Effects of an assumed cosmic ray-modulated low global cloud cover on the Earth's temperature

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RESUMEN

Hemos usado el Modelo Termodinámico del Clima para estimar el efecto de variaciones en la cubierta de nubes bajas sobre la temperatura superficial de la Tierra en el Hemisferio Norte durante el período 1984 – 1994. Suponemos que las variaciones en la cubierta de nubes bajas son proporcionales a las variaciones del flujo de rayos cósmicos medido durante el mismo período. Los resultados indican que el efecto en la temperatura es más significativo en los continentes, donde para julio de 1991, hemos encontrado anomalías del orden de 0.7 °C sobre el sureste de Asia y 0.5 °C al noreste de México. Para un incremento de 0.75% en la cubierta de nubes bajas, la temperatura de la superficie calculada por el modelo en el Hemisferio Norte presenta un decrecimiento del orden de 0.11 °C; en cambio, para un decrecimiento de 0.90% en la cubierta de nubes bajas, el modelo da un incremento en la temperatura del orden de 0.15 °C, estos dos casos corresponden a un factor de sensibilidad climática de 0.14 °C/Wm^{-2}, lo cual es casi la mitad del factor de sensibilidad climática para el caso de forzamiento por duplicación de CO_2 atmosférico. Estos decrecimientos o incrementos en la temperatura de la superficie por incrementos o decrecimientos en nubes bajas son diez veces más grandes que la variabilidad total de las series de tiempo del modelo sin forzamiento.

ABSTRACT

We have used the Thermodynamic Model of the Climate to estimate the effect of variations in the low cloud cover on the surface temperature of the Earth in the Northern Hemisphere during the period 1984-1994. We

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assume that the variations in the low cloud cover are proportional to the variation of the cosmic ray flux measured during the same period. The results indicate that the effect in the surface temperature is more significant in the continents, where for July of 1991, we have found anomalies of the order of 0.7 °C for the southeastern of Asia and 0.5 °C for the northeast of México. For an increase of 0.75% in the low cloud cover, the surface temperature computed by the model in the North Hemisphere presents a decrease of ~0.11 °C; however, for a decrease of 0.90% in the low cloud cover, the model gives an increase in the surface temperature of ~0.15 °C, these two cases correspond to a climate sensitivity factor of 0.14 °C/Wm^{-2}, which is almost half of the climate sensitivity factor for the case of forcing by duplication of atmospheric CO_2. These decreases or increases in surface temperature by increases or decreases in low clouds cover are ten times greater than the overall variability of the non-forced model time series.

Keywords: Low cloud cover, cosmic rays, solar activity, surface temperature.

1. Introduction

Some investigations suggest that cosmic ray flux variations could be considered as one of the main agents that induce important changes in the high and low atmosphere. Svensmark and Friis-Christensen (1997) noticed a possible connection between the global cloud cover and the cosmic ray flux, with a correlation coefficient higher than 0.9. They carried out their study using information compiled by the International Satellite Cloud Climatology Project C2 (ISCCP C2). The information covers the period between 1984 and 1990, also it comprises only the oceans and excludes the latitudinal band of ± 22.5°, considering that in this area the magnetic field of Earth inhibits the penetration of cosmic rays, and therefore the effect on the cloud cover is minimized.

Gierens and Ponater (1999) indicated that the findings of Svensmark and Christensen were only partially correct. They pointed out that cloud cover variations are significantly correlated with cosmic ray flux variation only on mid-latitudes in a narrow geomagnetic zone that corresponds to about 10% of the Earth's surface, and therefore it is not acceptable to extrapolate local results to planetary scales.

Later, Bagó and Butler (2000) analyzed cloud cover data from ISCCP D2, corresponding to 1983-1994. They examined the correlation between cloud cover and cosmic ray flux in different latitude zones and altitudes. They found that the low-level clouds for all latitudes excluding the poles are well correlated with the cosmic ray flux over the complete period, with correlation coefficients of 0.87 for the whole Earth, 0.72 at the tropics, 0.88 at mid-latitudes and 0.92 at mid-latitude oceans. This study confirmed the previous results of Svensmark and Christensen (1997).

