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High-resolution observation-based precipitation life cycle analysis of heavy rainfall events in the southeastern Alpine forelands

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The summer months in southeastern Austria are often characterized by severe rainfall from heavy thunderstorms. These events typically unfold rather quickly, with only a few minutes to hours between the formation of the first clouds and the end of the event. Though the intense precipitation during these thunderstorms often results in severe damage, it is still difficult to predict. Deepening our knowledge about the life cycle of such events, from formation to dissipation, is therefore crucial to increasing natural hazard resilience and improving forecasting skills.

Here, we use high-resolution observational data provided by the WegenerNet 3D Open-Air Laboratory for Climate Change Research (WEGN3D Open-Air Lab) located around Feldbach, Austria, to investigate the life cycle of 94 heavy rainfall events. With its 156 ground stations, one X-band radar, two radiometers, and six Global Navigation Satellite System (GNSS) stations, the WEGN3D Open-Air Lab provides high-resolution observations of key atmospheric parameters. In the study, we track 10 atmospheric parameters that are closely linked to heavy precipitation. This gives us insights into characteristic features of the different stages of the precipitation life cycle of small-scale rainfall events.

Starting with the 8 h before the event (i.e., formation stage), we identify distinct features and patterns in air temperature, integrated water vapor, liquid water path, and wind speed that are directly linked to the arrival of the first storm clouds. In the hours of the actual rainfall event (i.e., precipitation stage), the highly localized character of these events is clearly visible in the spatial variability of temperature, liquid water path, and cloud cover. The precipitation triggers a localized cooling effect, which is reflected in a strong correlation between precipitation amount and 2 m air temperature during the event. Subsequently, the integrated water vapor development during the event is also driven by the localized rainfall. In the 16 h after the event (i.e., dissipation stage), we observe the slow return of the atmospheric parameters to pre-event conditions.

The findings of our study are well in-line with the expected physical processes connected to small-scale rainfall extremes. Furthermore, we also demonstrate the WEGN3D Open-Air Lab's skill to monitor heavy rainfall events and their characteristics in high spatial and temporal resolution. This illustrates the dataset's high potential for applications in the improvement and verification of weather and climate models.