Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Remote Sensing and Ground Temperature Monitoring for Geothermal Resource Exploration in Northern Canada: A Case Study from the Burwash Landing Area of Yukon, Canada

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Keywords: remote sensing, Burwash Landing area, ground temperature monitoring, geothermal anomaly

INTRODUCTION

Burwash Landing is a small community in southwest Yukon with a population of 122 in 2025 (Government of Yukon, 2025). Previous studies have explored the geothermal potential of the area through geological synthesis (Witter, 2020), geophysical surveys (Tschirhart et al., 2022), and shallow well drilling aimed at evaluating the near-surface geothermal gradient. Geologically, Burwash Landing lies within a "mini pull-apart basin" associated with the eastern strand of the Denali Fault, an active, crustal-scale dextral strike-slip system in western North America (Fig.1).

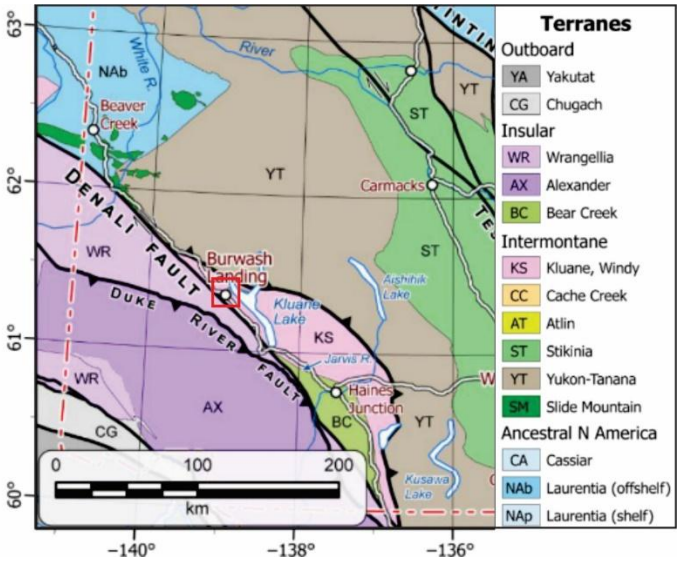


Figure 1. A geological map showing regional geological setting and location of the study area in Burwash Landing, north of Kluane Lake in southwestern Yukon (Map from Chen et al., 2024).

Based on regional geological information and available geoscience models, a conceptual geothermal play model has been proposed. The system is hypothesized to be a blind, amagmatic, fault-controlled convective hydrothermal play, similar to geothermal systems in the Great Basin Province of the western United States. In such settings, crustal extension and thinning elevate the geothermal gradient, while local extensional stresses enhance fracture development and rock permeability, providing pathways for geothermal fluids to rise to depths suitable for resource extraction (Tschirhart et al., 2022).

This study evaluates the proposed geothermal play model by identifying geothermal heat-flow-related anomalies using land surface temperature (LST) derived from Landsat-8 imagery, integrated with ground surface temperature (GST) monitoring data. The goal is to improve our understanding of surface geothermal signatures and their implications for geothermal exploration within the established geological and geophysical framework.

1 MATERIAL AND METHODS

1.1 Data

The (GST) data were collected using temperature data loggers (HOBO Water Temp Pro v2) that were deployed in July 2022 field season and data were collected in August 2023. A total of 64 stations were set in the study area

that recorded GST over one year with a programed temperature record for every 30 minutes. Two temperature loggers were deployed at each station, one at near ground surface with burial depth of 10 – 20 cm, and a deeper logger in depth range from 40 to 70 cm depending on soil condition at the station. For details of data collection and surface and topographic conditions, and quantitative measure for the impacts of vegetation on GST records, readers are referred to Chen et al. (2023). Two temperature loggers were set about 1.5 m above the ground and under shade condition to record the air temperature as a reference.

Fifty-two Landsat 8 (Level 1 and Terrain Precision Correction) image sets acquired over different seasons from February 2014 to January 2025 were downloaded from the USGS Earth Resources Observation and Science (EROS) Center (https://earthexplorer.usgs.gov/) for feature extraction. These image sets (8041x7941) were cropped to an 1301x1001 pixels rectangle centered on the Burwash Landing area for this study. Only 8 LST images were selected for GHF extraction after quality screening.

