RICE_2ka_v1: OSU Age Control Points and Age Interpolation

The RICE_2ka_v1 chronology: The RICE chronology is extended beyond the counting of annual layers in the core by eight depth-age constraints (Age Control Points, ACPs) (Table 1) from a combination of measurements including: counting of annual layers, chemical markers that can be correlated to volcanic events in the WAIS Divide ice core, and matching centennial scale variations in the composition of methane in occluded air within the RICE ice core to the well-dated WAIS Divide record (*WAIS Divide Project Membbers.*, 2015). Annual layers counts are documented to 38 meters depth in *Emanuelsson* (personal communication) and provide the best chronology for this part of the core. The deepest annual layer dates to 1900 C.E. (100 years before present, BP, where present defined as 2000 C.E.) and is used as an ACP to maintain consistency between the ALC and age modelling. One tephra-based volcanic ACP was established by matching the chemical signature to a tephra layer found in WAIS Divide and dated as 1251 C.E (749 years BP). (*Dunbar*, personal communication; *Sigl et al*, 2013). The methane concentration record was measured at Oregon State University (OSU) using discrete samples following methods detailed in *Mitchell et al* (2011) and six ACPs were chosen at times of distinct atmospheric changes.

Methane-based Age Control Points: A total of 86 RICE sample depths were measured for methane at OSU with a mean resolution of 1 sample per 26 years between 2320 and 100 years BP. WAIS Divide was chosen as a reference record because of its high sampling resolution, low age uncertainty over the desired timespan, proximity to the RICE ice core, and the benefit that much of the WAIS Divide methane record was measured in the same laboratory as the RICE samples. The WAIS Divide methane record measured at OSU has a mean sample resolution of about 8 years between 2320 and 115 years BP with an additional 148 samples measured at Pennsylvania State University (PSU) (*WAIS Divide Project Membbers.*, 2015).

Age Model: Interpolation of age for depths between ACPs follows a simple uniform strain model (*Nye*, 1963). This strain model accounts for the thinning and broadening of annual layers of ice buried in the ice sheet. We ran this model in steady-state by assuming constant ice sheet thickness at RICE. This assumption is probably acceptable for the top 320m of core (approximately the last 2100 years) where the sensitivity of the model to ice sheet thickness is small.

A complication in using ACPs from both the ice matrix as well as the gas matrix is an offset of age between gas at a specific depth and the ice encapsulating it, a phenomenon called ΔAge. This age offset exists because gas diffuses down through the upper most layers of an ice sheet as porous snow transforms into gas-impermeable ice. A modern ΔAge of 150 years was estimated from extrapolating the counting of annual layers to a depth where tortuosity becomes so high that gas diffusion rate is essentially zero. At RICE this depth is estimated as 48.6 m depth. Modeling of ΔAge can be accomplished by the Herron-Langway model (*Herron and Langway*, 1980) which estimates $\Delta Age = 149 years$ and verifies the annual layer count-based estimate. For the sake of this record, ΔAge is assumed constant at 150 years, an assumption justified by climate records that lack major changes in climate states over this time period.

Age Uncertainty: Interpretation of age for the RICE ice core needs to recognize several sources of uncertainty: the ability to match events from RICE in the WAIS Divide core (σ_{ACP}), uncertainty in the calculation of ΔAge ($\sigma_{\Delta Age}$), and the uncertainty inherent in the WAIS Divide chronology (σ_{Ref}) (*Sigl et al*, unpublished). Analyzing the uncertainty in ACPs is related to the type of ACP; the annual layer count based ACP and volcanic ACP are absolutely dated with error associated with counting uncertainty in the RICE and WAIS Divide core, respectively. Uncertainty in the relative age of the methane based ACPs is more difficult and related to the sampling resolution of both records, their measurement errors, and the fidelity which the ice cores record atmospheric events (*Kohler*, 2010). A simple estimate of the uncertainty that has been used by *Buizert et al* (2015) is based on the 25% and 75% rise (fall) of the associated event. Here we adopt the larger of the two uncertainty estimates: either half the sampling resolution (*Brook et al*, 2000) or half the length of time between 25% and 75 % rise (fall) of the event (*Buizert et al*, 2015). The uncertainty in estimating ΔAge is not well constrained, but for the last 2000 years the uncertainty in the steady-state Herron-Langway model is estimated as 10% of the ΔAge (15 years). *Fudge et al* (2014) investigate an additional source of uncertainty due to the technique used to interpolate between ACPs. Here we make no attempt to estimate this source of uncertainty.

Age Control Depth (m)	Ice Age (years before 2000)	Uncertainty $1-\sigma$ (years)	Type
37.95	100	4	Annual Layer Count
105.04	396	21.7	Methane
137.00	576	22.9	Methane
165.00	749	2	Volcano (1251C.E.)
224.00	1180	64.9	Methane
260.05	1535	22.1	Methane
302.05	2067	24.9	Methane
327.00	2437	24.0	Methane

Table 1: Age control points used in development of this chronology. The methane based ACPs are converted to ice age with an assumed constant 150 year ΔAge. Uncertainty in methane-based ACPs is the absolute uncertainty with respect to the uncertainty in the WAIS Divide methane record, the uncertainty in ΔAge and the correlation uncertainty (the larger of either half the sample resolution of RICE or half the 25% to 75% rise (fall) of the correlated methane event).

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