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# Thawing of permafrost may disturb historic cattle burial grounds in East Siberia

Boris A. Revich* and Marina A. Podolnaya

Institute of Forecasting, Russian Academy of Sciences, Moscow, Russian Federation

Climate warming in the Arctic may increase the risk of zoonoses due to expansion of vector habitats, improved chances of vector survival during winter, and permafrost degradation. Monitoring of soil temperatures at Siberian cryology control stations since 1970 has showed correlations between air temperatures and the depth of permafrost layer that thawed during summer season. Between the 1900s and 1980s, the temperature of the surface layer of permafrost increased by 2–4°C; and a further increase of 3°C is expected. Frequent outbreaks of anthrax caused the death of 1.5 million deer in the Russian North between 1897 and 1925. Anthrax among people or cattle has been reported in 29,000 settlements of the Russian North, including more than 200 Yakutia settlements located near the burial grounds of cattle that have died from anthrax. Statistically significant positive trends in annual average temperatures were established in 8 out of 17 administrative districts of Yakutia for which sufficient meteorological data were available. At present, it is not known whether further warming of the permafrost will lead to the release of viable anthrax organisms. Nevertheless, we suggest that it would be prudent to undertake careful monitoring of permafrost conditions in all areas where an anthrax outbreak has occurred in the past.

Keywords: *climate change*; *Arctic*; *anthrax*; *zoonoses*; *Russia*

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Climate change in the Arctic may increase the risk of propagation of zoonoses due to the expansion of vector habitats and development of more favorable climatic conditions for their survival during the winter season, increases in average air temperatures, and permafrost degradation. Between the 1900s and 1980s, the temperature of the surface layer of permafrost increased by 2–4°C (1), and a further increase of 3°C is expected (2). The second half of the 20th century was marked by accelerated increases in the temperature of the upper layer of permafrost and the depth of the seasonal melting layer. The Circumpolar Active Layer Monitoring network (http://www.udel.edu/Geography/calm) includes 20 Russian stations, all of which have reported increases in the annual average temperatures of the upper permafrost layer since the 1970s. The magnitude of the increase varies from 1.2–2.8°C in the Russian European North, to 1.0°C in the north of West Siberia, to 1.4–1.8°C in Central and South Yakutia, and to 1.3°C in other regions of East Siberia (3, 4). Various climate models predict the change in summer temperatures to be between 2.7 and 3.8°C in Yakutia cities by 2020. As the permafrost temperatures in Yakutia increase, permafrost degradation becomes evident. For example, the depth of permafrost varies between 250 and 350 m in the center of this region (Yakutsk city). Under natural conditions, the depth of seasonal melting is 1.5–1.7 m for clay loams, 1.6–2.0 m for sand clays, and 2.0–2.5 m for sands. The temperature of the surface layer of the permafrost is predicted to increase by 1.5–2°C in West Siberia and Yakutia, and by 1.0–2.0°C in Chukotka and the north regions of the Far East (5). The measurements of air temperature and permafrost temperature at the depth of 1.6 m at 52 stationary monitoring stations in Siberia showed linear correlation between these variables (6). Frequently observed rock sagging under building and engineering structures in Yakutia is explained by the decomposition of thermokarst, frost heave, waterlogging, and flooding (7).

As a consequence of permafrost melting, the vectors of deadly infections of the 18th and 19th centuries may come back, especially near the cemeteries where the victims of these infections were buried (8). Frequently repeated outbreaks of anthrax caused the death of 1.5 million deer in Russian North between 1897 and 1925 (9). Cases of anthrax among people or cattle have been


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reported in 28,986 settlements of the Russian Federation. There are also 13,885 cattle burial grounds, of which 4,961 sites do not meet Federal veterinary and sanitary standards (10). Other literature sources reported that more than half of these burial grounds did not meet sanitary standards and indicated lack of interaction between the State sanitary inspections and veterinary services. Some burial grounds have lost their official records of buried cattle or epizootic maps (11). Many settlements do not exist any more and have been erased from local sanitary databases. Other settlements have become almost deserted by people, who could potentially guide sanitary authorities in mapping the boundaries of the burial grounds (12). Many of the anthrax cattle burial grounds are located in Siberia, where 6,688 settlements received the status of 'stationary adverse' territories because of the risk of this disease. Taking into account the vast territory of Siberia, the density of such settlements is quite low (1.1 per 1,000 km$^2$), even though the absolute number of such settlements in Siberia is 2.5 times greater than in European Russia.

