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Original article

Features of Forming the Water Abnormal Thermal Regimes in the Kuril-Kamchatka Region

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Abstract
Purpose. The study aims to identify the cause-and-effect relations and mechanisms forming the water abnormal thermal regimes in the western and eastern water areas off the Kamchatka Peninsula as well as in the northern straits of the Kuril Ridge with regard to the influence of regional atmospheric processes during the warm season over the past four decades.
Methods and Results. Data from long-term observations performed at the coastal hydrometeorological stations (Hydrometeorological Centre of Russia) and NCEP/NCAR reanalysis data for the adjacent water areas permitted to study the interannual variability of thermal conditions in the region adjacent to Kamchatka in June–September period in 1980–2022. Cluster and correlation analysis were used to assess the variability of water and atmospheric circulation temperature regimes. An increase in extreme positive monthly mean values of surface water temperature has been revealed for the past two decades. The cause-and-effect relations between the anomalous changes in atmospheric field structure, their impact on water areas and the formation of abnormal thermal conditions were demonstrated.
Conclusions. Formation of the water abnormal thermal conditions in the Kamchatka Peninsula coastal regions and in the adjacent northern Kuril Ridge region is related to the intensity variability in development of such centres of atmospheric impact as the Okhotsk and Hawaiian Highs, the changes in their positions (including the spread of the North Pacific branch of the Hawaiian maximum to the northwest) and the local influence.

Keywords: Kamchatka Peninsula, northern Kuril Straits, hydrological conditions, temperature anomalies, atmospheric circulation

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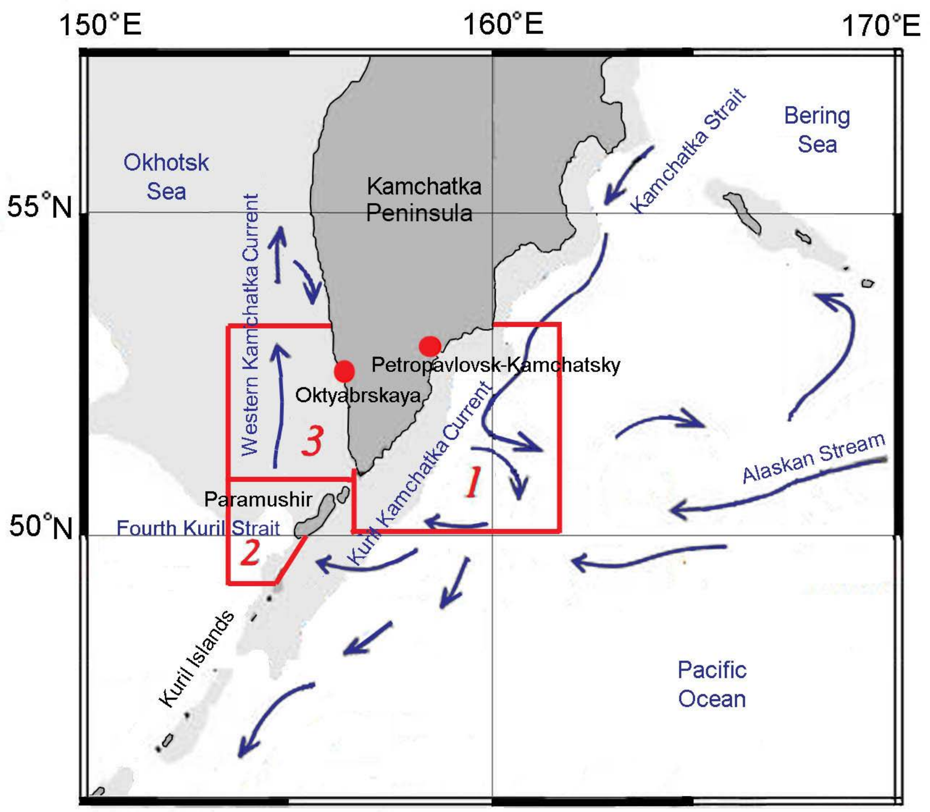
Introduction

The study region, encompassing waters off the southeastern and southwestern coasts of the Kamchatka Peninsula and the northern part of the Kuril Ridge (Fig. 1), is an economically significant area in eastern Russia.



F i g. 1. Region under study: *1* – Kamchatka eastern coast, *2* – northern Kuril, *3* – Kamchatka western coast (points denote hydrometeorological stations)

Amid ongoing global warming and the increasing frequency of extreme hydrometeorological events [1–4], concerns arise regarding the impact of changing temperature conditions on biological resources and fisheries in the waters of the Russian Far East. The response of aquatic organisms to optimal temperatures and food availability increases the migratory activity of commercially important species, resulting in shifts in fishing areas and complicating fisheries forecasting [5]. Therefore, studying the factors driving variability in thermal conditions, particularly the formation of anomalous thermal conditions that impact ecosystem productivity, is increasingly important.

It is well-established that the hydrological conditions of the study area are influenced by various water masses, including the Pacific waters from the Kuril-Kamchatka Current, transformed in the northern straits of the Kuril Ridge, and the Okhotsk Sea waters, as well as variability in water exchange through the ridge straits and the interaction of island and coastal currents [6, 7]. Key factors influencing temperature variability across the region and its water areas include variations in synoptic processes, climatic patterns, and monsoon-driven atmospheric processes with seasonal wind shifts.

