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COMMENTARIES ON THE ARTICLE "IMPACTS OF CLIMATE CHANGE ON LONG-TERM DYNAMICS OF SEASONAL FREEZING IN MOSCOW REGION: RETROSPECTIVE ANALYSIS AND UNCERTAINTIES IN FORECASTING FOR THE SECOND HALF OF THE 21st CENTURY" BY S.P. POZDNYAKOV, S.O. GRINEVSKYI, E.A. DEDIULINA

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The use of physical and mathematical models for forecasting the dynamics of seasonal freezing in Moscow region and the results' uncertainty have prompted the analysis of general and specific problems of physical and mathematical modeling of climate, as well as the climate system components and characteristics. The solution of these problems can contribute to the improvement of physical and mathematical models and long-term forecasting of climate change processes in the Earth's cryosphere.

Cryosphere, seasonally frozen layer, dynamics, prediction, simulation, solar radiation, variation of insolation, meridional gradient in insolation, climate change factors

The paper authored by [*Pozdnyakov et al., 2019*] have provided a quantitative analysis of the active layer (AL) dynamics in the 21st century using climate projections for five models of coupled atmosphere–ocean general circulation models (AO-GCMs) from the ensemble of CMIP-5 models based on modeling the snow cover dynamics on the surface, and vertical heat and moisture transfer in the underlying unsaturated zone. The input data (thermal and hydrophysical parameters) for the modeling were derived from results of the observations of heat and moisture transfer processes in soils of unsaturated zone in the area of Skadovsky Zvenigorod Biological Station of Moscow State University (ZBS MSU, Moscow Region). The authors arrived at the conclusion that the results of heat transfer modeling for five climate projections revealed differences that create uncertainty in forecasting long-term dynamics of seasonal freezing depth in the 21st century. The inference made in other works [*Sherstyukov, 2011; Anisimov and Kokorev, 2017; Fedorov and Grebennikov, 2018*] about the weakness in forecasting (big enough even to defy it) concerns a significant uncertainty of the results obtained by various models. However, they hope that the improvements in existing climate models can decrease the uncertainty range of model calculations thereby improving their accuracy. Besides the uncertainty of forecasting, the authors have made other inferences showing that providing an explanation of the causes of uncertainty is necessary, which can contribute to the improvement of physico-mathematical climate models.

Physico-mathematical climate modeling is recognized as advanced and indispensable instrumentation of scientific research. Modeling the climate processes is necessitated by: 1) heterogeneity of the climate system components; 2) diversity and complexity of the relationships (direct and inverse) between the climate system components; 3) persistent space and time depended changes in the state of individual components and the system as a whole; 4) the time and space scales involved in the relationship between the system components. Taking into account the significance of modeling natural phenomena, the improvement of the existing or building fundamentally new climate models based on cutting edge technologies is a highly topical issue in the light of latest advancements in natural sciences. Another reason for improvements to the models has been prompted by results obtained by the authors of the aforementioned paper and consists in problem definition and solution in modeling. The problems are primarily defined as general or specific. With respect to the physico-mathematical climate models, the former include problems associated with the energy signal entering the climate system. While specific problems include the authors' choice of the forecasting scenario (RSP8.5) and particularizes the input energy signal calculating in the Surfbal software used by the authors from the reconstructed minimum and maximum air temperature. Below we consider this in greater detail.

Incoming energy signal: Recommendations of the intergovernmental panel on climate change (IPCC)

Solar radiation is known to be the main energy source for hydrometeorological (atmospheric) processes. Presently, IPCC recommends using the data obtained from radiometric measurements of total radiant flux as external energy signal in the radiation block of physico-mathematical climate models (CLIM-5) of the global climate system [*Lean et al., 1995, 2005*] and reconstructions of total solar irradiance (TSI) (annual resolution since 1610; monthly resolution since 1882) [http://solarisheppa.geomar.de/cmip5]. The TSI reconstruction is based on variations in solar activity (the number of sunspots and solar flares). These reconstructed data however reflect neither changes in irradiance contrast associated with increased meridional heat transfer (the work of the "heat engine of the first kind") [*Shuleikin, 1953*], nor long-term variability of near-surface air temperature (SAT), sea surface temperature (SST), global sea level and sea ice extent [*Fedorov, 2018*]. Irradiance contrast (IC) is the difference between the annual radiation coming into the region of 0–45 degrees latitude (heat source) and 45–90 degrees latitude (heat sink) in each hemisphere (hemispheric averages are calculated for the Earth). Solar irradiance reflects the meridional gradient of insolation (MGI) at the upper bound of the atmosphere (UBA) or on the earth surface in the absence of atmosphere. MGI variations are associated with changes in the Earth's tilt [*Fedorov, 2018*].

