



Coastal ecosystem response to climate change in Peter the Great Bay (Japan/East Sea): advances and failures of long-term monitoring

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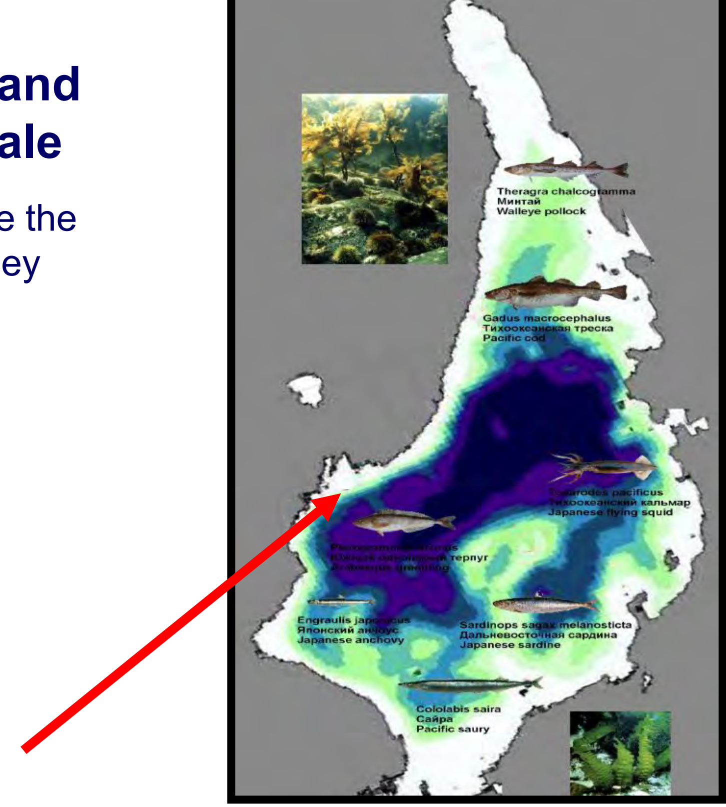
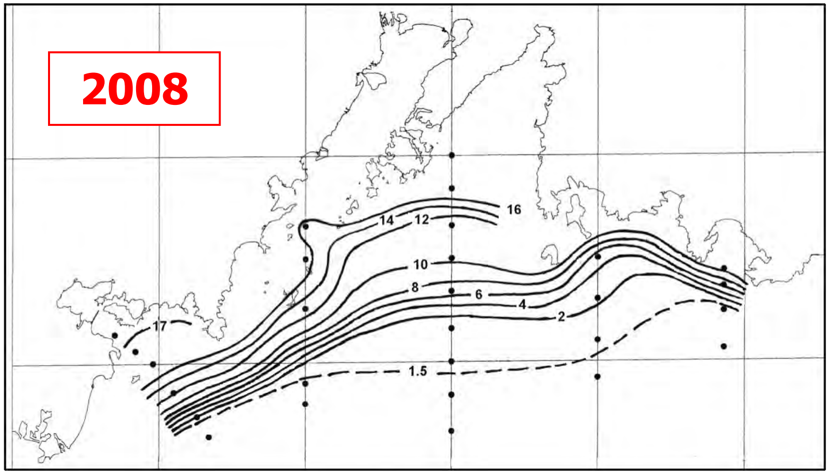
Goals: factual response of marine chemistry and biota to environments changes of climatic scale

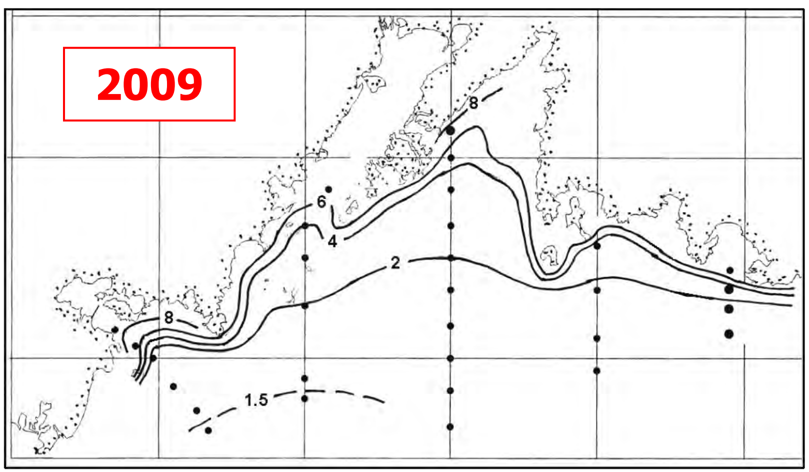
Great year-to-year variations, particularly at the sea bottom, are the reason of drastic changes in marine chemistry and biota. Do they cause the ecosystem reconstruction in climatic scale?

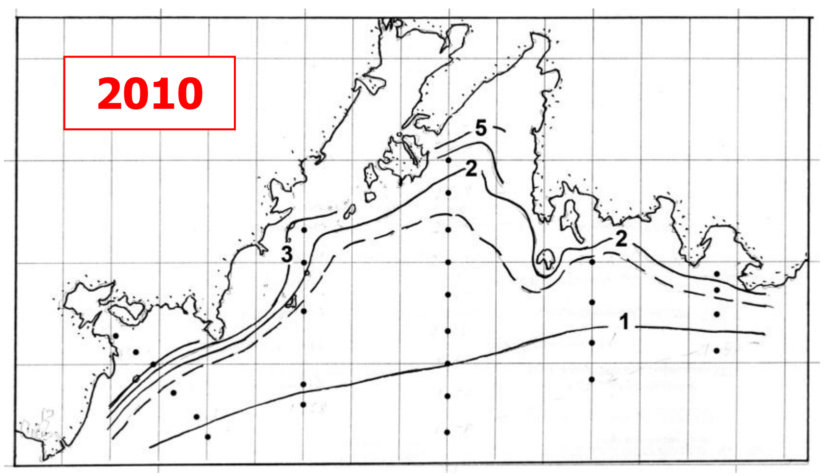




43°00

42°30





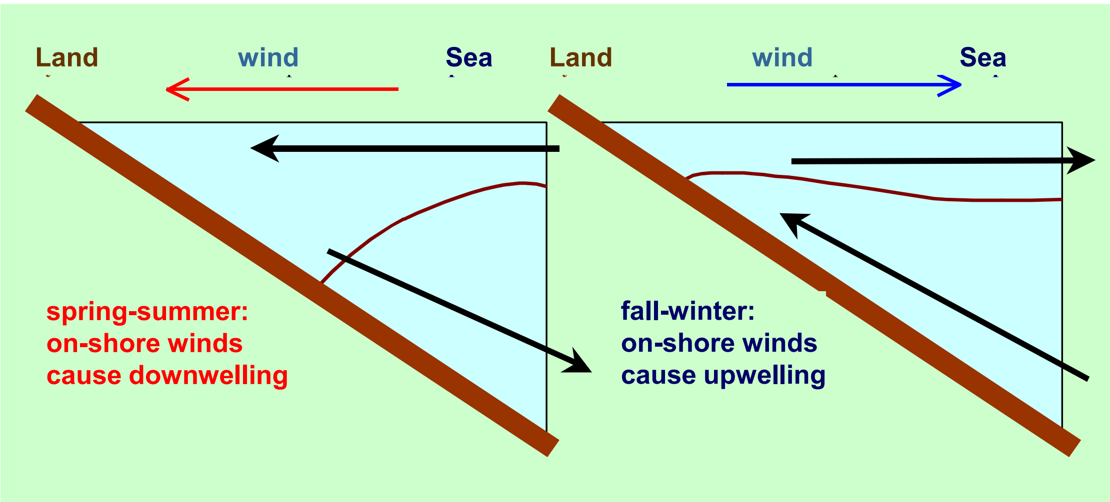
131°00 132°00 133°00

Examples of water temperature distribution at the sea bottom in early September (Sept.1-3) of three successive years

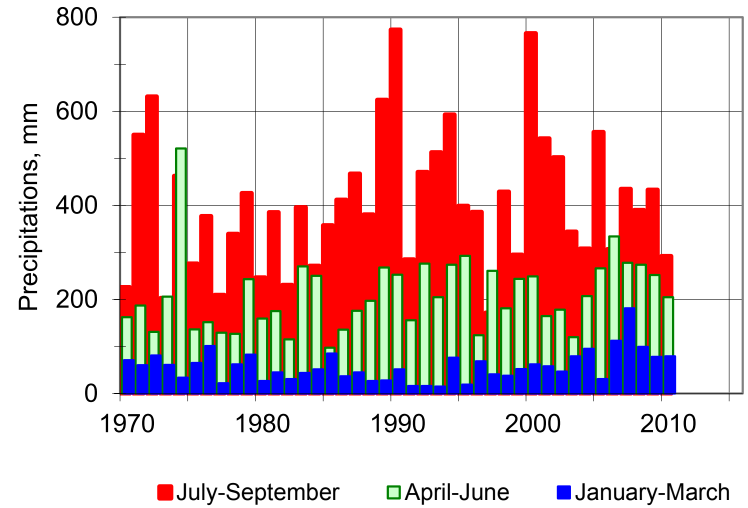
Goals: mechanisms of climatic changes in the area of land-sea interaction

Coastal zone is the area of mutual influence of marine processes, as advection or water mixing, and terrestrial processes, as river discharge of fresh water and nutrients. Both marine and terrestrial processes have changes in climatic scale. What of them dominates in coastal waters?

The Suifen/Razdolnaya is the largest river of Peter the Great Bay basin with annual runoff about 2.2 km^3



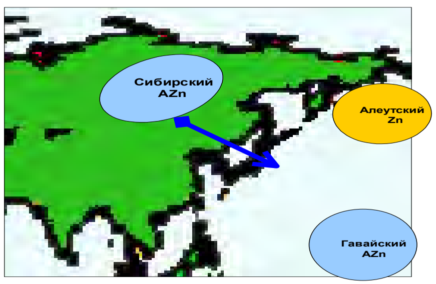
Scheme of monsoon on-shore and off-shore winds influence on water circulation and pycnocline topography at continental coast of the Japan Sea



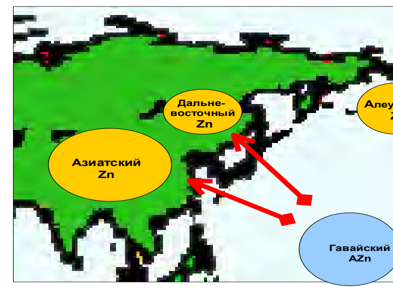
Whole volume of terrestrial fresh water is formed by precipitation, mostly in summer. Both winter and summer precipitations have positive trends in last decades

Goals: dependence of the climatic changes in Peter the Great Bay on large-scale processes and possible mechanisms of downscalling

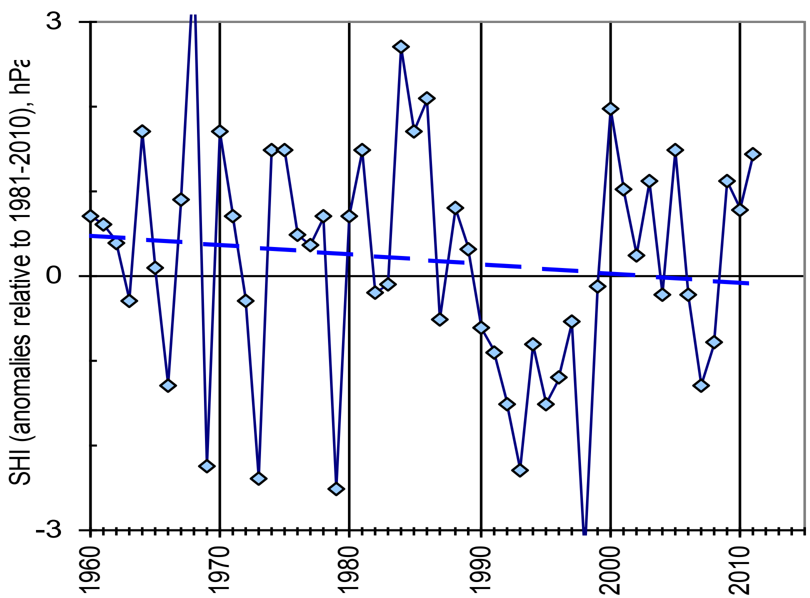
The changes in Peter the Great Bay happen in conditions of large-scale changes of monsoon system, different for different seasons. How these large-scale processes influence on a small coastal area and its ecosystem?



