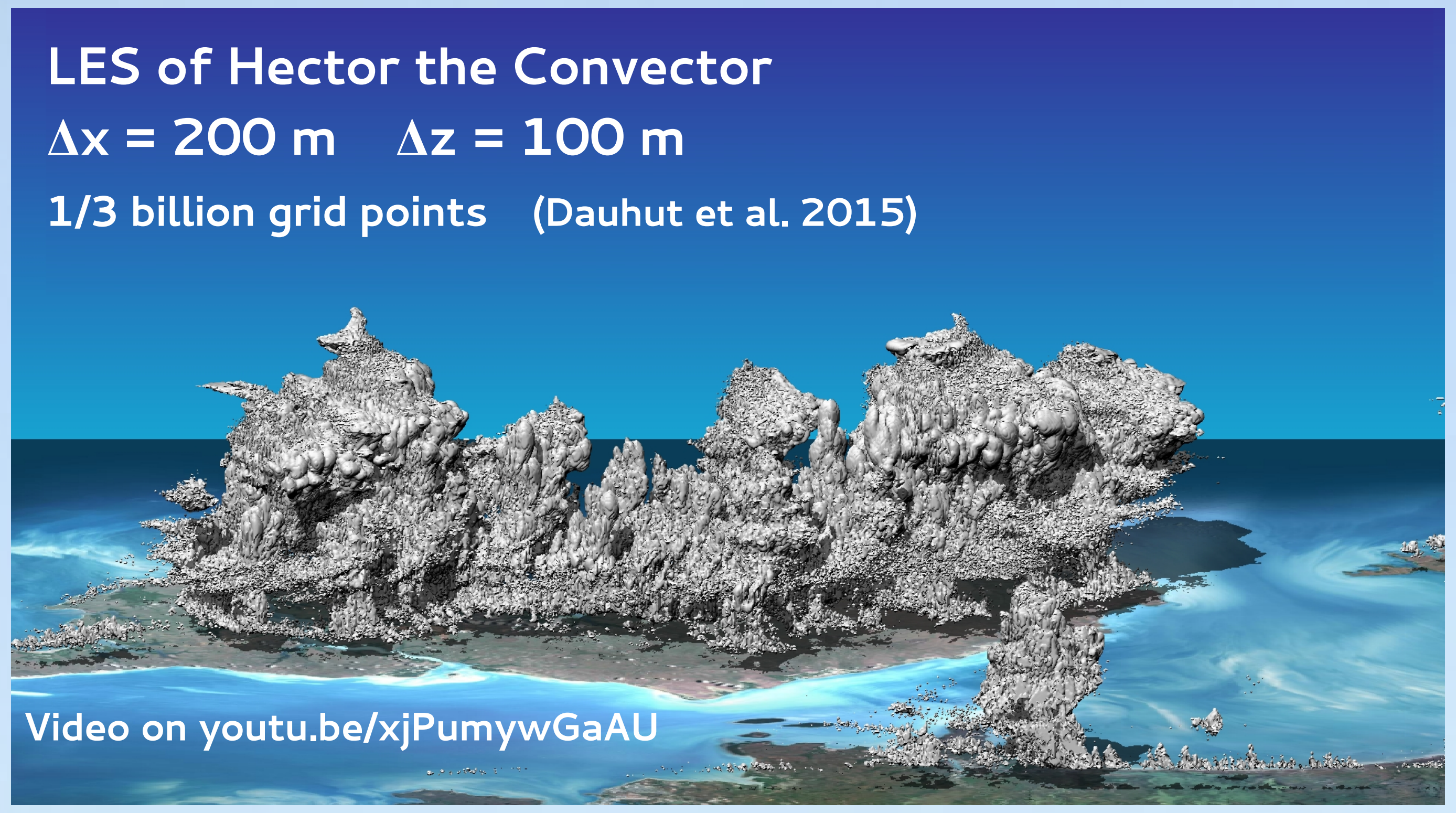
An isentropic perspective of the atmospheric overturning induced by Hector the Convector

Thibaut Dauhut[1], Jean-Pierre Chaboureau[1],
Patrick Mascart[1] and Olivier Pauluis[2]

[1] *Laboratoire d'Aérologie, Univ. de Toulouse, CNRS, UPS, France*
[2] *Courant Institute of Mathematical Sciences, New York University, New York, New York, and Center for Prototype Climate Modeling, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates*



LES of Hector the Convector
Δx = 200 m   Δz = 100 m
1/3 billion grid points   (Dauhut et al. 2015)

Video on youtu.be/xjPumywGaAU

Hector the Convector is a daily storm over the Tiwi Islands, Australia. On 30 November 2005, Hector reached 19 km altitude. Pockets of ice particles were observed above, in the stratosphere.

