ANALYSIS OF THE LONG-TERM AEROSOL TREND IN THE TROPOSPHERE OVER WESTERN SIBERIA

V.G. Arshinova, B.D. Belan, E.V. Vorontsova, G.O. Zadde, T.M. Rasskazchikova, O.I. Sem'yanova, T.K. Sklyadneva, and G.N. Tolmachev

Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences, Tomsk
Tomsk State University
Received December 30, 1996

The causes are analyzed of the trend of aerosol concentration observed during many years over Western Siberia. Two hypotheses are considered: the postvolcanic effect and a change in the general atmospheric circulation. The trend is shown to be caused by circulation processes, i.e., by strengthening of the westward zonal component of the air flow, and by a change in the meridional circulation over the region.

1. INTRODUCTION

Aerosol is one of the most variable components of the atmosphere, which essentially determines its radiation budget. Nowadays there exists understanding that the aerosol, along with clouds, may play, in some regions, the role of a feedback that smoothens the greenhouse effect growth caused by a globally increasing concentration of the greenhouse gases.[1] However, by the conclusion of the International group created by the UN initiative, knowledge of the global aerosol remains extremely small and does not correspond to its role in the atmospheric processes. So the study spatiotemporal variability of this component of the air over large regions is an urgent problem.

In this paper we consider and analyze the causes of a long-term variability of aerosol concentration that was first revealed in Ref. 2. For a long time we showed no interest in studying the falloff of the aerosol number concentration observed[2] during the period from 1983 till 1987 since no other data were available that could confirm this fact. Then the papers by G.M. Abakumova and E.V. Yarkho appeared, who separated out similar decrease in the aerosol optical thickness from actinometric data,[3] as well as the papers by D.J. Hofmann[4] who generalized the results of measurements by photoelectric counters lifted by sounding balloon and revealed the trend in the aerosol number density ($r \geq 0.25$ μm) during the period from 1982 till 1990. On the one hand, these results well demonstrated that the aerosol decrease in the troposphere over Western Siberia is not an artifact, but is a manifestation of the global processes. On the other hand, they required reasonable explanation of such a behavior of the aerosol. When analyzing possible causes of this phenomenon using a more vast material, in Ref. 5 we have proposed three hypotheses:

1) concentration of the anthropogenic aerosol decreased due to the nature protection activities, and it was represented in the total aerosol concentration;

2) since the series we have obtained starts in 1983, the trend revealed can be a long-term effect of the El-Chichon eruption (March-April 1982), direct or indirect;

3) the trends in aerosol components, which we and other authors have observed, reflect the cyclic behavior of the natural atmospheric processes, which, as known, have a series of long-term periods.

The first hypotheses was tested in Ref. 6, where it was shown that not more than 15% of the decrease of the aerosol concentration can be explained by the anthropogenic aerosol concentration decrease, while the total concentration decreased by several times.

In this paper we present the results of testing the second and third hypotheses.

2. AEROSOL CONCENTRATION TREND AS A POSSIBLE POSTVOLCANIC EFFECT

The data indicating that the volcanic eruptions can affect the weather and climate, were obtained many years ago. More than 200 years ago B. Franklin[7] related the cooling on the Earth to the volcanic eruptions occurred in 1783. The investigations performed later confirmed this conclusion. Now there is vast literature on the postvolcanic changes in the climate system. The reviews are presented in Refs. 7 and 8. However, these papers mostly deal with the stratospheric aerosol or with the radiative and thermal effects of the stratospheric aerosol overburden. There are no information about how the tropospheric aerosol concentration changes after the volcanic eruptions. The data series analyzed in this paper started just after the El-Chichon eruption, which, as is shown in Refs. 7–10,

0235-6880/97/08 577-06 $02.00

essentially affected the radiative properties of the atmosphere and the temperature regime of the near-ground layer. So one can not ignore this fact.

