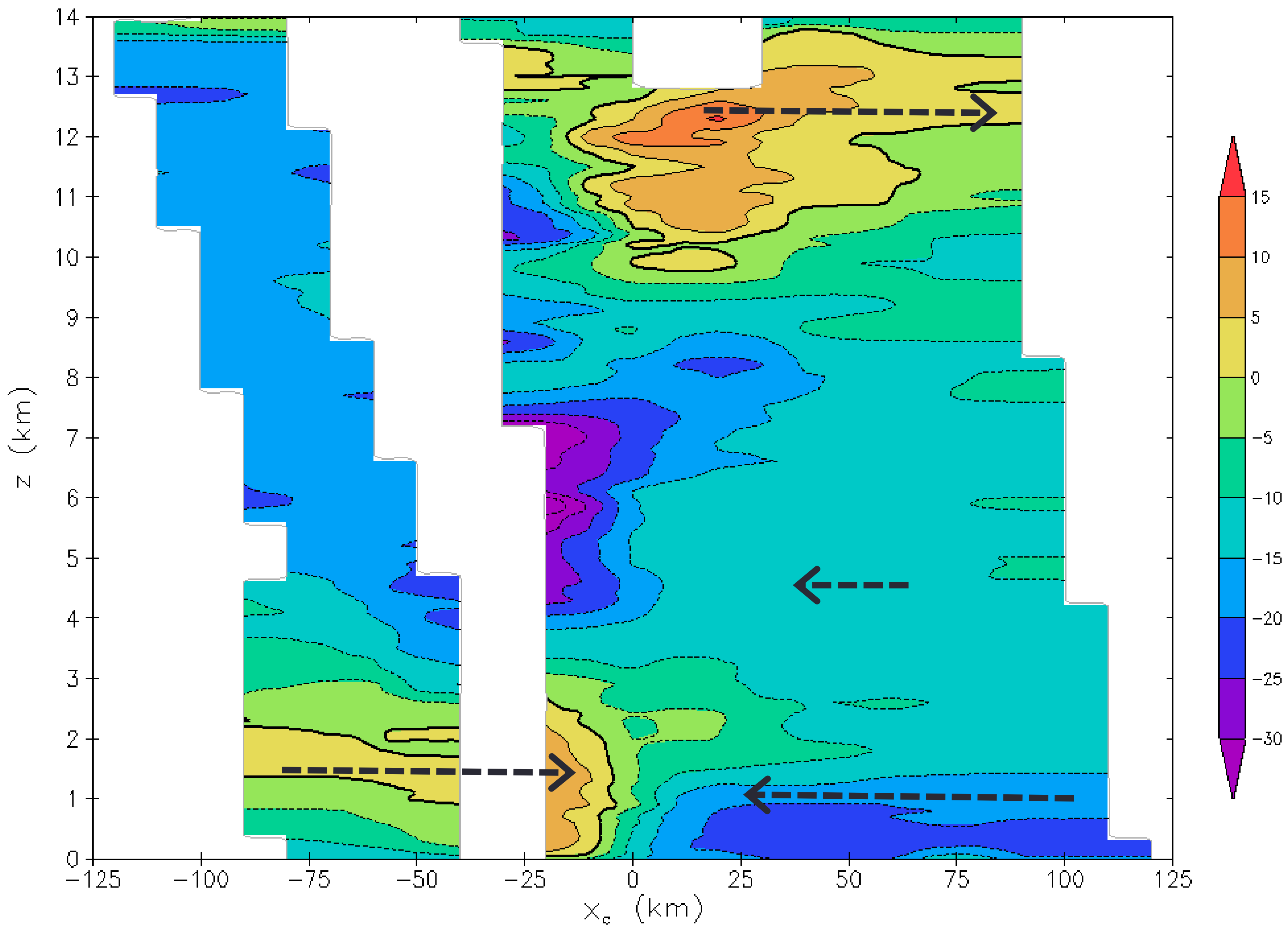
Mesoscale analysis: 2-pass Barnes method with $\Delta x = 10$ km, $\Delta z = 100$ m

Analysis of buoyancy (B; m s^{-2})

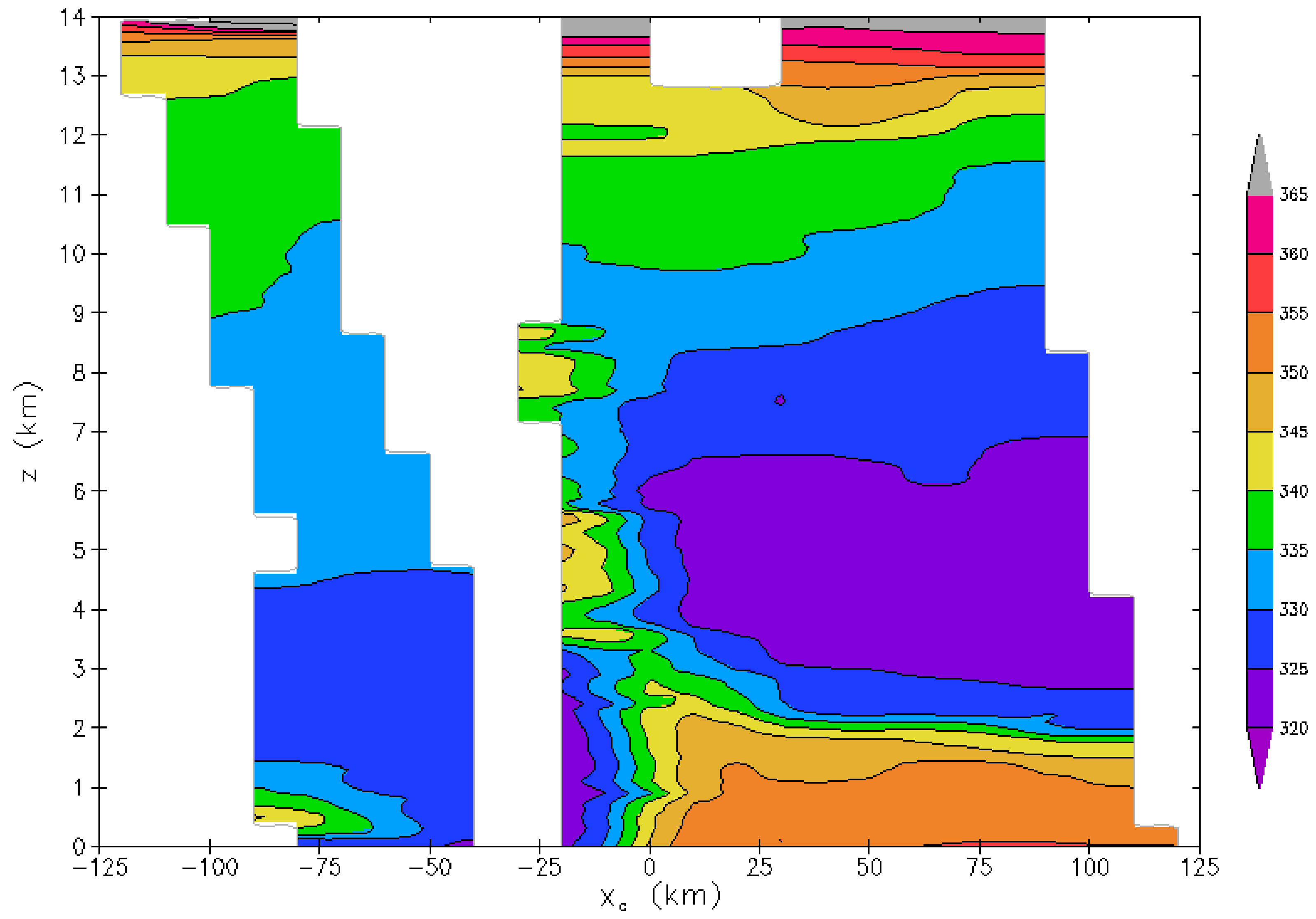
(using S1 as reference)



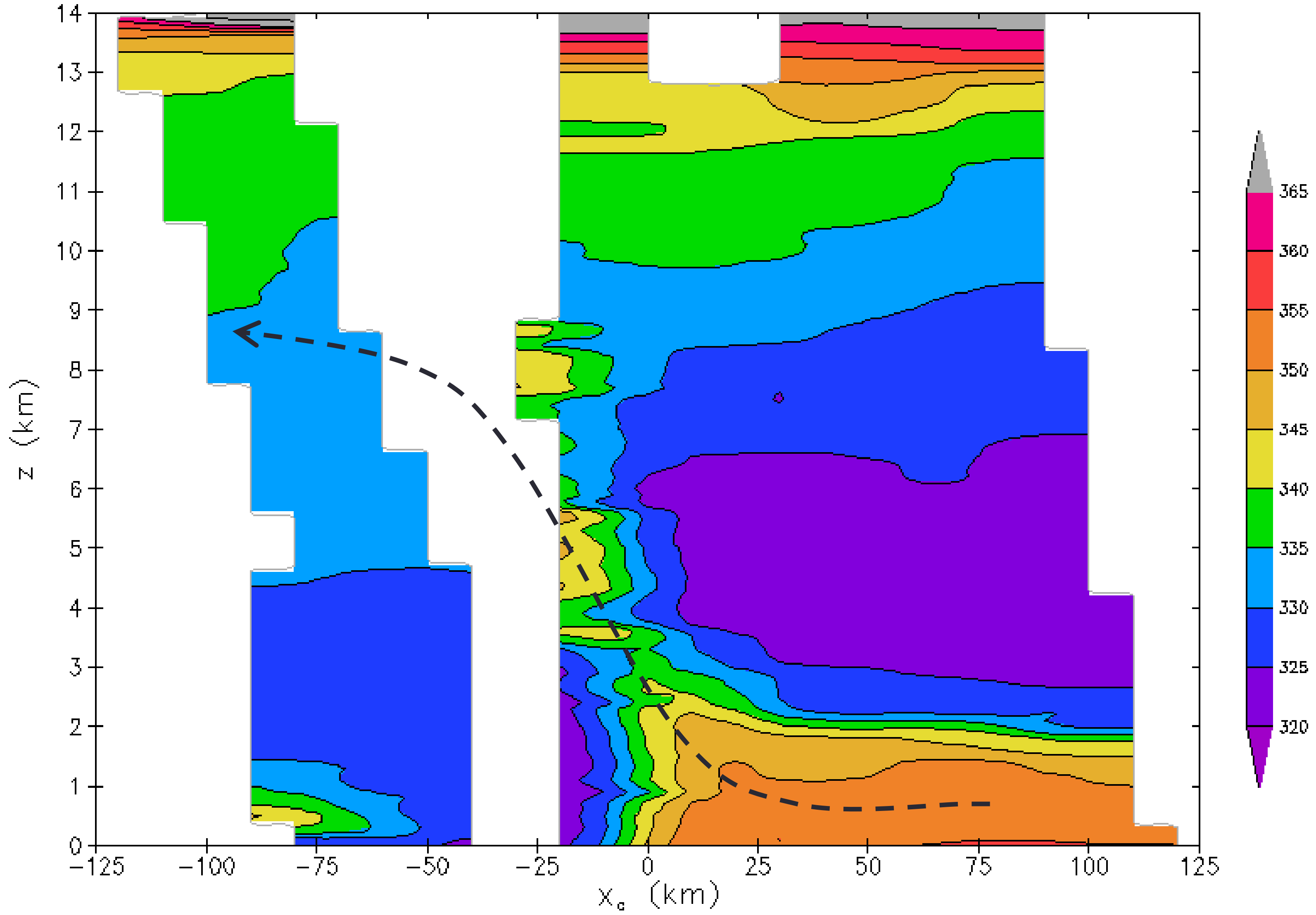
System-relative cross-line wind speed (U; m s^{-1})



