The effect of snow: How to better model ground surface temperatures

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COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Abstract

We present a method that reconstructs daily snow thermal conductivities using air and ground temperature, and snow depth measurements. We employed an inverse approach to recover daily snow thermal conductivities over the entire snow season. By using reconstructed snow conductivities we can improve modeling of ground surface temperatures. The developed method was applied to four permafrost observation stations in Alaska. Estimated snow thermal conductivities for the interior stations in Alaska indicated low conductivity values that reach their maximum towards the end of the snow season, while the northern stations showed high conductivity values that reach their maximum towards the middle of the snow season. The differences in snow conductivities between interior and northern stations are most likely due to wind compaction which is more pronounced in the northern Arctic lowlands of Alaska.

Background

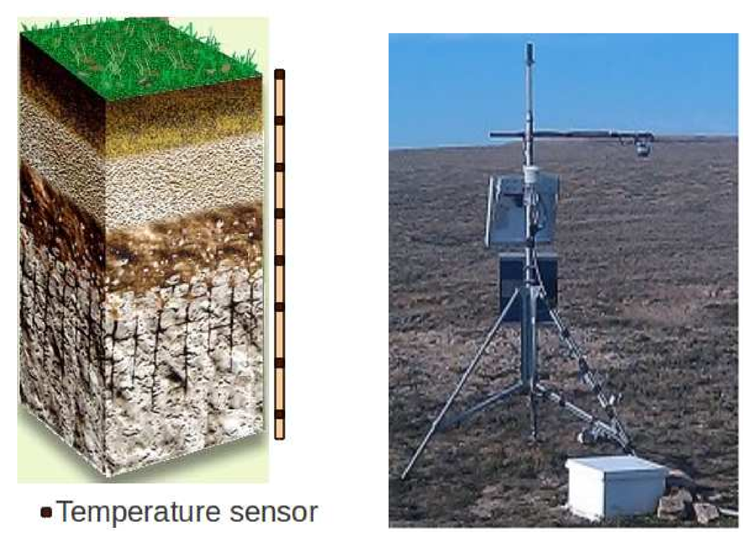

Figure: 1. The picture on the left shows schematic representation of the soil stratigraphy and the ground temperature measuring sensors. The photo on the right side of the Figure represents the permafrost observation station with the snow depth measuring sonic ranging sensor.

Measuring method: The permafrost observation site is instrumented with twelve thermistors arranged vertically at different depths, usually from 0 to 1 m and three soil moisture probes located in seasonal freeze/thaw zone. The temperature sensors are embedded into a plastic pipe inserted into a small diameter hole drilled into the ground (Figure1). The empty space between the sensors and the ground is filled with a slurry of similar material to diminish an impact of the probe to the thermal regime of soil.

Model Setup: We used known soil stratigraphy to set up thermo-physical properties for each soil layer. Measured air temperature and snow depth used at the upper boundary of the soil domain, and measured temperature at 1 m ground depth at the lower boundary.

Model Calibration: We calibrate soil thermal properties by simulating soil temperatures according to measured temperatures at the corresponding depths.

Numerical method

To calculate the heat exchange within the snow layer we solve the 1-D heat equation

$$C_s \frac{\partial T(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(k_s \frac{\partial T(x,t)}{\partial x}\right), \tag{1}$$

where $T(x,t)$ is the temperature; t stands for time, and; x is the spatial variable. k_s and C_s thermal conductivity and heat capacity of snow layer that both depend on snow density (Sturm et al., 1997; Douville et al., 1995). Snow density is not measured in field so we use the data assimilation to recover it, by minimizing the following cost function:

$$J(\rho_s(t)) = \frac{1}{\delta T^2}\frac{1}{t-\tilde{t}}\int_{\tilde{t}}^{t}(T_m(\tau) - T(0,\tau;\rho_s))^2 d\tau + \frac{1}{\delta\rho^2}\frac{1}{t-\tilde{t}}\int_{\tilde{t}}^{t}(\rho_s - \bar{\rho}_s)^2 d\tau. \tag{2}$$

The coefficient δT is an uncertainty in temperature measurements by the sensor at the ground surface and $\delta\rho$ uncertainty in the estimates of density which was determined from fitting the model to the data. $t-\tilde{t}$ is the number of days over which the difference between simulated and measured at the ground surface temperatures have been minimized and $\bar{\rho}_s(t)$ is averaged snow density on time interval $[\tilde{t}, t]$.