It is known that at the explosive eruption, to which the El-Chichon eruption is related, great amount of gaseous and aerosol substance is emitted into the atmosphere, that penetrate into the stratosphere as well. The gases and aerosol remaining in the troposphere are removed from air during weeks, or even months. The gases in the stratosphere condense, producing the sulfur-acid aerosol, which reacts with other ingredients present at these altitudes.[11]

The estimates presented in Refs. 7, 8 and 11 show that the main amount of aerosol stay in the stratosphere during a period from several months to 2 years. Then the aged aerosol particles settle to the underlying surface. That means that the substances and elements characteristic of the postvolcanic stratospheric aerosol should be found in the chemical composition of aerosol that we observed during airborne experiments in 1983 and 1984, along with the background one.[11,12]

C. Junge[12] has shown in one of his first papers about the stratospheric aerosol, that sulfur is the basic element of the aerosol particles. Al, Si and Ca are also present in particles, but as traces. The later investigations have led to the conclusion that the stratospheric aerosol particles contain about 76% of sulfuric acid,[13] in which there is an insoluble core consisting of the components different from H_2SO_4 and H_2O, Ref. 14. L.S. Ivlev, who studied a great number of volcanos, has come to a conclusion[15] that big enrichment in the moderate volatile elements, Al, Se, Pb, Cd and Zn, is characteristic of small particles, and in Si, Ca, Sc, Ti, Fe, Sn, To of big particles. Evidently, these components can compose the insoluble core. Hence, if the direct postvolcanic effect of El-Chichon occurred in the atmosphere over Western Siberia during the period analyzed, the trend of the above elements should be revealed. C. Hammer[16] has used approximately the same approach to estimation of the sulfuric acid aerosol settling to the underlying surface.

Figure 1 presents the temporal behavior of the annual average concentrations of some chemical elements determined by the authors in the particles composition and listed by L.S. Ivlev. It is seen from Fig. 1 that large amount of SO_4^{2-} ions was really present in the tropospheric aerosol composition in 1983, i.e., the next year after El-Chichon eruption. However, temporal behaviors of other elements do not confirm that they are of volcanic or stratospheric origin. In particular, they are Zn, Ti and partially Pb, which had different dynamics in this period. It is more likely, that there is a temporary coincidence here, but the increase in SO_4^{2-} concentration in 1983 had different origin.

Another criterion indicative of the origin of aerosol particles, is the enrichment coefficient that is 100–10000 times for the volcanogenic elements.[17,18]

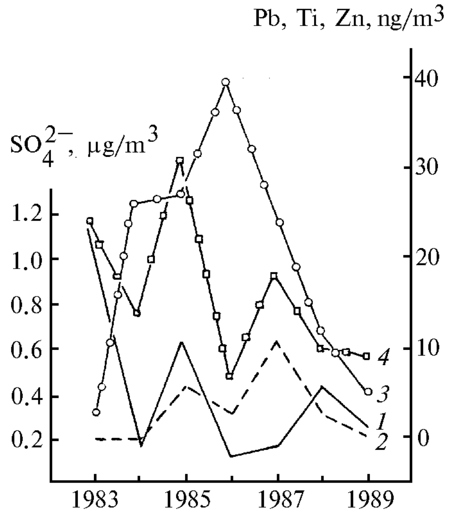

FIG. 1. Variations of the concentration of some elements in the annual average aerosol chemical composition over Western Siberia: 1) SO_4^{2-}; *2)* Zn; *3)* Ti; *4)* Pb.

As is seen from the Table I Pb and Cu correspond to such values of the enrichment factor in the aerosol composition over Western Siberia during the analyzed period. However, their temporal behavior also contradicts the hypotheses of the direct postvolcanic effect.

TABLE I. Enrichment coefficient for some chemical elements in aerosol over Western Siberia normalized to Si.

Year	1983	1984	1985	1986	1987	1988
Ti	0.14	1.71	1.22	2.75	0.54	0.54
Pb	400.00	23.30	516.70	116.70	300.00	16.70
Sn	2.11	1.41	0.00	1.41	4.93	6.00
Cu	24.32	78.37	454.10	1040.50	316.20	213.51
Cr	*	0.002	1.59	0.23	0.22	0.47
Ca	*	0.51	1.39	0.25	1.08	0.37

* No data are available.

Thus, one can reject the hypotheses of direct postvolcanic effect as a reason of the decrease in aerosol concentration in the troposphere over Western Siberia to a high degree of certainty.

Since the lifetime of the volcanic aerosol in the stratosphere is not the only parameter determining the effect of volcanos on the climate, the prolonged or indirect postvolcanic effect is analyzed in some papers.

As was shown numerically in Ref. 19 the effect of postvolcanic aerosol can manifest itself in the aerosol optical thickness during more than 4 years. The period during which the consequences of eruptions are observed, on the average, in all seasons and latitude zones is determined by L.P. Spirina[20] to be 5 to 7 years. Analysis of the results of lidar sounding has led V.V. Zuev to a conclusion that the consequences of Pinatubo eruption were observed in the stratosphere over Tomsk during 5 years after the event.[21] Hence, there are grounds to speak about a more long-term effect of volcanos on the climate, than 1–2 years after the eruption.

