Modeling of Ice Clouds Observed during ISDAC in Polluted and Pristine Air Masses

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ABSTRACT Ice clouds play an important role in the Arctic weather and climate system. Consequently, it is essential to fully understand their properties and especially their formation process. Measurements from ground-based sites and satellite in certain region of the Arctic have revealed the existence of two types of optically thin ice clouds (TIC). The first type, TIC-1, are characterized by a high concentration of small ice crystals and are typically observed in non-polluted areas. TIC-2a which are an extension on TIC-1, are also observed in non-polluted areas. On the other hand, TIC-2b are characterized by a low concentration of larger precipitating ice crystals. Recent studies suggest that TIC-2b are linked to highly polluted environments. Past field experiments have shown that most aerosols in the accumulation mode are coated by sulphuric acid in polluted episodes in the Arctic during winter. Recent laboratory experiments have shown that sulphuric acid coating can alter the efficiency of ice nuclei (IN) to nucleate ice crystals. In this study, we hypothesize that the resulting lower IN concentration found in polluted air masses leads to the decrease of the ice crystal concentration. Since there is in less competition for the available moisture, ice crystals reach precipitating sizes leading to the formation of TIC-2b.

This research aims to better understand the formation process of these two types of TIC using a new ice nucleation parameterization. This parameterization is based on a combination of the results from laboratory experiments and the classical heterogeneous nucleation theory has been implemented into the Limited Area version on the Global Multiscale Environmental Model (GEM-LAM). TIC-1 and TIC-2 observed during the Indirect and Semi-Direct Arctic Cloud (ISDAC) field experiment are simulated with GEM-LAM using respectively the uncoated IN parameterization and the acid-coated IN parameterization. TICs-2b observed on April 15th and 25th during ISDAC (polluted cases) and TICs-1 and TICs-2a observed on April 5th (non-polluted cases).

1.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-2b clouds during ISDAC. In our study, bulk quantities derived from these measurements are used for comparison with the model results: the ice water content, the number concentration and the mean radius of ice crystals. Using the same dataset, Jouan et al. (2012) have found that TIC-2b clouds observed during ISDAC seem to be associated to polluted air masses containing large concentration of SO_2, thus suggesting that highly-acidic aerosols were dominant.

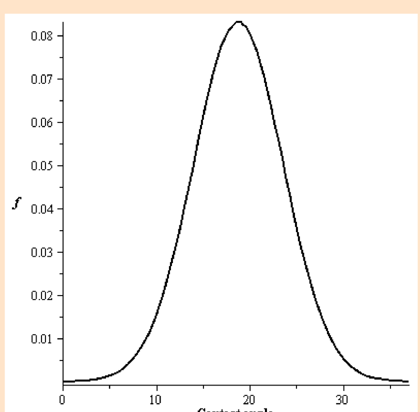
2. MODEL AND PARAMATERIZATION OF ICE NUCLEATION

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

The modified version of the MY scheme consists of implementing a new parameterisation for heterogeneous ice nucleation in the deposition (originally from Meyers et al. 1992 in the original version of the scheme) and immersion modes. The parameterization is based on the classical theory of ice nucleation where the contact angles have been derived from laboratory experiments of Eastwood et al. (2008; 2009) for both uncoated and sulphuric acid-coated kaolinite particles. The concentration of ice crystal nucleated in Δt is :

$$N_{ice} = N_{kaolinite} \exp(-J\, A_{kaolinite}\, \Delta t)$$

Where $N_{kaolinite}$ is the concentration of dust particles, J is the nucleation rate, $A_{kaolinite}$ is the surface area of the dust particles and Δt is the time step. J can be found with the classical theory of heterogeneous ice nucleation by deposition. J depends on the contact angle between the ice embryo and the dust particles. The contact angle Θ has been derived from laboratory experiments.



