Wind shear impacts on convection — Implication for convective organization parameterization in climate models

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Past studies of mesoscale parameterization

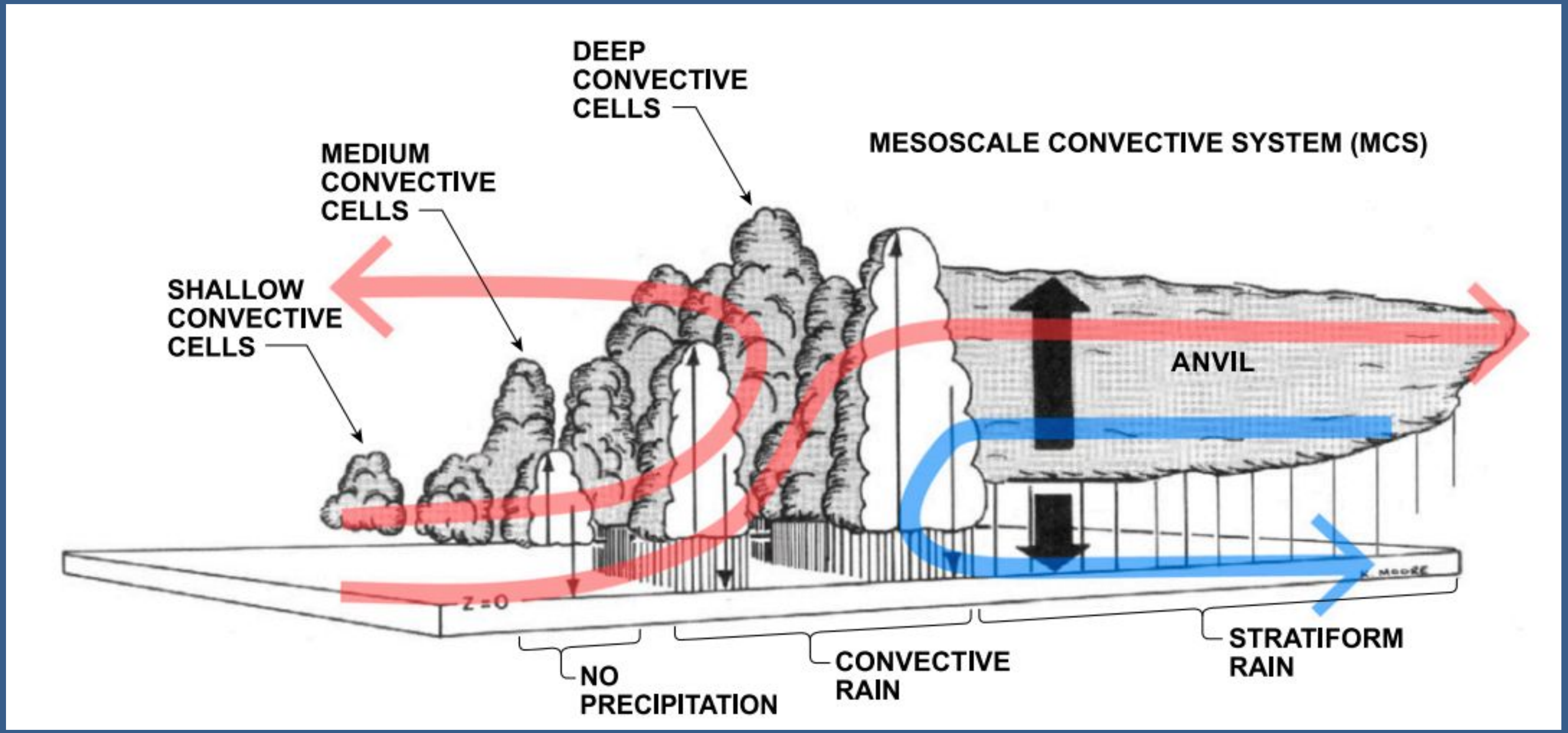
Multiscale Coherent Structure Parameterization (MCSP)

Donner 1993;

Donner et al. 2001

Mapes and Neale 2011 (*org*)

Moncrieff et al. 2017 (MCSP)



Slantwise layer overturning structure

$$Q = Q_c + Q_m$$

$$Q_m(p,t) = -\alpha_1 Q_c(t)\sin 2\pi\left(\frac{p_s - p}{p_s - p_t}\right)$$

Q: Convective heating

Qc: Heating from ZM deep convection scheme

Qm: Added mesoscale heating, depend on wind shear trigger

Motivations: LES study of vertical wind shear on cumulus ensembles

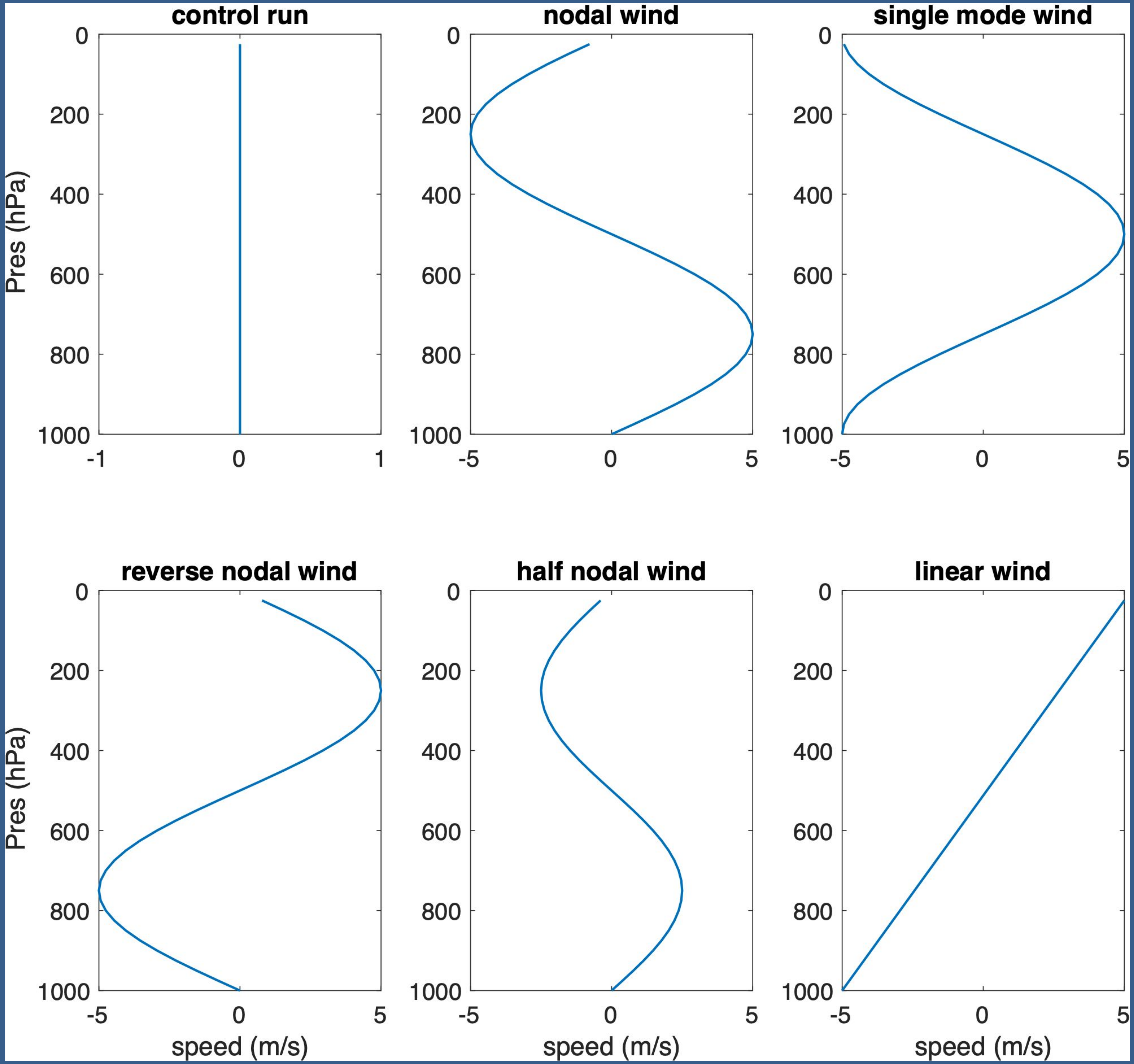
- Include a more robust convective organization trigger/response related to wind shear

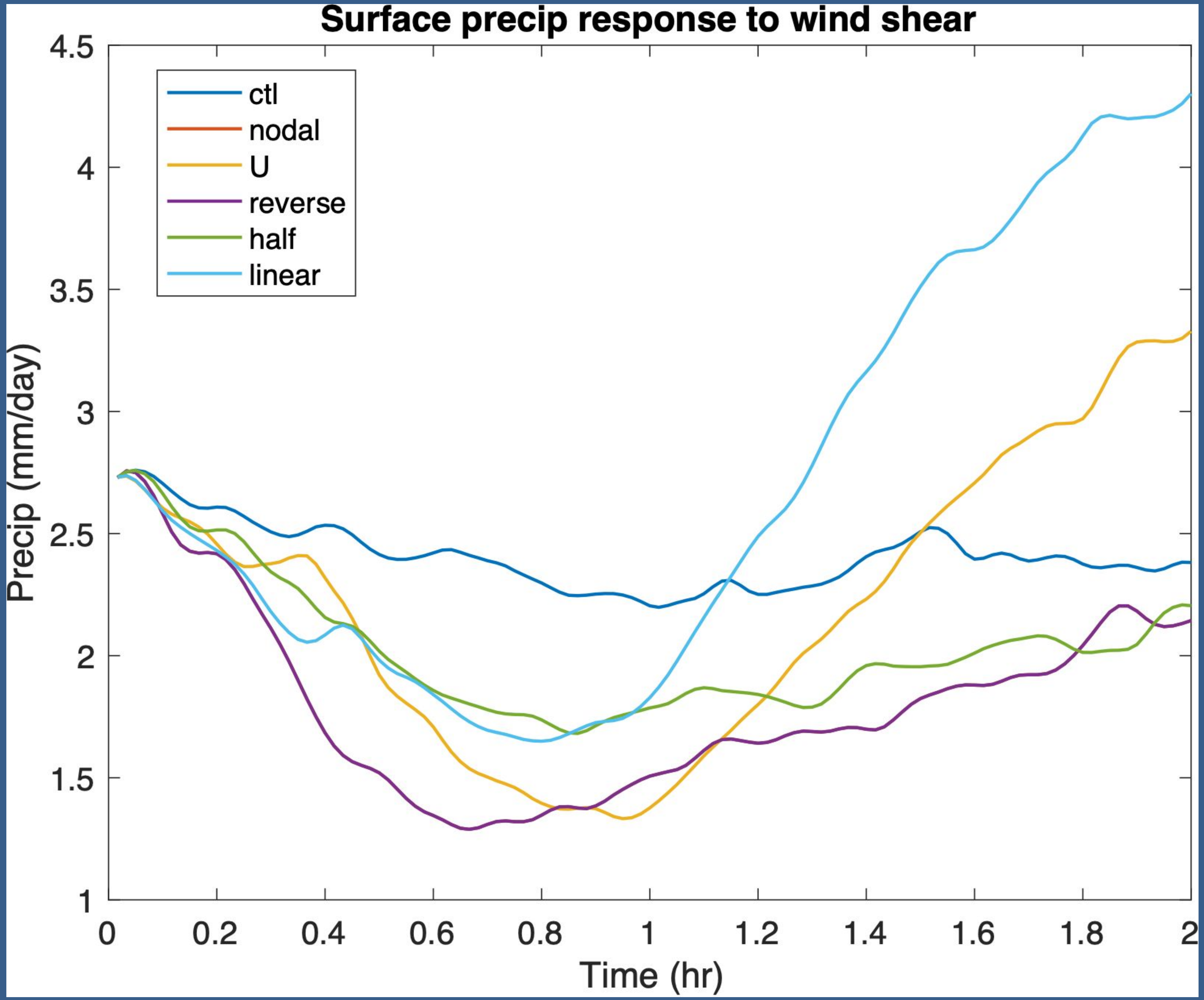
- Existing literatures are mostly focused on a single squall-line case or idealized warm bubble experiments

- We propose to get an ensemble convective response in a less storm-like and more realistic environment, and inform a physically-based convective organization-wind shear relationship to be used in climate models

Model setup

- Cloud-resolving model: SAM 6.11.6
- Radiative Convective Equilibrium (RCE) configurations, no large-scale forcing, except for the added zonal winds
- Model setup: 64 stretching vertical levels; 500m horizontal; 256 x 256 grid boxes; 10s temporal resolution
- After reaching RCE status on day 25, 20 ensemble members with each being run for 3 hours


control run
nodal wind
single mode wind
reverse nodal wind
half nodal wind
linear wind
Pres (hPa)
0
200
400
600
800
1000
-1
0
1
-5
0
5
speed (m/s)


