

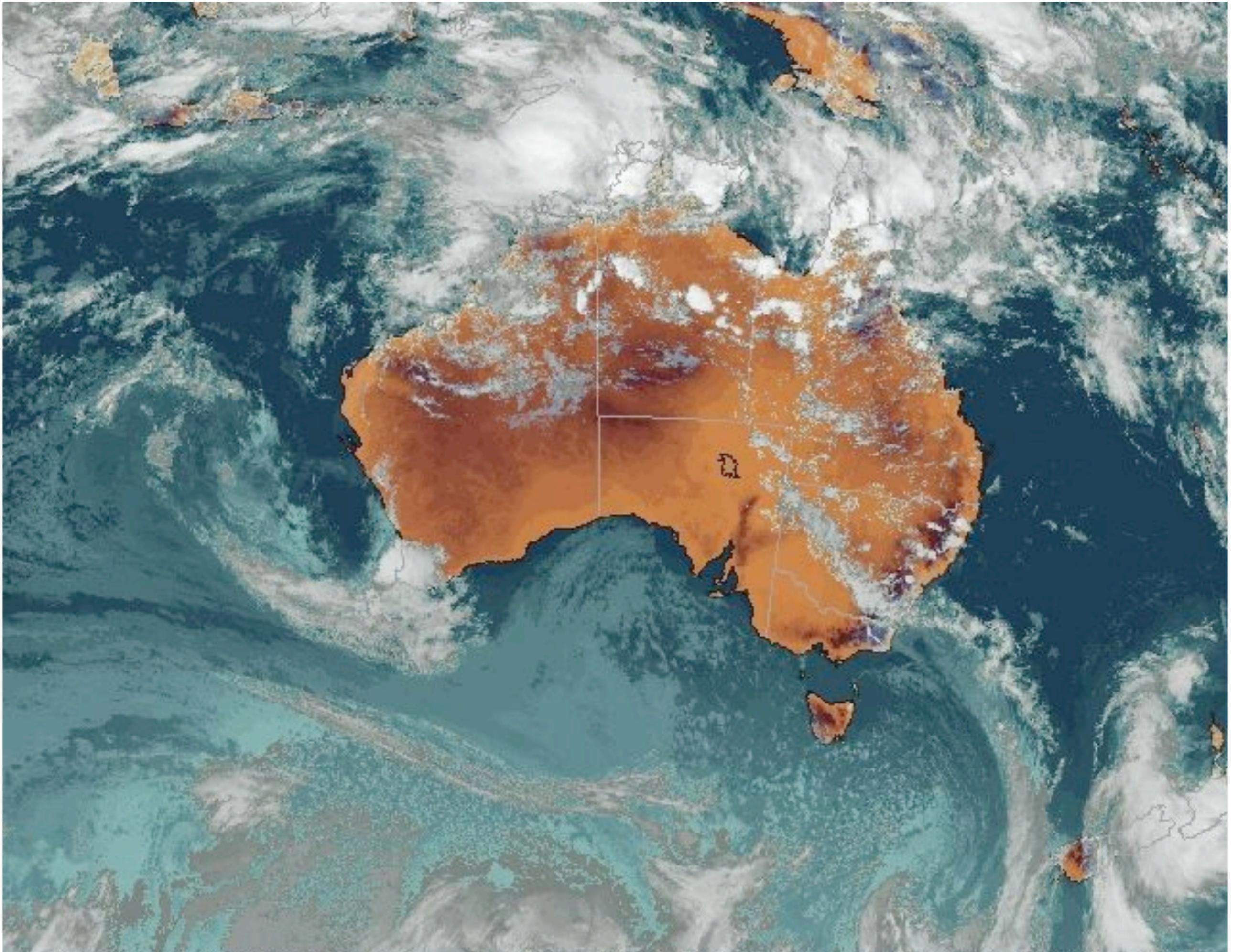
isentropic analysis of convective motions

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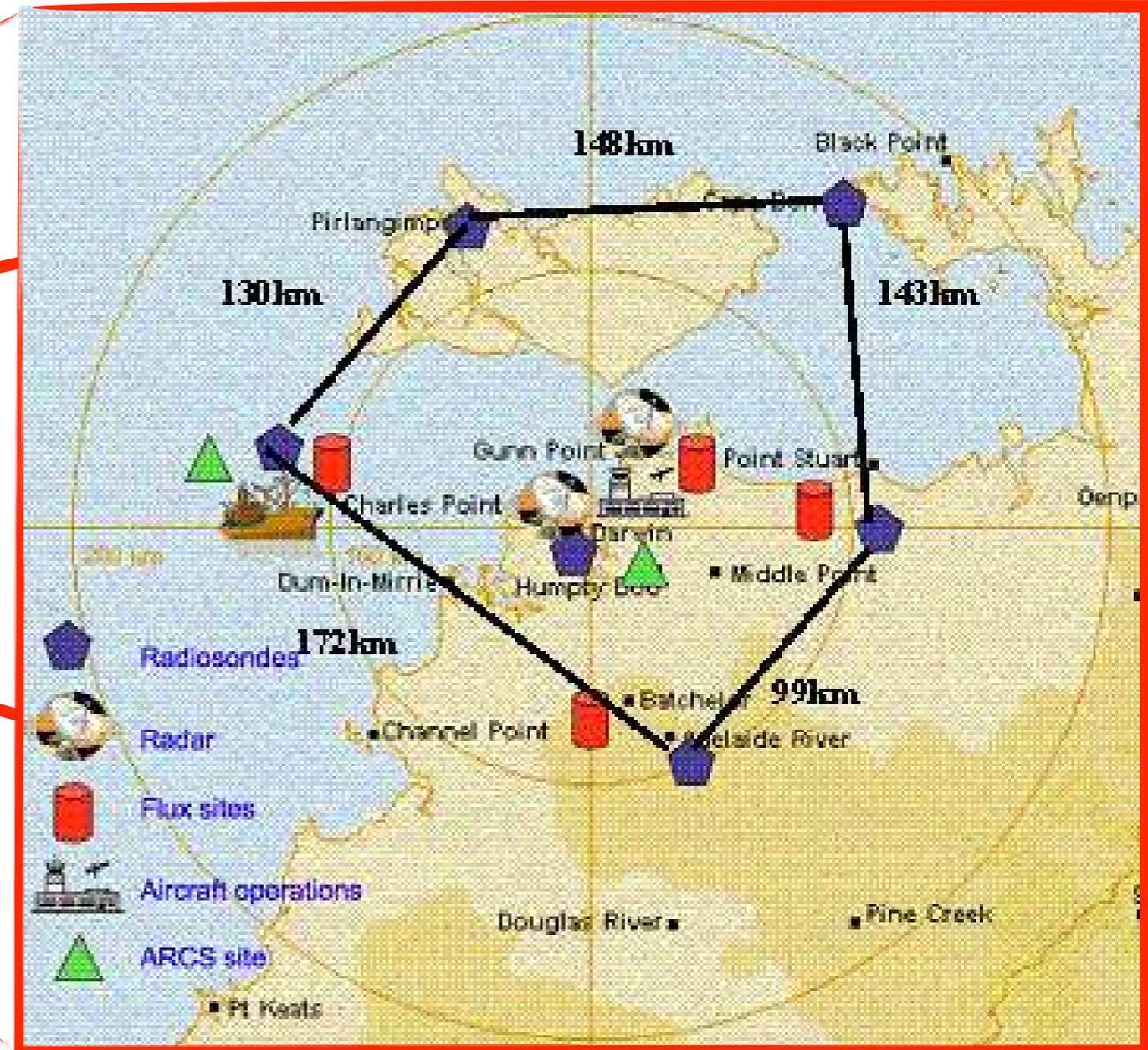
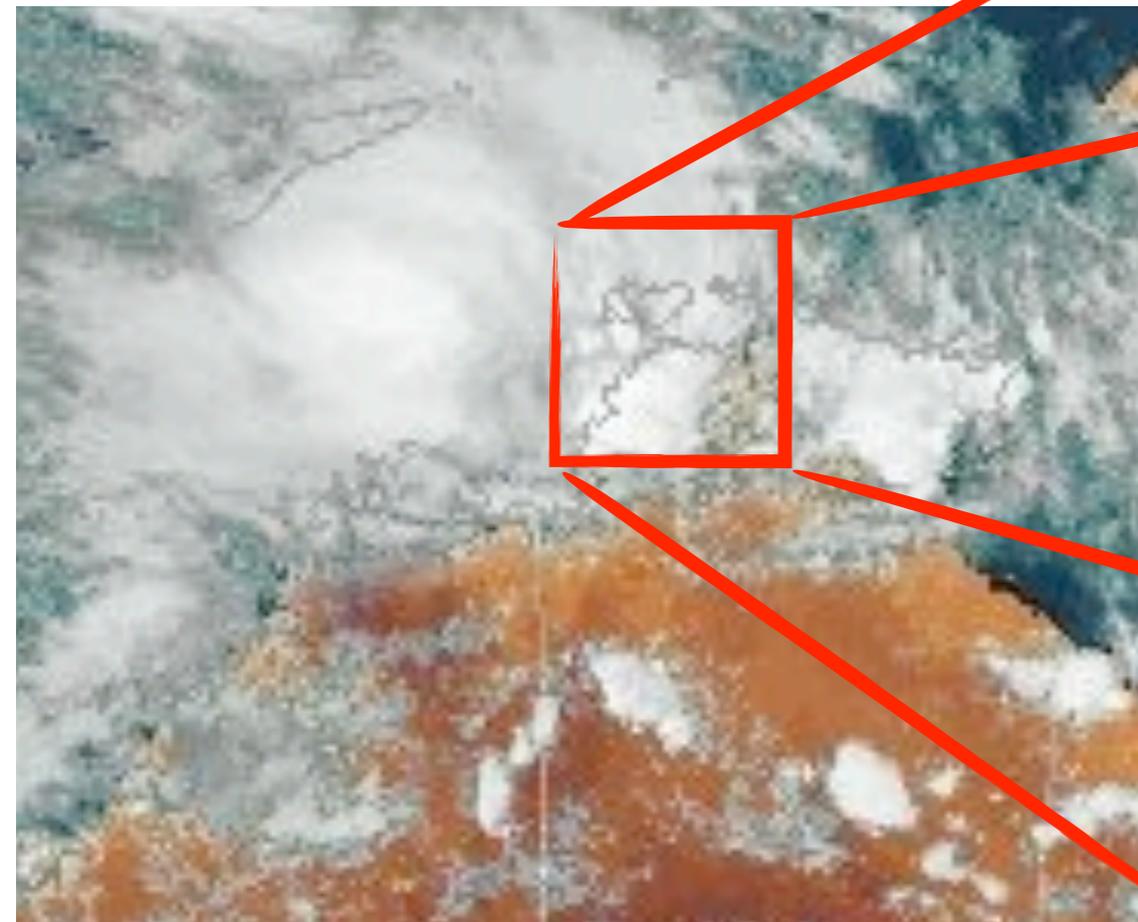


- case study and model
- convective systems
- gravity waves
- method
- results
- new applications



AUSTRALIAN GOVERNMENT - BUREAU OF METEOROLOGY 24 JAN 06 04:33 UTC

case study: mesoscale convective system (MCS)



- Case: TWP ICE 2006, active monsoon event of January 23 - 24 2006

- Intercomparison: Fridlind et al. 2010
Fridlind et al. 2012

TWP ICE - **Tropical Warm Pool International Cloud Experiment**

was a multi-agency project centered in Darwin, Australia. A detailed description of experiment conditions, general climate, and measurements can be found in May et al. (2008).

