

Supplementary information for:

## **Response of Botovskaya Cave to local and regional environmental dynamics**

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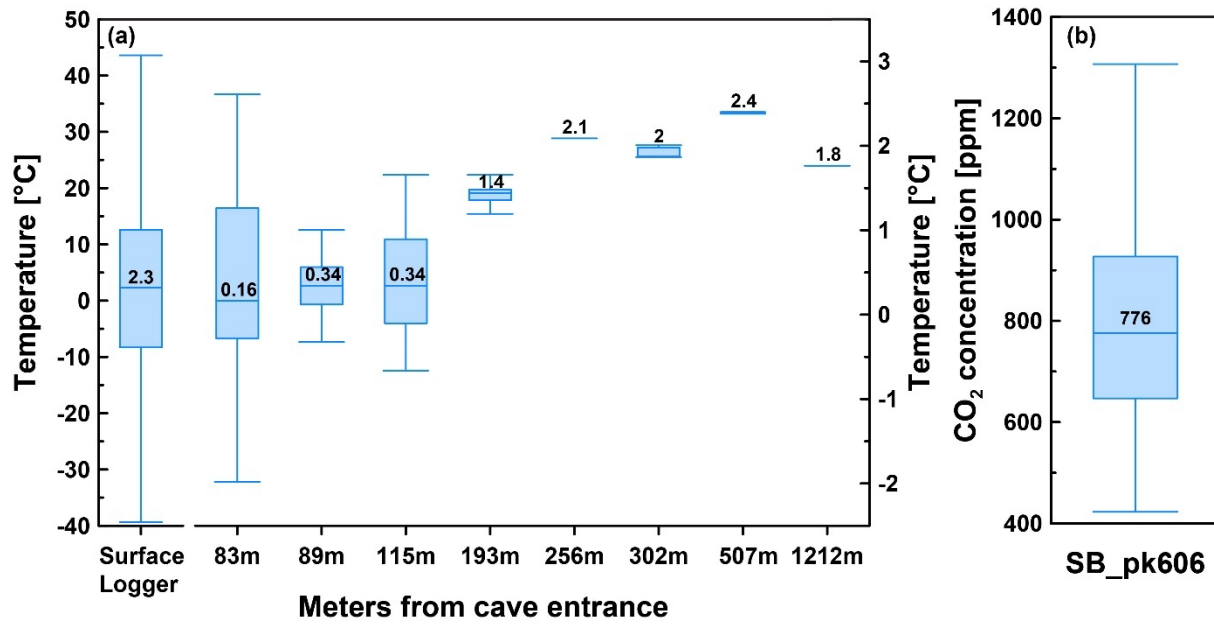
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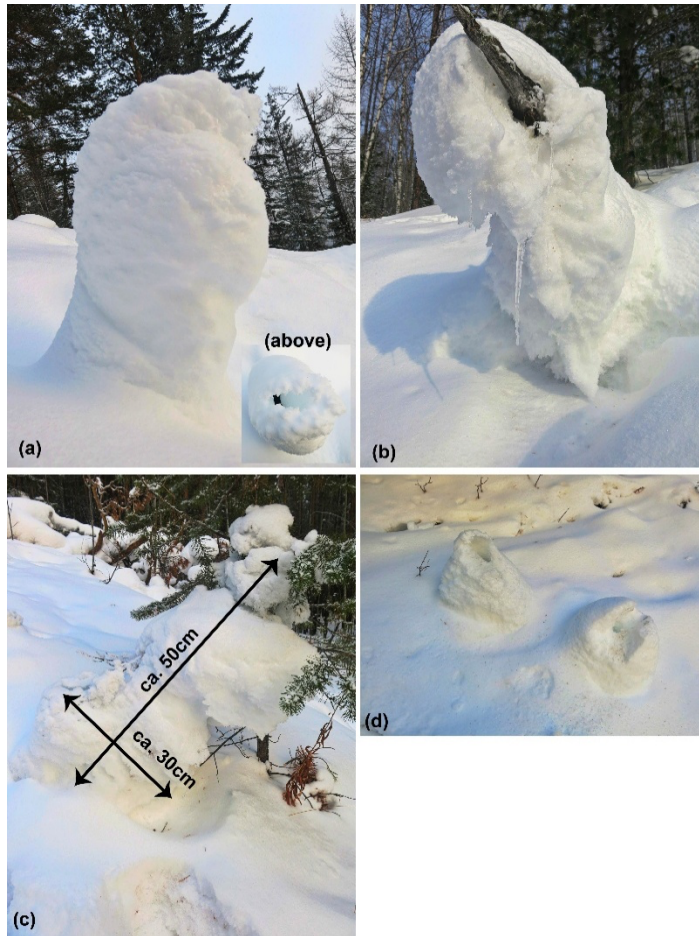
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**Supplementary Fig. S1.** a) Median temperature and range at each logging site, and (b) CO<sub>2</sub> concentration data for site SB\_pk606.



