Astrophys. Space Sci. Trans., 7, 315–318, 2011
www.astrophys-space-sci-trans.net/7/315/2011/
doi:10.5194/astra-7-315-2011

Astrophysics and Space Sciences Transactions

Forbush decreases – clouds relation in the neutron monitor era

A. Dragić[1], I. Aničin[1], R. Banjanac[1], V. Udovičić[1], D. Joković[1], D. Maletić[1], and J. Puzović[2]

[1]Institute of Physics, University of Belgrade, Pregrevica 118, Belgrade, Serbia
[2]Faculty of Physics, University of Belgrade, Studentski trg 16, Belgrade, Serbia

Received: 15 November 2010 – Revised: 15 February 2011 – Accepted: 23 March 2011 – Published: 31 August 2011

Abstract. The proposed influence of cosmic rays on cloud formation is tested for the effect of sudden intensity changes of CR (Forbush decreases) on cloudiness. An attempt is made to widen the investigated period covered by satellite observation of cloudiness. As an indicator of cloud cover, the diurnal temperature range (DTR - a quantity anticorrelated with cloudiness) is used. The superposed epoch analysis on a set of isolated Forbush decreases is conducted and the results for a region of Europe are presented. The effect of Forbush decrease on DTR is statistically significant only if the analysis is restricted to high amplitude FDs (above the threshold value of 7% with the respect to undisturbed CR intensity). The magnitude of the effect on DTR is estimated to be (0.38 ± 0.06) °C.

1 Motivation

A possible influence of cosmic-rays (CR) on climate has been suggested long ago (Ney, 1959) but the research on the subject intensified only after the findings of Svensmark and Friis-Christensen (1997) of correlations between low altitude cloudiness and the long-term variations of galactic CR flux. The proposed mechanism linking CR to clouds involves atmospheric ionization induced by CR. Ions thus formed produce molecular clusters in the atmosphere and act as cloud condensation nuclei. This does not happen directly, since water vapour supersaturation in the atmosphere is too low (Dickinson, 1975). Indirect mechanisms for ion contribution to cloud formation are proposed. In the process named ion-induced nucleation (Yu and Turco, 2000, 2001), the growth of clusters to over-critical size, when the further growth by condensation is preferred over evaporation, is supported by the presence of charge through Coulomb attraction.

Not only cloud cover, but also the physical properties of the clouds are investigated in connection with cosmic rays. Recently, Svensmark, Bondo and Svensmark (2009) found that the liquid water content of low clouds drops after Forbush decreases.

Clouds determine the Earth's radiation balance. They play an important role in the hydrological cycle, the transport of heat and moisture. If confirmed, a CR-cloud connection would have profound consequences on our understanding of climate forcing.

Any attempt to investigate the CR-cloud connection faces several problems. The analyses based on satellite observations of cloudiness are limited by a relatively short period of time spanned by satellite data of roughly two decades. Other limitations include: the shadowing of low altitude clouds by high altitude clouds, inter-calibration errors or errors resulting from satellite drifts. In traditional synoptic observations of total cloud cover, an observer estimates the number of oktas (1/8 of the sky) covered by clouds. This procedure is subjective and prone to systematic error. Additionally, the sky grid might be too coarse to be sensitive to a smaller effect.

We have decided to avoid the direct use of cloudiness data in the analysis of CR-cloud connection and replace it with a different, well defined physical quantity: diurnal variation of surface air temperature (DTR), which should be inversely correlated with cloud cover (Dai et al., 1999). The rationale for this is the following: if cloudiness is high in the daytime, more sunlight is reflected back to space and the daily temperature maximum is lowered; in the nighttime, less infrared radiation from the earth surface is emitted into outer space and the daily temperature minimum is increased. Therefore - more clouds means lower DTR. Another advantage in this approach is the availability of a temperature record for a long period of time.

Correspondence to: A. Dragić
(dragic@ipb.ac.rs)

Published by Copernicus Publications on behalf of the Arbeitsgemeinschaft Extraterrestrische Forschung e.V.

