R2 Solar Forcing and Climate Change of the last 1000 years SOLAR

[Depending on funding available; 1 PhD only in relation to WP1]

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1. Three research questions of the project

- How can the high-resolution solar variability during the last millennium be quantified?
- How can solar variability be converted into solar forcing?
- How can solar forcing be detected and attributed in climate records?

2. Research Summary

Cosmogenic radionuclides such as ^{10}Be in ice cores and ^{14}C in tree rings have proven to be useful proxies for long-term solar variability (Vonmoos et al. 2006) (Steinhilber et al. 2008a). However, these radionuclides reflect not only production changes induced by heliomagnetic and geomagnetic variability. They are also influenced by system effects (transport and deposition processes in the case of ^{10}Be; the global carbon cycle in the case of ^{14}C (transport and deposition processes in the case of ^{10}Be; the global carbon cycle in the case of ^{14}C Muscheler et al. 2000; Project R1 CLER). In previous work we developed a technique to separate the solar signal and the system effects by combining two ^{10}Be records with the ^{14}C record. Applying this technique to a new annual ^{10}Be record from North GRIP combined with an existing annual ^{10}Be record from Dye3 in Southern Greenland and the ^{14}C record from tree rings will enable us to produce a new high-resolution solar variability record (Beer et al. 2007) (Abreu et al. 2008).

In a second step this new solar variability record is used to derive the solar forcing function in terms of Wm^{-2}.

In the final step the solar forcing function is used for model runs (P1.1. Monalisa) and compared with paleorecords of climate change (P1.2. Palvarex-3) The ^{14}C system component derived in step 1 is compared with carbon cycle changes (Project R1 CLER) *and th*e ^{10}Be component with model runs using ECHAM-HAM (Heikkila et al. 2008).

3. Data and methods

A) Data: Since all records of a single cosmogenic radionuclide are composed of a production component reflecting solar and geomagnetic modulation of the cosmic rays and a system component reflecting the transport from the point of production in the atmosphere to the site of storage in an ice core (^{10}Be) or a tree (^{14}C), combining ^{10}Be and ^{14}C records provides a means to separate these two components because both records contain a common production signal (Masarik and Beer 1999), but a different system signal (^{10}Be is attached to aerosols and removed from the atmosphere within 1-2 years while ^{14}C forms $^{14}CO_2$ and enters the global carbon cycle). The geomagnetic production component can be removed using paleomagnetic records based on remanence measurements in lava and sediments. This procedure which is based on the PCA (principal component analysis) has been successfully applied to low resolution (40 y) long-term records (1-9 kyr BP) of ^{10}Be from ice cores and ^{14}C from tree rings (Beer et al. 2007) (Abreu et al. 2008).

Using the annual ^{10}Be records from Dye 3 (South Greenland) (Beer et al. 1990) (Beer et al. 1994) and a new annual ^{10}Be record from NGRIP (North Greenland) (Berggren et al. 2008) in combination with partly annual ^{14}C data from tree rings (Reimer et al. 2004) the same approach is used to produce a high-resolution solar variability record for about the past 600 years reflected by the first principal component (Abreu et al. 2008). The second principal component reflects the ^{14}C system variations. Whenever the ^{14}C signal deviates significantly from the production signal this is an indication of a change in the carbon cycle. A detailed analysis of the second principal component will be done in close collaboration with F. Joos making use of the Bern 3D-LPJ climate-carbon cycle model (Project R1 CLER).

B) Solar forcing: A quantitative high resolution solar forcing function is fundamentally important not only to model past climate changes, but also to distinguish between natural and anthropogenic forcing during the present and the future global warming. There are at least three reasons why the establishment of such a quantitative forcing in Wm^{-2} is difficult: 1. Direct measurements of the total solar irradiance (TSI) form satellite based radiometers are limited to the past 30 years, a period of comparatively high solar activity (Frohlich and Lean 2004). In particular, direct measurements for grand solar minima such as the Maunder Minimum (1645-1715) are missing. 2. The observed changes over an 11-year Schwabe cycle during the past 30 years are only about 0.1%. 3. The underlying physical processes relating the solar magnetic activity to the TSI are only rudimentary known. Nevertheless, there is growing evidence that the TSI is controlled by the magnetic fields in the convective zone and at the solar surface. Since it is the open magnetic solar field that modulates the cosmic ray intensity in the heliosphere cosmogenic radionuclides turn out to be a good tool to reconstruct past solar magnetic activity and a promising candidate for a proxy of the TSI (Steinhilber et al. 2008b).

C) Detection and attribution of solar forcing: The quantitative solar forcing function together with the annual ^{14}C and ^{10}Be system records derived from the PCA analysis provide a unique data set to study solar forcing and climate change. Putting the TSI record together with other forcing functions (e.g. volcanic forcing) into climate models will enable us to compare modelled and observed spatial and temporal climate variability. This will be done in close collaboration with P1.2. PALVAREX-3 (observations) and MONALISA-3 (modelling). In addition, the third principal component which is related to the transport of ^{10}Be and the second component related to the global carbon cycle will be interpreted in terms of climate forcing and climate change. The analysis in the time domain will be complemented by spectral analysis in the frequency domain.

