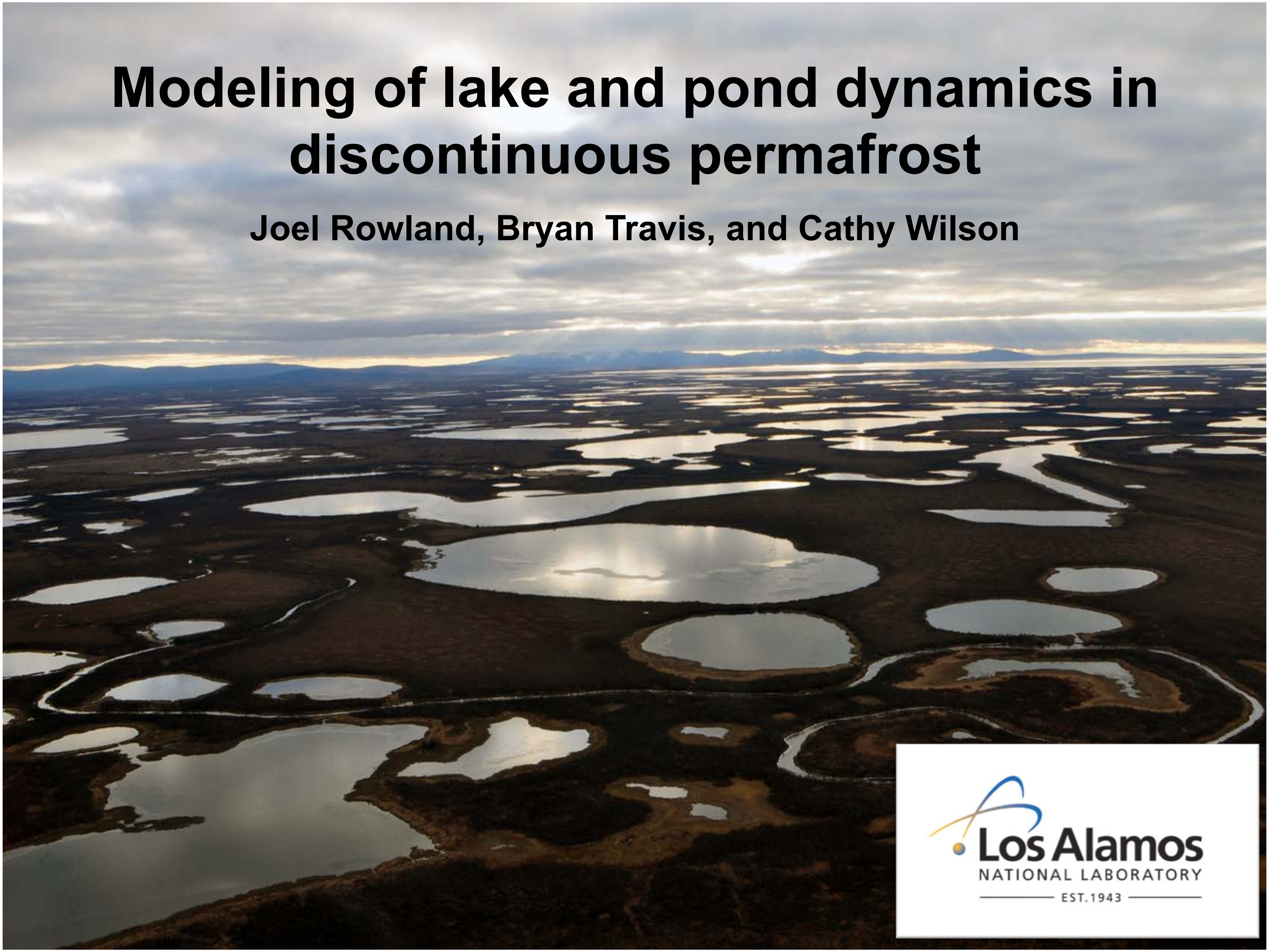
Modeling of lake and pond dynamics in discontinuous permafrost

