Global temperature: Potential measurement accuracy, stochastic disturbances, and long-term variations

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Within the analysis of scientific background of the Kyoto Protocol, the following issues are considered:

– what is the possible accuracy of determination of annual average global temperature using currently available observation tools of the global network?

– what kind of fluctuations can global temperature undergo if not subjected to any anthropogenic factor?

– what is the relation between global temperature changes caused by observed changes in atmospheric greenhouses gases and the natural stochastic variability of global temperature?

It is demonstrated that (i) the poor coverage of the globe by surface temperature measurements hinders reliable detection of long-term changes in global temperature values at a level of 0.4 K per century or higher; (ii) stochastic factors of global temperature variability give rise to random trends at a level of 0.4 K per century or higher with a high possibility; (iii) an energy equivalent of the stochastic factors of global temperature variability no less than by an order of magnitude exceeds that of the anthropogenic contribution caused by greenhouse gases emission to the Earth's energy balance; (iiii) carbon dioxide increase in the atmosphere is not a cause, but rather a result of the global temperature growth, which, in turn, results either from purely random variations in the factors governing the Earth's radiation balance or from long-term variation of the global temperature index.

Introduction

International environmental treaties signed in the last decades are quite binding in the economical aspect, but not always sufficiently justified in the scientific aspect. As an example, we can mention the Montreal Protocol on Substances that Deplete the Ozone Layer (1989) and supplemental agreements. In a relatively short time after signing these agreements, it became clear that they obviously underestimate natural factors governing the variability of the ozone layer and significantly (likely, deliberately) overestimate the consequences from anthropogenic emission of clorofluorocarbons into the atmosphere. As a result, some states suffer remarkable financial losses, and Russia, in addition, paid with an actual defeat of the chemical sector of its military-industrial complex.

Rumors on the necessity to toughen restrictions imposed on economics of the state parties to the Kyoto Protocol (KP), in particular, the Russian Federation, are actively exaggerated now. It is appropriate mention here that the Presidium of the Russian Academy of Sciences, responding to the inquiry of the President of the RF on the scientific validity of this Protocol, returned the negative answer. Keeping in mind that the thoughtless adherence to KP restrictions, especially, those limiting even more strictly the emissions of greenhouse gases, can cause damage to national economy far exceeding those caused by the Montreal Protocol, it is appropriate return here to scientific bases of the so-called global warming problem.

1. Formulation of the problem

The scientific ground of the Kyoto Protocol is based on three main principles[1]:

1. In recent years, we observe the unexampled (for the last millennium) increase of the temperature amounting to (0.6 ± 0.2) K for the period of 1860–2000.

2. This increase is caused by anthropogenic emissions of greenhouse gases absorbing thermal (infrared) Earth's radiation (CH_4, N_2O, and so on) and, especially, carbon dioxide (CO_2) produced upon burning of carbon-containing fuels.

3. Further anthropogenic emissions of CO_2 will cause the steady growth of its content in the atmosphere and the increase of global temperature.

In view of these statements, it is natural to formulate the following questions:

– what is the possible accuracy of determination of the annual average global temperature with the aid of observation tools of the existing global network?

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– What fluctuations can global temperature be subjected to in the absence of the anthropogenic impacts?

– What is the relation between global temperature variations caused by the observed change in the atmospheric content of greenhouse gases and the natural stochastic variability of global temperature?

In this paper, we undertake an attempt to obtain numerical estimates for all variables entering into the above questions and to relate them to energy balance distortions following from the statement on the presence and anthropogenic origin of global warming.

2. Can we detect an increase of 0.6 K in global temperature?

The WMO observation network conducting temperature measurements on the Earth's surface includes now 10 951 stations. The arrangement of these stations (quite irregular) is illustrated in Fig. 1.

If there is at least one station at a territory of 5°×10° (roughly corresponding to the synoptic scale), then we believe that this territory is covered by observations and show it in gray color in Fig. 1. Otherwise, the territory is shown as dark in the figure. The area covered by observations (according to the very liberal criterion described above) now makes up 47% of the Earth's surface. Hereinafter, this index will be referred to as coverage by observations. Now we can estimate the accuracy, with which annual average global temperature can be estimated under these conditions.

