Cloud phase profiles in mid-latitudes

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Introduction

- Presence of supercooled clouds at temperatures less than 273 K has significant impact on cloud feedbacks in GCMs but current models use different datasets to parameterize or validate minimum temperature for liquid to persist
- Feigelson (1978) find liquid in continental ex-USSR clouds from aircraft data down to ~ -40 ^{o}C but Bower et al. (1996) found no liquid below ~ -15 ^{o}C in maritime frontal clouds around British Isles
- In Naud et al (2006), liquid in mid-latitude storm cloud systems derived from MODIS found at different temperatures depending on geographical region or area within storm. But only for cloud top.
- Need to check if above true at all cloud levels => need cloud thermodynamic phase profiles, preferably over long time period: lidar depolarization ratio measurements = good candidate
  - phase product derived from depolarization at SIRTA (Paris, Fr)
  - Raman lidar 355 nm depolarization ratios at SGP but no phase
- Limitations: lidar attenuated in clouds of optical depth > 3 => statistics only valid for phase in optically thin clouds

Previous observations: aircraft and MODIS

Figure 8 from Bower et al. (1996, QJRMS)

red line=Feigelson (1978), table 2

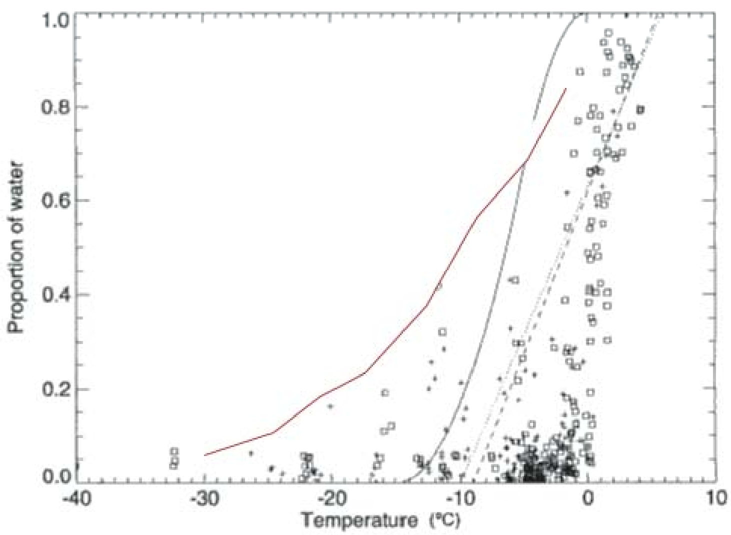
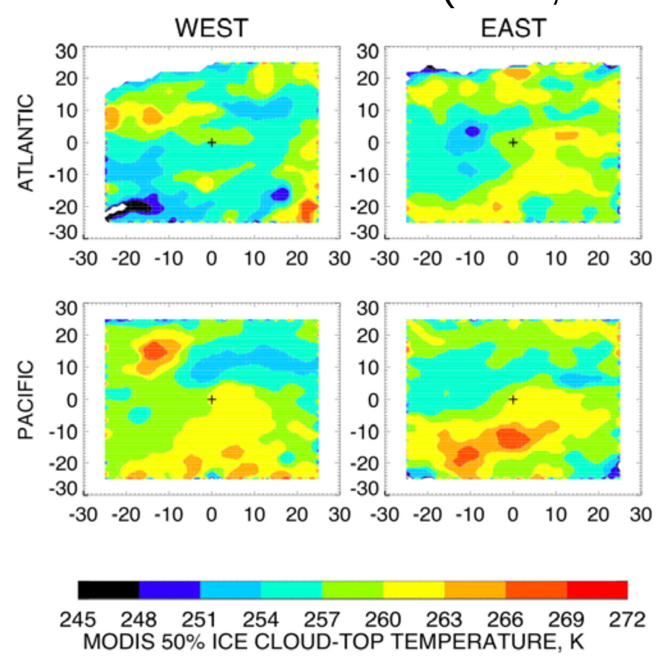


Figure 8. The phase ratio (the proportion of water to ice and water by mass) in cloud against temperature from the 11 frontal flights in Table 1. Each point represents the average value over a 2-minute horizontal leg in cloud. Crosses indicate clouds in continental airmasses and squares clouds in maritime airmasses. The dotted line is the best-fit line to the data for continental clouds and the dashed line for maritime clouds. The solid line is the current parametrization in the UK Meteorological Office atmospheric global-climate model.