Joel Rowland, Bryan Travis, and Cathy Wilson



Los Alamos
NATIONAL LABORATORY
EST. 1943

Lakes as indicators of change in Arctic

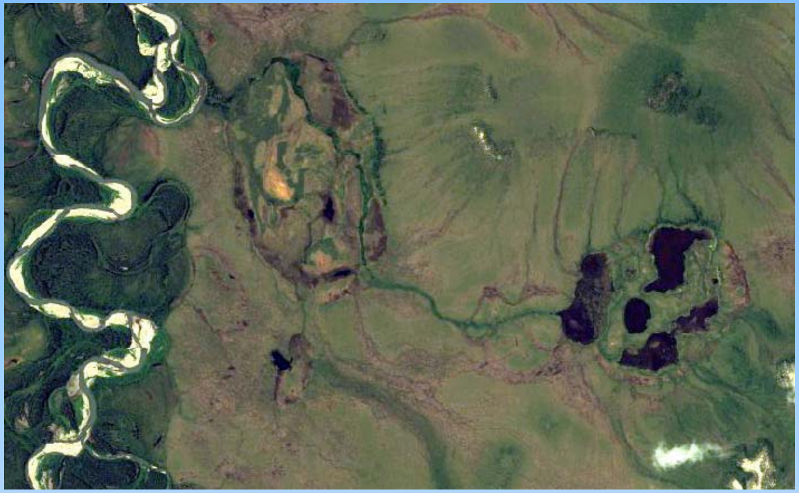
- •Changes in lake sizes and distributions past 50 years
- •Drainage interpreted to be related to permafrost loss
- •Increased surface drainage and potentially subsurface drainage

- •Alter local hydrology and habitat
- •Increase and decreases in greenhouse gas production