It should be emphasized that we say just above the lower estimate, rather than calculation. We believe that all the available stations measure temperature exactly or, at least, uniform temperature measurements are ensured on the Earth's surface for the last 150 years. Then the only source of error in determination of annual average global temperature is the error in calculation of the sampled average δ, which is determined as[2]:

$$\delta = \sigma/\sqrt{n}, \tag{1}$$

where σ is the RMS deviation of temperature; n is the sample size.

Figure 2 shows the RMS deviations of the annual behavior of temperature according to the widely used CIRA-86 empirical model for different latitude belts and the percentage of covering these belts with observations (coverage p).

It should be noted that the RMS deviations presented are *RMS deviations of monthly average values of the model of annual behavior*. Actual RMS deviations during a particular year are at least 15–25% higher, but we ignore this fact. Assuming for every latitude belt with a center at the latitude φ that the monthly mean temperature for the belt part covered by observations is calculated exactly and the temperature variance for the noncovered part is $\sigma^2(\varphi)[1 - p(\varphi)]$, we have

$$\delta(\varphi) = \sigma(\varphi)\sqrt{\frac{1 - p(\varphi)}{12}}, \tag{1a}$$

and averaging Eq. (1a) over latitude with the weight proportional to the belt area cosφ, we obtain δ = 0.28 K for the error of determination of annual average global temperature.

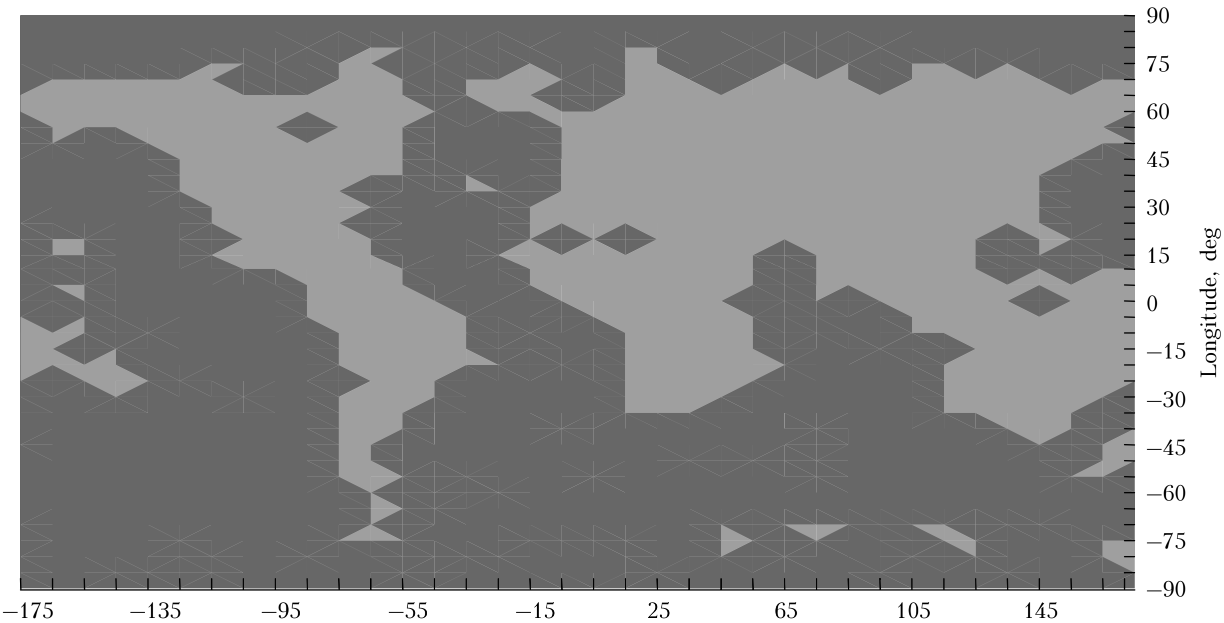

Fig. 1. Coverage of the Earth's surface by measurements of the surface temperature (2004).

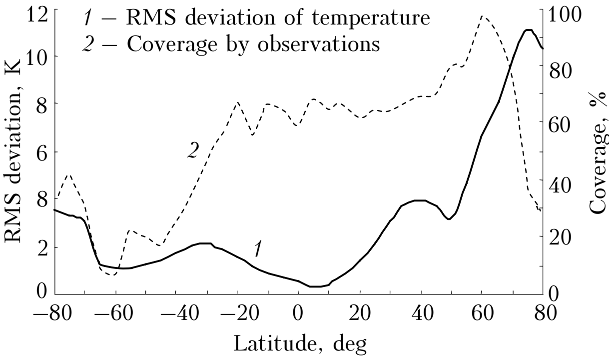

Fig. 2. Zonal distribution of temperature SD and coverage by observations.

