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

Aerosol-Driven Parameterization of Ice Nucleation and Secondary Ice Processes in EC-Earth3: Evaluation and Climate Impacts

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Objective

Improve the representation of clouds in the CMIP6 ESM EC-Earth3-AerChem by **updating the heterogeneous ice nucleation** representation.

Ice nucleation scheme based only on temperature

→

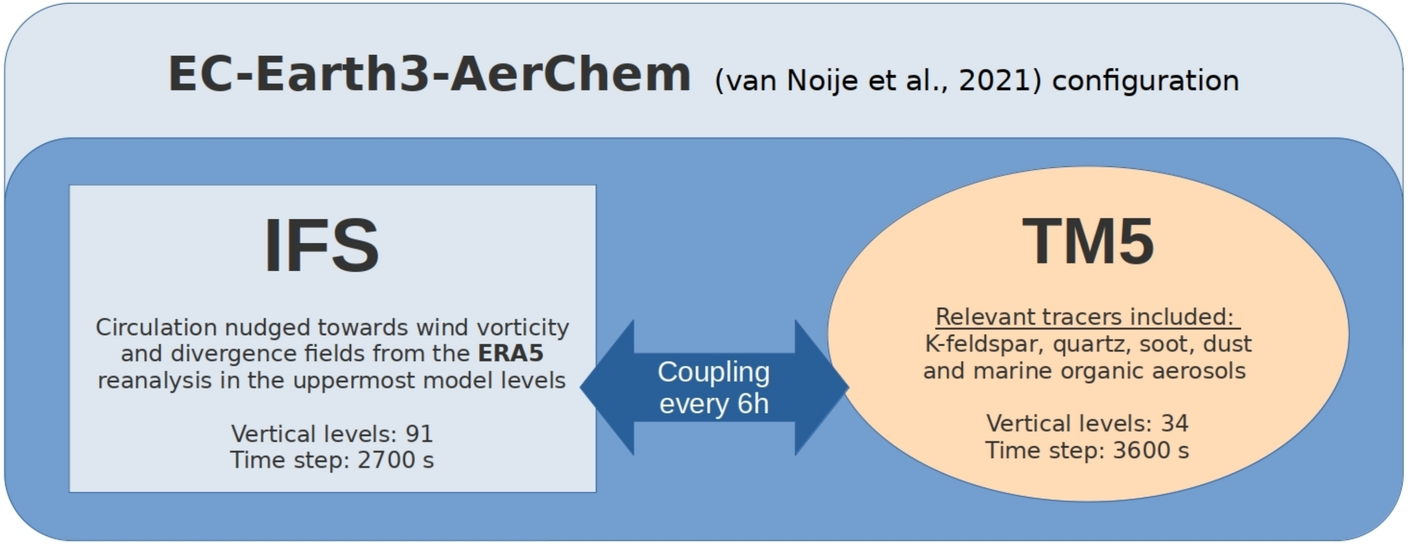
Aerosol and temperature driven ice nucleation parameterizations for primary ice nucleation (PIN)

+

Random forest model for secondary ice production (SIP)

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:



The modeled ice nucleating particles (INPs) were **evaluated** in EC-Earth3 against observations from the BACCHUS and Wex et al. (2019) in Costa-Surós et al. (in prep.).

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And the ice nucleation and growth scheme...

New heterogeneous ice nucleation param.

ICNC estimation

↓

Ice crystal growth by vapor deposition

Temperature-sensitive ice nucleation parameterization

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

Depositional growth parameterization

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

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New heterogeneous ice nucleation param.