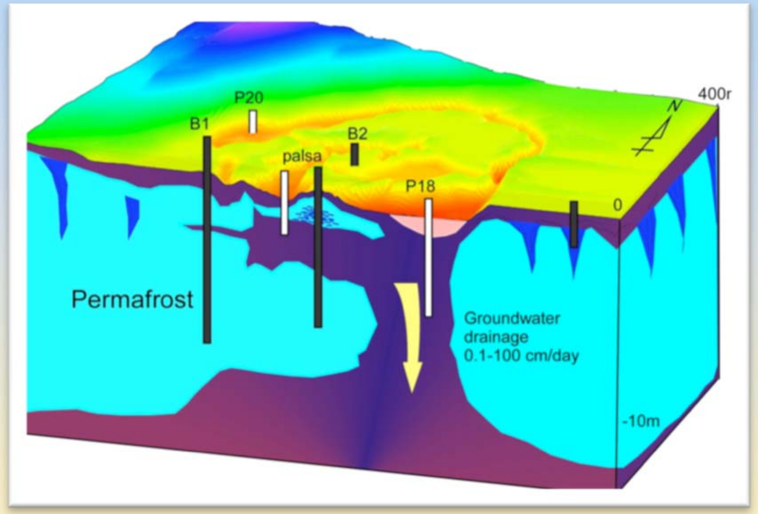
Mechanisms for lake drainage

Breaching

Phil Marsh



Subsurface drainage via Talik

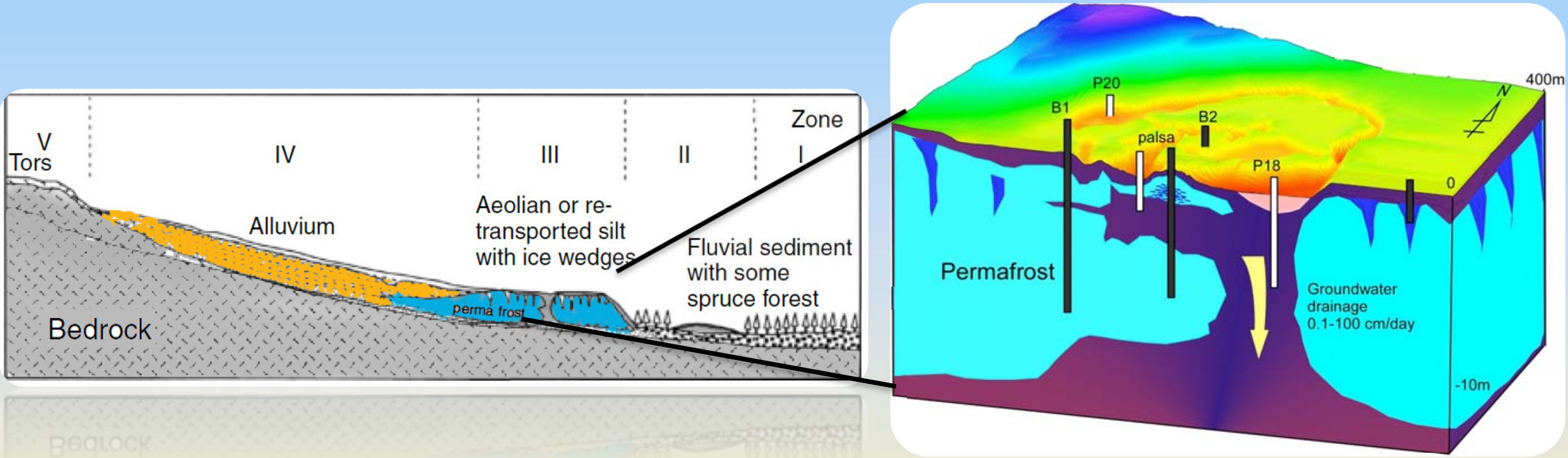


Yoshikawa and Hinzman, 2003

Larry Hinzman

Drained ponds with talik, Council, Alaska on the Seward Peninsula

- Loss of ponds between early 1900s and 2000s
- Warm, thin, discontinuous permafrost
- Geophysics indicate talik beneath drained ponds



