How does vertical wind shear influence hydrometeor characteristics in supercell thunderstorms?

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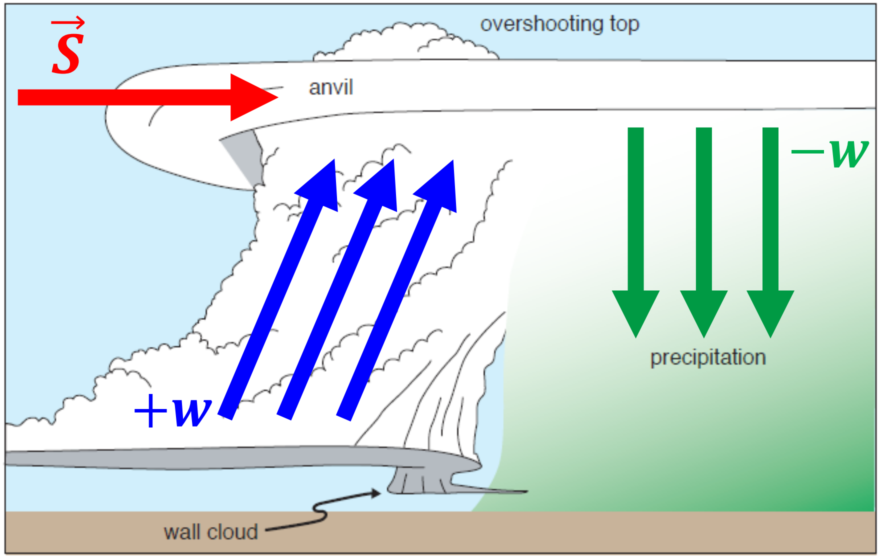
Background and motivation

- Vertical wind shear (shear; $\vec{S}$) thought to increase supercell longevity by increasing distance between updrafts and downdrafts/precipitation
  - e.g., Markowski and Richardson (2010; BOOK)
- Stronger/wider updrafts amid strong shear may foster more hydrometeors, leading to greater updraft hydrometeor loading
  - e.g., Warren et al. (2017; MWR); Jo and Lasher-Trapp (2022; JAS)
- Unclear which layer of shear is relatively most determinative of hydrometeor concentration and displacement in supercell updrafts



Markowski and Richardson (2010; BOOK)

Scientific questions

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(1) How does systematically varying shear magnitude across different vertical layers affect hydrometeor concentration and displacement relative to supercell updrafts?

(2) Do the results from (1) hold true across a range of free tropospheric relative humidity environments (dry vs. moist)?

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Hypothesis

Hypothesis: *in the case of stronger, compared to weaker, shear*

- Faster storm motions ➔
- Stronger low-level storm-relative inflow ➔
- Wider, less dilute, and stronger updrafts ➔
- Wider region over which condensate forms ➔
- Greater updraft hydrometeor loading (at least initially)

Previously shown
(e.g., Peters et al. 2019; JAS)

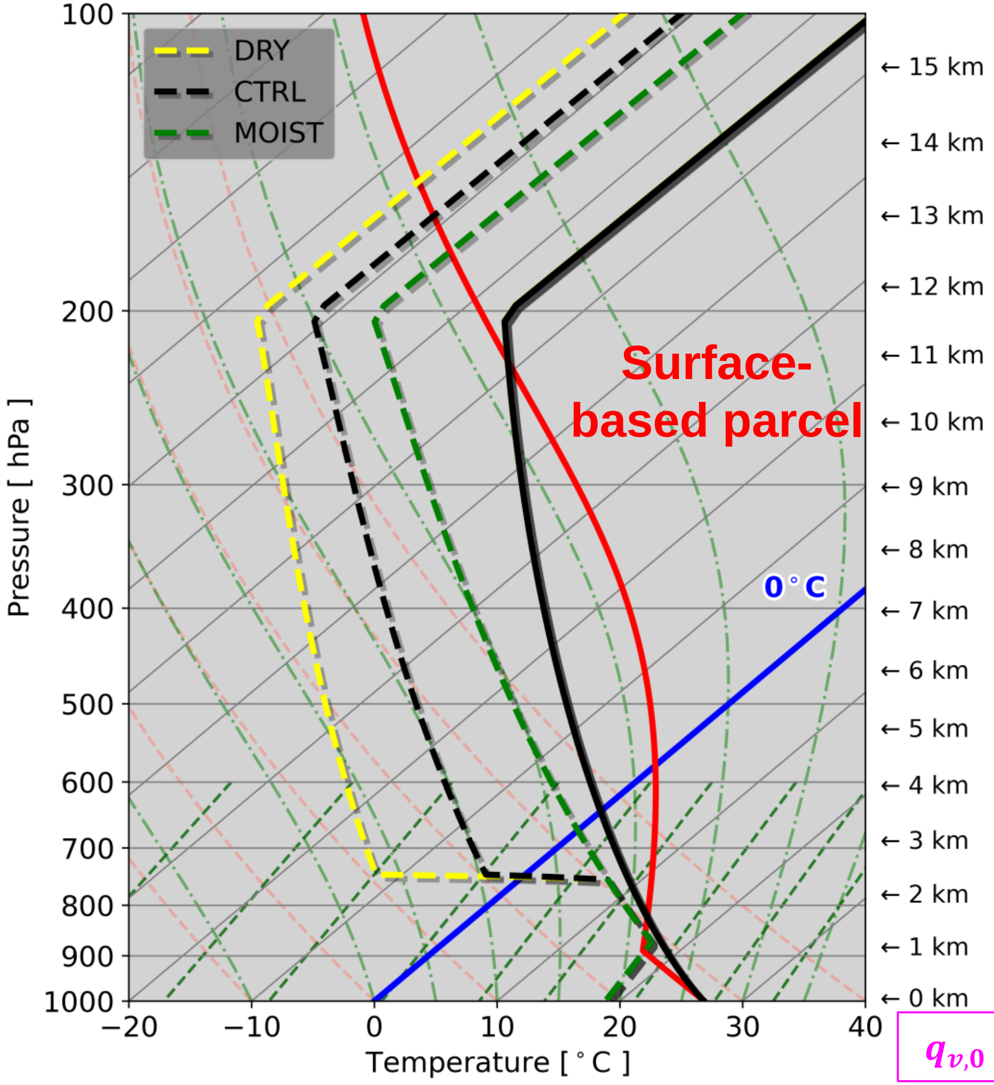
... but ...

- Stronger storm-relative winds ➔
- Greater amount of condensate laterally "spread out" downshear ➔
- Wider precipitation area and reduced updraft hydrometeor loading

Numerical modeling framework

- Idealized simulations using Cloud Model 1 (CM1), release 20.3
  - Horizontally homogenous
  - Steady base state
  - No surface fluxes, terrain, or Coriolis
- +3 K “warm bubble” convection initiation technique
  - Horiz. radius = 10 km; Vert. radius 1.4 km; Centered at ground level
- 250 m horiz. grid spacing; 50 m to 250 m stretched vert. grid spacing with 168 vertical levels
  - 225 x 225 x 20 km^3 domain
- Morrison two-moment microphysics scheme (“ihail” = hail)
  - Sensitivity tests:
    - (1) NSSL two-moment microphysics scheme
    - (2) Altering specified cloud droplet number concentration in Morrison scheme
- 3-h simulations; 10-min output