Accounting for measured and reconstructed (as recommended by IPCC) TSI as an input energy signal is considered wrong in climate modeling [http://solarisheppa.geomar.de/cmip5] for the reasons explained below. It reflects a change in the total incoming solar radiation. This change, as shown by the performed calculations of the solar radiation arriving to the Earth for the recent epoch, is insignificant (about 0.005 % over 6,000 yrs) [*Fedorov, 2015a, 2018*]. In respect to the total incoming solar radiation, these variations are calculated for discrete latitudinal zones along the cosine of latitude regardless of changes in the Earth's tilt. At this, small variations of the incoming solar radiation translate into small variations in the latitudinal zones of the Earth. In the recommended radiation data in CMIP-5 project, the extent of annual variations in the incoming radiation, for example since 1610, has amounted to about 4.5 W/m^2 (or 0.33 %). As such, this scope is characteristic of the equatorial region alone. At this, it is tending to decrease towards the poles, according to the cosine of latitude. Unlike variations in the incoming solar radiation, it is critical to consider variations in the distribution across latitudinal zones caused by changes in the angle of the Earth's tilt, inasmuch as these variations constituted ca. 3 % in the annual pattern over the time span of 6,000 years. It is a decrease in the axial tilt that determines an increase in the meridional gradient of insolation (MGI). The latter largely controls the energy (heat) meridional transfer in the ocean–atmosphere system, whereas MGI variations dictate the changes in the meridional heat transfer (MHT), prompting the amplified performance of the "heat machine of the first kind".

Specifically, IC variations mirroring MGI variations, account for the trends in SAT variations across the globe and in discrete latitudinal zones [*Fedorov, 2018, 2019*], and hence the reasons for these changes are expressed by the trends, since solar radiation is a major and almost only energy source in terrestrial hydrometeorological processes. Recent climate models largely focusing on variations in the incoming solar radiation tend to ignore changes in MGI and, accordingly, in the "ocean–atmosphere" system.

Correlation between variations of different physical nature in the total solar radiant flux variability

Modern climate models are built irrespective of variability of the proportions of variations of different physical nature in the incident solar radiation depending on the time resolution, and of their different effects on the climate formation and change. We designate variations related to the celestial mechanical processes (changes in the Earth–Sun distance, solar declination, etc.) as TSI_{CMP} (celestial mechanical process). TSI variations are associated with changes in solar activity are indicated as TSI_{SA} (solar activity).

It follows from the previously obtained data on the incident solar radiation, that the ratio between variations of different physical nature (even under slightly changing intensity of the solar radiation incidence) depends on time resolution [*Fedorov, 2018*]. Thus, the interannual variability of monthly solar radiation is derived from the TSI_{CMP} (55 %) and TSI_{SA} variations (45 %). The difference between the values of the components of interannual TSI variability associated with the celestial-mechanical processes and determined by changes in the solar activity, has a specific annual cycle. The interannual variatiability described as TSI_{SA}-driven exceeds the weightings of the TSI_{CMP}-driven interannual variability over a span of 4 months (1/3 year): June, July, December, January. The time intervals dominated by the TSI_{SA} variation are chronologically localized in the vicinity of the summer and winter solstice points. Over the remaining 8 months (2/3 of the year), the TSI interannual variability is dominated by the TSI_{CMP}-driven variations. The maxima in the TSI_{CMP} variations dominance account for the intervals localized in proximity to the equinox points. The ratio averages within the weighting values of 45.71 % (TSI_{SA}) and 54.29 % (TSI_{CMP}) during the 1978–2008 period of satellite radiometric observations [*Fedorov, 2015a,b, 2018*].

However, the values of the reconstructed TSI proposed by IPCC do not take this into account. In view of the obtained results, it is recommended to use the solar radiation and (or) irradiance contrast as the incoming energy signal in climate modeling. A relationship between the long-term SAT and SST anomaly variability, on the one hand, and solar radiation and IC (as seasonal contrast in insolation), on the other hand, was analyzed and estimated in [*Fedorov, 2015b, 2018*].

