Analysis of cloud-resolving simulations of a tropical mesoscale convective system observed during TWP-ICE: Vertical fluxes and draft properties in convective and stratiform regions (submitted, JGR)

http://pubs.giss.nasa.gov/authors/amrowiec.html

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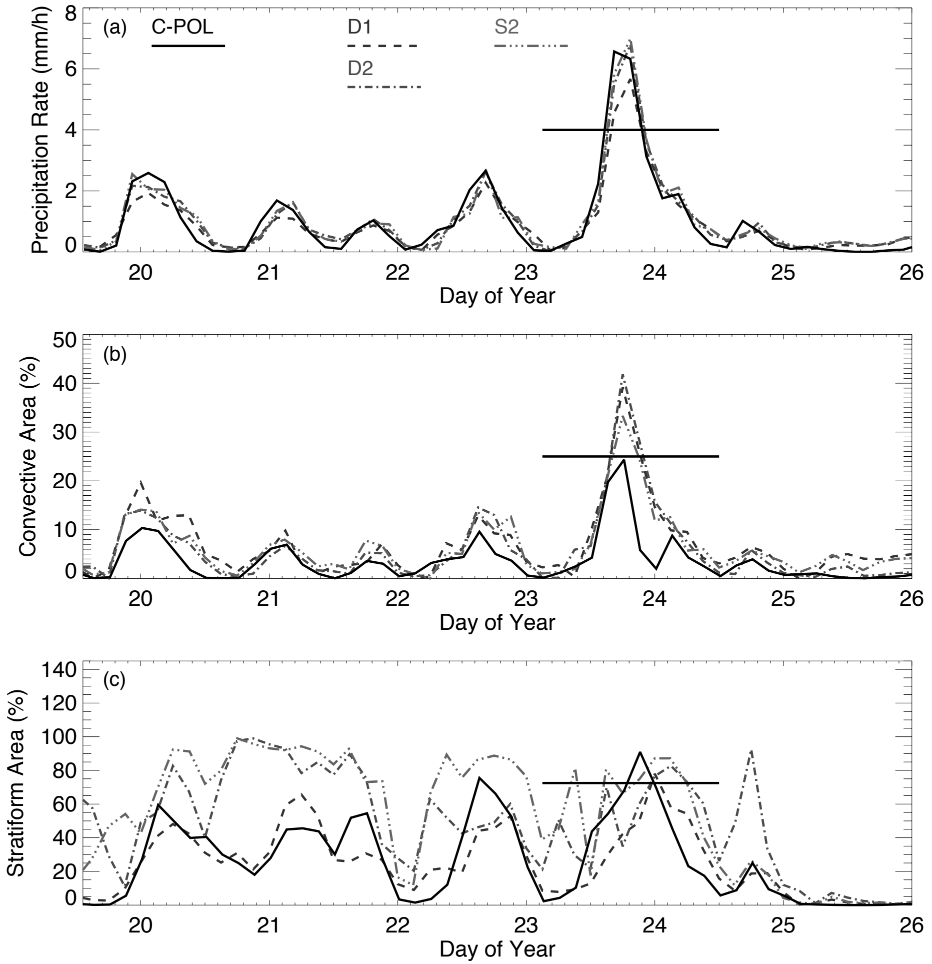
Structure of our study

We analyze three cloud-resolving model simulations of a strong convective event observed during the TWP-ICE campaign, differing in dynamical core, microphysical scheme or both.

We partition the cloud field into stratiform and convective regions using Steiner algorithm and comparison of the convective system's components among the models, including convective updrafts and downdrafts, stratiform updrafts and downdrafts and cold pools.

We discuss the relationship between updrafts and downdrafts in the convective region.



Based on simulated and observed radar reflectivity fields, simulations roughly reproduce observed convective and stratiform areal coverages.

Convective and stratiform updrafts and downdrafts in SAM

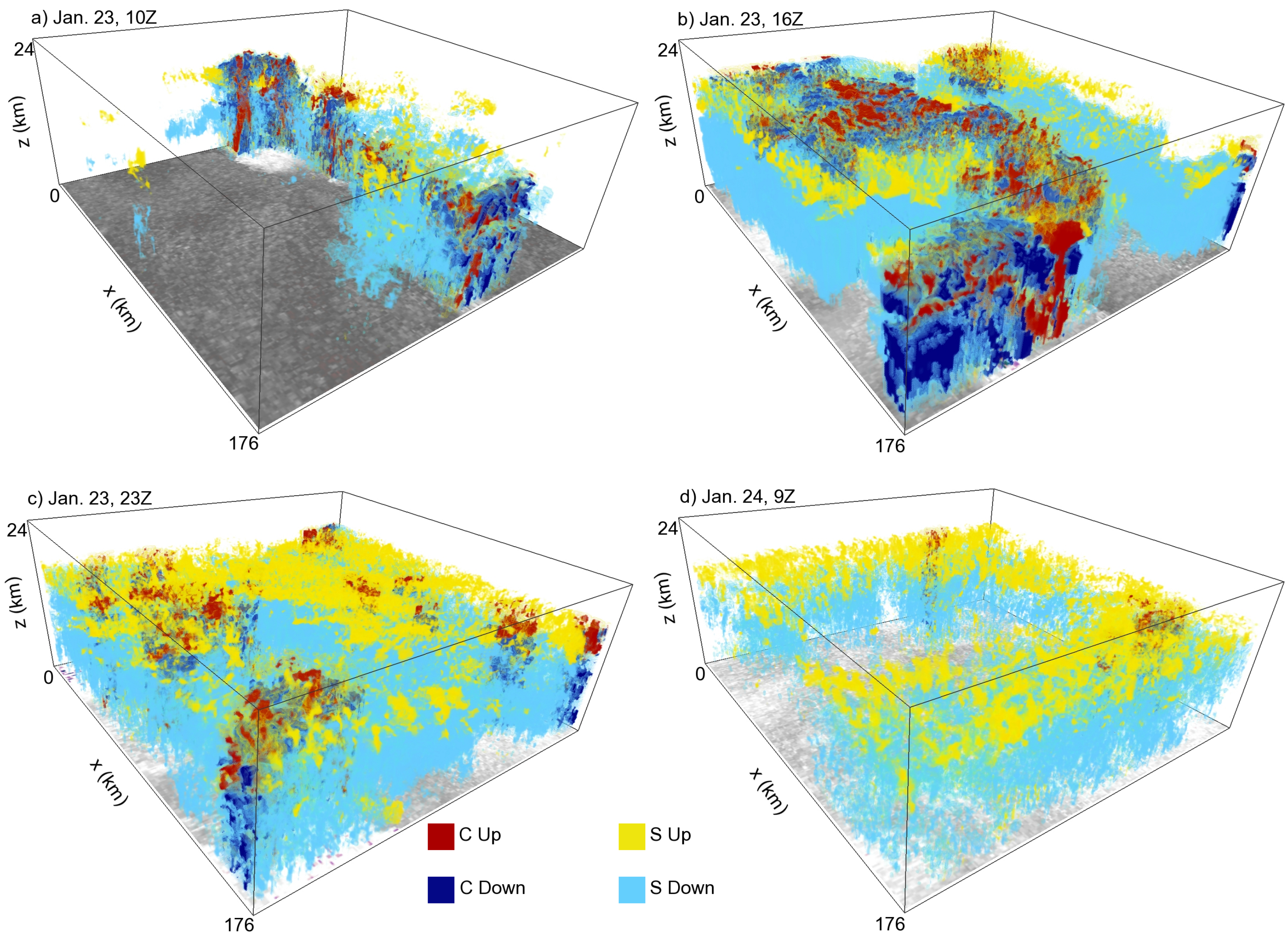
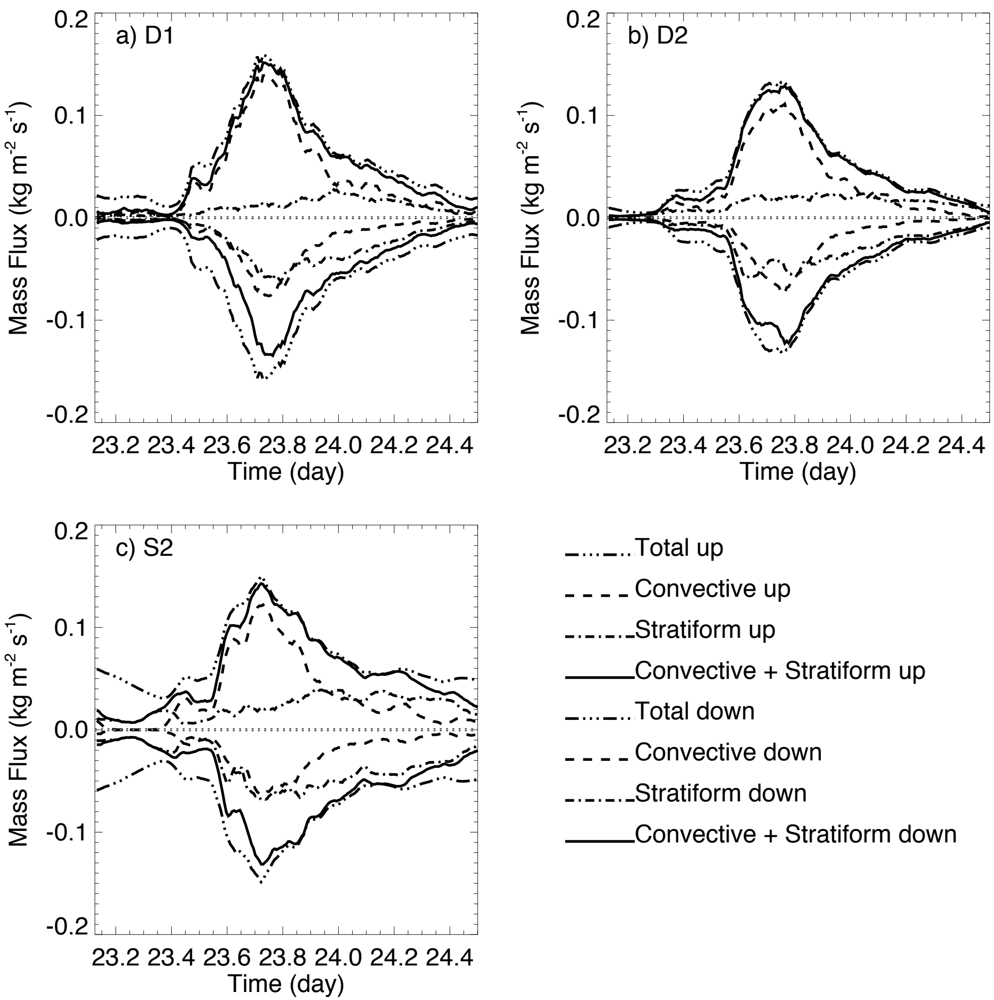


