Aerosol-cloud interactions in mixed-phase clouds and their role for climate

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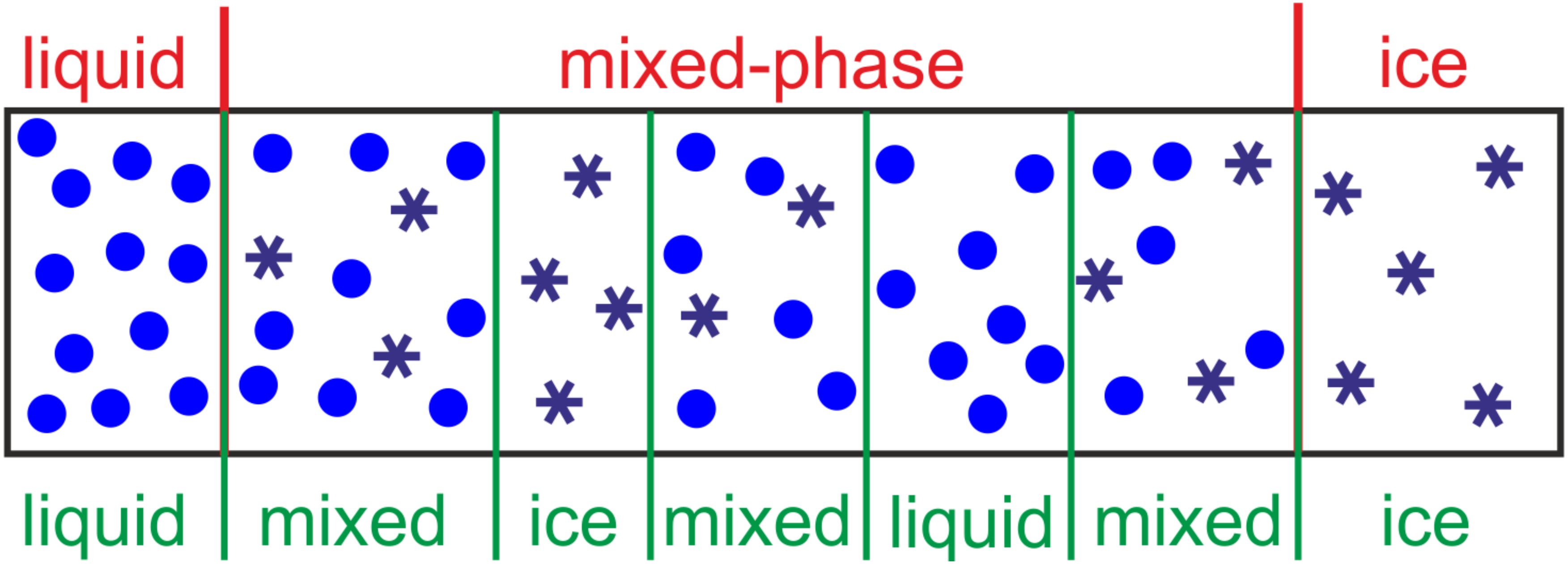
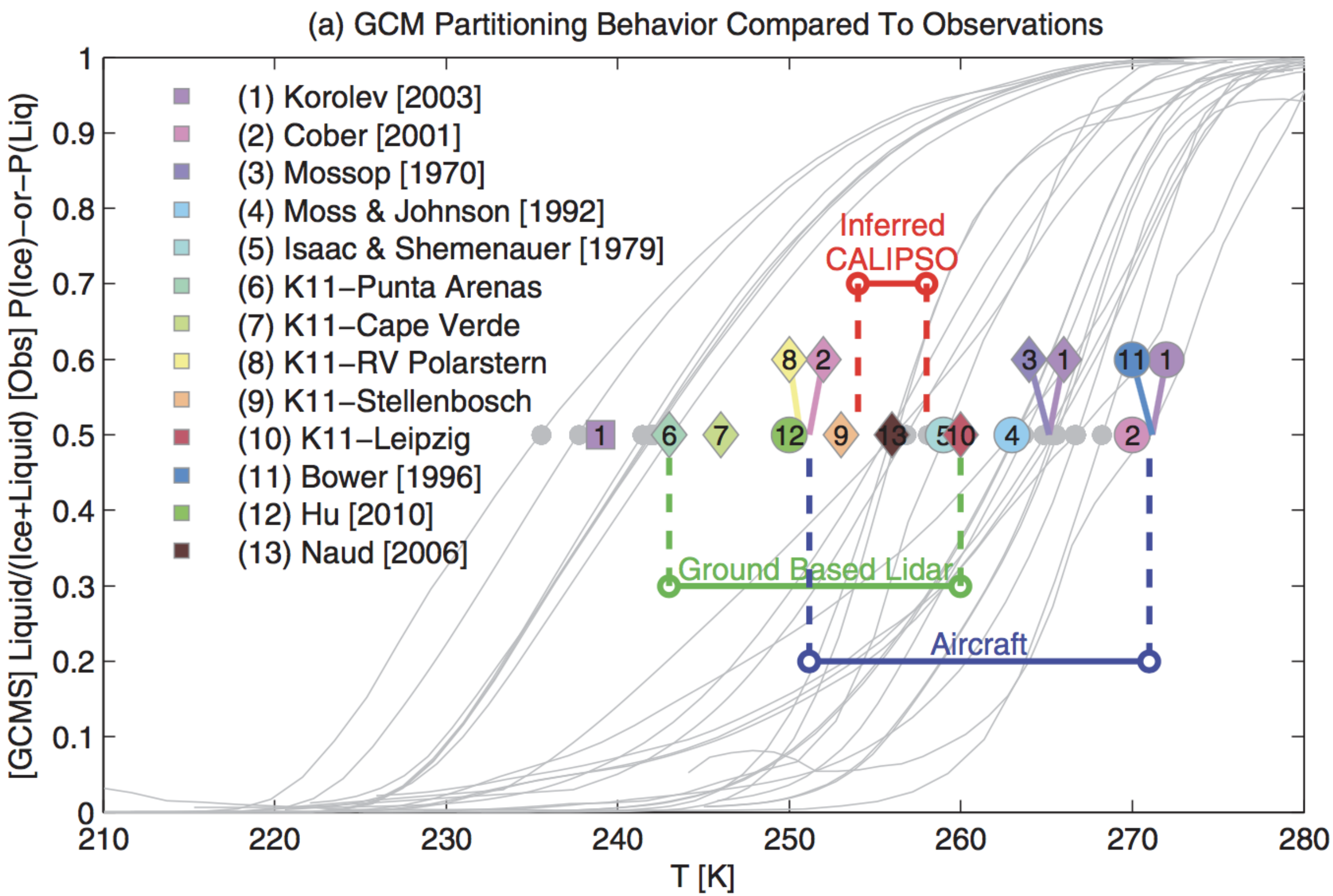
What is a mixed-phase cloud?



Why mixed-phase clouds?

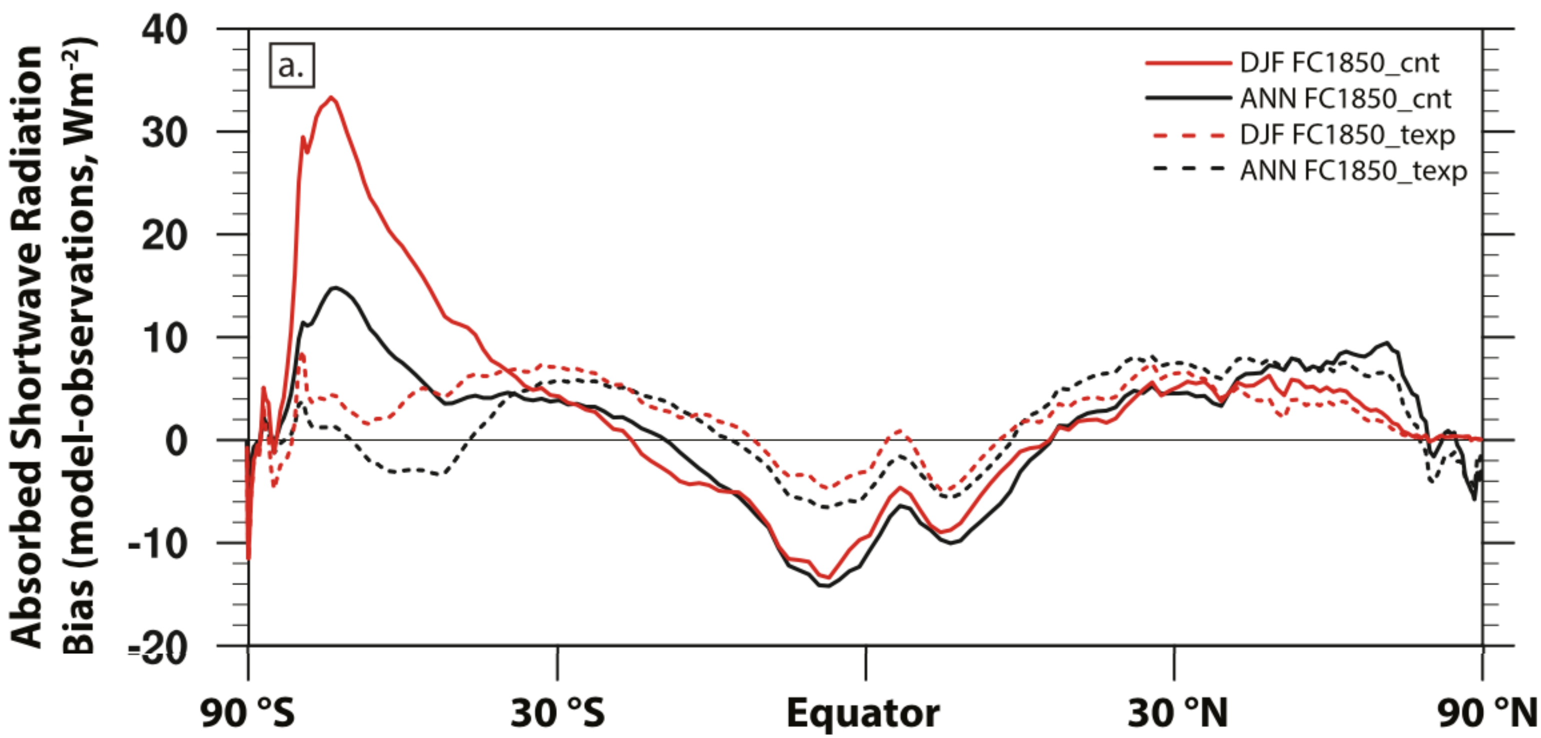


McCoy et al., JAMES, 2016

Southern Ocean bias and mixed-phase couds

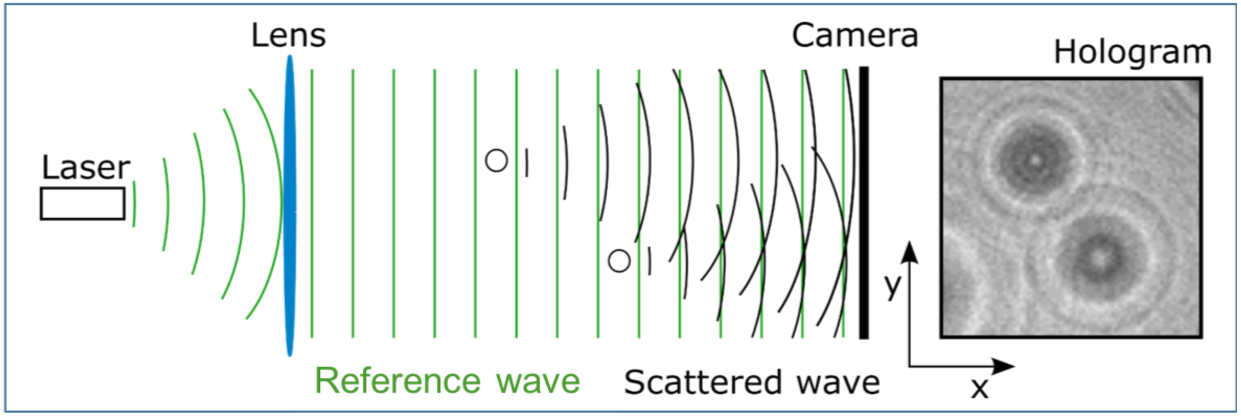
The ice fraction f is giver in CAM as:

