Synergistic Effect of Mid-level Dry Air and Vertical Wind Shear on Tropical Cyclone Ventilation Pathways

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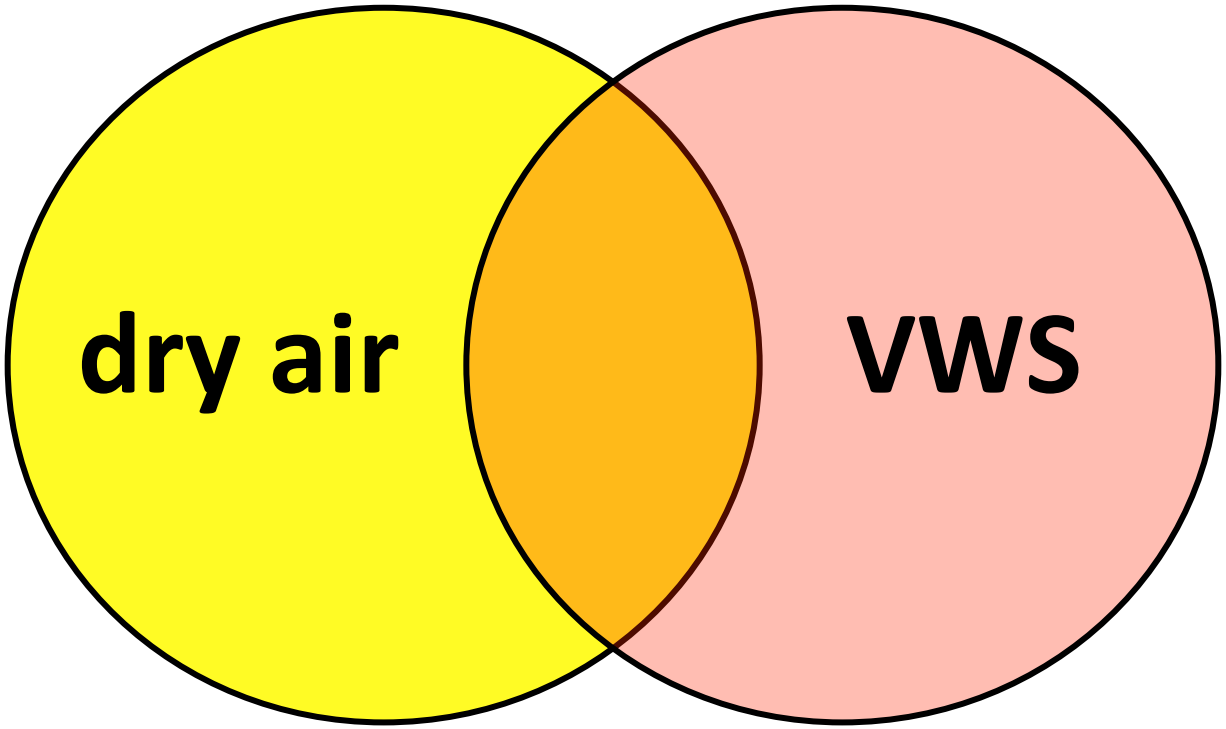
Motivation



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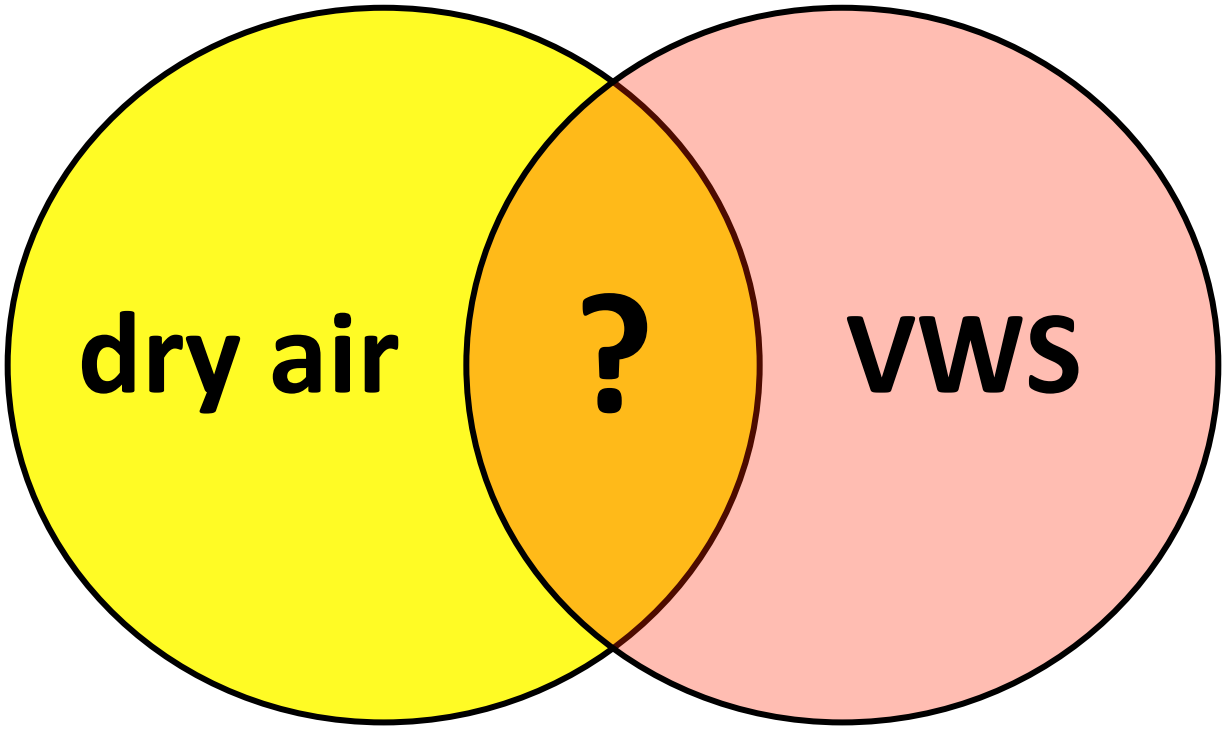


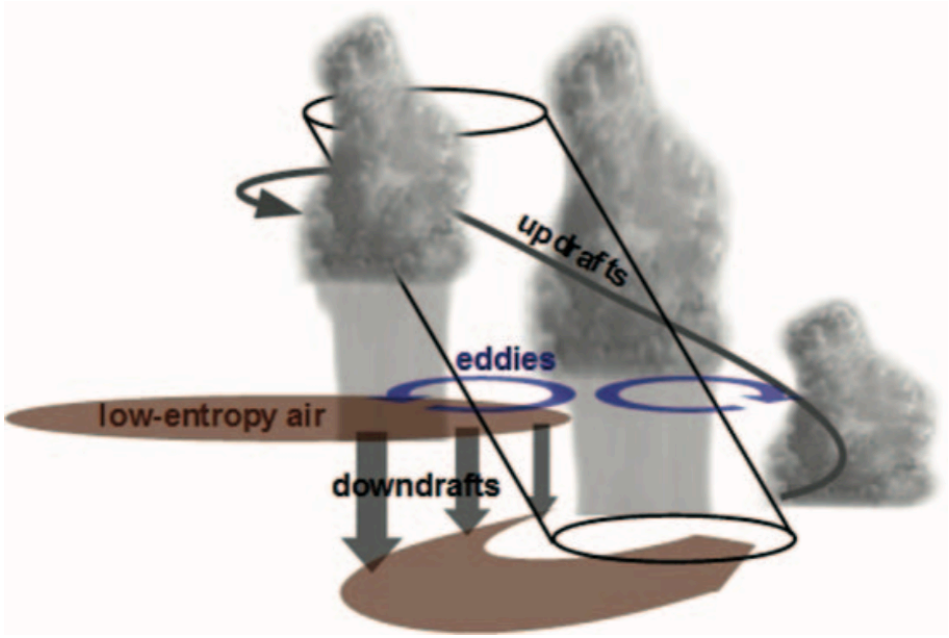
Motivation

Ventilation

- Flux of low-moist static energy (MSE) environmental air into TC inner core.
  - **Mid-level pathway:** Dry air ventilates midlevels.
  - **Low-level pathway:** Dry air ventilates subcloud layer via convective downdrafts.

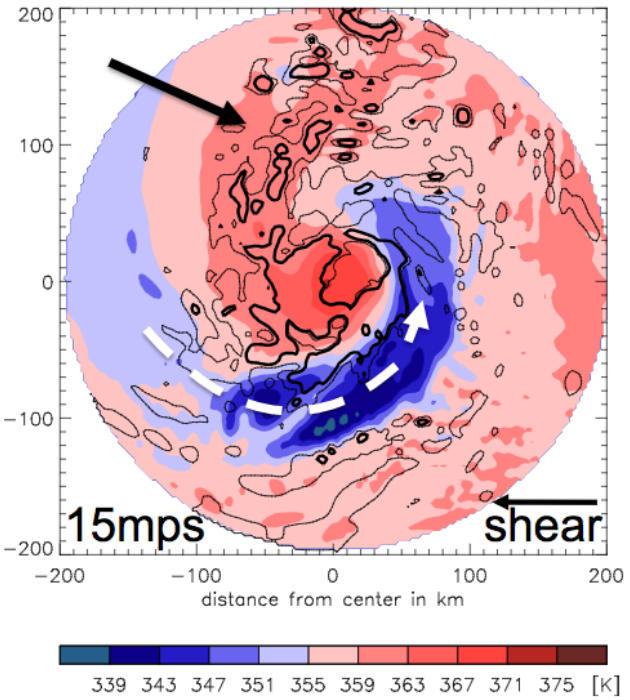
mid-level ventilation

Tang and Emanuel (2012)



low-level ventilation

Riemer et al. (2010)



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- Flux of low-moist static energy (MSE) environmental air into TC inner core.
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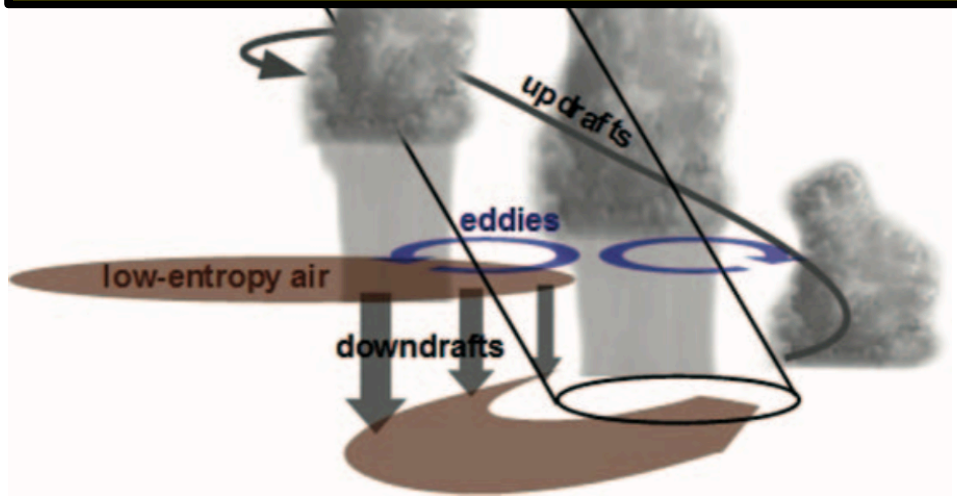
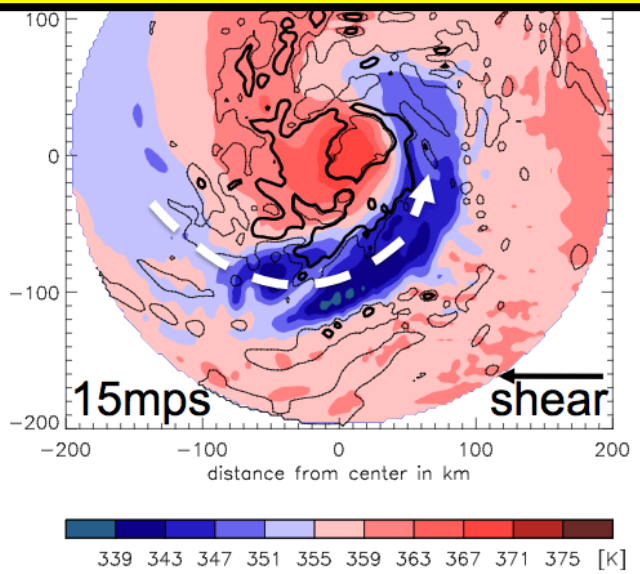
How does the magnitude of dry air and vertical wind shear affect the structure of these ventilation pathways during early development?



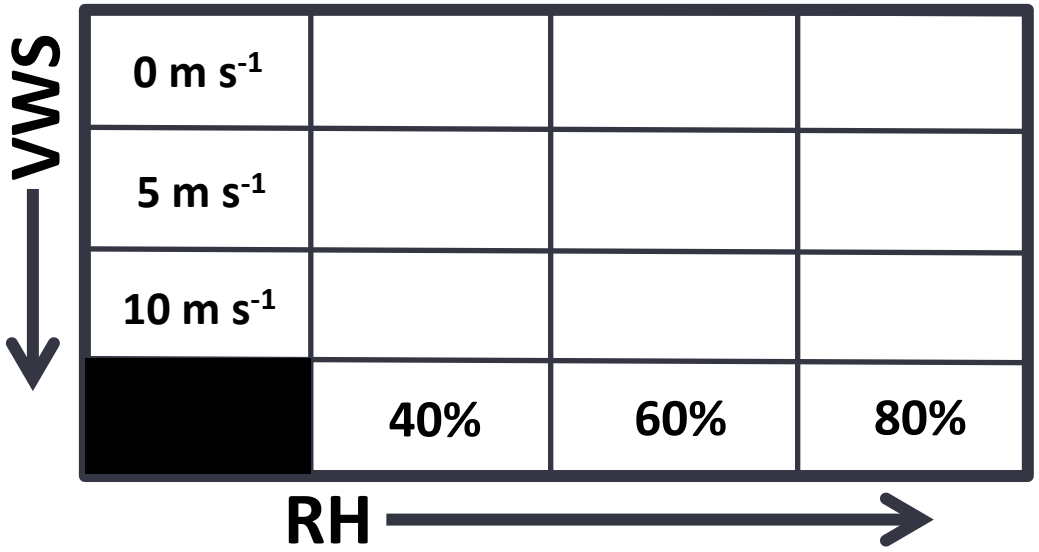


Methodology: Model Setup

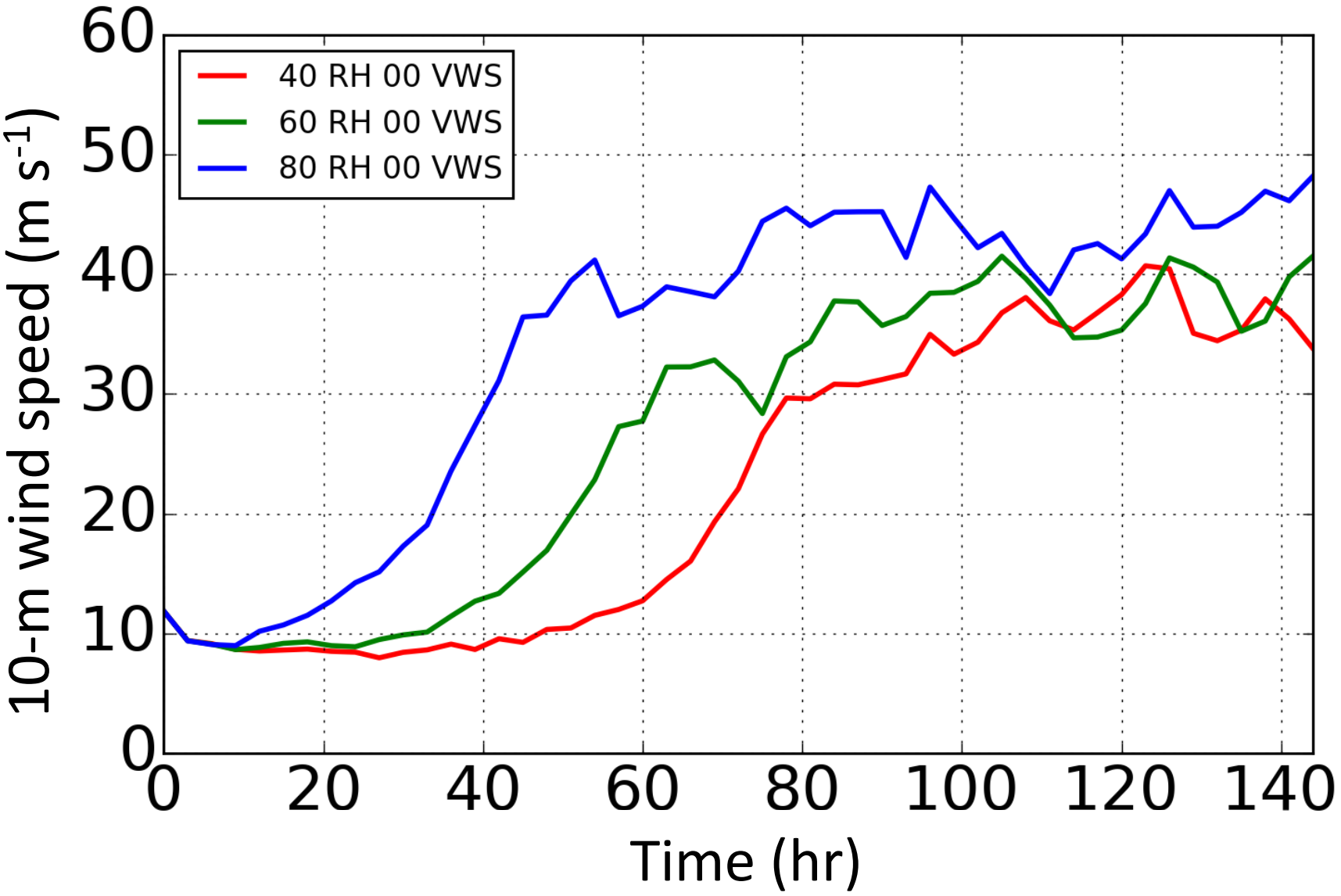
Model: CM1 (Cloud Model 1)

- **Resolution:** 4 km horizontal; 59 vertical levels
- **Microphysics:** Kessler (1969)
- **Radiation:** Newtonian Relaxation (Rotunno and Emanuel 1987)
- **Turbulence:** Down-gradient parameterization

- **Other specifications:**
  - *f*-plane with Coriolis parameter set to 5 x 10^{-5} s^{-1}
  - Initial vortex: Rotunno and Emanuel (1987)
  - Moist tropical temperature profile (Dunion 2011)
  - Sea surface temperature: 28°C



Azimuthally-Averaged Wind Speed



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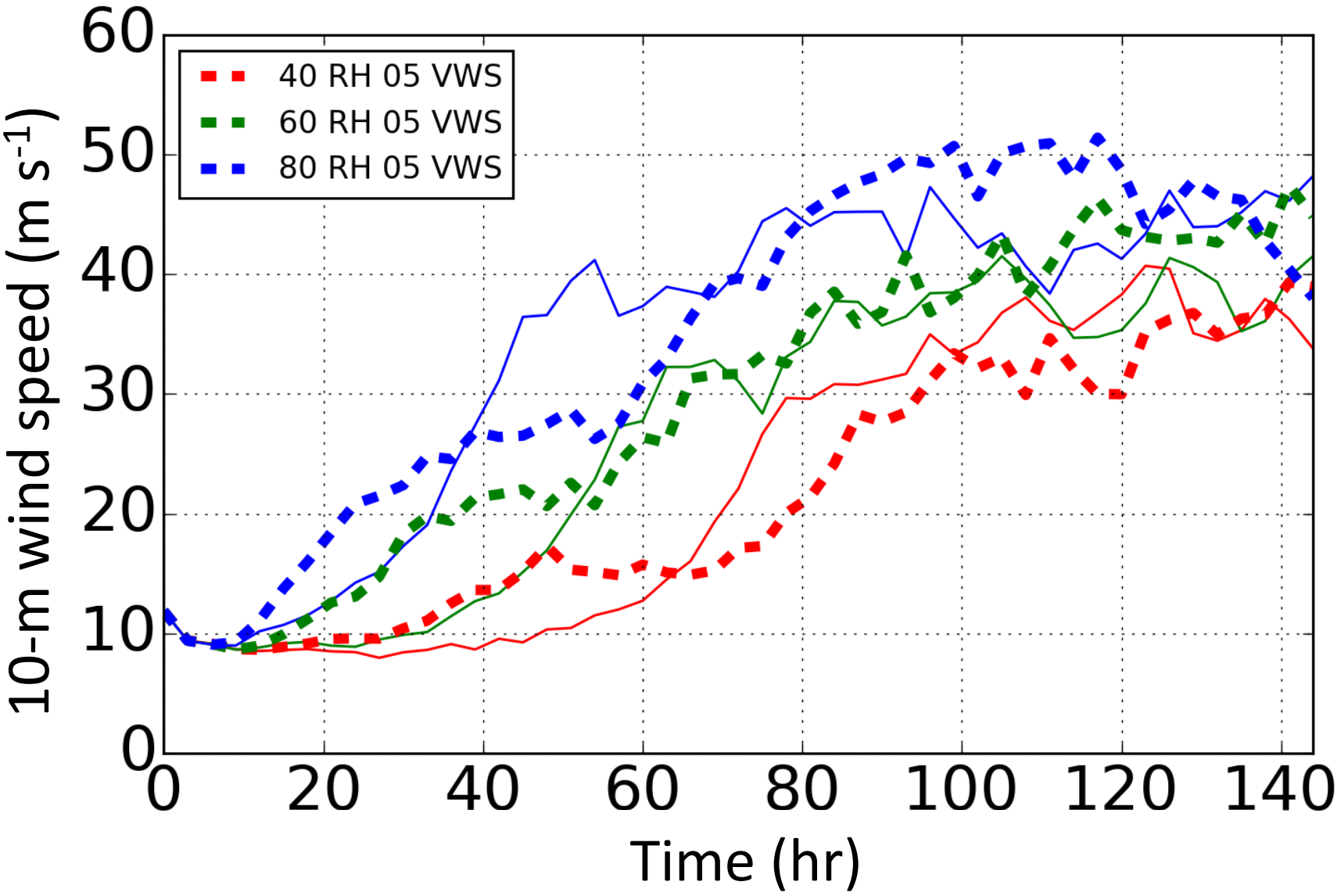

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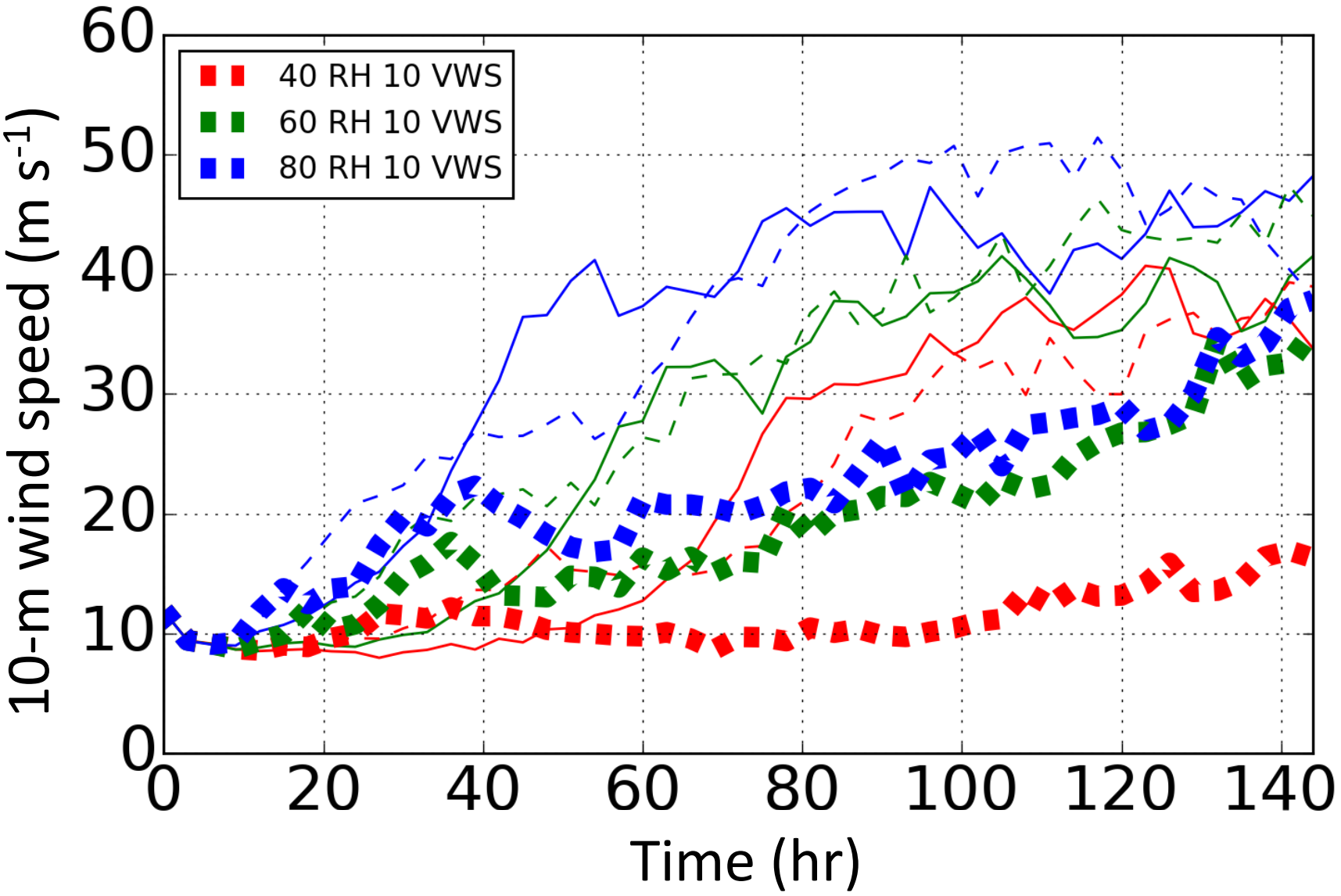

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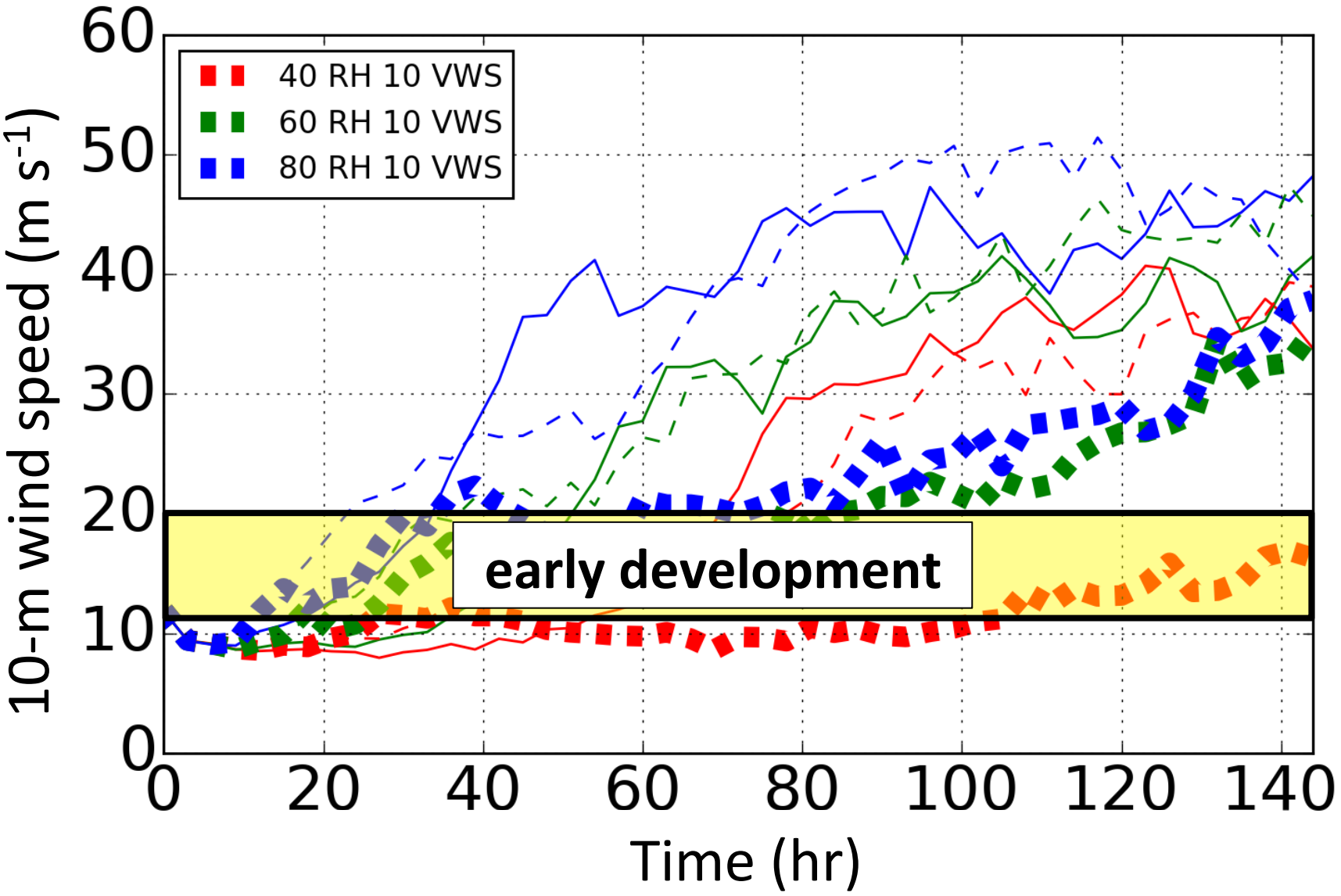
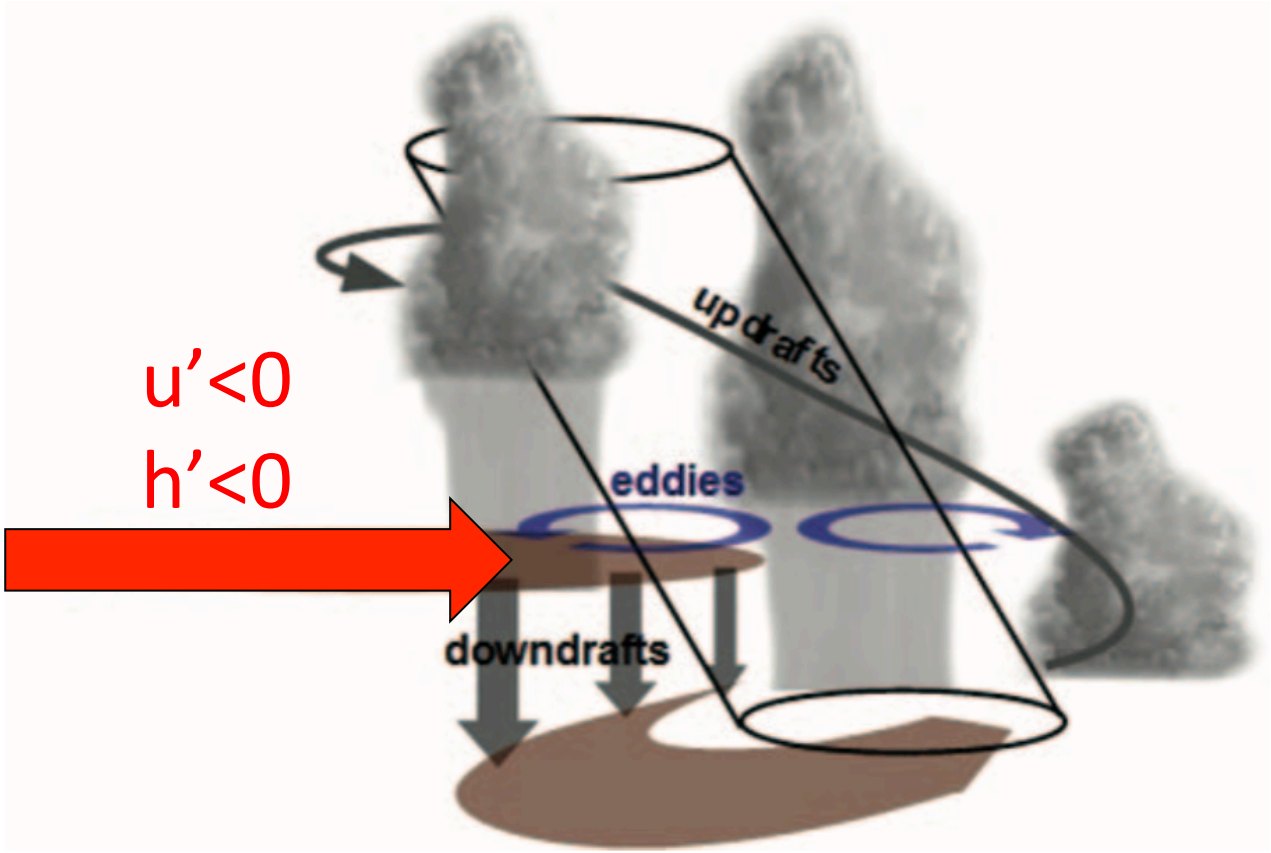
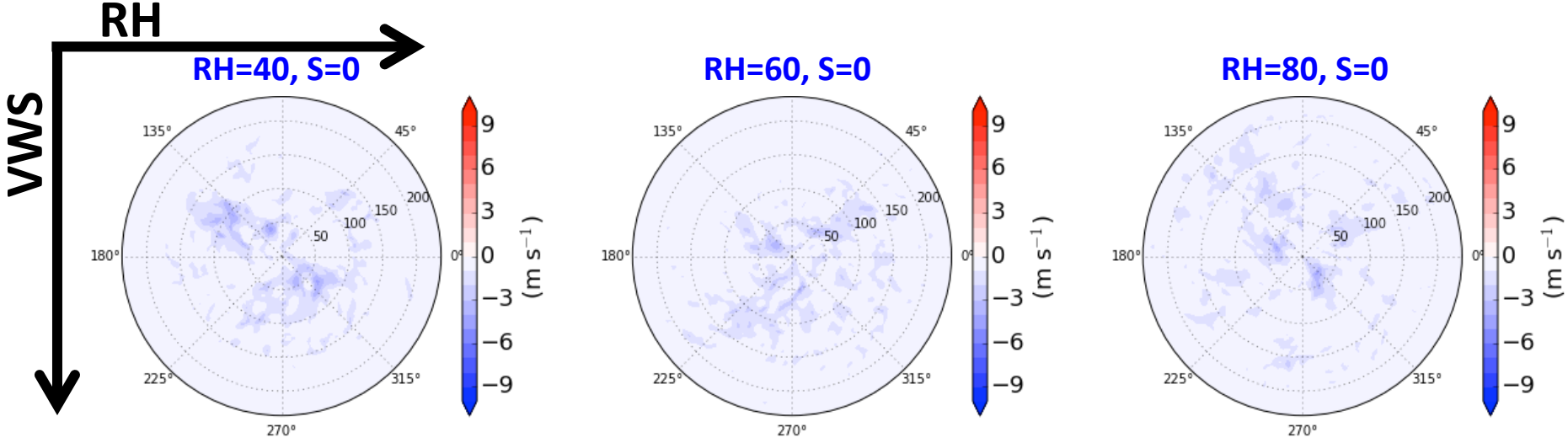


Mid-level ventilation

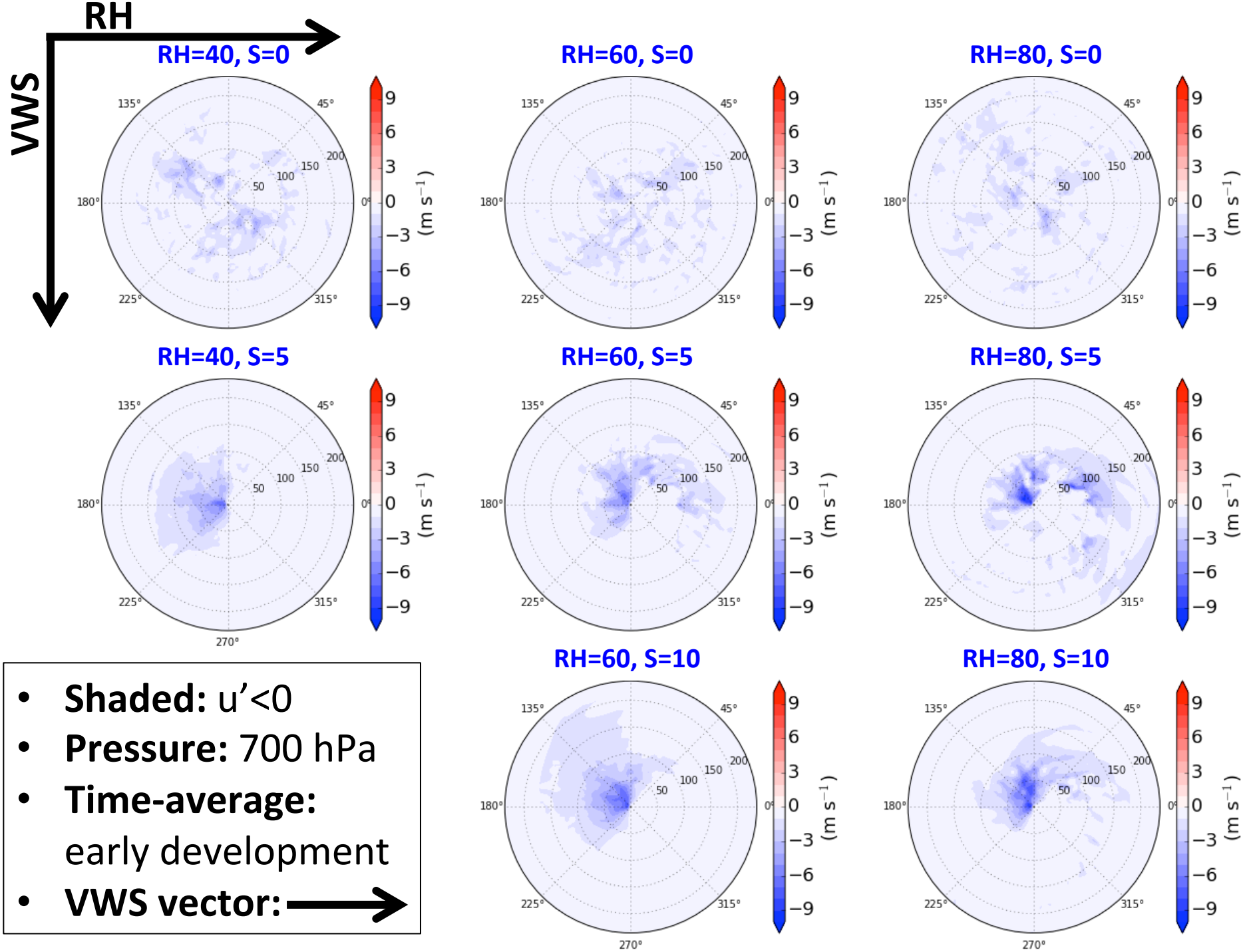
Inward flux of low-MSE air

$\rho u'h'>0$





- **Shaded:** u’<0
- **Pressure:** 700 hPa
- **Time-average:** early development
- **VWS vector:** ⟶



