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Modeling the Trooz Glacier's movement using air temperature data and satellite SAR observations in 2015–2022

Abstract. The aim of this study is modeling the dependence of maximum velocity of the Trooz Glacier (Kyiv Peninsula, West Antarctica) on air temperature. For this purpose, we processed a time series of meteorological observations at the Akademik Vernadsky station and the ice flow velocity of the Trooz Glacier. The ice velocities were determined from the synthetic aperture radar images, acquired by the Sentinel-1 satellite, for the period from May 2015 to November 2022. The SAR images were processed in the SNAP (Sentinel Application Platform) program using the Offset Tracking method. As a result, 219 ice flow velocity maps were obtained. During the studied period, the maximum velocities varied from 2.64 m/day (August 19, 2015) to 4.05 m/day (April 18, 2020). A functional dependence between the temperature data from the Akademik Vernadsky station and the remote-sensing data on the air temperature above the glacier's surface was established. We combined the three parameters (time series of the maximum velocities of the glacial flow, remote temperature measurements above the glacier, and direct temperature measurements at the Akademik Vernadsky station) in a linear model. In order to increase the accuracy of the modeling, an *a posteriori* optimization was carried out. As a result, the average error in determining the maximum velocity of the glacier reduced from 23 cm/day to 17 cm/day.

Keywords: *a posteriori* optimization, Akademik Vernadsky station, ice flow velocity, SAR images, Sentinel-1

1 Introduction

Under climate change, the world ocean's level rises rapidly due to the melting of grounded glaciers. A significant input to this process comes from the discharges of the Arctic and Antarctic Ice Sheets. In recent decades, significant efforts have been undertaken to study polar glaciers (Lemos et al., 2018; Stocker-Waldhuber et al., 2019; Friedl et al., 2021) and ice-flow velocity changes. The study regions cover Arctic Canada, Greenland, some individual European territories, including Svalbard, in the north, and the Antarctic Peninsula in the south.

The velocity of a glacier's movement depends on many factors, including the bed topography and structure of the underlying surface, atmospheric pressure, and temperature. Therefore, temperature distribution substantially affects modern glaciological and geomorphological processes. Glacier temperature is controlled by three main factors (Jiskoot, 2011): heat exchange with the atmosphere, geothermal heat flow, frictional heat due to ice movement.

A large number of publications indicate the relevance of this task, given the problems of climate change and ocean level (for example, Domingues et al., 2018; World Meteorological Organization, 2023).

The research on the Antarctic continent is gaining special importance. This is associated with the significant length of the coastline (18.000 km) as well as gaps in our knowledge about the current rates of ice cover change. In particular, this is caused by spatiotemporal changes in the velocity of glaciers, even for relatively small areas (within 100 km^2) (Tretyak, 2016; Li et al., 2023; Miles et al., 2023).

Special attention in glaciological research is paid to the Antarctic Peninsula. Climatic conditions of the peninsula experienced significant changes during the last 50 years (Cook &Vaughan, 2010). Substantial changes in ice dynamics along the east and west coasts of the northern part of the Antarctic Peninsula in 1992—2014 were found by a complex analysis of the observation time series (Seehaus et al., 2018). The average ice flow velocity in 1992—2014 grew from 0.6—0.8 m/day to 1.3—1.9 m/day. This indicates that, in general, the glacier movement velocity and the spatial heterogeneity of the speed distribution have increased. The rate of change in the surface area of glaciers on the Antarctic Peninsula depends on the amount of solar radiation they receive (determined, in particular, by their position and azimuthal orientation) and the atmospheric precipitation. Thus, Davies et al. (2012), based on observations on the Trinity Peninsula (1988—2001), established that the area of glaciers in the western part of the peninsula decreased less than in the east. This east-west difference is largely the result of temperature variation dependent on landforms and precipitation gradients on the Antarctic Peninsula. According to Cook et al. (2014), 90% of the 860 glaciers of the Antarctic Peninsula decreased in area between 1950 and 2004. This region is characterized by clear patterns in the increase in the ice loss from north to south. The east- and west-coast glaciers also differ significantly. The results indicate a general steady retreat of the glaciers since the 1970s, with a small re-advance in the late 1990s. The reduction in area differs significantly between types of glaciers and correlates with their shape, slope and type of ice front (Cook et al., 2014).

To establish correlation between the atmospheric temperature and the glacier movement velocity, it is necessary to process long-time series data (Christie et al., 2016; Hogg et al., 2016; Carr et al., 2017; Seehaus et al., 2018). That allows to follow seasonal changes in glacier dynamics (Cassotto et al., 2015; Boxall et al., 2022) and forecast them.

