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GEOPHYSICS

Nature of the Decrease in Global Warming at the Beginning of the 21st Century

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Abstract—Variations in the temperature of the Earth's surface over the period 1850–2014 are reproduced and analyzed using seven historical calculations in the INM-CM5 climate model following the scenarios suggested for the CMIP6 project of comparison of climate models. In all calculations, the mean surface temperature increased by 0.8 K to the date of final calculation (2014), which is consistent with observations. The periods of accelerated warming (1920–1940 and 1980–2000) and its stabilization (1950–1975 and 2000–2014) are correctly reproduced by the model. The decrease in global warming of 2000–2014, which is hardly reproduced by the models in the CMIP5 experiment, is reproduced due to the more precise scenario of variation in the solar constant of CMIP6 protocols. The spatial structure of warming for last 30 years is also reproduced by the model.

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Climate changes of last century are quite noticeable. Their most popular characteristic is related to the mean surface temperature (MST), the increase in which is first related to the response of the climate system to anthropogenic increase in the content of greenhouse gases [3]. Global warming, however, is characterized by a variable rate: there are two periods of its acceleration (1920–1940 and 1980–2000) and two periods of its stabilization (1950–1975 and 2000–2014). The reasons for the variable warming rate are actively being debated at present. For example, it is shown in [11] that the period of termination of the MST increase in 1950–1975 is related to the increase in anthropogenic SO_2 emission in Europe and North America. In addition, it also can be caused by the release of volcanic aerosols into the stratosphere [3].

The reason for the decrease in warming of 2000–2014 could be the decrease in the growth rate of methane and the tropospheric ozone concentration [4]. On the other hand, an assemblage of CMIP5 climate models, which take into account these aerosol and greenhouse impacts and corresponding reverse links, does not describe the termination of the MST growth in 2000–2014 (according to the assemblage, it increased with lower rate [3]). This can possibly be related to the internal variability of the climate system on temporal scales of 30–80 years [7] at the expense, for example, of Atlantic multidecade and Pacific decade oscillations (AMO and PDO). The work [6], however, casts doubt on the possibilities of AMO and PDO to affect significantly the MST changes.

The aim of this work is reproduction and analysis of MST behavior in 1850–2014. The data for the analysis are calculated using a new version of the INM-CM5 climate model of the Institute of Numerical Mathematics, Russian Academy of Sciences (INM RAS) [10], taking into account new protocols of change in anthropogenic and natural impacts proposed for the CMIP6 program.

The INM-CM5 climate model of the INM RAS is a modernized INMCM4 model [1] from the CMIP5 experiment. In the atmospheric block, the model has a spatial resolution of 2 × 1.5° along the longitude and latitude and 73 vertical levels up to a height of 0.2 GPa. The oceanic block is characterized by a resolution of 0.5 × 0.25° and 40 vertical levels. The model includes an interactive aerosol calculation block of the concentrations of ten types of aerosols [2]. Our experiment accounts for only the first indirect aerosol effect (influence of aerosol on the radius of the cloud drops). A detailed description of the model and the analysis of experiments of simulation of the present-day climate are given in [10].

Let us describe the numerical experiments on simulation of climate changes for the period 1850–2014.

