Process-oriented evaluation of UT cloud parameterizations using a Cloud System Concept

Example: Bulk ice scheme in LMDZ model

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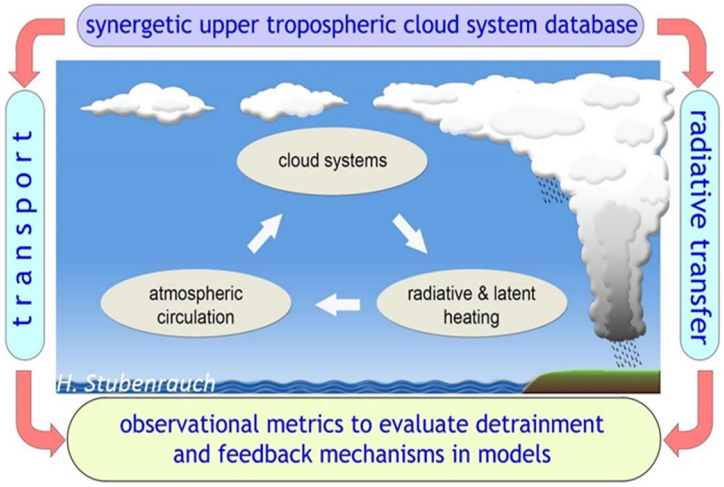
Monsoon Clouds over Bangladesh
(Archive: NASA, International Space Station)

GEWEX PROcess Evaluation Study on Upper Tropospheric Clouds & Convection

NASA Obs4MIPs meeting *(April 2014)*
-> need to use observations more intelligently to probe process understanding

UTCC PROES Working Group links communities from observation, radiative transfer, transport, process & climate modelling (so far 4 meetings since Nov 2015)



focus on tropical convective systems

Goals:
- understand relation betw. convection, cirrus anvils & radiative heating
- provide observational metrics to probe processes involving UT cloud systems

https://gewex-utcc-proes.aeris-data.fr/

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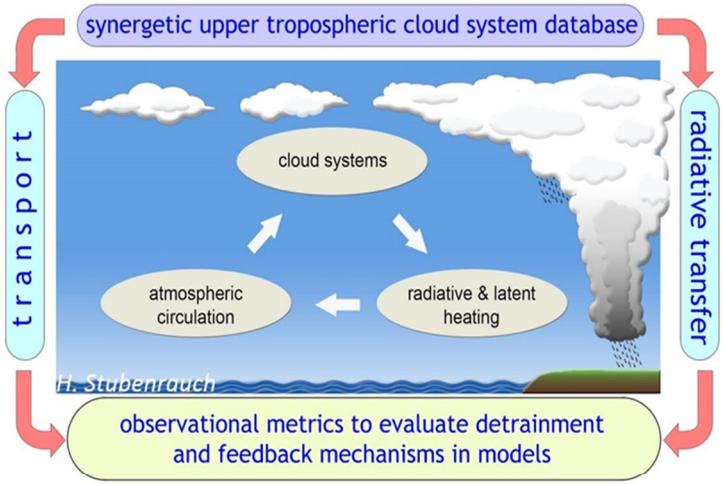

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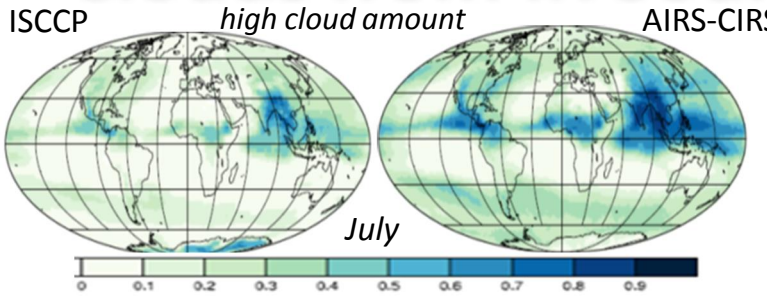
UTCC PROES Strategy:

- **Cloud System Concept, anchored on IR sounder data**
  (horizontal extent & convective cores/cirrus anvil/thin cirrus ***based on*** p_{cld}, ε_{cld})
  -> relationships between anvil properties & convective strength
- **build synergetic data** (vert. structure, atmosph. environment)
- **investigate how convective systems behave in CRM & in GCM simulations**
  (under different parameterizations of convection/detrainment/microphysics)

Clouds from IR Sounder (CIRS) -> Cloud System Concept



- long time series (HIRS, AIRS, IASI) & good areal coverage
- **good IR spectral resolution -> sensitive to cirrus**

similar performance day & night, COD_{vis} > 0.2, also above low clouds

(*Stubenrauch et al., ACP, 2017)*

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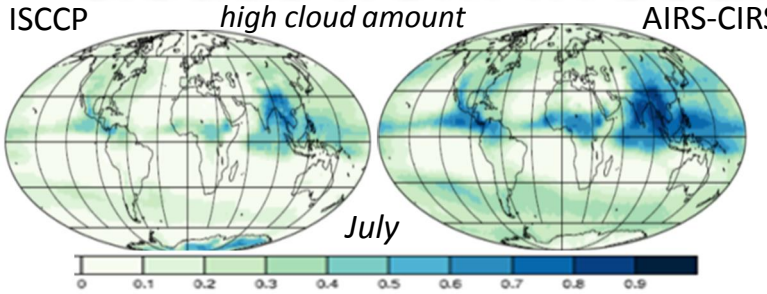

