New modeling of the Vostok ice flow line and implication for the glaciological chronology of the Vostok ice core

Frederic Parrenin (1,2), Frederique Remy (2), Catherine Ritz (1), Martin J. Siegert (3), Jean Jouzel (4), Jérôme Chappellaz (1)

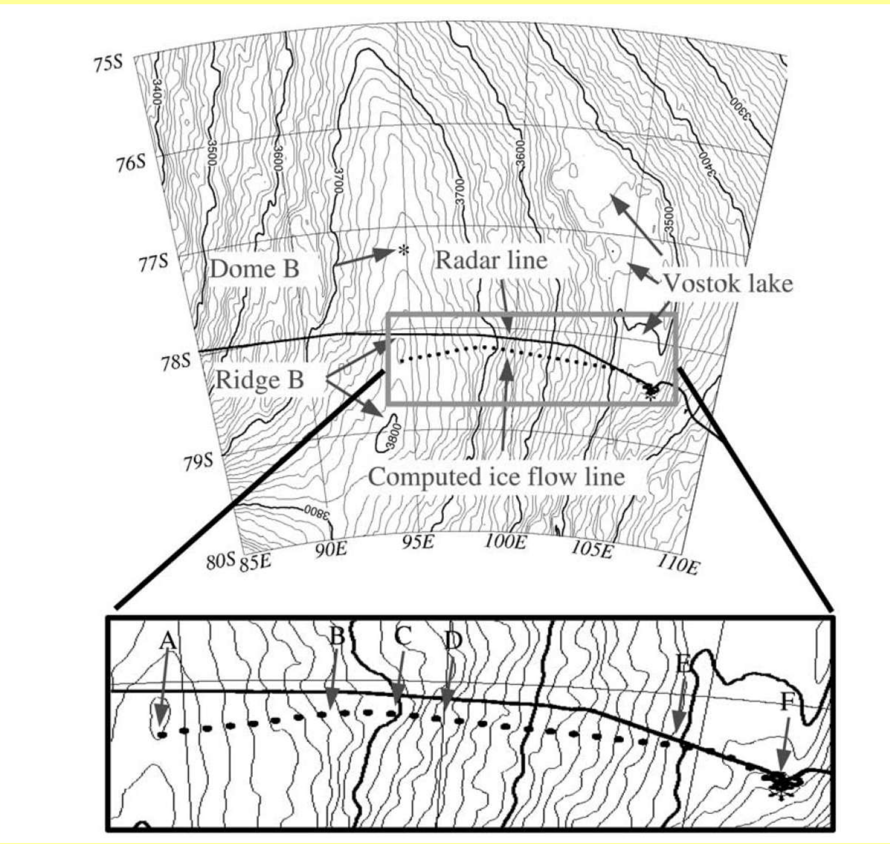
(1) Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France.
(2) Laboratoire de Géophysique et Océanographie Spatiales, Toulouse, France.
(3) Bristol Glaciology Center, Bristol, UK.
(4) Laboratoire des Sciences du Climat et de l'Environnement, Gif-Sur-Yvette, France.

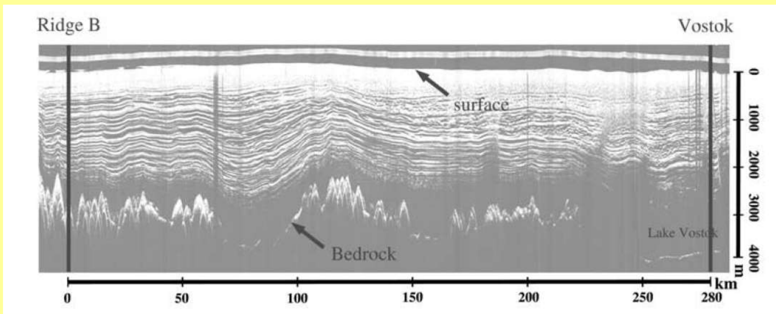
Abstract

We have used new spaceborne (elevation) and airborne (ice thickness) data to constrain a 2D1/2 model of snow accumulation and ice flow along the Ridge B-Vostok station ice flow line (East Antarctica). We show that new evaluations of the ice flow line geometry (from the surface elevation), ice thickness (from low-frequency radar data), and basal melting and sliding significantly change the chronology of the Vostok ice core. This new Vostok dating model reconciles orbital and glaciological timescales. At the same time, the new model shows significantly older ages than the previous GT4 timescale for the last glacial part, being thus in better agreement with GISP2 layer-counted chronology.

Method 1: The Vostok flow line

We used a topography of Antarctica obtained by satellite [Rémy et al., 1999] to **deduce the Vostok flow line from the greatest slope direction** (top figure, dotted line). Tthe **ice sheet thickness is deduced from an airborne radio echo sounding profile** (bottom figure) measured close to the Ridge B – Vostok ice flow line (top figure, continuous line) [Siegert and Kwok, 2000].





