Mineralogy sensitive ice nucleation parameterizations in Dust Regional Atmospheric Model (DREAM)

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Introduction

Aerosol-cloud interactions are one of the uncertainties in climate models (IPCC, 2013)

Atmospheric ice particles play a dominant role in determining the physical properties of clouds and the chemical composition of the troposphere and in physical processes such as radiative transfer, precipitation and cloud electrification (Lohmann et al., 2005).

Heterogeneous ice nucleation (IN) from the parent phase (liquid or gas) occurs when conditions such as temperature, relative humidity, and a surface for nucleation (like an INP) provide energetically favorable conditions for this process.

Dust Particles as Ice Nucleating Particles (INP)

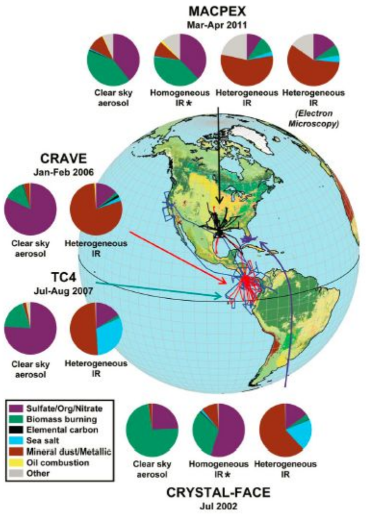
Deposition ice nucleation is the process in which ice nucleates from supersaturated vapor with respect to ice (RHi>100%) on an INP directly.

Immersion freezing refers to IN initiated by an INP that becomes immersed in a water droplet.

Desert dust aerosols are most common ice nucleating agent in immersion freezing mode (Cziczo et al., 2013).

Recognition of the role of dust as ice nuclei, parameterizations for immersion and deposition freezing due to dust have been developed (DeMott et al, 2015; Ullrich et al, 2017).

Feldspar minerals have shown to be a significantly more efficient ice nucleating agents than other dust minerals which led to the development of a ‘mineralogy sensitive’ immersion freezing parameterization (Atkinson et al, 2013; Harrison et al, 2019).



Cziczo et al., 2013

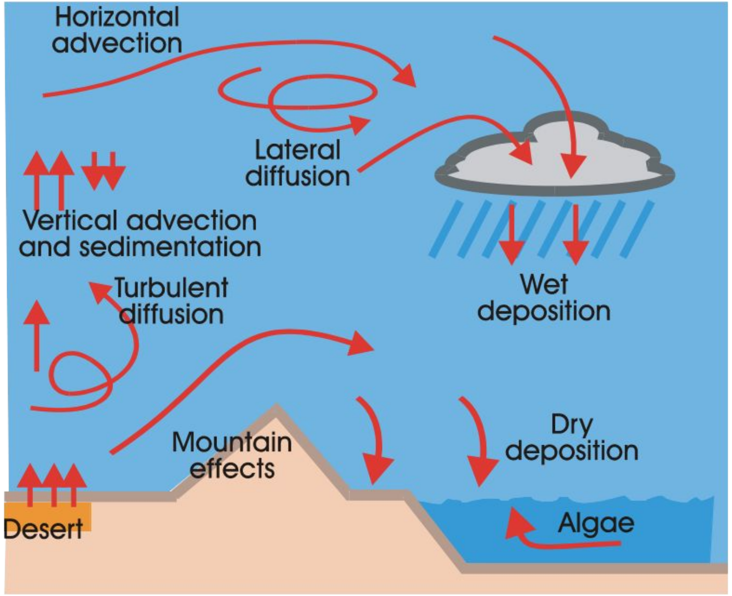
$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - \left(w - v_{gk}\right)\frac{\partial C_k}{\partial z} - \nabla\left(K_H \nabla C_k\right) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right)_{SOURCE} - \left(\frac{\partial C_k}{\partial t}\right)_{SINK}$$

Dust REgional Atmospheric Model (DREAM)

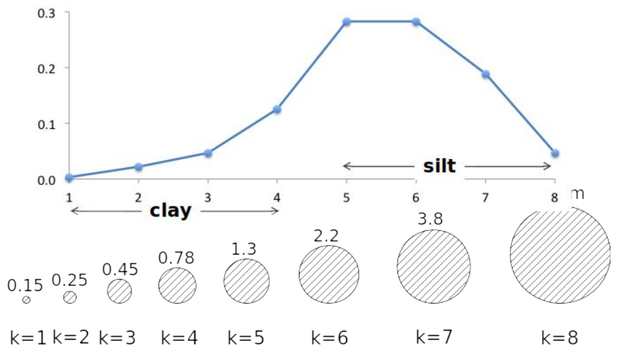
Developed as add-on component of an atmospheric model and is designed to simulate and/or predict the atmospheric cycle of mineral dust aerosol.

Simulates all major processes of the atmospheric dust cycle (Nickovic et al., 2001).

Dust concentration is one of the governing prognostic equations in an atmospheric numerical prediction model (Janjic, 1990, 1994)



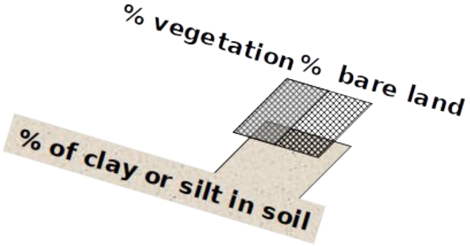
DREAM Model



In the dust emission scheme, aerosol injection into the atmosphere is controlled by type of soil, type of vegetation cover, soil moisture content, and surface atmospheric turbulence.

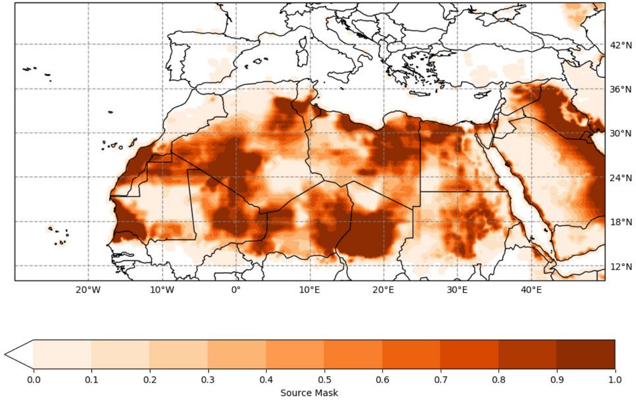
USGS global 1-km land cover data is used to distinct the dust productive soils from the others. USDA global 1-km soil texture is used to describe particle size distribution.