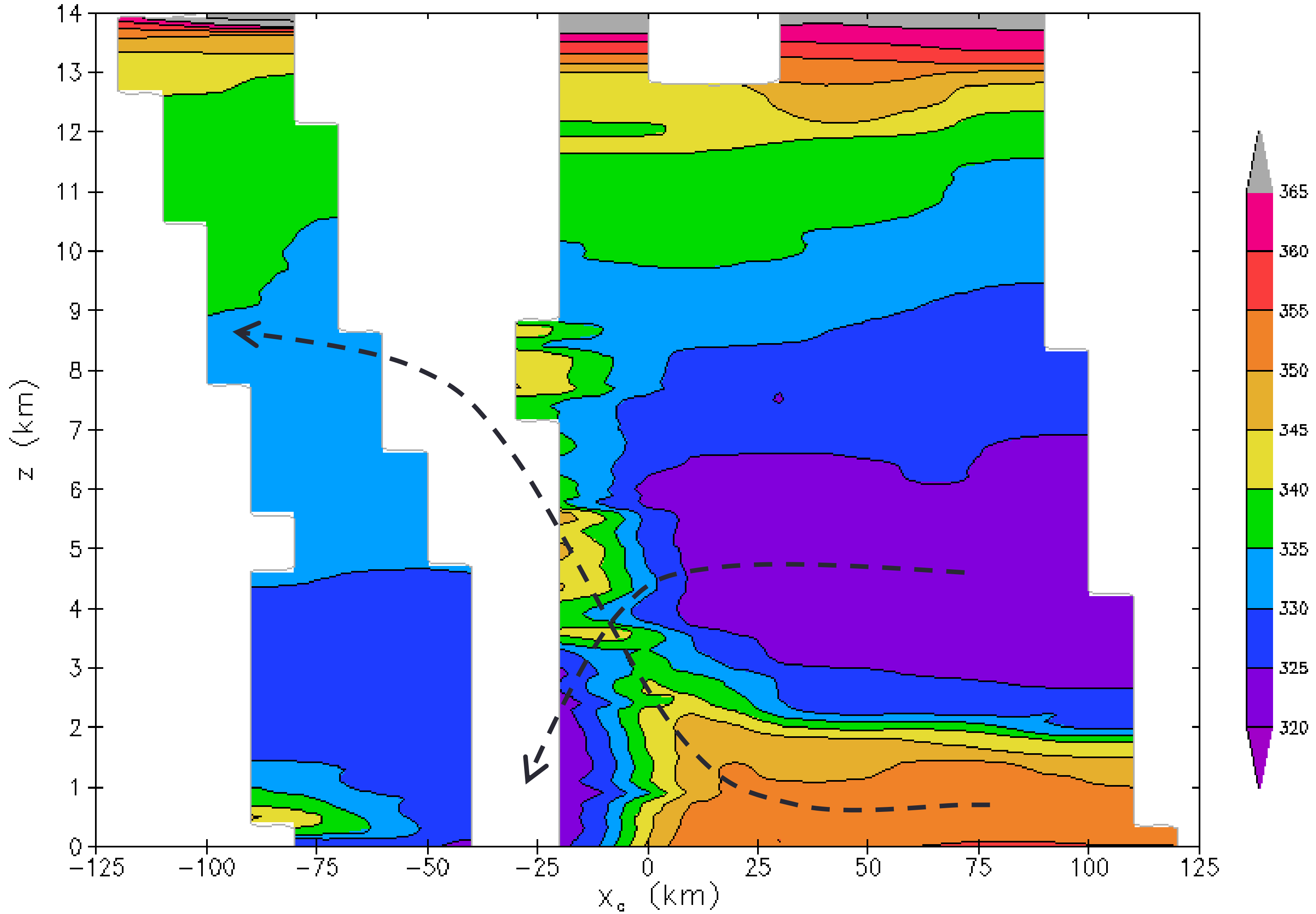
Analysis of equivalent potential temperature (θ_e; K)



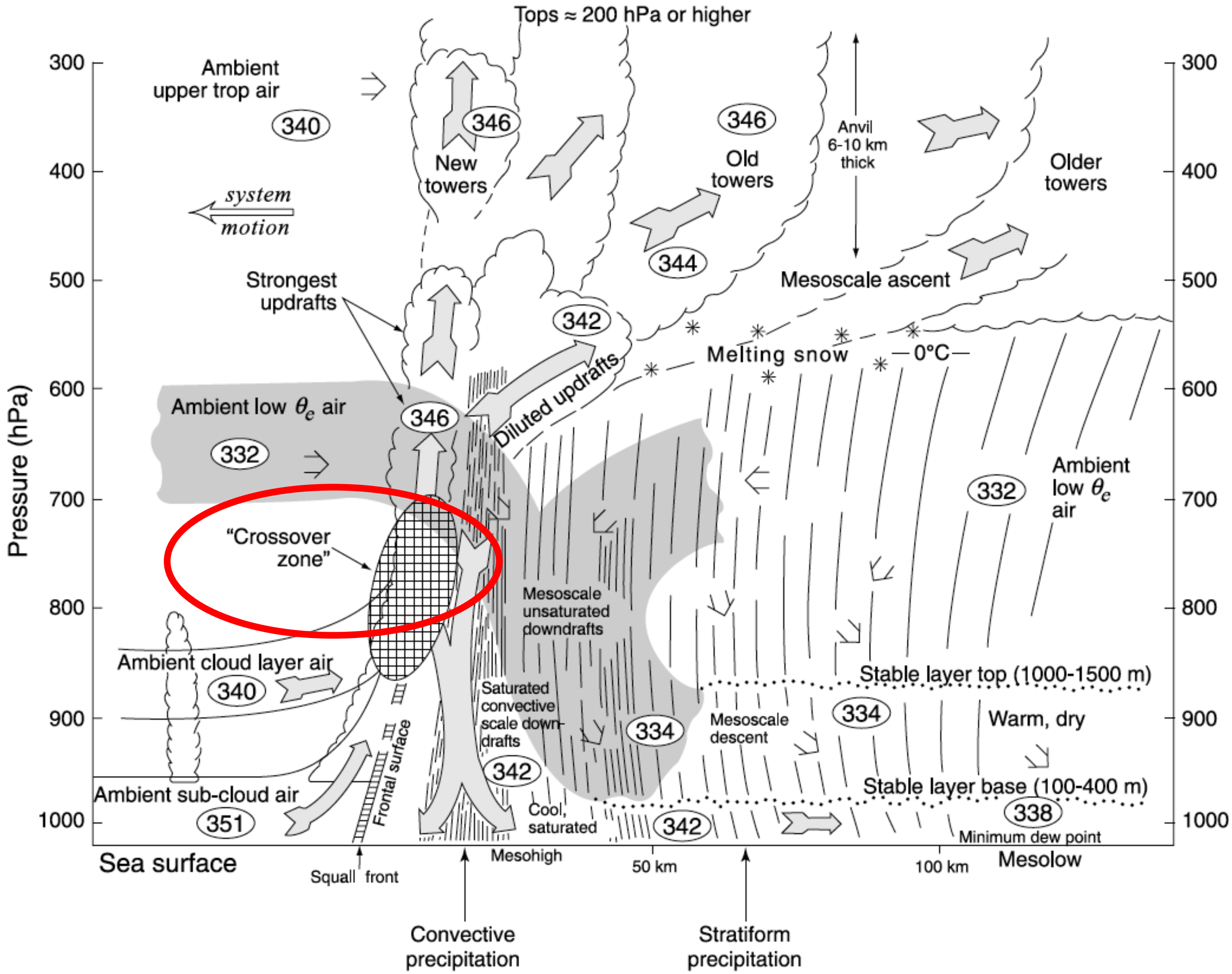
Analysis of equivalent potential temperature (θ_e; K)



Analysis of equivalent potential temperature (θ_e; K)



Conceptual model of tropical MCSs

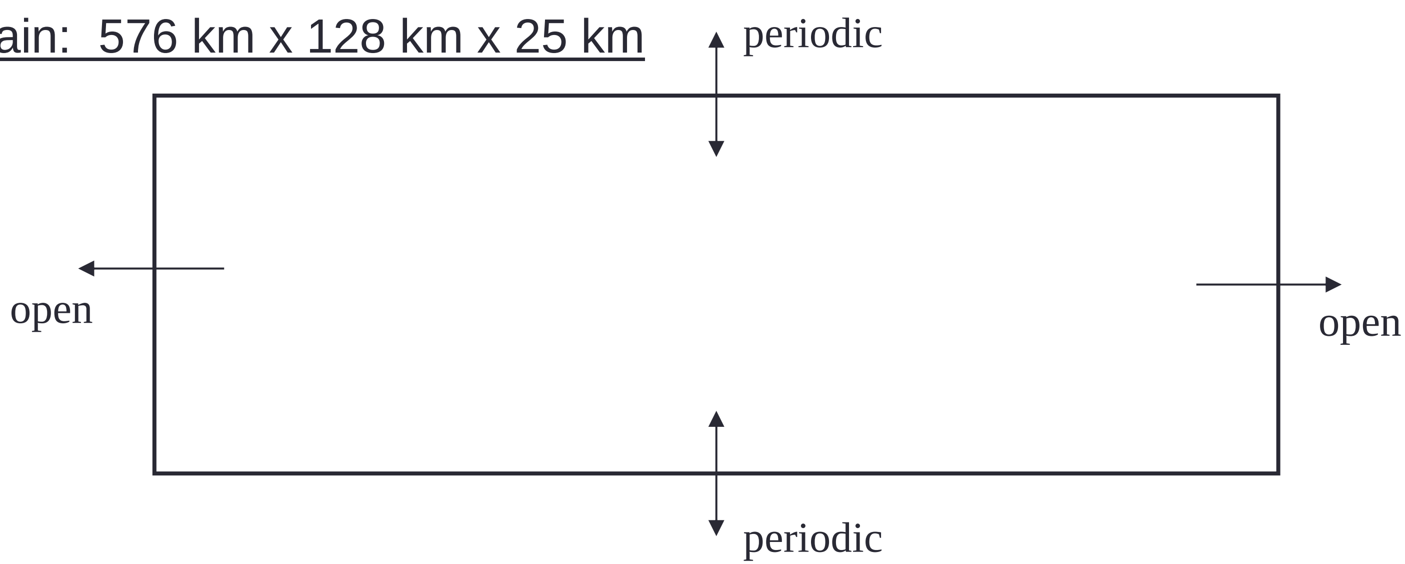


Zipser (1977), adapted by Houze (2004)

Numerical Simulations

- Numerical model: CM1 (“Cloud Model 1”, eg, Bryan and Fritsch 2002)
  - (compressible nonhydrostatic, similar numerics as WRF-ARW)
- Horizontal grid spacing (Δx): 4 km, 1 km, or 0.25 km
- 100 vertical levels for all simulations (Δz varies from 100 m to 400 m)
- Initial condition: S1 from 15 May 2009 (homogeneous)
- No radiation or surface heat fluxes (to keep environment fixed)
- Morrison et al (2009) double-moment microphysics

Domain: 576 km x 128 km x 25 km

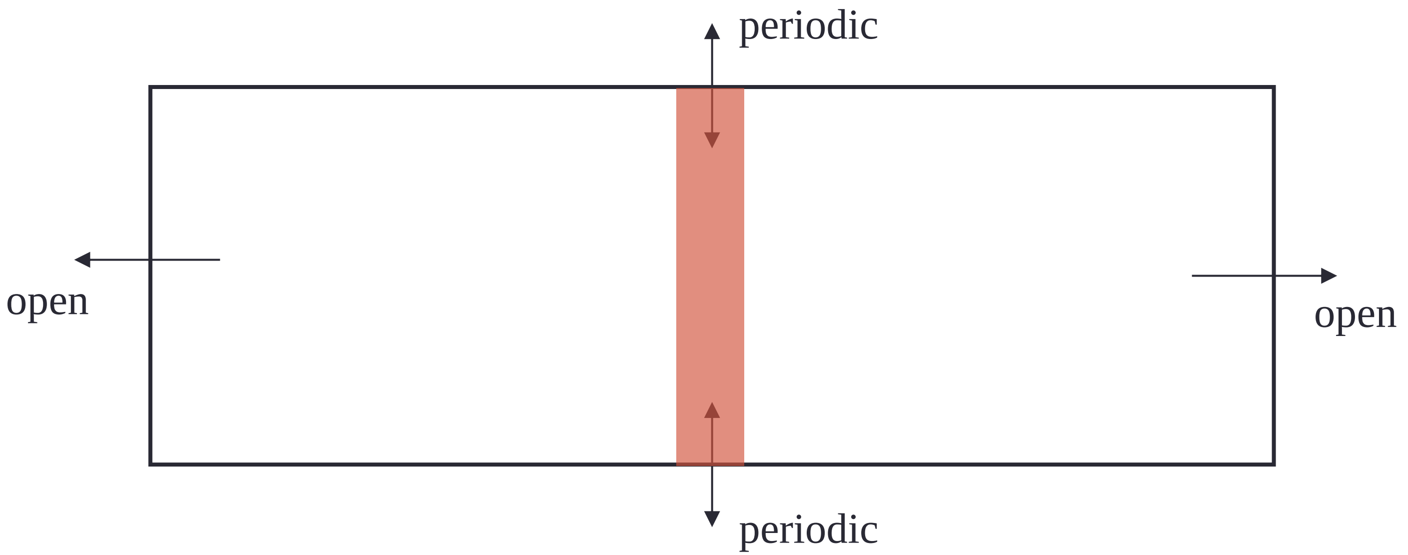


for more details: Bryan and Morrison (2012, MWR)

