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

New primary and secondary ice production parameterization for mixed-phase clouds in EC-Earth3-AerChem: climate impacts and the role of SIP

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Objective

Improve the representation of clouds in the CMIP6 ESM EC-Earth3-AerChem by **updating the heterogeneous ice nucleation** representation. The commonly used ice nucleation scheme based only on temperature is replaced with a state-of-the-art scheme sensitive to both aerosol and temperature and a secondary ice production parameterization based on a random forest model.

Methodology

Five 12-year-long simulations (1999 – 2020) with different ice nucleation parameterizations were run with the EC-Earth3-AerChem ESM with the configuration as in Fig. 1 and the ice nucleation and growth scheme as in Fig.2:

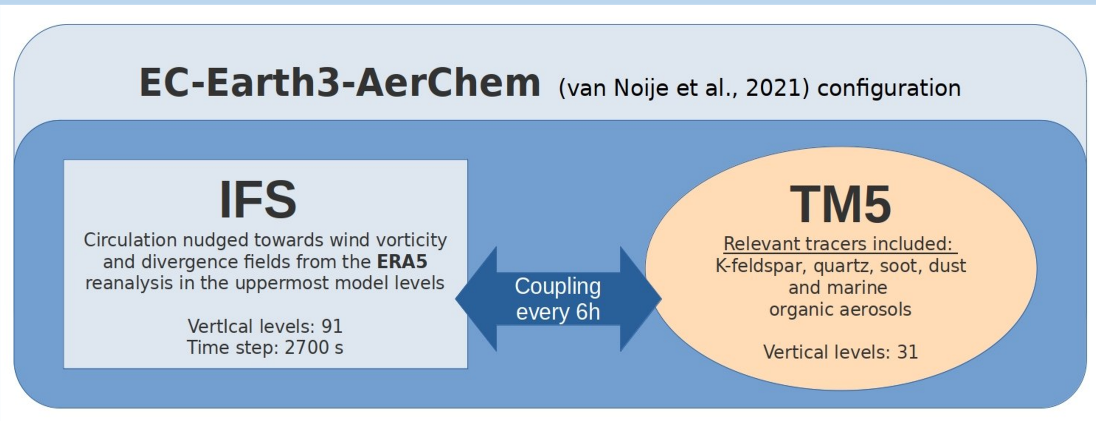

Fig. 1. EC-Earth-AerChem configuration

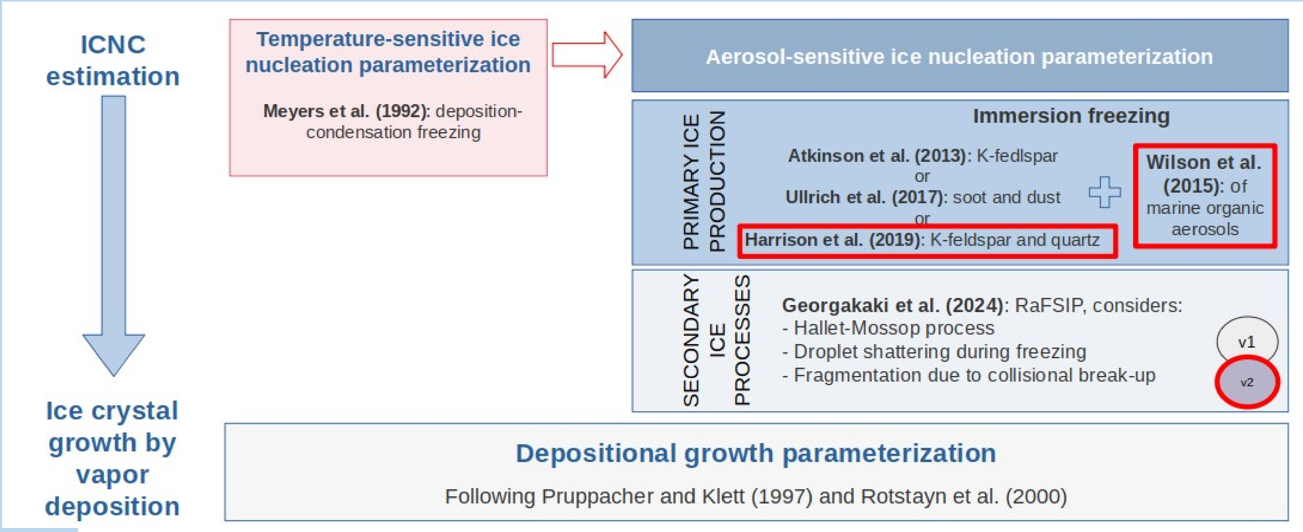

Fig. 2. Ice nucleation parameterizations used in the EC-Earth3-AerChem simulations.

1) The **Meyers** et al. (1992) parameterization used in the original ECMWF IFS model.
2) **Aerosol-sensitive** (A-s) ice nucleation parameterization including primary ice production (PIP) processes by **Harrison** et al. (2019) ("H").
3) A-s ice nucleation param. by Harrison et al. (2019) in combination with **Wilson** et al. (2015) ("H+W").
4) and 5) same as in "3" but in combination with a random forest model for secondary ice production **RaFSIPv1** and **RaFSIPv2** (Georgakaki and Nenes, 2024).

