Project: **1311**
Project title: **The importance of upper-troposphere aerosol formation for low- and mid-troposphere aerosol concentrations**
Principal investigator: **Anna Possner**
Report period: **2023-05-01 to 2024-04-30**

Resources utilization report

Table 1: Overview of project resources utilization from 2023-07-01 to 2024-04-24. All entries are given in Node hours.

Category	Amount
Granted	61’705
Consumed	16’487
Expired	30’272
Remaining	14’946

The resources were allocated to four main areas: data preprocessing, model setup, experiments, and postprocessing. These included *long-term global simulations* with idealized tracers to investigate the transport of upper tropospheric aerosols of tropical origin using the EMAC model, as well as *short-term, limited-area simulations* with ICON-NWP to simulate a case study of Amazonian convection related to the CAFE-Brazil field campaign. Approximately 10% of the resources were devoted to the case-study simulations.

Short-term, limited-area simulations with ICON-NWP

The limited-area, short-term simulations over the Amazon were initially planned for next year but were initiated earlier to meet the goals of an international model inter-comparison that is currently being organized. The inter-comparison aims to assess the inter-model (e.g., ICON, WRF, the Met Office Unified Model) uncertainty in simulating Amazonian convection at convection-permitting scales, based on a squall-line case that occurred during the CAFE-Brazil campaign. This campaign is expected to play a key role in understanding not just upward, but also downward tracer transport over the region. Evaluating tracer transport by Amazonian convection during CAFE-Brazil was part of the original proposal for TPChange, and the initiative to compare results from ICON and other models is expected to be highly beneficial for our study, justifying the decision to move these simulations ahead.

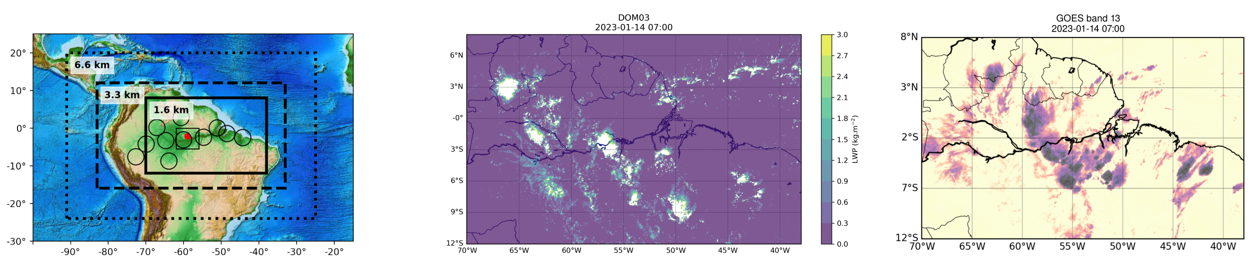

Figure 1: (left) Illustration of the domains used for the ICON-NWP short-term simulations (three outer rectangles). (center) Liquid water path in a snapshot at January 14, 07:00 UTC of the 1.6-km resolution ICON simulation initialized on January 13, 2023 at 00:00 UTC. (right) Image from GOES 16, band 13 (10.3 μm) corresponding to January 14, 07:00 UTC

The definition of the inter-comparison protocol is still in progress. Therefore, only preliminary simulations have been performed so far, with the intention of estimating the optimal settings, including the necessary spin-up period, for the case study in question. Figure 1 illustrates the domain configuration and a snapshot of the simulated liquid water path (LWP), as well as the GOES brightness temperature (BT) for reference. Results indicate that the optimal spin-up period with respect to Squall Line initiation is approximately 24 hours, including approximately 12 hours of conventional model spin-up plus approximately 12 hours for the squall line to evolve within the oceanic trade-wind inflow regime.

