STP064: Chemistry-climate model SOCOLv3:Be with the cosmogenic Beryllium-7 isotope cycle

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ABSTRACT

We present the new version of the Chemistry Climate Model (CCM) SOCOLv3:Be which was developed to trace beryllium isotopes in the atmosphere. The SOCOLv3:Be model includes new modules for production, deposition, and transport of beryllium. Production was modelled considering galactic cosmic rays, by applying the CRAC (Cosmic-Ray induced Atmospheric Cascade) model. Radioactive decay of ^{7}Be was explicitly considered. An interactive deposition scheme was applied including both wet and dry depositions. The modelling was performed, using a full nudging to the meteorological fields, for the period of 2003-2008 with a spin-up period of 1996-2002. The modelled concentrations of ^{7}Be in near-ground air were compared against the measurements, at a weekly cadence, in four nearly antipodal high-latitude locations, two in Northern and two in Southern hemispheres. Most importantly, the model results agree with the measurements in the absolute level within error bars, implying that the production, decay and lateral deposition are correctly reproduced by the model. The model also correctly reproduces the temporal variability of ^{7}Be concentrations on the annual and sub-annual scales, including a perfect reproduction of the annual cycle, dominating data in the Northern hemisphere.

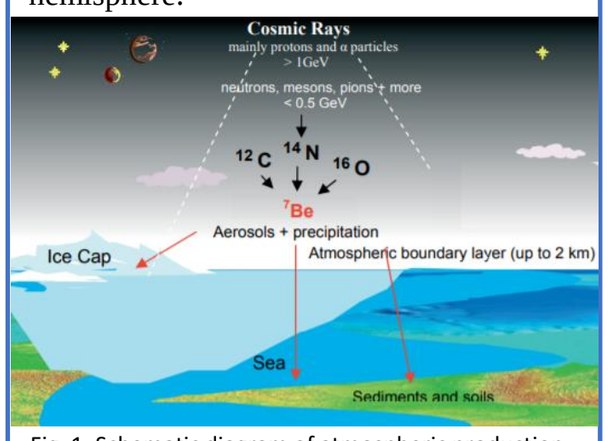

Fig. 1. Schematic diagram of atmospheric production and distribution of cosmogenic ^{7}Be

BERYLLIUM-7:

- was identified in precipitation by *Arnold and Al-Salih (1955)* and *Goel et al. (1956).*
- has a half-life of 53.4 days.
- are produced by spallation nuclear reactions induced by cosmic rays (solar and galactic) on oxygen, nitrogen and carbon (Fig. 1).
- has a short residence time in the atmosphere and a faster response to variability in production and climate change than other cosmogenic isotopes.

The combined effect of solar and geomagnetic shielding leads to a nonlinear production for all cosmogenic isotopes that is stronger in high latitudes than in the tropics and more pronounced in the stratosphere than in the troposphere *(Lal and Peters, 1967)*

Although most of the 7Be production occurs in the stratosphere, the troposphere plays more active control on the transport and fallout of the isotopes to the Earth's surface reservoirs.

SOCOLv3:Be =

CCM SOCOLv3 (*Stenke et al., 2013*)

+ SOCOL-AERv2 (*Feinberg et al., 2019*)

+ CRAC:Be (*Poluianov et al., 2016*)