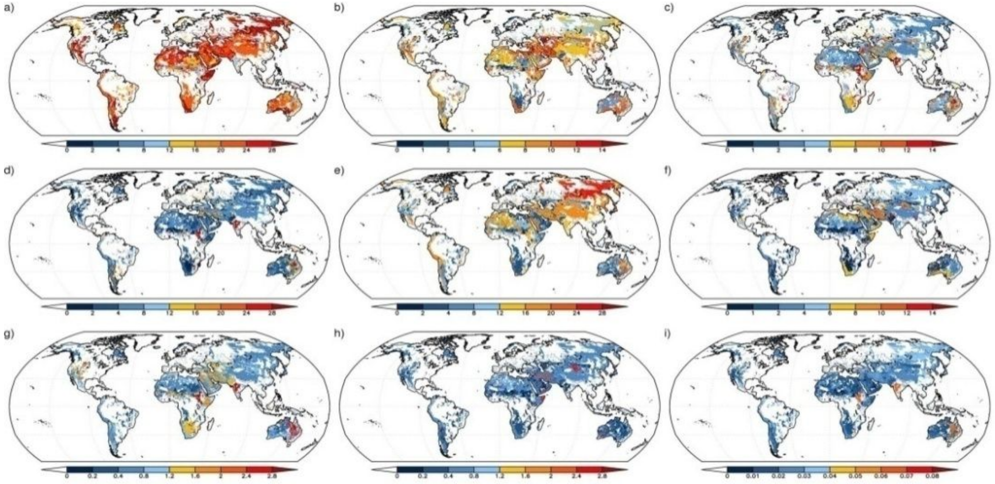
For each soil population (clay, silt, and sand) 8 particle size bins are calculated with effective radii of 0.15, 0.25 0.45, 0.78, 1.3, 2.2, 3.8 and 7.1 µm, respectively (Nickovic 2002).



Dust Mineral Composition Modeling

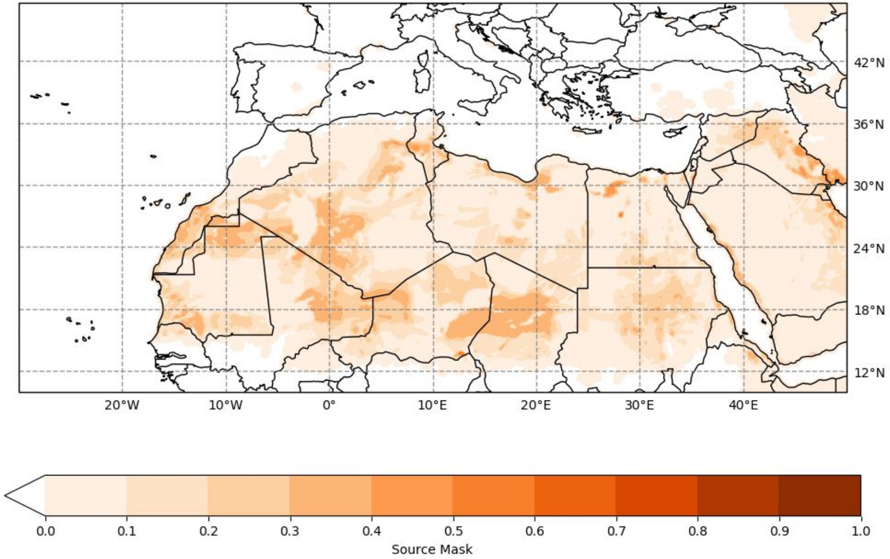
Simulation of particular mineral fraction atmospheric cycle using GMINER30 data (Nickovic et al., 2012).