Marsh and Svensmark (2000) also used the ISCCP D2 data finding that low latitude clouds and cosmic rays are well correlated, with a correlation coefficient greater than 0.6 over the 15% of the Earth's surface.

If indeed the cosmic rays can influence cloud formation, we expect that this flux should have an effect in the global radiation balance of the Earth-atmosphere system and therefore in the terrestrial surface temperature field.

Ramírez *et al.* (2004), using a balance energy model, called Climate Thermodynamic Model (CTM), calculated the response of the North Hemisphere (NH) surface temperature due to cosmic

ray modulated forcing on the global oceanic cloud cover during 1984-1990. They found that in the NH the surface temperature present a decrease of ~0.01 °C in average. This decrease is almost the same for continents and oceans. Nevertheless this value has the same order than the noise level of the non-forced model and therefore the modulation of the oceanic cloud cover does not affect significantly the surface temperature of the NH.

The purpose of the present work is to determine the changes in surface temperature induced exclusively by changes in the low cloud cover for the period 1984–1994, when a reasonable correlation between low cloud cover and cosmic rays has been found for the whole Earth.

2. The model

2.1 The Climate Thermodynamic Model

The model used here is the CTM (Adem, 1962), which assumes that the energy that maintains the atmospheric circulation is the solar radiation, and therefore the fundamental problem is to explain quantitatively how the transformation of radiant energy in mechanical energy is carried out.

The model consists of an atmospheric layer of about 10 km of height, which includes a uniform and single horizontal cloud layer (the plane-parallel cloud assumption), an oceanic layer of 100 to 50 m in depth and a continental layer of negligible depth. It also includes a layer of ice and snow over the continents and the ocean. The basic equations are those of hydrostatic balance, perfect gas, continuity and conservation of thermal energy applied to the atmosphere-ocean-continent system. A monthly time averaging of the variables is used. The details of the equations can be found in Adem *et al.* (2000).

In the model used until now, the horizontal transport of thermal energy by ocean currents and turbulent oceanic eddies is neglected and the thermodynamic energy equations are integrated using an implicit scheme. In this way the problem is reduced to solve an elliptical differential equation for the temperature in the mean level of the atmosphere. Then, the temperature of the surface can be obtained through a linear algebraic equation based on the temperature in the mean tropospheric level previously calculated. The horizontal and vertical heat transports, as well as the latent heat released at the cloud level and the net radiation can be calculated using the computed surface temperature and the computed temperature in the mean tropospheric level and its spatial derivatives.

The spatial integration of the model equations is carried out for the NH with the use of a grid with 1917 points, which uses a polar stereographic projection with a constant grid distance of 408.5km (Adem *et al.*, 2000). The resultant elliptical differential equation is solved as a finite difference equation by the Liebmann relaxation method with an error of 0.001 °C (Thompson, 1961).

The CTM is suitable for obtaining hemispheric averages (20-90° in latitude) of different meteorological variables and produces monthly, annual and seasonal predictions. Finally, we choose the CTM because on one hand it is a coupled model of the continent-atmosphere-ocean system that takes into account the feedback mechanisms inside this system, and on the other hand, it is relatively easy to manipulate.

