Airborne in-situ measurements of relative humidity and clouds over the Southern Ocean

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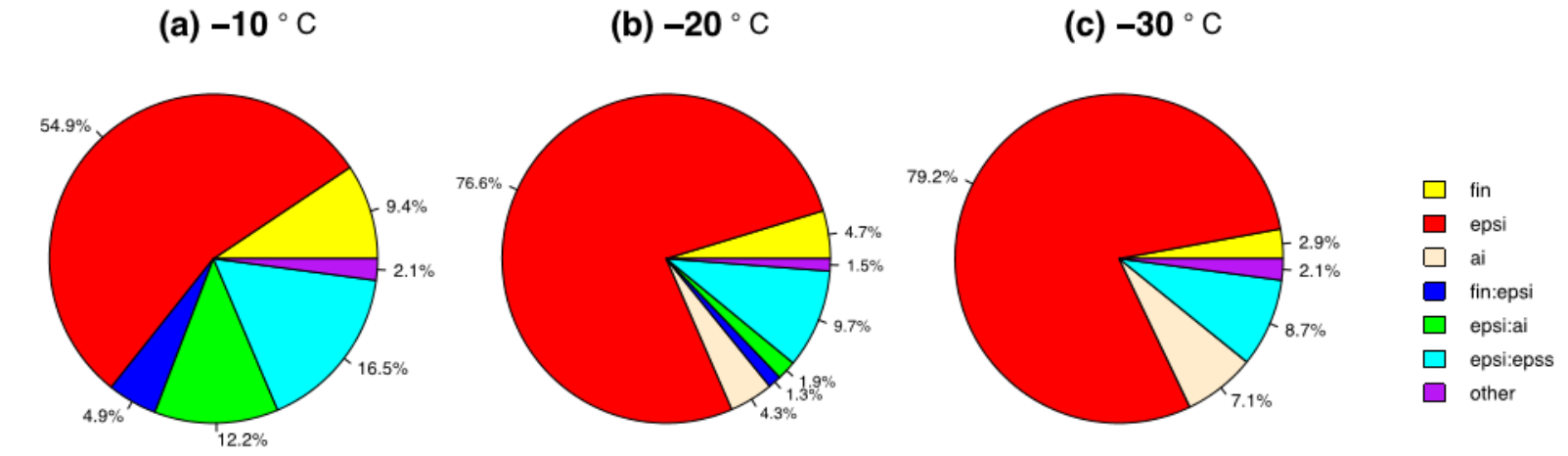
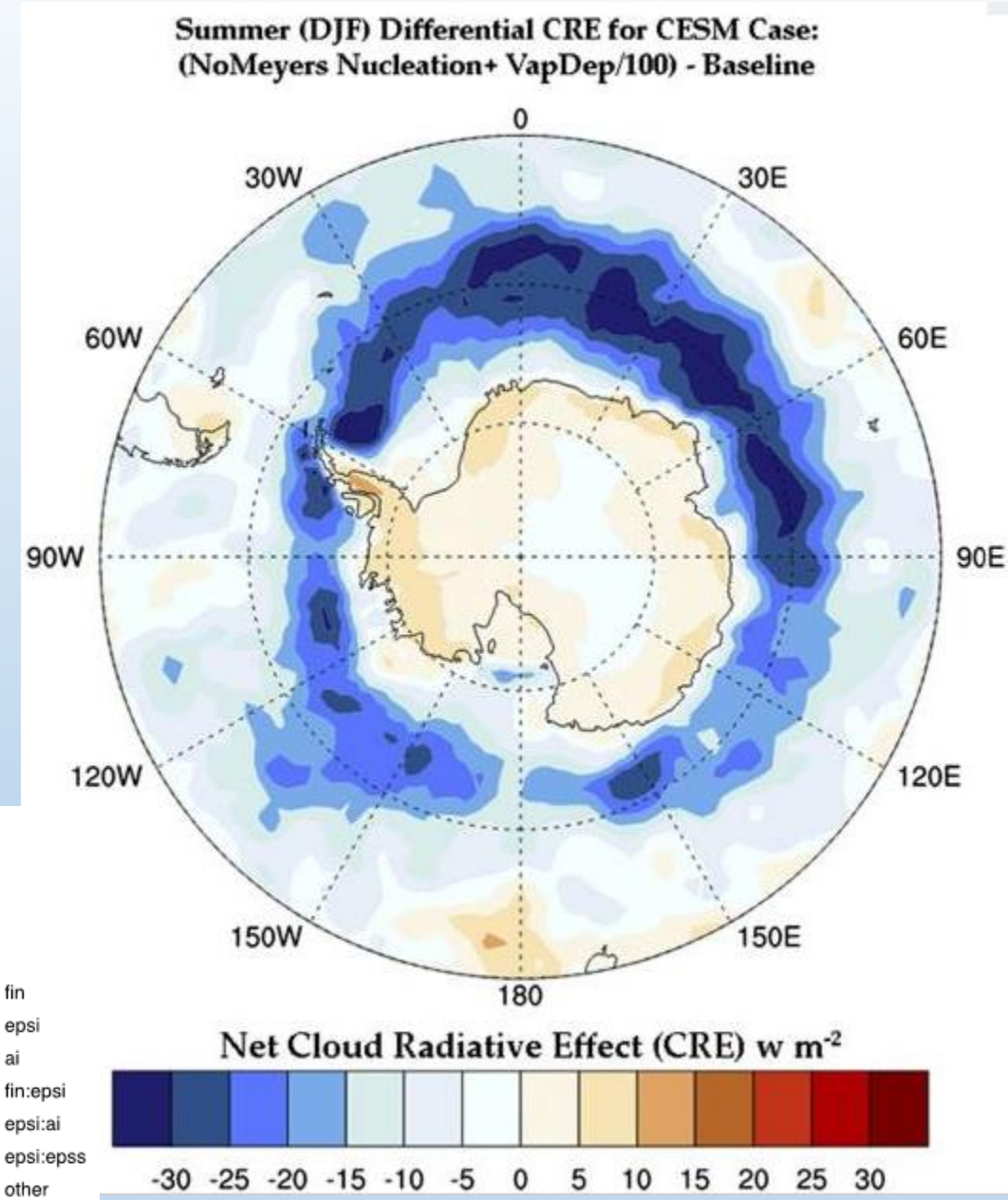
The ORCAS science team, RAF flight and ground crew

