^{7}Be in South America: detection by IMS radionuclide stations and possible applications for climate and environmental studies.

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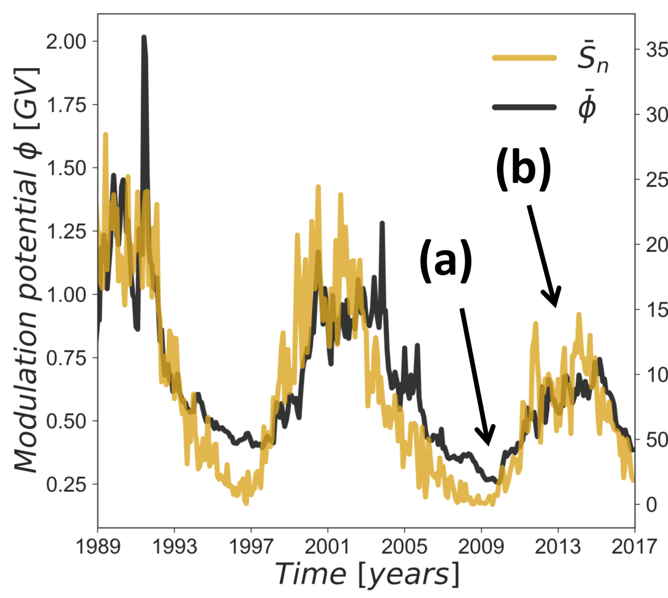
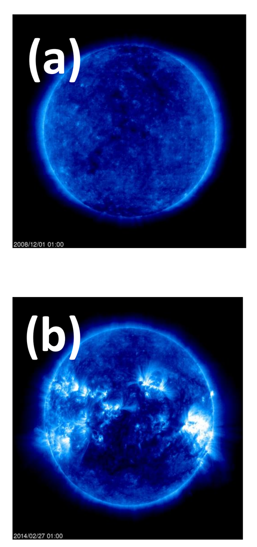
^{7}Be is one of the cosmogenic isotopes most efficiently produced in nuclear spallation reactions induced by the interaction of cosmic rays and atmosphere constituents, then it rapidly attaches to suspended aerosols and its fate is governed entirely by atmospheric dynamics. With a relative short half-life of 53.22(6)d it decays via electron capture and one of the by products of this transition is a gamma ray of 477.6 keV. Due to its abundance ^{7}Be concentration is quantified with a high degree of precision by the IMS radionuclide network. The focus of this work is to characterize the spatial and temporal variability of ^{7}Be concentration in South America analyzing the data collected by several IMS stations provided under a vDEC collaboration over the 2005-2016 time period. ^{7}Be concentration in air is dominated by a seasonal cycle for which the stronger effects are more evident around mid-latitudes, with periodicities closely related to the ones found in climate. Anomaly time-series were compared with climate parameters of interest and a conceptual model was developed to explain ^{7}Be inter annual variability. Anomalous ^{7}Be high concentration events were identified and using retro-trajectory analysis the enriched ^{7}Be air masses were traced back to its source.

