Isentropic analysis applied to hurricane circulation

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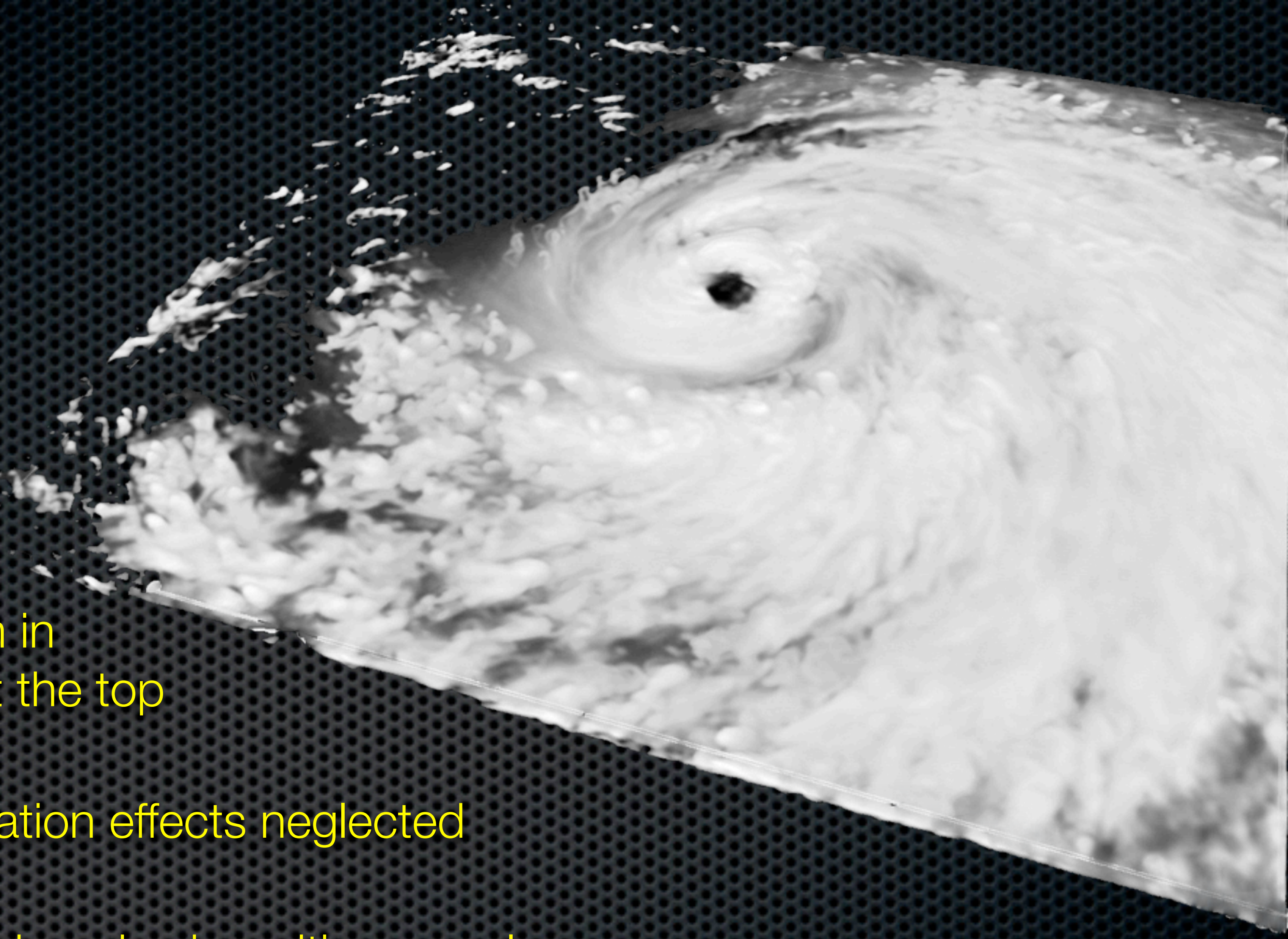
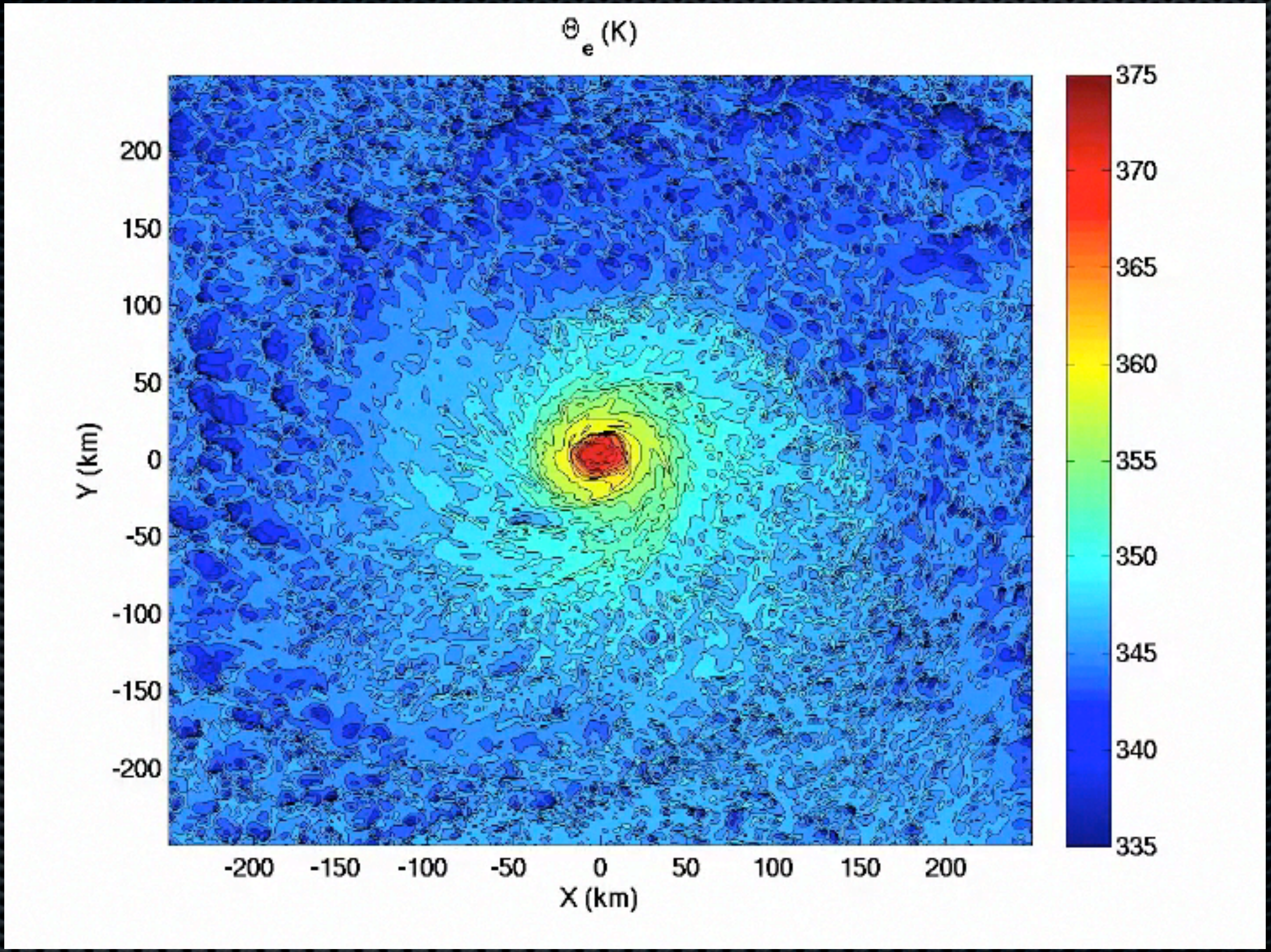
WRF 2.2 Simulation:

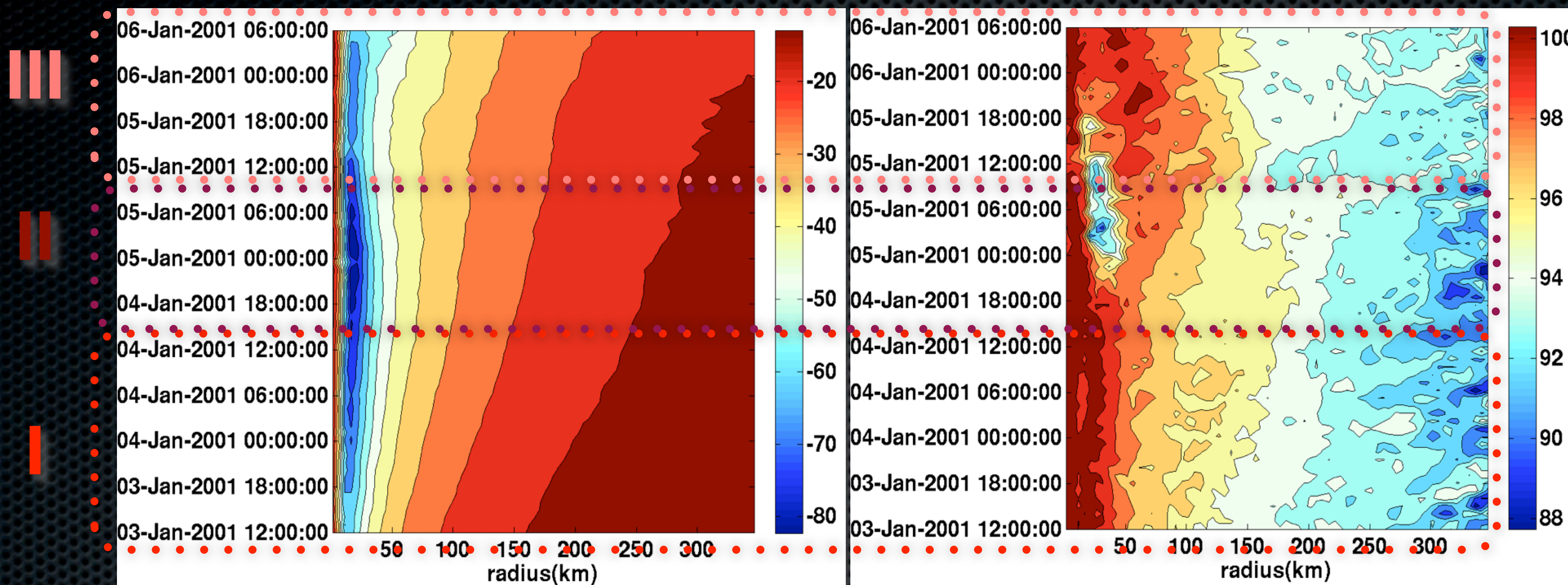


- domain 1000 km x 1000 km
- horizontal resolution 1km
- 35 levels stretched from 0.6 km in
  the boundary layer to 3.6 km at the top
- long-wave and short-wave radiation effects neglected
- WRF Single-Moment, 6-class microphysics with graupel
- Yonsei University turbulent fluxes scheme
- initialized with an axisymmetric vortex at 20 N with an initial radius of 102 km and tangential wind v_t = 16 m/s
- the temperature and humidity profiles following Jordan(1958) soundings

