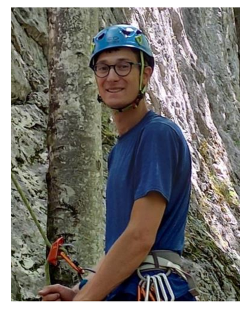
Summarizing Transient Permafrost Ensemble Simulations for Investigating Climatic Influences on Slope Failures.



Victor Pozsgay
Postdoctoral Fellow, Carleton University, Ottawa
victorpozsgay@cunet.carleton.ca

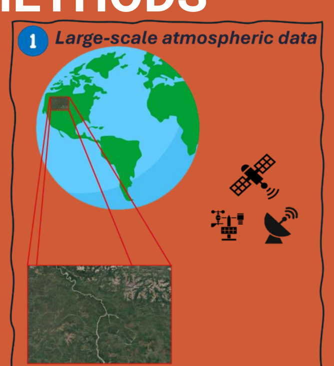
BACKGROUND

The magnitude and frequency of slope failures in permafrost zones have increased in recent decades. Understanding the link between permafrost thaw and slope movement is crucial for identifying and adapting to geohazards and increasing public safety in northern communities.

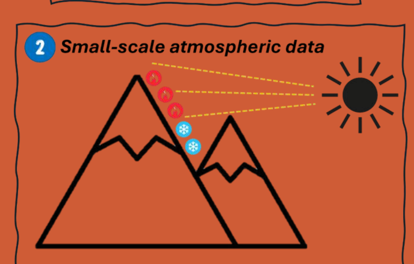
OBJECTIVE

Provide quantitative and time-dependent context for interpreting past slope failures and establish correlations between slope failures and potential permafrost-related driving factors, such as changes in air temperatures, **ground-surface temperatures (GST)**, thaw depth, and water availability.

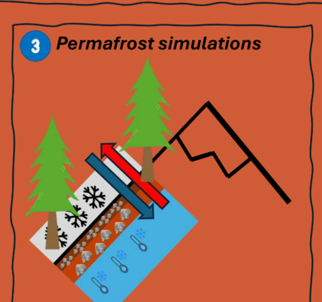
METHODS



Reanalysis data
- Based on collection of **observations** (satellites, weather stations, aircrafts, radars, etc.) and **models**
- Different products (ERA5, MERRA2, JRA3Q)
- **Global** and available over many past decades (from the '40s for some)
- BUT: **low resolution**, grid cells are ~50km across



Heuristic downscaling data using data from 1
- Meteorological timeseries for user-defined point location (GlobSim **[1]**)
- Accounts for local microtopography:
  - elevation
  - slope
  - aspect



Simulations using data from 2
- Solves energy/water balance (GEOtop **[2]**, GTPEM **[3]**)
- Simulates the land-surface boundary and the ground below it
- Accounts for phase transitions (soil freezing/thawing)
- Accounts for:
  - **snow** cover
  - **soil** type
  - **vegetation** type

We simulate the ground thermal regime (and hence permafrost) for:
- tens of point locations,
- hundreds of simulations per location (for varying elevation, slope, aspect, snow, soil, vegetation, etc.)
- several decades

Thousands of decades-long simulated time series!
How can we make sense of so much data?

RESULTS

SuPerSim (**Su**mmary for **Per**mafrost **Sim**ulations) **[4]**:
Python Package that produces quick and easy visualization of permafrost metrics and time series from ensemble simulations.

For **any point location in the world**, this workflow allows the user to produce a detailed yet easily-understandable set of plots that highlight the change in atmospheric drivers (e.g., air temperature, precipitation) and simulated metrics (e.g., ground-surface temperature (GST), snow depth, water production, permafrost depth of thaw) in time and space.

SuPerSim products support research efforts in **identifying landslide triggers**. **SuPerSim** enables a better understanding of large ensemble simulation results, simplifies their dissemination in the form of plots, and allows for **automated scrutiny and review of the simulations**, hence increasing the final product's quality.

