MULTI-YEAR VARIATIONS OF WATER AND AIR TEMPERATURES IN PETER THE GREAT BAY (SEA OF JAPAN)

Gayko L.A.

Institute of Marine Biology, Far East Branch, Russian Academy of Sciences, Vladivostok, Russia

Introduction

The study of climatic changes is topical in our days. The research in climatic changes in separate regions is especially interesting for estimation of their possible aftermaths and impact on the environment and economy. The study of long-term climatic features (more than half-century) is required for elaboration of strategies which would level their aftermaths on different branches of economy.

The laws of space-and-time distribution of hydrometeorological parameters in the coastal belt of Peter the Great Bay has not yet been studied adequately. Sporadical observations, conducted at separate points of the bay in different years, we do not uniform in time and give only a general idea on possible limits of space-and-time variations of hydrometeorological characteristics. We can single out two main trends of research. The first comprises works which shed light on water regime and some hydrometeorological features of the whole bay and its parts on the basis of surveys. The second trend includes works which analyze the hydrometeorological regime of the area in question on the basis of regular observations at coastal hydrometeorological stations. The latter enables us to elucidate periodic and nonperiodic fluctuations in regime's characteristics. Such research efforts have been undertaken earlier also (Vinokurova & Skokleneva, 1980 and 1981; Pokudov & Vlasov, 1980; Lastovetsky & Yakunin, 1981; Gayko, 1996-1999). This work continues research along these lines.

Material and Methods

The research in the hydrometeorological regime of coastal area of Peter the Great Bay in being conducted at four hydrometeorological stations (HMS) of State Hydrometeorological Service Network: Posyet, Gamov, Vladivostok and Nakhodka (Fig. 1). This work analyses multi-year series of data of observations over surface temperature of sea water, and air temperature, conducted in accord with standard procedures (Instruction..., 1984 and 1985; Shapovalova (Gayko), 1979-1981; *et al.*) at hydrometeorological stations over the period of instrumental observations (Table 1). Verification of data for uniformity was done in regime departments of Primorsky Board for Hydrometeorology and Environmental Control (PUGKS).

The principal statistical characteristics were calculated for estimation of temporal variations of the original series of hydrometeorological parameters. The space-and-time structure of monthly water and air temperature was studied using correlation analysis. Statistical significance was assessed with the Fisher criteria. In analyzing the fluctuations in the multi-year course of hydrometeorological parameters, a major role is assigned to establishment and assessment of climatic trends (tendencies) which mean a gradual change of a random variable during the entire time considered. The linear temperature trend in the temporal course of water and air temperatures at stations was calculated from regression equation. Regression analysis was used to reveal linear temperature trend in the temporal course of mean monthly and mean annual temperatures of water and air. Statistical significance of trends' values was determined using the Student criterion.

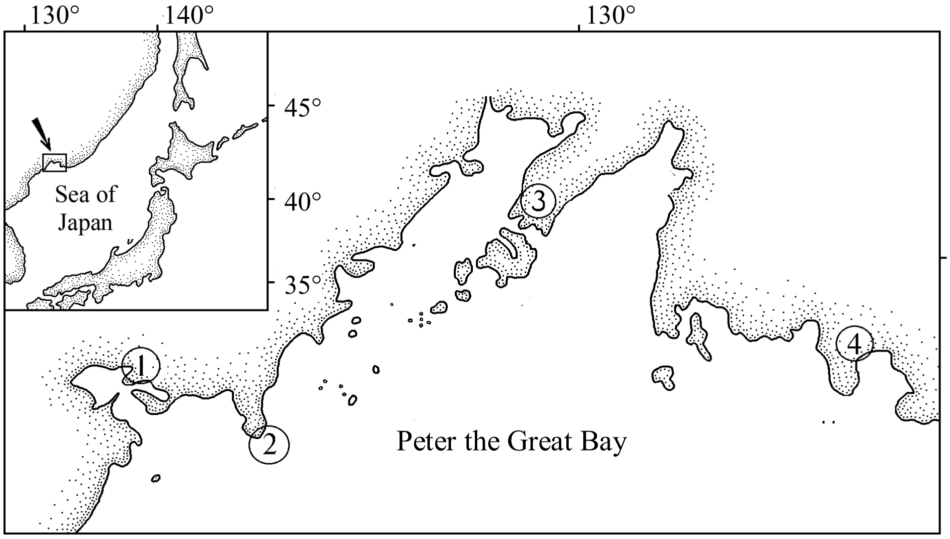

Fig. 1. Positions of Posyet (1), Gamov (2), Vladivostok (3) and Nakhodka (4) stations

