Using a Cloud System Concept to assess bulk ice schemes
(fall speed – eff. crystal size)
in the LMDZ GCM

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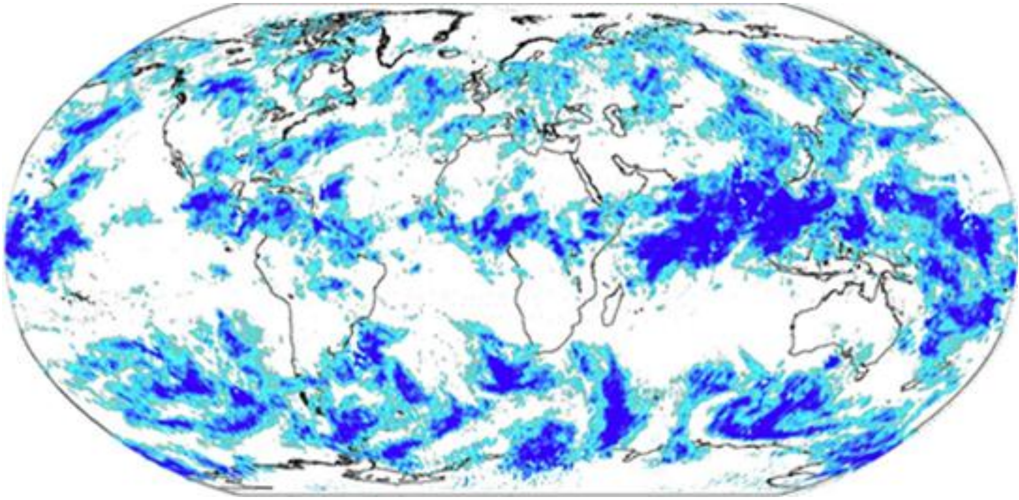
Motivation

UT clouds cover 30% of the Earth



Snapshot AIRS-CIRS
UT clouds: dark -> light blue,
according to decreasing ε_{cld}

In a GCM:

- *mass-weighted ice crystal fall speed* (v_m)
  strongly influences UT cloud occurrence & properties
  & has potential to influence climate sensitivity (e.g. *Sanderson et al. 2008*)

- D_e affects the radiative properties of UT clouds

Questions:

- **How do existing parameterizations of v_m and De compare with each other?**
- **How do they compare with the current parameterizations of the LMDZ GCM?**
- **How can we use the new "cloud system diagnostics" to assess high clouds in LMDZ?**
- **What is the effect of including a new bulk ice scheme (v_m - De) in the LMDZ GCM?**

1.

How do the existing parameterizations of v_m and De compare with each other?

Analytical expressions: D - > bulk properties

PSD generally expressed as:

$\mathbf{N(D) = N_0\, D^{\mu} e^{-\lambda D}}$

D maximum dimension ice crystals, λ slope, μ dispersion; exponential PSD: $\mu=0$

Cirrus bulk properties = mass- or area-weighted integrals of PSD,

with $m = a\, D^{b}$ $A = c\, D^{d}$

b=3 for sphere, b = 2 for aggregates, b = 1.5 for dendrites

$$\mathrm{IWC} = \int m(D)\, N(D)\, dD = \int a\, N_0\, D^{b+\mu} e^{-\lambda D}\, dD = a\, N_0\, \Gamma(b+\mu+1)/\lambda^{(b+\mu+1)}$$

$$D_m = \int D^3\, N(D)\, dD \,/ \int D^2\, N(D)\, dD = (b+\mu+0.67)/\lambda$$ *Mitchell et al. 1991*

$v_t \sim (m/A)^{0.6}\, D^{0.3}\, f(p)$ $\mathbf{v_t = AD^{B}}$

$$v_m = \int m(D)\, v_t(D)\, N(D)\, dD \,/ \int m(D)\, N(D)\, dD$$

$\mathbf{v_m = A' D_m^{B'}}$ *Heymsfield et al. 2013*

A & B for 3 D ranges
(Heymsfield et al. 2013)

A' & B' for 2 D ranges
(Furtado et al. 2015)

v_m and De in literature:
different retrieval methods
different meteorological conditions
different Temperature and IWC ranges

Empirical parameterizations : *$v_m = f(T, IWC)$*

Heymsfield et al. 2007 (H07): **20000 PSDs from 2 field campaigns tropical anvils (T > -70°C) & synoptic cirrus (T>-54°C)**

Deng & Mace 2008 (DM08): **from longterm ARM in situ statistics, retrieved from radar measurements; 1999-2005 -> 30000 hrs**
convective: TWP ARM (T> -75°C) synoptic: SGP ARM (T>-65°C)

Mitchell et al. 2011 (M11): **3 field campaigns** (TC4,NAMMA,ISDAC)
young anvil cirrus, aged anvil cirrus, in situ cirrus, Arctic cirrus
similar bevahour; except Arctic cirrus : v_m not dependent on IWC

Elsaesser et al. 2017 (E17): convective outflow
from 4 field campaigns (TC4, NAMMA, MC3E, SPARTICUS)
-> GISS GCM

Schmitt & Heymsfield 2009 (SH09): **2 field campaigns of TTL cirrus (-86°C to -56°C)** v_m = f(IWC)

v_m increases when T increases
when IWC increases

Parameterizations of moments/parameters of the PSD

Heymsfield et al. 2013 (H13): **10 recent field campaigns**
83000 in-cloud PSDs (tropics to Arctic, -86°C – 0°C)

-> parameterizations of *a*, *b*, *c*, *d*, λ, μ as fct of T & *A*, *B* as fct of D

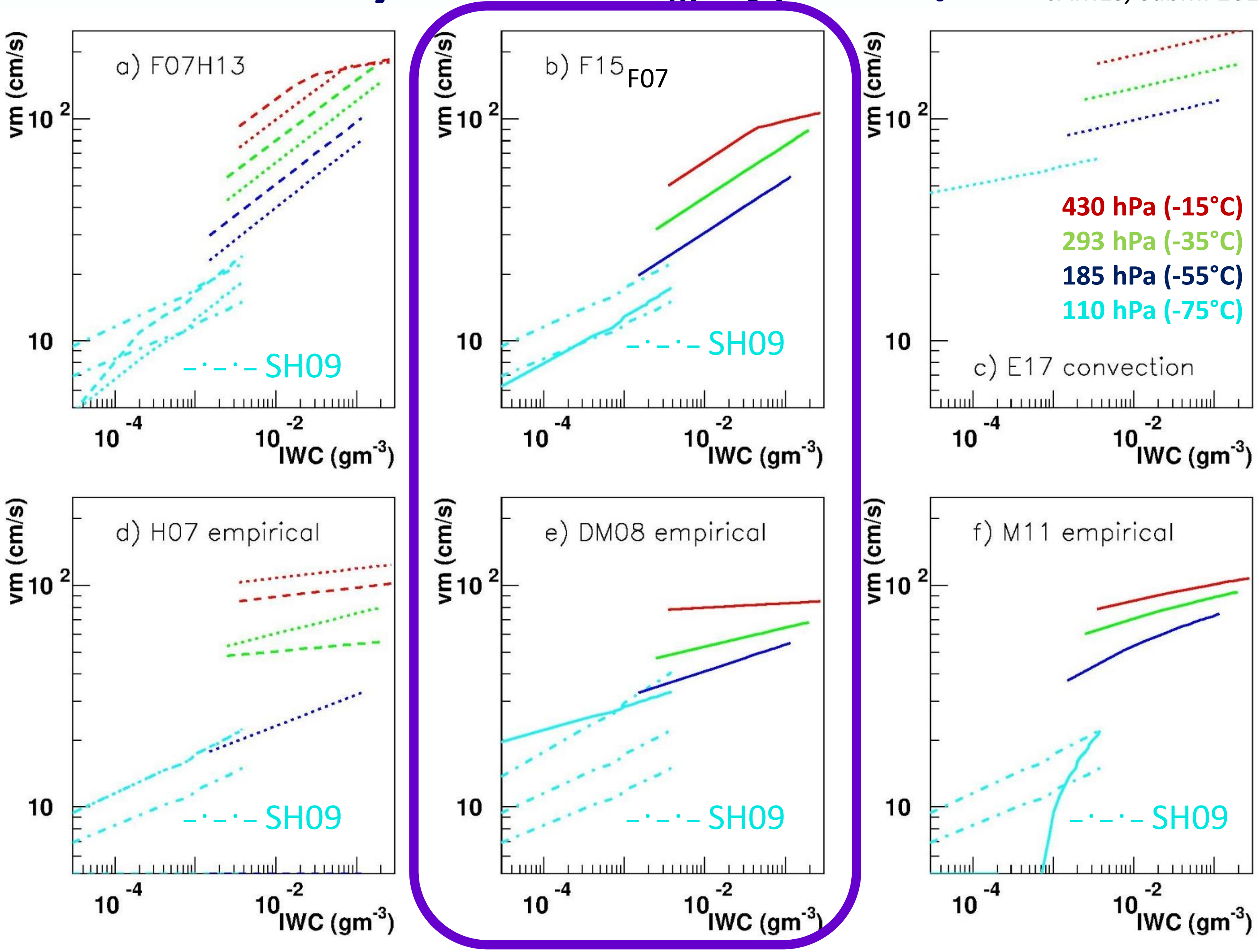
Field et al. 2007 (F07): **13000 PSDs, of 4 field campaigns (tropics & midlatitudes)**

