Lead-lag relationships between global mean temperature and the atmospheric CO_2 content depend on type and time scale of the external forcing

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GEOPHYSICS

A Lag between Temperature and Atmospheric CO_2 Concentration Based on a Simple Coupled Model of Climate and the Carbon Cycle

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Motivation

Year-to-year increments of the global mean SAT and q_{CO2} [Humlum et al., 2013]

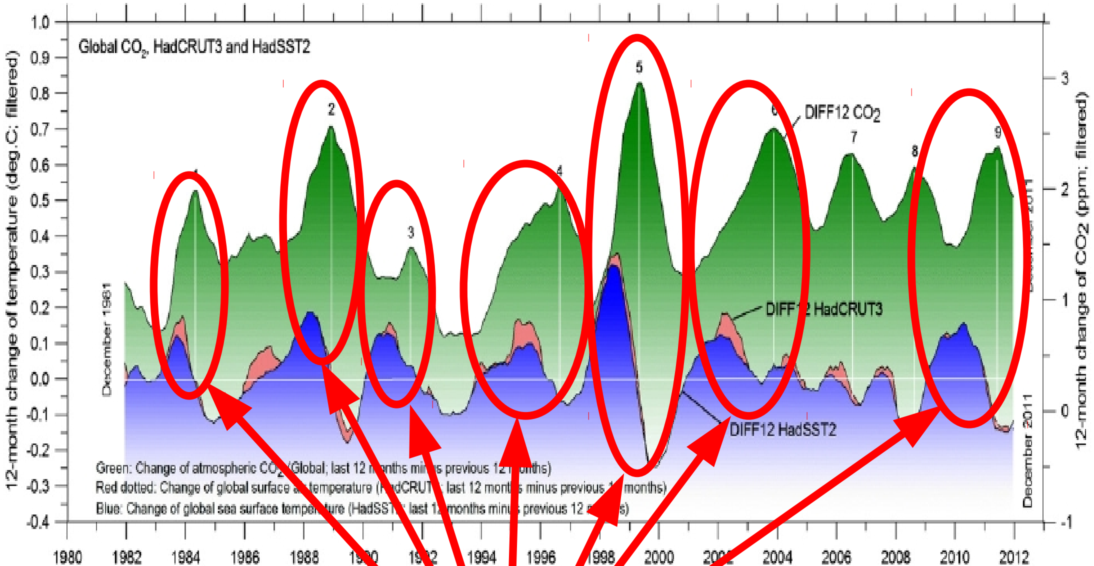


Fig. 2. 12-month change of global atmospheric CO_2 concentration (NOAA; green), global sea surface temperature (HadSST2; blue) and global surface air temperature (HadCRUT3; red dotted). The upper panel shows unfiltered monthly values (e.g. January 2000 minus January 1999), while the lower panel shows filtered values (DIFF12, the difference between the average of the last 12 month and the average for the previous 12 months in each data series). The numbers (1–9) on DIFF12 CO_2 peaks and the thin white lines refer to Table 1.

SAT leads q_{CO2} by 10 mo

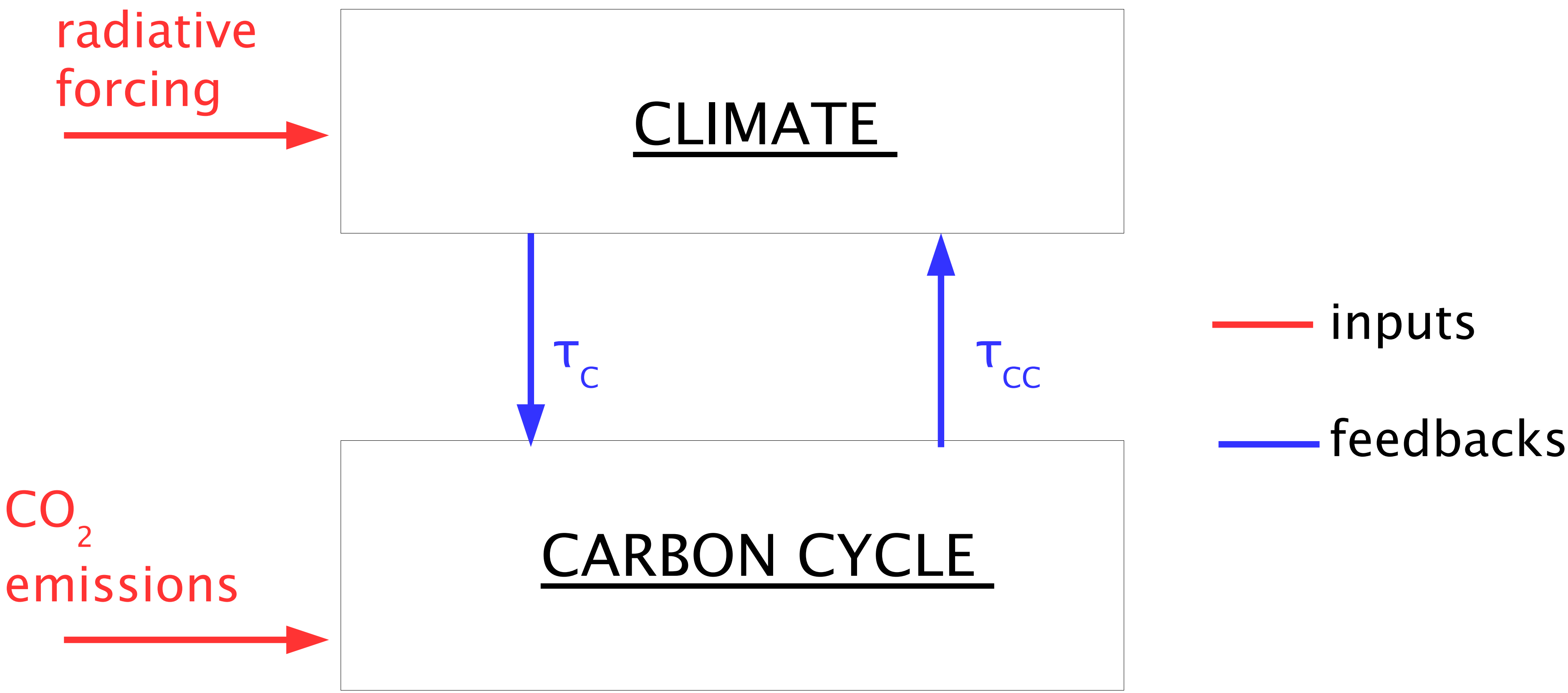
Based on this, it was stated that:

