Investigation of presence of cosmic factors in the inter-annual distributions of cloudless days and nights in Abastumani

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Abstract To reveal the influence of cosmic factors on cloud covering, we study the inter-annual distributions of cloudless days (CD) and cloudless nights (CN) in Abastumani Astrophysical Observatory (AAO - 41.75N, 42.82E), using the continuous data of CD and CN, covering three 11-year solar cycles. It was revealed that the greatest number of CD was in August, while the greatest number of CN was in September. This picture changed when geomagnetically disturbed conditions had been considered. For weak and moderate geomagnetic disturbances, the greatest number of CD moves to September, where the frequency of magnetically disturbed day-nights is the highest during a year. On the other hand, at geomagnetically quiet conditions the maximum number of CN appears in August. These observed properties in the inter-annual distributions of cloud cover may indicate the impact of cosmic factors on cloud formation process.

It is shown for the considered dataset that the inter-annual variations of relative numbers of CD are well described by the sum of harmonic functions with annual and semi-annual periods. By this description the maximum of the annual relative number of CD is in August and the amplitude of its variations does not depend on the planetary geomagnetic Ap index. For the semi-annual variations of these CD the maxima are in March and April, the amplitude depending on Ap index values, which also may indicate possible impact of cosmic factors on cloud cover. These maxima in March and April are significant at Ap≥8 and increase at Ap≥12 and Ap≥20.

Cloud covering processes differ during day-time and night-time which can influence the radiative balance at the Earth's surface. This influence is different in various seasons resulting in different variability of day- and night-time cloud covering which can affect the regional climate.

Keywords :Cloud covering; Geomagnetic activity; Galactic cosmic rays; Climate change

1. Introduction

Clouds have a significant impact on the Earth's radiative balance and thus on the climate (Gray et al. 2010). The influence of cosmic factors on cloud covering and its consequence on climate changes is still under investigation (Svensmark and Friis-Christensen, 1997; Marsh and and Svensmark, 2000; Veretenenko, 2003; Harrison and Carslaw, 2003; Kirkby, 2007, Kristjansson et al., 2008, Calisto et al., 2011, Usoskin, 2013, Rawal et al., 2013, and references therein). Together with the long-term variations of cloud cover, which can correlate with solar and geomagnetic activities, as well as galactic cosmic ray flux, with 11-year and other periodicities, it should be important to study their inter-annual/seasonal variations, which is the main purpose of this paper.

In the troposphere, where the climate is formed, the variations in humidity and mean daily temperature at the Earth's surface may provide different conditions for influence of cosmic factors on cloud formation processes. Hence, the variations in cosmic factors can cause changes in the mean radiative balance at the Earth's surface during a year and affect climate change.

Along with solar UV and X-ray radiation, the variations of which significantly determine the structural changes of the Earth's atmosphere, the important cosmic factor is the corpuscular radiation - solar wind (Sinnhuber et al., 2012), solar cosmic rays. The plasma emitted from the solar corona goes along the solar magnetic field (interplanetary magnetic field - IMF), propagates through the heliosphere and partially drives out the galactic cosmic rays (GCR), which is assumed to be the main source of ionization of the lower atmosphere (Tinsley, Zhou and Plemmons, 2006). Solar wind and IMF interact with the Earth's magnetosphere and generate geomagnetic disturbances. Thus, geomagnetic disturbances are coupled with solar activity and GCR flux variations that are caused by this activity (Kudela and Brenkus, 2004; Dorman, 2009). These processes can cause structural changes of the lower atmosphere and affect cloud covering. Thus, interconnection of cloud cover and geomagnetic disturbances also should indicate coupling of cloudiness with cosmic factors.

The inter-annual variations of geomagnetic field are relatively easy to observe, compared to solar activity and GCR flux variations. These geomagnetic field variations can be connected to solar differential rotation, as well as IMF and geomagnetic field geometry changes. For geomagnetic disturbances the most pronounced variations are semi-annual (Russell and McPherron, 1973). For such variations the maximal number of disturbances is around Spring (March/April) and Autumn (September/October) equinoxes, while their minimal number is in Summer (around June). It is assumed that during these periods geomagnetic dipole is parallel to the IMF Bz component, which should be favorable for generation of geomagnetic disturbances (especially antiparallel - Southward case). Hence geomagnetic disturbances and their inter-annual distribution are controlled mostly by cosmic factors. The coupling of inter-annual distribution of CD and CN with geomagnetic disturbances in turn should demonstrate the influence of cosmic factors on cloud covering processes.