Figure made with VAPOR

Mass fluxes evolution during event C

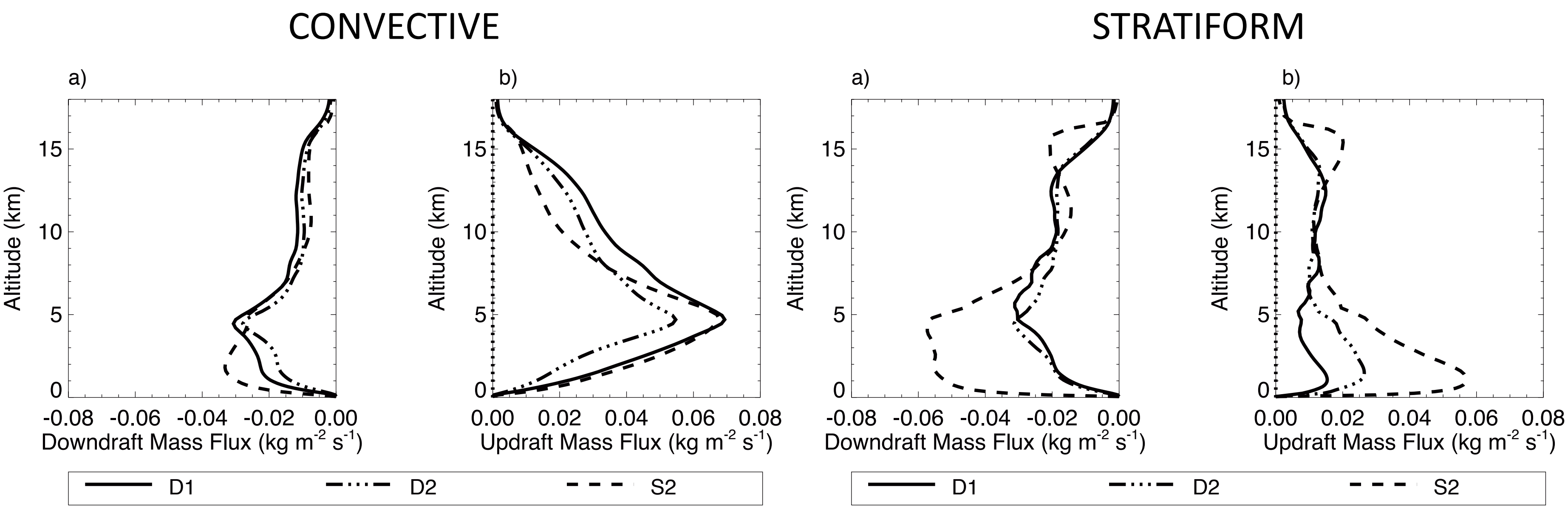


During the buildup stage and the peak of the event, most of the updraft mass flux is carried by the convective.

Stratiform updraft mass flux becomes comparable to convective mass flux during later stages of the event, after January 23. Convective and stratiform downdraft mass fluxes are similar during the buildup and peak of the event.

Many past studies (Johnson84, Houze89, Cheng89, Gray00) have shown that the stratiform region contribution to total mass flux in MCSs is non-negligible.

Mass fluxes during event C



To identify the characteristics of convective and stratiform drafts, independent vertical wind speed thresholds are calculated to capture 90% of total convective and stratiform updraft and downdraft fluxes.

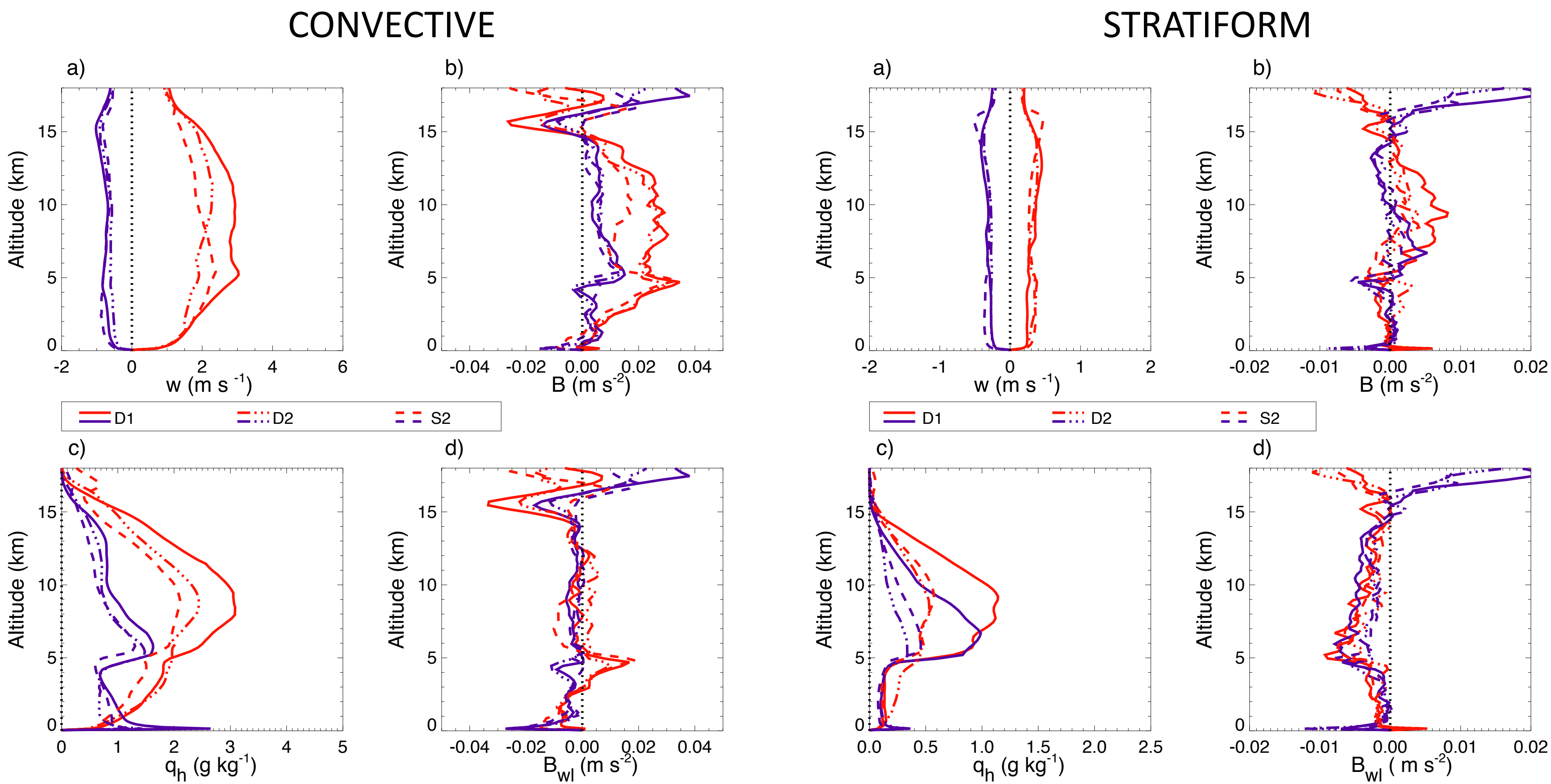
Convective downdrafts and stratiform updrafts and downdrafts mass fluxes vary notably below below the melting level.

Updraft and downdraft properties

Convectives downdraft and stratiform updrafts and downdrafts share similar vertically uniform draft velocities despite differing hydrometeor loadings.

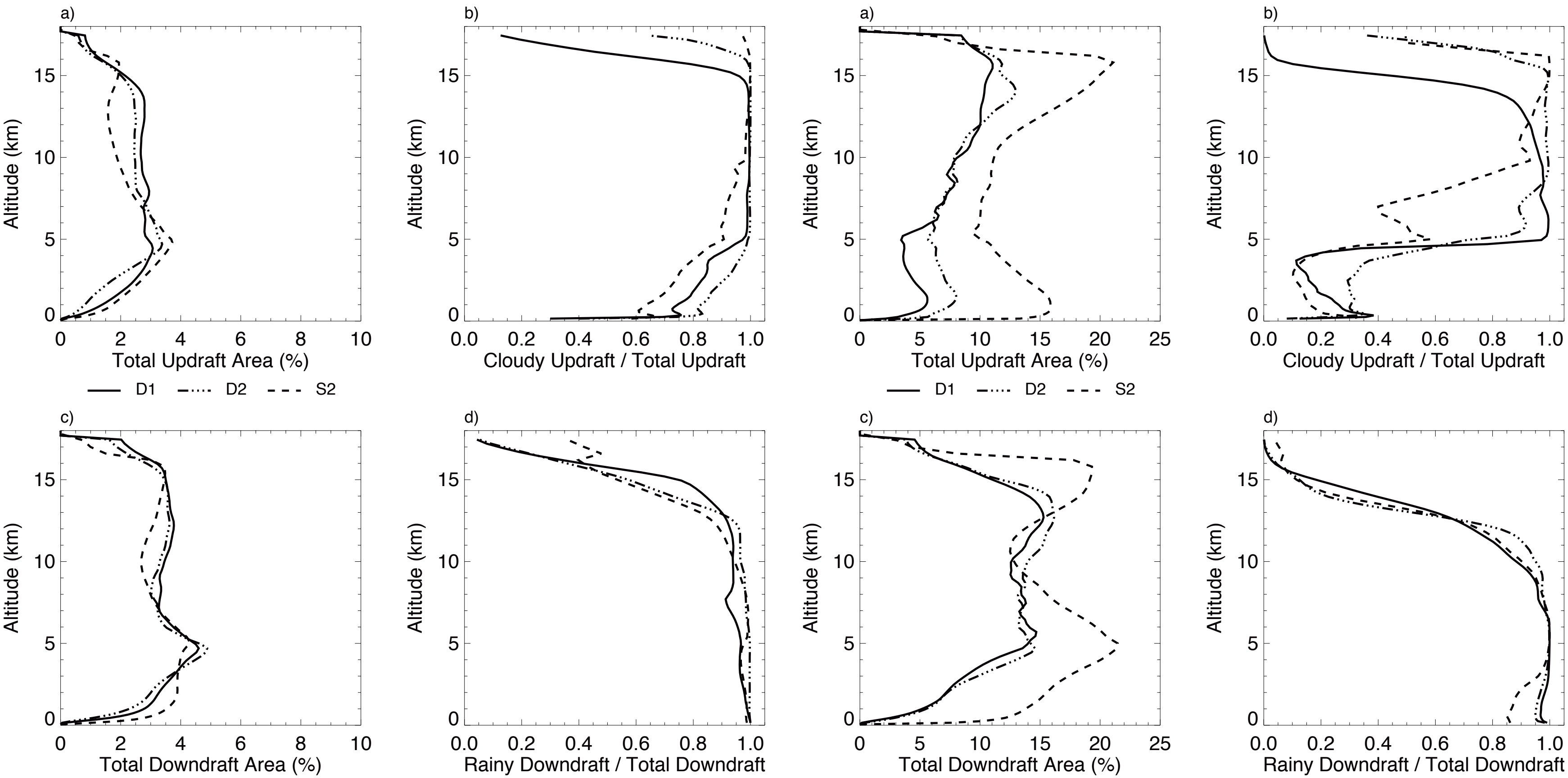
Water loading impacts updraft buoyancy

Signature of gravity waves above 16 km in negatively buoyant updrafts and positively buoyant downdrafts



