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Variability of Water and Air Temperature along the Coast of the Eastern Primorye and Khabarovsk Territory Based on the Weather Station Data

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Abstract
Purpose. The study is aimed at identifying (within the framework of continuous temperature monitoring) the features of annual and interannual dynamics of water and air temperature along the northwestern coast of the Sea of Japan and the western coast of the Tatarsky Strait in 1950–2020.
Methods and Results. Spatial-temporal structure of the monthly average water and air temperature was analyzed based on the data obtained at the coastal weather stations, namely Rudnaya Pristan, Sosunovo and Sovetskaya Gavan (the FSBI Primorsky Directorate for Hydrometeorology and Environmental Monitoring archive). Comparison of the intra-annual temperature distribution revealed the fact that in particular months, at the stations located to the north, it can be higher than that at the stations located to the south. In other words, the latitudinal temperature distribution correlation between the weather stations was broken, which was probably due to the local water circulation. Comparison of temperature anomalies from the basic and current climatic normals calculated for the periods of 1961–1990 and 1981–2010 (recommended by WMO) showed that water and air temperatures at the stations were mostly lower than the current normal, yet above the basic one. The regression analysis of interannual temperature variability revealed a positive linear trend with the 5% confidence level in the water temperature dynamics at the Sovetskaya Gavan and Sosunovo weather stations, and in the air temperature dynamics – at all the weather stations. It is shown that the coastal weather stations recorded increase not only of the temperature annual average values, but also of the seasonal ones, although at different rates. At the coastal stations, the water temperature increase is the highest during a warm season with its maximum at the Sosunovo weather station (0.24 ºC / 10 years), whereas that of the air temperature – during a cold season with its maximum at the Sovetskaya Gavan weather station (0.31 ºC / 10 years). The integral curves of temperature anomalies against the mean multi-year value were used to identify long-term trends of the water and air temperature decrease starting from around 1950 up to 1986–1988, that was followed by abrupt ascend of the integral curve till 1995. Then the temperature increase suspended up to 2001 and further ascended till 2020.
Conclusions. On the whole over the studied period, at the coast of the eastern Primorye and Khabarovsk territory, mainly negative anomalies of the water and air temperature were predominant starting from the 50ies of the last century, whereas from the late 80ies up to 2020, the positive anomalies dominated. At present temperature rise in the region under study is characterized by a stable statistically significant positive linear trend and by an increase in the climatic normals, i.e. a tendency to temperature increase along the whole coast is observed.

Keywords: temperature anomaly, coastal weather station, climatic normal, regional climate, water temperature, air temperature, temperature trend, Tatarsky Strait, Sea of Japan

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Introduction

The study area covers the northwestern coast of the Sea of Japan, as well as the western coast of the Tatarsky Strait, and is located in temperate latitudes with monsoon atmospheric circulation [1]. The cold Primorskoe Current, branches of the warm Tsushima Current, and local water circulation significantly impact the climate of this area [2, 3] [1–3]. The entire considered coastal zone is bounded from the west by the Sikhote-Alin Ridge, which has a height of more than 1000 m, which also plays an important role in the formation of the thermal regime of the entire coast, including rivers originating in the mountains and flowing into the Sea of Japan and the Tatarsky Strait. In their turn, the rivers are the spawning grounds of one of the main commercial salmon fish – the Primorsky pink salmon [4, 5]. In the modern period, against the background of global climate change, one of the most important tasks of climatology is to study regional climate changes, including in coastal areas, which are given great scientific and practical importance [4, 5]. It is also relevant to find the most vulnerable places affecting the thermal regime of the coastal zone by analyzing a series of instrumental data from hydrometeorological observations, which will allow us to further predict the development of background factors and offer recommendations when their activity increases [6]. Currently, a lot of works are devoted to the study of climate change by region [7–10]. One of the climate change indicators is the change in climatic norms calculated over successive periods of time. The climatic norm is the average value of a meteorological element statistically obtained from a long-term series of observations of it in a given area [11]. The World Meteorological Organization (WMO) recommended a period of 30 years as the baseline averaging period (starting from 1901–1930). In connection with the ongoing climate changes, WMO adopted a new technical regulation for climate change assessment: a baseline historical series (1961–1990) will be used to maintain a long-term climate assessment, and for the purposes of climate monitoring and assessments of operational changes – a new operational norm (1981–2010) [11].

The choice for the study of climatic changes of the coast of the Eastern Primorye and Khabarovsk Territory is due to the fact that this area has a complex terrain affecting atmospheric circulation; coastal waters are characterized by a complex system of currents and various hydrological parameters of basins. The obtained results may also be of great practical importance, including for studying the migration routes of the coastal pink salmon, since changing climatic

[1] Svinukhov, G.V., ed., 1983. [*Climate of Vladivostok*]. Leningrad: Hydrometeoizdat, 248 p. (in Russian).

[2] Yurasov, G.I. and Yarichin, V.G., 1991. [*Currents of the Sea of Japan*]. Vladivostok: DVO AN SSSR, 172 p. (in Russian).

[3] Directorate for Navigation and Oceanography, 1996. [*Coastal Pilot of the North-Western Coast of the Sea of Japan from the Tumannaya River to Cape Belkin*]. Saint Petersburg: GUNIO MO RF, 360 p. (in Russian).

[4] IPCC, 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom; N.Y., USA: Cambridge University Press, 1535 p.