Recent studies indicate that several areas of the Far Eastern seas have demonstrated correlations between variations in the thermal regime and changes in the intensity (pressure variability) and positions of regional atmospheric action centres (AACs) as well as changes in their local impact on water areas [8, 9]. Studies have identified differences in pressure field formation during years with anomalous thermal regimes and proposed methods for detecting and characterizing precursor pressure structures that drive extreme thermal conditions of waters impacting fishing conditions [10]. Concurrently, studies on climatic trends in thermal conditions of coastal water areas have revealed a complex response of the underlying surface to atmospheric circulation impacts [11]. As previously noted, to solve the problem of fishery forecasting for specific water areas has still been relevant and associated with regional peculiarities in the formation of anomalous thermal conditions [5, 8, 9].

This study is purposed at determining the cause-and-effect relations in the mechanisms of forming anomalous thermal conditions in specific zones of the Kuril-Kamchatka region caused by atmospheric processes.

In this study, the following tasks were addressed:

– analysis of interannual variability in the thermal regime of waters at hydrometeorological stations (HMSs) and adjacent areas, assessment of trend variability, and identification of years with anomalous thermal conditions in June – September for each region;

– investigation of interannual variability in the intensity (pressure variability) and position of seasonal AACs;

– evaluation of the role of seasonal AACs in the mechanisms underlying the formation of anomalous thermal regimes in water areas, taking into account hydrological conditions in each region.

Data and methods

Long-term variability of thermal conditions in the coastal waters of Kamchatka was investigated using water temperature data from the Unified System of Information on the World Ocean (ESIMO) (available at: http://portal.esimo.ru/portal/), the All-Russian Research Institute of Hydrometeorological Information – World Data Center (VNIIGMI-MCD) (available at: http://meteo.ru) and Roshydromet HMS data for 1980–2022.

Sea surface temperature data for 1980–2022 at grid nodes of 0.25° × 0.25° from the website http://ds.data.jma.go.jp/gmd/goos/data/rrtdb/jma-pro/cobe_sst_glb_M.html and the NOAA ERDDAP internet resource (available at: https://coastwatch.pfeg.noaa.gov/erddap/griddap/) were analyzed to study the thermal conditions of adjacent water areas. The *ODV* program was applied for data processing and visualization [1].

[1] Schlitzer, R. *Ocean Data View*. [online] Available at: https://odv.awi.de [Accessed: 17 June 2025].

Atmospheric circulation over the second natural synoptic region (2nd N. S. R.) was analyzed using reanalysis archives (NCEP/NCAR Reanalysis Monthly Means and Other Derived Variables [2]) of surface atmospheric pressure P_o and geopotential H_{500} at grid nodes of 2.5° × 2.5° for 1980–2022. Data on the intensity of the Okhotsk High (OH) were obtained from the Pacific Branch of the Russian Federal Research Institute of Fisheries and Oceanography (TINRO) (available at: https://tinro.vniro.ru). Anomalies (deviations of monthly average pressure values from long-term averages) were used to assess changes in the intensity of AACs. Surface pressure P_o and geopotential H_{500} maps for 2000–2022 compiled by the Japan Meteorological Agency (JMA) were used to analyze pressure fields. Correlation analysis was applied to evaluate the relations between the variability of thermal conditions and the intensity of AACs.

Monthly average anomalies of all parameters used in the study were calculated relative to the climatic norm for the period 1991–2020.

Results and discussion

Formation and variability of the thermal regime of waters

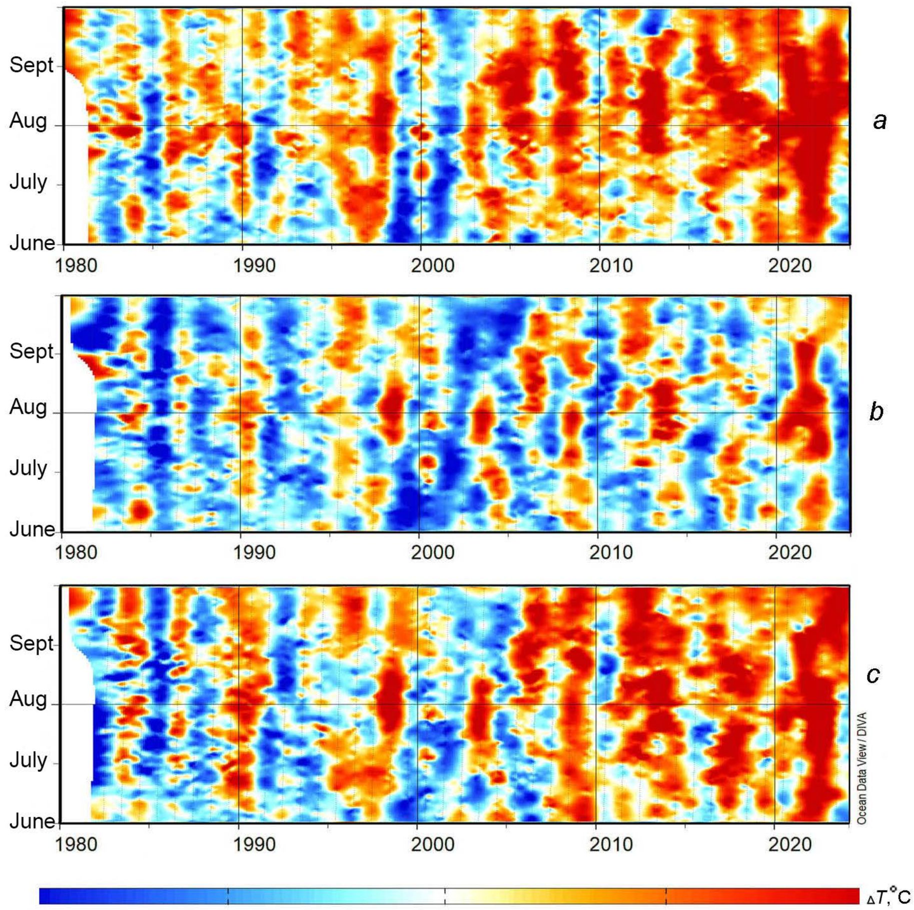
Area 1 — Eastern Pacific Coast of Kamchatka (Fig. 1). The formation of temperature characteristics of waters in this area is determined by the effect of waters of various origins. From the north, cold Bering Sea waters flow southward through the Kamchatka Strait with the Kamchatka Current, while a warmer branch of the Alaska Current influences the region from the east. During the warm season, the Kamchatka and Alaska Currents are characterized by the formation of predominantly anticyclonic eddies, which exhibit distinct thermohaline characteristics and contribute to the formation of the water area thermal regime [7, 12]. The thermal conditions of the area are highly variable, as evidenced by their interannual course (Fig. 2, *a*).

