Modelling the transition from grain-boundary sliding to power-law creep in dry snow densification. Supplementary Material.

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ABSTRACT. Site locations and citations for the groups of density profiles defined in the main paper are shown in Tables S1 to S6. Table S7 lists comments on sites for which the data presented in previous databases need correction or further discussion. Figs. S1 and S2 show the variation of the cost function Ψ for sites B36/B37 and B38 with ρ_T and $\Delta\rho$. Table S8 shows the horizontal divergences and thinning factors used to correct model estimates of bubble close-off depth.

S1. BACKGROUND DATA FOR DENSITY PROFILES

In this section further details are given for the data described in Section 3 of the main paper. Tables S1 to S5 supplement Tables A1 to A5. Table S6 gives locations and citations for rejected profiles and Table S7 lists comments on sites for which the data presented in the Spencer and Verjans databases (Spencer and others, 2001; Verjans and others, 2020) need correction or further discussion.

Table S1. Background data for gamma-ray attenuation density profiles

Core	Latitude °N	Longitude °E	Citations
EDC2	-75.100000	123.350000	EPICA Community Members (2004); Hörhold and others (2011)
BER11C95_25 (B25)	-79.614160	-45.724330	Gerland and others (1999); Gerland and Wilhelms (1999); Hörhold and others (2011)
DML95	-71.568000	-6.667000	Hörhold and others (2011)
DML97	-72.0640	-9.558300	Hörhold and others (2011)
NM03C98 _01 (FB9801)	-70.706667	-8.426667	Oerter and others (2000a,f)
DML18C98_04 (FB9804)	-75.250333	-6.000000	Graf and others (2002i,f)
DML19C98_05 (FB9805)	-75.167333	-0.995000	Oerter and others (2000a,b)
DML20C98_08 (FB9808)	-74.750667	0.999833	Graf and others (2002i,g)
DML03C98_09 (FB9809)	-74.499167	1.960833	Oerter and others (2000a,c)
DML21C98_10 (FB9810)	-74.667167	4.001667	Oerter and others (2000a,e)
DML22C98_11 (FB9811)	-75.084000	6.500000	Graf and others (2002j,i)
DML23C98_12 (FB9812)	-75.250833	6.501667	Graf and others (2002i,h)
DML16C98_13 (FB9813)	-75.167333	5.003333	Oerter and others (2000a,d)
DML15C98_14 (FB9814)	-75.083667	2.501000	Graf and others (2002j,d)
DML13C98_16 (FB9816)	-75.000000	-4.496333	Graf and others (2002i,c)
DML12C98_17 (FB9817)	-75.000667	-6.498333	Graf and others (2002j,b)
DML07C98_31 (B31)	-75.581500	-3.430333	Oerter and others (2004, 2002); Hörhold and others (2011)
DML05C98_32 (B32)	-75.002333	0.007000	Graf and others (2002i,a); Hörhold and others (2011)
DML17C98_33 (B33)	-75.167000	6.498500	Graf and others (2002i,e); Hörhold and others (2011)
B36/B37 (EDML)	-75.002500	0.068400	EPICA Community Members (2006); Hörhold and others (2011)
DML94C07_38 (B38)	-71.162100	-6.698900	Wilhelms (2007a); Hörhold and others (2011)
DML96C07_39 (B39)	-71.408300	-9.916700	Wilhelms (2007b); Hörhold and others (2011)
ngt03c93_2 (B16)	73.940200	-37.629900	Wilhelms (1996, 2000a); Hörhold and others (2011)
ngt06C93_2 (B17)	75.250400	-37.624800	Wilhelms (1996, 2000b); Hörhold and others (2011)
ngt14c93_2 (B18)	76.617000	-36.403300	Wilhelms (1996, 2000c); Hörhold and others (2011)
ngt27c94_2 (B21)	80.000000	-41.137400	Wilhelms (1996, 2000d); Hörhold and others (2011)
ngt37C95.2 (B26)	77.253300	-49.216700	Miller and Schwager (2000a); Hörhold and others (2011)
ngt42c95_2 (B29)	76.003900	-43.492000	Miller and Schwager (2000b); Hörhold and others (2011)
WDC06A (WAIS Divide)	-79.48278	-112.08833	Fitzpatrick and others (2014); Fegyversi and others (2011)

