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Supplement of

Stable water isotopes and accumulation rates in the Union Glacier region, Ellsworth Mountains, West Antarctica, over the last 35 years

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Supplementary Information

Equations S1a–S1d. Values of ssNa were calculated from Na and Ca concentrations based on the following equations (Röthlisberger et al., 2002):

(a) $ssNa = Na - \frac{nssCa}{R_t}$ and **(b)** $nssCa = Ca - R_m \cdot ssNa$

Hence, for calculating values of ssNa the following equation was applied:

(c) $ssNa = \frac{Na \cdot R_t - Ca}{(R_t - R_m)}$

where R_t is the ratio of Ca/Na in the earth's crust (1.78) and R_m is the ratio of Ca/Na in seawater (0.038) according to Bowen (1979).

Subsequently, values of nssS were calculated from S concentrations using the following equation (Sigl et al., 2013):

(d) $nssS = S - ssNa \cdot R_m$

where the ratio of S/Na in seawater (0.084) from Bowen (1979) is used for R_m.

Equation S2. Standardization has been done using the following equation:

$$z = \frac{x - \mu}{\sigma}$$

where x is the raw value, z the standardized value, μ the mean value and σ the standard deviation of the respective firn core record.

Equation S3. Signal-to-noise ratios (F) were estimated using the following equation (Fisher et al., 1985):

$$F = \frac{r_{xy}}{(1 - r_{xy})}$$

where r_{xy} is the cross-correlation coefficient between two individual time series. For more than two time series ($n > 2$) the cross-correlation coefficient r_{xy} is obtained by averaging all possible estimates of r_{xy} (i.e. $\frac{n \cdot (n-1)}{2}$ estimates of r_{xy}), which are calculated by combining the considered time series two by two.