Variation of meridional gradient in insolation on the upper bound of the atmosphere

General circulation models (GCMs) composed of two major blocks – atmospheric and oceanic GCMs (AGCM and OGCM) – are described by a system of equations of atmospheric hydrothermodynamics, reflecting the basic physical laws (i.e. laws of conservation of matter and energy, and momentum conservation). However, these equations describing the averaged, static atmosphere and the ocean [*Lorenz, 1970; Palmen and Newton, 1973*] disregard, for example, variations in MGI and in the ocean-atmosphere system. The performed solar radiation calculations show that due to the Earth's spherical shape, the equatorial area receives more sun's radiant energy, than the polar regions [*Fedorov, 2018*].

The meridional gradient of insolation is caused by uneven distribution of solar radiation coming to UBA. At present (at least over the last 5,000 years) there has been a gradual increase in annual MGI in the space enclosed between the polar circles, with the MGI increase maxima being localized nearby. In the polar regions, a gradual decrease in MGI is observed towards the poles. This is explained by a decrease in the Earth's tilt and increase in solar radiation in the zone located south of the Arctic circle (northern hemisphere) and northwards of the Arctic circle (southern hemisphere), and by a decrease in solar radiation in the polar regions. Thus, there are areas showing an increase (in the span from the equator to the Arctic circle) and decrease (from the Arctic circle to the pole) in MGI in each hemisphere. The maximum increase in annual MGI over 5000 years (by 1.25 %) is observed in the polar circle areas in each hemisphere. While the maximum decrease in MGI (by 2.56 %) occurs in polar regions [*Fedorov, 2018, 2019*].

The averaged annual energy transfer in the ocean-atmosphere system [*Lorenz, 1970; Palmen and Newton, 1973*] is linearly related to the averaged annual MGI [*Fedorov, 2018*]. The correlation coefficient is 0.98. Since the mean-annual transfer of energy within the ocean-atmosphere system is determined by the meridional gradient of annual mean insolation, the obtained MGI variations for the modern era can be manifested in the ocean-atmosphere system. Both the meridional heat exchange (the work of the "heat machine of the first kind") and its strengthening due to a decrease in the Earth's tilt angle are seen to be governed by MGI [*Fedorov, 2018, 2019*]. The obtained MGI variations should also be taken into account in the system of equations of hydrothermodynamics (equations of laws of conservation of mass, momentum, energy and gas state) for the atmosphere used in numerical experiments in the climate physico-mathematical models. The equations of hydrothermodynamics that describe A-GSM and O-GSM have recourse to the static atmosphere and ocean, which are not really static.

Anthropogenic factor of global climate change

The Climate Doctrine of the Russian Federation is largely based on the fundamental scientific knowledge and available expertise in weather and climate and related applied science. The scientific justification of this Doctrine "includes the recognition of the fact that the anthropogenic factor may have an effect on the climate system triggering an important reaction which is adverse and hazardous, first of all, for human beings and the environment" [http://kremlin.ru/events/president/news/6365]. As such, this scientific justification, however has thus far not been proven and is therefore disputable [*Sorokhtin, 2006; Abdusamatov, 2009; Malinin, 2012; Fedorov, 2018*]. In October 2018, Russian President Vladimir Putin who took part in a plenary meeting of the Russian Energy Week International Forum also expressed doubt about the formative role of the anthropogenic factor in global climate change stating: "Indeed, we are apparently witnessing global warming, but the reasons for this are not entirely clear, because there is still no answer. The so-called anthropogenic emissions are most likely not the main cause of this warming. It could be caused by global changes, cosmic changes, some changes in the galaxy that are invisible to us – and that's that, we don't even understand what is actually happening. Probably, anthropogenic emissions influence the situation somehow, but many experts believe they have an insignificant effect" [http://kremlin.ru/events/president/news/58701]. Earlier, a similar opinion was expressed by Andrei Kapitsa: "I do not support the theory of anthropogenic warming. I believe that combatting CO_2 is not the right way. Warming is associated with fluctuations in the Earth's axial tilt, with changes in the Earth-centered ecliptic coordinates, in solar activity and numerous environmental changes that cause drastic fluctuations in global climate. Human impact is negligible compared to the processes occurring in nature" [https://lenta.ru/conf/kapitsa]. It should also be noted and the conclusion of the Russian Academy of Sciences on the signing and ratification of the 2004 Kyoto Protocol: "Scientists recognize the fact of global warming, but note high degree of uncertainty of claims that warming occurs only due to anthropogenic impact, that is, man-made emissions" [https://regnum.ru/news/263047.html].