surface equivalent potential temperature



tangential wind — relative humidity



I - intensification

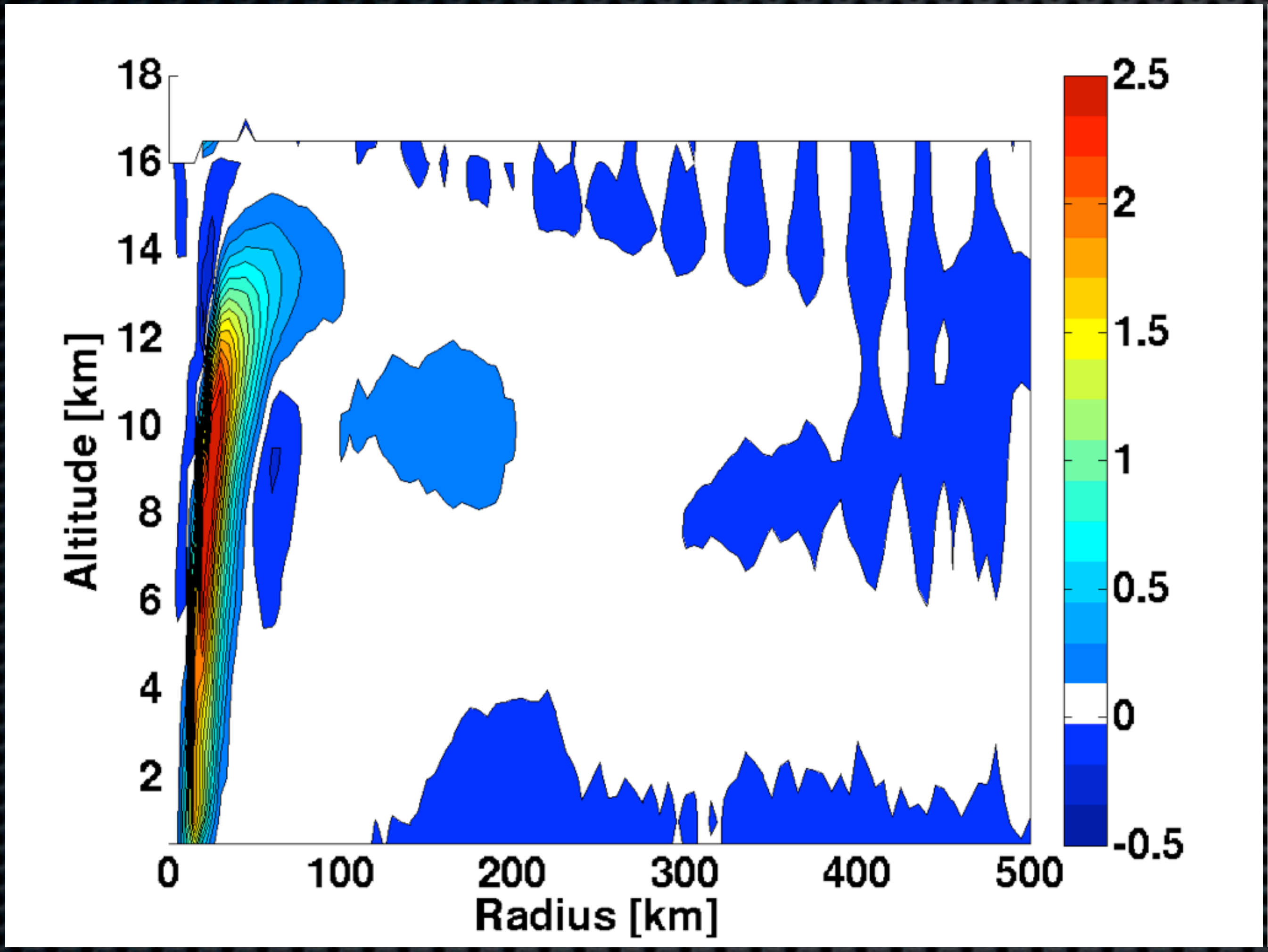
II - peak intensity

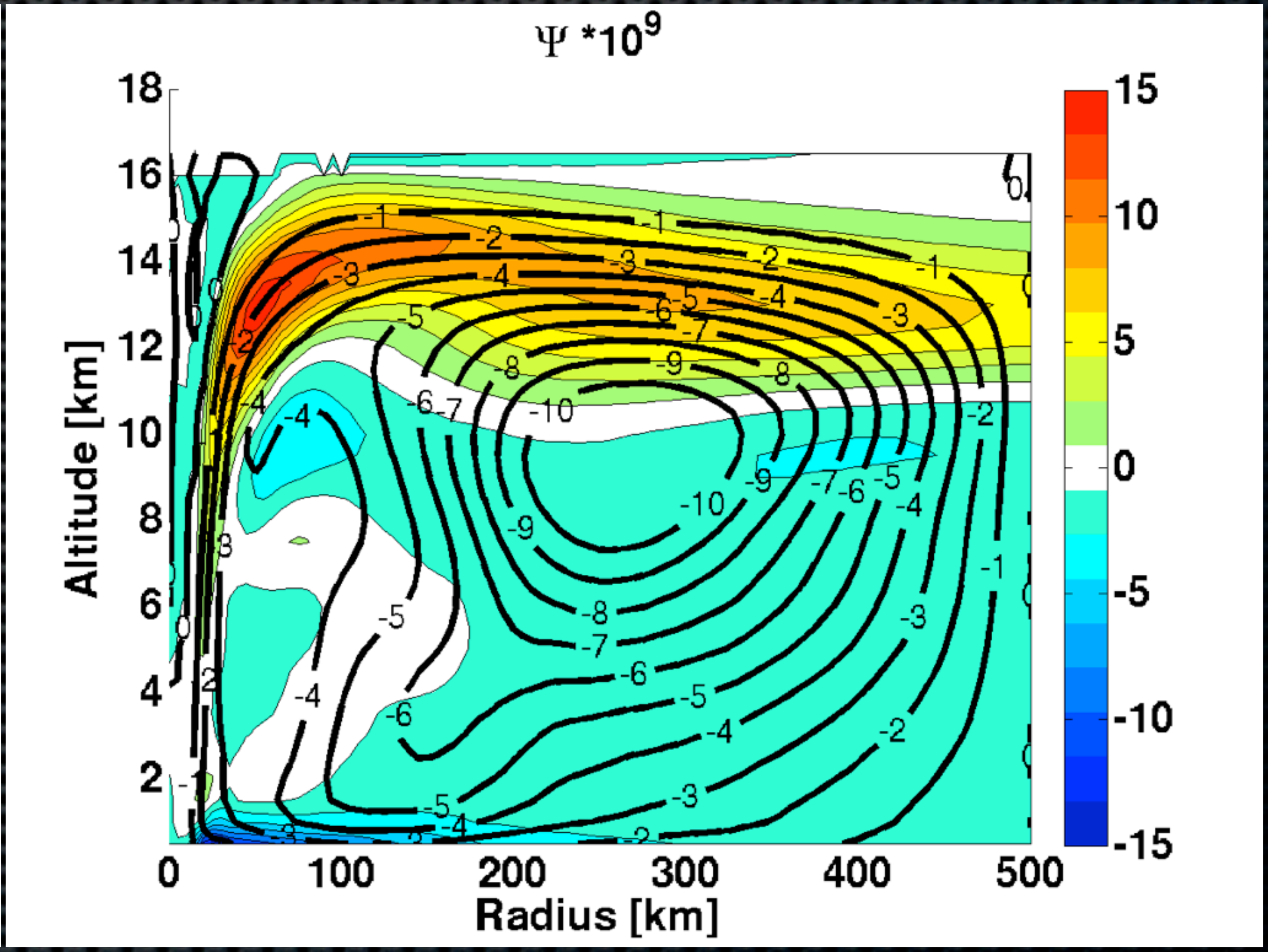
III - weakening

secondary circulation

vertical velocity

radial velocity
&
euerian streamfunction

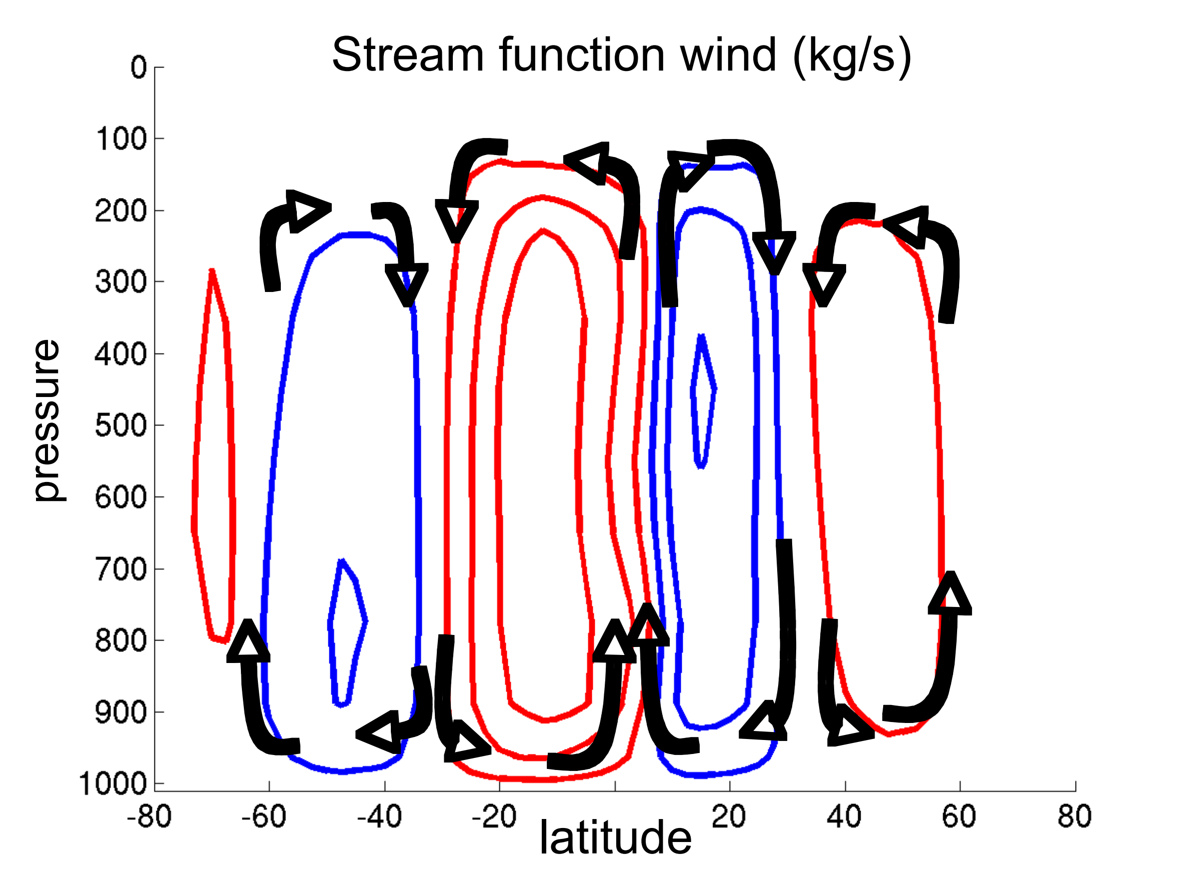




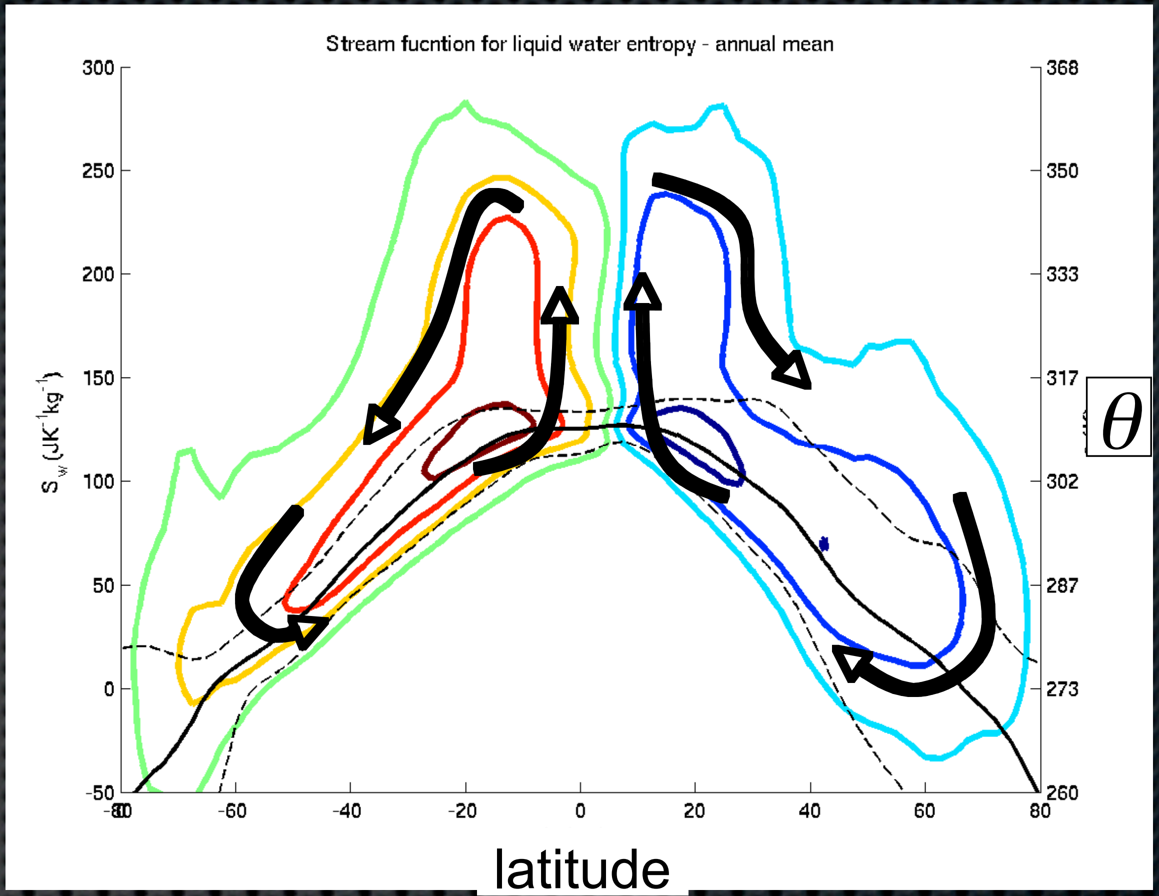
isentropic circulation

- the concept of analyzing motions on surfaces of constant entropy dates back to the early days of dynamical meteorology (Rossby 1937)
- entropy (or equivalent potential temperature) is conserved for reversible adiabatic processes and allows to track parcels even if they experience significant vertical displacement

eulerian-mean circulation



isentropic circulation



