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Cloud Thermodynamic Phase Partitioning Over The Southern Ocean

A Passive Space-Based Instrument Perspective

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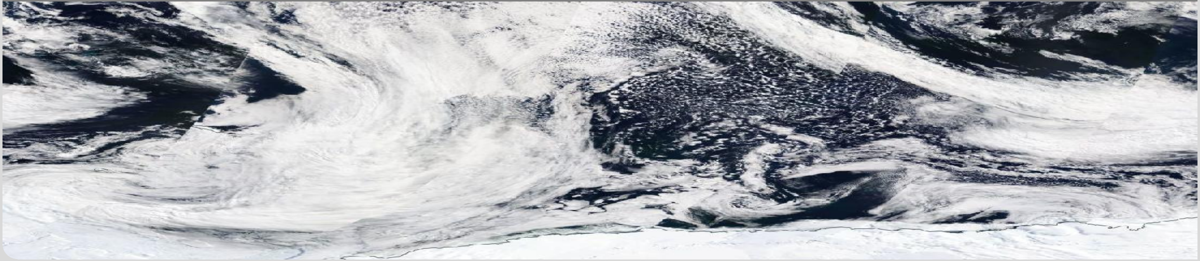
INSTITUTE OF METEOROLOGIY AND CLIMATE RESEARCH — DEPARTMENT TROPOSPHERE RESEARCH



Key points

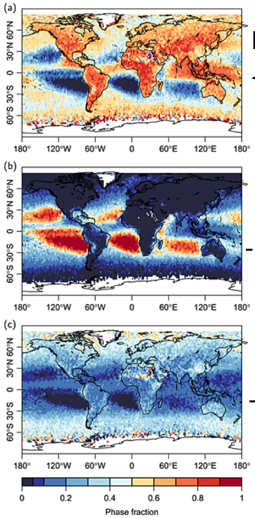
- We analyze the **thermodynamic phase partitioning of mixed phase clouds over the Southern Ocean**
- Evidence of processes showing **larger cloud droplets associated with higher ice fraction**
- Mixed phase clouds with larger cloud droplets are potentially associated with **higher ice crystal concentration**
- Clouds transition from liquid to ice via an **increase of the ice pocket density**

Note for the reader: On the outline slide you can choose the parts you are the most interested in, if you want to skip the introduction for example, on the bottom bar, etc. If you have any question or comment, you can contact me via email `quentin.coopman@kit.edu` or via the platform from EGU.

Outline

1. Introduction
   - Mixed phase clouds in models and observations
2. Data & Method
   - Geostationary space-based instrument SEVIRI
   - Mixed phase clouds from SEVIRI
3. Results & Discussions
   - Spatial distribution of mixed phase clouds
   - Which parameters do influence the ice fraction?
   - What is the spatial partitioning of ice and liquid pixels when clouds transition from liquid to ice?
4. Conclusion & Outlook

Phase transition triggers precipitation



Fraction of raining clouds that are:

- ice phase at cloud top

- liquid phase at cloud top

- mixed phase at cloud top

- 70% of precipitation is **produced via the ice phase**
- The phase transition has an impact on the net radiative properties of clouds

Source: Mülmenstädt et al. 2015

Models overestimate the ice content and disagree with each other

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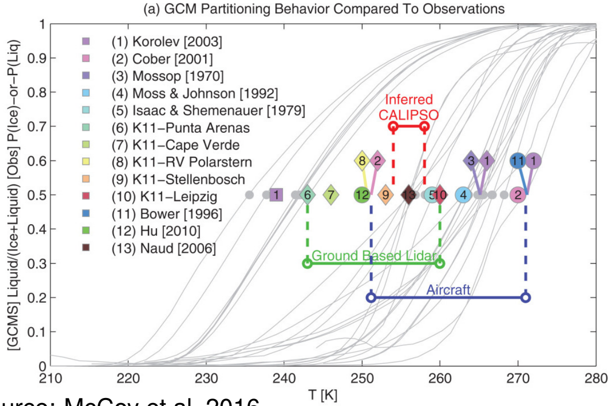


Source: McCoy et al. 2016

- The temperature for which the liquid cloud fraction is equal to 50% (T_{50}) from **different Global Cloud Models variate by 35°C**

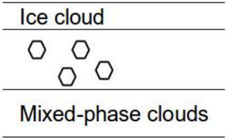
Phase partitioning in mixed phase clouds

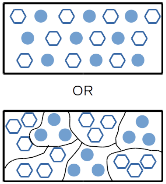
Why is there too much ice in models?