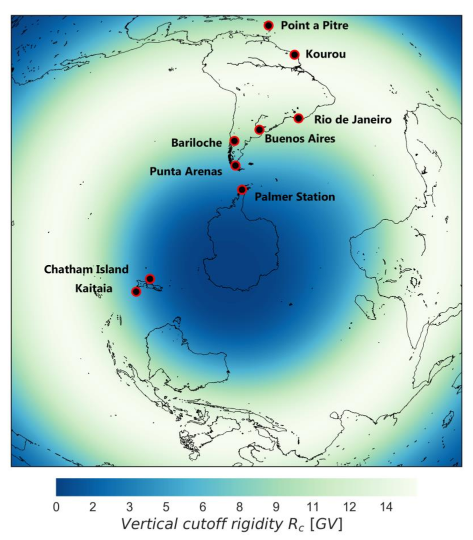
Natural ^{7}Be production on earth

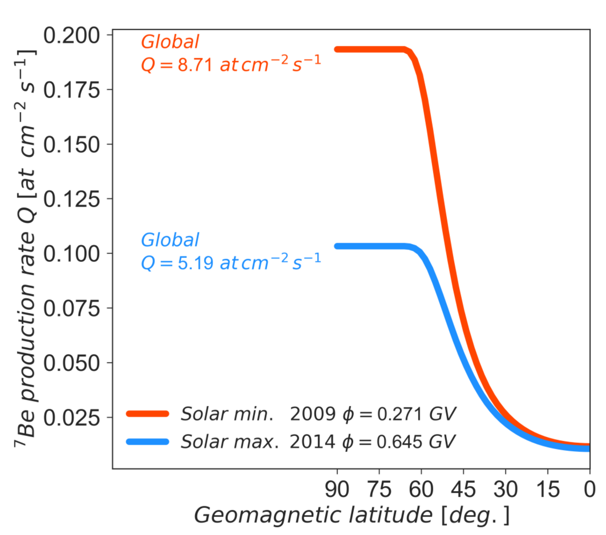
^{7}Be isotope is produced when high energetic cosmic rays induce nuclear spallation reactions with nitrogen and oxygen. Production depends on the variable solar activity, the geomagnetic latitude and the interaction depth or altitude where the cosmic ray interacts[1].





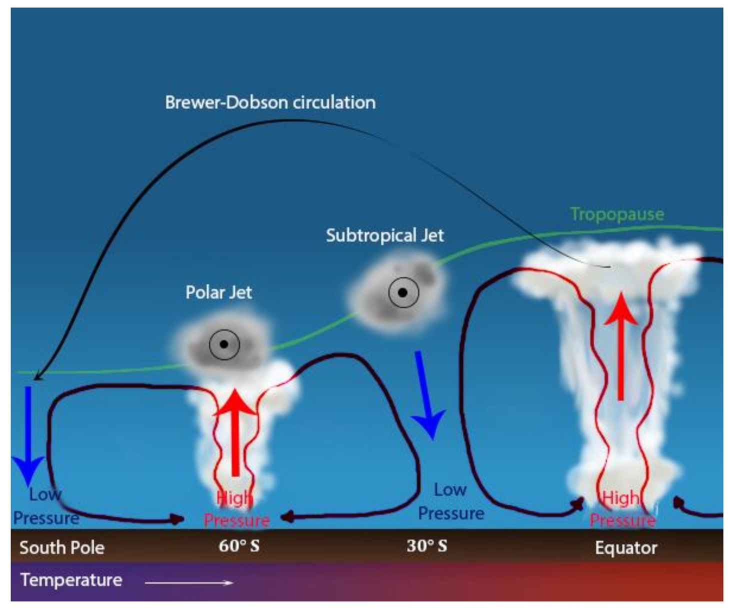
In a solar minimum (a) the production of cosmogenic isotopes is at a maximum, as it can be seen from the bottom right figure. Near the geomagnetic poles particles with lower momentum per charge can reach the surface without deviating. The locations under study are pointed out in the bottom left figure.





Transport and removal of 7Be

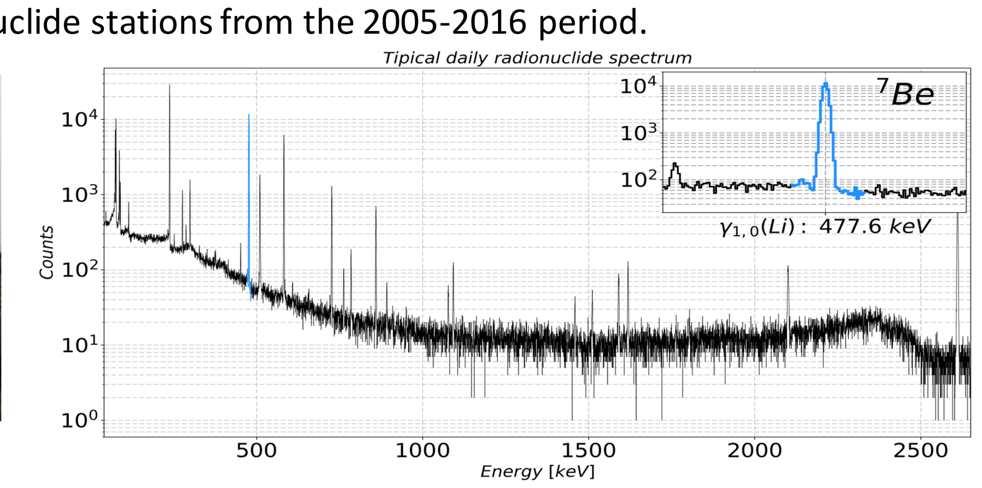
Once ^{7}Be is produced it rapidly attaches to suspended aerosols and its fate is totally governed by atmospheric dynamics. Aerosols can be removed from the atmosphere by wet or dry deposition.



