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Pollen forecasts in complex topography: two case studies from the Alps using the numerical pollen forecast model COSMO-ART

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Abstract Pollen concentrations on Alpine mountain tops are poorly known due to few observations and few modeling studies. We present two case studies from the Alps that provide insights into the spatial and temporal distribution of birch pollen. The numerical pollen dispersion model COSMO-ART (COnsortium for Small-scale MOdelling-Aerosols and Reactive Trace gases) was used to simulate the birch pollen transport during the 2017 pollen season. The model configuration included 1.1-km horizontal grid spacing and 80 vertical levels. The simulations were compared with daily pollen concentrations from two mountain tops in the Alps (Weissfluhjoch near Davos, Switzerland, at 2692 m and Schneefernerhaus, Germany, at 2650 m a.s.l.). In addition, the Swiss pollen stations at Davos (1587 m a.s.l.) and Buchs (446 m a.s.l.) were used. COSMO-ART simulations agreed well with the observations at Davos and Weissfluhjoch. At the Environmental Research Station Schneefernerhaus, the pollen concentrations were generally overestimated. We analyzed the pollen transport episode of 9 April 2017 at Weissfluhjoch in more detail using vertical cross sections of the COSMO-ART simulations. The results suggest that pollen can be lifted up to 3000 m in the morning hours and are subsequently transported by large-scale winds leading to higher birch pollen concentrations at Weissfluhjoch than at Davos. This suggests that the actual situation regarding sources, topography and wind determines the pollen distribution and not only altitude. Still, pollen levels at Weissfluhjoch are more than one order of magnitude lower than typical pollen levels at lowland Swiss stations such as Buchs.

Keywords High-resolution pollen forecasts · COSMO-ART · Complex topography · Birch pollen · Pollen dispersion models · Pollen transport

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1 Introduction

Minimizing pollen exposure is a common strategy to reduce the symptoms of allergy sufferers. Low exposure reduces the risk of serious health problems such as asthma (D'Amato et al. 2007; Eder et al. 2006). Hence, it is recommended to choose tourist

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destinations with low pollen levels. This requires knowledge on the temporal and spatial distribution of airborne pollen. However, detailed pollen information is mainly available for densely populated regions where also most of the pollen stations are located.

Generally, high elevations constitute a suitable environment for allergy sufferers because pollen levels are thought to be low (Clot et al. 1995; Gehrig and Peeters 2000). However, detailed pollen information for high altitudes is scarce (Pace et al. 2018). Hence, it is difficult to provide pollen forecasts for all parts of mountain ranges although they represent popular tourist destinations.

Numerical pollen dispersion models can provide detailed information for mountains because these models are area-covering. For an overview of the existing models, see Sofiev et al. (2016). In this study, we employ COSMO-ART (COnsortium for Small-scale MOdelling-Aerosols and Reactive Trace gases; Vogel et al. 2008, 2009). The complex topography of the European Alps requires high horizontal resolution. At MeteoSwiss, COSMO-ART is run operationally on a 1.1-km horizontal grid with 80 vertical levels. This allows to realistically represent all major valleys and mountains in the European Alps. However, due to a lack of observational data on mountain tops, the performance of COSMO-ART has not been validated for such locations. Here, we present two case studies that seek to shed light on the performance of COSMO-ART in the European Alps. In particular, we address the questions.

- What values of atmospheric pollen concentrations can be reached in mountain valleys and on mountain tops?
- Can we trust pollen forecasts of high-resolution numerical models such as COSMO-ART also in mountainous terrain?

2 Data and methods

In 2017, two Hirst pollen traps were in operation at Weissfluhjoch, Switzerland (2692 m a.s.l.), and at the Environmental Research Station Schneefernerhaus, Germany (2650 m a.s.l). Figure 1 shows their location. We use these two summit locations to validate COSMO-ART results. On Weissfluhjoch, there is also a meteorological station. In addition, the Swiss pollen network stations of Buchs (446 m a.s.l) and Davos (1587 m a.s.l) were used. Davos is located at the base of Weissfluhjoch summit (see Fig. 1). The resolution of the observations is daily. We restrict the analysis to birch pollen.

