THE 20TH CENTURY CLIMATE CHANGE IN THE ASIAN-PACIFIC REGION

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Introduction

The work is based on the previous studies of the climate variation and change in Primorye (Danchenkov *et al*., 1996), the whole Japan Sea (Ponomarev *et al*., 1996, Ponomarev & Salyuk, 1997; Minobe 1996, 1997; Kim *et al*., 1997, 1999), in Russia and Asian Far-East (Varlamov *et al.*, 1996, 1997, 1998; Rankova & Gruza, 1998). The first paper in 90^s on the estimations of the air temperature trends over Northwest Japan Sea coast during XX century last decades was the paper by Danchenkov *et al.* (1996). It was shown in this paper that the number of cold winters was substantially decreasing and number of warm winters increasing during last decades of the century.

Varlamov *et al.* (1996) has shown statistically significant positive centennial trends of monthly surface air temperature at the meteorological stations situated along the western Japan Sea coast for February – April, June and October – November in Busan (Korea) from 1904 to 1990, for November – June in Timiryazevsky (Russia, to the North from Vladivostok) from 1911 to 1990, for January and March in Bogopol (Russia, Primorye), from 1927 to 1990. The positive trends of $Ta\times W$, $Ta\times W^2$ (W is wind speed value) in Posyet (south-western part of the Peter the Great Bay) and the significant negative trends of the sums of the days with temperature below -10 °C and below -15 °C were found as well.

According to Varlamov *et al.* (1997) the positive semi-centennial trend of the annual mean air temperature time series from 1947 to 1995 is significant in the western and southern regions of the East Siberia and Russian Far East area studied 40°-75°N, 105°E-170°W. The most significant positive temperature trend of 0.02-0.04 °C/year was found for winter and spring in central Siberian area and in Far Eastern regions adjacent to the Northwest Japan and Okhotsk Seas.

The study of centennial climate tendencies in Russia including Siberia and Far East was presented by Rankova & Gruza (1998) in terms of annual and warm/cold half year seasonal mean surface air temperature, precipitation as well as index of droughtiness and index of extreme climate change (Karl *et al.,* 1996). It was shown that the positive centennial air temperature trend in Russia predominates over the narrow mid-latitude band 50°-55°N. The temperature change is about 0.9 °C/100 years for the annual mean time series, 1.3°C/100 years for the cold period of a year from October to April and 0.3 °C/100 years for the warm period from May to September. Thus, the predominant centennial warming, particularly, in central Siberia region and in some areas of the Russian Far East are also shown in this study. The similar general centennial tendency of warming over the subarctic marginal area adjacent to the Sea of Okhotsk is also found by Pestereva & Pushkina (1998).

Our paper is focused on analyses of both centennial and semi-centennial tendencies of the monthly mean air temperature over the wide Asian continental and marginal areas of the Asian – Pacific Region. At the same time, the goal of this paper is to show main feature of the long-term change in the potential temperature of the Japan Sea Proper Water resulted from climate change in surrounding areas. In this paper we demonstrate the climatic change of the potential temperature vertical profile in the Japan Basin using new precise observations in 1999.

Method and Data

The air temperature linear trends are estimated based on least-square-root method for monthly mean surface air temperature time series at meteorological stations. The area studied is the extratropic Asia from 65°E to the Bering Sea coast of Alaska Peninsula and from East China Sea and Taiwan to the Arctic coast. We also include data of meteorological stations situated in the Northwest Pacific Islands. Data at the mentioned stations have about 10-15% of missing values. For filling in missing data we used Multiple Imputation Algorithm described in (Graham & Schafer, 1999).

The linear trends are estimated for the time series of different length and time ranges associated with centennial/semi-centennial and quasi-centennial/semi-centennial periods. The air temperature trends in the area studied are found in four cases corresponding to:

1) the fixed 91 years period from 1900 to 1990 associated with centennial time series at 47 meteorological stations;
2) the different periods of observation at the meteorological stations from 1990 or from the beginning of observation in early 20th century (1900-1917) to 1990 at 75 meteorological stations;
3) the fixed 40 years period from 1951 to 1990 associated with semi-centennial time series at 111 meteorological stations;
4) the second half of the 20th century period, namely from 1951/1963 to 1990 and to 1998 for the meteorological stations in Japan. For the whole region there are 140 meteorological stations.

