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SOLAR INFLUENCE ON THE LOWER STRATOSPHERIC OZONE AND CLIMATE

Nataliya Kilifarska

Climate, atmosphere and water research institute – Bulgarian Academy of Sciences
e-mail: natalya_kilifarska@yahoo.co.uk

Key words: *solar and climate variability, galactic cosmic rays, lower stratospheric ozone*

Abstract: *Quasi-periodic variations in climate records, corresponding to the 11- and 22-yr periodicities in solar magnetic field, have been found long ago. Supposing that variations in heliomagnetic field are accompanied by corresponding variability in the solar electro-magnetic radiation, many authors suggested that solar 'signal' in climate records is a projection of solar irradiance variations on climate. However, contemporary satellite measurements of total solar irradiance reveals that its' variability within the 11-yr solar cycle does not exceed 0.07%. Such a small variability could not produce detectable variations in climatic variables. For this reason the mechanism of sola influence on climate is a subject of hot scientific debate. This paper offers a new point of view on this problem, revealing the existence of a chain of interaction between galactic cosmic rays, heliomagnetic and geomagnetic fields and Earth atmosphere. We have shown that in the lower atmospheric ionisation layer – known as a Regener-Pfotzer maximum – exist conditions for activation of ozone production. This secondary source of ozone is irregularly distributed across the globe (due to the irregularly distributed ionisation and humidity in the lower stratosphere). For this reason the amount of ozone produced in the lower stratosphere is also irregularly distributed. The existence of this second source of ozone production is able to explain not only the well-known asymmetry in the lower stratospheric ozone density, but also the irregular distribution of solar signal found in the near surface temperature records.*

ВЛИЯНИЕ НА СЛЪНЧЕВАТА АКТИВНОСТ ВЪРХУ ОЗОНА В НИСКАТА СТРАТОСФЕРА И КЛИМАТА

Наталия Килифарска

Институт за изследване на климата, атмосферата и водите – Българска академия на науките
e-mail: natalya_kilifarska@yahoo.co.uk

Ключови думи: *слънчеви вариации, изменение на климата,галактически космически лъчи; ниско-стратосферен озон*

Abstract: *Квази-периодичните вариации в климатичните променливи, съответстващи на 11- и 22-годишните периодичности в слънчевото магнитно поле, са открити отдавна. Предполагайки, че вариациите в хелиомагнитното поле са придружени от аналогична изменчивост на слънчевата електромагнитна радиация, много автори предполагат, че слънчевият „сигнал“ в климатичните записи се дължи на промяна в интензивността на слънчевото греене. Съвременните сателитни измервания на интегралната слънчева радиация разкриват, че неговата изменчивост в рамките на 11-годишния слънчев цикъл не надвишава 0,07%. Тази незначителна вариация не е в състояние да обясни наблюдаваните квази-десетилетни изменения в климатичните променливи. Поради тази причина механизмът на слънчевото влияние върху вариациите на климата е обект на горещ научен дебат. Настоящата статия предлага нова гледна точка върху този проблем, разкривайки съществуването на верига на взаимодействия между галактическите космически лъчи, хелиомагнитното и геомагнитното полета и земната атмосфера. Показано е, че в йонизационния слой в ниската атмосфера – известен като максимум на Регенер-Пфоцер – съществуват условия за активиране на производството на озон. Този вторичен източник на озон е неравномерно разпределен по целия свят (поради неравномерното разпределената йонизацията и влажността в ниската стратосфера). Съществуването на този вторичен източник на озон е в състояние да обясни не само добре известната асиметрия в плътността на ниско-стратосферния озон, но и неравномерното разпределение на слънчевия сигнал, открито в климатичните редове на приземната температурата.*

Introduction

Among different manifestations of solar activity, its luminosity (i.e. the radiative power to emit electromagnetic radiation) is the most likely factor influencing Earth's climate. Besides on the nuclear fusion in the Sun's core, the solar insolation depends on the transportation of radiated energy through solar *radiative* and *convective* zones, and on the emission of solar radiation by the photosphere. The variations in emitted total solar irradiance (TSI, i.e. the integral value over the whole emission spectra) are related to the individual features of the photosphere (i.e. *sunspots*, *plages*, *magnetic network*, etc., which in turn are controlled by the 11-yr periodicity of solar magnetic field), and to magnetic or thermal excitations near the bottom of the convective zone [1]. The estimations of the net effect of dark and bright magnetic contribution suggest that in high solar activity the amount of solar irradiance reaching the Earth is higher (despite the increased number of sunspots).