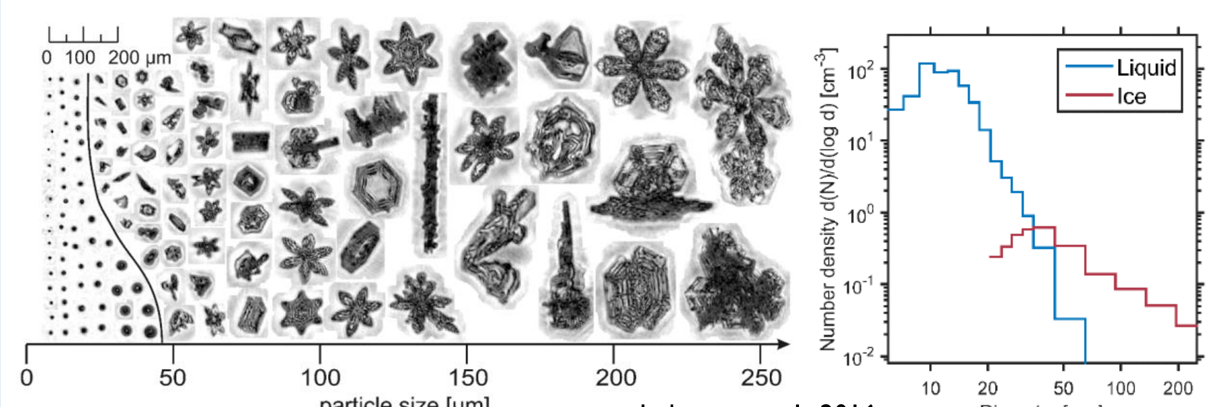
- $f = 0$; for $T > T_{ice}$, $T_{ice} = 268$ K in the control experiment
- $T_{ice} = 253$ K in the sensitivity experiment
- f increases linearily up of $f = 1$ for $T \leq 238.15$ K



Kay et al., 2016

Working principle of our holographic device

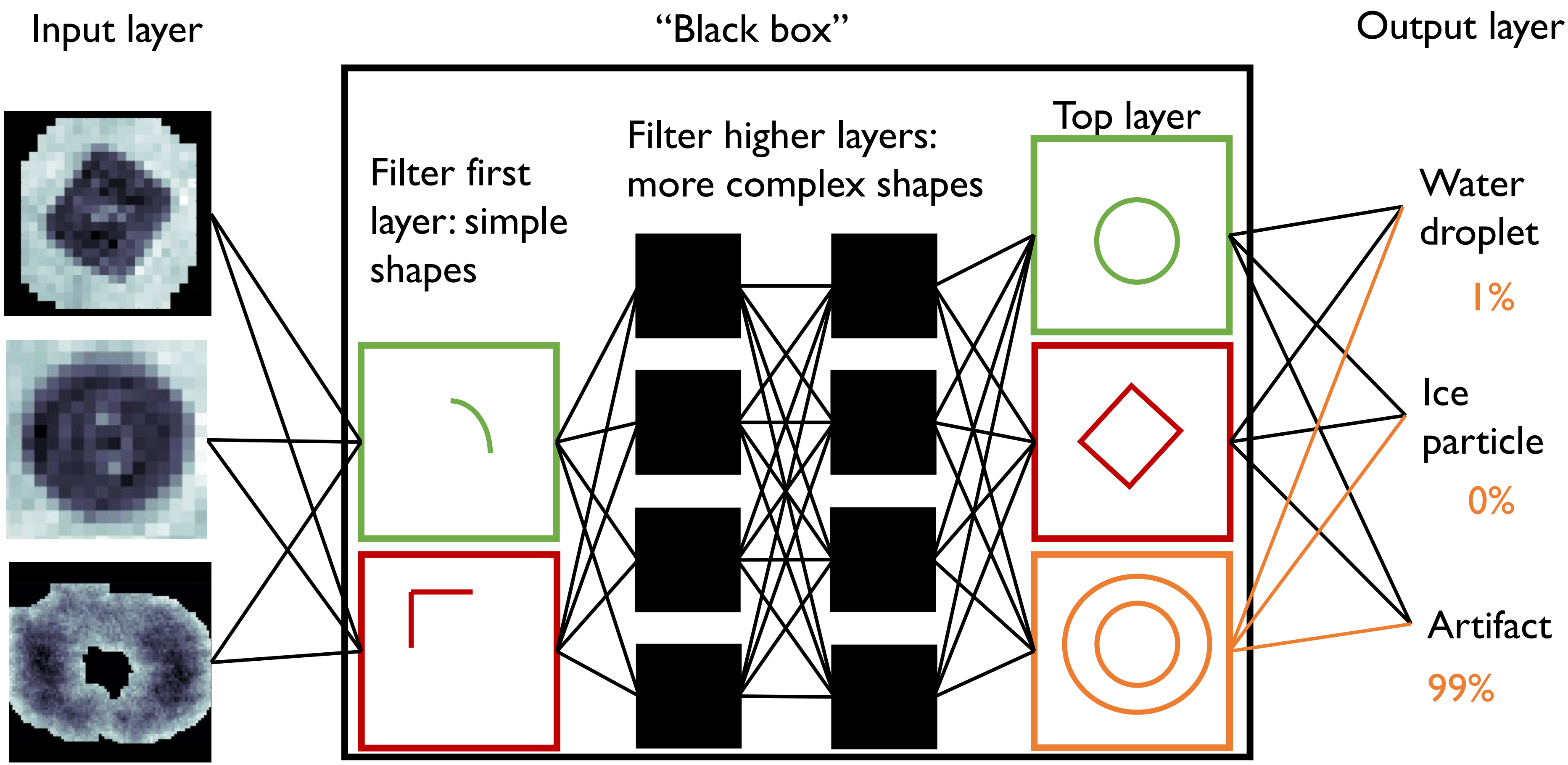




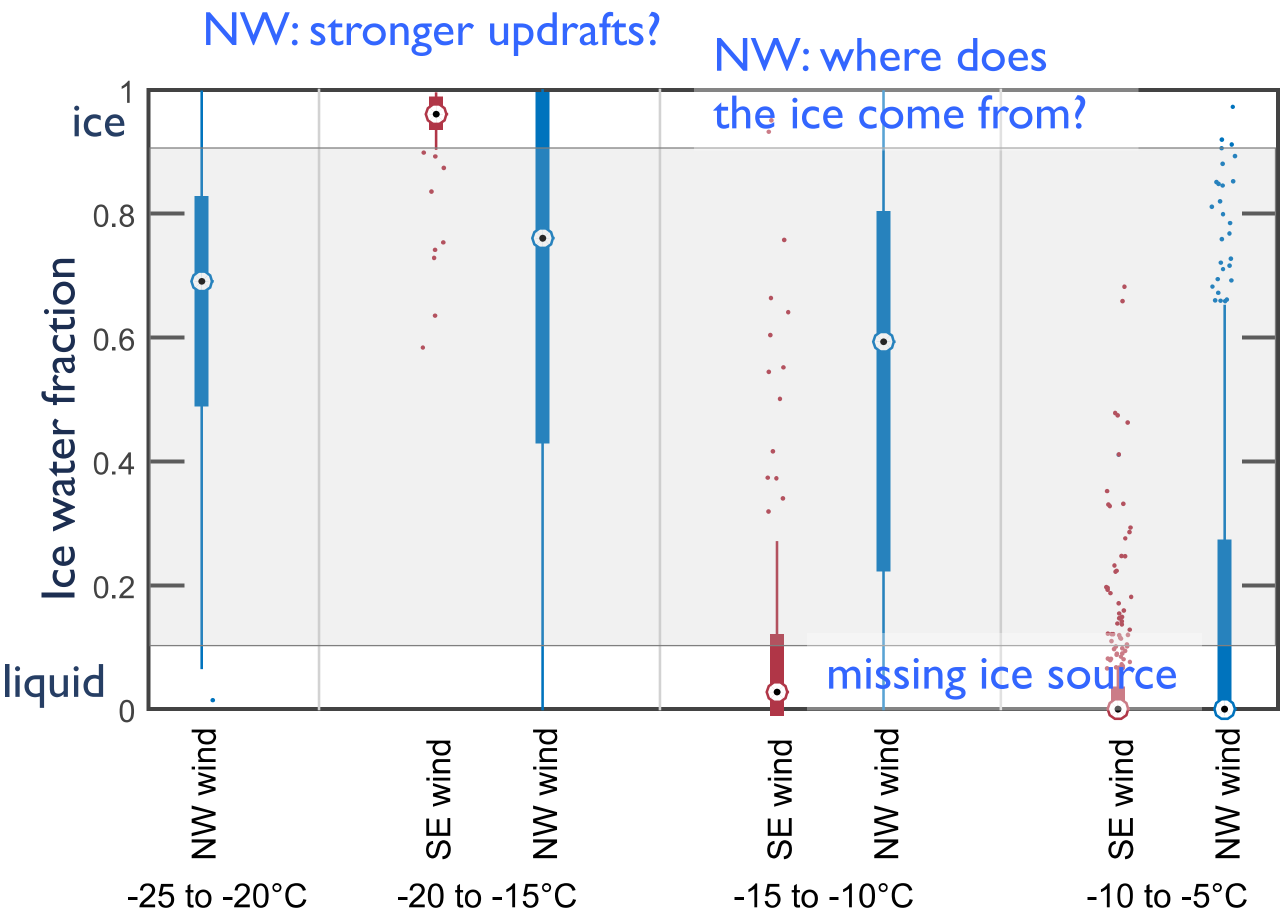
Lohmann et al., 2016

Classification of cloud droplets/ice crystals

Convolutional Neuronal Network



Observation of mixed-phase clouds

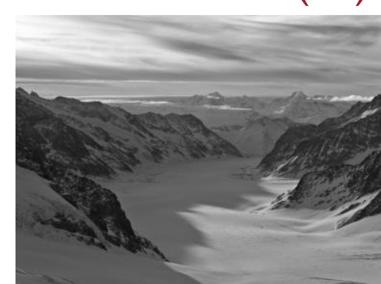


Ice water fraction: $\frac{\text{ice water (IWC)}}{\text{total water (TWC)}}$

North-West (NW)

