Change of the wind climate on the Eurasian Arctic coast in the end of the 20th century

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The wind climate of the past eight years from 1997 to 2004 at the conditional boundary of the Arctic, i.e., the circle at 70°N, has been analyzed. The initial information was the data on wind direction and speed calculated by reanalysis of the wind field (http://www.arl.noaa.gov) on a 6-hour interval scale during a month permanently for January, April, July, and October.

Introduction

The air exchange between arctic and mid-latitudinal regions is one of the important climate-forming processes for the entire Northern Hemisphere. Regularities of the distribution and variations of the meridional component of the wind at the Arctic boundary determine, to a high extent, the spatial and temporal variations of the atmospheric mass, heat, and moisture fluxes into the Arctic and out from it. This, in its turn, may affect various properties of the atmosphere and surface of the coastal regions and seas of the Arctic Ocean.

To study the wind climate at the conditional boundary of the Arctic (70°N latitude) in 1997–2004, the initial values of the wind speed and direction were used. These values were determined on a 6-hour interval scale permanently during a month from the reanalysis of the wind field using data from Ref. 1. The wind was analyzed at the points, lying on a circle of 70°N with the interval of 20° longitude at altitudes from the ground level to 9 km (1-km interval). Seasonal differences in the processes of air transport through the chosen boundary were considered based on the results for four months: January, April, July, and October. In this paper, detailed analysis is carried out for the Eurasian part of the Arctic – for the zone from 0 to 200°E. From here on, the positive values of the meridional velocity and flows correspond to the air transport to the Arctic, while the negative ones to those directed out from it.

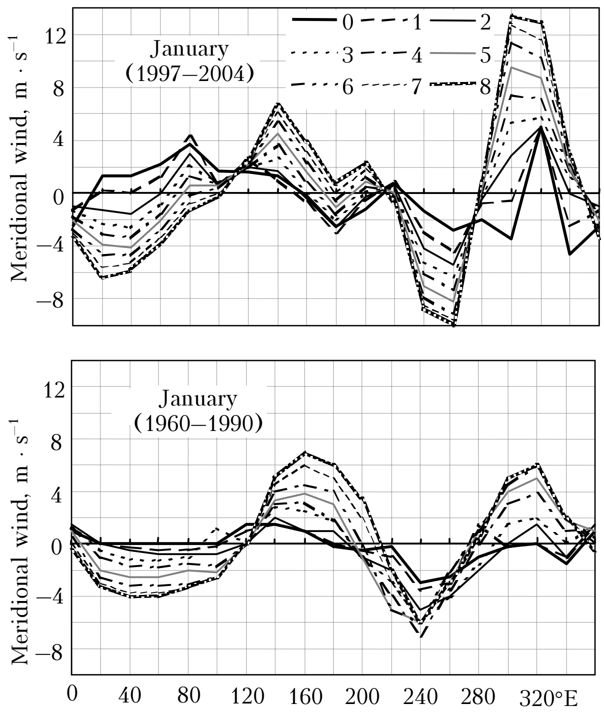

Fig. 1. Average distribution of the meridional wind component for January along the 70°N circle at different altitudes (altitude values in km are given in the legend).

1. Wind climate

Figures 1 and 2 show the average distributions of the meridional wind component along the 70°N circle in January and July for the period of 1997–2004 in comparison with 1960–1990 (according to data from Ref. 2).

It can be seen that the changes are significant, especially in the Eurasian sector. Besides the increased average value of the wind speed both in winter and summer, the most significant change is the alternation of the sign of the meridional wind in some areas of the territory under consideration: *for January* – the appearance of the air mass drift to the Arctic near 80°E and, to the contrary, from the Arctic near 180°E; *for July* – formation of an additional wave in the distribution of the meridional wind at altitudes above 2 km in the range of 40–140°E. In general, the meridional wind component alternates its sign along the 70°N circle more rarely in winter than in summer, which is connected with the more stable winter pressure and temperature distributions in the entire region. However, in the end of the 20th century the number of such sign alternations became larger, which is likely indicative of the lower stability of the atmospheric processes in general.