4. Milestones and deliverables

After 18 months:

- Separation of production and system effects based on ^{10}Be in 2 ice cores and ^{14}C in tree rings using PCA.
- High-resolution record of solar variability for the past 600 years
- Quantitative solar forcing in Wm^{-2} with estimated uncertainties

After 36 months:

- Comparison of spatial and temporal variability of model runs with observations
- Interpretation of the second and third principal component in terms of global carbon cycle changes and ^{10}Be atmospheric transport.
- Publications

5. Contribution to the WP1 and collaboration with other NCCR projects and 3rd parties

The interpretation of the PCA will be done in close collaboration with the project R1 CLER (F. Joos). A (combined ^{14}C and ^{10}Be) solar forcing is provided to P1.1 MONALISA-3 and compared with observations P1.2 PALVAREX-3.

References

Abreu, J. A., J. Beer, F. Steinhilber, M. Christl, and P. K. Kubik. 2008. ^{10}Be in ice cores and ^{14}C in tree rings: Separation of Production and Climate Effects. J. Geophys. Res. in preparation.

Beer, J., S. Baumgartner, B. Hannen-Dittrich, J. Hauenstein, P. Kubik, C. Lukasczyk, W. Mende, R. Stellmacher, and M. Suter. 1994. Solar Variability Traced by Cosmogenic Isotopes. Pages 291-300 *in* J. M. Pap, C. Fröhlich, H. S. Hudson, and S. K. Solanki, editors. The Sun as a Variable Star: Solar and Stellar Irradiance Variations. Cambridge University Press, Cambridge.

Beer, J., A. Blinov, G. Bonani, R. C. Finkel, H. J. Hofmann, B. Lehmann, H. Oeschger, A. Sigg, J. Schwander, T. Staffelbach, B. Stauffer, M. Suter, and W. Wölfli. 1990. Use of ^{10}Be in polar ice to trace the 11-year cycle of solar activity. Nature 347:164-166.

Beer, J., K. G. McCracken, J. A. Abreu, U. Heikkilä, and F. Steinhilber. 2007. Long-term changes in cosmic rays derived from cosmogenic radionuclides. *in* 30th Int. Cosmic Ray Conf. ICRC07, Merida.

Berggren, A.-M., J. Beer, G. Possnert, A. Aldahan, P. Kubik, M. Christl, S. Johnsen, U. Heikkilae, and J. A. Abreu. 2008. A 600-year annual ^{10}Be record from the NGRIP ice core, Greenland. Geophys. res. Let. submitted.

Frohlich, C., and J. Lean. 2004. Solar radiative output and its variability: evidence and mechanisms. Astronomy And Astrophysics Review 12:273-320.

Heikkila, U., J. Beer, and J. Feichter. 2008. Modeling cosmogenic radionuclides Be-10 and Be-7 during the Maunder Minimum using the ECHAM5-HAM General Circulation Model. Atmospheric Chemistry and Physics 8:2797-2809.

Masarik, J., and J. Beer. 1999. Simulation of particle fluxes and cosmogenic nuclide production in the Earth's atmosphere. J. Geophys. Res. 104:12,099 - 012,111.

Muscheler, R., J. Beer, G. Wagner, and R. C. Finkel. 2000. Changes in deep-water formation during the Younger Dryas event inferred from Be-10 and C-14 records. Nature 408:567-570.

Reimer, P. J., M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, C. J. H. Bertrand, P. G. Blackwell, C. E. Buck, G. S. Burr, K. B. Cutler, P. E. Damon, R. L. Edwards, R. G. Fairbanks, M. Friedrich, T. P. Guilderson, A. G. Hogg, K. A. Hughen, B. Kromer, G. McCormac, S. Manning, C. B. Ramsey, R. W. Reimer, S. Remmele, J. R. Southon, M. Stuiver, S. Talamo, F. W. Taylor, J. van der Plicht, and C. E. Weyhenmeyer. 2004. IntCal04 terrestrial radiocarbon age calibration, 0-26 cal kyr BP. Radiocarbon 46:1029-1058.

Steinhilber, F., J. A. Abreu, and J. Beer. 2008a. Solar modulation during the Holocene. Astrophys. Space Sci. Trans. 4:1-6.

Steinhilber, F., J. A. Abreu, J. Beer, and K. McCracken. 2008b. The interplanetary magnetic field during the past 9'300 years inferred from cosmogenic radionuclides. J. Geophys. Res. in preparation.

Vonmoos, M., J. Beer, and R. Muscheler. 2006. Large variations in Holocene solar activity: Constraints from Be-10 in the Greenland Ice Core Project ice core. Journal of Geophysical Research-Space Physics 111.