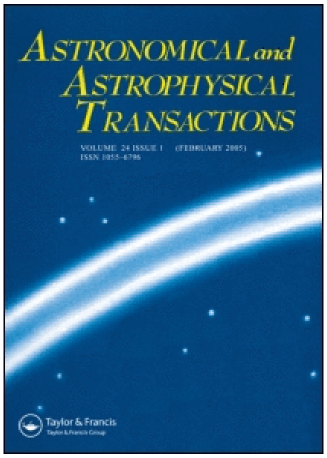

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LONG-TERM VARIATIONS OF SOLAR ACTIVITY AFFECT THE EARTH'S CLIMATIC CONDITIONS MODULATING THE CHARACTERISTICS OF THE MIDDLE ATMOSPHERE

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The balance of rates of solar energy input and output determines the thermal status of the surface atmosphere. The solar activity increase leads to a decrease of the lower atmosphere energy sink and consequently to warming. Also, a solar activity decrease signifies cooling. It is shown that the long-term decrease of the solar activity (like during the Maunder Minimum) can provoke an atmospheric temperature lowering of about 1K over 100 years.

KEY WORDS Solar activity, global change

1 INTRODUCTION

The problem of the influence of solar activity (SA) on climate is an important item in the investigation of the solar-terrestrial relationship. This problem has been under discussion for a long time. The main purpose is to find mechanisms through which the variable components of the solar radiation can act on the Earth's troposphere. A large number of hypotheses concerning the influence of SA variations with different scales of periodicity on climate were discussed at Symposiums GA.6.01 and GA.6.02 during the IAGA Assembly in Birmingham in 1999 (Schröder, 2000)

For example the solar wind, enhanced by the SA, modulates the flux of the galactic cosmic rays. This varies the ionization rate at heights of about 10 km (Veretenko and Pudovkin, 1997, 1998) and changes the water vapor condensation finally producing variations of the optical transparency of the atmosphere.

At latitudes lower than 55°N a positive correlation between the irradiance and the galactic cosmic ray flux is observed (Veretenko and Pudovkin, 1999). In this case the input of solar energy into the lower atmosphere *increases* during the increase of the SA due to the increase of the atmospheric transparency caused by the decrease of the cosmic ray flux.

As is well known, a positive correlation exists between the level of the SA and various climatic parameters (e.g. the global temperature). For example, see (Eddy, 1976; Herman and Goldberg, 1978). In this paper a new possible mechanism is suggested to explain long-term climatic variations.

2 FORMULATION OF THE PROBLEM

It is necessary to emphasize that the all above-mentioned research was practically restricted to the finding out possible variations of the solar energy *input*. Nevertheless the cause of the energy balance variations should be sought not only in the energy *input* but in its sink as well. As it is well known, the main channel of this process is the infrared heat radiation of the planet, controlled by the vapor contents of water, carbon dioxide, methane and the other small components.

The available research shows that a long term (by order of several years) change of the energy balance by +1% corresponds to a mean temperature change near the surface of the Earth by approximately +1.5 K (e.g. Budyko *et al.*, 1986). Thus, it is not surprising from the outlined point of view that the long solar activity decrease (Lean *et al.*, 1992) during the nearly 70-year Maunder Minimum in 1645–1715 was accompanied, as it is well known, by a noticeable cooling of about − 1 K (Eddy, 1976; Herman and Goldberg, 1978).

However, regular meteorological processes generate (besides thermal electromagnetic radiation) a wide spectrum of wave oscillations in the lower atmosphere. These are acoustic, internal gravity waves (IGW), tidal and planetary waves. All these waves transport their energy and impulse to the upper atmosphere at heights of about 100 km (Chunchuzov, 1978; Pogoreltsev and Sukhanova 1993).

Hines (1974) and Hines and Halevy (1977) suggested a hypothesis about the possible gravity wave flow modulation by the change of conditions of the IGW propagation in the middle atmosphere due to additional wind systems caused by the solar activity increase. The corresponding back influence on the lower atmosphere could have some weather effect. But Herman and Goldberg (1978) emphasized that this concept did not receive any further development.