Method 2: the dating model

Accumulation model

Accumulation is deduced from the isotopic composition of the ice through the following steps.
First, past temperatures at the inversion layer (T_I) and at the surface (T_S) are deduced from the δD record through the present-day spatially observed relationships.
Second, accumulation is deduced from the inversion temperature through the following relationship with a free parameter β:

$$A=A^0(x)f(T_I)/f(T_I^0)\,(1+\beta(T_I-T_I^0)$$

where A is the accumulation rate, T_I is the inversion temperature, $A^0(x)$ is the accumulation function of the distance from the ice divide, at a reference temperature T_I^0, β is constant, and $f(T_I)$ is the saturation vapour pressure relationship. The β parameter, which is poorly known, accpunts for parameters that are not linked to the saturation vapour pressure, like changes in wind intensity or changes in sursaturation. It will be reconstructed by the inverse method.

Flow model

The flow model used is 2.5D, that is to say that the third dimension is taken into account by the width of the ice flow tube. It has prescribed surface elevation from present-day data, and the past variations are taken from a 3D thermomechanical model of Antarctica [Ritz et al., 2001]. The velocity profile is prescribed as:

$$u_\zeta=-m/H-(a-m)/H\,\omega(\zeta)$$

where u_ζ is the normalised vertical velocity, H is the ice thickness, m is the basal melting rate and a is the surface accumulation rate. The ω shape function is given by:

$$d\omega/d\zeta(\zeta)=1+(1-s)(p+2)/(p+1)(1-\zeta^{p+1})$$

where s is the sliding rate and p is a shearing parameter. We used p=10 everywhere, s=0 everywhere except above the lake where s=1. We assumed that the freezing above the Vostok lake is spatially constant, as well as the melting upstream.These two values will be reconstructed by the inverse method.

Age markers

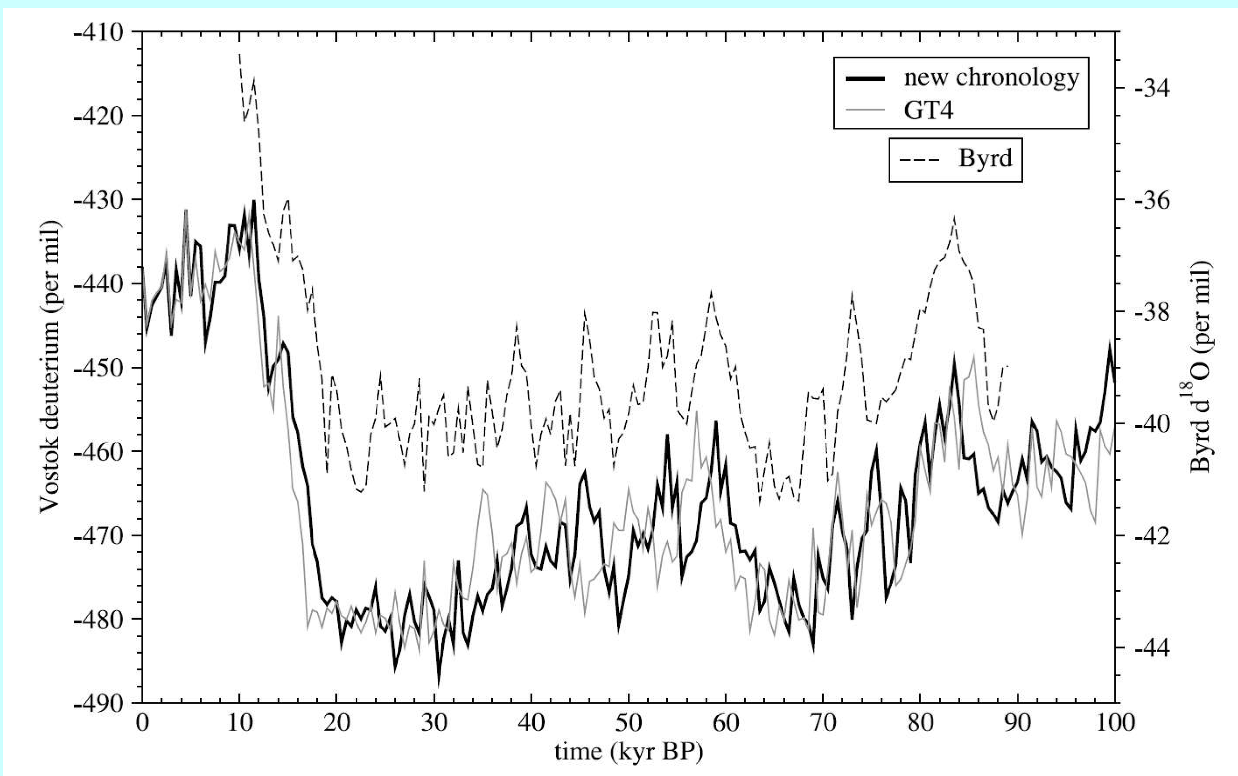
The Be10 record can be matched to the absolutely dated C14 record during the last 7000 yr [Raisbeck et al., 1998]. We used one age marker of 7180±100 yr at 178 m.
A Be10 peak recorded in the Vostok ice at 601 m corresponds to the Laschamp magnetic event, contemporary with D.O. event n°10, which dated at 41±2 kyr [Wang et al., 2001; Genty et al., 2003].
The comparison of δD and insolation variations (the so called orbital tuning method) allowed to derive 6 age markers with large uncertainty of 6000 yr.