[5] Yasukevich, V.V., Govorkova, V.A., Korneva, I.A., Pavlova, T.V. and Popova, E.N., eds., 2014. *Second Roshydromet Assessment Report on Climate Change and Its Consequences in Russian Federation: General Summary*. Moscow: Roshydromet, 54 p.

conditions leads to a redistribution of pink salmon migration flows along the coast [4, 5]. The author has devoted more than 20 years to studying variability of hydrological conditions of the coastal areas under consideration, which is reflected in papers, conference materials [6, 7], and monographs [5, 12–15]. This study is a continuation of the work on temperature monitoring off the Russian coast of the Sea of Japan and the Tatarsky Strait and is aimed at identifying patterns of spatial distribution and temporal changes in the characteristics of the thermal structure of the ocean and atmosphere, taking into account the data of observations at coastal stations in recent years.

The purpose of this work is to study the temperature characteristics of the Eastern Primorye and Khabarovsk Territory coastal areas based on long-term observations at hydrometeorological stations for 1950–2020. To do this, the following tasks were set: to identify the intra-annual temperature variation features; to calculate the basic and operational temperature norms for 30-year periods recommended by the WMO for each station; to calculate the temperature anomalies of each environment for stations relative to climatic norms and the average long-term value; to identify the features of the long-term dynamics of the average monthly and average annual temperature of water and air in the coastal zone according to weather stations data; to identify and evaluate climatic trends in the temporal variation of water and air temperature; to analyze the variability of temperature at stations relative to each normal (30-year) series; to identify sharp changes in the long-term variation of temperatures during the observation period from using integral-difference curves of anomalies of annual temperature values.

Materials and methods

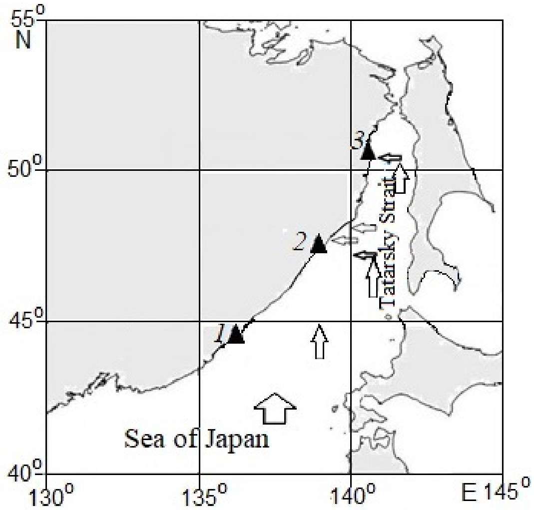
Currently, observations of the hydrometeorological regime of the area under consideration are carried out on only at three weather stations: the Sovetskaya Gavan (NW of the Tatarsky Strait, Khabarovsk Territory); Sosunovo (SW of the Tatarsky Strait, Primorsky Krai) and Rudnaya Pristan (NW of the Sea of Japan, Primorsky Krai) (Fig. 1). The work uses long-term observations of the sea water surface layer temperature and surface air temperatures obtained at these stations for the period of 1950–2020.

The monthly average temperature observations were selected from the fund of the Primorsky Territorial Administration for Hydrometeorology and Environmental Control. According to the observations for each station, the following were calculated: basic and operational climatic temperature norms for the WMO climatic periods (III (1961–1990) and IV (1981–2010)) by finding the average monthly values of water and air temperature for the corresponding 30 years; the average

[6] Gaiko, L.A., 2019. [Features of the Temperature Background of Primorsky Krai Coastal Zone According to Long-Term Data of Hydrometeorological Stations (North-Western Part of the Sea of Japan)]. In: MHI, 2019. *Seas of Russia: Fundamental and Applied Research: Abstracts of Reports of the All-Russian Scientific Conference*. Sevastopol, pp. 174-175 (in Russian).

[7] Gaiko, L.A., 2013. [Long-Term Variability of Water and Air Temperature along the Russian Coast of the Sea of Japan]. In: IPMT FEB RAS, 2013. *5th All-Russian Scientific and Technical Conference "Technical problems of the Development of the World Ocean", September 30 – October 4, 2013, Vladivostok, Russia: Conference Materials*. Vladivostok, pp. 335-340 (in Russian).

long-term value of the parameters for the entire study period (1950–2020); annual average values of the elements.



F i g. 1. Location of coastal weather stations: *1* – Rudnaya Pristan (SE of Primorye, north of the Sea of Japan); *2* – Sosunovo (NE of Primorye, SW of the Tatarsky Strait); *3* – Sovetskaya Gavan (SE of the Khabarovsk territory, NW of the Tatarsky Strait); scheme of general directions ⇧ of anadromous migration of pink salmon and the areas of its mass approaches ⇦ in the Sea of Japan along the coasts of the Primorsky and Khabarovsk territories in 2018 [8]

To identify the peculiarities of the temperature regime variability, deviations of water and air temperature from the corresponding climatic norm, as well as from the long-term average value, were calculated. To determine the shifts in the long-term temperature variation, integral-difference curves of anomalies from the long-term average value were constructed.

Trends in temperature variability at stations over a 70-year period, as is customary when analyzing long series of hydrometeorological parameter observations, in order to compare with the results in other regions, were calculated using standard trend analysis methods by the angle of the regression line; the presence of a linear trend was determined by the magnitude of the determination coefficient depending on the duration of the series. With the series duration of 70 years, the trend is significant at a 5% level at $R^2 \geq 0.058$ ($p < 0.05$).

Results

Intra-annual variability of water and air temperature at coastal weather stations. According to the results of the analysis of a long-term series of observations at the weather stations for the study of intra-annual temperature variability, the monthly average and annual average values of water and air

[8] Nazarov, V.A. and Lysenko, A.V., 2018. [The Results of Salmon Fishing in 2018 in Primorsky Krai]. In: TINRO, 2018. *Bulletin No. 13 of the Implementation of the "Concept of the Far Eastern Basin Program for the Study of Pacific Salmon"*. Vladivostok: TINRO-Tsentr, pp. 240-254 (in Russian).

temperature for each station for 1950–2020 period were calculated (Table 1). Since the study area is located in temperate latitudes with a monsoon character of atmospheric circulation, the seasons of the year are well expressed here. The minimum values of water temperature, according to the weather stations, are observed in January – February; air temperature – in January, and with an excess of 2–3 °C over the neighboring months; the maximum values of water and air temperature are in August (Table 1).

