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ESD EARTH SCIENCES DIVISION

Monitoring Freeze Thaw Transitions in Arctic Soils using Complex Resistivity Method

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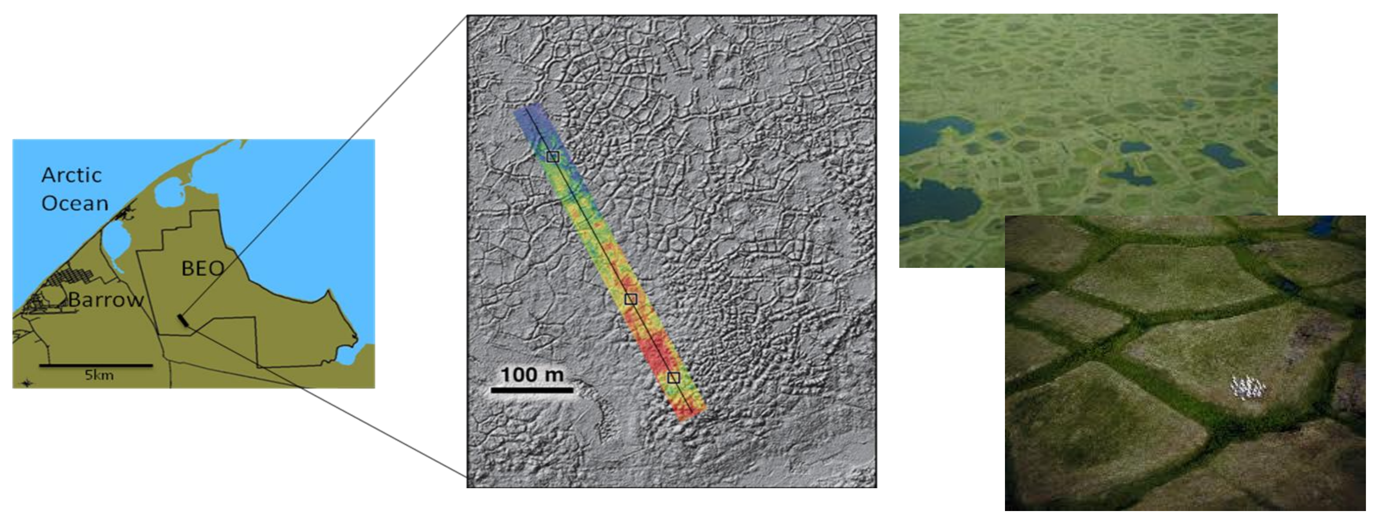
INTRODUCTION

The Arctic region is a sensitive system that has emerged as a focal point for climate change studies. It is characterized by a large amount of stored carbon and a rapidly changing landscape. Seasonal freeze-thaw transitions in the Arctic alter subsurface biogeochemical processes that control greenhouse gas fluxes. Our ability to monitor freeze thaw processes and associated biogeochemical transformations is critical to the development of process rich ecosystem models, which are in turn important for gaining a predictive understanding of Arctic terrestrial system evolution and feedbacks with climate. In this study, we conducted both laboratory and field investigations to explore the use of the complex resistivity method to monitor freeze thaw sates and transitions of arctic soils. The field site is located within the Barrow Environmental Observatory (BEO), Barrow, AK. Permafrost at this site is continuous, ice rich with thin active layer averaging 30-35 cm.



