Updates and Improvements to EC-Earth4: Mineral Dust Scheme and Cold Cloud Processes

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Objectives

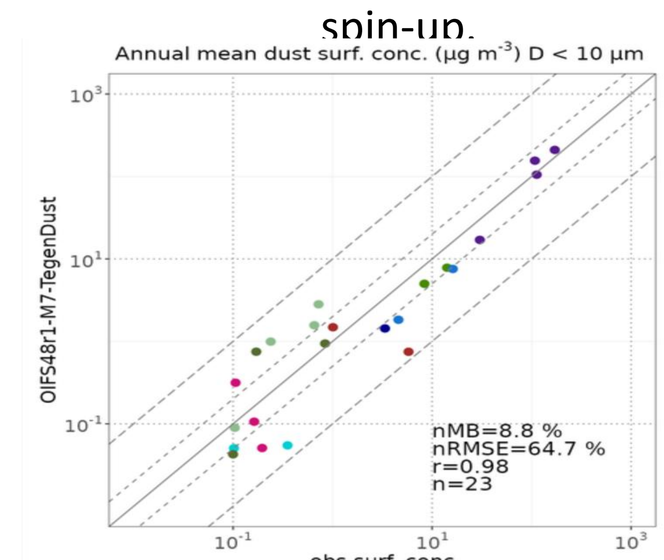
- Introduce and evaluate a **new dust emission** scheme aiming at a more climate-sensitive representation of dust emissions.
- Implement an explicit representation of key ice-nucleating minerals (**quartz and feldspar**) using state-of-the-art soil mineralogy atlases.
- Evaluate the impact of secondary ice production (SIP) implementation on clouds related parameters.

Methodology

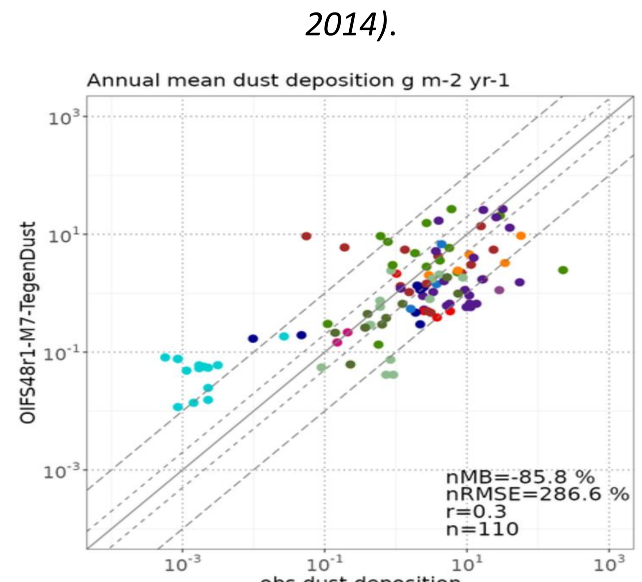
- **Dust emission scheme** by Tegen et al., (2002, 2004) is used which accounts for interactions between dust emissions and land-surface variables.
- **Minerals fractions** are precalculated based on mineralogical atlases from Claquin et al. (1999), Journet et al. (2014), or the EMIT NASA project and accounting for the emitted PSD by Kok et al. 2011.
- **The emissions of minerals** are calculated by multiplying mineral fraction on the soil by dust fluxes in **accumulation** and **coarse** modes.
- Dust mineral's **ageing** (coagulation, condensation, particle growth) and **transportation** is treated analogously as **internally mixed dust** (represented by M7)
- Mixed-phase clouds (MPC): implementation of SIP.

Results: Dust & INP evaluation

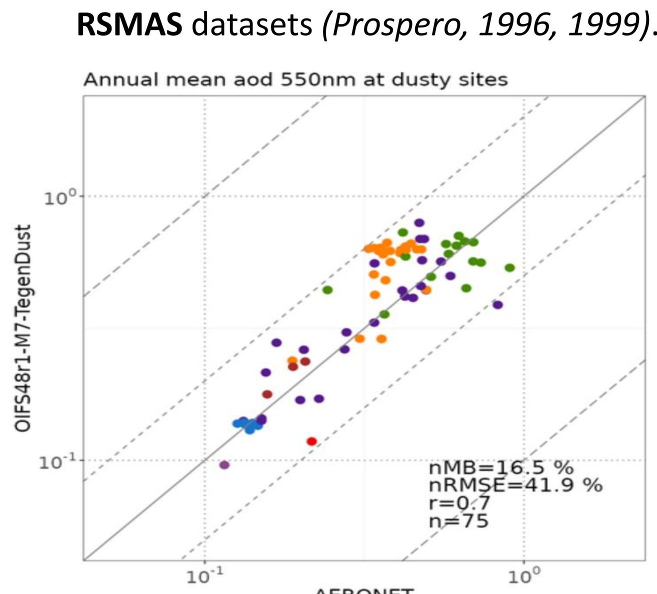
Dust Evaluation: Two-year full-run (2018–2019) with atmospheric nudging, prescribed ocean conditions and 1 year of spin-up.