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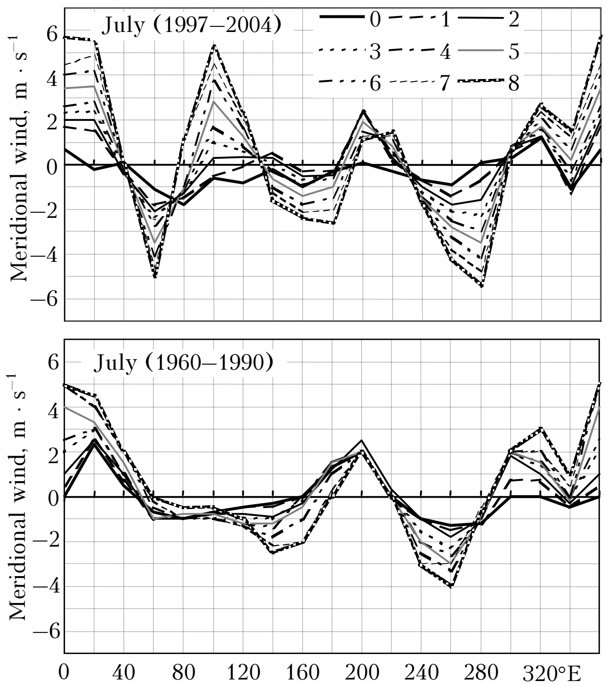

Fig. 2. The same as in Fig. 1, but for July.

Consider the Eurasian part of the 70°N circle in a more detail. Figure 3 characterizes the differences in the distributions of the average (over the altitude from 0 to 5 km) value of the meridional wind velocity component at the turn of the 21st century and in 1960–1990 (according to data from Ref. 3) in different seasons.

The following changes can be separated out in the meridional air transport in the low half of the troposphere on the Eurasian coast. *In January,* the directions of transport in the Atlantic and Pacific sectors has changed (from + to –), as well as between 60 and 80°E (from – to +). This must prevent from the inflow of warm air from the Atlantic and Pacific Oceans to the Arctic and, to the contrary, enhance the influence of the cold continental air from Northern Asia. *In April* the signs of the meridional wind velocity in the Atlantic and Pacific sectors also alternated, but the warm air from the Pacific Ocean now comes to the Arctic, to the contrary, more often. In addition, the velocities of air mass transport from the Arctic between 40 and 100°E increased markedly. *In July*, due to the higher divisibility of the distributions along the latitude (see Fig. 2), the direction of the air mass transport changed in three zones: in two narrow zones from 40 to 60°E and from 160 to 180°E (from + to –), while in the wide zone of 90–140°E the sign changed from – to +. This likely means that the warm (!) air from the continent came to the Arctic more efficiently. *In October*, the distribution of the meridional wind over the Eurasian coast of the Arctic changed only slightly. The most visible changes are the increase of the wind speed and the extension of the zone of air inflow to the Arctic in the zone of 100–160°E.

2. Mass fluxes

Air mass is, first of all, the *mass* of air, which is transported along the wind direction. Since the air density in the horizontal direction varies only slightly, Figure 3 can be also considered as a distribution of mass fluxes (in conditional units) in the lower troposphere up to 5 km at the boundary of the Arctic.