For uncoated dust particles, $\Theta = 12°$

For sulphuric acid-coated dust particles, $\Theta = 26°$

For Alpha-PDF, Θ is distributed over Gaussian function

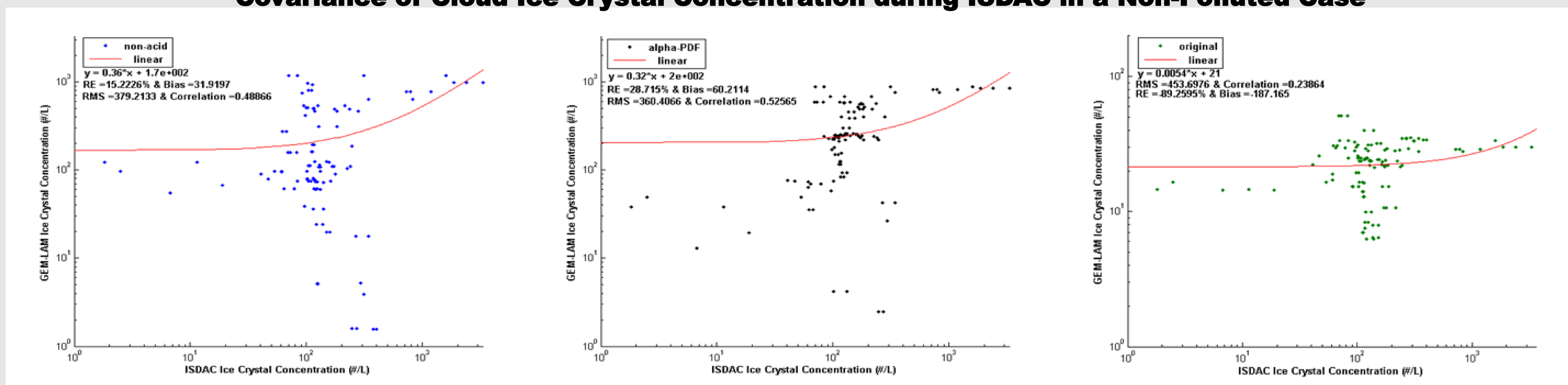
$$f(\theta) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\theta-\theta_0)^2}{2\sigma^2}\right)$$

Where Θ_0 is the most probable contact angle and σ the standard deviation $\Theta_0 = 18.8°$, $\sigma = 4.8°$

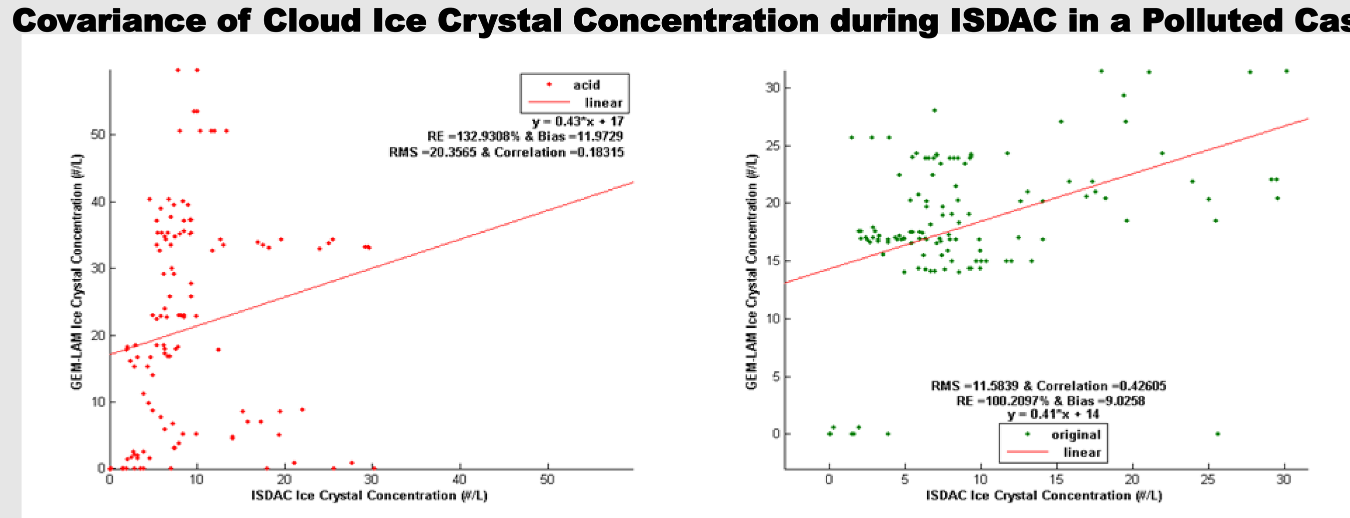
Eastwood *et al* (2009), *Geophysical Research Letters* 36: 763 doi:10.1029/2008GL035997.
Grenier et al. (2009), *Journal of Geophysical*, Research, Vol. 114, doi:10,1029/2008 JD010927
Jouan *et al* (2012), (Submitted to ACP)

