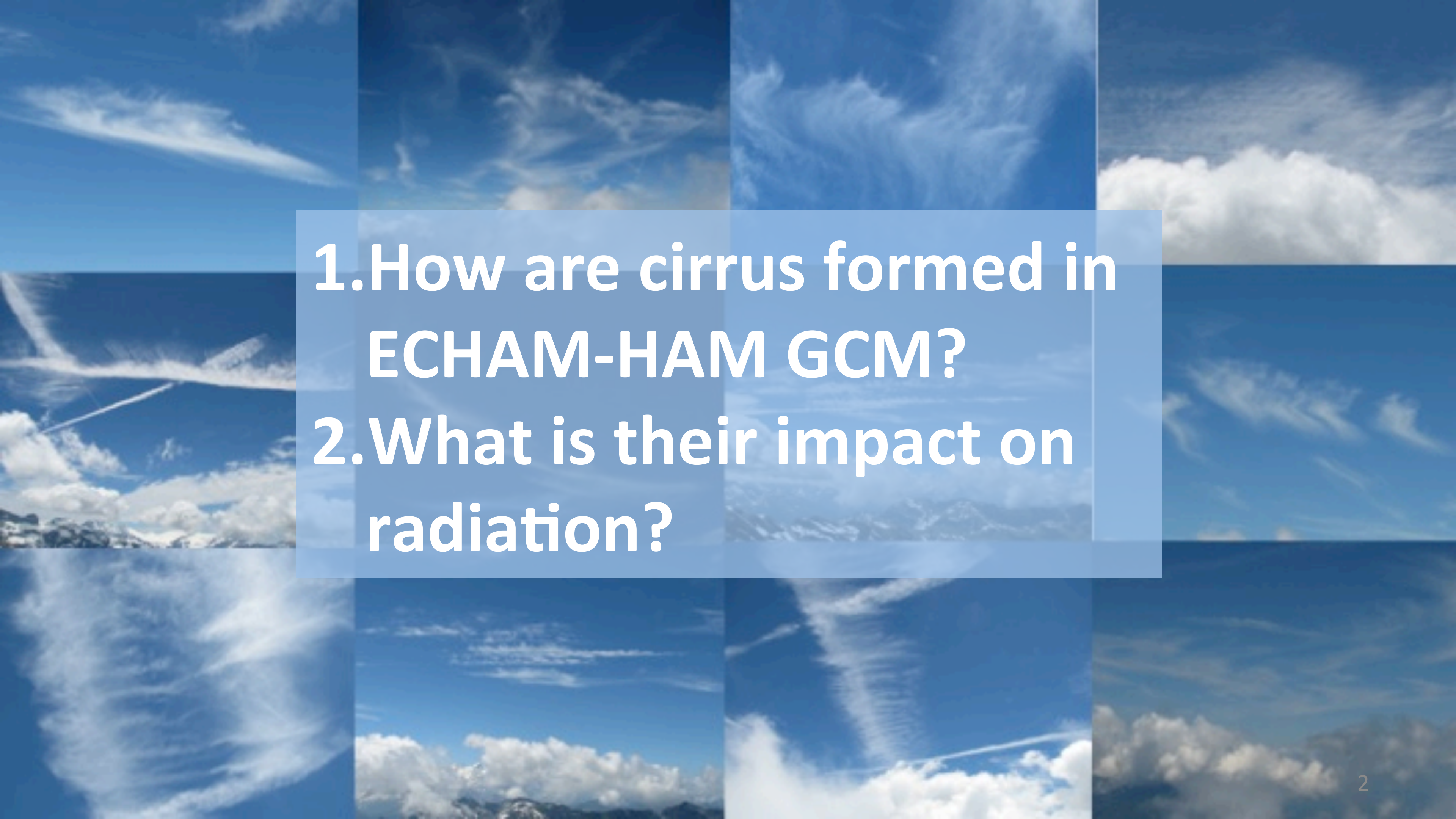
Cirrus cloud formation mechanisms in ECHAM-HAM GCM

Blaž Gasparini, ETH Zürich

Paris, 16th Nov 2015

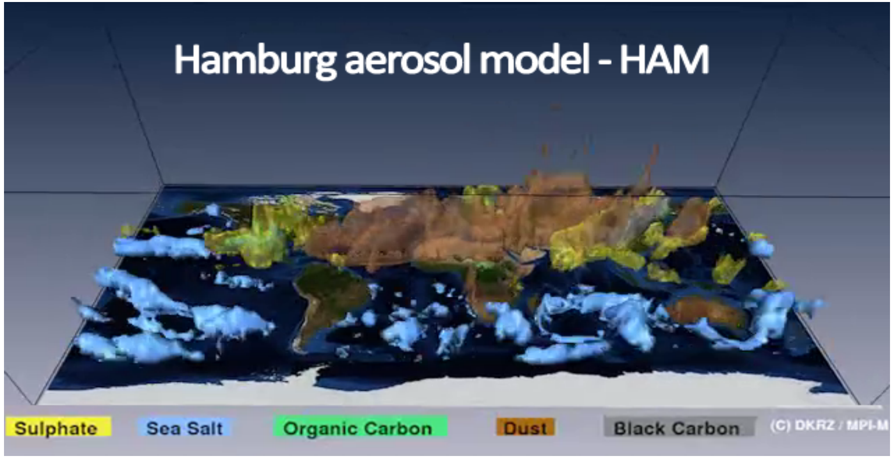


1. How are cirrus formed in ECHAM-HAM GCM?
2. What is their impact on radiation?

Model

ECHAM6.1 General Circulation Model with

- Horizontal resolution: 1.875°x1.875°
- 31 vertical layers, model top at 10 hPa (30 km)



HAM2.2 aerosol+cloud microphysics module (Zhang et al. 2012)

Cirrus scheme:

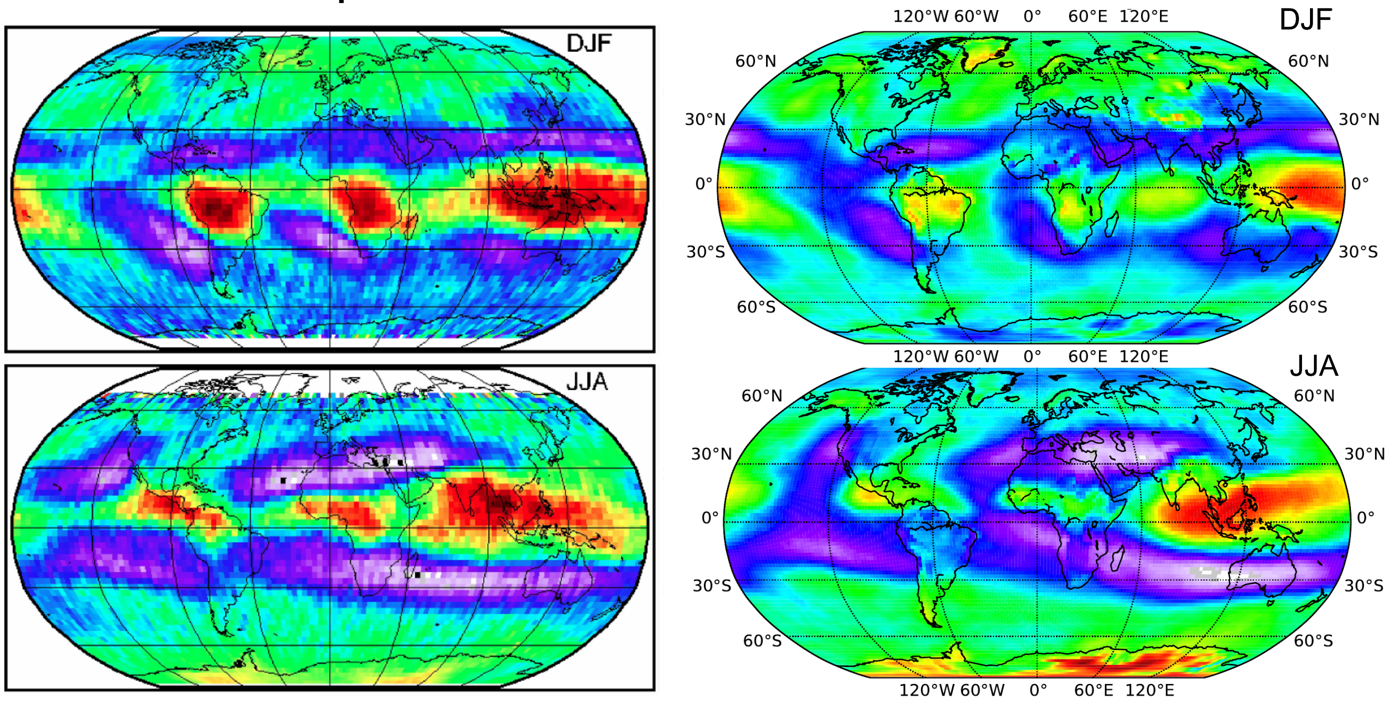
Kuebbeler et al., 2014

Kärcher et al., 2006

Is the model able to reproduce the ice clouds?