CM1 Base States – Thermodynamics

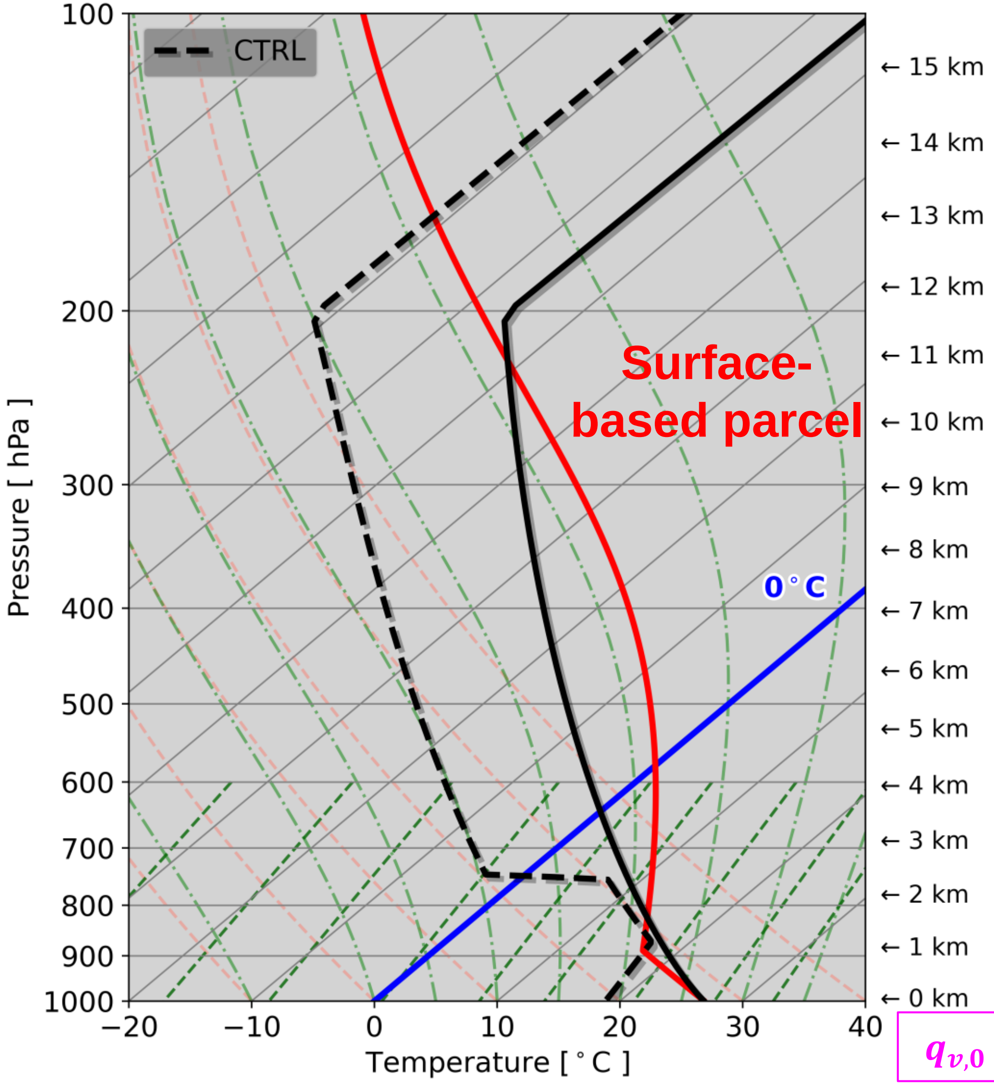


Parcel type	CAPE (J kg^{-1})	CIN (J kg^{-1})
Surface-based	**1725**	**-50**

$$q_{v,0} = 14\ g\ kg^{-1}$$

Weisman and Klemp
(1982; MWR)

CM1 Base States – Thermodynamics



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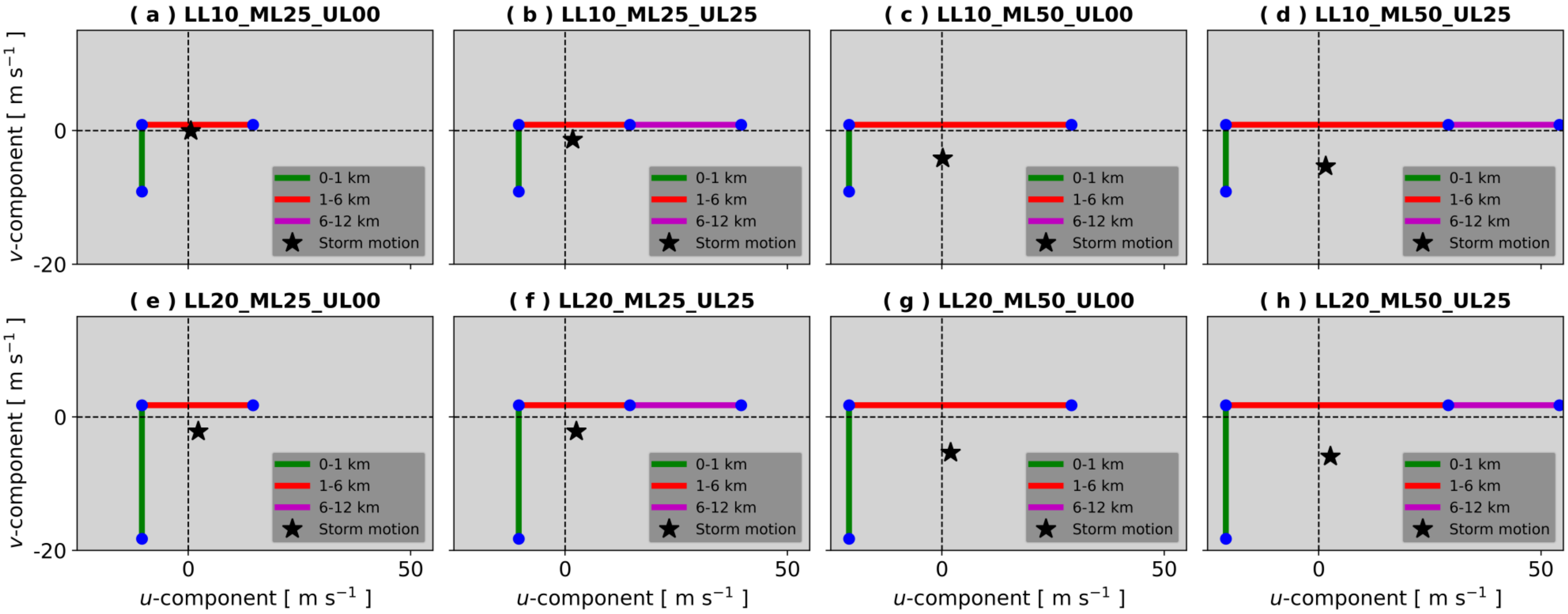
CM1 Base States – Shear

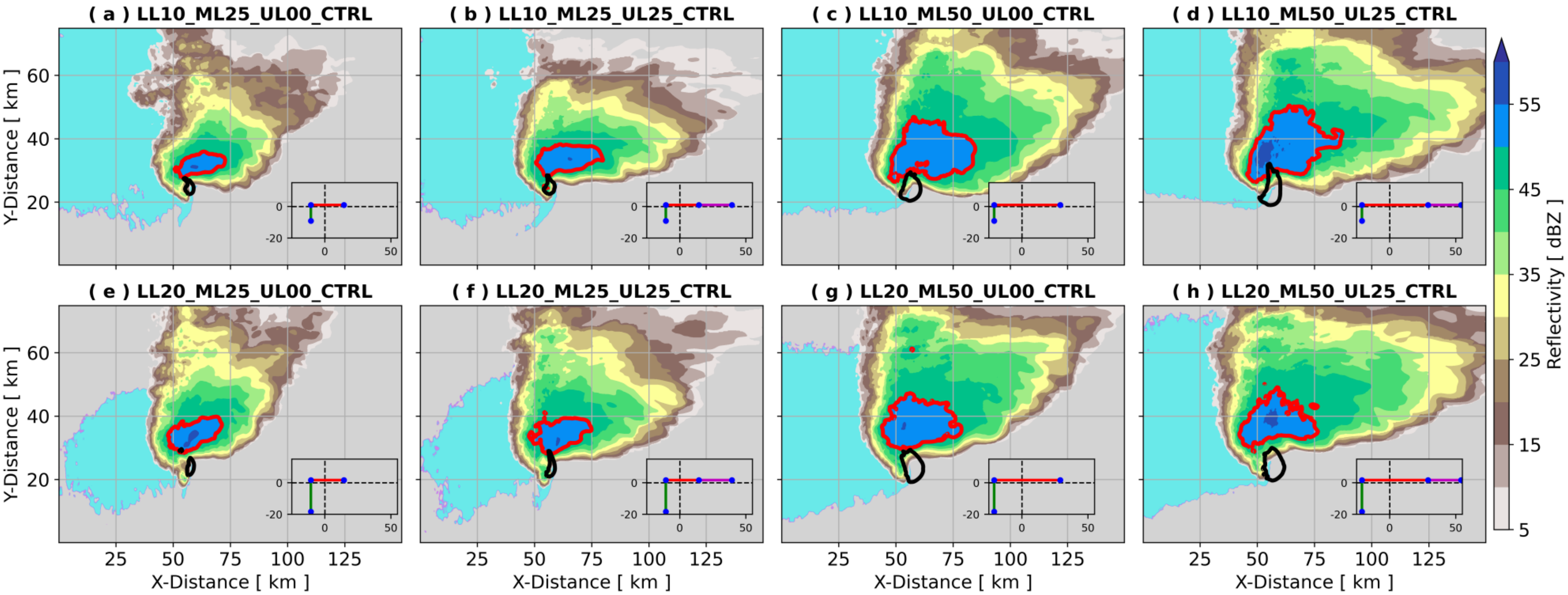


Simulation	**Bulk wind shear (m s^{-1})**
LL10 vs. LL20	10 vs. 20
ML25 vs. ML50	25 vs. 50
UL00 vs. UL25	00 vs. 25

