Long-term variations of air humidity characteristics on the territory of the Northern hemisphere in the second half of the twentieth century

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Long-term variations of temperature and specific and relative air humidity on standard isobaric surfaces in middle and high latitudes of the Northern Hemisphere are studied using NCAP/NCER Reanalysis data for the second half of the twentieth century.

Introduction

The presence of water vapor in the atmosphere has a substantial effect on thermal conditions of the atmosphere and earth surface. The water vapor intensively absorbs the long-wave radiation, emitted by the earth surface. In its turn, the water vapor itself emits this radiation, mostly returning back to the earth surface. This decreases the nighttime cooling of the surface and lower air layers.[1,2]

For this reason, variations of water vapor content may be one of the main factors determining the observed climate change on the planet. Therefore, the problem of time dynamics of water vapor content variations in the atmosphere is of special interest. Until recently, the solution of this problem was complicated by the absence of many-year data series.

In the recent years, the situation has changed: development and improvement of numerical methods favored the creation of databases, allowing us to analyze the water vapor content variations in the atmosphere during a few tens of years.

Quantitatively, the water vapor abundance in the atmosphere is expressed through the humidity characteristics. Its main characteristics are: partial pressure of water vapor, absolute and relative humidity, and mass fraction of water vapor (specific humidity). In this paper, we consider the distribution of specific and relative humidity of air.

Spectral analysis of variations of the humidity and air temperature characteristics

To study the spatial structure of long-term variations of air humidity characteristics at the standard isobaric surfaces in middle (50–65°N) and high (> 65°N) latitudes of the Northern Hemisphere, we used NCAP/NCER Reanalysis data (http://www.cdc.noaa.gov/) for period from 1948 to 2005. We divided the region of temperate latitudes into sectors: Atlantic (60–01°W), European (0–59°E), Siberian (60–119°E), Far Eastern (120–169°E), Pacific (170°E – 121°W), and American (120–61°W).

As an example, Figure 1 presents variations of air temperature and relative and specific humidity at standard isobaric surfaces in high-latitude sector in winter and summer seasons.

The division into seasons is required, firstly, because there are considerable annual variations and, secondly, because many-year variations of the considered characteristics have quite large amplitude in winter period, whereas the summer period is characterized by only weak variations.

Analysis of variations of the temperature and specific and relative humidity of air makes it possible to speculate that they consist of two (high- and low-frequency) components. To verify this speculation, we performed the spectral analysis of variations of air temperature and humidity characteristics (Fig. 2).

The obtained spectra well exhibit the presence of two components in the considered variations: first component is high-frequency quasi-periodic variations (quasibiennial), and the second component is long-term variations with characteristic time larger than 8 years.

It is quite natural to expect that these components are caused by different processes; therefore, subsequent study was conducted separately for each of the components.