The instrumental measurements of TSI show, however, that its variation within the most common ~11-year solar cycle is only ~0.07% [2]. This small amplitude of TSI variability is not able to explain the existing quasi-decadal variations in the near surface temperature, provoking in such a way a long lasting dispute regarding the mechanism of activation of decadal and bi-decadal periodicity in climatic variables [3].

The present paper describes a new explanation of the synchronous variability between solar magnetic activity and near surface climatic parameters. We show that heliomagnetic modulation of galactic cosmic ray flux, and their geomagnetic focusing in certain regions across the globe, are able to explain both – existence of solar periodicities in climatic records and the regional specificity of climate variability.

Data and methods of analysis

Air temperature at 2 m above the surface, the atmospheric pressure at 1000 hPa, the ozone mixing ratio at 70 hPa and water vapour specific humidity at 150 hPa are taken from ERA 20 century reanalysis. We have analysed the seasonal values, with winter values calculated from the winter month in each hemisphere, and summer ones – from the summer months. All data have been smoothed by the 11-yr moving window, to exclude the short-term variations. Monthly average deviations of all examined atmospheric parameters have been calculated from their dynamically evolving decadal means, due to the non-stationarity of these time series. These short lasting fluctuations we call '*dynamical anomalies*' and they do not possess any trend or long-term variations.

The long time series of galactic cosmic rays (GCR) – annual values (for the period 1700-2007) – is provided by the *World Data Centre for Paleoclimatology*, Boulder, and the *NOAA Paleoclimatology Program*. After 2007 the record has been extended by the calibrated data from Moscow Neutron Monitor. The short-term variability like the 11-year solar cycle has been excluded through data smoothening by a 22-year running average procedure.

The connectivity between galactic cosmic rays and atmospheric variables (surface temperature, near tropopause ozone and humidity) has been determined by applying lagged cross-correlation analysis. Due to the relatively lower power of this statistical method some authors [4] have recommended a replicating of the calculated correlations at different time lags and different groups of subjects. For this reason, each lagged correlation coefficient has been selected to be the maximal value among all coefficients calculated with time lags of 1 to 35 years. We have applied this technique for every two compared variables, in each grid point. This means that 684 pairs of time series have been analysed for each correlation map. Due to the fact that the maximal correlation coefficients are fond for different time lags, they have been preliminary weighed by the autocorrelation functions of forcing factor, corresponding to the time delay of dependent variable (for more details see [4, 3]). The correlation maps are drawn from statistically significant coefficients, applying the two tailed t-test of significance.

Results and Discussion

At long distances from the Earth's centre the geomagnetic field is fairly well approximated by a magnetic dipole. Near to the surface, however, the spatial irregularities in magnetic field become substantial. Besides the latitudinal, the longitudinal gradient of geomagnetic field is well detectable in the lower atmosphere (see Fig.1). The charge separation of energetic particles in a gradient magnetic field and the emerging electric field E, together with the ExB drift, expels the charged particles in the atmosphere (at lower part of their trajectories along the magnetic field lines). Thus, in regions with stronger particles' drift are expelled more charged particles than in regions with reduced drift. Interacting with the atmospheric molecules these primary particles create secondary products (i.e. electrons, protons and elementary particle), part of which are accumulated in the lower atmospheric maximum of ionisation, known as a Regener-Pfotzer max. Consequently, the geomagnetic lensing of highly energetic protons and alpha particles presume an irregular plasma density in the Regener-Pfotzer max [5].