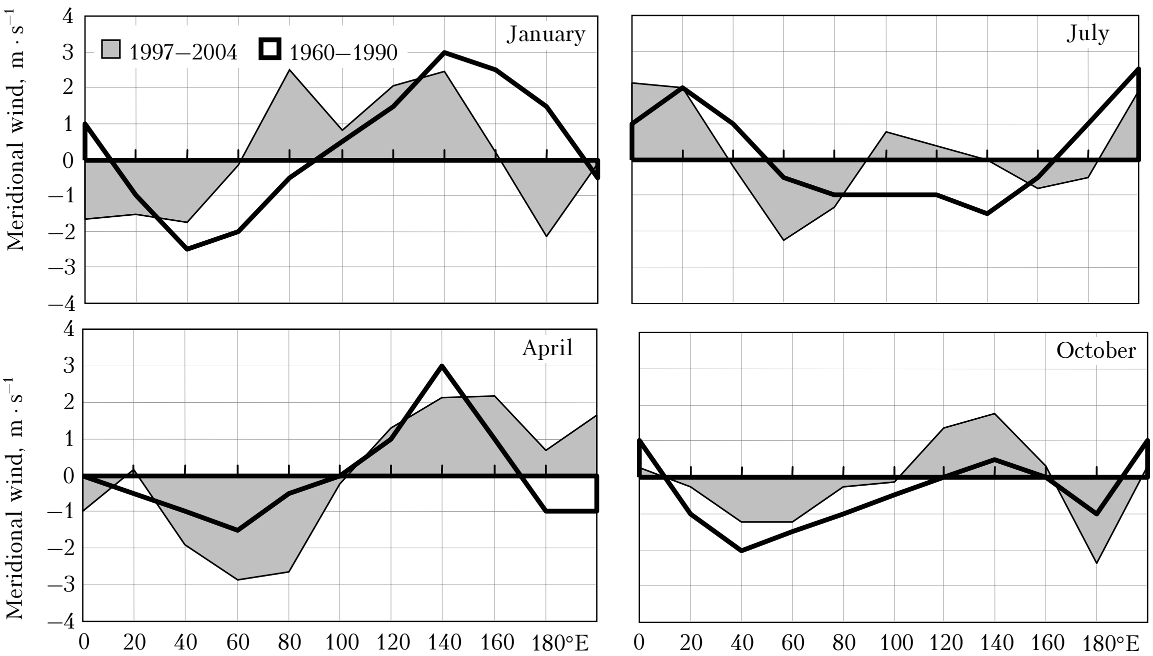

Fig. 3. Comparison of the average distributions (for 1997–2004 and for 1960–1990 [Ref. 3]) of the meridional wind component in the lower tropospheric layer from 0 to 5 km along the Eurasian part (0–200°E) of the 70°N circle for four months.

Figure 4 shows the altitude distribution of the meridional mass fluxes in the troposphere (as a total over the entire Arctic boundary of the Eurasia) and its change in the end of the 20th century. For estimation, we used the data from Ref. 4 on the vertical distribution of the air density in different months. It can be seen that, *in January* in the lower tropospheric layers, the mass is transported to the Arctic, as before. However, in recent years, the transport direction alternates at lower heights – at about 2 km from the surface (in contrast to 5 km in 1960–1990). *In July* the marked changes have occurred only in the surface layer, where the air mass is now transported from the Arctic region through the Eurasian part of the Arctic boundary.

For the tropospheric component, distributed uniformly from 5 km to the surface on the same imaginary wall along the 70°N circle from 0 to 200°E, the total mass fluxes in different months correspond to Fig. 5. It can be seen that *in April* and *in July* the patterns almost did not change with time (with a somewhat higher amplitude of the flux variations in April). *In January* and *October* the amplitudes have changed only slightly, but the values of the resultant fluxes have decreased. Ultimately, if the considered uniformly distributed ideal component does not undergo seasonal variations yet, then the total annual variations of the meridional flux of its mass at the Eurasian boundary almost did not change in the end of the 20th century. Its total annual flux through the considered part of the Arctic boundary is nearly zero. The last two conclusions depend also on whether the corresponding months are representative of the seasons, and the season lasts three months. The relations shown in Fig. 5 should be closest to actual ones for the air mass fluxes, as a whole. However, for other parameters and individual components of the atmosphere all these assumptions can hardly be accepted and, at least, the variations of the concentration during a year should be taken into account. Therefore, the rough estimates shown in Fig. 5 do not pretend to be accurate, but only illustrate the ways for the further development of this approach with the additional information available.

