Seasonal and long-term variability of temperature and pressure fields in Antarctic region

S.I. Clok[1] and G.M. Kruchenitskii[2]

[1]*Ukraine Scientific-Research Gidrometeorological Institute, Kiev, Ukraine*
[2]*Central Aerological Observatory, Dolgoprudny, Russia*

Received August 12, 2008

Diurnal, seasonal, and long-term variabilities of temperature and pressure fields in the Antarctic have been analyzed. The contribution of each above variability into the total variability of thermobaric fields has been estimated, as well as spatial distribution of these contributions. Spectra of seasonal behavior of pressure and temperature have been compared. Peculiarities of spatial localization of diurnal variations of thermobaric fields in the region are described. It has been shown that temperature trends here are positive while pressure ones are negative, and they are mostly pronounced in the Western Antarctica. Parameters of probable long-term variations of temperature and pressure in the region have been estimated.

1. Statement of problem

Spatial distribution of the parameters of temperature and pressure variabilities in the Antarctica is of essential interest owing to both physical and geographical peculiarities of the region and its minimal susceptibility to anthropogenic influence due to a significant remoteness from main centers of human economic activity. Routine temperature and pressure measurements in the region have been started comparatively recently (about 60 years ago). At present, there is a possibility to determine main parameters of diurnal and seasonal variabilities of thermobaric fields in the Antarctica on the basis of shortest (in view of climatology) series of continuous observations, and to estimate the character and statistical significance of long-term variations in these fields.

2. Initial data

Monthly-average temperature and pressure measured at the common hours (0; 6; 12; 18 h) and monthly-average daily mean temperature and pressure are used as initial data for estimating parameters of periodic and aperiodic variabilities of thermobaric fields in the Antarctica. These data were obtained at 42 stations of the region.[1] Positions of these stations as well as length and integrity of observational series at them are illustrated by Fig. 1. (The northmost station Campbell (52°N, 169°E) is absent in the map, because its imaging could require a strong scale reduction making the perception of stations arrangement near the Antarctic Peninsula and Shetland Islands difficult).

The series integrity was estimated by their fill factor, i.e., the ratio of a number of samples in a series to its length in moths. As is seen from Fig. 1 data on pressure measured directly at stations are available only for 28 stations, though data on sea-level pressure are available for 38 stations, i.e., all except for "mountain" ones. Four "mountain" stations are Vostok (78.5°S, 106.9°E, 3490 m), South Pole (2835 m), Byrd (80°S, 120°W, 1515 m), and Asuka (71.5°S, 24.1°E, 931 m).

Finally, note that two stations in the region have observation series noticeably longer than others. They are Grytviken (54.3°S, 36.5°W), where temperature has been measured since January, 1905 (the fill factor is 84%) and Orcadas (60.7°S, 44.7°W), where temperature (98%) and sea-level pressure (95%) have been measured since April, 1903.

3. Methods for thermobaric field variability parameterization

First, a regression model of seasonal variations of monthly means was developed for each station and each data series (temperature, pressure, and sea-level pressure):

$$V(t) = \sum_{k=0}^{5} A_k \cos[k\omega(t - \Theta_k)] + R_{Seaz}(t), \qquad (1)$$

where $V(t)$ is the problem variable; A_k is the amplitude of the kth harmonic of annual variations; $\omega = 2\pi/T$ is the angular frequency of the first harmonic of annual variations; t is the time (days) counted from January 1, 1900; Θ_k is the phase of the first harmonic of annual variations; $R_{Seaz}(t)$ are the reminders of seasonal variations.

