Dominant Conditions in the Existence and Formation of Cloud-Voids in Southern High-Latitude Mixed-Phase Clouds (Abstract: #443658)

Jackson Yip and Minghui Diao, Ph.D.

Department of Meteorology and Climate Science, San Jose State University

INTRODUCTION

Using microphysical instrumentation mounted on the National Science Foundation/National Center For Atmospheric Research Gulfstream-V High-performance Instrumented Airborne Platform for Environmental Research (HAIPER-GV), microphysical data were collected during the NSF Southern Oceans Clouds, Radiation, Aerosols Transport Experimental Study (SOCRATES). Specifically data from research flights 13 and 14 (RF13 and RF14) were analyzed as they successfully penetrated stratiforms located within the planetary boundary layer (PBL). These data were then processed to look specifically at the physical conditions from these cloud masses over the Southern Oceans.

Using the observed water vapor mixing ratio and liquid-water and ice-water content (LWC and IWC, respectively), numerous features were seen of dramatically lessened moisture for very short periods (passage of less than 3 seconds, or approximately 300 meters). In comparison with the surrounding liquid cloud masses, these features exhibited different microphysical characteristics of temperature (T), relative humidity (RH), 1-micron and larger aerosol concentration (Na), vertical wind velocity (w) and phase.

Within this study, these regions are redefined with two components of a total feature, the void-development zone (VDZ) and the stratiform cloud-void (SCV) itself. This study attempts to describe the deviations from surrounding cloud mass and the dominant characteristics found in these so-called cloud-void features. Of these features, three particular examples (Case 1, Case 2, and Case 3) are presented in this study.

AIM

Physical Understanding

The intent of this study is to better understand the microphysical properties of cloud-voids and attempt to further the definitions for features of this type within boundary layer stratiforms. In doing so, this research adds new insight to the understanding of not only the thermodynamic characteristics of these phenomena, but also the present concentrations of aerosols and water vapor in the development and existence of the voids.

Accurate Nomenclature

In addition to describing the features' physical structure, this study puts forth that a more accurate term than that which is used in previous studies [3][4][5][6], "cloud-holes," is an inaccurate way of portraying the phenomena. To this effect, the term used here, "cloud-void," is more appropriate to describe the features seen here and in previous studies that are not specifically a cylindrical feature that the previous nomenclature alludes to, and are in fact, significantly variable in shape, size, and character.

Flight Number (Case)	ΔRH (ice, in|out, 10s-avg in|out)	ΔRH (liq, in|out, 10s-avg in|out)	ΔT(K, in|out)	ΔW(m/s, in|out)
RF13 (Case 1)	-22.0538%|17.9729% - 8.1823%|6.0869%	-20.5716%|17.0045% - 7.5953%|5.7266%	1.5062| -1.0500	0.2147|-0.3996
RF14 (Case 2)	-4.3427%|1.6301% - 2.3168%|0.5014%	-3.6988%|1.5920% - 2.0086%|0.4270%	0.2048|-0.1402	0.0305|-0.5693
RF14 (Case 3)	-9.0358%|6.2361% - 4.2532%|1.3905%	-8.2905%|5.6410% - 3.8647%|1.2725%	0.6698|-0.5776	0.1874|-0.1256
Mean	-11.8108%|8.6130% - 4.9174%|2.6596%	-10.8536%|8.079% - 4.4895%|2.4754%	0.7936|-0.5893	0.1441|-0.3648

Table 1: Change observed in RH_{ice} , RH_{ice}(10-second average), RH_{liq}, RH_{liq} (10-second average), T, and W from beginning of VDZ to critical point of specific variable observed in SCV (in), and change from SCV critical point of respective variable to end of VDZ (out). Note in all cases and thus on average, entrance regions see decreased RH_{ice} and RH_{liq}, increased temperature, and increased W-velocities, and decreases similarly in the exit to the VDZ.

METHOD

Initial Conditions

- Relative Humidity
  - RH_{ice} and RH_{liquid} (%) were calculated using ambient temperature (K) and water vapor mixing ratio (ppmv) converted to water vapor partial pressure (e, (Pa))[1]. (Figures 1 and 2, subplot 1, right axis)
- Cloud Droplet and Aerosol Observations
  - Measurements from the HAIPER-GV CDP and 2DC probes were sorted based on size distribution to calculate phase [2] and thus, regions of in-cloud and out-of-cloud during the flights. (Figures 1 and 2)

Identifying Voids

- Cloud-Void Criteria
  - **Stratiform Cloud-Void**:
    - Regions of zero cloud droplet returns (mass or number concentration) that are shorter than 3 seconds (Figures 1 and 3, subplot 4, left axis)
    - Ambient pressure deviates less than 5 hPa to allude to constant altitude (Figures 1 and 3, subplot 2, right axis)
    - This definition defines the physical center of the observed feature (All figures, green region)
  - **Void-Development Zone**:
    - Regions surrounding the SCV where:
      - LWC and IWC (g/m³) begin to decrease to less than 50% of ambient cloud region (all figures, blue region)
      - Phase changes from liquid to large aerosol before out-of-cloud SCV region and vice versa
  - Regions that meet these conditions were then analyzed to better understand deviation from mean values of T, w, RH, and Na in the surrounding in cloud regions.