Among all the Arctic territories of the Russian Federation, Yakutia has the greatest number of settlements, where outbreaks of anthrax have been registered in the past, which is explained by very intense breeding of reindeer and horses. Between 1906 and 2004, 270 settlements reported outbreaks of this disease (13). The greatest numbers of epizootic events were recorded in 1949, 1951, 1957, 1969, 1970, 1980, 1986–1988, and the last outbreak occurred in 1993. There were 21 casualties among the Yakutia population between 1949 and 1996 due to anthrax contracted mostly from cattle and reindeer (14). The spores of Siberian Anthrax remain viable in permafrost for about 105 years (15). More than 30 years ago, Russian researchers confirmed viability of other microorganisms (fungus, diatoms, etc.) collected in Antarctic glacier samples (16). Other researchers observed metabolic activity of bacteria in permafrost at the temperature of about $-20°C$ (17). The spores of the bacterium anthrax may survive for 50–70 years more in the samples excavated at the depth of 1 m below the level of seasonal thawing in permafrost, as was observed in one Yakutia district (18). Potential hazard of the historic cattle burial grounds was confirmed by the outbreaks of Siberian anthrax among domestic reindeer in the Taymyr region of Russian Arctic in 1969 and 1977 (19). Microbiological tests of 18,000-year-old mammoth tissues confirmed the presence of *Bacillus non reactif* (*D. sphaericus*), *B. anthracis*, *B. cereus*, *B. anthracoides*, and other bacteria (20), but repeated analyses did not detect pX01 and pX02 plasmids in the brain of the grown-up mammoth (the researchers associate virulent properties of Siberian anthrax with these plasmids). Other researchers observed a strain of *Bacillus* sp. in frozen ground samples dated 3 million years (21).

Strengths, weaknesses, opportunities, and threats analysis in the Archangelsk region of the Russian European North showed that the influence of global warming on The cryolite zone would be insignificant provided that the rates of warming are small enough. However, higher rates of global warming could bring about destructive cryogenic processes (22). Mining, construction, or agricultural development of previously virgin areas around cattle burial grounds may result in infiltration of disease vectors in the organs of people or animals. Consequently, a new natural locus of infection may emerge. The risk of infection is usually greater during dry years when the layer of soil in the cattle grazing areas weathers out and the spores of disease vectors can penetrate into the organs of domestic animals (23). Today, there are 1.2 million domestic reindeer in the Russian North, or 62% of their global population, and about one million wild reindeer.

The objective of this research was to estimate the temperature trends near the burial grounds of cattle that died from anthrax in Yakutia. The territory of Yakutia was chosen for this project because of the greatest number of such sites there, compared to the other northern territories of the Russian Federation.

## Materials and methods

Due to the very extensive territory of Yakutia (3,083,000 km$^2$) it is hardly possible to estimate permafrost temperatures at all of its 200 cattle burial grounds, especially because most grounds are situated in very remote and hard-to-reach places. More than 40% of the Yakutia territory is situated above the Polar circle. We therefore used the data of weather stations located in the same administrative districts as the burial grounds to estimate the trends in local air temperatures. The geographical coordinates (latitude, longitude, and altitude) and international identification indexes of all the Yakutia weather stations are listed at the website of Russian Meteorological service (www.meteo.ru); their locations are available on the interactive map at http://www.3planeta.com/googlemaps/karty-google-maps.html. We retrieved the daily temperature data for these weather stations from the US National Climatic Data Centre website and selected the years 1961–2010 as the study period. The NCDC website maintains the most comprehensive archive of meteorological data collected all over the world up-to-date. The analysis of available archive data showed that only 17 out the of 26 selected district weather stations reported their daily temperature data for all years between 1961 and 2010, whereas the data for the remaining nine administrative districts were either incomplete or absent.

