Globsim v.3 Improvements to an open-source software library for utilizing atmospheric reanalyses in point-scale permafrost simulation

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The need for input data in point-scale permafrost simulation

Physically-based models are a powerful tool to investigate permafrost behaviour and dynamics in response to changing environmental conditions such as climate change and landscape disturbance. Often, these models require input data at daily or greater frequencies to drive boundary conditions and ensure adequate spin-up. Depending on the model and the nature of the investigation, these data typically include air temperature, radiative forcing, and precipitation, but may include other variables such as precipitation, wind velocity, or relative humidity.

Observational data are rarely adequate to meet this demand, due in large part to their patchy spatial coverage. Temporal coverage for observational records in typical field sites are is the order of years. Even when observing stations are established for remote field sites, they may not have all variables that are required. These challenges are exacerbated in increasingly remote or high-elevation locations.

Simulation in steep terrain

The impact of topography on radiative fluxes has a large impact on ground temperature and permafrost occurrence. Gridded surface-level data alone within a single grid cell do not capture many of the relevant topgraphic effects (Figure 2).

Unfortunately, dynamic downscaling to tens of metres is not feasible, and statistical downscaling needs observations which are not readily available at most permafrost study sites.

Figure 3: (a) Reanalysis spatial resolution obscures variability. *Figure from [2]* (b&c) Ground temperature is affected by solar aspect, slope and shading. In both cases, the GlobSim scaling and interpolation steps improve useability for point-scale simulation

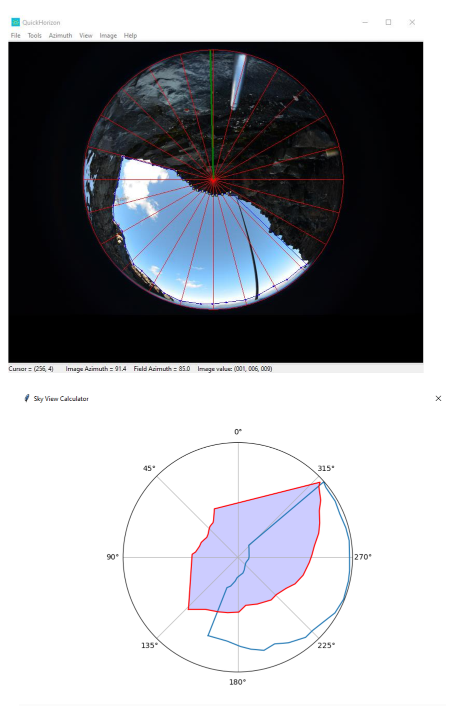

Figure 4: Digitizing horizon lines from digital photographs to calculate sky view factor for use with GlobSim.

In version 3 of GlobSim, we parameterize terrain effects as sky view factors—which represent the fraction of visible sky—and horizon lines—which affect shading of direct solar radiation (Figure 3). These measurements act to mask or scale solar radiation at the point scale. By applying corrections directly to input data at the scaling step of GlobSim, these microtopographic variations can be represented in any simulation regardless of which model is used.

We also use the TOPOscale algorithm [3] to partition incoming solar radiation into direct and diffuse components and correct for elevation differences in radiative fluxes at point locations within a grid cell.

Ensembles as a proxy for uncertainty

GlobSim works with data from multiple reanalyses (e.g., ERA5, MERRA2 and JRA55), each with different model physics and biases. This means multiple simulations can easily be run with different input data to reflect uncertainty in meteorological forcing and associated model uncertainty (Figure 3).

A standardized process now supports larger automated model workflows and simulation ensembles using multiple models, reanalyses and parameter combinations.

As of version 3 of GlobSim, data from the ERA5 ensemble can also be downloaded.

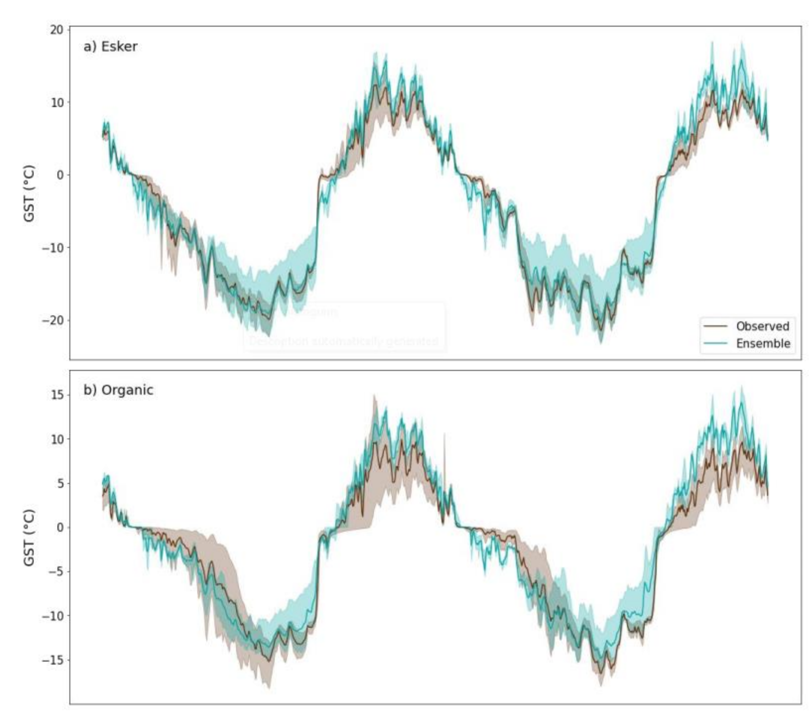

Figure 5: Using GlobSim-derived meteorology to simulate ground surface temperature (GST) with observations in different terrain types. Model *Image credit: Olivia Meier-Legault*

Harnessing 50+ years of meteorological data for any location

Atmospheric reanalyses provide meteorological variables relevant for permafrost simulation dating back to 1980 or earlier with global coverage (Figure 1).