Mixed-phase clouds (MPC) over the Southern Ocean

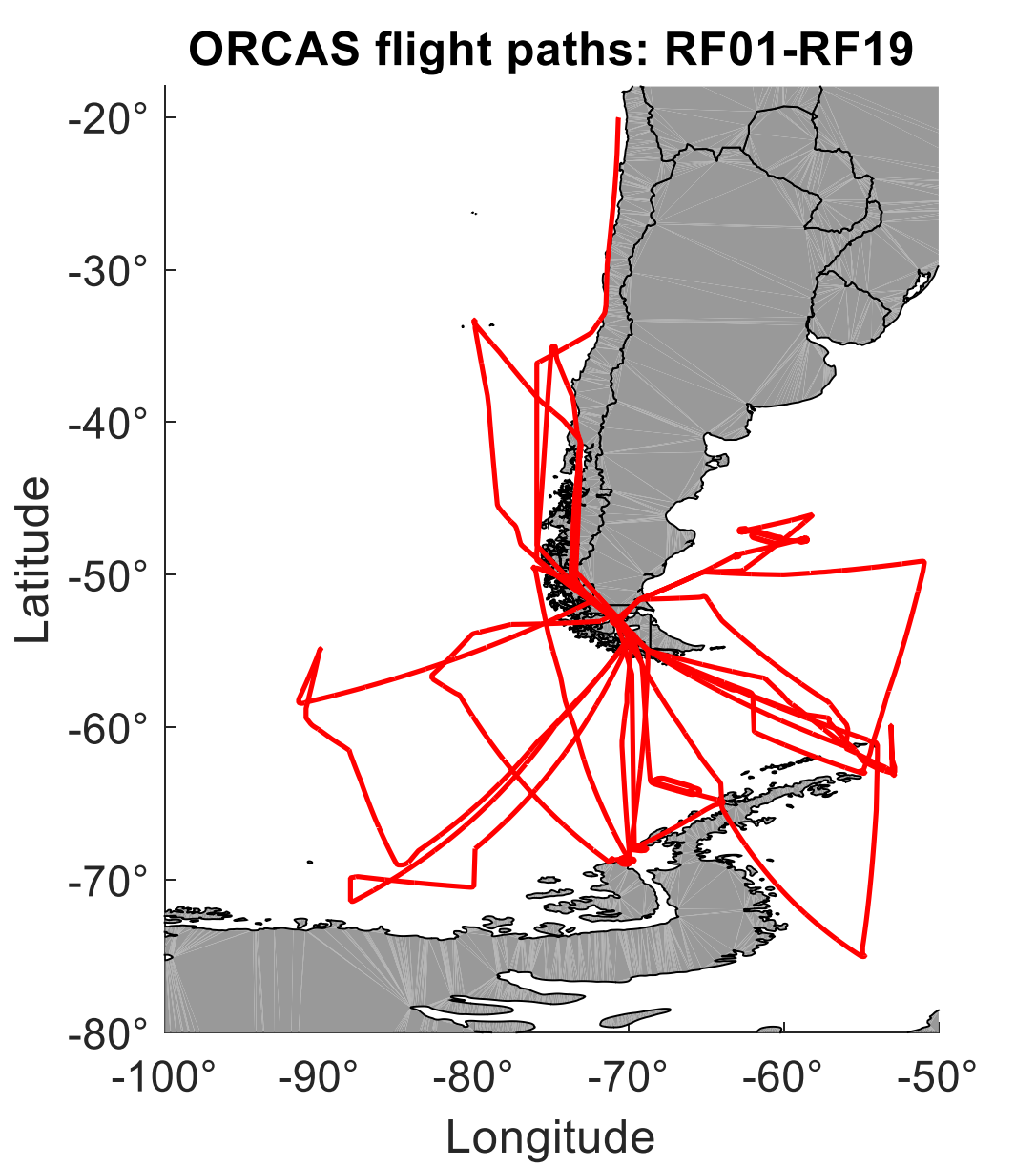
- *Lawson and Gettelman (2014)* found that nudging the Community Earth System Model (CESM) to match with in-situ observations over Antarctica lead to net cloud radiative effect from -5 to -30 W m^{-2} (right)
- *Tan and Storelvmo (2016)* found that the Wegener-Bergeron-Findeison process (WBF) accounts for the vast majority of variance of the cloud phase partitioning in MPC as simulated in the Community Atmosphere Model version 5 (CAM5) (in red below).