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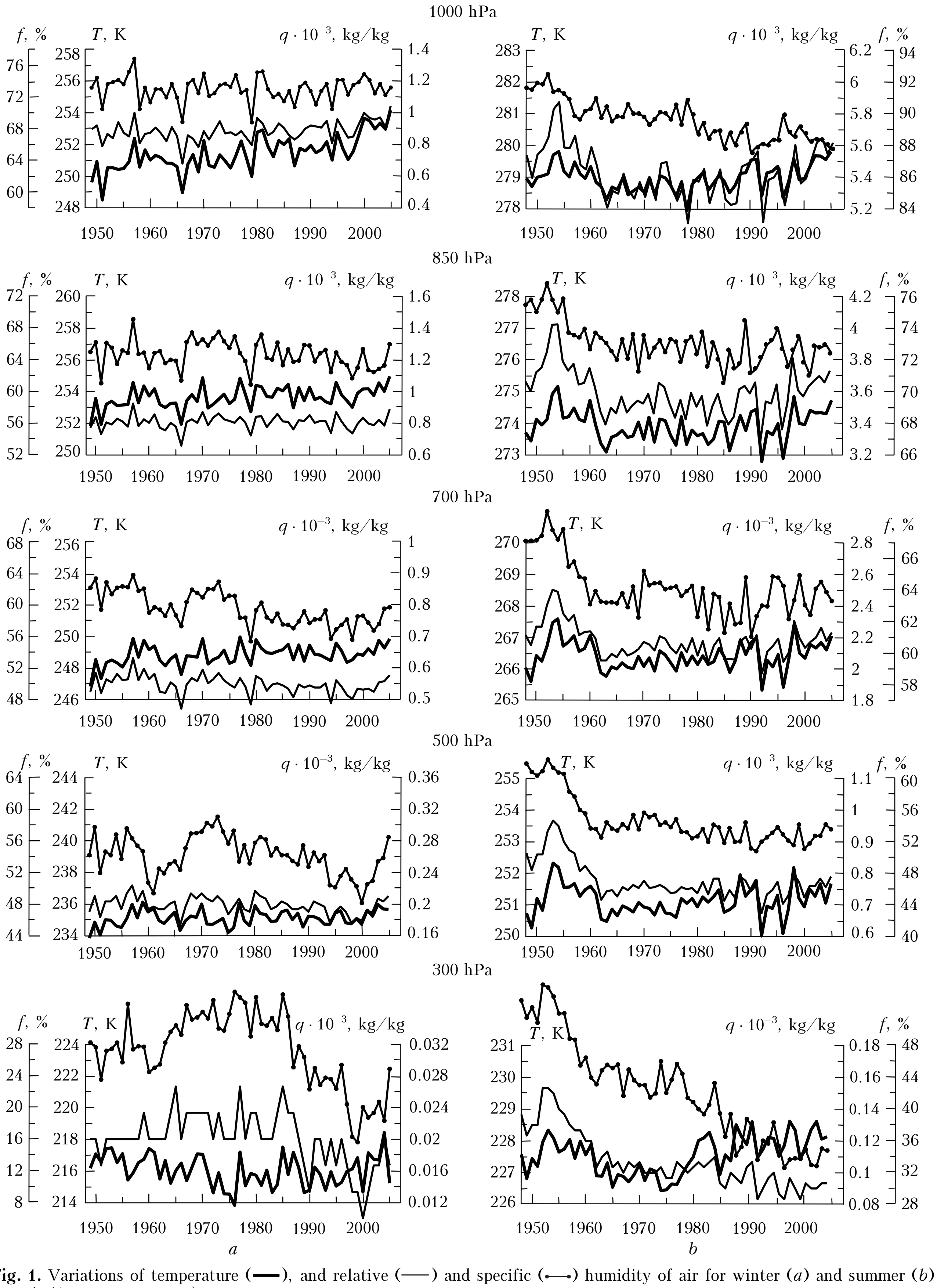

Fig. 1. Variations of temperature (━━), and relative (——) and specific (•—•) humidity of air for winter (*a*) and summer (*b*) periods (from 1948 to 2005).