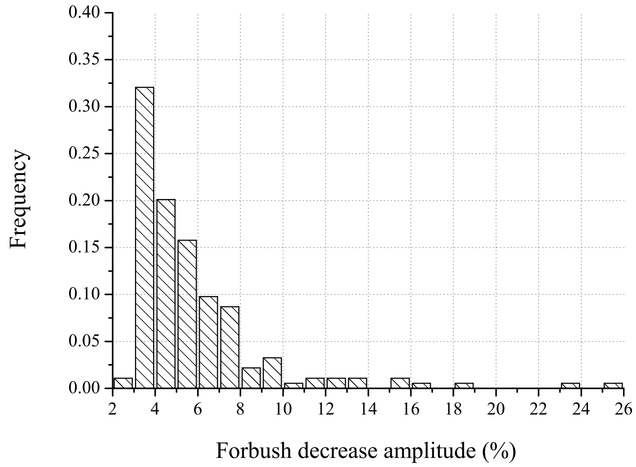

Fig. 1. The amplitude distribution of FD events. Small amplitude events occur most frequently.

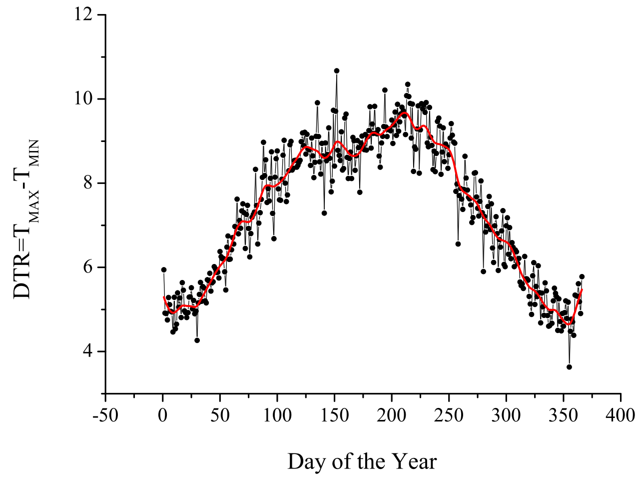

Fig. 2. The seasonal profile of the diurnal temperature range for a particular meteorological station, obtained by averaging DTR data over the 50 years period. The cubic spline fit to the data is also shown. DTR is given in °C.

2 Method

If CR influence cloud cover, changes in CR intensity should reflect on cloudiness. One remarkable change in CR intensity is the Forbush decrease (FD), a sudden drop of CR intensity with slow recovery lasting typically several days. We conducted the superposed epoch analysis of DTR deviation vs. epochs around FD. The analysis is restricted to the region of Europe. Only FDs with amplitudes higher than some predefined level are taken into account. This type of analysis has been used in the past in the search for the CR-climate connection (Pudovkin and Veretenenko, 1995).

The list of FD events for the analysis is taken from the Mt. Washington Observatory (Lockwood, 1990), supplemented to cover the period between 1954–1995. The list is cleared from those events for which another FD or ground level enhancement occurred within ±10 days, leaving only isolated FDs, with the purpose of avoiding the masking of the genuine effect. The filtered list contains 184 FD events with amplitudes higher than 3%. The amplitude distribution of Forbush events is shown in Fig. 1. Most numerous events are those below some 5% while the number of those with higher amplitudes decreases practically exponentially.

The DTR is influenced not only by clouds, but also by soil moisture, water vapour, etc. To reduce local effects and improve the signal/noise ratio, the DTR data from 189 European meteorological stations have been exploited. Stations were randomly selected, but cover the entire European region. Data have been gathered from the World Data Center for Meteorology. The data from all stations do not cover the entire investigated period. The list of meteorological stations and information on their geographic position is provided in the supplementary material.

The DTR exhibits strong seasonal dependance. For every meteorological station, DTR data were averaged over available complete years for every day of the year. A cubic spline curve has then been fitted to the data to yield the expected value for DTR for every day of the year. DTR deviation is defined as the difference between actual DTR and its expected value. An example for a particular station is shown in Fig. 2.