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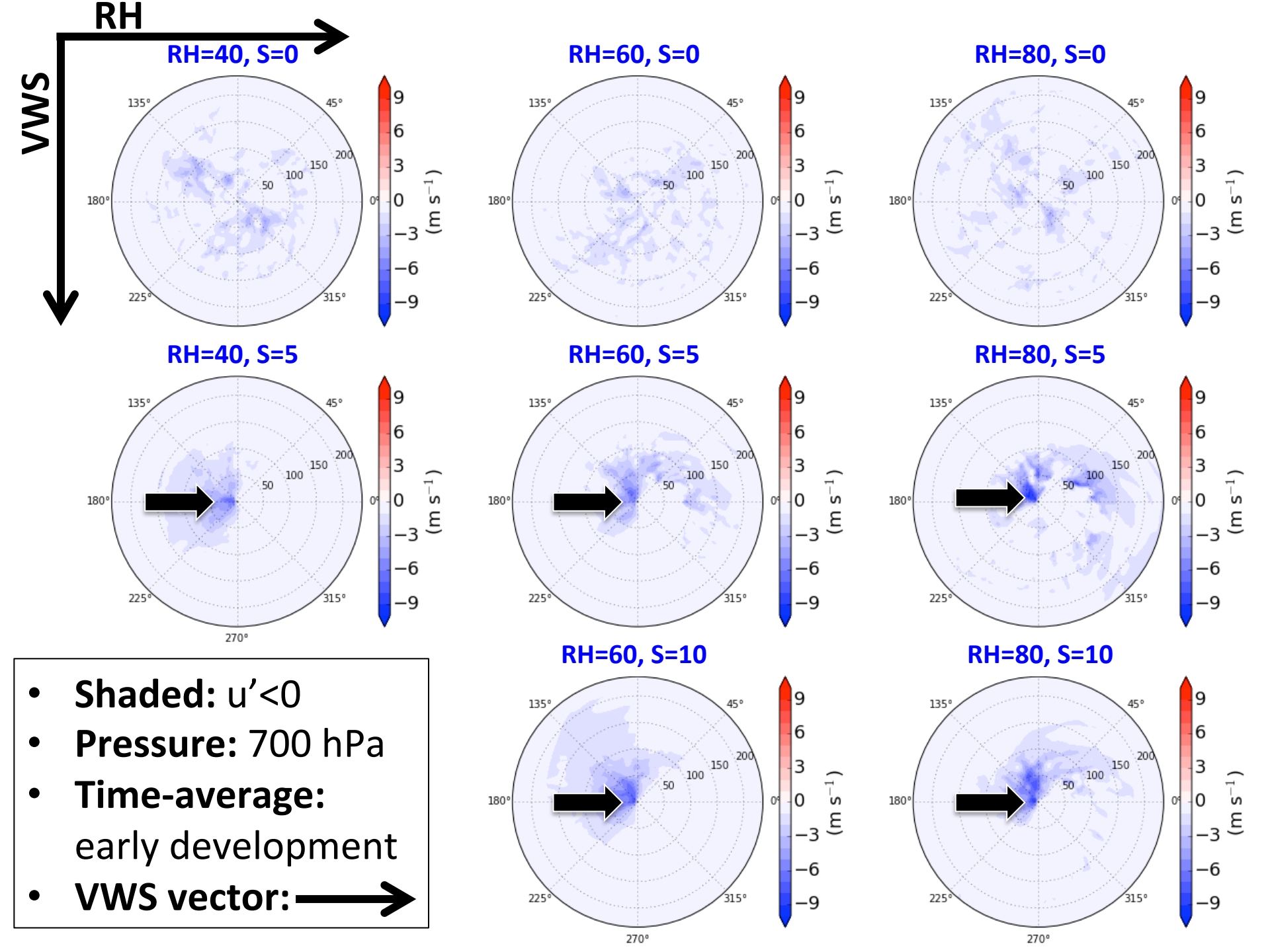
RH
VWS
RH=40, S=0
RH=60, S=0
RH=80, S=0
RH=40, S=5
RH=60, S=5
RH=80, S=5
RH=60, S=10
RH=80, S=10
135°
45°
180°
0°
225°
315°
270°
50
100
150
200
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6
3
0
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−6
−9
(m s^{-1})
• **Shaded:** u'<0
• **Pressure:** 700 hPa
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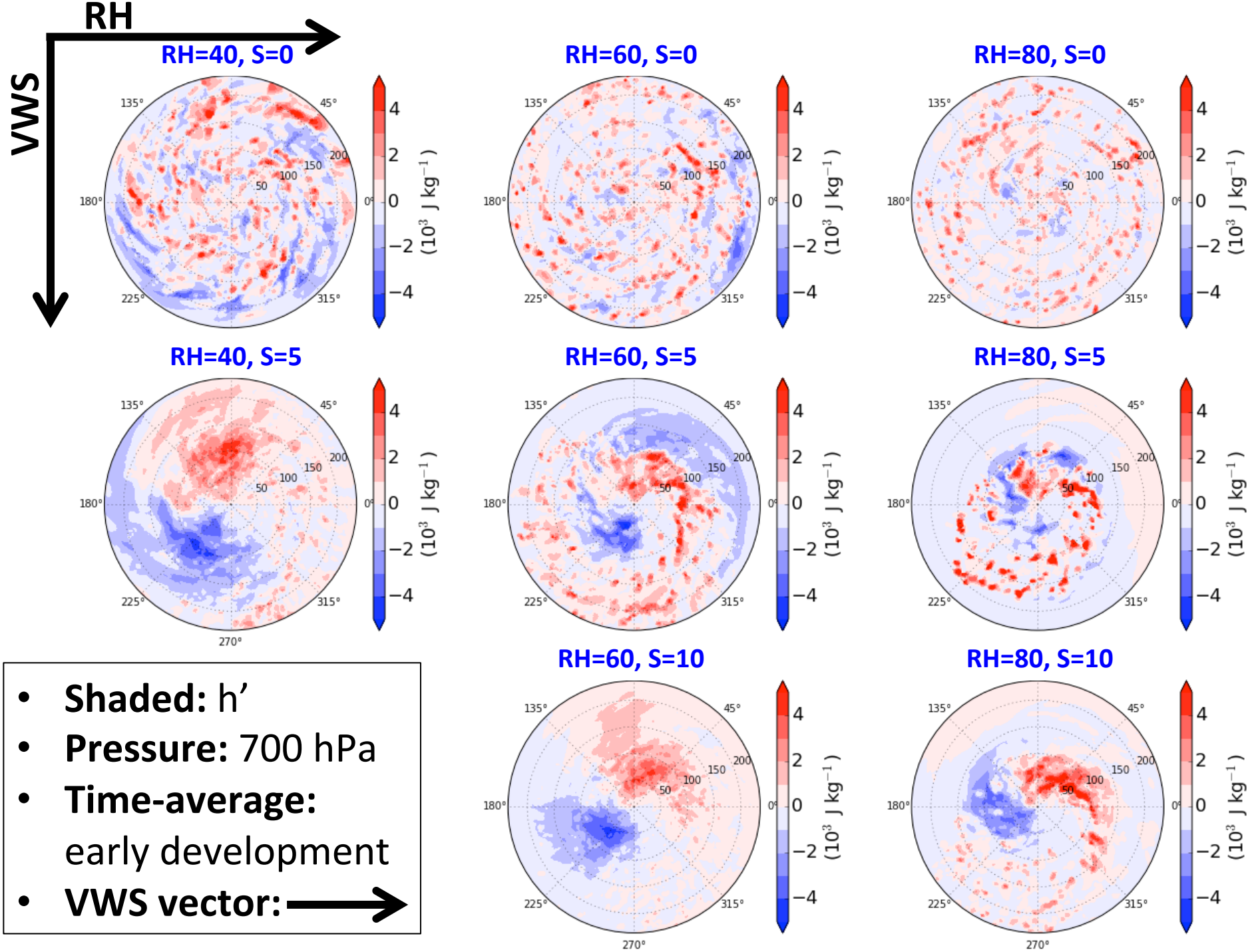

- **Shaded:** h’
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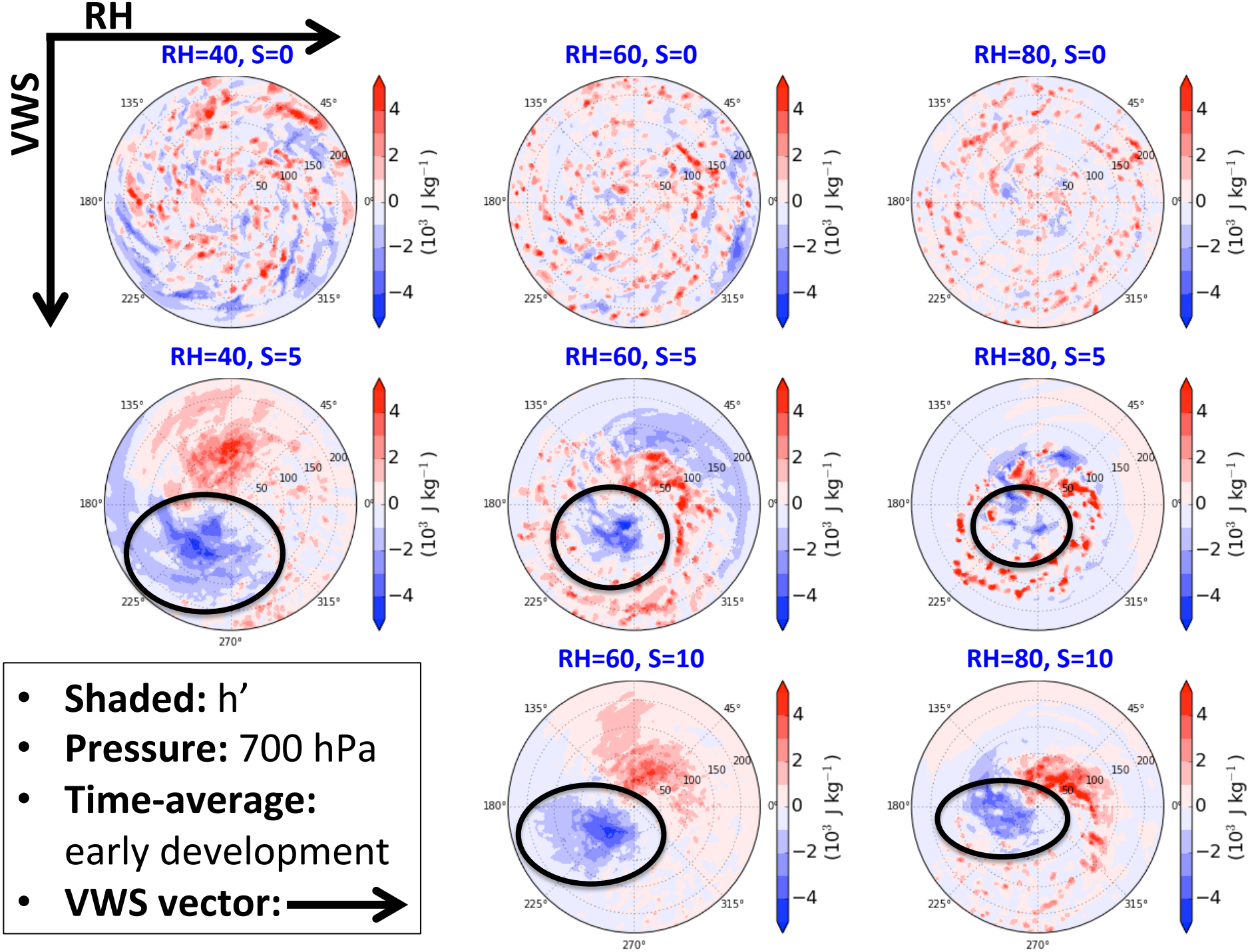
RH
VWS
RH=40, S=0
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RH=60, S=10
RH=80, S=10
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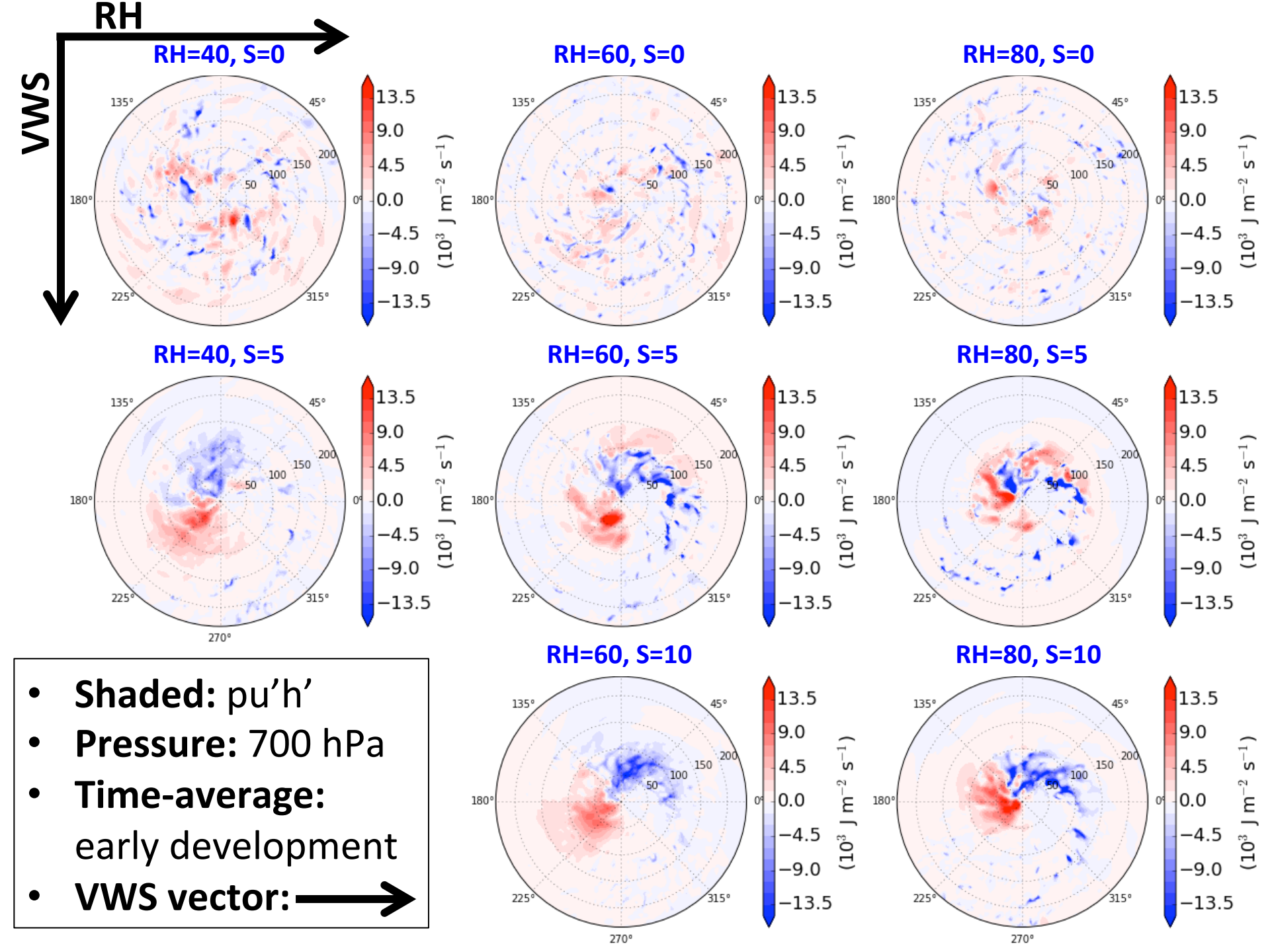
• Shaded: h'
• Pressure: 700 hPa
• Time-average: early development
• VWS vector: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RH=80, S=10
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180°
0°
225°
315°
270°
50
100
150
200
13.5
9.0
4.5
0.0
−4.5
−9.0
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$(10^3\ J\ m^{-2}\ s^{-1})$
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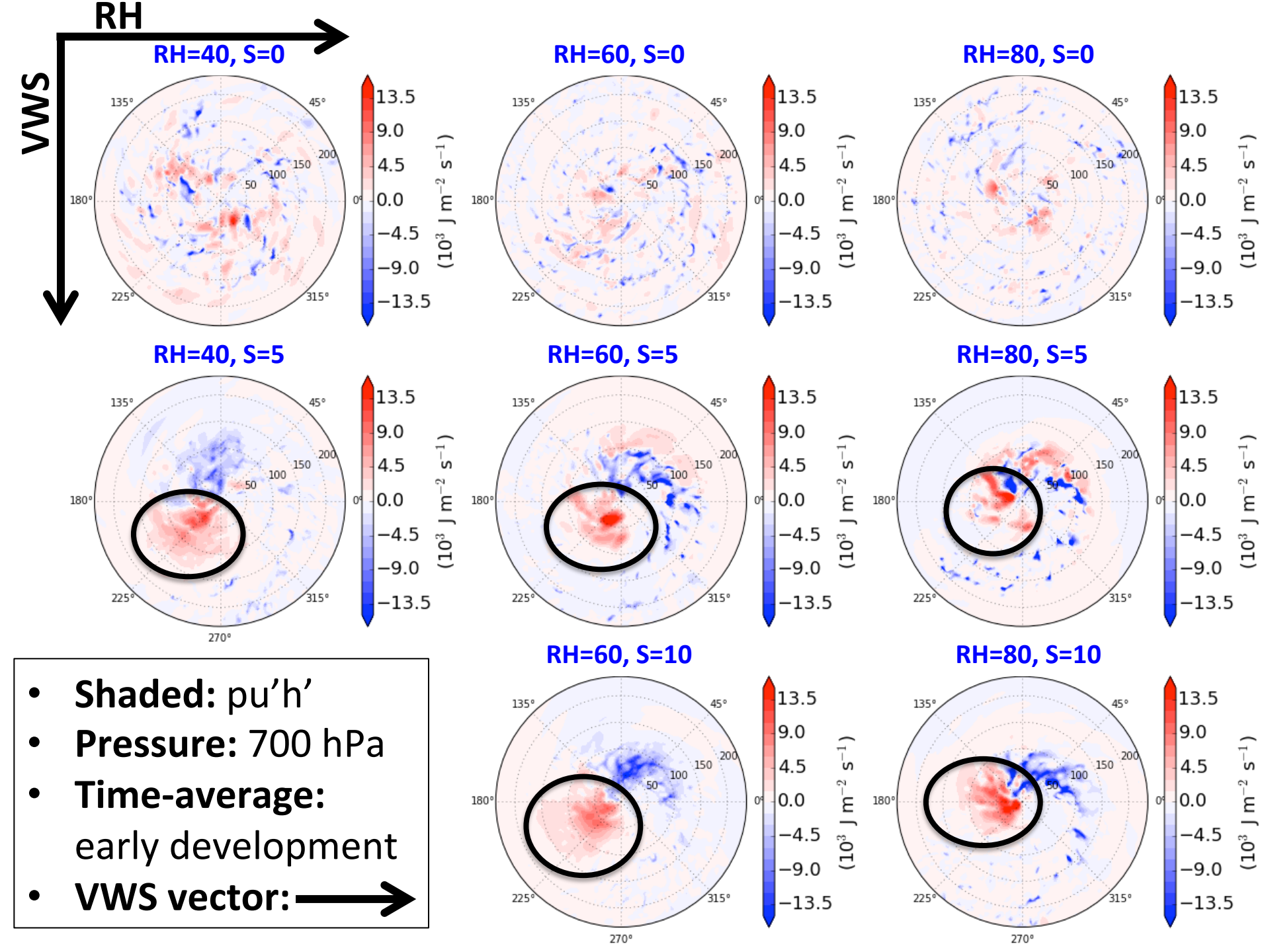
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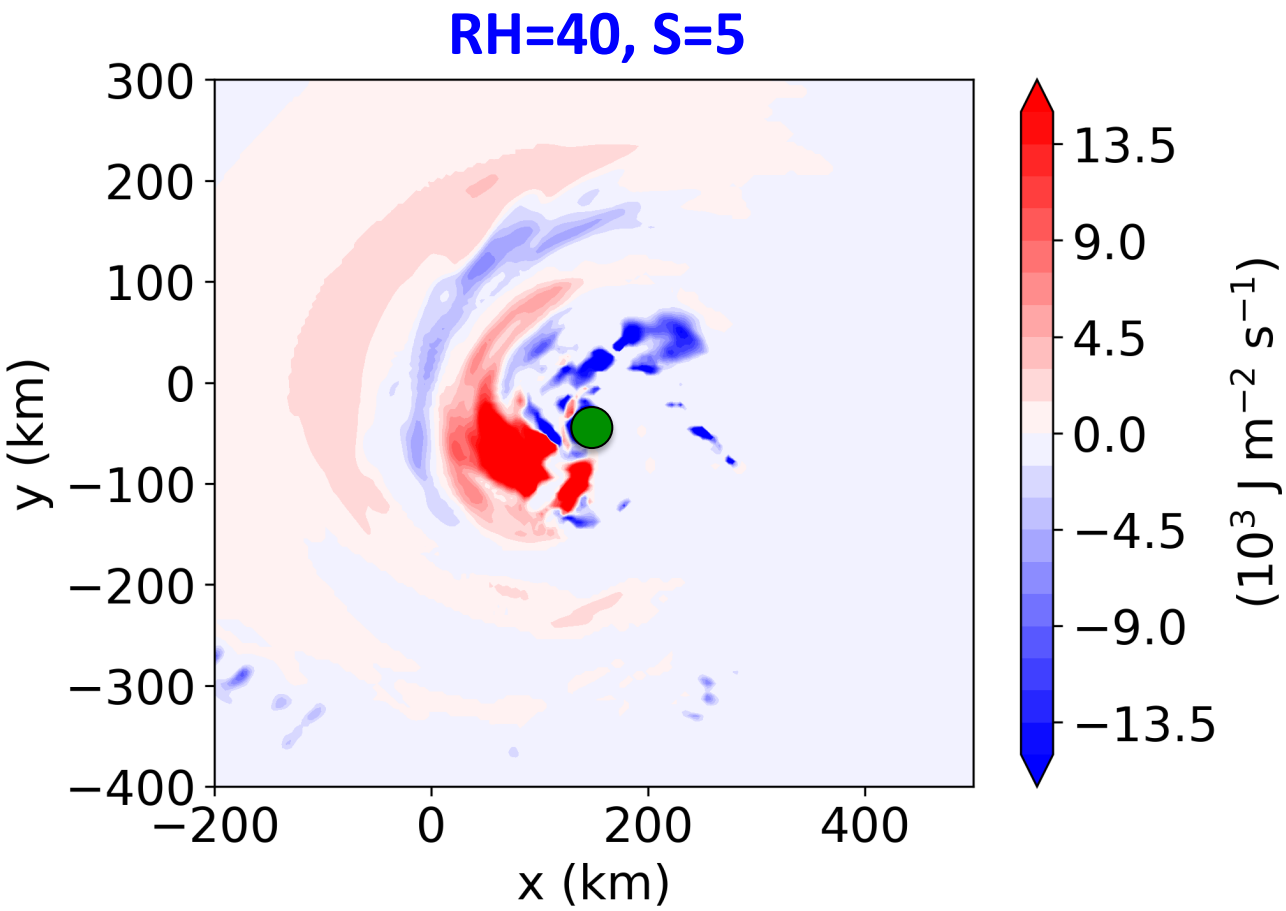
How does the mid-level ventilation structure affect convection?

Tool: Lagrangian parcel trajectories



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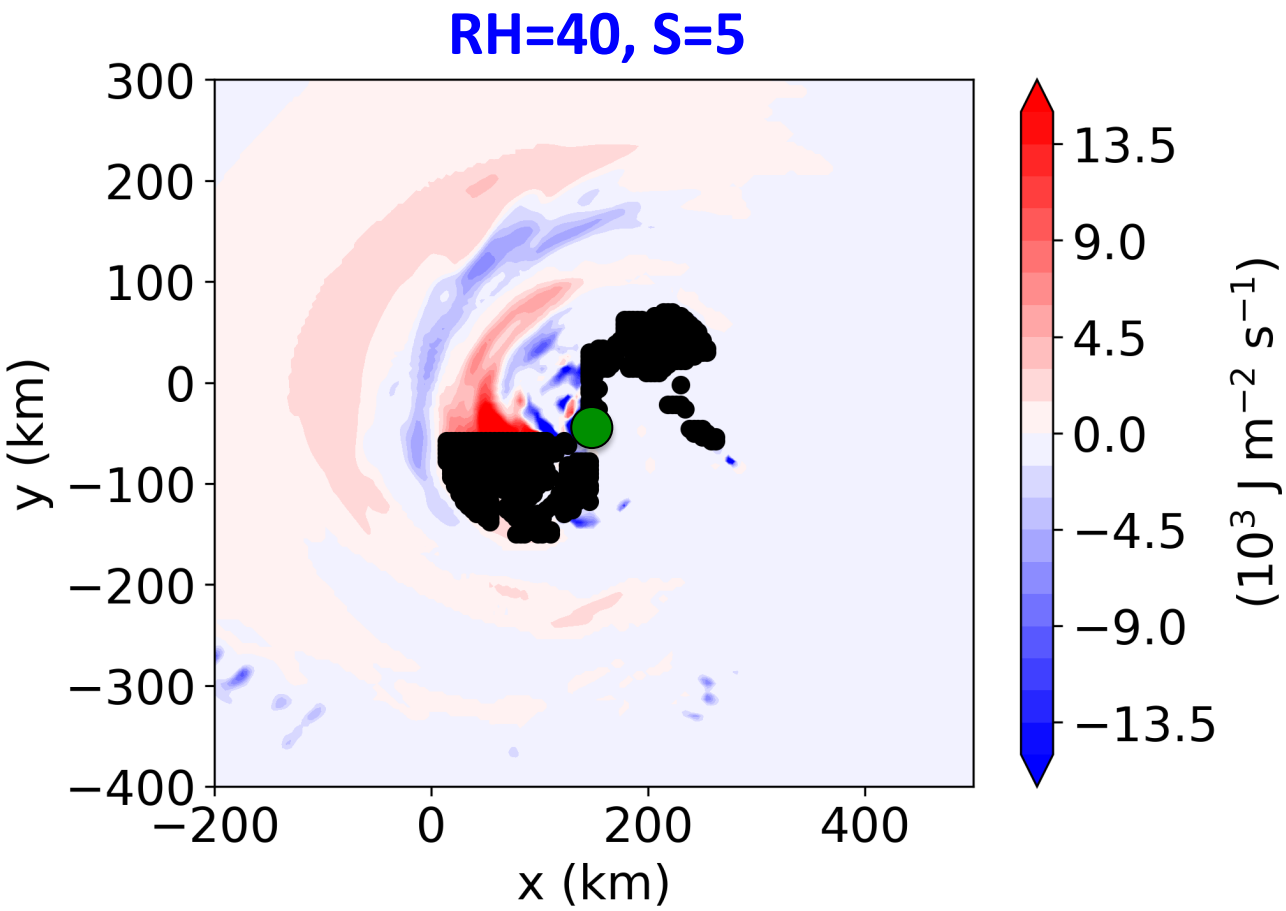
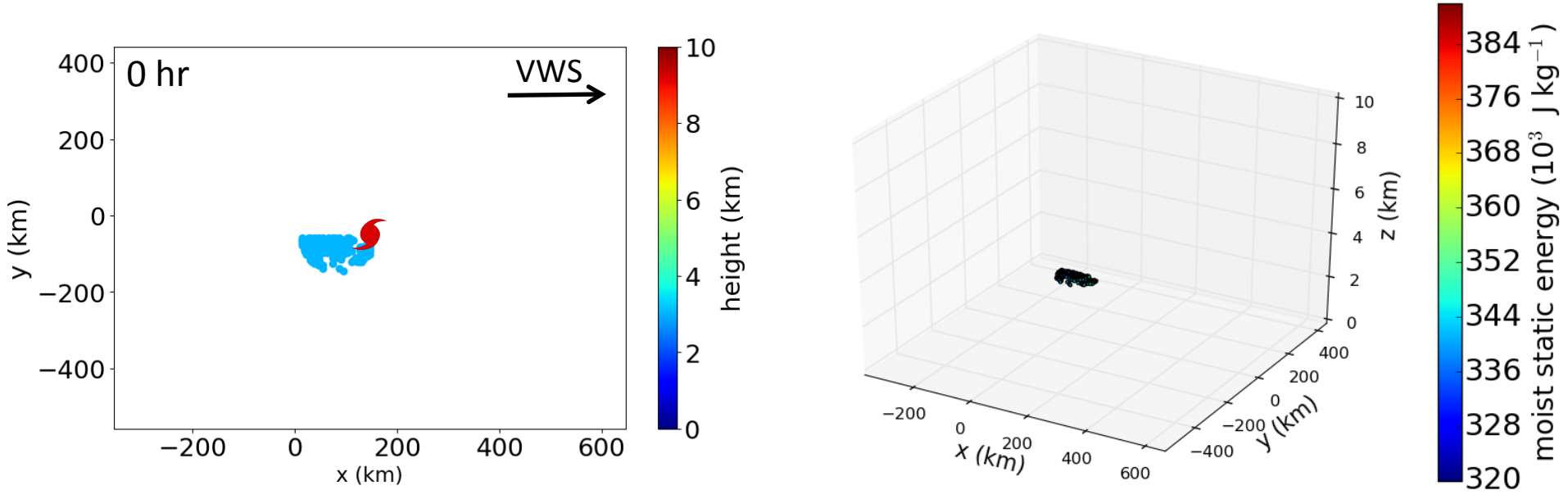


More mid-level ventilation



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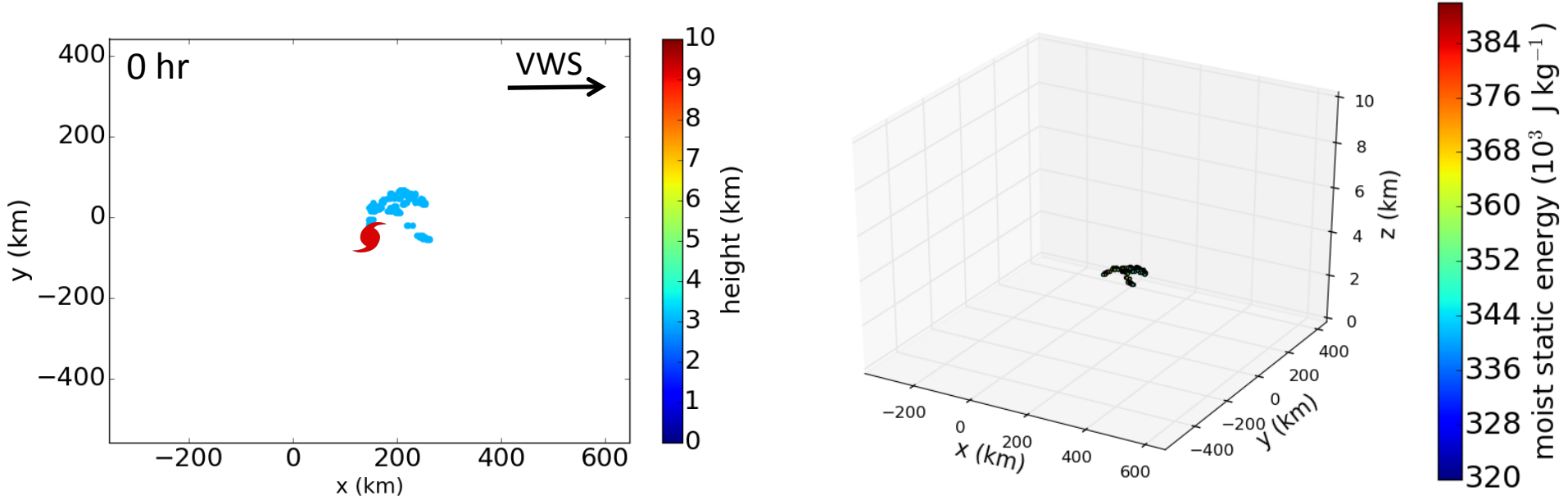

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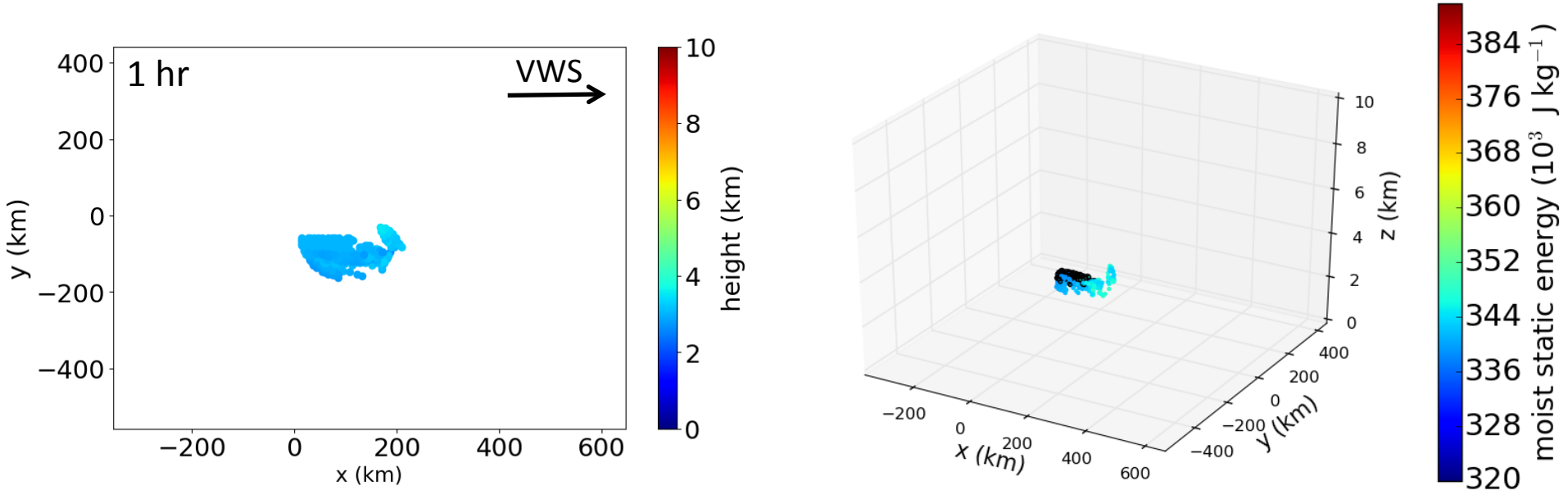

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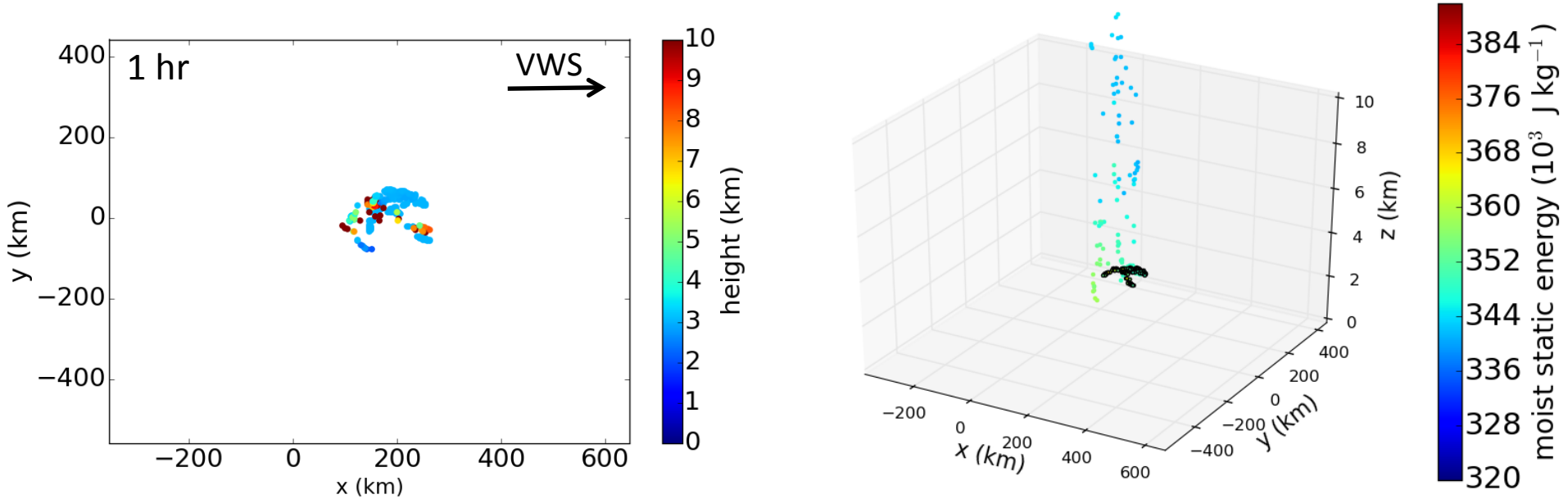

