Low frequency changes in the carbon cycle during the last 120 kyr and its implications for the reconstruction of atmospheric $\Delta^{14}C$ and the ^{14}C production rates estimates — a simulation study

Alfred Wegener Institute for Polar and Marine Research

P. Köhler[1], R. Muscheler[2] & H. Fischer[1]
(pkoehler@awi-bremerhaven.de)

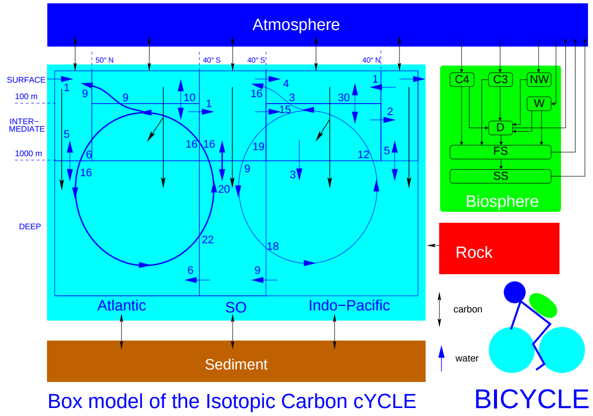
1: Alfred Wegener Institute f. Polar & Marine Research Bremerhaven, Germany
2: National Center for Atmospheric Research Boulder, CO, USA

NCAR

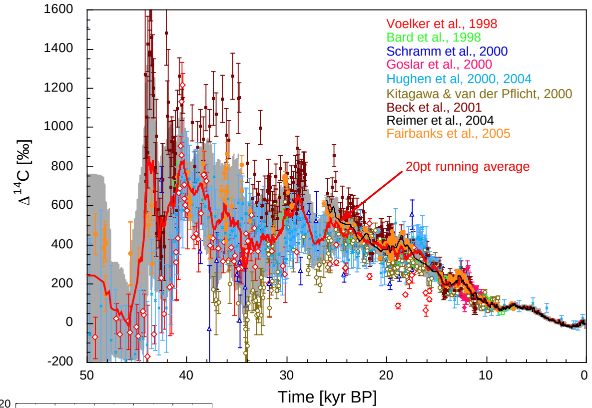
We use the ocean/atmosphere/biosphere box model of the global carbon cycle BICYCLE (Köhler et al. 2005) to reproduce low frequency changes in atmospheric CO_2 as seen in Antarctic ice cores during the last glacial cycle (∼ 120,000 years) (Köhler et al. 2006). We force the model forward in time by various paleo-climatic records derived from ice and sediment cores. The simulation results of our proposed scenario match a compiled CO_2 record from various ice cores with high accuracy ($r^2 = 0.89$). The processes that contribute most to the glacial/interglacial changes in CO_2 are variations in the sedimentation and dissolution rates of $CaCO_3$, ocean circulation, ocean temperature and glacial iron fertilization of the marine biota in the Southern Ocean. The BICYCLE model includes also calculations for the carbon isotopes ^{13}C and ^{14}C and we assess what changes in atmospheric $\Delta^{14}C$ might be based on variations in the carbon cycle. Our results suggest that during the last glacial cycle in general less than 120‰ of the increased atmospheric $\Delta^{14}C$ are based on variations in the carbon cycle, while the largest part of the variations has to be explained by changing ^{14}C production rates. Processes acting on the global carbon cycle that increase glacial $\Delta^{14}C$ are a restricted glacial gas exchange between the atmosphere and the surface ocean through sea ice coverage, a reduced glacial ocean circulation, and the enrichment of DIC with ^{14}C in the surface waters through isotopic fractionation during higher glacial marine export production caused by iron fertilization. From the available $\Delta^{14}C$ data covering the last 50,000 years and our carbon cycle-based simulation results we can infer changes in the ^{14}C production rates, which are then compared with two other estimates based on ^{10}Be and geomagnetic field reconstruction. The agreements and discrepancies between these three independent approaches to estimate the ^{14}C production rates are discussed and highlight the limitations and possible uncertainties in all three approaches.

Keywords: carbon cycle, ^{14}C cycle, ^{14}C production rates, glacial/interglacial, modeling, box model, radionuclides