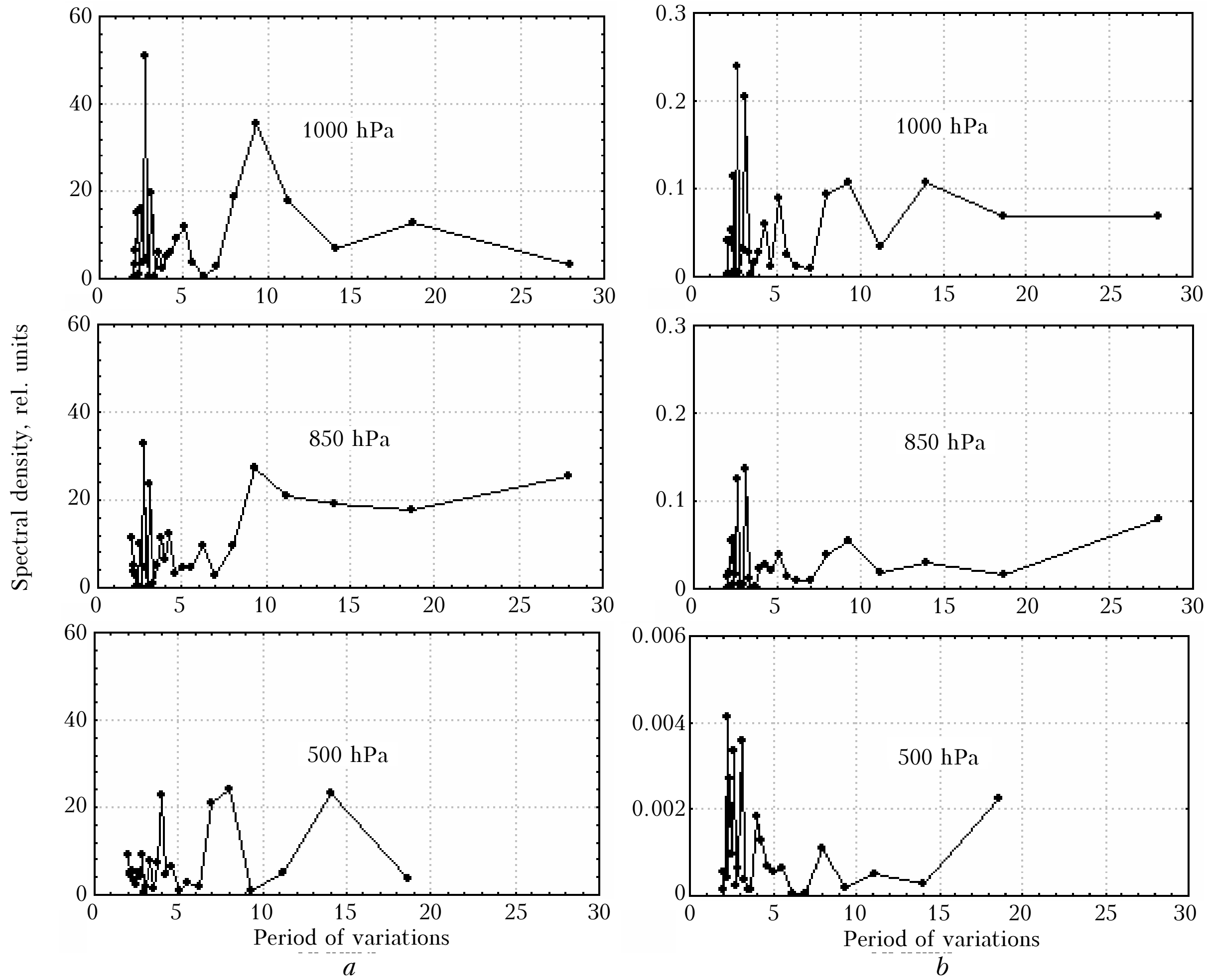

Fig. 2. The spectral density of relative (*a*) and specific air humidity (*b*) in winter season in the Siberian sector (60–119°E) from 1948 to 2005.

Short-period variations of humidity and air temperature characteristics

One of the main indicators of current climate changes on the planet is variations of the temperature regime. The study of interrelation between variations of air temperature and specific and relative humidity on standard isobaric surfaces by the method of linear correlation gave us correlation coefficients whose values are given in Tables 1 and 2.

The correlation analysis of interrelation between air temperature variations and variations of the specific humidity has shown that the quasibiennial (short-period) oscillations of water vapor content (specific humidity) quite well correspond to variations of air temperature in the given region, with correlation coefficient higher than 0.7. Analysis of interrelation between variations of air temperature and variations of relative humidity did not reveal analogous regularity.

Table 1. Correlation coefficients between short-period variations of specific humidity and air temperature for winter and summer seasons

Sector	Season									
	winter					summer				
	Standard isobaric surfaces, hPa									
	1000	850	700	500	300	1000	850	700	500	300
Atlantic	0.88	0.88	–	0.86	0.77	0.96	0.84	0.81	0.90	0.85
European	0.98	0.93	0.86	0.82	0.68	0.57	0.89	0.77	0.81	0.85
Siberian	0.95	0.95	0.93	0.90	0.51	0.78	0.89	0.84	0.76	0.80
Far Eastern	0.93	0.93	0.94	0.93	0.61	0.88	0.82	0.73	0.75	0.93
Pacific	0.96	0.92	0.87	0.91	0.60	0.97	0.91	0.79	0.76	0.90
American	0.95	0.93	0.91	0.91	0.56	0.93	0.89	0.87	0.79	0.84
Polar	0.80	0.85	0.81	0.73	0.52	0.94	0.90	0.87	0.85	0.59

Table 2. Correlation coefficients between short-period variations of relative humidity and air temperature for winter and summer seasons

Sector	Season									
	winter					winter				
	Standard isobaric surfaces, hPa									
	1000	850	700	500	300	1000	850	700	500	300
Atlantic	0.41	−0.12	−0.40	−0.26	0.39	0.09	−0.26	−0.25	−0.17	0.32
European	0.72	0.47	0.21	0.12	0.18	−0.32	−0.71	−0.42	−0.49	−0.24
Siberian	0.93	0.58	−0.35	−0.36	0.34	0.04	−0.29	−0.23	−0.29	−0.01
Far Eastern	0.70	0.67	−0.01	−0.01	0.29	−0.31	−0.51	−0.41	−0.31	0.08
Pacific	0.56	0.32	−0.31	−0.26	0.22	−0.17	−0.38	−0.29	−0.08	0.38
American	0.68	0.13	−0.26	−0.23	0.34	−0.52	−0.67	−0.69	−0.51	0.10
Polar	0.82	0.63	0.24	0.06	−0.26	−0.42	−0.28	−0.12	−0.06	−0.05