Numerical Simulations

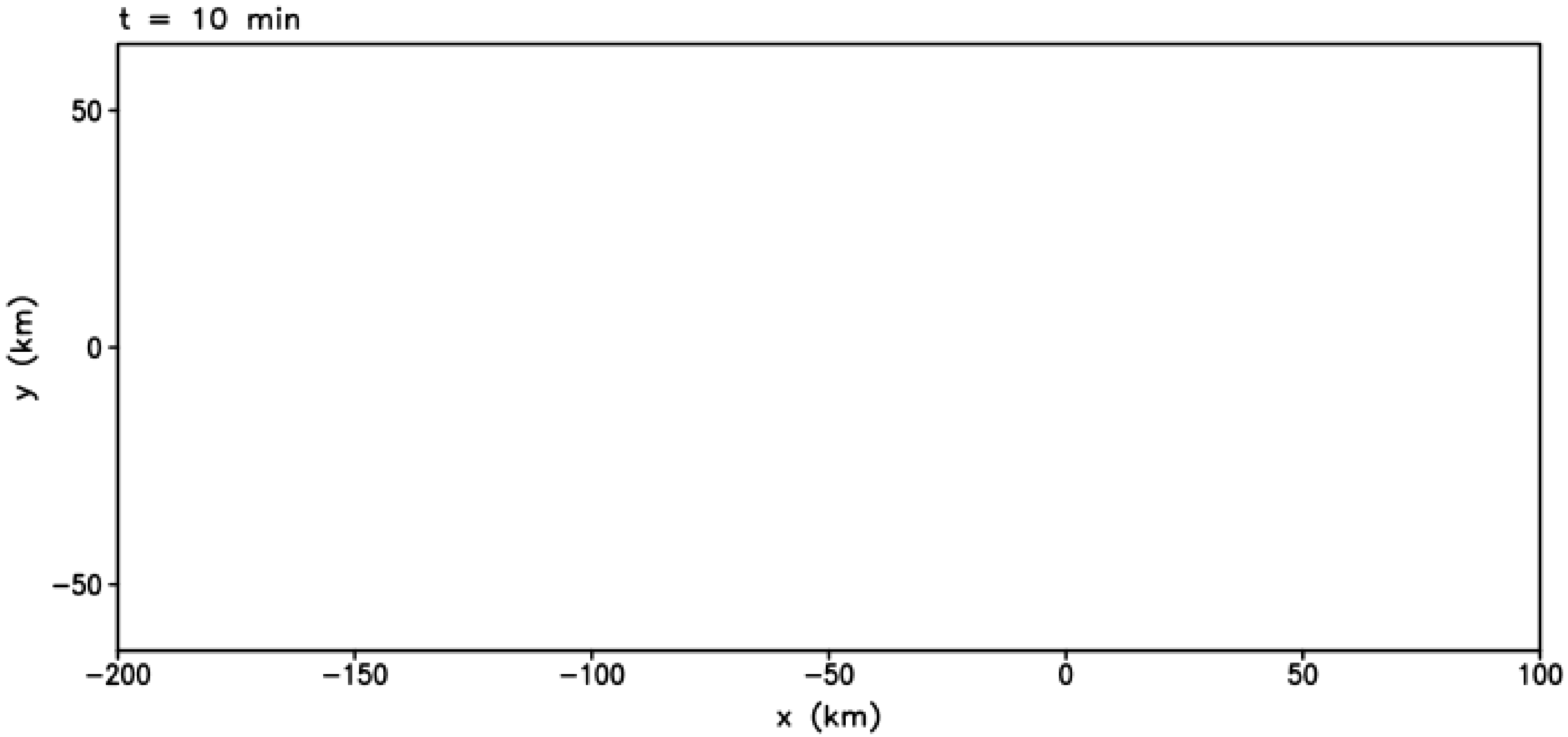
- Squall line is Initialized with a momentum source (Morrison et al. 2015, JAS)