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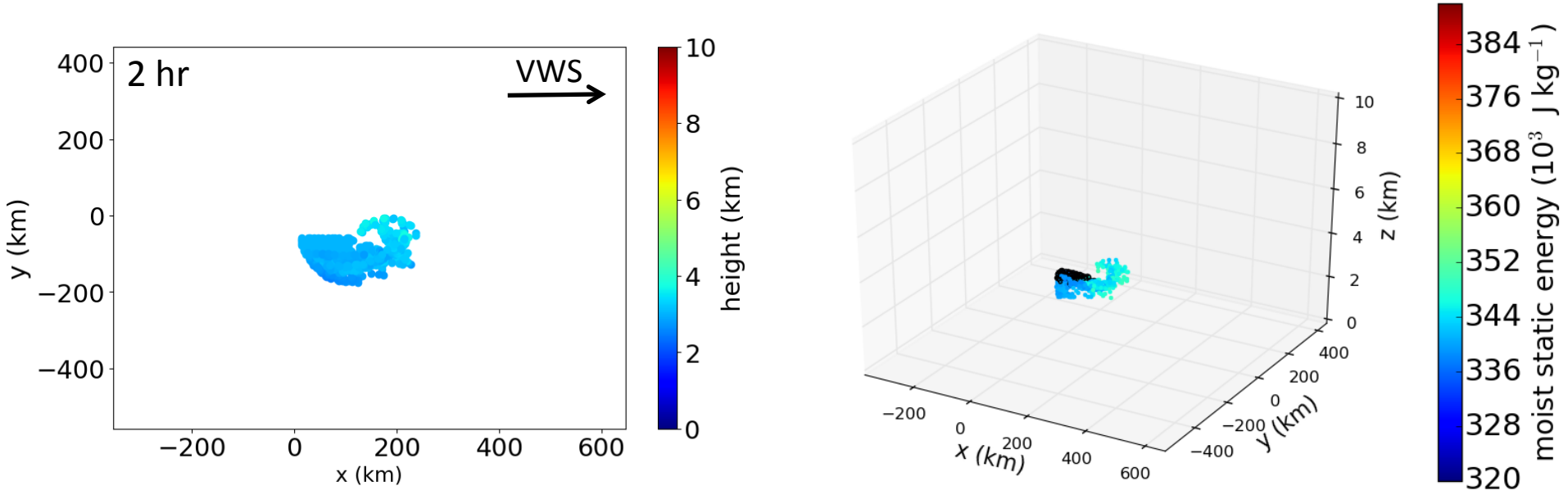

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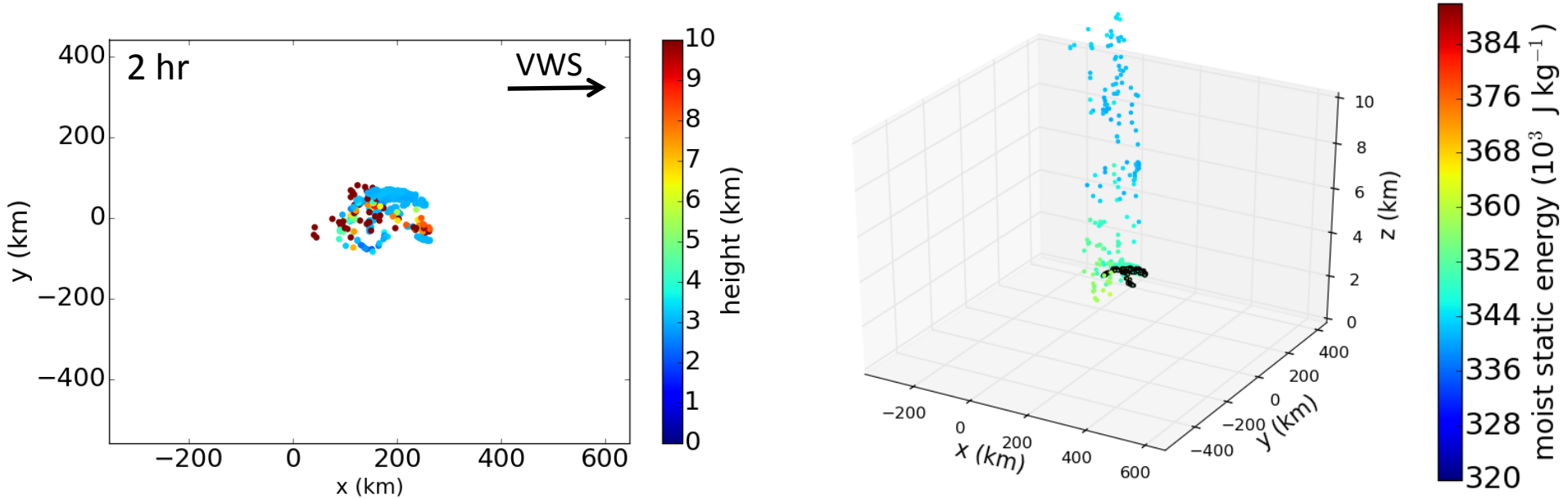

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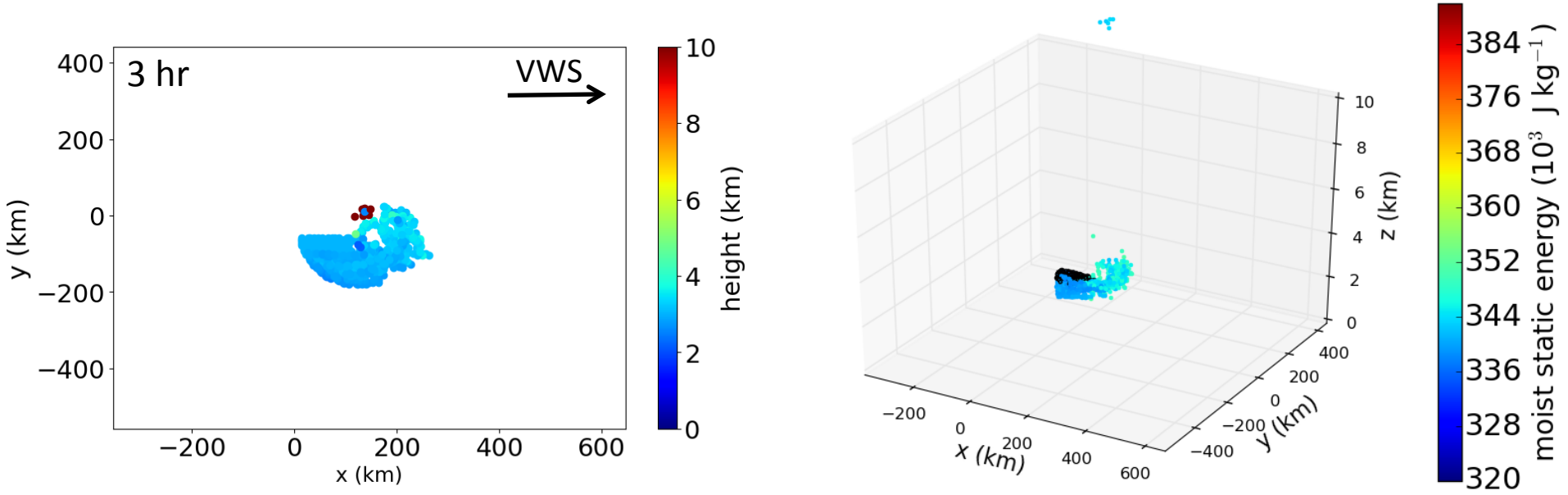

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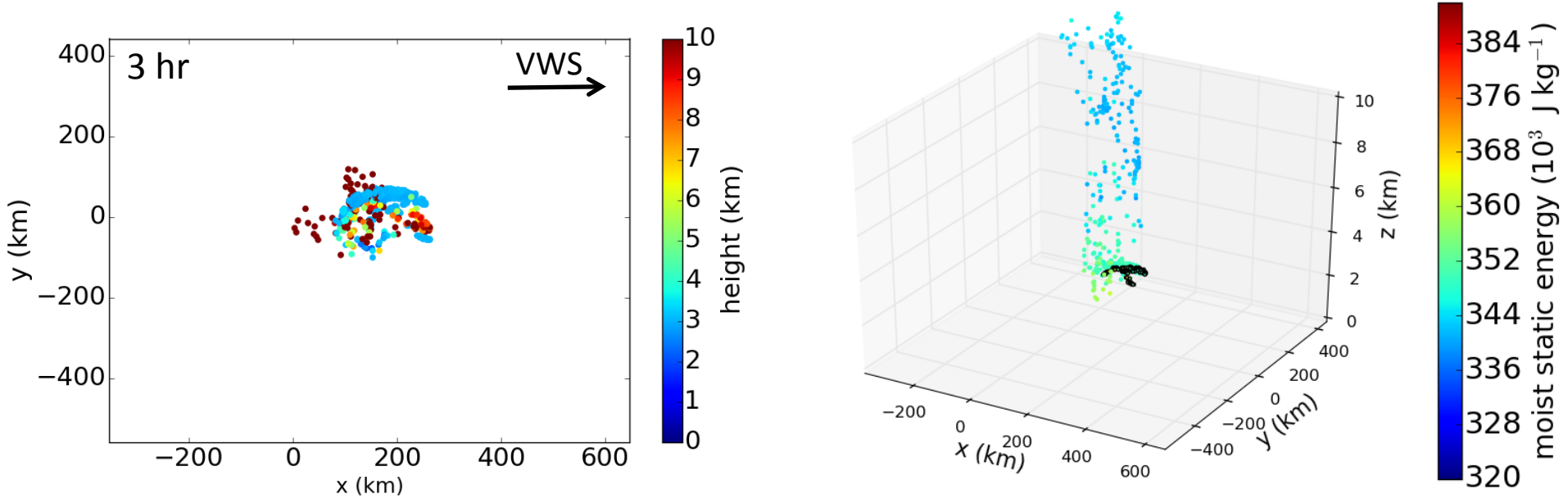

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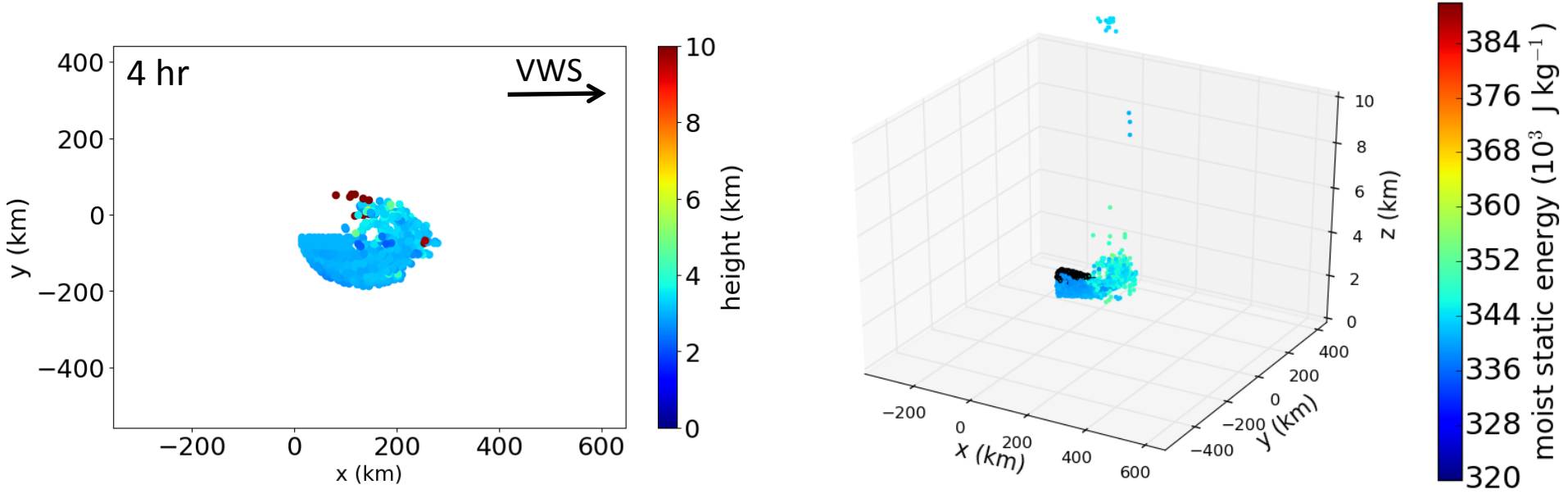

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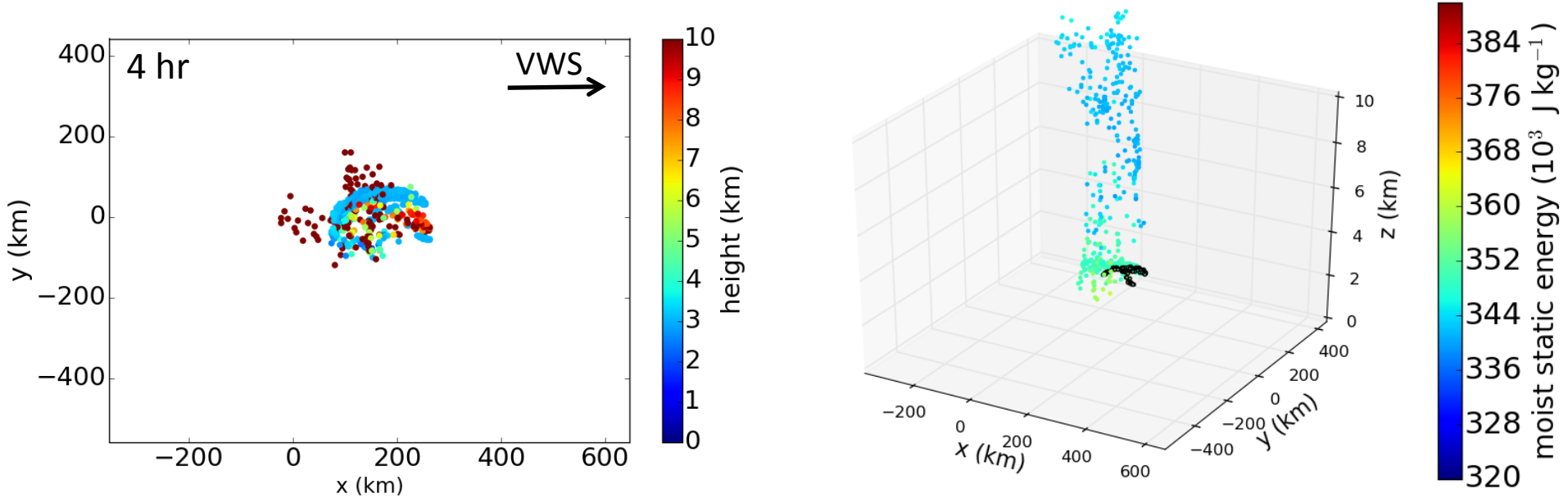

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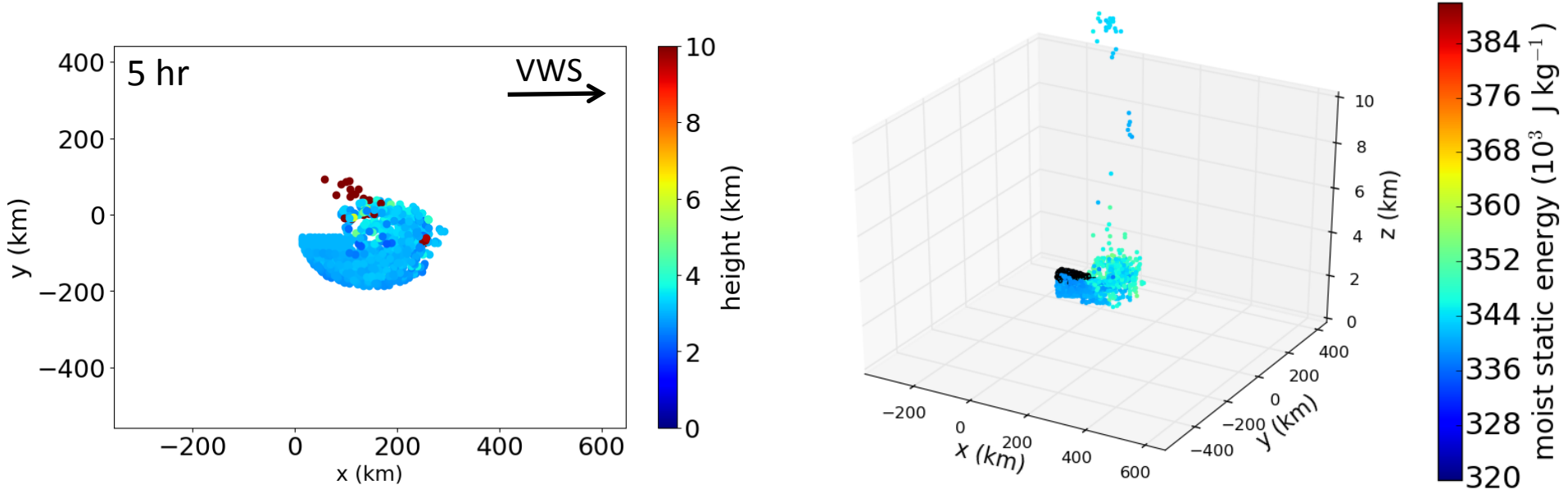

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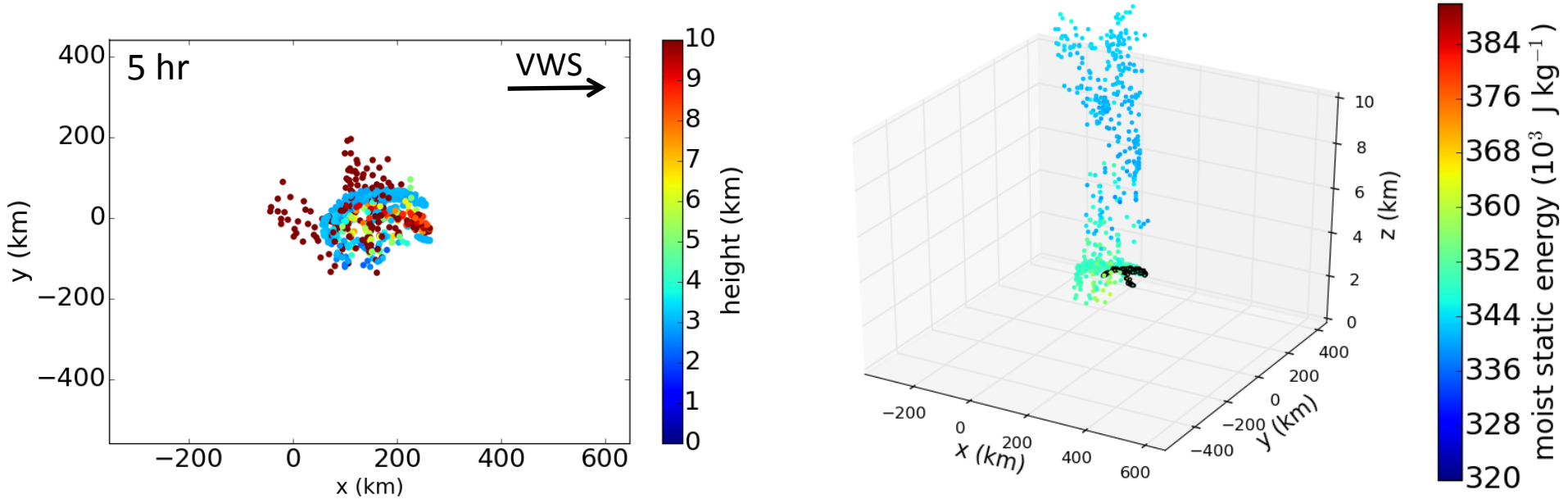

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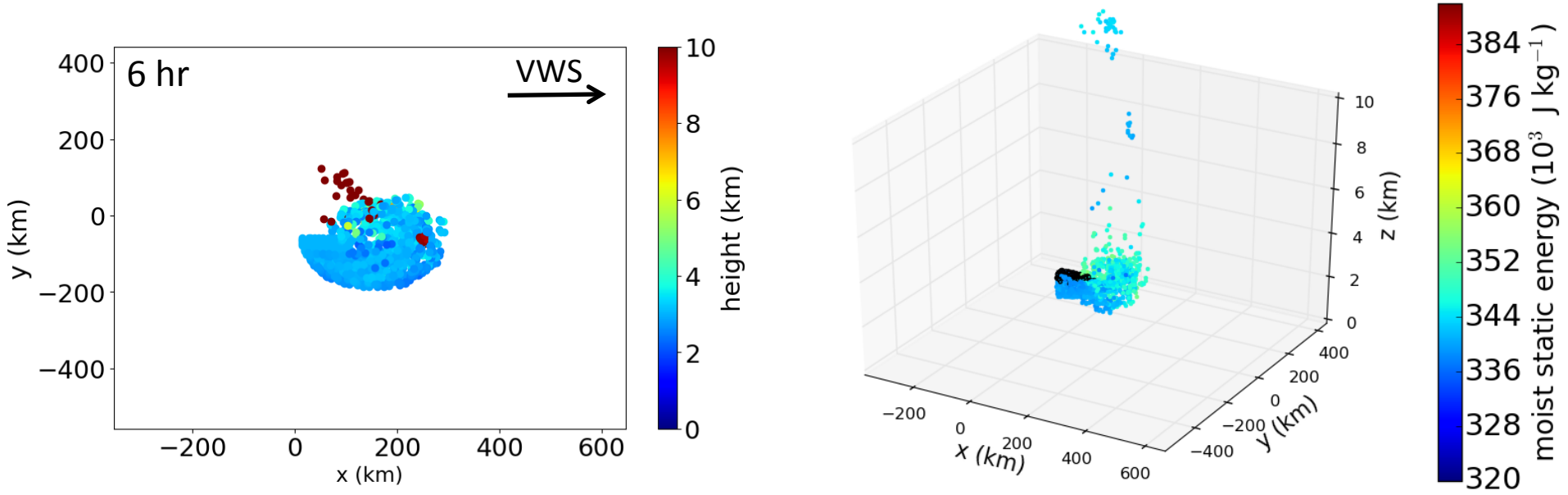

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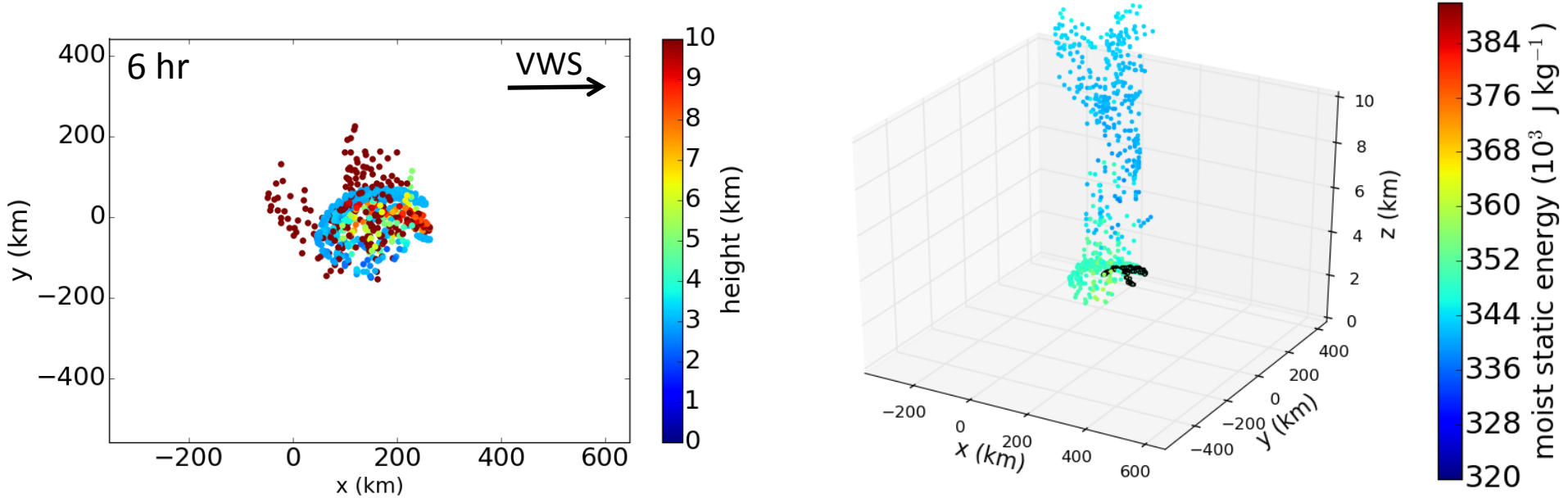

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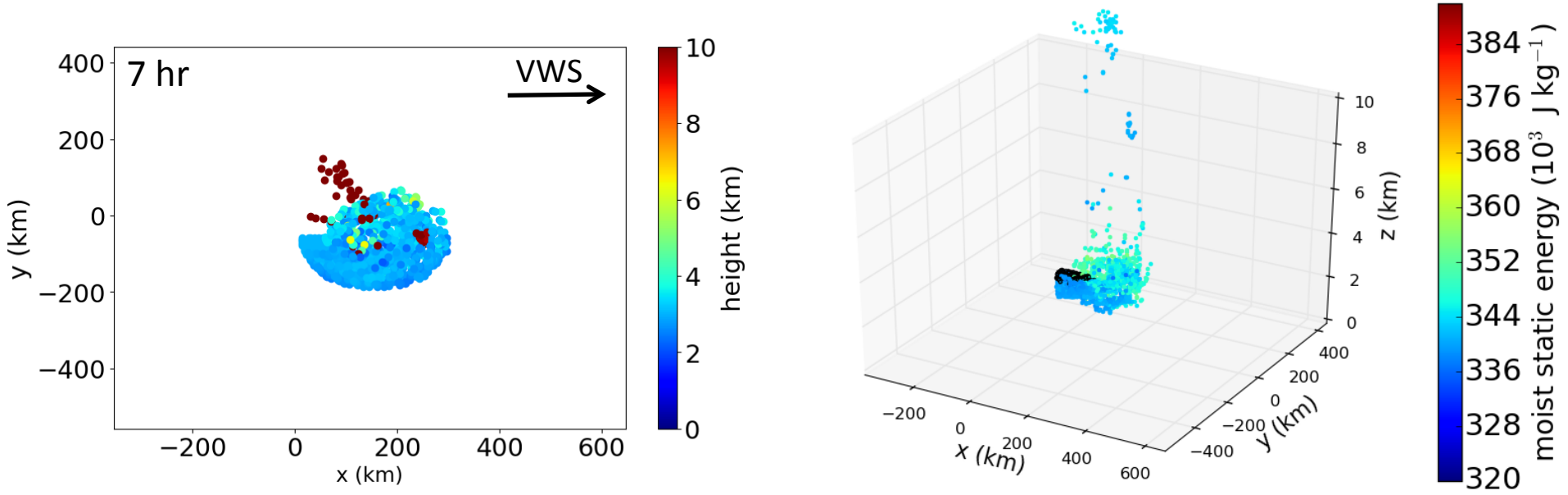

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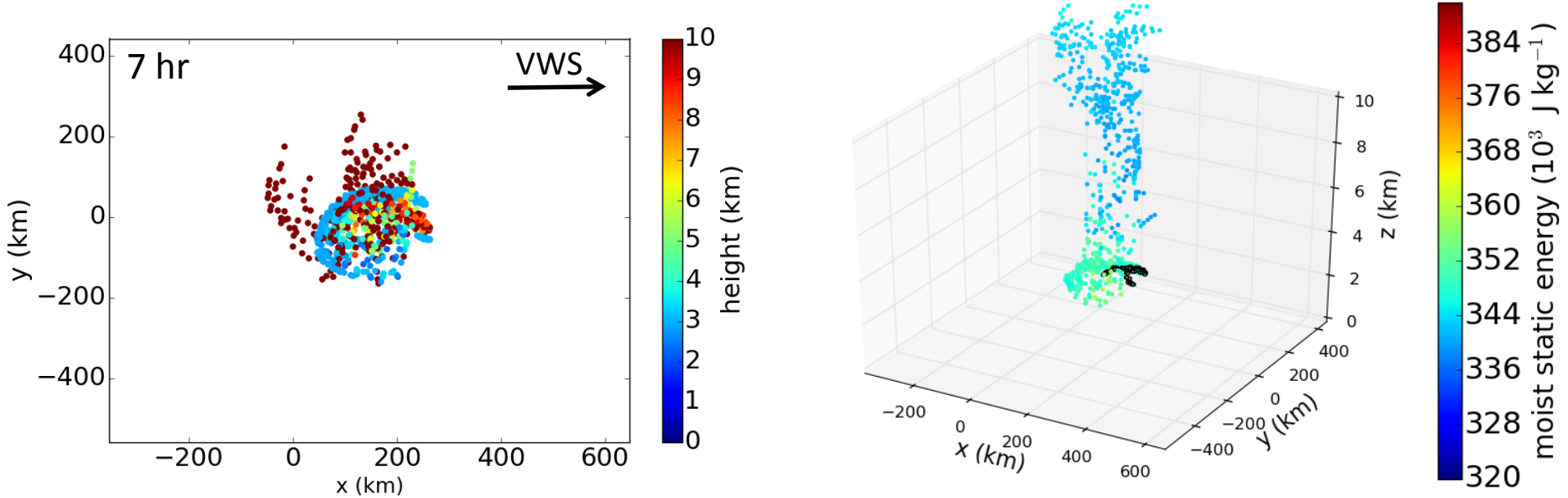

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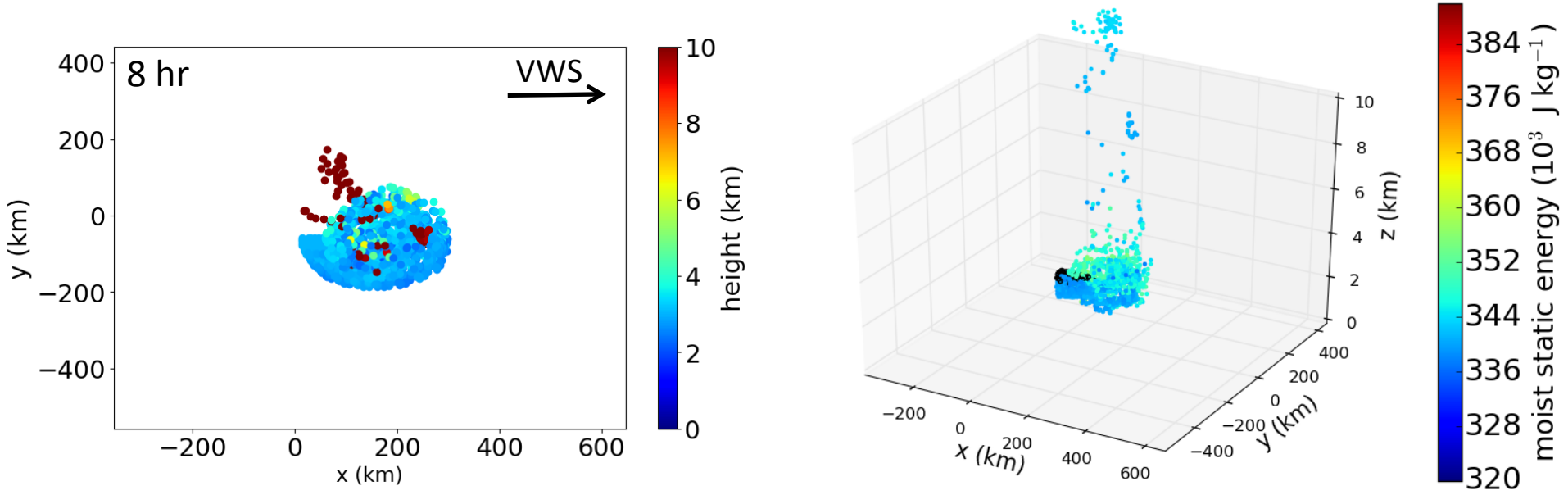

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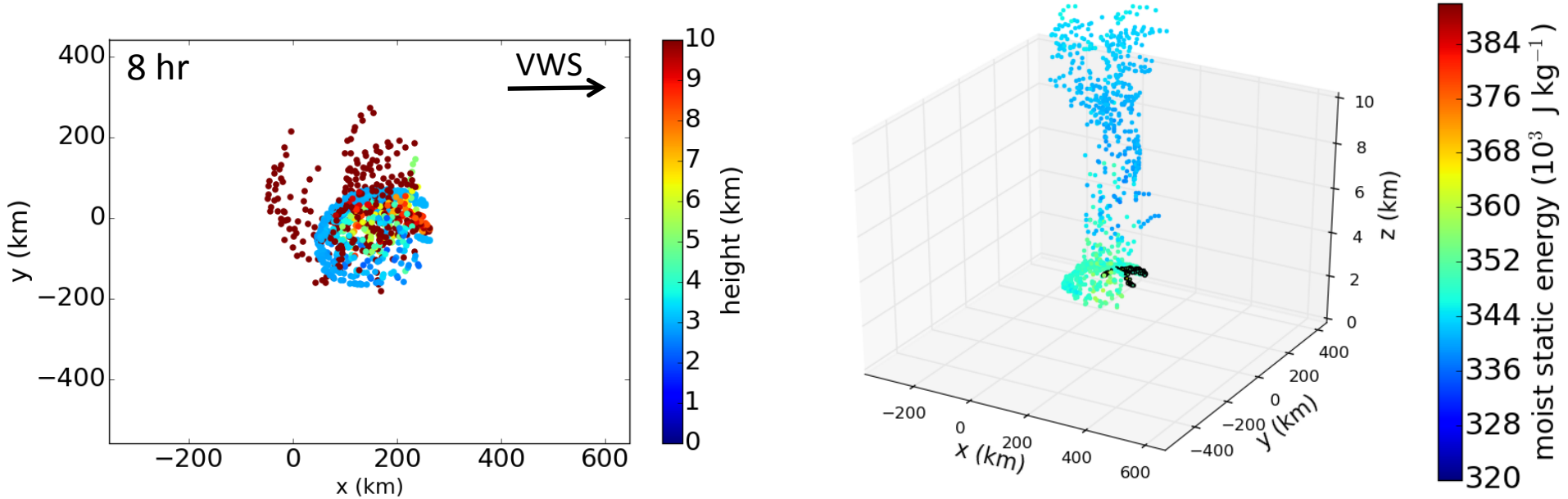

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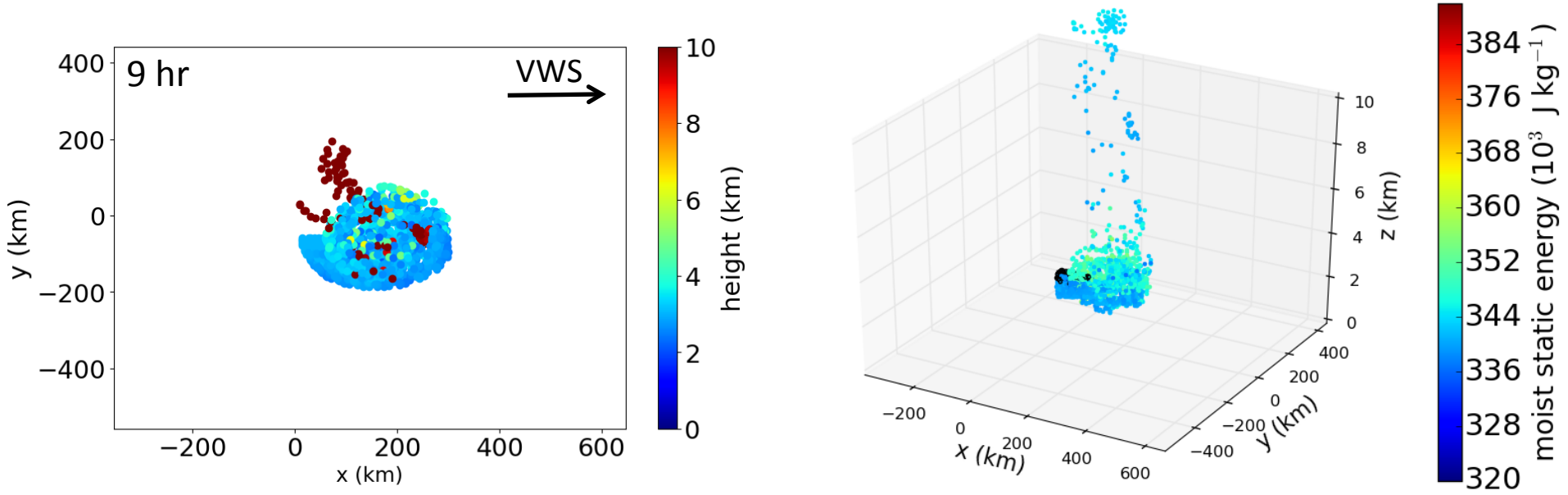

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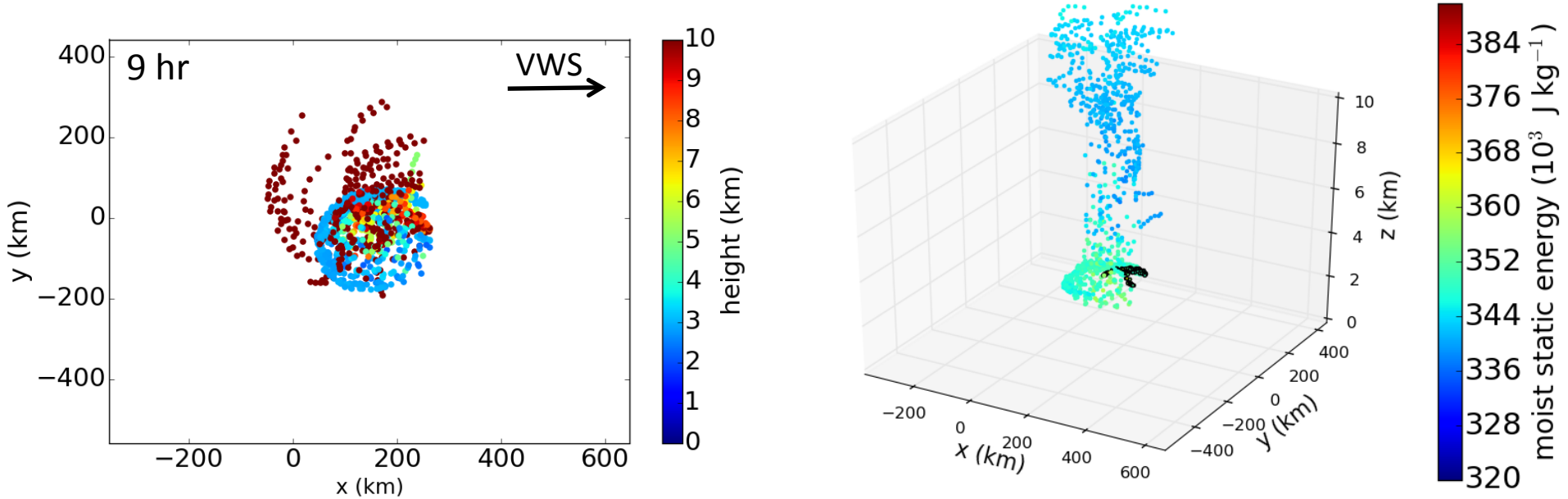