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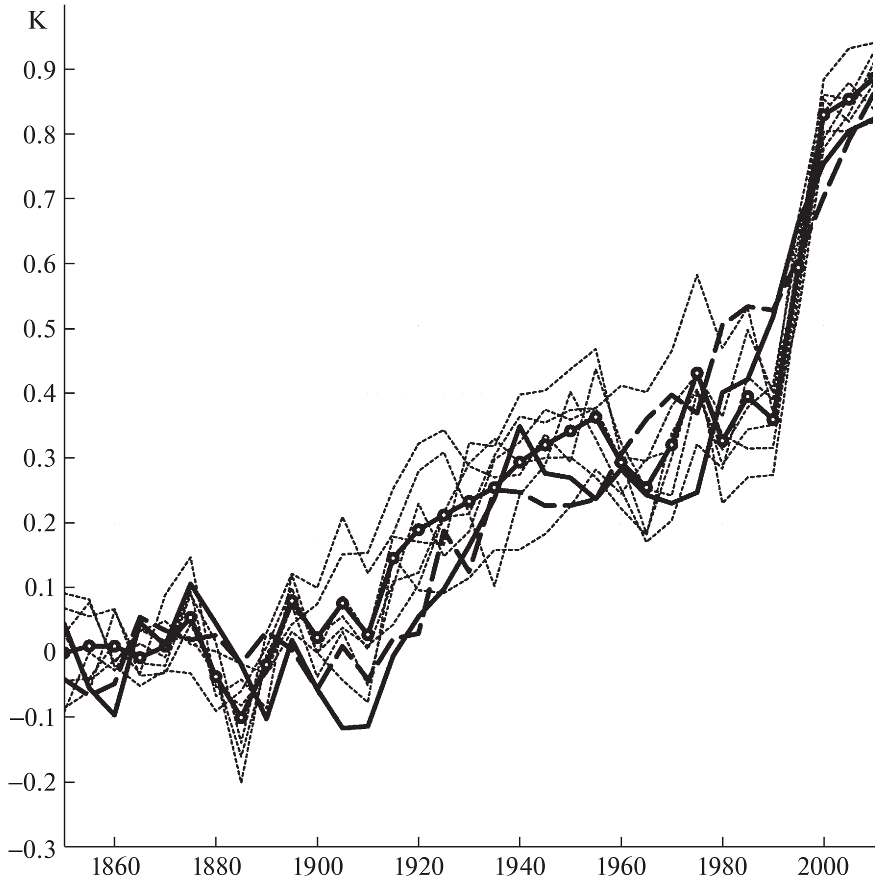

Fig. 1. Average MST anomaly for five years (K) relative to 1850–1899 calculated from HadCRUTv4 data (black solid line) and modeling data (solid line marked by circles, average by seven experiments; dotted fine lines, data of individual experiments; solid dash line, data of the INMCM4 model).

The temporal course of the contents of CO_2, CH_4, N_2O, O_3, and stratospheric sulfate aerosols and the values of the solar constant and spectrum of solar radiation, as well as the values of anthropogenic SO_2 emissions and black and organic carbon, are given according to CMIP6 recommendations (https://esgf-node.llnl.gov/search/input4mips/) for historical experiments. Simulation is conducted for 1850–2014; seven experiments are distinct only in the initial conditions of 1850. The initial conditions were chosen from preindustrial calculations with a model (i.e., when all impacts on the climate system are sustained at the level of 1850) 1200 years long, which was started after preliminary acceleration of a model that was 400 years long. Over this time, the characteristics of the upper layers of the ocean have time to be adapted to the atmospheric dynamics and the small trend of the climate characteristics of the deep ocean is still noticeable.

The observation data used for the comparison with data on MST modeling in 1850–2014 were taken from [8] (HadCRUT4 archive). The trends of the geographic distribution of the near-surface air temperature in 1979–2014 are calculated on the basis of ERA Interim archive data [6].

Let us analyze the dynamics of MST changes in 1850–2014 that resulted from the assembled calculations. As noted, the real MST demonstrates two periods of accelerated increase (1920–1940 and 1980–2000) and two periods of stabilization (1950–1975 and 2000–2014). The assemblage of CMIP5 models [3] weakly reproduces the MST stabilization in 2000–2014. In particular, the INMCM4 model [1] exhibits warming with a constant rate beginning from 1920.