We show the pollen levels at these locations along with the simulations by COSMO-ART and discuss the model performance. Vertical cross sections of a transport episode of the model data were used to investigate the transport mechanisms. Finally, the potential of COSMO-ART for forecasting pollen levels at high-elevation sites is assessed.

3 Results and discussion

Figure 2 presents daily averages of observed and simulated birch pollen concentrations (nearest model grid point to the observational site). The station of Buchs showed a strong local flowering peak at the end of March 2017. This peak is underestimated by the model. At Davos, the observed and simulated concentrations agree well although overestimations are quite prominent from 10 to 15 April. At Weissfluhjoch, parts of the observations are missing due to difficult sampling conditions on mountain tops. The available data show good agreement with the simulations. Interestingly, the observed Weissfluhjoch concentrations seem to be a bit higher than the ones at Davos. This is surprising because Weissfluhjoch is located 1000 m higher than Davos. The overall pollen concentration always stayed below 50 pollen/m^3 which is roughly one order of magnitude lower than typical pollen levels at lowland Swiss stations (Gehrig et al. 2012; Gehrig and Peeters 2000).

The situation at Schneefernerhaus (Fig. 2) is different from Weissfluhjoch. Hardly any birch pollen reached the station during the whole period. Only on April 10 daily average pollen concentrations higher than 10 pollen/m^3 were observed. However, the simulated concentrations by COSMO-ART are substantially higher. Similar to Davos, the location of Schneefernerhaus is also at the northern side of the Alps and birch pollen may originate from the valleys below. However, this was not the case in reality except on April 10 (Fig. 2). A reason could be overestimated birch density in the pollen source regions. In addition, the location of Schneefernerhaus may play a critical role. This research station is not situated on a mountain