Dust deposition fluxes: Compared with the global observational compilation *(Albani et al., 2014).*



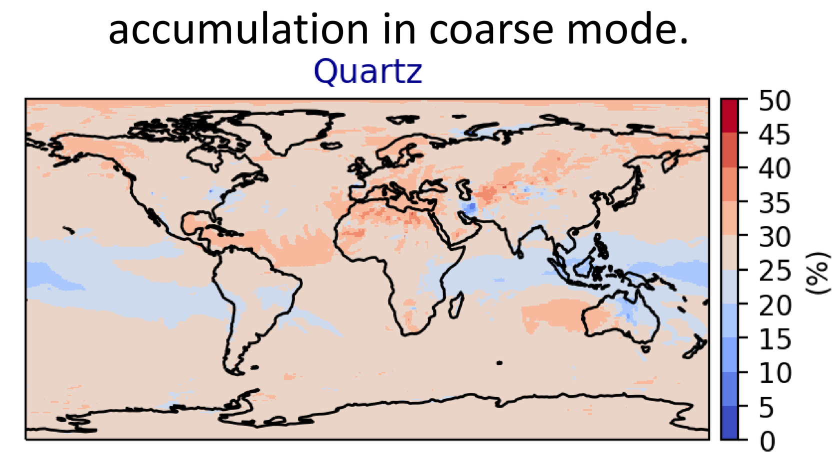
Surface dust concentrations: Compared with **AMMA** *(Marticorena et al., 2010)* and with **RSMAS** datasets *(Prospero, 1996, 1999).*

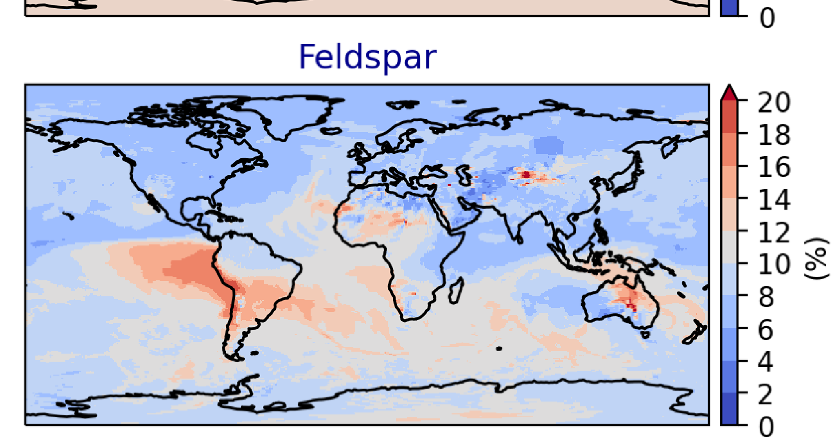


Aerosol Optical Depth (AOD): Compared with **AERONET** observations.