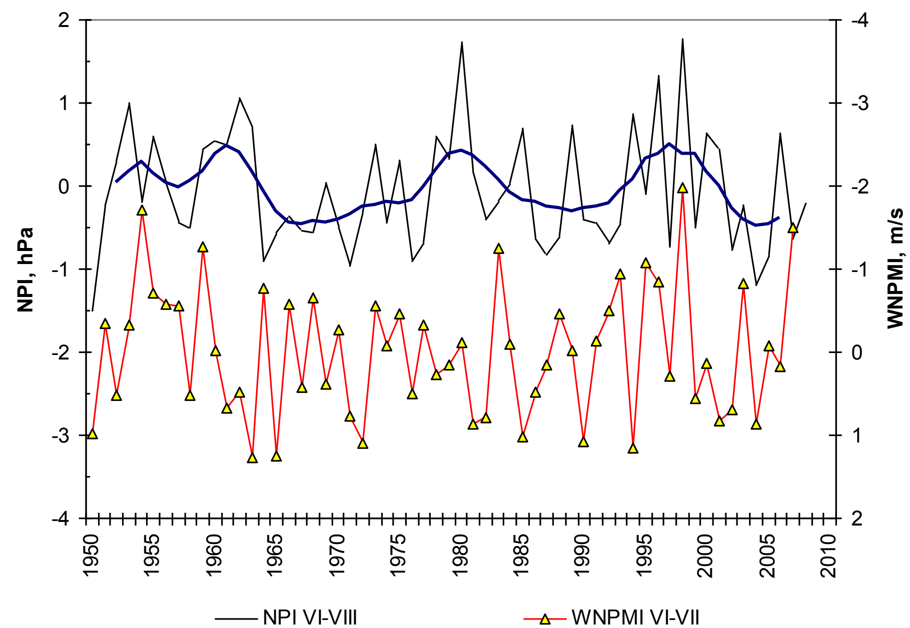
Scheme of winter monsoon formation



Scheme of summer monsoon formation



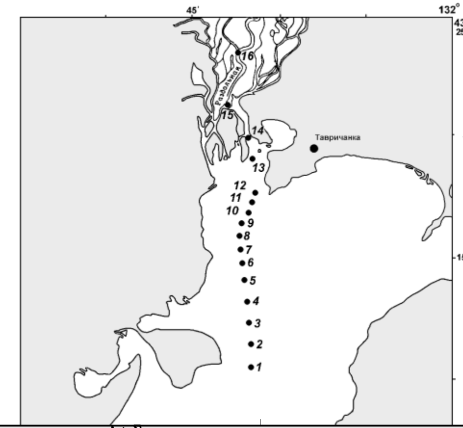
Year-to-year changes of winter monsoon strength (Siberian High Index). The monsoon has a tendency to weakening

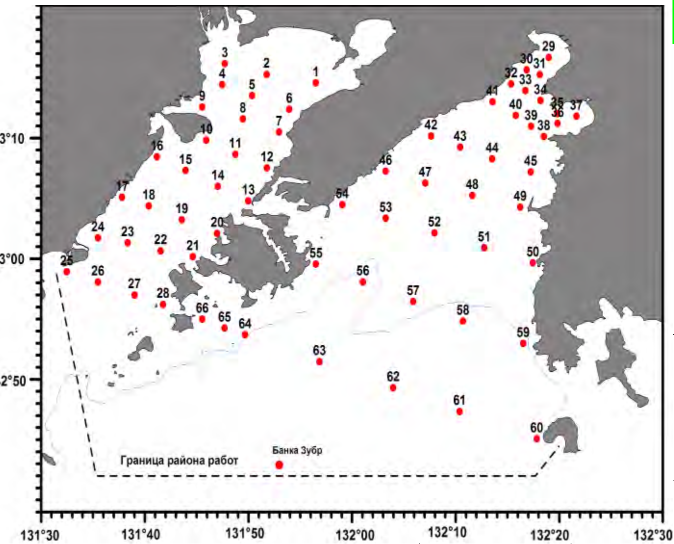


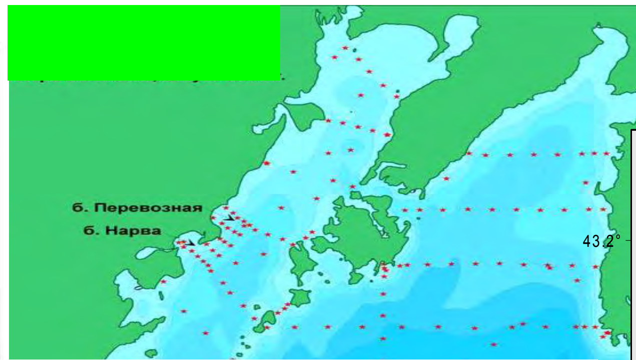
Year-to-year changes of summer monsoon strength (North Pacific Index and West North Pacific Monsoon Index for summer). Both indices have no any significant tendency in climatic scale

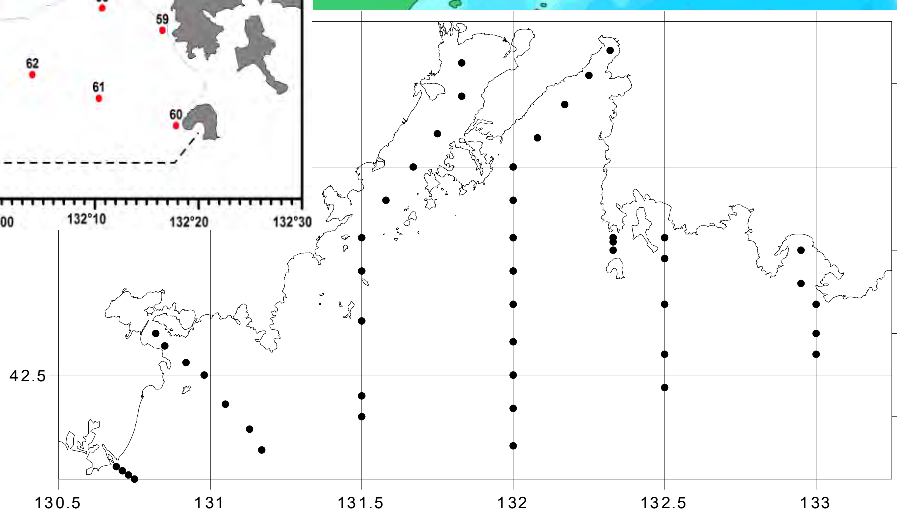
Amur Bay – the area of monitoring

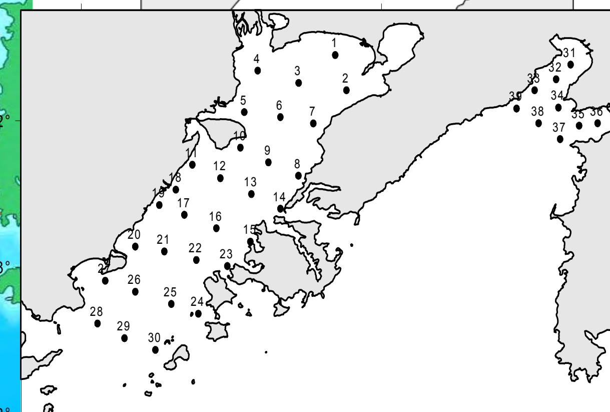
The Amur Bay is the secondary inlet of Peter the Great Bay located near Vladivostok. That’s why this area was monitored the most frequently, particularly after 1980. Now the series of **irregular but frequent** observations in the Amur Bay are long enough for climate change studies

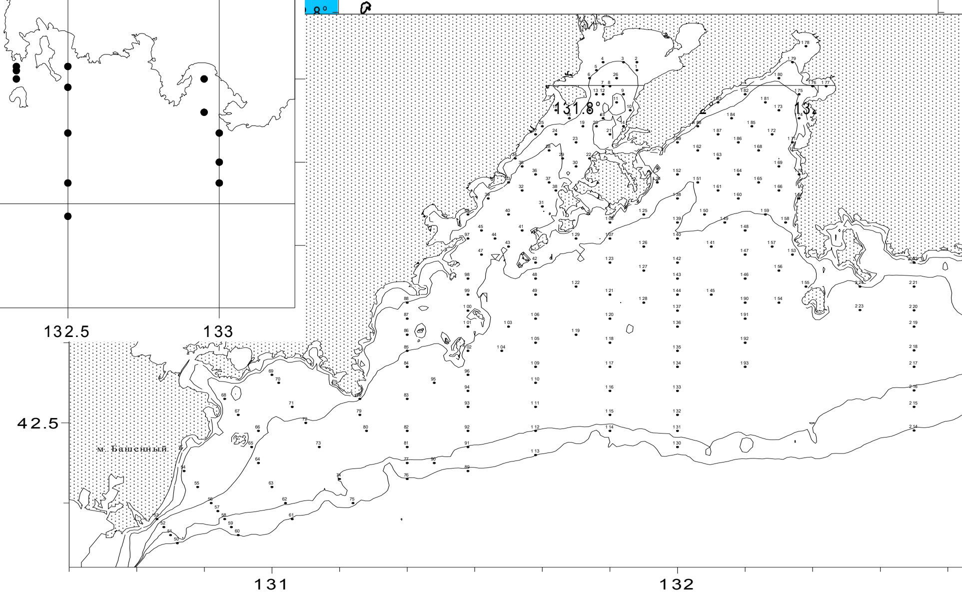








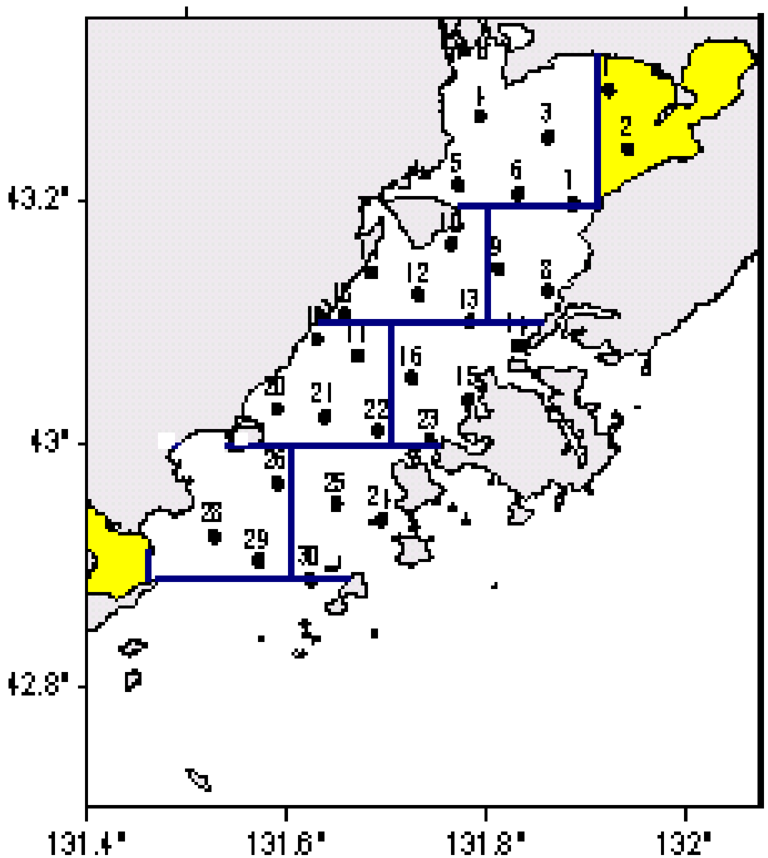




Some examples of monitoring stations in Peter the Great Bay in framework of different programs conducted in the period after 1980. All of them include the area of the Amur Bay

