Numerical predictions of permafrost thaw under climate change near Umiujaq (Nunavik) Québec: Only twenty years to go ?

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Quebec Water Research Centre

Sentinelle Nord

AGC-AMC-AIH
QUÉBEC 2019
Où les géosciences convergent
12-15 mai

GAC-MAC-IAH
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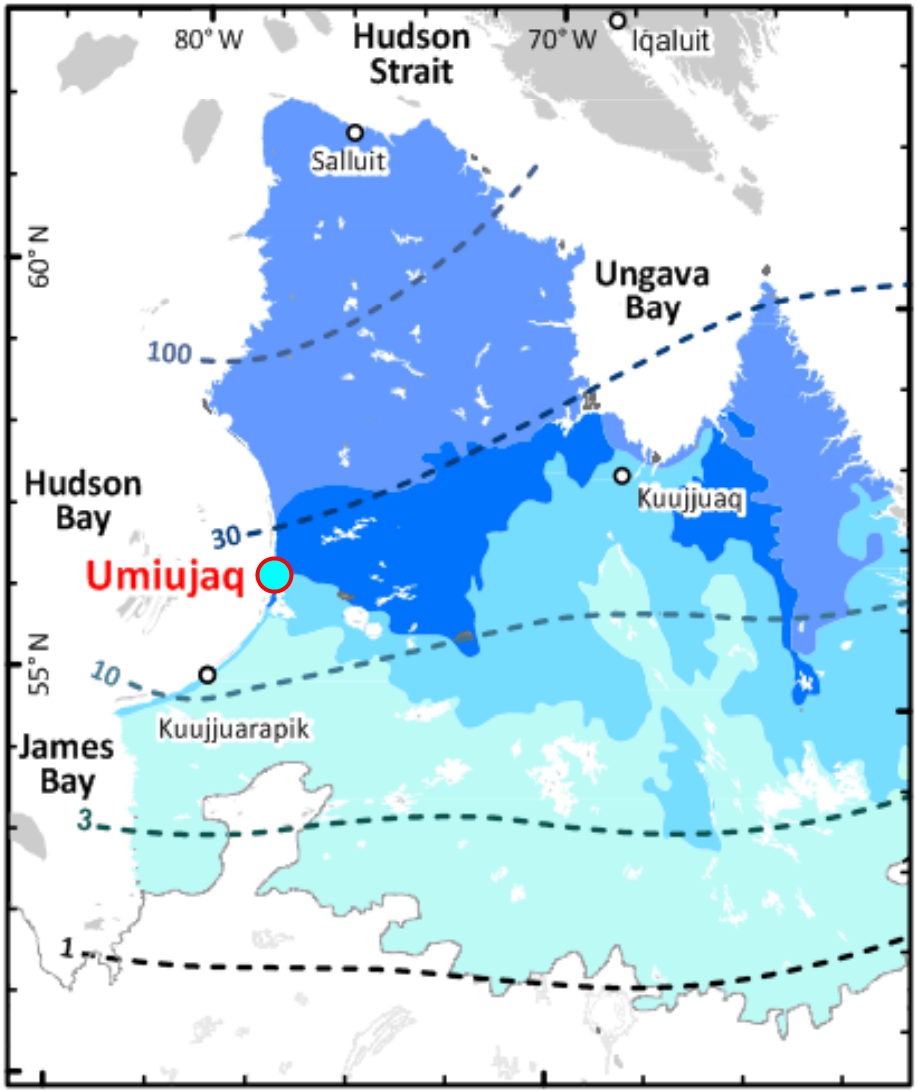
Where geosciences converge
May 12-15

Study Site : Umiujaq
Nunavik, Québec, Canada



Legend

Permafrost zones

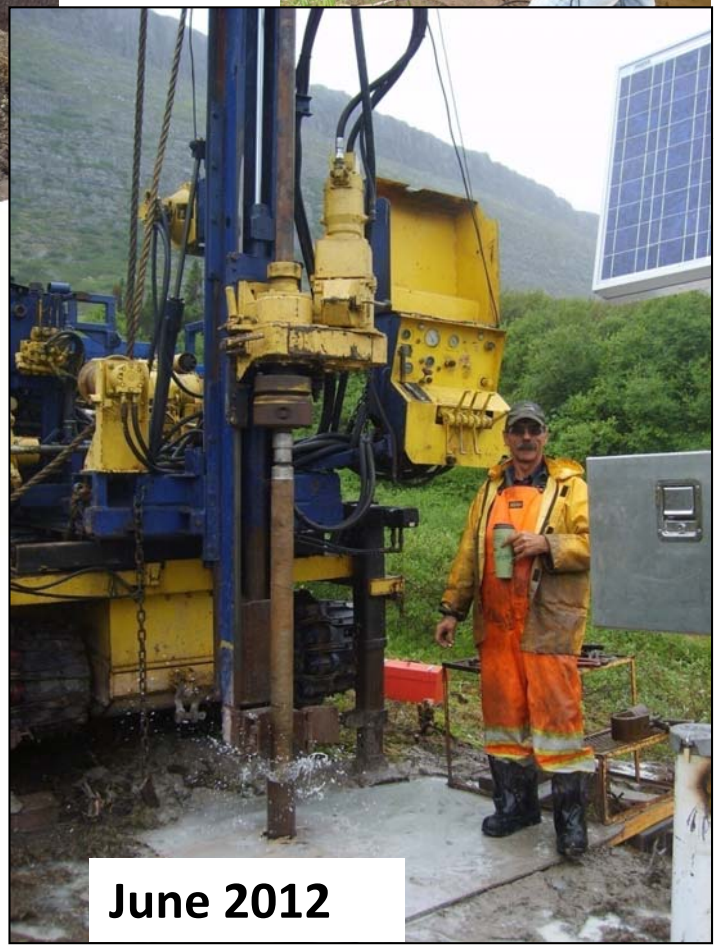
- Continuous
- Discontinuous but widespread
- Discontinuous but scattered
- Sporadic