T a b l e 1

Multi-year average monthly and annual water and air temperature at the coastal weather stations in 1950–2020

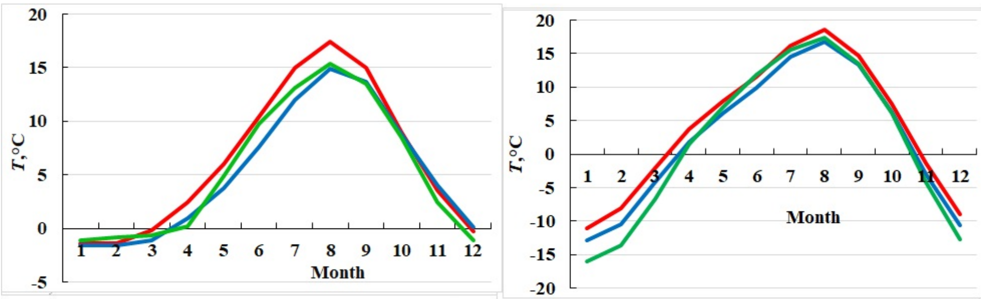
Station	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Water temperature, °C													
RP	–1.4	–1.3	–0.2	2.5	6.0	10.4	15.0	17.4	14.9	9.0	3.6	–0.3	6.3
S	–1.5	–1.6	–1.0	1.0	3.9	7.7	12.1	15.0	13.6	8.7	4.0	0.1	5.2
SG	–1.1	–0.8	–0.6	0.2	4.9	9.7	13.2	15.4	13.5	8.5	2.5	–1.1	5.3
Air temperature, °C													
RP	–11.1	–8.2	–2.1	3.8	8.0	11.6	16.2	18.6	14.7	7.5	–1.4	–8.9	4.1
S	–12.8	–10.4	–4.2	1.8	6.2	9.8	14.5	16.8	13.3	6.2	–3.1	–10.6	2.3
SG	–16.0	–13.6	–6.7	1.5	7.1	11.8	15.6	17.4	13.5	6.1	–4.2	–12.7	1.6

N o t e: RP – Rudnaya Pristan; S – Sosunovo; SG – Sovetskaya Gavan (here and in tables 2–4).

Negative air temperature is observed at the stations for 5 months (November – March), water temperature – for 4 months (December – March), with the exception of Sosunovo WS, where this period is only three months for water temperature (January – March) (Table 1).

When analyzing the distribution of water temperature by month, it turned out that at a station located northwards, the temperature may be higher than at a station located southwards, i.e. the natural temperature distribution characteristic of a given latitude of the station location is violated. Thus, in January – March and in May – August, the water temperature at the Sosunovo weather station – is lower than at neighboring stations, in November – December it is higher, and only in April, September and October the temperature is distributed according to the latitude of the station location. Also, on the southernmost weather station – the Rudnaya Pristan in January – February the water temperature is lower than at the northern weather station – the Sovetskaya Gavan. In the annual air temperature variation at the Sosunovo weather station, unlike the water temperature, the zoning is violated only in May – September, i.e. the temperature in these months is lower than at neighboring stations (Table 1). It is possible that this temperature distribution is affected by the peculiarities of local water circulation and the orography of the area [1–3]. The average annual amplitude of water temperature at the stations from north to south was 16.5, 16.6, and 18.8 °C, air temperatures were 33.4, 29.6, and 29.7 °C, respectively. A comparison of the average annual temperature values for the stations over the entire observation period revealed that in the annual aspect, the differences in water temperature do not exceed 1.0 °C, in air temperature 2.5 °C (Table 1).

Fig. 2 demonstrates the annual variation of water and air temperature at the stations. Analysis of the graphs shows that the increase in water temperature, i.e. its heating, occurs in January – August and is slower and with a greater variation in temperature values than its decrease, i.e. cooling, from August to December. In addition, the ascending branch to the Sosunovo weather station passes below the branch to the Sovetskaya Gavan weather station, except for April and December, although the station is located southwards. The variation of the water temperature distribution curve at the Sovetskaya Gavan weather station, located in the shallower part of the Tatarsky Strait, is somewhat different from the variation at other stations, there is a later spring and early winter transition of water temperature through 0°C. The variation of the air temperature curves is more uniform than the variation of the water temperature curves, especially in the warm period. In the cold period, the air temperature is lower at the Sovetskaya Gavan weather station, and in the first half of the warm period – at the Sosunovo weather station.



F i g. 2. Annual variation of the water (left) and air (right) temperature at the stations Rudnaya Pristan (red curve), Sosunovo (blue curve), and Sovetskaya Gavan (green curve)

Distribution of average water and air temperature anomalies at the coastal weather station. To identify the features of water and air temperature intra-annual variability at weather stations for 1950–2020 period, anomalies of average monthly and average annual temperatures for each station for each environment from the base (1961–1990) and operational (1981–2010) climatic norms were calculated (Table 2). When analyzing anomalies of average monthly water temperature from the base (III) norms, positive anomalies were detected at almost all stations in all months of the year with a maximum at the Sosunovo weather station in July (1.0 °C). Small negative anomalies were noted only at the Sosunovo and Rudnaya Pristan weather stations in November – December, as well as at the Rudnaya Pristan weather station in March. Anomalies of the average monthly air temperature at almost all stations are also positive, with the exception of the Sovetskaya Gavan and Sosunovo weather stations, where they have a negative value (in April and December, respectively). The total deviations for the year for water and air temperatures are also positive.