The Third Assessment Report[1] states that the annual average value of global temperature has increased by (0.6 ± 0.2) K for the period of 1860–2000 and presents the values of δ from 0.05 K for recent years to ~0.1 K for the midnineteenth century (p. 56). The following factors are listed as sources of the error: random measurement errors, uncertainties associated with subjective corrections for the ocean temperature, and inaccuracy of correction taking into account the land urbanization factor.

It can be seen that the contribution of only the second of the listed sources is somewhat (5.5 times) underestimated relative to the rather soft estimates of the minimal error. It follows from these estimates that the 95% confidence interval at the end of the analyzed period is 0.7 K, and even if (contrary to the fact of significant extension of the global observation network for 140 years) it is assumed to be the same as at the beginning of this period, then any plot of global temperature in a band having a half-width of 0.7 K about the abscissa should be interpreted as an evidence of no long-term trend. *Under these conditions, there are strong grounds to believe that the first of the three main principles, the Kyoto Protocol is based on, does not look doubtless, because it is unclear how to justify it from the data of the existing network of surface temperature observations.*

Now let us discuss the question how did the respected WMO experts succeed in obtaining the unjustifiedly optimistic estimate for the error in calculation of the global temperature index (GTI). This question is answered in Fig. 3.

Estimating the error in calculation of annual GTI value, these experts substituted the empirical RMS deviation for all nodes of the regular network having data for a particular year into the numerator of Eq. (1) and obtained the temporal behavior of the error in calculation of the annual GTI values (curve *1* in Fig. 3). This approach obviously ignores the circumstance that readings at different nodes of the regular network correspond to different (in area) parts of the Earth's surface and therefore should be taken into account with different weights in calculation of not only average values, but also RMS deviations.

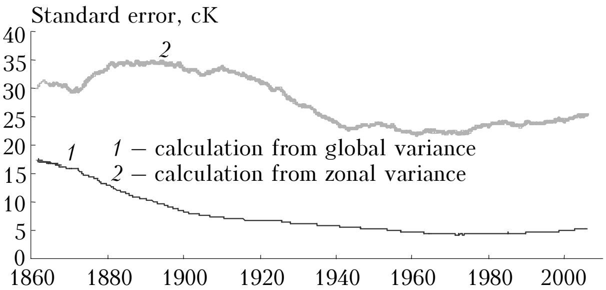

Fig. 3. Different estimates of the error in calculation of GTI.

The correct estimation of the error of sample averaging assumes the latitudinal calculation of the corresponding error and the following averaging with weights proportional to areas of latitudinal zones, that is, the cosine of latitude. This approach gives the temporal behavior of the error in calculation of annual GTI values shown by curve *2* in Fig. 3. It is easy to make sure that the estimates of the error in GTI calculation based on the CIRA-86 model (0.28 K) and on the correct calculation of *the empirical RMS deviation* (0.26 K) are close to each other and very far from the fantastic, from the physical point of view, estimate of the WMO experts (0.05 K). The last estimate is called fantastic, because for any physicist it is obvious without any calculations that the average temperature of a thermodynamically nonequilibrium system having a volume of $5\ 10^6$ km^3 cannot be calculated with an error of 0.05 K using 10 000 sensors regardless of the sensor quality, polling regime, and their arrangement in the system. (Strictly speaking, the concept of temperature is inapplicable to a thermodynamically nonequilibrium system, but since the time constant of temperature sensors used in the network is much shorter than characteristic times of nonequilibrium processes, readings of these sensors (thermometers) can be understood as temperature).

