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Firn-air Properties and Influences at the West Antarctic Ice Sheet Divide

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Site Characterstics and Field Work

Samples of firn air were collected at the West Antarctic Ice Divide (WAIS-D) in December 2005. The firn air sampling occurred at 79° 28'S, 112° 7'W at an elevation of ~1800m, approximately 1km from the deep ice coring site presently in use (Fig 1). WAIS-D is a site with moderate accumulation rate (24 cm ice equiv/yr) with a mean annual temperature of -31°C. The site was chosen to be an Antarctic glaciological analogue for Summit, Greenland.

Samples of firn air were collected from two holes horizontally separated by 21m and drilled to depths of 75.52 and 78.04m. Sampling protocols followed those described by Butler et al. (1999). Collection depths are given in Table 1.

Hole number	Depth (meters)
Surface	0.00
1	10.32
2	14.99
1	20.53
1	30.02
2	34.75
1	40.04
2	44.84
1	49.78
2	54.67
1	55.57
2	61.53
1	64.84
2	66.21
2	68.26
2	70.01
1	70.27
2	71.71
1	73.00
2	74.04
1	74.93
2	76.54

Table 1

Fig. 1

Laboratory Analyses & General Observations

Samples were returned to various labs and analyzed for a wide variety of species (see Table 2). Profiles of selected species are shown in Figs. 2-5. In general, observations are consistent with expectations born of earlier firn air work: Enrichment with depth due to gravity, seasonal thermal and atmospheric signals in the shallow firn, and long-term atmospheric trends in the deeper firn. The firn structure is also evident, with signs of a very limited convection zone, below that a region dominated by molecular diffusion, and just above the firn-ice transition, a substantial lock-in zone.

Flask Material	Laboratory	Species analyzed
Glass/PTFE	NOAA/CCGG (Tans)	CO_2, CH_4, CO, H_2, N_2O, SF_6
	CU/INSTAAR (White)	$\delta^{13}C$ and $\delta^{18}O$ of CO_2, $\delta^{13}C$ and δD of CH_4
	Scripps (Severinghaus)	$\delta^{15}N$ of N_2, $\delta^{18}O$ of O_2, $\delta O_2/N_2$, isotopic & elemental ratios of noble gases
Glass/PTFE	NOAA/HATS (Montzka)	Numerous halocarbons
Stainless steel	NOAA/HATS (Montzka)	Numerous halocarbons
Glass/PTFE	UC Irvine (Saltzman)	C_2H_6, C_3H_8, C_4H_{10}, CH_3Br, CH_3Cl, COS, CS_2, CH_3CN
Glass/Viton	Penn State (Sowers)	$\delta^{13}C$ and δD of CH_4, $\delta^{15}N$ and $\delta^{18}O$ of N_2O

Table 2

Modeling

We build upon the basic 1-dim. molecular diffusion model first proposed by Schwander *et al.* (1988). Following Trudinger *et al.* (1997) we account for downward advection of air due to accumulating firn with a moving coordinate system in an equal-mass coordinate system. We also characterize bulk air movement in the shallow firn (convection) with eddy-diffusion formalism following Kawamura *et al.* (2006). Our model does not include diffusion driven by thermal gradients. We tune the diffusivity profile using historical CO_2 data of Etheridge *et al.* (1996) and the NOAA/ESRL monitoring network.

Results: A shallow convective zone

We characterize the convective zone using $\delta^{15}N$ data from the deepest part of the diffusive zone in three different ways : a linear fit to the data *a la* Bender *et al.* (1994), a fit to the data with prescribed slope (effectively specifying local gravitational acceleration *g*), and a model-based estimate using eddy diffusivities *a la* Kawamura *et al.* (2006) . Results of the latter two methods are shown in Fig. 2. All point to a very shallow convective zone.