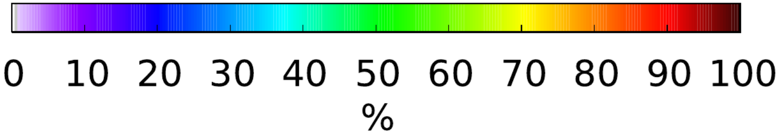
Calipso

ECHAM6.1-HAM2.2

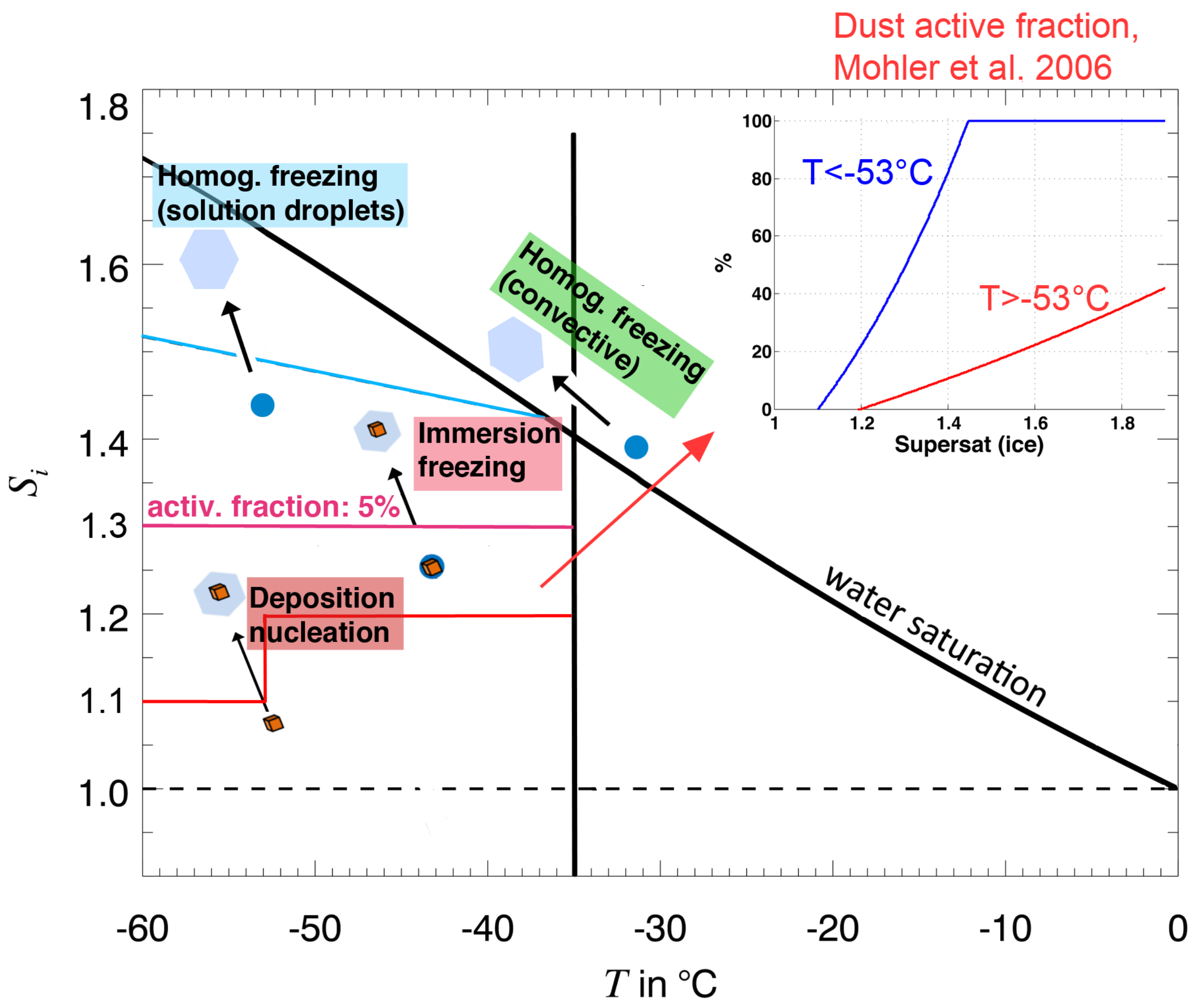


Ice clouds, at T<-40°C

- Underestimation of tropical convective outflow cirrus



Ice cloud occurrence frequency



Cirrus cloud formation in ECHAM-HAM

<u>Aerosols considered:</u>

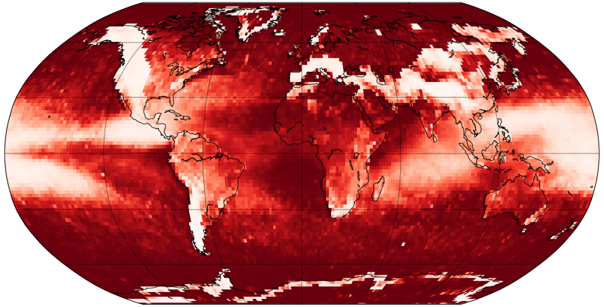
Hom. frz of solution droplets: soluble aerosols

Immersion frz: coated dust

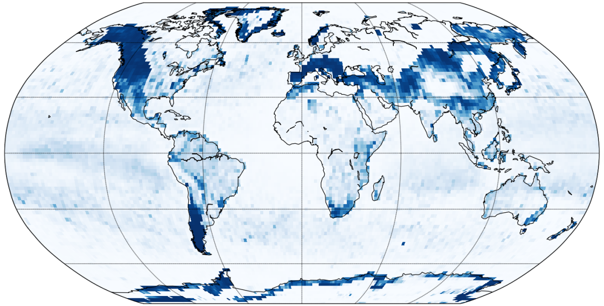
Deposition nucl.:dust

Talking later about:
HOM, HET, DETR

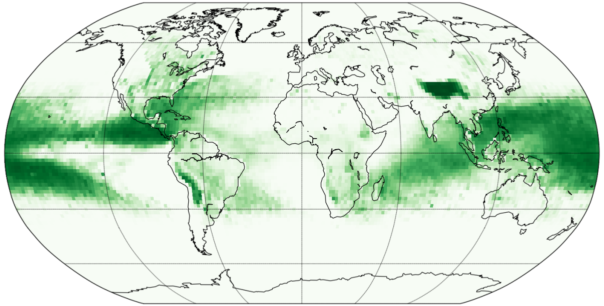
Heterogeneous IC



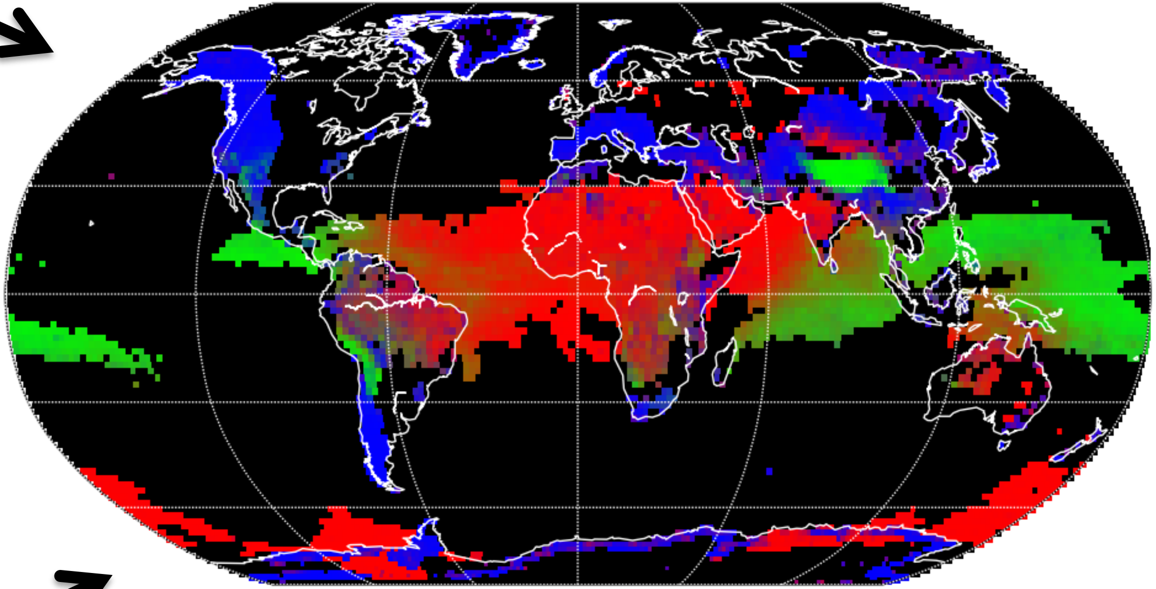
Homogeneous IC



Detrained IC



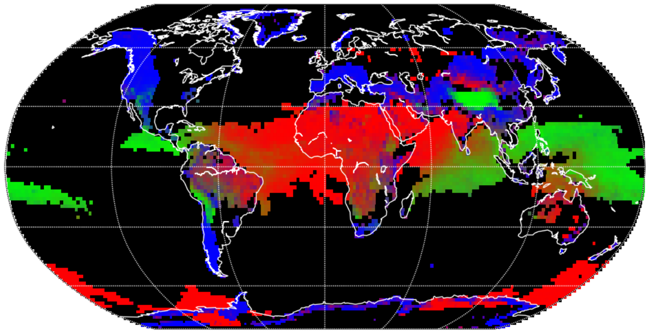
Source of ice crystals at 200 hPa



Black areas: only little IC formed (less than 1.5 IN/l)

A mixture of colors represents a mixture of processes

Source of ice crystals at 200 hPa



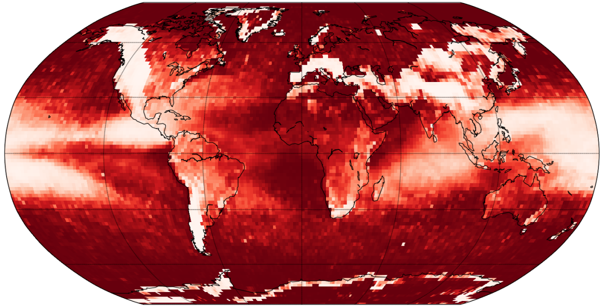
$$R=\frac{HET}{HOM+HET+DETR}$$

$$G=\frac{DETR}{HOM+HET+DETR}$$

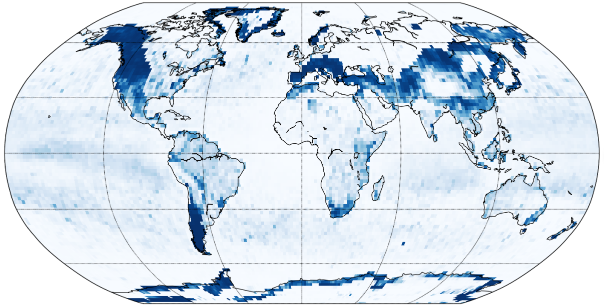
$$B=\frac{HOM}{HOM+HET+DETR}$$

Colour = (R,G,B)