For instance, whereas a good correlation between variations of air temperature and specific humidity is observed in all the considered regions at altitudes up to 300 hPa, the relative humidity correlates with the air temperature only in winter period near the underlying surface; in Pacific and Atlantic regions the correlation is most weakly expressed.

In all considered regions, the correlation between the relative humidity and the air temperature rapidly deteriorates with growing altitude. As an illustration of the above dependence, Figure 3 presents the short-period variations of the specific and relative humidity and the air temperature in Polar region on different isobaric surfaces in winter and summer seasons.

Since the correlation coefficient characterizes only the degree of interrelation between characteristics, we consider the coefficient of linear regression (tangent of the slope angle), characterizing the rate of the specific air humidity change with variations of the air temperature. Figure 4 presents the diagrams of point scatter and regression line between short-period variations of the specific humidity and air humidity on different isobaric surfaces in the high-latitude region.

In addition, Figure 4 presents the coefficients of correlations and the rate of the specific humidity change at a change of the air temperature. The performed analysis has shown that the response of specific humidity to variations of air temperature with the temperature increase is more pronounced in summer than in winter.

This effect, most likely, is associated with the change of the altitude profile of the mean air temperature in the considered region, i.e., the variations of air temperature are accompanied by large changes in the specific humidity for higher mean air temperatures. The spatial analysis of the response of air temperature has shown that the water vapor content increases with air temperature faster in the regions with larger mean air temperature. Thus, it can be concluded that the rate of change of specific humidity with variations of air temperature is largely related to the mean temperature and grows with the temperature increase.

At present, a large attention is given to the problem of determination of the causes of the observed climatic changes. More and more often, in addition to the internal causes of the climate system variation, external processes with respect to the system are also considered influential.[3] One of the external factors governing the climate changes may be the variations of solar activity.[4]

In this regard, we consider the behavior of short-period variations of air temperature and specific and relative humidity as functions of variations of the geomagnetic activity on standard isobaric surfaces. To describe the fluctuations of the geomagnetic field, the planetary index of geomagnetic activity AE is used.

The results of analysis of interrelations between short-period variations of specific and relative humidity, as well as air temperature, and geomagnetic activity have shown that the simple linear relation between these parameters is absent on a few-year time scale (see Fig. 3).

Thus, the above analysis of short-period variations of the considered parameters makes it possible to conclude that the variations of the specific humidity are mainly determined by the variations of air temperature, while the variations of relative humidity may be caused by variations of other factors and particularly by instability of atmospheric circulation due to influence of external impacts.

Long-term variations of air humidity and temperature characteristics

Analysis of connections between long-term variations of specific and relative humidity and the air temperature has shown that the regularities of the interrelation between the specific humidity and air temperature observed for short-period variations are the same for long-period variations. Most close interrelation between long-term variations of specific humidity and air temperature is observed near underlying surface, and it decreases with going away from the surface, i.e., in this case the interrelation degrades. Above the oceans, the interrelation between long-term variations of specific humidity and air temperature is observed up to higher altitudes than over land, persisting up to 300 hPa. It should be noted that in the upper tropospheric layers (above 700 hPa), there is a long-term decrease in the specific humidity, especially in the Polar region. This feature agrees with conclusions obtained in Ref. 5.