The centennial and semi-centennial air temperature tendencies in internal continental and marginal areas as well as in subtropic, subarctic and arctic climatic zones are compared in our work.

The Japan Sea mostly covered by oceanographic and meteorological observation data is an object associated with accumulator of climate change in the Northwest Pacific marginal area (Ponomarev *et al.*, 1996, Ponomarev & Salyuk, 1997, Ponomarev *et al.*, 2000). We have continued our estimation of climate change in the Japan Sea using data of temperature and dissolved oxygen profiles in the Japan Basin from the Pacific Oceanological Institute data base for the period from 1925 to 1999. The recent deep sea oceanographic data obtained in 90th in frame of International Projects of the Japan Sea Study are from:

- August 1992 – KEEP MASS Joint Expedition of Pacific Oceanological Institute Far-Eastern Branch of Russian Academy of Science, Taiwan National University and Taiwan National Oceanographic Institute, R/V "Academic Vinogradov";
- November-December 1995 – Joint Pacific Oceanological Institute (Vladivostok, Russia) and Environmental Agency of Japan, R/V "Academic Lavrentiev";
- April 1999 – Pacific Oceanological Institute Expedition, R/V "Pavel Gordienko";
- July-August 1999 – Joint Scripps Oceanographic Institute (USA), Pacific Oceanological Institute and FERHRI (Russia, Vladivostok), R/V "Roger Revelle", "Professor Khromov".

Centennial/Semi-Centennial Tendency of Surface Air Temperature in the Asian-Pacific Region

The steady 99% statistically significant centennial warming (1-3 °C/91 years) for the period from early 20th century to 1990 (cases 1, 2) all the year round occurs over the marginal area adjacent to Pacific ocean both in subtropic and subarctic zones (Figs. 1, 2). It is over the East China Sea/Yellow Sea coast from Taiwan to Korea, over Japanese Islands and Pacific coast of the Kamchatka Peninsula. The warming in the Pacific coastal zone expands from the Subtropics-Subarctic to the adjacent Arctic region in January (Fig. 1b).

The significant centennial warming (1°-3 °C/91 years) over the marginal continental area adjacent to the Northwest Japan and Okhotsk Seas takes place mainly from January (Fig. 1b) to June (Fig. 2a). It is maximal in June (Fig. 2a) and low in February (Fig. 1c) here. The substantial centennial warming of about 2-4 °C/91 years are also found in the certain continental areas within the latitude band 45-70°N from November to May. It is shown in Fig.1 for winter season.

The warming of semi-centennial scale of about 2-4 °C/40 years in the certain large scale continental areas are found in each month for the cold period from November to May. The most significant positive trend in the whole extratropic latitude band 35-70°E is found for December, in narrow mid-latitude band 50-70°E in March (Fig. 3a).

In the subarctic continental areas of the Northwest Pacific Margin the semi-centennial scale warming (2-3 °C/40 years) dominates from January to July, in the arctic western Bering Sea coast from June to July, in the Eastern Bering Sea Islands and Alaskan coast in December and June or July. In the subarctic marginal area occupied the Sea of Okhotsk and Northwest Japan Sea the warming of this scale dominates from April to July (Figs. 3, 4).

The substantial centennial cooling of about –1 °C – -2 °C/91 years in the warm season occurs in the moderate latitude continental area within the longitude range of 90-135°E, particularly, in July (Fig. 2b) and August (Fig. 2c) over the South Siberia. It is also occurs in the marginal zone adjacent to the Northwest Japan Sea, but from July (Fig. 2b) to October.

The centennial cooling in Southeast subtropic continental area takes place both in winter and summer (Figs. 1, 2). It occurs here practically all the year round. This area of cooling expands to 40-43°N in June, but to large- scale areas of the South Siberia (45-60°N) and South Primorye area including Vladivostok in July (Fig. 2b). In August (Fig. 2c) the area where the trend is negative occupies the largest continental region from the South Siberia to the eastern marginal area adjacent to the Northwest Japan Sea. In September – October there is practically no negative trend in the South Siberia, but it occurs in the area adjacent to the Northwest Japan Sea.

