

Digital tools for a cold world:

Quantifying cold region response using X-ray and Thermal tomography imaging systems

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Introduction and Purpose

Scientific research is notorious for pigeonhole studies wherein the findings of one research group are rarely linked with other (e.g. landscape or micro-) scale studies. By integrating data sources and pursuing a unified understanding of cold regions, from the micro to the landscape scale, the response to direct perturbation and climate trends can be quantified and reported to industrial and government partners.

The purpose of this presentation is to highlight potential avenues of research by providing examples of advanced research techniques applied to cold region features.

Objectives

Advent of low-cost data storage, coupled with advanced imaging methods (three of which will be approached in this review) allows researchers to acquire data of multiple resolutions and varied sources.

The primary objective of this review is to present the various applications of low-cost digital imaging systems currently undertaken by academic and industrial researchers. Secondary objectives are the presentation of the unified-region data concept and potential applications of emerging digital quantification techniques.

X-ray Computed Tomography

How has X-ray CT been applied in cold regions?

Application of X-ray CT is primarily conducted on intact soil columns, either artificial or sampled from cold regions, for the purpose of quantification of constituent form and structure. To date, X-ray CT has been applied to Ice-lensed soils (Fig. 1), high-arctic soils, highly structured soils (Fig. 2), and organic peat (Fig. 3) materials