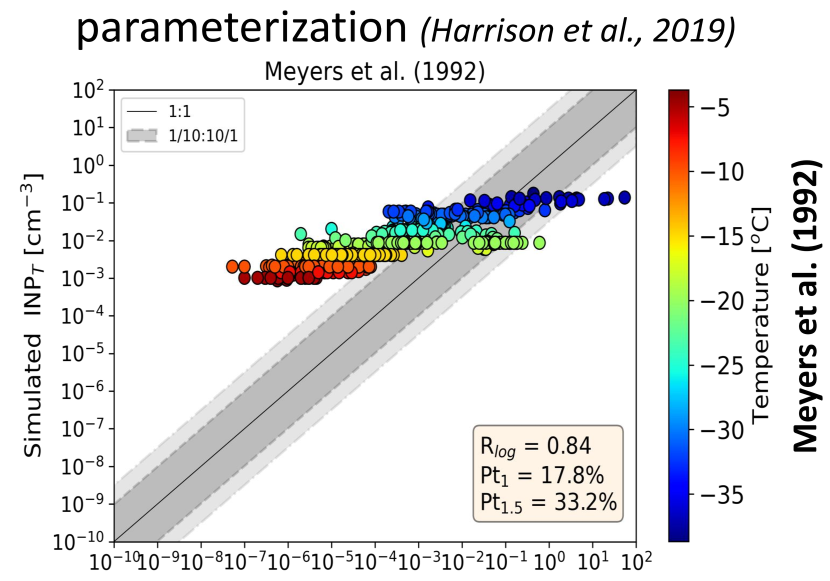
Overall, the new dust scheme shows **good agreement with climatological** observations:
- Spatial **patterns of dust concentrations** are well reproduced, with a **slight overestimation** in some regions.
- **Dust deposition fluxes** are slightly **overestimated**, particularly in **remote regions** (e.g., **Southern Hemisphere**) where observations are difficult to reproduce.
- **AOD_{550} comparisons** at selected **AERONET** sites **dominated** by **coarse aerosols** show **reasonable agreement** with observations.

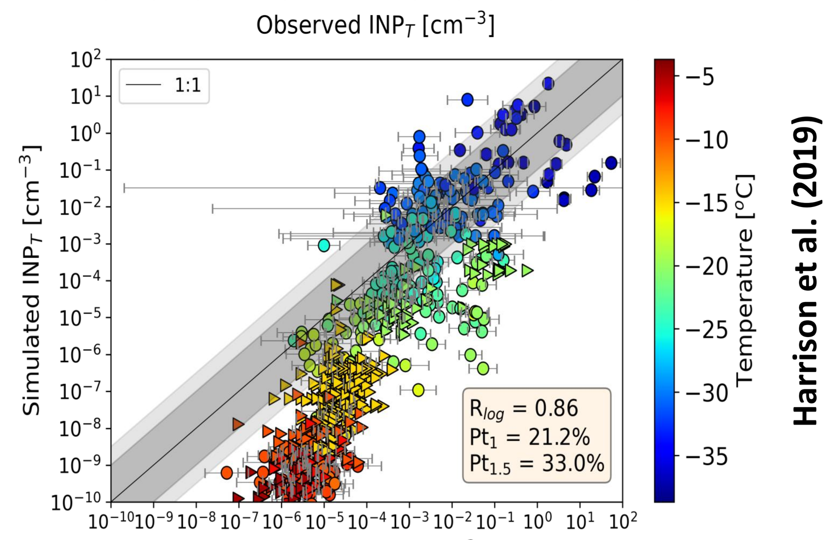
Mineral fractions in dust: Feldspar and Quartz contributions to soluble and insoluble accumulation in coarse mode.





INP evaluation: Offline INP concentrations compared with a global compilation of INP measurements using:
- **Temperature-based** parameterization *(Meyers et al., 1992)*
- **Dust minerals dependent** parameterization *(Harrison et al., 2019)*