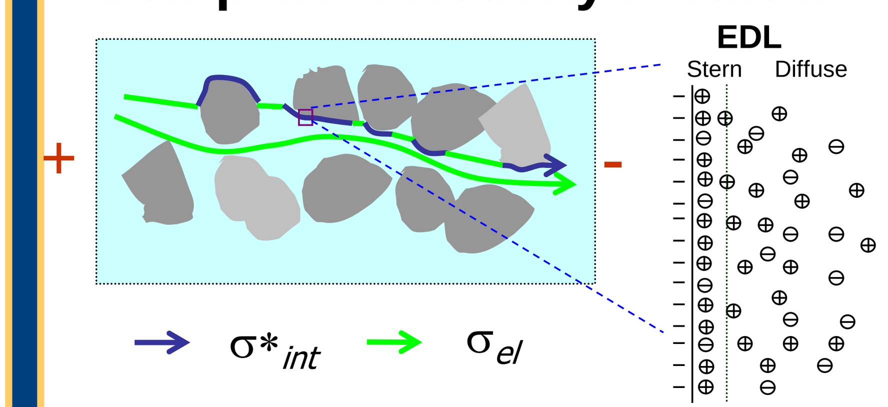
OBJECTIVE

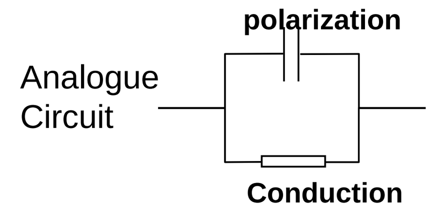
The objective of the study is to evaluate the sensitivity of complex electrical methods to the freeze thaw states and transitions of Arctic soils and its potential for field monitoring. To achieve this objective, both lab and field studies were conducted

- Laboratory column studies were conducted to understand complex electrical signals from freeze – thaw transitions induced under controlled T.
- Field data acquisitions were carried out to evaluate the sensitivity of the electrical methods to the freeze thaw state of the Arctic soils.

MATERIALS & METHODS

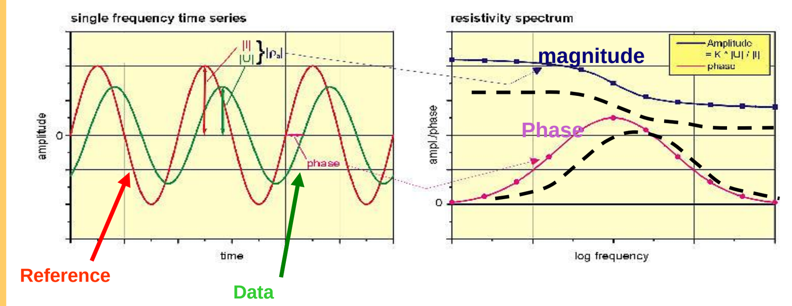
Complex resistivity method





$$\sigma^* = \frac{1}{\rho^*} = i\omega\varepsilon^* = \sigma'(\omega) + i\sigma''(\omega)$$

$$|\sigma^*| = \frac{1}{|\rho^*|} = \sqrt{\sigma'^2 + \sigma''^2} = \frac{1}{\sqrt{\rho'^2 + \rho''^2}}$$

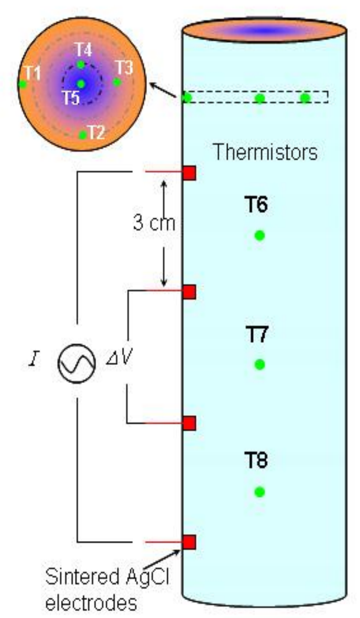


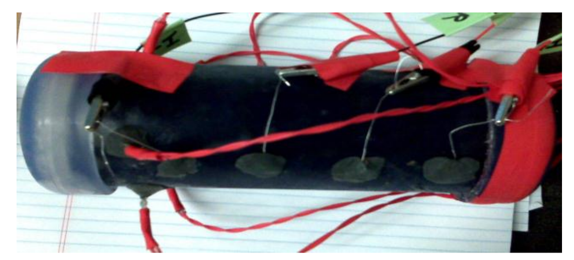
$$\phi = \tan^{-1}\left[\frac{\sigma''}{\sigma'}\right] = -\tan^{-1}\left[\frac{\rho''}{\rho'}\right] \approx \frac{\sigma''}{\sigma'}$$

$$\sigma^*(\omega) = \sigma_0\left[1 + m\left(\frac{(i\omega\tau)^c}{1 + (i\omega\tau)^c(1-m)}\right)\right]$$

Both resistivity and IP responses are expected to be sensitive to freeze thaw transitions