**Supplementary Fig. S2.** Examples of hoar frost (a-d) above Botovskaya Cave. Areas above the cave which display some form of cave exhalation of warm moist air that immediately freezes to form hoar frost. With continued low surface temperatures and above freezing in cave temperatures, the exhalation of moist warm air causes these features to grow.

**Supplementary Table S1.** Details for each of the instruments that were used to monitor temperature, humidity, and CO<sub>2</sub> concentration at each study site.

Monitoring parameter	Sample ID	Distance from cave entrance [m] and zone (brackets)	Approximate distance below cave surface [m]	Duration of monitoring	Instrument	Long term stability	Range	Accuracy
Air temperature [°C]	Surface logger	-15 (outside)	0	2010-2014 2019-2025	Hobosoft UA-001-64 Pendant logger	N/A	-30 to +50	± 0.5 between 0 - 40°C
	D236	83 (I)	1-20	2015-2018 2022-2024	Hobosoft® Pro RH/temp logger	N/A	-30 to +50	± 0.5 between 0 - 40°C
	SB_pk0155	89 (I)	1-20	2015-2017	Hobosoft® H8 pro series	N/A	-30° to +5	± 0.5 between 0 - 40°C
	SB_pk011	115 (I)	1-20	2022	Hobosoft® H8 pro series	N/A	-30 to +50	± 0.5 between 0 - 40°C
	SB_pk0139	193 (II)	1-20	2015-2017	Hobosoft® H8 pro series	N/A	-30 to +50	± 0.5 between 0 - 40°C
	SB_pk044	256 (III)	1-20	2022 2024	Hobosoft® H8 pro series	N/A	-30 to +50	± 0.5 between 0 - 40°C
	SB_pk0122	302 (III)	1-20	2010-2014	Hobosoft® H8 pro series	N/A	-30 to +50	± 0.5 between 0 - 40°C
	SB_pk606	507 (III)	20-40	2022 (6 month)	Goodsell CO <sub>2</sub> data logger	< 0.03 / year	-20 to +70	± (0.4°C + 0.023 × (T [°C] – 25°C))
	SB_pk6919	1212 (III)	60-80	2011-2014	Hobosoft® H8 pro series	N/A	-30 to +50	± 0.5 between 0 - 40°C
Relative humidity [%]	D236	83 (I)	1-20	2022 (6 month)	Hobosoft® Pro RH/temp logger	< 1 / year	0 – 100	±3% between 0 - 50°C
	SB_pk606	507 (III)	20-40	2022 (6 month)	Goodsell CO <sub>2</sub> data logger	< 0.25 / year	0 – 98	±3% at 25°C
CO <sub>2</sub> concentration [ppm]	SB_pk606	507 (III)	20-40	2022 (6 month)	Goodsell CO <sub>2</sub> data logger	± 50	0 – 10,000	±30 ppm ±2.5 ppm/°C

**Supplementary Table S2.** Precipitation isotope data collected between 2004 – 2022. Summer (June – August) and winter (December – February) mean isotope results were employed to calculate the weighted average. All precipitation data was measured at the Alfred Wegener Institute for Polar and Marine Research in Potsdam.