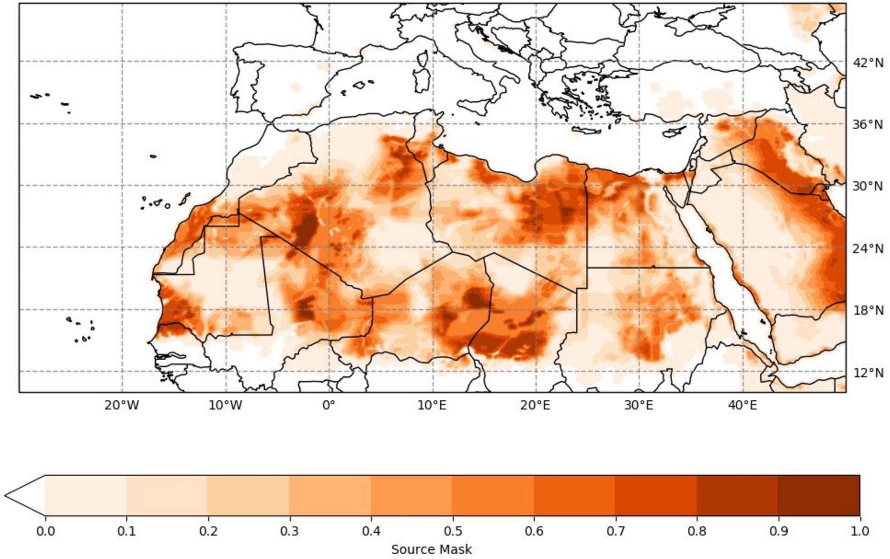




Nickovic et al., 2012

Silt Fraction Feldspar and Quartz Source Masks





DREAM IN Forecasts

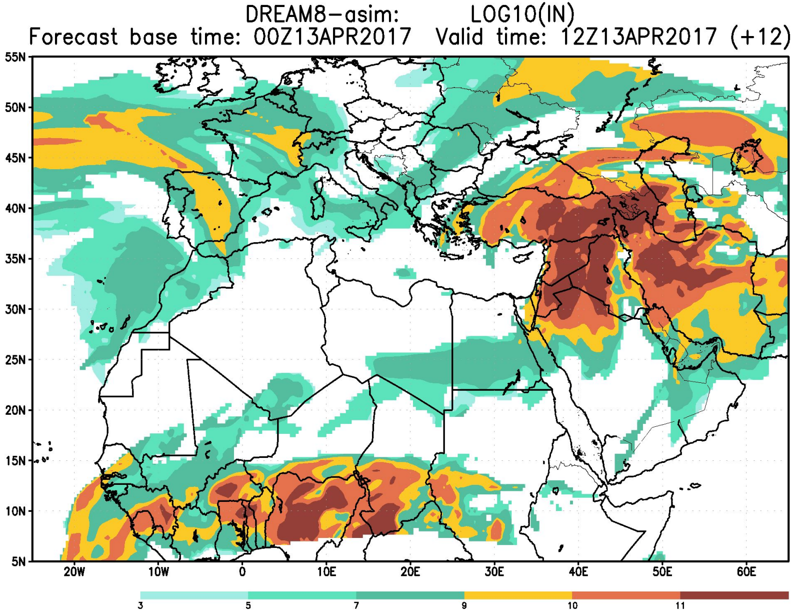
The operational forecast is performed by the Republic Hydrometeorological Service of Serbia under the activities of the South East European Virtual Climate Change Center, with the assistance of the Environmental Physics Laboratory, Institute of Physics Belgrade, Serbia (http://dream.ipb.ac.rs)

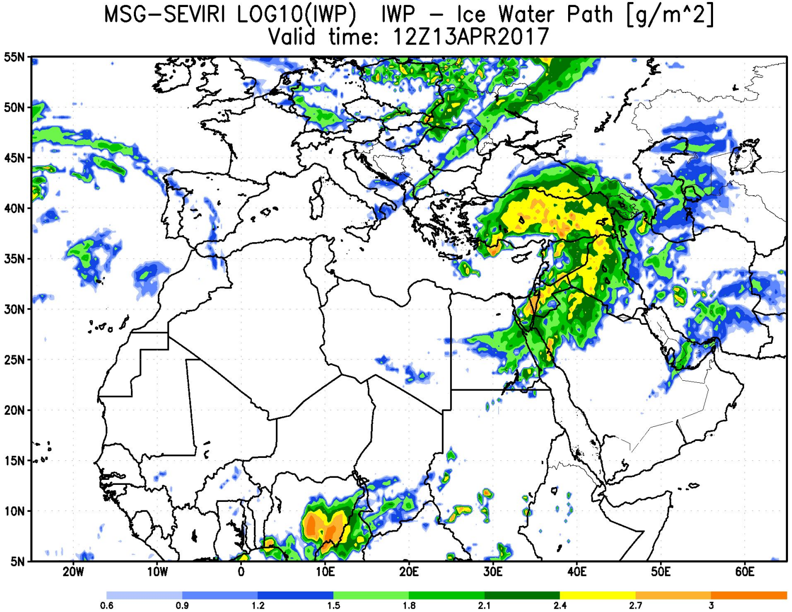
The calculation of the number of ice nuclei in the operational DREAM model is based on atmospheric parameters and on dust concentration (Nickovic et al, 2016).

For temperatures in the interval (-36°C; -5°C), the immersion ice nucleation parameterization developed by DeMott et al. (2015) is used. For temperatures in the interval (-55°C; -36°C), the Steinke et al. (2015) parameterization for the deposition ice nucleation was implemented (Nickovic et al., 2016).

Operational forecasts have been used in the PRE-TECT experimental campaign in Crete in April 2017. (http://pre-tect.space.noa.gr)

DREAM IN Operational Forecasts





Modeling Effects of Mineral Dust on Ice Nucleating Particle Concentrations (INPC)

Effects of Mineral Composition of Dust on INPC

Atkinson et al. (2013) concluded that feldspars, and especially K-Feldspar can be major components in INPC due to dust. They developed a parameterization to be used in atmospheric models for eight different minerals.

Welti et al. (2019) investigated different samples of K-feldspar and Na/Ca- rich feldspars to test their activity as INP in immersion mode. Further, they found that temperatures at which feldspars contribute to ice formation depend on the transported particle size.

Mineralogy sensitive emission and transport schemes and IN parameterizations can be the next step in modeling ice nucleation due to dust in regional atmospheric models.

Modeling of Dust Effects on INPC

Applicability of INPC parameterizations has been confirmed by several modeling and remote sensing studies (Nickovic et al., 2016, Vergara-Temprado et al. 2017, Marinou et al., 2019)

Boose et al. (2016) suggest the use of mineral specific parameterizations for feldspar and quartz components of mineral dust:

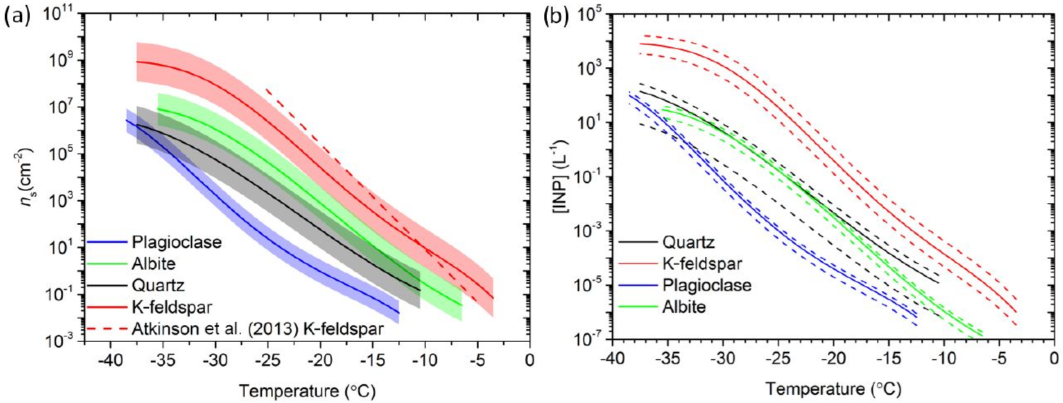
- K-feldspar for temperatures above 250 K and for lower temperatures additionally Na-plagioclase feldspars and quartz emissions and transport should be quantified.
- Since simulations of dust mineral composition this is complex and computationally expensive to implement, more studies quantifying the ice nucleation ability of dust as it is found in the atmosphere may circumvent this complexity.

IN Parameterization by Harrison et al. (2019)

Harrison et al. (2019) investigate relative importance of quartz to feldspars in immersion ice nucleation and use literature data and new experiments to develop a new parameterization.

In numerical models, explicit simulation of mineral dust fractions enables the use of 'mineralogy sensitive' immersion parameterizations.

They propose use of this new parameterization in numerical models.