Surface precip response to wind shear
ctl
nodal
U
reverse
half
linear
Precip (mm/day)
1
1.5
2
2.5
3
3.5
4
4.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (hr)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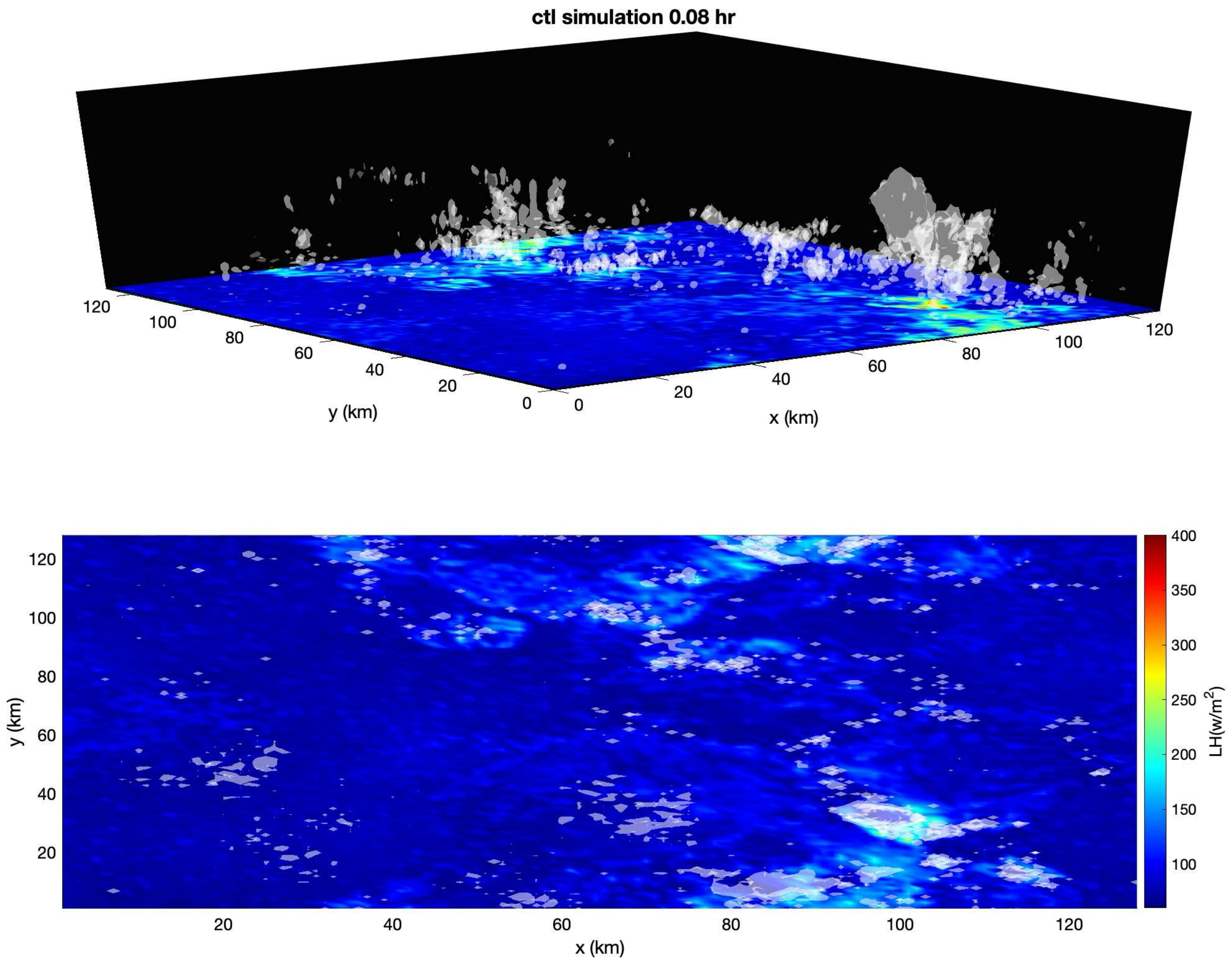
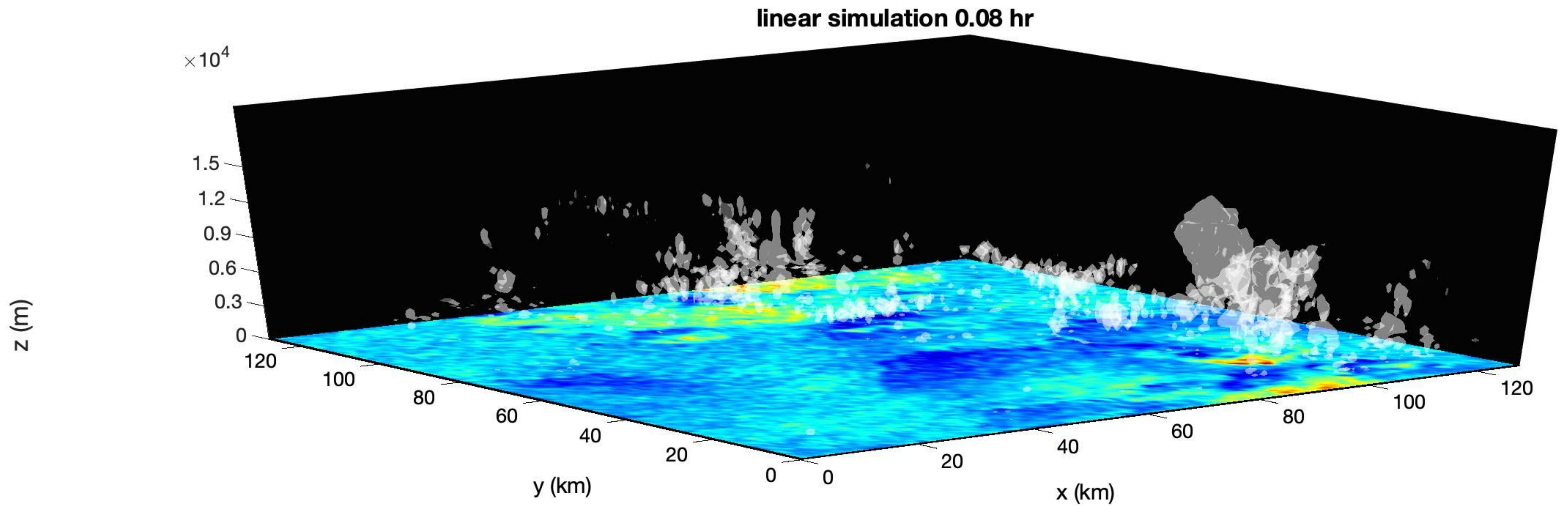
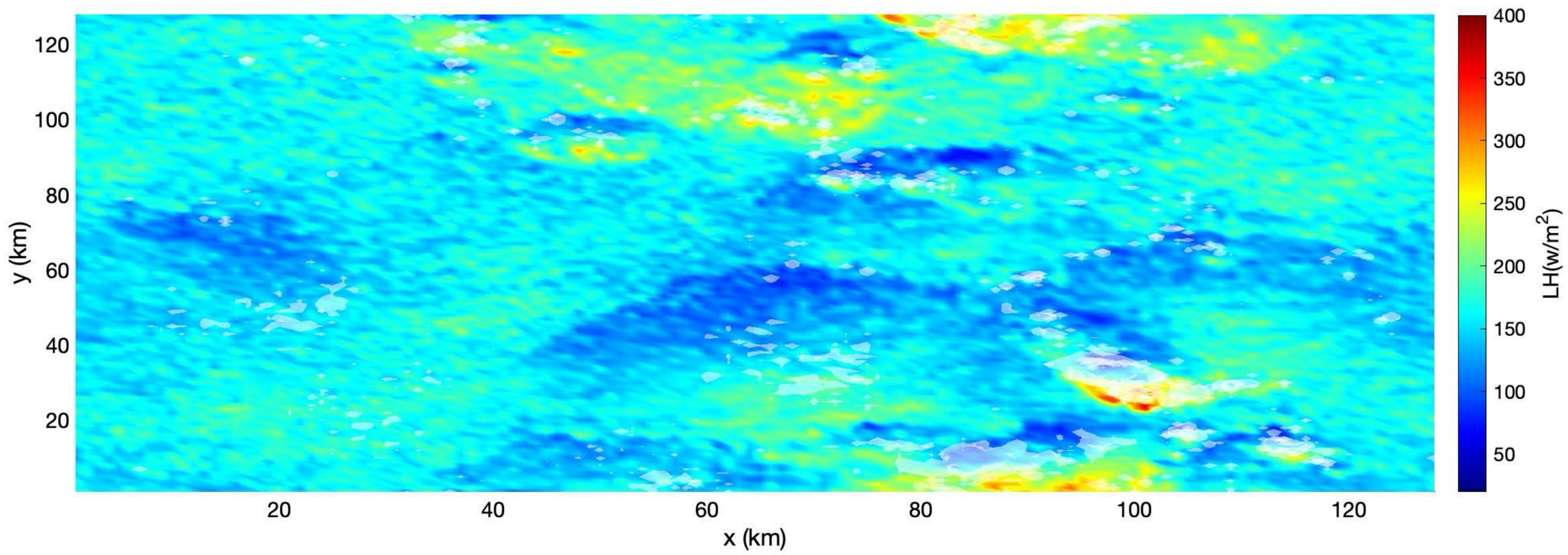


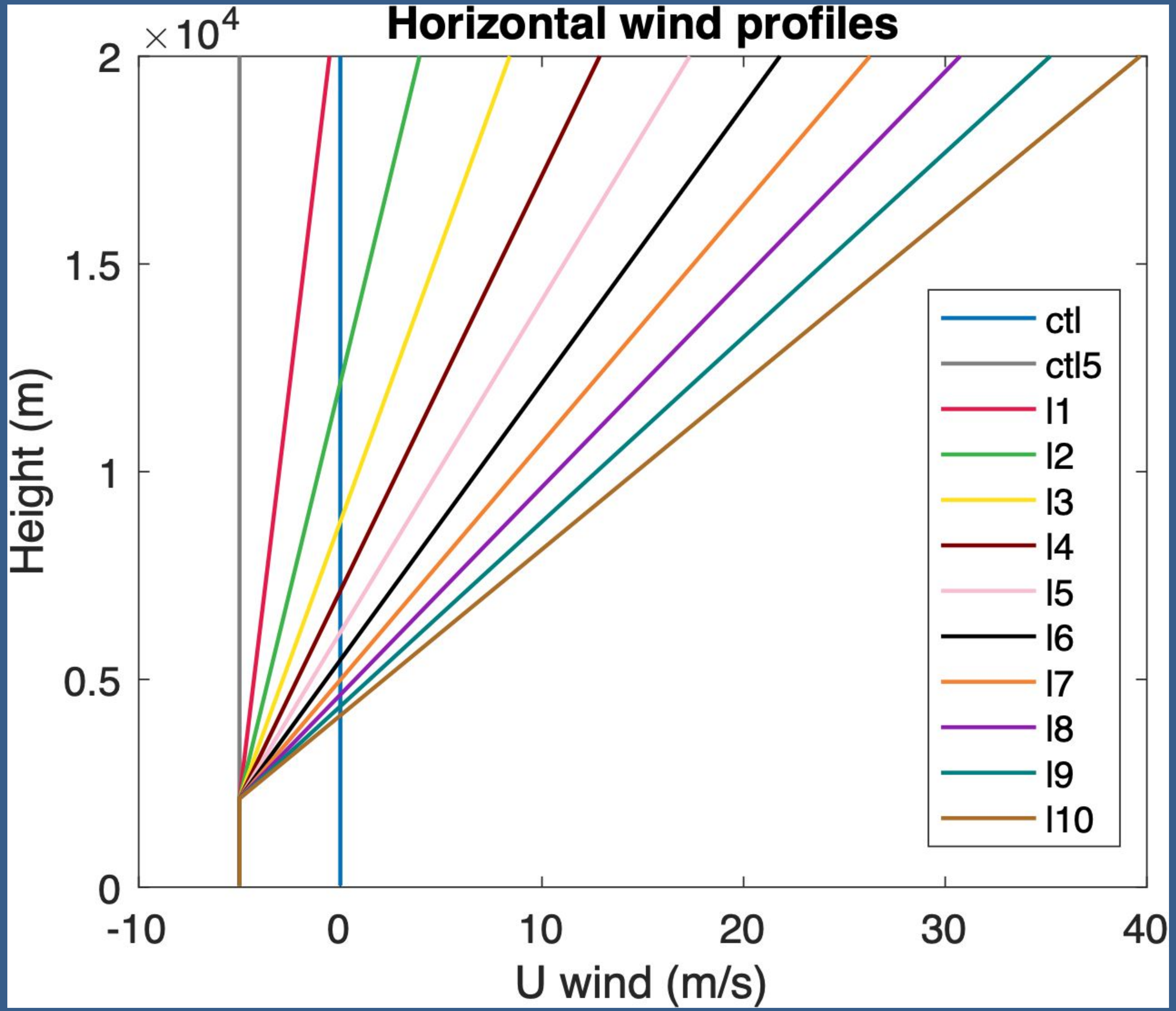
- For control scenario, 10 out of 20 ensemble members display organization (more circular)