After analyzing possible variants of the postvolcanic development of the processes, M.I. Budyko[22] came to a conclusion that they should manifest themselves indirectly. Many papers devoted to the temperature variations after the volcanic eruptions note that, on the average, it decreases by 0.2–0.5°C during 1–2 first years, being different in different physico-geographical regions. That should lead to the disruption of air circulation on the planet, and, hence, should be accompanied by variations in the climate. So one should estimate the indirect postvolcanic effect by the change of the circulation regime. Since this coincides with our hypothesis on the role of natural atmospheric processes, then below we will consider both these hypotheses (indirect effects of volcanos and circulation mechanisms) simultaneously.

3. CORRELATION OF THE DYNAMICS OF ATMOSPHERIC PROCESSES AND THE CHANGE OF AEROSOL CONCENTRATION

S.P. Khromov[23] has noted the relation of the atmospheric turbidity to the change of air masses yet in 1948. A lot of papers appeared since that time, in which it was shown that each air mass carries certain aerosol load. So let us first consider the problem of reproducibility of the principal types of air masses observed over Western Siberia during the period of airborne experiments (Fig. 2).

As seen from Fig. 2 the trend revealed in the period 1984–1990 is caused by a decrease in the frequency of occurrence of Arctic air mass and an increase in that of the polar ones. The number of measurements in 1983 and 1991 was not big so it is possible that the deviation from the general tendency in these years occurred due to an insufficient statistics. The frequency of occurrence of subtropical air mass over Western Siberia during the period of experiments was low. It appeared here only occasionally and, evidently, did not make a noticeable contribution to the aerosol trend.

Such a result slightly contradicts the current conception that Arctic air masses are most clean. It is shown in the detailed study[24] performed for Western Siberia that the aerosol overburden of air masses depends on season, altitude, mean temperature of the layer and the way, by which the specific air mass came to Siberia. Hence, it is necessary to analyze the general atmospheric circulation during the period under consideration.

Before starting such an analysis, and because the airborne measurements were not regular, it is expedient to check, how much the repetition rate of air masses, in which measurements were carried out, corresponds to the repetition rate of air masses recorded by the weather service during each year for the territory under study.

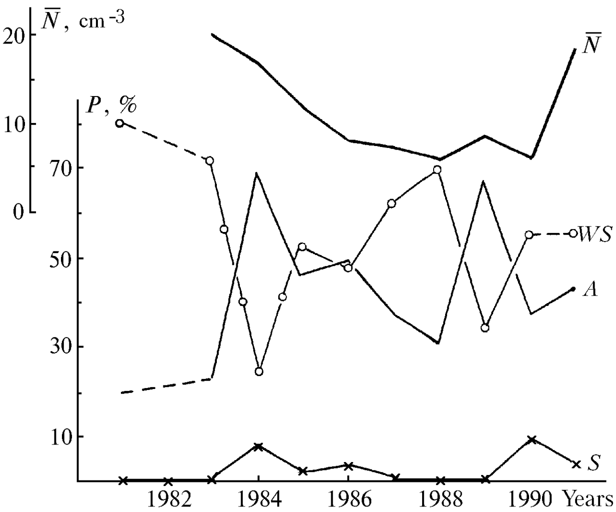

FIG. 2. Long-term behavior of the aerosol number density ($\bar{N}$) and the repetition rate of air masses: A – Arctic; S – subtropical; WS – polar during the period of the airborne experiments over Western Siberia.

It is seen in Fig. 3 that the variations in the air mass repetition rates in Western Siberia since 1981 till 1991 were similar to that observed in the airborne experiments (see Fig. 2). First of all, it is related to a decrease in the repetition rate for Arctic air masses and an increase in the number of the polar ones. The long-term behavior of subtropical masses is close to neutral.

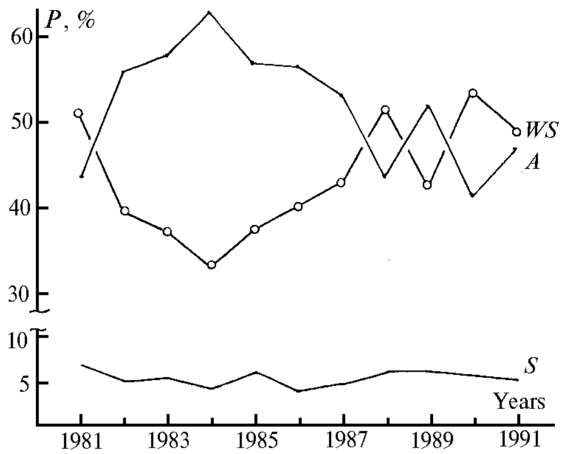

FIG. 3. Air masses repetition rates according to the data from the network of observations over Western Siberia: A – Arctic; S – subtropical; WS – polar.