FORCeS CERTAINTY

ICNC estimation

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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

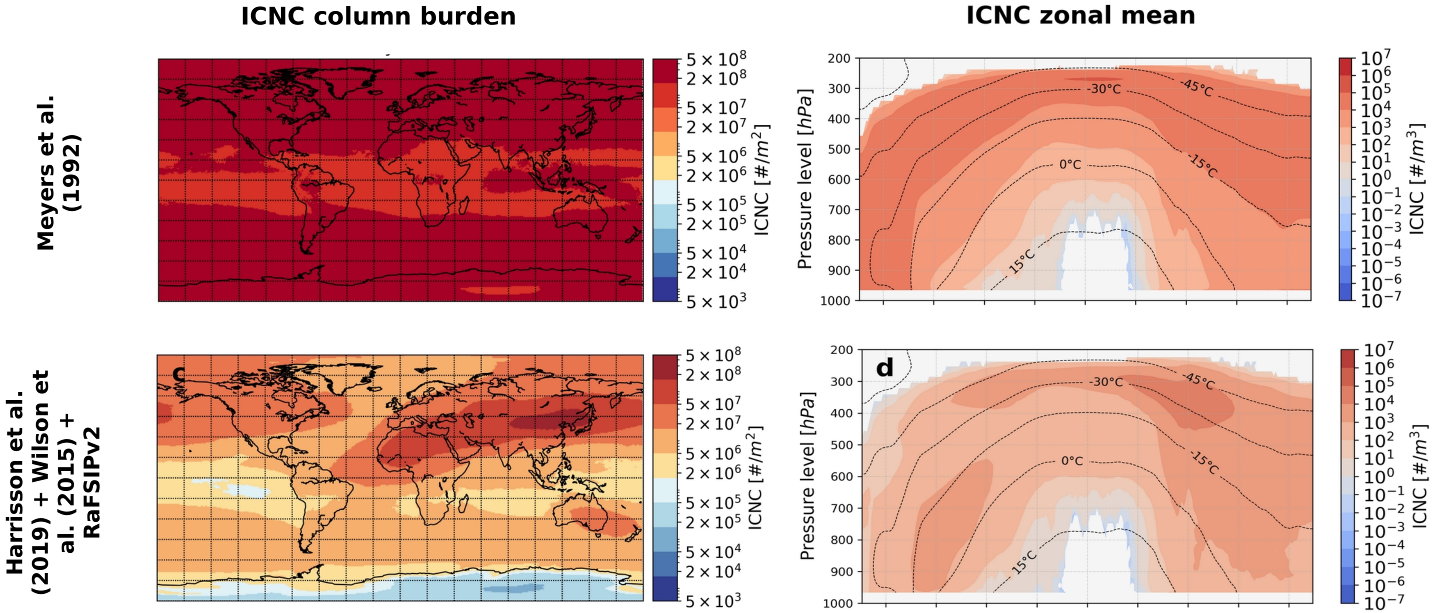
v2

Depositional growth parameterization

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

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**.