Sites and Resutls

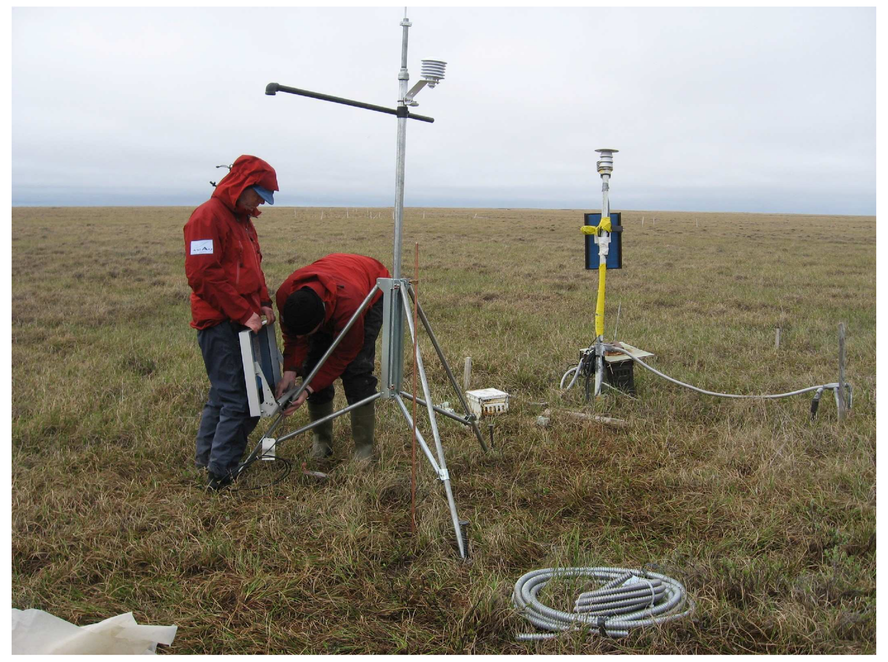

Figure: 2. The DeadHorse site photo lat:70.161283° lon:−148.465300°.

Figure: 3. The Smith Lake site photo lat:64.867517° lon: −147.858833°.