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cloud systems built from adjacent grid cells with similar p_{cld}; convective cores & cirrus anvil from ε_{cld}
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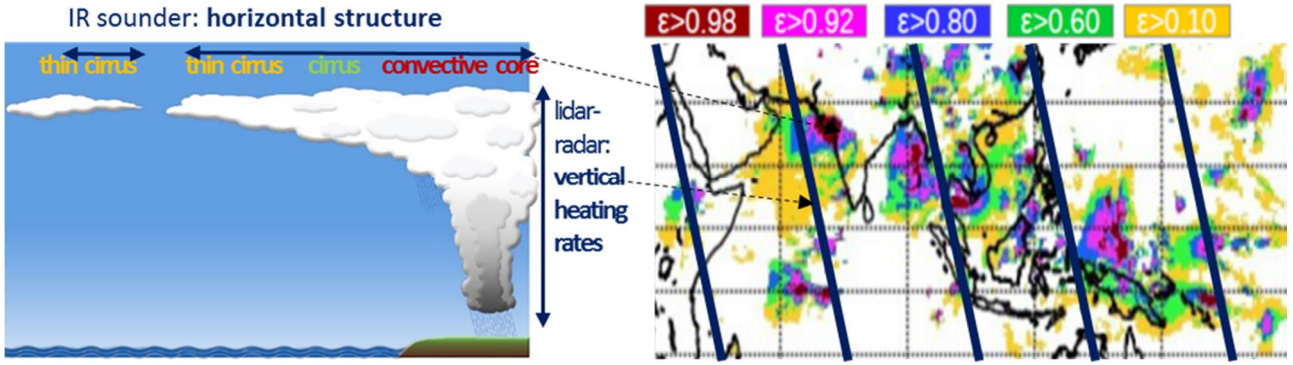

grid cell resolution 0.5°,
sub-grid Cb, Ci, thin Ci fractions
can be adapted to other resolutions
(from 0.25° to GCM resolution)

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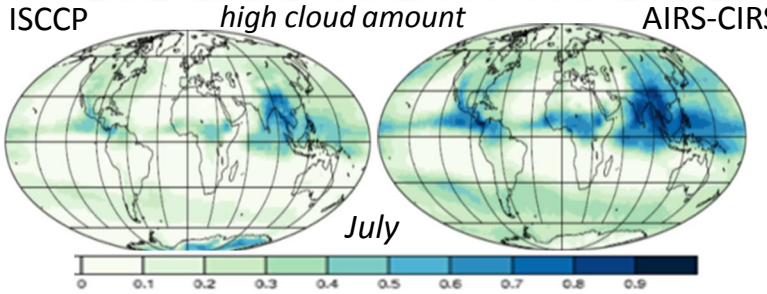

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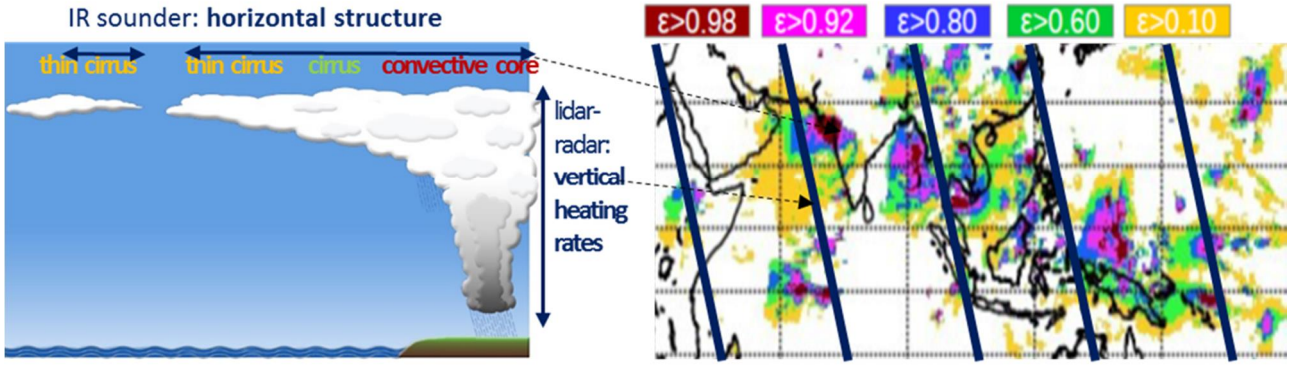

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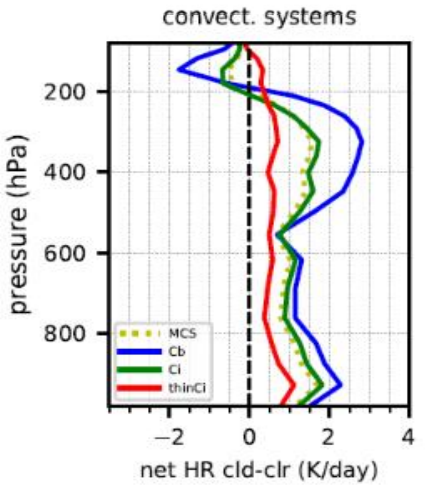
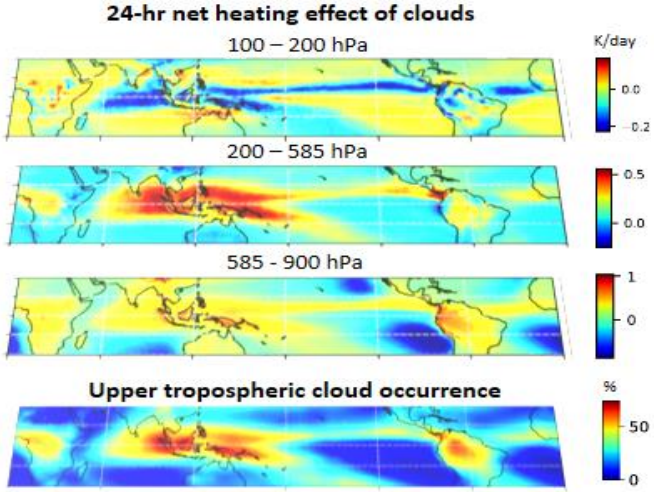
3D cloud systems from Machine Learning trained on CALIPSO-CloudSat (HR, DZ, RR) / TRMM (LH)