1.2 Methods

This study uses the land surface temperature (LST) derived from multispectral images from Landsat-8 and ground surface temperature (GST) from temperature prob that are deployed in soil at shallow depth. The variation in LST and GST are driven by two critical components, a time variant surface forcing of solar radiation (daily and annual cycles) with varying climate condition, from which the heat diffuses downward and is attenuated and phase shifted with depth; and b) a upward geothermal heat flow (GHF) from the Earth's interior that varies spatially with geological condition. We assume that the observed temperature, $\boldsymbol{T_{obs}}$, either LST or GST can be quantified by the following expression:

$$T_{obs} = T_{Solar} + T_{Earth} + T_{Lat} \quad (1)$$

where T_{Earth} is the temperature component from geothermal heat flux, and T_{Solar} is the temperature contribution from solar radiation, and T_{Lat} is the temperature component related to latent heat due to phase change.

Chen et al. (2025) developed an innovative method that employs time series of LST maps from different seasons to identify geothermal temperature anomalies, while Liu et al (2022) used heat flow inversion to estimate the geothermal heat component from the GST monitoring data. This study uses both methods to separate the solar component from observed temperatures to identify the geothermal anomalies from Landsat mages and analyze the monitoring GST records. For details of the method, the reader is referred to Chen et al. (2025) and Liu et al., (2022).

2 RESULTS

2.1 Geological Interpretation

Lineaments were extracted from multiple Landsat images using both automated and manual methods (Chen et al., 2024), creating a dataset for geological interpretation. These lineaments highlight surface features such as topographic breaks, drainage patterns, vegetation boundaries, and other geomorphic indicators. The identified features were grouped into spatial patterns and integrated with additional geoscience datasets and models, including geological and geophysical frameworks, to better understand regional structures that may influence the formation of natural resources.

A key component of the conceptual geothermal play model is a permeable fault network that provides pathways for geothermal fluids to migrate toward shallow depths. The main surface trace of the Denali Fault system is typically identified through field mapping or regional geophysical surveys; however, lineament interpretation from remote sensing can reveal subtle surface expressions that geophysical data alone may not capture.

Figure 2 illustrates manually interpreted lineaments along a river valley between mountain ranges, with Kluane Lake located at the southern end. Notably, a series of northeast-striking lineaments appears aligned in a north–south direction. Kluane Lake lies within the Shakwak Trench, a major tectonic feature directly associated with the Denali Fault system. The lake appears segmented, with the southern block of each segment displaced southeast, suggesting recent strike-slip movement.

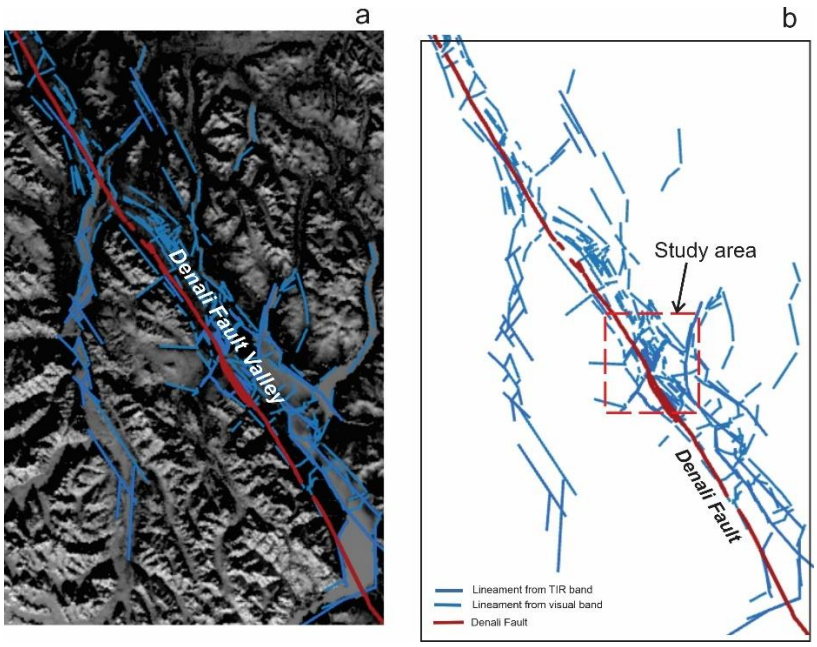


Figure 2. a) Landsat image (band 8, 2014-02-24) overlaying with hand-picked lineaments along Denali Fault valley in southwest Yukon; b) Lineaments from Landsat images showing the major trends of alignments of edges, river courses or sharp physical boundaries.

2.2 LST mapping

The geothermal temperature anomalies extracted from LST (Fig. 3) illustrate the spatial expression of the LST-derived component of geothermal heat flux (GHF), highlighting potential discharge zones of warm, deep-sourced fluids. Two major linear geothermal trends are evident. The first (a1), characterized by higher temperatures, appears aligned with the Duke River, striking NNE to NW. The second (a2), showing more moderate anomalies, occurs along or parallel to the Denali Fault zone (Fig. 3a).

