Drivers of Changes in the Permafrost Late Shoulder Season

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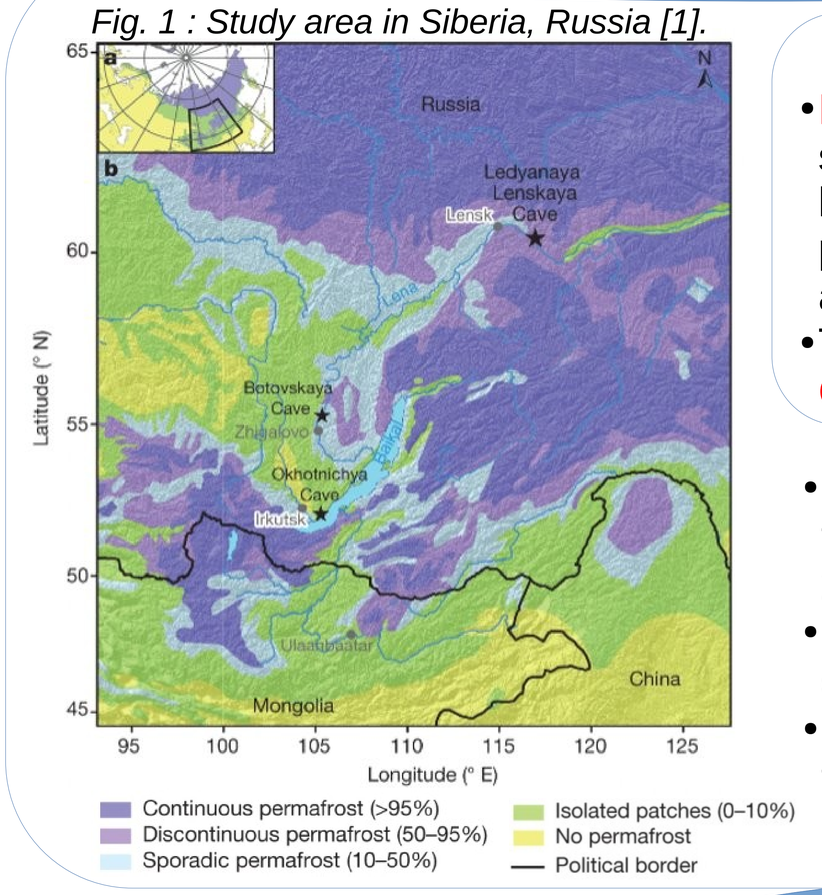
Objective : Identifying and quantifying the determinants driving the timing of the day of upper soil layer freeze during the late shoulder season (transition period after plant senescence and before active layer freezing) in permafrost regions. The permafrost is ground that stays at or below 0°C for at least two consecutive years.

Conclusions : The timing of upper soil layer freeze at the late shoulder season in permafrost regions seems to be dependent on the thermal regime of said permafrost. For each thermal regime, a combination of 6 variables can be used to explain this timing : elevation, timing of the first insulating snowfall, insulation of the vegetation, latitude, drop of 2m temperature below 0°C and soil humidity in July, with the 2 meter temperature being particularly important. Interdecadal trends in the timing of active layer of permafrost freezing have also been highlighted.

1. Timing of active layer freezing

Fig. 1 : Study area in Siberia, Russia [1].

