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Solar activity as a controlling factor of sunshine intensity at low latitudes

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Abstract. The processes connecting solar activity phenomena with lower atmosphere disturbances are traced. The influence of the long-term variation of solar activity and galactic cosmic ray (GCR) intensity on the sunshine and therewith on the cloudiness state at low latitudes was investigated. The solar radiation in the low atmosphere is controlled by the state of the cloudiness, and its variations can be one of the most important factors regulating the dynamics of the lower atmosphere. The results obtained allow one to suppose that GCRs influence differently the cloudiness state and therefore the dynamics of the lower atmosphere at high and low latitudes.

Introduction

The problem of the influence of solar activity on the atmosphere is still questioned. It is very important to find out the possible relationship between the long-term variation of the solar activity and the atmospheric phenomena and to determine the possible mechanisms of that influence. According to the present-day ideas, the solar activity affects the state of the lower atmosphere by means of modulation of the cosmic ray flux intensity (of both the solar and the galactic origin), which in turn changes the cloudiness and atmosphere's transmittance and thereby the solar radiation input into the lower atmosphere. The variation of the solar radiation intensity in the lower atmosphere results in noticeable changes of the altitudinal profiles of the temperature and pressure in the troposphere and stratosphere (a direct or primary effect of the cosmic ray flux variation). At the same time, it is quite evident that the change of the altitudinal pressure profile has to produce corresponding changes in the dynamics of the lower atmosphere, which has to result in an additional variation of the temperature and pressure profiles (a secondary effect). These secondary effects are especially important at middle and low latitudes where the direct effect of the cosmic ray variation decreases due to the geomagnetic field cutoff effect. Indeed, cosmic rays, first of all of Galactic origin, have an energy that is sufficient to penetrate down to the lower atmosphere, to ionize air molecules in the lower stratosphere, and therewith to effect significantly the velocity of physical-chemical processes in clouds and haze layers. The troposphere and stratosphere at high and low latitudes respond differently to the change of cosmic ray fluxes. This difference can be explained by the influence of the Earth‘s magnetic field (cutoff effect of the geomagnetic field). Only high-energy particles can penetrate to the lower stratosphere on middle and low latitudes. Thus the direct effect of cosmic rays seems to be implausible at low latitudes, and the mechanism of the influence of galactic cosmic rays and solar activity (SA) on the low atmosphere of middle and low latitudes have to be studied separately.

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Cyclic Variations of Cloudiness in Dependence on Solar Activity

Some investigators have already considered the problem of solar activity influence on cloudiness. Indeed, as was shown by *Veretenenko and Pudovkin* [1997, 1999], the total solar radiation intensity (I) in the course of the 11-year solar cycle at latitudes 60°–80° anticorrelates with the intensity of the galactic cosmic rays (GCR) flux; correspondingly, it is maximum at the epoch of the minimum of the solar activity and minimum at the epoch of the solar activity maximum; the amplitude of these variations amount to the value of about

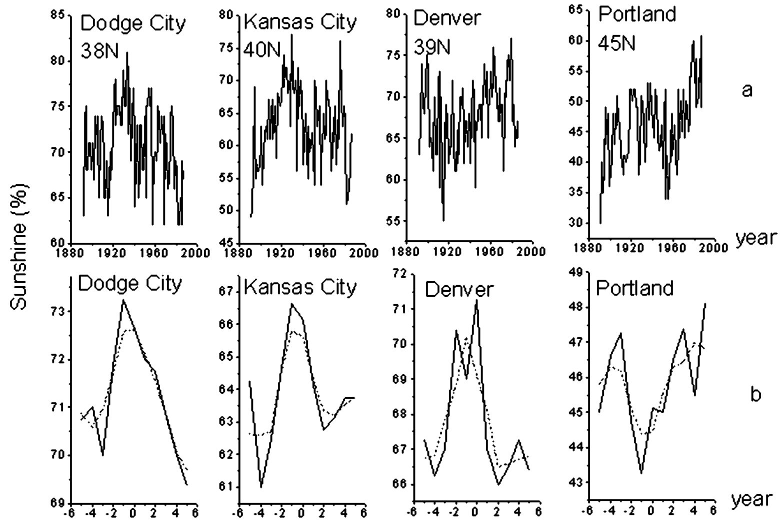

Figure 1. (a) Yearly mean data on sunshine, (b) results of superposed epoch analysis; the key year corresponds to the year of the minimum of the circle of solar activity.