In the present paper, to reveal possible effect of cosmic factors on cloud covering, the inter-annual distributions of cloudless days and nights in Abastumani Astrophysical Observatory (AAO - 41.75N, 42.82E) are studied for different levels of geomagnetic activity. The analytical description of annual and semi-annual periodicities in the distribution of cloudless days and nights will be studied for various geomagnetic disturbances.

2. Inter-annual distribution of the number of cloudless days and nights

We study the inter-annual distributions of monthly numbers of cloudless days (CD) and cloudless nights (CN) in Abastumani, using the data of the 1957-1993 period. During these years atmospheric studies by optical methods had been carried out almost continuously at AAO. Total ozone content had been observed during days and the nightglow at different wavelengths during nights. The observations required clear sky conditions during both day and night.

These data had been used by various authors to investigate different atmospheric parameters and their long-term variations (Megrelishvili 1981, Fishkova 1983, Givishvili et al. 1995, Gudadze et al. 2007, Gudadze et al. 2008, Didebulidze et al. 2011). In Abastumani the anthropogenic influence is small, and natural dust events are rare (Kokkalis et al. 2012). The site is located at 1600m a.s.l. At this altitude the conditions for water evaporation during day-time and rapid temperature change at low level cloud cover regions (<3.5km), where cosmic factor influence is more important (March and Swensmark, 2000), are different from those at lower heights. These features of the site gives possibility to reveal the signal of cosmic factors influence on cloud covering and possible regional climate. In recent study (Todua and Didebulidze, 2013) the coupling of inter-annual/seasonal variations of some nightglow parameters with solar and geomagnetic activities were considered. It was demonstrated that they may be coupled with night-time cloudiness in the lower atmosphere.

During this 37-year observational period, the total number of CD was 4323 and CN 1534. Nightglow observations had been carried out only under moonless conditions, so clear lunar nights are not counted. Monthly numbers of CD vary from 227 to 531 and those of CN from 78 to 199. A large part of these data is available at www.woudc.org. This dataset allows us to investigate long-term inter-annual (seasonal) distributions of clear days and nights and examine them at different helio-geophysical conditions.

As a proxy of geomagnetic disturbance, we use the planetary geomagnetic Ap index, which at some extent correlates with dynamical and structural changes of the mid-latitude atmosphere-ionosphere (Todua and Didebulidze, 2013; Mukhtarov and Pancheva, 2012) The levels of geomagnetic

In Figure 1 the inter-annual distributions of above mentioned monthly numbers of CD, indicated by circles are demonstrated. These values are taken for all days (black lines), for days with Ap≥12 (thin red lines) and those with Ap≥20 (thick red lines). Figure 1 shows that the greatest number of CD is in August. During this month the mean daily temperature is the highest for the most regions in Caucasus. High temperature provides the least favorable conditions for water vapor condensation and hence, cloud formation. But for geomagnetically disturbed days (Ap≥12, Ap≥20) we see that the greatest number of CD is in September and the second peak appears in March, when the frequency of geomagnetic disturbances is the highest (Russell and McPherron, 1973). This peak shift is visible from Ap=7 and greater (they are not demonstrated here for brevity).

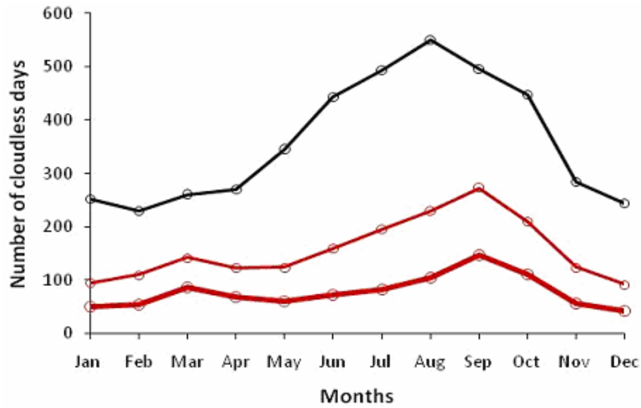

Figure 1. The inter-annual distributions of monthly numbers of cloudless days (CD) marked by circles: all CD (black line), at geomagnetic disturbances with planetary geomagnetic index Ap≥12 (thin red line) and Ap≥20 (thick red line), in Abastumani during 1957-1993.

