Microphysical and macrophysical characteristics of ice and mixed-phase clouds compared between in-situ observations from the NSF ORCAS campaign and the NCAR Community Atmosphere Model

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Outline

- **Motivation**
  - The importance of accurately representing supersaturation in cloud formation
- **Observations and model simulations**
  - The NSF ORCAS campaign
  - Weather Research and Forecasting (WRF) model and NCAR Community Atmosphere Model V5 (CAM5) simulations
- **Analysis of relative humidity, ice and mixed-phase clouds**

  1) Relative humidity distributions

  2) Microphysical properties of ice and mixed-phase clouds

  3) Macrophysical properties of ice supersaturated conditions and ice and mixed-phase clouds
- **Conclusion and future work**

Birthplace of ice crystals – ice supersaturation

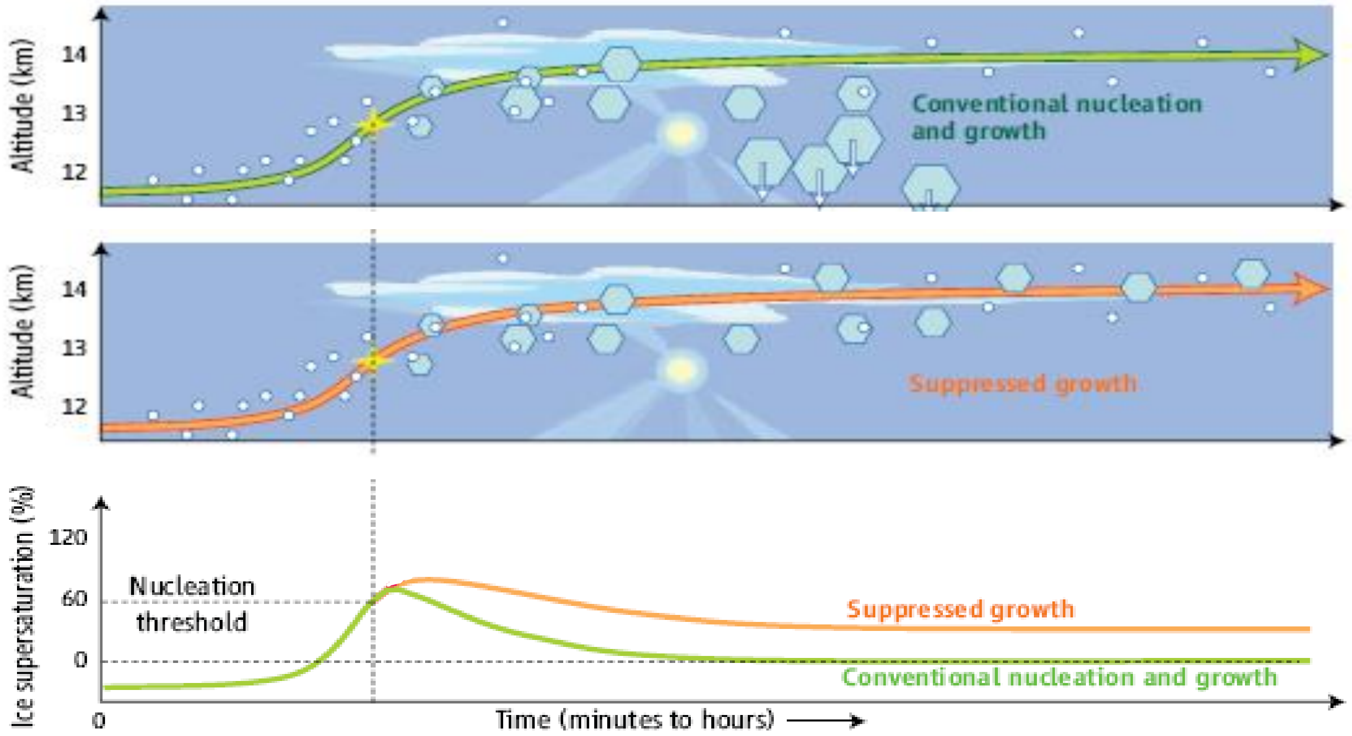
Ice Supersaturation (ISS)

Prerequisite condition for ice crystal formation

$$ISS = RHi - 1 = e / e_s - 1$$

- **e**: water vapor pressure
- $\mathbf{e_s}$: saturation vapor pressure wrt ice

(Peter *et al*. 2006)