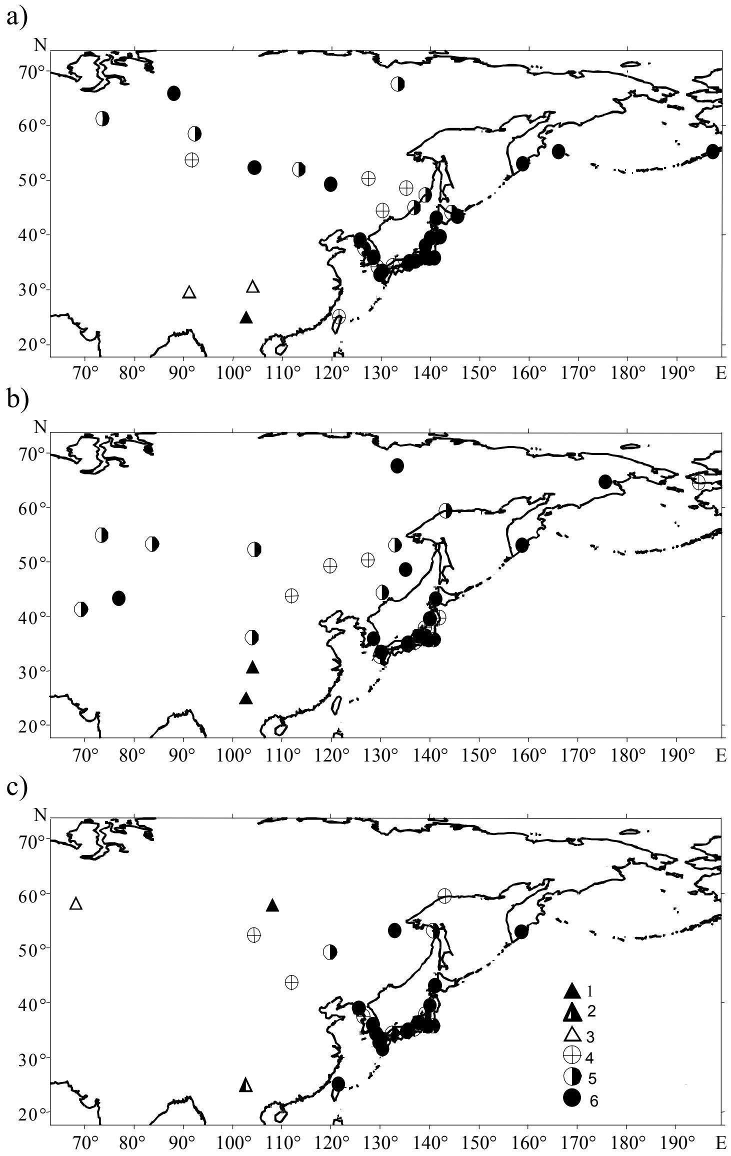

Fig. 1. Quazi-centennial negative (1, 2, 3) and positive (4, 5, 6) surface air temperature trends of 90% (3, 4), 95% (2, 5) and 99% (1, 6) significance level at the meteorological stations of the Asian-Pacific region in December (a), January (b) and February (c) for the time series from (1900-1917) to 1990

The semi-centennial cooling in the same areas of subarctic and subtropic climatic zones with similar change in the annual cycle is also revealed (Fig. 3, 4). In June and July it occupies internal continental areas, but from August (Fig. 4c) to October subtropic/subarctic marginal zone. In the offshore continental area of the Northwest Japan Sea latitude band the cooling dominates isin October. Some difference between quasi-centennial and semi-centennial cooling are following: the semi-centennial cooling (-1.6 °C– -3.3 °C/40 years) in the large scale Asian continental area of moderate latitude band is manifested in June (Fig. 4a) and July (Fig. 4b), while the significant centennial negative trend is typical for this area in July (Fig. 2b) and August (Fig. 2c). Contrary to that the warming occupies the marginal Northwest Pacific zone from subtropics to arctic region during these months. In comparison with significant centennial negative trend from June to November at the meteorological station “Vladivostok Mount” there is no statistically significant semi-centennial trend in the most of months, with the exception of the positive one in March.