Amur Bay – the area of monitoring

Changes of water temperature, salinity, dissolved oxygen content, nutrients concentrations, and zooplankton abundance and species composition are traced for 7 subareas in the Amur Bay (app. 6 x 6 miles) covered by observations in both 1980s and 2000s

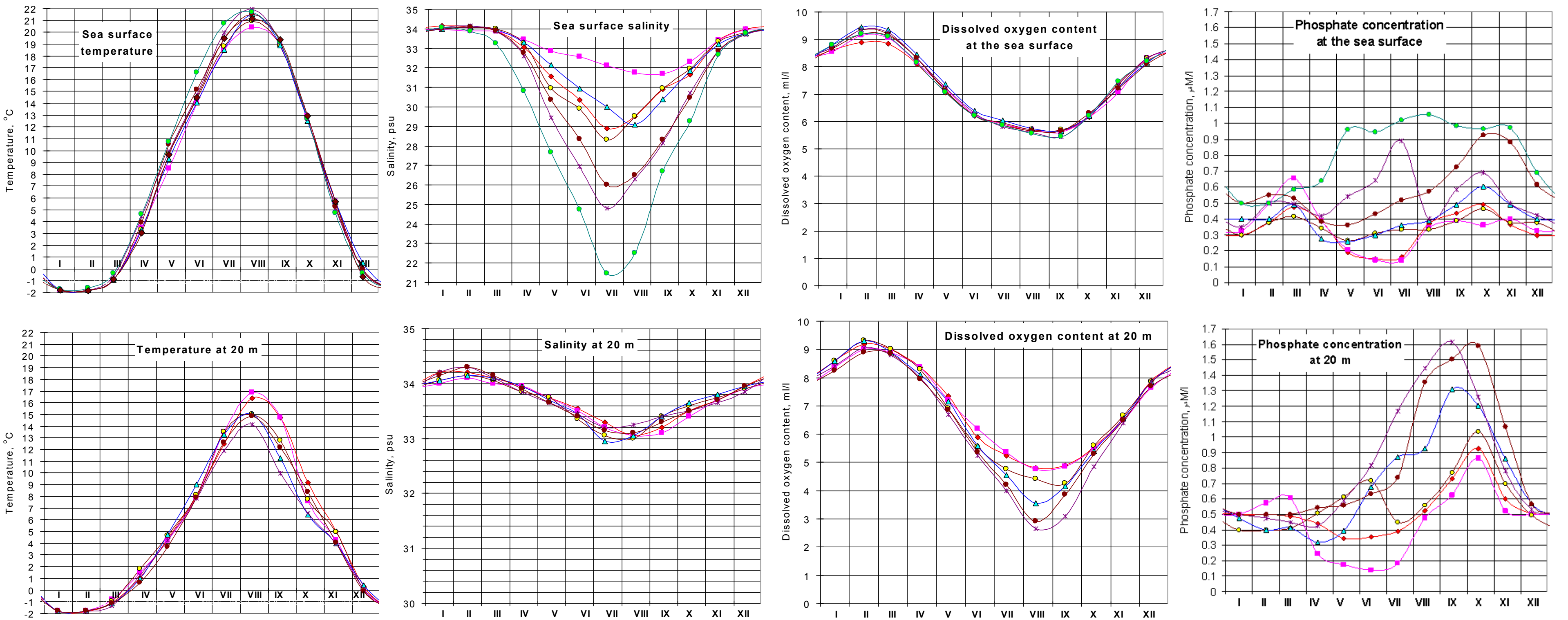


Scheme of spatial data averaging in the Amur Bay.
Areas with insufficient data coverage are yellow-colored

Amur Bay – the area of monitoring

To remove seasonal variability of environmental parameters, “normal” seasonal variation was calculated for each subarea from all data for 3 decades, then the norms were subtracted from observed values, taking into account the date of observation, then all anomalies were monthly averaged.

Data on zooplankton were enough numerous in both 1980s and 2000s for June only



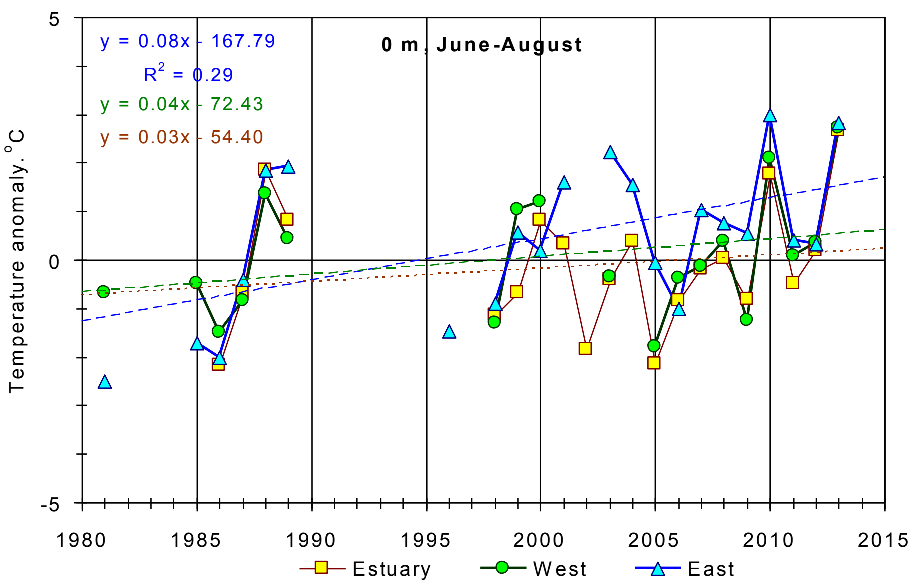
Examples of normal seasonal variations for water temperature, salinity, dissolved oxygen, and phosphate at the sea surface and at the depth 20 m in all investigated subareas

Amur Bay: year-to-year changes

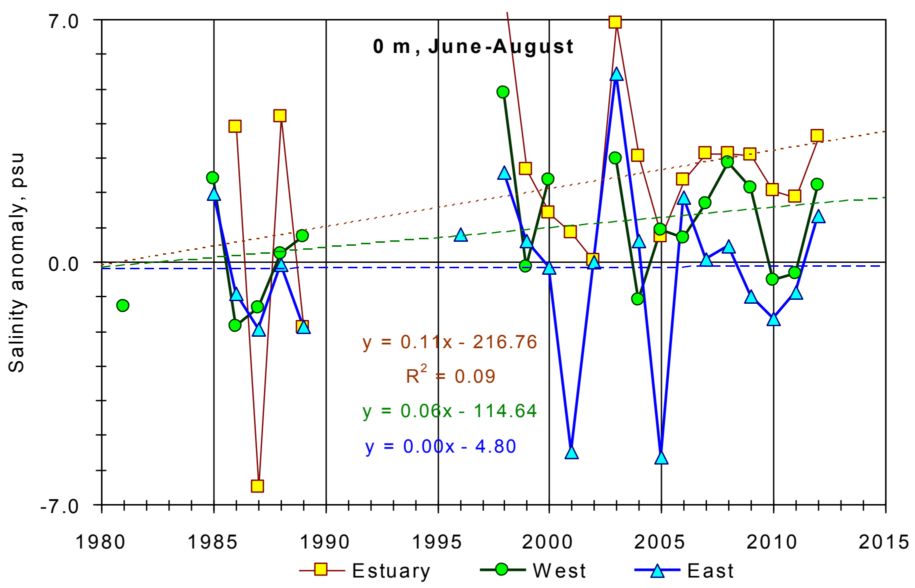
The year-to-year variability could be traced for temperature and salinity in May-September, because these parameters were observed in majority of years in the period after 1980.

Year-to-year fluctuations were usually similar in neighbor subareas, so the data could be averaged for all western and eastern subareas.

Moreover, the year-to-year fluctuations were similar is some neighbor months that allowed to integrate the data within each year: the sea surface data were integrated for the whole summer season and the data for deep layers – for early summer and late summer, separately.



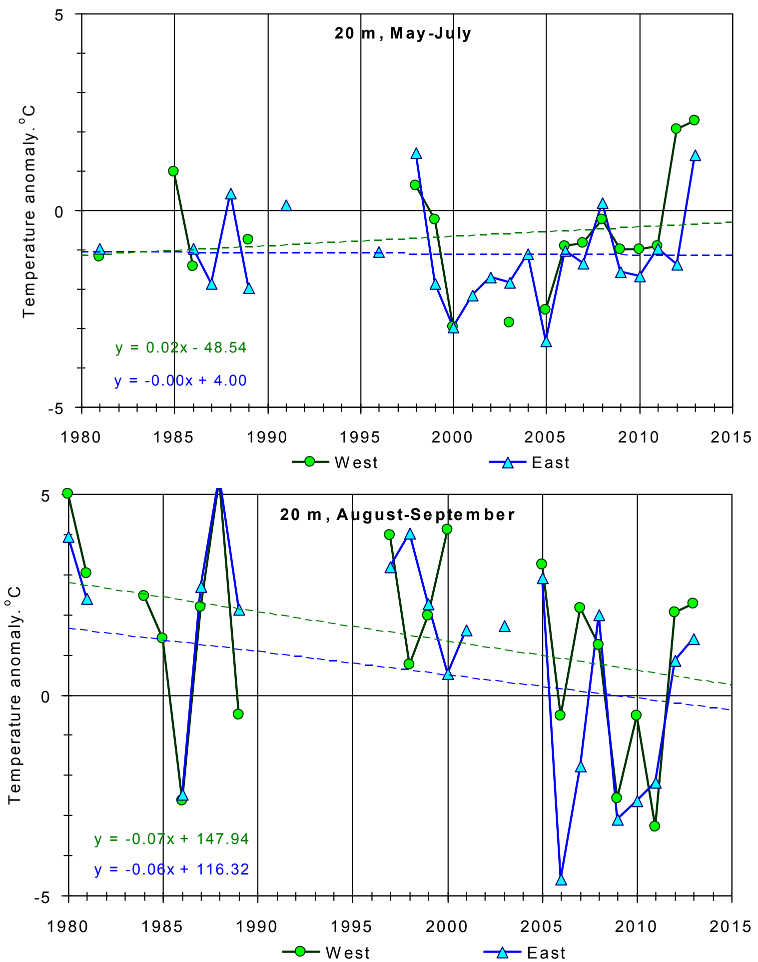
Year-to-year changes of summer SST. Trend to warming is observed in all subareas (statistically significant for the eastern part of the Amur Bay only)