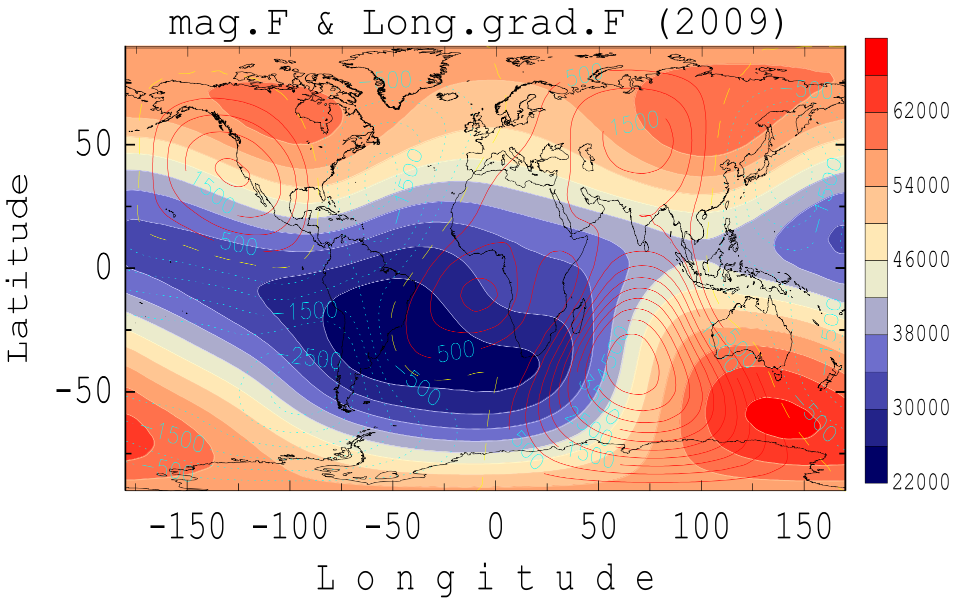

Fig. 1. Map of averaged geomagnetic intensity (shading) and longitudinal gradient (contours)

In addition, we have found that near the Regener-Pfotzer maximum there are conditions favouring ozone production in the lower stratosphere [6]. This means that the longitudinal variations in the lower atmospheric ionisation could be projected on the ozone profile. Examination of ozone profiles in regions with increasing and decreasing geomagnetic field shows well pronounced difference between them (see Fig.3). Note the higher O_3 values beneath the peak ozone density, in regions with strengthening magnetic field.