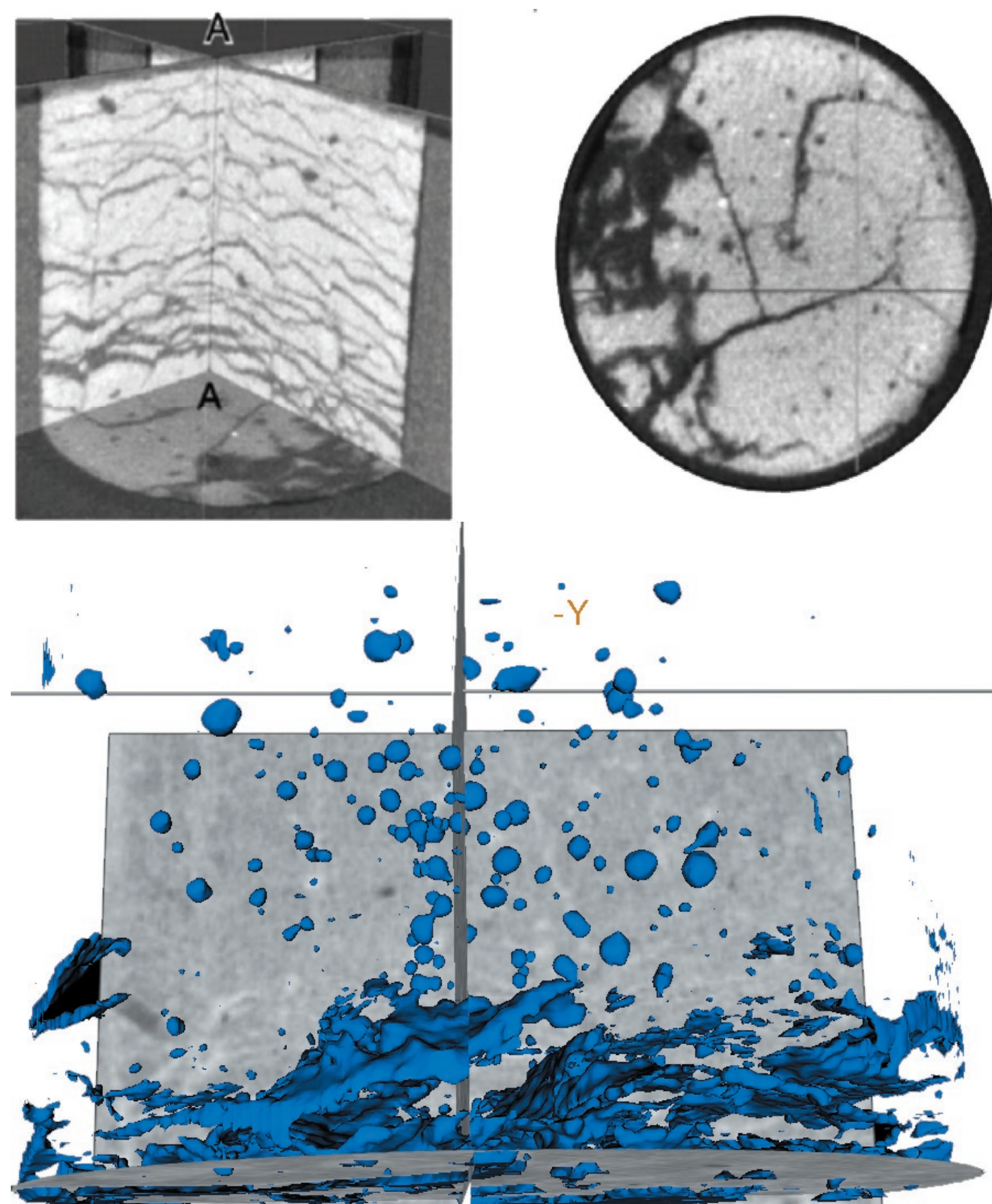


Figure 1. A. Ice lenses formed in a 65 mm soil core from Torrance, J.K., Elliot, T., R. Martin, R. and Heck, R.J. 2007. X-ray Computed Tomography of Frozen Soil. Cold Regions Science and Technology. B. 3D representation of ice lens connectivity and dispersed members

Current research

Current applications include:

1. contaminant impact on pedogenesis, (Torrance et al. 2007)
2. quantification of green-house gas (ghg) emissions due to alteration of soil structure and ambient temperature (Young et al. in preparation),
3. hydraulic transport (Quinton et al. in review), and
4. disruption of cryosolic pedogenic processes (Fourie et al. 2007)

What is it?

1. Imaging of intact samples at resolutions approaching 5 μm .
2. Imagery based on atomic density of sample material.
3. 3D 16-bit data volume for quantification and visualization of actual internal structure.