Composites, from 2 winters, centered on storm pressure minimum, of MODIS cloud top temperature for 50% ice fraction as a function of latitude-longitude

Figure 11 from Naud et al. (2006, JCLI)

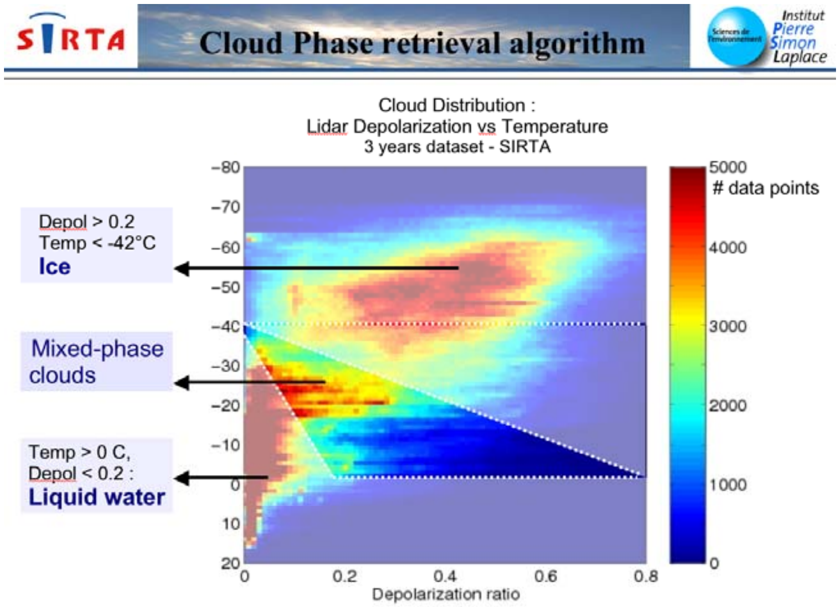


T50 warmer => larger ice fraction for a given temperature

How do we obtain phase at all cloud levels?

- Lidar depolarization ratios related to particle shape: ratio ~ zero for spherical drops but not for ice crystals (e.g. Sassen 1991)
- Limitations:
  - Multiple scattering in liquid clouds can cause large ratios
  - horizontally aligned ice crystals can cause zero ratios

  => Need fairly elaborate algorithm to automatically derive phase from ratios

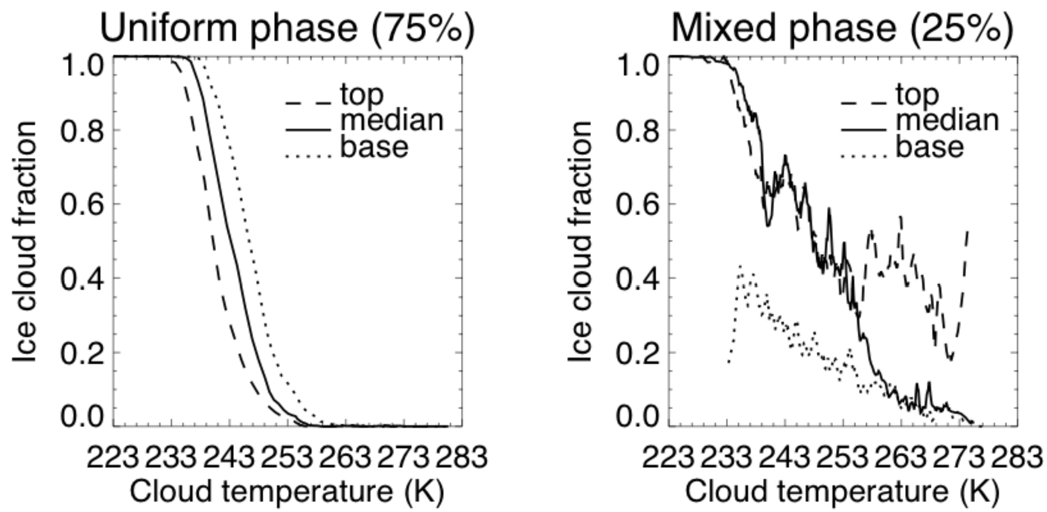


SIRTA algorithm: Cloud pixel distribution as a function of temperature and depolarization ratio for 3 years of lidar data.
Threshold on depolarization depends on temperature and based on arbitrary lines.
Mixed phase clouds have ice fraction function of temperature and distance from both thresholds. More on www.sirta.fr