The residence time of ^{7}Be in the atmosphere goes from days in the troposphere to years in the stratosphere. On the left a simplified convection cell atmospheric circulation model is presented. It consists of large scale convection in the tropical zones and subsidence at the mid latitudes and poles.

Detection by IMS stations

Due to its abundance ^{7}Be is detected by virtually every IMS radionuclide network on a daily basis. The main interest is to extract insights from the analysis of ^{7}Be time series from radionuclide stations located mainly in South America. Results obtained in this work are based on the reported values by the international data center located in Vienna. Through a vDEC research proposal access was granted to the ^{7}Be data collected by 9 radionuclide stations from the 2005-2016 period.

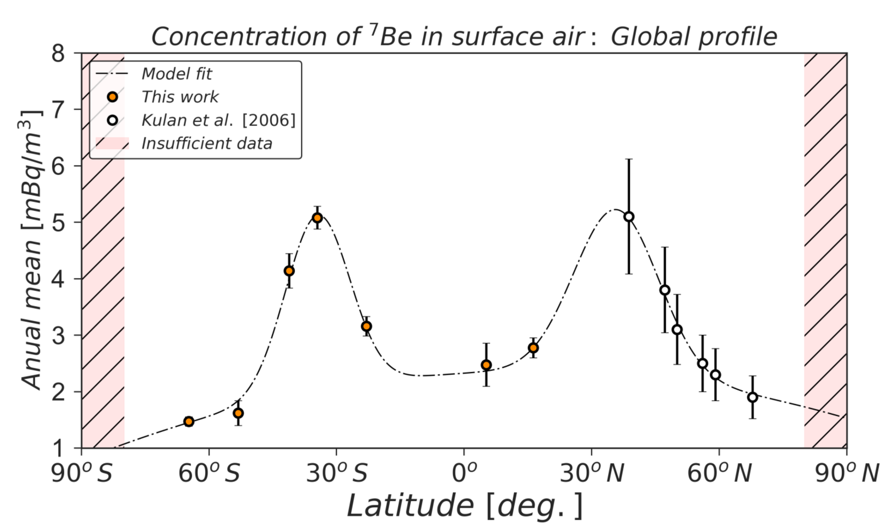


Its short half-life $T_{1/2}$ (^{7}Be) = 53.22 (6) days make it an excellent candidate to study the atmospheric dynamics. It decays by electron capture to ^{7}Li and one of the byproducts of this transition is a photon of 477.6 keV, which can be quantified accurately using the high-resolution gamma spectrometry technique.

Spatial variability

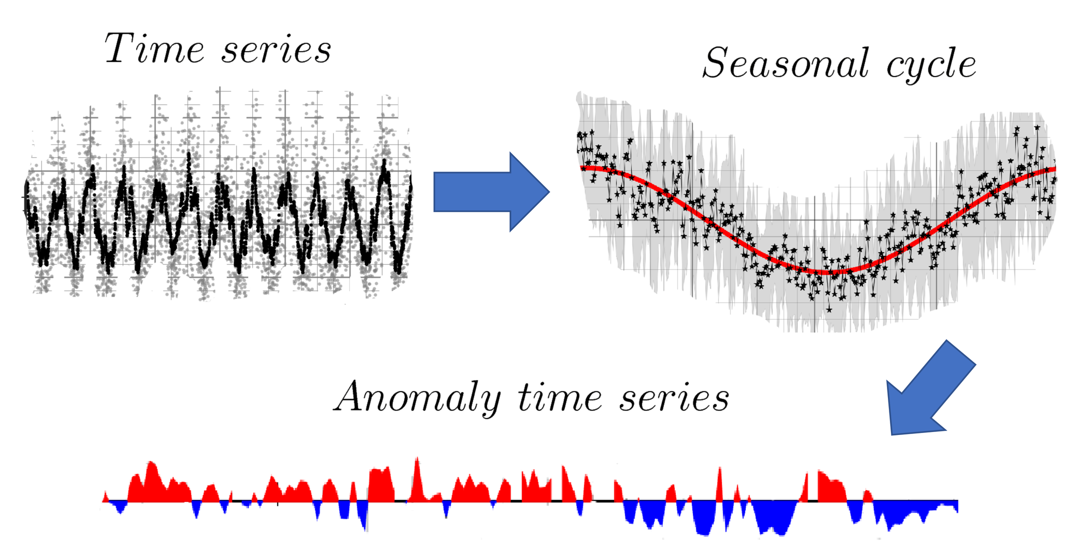
To study the spatial dependence of ^{7}Be the time series data was regrouped by year and a mean value was taken. Only stations from South America were considered.