Model — $\Delta^{14}C$ data — Results

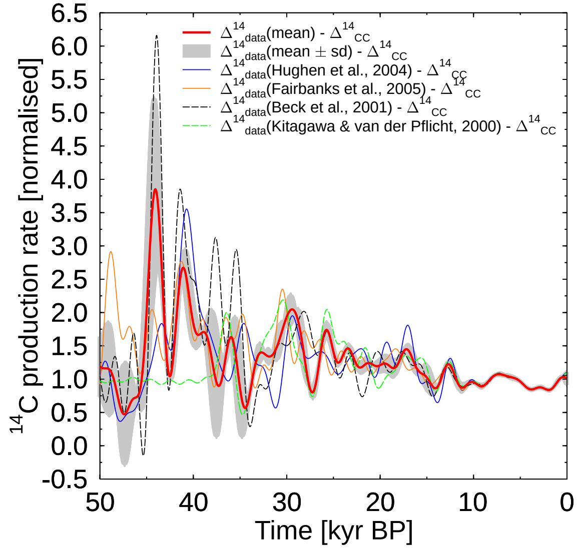


Box model of the Isotopic Carbon cYCLE BICYCLE



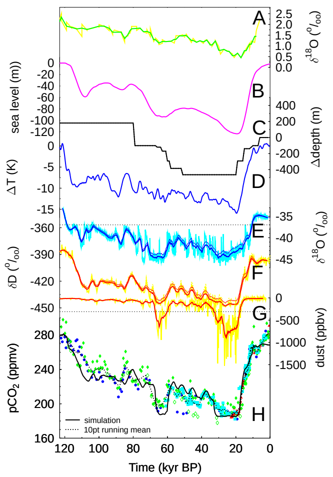
Top: Data based reconstruction of $\Delta^{14}C$.

Variable ^{14}C production rate

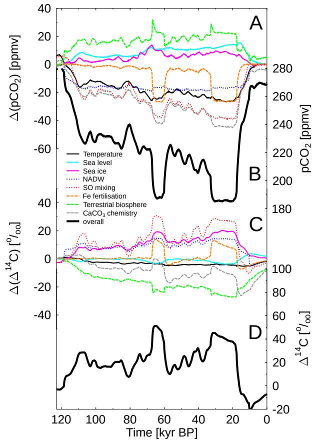


Carbon cycle-based reconstruction of ^{14}C production rate based on different $\Delta^{14}C$ data sets.

Forcing

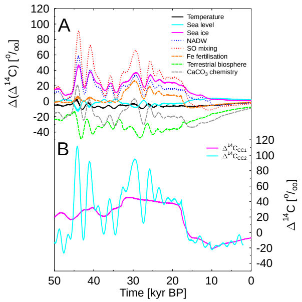


Simulation Results



Left: Different data sets forcing the model (A: equatorial SST proxy, B: sea level; C: lysocline; D: northern hemisphere temperature; E: North Atlantic SST proxy; F: Southern Ocean SST proxy; G: dust input in Southern Ocean; H: Data and simulation results for pCO_2.

Right: Simulation results. A: Process contribution to $\Delta(pCO_2)$; B: pCO_2; C: Process contribution to $\Delta(\Delta^{14}C)$; D: $\Delta^{14}C$ with constant ^{14}C production rate.

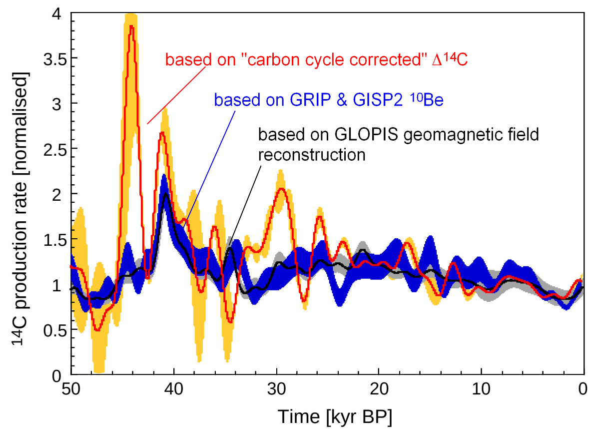


Top: Contribution of different processes and overall carbon-cycle based changes to $\Delta^{14}C$ with variable ^{14}C production rates.

References:

Bard et al. 1998. Radiocarbon, 40:1085–1092. **Beck et al. 2001**. Science, 292:2453–2458. **Fairbanks et al. 2005**. Quaternary Science Reviews, 24:1781–1796. **Goslar et al. 2000**. Nature, 403:877–880. **Hughen et al. 2004**. Science, 303:202–207. **Hughen et al. 2000**. Science, 290:1951–1954. **Kitagawa & van der Plicht 2000**. Radiocarbon, 42:369–380. **Köhler et al. 2005**. GBC, 19:GB4020, doi: 10.1029/2004GB002345. **Köhler et al. 2006**. GGG, submitted, doi: 10.1029/2005GC001228. **Laj et al. 2005**. Geophs. Monog. Series, 145:255–265. **Muscheler et al. 2005**. QSR, 24:1849–1860. **Reimer et al. 2004**. Radiocarbon, 46:1029–1058. **Schramm et al. 2000**. EPSL, 175:27–40. **Voelker et al. 1998**. Radiocarbon, 40:517–534.

Comparing three approaches to estimate ^{14}C production rates



^{10}Be from Muscheler et al. (2005) and GLOPIS from Laj et al. (2005).