Regional models of climate change in Yakutia have been developed only at a very broad geographic scale. There are only two such models: one all territories to the north of 65°N and the other covers all territories to the south of 65°N. The baseline period for both models is


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1951–1990. The first model reports the following changes in annual average temperatures relative to the baseline: 0.2°C for 1971–1980; 0.8°C for 1981–1990; and 0.1°C for 1991–2000. The second model reports the following temperature increments: 0.12°C for 1971–1980; 1.6°C for 1981–1990; and 0.3°C for 1991–2000 [(24). p. 14]. Such aggregated information was not sufficient to estimate the temperature trends in individual administrative districts. For this purpose, we used the records of daily temperatures for those 17 districts where such data were available. Even these datasets contained several periods of missing data and these were dealt with in the following way. If, for any given year, more than 15% of daily data were missing, we excluded this year from the analysis. If one month of daily data were missing, we used daily temperatures during the same month of the preceding year and calculated the annual average temperature using these 'proxy' data. Then, the time series of annual average temperatures between 1961 and 2010 were tested for a linear trend using least squares method. Significance of regression coefficients was measured by Fisher's $F$-test. The calculations were performed with STATISTICA 6 software.

## Results

The territory of Yakutia can be subdivided into four climate-geographic zones: the west part from the Laptev Sea to the south boundaries of the republic; the central plains part; the northeast part including the Arctic tundra and Novosibirsk islands; and the south highlands part (www.atlas-yakutia.ru). The survey of cattle burial sites showed that most of them were located in the western part (112 sites) and in the central plains part (112 sites), whereas the smallest numbers (43 sites) were located in the eastern part which is mostly occupied by mountains (Fig. 1).

The observed trends in the average annual temperatures in different parts of Yakutia between 1961–2010 are summarized in Table 1. This table contains only those administrative districts where sufficient meteorological information was available. The lowest air temperatures are typical for the eastern part, where the number of cattle burial grounds is the smallest. Statistically significant linear temperature trends were obtained for the eight administrative districts with the highest annual average temperatures. We calculated the change in the mean July temperatures between the 'historic' period 1961–1985 and the 'current' period 1986–2010. The smallest change was observed in Viluisky district, $\Delta T = 0.6°C$ ($T_{historic} = 17.9°C$ and $T_{current} = 18.5°C$). The greatest change was observed in Churapchinsky district, $\Delta T = 1.0°C$ ($T_{historic} = 17.9°C$ and $T_{current} = 18.9°C$). In Yakutsky district, the change between the mean July temperatures was $\Delta T = 0.9°C$ ($T_{historic} = 18.4°C$ and $T_{current} = 19.3°C$). It was interesting to observe that the annual warming rate in Viluisky district was also minimal among all studied districts (0.02°C/year), while the annual warming rate in Churapchinsky district was maximal (0.04°C/year).

Another characteristic of climate warming was the relative increase in the number of 'very hot' days defined as the days with average daily temperature above the respective long-term average for this date, calculated over the past 50 years. The proportions of such days ($N$) were calculated for the 'historic' and the 'current periods': $N_{historic} =$ 34.5% and $N_{current} =$ 52% in Viluisky district; $N_{historic} =$ 39.1% and $N_{current} =$ 56% in Yakutsky district; $N_{historic} =$ 38.9% and $N_{current} =$ 52% in Churapchinsky district. Average daily temperatures in July 2010 were higher than the long-term average temperature of July during all 31 days of this month.

The ranges of annual average temperatures observed in different parts of Yakutia are shown in Fig. 2.