5%. Besides, it was shown that the solar cycle effect disappears at a latitude of about 55°, and at the latitude of about 50°, the sign of the correlation between GCR and I values inverts, so the atmosphere's transmittance is maximum at the solar activity minimum. This result seems to contradict the observations by *Svensmark and Friis-Christensen* [1997]; according to their data, the increase of the GCR intensity is accompanied by the increase of the cloudiness within the latitudinal belt $-40^\circ < \varphi < 40^\circ$. Thus the sign of correlation of the solar activity level with the cloudiness at low latitudes, according to *Svensmark and Friis-Christensen* [1997], proves to be the same as that at high latitudes. One possible explanation of this contradiction may be associated with local peculiarities of atmospheric processes. Indeed, the relationship between the solar radiation and the GCR flux intensity was obtained by Veretenenko and Pudovkin on the basis of the data obtained at Russian observatories only, while the *Svensmark and Friis-Christensen* [1997] results are based on the global-scale data obtained onboard geostationary satellites. Of course, the territory of Russia is relatively large; however, some local effects still may take place. In this connection, in this paper the cyclic variation of the atmosphere transmittance is investigated with the use of independent data from observatories in the U.S. territory.

Analysis of Experimental Data

As the solar radiation in the lower atmosphere is controlled by the state of the cloudiness, one can judge on the state of the latter on the account of the variations of the former. Correspondingly, in this analysis, we considered yearly data of sunshine (percentage of maximum possible sunshine) at the surface of the Earth. The term "sunshine" is used for the solar radiation intensity at the ground measured by a spectral device (a kind of a glass sphere). The sunshine was measured at several stations in the United States distributed at latitudes from 30°N to 50°N for the years 1891–1987. Sunspot numbers were used for the same period of the time as a measure of solar activity. The intensity of GCR was measured by a neutron monitor at Climax (39°N, 106°W), Colorado State. Availability of data for a rather long period of time allows us to study the variation of cloudiness at low latitudes within the cycle of solar activity.

Figure 1 (top) presents variations of the annual-mean values of the relative sunshine intensity (S) (in percent of the maximum possible one) at several North American observatories: Dodge City ($\varphi = 38^\circ$), Denver ($\varphi = 39^\circ$), Kansas city ($\varphi = 40^\circ$), and Portland ($\varphi = 45^\circ$) for the years 1891–1987. The sunshine depends directly on the presence or absence of clouds in the sky and hence may characterize the state of cloudiness. As is seen in Figure 2, the S values exhibit distinctly the short period variations in the course of the solar activity cycle, and the amplitude of those variations amounts to the value of 5–10%. To reveal the 11-year variations of S, we have constructed, by the superposed epoch methods, cyclic variation of S (bottom panels in Figures 1 and 2); as the key year, the years of the minima of the solar activity were chosen. Data presented in Figure 1 convincingly shows

Table 1. Correlation Coefficient Between S, GCR Intensity, and Sunspot Numbers

	r_1		r_2	
Variable Observed	GCR	W	GCR	W
Dodge City	0.61	−0.54	0.87	−0.77
Kansas City	0.77	−0.71	0.93	−0.83
Portland	−0.34	−0.47	−0.76	0.81

