PROVEN MODEL OF PERMAFROST THAW HALO FORMATION AROUND A PIPELINE

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Table 1: Model Input

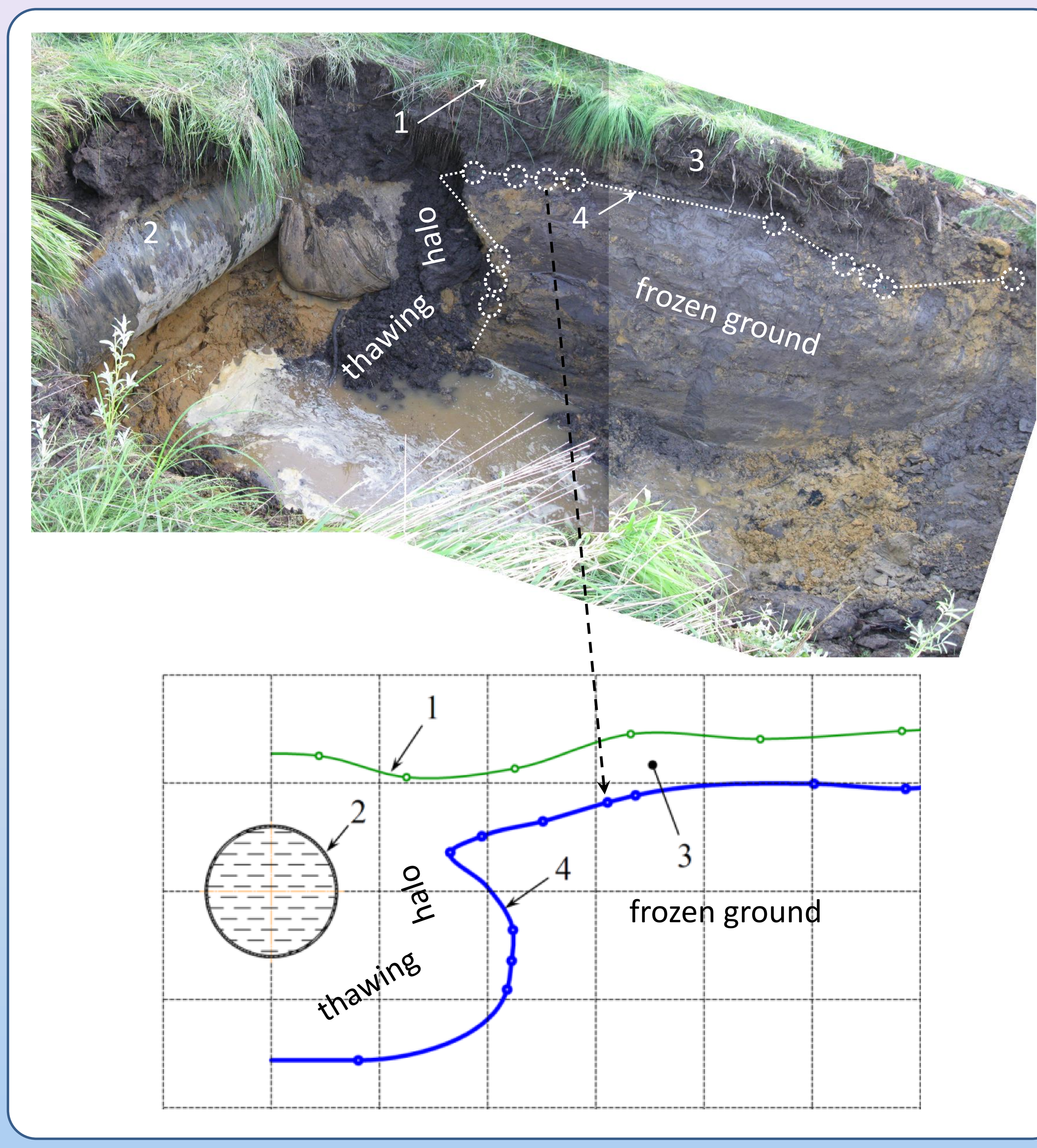
Pipeline parameters
Pipe wall temperature (t_{oil})
Pipe outside diameter
Pipe wall thickness
Thermal insulation coating thickness (h_{ins})
Thermal conductivity coefficient of thermal insulation coating
Trench geometry
Ground and backfill properties
Layer thickness
Thermal conductivity coefficient of thawing ground (S_t)
Thermal conductivity coefficient of frozen ground (S_f)
Heat capacity of thawing ground (C)
Moisture content
Density
Porosity
Melting temperature
Type
Thawing factor
Compressibility factor of thawing ground
Density
Permafrost parameters
Depth
Average annual temperature near the daylight surface (t_{perm})
Climate data
Average monthly temperatures
Average monthly wind speed
Average monthly snow depth
Power density of solar radiation
Air-ground heat transfer coefficient
Daylight surface albedo

Heat released from buried pipelines transporting warm hydrocarbons progressively thaws surrounding permafrost forming a permafrost thaw halo around the pipeline. Due to the non-uniform distribution of soil properties and massive ice deposits in the permafrost, differential settling of soil under the pipeline is likely to occur. This differential settlement results in bending strain in the pipe's wall which could lead to overstress and possible damage to the pipeline.