Several hypothesis:

- Too many ice nuclei particles
- **Ice seeding too efficient**
- Model resolutions are too coarse and clouds are uniformly mixed

- **Different types of clouds** can be mixed phase (stratus, deep convective. . .)
- The interaction of mixed phase clouds with aerosols, their radiative and dynamical effects, and their role in cloud electrification **are still undetermined**

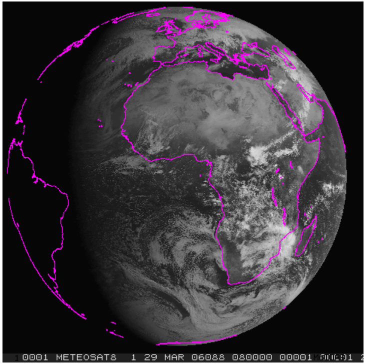




Sources: Tan and Storelvmo 2016
Korolev et al. 2017

Data & Method

Geostationary space-based instrument SEVIRI on board MSG



Picture source: NASA Langley pat Minnis group

- **SEVIRI** (Spinning Enhanced Visible and Infrared Imager) is a passive instrument on the METEOSAT Second Generation satellite
- 12-channel imager
- Spatial resolution **3 km**$\times$**3 km** at nadir
- Temporal resolution **15 mins**

Cloud properties are obtained from CLAAS-2

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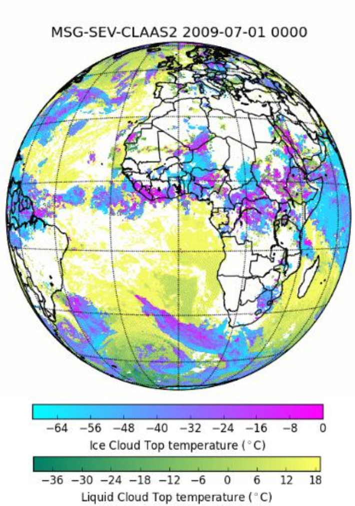
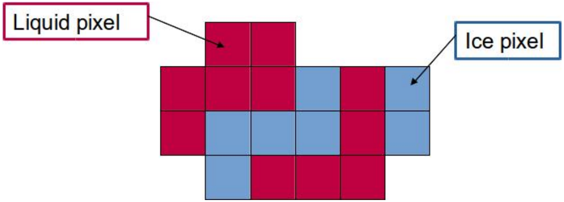


- **CLAAS-2** (Cloud properties dAtAset using SEVIRI) Benas et al. 2017
- Spatial resolution: $\mathbf{0.05}^{\circ} \times \mathbf{0.05}^{\circ}$
- Temporal resolution: **15 mins**
- CLAAS-2 retrieves information on cloud microphysical properties, **such as cloud top temperature, effective radius, optical depth, cloud top pressure, cloud phase. . .**

Mixed phase clouds from a geostationary satellite



Definition of mixed phase clouds from a passive instrument:

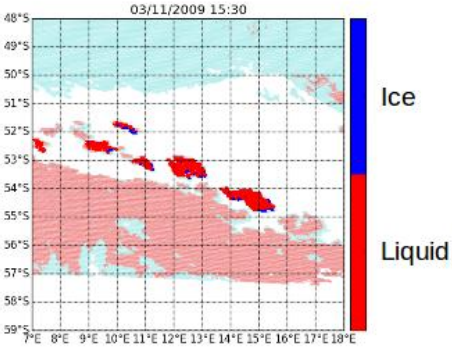
Cloud objects (connected cloudy pixels) which **contain both liquid and ice pixels** at **cloud top**. To avoid multi-layer scene, we constrain for the cloud top temperature variation to be less 10°C.