The most pronounced temperature trend was observed in the administrative districts around Yakutsk city (Fig. 3). There are more than 50 cattle burial grounds in these districts.

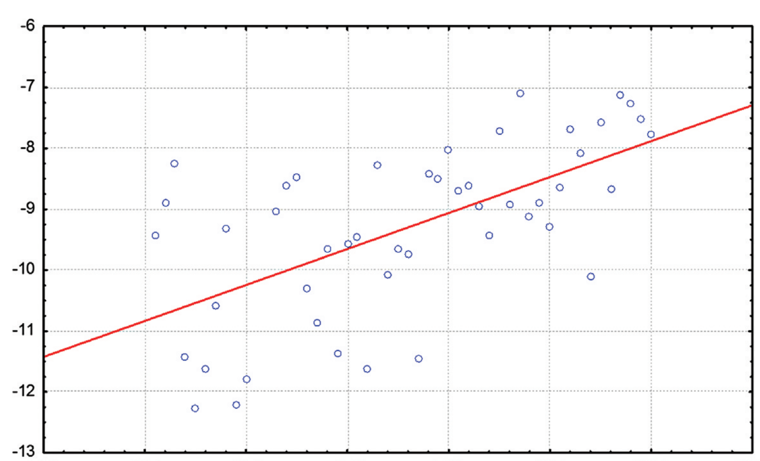


*Fig. 1.* Geographic distribution of burial grounds of cattle that died (+) from anthrax in Yakutia.

*Table 1.* Descriptive statistics of annual and July average temperatures in 1961–2010 and linear trends in annual average for selected administrative districts of Yakutia with the greatest numbers of anthrax cattle burial grounds

| Administrative district (number of cattle burial grounds) | Annual average | | | | | July average | | |
|---|---|---|---|---|---|---|---|---|
| | Mean (°C) | Min (°C) | Max (°C) | Trend (°C/year) | Significance level | Mean (°C) | Min (°C) | Max (°C) |
| West Yakutia (112), including | | | | | | | | |
| Viluisky (13) + Verhneviluisky (10) | −8.6 | −11.0 | −6.4 | 0.04** | <0.001 | 18.2 | 15.1 | 22.7 |
| Bulunsky (1) | −13.0 | −17.8 | −10.5 | 0.02 | 0.14 | 7.5 | 4.4 | 12.5 |
| Nurbinsky (17) | −8.3 | −10.9 | −5.4 | 0.04* | 0.02 | 17.3 | 14.4 | 21.5 |
| Suntarsky (6) | −7.1 | −10.2 | −5.0 | 0.04* | 0.01 | 18 | 14.9 | 21.7 |
| Zhigansky (6) | −11.2 | −13.7 | −9.0 | 0.02 | 0.09 | 16.1 | 12.3 | 21 |
| Mirninsky (29) | −7.1 | −11.6 | −4.2 | 0.02 | 0.16 | 17 | 13.8 | 20.5 |
| Olekminsky (20) | −6.0 | −8.5 | −4.1 | 0.02 | 0.13 | 18.1 | 14.9 | 21.8 |
| Oleneksky (10) | −11.6 | −14.3 | −8.4 | 0.02 | 0.11 | 14.9 | 11 | 19.5 |
| Central Yakutia (112) including | | | | | | | | |
| Ust-Maisky (2) | −8.7 | −11.5 | −5.1 | 0.04** | 0.001 | 18.3 | 15.3 | 21.2 |
| Khangalassky (9) | −7.6 | −10.0 | −4.7 | 0.04** | 0.001 | 17.7 | 14.4 | 21.4 |
| Yakutsk (7) + Namsky (13) + Ust-Aldansky (20) + Gorny (17) | −9.3 | −12.3 | −7.1 | 0.06** | <0.001 | 18.9 | 15.9 | 22.8 |
| Amginsky (15) | −10.0 | −13.0 | −6.9 | 0.04* | 0.01 | 18.2 | 15.3 | 21.6 |
| Churapchinsky (6) | −10.2 | −13.0 | −7.1 | 0.04* | 0.01 | 18.5 | 15.4 | 22.2 |
| Kobaisky (13) | −10.9 | −13.9 | −9.3 | 0.02 | 0.24 | 17.3 | 14.3 | 21.7 |
| Tomponsky (3) | −12.9 | −18.0 | −7.9 | 0.01 | 0.73 | 16 | 6 | 19.8 |
| East Yakutia (43) including | | | | | | | | |
| Verkhoyansky (4) | −14.5 | −17.4 | −9.7 | 0.01 | 0.39 | 15.9 | 11.8 | 21.5 |
| Oimyakonsky (10) | −15.5 | −19.0 | −9.7 | −0.002 | 0.92 | 14.8 | 11.5 | 23.1 |