Cloud phase profiles at SIRTA

- 4 winters from 2002 to 2006: base, top and median level temperatures used to distinguish populations where phase at three levels identical (uniform phase) from those where it is different (mixed phase)

- Mixed phase clouds further divided according to change in ice fraction from base to top. Only 6% of all are mixed phase with low ice fraction at cloud top. The majority of mixed phase show increase in ice fraction from base to top (17%) => different from M-PACE mixed phase clouds



Ice fraction versus temperature for uniform and mixed phase clouds

Uniform clouds (75%):
- difference between levels only due to different mean temperature
- No pure ice clouds for temperatures greater than 261 K

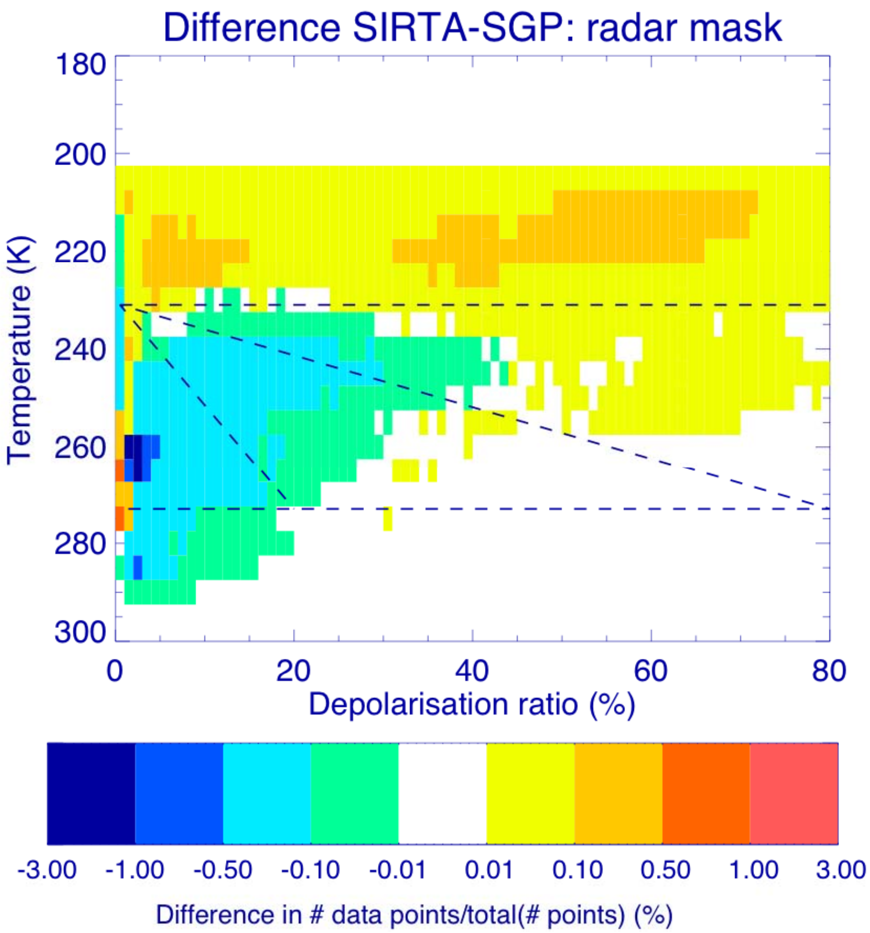
Mixed clouds (25%): mostly influenced by clouds with increasing ice fraction from cloud base, consistent with decrease of supercooled droplets as temperature decreases.

Cloud phase profiles at SGP (1/2)

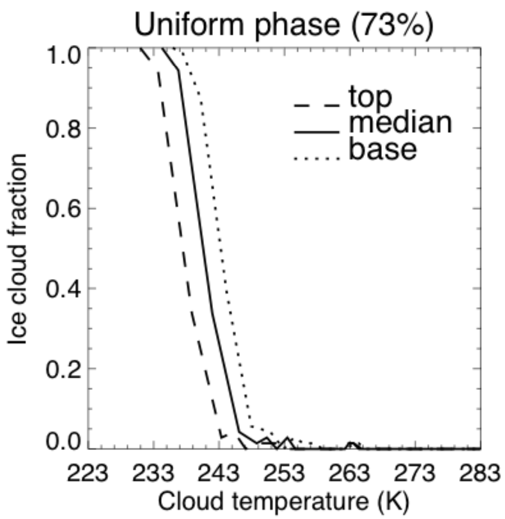
• 5 winters of 355 nm channel of Raman Lidar depolarization ratios but no phase retrieval => use SIRTA algorithm assuming thresholds still valid for:
- different wavelengths
- different instrument specifications
- different cloud masks => use of radar ARSCL cloud mask (lidar cloud mask only for ice cloud)

