Airborne Observation Case Studies of Cloud Phases in SOCRATES campaign

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ABSTRACT

Mixed-phase cloud, defined as a three-phase system consisting of water vapor, supercooled liquid droplets, and ice particles, exists mostly under the condition of temperature range between -40°C and 0°C. Mixed-phase cloud is a significant element in influencing cloud formation, cloud lifetime, and the radiation budget. While several methods have been used to identify mixed-phase cloud from observational data, it is also difficult for climate model to simulate. This study conducts comparisons among three cloud phases for the distributions of relative humidity with respect to liquid and ice (RHliq and RHice). The data are based on *in-situ* airborne observation, collected by the research flights of the Southern Ocean Cloud, Radiation, Aerosol Transport Experimental Study (SOCRATES) campaign over the 45°S to 60°S in the Australia and New Zealand sector. Segments consisting mixed-phase cloud or mixture of the three phases are selected in three case studies, i.e., Research Flight (RF) 04, 06 and 10. Long segments of purely ice or liquid phase cloud are expected to have RHliq distributions centered at 100%. Through comparing the original water vapor dataset (version2013.Princeton) and the newly calibrated water vapor dataset (version2018.1.Diao), we found that the newly calibrated water vapor data show much better RHliq frequency distributions that center at 100% in liquid phase and mixed phase clouds.

METHODOLOGY

***in-situ* Data**

Southern Ocean Cloud, Radiation, Aerosol Transport Experimental Study (SOCRATES) (water content, relative humidity, vertical velocity, etc)

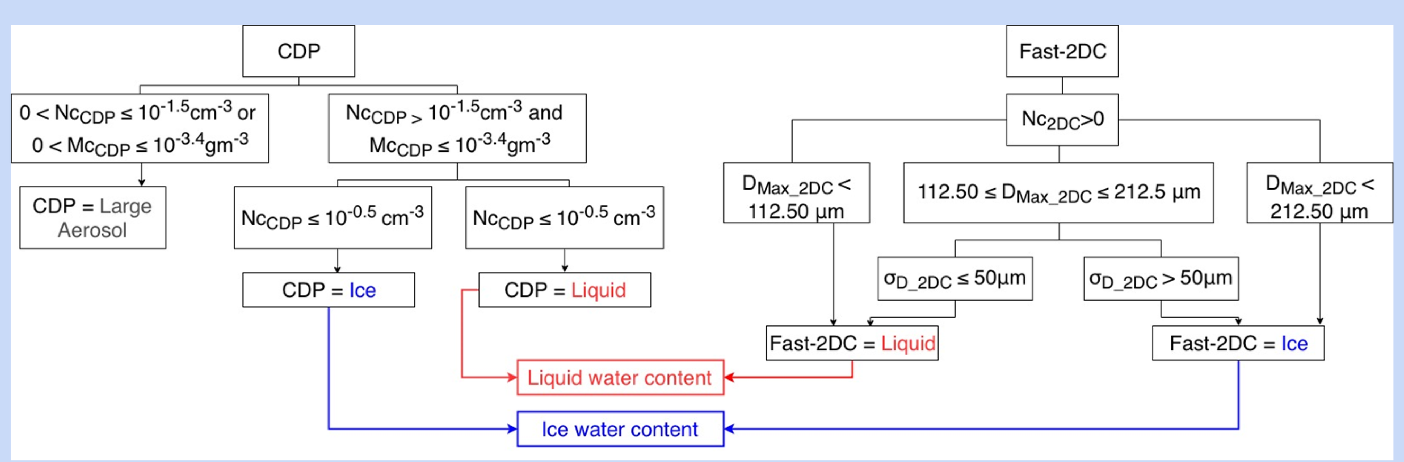
Water Quality Data

Community Atmosphere Model version 6 (CAM6)

Phase Identification

Comparison Analysis: Compare the cloud phase presented by model with the in-situ data, identify the dynamical condition of the atmosphere

Define Water Content



- Two-dimensional cloud (2D-C) probe: define water and ice water content by defining the particle number concentration (Nc_{2DC}), maximum particle size distribution (D_{max_2DC}), standard deviation of size distribution (σ_{D_2DC}).
- Cloud Droplet Probe (CDP): define water and ice water content by defining the particle number concentration (Nc_{CDP}) and mass concentration (Mc_{CDP}).

