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CERTAINTY
CLOUD-AEROSOL INTERACTIONS & THEIR IMPACTS IN THE EARTH SYSTEM

Modeling the interactions between aerosols and mixed-phase clouds

Montserrat Costa Surós

This project has received funding from Horizon Europe programme under Grant Agreement No 101137680 via project CERTAINTY (Cloud-aERosol inTeractions & their impActs IN The earth sYstem) and from the AXA Research Fund.

27/05/2025

Setting the Stage – Then Taking Action

CERTAINTY

CLOUD–AEROSOL INTERACTIONS
& THEIR IMPACTS IN THE EARTH SYSTEM

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Centro Nacional de Supercomputación

Consortium

CERTAINTY

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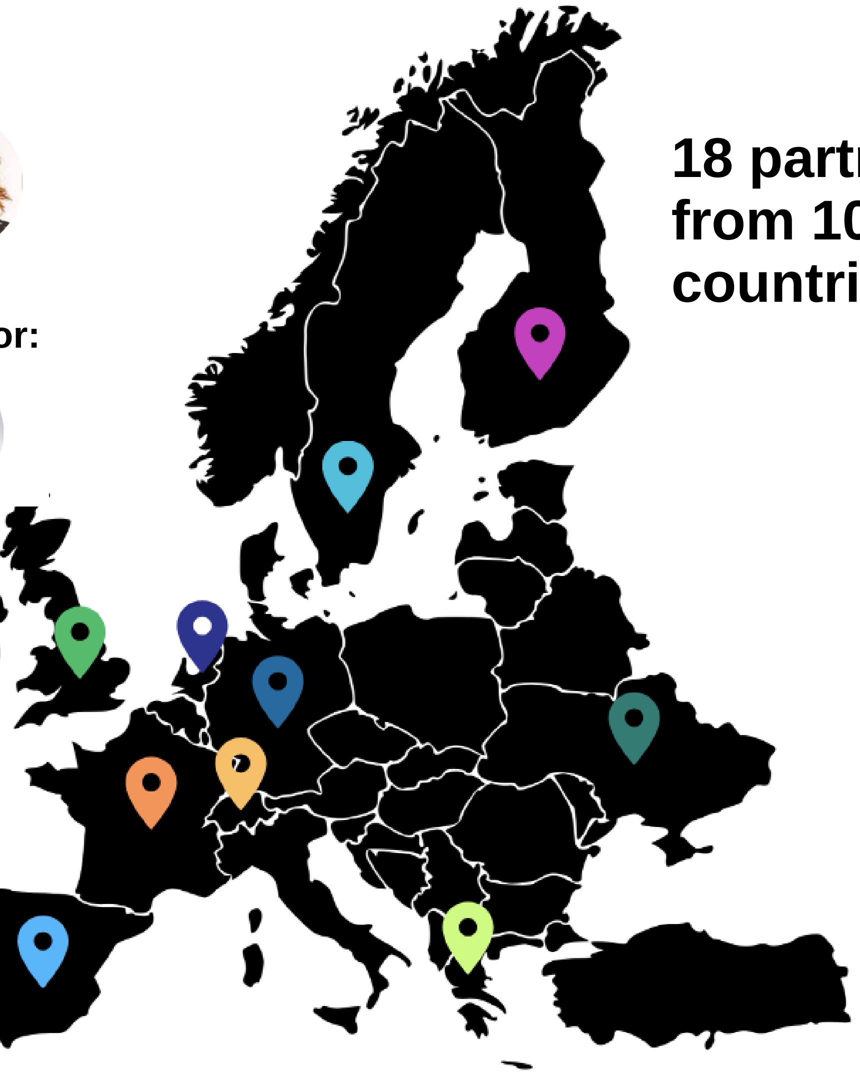
Jennie Thomas

cnrs IGE

Scientific coordinator:

Harri Kokkola

ILMATIETEEN LAITOS METEOROLOGISKA INSTITUTET FINNISH METEOROLOGICAL INSTITUTE



18 partners from 10 countries

cnrs
ILMATIETEEN LAITOS METEOROLOGISKA INSTITUTET FINNISH METEOROLOGICAL INSTITUTE
ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
Barcelona Supercomputing Center Centro Nacional de Supercomputación
Koninklijk Nederlands Meteorologisch Instituut Ministerie van Infrastructuur en Waterstaat
Stockholm University
DLR Deutsches Zentrum für Luft- und Raumfahrt
National Observatory of Athens
Lunds Universitet
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Helsingin Yliopisto
ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ TECHNICAL UNIVERSITY OF CRETE
ETH zürich
MAX-PLANCK-INSTITUT FÜR METEOROLOGIE
UHMI
pmod wrc
Imperial College London
MANCHESTER 1824 The University of Manchester

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Overarching objective

The overarching objective of CERTAINTY is to

deliver the knowledge and models that provide improved confidence and representation of the role of cloud–aerosol-radiation interactions in climate and weather.

This translates to **better understanding and predictions of extreme events** and facilitates planning **climate mitigation/adaptation strategies** for the good of European citizens and global society.

Total EU budget requested/granted: 8 million EUR (UK partners are now being moved out of this total)

Project duration: 1 January 2024 - 1 January 2028

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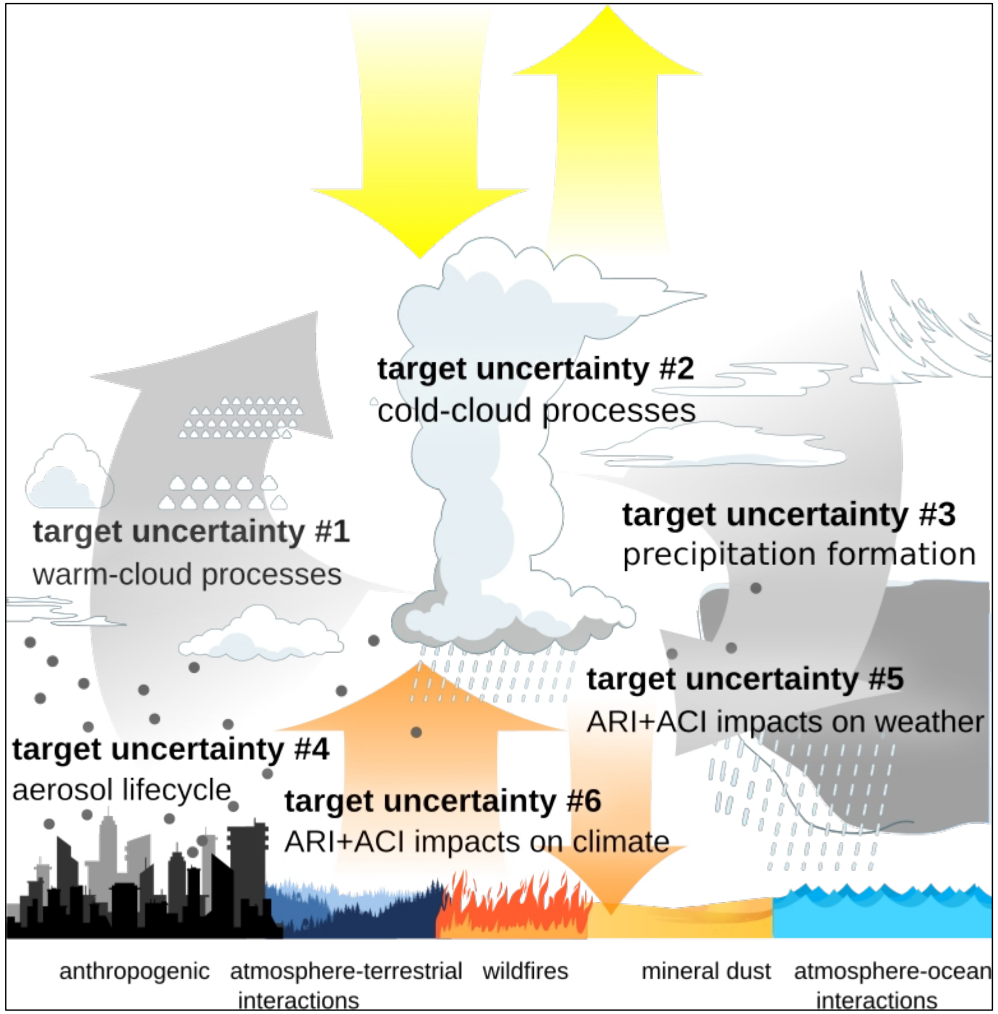
Target ACI uncertainties & processes

Specific Objectives (SOs):

- **SO#1 - #6**: address the six target uncertainties
- **SO#7**: Early adoption of EarthCARE and Metop-SG data into ACI science
- **SO#8**: Train the next generation of multidisciplinary, diverse ACI scientists
- **SO#9**: Use EU infrastructures to deliver FAIR and open science