Table 2

Deviations of the average monthly and annual water and air temperature from the climatic normal at the coastal weather stations in 1950–2020

Station	Normal	Month												Year
		1	2	3	4	5	6	7	8	9	10	11	12	
Water temperature anomalies, °C														
RP	III	0.0	0.1	–0.1	0.1	0.2	0.4	0.5	0.6	0.4	0.5	–0.1	–0.1	0.2
S	III	0.1	0.1	0.2	0.2	0.4	0.6	1.0	0.7	0.5	0.2	–0.1	–0.1	0.3
SG	III	0.1	0.1	0.2	0.1	0.4	0.6	0.6	0.3	0.7	0.4	0.2	0.0	0.3
RP	IV	–0.1	–0.1	–0.2	–0.1	–0.1	–0.2	–0.3	–0.3	–0.6	–0.1	0.2	0.0	–0.1
S	IV	–0.1	–0.2	–0.1	–0.2	–0.4	–0.7	–0.7	–0.4	–0.6	0.0	0.4	0.1	–0.1
SG	IV	–0.5	0.2	0.0	0.0	–0.2	–0.3	–0.1	–0.1	–0.4	–0.2	0.0	0.0	–0.1
RP	Δ*T*	–0.1	–0.2	–0.1	–0.2	–0.3	–0.6	–0.8	–0.9	–1.0	–0.6	0.3	0.1	–0.3
S	Δ*T*	–0.2	–0.3	–0.3	–0.4	–0.8	–1.3	–1.7	–1.1	–1.1	–0.2	0.5	0.2	–0.4
SG	Δ*T*	–0.6	0.1	–0.2	–0.1	–0.6	–0.9	–0.7	–0.4	–1.1	–0.6	–0.2	0.0	–0.4
Air temperature anomalies, °C														
RP	III	0.3	0.5	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.0	0.0	0.3
S	III	0.1	0.3	0.2	0.2	0.1	0.4	0.6	0.6	0.6	0.4	0.1	–0.2	0.3
SG	III	0.3	0.4	0.1	–0.2	0.0	0.1	0.4	0.2	0.5	0.3	0.1	0.1	0.2
RP	IV	–0.4	–0.6	–0.3	–0.2	–0.2	–0.3	–0.2	–0.4	–0.3	–0.2	–0.1	–0.4	–0.4
S	IV	–0.3	–0.2	–0.1	–0.2	–0.4	–0.5	–0.3	–0.3	–0.2	0.0	–0.1	–0.2	–0.3
SG	IV	–0.8	–0.3	–0.4	–0.2	–0.2	–0.5	–0.2	–0.5	–0.2	–0.4	–0.4	–0.3	–0.4
RP	Δ*T*	–0.7	–1.1	–0.6	–0.5	–0.5	–0.7	–0.6	–0.9	–0.7	–0.6	–0.1	–0.4	–0.7
S	Δ*T*	–0.4	–0.5	–0.3	–0.4	–0.5	–0.9	–0.9	–0.9	–0.8	–0.4	–0.2	0.0	–0.6
SG	Δ*T*	–1.1	–0.7	–0.5	0.0	–0.2	–0.6	–0.6	–0.7	–0.7	–0.7	–0.5	–0.4	–0.6

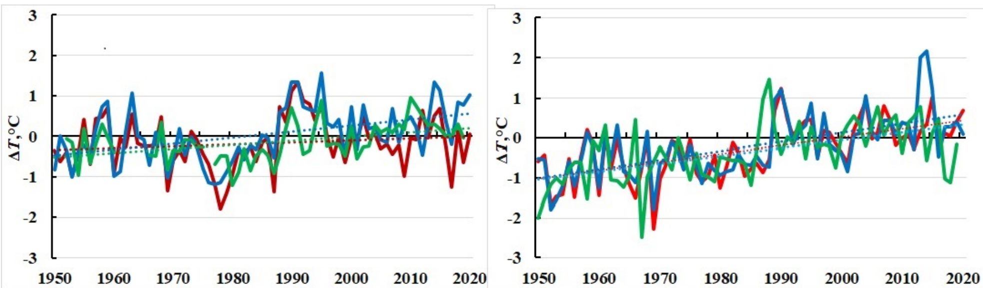
Note: Climatic normal III is calculated for 1961–1990, that of IV – for 1981–2010; Δ*T* is a difference (IV– III).

Analysis of the distribution of average water temperature anomalies from the operational norm (IV) by month showed a completely different picture. At all stations only in November – December, as well as at the Sovetskaya Gavan weather station in February – April and the Sosunovo weather station – in October, the water temperature was about or slightly above normal. In the remaining months, only negative anomalies with minima were observed: at the Sovetskaya Gavan weather station – in January (–0.5 °C), Sosunovo – in June – July (–0.7 °C), Rudnaya Pristan – in September (–0.6 °C). The total deviations for the year at all stations are negative (by –0.1 °C).

Deviations of monthly average air temperatures from the operational norm for the period under consideration at all stations were also negative in all months, with the exception of the Sosunovo weather station (October), where the values remained within the normal range. The minima at the stations were distributed as follows: at the Sovetskaya Gavan – in January (–0.8 °C), Sosunovo – in June (–0.5 °C), Rudnaya Pristan – in February (–0.6 °C). Cumulative average annual anomalies were also negative.

Thus, in 1950–2020, the water and air temperatures at these stations were mostly below the operational norm (1981–2010), but above the baseline (1961–1990). This indicates that the operational norm has become significantly higher than the basic one. The results confirm the indicators of an increase in norms, i.e. warming, in most of the southern half of Russia in recent decades [11].