Table 1

The periods of instrumental observations of hydrometeorological parameters at coastal HMS of the Peter the Great Bay

HMS	Periods of observations			
	Air temperature (°C)		*Water temperature (°C)*	
Posyet	1931-1998	(*68*)	1933-1998	(*66*)
Gamov	1923-1998	(*76*)	1937-1995	(*59*)
Vladivostok	1881-1998	(*118*)	1901-1998	(*98*)
Nakhodka	1932-1998	(*67*)	1934-1998	(*65*)

Year-to-Year Variations

Year-to-year variations of the hydrometeorological parameters were studied in some papers (Gayko, 1998 and 1999). The analysis of long-term water temperature monthly means at the stations shows that negative temperatures are observed in Posyet and Nakhodka during four months (from December to March). At Gamov station, situated on a cape, and in Vladivostok, where the influence of anthropogenic factors is more evident, the negative temperature period lasts for three months (January-March). Interestingly, in Vladivostok during the last two decades temperature monthly means in March were also positive. The extreme negative water temperature at these stations was observed in January-February. The extreme positive water temperature was observed in August, as a rule. Only in individual years maximum temperature was observed in September (Gamov, 1956, 1965, 1983, 1993; Vladivostok, 1956, 1983, Nakhodka, 1983), more rarely – in July (Posyet, 1987; Nakhodka, 1944), which testifies of the predominance of advective factors over the climatic ones on these occasions. It can also be assumed that in addition to advection (transfer of warmth), the location of station can cause a disturbance in the climatic regularities of water temperature distribution. Thus, at a more southern cape station Gamov summer temperature was lower and winter temperature was higher than at the stations Posyet, Vladivostok and Nakhodka situated in shallow-water bays and inlets that were more intensely warmed in summer and cooled in winter.

As for air temperature monthly means, it should be noted that negative temperature was observed at these stations during four months, and in Nakhodka – even five months (starting with November). Minimum temperature was observed in January, maximum – in August.

Correlation analysis of mean monthly water and air temperature distribution within a year for each of the four HMS (Gayko, 1998 and 1999a) helped establish that by and large in winter the bay featured the longest coupling of water temperatures between adjacent months in its SW part, and in summer – in SE part. The temperature of air masses lacked such difference. This seems to be connected with the effect of Primorsky Current and wind upwelling, that is, upheaval of cold waters of the northwest of Sea of

Japan coast (Zhabin *et al.*, 1993). This implies that the distribution of water temperatures is strongly affected by advective factors. Exploring this fact, we compared paired correlation coefficients between temperatures of water and air at stations. It was found that the SE part of the Bay (Nakhodka) had a low correlation between temperature of water and air, only 18% (Table 2). It is obvious that low correlation coefficients between temperatures of water and air is a criterion showing a breach in the process of natural radiational warning-through of water surface.

Table 2

Coefficients of pair correlation between water and air temperature

St	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Years
P	48	54	84	68	57	81	92	80	84	68	61	52	77
G	44	**23**	67	60	51	86	85	80	83	38	53	60	70
V	42	77	67	81	42	58	66	75	66	37	37	57	78
N	54	66	75	42	**-02**	**28**	42	41	46	56	50	54	**18**

Note: P – HMS Posyet, G – HMS Gamov, V – HMS Vladivostok, N – HMS Nakhodka.

The fact that changes in water and air temperature at Nakhodka HMS do not differ significantly from the changes of these elements at other HMSs is proved by the graphs of the distribution of water and air temperature at these stations within the year (Fig. 2a, b).

But if we compare mean square deviations of water and air temperature within the year at these stations, it becomes evident that for air temperature the course of these deviations between HMS is practically identical (Fig. 3a, b).