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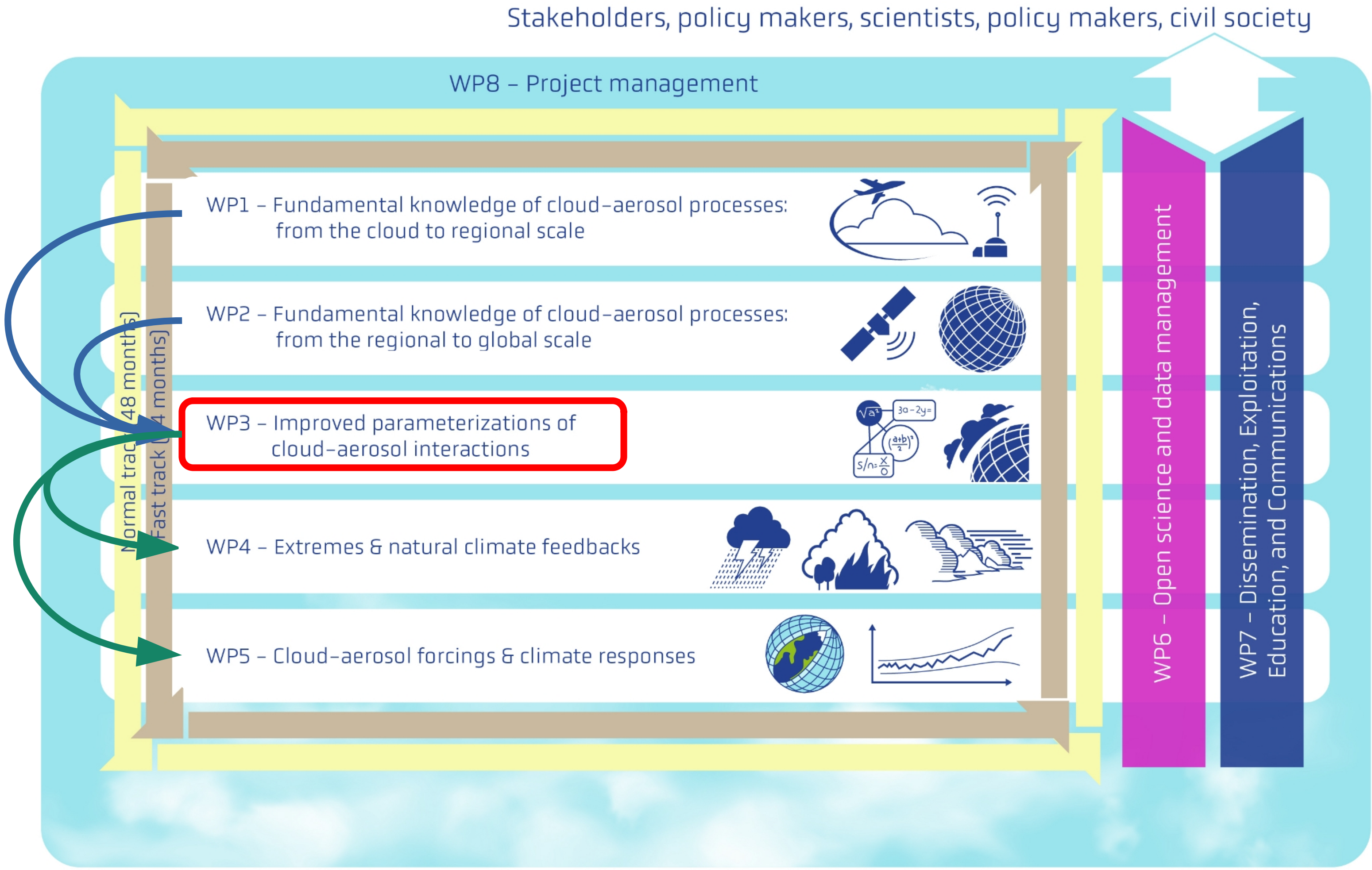
Work Packages structure



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WP3 – Improved parameterizations of cloud-aerosol interactions: the leads

Zamin Kanji
ETH zürich

Carlos Perez García-Pando
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Partners: BSC, ETH-Z, CNRS, FMI, KNMI, SU, NOA, LU, UEF, MPI-M, NOA, UMAN, UHEL

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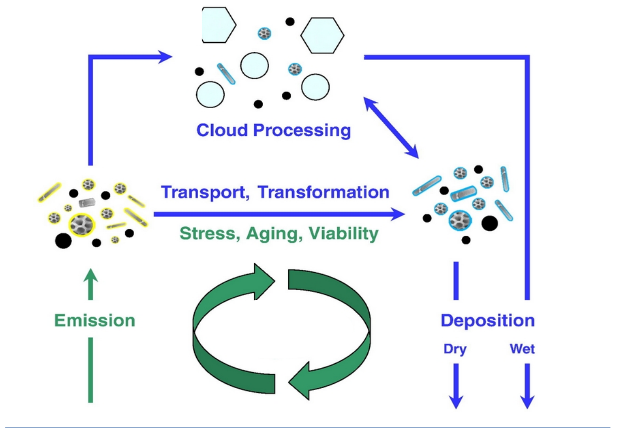
WP3 – Improved parameterizations of cloud-aerosol interactions: the tasks

Task 3.1: Improved representation of the **aerosol lifecycle with a focus on INPs**

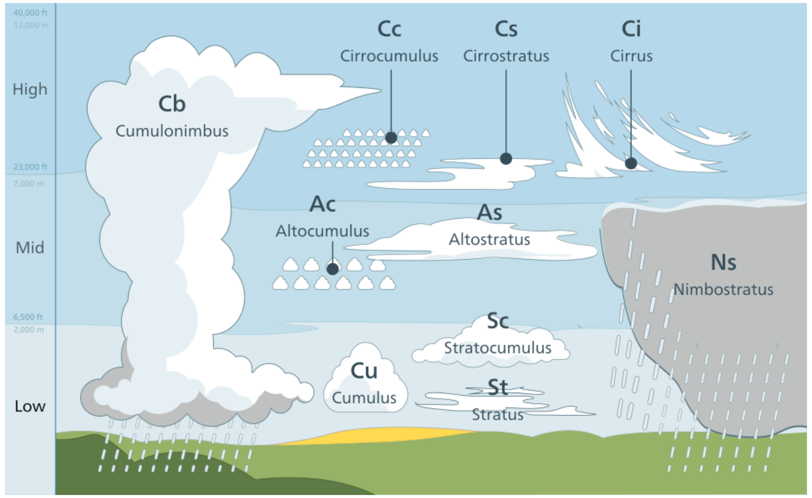
Task 3.2: Improved description of liquid cloud activation and **warm cloud** microphysics

Task 3.3: **Synthesis and implementation of existing** state-of-the-art **parameterizations for ice and mixed phase clouds**

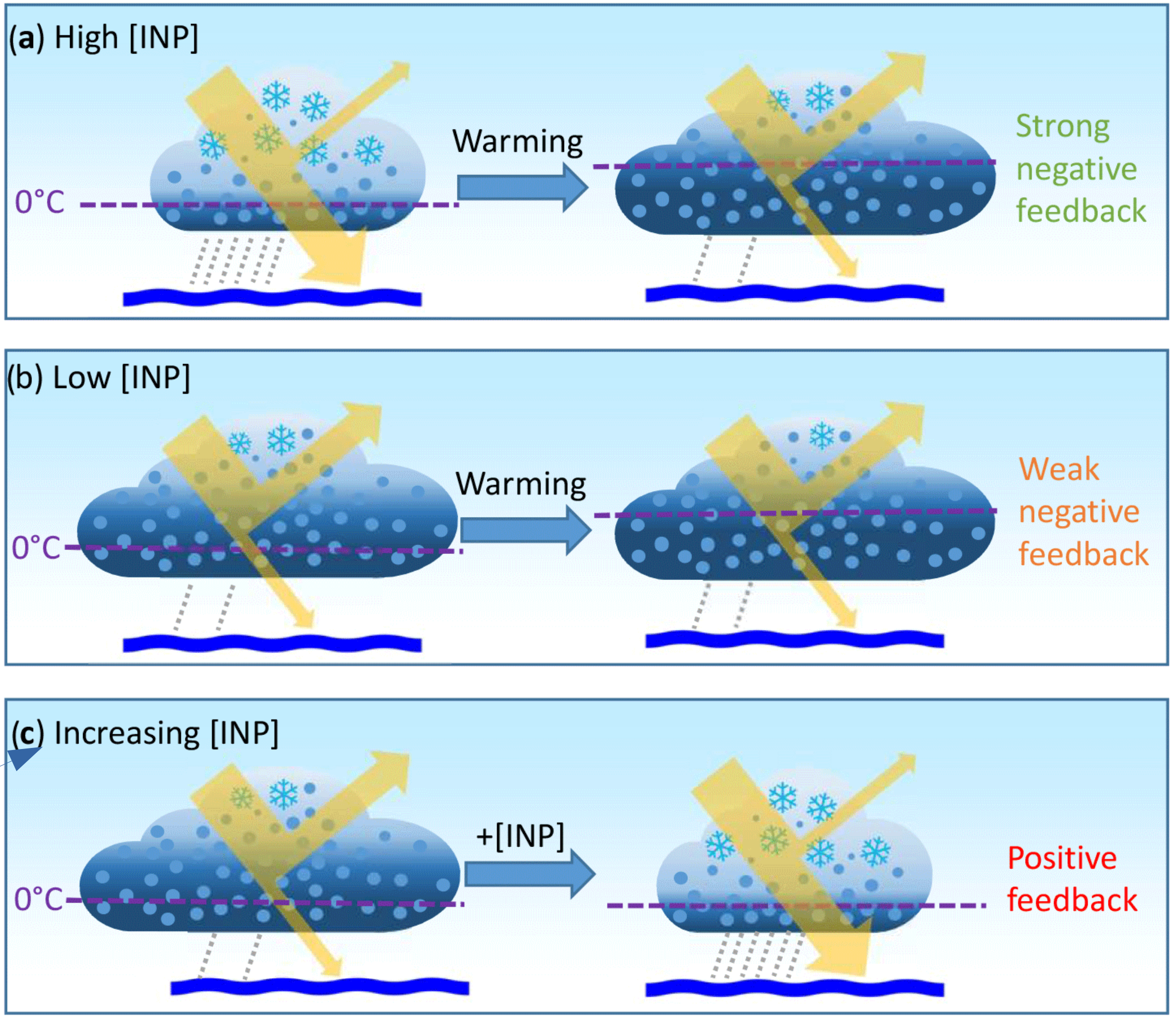
Task 3.4: **Development, implementation, and evaluation of new parameterizations for ice and mixed phase clouds**



Fröhlich-Nowoisky et al. (2016)



Why are INPs and the MPC important?