Interannual variability of water and air temperature in 1950–2020. For its research, the graphs of the average annual value deviations of water and air temperature from the long-term average were constructed. Fig. 3 (left) demonstrates the interannual variation of water temperature anomalies, which has a wave-like form with two unequal ridges and a hollow between them. The first wave (from –0.9 °C at the Sosunovo weather station in 1950 to the maximum of 1.0 °C there in 1963) is characterized by relative synchronicity of variation at all stations. Then there is a decrease in the water temperature at all stations, with preservation of synchronicity, to a minimum at the Rudnaya Pristan weather station in 1978 (–1.6 °C), then its slight fluctuations continue until 1987. That year there was a decrease in temperature at once at all stations with a minimum also at the Rudnaya Pristan weather station (–1.2 °C), after which the temperature began to rise sharply, and from 1988 to 1995 only positive anomalies were noted at all stations. The exception was the Sovetskaya Gavan weather station, where in 1992–1993 a slight decrease in temperature (–0.3 °C) took place. After 1998, the variation of water temperature anomalies took a sawtooth form with a violation of synchronicity, which is typical for a region with a complex hydrological regime. The maximum positive anomalies of water temperature in this area were noted at the Sosunovo weather station in 2020 (1.4 °C), and negative ones – at the Rudnaya Pristan weather station in 2017 (–1.1 °C). A positive temperature trend in the water temperature variation, significant at a 5% level, was recorded at the Sovetskaya Gavan and Sosunovo weather stations, although the regression line has a positive slope at the Rudnaya Pristan weather station (Table 3).



F i g. 3. Interannual variability of the annual average water (left) and air (right) temperature anomalies (ΔT) and their linear trends at stations Rudnaya Pristan (red curve), Sosunovo (blue curve) and Sovetskaya Gavan (green curve) in 1950–2020

T a b l e 3

Coefficients of the polynomial of the first degree (*A*, *B*) approximating the trend component of water and air temperature, and the determination coefficient (R^2)

Station	Water temperature, °C			Air temperature, °C		
	A	*B*	R^2	*A*	*B*	R^2
RP	0.0047	–0.1770	0.0238	0.0210	–0.7893	**0.3845**
S	0.0156	–0.4973	**0.2171**	0.0239	–0.8712	**0.3974**
SG	0.0112	–0.4548	**0.2361**	0.0219	–0.8151	**0.3781**

N o t e: The coefficients significant at the 5% level are in bold.

The interannual variation of air temperature anomalies for 1950–2020 is shown in Fig. 3 (right). There is greater uniformity in the distribution of air temperature than in the distribution of water temperature, but the impact of the station location latitude also affects here. The first half of the graph until the end of the 80s is characterized mainly by negative anomalies with a minimum in 1969 at the Rudnaya Pristan weather station (–2.3 °C); after 1987, only positive anomalies with a maximum at the Sosunovo weather station in 2014 (2.2 °C) were observed. At all three stations, in air temperature during the period under study, a significant 5% positive trend was revealed (Table 3). In [16], it was also noted that the section of the coast of the Sea of Japan from the Korean Peninsula to Hokkaido Island is characterized by secular positive trends in air temperature (with a significance of 5% and less), which corresponds to our conclusions.

Thus, there is no doubt that in 1950–2020 on the coast of the Eastern Primorye and Khabarovsk Territory an increase in water and air temperature took place, its dynamics is characterized by a stable positive statistically significant linear trend. It should be noted that the same situation in the Far Eastern region is observed in the Kamchatka Peninsula, where the type of climate of coastal areas is also characterized as monsoon one with marine features. During the average annual air temperature on the peninsula for the same period, a positive statistically significant linear trend was also revealed [10].

The increase in water and air temperature, according to coastal stations for the study period, was noted not only in average annual values but also by seasons, only at different rates. The magnitude of the temperature increase over decades is given in Table 4. The trend of the water temperature interannual increase at the Sovetskaya Gavan and Sosunovo weather stations was 0.11 and 0.16 °C / 10 years, respectively, and the air temperature at all weather stations was, on average, 0.20 °C / 10 years.

When considering the temperature variability by seasons, it was revealed that the greatest increase in water temperature occurs during the warm period at the Sovetskaya Gavan and Sosunovo weather stations (0.22 and 0.24 °C / 10 years, respectively), in the cold season the temperature is practically unchanged. In contrast to the water temperature, the greatest increase in air temperature exceeding 0.20 °C / 10 years occurs during the cold period with a maximum at the Sovetskaya Gavan weather station (0.31 °C / 10 years), with the exception of the Sosunovo weather station, where the increase is almost uniform in both seasons. Thus, it can be noted that, in general, the greatest increase in water temperature at stations occurs in the warm season, air temperature – in the cold season.

