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SUPPLEMENTARY INFORMATION

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High riverine CO_2 emissions at the permafrost boundary of Western Siberia

S. Serikova[1*], O. S. Pokrovsky[2], P. Ala-Aho[3,4], V. Kazantsev[5], S. N. Kirpotin[6], S. G. Kopysov[7], I. V. Krickov[6], H. Laudon[8], R. M. Manasypov[6,9], L. S. Shirokova[2,9], C. Soulsby[3], D. Tetzlaff[3,10,11] and J. Karlsson[1*]

[1]Climate Impacts Research Centre, Department of Ecology and Environmental Science, Umeå University, Umeå, Sweden. [2]GET UMR 5563 CNRS, Geoscience and Environment, University of Toulouse, Toulouse, France. [3]University of Aberdeen, Kings College, Aberdeen, Scotland. [4]Water Resources and Environmental Engineering Research Unit, Faculty of Technology, University of Oulu, Oulu, Finland. [5]Organization of the Russian Academy of Sciences A.M. Obukhov Institute of Atmospheric Physics RAS, Moscow, Russia. [6]BIO-GEO-CLIM Laboratory, Tomsk State University, Tomsk, Russia. [7]Institute of Monitoring of Climatic and Ecological Systems SB RAS, Tomsk, Russia. [8]Department of Forest Ecology and Management, The Swedish University of Agricultural Sciences, Umeå, Sweden. [9]N. Laverov Federal Center for Integrated Arctic Research, IEPS, RAS, Arkhangelsk, Russia. [10]IGB Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany. [11]Humboldt University Berlin, Berlin, Germany. *e-mail: svetaserikova22@gmail.com; jan.p.karlsson@umu.se

Supplementary Information

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S. Serikova[1]*, O.S. Pokrovsky[2], P. Ala-Aho[3,4], V. Kazantsev[5], S.N. Kirpotin[6], S.G. Kopysov[7], I.V. Krickov[6], H. Laudon[8], R.M. Manasypov[6,9], L.S. Shirokova[2,9], C. Soulsby[3], D. Tetzlaff[3,10,11] and J. Karlsson[1]

[1]Climate Impacts Research Centre (CIRC), Department of Ecology and Environmental Science, Umeå University, Linnaeus väg 6, 901 87 Umeå, Sweden.

[2]GET UMR 5563 CNRS, Geoscience and Environment, University of Toulouse, 14 Avenue Edouard Belin, 314 00 Toulouse, France.

[3]University of Aberdeen, Kings College, Old Aberdeen, AB24 3UE Aberdeen, Scotland.

[4]Water Resources and Environmental Engineering Research Unit, Faculty of Technology, University of Oulu, PO Box 4300, 900 14 Oulu, Finland.

[5]Organization of the Russian Academy of Sciences A.M. Obukhov Institute of Atmospheric Physics RAS, Pyzhyovskiy pereulok 3, 119 017 Moscow, Russia.

[6]BIO-GEO-CLIM Laboratory, Tomsk State University, Lenina 36, 634 050 Tomsk, Russia.

[7]Institute of Monitoring of Climatic and Ecological Systems (IMCES) SB RAS, Akademichesky Avenue 10/3, 634 055, Tomsk, Russia.

[8]Department of Forest Ecology and Management, The Swedish University of Agricultural Sciences, Skogsmarksgränd 17, 901 83 Umeå, Sweden.

[9]N. Laverov Federal Center for Integrated Arctic Research, IEPS, Russian Academy of Sciences, 23 Nab. Sev. Dviny, Arkhangelsk, Russia.

[10]IGB Leibniz Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 125 87 Berlin, Germany.

[11]Humboldt University Berlin, Unter den Linden 6, 100 99 Berlin, Germany.