Significant semi-centennial warming tendency over the most areas of the Pacific coastal zone including Japanese Islands and Kamchatka Peninsula on the contrary to centennial one is manifested only in some months, mainly in May -June and in October-November. Those months are associated with boundaries of hydrological summer. In the subtropic area of the marginal zone, namely, over the East China Sea coast, in southern regions of Korea and Japan the positive semi-centennial tendencies are also found in April, September, and January.

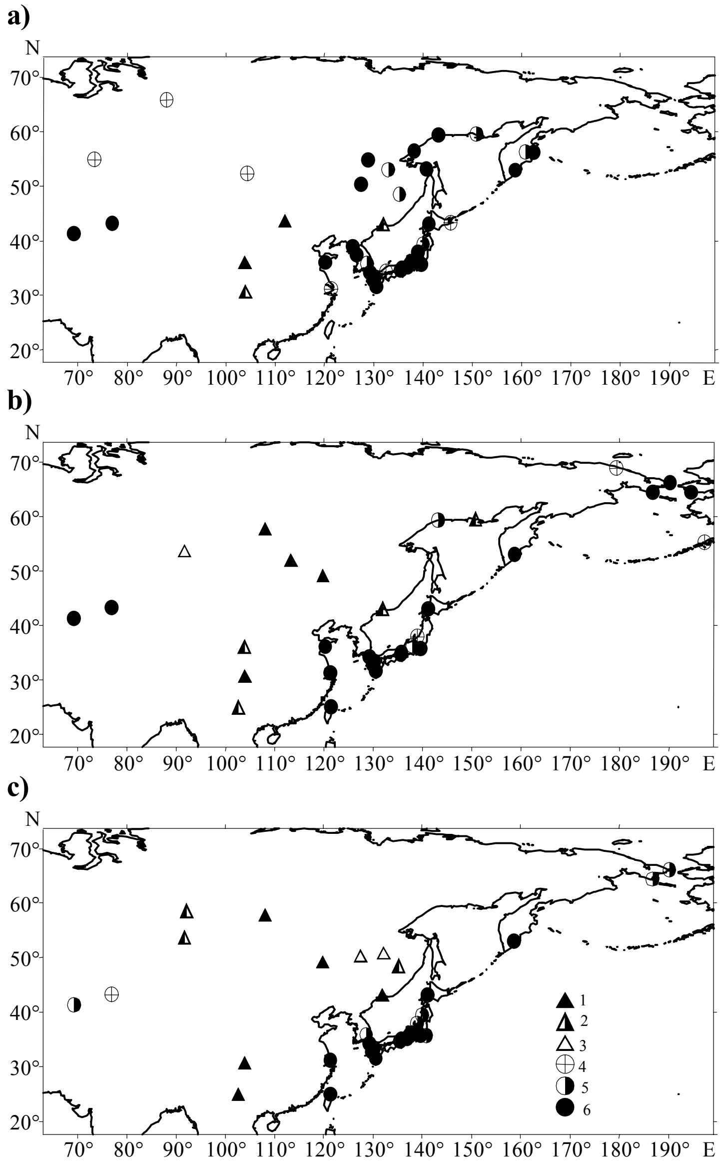

Fig. 2. Quazi-centennial negative (1, 2, 3) and positive (4, 5, 6) surface air temperature trends of 90% (3, 4), 95% (2, 5) and 99% (1, 6) significance level at the meteorological stations of the Asian-Pacific region in June (a), July (b) and August (c) for the time series from (1900-1917) to 1990

Thus, the anomalies of both centennial and semi-centennial scale are quite different in subtropic, subarctic, arctic, as well as in central continental, marginal and coastal regions. The distribution of positive/negative trends over the area studied also depends substantially on season. The positive anomaly generally prevails, but not everywhere and in all seasons. In the large – scale mid-latitude continental area the positive centennial / semi-centennial trends changes to the negative one from winter to summer. Therefore, a difference between summer and winter air temperature decreases in this continental area during 20th century, which is associated with amplification of ocean impact to the mid-latitude Asian continental areas.