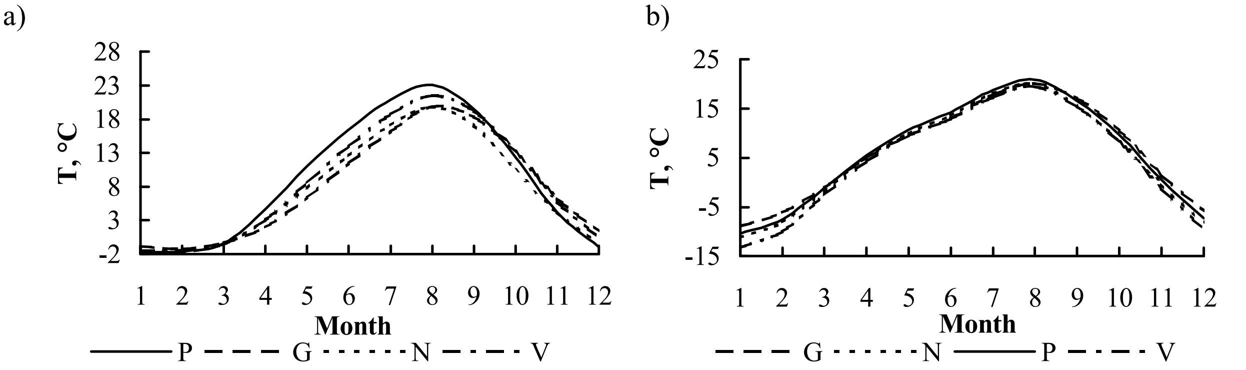

Fig. 2. Interannual variability of water (a) and air (b) temperature at HMS of Peter the Great Bay (1930-1996). Note: P - Posyet, G - Gamov, V -Vladivostok, N - Nakhodka

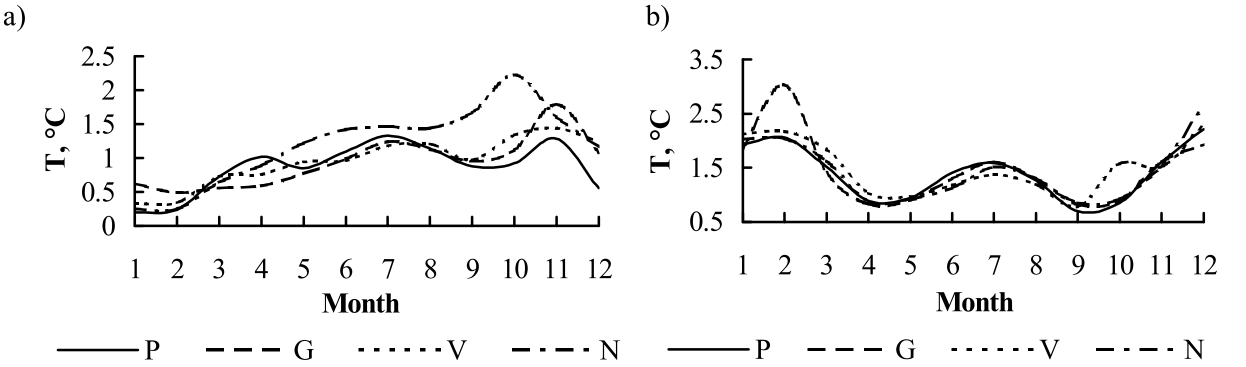

Fig. 3. Variability of mean square deviation within the year: a - water temperature (°C), b – air temperature (°C) in 1930-1996. Note: P – Posyet, G – Gamov, V – Vladivostok, N – Nakhodka

Moreover, for all the stations the highest variation is characteristic in the central months of winter and summer, and the lowest one – in the transition periods. Water temperature is prone to greater variation, the maximum is observed in April, June and November. The lesser variation was observed in January-February, which is due to the small range of the negative water temperature values. For Nakhodka the variation pattern of mean square deviations of water temperature was slightly different. At the generally high and uniform variation background the maximum in October is very prominent. This maximum is probably connected with wind upwelling that is observed in October-November at the north-western coast of the Sea of Japan (Zhabin *et al*., 1993).