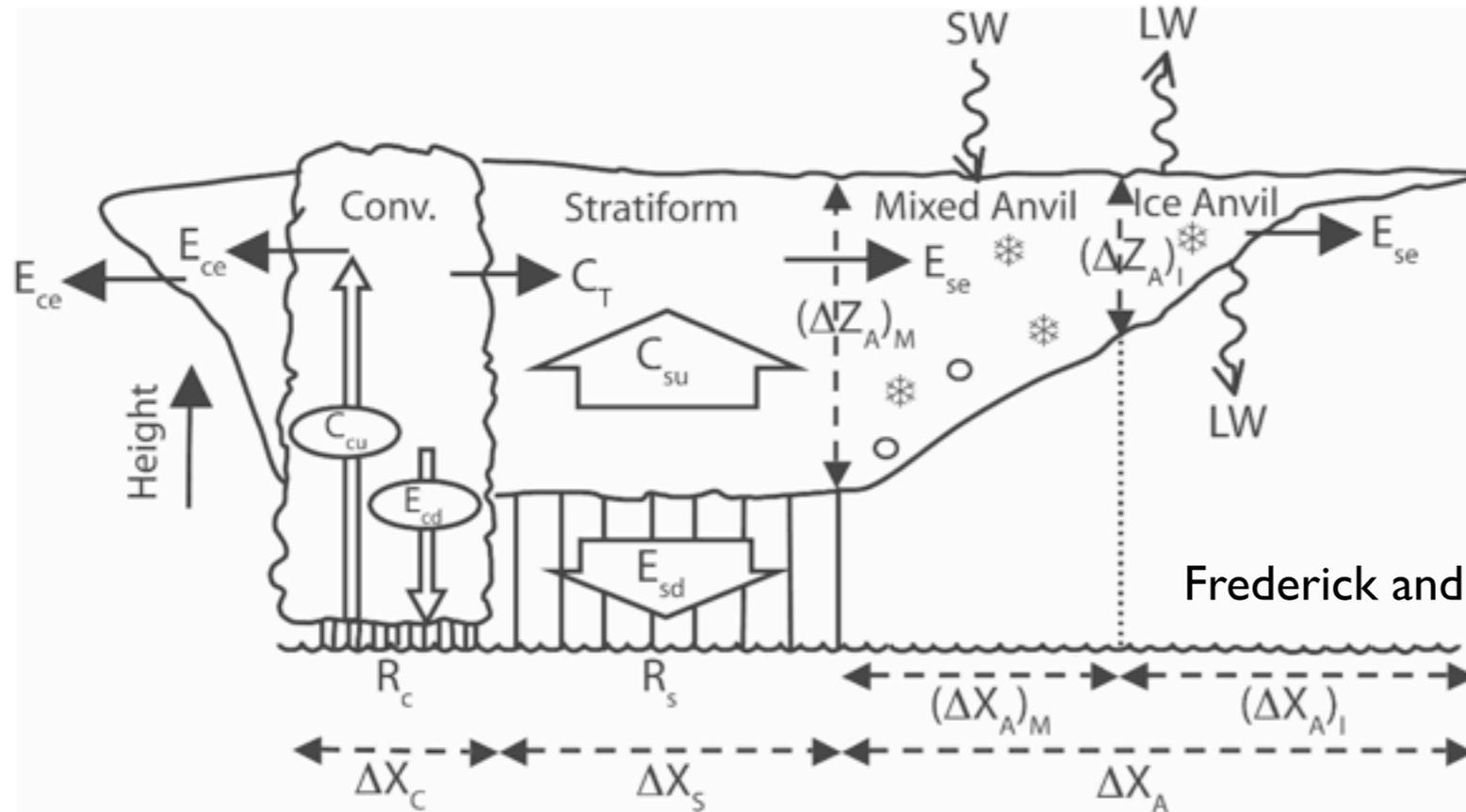
simulation

DHARMA - Distributed Hydrodynamic Aerosol and Radiative Modeling Application (Stevens et al., 2002; Ackerman et al., 2003) cloud resolving model

Detailed description of model configuration may be found e.g. in Fridlind et al. 2012 or Mrowiec et al. 2012

- domain 176 km 176 km
- horizontal resolution 900 m
- stretched vertical grid 100 - 250 m
- periodic lateral boundary conditions
- model domain height of 24 km
- initial conditions derived from the mean observed profiles of potential temperature and water vapor mixing ratio
- uniform sea surface temperature of 29C, experimental domain idealized as marine
- surface albedo fixed at 0.07
- large-scale forcings were based on observations (Xie et al., 2010)
- two-moment microphysics based on the 5-class scheme of Morrison et al. (2009)
- trimodal aerosol profile derived from observations (Fridlind et al., 2010)

structure of a thunderstorm



Frederick and Schumacher, MWR 2008



Building blocks from the point of view of convective parameterization:

- Convective updrafts
- Convective downdrafts
- Stratiform updrafts
- Stratiform downdrafts

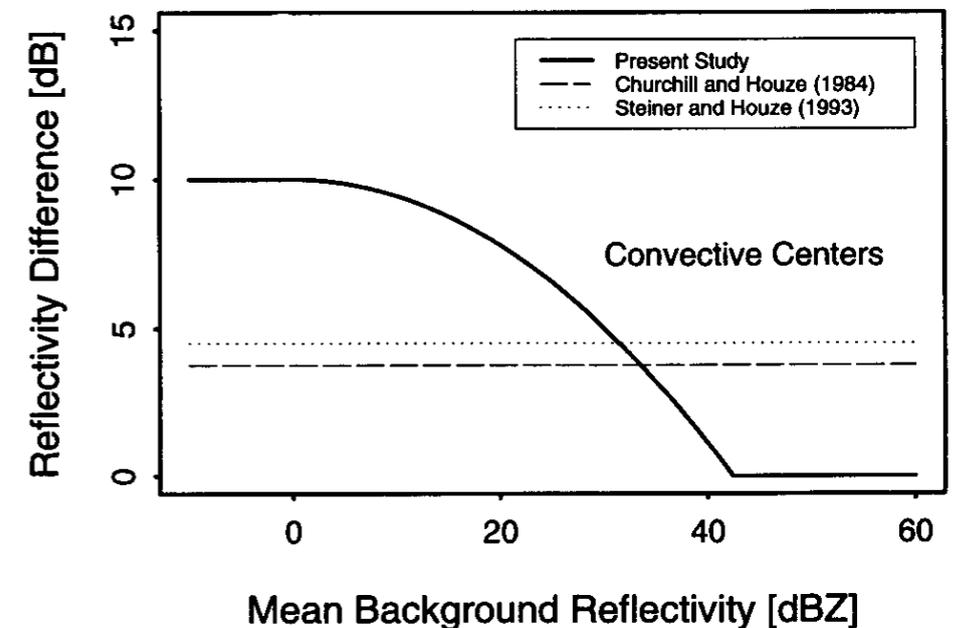
convective / stratiform partitioning

Steiner (1995) algorithm based on simulated radar reflectivity expressed in decibel (dBZ) and typically is normalized by the echo of a 1 mm diameter droplet:

$$Z_e \sim 10 \log (Z(1\text{mm})^{-1} \int C D^6 N(D) dD)$$

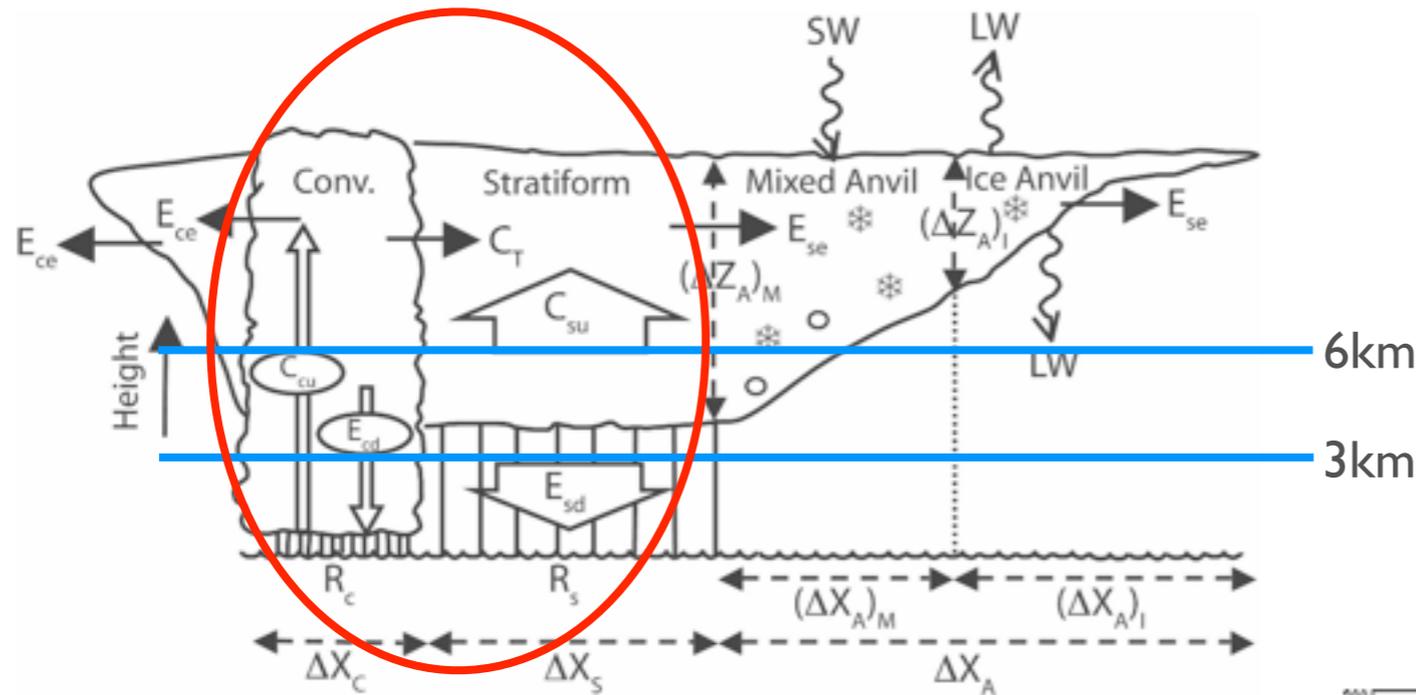
where C is a constant, D is droplet diameter and N is a droplet size distribution

- INTENSITY: any point with reflectivity higher than 40 dBZ is called **convective**
- PEAKEDNESS: any point that exceeds the average reflectivity taken over surrounding area (radius of 1 km) by reflectivity difference shown by the line below are also **convective**
- SURROUNDINGS: any point within a radius dependent on the mean background reflectivity from convective center is also included in **convective** area
- remaining precipitating areas are called **stratiform**



convective / stratiform partitioning

what rain radar can see



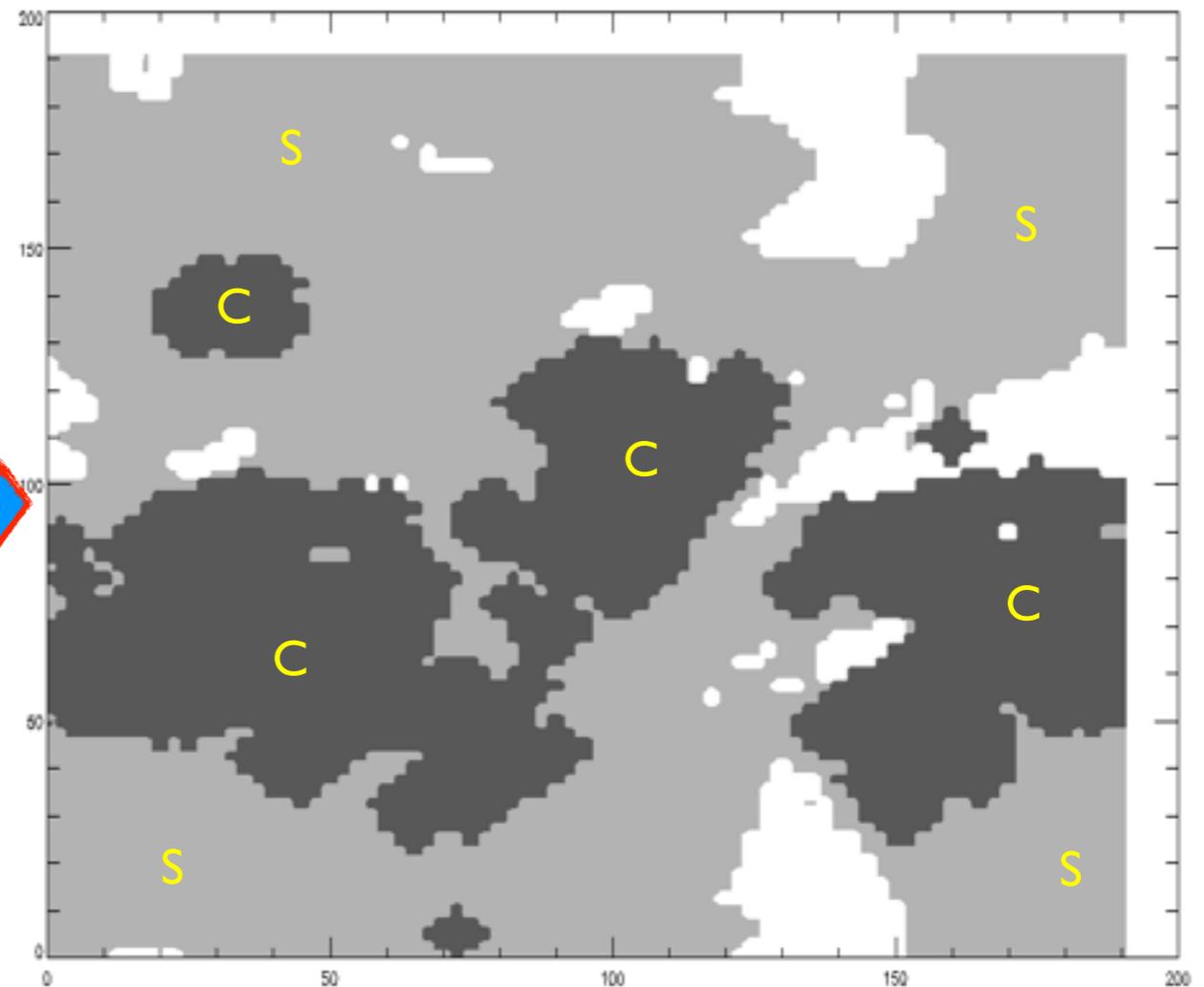
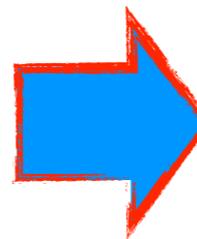
- partitioning done at altitude of 3km
- we have additional criterium of reflectivity greater than 5 dBZ at 6 km to eliminate shallow convection
- everything else we call a **non-precipitating** region

resulting cloud mask from a simulation at some time step during the peak of the event