Clear mid latitude peaks appear when we plot the concentration of ^{7}Be as a function of geographical latitude. For reference data from the Northern hemisphere have been added[2] . Minimum can be observed near the poles and in the tropics.

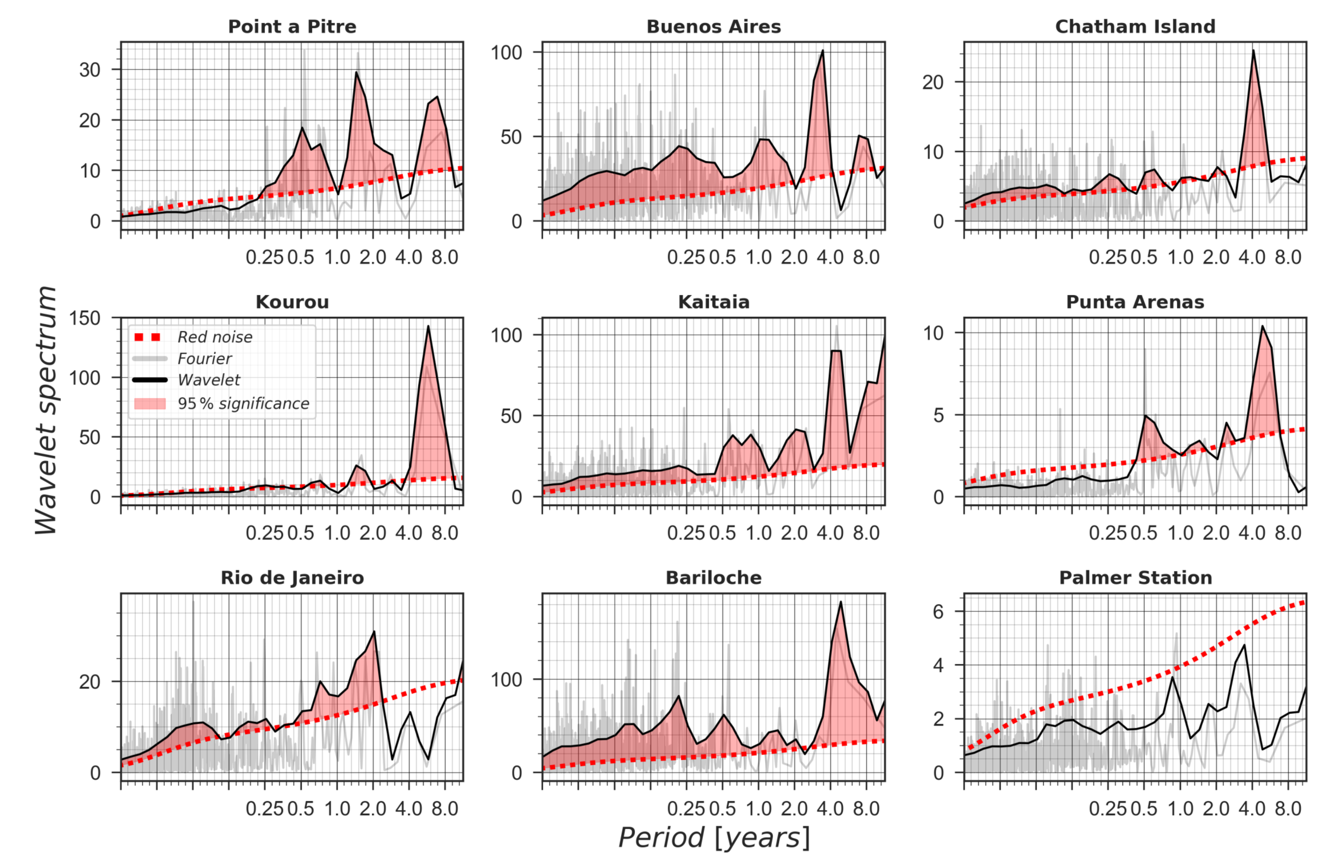


Temporal variability

In order to make a study of the sub and interanual variability of ^{7}Be its necessary to remove the seasonal cycle from the time series, constructing an anomaly time series. The seasonal cycle is approximated by the two first harmonics obtained from a Fourier transform.