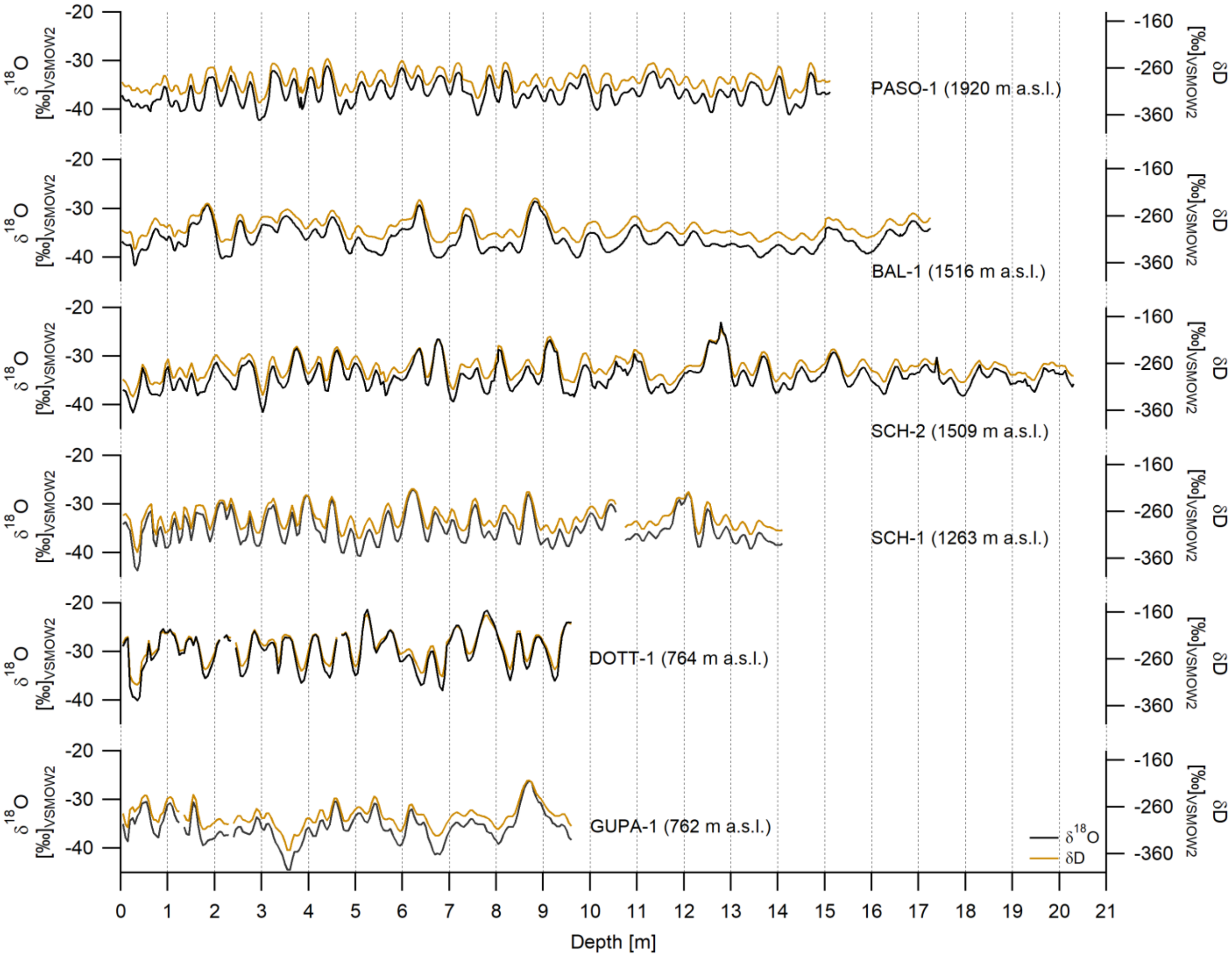

Figure S1. Profiles of the stable water isotope composition ($\delta^{18}O$ and δD) of the six firn cores from Union Glacier (UG) with respect to depth.

