Journal of Environmental Radioactivity 192 (2018) 454–466

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Influence of mineral dust on changes of ^{7}Be concentrations in air as measured by CTBTO global monitoring system

J. Kuśmierczyk-Michulec*, P. Bourgouin

International Data Centre, Comprehensive Nuclear-Test-Ban Treaty Organization, PO Box 1200, 1400, Vienna, Austria

ARTICLE INFO

Keywords:
CTBTO global monitoring system
Atmospheric aerosols
Beryllium-7
Mineral dust
Dry deposition
Atmospheric transport modelling

ABSTRACT

Atmospheric Transport Modelling (ATM) results were combined with ^{7}Be observations collected during the 2009–2015 period by the three radionuclide stations from the International Monitoring System (IMS), located in Mauritania (18.1 N, 15.9 W), Kuwait (29.3 N, 47.9 E) and Panama (9.0 N, 79.5 W), to study the influence of Saharan dust on changes in ^{7}Be surface concentrations. It is demonstrated that for long-range transport (> 3000 km), the overall impact of Sahara can be reproduced using a single point source located in the Bodélé depression (17.0 N, 18.0 E). To monitor the arrival time of dust plumes at the IMS stations, a series of 14-day forward simulations with daily releases from the Bodélé, during dusty episodes between 2009 and 2015, were generated. In total 1020 simulations with the output at the surface level (0–150 m) and 420 simulations with the output at 9 vertical layers ranging from the surface up to 10 km, were analysed. In the simulations, the analysed meteorological input data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) were used. It is demonstrated that an influx of dust at high levels (3–10 km) tends to locally increase surface ^{7}Be concentrations in area under the influence of subsiding dust plume. It is also shown that an influx of dust at lower altitudes (up to 1 km) will have the opposite effect on surface concentrations. In case dust is present in the whole column of atmosphere, its final impact depends on the ratio between its amount in the upper layers (3–10 km) and lower layers (0–1 km). In consequence an increase up to 30% or a decrease up 20% in daily ^{7}Be surface values may be observed during such an episode. On a monthly scale a few episodes related to an increase of ^{7}Be values or its decrease may follow each other. It was estimated that on average the presence of dust leads to the increase of ^{7}Be mean monthly surface values. The largest increase was noted at the station MRP43, of about 4.1 ± 1.3%; and the smallest at the stations KWP40, of about 2.0 ± 1.6% and PAP50, of about 2.0 ± 1.0%, respectively.

1. Introduction

The International Monitoring System (IMS) developed by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is a global system of monitoring stations, using four complementary technologies: seismic, hydroacoustic, infrasound and radionuclide (CTBTO, 2018). The radionuclide network comprises 80 stations, of which more than 60 are certified. The aim of radionuclide stations is a global monitoring of radioactive aerosols and radioactive noble gases supported by the atmospheric transport modelling (ATM) system. Stations monitor various radioactive aerosols but Beryllium-7 (^{7}Be) is one of two natural radionuclides measured on a daily basis.

^{7}Be ($T_{1/2}$ = 53.3 days), originates from spallation of nitrogen and oxygen nuclei by energetic particles associated with cosmic radiation entering the atmosphere (e.g. Benioff, 1956; Usoskin and Kovaltsov, 2008). The amount of ^{7}Be that reaches the surface depends on the production rate which is a function of latitude, altitude and solar activity (e.g. Masarik and Beer, 1999). The production rate varies by about 20% from the mean due to fluctuations in solar activity (e.g. Koch et al., 1996; Koch and Rind, 1998). Approximately 2/3 of ^{7}Be is produced in the stratosphere and the remaining 1/3 in the upper part of the troposphere (Lal and Peters, 1967; Zanis et al., 2003). ^{7}Be attaches predominantly to aerosol particles in the submicron size range (e.g. Ioannidou et al., 2005) with an activity mean diameter of typically 0.5–0.7 μm (e.g. Lange, 1994) and is removed from the atmosphere by dry and wet depositions (e.g. Kuśmierczyk-Michulec et al., 2015). ^{7}Be is one of the most important environmental radionuclides related to large-scale atmospheric circulation dynamics (Terzi and Kalinowski, 2017), often used as an aid in identifying a stratosphere–to-troposphere transport (STT) signature (e.g. D'Amours et al., 2013; Brattich et al.,