- This version consists of the general circulation model **MA-ECHAM5** *(Hommel et al., 2011),* the atmospheric chemistry module **MEZON** *(Egorova et al., 2003)* combined with an aerosol module **AER** *(Weisenstein et al., 1997).*
- The chemical part of the MEZON core includes 56 chemical species of oxygen, hydrogen, nitrogen, carbon, chlorine, bromine and sulfur groups, 295 gas-phase reactions, 64 photolysis reactions.
- SOCOL used **the horizontal resolution T42**, where T refers to triangular truncation and the number denotes the series of spherical harmonics.
- The horizontal resolution **is about 2.85^{0}x2.85^{0}** (300x300 km in the equatorial region).
- **The vertical grid is** defined using **a sigma-hybrid coordinate system**, which is calculated by a linear combination of surface pressure and constant coefficients that define the vertical coordinate.
- The model has **39 vertical levels** between the Earth's surface and the 0.01 hPa level.
- The CRAC model presents **a set of accurately computed yield functions of production of the cosmogenic isotopes** as function of the primary particle's type and energy and atmospheric depth **based on KORSIKA** simulation tool *(Heck et al., 1998)* **and using the GEANT4** *(Geant4 collaboration, 2020)* **Monte-Carlo simulation tool**.
- **Production rates**, computed for each location and with hourly temporal cadence were used **as an input for the SOCOL model**, providing 3D+time source of the isotope in the atmosphere.
- **Radioactive decay of ^{7}Be** was applied in a way like that used by Golubenko et al. (2020) for ^{222}Rn.
- **Deposition of ^{7}Be** is parameterized as a function of surface properties, solubility and reactivity of the considered species *(Kerkweg et al., 2006).* This **scheme considers actual meteorological conditions, different surface types, and trace gas properties like solubility and reactivity.**
- **^{7}Be is traced like a gas**, the dry-deposition scheme is like other gases in the model *(e.g., Revell et al., 2018).*
- **The interactive wet deposition scheme** exploited **the EAYSY2 version the Scavenging (SCAV)** submodule in the ECHAM/MESSy Atmospheric Chemistry (EMAC) model *(Tost et al., 2010).* This scheme utilize ECHAM5 variables such as liquid and ice water contents, cloud cover, convective and large-scale rain, ice formation, precipitation fluxes, and convective upward mass flux. **Scavenging coefficients for gas-phase species are calculated based on Henry's law equilibrium constants.**

NUMERICAL EXPERIMENT

- Was performed a 6-year **spin-up** of the model for the period 1996 – 2002 to allow Be to reach equilibrium conditions.
- Was initiated a 6-year (2002 – 2008) run with **full nudging** (a linear relaxation of thermodynamic parameters: temperature, divergence and vorticity of the wind field). In this way we can validate the model by comparing the results with measurements.

RESULTS AND CONCLUSION

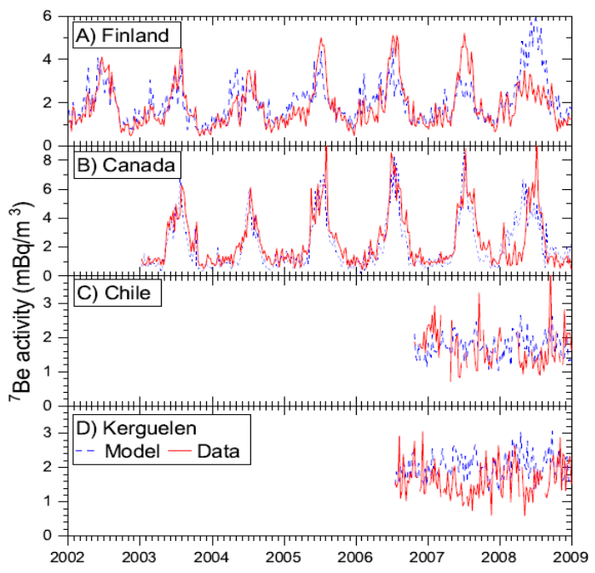

Fig. 2. ^{7}Be activity in the near-ground air including (panels A through D) Finland (a composite of four stations), Yellowknife (Canada), Punta Arenas (Chile), and Kerguelen island (France). The measured and modelled activities are shown as solid red and dashed blue curves.

- - The coherence is highly significant (confidence level above 95%) at all time scales between one month and two years, the model correctly reproduces some strong spikes in the beryllium activity, as e.g., in the earlier 2003, which are often related to sudden stratospheric warming (SSW) events.
- - An essential difference in 2007 and 2008 could be potentially related to the local atmospheric aerosol properties.
- - The overall mean level of modelled activity (2.15 mBq/m^3) is close to the measured one (2.4 mBq/m^3), within 10% (the difference is 0.24±0.22 mBq/m^3).

The model results generally agree well with the measurements in the absolute level within error bars, implying that the production, decay, and lateral deposition are correctly reproduced by the model on the local/regional spatial and monthly/annual temporal scales, including a perfect reproduction of the annual cycle, which dominates data in the Northern hemisphere, and the absence of this cycle in the Southern Hemisphere.

REAL OBSERVATIONS

Fig. 3. Map of ^{7}Be station's location.

- Radiation Protection Bureau of Health Canada (Yellowknife data).
- CTBTO (CL18 and FRP30 station) under a vDEC agreement (https://www.ctbto.org/vdec/).
- Radiation and Nuclear Safety Authority – STUK (Finnish data) (https://www.stuk.fi/).

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PUBLICATION

The paper in the process under review in Geoscientific Model Development (GMD) journal (https://www.geoscientific-model-development.net/).