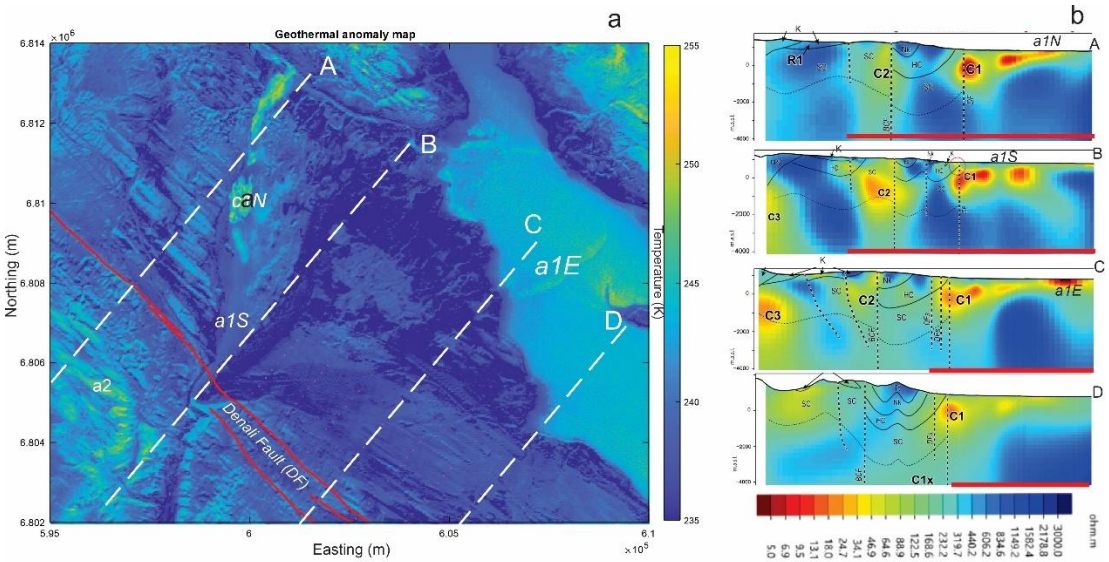


Figure 3. a) Extracted geothermal temperature anomalies from LSTs showing the spots that are likely related to high geothermal heat flux. b) resistivity cross sections from MT model Tschirhart, et al., (2022), showing relationship between identified surface temperature anomalies and known conductivity anomalies from the MT model.

A prominent feature within trend a1 is a strong anomaly in the central Duke River fan delta (a1N) (Fig. 3a). This anomaly comprises a high-temperature northern segment (a1N) and a weaker southern segment (a1S), both confined to a narrow linear zone north of the Denali Fault. Spatially, this anomaly coincides with conductivity feature C1 identified in a magnetotelluric (MT) resistivity model (Tschirhart et al., 2022).

Figure 3b presents four resistivity cross-sections from the 3D MT model (Tschirhart et al., 2022). The a1N anomaly directly overlies a shallow permeable zone represented by conductivity anomaly C1 in cross-section A (Fig. 3b). The southern part of the trend, a1S, also overlies the same conductive feature; however, the permeable zone dips southward and is buried slightly deeper beneath a1S than beneath a1N. This depth difference likely explains why a1S exhibits a weaker LST signal compared to a1N. Additionally, the temperature anomaly observed on the ice surface of Kluane Lake may reflect the eastern extension of the same conductivity structure C1 (a1E in Fig. 3a; feature C in Fig. 3b).

The temperature anomaly (a1N) in the Duke River fan delta (Fig. 4a) appears to be linked to a small pull-apart subsidence center within the Denali Fault zone. The structural model of this proposed mini pull-apart basin (Fig. 4b) is consistent with the geometry produced in physical pull-apart experiments by Liu and Konietzky (2018).