DEKLIM
Paleoclimate Research
German Climate Research Programme
Federal Ministry of Education and Research

(Bard et al. 1998; Voelker et al. 1998; Goslar et al. 2000; Hughen et al. 2000; Hughen et al. 2004; Kitagawa & van der Pflicht 2000; Schramm et al. 2000; Beck et al. 2001; Reimer et al. 2004; Fairbanks et al. 2005; Köhler et al. 2006; Muscheler et al. 2005; Laj et al. 2005)

Literatur

[Bard et al. 1998] Bard, E., Arnold, M., Hamelin, B., Tisnerat-Laborde, N., & Cabioch, G. 1998. Radiocarbon calibration by means of mass spectrometric 230Th/234U and 14C ages of corals. An update data base including samples from Barbados, Mururoa and Tahiti. Radiocarbon, **40**:1085–1092.

[Beck et al. 2001] Beck, J. W., Richards, D. A., Edwards, R. L., Silverman, B. W., Smart, P. L., Donahue, D. J., Hererra-Osterheld, S., Burr, G. S., Calsoyas, L., Jull, A. J. T., & Biddulph, D. 2001. Extremely large variations of atmospheric ^{14}C concentration during the Last Glacial Period. Science, **292**:2453–2458.

[Fairbanks et al. 2005] Fairbanks, R. G., Mortlock, R. A., Chiu, T.-C., Cao, L., Kaplan, A., Guilderson, T. P., Fairbanks, T. W., Bloom, A. L., Grootes, P. M., & Nadeau, M.-J. 2005. Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired ^{230}Th/ ^{234}U/ ^{238}U ans ^{14}C dates on pristine corals. Quaternary Science Reviews, **24**:1781–1796.

[Goslar et al. 2000] Goslar, T., Arnold, M., Tisnerat-Laborde, N., Czernik, J., & Wickowski, K. 2000. Variations of Younger Dryas atmospheric radiocarbon explicable without ocean circulation changes. Nature, **403**:877–880.

[Hughen et al. 2004] Hughen, K., Lehman, S., Southon, J., Overpeck, J., Marchal, O., Herring, C., & Turnbull, J. 2004. ^{14}C activity and global carbon cycle changes over the past 50,000 years. Science, **303**:202–207.

[Hughen et al. 2000] Hughen, K. A., Southon, J. R., Lehman, S. J., & Overpeck, J. T. 2000. Synchronous radiocarbon and climate shifts during the last deglaciation. Science, **290**:1951–1954.

[Kitagawa & van der Pflicht 2000] Kitagawa, H. & van der Pflicht, J. 2000. Atmospheric radiocarbon calibration beyond 11,900 Cal BP from Lake Suigetsu laminated sediments. Radiocarbon, **42**:369–380.

[Köhler et al. 2005] Köhler, P., Fischer, H., Munhoven, G., & Zeebe, R. E. 2005. Quantitative interpretation of atmospheric carbon records over the last glacial termination. Global Biogeochemical Cycles, **19**:GB4020, doi: 10.1029/2004GB002345.

[Köhler et al. 2006] Köhler, P., Muscheler, R., & Fischer, H. 2006. A model-based interpretation of low frequency changes in the carbon cycle during the last 120 kyr and its implications for the reconstruction of atmospheric Δ^{14}C and the ^{14}C production rates estimates. Geochemistry, Geophysics, Geosystems, Page submitted; doi: 10.1029/2005GC001228.

[Laj et al. 2005] Laj, C., Kissel, C., & Beer, J. 2005. High resolution global paleointensity stack since 75 kyr (GLOPIS-75) calibrated to absolute values. Pages 255–265, *in* Channell, J. E. T., Kent, D. V., Lowrie, W., & Meert., J. G. (editors), Timescales of the paleomagnetic field, volume 145 of Geophysical Monograph Series. AGU, Washington, USA.

[Muscheler et al. 2005] Muscheler, R., Beer, J., Kubik, P. W., & Synal, H.-A. 2005. Geomagnetic field intensity during the last 60,000 years based on ^{10}Be and ^{36}Cl from the Summit ice cores and ^{14}C. Quaternary Science Reviews, **24**:1849–1860; doi: 10.1016/j.quascirev.2005.01.012.

[Reimer et al. 2004] Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C. J. H., Blackwell, P. G., Buck, C. E., Burr, G. S., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Hogg, A. G., Hughen, K. A., Kromer, B., McCormac, G., Manning, S., Ramsey, C. B., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J., & Weyhenmeyer, C. E. 2004. INTCAL04 terrestrial radiocarbon age calibration, 0–26 Cal kyr BP. Radiocarbon, **46**:1029–1058.

[Schramm et al. 2000] Schramm, A., Stein, M., & .Goldstein, S. L. 2000. Calibration of the 14C time scale to 440 ka by 234U-230Th dating of Lake Lisan sediments (last glacial Dead Sea). Earth and Planetary Science Letters, **175**:27–40.

[Voelker et al. 1998] Voelker, A. H. L., Sarnthein, M., Grootes, P., Erlenkeuser, H., Laj, C., Mazaud, A., Nadeau, M.-J., & Schleicher, M. 1998. Correlation of marine 14C ages from the nordic seas with the GISP2 isotope record: implications for radiocarbon calibration beyond 25 kyr BP. Radiocarbon, **40**:517–534.