Harrison et al. (2019)

Implementation of Mineralogy Sensitive IN Parameterizations

The immersion and deposition ice nucleation parameterizations due to dust have already been implemented in the DREAM model, not taking into consideration the mineral composition of dust.

Model variables:

- Dust concentration
- Thermodynamic quantities
- Mineral fractions

are used to calculate ice nucleating particle concentration based on mineral specific immersion freezing parameterizations in appropriate temperature ranges for each parameterization.

DREAM INPC parameterizations in this study (I20)

Immersion (Harrison et al., 2019):

Quartz: $\log(n_s(T)) = -1.709 + (2.66 \times 10^{-4} T^3) + (1.75 \times 10^{-2} T^2) + (7 \times 10^{-2} T)$, ($-10.5$ to -37.5° C; 0.8);

K-feldspar: $\log(n_s(T)) = -3.25 + (-0.793T) + (-6.91\times10^{-2} T^2) + (-4.17\times10^{-3} T^3) + (-1.05\times10^{-4} T^4) + (-9.08\times10^{-7} T^5)$, ($-3.5$ to -37.5° C;0.8);

plagioclase feldspar: $\log(n_s(T)) = (-3.24\times10^{-5} T^4) + (-3.17\times10^{-3} T^3) + (-0.106T^2) + (-1.71T) - 12$, ($-12.5$ to -38.5° C; 0.5);

albite: $\log(n_s(T)) = (3.41 \times 10^{-4} T^3) + (1.89 \times 10^{-2} T^2) + (-1.79 \times 10^{-2} T) - 2.29$, ($-6.5$ to -35.5° C; 0.7).

Deposition (Ullrich et al.,2017): Not sensitive to mienral composition

3 INPC setup options in DREAM model

N16 (Nickovic et al., 2016): DeMott et al., 2015 immersion and Steinke et al., 2015 deposition

U17 (Ullrich et al., 2017 immersion and deposition

I20 (current development) Harrison et al., 2019 **mineralogy sensitive immersion** and U17 deposition

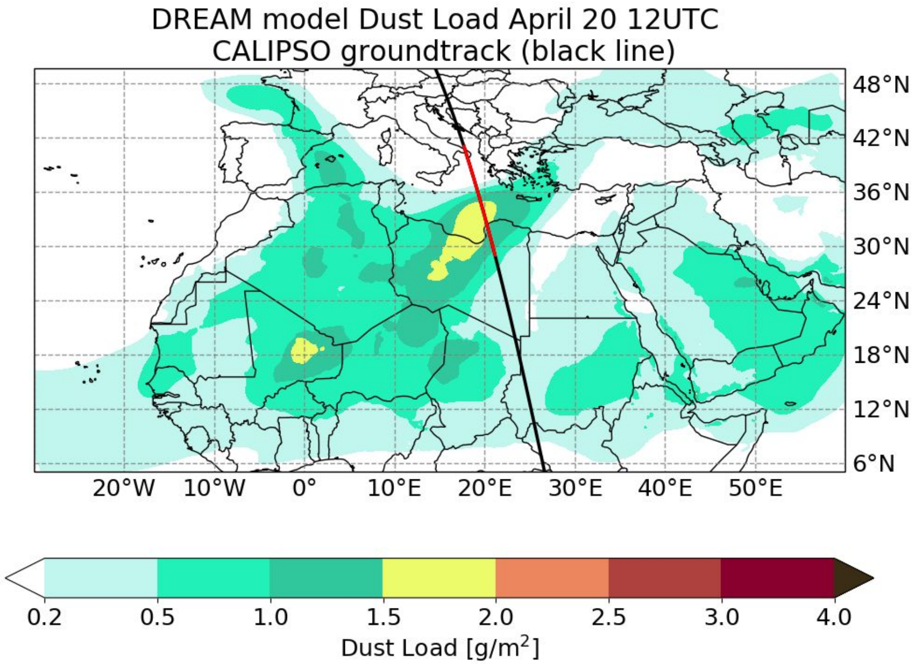
Dust Plume reaching Potenza and Cyprus, in April 2016

A case study related to the observations of geometrical and microphysical characteristics of the clouds formed in the Mediterranean, in April 2016 is considered.

We compare the model results with ice nucleating particle concentrations retrieved using lidar and radar ground-based remote sensing observations at Cyprus and Potenza.

The analysis explores how the mineral composition of dust and the parameterization of its effects on ice initiation could further improve ice nucleation representation in numerical models.

DREAM Model Set-up



DREAM domain covers Northern Africa, Middle East and the Mediterranean with horizontal resolution of ~15 km and 28 vertical levels

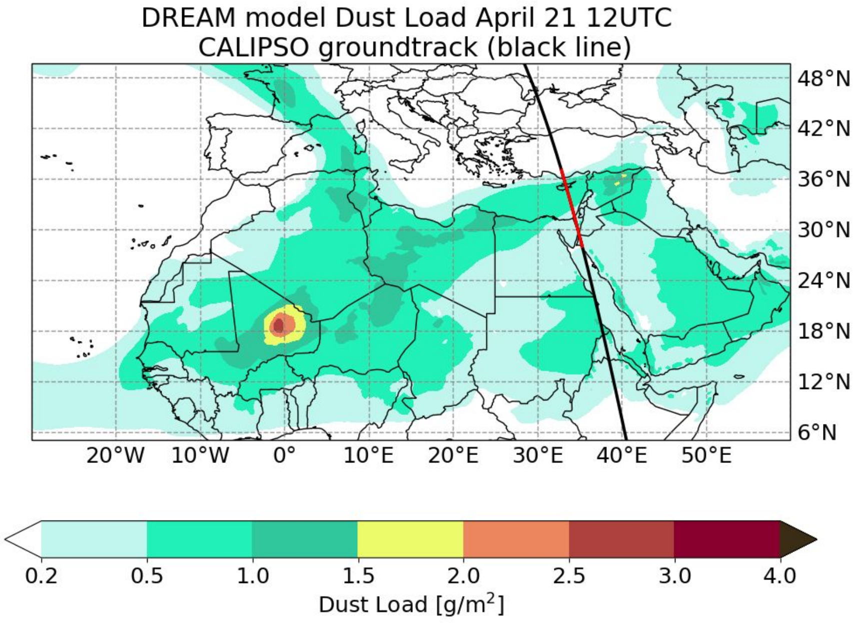
First results of mineralogy sensitive emission and different immersion parameterizations included in DREAM model are shown for a dust plume in April 2016.

