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A Model for Cold Region Hydrology: variable-density, two-phase groundwater flow coupled with heat transfer and phase change

My Code Has No Name (yet)!

Physical Equations

Energy Equation (temperature field)

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = K \nabla^2 T + \varphi_i$$

i = ice

Latent Heat Treatment (heat source/sink)

$$\varphi_i = \rho_i L_i \frac{\partial S_i}{\partial t} = \rho_i L_i \frac{\partial S_i}{\partial T} \frac{\partial T}{\partial t}$$

e.g., $S_i = \phi i$

Darcy's Law with Buoyancy (velocity field)

$$u_j = -\frac{k_j^r k(\phi)}{\mu_j} \nabla \left[P - \rho_j g z \right]$$

j = phase subscript

Fluid/Gas Cons. of Mass (fluid/gas saturation)

$$\frac{\partial S_j}{\partial t} + \nabla \cdot u_j = \Phi_j \qquad \sum_j \left(\nabla \cdot u_j - \Phi_j \right) = 0$$

Solute Field (salinity, etc)

$$\frac{\partial C}{\partial t} + \nabla \cdot (uC) = D \nabla^2 C + Q_c$$

Assumptions

- Darcy flow → Re << 1
- Water phase change is f(Temp,Press,Sal) according to UNESCO, 1983
- Volume change between ice/water not accounted for
- Density & specific heat in grid cell calculated with volume average
- Thermal conductivity in grid cell calculated with mixture model
- Relative permeability defined by Corey curves
- Absolute permeability is a function of porosity (which accounts for ice content, e.g. ice permafrost)
- Saturated conditions (not equipped for unsaturated zone)

Method of Solution

- Finite Volume Method (FVM) used to discretize the equations e.g.,

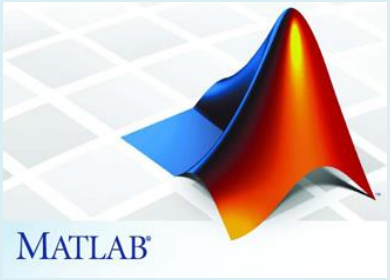
$$\int_V \int_t \sum_j \left(\nabla \cdot u_j - \Phi_j \right) = 0$$

- C++ used to code up the model
- Equations are solved using pre-conditioned iterative methods using the PETSc library

