News from the Past – Climate Simulations over the last 1200 Years

A long-standing task in climate research has been to distinguish between natural climate variability and anthropogenic climate change. A prerequisite for fulfilling this task is the understanding of the relative roles of external drivers – changes in solar radiation, volcanic eruptions and land use changes - and the internal variability of climate.

Therefore knowing about past climate evolutions is essential. A research group around Dr. Johann Jungclaus at the Max Planck Institute for Meteorology (MPI-M) investigated the historical period of the last 1200 years within a project called "Millennium". For the first time ensemble climate simulations including a fully interactive carbon cycle have been accomplished over this time period. The comprehensive coupled Earth system model MPI-ESM was used; so far these comprehensive climate-carbon cycle models had been applied mostly to the anthropogenic era and to study future changes in the carbon cycle-climate connection.

The results allow for both conclusions on the role of the external drivers in climate evolution and on how essential the anthropogenic forcing in the 20th and 21st century has been. By including the carbon cycle it is possible to describe the influence of CO2 variations on climate evolution and to better understand the causes for natural variations of greenhouse gas concentrations.

Why to simulate climate of the last millennium? "The last millennium is the best-documented period of climate change in a multi-century time frame. During the so-called Medieval Climate Optimum (in Europe ca. 900 -1250AD) Norwegian settlers populated the West coast of Greenland. The Little Ice Age (ca. 1400-1850 AD) was recorded by Dutch painters on paintings of frozen town canals showing ice-skating people," project coordinator Dr. Johann Jungclaus explains. Since reconstructions of the past climate beyond the instrumental record have to rely on relatively sparse data sources, the working group concentrates on the last millennium to better understand the processes and interaction mechanisms.

„For the first time we were able to perform several realisations of experiments with temporally variable external forcings spanning the time 800 AD to 2005 AD. This gives us a better estimate of the role of the internal variability in the climate system" explains Johann Jungclaus "Experiments with the same forcings build a so-called ensemble. In order to account for uncertainty in the solar forcing we ran an ensemble (E1) with relatively weak and another ensemble with stronger variations in solar radiation (E2). In addition, we performed sensitivity experiments with just one external forcing (e.g. volcanos) at a time."

What are the results found by the research group? First of all it demonstrates the ability of the model to reproduce important aspects of the recent period of global climate change (Fig. 1). The simulated Northern Hemisphere (NH) temperature evolution over the 20th century agrees well with the instrumental record. Both observed and modelled time series exhibit a warming trend of about 0.6°C over the 20th century that is superimposed by pronounced multidecadal variability. The recently diagnosed climate change over the last 150 years with its global warming trend cannot be explained simply by the changes in solar radiation or by internal variability, the human impact (CO2 emissions) must be taken into account.

At large the ensemble simulations follow the reconstructions of past climate (Fig. 1). Long-term temperature changes for the NH are significantly larger than the range of variation, which can be explained by internal variability. Modulation by solar irradiance and volcano eruptions has left clear and lasting traces in climate history. Extremely strong fluctuations appear, when volcano eruptions occur frequently (e.g. at the beginning of the 19th century) or solar and volcanic forcing interfere with each other (e.g. mid 15th century).