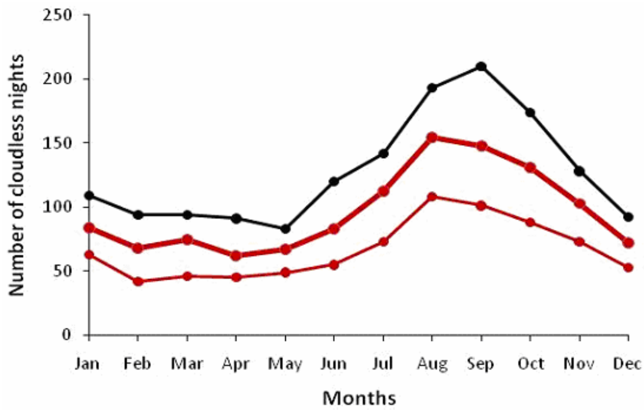

Figure 2. The inter-annual distributions of monthly numbers of cloudless nights (CN) marked by dots: for all days (black line), geomagnetically comparatively quiet Ap<12 (thin red line) and including weak disturbances Ap<20 (thick red line).

disturbances are classified as quiet (0 ≤Ap ≤7), unsettled (8≤Ap ≤15), active (16≤Ap≤29), minor storms 30≤Ap≤49 and strong geomagnetic disturbances/storms Ap≥50 (www.astrosurf.com/luxorion/qsl-perturbation5.htm).

Figure 2 demonstrates the inter-annual distributions of monthly numbers (indicated by dots) of CN for all days (black curves), geomagnetically comparatively quiet periods with Ap<12 (thin red curves) and for Ap<20 (thick red curve). The distributions of CN vary from those of CD: the greatest number of CN is in September. For relatively weak geomagnetic disturbances the peak shifts from September to August. These changes of peaks of CD and CN during different geomagnetic conditions may point at a possible impact of cosmic factors on cloud covering.

In the next section we'll describe theoretically the main variations of the inter-annual distributions of CD and CN, which can be caused both by seasonal changes of atmospheric parameters and cosmic factors.

3. Semi-annual and annual variations of the numbers of cloudless days and nights

As we saw for the considered dataset, the inter-annual distributions of monthly numbers of all cloudless days (Fig.1) and nights (Fig.2) are different. Both of them have a sharp maximum, but for CD it is on August and for CN - in September. Such distributions of CD and CN indicate their annual periodicity. Considering these distributions at various geomagnetic conditions, for magnetically relatively disturbed states (Ap≥8, Ap≥12 and Ap≥20) the sharp maxima still is present in September for CN, but for CD they switch from August to September. This observed fact, as well as maximum number of CD in March, when it is also expected a large number of magnetically disturbed day-nights, indicate possible impact of cosmic factors on cloud formation processes. It also points out the presence of variations with semi-annual periodicity (with maxima on March and September). These distinct annual and semi-annual variabilities allow us to define the inter-annual variations of mean monthly relative number of CD $N(t)$ (a ratio of number of cloudless days/nights in a month to all days in the same month) by the following equation:

$$N(t, Ap) = A_{12} \cdot \mathbf{cos}\left[\frac{2\pi}{T_{12}}(t-1) + \Psi_{12}\right] + \\ + A_6(t) \cdot \mathbf{cos}\left[\frac{2\pi}{T_6}(t-1) + \Psi_6\right] + c \quad , \quad (1)$$

where $t \geq 1$ is time, corresponding to months (t=1, 2,...,12): January, February,... December; A_6 and A_{12} are the amplitudes of oscillations with semi-annual ($T_6 = 6$) and annual ($T_{12} = 12$) periods, respectively; ψ_6 and ψ_{12} are their phases in January (t=1). We note that since there are slightly different number of days in months, the relative number of days $N(t) \leq 1$ better describes the mean yearly distribution of cloudless days. For example, $N(t = 8) = 1$ means that in August all days were cloudless, $N(t = 2) = 0.25$ means that in February one out of four days in average was cloudless.

In Eq. 1 the time-dependent amplitude $A_6(t)$ with semi-annual period and sharp maxima in March (t=3) and September (t=9) is well defined by the following equation:

$$A_6(t) = a_6 \cdot \left[\frac{1}{1 + a_6^{'}(t-3)^2} + \frac{1}{1 + a_6^{'}(t-9)^2}\right], \quad (2)$$

where the values of the parameters a_6 and $a_6^{'}$ are estimated by fitting the observed values to the empirical values of *N*, determined by Eqs (1) and (2). The $A_6(t)$ amplitude has peaks in March and September and, as we will see, fits quite well with observed values of the relative numbers for the CD.