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The colder the ground is, the faster it warms.

Climate change effects are intensified in cold ground and hence **permafrost thaw could be faster than expected, increasing landslide risks for northern communities.**

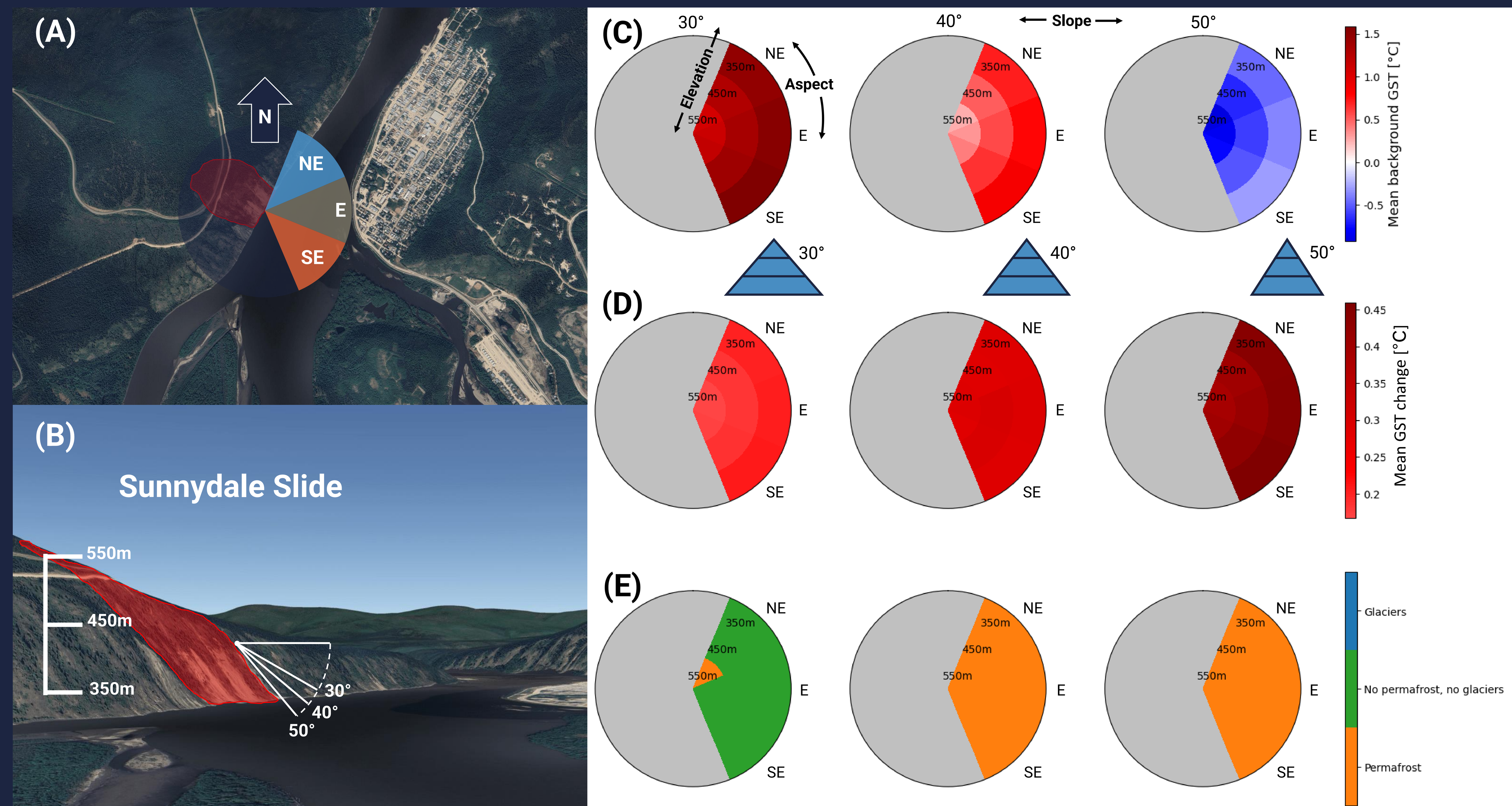


Figure 1: Representation of the three topographic variables for GST simulations of the Sunnydale Slide close to Dawson City: **(A)** aspect, **(B)** elevation and slope angle. Polar plot of **(C)** the modelled mean background (1980-2000) GST, **(D)** the modelled change in GST between the background and the transient period (2000-2023), and **(E)** the modelled presence of permafrost as a function of elevation, slope, and aspect.