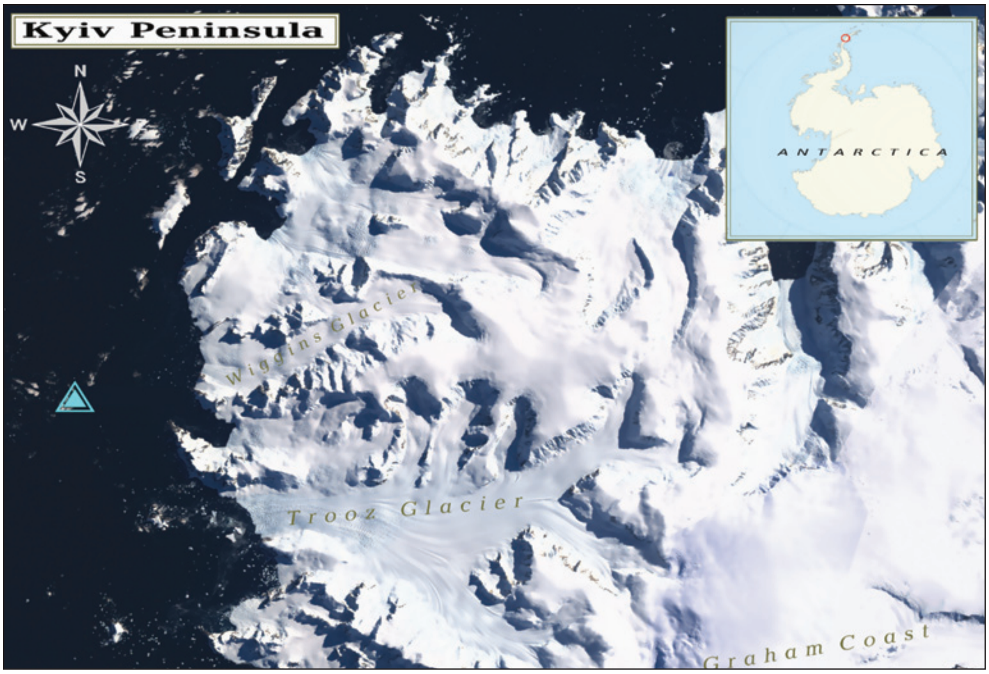
Satellite technologies are the most effective for monitoring the ice cover of hard-to-reach areas. Studies use data from the Sentinel satellites which are a part of the system for continuous and integrated monitoring of the Earth deployed in the framework of the European Copernicus program.

The Sentinel-1 mission is a constellation of two polar-orbiting satellites (Sentinel-1A and Sentinel-1B). These satellites provide the earth's surface remote sensing using synthetic aperture radar in the C-band at 5.405 GHz, regardless of the weather conditions or time of day. The revisiting time between acquisitions is 6—12 days. Having these parameters, Sentinel-1 satellites are a powerful tool and data source for studying ice flow velocity. Thus, we chose to determine glacier velocity using synthetic aperture radar (SAR) images from the Sentinel-1 satellite.

The high dynamic range and radiometric resolution of Sentinel-2A are very useful for snow and ice cover studies (Pope & Rees, 2014). Based on data for the Aletsch Glacier (Swiss Alps), Fox Glacier (New Zealand), Jakobshavn Isbree and neighboring glaciers in West Greenland, as well as a part of the Antarctic Peninsula near the Larsen C Ice Shelf, it was established that the movement of ice masses can be measured with the accuracy of at least 1—2 m (Kääb et al., 2016).

Analysis of Sentinel-1 SAR images showed seasonal changes in the speed of glacier movement. According to satellite observations of 105 glaciers in the west part of the Antarctic Peninsula from 2014 to 2021, the average acceleration of the movement of ice masses in summer was 12.4 ± 4.2%, and the maximum acceleration was 22.3 ± 3.2% (Wallis et al., 2023). The ice velocity determination within the Kyiv Peninsula confirmed that the speed of glacier movements can reach 3.5—4 m/day (Kadurin & Andrieieva, 2021).

The object of our study is the Trooz Glacier (65°20′S 63°58′W), located on the Kyiv Peninsula near the Ukrainian Antarctic Akademik Vernadsky station in West Antarctica (Fig. 1). This is the largest glacier on the peninsula. It flows into the northern part of Col-



The Ukrainian Antarctic Akademik Vernadsky station located on Galindez Island (65°15′S, 64°16′W)

Figure 1. Satellite image of the Kyiv Peninsula in West Antarctica (Image Source: Landsat Image Mosaic of Antarctica (LIMA), https://lima.usgs.gov/)

lins Bay. According to the Composite Gazetteer of Antarctica (https://data.aad.gov.au/aadc/gaz/scar), the width of the glacier at the mouth is 2.8 km and its length is 28 km. A peculiarity of this glacier is the area increasing by more than 1 km^2 over the past 60 years. A similar trend is registered on the Antarctic Peninsula in only one other glacier (Cook et al., 2014). The rest have grown smaller over the past 60 years.

The goal of this study is modeling the dependence of the Trooz Glacier's velocity on air temperature. The predictive model could be used for assessing the amount of ice that moves into the sea as a result of global temperature variations.

2 Data and methods

The ice flow velocities were determined from SAR images acquired by the Sentinel-1 satellite, data type GRD (Ground Range Detection) with horizontal polarization. In May 2015, the first image of this type was obtained for the studied area.

In order to obtain robust results, the time interval between acquisitions should be as short as possible. Therefore, the images for processing were chosen from the satellite-ascending part of the orbit, where the interval between acquisitions is 12 days. We processed the time series of all 220 available images obtained in 2015—2022. The data were downloaded through the Alaska Satellite Facility resource (https://search.asf.alaska.edu/). Processing was performed by using SNAP (Sentinel Application Platform) program (European Space Agency, 2022).

The air temperature was directly measured at the distance of 20 km away from the glacier at the Akademik Vernadsky station (Galindez Island). Access to the meteorological database was obtained via the State Institution National Antarctic Scientific Center (http://meteodata.uac.gov.ua/SYNOP_data/decoded_table_data/).

Weather station data from the Akademik Vernadsky station were supplemented with temperature data remotely measured directly above the surface of the

Trooz Glacier. These data were accessed at a web resource (https://earth.nullschool.net/) which presents global weather conditions updated every three hours with the possibility of forecasting. The website has access to databases starting from 2013.