Chavas and Dawson II
(2021; JAS)

Reflectivity, outflow, *w* composites

90-180 min avg



- Stronger 1-6 km AGL shear leads to wider mid-level updrafts, wider near-surface precipitation areas, and greater downshear precipitation spread
- Weaker shear leads to more “undercutting” of updrafts by cold pools

Reflectivity, outflow, *w* composites

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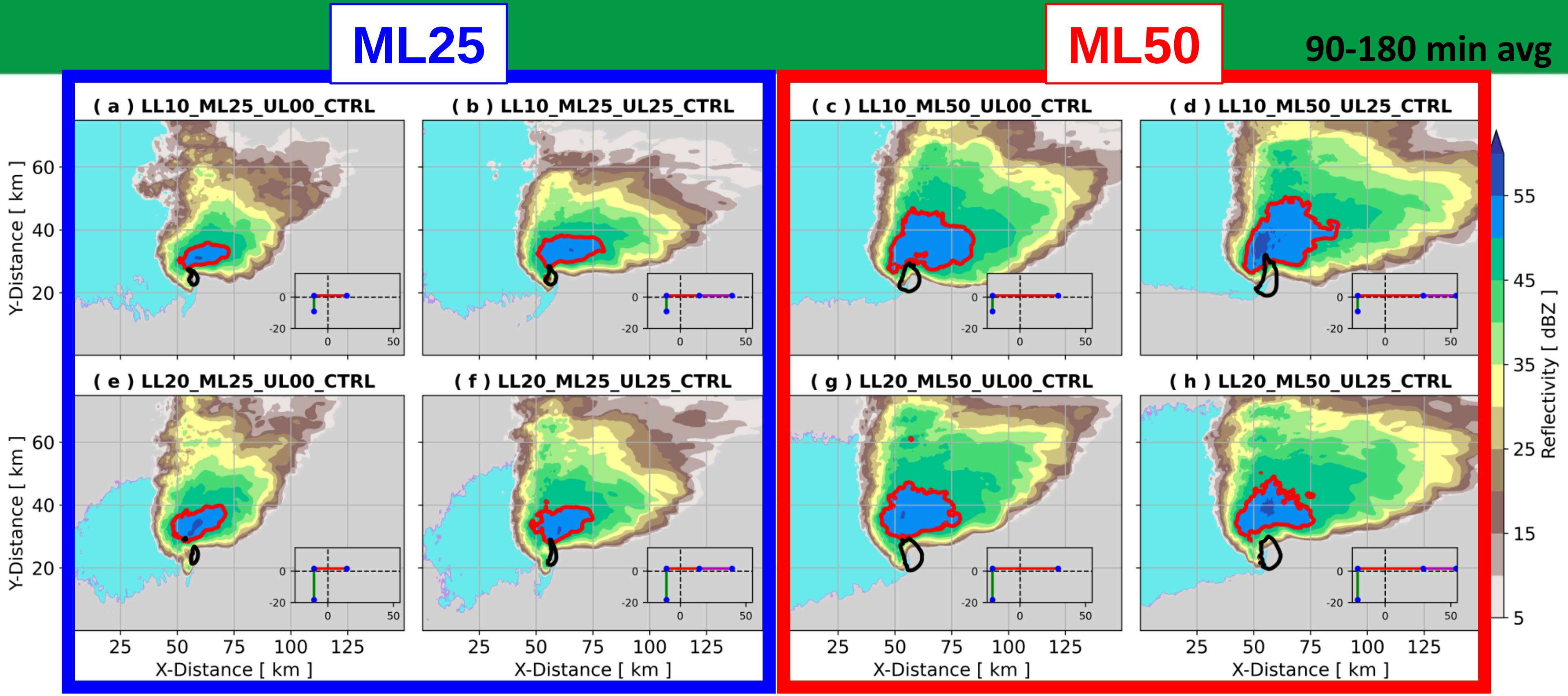

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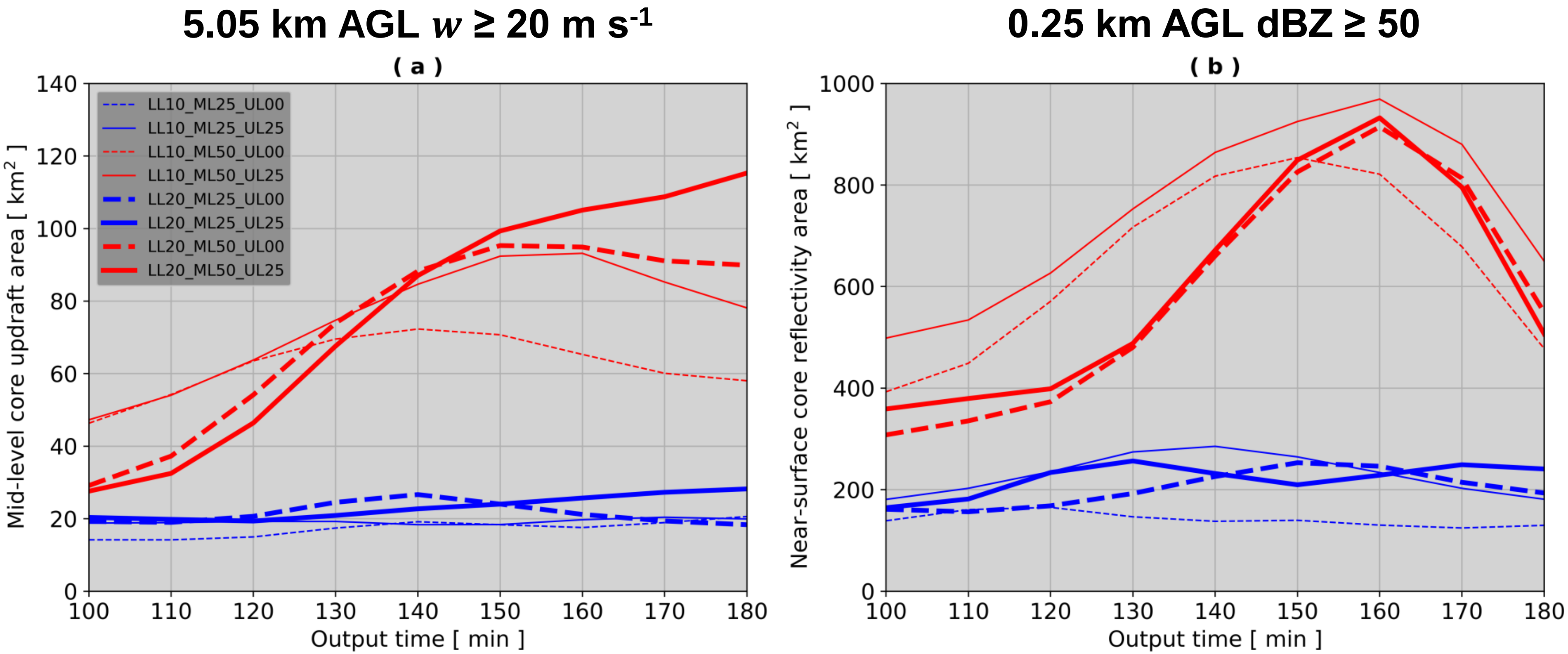
Updraft & reflectivity area time series