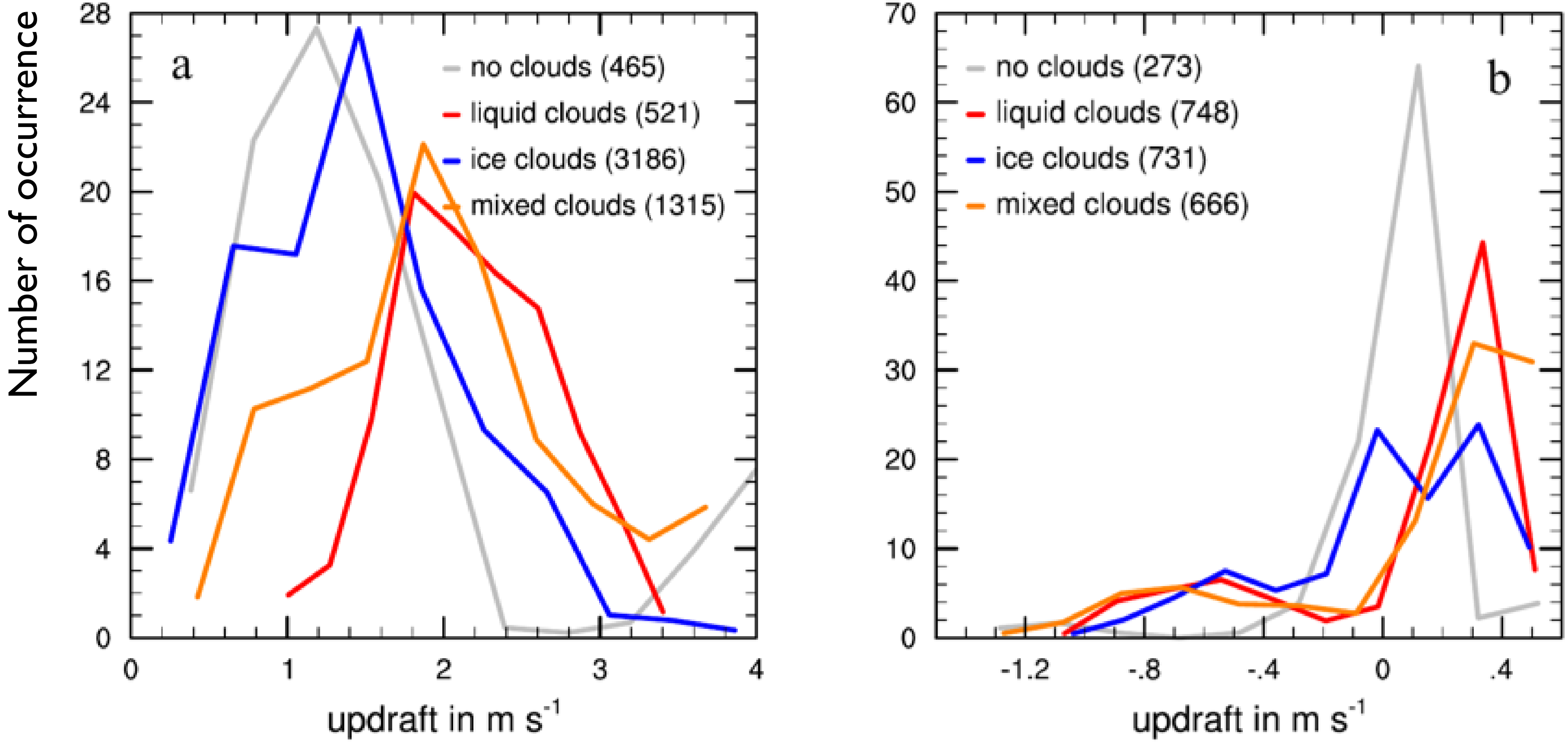
Jungfraujoch (JFJ)

South-East (SE)



Lohmann et al. 2016, GRL

Origin of cloud droplets – inferred from model results with COSMO

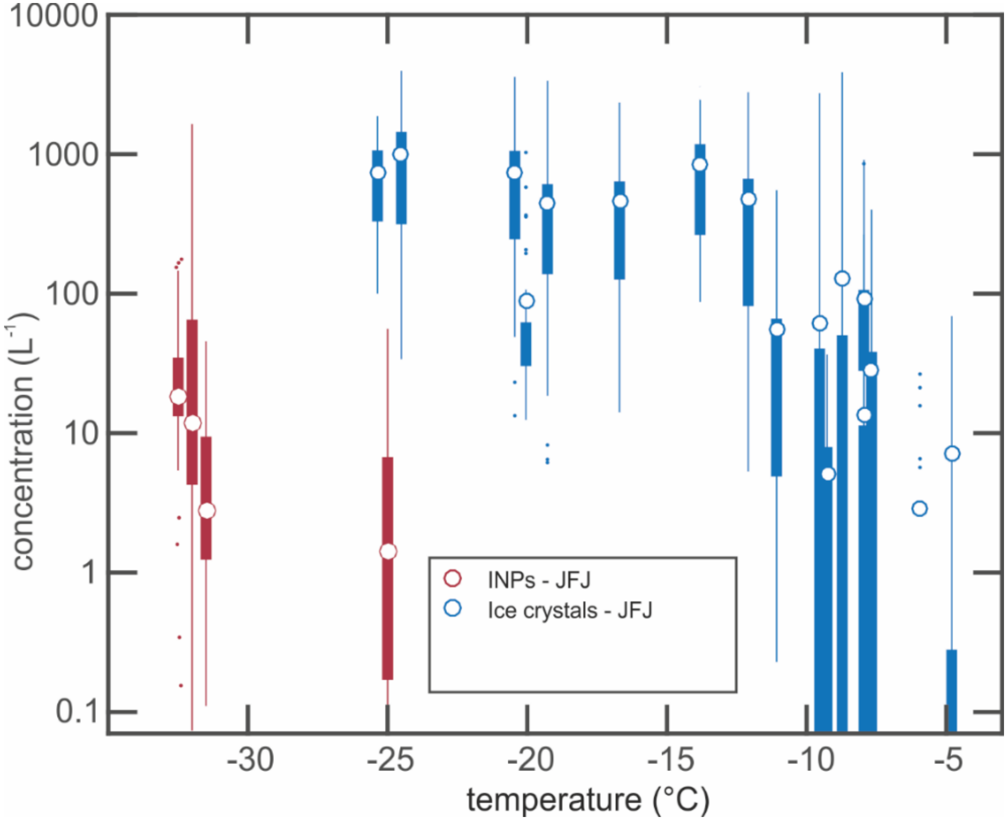


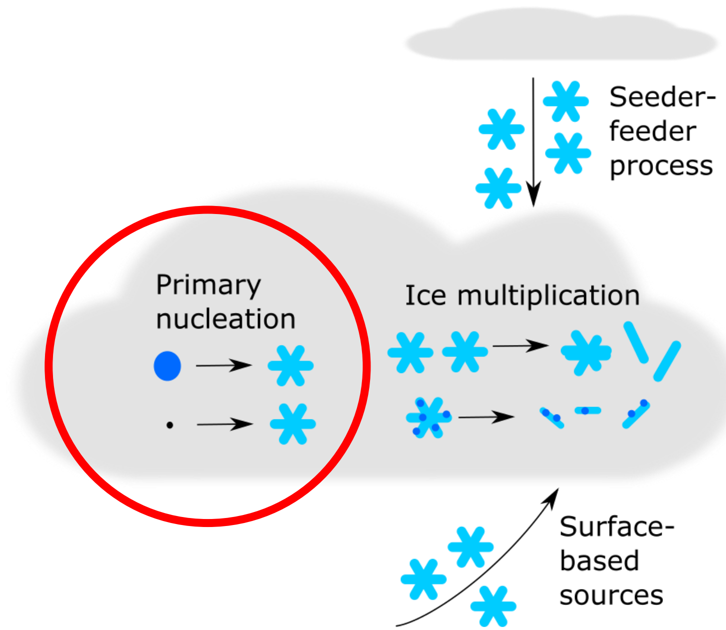
NW wind cases

SE wind cases

Lohmann et al., GRL, 2016

Origin of the ice crystals?



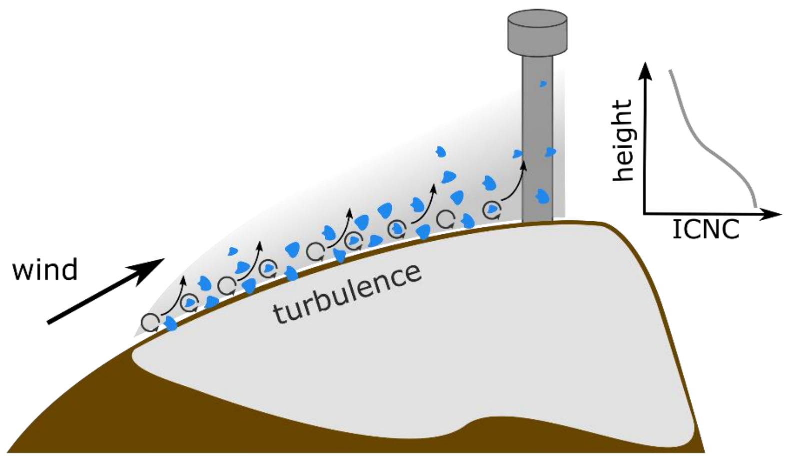


Beck et al., ACP, 2018

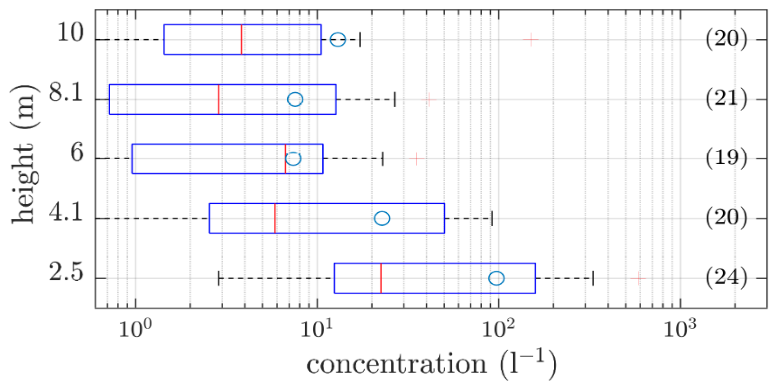
Origin of the ice crystals?

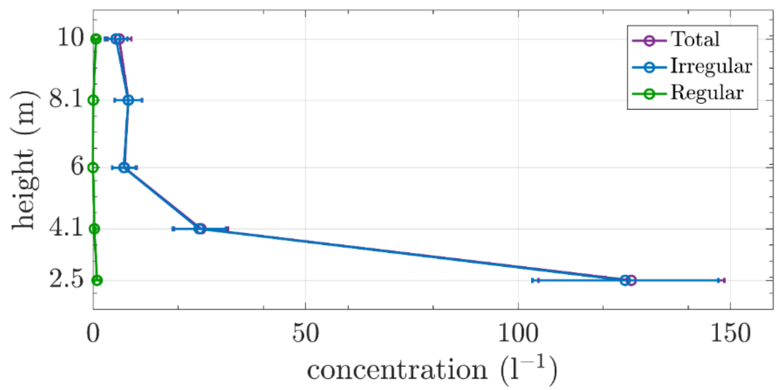
Expectations from surface-based processes:

- Mainly irregular ice crystals
- Decrease of ICNC with height



cloud-free





Beck et al., ACP, 2018

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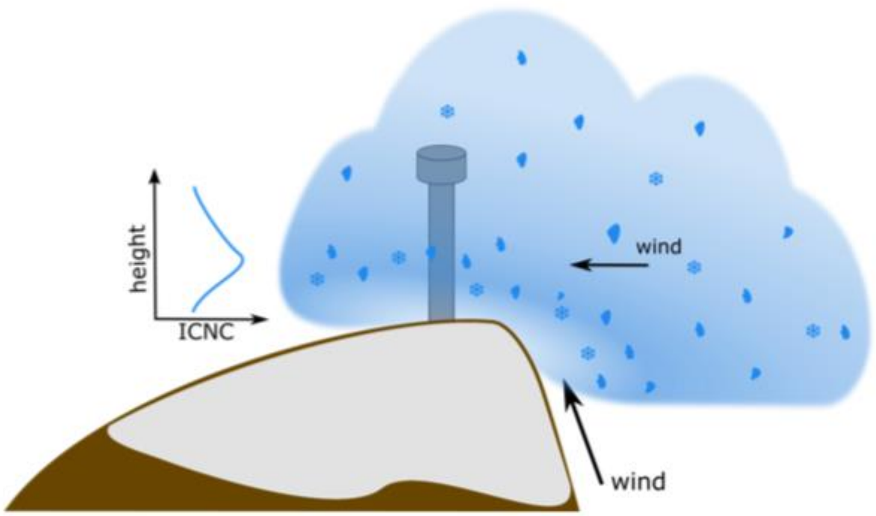
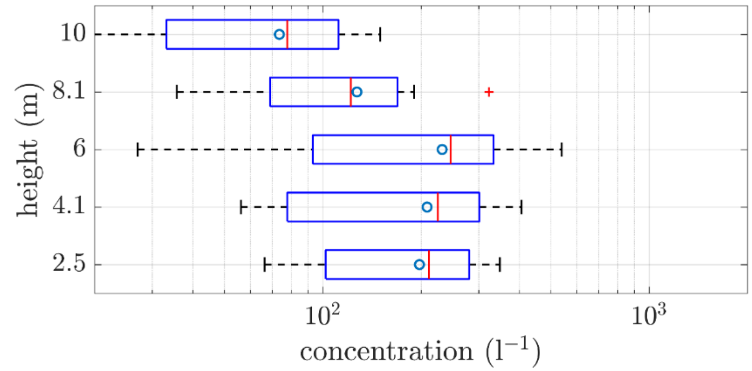
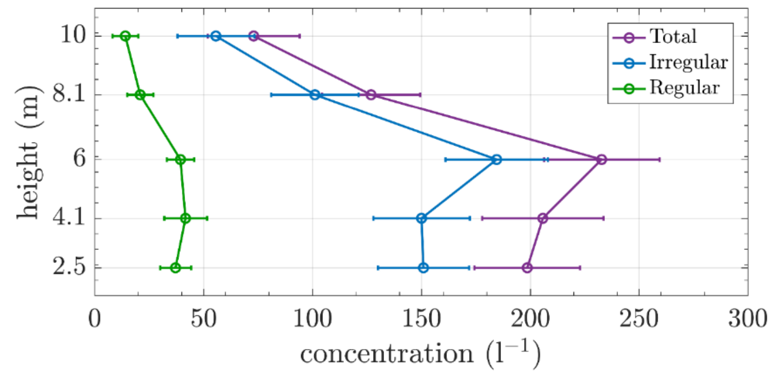


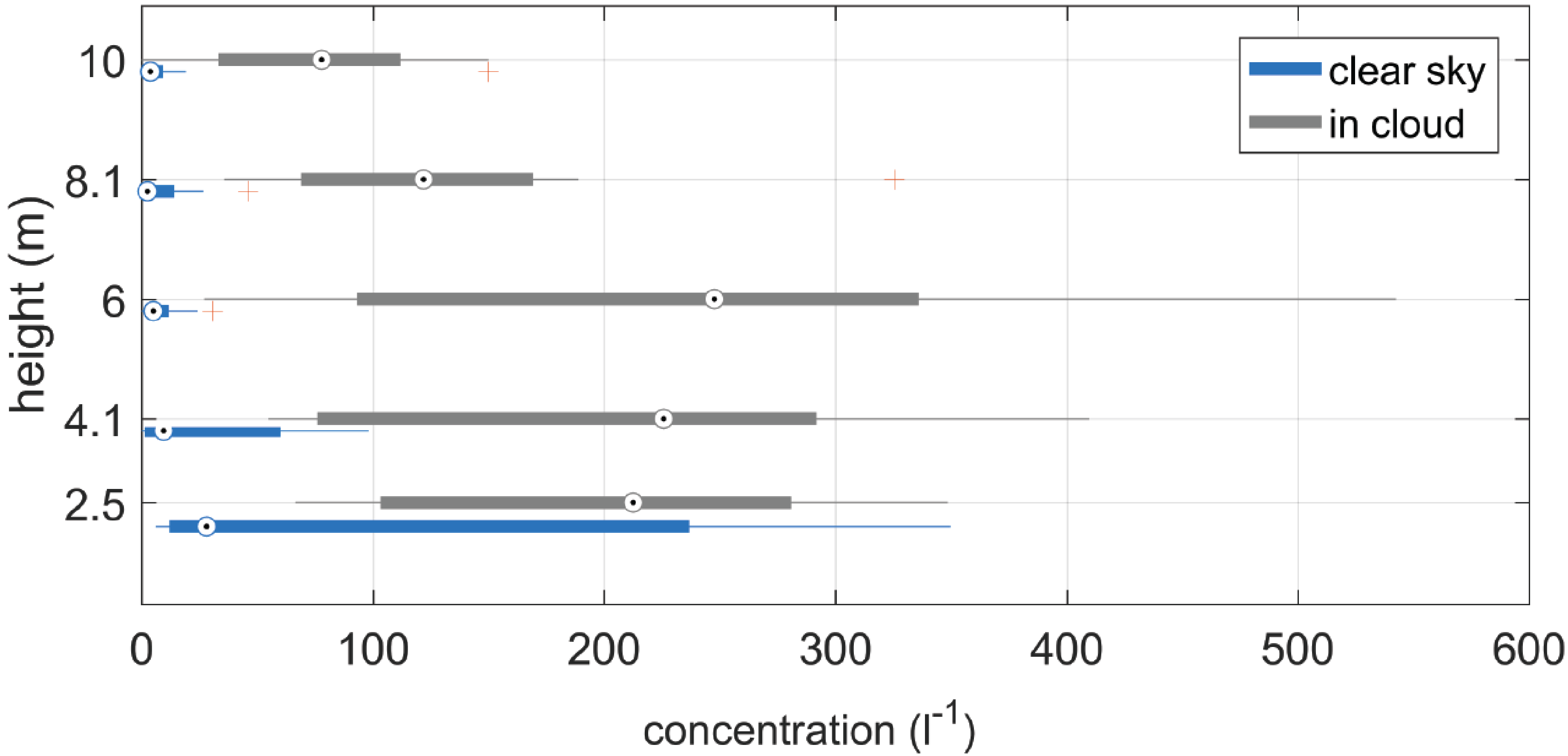
In-cloud





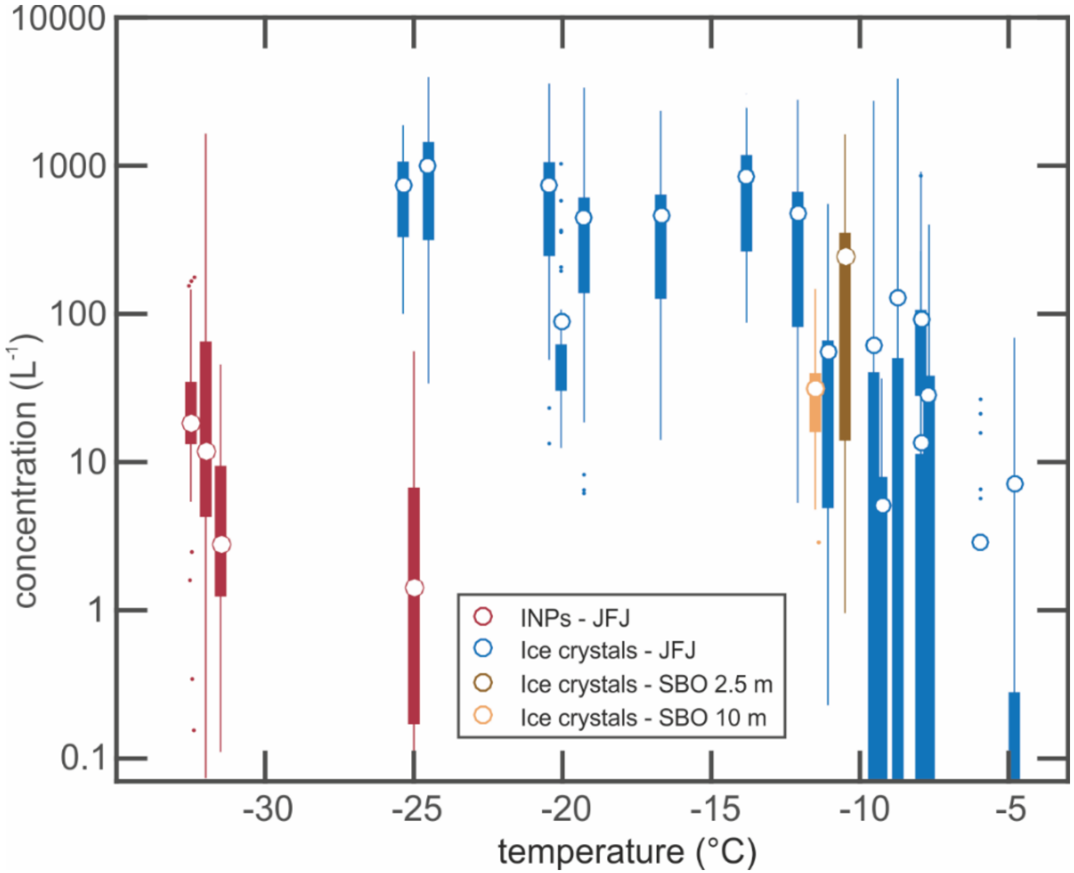
Beck et al., ACP, 2018

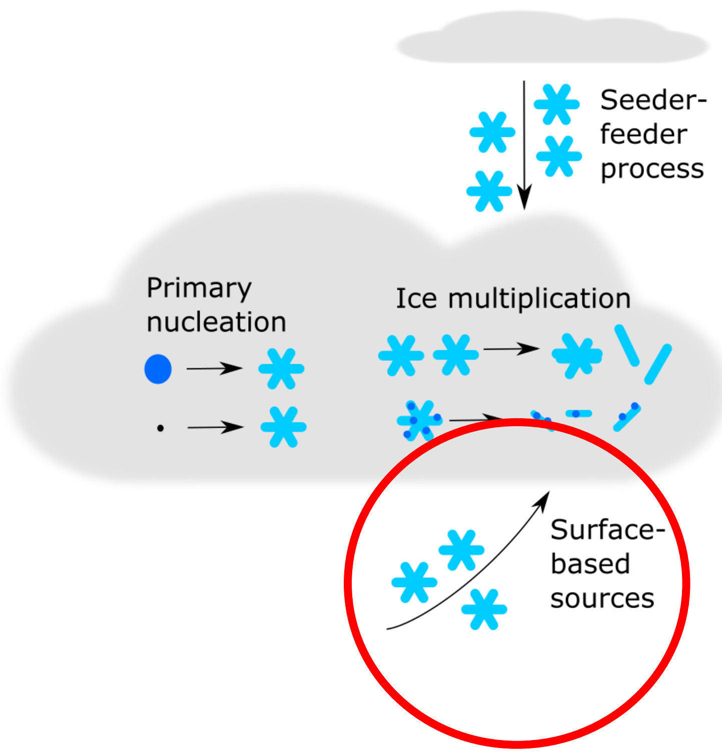
Mountain-top in-situ measurements are influenced by surface processes



Measurement at Sonnblick observatory (SBO), Austria

Origin of the ice crystals?