  + random θ perturbations to initiate 3d motions

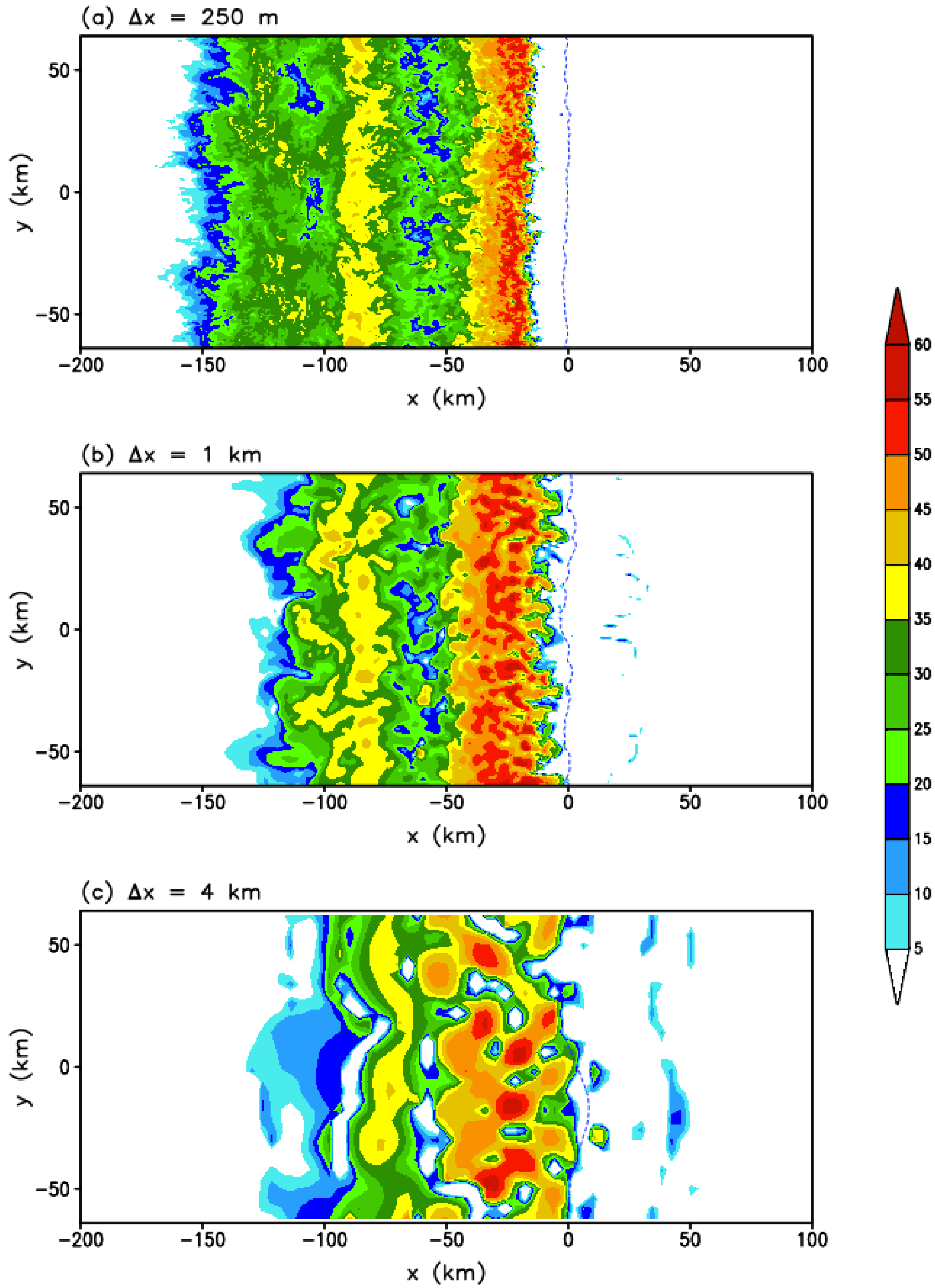


Reflectivity (dBZ) at 1 km AGL

Δx = 250 m

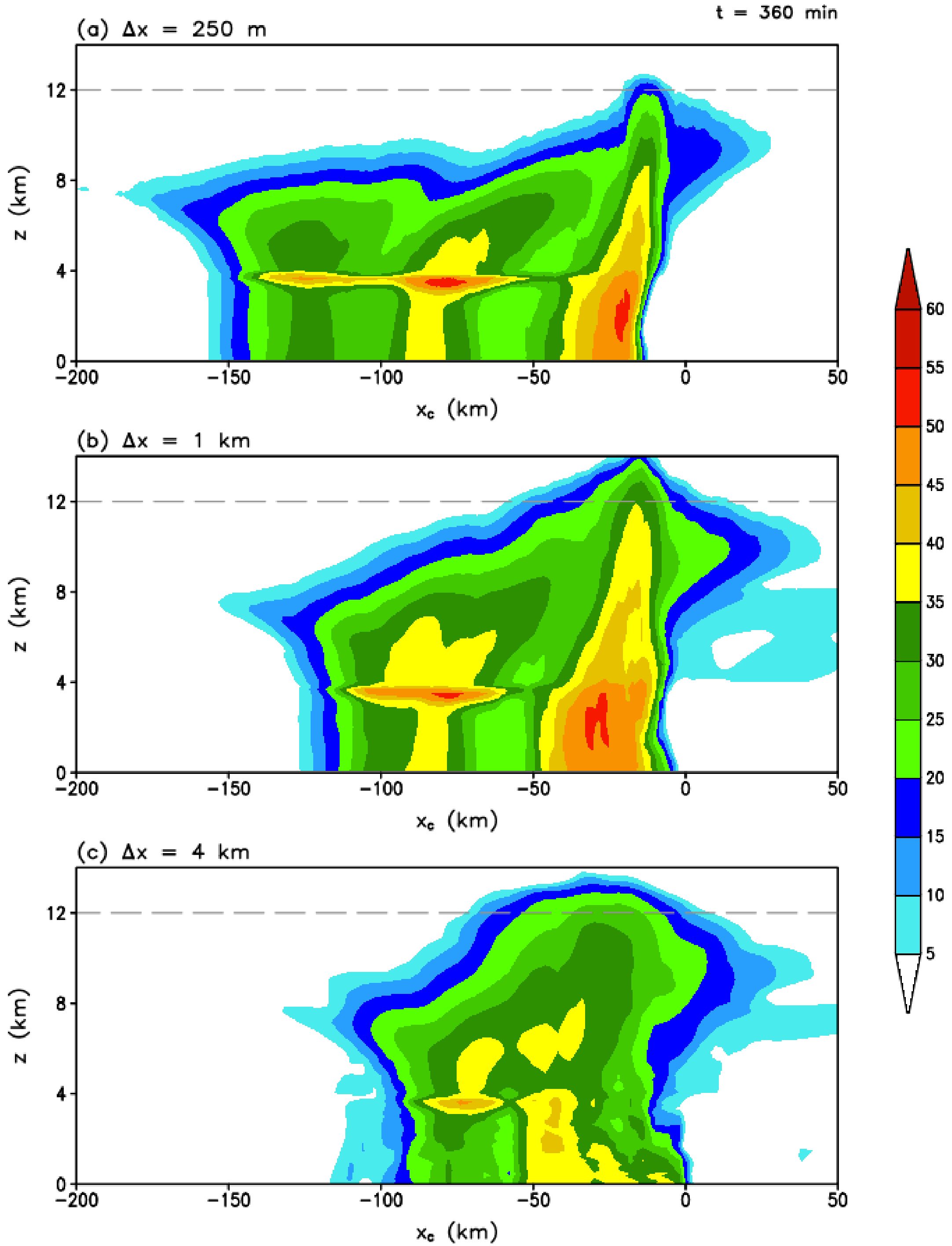


Reflectivity (dBZ) at 1 km AGL



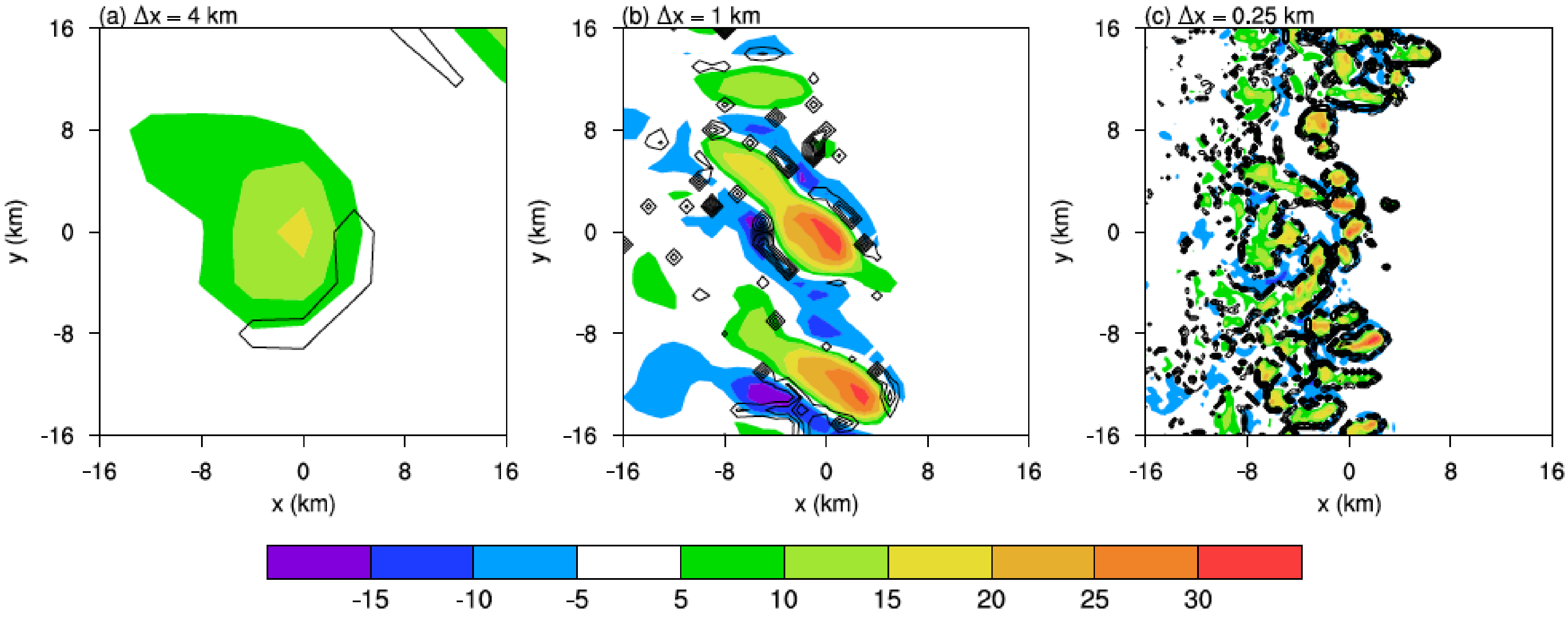
Reflectivity (dBZ), line-averaged vertical cross sections

(t = 6 h)

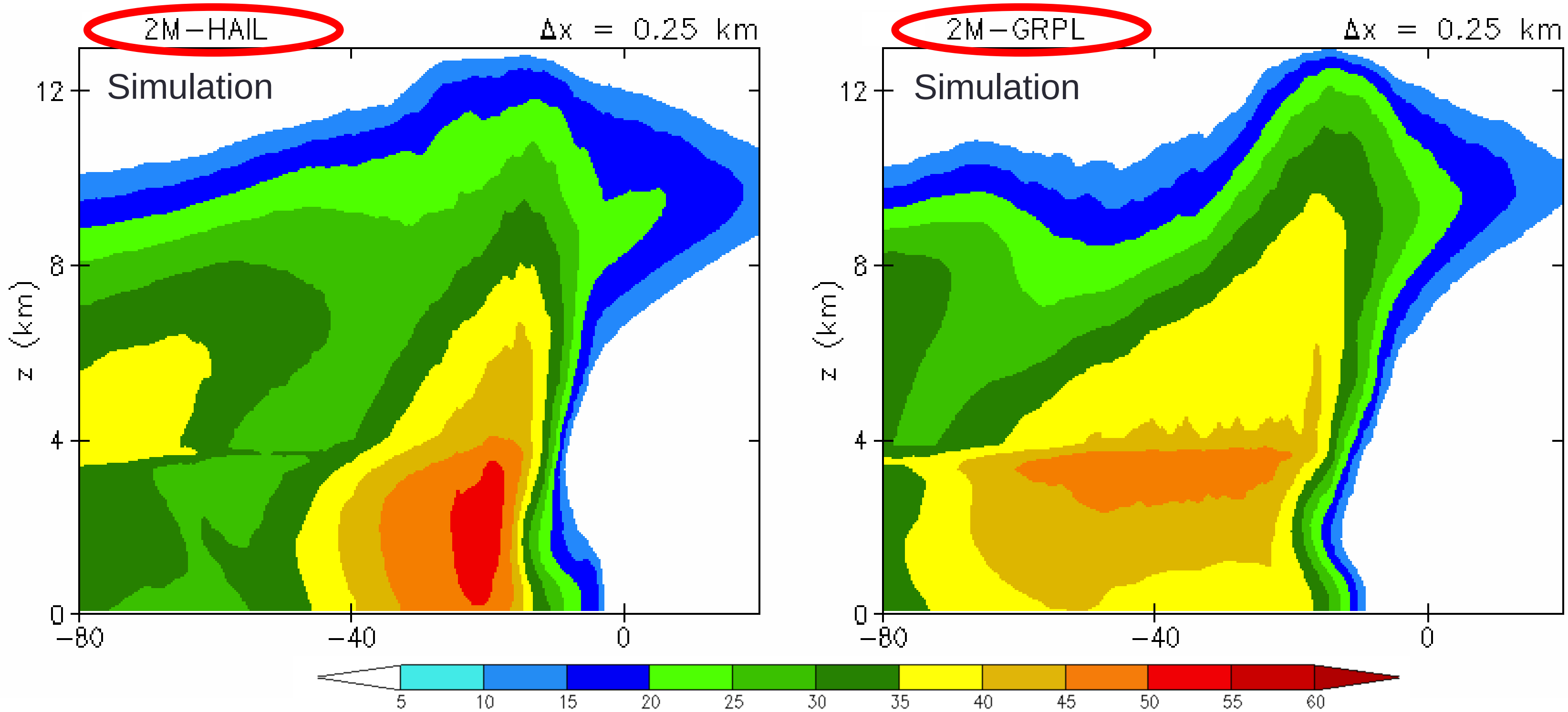


Vertical velocity (w, m s^{-1}) at 5 km AGL (shading)

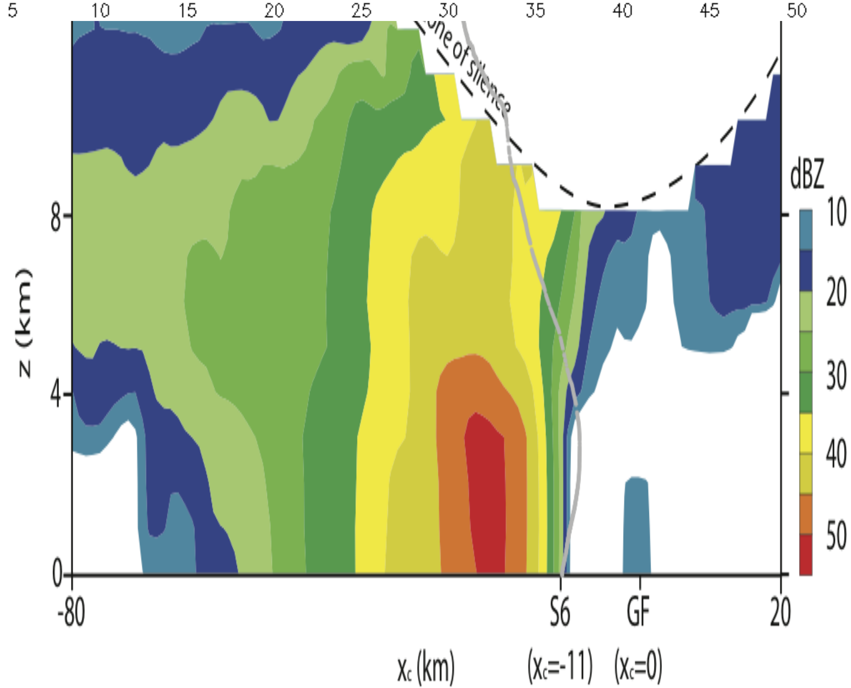
and cloudwater evaporation rate (black contours)



Bryan and Morrison (2012)



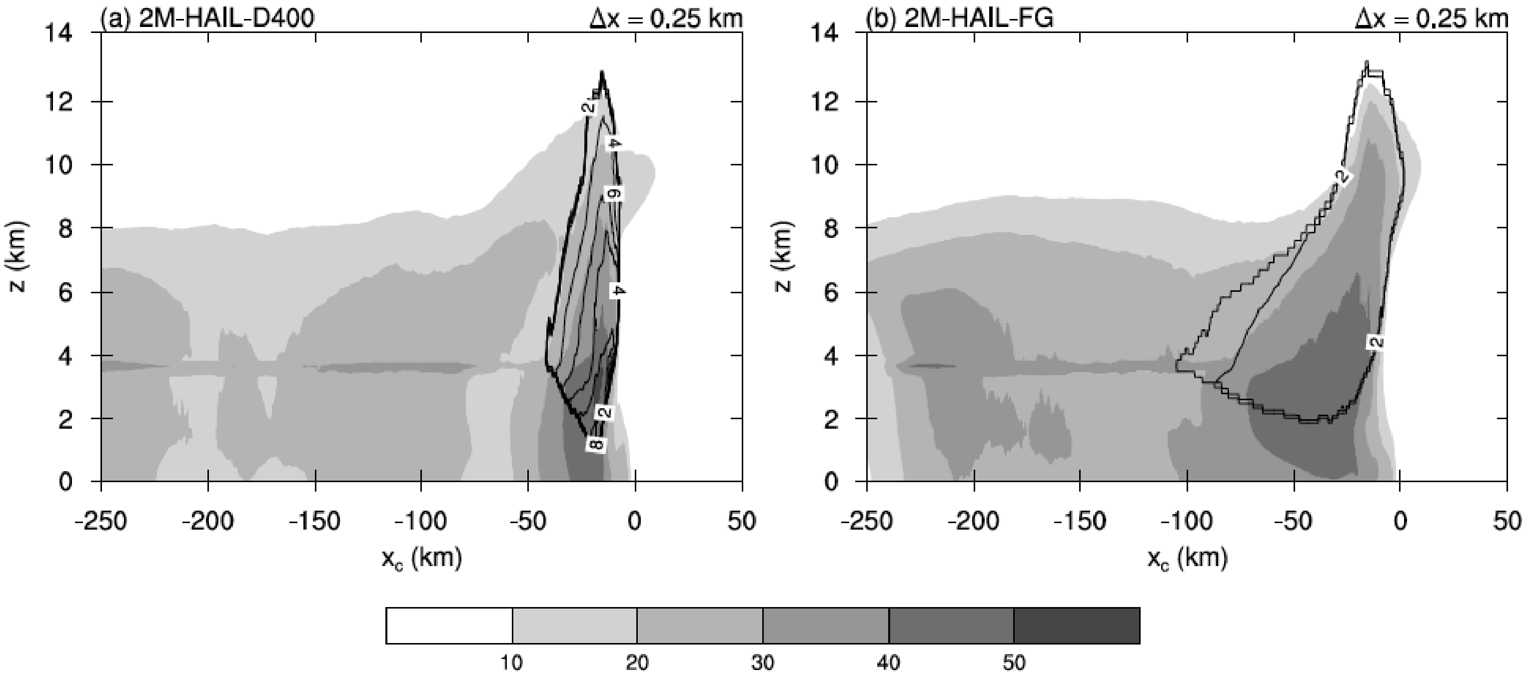
radar reflectivity (dBZ) assuming 10-cm wavelength