Figure 1 shows the MST changes according to the observations and INMCM4 and INM-CM5 models. Our data indicate that, in all experiments, the INM-CM5 model reproduces an acceleration of warming in 1980–2000 with a rate close to that observed, as well as termination of MST growth in 2000–2014 and 1950–1970. The refinement of change in the solar constant is the only significant distinction in the given external impacts in the CMIP6 protocol at the beginning of the 21st century relative to the CMIP5 protocol. Prior to 2005, CMIP5 and CMIP6 used values that are distinct from the almost time-independent value

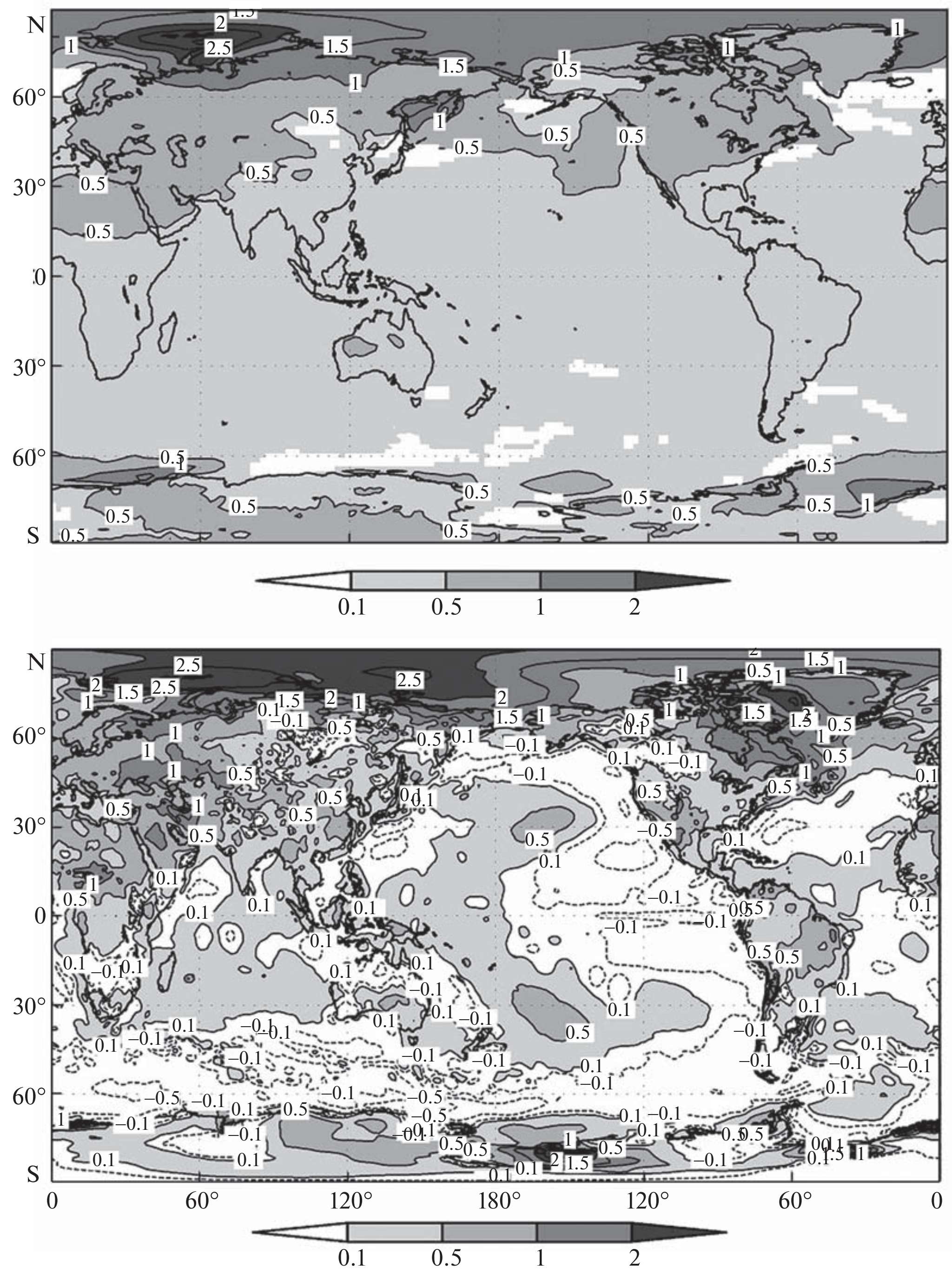

Fig. 2. Difference in the Earth's surface temperature (K) in 2000–2014 and 1985–1999 averaged by seven model experiments (top) and difference in the surface temperature for these years according to ERA Interim reanalysis (bottom). The areas are marked where variations in temperature are significant.