(*Stubenrauch et al., ACP, 2021*)





Cloud System Concept + 3D HR fields :

1) relation between convection – cirrus anvil
2) process-oriented GCM evaluation
3) dynamical response to atmospheric heating

Towards a coherent Bulk ice cloud scheme (v_m & D_{eff})

Cirrus bulk properties = mass- or area-weighted integrals of particle size distribution (PSD)

$m = \alpha D^b$ $A = c D^d$ *coefficients depend on ice crystal habit & size*

Fall speed v_m & ice crystal size distribution impact cirrus life time & radiative effects

$\varepsilon_{cld} = f(D_{eff}, IWC)$

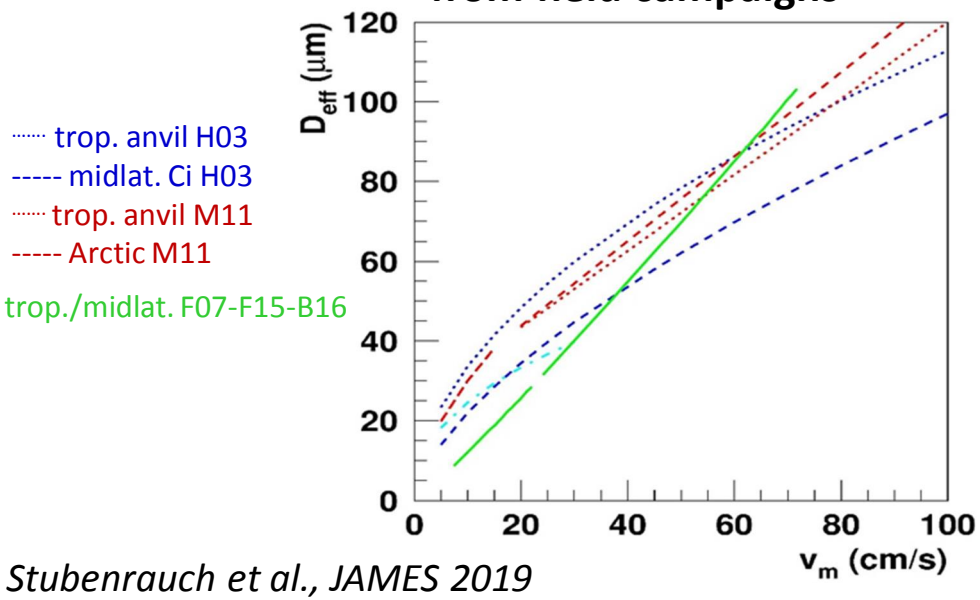
Goal: construct bulk ice cloud scheme which coherently treats ice cloud physics & radiation from reviewed existing parameterizations (paying attention to their validity range)

airborne & ground-based observations: $v_m = f(IWC, T)$

IWC & T classify distributions of ice crystal size & habit (*Field et al. 2007*)

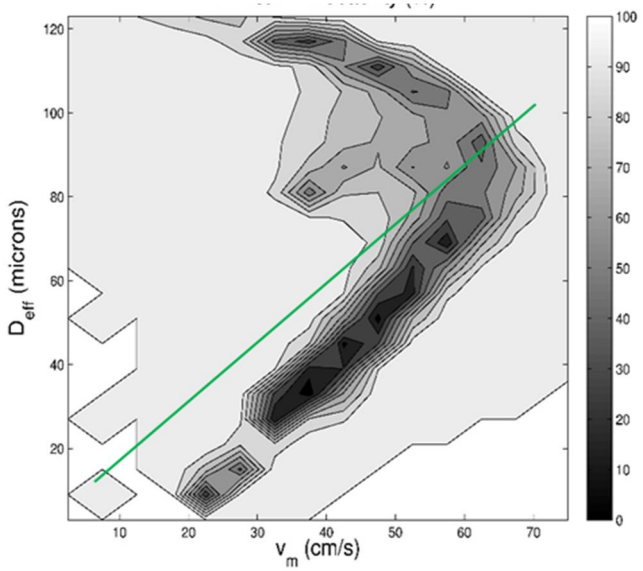
v_m & D_{eff} are closely related, as they both depend on ice mass / ice area