*Correspondence to S.S. (svetaserikova22@gmail.com)

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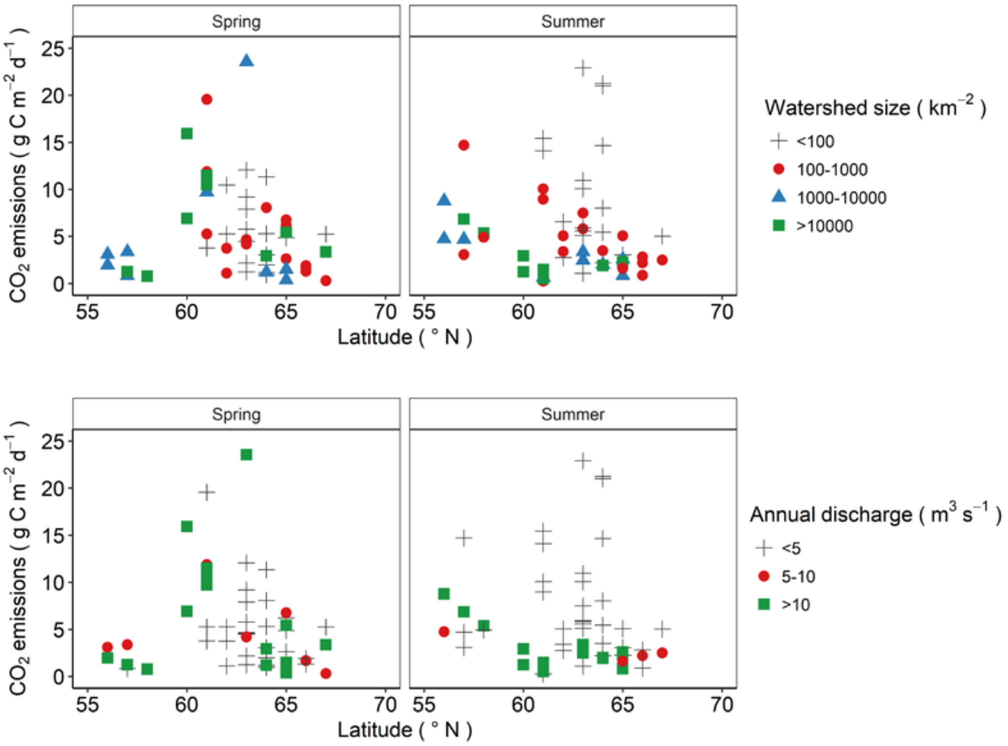

Figure 1. Seasonal CO_2 emissions per unit water area grouped based on watershed classes and annual discharge plotted against latitude. Watershed classes and annual discharge groups are shape- and color coded.