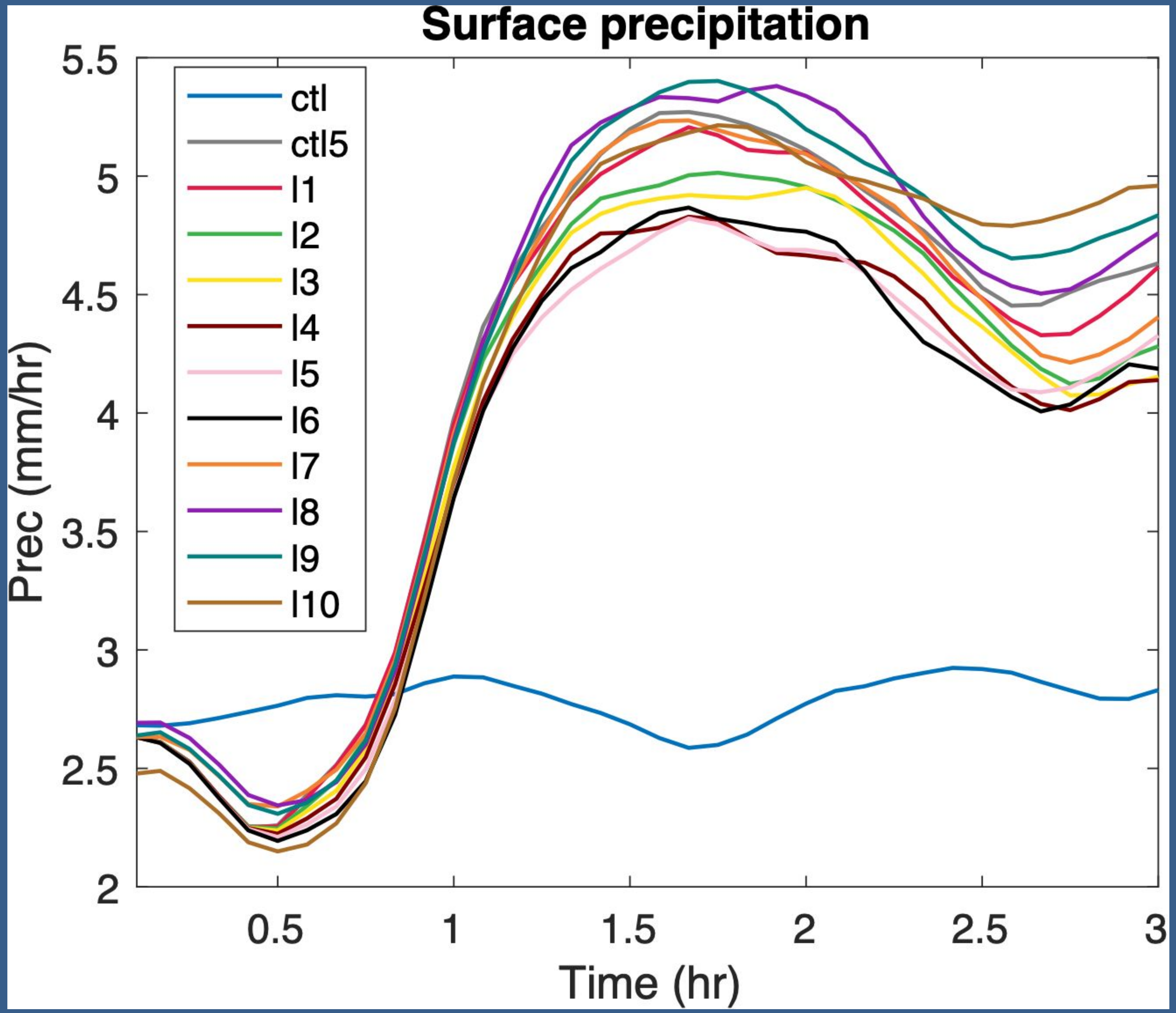




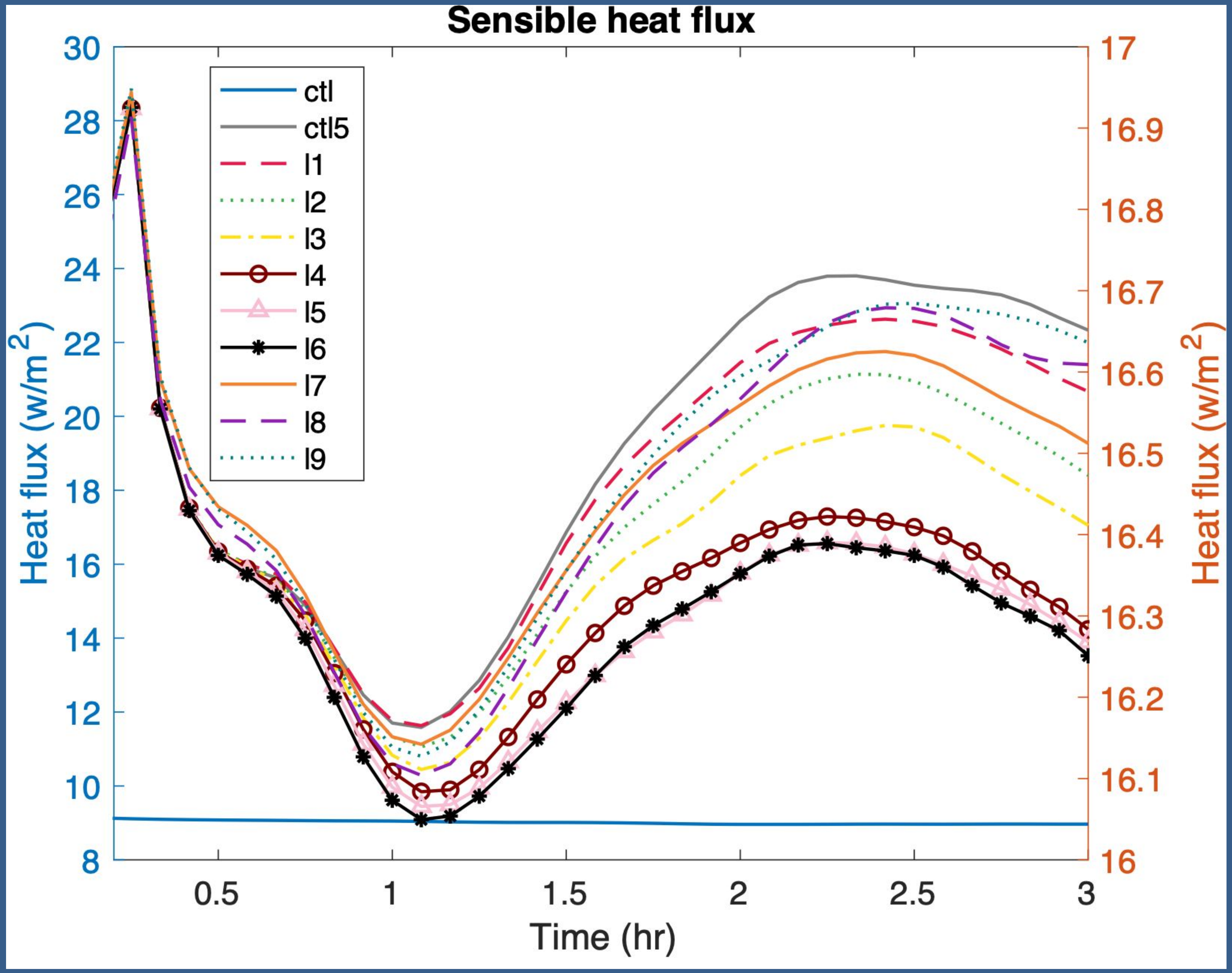
- For linear shear scenario, 15 out of 20 ensemble members display convective organization

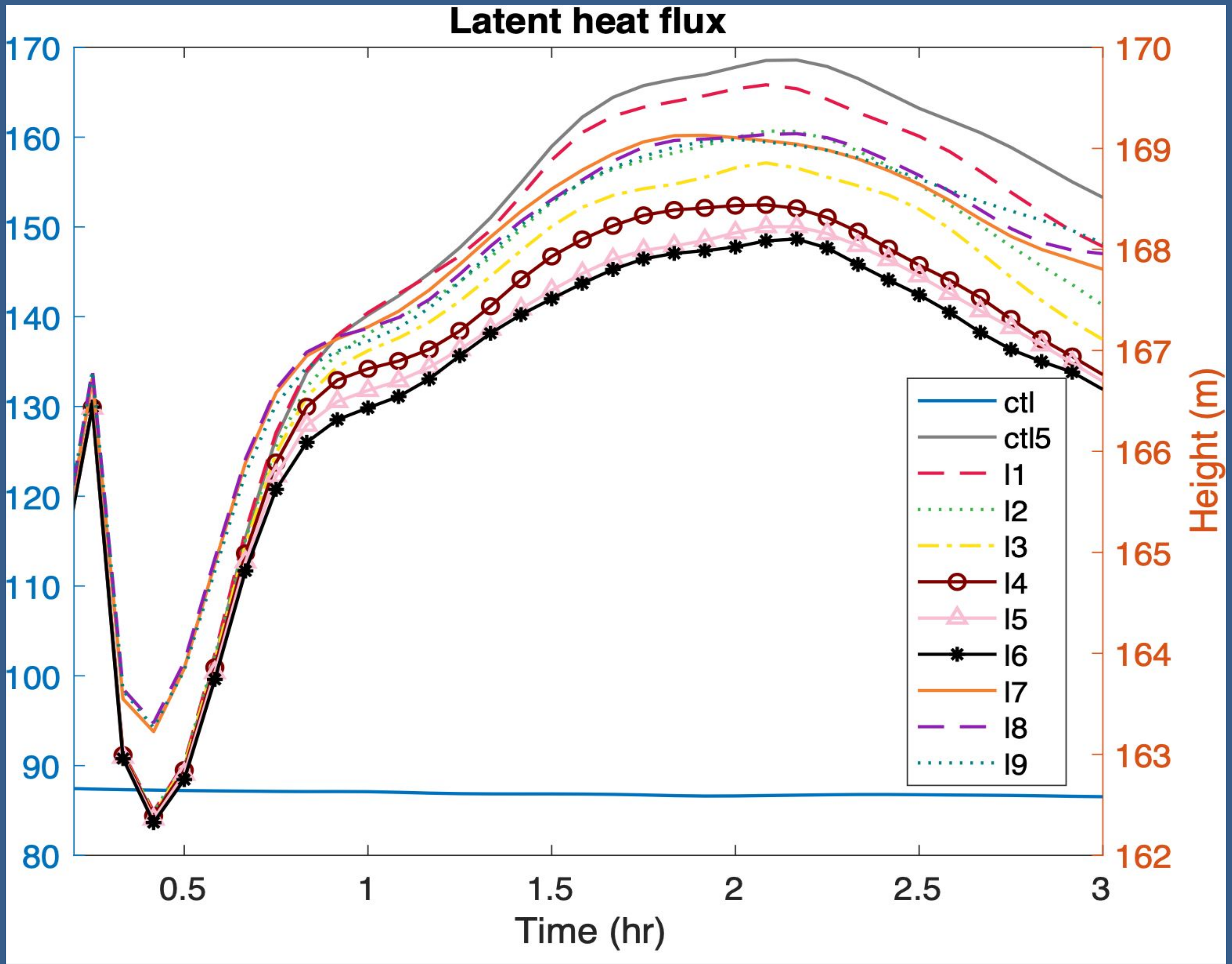
Precipitation responses to various magnitudes of shear



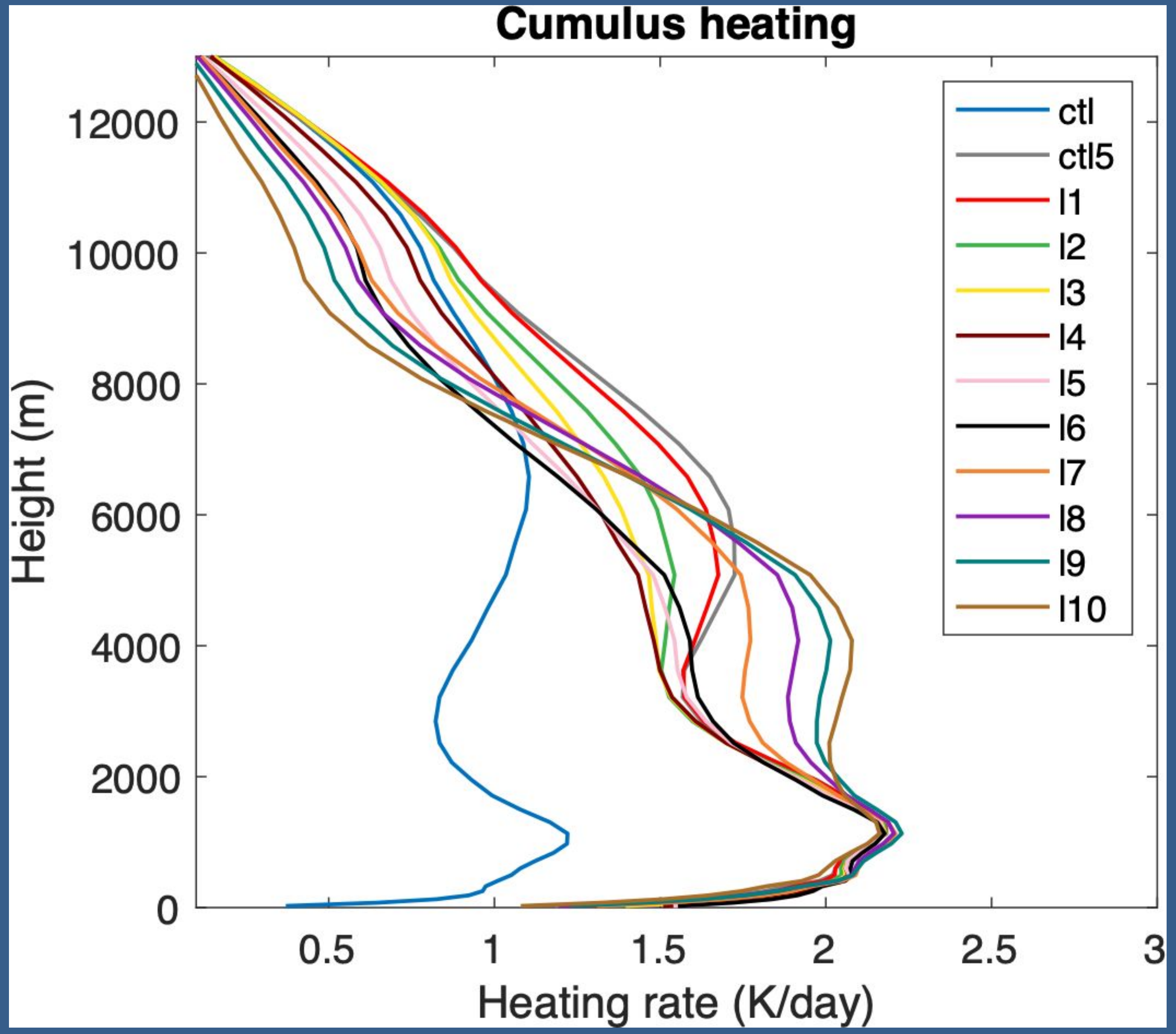


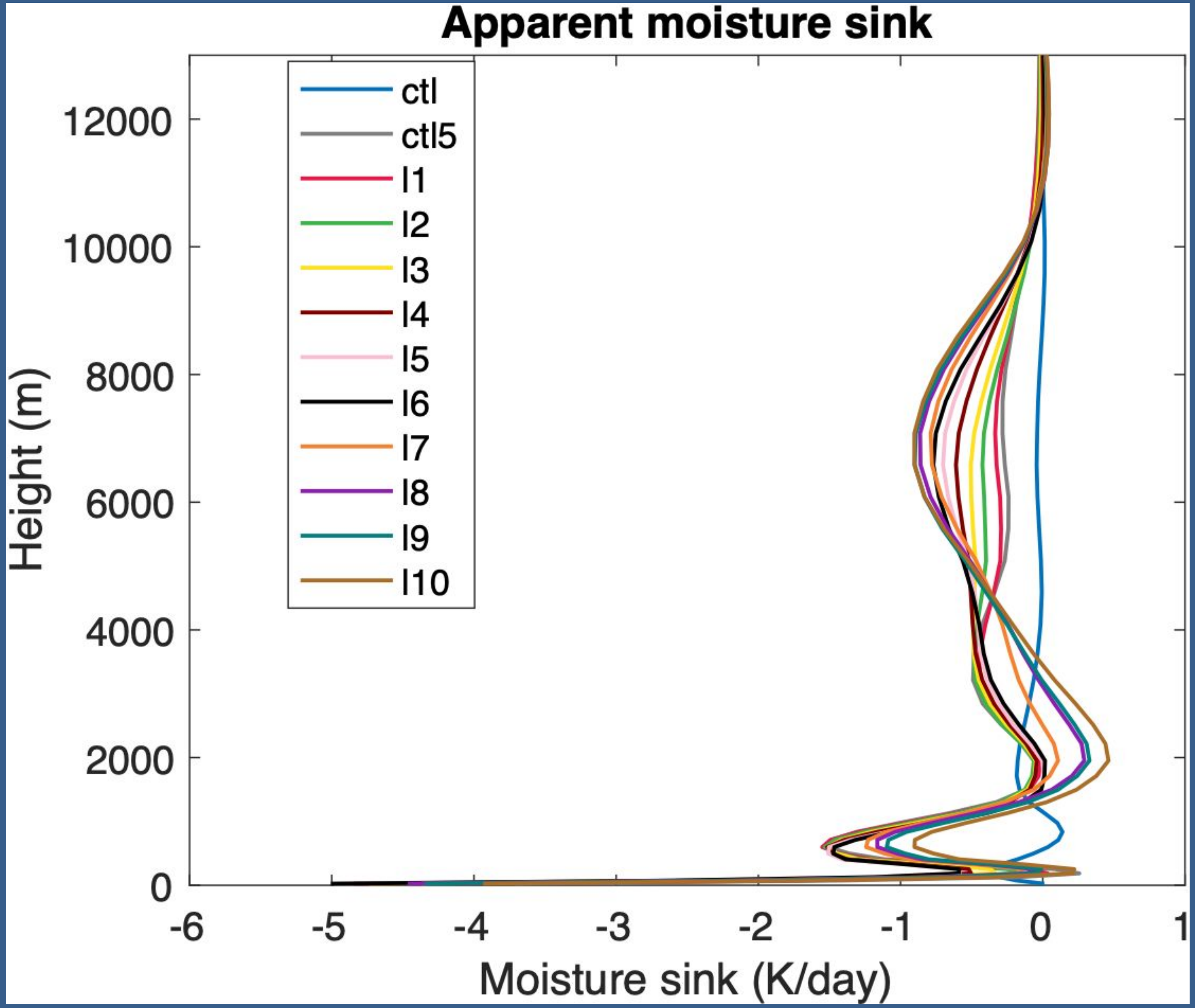
Other responses to various magnitudes of shear