from field campaigns



Stubenrauch et al., JAMES 2019

current version of LMDZ



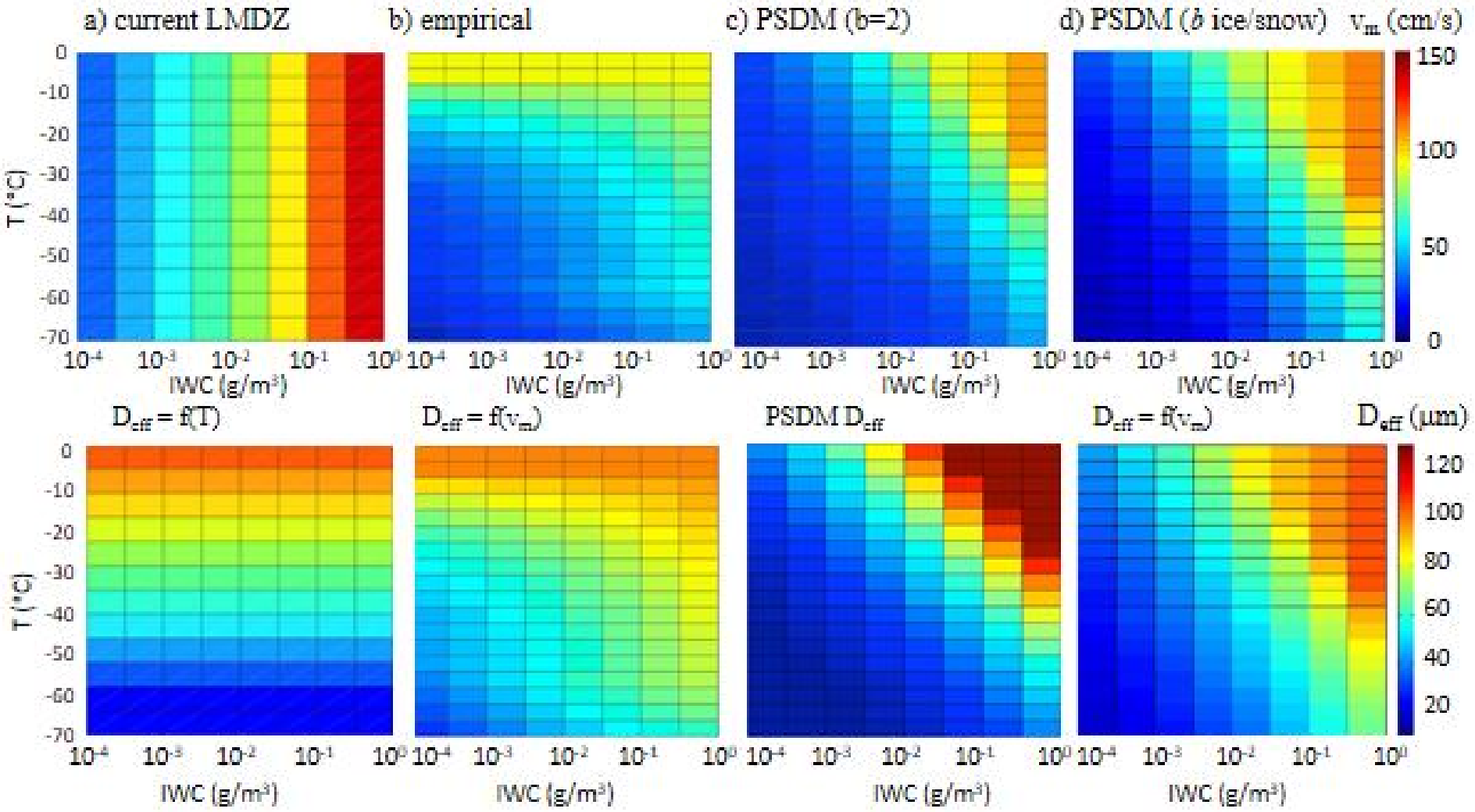
$v_m = f(IWC)$
$D_{eff} = f(T)$
v_m tuned (x 0.3) to achieve radiative balance

Synthesis : v_m & D_{eff} = f(T, IWC)

Stubenrauch, Bonazzola et al., JAMES 2019

empirical : v_m = f(IWC, T) *Deng & Mace 2008 / Schmitt & Heymsfield 2009*; D_{eff} = f(v_m)

v_m, D_{eff} from moments of PSD, parameterized as f(IWC, T) *Field et al. 2007 / Furtado et al. 2015 / Baran et al. 2016*



v_m

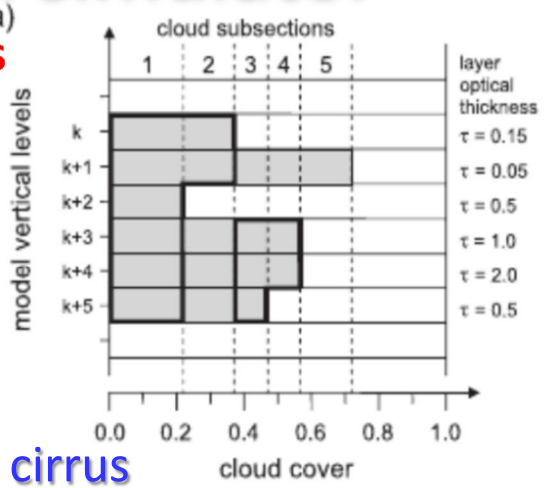
D_{eff}

New diagnostics using CIRS observation simulator

IR Sounders provide cloud height p_{cld} & emissivity ε_{cld}; **sensitive to cirrus**

- construct clouds from vertically contiguous cloudy layers
- clouds divided into sub-sections of similiar vertical structure
- keep only sub-sections with IR optical depth > 0.1
- filter observation times: 1:30AM, 9:30AM, 1:30PM, 9:30PM LT

-> *total & high cloud cover, p_{cld}, T_{cld}, ε_{cld}, z_{cld}, fraction of Cb, Ci, thin Ci*



advantages: allows to evaluate i) sub-grid fractions of Cb, cirrus & thin cirrus
ii) diurnal cycle of UT cloud properties

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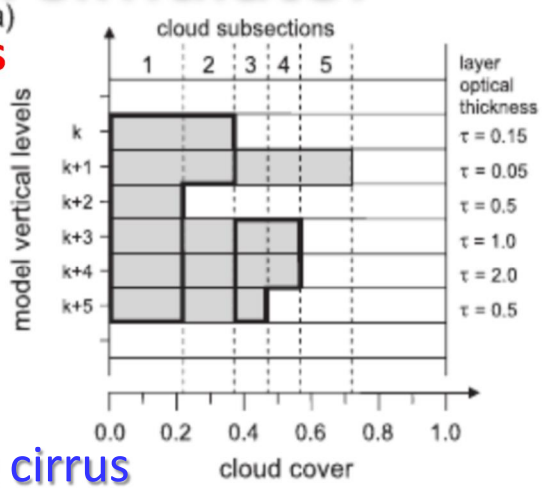

