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

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In some data sets, the atmospheric CO_2 content, q, lags behind global mean surface air temperature, T. It was claimed as an evidence against the dominant role of the anthropogenic forcing in the contemporary, century–scale climate forcing.

We employ an Earth system model of intermediate complexity (EMIC) developed at the A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences (IAP RAS CM) and explore mutual lags between T and q in dependence of the type and time scale of the external forcing. In the simulation, which follows the protocol of the Coupled Models Intercomparison Project, phase 5, T leads q for volcanically–induced climate variations. In contrast, T lags behind q for changes caused by anthropogenic CO_2 emissions into the atmosphere. In additional idealised numerical experiments, driven by periodic external emissions of carbon dioxide into the atmosphere, T always lags behind q as expected. In contrast, if the model is driven by the periodic non–greenhouse radiative forcing, T leads q for the external forcing time scale $\leq 4 \times 10^2\ yr$, while q leads T at longer scales. The latter is an example that lagged correlations do not necessarily represent causal relationships in a system. This apparently counter–intuitive result, however, may be understood as a direct consequence of i) temperature sensitivity of the soil carbon stock (which decreases if climate is warmed and increases if climate is cooled), ii) conservation of total mass of carbon in the system in the absence of external carbon emissions (fast–responding carbon stock q should lead the system to compensate inertial stock of the dissolved inorganic carbon in the ocean and fulfill this conservation of carbon mass), iii) increased importance of the oceanic branch of the carbon cycle at longer time scales. The results obtained with an EMIC are further interpreted with a conceptual Earth system model consisting of an energy balance climate model and a globally averaged carbon cycle model.

The obtained results have implications to the empirical studies attempting to understand the origins of the contemporary climate change by applying lead–lag relationships to empirical data.