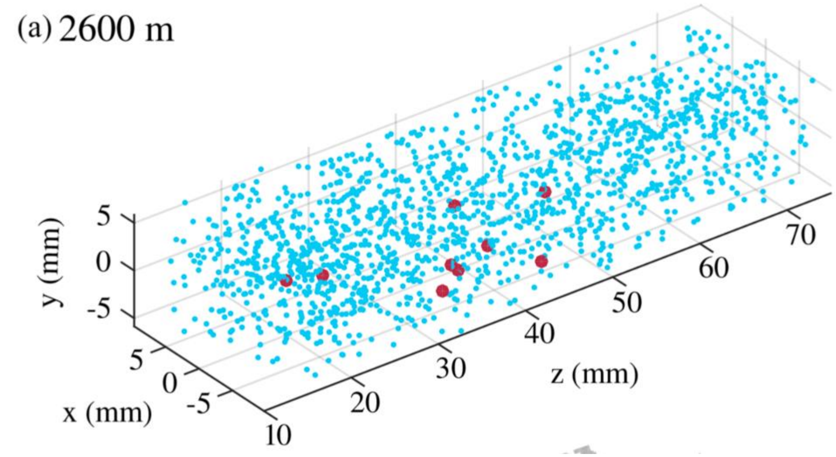


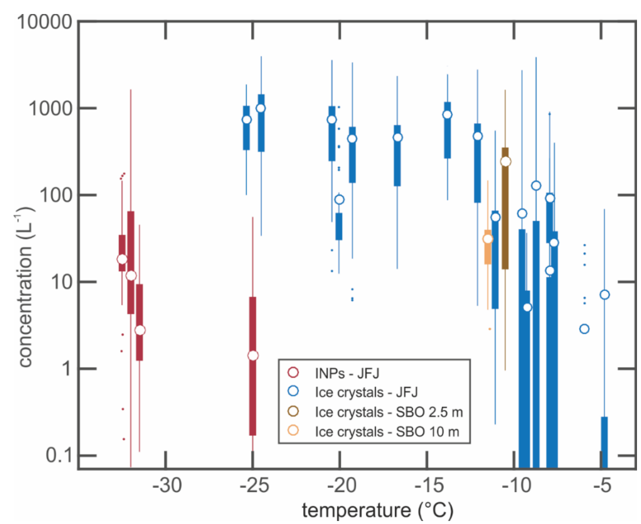


Beck et al., ACP, 2018

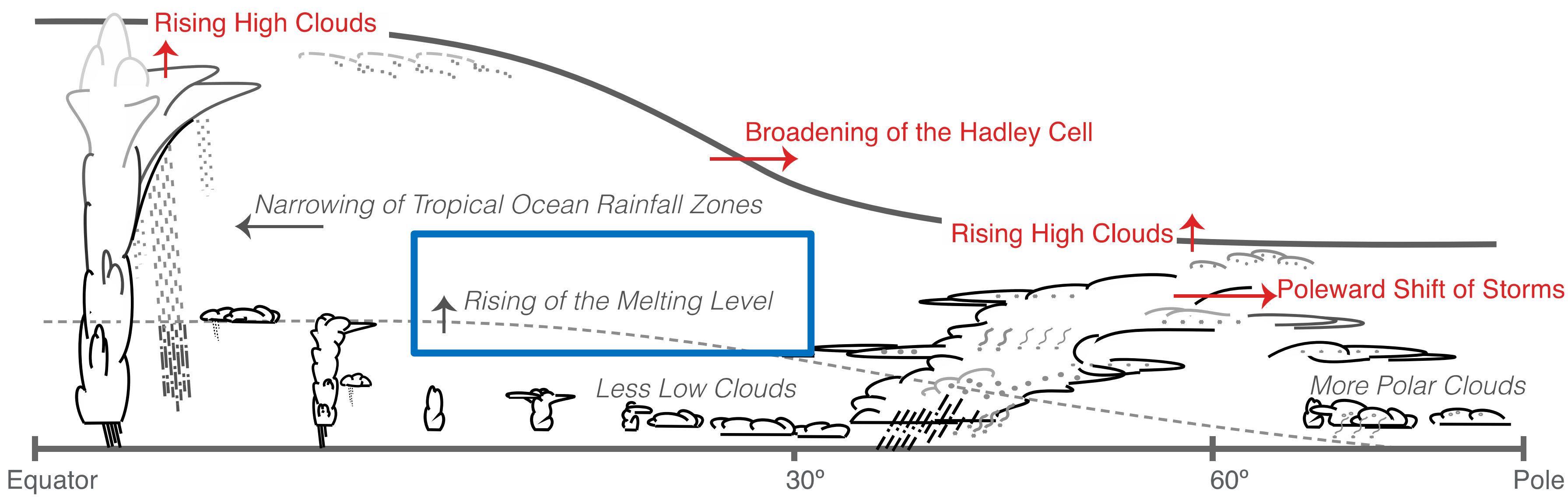
Take-home messages – observations

- Our holographic measurements provide information of the distribution of cloud particles on the mm-scale
- Ice nucleation and surface-based processes alone cannot explain the observed ice crystal number concentrations at Jungfraujoch
- Cloud droplets in orographic clouds are replenished in high updraft cases





Response of clouds to CO_2 doubling

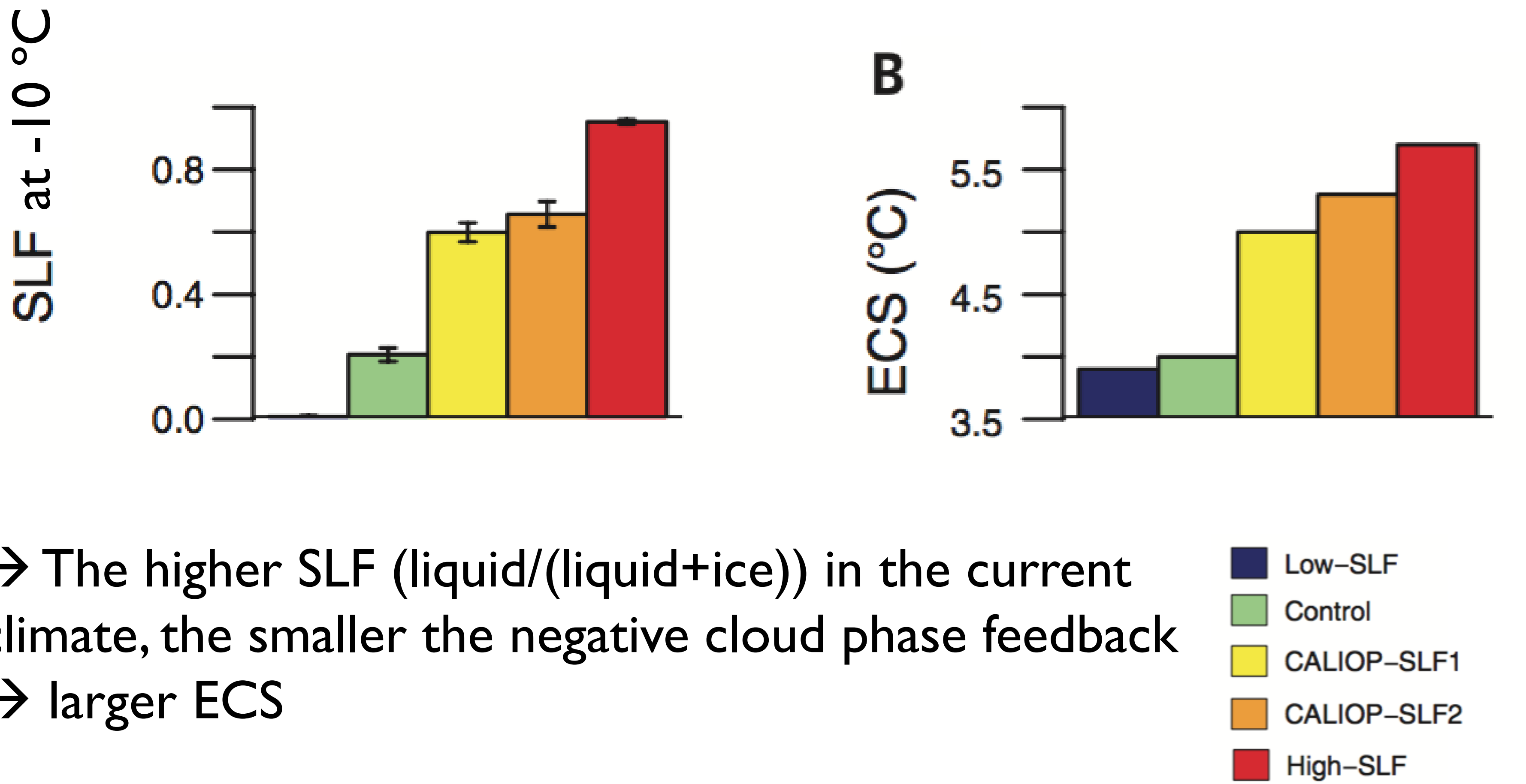


→ The net radiative feedback due to all cloud types is *likely* positive

→ Rising of the melting level causes more liquid instead of ice clouds → higher optical depth → negative cloud feedback

IPCC, 2013, Fig. 7.11

Supercooled liquid fraction (SLF) and equilibrium climate sensitivity (ECS)



→ The higher SLF (liquid/(liquid+ice)) in the current climate, the smaller the negative cloud phase feedback → larger ECS

Similar results in other models?