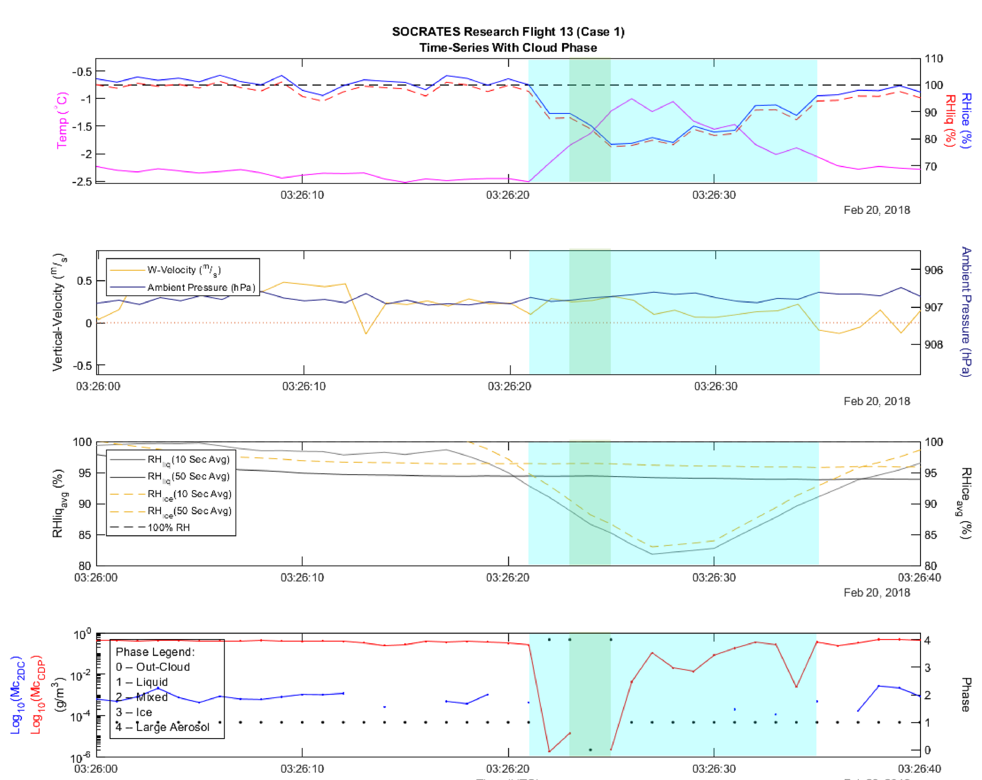

Figure 1: Time series of void observed as Case 1 in RF13 with VDZ and SCV shown in blue and green shading, respectively. Note phase change from entrance to VDZ and transition to SCV.

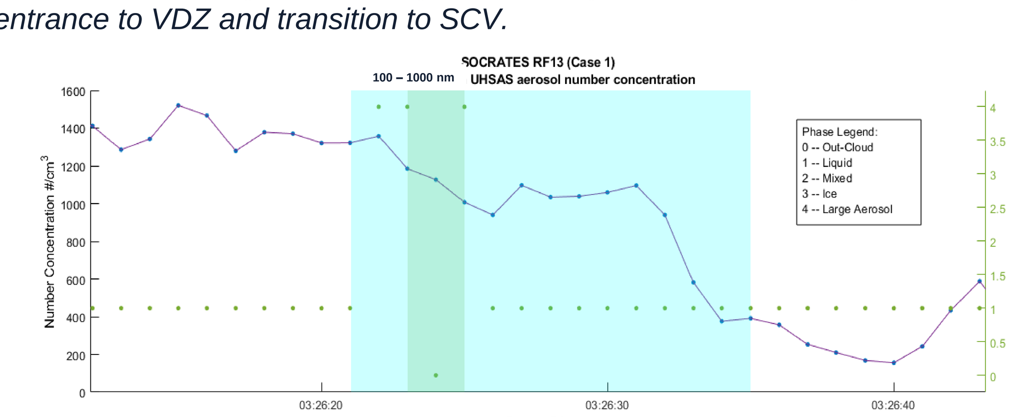

Figure 2: Present aerosol number concentration (#/cm³) with phase plotted on right axis during a void feature observed in RF13. Observations of the Ultra High-Sensitivity Aerosol Spectrometer (UHSAS) in the 100 – 1000 nanometer range. Note complex VDZ in this feature following SCV, at UTC 3:26:35 where LWC decreases abruptly, decrease in aerosols is seen as well.