10 Interpolated depth of the 0°C isotherm (m)

Umiujaq field campaigns

June 2018

2015



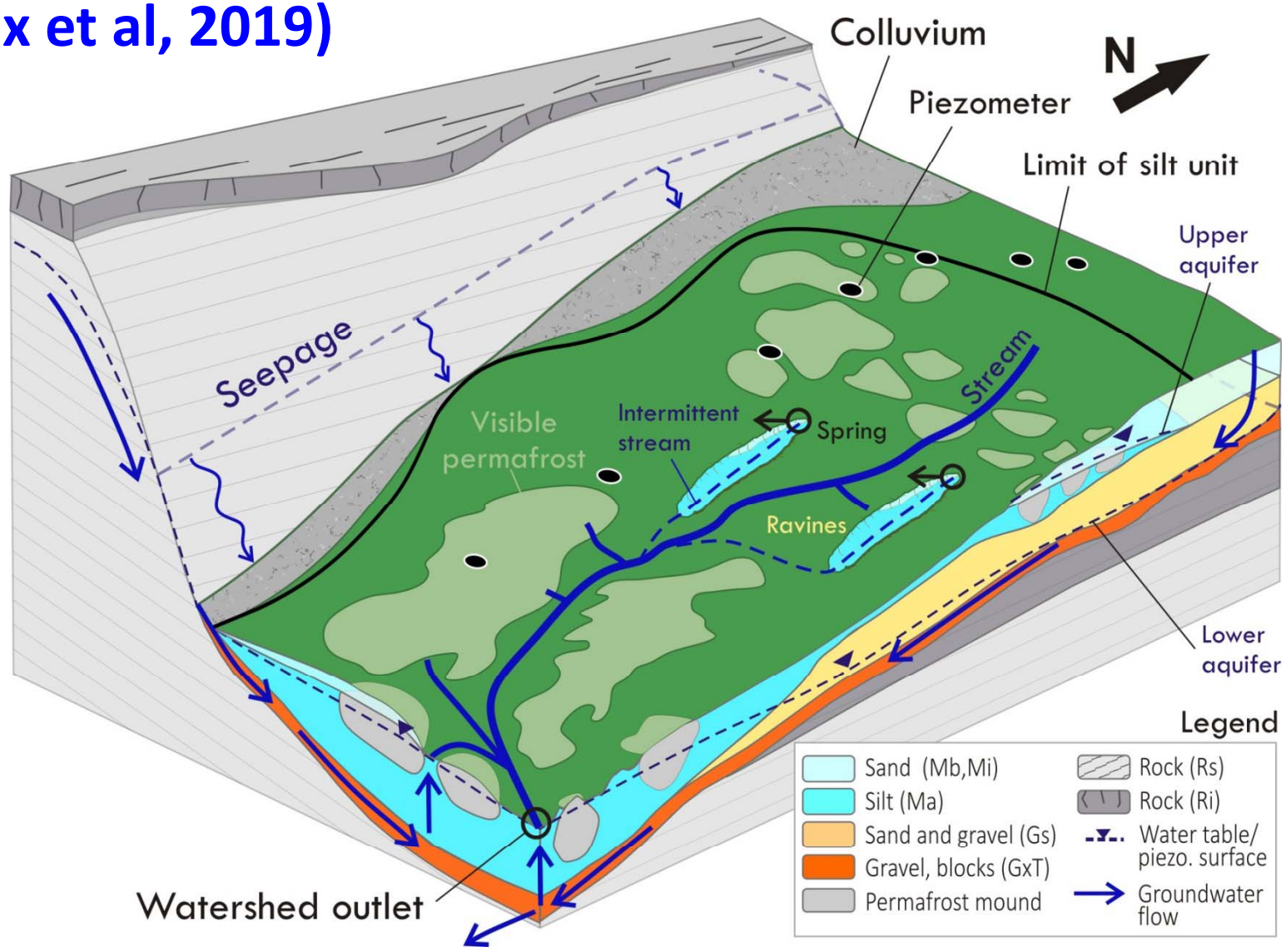
June 2012

Motivation and Objectives

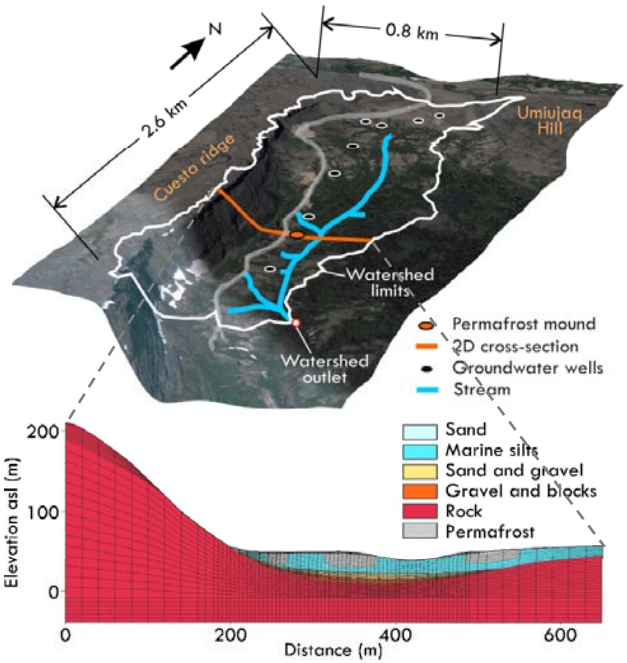
- Assess the impacts of climate change on groundwater resources (Quebec Climate Change Plan)
- Study groundwater dynamics in permafrost environments
- Hypothesis 1: Improved groundwater availability
- Hypothesis 2: Groundwater flow increases permafrost degradation