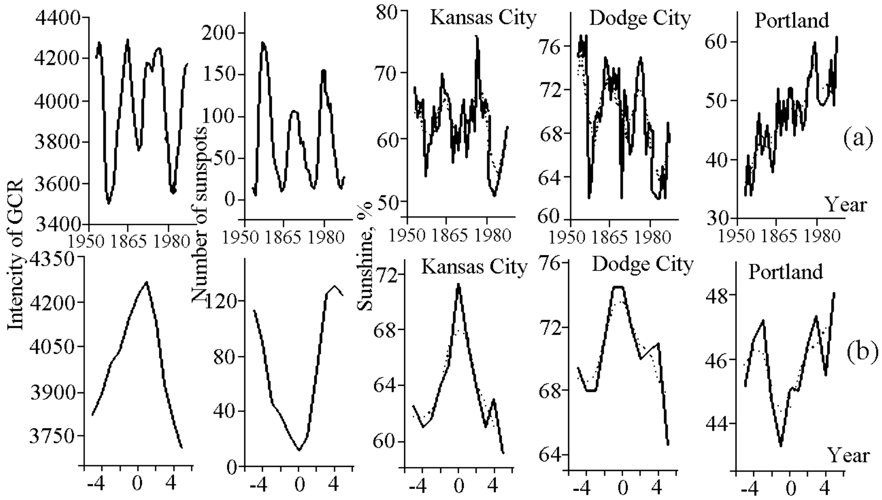

Figure 2. (a) Yearly data of intensity of GCR, sunspot number and sunshine; (b) results of superposed epoch analysis, relatively minimum of the circle of solar activity.

that at three of the four low-latitudinal observatories under consideration, the sunshine is maximum at the epoch of the solar activity minimum. This allows us to suppose that the cloudiness at those stations is minimum during the years of solar activity maximum, which quite agrees with the conclusions by *Veretenenko and Pudovkin* [1999] concerning the relationship between solar activity and cloudiness variations at low latitudes. Quite different from the variations of Dodge City, Denver, and Kansas City are variations of the sunshine intensity at the Portland observatory ($\varphi = 45°$). As is seen in the Figure 2, the sunshine at that station is minimum at the epoch of the solar minimum; thus on the North American continent, at $\varphi = 45°$, variations of cloudiness proceed in phase with those in Russia at $\varphi > 55°$. In this connection, it is worth to note that both geographic latitudes $\varphi = 45°$ at the longitude of Portland and $\varphi = 55°$ at the longitude of St. Petersburg correspond to the latitude $\approx 50°$. The change of sign of the correlation between the cloudiness and the solar activity in both regions under consideration take place at approximately the same latitude, which once more confirms the results of Veretenenko and Pudovkin.

As was said above, cycling variations of cloudiness and hence sunshine intensity are supposed to be caused by the corresponding variations of the intensity of the cosmic rays flux. Indeed, analysis of the cosmic ray intensity variations shows that contrary to the *Svensmark and Friis-Christensen* [1997] results, the maxima of S (correspondingly, minima of cloudiness) at the low-latitudinal observatories Kansas City and Dodge City are observed during the years of the maxima of the GCR flux intensity, which agrees with the results of *Pudovkin and Veretenenko* [1995] and *Veretenenko and Pudovkin* [1997].

To estimate quantitatively the observed relationship between the variations of the sunshine duration, GCR flux intensity and solar activity presents, in Table 1, coefficients of correlation between the corresponding values (r_1, for annual-mean values; r_2, for mean values averaged by superposed epoch method).

The data listed in Table 1 show that the increase of the intensity of GCR is really accompanied by an increase of sunshine intensity (correspondingly by a decrease of cloud cover) at low latitudes ($\varphi < 45°$).

Conclusion

Thus the data presented above show that at continental low-latitudinal observatories, the sunshine intensity increases (correspondingly the cloud cover decreases) with the increase of the cosmic ray flux intensity. At higher latitude (Portland, $\varphi = 45°$), the sign of correlation between the sunshine and the cosmic factors changes, and as might be expected, the increase of the cosmic rays flux causes an increase of the cloudiness. These observations are in a good agreement with the results of *Pudovkin and Veretenenko* [1995] and *Veretenenko and Pudovkin* [1997, 1998, 1999]. At the same time, these results raise at least two questions:

1. What is the physical mechanism responsible for the increase of the cloudiness at low latitudes during years of high solar activity;

2. What may be the cause of the obvious disagreement of the *Veretenenko and Pudovkin* [1997] and *Svensmark and Friis-Christensen* [1997] data concerning the cyclic variations of the cloudiness at the lower latitudes. This problem needs a special and more extensive investigation.

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