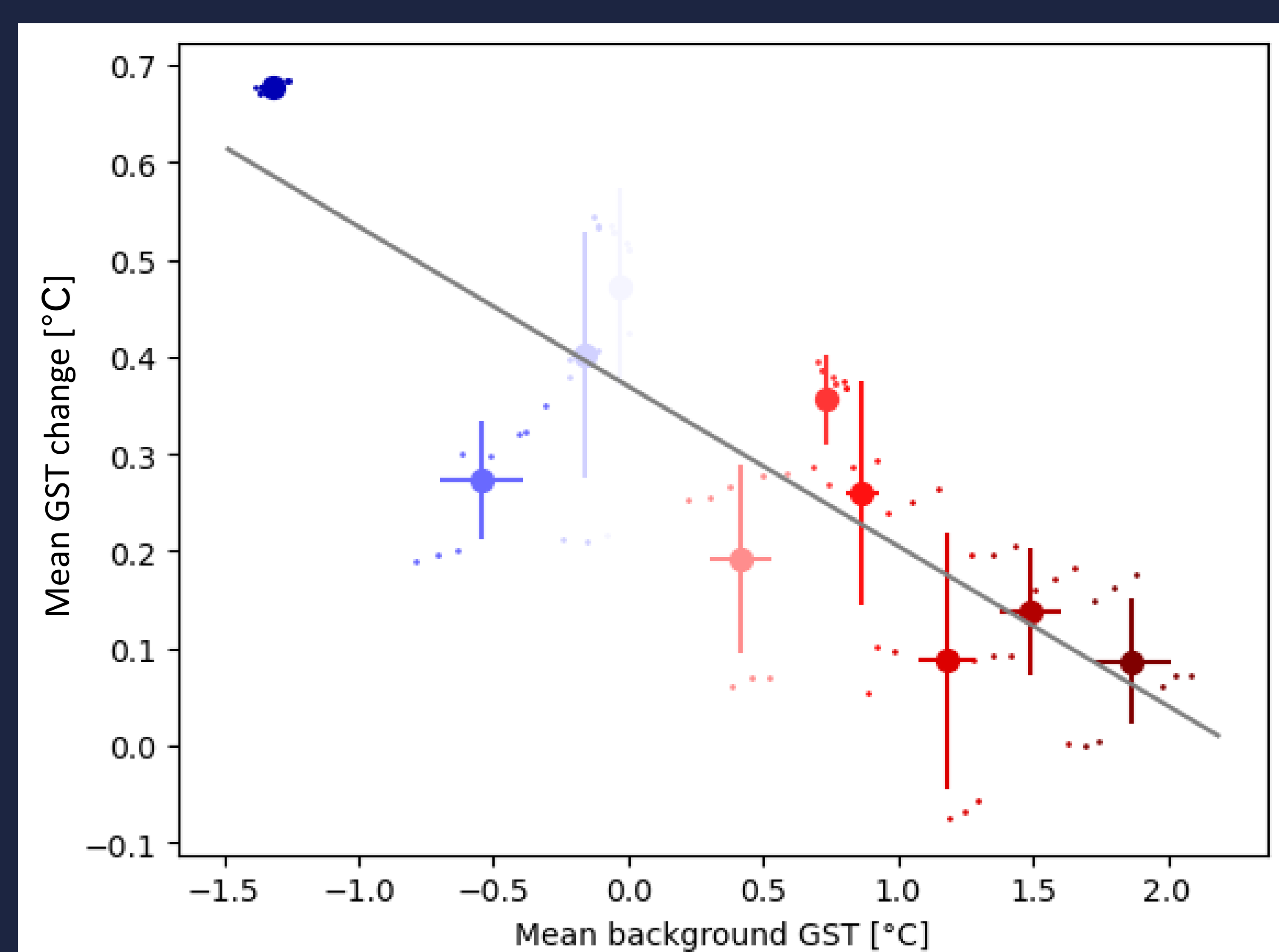


Figure 2: Scatter plot of the modelled change in GST (change between 1980-2000 and 2000-2023) against the modelled background value of the mean GST (average over 1980-2000).

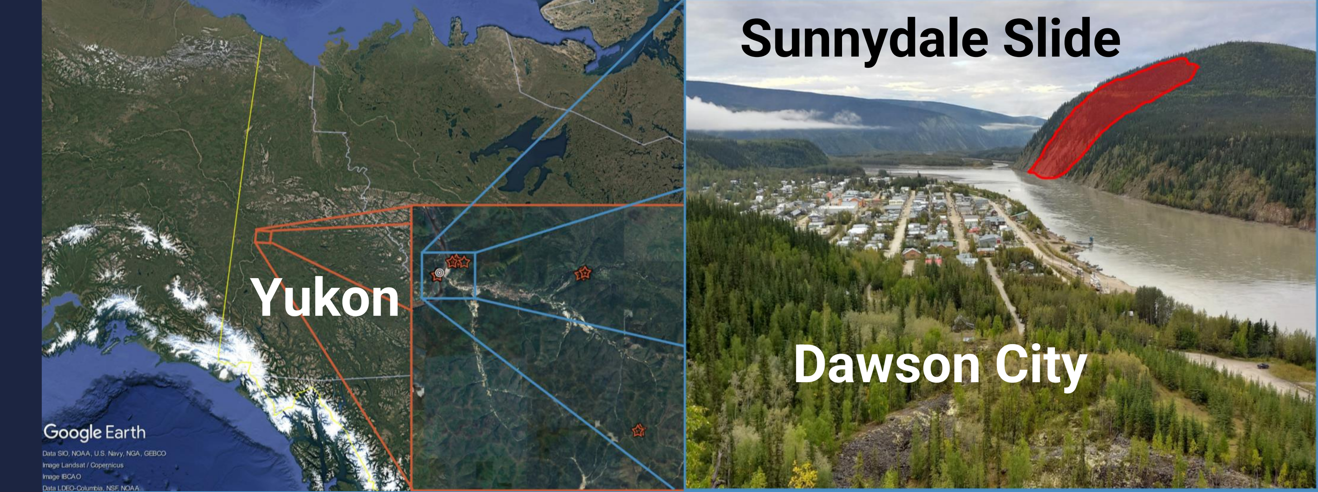
Simulations of GST are **colder** if:
- **north-facing**
- **steep**
- **high**

The simulations that start cold experience a higher warming.

Permafrost is present at all elevations and aspects simulated, if the slope is steep enough. For gentler slopes, permafrost is present at higher elevation and aspects closer to the North.

Every simulation agreed on a warming of the ground! This slope represents a **landslide risk**, and its **monitoring need to continue**.

ARCTIC CHANGE 2024



The air temperature warming drives permafrost thaw.
Is the relationship between air temperature and permafrost thaw easy?