Area 2 – Northern Kuril. The straits among the northern Kuril Islands are narrow and shallow. However, active sea–ocean water exchange occurs through the relatively wide and deep (over 500 m) Fourth Kuril Strait. A bidirectional current pattern is observed in the strait [7]. From the Pacific Ocean side, the strait is influenced by the waters of the Kuril Kamchatka Current propagating from the north. The inflow of the Pacific waters into the northern part of the strait is confirmed by oceanographic observations from Argo floats. Some floats from the Pacific Ocean enter the Okhotsk Sea through the strait [12, 13]. Cold Okhotsk Sea waters enter the southern part of the strait. The dynamics of waters in the strait and the adjacent water area determine the formation of thermal conditions. As in the previous area, thermal conditions here demonstrate significant interannual variability (Fig. 2, *b*).

Area 3 – Western Okhotsk Sea Coast of Kamchatka. According to water circulation in this area, the Pacific waters entering through the northern straits spread northward with the West Kamchatka Current along the southwestern coast

[2] APDRC. *NCEP/NCAR Reanalysis, Monthly*. [online] Available at: https://apdrc.soest.hawaii.edu/datadoc/ncep_mon.php [Accessed: 17 June 2025].

of the Kamchatka Peninsula [14]. Thus, the thermal conditions of the water area off the southwestern coast (including HMS Oktyabrskaya) are also formed under effect of waters of various origins: partly the Kuril Kamchatka Current, the Okhotsk Sea waters and waters transformed by tidal mixing in the strait (Fig. 2, *c*).



F i g. 2. Interannual variability of water temperature anomalies in June – September in the areas: *1* – Kamchatka eastern coast (*a*), *2* – northern Kuril (*b*) and *3* – Kamchatka western coast (*c*)

The variability in the development of current system components largely determines the redistribution of incoming heat and cold, shaping the long-term variability of the temperature background in each area.

The course of long-term changes in the thermal regime of waters (Fig. 2) indicates a warming trend in the study area as a whole over the past four decades, which is confirmed by previous studies [1]. According to the assessments of temperature condition variability, positive trends were found in each subarea for the period 1980–2022. Significant trends in July and August were observed in the eastern and western water areas (areas *1* and *3*) (Table 1).

T a b l e 1

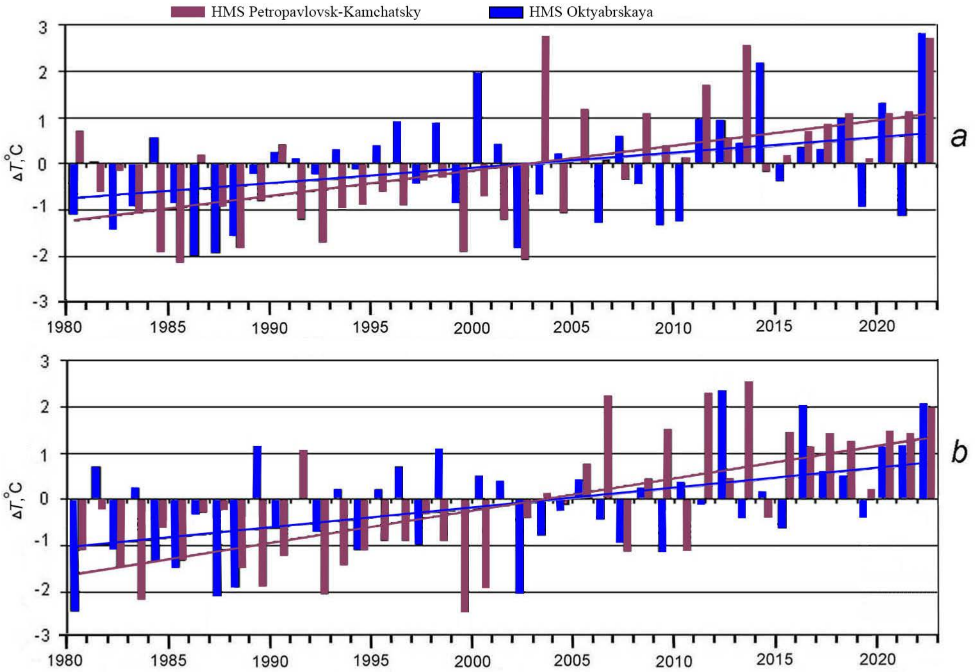
Linear trend coefficients for water temperature time series for June – September in 1980–2000, 2001–2022 and 1980–2022