90-180 min



5.05 km AGL $w \geq 20$ m s^{-1}

0.25 km AGL dBZ ≥ 50

- Stronger 1-6 km AGL shear leads to wider mid-level updrafts and wider near-surface precipitation/reflectivity areas

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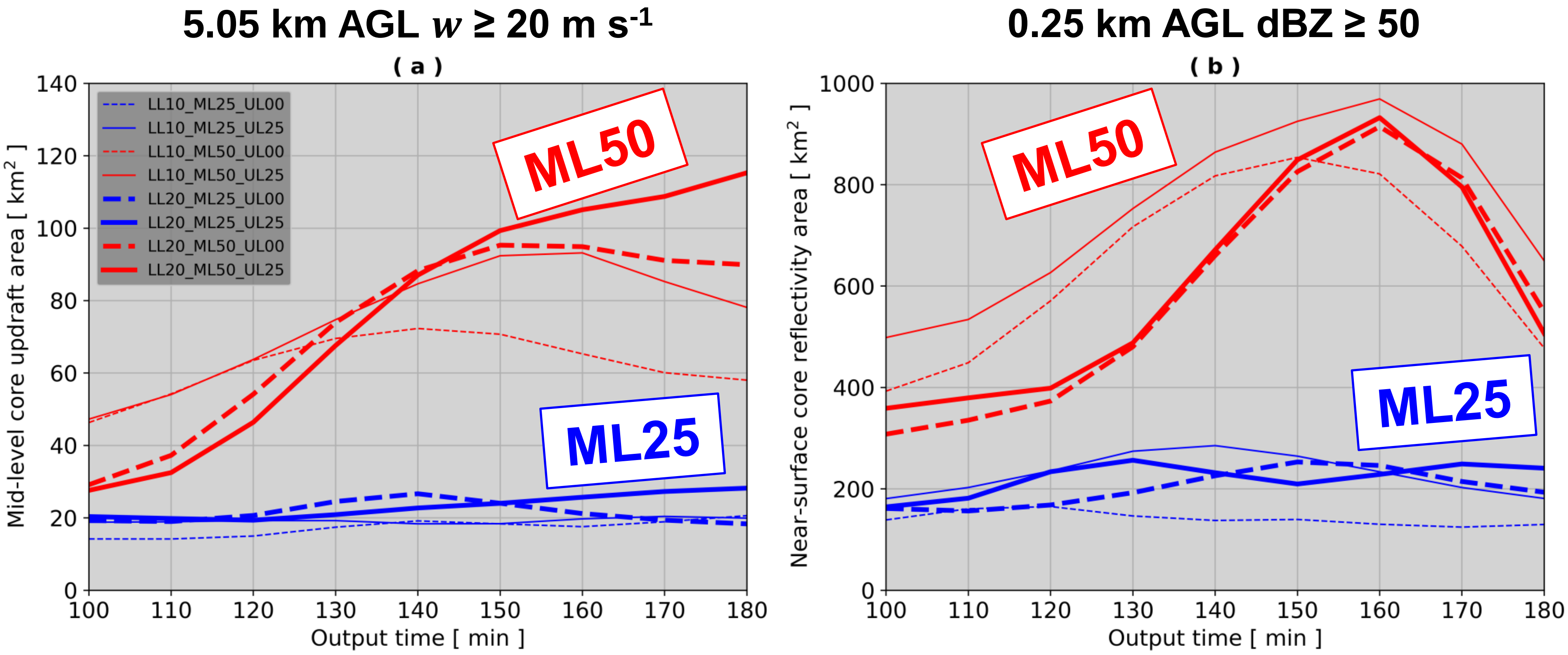

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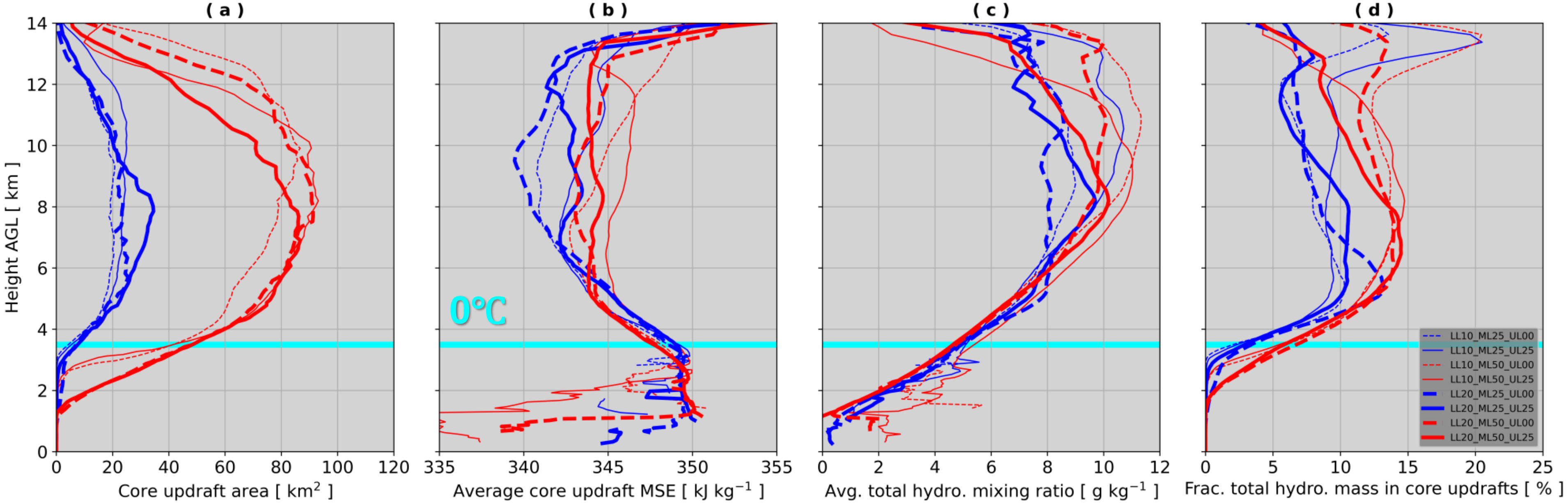
Core updraft characteristics

