Barcelona Supercomputing Center
Centro Nacional de Supercomputación

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

The Role of Secondary Ice Production in Shaping Mixed-Phase Clouds in EC-Earth4

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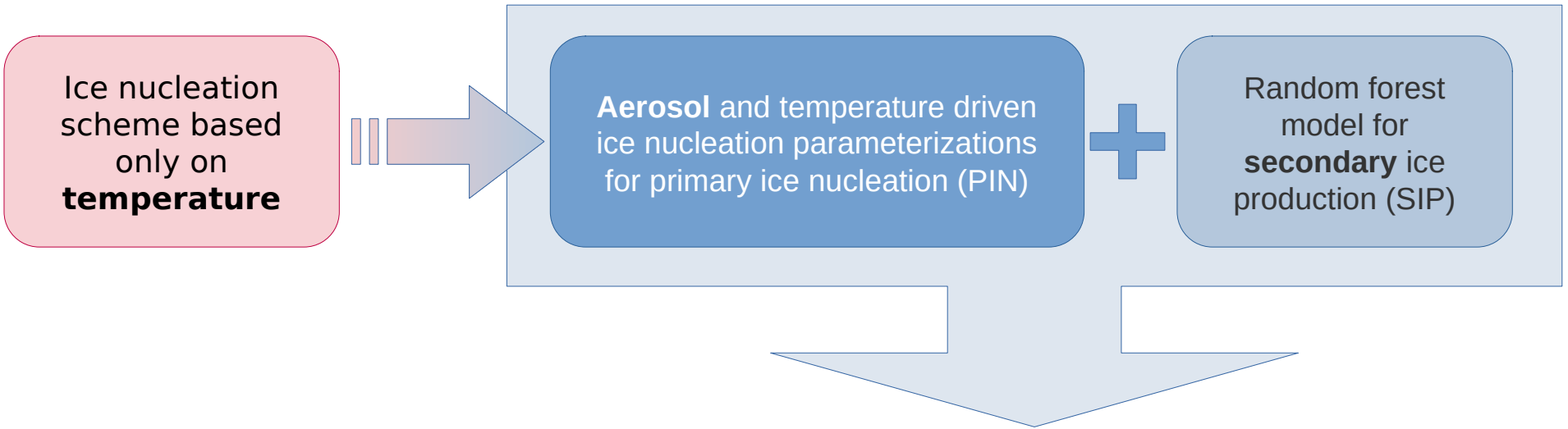
Objective

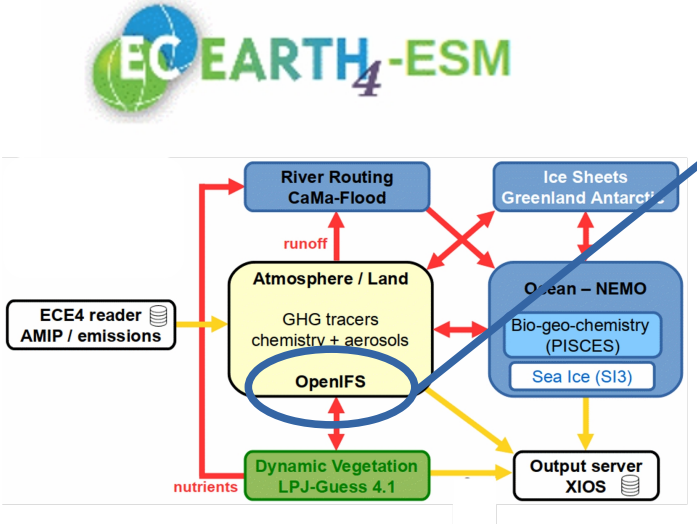
Improve cloud representation in the CMIP7 ESM EC-Earth4 by **updating the heterogeneous ice nucleation scheme**, enabling a more realistic sensitivity to present and future aerosol emissions and allowing assessment of their climate impact.