Note, that principal results related to centennial warming or cooling remains valid if time series length cut by 10 years from the beginning or the end. Moreover, the main features of the centennial scale air temperature tendencies corresponding to data in case 2 (section 2) are similar to those in case 1. The main features of semi-centennial scale tendency distribution in cases 3 are also similar to those in case 4. Some difference between cases 3 and 4 in significance of the positive semi-centennial tendency over Japanese Islands might be related to high amplitude interdecadal oscillation in this area.

Climate Change in the Sea of Japan

According to Gamo *et al.* (1986), the oxygen decreases and silicate increases in the lower deep (1500-2500 m) and bottom (2500 m – bottom) layers of the Japan Sea during the period from 1969 to 1984. These tendencies continued from 1984 to 1995 (Kim *et al.*, 1995, 1996, 1997; Ponomarev *et al.*, 1995, 1996; Ponomarev & Salyuk, 1997; Minobe, 1996) being typical for the last decades of the 20th century due to ventilation reduction (Riser *et al.*, 1999). Moreover, the change of chemical characteristics accompanies the temperature rise in the Japan Sea Proper Water (Ponomarev *et al.*, 1995, 1996; Minobe, 1996). Linear tendency of temperature rise and salinity decrease at the oceanographic section in the south-eastern/ subtropical sea area in the second half of the century was also shown by Dyakov (1996). But statistical significance of the tendencies was not estimated in the mentioned works.

Using data for the whole period of oceanographic observation until 1995 from Pacific Oceanological Institute Data Base the statistically significant positive trends of the Japan Sea Proper Water (JSPW) potential temperature were found within the deep layers below 250 m in the southern and central sea areas by (Ponomarev & Salyuk, 1997). No statistically significant positive temperature trend we found in the bottom layer (2500-3500) for the whole 80 years observation period, but as for the second half of the 20th century (from 1950) a significant temperature trend was also revealed in this work.

The fast proper water warming in the Japan Sea for the period from 1984 to 1995 is also revealed by (Ponomarev & Salyuk, 1997) as typical for the end of the century. It continues up to end of the century according to the 1999 expeditions data. The relatively fast rise of deep water temperature from mid 80s to the end of 20th century principally could be modulated by interdecadal oscillations (Minobe & Mantua, 1999). It would be indicated or not in the first decade of the next century when the observation time series will continue. Moreover, according to the estimation similar potential temperature rise in the Japan Basin in the layer 150-250 m both from mid 40 s to early 60s and from 1984 to 1999 is about 0.4-0.5 °C. In the low-lying layer 250-750 m potential temperature rise correspondingly is less than in the underlying one being about 0.2-0.3 °C for the same periods. Total rise from 40 s to 1999 is about 0.8-1 °C in the first layer and 0.4-0.6 °C in the second one.