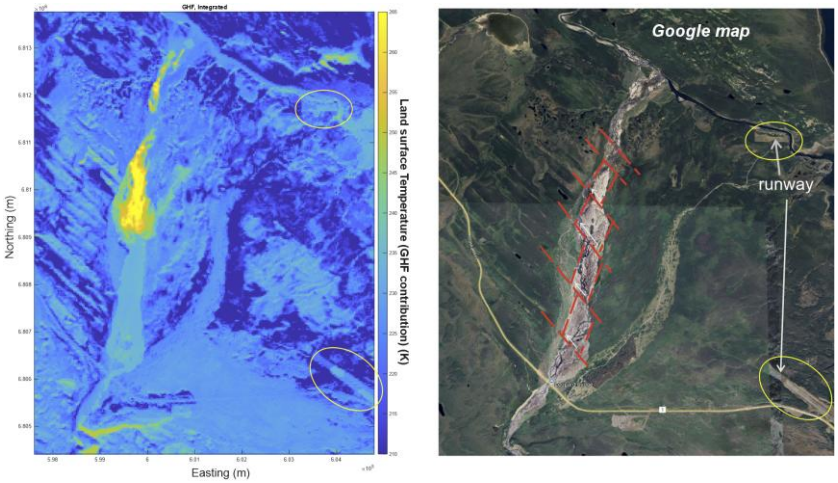


Figure 4. Geothermal anomalies extracted from land surface temperature estimates from multi-seasonal Land-8 of the study area a), and interpretation of small faults that offset the river channels from Google Earth image b).

2.3 Interpretation from GST monitoring data

Precisely determining geothermal heat flow from GST monitoring data collected above the permafrost zone is challenging. Nevertheless, the GST observations provide valuable insight into the spatial variability of geothermal heat flux. Figure 5 illustrates the winter minimum temperatures (30-day averages) recorded by the lower probes in the monitoring network, revealing spatial patterns in shallow soil temperatures. The elevated temperature trends indicated by the GST data are consistent with the LST-derived geothermal anomaly swarms, which align with major structural features, including the Denali Fault and the Duke River valley.

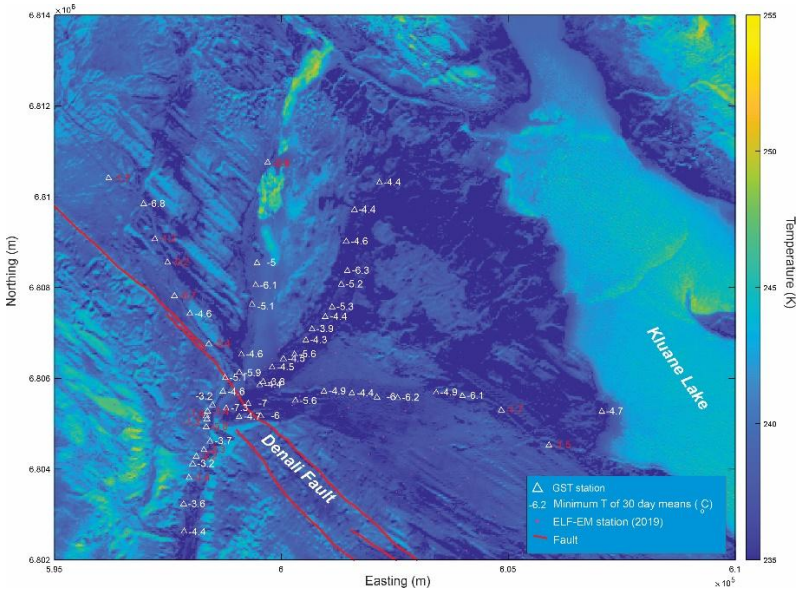


Figure 5. Comparison of the GHF temperature anomalies with the recorded ground surface temperature from the monitoring network in the study area.

3 CONCLUSION

A significant geothermal anomaly was identified in the Duke River fluvial fan, coinciding with a high-conductivity zone revealed by a recent 3D magnetotelluric resistivity model. We interpret this anomaly as a shallow permeable zone likely associated with a small pull-apart subsidence center within the Denali Fault system.

Two major geothermal anomaly trends emerged from LST-based geothermal heat-flow modeling and are corroborated by GST monitoring data. These temperature anomalies align closely with shallow conductive zones in the resistivity model, indicating fault-controlled fluid pathways. The anomalies are interpreted as products of strike-slip faulting along the Denali Fault and related mini pull-apart basins, which create permeable networks that enable deep geothermal fluids to migrate upward. The Duke River valley and delta trends represent local extensional zones with enhanced permeability, facilitating fluid flow from depth to near-surface environments.

Although Landsat multispectral imagery does not provide direct evidence of geothermal resources, this study demonstrates its value in detecting land surface temperature anomalies and structural features essential for conceptual geothermal models. When integrated with ground-based observations and geophysical data, remote sensing offers a cost-effective reconnaissance tool that can guide and prioritize more detailed, resource-intensive investigations.

ACKNOWLEDGEMENT

This is an output of GeoEnergy Program of the Natural Resources of Canada. Mr. Zachary Dewis and Dr. Di Lu of GSC Calgary helped with Lansat data preparation. Dr. Jon Liu helped on the ground temperature logger fieldworks.

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