3. Can global temperature increase in the absence of causes for this increase?

When looking at the plot of global temperature evolution (Fig. 4) borrowed from the authoritative web site http://www.cru.uea.ac.uk / cru /data / temperature/ (these data nearly coincide with those presented in Ref. 1, but start somewhat earlier (from 1856) and are supplemented every month), a question arises: *How should the global temperature plot look to raise no suspicion in the presence of long-term (no matter anthropogenic or natural) trends of this parameter?*

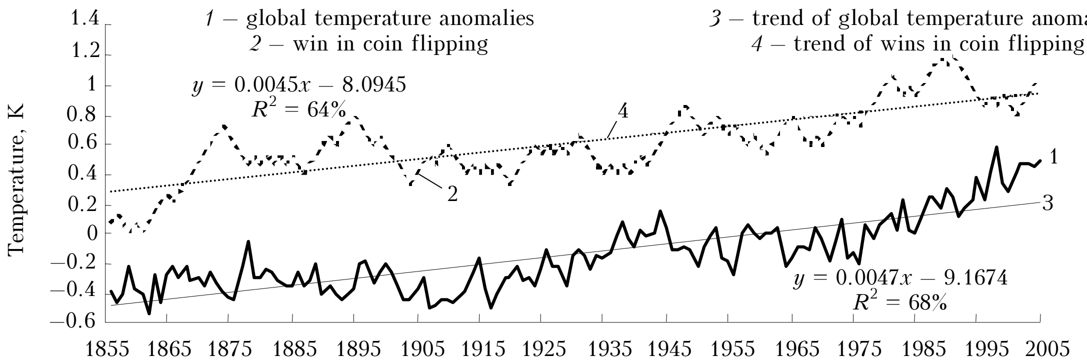

Fig. 4. Annual average anomalies of global temperature (solid lines) and results of random variation of global temperature with an annual step of 0.066 K.

The trivial answer "This plot should coincide with the abscissa" should be rejected as unrealistic, since a great number of stochastic processes inevitably giving rise to fluctuations in annual average values of global temperature are developing in the Earth's climatic system.

It should be emphasized that we say about fluctuations of just *global temperature values*, rather than results of global averaging of the measurements, whose fluctuations were considered in the previous section. Some of causes for fluctuations of global temperature are considered below, but now we take the intuitively obvious assumption that such causes exist.

From the lower curve in Fig. 4, the increase of global temperature seems to be doubtless. It is also confirmed by the equations of linear regression of temperature anomalies shown in Fig. 4 and by high values of the determination coefficient of positive linear trends (R^2). However, comparison of the curves shown in Fig. 4 raises some doubts in nonrandom conditioning of the increase of global temperature. The upper curve visualizes the results of the numerical experiment with *the knowingly stationary random process*. The essence of the experiment is the following. We assume that the global temperature anomaly in 1856 is equal to 0, and in every following year its value is assumed equal to that in the previous year accurate to 0.066 K, which is added or subtracted depending on the result of coin flipping. The interannual difference (0.066 K) was selected so that the RMS deviation of coin flipping was equal to the RMS deviation of global temperature anomalies for 150 years (0.25 K). In place of coin flipping results, in the numerical experiment we used the values of the Rnd(1) function of the Excel VBA script. Since the results shown in Fig. 4 were obtained without using the Randomize operator, they can be reconstructed by anyone.

To make sure that the close correspondence of the trend and the determination coefficient of temperature anomalies and the modeled random process is not accidental, the experiment was carried out 250 times with the use of the Randomize operator, which provides generation of independent random series. The average absolute value of the trend for the process of 150 readings was 0.0049 K/reading (that is, nearly the same as in global temperature anomalies: 0.0047 K/reading (this trend value, as can be easily calculated, corresponds to 0.7 K for 150 years)), and the RMS deviation was 0.0037 K/reading. (The rough estimate $k \simeq \dfrac{0.066\sqrt{150}}{150} \approx 0.0054$ K/reading coincides in the order of magnitude with the average value obtained in the numerical experiment.) The absolute trend values exceeded 0.0047 K/reading (for realization of 150 readings) in 107 cases of 250, and the trend turned out to be statistically significant at the 95% confidence interval in 224 cases. The histogram of the results of numerical experiment for series of 150 readings is shown in Fig. 5.

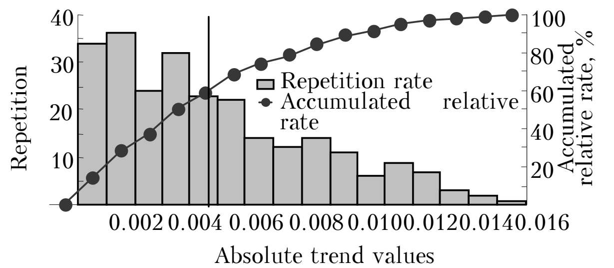

Fig. 5. Distribution of trends of wins in coin flipping in 250 series of 150 events at an error of 0.066 K (the vertical line corresponds to the global temperature trend for 150 years).