$w \geq 20$ m s^{-1}

90-180 min avg

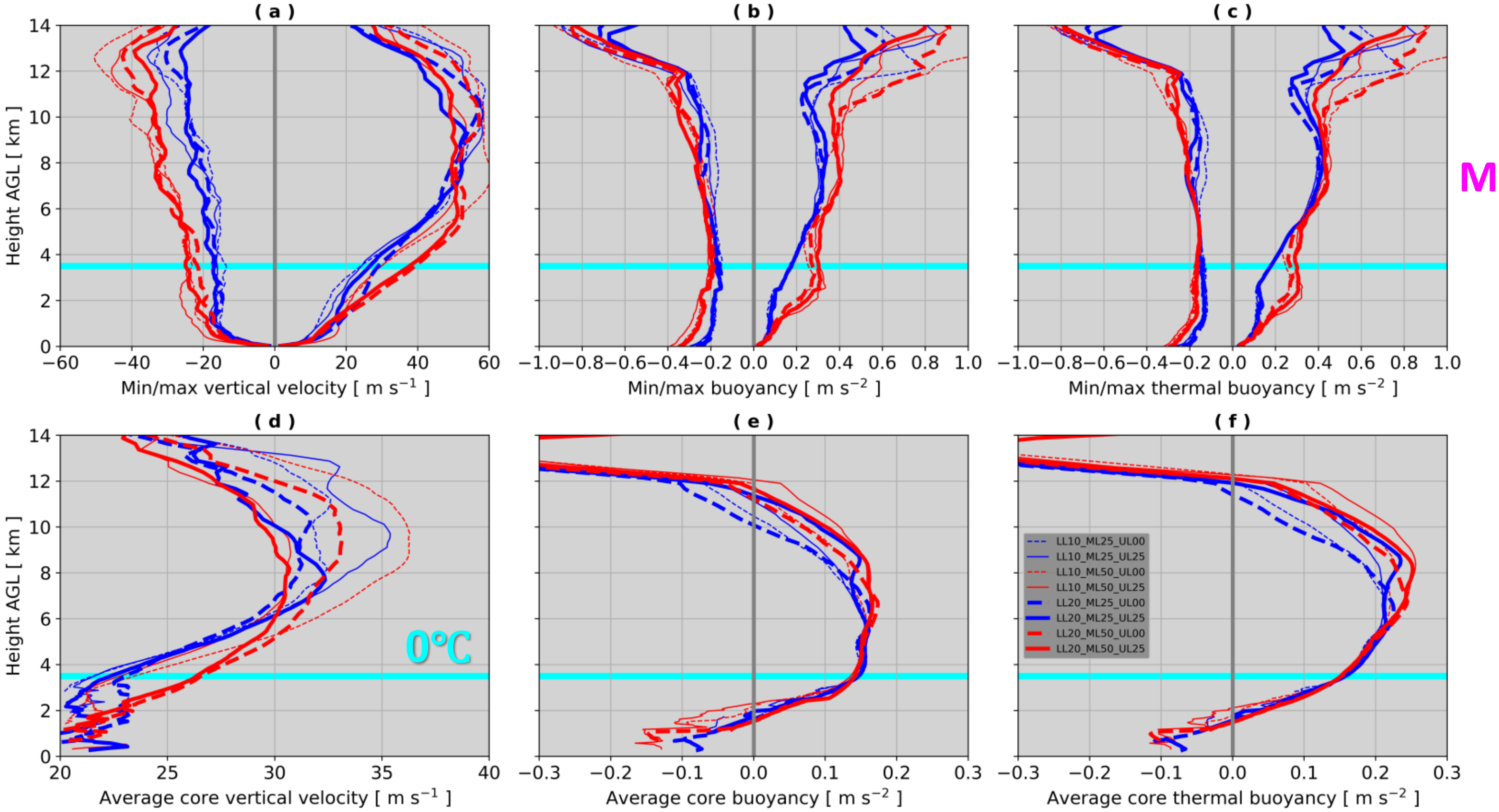


- Stronger 1-6 km AGL shear leads to...
  - ○ Wider core updrafts
  - ○ Less dilute core updrafts
  - ○ Greater hydrometeor loading
  - ○ Greater fraction of total hydrometeor mass within core updrafts

Core updraft characteristics

$w \geq 20\ \mathrm{m\ s^{-1}}$

90-180 min avg



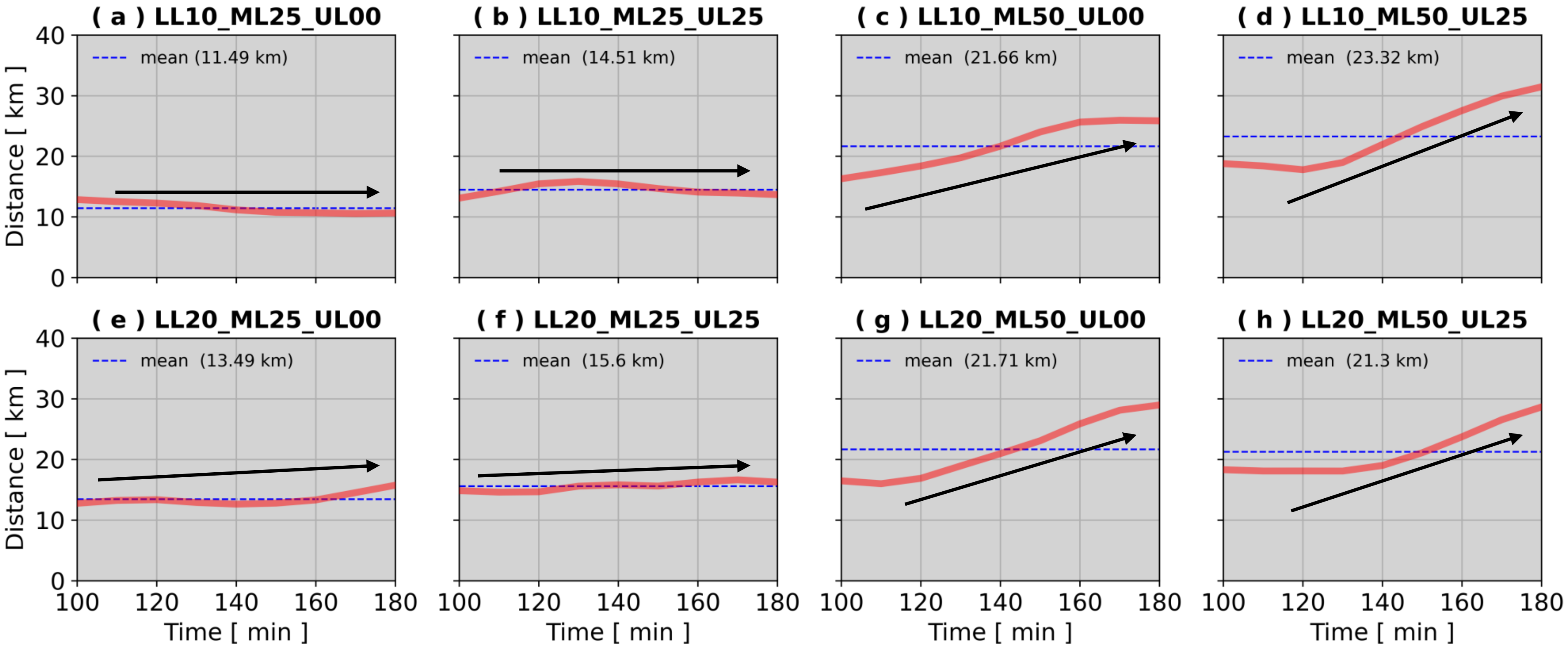
Min/max

Avg

- Stronger 1-6 km AGL shear leads to...
    - Stronger low-to-mid-level updrafts; stronger downdrafts everywhere
    - Greater buoyancy and thermal buoyancy (at low- and upper-levels)

