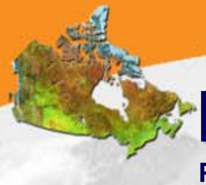

Permafrost Modelling for Norman Wells

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Reducing Canada's vulnerability to climate change

Introduction

Permafrost modelling is a key step towards assessing the costs of climate change impact and adaptation for northern community infrastructure. Through model-based simulations under various climate change scenarios for the coming decades, we can obtain an understanding of approximate timeframes when remediation/adaptation of infrastructure foundations may be required due to permafrost degradation, and of associated costs. We have chosen the Norman Wells community for the first case study, building on the previous ESS CCAF-funded study on northern community infrastructure (Robinson et al. 2001) and the ESS Earth-observation driven permafrost model (Zhang et al. 2003). See A3 poster for an overview.

Permafrost Model Description

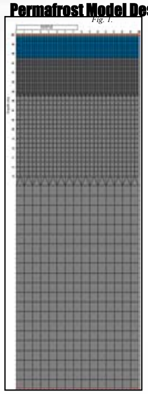


Fig. 1.

Using the software TEMP/W, a 2D finite element heat transfer model with water/ice phase change, a base permafrost model was constructed for the Norman Wells arena. The modelling space covers a transect across half of the arena and the parking lot, with a size of 30m wide x 75m deep (Fig. 1). The model was initialized by means of a steady-state run followed by 1961 downscaled climate scenario data. After about 10 years, the ground temperature change below active layer was less than 5%; it means that it reached near equilibrium. The model was then run uptil 2100, at a daily interval. The thermal properties used to construct the model are shown in Table 2. The N-factors used in the model are mostly measurement data (* in table 1) from GSC, other data were estimated by Robinson (2001)

Table 1. N-factors used in the base model

n_{th}, n_{fr} 0-9m	n_{th}, n_{fr} 9-13m	n_{th}, n_{fr} 13-16m	n_{th}, n_{fr} 16-30m
0.75, 0.82	0.90, 0.85	1.03, 0.4	1.2, 0.6

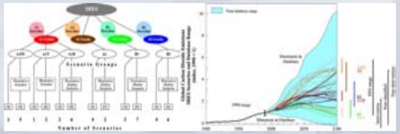
Table 2. Thermal properties used in the base model

Soil	Density	Conductivity (KJ/day/mK)		Heat Capacity (KJ/M³/K)		Water C.
	kg/m³	Frozen	Unfrozen	Frozen	Unfrozen	
Crushed shale	2.3	149.39	179.19	750	840	0.17
Silty clay	1.3	172.8	118.02	1740	2555	0.3
Bedrock	2.2	181.44	140.4	2483	3404	0.2

Scenario Data Downscaling

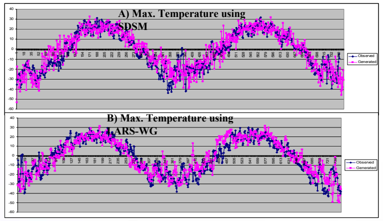
Global climate models (GCM) are considered to be the only credible tools currently available to simulate the response of the global climate system to increasing greenhouse gas concentrations at the global and regional scales. IPCC Third Assessment Report recommends four SRES storyline and scenario families (Fig.2, a,b) for climate change scenario projection and the subsequent impact assessments.

Fig 2a (left). Schematic illustration of SRES scenarios. Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. The set of scenarios consists of six scenario groups drawn from the four families. 2b) (right) Global CO_2 emissions related to energy and industry. The dashed time-paths depict individual SRES scenarios. (IPCC SRES, 2000)



We have chosen 2 climate change scenarios resulting from two extreme SRES scenarios, i.e. A1FI and B1 (Fig. 2b) for each GCM model, aiming to identify the best and the worst cases of anticipated impacts and costs to northern community infrastructure. However, climate change scenario data directly derived from GCM model outputs are inadequate in spatial and temporal resolutions. There are four main types of tools available for downscaling the GCM model results to localities for impact studies: a) synoptic weather typing; b) stochastic weather generator for temporal downscaling; c) regression-based approach (SDSM) for spatial downscaling; and d) dynamic climate model (RCM) for both temporal and spatial downscaling. For scenarios data available only monthly, we used LARS-WG to generate synthetic daily weather data, calculated the monthly mean of 1961 to 1990, subtracted the mean from GCM monthly output, and then added the difference to the generated daily data. For the daily data available from GCM outputs, we performed spatial downscaling for the maximum and minimum temperatures and precipitations using SDSM. The data for GCM model MK2, HadCM3, CGCM2, NIES was downscaled as shown in Fig 4a, b). In Fig 4, all data with initial label 'D-' are downscaled data. Fig. 3 gives a snap shot of comparison of observed and downscaled scenario data using SDSM (a) and LARS-WG (b). The comparison of the highlighted line, red and pink, in Fig. 4b, shows the significant improvement made.

Fig.3 Comparison of downscaled Scenario to observed data



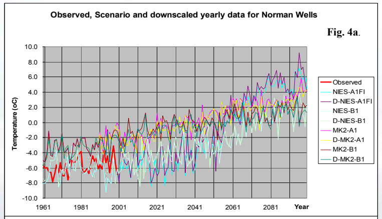


Fig. 4a.

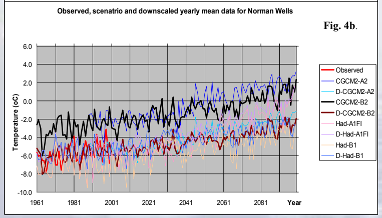
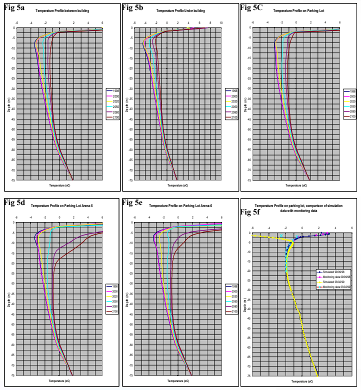


Fig. 4b.

