Project: **1004**

Project title: **Development and evaluation of aerosol processes in ECHAM-HAMMOZ**

Project lead: **Bernd Heinold, Ina Tegen**

Report period: **2020-07-01 to 2022-06-30**

The aim of his project is the on-going evaluation and coordination of further developments of the aerosol model HAM (Versions 2.2, 2.3) in close collaboration with scientists from the HAMMOZ consortium. The well-established global aerosol-chemistry-climate model ECHAM6-HAMMOZ is jointly developed by partners from several European universities and research institutes. The model code is hosted at the ETH Zurich where it is made accessible to the research community; partners include scientists at the Universities of Oxford, Helsinki, as well as at the German research institutes MPI Hamburg, TROPOS and GEOMAR. It simulates the lifecycles of the climate-relevant aerosol species including microphysical transformation processes, and their impact on clouds, radiation and climate. The model system includes the global atmospheric climate model ECHAM, the aerosol-microphysics model HAM, and the atmospheric chemistry model MOZART. The role of TROPOS in this project is to bring together the different aspects of the model development and to test the subsequent modifications in the aerosol distribution resulting from the changes of the aerosol parameterisation.

The ECHAM6.3-HAM2.3-MOZ (released 2017) model was further used and improved in several applications. Ongoing model tests and developments include the tests of the deposition scheme and updates in the sulphate oxidation scheme in HAMMOZ.

A large part of the granted computing time for the previous period was used for simulations of the extreme wildfires in Australia during the 2019/20 fire season. The unusual intensity and distribution of the fires was caused by an extreme drought in central and eastern Australia. Massive smoke plumes were lifted into the upper troposphere and lower stratosphere (UTLS) by pyro-convection. Subsequently the fire aerosol was transported over thousands of kilometres eastward by the prevailing winds, affecting the aerosol conditions throughout the southern hemisphere.

We have investigated the transport of the fire aerosol and its impact on the radiation budget by aerosol-climate simulations with the ECHAM6.3-HAM2.3 model at T63 horizontal resolution and 47 levels in the vertical. At the lower boundary sea surface temperatures and sea ice conditions were prescribed. Biomass burning emissions are prescribed by current GFAS fire information on a daily basis. For late 2019 and January 2020, the Australian wildfire emissions of e.g. BC aerosol extracted from this dataset are greatly increased compared to emissions averaged for the years 2000-2016 (Figure 1). As the horizontal model resolution is too coarse to explicitly resolve convection, the injection height of the smoke is prescribed near the tropopause on the days where pyroCb activity occurred and varied in terms of sensitivity studies. The model results for late 2019 and early 2020 are contrasted with a control simulation without Australian wildfire emissions and a base run in the standard configuration in which ECHAM-HAM emits 75% of the wildfire aerosol into the planetary boundary layer (PBL) and 17% and 8%, respectively, into the two layers directly above the PBL. Since the intention was to simulate the actual situation as realistically as possible to be comparable to observations, the model dynamics were nudged towards ERA5 reanalysis data (Hersbach et al., 2020).

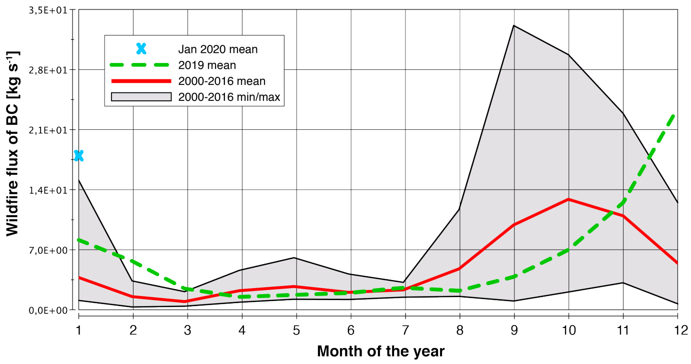

Figure 1: Annual cycle of wildfire emissions of black carbon across Australia. Compared is the monthly-mean area total for the period 2000–2016 with that of the years 2019/2020 from the GFAS fire inventory.

We find the best results in comparison to different observations (e.g. AERONET sun photometers and a TROPOS Polly Lidar located in Punta Arenas, Chile) when the smoke aerosol is injected at the first model level above the tropopause (Figure 2). In contrast, it makes almost no difference whether the aerosol is injected into the lower troposphere as in the standard configuration of ECHAM-HAM or there is no emission on the pyroCb days at all as in both cases the smoke does not arrive at altitudes greater than 10 km over South America. Thus, for the long range transport and the long-term effects injection in the UTLS region is crucial. Furthermore, the observed self-lifting of the aerosol layer with time can be reproduced by the model. Optical properties of the smoke aerosol, e.g. single scattering albedo have been found to agree well with the Lidar observations over South America (Ohneiser et al., 2020; 2022).