T a b l e 4

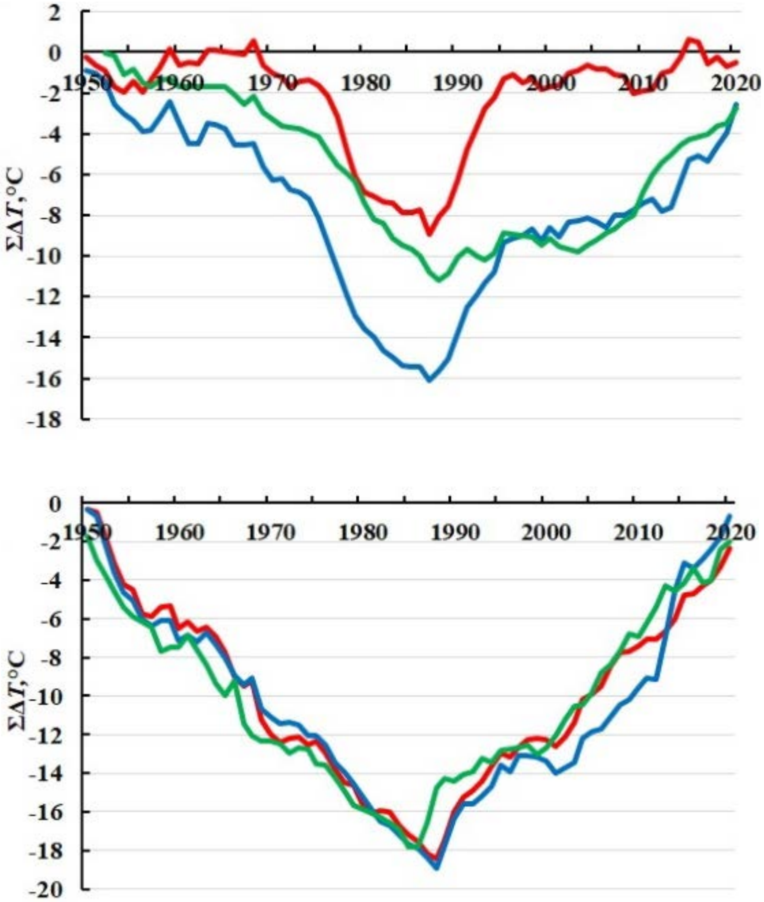
Increment of average annual and seasonal water (ΔT_w) and air (ΔT_a) temperature (ºC / 10 years) at the coastal weather stations

Station	Period	ΔT_w, ºC / 10 years	ΔT_a, ºC / 10 years
RP	Season	0.05	0.19
		0.04	0.24
	Year	0.05	0.21
S	Season	0.24	0.25
		0.02	0.23
	Year	0.16	0.23
SG	Season	0.22	0.13
		–0.01	**0.31**
	Year	0.11	0.22

N o t e: In the numerator, there are the coefficients for a warm half-year (April – December), in the denominator – for a cold one (November, December, January – March).

Shifts (abrupt changes) in the long-term temperature variation. In order to determine abrupt changes, the so-called shifts in the long-term temperature variation, integral-difference curves of average temperature anomalies were constructed (Fig. 4). With sequential averaging of anomalies using integral differences, the general patterns of temporary changes in the characteristics of the thermal structure are well manifested, and by the nature of the changes of the integral-difference curve course directions the changes in the course of temperature curves [9] are determined. Integral water temperature curves constructed for three stations (Fig. 4, on the left), have a rather complicated course, but in general, the synchronicity can be traced. In the 50s and 60s, there was either a slow decrease in water temperature, or an oscillation near the average long-term, then turning into a long branch of accumulation of negative anomalies up to the inflection in 1987–1988, after which there was a sharp rise in the integral curve until 1995, and then until 2001 – either a temperature variation near the average long-term or its uneven growth is already up to 2020. However, at each station, in the course of the curves of integral differences in the water temperature amplitude, its own peculiarities are observed.

[9] Chernysheva, L.S. and Platonova, V.A., 2009. [*Calculation and Interpretation of the Basic Climatic Parameters of Individual Meteorological Quantities*]. Vladivostok: Isdatelstvo Dalnevostochnogo Universiteta, 88 p. (in Russian).



F i g. 4. Interannual variability of the cumulative anomalies ($\Sigma\Delta T$) of water (left) and air (right) temperature against the average multi-year values (1950–2020) at the stations Rudnaya Pristan (red curve), Sosunovo (blue curve) and Sovetskaya Gavan (green curve)

At the Rudnaya Pristan weather station (Fig. 4, left) in 1950–1974, the water temperature varies within the average value with frequent changes in the sign of anomalies; then in 1974–1981 there is a sharp transition to a long-term trend of decreasing water temperature, then the decline slows down and (through a "step" in 1986) in 1987 there is an inflection of the curve and a rapid accumulation of positive anomalies takes place until 1995–1996; then, in 1996–2020, the temperature varies again within the average value, while 5 times the signs of anomalies change to the opposite, and in 2015–2016 the maximum is reached on this segment. At the Sosunovo weather station, located southward of the Sovetskaya Gavan weather station, a significantly greater accumulation of negative anomalies than at other stations takes place. In 1950–1974, a gradual slow decrease in water temperature occurs with an alternating change in the sign of anomalies; in 1974–1984, the decline sharply accelerates and "steps" goes to a minimum in 1987, after which the integral curve of anomalies changes its direction to growth and an uneven accumulation of positive anomalies begins:

sharp until 1995, slowing down by 2013 and then again sharply increasing until 2020, but with a single decrease in temperature in 2017. At the Sovetskaya Gavan weather station until 1975, a gradual decrease in temperature also takes place at first, then the decline rate increases until the curve bend in 1988, after which, as at other stations, there is a sharp increase in water temperature until 1995, which turns into a slight decrease by 2003; then, until 2020, the stable accumulation of positive anomalies continues again.

The curves of integral differences of air temperature anomalies, in contrast to water temperature, demonstrate synchronicity for all three stations (Fig. 4, right). Using the integral differences at the stations, a long–term trend of temperature decrease was revealed from about 1950 to a curve bend in 1986–1988, then an upward trend until 2020. At the same time, several short periods of accumulation of positive anomalies can be distinguished on the branches of negative differences: in 1956–1959 and in 1968 at the Rudnaya Pristan and the Sosunovo weather stations, in 1958–1961 and in 1966 – at the Sovetskaya Gavan weather station, as well as periods of temperature fluctuations within the average long–term value in 1971–1975 – at the Rudnaya Pristan weather station and in 1969–1974 – at the Sovetskaya Gavan weather station. At all stations, after the inflection in 1986–1988, until 1995, there is a rather steep rise in the difference curve, then until 2001, at the Rudnaya Pristan and the Sovetskaya Gavan weather stations, an air temperature fluctuation within the average long-term value, and at the Sosunovo weather station – even a slight decrease in temperature. After 2001, at all stations, the branches of the difference curves are again on the rise until 2020, but with slight decreases in air temperature in 2014 and 2017–2018 at the Sovetskaya Gavan weather station and in 2016 at the Sosunovo weather station.