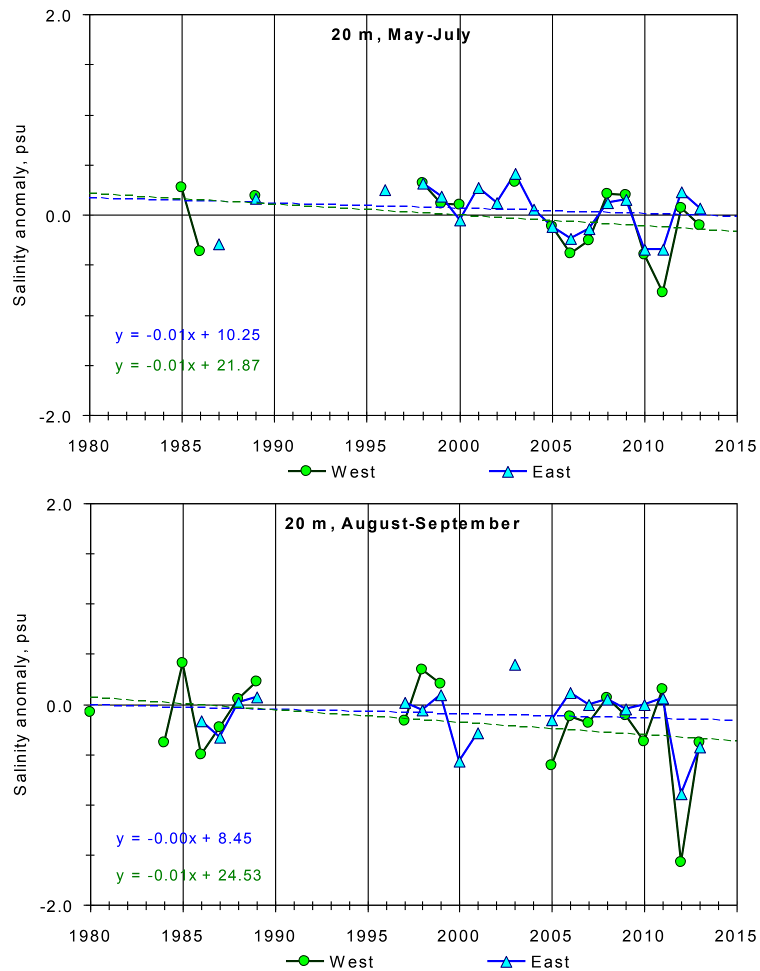
Year-to-year changes of salinity at the sea surface in summer. Salinity has tendencies to heightening in the western (coastal) subareas, particularly in the estuarine zone (statistically not significant)

Amur Bay: year-to-year changes

The variations of temperature and salinity at the sea bottom are different for the periods of early summer and late summer and fall seasons.



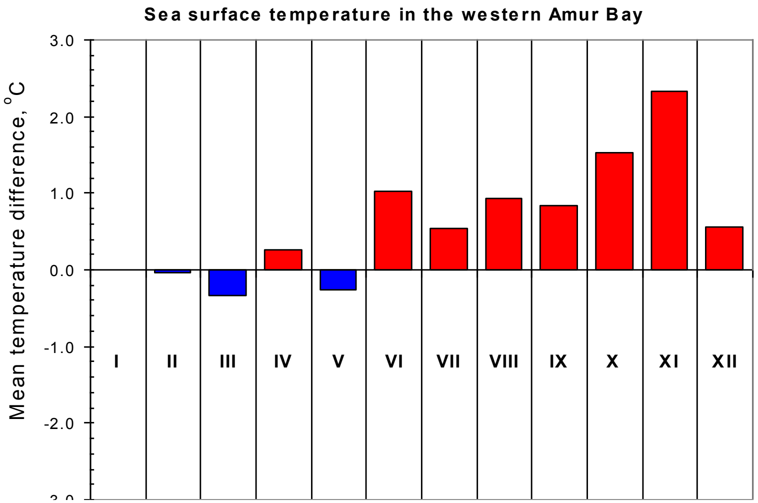
Year-to-year changes of temperature at 20 m depth in early summer and late summer. Trend to cooling is observed in late summer only (not significant)

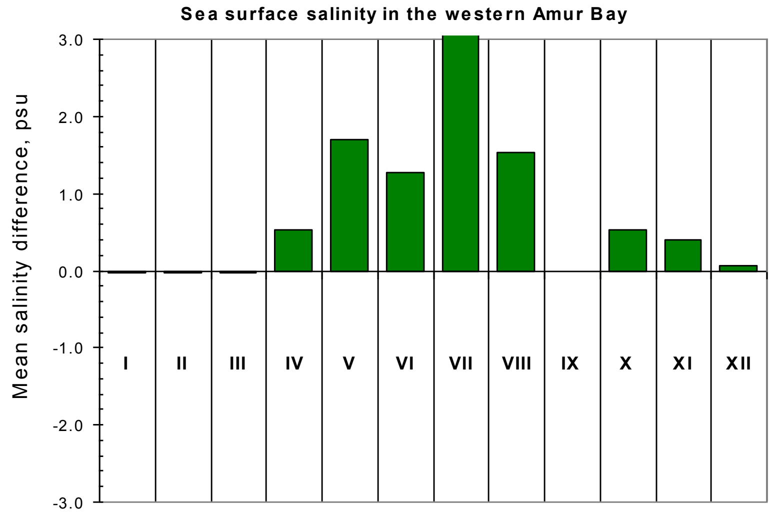


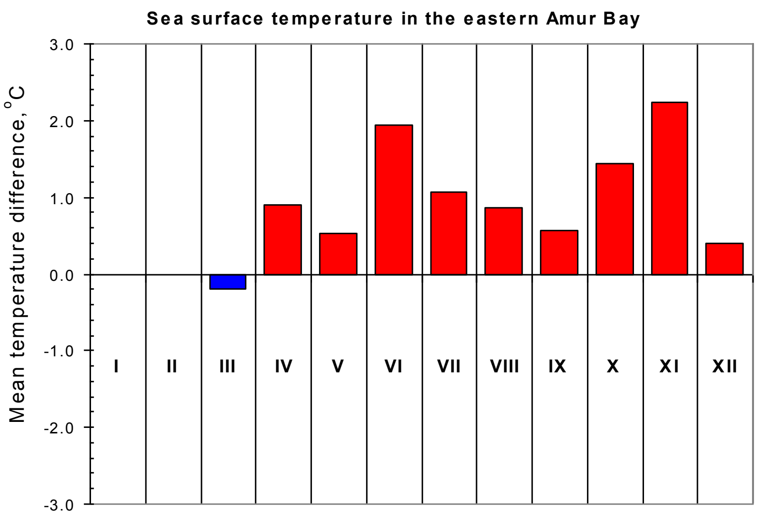
Year-to-year changes of salinity at 20 m depth in early summer and late summer. Slight trends to freshening are observed for both seasons

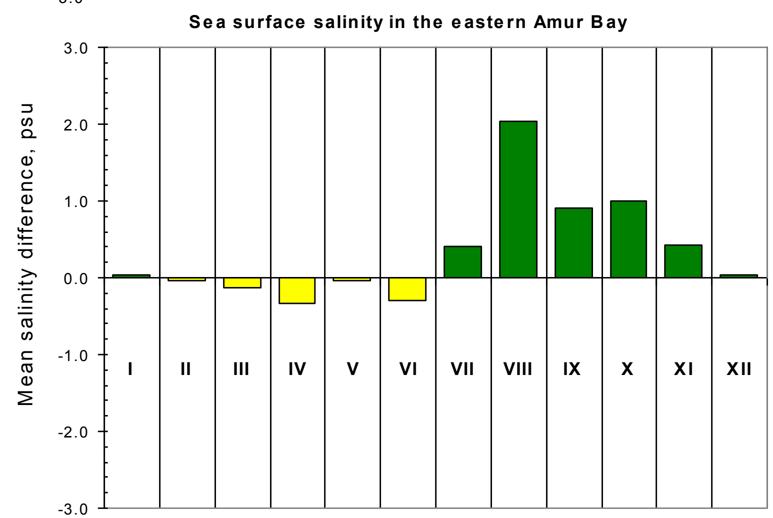
Amur Bay: temperature and salinity changes in climate scale

Climatic changes for all seasons could be explained as monthly differences between two decades with high number of data: 1980s and 2000s.







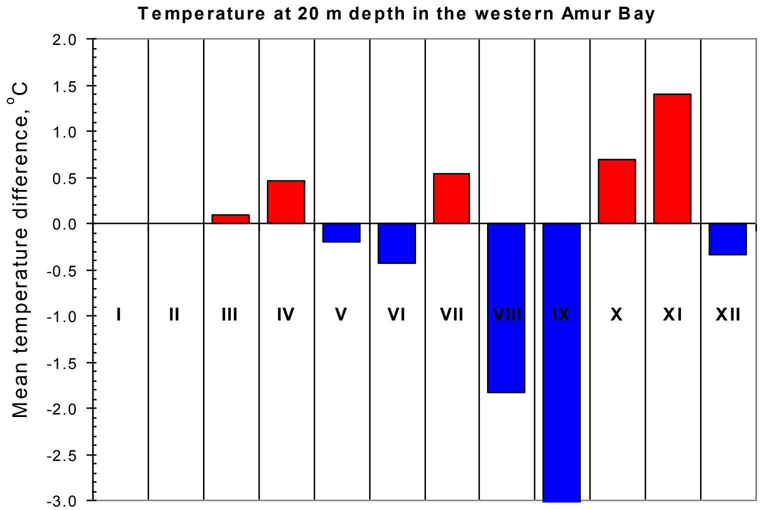


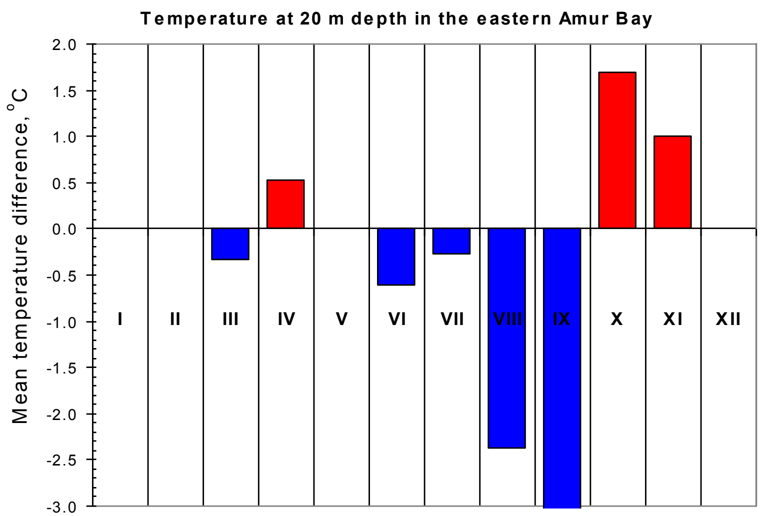
Change of the sea surface temperature between 1980s and 2000s. Summer and fall seasons become warmer everywhere, in spite of colder spring

Change of the sea surface salinity between 1980s and 2000s. The changes in early summer are different in the western and eastern parts of the Bay, though both areas become saltier in autumn