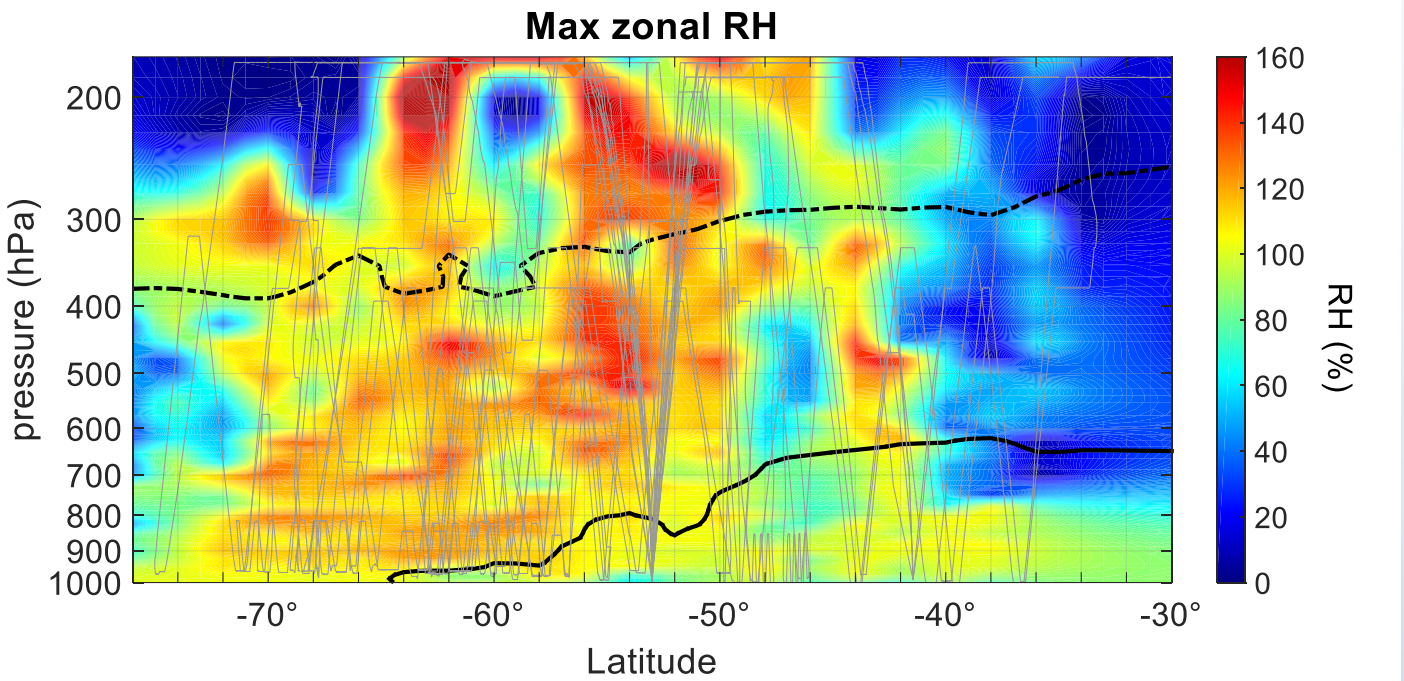
The NSF ORCAS campaign

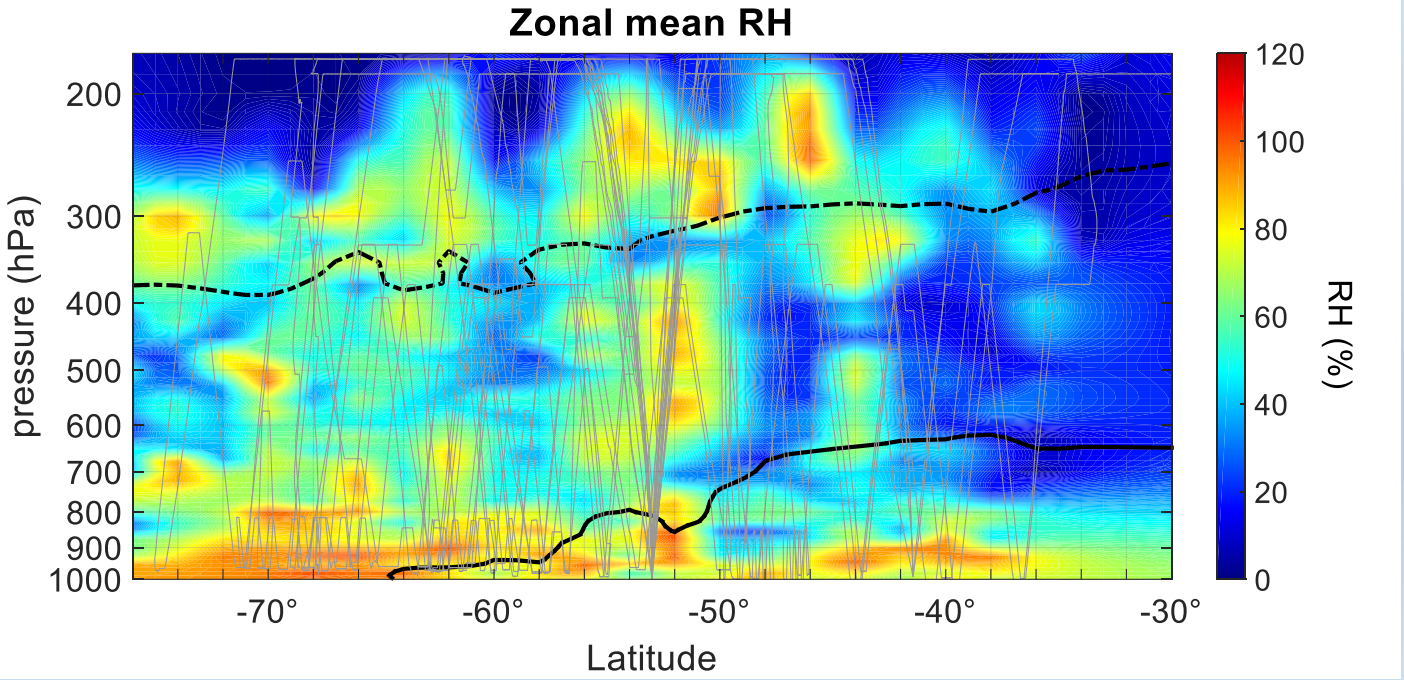
- The NSF O_2/N_2 Ratio and CO_2 Airborne Study (ORCAS)
  - Punta Arenas, Chile
  - January 15th – February 28th, 2016
  - 18 flights
  - ~100-250 m resolution
  - NCAR GV aircraft
- Cloud instrumentation:
  - Cloud Droplet Probe (CDP; 2-50 µm)
  - 2-Dimensional Optical Array Probe (2DC; 62.5-1600 µm)
  - Rosemount Icing Detector probe (RICE)
- Water vapor instrumentation
  - The Vertical Cavity Surface Emitting Laser Hygrometer (VCSEL)
    - 6% accuracy ± 1% precision