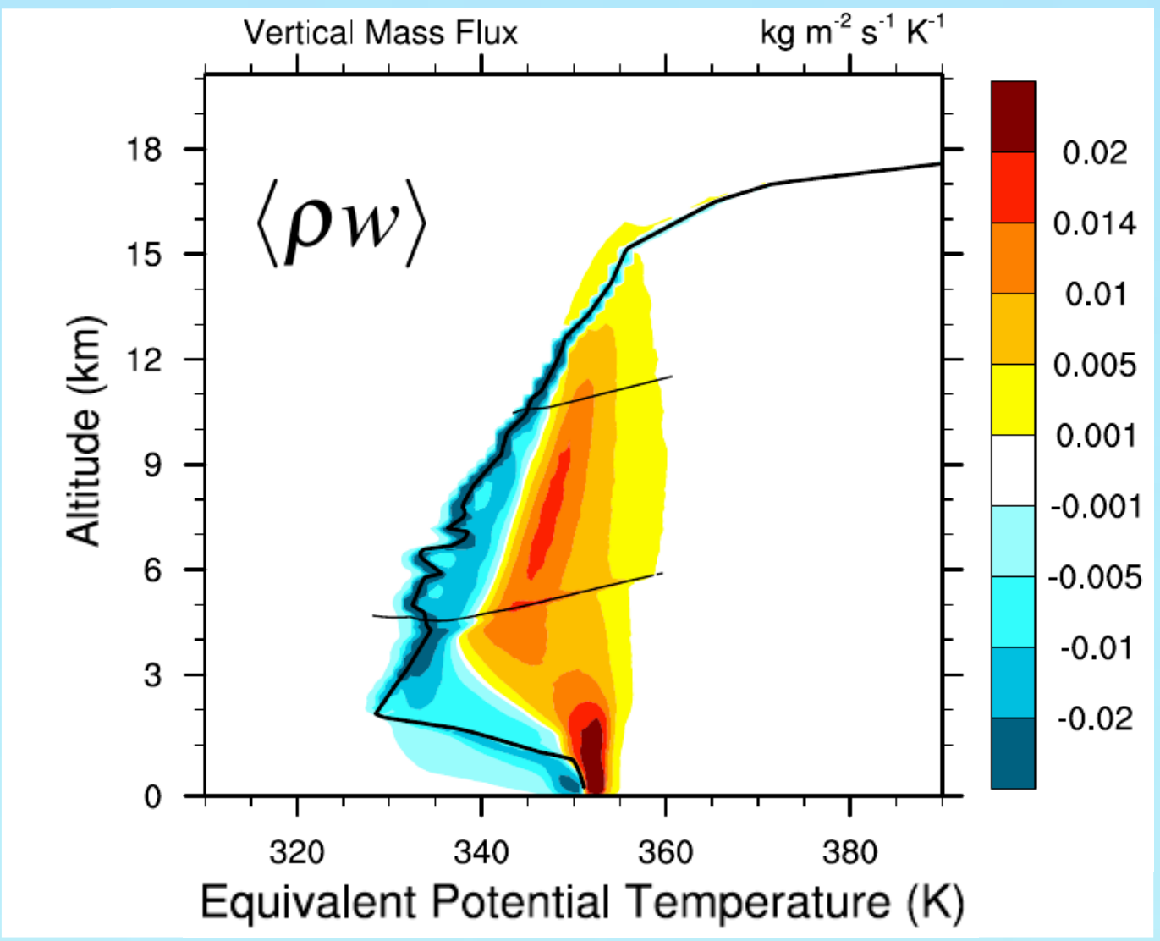
Three questions are addressed:

1. How does Hector transport air into the stratosphere?
2. What gives its strength to Hector?
3. How do microphysical processes provide energy?

0

The isentropic analysis gives an overview of the atmospheric overturning and allows to quantify the irreversible vertical transport by:

- filtering out the reversible motions like gravity waves
- taking into account the transport due to weak motions like turbulent eddies.