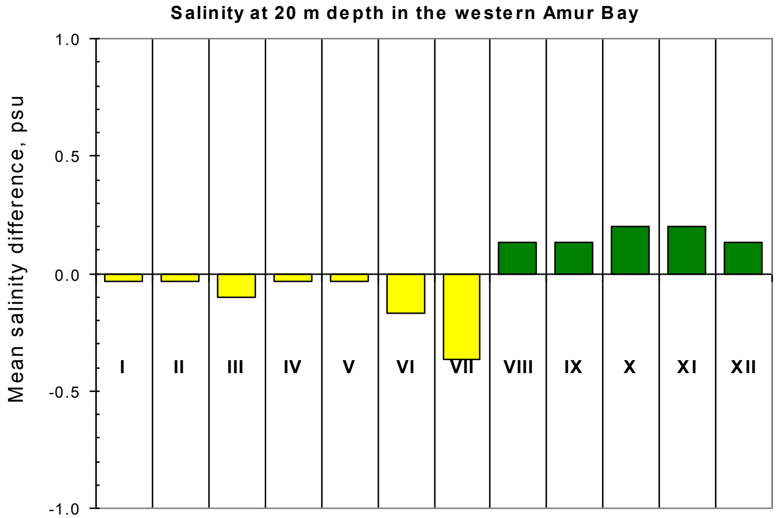
Amur Bay: temperature and salinity changes in climate scale

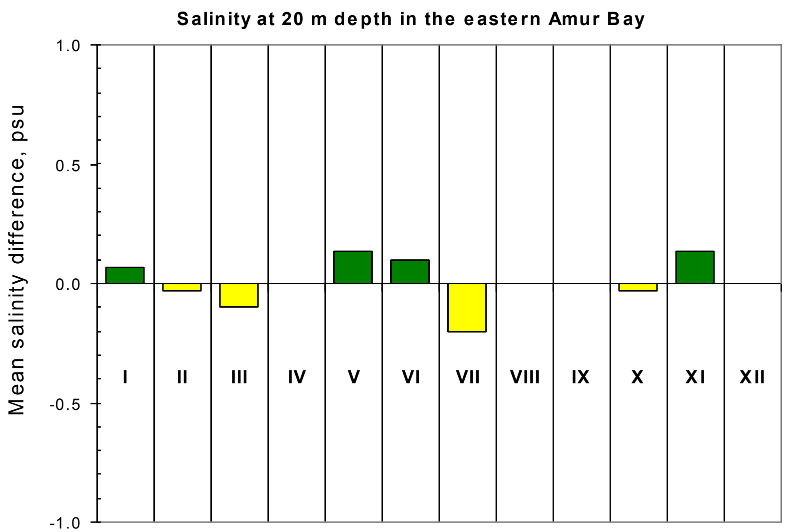
Climatic changes for all seasons could be explained as monthly differences between two decades with high number of data: 1980s and 2000s.





Change of the temperature at 20 m depth between 1980s and 2000s: cooling in summer but warming in autumn

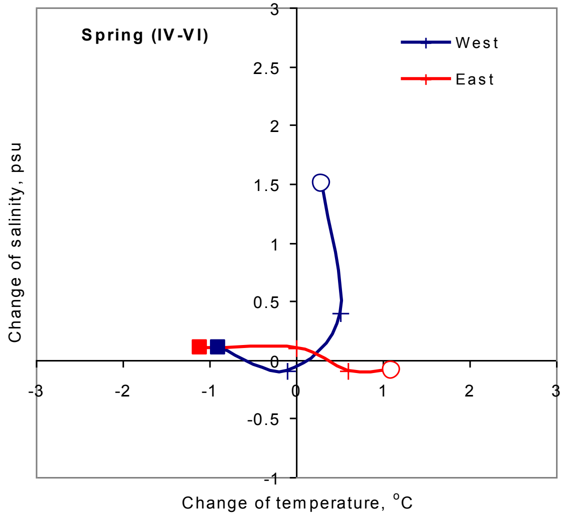


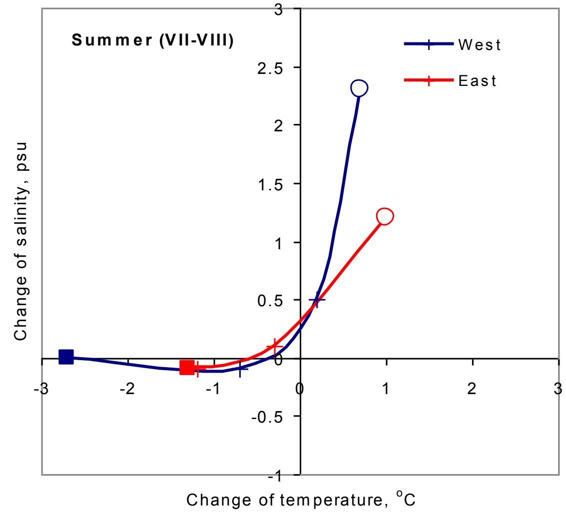


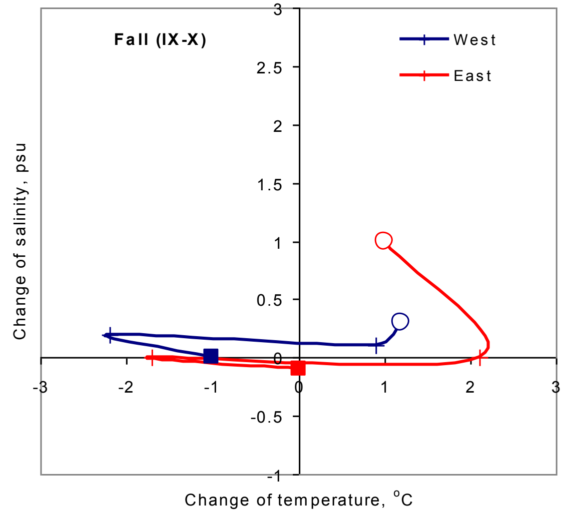
Change of the salinity at 20 m depth between 1980s and 2000s: slight freshening in summer but salinity heightening in fall season in the western (coastal) subarea

Amur Bay: temperature and salinity changes in climate scale

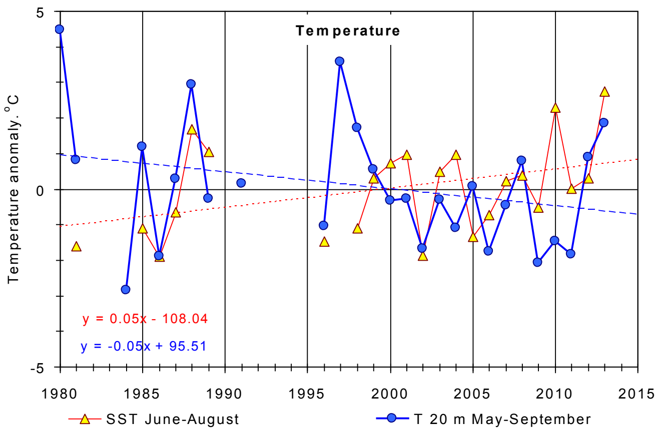
Shape of water temperature and salinity profiles changed between 1980s and 2000s. The most prominent changes happen is summer, when the upper layer becomes warmer and saltier, but the deeper layer becomes colder.

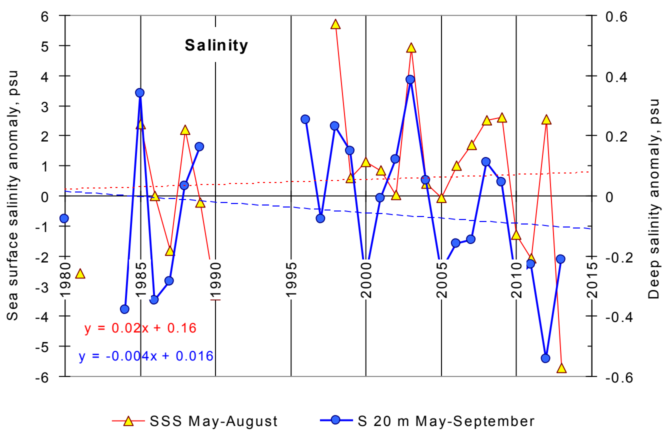






Change of temperature and salinity within water column (0-30 m) of the Amur Bay between 1980s and 2000s:
- Spring becomes saltier at the sea surface in the western suabareas, no great changes in other areas and depths;
- Summer becomes warmer and saltier in the upper layer, but colder and slightly less saline in the deeper layer;
- Fall becomes warmer and saltier in the upper layer, small changes in the deeper layer.

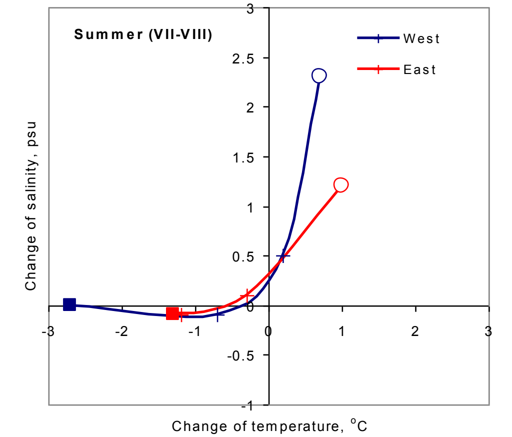


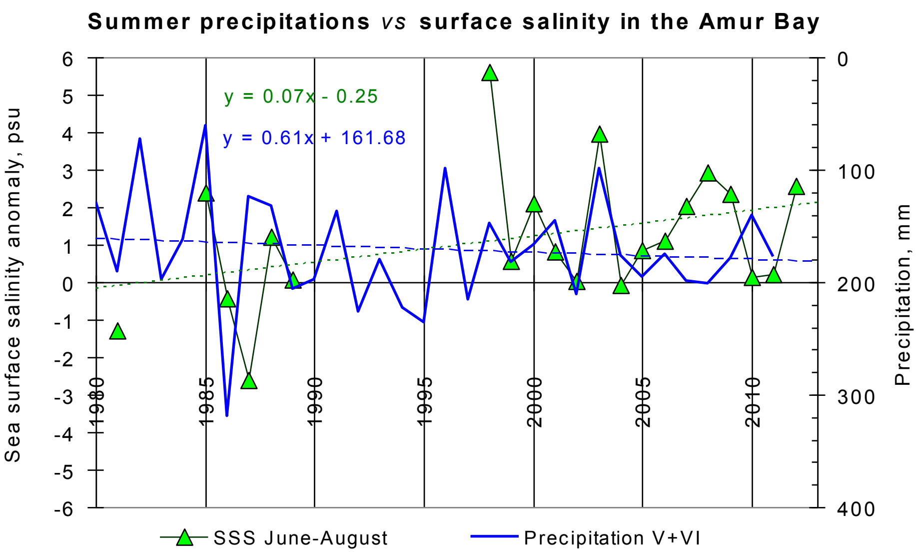


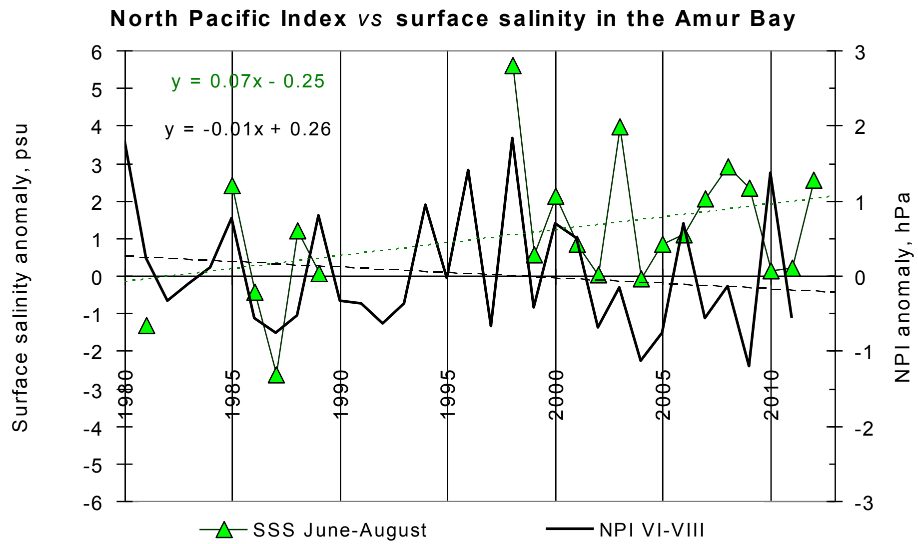
Year-to-year changes of water temperature and salinity in the upper and deeper layers of the Amur Bay.
Trends in different layers are opposite

Amur Bay: temperature and salinity changes in climate scale

Curiously, that changes of the sea surface salinity, even in the estuarine zone, are not correlated well with local precipitations! On the contrary, they have some correlation with fluctuations of atmospheric indices describing summer monsoon, as NPI: summer salinity is higher in the years with high atmospheric pressure in the North Pacific. However, the tendencies of these parameters are opposite: positive trend for salinity and negative trend for NPI.