Zonal RH distribution

- RH_{ice} where T < 0°C

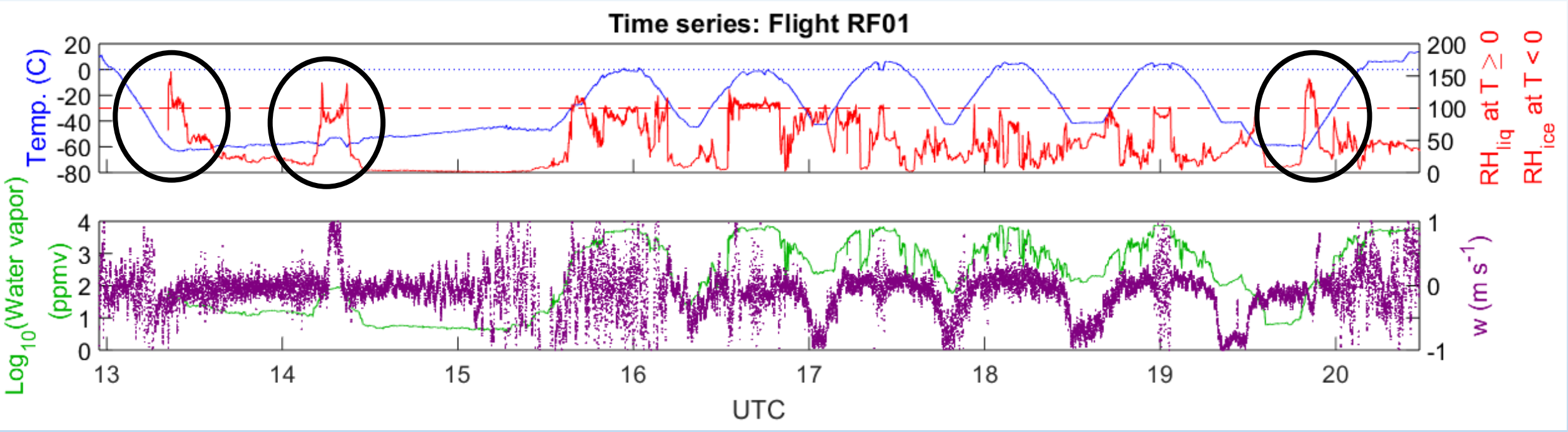




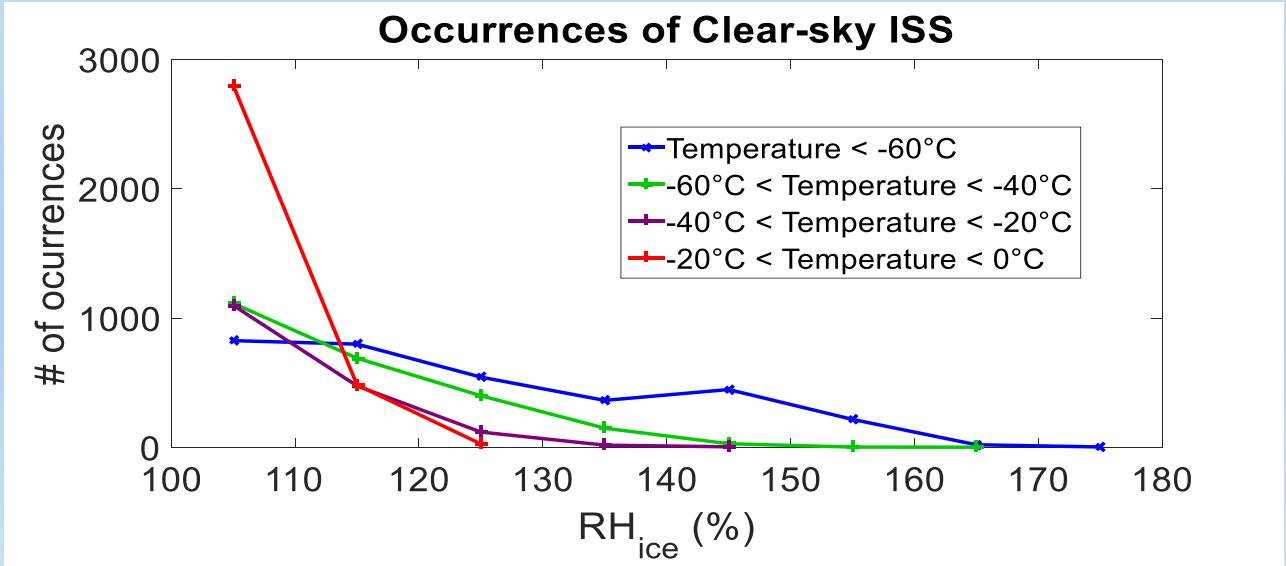
- High RH_{ice} values of 160%–170%
- Average RH_{ice} of ~80% in middle/upper troposphere.
- Low-level RH often near saturation.
- 10% of observations supersaturated (with respect to ice)

—— T = 0°C
- - - T = -40°C

Clear-sky ice supersaturation (ISS)