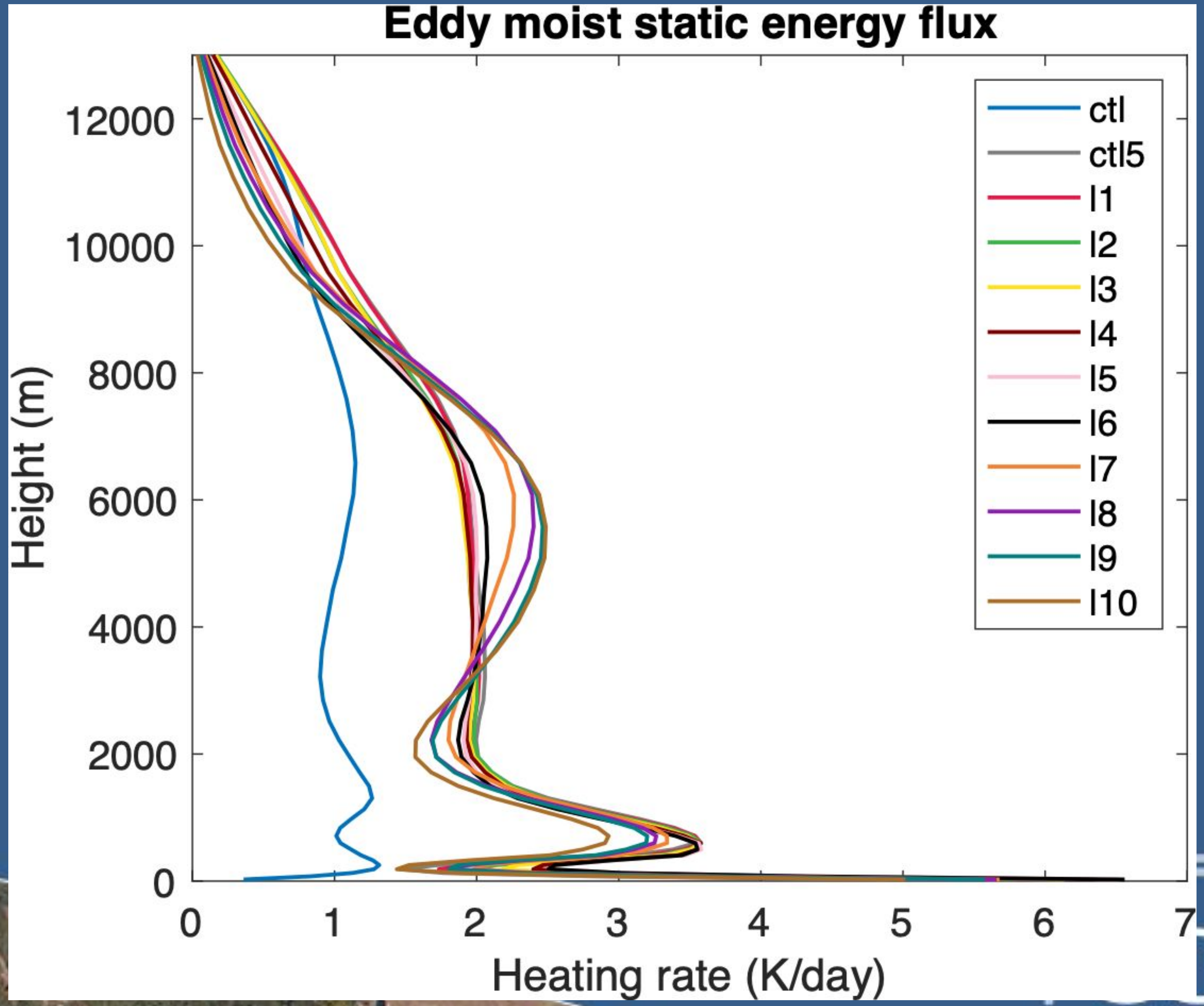




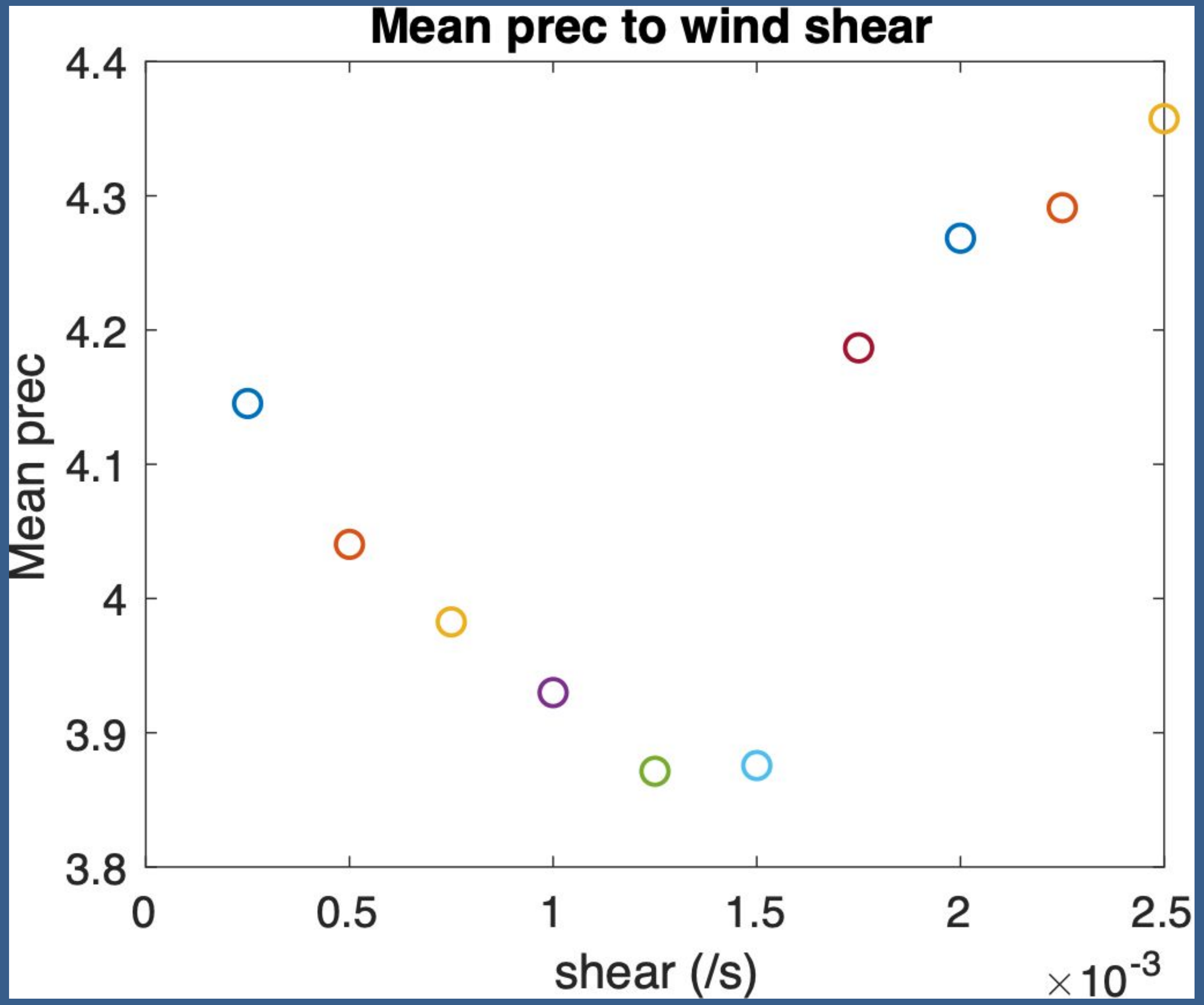
Other convective responses to various magnitudes of shear

