R1 Climate Lessons from radiocarbon data (CLER)

[depending on funding available; 1 PhD only in relation to WP1 and WP3]

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1. Three research questions of the project

- How did cosmogenic radiocarbon (^{14}C) production and solar activity vary over the last millennium and how did solar variability contribute to decadal-to-century scale variability in climate and atmospheric CO_2?
- What is the magnitude of the current radiocarbon production by cosmogenic particles?
- How do soil-climate-greenhouse gas feedbacks and permafrost variations affect past and future greenhouse gas concentrations?

2. Research Summary

The role of solar variability for climate change and the vulnerability of soil carbon to climate change and related soil-greenhouse gas-climate feedbacks are quantified. The overarching theme is to quantify the production of ^{14}C and its redistribution in the earth system (i) to infer the role of solar variability in driving earth system variability of the past, and (ii) to learn about soil overturning time scales and soil-climate-greenhouse gas feedbacks. We are in the unique position of having a carbon cycle-climate model that includes the relevant carbon reservoirs both on land and in the ocean in 3-dimensions and that is cost-efficient to allow for the millennial-scale simulations required to model the ^{14}C distribution within the Earth System. The research will be performed in close collaboration with the partner NCCR project R2 SOLAR (PI J. Beer) to exploit the complementary strengths of the two groups and two proxies (^{14}C and ^{10}Be).

3. Data and methods

A) Model: The Bern3D-LPJ climate-carbon cycle model includes an energy-balance atmosphere, a geostrophic-frictional balance 3-d ocean model (Tschumi et al. 2008), the Lund-Potsdam-Jena (LPJ) Dynamic Vegetation Model (Strassmann et al. 2007), ocean sediments, and representations for the global cycling of carbon and its isotopes as well as a suite of ventilation time scale, biogeochemical, and water mass tracers, a marine foodweb model, and a marine N_2O and Fe cycle, and a representation of anthropogenic land use and terrestrial methane emissions. The LPJ model will either be applied fully coupled to the Bern3D atmosphere-ocean component or run offline forced with precipitation and temperature data from observation or from AOGCM output (Frölicher et al. 2008).

B) Solar and Earth system variability: Solar forcing over the past millennium will be reconstructed on the basis of annually to decadally-resolved radiocarbon data by updating and improving earlier work in this direction (Muscheler et al. 2005, Muscheler et al. 2007). Climate-carbon simulations will be carried out for the past and the future. The individual taks are: 1) The current radiocarbon production rate will be estimated from atmospheric and oceanic ^{14}C data (e.g. Müller et al. 2008) and Bern3D-LPJ model derived inventory estimates for sediments and land and the ^{14}C decay rate. The observationally-constrained production record will provide a benchmarch for mechanistic cosmogenic isotope production models (Masarik and Beer 1999). 2) The latest INTCAL ^{14}C tree ring records for the Northern and for the Southern Hemisphere will be prescribed in the Bern3D-LPJ to deconvolve the ^{14}C production rate. The model will be spun-up over the past 25,000 years to properly account for the long life time of ^{14}C (8267 years). In turn, the ^{14}C production rate is used to reconstruct solar activity and to estimate solar forcing. 3) The reconstructed solar forcing is applied in combination with other forcing factors to simulate carbon cycle-climate variability during the last millennium (Gerber et al. 2003, Ammann et al. 2007). Step 2 and 3 will be done iteratively to account for the potential impact of climate-carbon cycle feedbacks on deconvolved radiocarbon production and to take into account the results from the ^{10}Be analysis of J. Beer (NCCR Project SOLAR) and coworkers. Specifically, the separation of the ^{14}C and ^{10}Be production records into a solar and Earth System component will be evaluated with a state-of-the art radiocarbon model.

C) The vulnerability of soils: The future evolution of the global climate system depends to a substantial degree on the nature and magnitude of the feedbacks between the physical climate system and the global carbon cycle (Solomon et al. 2007). Yet, these feedbacks are presently not well understood. Here, the task is to investigate the processes governing soil overturning and their sensitivity to climate and land use change. 1) Soil radiocarbon data will be used to evaluate soil overturning time scales (Perruchoud et al. 1999) in LPJ. 2) Land use maps from the HYDE data base will be applied to quantify the impact of anthropogenic land use changes (pasture, cropland, and built-up) on past and future climate-carbon cycle variability and the loss of soil carbon due to land use. 3) An important intermediate- to long-term goal is to include a more detailed process-oriented parameterization for permafrost soils in LPJ to account for the potential contribution of deep soil layers to the ^{14}C cycle and to the production of CH_4 and CO_2 under global warming. This last task is challenging and represents an ambitious goal that may not be achieved within the time frame of this project.

4. Milestones and deliverables

After 18 months:

- Present-day ^{14}C production rate diagnosed. Modelled and measured soil ^{14}C compared;
- Solar forcing reconstruction based on ^{14}C available for other groups.

After 36 months:

- Last millennium simulations with the latest solar forcing and land use data available;
- Soil-climate-greenhouse gas feedbacks and their uncertainties estimated;

5. Contribution and collaboration with other NCCR projects and 3rd parties

The solar forcing reconstruction will be done in close collaboration with the NCCR Climate Project SOLAR (also reserve) by J. Beer. Combined solar forcing data are provided to WP1 (P1.1 MONALISA-3 and P1.2 PALVAREX-3) as model input and output from WP1 can be used to drive LPJ. Global soil carbon modelling of CLER (this project) will benefit from exchange with WP3 and their work on soil carbon at different spatial and temporal scales (P31, P32, P33).

References

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