We will define the distribution of mean relative number of cloudless days by Eq. 1 for all and magnetically disturbed conditions with Ap≥8, 12, 20, 30, 40 and 50. In this description yearly variations have maximum in August, so $\psi_{12} = \frac{5\pi}{6}$. For geomagnetically disturbed conditions the peaks in cloudless days occur in March and September, therefore in Eq. 1 the initial phase of semi-annual variations is $\psi_6 = -\frac{2\pi}{3}$. With these values of initial phases, the inter-annual variations of mean relative numbers of cloudless days expressed by Eq. 1 is in good agreement with the observed data (the correlation between observed and theoretical data is high).

In the Table 1 there are presented annual A_{12} and semi-annual $A_6(t = 3; 9)$ amplitudes of oscillations of the relative numbers *N* of cloudless days, as well as the constant c, described by Eq. 1 and 2. The values are calculated for all cloudless days, those with Ap≥8, 12, 15, 20, 30, 40 and 50. R-square is a coefficient of determination between the empirical fit and the observed values. It is quite high for all CD, as well as for Ap≥8, 12 and 20 (R-square=0.93, 0.94, 0.96 and 0.93, respectively). As for Ap≥30, 40 and 50, the numbers of days with these levels of geomagnetic disturbances decrease, but despite of this, R-square is still quite high (R-square=0.84, 0.68, 0.78, respectively), showing big correlation between the empirical fit and observed data.

In the annual distribution of *N*, described by Eq.1 and 2, the amplitude A_{12} denoting the yearly periodicity (with maximum in August) does not change. The semi-annual variations at different Ap

Table 1. Annual A_{12} and semi-annual A_6 amplitudes of oscillations of the relative numbers N of cloudless days, annual distribution constant c (Eqs. 1 and 2). The values are calculated for all cloudless days, those with Ap≥8, 12, 15, 20, 30, 40 and 50. R-square is a coefficient of determination.

Geomagnetic condition	Amplitude of semi-annual variations, A_6 (t=3; 9)	Amplitude of annual variations, A_{12}	Annual distribution constant, c	R-square
All Ap	0.024	0.130	0.321	0.93
Ap≥8	0.052	0.143	0.306	0.94
Ap≥12	0.065	0.141	0.301	0.96
Ap≥15	0.054	0.134	0.311	0.94
Ap≥20	0.091	0.131	0.294	0.93
Ap≥30	0.087	0.138	0.303	0.84
Ap≥40	0.014	0.136	0.322	0.68
Ap≥50	0.003	0.140	0.319	0.78

values are described by the A_6 amplitude, changes of which may be caused by cosmic factors, as well as the shift of maximum number of geomagnetically disturbed CDs to September (starting from Ap≥8).

We note that Eq. 1 can also be used to describe the inter-annual distribution of CN as well, which in case of $A_6 = const$ also demonstrates Ap-dependent variations. In these cases the correlation between the empirical fit and observed data are relatively low (0.6<R-square<0.8). This case is not considered in this paper for brevity.

The empirical description (1) at Ap≥8, 12 and 20 (R-square=0.93, 0.96, 0.94, respectively) is well fitted with the observation data. The increase of the amplitudes of semi-annual variations A_6 is noticeable. This amplitude modulates the annual variation with the amplitude A_{12} and c coefficient does not depend on geomagnetic disturbances.

4. Discussion

To study possible coupling of cosmic factors and cloud covering, we investigated the inter-annual distributions of visually cloudless days (CD) and nights (CN) in Abastumani during 1957-1993 at different geomagnetic conditions. The maximum numbers of CD and CN in August at magnetically quiet conditions, when there is the highest mean daily temperature in most parts of Caucasus region (Elizbarashvili, 2007), are characteristic for yearly variations of meteorological parameters (temperature, humidity). Together with yearly changes of the cloud condensation nuclei density, they also should determine annual variations of cloud cover processes.