* Corresponding author.
E-mail address: jolanta.kusmierczyk-michulec@ctbto.org (J. Kuśmierczyk-Michulec).

https://doi.org/10.1016/j.jenvrad.2018.07.015
Received 18 April 2018; Received in revised form 5 July 2018; Accepted 14 July 2018

2017).

This study investigates the possible influence of Saharan mineral dust on changes in ^{7}Be concentrations near the surface. The Sahara desert is the largest natural source for airborne mineral dust worldwide (e.g. Middleton and Goudie, 2001). With the increased number of satellites and development of satellite imagery, it is possible to detect massive sandstorms blowing off the northwest African desert, with dust transported over the Atlantic (e.g. Niedermeier et al., 2014) and reaching the Amazon Basin (e.g. Yu et al., 2015). Based on the satellite data from CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) collected between 2007 and 2013, it was estimated that the annual average African dust deposition into the Amazon Basin is approximately 28 million tons per year (Yu et al., 2015).

Studies show that the most vigorous source for dust is the Bodélé depression in Northern Chad, emitting on average 0.7 million tons of dust per day (e.g. Koren et al., 2006). During dust storms, major part of mineral aerosols moves westward into the Atlantic Ocean but a considerable fraction is also transported across the Mediterranean basin towards Southern Europe and can even reach Central and Northern Europe (e.g. Moulin et al., 1998). The Sahara main range of influence is the area between the Equator and the parallel 30.0 N, and two meridians 80.0 W and 50.0 E. The presence of desert dust in that region is also confirmed by the high values of the Absorbing Aerosol Index (AAI) measured since 1978 on a regular basis by TOMS (Total Ozone Mapping Spectrometer) and for the last ten years by OMI (Ozone Monitoring Instrument). AAI, a ratio of measured to calculated UV radiances, indicates the presence of elevated absorbing aerosols in the Earth's atmosphere (Tilstra et al., 2010) in a quantitative manner. The high values of TOMS AAI also correspond to areas with high values of the dust optical thickness (i.e. in the range between 0.75 and 1.5 for the wavelength 440 nm) over Africa and close to its western coast. It should be emphasized that the Saharan dust is transported over the Atlantic throughout the year (e.g. Chiapello and Moulin, 2002) and the dust plume characterized by its high optical thickness is observed by various satellites (e.g. Myhre et al., 2004; Kuśmierczyk-Michulec and de Leeuw, 2005).

Recent studies suggest not only a dependency in reference to ^{7}Be and Saharan dust (e.g. Gordo et al., 2015) but also emphasize the importance of the altitude at which the air masses arrive over a certain location (e.g. Piñero-Garcia et al., 2015). Prospero et al. (1995) based on the measurements performed in Tenerife during summer periods reported a strong negative correlation between Saharan dust and ^{7}Be. This conclusion has been completed by Hernandez et al. (2008) who did measurements at the same island but during a longer period of one year and a half. The authors analyzing the measurements of atmospheric PM1 and PM10 matter (particulate matter with aerodynamic diameter below 1 and 10 μm) as well as ^{40}K and ^{7}Be concentrations, realized that the mineral dust from North Africa could be associated with high or low ^{7}Be depending on the season and on meteorological conditions. The high mineral dust concentrations present in the marine boundary layer, leading to a decrease in ^{7}Be concentrations, were attributed to dry gravimetric deposition from higher altitudes (Hernandez et al., 2008). The high ^{7}Be concentrations were associated with downward transport of air masses from very high altitudes during which ^{7}Be attached to mineral particles could act as a secondary source of ^{7}Be. Similar conclusions were also confirmed by Piñero-Garcia et al. (2015), who demonstrated that while Saharan intrusions at high altitudes (> 3000 m) are associated with ^{7}Be increases in the samples collected in southeastern Spain, intrusions travelling at lower heights within boundary layer (1500 m) have the opposite effect.