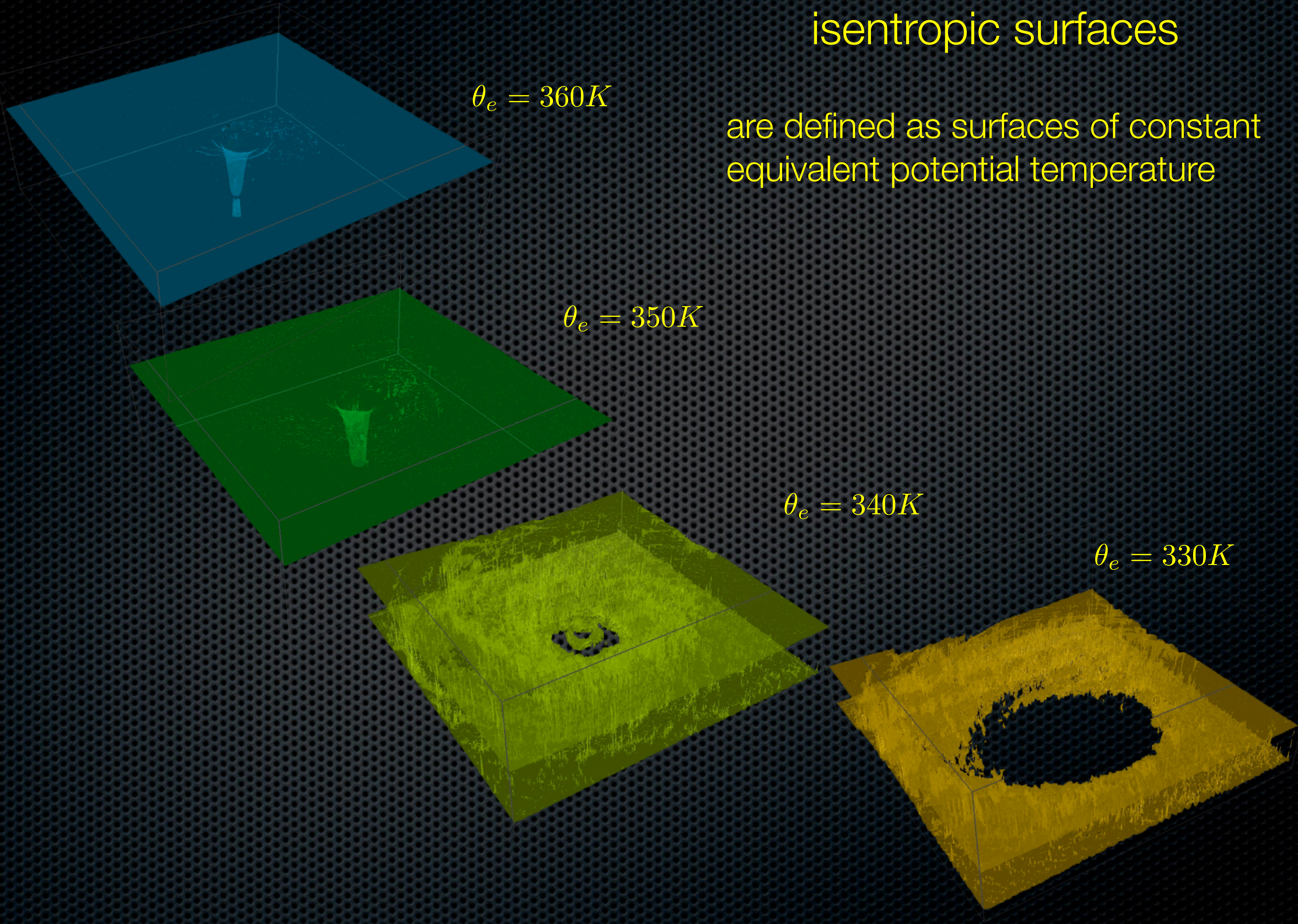
for the meridional circulation a streamfunction may be defined by averaging the velocity at constant pressure, resulting in the well-known three-cell structure

this averages out the 'weather'...

the differences between the eulerian and isentropic circulations show how the choice of the coordinate system for a turbulent flow can make it possible to include or exclude different aspects of the eddy transport into the circulation

isentropic surfaces

are defined as surfaces of constant equivalent potential temperature



isentropic analysis

we introduce ***isentropic averaging***, where we replace both horizontal coordinates (x, y) by Θ_e. In practice the properties of air parcels are averaged over finite size bins of equivalent potential temperature.