Kok et al. (2023),
Leung et al. (2025)

Murray et al. (2021)

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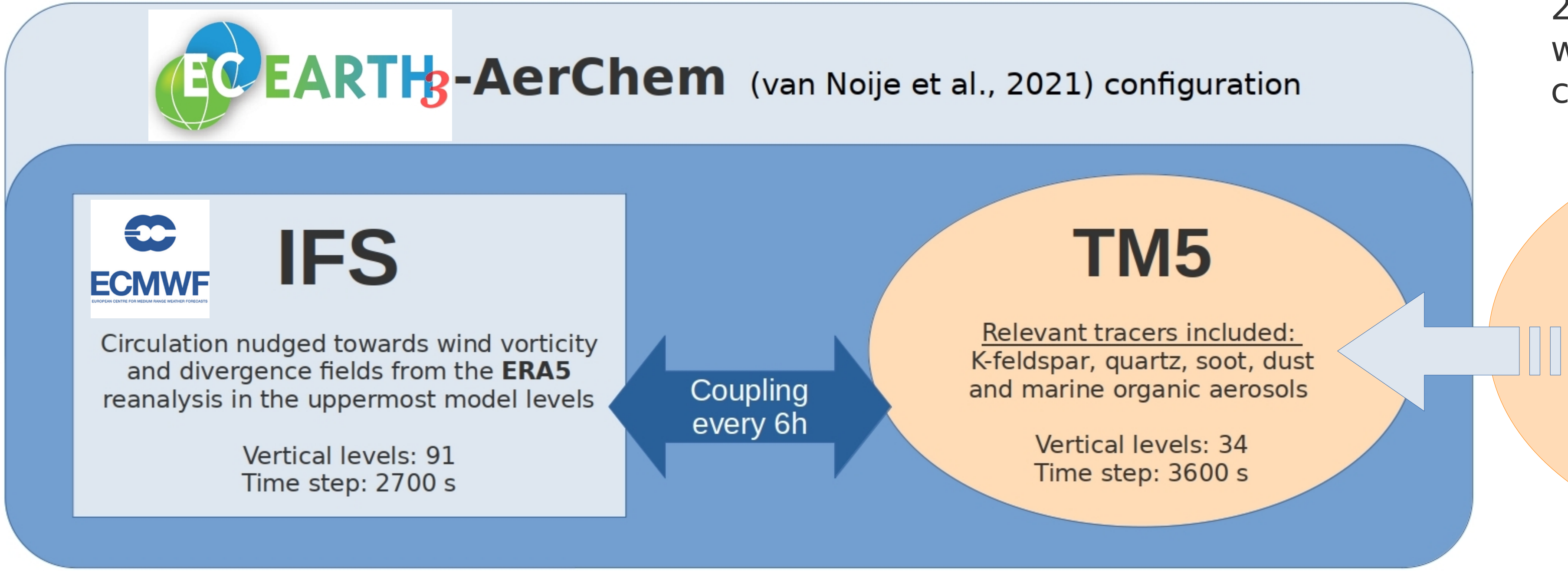
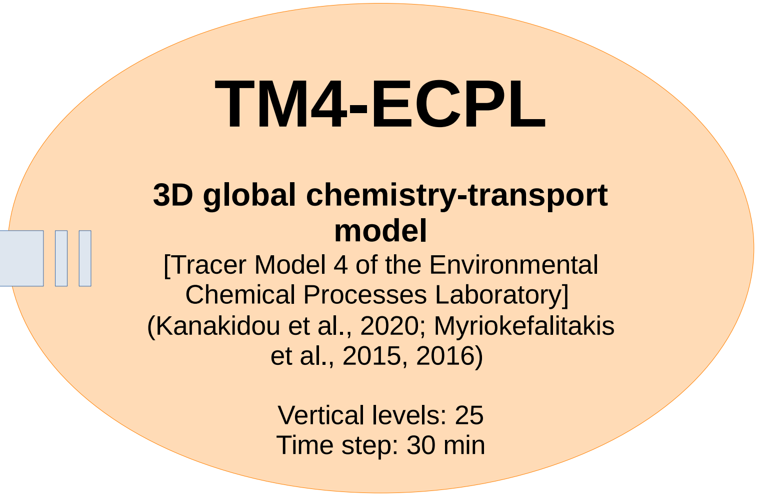
Methodology

Several 12-year-long simulations (2009 – 2020) with different ice nucleation parameterizations were run with the EC-Earth3-AerChem ESM with the following configuration:



6-year-long simulation (2009 – 2016) run with the TM4-ECPL with the following configuration:



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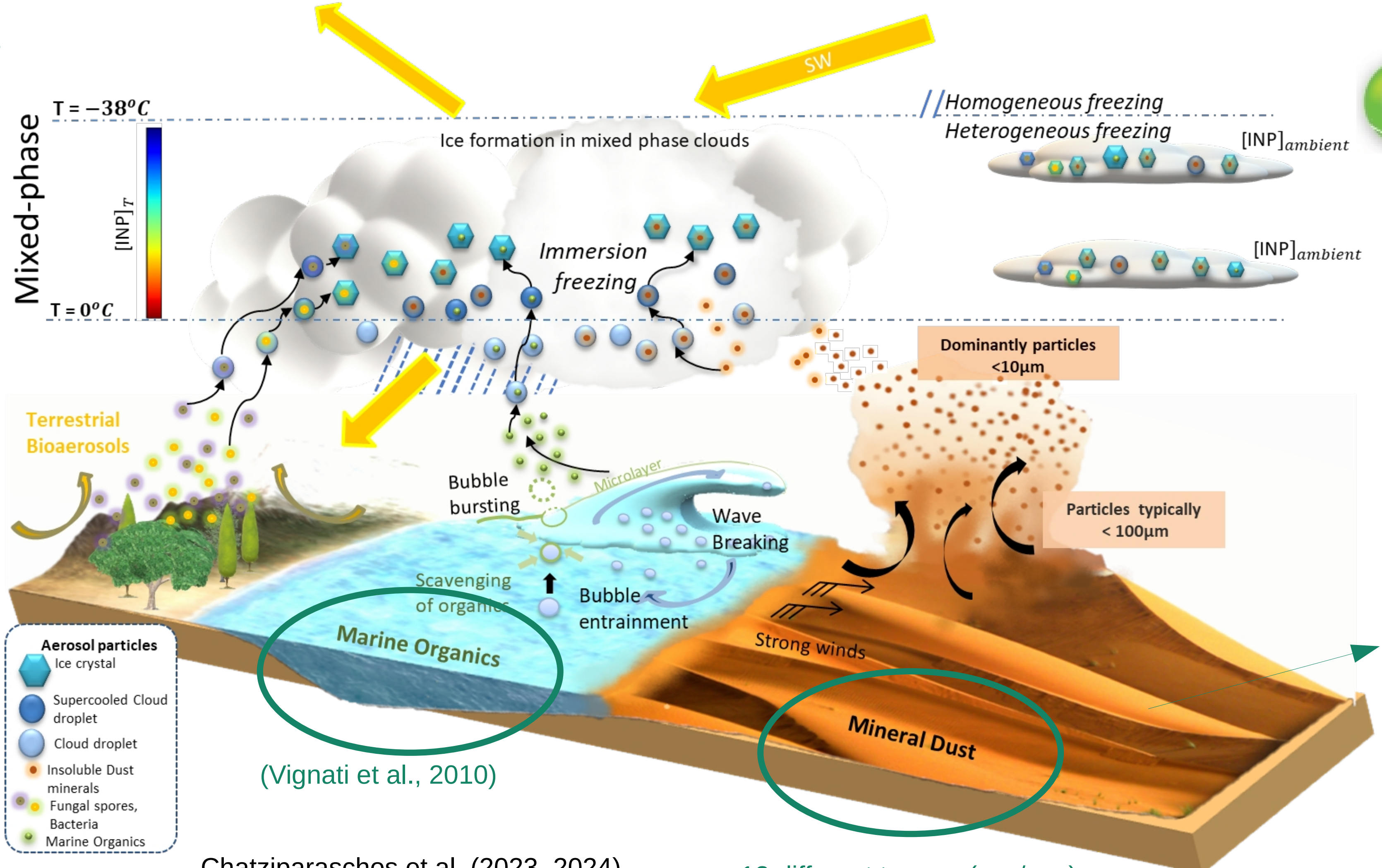
Improved representation of the aerosol lifecycle with a focus on INPs

Currently in ECE3



(Vignati et al., 2010)

2 different mineralogical datasets (Claquin et al., 1999 and Journet et al., 2012)

Brittle fragmentation Theory (size resolved mineral fraction at emission)

12 different tracers (acc/coa) as source of INP (K-fel. & quartz)

Chatziparaschos et al. (2023, 2024)
Costa-Surós et al. (in prep)

