Sensitivity of Precipitation Accumulation in Elevated Convective Systems to Small Changes in Low-level Moisture

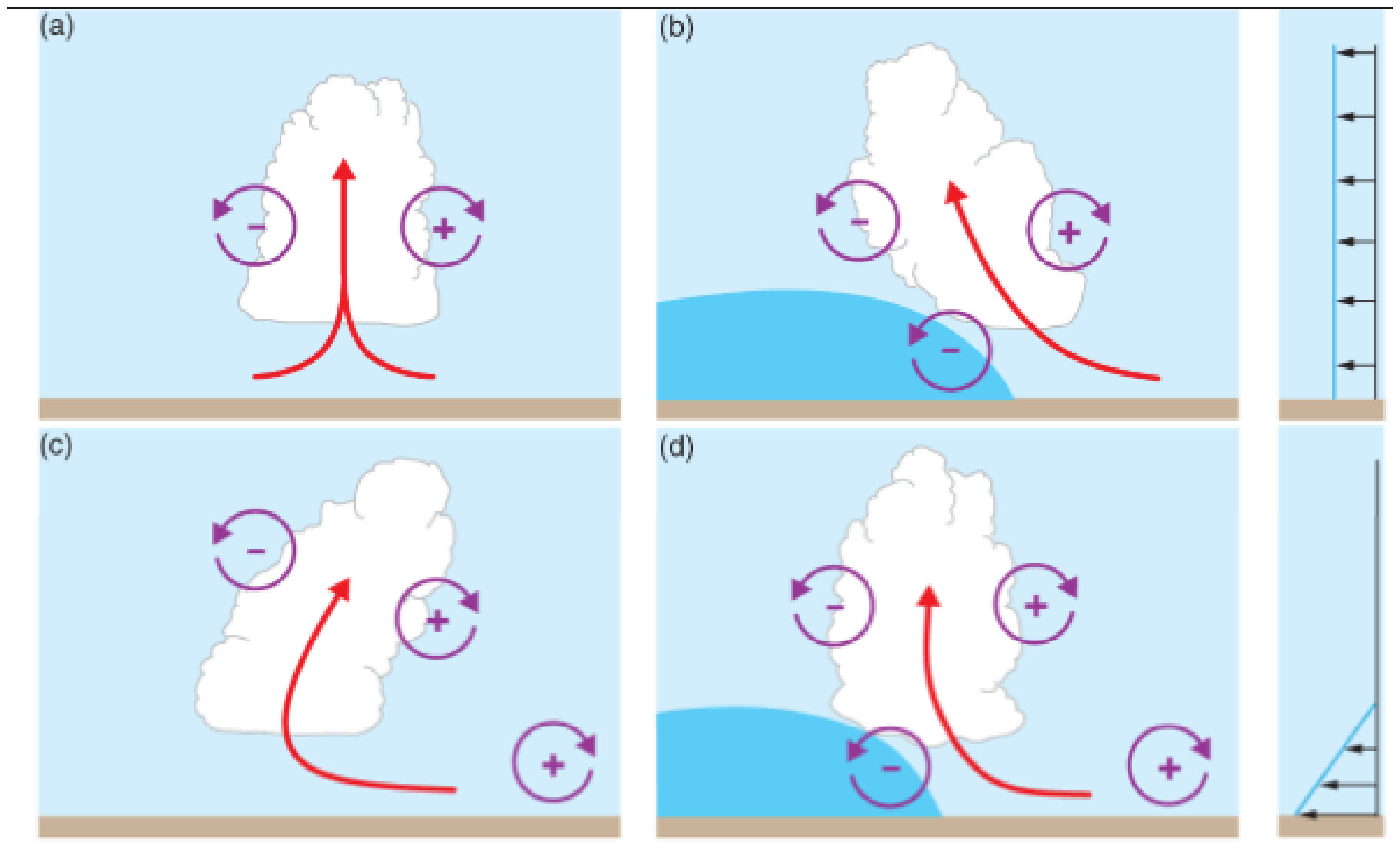
Russ S. Schumacher (JAS 2015)

Nocturnal Convective System Characteristics

- *The main difference between nocturnal MCSs and daytime MCSs is the lack of ascent for surface parcels [due to radiative cooling] -> "Elevated" convective systems*

- *Some types of mesoscale forcings that favor elevated MCS sustenance: (i) Frontal lifting, (ii) MCV*

- *Elevated MCS maintenance mechanism: Cold pool or gravity wave/bore?*



(Rotunno et al. 1988)

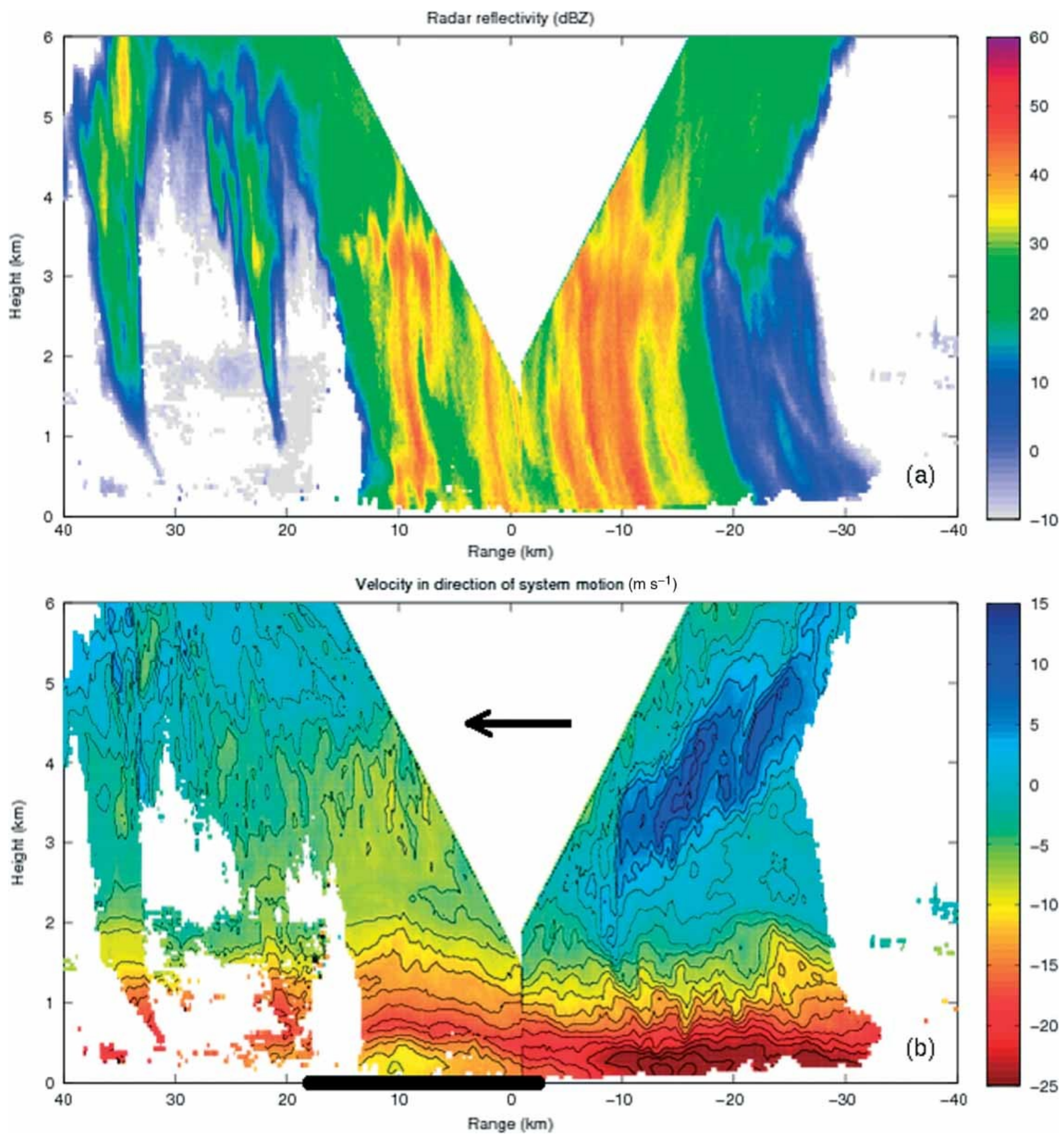
Missing puzzles in our current understanding on nocturnal MCS

- ***Gravity wave/bores created when convective outflow interacts with NBL seems to be the main mechanism for nocturnal MCS sustenance. (French and Parker 2010)***
- ***Does a continuum exist between surface-based and nocturnal MCSs?***

(1) Model simulation suggests that several hours of sustained cooling is needed before MCS becomes fully elevated (Parker 2008)

(2) Strong dynamical forcings (e.g. Upward PGF in nocturnal supercells) can ingest boundary layer parcels despite stable BL (Nowotarski et al. 2011)

- ***Sensitivity of the convection and associated hazard to near-storm environment?***



(Marsham et al 2010)

What does this paper address?