$$< f(\theta_e, z, t) >= \frac{1}{L^2} \iint f(x, y, z, t)\delta(\theta_{e0} - \theta_e(x, y, z, t))dx\ dy$$

the time mean isentropic ***mass flux*** may be defined as:

$$M(\theta_e, z) =< \rho w > (z, \theta_e)$$

the isentropic ***streamfunction***:

$$\overline{\Psi}(z, \theta_e) = \int_{\theta_{e,min}}^{\theta_e} M(\theta_e', z) d\theta_e'.$$

mass conservation:

$$\frac{\partial < \rho >}{\partial t} + \frac{\partial < \rho w >}{\partial z} + \frac{\partial < \rho \theta_e >}{\partial \theta_e} = 0$$

for a statistically steady case, this means that the mean trajectories are parallel to the streamlines

$$< \rho w >= \frac{\partial \Psi}{\partial \theta_e}$$

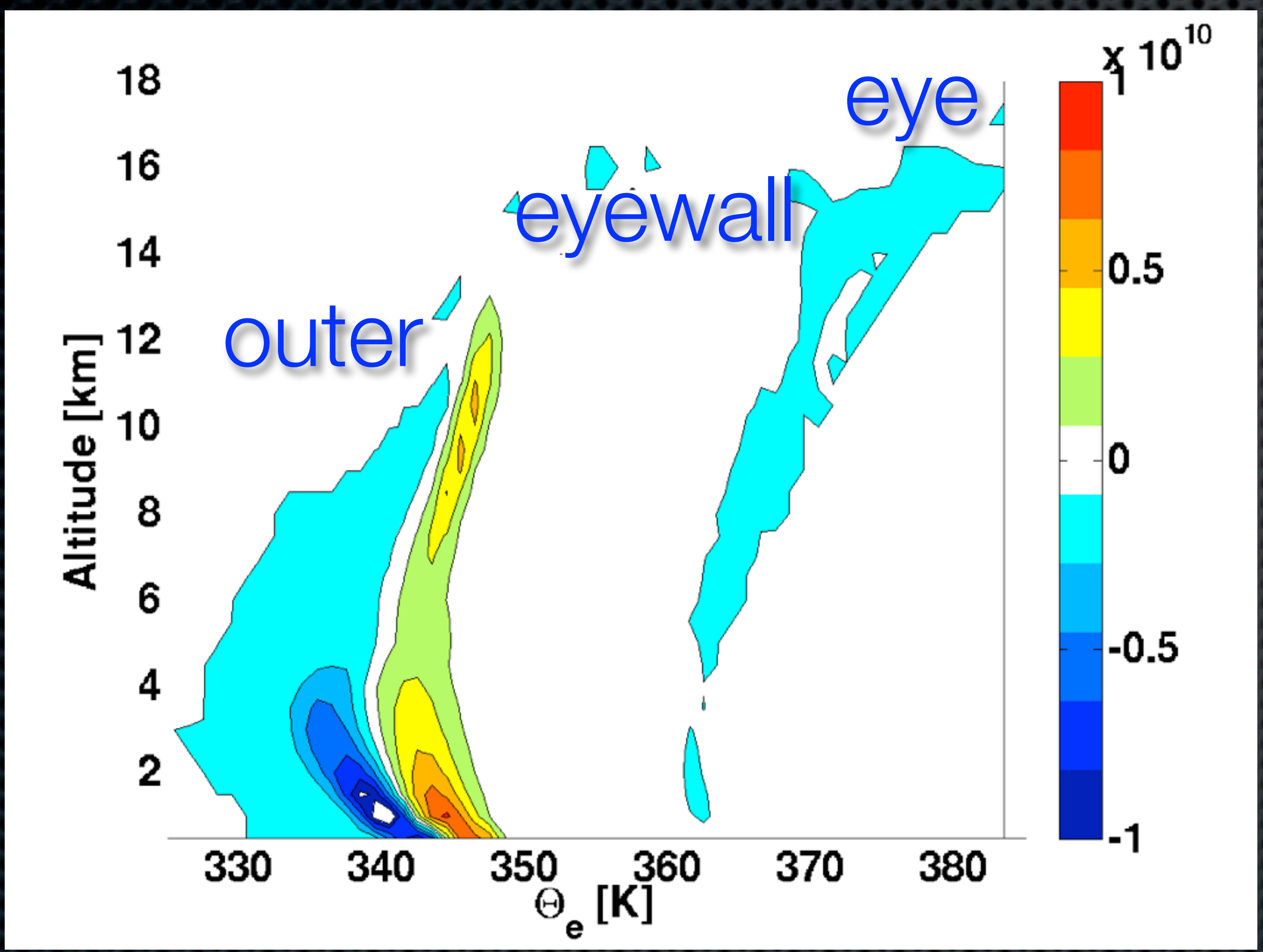
$$< \rho \theta_e >= -\frac{\partial \Psi}{\partial z}$$

and the diabatic tendency can be directly computed from the streamfunction.

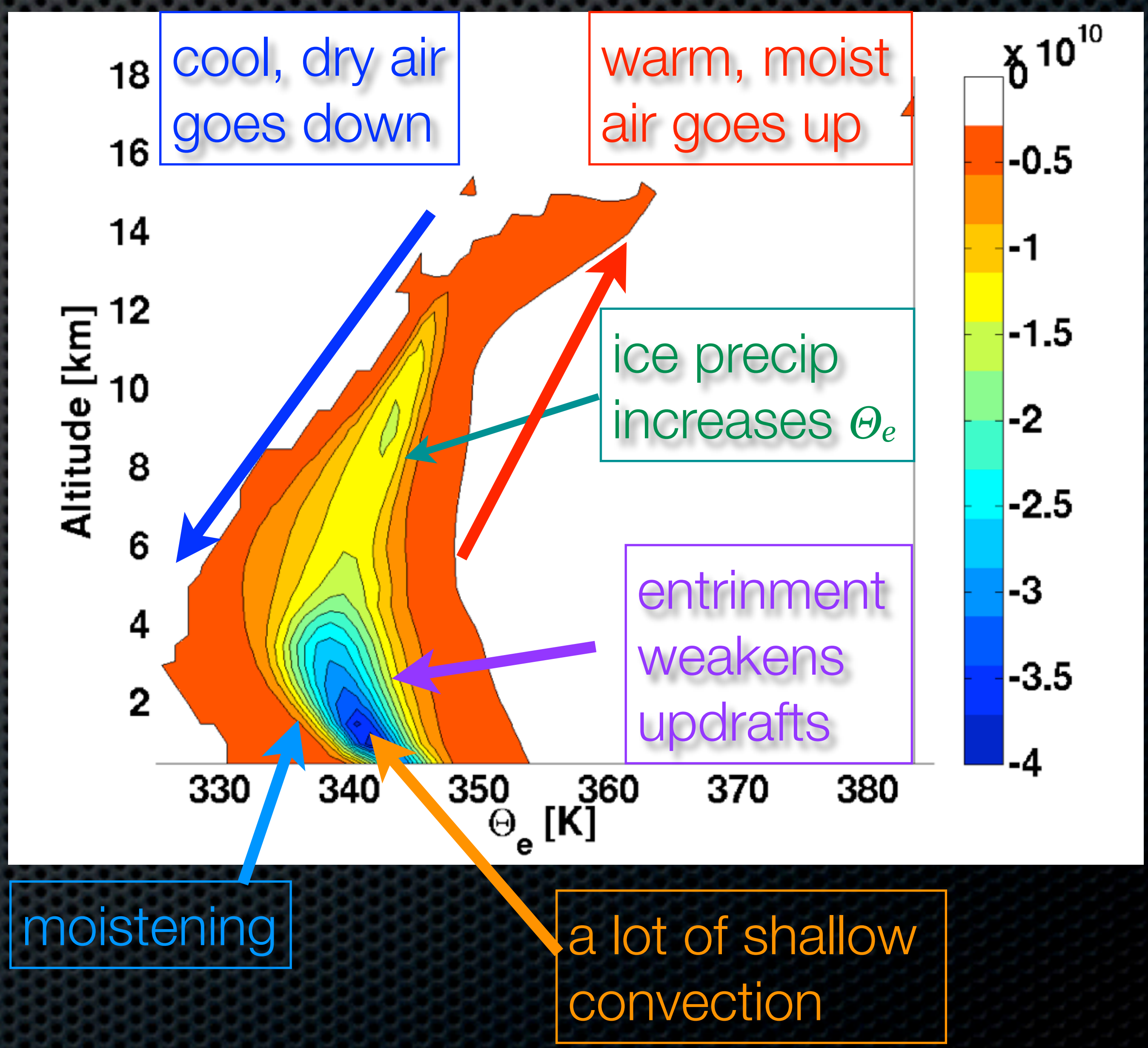
θ_e

(Pauluis & Mrowiec 2013)