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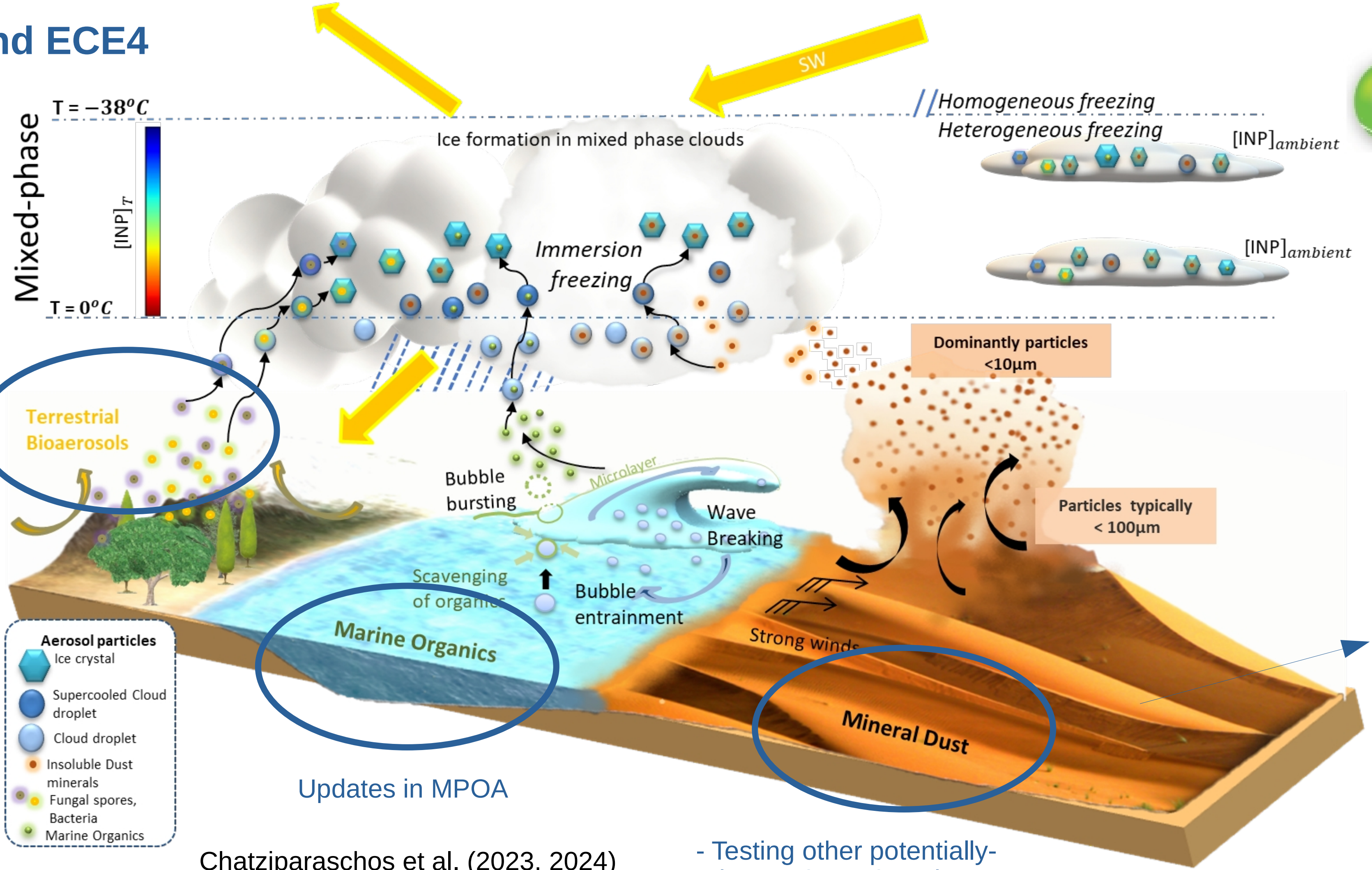
Improved representation of the aerosol lifecycle with a focus on INPs

Plans for ECE3 and ECE4

Bio-aerosols as source of INP (PBAPs):
- Bacteria (Burrows et al., 2009)
- Fungal Spores (Heald and Spracklen, 2009)
- Pollen (Jacobson and Streets, 2009; Hoose et al., 2010)



Updates in MPOA

Chatziparaschos et al. (2023, 2024)
Costa-Surós et al. (in prep)

- Agricultural (organic-rich)
- Solubilization/ageing schemes
- Observational constraints from field campaigns
- Massive evaluation with observations

New mineralogical dataset (EMIT-based, imaging spectroscopy)

- Testing other potentially-relevant dust minerals
- Supercoarse mode for dust

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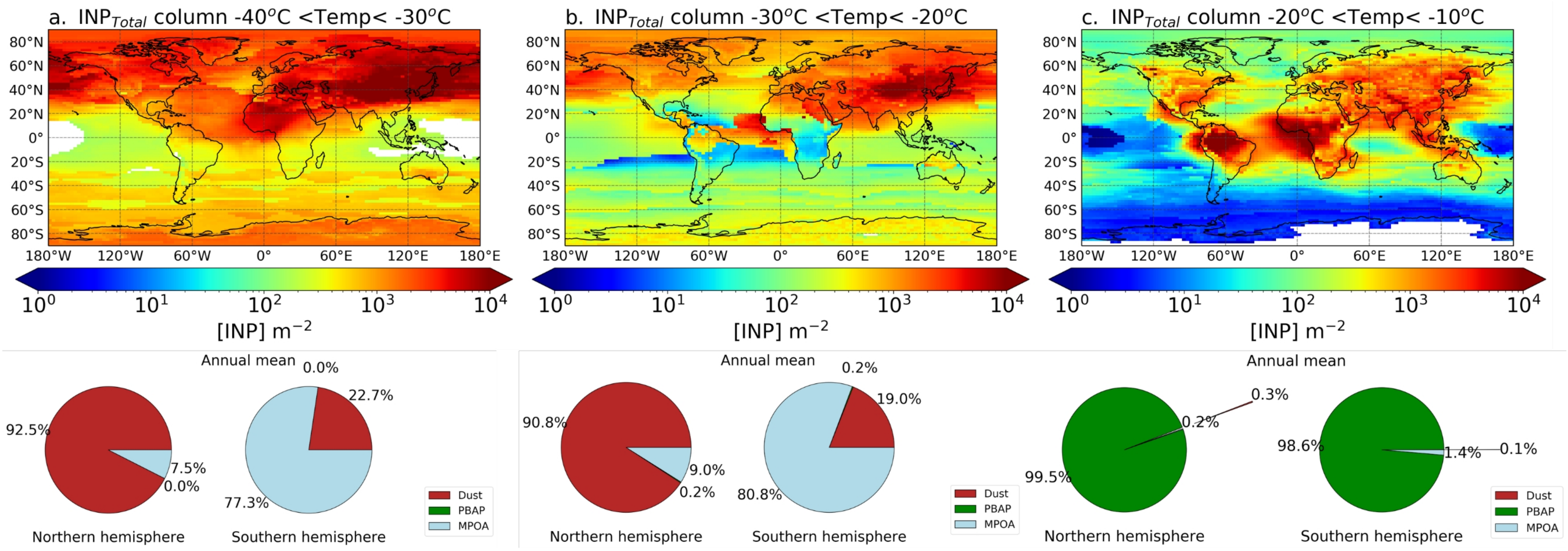
Improved representation of the aerosol lifecycle with a focus on INPs

Results with **TM4-ECPL**

CERTAINTY



Chatziparaschos et al. (2024 in review)

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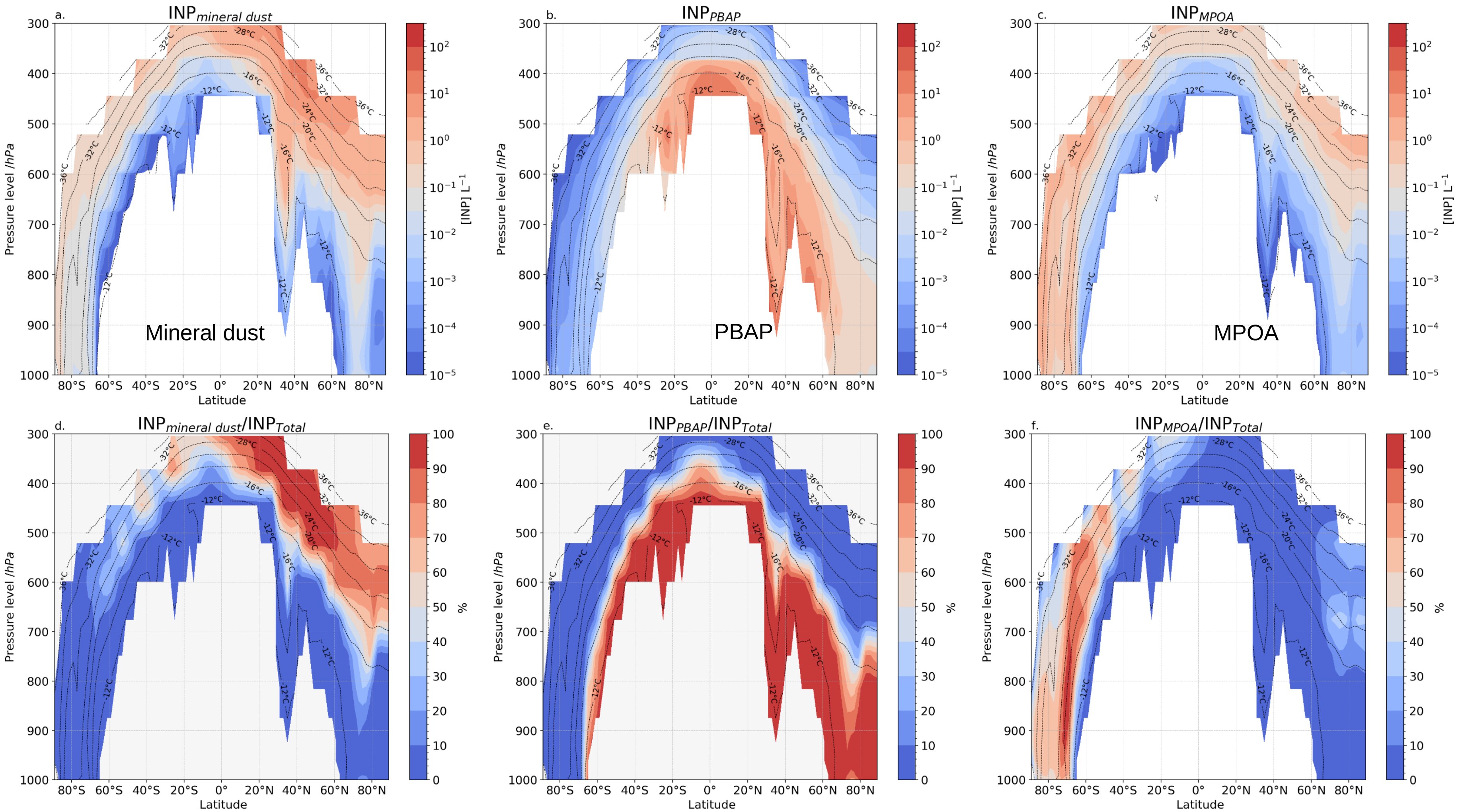
Improved representation of the aerosol lifecycle with a focus on INPs