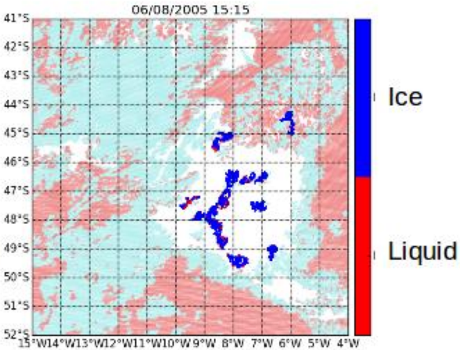
We look for different cloud top temperature (CTT) ranges:

- -8°C<CTT<0°C
- -20°C<CTT<-8°C
- -30°C<CTT<-20°C

Examples of mixed phase clouds from SEVIRI

In the example below of the 03/11/2009, there are six mixed phase clouds. In the example of the 06/08/2005, there are nine mixed phase clouds. The cloud objects in pastel blue or pastel red are not considered because they have **a variation of cloud top temperature greater than 10°C**.





Results & Discussions

Spatial distribution of mixed phase clouds

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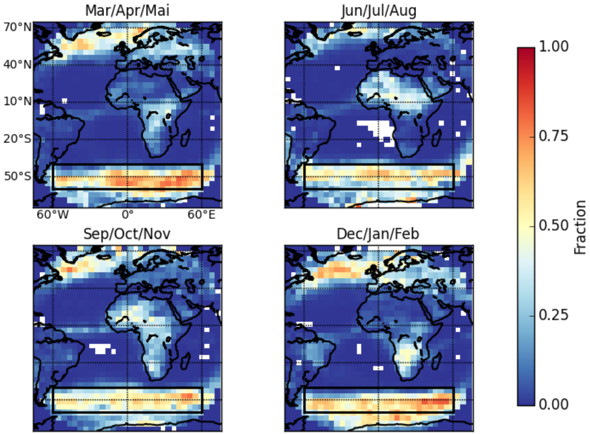
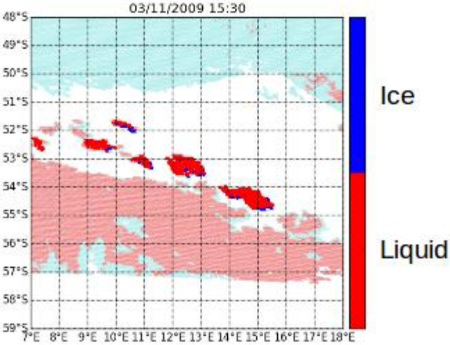
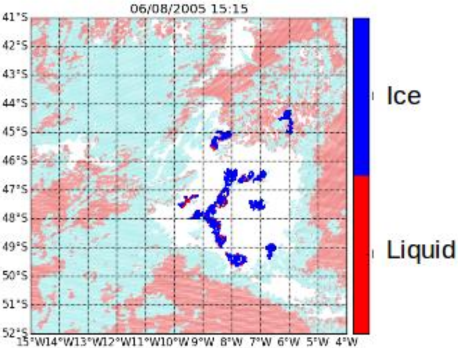


- Mixed phase cloud fraction relative to the total number of clouds over the entire temperature spectrum
- Similar to Figure 5.26 from Korolev et al. 2017 using active satellite measurements
- We focus on the **Southern Ocean** (black rectangle) from 2004 to 2015
- According to Gettelman and Sherwood 2016, the **uncertainty of the cloud feedback** mainly come from **the cloud thermodynamic phase over the Southern Ocean**

Which parameters do influence the thermodynamic phase transition?