Observations

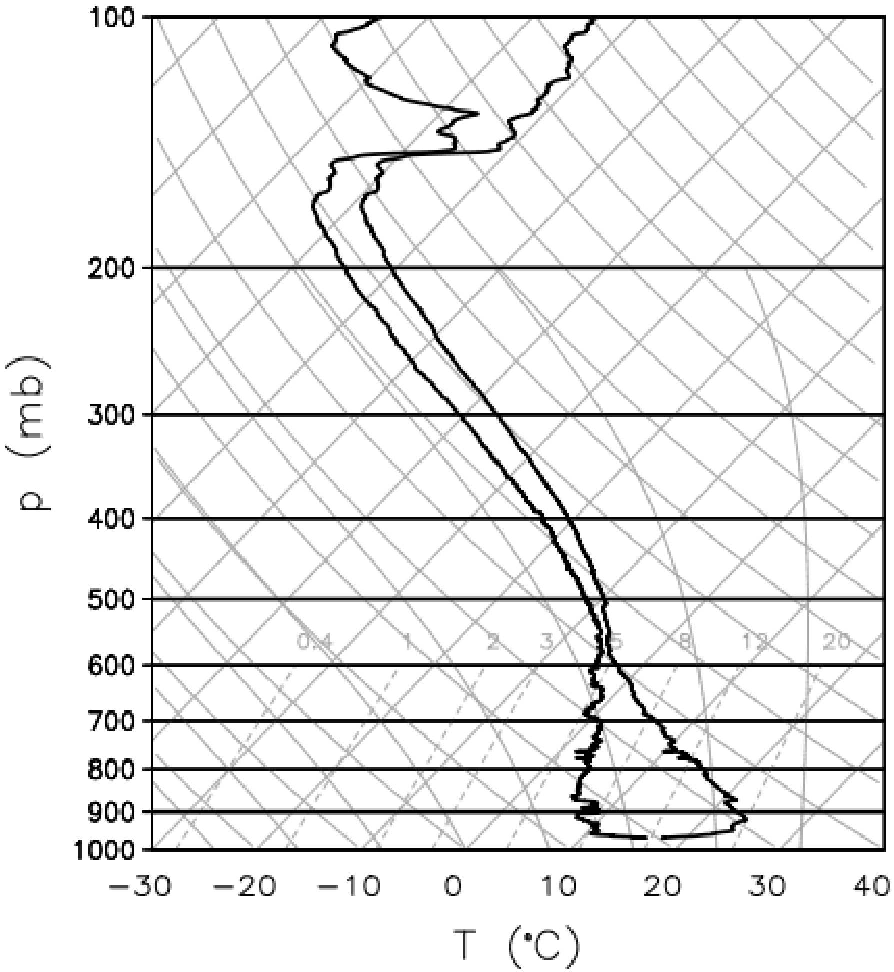
Radar reflectivity (shading)

and fall velocity of hail (left) / graupel (right) (black contours)

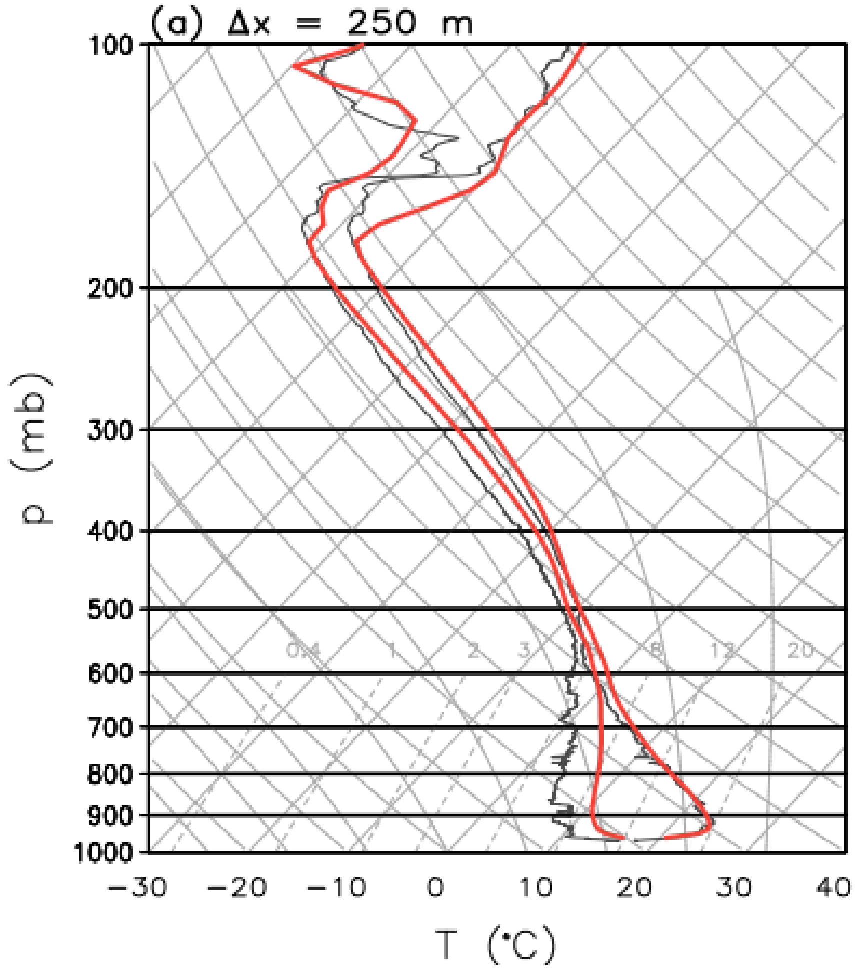


Bryan and Morrison (2012)

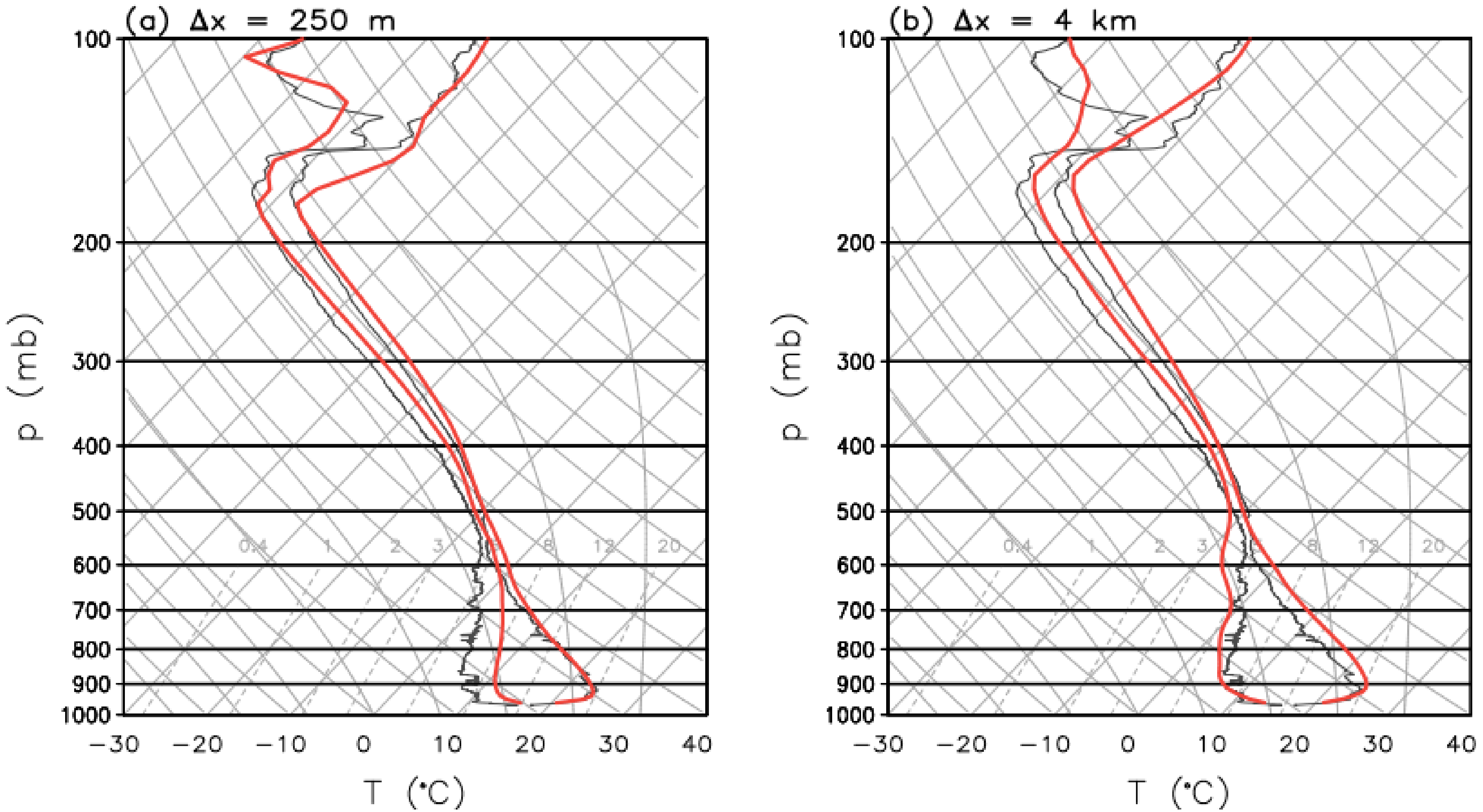
S7: sounding within trailing stratiform region



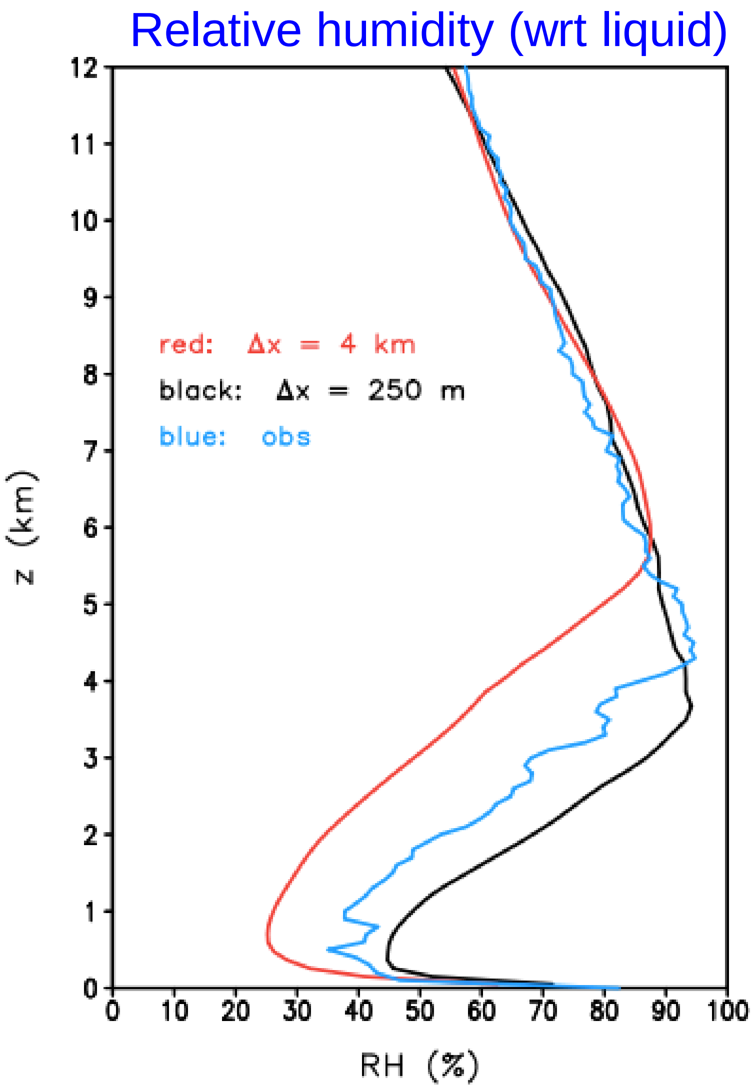
Soundings within trailing stratiform region

