Project: **1368**

Project title: **nextGEMS aerosols**

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Summary

Aerosols strongly influence the Earth's climate as they scatter and absorb radiation but also serve as condensation nuclei for cloud droplets. New climate models that run at kilometre resolutions allow us to examine long-standing questions related to these interactions. To perform simulations with the climate model ICON-Sapphire, we developed the one-moment aerosol module HAM-lite. HAM-lite is based on and traceable to the two-moment aerosol module HAM. Like in HAM, aerosols are represented as an ensemble of log-normal modes. Unlike in HAM, aerosol microphysics and chemistry are discarded and aerosol sizes and compositions are prescribed. To evaluate our model, we performed global simulations with four aerosol modes at resolutions of about five kilometres and over periods of up to one year. The simulations captured key elements of the aerosol cycle like the emission of dust aerosols by cold pools in the Sahara or the interplay of sea salt aerosols and tropical cyclones in the Pacific.

Implementation

The transport of prognostic tracers in ICON-Sapphire requires significant computational resources such that the two-moment scheme HAM can only be used in simulations at resolutions on the order of 100 kilometres (Salzmann et al. 2022). In order to make simulations at resolutions on the order of one kilometre possible, we reduced the physical complexity of HAM and developed the one-moment scheme HAM-lite. First, we discarded microphysical processes and prescribed the mean radius and particle composition such that we only needed prognostics tracers for particle numbers. And second, we discarded the hydrophobic and nucleation modes and in turn further reduced the number of prognostic tracers to about three to five. The prognostic tracers for particle numbers are advected through the atmosphere and influenced by various processes such as emission, wet deposition, dry deposition, and sedimentation. Figure 1 shows how the parameterisation schemes of ICON-Sapphire and HAM-lite interact with each other. Wet deposition is linked to the cloud microphysics scheme, optical properties of aerosols are factored into the radiation scheme, and dry deposition and emission are linked to the turbulence and land schemes. Sedimentation is called separately at the end of each cycle.

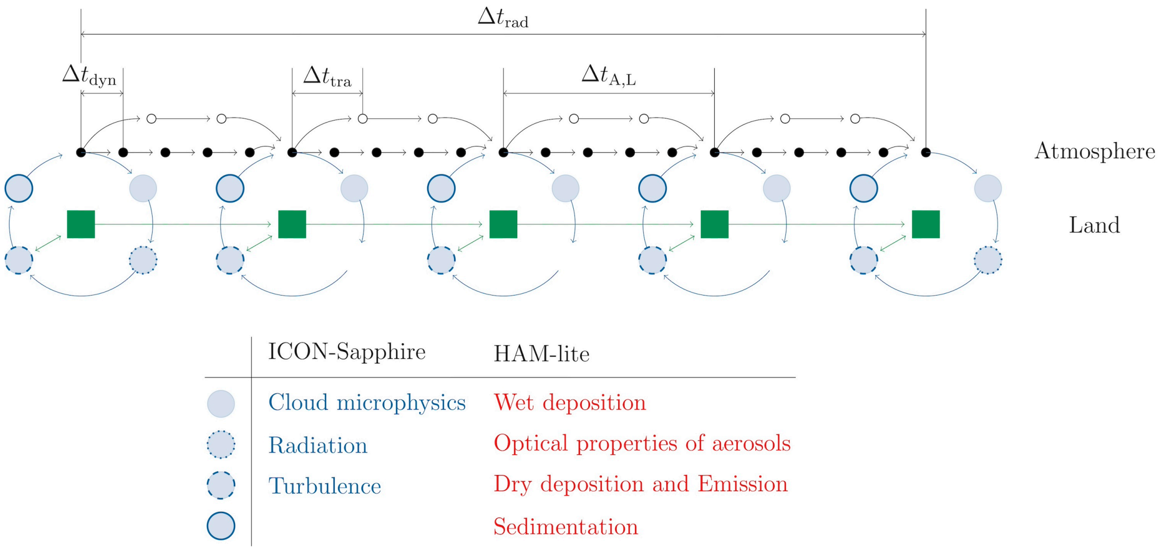

Figure 1: Time stepping and atmospheric processes: dynamical core and tracer transport (black), parameterized processes (blue), and land scheme (green). Processes of ICON-Sapphire are highlighted in blue, whereas processes of HAM-lite are highlighted in red.