Predictability of nocturnal MCS under different surface environmental conditions

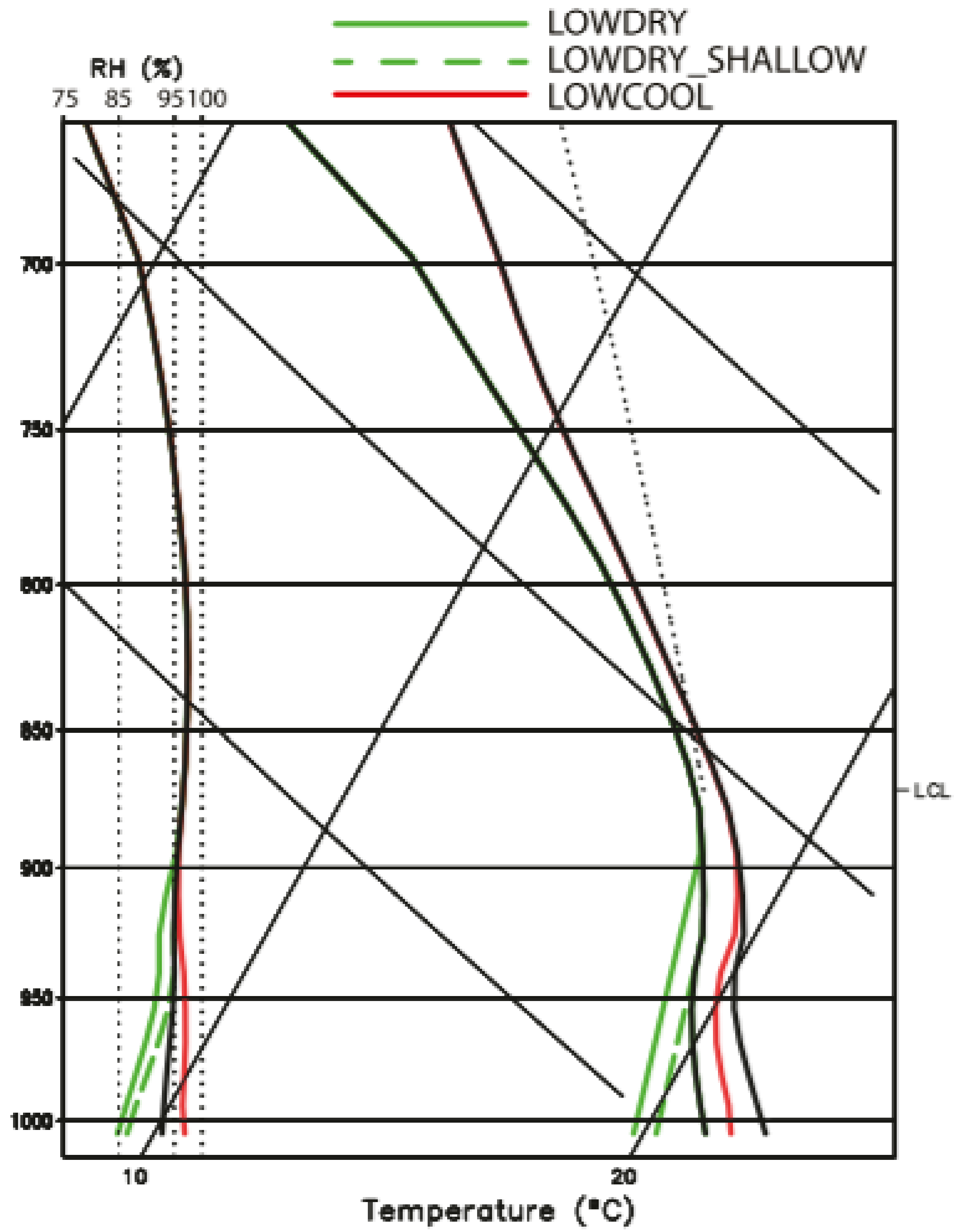
Can small changes in low-level moisture impact precipitation accumulation?

Their impacts on storm dynamics?

Methodology and experimental design

- *Model configuration is highly similar to Schumacher (2009), with slight differences including (a) Use of a two-moment microphysical scheme [Morrison], (b) Higher spatial resolution [Horizontal grid spacing ~500m in S15; 1km in S09; 61 stretched vertical levels]*
- *Simulations conducted with CM1 cloud model. MCS initiated by an applied momentum forcing -> causes a 3d convergence field [emulates MCV-induced MCSs]*
- *Initial sounding: Composited extreme rainfall sounding [Schumacher and Johnson (2009)]*

(1) Lowest 1.1 km (Nocturnal Stable Layer)
(2) Most unstable parcels height: ~875hPa
(3) Reverse wind profile [not shown]: emulate nocturnal LLJ



Methodology and experimental design: Sensitivity tests

TABLE 1. Details regarding the initial soundings for the numerical experiments. Differences from the control sounding are given in parentheses; percentage differences are given for IWV. The prefix MU refers to parcels lifted from the level with the highest θ_e; SB refers to parcels lifted from the lowest model level.

Experiment	T_{sfc} (°C)	Td_{sfc} (°C)	MUCAPE (J kg^{-1})	MUCIN (J kg^{-1})	SBCAPE (J kg^{-1})	SBCIN (J kg^{-1})	LFC_{MU} (hPa)	LFC_{SB} (hPa)	IWV (mm)
Control	22.5	21.2	1200	1	618	61	850	783	50.40
LOWDRY	22.5	19.8 (−1.4)	1200	1	113 (−505)	162 (+101)	850	682	49.87 (−1.0%)
LOWDRY_ SHALLOW	22.5	20.2 (−1.0)	1200	1	256 (−362)	122 (+61)	850	734	50.24 (−0.3%)
LOWCOOL	21.7 (−0.8)	21.2	1200	1	493 (−125)	70 (+9)	850	770	50.40

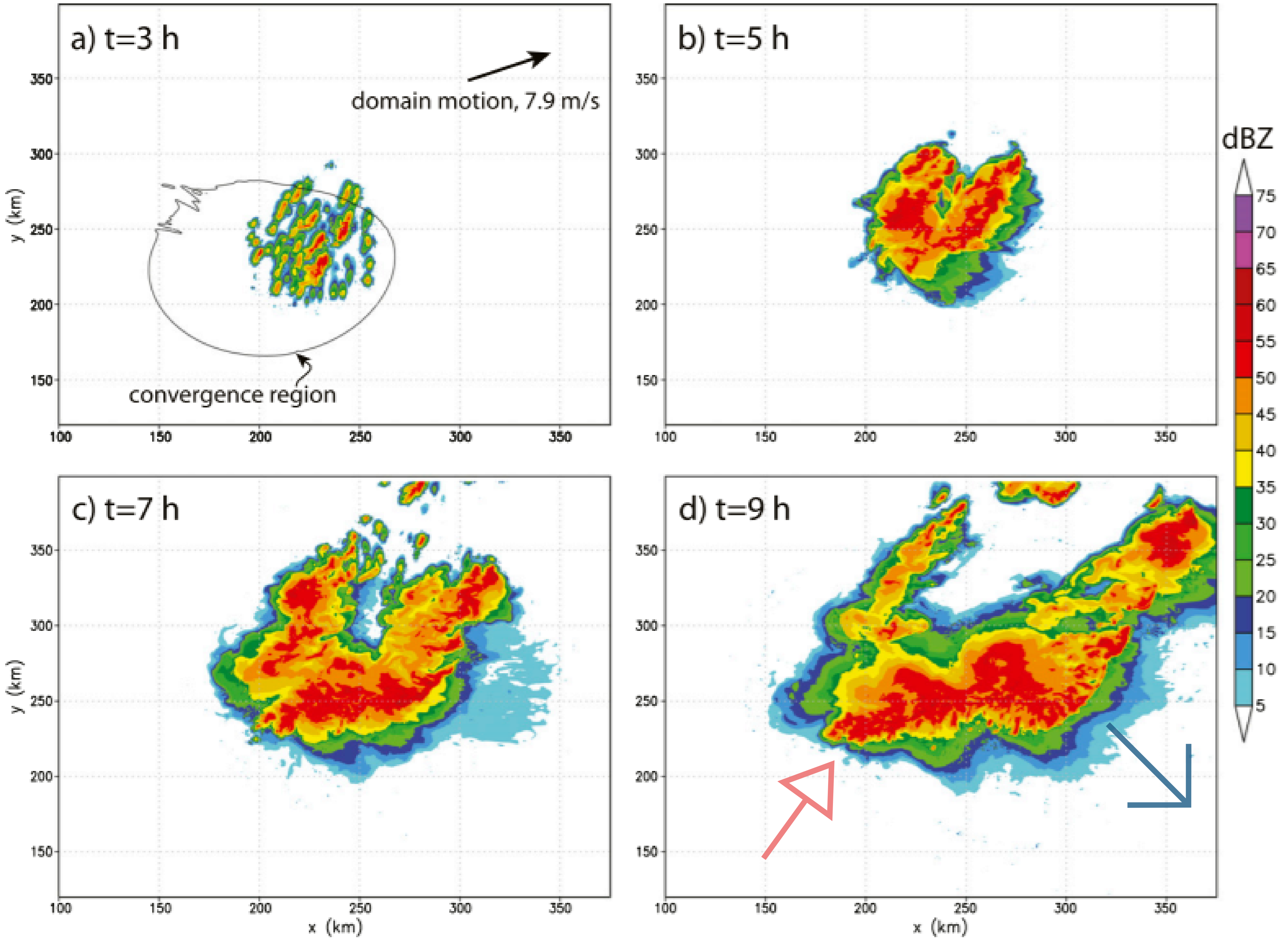
- *LOWDRY: Assumes lowest 1.1km to be well-mixed -> Lowest 1.1km effectively decreases comparing to CTRL [qv: 16.18 g/kg -> 14.62 g/kg]*
- *LOWDRY-SHALLOW: Apply moisture change only to the lowest 700m [qv: 15.05 g/kg]*

(Moisture difference between LOWDRY/LOWDRY-SHALLOW and CTRL are comparable to average RUC analysis moist bias within boundary layer [Coniglio (2012)]

- *LOWCOOL: To confirm if the difference between CTRL and LOWDRY/LOWDRY-SHALLOW are caused by moisture*

Results: General characteristics of CTRL simulation

- *Concurrent forward and backward propagating convective lines are occasionally observed in the region (Keene and Schumacher 2013; Peters and Schumacher 2015a,b)*
- *These systems have high local high precipitation potential*