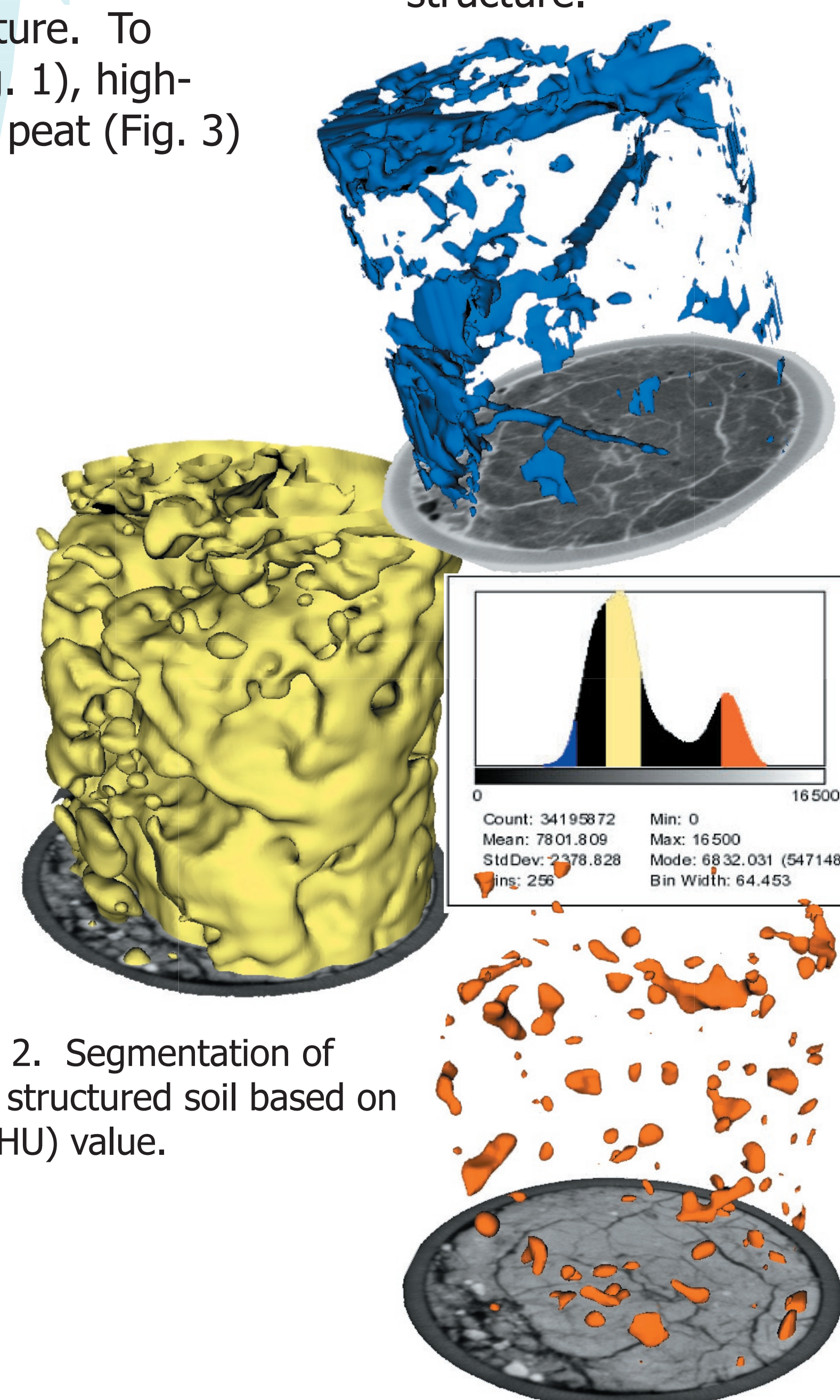


Figure 2. Segmentation of highly structured soil based on grey (HU) value.