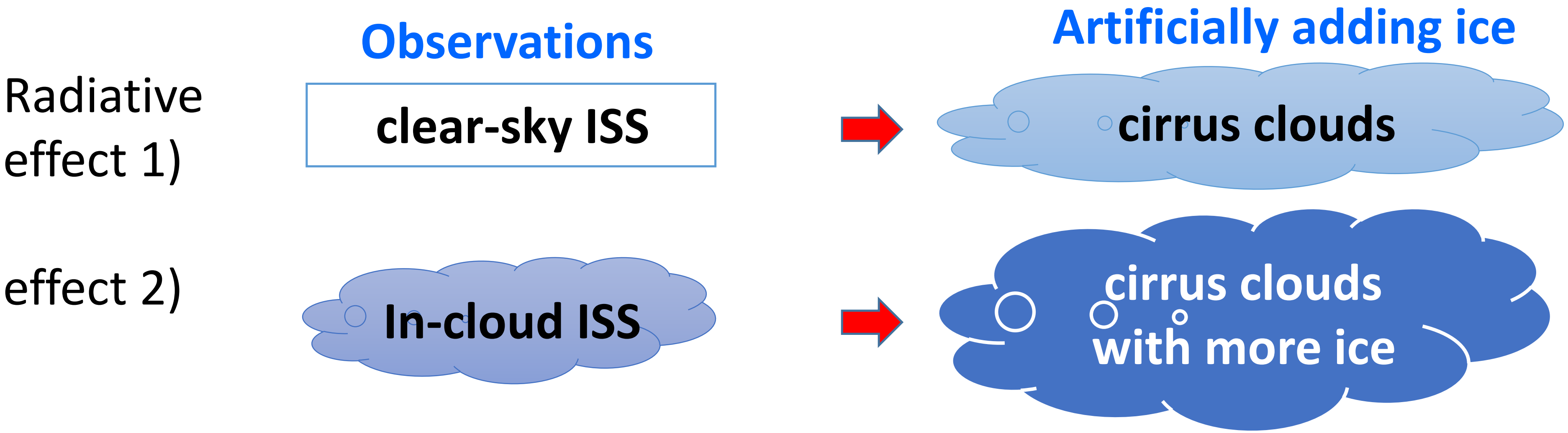


How often do we see:
(i) clear-sky ISS,
(ii) in-cloud ISS,
(iii) non-ISS clouds?

Important ISS characteristics:

1. *Magnitude of RHi*
2. *Occurrence frequency*
3. *Spatial extent*
4. *Relationship with cloud microphysical properties*

Radiative impacts of mistaking ice supersaturation for ice crystals



In-situ observations in five NSF flight campaigns with the ERA-interim data and RRTMG model calculation

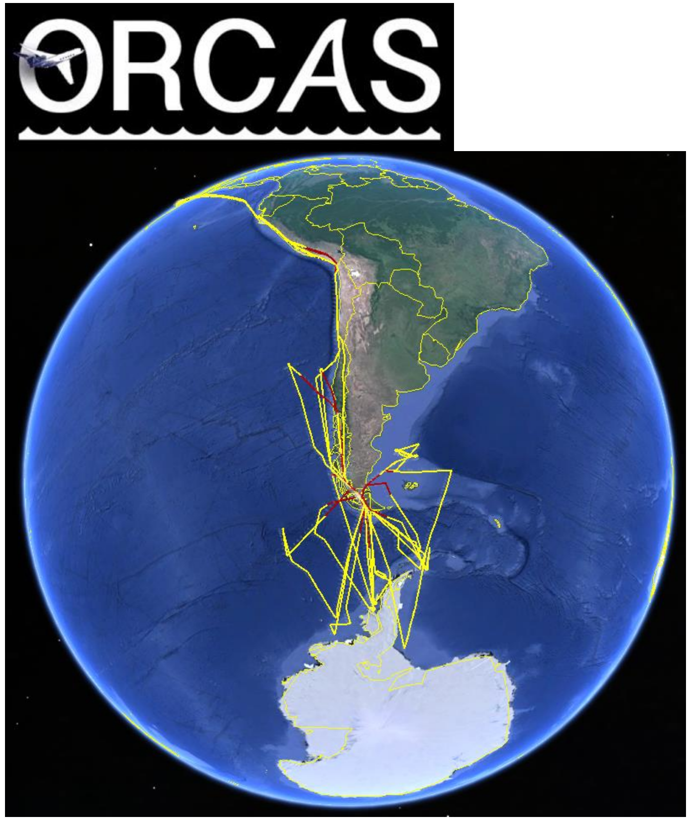
(1) Misrepresenting clear-sky ISS as artificial cirrus have **54 and 4.24 W/m^2 maximum and average effects on the net radiation at TOA, respectively**

(2) Radiative effects are **highly sensitive to the pre-existing ice water path with ISS**

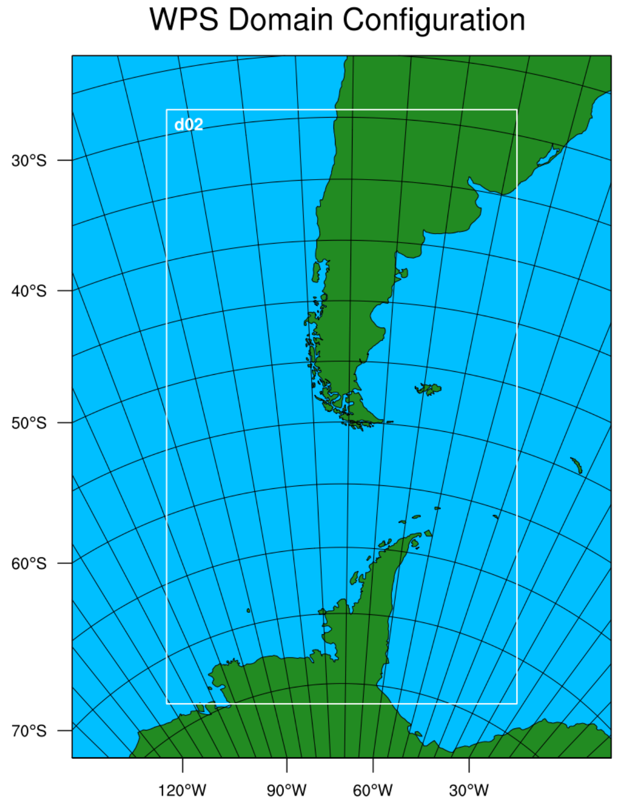
Tan, X., Y. Huang, M. Diao, A. Bansemer, M. A. Zondlo, J. P. DiGangi, R. Volkamer, and Y. Hu, 2016: An assessment of the radiative effects of ice supersaturation based on in situ observations. *Geophys. Res. Lett.*, **43**, 11039–11047, doi:10.1002/2016GL071144. Please check poster #A43F-0292 in the afternoon