Examples of mixed phase clouds from SEVIRI

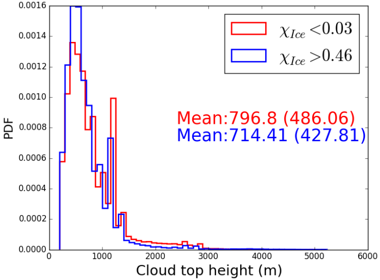


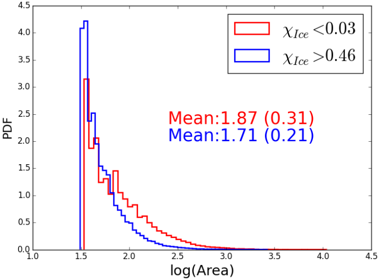


We look at the **distribution of cloud microphysical and radiative parameters** of mixed phase cloud for **different ice fraction** regimes

Parameter distributions for different ice fraction regimes

For cloud top temperatures ranging from -8°C to 0°C

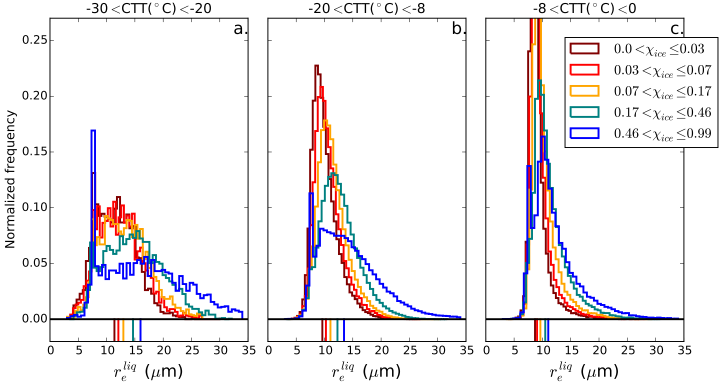




Explanations:

The means are indicated with the standard deviations in parenthesis. **The distributions between high and low ice fractions are similar for most of the parameters and do not seem to enhance or inhibit the phase transition**

Large cloud droplets are associated with large ice fraction



Results & Discussions

- This effect can be associated with **secondary ice production (SIP)** in line with Rosenfeld et al. 2011 and Coopman et al. 2020
- Secondary ice production is associated with an **increase in the ice concentration**
- This effect is observed at different cloud top temperature ranges

Secondary Ice Production (SIP) is associated with an increase in ice concentration

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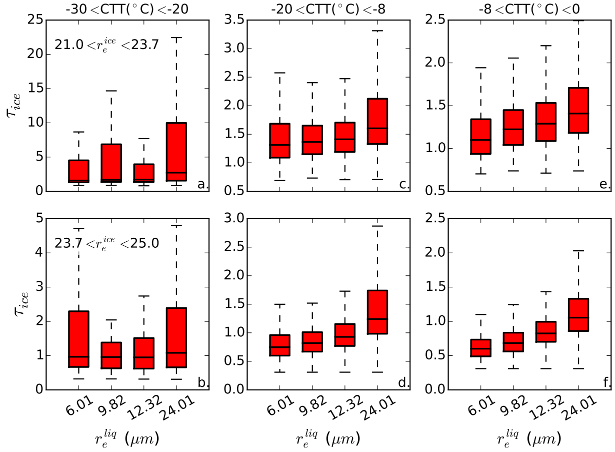
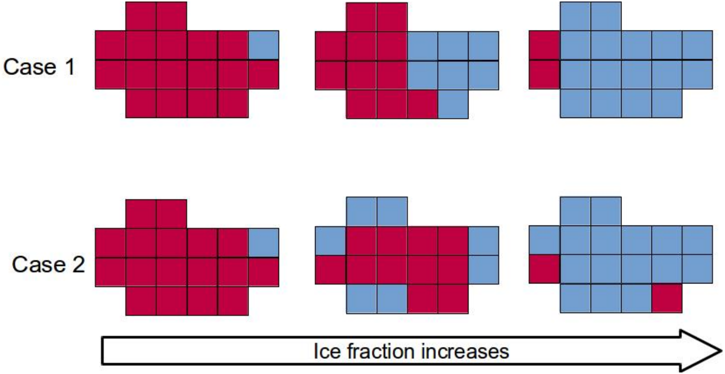


