1.9 CLIMATE VARIABILITY OF THE POLAR ATMOSPHERE BASED ON HISTORICAL RADIO SOUNDING DATA

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1. INTRODUCTION

The well-known effect of enhanced high-latitude warming had been revealed by surface air temperature (SAT) analysis (e.g. Polyakov et al, 2002). At the same time, preliminary results deduced with the database of the climatic characteristics of the free atmosphere in the Northern Polar Region (NPR), including unified technique data of soundings from 1959 up to 2000, showed that positive trends in SAT are accompanied by the cooling of the upper troposphere (Maistrova et al, 2001). The new version of the database together with an improved and extended data set of soundings from the drifting stations named "North Pole" has allowed us to investigate the temporal variability of the main characteristics of the low atmosphere above the Canadian Basin, to evaluate accuracy of NCEP Reanalysis, and to study spatial-temporal variability of humidity in different layers of the free atmosphere of NPR (60^0-90^0 N).

2. DATA

The data used for analysis had been prepared as part of the framework of the project “Climate variability of the polar atmosphere revealed with historical radio soundings information,” which was initiated by the International Arctic Research Center, UAF and Arctic and Antarctic Research Institute. This project is an international effort to create a new data set of the radio soundings, executed north of 65^0 N on the Russian coastal and island polar stations (data of more than 1 million soundings from 67 polar stations), and to improve and to extend the data set of soundings from the drifting stations "North Pole," up to 33,000 soundings. The positions of selected NP stations in 1956-1991, the data from which had been used for creation of relatively homogeneous data rows, characterizes the low atmosphere in January and July, which were chosen as before for investigations of temporal variability of total cloudiness in NPR (Makshtas et al, 1999). For comparison, similar data rows had been calculated from NCEP by interpolation from the regular grid to the NP station location for each day of the period under study. Investigation of spatial - temporal variability of the polar atmosphere in the North Polar Region had been fulfilled with improved database described by Maistrova et al (2001).

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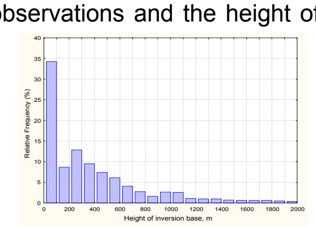
3. CLIMATE OF THE LOW ATMOSPHERE IN THE CENTRAL ARCTIC BASIN

3.1. *Characteristics of surface inversions and the atmospheric boundary layer*

To investigate the main characteristics of surface inversions and the atmospheric boundary layer (ABL) in the polar atmosphere we used a protocol described by Andreas et al (2000). Figure 1, constructed with data of more than 2500 soundings for each investigated month, shows that during winter, the inversion base is situated on the surface in 70% of the observations and the height of



elevated inversions does not exceed 1 km.

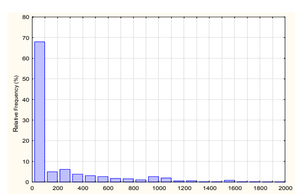


Figure 1.Relative frequency of the inversion base height in the Canadian Basin in January (left) and July (right).

In summer the probability of an elevated inversion, related likely to the advection of a warm air mass from southern continents and prevalent low-level cloudiness, has the same probability as surface based inversions.

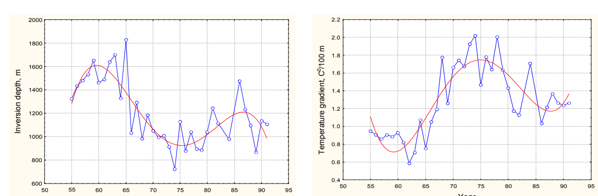
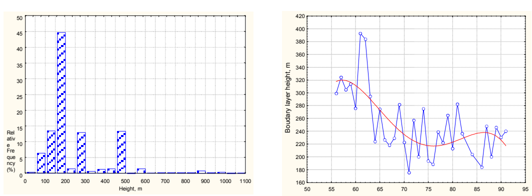


Figure 2. Interannual variability of mean depth (left) and temperature gradient (right) of the surface based inversions in the Canadian Basin (January).