1. The ongoing climate warming is not related to the anthropogenically induced rise of q_{CO2}.

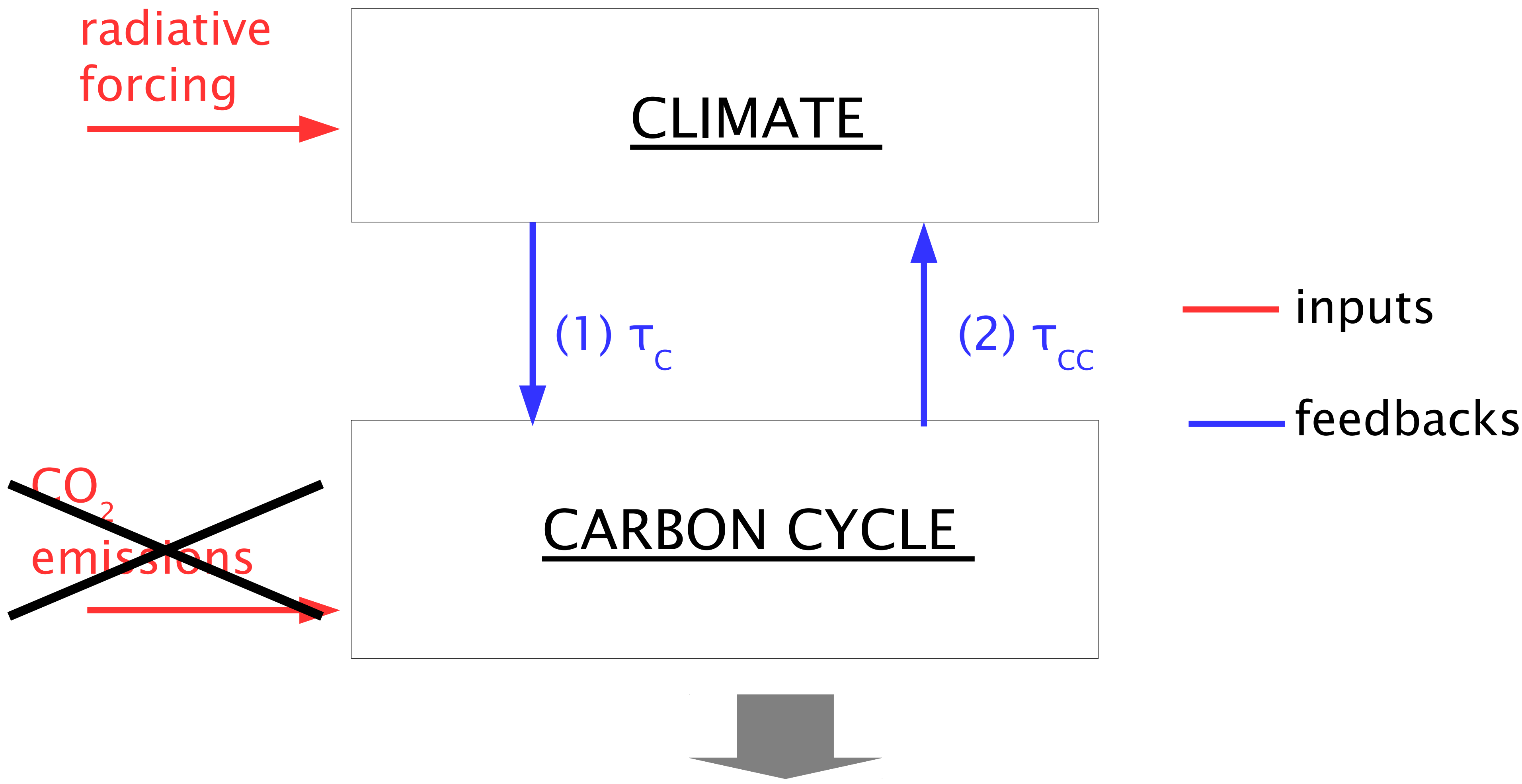
2. Climate models, which attribute this warming to the anthropogenic greenhouse effect, are wrong.