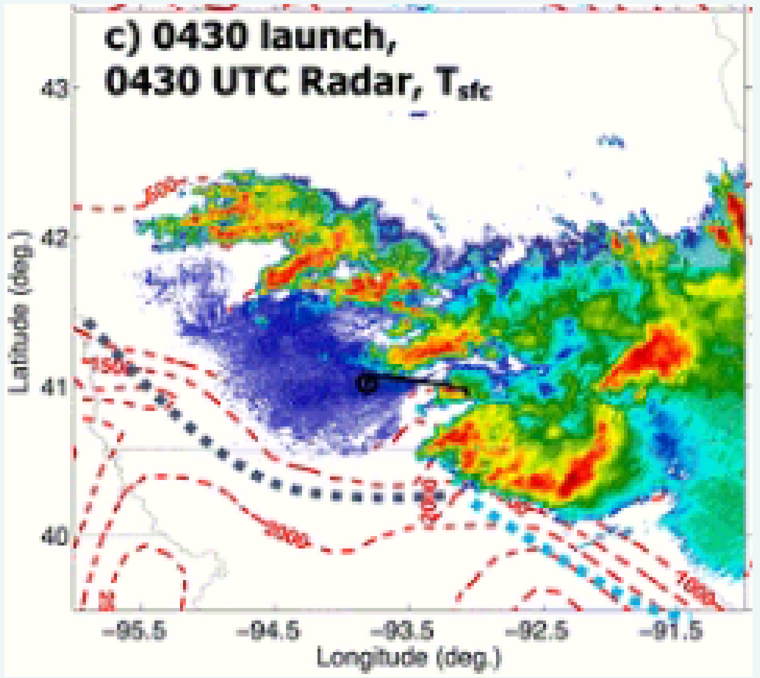


Results: General characteristics of CTRL simulation

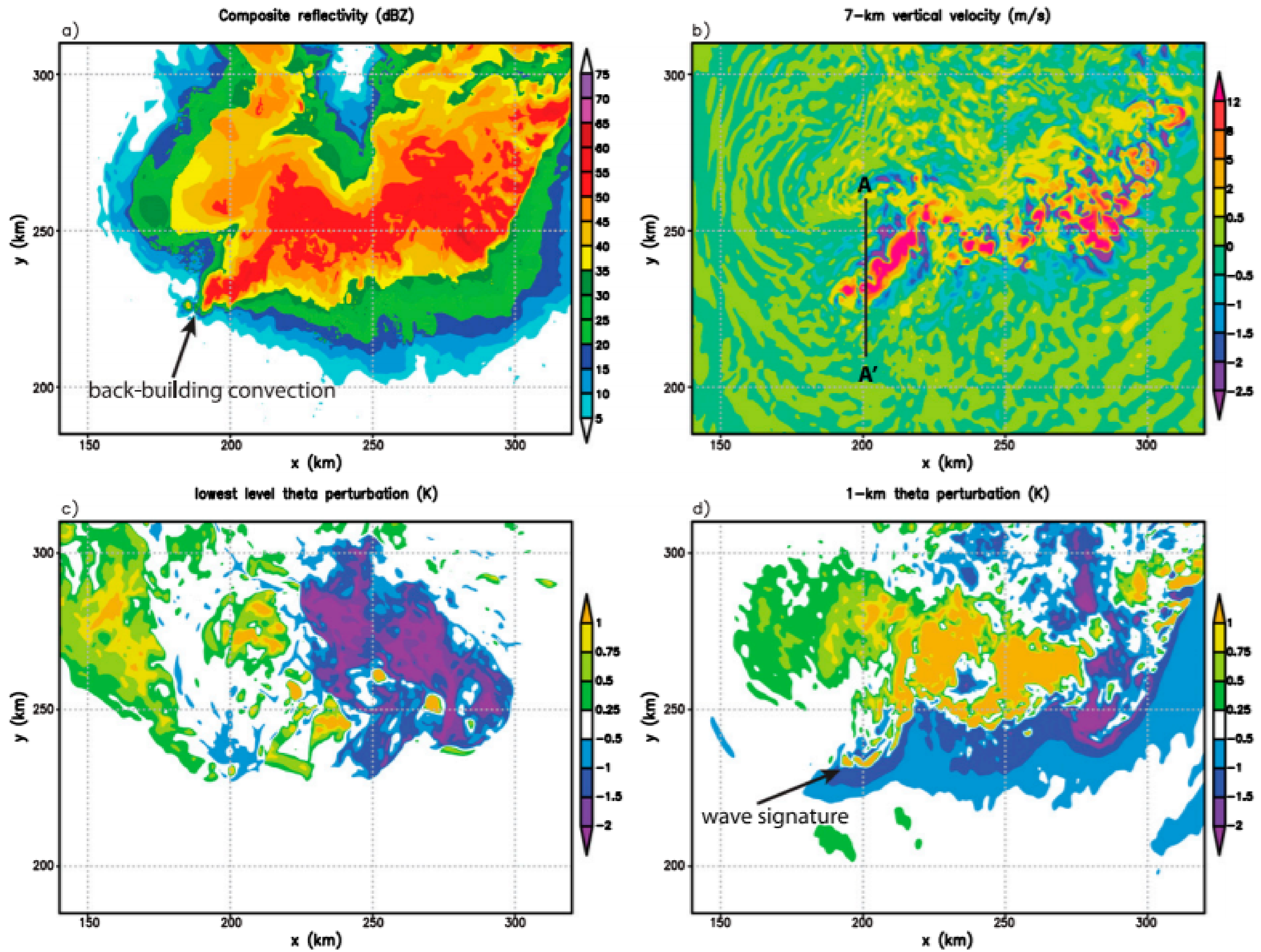
- *Potential temperature perturbation at 2 different levels (c,d) reveal different sustaining mechanisms for the convective lines:*

(a) SE-propagating line: Organization along cold pool

(b) Backbuilding convective line: Sustained by low-tropospheric gravity wave [d].



PECAN IOP15 (Peters et al. 2017)

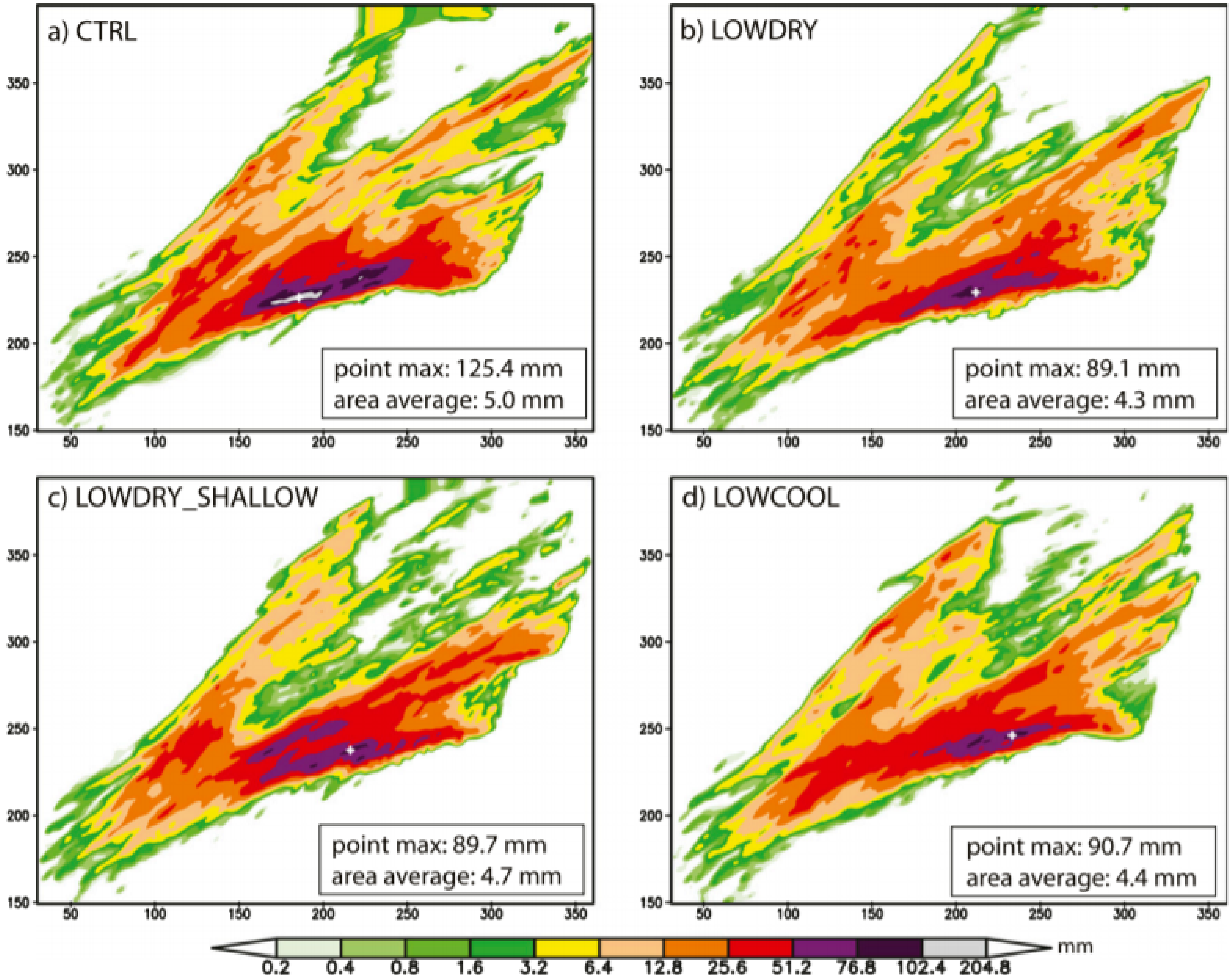


Results: Precipitation Accumulation

- ***Region of heaviest precipitation correlates well with back-building convections.***
- ***6hr precipitation of ~125mm is consistent with observed MCV-induced MCSs (Schumacher et al. 2013)***
- ***Precipitation spatial distribution are similar between 4 experiments, but rainfall accumulation was heavily impacted by environmental condition changes***
- ***Possible reasons for decreased surface precipitation:***

(a) Increased evaporation in subcloud layer
(b) Convective intensity change
(c) Difference in convective organization and propagation (cold pool? other mechanisms?)