Period	Area *1*	HMS Petropavlovsk	Area *2*	Area *3*	HMS Oktyabrskaya
			June		
1980–2022	0.02	0.02	0.01	0.03	0
1980–2000	0.01	−0.03	−0.02	0.02	0.03
2001–2022	**0.06**	**–0.06**	**0.06**	**0.09**	−0.01
			July		
1980–2022	**0.04**	**0.05**	0.03	**0.04**	0.02
1980–2000	−0.01	−0.03	0.02	−0.03	**0.08**
2001–2022	**0.11**	**0.05**	**0.08**	**0.09**	0.03
			August		
1980–2022	**0.05**	**0.06**	0.02	**0.05**	0.02
1980–2000	**0.05**	−0.04	0.04	**0.09**	**0.08**
2001–2022	**0.07**	0.03	0.04	**0.07**	0.02
			September		
1980–2022	0.03	0.04	0.03	0.03	0
1980–2000	**0.05**	**0.08**	0.01	**0.05**	0.03
2001–2022	**0.05**	0.04	0.04	**0.05**	−0.01

N o t e. Statistically significant (95%) estimates are highlighted in bold.

Furthermore, statistical estimates reveal differences in thermal variability between two twenty-year phases of the study period. For the 1980–2000 phase, trends in June – July were mostly insignificant and negative in all three areas, reflecting high frequency of cold thermal regimes during this period and indicating a relatively well-developed first stage of the Far Eastern summer monsoon and the OH effect [8, 9]. In contrast, for the second twenty-year period (2001–2022), significant positive trends indicate a weakening of the first cold stage of the monsoon and predominantly early formation of warm thermal regimes, characteristic of the second monsoon stage in July – August, occasionally September, influenced by the Hawaiian High (HH). However, no significant positive trends are observed in August–September in the northern Kuril zone (area *2*). Apparently, vertical tidal mixing in the ridge straits [7] “masks” the inflow of warmer waters with the branch of the Kuril Kamchatka Current.

The dynamics of anomalies at the HMSs reflect the long-term thermal variability off the eastern and western coasts of the Kamchatka waters. In the Pacific water area off the eastern coast of Kamchatka in Avacha Bay (HMS Petropavlovsk-Kamchatsky) and in the Okhotsk Sea water area off the western coast (HMS Oktyabrskaya), thermal conditions also vary significantly during the two twenty-year phases of the study period. Negative extremes of thermal regimes predominate in 1980–2000 contrasting with the positive anomalies observed in the following twenty years (Fig. 3).



F i g. 3. Interannual variability of water temperature anomalies in July (*a*) and August (*b*) and corresponding linear trends

Analysis of long-term variability of thermal conditions in the eastern (HMS Petropavlovsk-Kamchatsky) and western (HMS Oktyabrskaya) coastal areas of Kamchatka shows significant fluctuations in water temperature anomalies. In accordance with the assessment of interannual variability of thermal regimes at the HMSs off the western and eastern coasts of Kamchatka in June – September over the entire study period (1980–2022) performed using cluster analysis (K-means method), years with extreme thermal regimes were revealed. The study identified thermally homogeneous year groups categorized as follows: years with near-normal conditions demonstrating temperature anomalies with absolute values below 1.0°C, cold and warm regime years showing anomalies ranging between 1.0–1.5°C, extremely cold and warm thermal regimes defined by anomalies exceeding 1.5°C in absolute value (Table 2).

As shown in Table 2, the water areas adjacent to both western and eastern Kamchatka coasts are characterized by the formation of anomalously cold thermal regimes during 1980–1999. The period 2000–2022 marks a transition toward years with anomalously warm thermal regimes, with this trend becoming particularly pronounced during July – September of the most recent five-year period. The maximum temperature anomalies (reaching up to 3°C) were recorded at HMSs and adjacent water areas in July 2022 (Figs. 2, 3).

The thermal state and hydrodynamics of the sea surface are largely determined by surface wind conditions including direction and intensity of air mass transport. In turn, they are associated with the variability of atmospheric circulation and its local impact [2, 8, 9].