Figure 2 shows the interesting behavior of a winter surface-based inversion, similar to that revealed by

Bradley et al (1993) for Barrow: the decrease of the surface-based inversion depth from the 1950s to the 1990s. We found that this decrease was accomplished by an increase of the air temperature gradient in the inversion layer. A few possible physical mechanisms had been proposed by Bradley et al (1993): shifts in atmospheric circulation, an increase of cloudiness, an increase in arctic haze density, and the greenhouse effect. The last three mechanisms could explain the decrease of the inversion depth due to the increase of the surface temperature, but are unable to explain the increase of temperature gradient. Only the first mechanism gives the possible explanation of both features of the winter polar atmosphere. Indirect proof of such conclusions are revealed with the decrease of wind velocity on 925 hPa and 850 hPa isobaric surfaces from 60s to 70s up to 2 m/s, the increase of air temperature differences between the same isobaric surfaces and the atmospheric surface layer (up to 1.5 - 2^0C), and some reduction of the geopotential surface 925 hPa. All mentioned changes indicate the increase of anticyclone atmospheric circulation, warm air advection and the related growth of stability in the low atmosphere, which in turn increases the air temperature gradient and decreases the depth of the surface-based inversion in the region under study.

The probability and temporal variability of ABL height, defined by Andreas et al (2000) as a height where integral Richardson number exceeds its critical value 0.4, are shown in Figure 3.



a b

Figure 3. Histogram of probability (a) and temporal variability (b) of the monthly mean boundary layer height in the Canadian Basin in January.

Figure 3a shows that the most probable ABL height is from 150-200 m. Only in a few launchings out of 2500 did the ABL height exceed 1000 m. A comparison of histogram results with data of Terhersonde measurements during the Antarctic winter of 1992 (Andreas et al, 2000) shows its similarity. It allows us to conclude that, first, vertical resolution of the soundings, executed on drifting stations, makes it possible to investigate the structure of the lowest part of the atmosphere. Second, the processes in winter ABL in both polar regions are similar.

The temporal variability of monthly mean ABL height is similar to temporal variability of surface-based inversion height (gradual decrease with minimum in 70s). This circumstance allowed us to speculate that both characteristics of the low atmosphere in the polar regions are determined by the same large-scale atmospheric processes.

3.2. Comparison of NCEP Reanalysis and drifting stations "North Pole" data sets.

To investigate how NCEP Reanalysis reproduces recent climate change in the Central Arctic Basin, we combined data of standard meteorological observations and radio soundings executed on drifting stations and interpolated to the points where drifting stations were situated on each particular day. The comparison was carried out for January and July, typical winter and summer months.

Figure 4 and Table 1 represent the results of a comparison between atmospheric surface pressure (P), air temperature (T), surface wind velocity (U), heights of isobaric surfaces 925 and 850 hPa (H), and total cloudiness (N). The statistical characteristics of differences between NP and NCEP data demonstrate the best agreement between NP and NCEP atmospheric surface pressure, surface wind velocity calculated on the basis of NCEP pressure fields, and the heights of isobaric surfaces for both seasons. The reproduction by NCEP of the temporal variability of the air surface temperature (T_s) is less satisfactory, especially in summer, when the correlation falls to 0.56 and positive bias increases up to 0.7 C. Additionally, Figure 4 demonstrates positive trends of difference between measured and calculated for T_s for both seasons, about 0.2 C/10 years. The latter supports the Kalnay et al (1996) remark about the incorrectness of using NCEP data for calculations of long-term trends, because a different routine had been used for reanalysis before and after 1978.

Table 1. Mean values and mean square deviation (Msd) of differences between NP and NCEP data, and correlation coefficients (r) between time series of meteorological parameters.

Parameter	January			July		
	Mean	Msd	r	Mean	Msd	r
DP_s, mb	1.4	2.1	0.99	0.3	2.7	0.96
DU_s, m/s	0.3	1.5	0.83	0.5	1.6	0.72
DT_s, °C	-0.2	3.5	0.88	-0.7	0.6	0.56
DN, tenth	0.3	3.1	0.51	3.9	2.4	0.39
DH_{925}, m	-0.5	17.2	0.99	-2.4	24.6	0.95
DT_{925}, ^{0}C	-0.4	2.4	0.92	-0.6	2.0	0.87
DH_{850}, m	-5.0	18.7	0.99	-6.2	25.5	0.95
DT_{850}, m	0.3	0.2	0.94	0.1	2.1	0.87