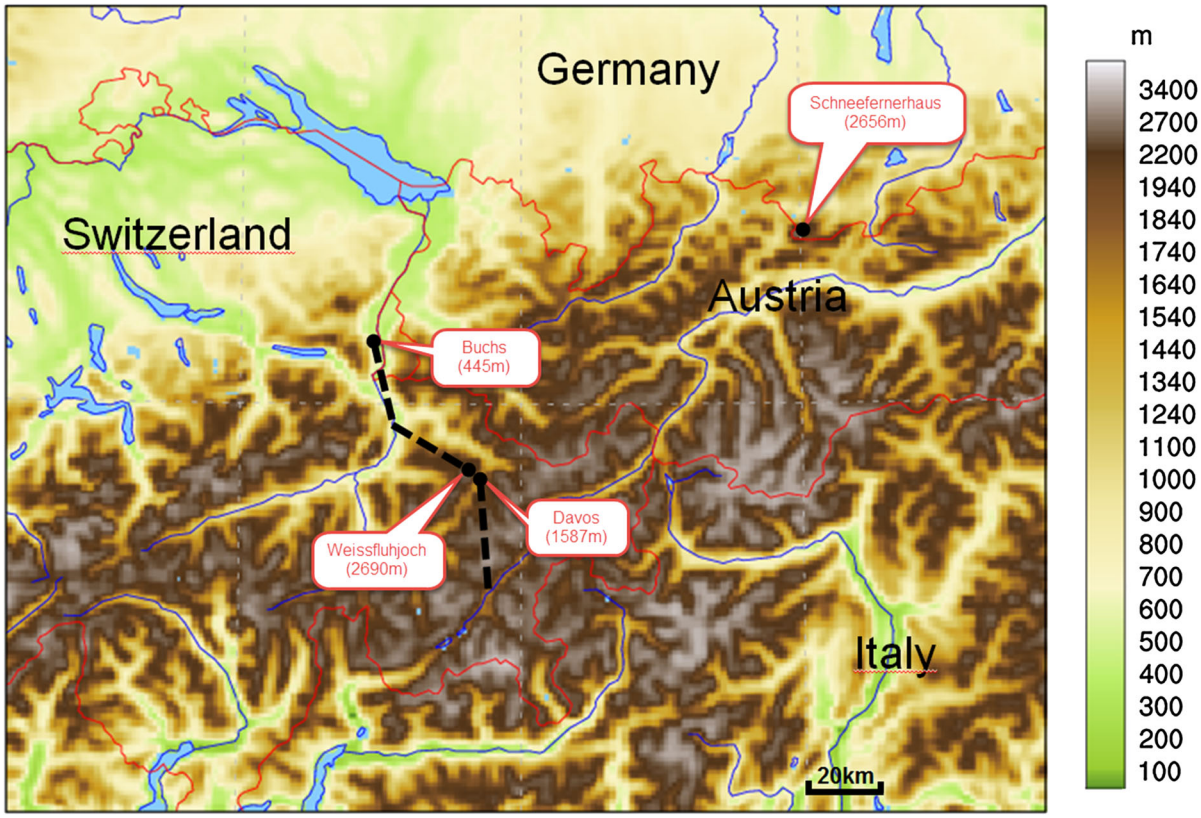

Fig. 1 Map showing the locations of the 4 pollen traps (black dots), the analyzed transect (dashed black line) and the COSMO-1 topography

top but rather 300 m below on the south side. Hence, it is difficult for pollen from the valley of Garmisch-Partenkirchen (the closest possible source) to reach the site. Unfortunately, no pollen observations from the valley of Garmisch were available in 2017. However, Jochner et al. (2012) published birch pollen observations from Schneefernerhaus and Garmisch covering the years 2008 and 2009. During those years, the birch pollen concentrations at Schneefernerhaus were much higher than in 2017 but roughly 5 times lower than in Garmisch. This shows that more years are needed to achieve robust results.

Vertical cross sections may provide insights into transport mechanisms. Figure 3 displays four time snapshots during April 9 along the slice shown by the black dashed line in Fig. 1. The slice includes parts of the Rhine valley, which is a possible source area of birch pollen at Davos and Weissfluhjoch. On April 9, the meteorological station on Weissfluhjoch recorded sunshine all day and constant wind of roughly 5 m/s from northwesterly directions rendering the Rhine valley a possible source of birch pollen.

Regarding observed and modeled pollen concentrations, April 9 is characterized by a distinct increase at Weissfluhjoch (see Fig. 2) although birch trees were flowering only below 1000 m a.s.l. during that period. As seen from Fig. 3a, high concentrations were present in the Rhine valley near the surface at 10 h UTC while the concentrations were low on the neighboring mountains. "Pollen clouds" were lifted to higher levels by turbulent vertical mixing as convection started during that fair-weather day. At 14 h UTC (Fig. 3b), high pollen concentrations (> 70 pollen/m^3) reached altitudes of 2500 m over the Rhine valley. In addition, a pollen cloud traveled up the slope and reached Weissfluhjoch. At 20 h UTC (Fig. 3c) high concentrations of more than 100 pollen/m^3 at altitudes up to 3000 m over the Rhine valley started moving toward the Alps. Finally, Fig. 3d shows that a pollen cloud at 2500–3000 m reached

