Drop in the Earth's temperature after catastrophic volcanic eruptions and impacts

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Abstract

This paper presents a simple semi-empirical method for calculating the drop in global temperature as a function of energy of a catastrophic process, which is causing a decrease in atmospheric transparency. Such processes include volcanic eruptions and impacts – falls of fairly large celestial bodies. Two empirical parameters used in the model are determined by comparing obtained results with observed natural data, and data of numerical calculations with using EdGCM global climate program. In EdGCM code calculations the relationship between the energy of the process and the dimming in the atmosphere was used that have been obtained in this work. Good agreement of all three types of data on the drop in global temperatures is presented. An extremely possible drop in global temperature is about of 55 K, when the Earth atmosphere is fully darkened.

Computed regional temperature anomalies for the cases of explosive eruptions of Pinatubo, Tambora and Yellowstone stratovolcanoes are also shown. Causes of mosaic pattern of temperature changes on the Earth due to these volcanic eruptions are briefly discussed.

Keywords: temperature, eruption, volcano, impact, meteoroid, disaster, energy, atmosphere, dimming, global cooling, year without a summer

I. Introduction

The equilibrium temperature of contemporary Earth is almost exclusively determined by solar radiation falling on it as the contribution of internal heat sources is almost 5000 times smaller. About of 30 % of the solar radiation is reflected, and the rest is absorbed by the atmosphere and the Earth surface approximately in the ratio 1 : 2. Thus there is an intensive interaction of the atmosphere with the underlying surface, so that the heat flows between them even superior the heat flux of the solar radiation [1]. It follows that the state of the atmosphere should strongly to influence on the global temperature of the Earth. Indeed, observations show that even a slight reduction in transparency of the atmosphere caused, for example, by appearance of aerosols after volcanic eruptions, quite noticeable was affecting on the surface temperature and lower air layers. There was watched, for example, the so-called «year without a summer», when, in 1816, after the biggest in the last centuries catastrophic eruption of Tambora volcano, the Earth's average temperature dropped by about 2.5 K, and its regional anomalies were of about 15 K [2, 3].

This effect is quite clearly manifested in the mathematical modeling of the climate, which is used to solve similar problems. Adapted version of GCM program for the calculation of global climate is available in the public domain as EdGCM training version of Columbia University [4]. However, to run a similar numerical programming is necessary to set certain input parameters, such as transparency of the atmosphere ψ after catastrophic event. But calculation of this value isn't completely trivial.

The proof of this statement is a formula in determining ψ-value from the book of a large group of authors [5]:

$$\psi = a \exp\left(-\frac{10^{-2} E}{b}\right), \qquad (1)$$

where E is the energy of phenomenon in megatons of TNT, a and b are constants (for dust a = 0.9, b = 6.22, see [5]). There implies from the formula (1) what at the absence of event the degree of transparency of the atmosphere will still fall to 0.9 of the nominal value. And such obvious absurdity didn't surprise any of the 26 co-authors of this book!

Another disadvantage of using exclusively numerical methods for calculating the climate effects after disasters is the impossibility of a general sight on the whole spectrum of the phenomena. In addition, numerical climate models, as experience has shown, are not stable for all input parameters, even if the result may be obtained on this mode, then we can't be sure in its correctness. For example, EdGCM program, which differs from the basic version by a fixed number of large grid cells (their number is equal to 45·20·9 = 8100 for the whole Earth in accordance with the description), on the test results is conditionally stable at the value of transparency $\psi < 0.38$, and absolutely unstable when $\psi < 0.28$. And for the atmosphere transparency close to nominal value ($\psi > 0.97 – 0.98$) there are noticeable fluctuations in numerical solution, which are equal to ± 0.1 K, that is approximately equal to the whole effect, which has been achieved by, for example, after the eruption of St. Helens in 1980 [6].

Thus, a simple theoretical model that correctly calculates degree of atmosphere transparency, and with a sufficient degree of accuracy determines the average global temperature of the Earth after catastrophic volcanic eruptions and impacts, workable in whole range of atmospheric transparency at $\psi = 0 - 1$, could be useful in climate researches. It is also important that when using this model for preliminary assessments of results we may obtain in just a few seconds, while for numerical solution on counting grid with large cells are required hours on a personal computer, and for fine grid – the use of supercomputers.

II. A theoretical model of average temperature drop of the Earth after volcanic eruptions and impacts

In the future, we will use for compactness of formulas degree of darkening of the atmosphere θ instead of the degree of transparency ψ:

$$\theta = 1 - \psi$$

The degree of darkening of light according to Buguer law [7] is equal to:

$$\theta = 1 - \exp(-\tau),$$

where τ is the optical thickness of the layer that scatters radiation.

The optical thickness of aerosol/dust layer τ, as is known, is defined as follows:

$$\tau = n\sigma D,$$

where n is the concentration of particles, σ is the interaction cross section of average aerosols/dust particle with light, D is the thickness of the layer on line of passing of light radiation. The section of aerosol particle interaction with characteristic dimensions of the order of 1 micron or more in optical range is equal to cross-sectional area of the particle S, that is

$$\sigma \approx S$$

For smaller particles in a first approximation, we can assume that

$$\sigma \sim S$$

Mass of aerosols/dust layer m is

$$m = \rho n V D S_E,$$

where ρ is the density of layer particles, V is their average volume, S_E is the occupied area of the layer (for our purposes, is normally the surface area of the Earth, or sometimes half of it). Ceteris paribus aerosol mass m in a first approximation is proportional to the energy of volcanic eruption or impact E:

$$m \sim V \sim E,$$

$$\tau \sim S \sim V^{\frac{2}{3}},$$

$$\tau \sim E^{\frac{2}{3}}$$

Than

$$\theta = 1 - \exp\left(-\frac{E^{\frac{2}{3}}}{\eta}\right), \qquad (2)$$

where η is empirical coefficient, which will be defined hereinafter. Thus, in the absence of event, that is, at the energy $E = 0$ the darkening $\theta = 0$ and the degree of transparency of the atmosphere, in contrast to the formula (1), will not change in this case.