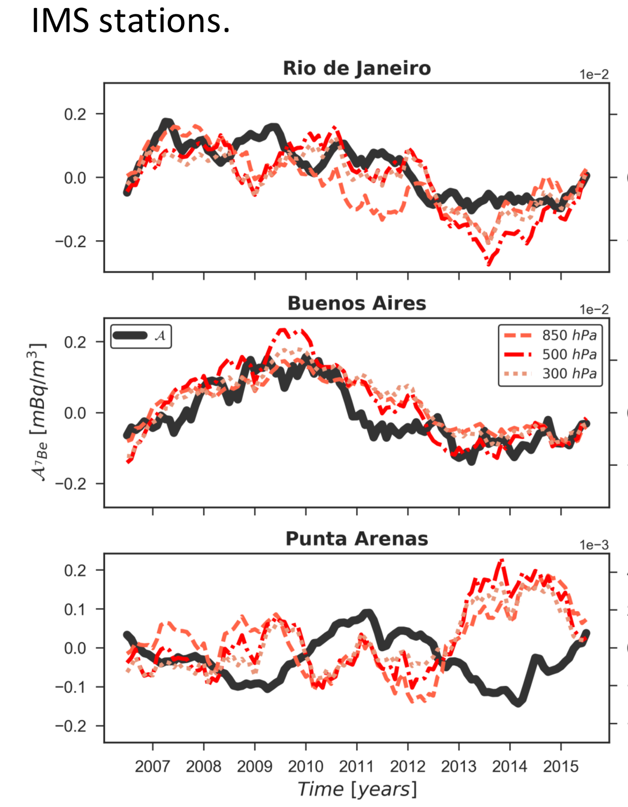
The frequency domain of the anomaly time series was studied using analysis of wavelets combined with a Fourier analysis. In this way the dominant periodicities and how the variance is distributed in the different bands could be studied.



It is presumed that the periodicities found are direct evidence of the impact that the atmospheric dynamics has on ^{7}Be variability. This is based on the fact that the dominant periodicities also characterize the climatic variability of both large-scale and regional scales.

Comparison with climate parameters

The anomaly time series were compared with climate parameters of interest taken from[3] , a monthly resampling and a 36-month rolling mean has been applied to focus on the interanual variability. The table shows the correlations found for three representative IMS stations.