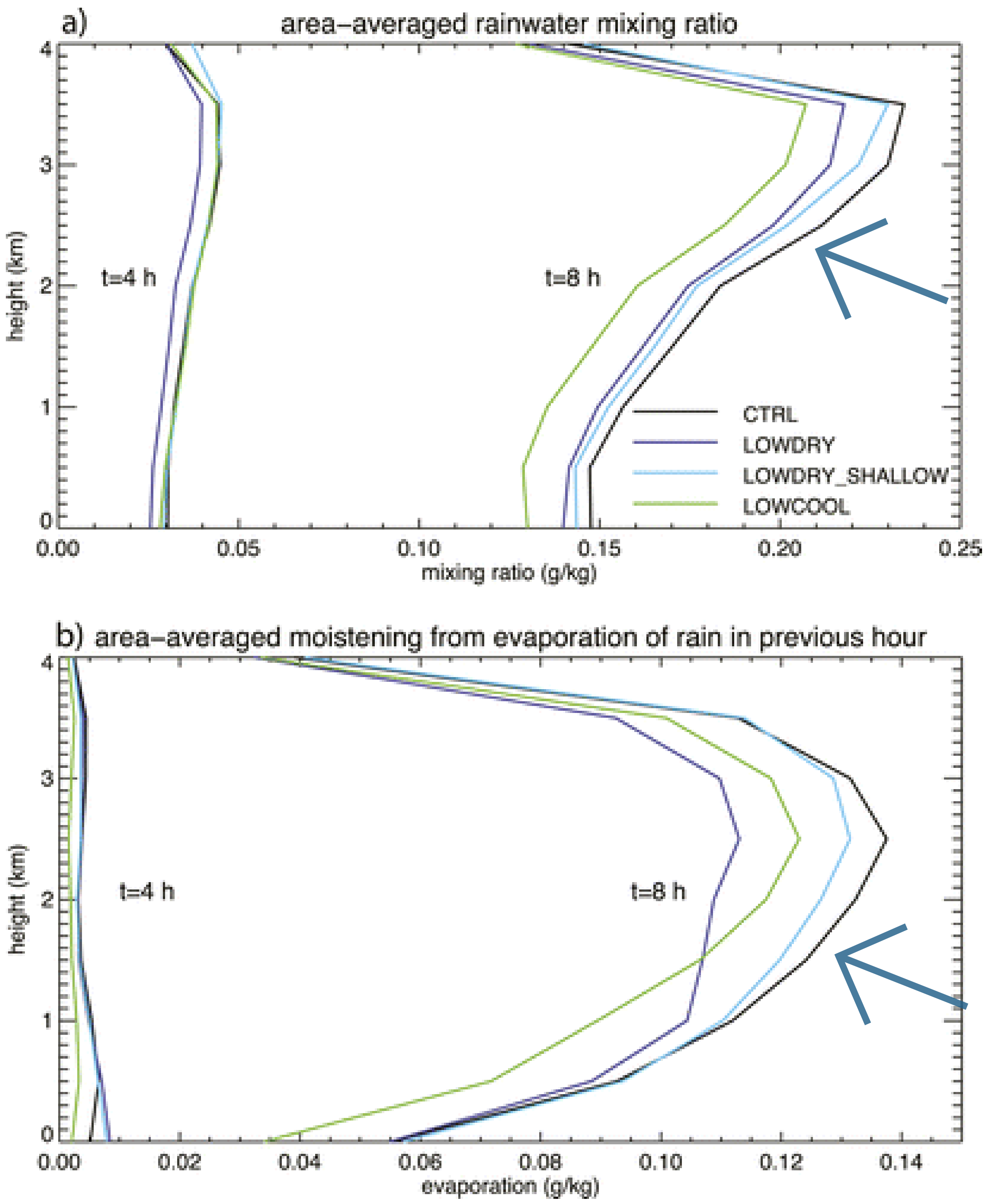
6hr accumulated rainfall



Experiment	Maximum (mm)	Difference (%)	Area average (mm)	Difference (%)
Control	125.4	—	5.0	—
LOWDRY	89.1	−29	4.3	−15
LOWDRY_SHALLOW	89.7	−28	4.7	−6
LOWCOOL	90.7	−28	4.4	−12

Results: Examining the cause of rainfall reduction

- *Slightly stronger subcloud evaporation for drier BL experiments (but only during developing phase)*
- *During mature phase (t=8h), CTRL evaporative rate > sensitivity tests [More rainwater is produced -> increased evaporative rate]*
- *LOWCOOL evaporative rate is small in the lowest 1.1km (largest RH), but precip rate < CTRL [Less rainwater is produced]*

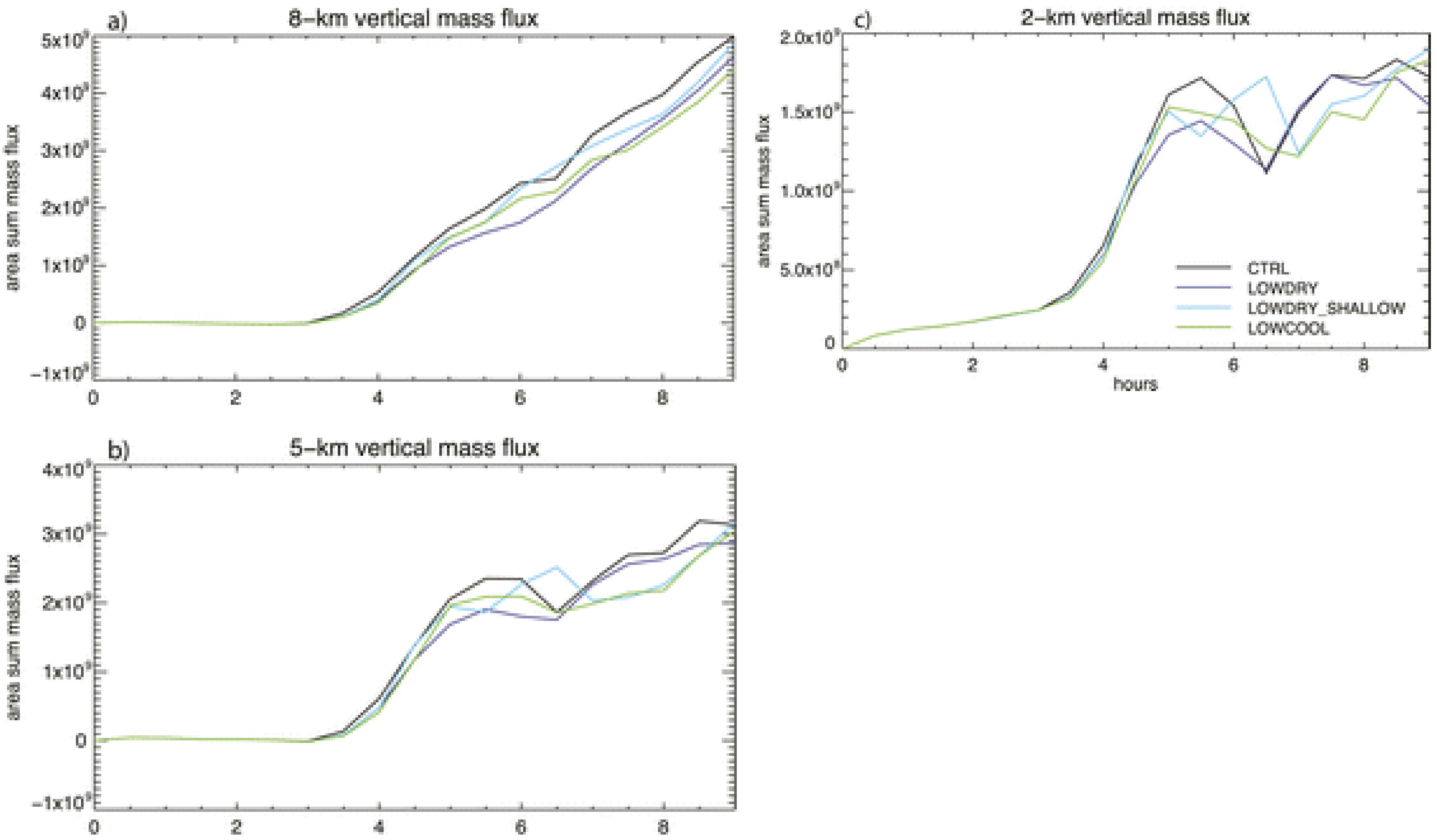


Results: Examining the cause of rainfall reduction

- ***Assuming the qr difference is caused by convective intensity difference, vertical mass flux should reflect this difference***

Findings

- Vertical mass flux tendencies similar between experiments: (Low-Mid levels: Steady increase through 6h, relative minima from 6-7h, resumed increase after 7h; High level: Steady increase throughout)
- CTRL vertical mass flux larger than sensitivity tests for nearly the whole integration period!



Results: Examining the cause of rainfall reduction

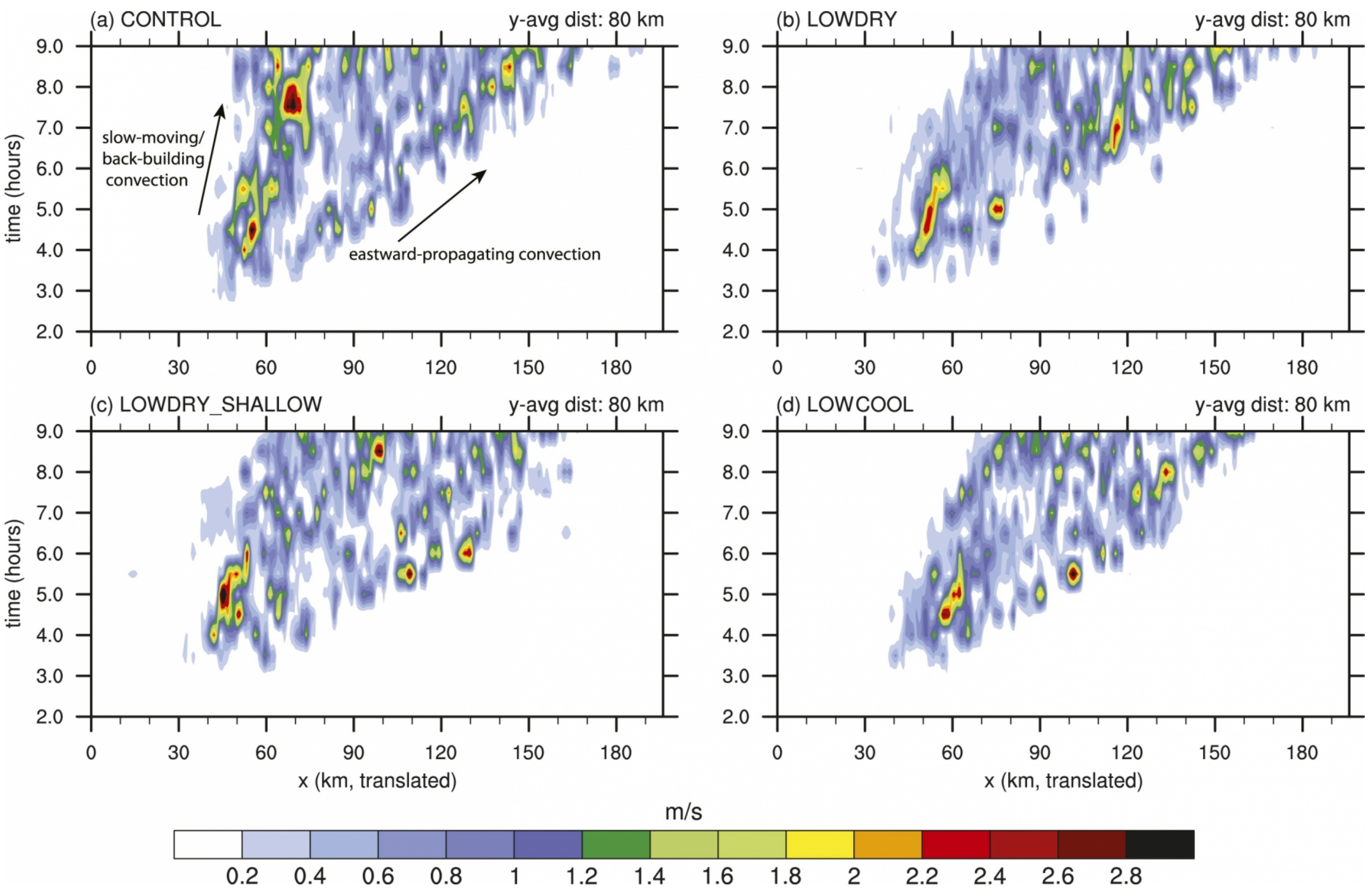
- ***We now examine the spatial factor for stronger vertical mass flux in CTRL (cold pool-dominated eastern line? GW-sustained QS line?)***