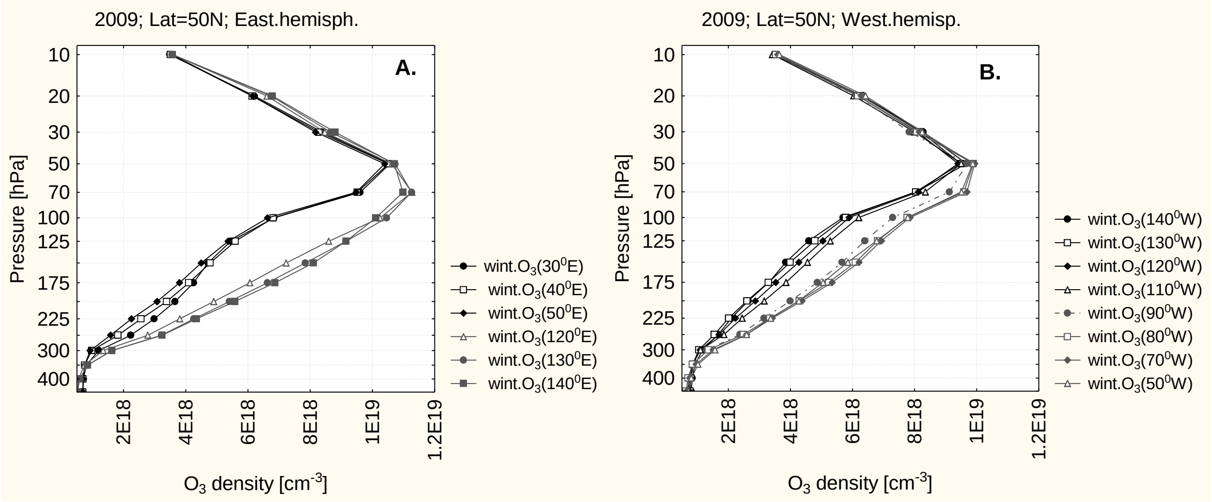

Fig. 3. Longitudinal variations of O_3 profiles at 50^0N latitude, detected in two sectors with *positive*, i.e. strengthening geomagnetic field, (140^0-110^0W; 30^0-50^0E) – red curves, and with *negative* longitudinal geomagnetic gradient – decreasing field intensity (90^0W-50^0W; 120^0E-140^0E) – black curves

Fig. 3 illustrates that heterogeneous distribution of GCR reaching the lower atmosphere is projected on the lower stratospheric ozone profile. The spatial distribution of their connectivity could be found in Fig. 4, presenting the centennial covariance of GCR and ozone at 70 hPa (coloured shading). The statistically significant correlation coefficients, used for the map creation, have been preliminary weighted by the autocorrelation function with time lag corresponding to the O_3 delayed response to the GCR forcing. This procedure, which substantially reduces correlation coefficients with longer time lags, is based on the reasonable assumption that the effect of the applied forcing in a given moment of time decreases with moving away from this moment.

Note that the ozone response to particles' impact is quite different – not only by amplitude, but even by the sign. Thus, at high latitudes and in Indo-Pacific Oceans, ozone changes synchronously with GCR. Having in mind the centennial negative trend in GCR, this means that O_3 decreases in the said regions. On the other hand, at the Northern Hemisphere extratropics and near the southernmost edge of Latin America both variables covariate in antiphase – meaning that in these regions ozone increases with time. Such heterogeneity in ozone response to particles' forcing could be attributed to the way of their penetration in the atmosphere. For example, the polar regions are accessible to the particles propagating along the open geomagnetic field lines. The tropics and mid-latitudes, on the other side, are shielded by geomagnetic field and are accessible only to very highly energetic particles. However, trapped radiation from the Van Allen radiation belts, accelerated in the magnetosphere to GeV energies, could penetrate deep in the atmosphere at these latitudes – creating or destructing the near tropopause ozone [7]. The criterion for differentiation of both processes appears to be the altitude of Regener-Pfotzer maximum – gradually decreasing toward the equator [8].