A comparison of coefficients of paired correlation between temperatures of water and air for each station for months (Table 2) helped to reveal that in May in Nakhodka the link between these parameters is absent altogether, and in June it is very small. And as a rule, in warm season it is lower in Nakhodka than in cold season. For Posyet and Gamov, a reverse picture can be observed. The highest coefficients of paired correlation was noted in Posyet in June (0.92). It is interesting to observe that for all stations the minimum scatter of coefficients is typical for cold months (December-March), except for Gamov, for which in February the link is practically absent. For the rest months this law cannot be traced.

To reveal interconnection between the stations for the water and air temperatures, for each month of the year we counted correlation 4×4 matrixes (Table 3). At 5% level for 60 year r_{cr}=0.26, therefore all links between the stations for each month are significant. However, one may observe that for water temperature the lowest correlation coefficient was recorded between HMS Nakhodka and HMS Gamov in May (0.37), and the highest – between water temperature at stations Vladivostok and Nakhodka in June (0.90).

Table 3

Correlation matrix of mean monthly water (lower triangle) and air (upper triangle) temperatures

HMS	G	P	V	N	G	P	V	N
	January				*February*			
G	**1.00**	0.51	0.90	0.84	**1.00**	0.47	0.48	0.49
P	0.57	**1.00**	0.52	0.53	0.46	**1.00**	0.86	0.88
V	0.40	0.77	**1.00**	0.88	0.46	0.79	**1.00**	0.91
N	0.66	0.68	0.60	**1.00**	0.50	0.67	0.57	**1.00**
	March				*April*			
G	**1.00**	0.69	0.65	0.62	**1.00**	0.85	0.82	0.74
P	0.80	**1.00**	0.93	0.95	0.71	**1.00**	0.86	0.83
V	0.40	0.41	**1.00**	0.91	0.62	0.65	**1.00**	0.81
N	0.84	0.85	0.42	**1.00**	0.75	0.72	0.50	**1.00**
	May				*June*			
G	**1.00**	0.74	0.73	0.66	**1.00**	0.77	0.79	0.74
P	0.76	**1.00**	0.82	0.89	0.90	**1.00**	0.72	0.86
V	0.62	0.60	**1.00**	0.81	0.80	0.75	**1.00**	0.78
N	0.37	0.40	0.44	**1.00**	0.56	0.53	0.57	**1.00**
	July				*August*			
G	**1.00**	0.85	0.72	0.76	**1.00**	0.72	0.72	0.69
P	0.88	**1.00**	0.76	0.87	0.73	**1.00**	0.85	0.81
V	0.86	0.79	**1.00**	0.74	0.84	0.64	**1.00**	0.85
N	0.68	0.66	0.63	**1.00**	0.55	0.40	0.49	**1.00**
	September				*October*			
G	**1.00**	0.81	0.74	0.62	**1.00**	0.73	0.50	0.71
P	0.84	**1.00**	0.84	0.81	0.64	**1.00**	0.64	0.76
V	0.70	0.70	**1.00**	0.84	0.52	0.58	**1.00**	0.50
N	0.69	0.59	0.63	**1.00**	0.61	0.65	0.64	**1.00**
	November				*December*			
G	**1.00**	0.67	0.73	0.71	**1.00**	0.71	0.78	0.67
P	0.84	**1.00**	0.77	0.81	0.82	**1.00**	0.85	0.80
V	0.71	0.50	**1.00**	0.90	0.76	0.76	**1.00**	0.81
N	0.77	0.64	0.68	**1.00**	0.75	0.70	0.75	**1.00**

Note: P – HMS Posyet, G – HMS Gamov, V – HMS Vladivostok, N – HMS Nakhodka.

Correlation coefficient between water temperature at HMS Vladivostok and the rest stations in March is twice as little. It may be explained by the fact that mean monthly water temperature in Vladivostok in March became positive, as distinct from other stations, which was said earlier. For the rest months we did not find such features. But for air temperature the similar picture is observed in January for Posyet, in February-March for Gamov, and to the lesser extent, in October for Vladivostok. Perhaps, nonuniformity in transport of air masses is introduced by relief features. The lowest correlation coefficient for air temperature was recorded HMS Posyet and HMS Gamov in February (0.47), and the highest – between air temperature at stations Posyet and Nakhodka in March (0.95).