$\mathbf{M_n = \int D^n N(D)\, dD = A(n) * e^{B(n)*T} * M_2^{C(n)}}$
$M_2 = IWC / a$
$\mathbf{D_m} = M_3 / M_2 = \boldsymbol{a}\, \mathbf{M_3 / IWC}$
$\mathbf{v_m = AD_m^B}$

Furtado et al. 2015 (F15): v_m computed from PSD moment parameterization of F07
with:
ice : *A* = 1042 / n= *B* = 1.0 (SI units)
snow : *A* = 14.3 / n= *B* = 0.416
for each D the smallest v_t of both:
ice D < 600 μm & snow D > 600 μm

Synthesis : $v_m = f(T, IWC)$

Stubenrauch & Bonazzola, JAMES, subm. 2018



—— *all* ········ *convective outflow* ---- *synoptic cirrus*

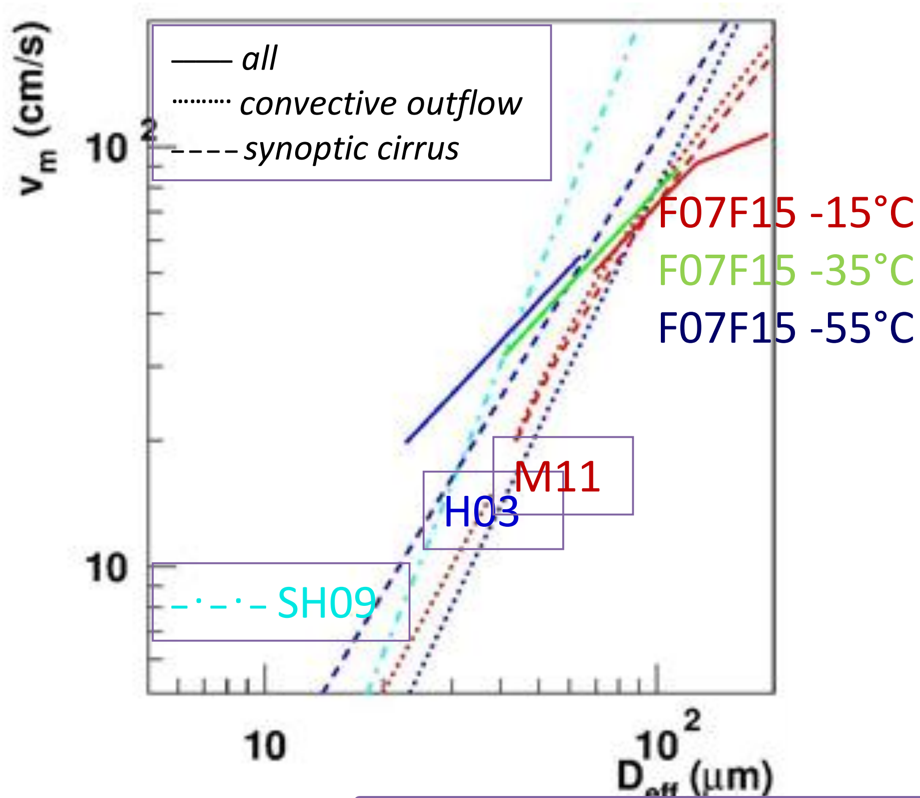
Synthesis : v_m - D_e

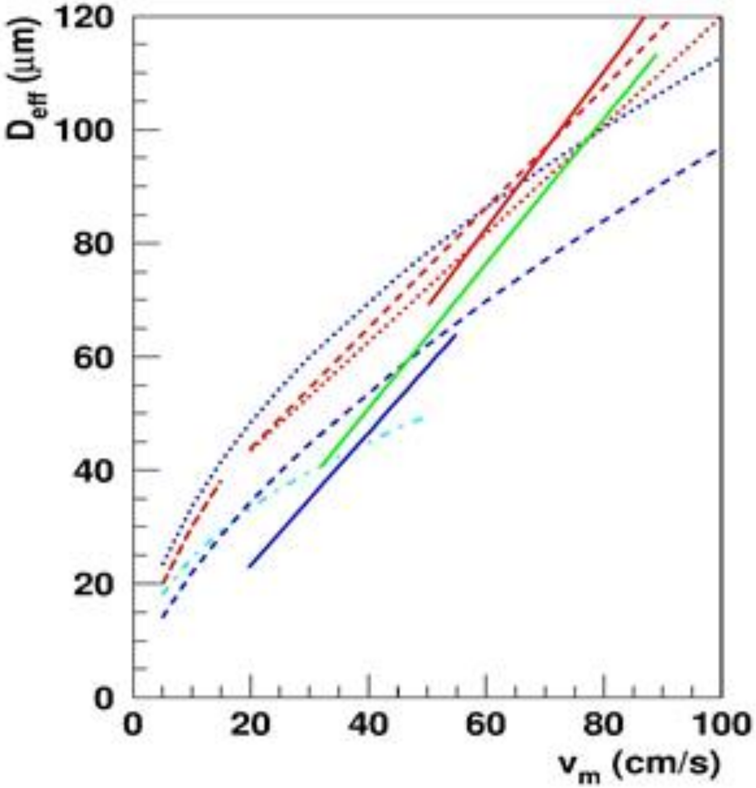
Analytical expression of D_e:

$$D_e = 3/2\ IWC / (\rho_{ice} \int A(D)\, N(D)\, dD) = 3\, a\, \Gamma(b+\mu+1) / (2\, \rho_{ice}\, c\, \Gamma(d+\mu+1))$$

uncertainties: a: 54%, c: 11%, b & d: < 10% (e.g. Erfani & Mitchell 2016)

-> D_e – v_m relationships from field campaigns:





$D_{eff} = f(v_m)$ of H03 (mean between synoptic & anvil cirrus)
D_m of F07 PSD momentum, $D_{eff} = 0.17 \times D_m$ *(Baran et al. 2016)*

v_m – D_e Strategies for LMDZ GCM

- v_m = f(IWC, T) of DM08 & SH09
  D_{eff} = f(v_m) of H03 (mean between synoptic & anvil cirrus)

- v_m = F07 PSD momentum & F15 A-B couples for ice / snow
  D_m = F07 PSD momentum
  D_{eff} = 0.17 x D_m (assumed aggregates, *Baran et al. 2016*)

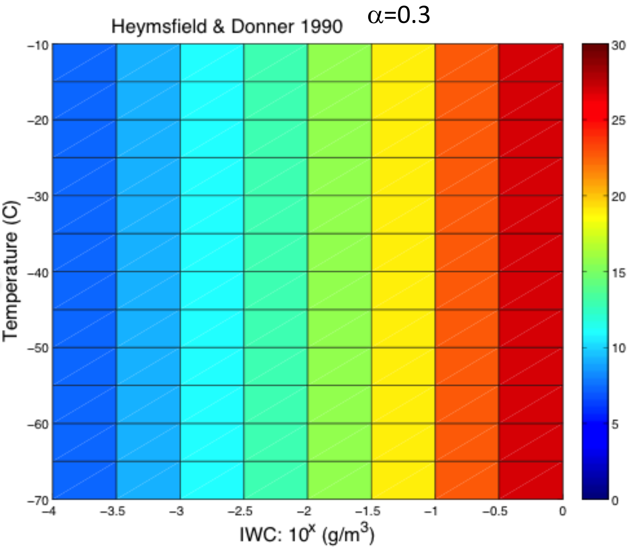
Next step: use for radiative transfer instead of D_{eff} directly
single scattering property (SSP) parameterization f(IWC,T) of Baran et al. 2016
(same PSDs as in F07)

2.

How do these parameterizations of v_m and De compare with the LMDZ parameterizations?