However ...

The Earth system

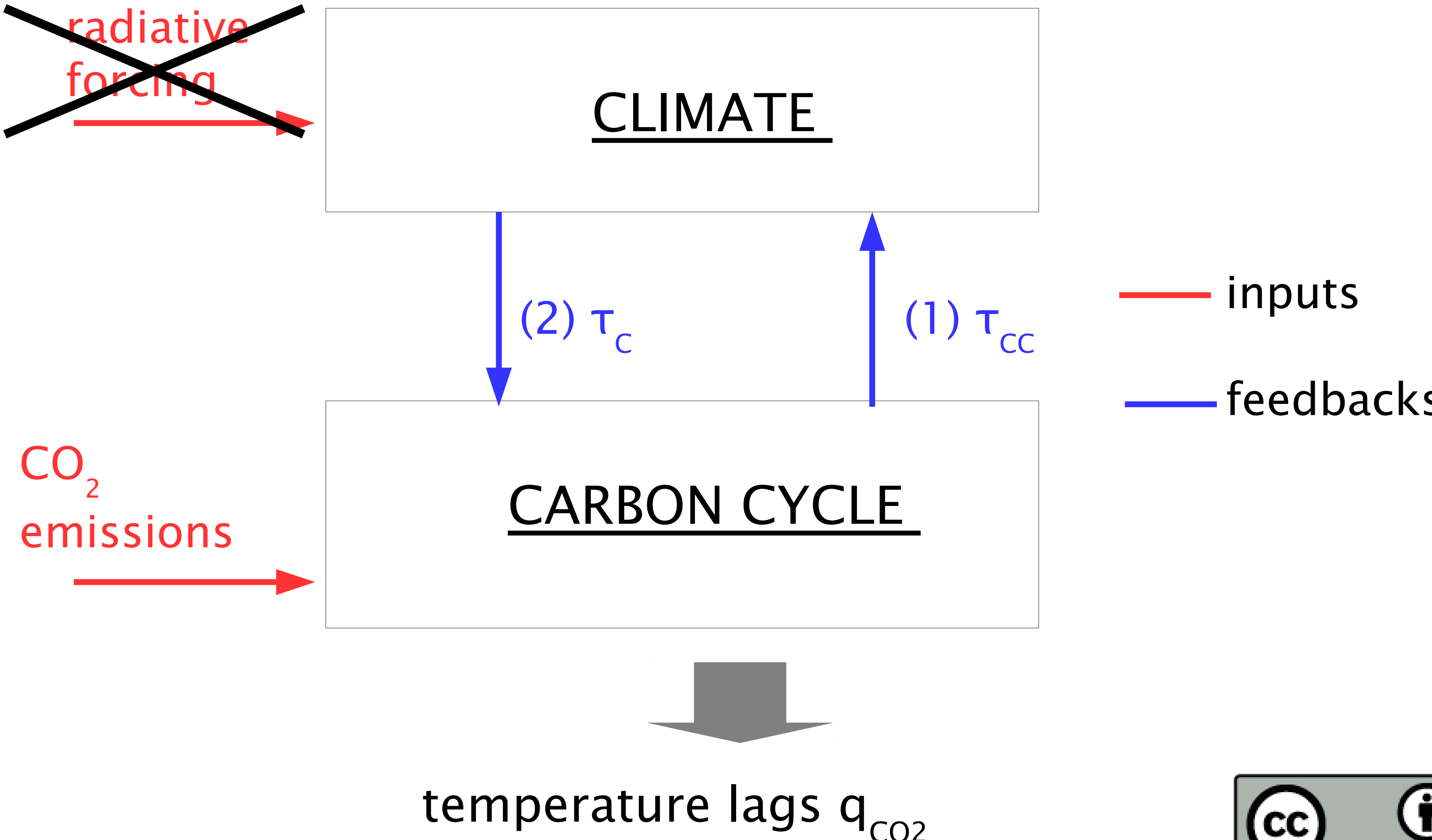


The Earth system: non-greenhouse RF

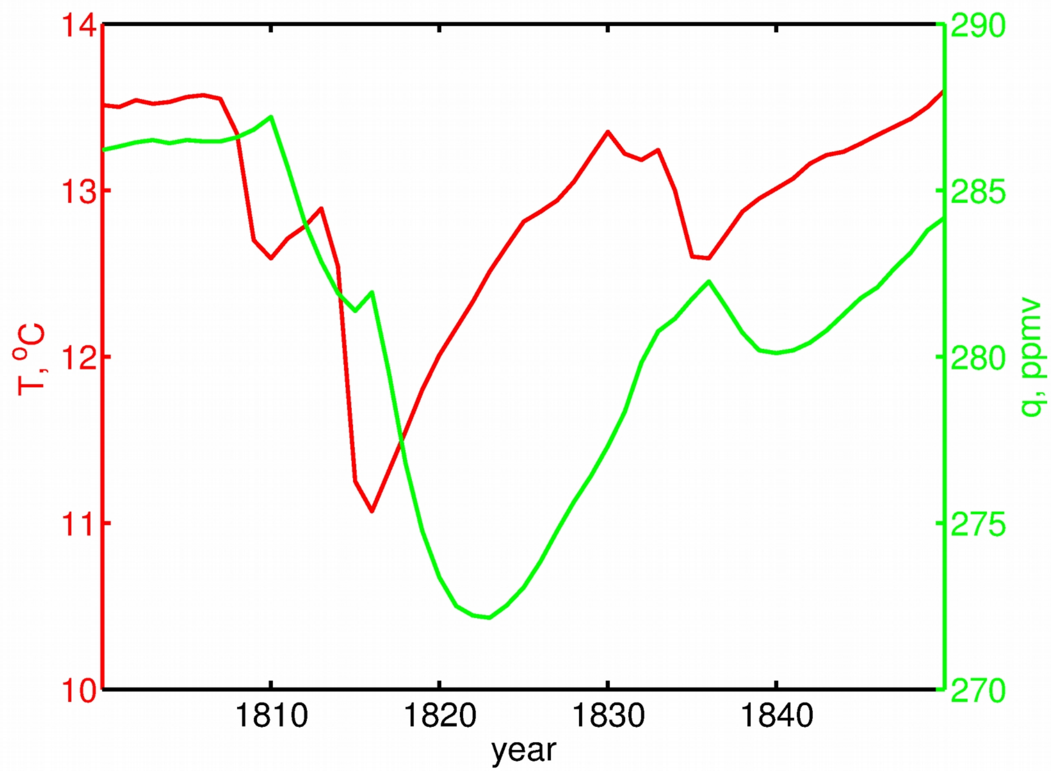