Climatic Trends

Tendencies of the mean annual air and water temperatures course. Analysis of fluctuations in the multi-year course of hydrometeorological parameters and the establishment and the assessment of climatic trends in HMS (Gayko, 1998 and 1999a). Analysis of year-to-year fluctuations of air temperature at all the stations in question revealed a positive trend, significant even at 1% level (Table 4). But trend of water temperature fluctuations is not simple. For Gamov and Posyet the trend unclear, and water temperature fluctuate about mean multi-year value. A positive trend, significant at 5% level, was found for Vladivostok. Nakhodka proves an exception: water temperature fluctuation tendency is also significant at 5% level, but negative, that is, water temperature is decreasing for over 50 years. As was specified in the preceding work (Gayko, 1998 and 1999), 1982-83 were critical years, that is water and air temperature trends changed its direction from decline to growth at all stations.

Table 4

Polynomial coefficients of the first degree approximating the trend components of water and air temperature and coefficient of determination, Student's criterion and probability for HMS of Peter the Great Bay

HMS	Period	A	B	R^2	t	P
			Water temperature (°C)			
Posyet	Season	0.004	15.325	0.000	1.000	0.321
		0.009	-0.359	**0.135**	**3.511**	**0.001**
	Year	0.006	8.814	0.058	1.975	0.053
Gamov	Season	0.004	12.416	0.000	1.019	0.313
		0.002	1.063	0.000	0.406	0.686
	Year	0.002	7.692	0.007	0.617	0.540
Vladivostok	Season	0.002	13.993	0.000	0.734	0.465
		0.014	-0.209	**0.374**	**7.782**	**0.000**
	Year	0.011	8.104	**0.171**	**3.717**	**0.000**
Nakhodka	Season	-0.030	13.55	**0.282**	**5.256**	**0.000**
		0.017	-0.488	**0.218**	**4.488**	**0.000**
	Year	-0.011	7.707	**0.105**	**2.712**	**0.009**
			Air temperature (°C)			
Posyet	Season	0.006	13.578	0.016	1.764	0.082
		0.037	-6.352	**0.299**	**5.575**	**0.000**
	Year	0.017	5.332	**0.247**	**4.650**	**0.000**
Gamov	Season	0.004	13.192	0.000	1.303	0.197
		0.222	-4.972	**0.210**	**4.258**	**0.000**
	Year	0.011	5.645	**0.160**	**3.570**	**0.001**
Vladivostok	Season	0.018	13.268	**0.235**	**4.820**	**0.000**
		0.040	-7.490	**0.383**	**6.699**	**0.000**
	Year	0.027	4.628	**0.427**	**7.067**	**0.000**
Nakhodka	Season	0.014	12.535	**0.186**	**4.169**	**0.000**
		0.046	-7.409	**0.424**	**7.168**	**0.000**
	Year	0.027	4.224	**0.459**	**7.423**	**0.000**

Note: 1) A, B – Polynomial coefficients; R^2 – coefficients of determination; t – Student's criterion; P – probability 2) Coefficients of warm season / Coefficients of cold season; 3) Significant coefficient of correlation are distinguished with bold font.

The trends discussed give an idea on water and air temperatures variations trends of Peter the Great Bay for over half a century. Temperature changes at stations for the recent 50 and 100 years are shown in Table 5. So we may assume that air temperature is characterized by a more stable up trend for the recent 100 years than that of water. For example, during the recent 100 years in Vladivostok water temperature rose by 0.64 °C, and air temperature, by 1.74 °C, that is nearly three times. Considering the last 50 years, the highest water temperature increase is observed in Vladivostok (0.94 °C), in so doing during 50 years temperature increase at this station was 1.5 times greater than for the entire 100 year period. Perhaps, anthropogenic factor is leading here. The rise of air temperature at stations is considerably higher than that of water temperature. For 50 years the highest temperature increase was in Vladivostok and Nakhodka, surpassing in this case by one degree the increase at two other stations (Table 5).