Results & Discussions

- **Cloud optical thickness of ice pixels (τ_{ice}) as a function of cloud droplet effective radius (r_e^{liq}).** Columns: different cloud top temperature ranges (CTT); rows: different effective radius of ice crystals (r_e^{ice})
- When the size of ice crystals is constrained, an **increase in τ_{ice} is associated with an increase in ice crystal concentration**
- The potential increase in ice concentration ($\propto$ SIP) is not observed for cloud top temperatures between -30°C and -20°C

What is the spatial partitioning of ice and liquid pixels when clouds transition from liquid to ice?

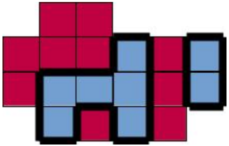
How does the ice fraction increase?



Two different conceptual ideas:

- **Case 1:** The glaciation spreads from pixels to pixels
- **Case 2:** Ice-pixel clusters are created (”ice pockets”) as the ice fraction increases

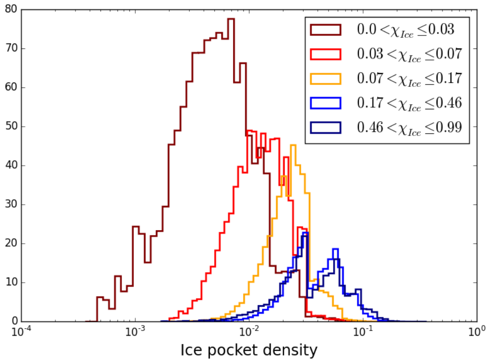
Ice pockets density increases with the ice fraction



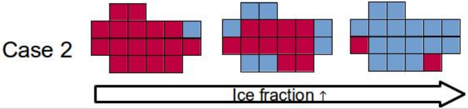
2 ice pockets and 3 liquid pockets

Results:

- Ice pocket density distributions for different regimes of cloud ice fraction
- **The increase in ice fraction is associated with an increase in ice pockets**



Most likely Case:



Ice pocket density for different regimes of cloud droplet effective radius

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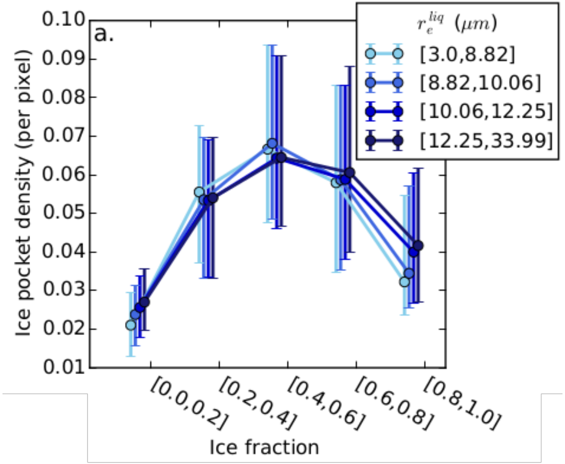


Results & Discussions:

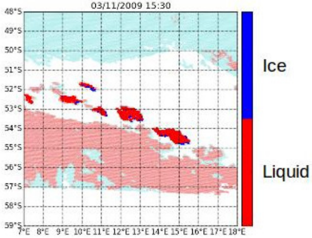
- Ice pocket density as a function of ice fraction for different regimes of cloud droplet effective radius (r_e^{liq})
- **The increase in ice fraction is associated with an increase in ice pocket density and then a decrease** (ice pockets merge)
- For the different regimes of r_e^{liq} there is not much difference in the number of ice pockets
- **The cloud droplet size does not influence the number of ice pockets**

Spatial distribution of liquid and ice phase

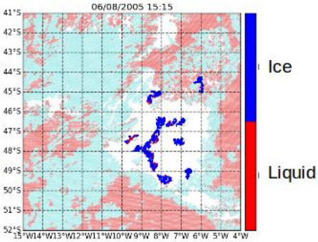
$$D(P) \propto 2 \cdot \frac{ln(P)}{ln(A)}$$