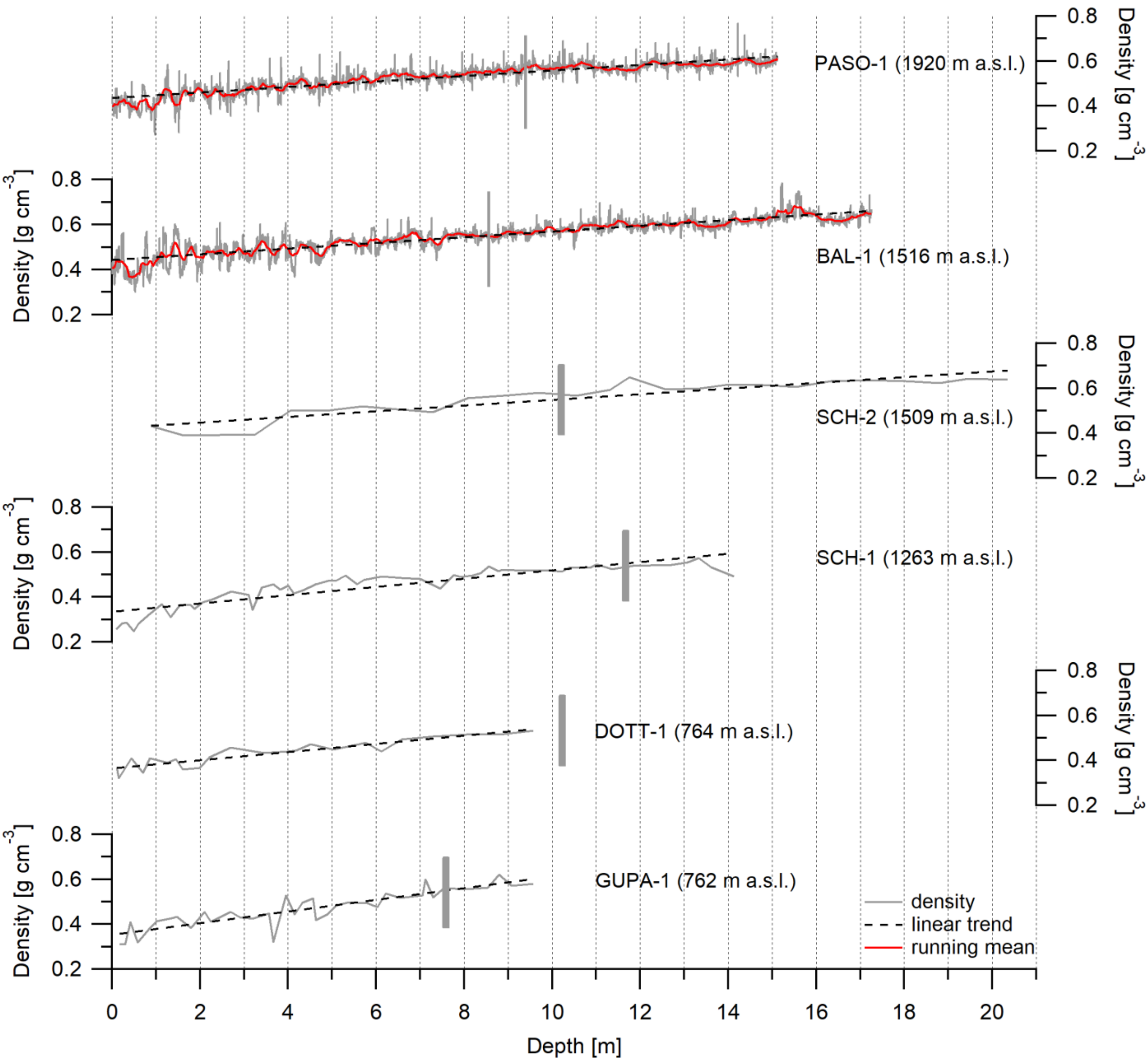

Figure S2. Density profiles of the six firn cores from UG. Density profiles of cores BAL-1 and PASO-1 were obtained by X-ray microfocus tomography and are at < 1mm resolution. The running mean is shown in red. The window size for calculating the running mean was set to 1700 points for BAL-1 and 1250 points for PASO-1 as these values correspond to a period of approximately half a year within the respective core record. For each core the linear trend of increasing density with depth due to firn compaction and the approximate depth of the snow-firn-density boundary (0.55 g cm^{-3}; grey bars) are indicated. Note that for core DOTT-1 the snow-firn-density boundary is not reached within the drill depth and therefore its location was determined by linear extrapolation at the lowest end of the core.