Sample ID	$\delta^{18}\text{O}$ [‰] SMOW	1 $\sigma$	$\delta^2\text{H}$ [‰] SMOW	1 $\sigma$	d excess	Year	Collection month	Precipitation type
N10 Jade	-23.2	0.04	-172.2	0.1	13.6	2022	2	Snow profile
N9 -"	-23.5	0.03	-175.1	0.2	12.6	2022	2	Snow profile
N8 -"	-23.0	0.03	-172.0	0.1	12.0	2022	2	Snow profile
N7 -"	-23.0	0.05	-168.4	0.2	15.6	2022	2	Snow profile
N6 -"	-22.1	0.04	-161.6	0.1	14.8	2022	2	Snow profile
N5 -"	-27.0	0.03	-201.3	0.2	15.0	2022	2	Snow profile
N4 -"	-30.5	0.11	-231.3	0.6	12.8	2022	2	Snow profile
N3 -"	-29.6	0.01	-224.2	0.0	12.3	2022	2	Snow profile
N2 -"	-30.4	0.01	-230.6	0.1	12.4	2022	2	Snow profile
N1 -"	-29.3	0.01	-219.1	0.0	15.2	2022	2	Snow profile
SCE-7 -"	-29.9	0.01	-220.7	0.0	18.8	2022	2	Snow
SSB11 -"	-33.1	0.01	-258.8	0.1	5.8	2022	2	Snow
SSB8 -"	-31.6	0.01	-240.4	0.0	12.1	2022	2	Snow
SST -"	-35.1	0.08	-268.1	0.3	13.0	2022	2	Snow
SOCA -"	-29.2	0.01	-217.7	0.0	15.9	2022	2	Snow
Zhigalovo 1 town	-5.5	0.0	-53.9	0.2	-9.7	2016	8	Rain
Zhigalovo 2 town	-7.0	0.0	-55.8	0.2	0.5	2016	8	Rain
Boty rain	-7.2	0.0	-59.1	0.3	-1.6	2016	8	Rain
Boty night rain	-9.5	0.0	-74.6	0.3	1.2	2016	8	Rain
Boty base day rain	-7.6	0.0	-68.0	0.3	-7.6	2016	8	Rain
Boty base rain	-10.1	0.0	-86.3	0.3	-5.6	2016	8	Rain
Rain	-5.1	0.0	-54.7	0.2	-14.0	2016	8	Rain
SCH23.2 u BASA	-29.4	0.0	-229.1	0.2	6.0	2004	2	Snow
SP 23.2.	-30.1	0.0	-233.3	0.2	7.4	2004	2	Snow

**Supplementary Table S3.** Dripwater and pondwaters collected from Botovskaya Cave across multiple expeditions between 2003 – 2022.