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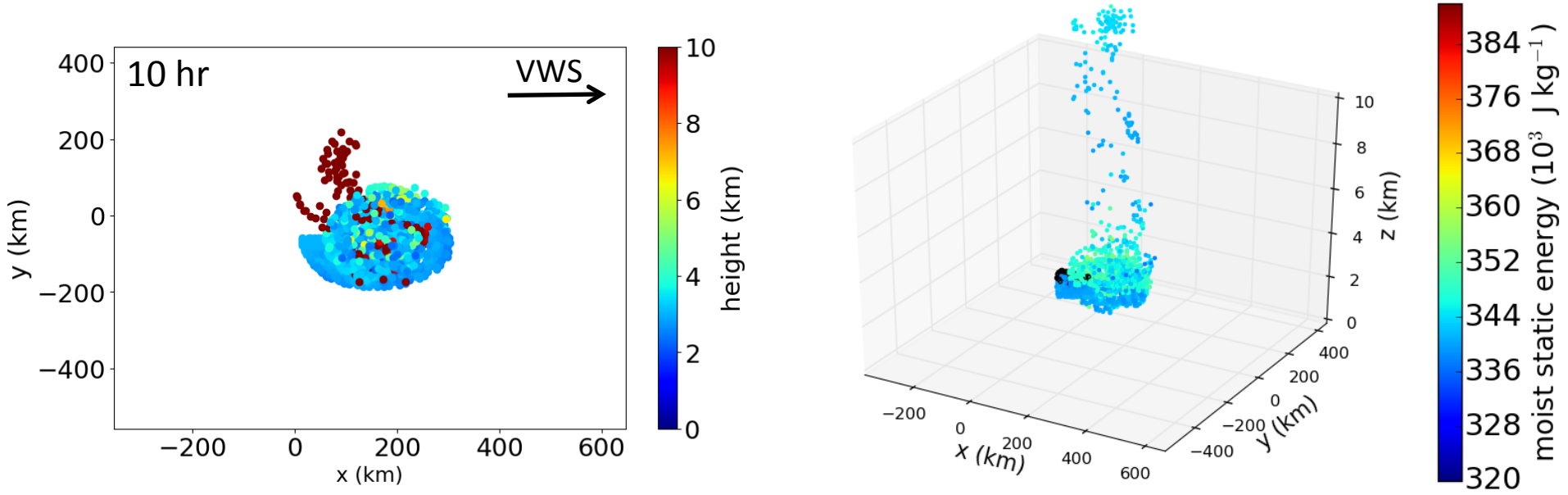

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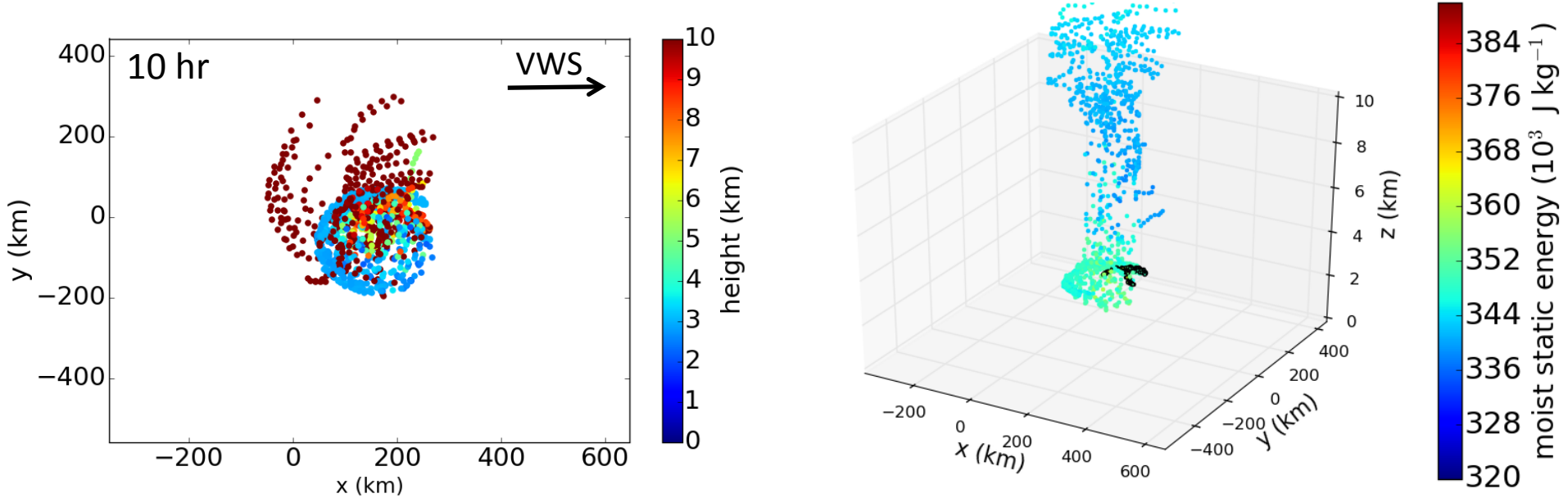

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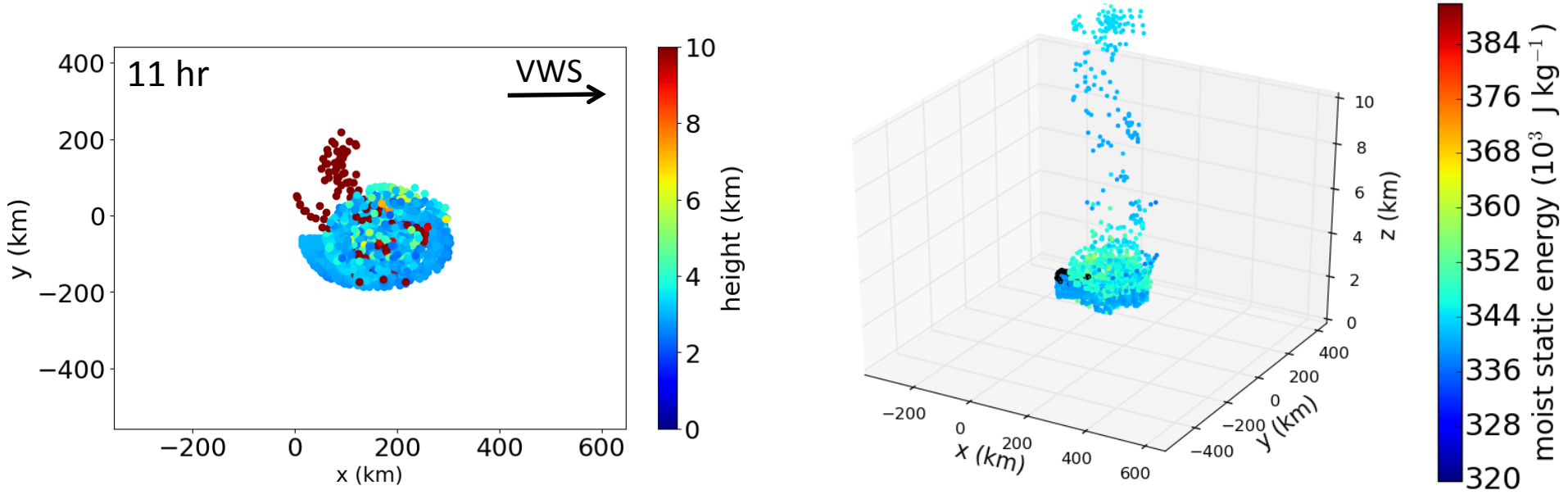

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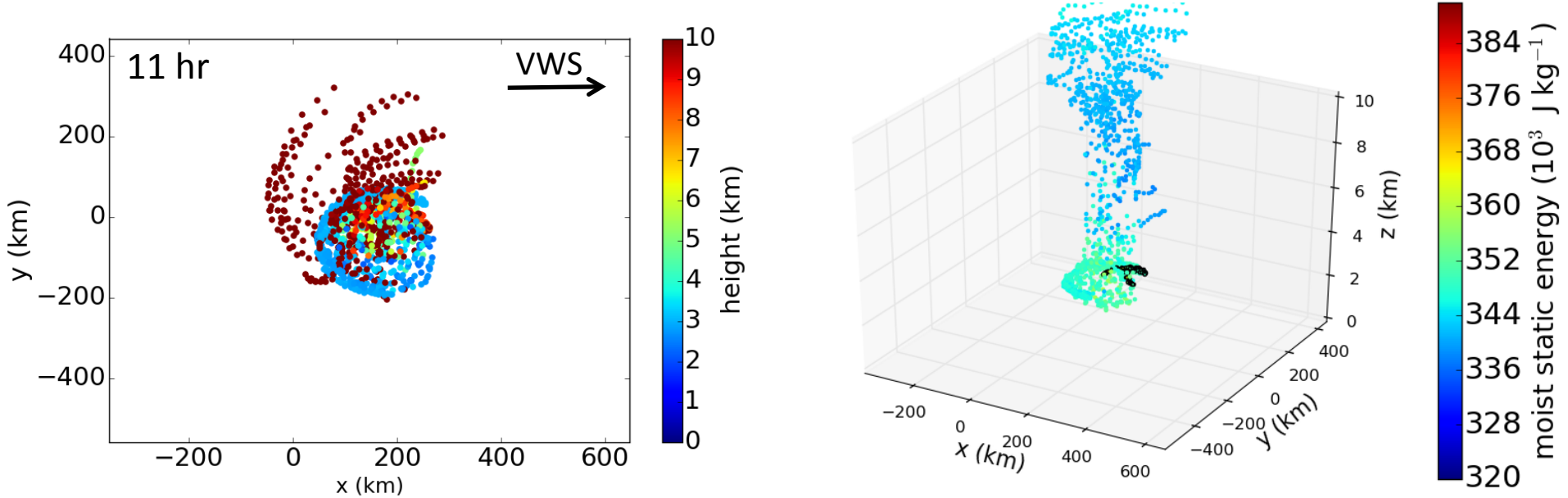
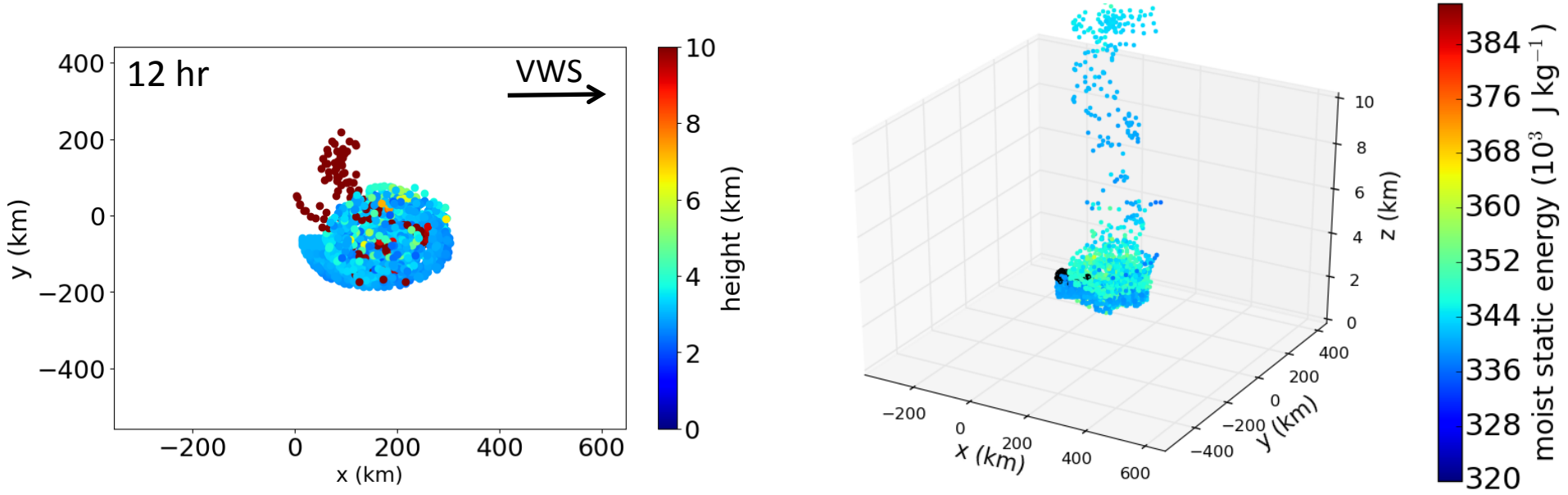
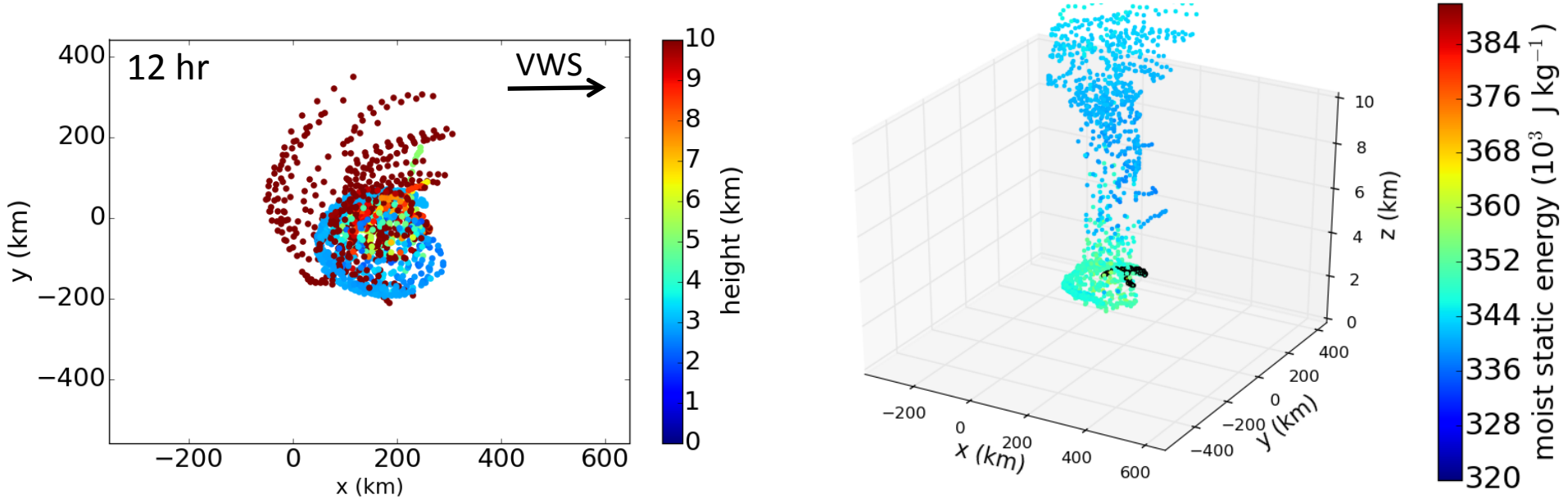


More mid-level ventilation



Less mid-level ventilation



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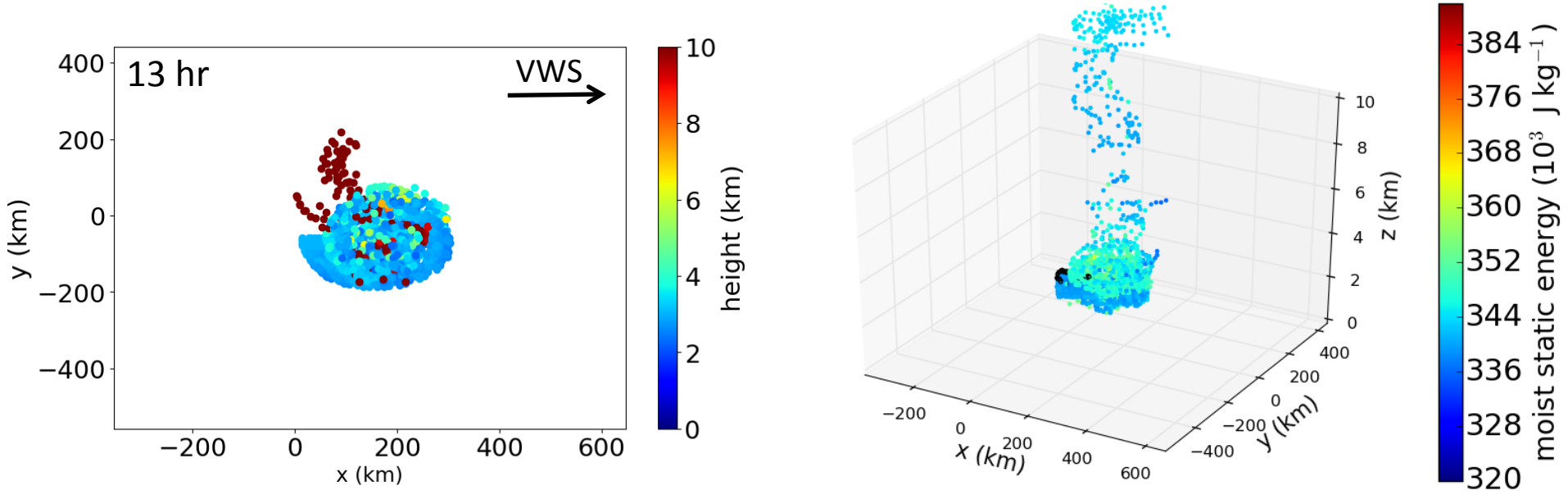

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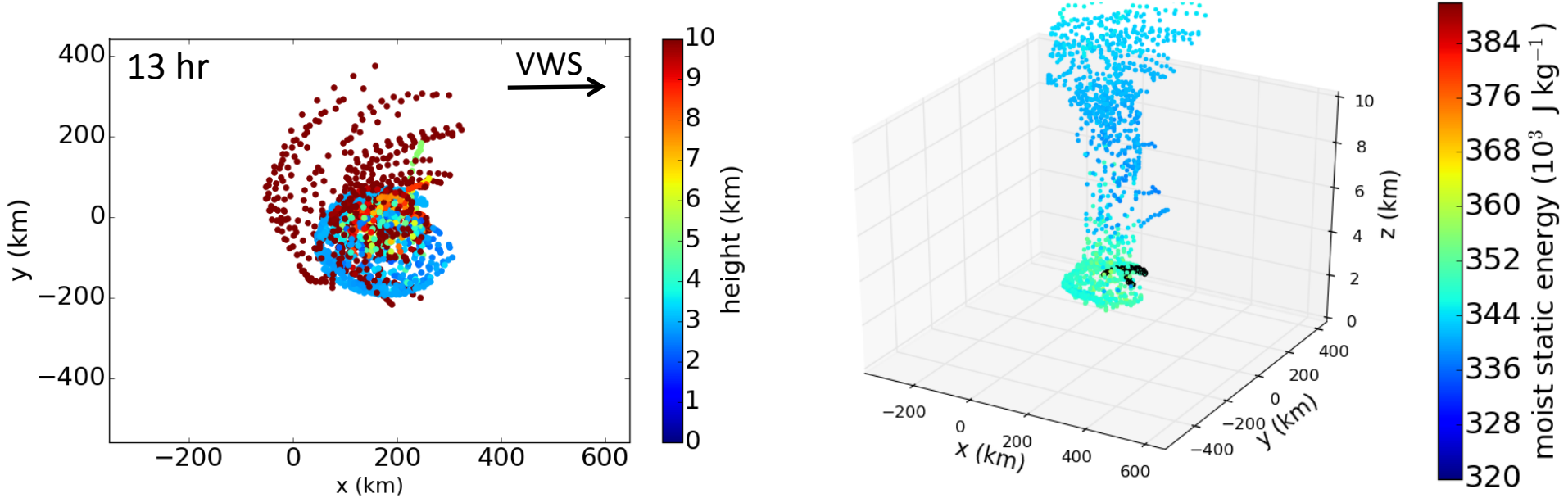

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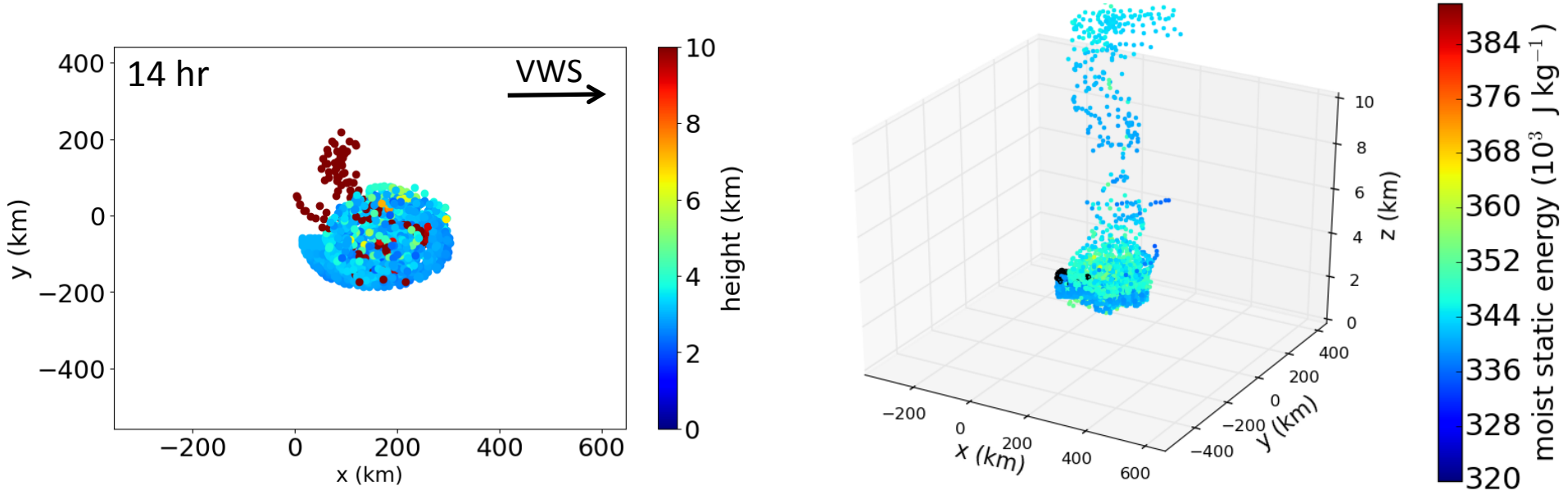
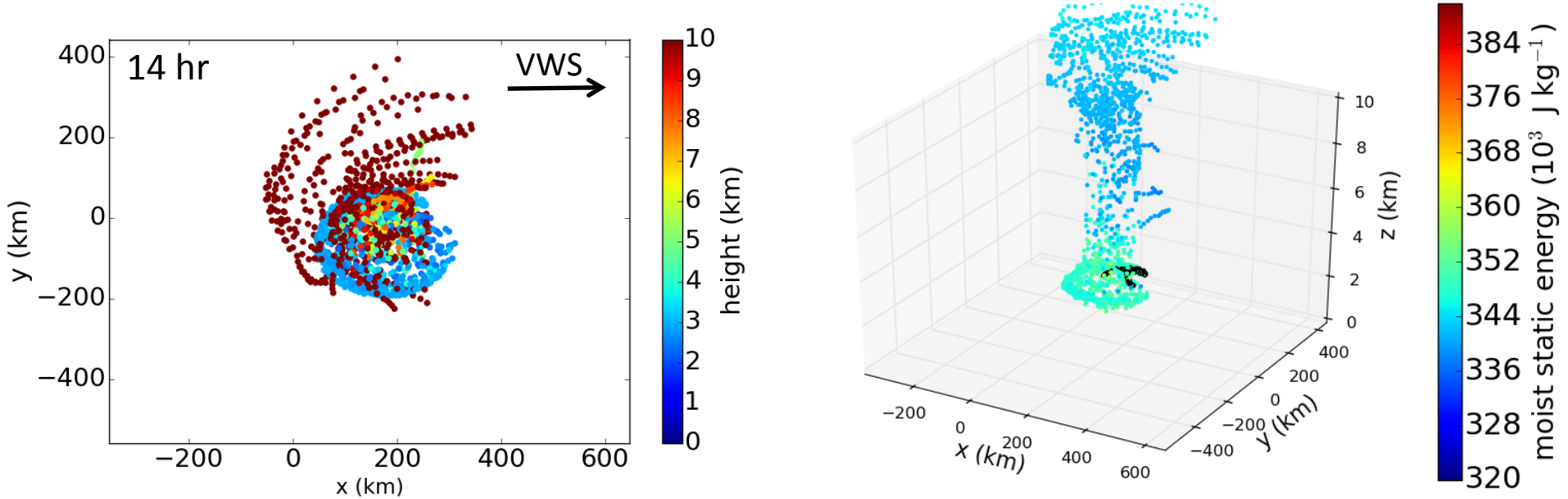
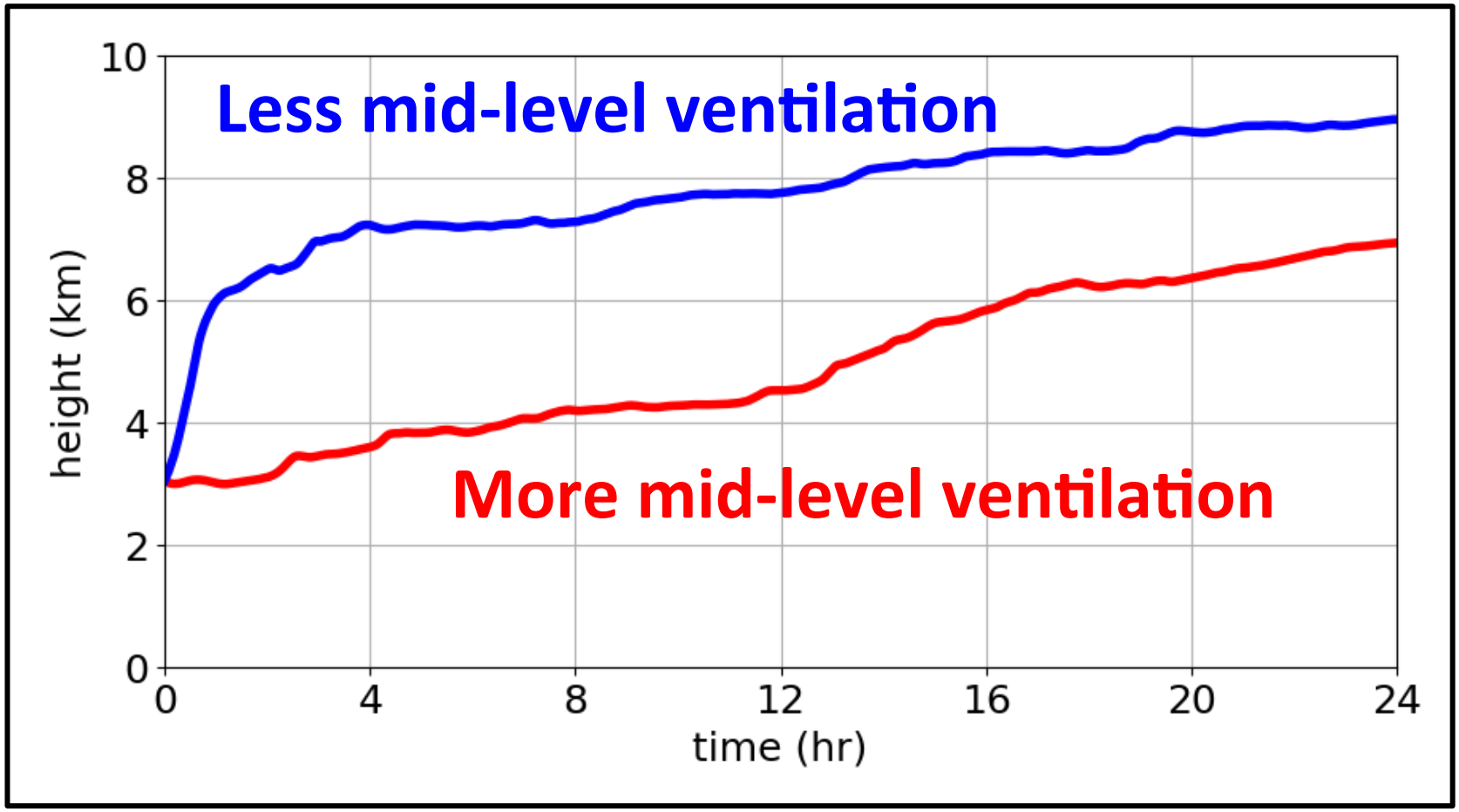


Less mid-level ventilation

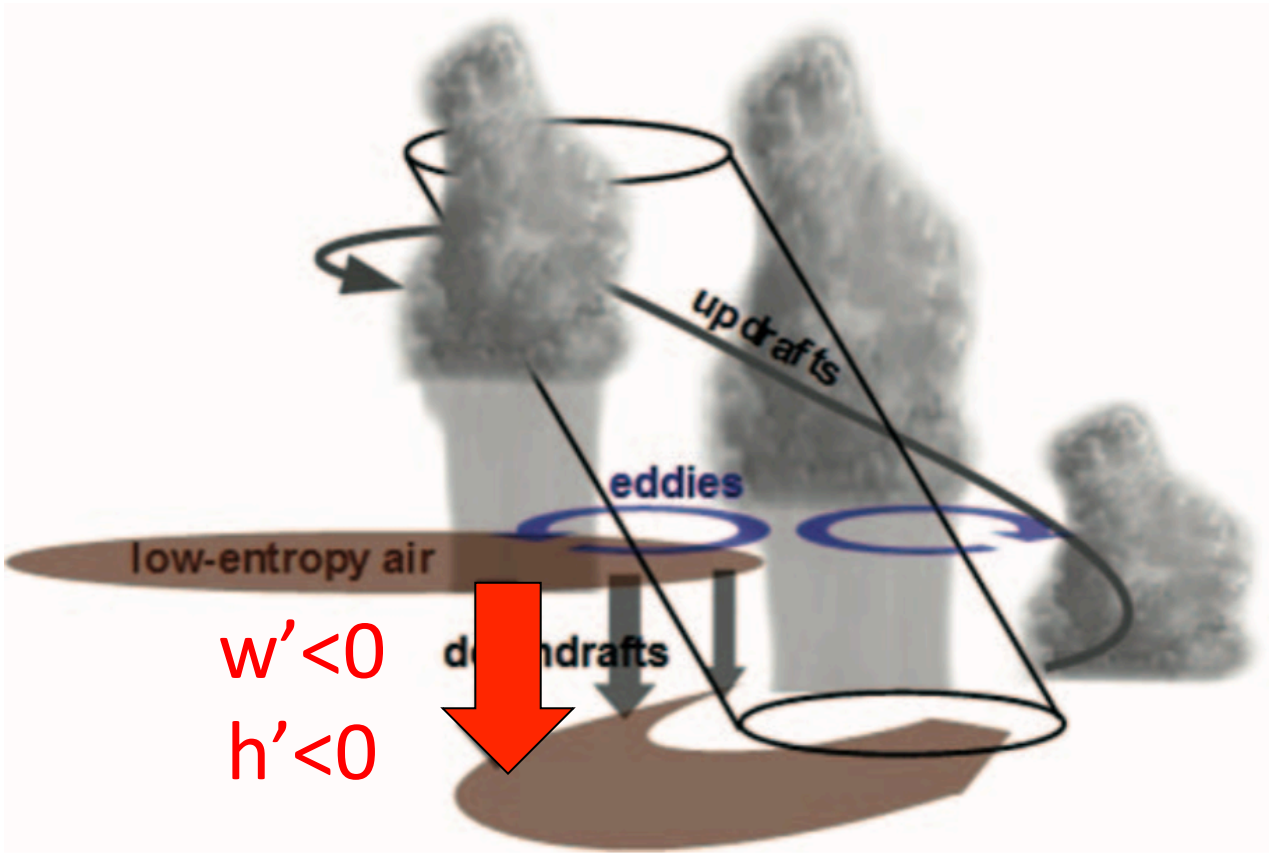


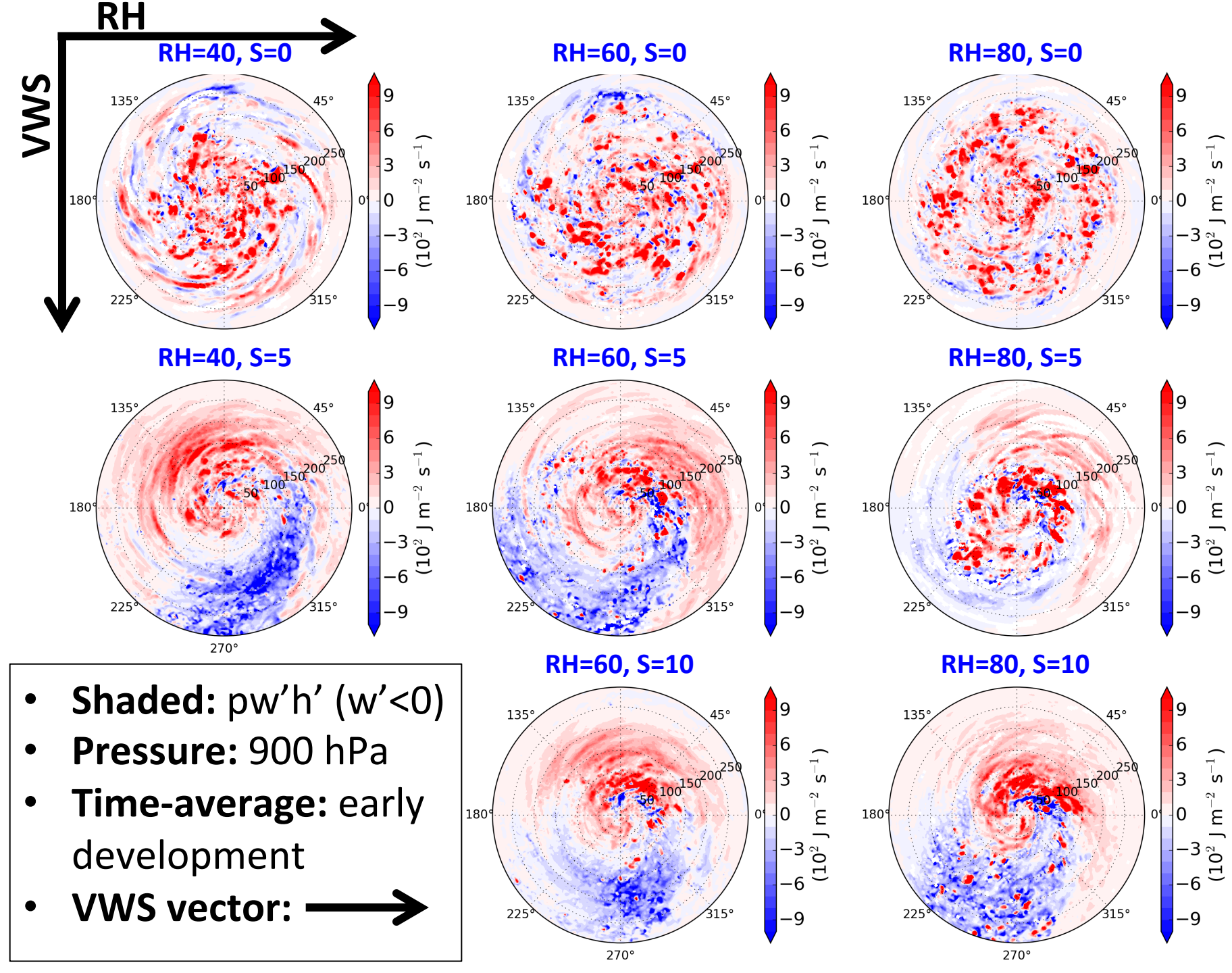

Less mid-level ventilation
More mid-level ventilation
height (km)
time (hr)
0
2
4
6
8
10
0
4
8
12
16
20
24