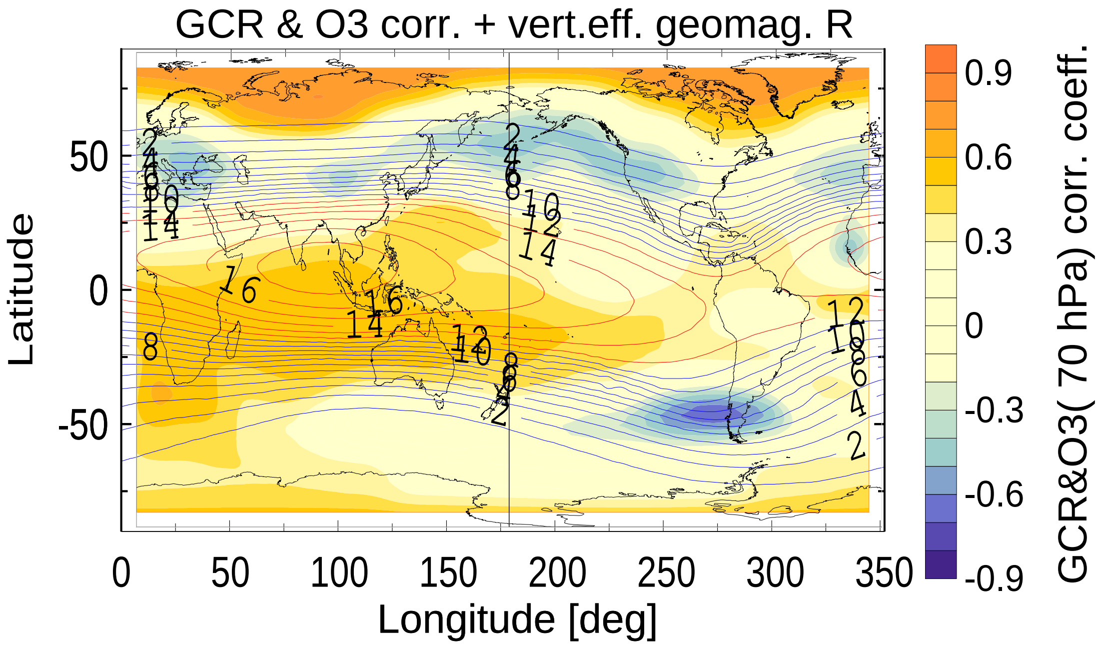

Fig. 4. Lag-corrected correlation map of GCR and O_3 at 70 hPa (shading), compared with modeled effective vertical cut-of rigidity of geomagnetic field (courtesy to Boschini M.J., Della Torre S., Gervasi M., Grandi D., Rancoita P.G. - www.mib.infn.it, and Bobik P., Kudela K. - http://space.saske.sk)

Fig. 4 shows in addition the effective vertical cut-off rigidity of geomagnetic field (contours), with the values greater than 12 GV being coloured in red. According to the Fig. 5.8 from [8], particles with geomagnetic rigidity greater than 12 GV are absorbed beneath the tropopause, which means that they destroy ozone at that level [9]. Juxtaposition of GCR-O_3 correlation map with the map of geomagnetic cut-off rigidity reveals that at latitudes where the Regener-Pfotzer max is situated in the lower stratosphere – there we have an ozone formation (despite the global negative centennial trend of ozone at 70 hPa). Oppositely, at tropical latitudes, where the ion-molecular reactions (activated by the ionization in the Regener-Pfotzer max) force ozone destruction, we have found an ozone reduction during the 20-th and the first decade of 21-st centuries (see Fig. 4).

In conclusion, the different pathways of particle penetration in the Earth's atmosphere, as well as the magnetic lensing of radiation trapped in the Van-Allen radiation belts, create irregularities in altitude and ionisation density in the Regener-Pfotzer maximum. These irregularities produce corresponding heterogeneity in the near tropopause ozone density, through activation of ozone production (above the tropopause) and ozone destruction beneath it. Thus we could explain how the homogeneous (in first order) GCR, arriving at the magnetospheric upper boundary, could produce irregularities in ozone density near the tropopause.

Direct ozone influence on the surface temperature, however, is quite small due to the mutually exclusive effect of stratospheric and tropospheric ozone in the planetary radiation balance. According to our hypothesis, the impact of the lower stratospheric ozone variability is transmitted down to the surface by the near tropopause atmospheric humidity, which in turn is controlled by the ozone through alteration of the wet adiabatic lapse rate [7]. Fig.5 compares the lag-corrected correlation maps of ozone mixing ratio at 70 hPa with: (i) GCR and (ii) humidity at 150 hPa. Note that latitudinal band of *antiphase* correlation between GCRs and ozone (dark shading), and *inphase* correlation between ozone and water vapour (red contours), coincide impressively well. In the Northern Hemisphere, this coincidence persists round the year, although being slightly reduced in summer. In the winter Southern Hemisphere, the area of synchronous variations of GCR, ozone and humidity is narrower and practically disappears in summer (Fig. 5d). The results presented in Fig. 5 are a good indication that ozone–humidity variations, which are projected down to Earth's surface by the strengthening of weakening of the greenhouse effect, are actually related to GCR variability.

Our hypothesis for the mediating role of GCR, near tropopause ozone and humidity in transmission of solar 'signal' down to the Earth's surface is capable of explaining a lot of observational evidence detecting such a 'signal' [10-16]. One of the greatest challenges for all hypotheses describing the mechanism of solar influence on climate is the irregular response of climatic system to the spatially homogeneous long-term solar variability (refer to Fig. 6). The mechanism proposed here addresses this problem, presenting a corresponding explanation of the regionality of climate variations.

