Project:	**1174**
Project title:	**Regional Effects of Absorbing Aerosols and Biomass Burning**
Project lead:	**Dr. Fabian Senf (TROPOS)**
Allocation period:	**1.7.2024 - 30.6.2025**

Overview

The compute project is dedicated to the question of how absorbing aerosols, such as black carbon and dust, influence both regional weather and climate. As part of the Leibniz Campus 'Smoke and Bioaerosol', the research focuses on smoke emissions from biomass burning, in particular on the meteorological conditions and characteristics of forest fires that drive the formation of pyroconvective clouds. Initial studies use high-resolution, idealized simulations with the ICON to provide a basis for fundamental understanding how extreme wildfires transition into pyroconvective events.

Resource Utilization

At the time this report was written, approximately 18% of the granted computing resources were being used by project members, while 58% expired unused and 24% are still remaining. Resources were mainly used by the PhD student in the project, thus supporting early career development. We would like the reduced use of resources to be interpreted as a success, as sufficient high-quality simulation results were achieved in the period to produce a scientific publication. Thanks to the very easy-to-use interface to DKRZ Jupyterhub, an important part of the work and therefore used resources was put into the scientific analysis of the generated simulation data.

Scientific Results

The largest part of the resources of the bb1174 compute project were used to run and evaluate high-resolution idealized limited area simulations with the numerical weather model ICON. Experiments were carried out both in the classic NWP configuration and in the large-eddy simulation configuration of ICON. The development of so-called Pyro-Cumulonimbus (PyroCb) events was investigated. PyroCbs are characterized by spontaneously occurring, very strong and deep convection, which is triggered by the extreme heat release from forest fires. Within PyroCbs, very large quantities of biomass-burning aerosols can be transported into the tropopause region and the lower stratosphere where the lifetime of the smoke increases by several orders of magnitude compared to tropospheric smoke. Although pyroCbs have been recognized as an important source of stratospheric aerosol, many aspects of their dynamics are still poorly understood.

To investigate the formation and dynamics of pyroCbs events, numerical experiments were carried out using the very strong "Australian new years eve pyroCb event" (ANY event) for case studies. A publication based on the results of these experiments is currently under review (Mueller et al., 2025). In this study, we investigate the heat emission threshold at which forest-fire plumes transition into pyroCbs and examine the sensitivity of the pyroCbs to further changes in the total amount of heat

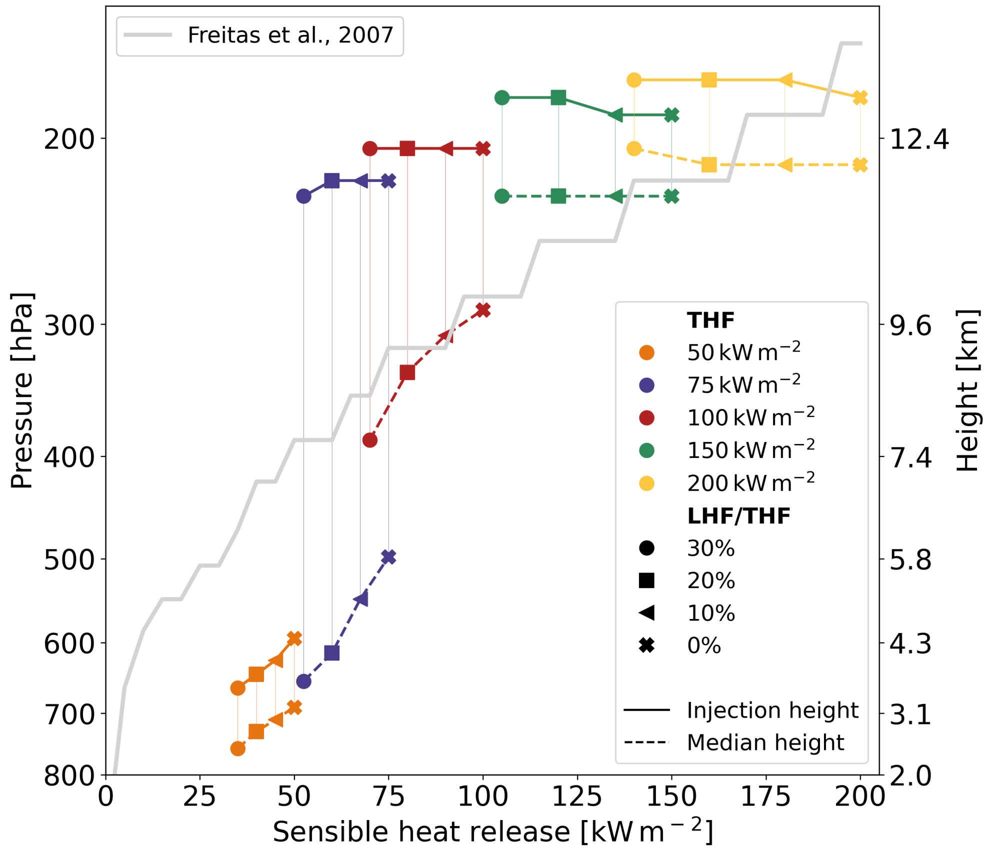

Figure 1: Injection heights (solid lines) and median heights (dashed lines) of different simulations. Simulations with the same THF are shown in the same color. Simulations with the same LHF to THF ratio are shown by the same marker. Injection height and median height of the same simulation are connected by a thin vertical line showing the range of tracer distribution (the range above which 50% and below which 95% of the tracers are located). The plume top heights calculated by the plume model by Freitas et al. (2007) are shown in light gray. See Mueller et al. (2025) for more detail.

released as well as to the latent to sensible heat flux ratio. Our results show a pronounced bimodal behavior of the plumes with an abrupt onset of pyroCb formation when the sensible heat flux exceeds 50 kW m^{-2} (see Fig. 1). When a cloud is formed within the plume, the smoke injection height is mainly controlled by the sum of the sensible and latent heat flux, while the ratio between the two plays a subordinate role. Increasing either heat flux leads to an increase in the plume water content and temperature anomaly within the cloud. The strong differences below the cloud between plumes with equal total heat flux but different sensible heat-to-latent heat ratios are buffered by changes in the cloud base height. These results show the importance of accurate estimates of heat and moisture released by fires for predicting PyroCb development. Encouragingly, a reliable estimate of the total heat flux is sufficient to characterize the behavior of PyroCbs, reducing the need for detailed partitioning of sensible and latent heat.

References

Freitas, S. R., and Coauthors, 2007: Including the sub-grid scale plume rise of vegetation fires in low resolution atmospheric transport models. *Atmospheric Chemistry and Physics*, **7 (13)**, 3385–3398, doi:https://doi.org/10.5194/acp-7-3385-2007.

Mueller, J., F. Senf, and I. Tegen, 2025: Impact of sensible heating and water vapor emission on pyro-convective plume characteristics. doi:10.22541/au.173998474.43150022/v1, URL http://dx.doi.org/10.22541/au.173998474.43150022/v1.