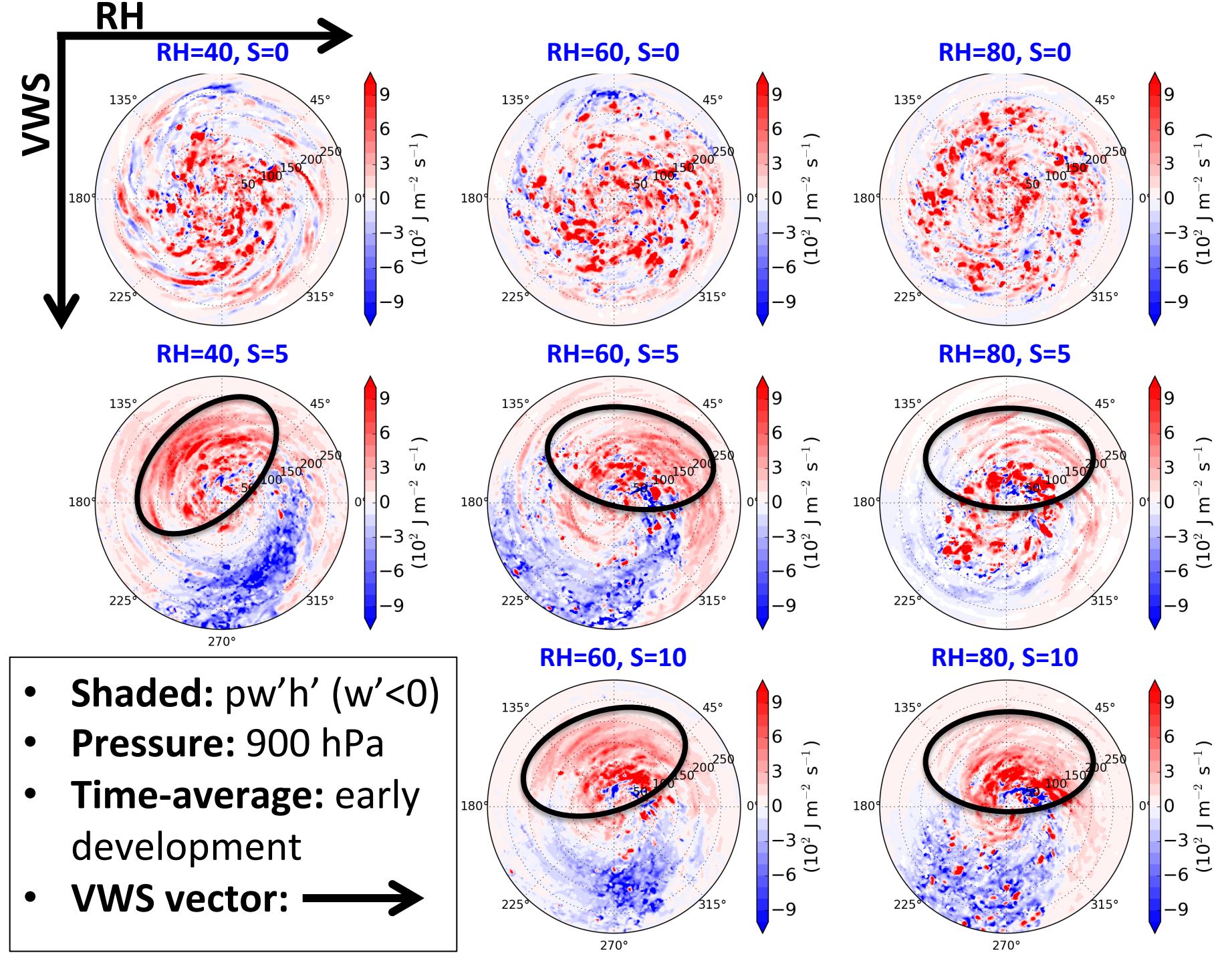
Low-level ventilation

Downward flux of low-MSE air

ρw'h'>0

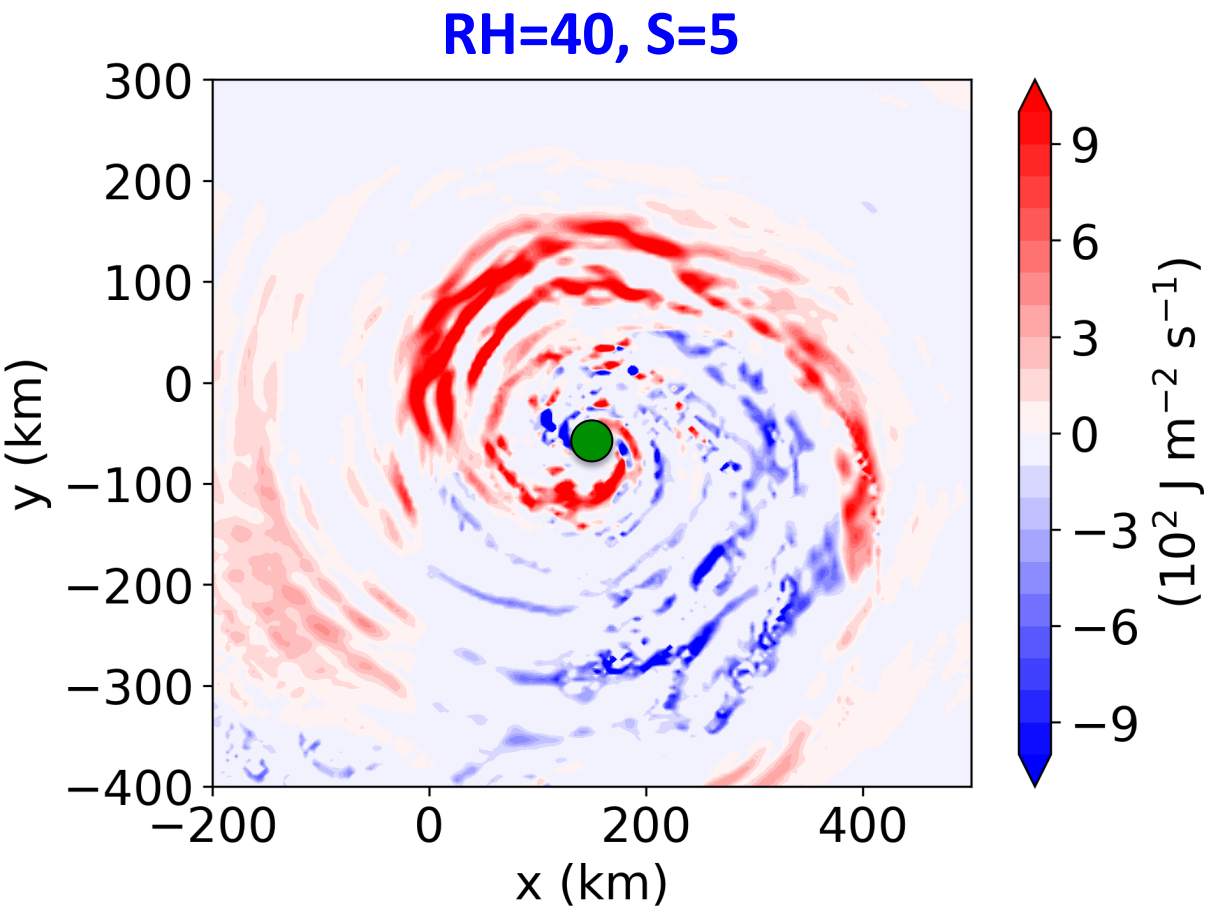



RH
VWS
RH=40, S=0
RH=60, S=0
RH=80, S=0
RH=40, S=5
RH=60, S=5
RH=80, S=5
RH=60, S=10
RH=80, S=10
135°
45°
180°
0°
225°
315°
270°
50
100
150
200
250
9
6
3
0
−3
−6
−9
$(10^2\ J\ m^{-2}\ s^{-1})$
• **Shaded:** pw'h' (w'<0)
• **Pressure:** 900 hPa
• **Time-average:** early development
• **VWS vector:**


RH
VWS
RH=40, S=0
RH=60, S=0
RH=80, S=0
RH=40, S=5
RH=60, S=5
RH=80, S=5
RH=60, S=10
RH=80, S=10
135°
45°
180°
0°
225°
315°
270°
50
100
150
200
250
9
6
3
0
−3
−6
−9
$(10^2\ J\ m^{-2}\ s^{-1})$
• **Shaded:** pw'h' (w'<0)
• **Pressure:** 900 hPa
• **Time-average:** early development
• **VWS vector:**

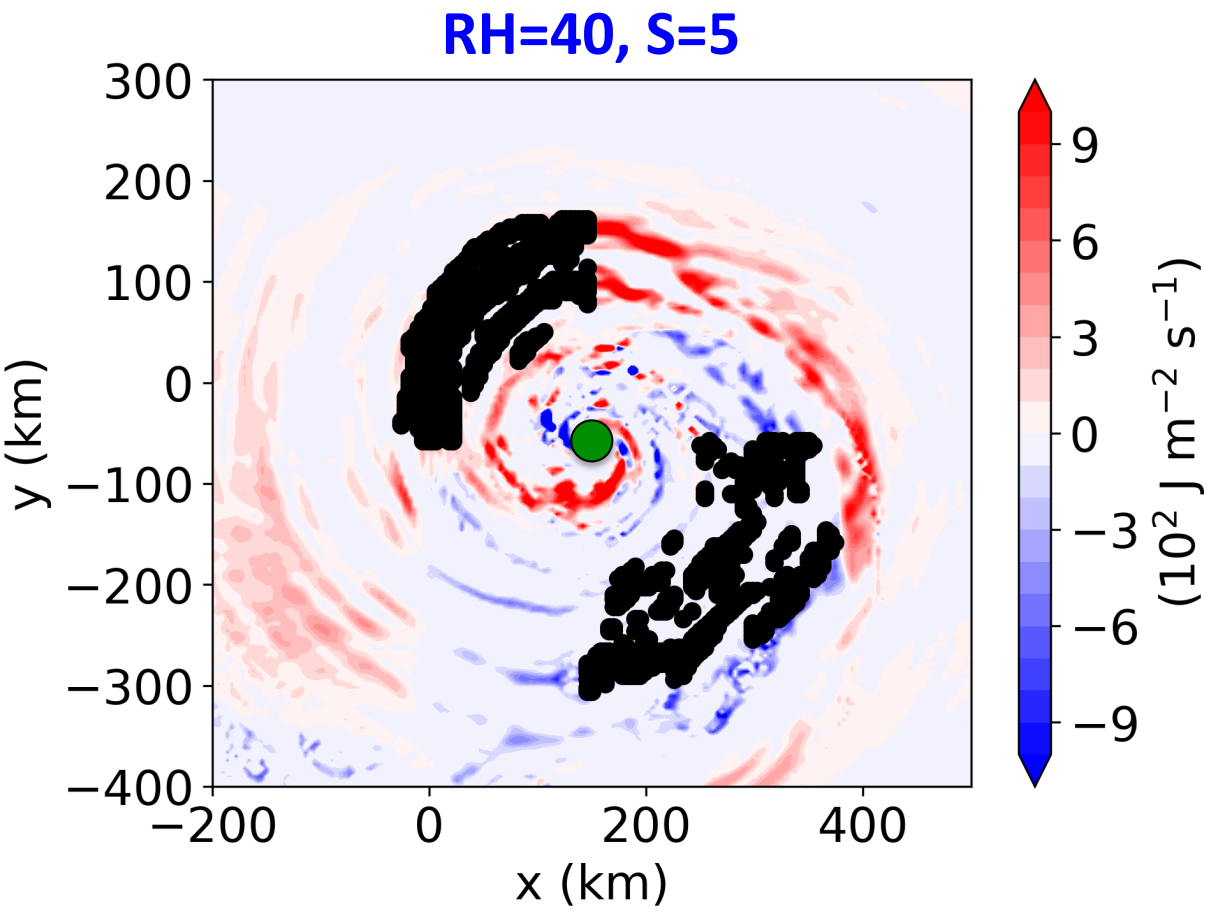
How does the low-level ventilation structure affect convection?

Tool: Lagrangian parcel trajectories

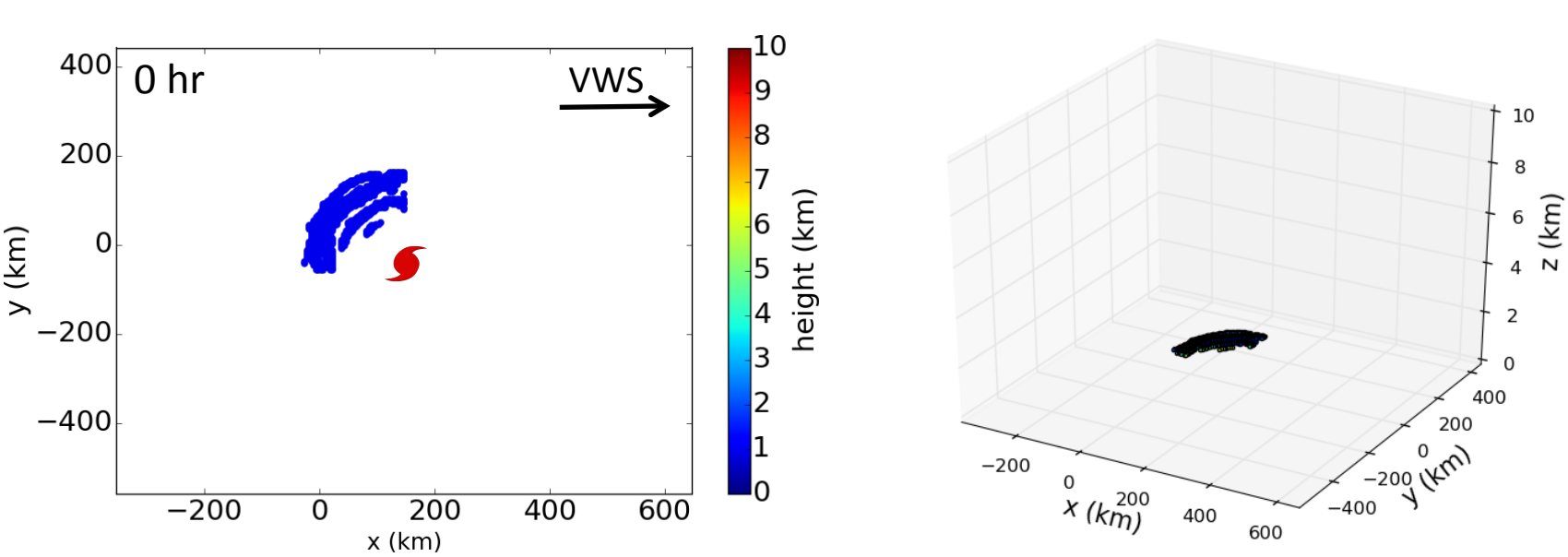


How does the low-level ventilation structure affect convection?