isentropic mass flux



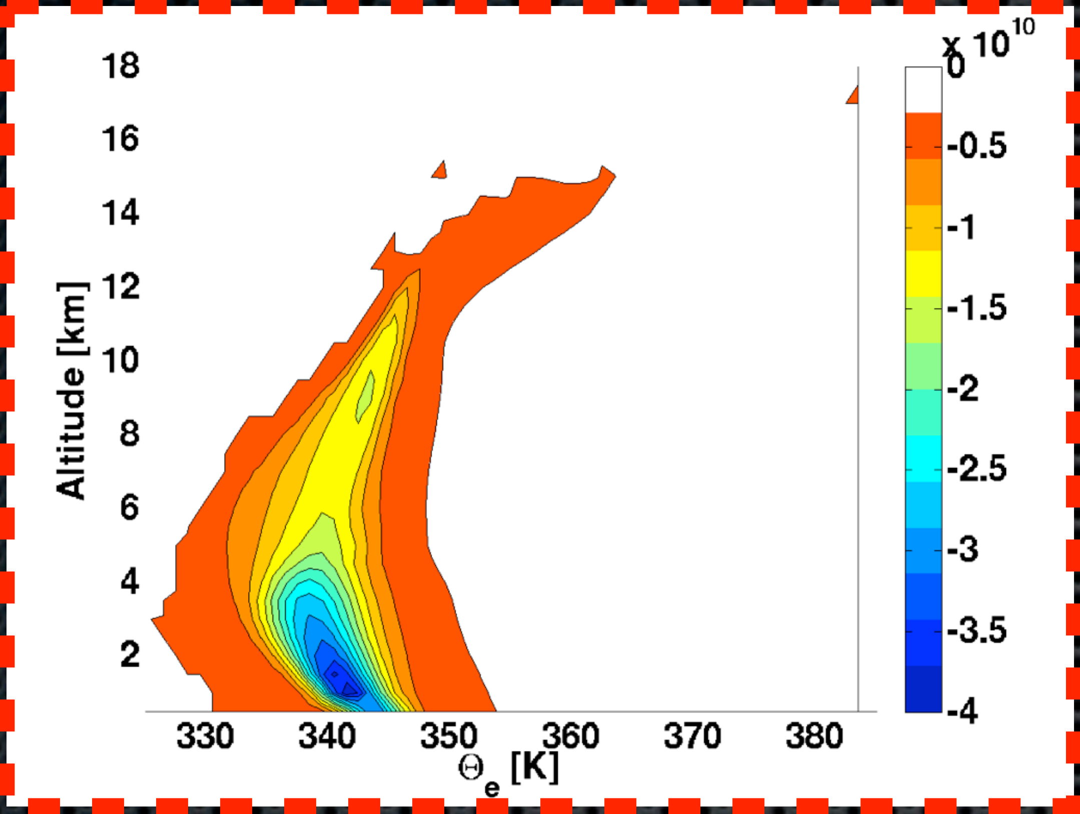
isentropic streamfuction

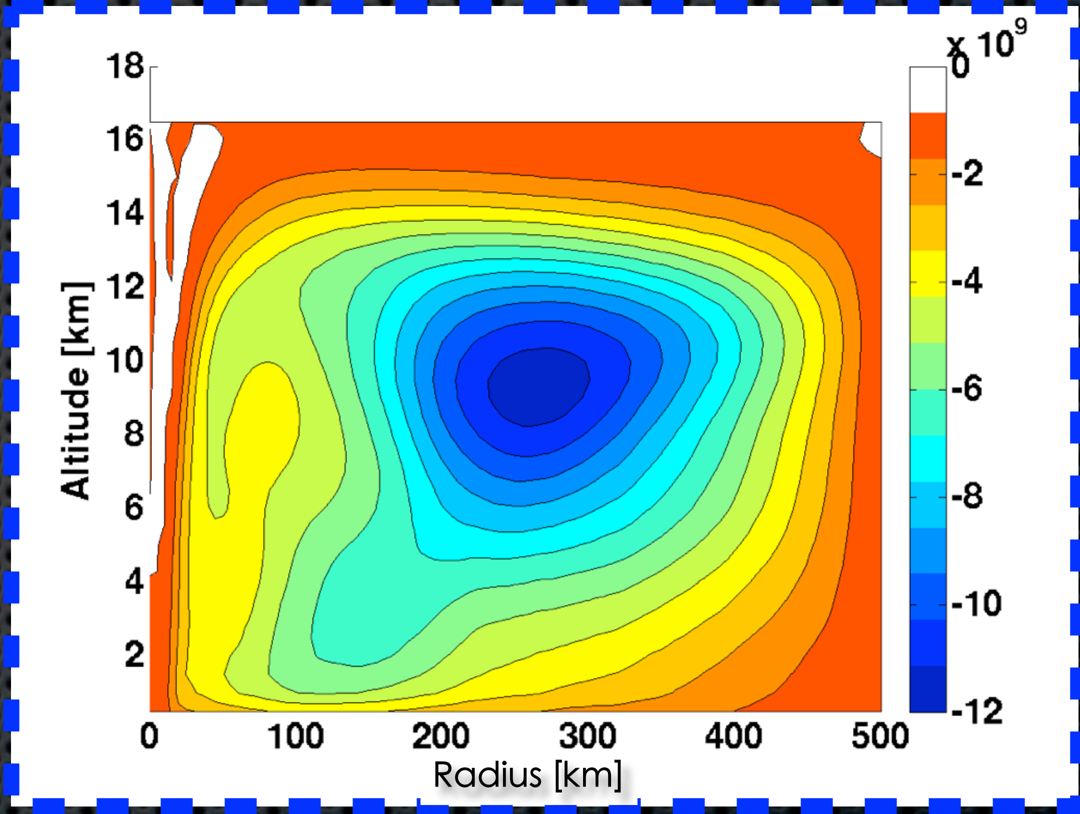


isentropic streamfuction

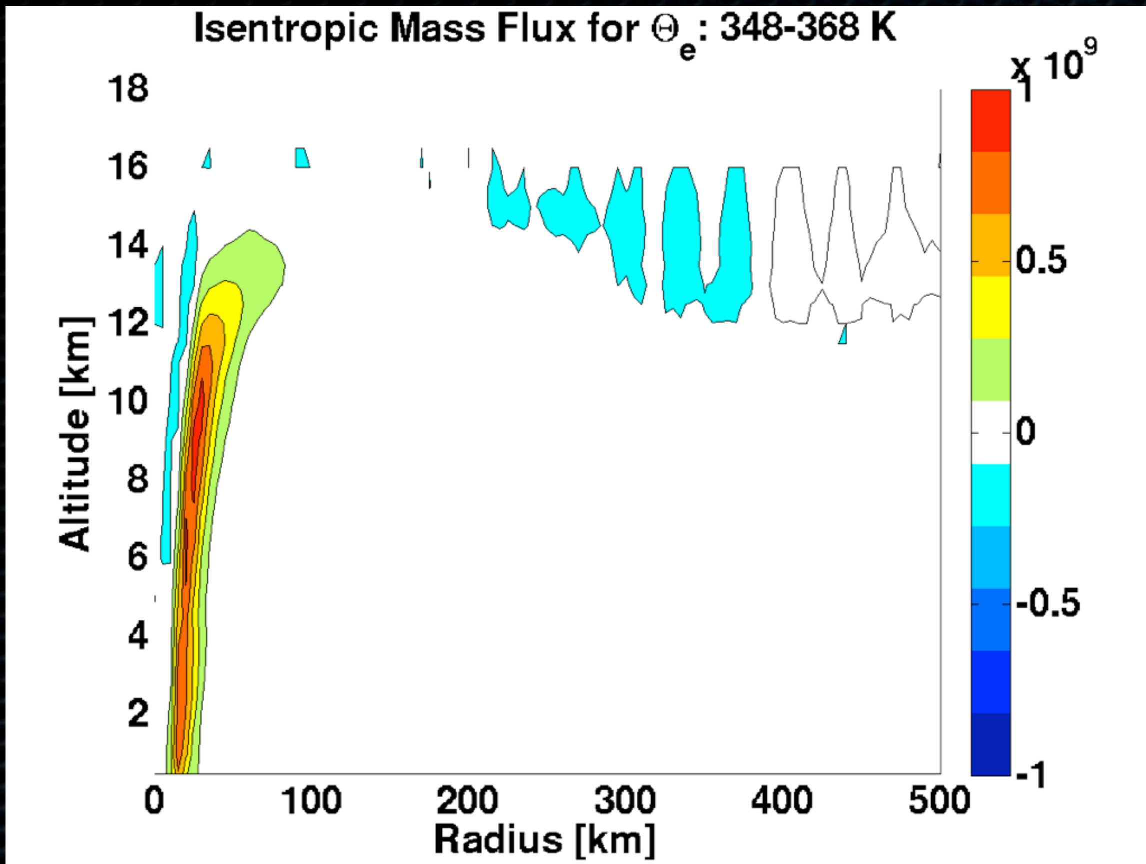
eulerian streamfuction

$$\Psi_{\theta_e}(\theta_{e0}, z, t) = \int_0^{L_x} \int_0^{L_y} \rho w H(\theta_{e0} - \theta_e(x, y, z, t)) dx\, dy.$$



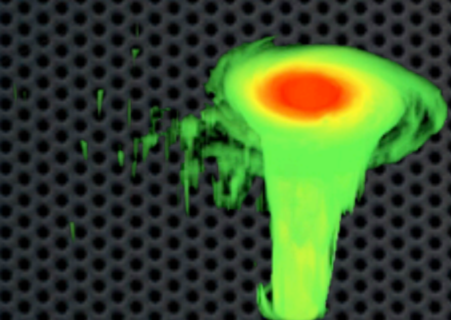


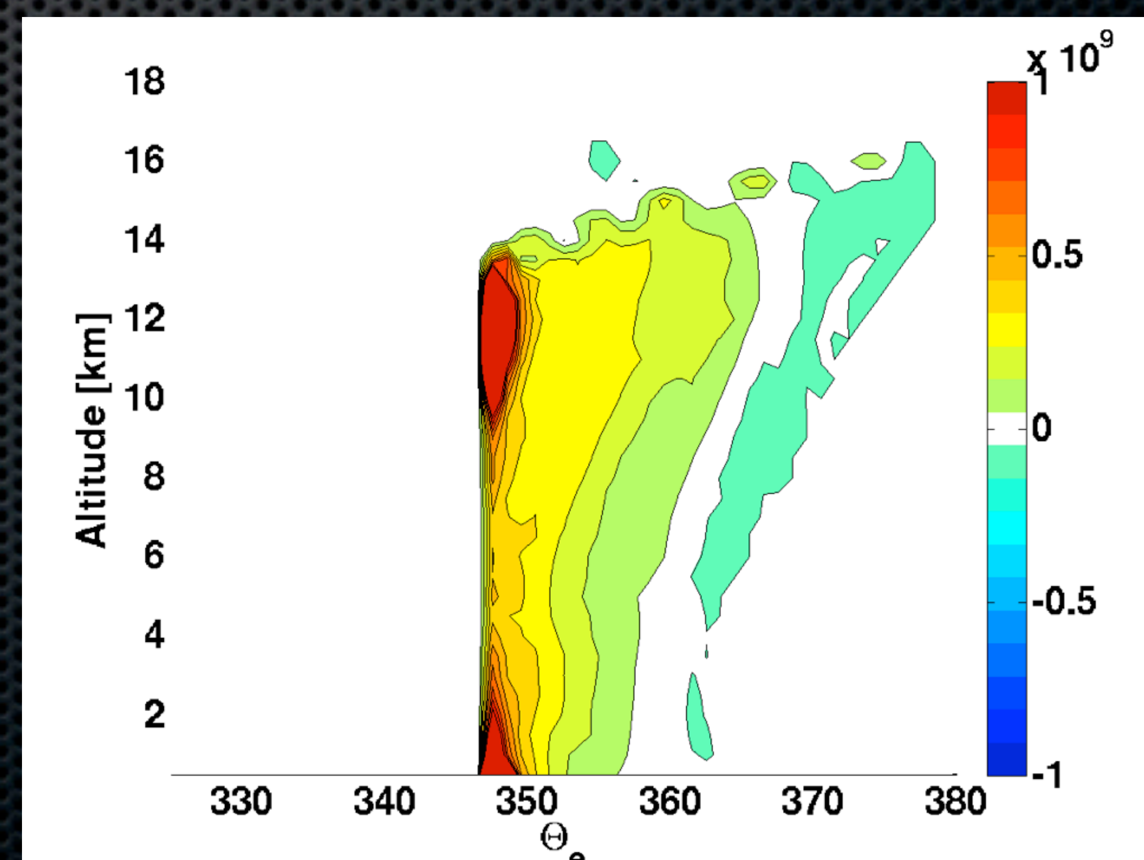
$$\Psi_R(r_0, z, t) = \int_0^{L_x} \int_0^{L_y} \rho w H(r_0 - r(x, y, z, t)) dx\, dy$$