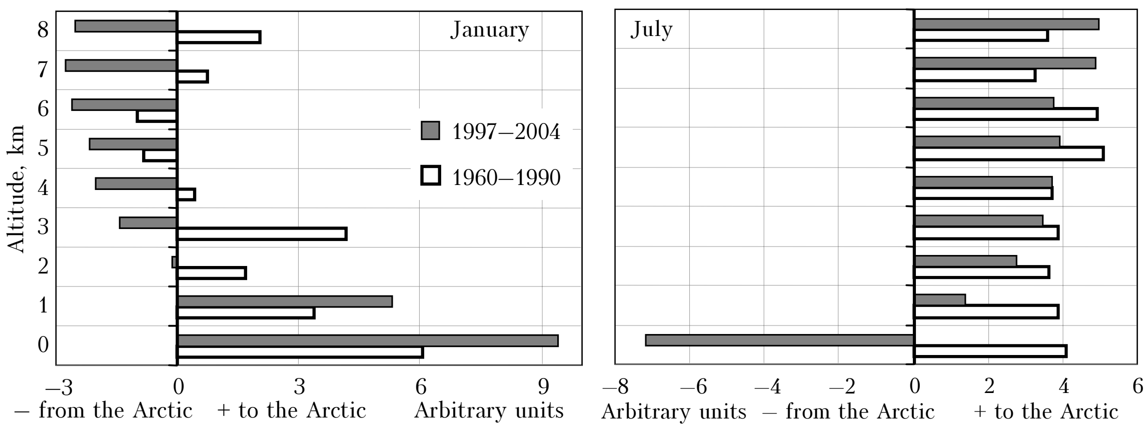

Fig. 4. Comparison of the vertical distributions (average for 1997–2004 and for 1960–1990 [Ref. 3]) of meridional air mass fluxes (total for the zone of 0–200°E along the 70°N circle) in January and in July.

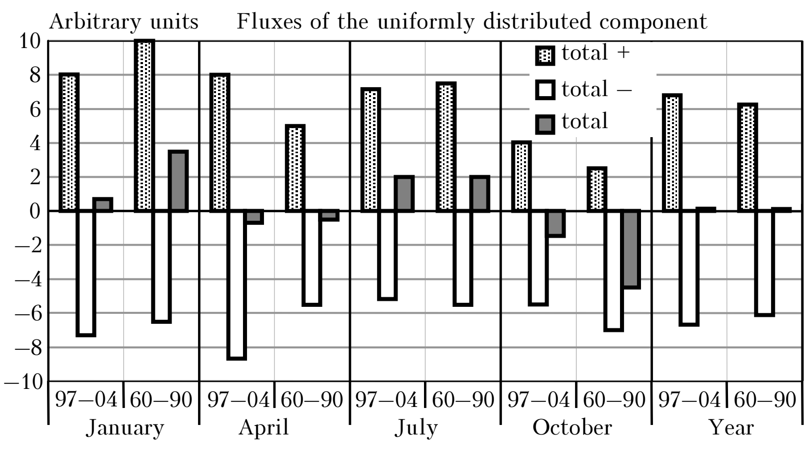

Fig. 5. Total meridional fluxes to the Arctic (+) and from it (–) for the atmospheric component uniformly distributed on the imaginary vertical wall 5 km high along the 70°N circle in the zone of 0–200°E in different months and for the year as a whole.

3. Energy fluxes

It is interesting to consider the meridional fluxes of kinetic energy and heat at the considered part of the boundary of the Arctic region. The problem of estimation and isolation of the territories, over which the air masses have the maximum wind-energy potential, is very important from the practical viewpoint of using wind as an ecologically clean and renewable energy source.[5] On the other hand, heat fluxes in the atmosphere are climatically significant characteristics, affecting the most evident climatic index – air temperature in some or other region.

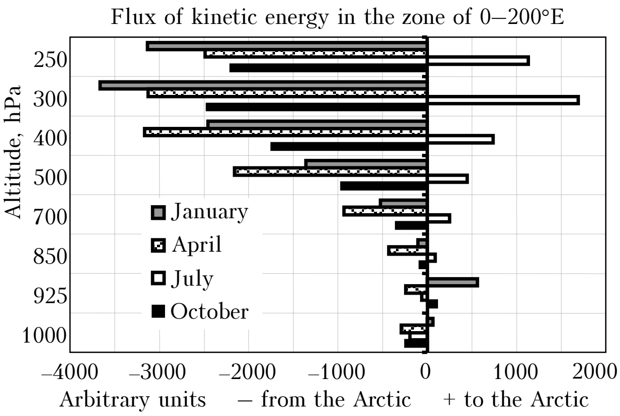

Fig. 6. Vertical distributions of the kinetic energy flux, total along the 70°N circle in the zone of 0–200°E in different months averaged over 1997–2004 years.