However, the assumption that the main cause of global climate change is the "greenhouse" effect associated with the emission of greenhouse gases, determined by the anthropogenic factor, has indeed become widespread [http://www.ipcc.ch; http://www.un.org/ru/documents/decl_conv/conventions/climate_framework_conv.shtml; http://www.wmo.int/pages/index_ru.html; *Gore, 2007*]. In this regard let's briefly outline the recent scientific understanding of major climate controlling forcings.

1. The Sun is the main source of energy determining the Erath's radiation and heat balance. The energy the Sun radiates provides heat and light for the Earth. The Sun's radiant energy is the main source of energy for hydrometeorological, biochemical and many other processes occurring in the atmosphere, hydrosphere, on the Earth's surface. The Sun's energy is the most important factor for evolution of life on Earth, providing the necessary thermal conditions for life and photosynthesis. "The Sun is the only source of heat, which is powerful enough to exert significant impact on the surface temperature of the Earth and of the ambient air" [*Voeikov, 1903*].

The annual solar radiation incident on the outer limit (upper boundary) of the Earth's atmosphere averages $5.49 \cdot 10^{24}$ J [*Fedorov, 2018*]. Given that this amount is largely dictated by seasonal, interannual and multiyear variations, solar radiation (solar resource) is variable. Variations in the amount of radiant energy coming to the Earth are governed by two reasons of different physical nature: (1) changing the intensity of the solar radiation (fluctuations of solar radiation); (2) celestial and mechanic processes affecting the Earth Mean Orbital Elements, specifically, its axial tilt.

The Sun's radiant energy is known to be the main source of heat on the Earth. The redistribution of energy coming to the Earth involves such important mechanisms of heat transfer defined [*Shuleikin, 1953*] as inter-latitude heat transfer ("heat machine of the first kind") and heat transfer between the ocean and the continents ("heat machine of the second kind"). Heat transfer in the global climate system is associated with the circulation processes in the atmosphere and ocean, and the elements of the atmosphere (amounts of H_2O), determining albedo and greenhouse effects and their variability.

2. The greenhouse effect traps heat arriving from the Sun that would otherwise escape Earth's atmosphere. Of all known "greenhouse gases" (carbon dioxide, methane, etc.) water vapor is the most important, whose content can reach 4 % per unit of air volume. Global CO_2 content averages only 0.04 %, with less than 1 % of this value accounting for carbon dioxide produced by human activity [*Golubev, 2010*]. Thus, the water vapor variation by volume in the atmosphere is interpreted as almost two orders of magnitude higher than natural and anthropogenic carbon dioxide, cumulatively. While levels of H_2O are estimated almost four orders of magnitude (10,000 times) higher than human-induced CO_2 is in the atmosphere. Our Earth is a water planet indeed!

The world ocean, which occupies two-thirds of the Earth's area, is the main source of water vapor in the atmosphere. Glaciers tend to develop in highlands, while sea ice is widespread in the polar regions. The two giant ice sheets, or polar ice caps (Antarctica and Greenland) are virtually formed from water in the solid phase. Satellite imagery shows envelope of clouds surrounding most of the Earth. The clouds in themselves is water vapor. On Earth, water can exist in three different states, either as solid ice, liquid water, or vapor gas. With each phase change a specific amount of latent heat is released or absorbed. Thus, the role of water, ice and water vapor in the global climate processes (formation and change) which involves the hydrological cycle, is not comparable with the impact of CO_2 on the processes of heat exchange and climate change. The content of other greenhouse gases (methane, etc.) is three orders of magnitude lower against CO_2. Thus, the global thermal regime is determined by two natural factors (forcings): the incoming solar radiation and the greenhouse effect (the atmosphere, heated by the absorption of Earth radiation by these greenhouse gasses, in turn radiates heat back to the Earth's surface increasing the Earth's surface temperature), with water vapor being the biggest player (an increase in humidity amplifies the warming from carbon dioxide). The average temperature of outer space around the Earth is –273 °C and the mean annual surface air temperature (SAT) of the Earth is about +15 °C, in which the fraction of incoming solar radiation is estimated to be approximately 86 % of the heat (249°), while the greenhouse effect accounts for 14 % (39°) [*Monin and Shishkov, 2000*].

The causes of global climate change should therefore be sought in variations of the main climate controlling factors: incident solar radiation and the greenhouse effect of the Earth, largely governed by water vapor content in the atmosphere.

