Studying secondary ice production mechanisms : from a remote sensing and hydrometeors dynamics perspective

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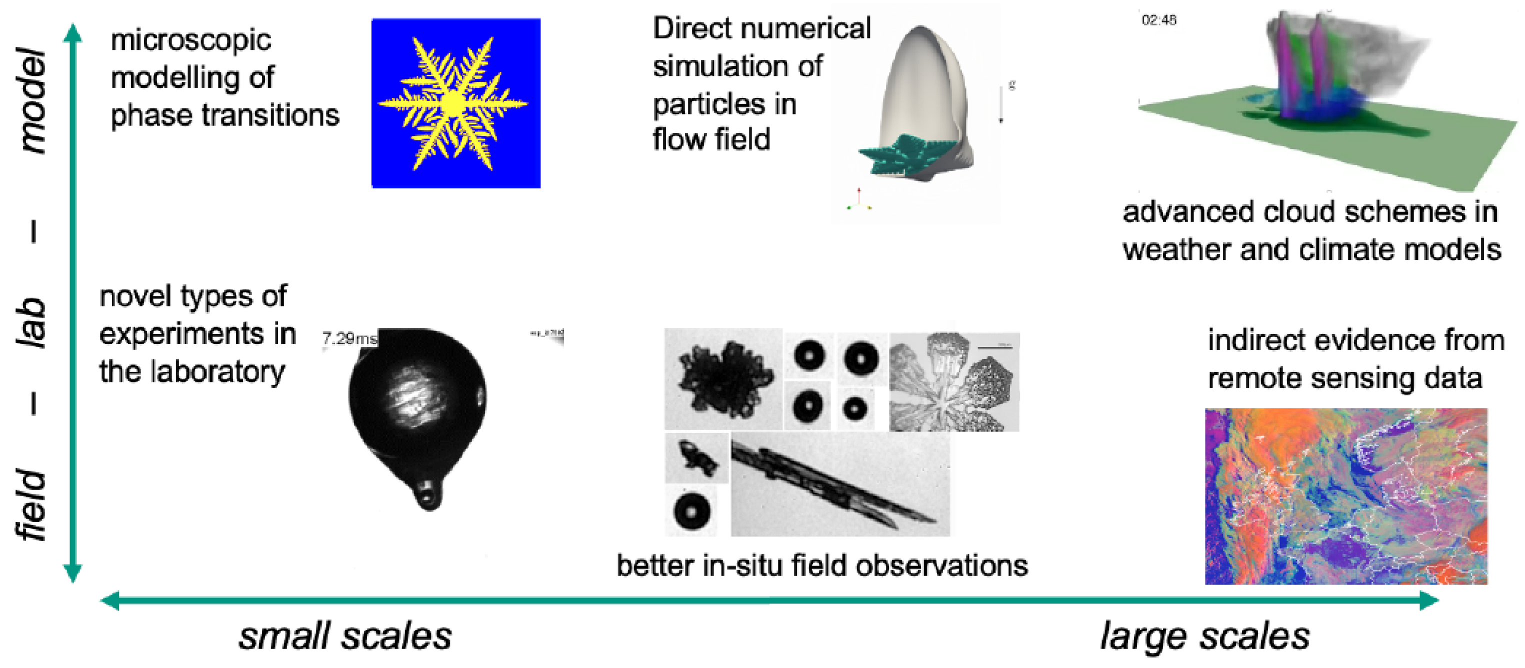
Introduction

Ice crystal number concentrations were often found to be orders of magnitude higher than the number concentration of ice nucleating particles; a finding that indicated the presence of **Secondary Ice Production** (SIP). Although 6 mechanisms of SIP have been both discovered and theorized, it is still not fully understood and the recent studies have been inconclusive in identifying the dominant process in real conditions.

At KIT, four different institutes are collaborating to further our knowledge in understanding the SIP mechanisms through different perspectives : across scales and with various experimental and computational methods. Here we show two different but complementary approaches : the use of remote sensing instruments and numerical simulations of hydrometeor dynamics.