In addition, a detailed analysis of the interannual variability graphs of cumulative anomalies of water and air temperature (Fig. 4) showed that at all stations, after the inflection of temperature anomaly curve in 1987–1988, from a fall to an increase, there was a sharp rise by 1995, after which the temperature increase stopped by 2001. It should be noted that it was 1995 that was an important milestone for breeding conditions of the Primorsky pink salmon – in its spawning area, the dominant generations changed from odd years to even years [4, 5] 7–8 years after the temperature transition from falling to growth. Thus, it is possible that the change of the dominant generations of pink salmon was preceded by sharp changes in the long-term temperature variation in the region.

If we analyze all 6 curves of integral differences in Fig. 4, it can be noted that at the Rudnaya Pristan weather station, located on the northwestern coast of the Sea of Japan, the sums of negative and positive water temperature anomalies are balanced by 2020, and at the Sosunovo and the Sovetskaya Gavan weather stations, located on the western coast of the Tatarsky Strait, during the period under study, the accumulation of negative anomalies prevails. It is possible that this distribution of water temperature anomalies is associated with various hydrological conditions of the Sea of Japan and the Tatarsky Strait basins, as well as with the peculiarities of local water circulation. In the course of the curves of integral differences in air temperature, such differences are not observed, and the sums of negative and positive temperature anomalies are balanced by 2020.

Integral-difference curves of anomalies have revealed in the studied area since about 1950 a long-term trend of lowering the temperature of water and air, passing after the inflection of the integral curve in 1986–1988 to an upward trend until 2020. Such a course of integral differences of temperature anomalies in the region corresponds to the general trends of the average annual air temperature in the western subarctic region of the Pacific Ocean [17], also along the coast of the Kamchatka Peninsula [10]. At the same time, it is worth noting that the transition in the temperature course from falling to rising along the coast of the Eastern Primorye and the south-east of Khabarovsk Territory, as well as along the coast of the Kamchatka Peninsula, began in the late 80s, and in the European part of Russia it occurred from the late 70s, i.e. 10 years earlier [9, 10]. There is no contradiction here since warming on the planet occurs in waves. The results of the performed studies are confirmed in the conclusions of climatologists engaged in the study of the Earth's climate system state. They identified several waves of global warming, including the period of 1975–1995 – the beginning of the "second wave of warming" and the period of 1996–2010 – the development of the "second wave of warming" [8].

Conclusion

According to the results of the study of the temperature regime variability of the Eastern Primorye and Khabarovsk Territory coastal areas on the basis of weather stations data for 1950–2020 period in the long-term course of the water and air average temperature, a significant 5% positive linear trend was revealed: in the water temperature variation – at the Sovetskaya Gavan and the Sosunovo weather stations, in the air temperature – at all stations. Although the trend in the distribution of water temperature at the Rudnaya Gavan weather station was not revealed, the regression line has a positive slope, i.e. the trend of temperature increase is traced.

The increase in temperature over the decades showed that in the interannual variation a trend for the water temperature increase at the Sovetskaya Gavan and the Sosunovo weather stations by 0.11 and 0.16 °C / 10 years, respectively, and the air temperature at all stations by an average of 0.20 °C / 10 years, was observed. When considering the temperature variability by seasons, it was revealed that, with the exception of the Rudnaya Pristan weather station, the main increase in water temperature occurs in the warm season with a maximum at the Sosunovo weather station (0.24°C / 10 years), air temperatures – in the cold season with a maximum at the Sovetskaya Gavan weather station (0.31 °C / 10 years). At the Rudnaya Pristan weather station, the water temperature changes slightly.

Analysis of distribution of the average water and air temperature anomalies from the operational and basic climatic norms by month showed that in 1950–2020 at the stations the water and air temperatures were mostly below the operational norm (1981–2010), but above the baseline (1961–1990). This confirms the fact that the operational norm has become significantly higher than the basic one, and indicates an increase in temperature in the region, but it is recommended to use the operational norm to solve operational tasks, and it is recommended to continue using the basic one to assess climate change.

Using the integral-difference curves of average temperature anomalies, it was revealed that in the 50–60s of the previous century, in the water temperature variation either its slow decrease or fluctuation within the long-term average value was observed, which then passed into a long period of accumulation of negative anomalies until 1987–1988. During these years, a curve inflection to the accumulation of positive anomalies occured, which also took place unevenly: firstly, a sharp rise in temperature until 1995, then its “stagnation” until 2001, and again an increase until 2020. It should also be noted that in this region, since 1995, a trend to increase in the number of fish returns of even years after the change of the dominant generations of the Primorsky pink salmon from odd years to even years has been revealed. Perhaps this is due to the general trend of temperature increase in the studied coastal area since the late 80s.

A comparison of the sums of water temperature negative and positive anomalies over the period under study revealed that by 2020 these amounts are balanced at the Rudnaya Pristan weather station (South of the Sea of Japan), and the sum of negative anomalies prevails at the Sosunovo and the Sovetskaya Gavan weather stations (West of the Tatarsky Strait), which is probably due to different hydrological conditions of the sea and strait basins and the peculiarities of local water circulation. The sums of negative and positive air temperature anomalies, unlike water temperature, are balanced at all stations.