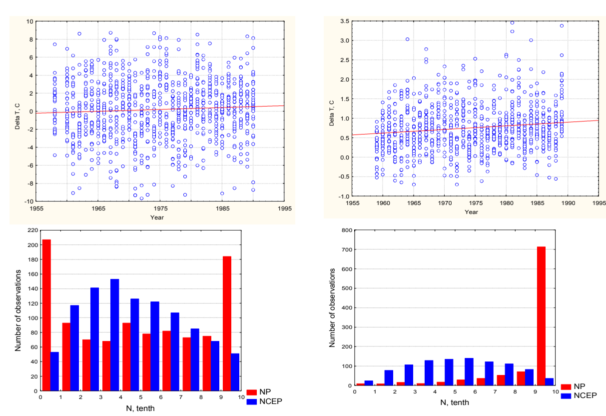


Figure 4. Comparison of surface layer air temperature (upper) and total cloudiness (bottom) in the Central Arctic Basin measured on the drifting stations “North Pole” and interpolated from NCEP for January (left) and July (right).

NCEP reproduces cloudiness in the Arctic Basin inadequately. The correlation between the measured and calculated N does not exceed 0.5 and there are principal differences between the shapes of observed and calculated frequency distributions of cloudiness for both seasons.

4. LARGE-SCALE TEMPORAL - SPATIAL VARIABILITY OF ATMOSPHERIC HUMIDITY IN THE NORTH POLAR REGION

In our previous paper (Maistrova et al, 2001), we described the long-term temporal-spatial variability of air temperature of the free atmosphere in NPR. The analysis of air temperature climatic variability for the period 1959 - 2000 was created under a unified technique database of soundings executed on island and continental meteorological stations (116 stations were used), and observations on ships and drifting stations. In the last two years the database had been supplemented by data about specific humidity.

Figure 5 shows that in the free atmosphere (850-300hPa) the values of specific humidity decreased on all isobaric surfaces up to 1987, the year of maximal negative anomalies, and closed to two mean square deviations. After 1987 the concentration of water vapor increased, especially in the low atmosphere (850-700 hPa), forming a weak positive trend on the 850 hPa isobaric surface. In the low troposphere (500 – 300 hPa), the statistically significant negative trends occured during the investigated period. In the atmospheric surface layer, the well-pronounced increase of specific humidity during the entire investigated period was registered. The positive trend was statistically significant on the 95% significant level. The coefficient of linear regression and explained dispersion are equal to 0.07 g/kg/10 years and 87% respectively. We need to mention that positive trends of specific humidity near the surface and on isobaric surface 850 hPa correspond to positive trends of air temperature (Maistrova et al, 2001).

It is known that spatial distribution of specific humidity is determined by peculiarities of atmospheric circulation and, especially in winter, by radiation cooling. Minimal concentrations of water vapor were found in winter in the large weak gradient area of the Central Arctic, from Northern Greenland to the Taymur peninsula. In summer, the maximum values of water content related to frequent cyclones coming from the Island and Aleutian minimums registered in the North Atlantic, Scandinavian and Kola peninsulas, and in Alaska.

Figure 6 shows the spatial distributions of annual mean trends of specific humidity in the atmospheric surface layer (follow Figure 5 the most expressed positive trend for whole NPR) and on the 700 hPs isobaric surface, where any pronounced trends for whole NPR were not found. Strong nonhomogeneity is evident in both distributions. Near the surface, the maximum positive trends of specific humidity are observed in the Atlantic and Pacific sectors and are possibly related to enhanced cyclone activity. At the same time, vast areas of negative trends are situated above Greenland and in the part of the Arctic Basin abutting to Siberia, the region of prevalent anticyclone circulation of the atmosphere.