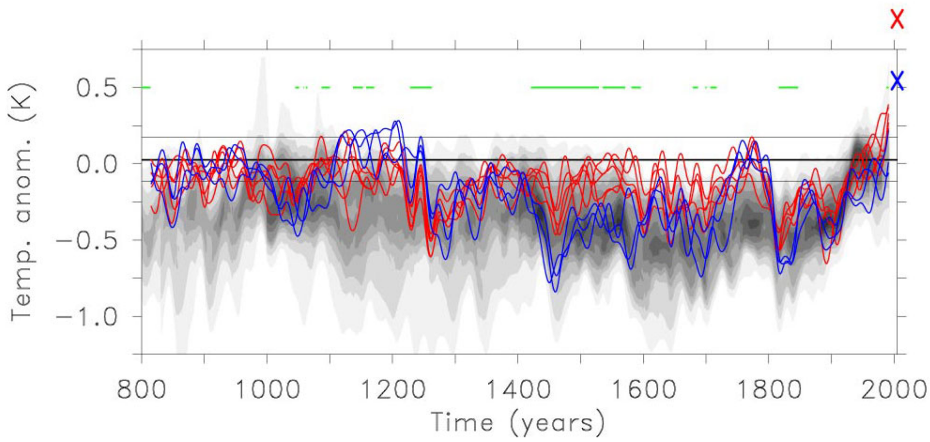

Fig. 1: Evolution of simulated temperature over the last 1200 years: Northern Hemisphere 2m land temperature anomalies with regard to the 1961–1990 mean for ensembles E1 (red) and E2 (blue) in comparison with the range of reconstructions (gray scale, redrawn from Jansen et al., 2007). Black horizontal lines indicate the control experiment mean and its 5th–95th percentile range. Green horizontal bars indicate periods where the ensembles do not overlap with each other. Time series are smoothed by a 31-year running mean.

In the two ensemble simulations the highest preindustrial temperatures appear between 1050 and 1250 AD and in the late 18th century, while the coldest periods occur in the early 16th and 18th century (Little Ice Age). Contrary to the E1 experiments, the E2 model runs show a clear Medieval Optimum, associated with a maximum in solar forcing in the 12th century. Differences cannot only be found between the two ensembles from 1400 to 1600 AD, but also within a single ensemble.

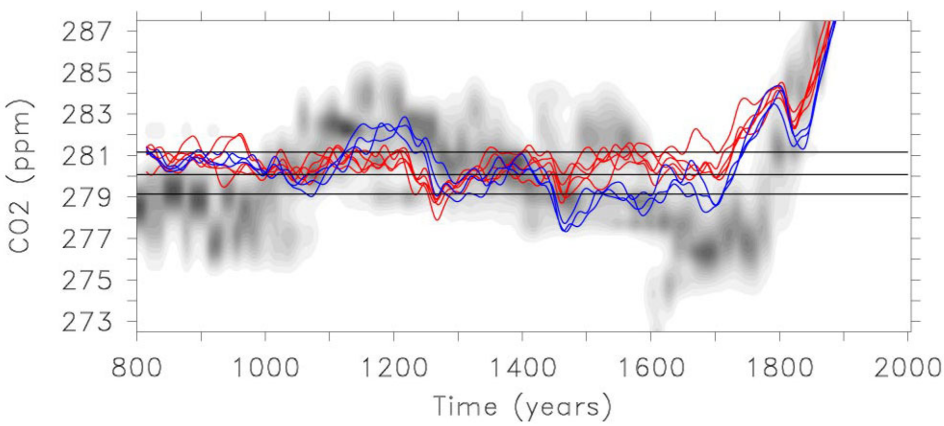

Fig. 2: CO_2 concentrations (31-year running mean) from ensembles E1 (red) and E2 (blue) in comparison with a compilation of ice core reconstructions (grey).

Preindustrial variations in CO_2 concentration in the last millennium are very small compared to the variations of about 100 ppm between glacial and interglacial periods. Ice core data show a reduction of CO_2 concentration from the Medieval Optimum to Little Ice Age. While the model is able to simulate the recent trend of CO_2 evolution with a strong increase from the 19th century on, the long-term variations in the preindustrial time are less than the reconstructions from ice cores. The differences may be due to long-term, natural variability which cannot be described in our simulations or to an underestimation of the carbon cycle sensitivity towards temperature variations.

Experiments with one single forcing component give information about the role of these factors for the historical evolution of climate and carbon budget. The role of land use changes is studied in detail. Earlier speculations that the Little Ice Age was caused by large scale reforestation could not be confirmed. The land biosphere contributed significantly to climate change due to strongly increasing agriculture from the 18th century on (Pongratz et al., 2009).

