Positive and negative rates of temperature changes at weather stations of Northern Hemisphere

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Abstract. Temperature data from 1956 to 2016 at 927 weather stations of the Northern Hemisphere is studied focusing on the emergent properties of the climate system. We introduce a measure to estimate climate variability. The measure is calculated as the correlation coefficient of mean-positive and mean-negative temperature rates which, respectively, are connected with the influent and effluent energies averaged over the observation interval. It has been found that the mean-positive and mean-negative rates are balanced and have a high degree of association with each other. A hypothesis about the essence of geospheric balancing is proposed, and estimates for it are obtained. Changes in the measure are calculated in the period from 1999 to 2016. The thus discovered properties open a way for comparisons of the observed and emergent characteristics that may foster the development of ideas related to climate. This approach is aimed at monitoring climate variability and paving a promising path to this goal.

1. Introduction and Problem Statement

Interest in timely receipt of physically reasonable estimates of climate variability and future most probable states of the climate system has been increasing. The reason is high uncertainty of the consequences of global stresses [1] predicted and increase in climate and weather variability with a further rise in global temperature. Approaches need to be developed to assess the variability, apparently a posteriori, but sufficient ones to see global trends.

The climatic system of the Earth is considered to be a combination of a large number of physical quantities, climatic elements that interact with each other and with the environment. Until thermodynamic characteristics change sufficiently slowly, a stable state is maintained in the system. Papers [2, 3] characterized such a system as an open one in a state of so-called flow equilibrium.

A study of the complex systems is useful only by identification of their distinctive properties, which are associated with the presence of the system itself and which cannot be reduced to properties of its subsystems and individual elements or superposition of their properties [2]. These system properties are known as emergent and should be identified.

We believe that the variability of the holistic climate system should be defined as its emergent property. The variability is a complex notion. Due to the accumulation and dissipation of external and internal energy in the open system, both the state of consistency and the stochastic state can be realized in various ratios. The consistency is decreased during energy dissipation and radiation beyond the boundary of the system. External forcing and heat storage create reverse processes. The conditions of realization of these states are far from clear. Therefore, additional empirical knowledge obtained by
monitoring of climate elements is needed, and new estimates of the state of the system, which are suitable for the introduced emergent property, will be useful in this problem.

The variability cannot be measured directly. Therefore, it is necessary to introduce a measure by calculating, with which it will be possible to estimate the variable state of the holistic climate system as a result of observations. The design of the measure is not apparent; it seems that it should be determined by a composite functional that depends on all the processes in the system, as far as they can be selected based on ideas and observable data.

These are not strict requirements; different options for constructing measures are possible, and they will estimate various aspects of the climate system variability. In any case, it is necessary to presume the presence of the emergent properties, and the criterion for the efficiency of the chosen measure will be new knowledge about the climate system.

As a possible option, we introduce the necessary measure using the correlation coefficient of influent and effluent components of energy at a specific weather station. The global imbalance of these energies is precisely the climate variability, also by this definition, the correlative measure implicitly contains information about the energy assimilation in the atmosphere, in the active soil layer, and about the transport of air masses, and the boundaries of temperature fields in space and time.

It was shown in [1, 4, 5] that global warming leads to an increase in the frequency and intensity of extreme weather events. Significant fluctuations in regional trends were observed. In this paper, the application of the rates of temperature changes suppresses the low-frequency components of local variations and, therefore, increases the sensitivity to global and discrete events that are present in the holistic climate system.

The existing circumstances urge one to estimate the variability of the holistic climate system more often, e.g., every year. For this, we apply the introduced correlative measure and study the related properties of the system.

2. Data and Calculated Values
We used a series of average monthly surface temperatures measured from 1955 to 2016 at 927 weather stations in the Northern Hemisphere provided by the University of East Anglia [6]. This data is based on the Global Historical Climatological Network (GHCN). The network contains the information needed to quantify climate changes and is internationally recognized [7]. A competent correction of the uniformity of data series is carried out there to minimize non-climatic effects, as well as automatic data quality control [8, 9]. Weather stations were selected if the continuous observation mode was supported, and the total period characterized by the lack of data did not exceed 3% of the number of monthly average values used.