Thus, the intuitive impression on the dynamic conditioning of the global temperature increase as follows from the lower curve in Fig. 4 appears to be illusory: there are no grounds to state that the increase of global temperature for the last one and half century is not fluctuation. For more detailed description of how correct statistical calculation destroys seemingly obvious ideas on the character of a stationary diffusion process, see the well-known book.[3] It should be noted that our selection of the calculation step (1 year) is caused by the fact that at a step of, say, 1 month neighboring readings are no longer independent, because the step is comparable with the duration of the synoptic cycle.[4] With a step of 1 month selected, the results of numerical experiment do not differ principally from those presented above. However, the adequacy of experiments in this case becomes doubtful, because the results of two consecutive coin tosses, in contrast to two consecutive monthly average anomalies of global temperature, are knowingly independent. It is important to emphasize that even if the data on evolution of global temperature are considered as absolutely reliable, that is, the estimates of errors presented in the previous section are ignored, than random interannual variations not larger than the measurement error declared in Ref. 1 can lead to the observed stochastic increase of global temperature with the probability comparable with unity. (We remind that the error of measurement of the average global temperature is declared in Ref. 1 at a level from 0.05 to 0.1 K, while in the numerical experiment the values of undetectable random variations are taken at a level of 0.067 K).

4. Are there some reasons for fluctuations of global temperature?

We consider only two of the causes mentioned above not because their contribution to global temperature fluctuations is most significant, but because this contribution is easy to estimate. We say about tropical cyclones (TCs) and global albedo.

Developing in tropical waters of the World Ocean, TCs intensively mix oceanic water at a depth down to 200–400 m, and their "trace" is seen for a long time as an oceanic zone with the temperature decreased by several degrees. It is natural that the presence of such zones leads to the heat sink from the atmosphere into the ocean. This is confirmed by Fig. 6, in which the negative correlation of the TC number and the global temperature index is clearly seen (GTI is the deviation of the annual average value from the average for the period 1960–2000 in hundredth shares of degree).

The value of the correlation coefficient is 50%, but we should keep in mind that the influence of TCs on global temperature is connected not only with the TC number, but also with individual values of TC parameters.

Unfortunately, the reliable data of the TC number and TC parameters became available only when spaceborne observation tools were implemented in practice, that is, starting from the 1970s. The earlier period is characterized by the large number of missed TCs. Estimate the energy contribution from variation of the annual average TC number to global temperature from the data taken from the RosHydroMet web site.[5] Assuming that the mean length of the TC trajectory is equal to 3 000 km, the mean width is 500 km, the mean depth of water mixing is 300 m, and the mean temperature of cooling is 2 K, we obtain that to compensate for the water cooling caused by mean TC, atmospheric energy of $\sim 3.7 \cdot 10^{21}$ J is required.

The TC number varies from year to year (for the last 30 years of the 20th century it ranged from 61 to 103). The empirical annual average TC number is 82.7 and the empirical RMS deviation is 8.8, which is in a good agreement with the physically sensible hypothesis on the Poisson nature of the TC flow ($\sqrt{82.7} = 9.1$). This hypothesis passes the standard testing[2]: the statistics χ_2^2 is 2.2 at a hypothesis dismissal threshold of 5.99. It follows from the above-said that natural (that is, at the level of RMS deviation σ) variations of the energy outgoing from the atmosphere to compensate losses caused by TCs are about $9 \cdot 3.7 \cdot 10^{21} = 3.3 \cdot 10^{22}$ J. This is equivalent to 2.2 W/m^2. It follows from the Stephan–Boltzmann law that the perturbation δP of the power density on the Earth's surface P corresponds to the perturbation of the brightness temperature T:

$$\delta T = \frac{\delta P}{4P_0(1 - A)} T, \qquad (2)$$

where $P_0 = 1368$ W/m^2 is the extra-atmospheric power density of sunlight flux; $A \sim 30\%$ is the Earth's albedo.