The effect of mineral dust is also noted by three IMS radionuclide stations, located in the area particularly influenced by dust events: MRP43 (18.1 N, 15.9 W) in Mauritania, KWP40 (29.3 N, 47.9 E) in Kuwait and PAP50 (9.0 N, 79.5 W) in Panama (Fig. 1). In this study we will investigate the role of Saharan dust on ^{7}Be variations using the Atmospheric Transport Modelling (ATM) and IMS ^{7}Be data collected during 2009–2015.

2. Experimental

The measurements of ^{7}Be activity concentrations were conducted using a high-volume air filtration unit operated on a routine methodology from a network of stations, which belong to the International Monitoring System (IMS) and is operated by the CTBTO. At each station, 500–1000 m^3/h of air is continuously filtered by using various types of filter papers. The particulate radionuclides collection efficiency is good; the collectors are designed to catch more than 80% of particles with diameter larger than 0.2 μm. Each sample was collected during a 24-h period. The activity concentration of ^{7}Be and other aerosol-bound radionuclides were measured with high-resolution germanium detectors (Schulze et al., 2000; Medici, 2001). The minimum detectable activity concentration (MDC) of ^{7}Be varies for different stations, but is on average about 5–30 μBq/m^3. It should be mentioned that according to the standard procedure a 24-h decay period is observed after sampling before analyzing samples. This period of time allows reducing all short-lived radionuclides that decayed in that time, thus improving the detection limit.

In this study, data collected during a 7-year period, from 2009 to 2015 were used. Table 1 presents a set of general information about the sampling sites, including location name, station code, coordinates, elevation and indication of the state responsible for each station. Table 1 also provides the number of months (N_m) to demonstrate the seasonal representativeness of the datasets used in further analysis. Fig. 1 presents a map showing all IMS radionuclide stations with special emphasize on the three stations discussed and analysed in this work.

Meteorological data was collected by meteorological equipment placed at the sampling stations and recorded every 10 min. The recorded parameters include: air temperature, wind speed, wind direction, relative air humidity, atmospheric pressure and rainfall. Data from the meteorological station were averaged over 24 h. The meteorological data together with collocated ^{7}Be activity concentration measurements were used in further analysis.

3. Methodology

The subsequent sections will provide a brief description of the Lagrangian particle dispersion model FLEXPART (Section 3.1) and its application for the purpose of global and real time monitoring, named as Atmospheric Transport Modelling (Section 3.2). Section 3.3 gives a brief overview of the Web-Grape software used to post-process and visualize the ATM outputs. The methodology explaining why the behaviour of Saharan dust can be represented by a single source is outlined in Section 3.4. Approach used to select dust episodes and to estimate the dust concentration is described in Section 3.5 and 3.6, respectively. Section 3.7 presents the method used to quantify the impact of Saharan dust on ^{7}Be concentrations.

3.1. FLEXPART model

FLEXPART (e.g. Stohl et al., 2005) is a Lagrangian particle dispersion model suitable for the simulation of atmospheric dispersion. It is an open-source code, released under the GNU General Public License and maintained by a scientific community (FLEXPART.EU, 2018). Similarly to other Lagrangian particle models, FLEXPART computes trajectories of a large number of so-called particles to describe the transport and diffusion of tracers in the atmosphere. These particles represent infinitesimally small air parcels, and they do not need to represent real particles.

The concentration in a grid cell is calculated by sampling the tracer mass fractions of all particles within the grid cell and dividing by the grid cell volume