Inverse method

Poorly known parameters of the accumulation model (i.e. A^0, β) and of the ice flow model (i.e. freezing and melting rates) lead to very large uncertainties in the chronology, so that we need to constrain these parameters with age markers along the ice core. This is done with a Monte Carlo inverse method, based on the Metropolis-Hastings algorithm [Parrenin et al., 2001].

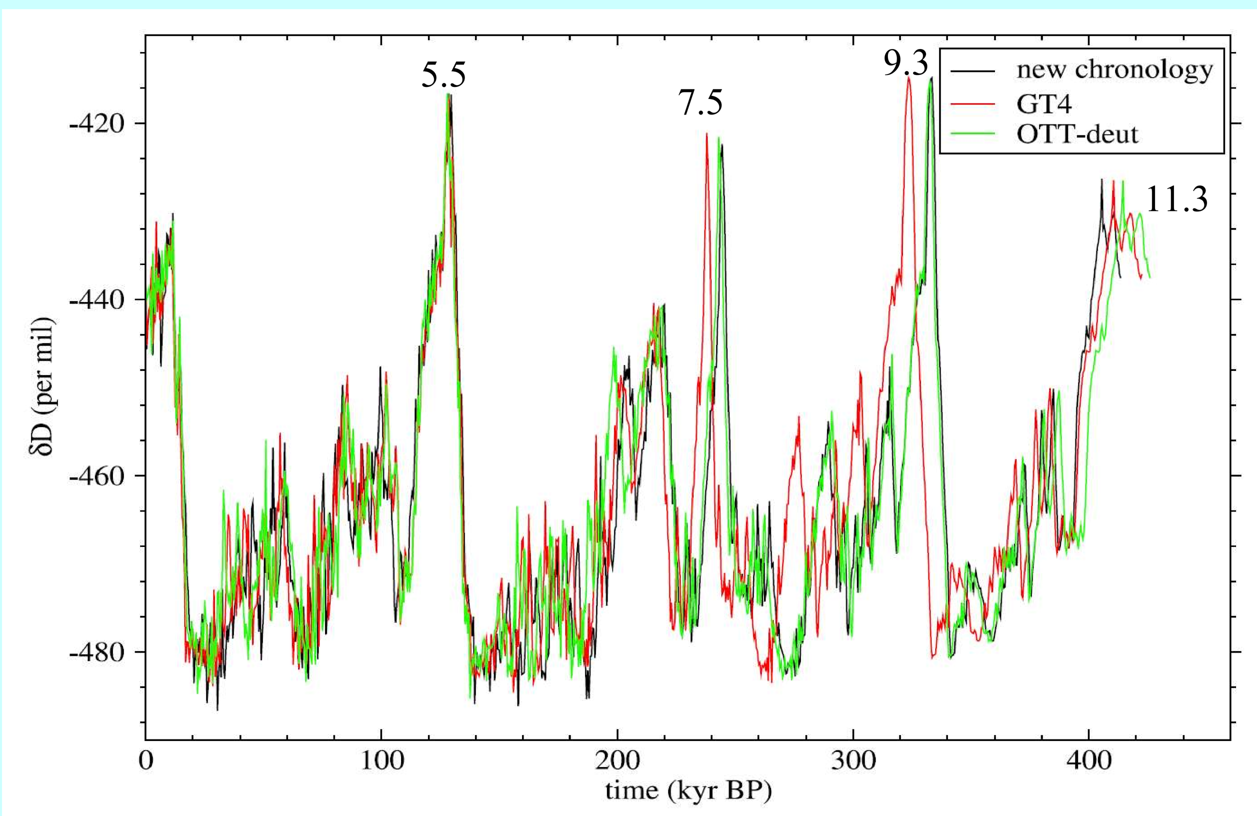
Result 1: Older chronology during stage 3, in better agreement with GISP2 chronology

Thanks to the new parametrisation of the Vostok ice flow line and to a reduced accumulation rate during glacial time, the chronology during the last glacial part (thick line) is older than for the GT4 chronology (grey dashed line), in better agreement with the Byrd ice core dated by comparison to GISP2 [Blunier and Brook, 2001], which is itself dated by layer counting [Meese et al., 1997].