2.2 Low cloud cover data

The low cloud data can be found at http://isccp.giss.nasa.gov/products/onlineData.html. We introduce this data in the CTM. The CTM has a single horizontal cloud layer with the lower boundary at 2.5km and the upper boundary at 4.0km. In a more realistic situation clouds appear in three different layers, therefore in order to compensate our approximation, the radiative parameters in the single layer are the weighted average values of the radiative parameters in each layer (Adem, 1964). In the present model, typically when the cloud layer fraction is about 0.5, clouds reflect ~25 % of the solar radiation, while when the cloud fraction is 1, clouds reflect 50 % back to space. The cloud layer absorbs short wave radiation from the Sun proportionally to the fraction of the cloud cover, for example when the cloud fraction is 0.5, the clouds absorb only 2 % of solar radiation, if the cloud fraction is 1, the clouds absorb 4 %. In the CTM it is also assumed that the cloud cover absorbs long–wave terrestrial radiation as a black body, thus the emitted radiation depends only on the temperature. More details about the radiative treatment of the clouds are in Adem (1962).

In the CTM, the cloud cover is introduced assuming that it is formed by a climatic value (average normal value) plus a fraction, which depends on the heat ceded to the troposphere by the condensation of water vapour at the cloud level. In this case the anomalies in the cloud cover are the changes in low cloud cover induced by change in the intensity of cosmic rays.

3. Results

3.1 The forced model

We ran the model introducing as only forcing the changes in the intensity of cosmic rays. We obtain the monthly surface temperature anomalies in the continents, the oceans and the NH. These results are shown in graphs; for all the data period of July 1984 to October 1994, we have left outside the seasonal variability constructing 12-year running means. In figures 1 to 3 the heavy lines represent the values, in percentage, of the changes in the low cloud cover, the thin lines corresponds to the surface temperature anomalies calculated by the model and the dashed lines corresponds to the observed surface temperature anomalies obtained from NOAA/NCEP reanalysis data available at http://www.cdc.noaa.gov.

The results for the NH, the continents and the oceans shown in figures 1, 2 and 3, respectively, indicate clearly that an increase in the low cloud cover produces in the model a decrease in the surface temperature, and on the contrary a decrease in the low cloud cover produces an increase in the surface temperature. The comparison between figures 2 and 3, shows that the extreme values of the observed and calculated surface temperature anomalies are greater on the continents that on the oceans, which must to that the oceanic layer of 50 to 100 m in depth stores considerably more thermal energy than the continental layer of negligible depth.

Extreme values in the low cloud cover are observed in April of 1987 and April of 1992. In April 1987 it is observed an increase in the low cloud cover of 0.70% for the NH (Fig. 1), while the model shows a cooling of −0.10 °C; in April 1992 a reduction in the low cloud cover of 0.95%, produces a heating of the order of 0.15 °C. For April 1987 and April 1992, the corresponding anomalies in

continents (Fig. 2) are −0.17 °C and 0.25 °C, respectively, whereas in the oceans the corresponding anomalies (Fig. 3) are −0.07 °C and 0.10 °C, respectively.
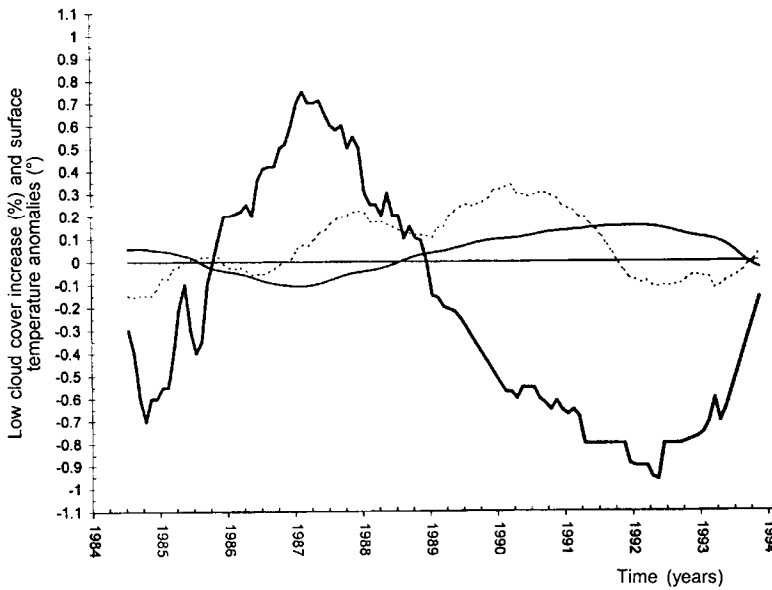