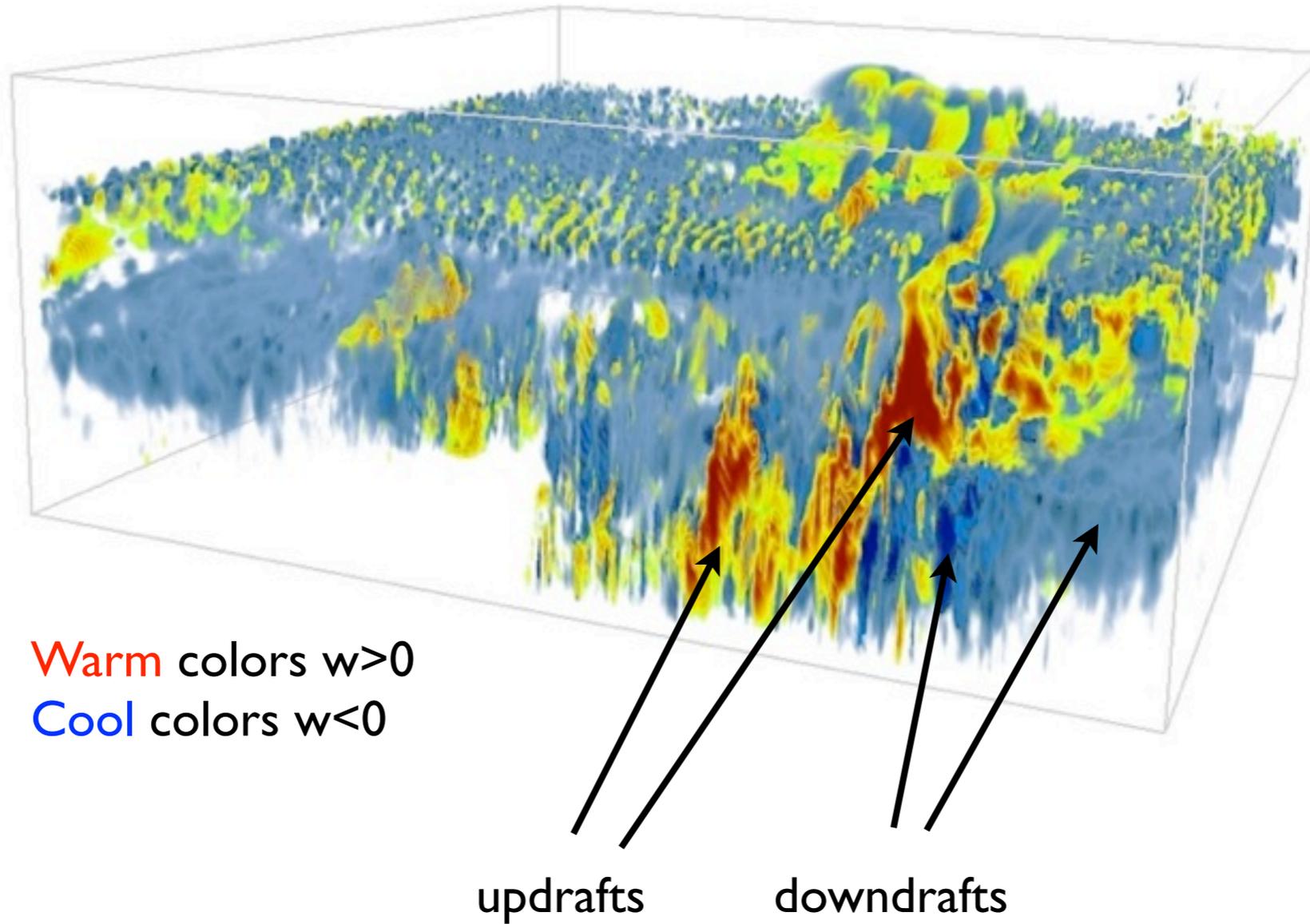
convective regions (C)

stratiform regions (S)

non-precipitating regions (white)

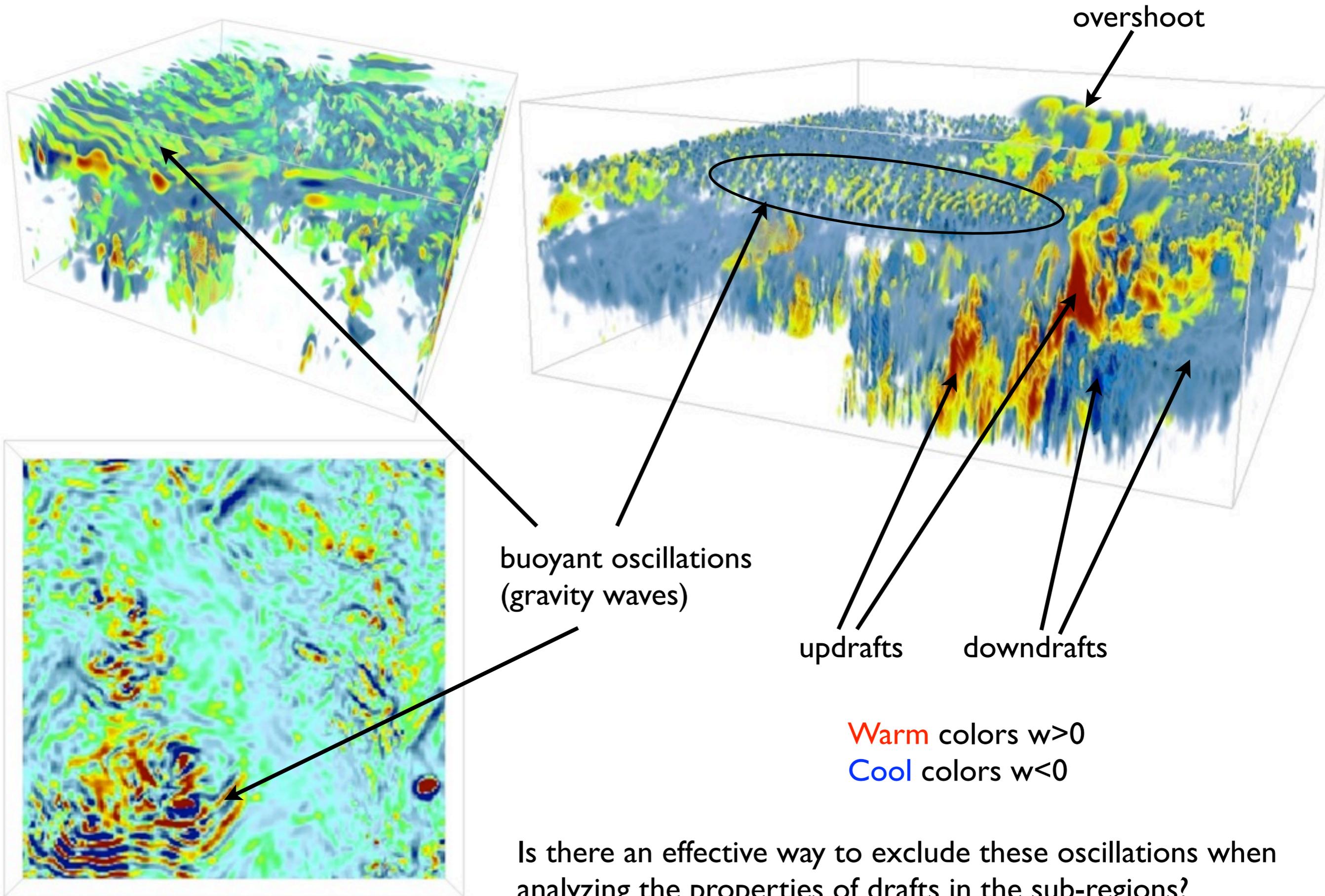


simulated MCS: updrafts / downdrafts



everything looks great...., right?

convective motions generate gravity waves...



Is there an effective way to exclude these oscillations when analyzing the properties of drafts in the sub-regions?

Isentropic Analysis of Convective Motions

Isentropic coordinates have been widely used in studies of the global circulation to separate large-scale planetary overturning from synoptic scale eddies. Here, we are using it to analyze convective scale overturning.

First, we define our isentropic surfaces as surfaces of constant equivalent potential temperature, defined following Emanuel (94) textbook.

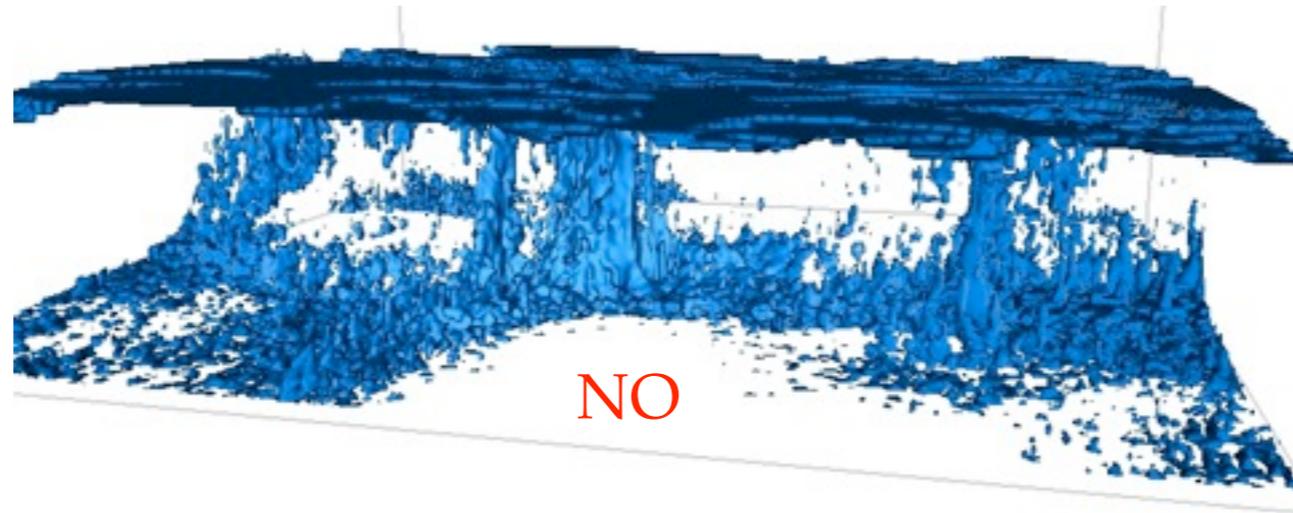
$$\theta_e = \frac{T}{\Pi} \text{RH}^{-\frac{R_v q_v}{C}} \exp\left(\frac{L_v q_v}{CT}\right) \quad \text{where} \quad C = c_p + c_l q_t$$

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.