The speed of glacier movement was calculated based on the results of determined movements of the ice flow between consecutive acquisitions. A number of preprocessing steps were performed for each satellite radar image after (Filipponi, 2019): application of orbit correction data; removal and reducing of noise effects by normalizing of the backscatter signal; and calibration (the digital value of each image pixel was converted into a radiometrically calibrated backscatter).

The preprocessing stage was based on the Sentinel-1 Level-1 GRD Sigma0 products. Unlike the original image, Sigma0 is an orbitally corrected and calibrated version in which all geometric distortions inherent in SAR images are corrected. The calibrated backscatter of Sigma0 allows to compare images from different times and determine the magnitude of horizontal movements. The offset tracking was done for each consecutive pair of images to create a velocity map of the glacier.

An example of the combination of the velocity map and the Sigma0 product (backscatter signal) is presented in Figure 2. Such a combination of images allows not only to obtain data on the glacier velocity but also to obtain a visual perception of the contours of the terrain and the coastline.

Due to the significant height heterogeneity of the territory and the tilt of the satellite's sensor, the radar image may be distorted. Reducing the geometric distortions was achieved by a terrain correction procedure (Terrain Correction). For this purpose, the data of the digital elevation model ACE30 were used (Serco Italia SPA, 2018).

3 Results

After processing all available radar images, we obtained 219 ice flow velocity maps, covering the period from May 2015 to November 2022. By using all created maps, the changes in the maximum velocity of the glacier were determined. Regardless of the season, the maximum velocities occurred in the same area, about three kilometers from the mouth of the glacier (Fig. 2). Figure 3 presents a graph of changes in the maximum velocities of the Trooz Glacier in 2015–2022.

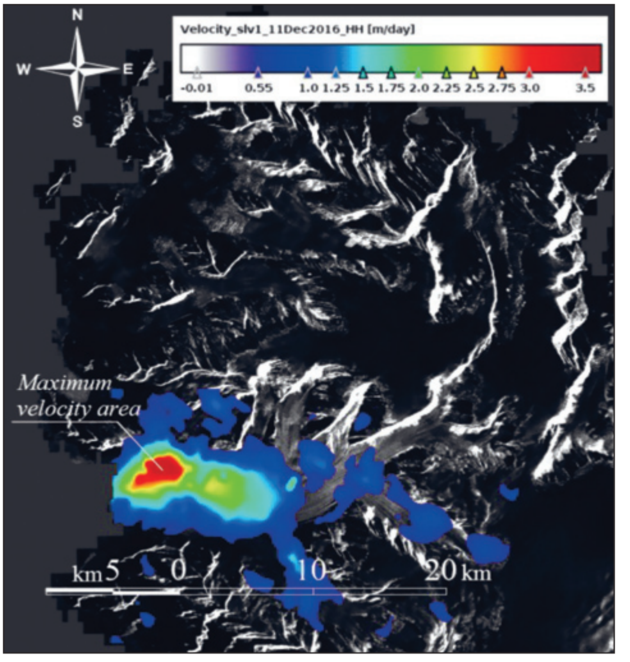


Figure 2. An example of a coregistered glacier's movement velocity map and Sigma0 product for the period 29 November 2016 – 11 December 2016

According to the obtained data, the maximum ice flow velocity varied from 2.64 m/day (August 19, 2015) to 4.05 m/day (April 18, 2020). The average velocity value for the area with maximum ice speed is 3.20 m/day.

In addition, the graph shows the seasonal cycles of velocity changes associated with changes in the temperature regime throughout the year. It was confirmed by the periodogram analysis, which was conducted by the ice velocity data. A strong spike occurred in the periodogram at point seven. It corresponds to seven cycles, which represent observation period of seven full years. In order to analyze such relationships, Figure 3 shows a diagram of air temperature according to the data of the Akademik Vernadsky meteorological station. The Antarctic summer periods (December–February) are marked by yellow vertical bars in the graph. These seasons are characterized by an