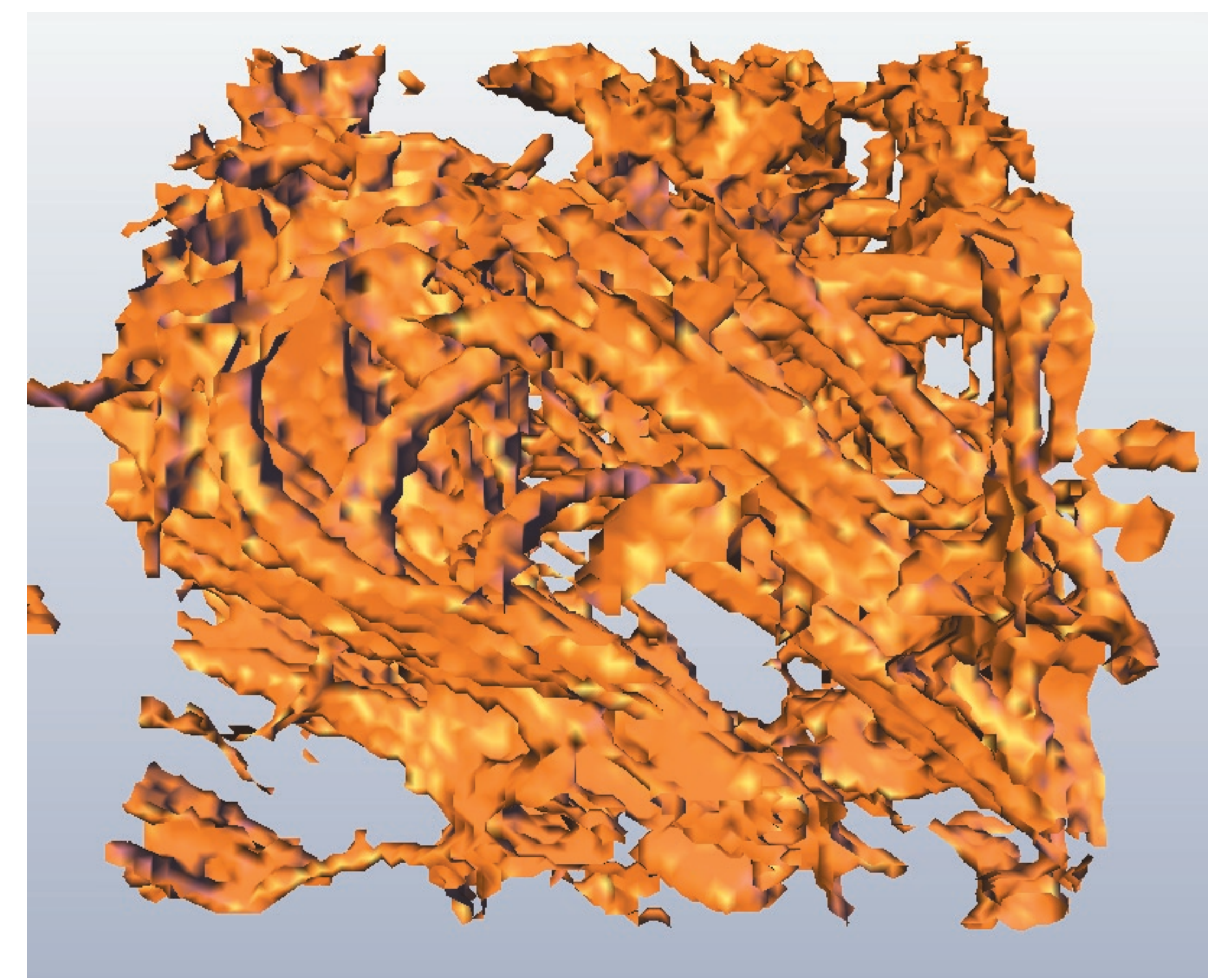


Figure 3. A 7.5 x 7.5 x 4.5 mm ROI Surface representation of peat organic matter under hydraulic tension. Note the fibrous structure, and comparatively massive void region between strands.

The advantage of X-ray CT in cold region science is...

...that application of X-ray CT to cold region geomaterials allows researchers to quantify soil structure that typically does not preserve well under traditional thin section methods.

...the data is available relatively immediately in digital format for numerical modeling.

...the samples are intact, ready for further macroscopic testing.

...micrometer resolution allows for in-depth analysis, that was previously unavailable, that will further understand of macro-scale concepts.

Thermal Tomography

What is it?

The thermal response (emission) of soil, following an incidental energy pulse (Fig. 4), is indicative of moisture content, compaction (air fraction), material composition and type, as well as ambient thermal gradient (Ochsner et al. 2001).

First used as a quality control mechanism for industry, thermal tomography provides insight, on the landscape scale, into soil composition to depths of 0.5-2 m in compacted soil and up to 10-15 m in loose sand.

How is it currently being applied?

Current applications of thermal tomography are in the exploration of Mars. Thermal imaging of the martian surface provides characteristic response curves based on subsurface composition.

If a set of thermal emissivity images are integrated over time, a 3D tomographic volume of spatio-temporal thermal data would indicate depth, extent and potentially contour information of subsurface objects. (Figure 5)