The number of harmonics is not larger than 5 due to the sampling theorem[2] stating that two samples for the period of the highest frequency in the signal spectrum are enough for its recovery at an infinite value of the signal-to-noise ratio. Inadvertent implementation errors make this ratio finite;

0235-6880/08/12 893-07 $02.00

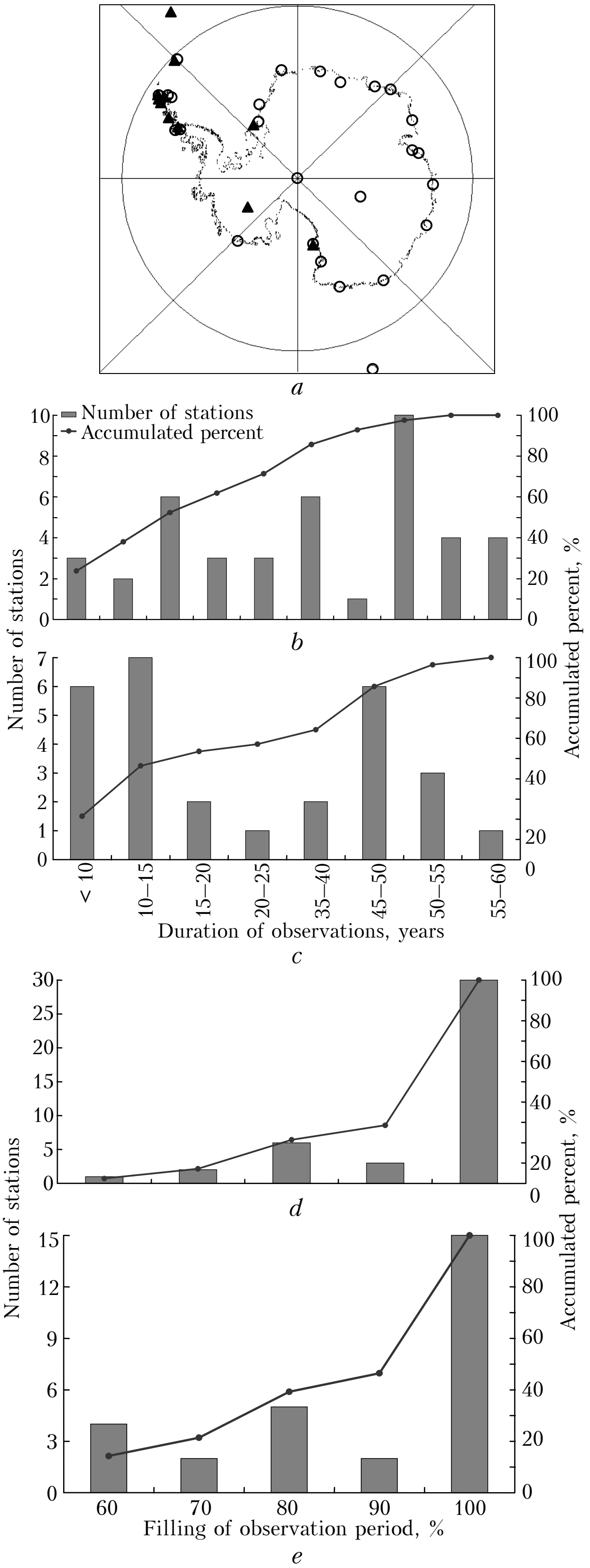


Fig. 1. Initial data: arrangement of observation stations (*a*, triangles designate stations where only temperature is measured and circles – both temperature and pressure); distribution of observation series over length (temperature (*b*) and pressure (*c*)) and the fill factor (temperature (*d*) and pressure (*e*)).

therefore, recovery of the parameters of the 6th harmonics is impossible. Only those harmonics statistic significance of which is not less than 95% have been kept in model (1). The reminders of the model were regressively tested on linear and quadratic trends:

$$R_{Seaz}(t) = kt + b + r(t), \tag{2a}$$

$$R_{Seaz}(t) = At^2 + Bt + C + r(t), \tag{2b}$$

where k and b are the parameters of linear trend; A, B, and C are the parameters of quadratic trend; $r(t)$ are the reminders of regression model.

The trend parameters are taken nonzero if the Fisher statistics values[3] for regression model (2) provided for its statistic significance at a level of not less than 95%.

4. Study results of seasonal variability

Success of simulation of seasonal variability by regression model (1) is shown in Fig. 2, where the fields of coefficients of model determination for temperature and pressure are visualized. Remind that the coefficient of model determination (or efficiency)

$$R^2 = 1 - \sigma_{res}^2/\sigma_m^2,$$

where σ_{res}^2 is the variance of simulation reminders; σ_m^2 is the variance of simulated process.