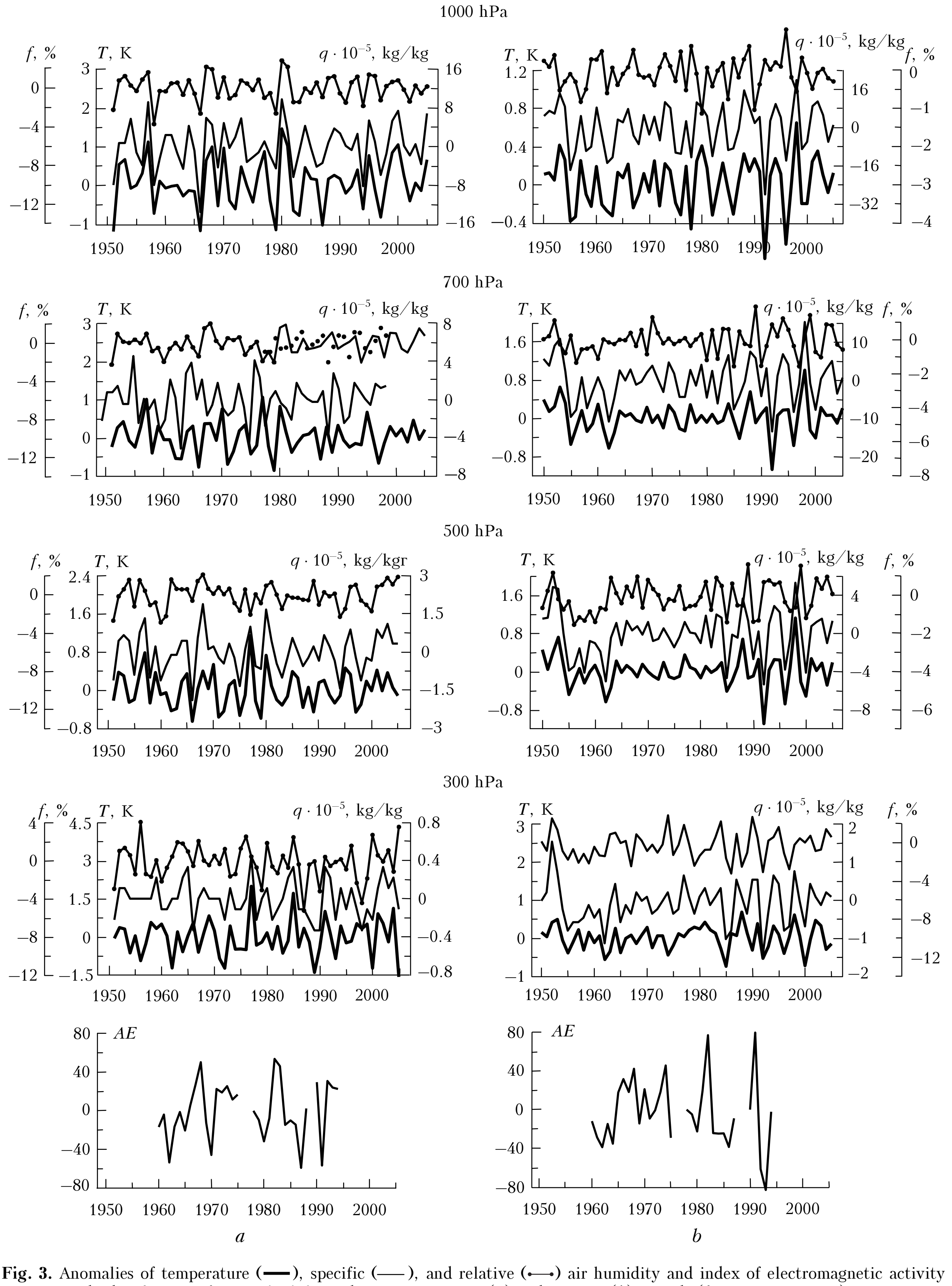

Fig. 3. Anomalies of temperature (▬▬), specific (——), and relative (•—•) air humidity and index of electromagnetic activity AE on standard isobaric surfaces in high-latitude sector in winter (a) and summer (b) periods (from 1950 to 2005).