Practical considerations limit the immediate applicability of reanalyses for point-scale simulation:

- Downloading the data can be quite cumbersome, and different approaches must be used depending on the product.
- The resolution of the grid cells is too coarse to resolve many important topographic phenomena.
- Timesteps, units, and available variables differ from those required by models.

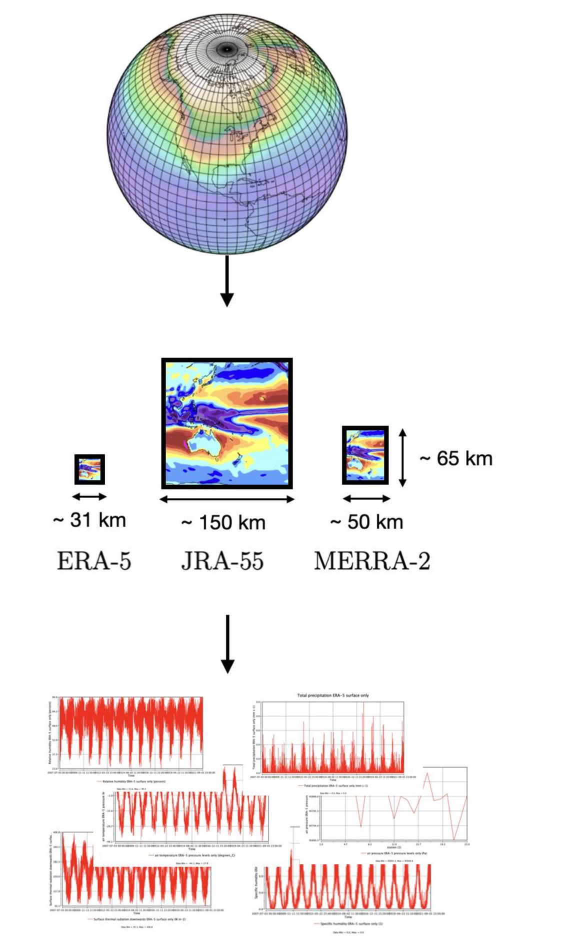

Figure 1: Simplified schematic for GlobSim workflow. *Figure Hannah MacDonell*

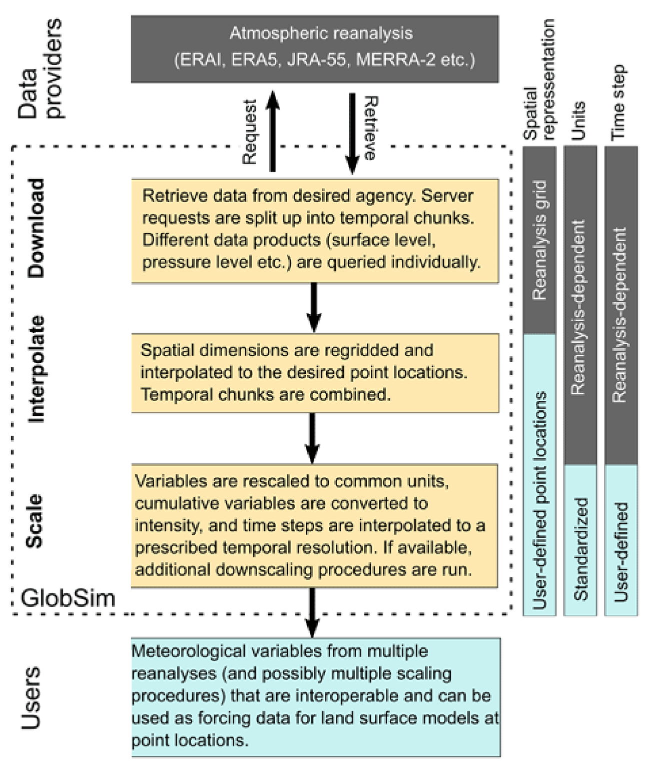

Figure 2: Detailed schematic for GlobSim workflow. As of version 3, additional corrections can be made in the scaling step. *Figure from Cao et al. (2019)*.

Converting multiple grid-based products into homogenous time series for point locations is too much effort for ad-hoc processing.

Instead, GlobSim [1] bridges this gap by providing a 3-step workflow to obtain simulation-ready data from reanalysis providers (Figure 2). Local-scale topographic effects are accounted for in Version 3.

Challenges and Next Steps

Investigations in Yukon, Canada identified that GlobSim-derived air temperatures underestimate inversions caused by cold air drainage and pooling [4]. Temperature inversions can strongly affect the spatial distribution of permafrost. We plan to improve representation of temperature inversions in the scaling step using algorithms such as REDCAPP [5] and improvements in the interpolation step for elevations below grid surface level.

As additional steps, we will continue to integrate GlobSim as part of a larger modelling toolchain to streamline bigger ensembles consisting of multiple reanalyses, models, and soil/vegetation profiles. We will also investigate the use of GlobSim as part of a permafrost prediction workflow by using it to debias CMIP data for scenario simulations.

Finally, simulation results will benefit from running GlobSim on dynamically downscaled reanalyses. This will improve several elements, such as the effects of mountains on cloudiness and precipitation.

References and acknowledgements

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github.com/geocryology/globsim

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