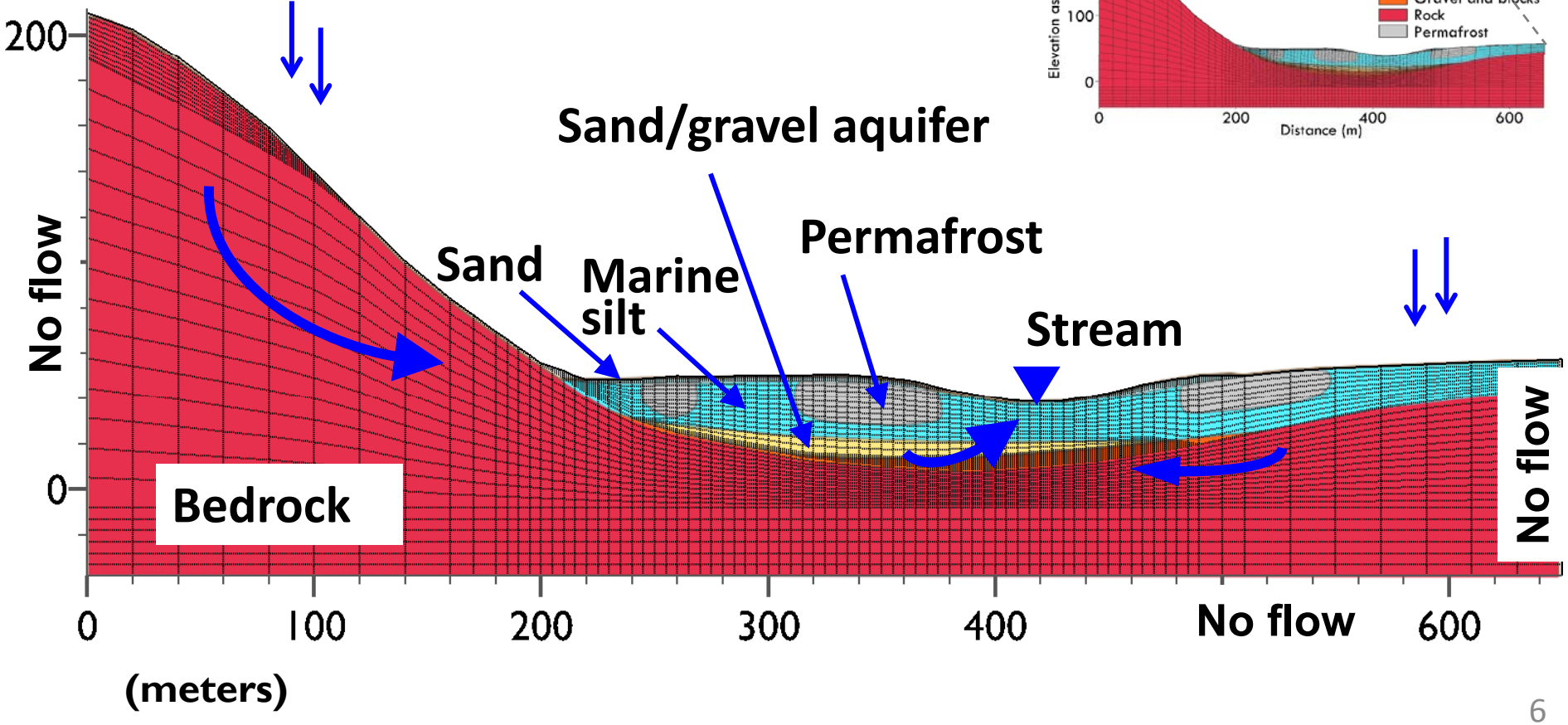
http://www.mddep.gouv.qc.ca/eau/piezo/index.htm

Conceptual Cryo-hydrogeological Model (Lemieux et al, 2019)