(CMIP5 recommendations for a given solar constant can be found, for example, at https://pcmdi.llnl.gov/mips/cmip5/forcing.html). In 2001–2008, the recommended values of the solar constant for CMIP6 are lower almost by 0.3 W/m^2 than for CMIP5. For 2009–2014, the CMIP5 suggested to use the solar constant values of the previous solar cycle, which resulted in its overvaluation by almost 1 W/m^2 relative to the CMIP6 recommendations. Additional calculation with emissions of anthropogenic aerosols stabilized at the level of 1850 demonstrates a gradual MTES increase in 1950–1970 (effect of increase in emission of anthropogenic SO_2 is now not taken into account) and its stabilization in 2000–

2014. This fact confirms the hypothesis that correct reproduction of the MST dynamic in 2000–2014 is caused by changes in the given solar constant rather than by anthropogenic aerosols.

Enhanced reproduction of the MST stabilization in 1950–1970 (Fig. 1) in the INM-CM5 model relative to the INMCM4 model is probably explained by using of new calculation block of aerosol concentrations with more detailed description of interaction between anthropogenic and volcanic aerosols and atmospheric radiation. It should also be noted that acceleration of warming in 1920–1940 similarly to the observed one can be modeled in four experiments, whereas the other three calculations demonstrate accelerated warming slightly later or earlier than the necessary period. This is evidence that the accelerated warming of 1920–1940 is a combination of external and internal factors.

Figure 2 shows the geographic peculiarities of change in the surface temperature over the last decade, which were averaged by the data of seven model experiments and reanalysis of the ERA Interim. The areas with statistically insignificant changes were determined using the T-test with a confidence level of 99% by the average annual values of the temperature field of the preindustrial experiment 1200 years long. The observation data appear somewhat noisy; however, it is clear that major peculiarities in the changes are correctly reproduced by the model. First, this is the Arctic increase in global warming [7] with a maximum in the area of the Barents and Kara seas reaching 2.5° according to simulated and observed data. The warming in high and moderate latitudes of Eurasia and Northern America reached 1 K, and the least warming is typical of the southern ocean. Some local peculiarities of the change in the field of the surface temperature (the area of the Circumpolar Current, zone of deep convection in the North Atlantic, and areas of breakdown of the Gulfstream and Kuroshio) are not produced by the model due to their strong internal variability in the climate system. No PDO-related structure is reproduced in the Pacific Ocean.

Thus, our studies allow the following conclusions.

(1) Correct description of the behavior of the solar constant in the CMIP6 protocol allows real reproduction of MST stabilization in 2000–2014 in numerical experiments with the INM-CM5 model. Stabilization of MST in 1950–1970, which is not described by the INMCM4 model in experiments of the CMIP5 program, is simulated in the new version of the model using a more correct radiation effect of stratospheric volcanic and tropospheric anthropogenic aerosols in the corresponding model block.

(2) No reproduction of the AMO and PDO phases is required for correct description of MST changes in 1980–2014. In particular, the MST dynamic in these years is reproduced in all seven experiments and the AMO and PDO phases are opposite to those in the three experiments.

(3) The model reproduces the geographic features of the trend of the surface temperature over the last decade including the Arctic increase with a maximum of 2.5° in the area of the Barents and Kara seas and moderate warming of 1° for the territory of Eurasia and Northern America. A great role in the general pattern of global warming belongs to internal variability.

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