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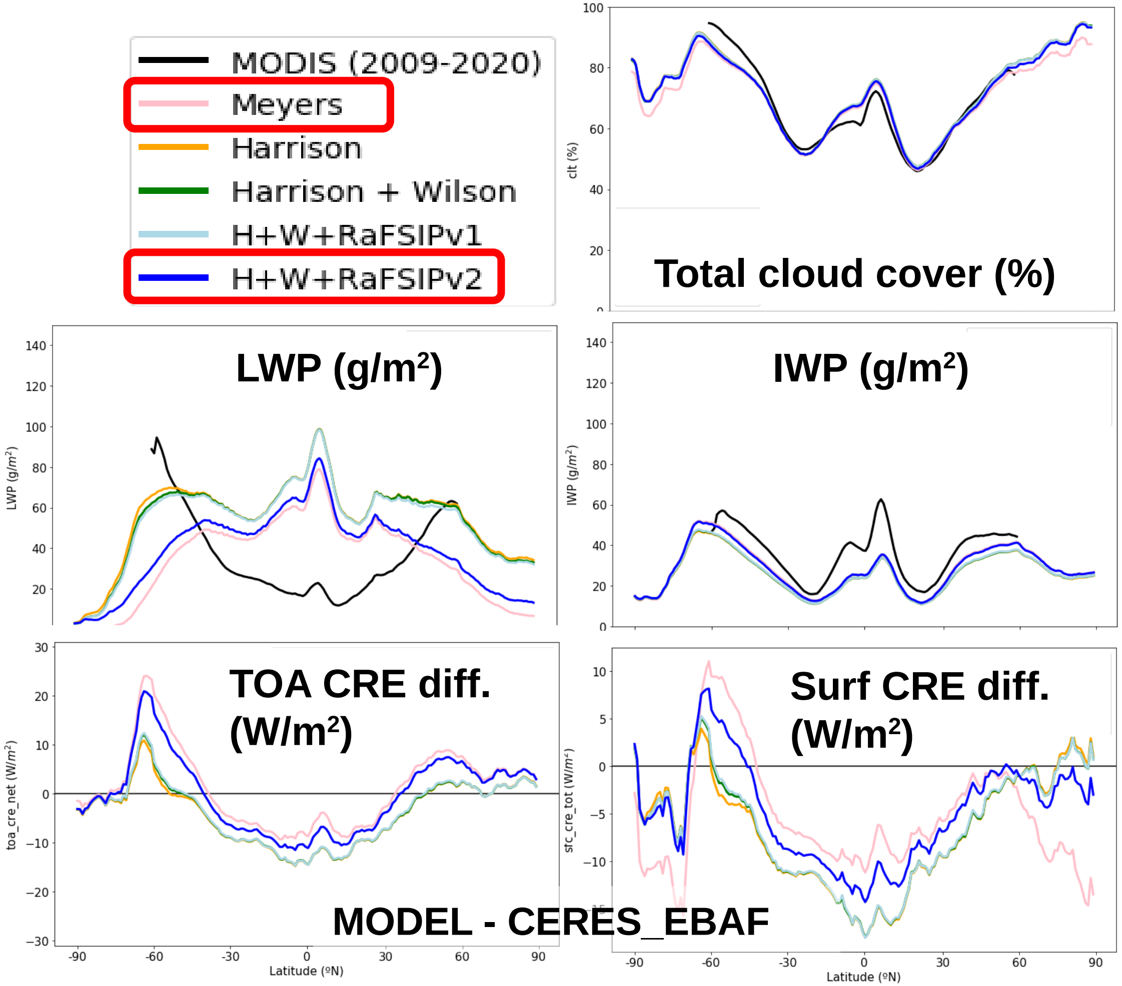
Results: New aerosol-driven parameterization climate impacts