Table S2. Background data for neutron scattering density profiles

Site	Latitude °N	Longitude °E	Citations
Katie	72.579	-38.47	Morris and Wingham (2011); Hawley and Morris (2006)
iSTAR01	-74.565	-86.913	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR03	-74.111	-89.224	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR04	-75.319	-90.524	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR05	-75.431	-92.060	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR06	-75.456	-93.718	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR07	-75.440	-94.460	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR08	-75.090	-95.070	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR09	-74.956	-94.631	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR10	-74.442	-93.448	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR11	-74.620	-92.700	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR13	-75.670	-94.690	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR14	-75.805	-94.231	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR15	-75.750	-96.730	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR16	-75.926	-96.898	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR17	-75.740	-97.930	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR18	-75.617	-99.073	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR19	-75.803	-99.048	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR20	-76.404	-99.828	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR21	-76.224	-100.770	Morris and others (2017); Mulvaney and Smith (2017)
iSTAR22	-75.804	-100.280	Morris and others (2017); Mulvaney and Smith (2017)

Table S3. Background data for Group A gravimetric density profiles

Core	Latitude °N	Longitude °E	Citation
iSTAR01	-74.565	-86.913	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR04	-75.319	-90.524	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR06	-75.456	-93.718	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR07	-75.440	-94.460	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR08	-75.090	-95.070	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR10	-74.442	-93.448	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR13	-75.670	-94.690	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR15	-75.750	-96.730	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR18	-75.617	-99.073	Konrad and others (2019); Mulvaney and Smith (2017)
iSTAR20	-76.404	-99.828	Konrad and others (2019); Mulvaney and Smith (2017)
Devon98	75.00	-82.00	Pinglot and others (2003); Clark and others (2007)
Site A	70.63491	-35.820	Clausen and others (1988); Spencer and others (2001)
Mizuho G6	-73.11278	39.75833	Spencer and others (2001); Kameda and others (1994)
Dyer Plateau 1988	-70.6711	-64.875	Thompson and others (1994); Raymond and others (1996)

Table S4. Background data for Group B gravimetric density profiles

Core	Latitude °N	Longitude °E	Citation
Eismitte	71.75	-40.75	Bader (1954)
Camp Century	77.1833	-61.1667	Kovacs and others (1969); Clausen and others (1988)
Styx A	-73.8517	163.6940	Jang and others (2019); Yang and others (2018); Han and others (2015); Nyamgerel (2019); Nyamgerel and others (2020)
Katie	72.579	-38.47	Hawley and others (2008); Gundestrup and others (1993)
Dome GRIP	72.58722	-37.64222	Hammer and Dahl-Jensen (1999); Bolzan and Strobel (1994)
NEEM 2009S2	77.45	-51.06	Masson-Delmotte and others (2015)
DIV2010	-76.7703	-101.7375	Criscitiello (2014)
THW2010	-76.9525	-121.2203	Criscitiello (2014)
ITASE02_6	-89.9333	144.3938	Schneider (2005); Dixon and others (2013, 2004, 2005, 2012); Sneed and others (2011); Bertler and others (2005); Mayewski and Maasch (2006); Kaspari and others (2004); Mayewski and others (2004, 2005); Yan and others (2005); Steig and others (2005)
Dome C	-74.6500	124.1667	Lorius and others (1979)
Site A (US)	70.75	-35.9583	Alley and Koci (1988); Spencer and others (2001)
Site B	70.65081	-37.4788	Clausen and others (1988); Spencer and others (2001)
Site E	71.7593	-35.8505	Clausen and others (1988); Spencer and others (2001)
Site G	71.15495	-35.8377	Clausen and others (1988); Spencer and others (2001)
James Ross Island	-57.685	-64.2017	Mulvaney and others (2012, 2014)
Fletcher Promontory	- 77.8567	-82.6050	Mulvaney and others (2014)
Skytrain Ice Rise	-79.7417	-78.5450	Mulvaney and others (2021)
T1 (Berkner)	-79.5483	-45.6783	Mulvaney and others (2007)
Beethoven Peninsula	-71.9	-74.6	Pasteur and Mulvaney (2000)
BAS M1	-77.0398	-10.5133	Hofstede and others (2004)
BAS ISOL	-74.9961	0.094717	Ming and others (2020)
Dyer Plateau 1989	-70.6711	-64.875	Thompson and others (1994); Raymond and others (1996)