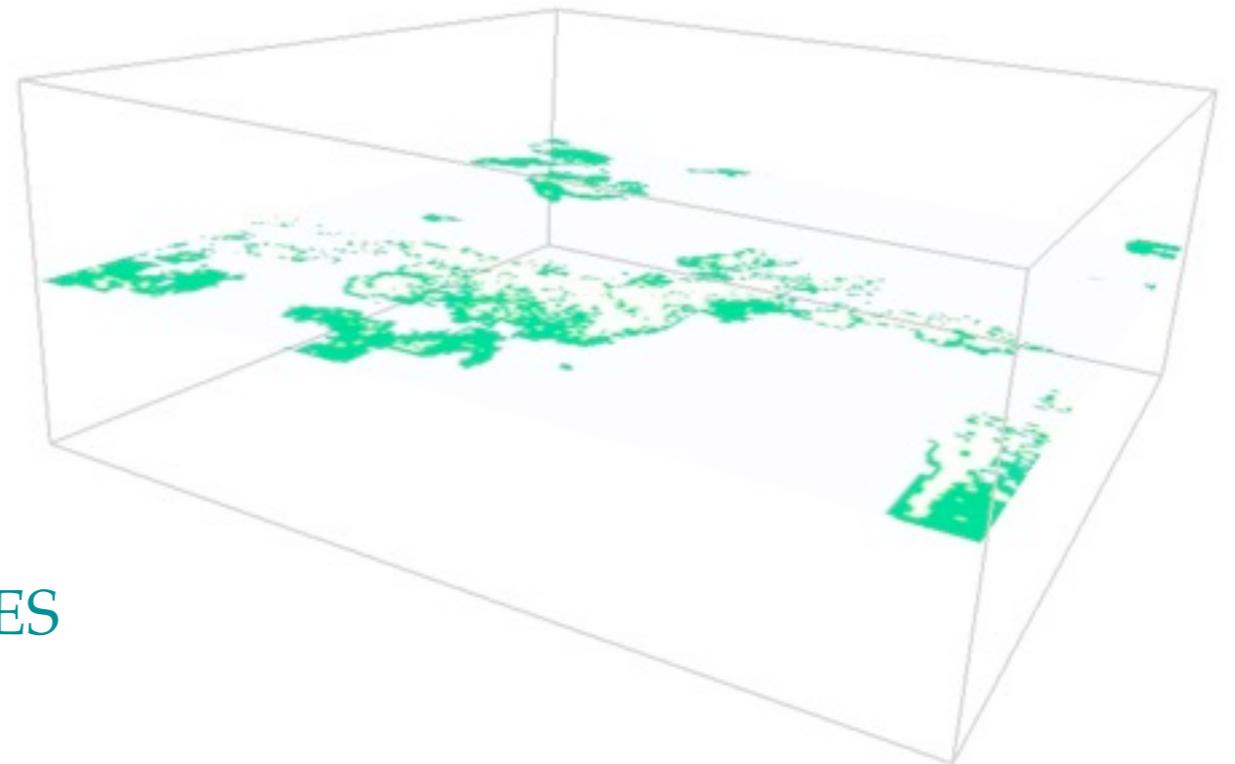
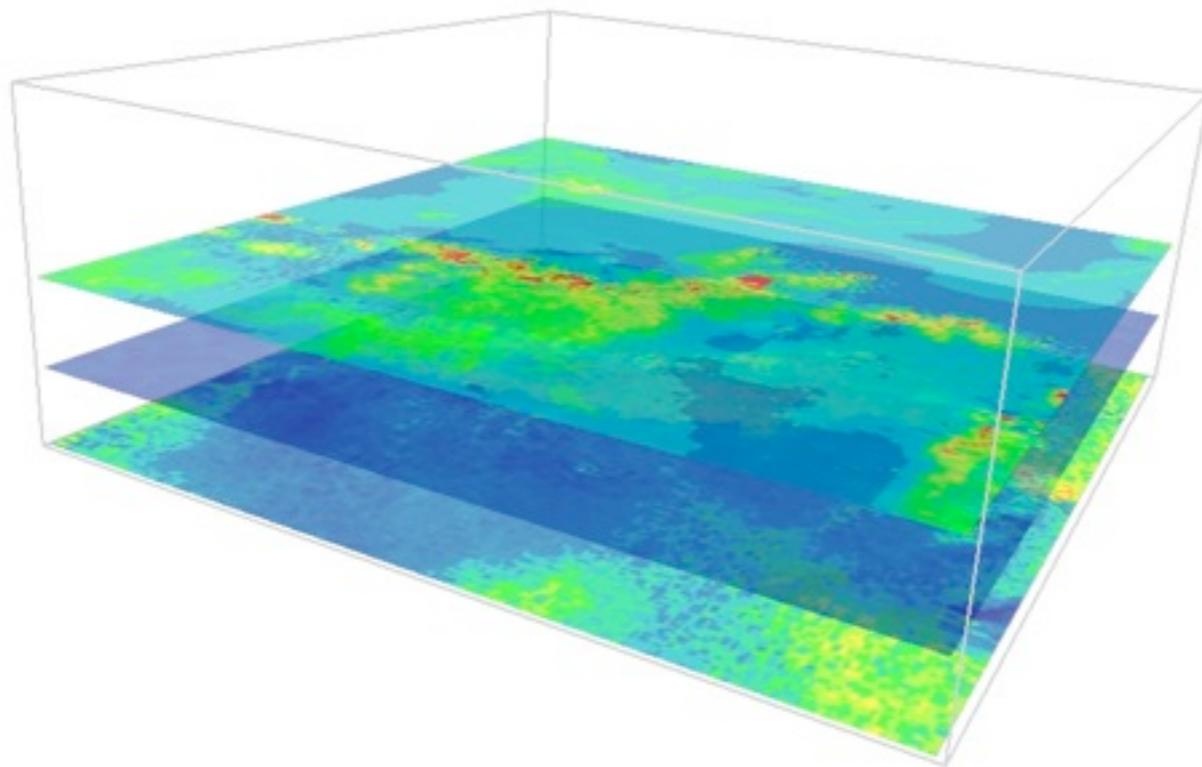
$$\langle f \rangle (z, \theta_{e0}) = \frac{1}{PL_x L_y} \int_0^P \int_0^{L_y} \int_0^{L_x} f(x, y, z, t) \delta(\theta_{e0} - \theta_e(x, y, z, t)) dx dy dt$$

(Pauluis and Mrowiec 2012)

constant equivalent potential temperature



at each z level, at each time step all particles that fall into a given Θ_e bin (0.5 K)



In the process of this conditional averaging the fast oscillatory motions are filtered out from the slower thermodynamically driven circulation.

isentropic analysis of convective motions

This method allows to follow parcels with similar thermodynamic properties even when their trajectories are quite complicated. Reversible buoyant oscillations happen fast, their properties will not change between upward and downward motions, therefore they should get averaged out.

Main updrafts are moist and have high equivalent potential temperature and downdrafts are drier and colder and will get nicely separated in this analysis.

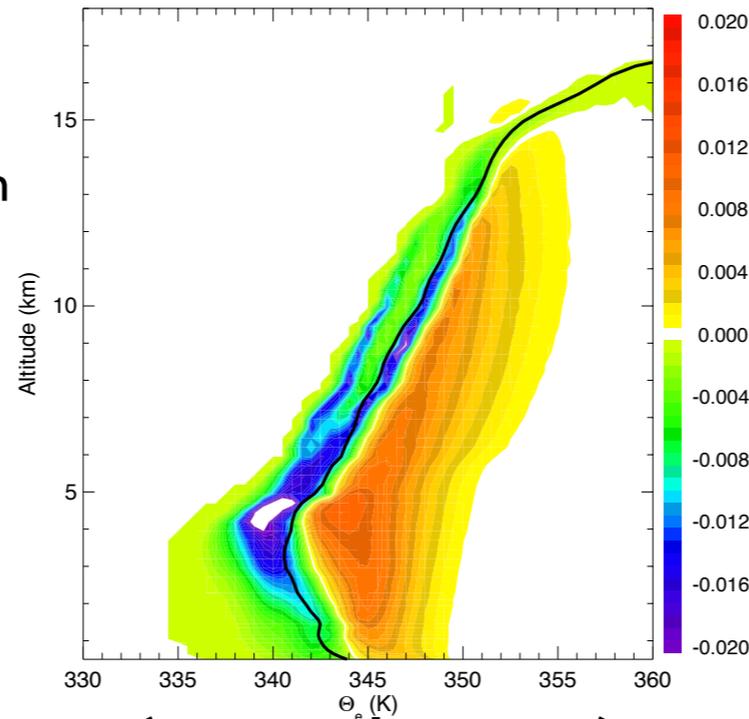
The mean isentropic mass flux may be defined as: $F_M = \langle \rho w \rangle (z, \theta_e)$

and the isentropic streamfunction:
$$\Psi(z, \theta_{e0}) = \int_{-\infty}^{\theta_{e0}} \langle \rho w \rangle (z, \theta'_e) d\theta'_e$$

Isentropic analysis provides a more direct Lagrangian description of a flow, but in an averaged sense. The spatial information is lost.

isentropic mass flux

Total

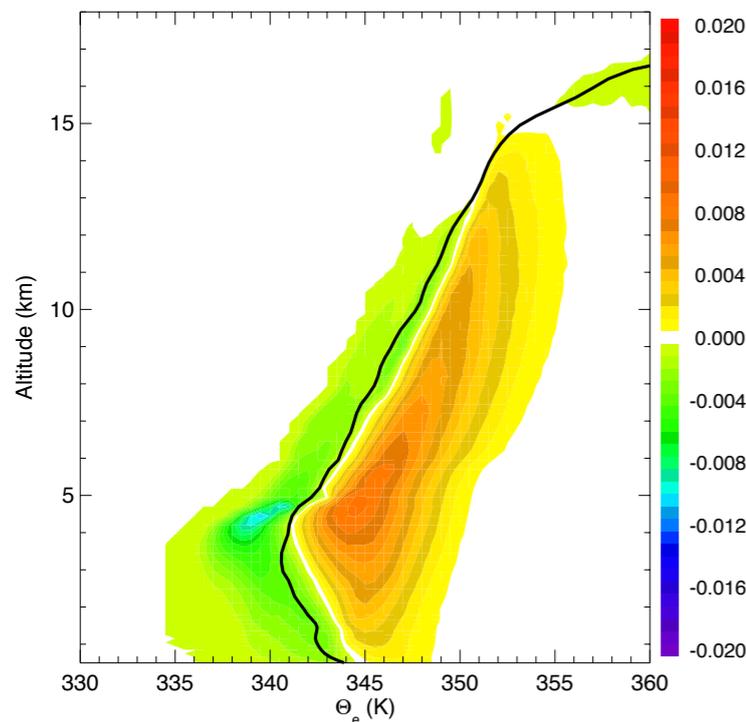


majority of the upward mass flux in C
strongest C fluxes initiated at about 5km
weak S ascent
no ascent in NP region
S downdrafts more mass flux than C
downdrafts

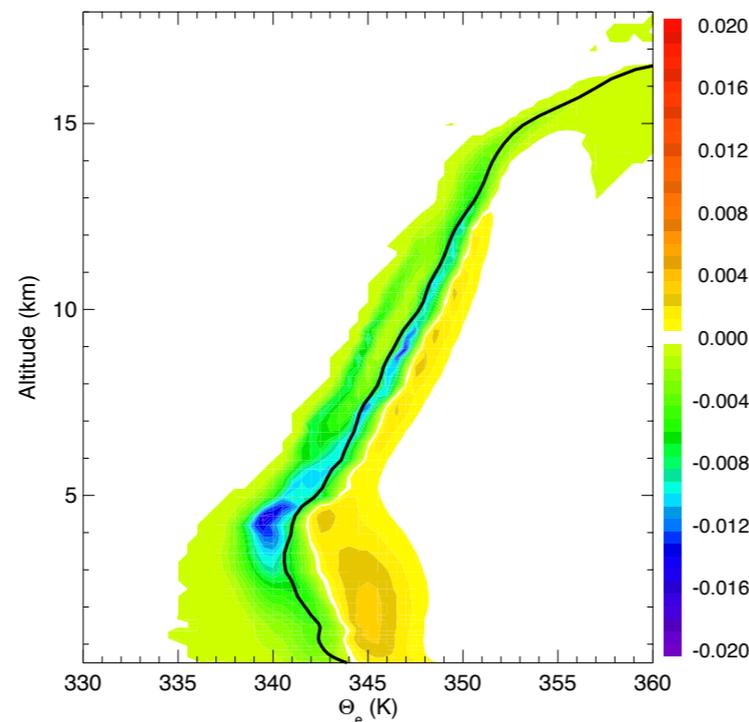
a significant overturning in the stratiform boundary layer - shallow convection after all?

upper level descent in S and NP has double minima - due to initial subsidence and then main convective burst that mixes up and warms the troposphere causing descent to be closer to the environmental mean

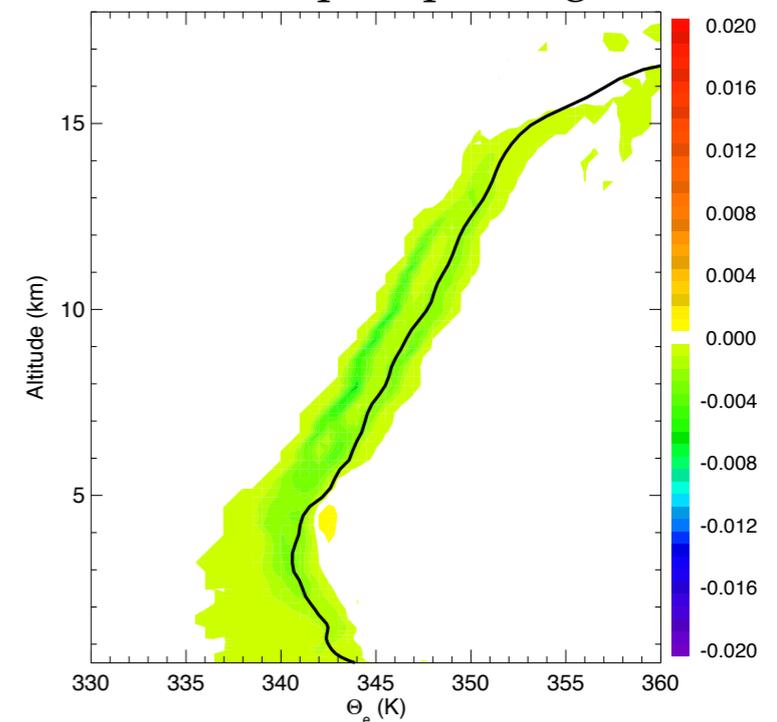
Convective (C)