The NSF ORCAS campaign, WRF model and the NCAR Community Atmosphere Model Version 5 (CAM5) simulations

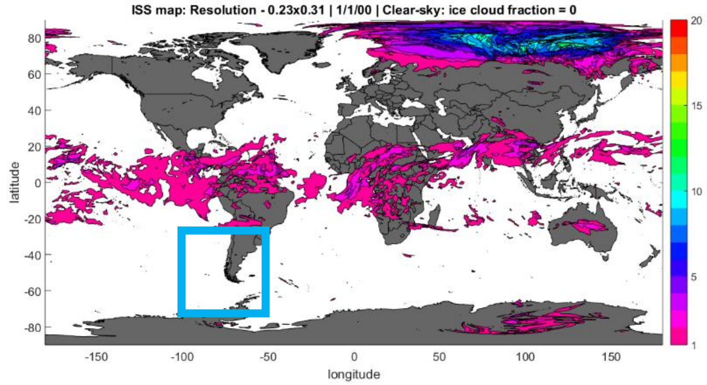
[1] The NSF O_2/N_2 Ratio and CO_2 Airborne Southern Ocean (ORCAS) Study;
18 flights in Jan – Feb 2016



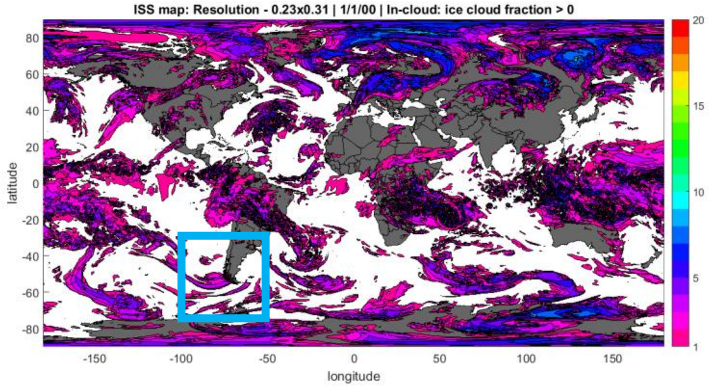
[2] WRF simulations:
Feb 24-26, 2016; 12 km – 2.4 km nested domains; double-moment microphysics scheme (Morrison et al. 2009)



[3] CAM V5.3 CESM1.2.0 simulations:
01/29 2002 – 12/01 2002; 0.23°×0.31°; 30 vertical levels; Output in the ORCAS domain (30-75°S, 92-50°W) are used for statistical comparisons.



