Lagrangian Analysis of Thunderstorms in Switzerland

Analysis Tools for Investigating Thunderstorm Initiation Conditions

Scientific Background

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1 Introduction and Research Question

During the summer months in Switzerland, thunderstorms occur frequently and cause a lot of damage (MeteoSwiss, 2018; Nisi et al., 2016; Trefalt et al., 2018). Although, they appear in Switzerland on small spatial scales (compared to e.g. a foehn storm), they have a high damage potential by hail, lightning, wind gusts and high precipitation amounts in short time periods (Doswell et al., 1996; García-Ortega et al., 2007; Trefalt et al., 2018). This reveals that in-depth understanding of these destructive weather events is of great importance and an accurate forecast a desirable target. Despite their frequent occurrence and damage potential, the initiation of thunderstorms is still incompletely understood. The goal of the analysis tools is to fill the above mentioned research gap and to answer the following research question:

- How far can the analysis tools unveil the atmospheric conditions and processes (basic ingredients) responsible for thunderstorm initiation?

2 Data

The data used in this project are simulations of the Weather Research and Forecasting (WRF) model. The WRF model was developed by the National Center for Atmospheric Research (NCAR) in the late 20$^{\text{th}}$ century and is one of the most used numerical weather prediction (NWP) models worldwide (Powers et al., 2017). Since the release in 2000, in the meanwhile the 4$^{\text{th}}$ version of the WRF model is developed, which is called the Advanced Research WRF (ARW). It is a subset of the WRF model and "encompasses physics schemes, numerics/dynamics options, initialisation routines, and a data assimilation package" (Skamarock et al., 2019, p. 1). In our case, the parameterisation of cloud (ice-phase) microphysics in the simulations is done with the predicted particle properties (P3) scheme (Morrison & Milbrandt, 2014). The state of the atmosphere is simulated with 5 minutes temporal resolution and 1.5x1.5 km spatial resolution (grid size). This high resolution is necessary for the analysis of mesoscale atmospheric phenomena like thunderstorms. From the two available WRF model domains, only the model output from the (smaller scale) inner domain is used for the analysis. The WRF model data contains close to 200 different variables in a 4D grid (x,y,z,t). The WRF simulations are made for May 2018.

3 Methods

This project follows an ingredients-based methodology after Doswell et al. (1996), which developed an approach to forecasting the potential for flash flood-producing storms. The idea behind this approach is to determine basic ingredients (atmospheric conditions and processes) of these extreme weather events and allocate the relative importance of each basic ingredient for the future occurrence of such an event. In this project, the procedure of Doswell et al. (1996) is implemented in reverse order. In contrast to their approach, the event (a thunderstorm in this case) already occurred and the focus lies on the determination of the basic ingredients (atmospheric conditions and processes) for thunderstorm initiation. Hence important variables for the indication of thunderstorms are investigated. The investigation of these variables is conducted based on generated analysis tools horizontal maps, soundings, vertical cross-sections, maps of trajectories and temporal evolution along trajectories.

On the basis of data output from the Thunderstorm Identification Tracking Analysis & Nowcasting (TITAN) program, which identified and tracked thunderstorms in the WRF model data, the locations of the thunderstorms can be specified, which is necessary for the following tracing part (Rt). Therein, the locations of the thunderstorms are defined in Lagranto, one of many different Lagrangian analysis tools available for atmospheric research. They all numerically solve the following trajectory equation:

$$\frac{Dx}{Dt} = u(x)$$

(Sprenger & Wernli, 2015). By solving this equation, trajectories of air parcels can be calculated backwards and forwards in time. This project uses the data of traced air parcels from the second version of Lagranto (Sprenger & Wernli, 2015). In the beginning, the starting points for Lagranto are defined by the location of the thunderstorm initiation, additional starting points in the surrounding of the thunderstorm initiation are added at a later stage. In addition, starting from the same location, trajectories are calculated starting up to one hour before the thunderstorm initiated (investigation of the pre-storm environment). The analysis of trajectory can then be divided into three stages: before the initiation, during initiation and after initiation (resp. convective ascent). First, the starting points of the trajectories are chosen from the entire air column (surface until approx. tropopause) and from height levels (pressure levels) with equal distance to each other. Later, in combination with 3D radar-based information of the thunderstorm cells, starting points are defined according to a specific height range (e.g. height of the planetary boundary layer). If once the spatial and temporal starting points are defined, one can choose the variable of interest which are traced along the trajectories. The Output of Lagranto are coordinates of the computed trajectories and gives information about the development of different variables along the traced trajectories. This output is used in this coding project for the analysis tools, which create maps of trajectories and show the temporal evolution along the trajectories. Finally, based on the analysis of variables and trajectories with the analysis tools, the conditions and processes (basic ingredients) before the initiation of the thunderstorm can be interpreted.

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