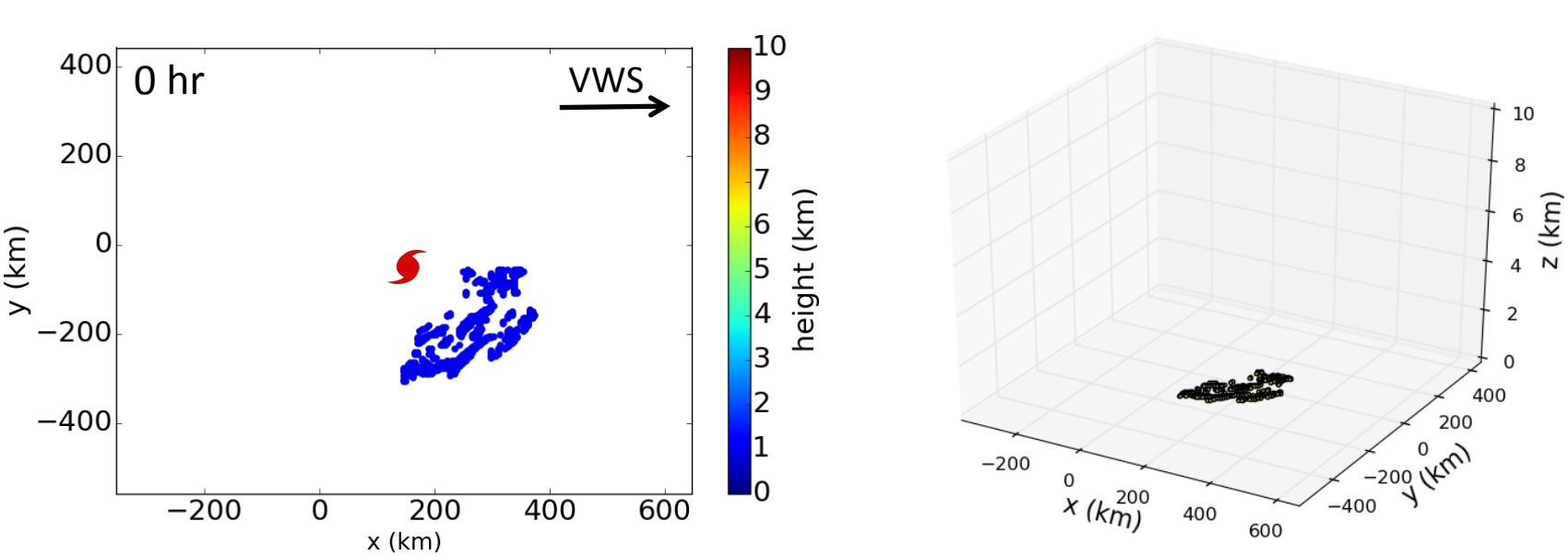
Tool: Lagrangian parcel trajectories



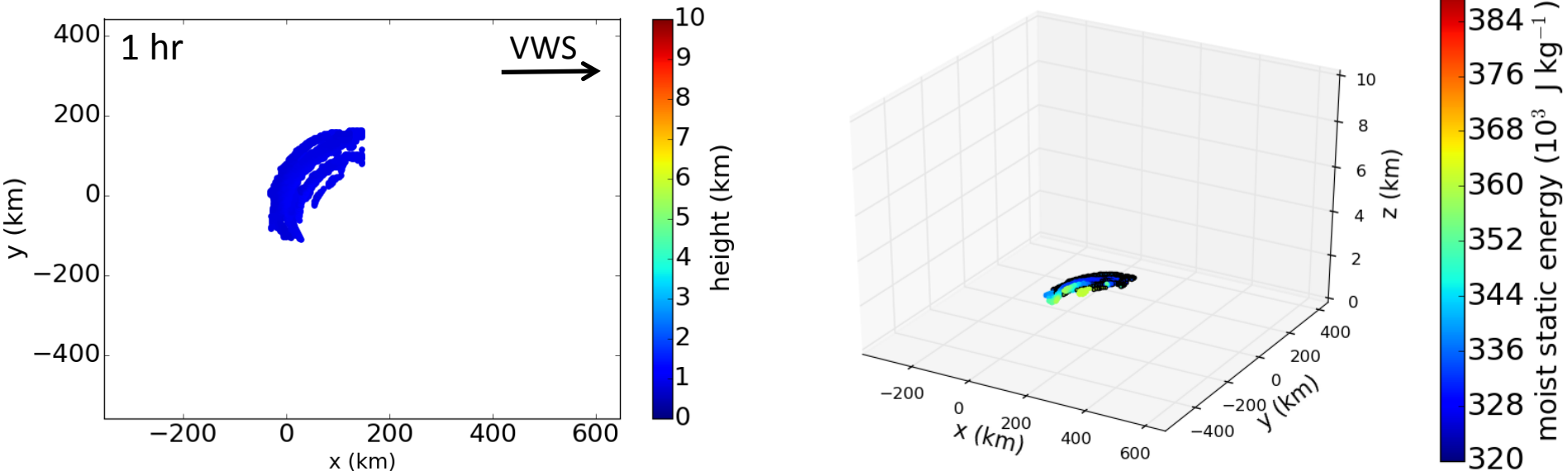
More low-level ventilation



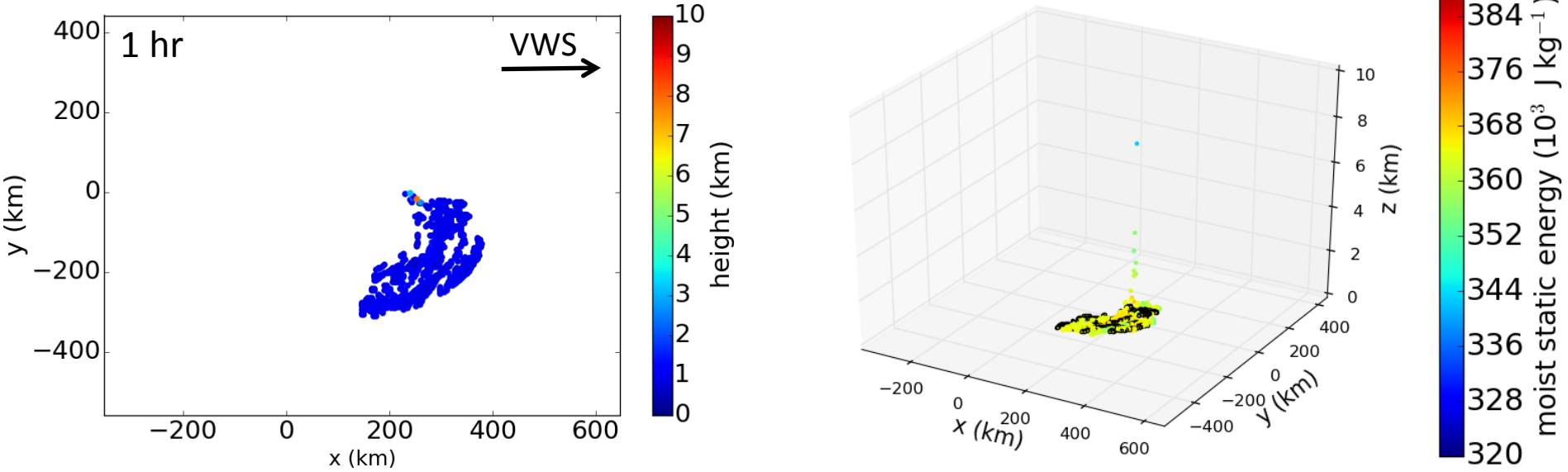
Less low-level ventilation



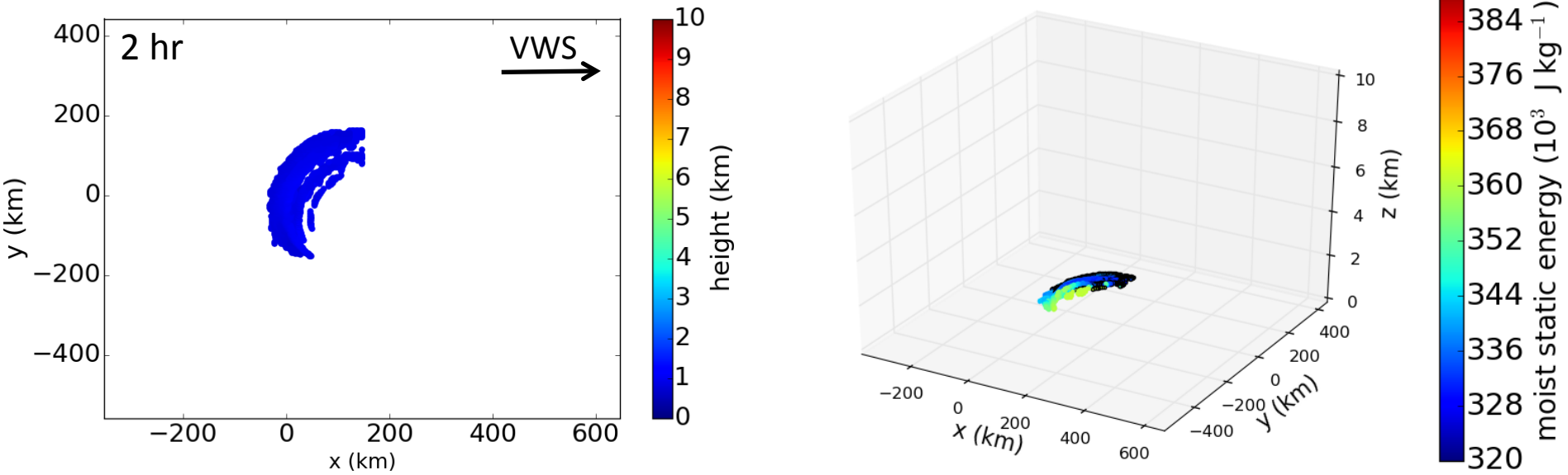
More low-level ventilation



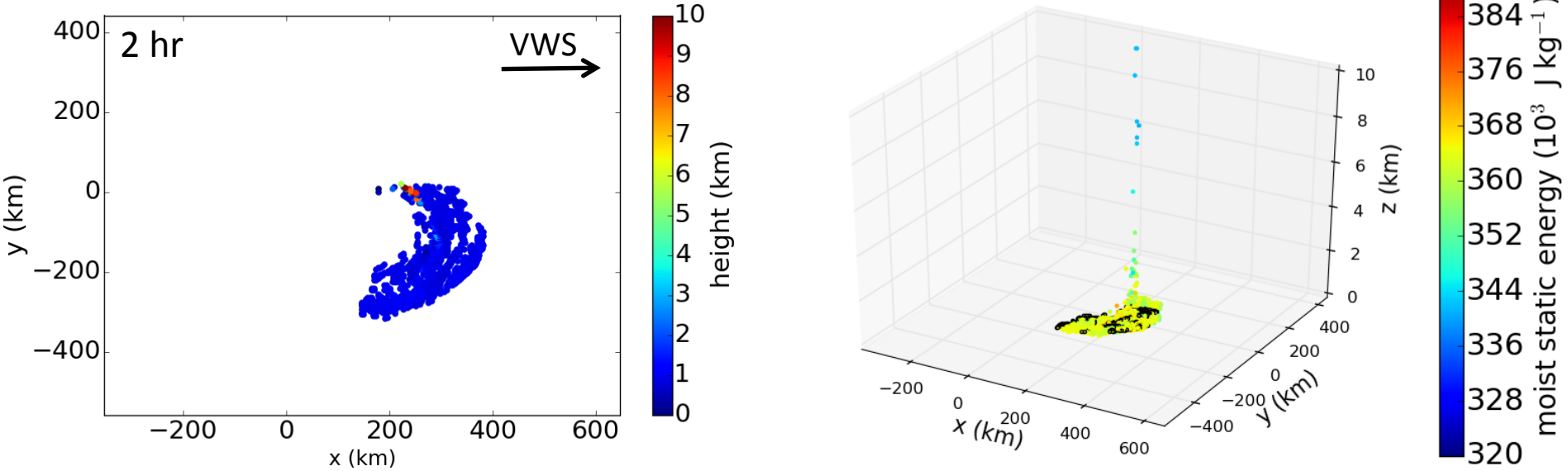
Less low-level ventilation



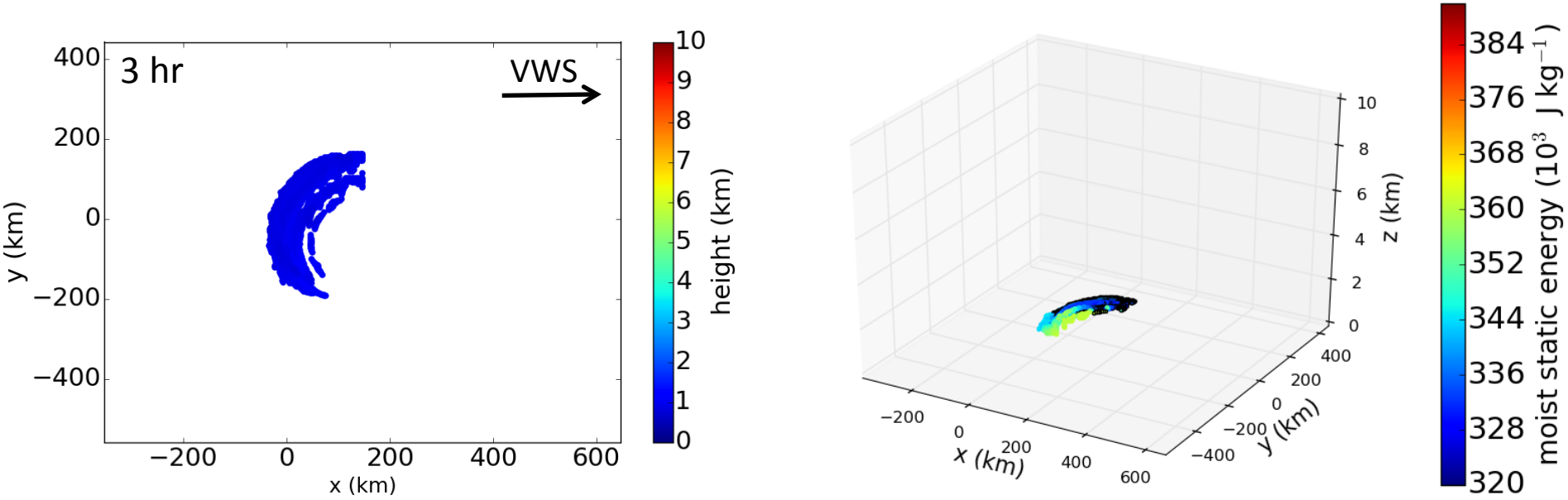
More low-level ventilation



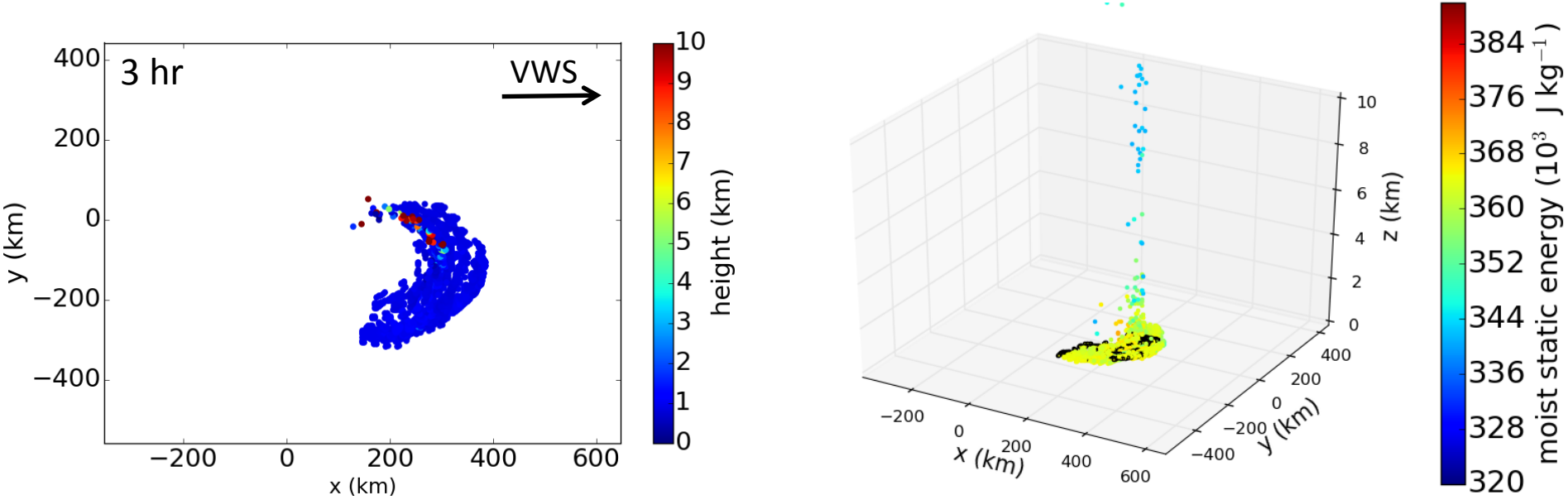
Less low-level ventilation



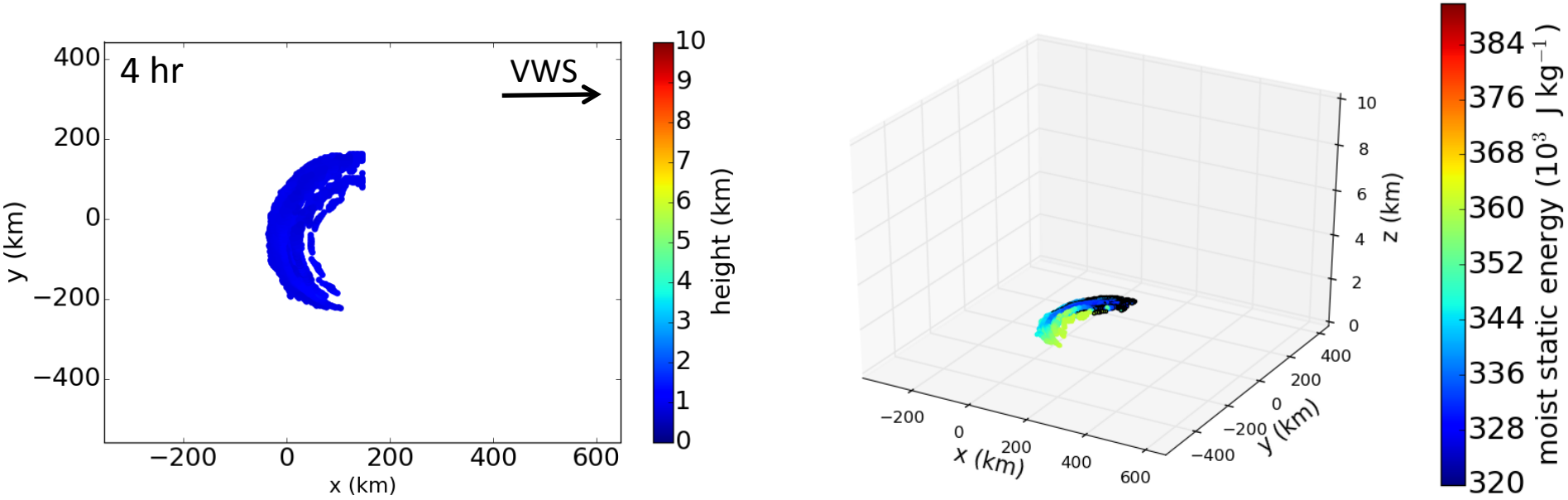
More low-level ventilation



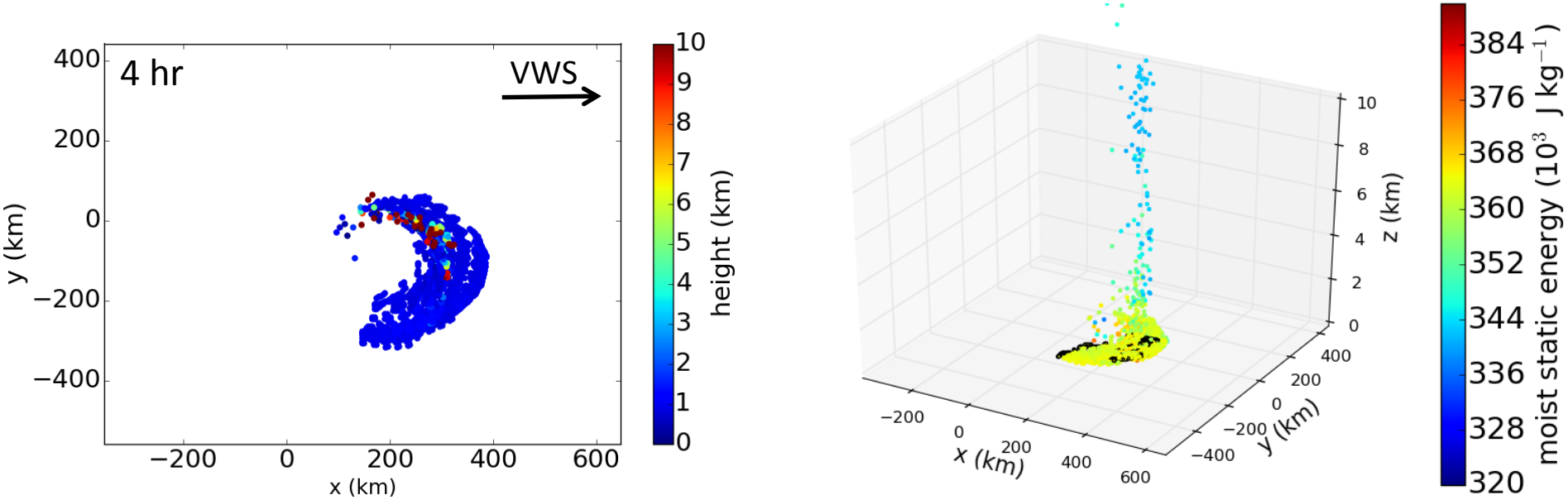
Less low-level ventilation



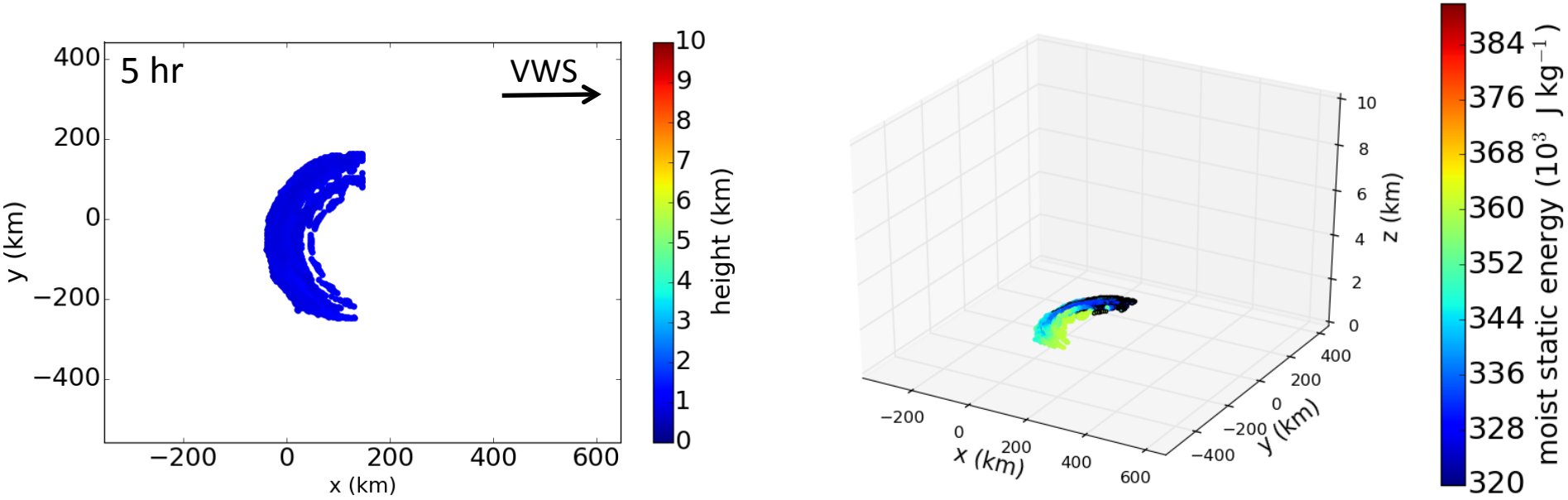
More low-level ventilation



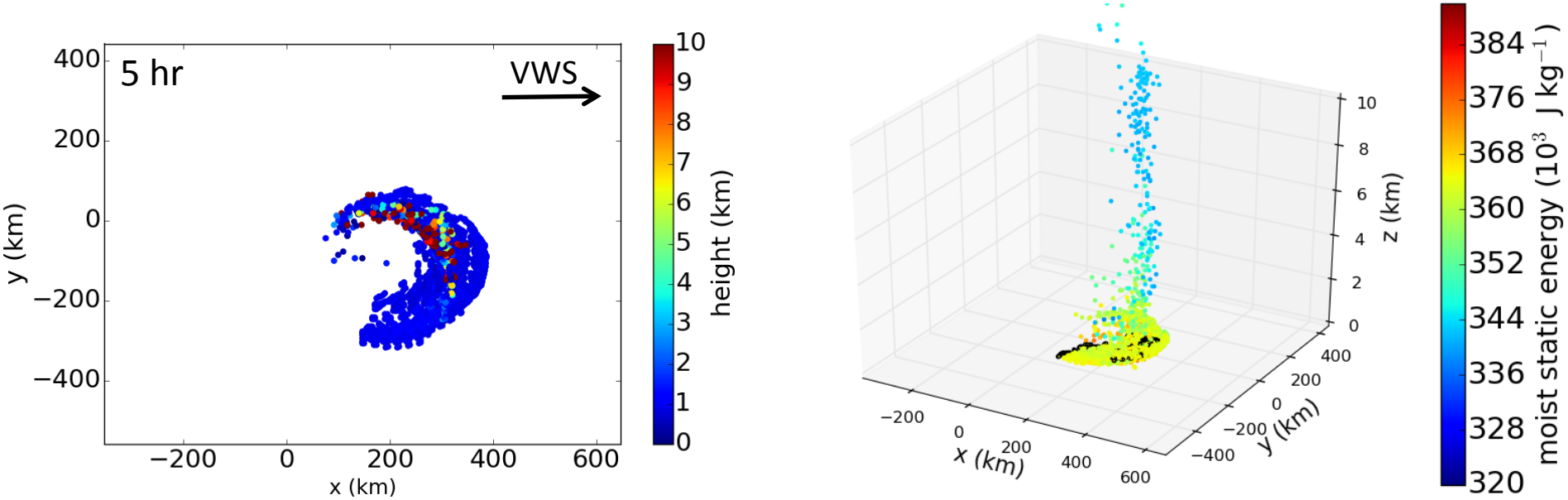
Less low-level ventilation



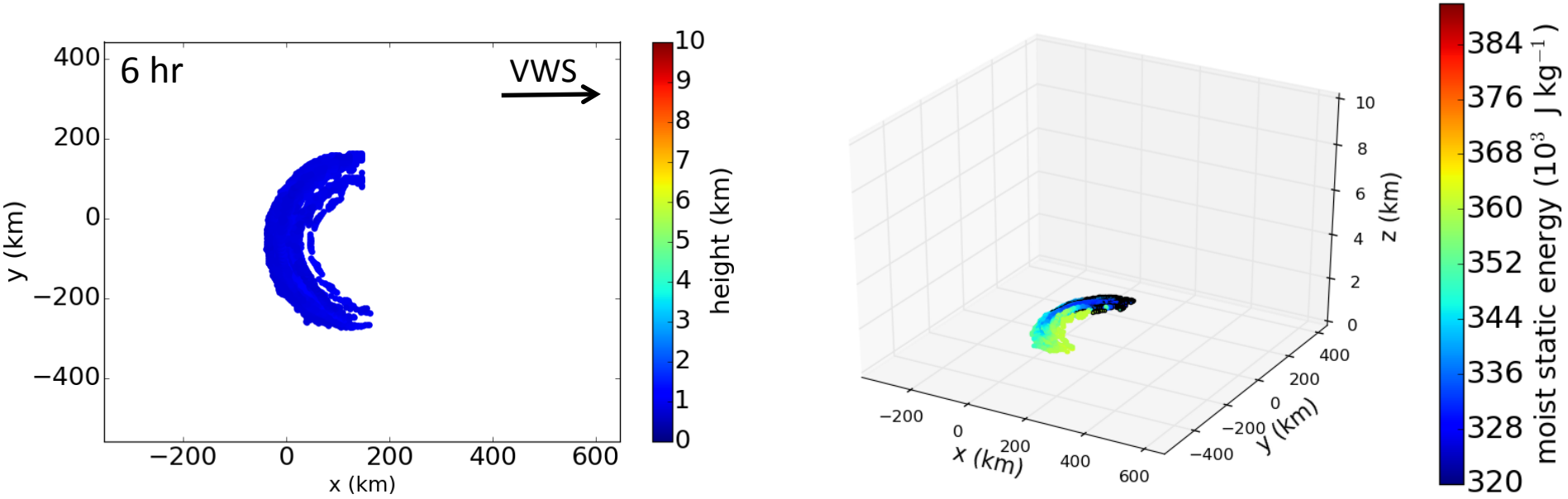
More low-level ventilation



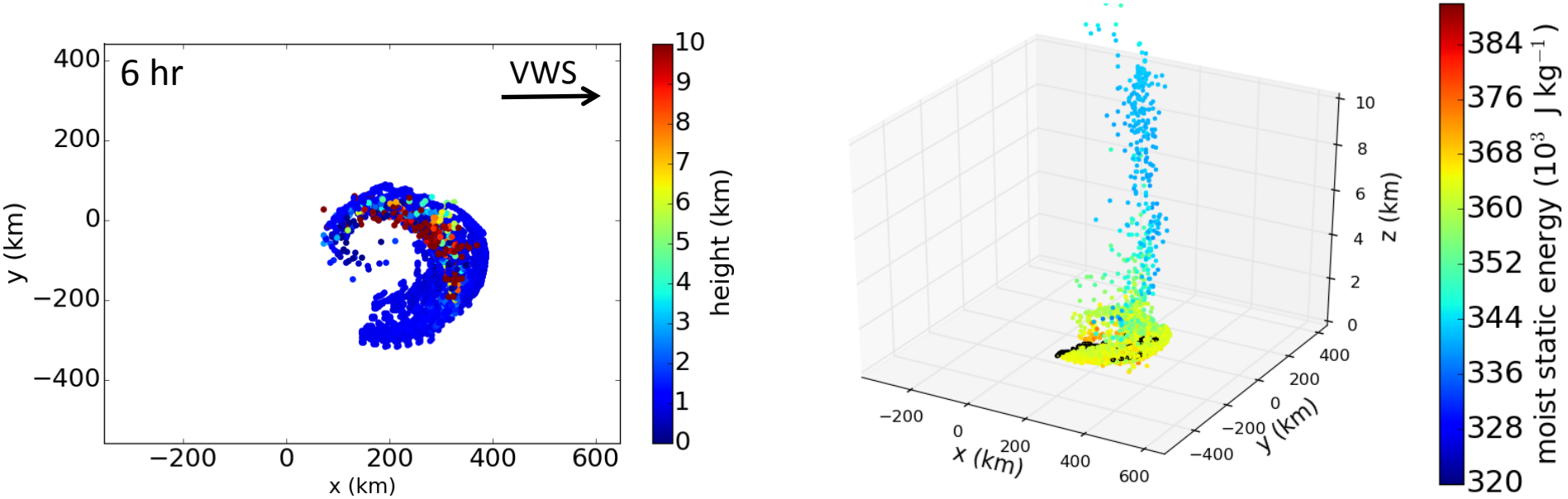
Less low-level ventilation



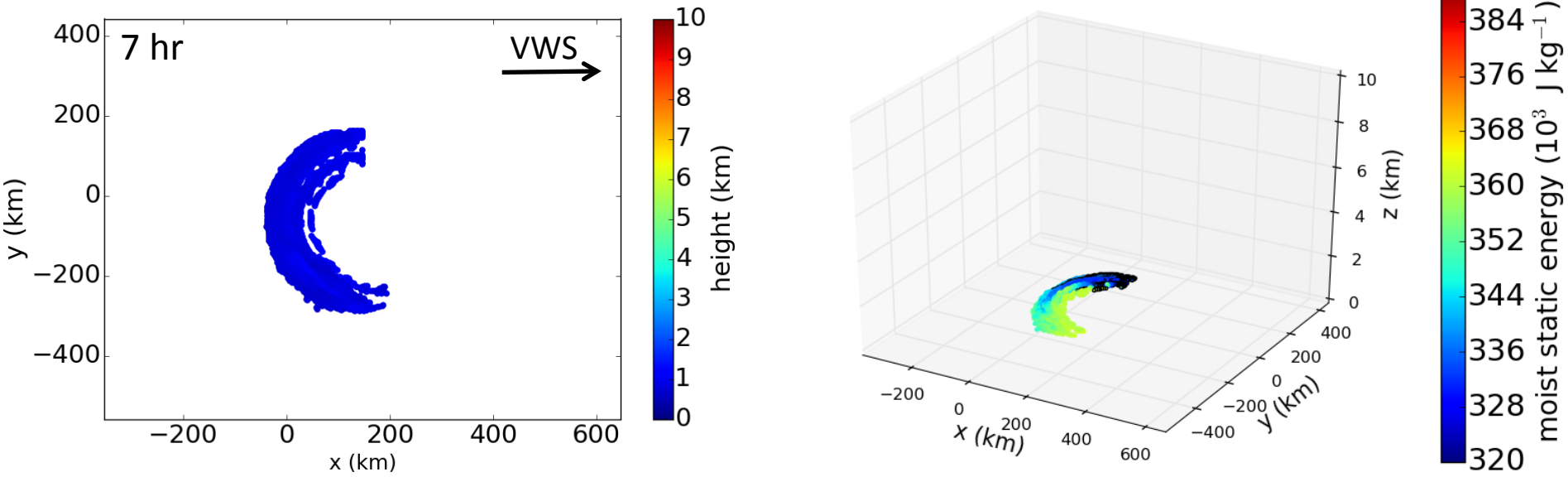
More low-level ventilation



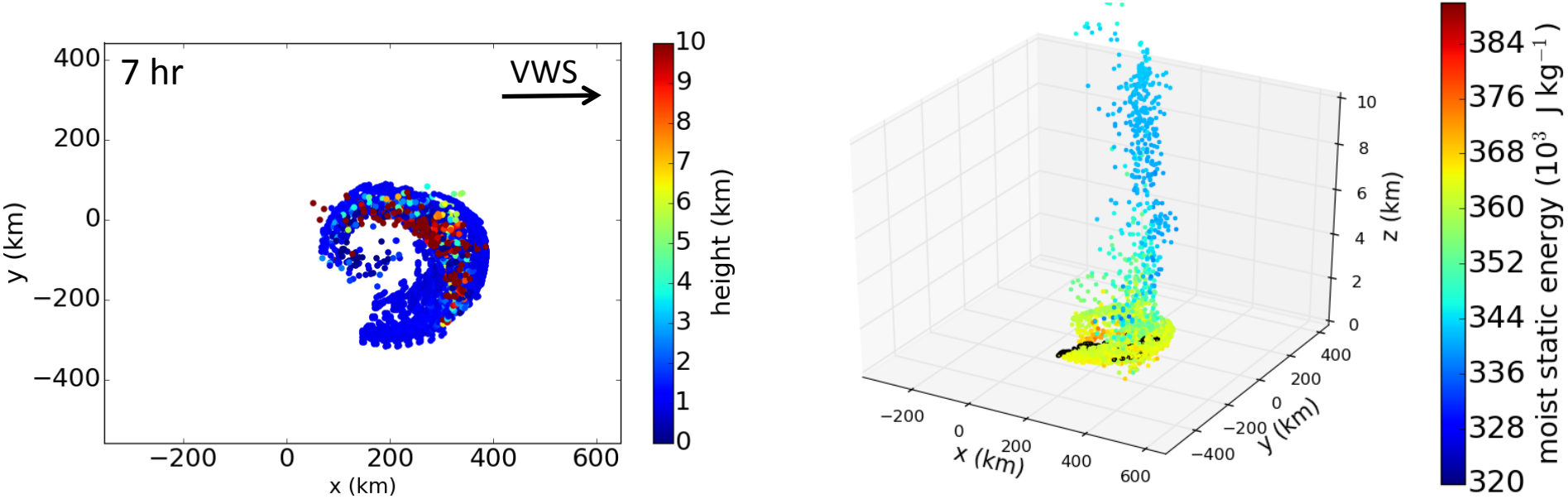
Less low-level ventilation



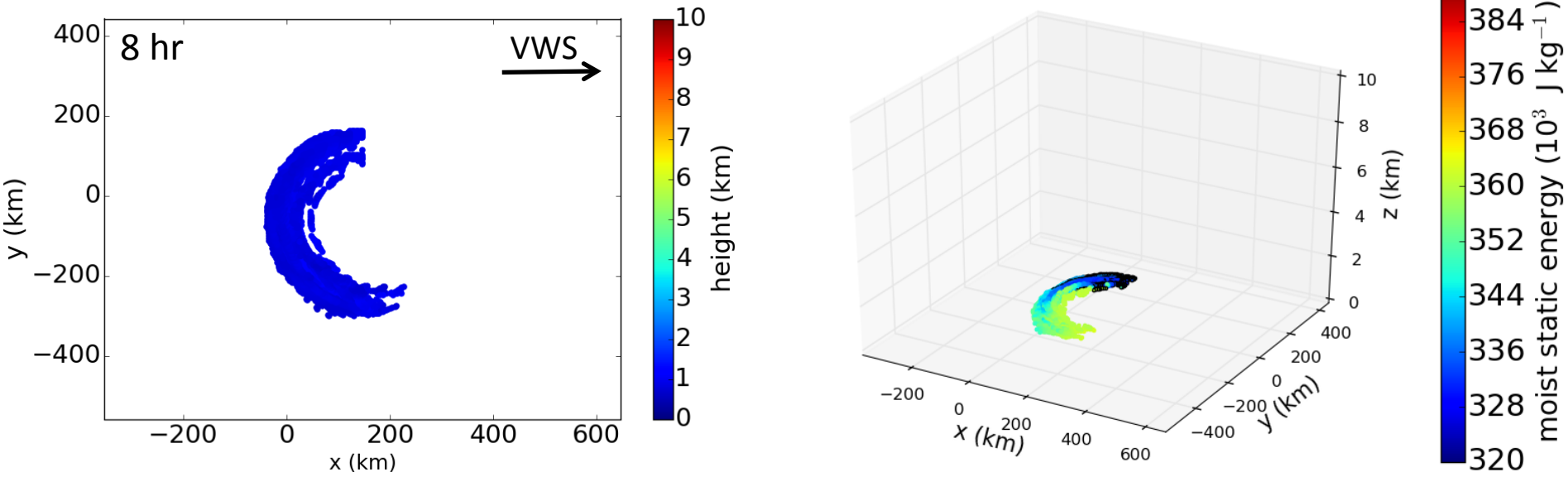
More low-level ventilation



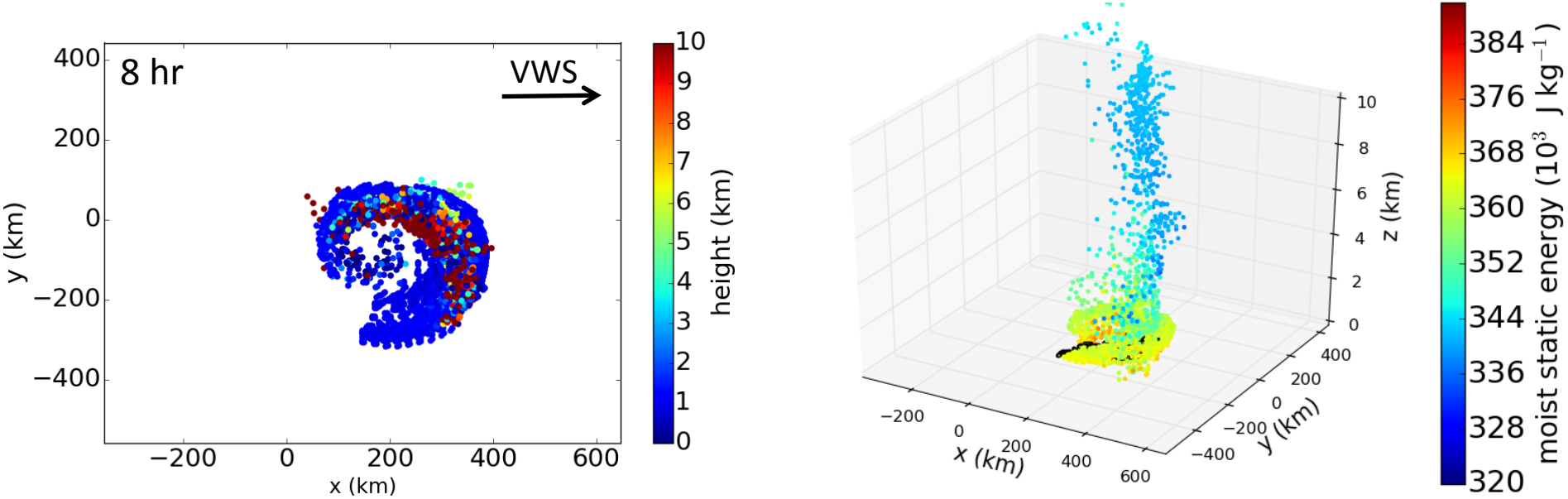
Less low-level ventilation



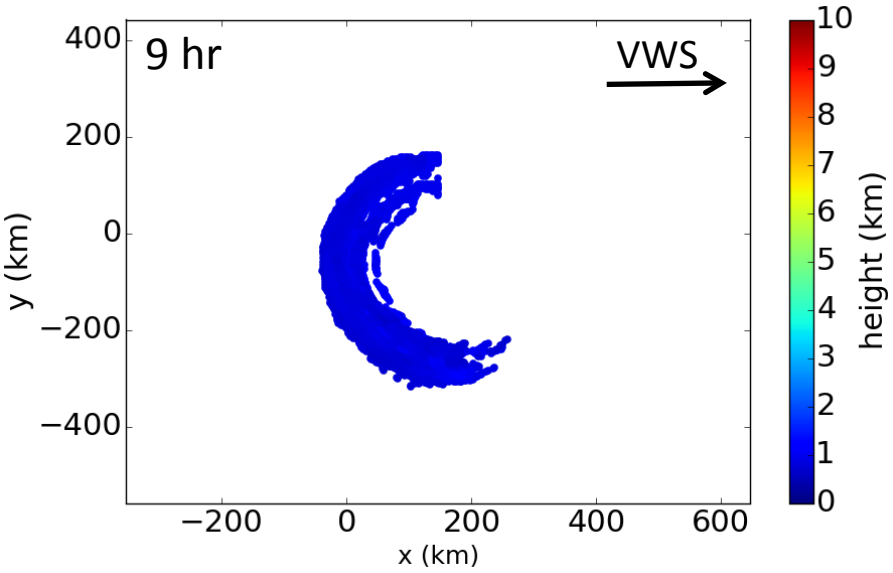
More low-level ventilation

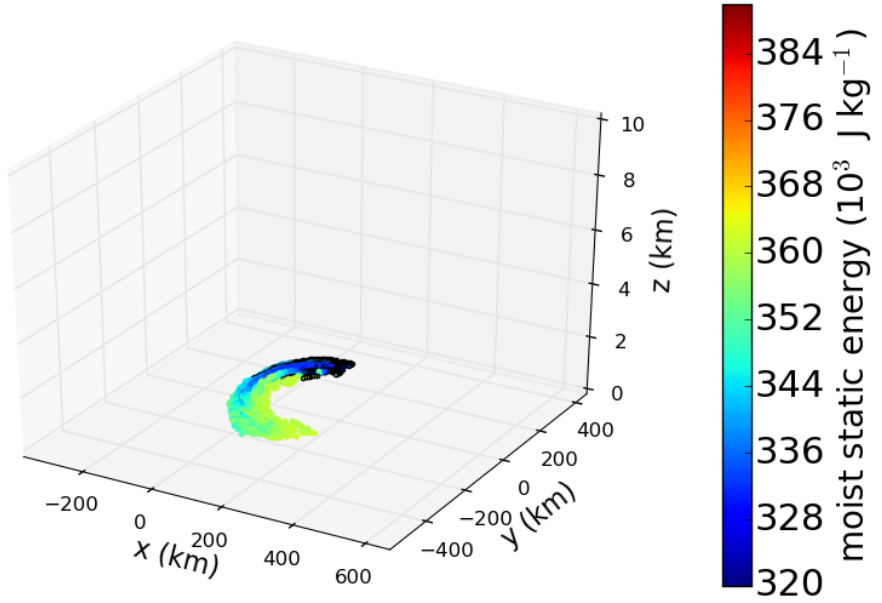


Less low-level ventilation

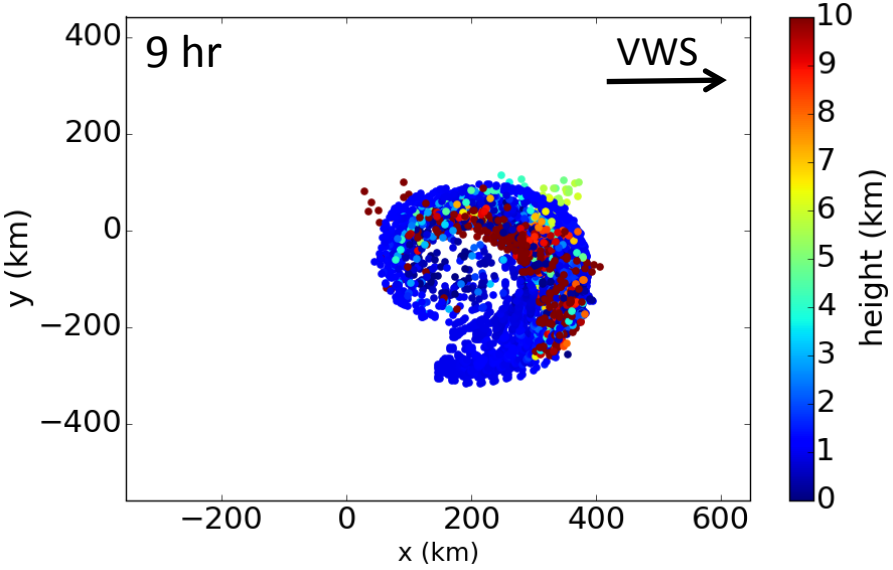


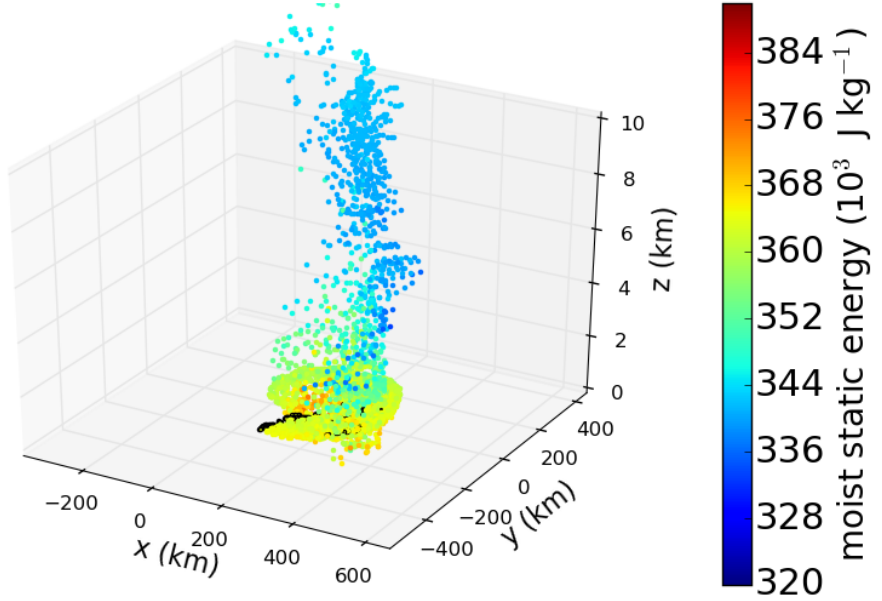
More low-level ventilation



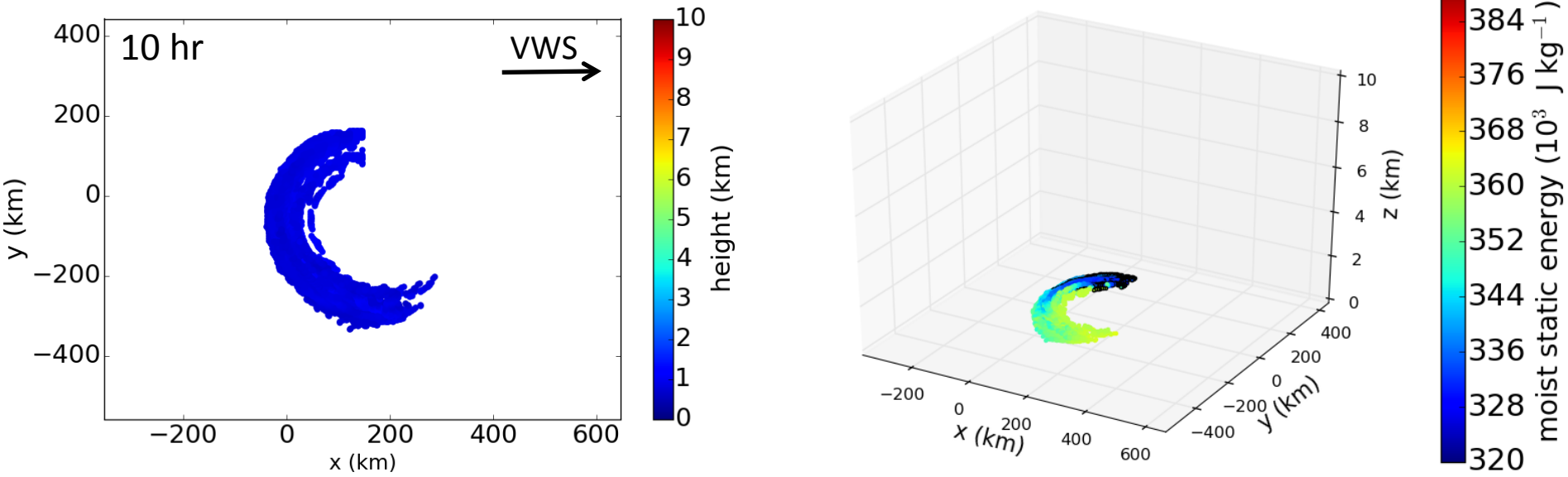


Less low-level ventilation

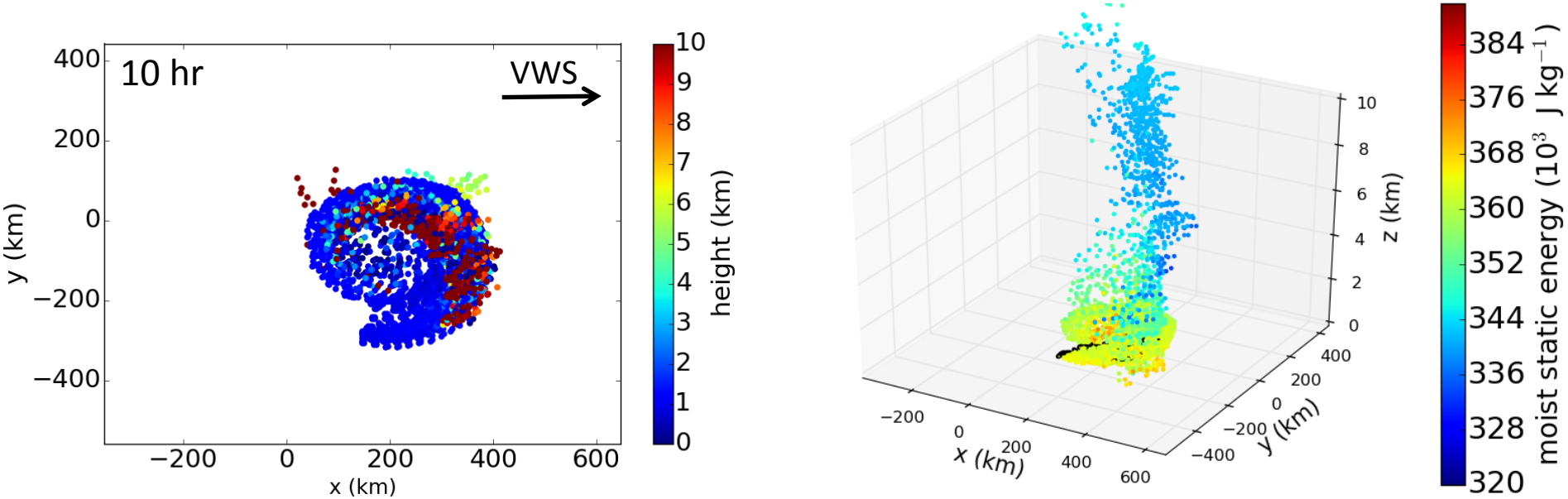




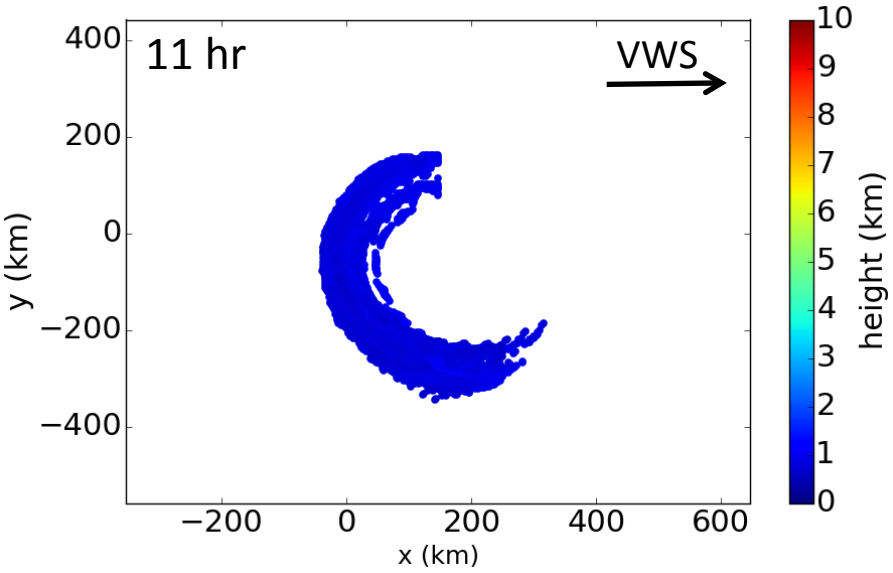
More low-level ventilation

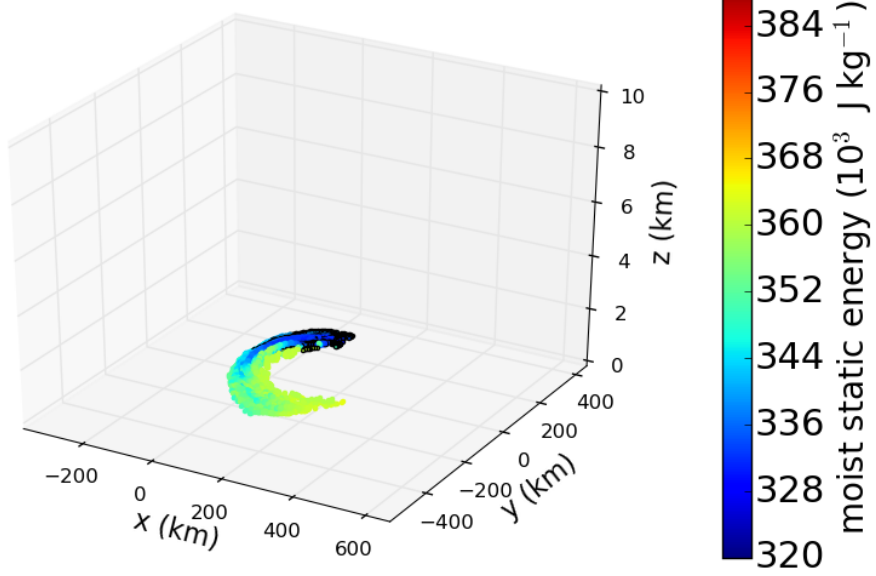


Less low-level ventilation

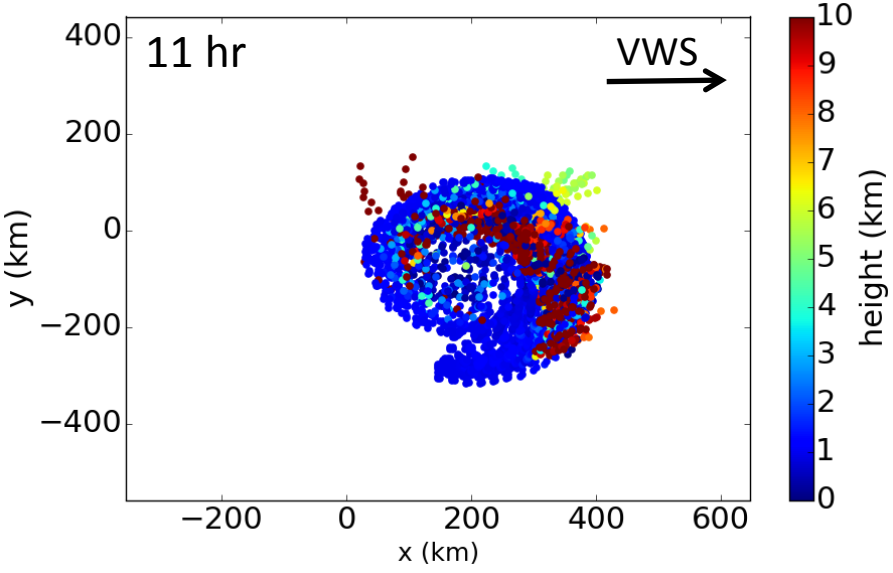


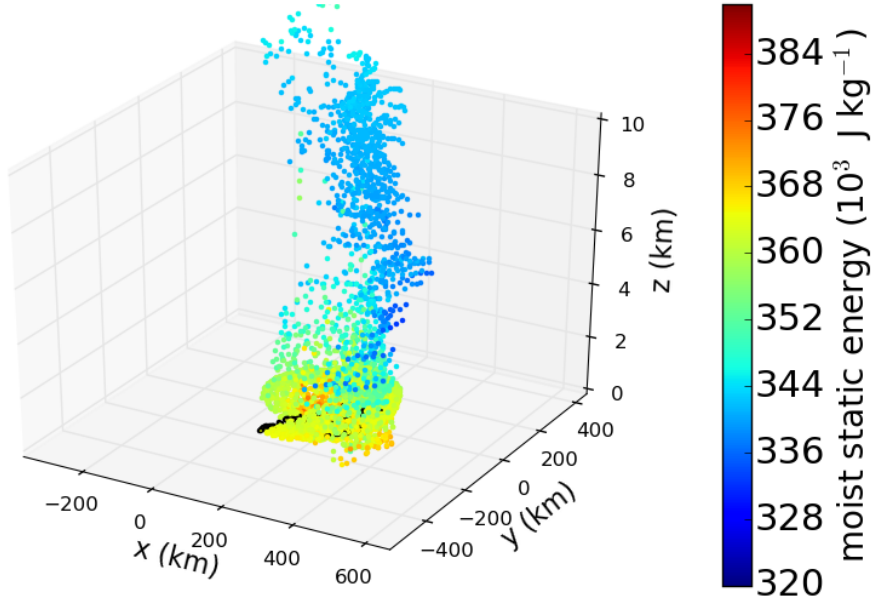
More low-level ventilation



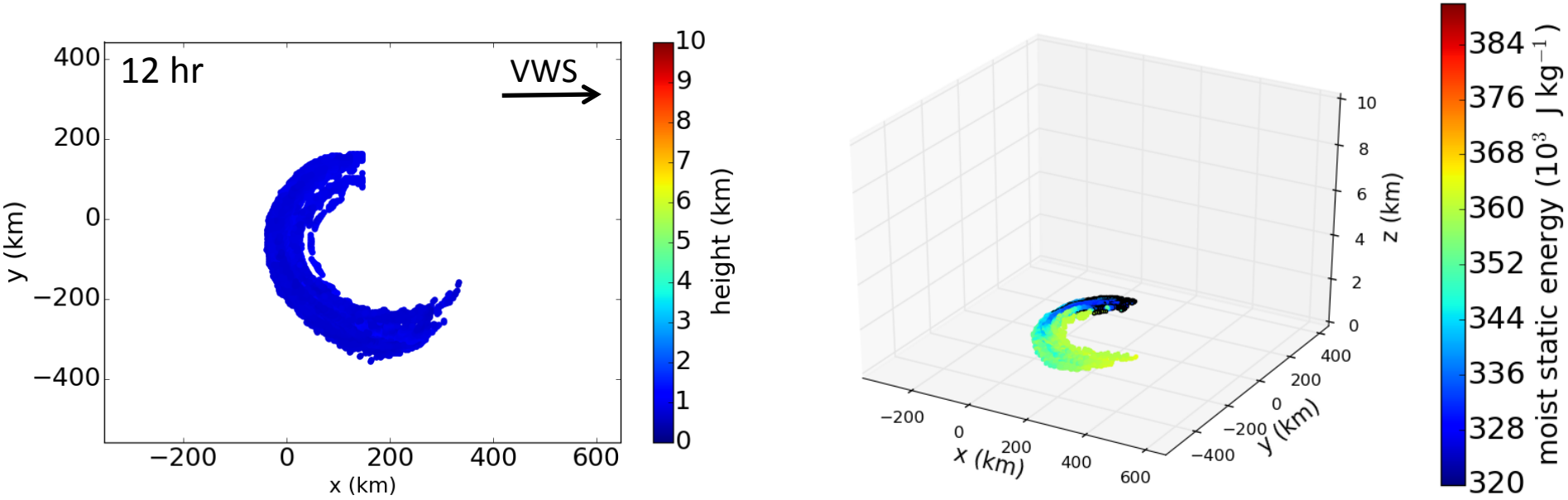


Less low-level ventilation