Focus on the role of SIP in modulating mixed-phase clouds (MPC)

Methodology

1-year-long simulations (2018) with different ice nucleation parameterizations were run with the **OIFS48r1** model:



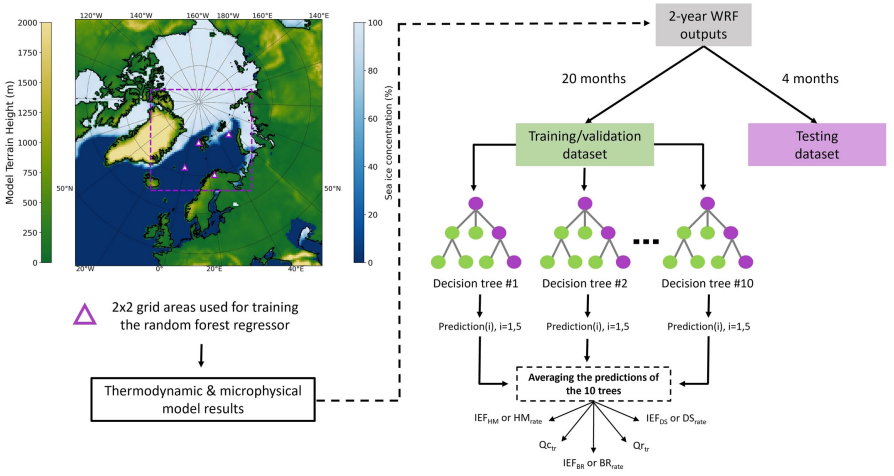
- Includes M7 module with:
  - dust traced in 4 modes (acc./coa. & sol./insol.)
  - black carbon traced in 2 modes (acc./coa. soluble)
- Vertical levels: 91
- Horizontal resolution: 255 lat x 512 lon. (~0.7º)
- Time step: 2700 s
- Model output: 4.5h

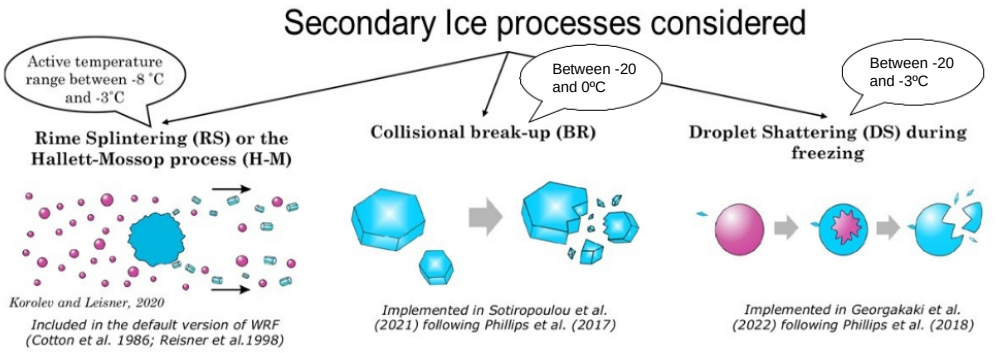
<u>Ice-nucleation parameterizations analized:</u>

1) Meyers et al. (1992): temperature dependent
2) Ullrich et al. (2017): aerosol-sensitive to dust and soot
3) Ullrich et al. (2017) + RaFSIP (Georgakaki and Nenes, 2024)

Random Forest for Secondary Ice Processes (RaFSIP)