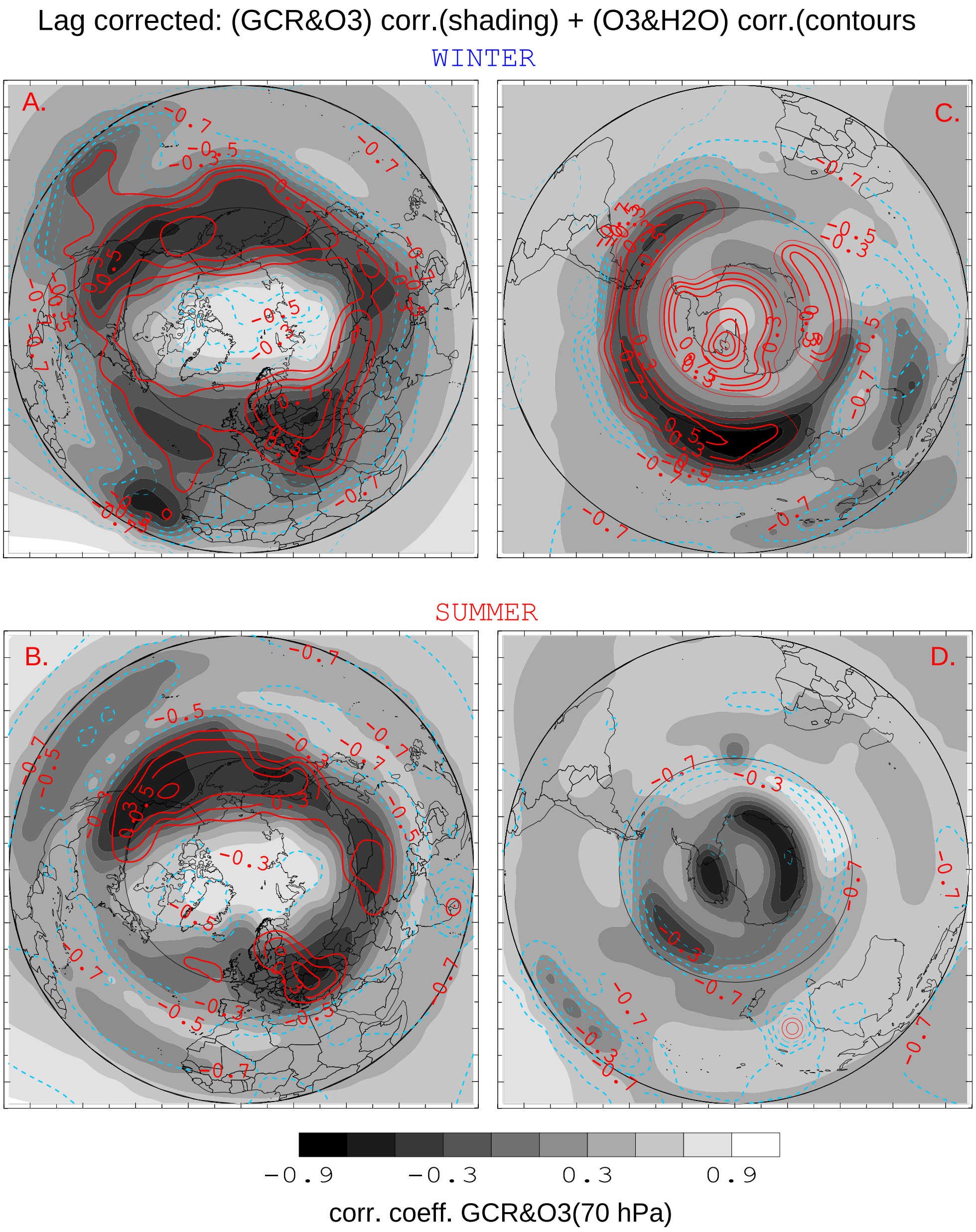

Fig. 5. Comparison of correlation maps of ozone at 70 hPa with GCRs (dark shading) and water vapour at 150 hPa (contours), for winter (A) and (C), and summer (B) and (D) panels