In literature:

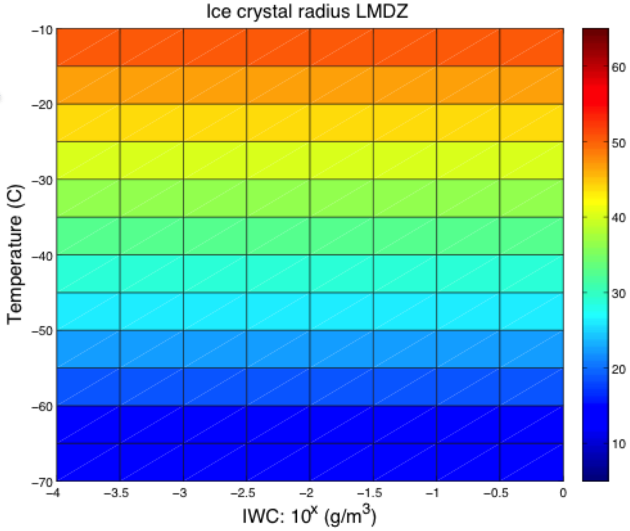
- v_m depends on T and IWC
- Relation between De and v_m



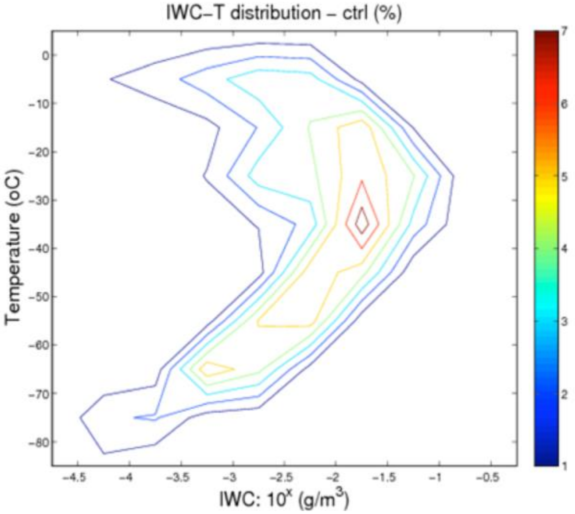
In LMDZ:

-v_m only depends on IWC

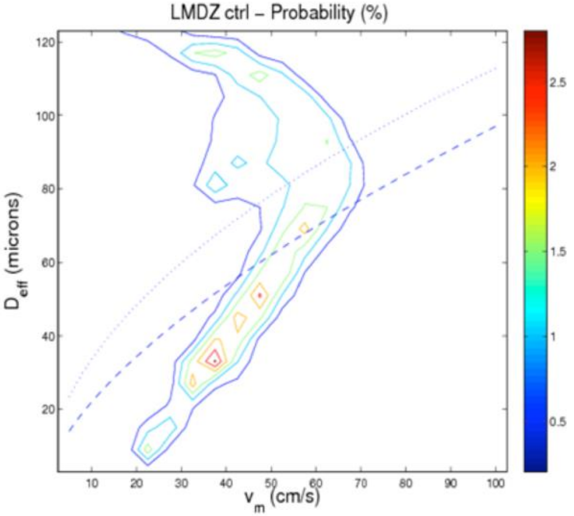
- De only depends on T



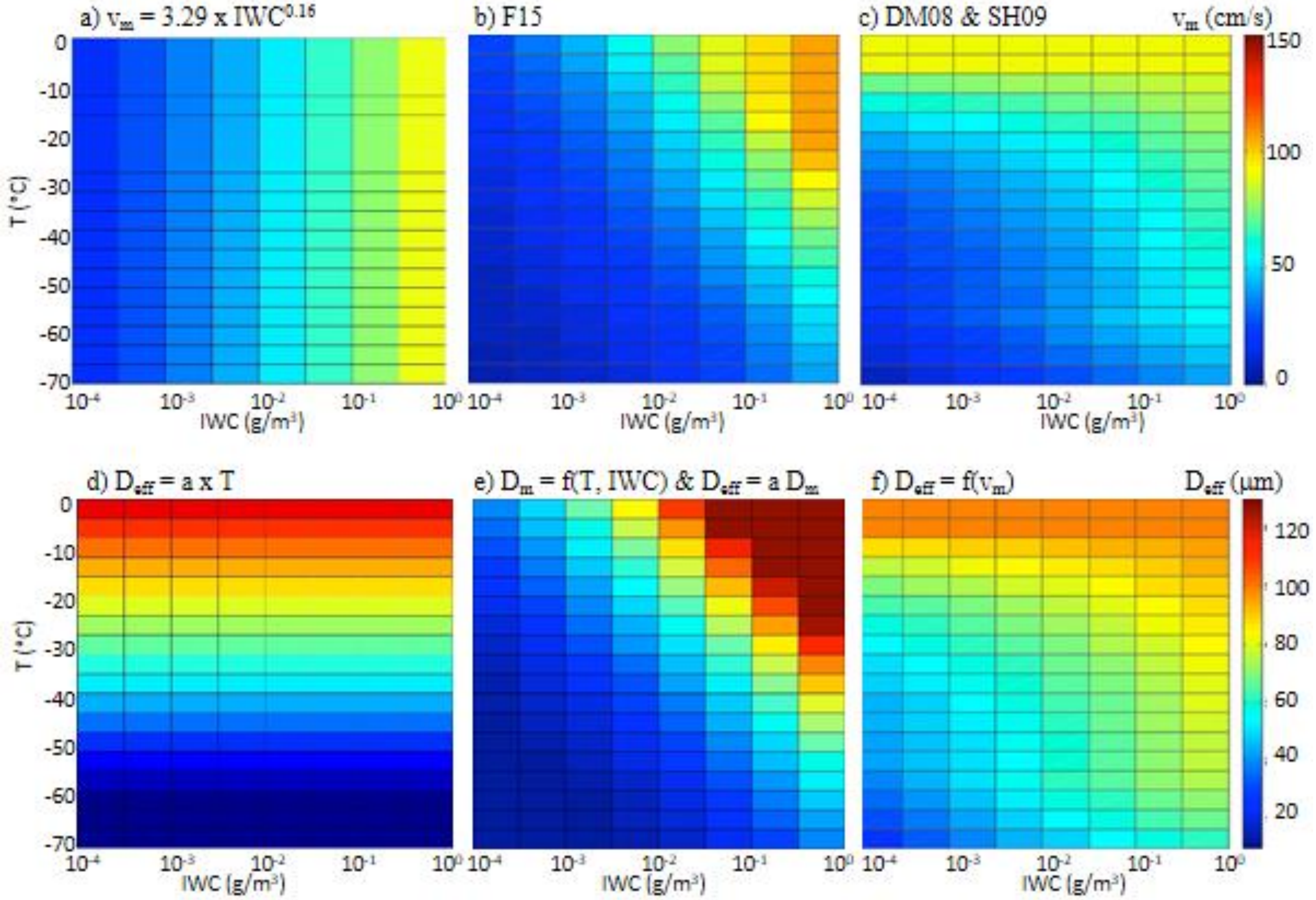
- For high clouds T and IWC are not perfectly correlated



- Relation between De and v_m different from those found in literature



v_m & D_{eff} as function of IWC & T



with scaling factor FALLICE=α=0.3, LMDZ v_m is very small compared to realistic v_m
-> integrating new bulk ice schemes needs retuning of remaining unconstrained parameters (RQH, EPMAX) to achieve radiation balance

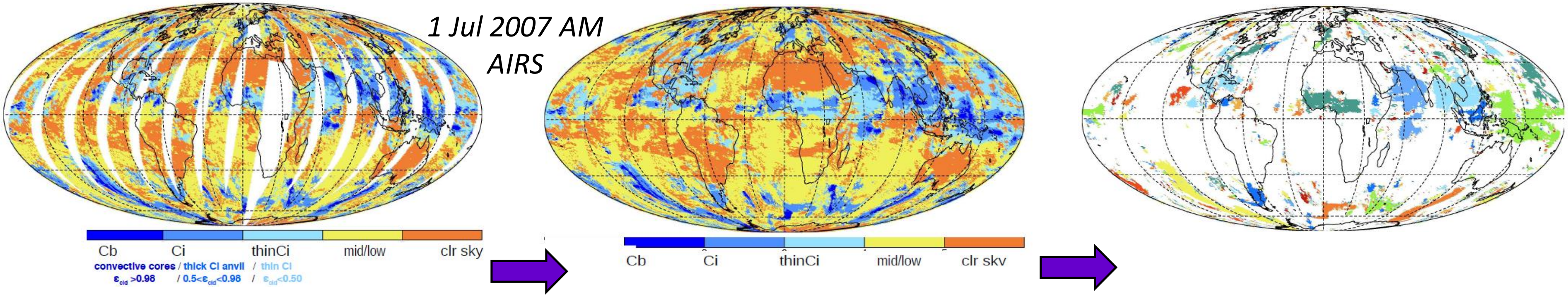
3.

How can we use the new “cloud system diagnostics” to evaluate high clouds in LMDZ?

From cloud retrieval to cloud systems

clouds are **extended objects**, driven by dynamics -> **organized systems**

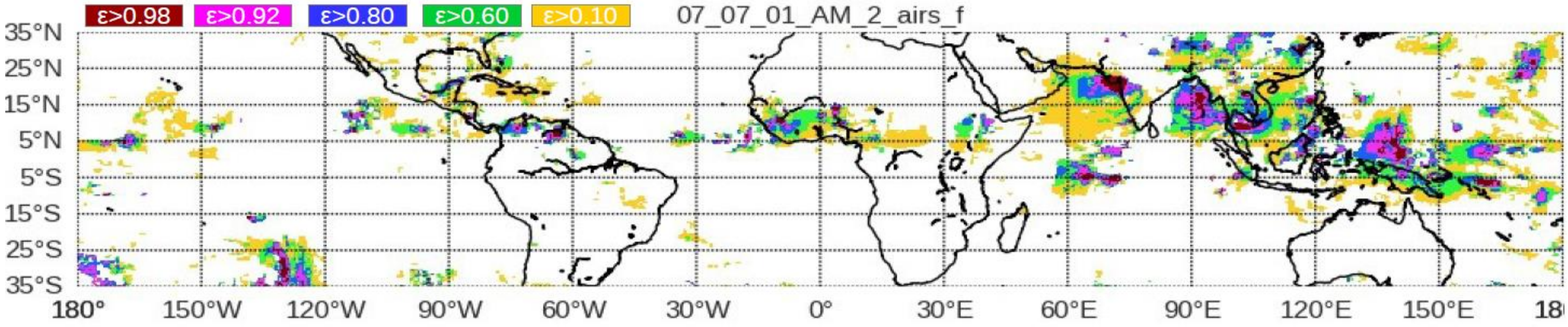
Method: 1) group adjacent grid boxes with high clouds of similar height (p_{cld})



fill data gaps using PDF method build UT cloud systems

Protopapadaki et al. ACP 2017

2) use ε_{cld} to distinguish convective core, thick cirrus, thin cirrus *(only IR sounder)*