Findings

- Eastward-propagating convective line strength similar between experiments (LOWCOOL/LOWDRY_SHALLOW slightly slower than CTRL)
- LOWDRY/LOWCOOL completely missed the back-building, intense convection on MCS upstream flank. Some back-building convection are predicted in LOWDRY_SHALLOW (weaker than CTRL though)

The intensity for back-building convection (not evaporation) is crucial!

Vertical Velocity Hovmoller Diagram



But why?

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Our current knowledge

- Elevated parcel instability essentially unchanged for all experiments
- Substantial SBCAPE in CTRL (despite considerable SBCIN in BL); Low SBCAPE and enhanced SBCIN for LOWDRY/LOWDRY_SHALLOW
- Higher LFC for surface parcels in LOWDRY/LOWDRY_SHALLOW

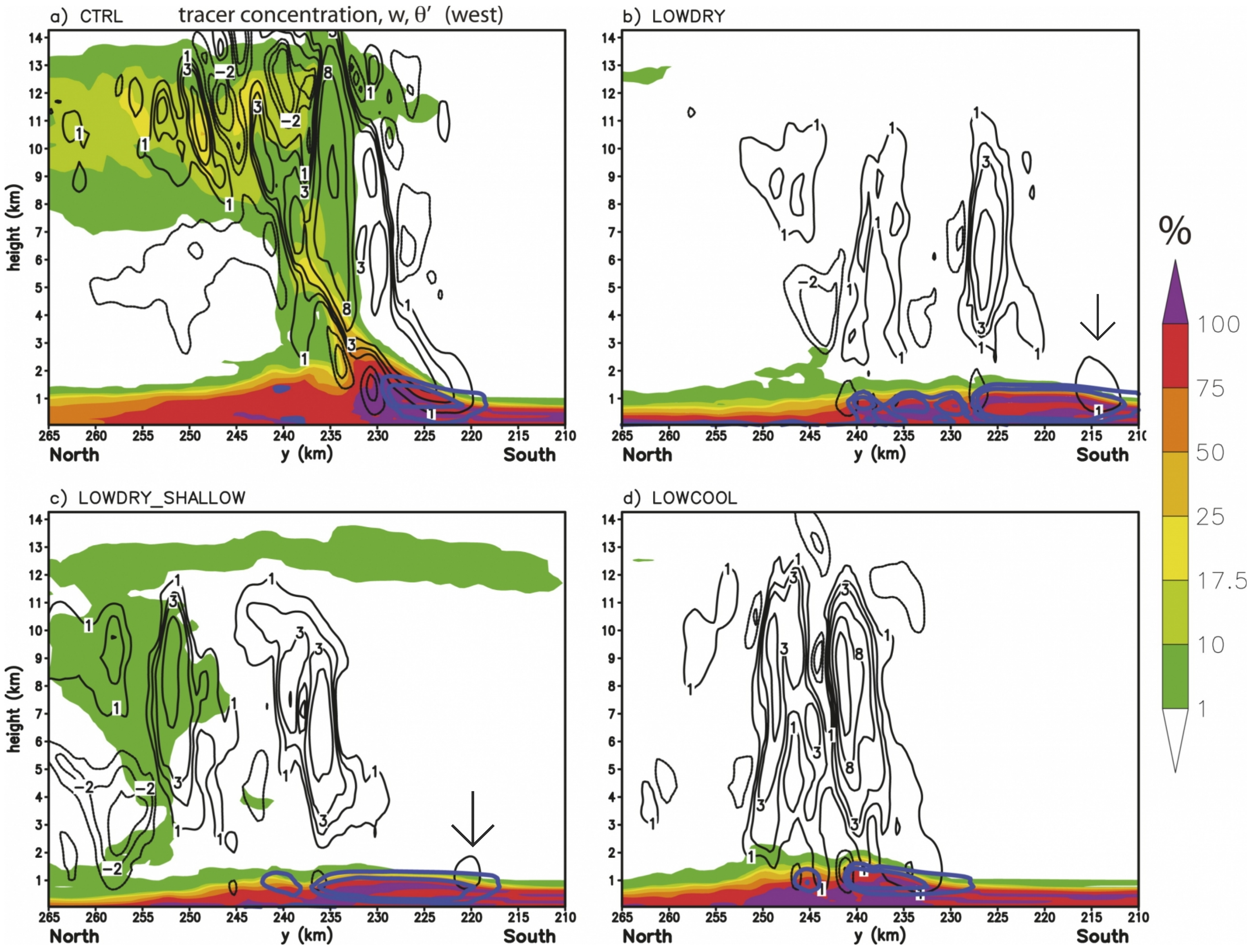
Author's Hypothesis

MCS in CTRL run ingested a considerable amount of near-surface air. LOWDRY/LOWDRY_SHALLOW MCSs more elevated

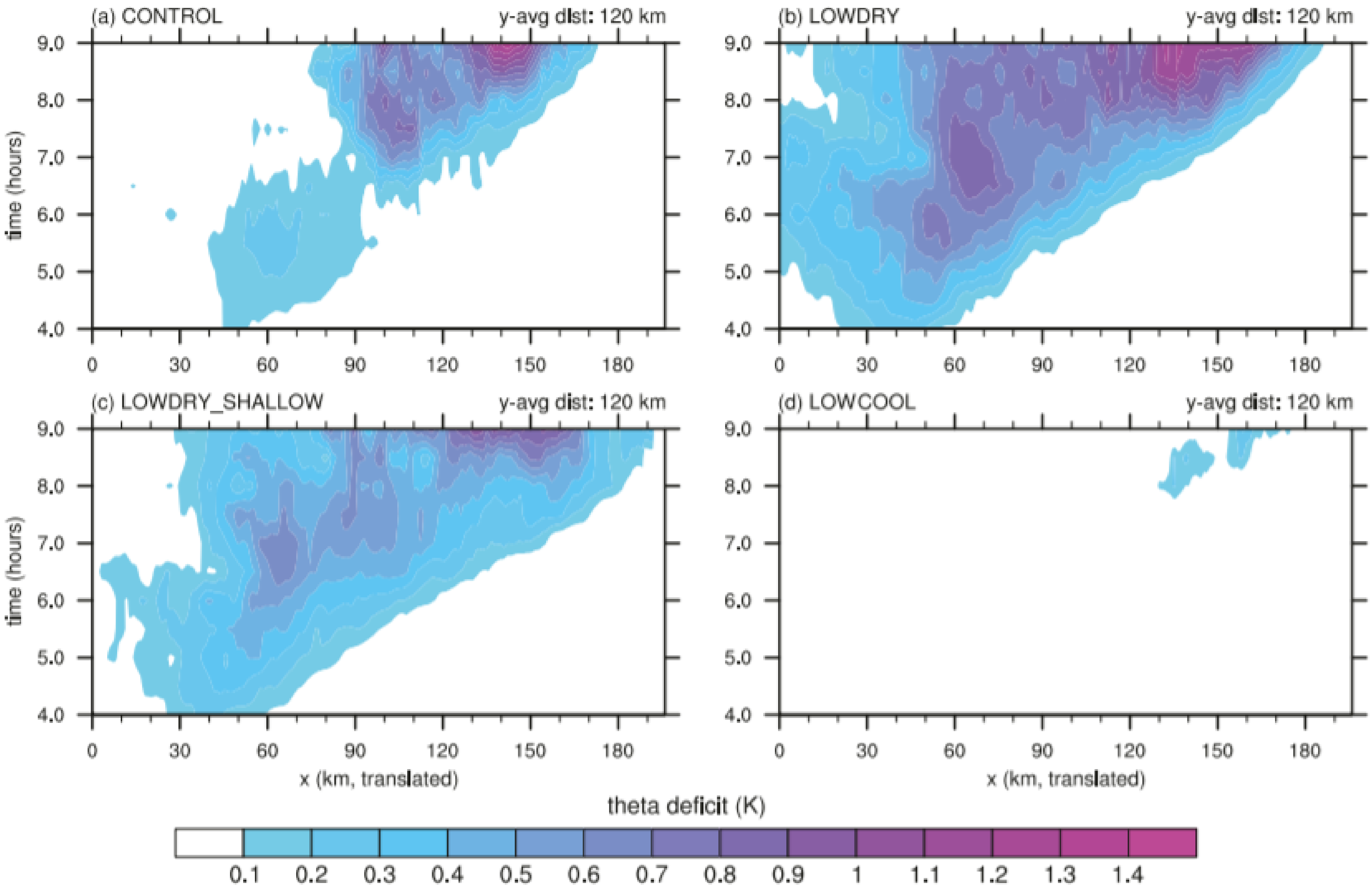
Results: Cross-section analysis (A)