Table S5. Background data for Group C gravimetric density profiles

Core	Latitude °N	Longitude °E	Citations
Vostok (BH-3, BH-5)	-78.4644	106.8373	Spencer and others (2001); Barnola and others (1987); Lorius and others (1985)
Inge Lehmann	77.95	-39.1833	Lenton (1968); Gow and others (1973)
PIG2010	-77.9569	-95.9617	Criscitiello (2014)
ITASE00_1 (WAIS)	-79.3831	-111.2286	Schneider (2005); Dixon and others (2004)
ITASE01_2	-77.8436	-102.9103	Schneider (2005); Dixon and others (2013, 2004, 2005, 2012); Bertler and others (2005); Mayewski and Maasch (2006); Kaspari and others (2004, 2005); Mayewski and others (2004, 2005); Yan and others (2005); Steig and others (2005)
ITASE01_3	-78.1202	-95.6463	as ITASE01_2
ITASE01_4	-77.6116	-92.2483	as ITASE01_2
ITASE01_5	-77.0593	-89.1376	as ITASE01_2
ITASE02_4	-86.5025	-107.99	as ITASE01_2
ITASE02_1	-82.001	-110.008	as ITASE01_2
Byrd	-80	-120	Gow (1968, 1975); Johnsen and others (1972)
DE08 DE08-2	-66.72194	113.19944	Etheridge and others (1996)
Dye3-4B-1983	65.18333	-43.83333	Spencer and others (2001); Dahl-Jensen and others (1998)
Mizuho G15	-71.1944	45.9792	Spencer and others (2001); Kameda and others (1994); Moore and others (1991); Kameda and others (1990)
Mizuho H15	-69.07944	40.78167	Spencer and others (2001); Kameda and others (1994); Kohno and others (1999)
Site D	70.63980	-39.6178	Spencer and others (2001); Clausen and others (1988)
South Pole 2001	-90		pers. comm. J Cole-Dai Winski and others (2019)

Table S6. Background data for rejected gravimetric density profiles

Core	latitude °N	longitude °E	Citations
Dominion Range	-85 15	166 30	Spencer and others (2001); Mayewski and others (1990)
Newall	-77.58	162.50	Mayewski and others (1995)
Upstream B	-83.4778	-138.0969	Alley and Bentley (1988)
Prospector-Russell Col, Mt. Logan	60.5833	-140.5	Gergely and others (2010); Fisher and others (2004)
JARE	-70.6983	44.3317	Spencer and others (2001); Kameda and others (1994)
JARE11	-70.6983	44.3317	Spencer and others (2001); Kameda and others (1994)
Taylor Dome	-83.4778	138.0969	Spencer and others (2001)
Law Dome DSS	-66.7697	112.8069	Spencer and others (2001)
Site 2	76.9833	-56.0667	Langway (1967); Robin, G de Q (1983)
Mizuho S25	-69.0317	40.4556	Watanabe and others (2000)
Ridge B-C	-83	-140	Alley and Bentley (1988)

Table S7. Comments on Group C and rejected data

Vostok(BH-3, BH-5)	Barnola and others (1987) give T_m = -55.5°C rather than the value of 216K (-57.15°C) given by Spencer and others (2001).
Inge Lehmann	The density profile for this station in the Spencer database has been replaced by a digitised version of the profile published in the primary source (Lenton, 1968)
PIG2010	The mean annual temperature has been determined by satellite remote sensing (Criscitiello, 2014).
ITASE traverse	The mean annual temperatures have been determined by satellite remote sensing (Criscitiello, 2014)
Byrd	The accumulation $\bar{a}$ = 0.156 m w.e. a^{-1} given in the Spencer database for the Byrd care was determined from the physical stratigraphy (Gow, 1968). However, Johnsen and others (1972) note that this technique is open to error and that accumulation rates vary considerably both up-slope from the site and locally. They fit the Byrd core to the Camp Century time scale using a best value of $\bar{a}$ = 0.196 m w.e. a^{-1} and comment that this is close to the best value of 0.2 m w.e. a^{-1} for fitting the measured temperature profile. We therefore use a value $\bar{a}$ = 0.2 m w.e. a^{-1} to model the density profile.
DE08 (Law Dome)	The primary source (Etheridge and others, 1996) gives $\bar{a} \approx 1.2$ m ice equivalent per annum. The Spencer database gives $\bar{a}$ = 1.2 m w.e. a^{-1}. We suspect this is an error in units and use $\bar{a}$ = 1.1 m w.e. a^{-1}.
Mizuho	Kameda and others (1994) model the densification of cores from Mizuho Station and quote values of T_m = -33.55°C and $\bar{a}$ = 0.09 m w.e. a^{-1} rather than the values of T_m = -33.15°C and $\bar{a}$ = 0.106 m w.e. a^{-1} given by Spencer and others (2001).
Mizuho H15	Kohno and others (1996, 1999) give $\bar{a} = 0.32 \pm 0.108$ m w.e. a^{-1} (determined by stake measurements) rather than the value of $\bar{a}$ = 0.10 m w.e. a^{-1} given by Spencer and others (2001). These authors cite Kameda and others (1994) as their source but in fact the mean annual accumulation is not given for this site in that paper.
Site D	The primary source Clausen and others (1988) gives the longitude of Site D as 320.3822 E (in a table and in a map) whereas Spencer and others (2001) gives 324.3822 E. The latter is clearly a misprint.
Mizuho S25	Spencer and others (2001) comment that the accummulation provided through personal communication with T. Kameda is suspect.