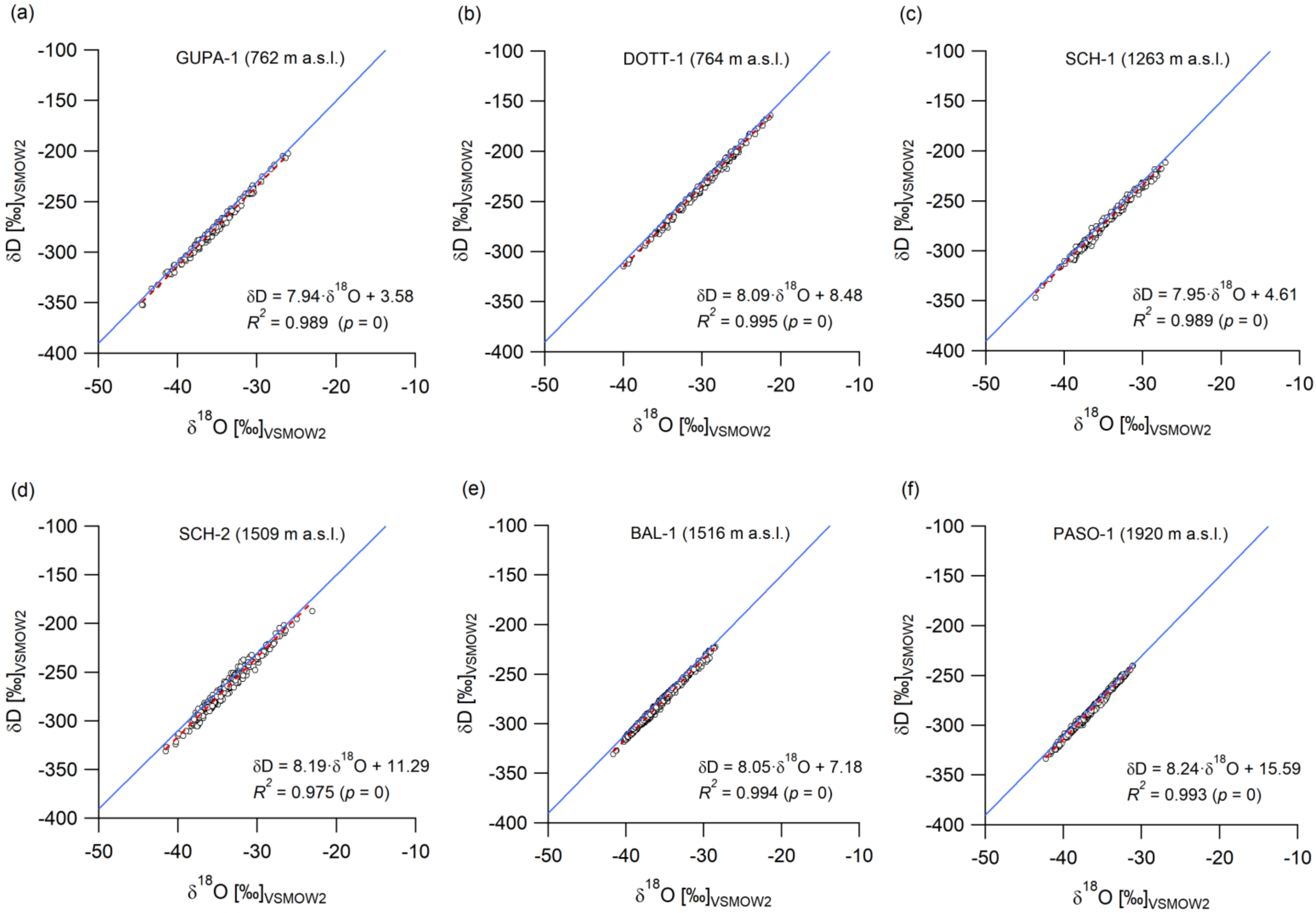

Figure S3a–f. Co-isotopic relationships ($\delta^{18}O$ vs. δD) for all individual samples (white dots) of the six firn cores from UG. For each firn core the equation, the coefficient of determination (R^2) and the *p* value (*p*) of the linear regression (red dashed line) is shown. The Global Meteoric Water Line (GMWL) is indicated in blue.