The modeled ice nucleating particles (INPs) were **evaluated** in EC-Earth3 against observations from the "Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding" (BACCHUS) (http://www.bacchus-env.eu/in/index.php) and Wex et al. (2019) in Costa-Surós et al. (in prep.).

Results

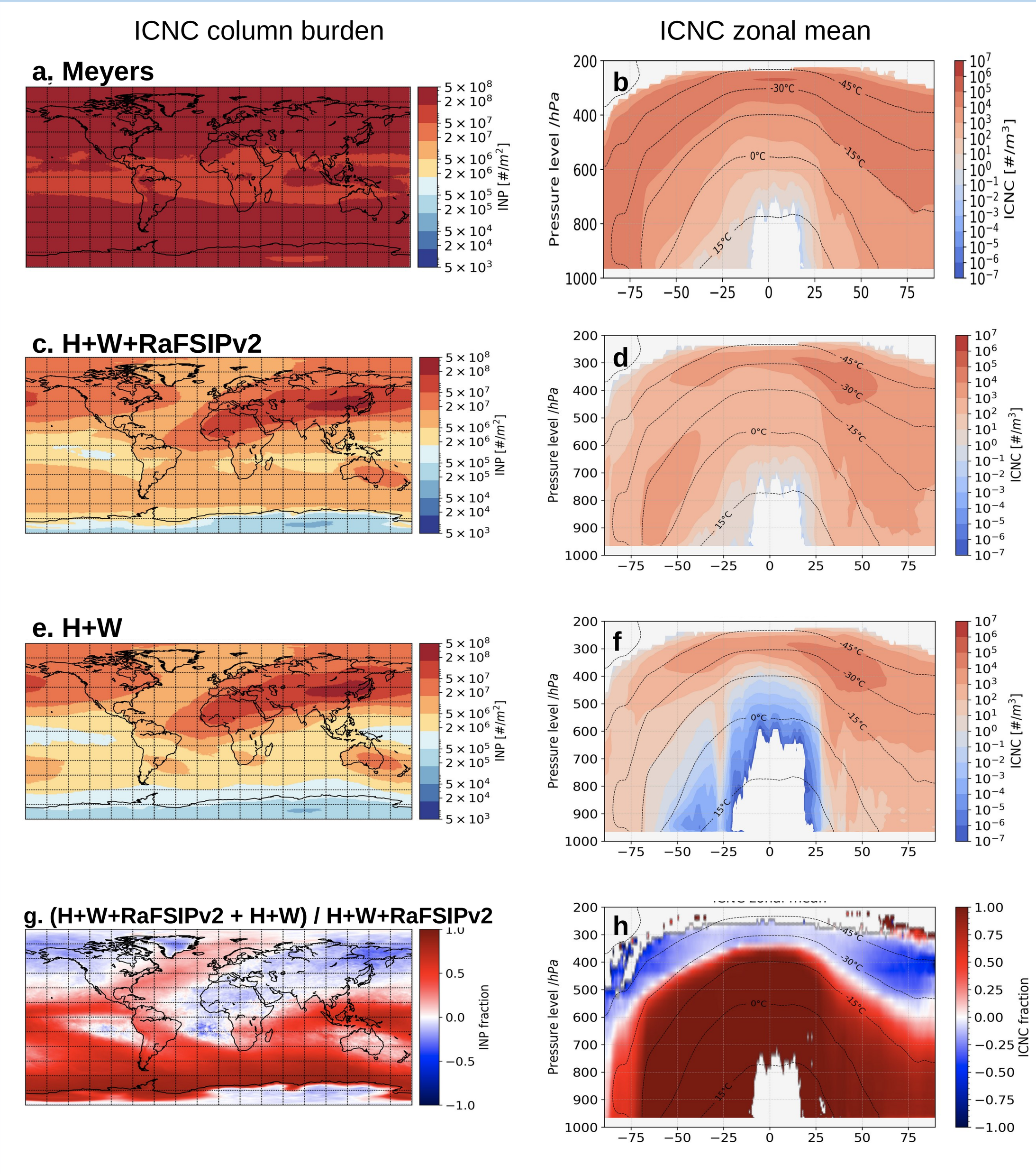

Fig. 3. ICNC colum burden and zonal mean cross-sections.

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. (Fig. 3a-d); 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** (Fig. 3c,d).

SIP importance

The **RaFSIPv2** is responsible for the majority of **ICNC production at the SH** (Fig. 3g) **and at low and mid altitudes** in both hemispheres, where the average temperature is higher than -30 ºC (~ -20ºC at the NH). For higher altitudes (and lower temperatures) the addition of the RaFSIPv2 reduces the amount of ICNC on average.