The initial values \(t_{s,y}\) are the average annual temperatures under time index \(y = 1955, 1956, \ldots, 2016\) at a weather station under number \(s = 1, 2, \ldots, 927\). They were calculated by averaging the original monthly values within a calendar year. Then series of ascending differences of the average annual temperatures were calculated using a one-year increment. These differences,

\[
\Delta t_{s,y} = t_{s,y} - t_{s,y-1}, \quad y > 1955,
\]

are proportional to the rates of temperature changes at weather stations under number \(s\) for years under number \(y\). The differences were used to calculate the positive

\[
\Delta t_{s,y}^+ = \Delta t_{s,y}, \quad \text{if } \Delta t_{s,y} > 0, \quad \text{else } 0
\]

and negative rates

\[
\Delta t_{s,y}^- = \Delta t_{s,y}, \quad \text{if } \Delta t_{s,y} < 0, \quad \text{else } 0.
\]

We introduce mean rates \(\langle \Delta t_{s,y}^+ \rangle\), and then calculate the mean-positive \(\langle \Delta t_{s,y}^+ \rangle\) and mean-negative \(\langle \Delta t_{s,y}^- \rangle\) rates, mp- or mn-rates below. The two last ones have different numbers of addends and are
calculated by averaging within the observation interval from 1955 to \( y \). The sums and differences of these quantities are of interest, but the following inequalities should be noted when calculating:

\[
\langle a t \rangle \neq \langle a t^+ \rangle \pm \langle a t^- \rangle \neq \langle a t^+ \pm a t^- \rangle .
\]  

(4)

The correlative measure under discussion as the modulus of the correlation coefficient of \( m_p \)-rates and \( m_n \)-rates for years under number \( y \) is defined and designated as

\[
\text{cmm}_y = \left| \text{corr} \left\{ \langle a t^+_{x,y} \rangle; \langle a t^-_{x,y} \rangle \right\} \right|.
\]  

(5)

In this expression, averaging is done over weather stations under number \( s \).

3. Results and Discussion

The differences \( \langle a t^+ \rangle - \langle a t^- \rangle \) are presented in Figure 1a; they were determined at each weather station of the Northern Hemisphere for the entire time interval under observation from 1955 to 2016. These mean values are positive as the definition (2, 3) and represent the average range of temperature variability.

Figure 1. Distribution of characteristics of the rates of temperatures at 927 weather stations. The observation interval is from 1955 to 2016. In panel (a) are differences of \( m_p \)- and \( m_n \)-rates, in panel (b) are sums of \( m_p \)- and \( m_n \)-rates. The color scale for circles on the panels is represented in Table 1. Numerical estimates of the quantities are in Table 2.

Table 1. Color scale for circles in Figure 1. The averaging value (°C/year) over the one-color space is designated by the vinculum.
The sums of the mp- and mn-rates \( \langle d^+ \rangle + \langle d^- \rangle \) were also calculated. In this case, a differential approach is implemented, since the addends have different signs. It allows one to see that the sums differ little from zero at many stations, and it is represented in Figure 1b.

On the other hand, it follows from the main heat transfer formula that the mp-rates have a monotone relationship with the energy influencing the area of the weather station during the observation period; in turn, the mn-rates are also connected with the energy effluent from there. Figures 1a and 1b show that these energies are close to each other. They represent a variable part of the total energy at weather stations.

This variable component globally increases together with latitude and locally with growing continentality. Also, it is decreasing in locations influenced by the warm Alaska Current and by the Gulf Stream. These facts correspond to many observations of warming at high latitudes. The phenomenology of similar manifestations was described in [10]. It is possible that an empirical ethnoscience concerning changing unusually cold seasons to unusually hot ones and vice versa is due to this fact. There are other examples of symmetry of the temperature characteristics. For instance, the authors of paper [11] showed that deviations of the average annual temperature from the average long-term temperature are symmetrical for two types of years: extreme warm and extreme cold ones. Besides, these deviations are more significant in regions with low temperatures than with high temperatures.

As regards this case, the distribution of samples of the sums is much sharper than the normal one (see Table 2). For this reason, it should be assumed that in the holistic climate system there is a mechanism balancing the influent and effluent energy. Such a mechanism can be considered as a spatially distributed accumulator with limited capacity.

The result of our calculations of the distribution of the temperature rates across continents does not contradict the existing ideas about the geography of climate. This correspondence indicates the correctness of the source data and the transformations.