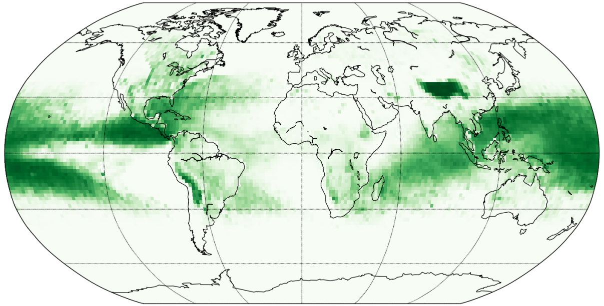
Heterogeneous IC



Homogeneous IC



Detrained IC



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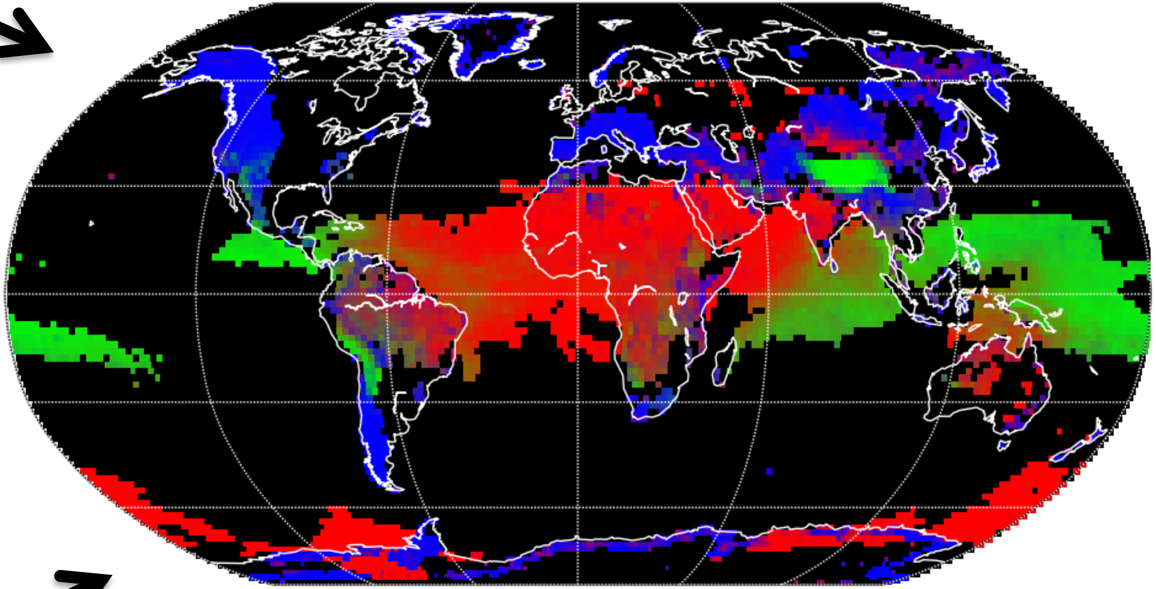
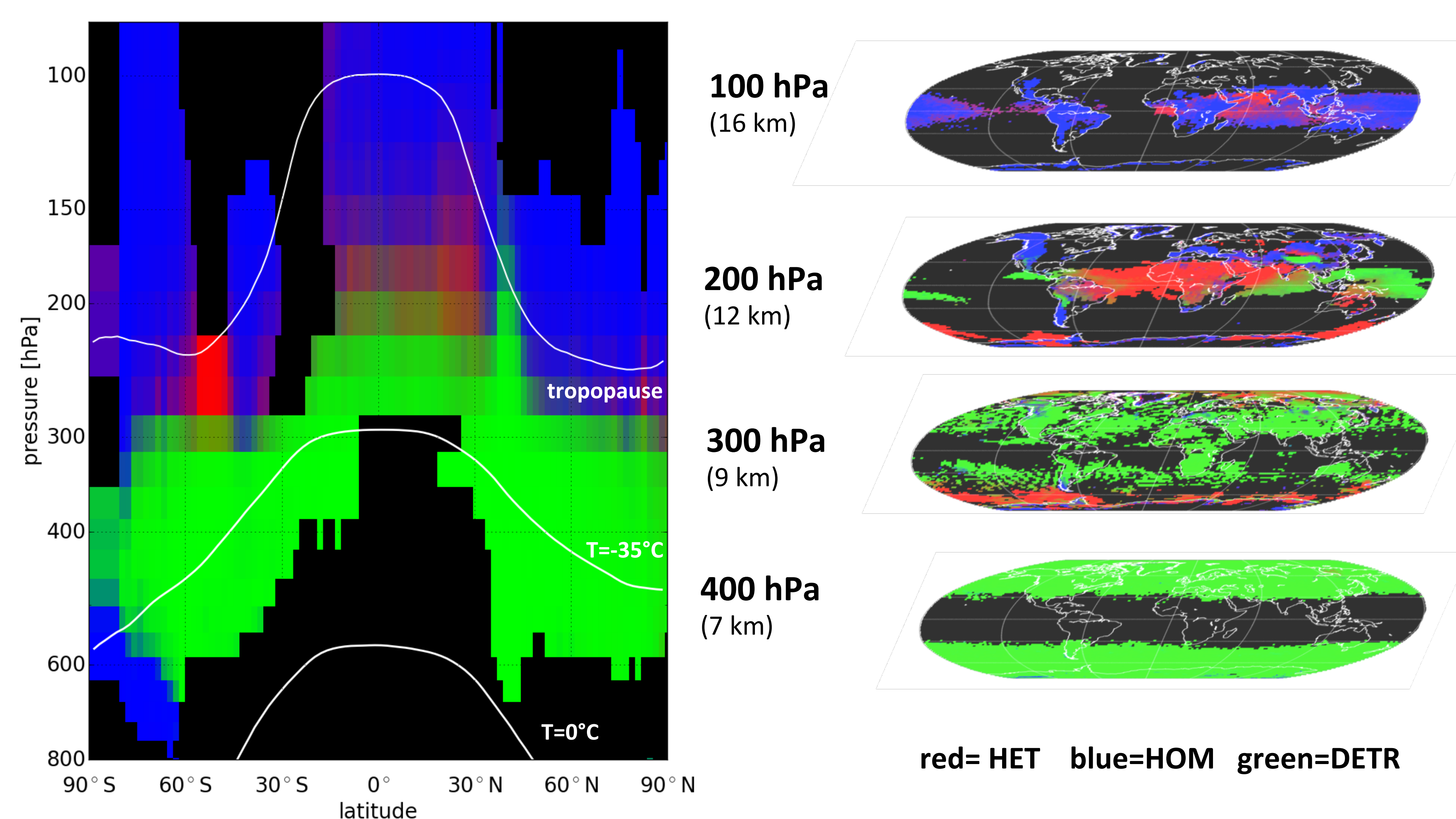


Black areas: only little IC formed (less than 1.5 IN/l)

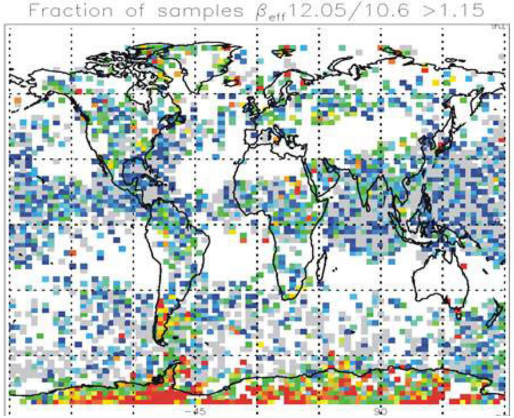
A mixture of colors represents a mixture of processes


100
150
200
300
400
600
800
pressure [hPa]
tropopause
T=-35°C
T=0°C
90° S
60° S
30° S
0°
30° N
60° N
90° N
latitude
100 hPa
(16 km)
200 hPa
(12 km)
300 hPa
(9 km)
400 hPa
(7 km)
red= HET
blue=HOM
green=DETR

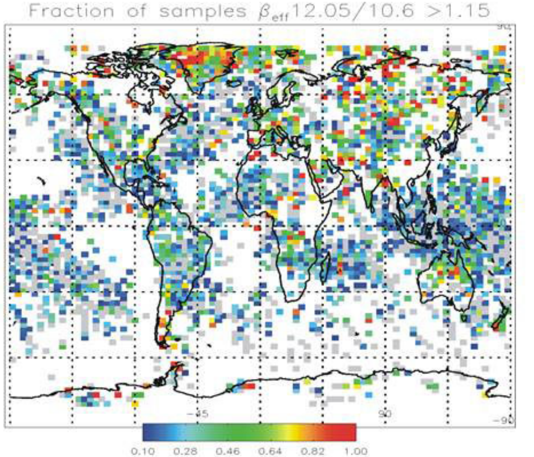
HOM cirrus fraction - Caliop derived,
David Mitchell, AGU 2015 abstract

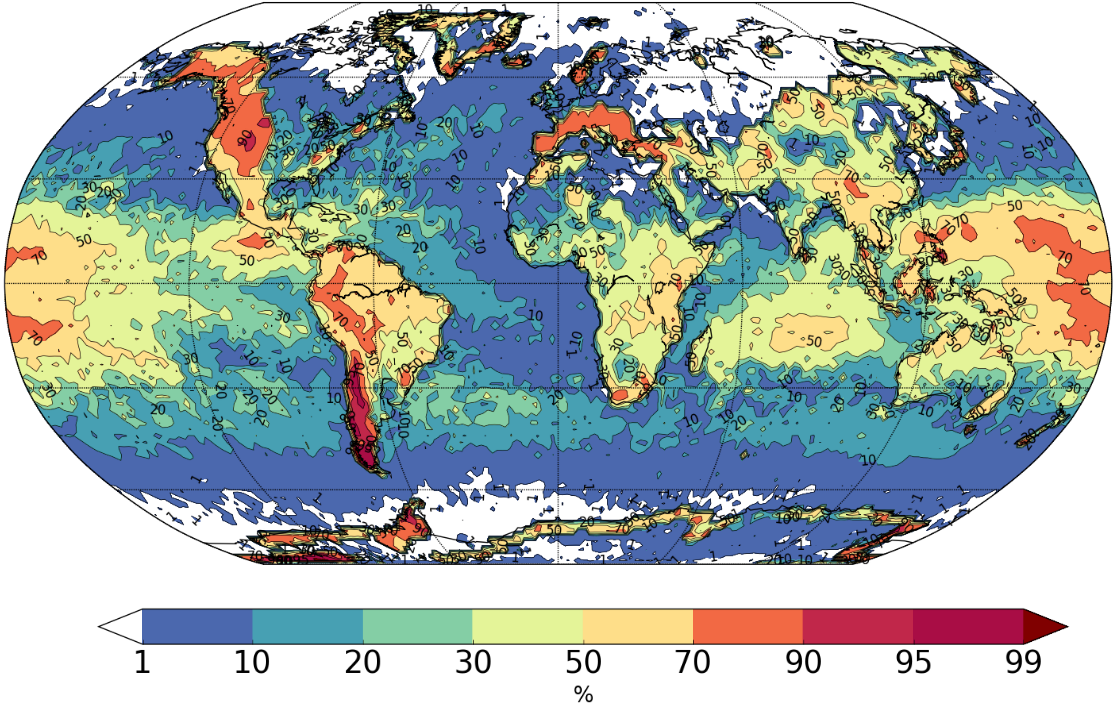
Cirrus IC HOM/(HOM+HET) fraction, vertically integrated