Yoshikawa and Hinzman, 2003

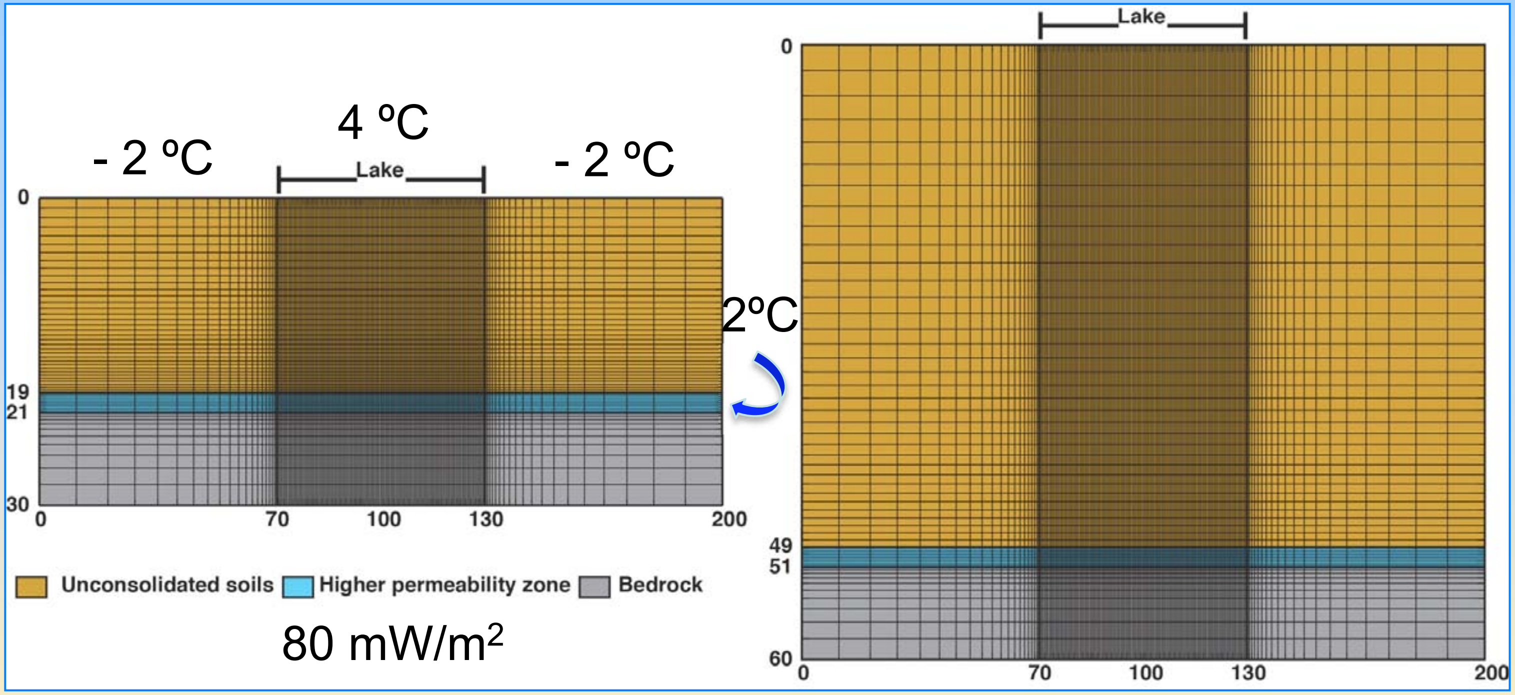
Arctic Hydrology (ARCHY) Model

- Coupled heat and multiphase flow, saturated and unsaturated
- Permeability varies with ice/water fraction
- Thermal conductivity and specific heat volume weighted between soil grains, water, ice and air
- Fluid density and viscosity are functions of temperature

- Goal: to explore the influence to sub-permfrost grounwater flow on permafrost thicknesses and response to disturbance. Quantify the role of advective heat transport on talik development and evolving connectivity between surface and groundwaters.

Model Setup

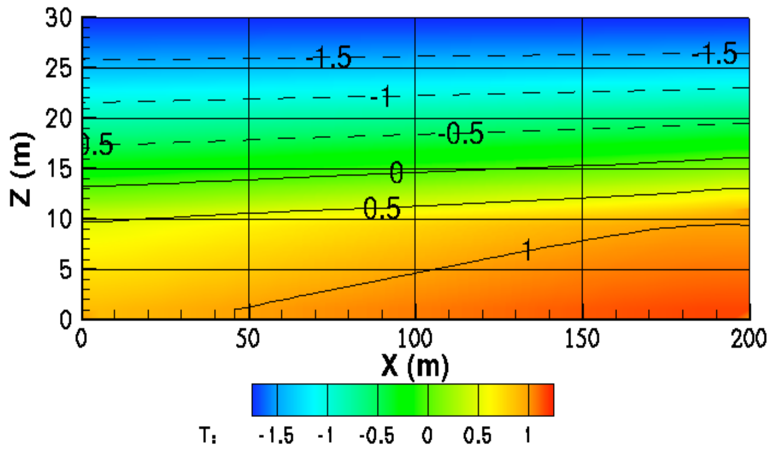
- Two sets of simulations – 1) groundwater in high permeability zone at 20 m and 2) at 50 m
- Constant temperature at upper surface and constant heat flux at base
- Lake represented by constant temperature at upper boundary
- Groundwater at gradient of 0.001 (similar to local topography)



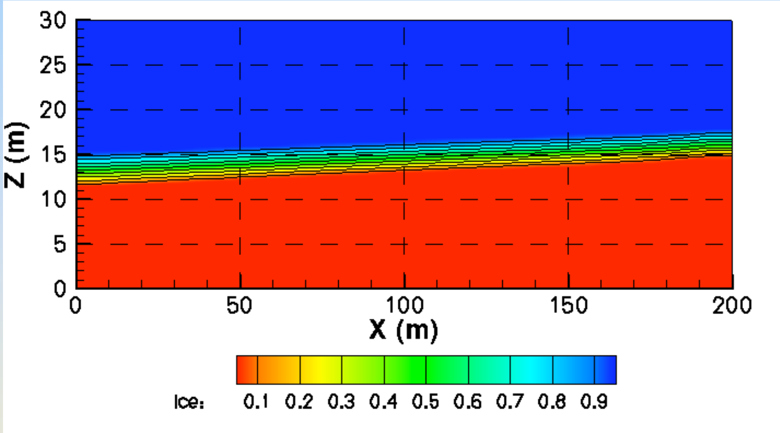
Steady State Runs

- Ran simulations with no lakes to achieve stable permafrost thicknesses – 16 m and 37 m
- Compared thickness to 1D simulation without groundwater – permafrost thickness = 78 m
- Model sensitive to flow rate and thickness of high permeability zone