If the kinetic and thermal energy of an air mass are characterized by, respectively, the square wind speed and absolute temperature, then it can be stated that the distribution of the average fluxes of the kinetic energy and heat in the lower tropospheric layer is determined roughly by the meridional component of the wind along the 70°N circle according to Fig. 3. This is connected with the fact that deviations of the characteristics from their average values are an order of magnitude smaller than the values of the characteristics themselves.

The vertical distributions of the average (for 1997–2004) meridional fluxes of the kinetic energy in the troposphere of the Eurasian part of the Arctic boundary for different months are shown in Fig. 6. Unfortunately, we failed to compare these data with the previous years, as in Fig. 4, because in Ref. 2 there are no initial data on the wind speed. It can be seen from Fig. 6 that almost during the whole year round and through the entire troposphere the total fluxes of the kinetic energy at the Eurasian coast correspond to the outflow of the wind energy from the Arctic to the mid-latitudes. Somewhat noticeable resultant flows of the opposite direction are observed only in winter at the 925 hPa (700–900 m) level and in summer above 850 hPa (1.5 km).

Of undoubted interest are the interannual changes in the wind characteristics and mass and energy fluxes in the region under consideration. The comparison of the distributions of the meridional wind for every year (Fig. 7) with the average over the considered 8-year period reveals anomalous years for every month.

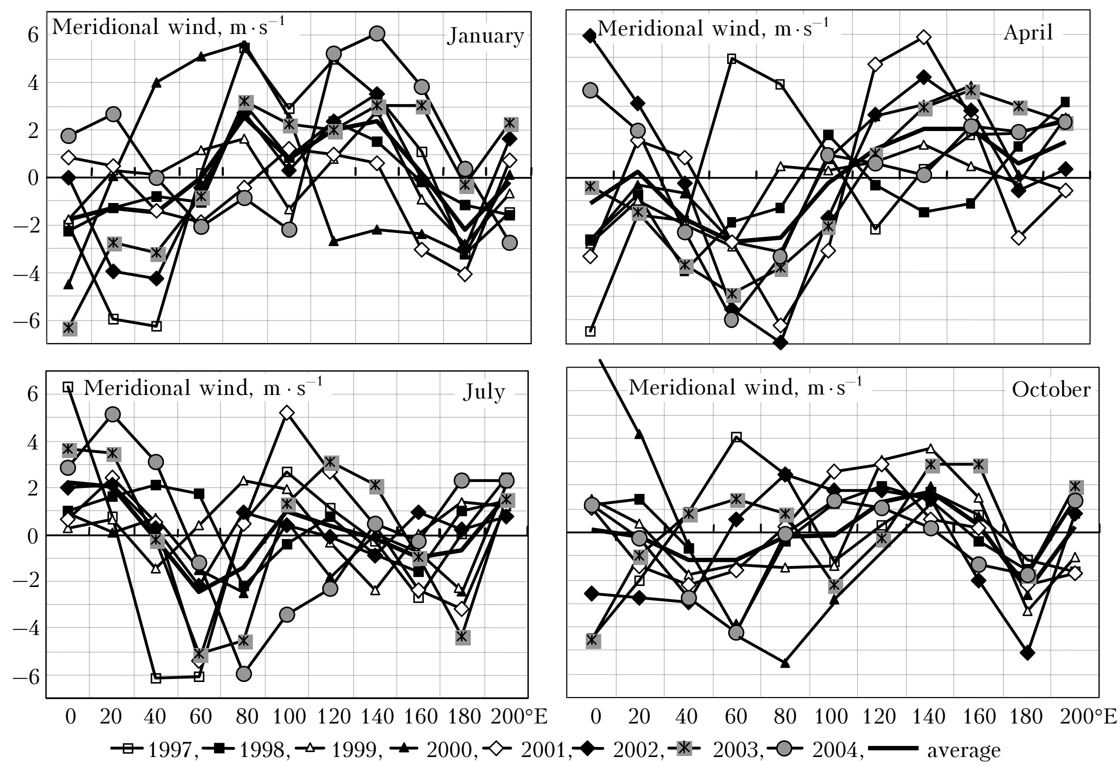

Fig. 7. Interannual changes of the distribution of the monthly average meridional component of the wind velocity along the 70°N circle in the tropospheric layer from 0 to 5 km for the zone of 0–200°E in different months.