Model results are compared with dust concentrations vertical profiles retrieved from lidar measurements (Ansmann et al., 2019), CloudNet measurements(Illingworth et al., 2007) , and DARDAR products (raDAR/liDAR; Delanoë and Hogan , 2008).

April 18-21 Dust Plume

From 14 to 20 April, anticyclonic conditions prevailed with a westerly flow of warm air, while from 21 to 27, cyclonic pattern with warm southwesterly air was present (Schrod et al., 2017).

Atmospheric conditions supported the transport of dust from the Sahara and Middle East (Floutsi, 2018).

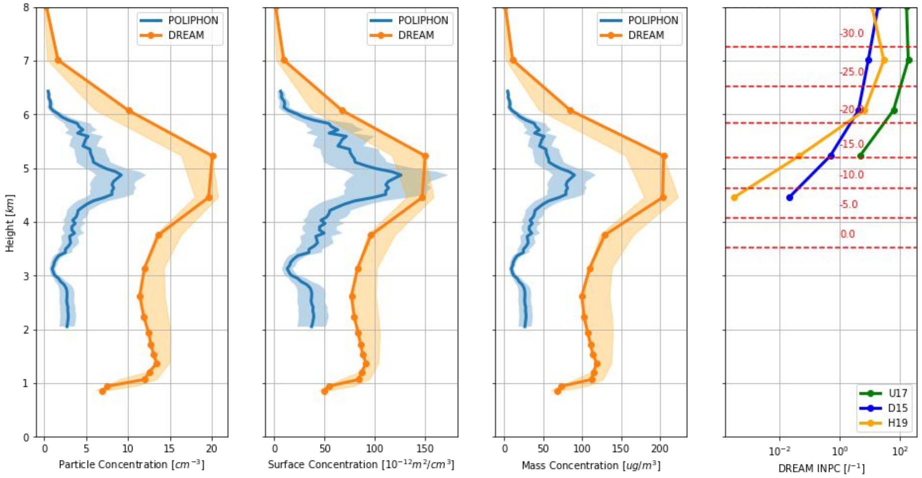


POLIPHON Profiles at Potenza on April 18 15UTC

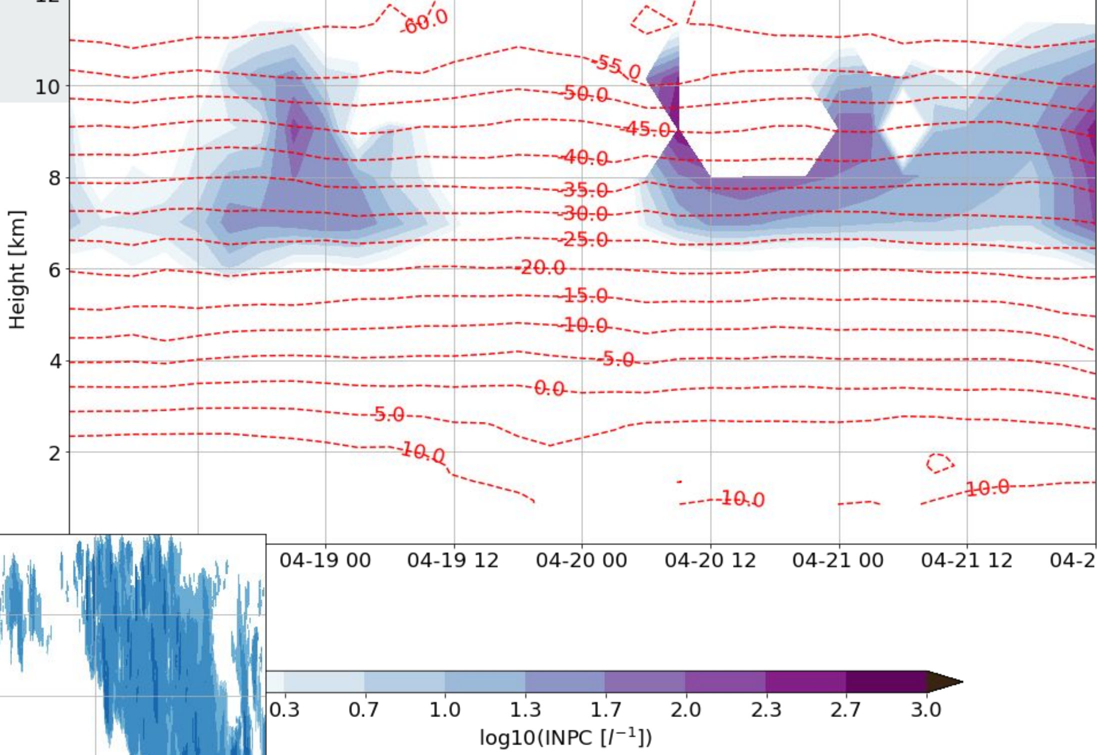
Model vertical profiles verification against lidar measurements.

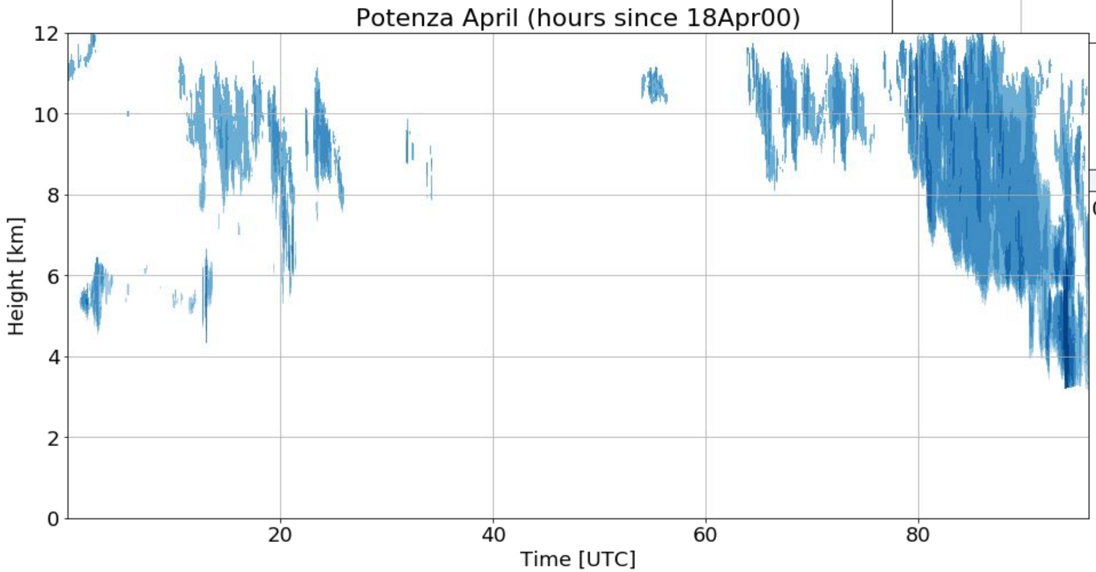
Comparison with vertical profiles retrieved from lidar measurements using the POLIPHON algorithm (Mamouri and Ansmann, 2016).