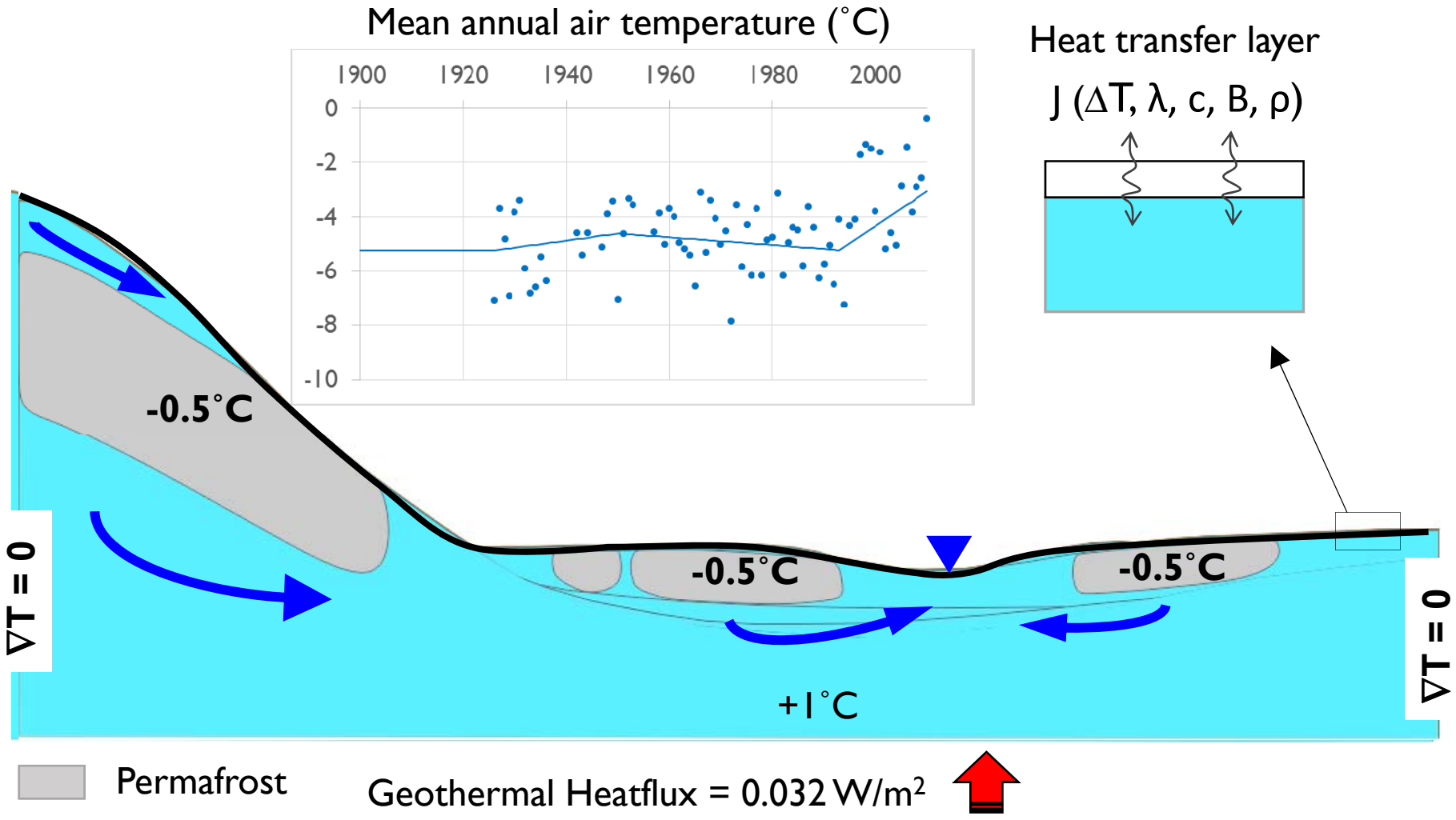
Conceptual Cryo-hydrogeological Model
(Dagenais et al, 2019)





Conceptual Model – Heat transfer

Boundary conditions and initial conditions (1900)



Heatflow/Smoker

(Molson & Frind, 2019)

Coupled processes :
Groundwater flow, heat transfer, freeze/thaw

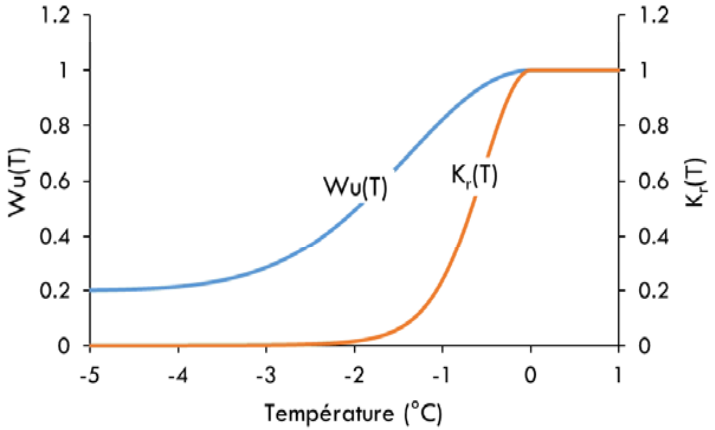
Flow: (ψ)

$$\frac{\partial}{\partial x_i}\left[K_{i,j}(T)\left(\frac{\partial \psi}{\partial x_j}+\rho_r(T)\cdot \bar{n}_j\right)\right]-\sum_{k=1}^{N} Q_k(t)\cdot\delta(x_k,y_k,z_k)=S_s\frac{\partial \psi}{\partial t}$$

Transport (T):