- Clear-sky ISS spatially correlated with updraft and higher water vapor concentrations (Diao et al., 2014)
- Lower temperatures have more ISS > 125%
- 4% of all observations clear-sky ISS and 76% clear-sky non-ISS (T < 0°C)



Determining Cloud Phase

	Nc_{CDP} (cm^{-3})	Nc_{2DC} (L^{-1})	Temperature (°C)
Liquid only	> 1	= 0	0 to -40
Mixed-phase	> 1	> 0	0 to -40
Ice only	= 0	> 0	< 0

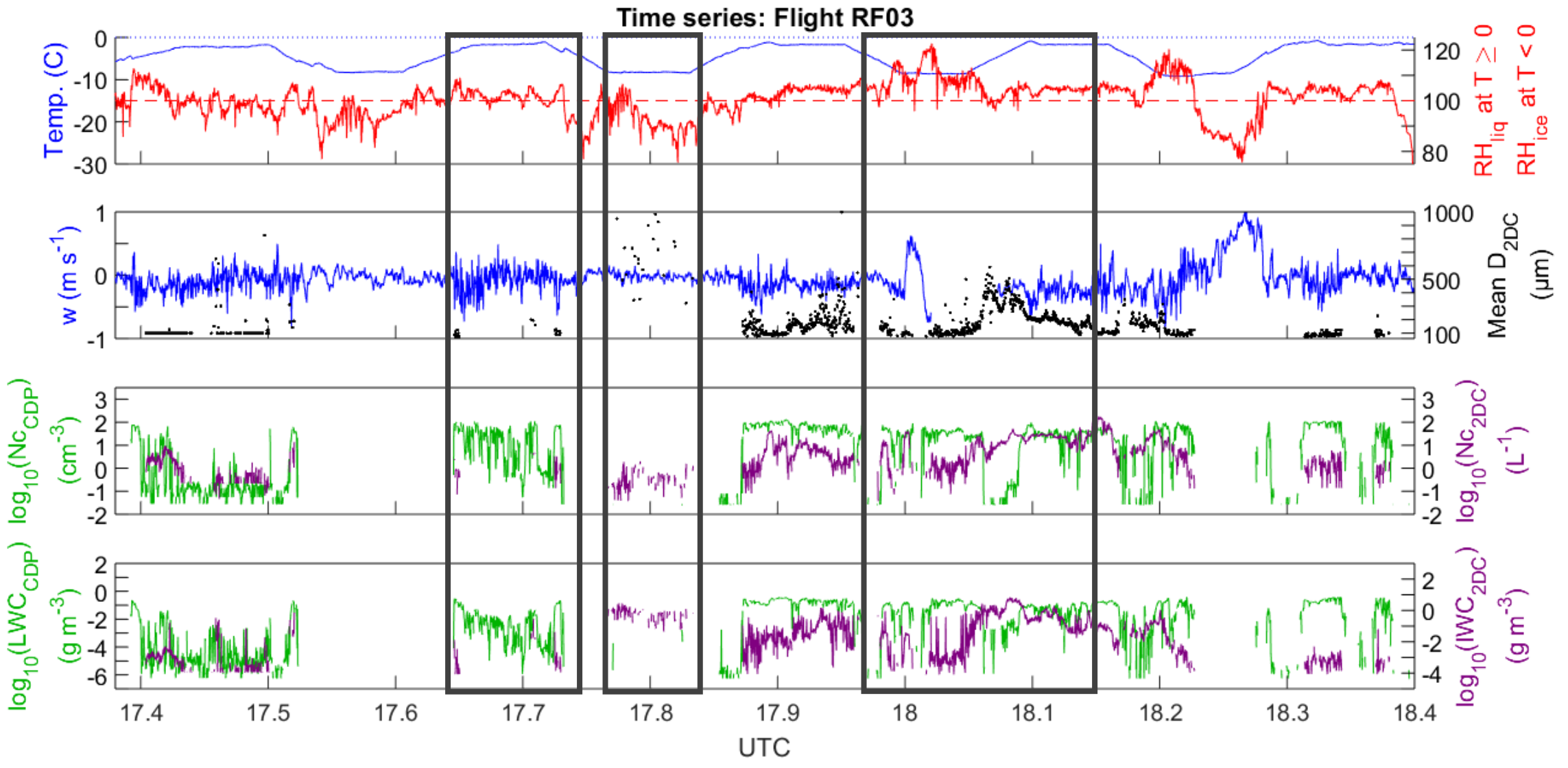
	Average cloud height (km)	Average RICE (dmV/ds)	Variance of w ($m\ s^{-1}$)
Liquid phase	1.60	12.17	0.22
Mixed phase	2.10	6.00	0.20
Ice phase	6.79	-1.548	0.28

Cloud detection:

- CDP sampling is sensitive to spherical particles, thus we use samples at 2-50 µm and >1 cm^{-3} to identify cloud droplets.
- Use Fast-2DC samples at 62.5-1600 µm to identify ice crystals, assuming most cloud droplets are smaller.

- Larger variance of w is seen in the ice phase compared with the other two phases.