Climatic trends of mean water and air temperatures in warm and cold seasons. To specify climatic features of the area it is important to reveal and assess half-year climatic trends of mean water and air temperatures in warm (April-October) and cold (November-March) seasons (Table 4).

Analysis of graphs describing water temperature change trend revealed that only Nakhodka's trend was significant at 5% level, the trend being negative. For the rest stations in warm season the trend of water temperature course was not found. For cold season a significant (at 5% level) positive trend was recorded for Nakhodka, Vladivostok and Posyet (Table 4). No trend was found for Gamov. A significant increase in air temperature was observed in Vladivostok, and Nakhodka for both seasons, and on Gamov and Posyet – only for cold season (Table 4).

Analysis of correlation matrixes, calculated for warm and cold seasons separately, showed connection between stations in air temperature, as compared to water temperature, for both seasons (Table 6). But both for water temperature and air temperature, the closest coupling between stations was recorded in the cold season.

Table 5

Temperature change for half-century and for century at stations of Peter the Great Bay (1881-1998)

Water temperature, °C		*Air temperature, °C*	
Posyet	+0.25 °C/50 years	Posyet	+0.95 °C/50 years
Gamov	+0.15 °C/50 years	Gamov	+0.73 °C/50 years
Nakhodka	-0.27 °C/50 years	Nakhodka	+1.82 °C/50 years
Vladivostok	+0.94 °C/50 years	Vladivostok	+1.96 °C/50 years
	+0.64 °C/100 years		+1.74 °C/100 years
			+1.21 °C/118 years

Table 6

Correlation matrix of average annual water and air temperatures for warm (lower triangle) and cold (upper triangle) seasons

HMS	P	G	V	N	P	G	V	N
	Water temperature, °C				*Air temperature, °C*			
P	**1.00**	0.80	0.66	0.78	**1.00**	0.69	0.83	0.83
G	0.70	**1.00**	0.72	0.81	0.75	**1.00**	0.75	0.75
V	0.69	0.65	**1.00**	0.72	0.70	0.64	**1.00**	0.93
N	0.47	0.47	0.51	**1.00**	0.81	0.67	0.80	**1.00**

Note: P – HMS Posyet, G – HMS Gamov, V – HMS Vladivostok, N – HMS Nakhodka.

Trends of water and air temperature for each month of the year. In Posyet Bay and Nakhodka Bay variations in hydrometeorological conditions were explored in more detail (Fig. 4, 5). Analysis of water and air temperature trends at HMS Posyet showed that from December to May the linear trend was positive at 5% significance level, that is, water and air temperatures gradually increased. From June to November the trend was not revealed. At the Nakhodka from November to May and September of air temperature line trend was positive at 5% significance level, and June, July and October at 10% significance level, that is, air temperature gradually increased with the exception of August. A significant increase in water temperature was observed from December to March, and from May to September water temperature fluctuation tendency is also significant at 5% level, but negative.