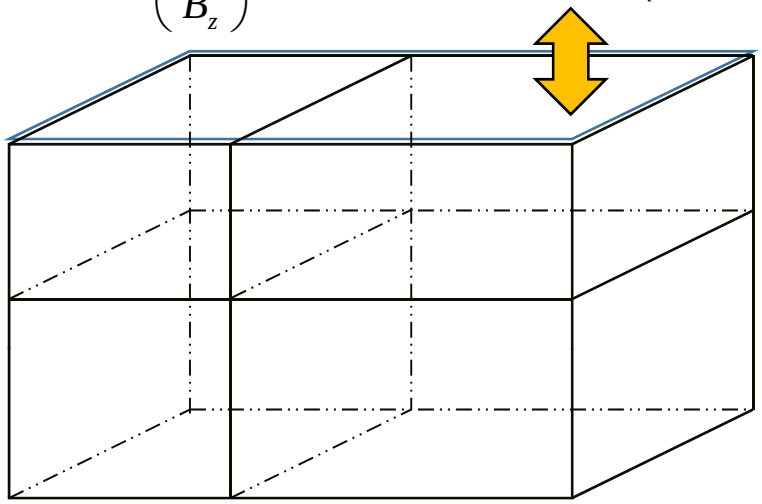
$$-\frac{\partial}{\partial x_i}\left(\theta S_w c_w \rho_w v_i T\right)+\frac{\partial}{\partial x_i}\left(\bar{\lambda}(T)+\theta S_w c_w \rho_w D\right)\frac{\partial T}{\partial x_j}+\Omega=\frac{\partial\left(C_o T\right)}{\partial t}$$

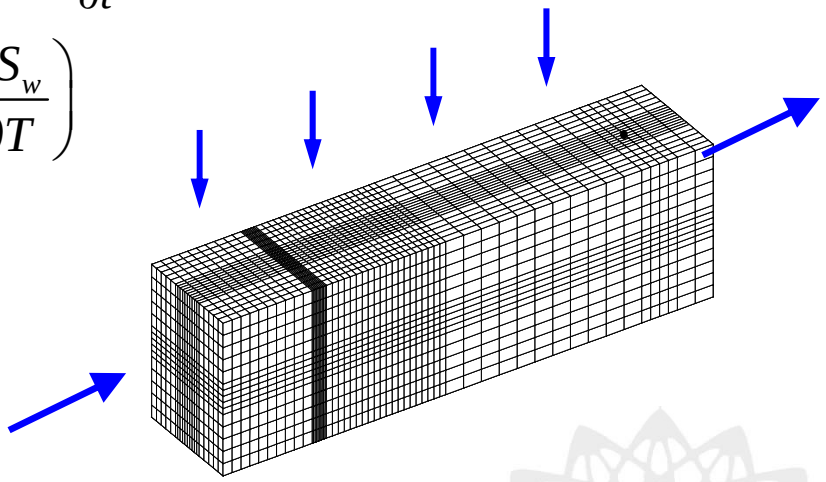
$$C_o=\theta S_w c_w \rho_w+\theta S_i c_i \rho_i+(1-\theta)c_s\rho_s+\theta\rho_i L\left(\frac{\partial S_w}{\partial T}\right)$$



Air-Ground
Thermal Boundary Condition

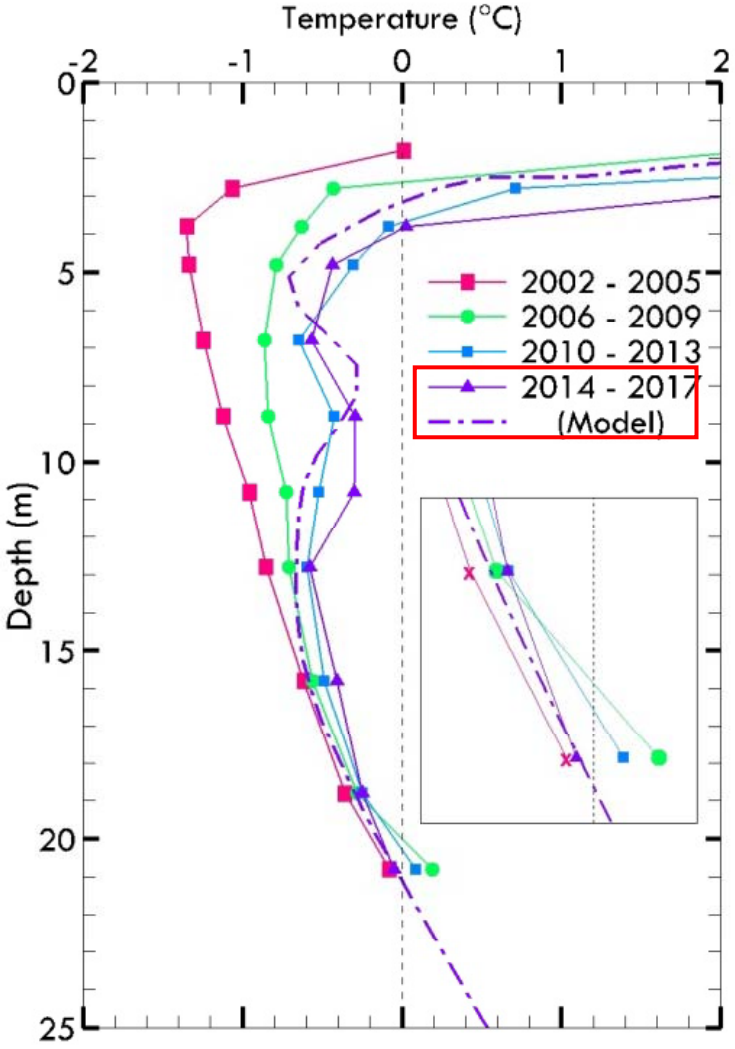
$$J_i=\left(\frac{\lambda_u}{B_z}\right)\left(T_a-T_s\right)+\left(q\cdot c_w\rho_w\right)\cdot\left(T_q-T_s\right)$$