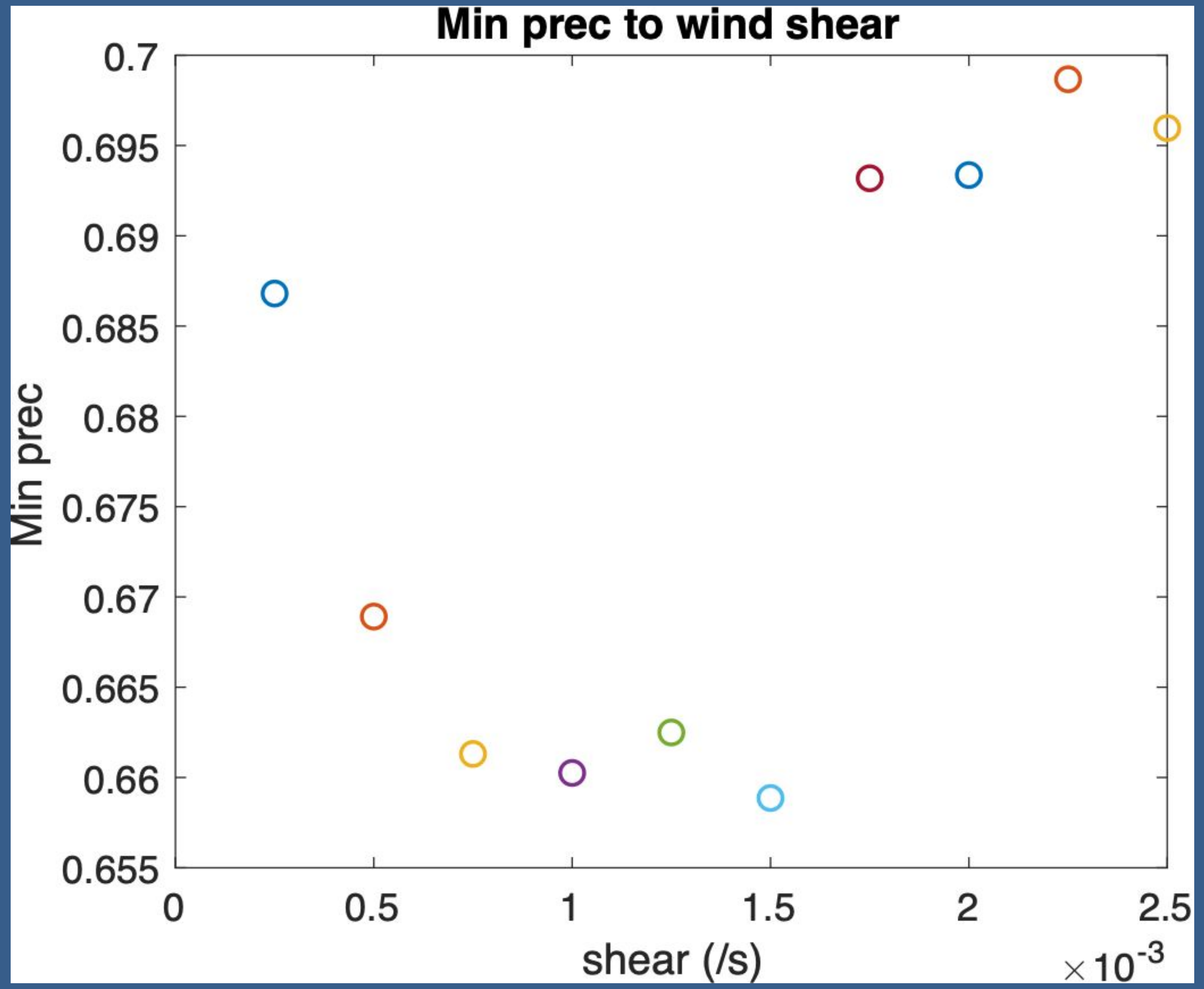


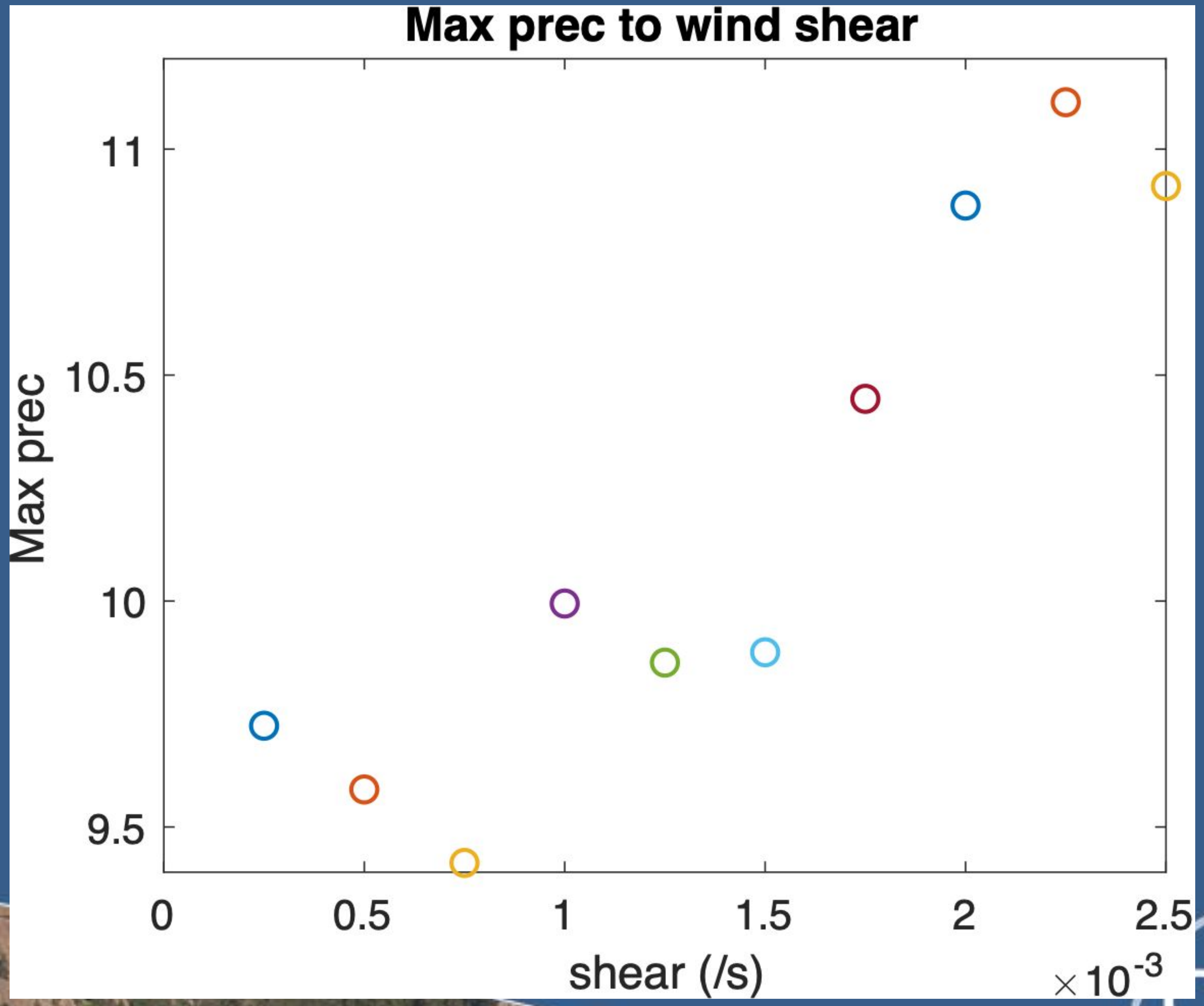




Precipitation response to wind shear







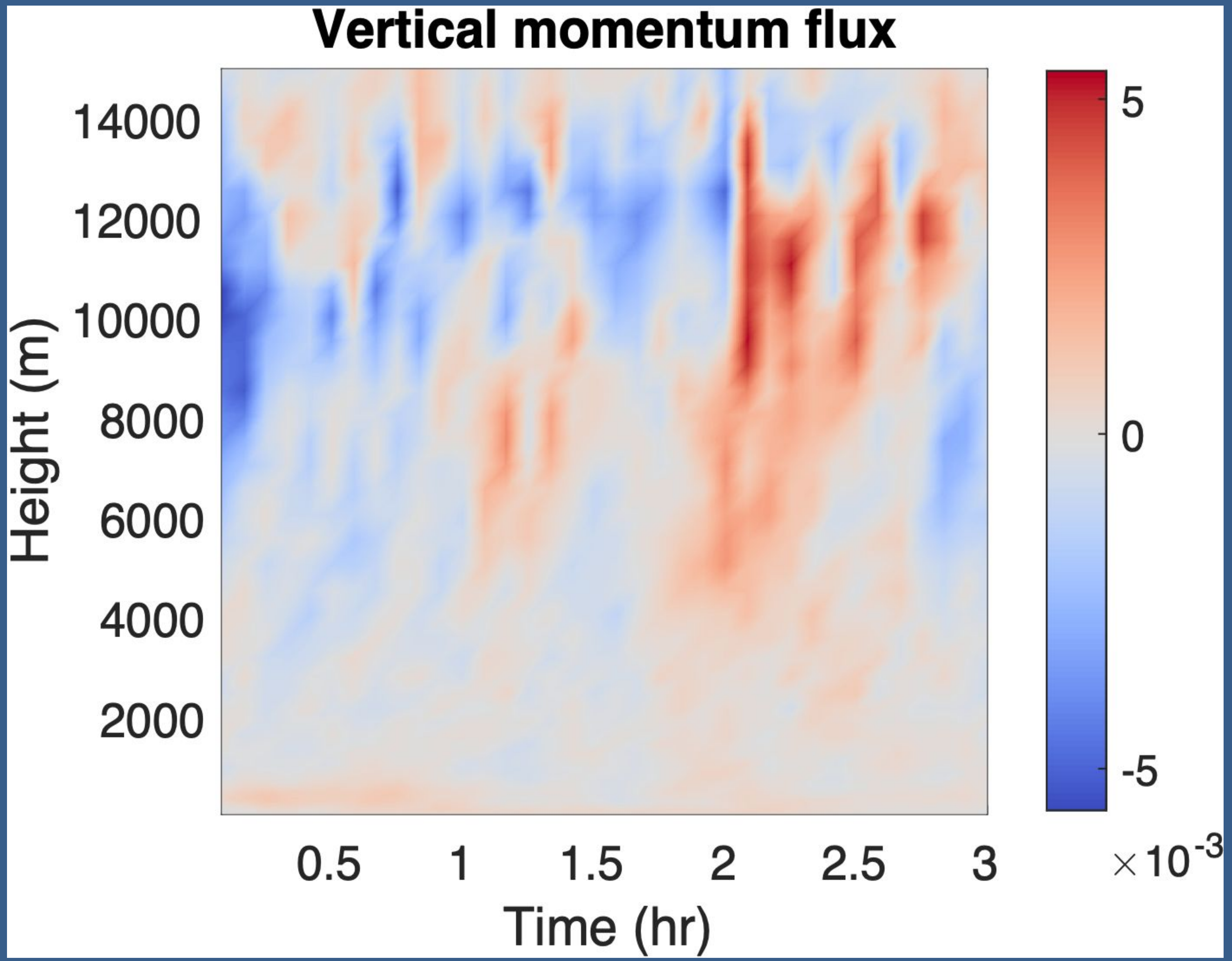
Scientific questions

- Why is there surface precipitation suppression in the first hour of simulation?

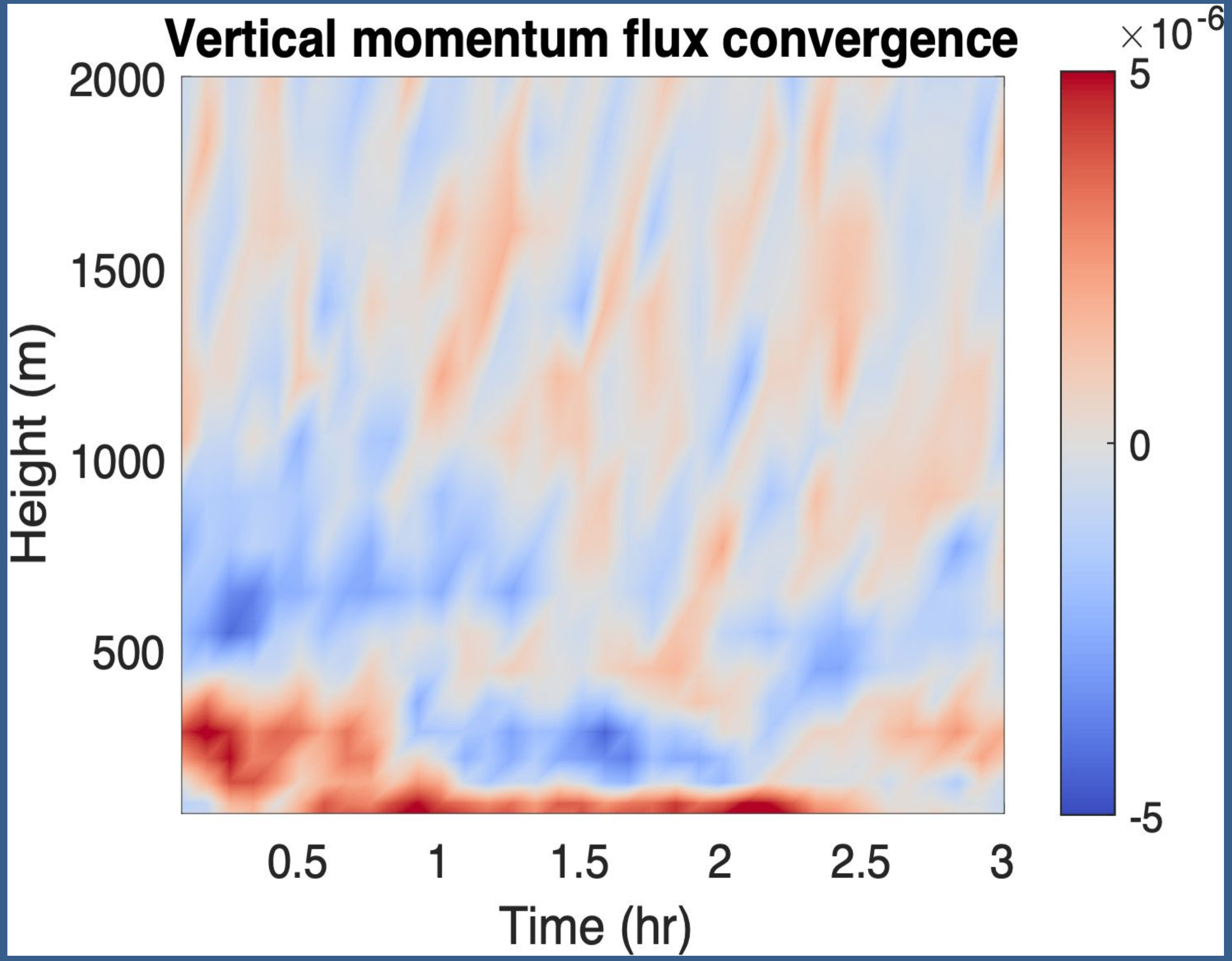
- Why is the convective response to wind shear non-monotonic?

- What determines the critical wind shear value?