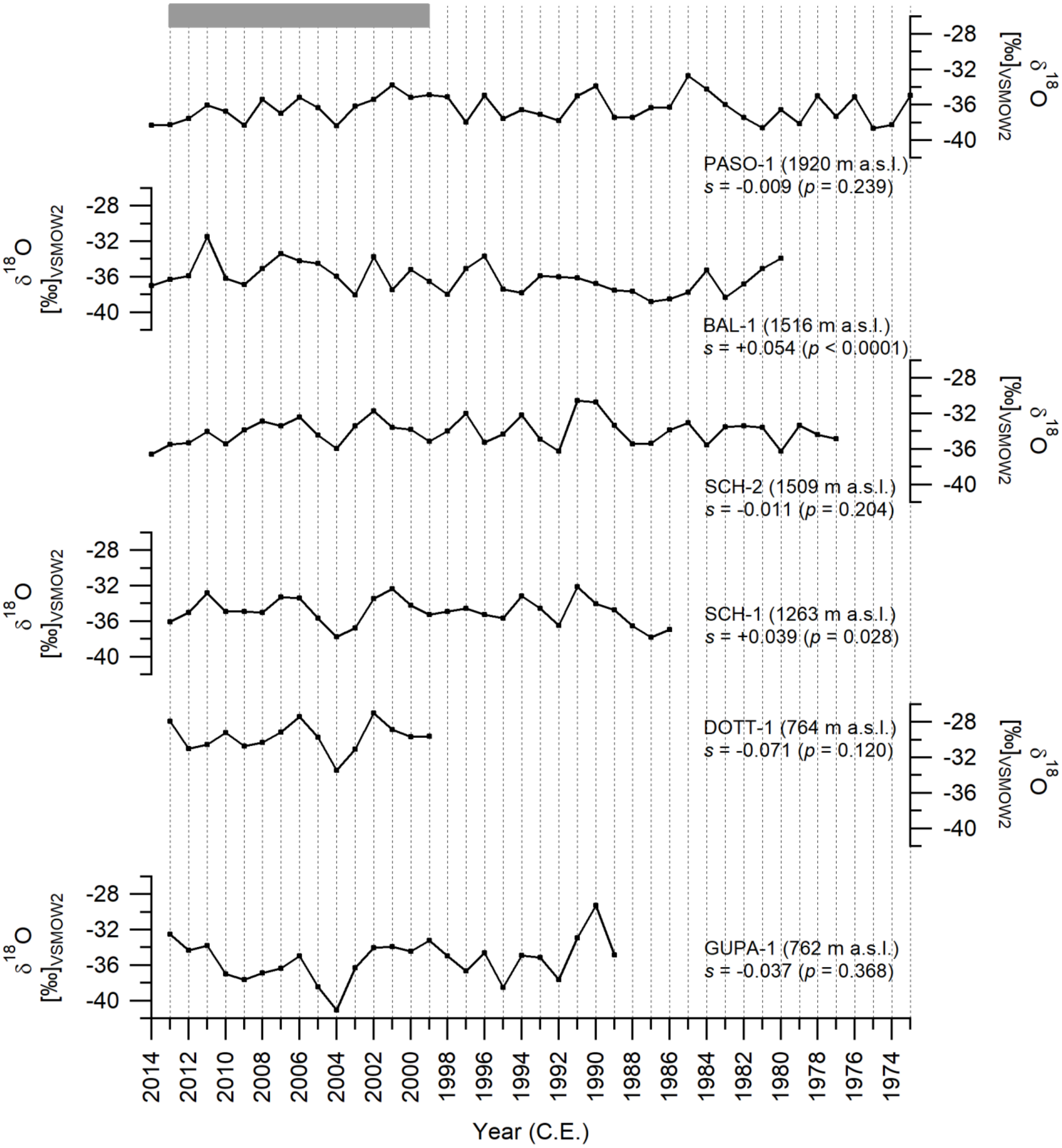

Figure S4. Non-standardized annual mean stable oxygen isotope composition of the six firn cores from UG for the period covered by the respective core. Sen slopes (*s* in ‰ a^{-1}) and *p* values (*p*) are given for each core. The grey bar indicates the overlapping period of the six firn cores (1999–2013).