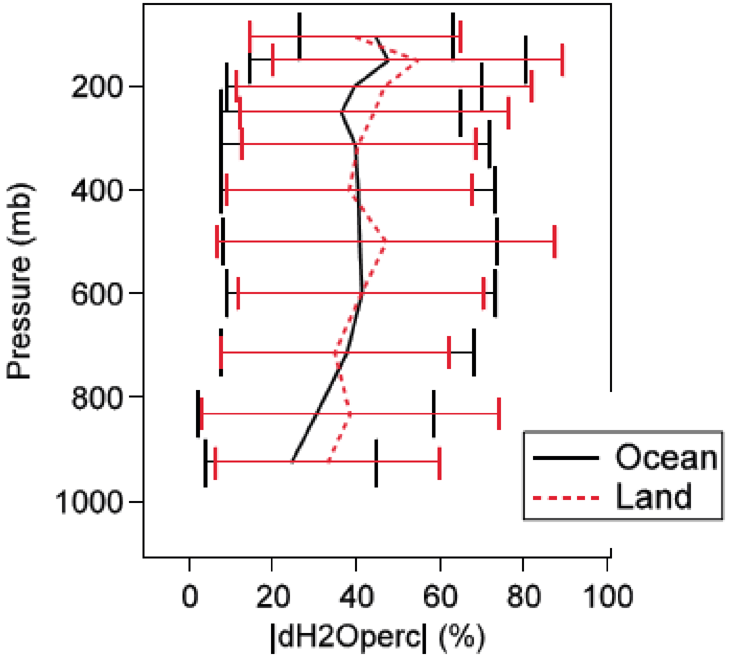
Example: clear-sky ISS occurrences



In-cloud ISS occurrences

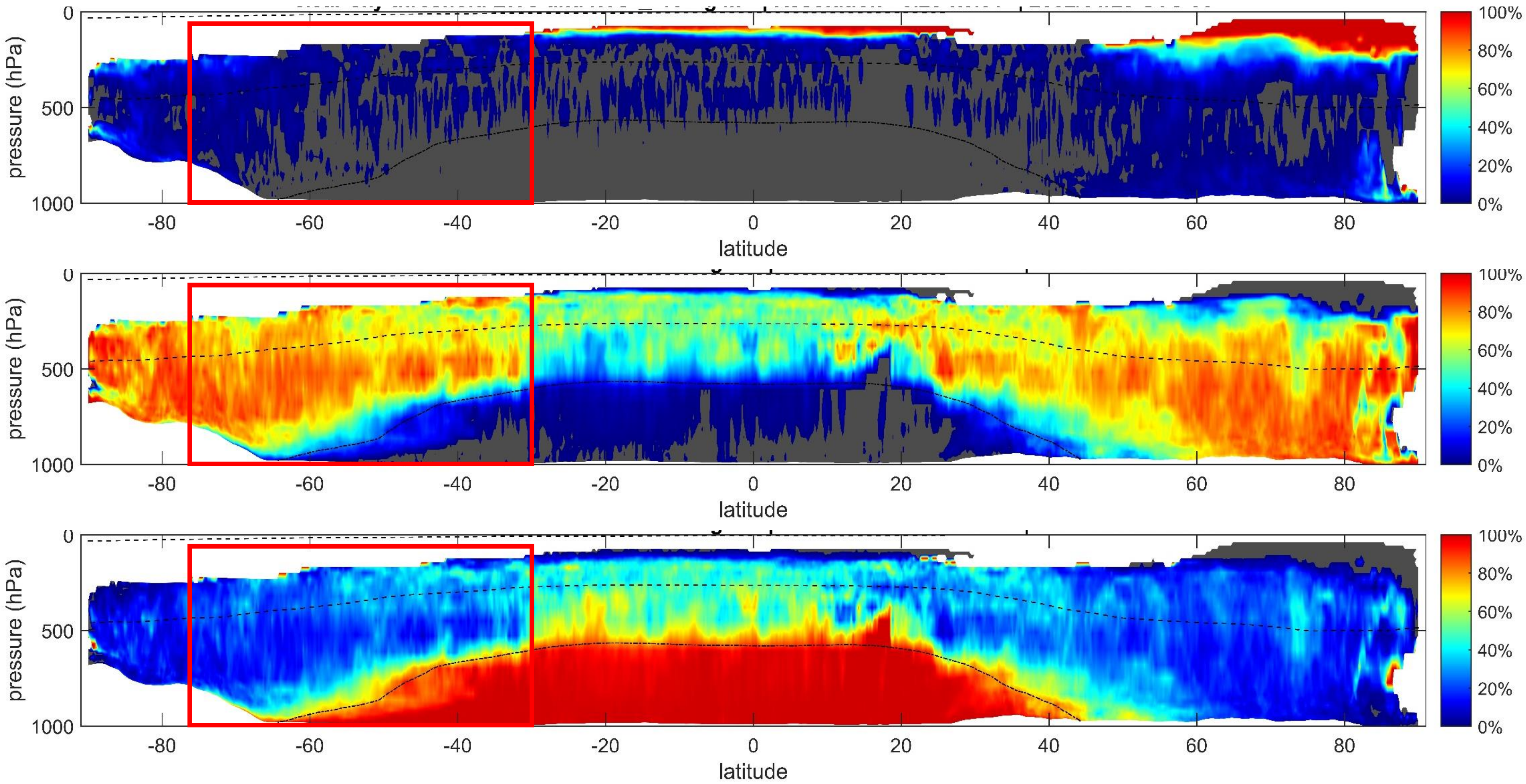
VCSEL hygrometer

- **Vertical Cavity Surface Emitting Laser (VCSEL) hygrometer**
  - Near infrared; 25 Hz; Analyses use 1 Hz;
  - Accuracy ≤ 6%; Precision ≤ 1% (Zondlo *et al*. 2010)
  - Combined with the temperature accuracy of ±0.3 K, the RHi accuracy is ~7%-8% at -40ºC to -77ºC, respectively.



Validation of NASA AIRS water vapor and temperature (Diao *et al*. 2013)
~40% **H_2O difference, ~1–2 K temperature difference** in the UT/LS