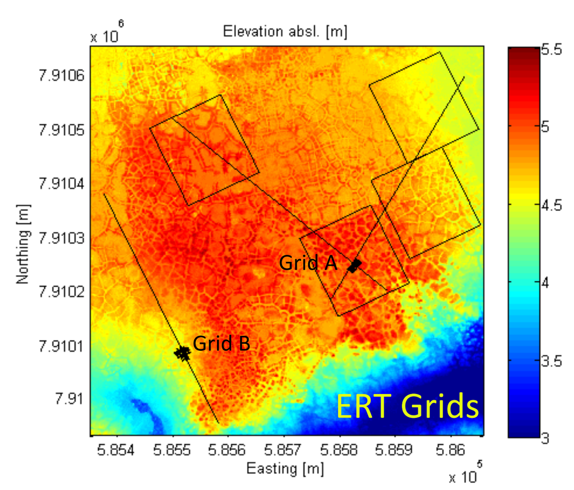
Laboratory column studies

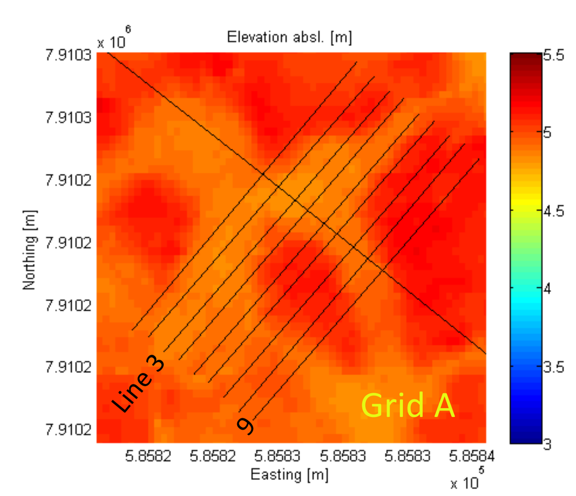




Freeze - thaw was induced by exposing the column to controlled T at 4 °C and -20 °C. Complex resistivity and temperature measurements were collected regularly during the freeze - thaw transitions using electrodes and temperature sensors installed along the column.

