Models used for ice core dating

For the thinning rate computation, we used an ice-flow model[1], with prescribed surface elevation[2]. It has two poorly known parameters: the melting at the base of the ice sheet (F) which is the condition for the vertical velocity at the base, and a parameter (*m*) for the vertical velocity profile. The vertical strain rate is assumed to be proportional to $1-(z/H)^{(m+1)}$, where z is the depth and H is the ice thickness. The accumulation rate is deduced from δD content of the ice in two steps. First, temperature above the inversion layer (called inversion temperature), where precipitation forms, is deduced from the δD record. As recently discussed[3,4], one can use for this purpose the present-day observed spatial relationship measured in this sector of Antarctica:

$$T_I=0.111*(\delta D-396.5)+235.2$$

where T_I is inversion temperature (K), and δD is the variation of the deuterium/hydrogen ratio of the ice (‰).

The accumulation rate (in cm of ice per year) is then calculated through a condensation model:

$$A=A_0*f(T_I)/f(T_I^0)*(1+\beta(T_I-T_I^0))$$

Where T_I^0 is the present-day inversion temperature (235.2 K), A_0 is the present-day accumulation rate, β is a constant, and f(T) is given by:

$$f(T)=(Bs/T-1)/T^2 * \exp(-Bs/T)$$

where Bs=6148.3 K. The f function basically takes into account the change of saturation vapour pressure, whereas the parameter β takes into account glacial-interglacial changes of accumulation that are not explained by this relationship, for example changes in over-saturation, changes in winds intensity, or changes in ablation.

The last modelling step of the chronology is the evaluation of the gas age – ice age difference (Δage), required to derive the age scales for the gas measurements. This is derived from a firn model[5], based on physical grain sliding and deformation laws, and that takes into account the diffusion of temperature in the firn. We compared this Δage value with the one from a different model[6], and found a very good agreement: no more than 50 years difference for a major part of the record, and reaching ~150 years for the glacial maxima.

The poorly known parameters (F, m, A_0 and β) of the models, are evaluated through the use of a small number of chronological controls, through a Monte Carlo inverse method[7,8]. Rather than constraining the chronology to be exactly tied to these ages, the method searches for an optimal agreement, within the limits of the confidence interval of each assigned age (i.e. we use control windows rather than control points) and using the same rules to define accumulation all along the record. For the upper part, as in the timescale (EDC1) used on the shallower part of the core[9], we used three control windows. The first (233 m = 7135±100 yr) is a match through volcanic events to the GT4 Vostok time scale[10], which is connected to the dendrochronology by matching[11] cosmogenic production rates of ^{10}Be and ^{14}C. The second (374 m = 12390±400 yr) is a match of water isotopes to the Byrd core, which is in turn connected to GRIP and GISP2 time scales by matching methane records[12]. The third (740 m = 41±2 kyr) is the well-known ^{10}Be peak. Since we have no strong reason at this point to alter the already published timescale (EDC1) for the top part of the core[9], we forced an additional control door with a narrow (±50 yr) opening at 800 m depth. This extra door has little effect on the timescale above or below 800 m, but it allows us to keep the same timescale that has already been used by many authors for the top 800 m (thus avoiding confusing discrepancies between timescales), while maintaining physical consistency in the new timescale. For the bottom part of the core (i.e., for the period older than 50 kyr), we used several age control windows derived by comparison to the stacked marine isotope curve of Bassinot[13], assuming a 4 kyr phase lag. These points are situated at Terminations II (1738 m =131±6 kyr), III (2311 m=245±6 kyr), IV (2593 m = 338±6 kyr), VII (3038 m = 626±6 kyr), VIII (3119 m = 717±6 kyr).

The inverse method used is explained in detail elsewhere[7]. It is based on a Monte Carlo exploration of the space of poorly known parameters. It allows computation of not only an optimal time scale and optimal model parameters, but also confidence intervals for the time scale and the poorly-known parameters from the confidence interval of chronological control windows. The inverse experiment presented here is based on 3500 scenarios, of which we selected those that give a good agreement with the chronological controls. The optimal values (and confidence interval) for the poorly known parameters are A_0=2.84 cm of ice per year (2.85±0.04), β=0.032 K^{-1} (0.035±0.012), m=1.58 (1.72±0.53), and F=0.76 mm/yr (0.73±0.07).

Comparison with either the Vostok or with the Dome Fuji isotopic profiles show significant differences in the ages of easily recognizable common events, as already pointed out[8] for the comparison between isotopic profiles for Vostok and Dome Fuji. In particular, Transition II is about 5 kyr younger at Dome C than at Dome Fuji which, although within the uncertainties of the inverse method, needs to be examined further. Work is in progress to get a common Antarctic ice core chronology accounting for information coming from these three deep ice core isotopic profiles and from other ice core time series such as the air $^{18}O/^{16}O$ isotopic ratio, as well from comparison with the deep-sea core record.

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