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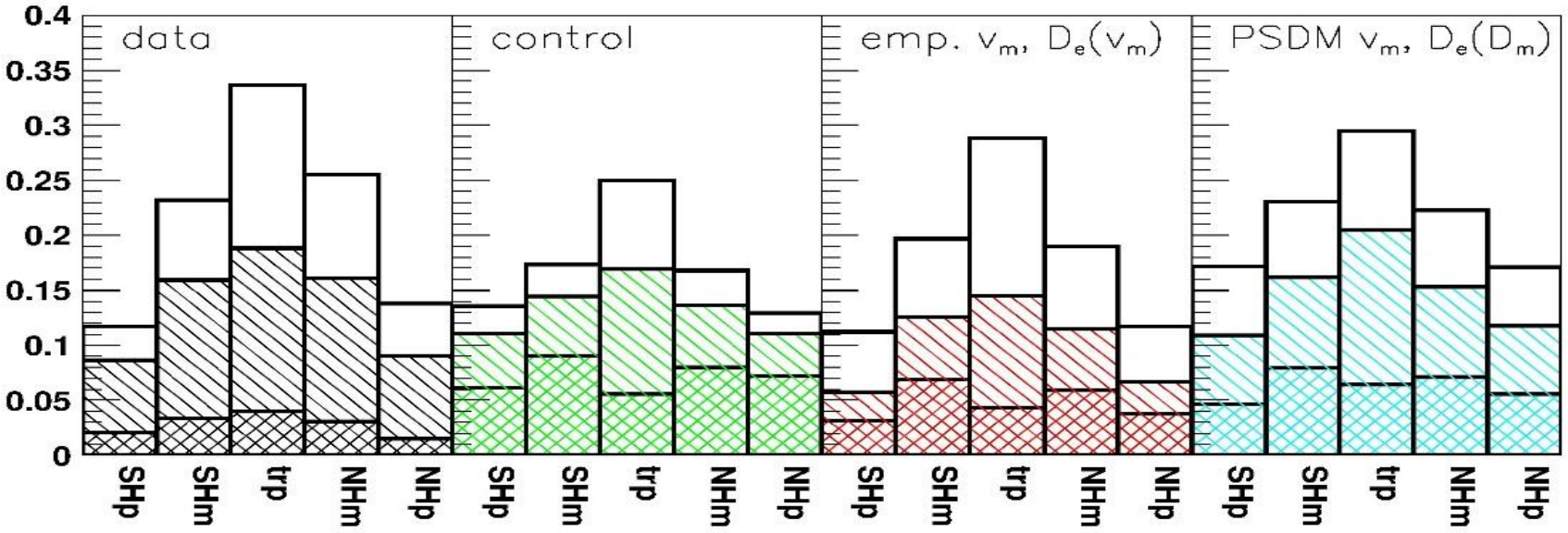
UT cloud cover & its composition (Cb, Ci, thin Ci)



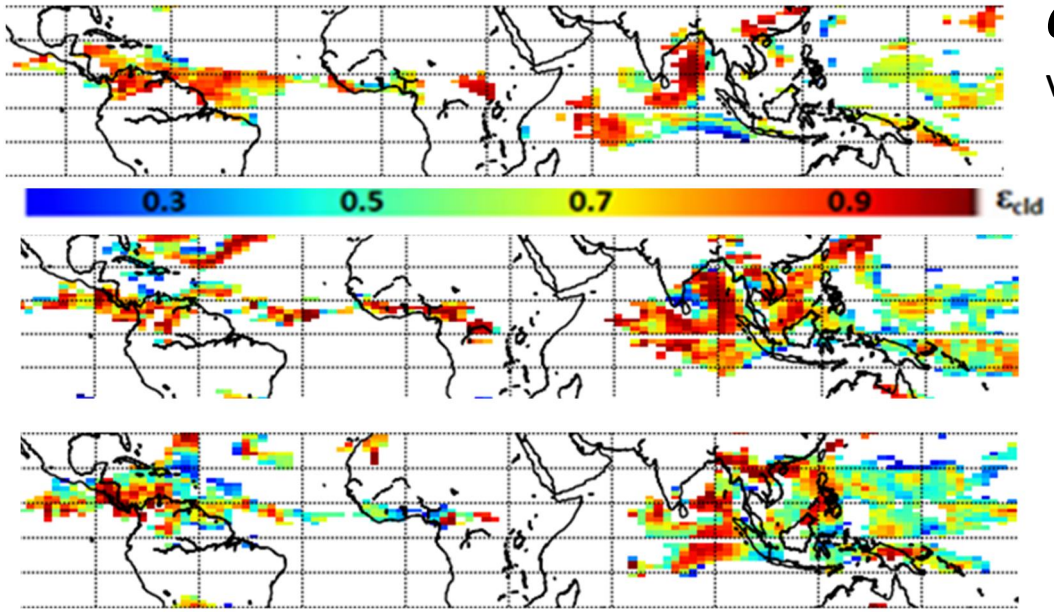
Control simulation too few high clouds with too many Cb
New bulk ice schemes -> increased high clouds, with more Ci & thin Ci, in better agreement with observations

UT Cloud System Concept to assess GCM parameterizations

Cloud System Concept relates anvil properties to processes shaping them
-> process-oriented evaluation of detrainment / convection / microphysics parameterizations

Example: Towards coherent bulk ice cloud scheme deduced from thermodynamics in LMDZ

spatial res. 2.5° x 1.25°



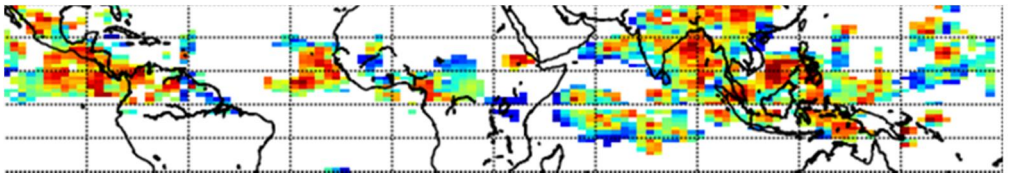
***Current LMDZ model*: v_m = f(IWC), De = f(T)**
v_m tuned to achieve balance (x 0.3)