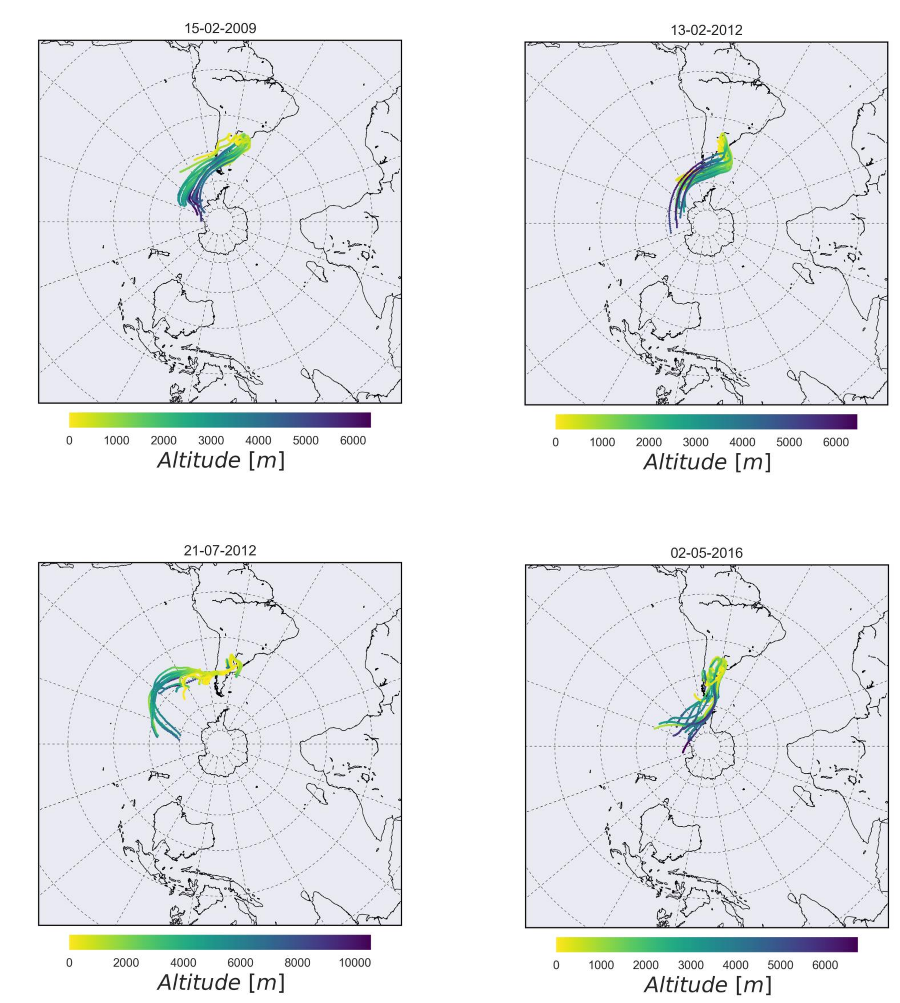


Variable	Rio de Janeiro	Buenos Aires	Punta Arenas
Surface temperature	-0.29	-0.78	-0.34
Relative Humidity	-0.02	-0.24	-0.51
Surface pressure	0.53	0.52	-0.56
Cloud cover	-0.36	-0.68	0.30
Precipitation	-0.74	-0.69	0.55
Omega wind (500 hPa)	**0.75**	**0.88**	**-0.60**
West east wind (850 hPa)	-0.43	-0.08	0.23
West east wind (300 hPa)	-0.18	-0.46	0.40
South North wind (850 hPa)	0.43	0.82	0.26
South North wind (300 hPa)	0.22	0.79	0.48

While that for Buenos Aires and Rio de Janeiro downwind anomalies correlate with positive anomalies of concentrations, in Punta Arenas is the opposite. This is consistent with high and significant correlations with precipitation, which are negative for Rio de Janeiro and Buenos Aires and positive for Punta Arenas. That is to say that high concentrations in the first two stations would be associated with dry depositions promoted by subsidence movements that also inhibit rain. In the case of Punta Arenas it is speculated that they could be associated with wet depositions produced by rain. Dynamic processes that link the variability of the physical variables associated with variations in the concentrations of ^{7}Be on inter annual and longer scales are similar to those that characterize the baroclinic Rossby waves.

Analysis of extraordinary events

To locate the source of extraordinary ^{7}Be activity concentration events measured in Buenos Aires the software HYSPLIT[4] was used to reconstruct 7-day back-trajectories. High tropospheric air parcels located in the southeast Pacific ocean and in the Antartic coast descend in a east-west direction and then south-north until they reach Buenos Aires.



In some cases, certain curvatures can be seen of the trajectories, first cyclonic (clockwise) and then anticyclonic (anti clockwise), this evidences the action of Rossby waves.

Conclusions

Studying the series of filtered monthly anomalies for Buenos Aires, Rio de Janeiro and Punta Arenas could find close and significant correlations between elements meteorological of interest. In particular, strong experimental evidence is provided that helps to identify the mechanisms that favor the deposition of ^{7}Be in South America. In particular, two consistent mechanisms were found: the first is characterized by an inhibition of the rain related to the descent of the masses of air that generate dry deposition, the second lies in the promotion of rain production due to the convection of air masses that generate wet deposition. The back-trajectory analysis is in perfect agreement with the correlations obtained for large-scale anomalies, which provides robustness to the analysis and reinforces the exposed hypothesis.

References

[1] Usoskin, I. G., and G. A. Kovaltsov (2008), Production of cosmogenic 7Be isotope in the atmosphere: Full 3-D modeling, J. Geophys. Res., 113, D12107.

[2] A. Kulan, A. Aldahan, G. Possnert, I. Vintersved. Distribution of 7Be in surface air of Europe,Atmospheric Environment,Volume 40, Issue 21,2006,Pages 3855-3868.

[3] NCEP-DOE AMIP-II Reanalysis (R-2): M. Kanamitsu, W. Ebisuzaki, J. Woollen, S-K Yang, J.J. Hnilo, M. Fiorino, and G. L. Potter. 1631-1643, Nov 2002, Bulletin of the American Meteorological Society.

[4] *Stein, A.F., Draxler, R.R, Rolph, G.D., Stunder, B.J.B., Cohen, M.D., and Ngan, F., (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc.,* ***96****, 2059-2077*