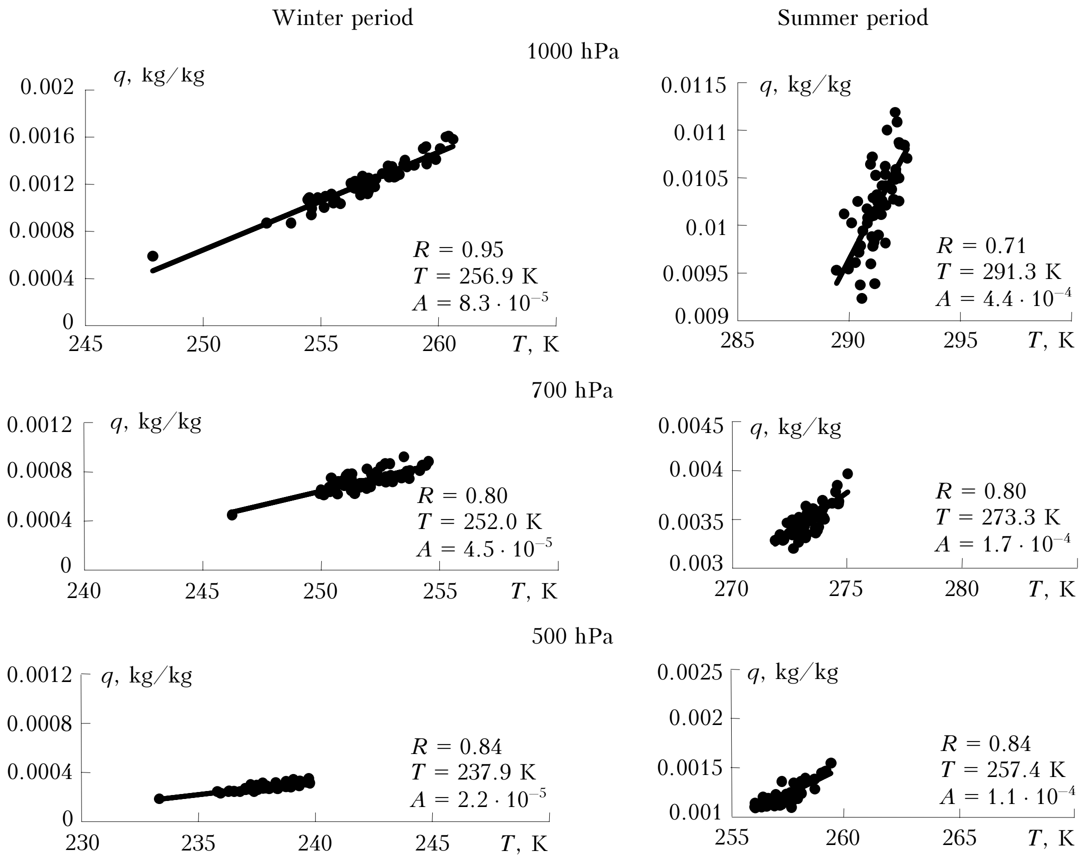

Fig. 4. Variation of the response of specific humidity to changes in air temperature on standard isobaric surfaces in the Siberian sector in summer and winter periods (from 1948 to 2005) (R is the correlation coefficient; T is the mean air temperature; and A is the coefficient in regression equation).

In addition, in the long-term variations of the considered characteristics we quite clearly see a considerable decrease of the relative humidity in all considered regions, especially marked in the upper troposphere, particularly in the summer period (10–15% at the 300-hPa level). Note that the observed long-term decrease of the relative humidity is only two times less than the amplitude of the annual variations of the relative humidity in this region.

Consider the behavior of long-period variations of humidity and air temperature characteristics as functions of AE variations at standard isobaric surfaces (Fig. 5).

The performed analysis demonstrates a good interrelation between long-term-variations of air temperature and geomagnetic activity near the surface; the interrelation in the Pacific sector is observed up to higher altitudes in the winter period. Analogous, though less pronounced, air temperature behavior can be observed in the Polar region and in the Far East and American sectors. Analysis of long-period variations of humidity characteristics has shown that the increase of the planetary index of geomagnetic activity AE in the second half of the twentieth century is accompanied not only by the growth of air temperature and specific humidity, but also by a decrease of relative air humidity in the lower and upper troposphere.

Conclusion

The spectral analysis of the specific and relative air humidity made it possible to divide the variations of the considered characteristics into two parts: high-frequency quasi-periodic (quasibiennial) variations and long-term variations with the characteristic time of more than 8 years.

The analysis of high-frequency quasi-periodic (quasibiennial) variations of air temperature and specific and relative humidity has shown that he water vapor variations (specific humidity) considerably depend on variations of air temperature; whereas the variations of the relative humidity are, possibly, a consequence of changes of the atmospheric circulation under impact of the external factors.

The regression analysis of interrelation between variations of the high-frequency and air temperature has revealed that the rate of variation of specific humidity at a change of air temperature decreases with height growth, and this process is faster in summer than in winter.