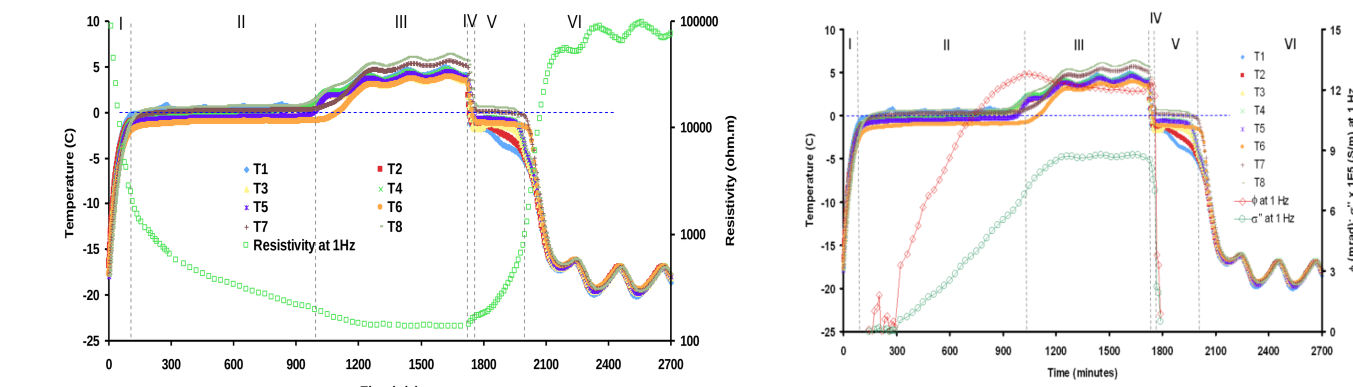
Field data acquisition campaign



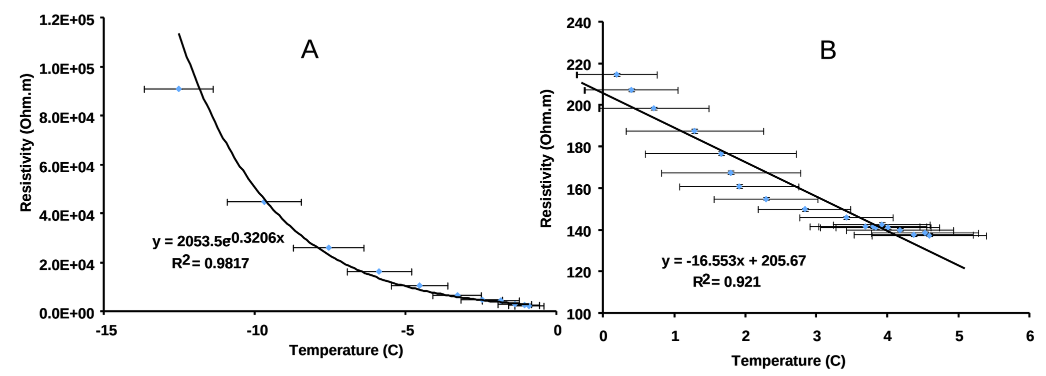


RESULTS

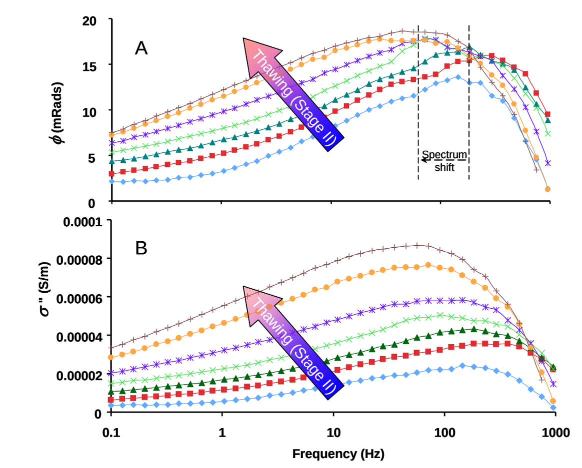
Laboratory results



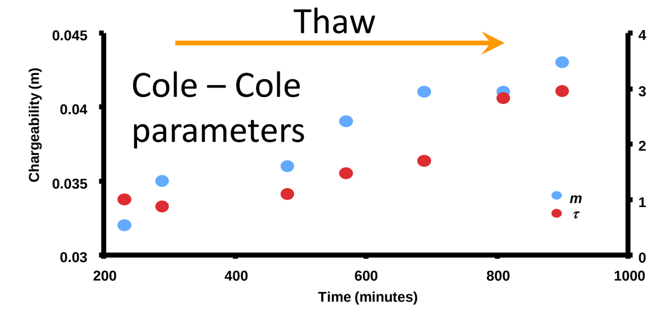
Changes of T, Resistivity and IP response during freeze - thaw transition. The freeze - thaw cycle is divided into six stages: I, initial temperature increase at below 0 °C; II, isothermal thawing; III, temperature increase above 0 °C; IV, temperature decrease at above 0 °C; V, isothermal freezing and VI, temperature decease at below 0 °C.



Correlation between resistivity and T at (A) below 0 °C, (B) above 0 °C.

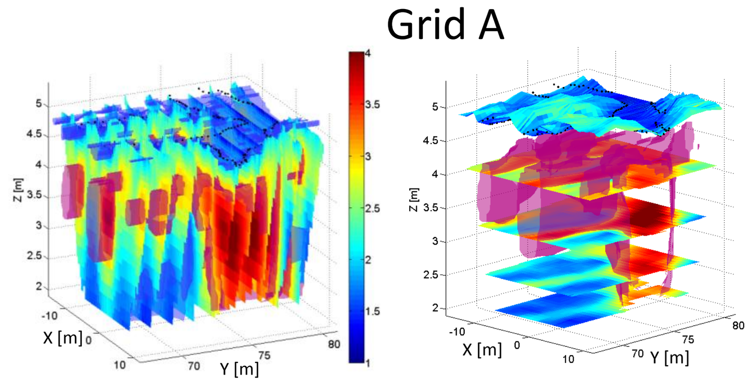


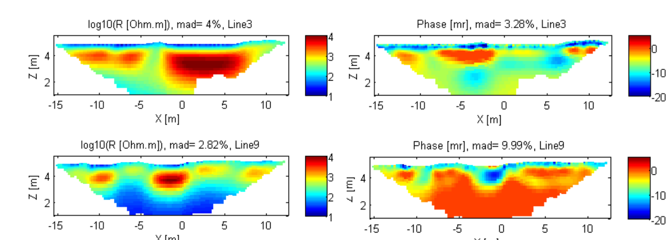
Spectral electrical response during thawing process in stage II of the experiment. (A): Phase (ϕ); (B) Imaginary conductivity (σ'')