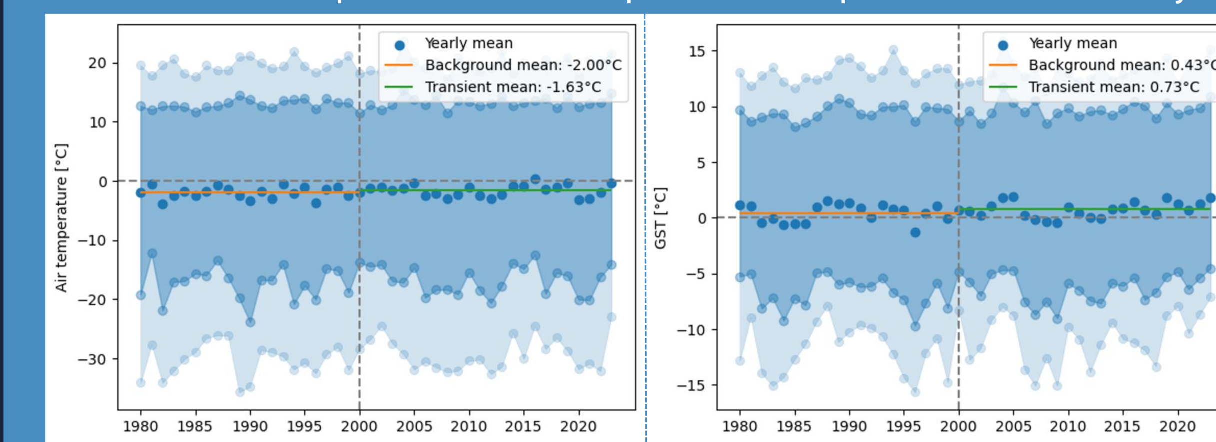
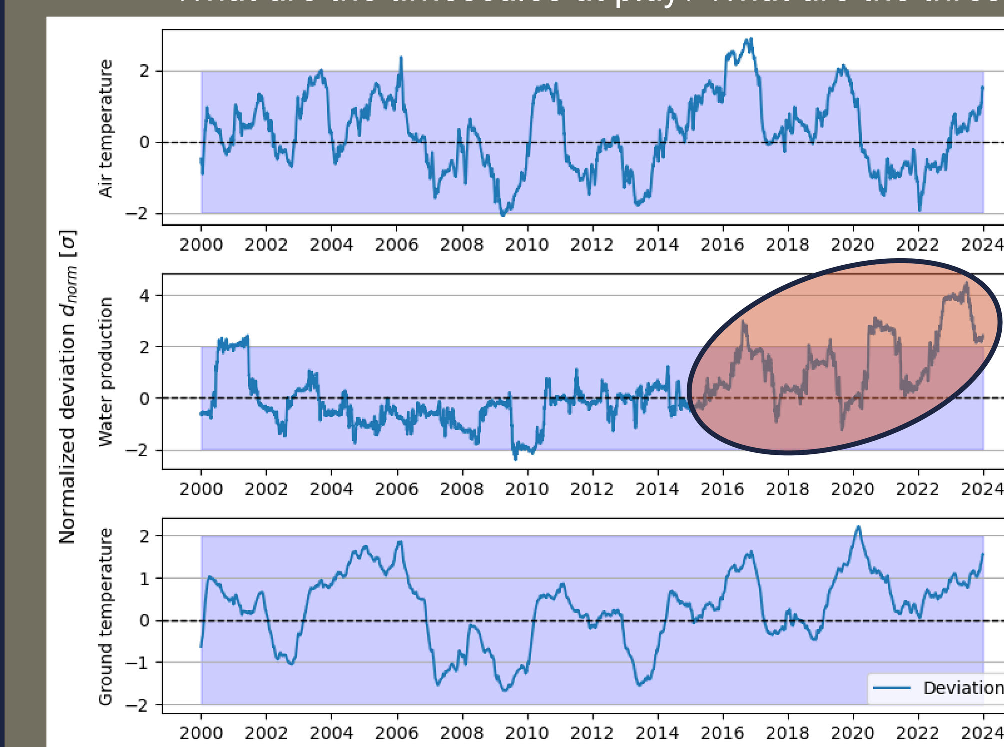


Figure 3: Yearly mean and spread of daily GST and air temperatures from 1980 to 2023.

Main **landslide triggers** include high temperatures and precipitation levels.
What are the timescales at play? What are the thresholds?



Water production shows a clear trend in extreme values.