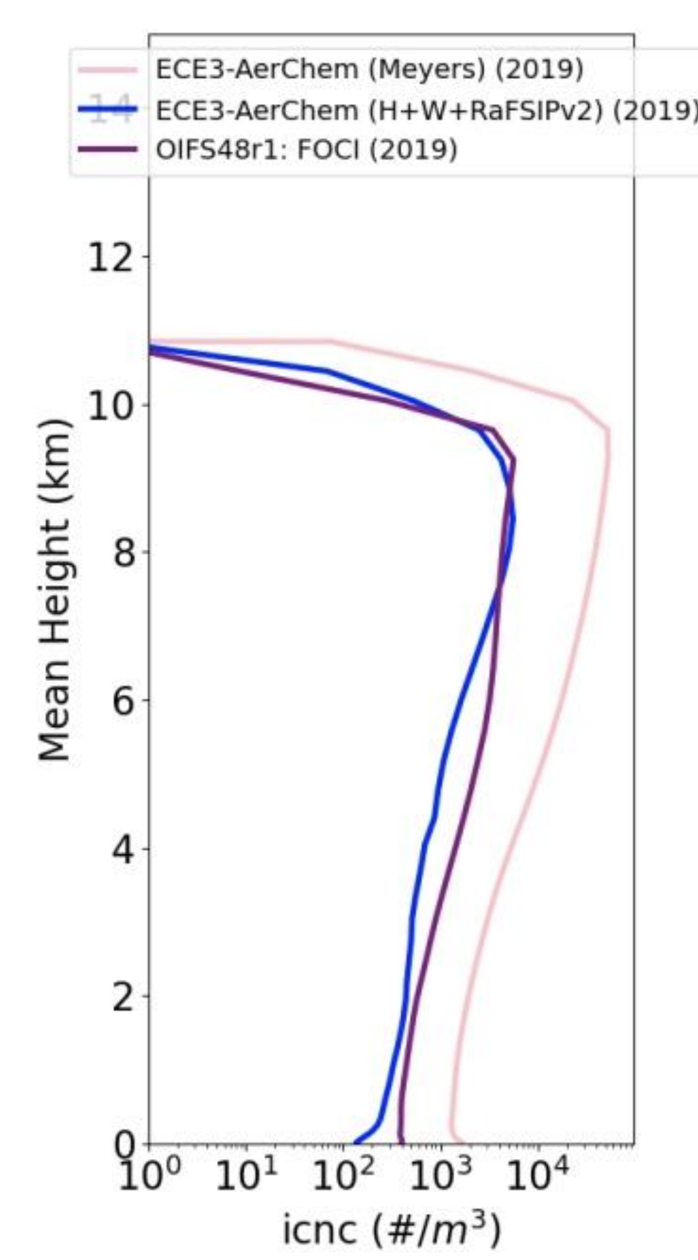


Global INP observations from the **BACCHUS database**, including **Arctic, Southern Ocean, and multi-ocean ship-based measurements** (Wex et al., 2019; McCluskey et al., 2018a; Tatzelt et al., 2020; Welti et al., 2020).

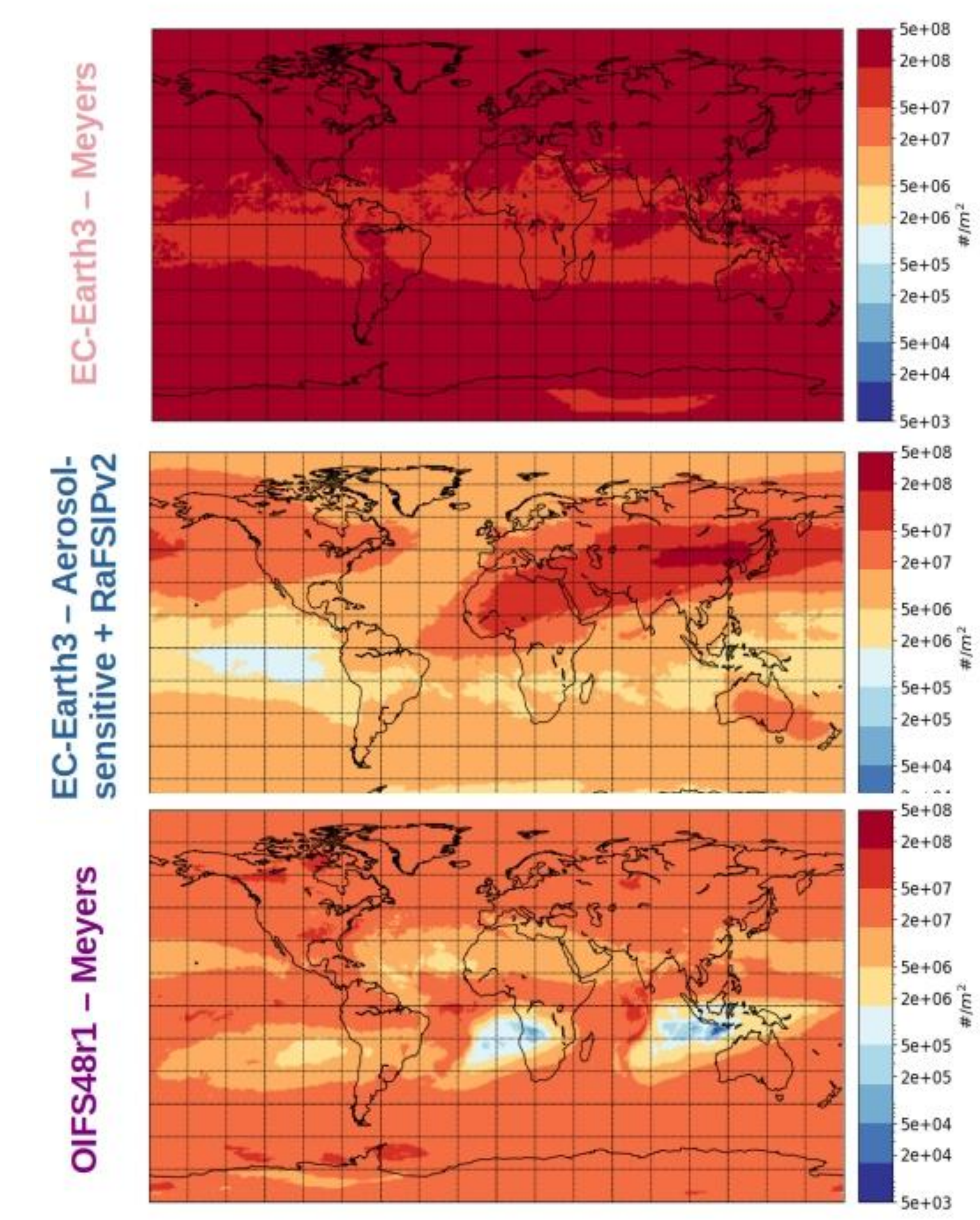
- **Mineral dust–derived INPs** show **better correlation** with observations at **colder temperatures**.
- A **significant underestimation** occurs at **warmer temperatures** (> −20 °C).
- This likely reflects **missing INP** sources in the model, such as primary marine and terrestrial **bioaerosols**.