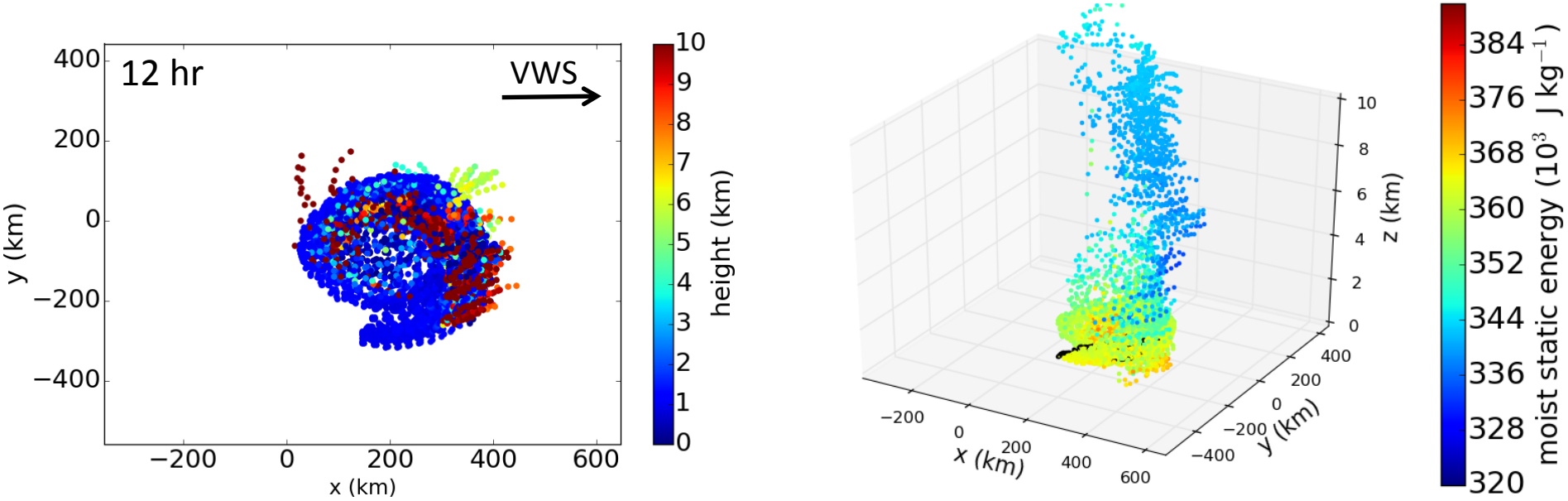




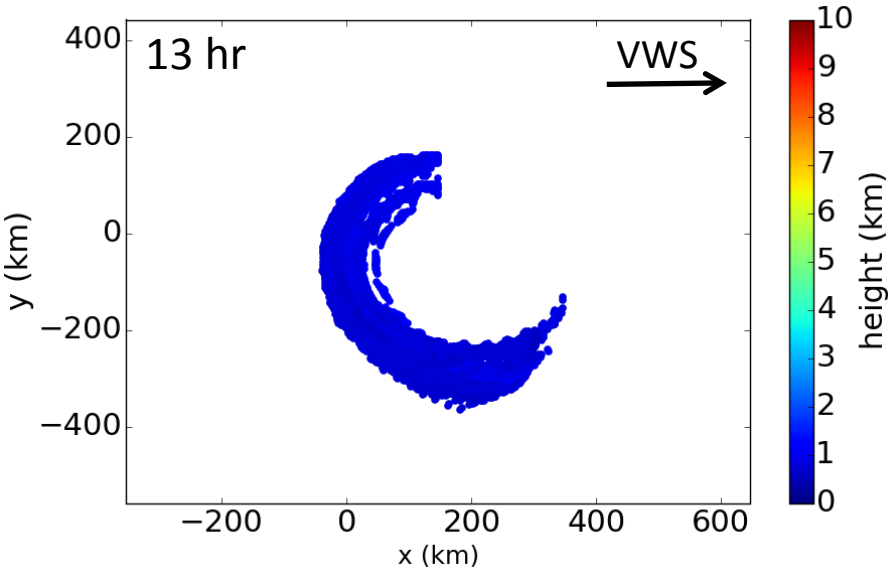
More low-level ventilation

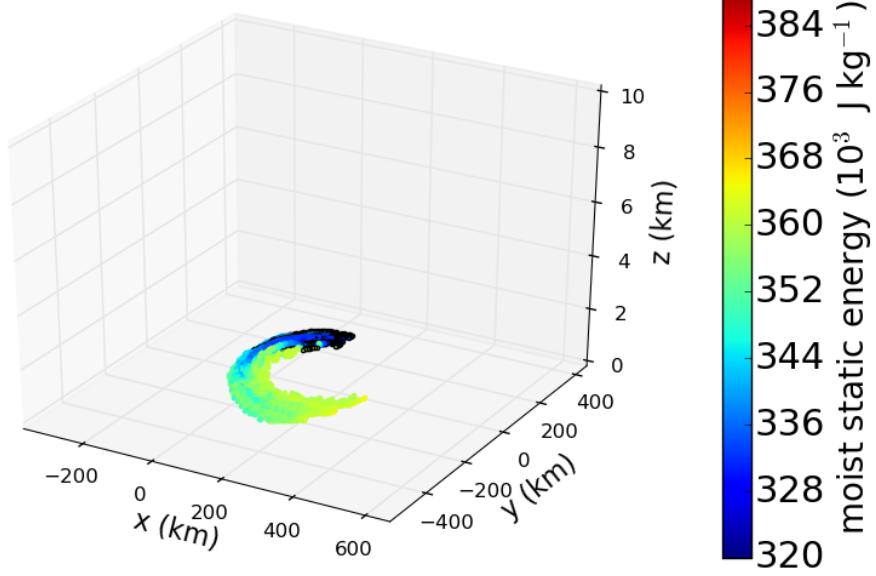


Less low-level ventilation

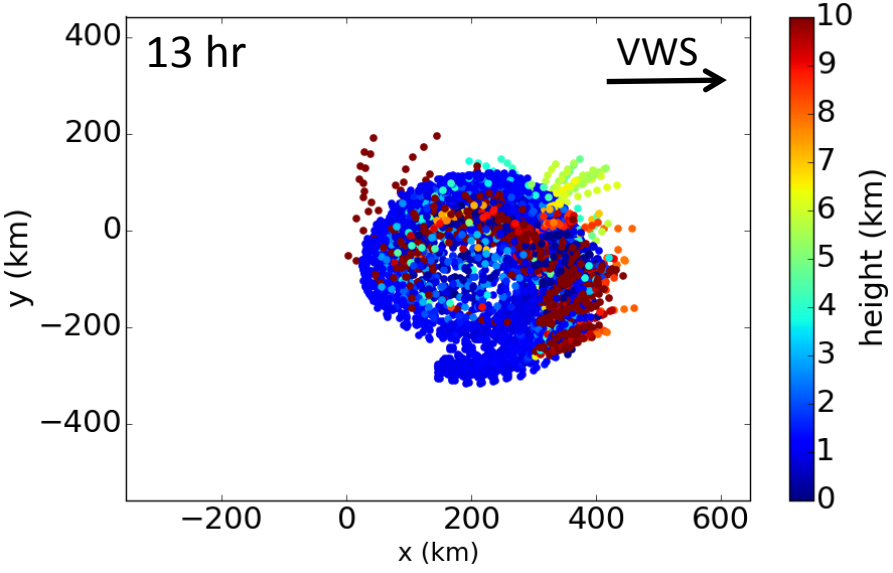


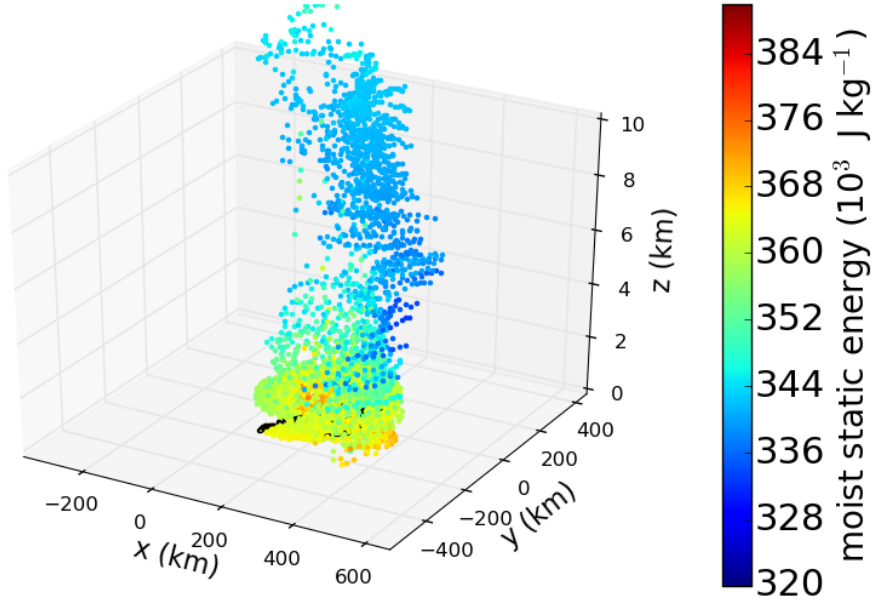
More low-level ventilation



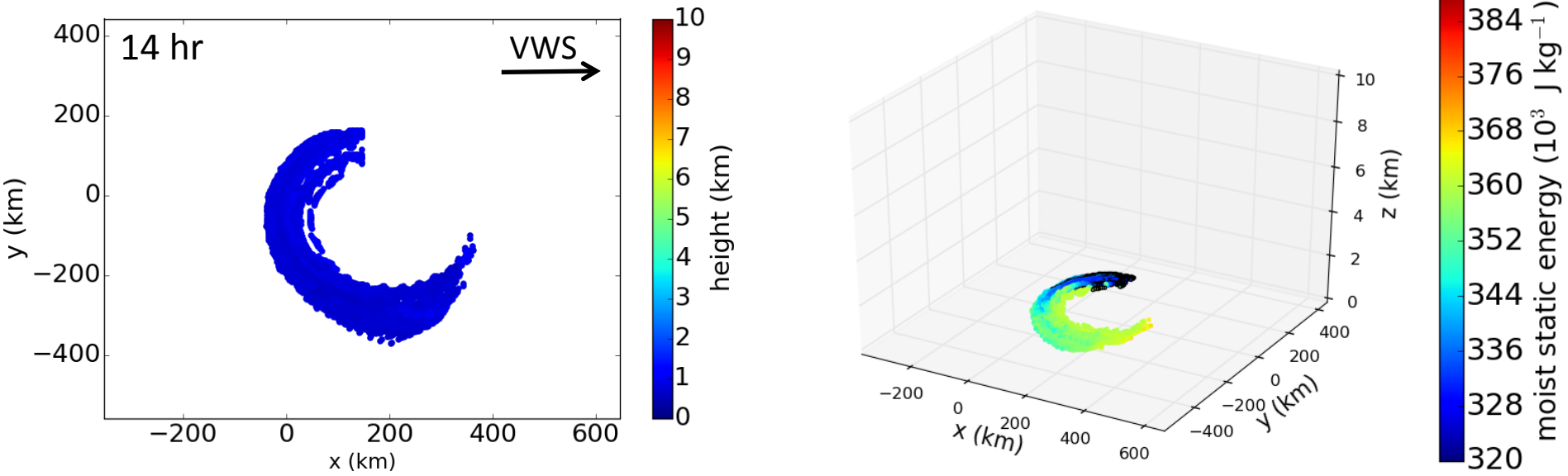


Less low-level ventilation

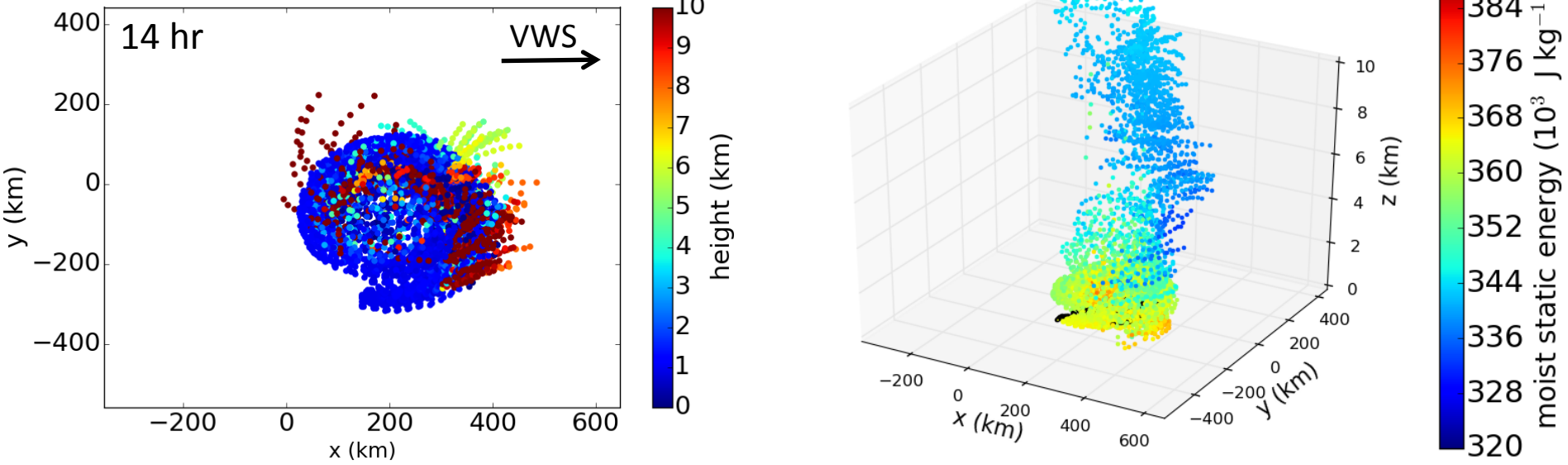




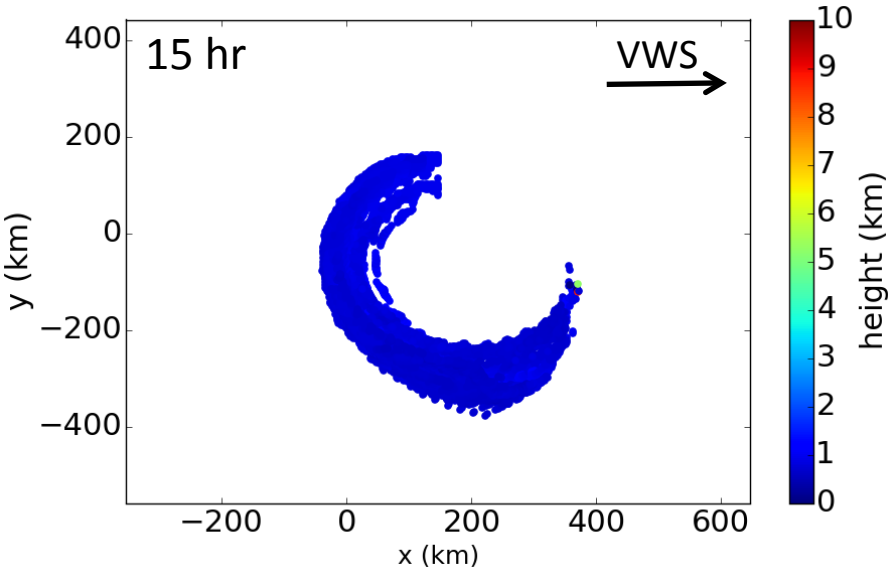
More low-level ventilation

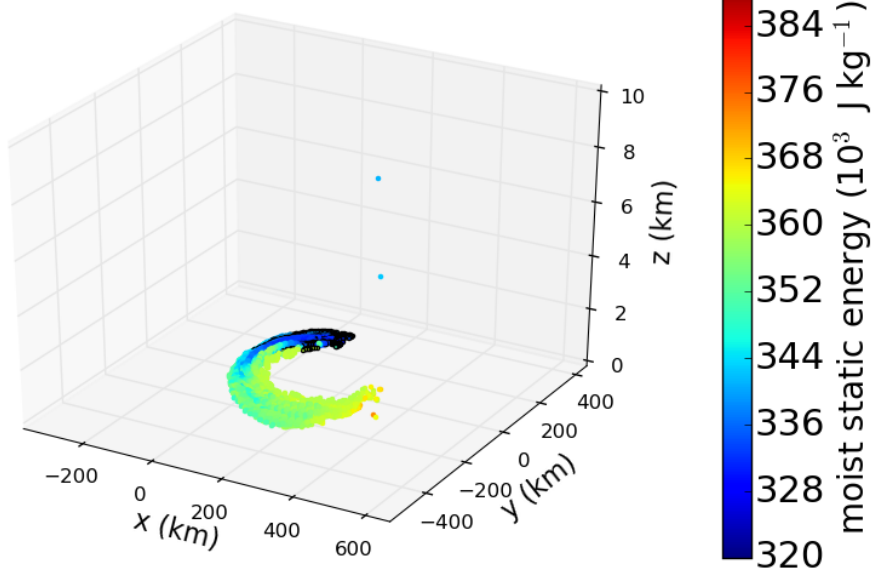


Less low-level ventilation

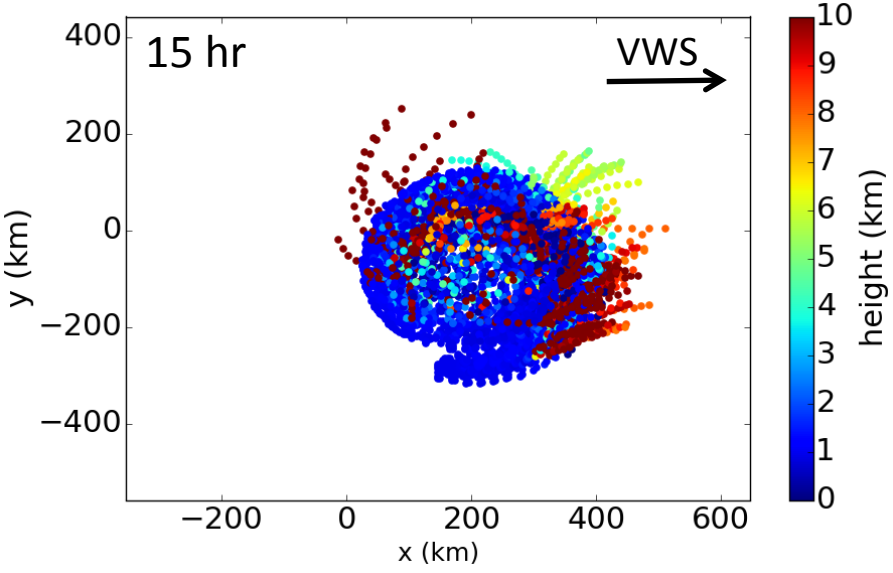


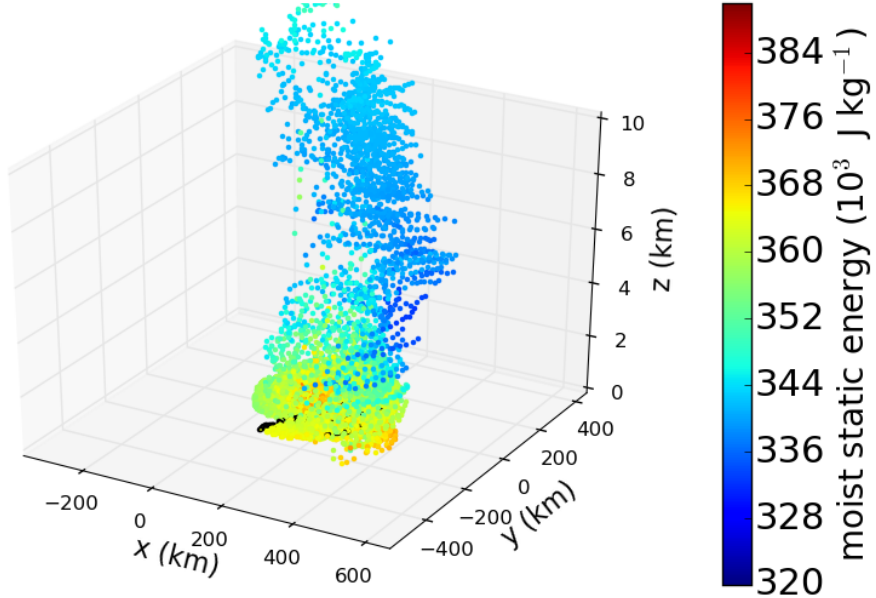
More low-level ventilation



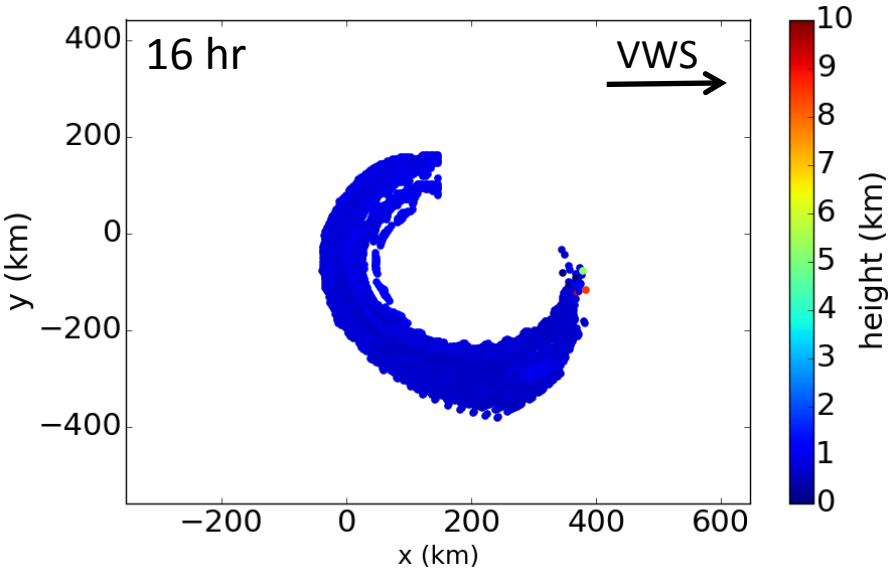


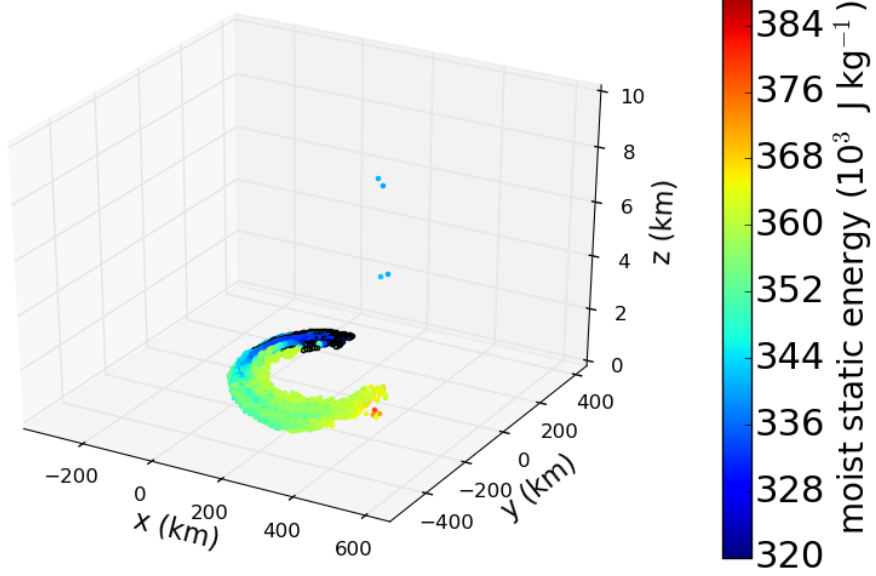
Less low-level ventilation



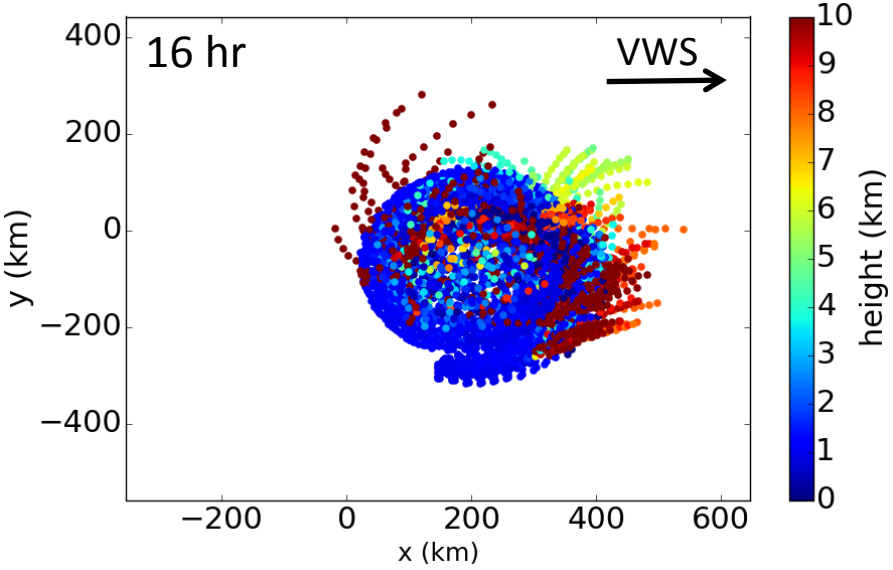


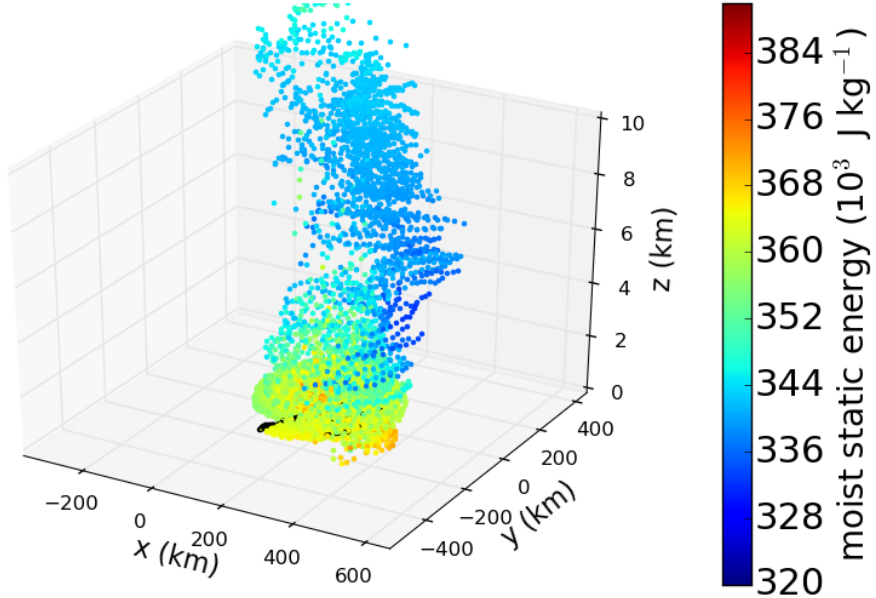
More low-level ventilation



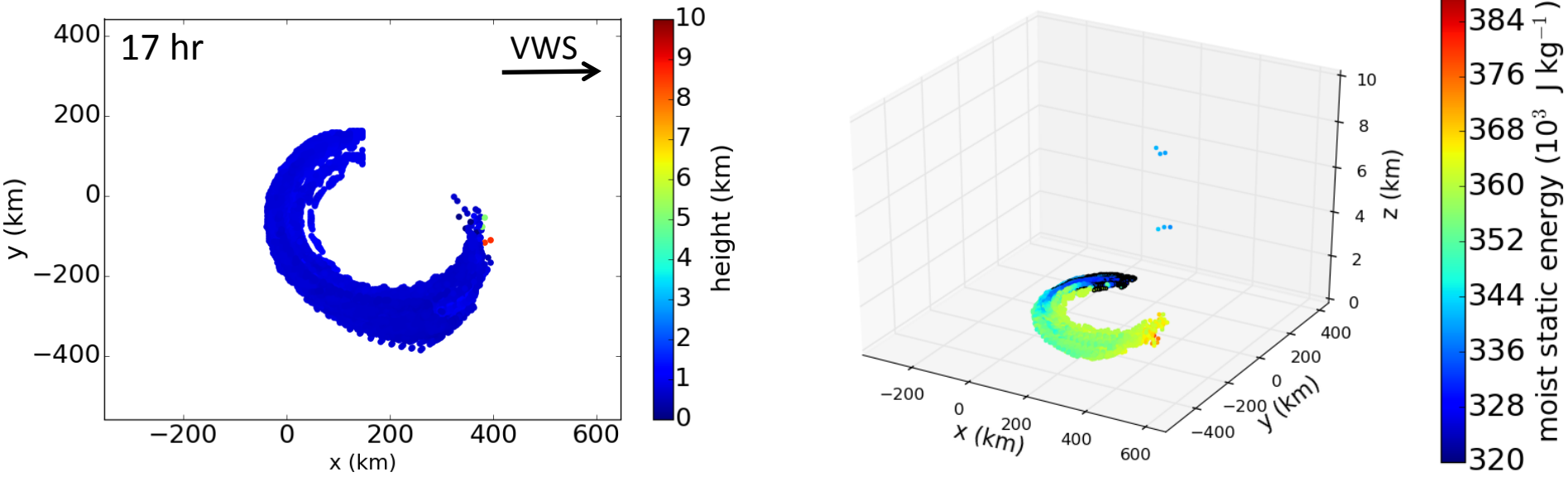


Less low-level ventilation

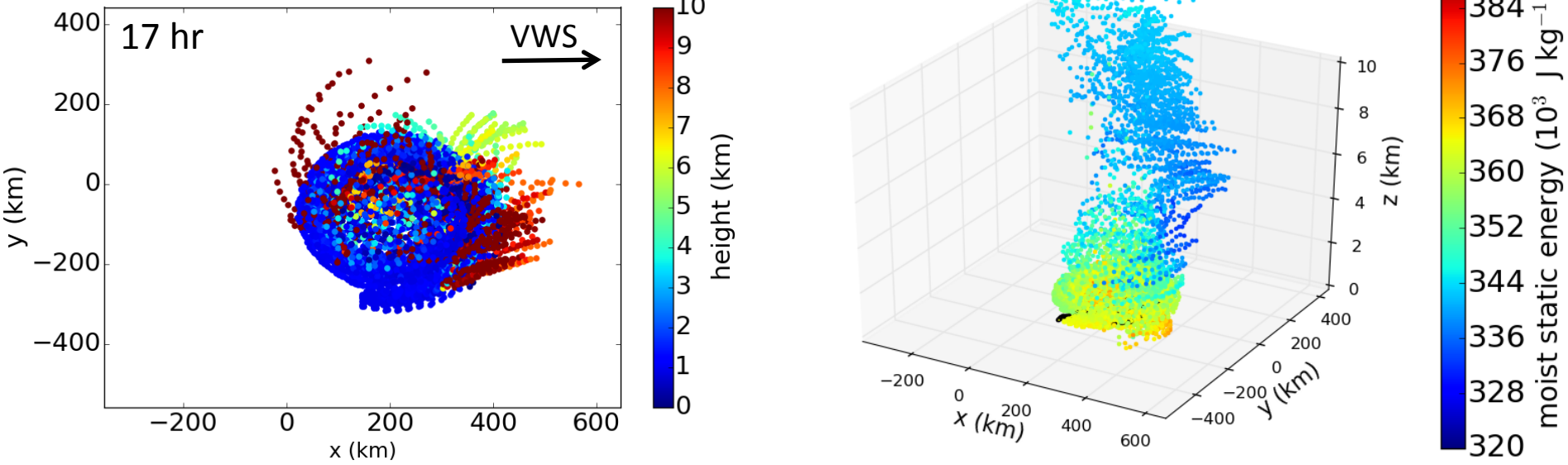




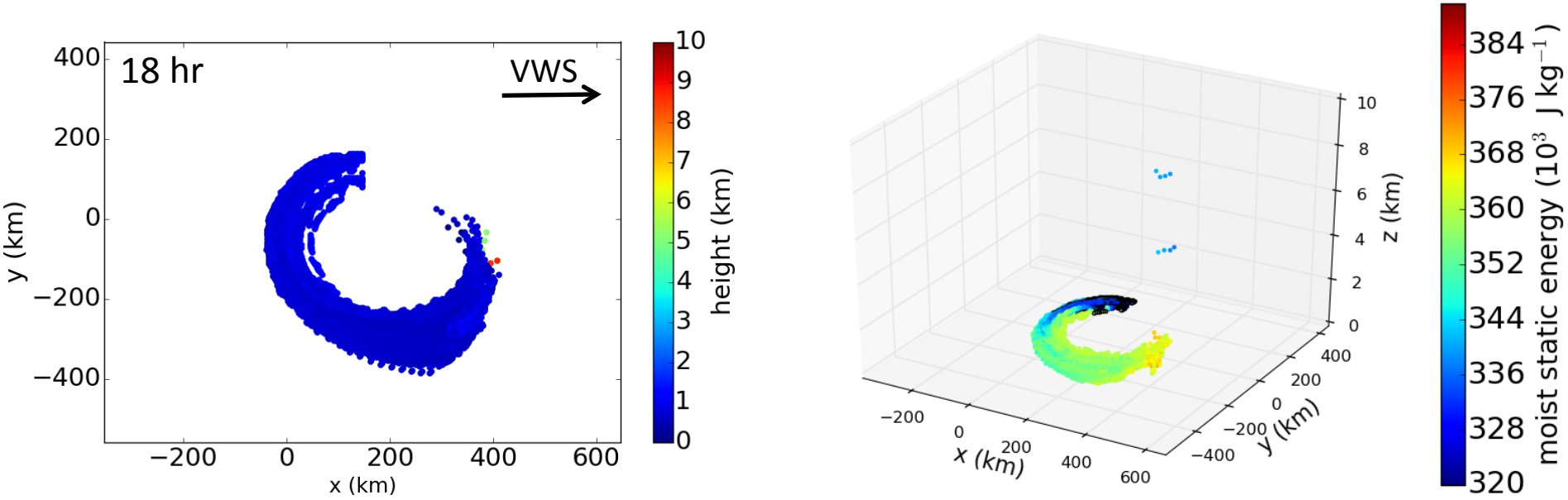
More low-level ventilation



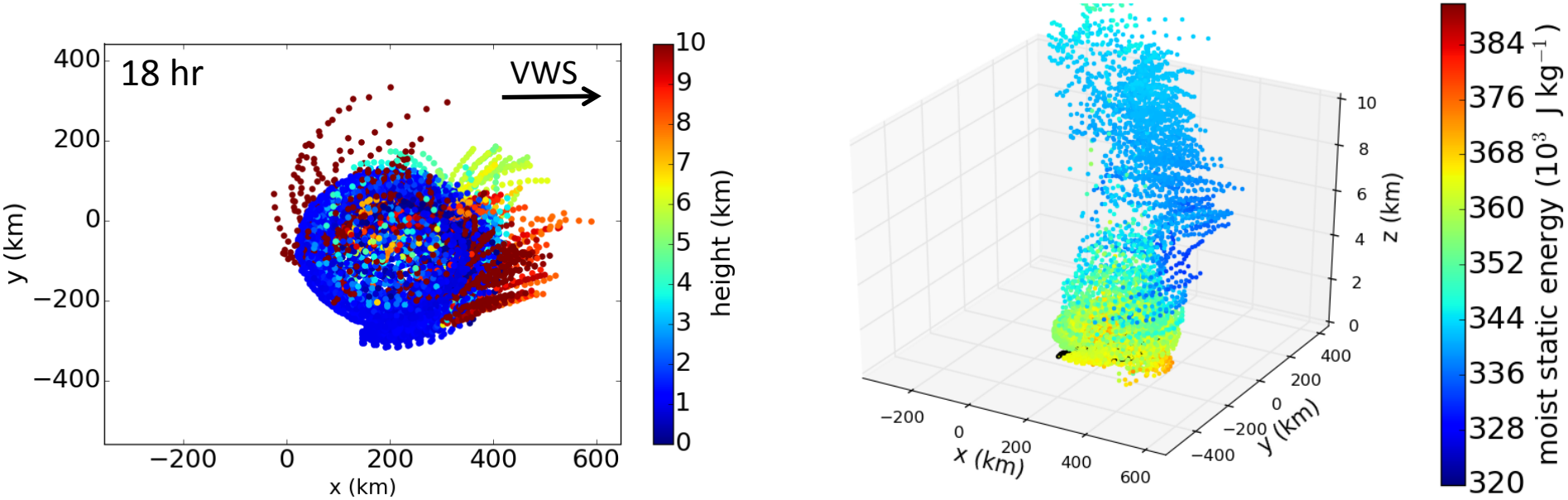
Less low-level ventilation



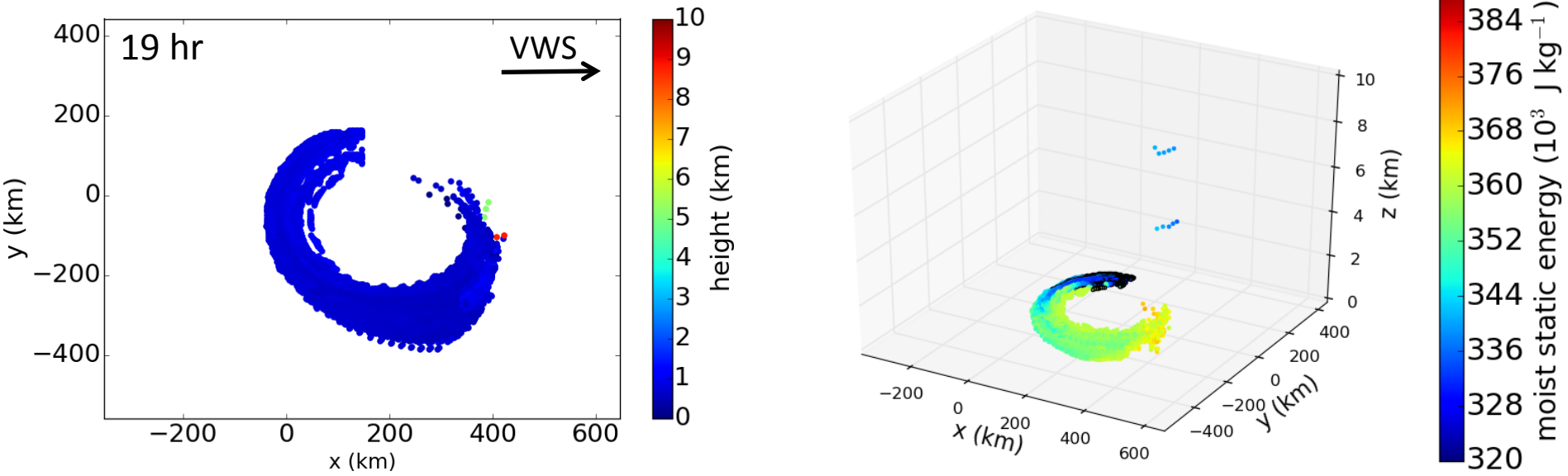
More low-level ventilation



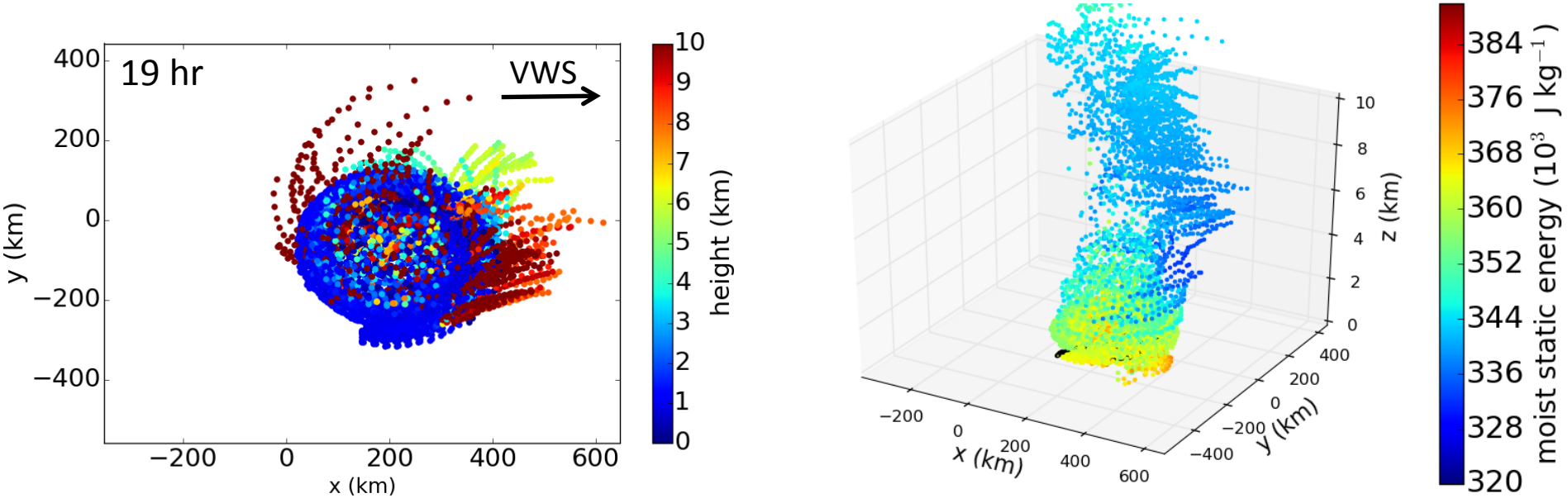
Less low-level ventilation



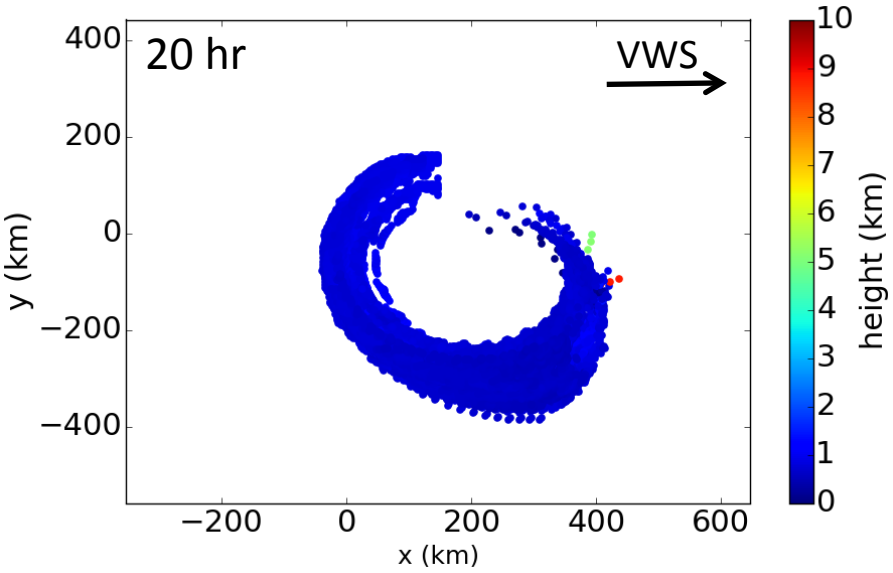
More low-level ventilation

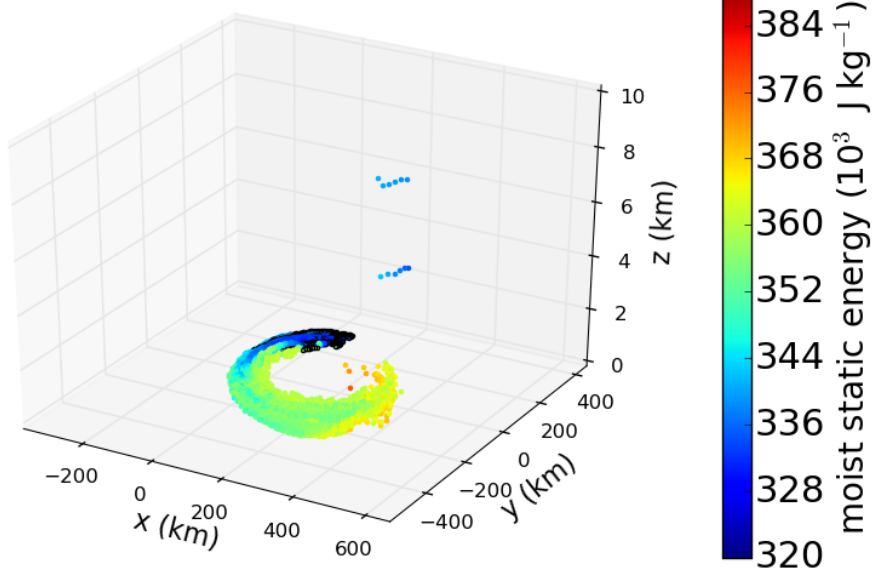


Less low-level ventilation

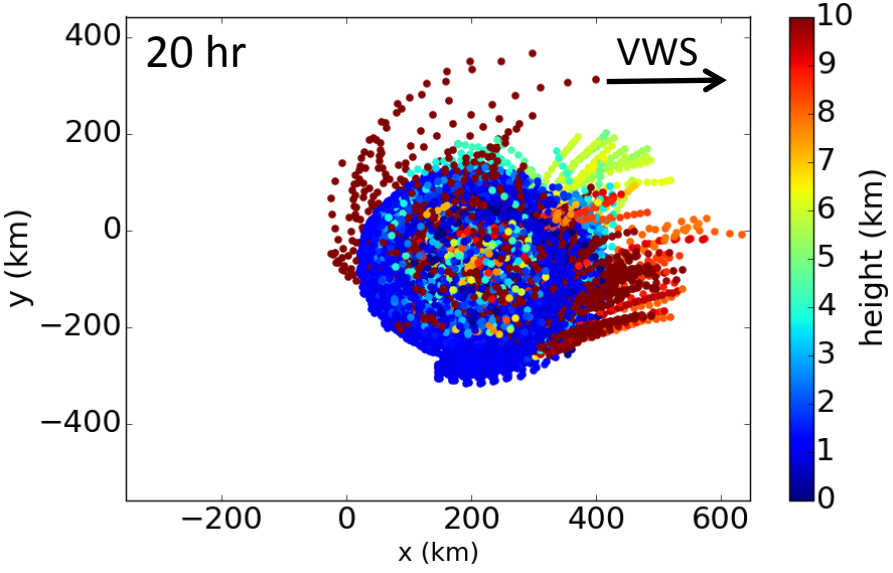


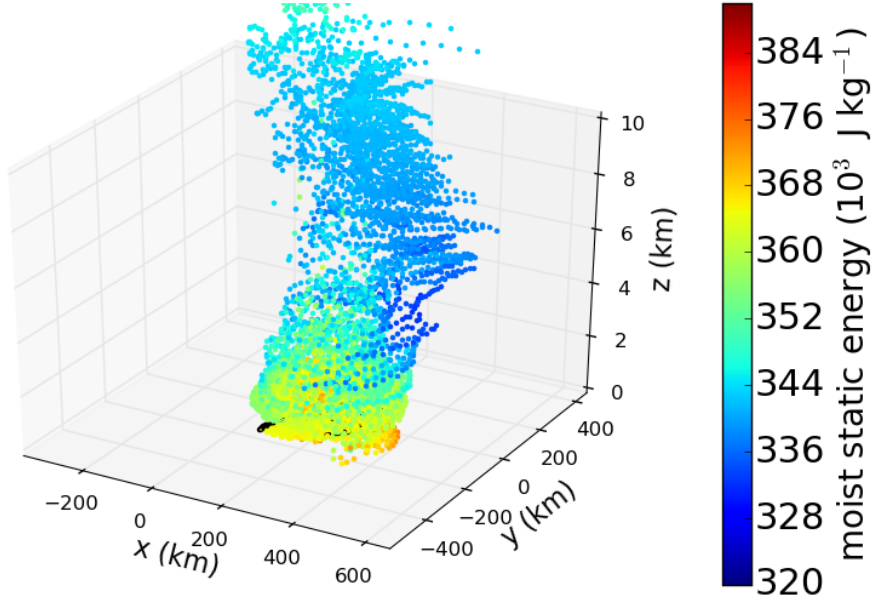
More low-level ventilation



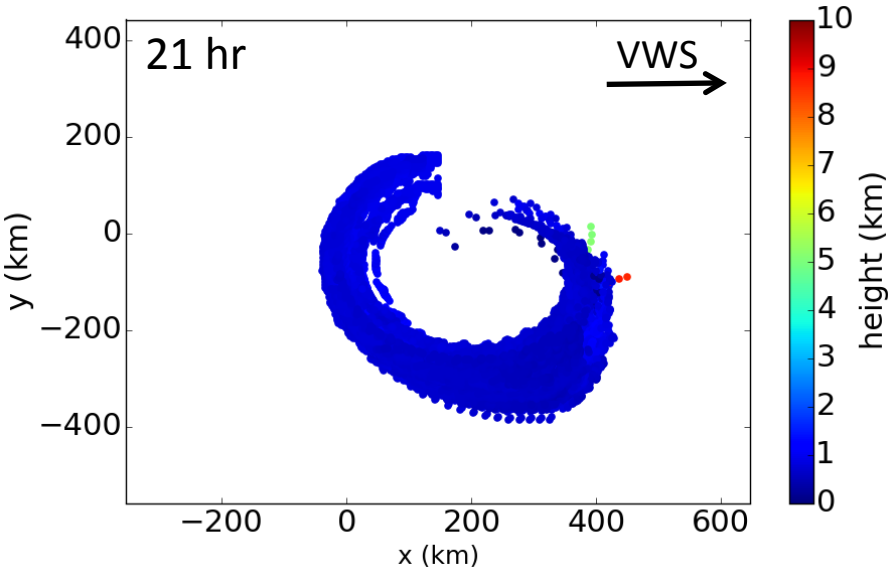


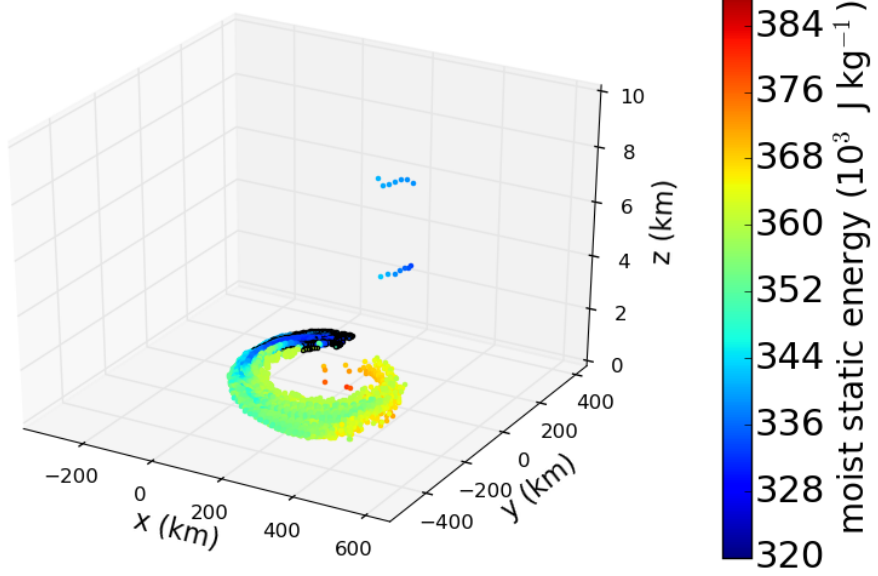
Less low-level ventilation



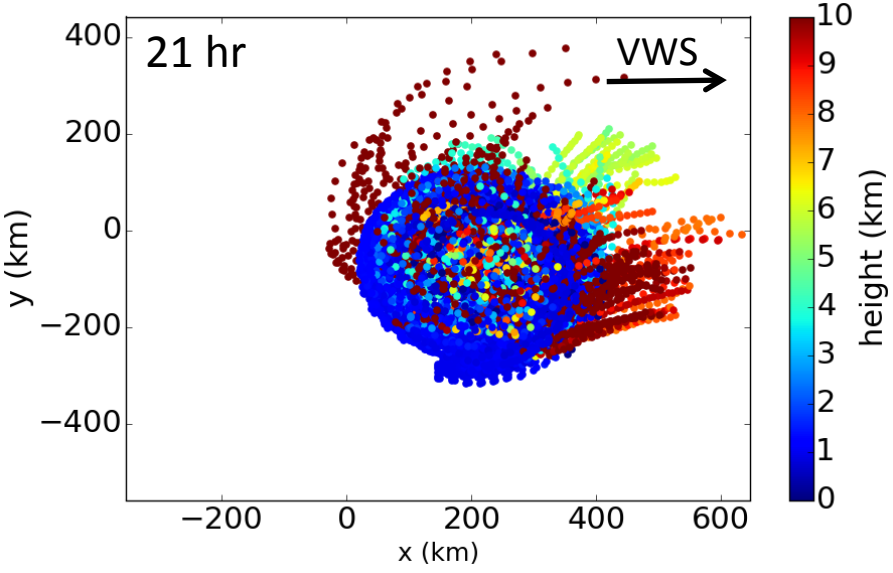


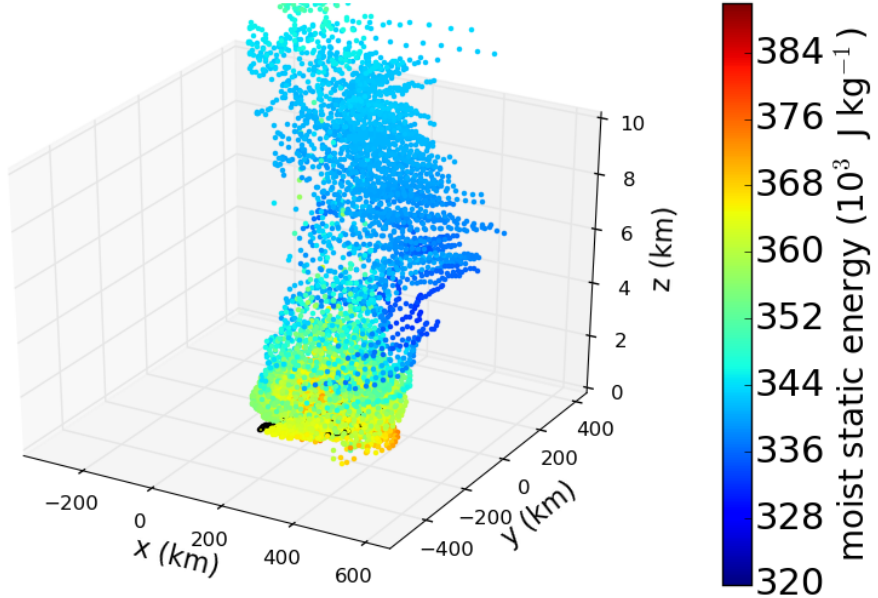
More low-level ventilation



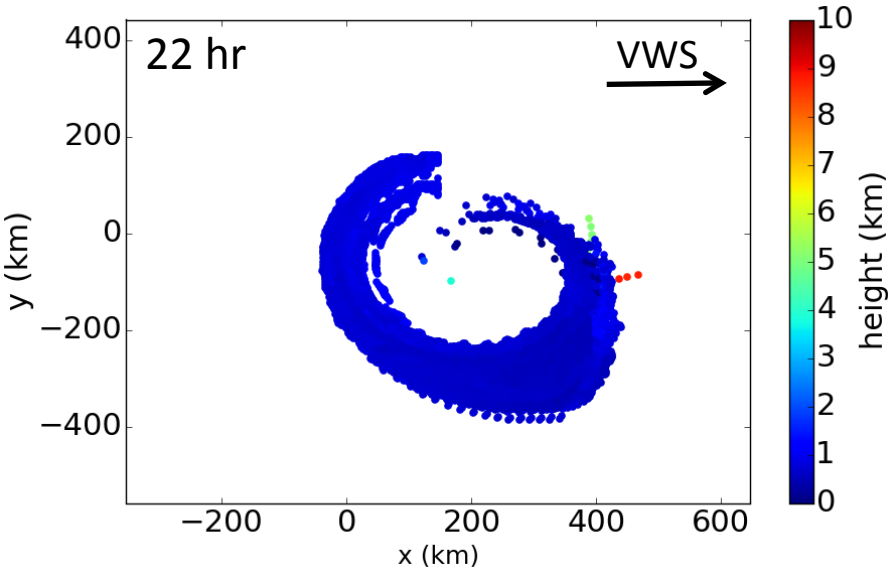


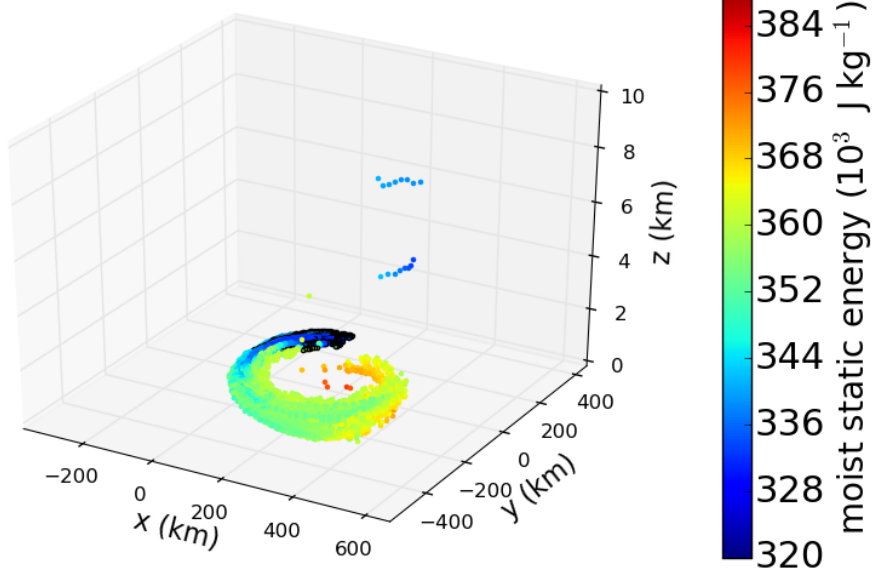
Less low-level ventilation