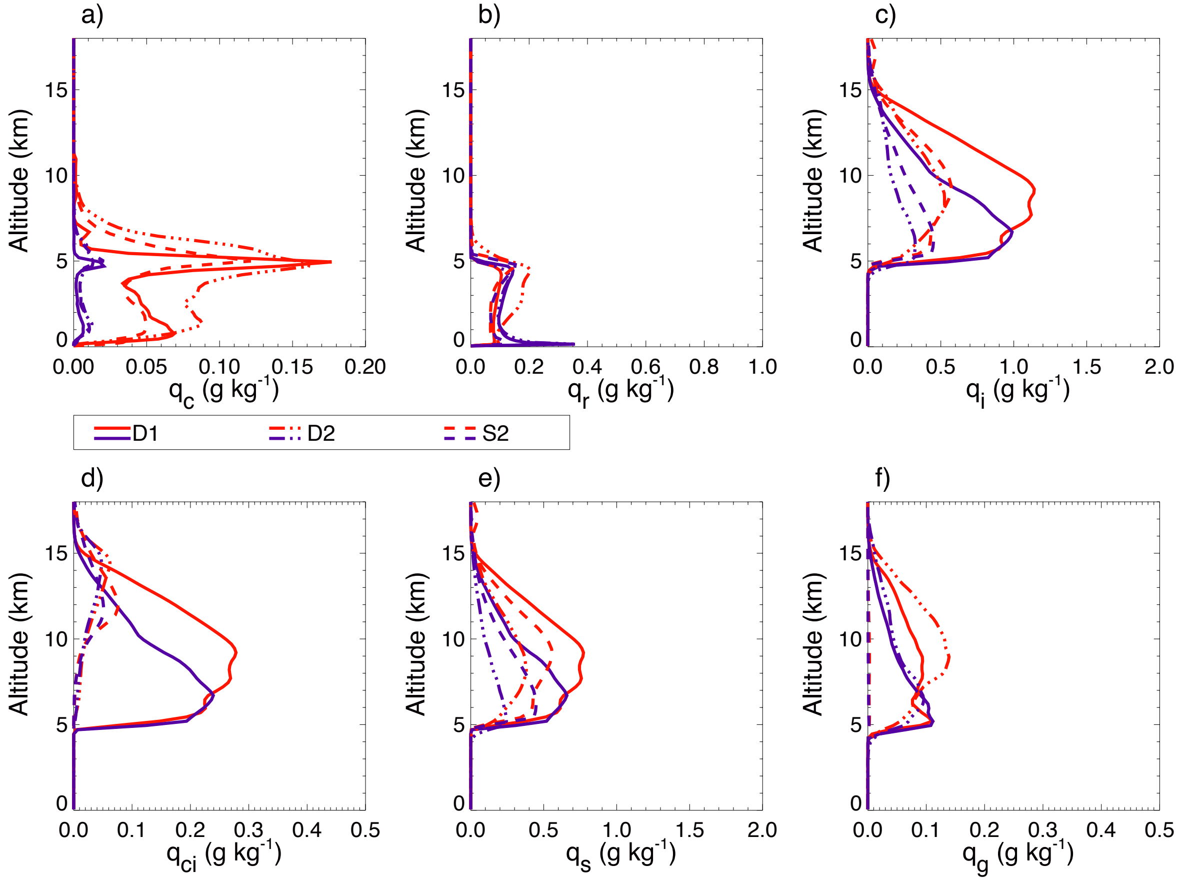
Cloudy updrafts and precipitating downdrafts

CONVECTIVE STRATIFORM



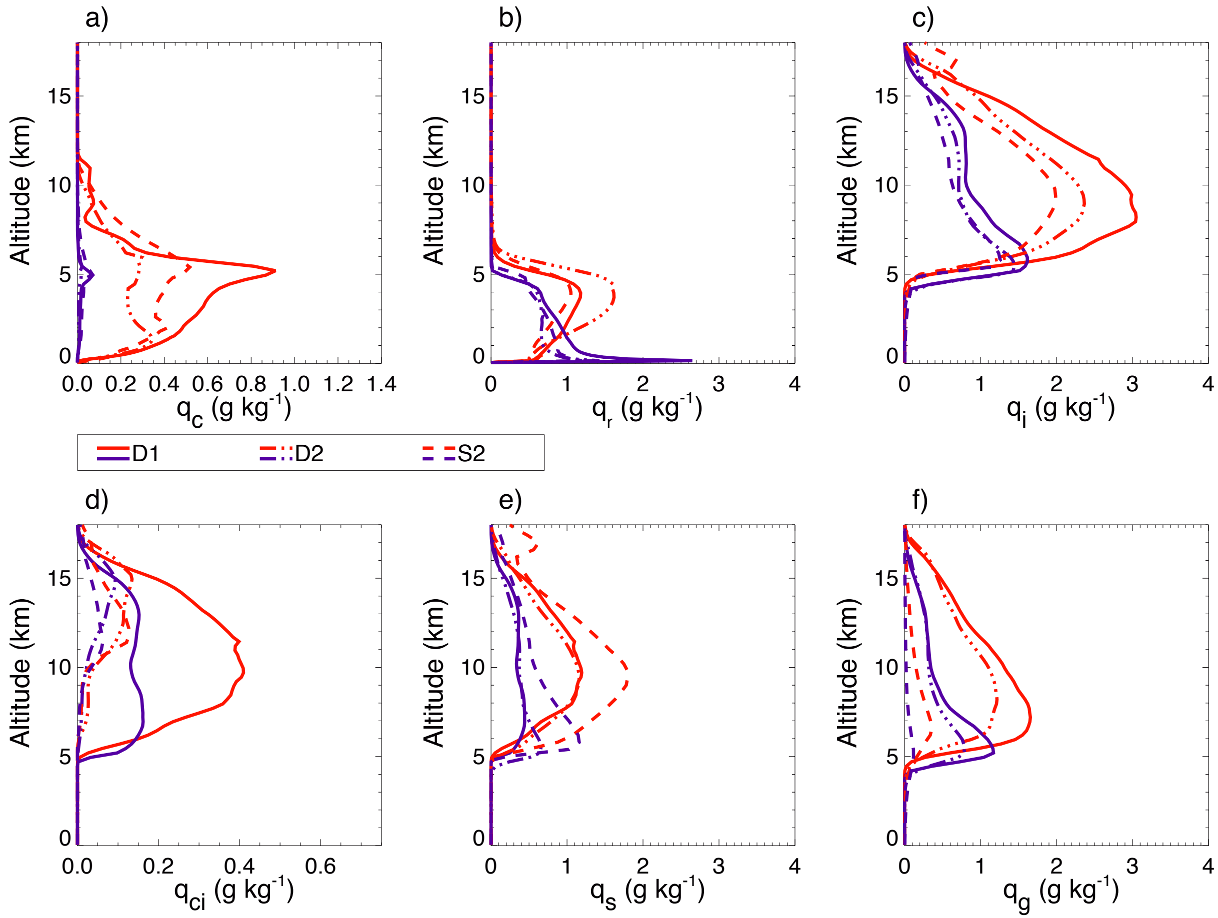
All convective and stratiform downdrafts contain precipitation below ~10 km and nearly all updrafts are cloudy above the melting level.

Convective mass mixing ratios



The vertical distribution of cloud water (a) in updrafts is very similar in the boundary layer for all models but above 2 km it departs in D1. There is almost no cloud water in the convective downdrafts. The rain water mixing ratio profile (b) is similar across the simulations.
The total ice mixing ratio profiles (c) are comparable in all simulations, but the partitioning into cloud ice, snow and graupel (bottom row) shows large differences.

Stratiform mass mixing ratios

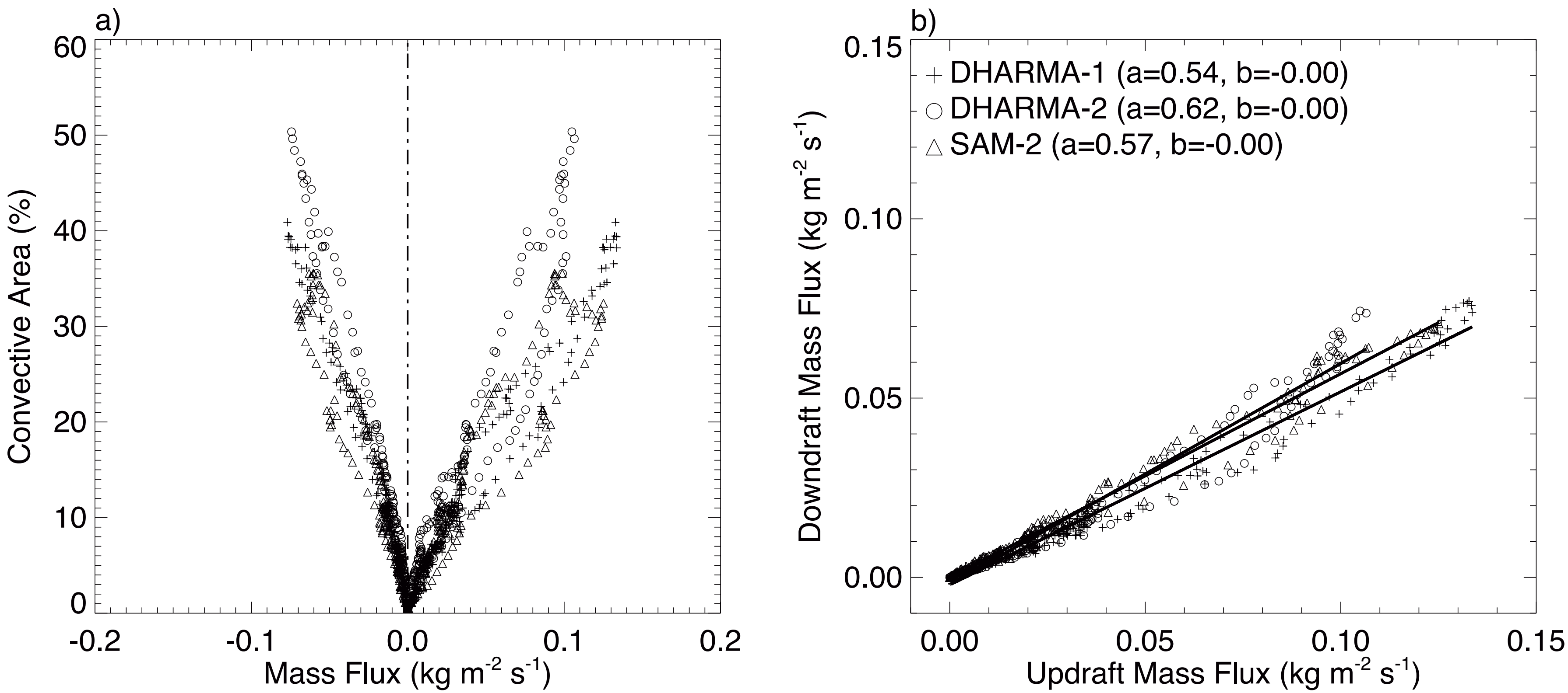


Cloud water (a) and rain (b) are much reduced in the stratiform region for updrafts and downdrafts relative to the convective region. Most condensed water is in the form of ice (c). Most of the cloud ice (d) in the models with two-moment schemes is located in the upper troposphere. Simulations have similar vertical profiles for snow (e) in updrafts and downdrafts. Graupel (f) is the least abundant.