Small scale variability in cloud phase



In-situ obs reveal high spatial heterogeneity of cloud phases

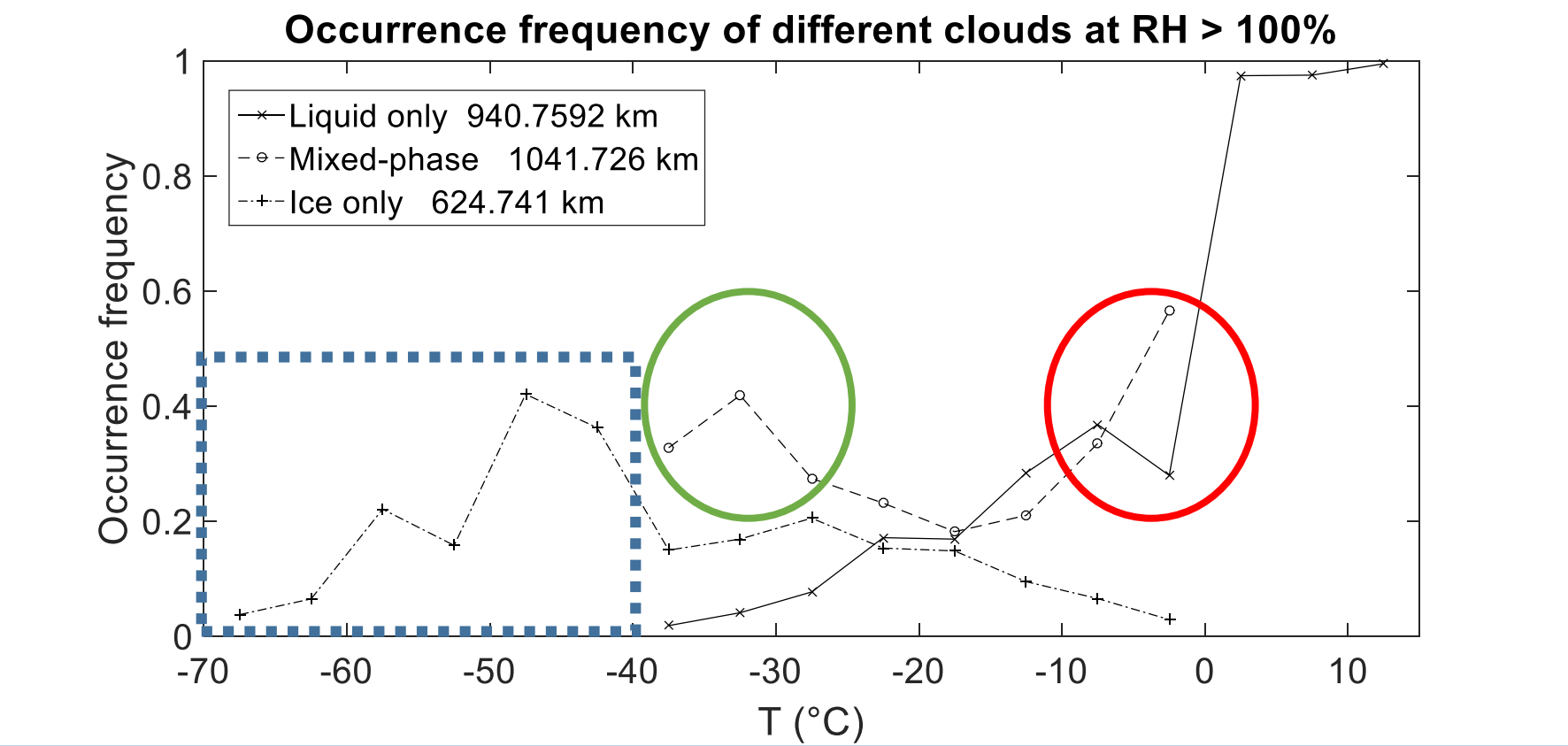
SLW
-40 km

Ice
-155 km

Pockets of ice/MP

- Varying D_{2DC}
- Nc_{CDP} and Nc_{2DC} > 100 cm^{-3} and > 100 L^{-1}, respectively

Occurrence frequencies of supersaturation in various cloud phases



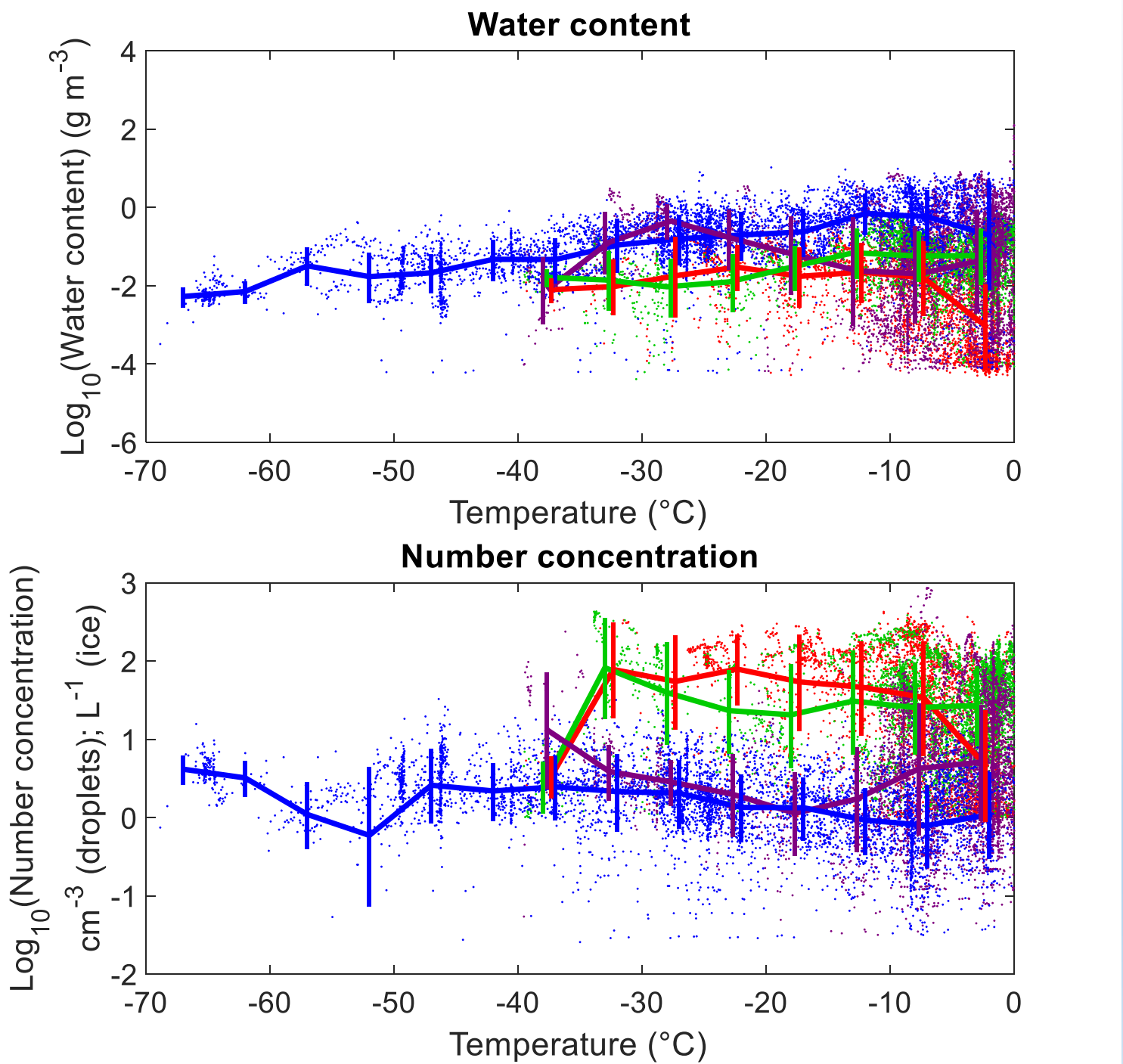
Supersaturation occurs at:
mixed-phase/SLW
primarily at -10 °C < T < 0°C