As a result of observations and elementary calculations, an impressive fact can be stated that the mean-positive and the mean-negative temperature rates calculated for the entire observation period at the same station are close to each other in absolute value in a large number of cases.

| Table 2. Characteristics of the distribution of sums of mp- and mn-rates of temperatures at 927 weather stations presented in Figure 1b in comparison to the normal distribution. The time interval is from 1955 to 2016. |
| --- |
| Characteristics of distribution | Dimension | Values in Figure 1b | Normal |
| Sample value | Stations | 927 |  |
| Min value | °C/year | -0.452 | -∞ |
| Max value | °C/year | 0.492 | ∞ |
| Mean value | °C/year | 0.016 | 0 |
| RMS deviation | °C/year | 0.119 | σ |
| Skewness |  | 0.035 | 0 |
| Kurtosis |  | 1.769 | 0 |
| σ rule | % | 74.87 | 68.26 |
| 2σ rule | % | 94.71 | 95.44 |
| 3σ rule | % | 98.17 | 99.73 |

Figure 2 shows the results of the calculation of the introduced correlative measure cmm.; these values were calculated using all 927 weather stations. From 1955 to each year with number y, the most prolonged intervals were used to find the mp- and mn-rates. It is known, following the
recommendations given in the International Meteorological Organization, that a 30-year averaging interval is used to determine climate estimates. It was determined that the minimal length of the interval which is suitable for performing the linear regression for cmm, also comes to 30 years. Therefore, the regression line was calculated for 31 points, with y increasing from 1986 to 2016.

Looking at Figure 2 one can conclude that the interval length in the implemented boundaries is not decisive for calculating the correlative measure. The measure cmm, deviates from the regression line and approaches it over long ranges of y that indicate the natural behavior of the measure corresponding to the observed data.

The correlative measure characterizes the consistency of the mp- and mn-rates of temperatures. The consistency changes under the influence of energy whose source can be both external and internal forcing. The regression line shows the regular part of the correlative measure. As the determination coefficient shows, this part is equal to 0.934, and exceeding the last value of the regression line over the first one is about to 4%. At every weather station in the period from 1986 to 2016 the influent and effluent energies, in total, affect the climate variability, which is characterized by the calculated correlative measure.

![Figure 2. Estimates of the correlative measure are indicated by red circles; the regression line is blue.](image)

| #   | Sample value | 31 |
|-----|--------------|----|
| #2  | Level of significance | 0.01 |
| #3  | Student's bilateral criterion | 2.756 |
| #4  | Determination coefficient | 0.934 |
| #5  | Slope coefficient of regression line | $1.223 \cdot 10^{-3}$ |
| #6  | Standard error of the slope coefficient | $6.026 \cdot 10^{-5}$ |
| #7  | Confirmation of significance of the slope: #3<#5/#6 | $2.756<20.297$ |
| #8  | Exceeding the last value of the regression line over the first one | 4.05% |

4. Conclusions
Once the reality of the climate system is recognized, the existence of some emergent properties becomes necessary. We chose the variability of climate as an emergent property of the system. Estimating the variability also assumes some options, and in this paper we have introduced a correlative measure. It allowed us not to use the traditional elements of climate directly and paved a
way for the construction of functionals characterizing the climate system in various aspects. This path may be helpful for a subsequent conceptual foresight.

The above mean-positive and mean-negative rates were studied from 1956 to 2016 at 927 weather stations in the Northern Hemisphere of the Earth. For the first time, resulting in observations and elementary calculations, some regularities that are inherent in the climate system have been established. We formulate them qualitatively; their numbers are given in the main text.

The distribution of sums of mean-positive and mean-negative rates of temperature is much sharper than a normal one. Therefore, these pairs at the same station are close to each other in absolute value in many cases.

The above-introduced correlation measure takes into account some information about the rates of temperature changes. The estimates of the measure demonstrate a statistically significant increasing consistency in the climatic system during the period under study in the Northern Hemisphere.

Some cyclical movements are an intrinsic property of the external forcing. Therefore, these unique features will be repeated if the state of flow equilibrium is maintained. In this context, they can be used as a test of climate models and serve to correct them.

Still, it constitutes only a part of total climate variability, and at the moment there is no necessary information to compare these results with real events. To solve these problems, some empirical base is necessary. However, the physical conditionality and the possibility of comparing theoretical and observed values deserve attention. In any case, the introduction of the correlative measure seems to be justified.

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