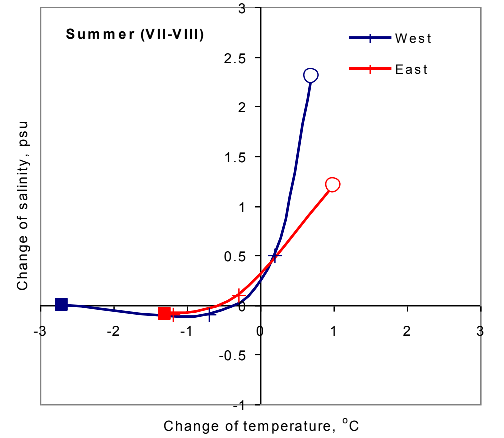




Change of the sea surface salinity and precipitations in the Suifen River valley in summer. Low or high precipitations had conditioned some salinity extremes, but positive trend of precipitation cannot be a reason for positive trend of salinity

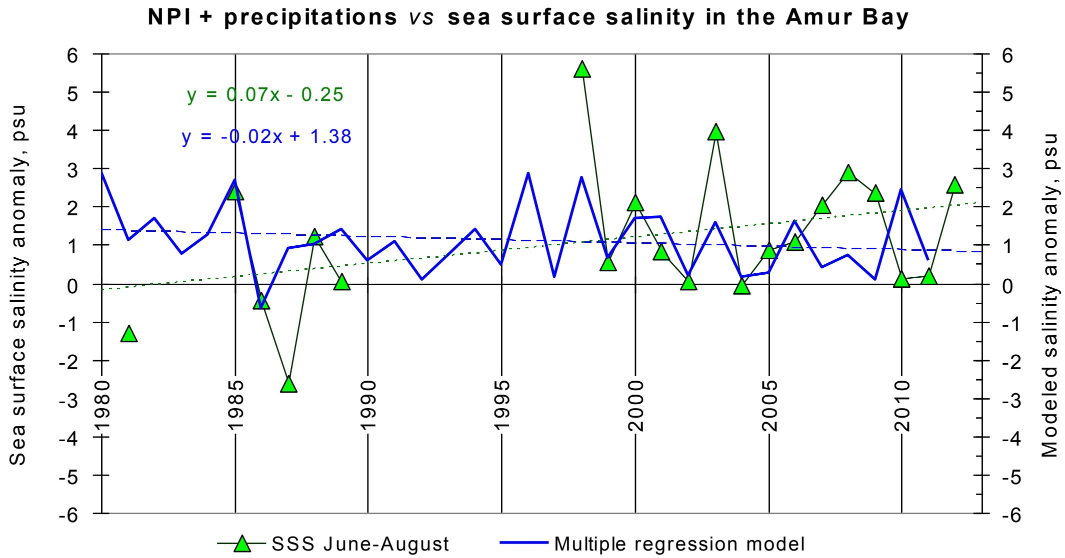
Change of the sea surface salinity and NPI in summer. High NPI (strong summer monsoon) promoted to some salinity peaks because of saline marine water advection to the coast, but its negative trend cannot be a reason for positive trend of salinity. Observed opposite changes of salinity in the upper and deeper layers could not be caused by weakening of the monsoon.

Amur Bay: temperature and salinity changes in climate scale



The changes in coastal areas could be a result of combined influence of both marine and terrestrial processes; anyway, the positive trend of the sea surface salinity is not understandable yet *(maybe, vertical mixing?).*

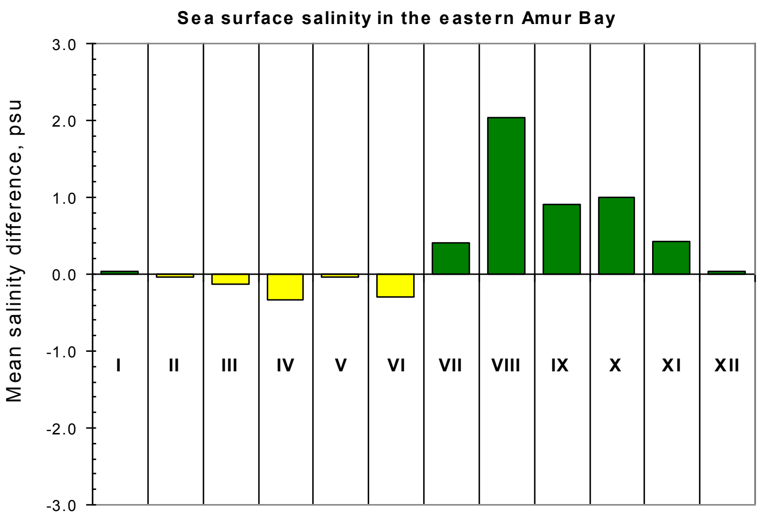
The eastern (marine) part of the Amur Bay is more influenced by advective processes, so slight decreasing of salinity in early summer can be conditioned by weakening of summer monsoon.



Comparison of the sea surface salinity change in the Amur Bay with its multiple regressive model:

$$SSS = 0.80\ NPI - 0.009\ Prec + 2.6\ (r^2 = 0.18).$$

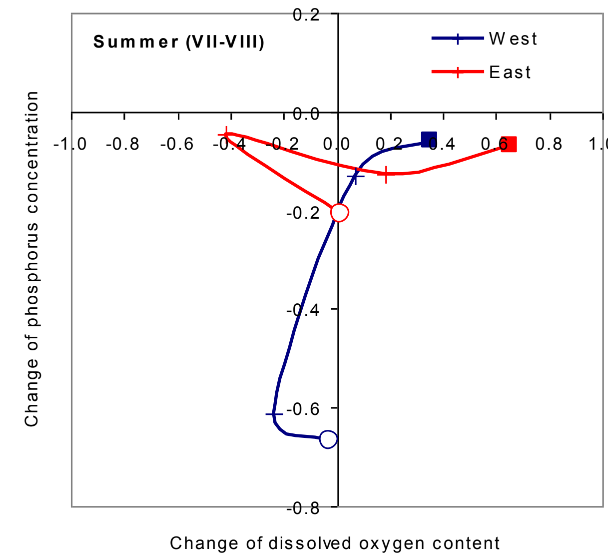
Even after fitting the model to real data, its determination is too low and the real positive trend is not simulated.



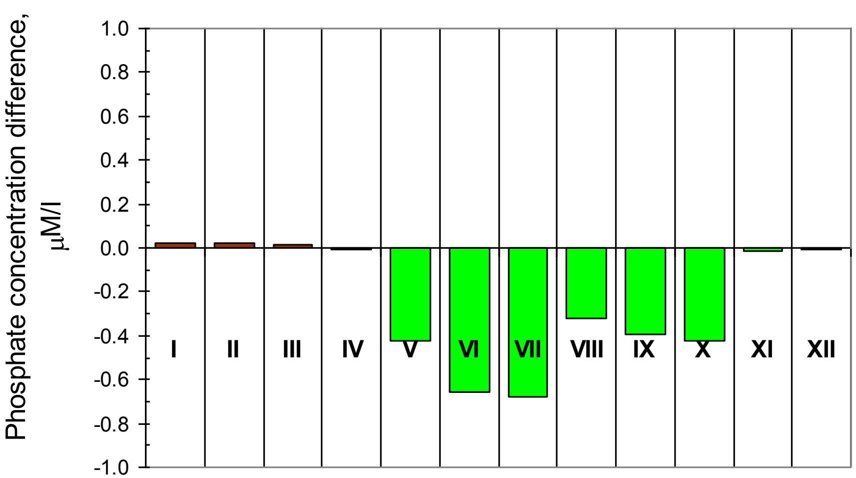
Change of the sea surface salinity in the eastern (marine) part of the Amur Bay between 1980s and 2000s. Slight decreasing in early summer is conditioned by weakening on-shore advection during summer monsoon

Amur Bay: changes in marine chemistry

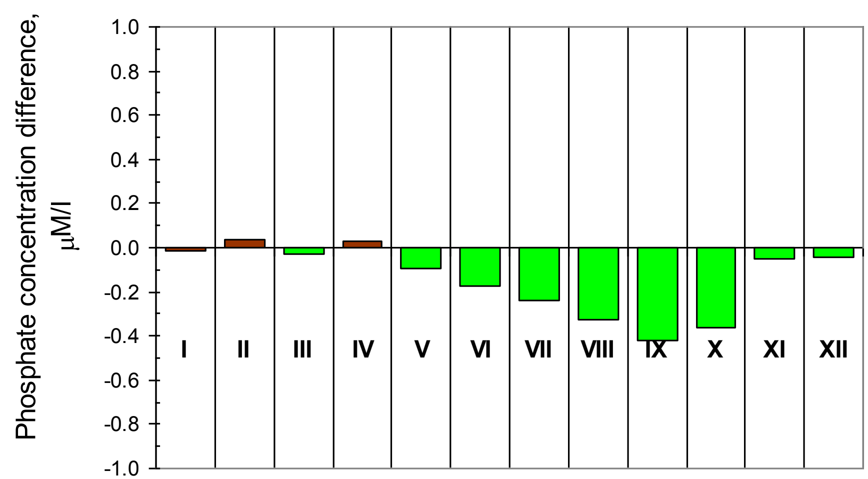
Nutrients concentrations at the sea surface become lower in summer of the 2000s in compare with the 1980s. This lowering corresponds to salinity increasing and is possibly related with weakening of terrestrial water discharge influence on the Amur Bay. Dissolved oxygen content at the sea surface is rather stable.