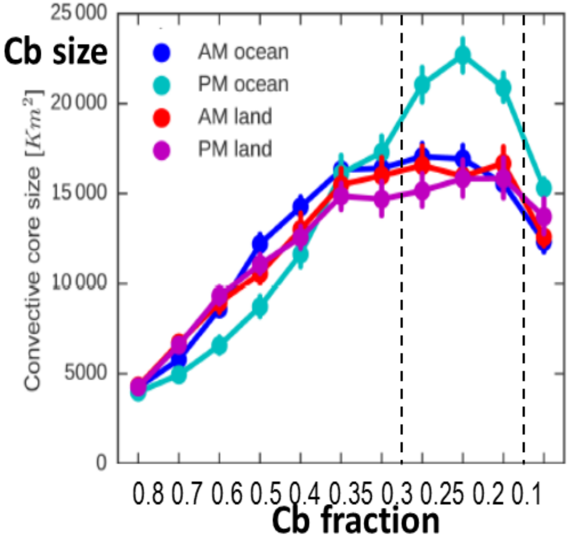


30N-30S: UT cloud systems cover 25%, those without convective core 5%
50% of these originate from convection *(Luo & Rossow 2004, Riihimaki et al. 2012)*

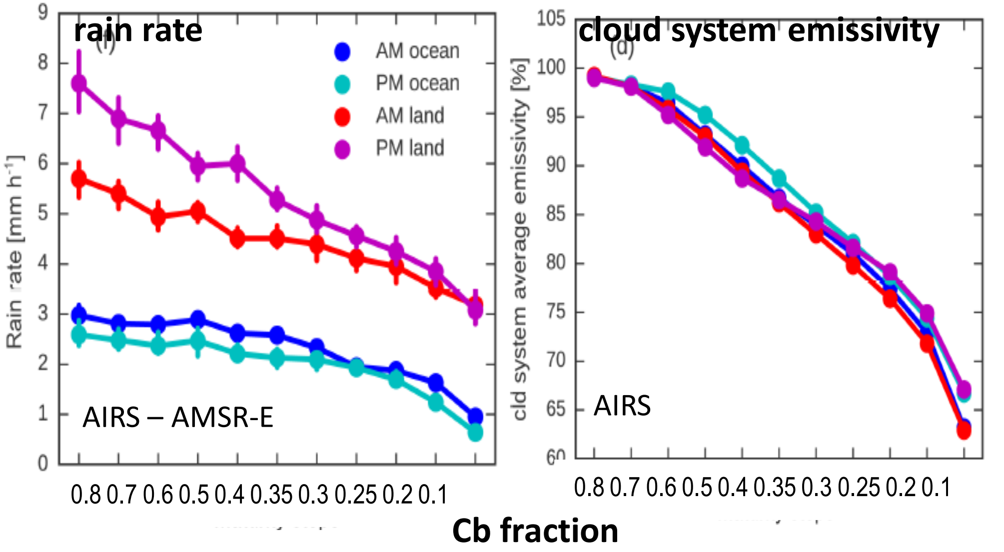
Process-oriented UT cloud system behaviour

convective core fraction within system proxy for system life stage

Protopapadaki et al. 2017



increasing age of system



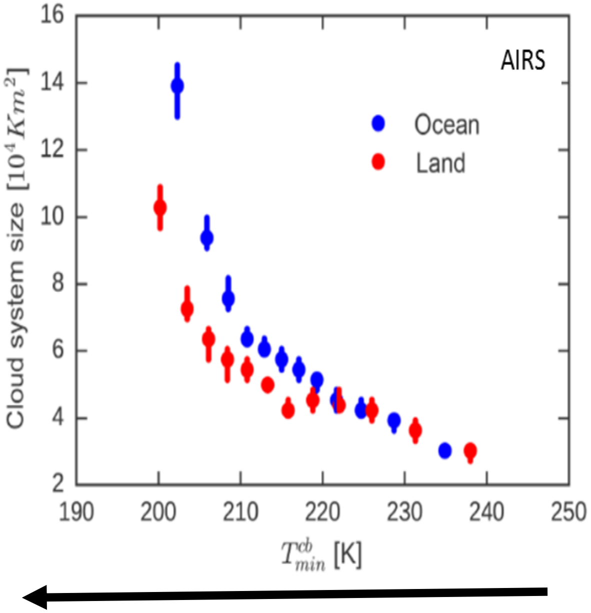
increasing age of system

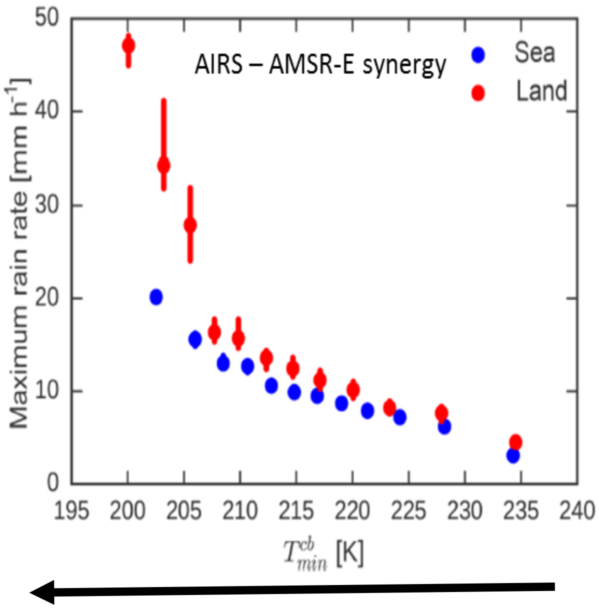
Convective core size increases up to system maturity & then decreases
Convective rain rate and anvil emissivity decrease

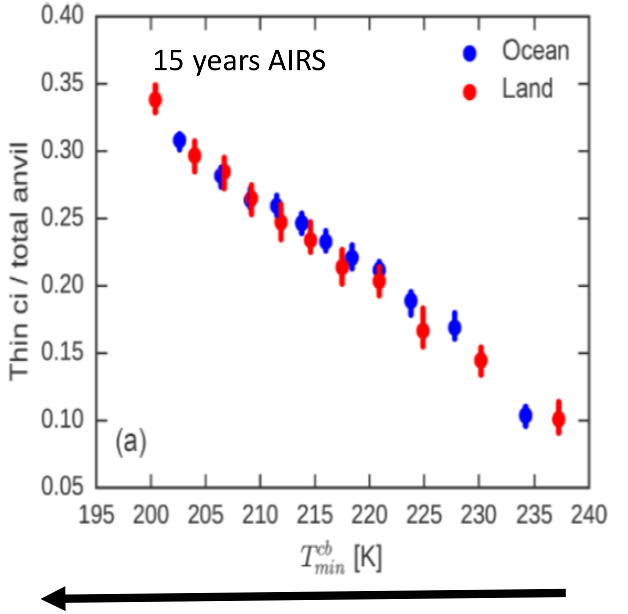
Process-oriented UT cloud system behaviour

convective core temperature proxy for convective depth (mature systems)