Define Cloud Phases

Mass Concentration Definition for Three Phases
Mass fraction of liquid = LWC / (LWC + IWC)

Ice Cloud	Mass fraction of liquid < 0.1
Mixed Cloud	0.1 ≤ Mass fraction of liquid ≤ 0.9
Liquid Cloud	Mass fraction of liquid > 0.9

RESULTS

Case Study of RF04: Ice Phase

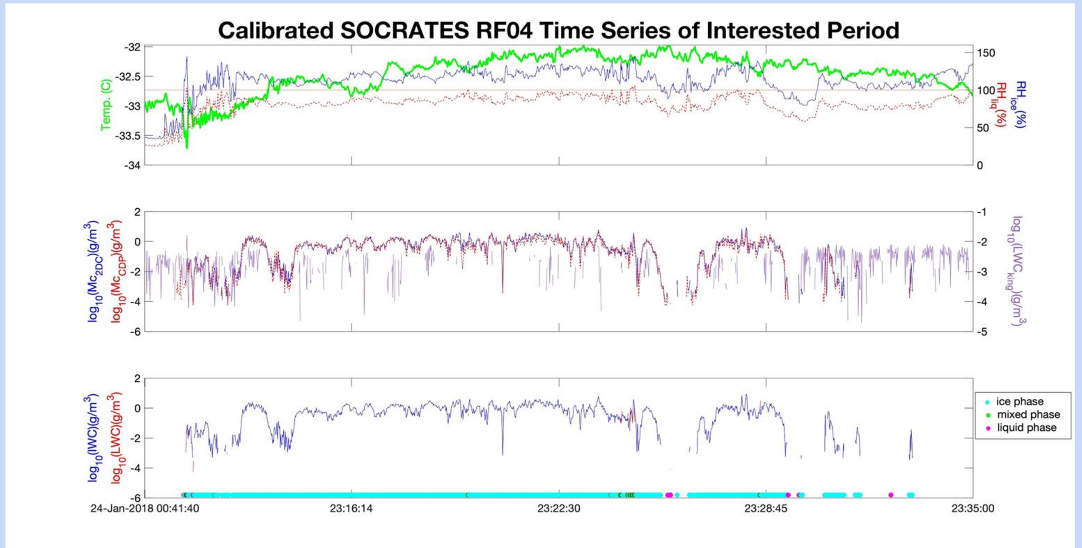


Figure 1: Time series of (top) temperature and relative humidity for ice and liquid, (middle) mass concentrations from 2DC, CDP and King probe instruments, and (bottom) ice and liquid water contents and associated cloud phases for a section of SOCRATES Research Flight 4.
The research flight was in 6 km height with temperature approximately -32°C, skimming the top layer of cloud. A long sector of ice phase cloud was detected by the instruments. RH_{ice} are mostly over 100% while the RH_{liquid} are slightly below 100%.