The solar radiation passes through not dusty Earth's atmosphere relatively freely, heating the solid surface and the water, which, in turn, are heating the atmosphere. Part of received energy is emitted back in an infrared range. Aerosols/dust, floating in the upper atmosphere, intercepts a part of solar radiation, heating up themselves, and re-emits the energy in the same infrared range. But since they are in the upper atmosphere, where its density is dozens of times lower than that on the Earth's surface (an order of magnitude the density of the air falls at heights of about 18 km), we may neglect the direct heating of the atmosphere owing to aerosols/dust.

Because of the symmetry half of intercepted and reradiated flow of energy from layer of aerosols/dust leaves into space, and half – to the Earth's surface. Thus, at reducing the solar radiation by some amount owing to dust, half of it is lost for the underlying Earth surface irretrievably. Since the flow of energy from the radiating body is proportional to the fourth power of the temperature, then:

$$\Delta T_1 = T_0\left[1-\left(1-\frac{\theta}{2}\right)^{\frac{1}{4}}\right] \qquad (3)$$

where ΔT_1 is the reduction in the average global temperature due to the darkening of the atmosphere (in Kelvin, K), T_0 is the average global temperature before the incident (T_0 = 286.4 K [4]).

But in the formula (3) isn't considered that under $(\tau, E) \to \infty$ the global average temperature T_2 of the outer surface of the aerosol/dust layer, the atmosphere above of which is small compared with the normal atmosphere above the Earth's surface, tends to temperature of the Earth's surface without atmosphere, that is $T_2 \to 278.6$ K, what is lower on 7.8 K than T_0. This follows from the fact that at degree of blackness at optical wavelengths k_1 and at infrared wavelengths k_2, the spherical celestial body in equilibrium at Earth's orbit under the action of solar radiation is heated up to a temperature of:

$$T = \left(\frac{k_1 s}{4k_2\sigma}\right)^{\frac{1}{4}}, \qquad (4)$$

where s = 1367 W/m^2 is the solar constant, $\sigma = 5.670\cdot10^{-8}$ W$\cdot$m^{-2}K^{-4} is Stefan-Boltzmann constant, and the number 4 in the denominator of the formula (4) is obtained from the fact that the area of the sphere, radiating heat, 4 times greater than the area of a circle the globe, the surface of which is normal to flow of solar radiation.

Due to proximity of wavelengths of sunlight, and the near-infrared range, corresponding to the maximum at the temperatures in a question, we can assume in the first approximation that $k_1 \approx k_2$, and then the average equilibrium temperature of the Earth without atmosphere is equal $T_2 \approx 278.6$ K. Thus, in a first approximation, influence of the Earth's atmosphere increases the Earth's average temperature at 7.8 K, and the stratospheric aerosol layer heated by solar radiation will have a temperature lower than the temperature of the air layer near the surface around this value. It will be refined in the next section.

Therefore empirical correction ΔT_2 is introduced that has significant value only at high energy of disaster:

$$\Delta T_2 = (T_0 - T_2)\theta^{\frac{3}{2}}, \qquad (5)$$

and which is proportional to the energy of the event E for small values of θ:

$$\theta \sim E^{\frac{2}{3}}$$

It is used to account for the greenhouse effect. For small values of the energy E, this correction is negligible.

As a result, we obtain the final expression for the drop in global mean temperature:

$$\Delta T = \Delta T_1 + \Delta T_2 \qquad (6)$$

It should be remembered that the positive values of the parameter ΔT give a value of reduction in the average temperature of the surface layer of the Earth's atmosphere.

III. Determination of the empirical parameters of the model and verification of computational formulas

It is supposed that formulas (2) – (6) are valid for explosive eruptions of stratovolcanoes, catastrophic impacts and possibly for processes of the «nuclear winter» type, in which a huge amount of carbon black are released in the stratosphere.

Gas released from volcanoes, consists on 50 – 85 % of water vapor. More than 10 % is the proportion of carbon dioxide, about 5 % – of sulfur dioxide, 2 – 5 % – hydrogen chloride and 0.02 – 0.05 % – hydrogen fluoride [8]. At the case of the most probable variant of falling of a large meteoroid – into the ocean, emissions also are largely consisted up of water vapor. The exact ratio of steam and mineral components at the impact will depend on the energy of the meteoroid and the depths of the ocean in the crash site, so a priori it is impossible to say anything very definite. If meteoroid will fall onto a hard surface, in that case the ejection into the stratosphere will be less for the same amount of energy, but it mainly will consist of fine mineral dust that will produce greater darkening than steam. Therefore, in accordance with the provisions described in the book [5], it is assumed that for all these processes the value of the empirical coefficient η, as a first approximation, will be the same. If carbon black after large fires creates in the stratospheric reflective layer, due to a lot more of its influence on the process, as well as the fact that in this case the energy of thermonuclear explosions is mainly used to run the firestorms that create these giant black mass, the meaning of parameter η should be much lower and the same effect can be achieved at a much lower energy of the process. This version of events is excluded from consideration in this study.

