Estimating time lags in a simple coupled climate-cabon cycle model

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The carbon dioxide exchange between the atmosphere, ocean, and land, in presence of periodic external forcing of different type is considered. The aim is to determine the delay between global temperature, concentration of atmospheric, and oceanic carbon stock.

The exchange of CO_2 between the atmosphere and the ocean is described by a Bacastow-type model but with a temperature-dependent chemical constants in the ocean. CO_2 fluxes from atmosphere to land ecosystems and ocean are determined by

$$G = \beta_L(q-q_0)+\gamma_L T ,$$
$$F = F_0 \chi (q - q_0 - \zeta Dq_0/D_0) ,$$

where T is deviation of global temperature from the initial value, q is concentration of CO_2 in the atmosphere, D is deviation of carbon stock at the ocean from its initial value $D_0 = 1.5*10^5$ PgC, $q_0 =$ 278 ppm, $\beta_L = (0.01 – 0.02)$ [GtC/ppm], $\gamma_L = 0.05$ [GtC/Kyear], and $F_0 = (2.5 – 4.5)$ [GtC/year] are coefficients, χ is the solubility of CO2 in the sea water, ζ is evasion factor.

The coupled climate-carbon system is governed by equations:

$$C_0(dq/dt) = E(t) – F – G ,$$
$$dD/dt = F ,$$
$$C\,(dT/dt) = p \ln(q/q_0) + R(t) – \lambda T,$$

where E(t) is external (e.g., anthropogenic) CO_2 emissions to the atmosphere, R(t) is temperature forcing, p= 5.34 [J/m^2 year], $C_0 = 2.123$ [GtC/ppm], C is heat capacity per unit area ($6*10^7$ J/m^2 K), λ is feedback factor (1.37 W/m^2 K).

The temperature and emission forcing for simplicity are in the form of a sinusoid with the period from one thousand to 10 thousand years. Forcing of this type produces oscillations of T, q, and D. We determined mutual delays between these variables by maxima of the lagged correlation between them.

When temperature forcing is applied, q lags T by about one hundred years. If the period of the external forcing is changed, the lag increases approximately in proportion to this period. At an emission forcing T is late concerning q for 1 year (a time step of the model).

References:

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2. Meier-Reimer E. and Hasselmann K. (1987). Transport and storage of CO2 in the ocean – an inorganic ocean-circulation carbon cycle model. *Climate Dynamics*, **2**, 63-90.

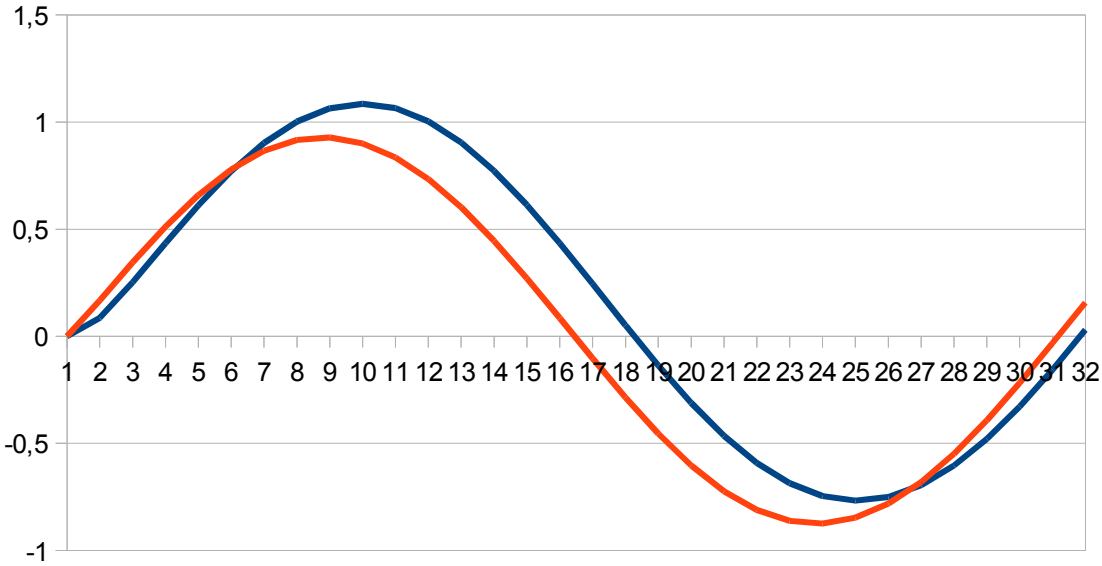

Figure 1. Time series of T [K] (red line) and q/q_0-1 (blue line) . Time is in centuries.