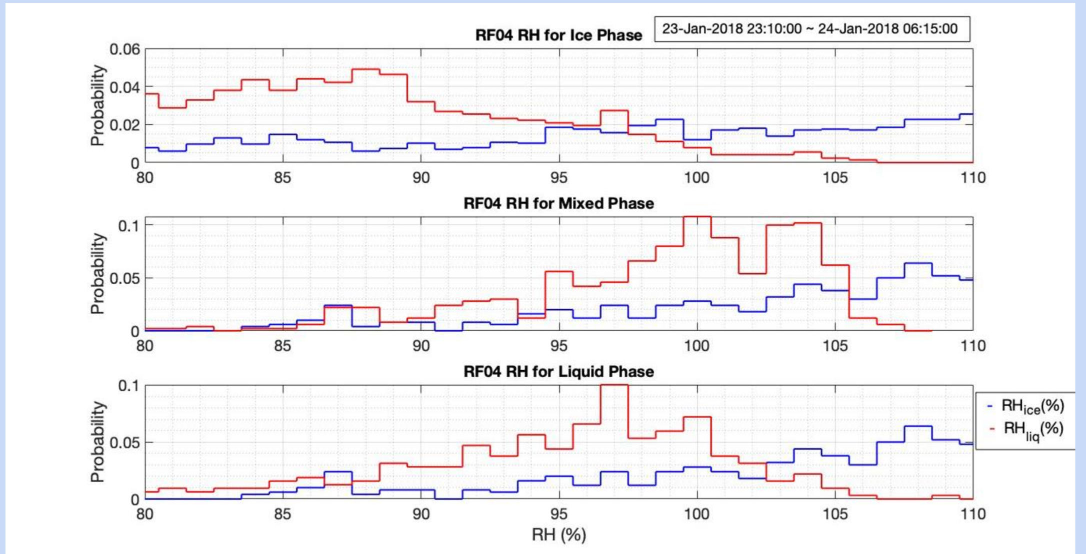


Figure 2: The relative humidity histogram of ice, mixed, and liquid phases for the entire time period of Research Flight 4. For ice phase, there is a higher probability of RH_{ice} excessing 97% than RH_{liq}. On the other hand, mixed and liquid phase peak at around 100% and 104%, 97% and 100% respectively.

Case Study of RF06: Liquid Phase

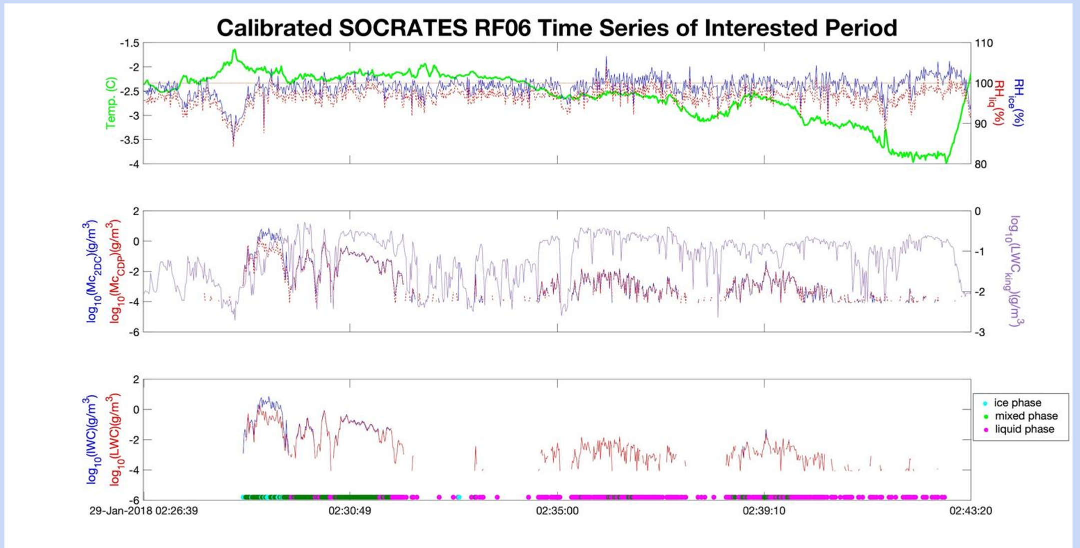


Figure 3: Time series of (top) temperature and relative humidity for ice and liquid, (middle) mass concentrations from 2DC, CDP and King probe instruments, and (bottom) ice and liquid water contents and associated cloud phases for a section of SOCRATES Research Flight 6.
The beginning of this sector are mostly mixed-phase clouds and the rest are liquid. The flight samples in-cloud condition at about 1 km, recording the transition from precipitating cloud to non-precipitating cloud.

