World-wide seasonal variation of $^{7}$Be related to large-scale atmospheric circulation dynamics \cite{1}

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Abstract

Meteorological processes can be deciphered using $^{7}$Be as aerosol tracer. Especially ground based observation of $^{7}$Be world-wide over a long period of time can reveal information about large-scale atmospheric circulation dynamics. The CTBT through its radionuclide network collects the activity concentration of these tracers since over 15 years and built up unique and powerful datasets that can be interpolated into global concentration maps. Maps of observed $^{7}$Be seasonal variation as an expression of atmospheric cell migration such as Hadley, Ferrel and Polar cells. Previous studies used data from IMS stations to correlate beryllium trends to atmospheric patterns but on a local or regional scale. In this paper, we demonstrate how for the first time a worldwide beryllium concentration map is reconstructed using 15 years of data from 63 IMS radionuclide stations.

Highlights

• Analysis of $^{7}$Be activity values measured from 63 IMS stations worldwide from 2001 to 2015.
• Observed $^{7}$Be global seasonal variation as an expression of atmospheric cell migration.
• Reconstruction of a global $^{7}$Be concentration map over time.
• Findings on correlation between $^{7}$Be global patterns with seasonal shift of ITCZ and Hadley-Ferrel cell boundary, tropopause height, Walker circulation, El Nino Southern oscillation (ENSO), quasi-biennial oscillation (QBO), sudden stratospheric warming (SSW), solar energetic particle (SEP) events, Indian Monsoon.

Introduction

CTBT has established an IMS for treaty verification based on waveform and radionuclide (RN) technology.

• The RN network, comprises 80 stations of which 63 are certified and operational as of mid-2016. Each RN station collects daily radionuclide aerosols into a sample of which a gamma spectrum is sent to the international data centre (IDC) in Vienna for analysis. Stations are run at high data availability.

• $^{7}$Be is one of the sampled particle-bound natural radionuclides. It decays with a 53.3 days’ half-life and is largely produced in the lower stratosphere and upper troposphere \cite{2} as a result of spallation of nuclei of atmospheric gases, mainly oxygen and nitrogen. $^{7}$Be attaches to aerosol particles and is removed mainly by wet deposition, this effect of wash out by precipitation is highly marked in the intertropical convergence Zone (ITCZ) \cite{3}.

• The atmospheric circulation cells in the northern and southern hemisphere consist of three main types of convergence zones: Polar-Ferrel, Hadley-Ferrel and inter tropical. Hadley-Ferrel mark the increase in beryllium concentrations because of the vertical downward air flux producing a double high activity band, one in each hemisphere.

Methods

• This study uses monthly averages of $^{7}$Be (µBq/m³) time series as long as 15 Years (2001 to 2015) for a total of over 200 000 days of analysed data.
• Seasonal variation pattern were found especially for latitudes between 10 and 50 (-/+).
• To highlight seasonal variations, time series from two stations with different latitude and similar longitude are compared to see the pattern shift (Figure 2).
• The shift represents the progression of atmospheric cells convergence zones.

Results

• Finally monthly averaged concentration for each station are interpolated into a global $^{7}$Be map grid for each month (Figure 6).
• Green-blue areas are symmetric for ITCZ and PFZ while yellow-orange red are related to HFZ in both Northern and Southern Hemispheres.
• $^{7}$Be levels increase between June and August in the top right corner of the map (Figure 7). That area is correlating with the Hadley-Ferrel Convergence Zone in the Northern Hemisphere \cite{4}.
• In the Southern Hemisphere, HFZ is strong in December January and decreases till a minimum is reached in June.

Figure 2. Normalized ($^{7}$Be concentration / $^{7}$Be concentration 2015)

• Stations are divided into 12 longitudinal bands to compare the seasonal variation for stations with a common longitude.
• $^{7}$Be time series are then interpolated into surface graphs to plot $^{7}$Be activity concentration versus latitude (Figure 3, right plot) confirming the theoretical model (Figure 3, left plot) with two maximum concentration lines related to the HFZ, alternated by three minimum concentration lines related to one ITCZ and two PFZ (northern and southern hemisphere).