Results: ICNC, LWP & IWP

MPCs-ICNC mean profiles

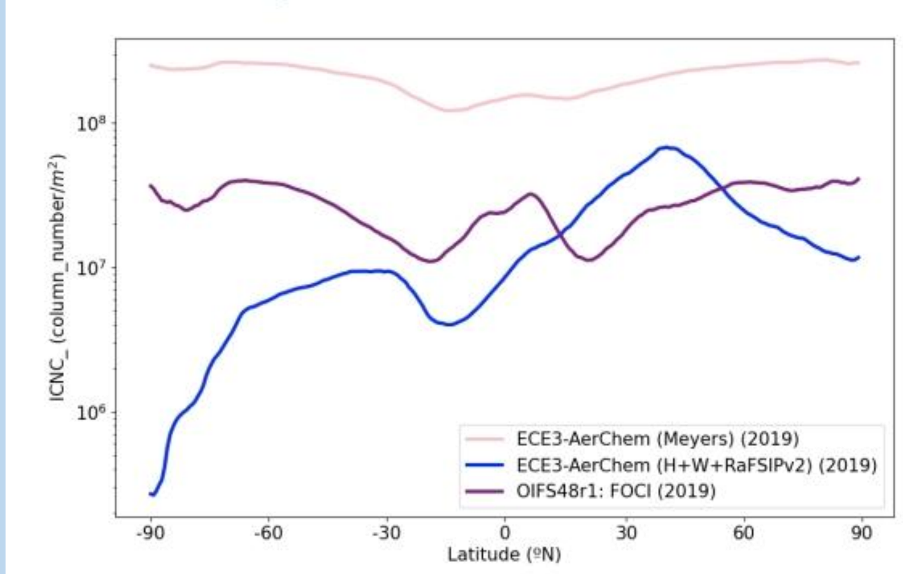


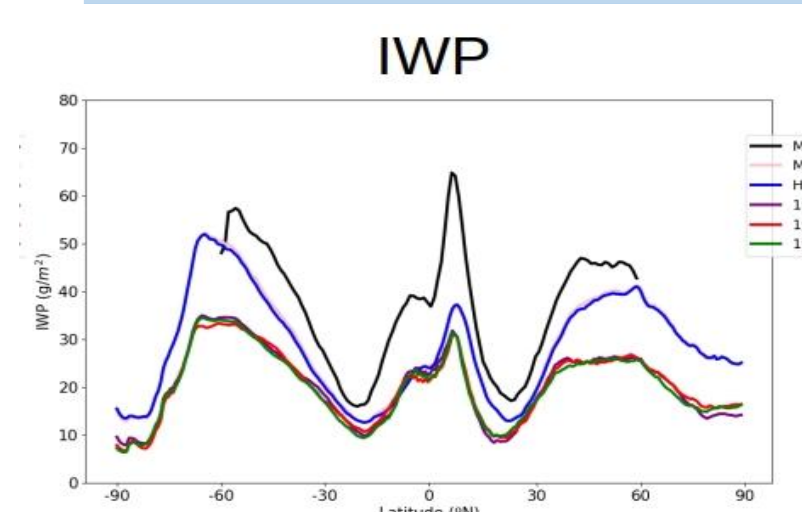
Global distribution of column MPCs-ICNC load