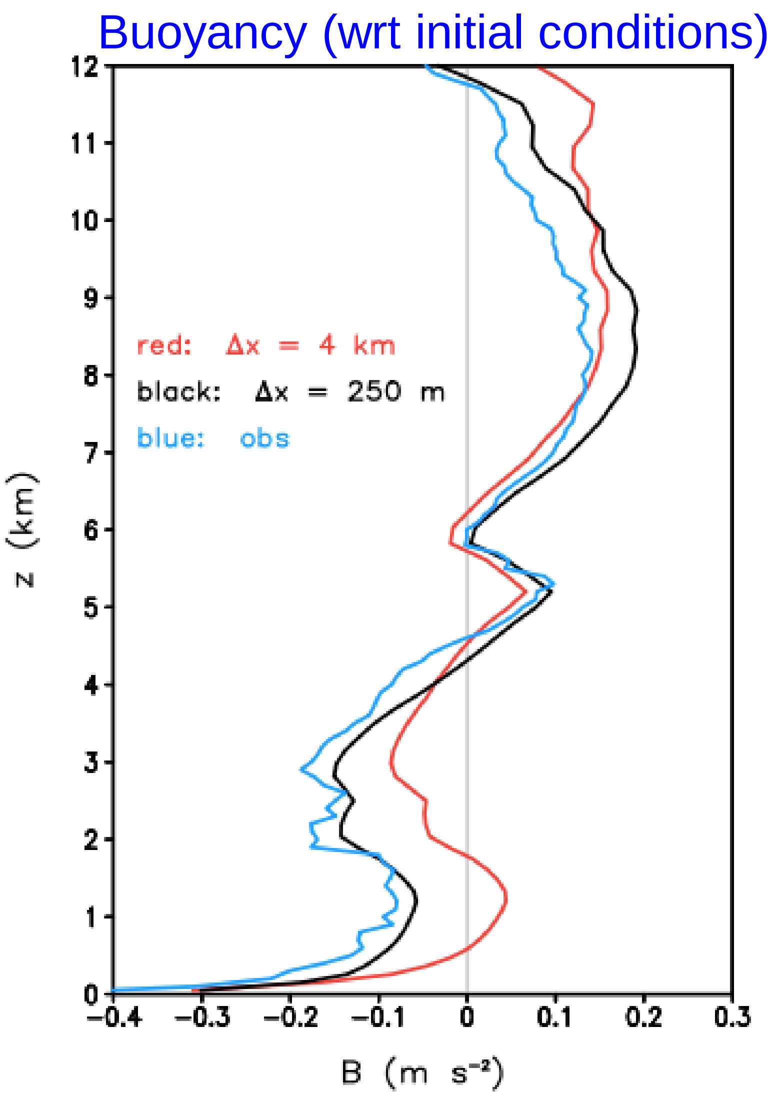


Soundings within trailing stratiform region

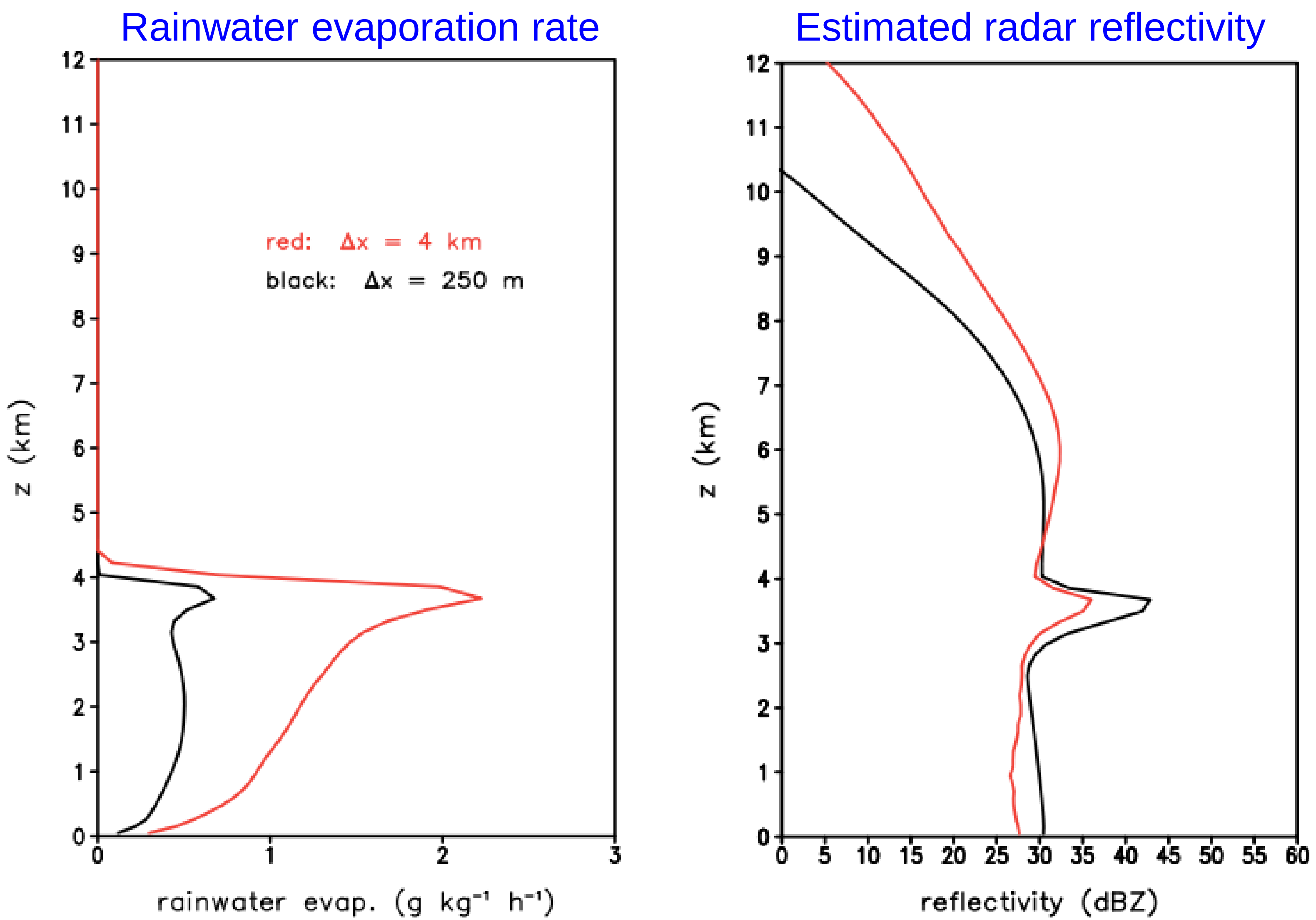


Profiles at x_c = -70 km



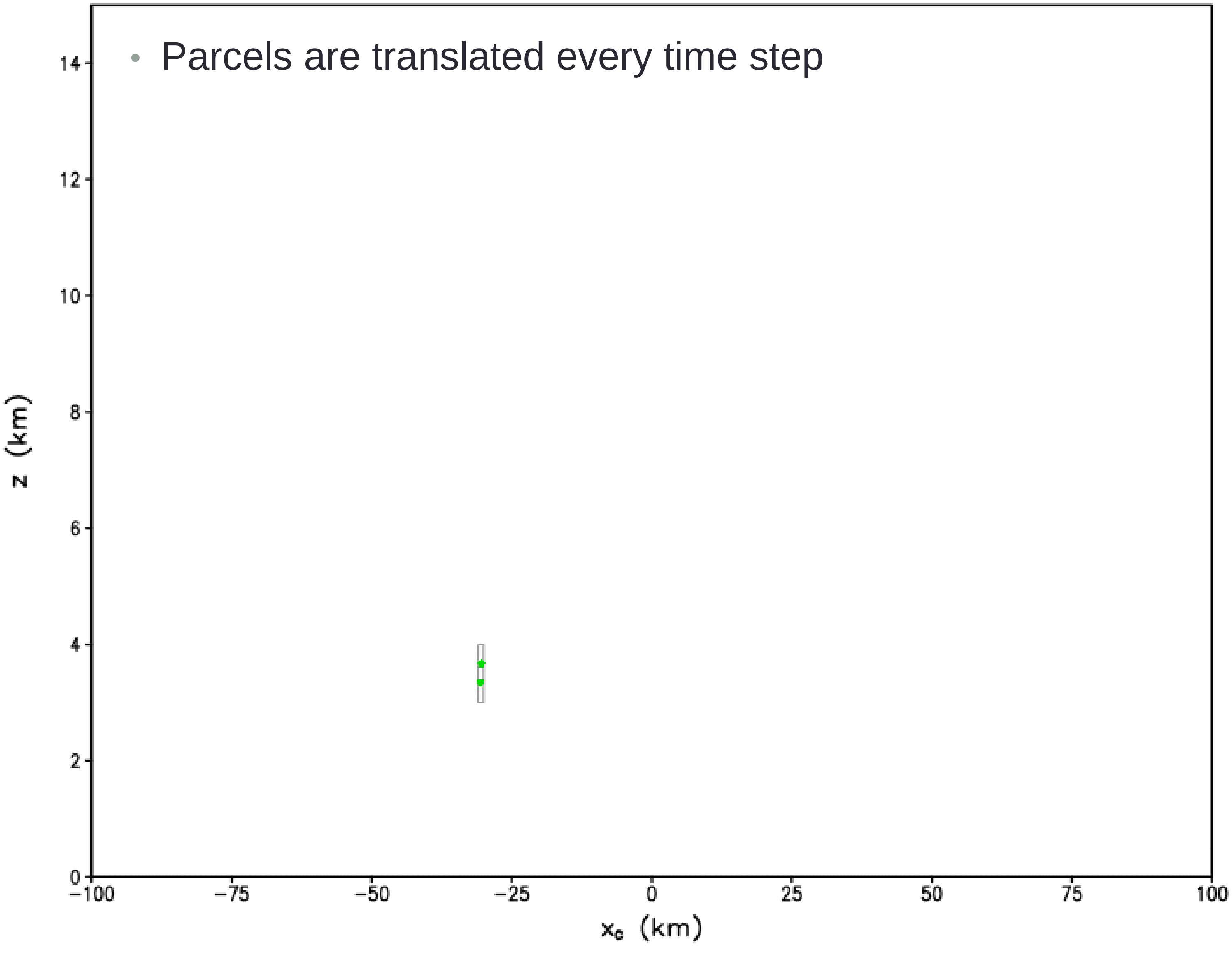


Averages for -100 km ≤ x_c ≤ -40 km



Trajectory analysis

- Parcels are translated every time step

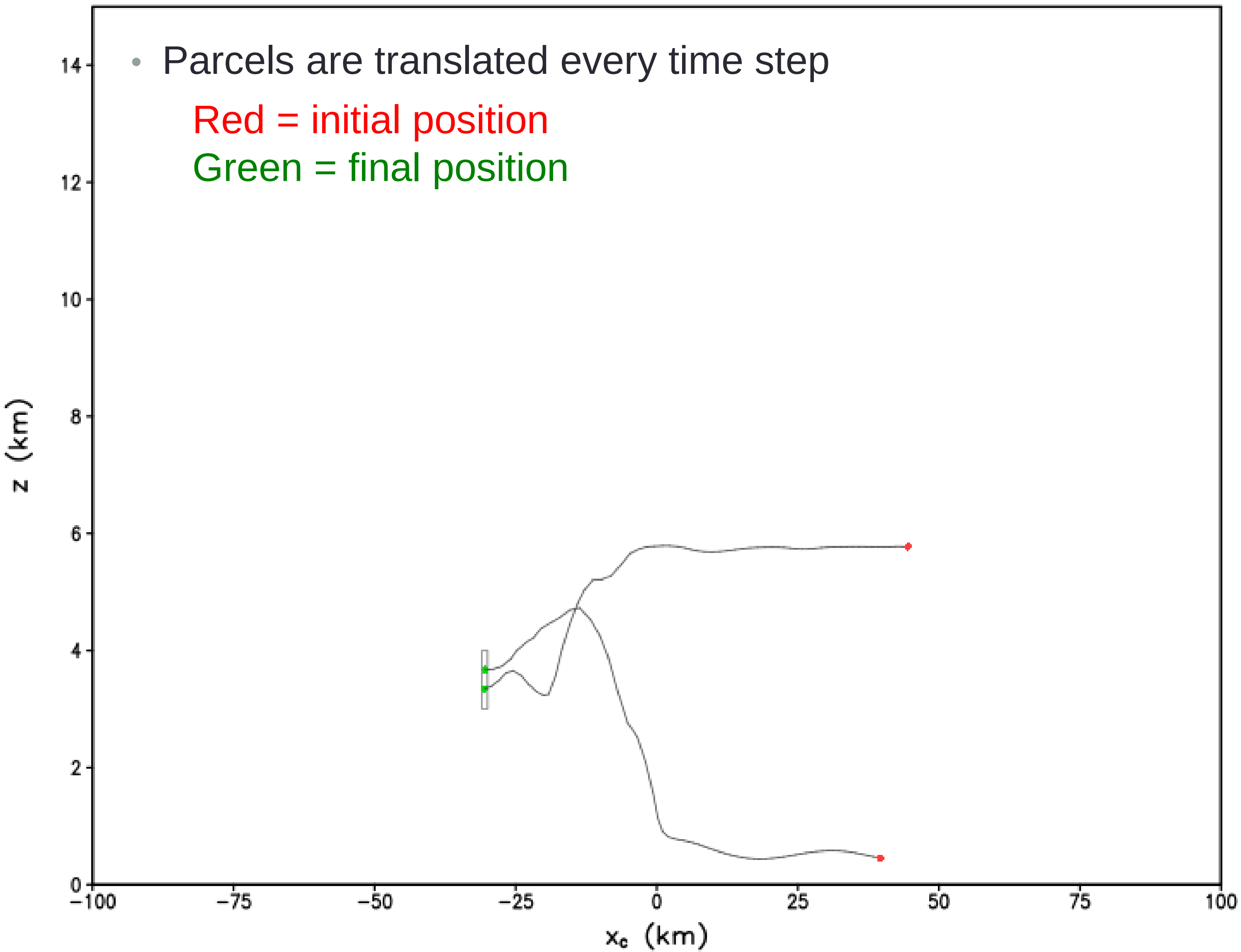


Trajectory analysis

- Parcels are translated every time step