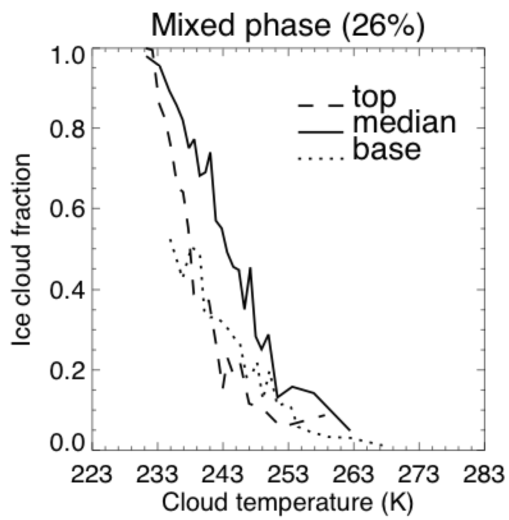
• Number of data points over total of points as a function of temperature and depolarization ratio: difference between SIRTA and SGP winter statistics (right)

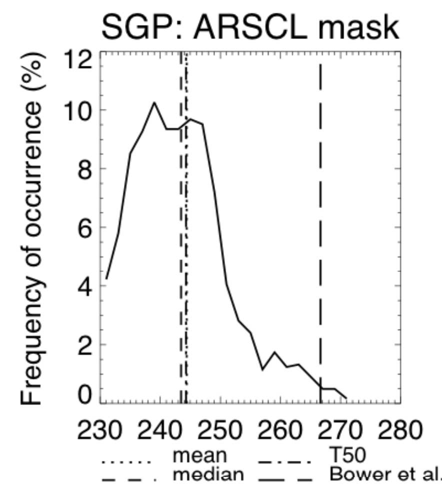
• More mixed and liquid clouds at SGP but fewer cold ice clouds: why?
- no improvement if lidar cloud mask used (even if more sensitive to thin clouds than radar)
- fewer cold ice clouds or more attenuation at SGP due to multiple layer clouds or optically thick clouds, different dynamical conditions??

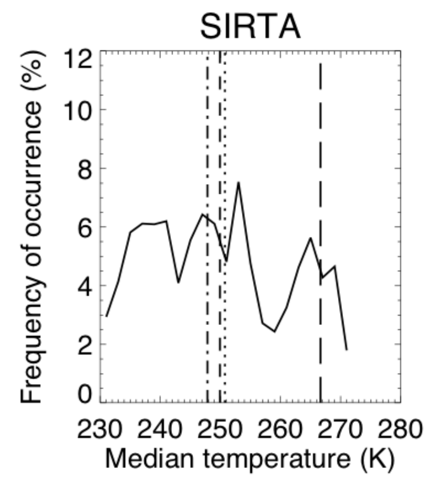


Cloud phase profiles at SGP (2/2)









-Similar proportion of uniform vs mixed phase clouds, no pure ice for temperature greater than 259 K

- less difference between cloud levels for mixed phase clouds than at SIRTA

- T50 or median/mean median level temperature for mixed phase clouds very similar. SGP T50 ~ 244 K < SIRTA T50 ~ 248 K, consistent with west vs east Atlantic, << Bower et al (1996) ~ 266.5 K

Conclusions

- Ice fraction versus temperature at SIRTA for optically thin clouds shows no difference whether at cloud base, top or median level.
- SIRTA clouds found preferentially in advance of warm front, at SGP more in advance of cold front.
- Problem at SGP due to lack of phase retrieval so still uncertainties
- But assuming same algorithm can be applied at both sites without adjustments for instrument differences, SGP shows results consistent with SIRTA of ~ 3/4 uniform vs ¼ mixed phase clouds
- Differences in T50 at the two sites consistent with MODIS differences in T50 for West vs East Atlantic storms, although colder
- Difference in T50 between both sites and different measures of T50 much smaller than difference with Bower et al T50=266.5 K => latter should not be used as a universal parameterization or validation standard in GCMs
- Optically thick clouds: only aircrafts for phase profiles, or other techniques available?