The technique consists in reducing the four spatio-temporal coordinates into two
(x,y,z,t) → (z, θe)

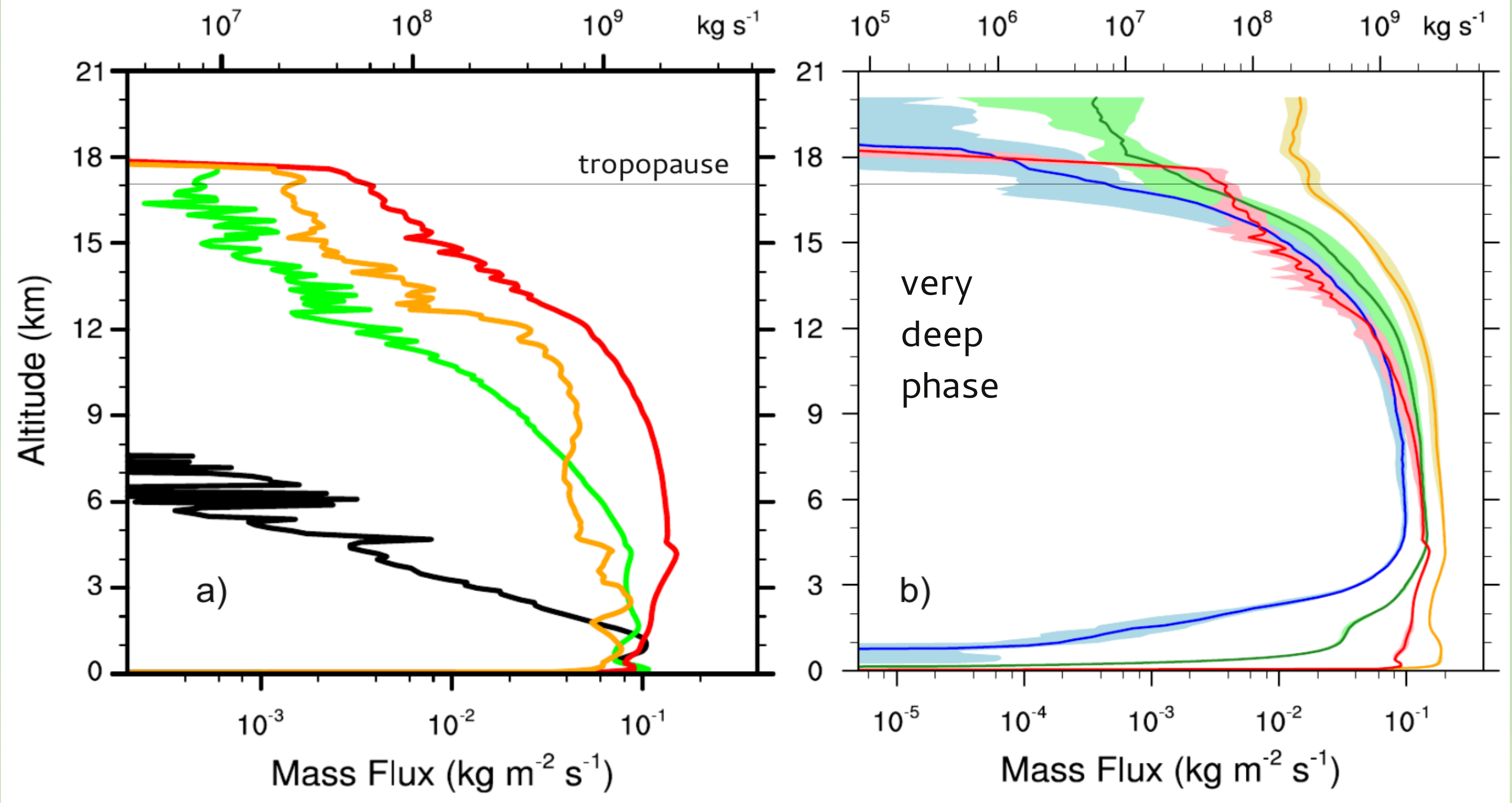
$$\langle \rho w\rangle(\theta_{e0},z_0) = \frac{1}{P L_x L_y}\int_0^P\int_0^{L_x}\int_0^{L_y} \rho w(x,y,z_0,t)\,\delta[\theta_{e0}-\theta_e(x,y,z_0,t)]\,dy\,dx\,dt$$

- Gravity waves are filtered out by average.
- All transport is considered in absence of threshold.