Since there are known strong volcanic eruptions in historical time, for which are registered certain values of the average global temperature drops, for the first two catastrophic processes (volcanoes eruptions and impacts), the value of the parameter η may be determined experimentally. At least for two strong eruptions – Pinatubo volcano in 1991 and Tambora volcano in 1815 are known quantities of diminishing in global temperature with a sufficient degree of certainty. In paper [9] on the basis of the effects produced by a shock wave in the air, we have calculated the energy of the explosion of volcanoes Tambora (1815) and Krakatoa (1883). There were found that they are to be 5.4 Gt and 1.09 Gt of TNT, respectively. Volcanologists themselves determine the amount of volcanic disasters mainly by V_v – the volume of ejected volcanic materials: tephra, lava and others. The estimates of various volcanologists have always some variations, however, the consensus values for the case of these two volcanic disasters in terms of dense rock equivalent (DRE) are obtained quite certain – 100 km^3 and 20 km^3, respectively [5, 10, 11] . Thus, it appears that their relationship with accuracy to within 1 % is consistent with the ratio of the energy of the explosions, that is,

$$E \sim V_v$$

Therefore, as a first approximation, at known volume of material ejected during a volcanic eruption, its energy may be counted through the energy of the eruption of any of these two volcanoes. The base value will then be used just rounded parameters of Krakatoa explosion: E = 1.1 Gt, V_v = 20 km^3.

Calculations of drop in average global temperature after eruptions Mount Pinatubo and Tambora volcano by formulas (2) – (6) have been carried out at first stage of work (ejections of Mount Pinatubo was 9.4 ± 1.0 km^3 [12], so that the energy of its eruption was be 0.47 ± 0.05 from Krakatau energy). The parameter η has varied, and the method of least squares has been used by for minimizing the relative deviation of drops in the estimated temperature ΔT in these eruptions from the observed temperature drops ΔT_e. The minimum deviation is achieved with η = 46.0 $Gt^{2/3}$ and was equal to 2.1 % (see Table 1).

Table 1

N	Disaster	E (Gt)	V_v (km^3)	θ	ΔT (K)	ΔT_e (K)
1	**Pinatubo**	0.52	9.4	0.0140	0.51	0.5
2	**Tambora**	5.4	100	0.0647	2.47	2.5
3	**Yellowstone**	55	1000	0.2698	11.3	11.1

The data on the alleged eruption of Yellowstone supervolcano have been added then – as earlier reported the energy of this eruption, as expected, will be 1,000 times more than the eruption of St. Helens in 1980, and drop in the average temperature on Earth will be 20° F, that is 11.1 K [13]. As is known, volume of the ejected materials during St. Helens eruption was 1.0 km^3 [14, 15]. It follows that the energy of the eruption of Yellowstone should be 50 times greater than that of Krakatoa in 1883 (see Table 1, last line). Under these conditions, the standard deviation of the results in three reference points was only 1.9 %. Thus the results of theoretical calculations by formulas (2) – (6) are consistent well with the existing observed data for the value of the parameter η = 46.0 $Gt^{2/3}$.

Comparison of the results of theoretical calculations (ΔT) with the data obtained using EdGCM program (ΔT^*), entrance magnitude of darkening of which was calculated with formula (2), and the time of restoration of normal atmospheric transparency was 3 years, was carried out on the second stage of this work. Calculations at relatively low energy levels have been carried out in the same three points that are described in Table 1, to which were added three points related to volcanic eruptions of St. Helens, El Chichon and Krakatau [10, 11, 14 – 17]. In addition to them, at greater values of energy four calculation points CP-1 – CP-4 were added, see Table 2. All available natural observed or other external data on the average temperature drop (ΔT_e) are shown in six points of the table 2.

Table 2

N	Disaster	E (Gt)	θ	ΔT (K)	ΔT^* (K)	ΔT_e (K)
1	**St. Helens**	0.05	0.0029	0.11	–	0.1
2	**El Chichon**	0.27	0.0090	0.33	–	0.3
3	**Pinatubo**	0.52	0.0140	0.52	0.59	0.5
4	**Krakatau**	1.1	0.0229	0.86	0.92	0.87
5	**Tambora**	5.4	0.0647	2.50	2.51	2.5
6	**CP-1**	24	0.1655	6.75	6.45	–
7	**Yellowstone**	55	0.2698	11.5	11.3	11.1
8	**CP-2**	140	0.4435	20.2	20.2	–
9	**CP-3**	250	0.5780	27.5	27.9	–
10	**CP-4**	330	0.6459	31.5	32.6	–

The empirical term T_2 (see Eq. (5)) has been verified in these calculations by the least squares method. The smallest difference between the calculated values of ΔT and ΔT^* were obtained for difference $T_0 - T_2 = 9.4$ K, that is on 1.6 K larger than for value T_2, obtained from the formula (4). That is, the equilibrium temperature of Earth's without atmosphere is equal 277 K. Obviously, this is due to the fact that the degree of blackness of the Earth in the infrared range is 2.3 % more than in the optical range. Therefore, the temperature drop by the formulas (2), (3), (5) and (6) in three cases, shown in Table 1, has increased by 0.01 – 0.2 K. The minimum mean square deviation of the calculated results in these six points from Tambora up to CP-4 amounted to 2.6 %.