Model Calibration

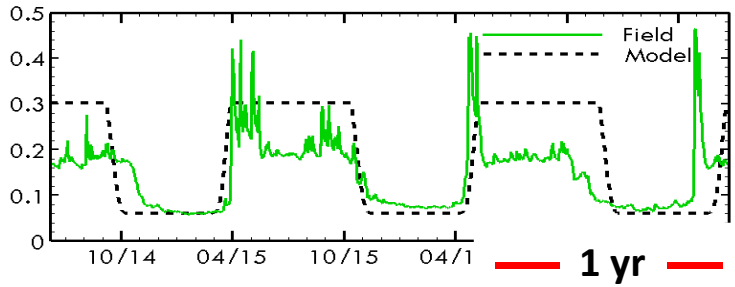
Temperature Profiles



Ground properties: 10 cm depth

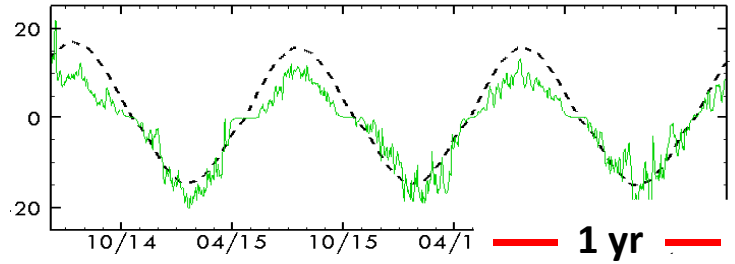
Unfrozen water content

(-)



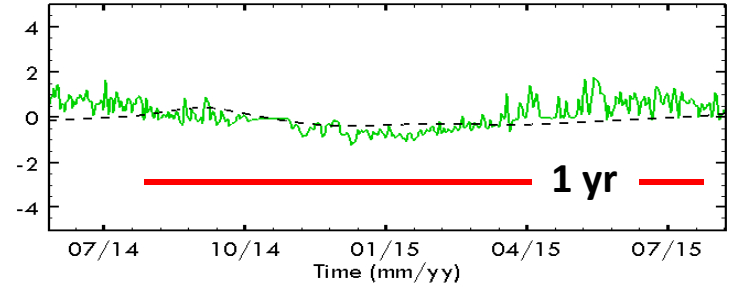
Ground temperature

(°C)