Long-term, global simulations with EMAC

To investigate the significance of the recently identified source of aerosols from the tropical upper troposphere to other regions globally, we performed long-term simulations using ICON during the 2022-2023 allocation period, incorporating inert passive tracers. Further simulations were planned for the current allocation year, including the effects of wet scavenging, dry deposition, and sedimentation on our tracers. Our initial plan was to utilize ICON's dynamical core and basic parameterizations, along with tracer-specific parameterizations from the MESSy framework. However, unanticipated challenges in adapting ICON to MESSy, undertaken by TPChange collaborating partners, hindered the timely completion of this task. In numerous attempts, the originally planned four-domain tracer setup was tested with the coupled ICON-MESSy, contributing to identifying, reporting, and fixing various coupling bugs, but we were unsuccessful in achieving a functional setup during the current allocation period. Approximately 50% of the allocated resources for the current period had expired at the time of this report (i.e., 2023-07-01 to 2024-04-24) due to these technical difficulties.

Nevertheless, towards the end of the third quarter of the allocation period, we strategically transitioned to EMAC, enabling us to perform the 1-year simulations, albeit with some settings that required further fine-tuning. Additionally, due to the increased computational cost of EMAC's dynamical core compared to ICON's, and the challenges in implementing parallel domain refinements with EMAC, we opted to maintain only the global setup with a resolution of approximately 120 km at the Equator, instead of the previous ICON setup with an effective resolution of approximately 80 km at the global scale and three extra limited-area domains.

Two sets of tracers were implemented in the EMAC tests: one set of age-of-air tracers, which increased linearly with time within the forcing region and were only transported via resolved advection, parameterized convection, and turbulent mixing; and another set of constant tracers, which evolved via transport, plus wet scavenging, dry deposition, and sedimentation. These two sets aimed to address two complementary questions: (i) how long does transport from the forcing region to another given region take? and (ii) how much aerosol reaches there?

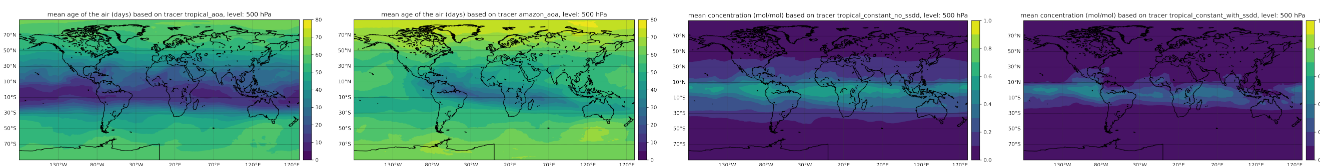

Figure 2: Mean age of air from the inert tropical and Amazon tracers (left), and mean mass concentration from the tropical tracer with and without sinks (right), at 500 hPa in the EMAC simulations

The mean age of air and aerosol concentration at 500 hPa in the simulations are illustrated in Fig. 2. Consistent with our previous tests using only resolved advection in ICON, we found that the fastest aerosol transport pathways from the tropical upper troposphere lie within the tropics, taking typically one week for 1% of the grid points within the $500 - 700$ hPa layer to be directly affected by air from the source region. In contrast, for a tracer initialized at similar levels but only over the Amazon, downward transport to that layer typically takes longer than three weeks. Our results also revealed that for particles with a mean radius of 20 nm, the combined effect of wet scavenging, dry deposition, and sedimentation leads to a $25 - 75\%$ reduction in the 99^{th} percentile of mid-tropospheric particle concentrations in the tropics and mid-latitudes compared to a passive tracer.

Next steps

During the upcoming allocation period, we plan to finalize the limited-area simulations for the Amazon case study, adhering to the soon-to-be-defined inter-comparison protocol. This will help us evaluate the role of convection-scale downward transport in redistributing upper-tropospheric aerosols. In the next phase of our long-term global study, we will perform a set 10-year simulations with varying microphysics and convection to gather more robust statistics about the uncertainties related to wet scavenging in our results. At a later stage (not included in the next allocation period), we will incorporate the full life cycle of the aerosol after nucleation, including aerosol growth mechanisms.