August 2013

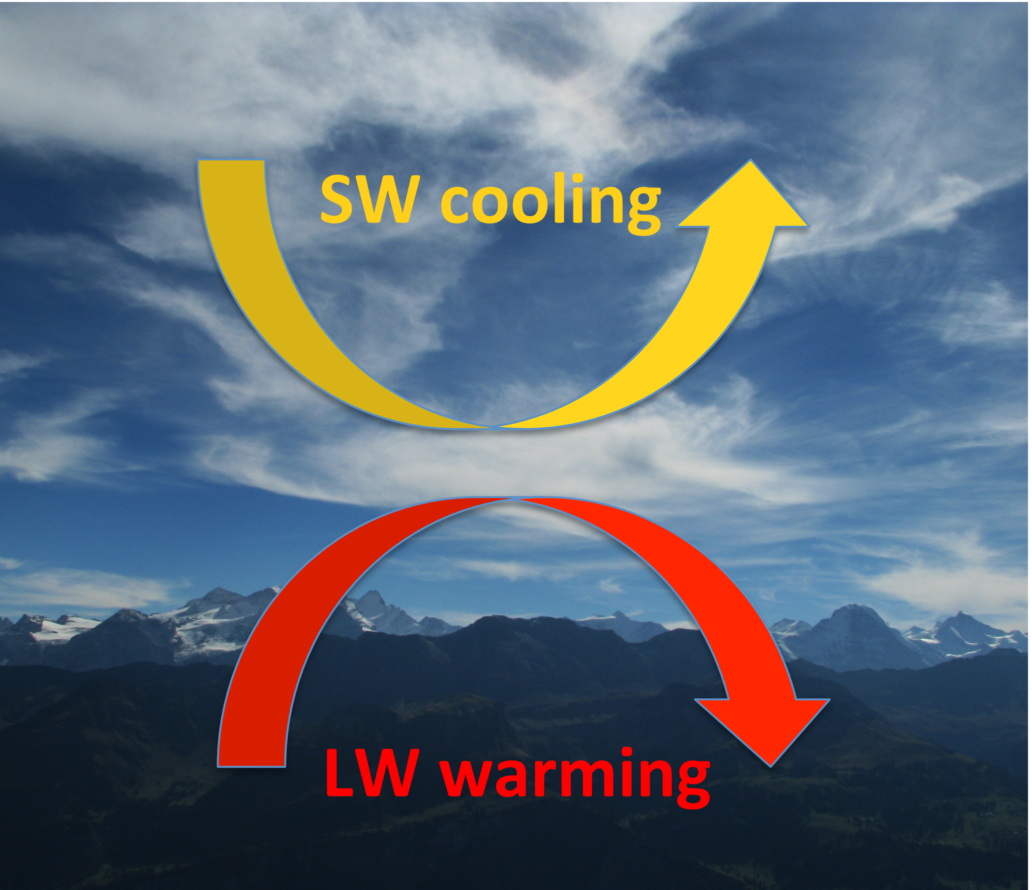


January 2015





Radiative effects of cirrus clouds



Radiative effects depend on

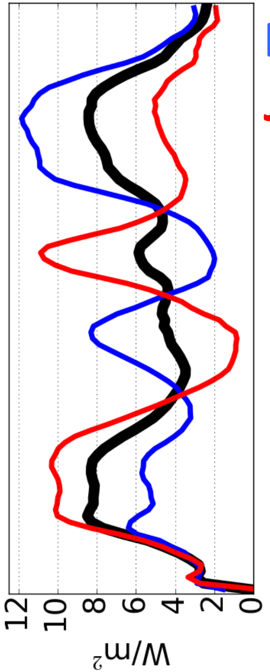
1. Cloud macrophysics:
Altitude, thickness, temperature

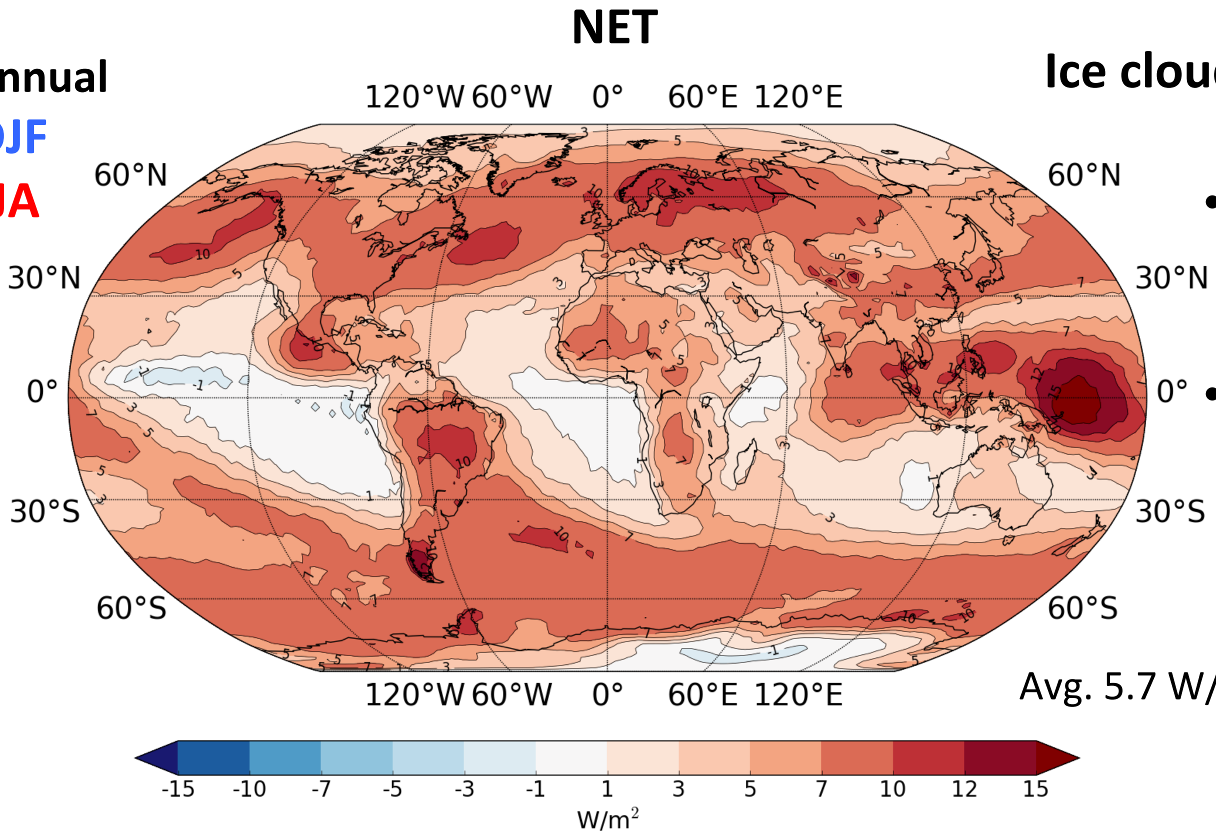
2. Cloud microphysics:
Ice nucleation, diffusional vapour growth, aggregation

