AI methods application for classifying stratigraphic layers of snow cover with Snow micro pen device

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Abstract. In this work, AI methods were used to classify stratigraphic layers of the snow strata using measurements from the snow micro pen device. The data from the device were processed and the classified stratigraphic layers of the snow strata were compared with the direct snow pitting data. In the future, it was possible to classify stratigraphic layers of the snow strata using the available classified data of the device by the K-nearest neighbours clustering method according to the newly obtained data of the device without additional manual pitting.

1 Introduction

Observations of snow cover have been conducted at the site of the meteorological observatory by the staff of the Faculty of Geography of Moscow State University for a long time [1, 2]. The problem of classifying layers in the snow cover has been studied and researched by many authors [3-8]. In this paper, an attempt is made to use AI methods to classify stratigraphic layers of the snow column based on measurements of a snow micro pen device, similar to, for example, in the article "Snow micro pen" [9, 10].

2 Main part

In the winter season of 2023-2024 in Moscow, the actual temperature of the first half of November according to observations was 6.2°C [https://rp5.ru/], although the norm of average monthly temperature in November in Moscow is -0.5°C [http://www.pogodaiklimat.ru/], and thus the deviation from the norm for the first half of the month amounted to +6.7°C (Fig. 1).

As can be seen in Figure 1, Moscow had abnormally warm weather in the first half of November 2023, exceeding the November norm by several degrees. Generally, according to the new climatic norms (1991-2020), a steady transition of air temperature through 0°C towards negative values occurs in Moscow from 12 November. However, in 2022 this transition occurred on 15 November, and in 2023 it occurred on 17 November. So, in 2023, the arrival of meteo winter in Moscow (i.e., the moment when there is a steady transition of average daily temperatures through zero towards negative values) occurred only on 17

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November. On 23-24 November snow began to fall intensively and snow cover began to be established. Thus, on 24 November the thickness of the snow cover in Moscow was 8 cm, and on the morning of 25 November it reached about 15 cm, which is the highest value for 25 November since 2004 and is usually reached by 17 December. Temperatures on 24 and 25 November in Moscow were around -6°C to -8°C degrees Celsius. During the afternoon of 26, snowfall did not increase, while temperatures rose to -3°C. There was very heavy snowfall on the evening of 26 and the night of 27. There was also freezing rain on the morning of 27 November, and a slight thaw to +2°C degrees on the afternoon of 27 November. The snow cover thickness on 27 November in Moscow at the VDNH weather station was 21 cm. About 16 mm of precipitation fell on the night of 27 November. On 28 November there was also a light snowfall. In the morning of 29 November in Moscow it got cold to -10°C. Snow thickness in Moscow at VDNH on the morning of 29 November was 18 cm, and three snow horizons and a crust were detected in the snow layer at the time of the study at the meteorological site on 29 November. The results of snow cover studies at the MSU meteorological observatory site on 29 November 2023 are shown in Fig. 2 and in the Table 1:

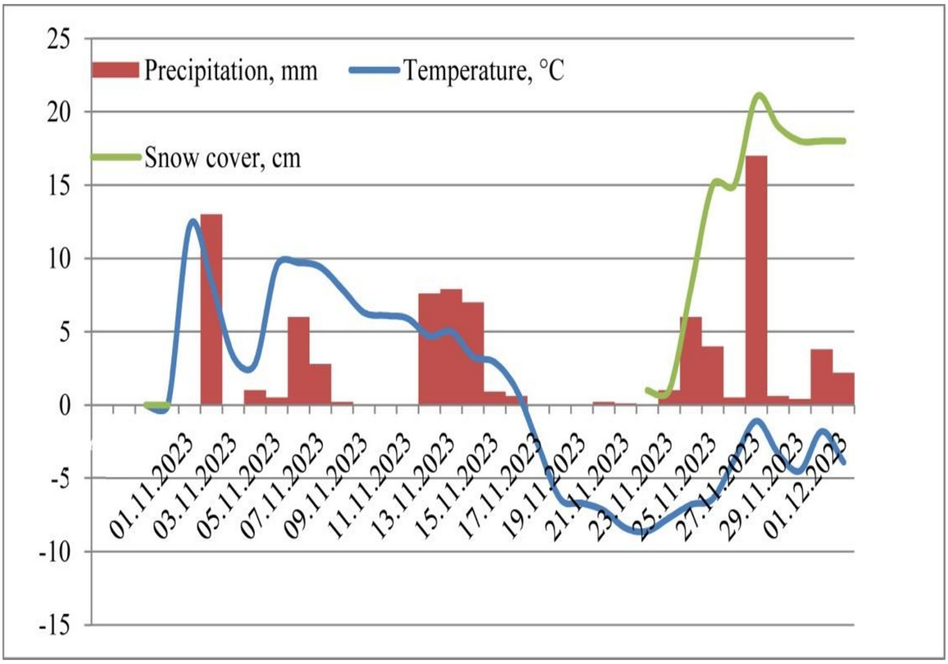

Fig. 1. Change in air temperature and snow cover thickness in Moscow at VDNH weather station on 29 November 2023

Fig. 2. Snow layer structure on 29.11.2023 at the meteorological site of MSU

Table 1. Structure of the snow layer at the MSU weather observatory site on 29 November 2023

	Layer, cm	
1	21-23	Freshly fallen snow layer
2	19-21	Ice crust
3	16-19	Layer of loosened snow with ice formations with initial stage of faceting and grain size up to 1 mm (155, 163, 155 average density 157 kg/m^2)
3	9-16	The layer of fine-grained snow with a grain size of 1 mm (four fingers penetrate) (159, 161, 174 average density 164 kg/m^2) is less dense than the lower one
4	0-9	Layer of relatively compacted snow with grain size 1-2 mm (fist penetrates) (212, 217, 214 average density 214 kg/m^2)

Temperatures at the time of the surveys in the snowpack were: at the bottom (0 cm) -0.2°C, at the 10 cm level -2.2°C, at the 20 cm level -5.6°C, and at the 23 cm level -4.8°C.

Machine learning is the use of mathematical models of data that help a computer learn without direct instruction. It is considered a form of artificial intelligence (AI). Machine learning uses algorithms to identify patterns in data. The main machine learning algorithms are linear regression, logarithmic regression, decision tree, K-nearest neighbours method (Figure 3) and others.

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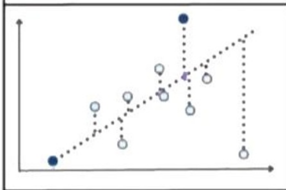
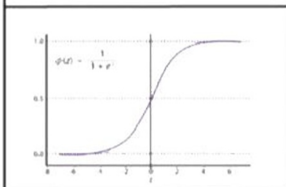
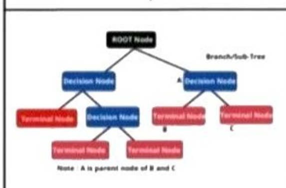
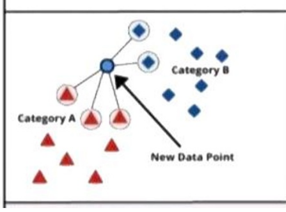
Representation	Algorithm Name
	Linear Regression
	Logistic Regression
	Decision Tree
	K-Nearest Neighbors

Fig. 3. Basic machine learning algorithms and their representation.

The essence of these algorithms is well enough described in the scientific literature [11-12].

In this paper, we attempted to use AI methods to classify stratigraphic layers of the snow strata based on snow micro pen measurements. Snow micro pen (or snow micro penetrometer) is a device that allows one to determine the hardness of snow layers in 4 micrometre increments by pushing a stylus with a mechanical resistance sensor into the snow [13-15] (Fig. 4).

Fig. 4. Exterior view of Snow micro pen device operation (www.slf.ch/en)

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The instrument data were processed and the classified stratigraphic layers of the snow strata were compared by comparing them with the direct snow pitting data. In the future, it was possible to classify stratigraphic layers of the snow strata using the available classified instrument data of the snow stratigraphic layers by the K-nearest neighbours clustering method according to the newly obtained instrument data without additional manual pitting (Figure 5).