Unlike the concentration of CO_2, which at climatic time scales could be treated as homogeneous across the globe, the mediator of GCR-O_3 influence on climate – i.e. the near tropopause *water vapour* – is distinctly heterogeneously distributed. Consequently, the spatial heterogeneity of climate response to the contemporary warming (refer to Fig. 6) could be logically attributed to the three main factors: (i) geomagnetic lensing of GCR, creating irregularities in the Regener-Pfotzer maximum ionisation; (ii) heterogeneous distribution of ozone (due to the activation of ozone producing or ozone destructive ion-molecular reactions near the tropopause); and (iii) spatial irregularities of the atmospheric water vapour distribution.

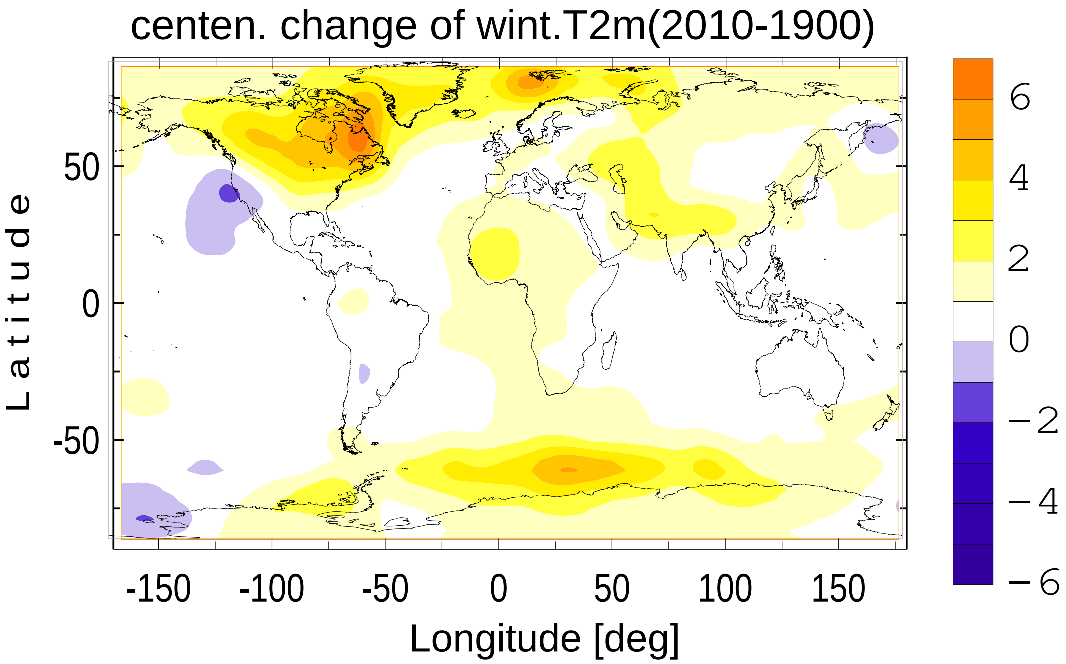

Fig. 6. Difference of the air temperature at 2 m above the surface, between first decades of the 21-st and 20-th centuries

Conclusion

Our analysis supports the suggestion that solar influence on the Earth's climate is not due to the variations in solar electromagnetic luminosity (which appears to be very weak) but more probably to the solar and geomagnetic modulation of cosmic rays (CR). The mechanism of transmission of solar signal down to the surface includes: (i) focusing of CR in some regions over the globe] (ii) creation or destruction of ozone near the tropopause (depending on the altitude of Regener-Pfotzer maximum); (iii) moistening or drying of the upper troposphere followed by strengthening or weakening of the water vapour greenhouse effect.

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