The maximum numbers of CD and CN in September and March at magnetically disturbed conditions, which are more observable for CD, indicate semi-annual variations of cloud cover, which could be due to the effect of cosmic factors. This effect is also suggested by the fact that in the inter-annual distribution of CD the maxima in March and September appears at Ap≥8 ($A_6 \approx 0.05$), modulating the annual distribution of all CD and shifting the maximum number from August to September (Fig. 1). These maximum numbers of *N* in March and September increase for Ap≥12 and Ap≥20 ($A_6 \approx 0.09$). The maximum in September is maintained at greater geomagnetic disturbances as well (Ap≥30, 40, 50).

The noticeable annual periodicity with almost steady amplitude ($A_{12} \approx 0.138$), probably caused by yearly variations of meteorological parameters, and the semi-annual periodicity due to the dependence on the planetary Ap index are well described by Eq. 1 and 2. The correlation of the relative numbers of cloudless days $N(t)$ with the observed ones, described by Eq. 1, is high (R-square≥0.93) for all Ap-s (Ap≥8,12,15,20) and reaches its maximum fitting (R-square=0.96) at Ap≥12, when the amplitude corresponding of semi-annual changes are the biggest ($A_6 \approx 0.091$).

The correlation is also good for strong geomagnetic disturbances Ap≥50 (R-square=0.78), though their number is small and hence large fluctuations are expected. In this description it is also important that the term c ($c \approx 0.308$) for the considered dataset is also independent of Ap index values. This fact also indicates that changes of $N(t)$ values, dependent on Ap, are caused mainly by semi-annual variations.

We note here that the distribution of relative numbers *N* of CN described by Eq.1, where only moonless nights are counted, in cases when there is no time dependence on the amplitude of semi-annual variations A_6, also correlate with observed data (0.6<R-square<0.8) and is not demonstrated here for brevity. As the inter-annual distribution of CN shows (Fig. 2), together with the annual and semi- annual variations, other periodicities are also possible. Such seasonal-like periodicity can be manifested differently in the inter-annual distributions of CD and CN.

The different sensitivity of cloud cover during day-time and night-time to cosmic factors could affect the radiation balance at the Earth's surface in the considered region and therefore on climate change. The increase of the number of CD at magnetically disturbed conditions (for example, at equinoxes), enhances the absorption of solar electromagnetic radiation by the Earth surface and could increase the temperature in lower troposphere. If at the same time, the night-time cloudiness increases or does not change, the Earth's surface infrared thermal radiation will be less and the mean annual temperature will increase for given region. During long-term increase of geomagnetic activity and possible decrease in the GCRs flux, the cosmic factors could affect global warming tendencies, which are, however, not considered here.

We note that rapid thermal variations in the lower atmosphere during cloud formation can generate waves, so their vertical propagation and dissipation can appear in the lower and upper atmosphere couplings. Thus, along with the yearly changes of cloud cover, the semi-annual variations observed in the upper atmosphere (Fishkova, 1983) can be coupled with cosmic factors. It is important to consider annual and semi-annual variations in the long-term changes of the upper atmosphere and ionosphere parameters, which also are sensitive to geomagnetic disturbances (Didebulidze et. al., 2011; Todua and Didebulidze, 2013). The coupling between the variations of galactic cosmic rays at cloudless days and nights and inter-annual variations of cloud cover is important. It is important also to study the processes that precede or follow geomagnetic disturbances (including GCRs), i.e. variations of solar UV and X-ray radiation, that affects the atmosphere and ionosphere structure, which is also a subject for further consideration.

5. Conclusions

The different inter-annual distributions of cloudless days (CD) and cloudless nights (CN) in Abastumani Astrophysical Observatory (AAO, 41.75N; 42.82E) have been observed for various levels of geomagnetic activity. The number of CD is the greatest in August when daily mean temperature at the Earth's surface is the highest in this region. For geomagnetically disturbed conditions, when planetary geomagnetic index Ap≥12, the greatest number of CD shifts to September. Such a coupling between the observed inter-annual distribution of CD and the occurrence of geomagnetic disturbances indicates a possible link between cloud covering processes and cosmic factors. Unlike CD, the biggest number of CN occurs in September and moves to August for comparatively quiet geomagnetic conditions (Ap<12).

It is demonstrated that the inter-annual distribution of relative numbers of CD can be expressed by the sum of harmonic functions with the annual (with the maximum in August) and semi-annual (with the maxima in March and September) periods. In this analytical description the amplitudes of the annual variations for the given dataset is almost constant ($A_{12} \approx 0.138$), but for semi-annual variations they depend on Ap index values, which also may suggest the cosmic factor effect on cloud cover. In the semi-annual variations of CD the maxima in March and April are important for Ap≥8 ($A_6 \approx 0.05$) and increase for Ap≥12 ($A_6 \approx 0.063$) and Ap≥20 ($A_6 \approx 0.09$).