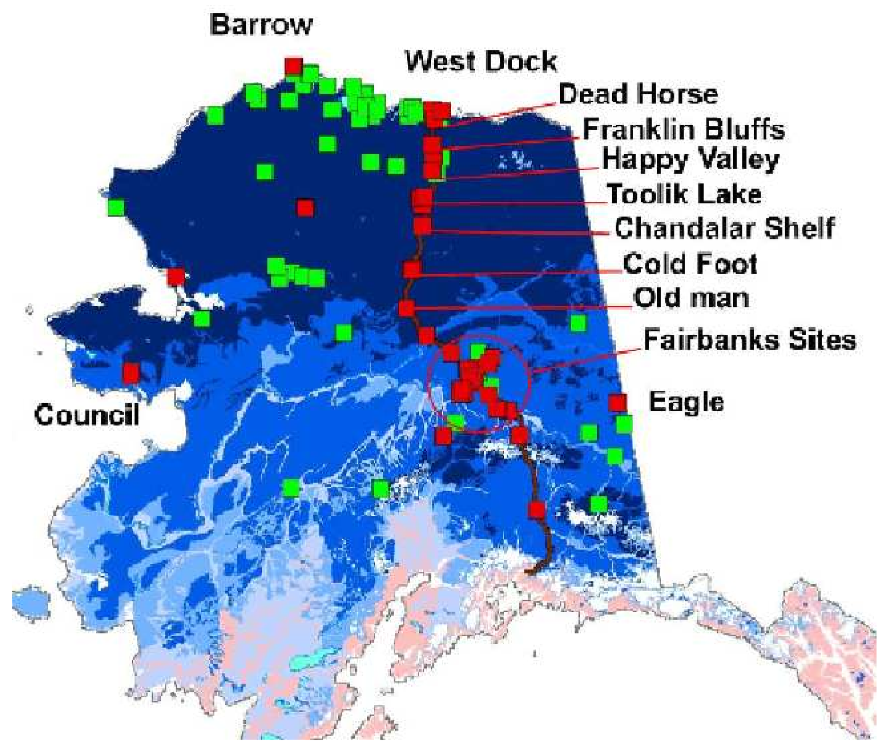

Figure: 4. Map of the permafrost distribution in Alaska and permafrost observation stations.

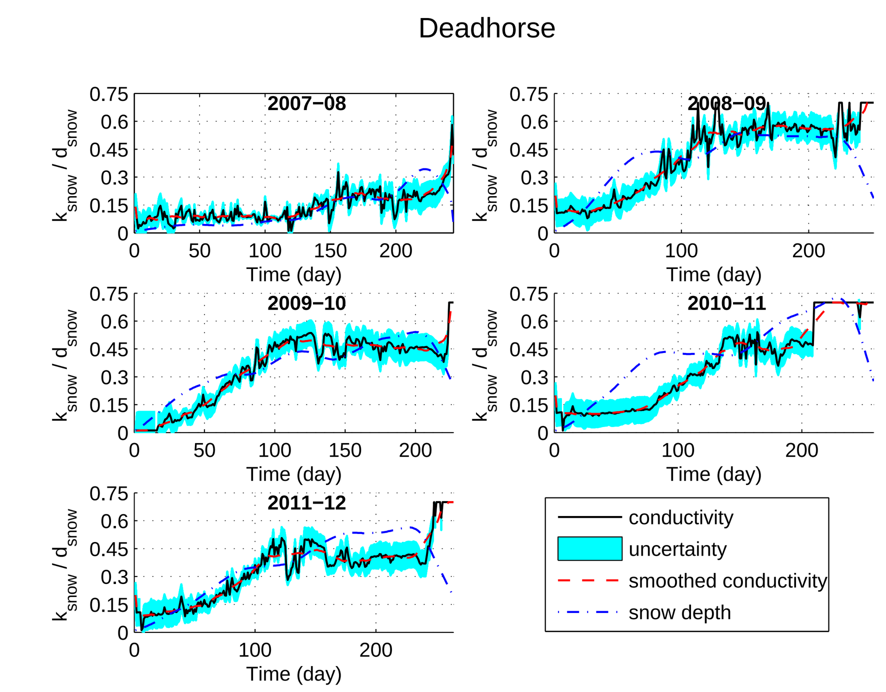

Figure: 5. The estimated snow thermal conductivities $[Wm^{-1}K^{-1}]$ (black solid curve) at the Deadhorse permafrost station and the corresponding uncertainties (solid cyan) for 2007-2012 snow seasons. The dash red curve corresponds to the rounded thermal conductivities and the dot-dash blue curve corresponds to the snow depth $[m]$.