Results with
TM4-ECPL

CERTAINTY



Considering
Harrison et al. (2019) for dust
Wilson et al. (2015) for MPOA
Tobo et al. (2013) for PBAP

Chatziparaschos et al. (2024 in review)

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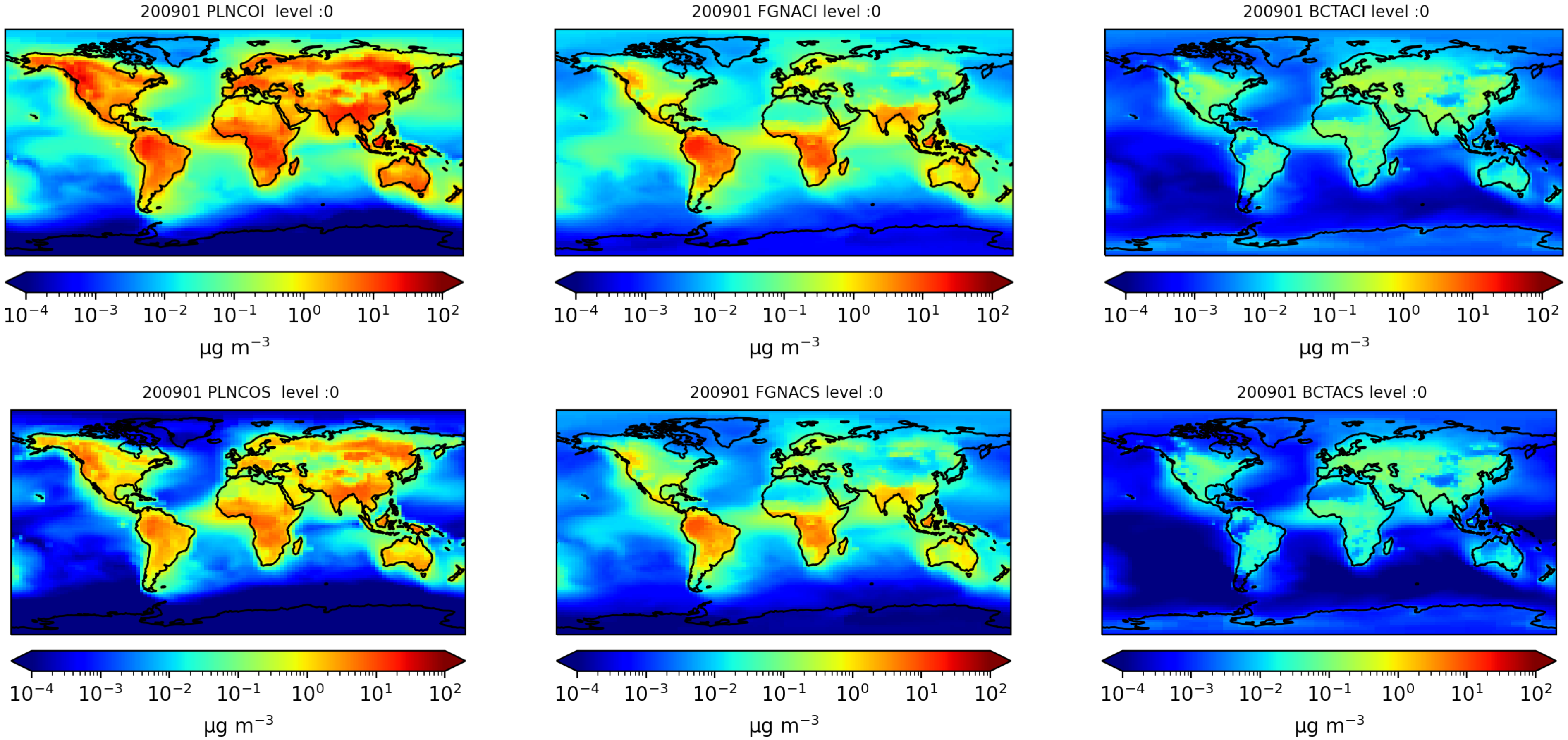
Improved representation of the aerosol lifecycle with a focus on INPs

Results with **TM4-ECPL**

CERTAINTY

Pollen ***Fungal Spores*** ***Bacteria***



Chatziparaschos et al. (in review)

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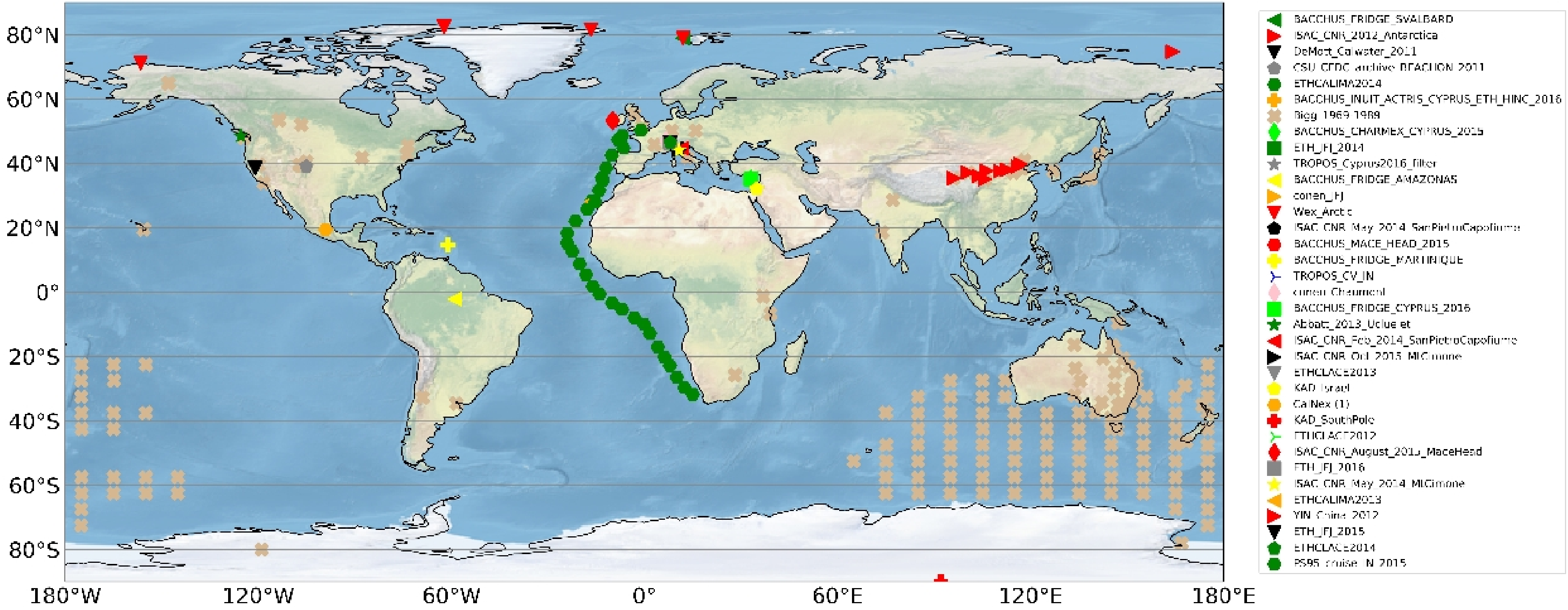
Improved representation of the aerosol lifecycle with a focus on INPs

Extended compilation of INP observation by BSC.
To be complemented by new compilation from ETH



Chatziparaschos et al. (2024 in review)

