



Does fog chemistry in Switzerland change with altitude?



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ABSTRACT

During two extended summer seasons in 2006 and 2007 we operated two battery driven versions of the Caltech active strand cloud water collector (MiniCASCC) at the Niesen mountain (2362 m a.s.l.) in the northern part of the Swiss Alps, and two devices at the Lägeren research tower (690 m a.s.l.) at the northern boundary of the Swiss Plateau. During these two field operation phases we gained weekly samples of fog water, where we analyzed the major anions and cations, and the isotope ratios of fog water (in form of $\delta^2\text{H}$ and $\delta^{18}\text{O}$). Dominant ions in fog water at all sites were NH_4^+ , NO_3^- , and SO_4^{2-} . Compared to precipitation, the enrichment factors in fog water were in the range 5–9 at the highest site, Niesen Kulm. We found considerably lower summertime ion loadings in fog water at the two Alpine sites than at lower elevations above the Swiss Plateau. The lowest ion concentrations were found at the Niesen Kulm site at 2300 m a.s.l., whereas the highest concentrations (a factor 7 compared to Niesen Kulm) were found in fog water at the Lägeren site. Occult nitrogen deposition was estimated from fog frequency and typical fog water flux rates. This pathway contributes $0.3\text{--}3.9 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ to the total N deposition at the highest site on Niesen mountain, and $0.1\text{--}2.2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ at the lower site. These inputs are the reverse of ion concentrations measured in fog due to the 2.5 times higher frequency of fog occurrence at the mountain top (overall fog occurrence was 25% of the time) as compared to the lower Niesen Schwandegg site. Although fog water concentrations were on the lower range reported in earlier studies, fog water is likely to be an important N source for Northern Alpine ecosystems and might reach values up to 16% of the total N deposition and up to 75% of wet N deposition by precipitation.

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1. Introduction

Fog and cloud water can be a significant source of water input to montane ecosystems (Walmsley et al., 1996; Dawson, 1998; Bruijnzeel et al., 2005), and chemical solutes in fog and cloud water can add relevant amounts of nutrients or pollutants to these ecosystems (e.g., Thalmann et al. (2002); Burkard et al. (2003)). Although in Central Europe fog does not yield significant amounts of water compared to precipitation, deposition of nutrients such as nitrogen or sulfur can lead to over-nutrition, mainly in forest ecosystems (Thalmann et al.,

2002). However, it is unknown, whether such findings also apply to mountain peaks, or only to lower mountains that are within the anthropogenically polluted atmosphere. We addressed this question by collecting fog water and analyzing its composition at four sites grouped at two localities, (a) Mount Niesen, Switzerland (2362 m a.s.l.), and (b) the low mountain site Lägeren (682 m a.s.l.) (Fig. 1).

Many factors influence the chemical composition of fog and cloud water, namely the provenience of the air mass, cloud dynamics, and microphysics (Cini et al., 2002). In industrialized countries, concentrations of solutes are generally higher than in precipitation up to a factor of 100 (Fuzzi et al., 1996; Choularton et al., 1997; Thalmann et al., 2002; Burkard et al., 2003; Lange et al., 2003). Acidification as a