4. RESULTS

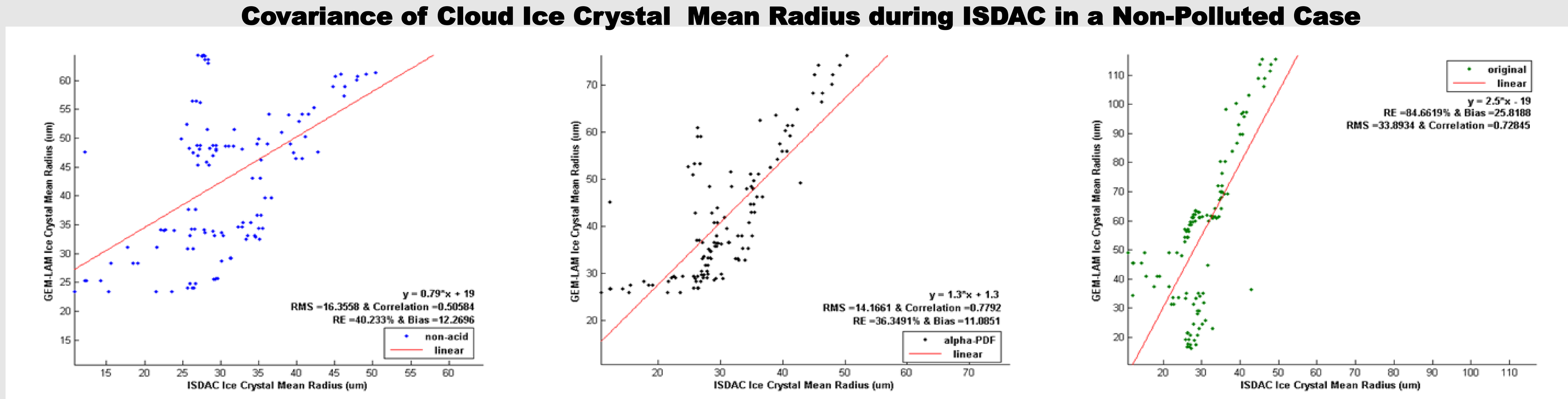
Covariance of Cloud Ice Crystal Concentration during ISDAC in a Non-Polluted Case