Latitudinal distributions of supersaturation (SS) occurrence frequency in CAM5



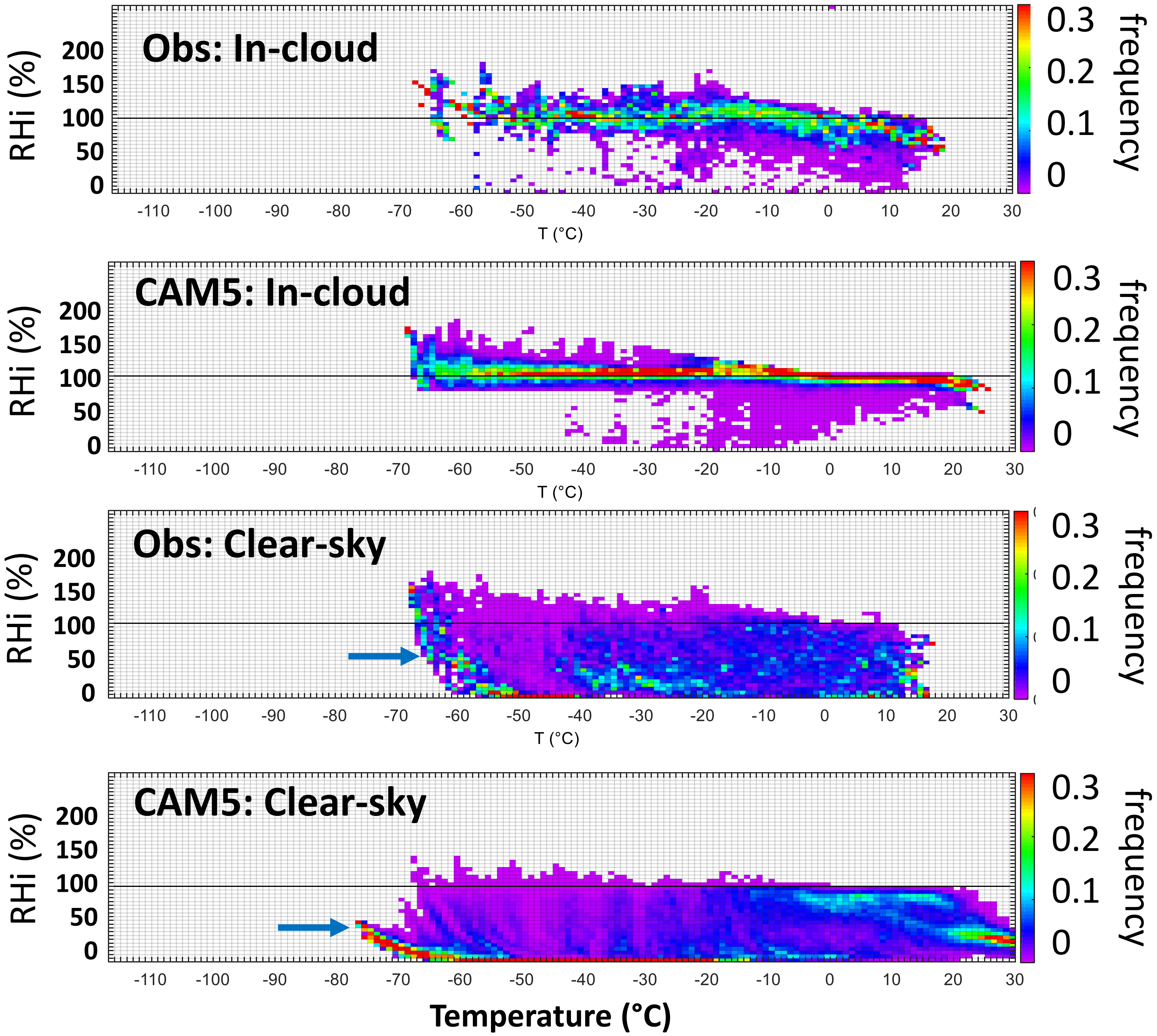
Clear-sky SS
~28% in ORCAS
(*low bias* in CAM5)

In-cloud SS
~33% in ORCAS
(*high bias* in CAM5)

Non-SS clouds
~39% in ORCAS
(*similar* in CAM5)

CAM5 simulations can capture three conditions: clear-sky SS, in-cloud SS and non-SS clouds, but ***underestimate*** the ***clear-sky ISS*** occurrence frequency

Comparison of RH – T distributions between ORCAS and CAM5 simulations



In-cloud and clear-sky definition:

1. Cloud Droplet Probe (**CDP**): 2 – 50 µm; sensitive to spherical particles; 1Hz
2. Fast 2-dimensional probe (**Fast-2DC**): 75 – 1600 µm; > one particle at 1 Hz
3. CAM5: IWC or LWC > 10^{-7} g m^{-3}

RH_{liq} *for T > 0 °C;* RH_{ice} *for T ≤ 0 °C*

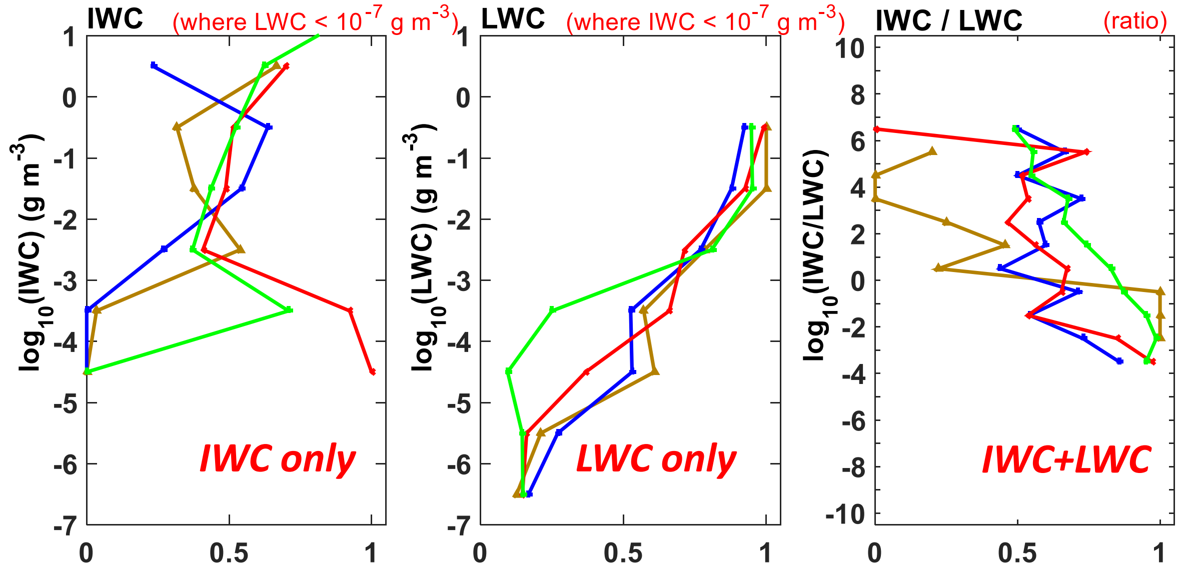
Comparison results:

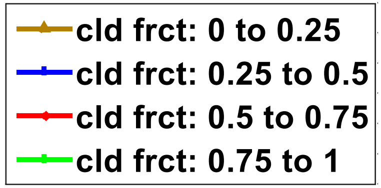
(a) The upper limit of in-cloud RH is similar between ORCAS and CAM5;

(b) Underestimation of clear-sky RHi > 50% in CAM5 at temperature below -40°C.