Statistical relationships in convective updrafts and downdrafts

Despite differences in hydrometeor loadings and cold pool properties, the convective updraft and downdraft mass fluxes are roughly linearly correlated with convective area.

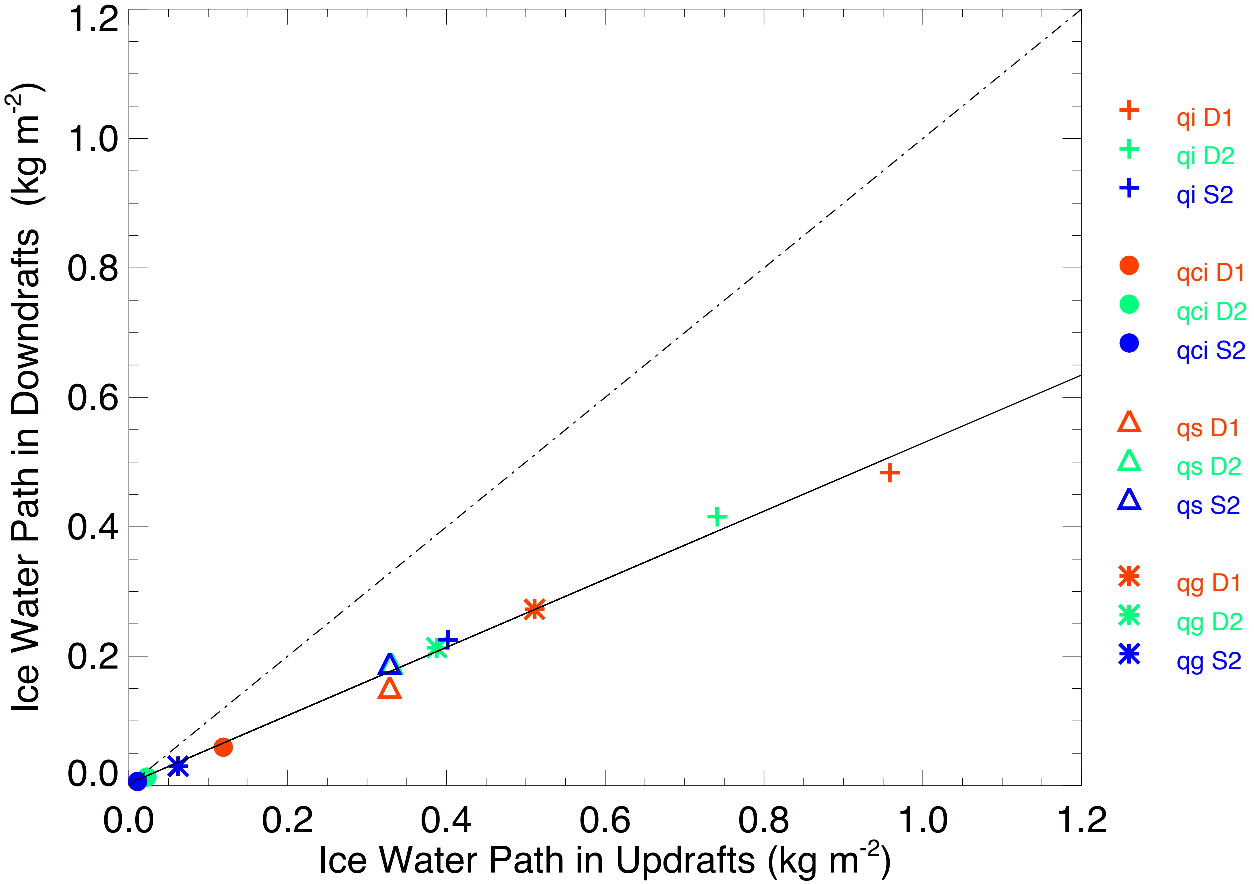
The ratio of downdraft to updraft mass flux in convective regions is about 0.5-0.6 which can be related to precipitation efficiency.



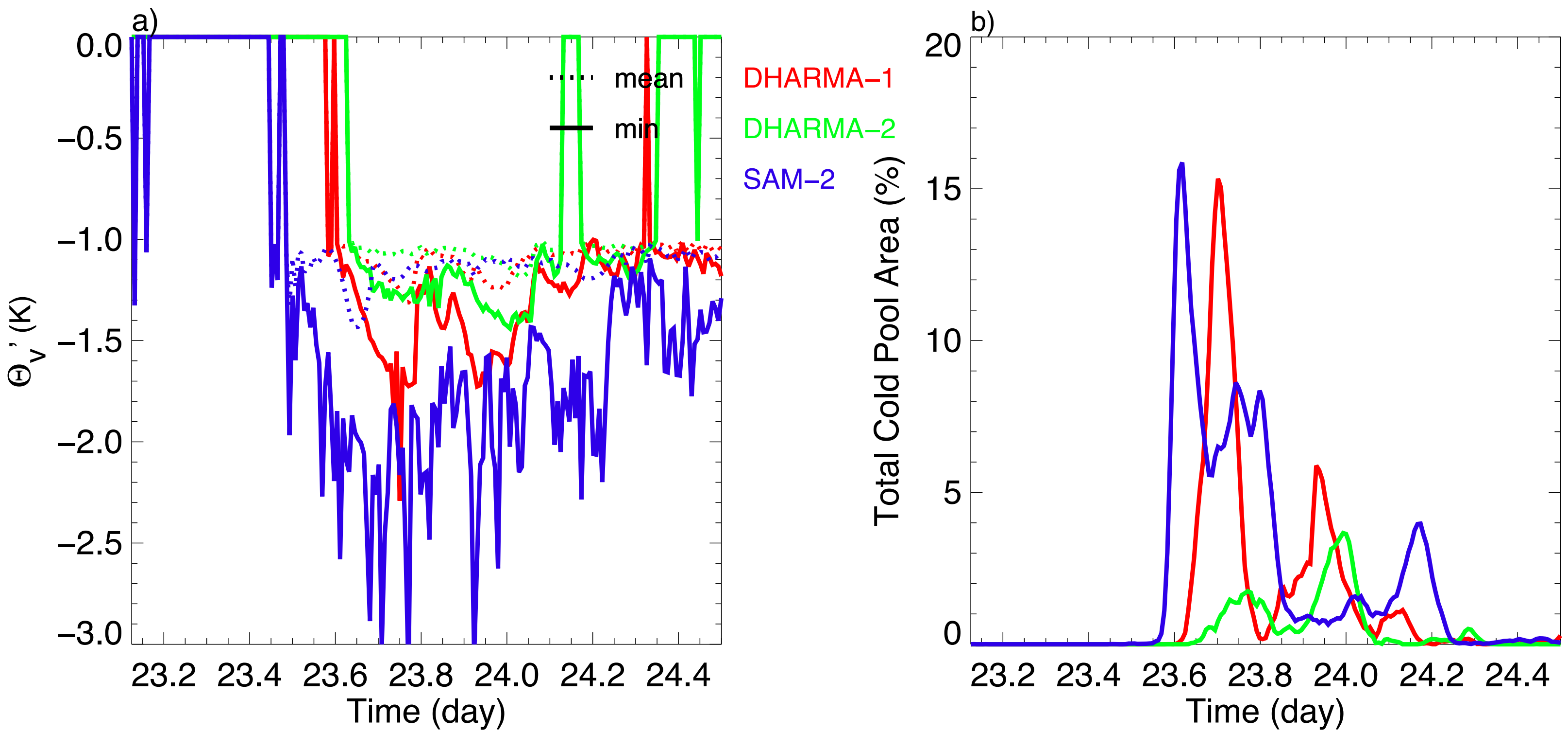
Ice water path in updrafts & downdrafts

On average the ratio of ice in convective downdrafts to the ice mixing ratio in the convective updrafts is about 0.5, independent of hydrometeor type across all simulations.

Assuming the bulk of downdraft ice mass is generated in updrafts, roughly half of the updraft ice mass is detrained, diluted, melted or evaporated, which may be related to a precipitation efficiency for the convective region.