Sample ID	Distance	$\delta^{18}\text{O}$ [‰] SMOW	1 $\sigma$	$\delta^2\text{H}$ [‰] SMOW	1 $\sigma$	d excess	Year	Collection month	Dripwater type	Laboratory (method)
23	167.25	-15.84	0.03	-121.34	0.27	5.41	01/02/2003	2	Dripwater	AWI, Potsdam
24	173.96	-16.11	0.00	-122.09	0.04	6.80	2022	2	Pondwater	AWI, Potsdam
25	173.96	-16.12	0.01	-121.81	0.08	7.13	2022	2	Pondwater	AWI, Potsdam
3239	298.03	-16.24	0.05	-123.75	0.18	6.15	01/02/2003	2	Dripwater	AWI, Potsdam
4389	464.98	-16.24	0.02	-125.64	0.13	4.31	2022	2	Pondwater	AWI, Potsdam
145/1	129.39	-16.27	0.04	-126.68	0.15	3.50	01/02/2003	2	Dripwater	AWI, Potsdam
132	252.89	-16.33	0.00	-124.41	0.04	6.22	2022	2	Dripwater	AWI, Potsdam
341.1	435.41	-16.38	0.03	-123.34	0.15	7.71	2022	2	Pondwater	AWI, Potsdam
SB10-2-Wp.6945	1132.10	-16.39	0.06	-124.53	2.93	6.55	2010	2	Dripwater	AWI, Potsdam
18	143.89	-16.39	0.01	-124.25	0.06	6.91	2022	2	Pondwater	AWI, Potsdam
341	435.41	-16.58	0.02	-125.35	0.06	7.31	2022	2	Pondwater	AWI, Potsdam
28	198.01	-16.60	0.01	-125.19	0.03	7.62	2022	2	Pondwater	AWI, Potsdam
4395	481.20	-16.82	0.01	-128.38	0.05	6.20	2022	2	Dripwater	AWI, Potsdam
4389	464.98	-16.88	0.01	-127.02	0.06	8.00	2022	2	Dripwater	AWI, Potsdam
0606	452.15	-16.90	0.02	-129.02	0.07	6.17	2022	2	Dripwater	AWI, Potsdam
162	25.94	-17.15	0.01	-134.67	0.06	2.50	2022	2	Dripwater	AWI, Potsdam
95	431.02	-17.15	0.04	-133.43	0.43	3.80	01/02/2003	2	Dripwater	AWI, Potsdam
1619	454.43	-18.02	0.01	-136.94	0.01	7.18	2022	2	Dripwater	AWI, Potsdam
TK 6942	1129.78	-18.19	0.03	-139.08	0.29	6.44	01/02/2003	2	Dripwater	AWI, Potsdam
B11-01140-dw	1064.80	-18.28	0.06	-139.05	1.45	7.18	2011	2	Dripwater	AWI, Potsdam
Pond Boti Okean und Morje	1071.74	-18.36	0.03	-139.30	0.20	7.58	01/02/2003	2	Pondwater	AWI, Potsdam
Pond Boti Okean und Morje	1071.74	-18.39	0.05	-140.50	0.30	6.62	01/02/2003	2	Pondwater	AWI, Potsdam
Pond Boti Okean und Morje	1071.74	-18.53	0.01	-141.00	0.30	7.24	01/02/2003	2	Pondwater	AWI, Potsdam
SB10-2-Wp.6940	1124.58	-18.57	0.07	-141.72	2.65	6.84	2010	2	Dripwater	AWI, Potsdam
Pond Boti Okean und Morje	1071.74	-18.58	0.04	-140.20	0.40	8.44	01/02/2003	2	Pondwater	AWI, Potsdam
SB10-2-Wp.6998	1237.47	-18.60	0.03	-140.14	3.27	8.63	2010	2	Dripwater	AWI, Potsdam