Relationships between supersaturation and microphysical properties

ORCAS observations



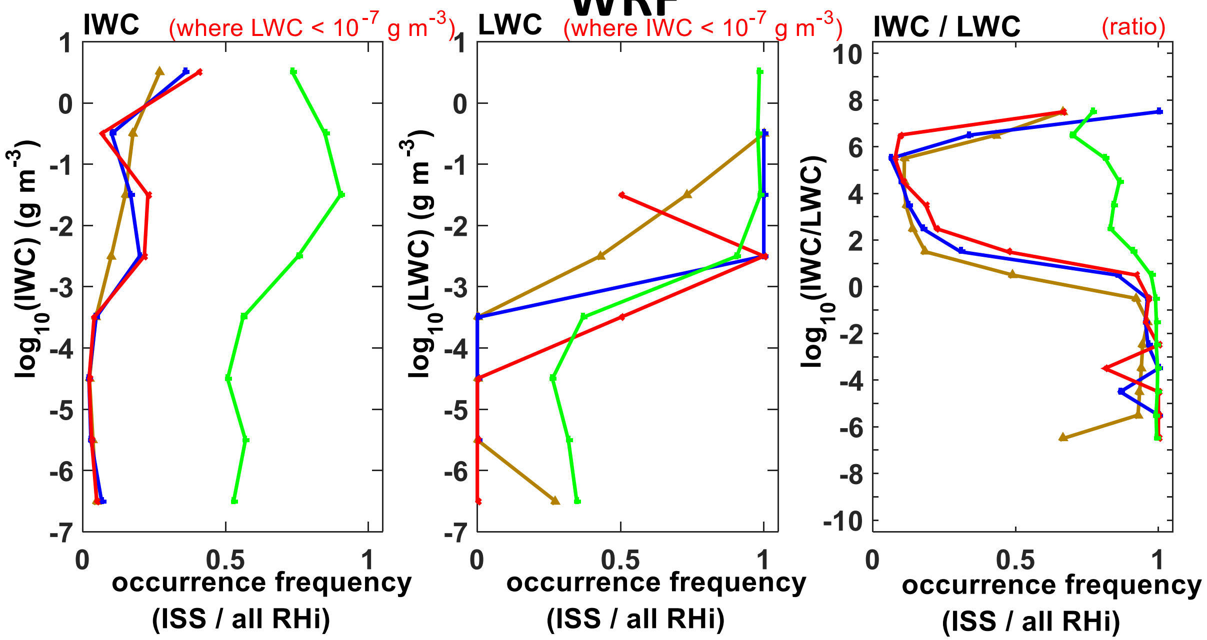


Note that ice cloud fraction (CF) in CAM5 is represented as (Gettelman *et al.* 2010):

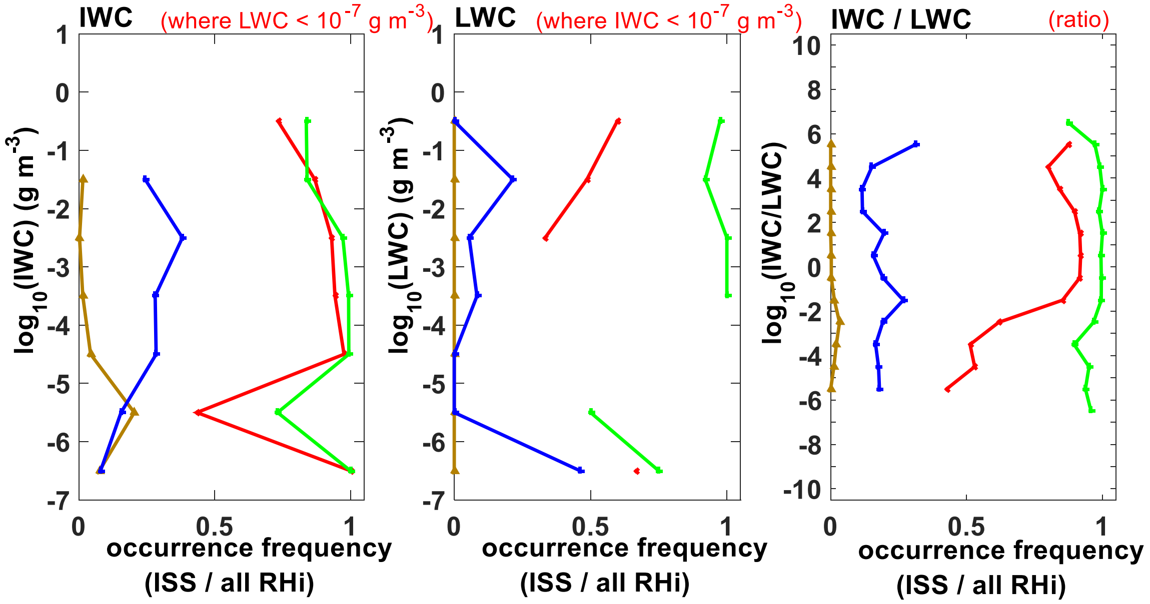
$$CF_i = \min(1, RH_d^2)$$

$$RH_d = \max\left(0, \frac{RH_{ti} - RHi_{\min}}{RHi_{\max} - RHi_{\min}}\right)$$