Findings

- About 25% of near-surface tracers could be lifted by the back-building convection on the upstream flank of CTRL run. <1% when lower BL temperature/moisture is applied.
- Notable convective weakening for two moisture-related tests (LOWDRY/LOWDRY_SHALLOW)
- Stronger cold pool in the moisture-reduced runs overwhelmed gravity wave lifting in the two LOWDRY runs.
- Robust GW forcing -> allows for repeated CI along QS wave packets

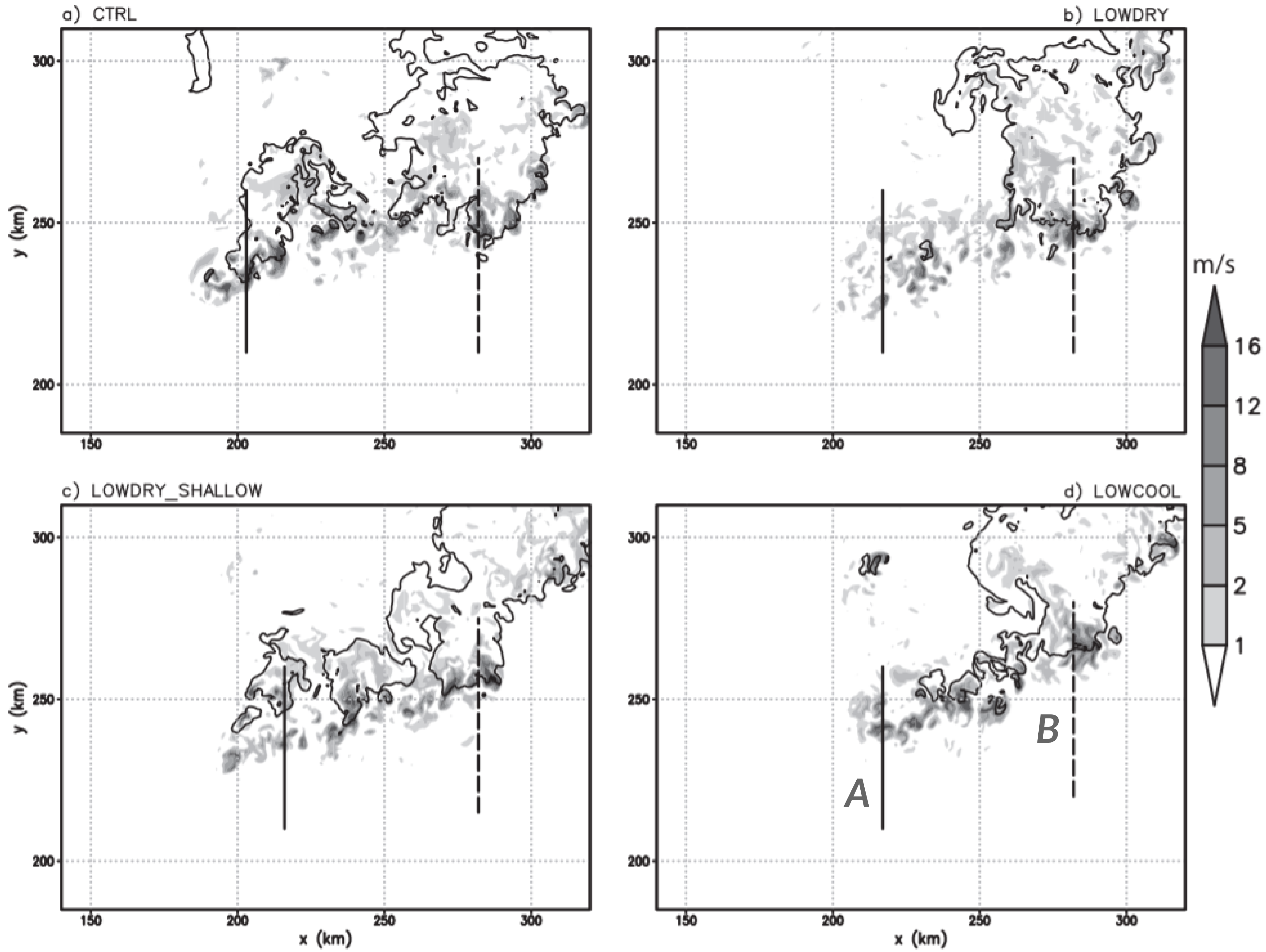


Results: Cold pool comparison



Potential temperature deficit (K) at the lowest model level

Results: Tracer analysis

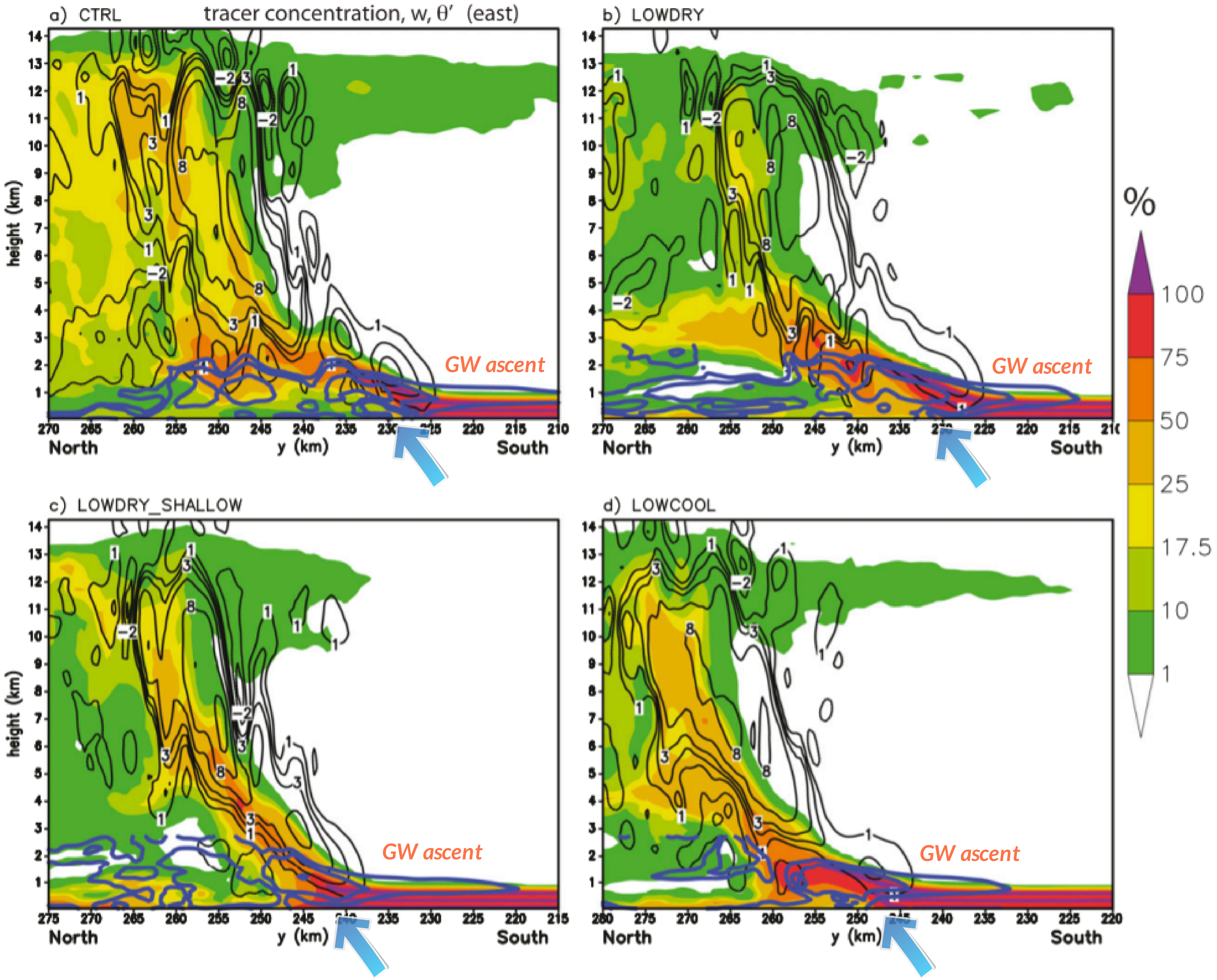


Vertical Velocity (shading), tracer concentration (contour) at z=8km

Results: Cross-section analysis (B)