+ insolation,
surface temperature

Top of the atmosphere cloud radiative effects (CRE)
annual balance

ECHAM-HAM
Ice clouds, at T<-35°C





- Larger forcing in winter hemisphere
- ITCZ

Avg. 5.7 W/m²

Conclusions

1. Large areas where heterog. nucleation mechanisms prevail
2. Cirrus on average warm the climate

To-do

1. Finish the comparison of cirrus with Calipso data
2. Radiative balance from Calipso data
3. Cirrus seeding

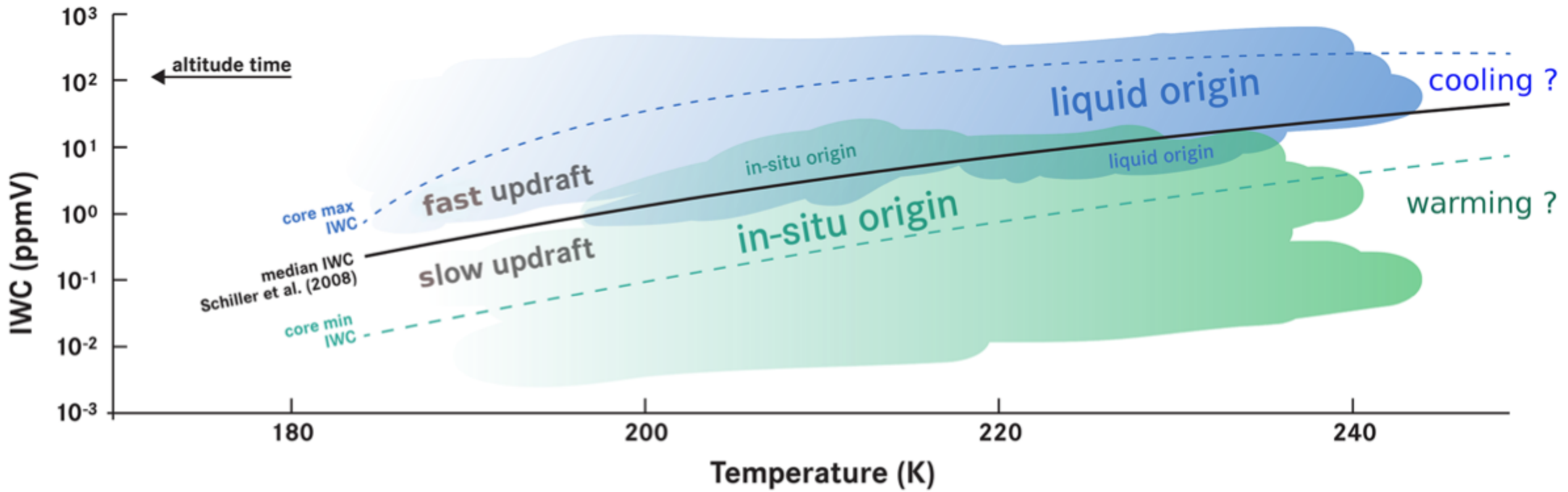
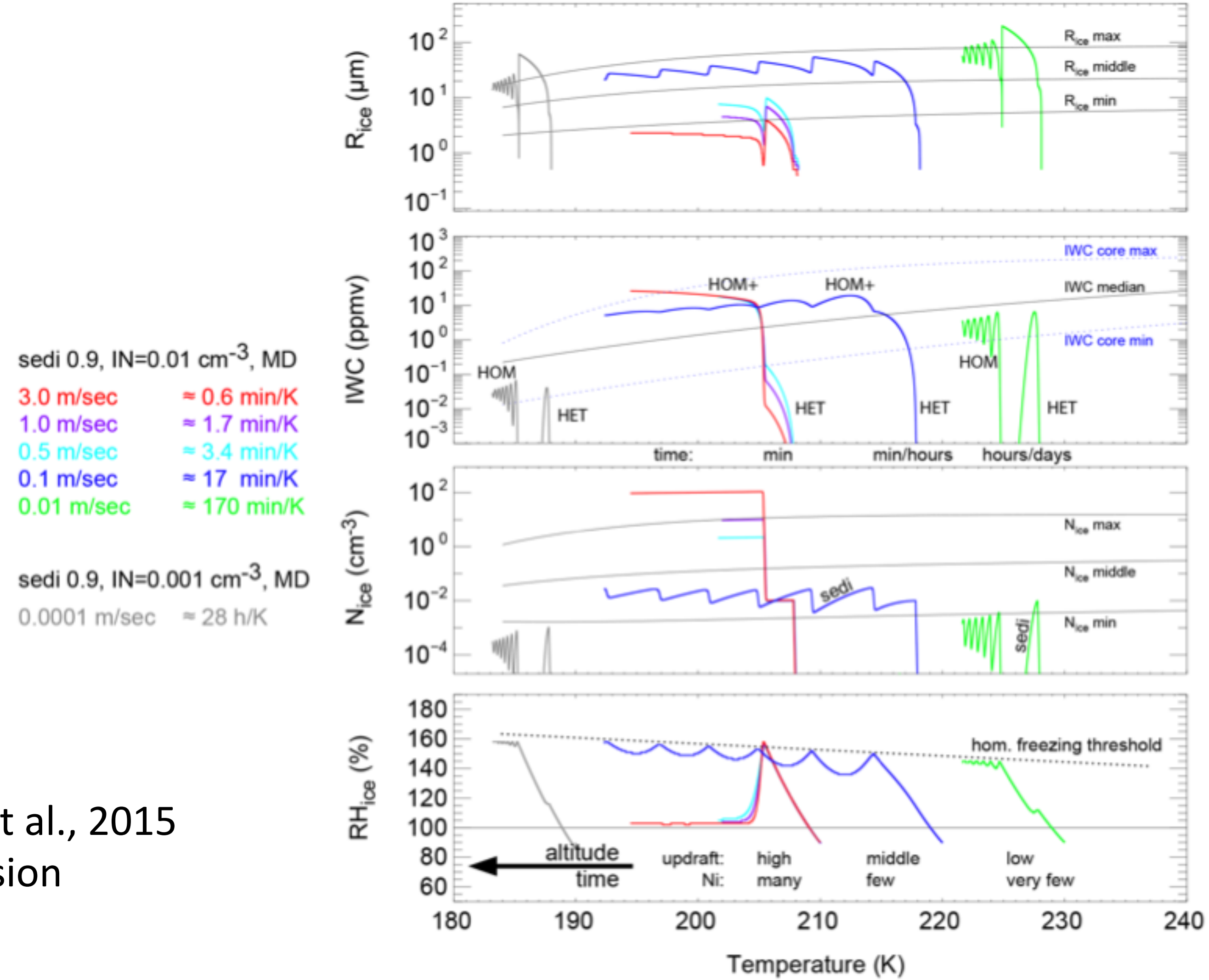


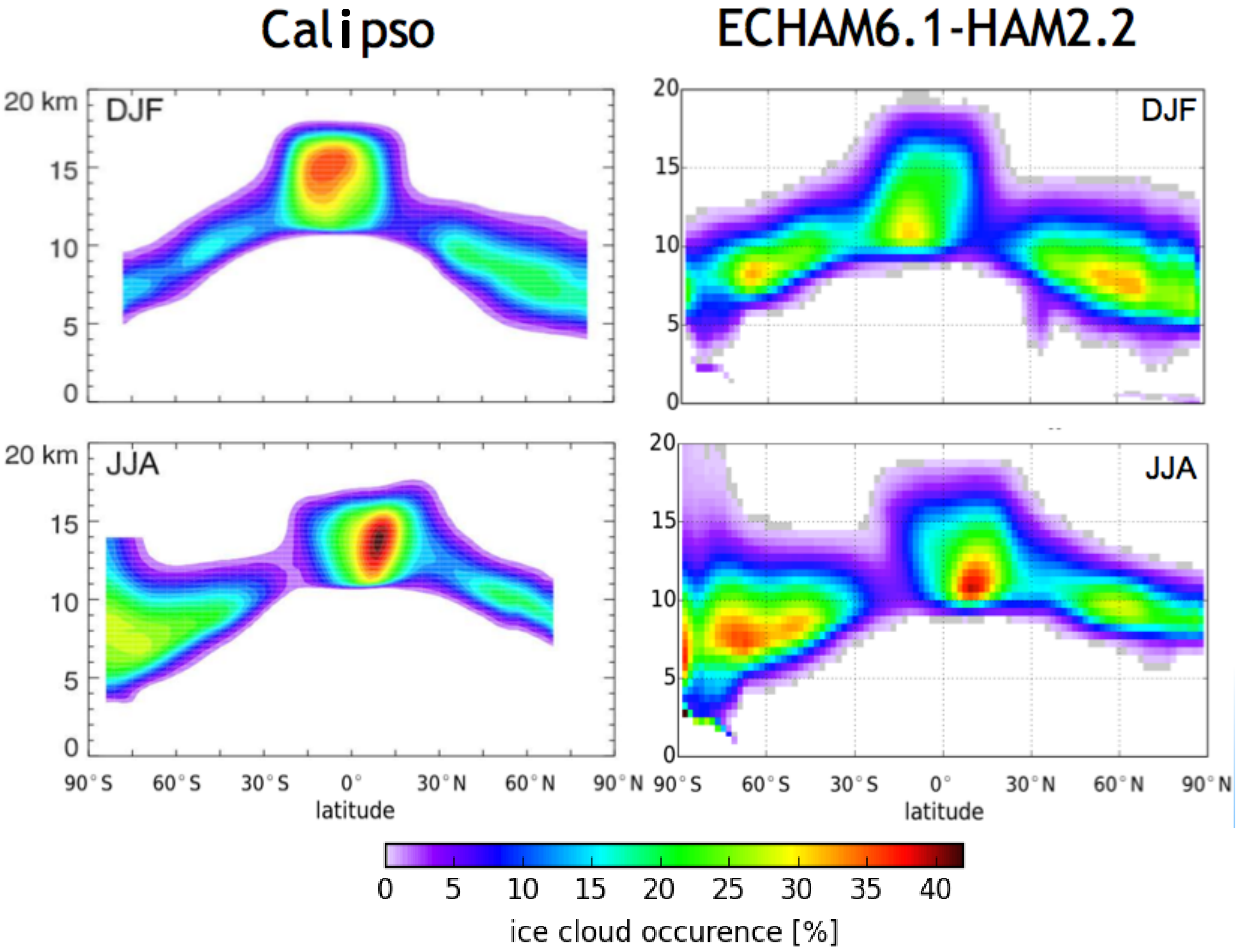
Figure 13. Sketch of in-situ and liquid origin cirrus (large letters: high frequency of occurrence, larger ice crystals, stronger sedimentation, longer lifetimes; small letters: low frequency of occurrence, smaller ice crystals, lesser sedimentation, shorter lifetimes). **In-situ origin cirrus** (greenish color): ice crystals form heterogeneously+homogeneously directly from the gas phase. In-situ cirrus are preferably thin with lower IWC. They divide in two classes (see also Fig. 9): (1) thin cirrus forming in slow updrafts consisting of few, large ice crystals with a large geographic coverage and a long lifetime, (2) thicker cirrus forming in fast updrafts consisting of many, small ice crystals with a smaller geographic coverage. **Liquid origin cirrus** (blueish color): ice crystals stem from frozen liquid drops which are uplifted from farther below in the atmosphere into the cirrus temperature range. Liquid origin cirrus are mostly thick with higher IWC and have larger ice crystals than the in-situ cirrus (for more detail see Luebke et al., 2015). Their geographic coverage/lifetime depend on the meteorological situation: larger/longer in warm conveyor belts, smaller/shorter in convective systems.