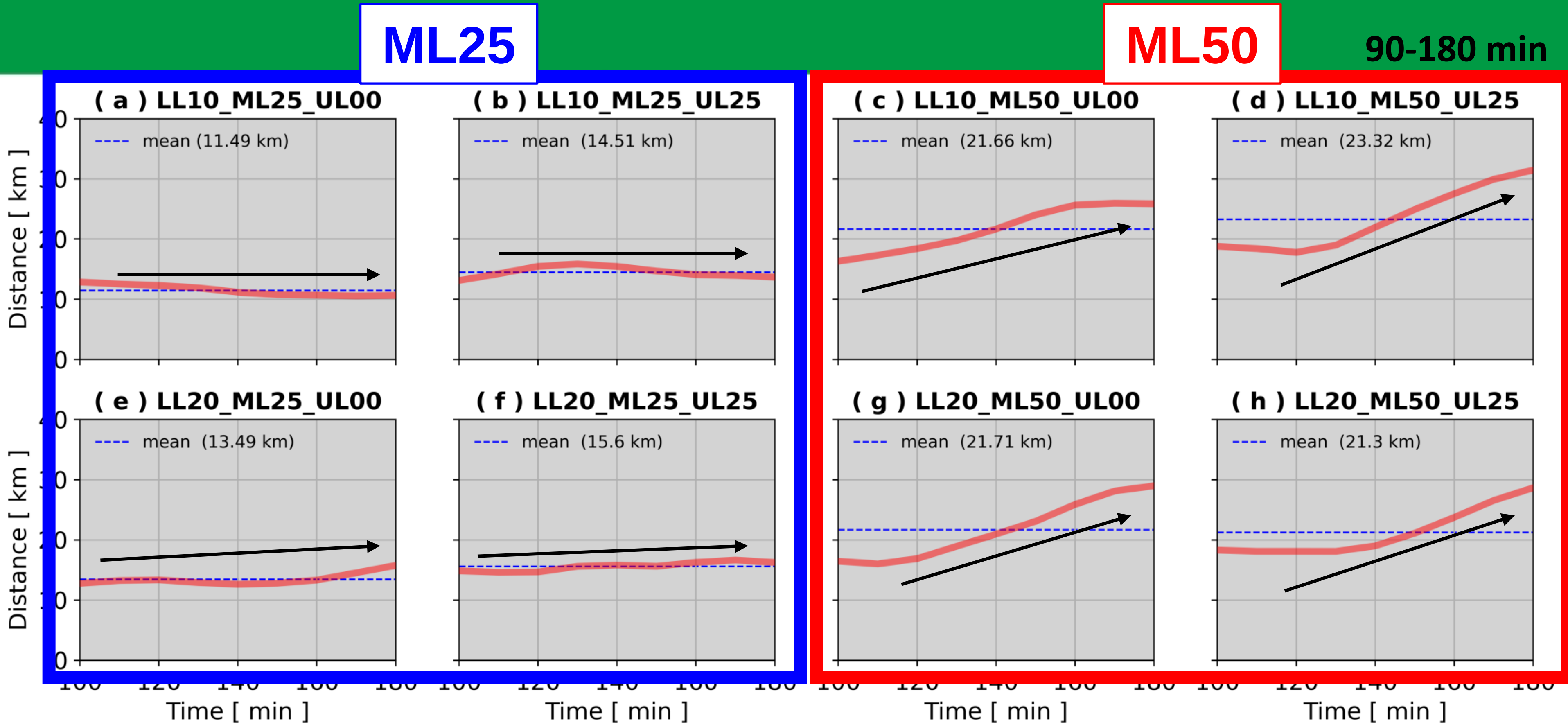
Updraft vs. precip core displacement

90-180 min



- Stronger 1-6 km AGL shear leads to greater separation between mid-level updraft core and near-surface precipitation core centroids
- Separation between mid-level updraft core and near-surface precipitation core centroids increase with time for stronger shear

Updraft vs. precip core displacement



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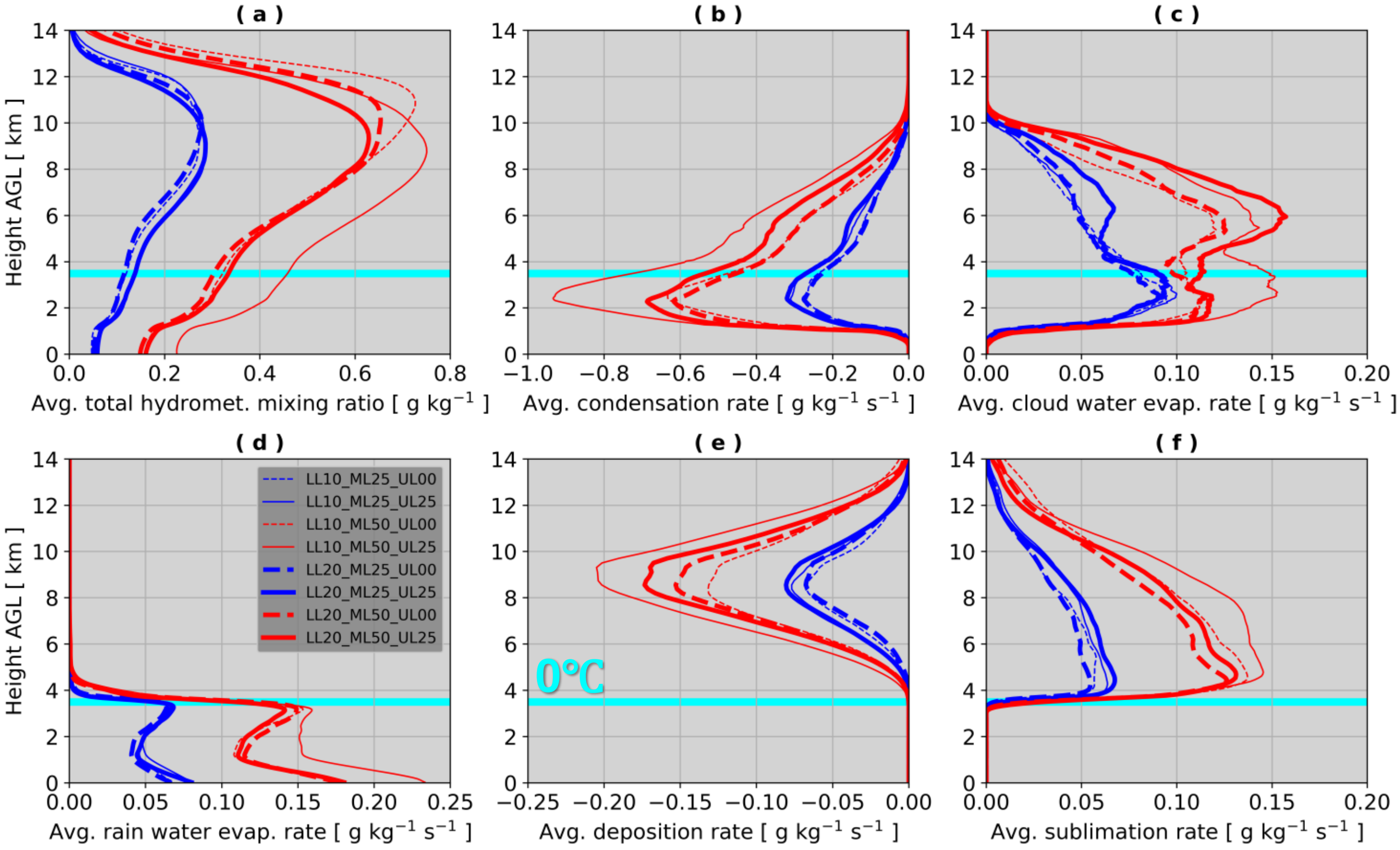
Outside core updraft characteristics

w < 20 m s^{-1}

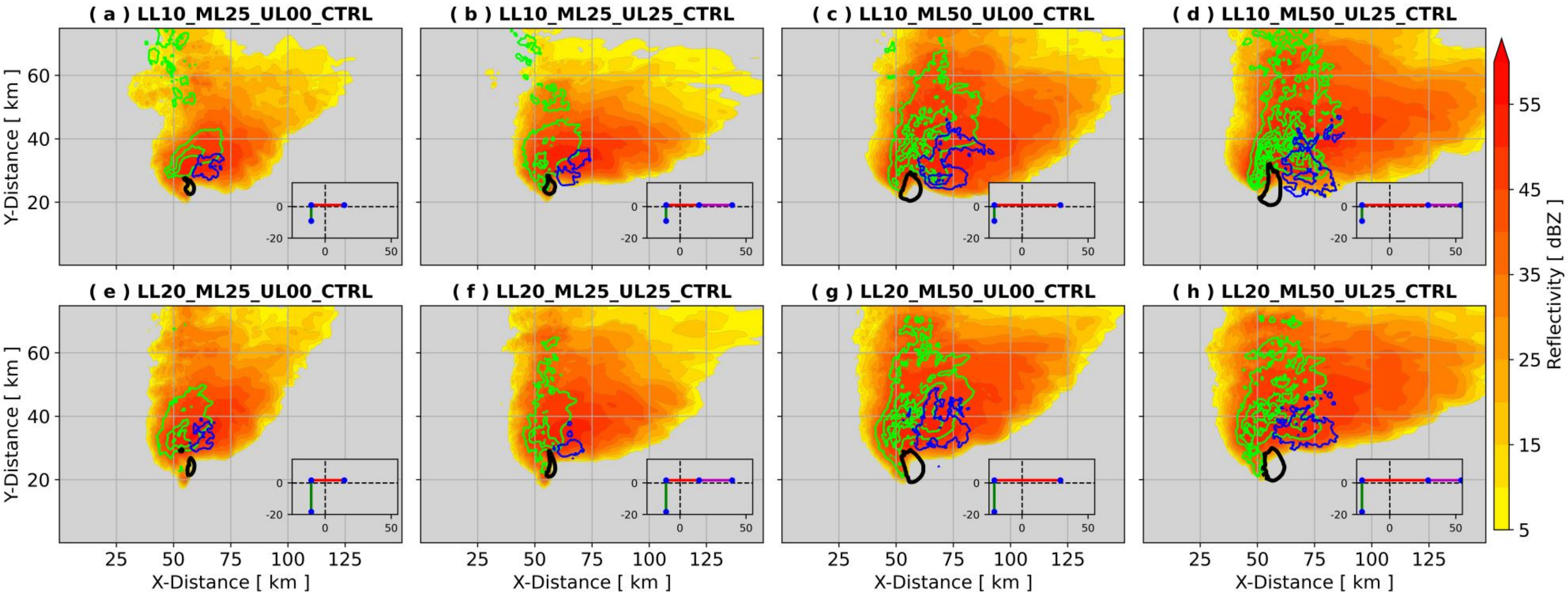
90-180 min avg



- Stronger 1-6 km AGL shear leads to...
  - Greater hydrometeor mass outside core updrafts
  - Greater ice sublimation at upper-levels and rain evaporation at low-levels

