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The negative correlation between the changes in Moscow's continentality index and mean annual temperature

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Abstract. Natural variability plays a large role in local climate that makes it difficult to detect the local signal of global climate change even on a multi-decadal timescale. Due to this reason, searching for climate indices that are less sensitive to natural variability and more sensitive to global climate change is an important scientific activity. Here, we show that the observed changes in Moscow's continentality index – four percent decrease per degree increase in mean annual temperature – are in line with climate model simulations, and hence they could be attributed to the global climate change, at least in principal.

1. Background

Any state of the climate system is portrayed by a certain set of regional climatic conditions, in brief, local climates. Essential changes in the state of the climate system go along with the changes in the set of local climates. Among the various characteristics of the local climate, the seasonal course of monthly air temperature is very generic one [1]. It represents the nonlinear response of the climate system to seasonal changes in spatial distribution of radiation balance, and therefore its amplitude is not completely determined by incoming solar radiation. Other factors (e.g., atmospheric circulation) are also important. The effect of these factors could be described by Gorczinski's continentality index (GCI).

GCI was proposed by Wladislaw Gorczynski in the beginning of 19-th century [2]. Since Gorczynski is known as a pioneer of actinometric measurements (cf. Moll-Gorczynski pyranometer), his interest to measuring continentality may be related to the question posed by Voeikov in 1884 [3], "… everywhere, the air temperature is higher than it could be expected from the solar heat supplied depending on latitudinal gradient as compared to that at equator. Should one conclude from here that moderating effect of water could be noticed not only in reducing the temperature extremes between winter and summer but also in reducing the differences between latitudes?"

Gorczynski noticed that the difference between mean air temperature of the warmest month and that of the coldest month (A_o) over the ocean between 30°S and 60°S (i.e., in the areas most remote from land) depends on the sinus of latitude, $A_o(\phi)=12\sin\phi$, and proposed to measure continentality using the following equation:

$$K=c(A-A_o(\phi))/\sin\phi$$

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where A is the difference between mean air temperature of the warmest month and that of the coldest month in the point of observations, c is a calibration coefficient chosen to make K equal to 100% at Verkhoyansk (i.e., in the area the most remote from the ocean under westerlies):

$$c=100/(A_{\text{Verkhoyansk}} - A_{\text{o}}(\phi_{\text{Verkhoyansk}})) = 1.7$$

GCI is used to characterize the climatic conditions of the European continent [4-5], and calculated using the equation:

$$K=1.7A/\sin\phi - 20.4$$

A local climate is defined as transitional maritime for $0 \leq K < 33$, continental for $33 \leq K < 67$, and extremely continental for $67 \leq K < 100$.

In this paper we evaluate the hypothesis that Moscow's climate may become transitional maritime under global climate change associated with radiative forcing caused by human-induced emissions of carbon dioxide.

2. Methods

The expected changes in Moscow's CGI under global climate change were derived from the runs of MPI-ESM [6-7], one of the well-known models of the climate system. The outputs of the model runs include the data on monthly air temperature at 1.875° grid. These data were used to calculate the CGI and mean annual temperature (MAT) for the Last Millennium (850–1850) and for the period 1961-90 in the grid cells that fall within a rectangle surrounding the Moscow and covering the central part of the East European Plain located between 51 - 59°N and 31 - 42°E.

To detect the signal of global climate change in the data of observations at the Moscow's weather station we calculated 30-year moving average values of monthly air temperature:

$$T_{30}(m,n) = \frac{1}{30} \sum_{k=n-14}^{n+15} T(m,k)$$

where $T(m,k)$ is the mean air temperature in the month m of the year k, $T_{30}(m,n)$ is the mean air temperature in the month m averaged over 30 years between the year (n-14) and the year (n+15).

Then, we used $T_{30}(m,n)$ values for n from 1965 to 2000 to calculate the time series of GCI and MAT shown at figure 1.

3. Results

Comparing the MPI-ESM runs we found 2.7-5.3% decrease in CGI at the grid cells surrounding Moscow accompanied by 0.76-1.17 °C increase in MAT. The ΔGCI/ΔMAT ratio ranges between -5.38 and -2.56 %/°C with median value -3.94 %/°C and suggests that Moscow's climate would become less continental under global climate change associated with radiative forcing caused by human-induced emissions of carbon dioxide.

Linear regression of CGI on MAT derived from the data of observations at the Moscow's weather station (WMO Station Index: 27612) leads to the similar conclusion about the rate of CGI decrease with increasing MAT: the slope of regression line (figure 1) is equal to -3.96±0.93 %/°C.

Since the MPI-ESM fits well the relationship between GCI and MAT found in the observations (figure 1), one may conclude that the changes in continentality of Moscow's climate could be attributed to the global climate change.