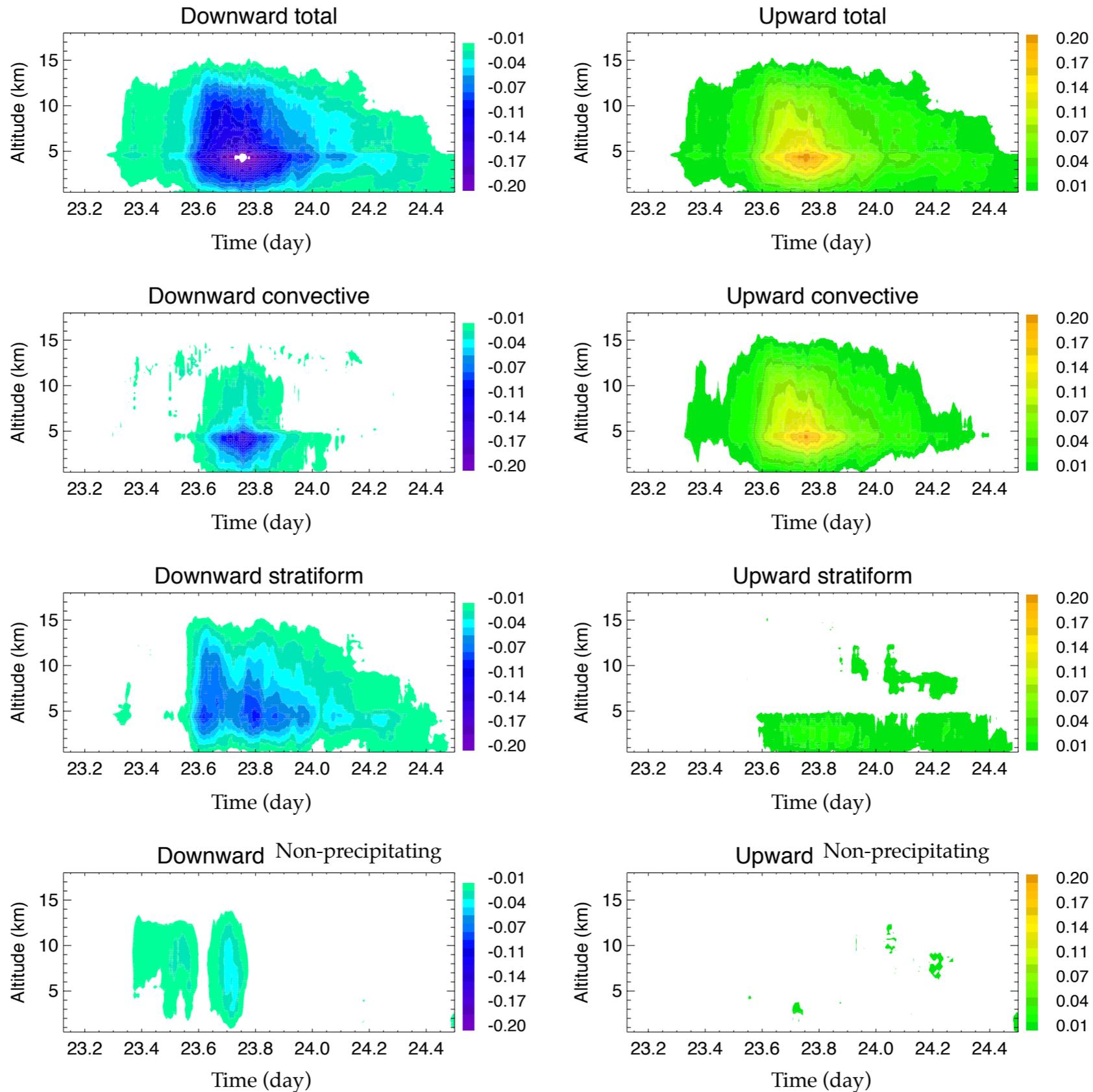
Stratiform (S)



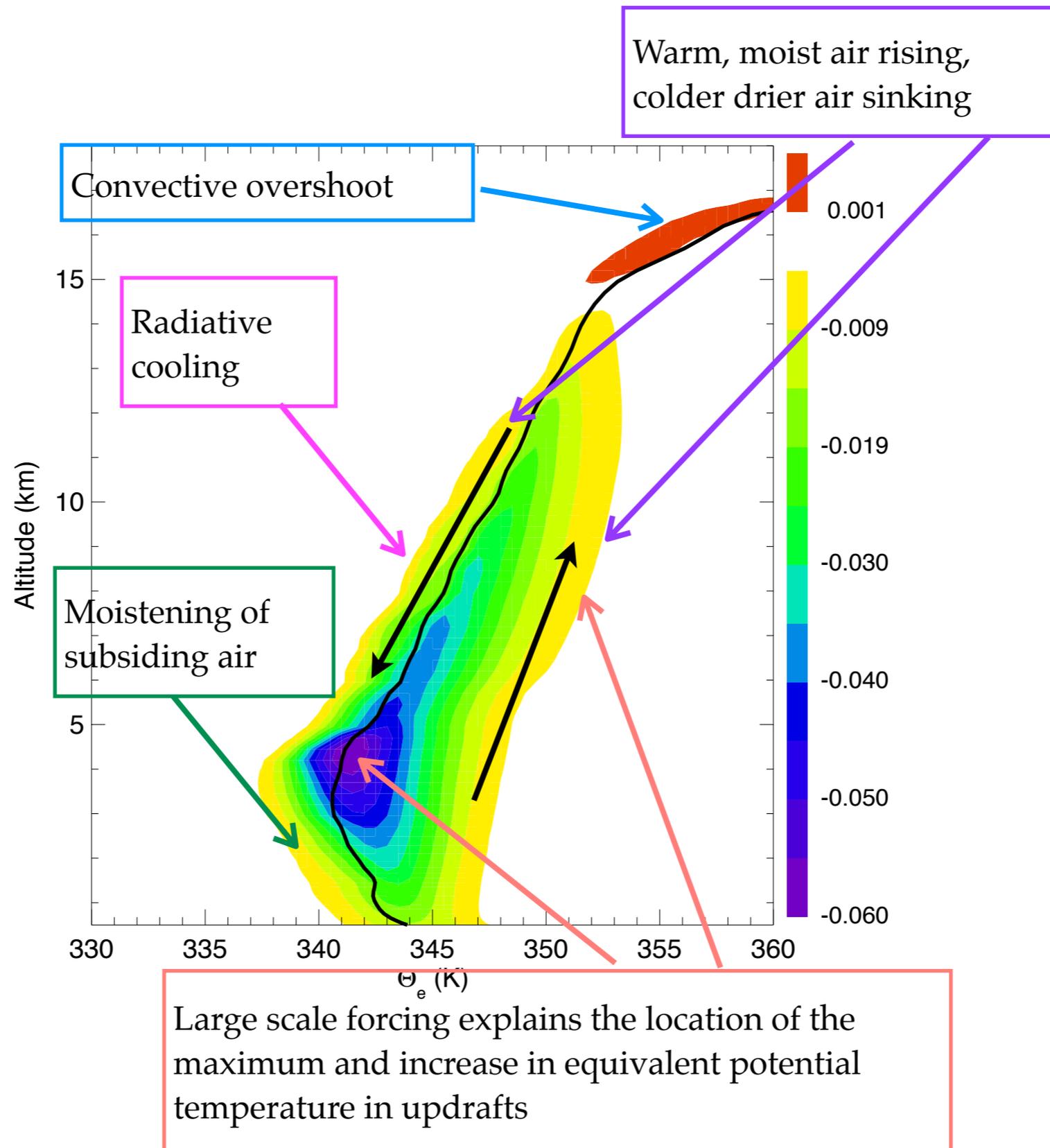
Non-precipitating (NP)