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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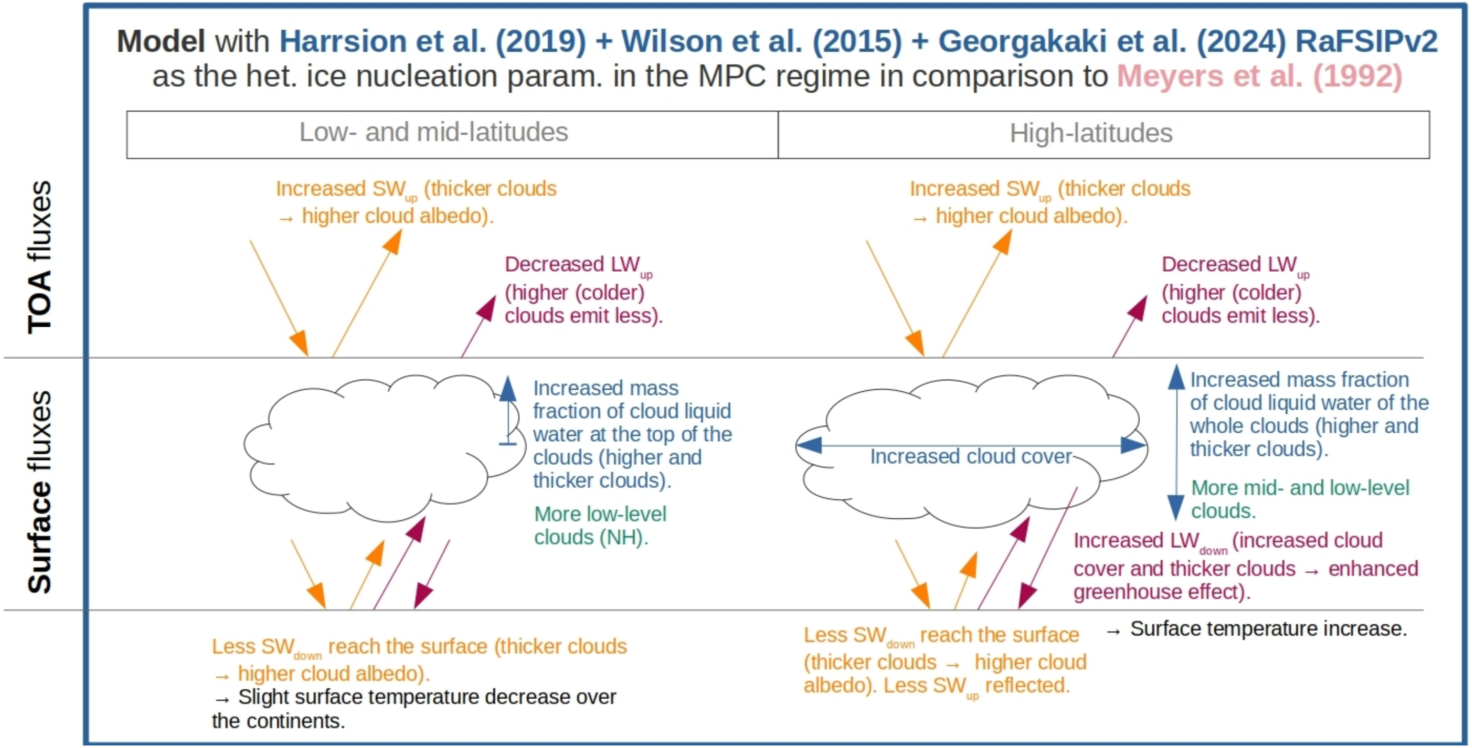
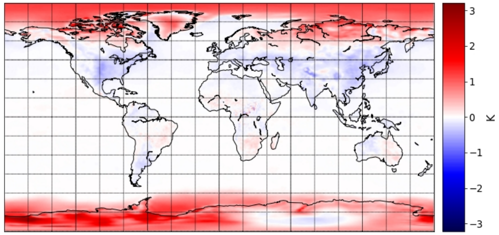
Results: New parameterization climate impacts



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



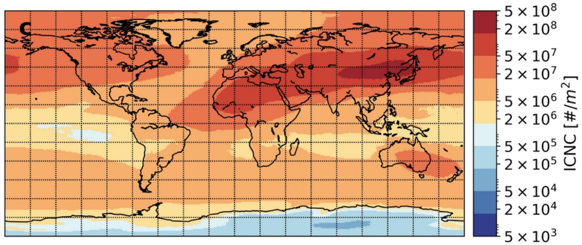
Summary:

- 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).

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



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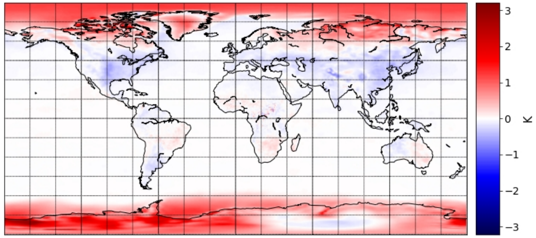

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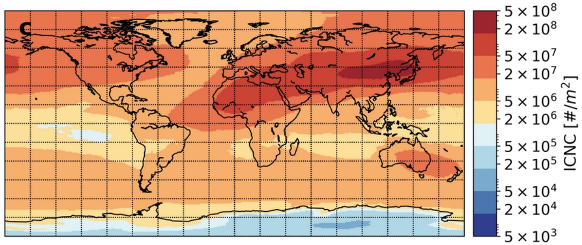

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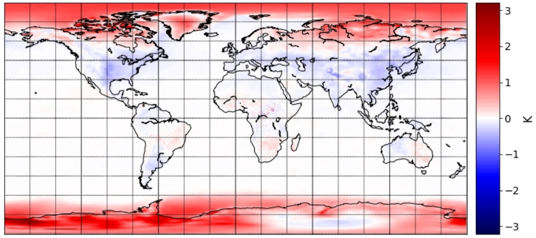

Next steps:

- 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.

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