The comparison of data presented in Fig. 2 and Fig. 3 shows that the experiments were carried out under conditions close to the average ones for this territory, and that the trend of the aerosol concentration is connected with the year-to-year change of the repetition rate of Arctic and polar masses.

Let us analyze the circulation forms in 80s. Such analysis is usually carried out using different circulation criteria.[25] Figure 4 shows the Kats,[27] Vangengeim,[26] and Blinova[28] circulation criteria calculated for this period.

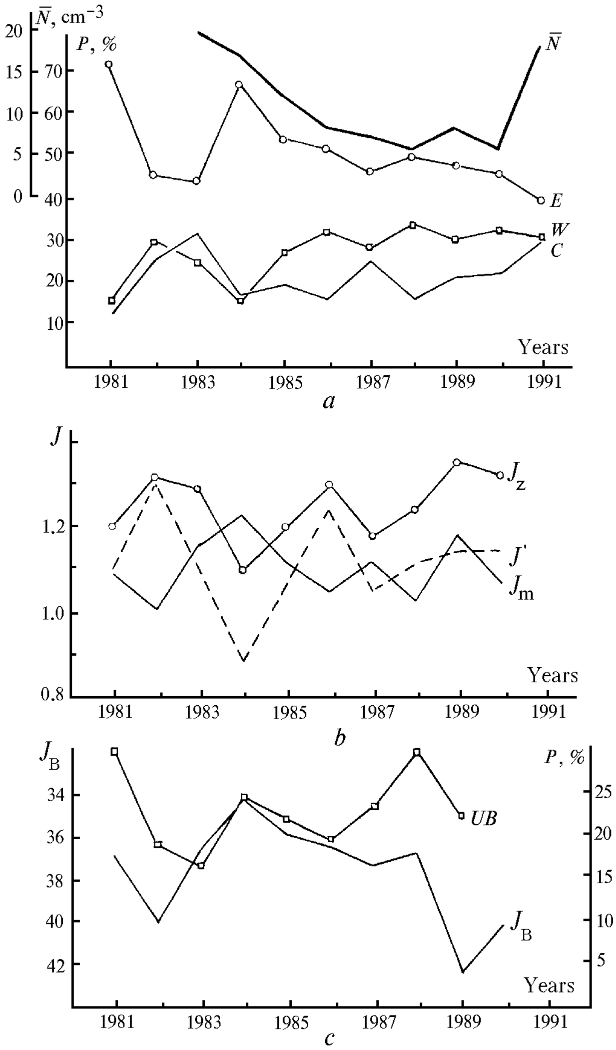

FIG. 4. Temporal behavior of the circulation criteria: a) long-term behavior of the aerosol number density ($\bar{N}$) and the repetition rate of the westward (W), eastward (E) and meridional (C) forms of circulation; b) Kats circulation criteria: J_z – zonal; J_m – meridional; J' – their ratio; c) Blinova circulation criterion (J_B) and the repetition rate of the Ural block (UB) over Western Siberia.

It is seen from Fig. 4*a* that a decrease in the aerosol number density over Western Siberia occurred from 1984 till 1990 was accompanied by a decrease in the number of eastward forms of circulation over this territory and by a small increase of the westward and meridional forms. The data for 1983 and 1991 deviate from this tendency. Most likely this is due to statistics.

One can draw similar conclusion, when considering the Kats circulation criteria shown in Fig. 4*b*. It is seen that the decrease in the aerosol concentration occurred on the background of the general increase in the intensity of the zonal form of circulation at a relatively small variation of the meridional form intensity.

Comparison of the data presented in Figs. 4*a* and *b* shows that the trend of the aerosol concentration in the middle 80s was caused by the circulation processes, namely the increase of repetition rate and intensity of the westward zonal circulation at an increase in the repetition rate of the meridional circulation without a significant change of its intensity.

