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# IMPORTANCE OF PHYSICO-CHEMICAL PROPERTIES OF AEROSOLS IN THE FORMATION OF ARCTIC ICE CLOUDS

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## 1. INTRODUCTION

### a. Why?

Ice clouds play an important role in the Arctic weather and climate system but interactions between aerosols, clouds and radiation are poorly understood. Consequently, it is essential to fully understand their properties and especially their formation process.

### b. Hypothesis

Extensive measurements from ground-based sites and satellite remote sensing reveal the existence of two Types of Ice Clouds (TICs) in the Arctic during the polar night and early spring. TIC-1 are composed by non-precipitating very small (radar-unseen) ice crystals whereas TIC-2 are detected by both sensors and are characterized by a low concentration of large precipitating ice crystals. It is hypothesized that TIC-2 formation is linked to the acidification of aerosols, which inhibit the ice nucleating properties of ice nuclei (IN). As a result, the IN concentration is reduced in these regions, resulting to a smaller concentration of larger ice crystals.

Over the past 10 years, several parameterizations of homogeneous and heterogeneous ice nucleation have been developed to reflect the various physical and chemical properties of aerosols (Hoose and Möhler, 2010). These parameterizations are derived from laboratory studies on aerosols of different chemical compositions. The parameterizations are based on two main approaches: stochastic (that nucleation is a probabilistic process, which is time dependent) and singular (that nucleation occurs at fixed conditions of temperature and humidity and time-independent).

### c. Objective

This research aims to better understand the formation process of TICs using a newly-developed ice nucleation parameterizations. For this purpose, we have implemented parameterizations based on both approaches into the Limited Area version of the Global Multiscale Environmental Model (GEM-LAM) and used them to simulate ice clouds observed during the Indirect and Semi-Direct Arctic Cloud (ISDAC) field experiment in Alaska. Simulation results of the TICs-2 observed on April 15th and 25th (polluted or acidic cases) and TICs-1 observed on April 5th (non-polluted cases) are presented.

## 2. OBSERVATIONS

The indirect and Semi-Direct Aerosol Campaign (ISDAC) took place in Alaska in April 2008. In-situ measurements were performed in TIC-1 and TIC-2 clouds during ISDAC. Four flights were used in our study. These clouds (2 TIC-1 and 2 TIC-2) have similar ice water content.

| | |
|---|---|
| F12 Barrow, AK April 5th 2008 Non-Polluted case | F13 Barrow, AK April 5th 2008 Non-Polluted case |
| F21 Barrow, AK April 15th 2008 Polluted case | F29 Fairbanks, AK April 25th 2008 Polluted case |

## 3. MODEL AND PARAMATERIZATION OF ICE NUCLEATION

The limited-area version of the Canadian Global Environmental Multiscale Model (GEM-LAM) is used in this study. The microphysics scheme used is a modified version of the Milbrandt and Yau (2005).

A new parameterization for heterogeneous ice nucleation in the deposition and immersion modes has been implemented into the MY scheme. The parameterizations are also developed according to two main approaches:

$J$ : Found with the classical theory of heterogeneous ice nucleation by deposition