Temperature



Ice Fraction

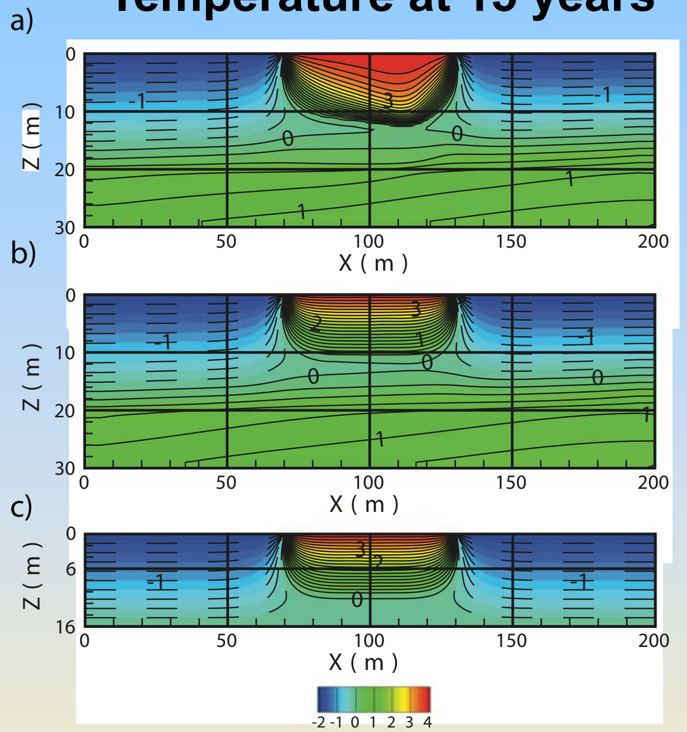


Results

- Three lake scenarios – static head, gravity only, conduction only (no advective heat transport)

- Conduction only – permafrost thickness set to steady state with linear temp profile