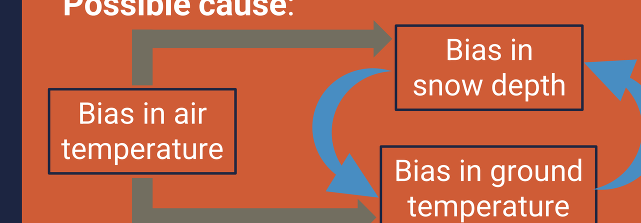
Extremes in air temperature and GST differ hence simulations are important.

Figure 4: Dimensionless measure of extreme simulated values for the air and ground-surface temperature, and the total water production for 2000-2023.

A glimpse into the current work

How reliable are the simulations? How can we include other physical effects?

Mismatch in both GST and snow depth.
Possible cause:



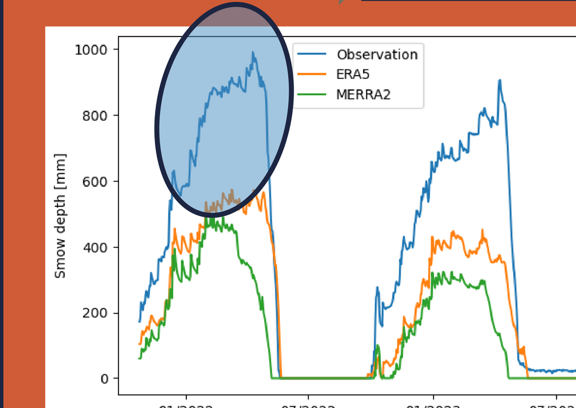


Figure 6: Comparison of observed and simulated snow depth.

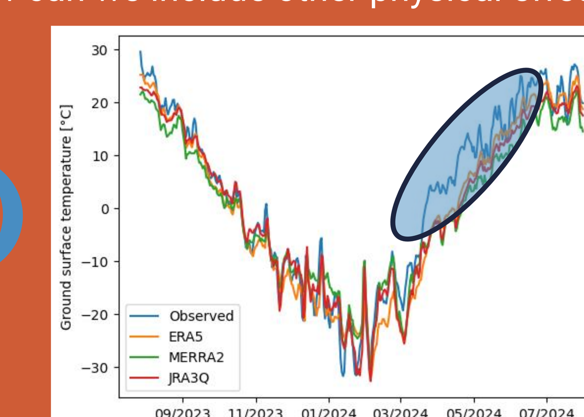


Figure 5: Comparison of observed and simulated GST.

Possible solution:

Account for **temperature inversions** (cold-air pool) to align forcing data and observed air temperatures

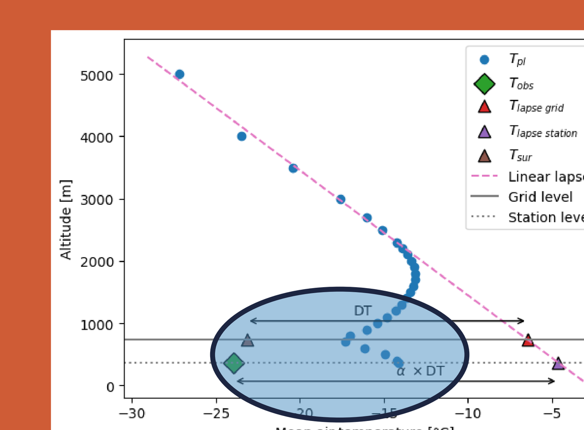


Figure 7: Modelling of temperature inversions above the Dawson airport.

REFERENCES
[1] Cao, B., Quan, X., Brown, N., Stewart-Jones, E., and Gruber, S., GlobSim (v1.0): deriving meteorological time series for point locations from multiple global reanalyses, Geosci. Model Dev., 2019.
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[3] Brown, N., Grid Toolkit for Permafrost Ensemble Modelling, GitLab, 2020.
[4] Pozsgay, V., SuPerSim, GitHub, 2024.

Carleton University
Victor Pozsgay, Stephan Gruber, Nick Brown, Derek Cronmiller