A method for dating of Dome Fuji ice core based on a state space modeling

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A technique for estimating the age–depth relationship in the ice core from Dome Fuji in Antarctica has been developed. The ice core obtained in Antarctica provides valuable information on climate changes in the past, and this information could also be useful for discussing future climate. In order to make use of the information from the ice cores, it is important to accurately estimate the age as a function of depth in an ice core. Our technique estimates the age–depth relationship based on age markers and δ^{18}O data by using the following equation:

$$x(z) = \int_S^z \frac{dz'}{A(z')\,\Theta(z')}, \tag{1}$$

where z denotes the vertical coordinate for depth from the surface of the ice sheet, x is the age in year at the given z (past is positive), A is the snow accumulation rate per year, and Θ represents the thinning factor due to long-term deformation within the ice sheet. We discretize the vertical coordinate z with an interval Δz. The integral in Eq. (1) is then approximately obtained by the following recurrence relation:

$$x_{z+\Delta z} = x_z + \frac{\Delta z}{A_z \Theta_z} + \zeta_z \Delta z \quad (z = 0, \Delta z, 2\Delta z, \ldots), \tag{2}$$

where x_z denotes the age at z and Z denotes the depth at the bottom end of the core. We define A_z and Θ_z as the accumulation rate and the thinning factor in the interval from z to $z + \Delta z$, respectively. The accumulation rate A_z is treated as an unknown variable and its transition from z to $z + \Delta z$ is described by the following recurrence relation:

$$\log A_{z+\Delta z} = \log A_z + \eta_z \Delta z \quad (z = 0, \Delta z, 2\Delta z, \ldots). \tag{3}$$

The term $\zeta_z \Delta z$ in Eq. (2) and the term $\eta_z \Delta z$ in Eq. (3) represent variations due to unknown processes that are taken into account neither in Eq. (2) nor in Eq. (3). An age marker y_k is associated with the modeled age x_z at the corresponding depth:

$$y_k = x_z + \varepsilon_z, \tag{4}$$

and the accumulation rate A_z is assumed to be associated with δ^{18}O as follows:

$$\delta^{18}\mathrm{O}_z = \alpha \log A_z + \beta + \delta, \tag{5}$$

where ε_z represents the discrepancy between the modeled age and the age marker, and δ represents the short-term variation of δ^{18}O that is not effective for the accumulation. Using a Bayesian approach, we can estimate x_z and A_z given all the age markers and the δ^{18}O data for each discrete depth. The estimation can be achieved by the merging particle filter/smoother. The parameters in Eqs. (1)–(5) are also estimated by combining the Metropolis method with the merging particle filter. We will demonstrate the estimated age and accumulation rate.