WRF

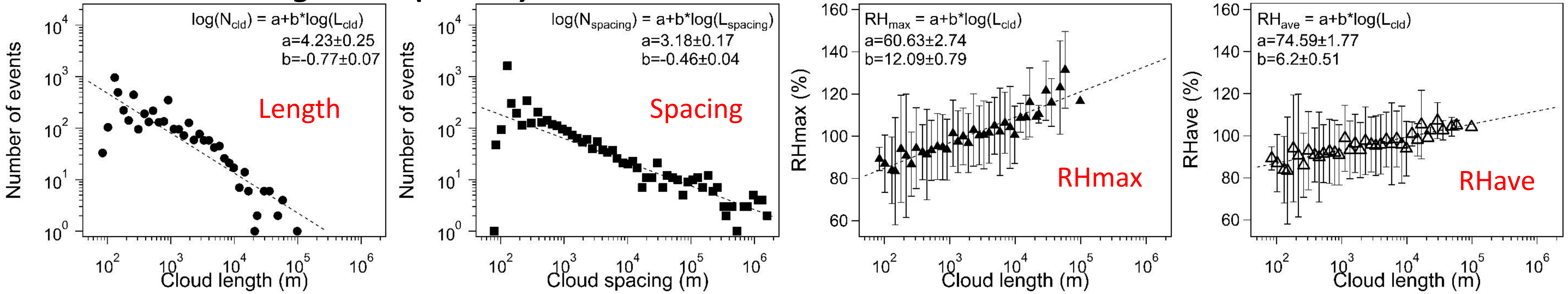


CAM5

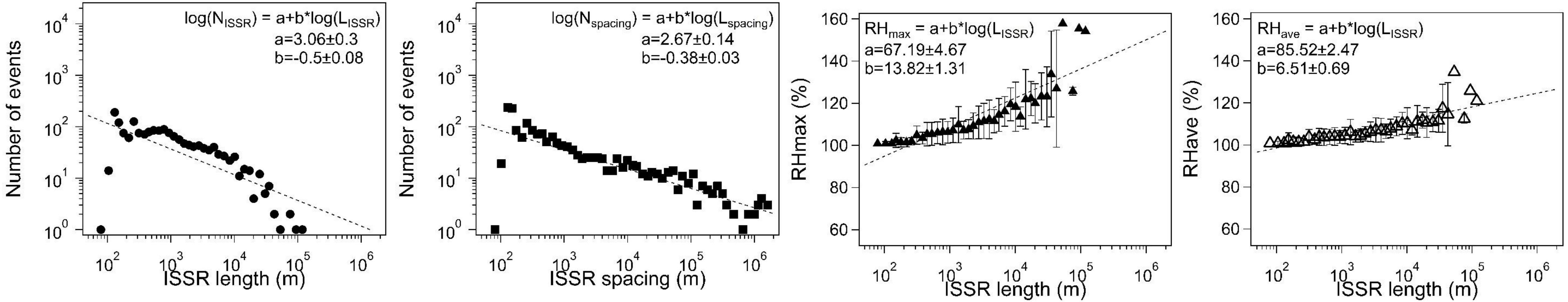


Macrophysical properties of ice and mixed-phase clouds and ice supersaturated regions in ORCAS

Cloud horizontal segments (T< 0°C)