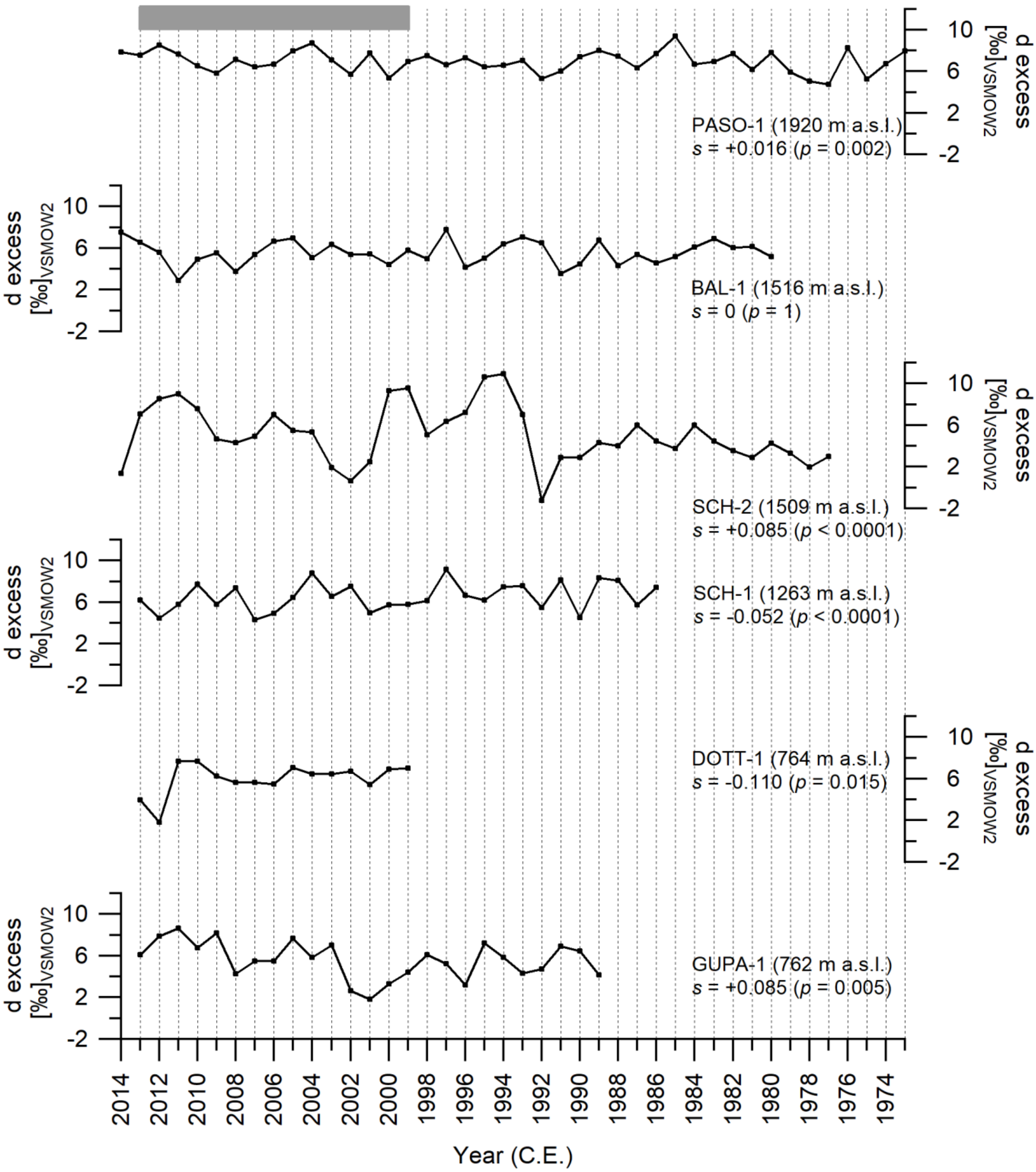

Figure S5. Non-standardized annual mean d excess of the six firn cores from UG for the period covered by the respective core. Sen slopes (*s* in ‰ a^{-1}) and *p* values (*p*) are given for each core. The grey bar indicates the overlapping period of the six firn cores (1999–2013).

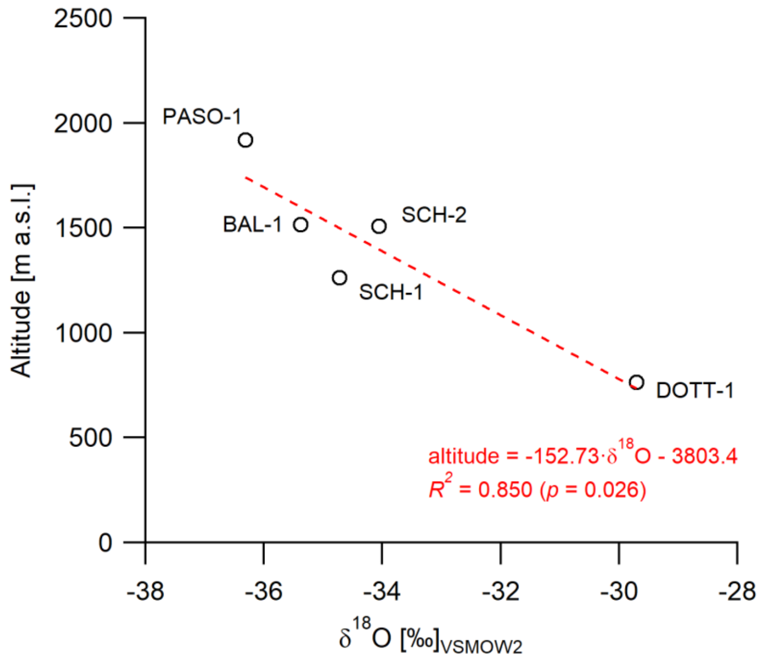

Figure S6. $\delta^{18}O$-altitude-relationship for UG firn cores (excluding GUPA-1) calculated from $\delta^{18}O$ annual means for the overlapping period 1999–2013. The coefficient of determination (R^2) of the linear regression (red dashed line) and the respective *p* value (*p*) are also given.