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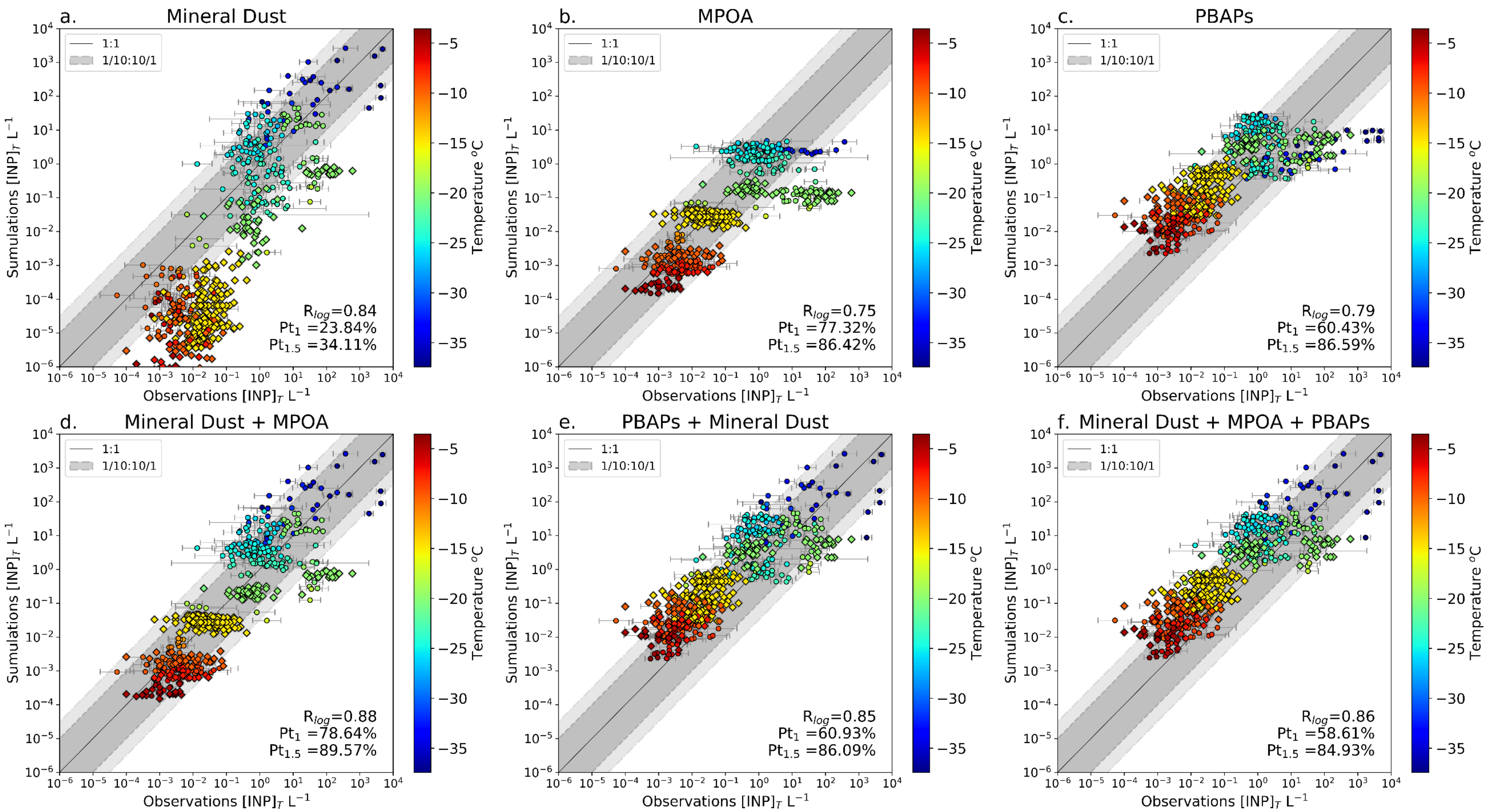
Improved representation of the aerosol lifecycle with a focus on INPs

Results with **TM4-ECPL**

CERTAINTY



Chatziparaschos et al. (2024, in review)

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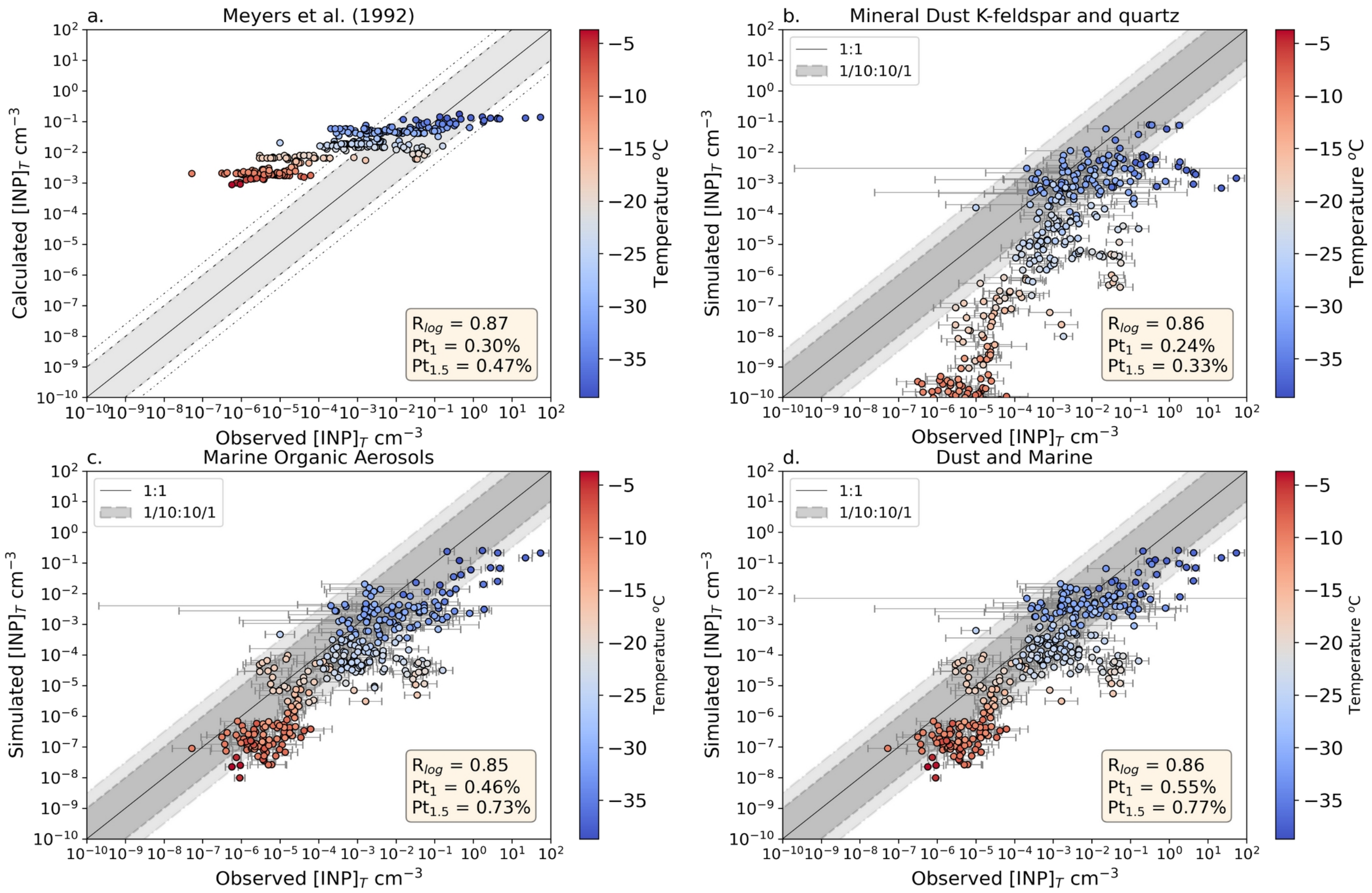
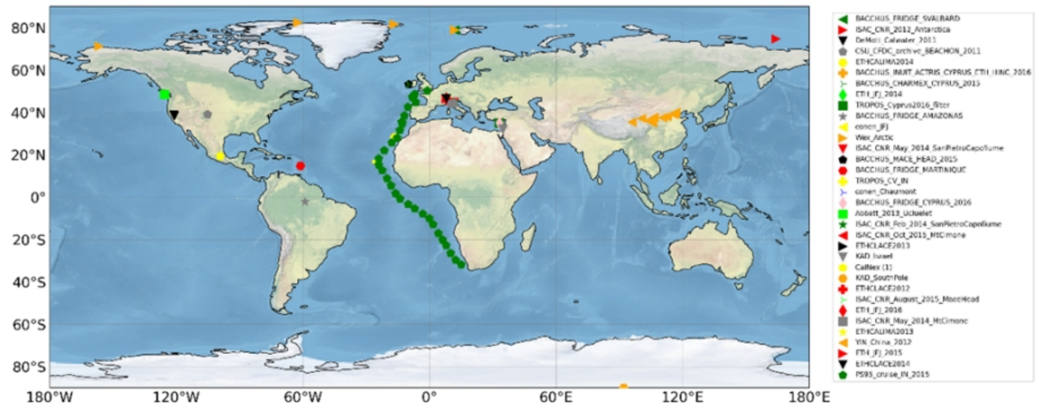
Improved representation of the aerosol lifecycle with a focus on INPs





Evaluation of INP from Dust and MPOA in EC-Earth3

Ongoing addition of PBAPs INP

Costa-Suros et al. (in prep)