T a b l e 2

Years with anomalous thermal regimes at HMSs during 1980–2022

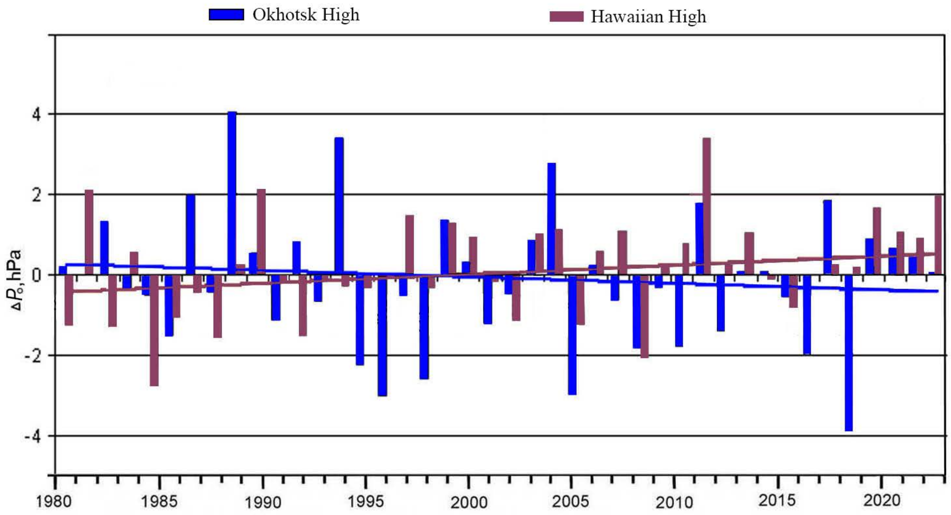
HMS	Thermal regime	
	cold	warm
June		
Petropavlovsk	1985, 1994, 1999, 2000, 2001, 2018	2003, 2009, 2013, 2014
Oktyabrskaya	1980, 1985, 2017	–
July		
Petropavlovsk	1984, 1985, 1988, 1992, 1999, 2002	2003, 2011, 2013, 2022
Oktyabrskaya	1986, 1987, 1988, 2002	2000, 2014, 2022
August		
Petropavlovsk	1983, 1988, 1989, 1992, 1999, 2000	2006, 2009, 2011, 2013, 2022
Oktyabrskaya	1980, 1985, 1987, 1988, 2002	2012, 2016, 2022
September		
Petropavlovsk	1999, 2001, 2012	2008, 2014, 2015, 2020, 2021
Oktyabrskaya	1983, 2002	2006, 2020, 2022

To identify the mechanisms responsible for the formation of anomalous thermal conditions in specific years across the study area, we analyzed variability in regional atmospheric processes and their impact on the underlying sea waters.

Role of atmospheric circulation in the formation of anomalous thermal conditions in water areas

Atmospheric circulation and air mass transport in the Kamchatka region during the Far Eastern summer monsoon period characterized by winds of southern directions are mainly determined by such AACs as the OH forming over the Okhotsk Sea, the tropospheric depression (TD) in upper-level fields, and the HH from the Pacific Ocean side. In June–July, during the first stage of the Far Eastern summer monsoon, cold air masses, predominantly of Arctic origin, emerge over the Okhotsk Sea in the rear part of the TD. They can be observed on synoptic maps as small anticyclones that support the high-pressure area (OH) over the Okhotsk Sea. It was determined that under a developed OH, cold air masses generated reduced thermal background conditions in the underlying sea surface. Conversely, with intensification of the HH influence (characteristic of the monsoon second phase), a warming effect occurs forming positive thermal background conditions [8, 9].

Analysis of long-term surface pressure variability over the studied forty-year period reveals a steady trend toward increasing intensity of the HH (Fig. 4), while the OH is characterized by significant fluctuations. In the period 1980–2000, years with positive pressure anomalies (OH intensive development) predominated while the second phase was characterized by the formation of predominantly negative anomalies. The resulting negative trend indicates a weakening of this AAC.



F i g. 4. Interannual variability of near-land pressure anomalies (ΔP_o) in July and corresponding linear trends

T a b l e 3

Correlation coefficients between the anomalies of water temperature and H_{500} geopotential over the Okhotsk Sea for June–September in 1980–2022, 1980–2000 and 2001–2022

HMS, Area	June	July	August	September
		1980–2022		
Area *1*	0.23	**0.45**	0.28	0.26
Petropavlovsk	**0.54**	**0.47**	0.27	0.13
Area *2*	0.25	**0.49**	**0.32**	0.23
Area *3*	0.16	**0.44**	**0.39**	0.28
Oktyabrskaya	**0.32**	0.13	0.14	−0.14
		1980–2000		
Area *1*	0.36	0.29	0.21	0.11
Petropavlovsk	**0.59**	0.13	0.06	0.10
Area *2*	0.30	**0.50**	0.06	0.21
Area *3*	**0.47**	**0.43**	0.15	0.26
Oktyabrskaya	0.37	0.12	−0.17	−0.09
		2001–2022		
Area *1*	0.08	**0.48**	0.22	0.37
Petropavlovsk	**0.60**	**0.53**	0.30	0.14
Area *2*	0.20	**0.48**	**0.43**	0.24
Area *3*	−0.06	0.32	**0.46**	0.28
Oktyabrskaya	0.27	0.15	0.34	−0.19

N o t e. Statistically significant (95%) estimates are highlighted in bold.