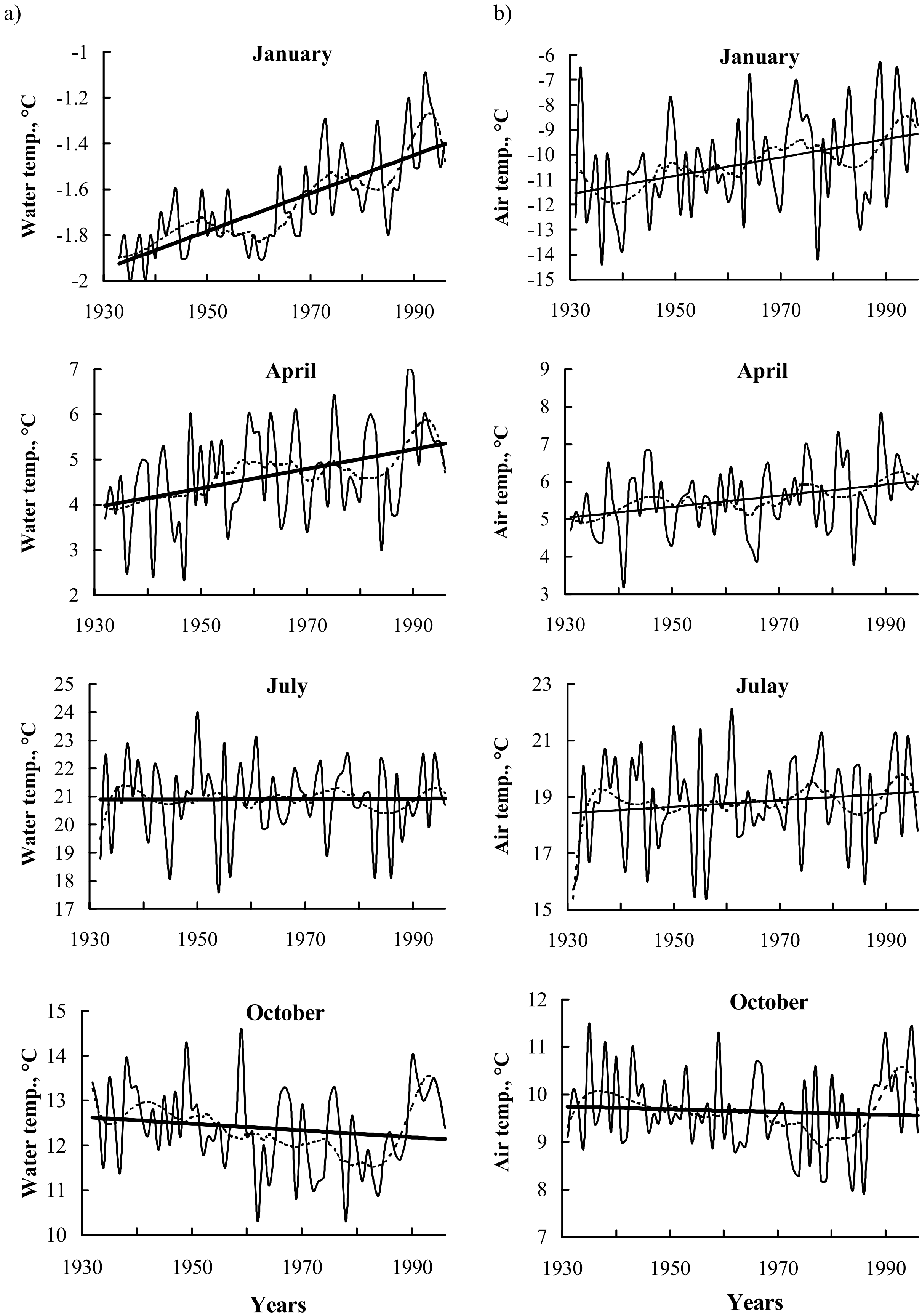

Fig. 4. Multi-year dynamics of water and air temperatures and their trend component for the central months of year for the period of 1931-1996 at Posyet HMS. Note: —— 1 ········ 2 ▬▬ 3