Temperature at 15 years

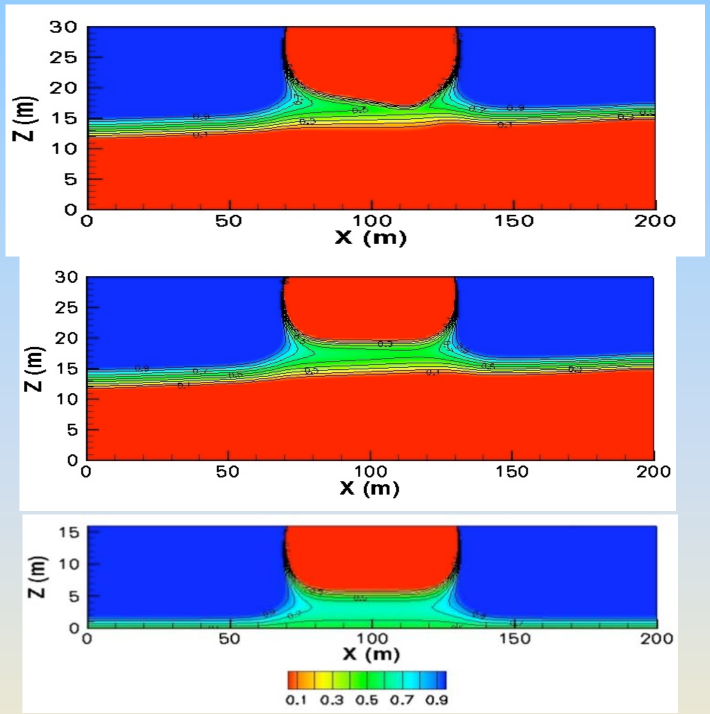


2.5 m static head

Gravity and density only

Conduction only

Ice content at 15 years

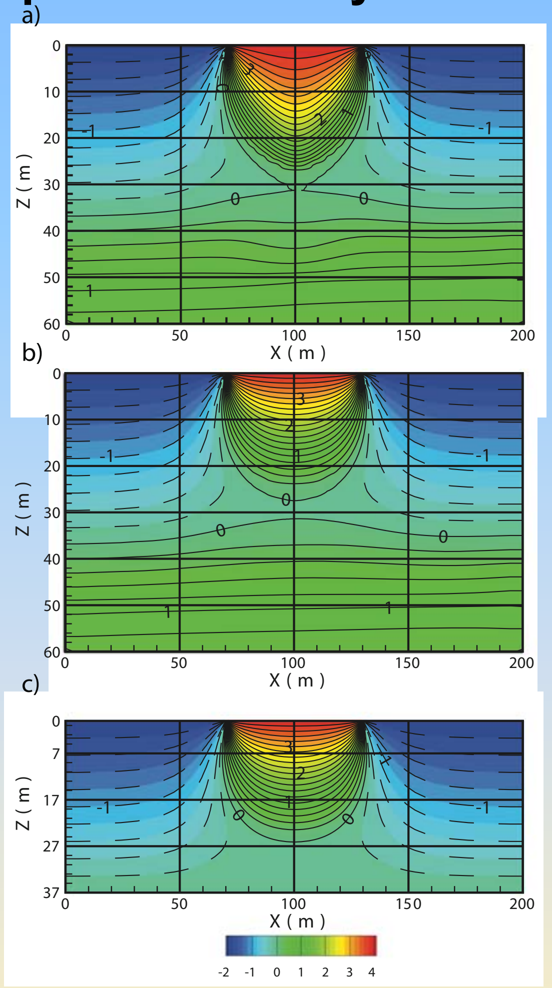


Rowland et al. 2011

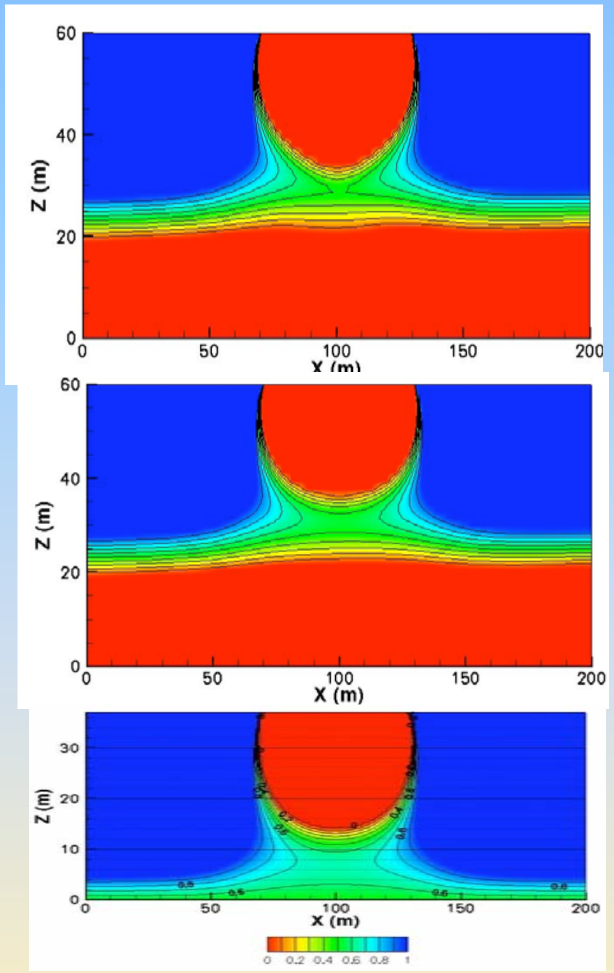
Results

60m thick model domain – 37m permafrost

Temperature at 65 years



Ice content at 65 years



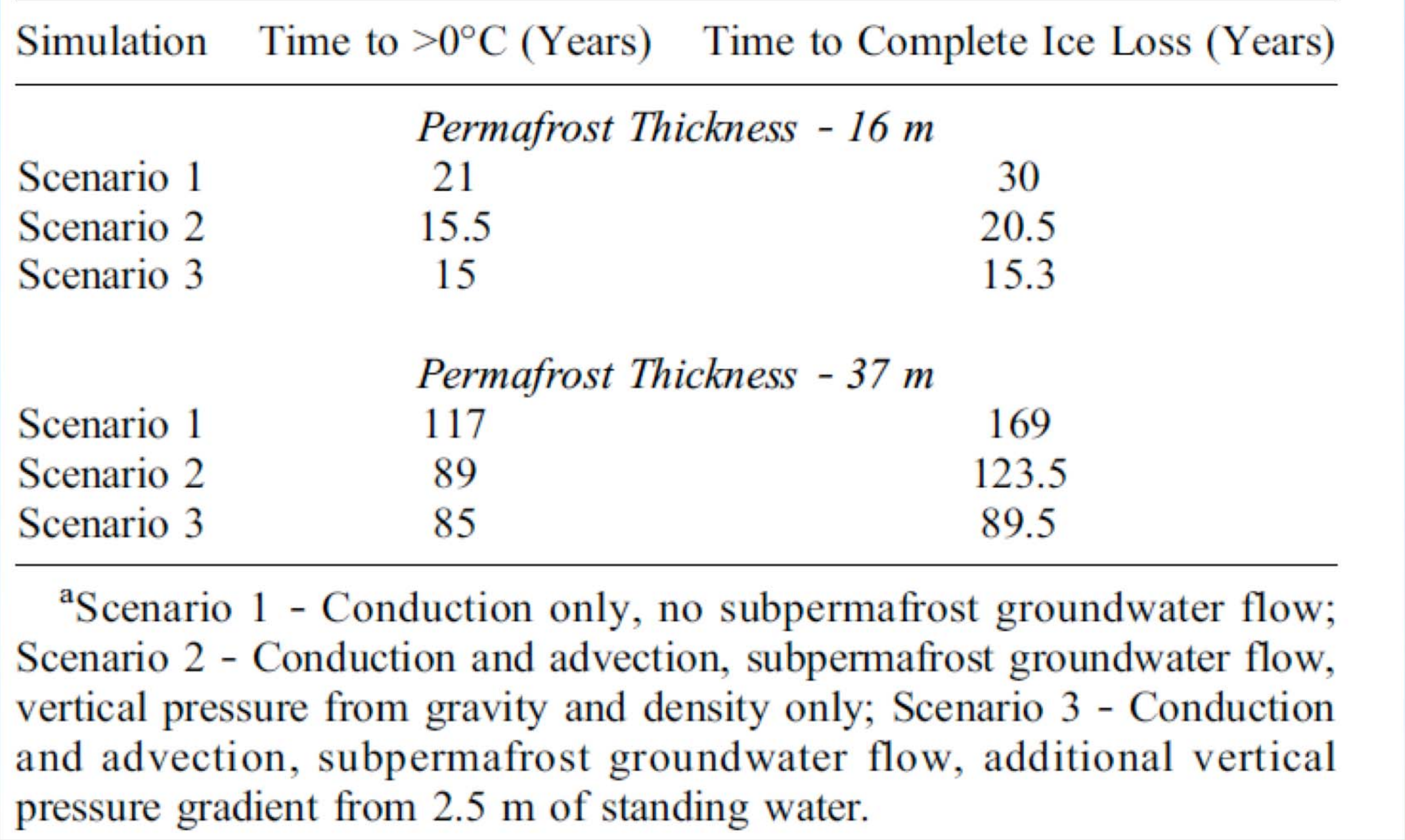
2.5 m static head

Gravity and density only

Conduction only

Rowland et al. 2011

Results



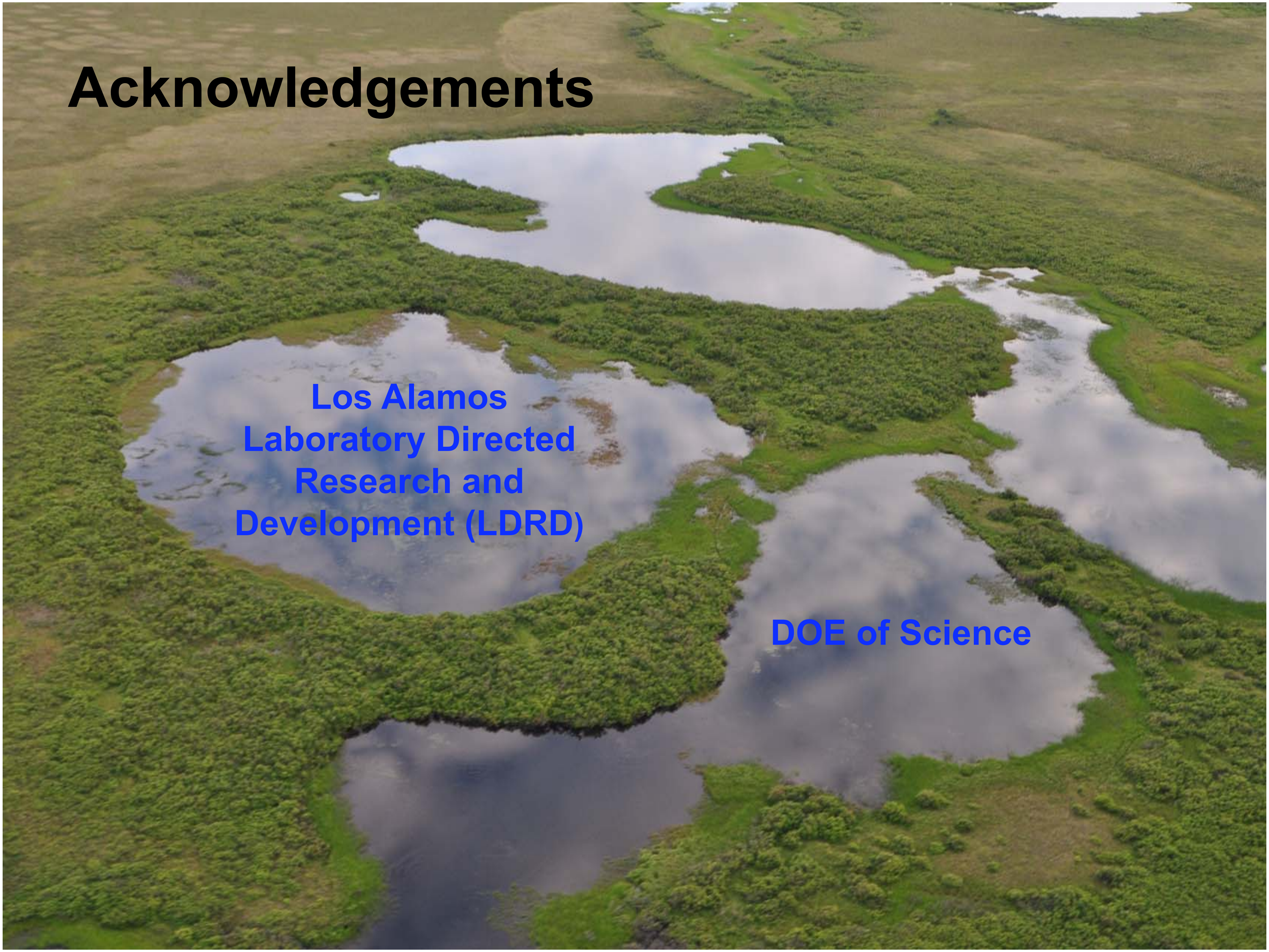
Simulation	Time to >0°C (Years)	Time to Complete Ice Loss (Years)
	Permafrost Thickness - 16 m	
Scenario 1	21	30
Scenario 2	15.5	20.5
Scenario 3	15	15.3
	Permafrost Thickness - 37 m	
Scenario 1	117	169
Scenario 2	89	123.5
Scenario 3	85	89.5

[a] Scenario 1 - Conduction only, no subpermafrost groundwater flow; Scenario 2 - Conduction and advection, subpermafrost groundwater flow, vertical pressure from gravity and density only; Scenario 3 - Conduction and advection, subpermafrost groundwater flow, additional vertical pressure gradient from 2.5 m of standing water.

Summary

- Stable permafrost thickness decreased by 2 to 5 times compared to simulation without this added heat source
- Through going talik developed 40% faster than in simulations with conductive heat transport only
- Complete loss of pore-ice 30-40% faster with advective heat transport

- **Ongoing Work**: Embed lake in domain and allow for lake drainage to explore post- through-going talik dynamics with seasonal thaw cycles.



Acknowledgements

Los Alamos Laboratory Directed Research and Development (LDRD)

DOE of Science