Project: **1311**
Project title: **The importance of upper-troposphere aerosol formation for low- and mid-troposphere aerosol concentrations**
Principal investigator: **Anna Possner**
Report period: **2024-05-01 to 2025-04-30**

# Resources utilization report

During this period, resources were allocated to two main areas: observational analysis of upper tropospheric aerosol nucleation over the Amazon, and global modeling of upper tropospheric aerosol transport. The former included contributions to the analysis of data from the CAFE-Brazil field campaign, as well as the retrieval of supplementary information to support the campaign's measurements. Approximately 5% of the resources were dedicated to the field campaign analyses. The global modeling activities encompassed preprocessing, model setup and testing, execution of production experiments, and postprocessing of 16 years of global simulations using the EMAC model.

Table 1: Overview of project resources utilization from 2024-07-01 to 2025-04-11. All entries are given in Node hours.

| Category | Amount |
|---|---|
| Granted | 18'207 |
| Consumed | 13'758 |
| Expired | 214 |
| Remaining | 4'235 |

## Long-term, global simulations with EMAC

To assess the global significance of the recently identified aerosol source in the tropical upper troposphere, we conducted long-term simulations using the EMAC model during the 2024–2025 allocation period. These simulations incorporated inert passive tracers initialized in the tropical upper troposphere, with subsets constrained to longitudes over key continental regions: South America (Amazon), Sub-Saharan Africa (Africa), and the Maritime Continent (Mar-Cont). Two tracer types were implemented: (1) age-of-air tracers, which increased linearly with time within the source region and were transported solely via resolved advection, parameterized convection, and turbulent mixing, providing a measure of the mean age of air at a given location; and (2) constant tracers, which evolved through transport processes as well as wet scavenging, dry deposition, and sedimentation. These tracer sets addressed two complementary questions: (i) how long does it take for air from the source region to reach another region? and (ii) how much aerosol is ultimately transported there? Simulations were run for 11 years at approximately 120 km resolution at the Equator.

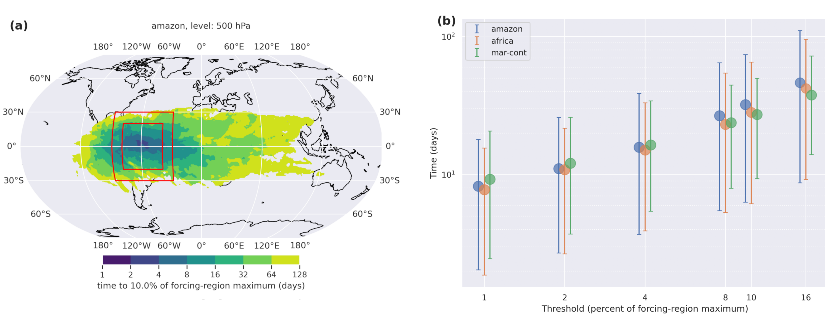


Figure 1: (a) Average time to reach 10% of the maximum value in the forcing region (inner red square) for the Amazon tracer, derived from tracers initialized once a month during one year. Panel b shows the mean inside the outer red square in panel a (and corresponding regions at other continental longitudes), for different percentage thresholds.

The mean age-of-air approach offers an effective means of estimating the most likely transit time for air parcels arriving at a given location. In our tests, large mean age values—on the order of $10^2$ days—at 500 hPa reflect substantial mixing during transport from the source to the target region, especially for regionally constrained tracers. While a more detailed understanding of the distribution of transit times within a parcel can be obtained through the age spectrum, deriving this from our 10-year simulations would require a large number of pulse tracers, which is computationally unfeasible. As an alternative, we adopt a complementary approach that estimates the time required for a specified fraction of the tracer concentration in the source region to be reached at the target location. This method, applied to the constant regional tracers, allows us to investigate potential early impacts in the target region from even small fractions of the material originating in the forcing region.