Cold pool properties

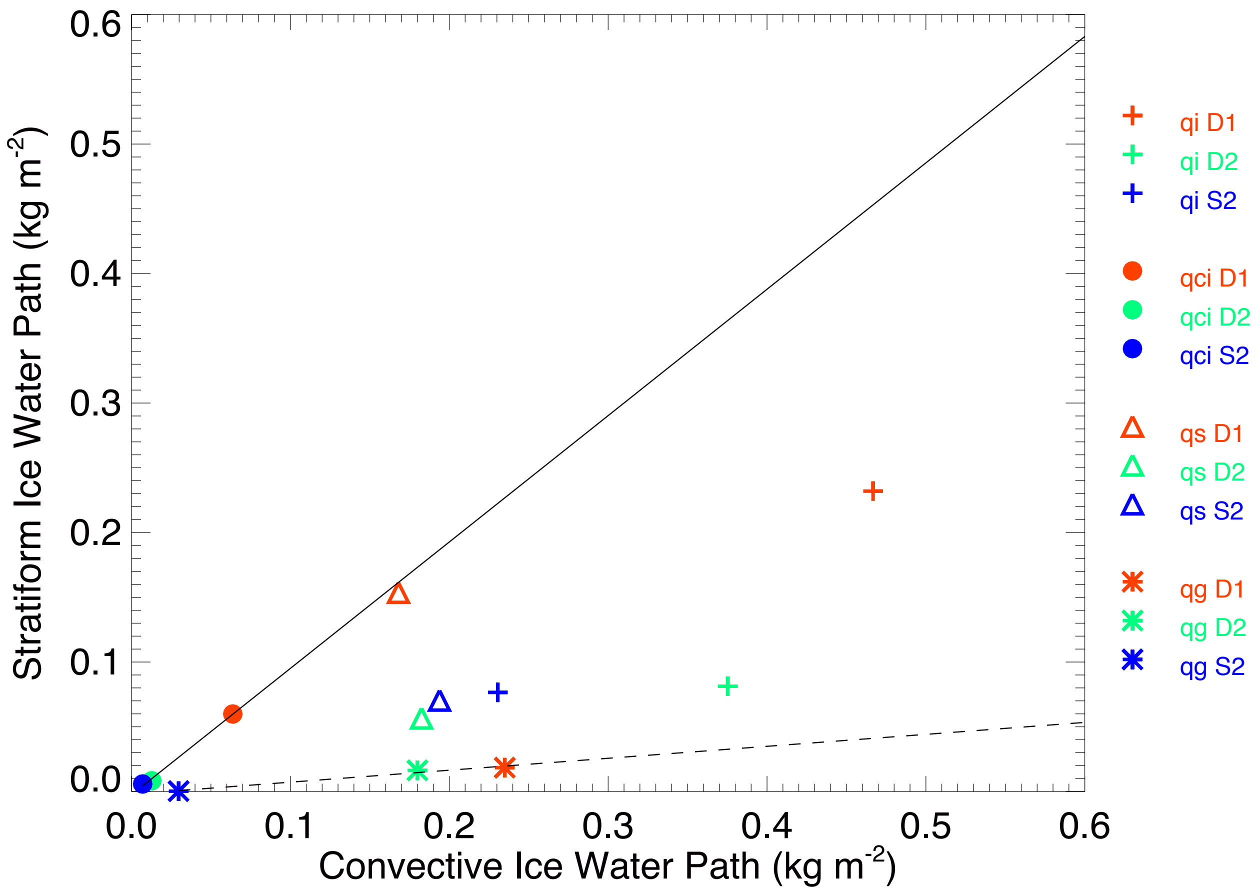


Cold pools were selected with -1K threshold in virtual potential temperature.

Even when downdraft mass flux profiles and downdrafts velocities agree, cold pool properties diverge substantially.

Ice water path in stratiform & convective regions

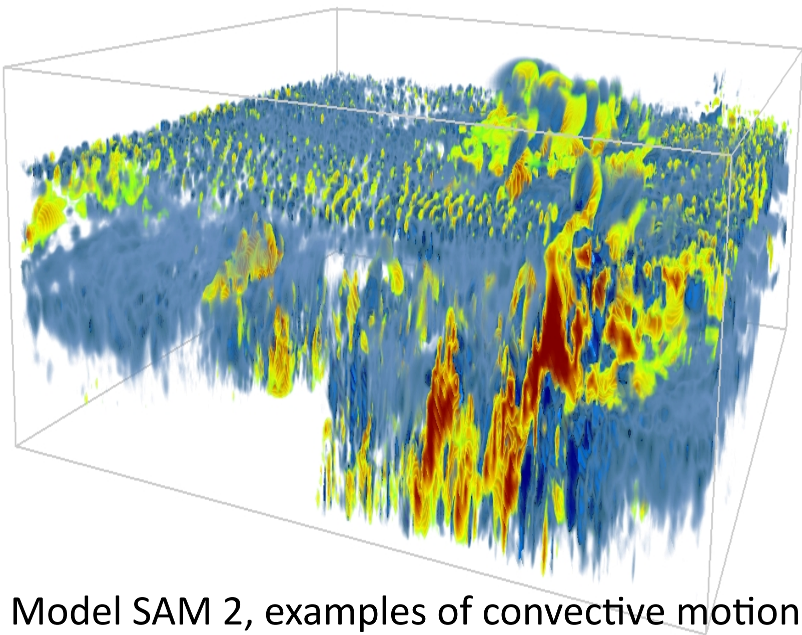
Hydrometeor loading in stratiform regions was found to be a fraction of hydrometeor loading in convective regions that ranged from ~10% (graupel) to ~90% (cloud ice).

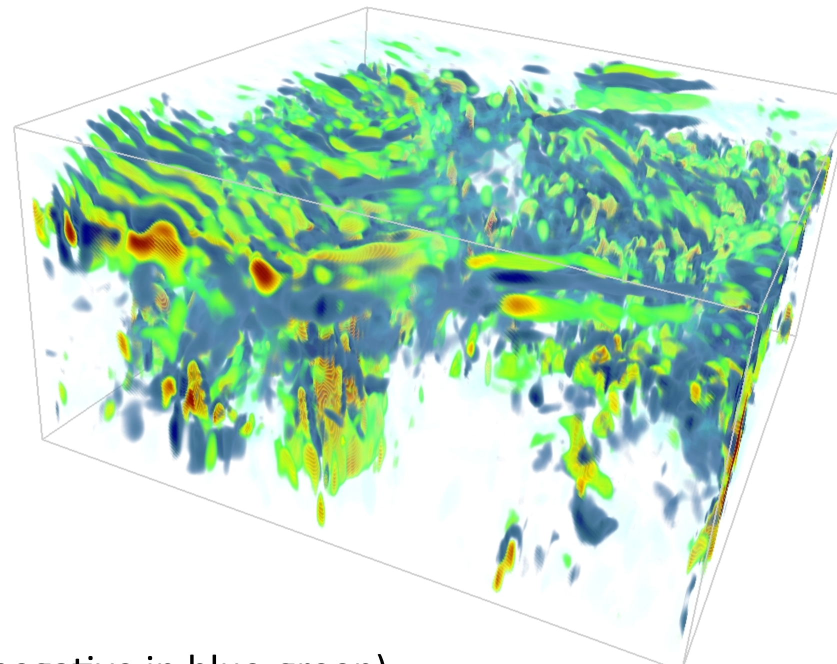


Application of the isentropic analysis of convective motions* for gravity waves filtering

A. Mrowiec, O. Pauluis, A.Fridlind, A. Ackerman, J. Fan

- Convective motions generate gravity waves which are spatially and temporally collocated with them





Model SAM 2, examples of convective motions
Vertical velocity field (positive in red – yellow, negative in blue-green)

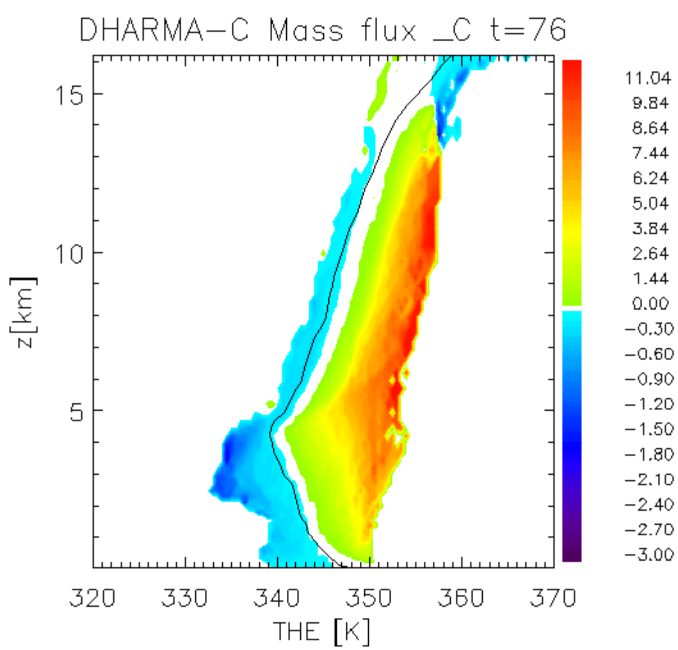
- When studying the convective and stratiform elements of the MCS it is hard to simply extract wave-free signal

* "Isentropic analysis of convective motions", O. Pauluis – publication in preparation

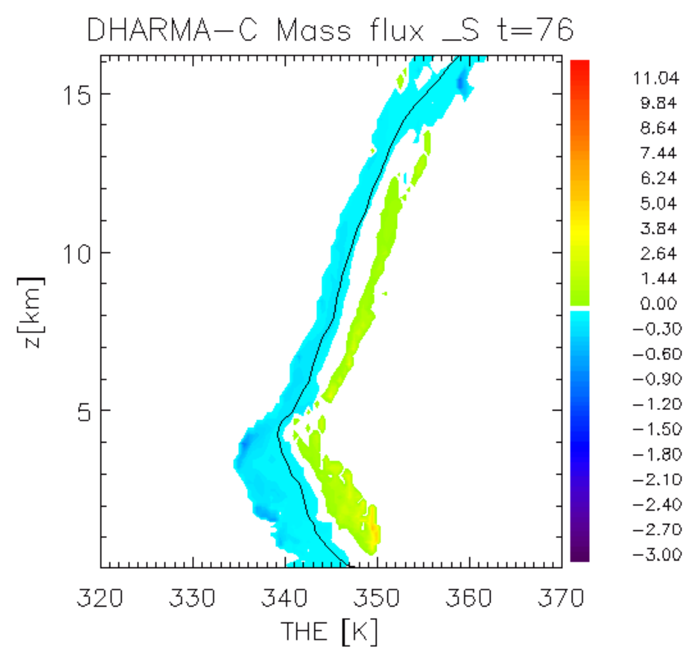
- Using a method based on averaging of various properties of drafts along adiabatic invariant of the flow allows for separation of convective motions from gravity waves associated with parcels oscillations around their level of neutral buoyancy.

- Convective circulation on isentropic surfaces likely follows the same set of air parcels and offers a way to identify updrafts and downdrafts and to study their averaged properties.