The DTR seasonal profile shown, with relatively flat plateau-like behavior in the summer and small DTR values in the winter, is quite common in Europe, but not universal. It is one of the several profile types occurring in the European meteorological data. In the present work, no attempt is made to run separate analyses for stations grouped by DTR seasonal profile, geographic latitude or any other parameter. Only an analysis with all stations combined has been carried out.

The superposed epoch analysis is a statistical technique used in different scientific disciplines to test the effect of the occurrence of a certain type of event (named a key event) on a specified physical variable. It is especially well suited for revealing the effect buried into the noise. The data are organized into synchronized groups with respect to the time of the occurrence of the key event and the means of these groups are compared. The response to the key event should manifest itself as the difference in the means for groups before and after the key event.

3 Results

The superposed epoch analysis on the set of Forbush decreases above certain amplitude cut has been performed. When the cut is raised to 7%, the DTR deviations start to differ significantly from zero in the days following FD. The total number of FD events in the list with amplitude above

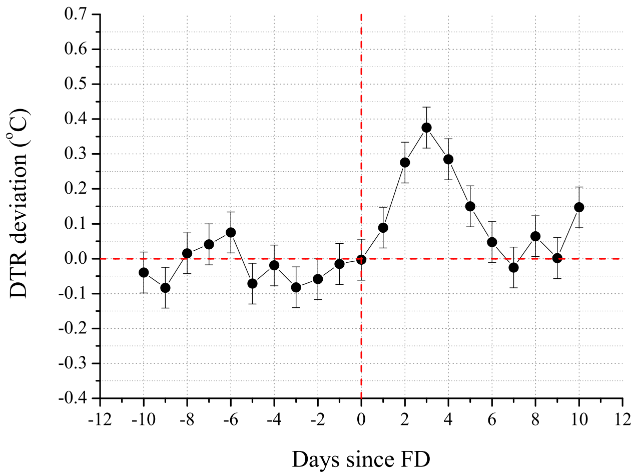

Fig. 3. Superposed epoch analysis of DTR deviation before and during Forbush decrease with amplitude higher than 7% (35 FD events). Zero epoch is the day of the FD start. The error bars represent the standard error of the mean.

7% is 35. The result of superposed epoch analysis for this group of Forbush decreases is presented in Fig. 3.

Within several days following the FD events, DTR deviation increases by $0.3-0.4\,°C$. The statistical test of the significance of this difference, based on t-statistics, has been performed. It confirms a significant difference at 99% level between a day -1 (day before FD) and days $+2, +3$ and $+4$.

The FDs of smaller magnitude did not produce a significant result. For purposes of illustration, the result of the same kind of analysis but with all FD events with amplitudes higher than 5%, is presented in the upper panel of Fig. 4. There are 81 events in this group.

If the effect is genuine, one would expect its magnitude to be related to the FD amplitude. Furthermore, the fluctuations in the DTR deviation itself mask the effect of the driver event and can make it unobservable. The method critically relies on large statistics in order to improve the signal-to-noise ratio and to reach the ”detection limit”. Therefore, it does not come as a surprise to have a threshold in the FD amplitude responsible for the effect. What might be surprising is the quite different response to Forbush events with amplitudes exceeding 7% (Fig. 3) when compared to those exceeding 5%. This needs further elaboration and a more “differential” view. To this end, the effect of FDs with amplitudes in the interval $5-7\%$ is plotted in the lower panel of Fig. 4. Although the DTR deviation seems to be systematically lower in the days after FD, none of the points is significantly different from zero.

On the higher amplitude side, the results of superposed epoch analysis with FDs having amplitudes in the $7-10\%$ interval (upper panel) and above 10% (lower panel) are shown in Fig. 5. To make visual comparison easier, the scale on the y-axis is the same on all of the superposed epoch anal-