The hemispheric extent of the aerosol layer and the accumulation of smoke over the Antarctic continent in the UTLS has a significant effect on the radiation budget. The instantaneous radiative forcing at the top of the atmosphere under all-sky conditions is estimated to be +0.35 to +0.5 W/m^2 averaged over January to March 2020 on the Southern Hemisphere. These values, if expanded to the entire globe, are comparable to the most recent estimates of global instantaneous forcing by anthropogenic black carbon of +0.28 (+0.13 – +0.37) W/m^2 (Thornhill et al., 2021). Surface dimming in the three months after the wildfires is of the same order of magnitude as after a large volcanic eruption.

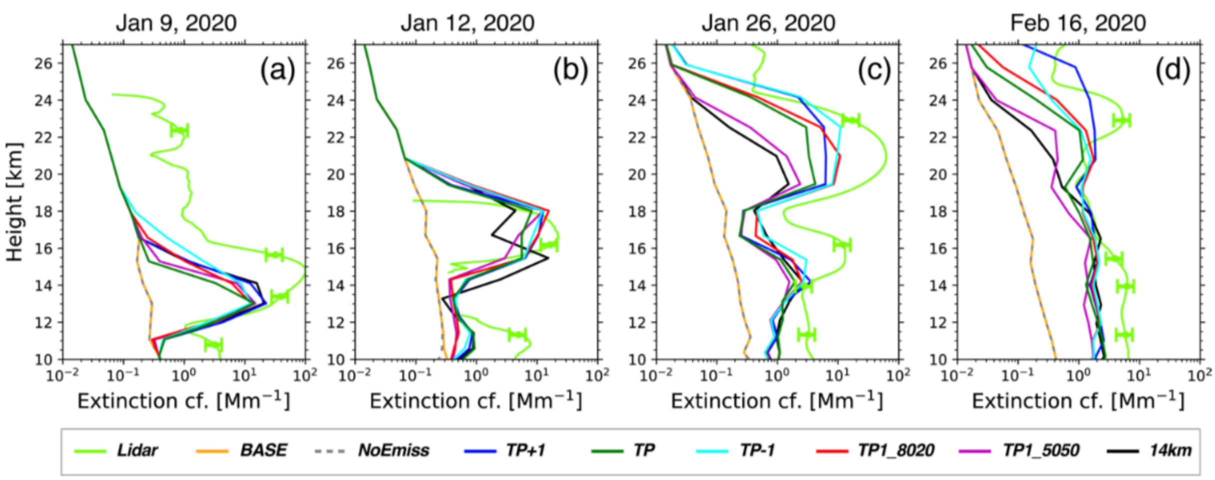

***Figure 2**:* Comparison of observed (green) and simulated Lidar extinction coefficient profiles from ECHAM6.3-HAM2.3 model simulations at Punta Arenas, Chile (53.14°S, 70.89°W) on selected days in Jan and Feb 2020. From *Heinold et al.* (2022)

The anomalous warming in the mid-latitude UTLS of the Southern hemisphere even affects the global circulation. It alters the thermal gradient in the UTLS which has implications on meridional and vertical motion. In the Transformed Eulerian Mean framework a weakening of the tropospheric circulation becomes apparent. At the same time, the Brewer-Dobson circulation in the (lower) stratosphere is affected in a way that an anomalous northward meridional motion occurs, which has the potential to warm even the lower stratosphere of the Northern Hemisphere.

Recently, the nudged simulations, which are intended to reproduce the actual situation, were complemented by two ensemble simulations without nudging. The ensembles consist of six members each and serve to further investigate the circulation response to the Australian wildfires.

As a next step, it is planned to extend part of the sensitivity studies in time until the end of the year 2020 to study the continued evolution of the smoke aerosol layers and its effects on radiation and dynamics in order to quantify the aerosol-climate impact. This is motivated by measurements of the TROPOS Polly Lidar in Punta Arenas which show a persistent presence of smoke in the UTLS throughout the year 2020, but will also be expanded to other wildfire smoke events.

In 2021, the new aerosol-climate model ICON-HAM (Salzmann et al., 2022) became available as the successor to ECHAM6.3-HAM2.3. Here, the HAM (version 2.3) aerosol model is coupled to the climate model ICON-A (icon-aes-1.3.00). TROPOS has the responsibility to prepare and maintain the input data for the new model system. Thus, to enable users to fully explore the new model a comprehensive set of input data was prepared in the allocation period. It contains, e.g., different emission inventories, future emission scenarios, concentrations of oxidant species, surface data relevant for mineral dust emission, etc. Part of the granted computing time was used to perform numerous test simulations with the new input datasets, most of them covering 6 months each.

Publications:

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