This work is dedicated to the prediction of permafrost thaw halo formation around a pipeline. A reasonably accurate predictive model of pipeline thermal interaction with permafrost is difficult but realizable if detailed data on all of the relevant factors influencing this interaction are available. But today obtaining full and precise information about these factors is quite difficult.

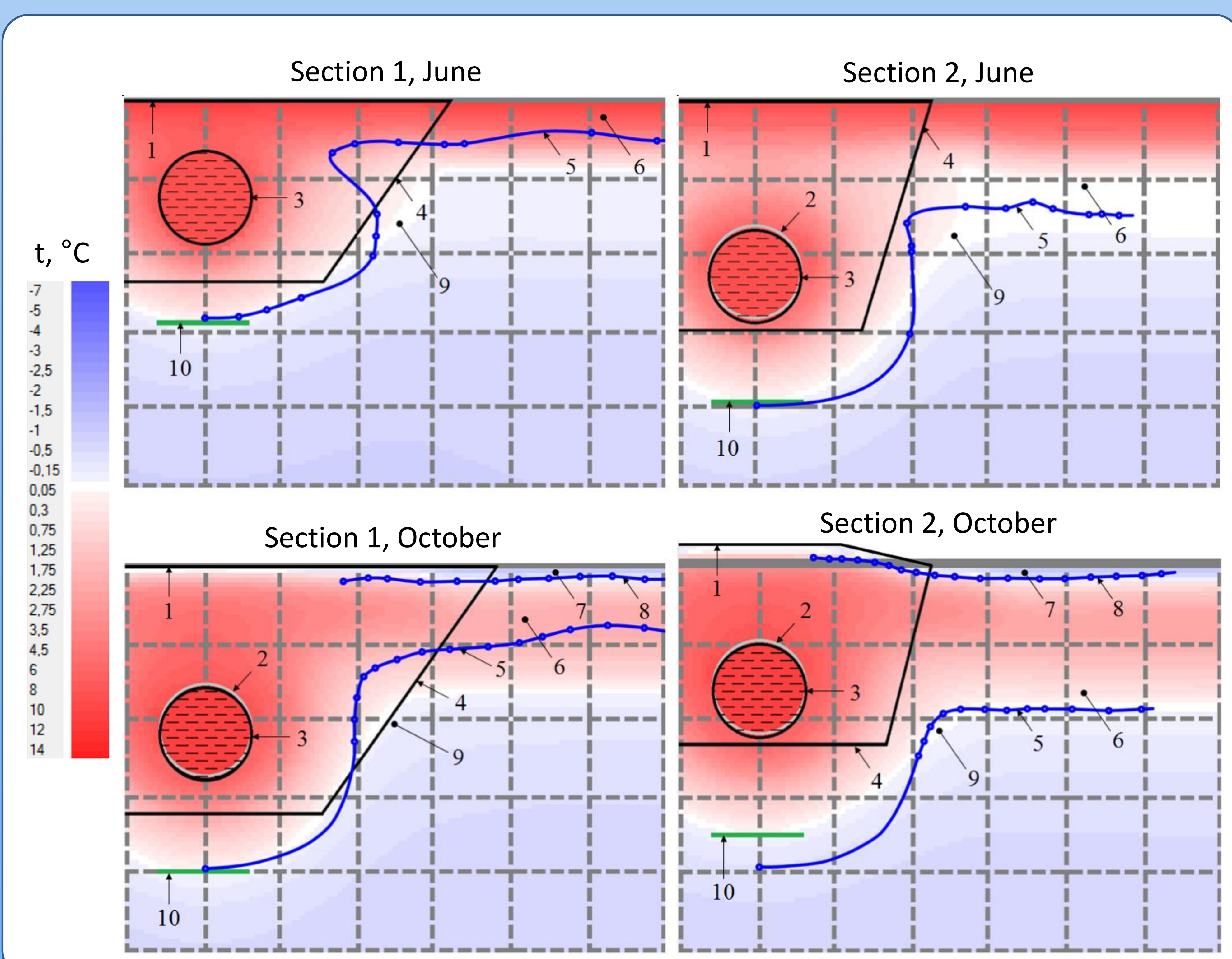
The aim of this work is to develop a predictive model that provides high ratio of the accuracy in estimating thawing halo dimensions to the quality of input data. In order to achieve this aim we solved the following problems:

Figure 1: Permafrost thaw halo measurement



Notations: 1 – a daylight surface; 2 – a pipeline; 3 – a seasonally thawing layer; 4 – a measured border of the thawing halo. The size of cells is 1 x 1 m.