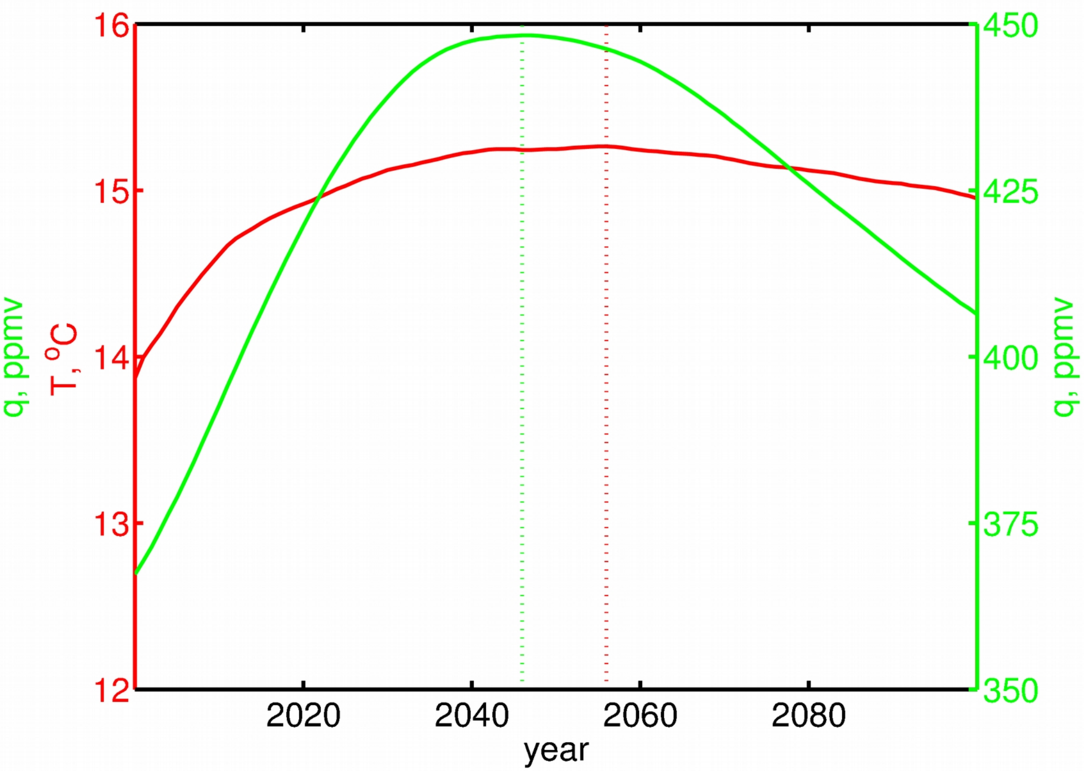
temperature leads q_{CO2}

The Earth system: CO_2 emissions



IAP RAS CM: CMIP5
('historic' + RCP 2.6)