Anomalies may occur both in amplitude and in the sign of the wind velocity, that is, the air transport direction. This all may appear to be important for particular experimental observations conducted near the Arctic coast of Eurasia and for the interpretation of the results of these observations. For some years, the deviations from the average distribution in the European part have the opposite character as compared to the Asian regions, which correlates with the data on the regularly observed ice oppositions in the western and eastern Arctic seas of Russia.[6]

The spatial distribution of the near-surface air temperature is determined, to a great extent, by the temperature of the Earth's surface. It is well known that at the altitudes of 5 km the horizontal distribution of the air temperature becomes close to zonal,[4] and in the upper layers it is determined by the solar heating of the atmosphere in the corresponding latitudes. Analysis of the many-year data on the air temperature at different altitudes, obtained from reanalysis of the temperature field,[1] shows that the surface effects smooth somewhat already at the level of 850 hPa, while remaining yet clearly seen. Therefore, in estimating the average heat fluxes through the 5-km high imaginary wall, we considered just the air temperature at the altitude corresponding to 850 hPa as the average (over the vertical) thermal characteristic of the air.

It is seen from Fig. 8 that the mass and energy fluxes on the Eurasian coast of the Arctic vary very widely both in the amplitude and in the sign from year to year in different seasons and during a year. Certainly, the period of eight years is too short to draw some conclusions about the long-term tendencies in these variations, and therefore the positive linear trend of the annual average heat flux (lower diagram in Fig. 8) should be treated with care. The reliability of this approximation is low, as R^2 is only 0.16. In addition, it is disturbed by the uncertainty due to the assumption of equal seasons and because of the use of the results obtained for one month that presents the season as a whole.

Certainly, the horizontal heat transfer at the Arctic boundary is not a sole process, regulating the temperature of the environment in the region under study. It is still undoubted that just the warm and cold air fluxes determine the interannual differences between the conditions observed experimentally in the areas adjacent to this boundary. For example, the fall months in 2003, which were warmer than in 2002, in the East Siberian Sea and Chuckchee Sea, as noted in Ref. 7, agree with the lower diagram in Fig. 8 and with the distribution of the meridional wind in fall (see Fig. 7).

In Ref. 6, the correlation of the baric distributions in the Arctic air basin and the presence/absence of the ice opposition with the characteristics of solar cycles is shown purely statistically (without analysis of the correlation mechanisms). This is indicative of the complex and not fully understood nature of these phenomena. Since the wind is determined, to a significant degree, just by the atmospheric pressure field, the spatial wind distributions (see Figs. 1–3, 7) are opposite over the Eurasian and Asian territories near the 70°N latitude. If we consider individually the heat fluxes across the European (from 40 to 80°E) and the Asian (from 120 to 160°E) parts of our imaginary boundary on the 70°N circle (Fig. 9), it becomes clear that, on the whole for a year, they are areas of heat outflow (over the European coast) and inflow (over the Asian coast) in relation to the Arctic region.