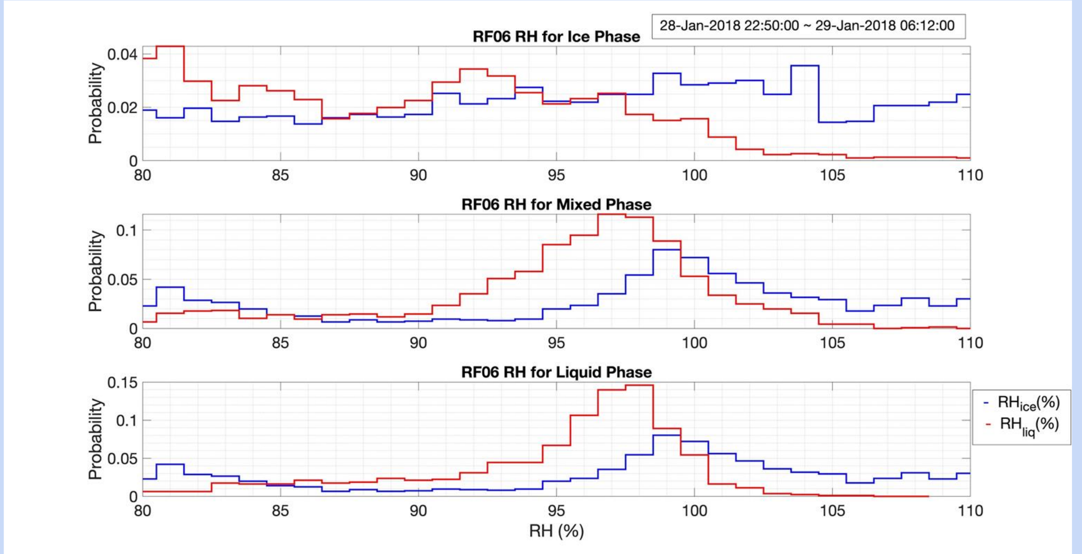


Figure 4: The relative humidity histogram of ice, mixed, and liquid phases for the entire time period of Flight 6. Similar pattern from Flight 4 was observed. For ice phase, there is a higher probability of RH_{ice} excessing 97% than RH_{liq}. The RH_{liq} of mixed and liquid phase peak at 97%.

Case Study of RF10: Mixed Phase

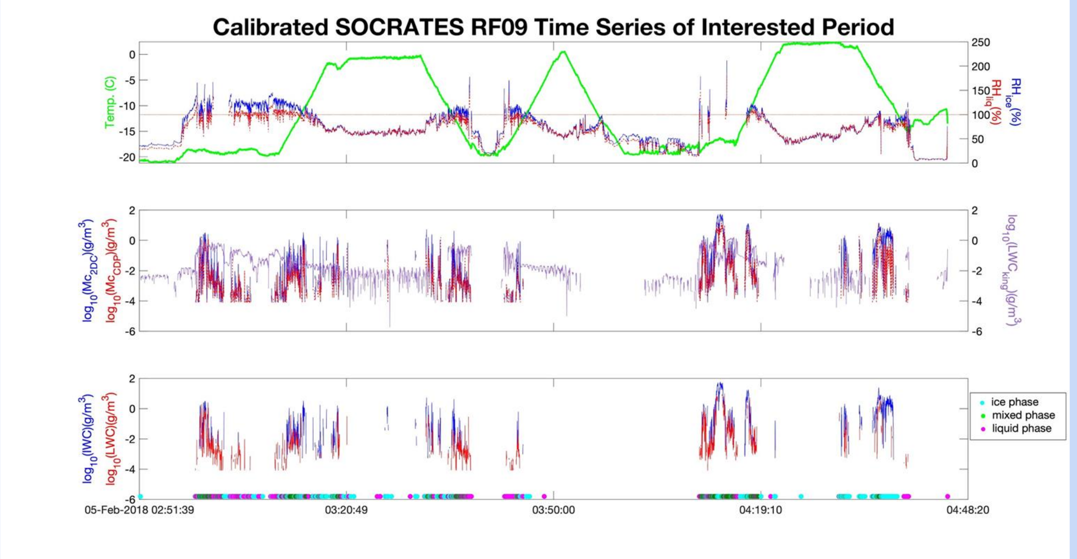


Figure 5: Time series of (top) temperature and relative humidity for ice and liquid, (middle) mass concentrations from 2DC, CDP and King probe instruments, and (bottom) ice and liquid water contents and associated cloud phases for a section of SOCRATES Research Flight 10.
The research flight targeted a cold sector of lower level cloud behind a low located at the Southeast of Tasmania. Weak surface inversion led to a lower level "overshooting top" above stratocumulus. The flight ascended and descended a couple times to conduct data above the cloud, in cloud, and below the cloud. All cloud segments have all three phases - ice, liquid, mixed phases.

