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Multi parameter tuning of a firn air transport model for the NEEM ice core site in Northern Greenland

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The compacted snow (firn) found in the accumulation zone of major ice sheets acts as a unique archive of old air. Contrary to ice cores, large sample volumes can be pumped from the firn, making this archive especially suited for studying changes in the isotopic composition of atmospheric trace gases. At the NEEM deep drilling site in northern Greenland firn air has been sampled from 4 different bore holes during two field campaigns. Through a collaboration of several laboratories NEEM firn air has been analyzed for an unprecedented number of analytes, including isotopes of CO_2, CH_4, N_2O, CO and H_2.

The atmospheric signal as recorded in the firn is affected by a number of processes such as diffusion, advection and gravitational enrichment. Modeling of gas transport is therefore essential for the interpretation of firn gas records. For the NEEM site there is a joint effort to derive the firn transport properties by comparing the output of four different firn models.

How the molecular diffusivity changes with depth is uncertain, and it is common practice to tune the model by forcing it with a gas of relatively well-known atmospheric history (usually CO_2), and subsequently optimizing the fit to experimental data. By tuning to a single atmospheric history, the problem is under-determined. Many gas age distributions can be found that optimize the fit. To constrain the problem better the NEEM diffusivity profile is tuned to an ensemble of analytes, including CO_2, CH_4, SF_6, $\Delta^{14}CO_2$, and several CFCs.

It is however not a priori clear how to combine constraints from different gases in the tuning procedure. We introduce a method that can quantify how well a certain gas constrains the diffusivity profile at each depth, based on 1) the particular shape of its atmospheric history and uncertainties therein, 2) measurement uncertainties and 3) the possibility of in situ alteration.

By taking these three factors into consideration, we can determine for each depth how to weigh the individual contributions of the different gases in the ensemble. We let the gas that places the most stringent constraint carry the most weight, thus exploiting the relative strength of each gas to the fullest.