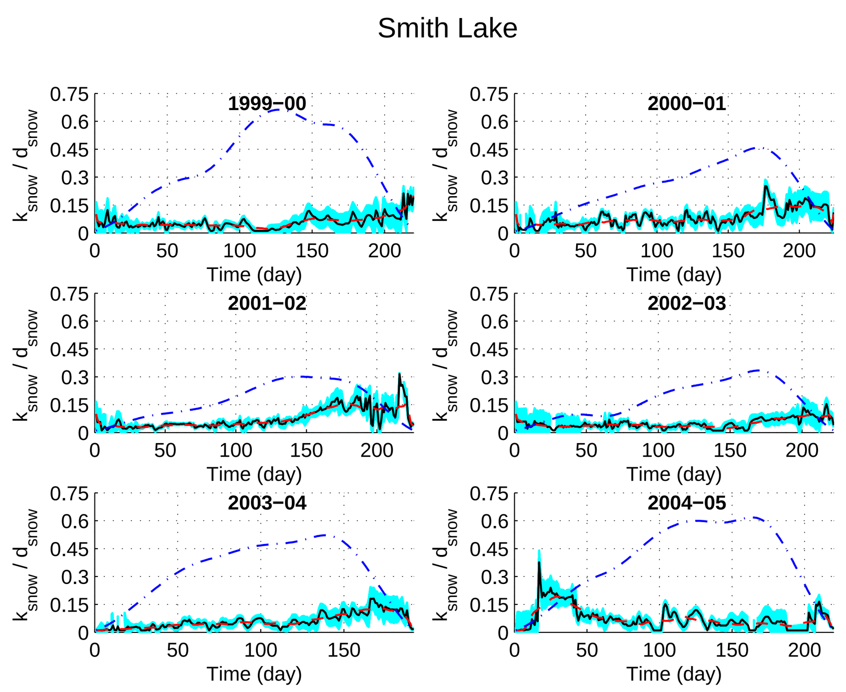

Figure: 6. The estimated snow thermal conductivities $[Wm^{-1}K^{-1}]$ (black solid curve) at the Smith Lake permafrost station and the corresponding uncertainties (solid cyan) for 1999-2005 snow seasons. The dash red curve corresponds to the rounded thermal conductivities and the dot-dash blue curve corresponds to the snow depth $[m]$.

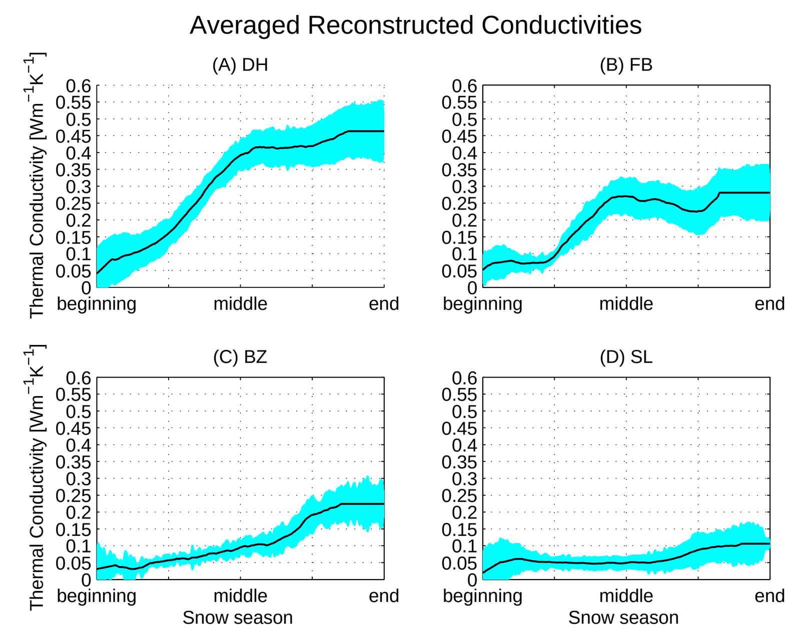

Figure: 7. Averaged snow thermal conductivities (solid black curve) obtained from average of rounded thermal conductivities over each snow season for (A) Deadhorse, (B) Franklin Bluffs, (C) Bonanza Creek and (D) Smith Lake stations, and their corresponding uncertainties (solid cyan).

Conclusion

Estimated snow thermal conductivities (Fig. 7) showed higher values at the northern sites which could be associated with differences in climatic factors and in particular with compaction due to wind effect. The snow cover for the two interior stations did not experience so much wind and, therefore, had lower conductivities (Fig. 7-C,D). Thin ice layer might form at the ground surface floor and could cause high snow conductivities for the Deadhorse station.

References:
1. Sturm, M., Holmgren, J., Konig, M., and Morris, K.: The thermal conductivity of seasonal snow, Journal of Claciology, 43, 1997.
2. Douville, H., Royer, J. F., and Mahfouf, J. F.: A new snow parameterization for the Meteo- France climate model., Climate Dynamics, 12, 21–35, 1995.

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