In small neighborhoods of points of Pinatubo and Krakatau the numerical calculations were carried out 3 times with some variation of the energy given by the eruptions. From these, it was found that there are fluctuations in the numerical results of EdGCM program, and they are about ± 0.1 K. Because of this, the average drop in temperature values for these three points is shown in Table 2 in these two cases. Thus, the influence of fluctuations of numerical data lead to errors in these points from 11 % to 20 %, so they are impractical to use in order to optimize correction amount $T_0 - T_2$. The values of numerical errors due to the fluctuations at the points of El Chichon and St. Helens are already between 30 % and 100 % of the computed quantities, so these calculations haven't been carried out. With given magnitudes of the fluctuations in first three reference points (Pinatubo, Krakatoa and Tambora) there is complete coordination of the values obtained with the help of theoretical and computational methods.

In addition, it was found that at the energy of the process more than 300 Gt stable numerical calculations could be obtained only at the initial stage, but the emergency stop of EdGCM program occurred at the fourth – fifth year after the disaster. When energy of catastrophic process is exceeding the value of 445 Gt ($\theta \approx 0.72$), no results could be obtained with using this program due to its instability. With increasing of instability of the numerical calculations, differences between computational and theoretical data begin to accumulate. In the latter conditionally stable point with energy E = 445 Gt of TNT numerical results have exceeded the theoretical value on 13.5 %. It was concluded from all received information that for high energies and, accordingly, for great darkening (E > 300 – 330 Gt, $\theta > 0.62 - 0.65$) the data obtained via EdGCM program are unreliable and cannot be used.

Natural observed magnitude of drop in average temperature after the eruption of Krakatoa was also added in Table 2. According to the available sources there is a huge scattering of this value, and it seemed that nobody may to extract anything useful from these data. However, after this temperature was obtained by theoretical and computational techniques the idea arose to analyze these «pseudo-natural data». All available Internet values of this parameter have been found with the help of Google search. Total found 8 different values in Russian segment of the global network, and 7 – in English segment. They were in the range from 0.15 K to 2 K. However, the average temperature drop value for these 15 variants was 0.87 K, which is practically equal to the calculated data, see Table 2. The results of calculation on formulas (2), (3), (5), (6) are also in good agreement with the natural observed data of volcanic eruptions St. Elena and El Chichon. The standard deviation of theoretical and observed data from Table 2 in four points from Pinatubo up to Yellowstone was also 2.6 %.

Fig. 1 shows curve calculated according to the formulas (2), (3), (5), (6) when $\eta = 46.0$ and $T_0 - T_2 = 9.4$ K, where the ordinate axis represents the parameter lg $(1 + E/E_0)$, $E_0 = 1.0$ Gt. The first two points on the curve are the observed values of the temperature drop after the eruptions of St. Helens and El Chichon, and then – calculated values from Pinatubo up to CP-4, inclusive, obtained by EdGCM program. All these data are presented in rows 1 – 10 of Table 2. In the limit, when the energy tends to infinity, maximum drop in the average temperature at the Earth's surface is 55.0 K. With precision up to 0.05 K this is achieved at the energy of process E = 7560 Gt and the darkening $\theta = 0.9998$.