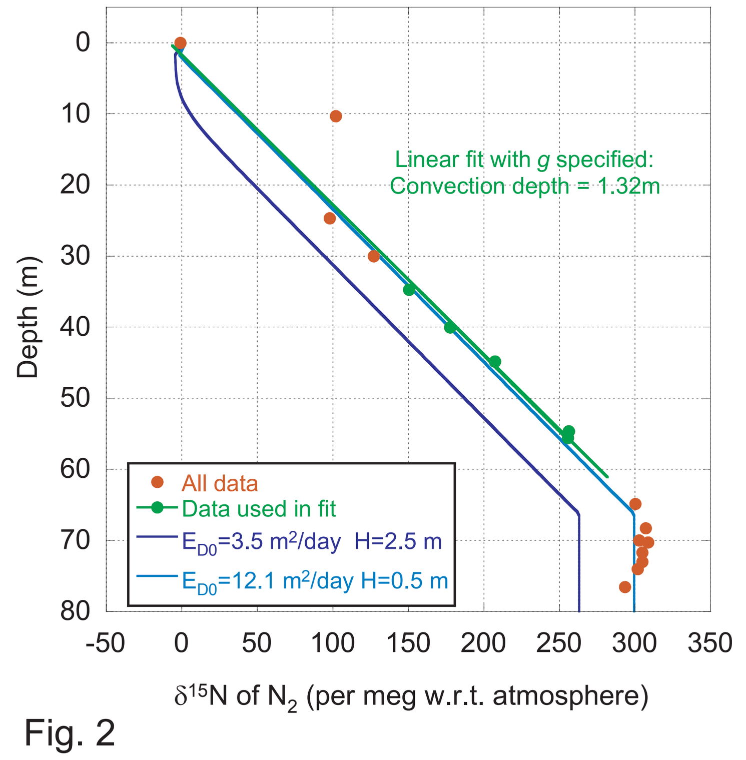

Fig. 2

References:

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Kawamura, K. *et al*. Convective micing of air in firn at four polar sites *Earth Plan. Sci. Lett.* **244** 723-727 (2006)

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Results: Advection is minor

Direct comparison of the moving-coordinate model with a static model (Battle *et al.*, 1996) indicates that the accumulation rate is low enough at WAIS-D to make advection a negligible influence on firn air composition. See Fig. 3

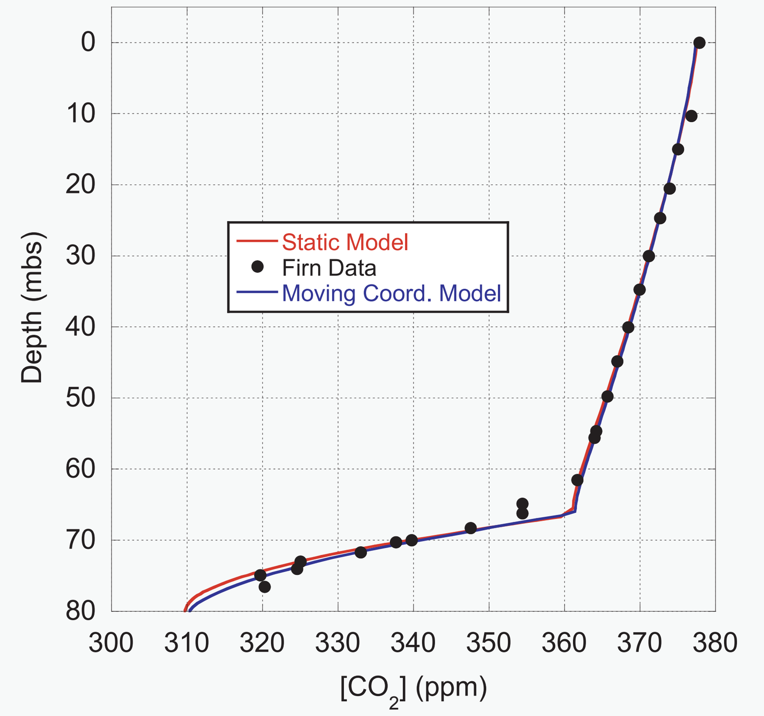

Fig. 3

Results: Mean air age <~45yrs

Model studies of 1-year-long step pulse inputs indicate that air at the bottom of the diffusive column has a mean age that is generally less than 10 years old, while air at the firn-ice transition is less than 45 years old. Due top varying diffusivity, age also depends on species. See Fig. 4