Comparison of different IN parameterizations.



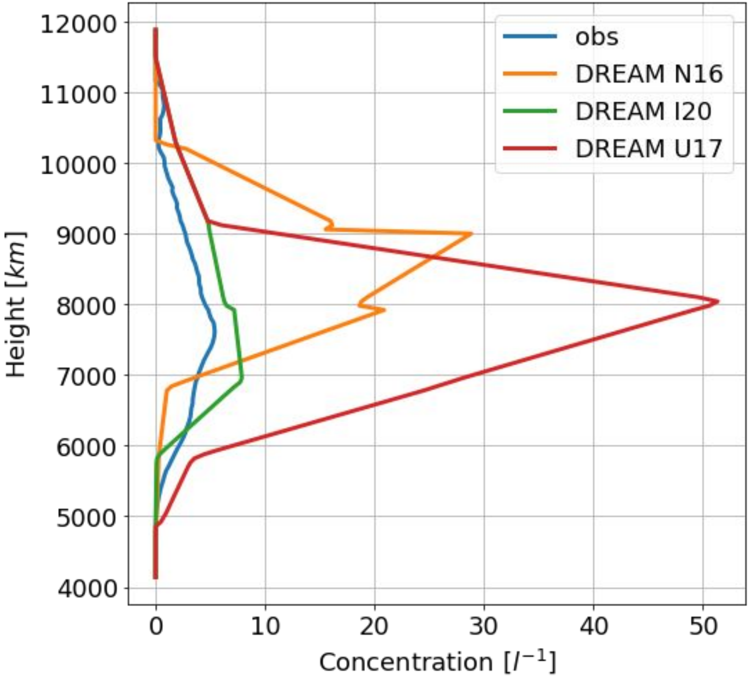
CloudNet at Potenza

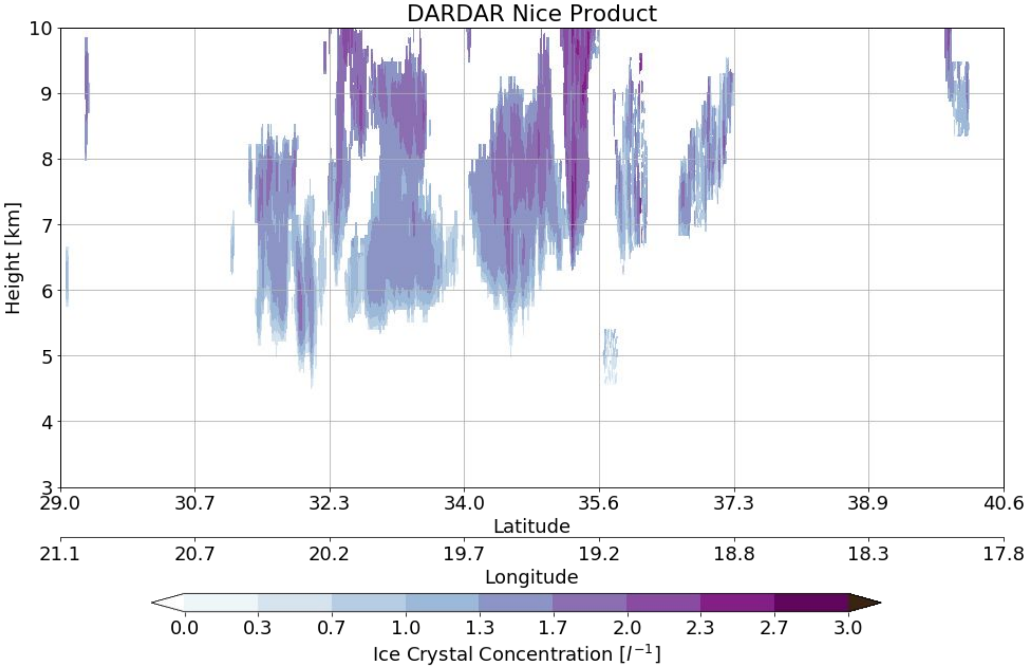




CloudNet Ice Water Content vs DREAM INPC

CALIPSO Overpass on April 20, Mean Dust Plume Profile, Ice Crystal Concentration vs INPC



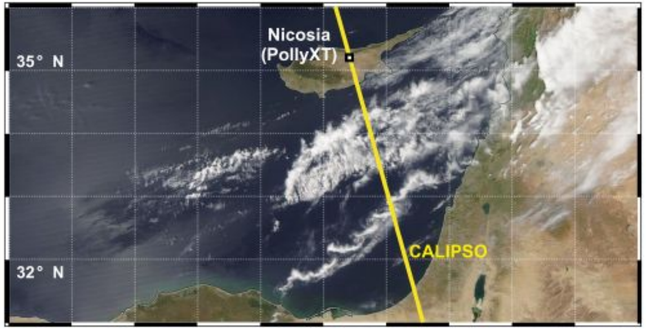


INUIT-BACCHUS-ACTRIS Campaign
Cyprus, April 2016

Ice Nuclei Research Unit (INUIT; https://www.ice-nuclei.de/the-inuit-project)

Impact of Biogenic versus Anthropogenic emissions on Clouds and CLimate: towards a Holistic UnderStanding (BACCHUS; http://www.bacchus-env.eu)

Aerosols, Clouds, and Trace gases Research Infrastructure (ACTRIS; https://www.actris.eu)