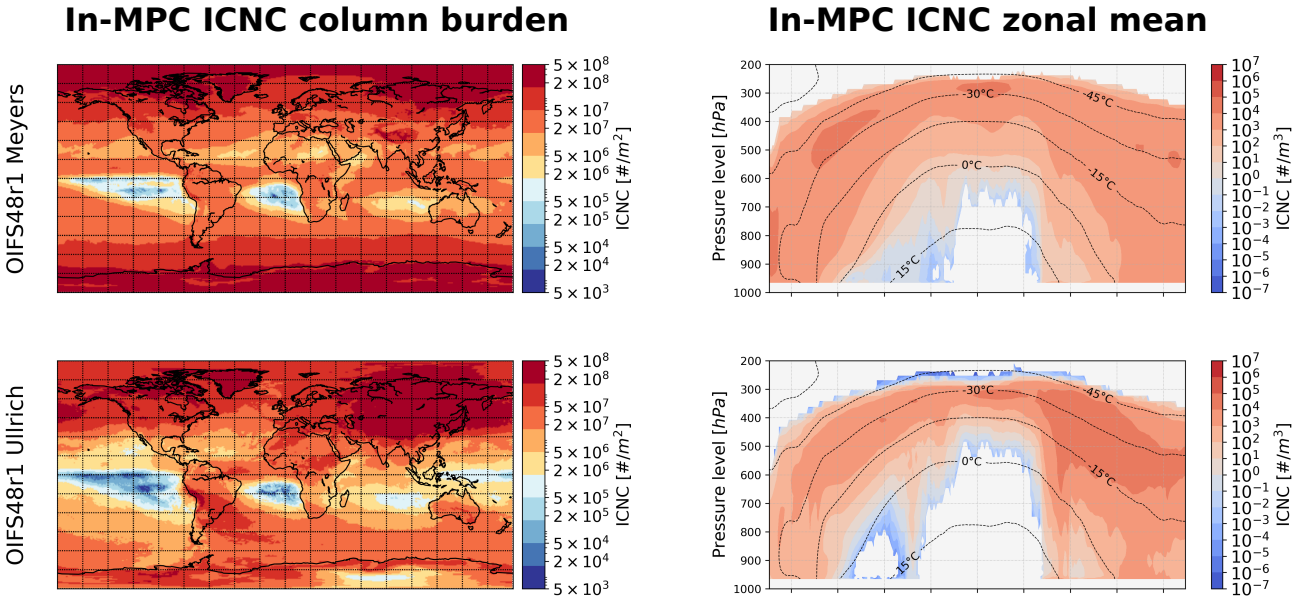
The RaFSIP (Georgakaki and Nenes, 2024) model was developed from 2-years of simulation data with WRF.