This conclusion is confirmed by the increase of the Blinova's circulation criterion (Fig. 4*c*) that is the ratio of the linear velocity of the air motion along the latitude circle to the distance to the Earth rotation axis. It follows from Fig. 4*c* (inverse ordinate) that the criterion increased since 1984 till 1989 from 34 to 42, i.e. the intensity of the zonal circulation increased during this period.

To assess the role of the meridional processes, let us use the data on the repetition rate of the so called "Ural blockB kindly presented by A.I. Kuskov from Tomsk State University, and shown in Fig. 4*c*. The important role of this process for Western Siberia was revealed by L.I. Bordovskaya.[29] The matter is that the probability of formation of the altitude pressure ridge, that serves as a block, increases with the increase of the intensity of the westward zonal flow over Ural mountains. In this case the air masses from the Arctic Ocean come to Western Siberia via the ultrapolar trajectories.

It follows from Fig. 4*c* that the increase of the repetition rate of the blocking processes over Ural from 16% in 1983 to 30% in 1988 occurred on the background of the intensification of the westward zonal circulation. From that it follows that the aerosol trend was caused by superposition of two processes: the increase in the repetition rate of the polar air masses coming from the Atlantic Ocean via zonal trajectories, and the change of the trajectory of the Arctic masses which came to Western Siberia not through the European part of Russia, but via the ultrapolar (meridional) trajectories from Kara Sea. So the Arctic masses were more clean.

Such a conclusion is based not only on the analysis of the circulation criteria. If one considers Fig. 5, then one can see that the content of NH_4^+ and Na^+, which are related to the marine aerosol, in the aerosol composition significantly increased during the period under consideration. One can certainly exclude the anthropogenic factor from the increase of these components.[30]

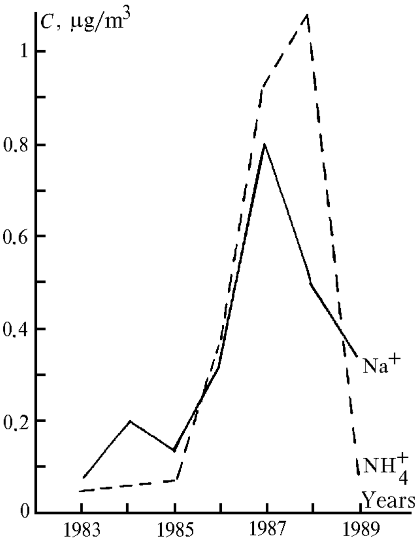

Fig. 5. Annual mean concentration of Na^+ *and* NH_4^+ *ions in the composition of aerosol over Western Siberia.*

4. DISCUSSION OF POSSIBLE MECHANISMS OF THE CIRCULATION CHANGE

The data presented above are indicative of the fact that the change of the aerosol concentration over Western Siberia in 80s was caused by the circulation processes. However, these data do not enable us to answer the question on the mechanism of the circulation change. Was it the consequence of the postvolcanic processes, or it was the natural process of the change of circulation epochs.

The matter is that the extremely intensive phenomenon "El-Ninyo/Southern oscillation,B Refs. 31–33, which is comparable with the volcanos in its effect on the general atmospheric circulation, appeared almost simultaneously with the El-Chichon eruption. Evidently, it is not occasional that the temperature increase was observed in different regions of the Earth after El-Chicon eruption[8,10,34] instead of the expected cooling. So, as K.Ya. Kondrat'ev[8] correctly noted, it is hardly possible to isolate the volcanic signal under such conditions. The results from Ref. 35, where the change of the circulation forms is related to the north-atlantic and southern oscillations, and high correlation coefficients obtained for such relations, favor this note.

5. CONCLUSION

Based on the analysis of the long-term behavior of the aerosol number density, its chemical composition and the circulation regime of the atmosphere, one can conclude that the trend in the aerosol concentration revealed over Western Siberia in 80s is mainly caused by the circulation processes, and, in particular, by the intensification and increase of the repetition rate of the westward zonal component and by the change in the meridional component.

AKNOWLEDGEMENTS

This work was supported by the grants for initiative projects of the Environmental Diagnostics Department of the Institute of Atmospheric Optics in 1996 and by Russian Foundation for Basic Research (grant No. 96–05–64322).

