

Probability of Permafrost

1. Brief Summary

The permafrost probability model for the southern Yukon and northern British Columbia is a interpolative combination of seven local high-resolution empirical-statistical models (30 x 30 m grid cells), each developed by using the measured temperature at the bottom of the snowpack (BTS) in winter and by verification of frozen-ground in summer.

The seven local models were blended to generate a map of permafrost probability over an area of almost 500 000 km² between 59°N and 65°N. The result shows general spatial patterns, which are largely similar to previous permafrost maps with an average permafrost probability of 58% for the region as a whole, but contains orders of magnitude more data.

The model results are presented in two ways, the first uses traditional classifications into permafrost zones, and the second presents the raw results of the probability of permafrost.

2. Methods

- Field Data

Individual local empirical-statistical permafrost probability models were generated for seven field areas ranging in size from 200 to 1400 km²: Wolf Creek, Ruby Range, Haines Summit, Johnson's Crossing, Faro, Keno and Dawson. Local models were based on a combination of BTS measurements in winter and ground-truthing in summer to verify directly the presence or absence of frozen ground. Logistic regression was then used to relate predicted BTS temperatures to the ground-truthing observations.

Full descriptions of the methods have been outlined in previous publications (Lewkowicz and Ednie, 2004; Bonnaventure and Lewkowicz, 2008; 2012).

- Digital Elevation Model.

A digital elevation model (DEM) was needed to allow predictions to be made for the entire region. The Yukon portion of the DEM was provided by the Yukon Geological Survey (Geomatics Yukon, 2006) with a resolution of 30 x 30 m. Sections at the same resolution were added for parts of British Columbia to the south and the Northwest Territories to the east (both provided by Geobase, 2010) and Alaska to the west (provided by the United States Geological Survey, 2010). These outer DEM sections were included to extend the modelled area into northern British Columbia and to eliminate errors associated with boundary edge effects during analysis.

- Solar Radiation Modelling.

The solar modelling processes were essentially the same as those described in Bonnaventure and Lewkowicz (2008, 2010). However, the creation of a potential incoming solar radiation (PISR) model for the entire study region that took into account latitude changes represented a considerable challenge. As a result of software restrictions in the ArcGIS Area Solar Radiation tool, required 34 relatively small sections of the PISR model to be run individually. The total area was thus divided into 34 sections of the DEM that were 0.5° in latitude, and varied in longitude from about 0.5° to about 2°. These sections were overlapped by 0.125° in both latitude and longitude to eliminate any errors associated with topographic edge effects and shading.

The climatic inputs needed to run the Area Solar Radiation tool were derived from: (1) air and ground temperatures; (2) light-intensity logger data from our logger network (Lewkowicz and Bonnaventure, 2011); and (3) cloud cover data from nearby Environment Canada stations. The cloud cover percentages during the snow-free period were classified daily as 0, 50 or 100 per cent. The percentage was assigned by examining the offset between air and ground temperatures (Bonnaventure and Lewkowicz, 2008). When ground temperatures rise more rapidly than air temperatures during the day this reflects clear conditions, whereas the opposite reflects overcast conditions. These interpretations were compared to the light-intensity logger data as well as the hourly cloud cover percentages from the nearest meteorological station. The amount of cloud cover (diffusivity) for each of the 34 DEM sections was set to one of three values based on the results of the analyses (65, 70 or 75%).

The snow-free period, which is needed to decide the duration of the PISR calculations, was established by examining logger data from all of the study areas to determine typical dates when snow covered the surface (autumn) and when ground temperatures rose above 0 °C (spring). The snow-free period varies within the region and from year to year, and is partially controlled by elevation and local site characteristics. For the purpose of this model, however, it was set from 15 May to 30 September. The highest elevation sites may have a snow-free season that are slightly shorter than that used (i.e. PISR values may be over-predicted), but this has a limited impact on the final outputs of the permafrost model as these areas already exhibit high permafrost probabilities. Once all 34 PISR models had been created, they were assembled into one grid using the Mosaic tool in ArcGIS. Modelled PISR is in MJ/m² with the highest values being predicted for south-facing, high-elevation slopes, and the lowest values for steep, low-elevation, north-facing slopes.