Fig. 1. North Hemisphere surface temperature anomalies using 12-year running means. The heavy line represents the values, in percentage, of the changes in the low cloud cover, the thin line corresponds to the surface temperature anomalies calculated by the model and the dashed line corresponds to the observed surface temperature anomalies.
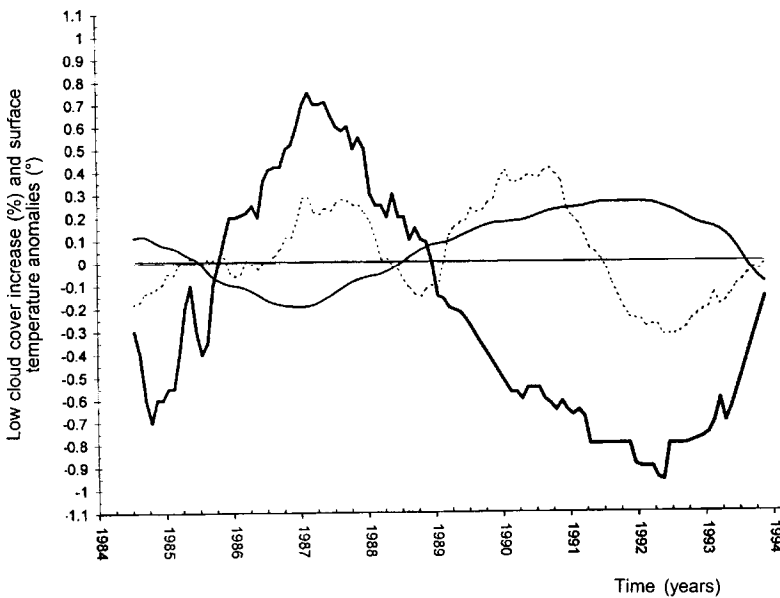

Fig. 2. Continental surface temperature anomalies using 12-year running means. Lines as in Figure 1.
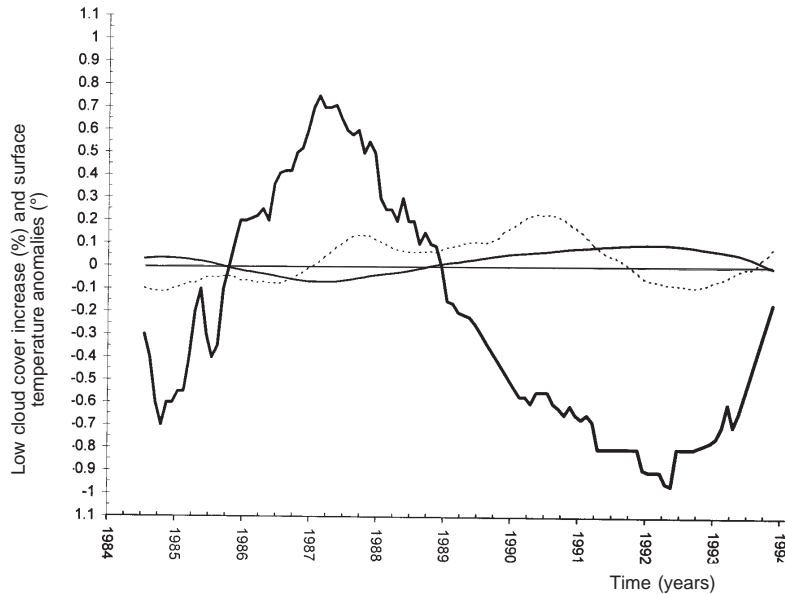
Figure 3. Oceanic surface temperature anomalies using 12-year running means. Lines as in Figure 1.