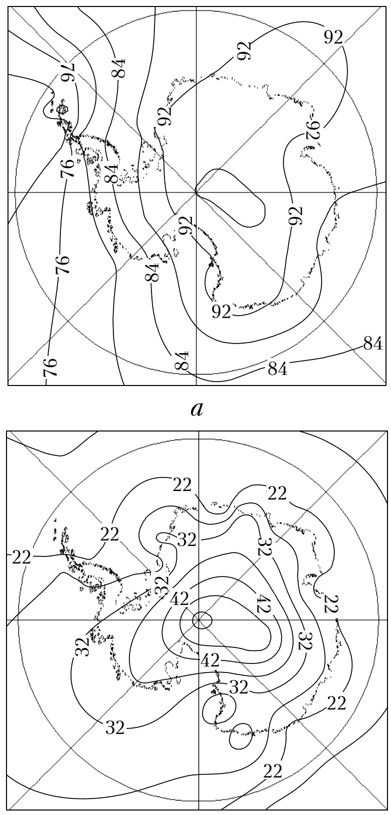


Fig. 2. Efficiency of regression simulation of seasonal variations of temperature (*a*) and pressure (*b*) in the Antarctica, %.

The coefficient of determination (usually expressed in percents) shows which part of simulated process variability the model describes.

It is seen from Fig. 2 that seasonal variability of temperature with respect to its total variability is essentially larger in comparison with those of pressure.

Statistically significant seasonal variability of pressure was impossible to distinguish at the Rothera station (67.5°S, 68.1°W), though the observations have been carried out since 2001. Note also that pressure varies with time essentially more rapid even in regionally average data (see Fig. 3).

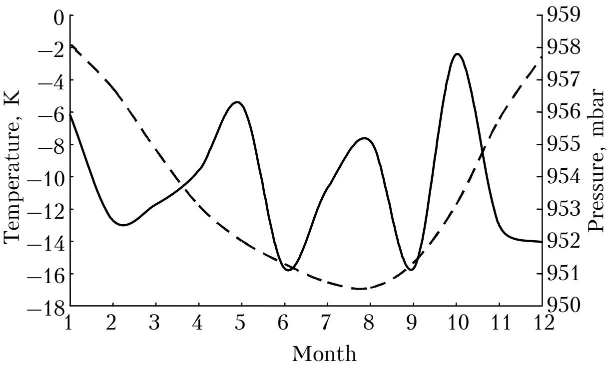


Fig. 3. Regionally average seasonal variations of temperature (dashed line) and pressure (solid line).

To assess this effect for all the regional stations, the energy center of gravity of seasonal variability spectra of temperature and pressure have been calculated:

$$f_c = \sum_{\text{significant}} kA_k^2 \Big/ \sum_{\text{significant}} A_k^2,$$

where summation is performed over all statistically significant harmonics of the annual trend, and f_c is expressed in reciprocal years. Figure 4 confirms that seasonal variations of pressure occur much more rapid than temperature ones all over the Antarctic region.

This fact is evident for any other region because seasonal temperature variations are much more inertial in nature; but such situation is nontrivial in the Antarctica, where a pronounced, stable, and quasi-stationary polar vortex exists almost half of year, and is to be validated by observation data. Figure 4 illustrates this validation. Note that the closest to the Antarctica continents (South America and Australia) increase the rate of seasonal variability of pressure and decrease those of temperature.

The profile of seasonal variations of temperature at individual stations virtually coincides with the profile of regional mean, which is witnessed by closeness to unit of the correlation coefficients between these functions. The difference is in the "range" of seasonal variations. The situation for pressure differs in principle. Figure 5 shows the profiles of its seasonal variations are quite various and strongly influenced by the neighboring continents, especially South America. Seasonal variabilities of pressure and temperature fields are presented in Fig. 6.