Thus, during the period under study, mainly negative anomalies of water and air temperature prevailed on the coast of the Eastern Primorye and Khabarovsk Territory from the 50s of the previous century, and from the late 80s until 2020, positive anomalies began to dominate. In general, the increase in water and air temperature is not in doubt, since its dynamics is characterized by a stable statistically significant linear trend and an increase in climatic norms, i.e. in this region in 1950–2020 a trend of temperature increase along the entire coast takes place.

In the future, a more detailed study of the temperature regime peculiarities of the Russian coast of the Sea of Japan and the Tatarsky Strait is planned.

REFERENCES

1. Pokudov, V.V. and Vlasov, N.A., 1980. Temperature Regime of Coastal Waters of Primorye and Sakhalin Island According to the GMS. In: FERHRI, 1980. *Trudy Dal’nevostochnogo Nauchno-issledovatel’skogo Gidrometeorologicheskogo Instituta*. Vladivostok. Issue 8, pp. 109-118 (in Russian).

2. Danchenkov, M.A. and Aubrey, D.G., 1999. Scheme of Surface Water Circulation of the Northern Japan Sea. In: *Annual Report, PICES 8th Annual Meeting, October 8-17, Vladivostok, Russia*. Vladivostok: Dalnauka, pp. 130–132.

3. Andreev, A.G., 2018. Peculiarities of Water Circulation in the Southern Tartar Strait. *Izvestiya, Atmospheric and Oceanic Physics*, 54(9), pp. 1050–1056. https://doi.org/10.1134/S0001433818090037

4. Goryainov, A.A., Shatilina, T.A., Tsitsiashvili, G.Sh., Radchenkova, T.V. and Lysenko, A.V., 2007. [Climatic Reasons of the Reduction of Fish Stocks of Amur Salmon in the 20th Century]. *DV Region–Rybnoe Khozyaistvo*, (1-2), pp. 94-113 (in Russian).

5. Lysenko, A.V., Shatilina, T.A. and Gayko, L.A., 2021. Effect of Hydrometeorological Conditions on Dynamics of Catches (Abundance) of the Primorye Pink Salmon Oncorhynchus gorbusha Based on Retrospective Data (Sea of Japan, Strait of Tartary). *Journal of Ichthyology*, 61(2), pp. 280-292. https://doi.org/10.1134/S0032945221020119

6. Metreveli, G.S. and Metreveli, M.G., 2001. Background Factors of Global Climate Warming in the Coastal Zone of the Black Sea. *Water Resources*, 28(5), pp. 568-573.

7. Latysheva, I.V., Belousova, E.P., Olemskoy, S.V. and Loshchenko, K.A., 2010. Modern of climate change on the territory of Irkutsk Range. *Izvestiya Irkutskogo Gosudarstvennogo Universiteta. Seriya «Nauki o Zemle»*, 2, pp. 110-125 (in Russian).

8. Morozova, S.V., Levitskaya, N.G. and Orlova, I.A., 2013. Climate Changes of the Lower Volga Region on the Background of Global Warming (on the Example of Saratov). *Izvestiya of Saratov University. Earth Sciences*, 13(1), pp. 45-50. doi:10.18500/1819-7663-2013-13-1-45-50 (in Russian).

9. Perevedentsev, Yu.P., Shantalinskii, K.M. and Vazhnova, N.A., 2014. Spatiotemporal Variations of Major Parameters of Temperature and Humidity Regime in the Volga Federal District. *Russian Meteorology and Hydrology*, 39(4), pp. 228-239. doi:10.3103/S1068373914040037

10. Shkaberda, O.A. and Vasilevskaya, L.N., 2013. The Estimation of Air Temperature Changes in Kamchatka over the Last 60 Years. *Vestnik DVO RAN*, (3), pp. 69-77 (in Russian).

11. Korshunova, N.N. and Shvets, N.V., 2014. The Change in Major Climate Parameter Standards over the Russian Area for the Past Decades. In: World Data Center, 2014. *Trudy VNIIGMI-MTsD = Proceedings of All-Russian Research Institute of Hydrometeorological Information – World Data Center*. Obninsk: World Data Center. Vol. 178, pp. 11-24 (in Russian).

12. Gayko, L.A., 2007. [Dynamics of Water and Air Temperature Variability in Coastal Areas of the Northwestern Part of the Sea of Japan]. In: IMTP FEB RAS, 2007. *Proceedings of Scientific Conference "Technical Problems of the Development of the Oceans"*. Vladivostok, IMTP FEB RAS. Vol. 2, pp. 473-477 (in Russian).

13. Gayko, L.A., 2016. Climate Change in the Coastal Zone of Primorsky Krai in the Modern Period (the North-Western Part of the Sea of Japan). *Wschodnioeuropejskie Czasopismo Naukowe*, (10), pp. 35-42 (in Russian).

14. Gayko, L.A., 2019. Temperature Changes in Air and Water along the Coast of Primorsky Krai in the Modern Period (North-Western Part of the Sea of Japan). *Bulletin of the North-East Scientific Center, Russia Academy of Sciences Far East Branch*, (2), pp. 29-37. doi:10.34078/1814-0998-2019-2-29-37 (in Russian).

15. Gayko, L.A., 2012. Water and Air Temperature Variability along the Coast of Primorye (Japan/East Sea). *Current Development in Oceanography*, 5(2), pp. 49-58.

16. Ponomarev, V.I., Ustinova, E.I., Salyuk, A.N. and Kaplunenko, D.D., 2000. Climatic Variations in the Japan Sea and Adjacent Areas in 20th Century. *Izvestiya TINRO*, 127(1), pp. 20-36 (in Russian).

17. Rostov, I.D., Dmitrieva, E.V. and Rudykh, N.I., 2021. Climatic Changes of Thermal Conditions in the Pacific Subarctic at the Modern Stage of Global Warming. *Physical Oceanography*, 28(2), pp. 149-164. doi:10.22449/1573-160X-2021-2-149-164

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