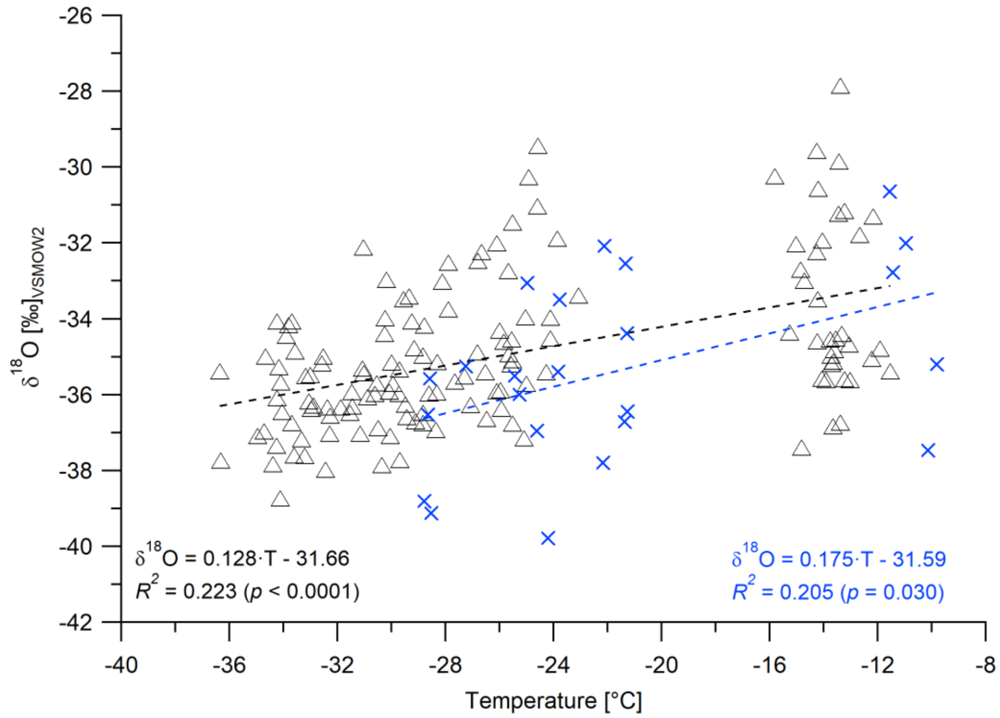

Figure S7. $\delta^{18}O$-temperature-relationship for UG firn cores (excluding GUPA-1) calculated from stacked seasonal means of non-standardized firn core $\delta^{18}O$ and seasonal means of near-surface air temperature derived from **(a)** the AWS composite record for the period February 2010 – November 2015 (blue crosses) and **(b)** ERA-Interim reanalysis data for the period 1980–2014 (black triangles), respectively. For both linear regressions (dashed lines) the coefficient of determination (R^2) and the respective *p* value (*p*) are also given.

Table S1. Diffusion length at the maximum drill depth and mean annual layer thickness of the six firn cores from UG.

Firn Core	**GUPA-1**	**DOTT-1**	**SCH-1**	**SCH-2**	**BAL-1**	**PASO-1**
Depth (m)	9.58	9.57	14.13	20.25	17.28	15.04
Diffusion length at maximum depth (cm)	11.17	8.72	8.70	7.54	7.45	7.15
Mean annual layer thickness (cm)	36.35	59.69	48.39	51.15	46.93	34.74

Table S2. Results of cross-correlation and signal-to-noise ratio (*F*) analyses for accumulation rates and mean annual stable water isotope composition of the six firn cores from UG with respect to the maximum overlapping period between two individual cores. Prominent correlations with a low *p* value ($p < 0.1$) are marked in bold and if statistically significant ($p < 0.01$, $\alpha = 0.05$) in bold and italic.

Accumulation	**GUPA-1**	**DOTT-1**	**SCH-1**	**SCH-2**	**BAL-1**	**PASO-1**
GUPA-1	1	–0.076	**0.422**	**0.449**	0.250	**–0.405**
p	0	0.787	0.036	0.024	0.229	0.044
F		–0.071	0.729	0.815	0.333	–0.289
DOTT-1		1	0.399	0.314	**0.444**	0.260
p		0	0.140	0.255	0.098	0.350
F			0.665	0.457	0.798	0.351
SCH-1			1	***0.626***	**0.335**	–0.046
p			0	0.000	0.081	0.816
F				1.674	0.504	–0.044
SCH-2				1	**0.365**	**–0.346**
p				0	0.031	0.034
F					0.575	–0.257
BAL-1					1	–0.212
p					0	0.220
F						–0.175
PASO-1						1
p						0
$\delta^{18}O$						
GUPA-1	1	**0.634**	***0.548***	**0.454**	0.005	***0.595***
p	0	0.011	0.005	0.023	0.982	0.002
F		1.734	1.211	0.832	0.005	1.466
DOTT-1		1	**0.585**	**0.521**	0.228	0.433
p		0	0.022	0.046	0.414	0.107
F			1.408	1.088	0.295	0.765
SCH-1			1	***0.658***	**0.441**	***0.480***
p			0	0.000	0.019	0.010
F				1.925	0.790	0.924