1

Intense transport across the tropopause during 1h only (the very deep convection phase)

In contrast with Eulerian computations, isentropic analysis is not sensitive to any threshold.

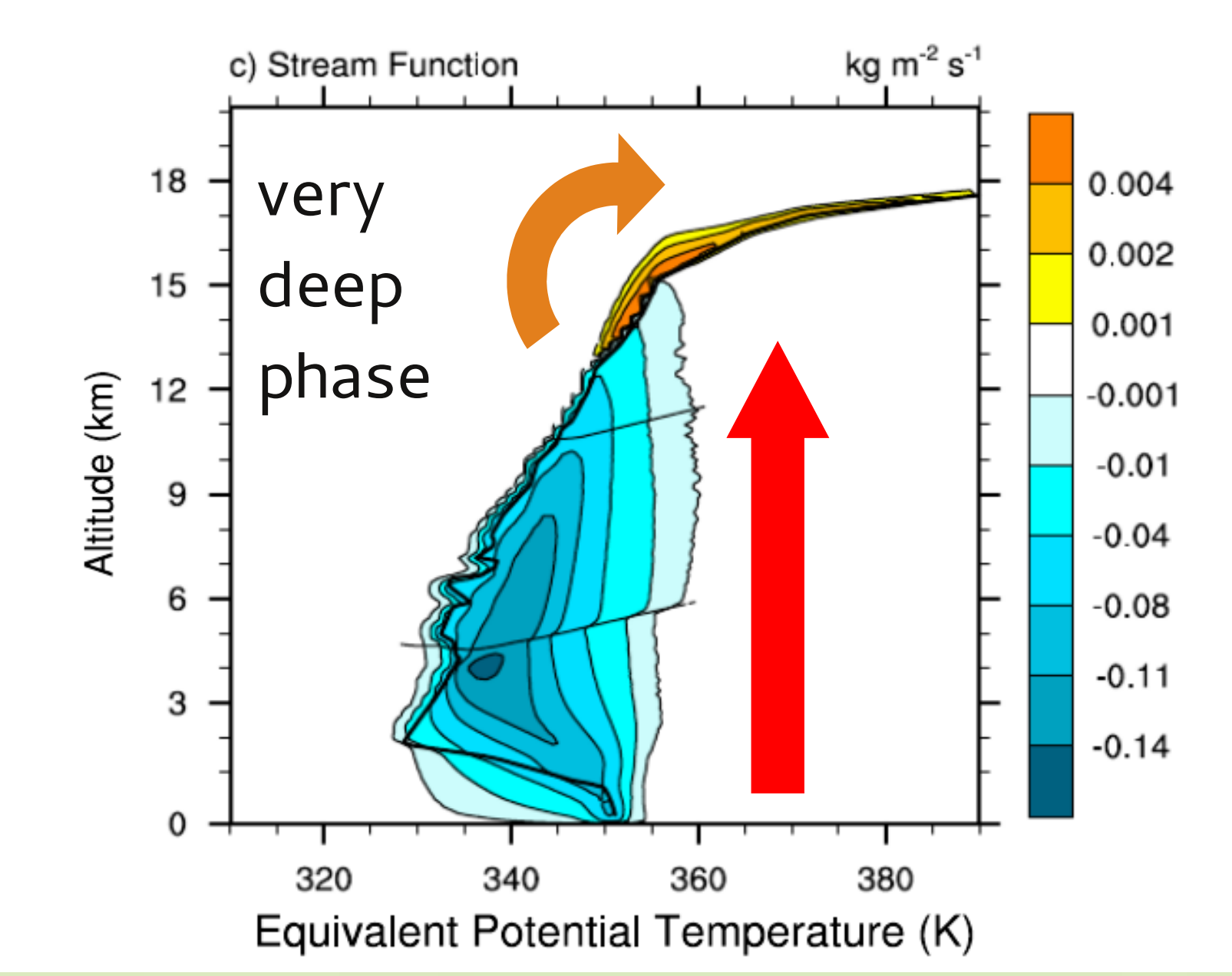


a) Four phases of convection are defined

▬ Congestus from 11:15 to 12:15
▬ Deep from 12:15 to 13:15
▬ Very deep from 13:15 to 14:15
▬ Mature from 14:15 to 15:15

b) Comparison of transport computations

▬ with isentropic analysis
▬ in upward motions > 1 m/s
▬ in upward motions > 5 m/s
▬ in upward motions > 10 m/s