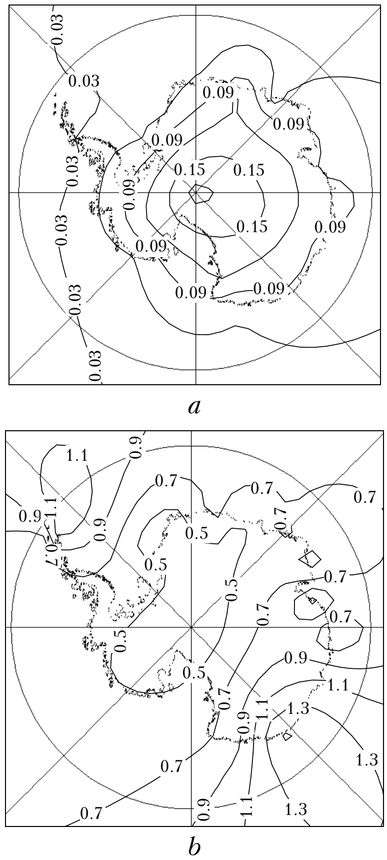
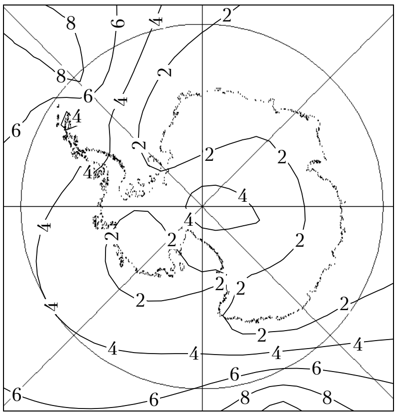


Fig. 4. Shift (year^{-1}) to the high-frequency region of energy center of gravity of seasonal variability of temperature, K (*a*) and pressure, mbar (*b*) with respect to the first harmonic of annual trend.

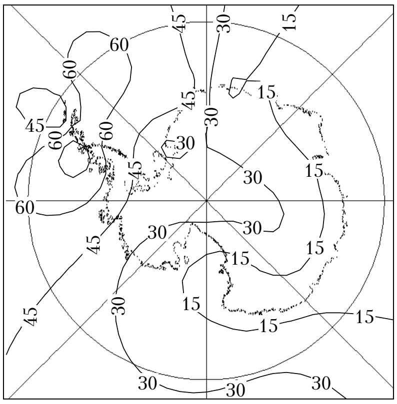
Fields of rms deviations of diurnal pressure and temperature values look unexpectedly (Fig. 7).

While there are virtually no diurnal variations of pressure in the Eastern Antarctica, they are anomalously high in the western part of the continent and almost similar in winter (October–March) and summer (April–September). Emphasize that not only values of diurnal variation isopleths are close but their profiles as well. This allows assumption that anomalously high diurnal variations of pressure in the Western Antarctica (which is a relatively young geologic formation, about 500 millions of years, as compared with the eastern part of the continent, about 3 billions of years) are caused by interaction of geospheres, at least partly. This assumption is indirectly confirmed by the fact of seepage of actively emitted gas and energy of rift fault toward the Antarctic margin between the Bellingshausen and Ross Seas.[4]

The isopleths of temperature diurnal variations are located similarly abnormally. Though these variations are two-times higher in summer than in winter, the profiles of isopleths are similar and mainly closed curves grouped around the active Erebus volcano (77°S, 167°E). This also points out to probable lithosphere conditionality of the observed diurnal variations of temperature.



a



b

Fig. 5. Difference from the 100-% correlation of seasonal temperature (*a*) and pressure (*b*) variations with the corresponding regional average seasonal variations.

5. Study results of long-term variability

Series of monthly mean temperatures are available for 42 stations of the Antarctica; the 95-% statistically significant linear trend (2a) was revealed at 18 and quadratic one (2b) at 11 stations, and both trends were statistically significant at 6 stations. The significance of the quadratic trend was higher at all the 6 stations. Series of monthly mean pressures are available at 28 stations; the 95-% statistically significant linear trend (2a) was revealed at 10 and quadratic one (2b) at 3 stations; both trends were significant at 3 stations. All values of the linear trend were negative for temperature and positive for pressure. Their geographic distribution is shown in Fig. 8.