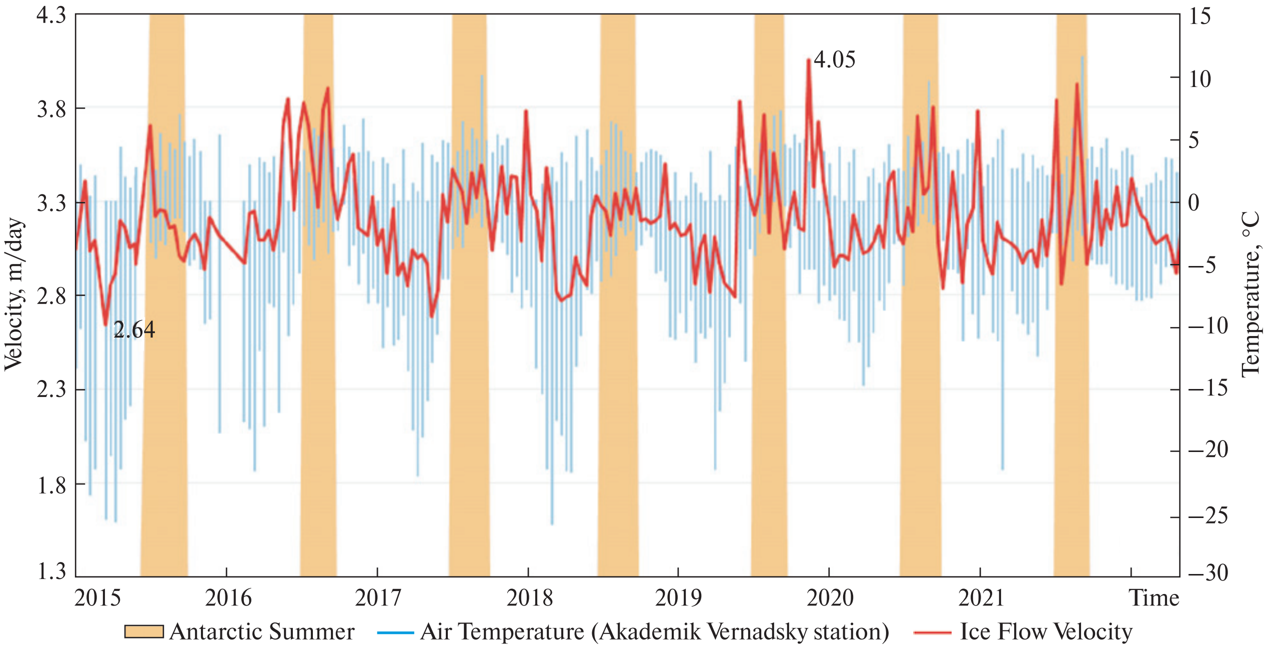


Figure 3. The graph of changes in the maximum velocities of the Trooz Glacier movement. The highest value – 4.05 m/day (18 April 2020); the lowest value – 2.64 m/day (19 August 2015). The time span from May 2015 to November 2022 was analyzed. Yellow bars indicate the austral summers (December–February)

increase in temperature and generally are accompanied by an increase in the ice flow velocity.

3.1 Statistical analysis of time series

The glacier mass displacements occur under the influence of various factors: relief and structure of the bed topography, atmospheric pressure and air temperature, heat exchange with the atmosphere, geothermal heat flow, frictional heat caused by the movement of the glacier (Jiskoot, 2011). Therefore, it is necessary to consider these influences separately or create sufficiently complex models to take all these factors into account. To develop a model of glacier movement, it is necessary to analyze the time series of ice displacements and changes in the outer factors. We attempted to develop a simple model of the relationship between air temperature and ice velocity.

To establish the spatiotemporal relationship between the ice flow velocity and air temperature, we analyzed the changes in air temperature during 2015–2022. At the Akademik Vernadsky station, air temperature is measured every 3 hours. The long-term changes in temperature during the studied period (2015–2022) are shown in Figure 3 (blue line).

As the temperature is liable to vary within a few degrees during the day, it is necessary to average the initial data. The measurement results were approximated by the Fourier series:

$$t_{Vern} = a_0 + \sum_{i=1}^{n} \left[c_i \cdot \cos(i \cdot f) + s_i \cdot \sin(i \cdot f) \right], \quad (1)$$

where n – the number of harmonics of the Fourier series; a_0, c_i, s_i – constant coefficients, determined by approximation; $f = \Delta T / 2\varpi$, where ΔT – the time interval between the first and last measurement. Averaging the temperature change was done for $n = 50$ which allows tracking seasonal patterns as well as certain deviations.

The Akademik Vernadsky station is located 20 km from the Trooz Glacier. Thus, the weather conditions of the station and the glacier are somewhat different. However, with a certain degree of accuracy, it can be assumed that the differences in air temperatures at the two locations have similar behavior. Figure 4 shows the air temperature variation at the station and over the middle part of the glacier with an interval of 12 days in 2015–2022.

From Figure 4, according to the maximally simplified approximation (by the 2nd harmonic), the temperature above the glacier is generally lower than at the Akademik Vernadsky station. The temperature difference between trends varies over time. From *in situ* measurements, the lower temperature at the Akademik Vernadsky station, the greater temperature difference. This pattern is especially clear during winter. The deviations from this pattern may be related to errors in remote measurements over the Trooz Glacier.

In the first approximation, the dependence between the air temperature at the station and over the middle part of the glacier can be represented by a linear equation:

$$t_{Trooz} = b + d \cdot t_{Vern}, \quad (2)$$

where b, d – constant coefficients. To determine these coefficients with the least influence of other meteorological factors and measurement errors, we generalized temperature variation over 12-day intervals. Reducing the number of harmonics for approximating the temperature change causes the trend to deviate from the real data. Based on the approximation of the time series of air temperature at the Akademik Vernadsky station and over the Trooz Glacier at different numbers of harmonics, the values of b and d and the accuracy of their determination m_b and m_d, were calculated (Table).

In Table, the coefficients b and d are practically the same when temperature data are approximated with a Fourier series, for the number of harmonics ranging from 10 to 50. Coefficients b and d obtained by approximation for the 2nd harmonic significantly differ from the values for 10th–50th harmonic. This is explained by the maximum smoothing of the approximation curve determined by the 2nd harmonic (Fig. 4). The coefficients determined by the empirical data also significantly differ from the approximations. In this case, the coefficients b and d are distorted by the errors of remote measurement, as seen from the significantly larger m_b and m_d.