Preliminary Results and Sensitivity Analysis

Preliminary Outputs

Ground temperature profiles as simulated by the base model runs are visualized below in Fig. 5 for three locations for the day Sep 15 of years 1998, 2000, 2020, 2050, 2080 and 2100, respectively. These locations are: a) 6m from the centre of the arena; b) 16m, on the edge of the arena; c) 26m, under the parking lot. Fig. 5 also show simulation results under different SRES. Fig. 5a, b, and c use scenario CGCM2-A2, Fig. 5d and 5e use scenario NIES-A1FI and B1 respectively. Fig. 6 shows the active layer depth change with time at the three locations for different runs. Parameters used in each run are described in table 3. Overall the results show that, under different climate change scenarios, permafrost will undergo various degrees of degradation in the next few decades. For example, on the parking lot, the active layer will change from 2m to 18m in the worst case (scenario NIES-A1FI at year 2100).



Verification

The model verification has been performed through the comparison of monitoring data of borehole 98 with simulation results at Sep. 2, 1998 and Mar. 2, 1999. Since there is a very good match, the model physics and parameters are credible.

Table 3. Parameter changes from base model for sensitivity analysis

Model runs	Purpose and parameter change from the base model
Arena-2	Sensitivity of n-factor, 1.2, 0.2 on the parking lot
Arena-3	Sensitivity of Water Contents, 0.4 and density: 1.0
Arena-4	Sensitivity of Scenario data, CGCM2-B2
Arena-5	Sensitivity of Scenario data, NIES-A1FI
Arena-6	Sensitivity of Scenario data, NIES-B1

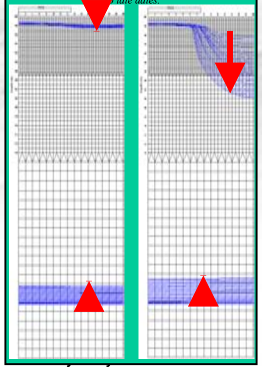
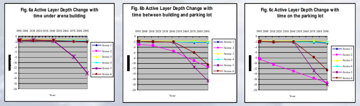
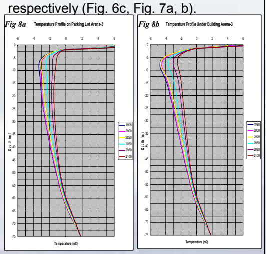


Fig. 7 Freeze-thaw line change from 1971 to 2100 on Sep. 15 every 5 years. Left, Area-1, right, Arena-2. The red arrow represents the direction of change from early to late dates.



In order to get a better understanding of the permafrost physical process and the validity of the model, we set up six runs (including the base model) with different parameters of n-factor and water content set for sensitivity analysis. Table 3 describes the purpose of each run and the associated parameter change from the base model.

<u>N-factor</u> The n-factor is defined as the ratio of the surface freezing or thawing index to the air freezing or thawing index. N-factors depend on climatic condition and on the type of ground surface. TEMP/W allows us to use n-factor to empirically simulate the complex energy balance at the ground surface. From the model output of the base run (Arena-1) and Arena-2, the n-factor showed considerable impacts on the active layer depth. Decreasing the freezing n-factor on the parking lot from 0.6 (Arena-1) to 0.2 (Arena-2) resulted in a change in active layer depth from –2.08m to 13.6m and from –2.455m to –17.36m at year 2050 and year 2080, respectively (Fig. 6c, Fig. 7a, b).



<u>Water Content</u> Soil moisture influences soil thermal properties. TEMP/W can only treat water content as a constant. There are no water dynamics involved. Fig. 9 shows that increasing water content by 10% in Arena-3 does not give significant change in the active layer depth (Fig. 4). However, water has been found to be a significant factor in affecting permafrost performance in the Inuvik community of the Northwest Territories. A 10% increase may not be big enough, especially when the initial value is small or the temperature increase of the CGCM2-A2 scenario is too small. Further work needs to be done to confirm this, for example, trying to use other scenario data to test the sensitivity of water content.

Discussion

The preliminary results of permafrost modeling for Norman Wells show that under various climate change scenarios, permafrost will undergo various level of degradation. At 2100, the active layer depth will be 2m for the best case, and 18m for the worst case. Overall, after 2050, the degradation process will be faster as shown in Fig. 6.

The sensitivity analysis of n-factor shows that n-factors play a very important role in the model. The identification of a "good" n-factor value, however, is very difficult. The values of n-factor reported in the literature have a wide range for the same ground surface type. Also, measured n-factors, theoretically, are reliable only for the time and place when and where the measurement is taken. As climate warms, n-factor will likely change due to anticipated changes in ground surface conditions, such as snow depth and the dynamics of the ground conditions near the surface. Consideration of these changes in the TEMP/W model is impossible since the model can only use fixed n-factors. A physical thermal process model that incorporates both surface and ground dynamics into the heat process is required to effectively deal with the n-factor problem. Currently, no such model is available.

Air temperature is the driving force of the permafrost thermal regime. The air temperature from scenario data has a very significant impact on the permafrost stability. Significant differences exist between the climate change scenarios generated from different GCM models, each producing a very different data range. We suggest using as many GCMs as possible to produce an envelope of potential impacts. More importantly, downscaling is necessary in using any GCM outputs, especially for local scale assessment. Because of the inadequacy of GCM outputs in spatial and (for some outputs) temporal resolutions.

Acknowledgements

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Key References

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