scale separation: mass flux

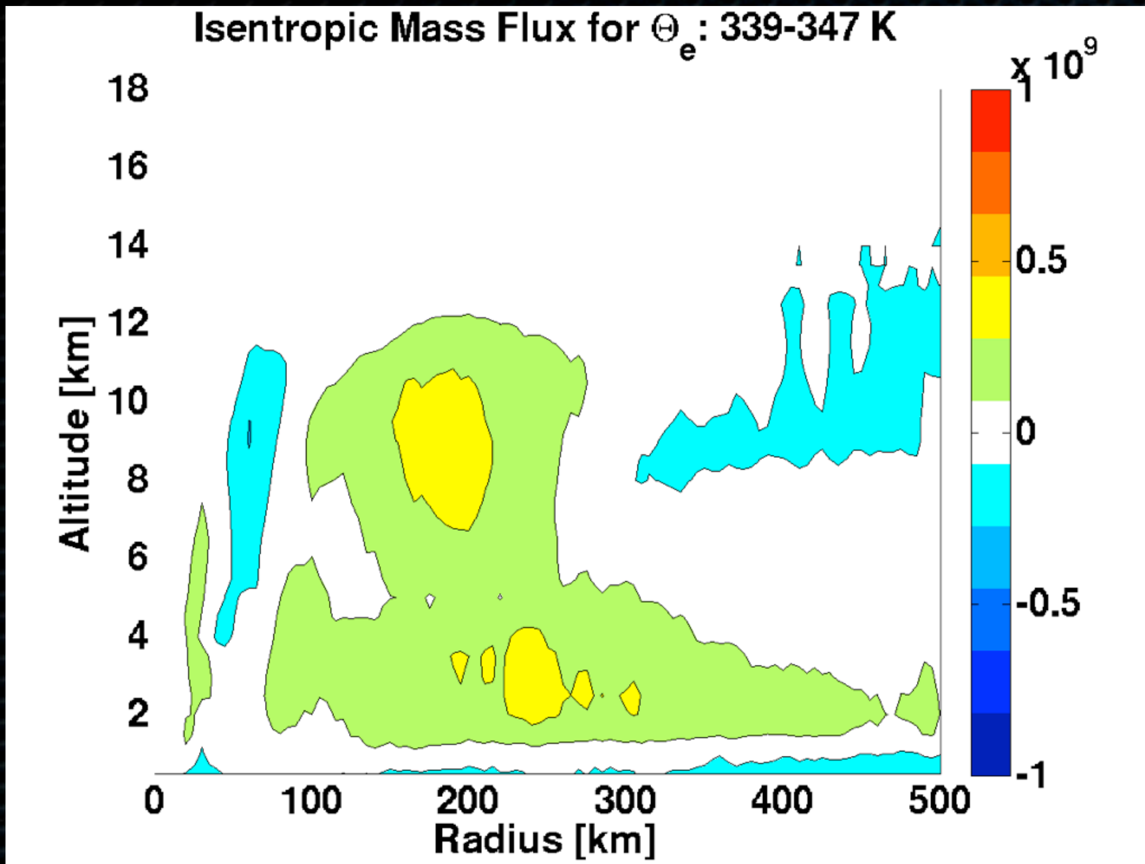
$$348K > \theta_e > 368K$$

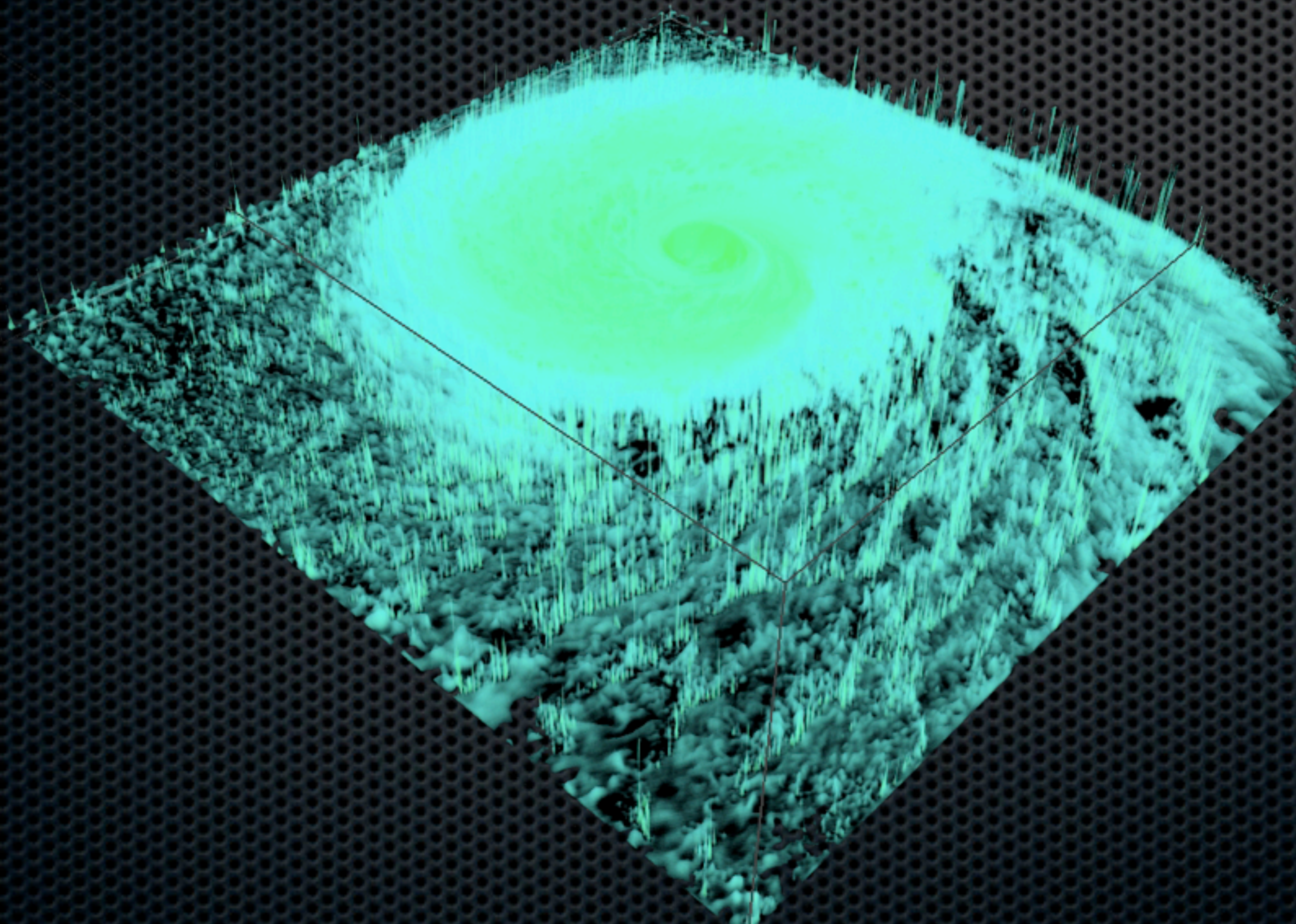


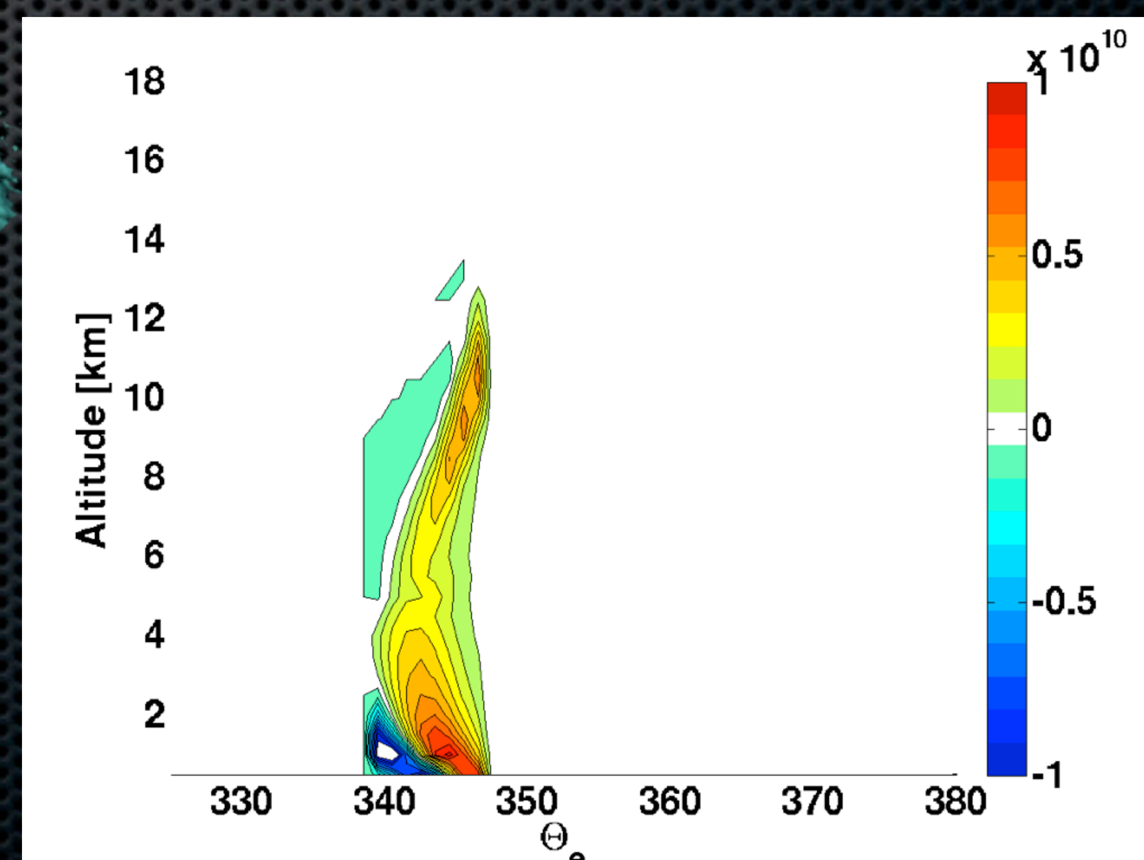


scale separation: mass flux

$$339K > \theta_e > 347K$$

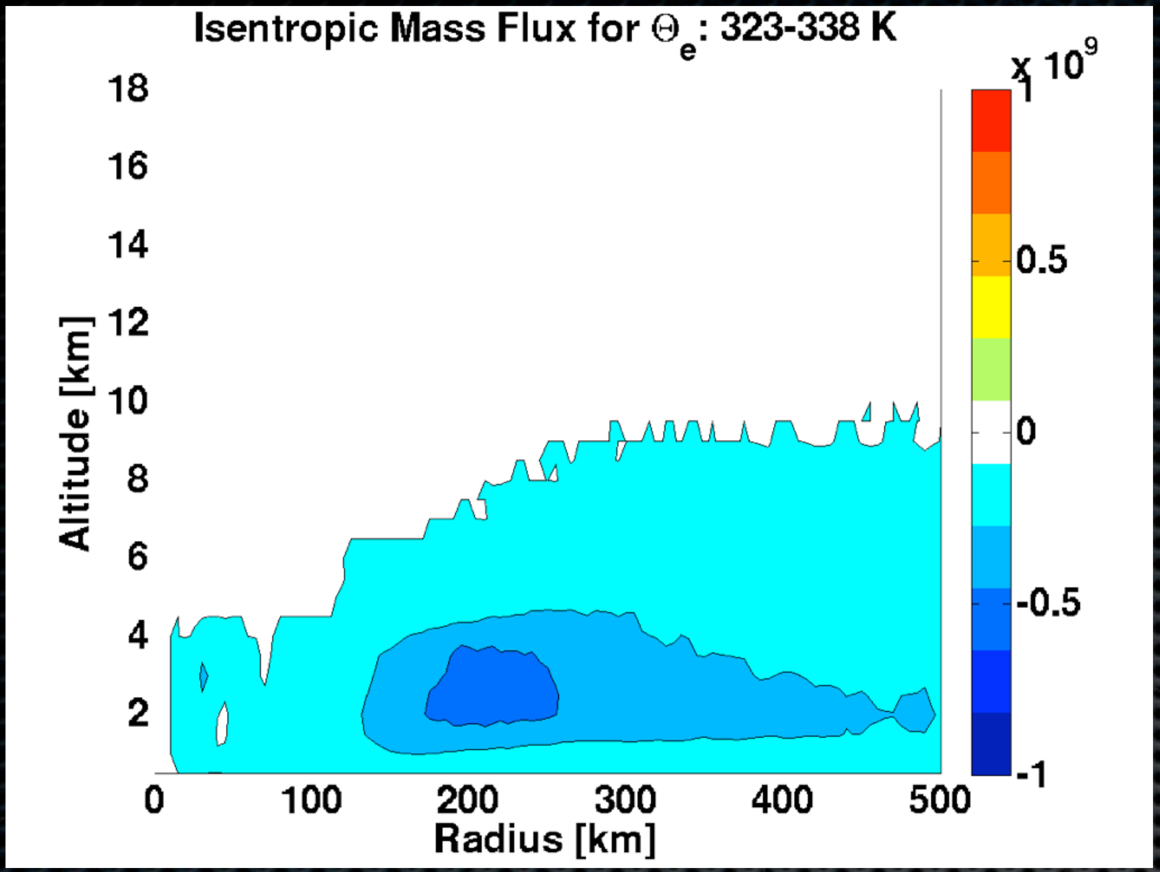


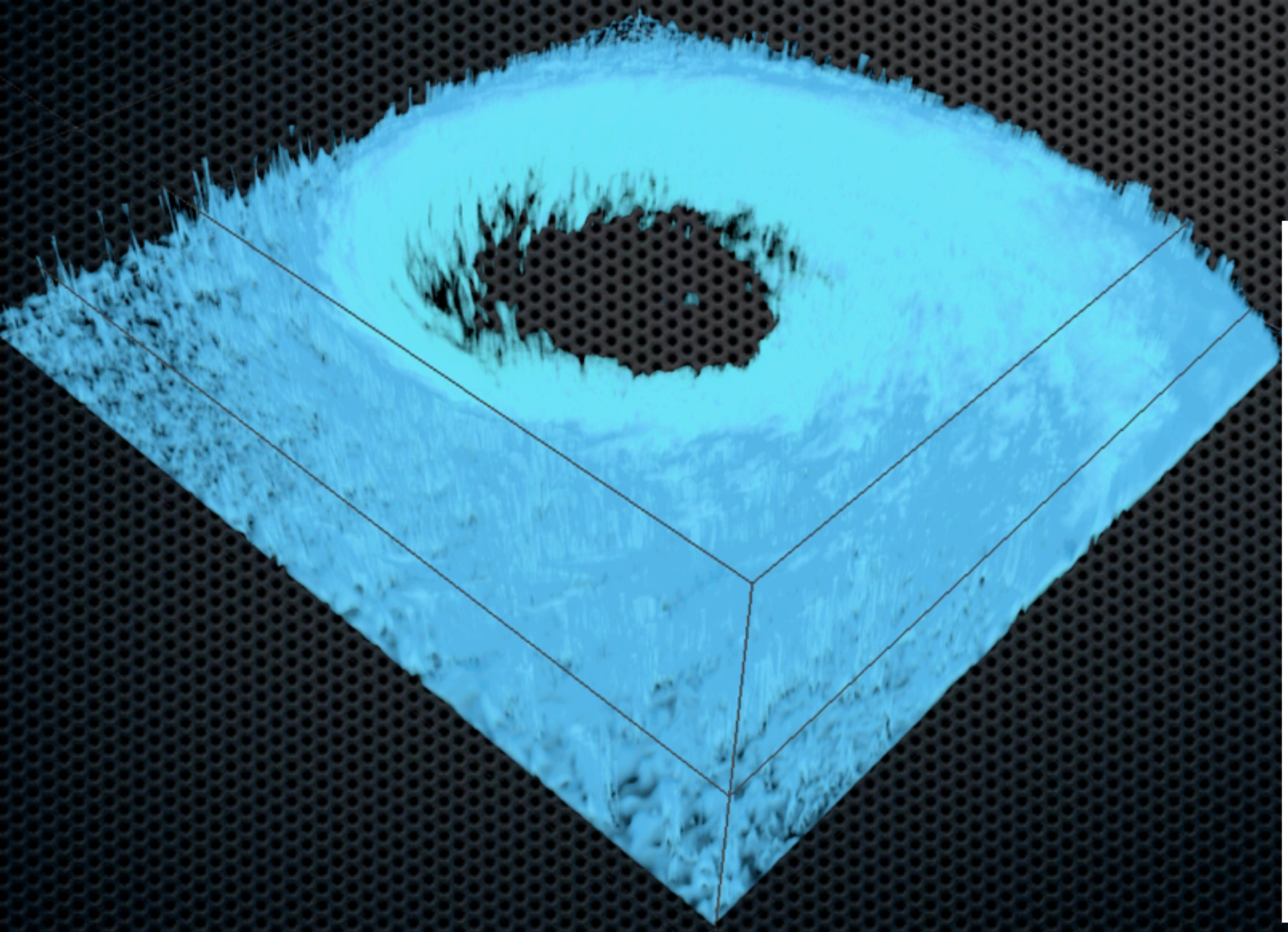


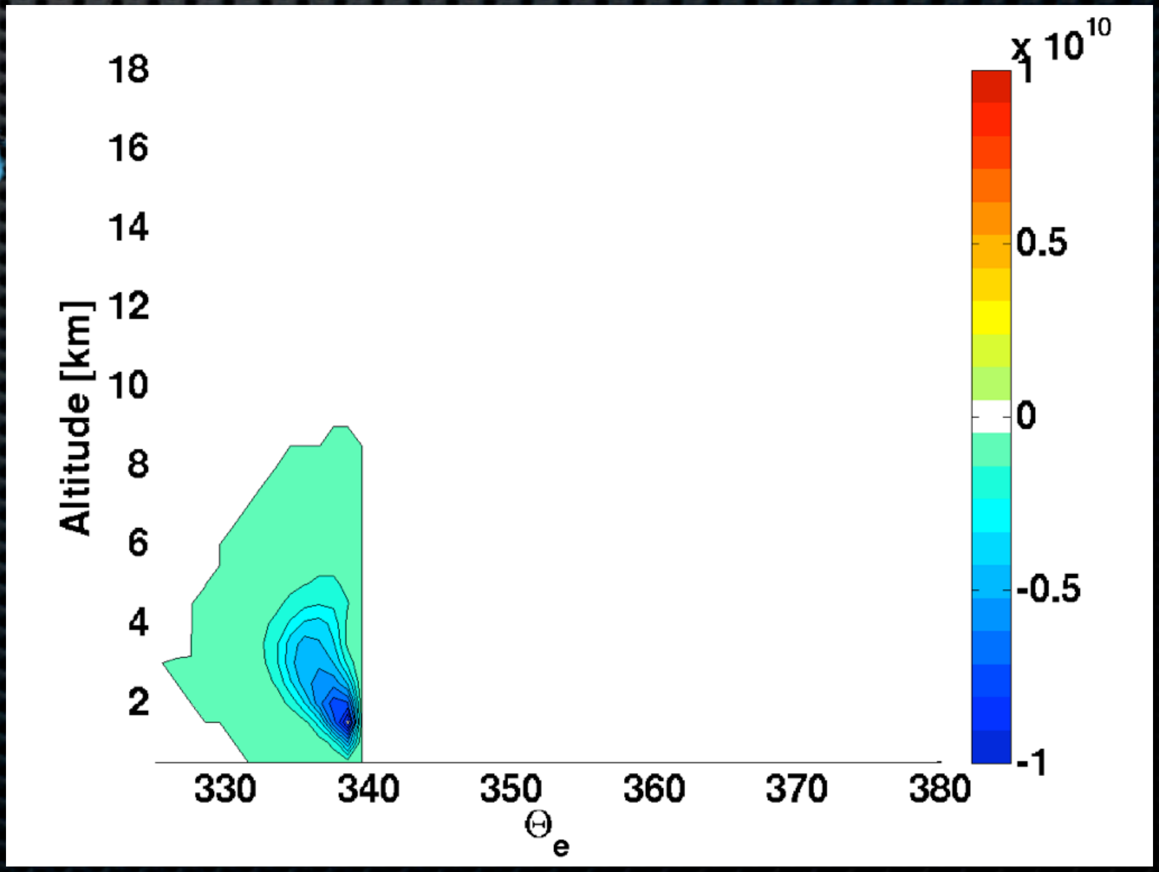


scale separation: mass flux

$$323K > \theta_e > 338K$$





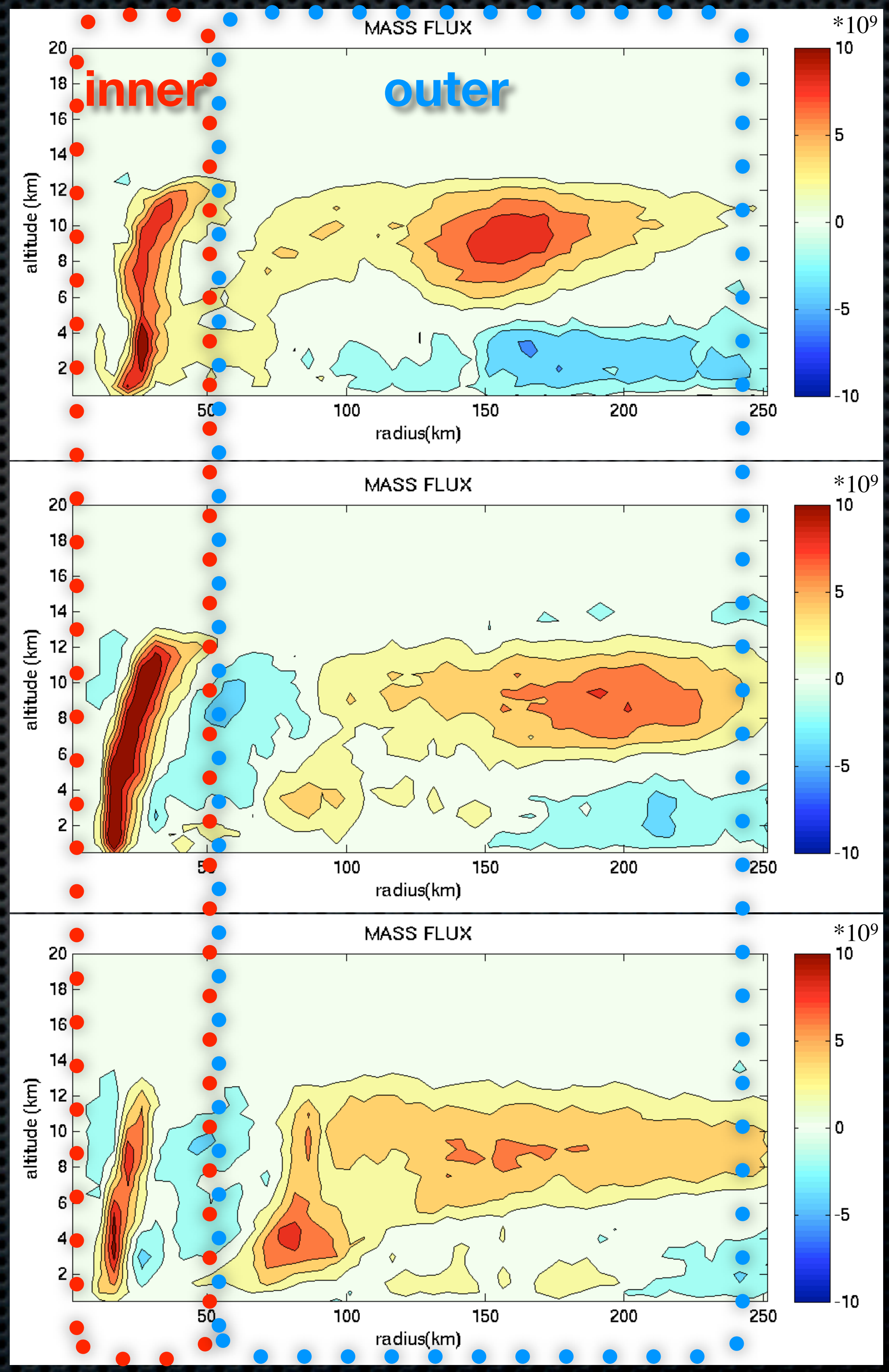