The correlation between signs of temperature and pressure trends is hydrostatically natural. Geographical localization of trends of both parameters is close and tied to the Western Antarctica. An assumption connecting the positive temperature trend in the Antarctica with global warming looks natural.[5] (For completeness of opinion representation, cite the well-known encyclopedia “Wikipedia” (http://ru.wikipedia.org): “Despite the global warming, the temperature in the Antarctica essentially decreased during last 35 years. The air temperature near surface decreases by 0.7°C every 10 years. The total temperature decrease in the Antarctica is a riddle for scientists since the majority of scenarios of climate changes supposes that the global warming should affect the polar regions of Earth sooner and more intensive”). It is partly confirmed by localization of the highest-trends region between the habitable territories, i.e., Australia and South America.

At the same time, there are circumstances pointing out to a possibility of other reasons for trend formation. In addition to localization of the highest-trends region in the endogeneously active Western Antarctica, this may be different signs of the coefficient A in model (2b) at different stations for both temperature and pressure. There is no physical sense to interpret the presence of a significant quadratic trend in a parameter as an evidence of infiniteness of its values in the past and future; therefore, it is natural to interpret such a trend as an evidence of oscillating changes in development of this parameter with a period larger than the total duration of observational series.

Alteration of signs at the highest term of the quadratic trend at different stations witnesses that the long-term oscillating variations at these stations are out-of-phase. It is clear that if observations take place near zeros of slow oscillation (it is natural to consider an oscillation with a period, lowest harmonic of which is much longer or, at least, comparable with an observation period, as a slow oscillation) then we obtain a statistically significant linear trend.

When an observation period is close to extremums of slow oscillation, a quadratic trend with a sign at the highest term, corresponding to the extremum type (minimum – plus, maximum – minus), gets the statistic significance. Finally, the more symmetric an observation period with respect to the extremum of slow oscillation the larger the degree of decrease in significance of linear trend.

From these considerations, admit that the above data on trends at different stations allow one to assume just oscillating character of long-term temperature and pressure variations in the Antarctica, which is confirmed by the profiles of regionally average series of the reminders of seasonal variations of these parameters.

To estimate the profile of these oscillations, nonlinear regression models have been developed for the above series:

$$R_{Seaz}(t) = \sum_{k=0}^{5} B_k \cos\left[k\frac{2\pi}{T_l}(t - \Psi_k)\right] + r(t), \qquad (3)$$

where the period of first harmonic T_t was used as a fitted parameter (by the criterion of maximum of the determination coefficient) in addition to amplitudes and phases of five harmonics (B_k, ψ_k). This period equals 88 years for temperature and 55 years for pressure (Fig. 9). In this case, the values of determination coefficient twice as higher as for linear trend (2a): 8.5% for temperature and 2.7% for pressure.