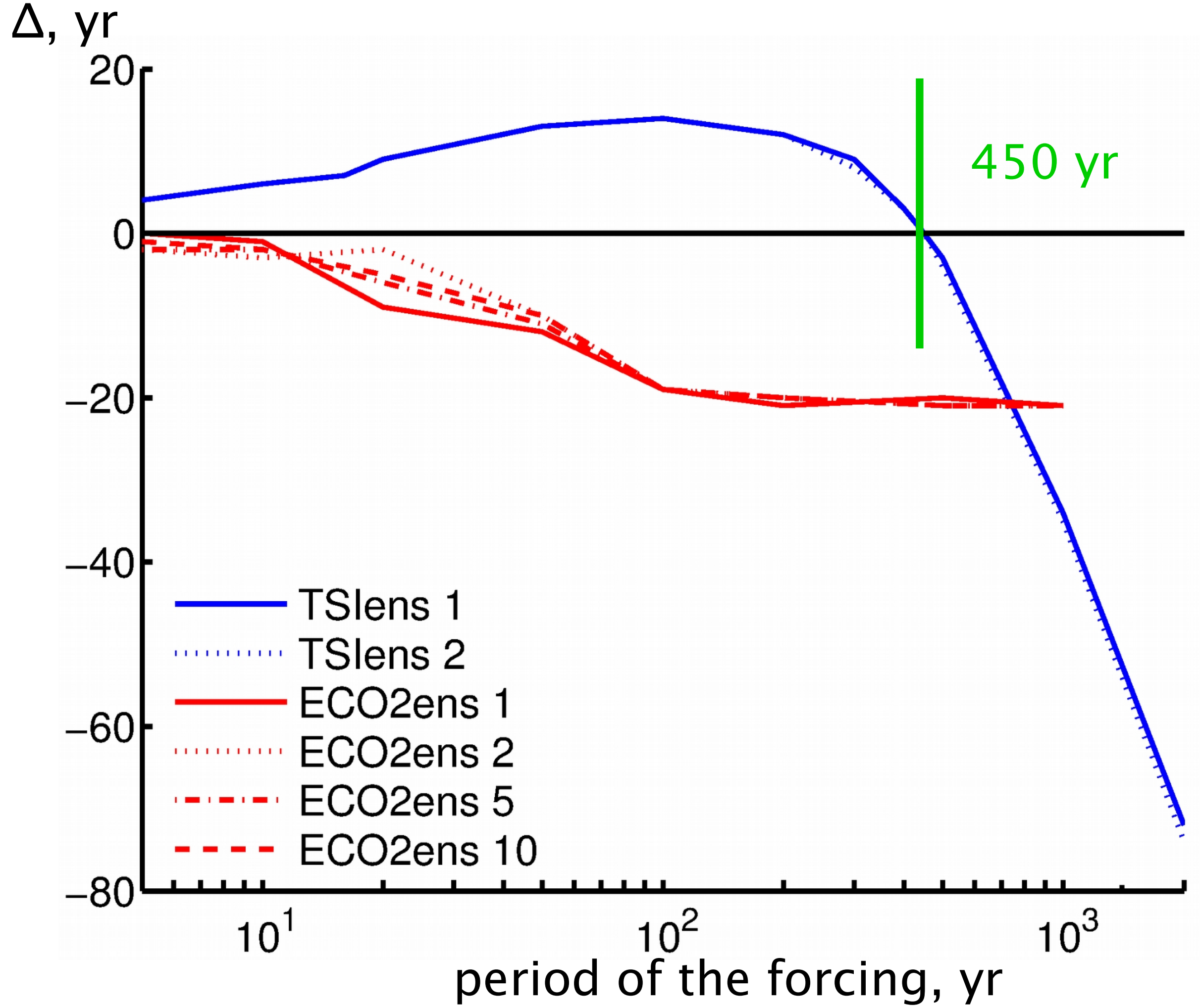


T leads q_{CO2}

q_{CO2} leads T

IAP RAS CM: idealised periodic forcing

(lag Δ is calculated by maximising correlation between T_g and q_{CO2})