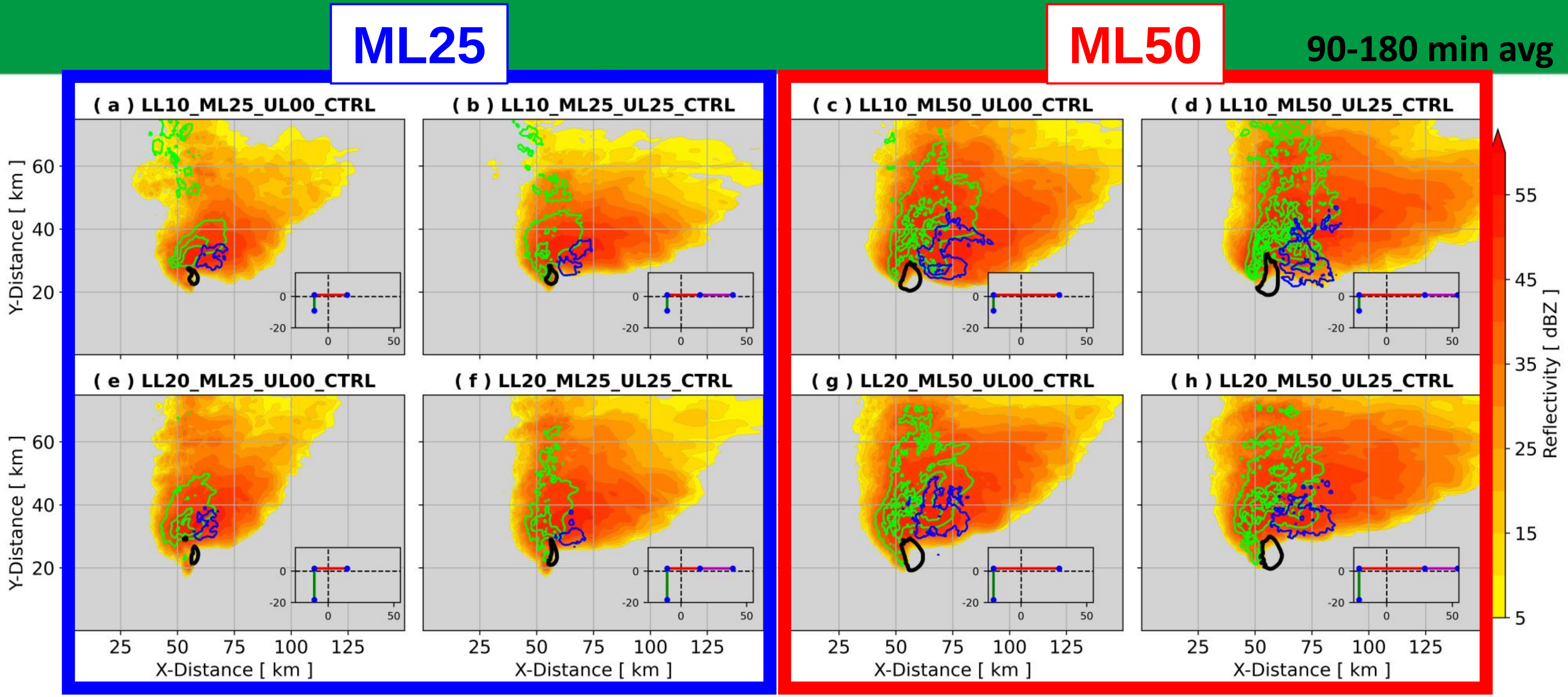
Ice sublimation & rain evaporation

90-180 min avg



- Stronger 1-6 km AGL shear leads to...
  - Larger regions of ice sublimation at upper-levels and rain evaporation at low-levels, especially downshear

Ice sublimation & rain evaporation



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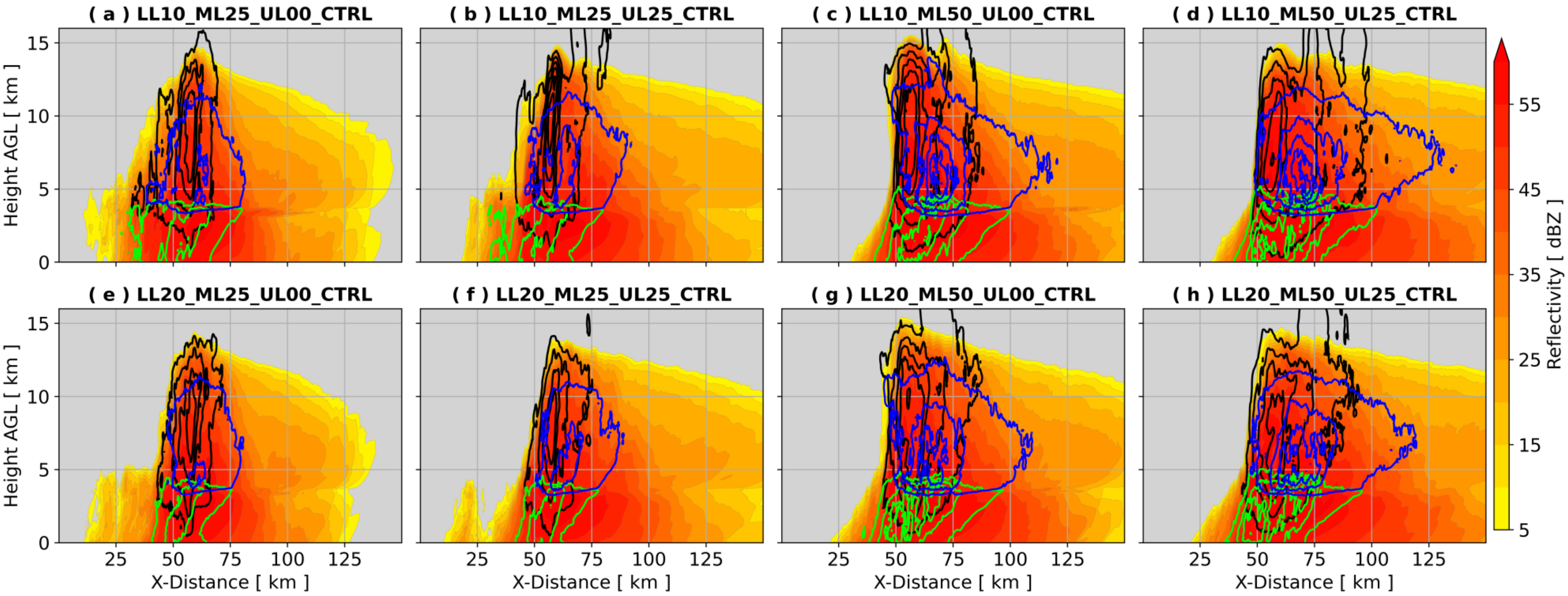