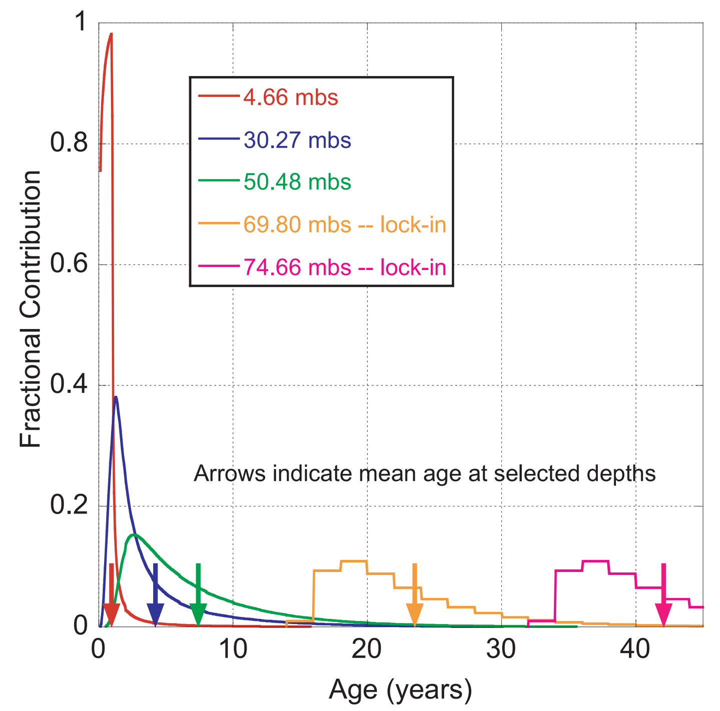

Fig. 4

Results: Diffusivity vs. depth good, D_{F11}/D_{CO2} enigmatic

After tuning diffusivity of the firn vs. depth using CO_2, data-model agreement for species with very different atmospheric histories, such as HFC134a (Fig. 5, bottom) and CH_4 (not shown) gives confidence in the inferred diffusivity throughout the firn column. However, the diffusivities of some species (relative to CO_2) require adjustments from nominal values calculated from collisional data and semi-empirical methods (Butler *et al.*, 1999). CH_3CCl_3 model predictions agree best with data when $D_{CH3CCl3}$ is scaled by 80% (Fig. 5, top). This is consistent with previous firn work from South Pole (Butler *et al.*, 1999). In contrast, F11 data-model agreement is excellent with no scaling of D_{F11} needed, (Fig. 5, middle) despite the need for 10% reduction in the South Pole dataset (Butler *et al.*, 1999). Further study of this issue is required.

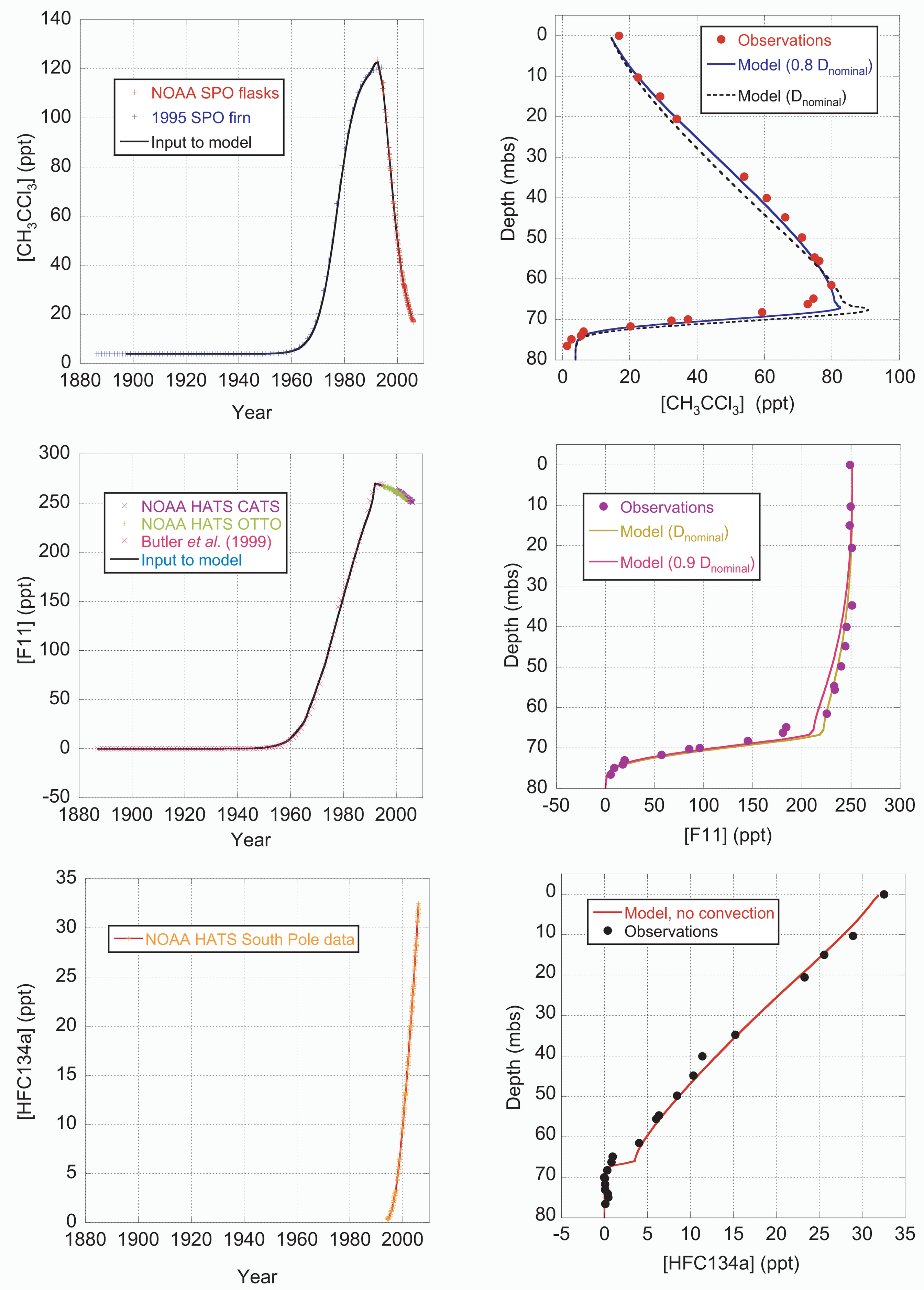

Fig 5.

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