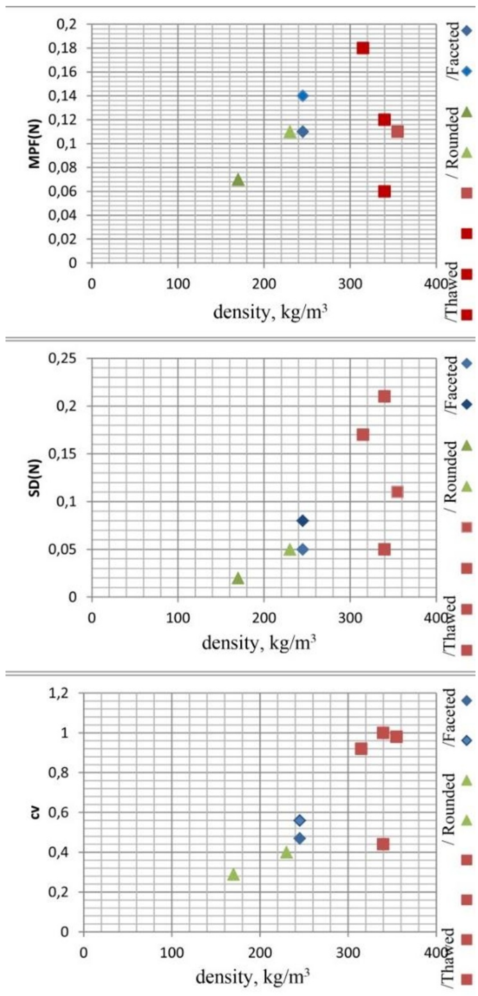

Fig. 5. Classification of stratigraphic layer types based on Snow micro pen data

3 Conclusions

Figure 1 (b) shows that the resulting metamorphic ice crystal shapes in the snow column (rounded->faceted->melted) differ both in density and in the parameters obtained from Snow micro pen data processing (MPF(N) - mean resistivity force SD(N)- its standard deviation, and cv- its covariance). This makes it possible to cluster these processed device data and to type new device measurement data without involving the results of direct manual pitting.

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References

1. D.M. Frolov, Y.G. Seliverstov, et.al., Arctic and Antarctica **1.** 1 – 13 (2023). DOI: 10.7256/2453-8922.2023.1.40448.2
2. D.M. Frolov, G.A. Rzhanitsyn, S.A. Sokratov, et. al., E3S Web of Conferences **371**, 03004 (2023). DOI: 10.1051/e3sconf/202337103004
3. M. Proksch, N. Rutter, Ch. Fierz, M. Schneebeli, The Cryosphere**. 10 (1):**371–384 (2016). https://doi.org/10.5194/tc-10-371-2016
4. M. Sturm, J. Holmgren, G.L. Liston, Journ. of Climate. **8** (5 (Part 2)): 1261–1283 (1995). https://doi.org/10.1175/1520-0442(1995)008<1261:ASSCCS>2.0.CO;2
5. Ch. Fierz, R.L. Armstrong, et.al., The international classification for seasonal snow on the ground (UNESCO, IHP (International Hydrological Programme)–VII, Technical Documents in Hydrology, No 83; IACS (International Association of Cryospheric Sciences) contribution No 1) (2009)
6. S. Colbeck, A review of the metamorphism and classification of seasonal snow cover crystals, IAHS Publication, **162**, 3–24, (1987)
7. C. B. Ménard, et.al., Earth System Science Data, **11**, 865–880, (2019)
8. J. King, et.al., The Cryosphere, **14**, 4323–4339, (2020)
9. J. Kaltenborn, et.al., Pre-trained Models for SMP Classification and Segmentation, (2022). https://doi.org/10.5281/zenodo.7063521,
10. J. Kaltenborn, et.al., Geosci. Model Dev., **16**, 4521–4550 (2023), https://doi.org/10.5194/gmd-16-4521-2023
11. N. Nguyen, Y. Guo, *Comparisons of sequence labeling algorithms and extensions,* Proceedings of the 24th international conference on Machine learning, pp. 681–688, (2007)
12. G., Lemaître, F., Nogueira, C. K. Aridas, The Journal of Machine Learning Research, **18**, 559–563, (2017)
13. M. Schneebeli, J. B. Johnson, Annals of Glaciology, **26**, 107–111, (1998)
14. H. Löwe, A. Van Herwijnen, Cold Regions Science and Technology, **70**, 62–70, (2012)
15. J. B. Johnson, M. Schneebeli, Snow strength penetrometer, uS Patent 5,831,161, (1998)