REFERENCES

1. D. Stannes and Ph. Bourdean, eds., *Climate Change* (Copenhagen, 1995), pp. 513–522.
2. B.D. Belan, in: *Abstract of Reports at the 10th All-Union Symposium on the Propagation of Laser Radiation in the Atmosphere*, Tomsk (1989), p. 77.
3. G.M. Abakumova and E.V. Yarkho, Meteorologia i Gidrologia, No. 11, 107–113 (1992).
4. D.J. Hofmann, J. Geophys. Res. **98**, No. D7, 12753–12766 (1993).
5. B.D. Belan, M.V. Panchenko, and V.V. Pol'kin, in: *Proceeding of the 4th International Aerosol Conference. Pt. 2* (Los Angeles, 1994) pp. 871–872.
6. B.D. Belan and G.N. Tolmachev, Atmos. Oceanic Opt. **9**, No. 1, 60–63 (1996).
7. S.L. Asaturov, M.I. Budyko, K.Ya. Vinnikov, et al., *Volcanos, Stratospheric Aerosol and Earth's Climate* (Gidrometeoizdat, Leningrad, 1986), 256 pp.
8. K.Ya. Kondrat'ev, *Global Climate, Ser. Meteorologia i Gidrologia* **17** (VINITI, Moscow, 1987), 316 pp.
9. A. Robock and J. Mao, Geophys. Res. Lett. **19**, No. 24, 2405–2408 (1992).
10. V.F. Loginov, *Volcanic Eruptions and Climate* (Gidrometeoizdat, Leningrad, 1984), 64 pp.
11. K.Ya. Kondrat'ev, ed., *Aerosol and Climate* (Gidrometeoizdat, Leningrad, 1991), 544 pp.
12. C.E. Junge and J.E. Manson, J. Geophys. Res. **60**, No. 10, 2163–2182 (1961).
13. J.L. Gras and J. Laby, J. Geophys. Res. **84**, No. 2, 303–307 (1979).
14. J.M. Rosen and D.J. Hofmann, Geophys. Res. Lett. **7**, 669–672 (1982).
15. L.S. Ivlev, Atmos. Oceanic Opt. **9**, No. 8, 657–669 (1996).
16. C.U. Hammer, Nature **270**, 482–486 (1977).
17. P. Buat-Menard and M. Arnold, Geophys. Res. Lett. **5**, No. 4, 245–248 (1978).
18. W.A. Sedlacek, G. Heiken, and W.H. Zoller, Science **126**, No. 4550, 119–121 (1982).
19. M.L. Asaturov, Meteorologia i Gidrologia, No. 11, 59–66 (1984).
20. L.P. Spirina, Trudy Gl. Geofiz. Obs., issue 330, 126–130 (1975).
21. V.V. Zuev, Atmos. Oceanic Opt. **9**, No. 9, 745–753 (1996).

22. M.I. Budyko, *Current Climate Change* (Gidrometeoizdat, Leningrad, 1977), 47 pp.
23. S.P. Khromov, *Principles of Synoptical Meteorology* (Gidrometeoizdat, Leningrad, 1948), 700 pp.
24. M.V. Panchenko and S.A. Terpugova, Atmos. Oceanic Opt. **8**, No. 12, 977–980 (1995).
25. N.A. Bagrov, K.V. Kondratovich, D.A. Pud', and A.I. Ugryumov, *Long-term Ecological Forecasts* (Gidrometeoizdat, Leningrad, 1985), 248 pp.
26. G.Ya. Vangengeim, Trudy AANII **34** (1952), 314 pp.
27. A.L. Kats, *Seasonal Variations of the General Atmospheric Circulation and Long-Term Weather Forecasts* (Gidrometeoizdat, Leningrad, 1960) 270 pp.
28. E.N. Blinova, Meteorologia i Gidrologia, No. 10, 23–32 (1972).
29. L.I. Bordovskaya, in: *Materials of the Scientific Conference "Problems of Glaciology of AltaiB* (Publishing House of Tomsk State University, Tomsk, 1974), pp. 95–117.
30. D.S. Lee and D.H.F. Atkins, Geophys. Res. Lett. **21**, No. 4, 281–284 (1994).
31. T.L. Belle and A. Abdullah, in: *Abstracts of Reports at the Third Conference on Climate Variations and Symposium on Contemporary Climate: 1850–2100*, Los Angeles (1985), pp. 89–90.
32. V.V. Klimenko, Energia, No. 2, 11–17 (1994).
33. N.A. Yasmanov, *Earth's Life: Nature and Society* (Moscow State University, Moscow, 1993) pp. 31–42.
34. J.K. Angell and J. Kozshover, Mont. Weather Rev. **12**, No. 7, 1457–1463 (1984).
35. O.A. Razorenova and I.I. Zveryaev, Meteorologia i Gidrologia, No. 6, 73–81 (1996).