The most realistic assumption is that the change of conditions of the wave reflection and transmission at heights of about 50–100 km may have two consequences. One is an atmospheric wave energy sink (after wave dissipation followed by molecular O_3 and CO_2 infrared emission). Another is wave reflection back to the troposphere which diminishes the losses of energy. Garcia *et al.* (1984) showed that an additional wind flow should appear at heights of 45–80 km in the years of the SA maximum. Actually, Namboothiri *et al.* (1994), Vergasova and Kazimirovsky (1994), and Petrukhin (1995) determined that during the years of the SA maximum the predominant wind velocity at heights 55–90-km increases nearly twofold.

According to Namboothiri *et al.* (1994) the winter mean zonal wind velocity U at heights 55–90 km closely correlates ($r \sim 0.83$–0.90) with the SA level. Finally the dissipation of the main bulk of energy of various atmospheric waves occurs at heights of about 90–100 km and practically in the region of the lower and middle latitudes. The total energy production is found in the form of turbulence in the atmospheric layer with the turbopause as its upper border.

3 DISCUSSION

Estimation of the energy of this processes shows that the difference between the diurnal solar energy input $E_{\odot}(86400\bar{E})$ at SA maximum and minimum relative to the global thermal energy of the atmosphere E_T for the same time and atmospheric layer for the height interval $z \approx 45$–90 km and epochs of the 1989 maximum and 1995 minimum is $\Delta \approx 0.04$-0.06.

It is interesting to note that in the equatorial latitudes from −46 to +46° the height of the turbopause and its turbulent intensity vary with a phase inverse to the phase of the solar activity variation (Korsunova *et al.*, 1985). This is important because the waves dissipate at heights of about 90–100 km. The parameters of this E_S layer characterize the condition of the turbulence (Gallet, 1955; Gorbunova and Shved 1984; Whitehead, 1970).

There is one important peculiarity of the processes around the circumpolar latitudes. Additional cyclone-like systems of circulation originate in the troposphere around the pole due to geomagnetic storms produced by SA. They embrace the atmospheric region from the pole to latitudes 40–50° N over tens of days (Smirnov and Kononovich, 1996). As a result planetary waves originate with the wave numbers 3–4. Chernous'ko (1980), Dolzhanskiy (1981), and Dovzhenko *et al.* (1981) theoretically and experimentally investigated the origin of such vortex structures in the troposphere as a consequence of the wind velocity shift.

According to the modern data, the turbulent kinetic energy W near the height 100 km is about 700–2000 $\mathrm{m}^2\,\mathrm{s}^{-2}$ per unit mass (Chunchuzov, 1978). This means that a mean energy of $W = 8 \times 10^3$ erg cm^{-2} is available in a layer of 20 km thickness. The change of ΔW from the minimum to the maximum also corresponds to this value. Besides, it is necessary to take into account the energy of the wind motion induced by the wave dissipation. Obviously it is quite possible for the first approximation to double the above-obtained estimation of the energy.

Thus, it is possible to accept that the observed change from the minimum to maximum of the turbulent kinetic energy ΔW occurs on account of a change of the wave propagation conditions also organized under the influence of the SA. The relaxation time τ of the stationary state in a turbulent layer at 100 km height is about 3 hours (Chunchuzov, 1978). Thence the global temperature change ΔT in the troposphere may be estimated by the equation

$$5/2Nk\Delta T = -2\Delta W \Delta t/\tau,$$

where N is the molecule particle density (cm^{-2}) in the lower atmosphere, and k is Boltzmann's constant. Thereby, ΔT is about -1 K for the time interval $\Delta t = 100$ years. This satisfactorily corresponds with the data for the Maunder Minimum (Eddy, 1976). Also it is in agreement with the Earth surface temperature measurements made from 1960–1990 in equatorial Africa (Zaire). They indicate a definite positive correlation with the solar activity during the 11-year cycle with an amplitude of 0.1–0.2° C (Sanga-Ngoie and Fukuyama, 1996). The existence of correlation between SA and temperature of the lower atmosphere also follows from statistical analysis (Smirnov and Kononovich, 1995). Nevertheless, further research is very desirable.

4 CONCLUSION

The above-presented data obviously lead us to the conclusion that there are a lot of different mechanisms in the middle atmosphere affecting the solar activity's influence on the energy input and sink from the lower atmosphere. Therefore, the middle atmosphere is an effective regulator of global climate change in the atmosphere.

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