isentropic mass flux time series

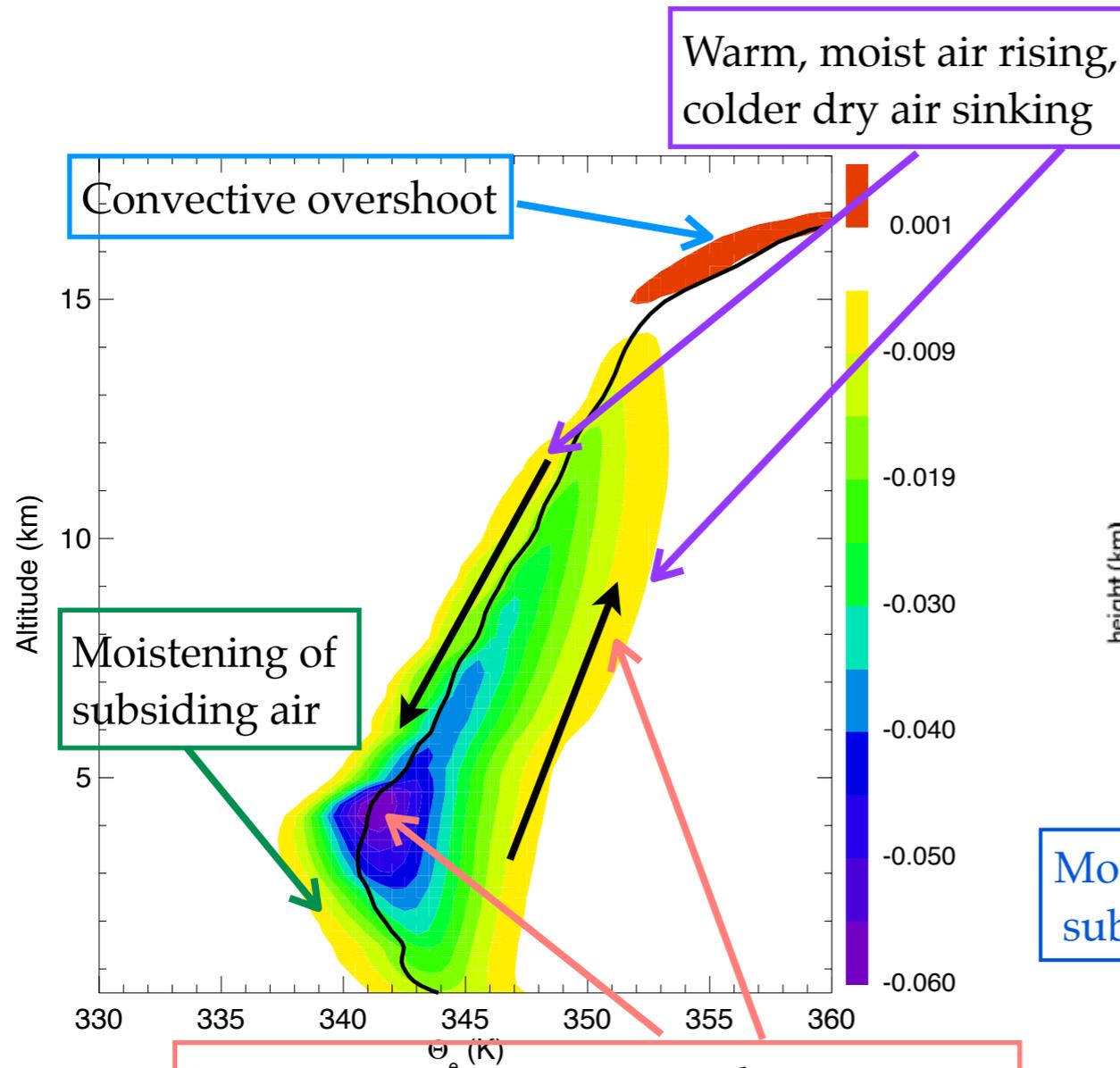


isentropic streamfunction

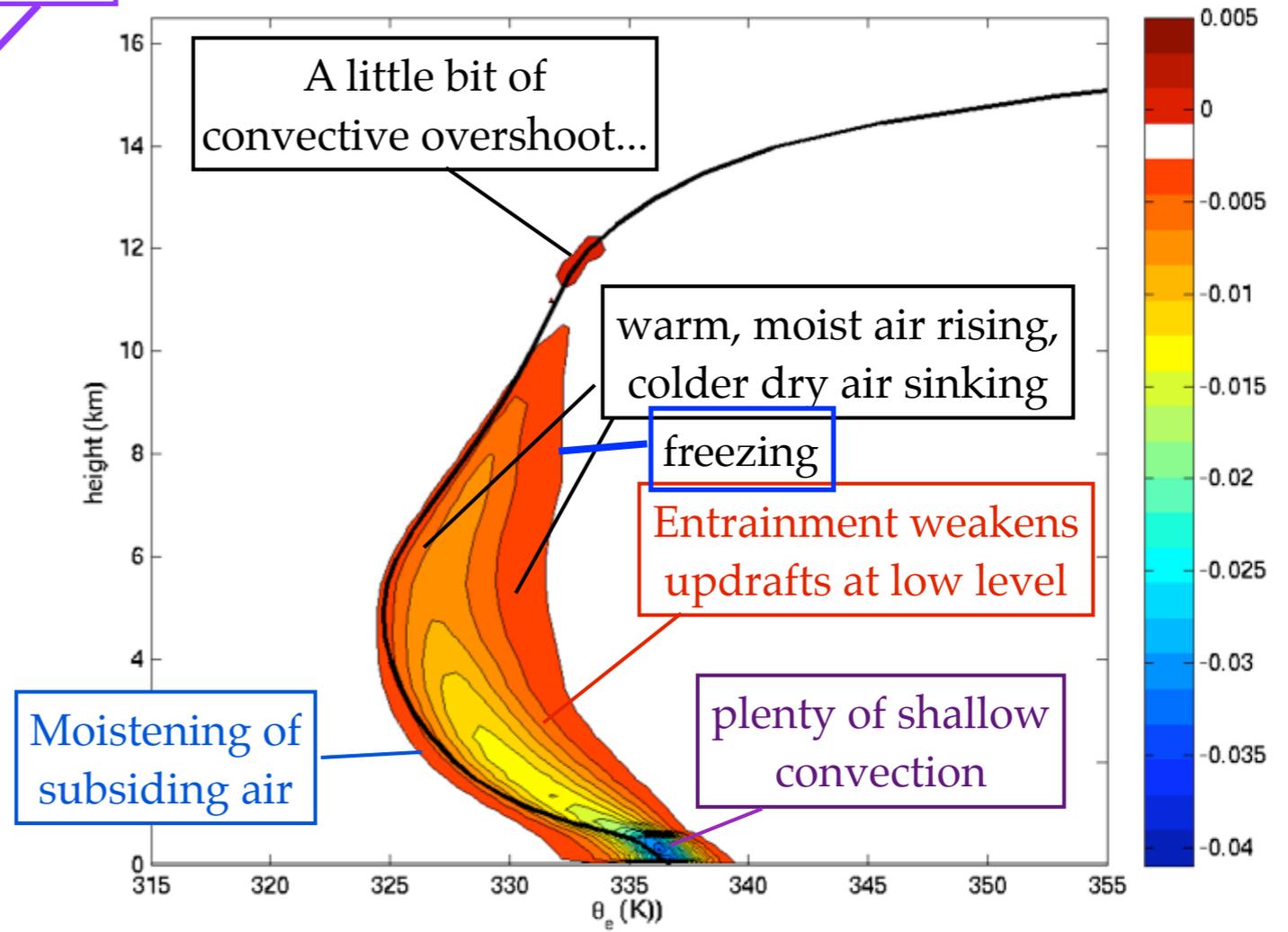


isentropic streamfunction

TWP-ICE

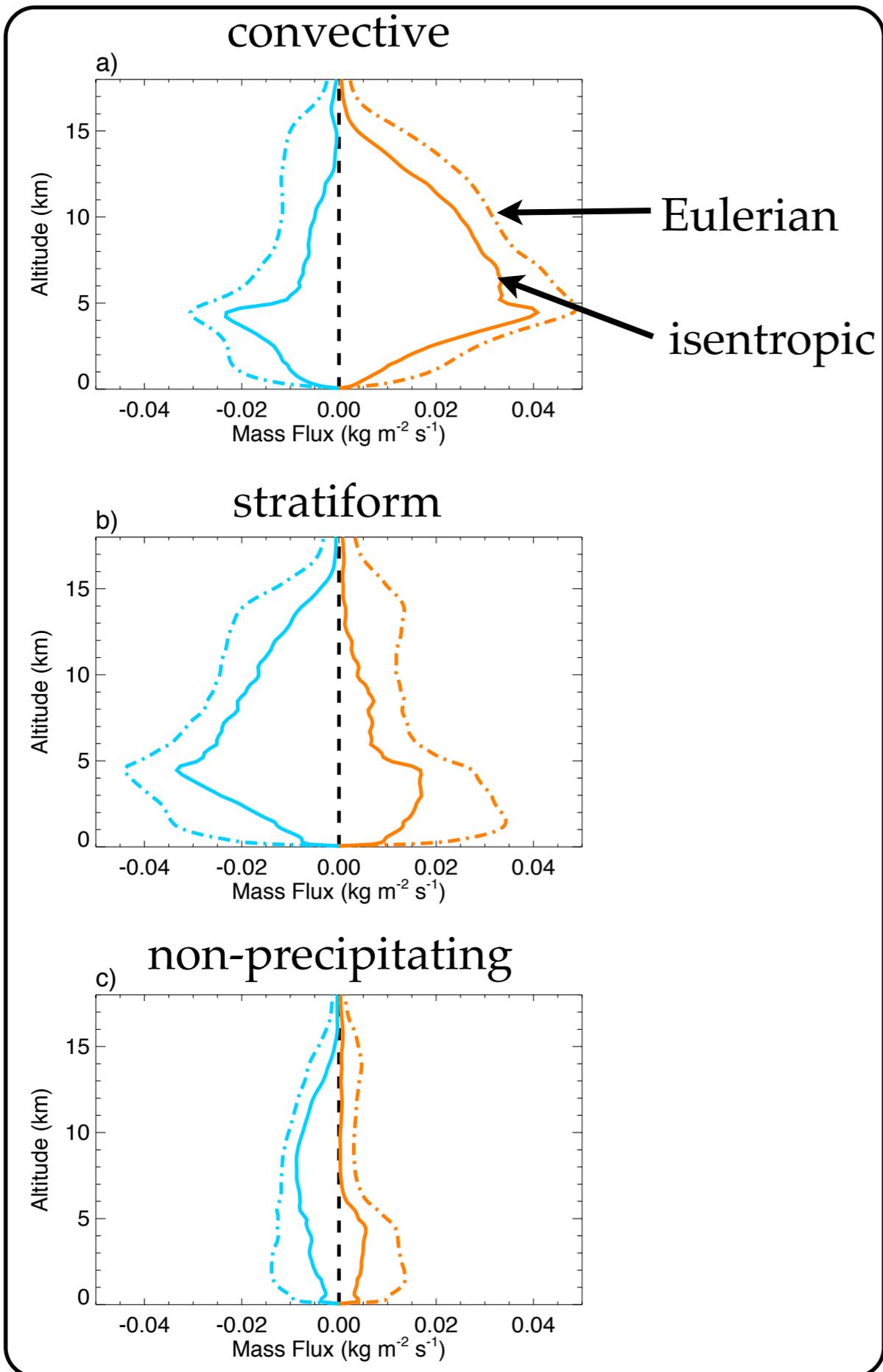


RCE



(Pauluis and Mrowiec 2012)

isentropic vs. eulerian mass flux



as expected the isentropic mass fluxes are smaller

the same amount of mass flux is removed from upward and downward components

stratiform updrafts are greatly reduced

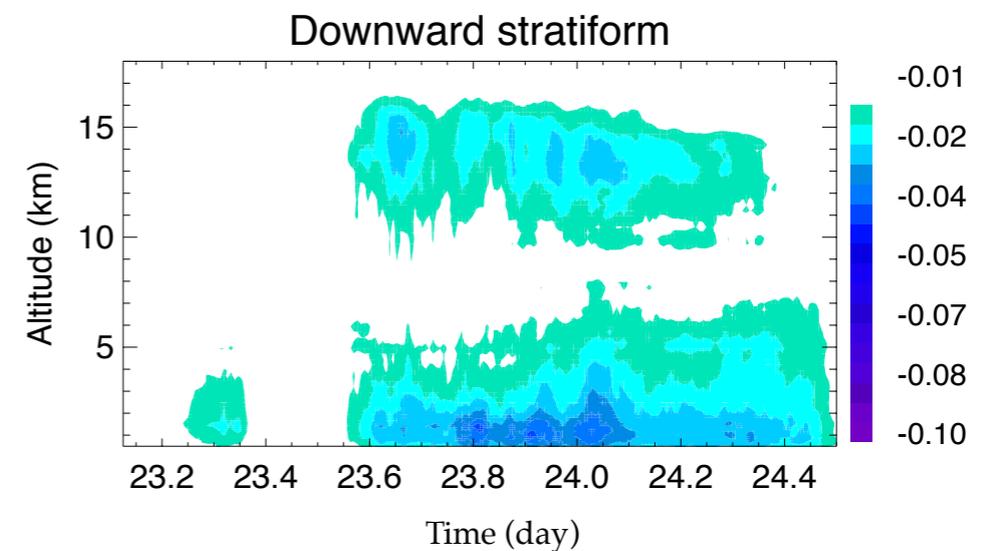
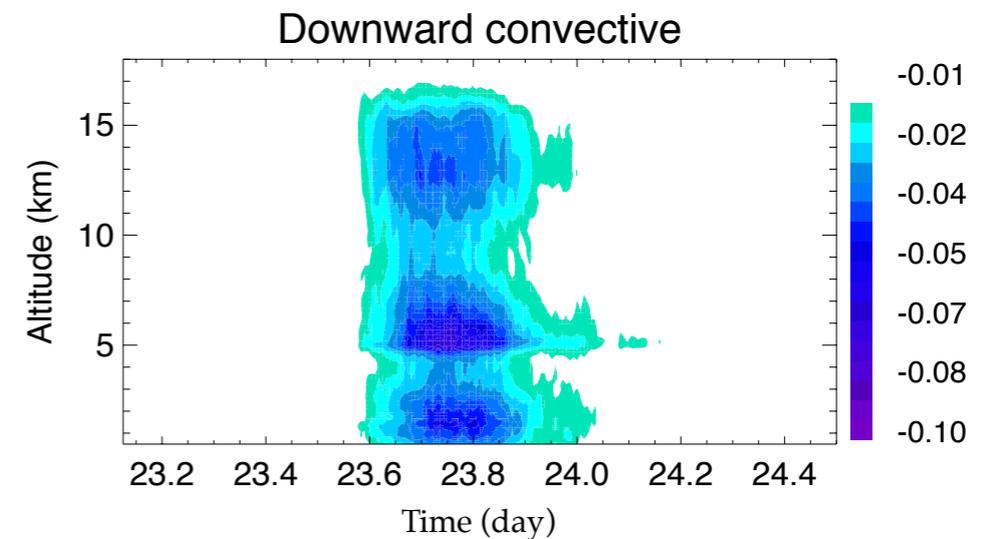
non-precipitating region dominated by the large scale subsidence

isentropic vs. eulerian mass flux difference

in **convective** region oscillations co-located with the main convective burst with the maxima near the surface, near the tropopause and at about 5km where the updrafts are initiated and where the forcing is strong.

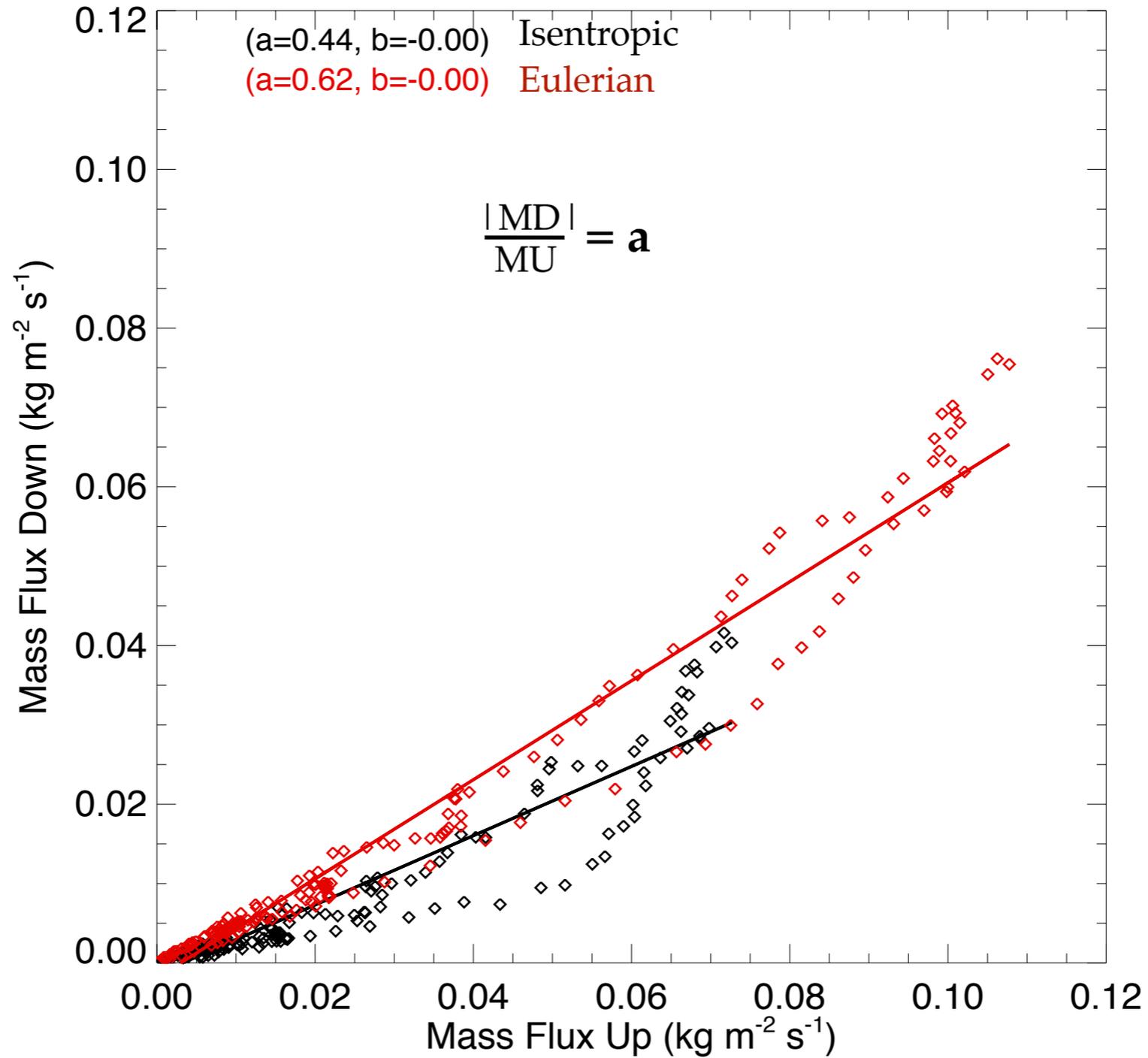
in the **stratiform** region there are two major regions of wave activity: in the boundary layer and near the tropopause.