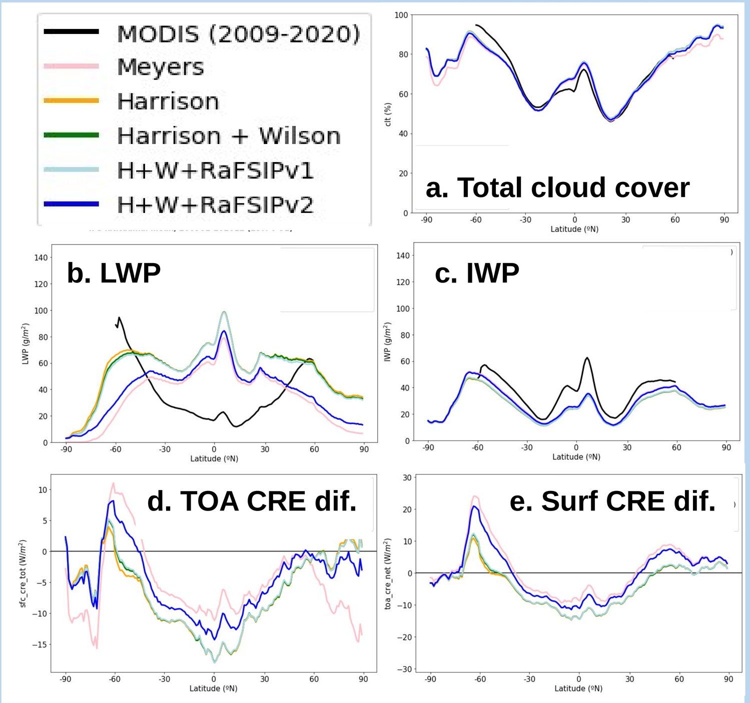

Fig. 4. a) Total cloud cover, b) LWP and c) IWP zonal means. d) TOA and e) surface CRE radiative balances differences with CERES-EBAF obs. zonal means.

Climate impacts

Globally, there is, on average, an increase in **cloud cover** (Fig. 4a) 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** (Fig. 4b). **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 (Fig. 4d-e and 5).

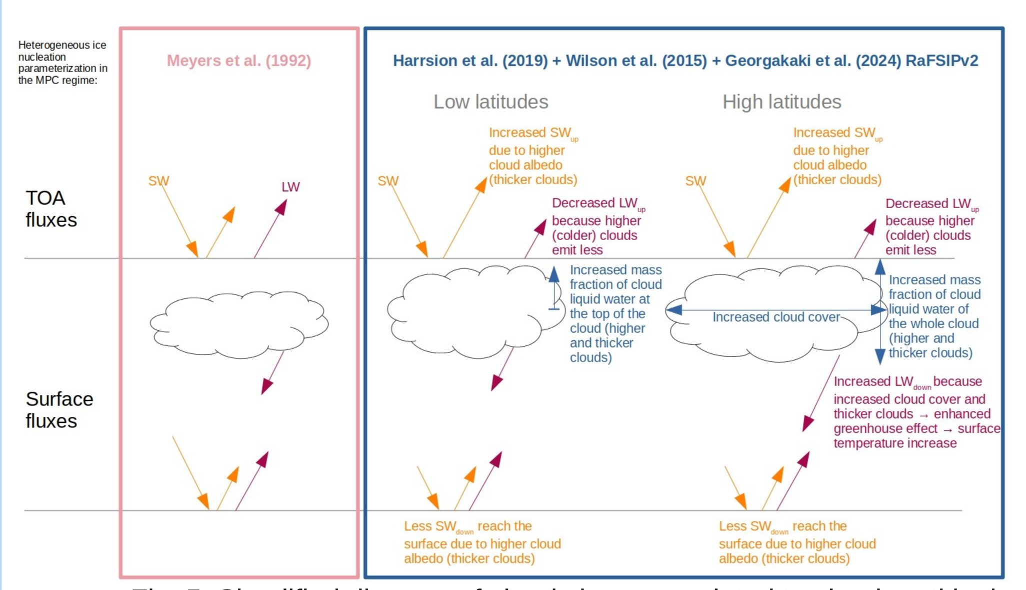

Fig. 5. Simplified diagram of cloud changes, related to cloud partitioning changes that impact the radiation fluxes.

Conclusions

- The novel aerosol-sensitive ice nucleation parameterization, including primary ice nucleation (combination of Harrison et al. (2019) and Wilson et al. (2015)) and secondary ice processes (RaFSIPv2 by Georgakaki and Nenes (2024)), provides a **comprehensive new parameterization** that can substitute the temperature-dependent parameterization by Meyers et al. (1992).
- The new ICNC distribution seems **more realistic** since it depicts a clear association of the simulated ICNC with the **mineral-dust emission sources and transported areas**.
- **SIP** plays an important role in the **ICNC production at the SH and mid-low altitudes**.
- 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).

Future developments

- 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 **EC-Earth4**, ensuring a comprehensive and physically consistent representation of cloud microphysical processes in the next-generation Earth system model.

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