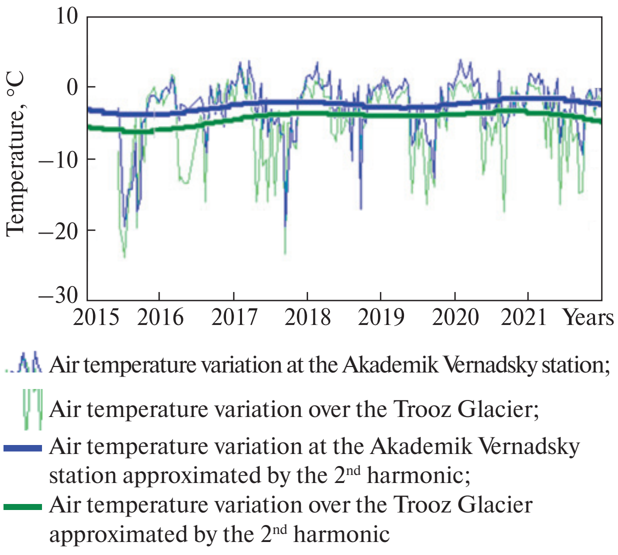
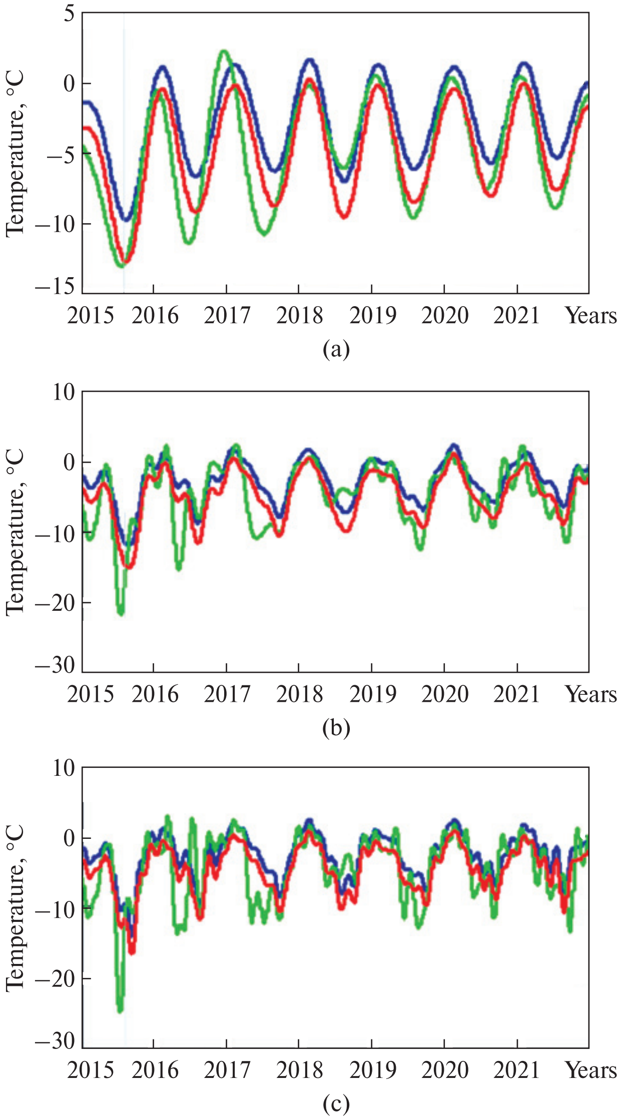


Figure 4. Air temperature variation at the Akademik Vernadsky station and over the middle part of the Trooz Glacier with an interval of 12 days in 2015–2022

The selection of the approximation harmonics number in the range from 10 to 50 does not have a significant effect on the generalized coefficients b and d. By substituting the extreme value of the temperature t_{VERN} = –20 °C into expression (2) and using the coefficients b and d determined for the 10th and 50th harmonic, we recalculated temperature values on the surface of the glacier (–24.3 °C and –22.8 °C,

Table. The values of coefficients b and d calculated by approximating temperature time series with different number of harmonics n^{th}, and based on the results of empirical data

Number of harmonics, n^{th}	Parameter		Mean squared error of parameter	
	b	d	m_b	m_d
2	–1.342	1.190	0.022	0.008
10	–1.665	1.132	0.039	0.010
20	–1.618	1.171	0.050	0.013
30	–1.576	1.130	0.055	0.014
40	–1.596	1.082	0.060	0.015
50	–1.687	1.055	0.062	0.015
By empirical data	–1.992	1.020	0.269	0.056



— approximation curve of air temperature variation at the Akademik Vernadsky station;

— approximation curve of air temperature variation over the Trooz Glacier;

— air temperature variation recalculated from measurements at the Akademik Vernadsky station to the Trooz Glacier using coefficients *b* and *d*

Figure 5. The air temperature variations approximated by the Fourier harmonics at the Akademik Vernadsky station and over the middle part of the Trooz Glacier during 2015—2022: (a) approximation by 10^{th} harmonic of the Fourier series; (b) approximation by 20^{th} harmonic of the Fourier series; (c) approximation by 50^{th} harmonic of the Fourier series

respectively). For temperatures from +10.0 °C to –30.0 °C, this difference does not exceed 6% of the absolute temperature value.

Figures 5a, 5b, and 5c show air temperature variations approximated by the 10^{th}, 20^{th}, and 50^{th} harmonics at the Akademik Vernadsky station and over the middle part of the Trooz Glacier in 2015—2022. These figures also show air temperature variation recalculated from measurements at the station to the Trooz Glacier using coefficients *b* and *d*. From the curves of temperature variation, it follows that with the increase in the number of harmonics of the Fourier series, the differences between the approximated and recalculated temperatures on the Trooz Glacier from the Akademik Vernadsky station increase. This is due to the errors in the remote measurement of the temperature above the glacier. Regardless of the number of harmonics, deviations are especially noticeable before 2019. After 2019, the curves of the approximated and recalculated temperatures over the glacier have minimal deviations.