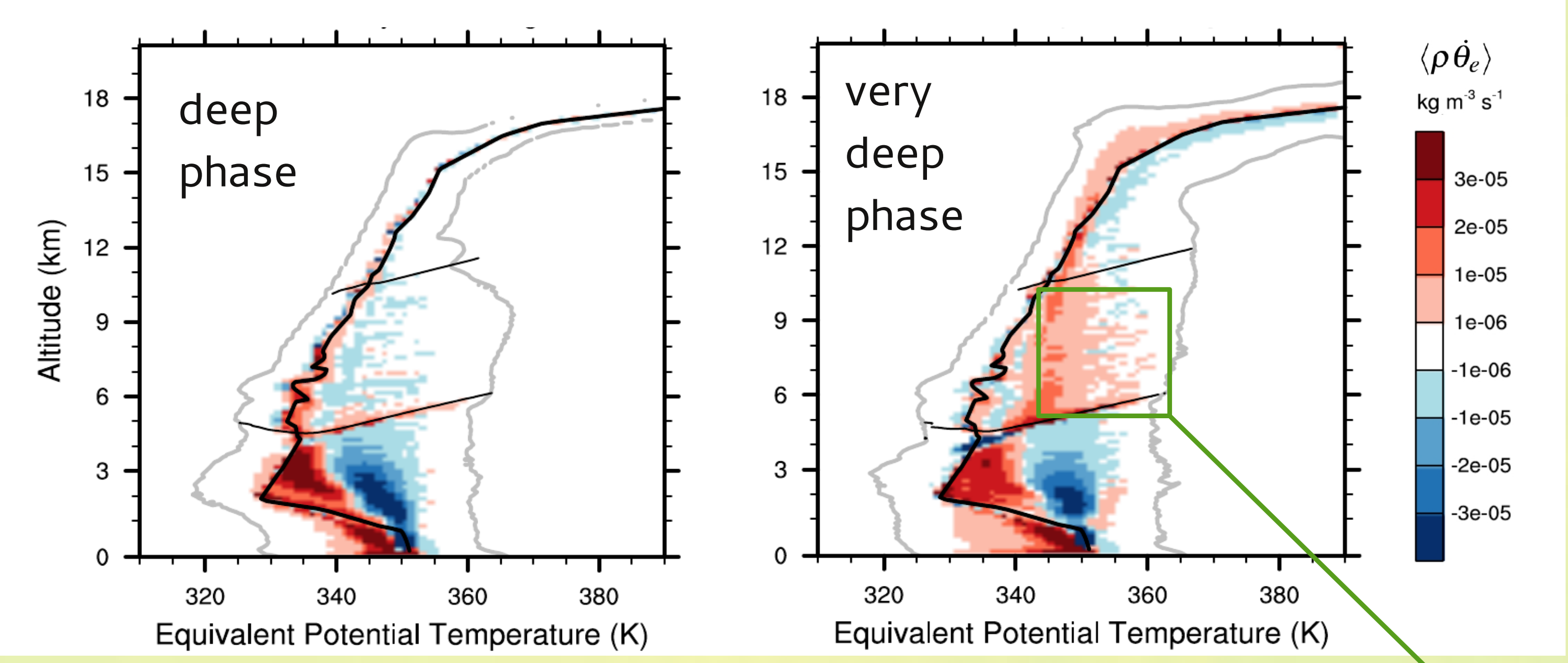
The transport is organised into two overturning cells:

- a tropospheric cell, with an ascending branch into the TTL of ~ 0.1 kg/m²/s where θe is large and conserved along the altitude

- an overshooting cell, crossing the tropopause with an intensity 30 times lower than the tropospheric cell.