Result 2: Older chronology during stages 7, 8 and 9, in better agreement with orbitally tuned chronologies

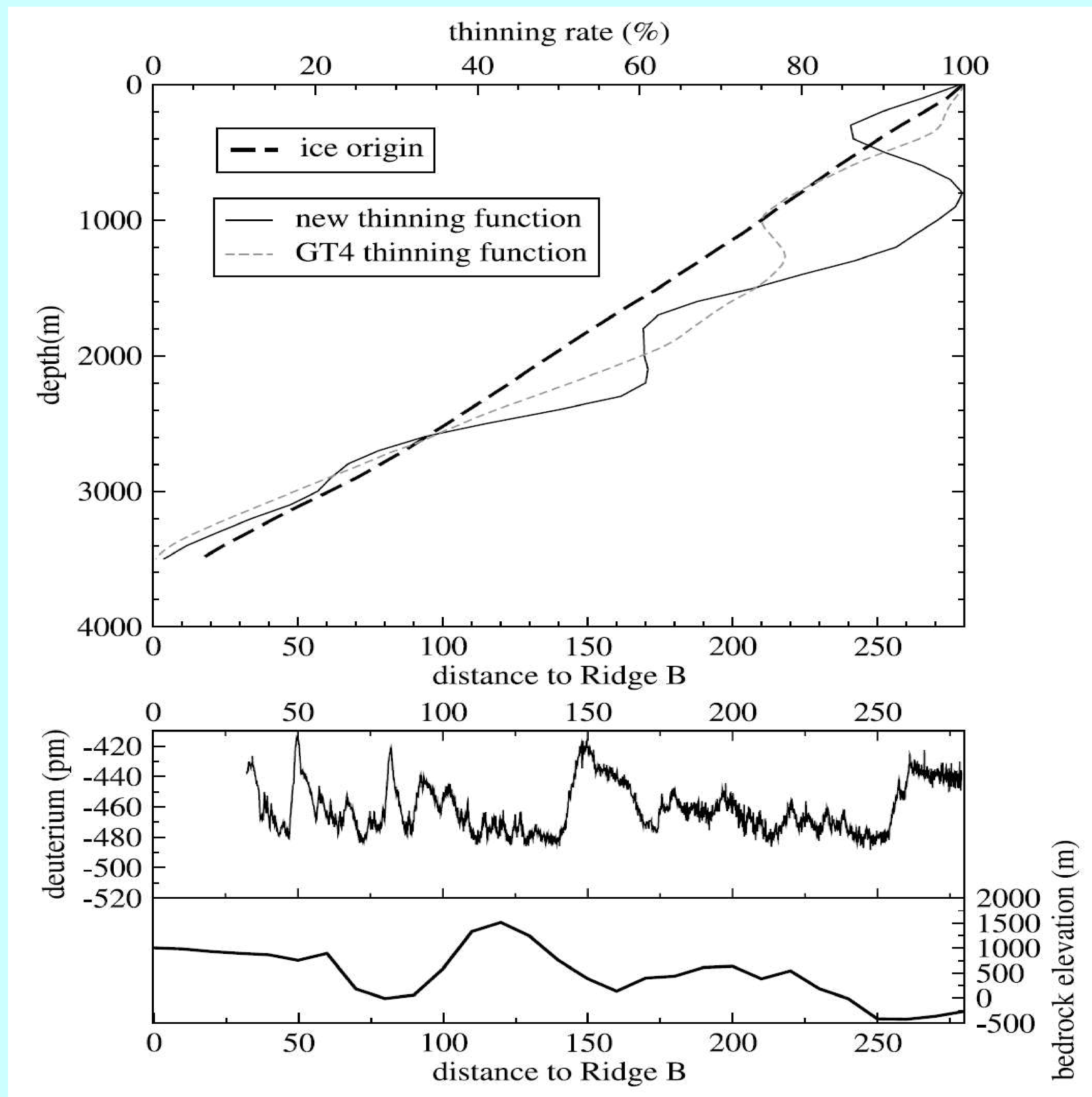
Thanks to the new parametrisation of the Vostok ice flow line, the new chronology is significantly older for stages 7, 8 and 9 than the GT4 chronology, in better agreement with the orbitally tuned chronology.



Result 3: New ice origin and thinning functions

We show that the thinning function at Vostok is related to the topography of the bedrock upstream: when the ice originates from a bedrock moutain, the ice has overall less thinned, and conversly.
As a consequence of the new bedrock elevation data, the new thinning function is significantly different from the one used to derive the GT4 chronology.

The ice origin is roughly linearly related to the depth in the drilling.



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