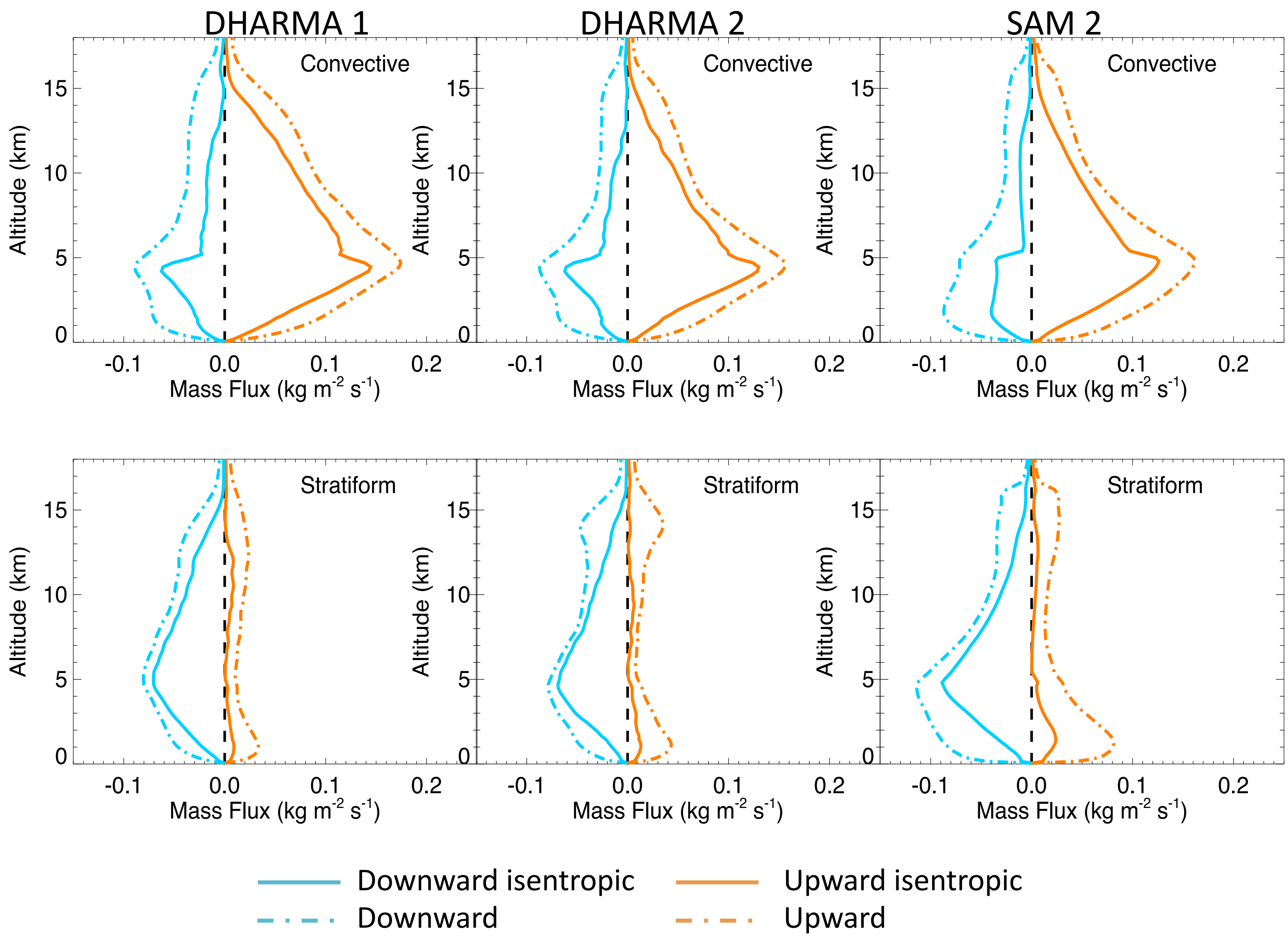
Convective



Stratiform



Time averaged upward and downward mass flux in regular and isentropic framework



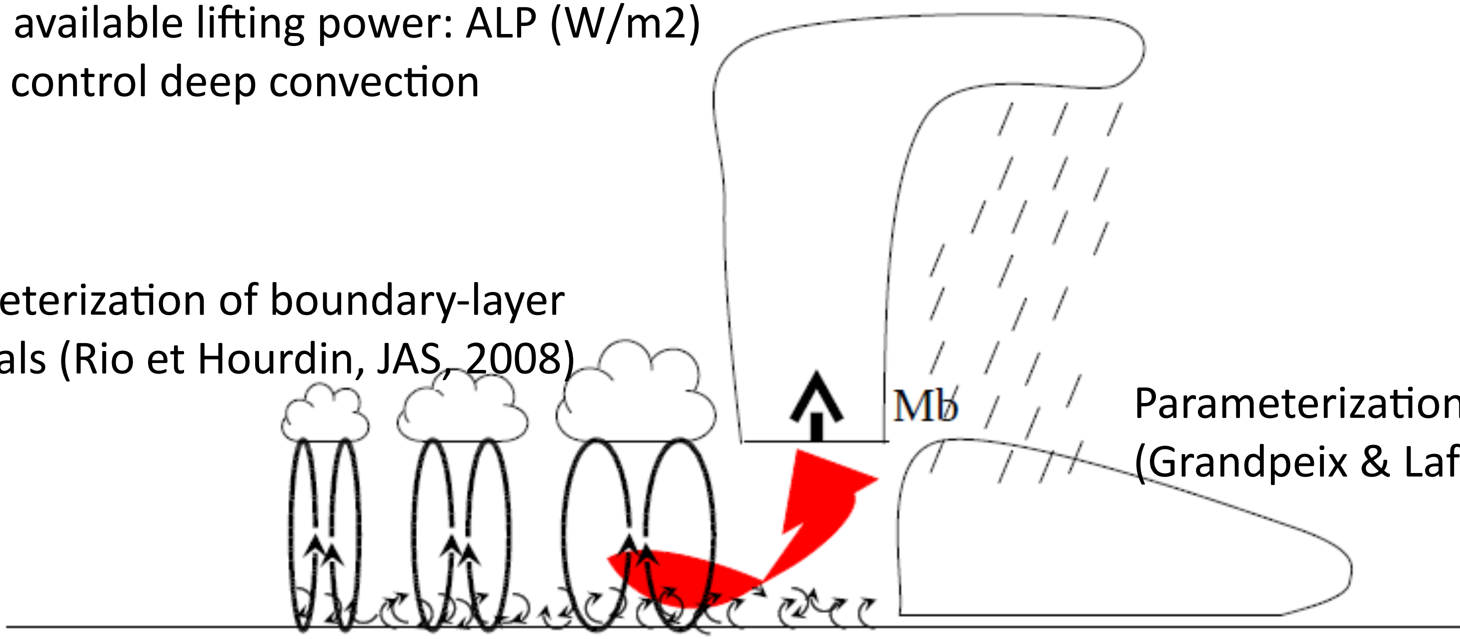
* publication in preparation (Mrowiec, Pauluis, Fridlind, Ackerman, Fan)

Control of deep convection by sub-cloud lifting processes:
The ALP closure in the LMDZ5B general circulation model

Rio et al., *in revision for Clim. Dyn.*

Sub-cloud lifting processes, boundary-layer thermals (th) and cold pools (wk), provide:
> an available lifting energy: ALE (J/kg) and
> an available lifting power: ALP (W/m2)
that control deep convection

Parameterization of boundary-layer thermals (Rio et Hourdin, JAS, 2008)



Parameterization of cold pools (Grandpeix & Lafore, JAS, 2011)

Triggering:

MAX(ALEth, ALEwk) > |CIN|

Closure:

$$M_b = \frac{ALP}{[|CIN| + 2{w_b}^2]}$$

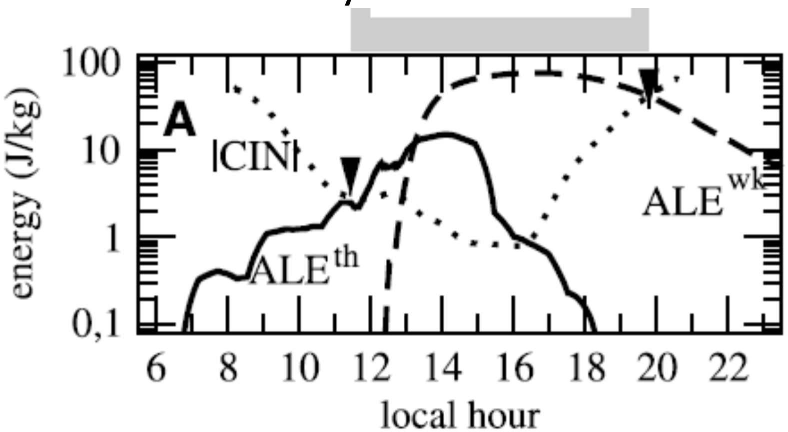
ALP = ALPth+ALPwk ~ w'3

wb=1m/s

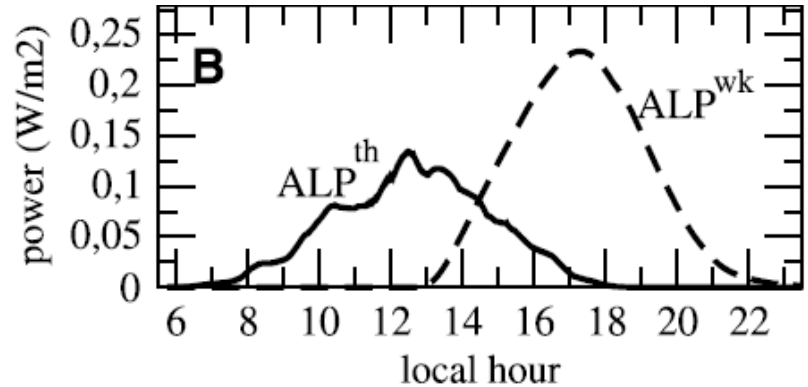
Already tested and evaluated on a case of mid-latitude deep convection over land
Rio et al., GRL, 2009