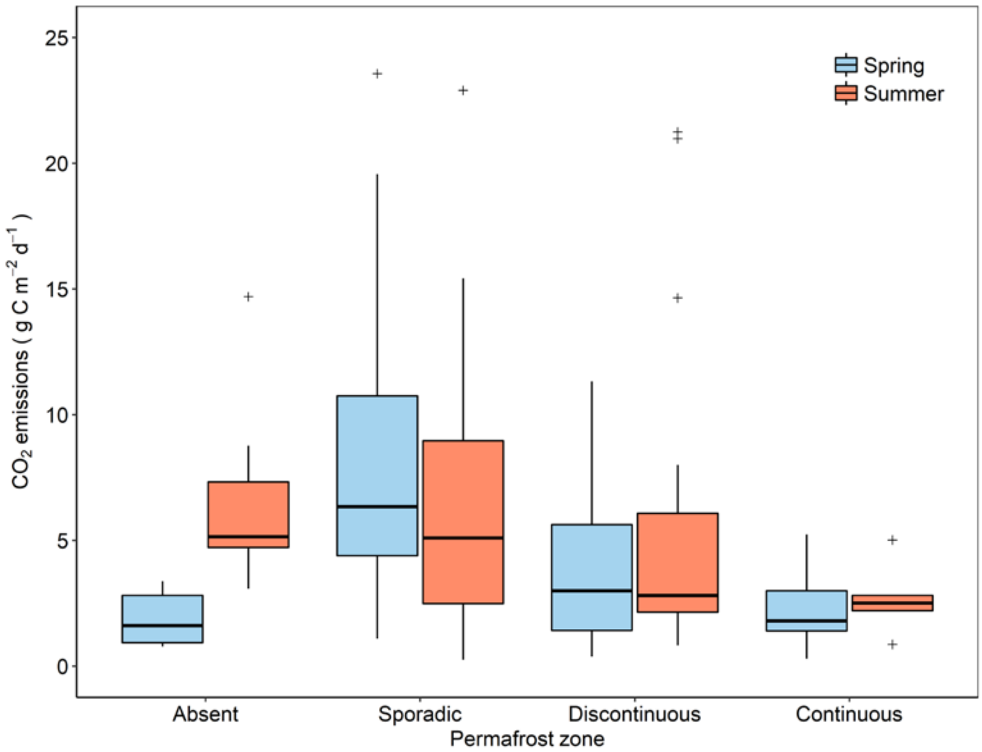

Figure 2. Seasonal CO_2 emissions per unit water area across different permafrost zones. Boxes are bound by 25th and 75th percentiles. Whiskers show 1.5 interquartile range (IQR). Solid line represents median values while crosses indicate outliers. For sample size see Supplementary Information Table 1.

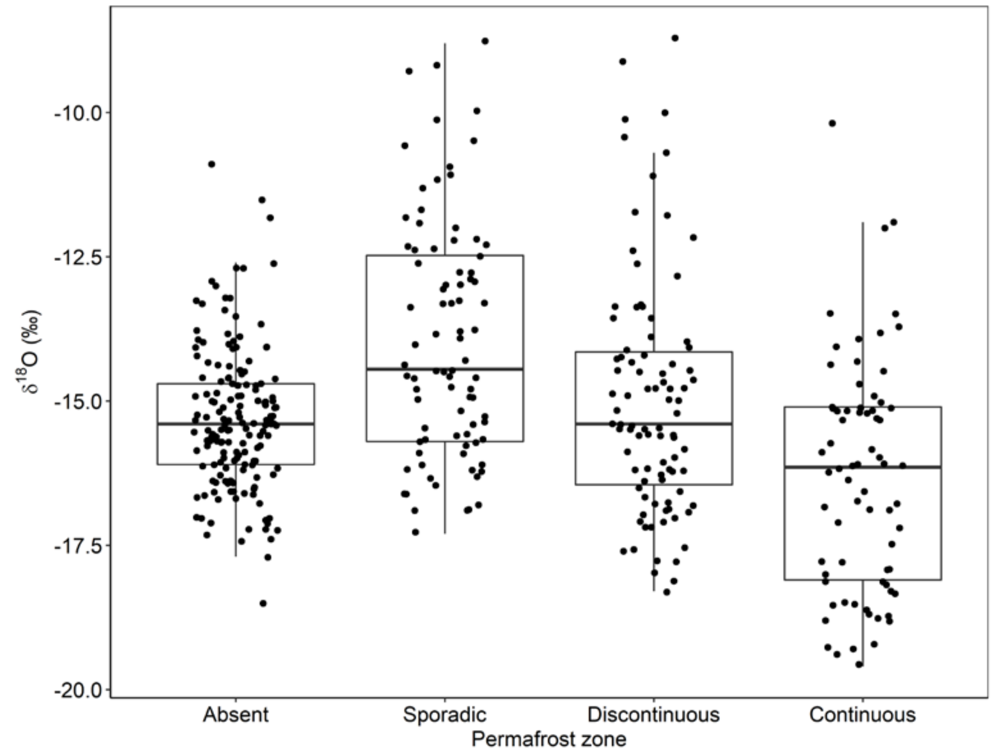

Figure 3. River $\delta^{18}O$ across different permafrost zones. Boxes are bound by 25th and 75th percentiles. Whiskers show 1.5 interquartile range (IQR) while solid line represents median values. The isotope variability is lower in permafrost-free zone ($F_{3,407}$ = 13.6, P < 0.05) suggesting deeper flow-paths in permafrost-free soils. In other permafrost zones, the isotope variability is greater, implying a more rapid hydrological response, when water flow is restricted to overland flow and has shorter travel times.