Protopapadaki et al. 2017







increasing convective depth

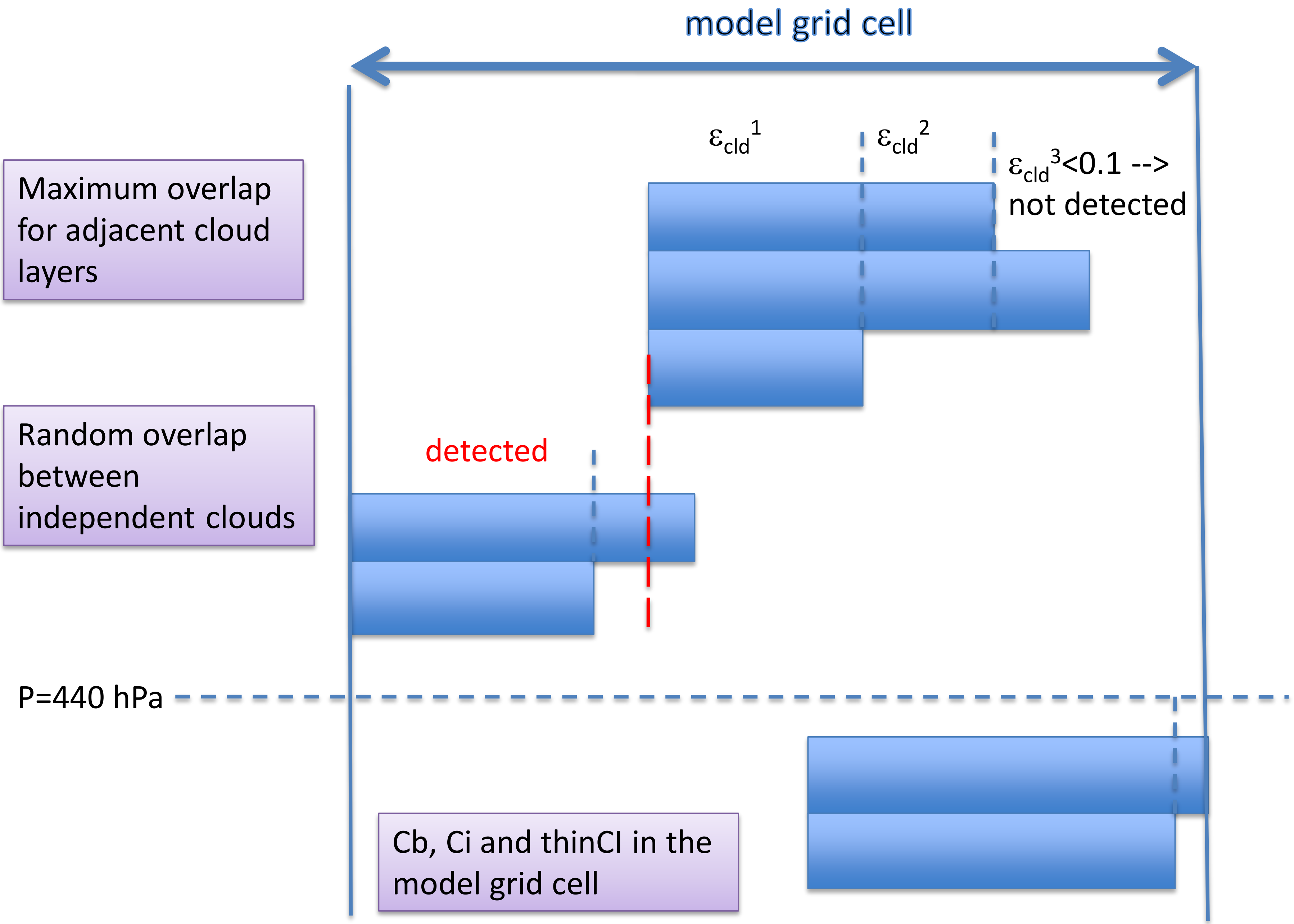
cloud system size / max rain rate increase with convective depth,

land* – *ocean *differences : difference in entrainment (Takahashi et al. 2017)*

Thin cirrus in/around anvil increases with convective depth

(UT environmental predisposition or UT humidification from cirrus outflow ?)

Methodology: The AIRS/IASI simulator



Maximum overlap for adjacent cloud layers

Random overlap between independent clouds

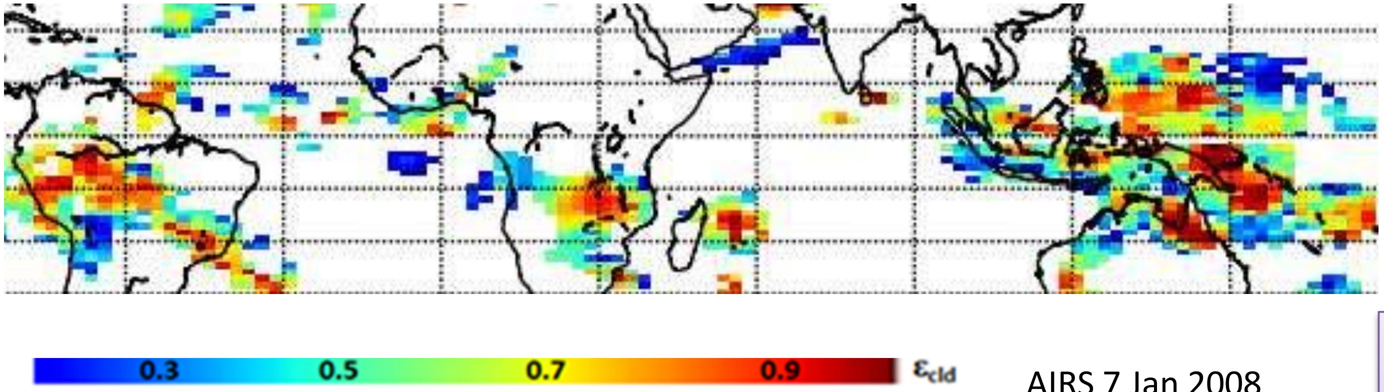
Cb, Ci and thinCI in the model grid cell

UT Cloud System Concept to assess GCM parameterizations

analyze GCM clouds as seen from AIRS/IASI, via simulator
& construct UT cloud systems

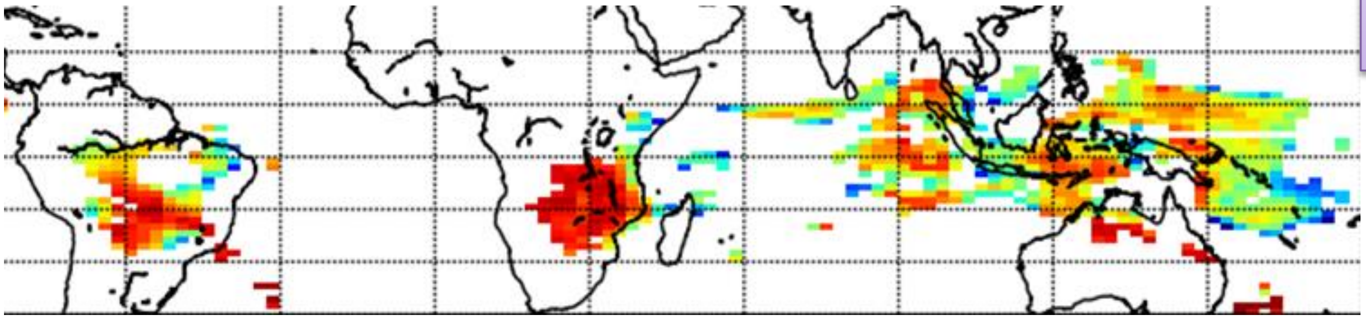
M. Bonazzola, LMD

-> evaluation of GCM convection schemes / detrainment / microphysics



AIRS 7 Jan 2008

Cloud systems are constructed from AIRS data and LMDZ outputs at the same spat. resolution



LMDZ CTRL

4.

What is the effect of including new v_m – De parameterizations in the LMDZ GCM?

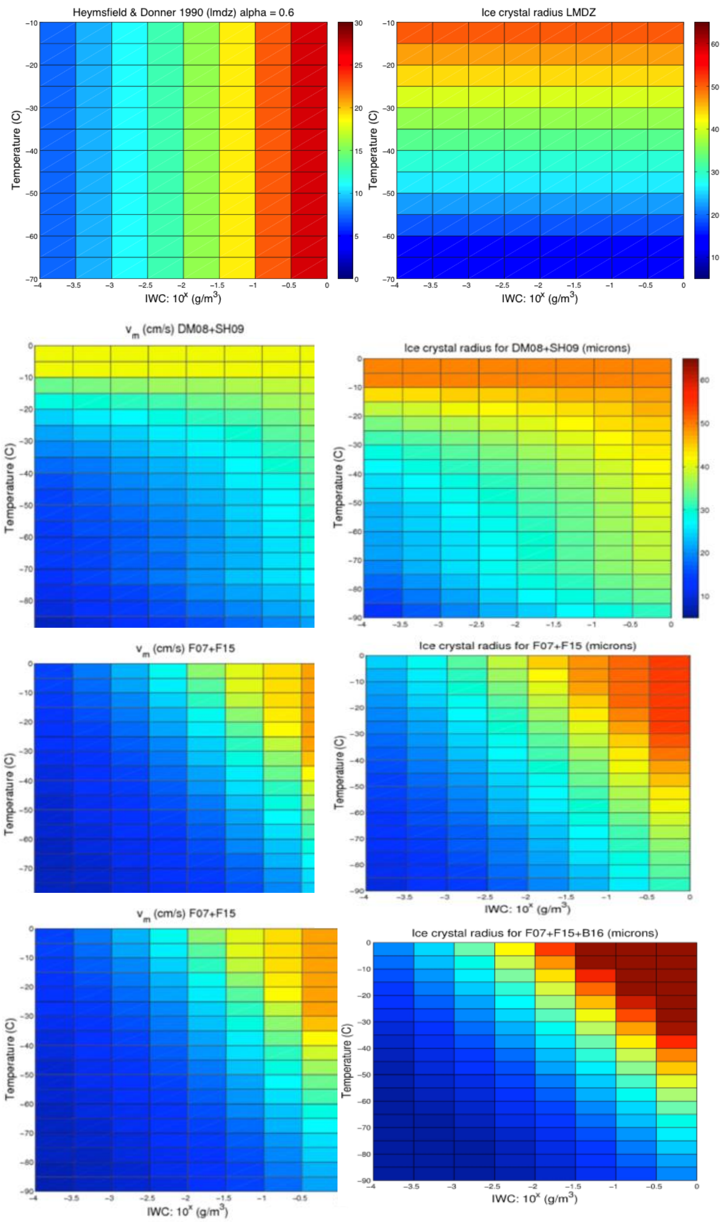
Tuning parameters concerning high clouds for radiation balance