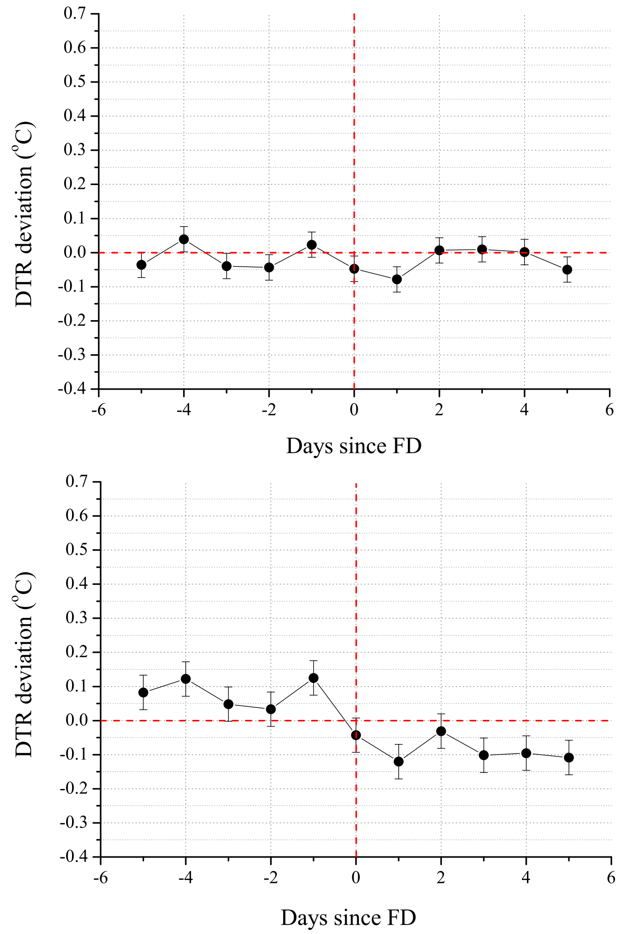

Fig. 4. Upper panel: superposed epoch analysis for all FD events having amplitude higher than 5% (81 events). Lower panel: the same as upper panel, but with FD events having amplitude in the interval $5-7\%$ (46 events).

ysis graphs. In view of the FD amplitude distribution (Fig. 1) with the increase of the amplitude, a progressively smaller number of FD events is available and the statistical uncertainties are higher. The 22 events belong to the $7-10\%$ group while there are only 13 events with amplitudes above 10%. However, this is still more than is usually available to analysis with satellite data. In a recent study of CR decrease-cloudiness connection with a negative result (Calogovic et al., 2010), only six high amplitude FDs are used. Similarly, in the work of Kristjansson et al. (2008) 6 out of 22 FDs exceed 10% in amplitude.

The entire procedure has also been tested against possible bias introduced by a trend in DTR data during the investigated period. The DTR data from some meteorological stations exhibit long term trends during the investigation period, raising the possibility that these might introduce a bias into the results. However, detrending did not alter the result of superposed epoch analysis significantly.