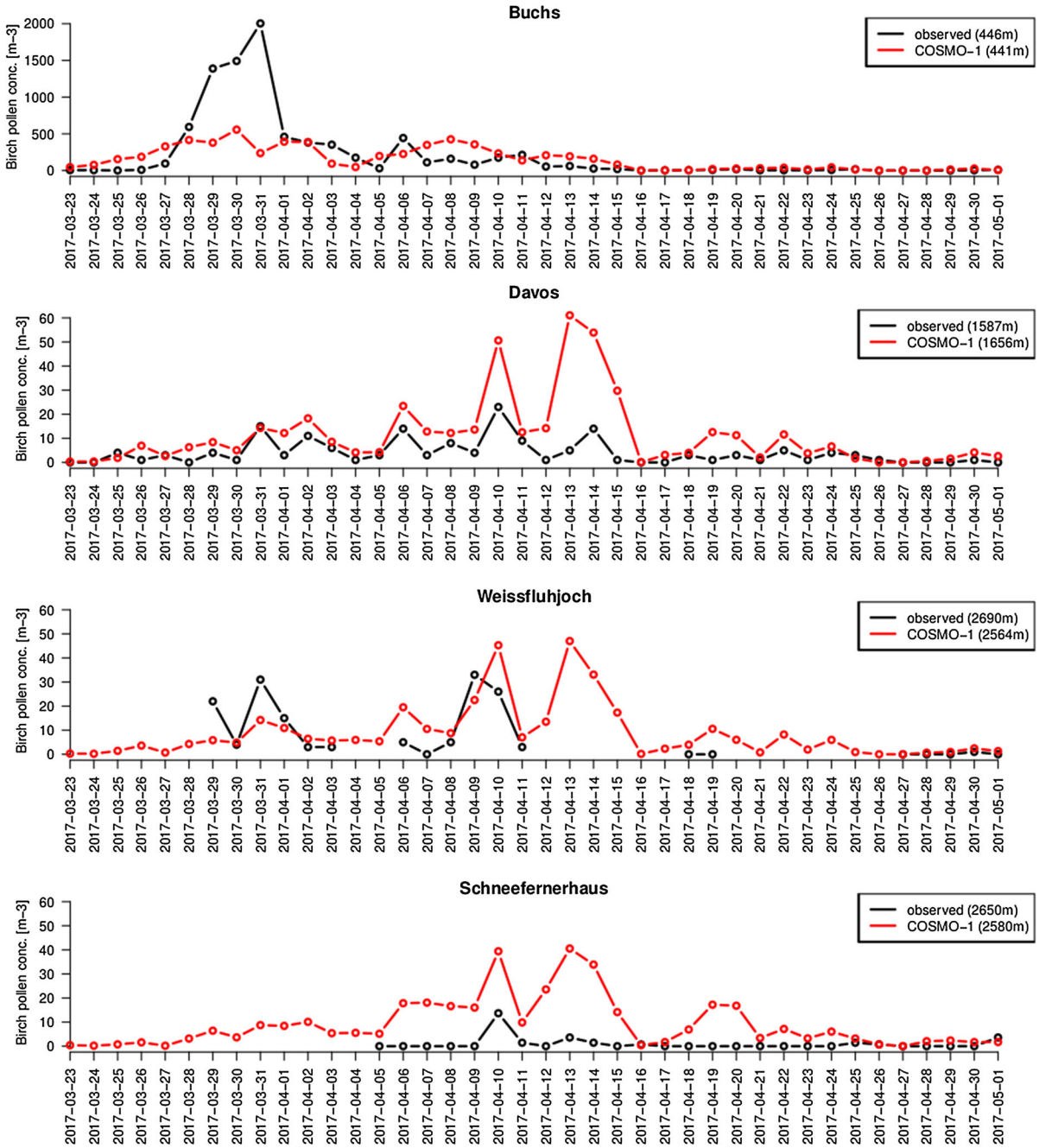

Fig. 2 Daily averages of observed and simulated birch pollen concentrations at the stations of Buchs, Davos, and the nearby station of Weissfluhjoch (all Switzerland) and Schneefernerhaus (Germany). The model data are the nearest grid point to the observation location

Weissfluhjoch and continued traveling to the next mountain ridges while pollen levels at Davos remain moderate. Interestingly, the pollen cloud did not settle compared to 20 h UTC (Fig. 3c) although thermally induced turbulent mixing is largely absent during the night. This suggests that the pollen source includes also regions other than the Rhine valley.

COSMO-ART suggests that pollen was suspended by turbulent vertical mixing in the morning from their sources below 1000 m a.s.l. to 2000–3000 m a.s.l. and