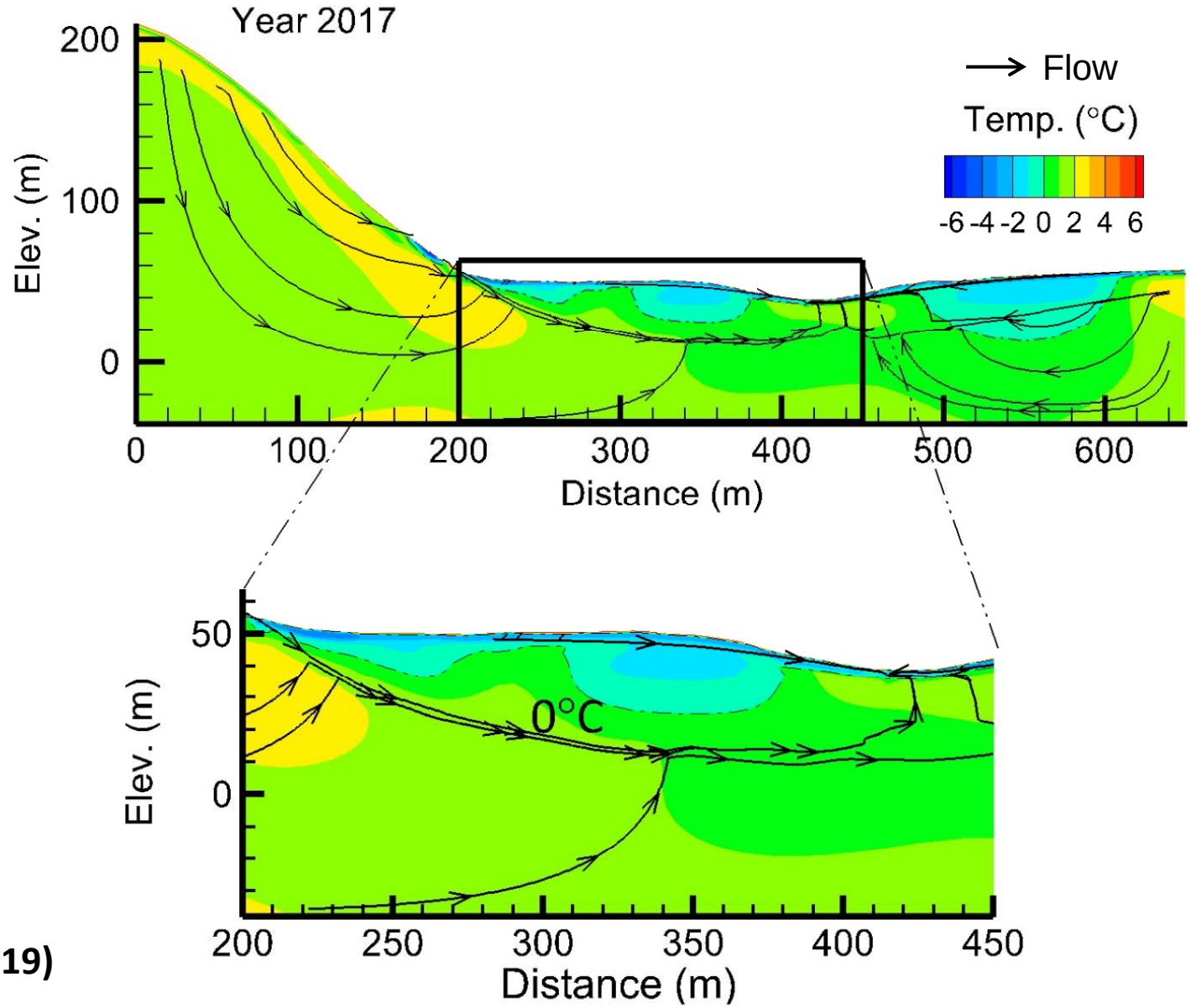


Ground heat flux

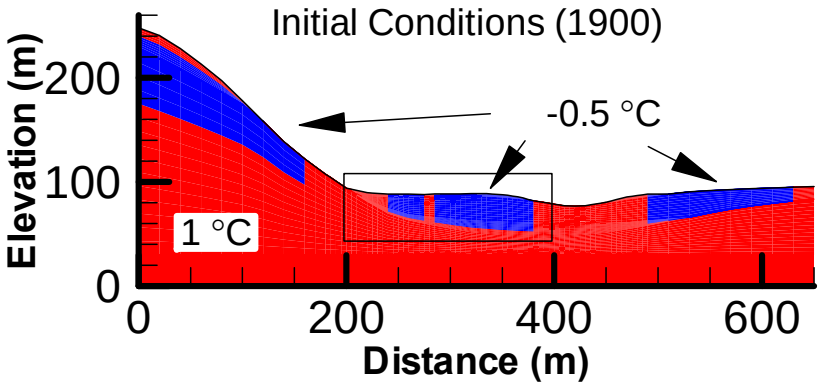
(W/m²)



Simulated Flow System & Temperatures 1900-2017

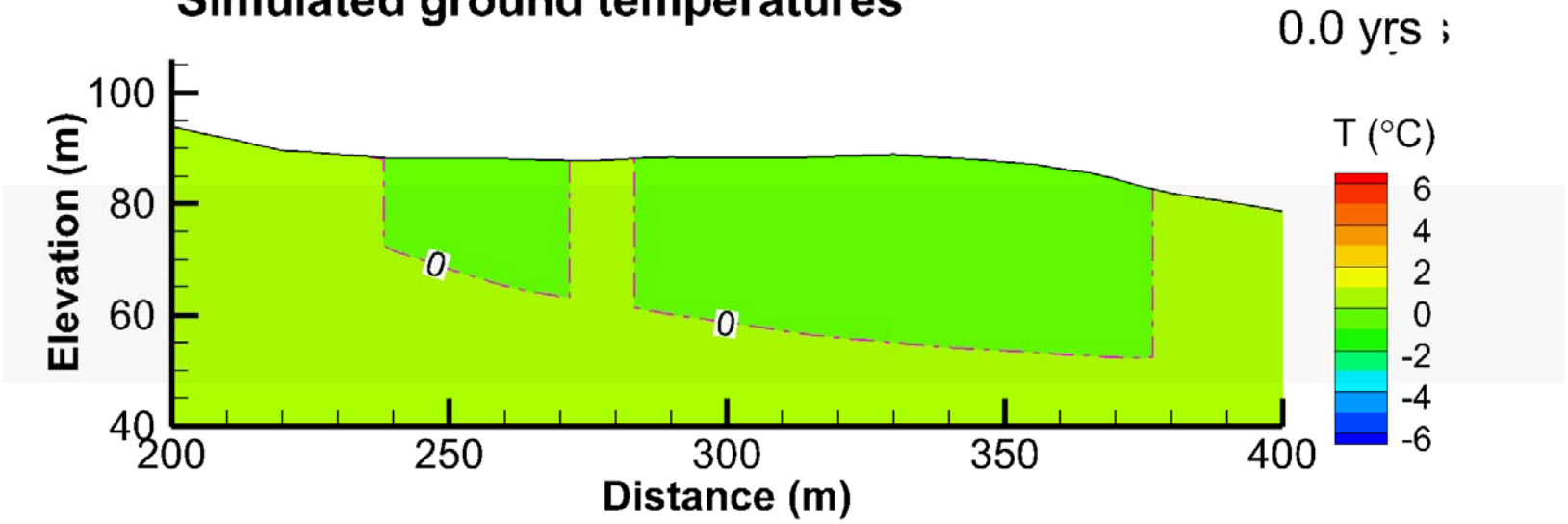


HEATFLOW model
(Molson & Frind, 2019)