The modelled temperature is not similar to the observed temperature in any of the analyzed cases, due to the fact that the observed temperature has various forcings which are not included in the computed temperature that has as only forcing the low clouds.

Working with monthly values for the year 1987 to study seasonality, figures 4 and 5 show that on the continental surface the cooling due to an increase in low cloud cover is smaller in January (Fig. 4) than in July (Fig. 5), nevertheless the oceans do not show this seasonal thermal contrasts. The figures also indicate a noticeable thermal contrast between the oceans and continents, the cooling is stronger on the surface of the continents that on the surface of the oceans, mainly in the month of July. In January on the continental polar regions, above of 45° N, it is observed that the cooling of the surface, produced by the reflection of the solar radiation due to the increase of the low cloud cover, is damped and in great regions as Alaska, the northwest of Canada, north of Asia and Europe the surface temperature anomalies change of sign as result of a long wave radiation balance between the surface of ice and snow and the low cloud cover, which is assumed that absorbs and emits long wave radiation as black body.

3.2 *Climate model sensitivity factor*

Most studies using external forcing are concerned with the incoming solar radiation and with the atmospheric composition. Sensitivity studies compute the increase of the climatic variables (temperature, humidity, etc.) due to an assumed increase or decrease of for instance 1% in the solar constant (in short, $\pm$ 1% SC) or an assumed atmospheric CO_2 doubling ($2 \times CO_2$). The solar constant forcing are often applied to calibrate and compare models. The CO_2 doubling is the common reference level to estimate the anthropogenic global warming.
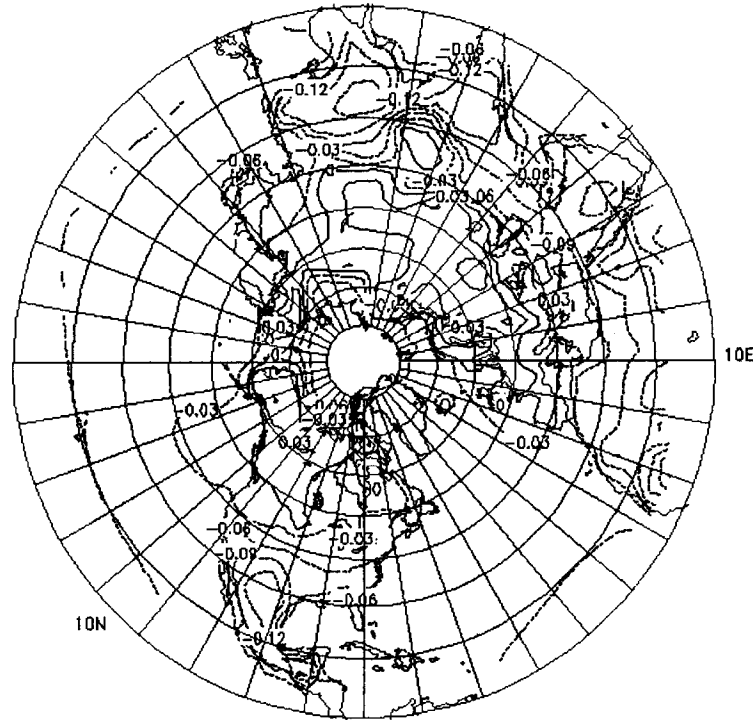
Fig. 4. Computed monthly surface temperature anomalies (°C) for January 1987
when an increase of low cloud cover is incorporated as forcing.

Being the net radiation the difference between the incoming solar or short wave radiation and the outgoing terrestrial or long wave radiation, we define ΔQ as the increase of the net radiation at the top of the atmosphere, usually the tropopause. It is computed as the difference between the top net radiation with and without forcing before the climate system reacts (namely, before the surface temperature change). Thus, ΔQ is the basic measure of the external forcing intensity. The consecutive climate change is measured with the change in surface temperature (ΔT). The reason of these two quantities, $\rho = \Delta T/\Delta Q$, is a "response factor" of the climatic system to the initial radiative perturbation (Garduño and Adem, 1994).

