Journal of Environmental Radioactivity 172 (2017) 218–231

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Short-term variability of gamma radiation at the ARM Eastern North Atlantic facility (Azores)

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ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form
5 January 2017
Accepted 31 March 2017

Keywords:
Gamma radiation
Radon
Aerosols
Precipitation
ARM programme

ABSTRACT

This work addresses the short-term variability of gamma radiation measured continuously at the Eastern North Atlantic (ENA) facility located in the Graciosa island (Azores, 39N; 28W), a fixed site of the Atmospheric Radiation Measurement programme (ARM). The temporal variability of gamma radiation is characterized by occasional anomalies over a slowly-varying signal. Sharp peaks lasting typically 2–4 h are coincident with heavy precipitation and result from the scavenging effect of precipitation bringing radon progeny from the upper levels to the ground surface. However the connection between gamma variability and precipitation is not straightforward as a result of the complex interplay of factors such as the precipitation intensity, the PBL height, the cloud's base height and thickness, or the air mass origin and atmospheric concentration of sub-micron aerosols, which influence the scavenging processes and therefore the concentration of radon progeny. Convective precipitation associated with cumuliform clouds forming under conditions of warming of the ground relative to the air does not produce enhancements in gamma radiation, since the drop growing process is dominated by the fast accretion of liquid water, resulting in the reduction of the concentration of radionuclides by dilution. Events of convective precipitation further contribute to a reduction in gamma counts by inhibiting radon release from the soil surface and by attenuating gamma rays from all gamma-emitting elements on the ground. Anomalies occurring in the absence of precipitation are found to be associated with a diurnal cycle of maximum gamma counts before sunrise decreasing to a minimum in the evening, which are observed in conditions of thermal stability and very weak winds enabling the build-up of near surface radon progeny during the night.

1. Introduction

The omnipresence of Radon (Rn-222) in natural environments, its noble gas nature, and its half-life of 3.8 days, make it particularly suitable as a natural environmental tracer in diverse geoscience applications (e.g. Barbosa et al., 2015). Radon has been extensively used as an atmospheric tracer (Wilkening, 1981), including as an indicator of atmospheric turbulence (e.g. Sesana et al., 2006) and as a tool to characterize the nocturnal stable boundary layer (e.g. Williams et al., 2013). Radon measurements over the oceans have been used to identify radon-rich air masses that have originated from continental areas (e.g. Arnold et al., 2009; Chambers et al., 2009), particularly in remote oceanic locations such as the Hawaii (Whittlestone et al., 1992; Chambers et al., 2013).

Continuous radon monitoring, particularly in the case of very low concentrations such as typically found in the atmosphere, is much more challenging than the continuous monitoring of radon progeny, fostering the measurement of the gamma radiation from the radioactive decay of radon progeny as an alternative to the direct measurement of radon. Crystal scintillators for gamma rays have higher relative sensitivity in comparison to solid-state alpha detectors and ionization chambers, allowing for a more detailed characterization of the temporal variability of environmental radioactivity, particularly in the case of fast changes (Zafrir et al., 2011).

In the present study the temporal variability of gamma radiation is examined at a remote oceanic site, on a small island in the middle

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http://dx.doi.org/10.1016/j.jenvrad.2017.03.027
0265-931X/

of the North Atlantic Ocean (Graciosa island, Azores). The specific geographical location of the site is a crucial aspect of the study. Graciosa is sufficiently remote to be clear of direct continental influence (~1500 km from Europe) and typically experiences relatively clean conditions advected from the central North Atlantic, but is also subject to periodic episodes of continentally influenced polluted air masses from Western Europe, North Africa, and North America (Logan et al., 2014; Wood et al., 2015). Continuous monitoring of gamma radiation is carried out at the Eastern North Atlantic (ENA) facility, a fixed site of the Atmospheric Radiation Measurement programme (ARM), established and supported by the Department of Energy (DOE) of the United States of America with the collaboration of the local government and University of the Azores. The collection of data at the ENA facility ensures the existence of detailed knowledge on the atmospheric conditions at the site (Rémillard et al., 2012; Dong et al., 2014; Mann et al., 2014) and the availability of a comprehensive suite of very detailed and high-quality atmospheric measurements that can be used as unique source of ancillary observations for the interpretation of the radiation measurements.