Model performance and evaluation

We performed global simulations with ICON-Sapphire together with HAM-lite at resolutions of about five kilometres and over periods of up to one year. Apart from prescribing the sea surface temperature and sea ice instead of simulating an interactive ocean (Taylor et al. 2000), the simulations were configured like in the work of Hohenegger et al. (2023). The aerosols are represented with four modes. There are two pure modes, one of dust and one of sea salt, and two internally mixed modes, both of organic carbon, black carbon, and sulfate. The first mixed mode represents aerosols from biomass burning emissions and the second mixed mode represents aerosols emitted from anthropogenic and volcanic emissions. The computational throughput is about 40 simulated days per day on 400 compute nodes each with 128 cores and 256 gigabyte memory. One variable at one level and one time step requires about 0.08 gigabytes of disk space. In summary, we stored about 200 terabytes for one year including three-dimensional and high-frequency fields to analyse various processes in the atmosphere.

The simulations captured key elements of the global aerosol cycle, of which some are missing entirely in coarse-scale simulations. Figure 2 shows the burden of sea salt aerosols together with cloud water and ice and surface precipitation. The inset on the right captures two tropical cyclones in front of the Mexican coast. The cyclones emit and deposit large amounts of sea salt aerosols due to their strong surface winds and precipitation. Figure 3 shows the mixing ratios of all four aerosol modes together with cloud water and ice. The curtain on the right visualises various processes throughout the vertical column. Dust aerosols are picked up by convective updrafts in the Sahara, sea salt aerosols are washed out by low clouds over the ocean, and biomass burning aerosols are advected over the ocean by trade winds.

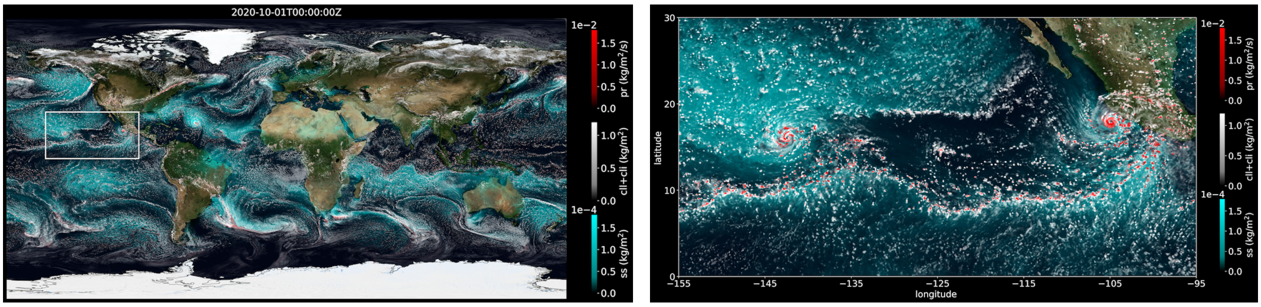

Figure 2: Global and regional map of sea salt, cloud water and ice, and surface precipitation.

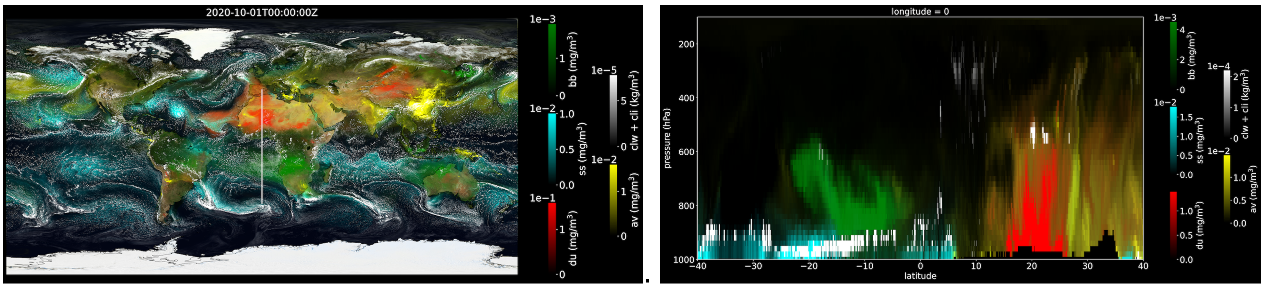

Figure 3: Global map and curtain plot of all four aerosol modes, i.e., dust, sea salt, biomass burning, and anthropogenic volcanic, together with cloud water and ice.

References

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