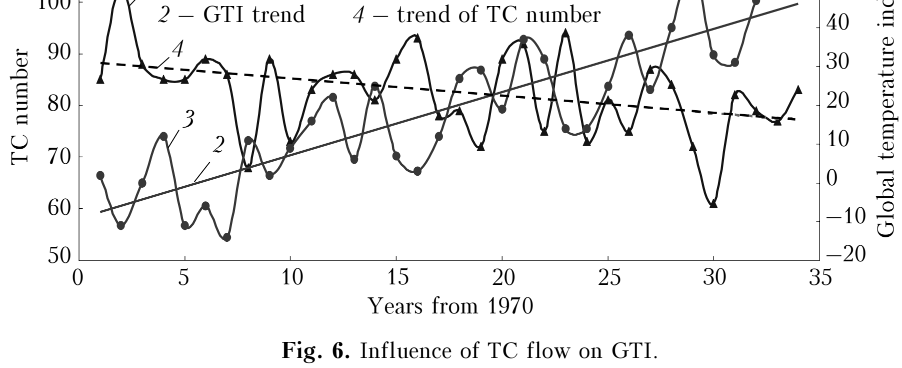

Fig. 6. Influence of TC flow on GTI.

Consequently, Poisson fluctuations of the TC flow should give rise to variations of the Earth's brightness temperature at a level of 0.14 K, that is, twice as high as used in the numerical experiment. (The brightness temperature of the Earth corresponds to the atmospheric temperature at an altitude of ~5.6 km at the "center" of the atmosphere, and its variations should correspond to variations of the surface temperature in the order of magnitude. In any case, no publications reporting observation of trends of the vertical temperature gradient are known to the author.) It follows from the above-said, in particular, that TCs form one of the mechanisms of negative feedback stabilizing global temperature. Actually, TCs can appear only if the temperature of waters is ≥ 300 K. The more often occurrence of such warm waters, which is inevitable at the increase of global temperature, leads to the more often occurrence of TCs, which, in its turn, decreases GTI.

Now let us consider another possible mechanism of GTI randomization. As is known from the simplest energy-balance climatic models, the change of global brightness temperature T is related to the change in total albedo of the Earth A as

$$\frac{dT}{dA} = -\frac{T}{4(1-A)}. \tag{3}$$

It follows herefrom that at the current values $A \sim 30\%$ and $T \sim 259$ K the global temperature (certainly, Eq. (3) corresponds to the global *radiation temperature*, but for estimates the difference between *changes* of the global surface and the radiation temperatures is insignificant) changes by ~0.9 K as the albedo changes by 1% (temperature increases, as the albedo decreases). The traditional method of albedo measurement is the measurement of the light flux from the dark part of the moon disc. These measurements give the current value $A = 29.75\%$. They are in a good agreement with TOMS reflectance measurements. The TOMS measurements are conducted by ozonometric instruments (Fig. 7) operated since 1978 (with a small gap) aboard Nimbus-7, Meteor-3, and Earth Probe satellites.[6]

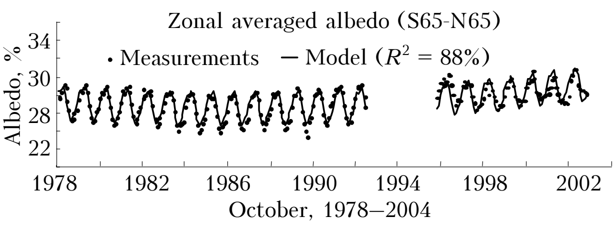

Fig. 7. Global albedo: model seasonal behavior and random component.

The average reflectance for these years is 30.1%, the RMS deviation of the seasonal behavior is ~1.8%, and the RMS deviation of the stochastic component (taking into account the discrepancies between TOMS versions VII and VIII) is no lower than 0.3%. It should be noted that the RMS deviation of interannual variations of 0.3% is equivalent to the RMS deviation of interannual variations of the external radiative action ~1.4 kW/m^2·0.3% ≈ ≈ 4.2 W/m^2. It follows from Eq. (2) that this should lead to stochastic variations of global temperature ~0.25 K (the RMS deviation of global temperature in Ref. 1 turned out to have just this value).

Naturally, a question arises: why the total RMS deviation of global temperature is relatively small (at the level of the contribution from only one of many causes)? The fact is that GTI variations are likely strongly damped by negative feedbacks in the climatic system of the Earth, which, certainly, are not limited to the feedback mentioned above.

In conclusion, we compare the contribution to the energy balance from natural variations of parameters of the Earth's climatic system (at a level of 2.5 RMS deviations) and the contribution caused by anthropogenic emissions of greenhouse gases.[1] These contributions are shown in Fig. 8. It follows from the figure that the anthropogenic effect on GTI is detected, on the most optimistic estimate, at a signal-to-noise ratio at a level of 19 dB. Seemingly, this problem is beyond the capabilities of the existing observation network.