Remote sensing approach

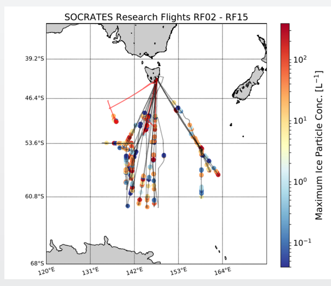
Main Question:

Can we *identify, characterize, explain* SIP events using remote sensing retrievals?

For this study we consider two main data sets: In-situ flight campaign measurements and satellite retrievals.

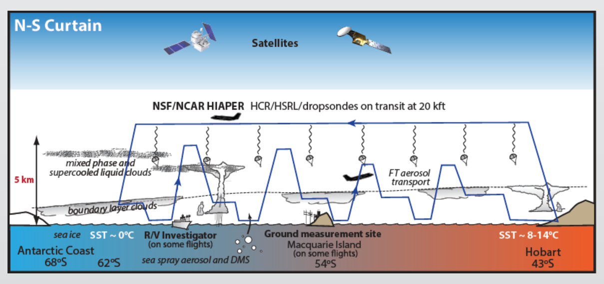
Data Sets :

SOCRATES (Southern Ocean Clouds Radiation Aerosol Transport Experimental Study): The Southern Ocean is characterized by a pristine environment which makes it unique for studying liquid and ice clouds. The SOCRATES flight campaign uses the NSF/NCAR G-V aircraft over the Southern Ocean for 6 weeks between **January and March 2018**. Parameters of interest: Concentration of ice particles at different size ranges and concentration of drizzle.



[Järvinen et al., 2022]

Himawari-8 Cloud Product: Himawari is a geostationary satellite operated by the Japan Meteorological Agency. It has a **spatial resolution of 5km and a temporal resolution of 10 minutes**. Parameters of interest: Cloud top temperature, cloud optical depth, cloud top height, cloud effective radius, and cloud type.

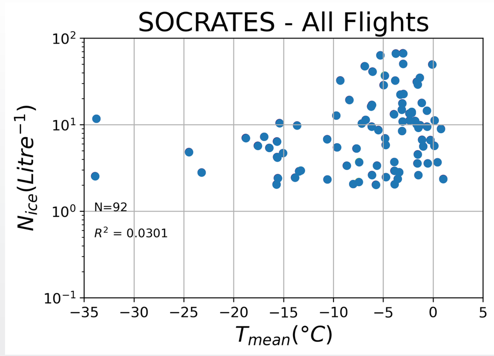


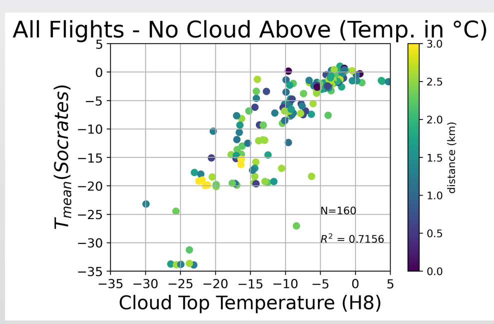
[McFarquhar et al., 2020]

Preliminary Results

We first looked at correlations between various parameters from both data sets. Here are two examples:

- 1st plot (SOCRATES parameters): N_{ice} (the concentration of ice particles per litre) and the T_{mean} (temperature), we find a low R^2 value
  ⇒ this may not be a bivariate system.
- 2nd plot: T_{mean} vs CTT from Himawari. Only observations where the flight had 'No Clouds Above' the plane were considered here.
  The scatter plot also is color coded according to the distance between the flight location and the center of the Himawari pixel.
  ⇒ very promising result!





Future and on-going work

Main Objective: Identify relationships between in-situ campaign observations and (raw) satellite data that can be used to study SIP globally.

- Take into account the space and time lag between SOCRATES and Himawari.
- Consider multi-channels from Himawari for a multivariate analysis with SOCRATES data sets.
- Include other relevant parameters: humidity, cloud lifetime, cloud type, etc.
- Case studies of each flight segment.
- Making use of lidar/radar profiles.
- Study the variability of SOCRATES data.