$A_{kaoline}$ : The surface area of the dust particules

$Dt$ : time step

$N_s$ : Ice number concentration

$N_{tot}$ : Concentration of dust particules

$n_s$ : The density surface of active sites

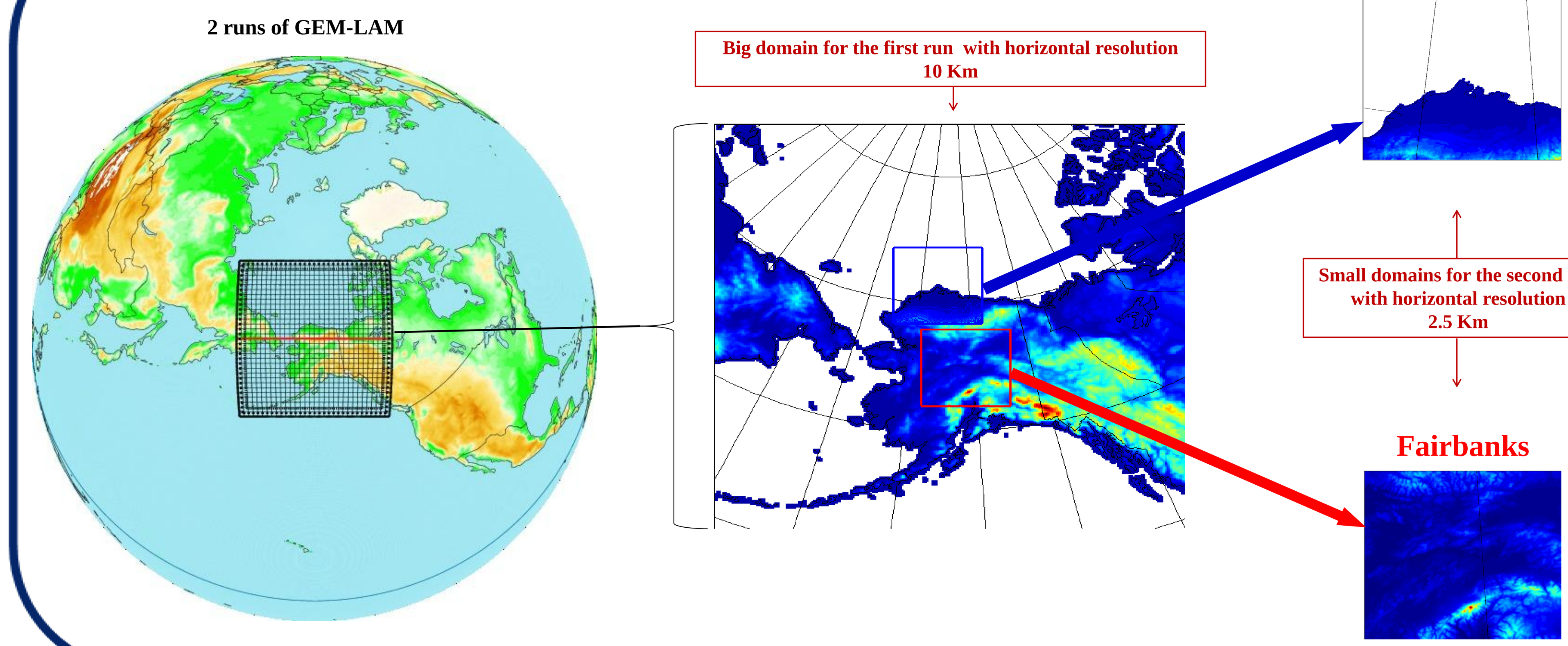
$S_i$ : ice saturation ratios

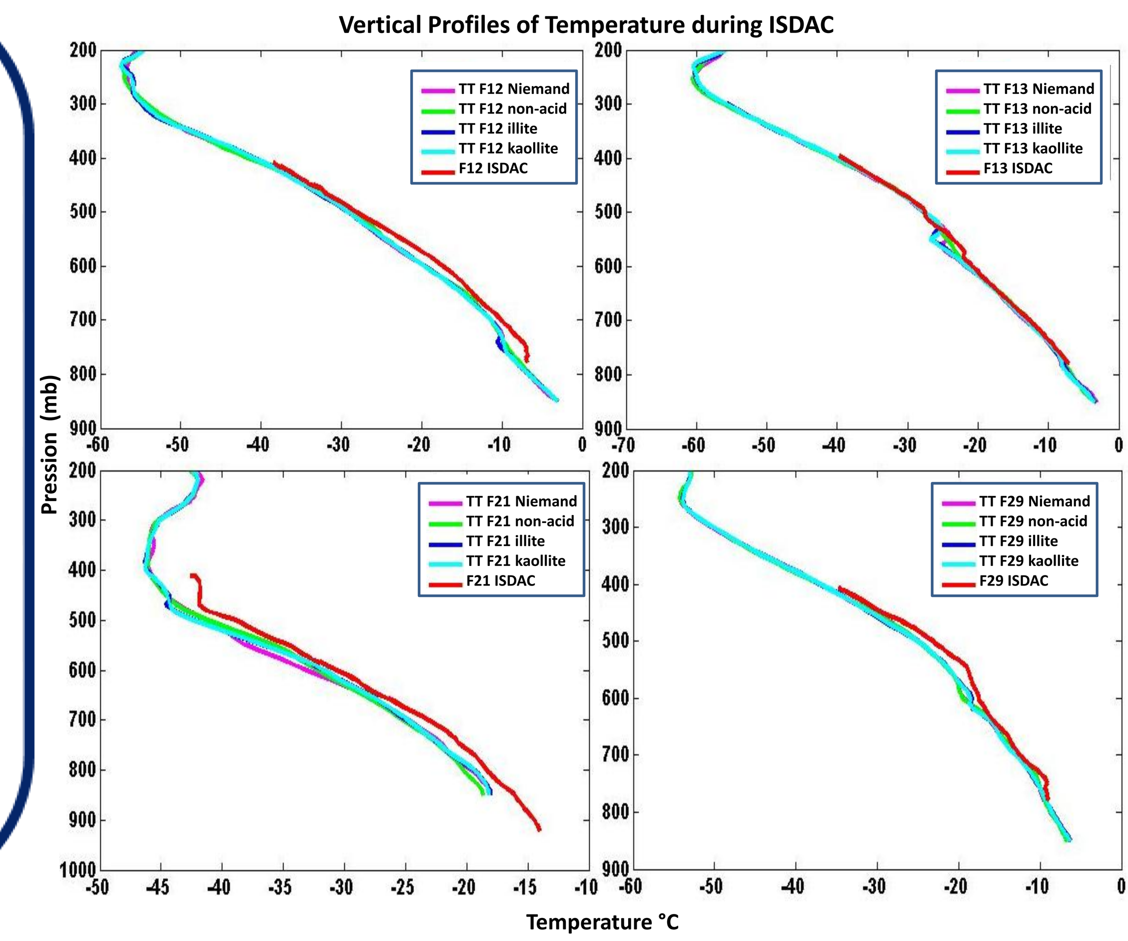
**Approaches:**

**singular**
- nucleation occurs at fixed conditions of temperature and humidity and time-independent
- $N_{ice} = N_{tot}(1-\exp(-n_s A_{kaoline}))$
- The surface density of active sites $n_s$ have been derived from laboratory experiments. Bertram et al.2012
  - Bertram et al.2012
    - $n_s(S_i)=1.2e^{10}(S_i+0.8547)$ Kaolinite
    - $n_s(S_i)=1.46e^{10}(S_i+0.9415)^2$ Illite
  - Niemand et al.2012
    - $n_s=\exp[-0.517(T-273.15)+8.934]$ natural desert dust