***observations*: v_m = f(IWC,T), De = f(IWC,T)**

***empirical*: v_m = f(IWC,T), De = f(v_m)**
Deng & Mace (2008), Heymsfield et al. 2003

***PSDM*: v_m, De from moments of ice crystal size distributions as f(IWC,T)**
Field et al. (2007), Furtado et al. 2015, Baran et al. 2016

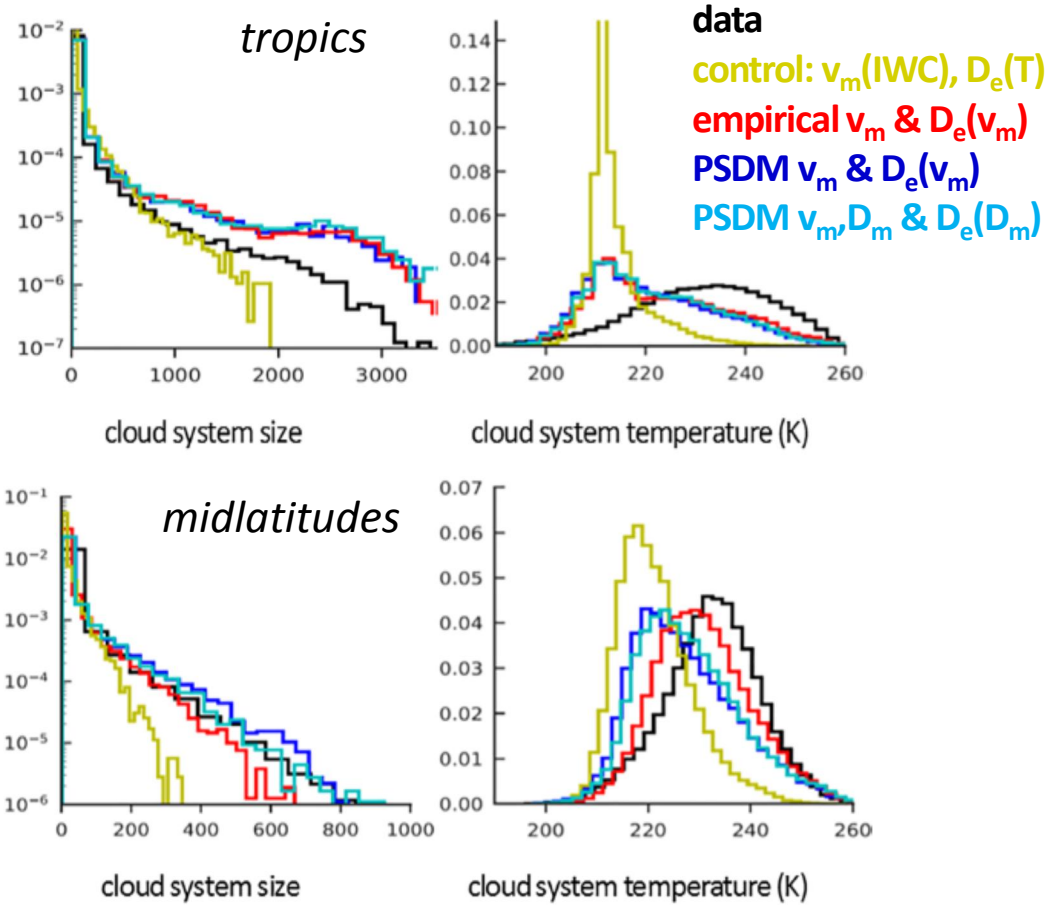
horizontal cloud system emissivity structure sensitive to v_m, De



AIRS snapshot 3 July 2008 AM

UT cloud system statistics

New ice schemes



New parameterizations -> improvement of cloud system property distributions

UT cloud system statistics

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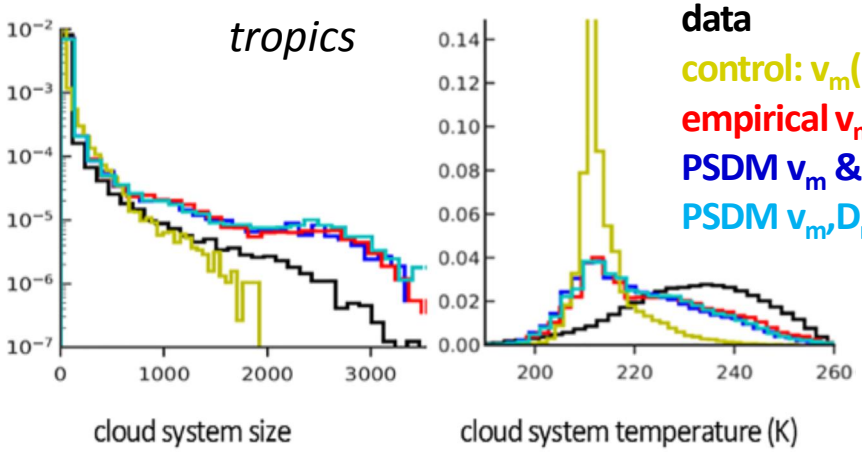
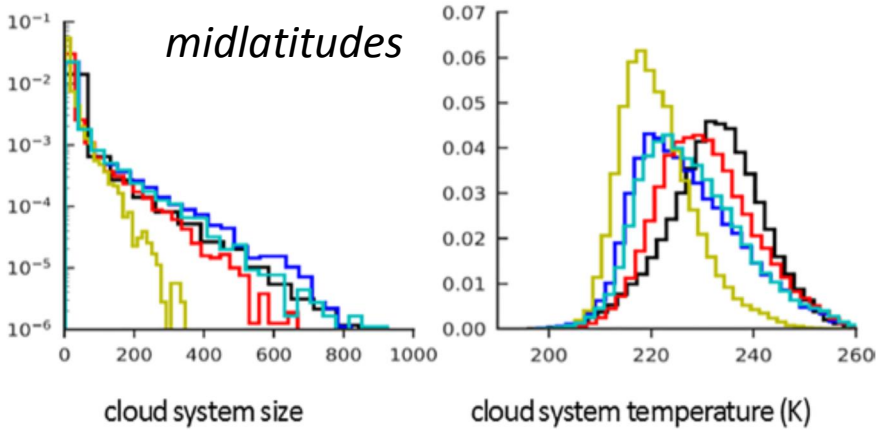
tropics