Ctl

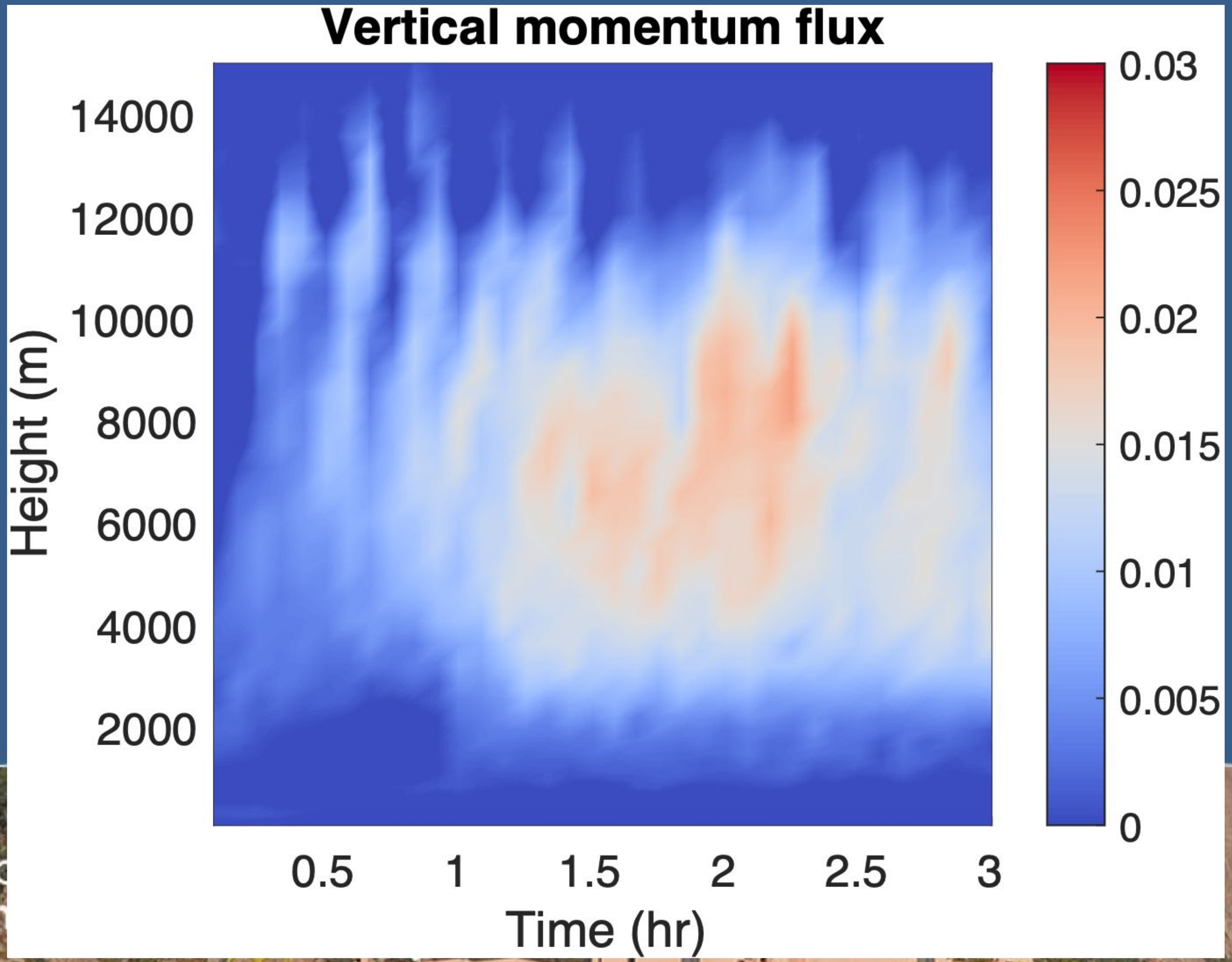


Vertical momentum flux
Height (m)
Time (hr)
×10^-3

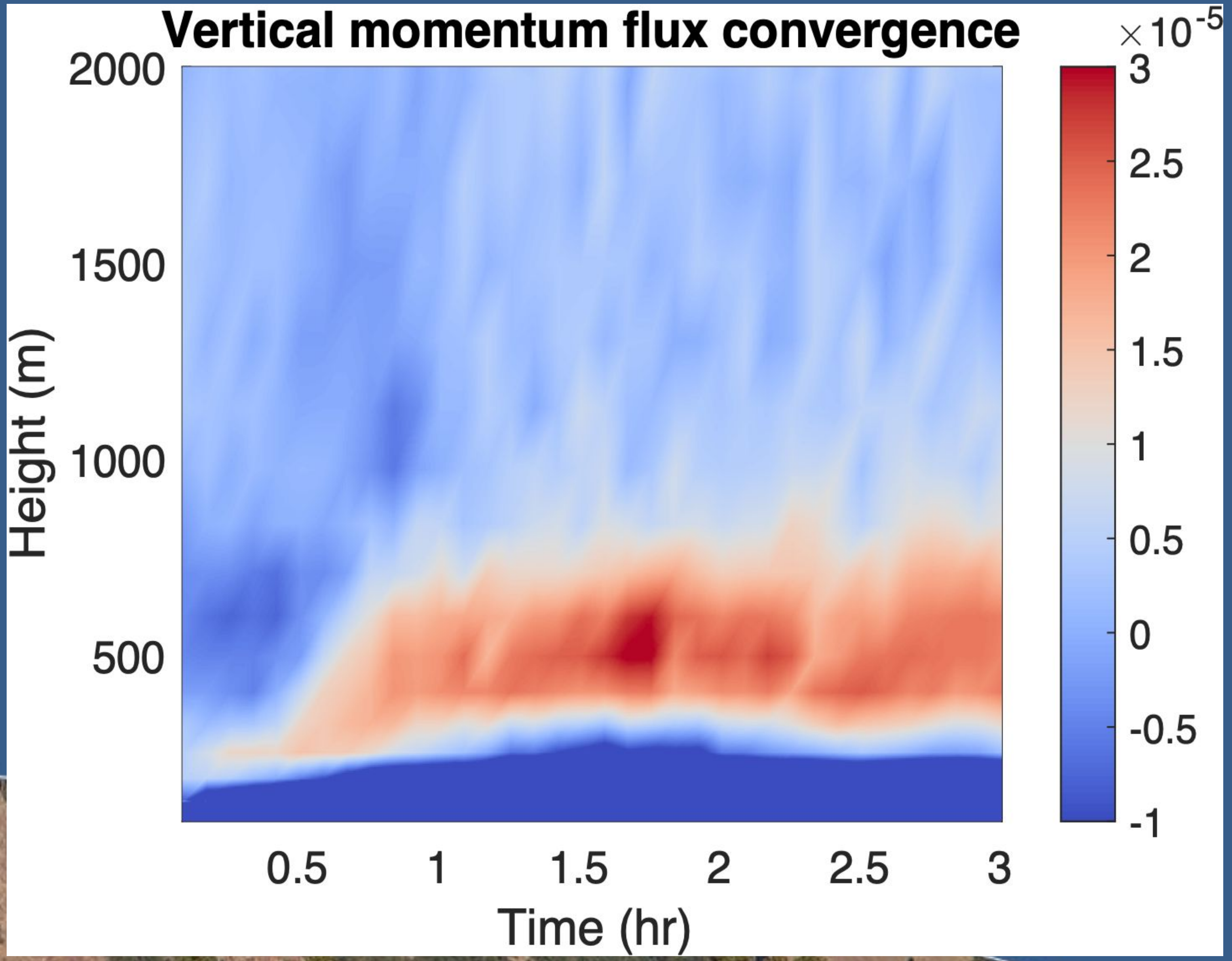


Vertical momentum flux convergence
Height (m)
Time (hr)
×10^-6

Ctl5



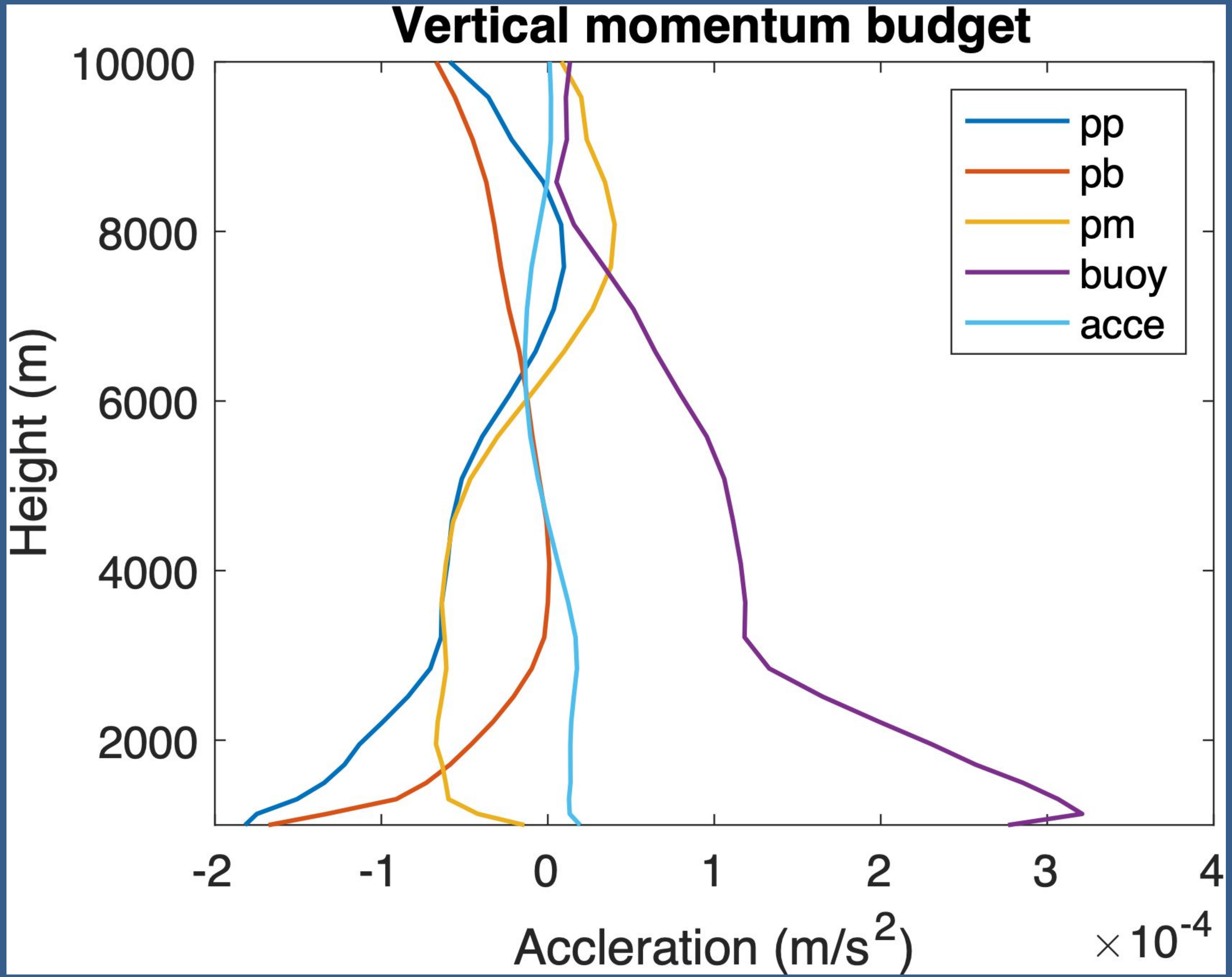
Vertical momentum flux
Height (m)
Time (hr)



Vertical momentum flux convergence
Height (m)
Time (hr)
×10^-5

Vertical momentum budget analysis

Cloudy updrafts buoyancy, PP, acceleration



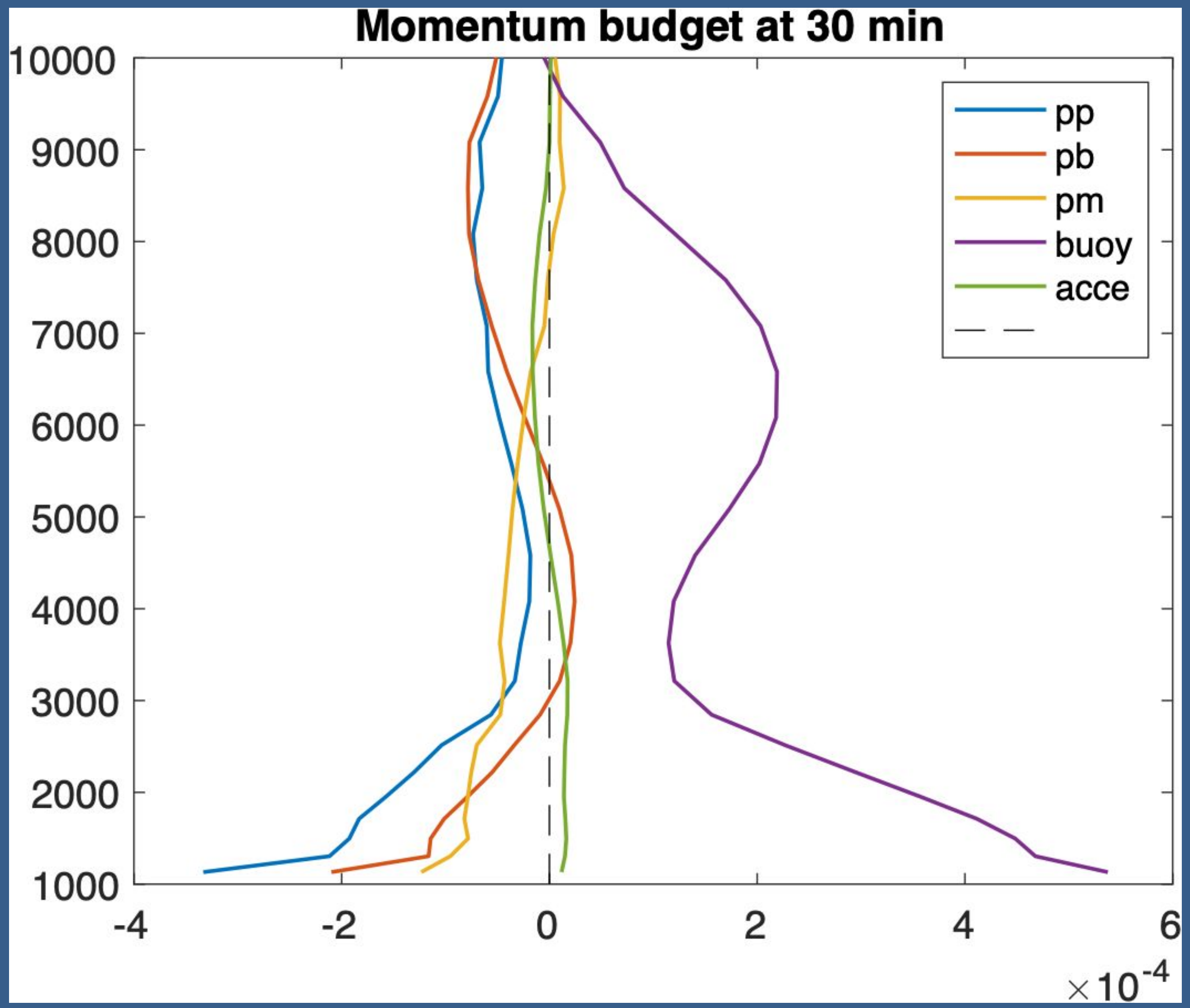
$$\frac{1}{2}\frac{\partial \bar{w}^2}{\partial z} = \bar{B} - \frac{1}{\rho}\frac{d\bar{p}'_B}{dz} - \frac{1}{\rho}\frac{d\bar{p}'_M}{dz} - \epsilon \bar{w}^2$$

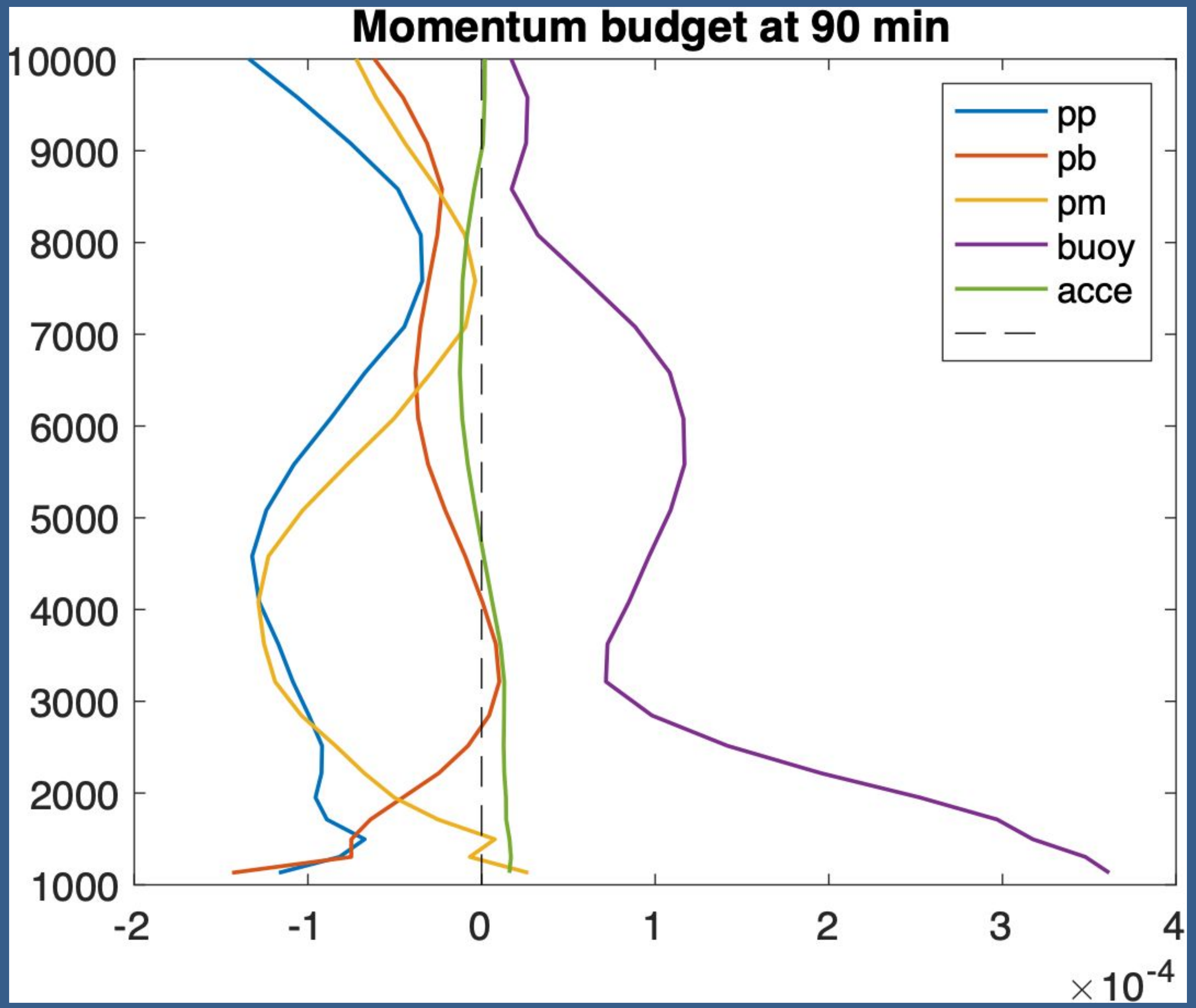
$$\nabla^2 p'_B = \partial_z(\rho_0 B),$$