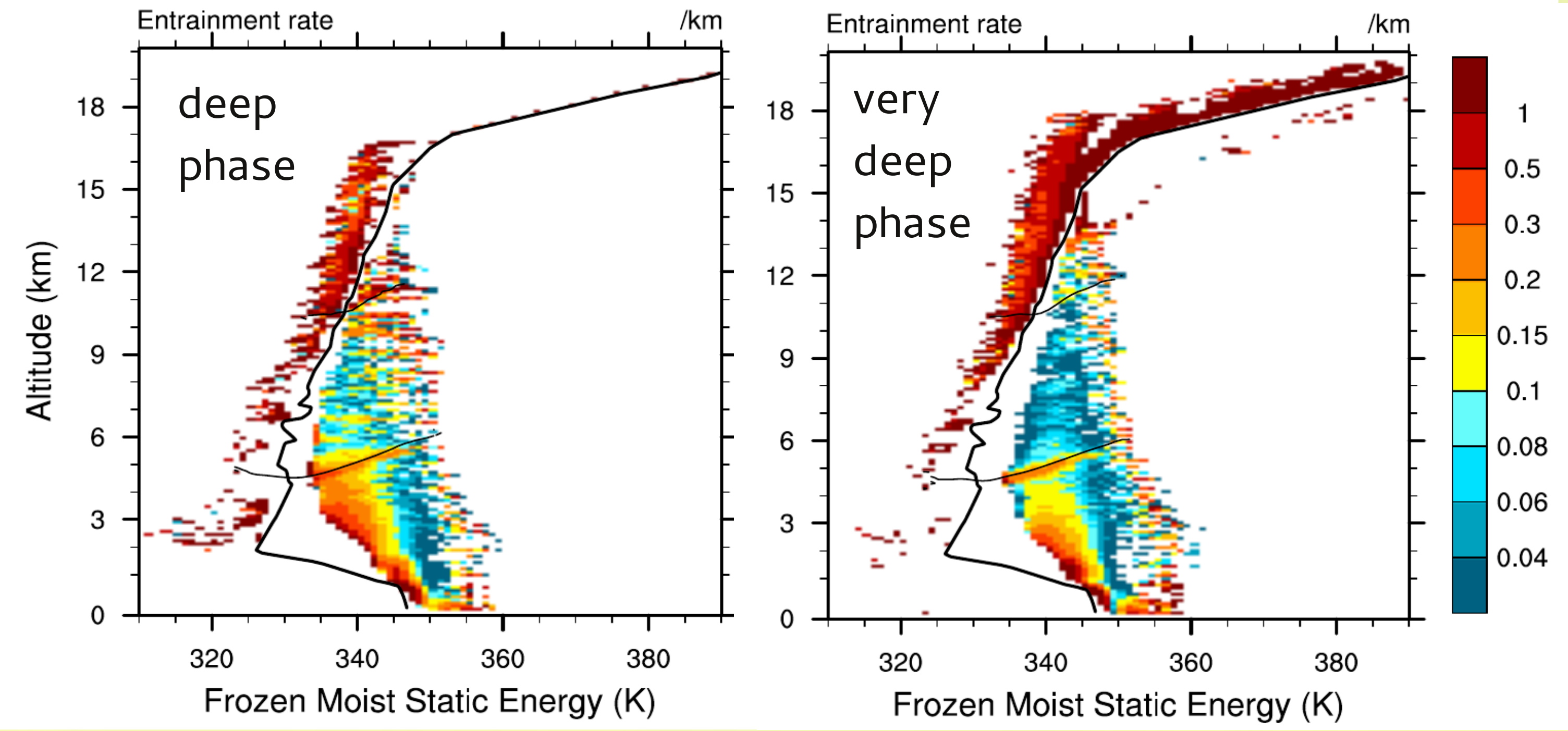
2

The strength of Hector is due to large latent heat release...



Large positive diabatic tendencies characterise the very deep convection phase, in contrast with the deep convection phase.

...and to very weak dilution of the ascending branch.