Supplementary Tables

Table 1. Mean seasonal surface water chemistry parameters and emission rates per unit of water area (± interquartile range, IQR) across permafrost zones. Dash stands for missing values.

	Permafrost zone							
	Absent		**Sporadic**		**Discontinuous**		**Continuous**	
	Spring	**Summer**	**Spring**	**Summer**	**Spring**	**Summer**	**Spring**	**Summer**
n	6	8	26	26	16	16	6	5
pCO_2, µatm	3511 (± 287)	5328 (± 2397)	5072 (± 1615)	4997 (± 1745)	4155 (± 2998)	4274 (± 4345)	2402 (± 502)	2187 (± 53)
CO_2 emissions, g C m^{-2} d^{-1}	1.8 (± 1.8)	6.6 (± 2.6)	12.0 (± 7.2)	7.5 (± 7.2)	3.9 (± 4.2)	6.0 (± 3.9)	2.2 (± 1.6)	2.6 (± 0.6)
k, cm^{-1} h^{-1}	5.1 (± 6.1)	6.2 (± 5.1)	16.5 (± 16.9)	10.3 (± 4.8)	7.0 (± 6.8)	8.2 (± 4.7)	5.1 (± 3.0)	7.0 (± 3.3)
*k_{CO_2}, min^{-1}	0.001 (± 0.001)	0.003 (± 0.004)	0.007 (± 0.003)	0.005 (± 0.005)	0.003 (± 0.003)	0.004 (± 0.004)	0.001 (± 0.001)	0.004 (± 0.000)
n	9	7	26	27	16	16	6	6
DOC, mg L^{-1}	29.0 (± 24.2)	21.3 (± 16.2)	16.9 (± 7.4)	16.7 (± 9.3)	12.2 (± 2.8)	14.6 (± 4.8)	11.8 (± 1.4)	14.3 (± 3.6)
DIC, mg L^{-1}	14.1 (± 5.6)	56.1 (± 31.8)	2.1 (± 1.5)	4.1 (± 2.7)	1.6 (± 1.4)	2.7 (± 1.4)	2.4 (± 1.3)	7.5 (± 2.0)
DOC:DIC ratio	2.4 (± 2.7)	0.5 (± 0.5)	15.9 (± 12.4)	9.1 (± 10.4)	12.9 (± 6.2)	9.6 (± 4.3)	5.4 (± 3.2)	2.1 (± 0.2)
n	9	4	26	22	16	16	6	6
Conductivity, µS cm^{-1}	150.4 (± 33.0)	523.2 (± 72.7)	50.7 (± 23.2)	66.1 (± 24.0)	35.9 (± 18.7)	41.1 (± 22.2)	45.6 (± 31.2)	94.1 (± 23.2)
pH	7.4 (± 0.2)	7.6 (± 0.1)	5.8 (± 0.6)	6.1 (± 0.7)	6.0 (± 0.8)	5.9 (± 0.8)	6.5 (± 0.4)	7.1 (± 0.2)
n	6	-	25	3	12	-	-	-
CH_4, mg L^{-1}	0.008 (± 0.00)	-	0.02 (± 0.02)	0.02 (± 0.03)	0.04 (± 0.03)	-	-	-
n	6	-	23	3	11	-	-	-
CH_4 emissions, g C m^{-2} d^{-1}	0.03 (± 0.02)	-	0.27 (± 0.19)	0.01 (± 0.01)	0.25 (± 0.17)	-	-	-
n	3	4	26	24	16	16	6	6
$SUVA_{254}$	3.2 (± 0.9)	3.2 (± 0.2)	4.5 (± 0.4)	4.6 (± 0.4)	4.3 (± 0.5)	4.5 (± 1.1)	3.9 (± 0.3)	3.9 (± 0.4)

*For k_{CO2} in the sporadic permafrost zone n=25.