Field results

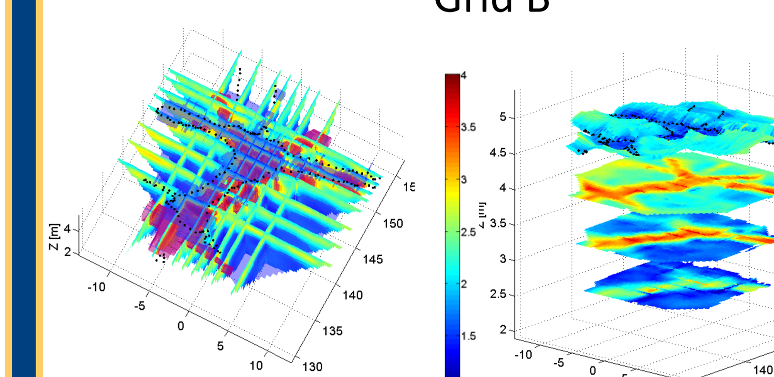
Grid A



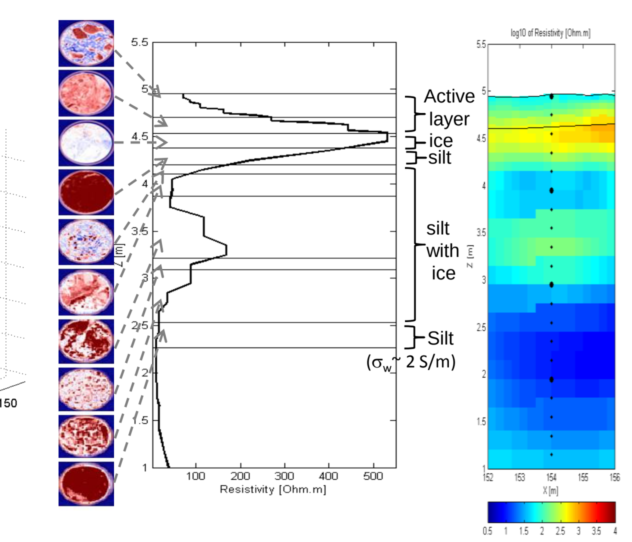


Resistivity and phase shift along Line 3 and 9

Grid B



Field ERT data showing ice wedge features (red) located mainly below troughs



CT scans comparing with resistivity at the same borehole location

SUMMARY AND CONCLUSIONS

- Over two orders of magnitude of resistivity variations were observed when the temperature was increased or decreased between -20 °C and 0 °C.
- Smaller resistivity variations were also observed during the isothermal thawing or freezing processes that occurred near 0 °C.
- Phase and imaginary conductivity were found to be exclusively related to the unfrozen water in the soil matrix, suggesting that these geophysical attributes can be used as a proxy for the monitoring of the onset and progression of the freeze - thaw transitions.
- A shift of the observed spectral response to lower frequency was observed during isothermal thawing process, which we interpret to be due to sequential thawing, first from fine then to coarse particles within the soil matrix.
- At field scale, resistivity data show large contrast between frozen and unfrozen features which is very useful to delineate boundary between active layer and permafrost as well as the presence of ice wedges or high saline features. Phase values are more noisy due to high contact resistance but show higher values for the active layer and lower values for deep saline features, consistent with theory.
- Our studies demonstrate the sensitivity of complex resistivity signals to freeze - thaw transitions of arctic soils and provide the foundation for exploring the potential of the complex resistivity signals for monitoring spatiotemporal variations of freeze - thaw transitions over field-relevant scales.

REFERENCES

Wu, Y., S.S. Hubbard, C. Ulrich and S. D. Wullschledger, Remote Monitoring of Freeze-Thaw Transitions in Arctic Soils Using the Complex Resistivity Method, **Vadose Zone Journal**, In press, doi:10.2136/vzj2012.0062

Hubbard, S.S., C. Gangodagamage, B. Dafflon, H. Wainwright, J. Peterson, A. Gusmeroli, C. Ulrich, Y. Wu, C. Wilson, J. Rowland, C. Tweedie and S.D. Wullschleger, Quantifying and relating land-surface and subsurface variability in permafrost environments using lidar and surface geophysical datasets, **Hydrogeology Journal**, In press.

ACKNOWLEDGMENTS

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