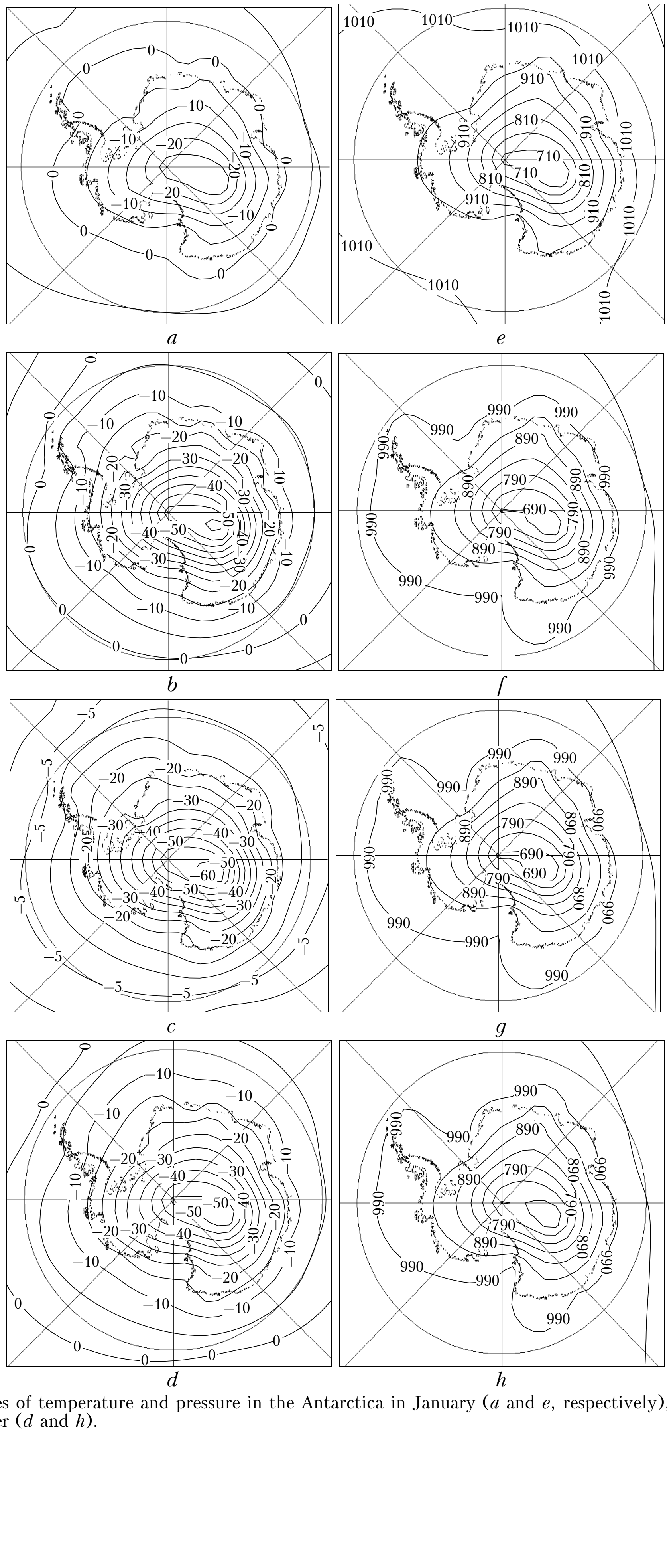


Fig. 6. Seasonal values of temperature and pressure in the Antarctica in January (*a* and *e*, respectively), April (*b* and *f*), May (*c* and *g*), and October (*d* and *h*).