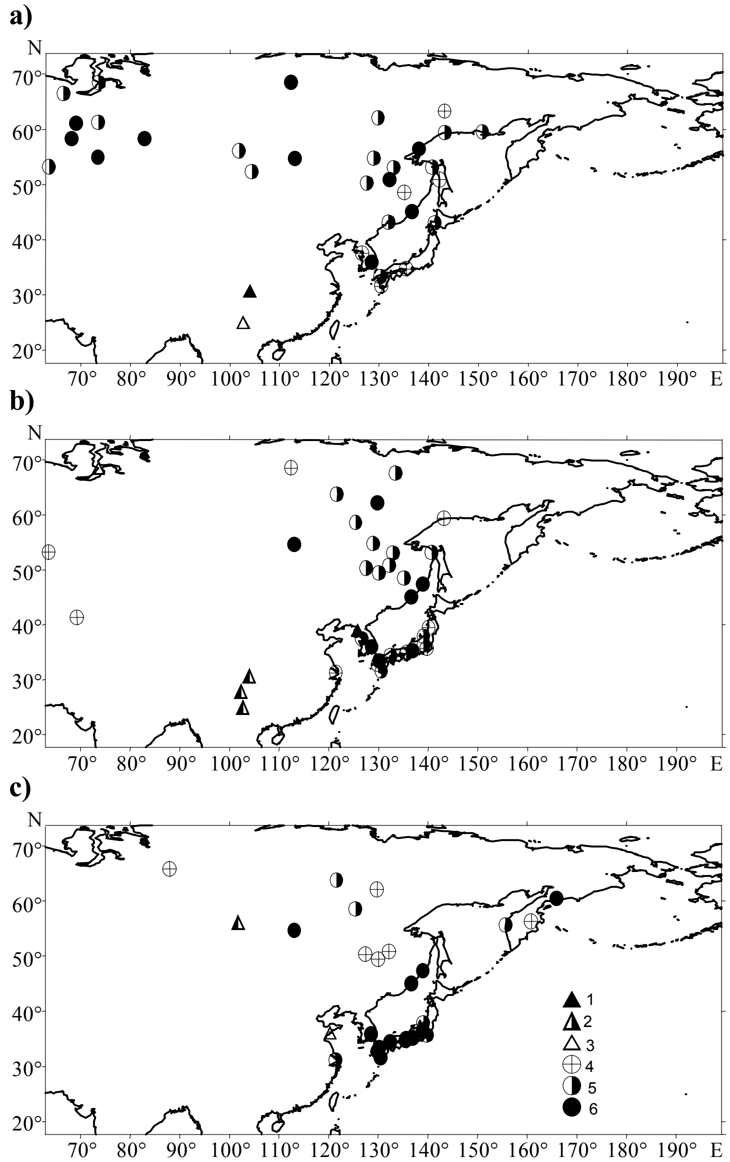

Fig. 3. Semi-centennial negative (1, 2, 3) and positive (4,5, 6) surface air temperature trends of 90% (3, 4), 95% (2, 5) and 99% (1, 6) significance level at the meteorological stations of the Asian-Pacific region in March (a), April (b) and May (c) for the time series from (1951-1963) to (1990-1998)

Fig. 5 shows the vertical potential temperature profiles within the layer 100 m – bottom in the central area of the Japan Basin area for certain years of the time series from 1925 to 1999. The profiles were made by using potential temperature values averaged within the layers: 50-150 m, 150-250 m, 250-750 m, 750-1250 m, 1250-1750 m, 1750-2250 m, 2250-2750 m, 2750 m – bottom. The vertical stability of the water layers is practically characterized by this profiles due to potential density vertical gradient, at least, below 100 m depth, depends mainly on potential temperature gradient.

The positive difference between of potential temperature values in 1960 and 1950, 1999 and 1981, as well as between 1999 and 1950 are revealed in this case in all layers below 100 m, but it decreases with depth (Fig. 5). Thus, the regional climate warming of mentioned scales is accompanied by vertical stability increase in the main pycnocline and in the whole JSPW, but dissolved oxygen decreases only in lower deep (1000-2500 m) and bottom (below 2500 m) waters of the deep basins. It corresponds to substantial ventilation reduction of the Japan Sea deep basins during the warming period verified by chlorofluorocarbon (CFC) measurements (Riser *et al.*, 1999).

On the base of positive temperature and negative salinity trends estimated by (Dyakov, 1996) on the standard section in the southeast sea area we can suppose that the temperature of inflow subtropical water through the Korean Strait is also increase. In this case annual mean heat flux from this water to