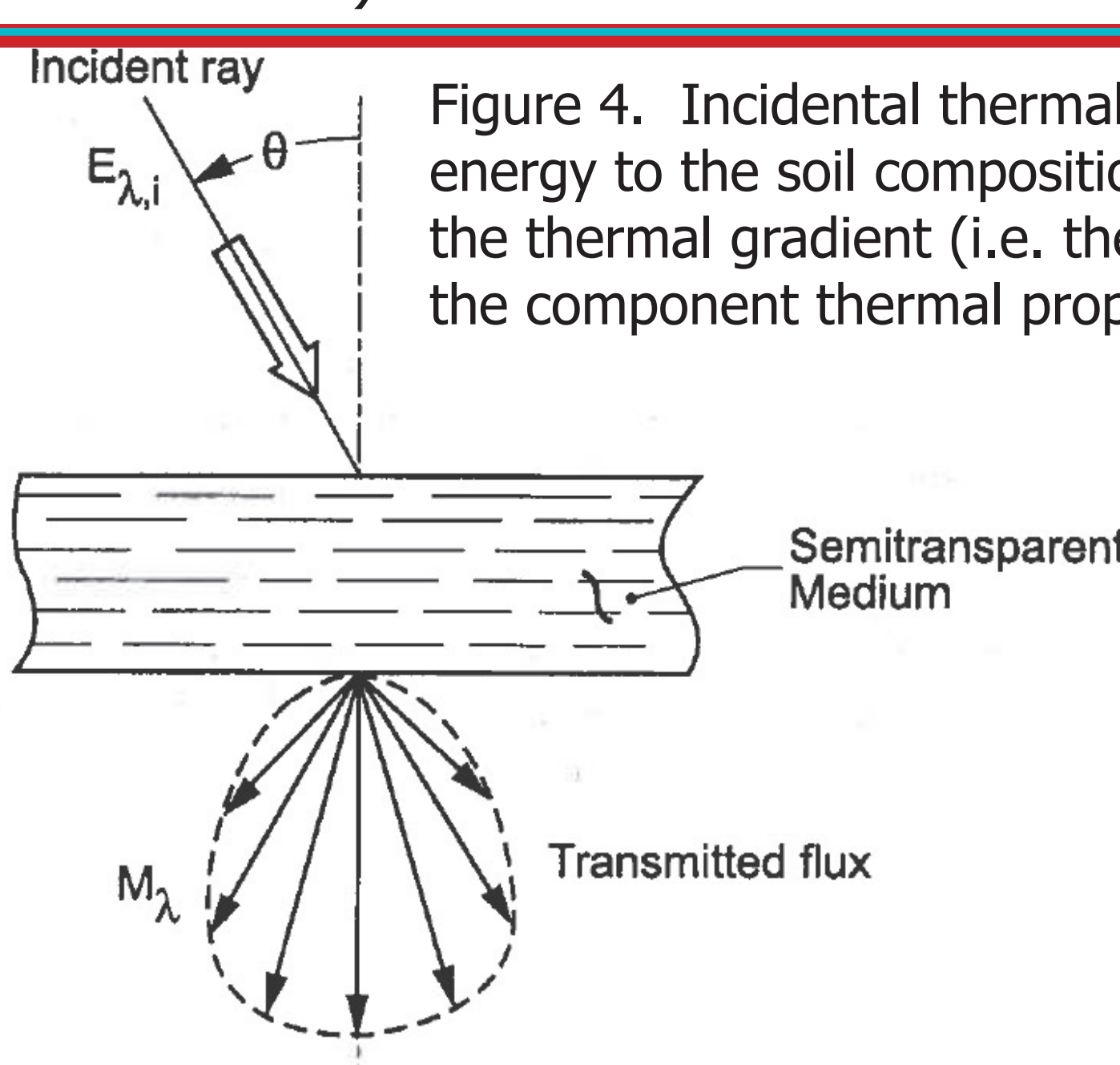


Figure 4. Incidental thermal pulse penetrates a surface, transmitting energy to the soil composition. The energy is resident until a reversal of the thermal gradient (i.e. the sun goes down) and is released according to the component thermal properties. (Maldague, 2003)

The advantage of Thermal Tomography in cold region science is...

...that application of Thermal Tomography to cold region landscapes can be done by routine fly-overs or satellite based imaging.

...the computational power is minimal with no specialized equipment needed other than a calibrated thermal imager.

...the data can be integrated with micro-scale X-ray CT data.