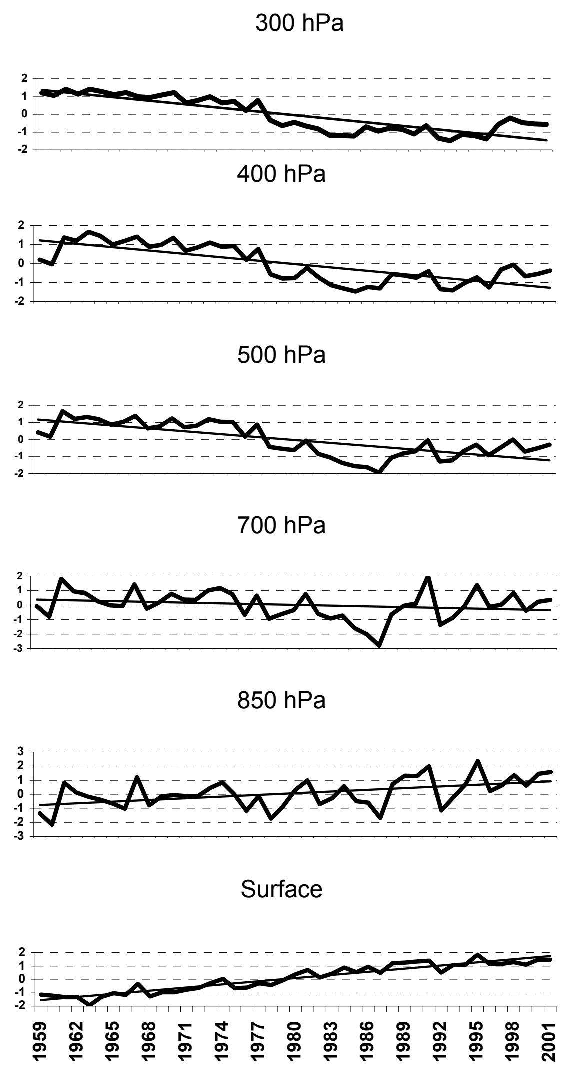


Figure 5. Time series of annual mean specific humidity anomalies normalized on mean square deviation in NPR.

On the isobaric surface 700 hPa the spatial distribution of mean annual trends of specific humidity is quite different, especially in the Atlantic part of NPR, where a strong positive trend of specific humidity near the surface is replaced by a negative trend. In general the distribution of trends on this isobaric surface has a bimodal character. Its explanation requires additional investigations of processes related to large-scale atmospheric circulation.

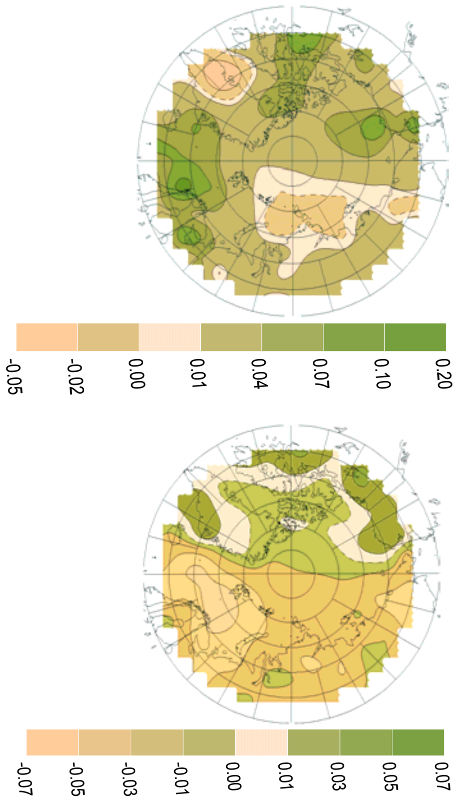


Figure 6. Trends of annual mean specific humidity in the upper atmospheric surface layer and on the isobaric surface 700 hPa (bottom) for 1959 – 2001, g/kg/10 years

5. CONCLUSIONS

The investigation of the free atmosphere above the Central Arctic Ocean was completed with data from the drifting stations "North Pole." The investigation showed that during winter in 70% of the soundings the inversion base was on the surface, the boundary layer height did not exceed 200 m, and the mean air temperature gradient in the inversion layer was 0.5-1.0 C^0/100 m. During the investigated period (1955-1991) the boundary layer height and surface inversion depth tended to decrease, and the temperature-change through the inversion tended to increase. The main reason for such features might be the changes in atmospheric circulation.

Comparison of NP and NCEP data shows a good agreement between observed and calculated atmospheric surface pressure, surface wind velocity, and the heights of isobaric surfaces. The reproduction by NCEP of the temporal variability of the air surface temperature (T_s) is not dependable, especially in summer, when the correlation falls to 0.56, positive bias increases up to 0.7 C and positive trends of a difference between measured and calculated T_s for both seasons is about 0.2 C/10 years. NCEP reproduction of cloudiness in the Arctic Basin is inadequate. The correlation between measured and calculated N does not exceed 0.5 and there are principal differences in the shapes of observed and calculated frequency distributions of cloudiness for both seasons.

Long-term variations of monthly mean air humidity in the free atmosphere above the North Polar Region (60-90^0 N) have been investigated using the original database, prepared by Maistrova's group. Preliminary estimations of temporal variability of mean specific humidity on 850, 700, 500, 400 and 300 hPa show its pronounced increase from surface to 850 hPa and decrease above 850 hPa. The spatial distributions of specific humidity trends demonstrate strong nonhomogeneity.

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6. AKNOWLEDGEMENTS

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