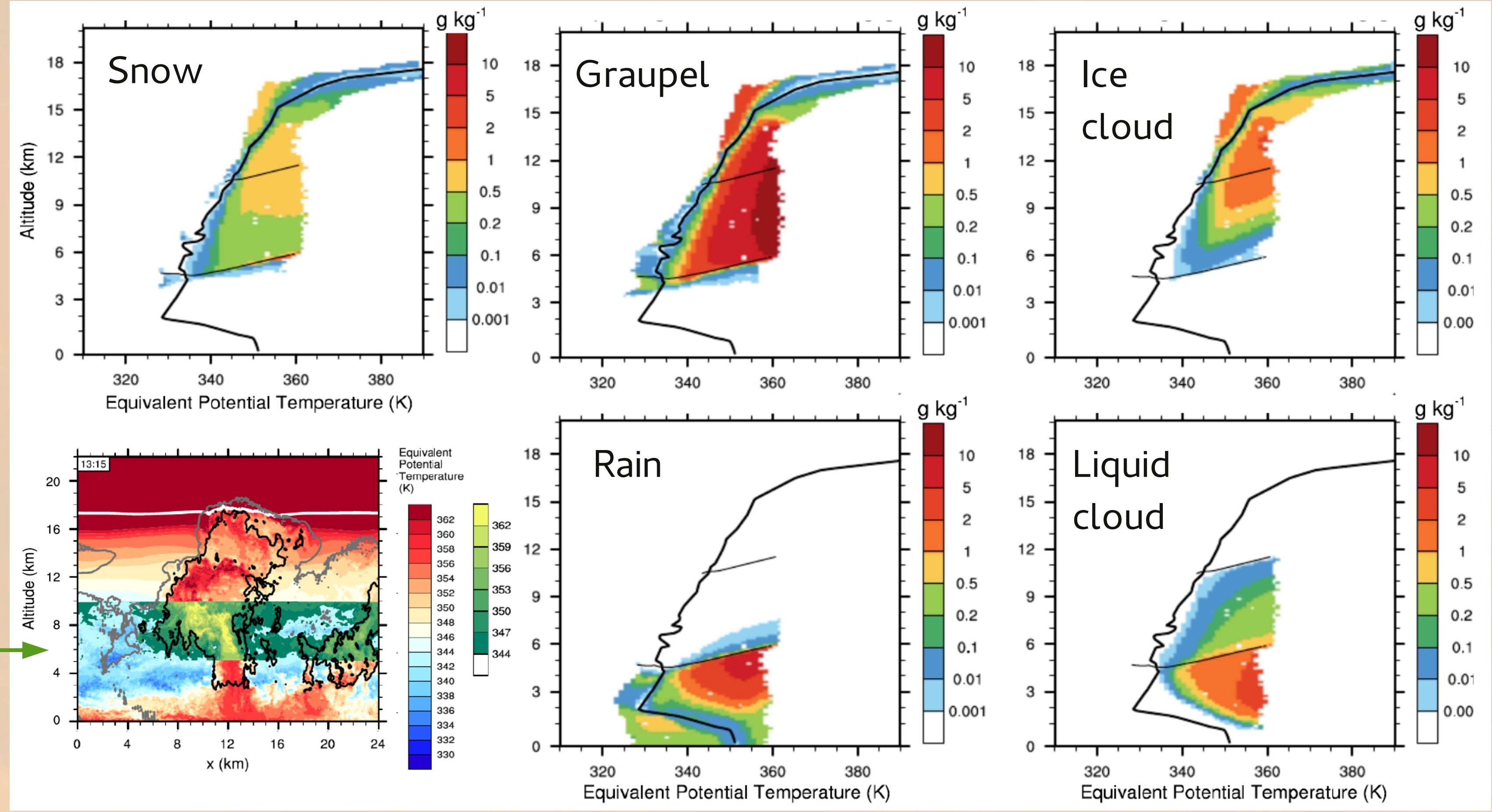
Entrainment rate is minimal during the very deep convection phase, as low as 0.04 /km for many energetic air parcels.

Dauhut et al. 2017: The atmospheric overturning induced by Hector the Convector, J. Atmos. Sci, under review.
Dauhut et al. 2016: Giga-LES of Hector the Convector and its two tallest updrafts up to the stratosphere, J. Atmos. Sci, 73, 5041-5060.
Dauhut et al. 2015: Large-Eddy Simulations of Hector the Convector that make the stratosphere wetter, Atmos. Sci. Lett, 16, 135–140.