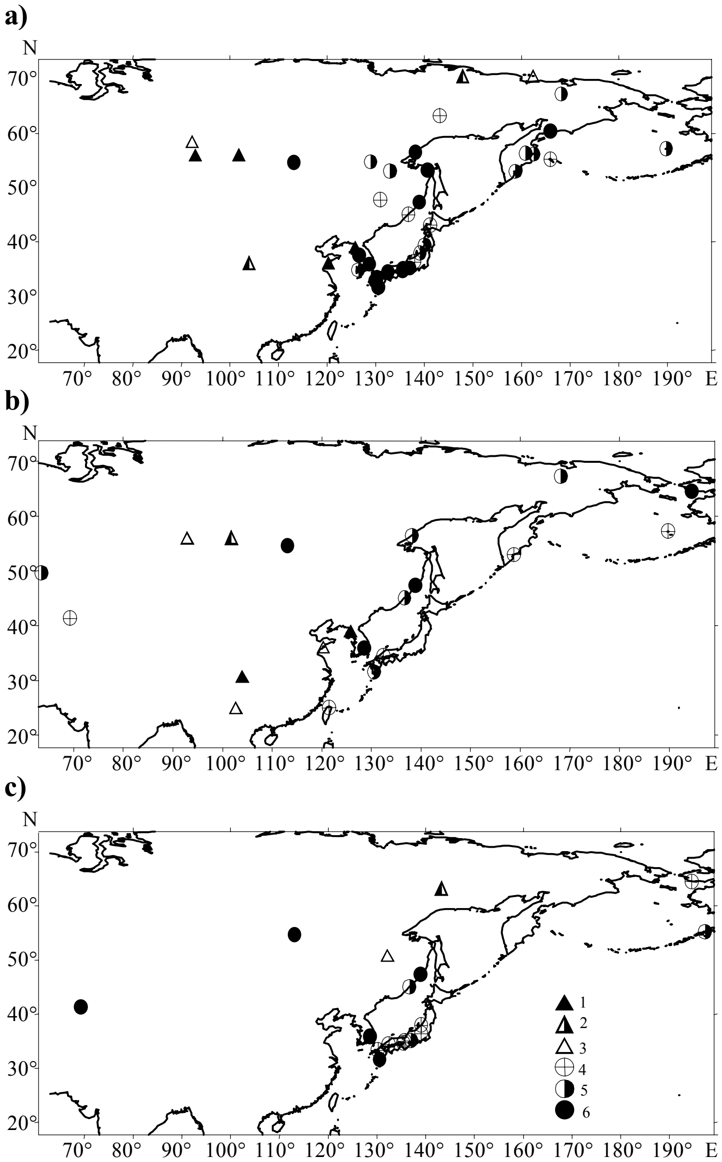

Fig. 4. Semi-centennial negative (1, 2, 3) and positive (4, 5, 6) surface air temperature trends of 90% (3, 4), 95% (2, 5) and 99% (1, 6) significance level at the meteorological stations of the Asian - Pacific region in September (a), October (b) and November (c) for the time series from (1951-1963) to (1990-1998)

lower layer and to the atmosphere have to increase as well while the subtropical water propagates over the Sea of Japan. The finding of the Japan Sea Proper Water warming really indicates the significant annual and multiannual mean positive downward heat flux from the warm subtropical water to the deep and bottom waters, at least, during two mentioned 15-16 years periods. Winter ventilation and cooling of the deep and bottom water were weaker and shorter in comparison with cooling in 40^s.

Thus, the Japan Sea proper water has been accumulating heat during the second half of the 20^{th} century. The Japan Sea warming is in accordance with climatic tendencies in the atmosphere over the Japan Sea area and subtropic-subarctic Northwest Pacific Marginal area which is described in section 3.

Conclusion

Tendency of both centennial and semi-centennial warming is revealed mainly in winter and spring months for the most of regions in the mid-latitude band (40-65°N) of the area studied. The most substantial centennial warming trend in the large - scale continental area of the mentioned mid-latitude band is found mainly for three months of cold season, namely, for December, January and March. In April and June it takes place only in the western and eastern continental areas of Asia, in May only in the Eastern Marginal zone.

The semi-centennial/centennial cooling occurs in South Siberia in June-July/July–August, and in the Subarctic Marginal zone adjacent to the Northwest Japan Sea from August to October. Difference between summer and winter temperature in the areas of summer cooling decreases in the 20^{th} century. The general tendency of cooling practically all the year round is typical for the southeastern internal continental Asian region in subtropic climatic zone.

The positive surface air temperature trend of 99% significance level all the year round for the period from 1900 to 1990 is marked only over the Japanese Islands and Pacific coast of the Kamchatka Peninsula.

The recent observations in late 90^{th} confirm that the Japan Sea Proper Water indeed accumulates the heat, at least, during second half of this century up to 1999. The significant tendency of warming in the Japan Sea is accompanied by vertical stability increase in the main pycnocline and in the deep layers.