<b>SB10-2-Wp.6939</b>	1124.58	-18.60	0.03	-141.52	2.00	7.27	2010	2	Dripwater	AWI, Potsdam
<b>SB10-2-Wp.6921</b>	1211.89	-18.60	0.03	-141.54	3.07	7.25	2010	2	Dripwater	AWI, Potsdam
<b>TK 6918</b>	1197.34	-18.66	0.05	-142.79	0.37	6.47	01/02/2003	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-6921</b>	1211.89	-18.82	0.06	-142.78	1.33	7.80	2013	2	Dripwater	AWI, Potsdam
<b>B-11-6945-dw</b>	1132.10	-18.94	0.05	-145.49	1.86	6.05	2011	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-01140</b>	1064.80	-18.96	0.06	-144.28	1.27	7.37	2013	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-6942</b>	1130.21	-19.08	0.05	-145.29	1.49	7.36	2013	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-6998</b>	1237.47	-19.12	0.05	-145.35	1.06	7.62	2013	2	Dripwater	AWI, Potsdam
<b>SB10-2-Wp.6914</b>	1171.07	-19.19	0.04	-145.63	3.07	7.90	2010	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-6940</b>	1124.58	-19.19	0.04	-145.80	0.86	7.75	2013	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-6935-O</b>	1206.57	-19.22	0.05	-145.83	1.83	7.91	2013	2	Dripwater	AWI, Potsdam
<b>B-11-6940-dw</b>	1064.15	-19.22	0.05	-148.15	3.15	5.64	2011	2	Dripwater	AWI, Potsdam
<b>B-11-6914-dw</b>	1124.17	-19.34	0.05	-149.51	3.12	5.20	2011	2	Dripwater	AWI, Potsdam
<b>SB-14-07-PK-6914</b>	1171.07	-19.78	0.05	-151.03	1.98	7.21	2013	2	Dripwater	AWI, Potsdam
<b>SB_pk606</b>	507.00	-17.06	0.05	-128.47	0.20	8.02	11/02/2022	2	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.03	0.05	-128.53	0.20	7.68	18/02/2022	2	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-16.84	0.05	-127.61	0.20	7.14	25/02/2022	2	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.00	0.05	-128.05	0.20	7.97	04/03/2022	3	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.02	0.05	-128.11	0.20	8.07	11/03/2022	3	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.05	0.05	-128.87	0.20	7.51	18/03/2022	3	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.00	0.05	-128.18	0.20	7.86	08/04/2022	4	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.05	0.05	-128.40	0.20	8.00	15/04/2022	4	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-16.72	0.05	-127.56	0.20	6.23	22/04/2022	4	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.04	0.05	-128.84	0.20	7.51	08/07/2022	7	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-16.82	0.05	-128.38	0.20	6.15	15/07/2022	7	Autosampled Dripwater	IEC, Irkutsk

<b>SB_pk606</b>	507.00	-17.02	0.05	-128.63	0.20	7.49	22/07/2022	7	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.02	0.05	-128.75	0.20	7.38	29/07/2022	7	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-17.05	0.05	-128.85	0.20	7.51	05/08/2022	8	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-16.99	0.05	-128.35	0.20	7.56	12/08/2022	8	Autosampled Dripwater	IEC, Irkutsk
<b>SB_pk606</b>	507.00	-16.58	0.05	-127.33	0.20	5.30	19/08/2022	8	Autosampled Dripwater	IEC, Irkutsk

**Supplementary Table S4.** Results collected from the CO<sub>2</sub> logger at site SB\_pk606. The average 12 hour CO<sub>2</sub> differences and 3-hour averages for each month are also shown.

	<b>February</b>	<b>March</b>	<b>April</b>	<b>May</b>	<b>June</b>	<b>July</b>	<b>August</b>
<b>Average 12h CO<sub>2</sub> difference</b>	84.6	101.6	123.4	52.5	33.2	15.2	24.8
<b>SD</b>	62.9	70.5	88.8	51.2	26.3	13.4	16.5

	<b>CO<sub>2</sub> [ppm]</b>						
<b>Time</b>	<b>February</b>	<b>March</b>	<b>April</b>	<b>May</b>	<b>June</b>	<b>July</b>	<b>August</b>
<b>00:00</b>	935.3	995.4	876.2	694.7	759.4	925.2	1004.0
<b>03:00</b>	932.2	970.3	870.2	702.4	760.3	926.6	1003.5
<b>06:00</b>	937.4	959.9	830.1	691.2	756.7	921.0	993.0
<b>09:00</b>	916.7	980.2	790.1	674.0	760.0	925.7	996.7
<b>12:00</b>	894.9	996.0	765.3	680.0	758.8	928.8	1002.0
<b>15:00</b>	906.7	1022.6	772.9	691.9	762.6	929.9	994.2
<b>18:00</b>	919.5	1018.5	804.7	691.0	763.9	932.4	986.3
<b>21:00</b>	931.8	1003.5	843.9	691.6	763.3	928.1	1004.0
<b>Average</b>	921.8	993.3	819.2	689.6	760.6	927.2	998.0
<b>SD</b>	15.2	22.1	42.6	8.8	2.5	3.5	6.5