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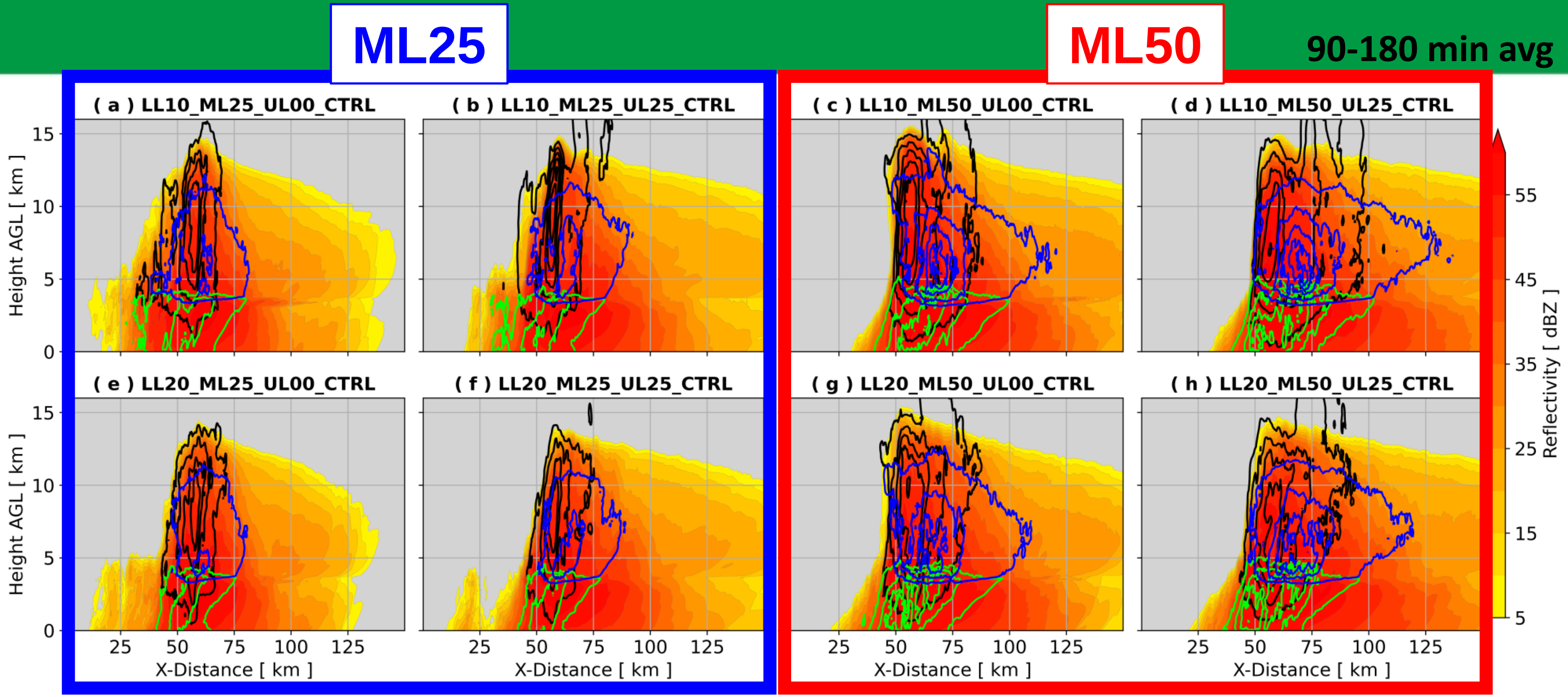

90-180 min avg

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Outside core updraft characteristics

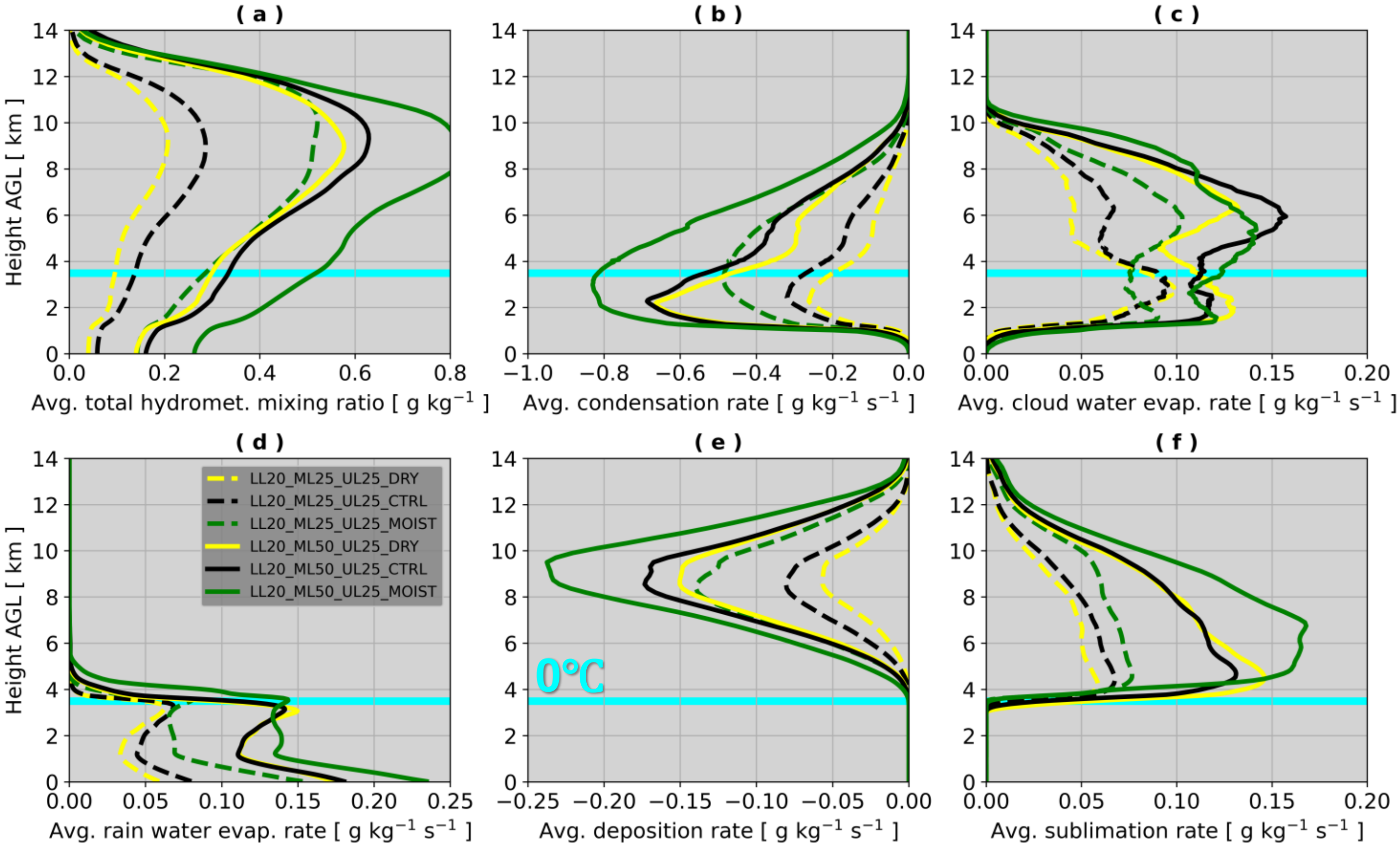
$w < 20$ m s^{-1}

DRY

CTRL

MOIST

90-180 min avg



- Higher free tropospheric RH leads to...
  - Greater hydrometeor mass outside core updrafts
  - Greater ice sublimation at upper-levels and rain evaporation at low-levels
  - *Same sensitivities to stronger 1-6 km AGL shear as shown previously*

Conclusions and discussion

- *Increasing 1-6 km AGL shear leads to…*
  - Wider updrafts with greater hydrometeor loading
  - Greater downshear “spread” and area of precipitation
  - Greater hydrometeor mass outside of core updrafts
  - Greater rates of ice sublimation and rain evaporation

- *Increasing free tropospheric relative humidity leads to…*
  - Wider updrafts and near-surface precipitation areas
  - Slightly greater hydrometeor loading (especially for weaker sheared updrafts)
  - Greater hydrometeor mass outside of core updrafts
  - Greater rates of ice sublimation and rain evaporation

- *Results are consistent when changing microphysics scheme and cloud droplet number concentration*
  - Not explicitly shown here, but I am more than happy to share if requested!

Thank you for your attention!
Any questions?

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