FALLICE: scaling of fall speed

EPMAX: maximum precipitation efficiency

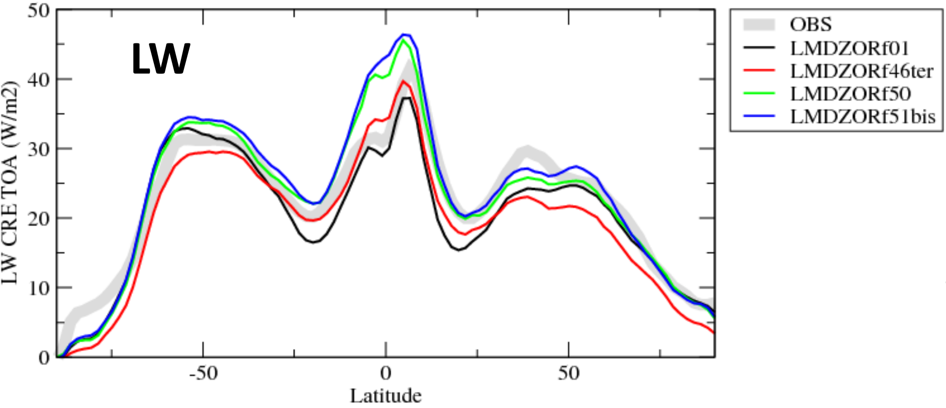
RQH: Rel. width of sub-grid water distribution above 250 hPa

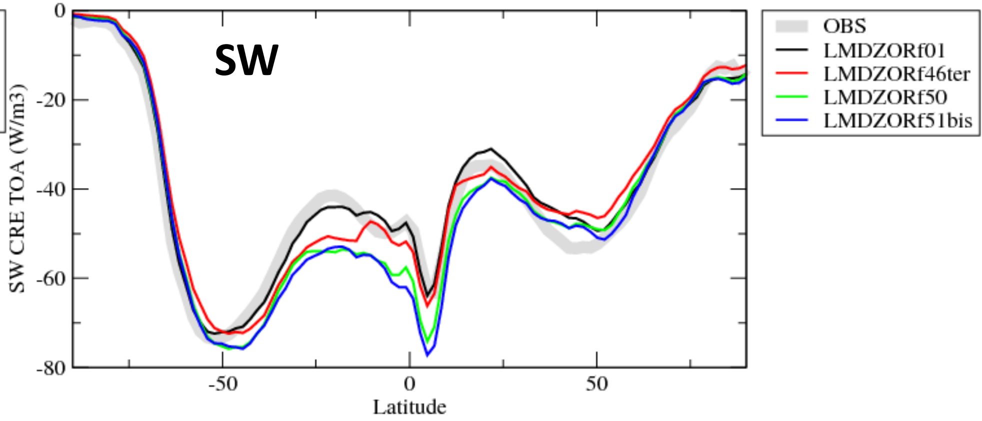
	FALLICE	EPMAX	RHQ
CTRL	0.6	0.9985	0.4
DM08+De(v_m)	0.9	0.9991	0.05
F07F15+De(v_m)	0.9	0.9992	0.002
F07F15+De(IWC,T)	0.9	0.9991	0.05

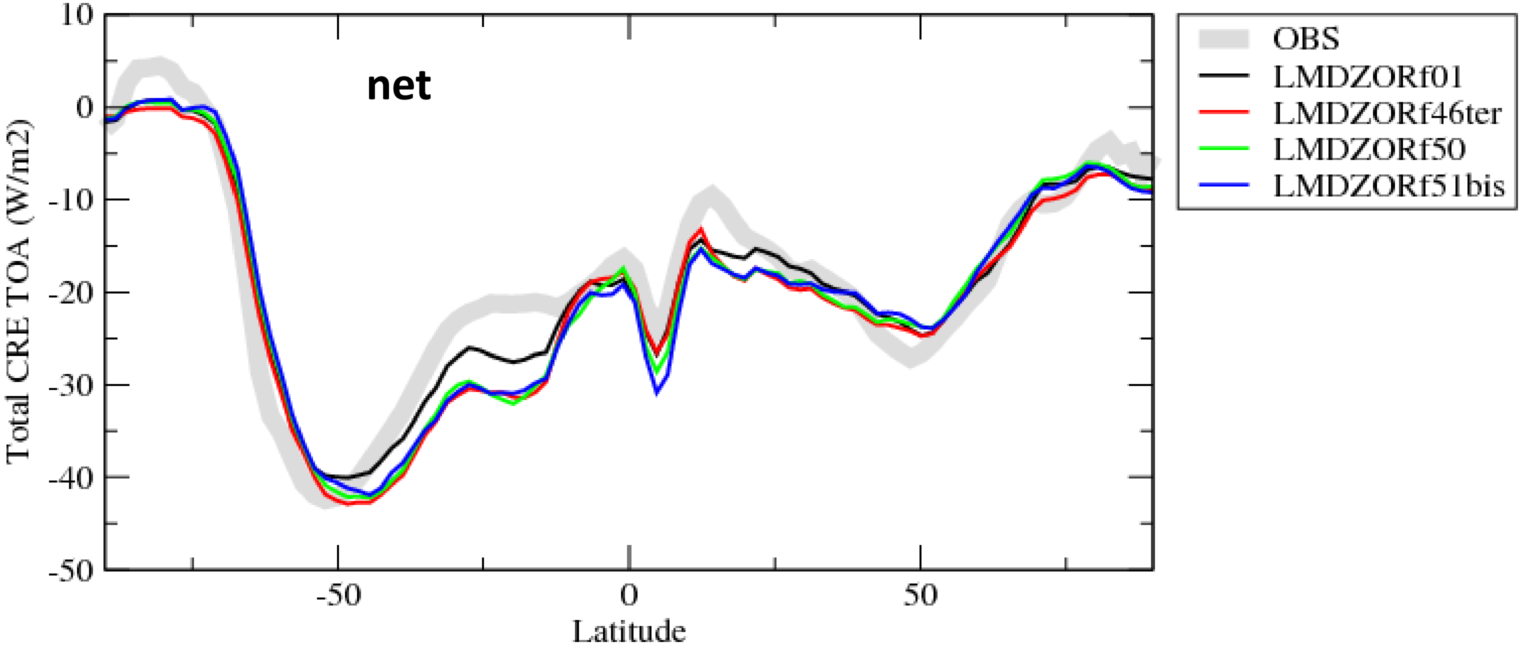


CRE and total radiative budget at TOA

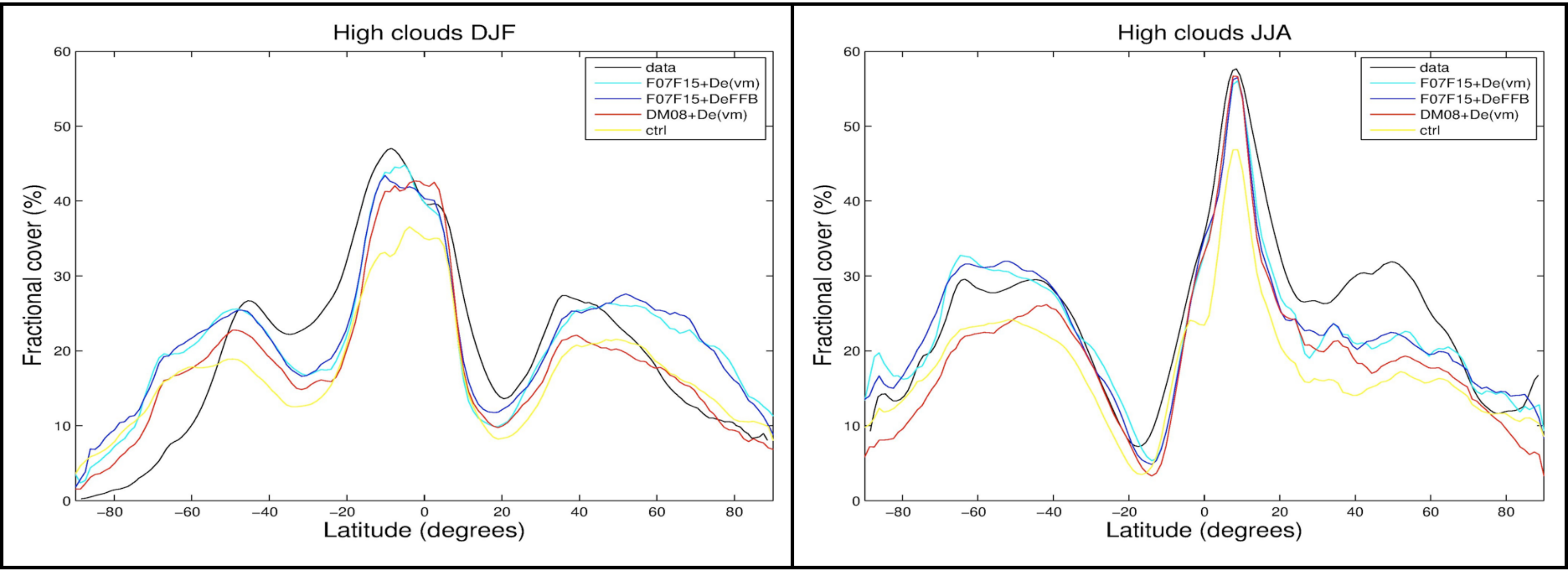
Total radiative budget TOA (W/m^2)	
CTRL	3.67
F07F15+De(v_m)	3.51
F07F15+De(IWC,T)	3.45
DM08+De(v_m)	3.62







