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Runoff evaluation in an Earth System Land Model for permafrost regions in Alaska

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S1. Vertical discretization of the soil column in E3SM-ELM

The soil column is discretized into fifteen vertical layers (Table S1). The depth of the center of the soil layer *i*, or node depth z_i (m), is defined as

$$z_i = f_s \left\{ \exp\left[0.5\left(i - 0.5\right) \right] - 1 \right\}, \tag{S1}$$

where f_s = 0.025 m is a scaling factor controlling the vertical stretching of the grid.

The thickness of each soil layer Δz_i (m) is computed as

$$\Delta z_i = \begin{cases} 0.5\left(z_1 + z_2\right), & i = 1 \\ 0.5\left(z_{i+1} - z_{i-1}\right), & i = 2, 3, ..., N_{levgrnd} - 1, \\ z_N - z_{N-1}, & i = N_{levgrnd} \end{cases} \tag{S2}$$

where $N_{levgrnd}$ = 15 is the total number of soil layers.

The depths at the layer interfaces $z_{h,i}$ (m) are given by

$$z_{h,i} = \begin{cases} 0.5\left(z_i + z_{i+1}\right), & i = 1, 2, ..., N_{levgrnd} - 1 \\ z_{N_{levgrnd}} + 0.5\Delta z_{N_{levgrnd}}, & i = N_{levgrnd} \end{cases} \tag{S3}$$

The exponential form of equation (S1) is adopted to provide higher vertical resolution near the soil surface, where soil water gradients are generally strongest.

Table S1. E3SM-ELM's soil layer structure. Layer node depth z_i, layer thickness Δz_i, and depth at the layer interface $z_{h,i}$, for the fifteen-layer soil column. All quantities are given in meters.

Layer	z_i	Δz_i	$z_{h,i}$
1 (top)	0.0071	0.0175	0.0175
2	0.0279	0.0276	0.0456
3	0.0623	0.0455	0.0906
4	0.1189	0.0750	0.1655
5	0.2122	0.1236	0.2891
6	0.3661	0.2038	0.4929
7	0.6198	0.3360	0.8289
8	1.0380	0.5539	1.3828
9	1.7276	0.9133	2.2961
10	2.8646	1.5058	3.8019
11	4.7392	2.4826	6.2845
12	7.8298	4.0931	10.3775
13	12.9253	6.7484	17.1259
14	21.3265	11.1262	28.2520
15 (bottom)	35.1776	13.8512	42.1032

Table S2. Properties of soil layers (*acrotelm*, *catotelm*, and mineral) used in ATS Sag River simulations.

Soil layer	***Acrotelm***	***Catotelm***	**Mineral**
Porosity (-)	0.88	0.8	0.457
Permeability (m^2)	1.29e-10	4.72e-12	1.82e-13
van Genuchten α (Pa^{-1})	7.78e-4	1.71e-4	6.94e-05
van Genuchten n (-)	1.41	1.57	1.54
Residual saturation (-)	0.08	0.08	0.04
Thermal conductivity, saturated ($W \cdot m^{-1} \cdot K^{-1}$)	0.52	0.63	1.34
Thermal conductivity, dry ($W \cdot m^{-1} \cdot K^{-1}$)	0.07	0.09	0.23