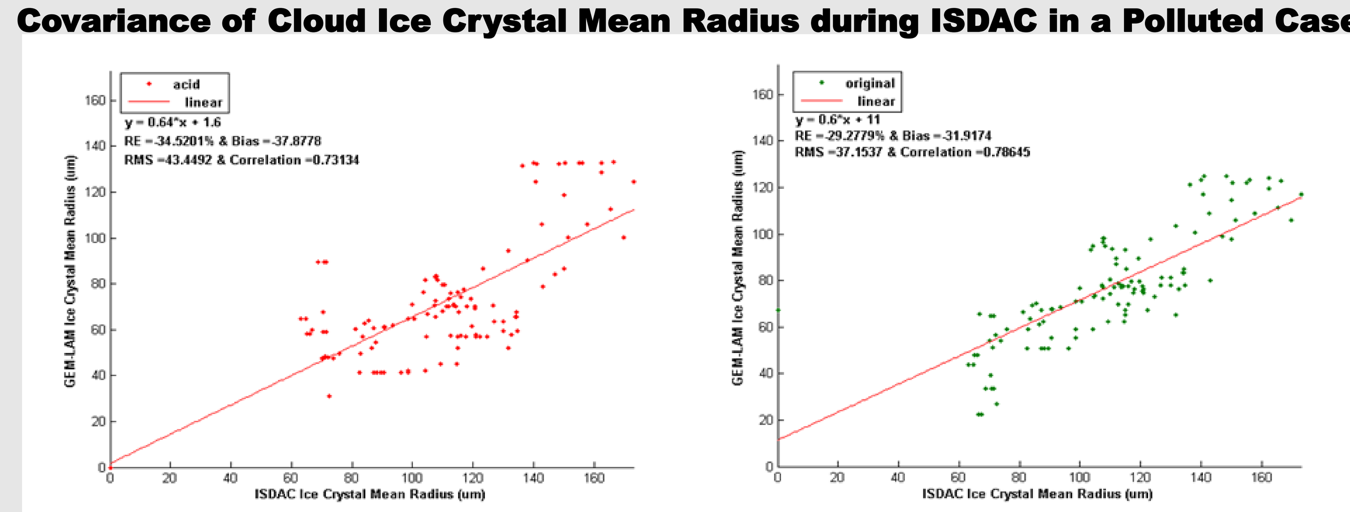
Covariance of Cloud Ice Crystal Concentration during ISDAC in a Polluted Case