Thus, it can be concluded that after 2019 there were some changes that improved the data provided by the https://earth.nullschool.net website. This website uses data from various sources, including weather models and observation, to create interactive air temperature maps and other weather-related visualizations. Some common sources of air temperature data include: weather stations, Earth-observing satellites equipped with different types of remote sensing instruments, automatic weather stations, climate reference networks, international climate data centers, and others. These sources work together to provide a comprehensive understanding of global and local temperature trends. We indicate a few facts that led to improvements and were seen in approximation curves (Fig. 5) after 2019.

Several experiments conducted for numerical weather prediction modeling in the southern high-latitude regions (Chtirkova et al., 2021) show that all meteorological variables are affected by the sea surface temperature. In addition to existing data sources, on 25 April 2018 there was successfully launched Sentinel-3B satellite. This is the second of four planned satellites that join as a counter-orbit satellite to the

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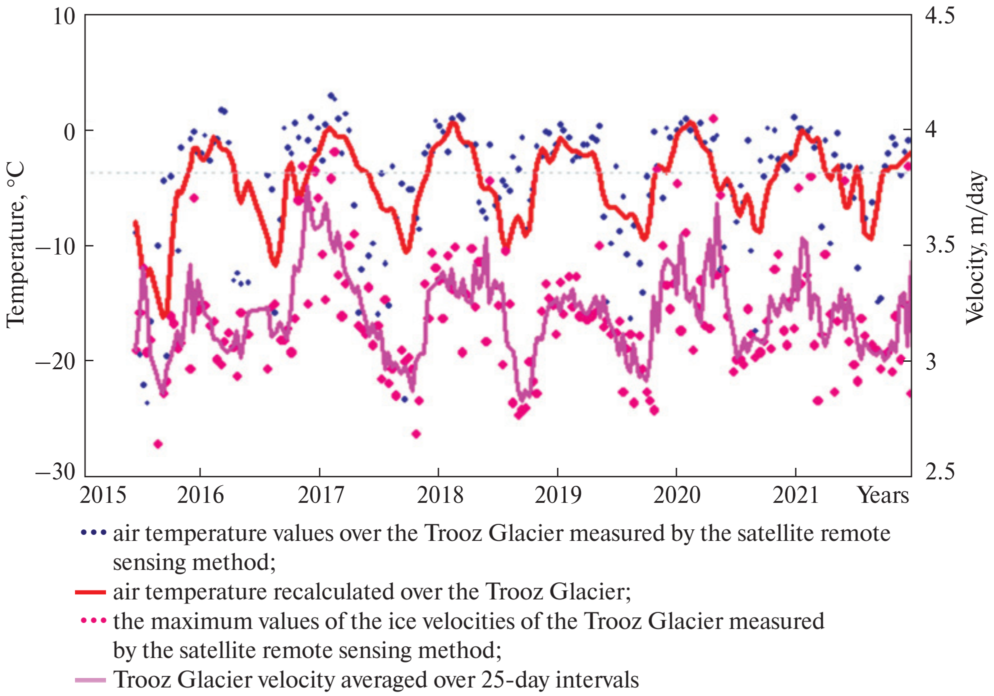

Figure 6. Air temperature variation and ice flow velocity of the Trooz Glacier during 2015–2022

Sentinel-3A satellite. One of the main objectives of the Sentinel-3 constellation is to measure sea and land surface temperature.

The meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF) are widely used in the Antarctic region for different purposes (Semmler et al., 2016; Bello et al., 2022). In 2019, ECMWF implemented a substantial upgrade of its Integrated Forecasting System (IFS Cycle 46r1), which significantly improved global medium-range weather forecasts (Haiden et al., 2020). One of the key novelties in the upgraded system was making data assimilation more continuous. It was noticed that forecast skill during summer 2019 was higher than in previous seasons. The Integrated Forecasting System upgrade has improved the high-resolution forecast across a range of parameters and atmospheric levels, including surface weather parameters. For example, the forecast skill for strong winds reached its highest-ever value in 2019. There was also a slight increase in forecast skill for 2-meter temperature and a gain in precipitation forecast skill. Tests carried out at ECMWF in 2019 have demonstrated that new wind profile observations from ESA's Aeolus satellite significantly improve weather forecasts, particularly in the southern hemisphere (European Centre for Medium-Range Weather Forecasts, 2019). Aeolus was the first satellite that acquires profiles of Earth's wind on a global scale. It was launched on 22 August 2018. All the presented facts testify to the improvement of forecast models and the reliability of temperature data determined by remote sensing methods.

Based on the results of measurements and performed calculations, Figure 6 presents the distribution of air temperature and the velocities of the Trooz Glacier movement in 2015–2022. The ice flow velocity curve shows measured velocities averaged over 25-day intervals. This is the minimum possible averaging interval with a frequency of ice velocity measurements of 12 days. Accordingly, this curve represents the result of continuous averaging of three consecutive measurements. In Figure 6, the curves of the temperature variation over the Trooz Glacier and the ice flow velocity have the same period and are synchronized in time. This is especially clear after 2018.

3.2 The glacier movement dependency on the temperature

The data presented in Figure 7 show the dependence between the measured maximum velocity of the Trooz Glacier on the recalculated air temperature above its surface. With some deviations, it is close to linear.

The correlation coefficient between velocity V and recalculated temperature t_r is 0.59. Accordingly, the dependence between measured maximum velocity of the Trooz Glacier movement and the recalculated air temperature t_r is also expressed by linear equation:

$$V_i = e + f \cdot t_{r_i}, \tag{3}$$

where e and f are coefficients determined by approximation of the linear dependence between V_i and t_{r_i}.