Eulerian - isentropic time series



convective region downdraft to updraft mass flux ratio

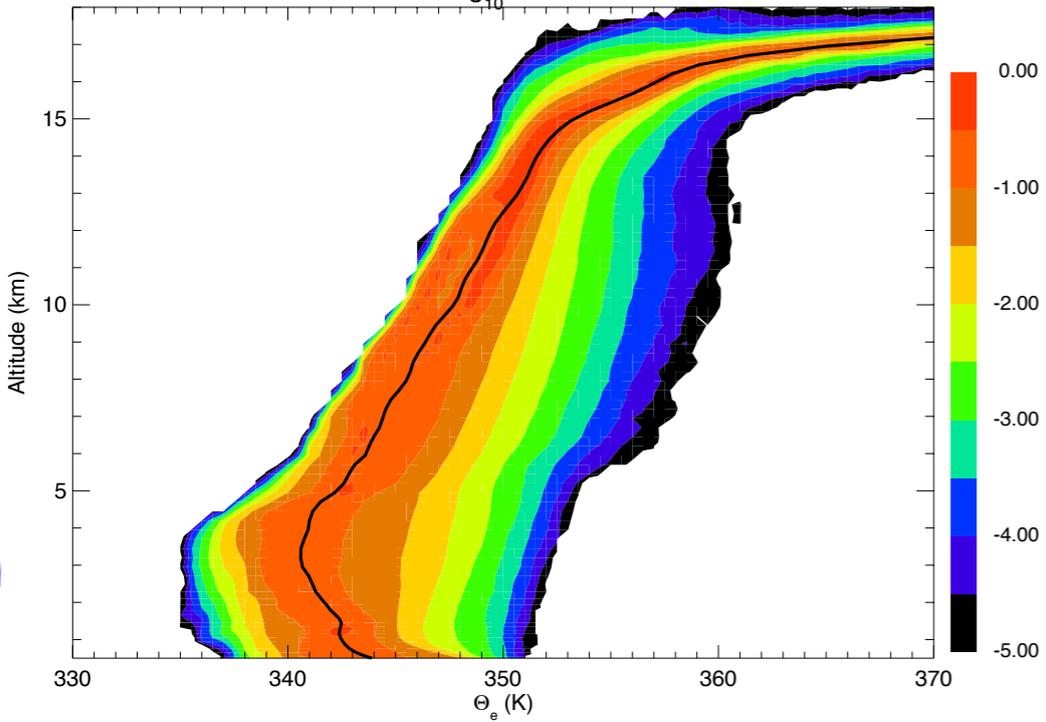
How much convective downdraft is there?



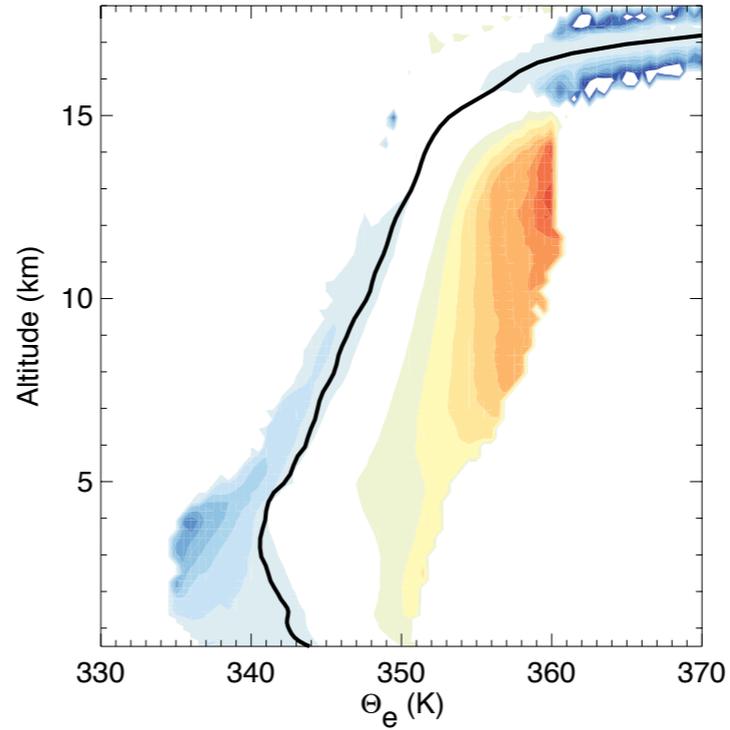
other parameters

convective

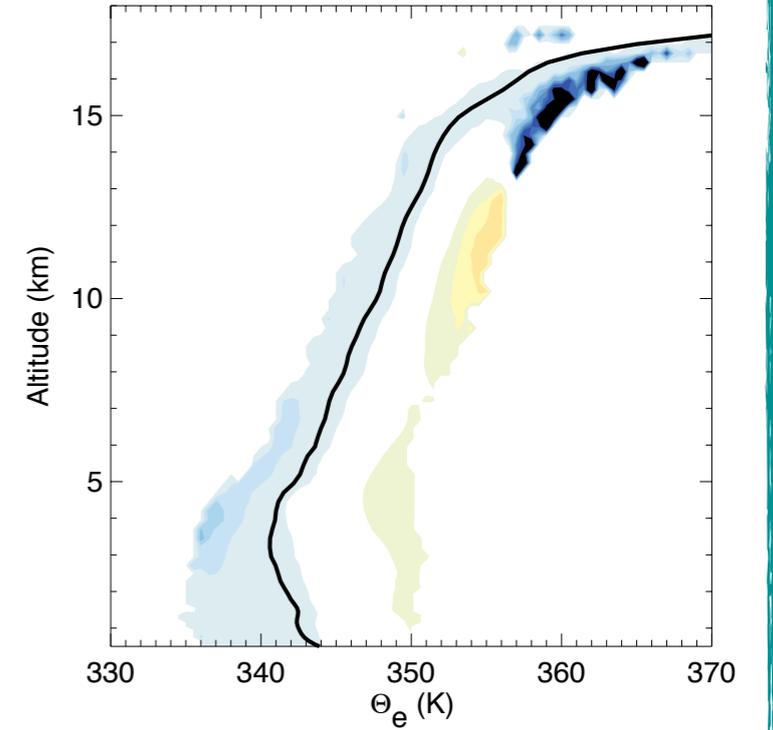
\log_{10} PDF



Convective



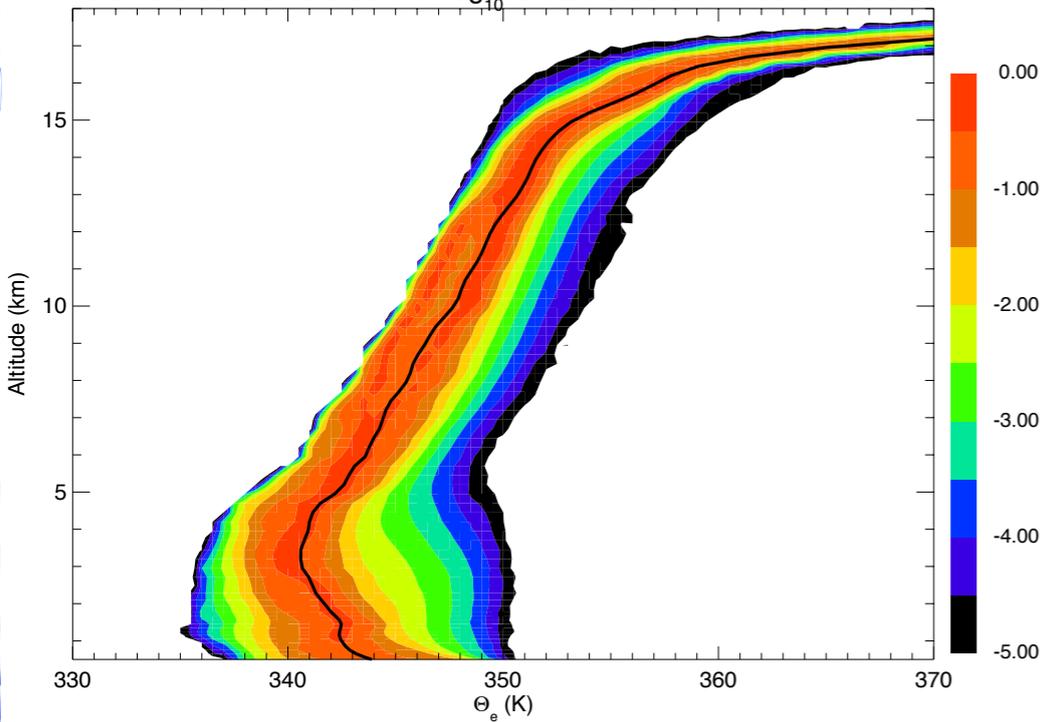
Stratiform



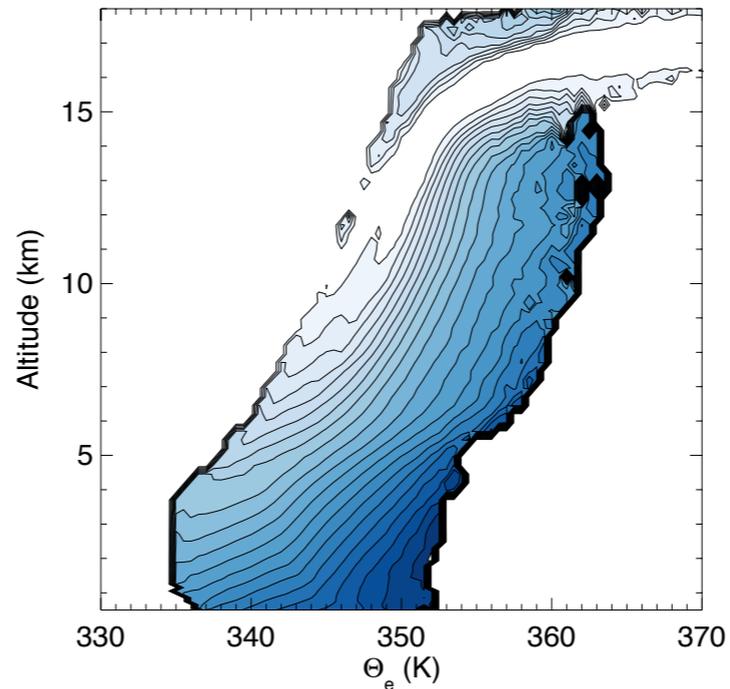
Vertical Velocity (m s^{-1})

stratiform

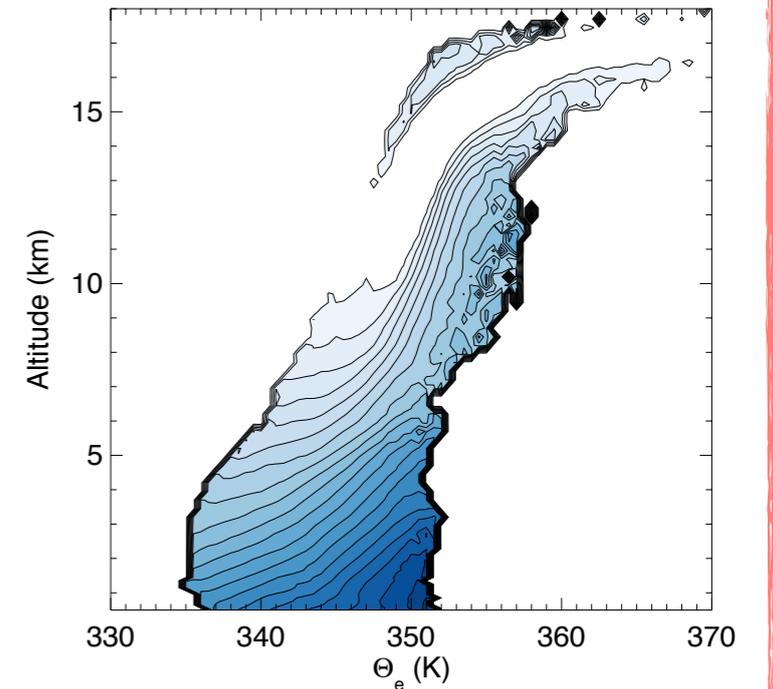
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Convective