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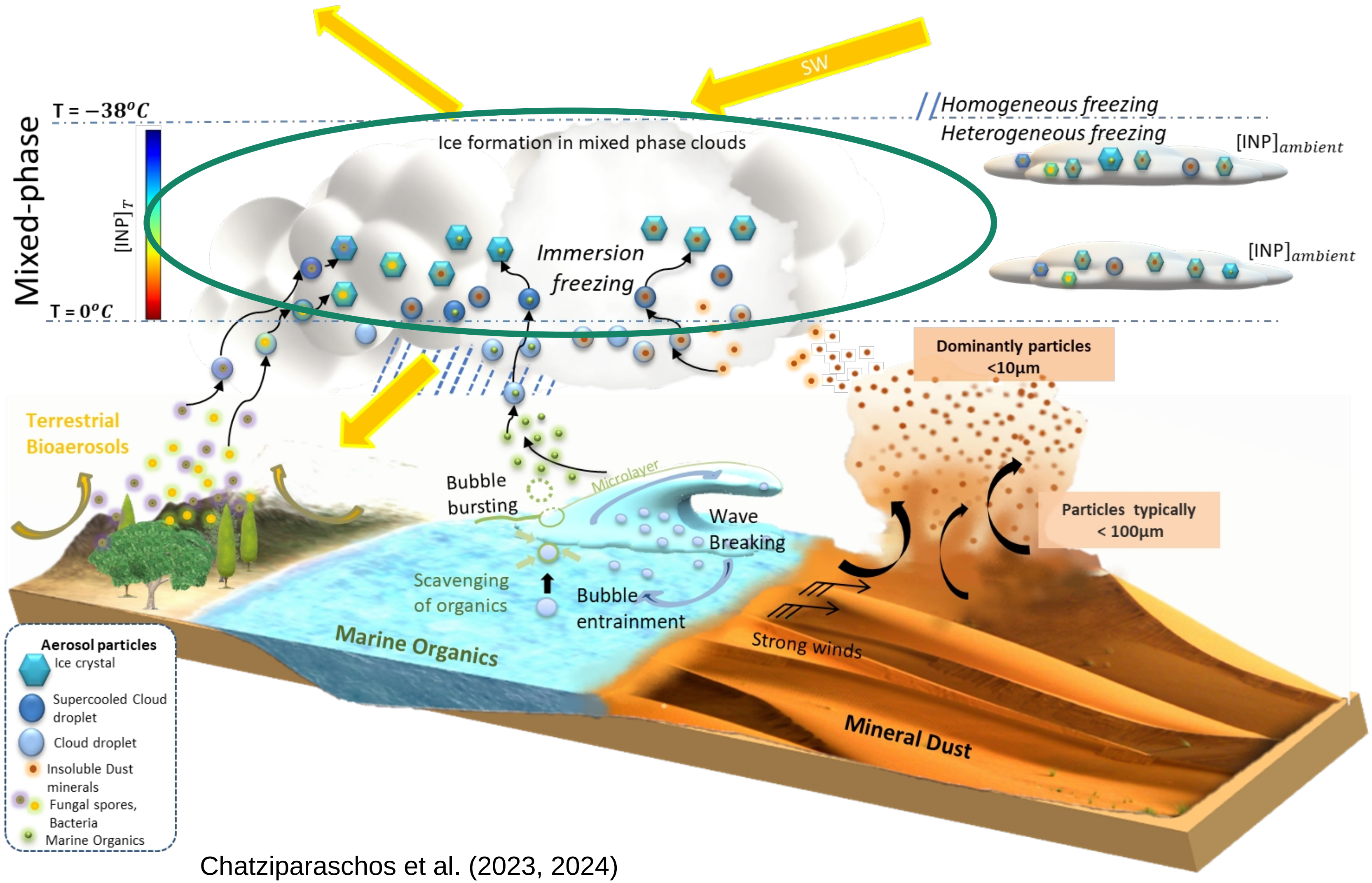
Methodology II: EC-Earth3



Chatziparaschos et al. (2023, 2024)
Costa-Surós et al. (in prep)

New heterogeneous ice nucleation parameterization

ICNC estimation

Temperature-sensitive ice nucleation parameterization

Meyers et al. (1992): deposition-condensation freezing

Ice crystal growth by vapor deposition

Depositional growth parameterization

Following Pruppacher and Klett (1997) and Rotstayn et al. (2000)

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New heterogeneous ice nucleation parameterization

ICNC estimation

Temperature-sensitive ice nucleation parameterization

Meyers et al. (1992): deposition-condensation freezing

Aerosol-sensitive ice nucleation parameterization

PRIMARY ICE PRODUCTION

Immersion freezing

Atkinson et al. (2013): K-feldspar
or
Ullrich et al. (2017): soot and dust
or
Harrison et al. (2019): K-feldspar and quartz

\+ **Wilson et al. (2015)**: of marine organic aerosols

SECONDARY ICE PROCESSES

Georgakaki and Nenes (2024): RaFSIP, considers:
- Hallet-Mossop process
- Droplet shattering during freezing
- Fragmentation due to collisional break-up

v1

v2

Ice crystal growth by vapor deposition

Depositional growth parameterization

Following Pruppacher and Klett (1997) and Rotstayn et al. (2000)

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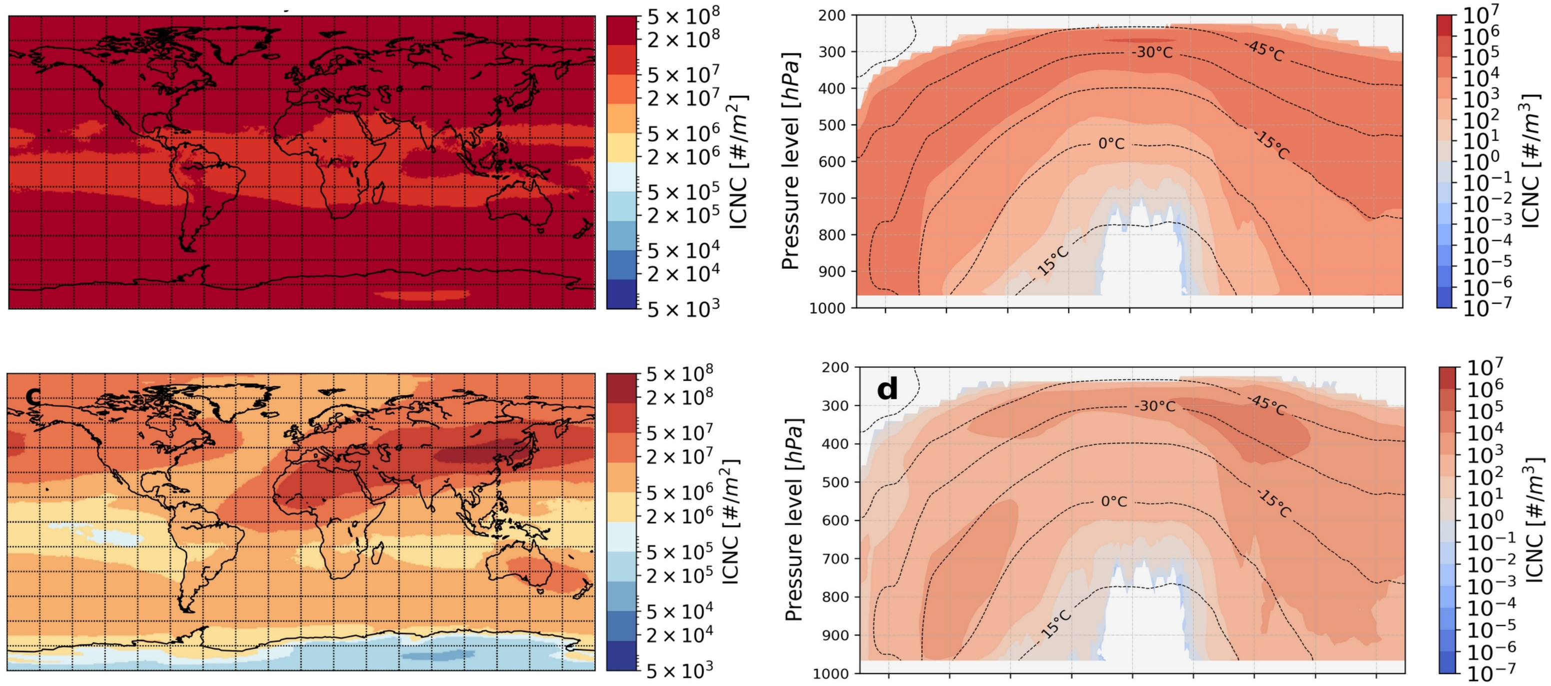
Results: parameterizations' impact on the ICNC

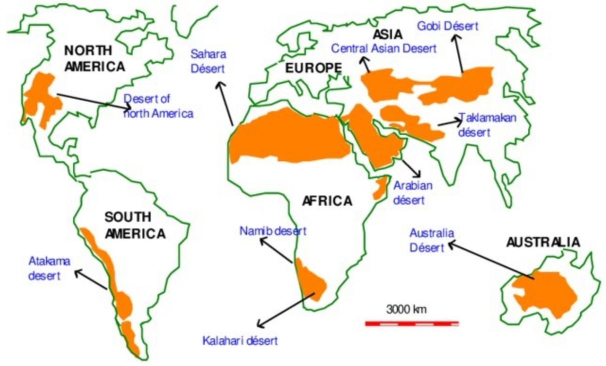
The global column concentrations and zonal means show a reduction in ice crystal number concentration (ICNC) with the new aerosol-dependent ice nucleation parameterization in comparison to Meyers et al. (1992); however, the distribution seems **more realistic** since it depicts a clear association of the simulated ICNC with the **mineral-dust emission sources and transported areas**.

ICNC column burden | **ICNC zonal mean**

Meyers et al. (1992)

Harrisson et al. (2019) + Wilson et al. (2015) + RaFSIPv2





Remini (2020)