Based on the solution of the linear equations system (3) compiled for all periods of measurement, the values of the coefficients $e = 3.3389$ and $f = 0.0306$ as well as their mean squared errors $m_e = 0.026$ and $m_f = 0.005$ were determined. The calculation errors of these coefficients are an order of magnitude smaller than their values, indicating high accuracy. The mean squared error of determining the maximum velocity of the Trooz Glacier is $m_V = 23$ cm/day.

The accuracy of the developed model is a function of two parameters: m_V and the generalized dispersion (degree of random scattering of the model) of the covariance matrix $q = det(A^TA)^{-1}$, where A is the matrix of coefficients e and f of the equations system (3). In order to increase the accuracy of the developed model, we apply *a posteriori* optimization (Tretyak et al., 2014). The measurement results of temperature and ice velocity used for the model developing were burdened with errors of various magnitudes. If we remove measurements with maximum errors from our model, the accuracy of the model will improve, but at the same time parameter q will increase and the reliability of the model will be underestimated. Therefore, it is necessary to find the optimal relationship between m_V and q. For the optimal exclusion of measurements burdened with maximum errors from the developed model, we apply the methodology developed in (Tretyak et al., 2014). To determine the optimal ratio of these parameters differing in physical nature, the concept of entropy H of measurement accuracy and generalized dispersion q of the model is introduced, described by the function:

$$H(k) = -\int \left| \frac{dm_v(k)}{m_v(k)dk} \right| - \int \left| \frac{dq(k)}{q(k)dk} \right| =$$

$$= -\ln\left[m_V(k)\right] - \ln\left[q(k)\right], \tag{4}$$

where k is the number of consistently excluded measurements from the model which have the absolute maximum deviations Δ from the model. The maximum deviations Δ are determined by the expression:

$$\Delta = |e + f \cdot t_r - V|. \tag{5}$$

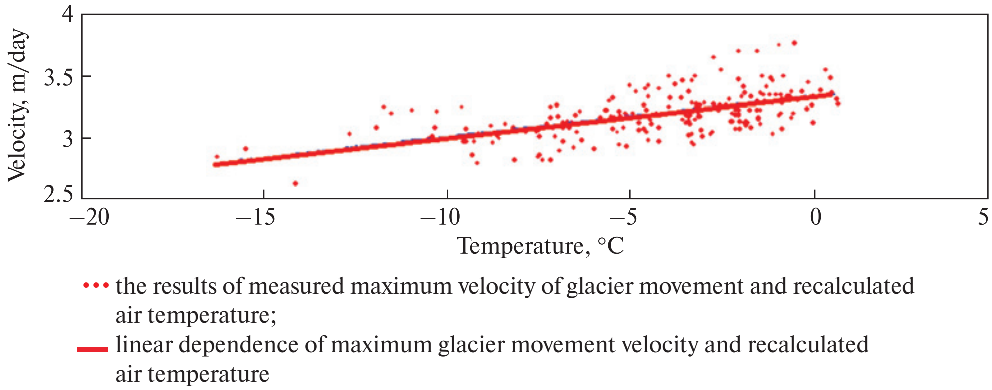

Figure 7. The dependence between maximum velocity of the Trooz Glacier and recalculated air temperature

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To implement this technique, a time period is determined which corresponds to a set of measurements of the temperature t_r and the ice flow velocity V with the maximum value Δ. These measurements are excluded from the model and e and f are recalculated. Measurements with the maximum value of Δ are determined again. The parameters m_V and q are calculated for each iteration. The model is considered optimal when the minimum value of H is reached.

Figure 8 shows the variation in m_V, q, and H with an increase in the number of extracted measurements k with maximum Δ.

According to Figure 8, consecutive removal of measurements with the maximum Δ from the model leads to a decrease in the error of determining the velocity m_V and an increase in the generalized dispersion of the model q and entropy H. When removing $k = 24$ measurements of temperature and ice velocity, the value of H reaches a maximum. At $k = 24–80$, H practically does not change. Further removal of measurements leads to a sharp decrease in the entropy (H) and the reliability of the model.

From the above calculations, it turns out that the optimal model of the relationship between the recalculated air temperature and the maximum velocity of the Trooz Glacier is achieved when 24 measurements are removed. The number of removed measurements is within 11% of their total number. Figure 9 shows the relationship between V and t_r after discarding measurements with maximum Δ. The correlation coefficient between V and t_r after optimization is 0.71.

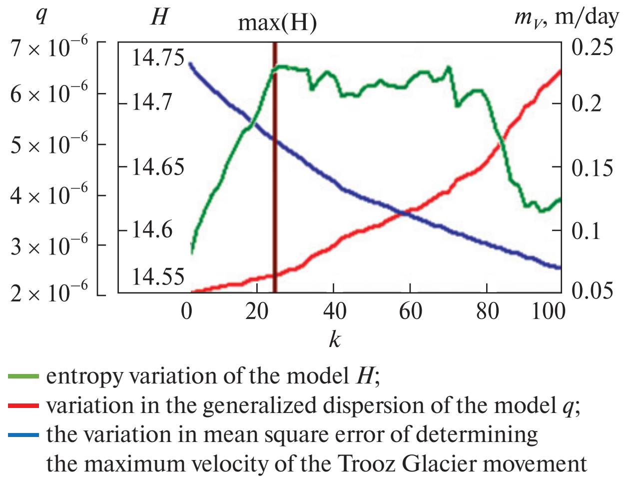

Figure 8. The variation in parameters m_V, q i H with a number of extracted measurements k with maximum Δ

The accuracy of determining the maximum velocity of the glacier increases to m_V = 17cm/day. The recalculated values of the coefficients are $e = 3.3446$ and $f = 0.0373$, and the mean squared errors of their determination are $m_e = 0.020$ and $m_f = 0.003$, respectively.