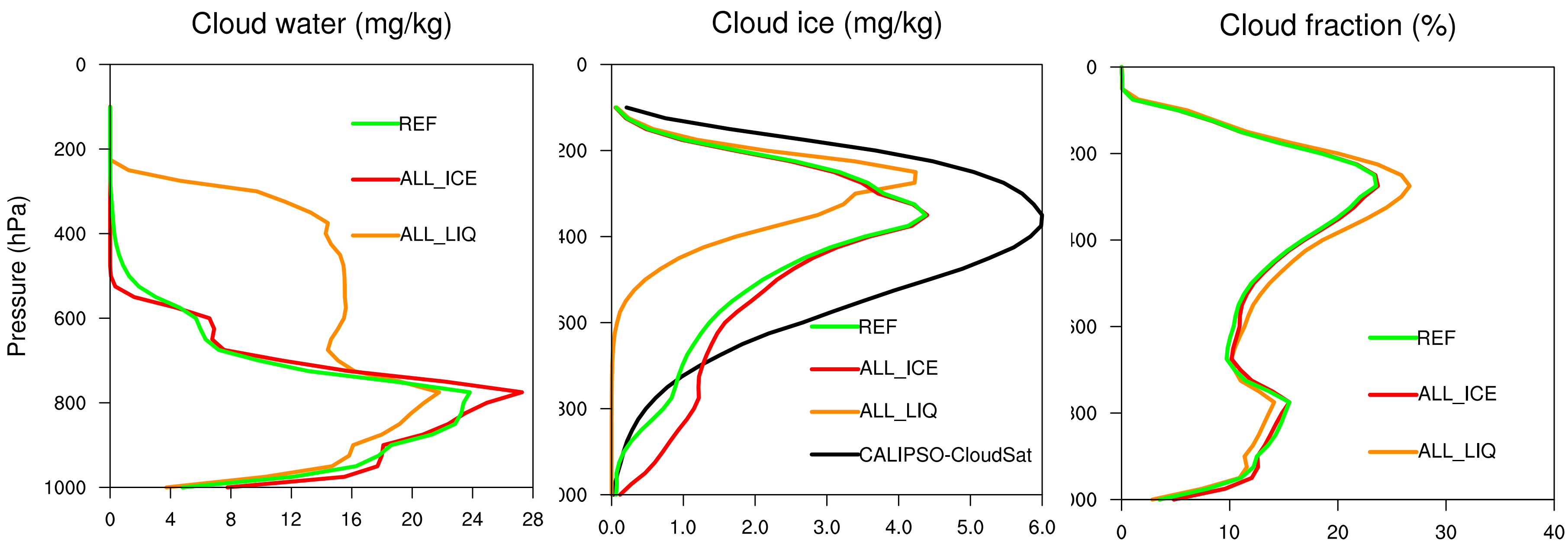
Tan et al., Science, 2016

Sensitivity studies with ECHAM6-HAM2

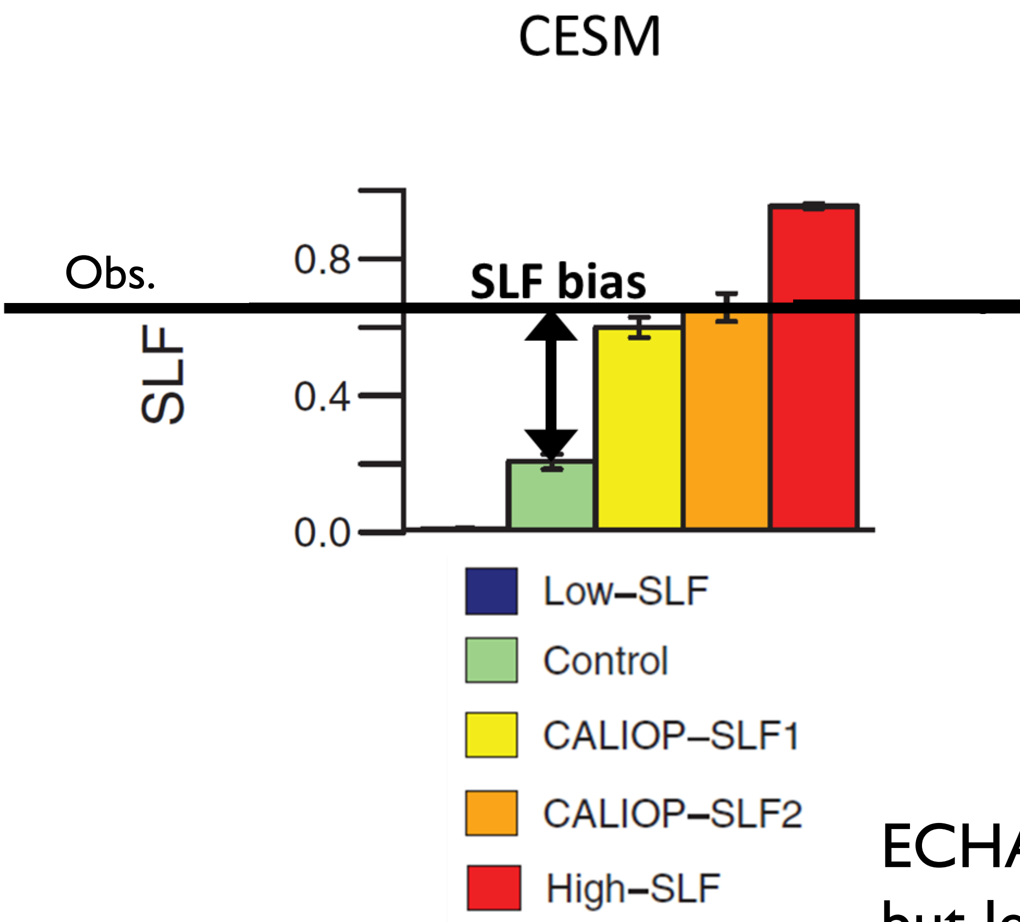
Sim.	**Description**
REF	Release version ECHAM6.3-HAM2.3
ALL_ICE	no supercooled liquid water at T < 0 °C
ALL_LIQ	only supercooled liquid water at T > -35 °C

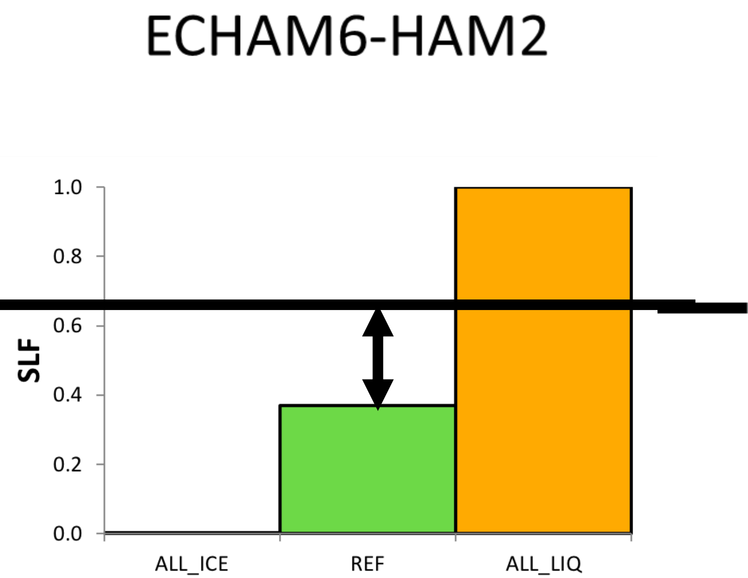
Lohmann and Neubauer, ACP, 2018

Annual global mean cloud properties



Supercooled liquid fraction (SLF)

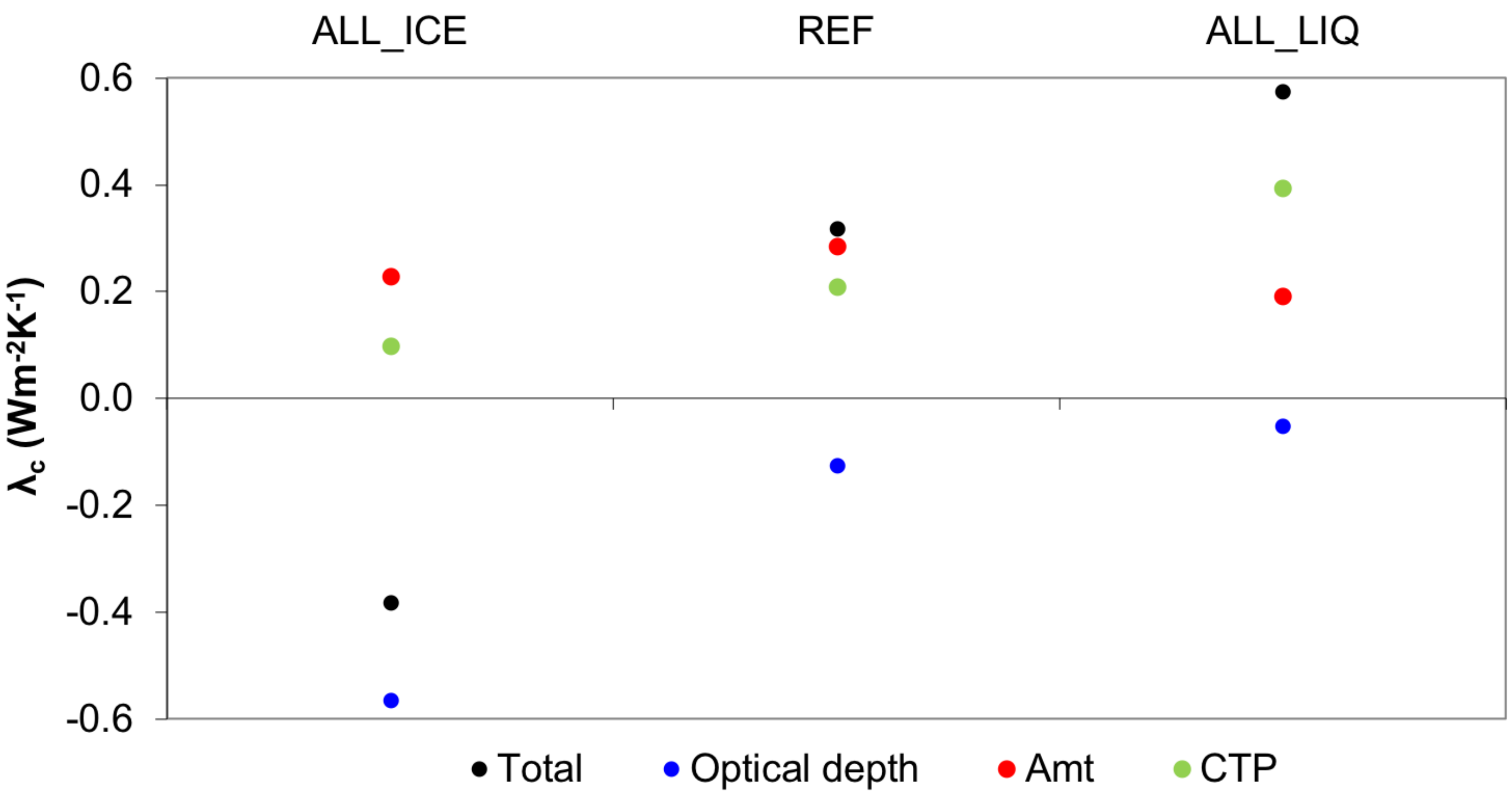




ECHAM also underestimates SLF, but less than CESM
→ do we also underestimate ECS? And if so, by how much?

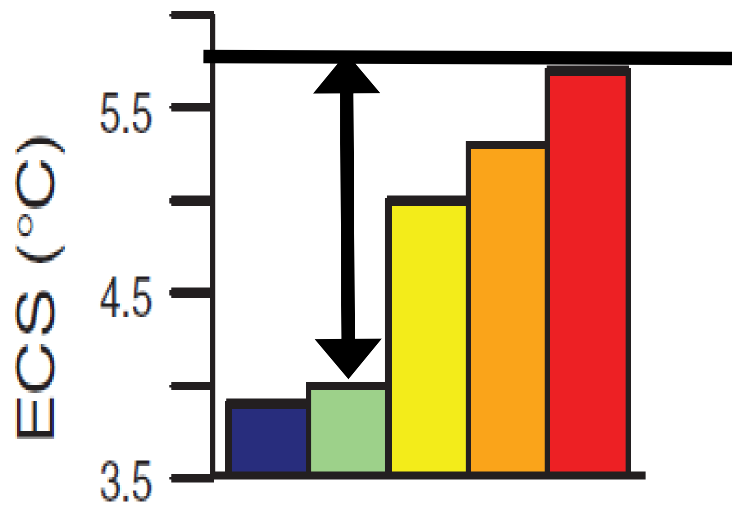
CESM Figure from Tan et al. (2016)