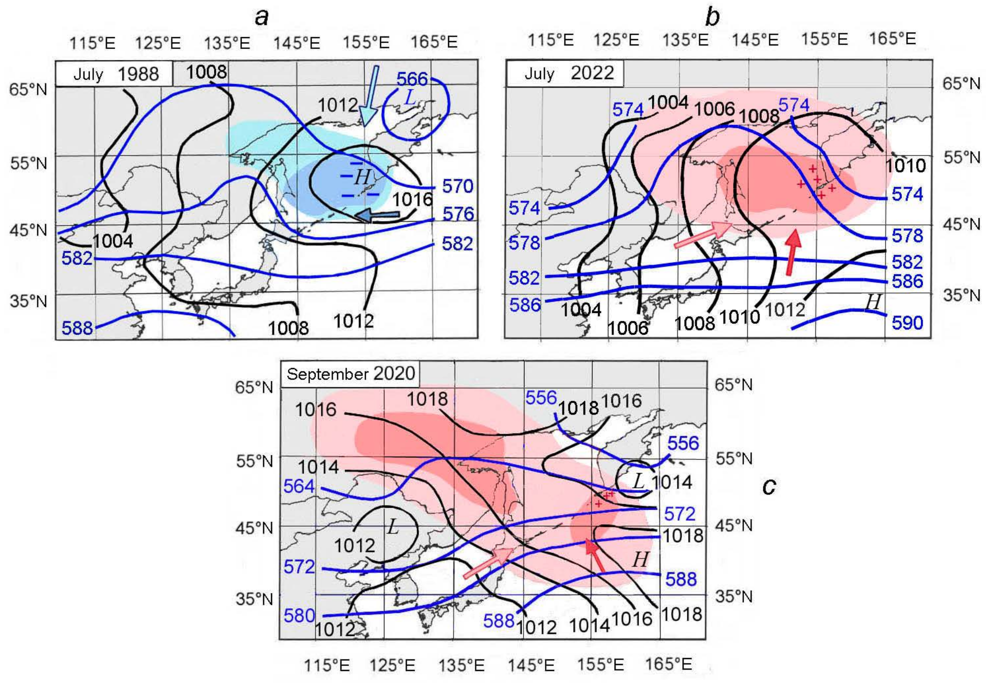
Correlation analysis between water temperature anomalies and pressure anomalies over the Okhotsk Sea showed a significant correlation (June – July period) between water temperature anomalies and H_{500} geopotential anomalies, characterizing the development of the TD (Table 3). Maximum correlation coefficients (~ 0.6) were observed in June at the HMS Petropavlovsk-Kamchatsky. High correlation coefficients (~ 0.4–0.5) were also noted in July in almost all studied water areas.

Concurrently, correlation analysis of water temperature anomalies with pressure anomalies in the HH showed low correlation and no significant relations. However, ambiguous relation between thermal regimes and pressure variability in regional AACs was previously identified: along with the intensity of development, the variability in the positions of such atmospheric pressure formations and their corresponding local impact play an important role [8, 9]. This can be one of the causes for low correlation between the occurrence of temperature extremes in water areas and intensity of development of such a large-scale pressure formation as the HH.

The study of pressure patterns during years with anomalous cold or warm thermal conditions in the investigated water areas corroborates prior findings from other regions of the Far Eastern seas [9]. These results confirm distinct differences in both structure of pressure fields and positioning of AACs during such years. Consequently, this leads to varying localized impacts and fundamentally different mechanisms governing the formation of thermal water regimes.

As noted above, in the study period 1980–2000, anomalously cold temperature conditions were formed in certain years in the Kamchatka coastal water areas (see Table 2). A characteristic example is the structure of pressure fields in July 1988 (Fig. 5, *a*). In the near-land pressure field, a developed OH localized over the northeastern water area of the Okhotsk Sea is observed. In the mid-troposphere, the 500-mbar geopotential height (AT_{500}) map reveals a cold trough positioned over the Kamchatka Peninsula and extending toward the Kuril Islands. The trough delta features an extreme geopotential height (H_{500}) minimum where descending air currents accumulate cold air near the surface creating conditions for extreme cold thermal anomalies. Such a structure of atmospheric fields contributes to the transport of cold air masses from the north and northwest over the entire study area. The temperature background of the underlying surface decreases. Negative temperature anomalies in July 1988 in the eastern and western Kamchatka coastal water areas were ~ −2°C (see Fig. 3). Under dynamic wind impact from the north and northwest, the Kuril Kamchatka Current intensifies, increasing the inflow of the cold Bering Sea and Pacific waters into the northern Kuril area [15–17], which collectively contributes to the formation of an anomalously cold thermal regime in the studied water area.

The mechanism of forming anomalously warm thermal regimes in the entire water area (characteristic of the second phase of the study period) is due to the absence of cold depressions over the Okhotsk Sea and Kamchatka. An example is 2022, the year with extremely warm thermal regime (see Figs. 2, 3). Differences in the structure of pressure fields in 1988 and 2022 should be noted. In 2022, zonality of isohypses in the H_{500} field is evident, reflecting the westerly transport of air masses (Fig. 5, *b*). The HH ridge, at the vertex of which a zone of increased H_{500} geopotential is observed, spreads over the entire study area. As the North Pacific branch of the HH stretched northwestward, it generated a surface-level center of extreme positive air temperature anomalies over the region, accompanied by record warm water temperatures throughout the areas. Such a structure of atmospheric fields with significant northwestward spread (into the Okhotsk Sea water area) of the HH North Pacific branch, transport of warm air masses along its western periphery and formation of anomalously warm thermal regimes in the Kamchatka coastal water areas is characteristic of the last five years. Easterly and southeasterly winds, weakening the Kuril-Kamchatka Current, contribute to the westward inflow of warmer waters with eddies of the Alaska Current extension, which also influences the thermal regime of waters in this area [12, 13].