EUROCS case (Guichard et al., 2004), 27 June 1997, Oklahoma

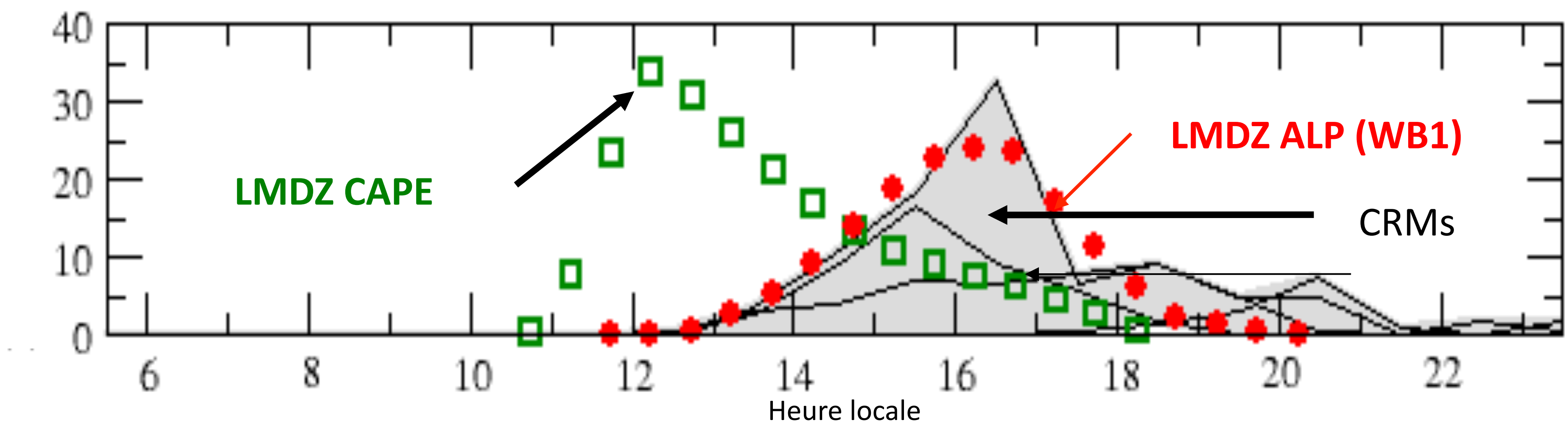
Diurnal cycle of ALE and CIN



Diurnal cycle of ALP



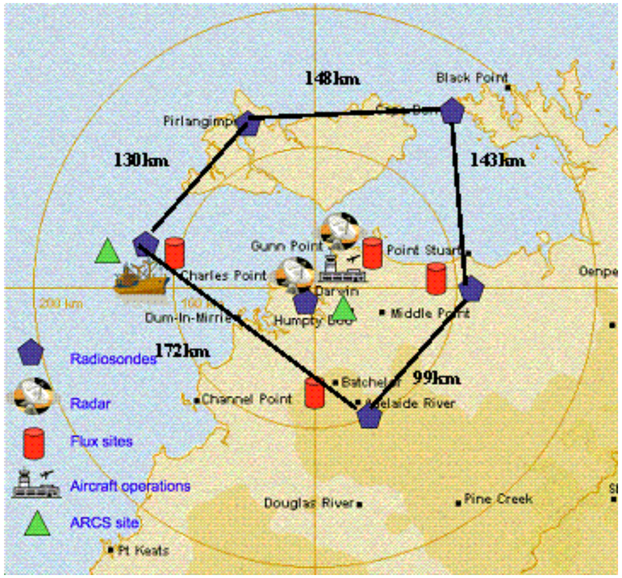
Diurnal cycle of precipitation



Diurnal cycle of continental precipitation in phase with CRMs

Evaluation over tropical ocean: The TWP-ICE case-study

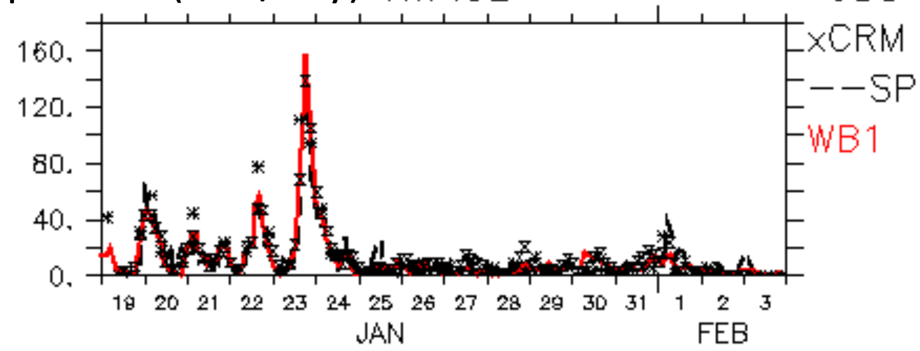
Darwin, Australia,
19 January - 4 February 2006



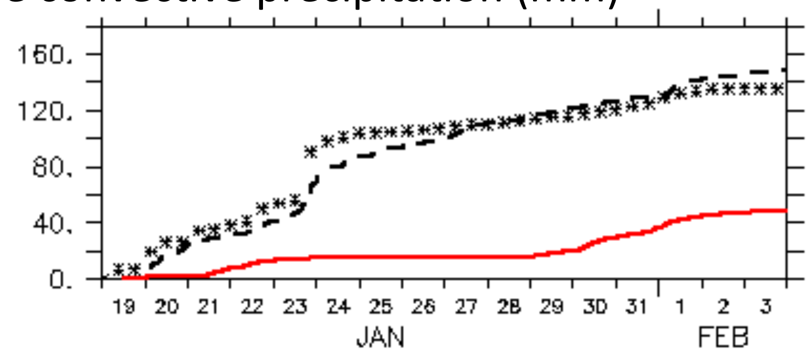
Forcing from observations:
- forced SST
- horizontal advection
- large-scale vertical velocity
- nudged winds

Simulations used:
CRM DHARMA (Fridlind et al., JGR, 2011)
LMDZ1D SP (CAPE closure)
LMDZ1D WB1 (ALP closure)

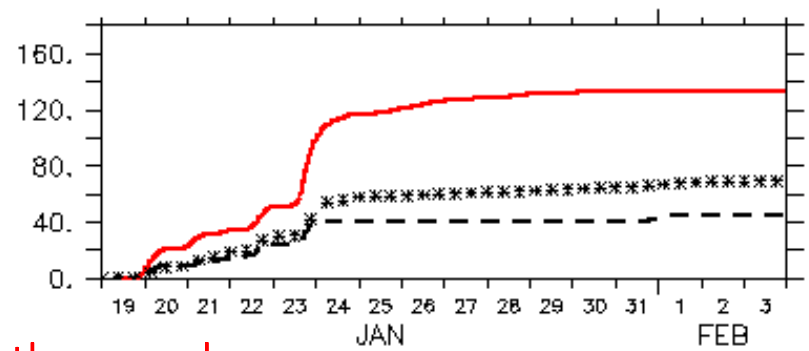
Total precipitation (mm/day)



Cumulative convective precipitation (mm)



Cumulative large-scale precipitation (mm)



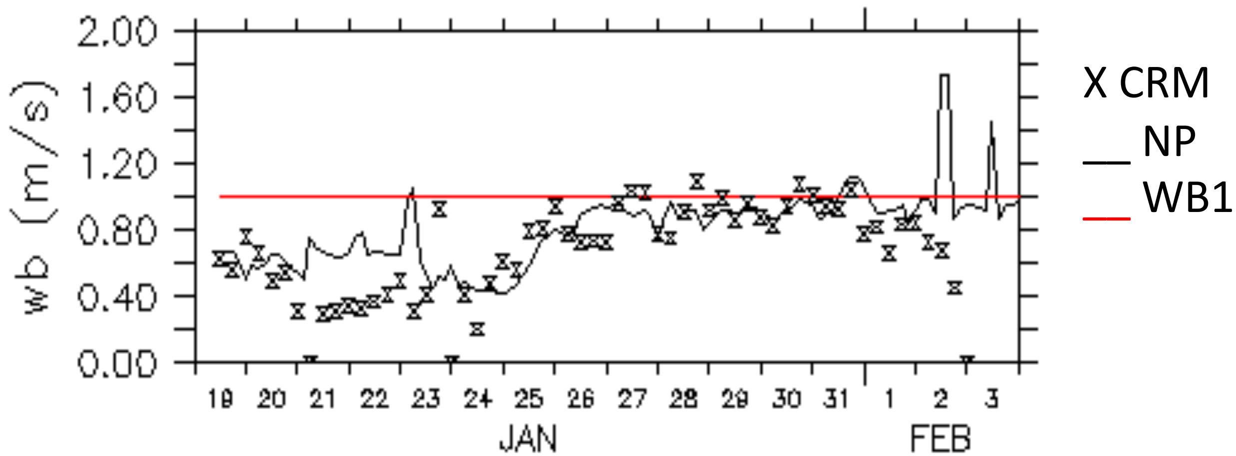
Underestimation of convection intensity with the new closure

Use of the CRM simulation to evaluate internal variables of the parameterization

The updraft vertical velocity at level of free convection

WB1: wb=1m/s

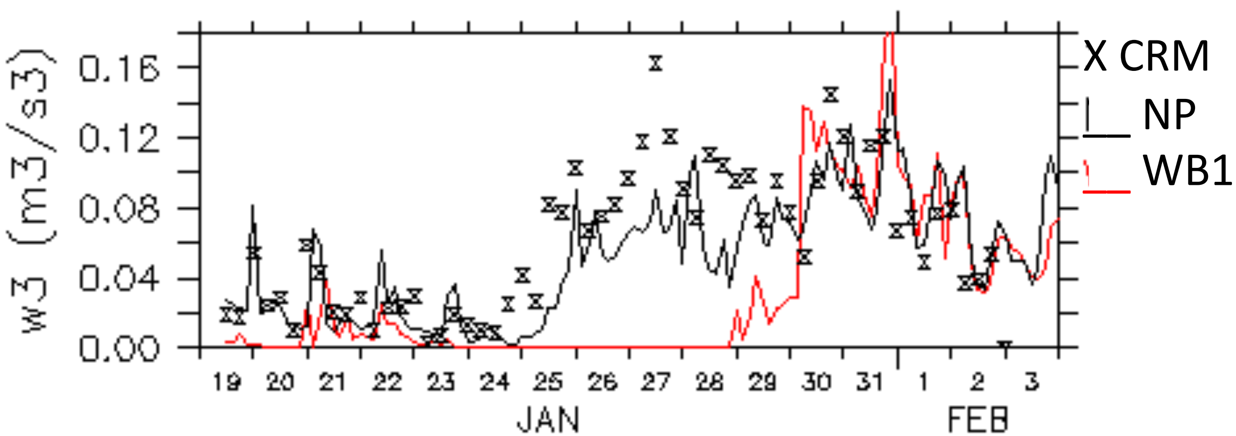
NP: wb = f(plfc)



Higher LFC > larger CIN > stronger wb as only the faster parcels overcome CIN

The third order moment of the vertical velocity (used to compute ALP)

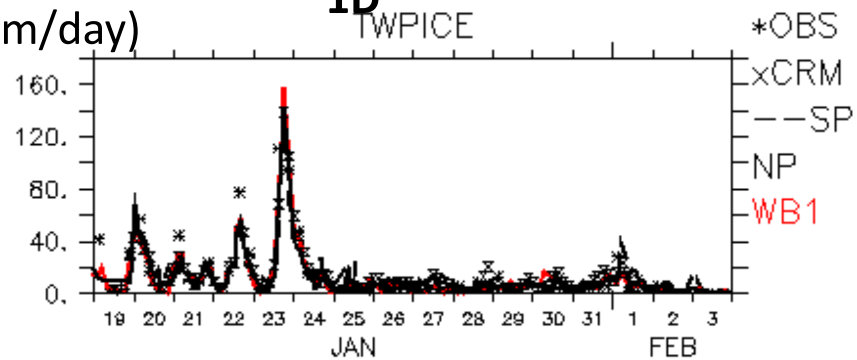
Evaluation of the representation of sub-cloud lifting processes