  Red = initial position

  Green = final position



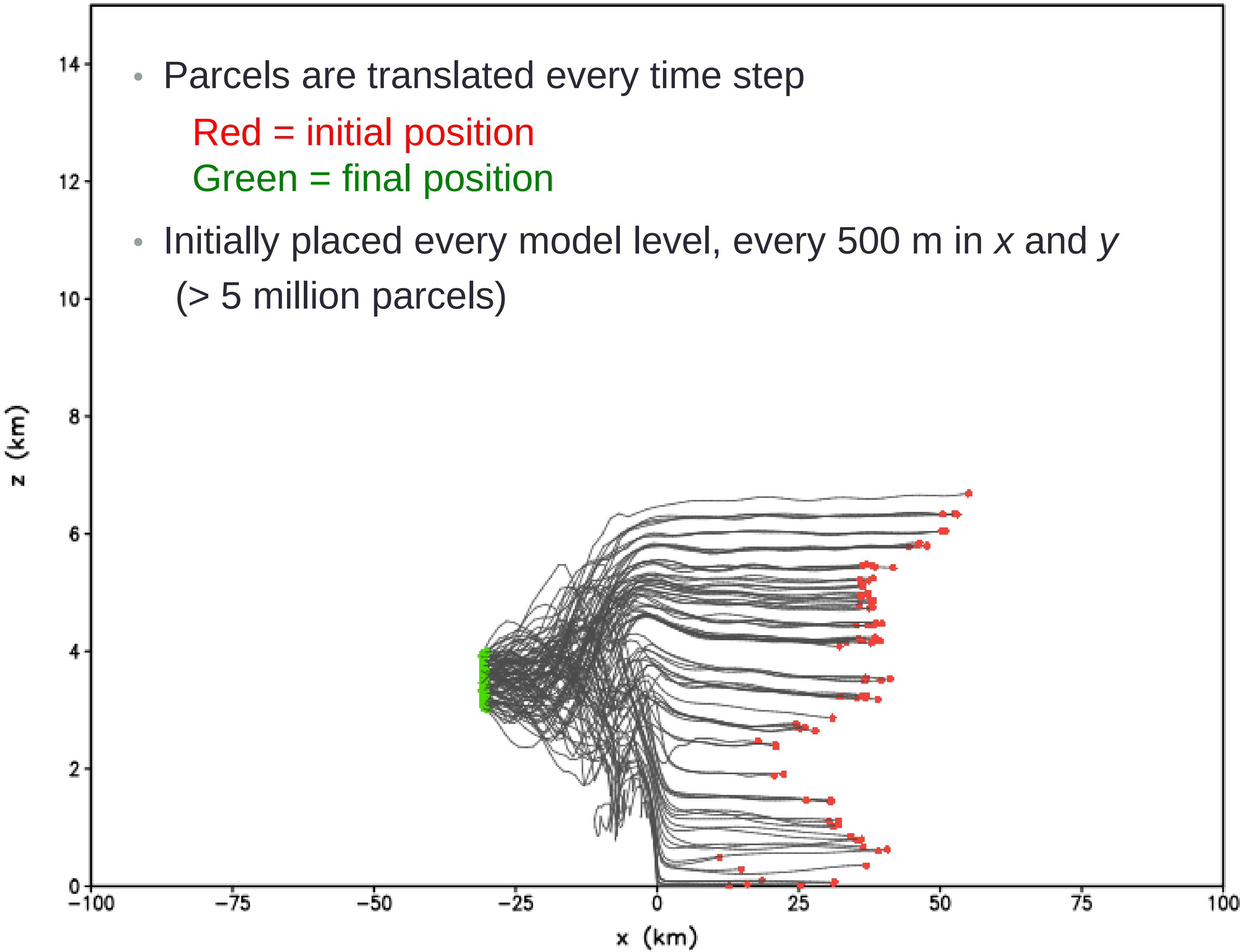
Trajectory analysis

- Parcels are translated every time step

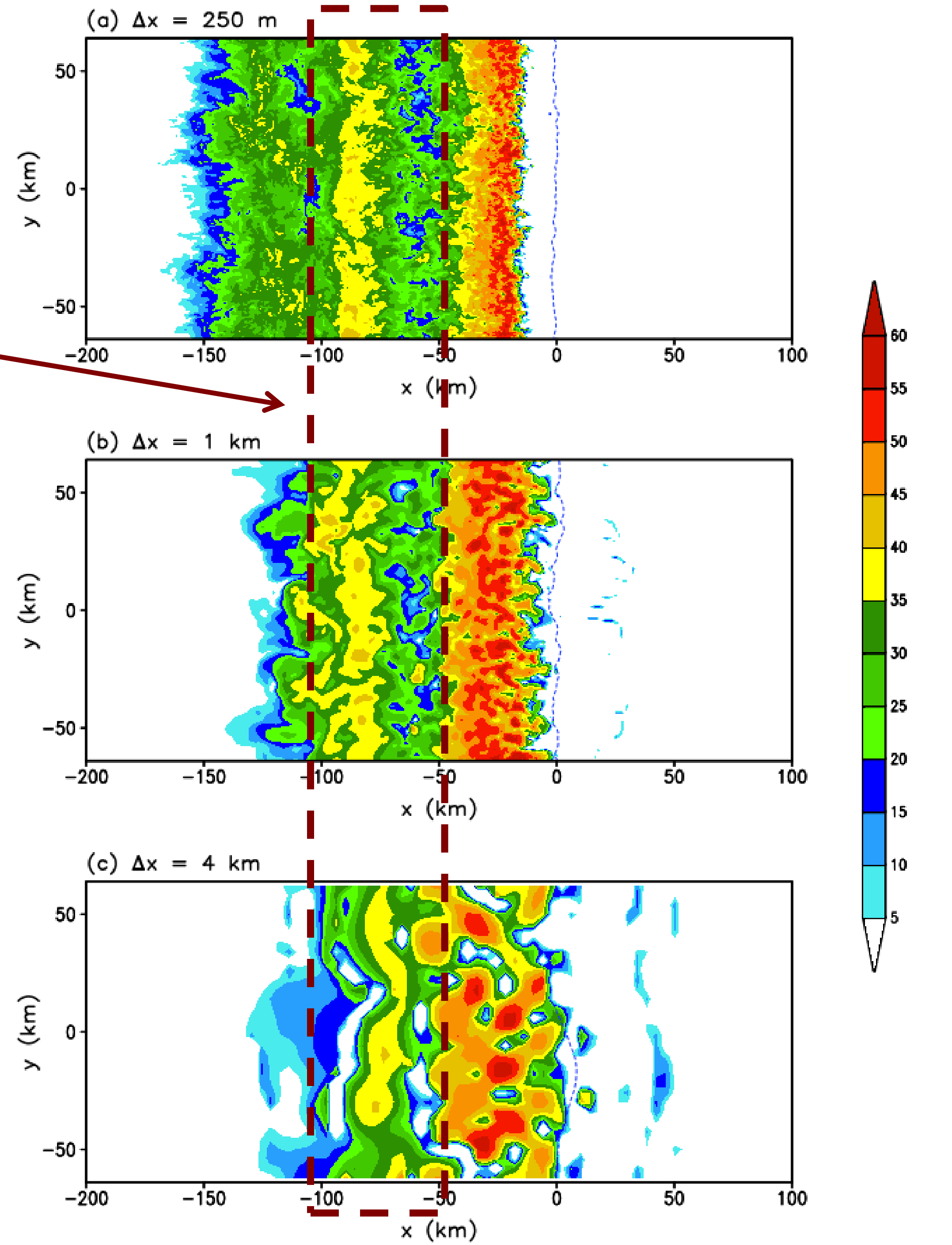
  Red = initial position

  Green = final position

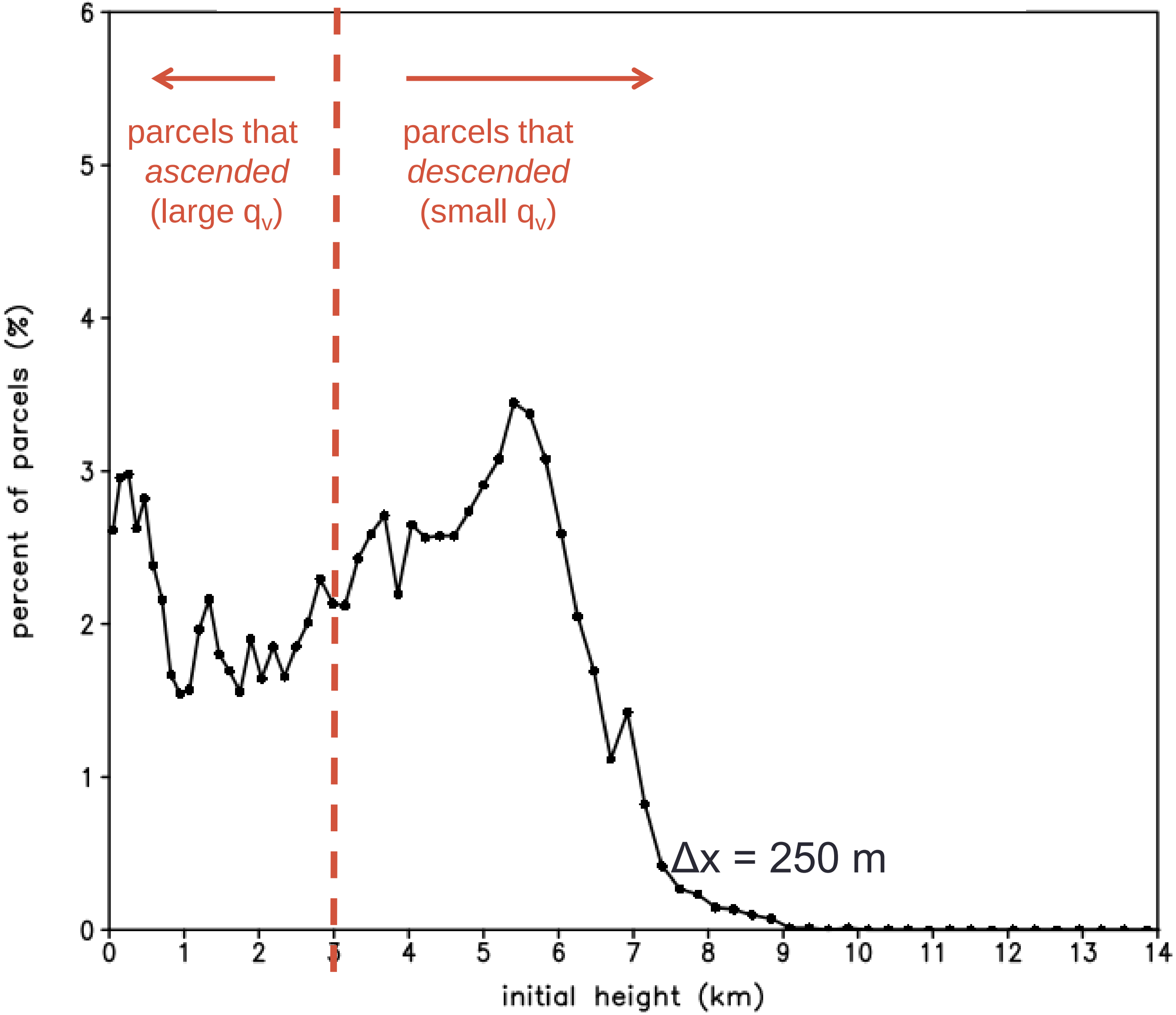
- Initially placed every model level, every 500 m in *x* and *y* (> 5 million parcels)