Figure 2: Comparison of the measured and calculated permafrost thaw haloes



Notations: 1 – a daylight surface; 2 – an initial position of the pipeline; 3 – a current position of the pipeline (by taking into account ground subsidence); 4 – a border of the trench; 5 – a measured border of the thawing halo; 6 – a seasonally thawing layer; 7 – a seasonally frozen layer; 8 – a measured border of the seasonally frozen layer; 9 – a calculated border of the thawing halo; 10 – a calculated depth of the thawing halo under the pipeline. The size of cells is 1 x 1 m.

First, we constructed a list of factors (see Table 1) that possibly influence permafrost-pipeline thermal interaction and from this list we developed a model that predicts interaction with a pipeline and thaw halo extent.

Second, we measured the permafrost thaw halo around the oil pipeline (Ø = 1,22 m) located in Eastern Siberia, Russia (see Figure 1). Measurements of thaw halo extent were taken for two sections of the pipeline after 3 years from the start of its operation. In addition, we collected all information as accurately as possible about local conditions that affect permafrost-pipeline thermal interaction.

Third, we predicted the thawing halo formation around the pipeline using our model and conditions recorded at the pipeline. We compared calculated halo dimensions with measurements of the thawing halo for each of two sections during June and October in the third year of the pipeline's utilization. Figure 2 demonstrates the agreement between calculated and measured results.

Table 2: Influence of each factor on permafrost thaw halo formation

	-				Nominal input				+			
	Thawing halo dimensions, m		STL, m	SFL, m	Thawing halo Dimensions, m		STL, m	SFL, m	Thawing halo Dimensions, m		STL, m	SFL, m
	Depth under a pipe	Half-width			Depth under a pipe	Half-width			Depth under a pipe	Half-width		
Section 1, June												
C (-/+ 30%)	2,90	2,81	0,91	-	2,90	2,84	0,91	-	2,90	2,97	0,91	-
t_{oil} (-/+ 30%)	2,78	2,56	0,91	-					3,10	3,03	0,91	-
S_f (-/+ 30%)	3,10	2,69	0,91	-					2,85	2,97	0,91	-
S_t (-/+ 30%)	2,90	2,34	0,84	-					2,90	3,09	0,91	-
h_{ins} (on/off/-)	2,55	2,66	0,91	-					-	-	-	-
t_{perm} (-/+ 30%)	2,85	2,50	0,91	-					3,10	3,25	0,91	-
Section 2, June												
C (-/+ 30%)	3,93	2,13	1,41	-	3,93	2,13	1,41	-	3,93	2,13	1,41	-
t_{oil} (-/+ 30%)	3,73	1,88	1,72	-					4,10	2,38	1,84	-
S_f (-/+ 30%)	4,13	2,31	0,94	-					3,80	1,97	1,41	-
S_t (-/+ 30%)	3,88	2,00	0,97	-					3,98	2,25	1,91	-
h_{ins} (on/off/-)	3,43	1,91	1,41	-					-	-	-	-
t_{perm} (-/+ 30%)	3,78	1,94	1,09	-					4,09	2,31	1,53	-
Section 1, October												
C (-/+ 30%)	3,98	2,75*	1,91	0,19	3,98	2,15	1,60	0,18	3,95	2,16	1,69	0,19
t_{oil} (-/+ 30%)	3,75	1,97	1,69	0,19					4,15	2,38	1,69	0,19
S_f (-/+ 30%)	4,20	2,25	1,63	0,13					3,80	2,06	1,69	0,19
S_t (-/+ 30%)	3,93	2,00	1,44	0,28					3,98	2,06	1,69	0,19
h_{ins} (on/off/-)	3,38	1,94	1,63	0,19					-	-	-	-
t_{perm} (-/+ 30%)	3,80	2,00	1,56	0,19					4,20	2,41	1,91	0,19
Section 2, October												
C (-/+ 30%)	3,50	2,70*	1,91	0,19	3,48	2,20	1,87	0,18	3,48	2,70*	1,91	0,19
t_{oil} (-/+ 30%)	3,30	2,5*	1,88	0,19					3,65	3,05*	1,88	0,19
S_f (-/+ 30%)	3,68	3,00	1,88	0,13					3,35	2,65	1,94	0,22
S_t (-/+ 30%)	3,43	2,28	1,66	0,28					3,50	2,90	1,91	0,09
h_{ins} (on/off/-)	3,00	2,60	1,88	0,19					-	-	-	-
t_{perm} (-/+ 30%)	3,35	2,65	1,72	0,19					3,56	2,85	2,16	0,19

Finally, we conducted a series of numerical studies to evaluate the individual influence of each factor on permafrost thaw halo formation (see Table 2), allowing us to estimate the requirements for input condition.

In conclusion, we have developed and tested a predictive model of permafrost thaw halo formation that makes reasonable demands on initial data accuracy and provides sufficient accuracy of calculated thawing halo dimensions. According to the results of the numerical studies, the dimensions of the thawing halo are most sensitive to the temperature of the transported hydrocarbons, thermal conductivity of frozen soil and the initial temperature field of permafrost within the region of the pipeline's thermal influence. This model can be used as a basis for further investigations of the stress state of a pipeline in the conditions of soil subsidence.

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