The obtained different sensitivity of day- and night-time cloud covering to the influence of cosmic factors can cause variations of the radiative balance at the Earth's surface in this region and consequently affect the climate change.

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References

Calisto, M., Usoskin, I., Rozanov, E., and Peter,T.: 2011, Atmos. Chem. and Phys., Vol. 11, Issue 9, 2011, p.4547, DOI: 10.5194/acp-11-4547-2011

Didebulidze, G. G., Lomidze, L. N., Gudadze, N. B., Pataraya, A. D., and Todua, M.: 2011, Int. J. Remote Sens., 32, 3093.

Dorman, L.: 2009, Cosmic rays in magnetospheres of the Earth and other planets. Astrophysics and Space Science Library, 358. Springer Netherlands. DOI: 10.1007/978-1-4020-9239-8

Elizbarashvili, E.: 2007, Climatic Resources of Georgia, Institute of Hydrometeorology Press, Tbilisi.

Fishkova, L.M.: 1983,. The night airglow of the Earth midlatitude upper atmosphere. Metsniereba Press, Tbilisi (in Russian).

Givishvili, G. V., Leshchenko, L. N., Shmeleva, O. P., and Ivanidze, T. G.: 1995, J. Atm. Terr. Phys., 57, 871.

Gray, L. J., Beer, J., Geller, M., Haigh, J. D., Lockwood, M., et al.: 2008, Ann. Geophys., 26, 2069.

Gudadze, N. B., Didebulidze, G. G., Javakhishvili, G. Sh., Shepherd, M. G., and Vardosanidze, M. V.: 2007, Can. J. Phys., 85(2), 189.

Harrison, R. G. and Carslaw, K. S.: 2003, Rev. Geophys., 41(3), 2. DOI : 10.1029/2002RG000114

Kirkby, J.: 2007, SGEO, Vol. 28, Issue 5-6, p. 333. Kokkalis, P., Mamouri, R. E., Todua, M., Didebulidze, G. G., Papayannis, A., et al.: 2012, Int. J. Remote Sens., 33(16), 4886. DOI: 10.1080/01431161.2011.644593

Kristjánsson, J. E., Stjern, C. W., Stordal, F., Fjaraa, A. M., Myhre, G., and Jónasson, K.: 2008, Atmos. Chem. Phys., 8(24), 7373. DOI:10.5194/acp-8-7373-2008

Kudela, K. and Brenkus, R.: 2004, J. Atmos. Sol. Ter. Phys., 66, 1121. DOI: 10.1016/j.jastp.2004.05.007

Marsh, N.D. and Svensmark, H.: 2000, Low Physical Review Letters, 85, 5004. DOI: 10.1103/PhysRevLett.85.5004

Megrelishvili, T.G.: 1981, Regularities of the variations of the scattered light and emission of the Earth twilight atmosphere. Metsniereba Press, Tbilisi (in Russian).

Mukhtarov, P. and Pancheva, D.: 2011, J. Atmos. Sol. Terr. Phys., 90, 132. DOI: 10.1016/j.jastp.2012.02.013

Rawal,A.,Tripathi, S.N., Michael, M.,Srivastava, A. K., and Harrison, R.G.: 2013, J. Atmos. Sol. Terr. Phys., 102, 243. Russell, C.T. and McPherron, R.L.: 1973, JGR, 78(1), 92.

Sinnhuber, M., Nieder, H., and Wieters, N.: 2012, Surv. Geophys. 33, 1281. DOI 10.1007/s10712-012-9201-3.

Svensmark, H., and Friis-Christensen, E.: 1997, J. Atmos. Sol. Terr. Phys., 59, 1225. DOI: 10.1016/S1364-6826(97)00001-1

Tinsley, B.A., Zhou, L., and Plemmons, A.: 2006, Atmos. Res., 79, 266. DOI: 10.1016/j.atmosres.2005.06.004

Todua, M., Didebulidze, G.G.: 2013, Acta Geophys., 62(2), 381. Usoskin I.: 2013, Living Rev. Sol. Phys., vol. 10, no. 1.

Veretenenko, S.V.: 2003, Adv. Space Res. 31 (4), 1007.