Phosphate at the sea surface in the western Amur Bay



Phosphate at the sea surface in the eastern Amur Bay

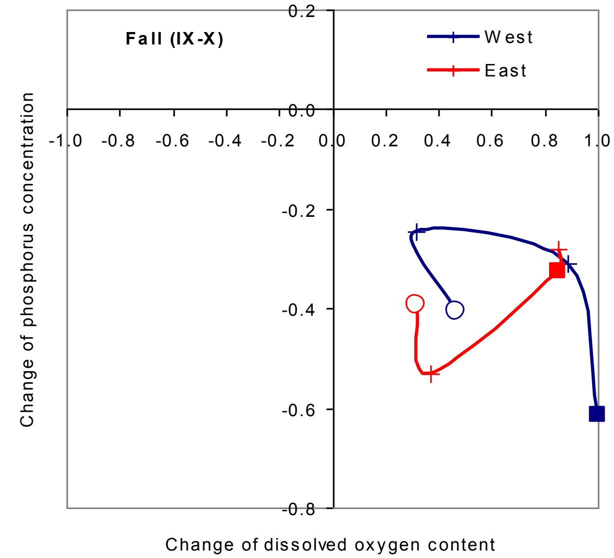


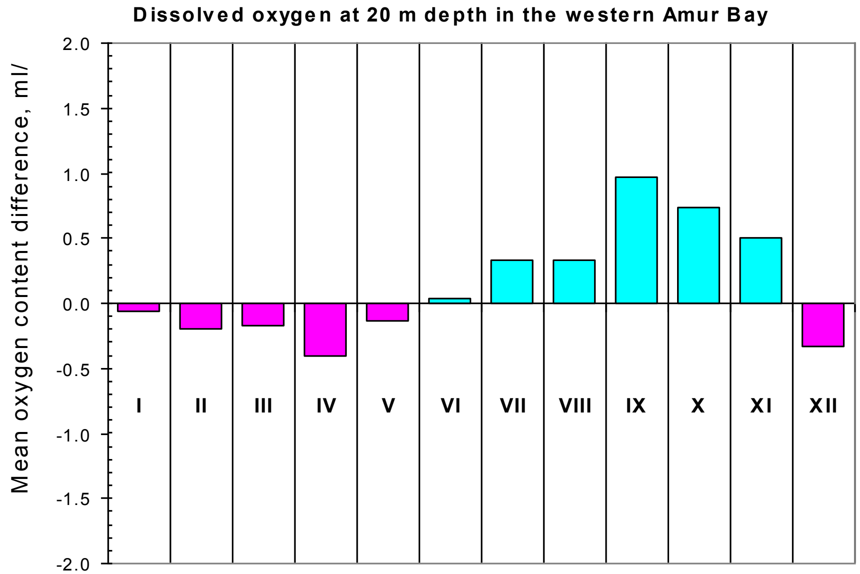
Change of phosphate concentration at the Amur Bay surface between 1980s and 2000s. In summer the concentration becomes lower everywhere, that can be related with weakening of terrestrial influence

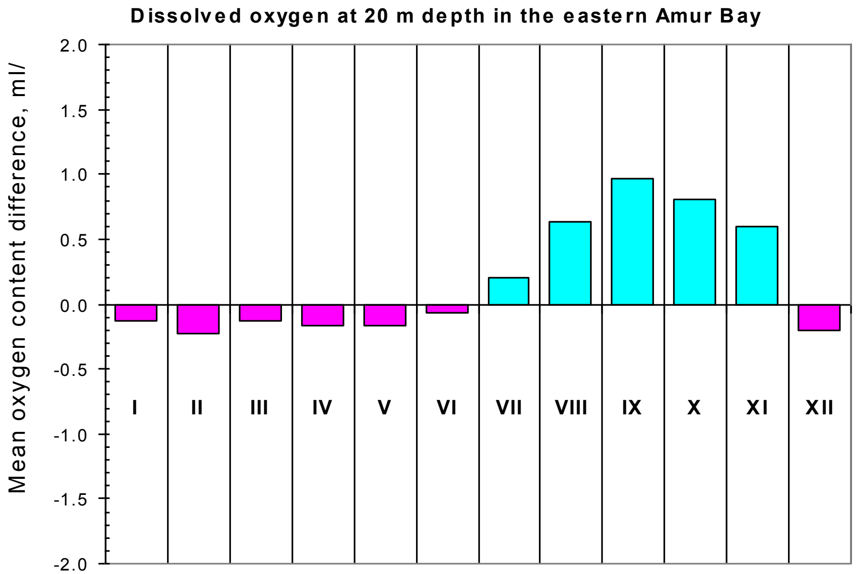
Amur Bay: changes in marine chemistry

At the sea bottom, nutrients don't have significant changes between 1980s and 2000s, but dissolved oxygen content became higher, in particular in fall months.

The oxygen content heightening at the sea bottom is the sigh of lowering productivity, because the oxygen is consumed during mineralization of organics.



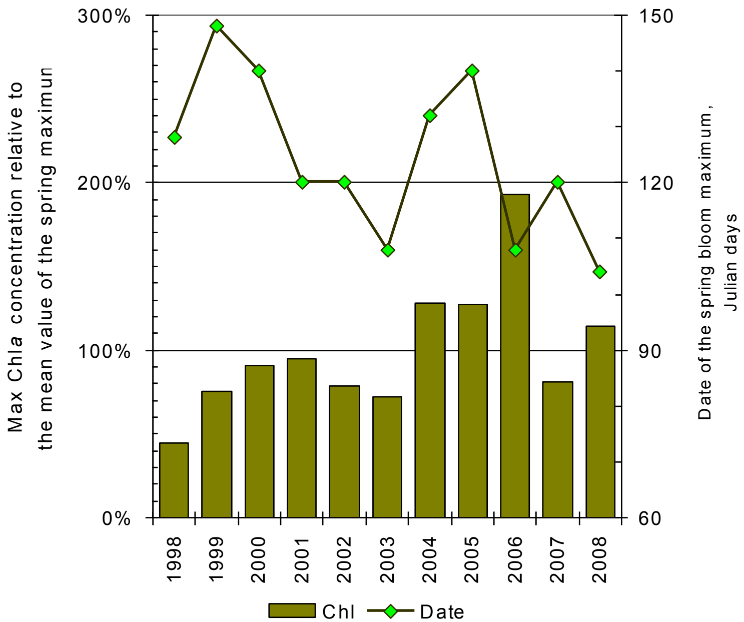




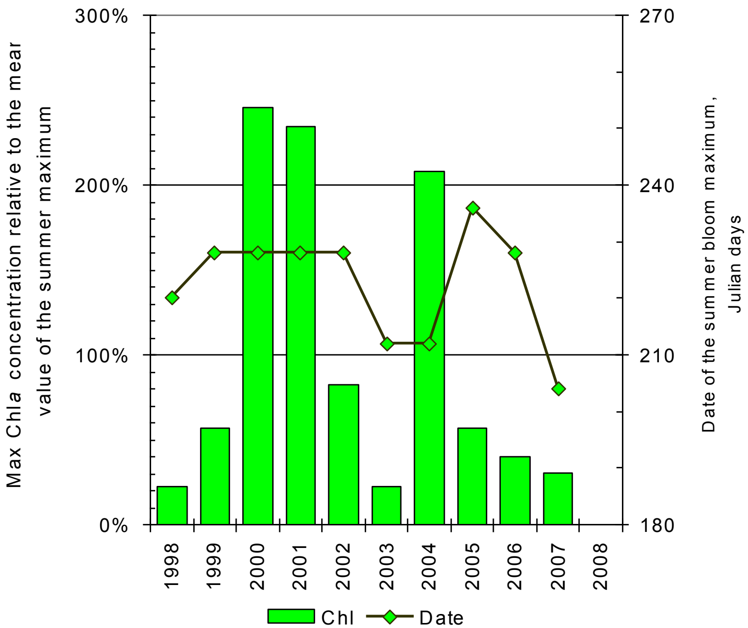
Change of dissolved oxygen content at the Amur Bay bottom between 1980s and 2000s. In summer-fall the content becomes higher everywhere, that corresponds to decreasing of nutrients concentration and can be related with weakening of terrestrial influence

Amur Bay: changes in phytoplankton

Phytoplankton abundance can be characterized by Chl *a* concentration – satellite data (scanner SeaWiFS) are available since 1998. During the last decade, spring bloom becomes earlier and stronger and summer bloom has no any significant tendencies. Possibly the timing of summer bloom was earlier in the 1980s (late July in the 1980s but August in the 2000s) (Zuenko, 2012)



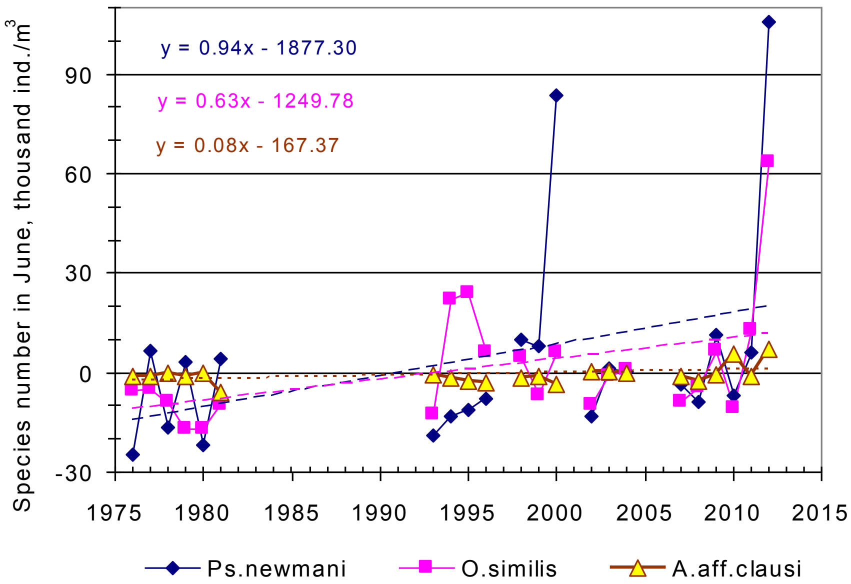
Year-to-year changes of strength and date of the spring bloom in the southern Amur Bay



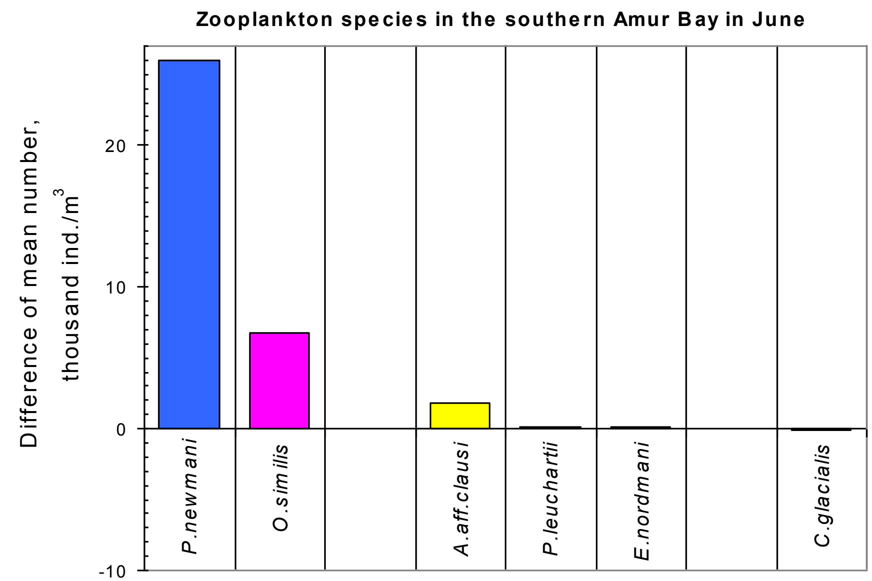
Year-to-year changes of strength and date of the summer bloom in the southern Amur Bay

Amur Bay: changes in zooplankton

Copepods *Pseudicalanus newmani, Oithona similis*, and *Acartia aff. clausi* dominate in zooplankton of the Amur Bay; another numerous group is Cladocera (mostly *Evadne nordmani* and *Podon leuchartii*). All these mass species have a tendency to increase their number; their year-to-year also have some similarity, though the most numerous species *P.newmani* has extremely high abundance in some years.