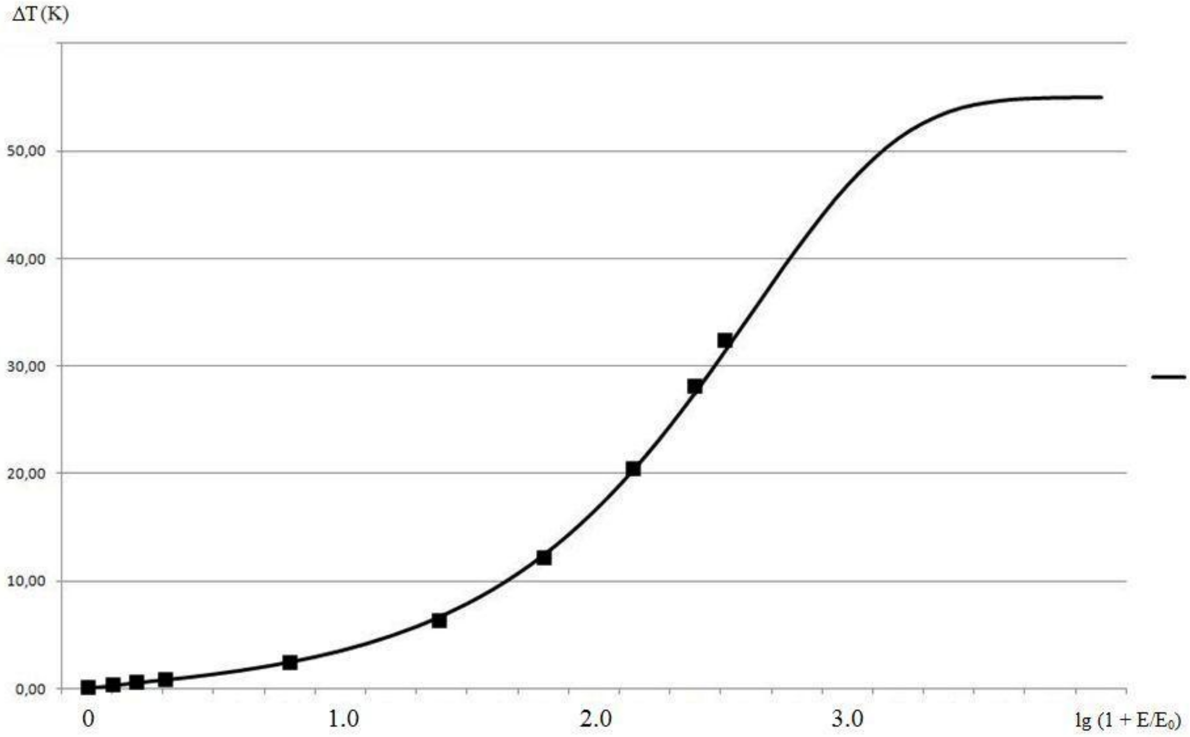

Fig. 1

Note that the graph of drop of average global temperature by the logarithm of the energy of process in Fig. 1 essentially is typical s-shaped curve characteristic of many transients.

IV. Regional anomalies in the Earth's temperature after volcanic eruptions

Consider now the regional changes in the Earth's temperature in first and second years after the disaster, when the temperature anomalies are maximal, for two real and one hypothetical case of volcanic eruptions. These results were obtained by EdGCM program. Fig. 2 shows a map of distribution of mean annual temperature anomalies of the air at the surface of the Earth after the eruption of Mount Pinatubo in 1991 in the first year after the disaster, and Fig. 3 – in the second year.

