Influence of climate system nonlinearity on the time lag between changes in global temperature and atmospheric CO_2 content

Muryshev K.E.[1], Eliseev A.V.[1,2], Mokhov I.I.[1,2], Denisov S.N.[1], Arzhanov M.M.[1], Timazhev A.V.[1], Narizhnaya A.I.[1]

[1]A.M. Obukhov Institute of Atmospheric Physics RAS

[2]Lomonosov Moscow State University

kmuryshev@mail.ru

The numerical simulations with IAP RAS climatic model (IAP RAS CM) under idealized scenarios of external forcing for the Earth system are performed. The external forcings include anthropogenic emissions of CO_2 into the atmosphere $E_{CO2}(t)$ and variations of the solar constant $F(t)$. The following scenarios of external influences are used:

1. Greenhouse	$F = 0$	$E_{CO2} = E_{CO2,A} \sin(\omega t)$
2. Non-greenhouse	$F = F_A \sin(\omega t)$	$E_{CO2} = 0$

Here $E_{CO2,A}$ and F_A are the amplitudes of the forcing, ω – is the frequency of the forcing. The simulations were performed with external forcings at the time scales $P = 2\pi/\omega$ from 10 to 2000 years with amplitudes of emissions $E_{CO2,A} = \{1, 2, 5, 10\}$ GtC/yr, the amplitudes of variations of the solar constant $F_A = \{6.825, 13.65, 27.3\}$ W/m^2 corresponding to its deviations by 0.5, 1 and 2 % from the current value of 1365 W/m^2.

The time lag Δ between the series of global temperature T and atmospheric CO_2 content q obtained in these numerical experiments was investigated.

It was previously shown that the sign of Δ depends on the type of external forcing and its time scale [1-3]. In this work, it was found that when Δ is calculated using narrow time intervals (of the order of $P/2$), its sign depends on whether T and q increase or decrease over these intervals, as well as on the amplitude of their variations. When the amplitudes of T and q variations are large enough, the response of one variable to changes in the other is markedly different from the linear one. The dependence of T on changes in q is close to logarithmic, and the dependence of q on changes in T is exponential.

As a result, if the variations of T and q are approximately in-phase, then at the growth stage T is leading q, and at the decreasing stage q is leading T, regardless of the type of external forcing, greenhouse or non-greenhouse (see Figure 1).

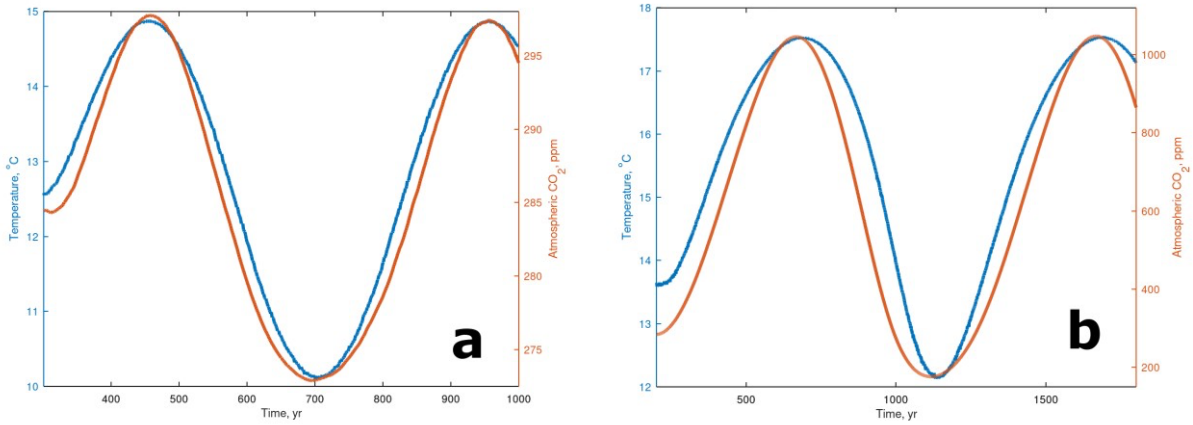

Fig. 1. Changes in global temperature T (blue curve) and atmospheric CO_2 concentration q (orange curve) in the numerical simulations with IAP RAS CM under non-greenhouse external forcing with P = 500 yr and F_A = 27.3 W/m^2 (a) and greenhouse forcing with P = 1000 yr and $E_{CO2,A}$ = 10 GtC/yr (b).

For small amplitudes of T and q variations, their response to each other's changes is close to linear, so the sign of Δ does not depend on the increase or decrease of the variables over the considered time interval.

This study was supported by the Russian Science Foundation (project no. 19-17-00240).

References

1. Muryshev K.E., Eliseev A.V., Mokhov I.I., Timazhev A.V. A lag between temperature and atmospheric CO_2 concentration based on a simple coupled model of climate and the carbon cycle. *Doklady Earth Sciences,* 2015, V. 463, Part 2, P. 863-867
2. Muryshev K.E., Eliseev A.V., Mokhov I.I., Timazhev A.V. Lead-lag relationships between global mean temperature and and the atmospheric CO_2 content in dependence of the type and time scale of the forcing. *Global and Planetary Change,* 2017, V. 148, P. 29–41.
3. Muryshev K.E., Eliseev A.V., Denisov S.N., Mokhov I.I., Arzhanov M.M., Timazhev A.V. Phase Shift between changes in global temperature and atmospheric CO2 content under external emissions of greenhouse gases into the atmosphere. *Izvestiya, Atmos. Ocean. Phys.*, 2019, V. 55, P. 235–241.