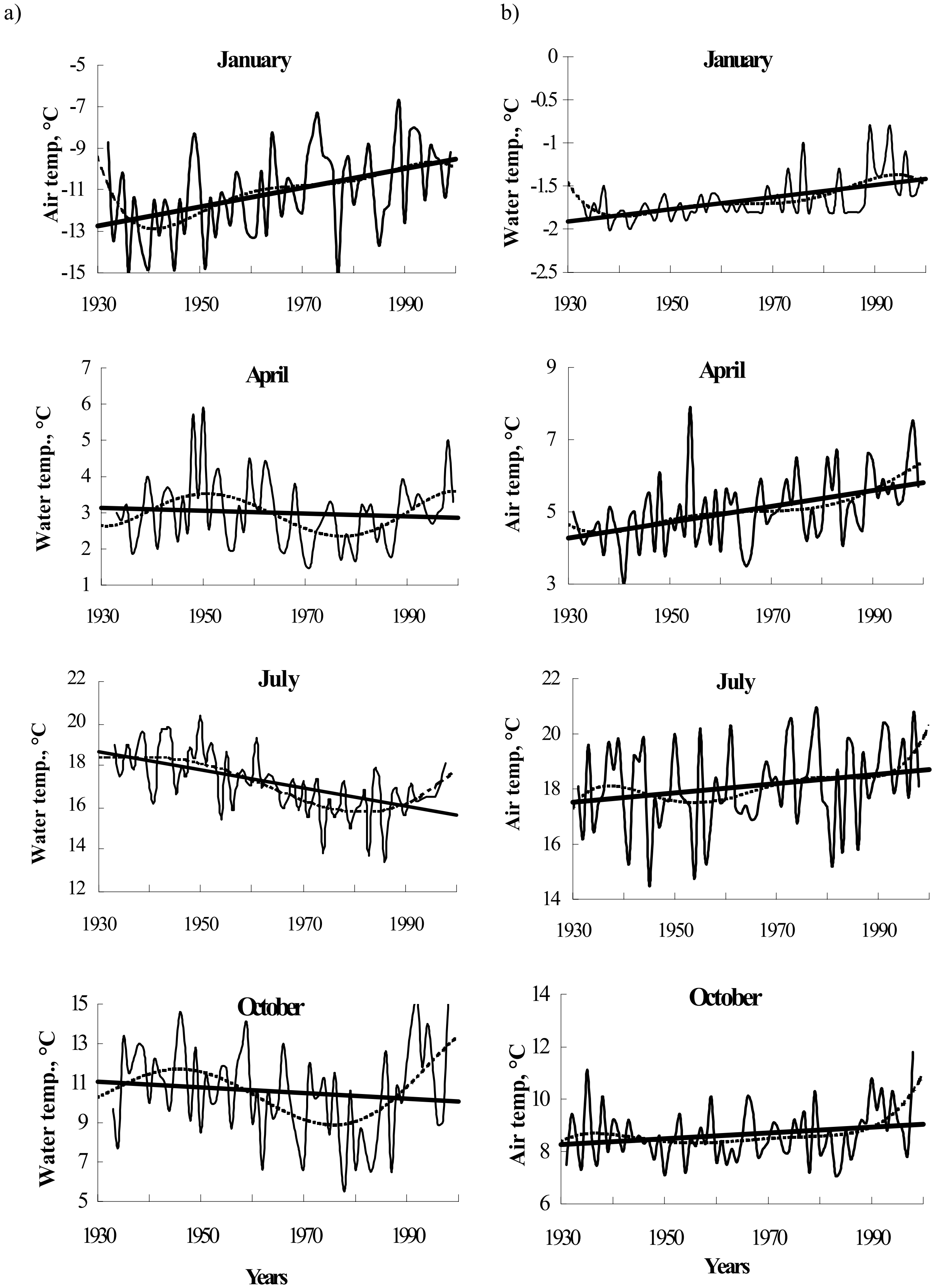

Fig. 5. Multi-year dynamics of water and air temperatures and their trend component for the central months of year or the period of 1932-1998 at Nakhodka HMS

Conclusions

- Water temperature increases in Vladivostok, connected with increasing effect of anthropogenic factors, and decreases in Nakhodka.
- The trend in water temperature is not found for stations Gamov and Posyet.
- In winter significant positive trend was found for stations Vladivostok, Nakhodka and Posyet; in summer– negative trend -for Nakhodka.
- At all the stations considered, in the course of mean annual air temperature there was revealed 1% level significant positive trend that is, for the period of instrumental observations, there was recorded an uptrend for temperatures. In Vladivostok and Nakhodka this trend is specific to both half-year, and on Gamov and in Posyet – only for the cold season.
- The analysis of the climatic trends of water and air temperature in Posyet Bay showed that winter and spring months were characterized by a rise in the temperature of water and air, significant at 5% level, for over half-century, while for summer and autumn months temperature oscillated about the norm. May and November are transitive months in the change of weather conditions. Practically throughout the year, one can trace an increase in water temperature (except for August), and increase in water temperature – only in the cold period. In warm period a significant (5% level) water temperature decline occurs.
- Low connection between these parameters was recorded in Nakhodka, which is most likely connected with specificities of hydrometeorological conditions in this part of the bay. Bat for recent 16 years (1983-1998) an uptrend for both water and air temperatures was recorded for the entire Peter the Great Bay. One may suppose that upwelling did not work (exist) in the recent decade.

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