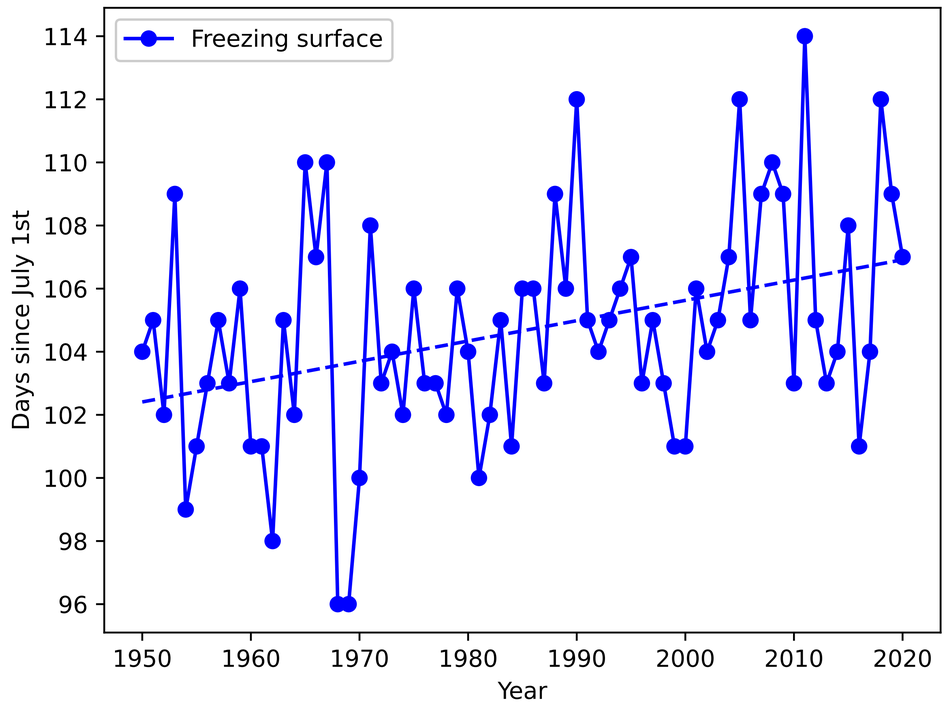


Why ?

- No large scale view of the seasonal dynamic of the active layer, the soil layer above the permafrost that undergo freezing and thawing each year.
- Thawing periods associated with GHG release.

- 5-days delay of upper soil layer freeze : positive trend from 1950 to 2020.
- Complementary information to field data with ERA5 reanalysis [2].
- What are the factors influencing this trend ?

Fig. 2 : Time series of the day of upper soil layer freeze (ERA5 reanalysis).



2. Spatial Regression : Spatial Error Model

$$Y_i = X_i \beta + \epsilon_i$$

Error

Y_i : Dependent variable

$X_i \beta$: Independent variables coefficients

$\epsilon_i = \lambda \omega_i \epsilon_i + \mu_i$

$\lambda \omega_i \epsilon_i$: Spatially structured error

μ_i : Random error

- Takes into account spatial autocorrelation of the data.
- If errors OLS = spatially correlated, correction with Spatial Error Model.

The independent variables studied are correlated with the timing of the freezing of the upper layer of soil, as shown in Fig. 3.

Fig. 3 : Time series of the days of upper soil layer [0 – 7 cm] freeze, insulating snow layer and air temperature < 0°C for a cell of the study area.

3. Results : Model of the day of the upper soil layer freeze

Spatial determinants of the timing of upper soil layer freezing for each thermal regime of the permafrost

Standardized coefficients	Elevation [3]	Timing of first insulating snow (Thickness = 14 cm) [2]	Insulation of the vegetation [4]	Latitude	Timing of below 0°C 2m air temperature [2]	Soil humidity in July [2]
Isolated	1.46	-0.76	0.52	2.86	8.69	
Sporadic		-1.65		1.12	7.98	
Discontinuous		-1.83		0.59	7.35	0.41
Continuous	0.26		0.35		7.02	

Table 1 : Standardized coefficients of the Spatial Error Models

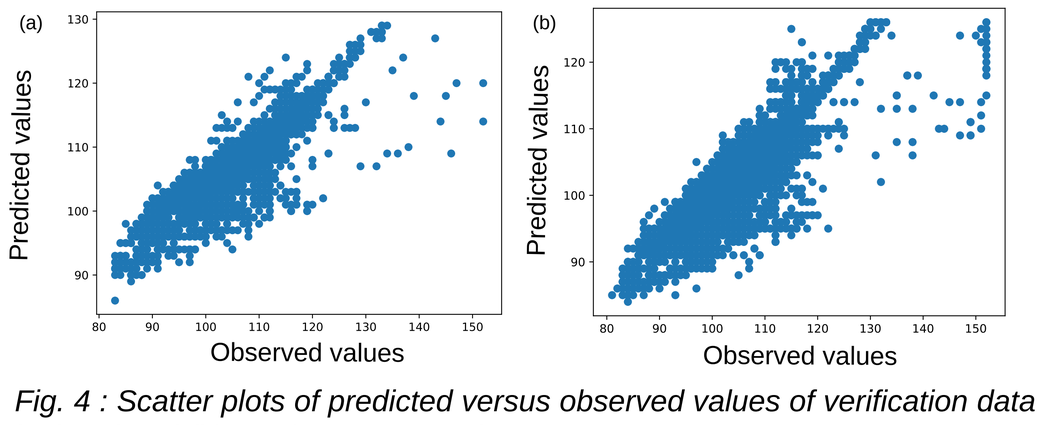


Fig. 4 : Scatter plots of predicted versus observed values of verification data for (a) isolated and (b) continuous permafrost

- Permafrost area decomposed into 4 thermal regimes : **insulated**, **sporadic**, **discontinuous**, **continuous.**
- Good skill of the model across all 4 thermal regime of permafrost (Corr ~0.86).
- Continuous permafrost still shows many outliers.

[1] Vaks et al 2020, Nature 577, 221-225.
[2] Muñoz Sabater 2021, Copernicus Climate Change Service (C3S) Climate Data Store (CDS).
[3] Fick et al 2017, International Journal of Climatology 37, 4302-4315.
[4] Global Land Cover 2000.