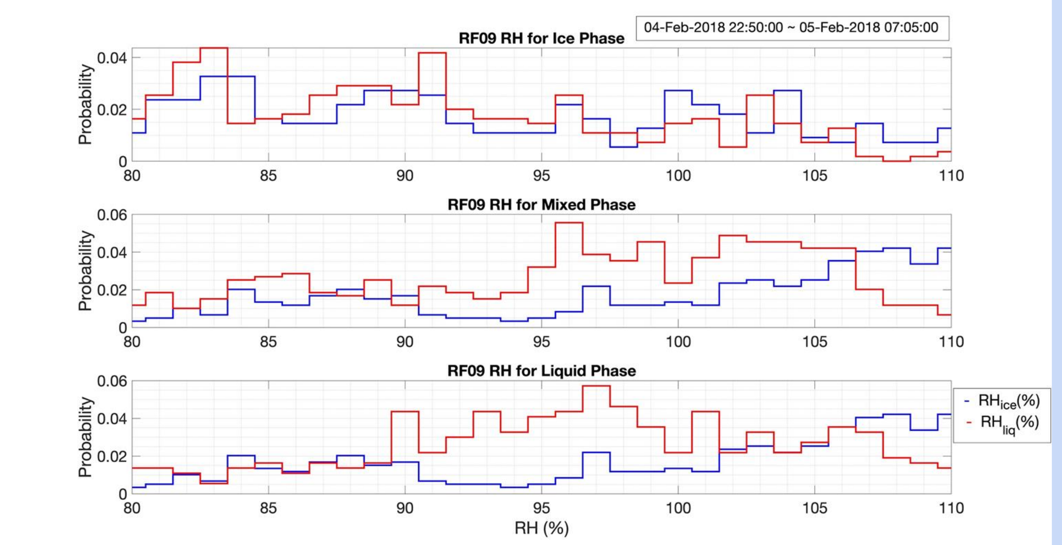


Figure 6: The relative humidity histogram of ice, mixed, and liquid phases for the entire time period of Flight 10.

Calibration of water vapor dataset

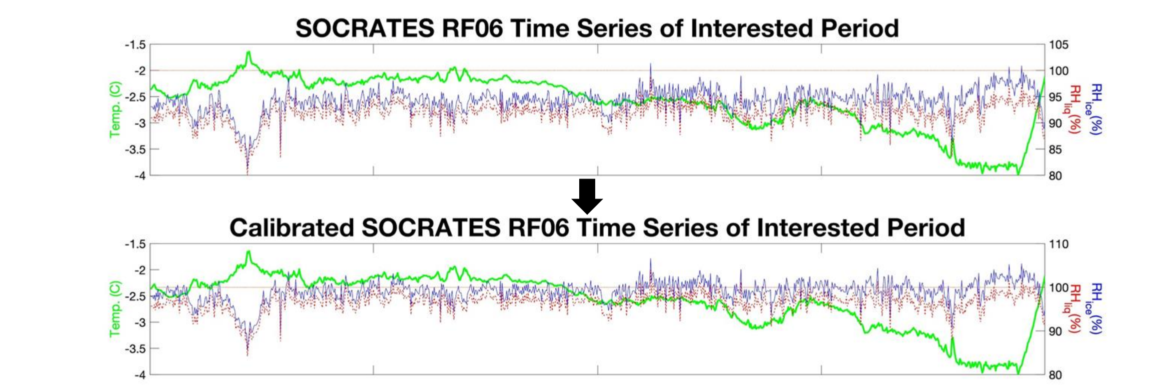


Figure 7: After the volume mixing ratio was calibrated, the values of RH_{liq} improved from about 90%-95% to about 98%-100%, closer to 100% saturation.