Table I shows the results obtained with the CTM with ± 1% SC, 2 × CO_2, and an increase of 0.75% and a decrement of −0.90 % in the low cloud cover (+ 0.75 % $\Delta\varepsilon$ and −0.90 % $\Delta\varepsilon$).

Other more complex models, for example the general circulation models, have response factors of the order of 1°C/Wm^{-2} for ± 1% SC and 2 × CO_2 (Rind et. al., 1999). In comparison the CTM has a sensitivity factor which is approximately 3 times lower.

Table I. Initial radiative perturbation (ΔQ) by increase in the solar constant ($\pm 1\%$ SC), atmospheric CO_2 ($2\times CO_2$) and low cloud cover ($+0.75\%$ $\Delta\varepsilon$ and -0.90% $\Delta\varepsilon$), as well as surface temperature increase ΔT and climate response factor (ρ) to the initial radiative perturbation.

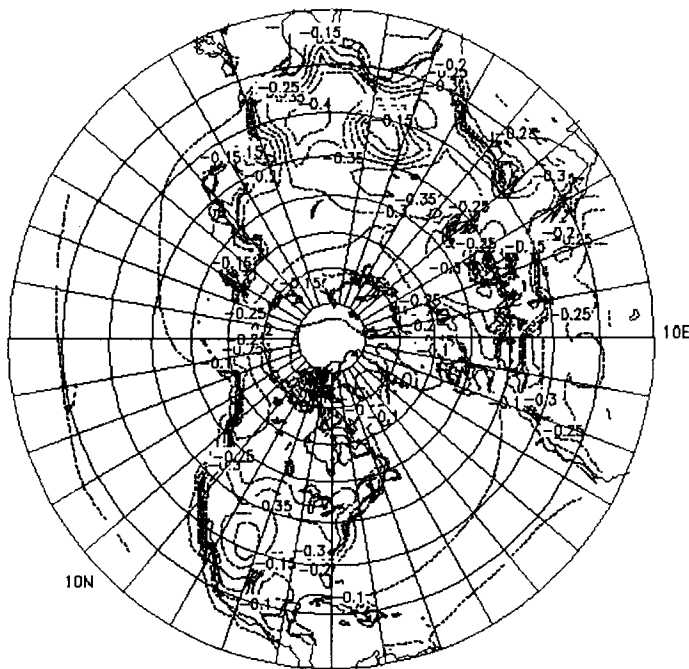| Forcing	ΔQ (Wm^{-2})	ΔT(°C)	ρ(°C/Wm^{-2})
+1% SC	2.08	0.73	0.35
−1% SC	−2.08	−0.73	0.35
$2 \times CO_2$	2.79	0.8	0.29
+0.75% $\Delta\varepsilon$	−0.76	−0.11	0.14
−0.90% $\Delta\varepsilon$	1.05	0.15	0.14

Figure 5. Computed monthly surface temperature anomalies (°C) for July 1987 when an increase of low cloud cover is incorporated as forcing.

4. Discussion

The cosmic rays are the main source of atmospheric ionization between 0 and 35 km with a maximum at ~ 15 km (Oda *et al.*, 1983; Grieder, 2001). They are registered by detectors located on the surface. The lowest energy that can be detected depends on the geomagnetic latitude, 0.01 GeV in stations located in the geomagnetic poles, versus up to 15 GeV in the stations near to the geomagnetic equator. Then, we should expect that high altitude and latitude clouds would be the most affected by cosmic rays. However, the previously mentioned results indicate that low altitude clouds at low latitudes are more influenced than higher altitude and latitude clouds. No satisfactory explanation is at hand, and some speculations point to the different physical state of the cloud

droplets over the polar (ice clouds) and tropical regions (liquid clouds) and the effect of cosmic rays over them. Moreover, Yu (2002) has proposed that an increase in cosmic ray fluxes generally leads to an increase in particle production in the lower troposphere but a decrease in particle production in the upper troposphere.