Components of the globally averaged cloud feedback parameters

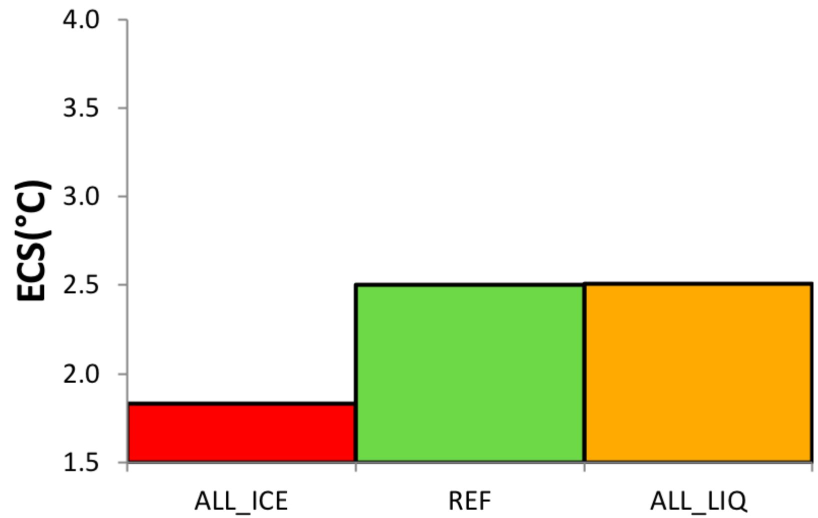


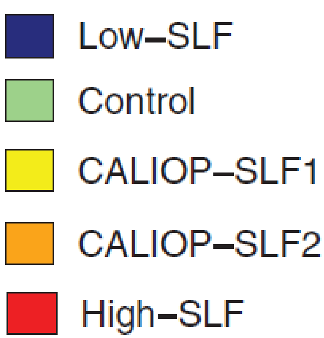
Equilibrium climate sensitivity

CESM



ECHAM6-HAM2

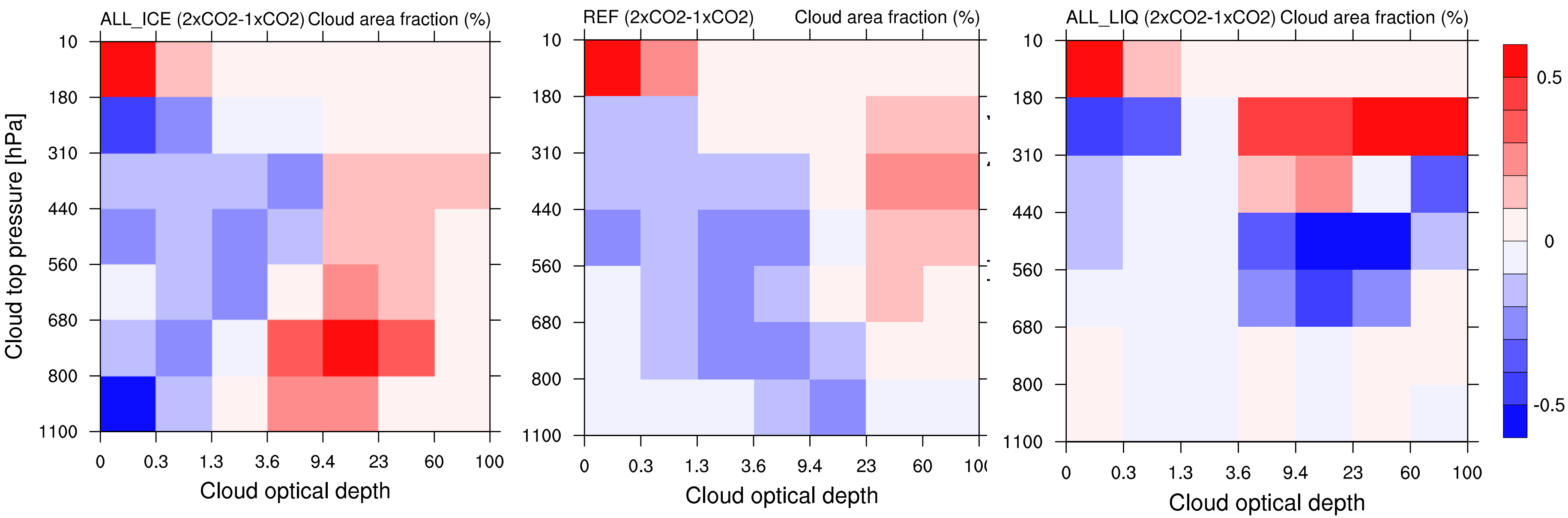




No ECS shift from cloud phase feedback between the reference simulation and ALL_LIQ in ECHAM6-HAM2 despite the smaller cloud phase feedback → why not?

CESM Figure from Tan et al. (2016)

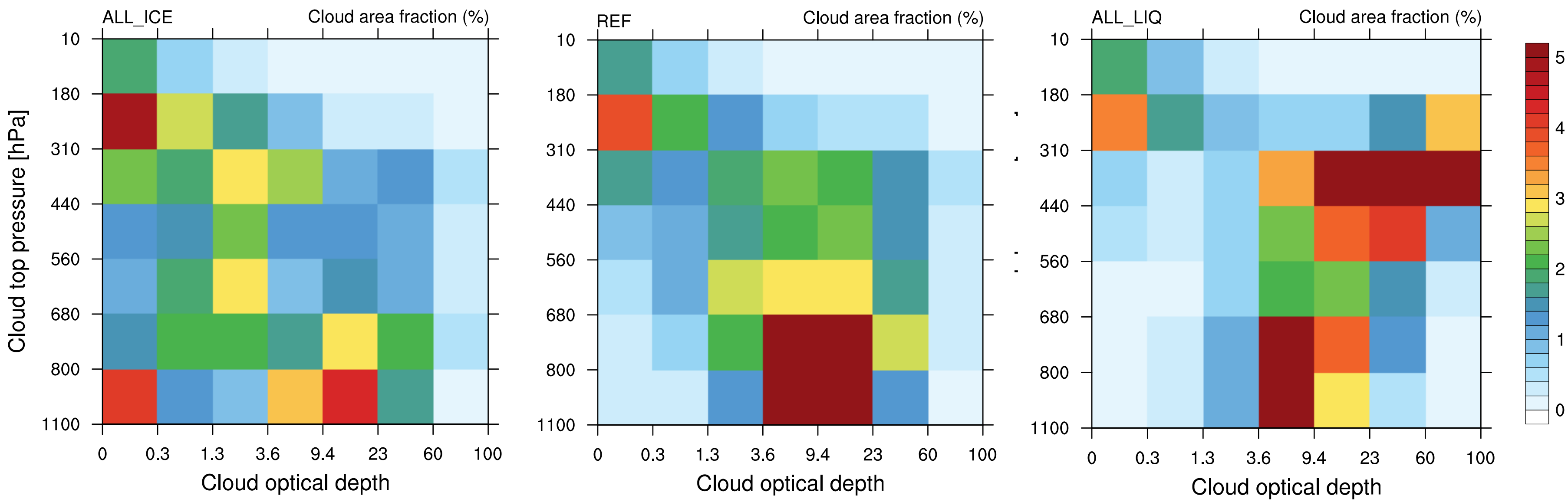
Changes of extratropical clouds (> 40° S/N) in a warmer climate

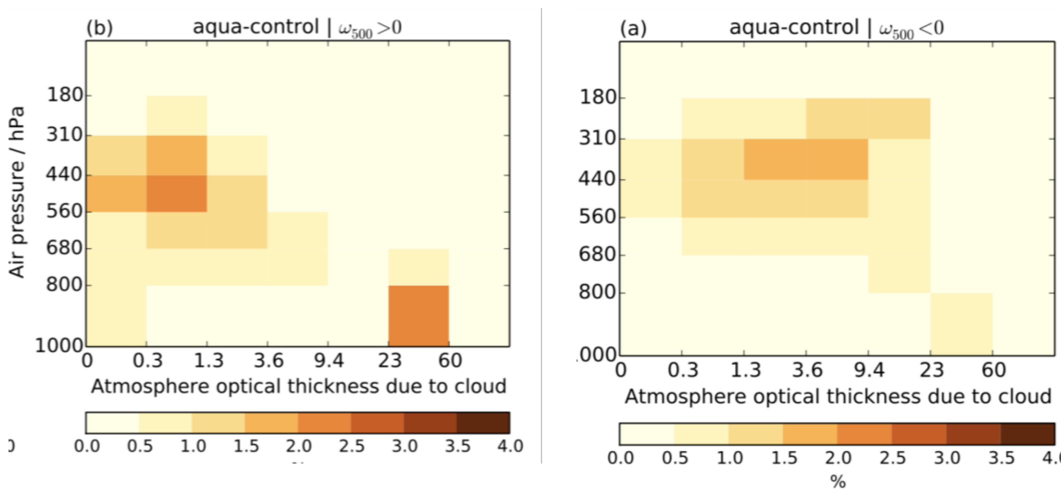


→ ALL_ICE: larger shift from optically thin to optically thick low and mid-level clouds than in REF

→ ALL_LIQ: high level clouds become optically thicker than in REF

Why is the cloud phase feedback not important in ALL_LIQ?

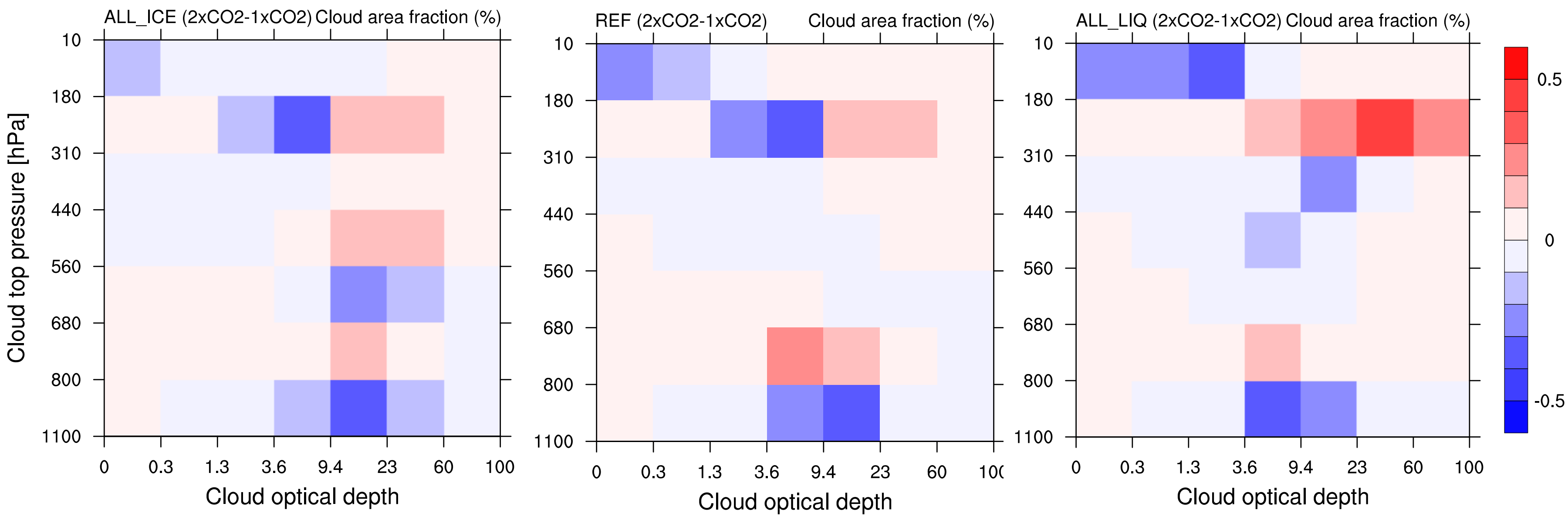




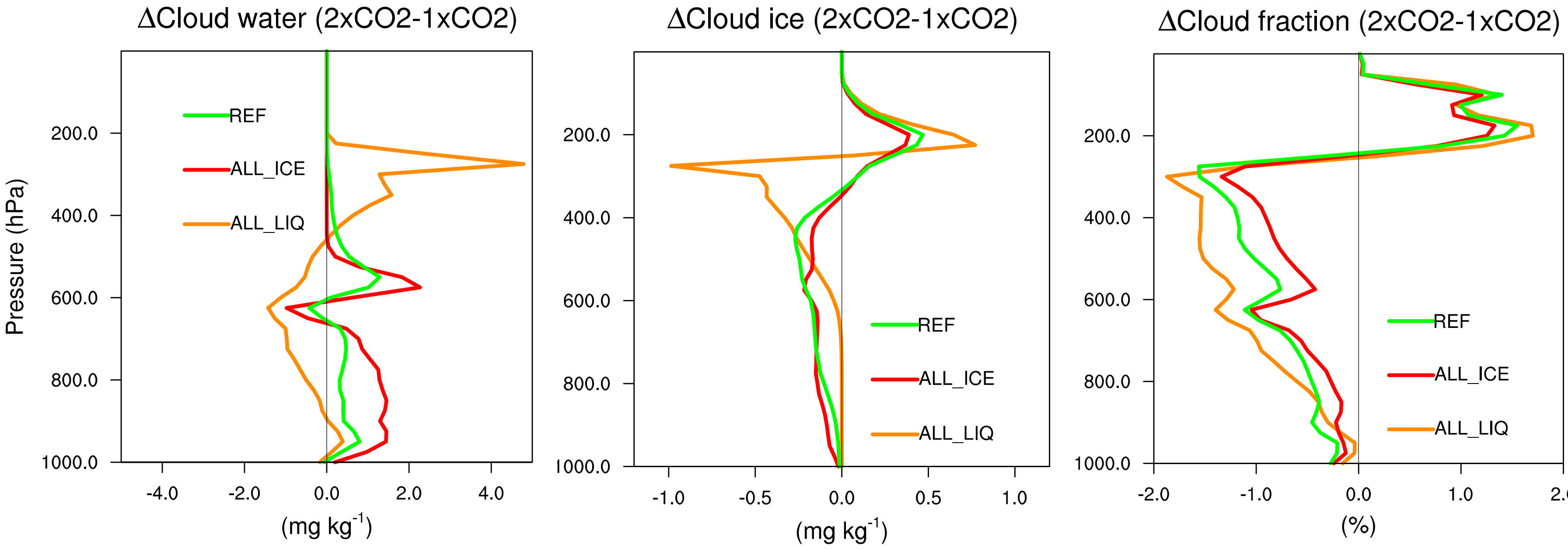
	Ascending	Descending
ΔCRE_{SW}	−3.2	−2.5
ΔCRE_{LW}	+2.4	+0.6
ΔCRE_{TOT}	−0.8	−1.8