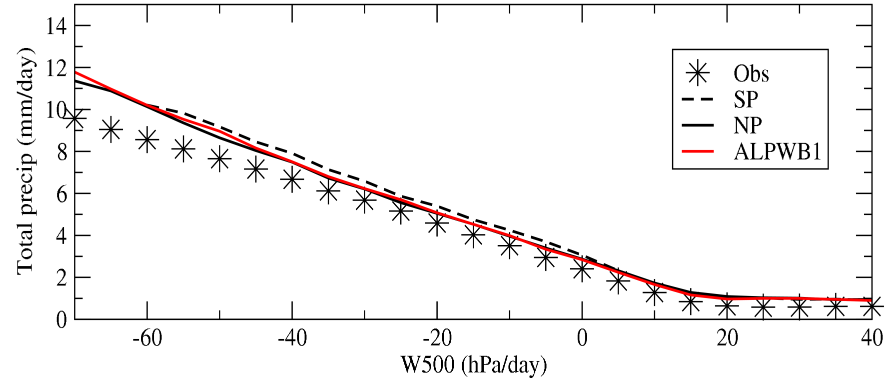
Convective vs large-scale precipitation in 1D versus 3D simulations

Total precipitation (mm/day)

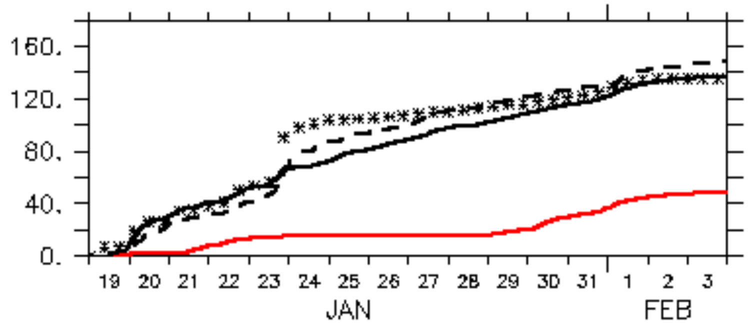
1D

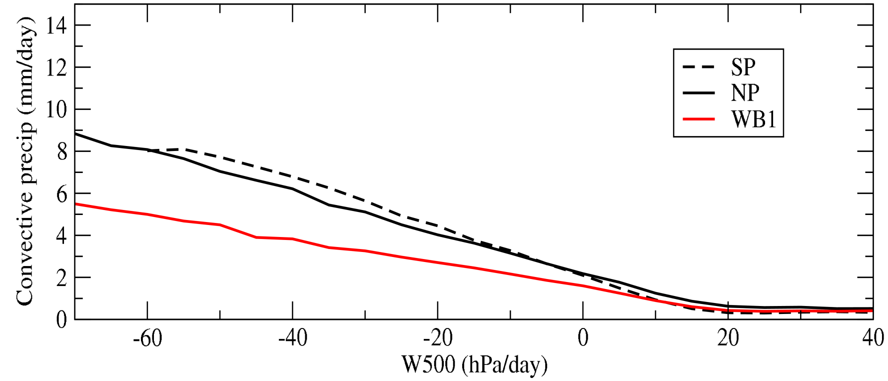


3D

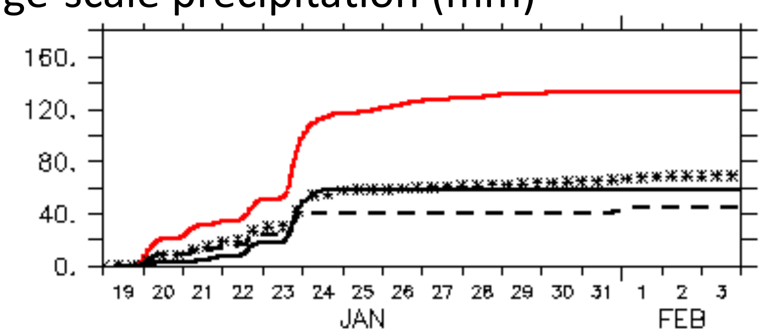


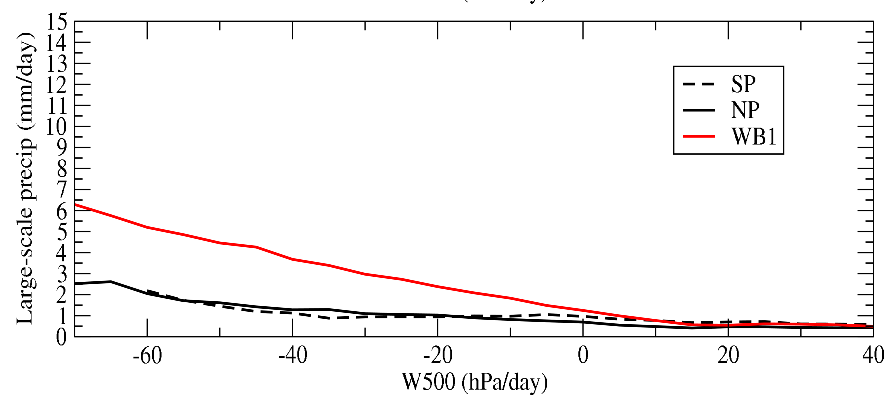
Convective precipitation (mm)





Large-scale precipitation (mm)





Re-intensification of convection in simulation NP

Same behavior in 3D as in SCM in the Tropics

Diurnal cycle of continental convection in 1D versus 3D

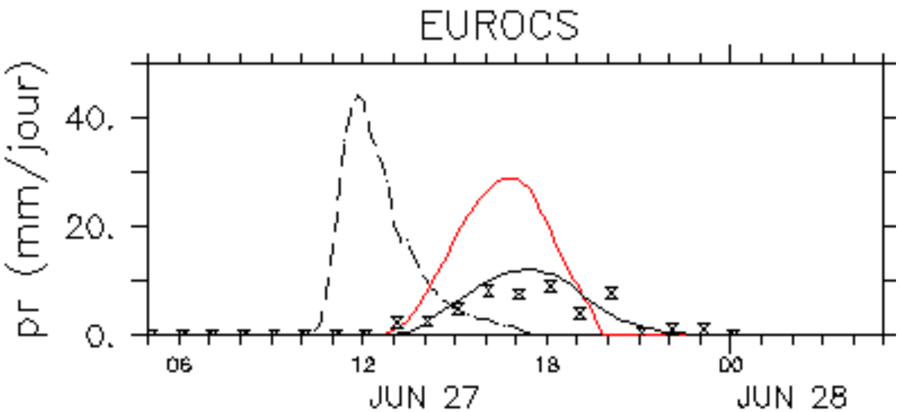
1D

X MESONH

--- SP

__ NP

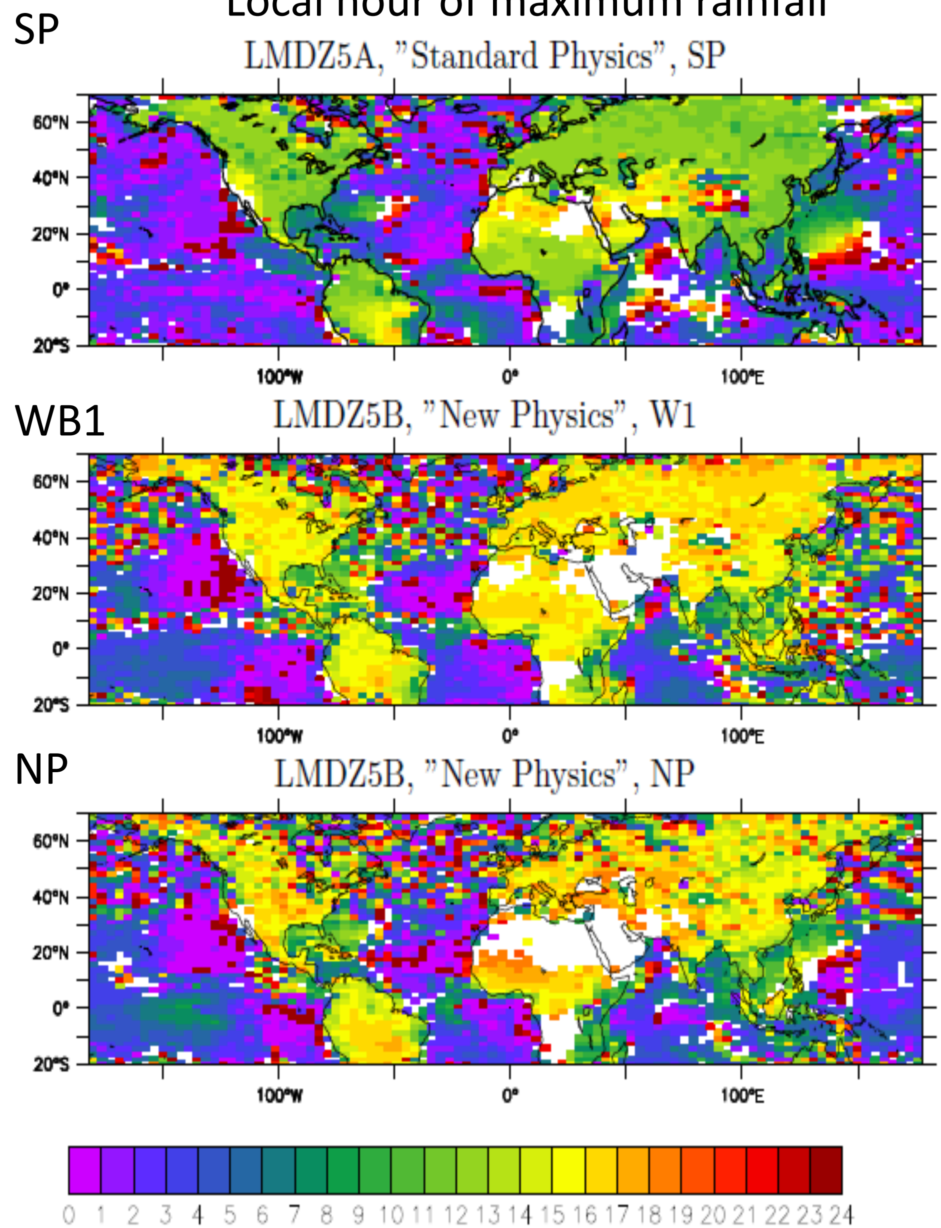
__ WB1



Maximum of continental rainfall delayed from 12h to 16-17h in 3D simulations

3D

Local hour of maximum rainfall



GISS CRM group contributions to FASTER

- Past work
  - two papers submitted (Mrowiec et al., Rio et al.)
  - two papers coming soon
    - CRM gravity wave filtering technique (Mrowiec)
    - CRM- and observation-based evaluation of ModelE and LMDZ during TWP-ICE (Rio and Mrowiec)
- Future work
  - RACORO case study development
  - CRM reporting variables and format