Geophysical Research Abstracts,
Vol. 10, EGU2008-A-04142, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-04142
EGU General Assembly 2008

Orbital tuning of ice core age scales: Improvements with a physically based model

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Ice core records of the total air content (TAC) and molecular fractionation (FRAC, e.g. O_2/N_2) in air bubbles from low accumulation sites such as Vostok, Dome C and Dome Fuji, Antarctica, co-vary with local insolation. This empirical link between TAC, FRAC and insolation has recently been used to orbitally tune and thus improve ice core time scales. However, the physical origin of this link is controversial and the orbital tuning relies on the assumption that the imprint of the insolation signal in the snow and firn occurs without a significant temporal lead or lag. Based on micro tomography results, we propose that an anisotropy of the pore space geometry in snow and firn forming during temperature gradient metamorphism can explain the observed link between TAC, FRAC and local insolation. Physically based modelling of past changes in temperature gradient metamorphism, anisotropy, TAC and FRAC records allows estimating the systematic uncertainties in orbital tuning exercises and thus to significantly improve ice core time scales. For instance, the results suggest that simply tuning O_2/N_2 and TAC records to local summer insolation are prone to systematic dating errors of up to $\sim$2.5 ka and $\sim$5 ka, respectively, which can be eliminated with the model. In addition, the model reveals insolation-induced shifts in the delta age (age difference between the air bubbles and the neighbouring ice) of up to several hundred years, which can help reconcile gas and ice age scales.