SCH-2				1	0.022	**0.359**
p				0	0.900	0.027
F					0.022	0.560
BAL-1					1	0.006
p					0	0.973
F						0.006
PASO-1						1
p						0
δD						
GUPA-1	1	**0.567**	**0.501**	**0.471**	–0.018	***0.565***
p	0	0.028	0.011	0.018	0.932	0.003
F		1.308	1.004	0.889	–0.018	1.298
DOTT-1		1	**0.597**	**0.569**	0.285	0.424
p		0	0.019	0.027	0.304	0.115
F			1.483	1.322	0.398	0.736
SCH-1			1	***0.707***	**0.426**	**0.435**
p			0	0.000	0.024	0.021
F				2.407	0.741	0.770
SCH-2				1	0.028	**0.341**
p				0	0.873	0.036
F					0.028	0.517
BAL-1					1	–0.037
p					0	0.831
F						–0.036
PASO-1						1
p						0
d excess						
GUPA-1	1	–0.059	–0.119	0.244	–0.100	0.188
p	0	0.836	0.572	0.240	0.635	0.368
F		–0.055	–0.106	0.323	–0.091	0.232
DOTT-1		1	**0.455**	–0.053	–0.296	–0.391
p		0	0.088	0.852	0.284	0.150
F			0.835	–0.050	–0.229	–0.281
SCH-1			1	–0.043	0.081	0.095
p			0	0.829	0.683	0.632
F				–0.041	0.088	0.104
SCH-2				1	–0.112	0.149
p				0	0.515	0.371
F					–0.101	0.175
BAL-1					1	–0.006
p					0	0.974
F						–0.006
PASO-1						1
p						0

Table S3. Results of cross-correlation and signal-to-noise ratio (F) analyses for accumulation rates and mean annual stable water isotope composition of the six firn cores from UG with respect to the common overlapping period (1999–2013). Prominent correlations with a low p value ($p < 0.1$) are marked in bold and if statistically significant ($p < 0.01$, $\alpha = 0.05$) in bold and italic.

Accumulation	**GUPA-1**	**DOTT-1**	**SCH-1**	**SCH-2**	**BAL-1**	**PASO-1**
GUPA-1	1	–0.076	–0.001	–0.258	–0.159	**–0.494**
p	0	0.787	0.997	0.353	0.571	0.061
F		–0.071	–0.001	–0.205	–0.137	–0.331
DOTT-1		1	0.399	0.314	**0.444**	0.260
p		0	0.140	0.255	0.098	0.350
F			0.665	0.457	0.798	0.351
SCH-1			1	**0.545**	0.141	0.192
p			0	0.036	0.617	0.492
F				1.195	0.164	0.238
SCH-2				1	–0.102	0.102
p				0	0.717	0.716
F					–0.093	0.114
BAL-1					1	0.165
p					0	0.558
F						0.197
PASO-1						1
p						0
$\delta^{18}O$						
GUPA-1	1	**0.634**	**0.529**	0.203	0.097	0.430
p	0	0.011	0.043	0.469	0.731	0.110
F		1.734	1.123	0.254	0.107	0.753
DOTT-1		1	**0.585**	**0.521**	0.228	0.433
p		0	0.022	0.046	0.414	0.107
F			1.408	1.088	0.295	0.765
SCH-1			1	**0.575**	**0.492**	**0.588**
p			0	0.025	0.063	0.021
F				1.355	0.967	1.424
SCH-2				1	0.321	**0.551**
p				0	0.244	0.033
F					0.472	1.227
BAL-1					1	0.079
p					0	0.781
F						0.085
PASO-1						1
p						0

δD						
GUPA-1	1	**0.567**	**0.472**	0.277	0.116	0.354
p	0	0.028	0.076	0.318	0.681	0.196
F		1.308	0.894	0.382	0.131	0.548
DOTT-1		1	**0.597**	**0.569**	0.285	0.424
p		0	0.019	0.027	0.304	0.115
F			1.483	1.322	0.398	0.736
SCH-1			1	***0.660***	**0.496**	**0.575**
p			0	0.007	0.060	0.025
F				1.941	0.983	1.352
SCH-2				1	0.436	**0.546**
p				0	0.104	0.035
F					0.773	1.202
BAL-1					1	0.062
p					0	0.825
F						0.067
PASO-1						1
p						0
d excess						
GUPA-1	1	–0.059	–0.048	0.330	0.052	0.326
p	0	0.836	0.866	0.229	0.855	0.236
F		–0.055	–0.046	0.493	0.055	0.484
DOTT-1		1	**0.455**	–0.053	–0.296	–0.391
p		0	0.088	0.852	0.284	0.150
F			0.835	–0.050	–0.229	–0.281
SCH-1			1	–0.261	–0.179	0.077
p			0	0.347	0.524	0.784
F				–0.207	–0.152	0.084
SCH-2				1	–0.210	0.105
p				0	0.452	0.710
F					–0.174	0.117
BAL-1					1	0.093
p					0	0.742
F						0.102
PASO-1						1
p						0