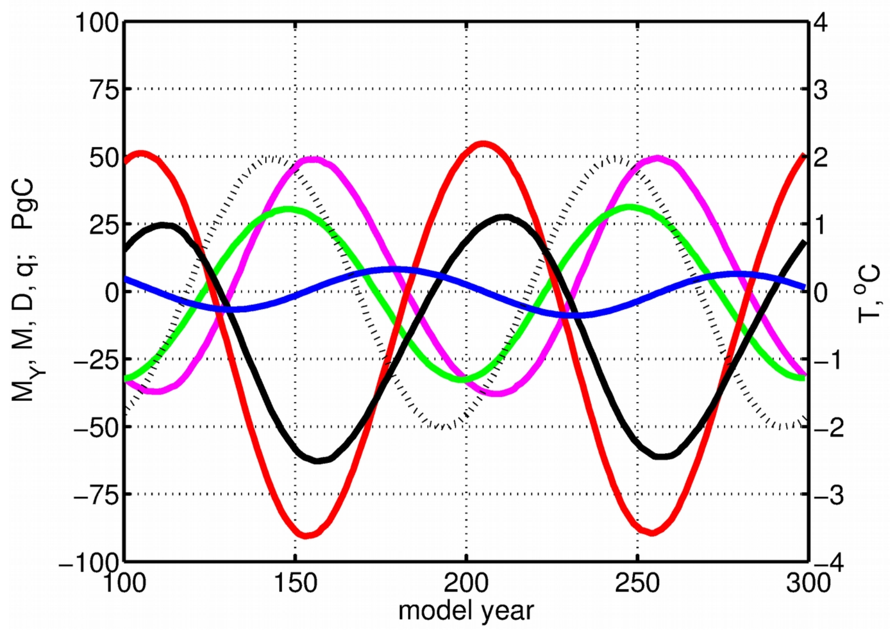


$\Delta > 0$:
T_g leads q_{CO2},

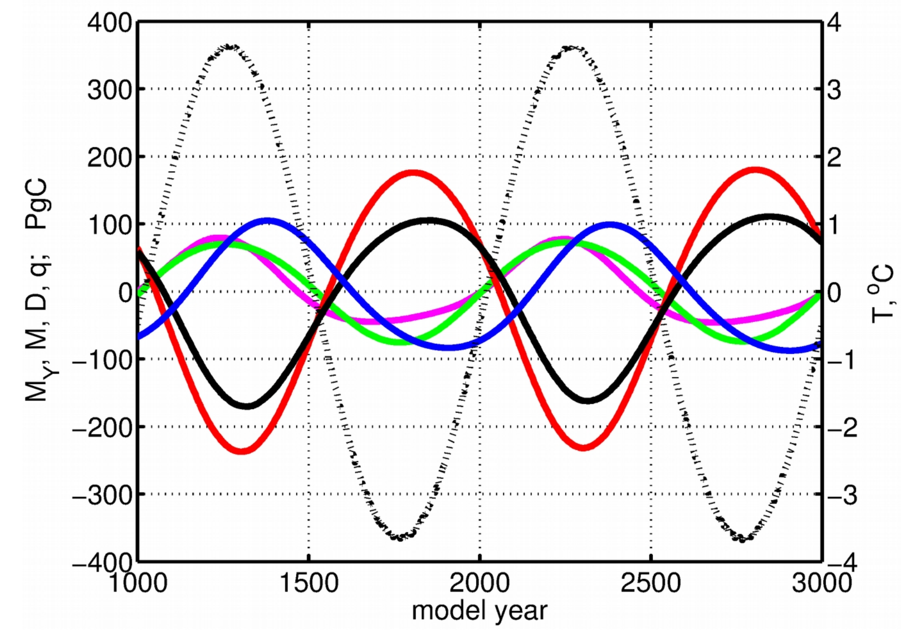
$\Delta < 0$:
q_{CO2} leads T_g

TSIens: TSI changes (non−greenhouse RF)
ECO2ens: external CO_2 emissions into the atmosphere

TSIens 2, P = 100 yr



TSIens 2, P = 1000 yr



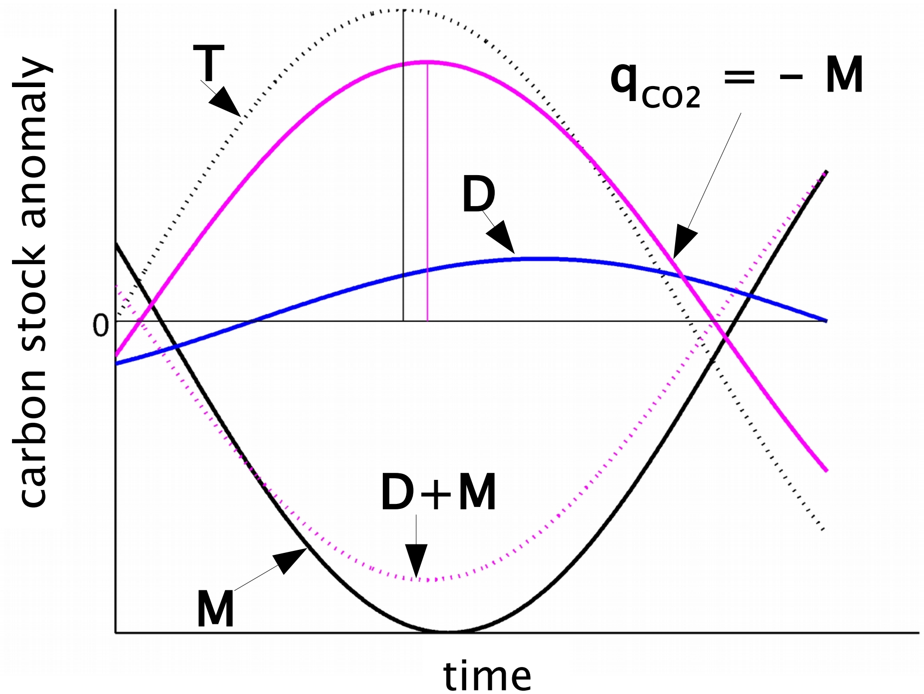
- M_v (vegetation)
- M_s (soil)
- M ($= M_v + M_s$)
- D (oceanic DIC)
- q (atmosphere)
- T_g (temperature)