Krämer et al., 2015
in discussion



Krämer et al., 2015
in discussion

Ice clouds, at T<-40°C

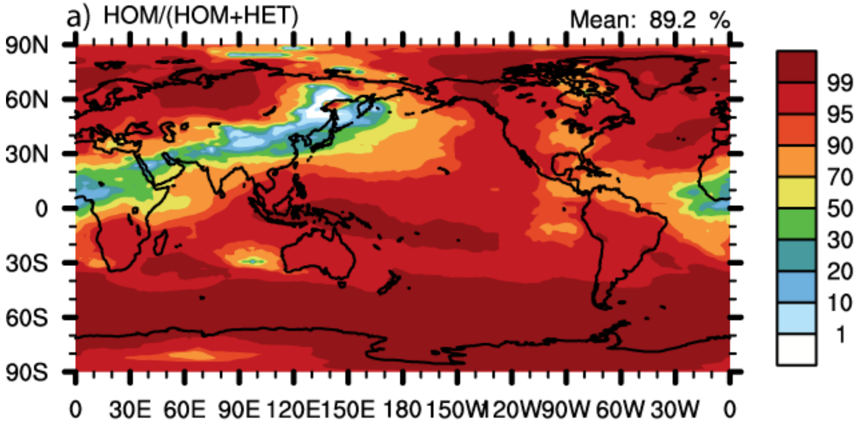


- Cirrus vertical spread larger in model
- Convective cirrus – too low?
- Some model issues over Antarctica

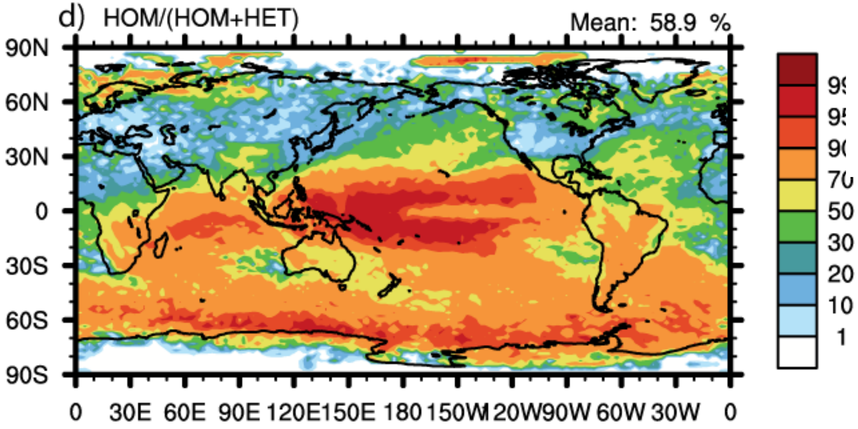
COMPARISON TO CAM5 GCM
HOM/(HOM+HET) fraction at 200 hPa
Neglected detrained/convective part!!!