P: Cloud perimeter
A: Cloud area
Source: Batista-Tomás et al. 2016

D(P)<1.96
Clouds have **regular boundaries**
(cumulus type)



D(P)>2.13
Clouds have **ragged boundaries**
(frontal type)



Ice pocket density for different regimes of D(P)

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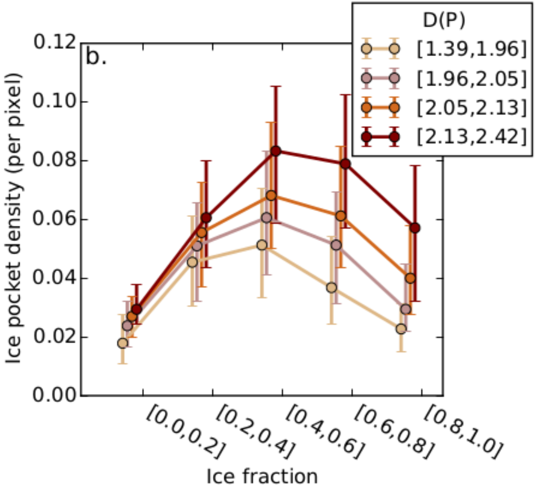

Results & Discussions:

- Ice pocket density as a function of ice fraction for **different regimes of D(P)**
- **The larger the D(P), the higher the ice pocket density**
- Ragged-boundary clouds have a higher ice pocket density, the cloud shape influences the number of ice pockets (or reverse ?!)
- Clouds with regular boundaries are in a **more uniform environment**, the glaciation spreads from pixels to pixels or clouds are glaciated more quickly

Size of liquid and ice pockets

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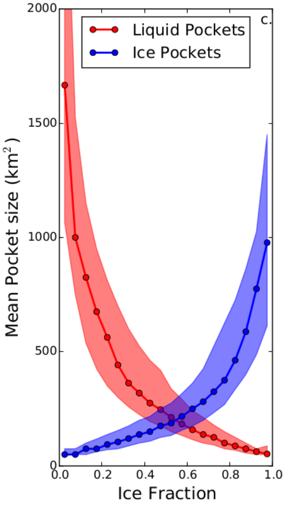
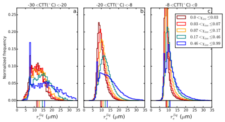


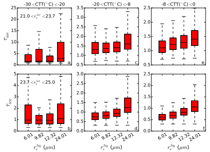
Results & discussions

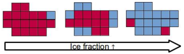
- Mean pocket size as a function of the ice fraction for liquid and ice pockets
- Considering ice pockets, **at first ice pocket size increases slowly** until ice fraction equals to 0.6 and **then increases rapidly** for ice fraction greater than 0.6
- Ice pocket density is increasing and growing and then they merge.
- The opposite is observed for liquid pockets

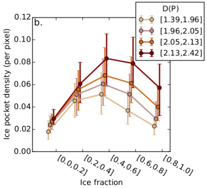
Conclusions

- We analyzed the thermodynamic cloud **phase partitioning** for different temperature ranges,
- Analysis of the distributions for different parameters
- Evidence of processes showing a **larger cloud droplet effective radius (r_e^{liq}) is associated with higher ice fraction**
- Mixed phase clouds with **larger r_e^{liq} are potentially associated with higher ice crystal concentration**
- Clouds transition from liquid to ice by an **increase of the ice pocket density**
- The shape of clouds impact the number of ice pockets









Outlook

- Compare our results with lidar-radar **DARDAR** products from CALIPSO/CLOUDSAT which retrieve directly the **ice concentration** (Sourdeval et al. 2018), to confirm that large cloud droplets are associated with higher ice crystal concentration in mixed phase clouds
- Comparing our results with **field campaigns** in the Southern Ocean
- . . .

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