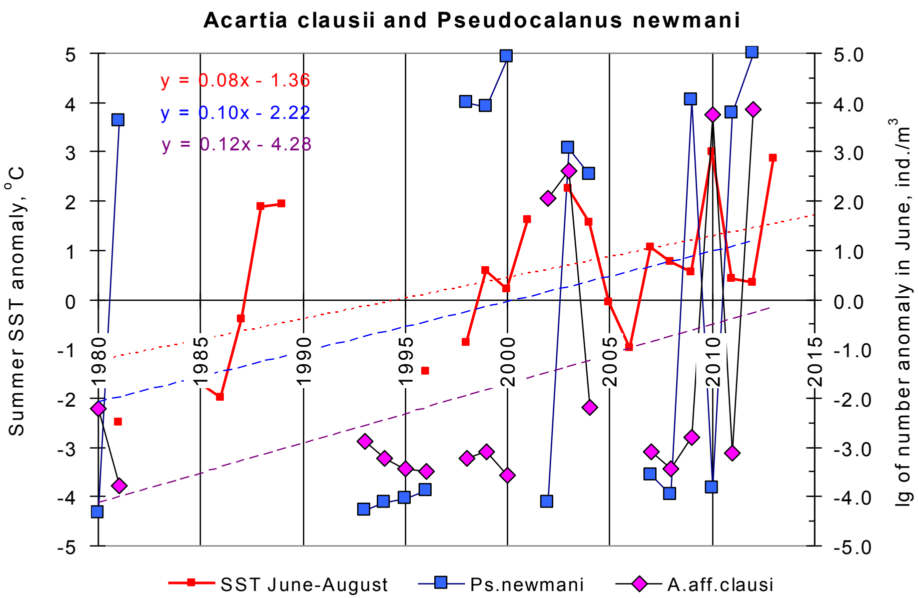
Year-to-year changes of mass zooplankton species number in the Amur Bay in June

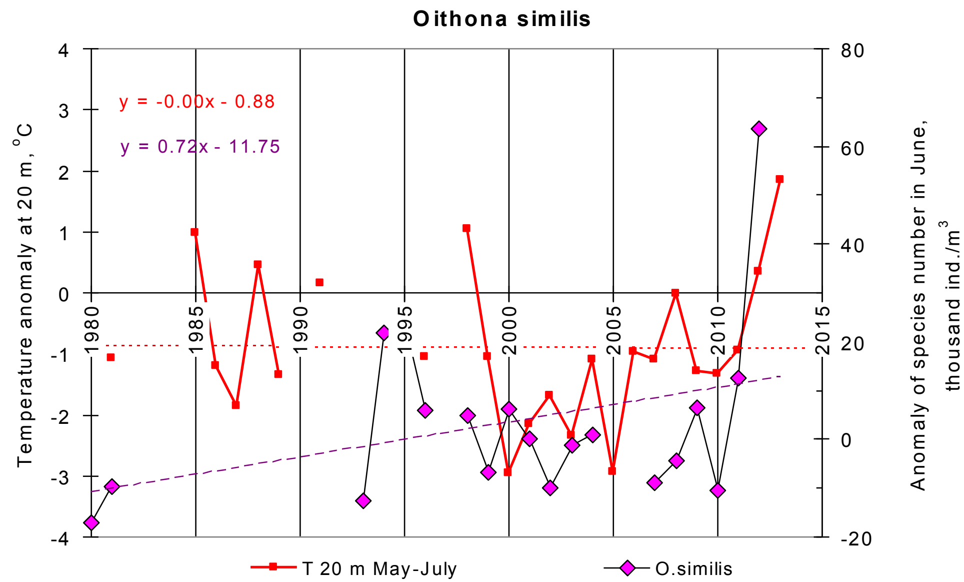


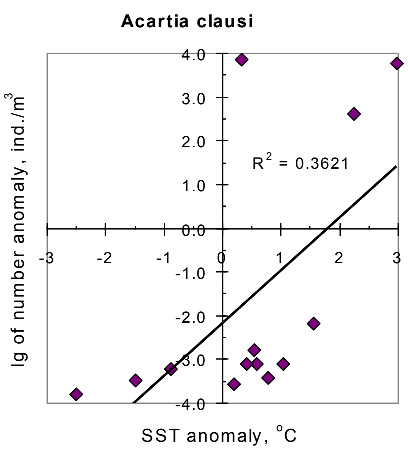
Change of mass zooplankton species number in the Amur Bay between 1980s and 2000s

Amur Bay: changes in zooplankton

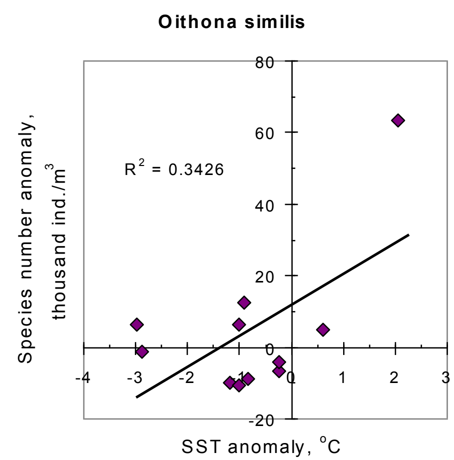
Those great blooms of *P.newmani* cannot be explained by any environmental process, maybe they have some biological nature – this species biology is still poorly known.
Moderate fluctuations of *O.similis* and *A.clausi* have some relationships with temperature changes, and their positive trends coincide with warming tendency. However, we still have no idea why water heating (but salinity increasing and nutrients decreasing) is good for copepods.







Year-to-year changes of A.clausi and P.newmani abundance in June and dependence of A.clausi number on summer SST



Year-to-year changes of O.similis abundance in June and dependence of its number on summer SST

Advances:

Climatic changes are determined:

- Warming the surface layer in summer and fall
- Cooling of bottom layer in summer, but warming in fall
- Salinity heightening at the sea surface in summer
- Nutrients decreasing at the sea surface in summer-fall
- Oxygen increasing at the sea bottom in summer-fall
- Zoplankton abundance increasing

Long-term and year-to-year changes are mostly similar for entire coastal zone, including pre-estuarine areas

Salinity and nutrients values in coastal zone, and even In pre-estuarine zone don't depend directly on river run-off (precipitations)

Salinity in coastal zone is influenced by summer monsoon strength: strong monsoon causes extremes of salinity

All mass zooplankton species have similar changes and tendency to increasing of their abundance

Failures:

Almost all found trends are not statistically significant (except of warming) because of high year-to-year variability

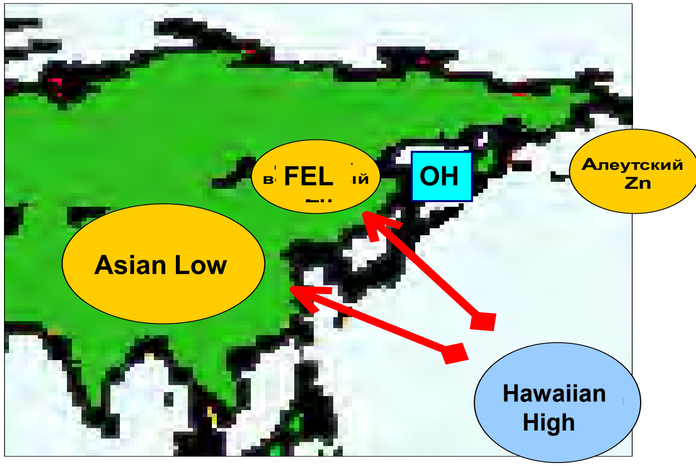
Mechanisms of variability are not clear yet for almost all parameters

What do they depend on?

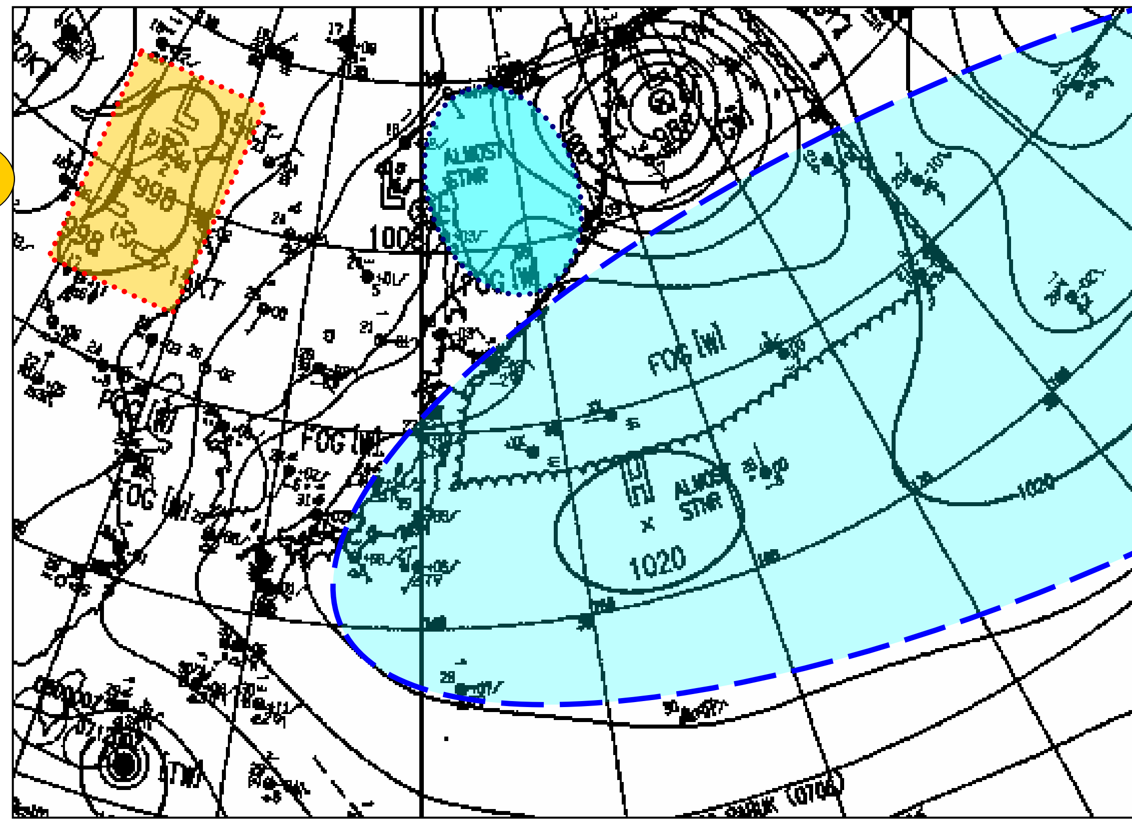
There is no atmospheric index that describes well the summer monsoon strength for the Japan/East Sea

Mechanisms of their variability and reasons of increasing are not clear yet, maybe they have a biological nature, but biology and life cycles of small neritic species are poorly known

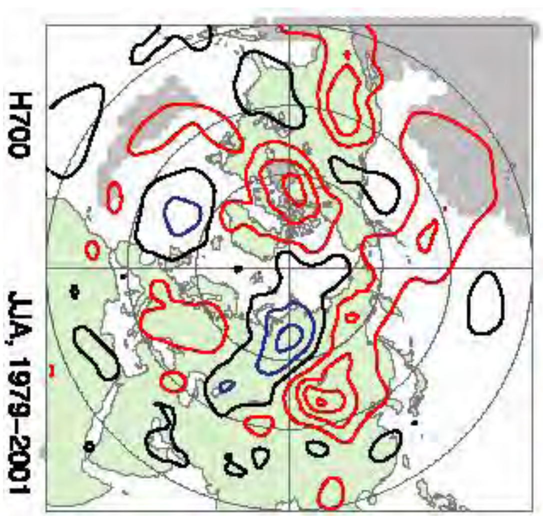
Comments on summer monsoon indices:



FEL = Far Eastern Low
OH = Okhotsk Sea High



Schematic and real (August 7, 2007) arrangement of the atmosphere centers: Hawaiian High, Okhotsk Sea High, Far-Eastern Low, Asian Low



Changes of the H700 hPa height from 1979 to 2001 (Trenberth et al., 2007).
(red isolines – heightening, blue isolines – lowering)
Far Eastern Low becomes weaker, while almost no changes in the Asian Low area