Figure 3. Normalized ($^{7}$Be concentration / $^{7}$Be concentration 2015)

• Figure 4 shows the resulting concentrations as they change over time for each longitudinal band.
• The convergence zone structures can be well seen by the concentration minima (blue-green) and maxima (orange-red).

Figure 4. $^{7}$Be normalized concentration time series for each of the 12 longitudinal bands (µBq/m³ time series as long as 15 Years)

• To highlight monthly modulations normalized values (Figure 7) were calculated dividing the monthly average by the average over all months for each grid point.
• Northward trend is visible from January to July and southward from July to December with peaks in March/April and October.

Figure 5. $^{7}$Be normalized concentration time series for each of the 12 longitudinal bands (µBq/m³ time series as long as 15 Years)

• Indian monsoons
• Onset and withdrawal of Indian monsoons is of one of many meteorological phenomena correlation that has been tested with $^{7}$Be activity concentrations.
• Monsoon withdrawal is caused by southward movement of the ITCZ via displacement of warm dry air, anticyclonic flow, and rainfall reduction. The relative humidity and temperature thresholds as cross points can be used to predict monsoon onset and withdrawal \cite{5}.
• Following \cite{5} approach we looked for cross points in $^{7}$Be time series for RN42 and RN37 as both stations are located in regions affected by Indian monsoons.

• The drop of $^{7}$Be levels appears about 30 days prior to the monsoon onset, this may indicate the possibility to use cross points (i.e. where levels of $^{7}$Be are equal for both locations) as new monsoon-indicating threshold. Rather than considering the increase of $^{7}$Be concentration at RN37 alone, cross points indicate the position of an atmospheric cell relative to two locations giving more guarantee that the time window delimited by the cross point is indeed monsoon related.

Figure 6. $^{7}$Be normalized concentration time series for each of the 12 longitudinal bands (µBq/m³ time series as long as 15 Years)

• Similar pattern were found for RN09-RN52.

Conclusions

• For deciphering various meteorological processes, the global network of IMS RN stations offers an unprecedented opportunity using a new aerosol tracer. In this study it is shown how one can reconstruct the location of the Hadley-Ferrel cell convergence zone (HFPCZ) worldwide and its progression at any point in time using $^{7}$Be. $^{7}$Be measurements injected at 63 different IMS stations around the globe.

• Time series of $^{7}$Be fluxes can be interpreted as precipitation associated to monsoons and accordingly associated with Walker circulation patterns and ENSO.

• Further possibilities of relating $^{7}$Be concentrations to global atmospheric circulation patterns such as tropopause height, sudden stratospheric warming (SSW), solar energetic particle (SEP) events and quasi-biennial oscillation (QBO) are presented and it is demonstrated that these would benefit from further studies.

• Practical applications may arise from utilizing $^{7}$Be concentration patterns to validate and complement other methodologies for determining global atmospheric phenomena and $^{7}$Be might possibly serve as an early warning indicator for emerging El Niños and Indian monsoons. Most promising are the onsets of $^{7}$Be concentrations at RN37 in Okinawa, Japan, in comparison with the levels at RN42, Taranai Rata, Malaysia. A 30-day warning prior to monsoon onset appears achievable.

• The final purpose of this project is not only to attempt studying circulation pattern to suggest new scientific work, but to demonstrate the power of global RN tracer datasets that can be interpolated into a global concentration map.

Dataset Access (vDEC)

Dataset used in this paper can be accessed via the virtual Data Exploitation Centre (vDEC), vDEC provides scientists and researchers with access to CTBT IMS data to conduct research and to publish new findings. Further details on data request procedure can be found at www.ctbt.org.

Acknowledgement

The data presented in the study were obtained thanks to IMS Station Operators, IMS support staff and IDC analysts.

Disclaimer

The views expressed on this poster are those of the author and do not necessarily reflect the view of the CTBTO.

References

\cite{1} Peer-reviewed paper on the topic of this poster has been submitted and is currently under review.


\cite{2} Kusmierczyk-Michulec, J., A. Ghidoussi, M. Nikkimeyer, 2015. Influence of precipitation on $^{7}$Be concentrations in air measured by CTBTO global monitoring system, Journal of Environmental Radioactivity 144, 140-151.