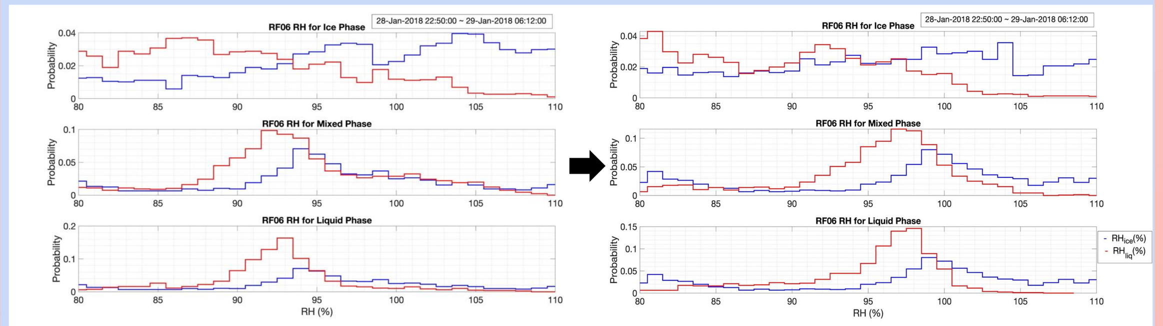


Figure 8: A PDF of RH for RF6 showing a noticeable improvement of RH_{liq} peak shifts from 92% to 99%.

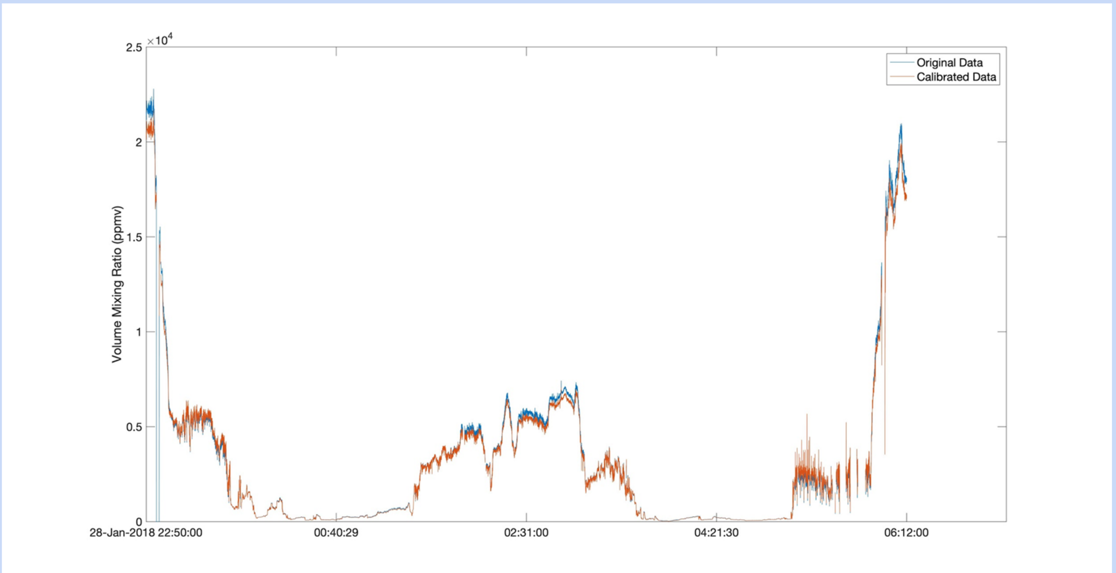


Figure 9: Example of Research Flight 6 showing slight differences between the original and calibrated volume mixing ratios.

MAJOR FINDINGS

- While liquid phase is expected to have relative humidity for liquid close to 100%, most of the flights have shown a peak of relative humidity at roughly 95% with the original water vapor data.
- After calibrating the water vapor volume mixing ratio, a variable that influences the relative humidity, most liquid phase cloud show **peak of the probablity density function (PDF) of RHliq at 100%**.
- The pattern of both relative humidity of liquid and ice for the three phases are similar across flights.

FUTURE WORK

- Focusing on the interested segments from each flight, extract the simulation from CAM6 for the same pressure level.
- Compare the phase representation in CAM6 with the cloud phase observed.
- If the phase representation does not match the observation, hypothesize and identify dynamic conditions that might cause such difference.
- Further differentiate atmospheric conditions, flight targets, flight locations, and flight altitude, relate these background information to the corresponding cloud phases to determine the dynamics.

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