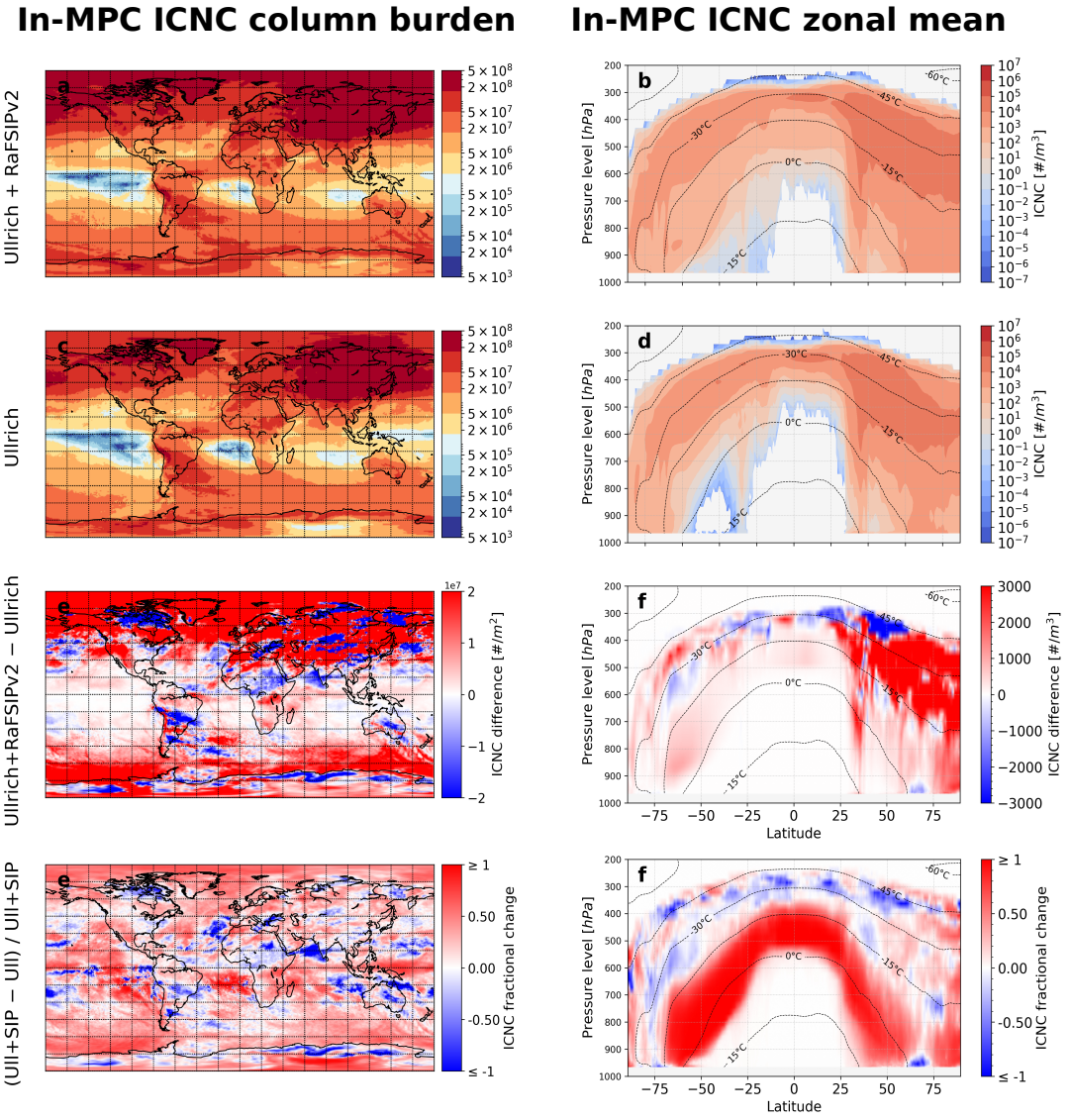
Impact of aerosol-sensitive PIN parameterization on ICNC

Reduction in ice crystal number concentration (ICNC) with the new aerosol-dependent ice nucleation parameterization compared to Meyers et al. (1992) in the SH, while in the NH there is an increase. However, as already found in EC-Earth3 (Costa-Surós et al., 2025), the distribution seems **more realistic**, as it depicts a clear association between the simulated ICNC and **mineral dust emission sources and transport pathways**.