Bodas-Salcedo, GRL, 2018

Changes of tropical clouds (15°S – 15°N) in a warmer climate



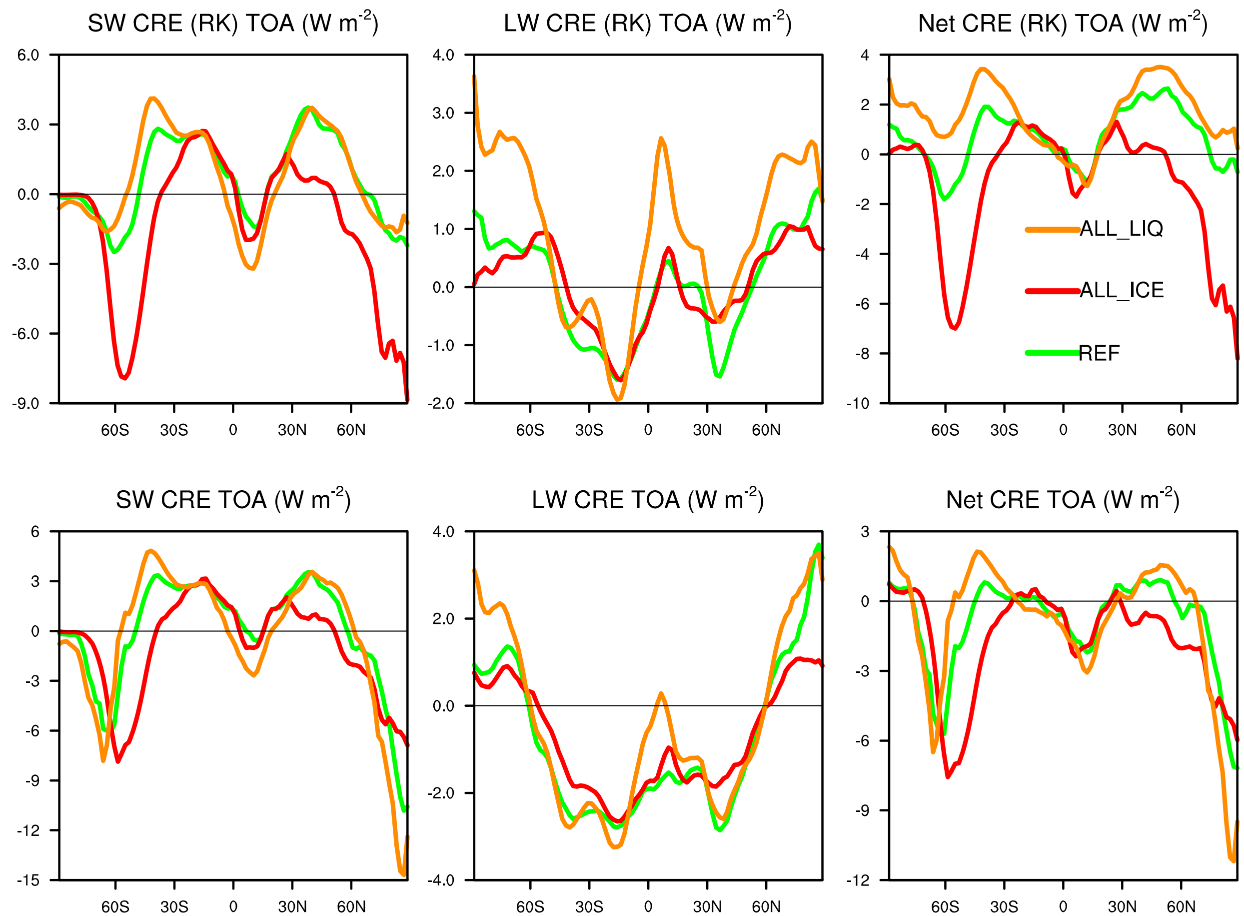
Changes of cloud properties in a warmer climate



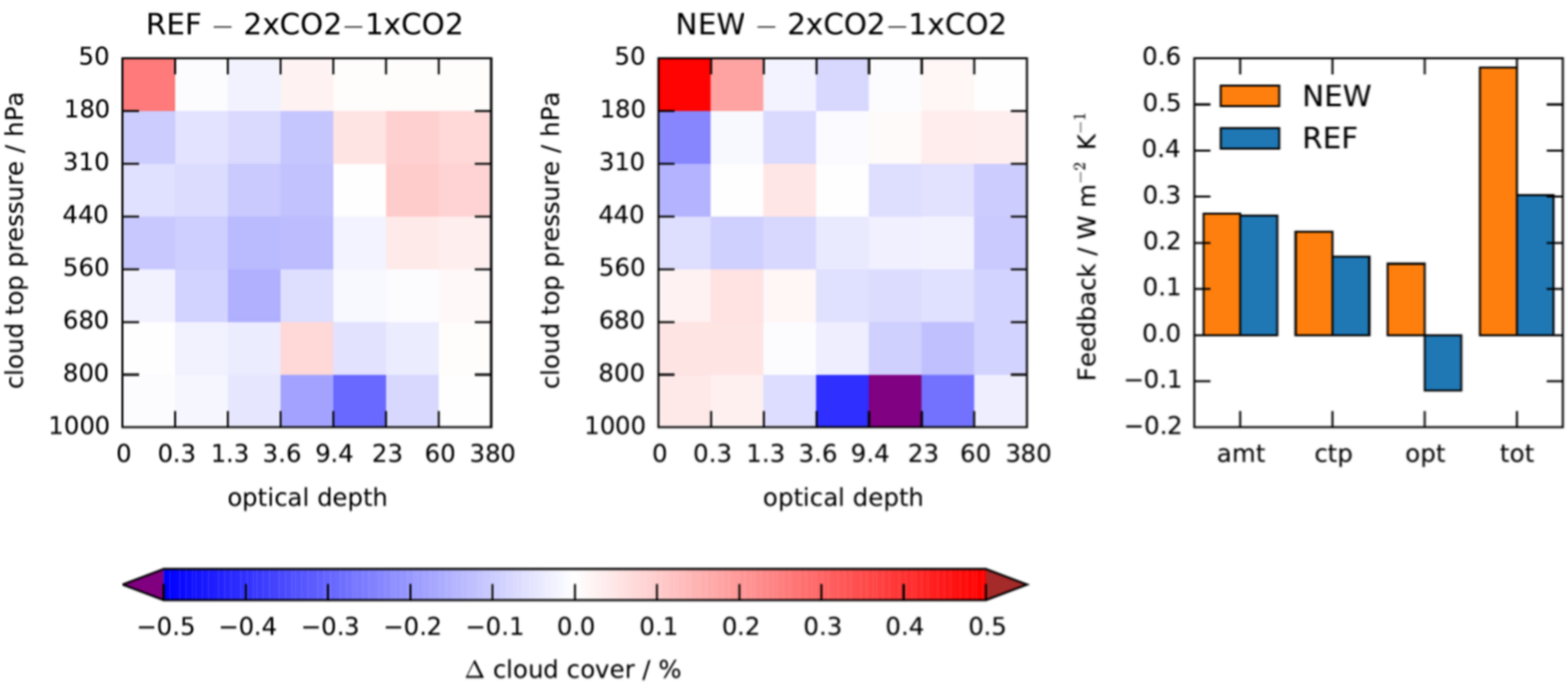
Changes in cloud radiative effects (CRE) in a warmer climate

CRE (radiative kernel method; only changes in clouds)

CRE (includes changes in water vapor, CO_2, surface temperature, albedo)



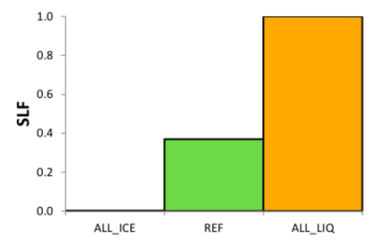
Impact of a new ice microphysics scheme

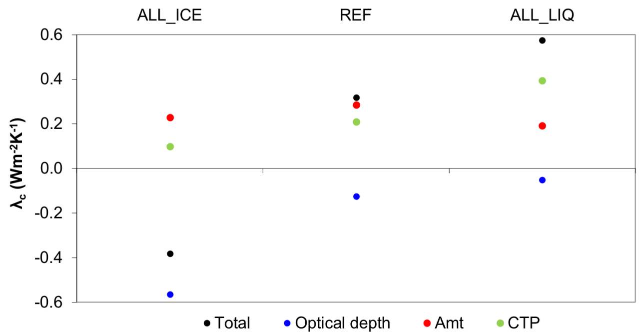


With our new ice microphysics scheme (Dietlicher et al., ACPD, 2018) the cloud optical depth feedback becomes positive and climate sensitivity increases to 3.8 °C (vs. 2.5 °C in REF)

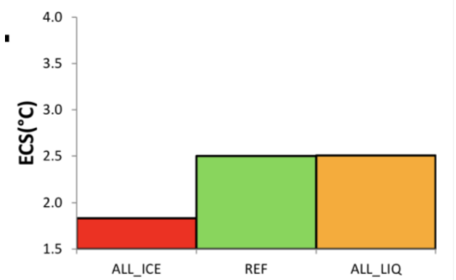
Take-home messages – modelling results

- The supercooled liquid fraction is not a good indicator for the cloud phase feedback because cloud phase matters most for clouds not shielded by higher clouds





- If cloud phase changes for optically thick clouds then changes in the shortwave and longwave compensate each other (consistent with the findings by Bodas-Salcedo, 2018)



- ECS is significantly higher when using the new ice microphysics scheme (Dietlicher et al., ACPD, 2018) with 3.8 °C vs. 2.5 °C. The reasons for this require further analysis but could be linked to a smaller contribution of mixed-phase clouds in that scheme.

Classification

Train and test on same dataset (accuracy %)

Simple approach	Normal tree	SVM	Deep Learning
88.6 ± 3.3	95.3 ±1.4	98.1 ± 0.7	97.4 ± 0.5

Train on four datasets, test on unseen dataset (accuracy %)

	Simple approach	Normal tree	SVM	Deep Learning
2016 iHOLIMO 3G	70.4	89.6	95.5	96.2 ± 0.2
2016 iHOLIMO 3M	61.7	94.7	96.3	98.0 ± 0.2
2016 JFJ 3G	72.0	90.4	95.0	96.8 ± 0.2
2016 SON 3G	71.8	81.1	75.7	91.1 ± 1.6
2017 SON 3G	87.1	90.5	82.6	97.0 ± 1.0

80% 90% 95%

Annual-zonal mean cloud properties