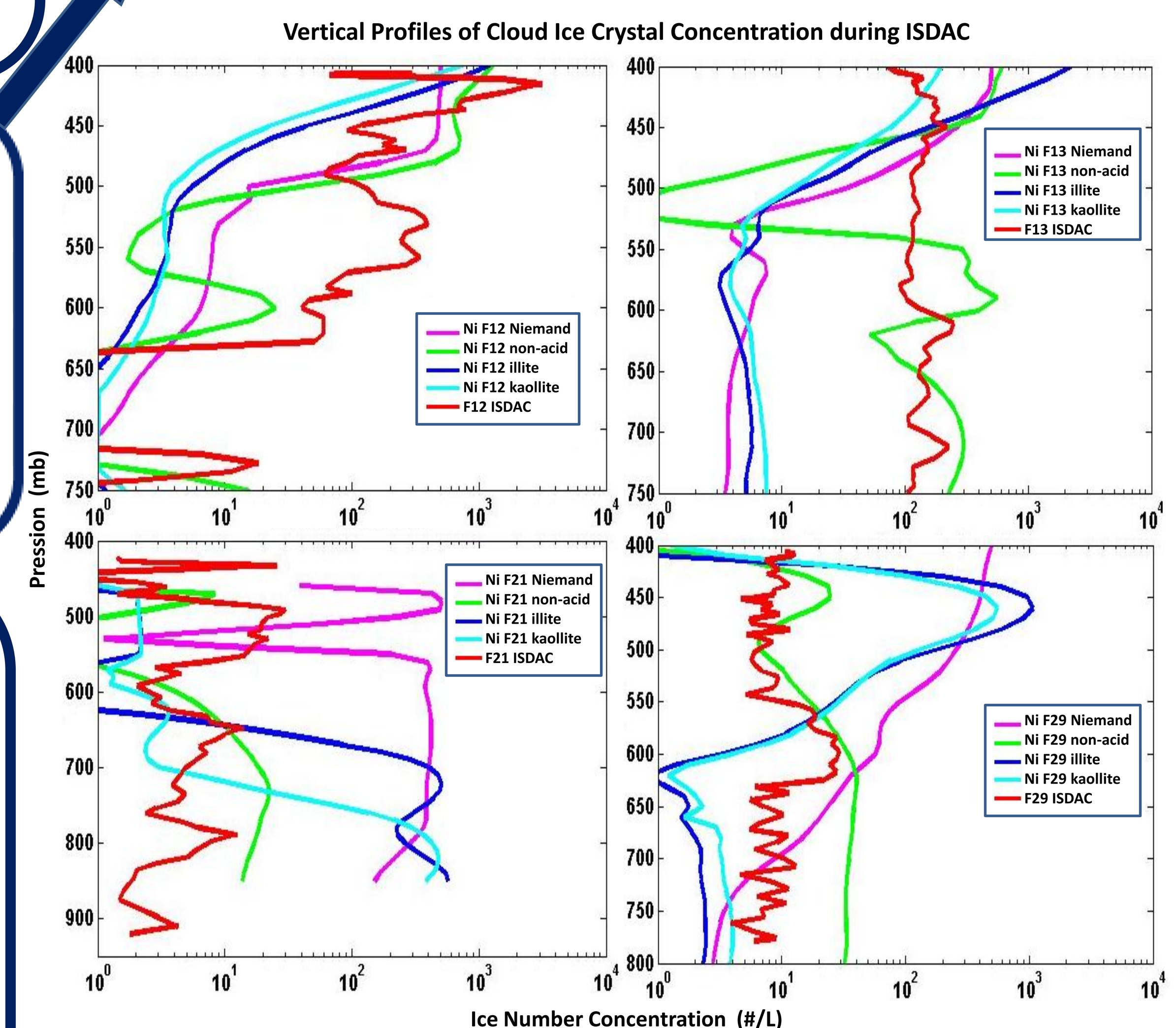
**stochastic**
- nucleation is a probabilistic process, which is time dependent
- $N_{ice} = N_{tot}\exp(-J A_{kaoline} Dt)$
- The contact angle have been derived from laboratory experiments of Eastwood et al. (2008; 2009)
  - For uncoated dust particles, θ = 12°
  - For sulphuric acid-coated dust particles, θ = 27°