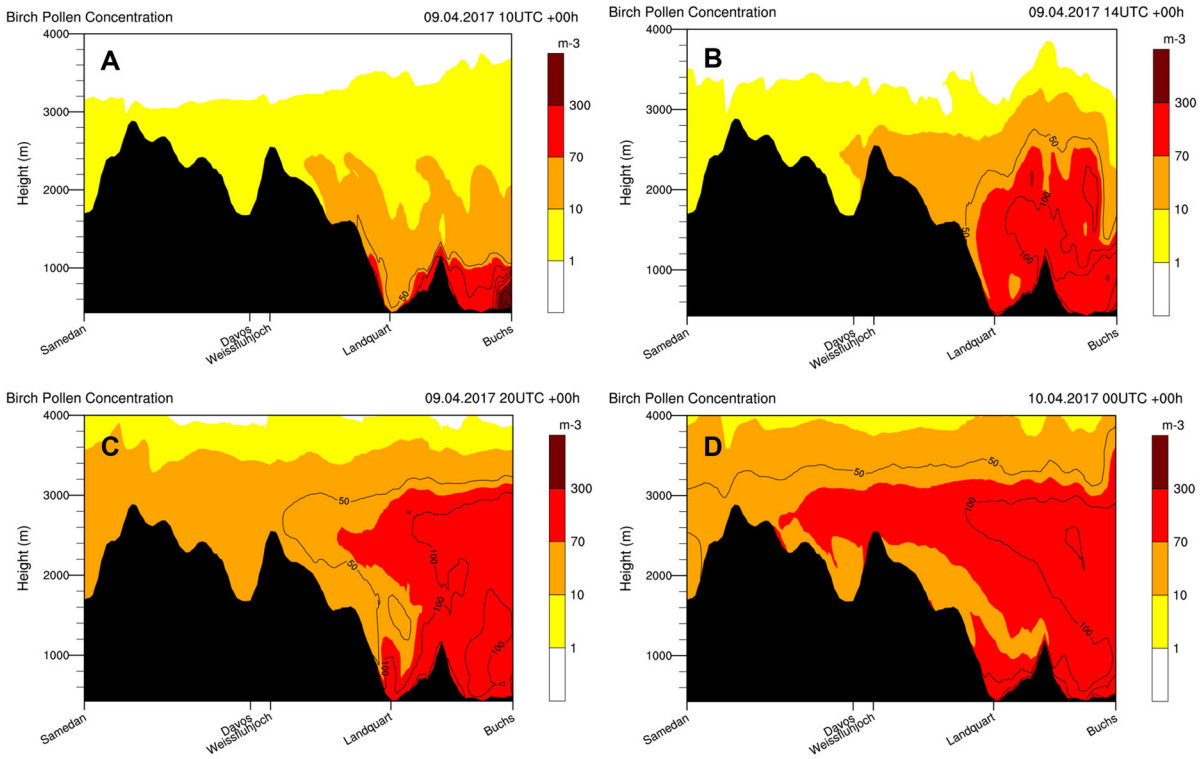

Fig. 3 Vertical cross sections of birch pollen concentrations simulated by COSMO-ART at 1-km horizontal resolution. The slice is defined by the indicated locations and is approximately 80 km long. It is marked by the dashed black line in Fig. 1. The four panels represent time snapshots on April 9, 2017 (10 h, 14 h, 20 h and 24 h UTC), and illustrate the course of pollen dispersion during that day

was subsequently transported by northwesterly winds to Weissfluhjoch station. This process was also suggested by Markgraf (1980) who concluded based on an aerobiological and meteorological measurement campaign on Niederhorn mountain (Switzerland) that pollen levels at 2000 m elevation cannot be explained by dispersal through local upslope winds but through winds from the general prevailing direction.

This case demonstrates how pollen clouds build in COSMO-ART and what altitude they can reach. It also suggests a transport mechanism that may help explain why both observed and modeled concentrations at Weissfluhjoch have increased sharply during April 9, while concentrations at Davos stayed at low to moderate levels (Fig. 2). It also demonstrates that altitude is no guarantee for low pollen levels. Instead, the actual situation regarding sources, topography and wind determines the spatial and temporal distribution of pollen.

4 Conclusions

Based on the Weissfluhjoch case study, we have shown that pollen levels on mountain tops can reach values that are comparable to much lower locations. Not altitude, but rather the actual transport situation (plant distribution, phenology and weather) determines pollen levels both on mountain tops and nearby valleys. The good agreement of modeled and observed pollen concentrations at the stations of Weissfluhjoch and Davos (Switzerland) as well as consistent wind measurements at Weissfluhjoch suggest that COSMO-ART modeled the transport processes realistically on April 9, 2017, in the Weissfluhjoch region. However, the Schneefernerhaus case study demonstrated that systematic biases may occur.

Mountains represent a suitable tourist destination for allergy sufferers because of their generally low pollen loads. High-resolution numerical dispersion models such as COSMO-ART can be used as a source of pollen information if it was validated to a sufficient

extent. This study was based on 2017 data only. Therefore, more pollen seasons and stations should be analyzed to draw general conclusions.

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