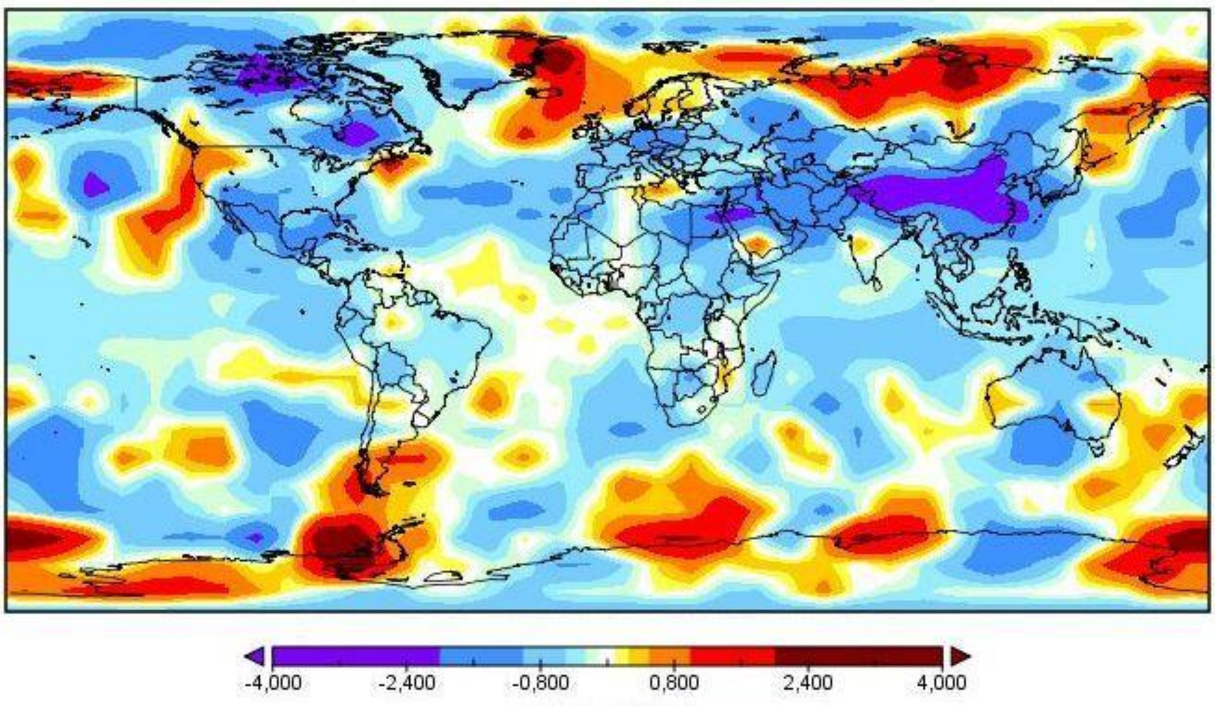

Fig. 2

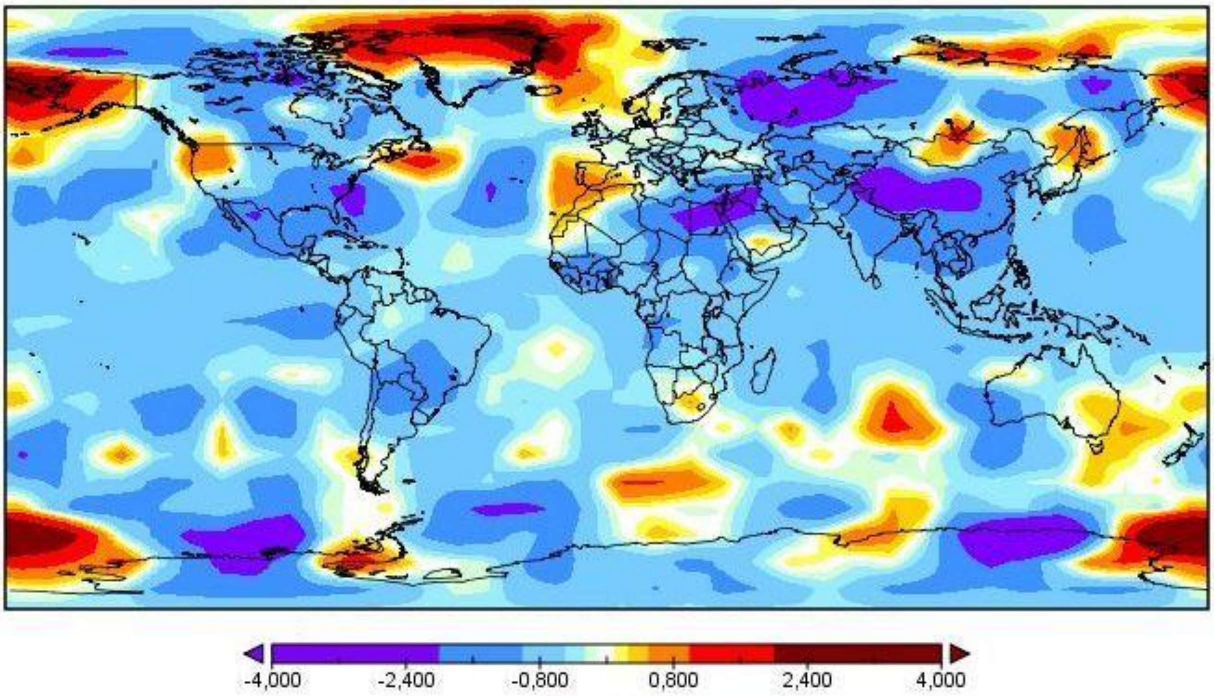

Fig. 3

Distributions of average annual anomalies of surface air temperature in the first and second years after the eruption of Tambora are shown in Figs. 4, 5. According to these four maps, we can see a large mosaic pattern of temperature changes due to volcanic eruptions, leading not only to regional cooling, but even to warming. According to these maps and to Table 3 we can see that the average regional anomalies (ΔT_{min} and ΔT_{max}) modulo a lot more than the change in global temperature (ΔT_g), and they are almost always stronger in the second year than the first. Calculations have shown, however, that the monthly anomalies are the most extreme in the first year after the event. So, after the eruption of Tambora the maximum monthly regional temperature was drop in June, in year without summer, reaching – 15.7 K. The maximum monthly warming was 8.8 K.