Despite the fact that global climate is controlled by a host of known interacting factors, most researchers (e.g., the IPCC) regard the increase in carbon dioxide emitted by human activities as major factor of the observed global climate warming [http://www.wmo.int/pages/index_ru.html; http://www.ipcc.ch/]. These views form the scientific basis of the United Nations Framework Convention on Climate Change (UNFCCC), the Climate Doctrine of the Russian Federation [http://kremlin.ru/events/president/news/6365] and the 2015 Paris Climate Agreement (Paris Climate Accords) which claim to chart a new course in the global climate effort [http://www.un.org/ru/documents/decl_conv/conv2010.shtml].

Even though these ideas have gained enormous traction around the world, the link between changes of global climate atmospheric CO_2 is not obvious. Neither a scientific substantiation has been provided thereto. The Earth's tilt (relative to the perpendicular to ecliptic plane) is known to be responsible for the changing seasons. One of the first explanation as to how seasons of the year succeed each other was given by Hipparchus back in the II century BC. The phenomenon has been associated with a change in the inclination of the solar incidence angle upon the motion of the Earth around the Sun (the word *klima* (climate) means the *tilt* in Greek language).

The incoming amount of solar radiation to equatorial regions shows an increasing trend (at least, in the span between 3000 BC and 2999 AD), while it is decreasing in polar regions of the northern hemisphere (Fig. 1). Due to the Earth's axial tilt, the hemisphere receives about 2 times more solar radiation in the summer, than during the winter. Presently, the angle of inclination is about 23.5° and is slowly decreasing. As a result of calculations of the Earth's insolation of [http://www.solar-climate.com/index.htm; *Fedorov, 2018*] and conducted geophysical studies, we have obtained scientific evidence that global climate warming is determined by natural causes. The most important of them is the Earth's tilt [*Fedorov, 2015a,b, 2018, 2019*], which entails an increase in the meridional heat transfer from the equator to the poles, prompting the amplified performance of the "heat machine of the first kind".

As such, the energy transfer is associated with the developing vortices (tropical and extratropical cyclones). Long-term variations in CO_2 levels result from the observed increase in the ocean surface temperature due to a decrease in the angle of the Earth's tilt and increased meridional heat transfer from the equatorial (heat source) to polar areas (heat sink). As the ocean surface temperature increases, the solubility of the carbon dioxide in water decreases, while atmospheric CO_2 tend to be increasing. The long-term variability of carbon dioxide content is thus not a cause but rather a consequence of global climate warming, determined by the change in Earth's tilt. Which is why there has never been and cannot be any scientific proof of any material impact of anthropogenic carbon dioxide on global climate change. According to our research results, long-term changes in the surface air temperature, ocean surface temperature, world ocean level, glacier mass balance of mountain glaciers and sea ice-covered area in the Arctic by more than 80 % are determined by IC or increased meridional heat transfer related to decreased Earth's axial tilt [*Fedorov, 2018, 2019*].

The scientific basis adopted in the Climate Doctrine of the Russian Federation on the anthropogenic factor of climate change implies a threat to the safe and sustainable development of the Russian Federation associated with the uncertainty of forecasts. The IPCC scenario forecast [https://archive.ipcc.ch/pdf/supporting-material/expert-meeting-ts-scenarios-ru.pdf] is based on possible scenarios of global mean atmospheric carbon dioxide (CO_2) concentrations from the perspective of anticipated levels of world industry development. For example, the calculations performed in [*Pozdnyakov et al., 2019*] consider only the RSP8.5 scenario.

However, since it is not known exactly what the real level of world production will be (in 10, 15 year and more), the forecast always contains uncertainty. In addition, as already noted, carbon dioxide is not the cause of climate change, but rather its consequence. The IPCC recommendation thus exclude the possibility of real forecasting of upcoming climate changes and therefore an adequate assessment of the climate change consequences and its impact on the quality of life of the population both in Russia and in other countries – Paris Climate Accords participants. This uncertainty is also noted in the Climate Doctrine of the Russian Federation. "Despite the extensive and compelling scientific evidence on the ongoing and projected global climate changes, there remains considerable uncertainty in the assessment of how climate change will proceed and what its impact on the environmental systems will be like, and implications for economic and political activities, and social processes in different countries and regions" [http://kremlin.ru/events/president/news/6365].

