



Modelling the Northern Hemisphere temperature for solar cycles 24 and 25

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ABSTRACT

It is uncertain whether the solar cycle 24 will have a high or a low sunspot maximum number. In its last revision the Solar Cycle 24 Prediction Panel indicates that the low prediction is the most likely. Also, solar cycle 25 is considered to present an equal or lower activity than cycle 24. In order to assess the possible effect of the solar activity on temperature, in the present work we attempt to model the tendency of the Northern Hemisphere temperature for the years 2009–2029, corresponding to solar cycles 24 and 25, using a thermodynamic climate model. We include as forcings the atmospheric carbon dioxide (CO₂) and the solar activity by means of the total solar irradiance, considering that the latter has not only a direct effect on climate, but also an indirect one through the modulation of the low cloud cover. We use two IPCC-2007 CO₂ scenarios, one with a high fossil consumption and other with a low use of fossil sources. Also we consider higher and lower solar activity conditions. We found that in all the performed experiments the inclusion of the solar activity produces a noticeable reduction in warming respect to the IPCC-2007 CO₂ scenarios. Such reduction goes between ~14% and ~44%. In order to evaluate the efficiency of the TCM, we use the root mean square (RMS) between the observed and model temperatures for the period 1980–2003. We find that the RMS for the experiment using the CO₂ as the only forcing is 0.06 °C, while for the experiment that includes also the solar activity it is higher, 0.13 °C.

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1. Introduction

After analysing more than 50 predictions, the Solar Cycle 24 Prediction Panel attempted to develop a consensus for the maximum sunspot number of this cycle, however, the Panel could not decide if cycle 24 will have either a high or a low sunspot maximum number. The Panel high prediction was 140 ± 20 to occur in the year 2011 and the low prediction was 90 ± 10 to occur in the year 2012 (Pesnell, 2008).

Nevertheless, solar activity phenomena have been measured as declining. For instance, the sunspot number, the total solar irradiance (TSI) and the open magnetic flux peaked around 1985 and 1987 and have declined since (Lockwood and Fröhlich, 2007). In particular, for the declining phase and minimum of solar cycle 23 the measurements indicate that: the TSI has fallen below the minima seen during the previous two solar minima (Lockwood and Fröhlich, 2007). The solar polar magnetic fields are two to three times weaker than for the previous two cycles and in general the heliospheric magnetic flux has decreased in comparison to the previous minimum (Smith and Balogh, 2008). Observations of solar wind from both large polar coronal holes during Ulysses' third orbit showed that the fast solar wind was

slightly slower, significantly less dense, cooler, and had less mass and momentum flux than during the previous solar minimum (McComas et al., 2008). Moreover, in its last revision the Panel indicates that the low prediction is the most likely and that the corresponding maximum sunspot number will occur in 2013 (<http://www.swpc.noaa.gov/SolarCycle/SC24/index.html>).

If it turns out that in fact the low prediction is the correct one for cycle 24, this maximum sunspot number would be the lowest in the past century. Such low solar cycle 24 may have consequences on the Earth's climate. Several attempts have been made to estimate the impact of solar variability on climate through the study of solar or solar-associated phenomena such as the sunspots or geomagnetic activity (e.g. Dobrica et al., 2009; Paluš and Novotná, 2009; Souza-Echer et al., 2009; Kossobokov et al., in press), the TSI (e.g. Lean et al., 1995; Cubasch and Voss, 2000; Kristjánsson et al., 2002; Shindell et al., 2006; Mendoza and Velasco, 2009), the ultraviolet radiation (e.g. Haigh, 1996; Shindell et al., 1999), the solar wind modulation of the global-electric circuit (Tinsley, 2000), and the galactic cosmic ray flux (e.g. Tinsley and Deen, 1991; Pudovkin and Veretenenko, 1995; Marsh and Svensmark, 2000; Pallé-Bagó and Butler, 2000; Usoskin et al., 2004; Svensmark, 2007).

After finding a good correlation between cloud cover changes and galactic cosmic rays (CR) along 1983–1994 Svensmark and Friis-Christensen (1997) suggested that CR modulate the production of clouds on time scales of decades and longer. At the present

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time the question of whether CR modulate climate through cloud changes is not yet settled. The spectrum of opinions goes from the view that the CR are the main contributor to radiative forcing through clouds (e.g. Svensmark, 2007) or that cosmic rays can partially affect cloud formation (e.g. Voiculescu et al., 2006), to consider that CR have a negligible effect on climate (e.g. Kristjánsson et al., 2008; Erlykin et al., 2009). However, it is also possible that the correlation between CR and clouds is due to the fact that CR fluxes are a proxy of another phenomenon which may influence climate: the TSI, that anticorrelates with CR (Lockwood, 2002). Pallé-Bagó and Butler (2000) found that the low cloud cover (LCC) annual means present a slightly higher anticorrelation with sunspot numbers compared with the correlation with CR (although they did not comment on that). Kristjánsson et al. (2002) showed that the anticorrelation of the LCC with TSI and sunspots is higher and more consistent than the correlation with cosmic rays. Yet, due to the anticorrelation between TSI and CR, it is difficult to tell which of the two mechanisms is at work, or what combination of the two.