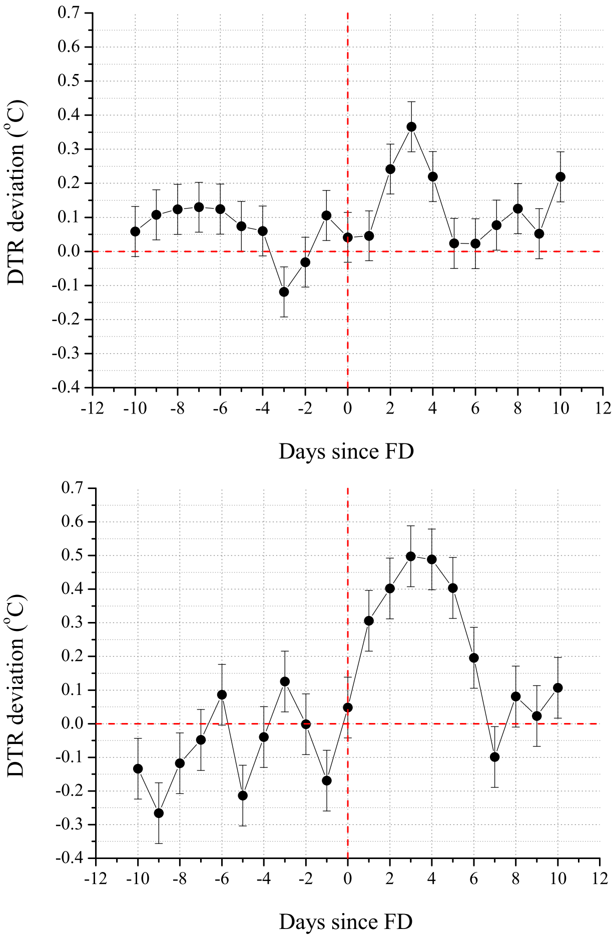

Fig. 5. Upper panel: superposed epoch analysis for all FD events having amplitude in the interval 7 – 10% (22 events). Lower panel: the same as upper panel, but with FD events having amplitude higher than 10% (13 events).

4 Conclusions

The superposed epoch analysis confirmed the statistically significant influence of CR intensity decrease on the state of the atmosphere. The effect is visible only if FDs exceeding the threshold (7% amplitude with the Mt. Washington data) are considered. The result strongly supports the idea that cosmic rays influence the atmospheric processes and climate. The natural variability of atmospheric parameters makes the CR contribution difficult to detect. The DTR appears to be a useful quantity to consider in connection with CR intensity, avoiding some of the difficulties associated with satellite measurements of cloudiness. The present study should be considered as a preliminary one. Several consequences of DTR-CR connection remain to be tested:

- DTR vs. FD behavior in different regions of the Earth
- DTR vs. CR increase if sufficient statistics are available. On the basis of the present result, the response opposite in sign and with different temporal development should be expected.
- Dependence of the effect on geographic latitude. CR-related events should exhibit a latitude effect.

Supplementary material related to this article is available online at: http://www.astrophys-space-sci-trans.net/7/315/2011/astra-7-315-2011-supplement.pdf

Acknowledgements. The support from the Ministry of Science and Technology of the Republic of Serbia through project number 141002 is gratefully acknowledged.

Edited by: B. Heber
Reviewed by: two anonymous referees

References

Calogovic, J., Albert, C., Arnold, F., Beer, J., Desorgher, L., and Flueckiger, O.: Sudden cosmic ray decreases: No change of global cloud cover, Geophys. Res. Lett., 37, L03802, doi:10.1029/2009GL041327, 2010.

Dai, A., Trenberth, K. E., and Karl, T. R.: Effects of Clouds, Soil Moisture, Precipitation and Water Vapor on Diurnal Temperature Range, J. Climate, 12, 2451–2473, 1999.

Dickinson, R. E.: Solar variability and the lower atmosphere, B. Am. Meteorol. Soc., 56, 1240–1248, 1975.

Kristjánsson, J. E., Stjern, C. W., Stordal, F., Fjæraa, A. M., Myhre, G., and Jónasson, K.: Cosmic rays, cloud condensation nuclei and clouds - a reassessment using MODIS data, Atmos. Chem. Phys., 8, 7373–7387, 2008.

Lockwood, J. A.: List of Forbush decreases 1954–1990 with supplemental information, Solar Geophys. Data, 549, 154–163, 1990.

Ney, E. P.: Cosmic radiation and the weather, Nature, 183, 451–452, 1959.

Pudovkin, M. I. and Veretenenko, S. N.: Cloudiness decreases associated with Forbush-decreases of galactic cosmic rays, J. Atmos. Solar Terr. Phys., 57, 1349–1355, 1995.

Svensmark, H. and Friis-Christensen, E.: Variation of cosmic ray flux and global cloud coverage - a missing link in solar-climate relationship, J. Atmos. Solar Terr. Phys., 59, 1225–1232, 1997.

Svensmark, H., Bondo, T., and Svensmark, J.: Cosmic ray decreases affect atmospheric aerosols and clouds, Geophys. Res. Lett., 36, L15101, doi:10.1029/2009GL038429, 2009.

Yu, F. and Turco, R.: Ultrafine aerosol formation via ion-mediated nucleation, Geophys. Res. Lett., 27, 883–886, 2000.

Yu, F. and Turco, R.: From molecular clusters to nanoparticles: Role of ambient ionization in tropospheric aerosol formation, J. Geophys. Res., 106, 4797–2814, 2001.