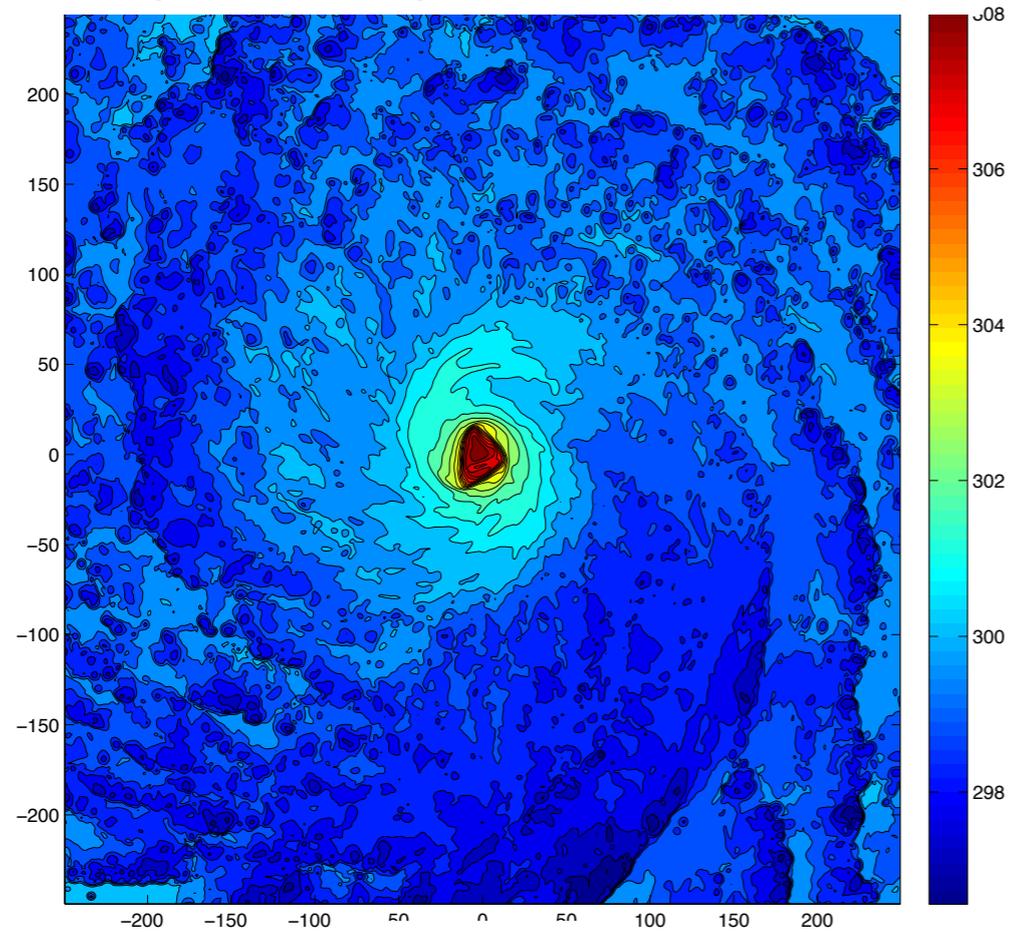
Stratiform



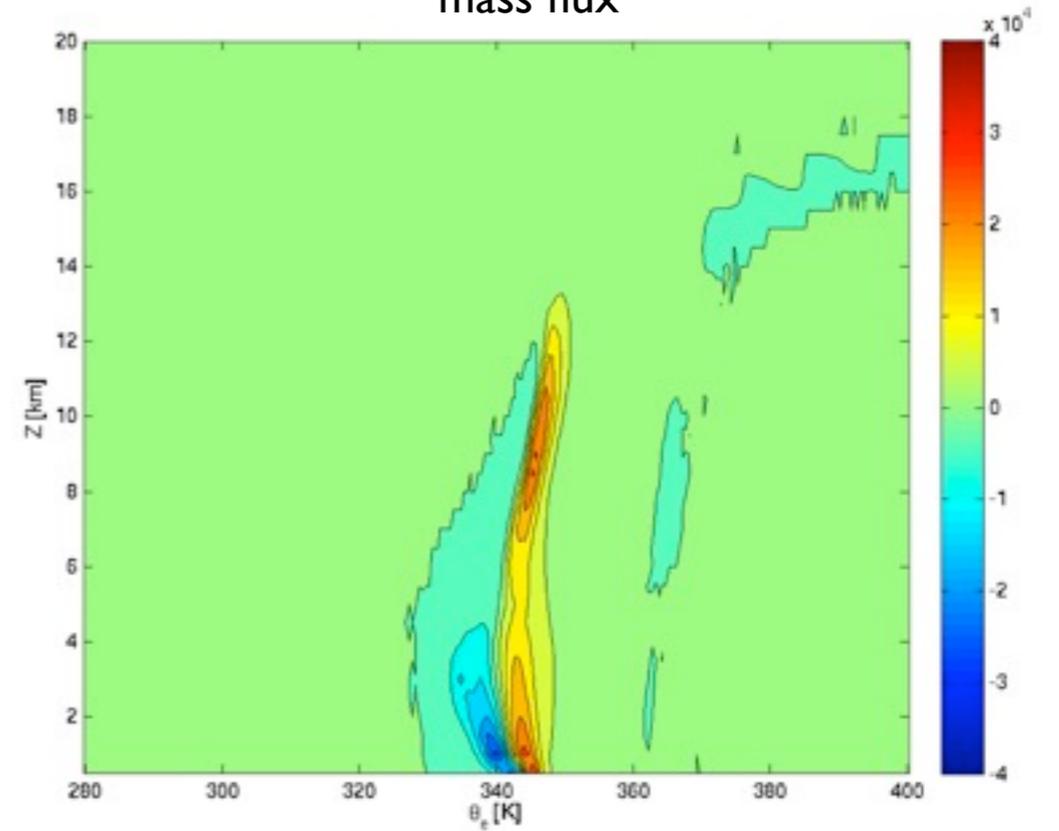
Total Water mixing ratio (g kg^{-1})

other applications: hurricane simulations

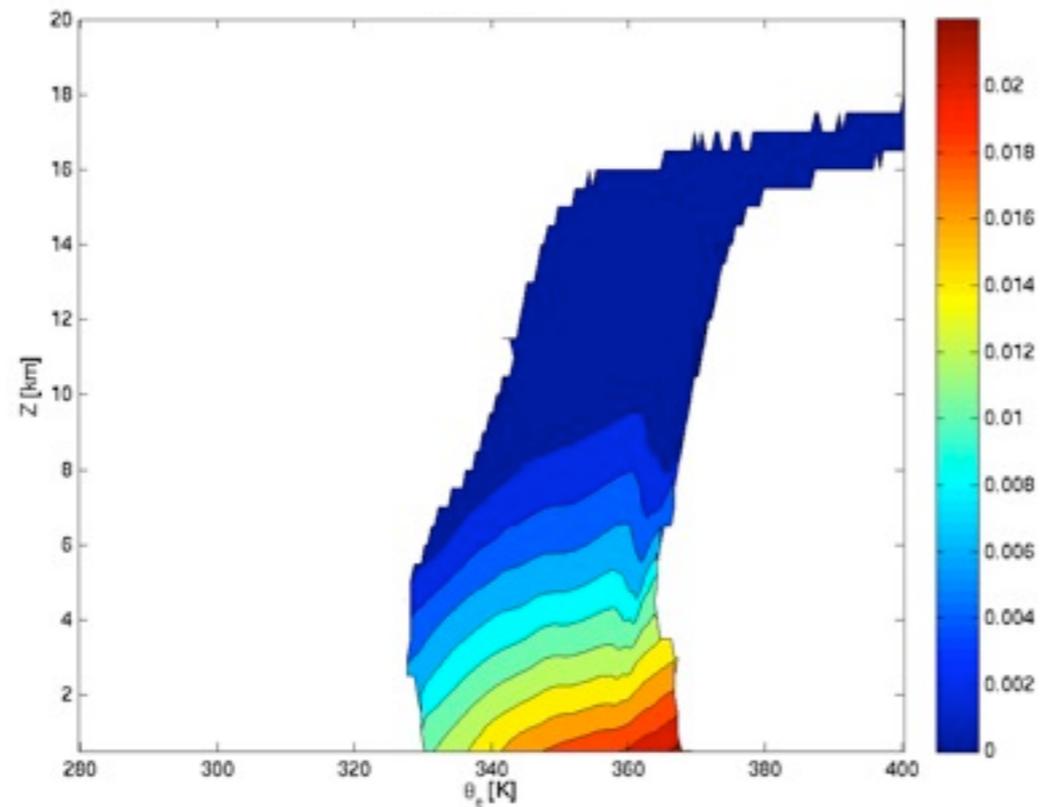
potential temperature at the surface



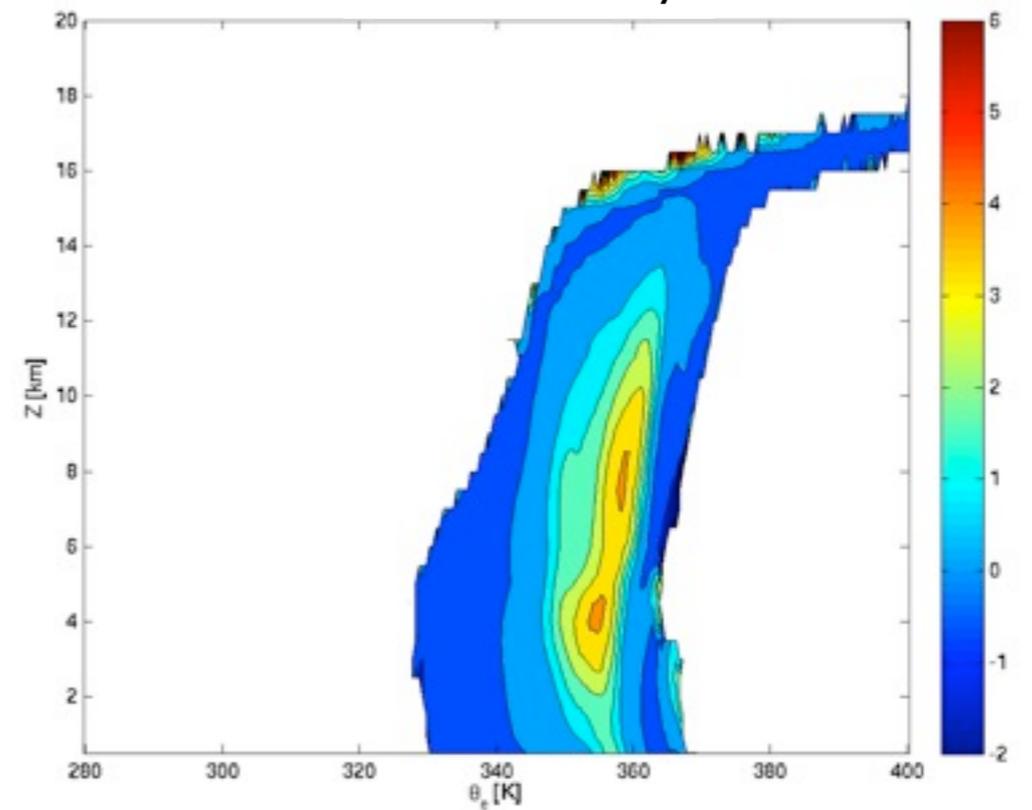
mass flux



water vapor



vertical velocity



Summary

- We introduce an isentropic analysis of convective systems by conditionally averaging the properties of the flow along the equivalent potential temperature lines
- We can study properties of thermodynamically similar air parcels and separate between warm, moist updrafts and cool drier downdrafts - which are fundamental aspects of moist convection
- We define isentropic streamfunction which depicts the convective overturning
- We determine the mean values of rising and subsiding parcels (vertical velocity, buoyancy, humidity and hydrometeors mixing ratios)
- We find that after the removal of reversible oscillations the ratio of downward to upward mass flux decreased from 0.6 to 0.4 - in this model, under monsoon conditions
- Isentropic analysis of convective motions can be used as a basis for comparison between cloud resolving models and cloud resolving model evaluation tool