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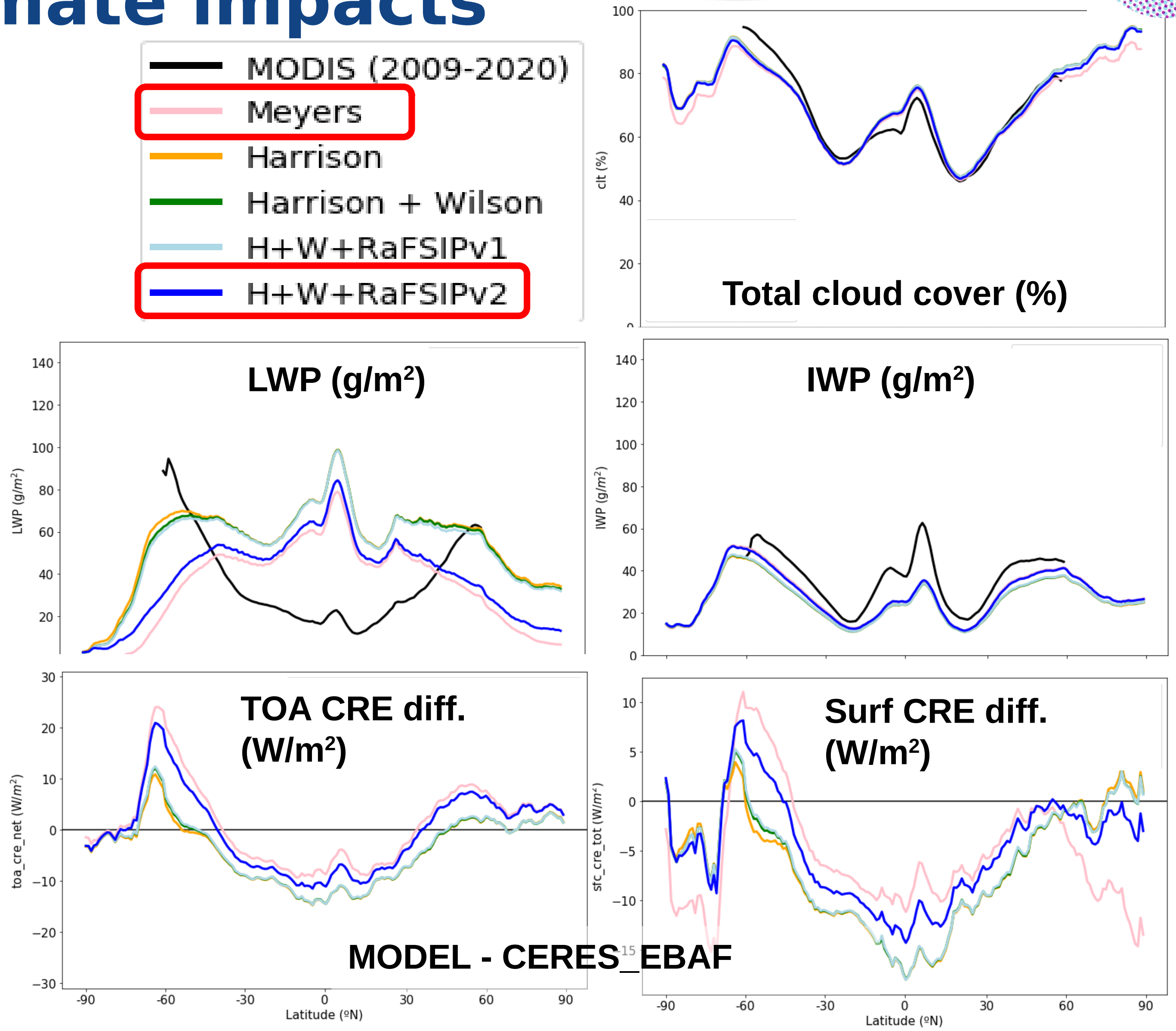
Results: New aerosol-driven parameterization climate impacts

Globally, there is, on average, an increase in **cloud cover** with the new ice nucleation parameterization (**PIP+SIPv2**), in comparison to the Meyers et al. (1992) simulation, due to an increase of **liquid water path**.

Radiative fluxes change at the top of the atmosphere (TOA) and at the surface are consistent with the cloud cover differences and the amount of liquid and cloud ice in the different latitudes.



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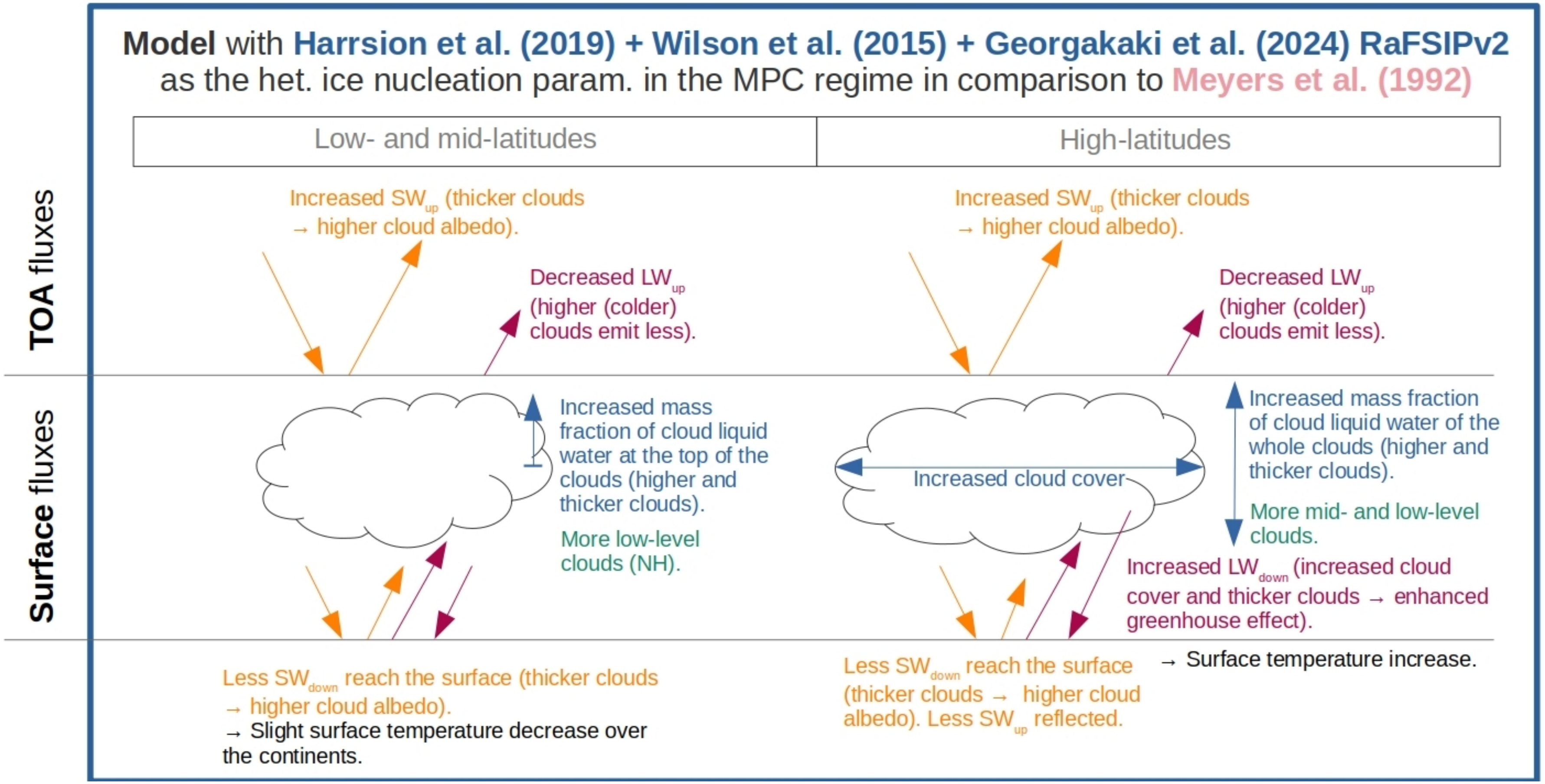
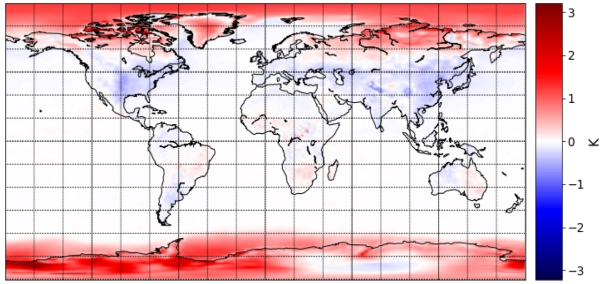
Results: New aerosol-driven parameterization climate impacts



Near surf. temperature (12y)
Ref. - Meyers (Nudged runs)



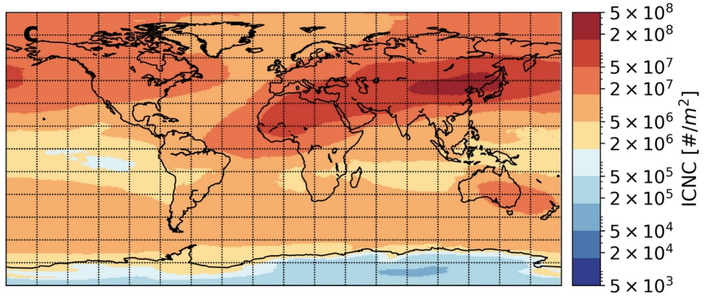
Summary and next steps

- The novel aerosol-sensitive ice nucleation parameterization provides a comprehensive new parameterization that can substitute the temperature-dependent parameterization.

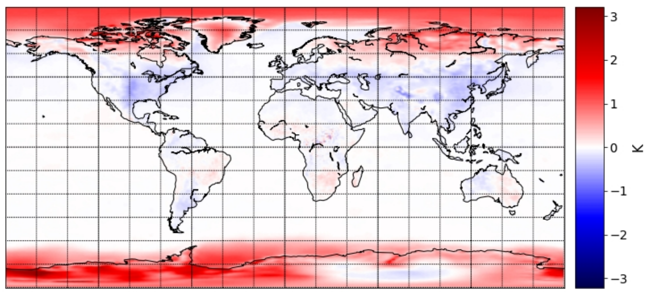
Meyers et al. (1992) → Harrison et al. (2019) + Wilson et al. (2015) + RaFSIPv2: Georgakaki and Nenes (2024)

- The new ICNC distribution seems more realistic.
- A large model sensitivity to ICNC is found: globally increased cloud cover (+0.9%) linked to an increase in LWP (+31%). Radiative fluxes change that lead to near-surface temperature increases mostly at high latitudes (+0.05 K globally, regionally ranging from -2.4 to 3.6 K).
- Implementation of primary biological aerosol particles (PBAPs) in the parameterization framework to better capture their role in ice nucleation.
- Integration of the primary and secondary ice production parameterizations into the next-generation Earth system model EC-Earth4.
- Evaluation done with MODIS, CALIPSO, and CERES-EBAF. Next: CloudSat, ISCCP, *DARDAR ice/cloud products*

ICNC col. burden (12y mean)
Aerosol-driven – Meyers (nudged run)



Near surf. Temperature (12y mean)
Aerosol-driven – Meyers (nudged run)



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