Mixed-phase dominant
at -40°C < T < -20°C

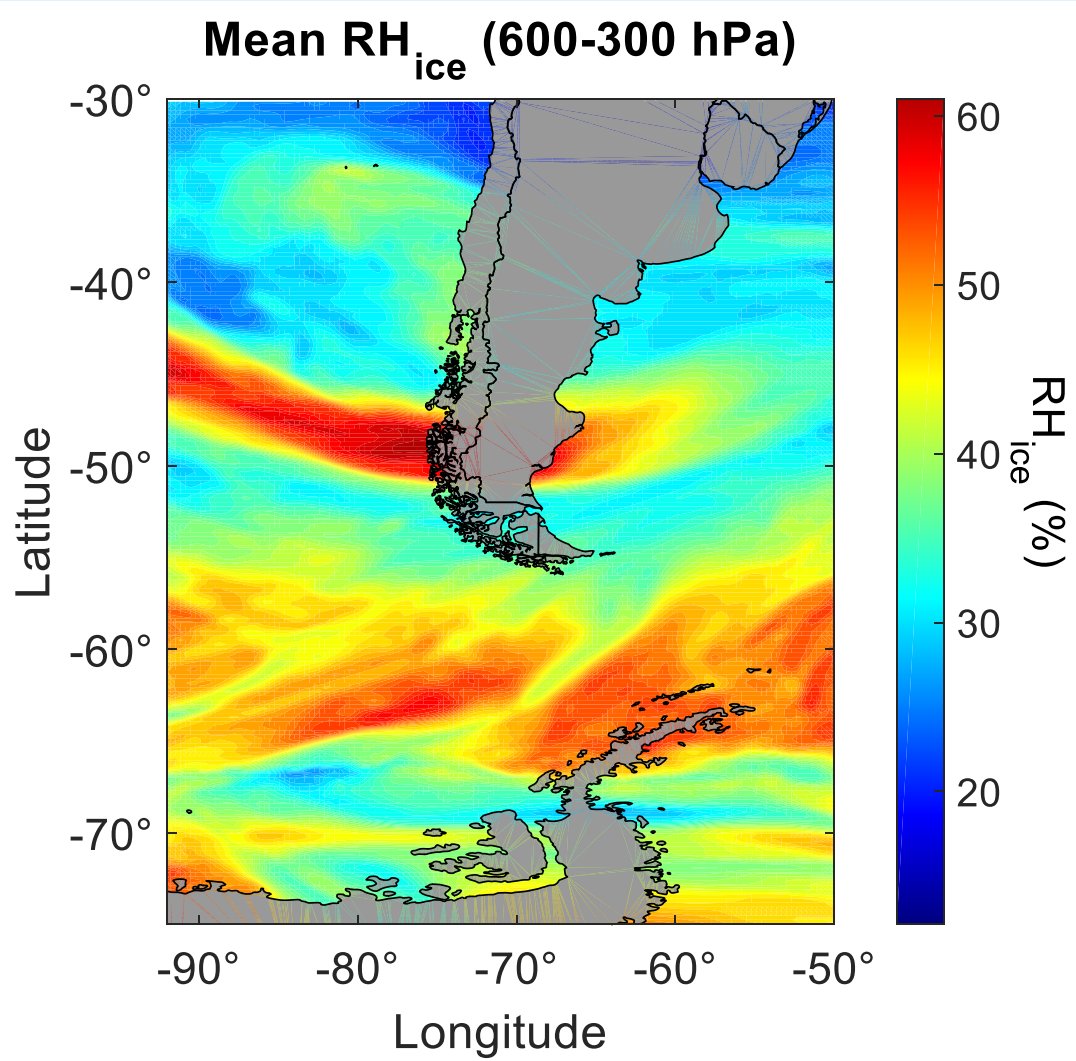
Occurrences of clear-sky ISS more frequent than in-cloud ISS at T < -40°C