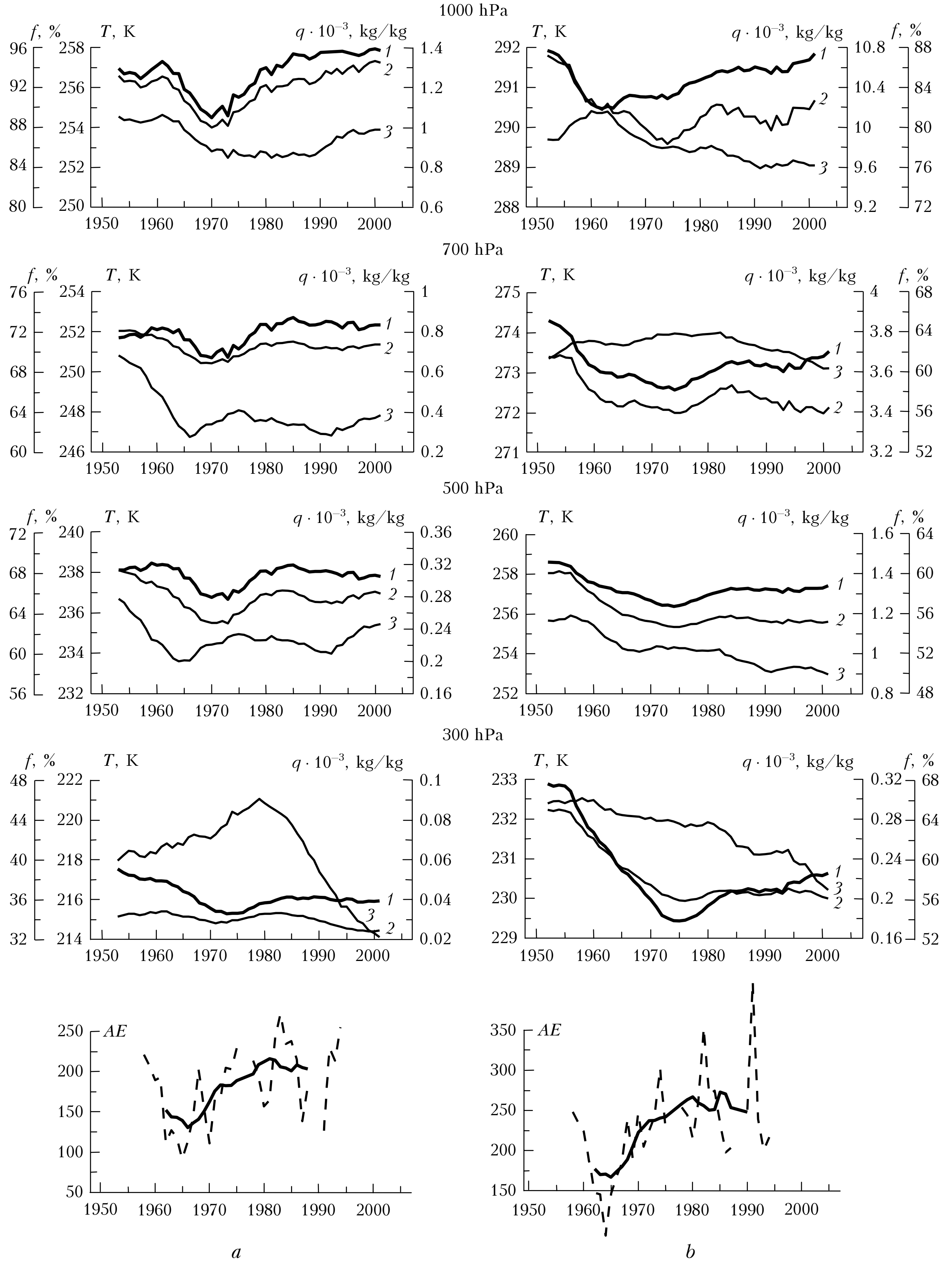

Fig. 5. Variations of air temperature (*1*), specific (*2*) and relative (*3*) humidity and the index of geomagnetic activity *AE* at the standard isobaric surfaces in the Siberian sector in winter (*a*) and summer (*b*) periods (from 1950 to 2002).

The spatial analysis of the response of the specific humidity to the change of air temperature has shown that the water vapor content increases with air temperature faster in the regions with larger mean air temperature.

The study of long-term variations of the considered characteristics revealed that the increase of the planetary index of geomagnetic activity *AE* in the second half of the twentieth century is accompanied by the increase of the specific humidity and decrease of the relative air humidity in the lower and middle troposphere in most considered regions. These regularities are most marked in the winter period.

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