Project:	**1174**
Project title:	**Effects of Absorbing Aerosols on Cloud Cover over Germany**
Project lead:	**Dr. Fabian Senf (TROPOS)**
Allocation period:	**1.7.2020 - 30.6.2022**

Overview

The project is dedicated to address the research question how the presence of absorbing aerosol such as black carbon changes the atmospheric state including clouds. Aerosol-mediated changes in the atmosphere occur at rather short time scales compared to other climatic changes, and thus appear to be mainly independent of near-surface temperature changes. Therefore, the changes in the atmospheric state due to aerosol absorption are assigned to the so-called rapid adjustments to aerosol-radiation interactions (ARI) - formerly known as semi-direct effects - which together with the direct (or instantaneous) radiative forcing of aerosol can be combined to the effective radiative forcing. Within the allocation period, the resources in project bb1174 helped to (details below)

(i) assess the mechanisms of cloud-cover adjustments to changes in aerosol absorption using hectometer-scale ICON-LEM simulations (data originally created within project bm0834) over Germany, and

(ii) support the investigation of simulation sensitivities to absorption strength using a set of ICON-LEM simulations with respectively perturbed aerosol radiative properties.

Mechanisms of Cloud-Cover Adjustment

The resources of the bb1174 project were partially used to retrieve, post-process and analyze large amounts of hectometer-scale ICON-LEM simulations (orignially created within the bm0834 project) using DKRZ-hosted tools such as cdo and jupyterhub at the DKRZ HLRE (the great support by DKRZ is acknowledged). Based on a 24-hour case-day simulation, it was found that increasing aerosol absorption from zero to representative present-day levels can lead to a reduction of cloud cover of around 1%. This reduction mainly involves low-level cloud cover with an immediate influence onto the solar radiation reflected back to space. By detailed analysis of the existing data output, it was found that both, the direct and adjustment (or semi-direct) part of the ARI forcing are positive and of similar size. In the region considered (Germany and parts of neighboring countries) an effective radiative forcing of around 5 Wm^{-2} at TOA was derived. The ICON-LEM data further allowed to explore the mechanisms that lead to the adjustment of the cloud cover. It was identified that a superposition of two effects needs to be considered: localized atmospheric heating and surface dimming both had negative influence on low-level cloud cover. First, the boundary-layer aerosol lead to a radiative heating in the cloud layer. The developing positive temperature anomaly lead to decreased relative humidity in the lower troposphere. Second, the aerosol absorption reduced the amount of solar radiation reaching the Earth's surface. The resulting rapid adjustments in the surface energy budget lead the decreases in turbulent latent and sensible heat fluxes making less evaporated water and less convective energy available from the surface. Both effects are interesting in itself, but also entangled in a complex fashion - therefore more sensitivity runs within ICON-LEM were performed within this DKRZ project (see paragraph below). More details on the scientific results can be found in Senf et al. (2021). To follow FAIR principles, analysis data were made available through DKRZ LTA under Senf (2020) and Senf (2021a), and analysis software was published at Senf (2021b).

Sensitivities to Absorption Strength

A significant portion of the compute resources of project bb1174 was invested into ICON-LEM sensitivity runs. Using a smaller domain, horizontal grid spacing of 600 m and a considerably newer ICON version (v2.6.1 vs. v2.1.00), the essential results found earlier could be reproduced with the new ICON setup. As next step, aerosol absorption was scaled by pre-factors of 0.5, 1.5 and 2 to assess how linear and how systematic responses of cloud and circulation measures are. With the set of sensitivity experiments, we found convincing evidence that the response of atmospheric variables including cloud cover predominantly scales with absorption strength (see Fig. 1). This leads to the conclusion that the atmospheric response is robust and not dominated by chaotic weather noise on the considered time scales.

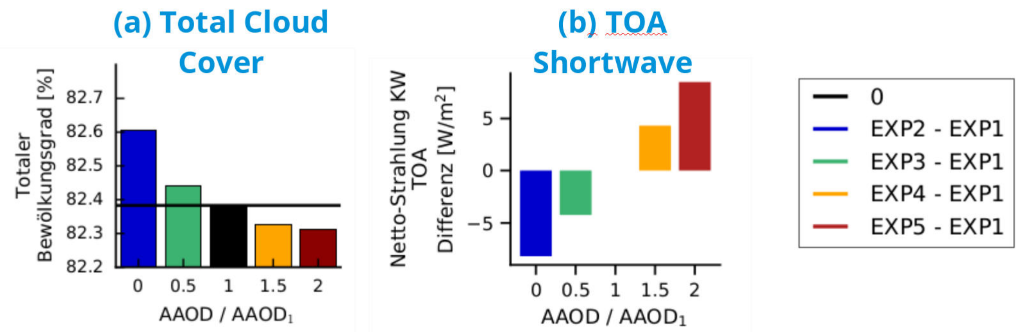

Figure 1: Domain- and time-averaged (a) total cloud cover and (b) net shortwave radiation difference at TOA for a set of sensitivity experiments with the ICON-LEM model. Colors from blue to red indicate experiments with different aerosol absorption strength going from zero up to two (see main text). Figures is taken and adapted from Paul (2021).

Further ICON-LEM experiments were conducted during the allocation period in which the reduction in aerosol absorption was compensated by increased aerosol scattering to make first attempts to systematically split the mentioned atmospheric heating effects from surface dimming. Unfortunately, these experiments did not show the expected sensitivity which hints to missing consistency in the description of aerosol radiative impacts. Debugging is currently going and reruns are planed for the next allocation period.

References

Paul, S., 2021: Einfluss absorbierender Aerosole auf die Bewölkung über Deutschland - Sensitivitätsstudie mit ICON. Bachelorthesis, University of Leipzig.

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