3

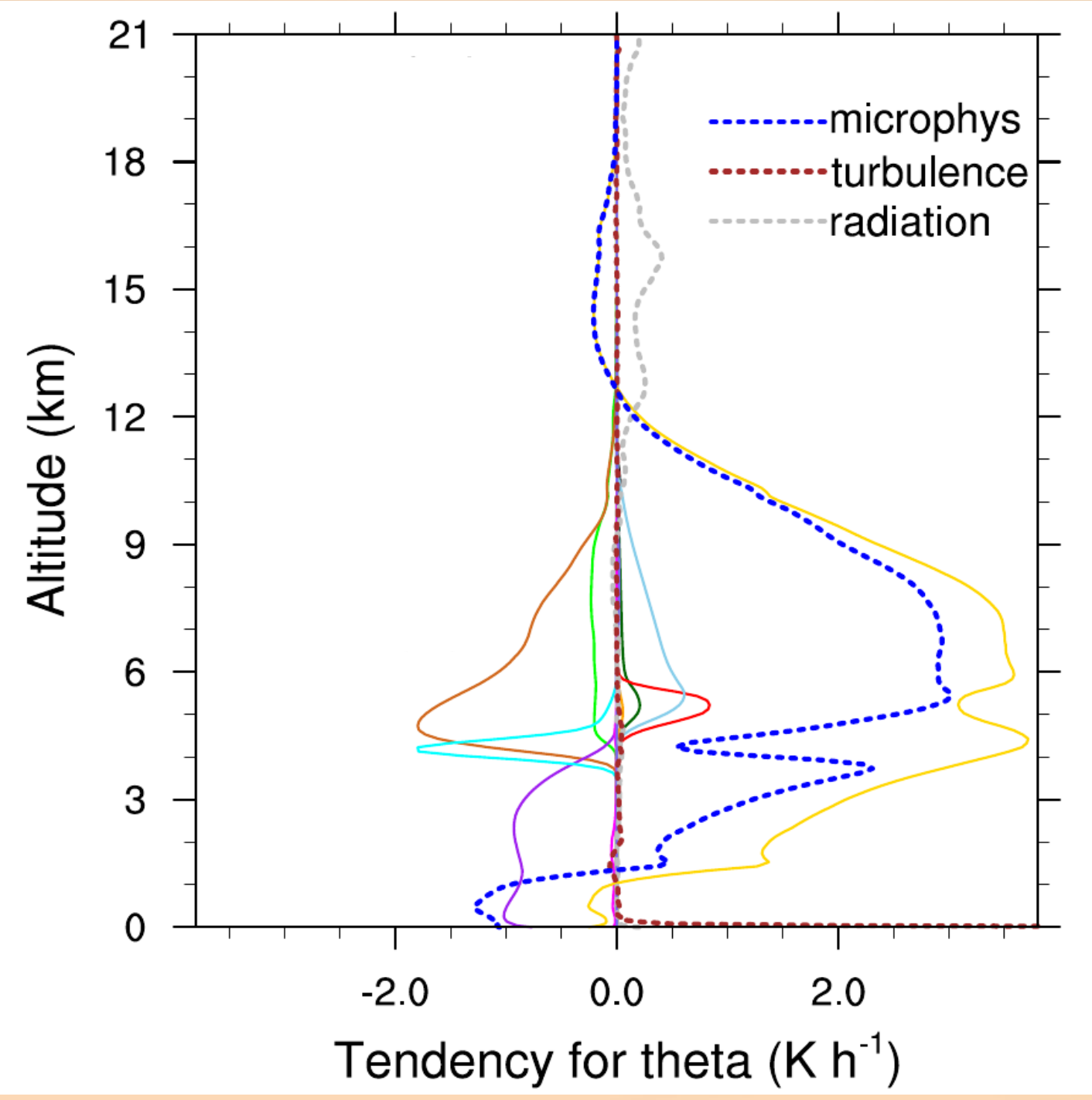
Intense ice formation in the ascending branch...

very deep phase



The ascending branch corresponds to the strong updrafts where w > 10 m/s.
The mixing rates of icy hydrometeors are large, especially for graupel.

..mainly due to vapour deposition on icy hydrometeors.



In only-ice cloud (above 12 km)
Balance between the positive radiative tendency and the negative tendency due to ice sublimation (both ~0.5 K/h).

In mix-phase cloud and warm cloud
▬ condensation and deposition of vapour dominates the positive tendency (up to 3 K/h) due to microphysics.

▬ Bergeron-Findeisen
▬ Ice cloud melting
▬ Graupel melting
▬ Graupel dry growth
▬ Graupel wet growth

▬ Rain accretion
▬ Liq cloud rimming
▬ Rain evaporation
▬ Graupel sublimation
▬ Snow sublimation