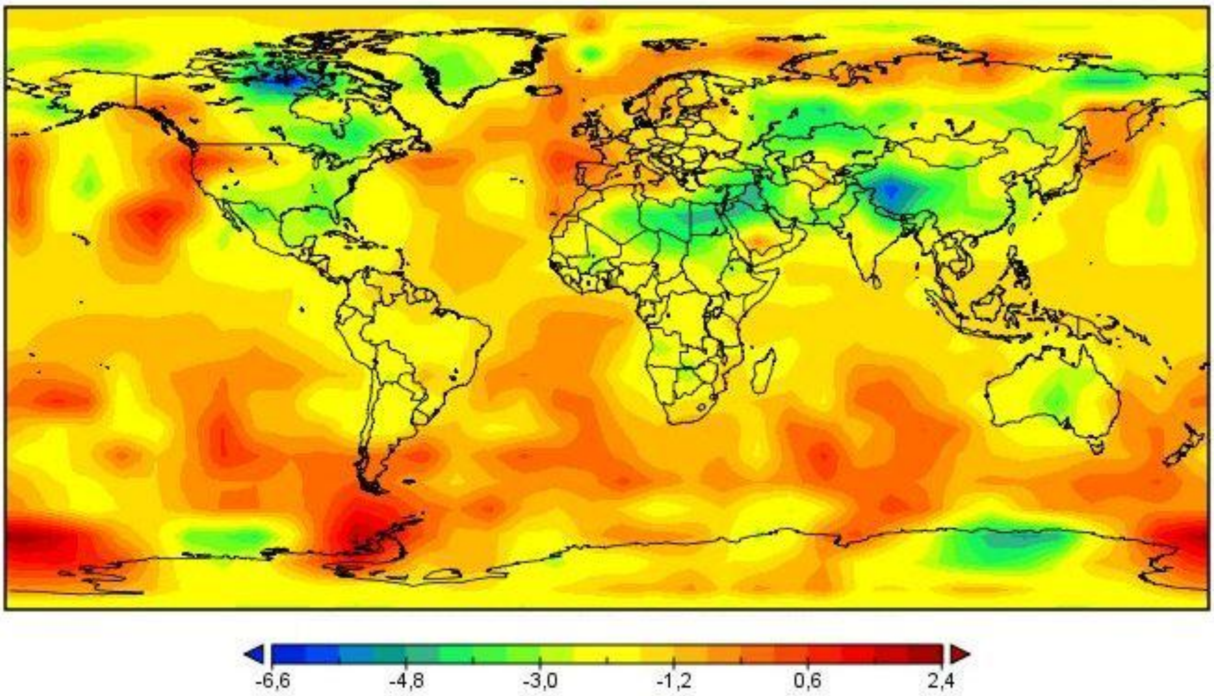

Fig. 4

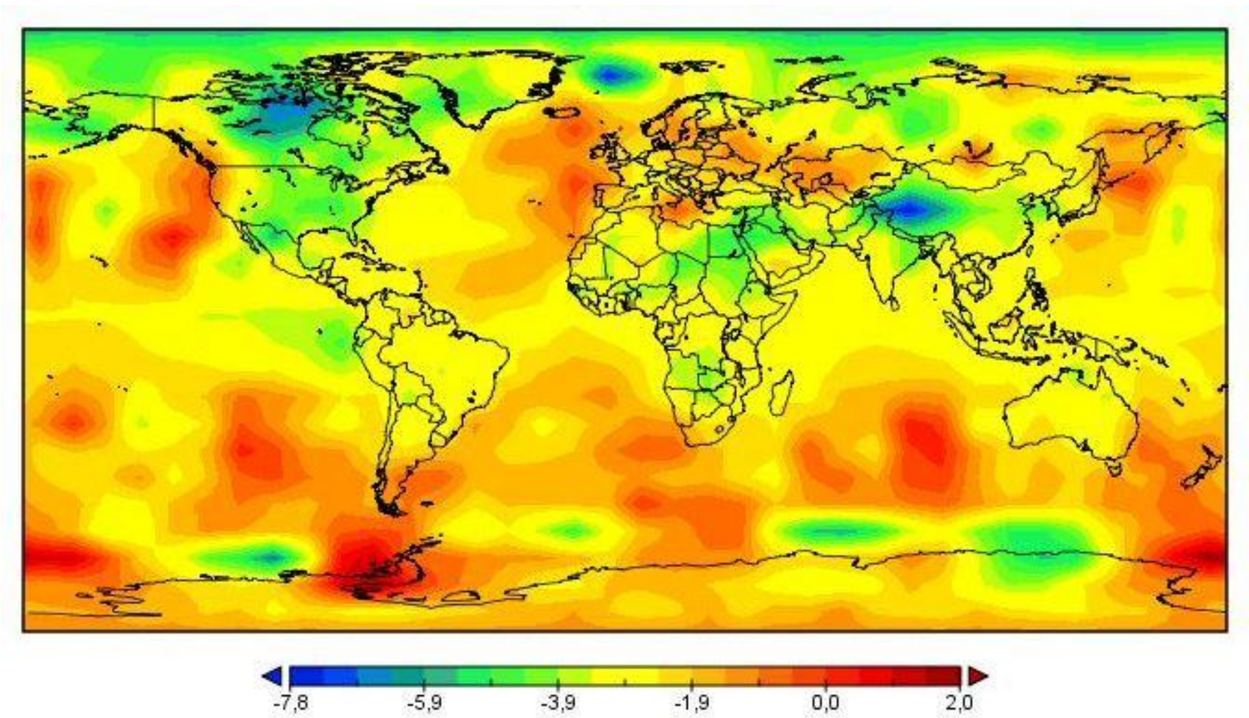

Рис. 5

Table 3

N	Disaster	First year			Second year		
		ΔT_g (K)	ΔT_{min} (K)	ΔT_{max} (K)	ΔT_g (K)	ΔT_{min} (K)	ΔT_{max} (K)
1	**Pinatubo**	– 0.58	– 3.93	3.79	– 0.59	– 5.30	5.23
2	**Tambora**	– 2.41	– 6.55	2.37	– 2.51	– 7.85	2.01
3	**Yellowstone**	– 10.6	– 18.8	– 0.85	– 11.3	– 24.8	– 3.96

Zones of the maximal regional cold snaps are concentrated, as one would expect, on the mainland or in the immediate vicinity of it because of large thermal inertia of the ocean. It may be noted that the relative warming occurs, usually in the polar regions of the world. The maximum deviations of the average regional extreme values from global temperature anomaly in these two cases under consideration reaches 6 K, and for a much more powerful hypothetical eruption of Yellowstone Supervolcano – up to 13.5 K, see Table 3. At low energies, the global temperature anomalies in the first and second years after event are changing slightly within the numerical fluctuations, but when the process energy is measured in the tens gigatons of TNT, the difference between them is becoming somewhat more pronounced.

Figure 4 corresponds to 1816 that was named as «year without a summer» in North America and Europe, with the exception, perhaps, of extreme west of Europe. The estimates are broadly in line with historical records, especially for North America. It has been reported, in particular, that in the US national holiday July 4, 1816, in subtropical Savannah (GA), the temperature was below 8° C at average minimum for July of 23° C [3]. So, it fell from magnitude of normal July low on the value of maximum monthly anomaly (~ 15 K) what indicates the qualitative agreement between the calculated and observed data, at least. At the same time, according to fig. 4, the average annual temperature drop in Savannah in 1816 was about 4 K, which is 1.5 times more than the average in the Earth.

In general, at reducing the Earth's temperature by about 11 K, as in the supposed eruption of Yellowstone, no longer occurs of zones with temperature raising – the temperature falls even in the most relatively «warm» anomalies (see Figure 6 and Table 3). Regional anomalies in this case are mainly determined by the thermal inertia of the ocean, and, therefore, more or less relatively warm zones are located only over it. The only exception is the area of cold Antarctic Circumpolar Current, which is the largest in the world, exceeding flow of Amazon River 700 times, and, partly, in equatorial zone near the Pacific coast of South America (the Southern Oscillation zone), where the northern branch of the Antarctic Current – Humboldt Current flows [18 – 21]. Despite this the anomalous cooling of Antarctica is less than the Arctic, the Americas, Africa and Siberia.