Laut (2003) has raised serious criticism concerning the results of Svensmark and Friis-Christensen (1997) and Marsh and Svensmark (2000). He points out that updated data of low clouds and cosmic rays for the period 1984 – 1998 show a questionable agreement after 1984, but after 1994, there is not agreement at all. Marsh and Svensmark (2003) claim that the disagreement could be an artifact related to problems experienced with the ISCCP inter-calibration between September 1994 and January 1995, however, this claim remains to be further investigated.

Even more, Laut (2003) noticed that the plots of Marsh and Svensmark (2000) show that the cloud cover is delayed more than half a year relative to the cosmic rays, while the formation of clouds favoured by galactic cosmic rays should take few days. Another problems come from the interpretation of low cloud cover data based exclusively on infrared measurements from satellites: most low clouds below higher clouds can not be detected.

Cosmic rays are not the only candidates for a possible influence from solar activity upon cloud cover. Kristjánsson et al. (2002) used independent estimates of low cloud cover from the ISCCP along 1984-1999 together with cosmic ray fluxes and total solar irradiance (TSI) measurements. They found that TSI correlates better and more consistently with low cloud cover than cosmic rays.

In our opinion the basic question of whether or not cosmic rays are modulating the low cloud cover in time scales of the solar cycle is strongly debatable and deserves further investigations. In the mean time however, we find temperature responses of few tenths of °C to the supposed cosmic ray modulation of low cloud cover. As we work with a low sensitivity model, stronger temperature anomalies should be expected if higher sensitive models are used, in this sense the present model gives a lower estimate of the forcing. These temperature responses are higher than the responses found by Ramírez et al. (2004) using total cloud cover.

We notice that our model is producing temperature responses similar to other forcing: climate models using TSI forcing increases of ~ 0.1 % estimate a temperature increase of several tenths of °C over the past 100 years (e.g. Cubasch and Voss, 2000). Models including the response of the stratospheric ozone to UV radiation also show temperature increase of several tenths of °C over the 20th century (e.g. Shindell et al., 1999). Furthermore, from Table I, a decrement of -0.90 % in the low cloud cover corresponds to a change in the NH radiation budget of about 1.05 Wm^{-2}, this change is significant when compared with the radiative forcing from anthropogenic CO_2 emissions during the 20th century of 2.4 W/m^{-2} (Houghton et al., 1996).

5. Conclusions

We have attempted to quantify the changes upon surface temperature due to changes in low cloud cover, which could be caused by cosmic rays, having found the following:

1) On the surface of continents the cooling due to an increase in the low cloud cover is stronger during the summer season than in winter season, while the oceans do not show this seasonal thermal contrasts. The results also indicate a noticeable thermal contrast between the oceans and continents, as the cooling is stronger on the continental surface than on the ocean surface, mainly in summer, this is due to the ocean's greater heat capacity.

2) In January, on the polar regions it is observed that the cooling of the surface, produced by the reflection of solar radiation due to the increase in the low cloud cover, is damped as result of a long wave radiation balance between the surface of ice and snow and the low cloud cover.

3) As the model used here has a low response factor to initial radiative perturbation (0.14 °C/Wm^{-2}), the surface temperature anomalies found should be considered as lower estimates. Stronger anomalies should be found with higher sensitivity models such as the general circulation models, which have sensitivity factor of order of 1 °C/Wm^2.

4) If indeed cosmic rays are modulating the low cloud cover for time scales of the solar cycle, we found that they have an appreciable effect on the surface temperature in some regions of the continental part of the North Hemisphere, producing temperature anomalies of the order of tenths of °C, competing with the forcing produced by anthropogenic CO_2 emission.

Acknowledgements

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