Relationships between global surface temperature, carbon dioxide atmospheric content, solar and volcanic activity during the last 150 years

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Global surface temperature (GST) has considerably increased during the last century [1,2]. Revealing the relative contribution of the natural and anthropogenic factors to the climate change is one of the key global problems [1,3]. The purpose of this work is to estimate relative influence of different factors including solar and volcanic activity and carbon dioxide (CO_2) atmospheric content on the GST changes from observational data with the aid of empirical bivariate and multivariate autoregressive (AR) models [4].

We analyzed the time series of GST anomalies during the last 150 years (1856-2005) [2]. Let us denote it $\{T(t)\}_{t=1856}^{2005}$. Solar activity $\{I(t)\}$ was represented by reconstruction [5]. Volcanic activity (1856-1999) is represented by the time series $\{V(t)\}$ of the stratospheric aerosol optical depth [6]. CO_2 concentration $\{n(t)\}$ in the atmosphere (1856-2004) is taken from [7].

First, we constructed an individual autoregressive (AR) model of GST variations in the form

$$T(t) = a_0 + a_1 T(t-1) + ... + a_d T(t-d) + \xi(t), \qquad (1)$$

where $\xi(t)$ is Gaussian white noise, coefficients a_j are estimated via the least-squares technique, the model order d is selected so to provide the least prediction error σ_ξ^2 maintaining "parsimonious" model. We found that the optimal order is d = 4 which provides noise variance $\sigma_\xi^2 = 0.01\,K^2$. The model AR-process appears stationary. It exhibits time series quite close to the observed one. However, the GST increase in 1985-2005 is not predicted by the model constructed from the interval 1856-1985 (Fig.1). It implies that something has changed in the external influences during the period 1985-2005.

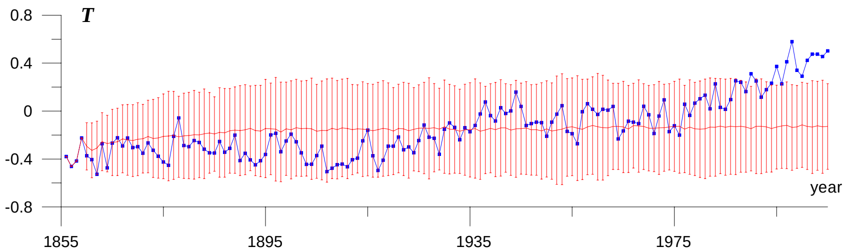

Figure 1: The observed time series of GST (in K) [2] (blue line) and an ensemble of time realizations of the model (1) of the order d = 4 constructed from the time interval 1856-1985. The ensemble is represented by its mean (red line) $\pm$ double standard deviation (error bars).

Relative value of the model prediction error for the period 1856-1985 is $\sigma_\xi^2 / \mathrm{var}[T] = 0.34$, i.e. one third of the GST empirical variance is attributed to the external influences. This part of GST variations can be to some extent explained by taking into account the other factors. If so, one infers the presence of the corresponding influences. This is the idea of the Granger causality estimation.

We constructed joint AR-models taking into account only one of the above three factors, or two of them, or all three of them. Influences of all three factors are detected. An optimal bivariate model accounting for the influence of solar activity has the form

$$T(t) = a_0 + a_1 T(t-1) + a_4 T(t-4) + b_I I(t-1) + \xi(t). \qquad (2)$$

E.g., if the data [5] for the period 1856-1985 is used for model fitting, then the solar variations influence is statistically significant at the significance level $p < 0.035$. However, the influence is not strong: the model (2) reduces the noise variance σ_ξ^2 only by 2.8 % as compared to the model (1). Thus, the model (2) gives somewhat better predictions than the model (1) but is not capable to predict GST increase in 1985-2005 as well.

A bivariate model accounting for the volcanic activity influence during the period 1856-1985 reduces σ_ξ^2 only by 1.2 % as compared to model (1) and does not predict the recent GST increase.

