Section 3

Computational studies including new techniques, the effect of varying model resolution, parallel processing

An Online Trajectory Module for the COSMO-model

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The Lagrangian perspective on atmospheric motion has become an important analysis method for investigating atmospheric phenomena at many different spatial and temporal scales: Trajectory analyses have been used for instance in studies of extratropical cyclone dynamics (e.g., Wernli and Davies, 1997) and stratosphere-troposphere exchange (e.g., Sprenger and Wernli, 2003) as well as for investigating smaller scale phenomena as the dispersion of atmospheric pollutants in the planetary boundary layer (e.g., Weil et al. 2012) and entrainment rates for stratocumulus clouds (e.g., Stevens et al. 1996). Particularly for studying atmospheric phenomena at small spatial and temporal scales, simulations at very high spatial resolution are required. In order to fully take advantage of the high spatial resolution of the models, wind fields at high temporal resolution are needed as input for the trajectory computation. This high temporal resolution can either be obtained by storing the complete wind field of the Eulerian model at many time steps or by performing the computation of the trajectories online, i.e., during the integration of the Eulerian model. While the latter has the disadvantages that trajectories can only be computed forward in time and that some a priori knowledge on the spatiotemporal occurrence of interesting phenomena is required, it allows to keep the Eulerian model output frequency low and to use the wind fields at each time step of the Eulerian model for the trajectory calculation. We therefore implemented a module for the online computation of trajectories in the non-hydrostatic numerical weather prediction model COSMO (Baldauf et al. 2011), which is described in detail in Miltenberger et al. (2013). The module will soon become part of the official COSMO-model release.

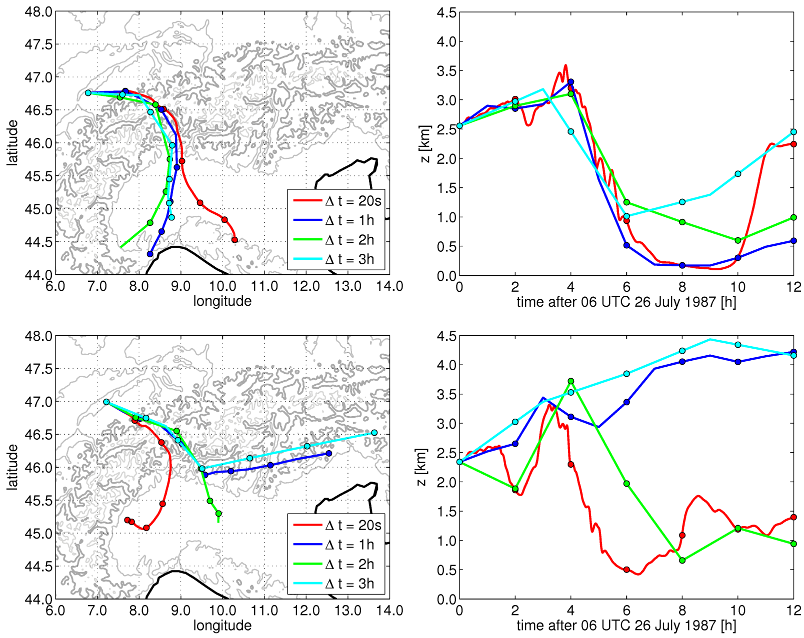

Figure 1. Two examples of online trajectories (*red*) from a foehn case study starting at different geographic locations (*top and bottom rows*). Their path is compared to offline trajectories based on one-, two- and three-hourly model output (*blue, green and cyan*), which have been started at the same location and time as the online trajectories. Filled circles mark the trajectory position every two hours.

1 METHOD

The trajectory equation $\frac{D\vec{x}}{Dt} = \vec{u}$ is solved at each model time step (in COSMO usually 20 s for a horizontal resolution of 2 km) using the Petterssen scheme (Petterssen 1940), which is a second-order semi-implicit scheme. For the integration of the trajectory equation the wind components are needed at the trajectory position and therefore they have to be interpolated from the model grid points to the trajectory position. In the current implementation we use a three-dimensional linear interpolation along the coordinate axes of the COSMO model (staggered Arakawa C grid). The same interpolation method is also used to interpolate other variables, which are traced along the trajectory. The implementation

of the online trajectory module takes full account of the spatial domain decomposition of the COMSO-model for operation on multi-processor machines.
A new namelist block in the configuration file of the COSMO-model allows the user of the trajectory module to specify the start locations and times of the trajectories, the traced variables and the output time step. The output files of the module are written in NetCDF format.

2 CASE STUDY OF ALPINE FOEHN FLOW

To illustrate the effect of different temporal resolutions of the wind fields used for the trajectory calculation, we computed online and offline trajectories for an Alpine foehn event on 26 July 1987. From the 24615 trajectories started above the British Isles we consider for the following analysis only those ending up in the exit of the Simplon-Gotthard region to the Po valley, i.e., those particular relevant for the foehn air warming observed in this event. The offline trajectories were computed with the trajectory model LAGRANTO (Wernli and Davies, 1997) based on COSMO wind fields at temporal resolutions between one and six hours. Comparing the online trajectories to offline trajectories starting at the same time and location shows often significant differences (Fig. 1 *bottom row*), though sometimes the path is also remarkably similar (Fig. 1 *top row*). The amplitude of the maximum deviation between an online trajectory and an offline trajectories starting at the same time and location depends strongly on the flow patterns they encounter. In our case study the offline trajectories are on average displaced by 450 to 600 km in the horizontal and 900 to 1400 m in the vertical with respect to the online foehn trajectories after a travel time of 48 h (Fig.2). This illustrates the substantial sensitivity of trajectories to the temporal resolution of the input wind fields.

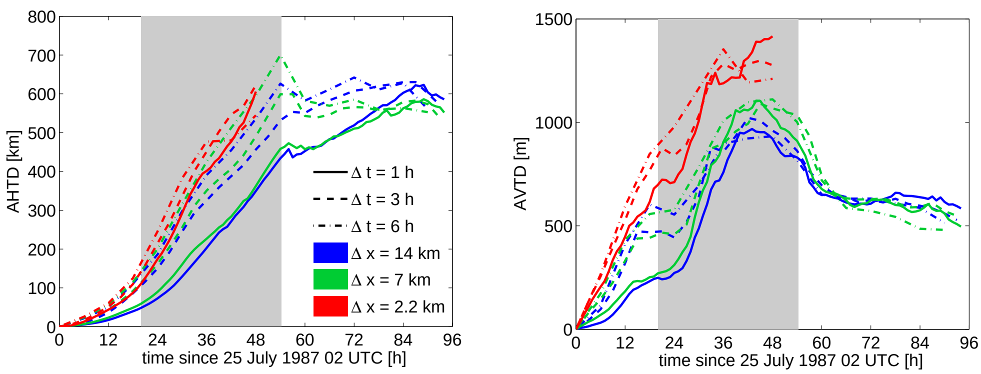

Figure 2. Average horizontal (*left*) and vertical (*right*) transport deviation for foehn trajectories. For each horizontal model resolution the online trajectories are used as reference and offline trajectories computed with LAGRANTO based on COSMO output with different temporal resolution are used as test dataset.

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