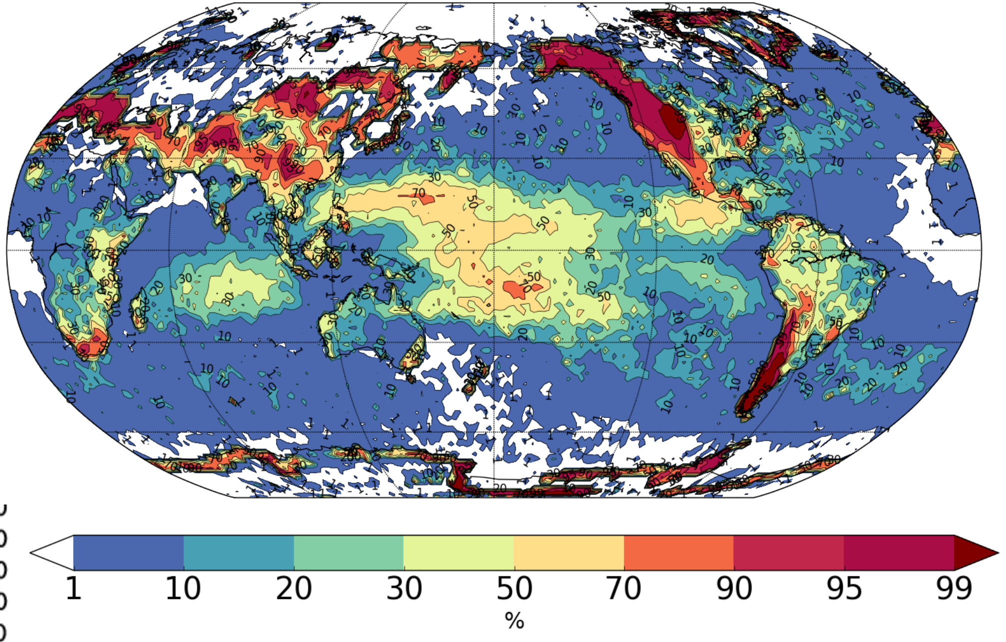
Penner et al. 2015

W02+DUST

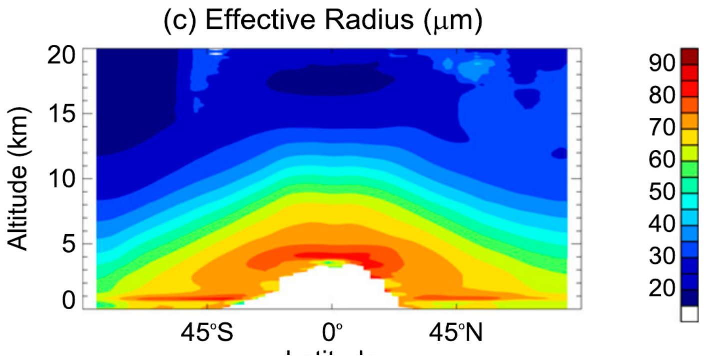


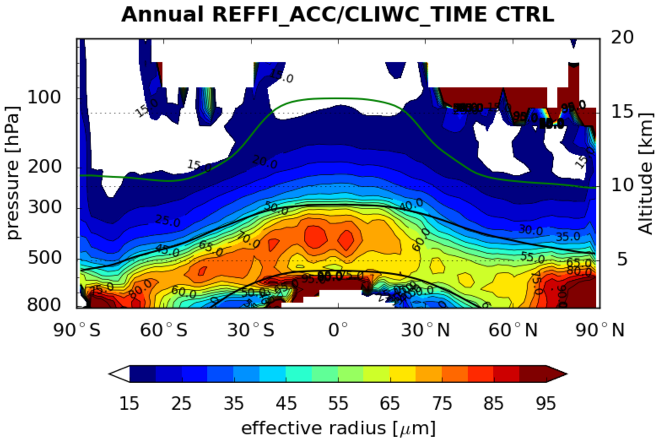
PRE+SOAIN01

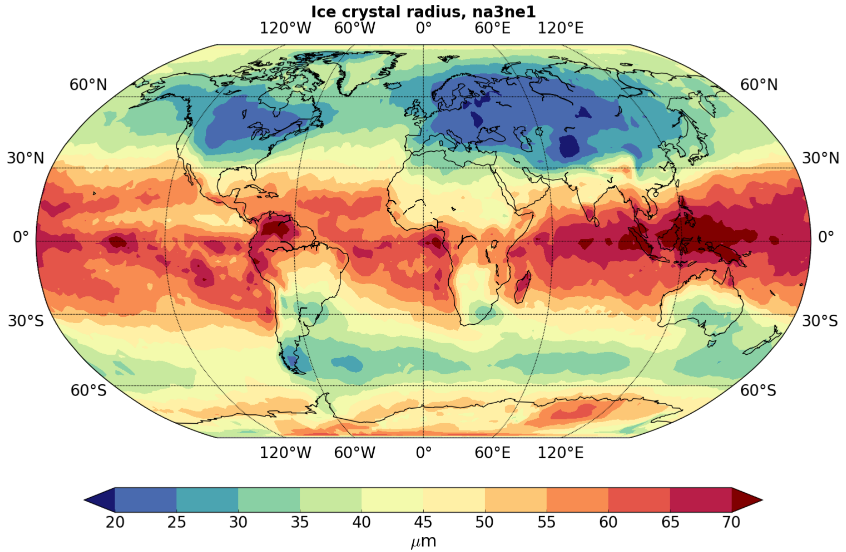


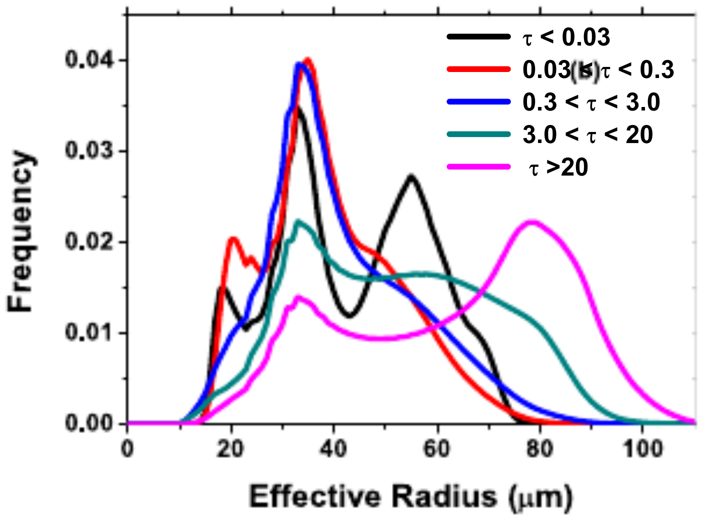


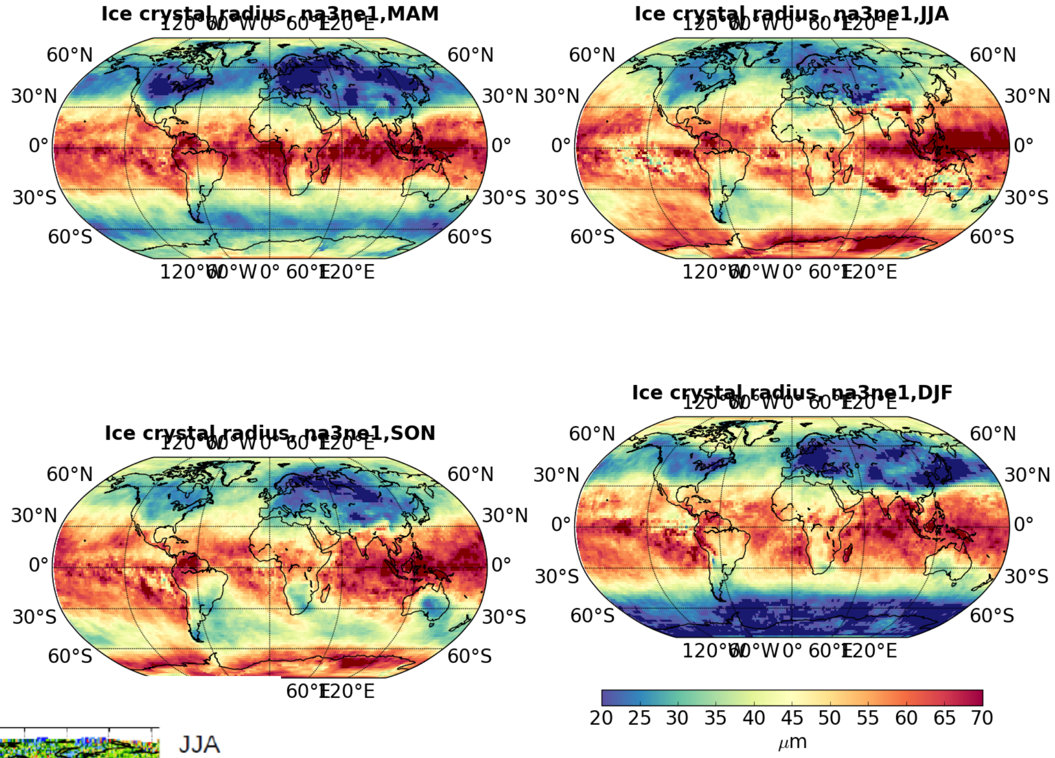
IC radius, FULL scheme

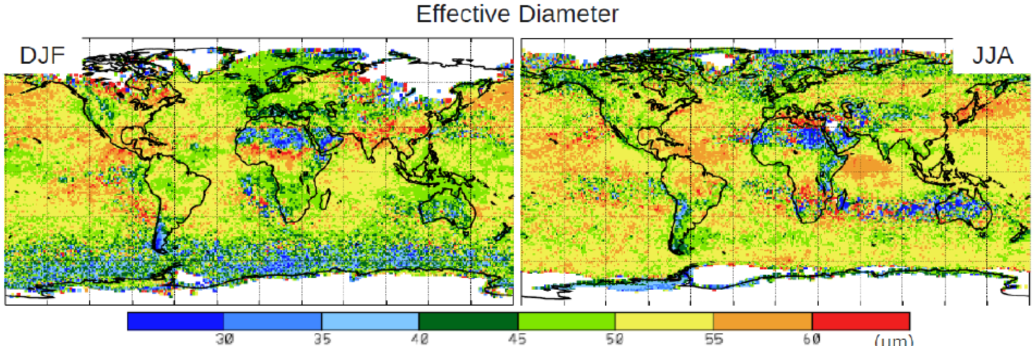




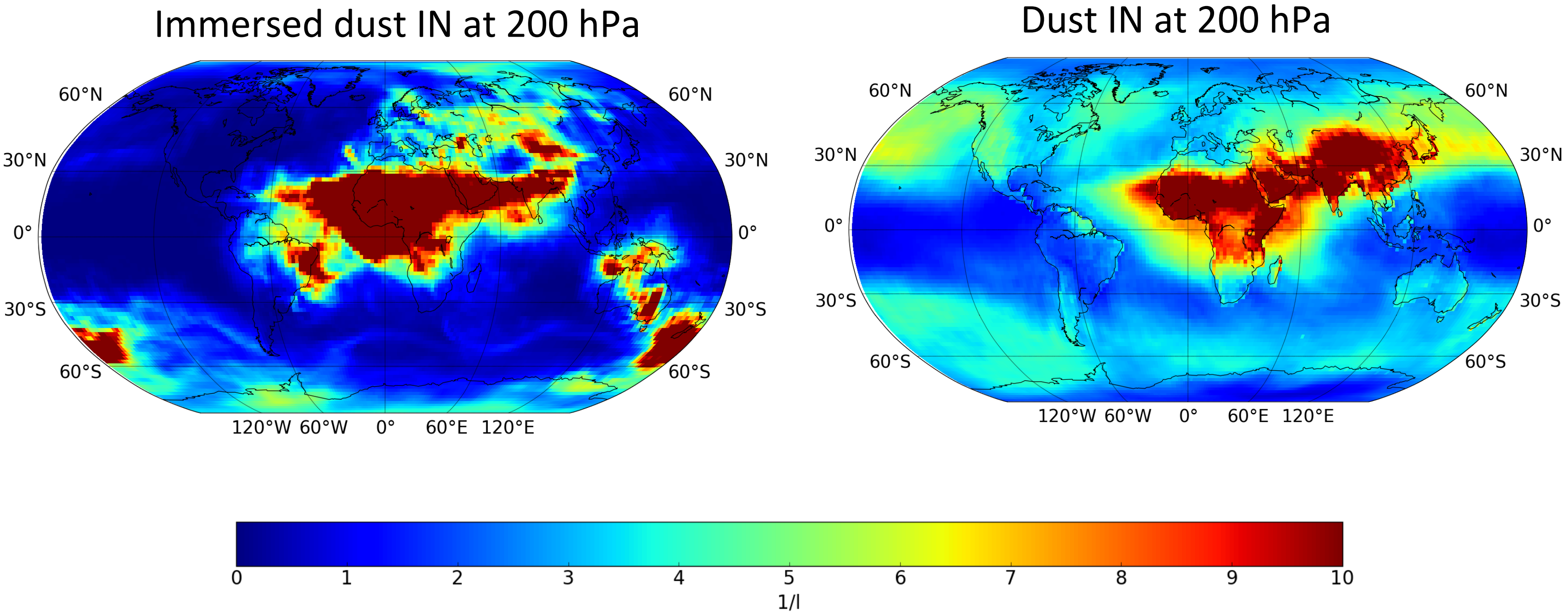



τ < 0.03
0.03 ≤ τ < 0.3
0.3 < τ < 3.0
3.0 < τ < 20
τ >20
Frequency
Effective Radius (μm)
0.00
0.01
0.02
0.03
0.04
0
20
40
60
80
100


Ice crystal radius, na3ne1,MAM
Ice crystal radius, na3ne1,JJA
Ice crystal radius, na3ne1,SON
Ice crystal radius, na3ne1,DJF
60°N
30°N
0°
30°S
60°S
120°W 60°W 0° 60°E 120°E
20 25 30 35 40 45 50 55 60 65 70
μm


Effective Diameter
DJF
JJA
30
35
40
45
50
55
60
(μm)

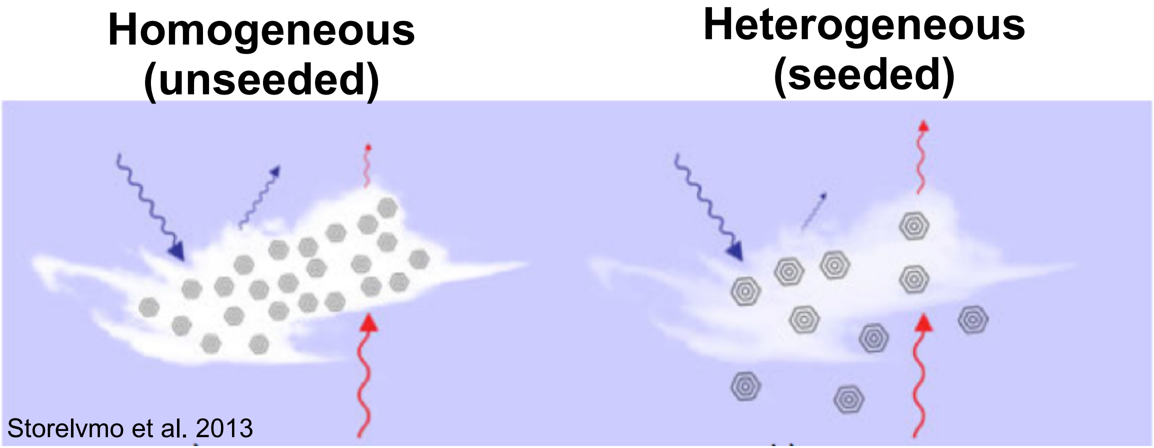
Where is the dust coming from?



Cirrus seeding

Based on 2 assumptions:

- cirrus clouds prevalently warm the climate
- There are large areas where homogeneous seeding prevails



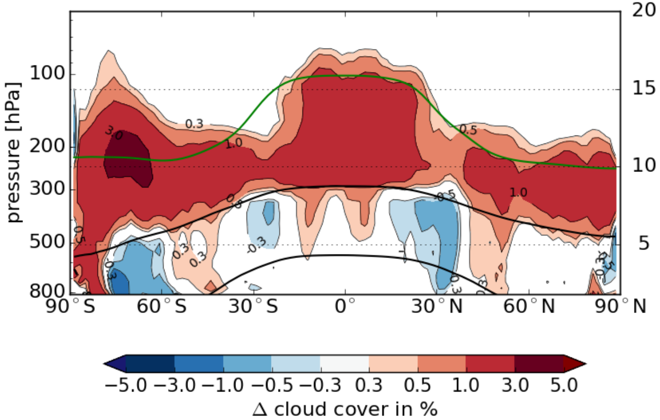
Expected effect of seeding

1.) Larger ice crystals with higher sedimentation velocities => decrease in cloud cover

2.) Less but larger ice crystals; The cloud is more transparent for outgoing longwave radiation