In the present work we attempt to model the Northern Hemisphere (NH) temperature tendency for the solar activity cycles 24 and 25 considering the predictions of high and low solar activity. As climate forcings we include the atmospheric CO₂, the TSI and the LCC. Moreover, we shall assume that the LCC presents anomalies coming from two sources: one is the atmospheric internal processes, the other is from external factors that we attribute to solar activity through the indirect effect of the TSI–CR variations. In this context, the effect of solar activity on climate would be twofold: higher/lower solar activity will produce an increase/decrease in the TSI with the consequent heating/cooling of the surface. This effect would be reinforced by a reduction/increase in the LCC and therefore in the albedo, produced indirectly either by the increase/decrease of the TSI, or by the CR that are anticorrelated with TSI. But because of this anticorrelation, we can use either the TSI or the CR in order to find the LCC. In the present work we use the TSI because it has a well known good correlation with sunspots (e.g. Solanki and Krivova, 2006), and the only predicted parameter that we have for solar cycles 24 and 25 is the sunspot numbers. Also, in this paper we use the sunspots to obtain the LCC for the same time span.

2. The model

We use a thermodynamic climate model (TCM), which assumes that the source of energy that maintains the atmospheric circulation is from solar radiation, and therefore the fundamental problem is to explain quantitatively how the transformation of radiant energy into mechanical energy is carried out (Adem et al., 2000).

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 50–100 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, ideal gas, continuity and conservation of thermal energy applied to the atmosphere–ocean–continent system, a monthly time averaging of the variables is used. The latitudinal transport of heat from the tropical latitudes to the pole, carried out by cyclones and anticyclones of mean latitude, is parameterised by a constant “Austausch” coefficient of $4.5 \times 10^4 \text{ m}^2/\text{s}$ for winter and $3.5 \times 10^4 \text{ m}^2/\text{s}$ summer, in the present work this transport is neglected in the ocean.

In the model the surface temperature on the oceans and continents is expressed as a function of the mean temperature of

the atmospheric layer through a linear algebraic equation. On the other hand, the mean temperature of the atmospheric layer is computed from a linear elliptic differential equation, which is solved as a finite difference equation by the Liebmann relaxation method described by Thompson (1961), where the relaxation finishes when the numerical solutions in two consecutive iterations have a difference of about 0.001 °C, which means that the model errors are about 0.001 °C for all the points in the integration region (Adem, 1964).

Since this model is basically a thermodynamic model, with a large diffusivity “Austausch” coefficient, the noise level is not significant, which means that the model can be run with slightly different initial condition obtaining always, in the steady-state, the same solution that depends on the external forcing. This is different from the dynamical models for which the internal variability can be large. The integration of the model equations is carried out for the NH with the use of the National Meteorological Center of USA (NMC) grid with 1917 points, which uses a polar stereographic projection with a constant grid distance of 408.5 km (Adem et al., 2000). We also assume that the heat transport through the lateral boundary (close to 12°N) is zero.

The TCM is suitable for obtaining hemispheric averages (12°–90° in latitude) of the anomalies of different meteorological variables. The model also produces monthly, annual, and seasonal predictions. Finally, we choose the TCM because it is a coupled model of the continent–atmosphere–ocean system with a snow and ice layer over ocean and continents whose boundary is coupled with the isotherm of 0 °C, that takes into account the feedback mechanisms inside this system, and it is relatively easy to manipulate (Adem, 1982). The surface albedo is generated internally in the model by coupling the computed 0 °C isotherm, of the continent and ocean, with the boundary of the snow–ice cover. This coupling yields the snow–ice–temperature feedback used in the experiments. In this way, only the horizontal snow–ice extent is generated (and so the albedo is affected). As the thickening or thinning of the snow–ice layer is not considered, the albedo is not affected by this type of changes.

To see the link between the TCM and the general circulation models, we can say that for large time scales, for instance a month or a season, we assume that the thermodynamic equations become the important ones, and we can think in a simplification in which the dynamical equations (important for general circulation models) are subordinate to the thermodynamic equation, in the sense that the horizontal turbulent eddies can be incorporated into the mechanism of meridional heat transport by the use of an “Austausch” coefficient (Adem, 1964).

2.1. Modelling of the cloud cover

In the TCM, the single horizontal cloud layer has the lower boundary at 3 km and the upper boundary at 4.5 km. 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. 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, and when the cloud fraction is 1, the clouds absorb 4%. The TCM also assumes that the cloud cover absorbs long-wave terrestrial radiation as a black body, thus the radiation emitted depends only on the temperature (Adem, 1962).

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