CALIPSO Overpass on April 21

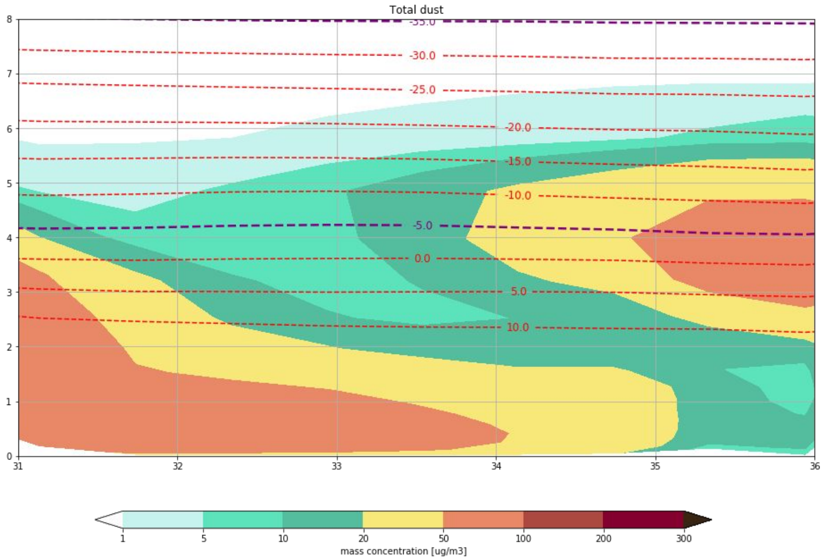
True color observations from the MODIS instrument (Moderate Resolution Imaging Spectroradiometer) on board Aqua satellite are used (https://worldview.earthdata.nasa.gov).

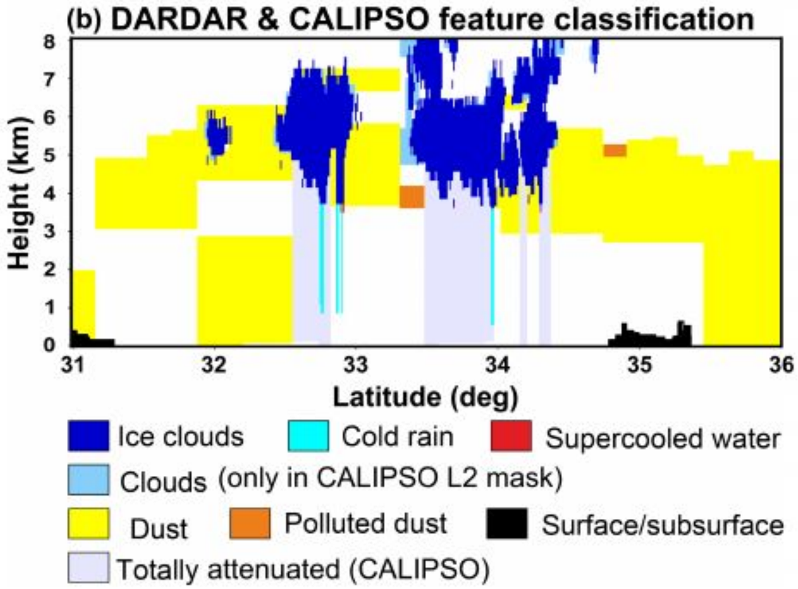
To get a better insight into the vertical cloud structure, we use outputs from the synergistic radar–lidar retrieval DARDAR.

The DARDAR retrieval uses collocated CloudSat, CALIPSO, and MODIS measurements and provides an ice cloud retrieval product (DARDAR-Cloud; Delanoë et al., 2014) on a 60 m vertical and 1.1 km horizontal resolution.

Spatial distribution of the DARDAR ice particle number concentrations at 11:01 UTC on 21 April 2016

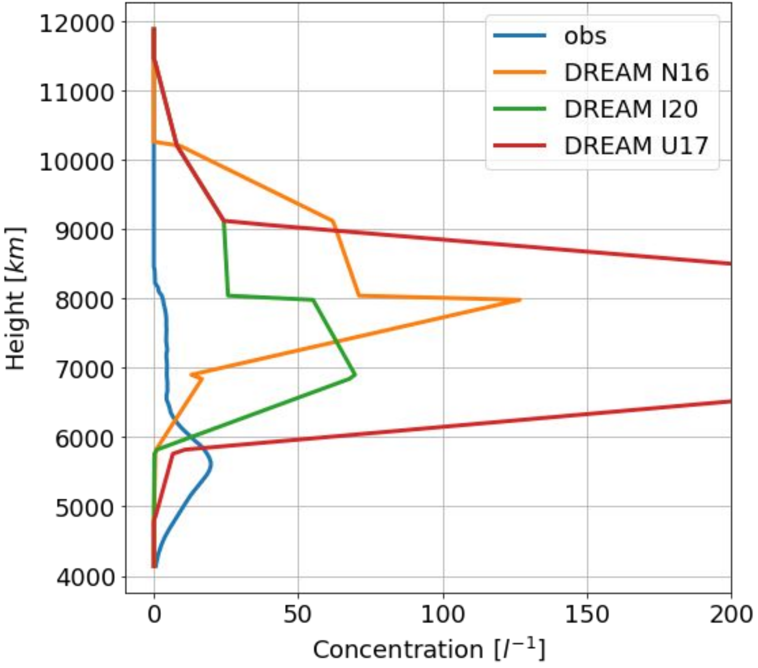
DREAM Dust Concentrations along CALIPSO Ground Track