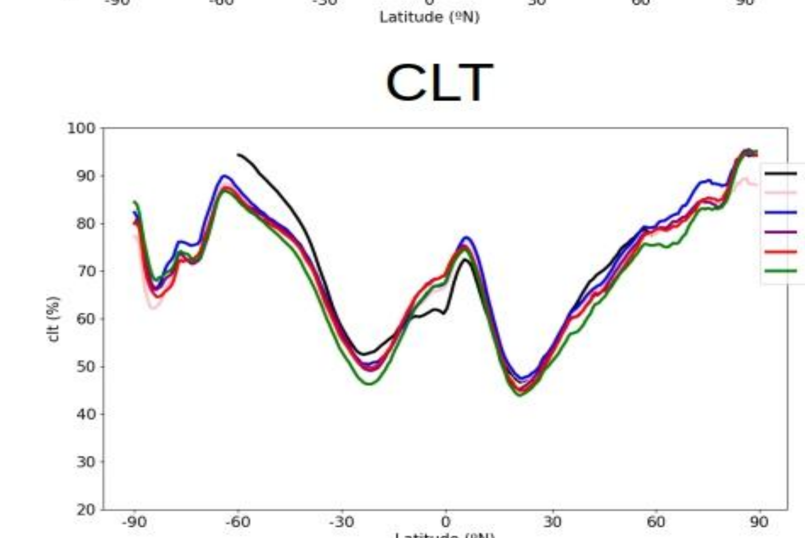


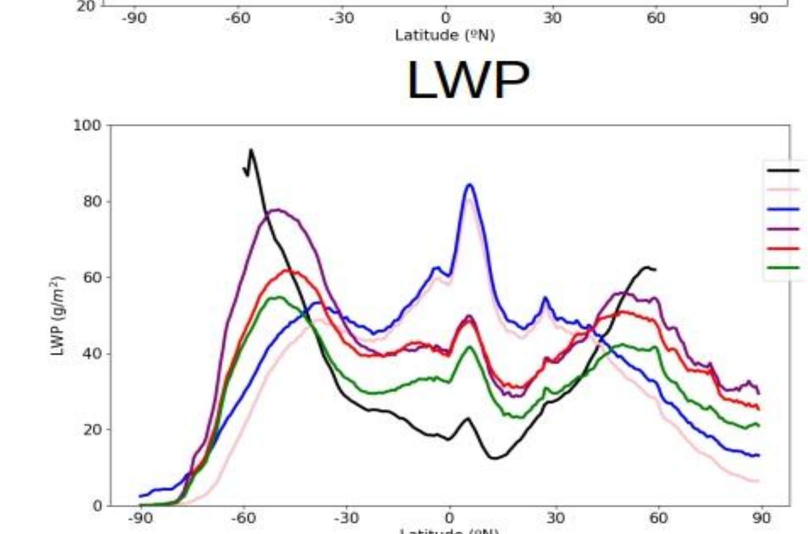
- The MPC ICNC annual mean calculated using the Meyers et al. (1992) scheme produces **large ICNC** values across **all latitudes**, which is consistent with previous EC-Earth3 results (Costa-Surós et al., 2026).
- ICNC magnitudes are about **one order of magnitude lower**, mainly due to the narrower **temperature range** used in **OIFS48r1** (−5 to −38 °C) compared to EC-Earth3 (0 to −38 °C).

1-year MPCs-ICNC zonal mean









- In OIFS48r1, the mid-latitude **LWP underestimation** is partially **corrected** and tropical **overestimation is reduced**, while **IWP** is generally **lower** and **closer** to other models (MODIS values are shown for reference but are not directly comparable).
- **RaFSIPv2** (Georgakaki & Nenes, 2024) has been **implemented** in OIFS48r1. A test run combining RaFSIPv2 with the Meyers et al. (1992) parameterization was performed, even though these schemes are not intended to be used together. The SIP process has an impact comparable to a 2×ICNC test (not shown).
- A full evaluation will follow once RaFSIPv2 is combined with aerosol-sensitive primary ice nucleation.

Next Steps

- Constrain the ice-nucleating ability of dust minerals (quartz and feldspars) using aerosol-sensitive INP parameterizations.
- Implement marine organic aerosols and terrestrial bioaerosols, linking them to primary ice nucleation processes.
- Constrain aged dust minerals as weak or non-effective INPs based on CERTAINTY observations.
- Implement the COSPv2 simulator for comparison with MODIS and CALIPSO satellite observations.

Acknowledgments

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