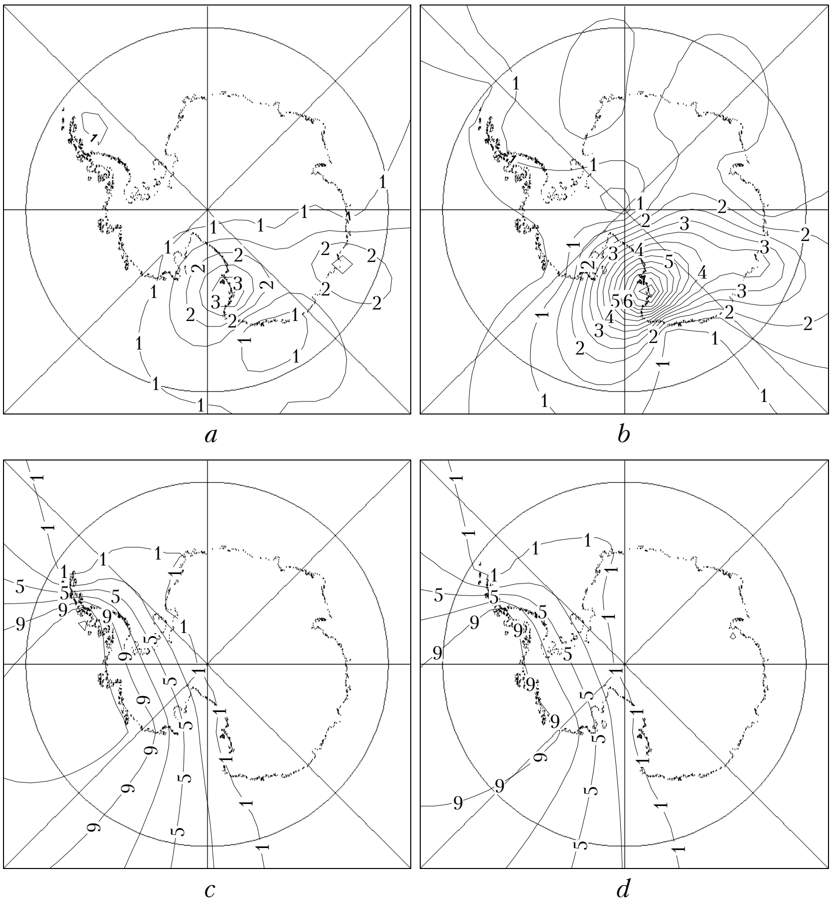


Fig. 7. Rms deviations of diurnal variations of temperature, K, in winter (*a*) and summer (*b*) and pressure, mbar, in winter (*c*) and summer (*d*).

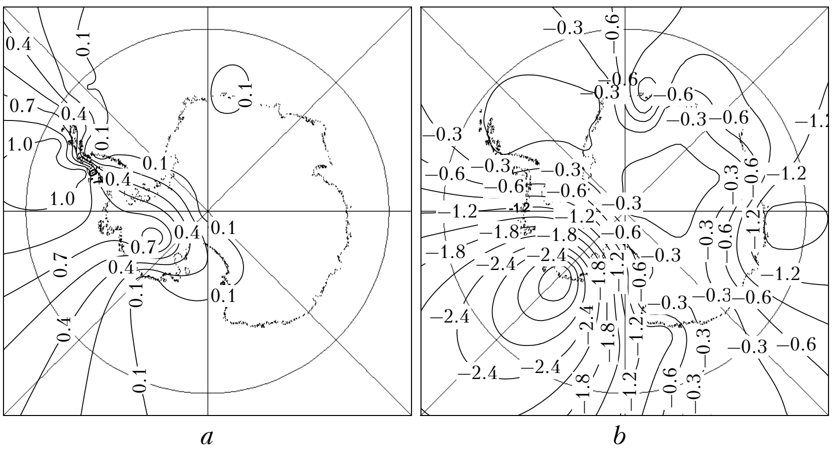


Fig. 8. 10-year linear trends of temperature, K (*a*) and pressure, mbar (*b*) in the Antarctica.

Relatively low values of determination coefficients are explained by the above-noted out-phasing of long-term variations at different stations and a resulting high contribution of the phase noise in series of regionally average reminders of seasonal variations.

Finally, note one important circumstance. The periodic model of long-term variability of antarctic temperature points out to the presence of its anomously high values (up to 5.6 K above the climatological norm) in the beginning of 40th years of the 20th century and, hence, forecasts the same values at the turn of 20–30th years of this century (Fig. 10).

We can confirm the past (only partly, because it is clear that the comparison between a *regional* model and *local* counts is not quite reasonable, but we have no choice) by the data of only two stations, where the observations were carried out. The anomaly was +5.5 K in February, 1942 at the Grytviken station (54.3°S, 36.5°W) and 5 months later at the Orcadas station (60.7°S, 44.7°W).