*$p < 0.05$; **$p < 0.01$.

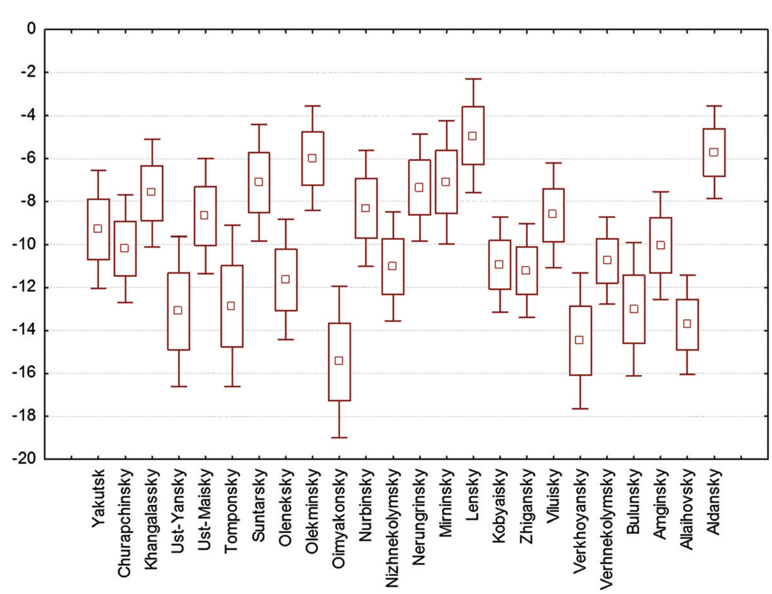


*Fig. 2.* The ranges of annual average temperatures observed in different parts of Yakutia.


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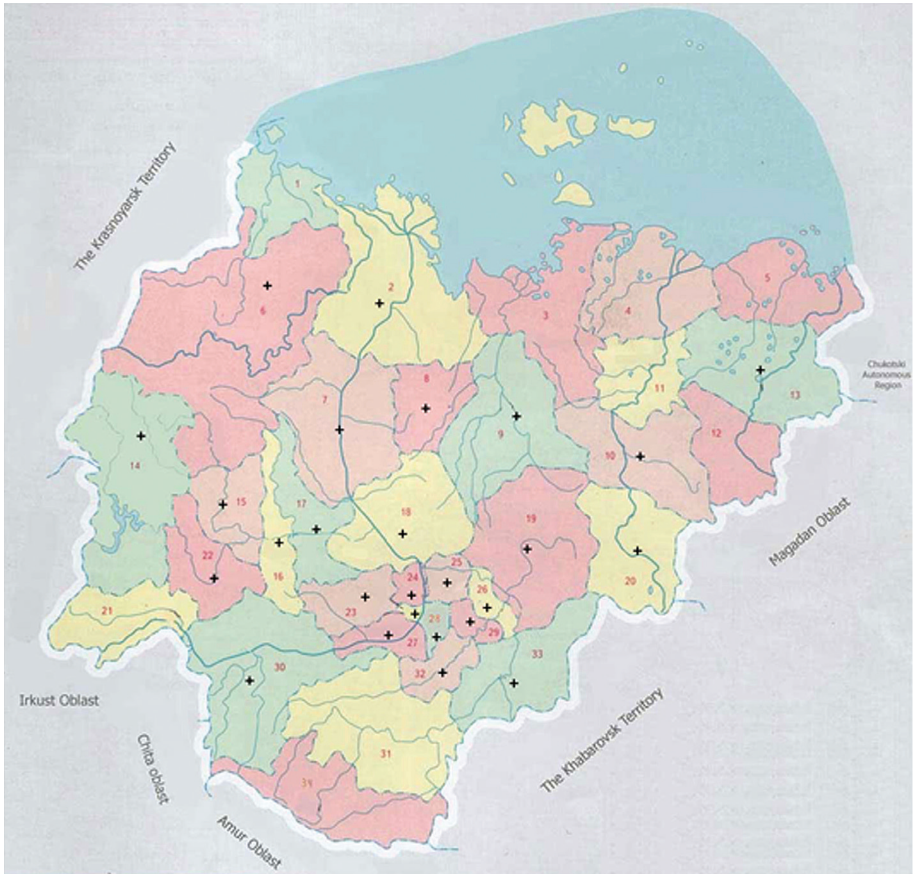