Thus, using the proposed method, it is possible to develop a spatial model of the glacier movement velocity variation and to calculate the volume of discharged ice.

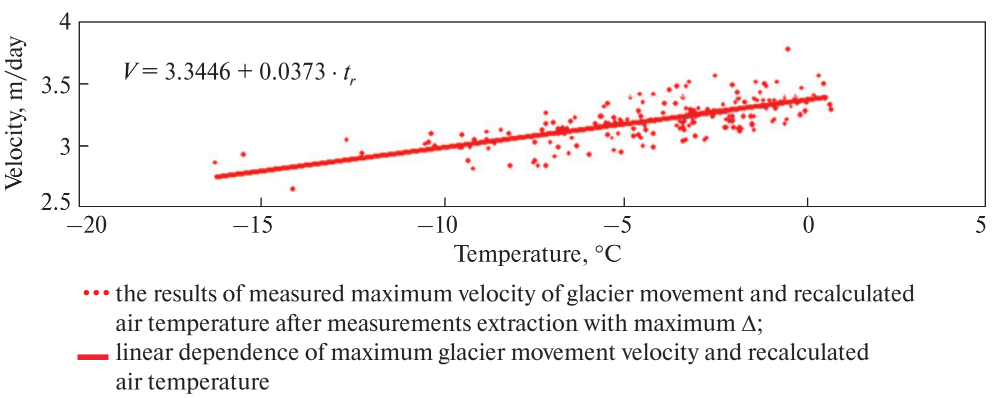

Figure 9. The dependence between maximum velocity of the Trooz Glacier and recalculated air temperature after optimization

4 Conclusions

A functional dependence between the temperature at the Akademik Vernadsky station and the air temperature above the surface of the glacier measured from a satellite was established. The deviations between the approximations of both datasets may be related to errors in determining the temperature by the satellite method and the peculiarities of the weather conditions at the Akademik Vernadsky station and the Trooz Glacier. Based on the obtained functional dependence, the results of air temperature measurement at the weather station were recalculated to the surface of the Trooz Glacier. The graphs clearly show a decrease in the differences between the approximated and the recalculated to the surface of the glacier temperature after 2019. This result indicates the improvement of the technology for determining air temperature by remote sensing data in the Antarctic region after 2019.

A linear model of the maximum movement velocity of the Trooz Glacier and the recalculated to the glacier's surface air temperature was developed. The accuracy of the developed model was improved by *a posteriori* optimization. Thus, by excluding 11% of measurement results, the accuracy of determining the maximum velocity of the glacier increased from 23 cm/day to 17 cm/day.

The use of satellite radar images is a constant source of data for developing a predictive model of glacier dynamics in response to global air temperature changes on the planet. Further research will be aimed at improving the predictive model and determining the amount of ice that moves into the sea.

Data availability: http://meteodata.uac.gov.ua/SYNOP_data/decoded_table_data/ – Meteorological data of State Institution National Antarctic Scientific Center, Ukraine (89063 Akademik Vernadsky station).

Author contributions. D.K.: processing of satellite images and ice velocity determination. K.T.: model developing and *a posteriori* optimization.

Conflict of Interest. The authors declare that they have no conflict of interest.

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Моделювання руху льодовика Труз за даними температури повітря та супутникових радіолокаційних спостережень з 2015 по 2022 р.

Реферат. Метою даного дослідження є побудова моделі залежності максимальної швидкості руху льодовика Труз (півострів Київ, Західна Антарктика) від температури повітря. Для цього виконано опрацювання часових серій даних метеорологічних спостережень на станції «Академік Вернадський» та швидкостей руху льодових мас льодовика Труз, визначених за даними опрацювання радіолокаційних знімків супутником Sentinel-1 за період з травня 2015 р. до листопада 2022 р. Опрацювання виконувалось в програмі SNAP (Sentinel Application Platform) методом Offset Tracking. У результаті отримано 219 карт швидкостей льодового потоку. Встановлено, що впродовж досліджуваного періоду часу, максимальні швидкості змінювались в діапазоні 2.64 m/day (19 August 2015) — 4.05 m/day (18 April 2020). Усереднення високочастотних результатів вимірювання температури повітря на станції «Академік Вернадський» виконано шляхом апроксимації даних із застосуванням рядів Фур'є. Встановлено функціональну залежність між результатами вимірювання температури на метеостанції «Академік Вернадський» та результатами визначення температури повітря над поверхнею льодовика методом супутникового дистанційного зондування. На основі статистичного опрацювання рядів максимальних швидкостей руху льодовика Труз, результатів дистанційного вимірювання температури повітря над льодовиком, температурних даних метеостанції «Академік Вернадський», побудована лінійна модель взаємозв'язку цих параметрів. З метою підвищення точності розробленої моделі проведено її апостеріорну оптимізацію. У результаті, середня похибка визначення максимальної швидкості льодовика зменшилась з 23 см/добу до 17 см/добу.

Ключові слова: Sentinel-1, апостеріорна оптимізація, радар із синтезованою апертурою, станція «Академік Вернадський», швидкість руху льодовика