High cloud cover

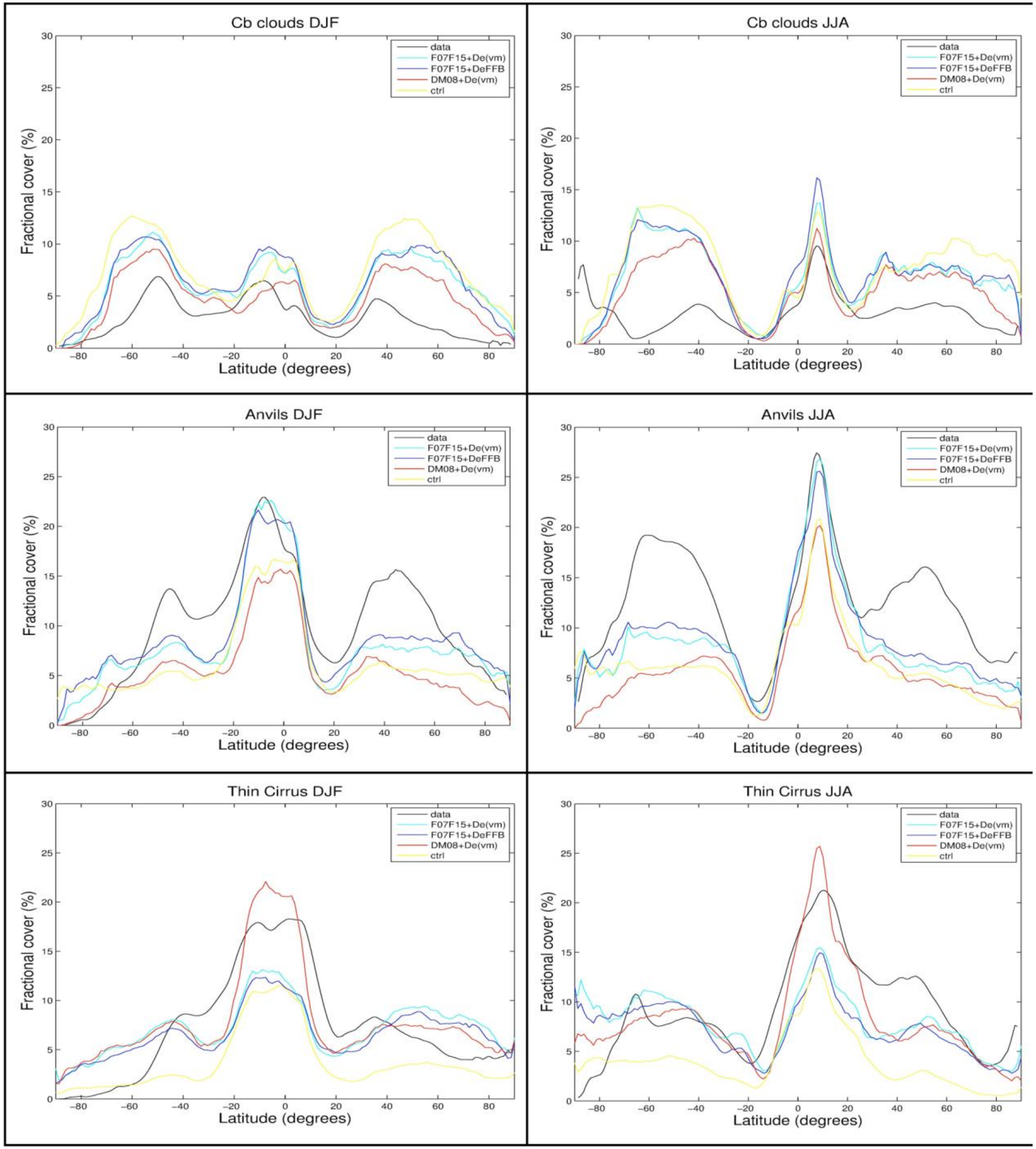


New parameterizations: More high cloud cover than in CTRL, **in better agreement with observations (except at higher latitudes)**

Improvement: Less Cb in midlatitudes

Improvement for F07F15: more Ci

Improvement:
more thinCi
(more thinCi in polar regions than in obs., but thin clouds over ice difficult to detect)



UT Cloud System Concept to assess GCM parameterizations

analyze GCM clouds as seen from AIRS/IASI, via simulator

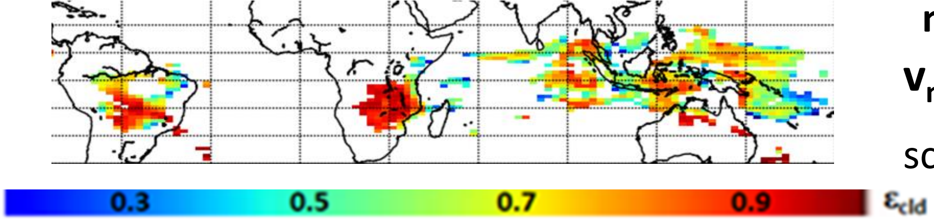
M. Bonazzola, LMD

& construct UT cloud systems

-> evaluation of GCM convection schemes / detrainment / microphysics

Goal: build coherent v_m- De parameterization

spatial res. 2.5° x 1.25°



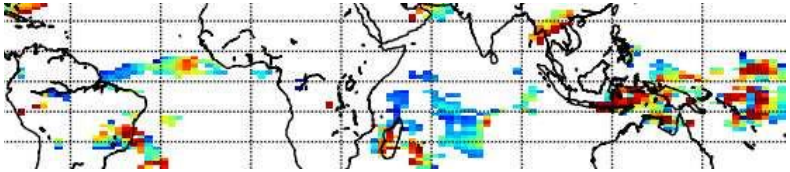
nominal fall speed

v_m = 0.3 x f(IWC) **De = f(T), ε = f(De, IWC)**

scaled v_m too small compared to observations

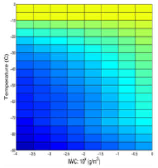
v_m = 0.9 x f(IWC, T) **De = f(v_m)** *Heymsfield et al. 2003*

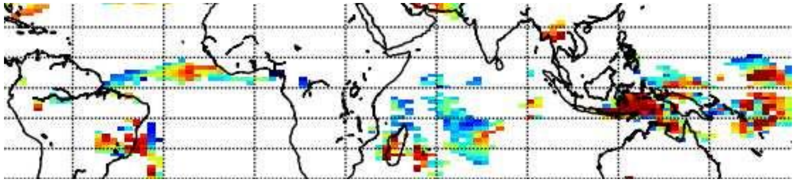
v_m increases with IWC & T, v_m closely related to De



Deng & Mace 2008

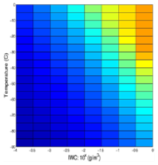
v_m increase with IWC *weaker* towards warm T