<u>at the centennial time scale:</u> $D \ll q, M$; $q \approx -M$

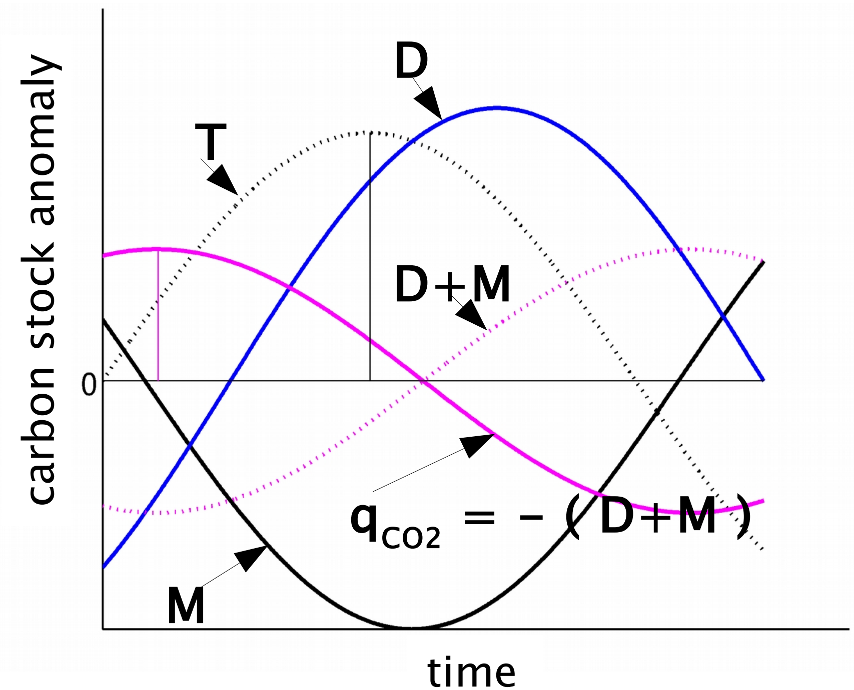
<u>at the millennium time scale</u>: D, q, M are of the same order of magnitude

Mechanism leading to change of the sign of Δ under non-greenhouse RF

TSIens 2, P ~ 10^2 yr: $\Delta > 0$



TSIens 2, P ~ 10^3 yr: $\Delta < 0$



1. Warming leads to carbon release from the soil into the atmosphere (M lags behind T);
2. If P ≲ 400 yr, the excessive atmospheric CO_2 is mostly taken up by terrestrial ecosystems; if P ≳ 400 yr it is basically taken up by the ocean;
3. If external CO_2 emissions are absent then, because of the carbon mass conservation, $\delta q_{CO2} = -(\delta D + \delta M)$

⇒ $$\sin\phi_{0,q} = -\frac{D^{(0)}}{q^{(0)}}\sin\phi_{0,D}$$

($Y^{(0)}$ is amplitude, $\phi_{0,Y}$ is initial phase for Y; we assume that $\phi_{0,M}=0$)

⇒ q_{CO2} leads M and may lead T_g provided that $D^{(0)}$ is sufficiently large.

Conceptual ESM

$$\begin{cases} C\dfrac{dT_g}{dt} = R - \lambda T_{\mathrm{g}} = \\ \qquad = R_X(t) + R_0 \ln\left(1 + \dfrac{q_{\mathrm{CO_2}}}{q_0}\right) - \lambda T_{\mathrm{g}} \\ \dfrac{dq_{\mathrm{CO_2}}}{dt} = E - F_{\mathrm{l}} - F_{\mathrm{o}} \end{cases}$$

C – heat capacity per unit area

T_g – global mean SAT

λ – climate sensitivity

Oceanic carbon uptake is calculated by using the modified Bacastow model

$$F_o = F_o(q_{CO2}, T_g, D)$$

taking into account temperature dependencies of the constants of chemical reactions