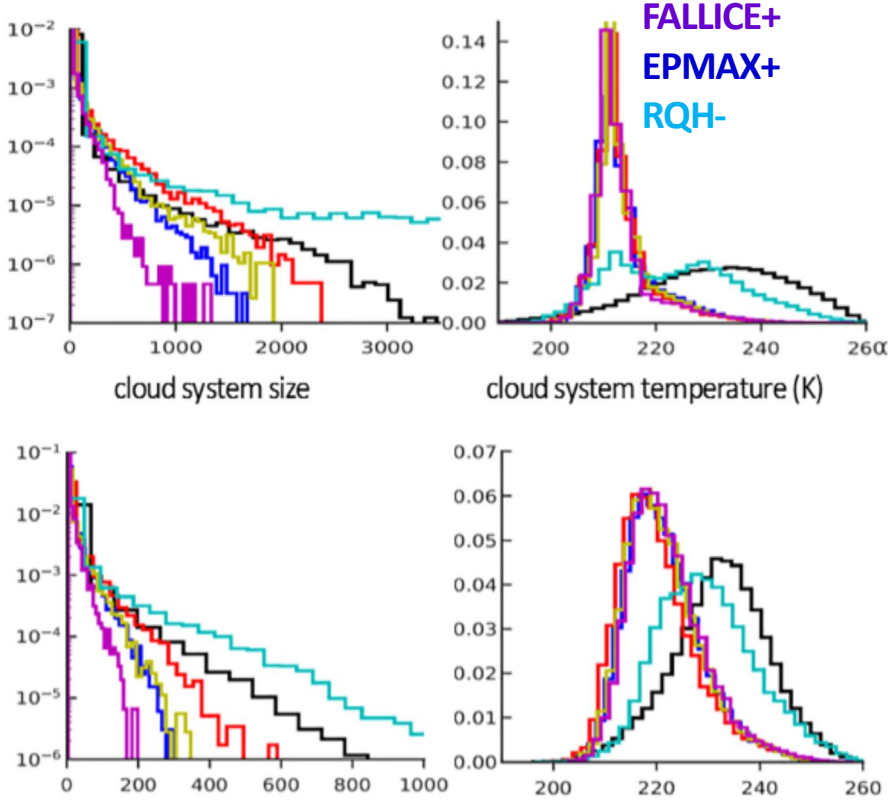
data
control: v_m(IWC), D_e(T)
empirical v_m & D_e(v_m)
PSDM v_m & D_e(v_m)
PSDM v_m,D_m & D_e(D_m)

midlatitudes



Sensitivity Study

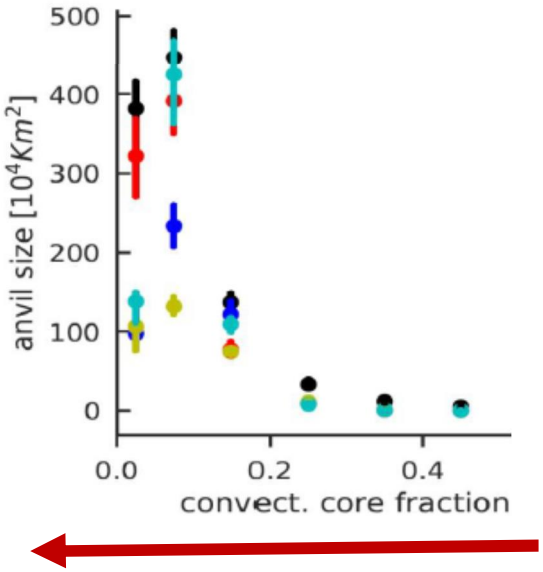
control
scaled v_m(IWC,T)
FALLICE+
EPMAX+
RQH-



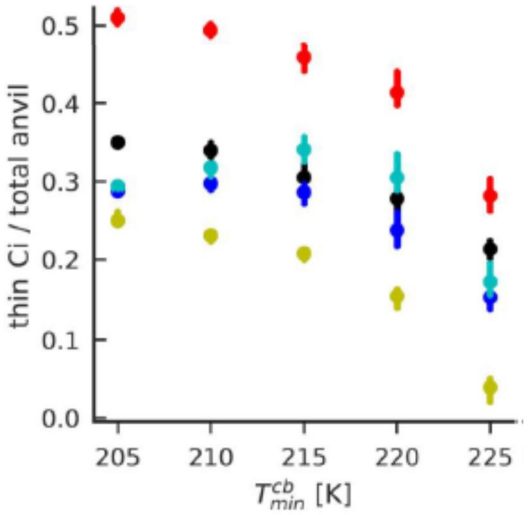
New parameterizations -> improvement of cloud system property distributions

Introduction of IWC-T dependence -> improvement of cloud system size distribution
Decrease of RQH -> improvement of cloud system T distribution

process-oriented UT cloud system behavior



increasing age of system



increasing convective depth

data

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

empirical v_m(IWC,T)& $D_e(v_m)$

PSDM v_m & $D_e(v_m)$

PSDM v_m & D_e

New process-oriented diagnostics based on Cloud System Concept powerful constraint:

more realistic v_m –D_{eff} -> more realistic anvil size & ε horizontal structure (increasing thin Ci) development