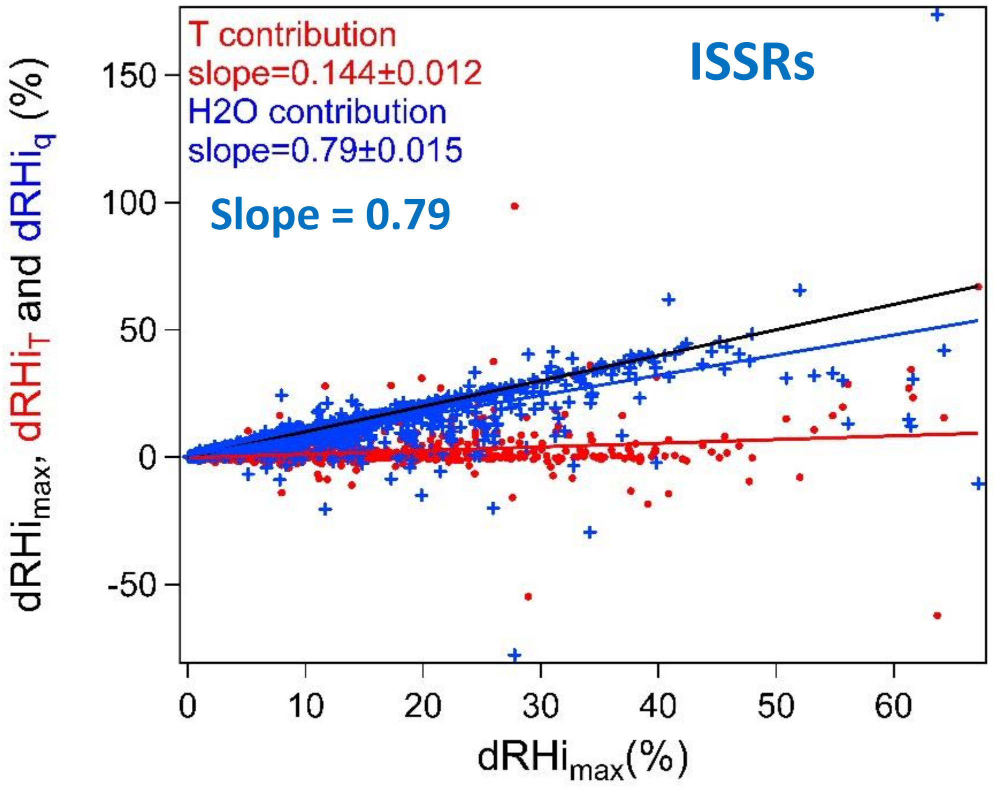


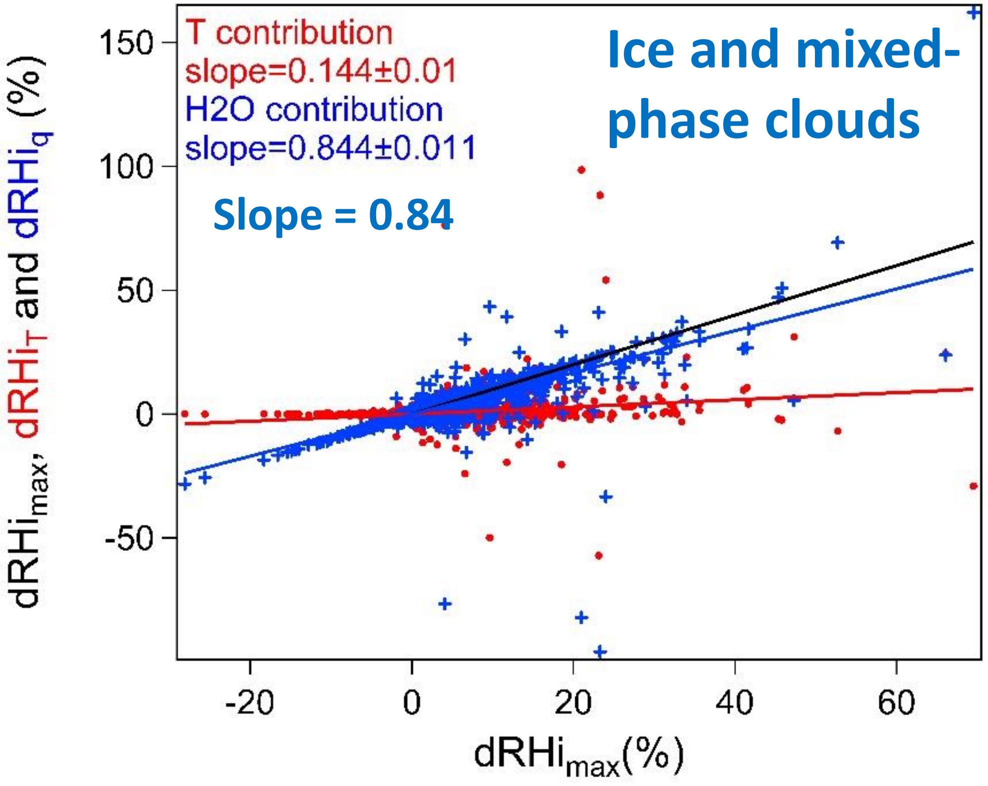
Ice supersaturated regions



(1) Large spatial heterogeneities in ice/mixed-phase clouds and ice supersaturated regions with patchy structure, small horizontal lengths; (2) Increasing RHmax and RHave with increasing horizontal lengths.

Importance of sub-grid scale variability of water vapor





ORCAS data showed that the difference in RH in- and out-of-clouds (or ISSRs) are dominated by the water vapor spatial heterogeneities.

Wu et al. (2016) found that the missing clouds in CAM5 are likely due to the lack of water vapor spatial variability. (Please see poster #**A43F-0297** in the afternoon)

C. Wu, X. Liu, M. Diao, K. Zhang, A. Gettelman, Z. Lin, Direct comparisons of ice cloud macro- and microphysical properties simulated by the Community Atmosphere Model CAM5 with HIPPO aircraft observations, submitted.

Conclusions

1. Relative humidity distributions

- CAM5 simulations ***underestimate*** the frequency of clear-sky SS and ***overestimate*** the frequency of in-cloud SS.

2. Microphysical properties of ice and mixed-phase clouds

- Relationships between microphysical properties (i.e., IWC, LWC) and frequency of SS are more comparable between WRF simulations and observations, but ***not well represented by CAM5*** simulations.

3. Macrophysical properties of ice and mixed-phase clouds

- Large spatial heterogeneities are found for ice and mixed-phase clouds: ***~1 km horizontal lengths and patchy structure***;
- Dominant contributions from ***water vapor spatial heterogeneities*** to the difference in RH in- and out-of-clouds.

Thank you!
Questions?