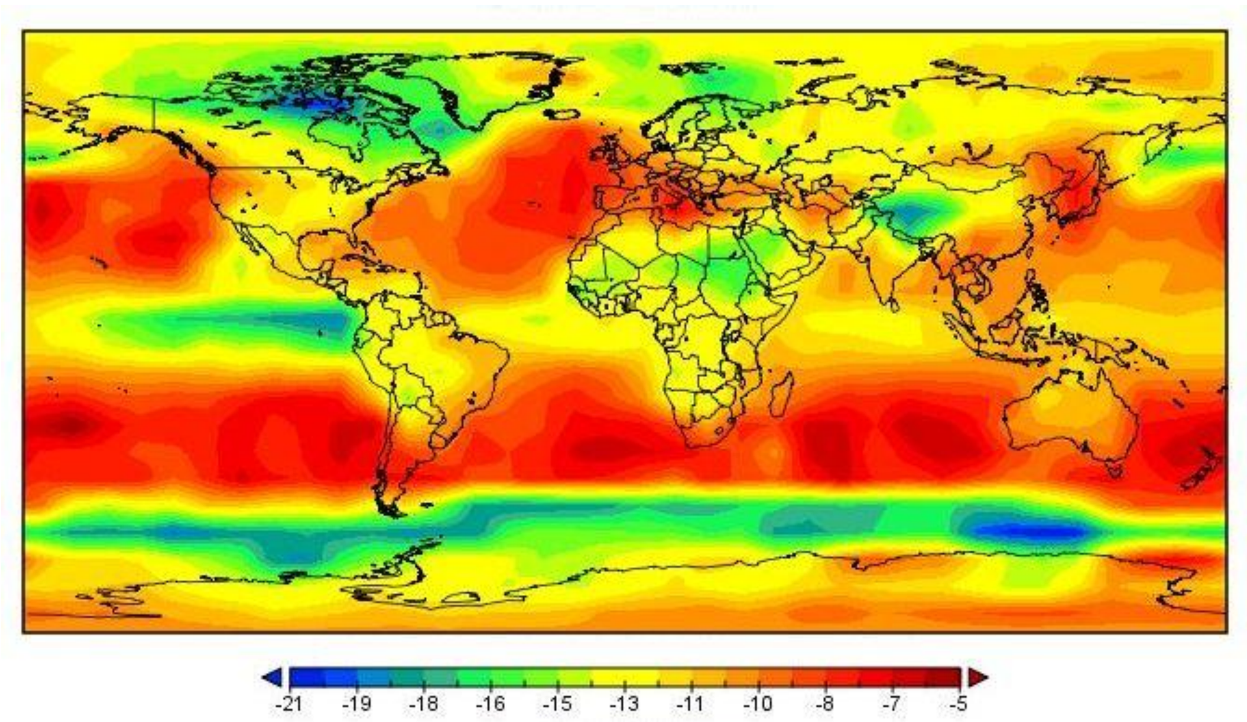

Fig. 6

Normal lighting in the summer in the middle latitudes is $I_{max} \approx 17 \cdot 10^3$ lx (lux) and in cloudy weather – $I \approx 12 \cdot 10^3$ lx [22]. Then the change in average daily surface air temperature over a local zone in the Earth's middle latitudes, it is possible to estimate at a first approximation by the following formula:

$$\Delta T_3 \approx T_0 \left\{ \left[1 + \frac{1}{2} \cdot \frac{2}{3} \left(\frac{I_{max}}{I} - 1 \right) \right]^{\frac{1}{4}} - 1 \right\} \tag{7}$$

It is assumed in formula (7) that the ratio of illumination at normal and cloudy weather persists during daylight for 2/3 day and half of the loss of direct solar radiation is compensated by re-emission of clouds in the infrared range, and steady-state temperature, as always, is proportional to the fourth root of the incident energy flux on the surface. Hence, with an average temperature of $T_0 = 286.4$ K, we may find that $\Delta T_3 \approx 9.5$ K. This is the order of magnitude's estimate of the maximum temperature rise in the center of the anticyclone in summer under normal atmospheric conditions.

In winter, when the direct solar radiation is relatively small, and the temperature of such Earth's zones is supported mainly by heat exchange with the ocean and with warmer regions of the Earth's atmosphere, on the contrary, shielding of infrared radiation of terrestrial surface by clouds formed by cyclone, leads to increase in surface air temperature. We can expect that in the center of the cyclone maximal possible increase in temperature in winter is in order of magnitude the same as in the center of anticyclone in summer, that is, at the level of about 10 K. This is why during not too strong reduction of global transparency of the atmosphere there are regional areas, where the temperature increases after incident of small or moderate scale. Because of this, basically, the temperature increase must occur not only over the oceans that are heat accumulators, but in the polar regions, at a greater cooling in tropics that is generally consistent with regional temperature anomalies, represented in Fig. 2 – 6. Hence, by the way, it also follows that the decrease in the maximum temperature after disaster occurs in the summer, what was seen after Tambora eruption in 1816.

Conclusions

1. A proposed simple semi-empirical method for calculating of drop of the global temperature in the dependence of the energy of catastrophic process, which is causing a decrease in atmospheric transparency, gives results that agree well with the observed and numerical data.
2. Limit of global temperature drop at the total eclipse of the atmosphere is about 55 K.
3. There is a large mosaic pattern of regional temperature changes in considered catastrophic processes, especially at relatively low energies of the disaster.

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