Cosmogenic Proxies (COPROX)

Simulations of the Atmospheric Transport and Deposition of Cosmogenic Isotopes as Proxies for Solar Activity and Atmospheric Dynamics

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In Short

- Extracting information from cosmogenic isotopes
- Cosmogenic Proxies for solar dynamics such as SPE
- Cosmogenic Tracers for atmospheric processes such as mass exchange between strato- and troposphere
- Modelling with modular chemistry-climate model

Within the COPROX project, we model the transport and deposition of cosmogenic isotopes such as Beryllium-10 (^{10}Be), Beryllium-7 (^{7}Be) and Carbon-14 (^{14}C) produced by galactic cosmic rays (GCR) as well as solar proton events (SPE). After their production and transport the isotopes are deposited in natural archives e.g. ice cores or tree rings (see e.g. [5, 6]). The concentration of cosmogenic isotopes within these archives varies on multiple time-scales and depends on the production rate. The aim of the project is to simulate and reproduce the data and pathways and extract information about solar and atmospheric activities from cosmogenic isotopes as proxies e.g. to explore the mass exchange between the stratosphere and troposphere and investigate the role of the seasonality, simulate the impact of man-made climate change on the transport and deposition of the isotopes, look at the impact of solar variations and improve the forecast of large scale weather systems such as monsoon [4, 1, 2, 3].

The model simulations are performed with the CCM EMAC (ECHAM/MESSy Atmospheric Chemistry). EMAC is based on the ECHAM5 general circulation model (GCM) developed at the MPI for Meteorology, originally derived from the weather forecast model of the ECMWF ("European Centre for Medium-range Weather Forecasts"), and has been extended to a modular CCM at the MPI for Chemistry allowing the implementation of multi-institutional codes via the MESSy ("Modular Earth Submodel System") interface [7]. EMAC is specifically qualified for the goals of COPROX because it allows the description of the dynamics and chemistry of the stratosphere and troposphere coupled to the ocean system as well as the impact of solar variations on the Earth system.

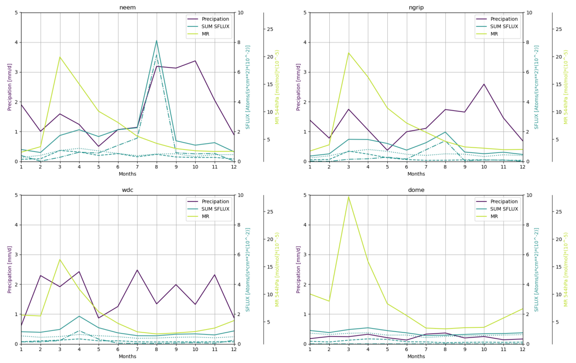

***Figure 1:** ^{10}Be saisonal mean surface flux (SFLUX), precipitation and mixing ratio (MR) at 544 hPa for the four drilling sites NGRIP, NEEM, WDC and Dome Fuji over the first two years after the AD 774/5 SPE. The turquoise line indicates the SFLUX, which is the sum of sedimentation (dotted line), wet deposition (dot-dashed line) and dry deposition (dashed line).*

Within the last reporting period of COPROX we extended our SPE simulations with a dynamical galactic cosmic ray (GCR) background, based on data from the WArning System for AVIation Exposure to Solar energetic particle (WASAVIES, see e.g. [8]). The GCR background varies in time according to the time-varying modulation potential, which is a parametric representation of the dynamics of the heliosphere (e.g. Schwabe-Cycle). While the amount of cosmogenic ^{10}Be produced in the troposphere for the AD 774/5 and 993/4 SPEs considered in our investigation (approximated based on the GLE69 from 2015, [6]) is only around 6%, the amount of cosmogenic ^{10}Be produced in the troposphere for GCR lies between 35% and 40%. Since the particle size distribution of the aerosols in the troposphere tends to be broader than in the stratosphere and incorporates larger radii, we presume that a reasonable amount of the ^{10}Be produced by GCR couples to much larger aerosols than the main of the isotopes produced by the SPE. Therefore we use two different particle size distributions of the aerosols, one for isotopes produced in the troposphere (mean radius R approx. $1\mu m$, geometrical standard deviation S = 2.0) and one for stratosphere (R = $0.08\mu m$ and S = 1.6, consistent with [4]). With this approach for the simulation of the SPE combined with GCR, we get a good agreement with proxies from four different drilling sites in Greenland and Antartica (NEEM, NGRIP, WDC, Dome Fuji) which was not feasible without the split of the distributions.

Furthermore, the new approach suggests an important role for sedimentation as the leading deposition mechanism of GCR-produced ^{10}Be above the poles. Figure 1 shows the seasonal dynamics of the surface flux, precipitation and mixing ratio at NGRIP, NEEM, WDC and Dome Fuji for the first two years after the SPE. Wet deposition only dominates the surface flux in the summer months above Greenland (NGRIP, NEEM) when precipitation is increased. For the rest of the season and specially for areas with lower precipitation such as Dome Fuji, sedimentation is the dominating deposition mechanism. The reason for this is that a large part of the isotopes produced by GCR couple to large aerosols directly within the troposphere, which are then carried to the ground by sedimentation due to their size.

The results of our current COPROX simulations on ^{10}Be have been presented at the COSPAR conference in Athen (July 2022).

The second focus within the last reporting period of COPROX was the implementation of a new MESSy submodel SCARBCM, which describes the net primary production of ^{14}C within vegetation based on a modified empirical model [9] and is required to compare the results of our SPE simulations to ^{14}C proxies from tree rings. So far, the submodel is implemented and running, but further optimization and fine tuning has to be done.

The third focus within the last reporting period of COPROX was the preparation of simulations for the time period 1950-2020 with a dynamic ocean to investigate the transport and deposition of 7Be produced by GCR. Here we worked out, that a full description of the chemistry of the atmosphere is not required for our particular interests. Thus, we reduced our setup to simulations with only a prescribed Ozone field, coming from former SOLCHECK simulations (HLRN project bek00022). Since this reduction speeds up our simulations considerably, we can run much more ensemble runs to statistically stabilize our results and really compare them to empirical data plus perform more testing and deeper analysis.

More Information

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