$$\nabla^2 p'_M = -\nabla \cdot (\rho_0 \vec{v} \cdot \nabla \vec{v}).$$

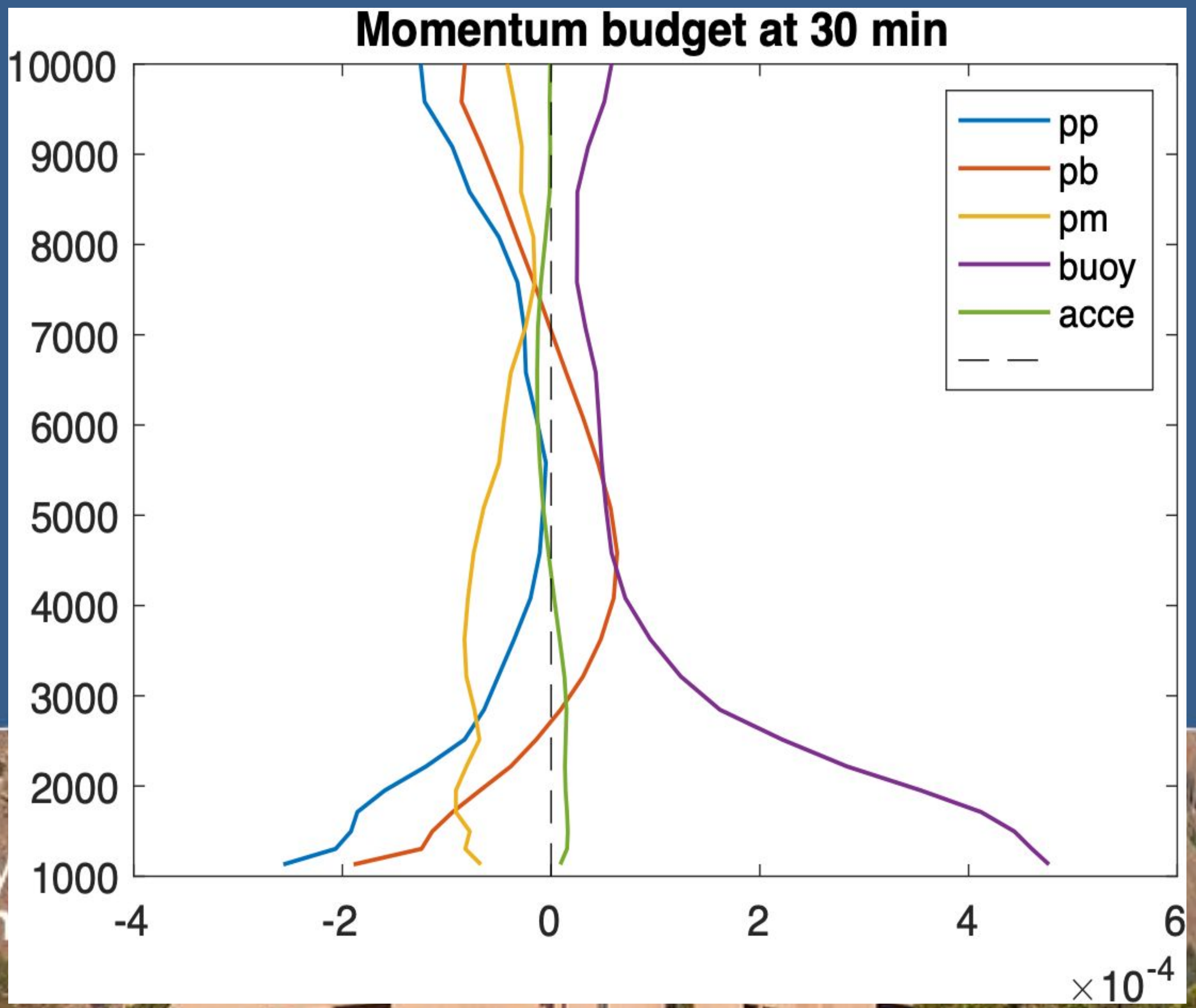
Momentum budget temporal evolution of cloudy updrafts