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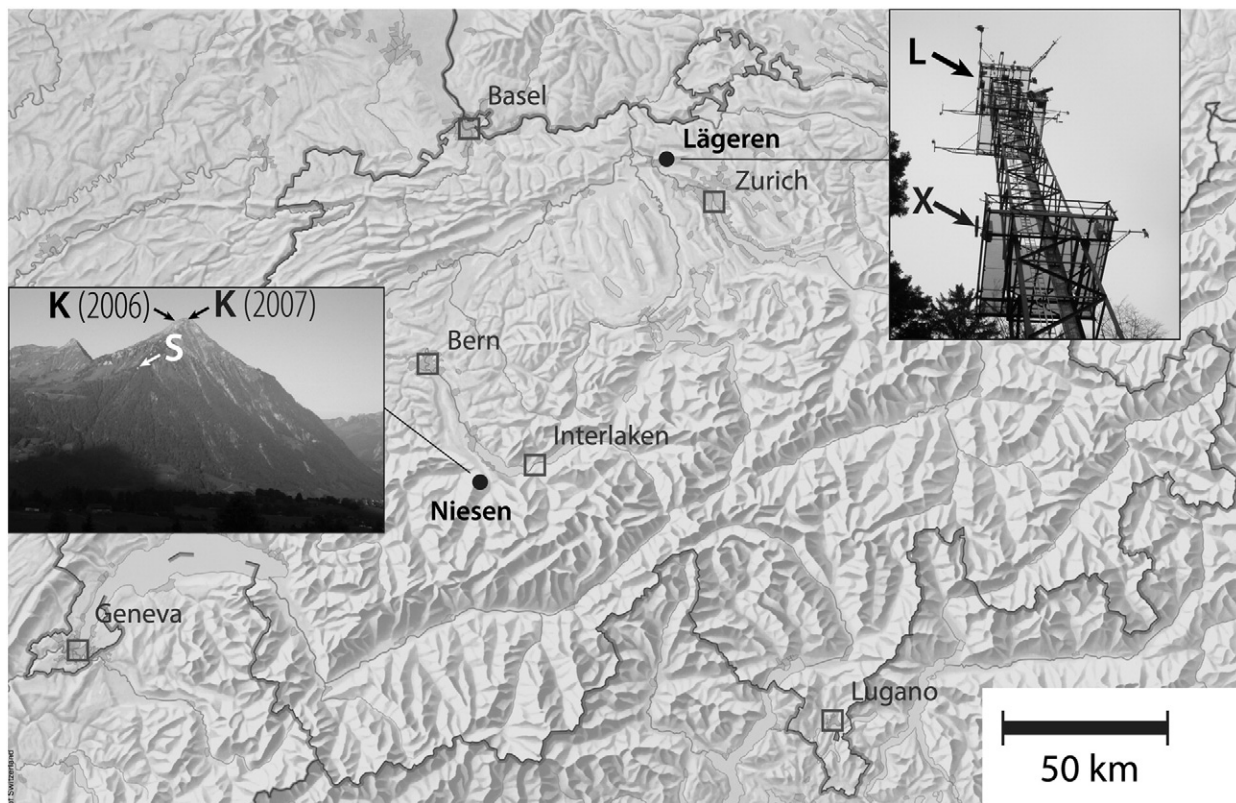


Fig. 1. Localities and sites. Base map ©swisstopo.

result of high SO_2 emissions was especially problematic in the border area of Germany, the Czech Republic and Poland (Lange et al., 2003; Błaś et al., 2008, 2010). Furthermore in North America fog was found to be a major source of acidification via hydrogen ion deposition (Schemenauer, 1986; Schemenauer et al., 1995). The common definition of fog is a cloud in contact to ground with a meteorological visibility ≤ 1000 m. Therefore, cloud and fog are the same phenomena in the context of this study.

So far, the focus of the research has mainly been on areas with high atmospheric pollution, and on tropical montane cloud forests where high biodiversity is coincident with frequent occurrence of fog. However, little is known about the relevance of chemical compounds in fog in mountain areas of Switzerland, where fog is frequent during the vegetation period and where ecosystems tend to be specialized to grow optimally under low-nutrient conditions. Cloud and precipitation chemistry at higher elevations and along an altitudinal gradient in Switzerland had only been investigated in 1984/1985 at Mt. Rigi (1798 m a.s.l.) which is located 75 km NE of our main study site (Stahelin et al., 1993; Collett et al., 1993a,b).

In mountainous areas, deposition chemistry is largely influenced by topography, altitude, valley orientation and exposure to main wind directions (Rogora et al., 2006). An assessment of atmospheric deposition in the Alpine region, mainly focusing on nitrogen deposition, can be found in Rogora et al. (2006). They used data from previous and ongoing projects to investigate geographical variability and temporal trends of wet deposition. Although air pollution has

decreased in the last decades (e.g. Barmadimos et al. (2011)), the deposition of nitrogen is still expected to be a critical factor at some sites. The role of cloud and fog deposition remains unknown, but should not be ignored, as Rogora et al. (2006) emphasize. Previous studies have shown the importance of altitudinal gradients (Miller et al., 1993), where deposition rates were found to increase with altitude, which would imply highest deposition rates at the mountain tops.

The goal of our study hence was to quantify concentrations in fog water at a mountain in the Prealps (Niesen) that is prominently exposed to northerly winds from the densely populated Swiss Plateau. We hypothesize that even at such relatively remote locations substantial amounts of plant-accessible nitrogen may be deposited by fog. We expect this to be most relevant at times, when the Niesen mountain may be affected by pollutants originating within a few tens of km distance, whereas at other times its elevation is clearly above the polluted atmospheric boundary layer. To distinguish mountain top (exposed) conditions from mid-elevation conditions at the mountain, and to resolve altitudinal differences in fog chemistry, measurements were carried out in parallel at two sites at ≈ 2300 m and 1650 m a.s.l. (Fig. 1). Moreover, additional samples were taken at the Lägeren Mountain site (682 m a.s.l.) to allow for a direct comparison with earlier fog water flux studies (Burkard et al., 2003). As an outcome, the first order-of-magnitude estimate of N deposition by fog for a mountain top in the Alps was attempted in order to assess the relevance of fog as an N deposition pathway for alpine vegetation.

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