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Consistent histories of anthropogenic Western European air pollution preserved in different Alpine ice cores

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Individual high-Alpine ice cores have been proven to contain a well-preserved history of past anthropogenic air pollution in Western Europe. The question, how representative one ice core is with respect to the reconstruction of atmospheric composition in a given source region, has not been addressed so far. Here, we present the first study systematically comparing long-term ice-core records (AD 1750-2015) of various anthropogenic related compounds, such as major inorganic aerosol species, black carbon (BC), and trace species obtained from four high-Alpine sites located in the French and Swiss Alps. We observe a consistent timing in anthropogenic changes of BC, Cd, F-, NH4+, NO3-, Pb, and exSO42- (non-dust, non-sea salt SO42-) at all investigated Alpine sites. This is related to common source regions of anthropogenic pollution impacting the four sites including Western European countries surrounding the Alps, i.e. Switzerland, France, Italy, Germany, and Spain. For individual compounds, the newly obtained Alpine ice core composites allow us to precisely time the anthropogenically caused onset of increased pollution levels. BC, exSO42-, Pb, and NH4+ concentrations exceeded pre-industrial levels (AD 1750-1850) already in the 1870s and 1880s, mainly related to emissions from coal combustion and agriculture, respectively. The observed maxima of BC, Cd, F-, Pb, and exSO42- concentrations in the 20th century and a significant decline afterwards, clearly reveal the efficiency of air pollution control measures such as desulphurisation of coal, the introduction of filters and scrubbers in power plants and metal smelters, and the ban of leaded gasoline improving the air quality in Western Europe. In contrast, the composite records of NO3- and NH4+ in the beginning of the 21th century are unprecedented in the context of the past 250 years, indicating that the introduced abatement measures to reduce these pollutants were still not sufficient to have a major effect on recent levels at high altitudes over Western Europe. Only four composite records (BC, F, Pb, exSO42-) of the seven investigated pollutants are in agreement with their modelled deposition or estimated emissions of their precursor species suggesting a large uncertainty in emission estimates. Our results demonstrate that individual ice-core records from different sites in the European Alps provide a spatial representative signal of anthropogenic pollution from Western European countries and are essential to constrain emission or deposition data of air pollutants in this region.

Primary authors: EICHLER, Anja (PSI - Paul Scherrer Institut); LEGRAND, Michel (Institut des Géosciences de l'Environnement, Université Grenoble Alpes, Grenoble, France); JENK, Theo Manuel (PSI - Paul Scherrer Institut); PREUNKERT, Susanne (Institut des Géosciences de l'Environnement, Université Grenoble Alpes, Grenoble, France); ANDERSSON, Camilla (Swedish Meteorological and Hydrological Institute, Norrköping, Sweden); ECKHARDT, Sabine (NILU, Norwegian Institute for Air Research); ENGARDT, Magnuz (SLB-analys, Stockholm); PLACH, Andreas (Department of Meteorology and Geophysics; University of Vienna, Austria); SCHWIKOWSKI, Margit (PSI - Paul Scherrer Institut)

Presenter: EICHLER, Anja (PSI - Paul Scherrer Institut)

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