Covariance of Cloud Ice Crystal Mean Radius during ISDAC in a Non-Polluted Case



Covariance of Cloud Ice Crystal Mean Radius during ISDAC in a Polluted Case



F12
Barrow, AK
April 5th 2008
Non-Polluted

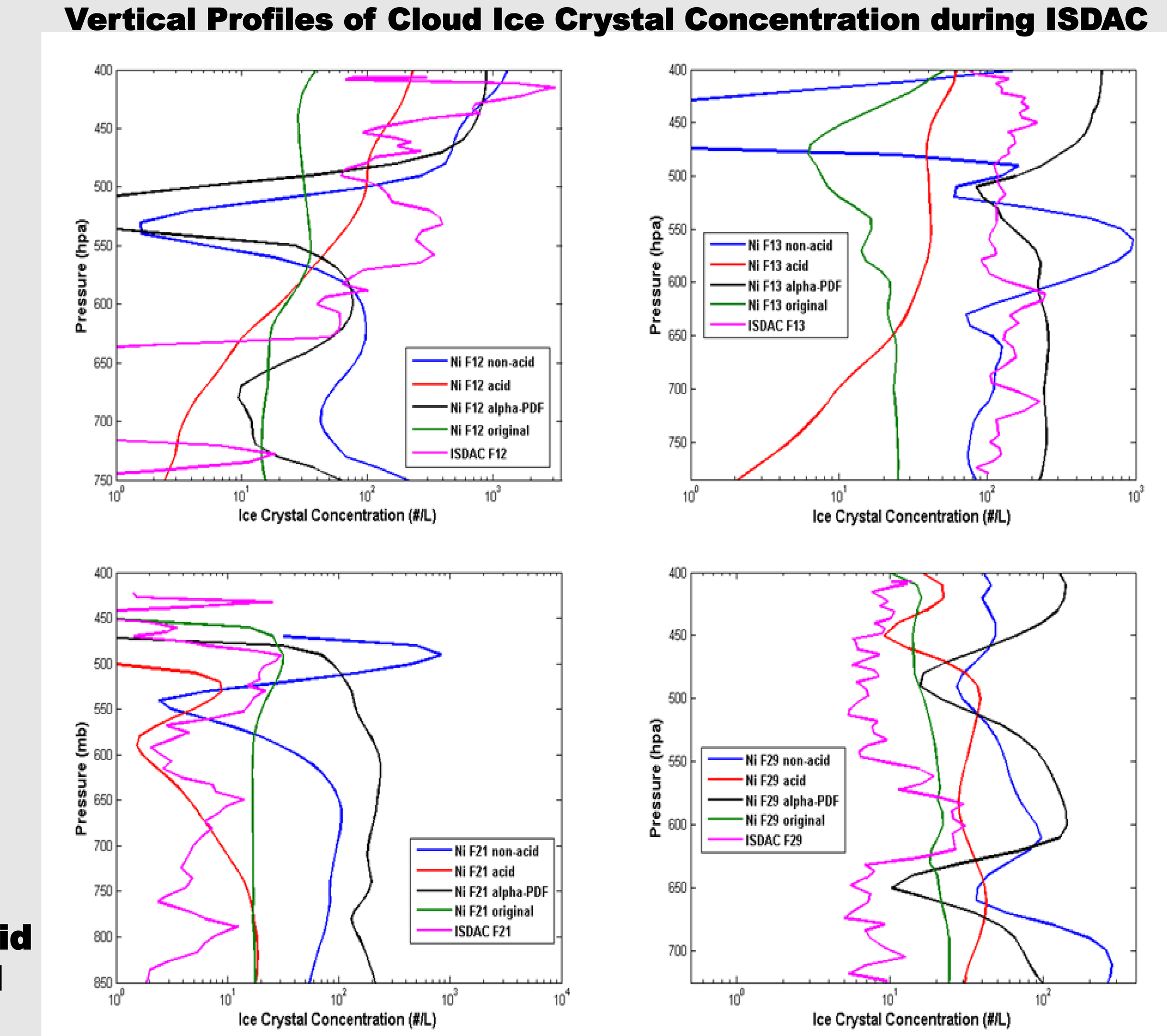
F21
Barrow, AK
April 15th 2008
Polluted

F13
Barrow, AK
April 5th 2008
Non-Polluted

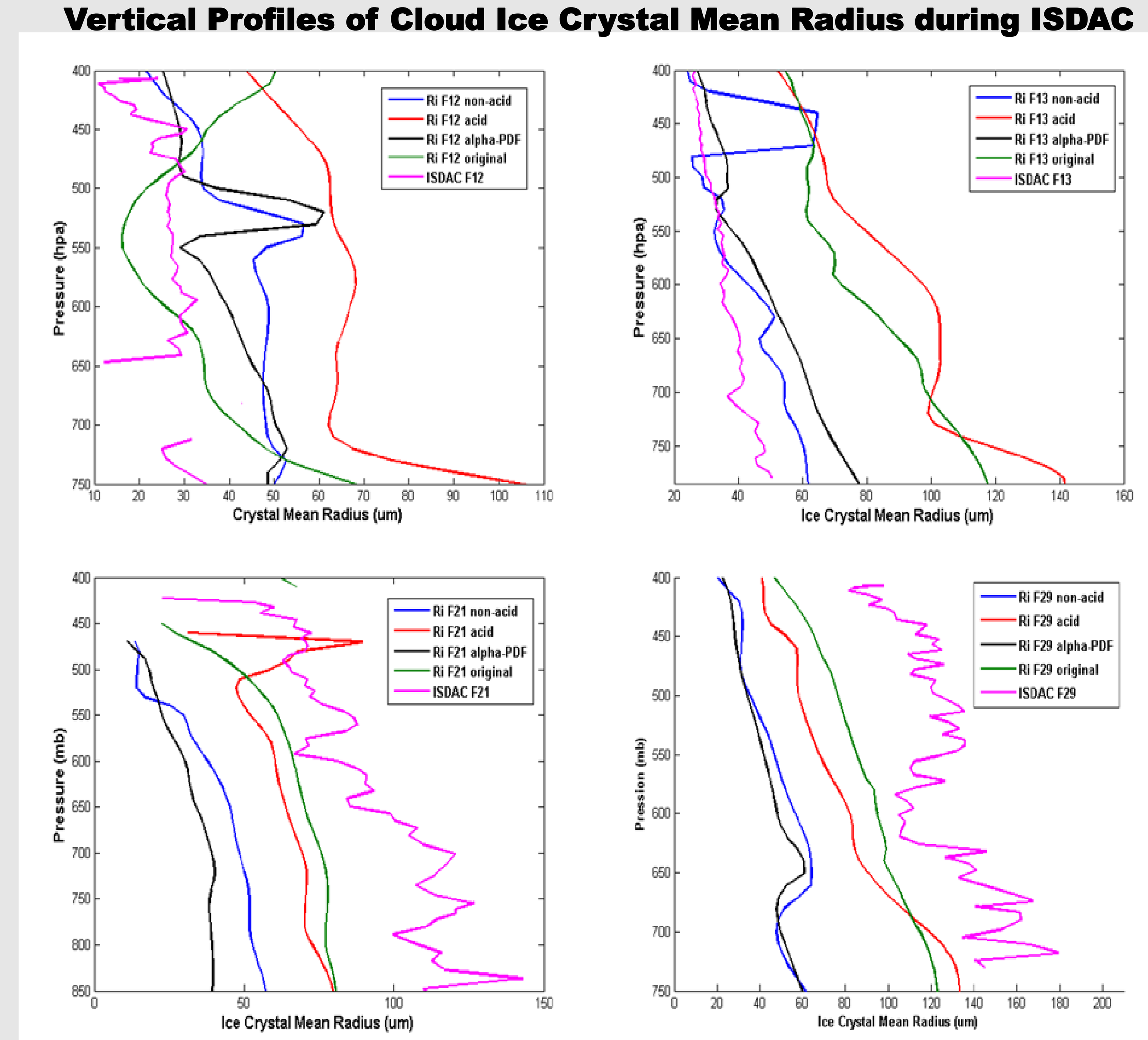
F29
Fairbanks, AK
April 25th 2008
Polluted

