A phase shift between the changes of global temperature and carbon dioxide concentration in the atmosphere in a simple coupled climate-carbon cycle model

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The atmosphere-ocean-land carbon dioxide exchange with periodic external forcings of different types is considered. The aim is to determine the phase shift between the global temperature and the atmospheric carbon dioxide concentration.

The coupled climate-carbon system is governed by the following equations:

$$C_0(dq/dt) = E(t) - F_{oc} - F_{land}\,,$$

$$dD/dt = F_{oc}\,,$$

$$d(M_b + M_s)/dt = F_{land}\,,$$

$$C\,(dT/dt) = R_x \ln(q/q_0) + R(t) - \lambda T\,,$$

where q is the deviation of atmospheric CO_2 concentration from the preindustrial value q_0 = 278 pmm; D is the corresponding deviation of carbon stock in the ocean; M_b и M_s are the deviations of carbon stock in biota and soil, respectively; T is the temperature deviation; c_0 = 2.123 GtC/ppm; F_{oc} is the CO_2 flux from atmosphere to ocean; F_{land} is the CO_2 fluxes from atmosphere to land ecosystems; $C = 10^9$ J/m^2·K is the heat capacity per unit area; R_x = 5.34 W/m^2, λ = (0,82 ÷ 2,46) W/m^2·K is the feedback factor, $R(t)$ is the radiative forcing (RF), $E(t)$ is the external (e.g., anthropogenic) CO_2 emission to the atmosphere.

The CO_2 exchange between the atmosphere and the ocean is described by a Bacastow-type model but with temperature-dependent chemical constants in the ocean [Meier-Reimer E. and Hasselmann K., 1987]. The CO_2 flux from the atmosphere to land ecosystems and ocean is determined according to [Eliseev, Mokhov, 2007].

Numerical simulations were performed with the above-described model for different types of periodic forcing:

1) $R(t) = R_0 \sin(\omega t),\ E(t) \equiv 0;$
2) $R(t) = R_0 \sin(\omega t),\ E(t) = E_0 \exp(At).$

Case 2) is modeling the situation in the 20th century.

In case 1) T can lag behind q or lead it depending on the forcing period. Long-period RF causes leading q, short-period RF causes leading T (Fig. 1).

In case 2) the result is identical to case 1). This result can be explained when considering the linearized model.

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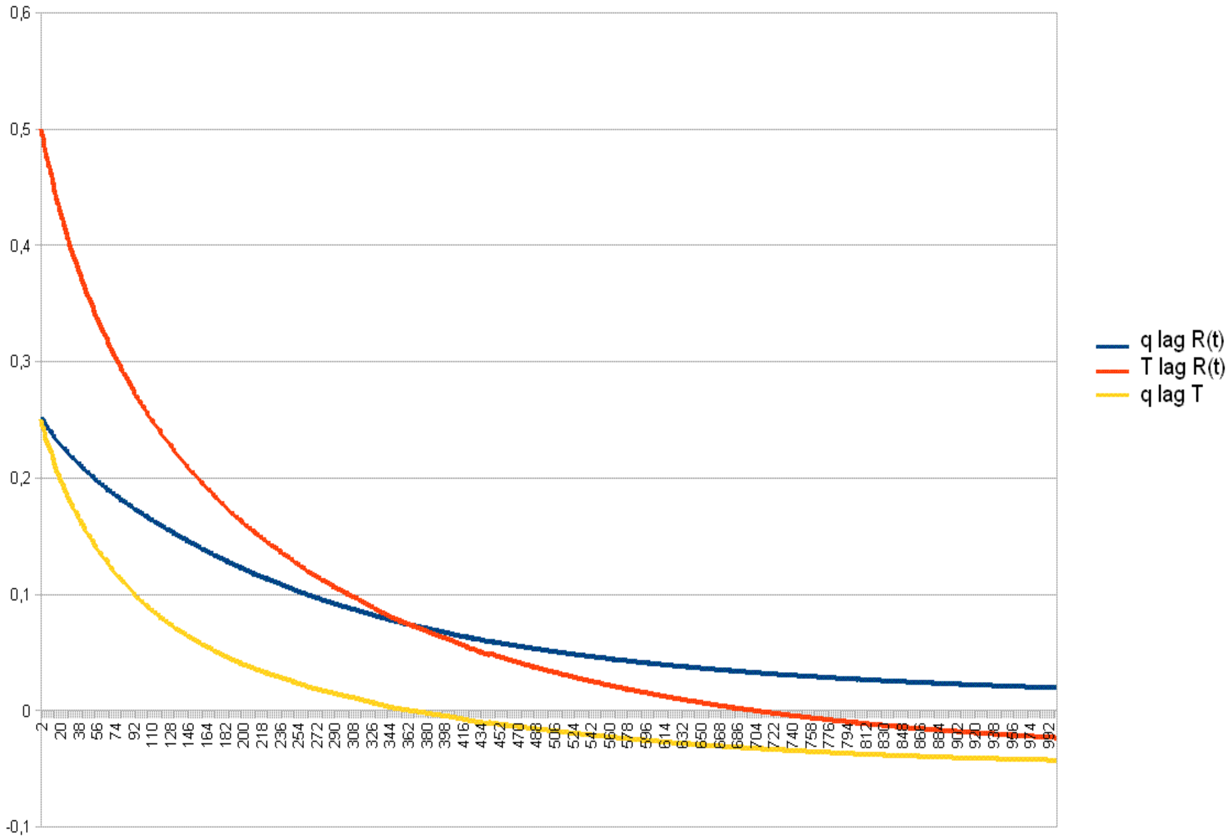

Figure 1. The phase shift divided to the RF period as a function of RF period (centuries).