Findings

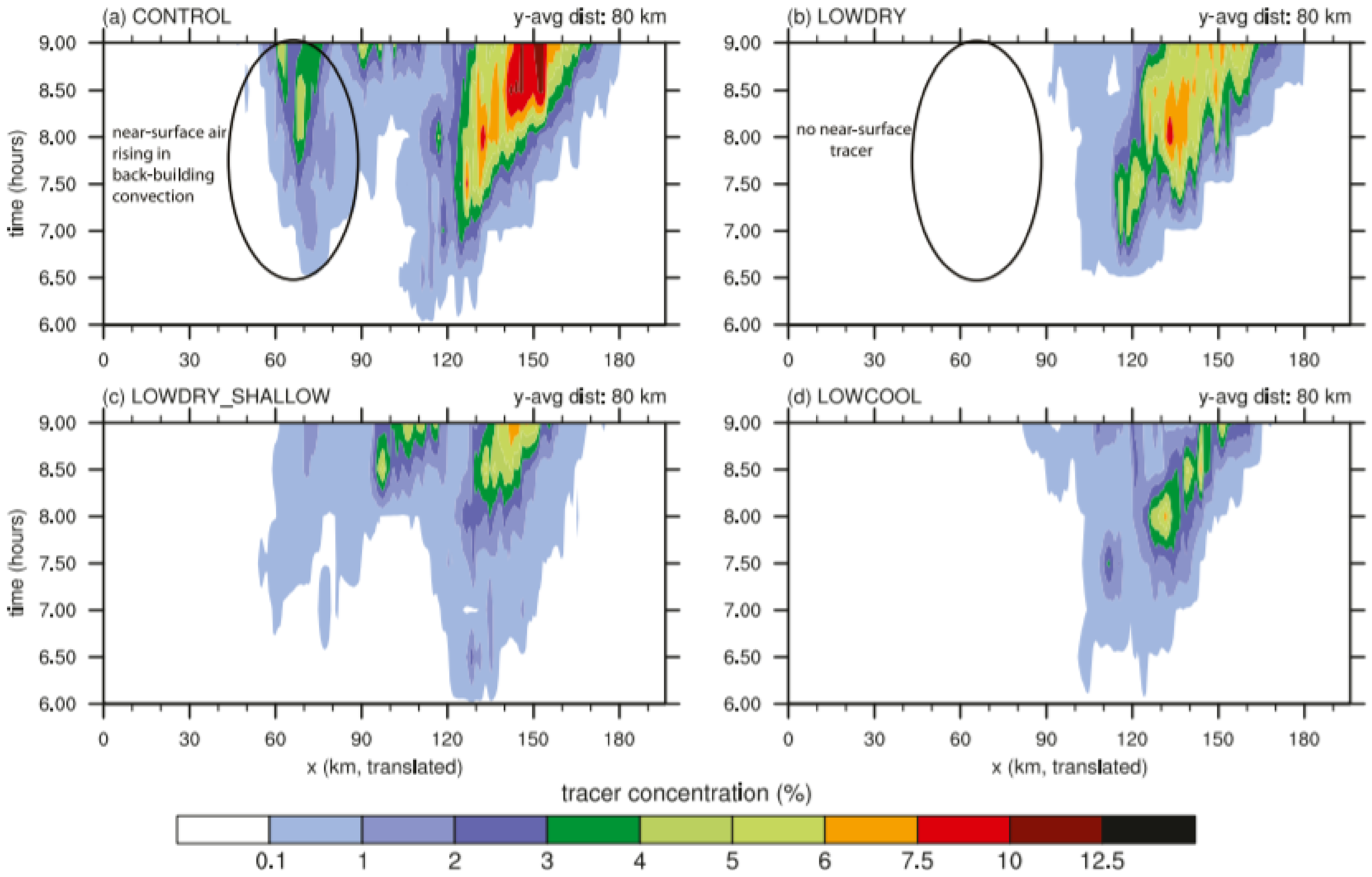
- Consistent with Tracer analysis (Fig.11), all experiments lift a substantial amount of BL tracers aloft
- Main lifting mechanism for forward-propagating convective line is the concentrated lifting along ~2km deep cold pool
- Evidence of low-level GW ascent south of cold pool from potential temperature perturbation
- Cold pool lifting more effective in lifting near-surface tracers than GW lifting [tracer concentration aloft for CTRL cross section B > tracer concentration aloft for CTRL cross section A]



Results: Near-surface tracer hovmollers

Findings

- A considerable amount of near-surface air was lifted by the GW-initiated back-building convection in the western flank of CTRL MCS.
- Next to no near-surface air was lifted in this region.
- As previously discussed. All forward-propagating systems were able to lift BL air aloft (although slight concentration difference existed)



Hovmollers for near-surface [lowest 700m] tracer concentration at z=8km

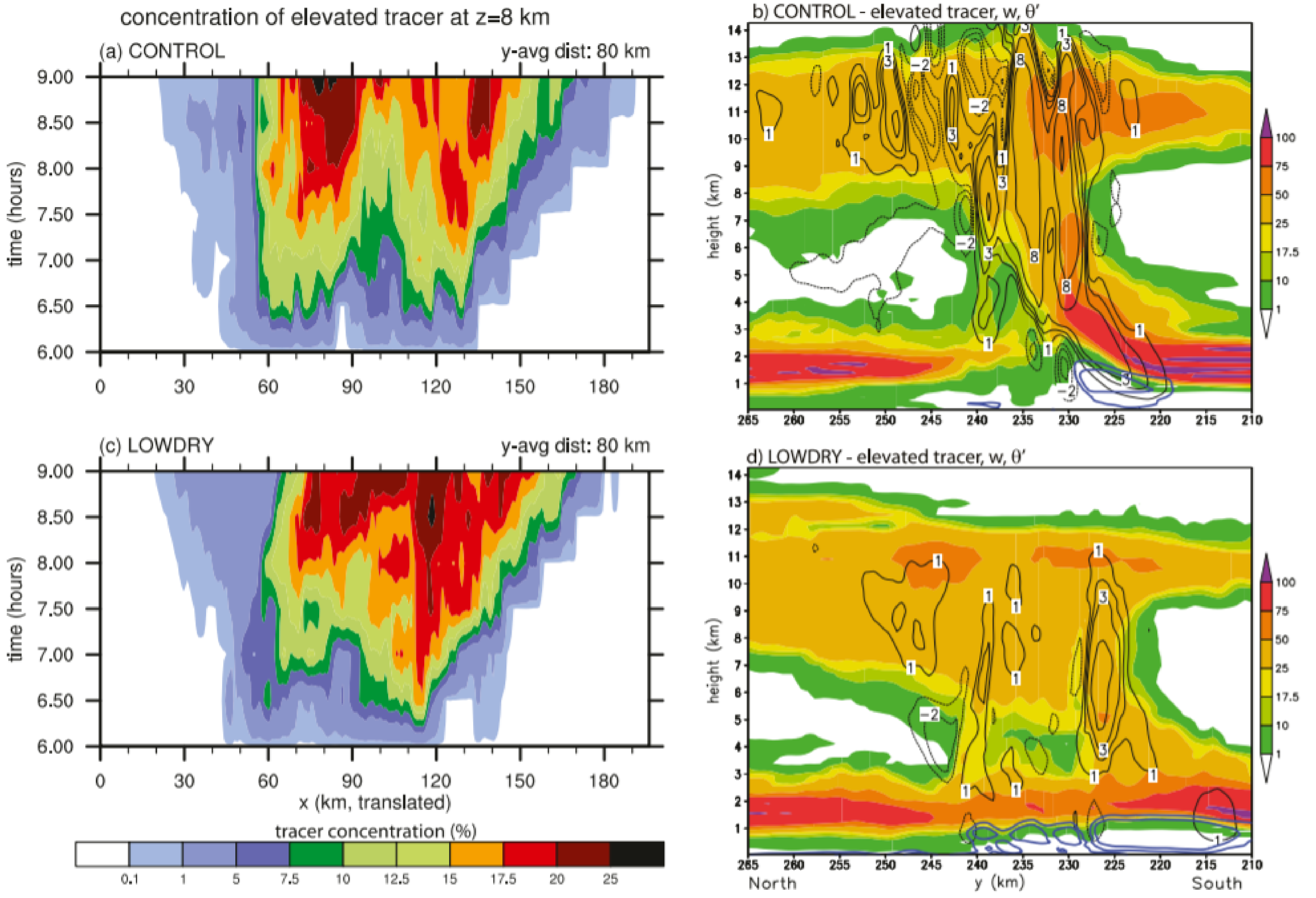
Results: Elevated tracer analysis

Findings

- The inability for back-building convection to ingest BL parcels can be further illustrated by compared elevated tracer lifting
- Note that CTRL and moisture-reduced run (e.g. LOWDRY) have negligible difference in terms of elevated parcel lifting

Summarize our findings

Stability for near-surface parcels directly impacted GW-initiated convection -> less extreme precip



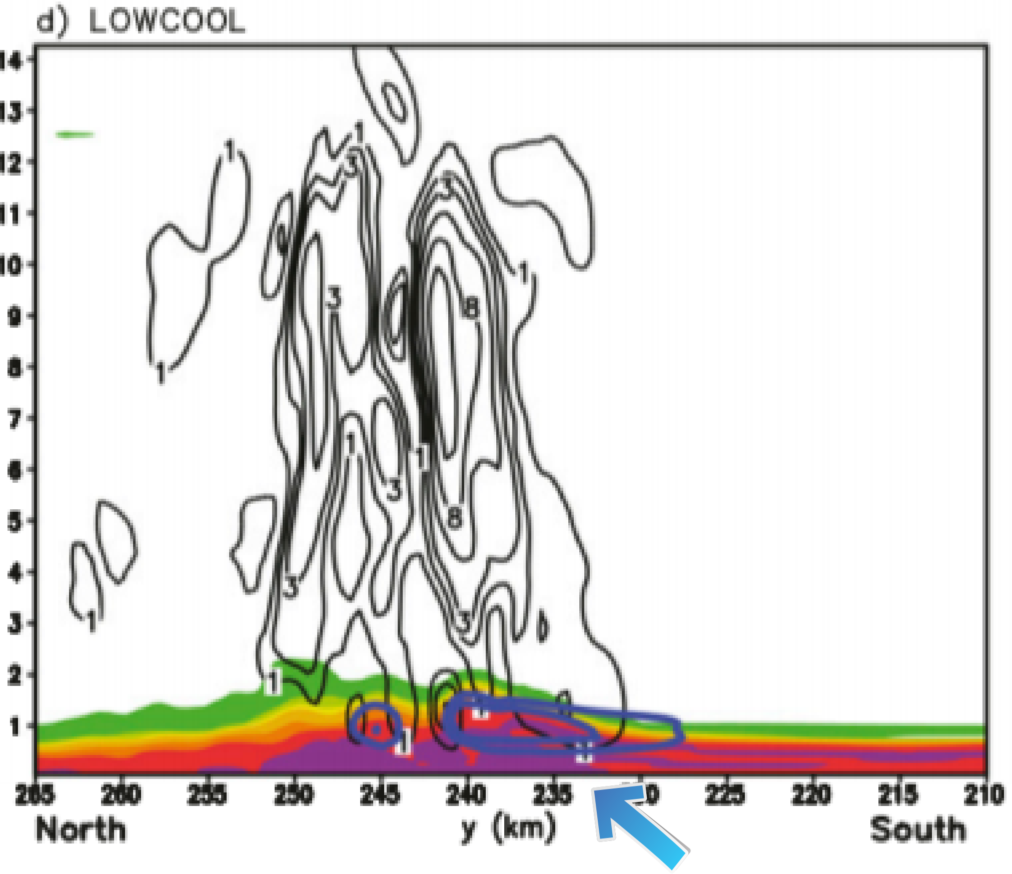
Hovmollers for elevated [1.1-2.5km] tracers concentration at 8km [a,c]. Cross sections [b,d]