An optimal bivariate model accounting for the CO_2 concentration influence during 1856-1985 is

$$T(t) = a_0 + a_1 T(t-1) + a_4 T(t-4) + b_{1,n} n(t-1) + b_{2,n} n(t-2) + \xi(t)\,. \qquad (3)$$

It reduces σ_ξ^2 by 8.8 % and adequately predicts the GST increase in 1985-2005 (Fig.2). If constant value of CO_2 is used as the driving signal, the trend in GST is not observed.

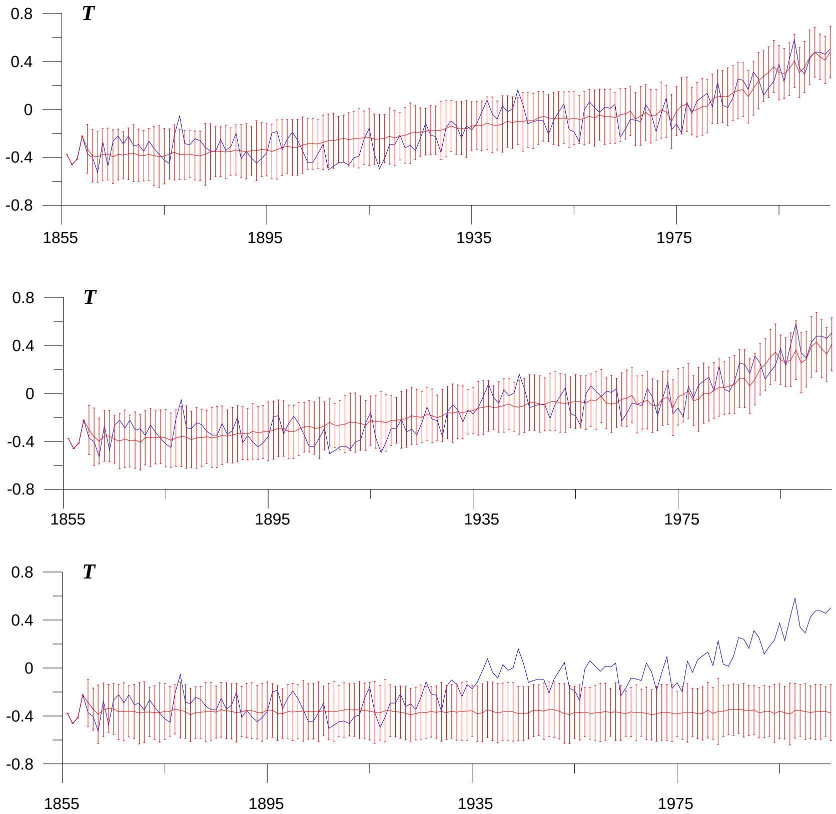

Figure 2: The observed time series of GST [2] (blue line) and ensembles of time realizations of the model (3) under different conditions. Upper panel: the model is constructed from the interval 1856-2005, the observed record of CO_2 (1856-2005) is used as a driving signal. Middle panel: the model is constructed from 1856-1985, the observed record of CO_2 (1856-2005) is used as a driving signal. Lower panel: the model is constructed from 1856-1985, constant CO_2 concentration (at the level of 1856) is used as a driving signal.

An optimal model with all factors has the form

$$T(t) = a_0 + a_1 T(t-1) + a_4 T(t-4) + b_I I(t-1) + b_{1,n} n(t-1) + b_{2,n} n(t-2) + b_V V(t) + \xi(t)\,, \qquad (4)$$

i.e. current value of GST depends on the previous-year solar activity, current-year volcanic activity, and CO_2 concentration for the two previous years. This joint model reduces the value of noise variance by 10 % as compared to the model (1). Such an improvement is highly statistically significant. About 8-9 % should be attributed to the CO_2 influence and only 1-2% to solar and volcanic activity together.

Nonlinear AR-models were also constructed. However, they involve more free parameters then linear models. The use of nonlinear models did not allow confident conclusions about coupling, most probably, due to the shortness of the available time series.

According to our analysis the most important anthropogenic factor (CO_2 concentration) determines the GST increase during last decades to a significant extent while the influence of solar and volcanic activity is by the order of magnitude weaker.

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