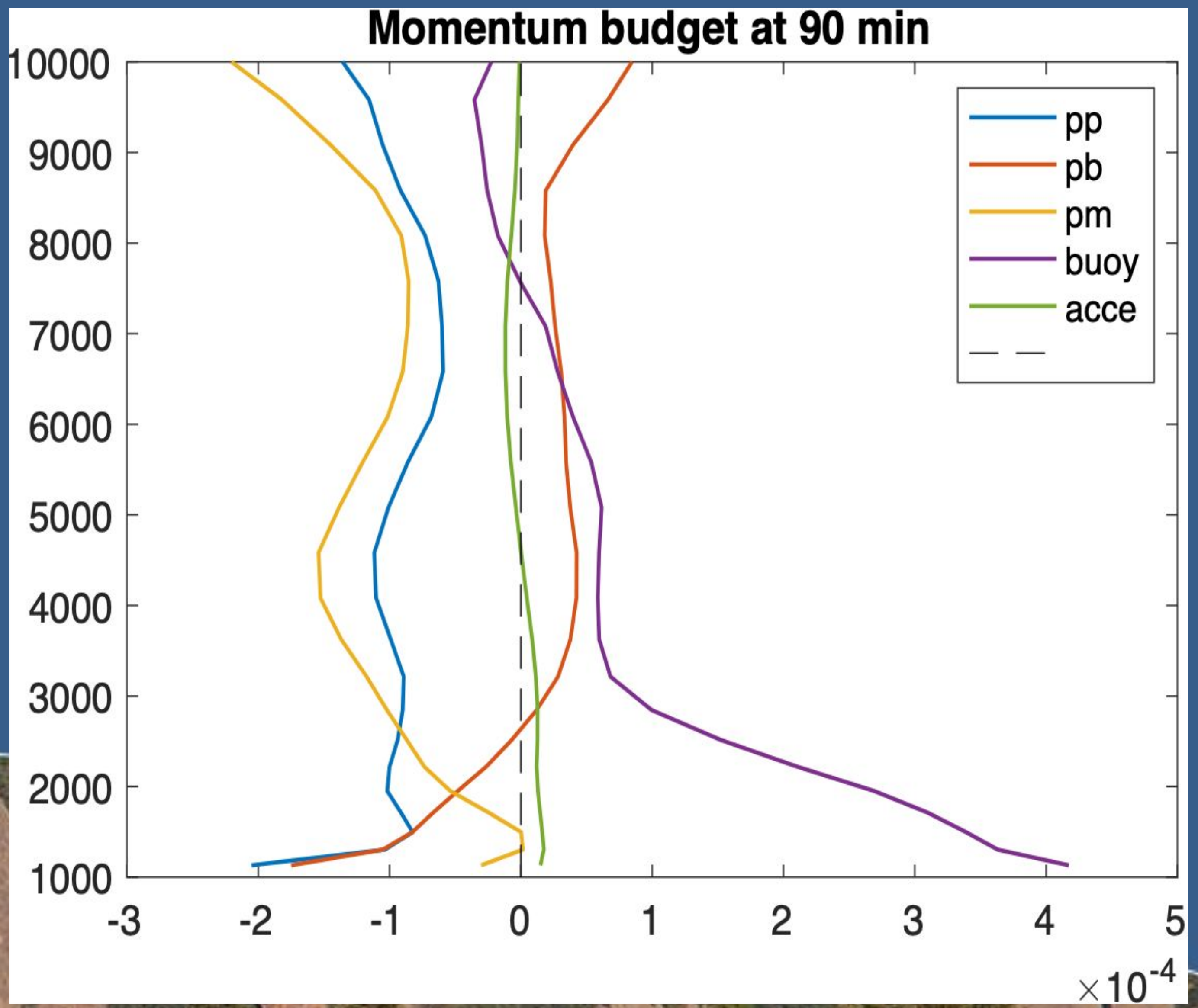
Ctl5





Linear6



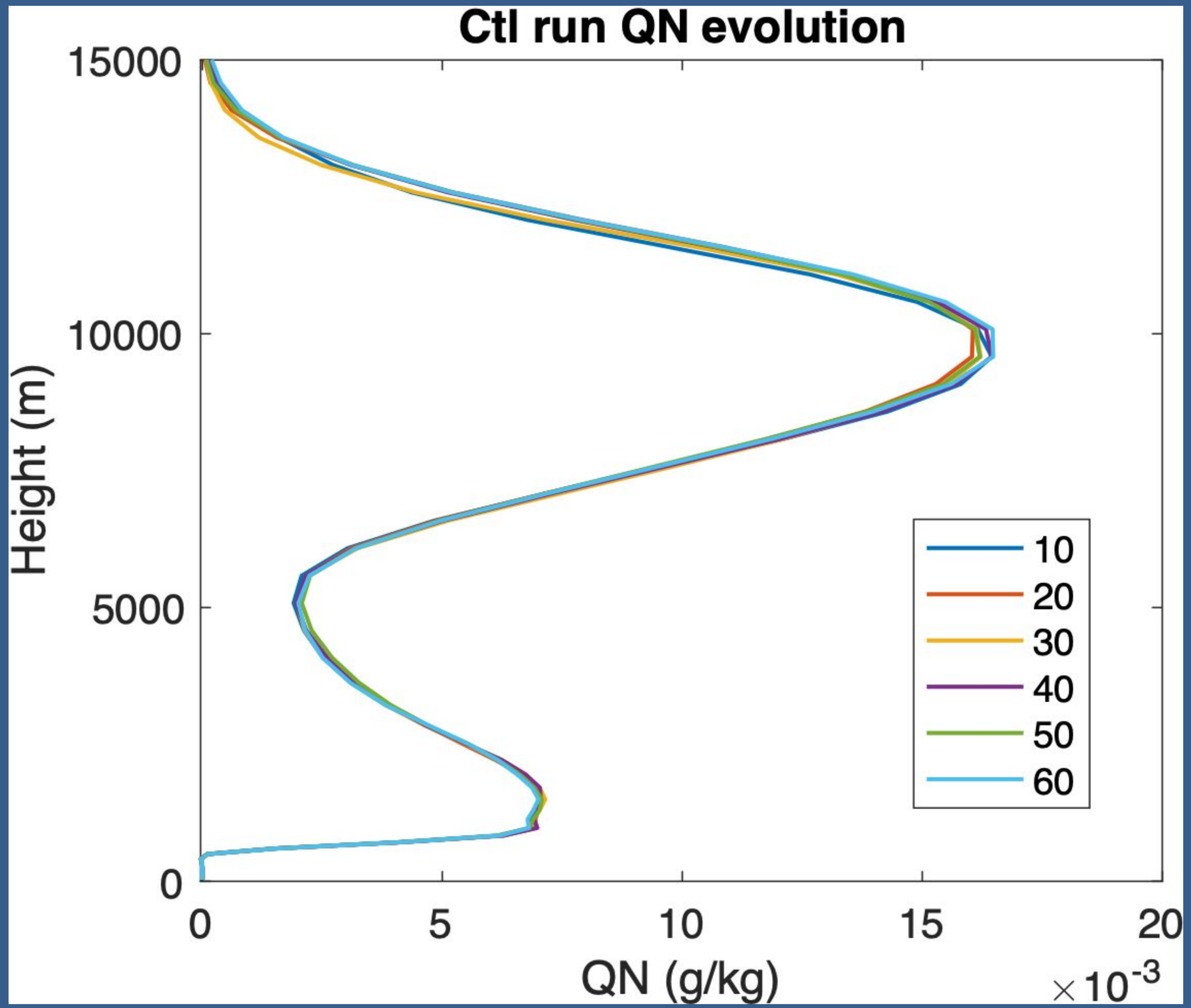


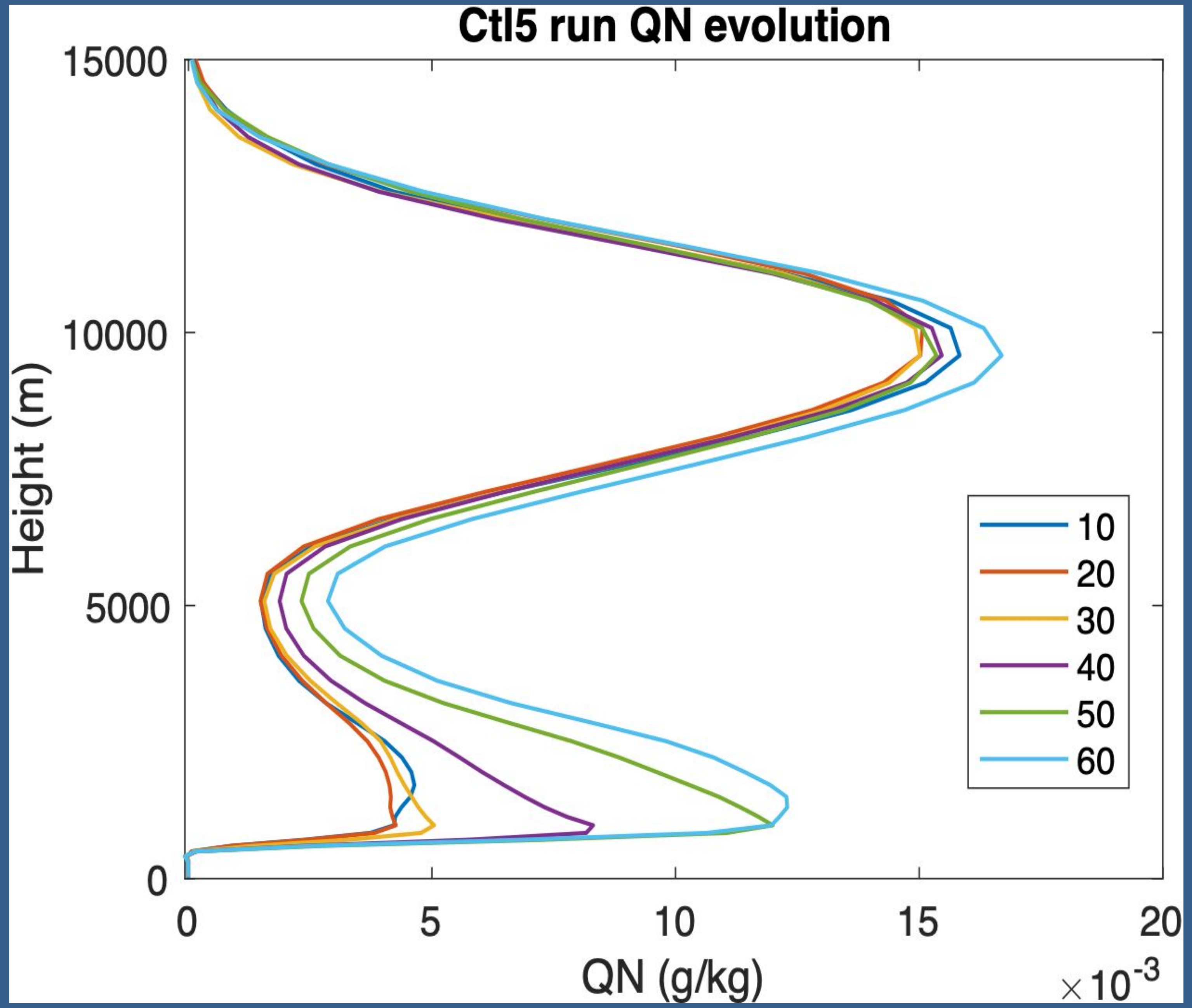
Take-home messages

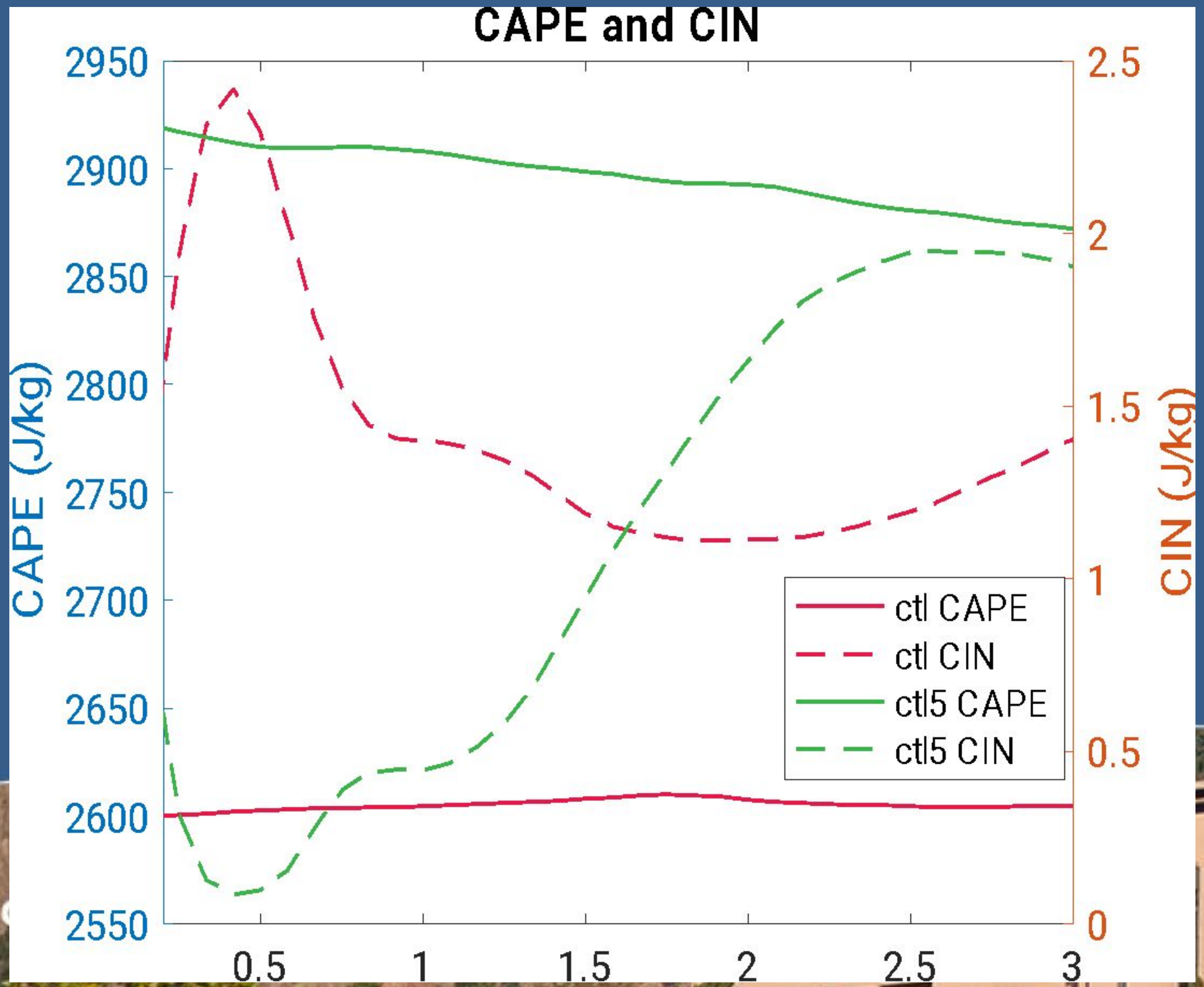
- Cumulus ensembles response to imposed wind shear in a non-monotonic behavior

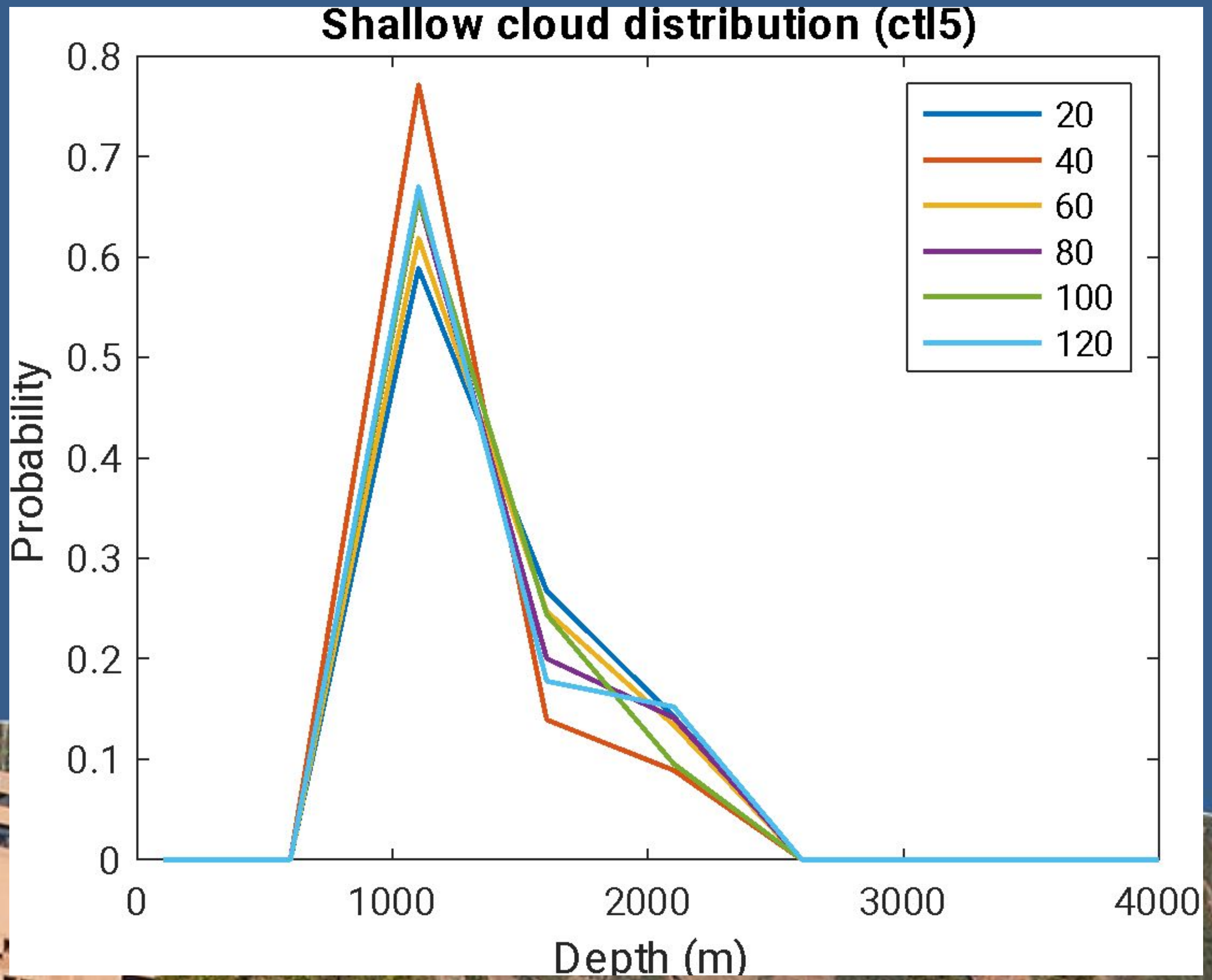
- A physically- and process- based convective trigger could be implemented to better characterize MCSs in coarse-resolution climate models.

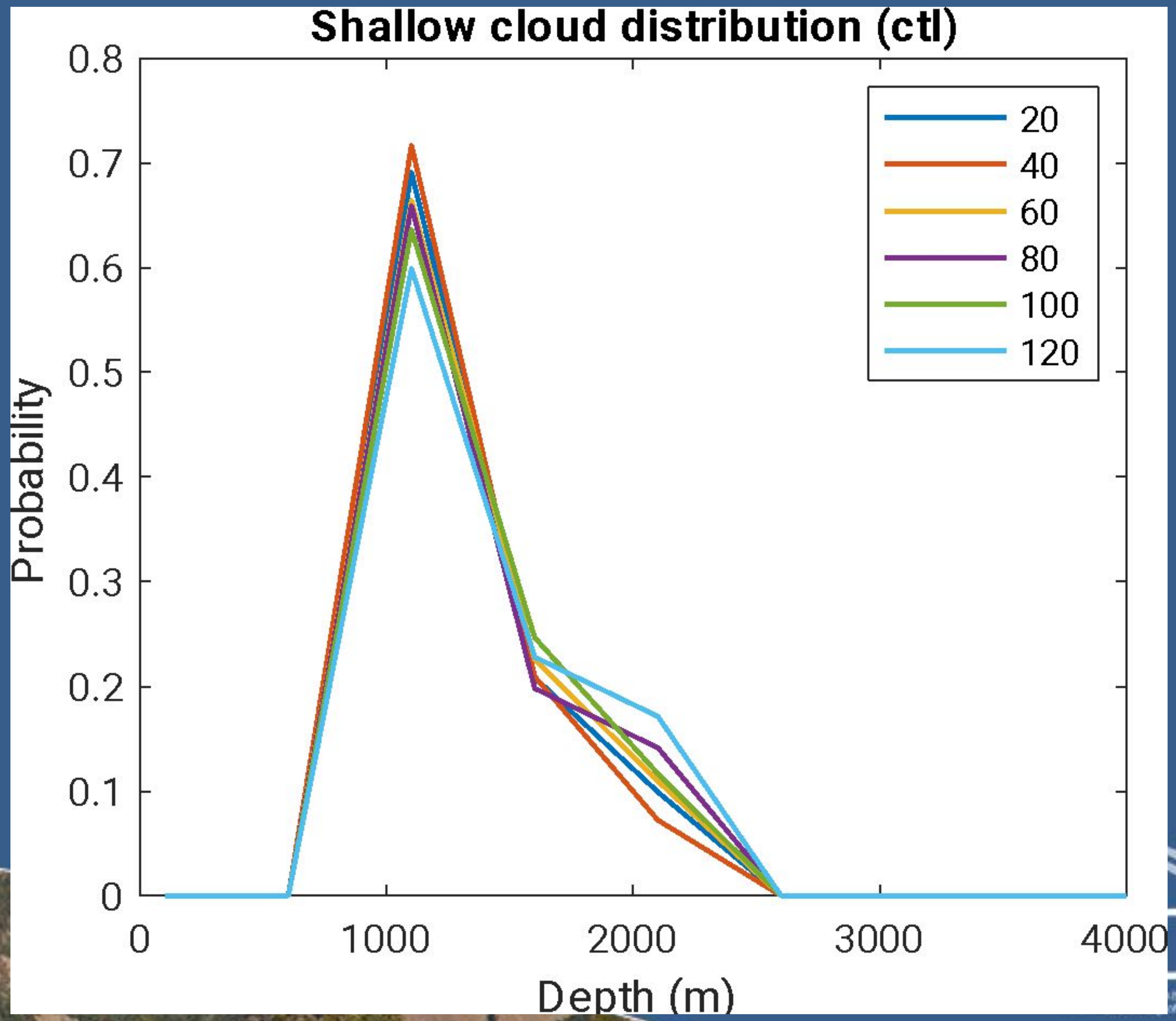
- A competing mechanism between pressure drag and surface fluxes. The immediate reduction can be related to pressure drag, then it takes about an hour for a convective cell to reach to the upper troposphere, that's where the surface fluxes kick in.


Ctl run QN evolution
Height (m)
QN (g/kg)
×10^-3
0
5000
10000
15000
0
5
10
15
20
10
20
30
40
50
60


Ctl5 run QN evolution
Height (m)
QN (g/kg)
×10^-3
0
5000
10000
15000
0
5
10
15
20
10
20
30
40
50
60


CAPE and CIN
CAPE (J/kg)
CIN (J/kg)
2550
2600
2650
2700
2750
2800
2850
2900
2950
0
0.5
1
1.5
2
2.5
0.5
1
1.5
2
2.5
3
ctl CAPE
ctl CIN
ctl5 CAPE
ctl5 CIN


Shallow cloud distribution (ctl5)
Probability
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
1000
2000
3000
4000
20
40
60
80
100
120


Shallow cloud distribution (ctl)
Probability
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
1000
2000
3000
4000
20
40
60
80
100
120