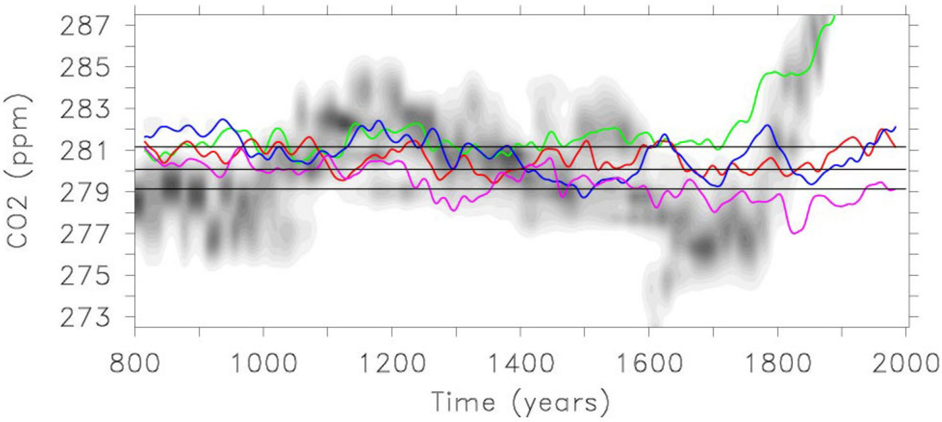

Fig. 3: Respective CO2 concentrations from the experiments forced by one single component, i.e. standard solar forcing (red), strong solar forcing (blue), land-cover change (green), and volcanic aerosols (purple).

The external drivers such as solar radiation, volcanos and land use also have influence on the CO2 budget and the CO2 concentration in the atmosphere as shown by experiments with one single forcing (Fig. 3). While in general the E2 ensemble shows lower CO2 concentrations during the Little Ice Age (Fig.2), the decrease in the early 17th century seems not be caused by the solar forcing (positive anomaly of the blue line around 1610 AD).

Brovkin et al. (2010) investigate the reaction of the carbon cycle on an eminently heavy volcano eruption in the middle of the 13th century (Fig. 3, purple line). The authors show that especially the tropical land vegetation resp. the intensified uptake by soils is responsible for the decrease of atmospheric CO2 concentration.

Conclusion: Ensemble simulations are necessary to fully describe the internal variability in the climate system. Several realizations of the past millennium with different external forcings (solar radiation, volcanos, land use) in these ensemble runs allow to quantify the role of individual forcings for the climate system. The long-term climate changes of the past 1000 years (Medieval Optimum, Little Ice Age) can be described with internal variability and external forcings. Furthermore it is possible to quantify the role of the developing agriculture for the preindustrial climate (Pongratz et al., 2009).

The last millennium simulations clearly show that the recent climate change cannot be explained only by the internal variability and the solar forcing (solar radiation). Only by taking the anthropogenic CO2 emissions into account the temperature increase can be reproduced.

Link to the original publication:

http://www.clim-past.net/6/723/2010/

J. H. Jungclaus, S. J. Lorenz, C. Timmreck, C. H. Reick, V. Brovkin, K. Six, J. Segschneider, M. A. Giorgetta, T. J. Crowley, J. Pongratz, N. A. Krivova, L. E. Vieira, S. K. Solanki, D. Klocke, M. Botzet, M. Esch, V. Gayler, H. Haak, T. J. Raddatz, E. Roeckner, R. Schnur, H. Widmann, M. Claussen, B. Stevens, and J. Marotzke: Climate and carbon-cycle variability over the last millennium. Clim. Past, 6, 723–737, 2010; doi: 10.5194/cp-6-723-2010.

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Project page „Millennium“:

http://www.mpimet.mpg.de/en/wissenschaft/interne-projekte/millennium.html

Contact:

Dr. Johann Jungclaus
Max Planck Institute for Meteorology
Phone: +49 (0)40 41173 109
Email: johann.jungclaus@zmaw.de

Dr. Victor Brovkin
Max Planck Institute for Meteorology
Phone: +49 (0) 40 41173 339
Email: victor.brovkin@zmaw.de

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