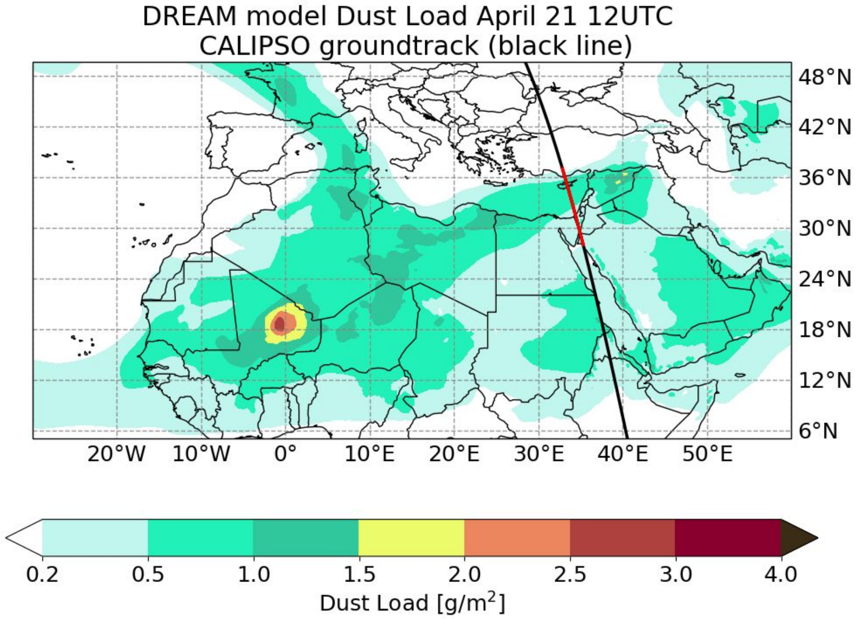




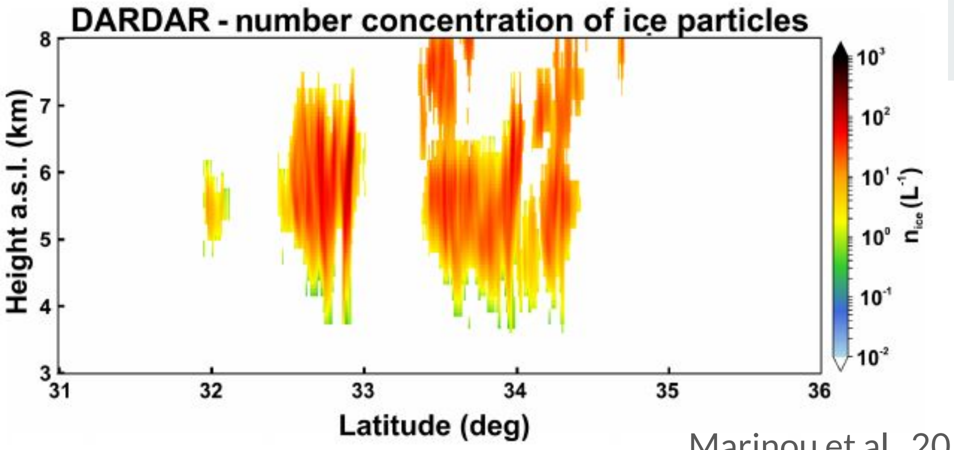
Marinou et al., 2019

CALIPSO Overpass on April 21, Mean Dust Plume Profile, Ice Crystal Concentration vs INPC





DREAM and DARDAR-Cloud Comparison



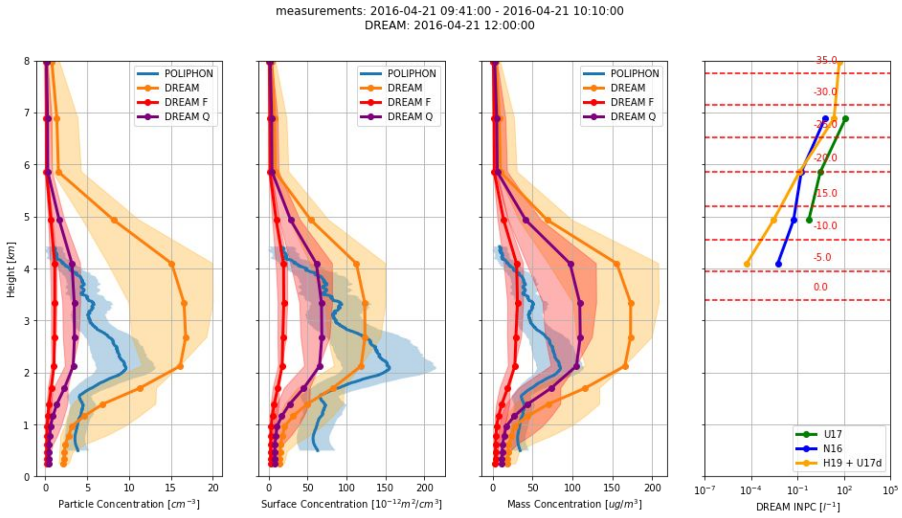
Marinou et al., 2019

Vertical distribution along CALIPSO ground path of the DARDAR ice particle number concentrations at 11:01 UTC on 21 April

Model results at 12UTC for coordinates

32.9393N 33.9636E

34.1396N 33.6312E



Conclusions and future work

The first implementation of mineralogy sensitive IN parameterizations (H19) in a regional NWP model (DREAM) was presented.

We have shown that computational complexity, while it can be an issue can extend the model running time by ~15-20% for each mineral which is manageable even in operational environment.

We have shown that such parameterizations can provide reasonable results and show good agreement with results of remote sensing retrieval algorithms.

Conclusions

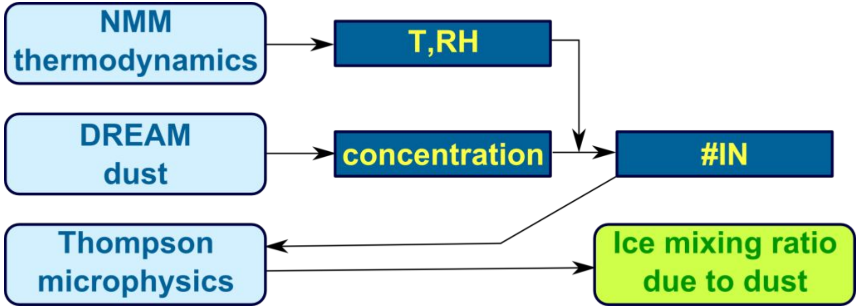
Mineralogy sensitive INPC agrees within the order of magnitude with Ice Crystal Concentration.

SImulated INPC correlates very well with Ice Crystal Concentrations and in the presented cases seems to be good proxy for Ice Crystal Concentration in comparison to other INPC parameterizations implemented in the model.

INPC results are highly dependant on the quality of the dust forecast. Slight differences in feldspar contribution to dust and feldspar properties as IN significantly affect the INPC profiles.

Results are encouraging regarding the next steps in model development but additional tests and a comprehensive verification against measurements will provide us with a better insight.

Future Work



Verification of model results against lidar measurements, CloudNet measurements and DARDAR product, and in situ measurements.

Development of an integrated geophysical system:

- Implementation of Thompson and Eidhammer (2014) microphysical scheme
- Simulations of thermodynamic conditions and dust concentrations and mineral composition at each model time step as input to microphysics scheme
- Extension of capabilities of: Operational weather forecasting, Real time validation, Climate simulations

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Thank you!

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