F i g. 5. Structures of the fields of near-surface pressure P_o, hPa (black isobars) and geopotential H_{500}, hPa (blue isohypses) in the years of forming the negative (*a*) and positive (*b*, *c*) anomalies in thermal regimes. *H* is high pressure, *L* is low pressure; "–" and "+" are negative and positive water temperature anomalies, respectively; centres of negative and positive anomalies of the H_{500} geopotential are shown in blue and pink, respectively; centres of anomalously low and high air temperature – in blue and red; arrows indicate the movement of cold and warm air masses (blue and pink – in the mid troposphere, blue and red – in the near-land layer, respectively)

As discussed, thermal anomalies in the coastal waters, which influence the ecosystem productivity, are critical to their functioning. Anomalously warm thermal regimes can be associated with the formation of anomalous hydrological conditions that affect ecosystems and hydrobionts negatively, as observed in September and October 2020 [18]. Fig. 5, *c* shows the structures of atmospheric fields in September 2020. Against the background of the formed anomalously warm thermal regime of waters (increase in positive temperature anomalies up to 1.5°C), cyclones passed off the southeastern coast of Kamchatka causing changes in the structure of the surface pressure field. Such changes led to a local shift in wind direction near the coast from southeasterly to northeasterly and northerly. The passage of cyclones apparently contributed to the formation of upwelling and, as noted in [19], the influx of nutrients from deeper layers, causing blooms of toxic microalgae under favorable anomalously warm temperature conditions in the surface photic layer. The spread of such microalgae blooms along the coast according to water circulation and further toward the northern Kuril straits resulted in adverse effects on the ecosystem of a significant part of the water area.

These studies highlight the importance of considering surface pressure variability, positions of AACs and corresponding local impacts when analyzing the formation of the anomalous thermal conditions.

Analysis of regional atmospheric variability and its impact on the underlying water area revealed cause-and-effect relations. The formation of anomalous thermal conditions is associated with regional atmospheric circulation patterns, including anomalous changes in the development and positions of seasonal AACs and their local effects on thermal conditions.

Conclusion

Analysis of long-term variability of temperature conditions in the studied water areas in June – September for the period 1980–2022 revealed positive trends, with statistically significant increases in July and August.

Differences in the variability of temperature conditions during two twenty-year phases of the study period were identified. From 1980 to 2000, trends in June–July were mostly negative in all areas of the region. This reflects high frequency of cold thermal regimes during this phase and indicates a relatively well-developed first stage of the Far Eastern summer monsoon and the OH influence. During this period, anomalously warm regimes were not observed in the water areas off the western and eastern Kamchatka coasts. Analysis of the second phase (2001–2022) revealed significant positive trends, indicating a weakening of the first cold stage of the monsoon and predominantly early formation of warm thermal regimes. In this phase, we note a transition to the occurrence of years with anomalously warm thermal regimes most clearly manifested in July – September of the past five years.

A significant correlation was found between water temperature anomalies and H_{500} geopotential anomalies, characterizing the intensity of the TD development which, in turn, supports the OH development. For the first twenty-year phase of pressure variability in the OH area, the formation of positive anomalies (intensive development) was typical but the second phase was characterized by the formation of predominantly negative anomalies, indicating a weakening of this AAC.

Correlation analysis of interannual variability of water temperature anomalies and pressure anomalies in the HH area revealed no significant relations. The formation of temperature extremes in water areas is local in nature, which can be one of the causes for the low correlation with the intensity of development of such a large-scale pressure formation as the HH, despite a relatively good correlation with the OH regional AAC. It is shown that, along with the intensity of development of these AACs, their positions play a key role in the thermal regime formation. It is established that the HH has a steady trend toward increasing intensity of development. Under conditions of the OH weakening and the northwestward propagation of the HH North Pacific branch, the thermal and dynamic impact of this high on the studied water areas increases, contributing to the formation of water thermal regimes with positive anomalies.

It is shown that the formation of anomalous thermal conditions is associated with regional features of atmospheric circulation: anomalous changes in the development and positions of seasonal AACs and in their local impacts.

Findings from this study can be used in fisheries oceanography and incorporated into regional predictive models.

REFERENCES

1. Rostov, I.D., Dmitrieva, E.V., Rudykh, N.I. and Vorontsov, A.A., 2020. Climatic Changes in Thermal Conditions of Marginal Seas in the Western Pacific. *Russian Meteorology and Hydrology*, 45(3), pp. 169-178. https://doi.org/10.3103/S1068373920030048

2. Byshev, V.I., Neiman, V.G., Ponomarev, V.I., Romanov, Yu.A., Serykh, I.V. and Tsurikova, T.V., 2014. The Influence of Global Atmospheric Oscillation on Formation of Climate Anomalies in the Russian Far East. *Doklady Earth Sciences*, 458(1), pp. 1116-1120. https://doi.org/10.1134/S1028334X14090025

3. Johnson, G.C. and Lyman, J.M., 2020. Warming Trends Increasingly Dominate Global Ocean. *Nature Climate Change*, 10(8), pp. 757-761. https://doi.org/10.1038/s41558-020-0822-0

4. Jiang, X., Li, Y., Yang, S. and Wu, R., 2011. Interannual and Interdecadal Variations of the South Asian and Western Pacific Subtropical Highs and Their Relationships with Asian-Pacific Summer Climate. *Meteorology and Atmospheric Physics*, 113(3-4), pp. 171-180. https://doi.org/10.1007/s00703-011-0146-8

5. Shuntov, V.P. and Ivanov, O.A., 2019. Climate Changes and Current State of Biota in the Russian Waters of the Far-Eastern Seas. *Izvestiya TINRO*, 197, pp. 83-107. https://doi.org/10.26428/1606-9919-2019-197-83-107 (in Russian).