transient structure: mass flux

I - intensification

II - peak intensity

III - weakening

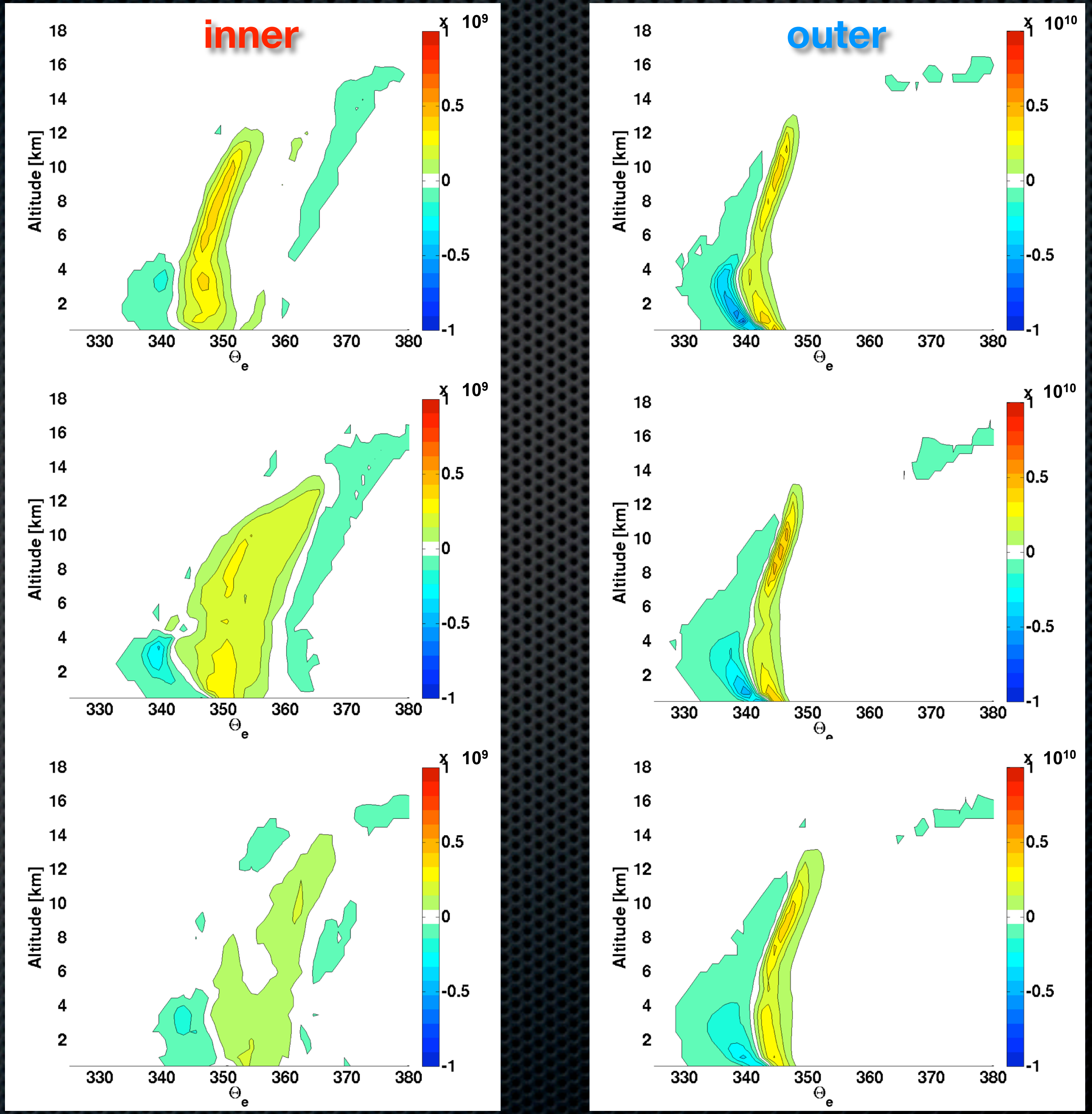


transient structure: isentropic mass flux

I - intensification

II - peak intensity

III - weakening



summary

- the mass transported by the eye is much smaller than the mass transported by the outer region in the hurricane
- it is possible to separate the inner flow (eye + eyewall) from the outer flow based on equivalent potential temperature
- It can be used to diagnose many aspects of convection, such as diabatic heating, entrainment or downdrafts and to identify different convective regimes.
- we can study properties of thermodynamically similar air parcels and separate between warm, moist updrafts and cool drier downdrafts
- we can analyze dynamics and thermodynamics relationship in hurricanes and other convective systems
- isentropic analysis of convective motions can be used as a basis for comparison between cloud resolving models