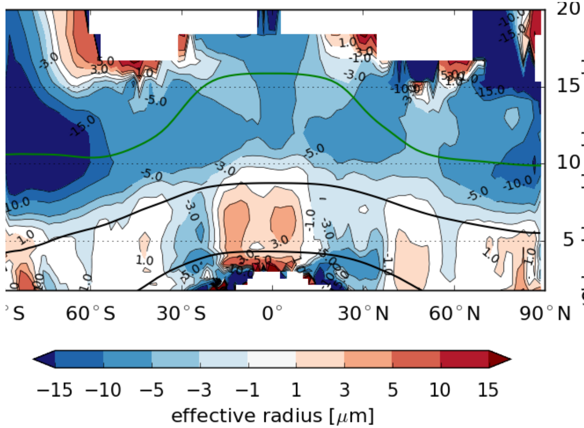
Seed 1 IN/liter, FULL scheme

Cloud cover anomaly



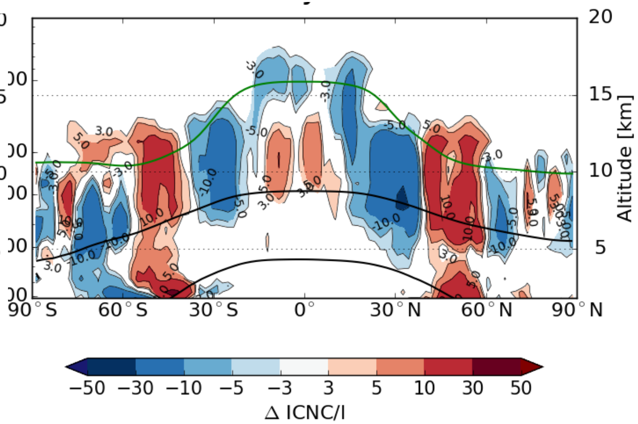
Increase in cirrus cloud cover

In-cloud IC radius anomaly

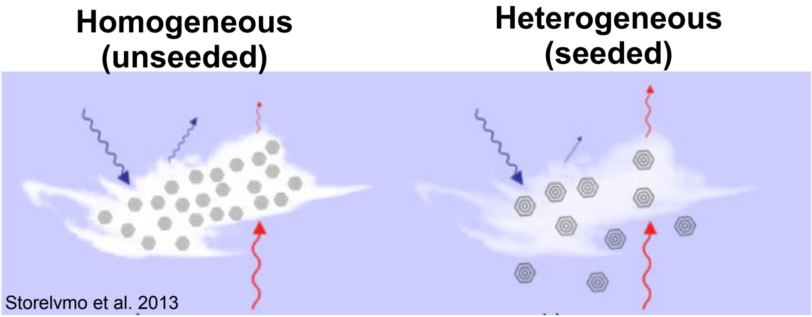


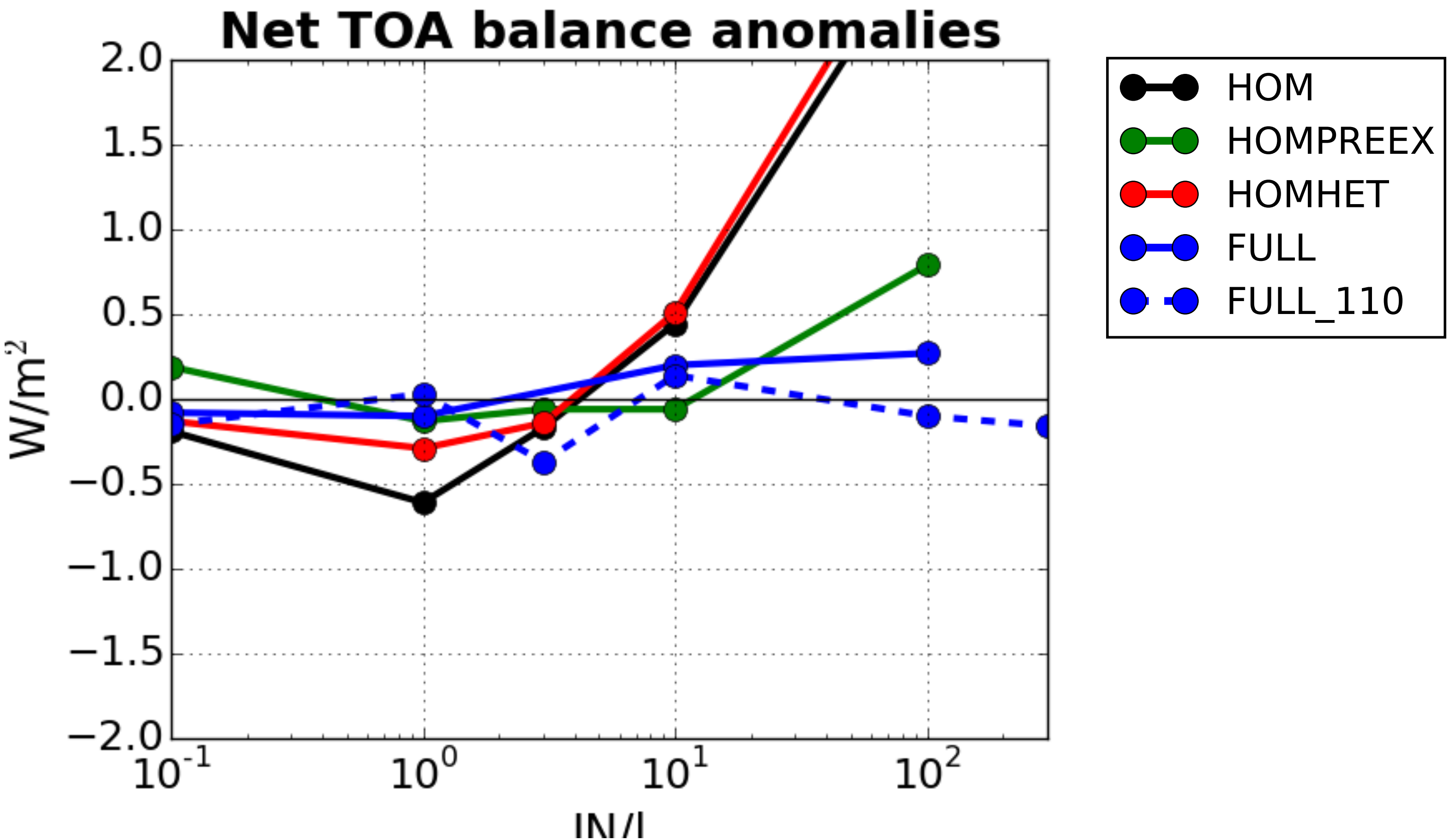
Decrease in IC size

In-cloud ICNC anomaly

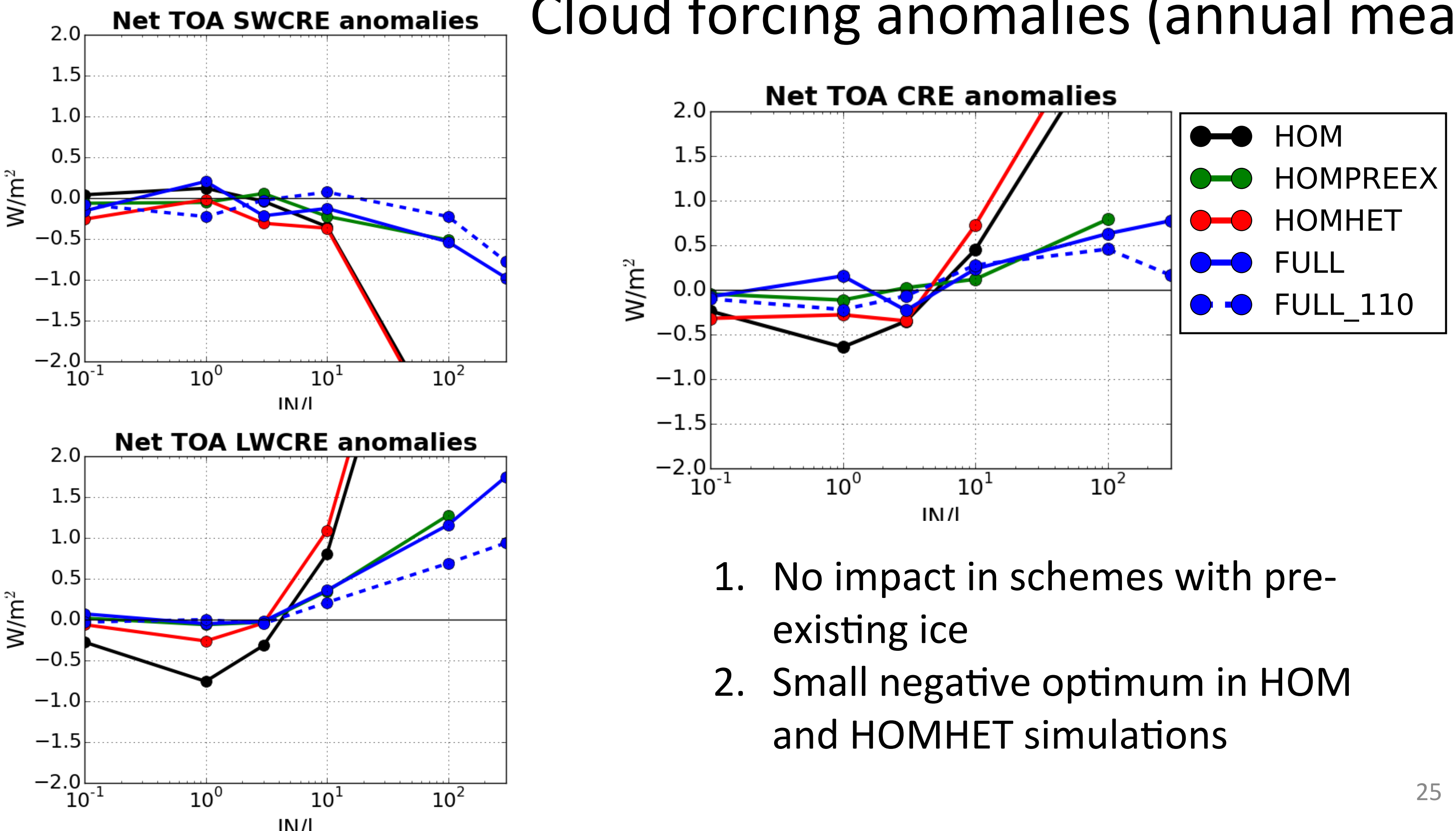


No real ICNC signal




Net TOA balance anomalies
W/m²
IN/I
HOM
HOMPREEX
HOMHET
FULL
FULL_110
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
10⁻¹
10⁰
10¹
10²

Cloud forcing anomalies (annual means)



1. No impact in schemes with pre-existing ice
2. Small negative optimum in HOM and HOMHET simulations