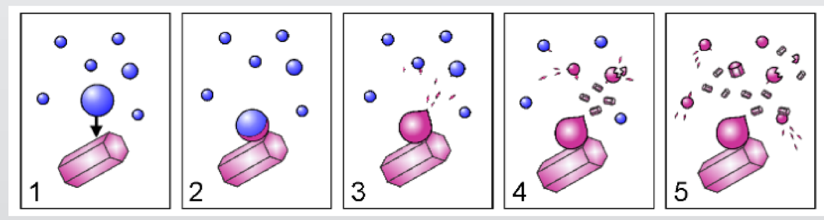
Numerical simulations of hydrometeors dynamics

Motivation :

Turbulence is an intrinsic feature of clouds and plays a major role in the interactions between the microphysical and dynamic processes involved in their evolution. For example, its importance in droplet growth has been studied and it has been shown that the collision rate can be increased due to interactions, at small scales, between the particles and the turbulence [Shaw, 2003].
⇒ Turbulence could also be **important** for SIP-mechanisms as it affects the hydrometeors dynamics.

Idea :

Use direct numerical simulations (DNS) of homogeneous-isotropic turbulence (HIT) at low Reynolds numbers with point-particle tracking to study and analyse **SIP**-mechanisms and in particular those involving collisions between particles (ice-ice collisions and break-up, rime-splintering and droplets freezing and shattering) and the cascade effect.

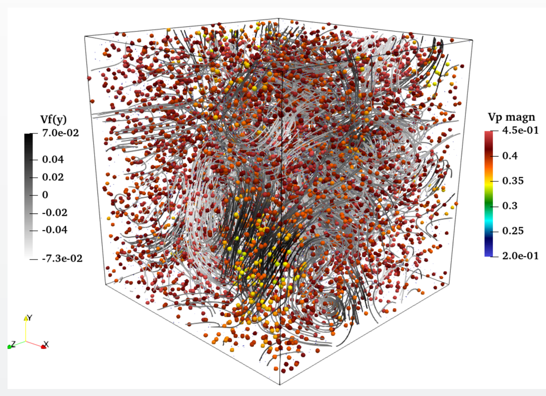


Conceptual model of SIP due to shattering of freezing drops ⇒ cascading effect [Korolev et al., 2020]

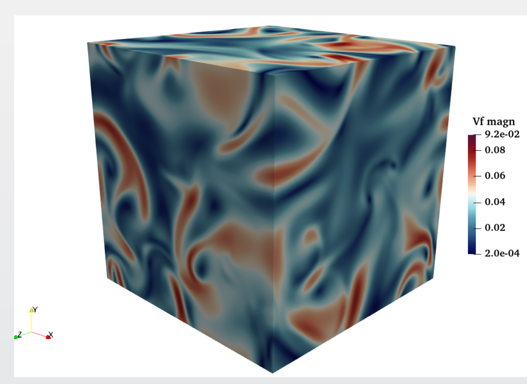
Methodology and on-going work

- In DNS, the Navier-Stokes equations are solved numerically without any sub-grid turbulence model which means the whole range of spatial and temporal scales of the turbulence is resolved.
- **Point-particle method**. The real shape of the hydrometeors is not taken into account.
- The force exerted by the particles on the fluid is neglected since the particle volume fraction is very low ⇒ **One-way coupling**.

Simulation of particles settling in HIT. Used code : ch4-project [Calzavarini, 2019]



Fluid streamlines colored by the fluid vertical velocity. Particles are colored by their velocity magnitude. Particle size is x70.



Visualisation of the flow structure and fluid velocity magnitude.

Determining factors :

- Concentration and size of hydrometeors
- Turbulence intensity
- Probability of ejection of secondary ice fragments after collision and/or freezing, as well as their size and number

Next steps :

- implement the particle collision detection and consider the emission of secondary ice fragments after the collision,
- take into account the depositional growth for tiny secondary ice fragments.

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