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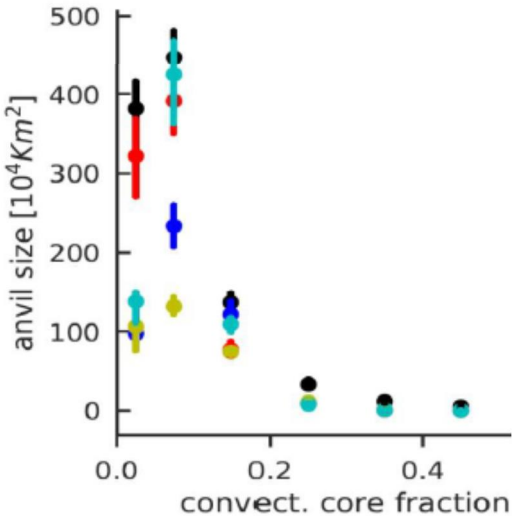

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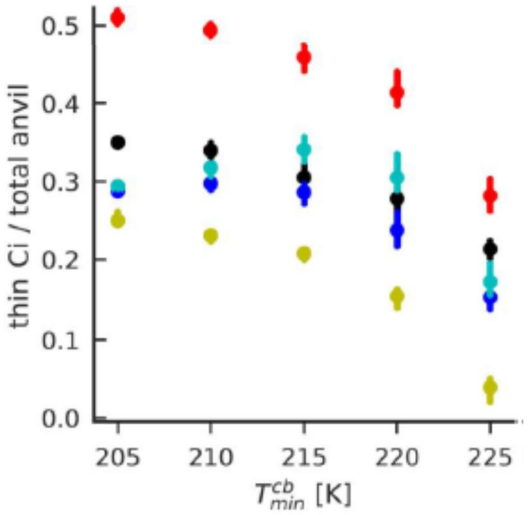

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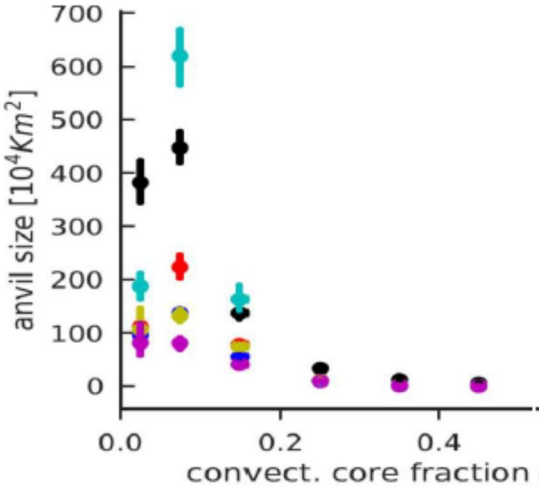

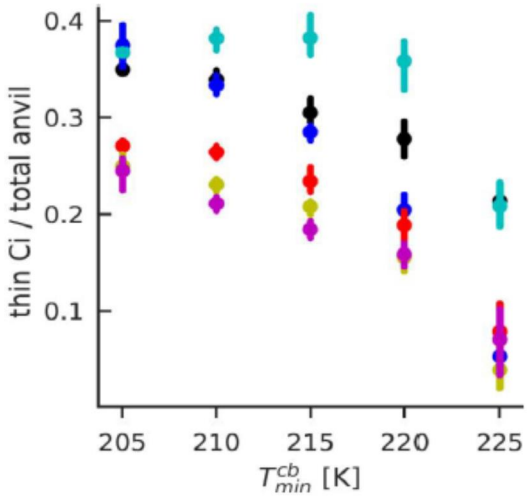

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scaled PSDM v_m

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RQH-

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Tuning adjustment of UT sub-grid water variability (RQH) -> larger anvils & more thin cirrus

Summary & Outlook

- **Cloud System diagnostics provides powerful constraints:**
  coherent bulk ice schemes -> larger cloud systems & slightly less emissive anvils,
  in better agreement with CIRS observations

- **Cloud System Concept links anvils to convection, allows process-oriented evaluation:**
  coherent bulk ice schemes improve
  behavior of anvils with increasing convective depth & along statistical life cycle

Stubenrauch, C. J., Bonazzola, M., Protopapadaki, S. E., & Musat, I., **New cloud system metrics to assess bulk ice cloud schemes in a GCM**. J. Advances in Modeling Earth Systems, 11, doi:10.1029/2019MS001642, 2019

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- **Replace D_{eff} directly by β_{ext}, ω_0, g (λ, IWC, T) of *Baran et al. 2016***
- **Evaluation with radiative heating rates deduced from A-Train Observations & Machine Learning**
- **Try to use HighTune for tuning**
- **Use Cloud System Concept for evaluation of new parameterizations of RQH & EPMAX**

Stubenrauch, C. J., Caria, G., Protopapadaki, S. E., & Hemmer, F., **3D Radiative Heating of Tropical Upper Tropospheric Cloud Systems derived from Synergistic A-Train Observations and Machine Learning**, Atmos. Chem. Phys., 21, doi:10.5194/acp-21-1015-2021, 2021

Discussion

Cloud System approach for evaluation of GCMs complementary to process-oriented evaluation using LES & regional field campaigns

It needs:

1) Implementation of CIRS observation simulator (-> sub-grid structure of Cb, Ci, thCi)

2) Reconstruction of UT cloud systems at GCM resolution
(of GCM simulations & CIRS L2 data)

3) Analysis of UT cloud systems & corresponding vert structure & HRs
(from GCM simulations & data)

We can provide these tools
However they need to be rewritten to be more user friendly
Is there interest in this community ?

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