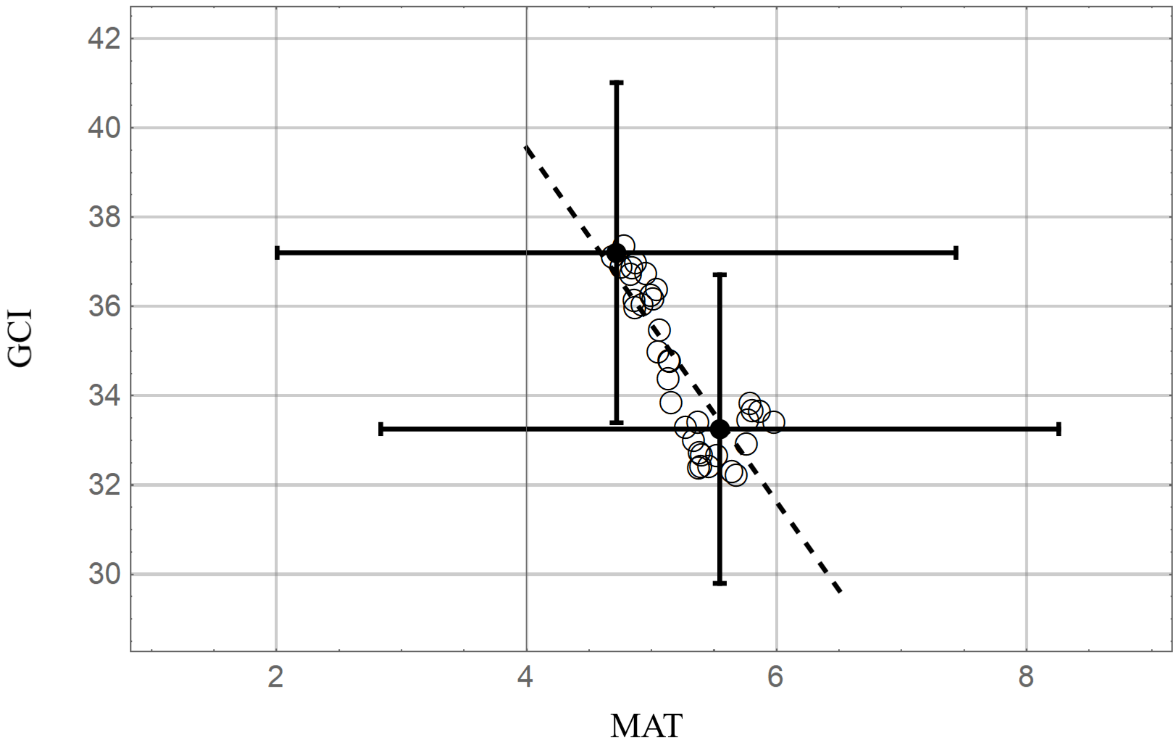

Figure 1. The relationship between GCI and MAT: open circles display the values calculated from the time series of 30-year moving average of monthly air temperature observed at the Moscow's weather station in 1951-2015; dashed line is the regression line (GCI=55.4 – 3.96 MAT, R^2=0.6885) derived from the observations at the Moscow's weather station; filled circles show the medians of GCI and MAT values in MPI-ESM runs for 850-1850 and for 1961-90 in the grid cells that fall within a rectangle around Moscow; error bars show the range of GCI and MAT values in the grid cells that fall within the rectangle.

4. Discussion and conclusions

This study further highlights the negative correlation between MAT and the amplitude of annual temperature cycle (AAT) reported by Eliseev and Mokhov [8]. They applied the method of amplitude-phase characteristics [9] to the global fields of meteorological data and found positive correlation only in Northern Africa and Central America. Later, they applied the same method to climate model runs and found the negative correlation between AAT and MAT over major part of land [10]. These and more recent studies on this subject [11-15] show that AAT could be used for diagnosing climate change in line with such a traditional climate change indicator as MAT.

AAT is influenced by the amplitude of seasonal changes in incoming solar radiation (AAR), by the underlying surface conditions and by the atmospheric circulation. Since AAT over the ocean is smaller than over the land, decrease in AAT over the land is often considered as a sign of stronger ocean-to-land heat transfer [11].

GCI is more sensitive to atmospheric circulation than AAT. Since AAR depends on latitude, the AAT divided by the sinus of latitude is less depending on AAR than AAT. Hence, the negative correlation between GCI and MAT found in the data of observations at the Moscow's weather station could reflect the changes in atmospheric circulation induced by radiative forcing caused by human-induced emissions of carbon dioxide.

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