S2. VARIATION OF THE COST FUNCTION

In this section the variation of the cost function, Ψ with transition half-width, $\Delta\rho$, and transition density, ρ_T, is given for the two example profiles discussed in Section 4 of the main paper. The values of Ψ have

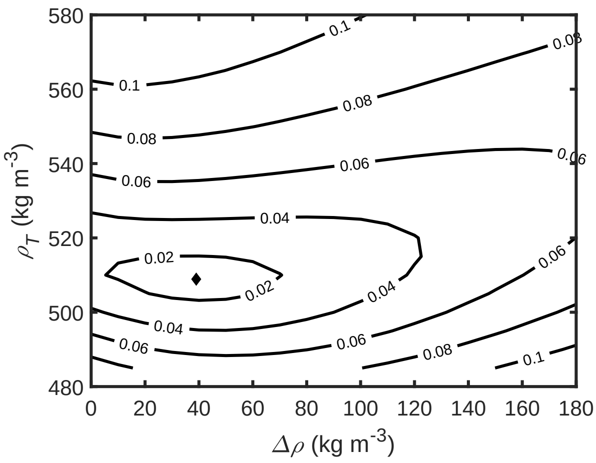

Fig. S1. The cost function Ψ as a function of the transition half-width, $\Delta\rho$, and transition density, ρ_T, for profile B36/B37 (EMDL). The minimum lies at $\Delta\rho = 39$ kg m^{-3}, $\rho_T = 509$ kg m^{-3}.

been calculated at intervals of 5 kg m^{-3} in ρ_T and 10 kg m^{-3} in $\Delta\rho$. Contours have been plotted using the Matlab function "contour" and the minimum value calculated using the Matlab function "fminsearch".

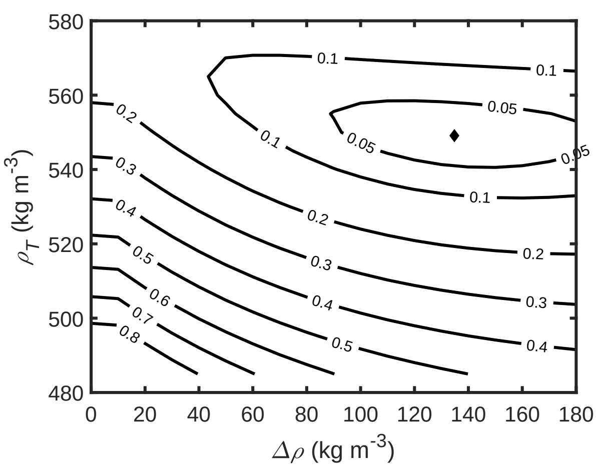

Fig. S2. The cost function Ψ as a function of the transition half-width, $\Delta\rho$, and transition density, ρ_T, for profile B38. The minimum lies at $\Delta\rho = 135$ kg m^{-3}, $\rho_T = 549$ kg m^{-3}.

Table S8. Horizontal divergence and thinning correction

Core	$\dot{\varepsilon}_H$ $10^{-4}\mathrm{a}^{-1}$	θ_{BCO} m	Citations
EDC2	0.1	-0.92	Parrenin and others (2007)
BER11C95_25 (B25)	≈ 2	≈ -1.1	
B38	7.8	-1.66	Drews and others (2013)
B39	≈ 10	≈ -2.2	
WDC06A	1.0	-0.69	Sigl and others (2016)
Devon98	7.5	-3.05	Paterson and Waddington (1984)
GRIP	1.1	-0.83	Dahl-Jensen and others (1993)
NEEM	1.1	-0.73	Rasmussen and others (2013)
Fletcher Promontory	≈ 6	≈ -3.0	
James Ross Island	≈ 19	≈ -3.2	
Skytrain Ice Rise	3.4	-1.6	Mulvaney and others (2021)
T1	≈ 2	≈ -1.0	
Vostok	0.12	-1.18	Parrenin and others (2004)
South Pole 2001	0.40	-1.96	Kahle and others (2020)
DE08	≈ 10	≈ -2.3	

S3. THINNING CORRECTION

Table S8 shows the horizontal divergence and thinning correction for the profiles discussed in Section 5.3 of the main paper. The citations are for papers that give a thinning function for a given ice core; otherwise we have estimated values using the Nye approximation (Nye, 1963).

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