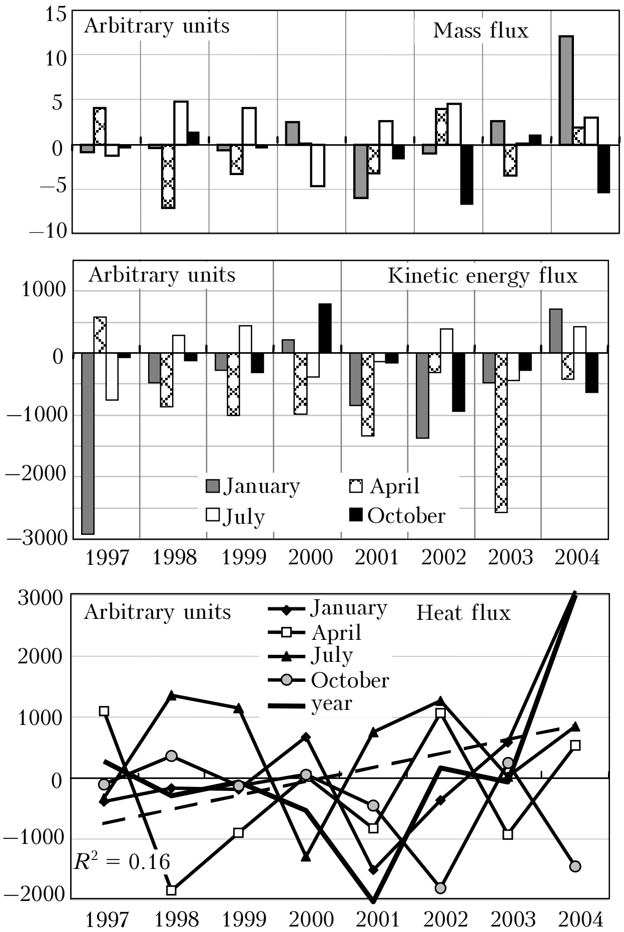

Fig. 8. Interannual variations of the total meridional fluxes of mass, kinetic energy, and heat in the lower tropospheric layer of 0–5 km along the 70°N circle in the zone of 0–200°E in different months and for a year as a whole (for the heat flux). The dashed line in the lower diagram is the linear trend of the annual heat flux.

The effects in different seasons are different, and the coefficient of correlation between the European and Asian indices (a total of 8 pairs of values for 8 years) is most significant in winter (–0.69), close to –0.5 in spring and summer, and very low in fall. Nevertheless, the trends of the total heat flux for a year (see Fig. 9) have a rather high reliability, thus proving that at the turn of the century these zones actually were the zones of heat energy inflow and outflow from the Arctic. In recent years, the heat fluxes through these zones increase especially noticeably in the European part and less stably in the Asian part.

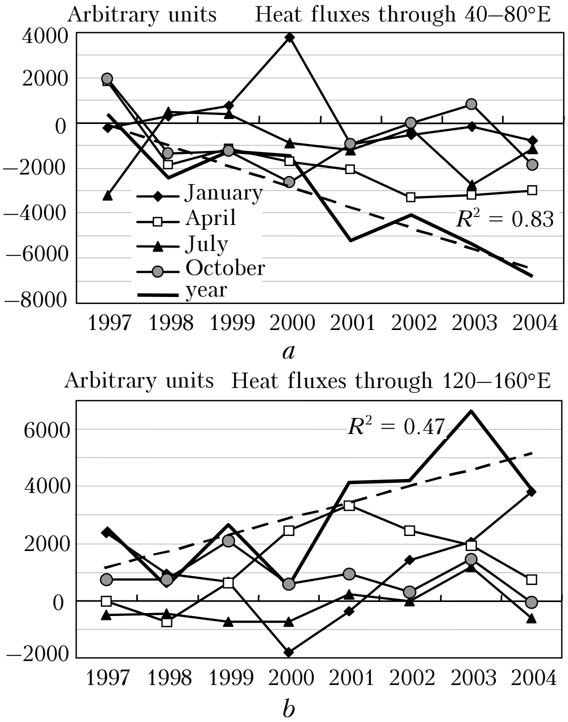

Fig. 9. Interannual variations of the total meridional heat fluxes in the tropospheric layer of 0–5 km along the 70°N circle in the European (*a*) and Asian (*b*) zones in different months and a year as a whole.

Conclusions

Thus, analysis of the wind climates at the Arctic boundary at the turn of the century has shown significant changes in the conditions of the meridional air transport between the Arctic and the mid-latitudinal regions. The especially marked changes in the end of the 20th century as compared to the period of 1960–1990 occurred on the Eurasian coast of the Arctic Ocean. These changes manifested themselves both at the level of the monthly (seasonal) average characteristics and in their vertical and horizontal distributions. The interannual variations of the wind climate in the lower troposphere in the European and Asian parts of the Eurasian coast are often opposite. As a result, these zones serve for the heat outflow and, to the contrary, inflow (during a year as a whole) to the Arctic region. These processes are also significant from the viewpoint of inflow of anthropogenic pollutants to the atmosphere over the Arctic Ocean, its cleaning, and pollutant redistribution over the Northern Hemisphere. The current distributions of the meridional mass and energy fluxes through the Eurasian boundary of the Arctic can serve additional information in interpreting the results of various field observations in the Arctic region.

Acknowledgments

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