The uncertainty is thus related to the accepted scientific justification (anthropogenic factor of climate change) of the Climate Doctrine of the Russian Federation, which is not supported by scientific evidence and is therefor disputable. Solution of the discussed general problems is possible in concert with our calculations of the Earth's insolation, which can contribute to the improvement of physico- mathematical climate models and forecast simulations of its changes.

The general problems of physico-mathematical modeling result in specific issues to be solved. Thus, in the Surfbal model used by S.P. Pozdnyakov and his co-authors, solar radiation measured or reconstructed at minimum and maximum temperatures is taken as input energy signal. However, as noted above, temperature is determined by meridional heat transfer rather than the incoming solar radiation alone. This entails the problem relating reliability of the input energy signal used in the model.

A wide spectrum of major general and specific problems of physical and mathematical models mainly stems from the underestimated variations in the meridional heat transfer (MHT) associated with a decrease in Earth's tilt. The conceptual algorithm is developed on the basis of slight variations of incoming solar radiation, which fails to adequately reflect the observed trends in global temperature changes. To solve this problem (instead of MHT variation analysis), the model is generally complemented by a chemical block allowing the CO_2 trend to model the global temperature trend adequately.

Solar radiation is calculated from forecasting the mean daily and annual course for given values of latitude, longitude and time (without taking into account their long-term changes). As a result, CO_2 is taken as a factor changing the thermal regime of the climate system, whereas in reality CO_2 is not the cause but the consequence of its change. However, in the absence of projections for future CO_2 concentrations, different scenarios are proposed (using one of them, RSP8.5, S.P. Pozdnyakov and colleagues estimated the seasonal freeze depth (SFD) dynamics), i.e. there is an obvious uncertainty. The predicted SFD dynamics was calculated by the authors only for one of the IPCC scenarios. In the case of calculating the SFD dynamics for all proposed scenarios, the level of uncertainty would be 100 %.

The predicted CO_2 levels for 2050 is 466 ppm and its increase relative to 2015 (the year of the Paris Climate Agreement execution) is predicted to be 65.5 ppm. Thus, the anticipated increase in CO_2 concentration will be about 16.3 % regardless of the efforts of the countries participating in the Paris Climate Agreement (the IPCC scenarios are therefore of no avail). This is because less than 1 % of atmospheric CO_2 is of anthropogenic origin, while long-term variability almost 99 % of such CO_2 is dictated for many years by IC variability [*Fedorov et al., 2018*]. In respect to MGI and IC variations, the estimated forecast of global SAT variations also appears to be fairly well-defined (Fig. 1).

In the cold phase of the 60-year oscillation, the SAT anomaly will be approximately 0.1 °C below the calculated values, and higher in the warm phase. Fig. 3 and 6 in [*Pozdnyakov et al., 2019*] allow an inference that the authors could have obtained an approximate but fairly definite (against the model result) forecast by approximating the actual data using a linear or polynomial equation. However, uncertainty in seasonal freezing layer dynamics has resulted from of the models used by the authors.

Unfortunately, the authors are under the necessity of utilizing the modeling instrumentation, which currently appears problematic and needs improvement, primarily the conceptual definitions and logic of cause-and-effect relationships as part of the climate system and the factors affecting it and causing changes, rather than the computational sphere (space and time resolution, etc.) alone. The inference made by the authors indicate the relevance of these problems solution in the physical and mathematical aspects in climate modeling. In our opinion [*Fedorov, 2017*], the scientific justification of the Climate Doctrine of the Russian Federation also requires renovating.

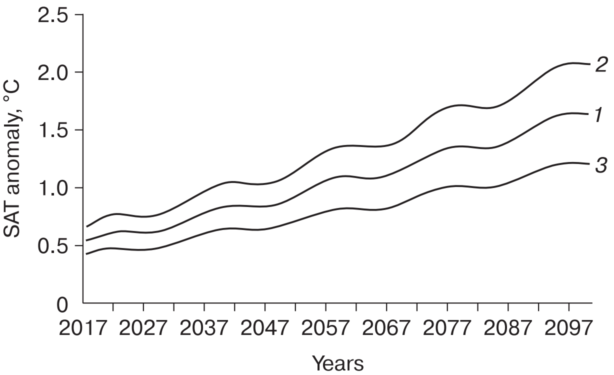

Fig. 1. Forecasting surface air temperature (SAT) in linear regression model.

1 – Earth; *2* – Northern Hemisphere; *3* – Southern Hemisphere.

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