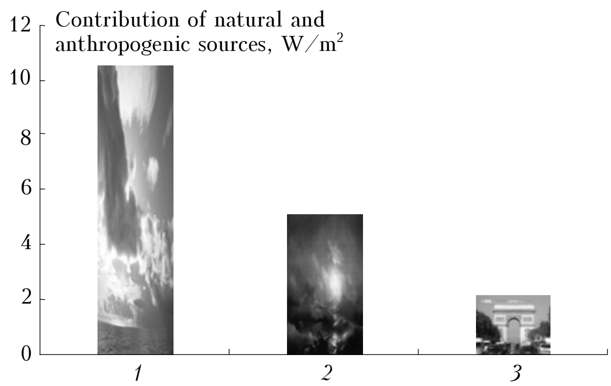

Fig. 8. Radiative effect of natural and anthropogenic processes: (*1*) variations of albedo; (*2*) variations of TC flow; (*3*) anthropogenic greenhouse effect.

The level of 19 dB is not an insurmountable obstacle for detection (as follows, for example, from the experience of radio-astronomical observations), but it imposes rather strict requirements on both instrumental and methodical observation tools.

Finally, a few words should be said on the anthropogenic conditioning of the increasing CO_2 content in the atmosphere. Elementary estimates give rise to serious doubts in this conditioning. Namely,

– the total CO_2 content in the atmosphere is $3 \cdot 10^{12}$ tons;

– CO_2 solubility in the ocean at the increasing temperature changes by 41.5 l/(ton·K);

– reaction of the sensitive oceanic layer (estimated as 30 m minimally) to temperature change is $9 \cdot 10^{11}$ ton/K;

– anthropogenic emission amounts to $2 \cdot 10^{10}$ ton/year ~ 2.4 ppm;

– ocean reaction to fluctuations of 0.06 K is 7.5 ppm;

– reaction accumulated for 140 years is 7.5 ppm $\sqrt{140} \approx 90$ ppm.

Thus, the current anthropogenic CO_2 emission of half order of magnitude smaller than the minimal reaction of the World Ocean to undetectable variations of global temperature, and the observed increase of the CO_2 mixture ratio in the atmosphere can be nearly exhaustively explained by this reaction.

Based on the above-said, it is reasonable to return to the issue of prognosis of the global temperature index. Followers of the Kyoto Protocol solve this problem mostly based on the linear trend. Fig. 9 compares the efficiency of the linear trend and the nonlinear regression of the GTI series at low-frequency harmonics, whose number is determined by the least-squares method. This frequency corresponds to a period of 178 years, the number of statistically significant harmonics appears to be equal to five, and the efficiency of the regression is 1.5 times higher than that of the linear trend.

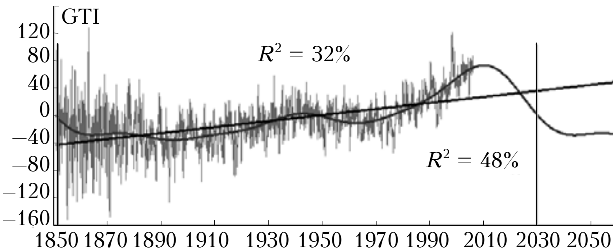

Fig. 9. Comparative efficiency of extrapolation of the global temperature index by the linear trend and by low-frequency harmonics (light vertical lines show the period of the first harmonic).

It should be noted that for practical fitting of the frequency, it is convenient to use the MS Excel Solver method. The nonlinear regression model, in particular, predicts the GTI maximum at the beginning of the next decade and the following relatively fast decrease of average global temperature. It is also interesting that the model predicts the previous GTI minimum near 1890, which is confirmed by observations.

Conclusions

1. The relatively poor coverage of the Earth's surface by surface temperature measurements does not allow the reliable detection of long-term changes in global temperature at a level of 0.4 K per century.

2. Stochastic factors of variability of global temperature with high probability give rise to random trends at a level of 0.4 K per century and far higher.

3. The observed increase of the carbon dioxide content in the atmosphere is not a cause, but a consequence of stochastic temperature fluctuations.

4. The energy equivalent of stochastic factors of variability of global temperature no less than an order of magnitude exceeds the energy equivalent of the anthropogenic contribution to the Earth's energy balance due to emission of greenhouse gases.

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