- **Equivalent Elevation.**

The relationship between permafrost distribution and elevation is complex and non linear in this region. In addition different patterns of temperature change with elevation are observed both above and below treeline. The concept of equivalent elevation (Lewkowicz and Bonnaventure, 2011) was developed to deal with these complexities. True elevations in a DEM are adjusted to reflect mean annual air temperatures (MAATs) based on local Surface Lapse Rates (SLRs). The numerical elevations of grid cells below treeline are changed to take into account weakened or reversed SLRs in the forest compared to the strong normal negative SLRs above treeline. Thus grid cells that are well below treeline may be increased significantly in elevation, areas close to treeline are changed very little and areas above treeline remain unchanged.

From equivalent elevation to permafrost probability

Each of the individual local models was used with the regional DEM (slope grid), the regional PISR grid and the regional equivalent elevation grid to make permafrost probability predictions for the entire area. The regional model was assembled from these predictions using a distance-decay function to weigh the contribution of each of the seven individual models to a given grid cell and then assigning a permafrost probability value based on a sum of scores.

3. Use and Interpretation

- This model should be cited as: Bonnaventure, PP, Lewkowicz AG, Kremer M, Sawada MC. 2012. A Permafrost Probability Model for the Southern Yukon and Northern British Columbia, Canada. *Permafrost and Periglacial Processes* **23**: 52-68. DOI: 10.1002/ppp.1733.
- Academic environmental modelling as an input layer.

- Primary analysis of permafrost conditions and distribution however, detailed site investigation is needed.

4. Applications to Climate Change Modeling

- This Model is currently being used to investigate the permafrost probability distribution change for air temperature change scenarios changes which include $\pm 1, +2, +3, +4, +5$ °C, as well as IPCC scenarios A1B, A2 and B1. Please contact the authors for more information and publications.

5. Reference List

Bonnaventure P.P., Lewkowicz A.G., Kremer M., Sawada M.C. 2012. A Permafrost Probability Model for the Southern Yukon and Northern British Columbia, Canada. *Permafrost and Periglacial Processes* **23**: 52-68. DOI: 10.1002/ppp.1733

Bonnaventure P.P. and Lewkowicz A.G. 2010. Modelling climate change effects on the spatial distribution of mountain permafrost at three sites in northwest Canada. *Climatic Change* **105**: 293-312. DOI 10.1007/s10584-010-9818-5

Bonnaventure P.P. and Lewkowicz A.G. 2012. Permafrost probability modeling above and below treeline, Yukon, Canada. *Cold Regions Science and Technology* **79-80**: 92-106. 10.1016/j.coldregions.2012.03.004

Bonnaventure PP, Lewkowicz AG. 2008. Mountain permafrost probability mapping using the BTS method in two climatically dissimilar locations, northwest Canada. *Canadian Journal of Earth Sciences* **45**: 443-455. DOI:10.1139/E08-013

Lewkowicz AG, Bonnaventure PP. 2008. Interchangeability of Mountain Permafrost Probability Models, Northwest Canada. *Permafrost and Periglacial Processes* **19**: 49-62. DOI: 10.1002/ppp.612

6. Disclaimers

This set of spatial data for permafrost probability (the “Data”) is a model only and use or application of the Data is not a substitute for site investigations. The Data is made available on an “as is” basis. The authors of the Data and/or the University of Ottawa make no representation, condition or warranty of any kind with respect to the accuracy, usefulness, completeness or currency of the Data; and disclaim any express or implied condition or warranty of merchantability or fitness for a particular purpose of the Data. The entire risk as to the access, possession, performance, application or other use of the Data is assumed by the user. In no event shall the authors of the Data and/or the University of Ottawa, its directors, officers, appointees, employees, agents or contractors be liable to any party for any damages of any nature or kind whatsoever arising out of the use of the Data

7. Provisions

This data is meant to be open access for publication and to be distributed by Yukon Geological Survey.

8. Authorship

Bonnaventure P.P. and A.G. Lewkowicz (2012)

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