The Japan Sea, as a deep basin with shallow straits situated in both subtropic and subarctic climatic zones, is very sensitive to the 20^{th} century climate warming in the atmosphere dominated in both mid-latitude Asian continental area and Northwest Pacific Marginal zone during winter and spring. The trace of the long –term warming is also should be found, in the East-China Sea Kuroshio branch.

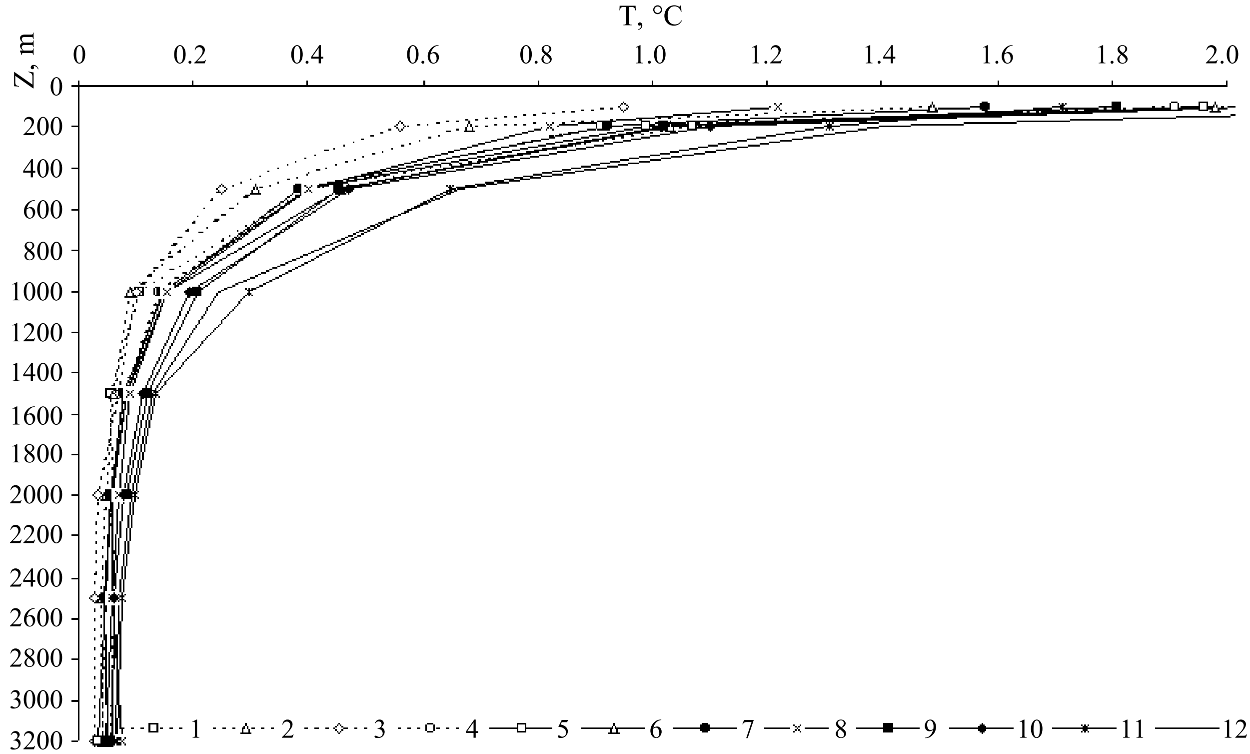

Fig. 5. Potential temperature vertical profiles in central area of the Japan Sea Basin in Oct. 1925 (1), Jun. 1933 (2), Jan. 1950 (4), Jun. 1960 (4), Jun. 1969 (5), Aug. 1979 (6), Jun. 1981 (7), Apr. 1983 (8), 1992 (9), Nov.1995 (10), Apr. 1999 (11), Aug. 1999 (12). The vertical profiles were built by using mean potential temperature values for the layers 50-150 m, 150-250 m, 250-750 m, 750-1250 m, 1250-1750 m, 1750-2250 m, 2250-2750 m, 2750-bottom

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