6. Terziev, F.C., ed., 1998. [*Gidrometeorology and Gidrochemistry of Seas. Vol. 9. Okhotsk Sea. Iss. 1. Gidrometeorological Conditions*]. Saint Petersburg: Gidrometeoizdat, 398 p. (in Russian).

7. Bogdanov, K.T. and Moroz, V.V., 2004. The *Kuril-Kamchatka Current and Oyashio Currents Water*. Vladivostok: Dalnauka, 141 p. (in Russian).

8. Shatilina, T.A., Tsitsiashvili, G.Sh. and Radchenkova, T.V., 2019. Features of the Summer Atmospheric Force Centers Variability over the Far East and Climatic Extremes in the Period

1980–2017. *Proceedings of the Russian State Hydrometeorological University*, (56), pp. 61-80. https://doi.org/10.33933/2074-2762-2019-56-61-80 (in Russian).

9. Moroz, V.V. and Shatilina, T.A., 2022. Features of Forming the Water Extreme Thermal Regimes in the Kuril Ridge Region in Summer under the Impact of the Changeable Atmospheric Processes. *Physical Oceanography*, 29(5), pp. 435-448. https://doi.org/10.22449/1573-160X-2022-5-435-448

10. Shatilina, T.A., Tsitsiashvili, G.Sh. and Radchenkova, T.V., 2021. Application of Interval Approach to Pattern Recognition for Identification of Preceeding Baric Structures that Determine Extreme Thermal Modes in the South-Kuril Area in Summer. *Izvestiya TINRO*, 201(2), pp. 470-483. https://doi.org/10.26428/1606-9919-2021-201-470-483 (in Russian).

11. Rostov, I.D., Dmitrieva, E.V. and Vorontsov, A.A., 2018. Tendencies of Climate Changes for Thermal Conditions in the Coastal Waters of the Western Bering Sea and Adjacent Areas in the Last Decades. *Izvestiya TINRO*, 193(2), pp. 167-182. https://doi.org/10.26428/1606-9919-2018-193-167-182 (in Russian).

12. Rogachev, K.A. and Shlyk, N.V., 2018. The Role of the Aleutian Eddies in the Kamchatka Current Warming. *Russian Meteorology and Hydrology*, 43(1), pp. 43-48. https://doi.org/10.3103/S1068373918010065

13. Andreev, A.G. and Zhabin, I.A., 2015. Impact of Continuation of the Alaskan Stream Flux Changes on the Water Dynamics in the Eastern Okhotsk Sea. *Vestnik of Far Eastern Branch of Russian Academy of Sciences*, (2), pp. 87-92 (in Russian).

14. Zhigalov, I.A., 2012. Seasonal and Year-to-Year Variability of Geostrophic Currents at West Kamchatka. *Izvestiya TINRO*, 169, pp. 94-99 (in Russian).

15. Rogachev, K.A. and Shlyk, N.V., 2005. Multiyear Variability of the Wind Stress Curl and Sea Level in the Kamchatka Current. *Oceanology*, 45(3), pp. 317-326.

16. Zhabin, I.A., Lobanov, V.B., Watanabe, S., Wakita, M. and Taranova, S.N., 2010. Water Exchange between the Bering Sea and the Pacific Ocean through the Kamchatka Strait. *Russian Meteorology and Hydrology*, 35(3), pp. 218-224. https://doi.org/10.3103/S106837391003009X

17. Isoguchi, O. and Kawamura, H., 2006. Seasonal to Interannual Variations of the Western Boundary Current of the Subarctic North Pacific by a Combination of the Altimeter and Tide Gauge Sea Levels. *Journal of Geophysical Research: Oceans*, 111(C4), C04013. https://doi.org/10.1029/2005JC003080

18. Pichugin, M.K., Gurevich, I.A., Khazanova, E.S. and Salyuk, P.A., 2020. Some Features of Oceanological Conditions of the Microalgae Autumn-Flowering near the Southeast Shore of Kamchatka. *Underwater Investigations and Robotics*, 4(34), pp. 70-73. https://doi.org/10.37102/24094609.2020.34.4.010 (in Russian).

19. Tskhay, Zh.R. and Shevchenko, G.V., 2022. Distribution Features of Chlorophyll a Concentration off the East Coast of Kamchatka in Autumn 2020 from Satellite Data. *Sovremennye Problemy Distansionnogo Zondirovaniya Zemli iz Kosmosa*, 19(1), pp. 226-238. https://doi.org/10.21046/2070-7401-2022-19-1-226-238 (in Russian).

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