## 4. METHODOLOGY



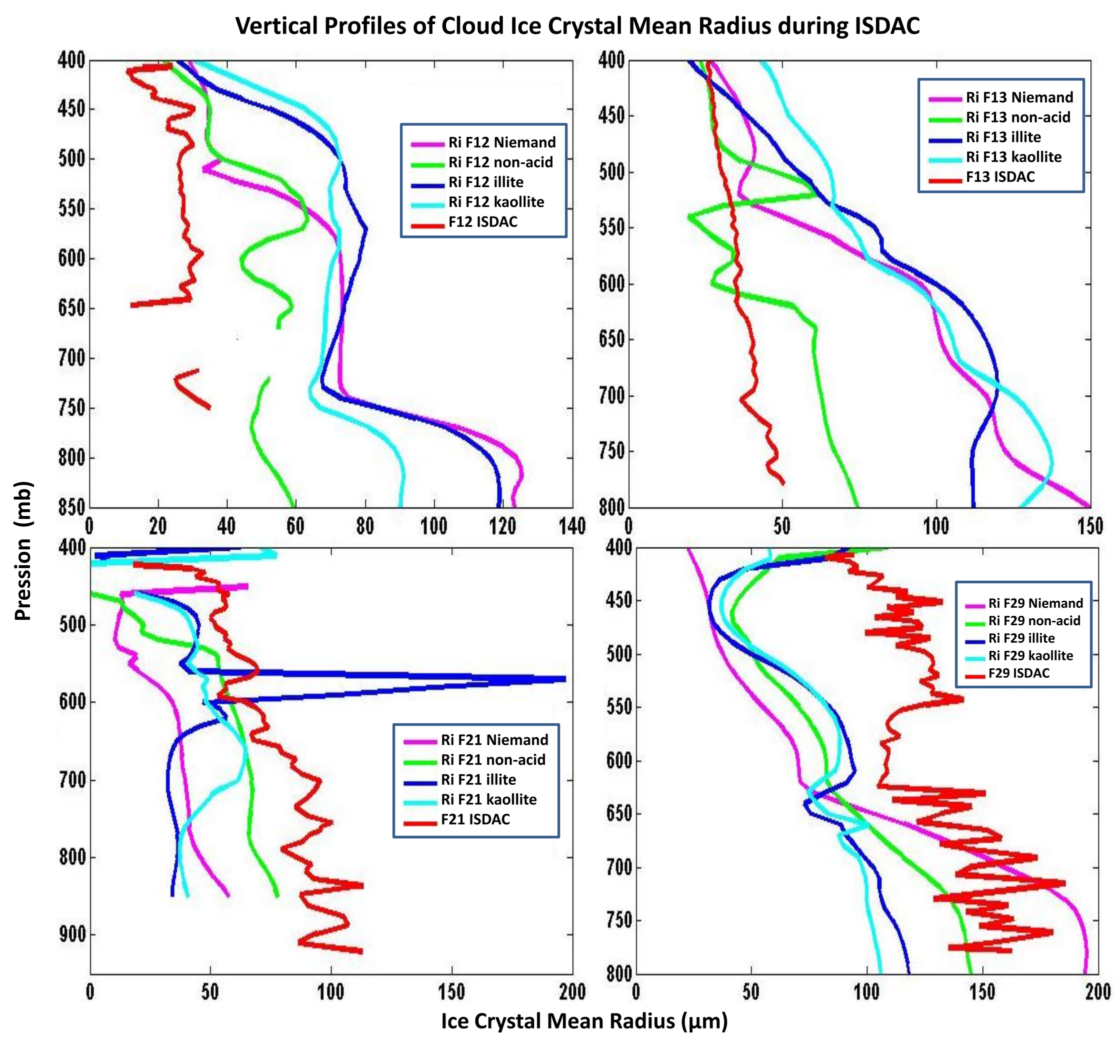

## 5. RESULTS

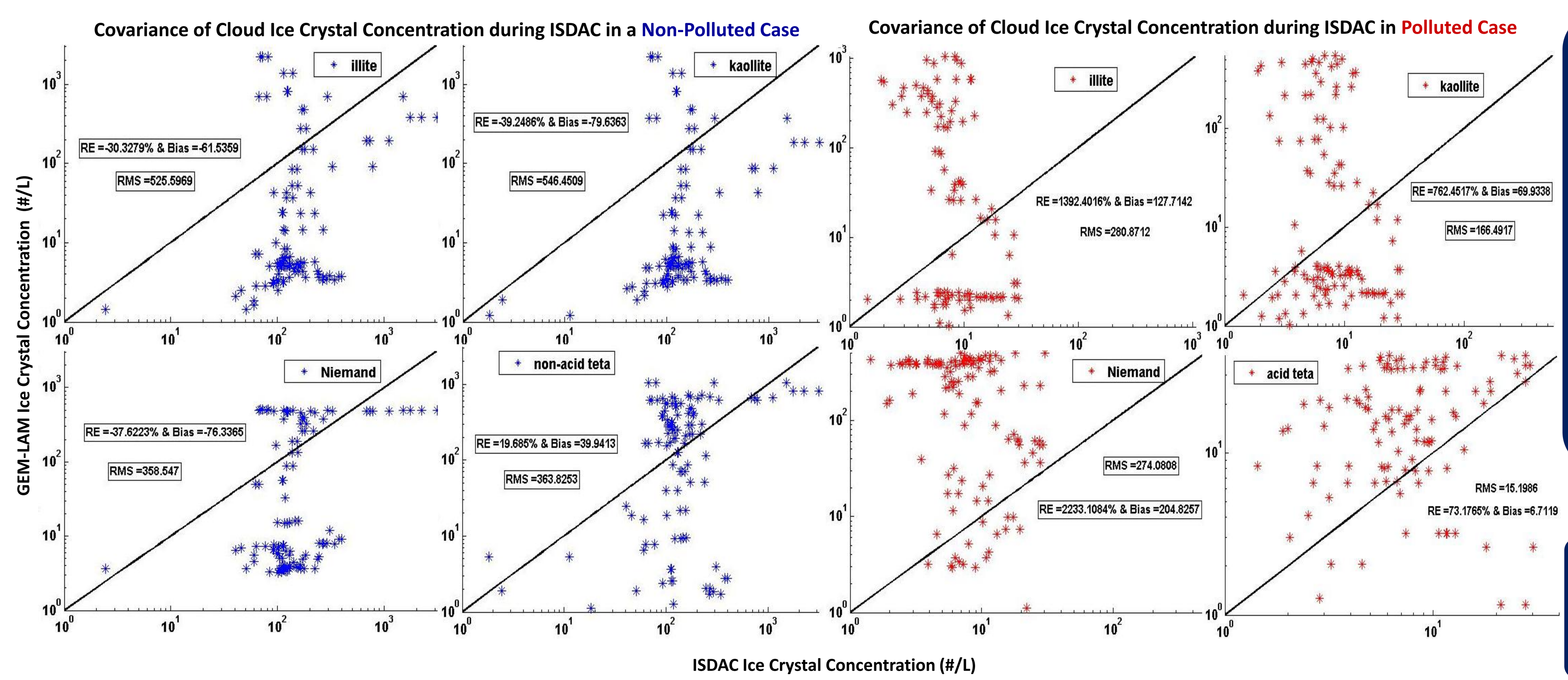



Results show that the non polluted cases (F12&F13) are better reproduced by both parameterisations. The non-acid (θ=12°) scenario has the lowest Ni bias and RE (mean relative error) followed by illite, kaolinite and Niemand. Both approaches do a really good job at reproducing values of Ni except for F13 where they underestimate Ni in the lower levels (Pressure <500 mb). The fourth scenario do a really good job at reproducing large values of Ri at cloud top (Pressure >500 mb) but illite, kaolinite and Niemand substantially overestimate in the lower levels. This result was expected and confirms that these 4 models are representative of the ice crystal formation in pristine air masses.

Only the acid-coated scenario (θ=27°) better reproduces the polluted cases (F21 & F29). The other schemes substantially overestimate Ni. The acid-coated scenario (θ=27°) does a really good job at simulating the ice crystal number concentration in both flights while it slightly underestimates the crystal mean radius. Both stochastic scenarios underestimate Ri in the lower levels of the F21 TIC while they underestimate Ri in the higher levels of the F29 cloud.

For both Ni and Ri, the non-acid case has a lower bias, RE and RMS as well as a higher correlation with the ISDAC measurements.




## 6. CONCLUSION

- For both polluted cases (F21 & F29), the aci-coated scenario (θ=27°) simulates quite well the formation of TIC-2, which is often associated to acid coated ice nuclei.

- On the other hand, the non-acid (θ=12°), illite, kaollinite and Niemand versions of the scheme do a good job at simulating the formation of a TIC-1 (F12) and (F13) commonly found in non-polluted air masses.

- The next step is to implement these schemes to GEM-MACH (transport and chemical GEM model) in order to use the right ice nucleation parametrization to the chemical composition of IN.

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