Average IWC, LWC, Nc_{ice}, Nc_{liq}

- Average $IWC_{ice\text{-}only}$ increases with temp.
- Average $IWC_{mixed\text{-}phase}$ is lower than average $IWC_{ice\text{-}only}$ at temperatures above -20°C
- Average Nc_{liq} ~100 cm^{-3} in liquid phase
  - $Nc_{liq,liquid\text{-}only} > Nc_{liq,mixed\text{-}phase}$ (-30°C to -10°C)



Comparing NCAR Community Atmosphere Model version 5 (CAM5) with ORCAS



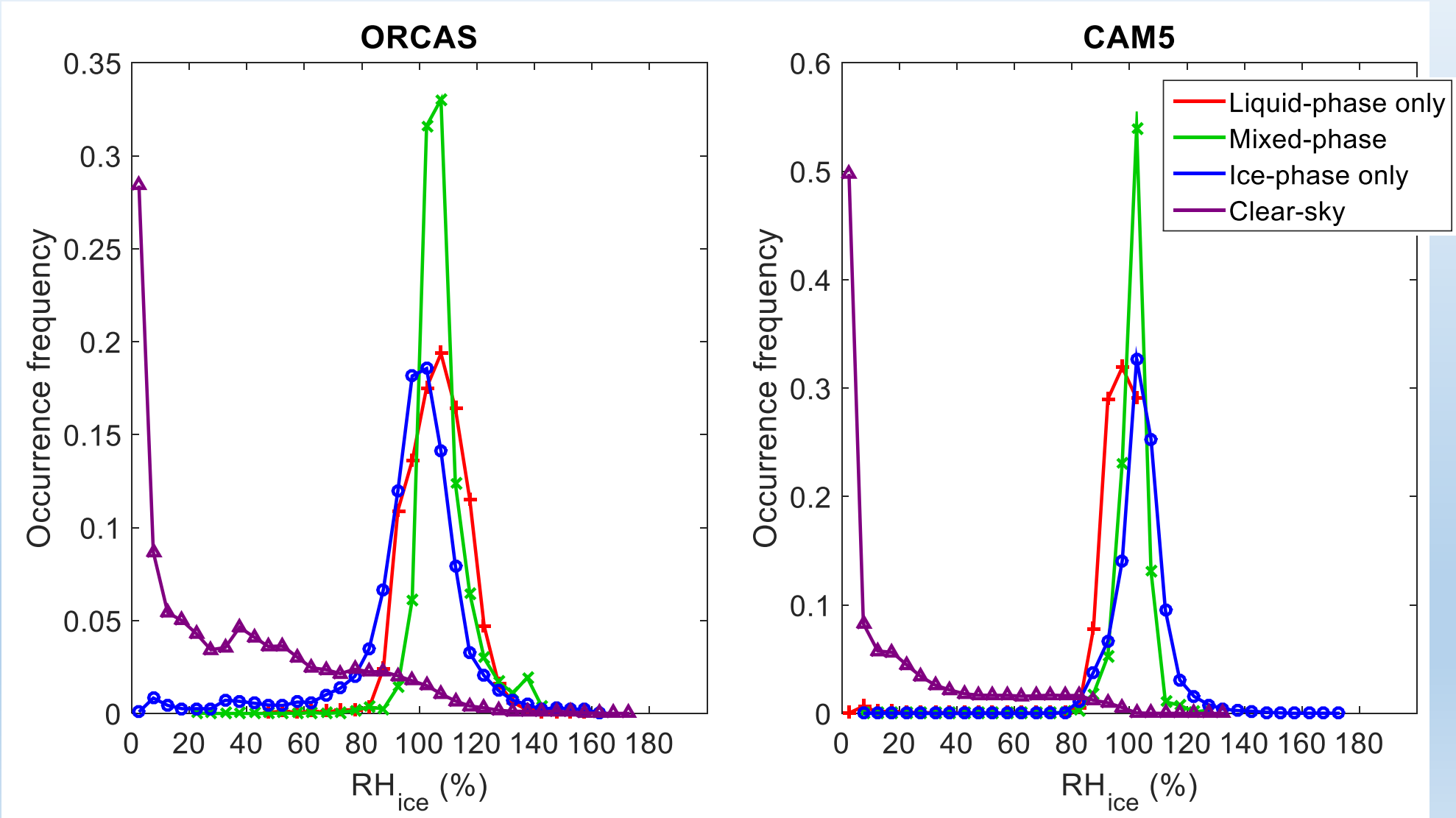
Simulation details

- 0.23°x0.31° horizontal resolution
- 30 vertical levels
- Restricted analyses to ORCAS domain
- Compared ORCAS data with multiple outputs during Austral Summer (DJF)

Results shown for 01/29/02 UTC 2100

Comparing observations with CAM5 simulations: RH_{ice} distributions over the Southern Ocean

- Restricted to T < 0°C
- Lack of clear-sky ISS in CAM5
- Slightly narrower peaks for all PDFs of in-cloud RHi distributions in CAM5.
- PDFs of liquid and ice only phases show low and high biases for peak positions in CAM5, respectively.



Conclusions

The NSF ORCAS campaign provides in-situ measurements on various cloud phases over the Southern Ocean

1. High spatial heterogeneities, with small pockets of ice in SLW clouds and vice versa.
2. Higher variance of w in ice phase compared with liquid and mixed phases.
3. Average $IWC_{mixed\text{-}phase}$ is lower than average $IWC_{ice\text{-}only}$ at temperatures above -20°C

PDFs of RH_{ice}:

1. More clear-sky ISS was observed during ORCAS compared with CAM5 simulations.
2. CAM5 has narrower peaks at RH_{ice} = 100% for all cloud phases.
3. Liquid and ice phases show low and high biases in RH_{ice} peak positions in CAM5, respectively.