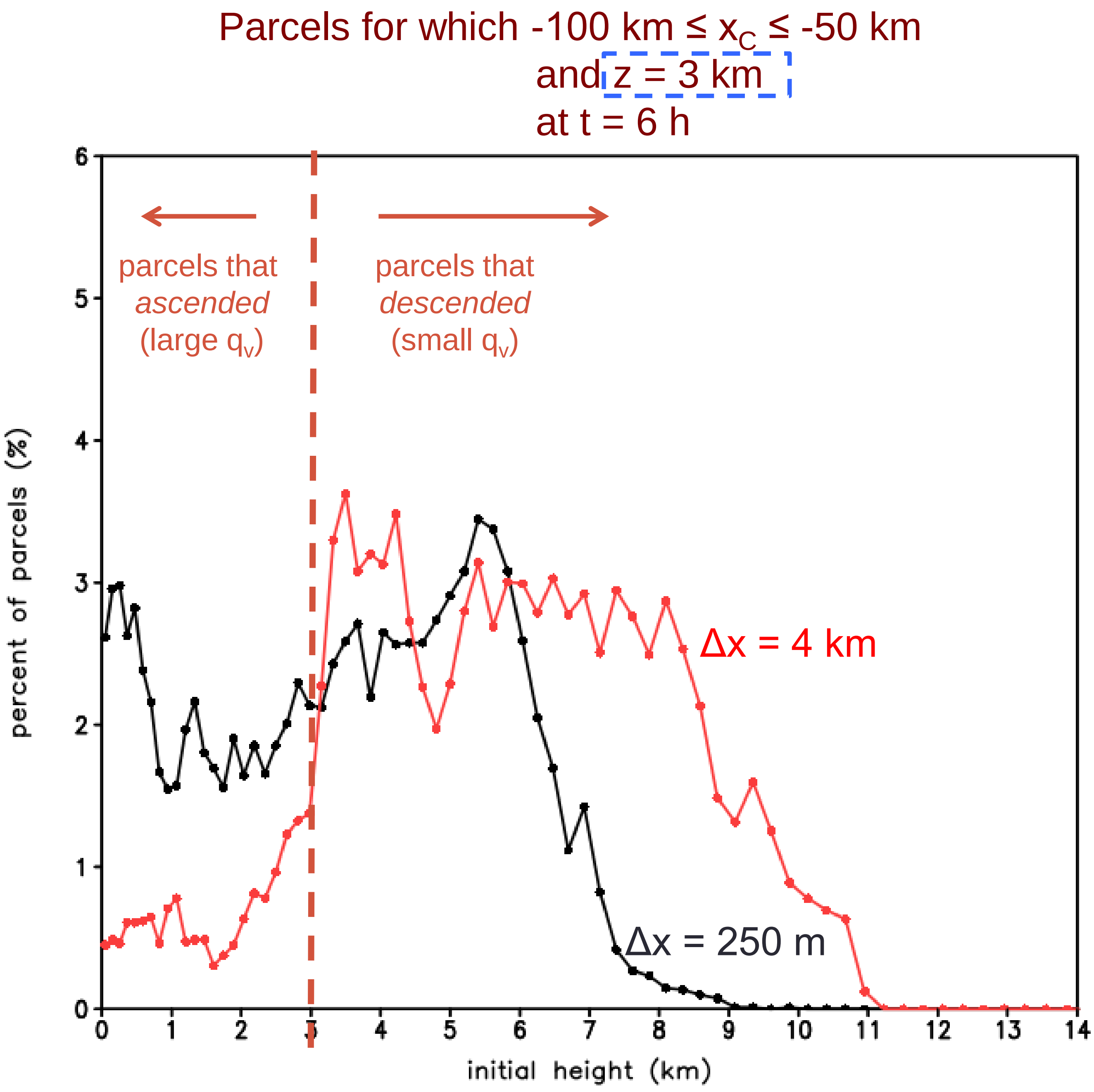


Find all parcels in this region
(-100 km ≤ x_c ≤ -50 km)
at t = 6 h



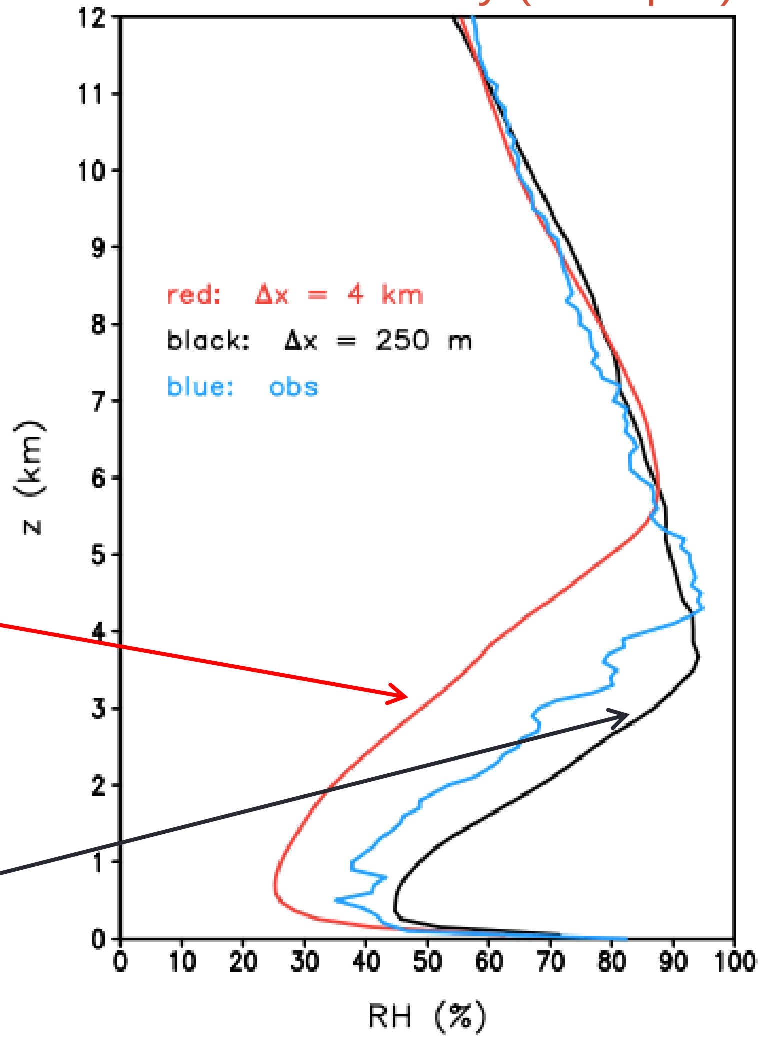
Parcels for which -100 km ≤ x_C ≤ -50 km
and z = 3 km
at t = 6 h





Parcels for which -100 km ≤ x_C ≤ -50 km
and z = 3 km
at t = 6 h
parcels that
ascended
(large q_v)
parcels that
descended
(small q_v)
Δx = 4 km
Δx = 250 m
percent of parcels (%)
initial height (km)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

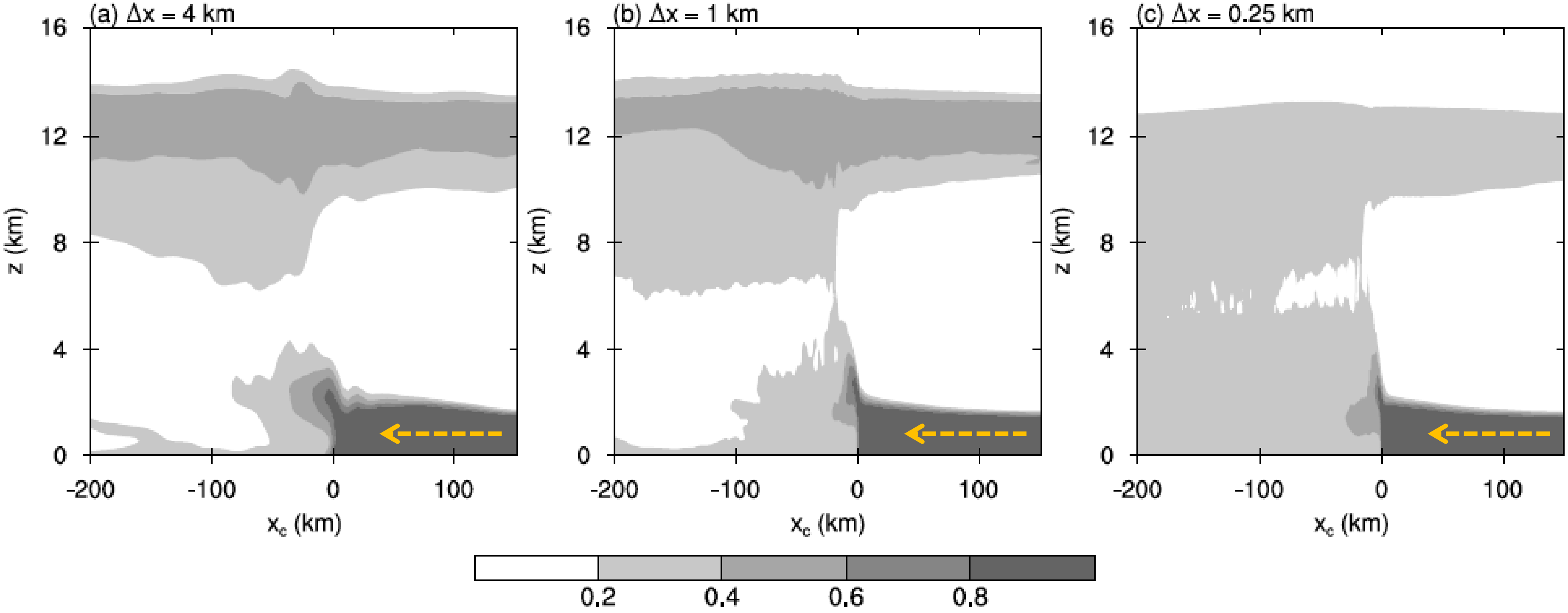
Relative humidity (wrt liquid)



Mostly air from aloft

A mixture of air from aloft and air from PBL

Sensitivity to Δx: passive fluid tracer (g kg^{-1})



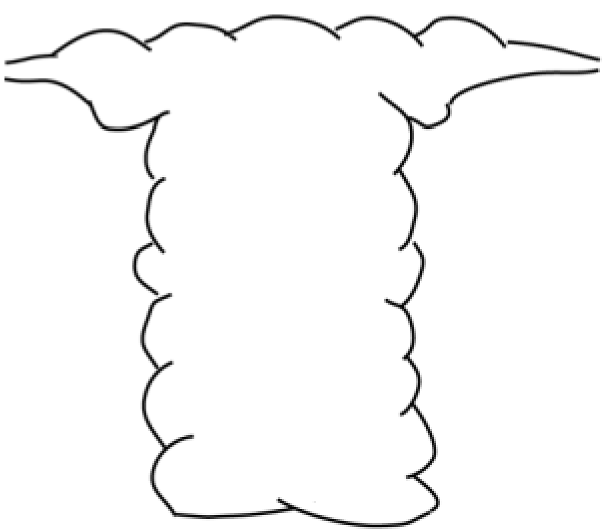
Bryan and Morrison (2012)

Summary

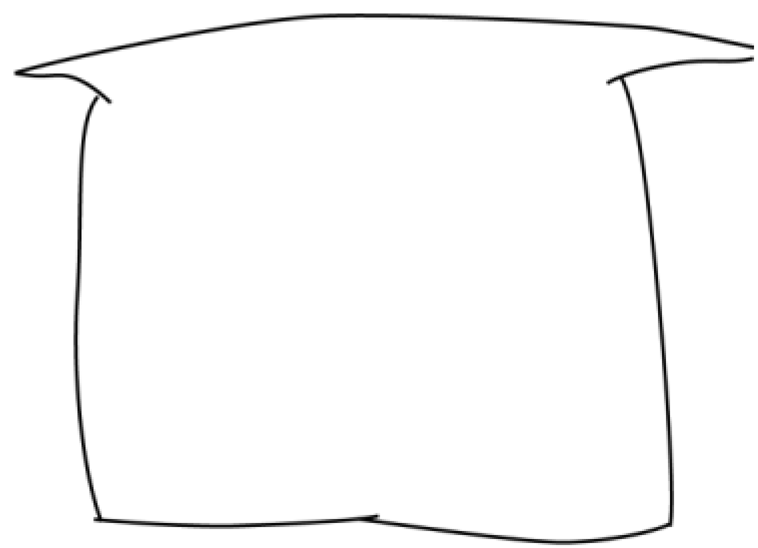
- With “eddy-resolving” grid spacing (Δx ≈ 100 m):
  - air from PBL mixed throughout the troposphere
  - thus, acts to moisten mid-levels (*detrainment*)

- With “cloud permitting” grid spacing (Δx ≈ 4 km)
  - air from PBL does not mix … it all ends up near the tropopause
  - thus, mid-level air in stratiform region is relatively dry

Δx ≈100 m (and real clouds)



Δx ≈4 km



Discussion Topics

- Eddy-resolving grid spacing of ≈100 m is not possible in operations
  - But, they show us what is (probably) happening in the "real world"
- So how can we improve operational models ($\Delta x \approx 4$ km)?
  - We need a better in-cloud turbulence/mixing parameterization for these models (*detrainment* parameterization)
  - But, in my experience: more turbulence/mixing can "kill" the convection
- How does this affect forecasts?
  - Precipitation rates: $\Delta x \approx$ 1-4 km tend to overestimate rainfall
  - Radiative feedbacks? (due to changes in cloud top/bottom)
    - Implications for medium-range forecasts