RESULTS

Temperature

- VDZ shows increasing T
  - In all observed cases, a symmetrical peak in temperature is seen as the aircraft enters the VDZ. On average, temperature is seen to increase by 0.7936 K inside of a feature and decrease by 0.5368 K upon departure.

Relative Humidity

- VDZ shows decreasing RH
  - In all cases observed of single continuous voids, a sharp decrease (>10%) is seen in the aircraft's entrance to the VDZ and a symmetric increase in both RH_{ice} and RH_{liq} values upon exit.
- SCV shows the minimum RH
  - In each SCV, values for both RH_{ice} and RH_{liq} were greater than 10% lower than the entrance of the VDZ

Vertical Velocities

- VDZ shows increasing w
  - In all cases, vertical velocities increase from the entrance of the VDZ to the critical point seen in the void center.
  - M-structures of vertical velocities are observed in the VDZ such that along the borders of the SCV, vertical velocities decrease on the order of 10^{-1} m/s, though values are still more positive than in the entrance of the VDZ and the exit. This slight decrease is seen in previous studies [4] as well, though the characteristics of this interface zone are less clear.

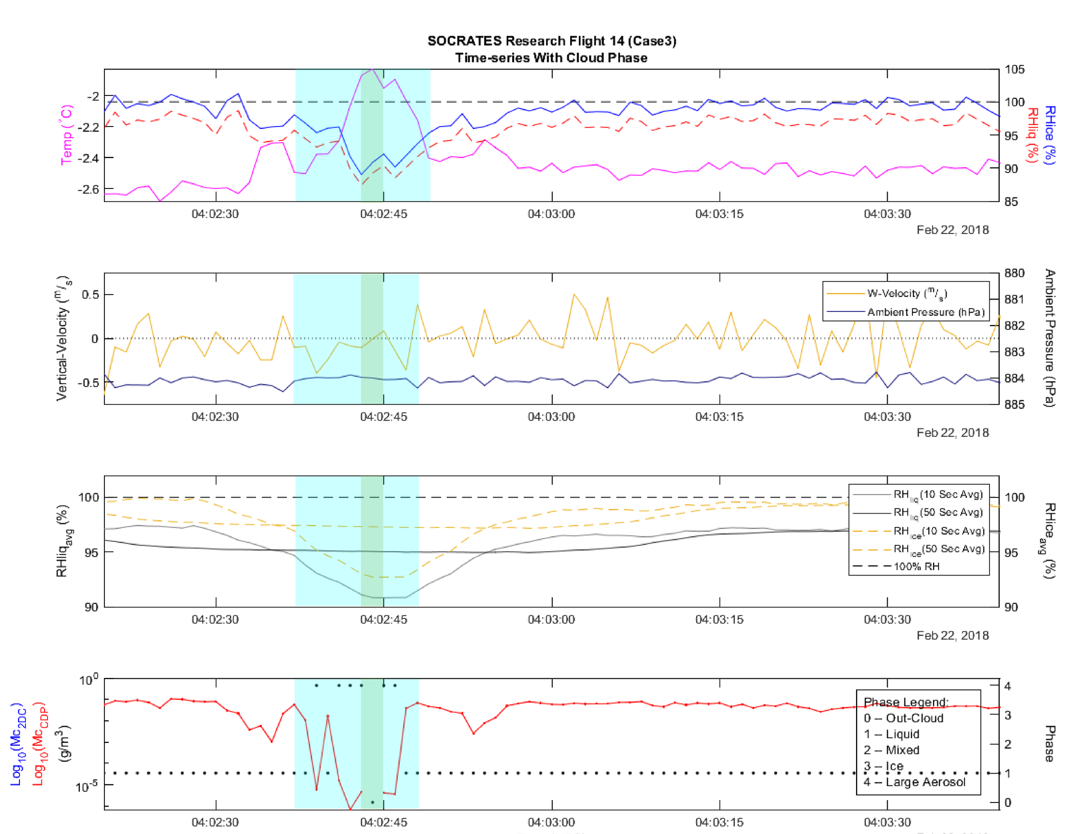

Figure 3: Case 3 from RF14 shows a more complex segment where CDP mass concentration declines dramatically, initially changes phase to the large aerosol size class, before returning to liquid. Eventually a void is formed, as seen by the transition into SCV.