To implement this, two 2.5-year simulations were performed using only constant tracers. In one simulation, tracers were initialized monthly over a one-year period. In the other, tracer evolution included or excluded parameterized convection and vertical diffusion, to evaluate the roles of these processes in controlling the fastest transport timescales. Fig. 1 shows the mean time required to reach 10% of the maximum tracer concentration in the source region, calculated from 12 tracers initialized monthly over one year. The figure also illustrates how area-averaged values vary with the selected percent threshold. These threshold levels are comparable to the fraction of aerosols generated by secondary nucleation in the boundary layer, relative to those produced in the upper troposphere over pristine regions.

### CAFE-Brazil data analysis

The CAFE-Brazil field campaign was conducted in the Brazilian Amazon basin between December 2022 and January 2023. In the second half of 2024, an intensive collaborative effort led to the completion of data analysis and the synthesis of the campaign's main findings, culminating in the publication of a research paper in Nature (Curtius et al., 2024). This work is directly aligned with the objectives of TPChange and was anticipated in the original research plan for subproject C06, for which this resource allocation was initially requested. DKRZ resources allocated to our project were used to generate a 48-hour back trajectory database for every 1-minute aircraft position across 15 research flights, each lasting approximately 8 hours. The back trajectory algorithm was developed in Python, and the results were stored in JSON format. Two trajectory sets were produced—one based on aircraft-measured wind speeds and the other using satellite-retrieved wind data.

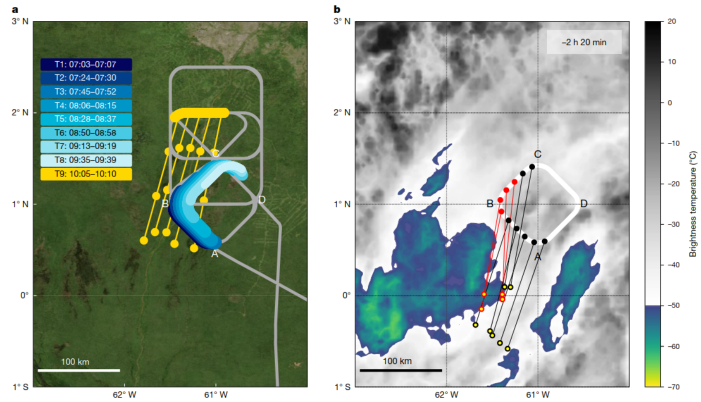


Figure 2: Flight path of Research Flight 19 (grey), with segments where new-particle formation (NPF) was detected highlighted in blue and yellow (a), and regions linked to prior convection shown in red and black (b). In panel (a), thin yellow lines with 1-hour markers represent 3-hour back trajectories from the NPF period T9. Panel (b) shows back trajectories from aircraft positions between 08:05 and 08:15 local time (black and red markers), traced back 140 minutes (yellow-centered markers). Source: Curtius et al. (2024, Nature).

Figure 2 illustrates an example application of the back-trajectory analysis. In this case, the calculations used horizontal wind speed and direction measured by the research aircraft. Back trajectories initialized from flight section T9 were used to identify and define periods T1–T8, thereby linking different stages of a strong new-particle formation (NPF) event. This represents the first time such a temporal evolution of NPF has been captured during research flights. The trajectories also enabled tracing air parcels in which NPF was detected (red circles) back to a convective cloud event several hours earlier. This supports the hypothesis that nucleation precursors were lofted by deep convection during the preceding afternoon and night.

### Next steps

During the final trimester of the current allocation period, the remaining resources will be used to investigate the impact of numerical diffusion on simulated transport. This will involve testing an alternative advection scheme and potentially varying model resolution in a series of 2.5-year simulations. As outlined in the previous report and resource request, regional simulations using ICON-NWP will also be conducted as part of a model intercomparison effort based on a CAFE-Brazil case study. This case focuses on the development of a squall line near the HALO flight path and the ATTO tower. The intercomparison protocol was released earlier this year, and simulations are due by the end of May.
In the upcoming allocation period, we plan to carry out additional simulations based on the CAFE-Brazil configuration to investigate the role of small-scale transport processes not explicitly represented in the global EMAC simulations.

### Presentations

This work was presented at conferences and workshops including ICCP, EGU, EAC, and TP-Challenges.