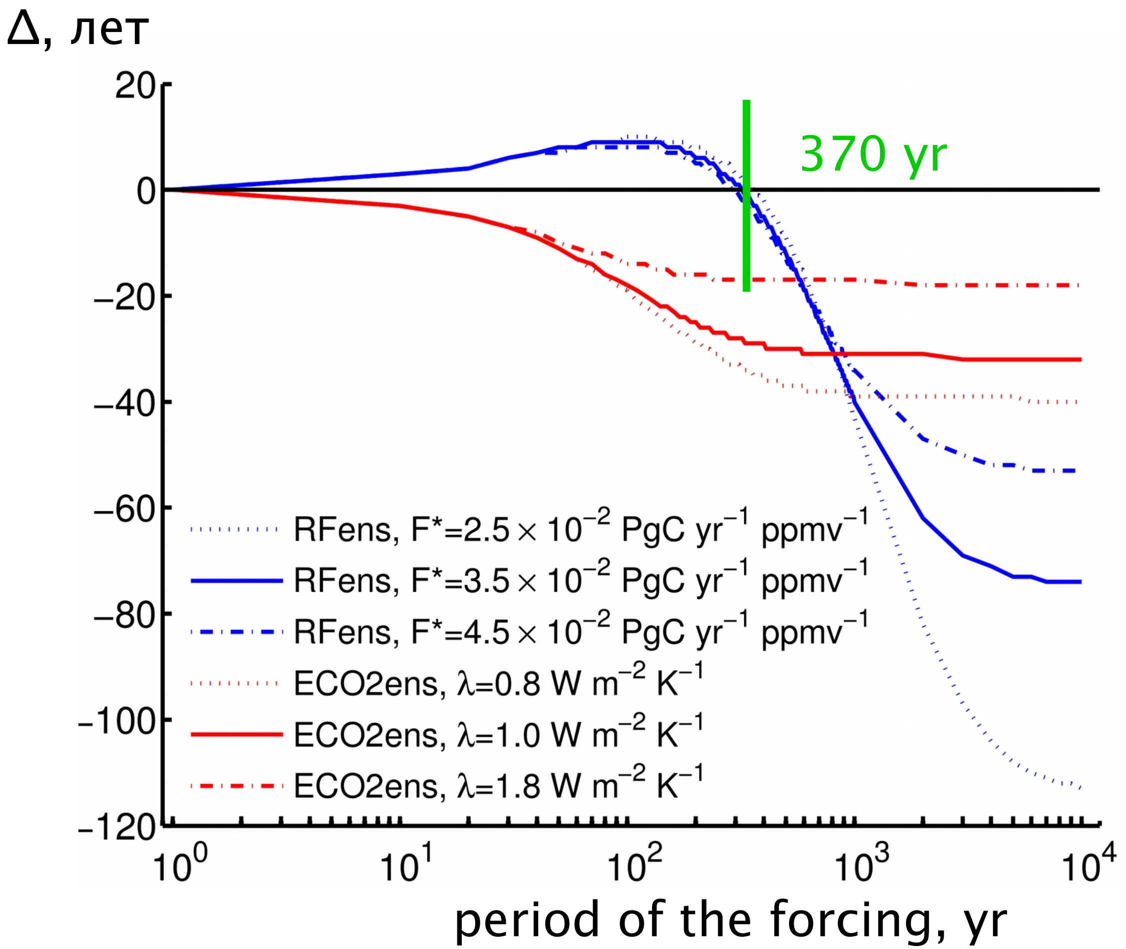
Terrestrial carbon uptake

$$F_l = F_l(q_{CO2}, T, C_v, C_s)$$

is calculated following [Lenton 2000; Eliseev and Mokhov, 2007] (C_v и C_s are carbon stocks in vegetation and soil, respectively).

Conceptual ESM: idealised periodic forcing

(lag Δ is calculated by maximising correlation between T_g and q_{CO2})



$\Delta > 0$:
T_g leads q_{CO2},

$\Delta < 0$:
q_{CO2} leads T_g

RFens – simulations with non–greenhouse RF
ECO2ens – simulations with external CO_2 emissoins into the atmosphere

F* – coefficient of the oceanic CO_2 uptake
λ – climate sensitivity

The IAP RAS CM results are reproduced both with the original and with linearised versions of the conceptual ESM

Conclusions

- Lag between two variables may or may not not be indicative for casual relationship between them and should be supported by hypotheses about the nature of their interaction.

- The lags between changes in the global temperature T_g and the q_{CO2} depend on the type of external forcing, period P of this forcing, and characteristics of the feedback between climate and carbon-cycle:

$E(t) \neq 0, R(t) \equiv 0$ ⇩ q_{CO2} leads T_g

$R(t) \neq 0$

$P \lesssim 4 \cdot 10^2$ yr ⇩ T_g leads q_{CO2}

$P \gtrsim 4 \cdot 10^2$ yr ⇩ q_{CO2} leads T_g

- Change of sign of lag between T_g and q_{CO2} under non-greenhouse RF is due to
1) Enhanced (suppressed) carbon release from the soil under climate warming (cooling).
2) increased importance of the oceanic carbon uptake at larger time scale of the external forcing;
3) carbon conservation in the absence of the external CO_2 emissions.