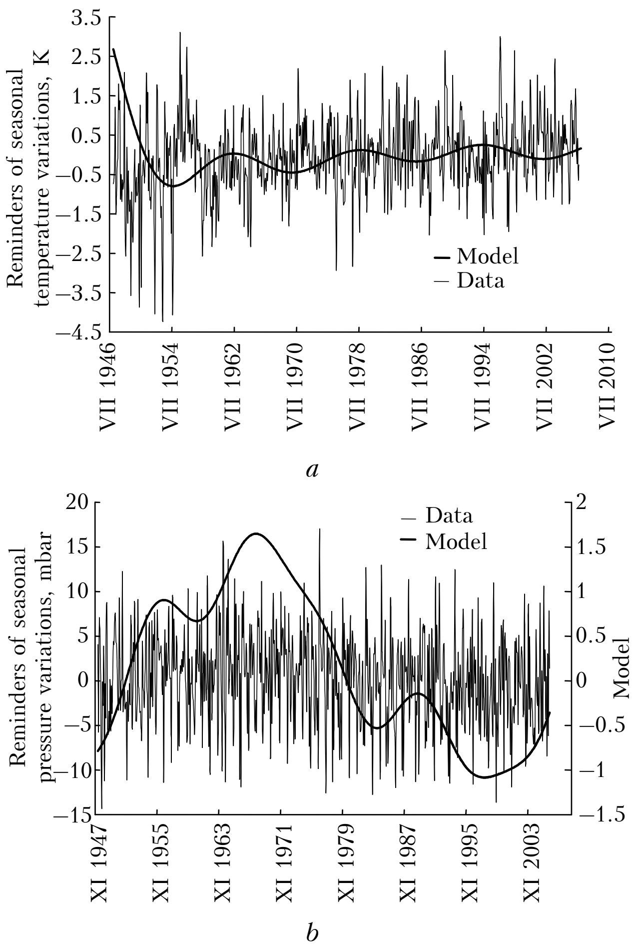


Fig. 9. Periodic model of long-term variability of temperature (*a*) and pressure (*b*) in the Antarctica.

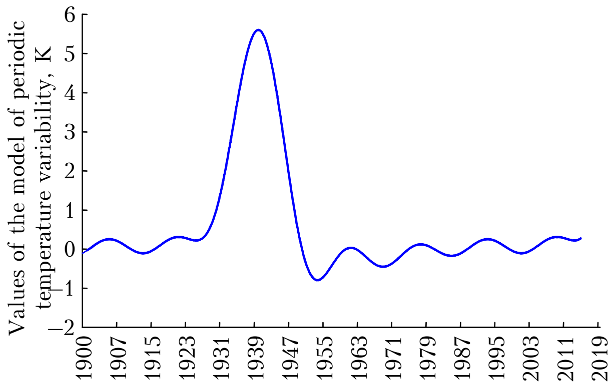


Fig. 10. Dynamic range of the periodic model of long-term temperature variability.

Note also that close in values anomalies are observed now in the Arctic, but a little closer to the pole.

Conclusion

1. It has been ascertained that seasonal variability of temperature in the Antarctica makes up from 76 to 96% of its total variability and of pressure – from 22 to 52%. Seasonal variations of pressure are much more rapid that those of temperature; the energy center of gravity of their spectrum is essentially shifted toward the high-frequency region with respect to the annual harmonic (sometimes more than two time), while the corresponding shift of temperature does not exceed 18%.

This results in more variety in shapes of seasonal variation curves for pressure in different parts of the Antarctica as compared with temperature. The geographic distribution of shift of the energy center of gravity of the temperature seasonal variability spectrum is close to zonal, while the region of large shifts for pressure is evidently shifted toward the neighboring continents (Australia and South America).

2. It has been ascertains that diurnal variations of both pressure and temperature are mainly concentrated in the Western Antarctica; at that, if the value of rms deviation of pressure is virtually independent of season, it is about two times higher in summer than in winter for temperature.

3. Linear trends for temperature (positive) and pressure (negative) are localized mainly in the Western Antarctica. At the same time, the available observation data do not contradict the assumption about oscillating character of long-term variations of pressure and temperature in the Antarctica. In this case, the first harmonic of long-term variations can be equal to about 88 years and the dynamic oscillation range – to about 6 K, the respective values for pressure are 55 years and 3 mbar.

Reference

1. http://cdiac.ornl.gov/epubs/ndp/ndp032/ndp032.html
2. M.T. Ivanov, A.B. Sergienko, and V.N. Ushakov, *Theoretical Basis for Radiotechnique* (Vyssh. Shk., Moscow, 2002), 260 pp.
3. D. Hudson, *Statistics for Physicists* (Mir, Moscow, 1967), 242 pp.
4. O.A. Sorokhtin and S.A. Ushakov, *Earth Development: Textbook* (Publishing House of MSU, Moscow, 2002), 560 pp.
5. Third Assessment Report – Climate Change 2001 (http://www.ipcc.ch/).