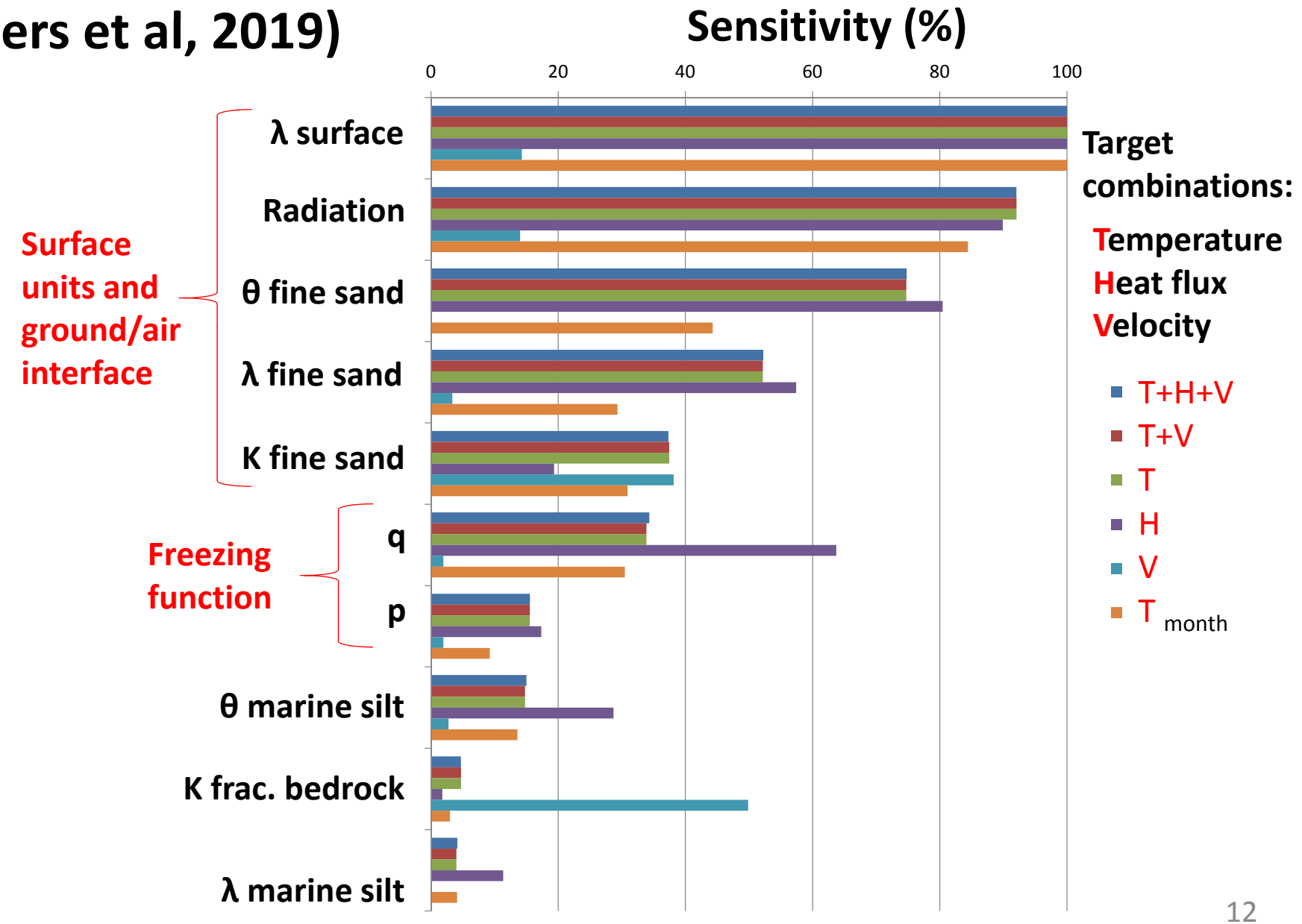
1900 – 2050 AD
0 – 150 yrs

Umiujaq Model
Simulated ground temperatures



Parameter Sensitivity (PEST)

(Albers et al, 2019)



Take-Home Points:

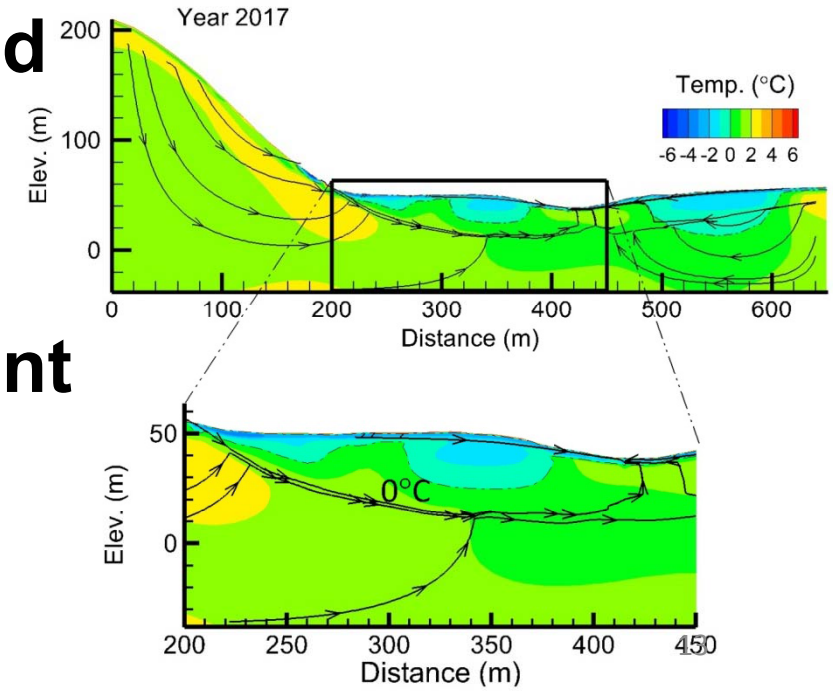
- **Groundwater flow can contribute to permafrost thaw <u>from above and below</u>**

- **Most sensitive to surface and near-surface properties**

- **Groundwater flow can maintain cold T downgradient**

- **Thaw rate at Umiujaq :**
  - **surface: 12 cm/yr**
  - **base : 80 cm/yr**

  complete thaw by ~2040 ?



Acknowledgements