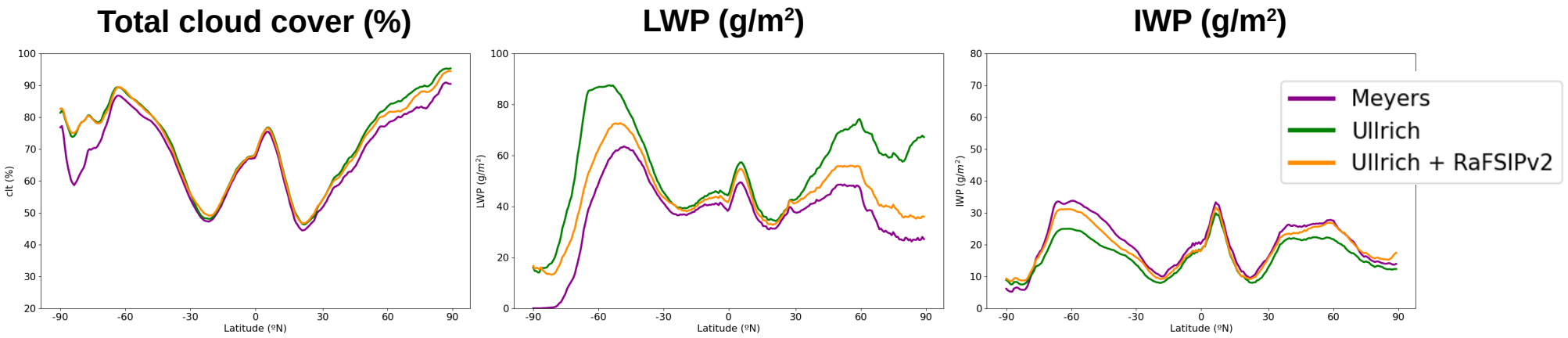
Impact of SIP on ICNC

Global increase in in-MPC ICNC, with largest absolute changes at mid–high NH latitudes and strongest relative increases at low to mid-level altitudes where ICNC is lowest.



Impact of the new aerosol-driven parameterization and SIP on cloud fields

Globally, the new ice nucleation parameterization (PIP+SIP) leads, on average, to an **increase in cloud cover** compared to the Meyers et al. (1992) simulation. This increase is more pronounced at mid- to high latitudes and is primarily driven by an **increase in LWP**, which outweighs the comparatively smaller **reduction in IWP**.

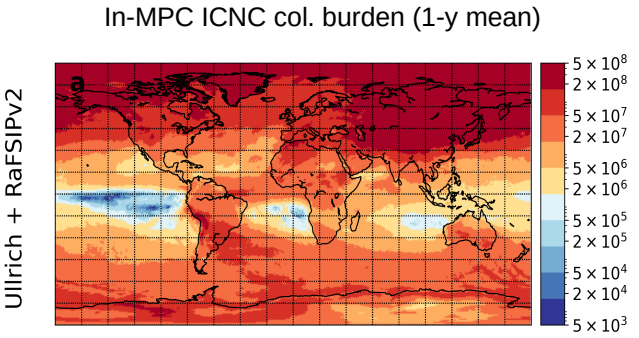


With the addition of **RaFSIPv2**, LWP decreases and becomes closer to Meyers, although it remains slightly higher. IWP increases and is now also closer to Meyers than before.

Summary:

- The novel aerosol-sensitive ice nucleation parameterization provides a comprehensive new parameterization that can substitute the temperature-dependent parameterization in OIFS48r1, and seems more realistic.

Meyers et al. (1992) → Ullrich et al. (2017) + RaFSIPv2: Georgakaki and Nenes (2024)



- Large model sensitivity to ICNC is found: globally increased cloud cover (+3.4%) linked to an increase in LWP (+13.1%) and decrease in IWP (-7.7%).
- Extending the SIP analysis from EC-Earth3 to EC-Earth4/OIFS48r1 allows us to better understand how SIP interacts with aerosol-driven ice formation and improves the reliability of future cloud projections.

Next steps:

- Implement quartz, feldspar, marine organic aerosols, and primary biological aerosol particles in the parameterization framework, and test additional aerosol-dependent ice nucleation schemes (Atkinson et al., 2013; Harrison et al., 2019; Wilson et al., 2015).

The modeled ice nucleating particles (INPs) were **evaluated** against observations (e.g. from the BACCHUS and Wex et al., 2019) → see **Marios Chatziparaschos**' talk

Thu, 07 May, 14:20, Session AS3.7
Room F2 → Linking Dust Mineralogy and Ice Nucleation in Mixed-Phase Clouds in EC-Earth4

- Integration of the aerosol-senstive primary and secondary ice production parameterizations into EC-Earth4.

ECMWF OpenIFS → EC-EARTH 4-ESM

- Implement the COSPv2 simulator for comparison with MODIS and CALIPSO satellite observations.
- Assess the long-term climate impacts of these developments.

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