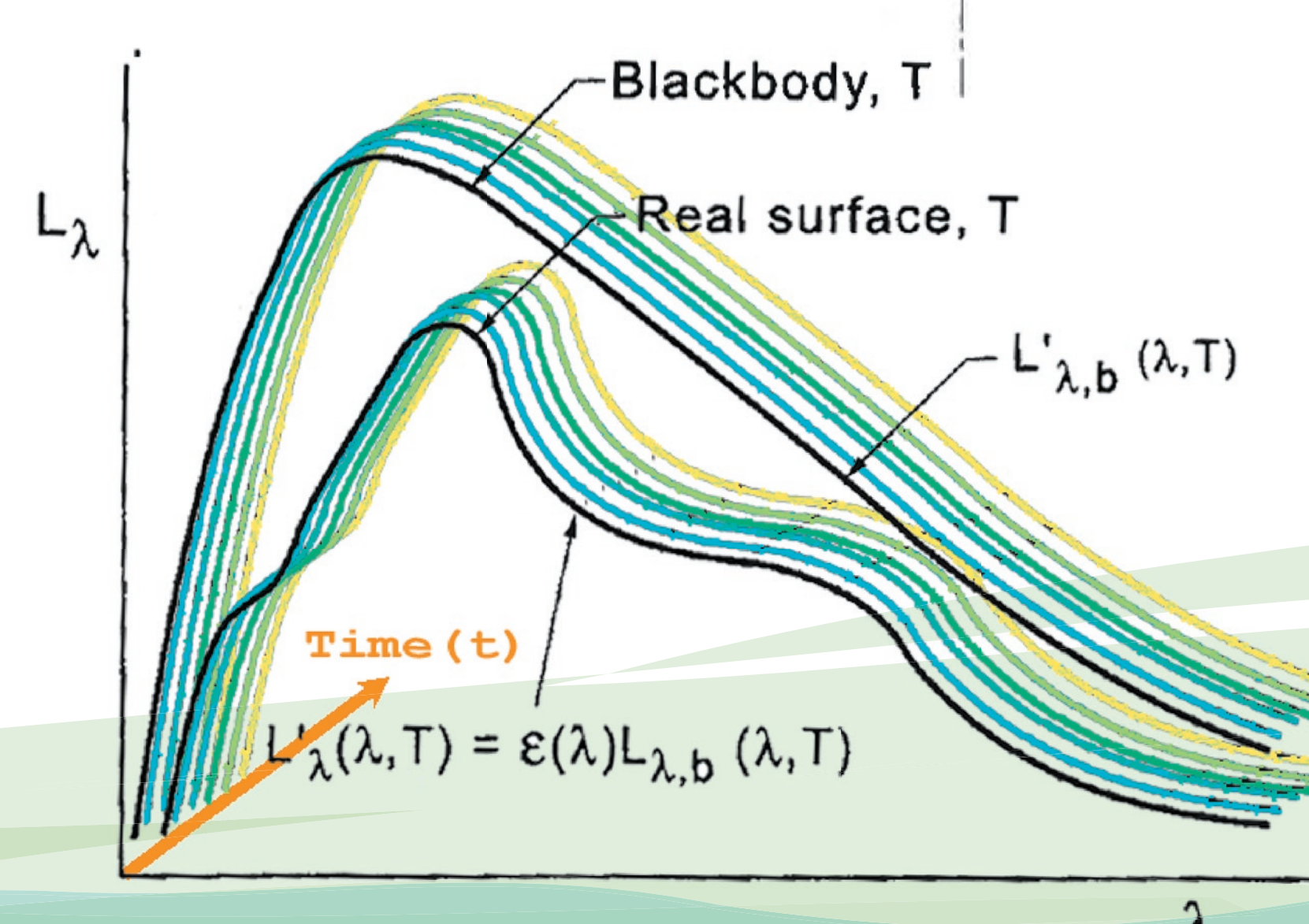


Figure 5. Spatio-temporal thermal emissivity graph. By stacking actual thermal imagery in the same manner, the sub-soil composition will become apparent if the emission curve of the soil can be normalized against a blackbody model.

The unified-region data concept...

Spatial scale in analysis has been historically approached as an exercise in statistics. The advent of large scale personal data storage, ease of data acquisition, and relevant scales of observation allow researchers to gather a full spectrum of data on a specific region.

Much like the nesting hierarchy of the FAO, a unified-region data concept would be utilized at the scale most relevant to the research question, while retaining the potential for future exploration of the formative factors (micro-) or associative factors (landscape) of the region.

References
Fourie, W.J., Barnes, D.L., Shur, Y. The formation of ice from the infiltration of water into frozen coarse grained soil. Cold regions science and technology. v.48 p.118-128 2007.

Torrance, J.K., Elliot, T., Martin, R., Heck, R.J. X-ray computed tomography of frozen soil. Cold regions science and technology. v.xx 2007.

Maldague, X.P.V. Theory and Practice of Infrared Technology for Nondestructive Testing. John Wiley & Sons, Inc. New York. 2003.

Ochsner, T.E., Horton, R., Ren, T. A New Perspective on Soil Thermal Properties. Soil Science Society of America. v.65 p 1641-1647 2001.