PETSc

Argonne NATIONAL LABORATORY

- Post-processing and visualization done with MATLAB and Visit software

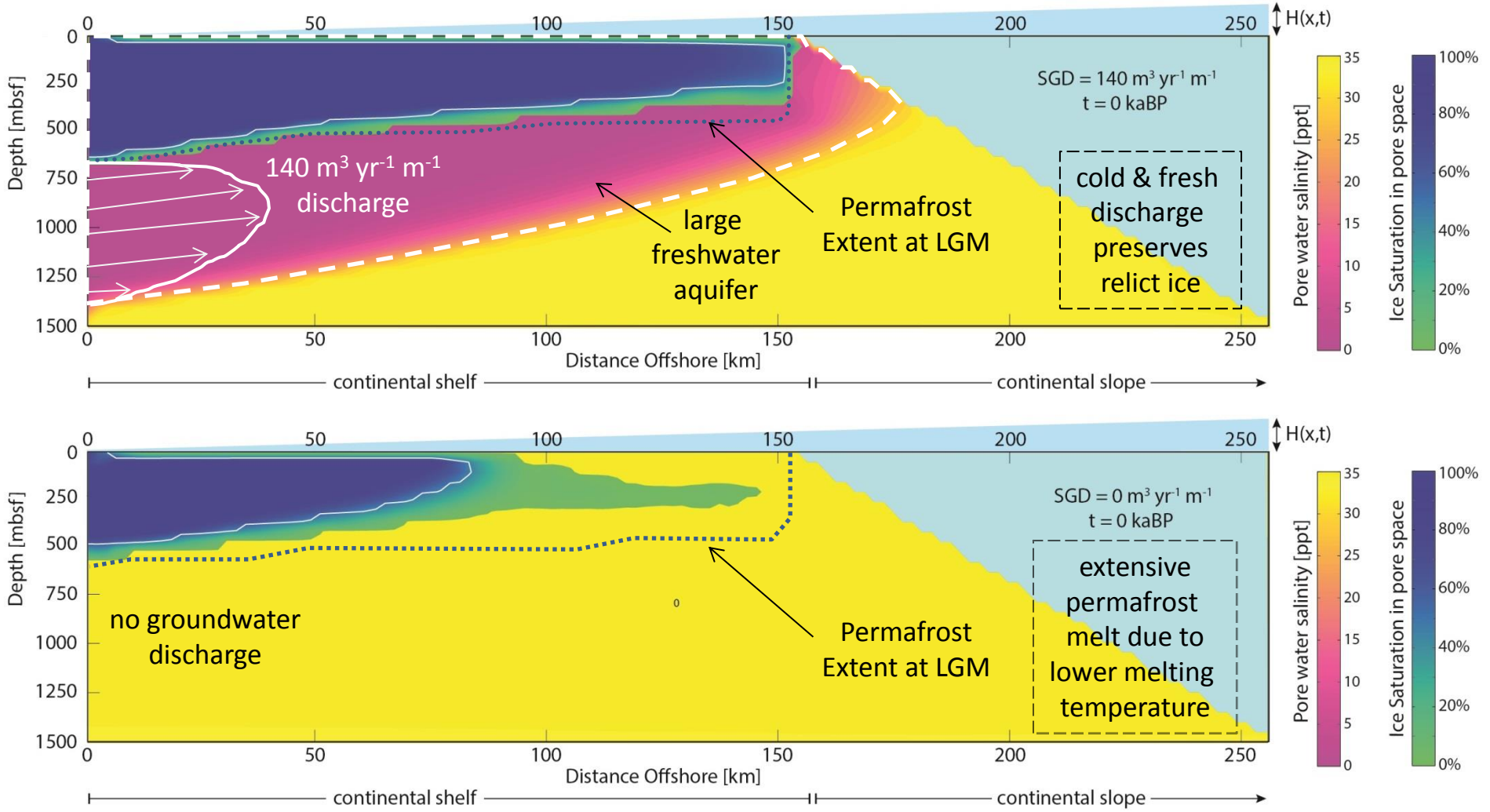


VISIT

Model Applications

Investigating the effect of submarine groundwater discharge on relict Arctic submarine permafrost:

Frederick & Buffett (2014), *JGR, in review*



Frederick & Buffett (2014), *JGR, in review*

Model Applications

Frederick & Buffett (2014), *JGR Earth Surface*

Investigating methane gas venting through several taliks in relict Arctic submarine permafrost:

*(the taliks are formed by heat input from river at surface, red line)

river* width:

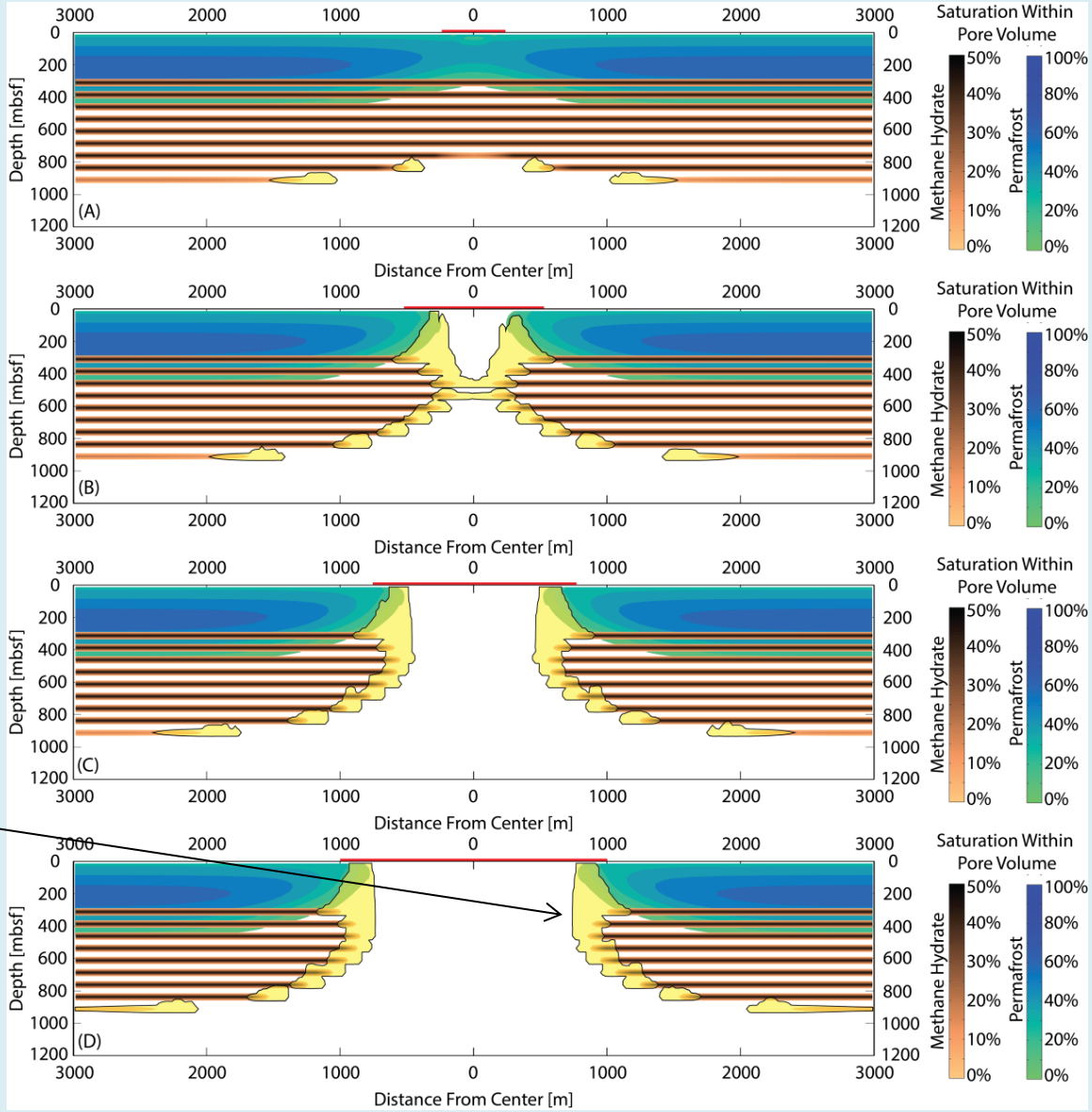
0.5 km

1.0 km

1.5 km

2.0 km

methane gas (yellow)



Benchmarks

- I can run all benchmarks except the unsaturated ones
- Timeline to complete benchmark cases is flexible
- I am interested in a joint publication

Please feel free to contact me anytime!

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