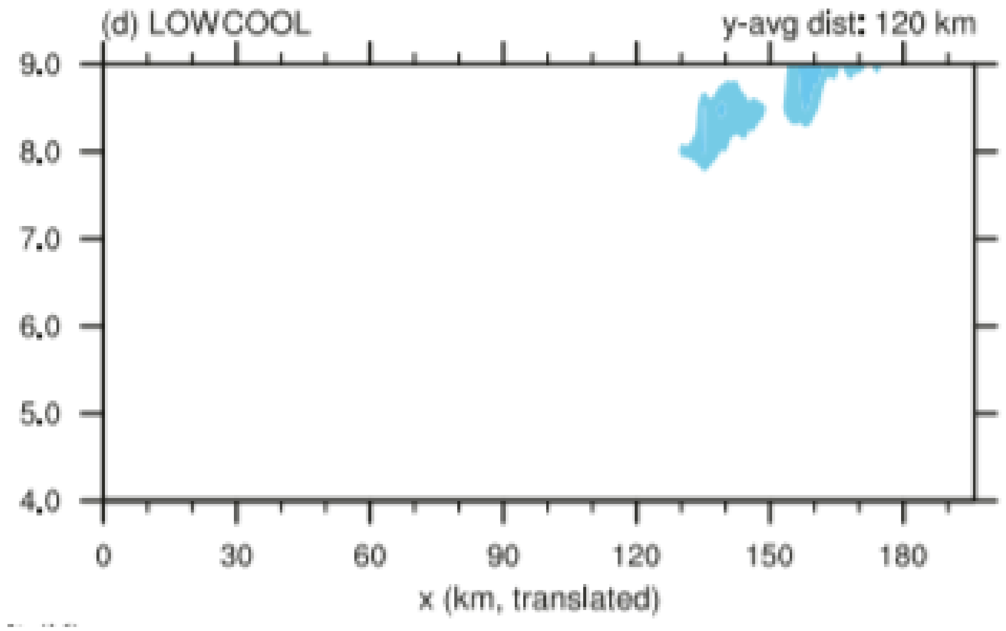
Results: Environmental stabilization via temperature

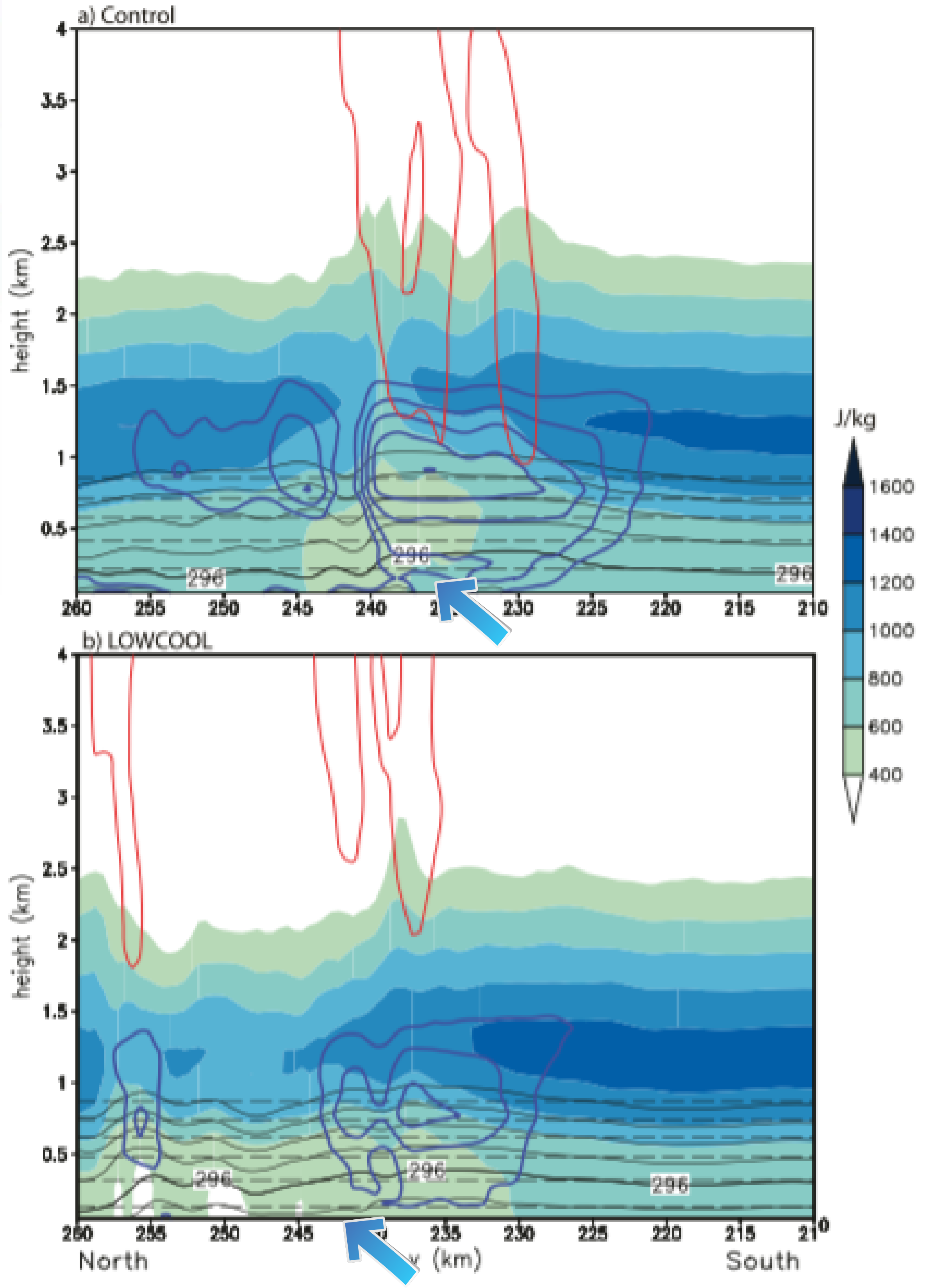
Findings

- Nearly no surface parcels are lifted by convection on the western flank of MCS
- Unlike moisture-reduced runs cold pool was evenly weaker than CTRL
- The difference was largely caused by weaker (shallower) wave activity -> Parcel lifting inhibited

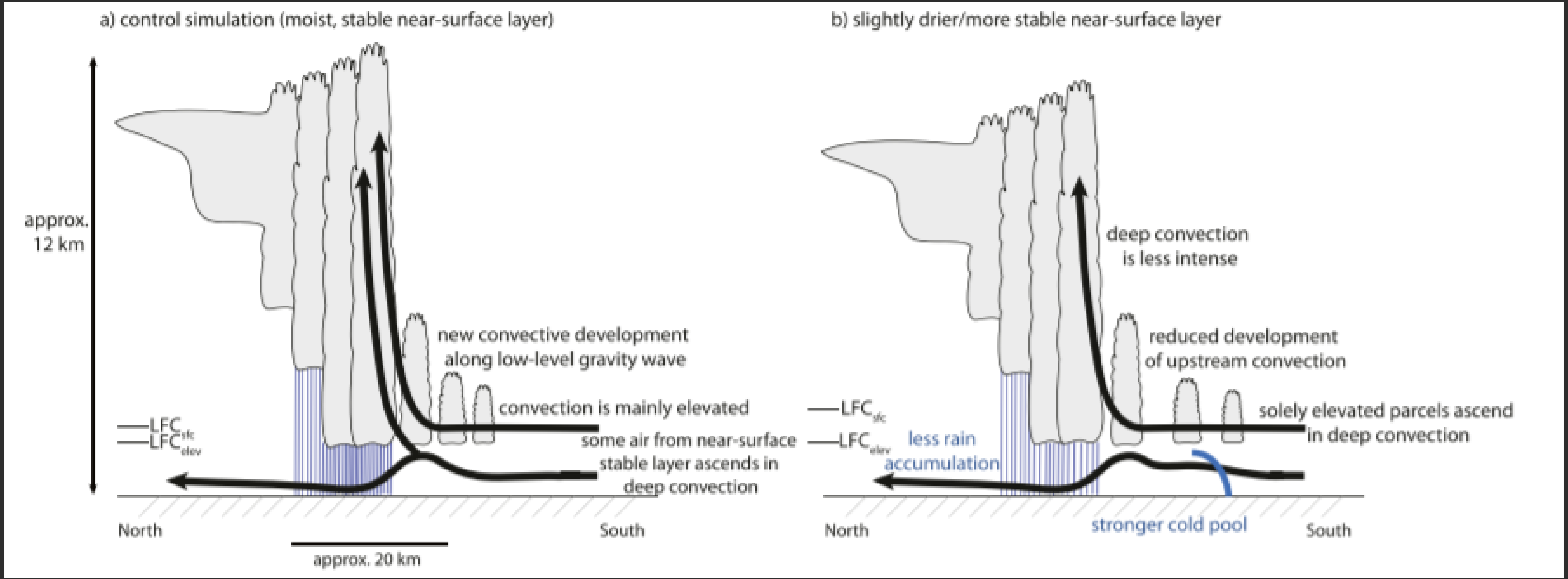
Consistent with moisture tests







Summary



a) control simulation (moist, stable near-surface layer)
approx. 12 km
new convective development along low-level gravity wave
convection is mainly elevated
LFC$_{sfc}$
LFC$_{elev}$
some air from near-surface stable layer ascends in deep convection
North
South
approx. 20 km
b) slightly drier/more stable near-surface layer
deep convection is less intense
reduced development of upstream convection
solely elevated parcels ascend in deep convection
LFC$_{sfc}$
LFC$_{elev}$
less rain accumulation
stronger cold pool
North
South

Possible future research routes

Sensitivity of rainfall accumulation to other initial condition modifications

Is rainfall increase caused by the extra surface-based CAPE or increase in updraft numbers? (Quality or Quantity?)

Impact of different model parameterizations on our conclusion?

THE END

Thank you for listening