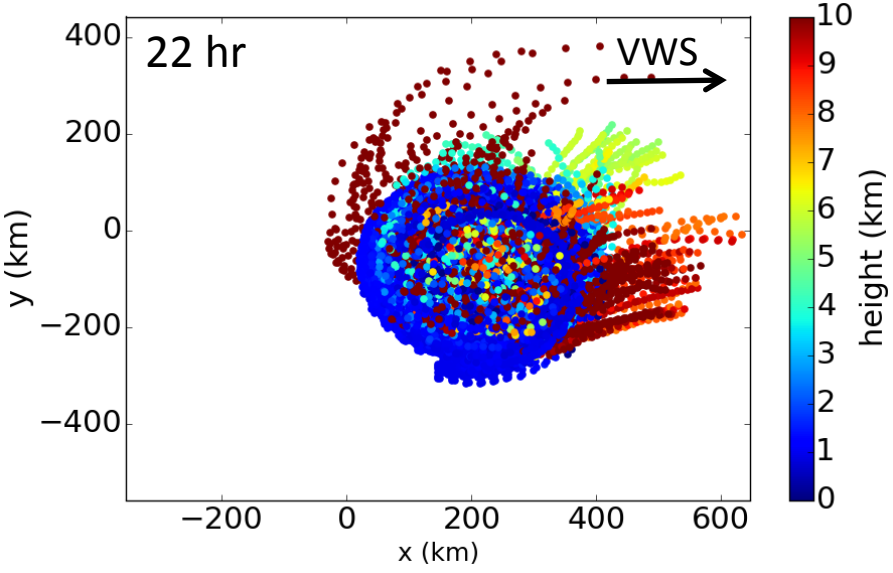


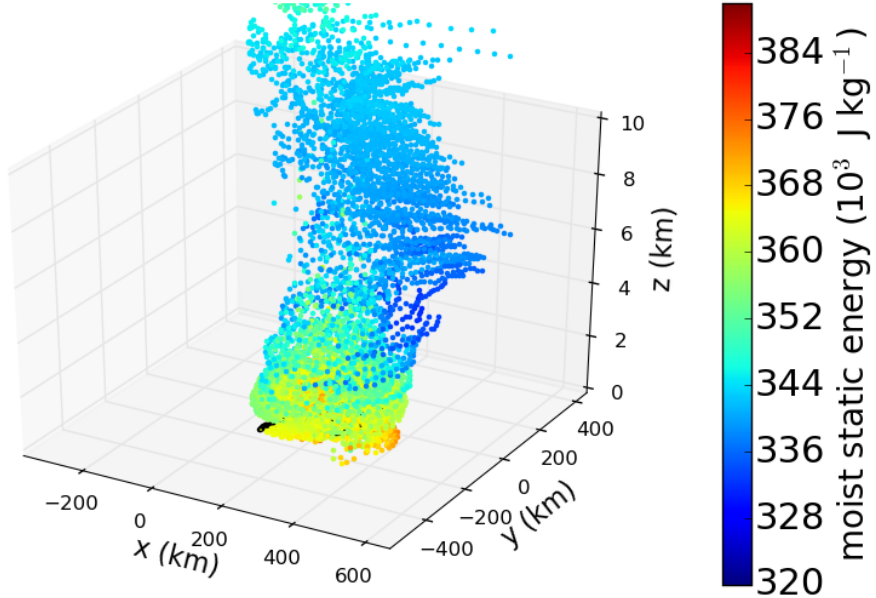
More low-level ventilation



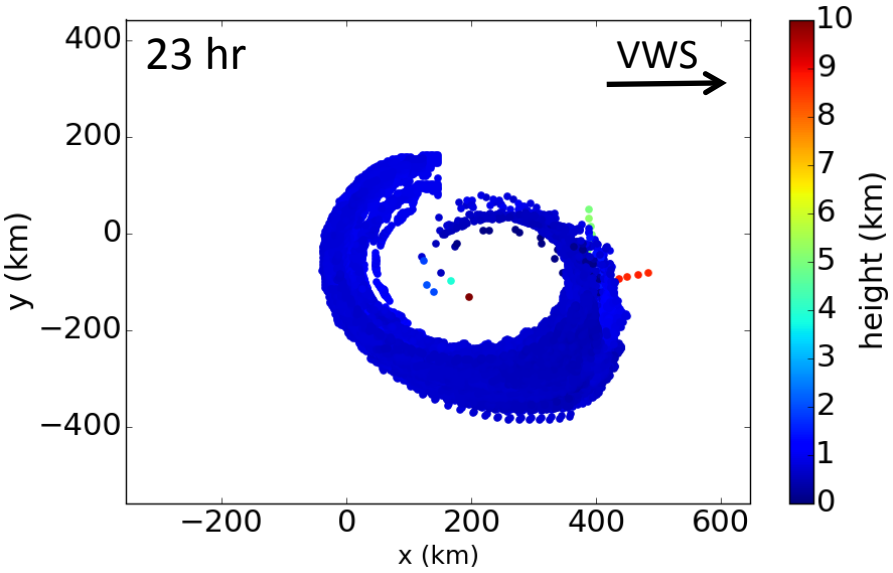


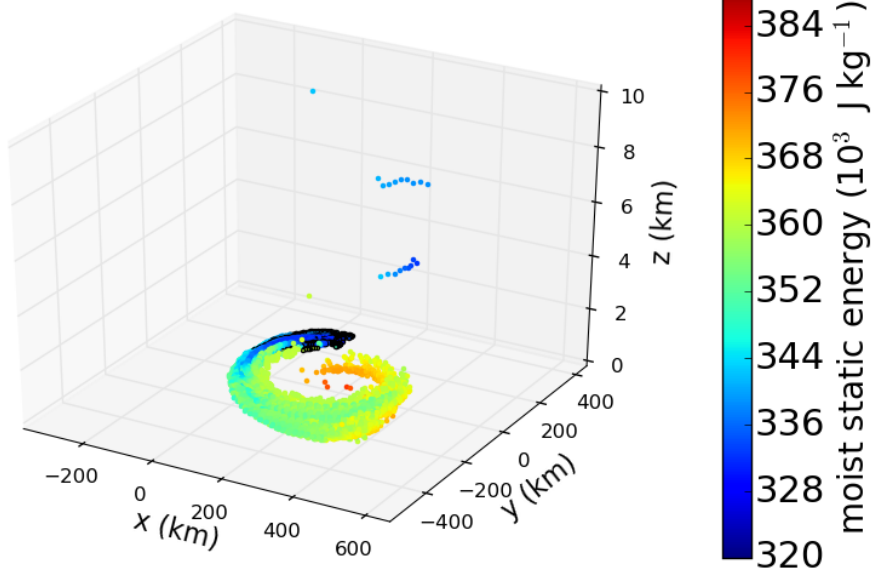
Less low-level ventilation



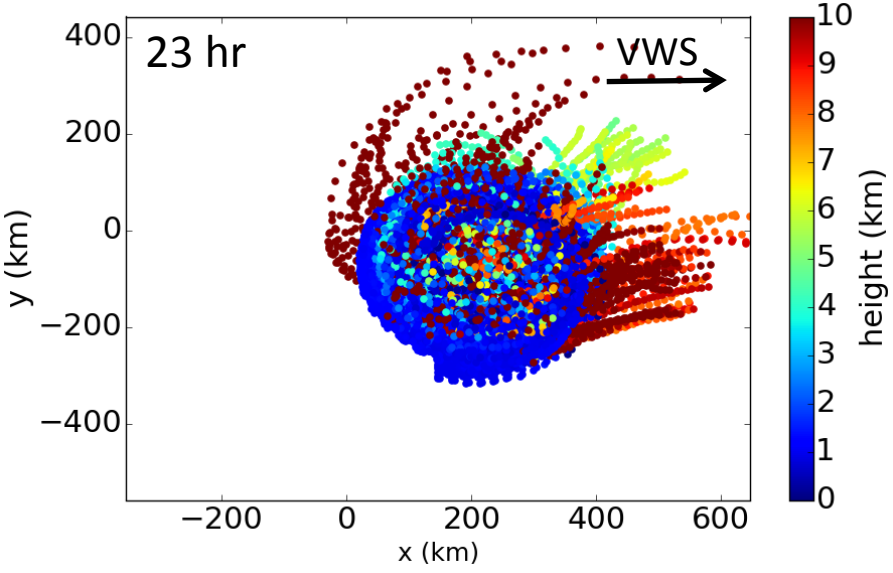


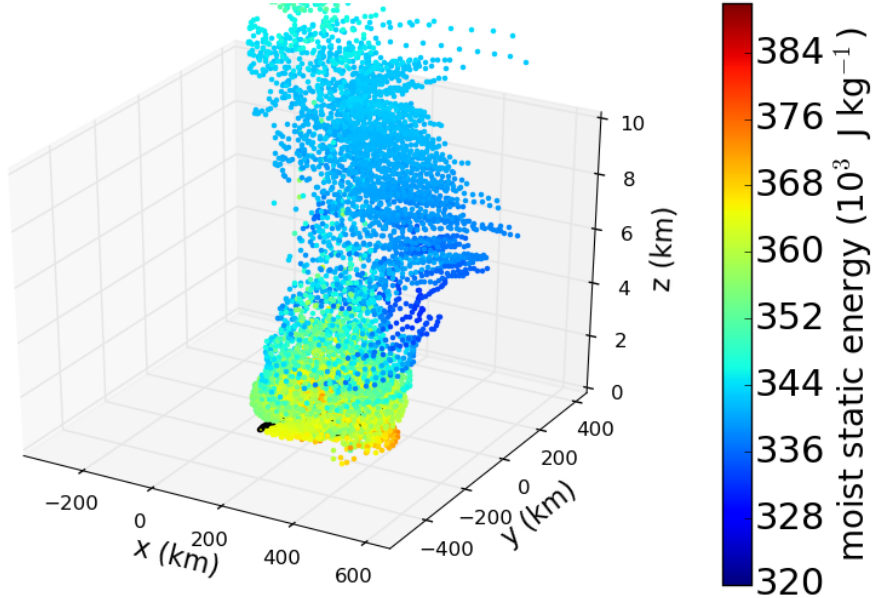
More low-level ventilation



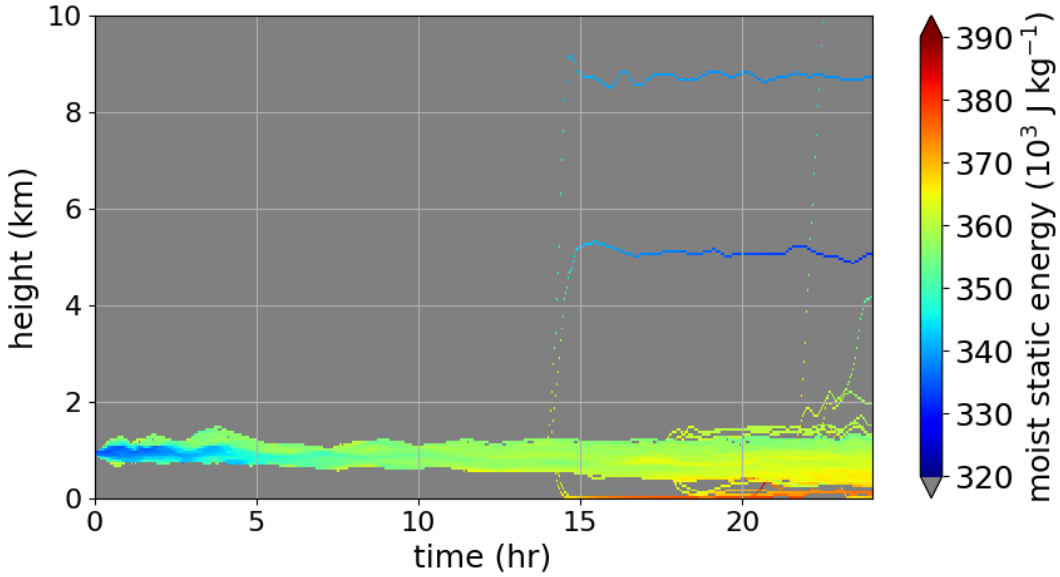


Less low-level ventilation

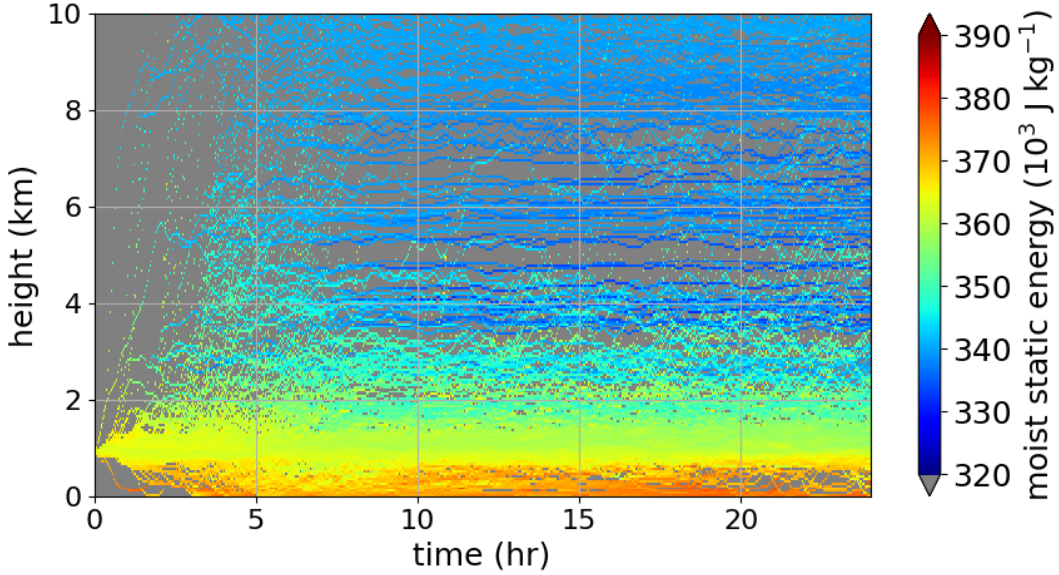




More low-level ventilation



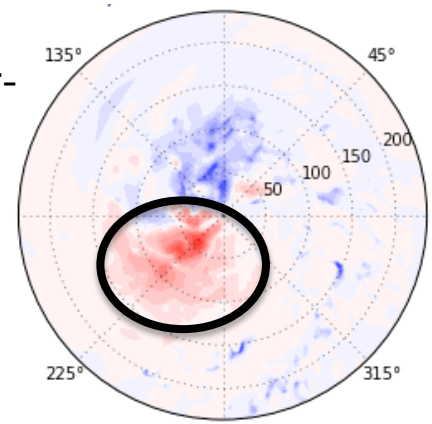
Less low-level ventilation



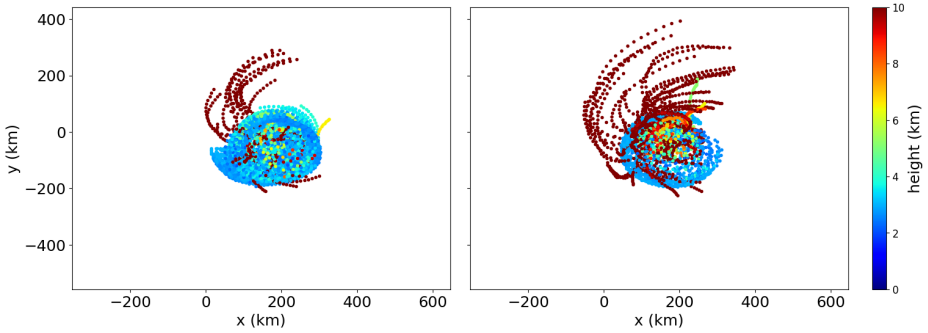
Conclusions

Spatial structure of mid-level ventilation

- Greater mid-level ventilation in upshear-right quadrant.
- Similar pattern across bivariate parameter space.

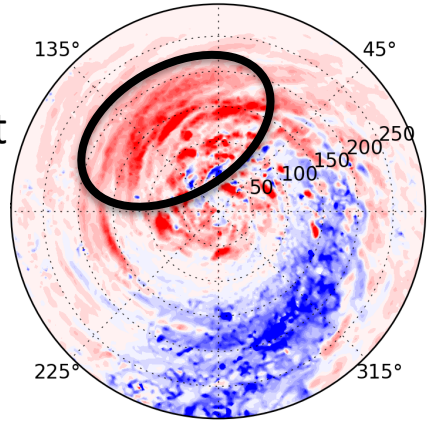


- **Impact on convection:** Reduces strength and height of upward motion.

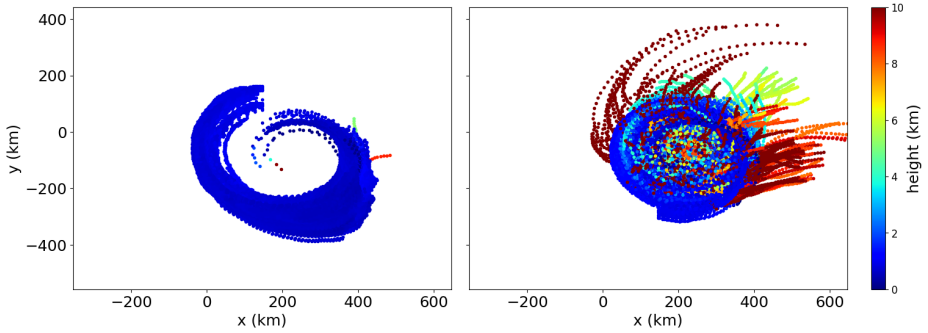


Spatial structure of low-level ventilation

- Greater low-level ventilation left of shear and upshear-left quadrant.
- Similar pattern across bivariate parameter space.



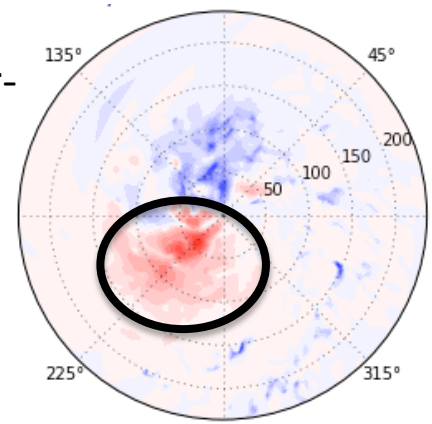
- **Impact on convection:** Longer recovery time and an inhibition of convection.



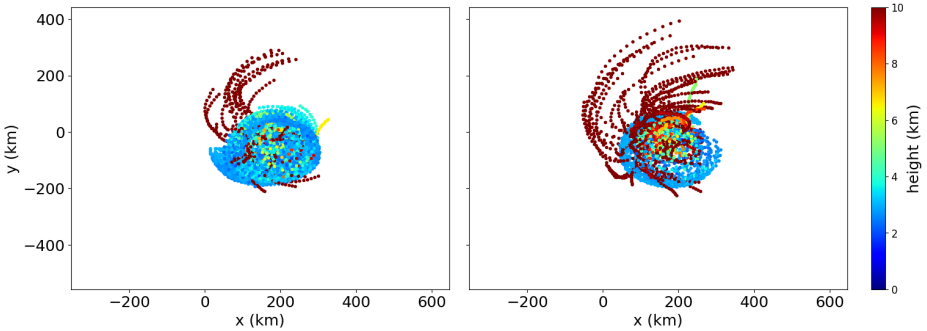
Conclusions

Spatial structure of mid-level ventilation

- Greater mid-level ventilation in upshear-right quadrant.
- Similar pattern across bivariate parameter space.

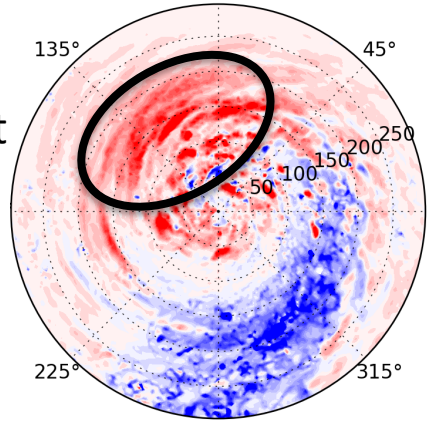


- **Impact on convection:** Reduces strength and height of upward motion.



Spatial structure of low-level ventilation

- Greater low-level ventilation left of shear and upshear-left quadrant.
- Similar pattern across bivariate parameter space.



- **Impact on convection:** Longer recovery time and an inhibition of convection.

Thank you to Dr. George Bryan for distributing CM1 and Dr. Michael Sprenger for distributing Lagranto.