*Fig. 3.* Annual average temperature trend in Yakutsk city.

## Discussion

Statistical analysis confirmed a significant 0.1% level positive trend in the annual average temperatures in Yakutsk. Similar results have been obtained earlier (24): climate warming is more pronounced in Central and South Yakutia than in North Yakutia. The districts with the greatest increments of annual average temperatures also reported the highest numbers of outbreaks of anthrax: between four and 11 cases during the last 80 years. According to veterinary experts, these districts present the greatest risks of anthrax (14). From an epidemiology standpoint, thorough monitoring of anthrax cattle burial grounds is recommended for the entire territory of Yakutia, not just for several selected parts. This monitoring should include regular surveys of cattle burial sites, checks of fences around them, inspections of land-use permits, and other documentation, in addition to detailed measurements of permafrost parameters around such sites. The trends in permafrost temperatures may vary greatly even within a single administrative district (24). Unfortunately, the authors could not find any information about the current condition of Siberian anthrax cattle burial sites, cropping out the remains or soil erosion. The authors recommend thorough monitoring of activity of airborne anthrax both in the northern and southern parts of Yakutia, especially in light of the findings obtained in Central Asia (Kazakhstan), where geographic distribution of *B. anthracis* was studied (25).

## Conclusions

More than 200 locations in Yakutia have previously reported outbreaks of anthrax among people. The same locations have burial grounds of cattle that have died from anthrax. Statistically significant positive trends in the annual average temperatures were established in eight out of 17 administrative districts of Yakutia for which sufficient meteorological data were available. These eight districts should be carefully monitored in the first place, but all regions where the outbreaks of Siberian anthrax took place in the past deserves equal attention from of epidemiologists.

Gradual phase out of these burial grounds should use modern technologies of utilization of cattle remains. Unfortunately, this is an extremely time-consuming and resource-consuming activity. It is quite important, therefore, to estimate the threshold temperatures above which depreservation of the frozen remains becomes significant. Temperature thresholds of permafrost degradation are estimated on the basis of geomorphological indicators (segregated frost heave mound – palsa), but they provide only indirect information about the epidemiologic situation. Detailed field surveys on the state of cattle burial grounds and the measurements of air and permafrost temperatures are needed for objective assessment of the epidemiologic threat. Besides, public health authorities should be permanently on the alert with regard to anthrax. Massive vaccination of domestic animals has proven effective to reduce the rates of this disease among both domestic animals and people living in the Russian Arctic.

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***Boris A. Revich**
Institute of Forecasting
Russian Academy of Sciences
Nachimovsky av, 47, RU-117 418, Moscow, Russia Federation
Tel: +7 499 129 18 00
Fax: +7 495 718 97 71
Email: revich@ecfor.ru