RE : Relative Error
RMS : Root Mean Square Error

Vertical Profiles of Cloud Ice Crystal Concentration during ISDAC



Vertical Profiles of Cloud Ice Crystal Mean Radius during ISDAC



The results show that the non polluted cases (F12&F13) are better reproduced by the non-acid and alpha-PDF parameterisations. The non-acid scenario has the lowest N_i bias and RE (mean relative error) followed by alpha-PDF whereas the roles are inverted for R_i. Both parameterizations do a really good job at reproducing large values of Ni (~ 10^3 #/L) while they underestimates it when $N_i < 10^2$ #/L. The alpha-PDF scenario does an excellent jobs at simulating cloud top R_i (~20 um) in both F12 & F13 whereas the non-acid version overestimate R_i slightly more. The ice crystal number concentration and mean radius are by far better reproduced by those two versions of the scheme compared to the acid and original versions, which substantially overestimate R_i and underestimate N_i. This result was expected and confirms that these 2 models are representative of the ice crystal formation in pristine air masses.

The acid and the original versions of the MY scheme better reproduce the polluted cases (F21 & F29). Both the acid and original versions do a really good job at simulating the ice crystal number concentration in both flights while they slightly underestimate the crystal mean radius. Both models underestimate R_i in the lower levels of the F21 TIC-2B while they underestimate R_i in the higher levels of the F29 cloud. For both N_i and R_i, the original version of MY scheme has a lower bias, RE and RMS as well as a higher correlation with the ISDAC measurements. Even thought the original version of the scheme is not conceived to reproduced polluted event, its limitation in ice nucleation yields results that fits surprisingly well the ISDAC polluted measurements.

In general, GEM-LAM reacts well to changes in the MY scheme. For a given case (polluted or clean), the appropriate versions of the MY scheme reproduce quite well the in-situ measurements obtain during that given flight. For both polluted cases (F21 & F29), the acid and original version of the scheme have simulated quite well the formation of TIC-2b, which are often associated to acid coated ice nuclei. On the other hand, the non-acid and alpha-PDF versions of the scheme have done a good job at simulating the formation of a TIC-1 (F12) and a TIC-2a (F13) commonly found in non-polluted air masses. The progressive nature of the alpha-PDF model helps the reproduction of the smaller concentration that are overlooked by the non-acid model.

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