Gamma radiation measured in the air at ~1 m above the ground (the standard height for gamma dose rate measurements) comprises gamma rays from both the surface and the atmosphere. The largest surface contribution is from gamma rays originating inside mineral grains in the soil matrix, either from the long-lived gamma-emitting elements (K-40, U-238, Th-232) or from Rn-222 and its progeny, and is therefore stable in time, since the concentration of radionuclides inside the mineral grains is constant in time. The surface contribution also includes radon atoms emanated from the solid grains to the air or water-filled space of the porous medium which varies in time according to the overall up or downward transport of radon inside the porous medium. The atmospheric contribution includes gamma rays emitted by radon gas progeny in the near-surface atmosphere as well as progeny brought down from the upper atmosphere by below-cloud wash-out and in-cloud scavenging by nucleation or impaction (e.g. Levin and Cotton, 2008). Stratiform and stratocumulus clouds (Wood, 2012) typically at low height and with small thickness, are limited to scavenge radon progeny within the boundary layer, while dynamically active cumuliform clouds with high cloud tops are able to scavenge radon progeny from the troposphere.

This study focus on the short-term variability (daily and sub-daily time scales) of gamma radiation measured continuously at the ARM-ENA facility, and its association with atmospheric conditions. The temporal variability of gamma radiation has been repeatedly addressed (e.g. Minato, 1980; Takeuchi and Katase, 1982; Inomata et al., 2007; Mercier et al., 2009; Yakovleva et al., 2016) as it is a crucial aspect in practical applications such as the routine monitoring of nuclear facilities. In this environmental surveillance context it is fundamental to discriminate between increased levels of gamma radiation associated with artificial radioactivity, and the natural variability in gamma radiation associated with specific atmospheric conditions such as the occurrence of precipitation. Furthermore, the scientific applications relying on radionuclides as atmospheric tracers require a detailed understanding of the different processes influencing their variability. Several studies reported strong short-term variations in environmental gamma radiation associated with precipitation, but its dependence with the rate, duration and amount of precipitation is found to be highly variable (Fujinami, 1996; Inomata et al., 2007; Burnett et al., 2010). Furthermore, strong enhancements in gamma rays have been reported even in the absence of precipitation (Inomata et al., 2007; Yakovleva et al., 2016) as well as cases of precipitation events producing no detectable effects in the gamma radiation, and interpreted as the result of the distance between the precipitation measuring station and the gamma monitoring site (Yakovleva et al., 2016). An obvious hindrance of previous studies is the lack of temporal and/or spatial resolution of gamma and meteorological measurements, for example relying on hourly averaged precipitation (e.g. Inomata et al., 2007) or precipitation data collected only once every 12 h (Yakovleva et al., 2016). Another evident limitation is the noncontiguous location of gamma and precipitation measurements (e.g. Yakovleva et al., 2016).

Here the link between gamma radiation short-term peaks and precipitation is investigated in-depth taking advantage of the extensive meteorological infrastructure available at the ARM-ENA site. The monitoring site is described in section 2.1, the instrumental set-up is depicted in section 2.2., and the data used in the study are presented in section 2.3. The results are shown in section 3 and discussed in section 4, along with concluding remarks.

2. Material and methods

2.1. Geographical setting

The Graciosa Island (39°N 28°W) is the second smallest island of the Azores Archipelago (Portugal). It is a small (~60 km^2 area) and low lying (~400 m) volcanic island dominated by a 1.6 km wide central caldera in the southeast (Fig. 1). As a result of its location between the subtropics and the mid latitudes, Graciosa experiences a diverse range of air mass histories and is subject to strong synoptic meteorological variability including cyclonic systems, fronts, and periods of extensive low-level cloudiness. The island is small and low enough that clouds above are not strongly influenced by its presence, making it a very suitable site for the study of the Marine Boundary Layer (MBL). While not subject to direct continental influence because of its remote oceanic location, Graciosa experiences in addition to pristine arctic air masses from the north also air masses that have been circulating around the Azores high pressure system over the ocean for several days as well as markedly polluted continental air masses from both North America and Europe, making it a very suitable site for studies on aerosols and microphysical cloud properties (Wood et al., 2009).

Following the deployment of the ARM mobile facility at Graciosa (2009–2010) in the context of the Clouds, Aerosol and Precipitation

Fig. 1. Geographical location of the ARM-ENA facility at the Graciosa island, Azores archipelago.