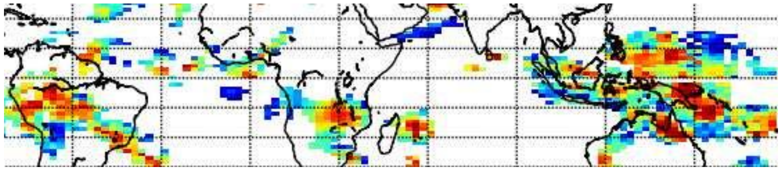
Field et al. 2007, Furtado et al. 2015

PSD moment parameterization



Rad. balance -> precip. efficiency, UT hum variability

horizontal cloud system emissivity structure sensitive to v_m, De

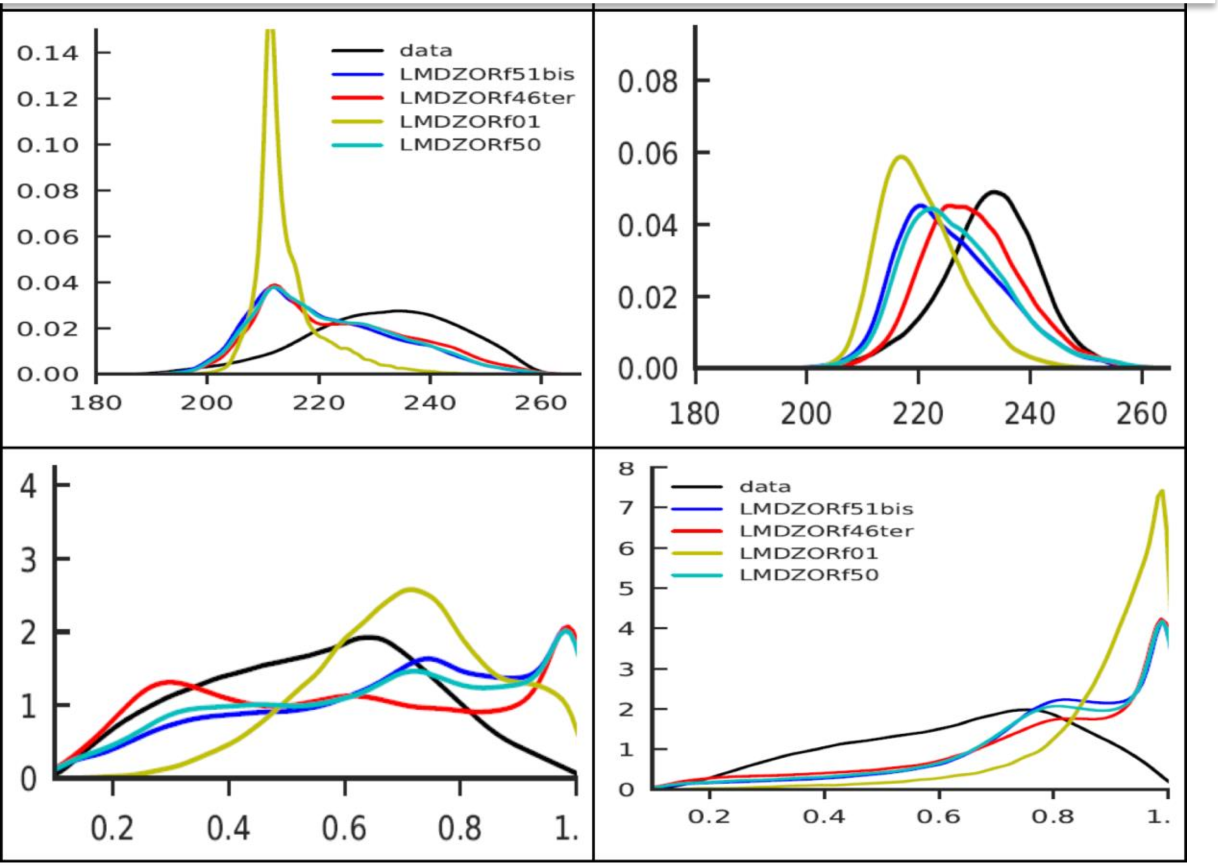


AIRS 7 Jan 2008

Analysis of cloud systems

Top: Temperature
Bottom: Emissivity

Tropics *Mid-latitudes*

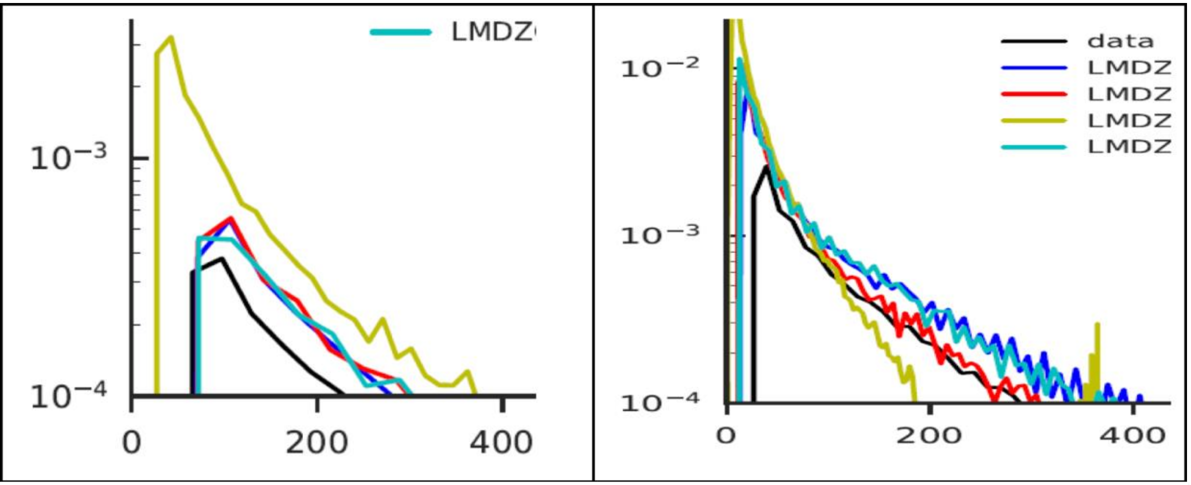


Improvement of :

- emissivity (less emissive cloud systems),
-Temperature (warmer cloud systems).

CTRL
F07F15+De(v_m)
F07F15+De(IWC,T)
DM08+De(v_m)

Analysis of cloud systems



Tropics *Mid-latitudes*

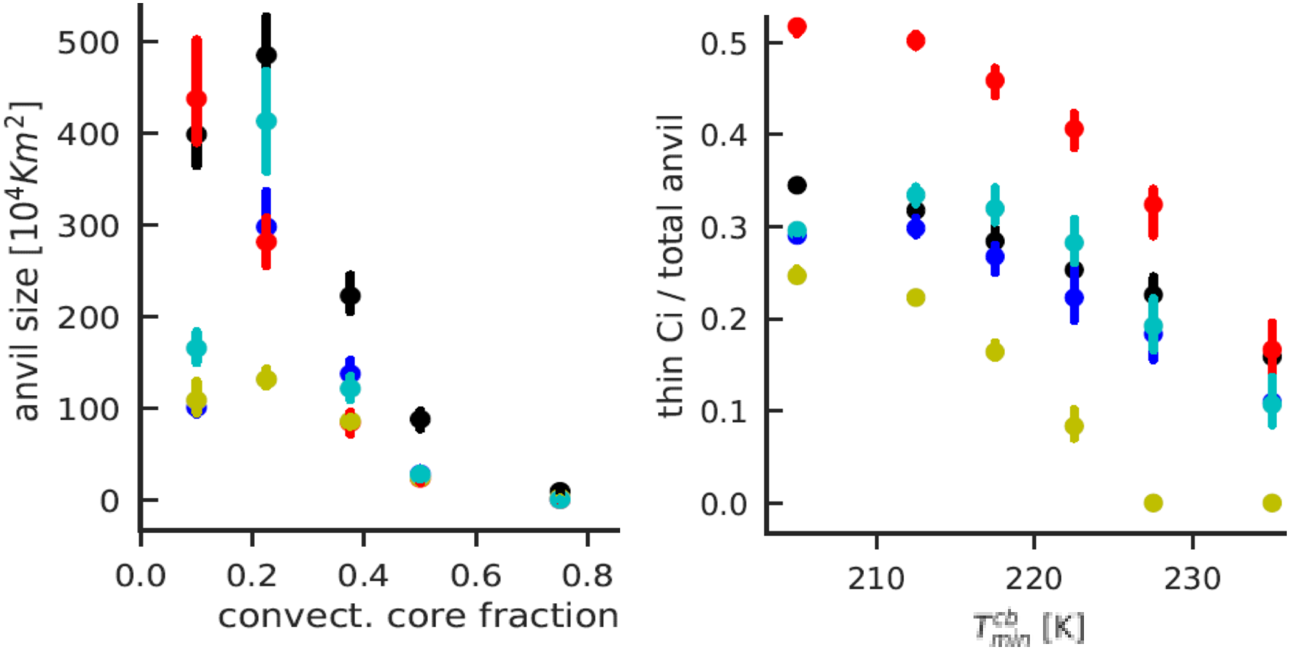
Improvement of cloud system sizes

	Tropics	Midlatitudes
data	233 (473)	88 (132)
CTRL	66 (143)	16 (28)
F07F15+De(v_m)	98 (427)	47 (107)
F07F15+De(IWC,T)	91(376)	47 (108)
DM08+De(v_m)	142 (446)	38 (83)

For convective/ frontal cloud systems

CTRL
F07F15+De(v_m)
F07F15+De(IWC,T)
DM08+De(v_m)

process-oriented UT cloud system behaviour



Data

control v_m =0.3 x f(IWC)
De = f(T)

DM08 v_m = f(IWC,T)
De = f(v_m)

F07-F15 v_m = f(IWC,T)
De = f(v_m)

F07-F15 v_m = f(IWC,T)
De = 0.17(D_m)

preliminary

increasing age of system

increasing convective depth

including T dependency of v_m -> larger spread in T

more realistic v_m –De very promising: leads to more realistic anvil size development and thin Ci increasing

Next steps: integrate single scattering properties developed by *Baran et al. 2016* from PSD's of F07
more realistic UT humidity variability threshold (AIRS climatology of *Kahn et al. 2009, 2011*)
precipitation – detrainment efficiency parameterization

Conclusions

- 2 bulk ice cloud schemes which coherently couple v_m (cloud physics) and De (cloud radiative effects) have been constructed from existing parameterizations

The new schemes use a **realistic v_m** (about 3 x larger than the original, tuned v_m in LMDZ), which also depends on IWC & T, instead of IWC alone
De is now linked to (IWC,T) or directly to v_m
-> UT water sub-grid variability had to be reduced for radiation balance

- Cloud System diagnostics provides additional constraints:
new bulk ice schemes -> larger cloud systems & slightly less emissive anvils,
in better agreement with AIRS observations

- Cloud System Concept links anvils to convection
-> allows process-oriented evaluation
(behavior of anvils with increasing convective depth, along statistical life cycle)

- new ice cloud schemes seem to improve this behavior,
compared to observational cloud system analysis

- AIRS-IASI cloud observational simulator will be made available in COSP