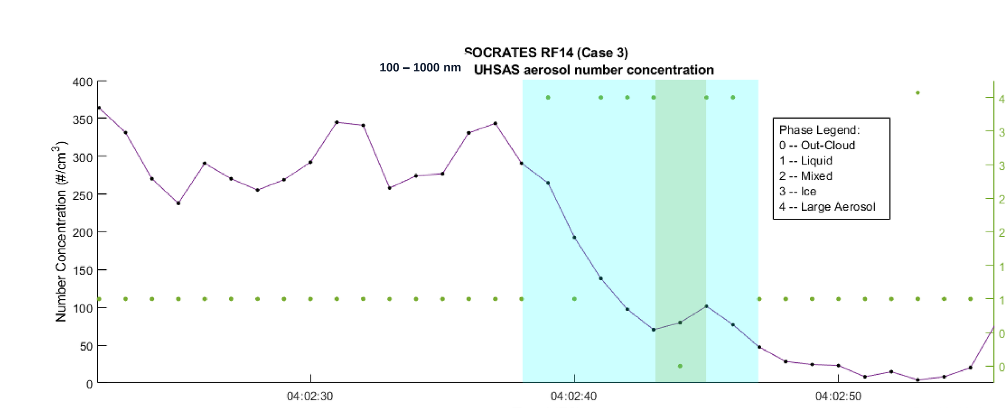

Figure 4: Present aerosol number concentration (#/cm³) with phase plotted on right axis during a void feature observed in RF14, observations of the UHSAS in the 100 – 1000 nanometer range. Note decreasing values through VDZ entrance into exit as seen in Figure 2

DISCUSSION

A number of characteristics are suggested by these in-situ data. Namely, these data suggest new insights into the underlying process of forming cloud-void features. In each observed case, two simultaneous processes occurred, those being a drastic reduction in relative humidity and an abrupt phase change from liquid to large aerosol sized particles. These regions are ultimately the indication of the beginning of a void development zone, only being confirmed by a second phase change from large aerosol to out-of-cloud region in the stratiform cloud-void itself.

This phase change suggests that the **subsaturated air** is a potential cause for liquid droplets to begin evaporating, being read as they pass through the size class of large aerosols. This can be seen further in Figure 3 where number concentration of aerosols larger than 0.1 micron decreases along a continuous slope during Case 3.

Based on the findings of these regions of phase change and of void, it stands to reason that a better understanding of these features is gained from determining their components. These data suggest that there are three regions associated with cloud-void features as referred to in this study. These are as such described as in-cloud segments where cloud droplets are observed, as a mixed region where cloud droplet concentration abruptly decreases (i.e., the VDZ), and lastly the region where no droplets are observed at all, the SCV. Within each of these regions, unique physical characteristics are observed that deviate from the surrounding clouded region.

This results find contrary results to those seen in previous studies that suggest that ***negative velocities*** are present in the voids, relative to their surroundings. Previous results are seen to be partially true, where many conditions described such as reduced vertical velocities, lowered temperature, and lowered RH_{ice} and RH_{liq} are apparent within SCVs but not in VDZs as shown by these examples. To this effect, there are two interface zones seen as described above based on observed phase change as an indicator, and these features should be considered as the components that exhibit these transitions.

Future study is needed as these cases observed during the SOCRATES campaign are sampled at 1-Hz, where these voids can be seen to be far smaller than the observable distance [4] with the current instrumentation.

REFERENCES

[1] Murphy, D. M. and Koop, T. (2005), Review of the vapour pressures of ice and supercooled water for atmospheric applications. Q.J.R. Meteorol. Soc., 131: 1539-1565. doi:10.1256/qj.04.94

[2] D'Alessandro, J., M. Diao, C. Wu,, X. Liu, B. Stephens, and J.B. Jensen, "Cloud phase and relative humidity distribution over the Southern Ocean based on in-situ observations and global climate model simulations", *Journal of Climate, in revision*.

[3] Haman, K. E. (2009), Simple approach to dynamics of entrainment interface layers and cloud holes in stratocumulus clouds. Q.J.R. Meteorol. Soc., 135: 93-100. doi:10.1002/qj.363

[4] Gerber, H., G. Frick, S.P. Malinowski, J. Brenguier, and F. Burnet, 2005: Holes and Entrainment in Stratocumulus. *J. Atmos. Sci.*, **62**, 443–459, https://doi.org/10.1175/JAS-3399.1

[5] Yamaguchi, T., W.A. Brewer, and G. Feingold, 2013: Evaluation of Modeled Stratocumulus-Capped Boundary Layer Turbulence with Shipborne Data. *J. Atmos. Sci.*, **70**,3895–3919, https://doi.org/10.1175/JAS-D-13-050.1

[6] Korolev, A. V., and I. P. Mazin, 1993: Zones of increased and decreased droplet concentration in stratiform clouds. J. Appl. Meteor., **32**, 760–773

ACKNOWLEDGEMENTS

The authors would like to acknowledge NSF Division of Atmospheric and Geospace Sciences (AGS) (grant #1642291), and NSF Office of Polar Program (OPP) (grant #1744965).

SAN JOSÉ STATE UNIVERSITY