Table 2. Mean annual river C fluxes per unit water area and mean annual terrestrial flux per unit catchment area (± interquartile range, IQR) across permafrost zones.

	Permafrost zone			
	Absent	**Sporadic**	**Discontinuous**	**Continuous**
n	9	26	16	6
*River CO_2 emissions, kg C m^{-2} yr^{-1}	1.02 (± 0.36)	1.65 (± 1.14)	0.78 (± 0.52)	0.36 (± 0.21)
River C export, kg m^{-2} yr^{-1}	1.03 (± 0.47)	0.72 (± 0.26)	0.46 (± 0.18)	0.69 (± 0.21)
River C emission:export	1.18 (± 0.36)	2.65 (± 2.29)	1.80 (± 1.80)	0.56 (± 0.31)
Terrestrial C export, kg m^{-2} yr^{-1}	0.011 (± 0.004)	0.016 (± 0.011)	0.009 (± 0.003)	0.007 (± 0.002)

*For River CO_2 emissions in the sporadic permafrost zone n=27.

Table 3. Summary of water chemistry parameters (mean of summer ± interquartile range, IQR of summer) across permafrost zones.

	Permafrost zone			
	Absent	**Sporadic**	**Discontinuous**	**Continuous**
n	9	26	16	6
O_2, mg L^{-1}	6.75 (± 4.40)	7.44 (± 2.37)	8.75 (± 3.40)	12.16 (± 0.70)
n	9	27	16	6
DIN, mg L^{-1}	0.20 (± 0.25)	0.06 (± 0.05)	0.07 (± 0.05)	0.05 (± 0.05)
TN, mg L^{-1}	1.28 (± 0.35)	0.82 (± 0.45)	0.68 (± 0.10)	0.71 (± 0.28)
TOC, mg L^{-1}	37.55 (± 41.00)	23.96 (± 8.50)	18.93 (± 6.87)	18.58 (± 5.75)
PO_4, mg L^{-1}	0.03 (± 0.04)	0.02 (± 0.01)	0.02 (± 0.01)	0.04 (± 0.02)
TP, mg L^{-1}	0.19 (± 0.05)	0.15 (± 0.10)	0.19 (± 0.10)	0.16 (± 0.07)
n	8	26	16	6
TC, mg L^{-1}	1.25 (± 0.59)	1.95 (± 1.44)	1.77 (± 1.01)	3.84 (± 4.13)

Table 4. Statistical results of orthogonal contrasts. Between-seasons comparison of pCO_2 concentrations. For details on statistics see Methods.

Contrast	Estimate	SE	df	t.ratio	p.value
Spring_Absent-Summer_Absent	0.156	0.103	109.000	1.507	0.134
Spring_Sporadic-Summer_Sporadic	-0.021	0.053	109.000	-0.400	0.689
Spring_Discontinuous-Summer_Discontinuous	-0.029	0.067	109.000	-0.436	0.663
Spring_Continuous-Summer_Continuous	-0.0411	0.116	109.000	-0.354	0.723

Table 5. Statistical results of orthogonal contrasts. Between-seasons comparison of CO_2 emissions. The star indicates statistically significant difference at 0.05 level. For details on statistics see Methods.

Contrast	Estimate	SE	df	t.ratio	p.value
Spring_Absent-Summer_Absent	0.579	0.215	66.465	2.690	0.009*
Spring_Sporadic-Summer_Sporadic	-0.246	0.108	52.145	-2.276	0.026*
Spring_Discontinuous-Summer_Discontinuous	0.131	0.137	50.221	0.951	0.345
Spring_Continuous-Summer_Continuous	0.153	0.237	54.790	0.643	0.522