# Year-to-year changes of pre-winter environmental conditions and chlorophyll-*a* concentration in the central and southern Japan Sea

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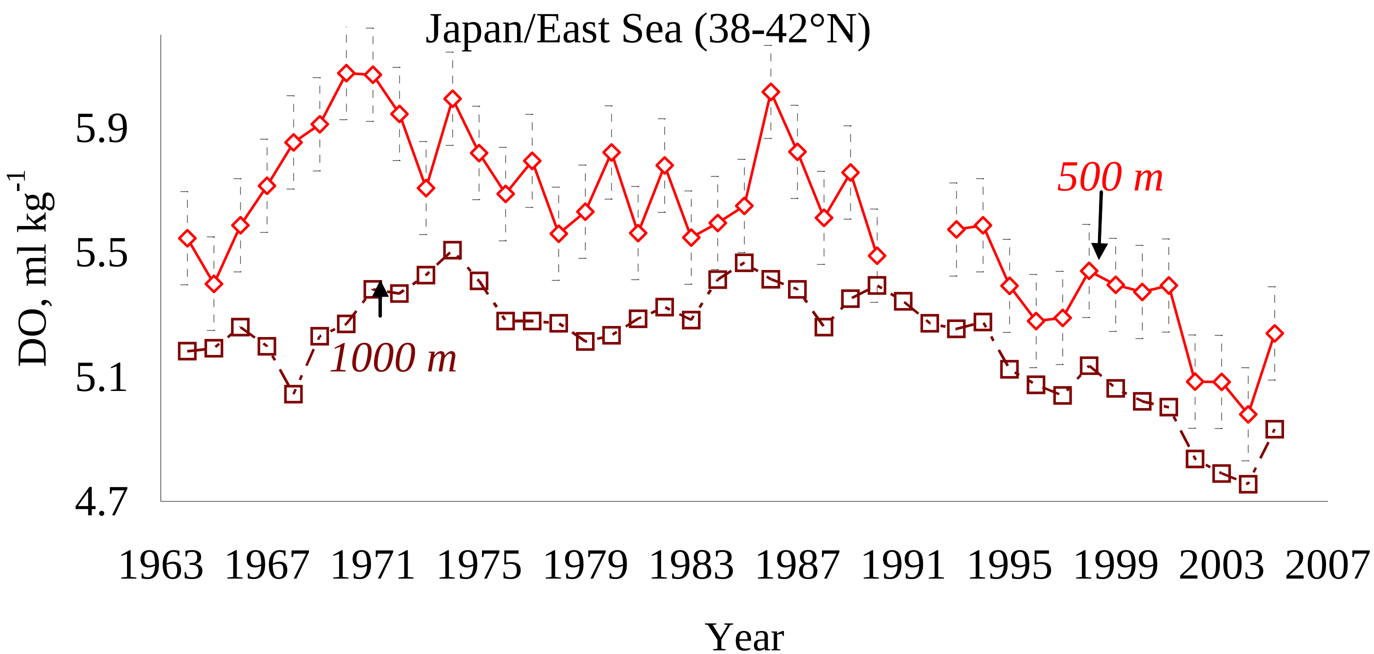
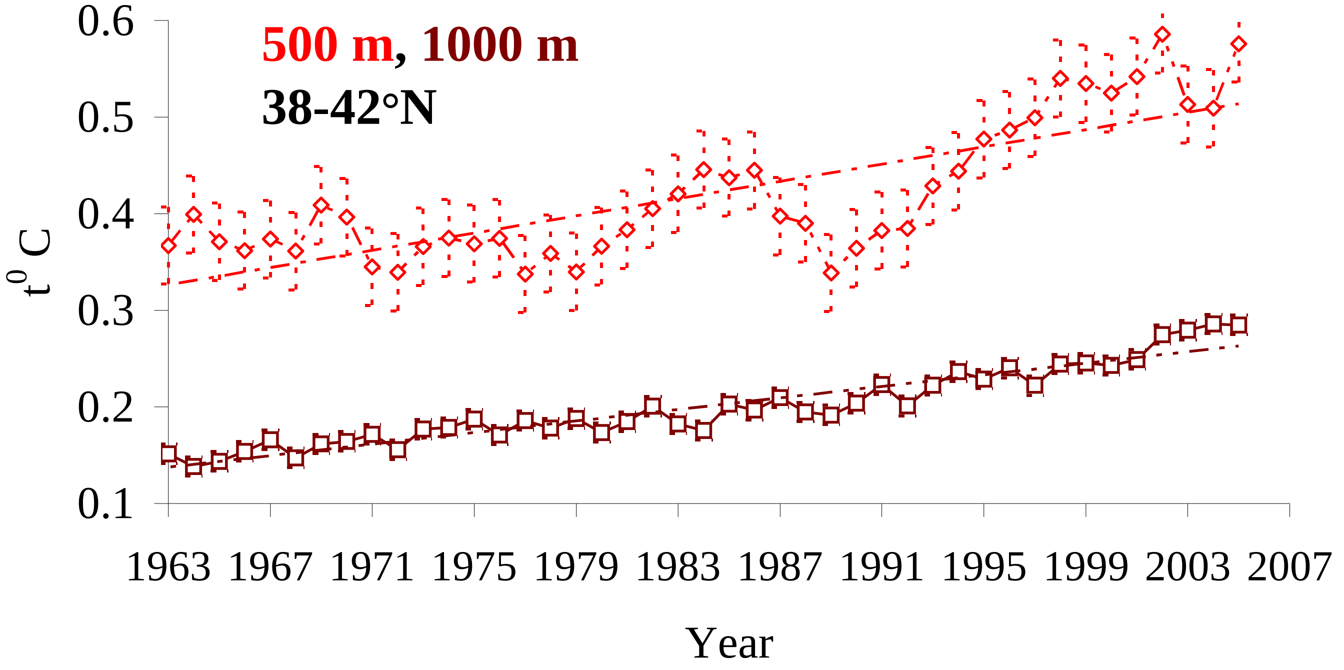
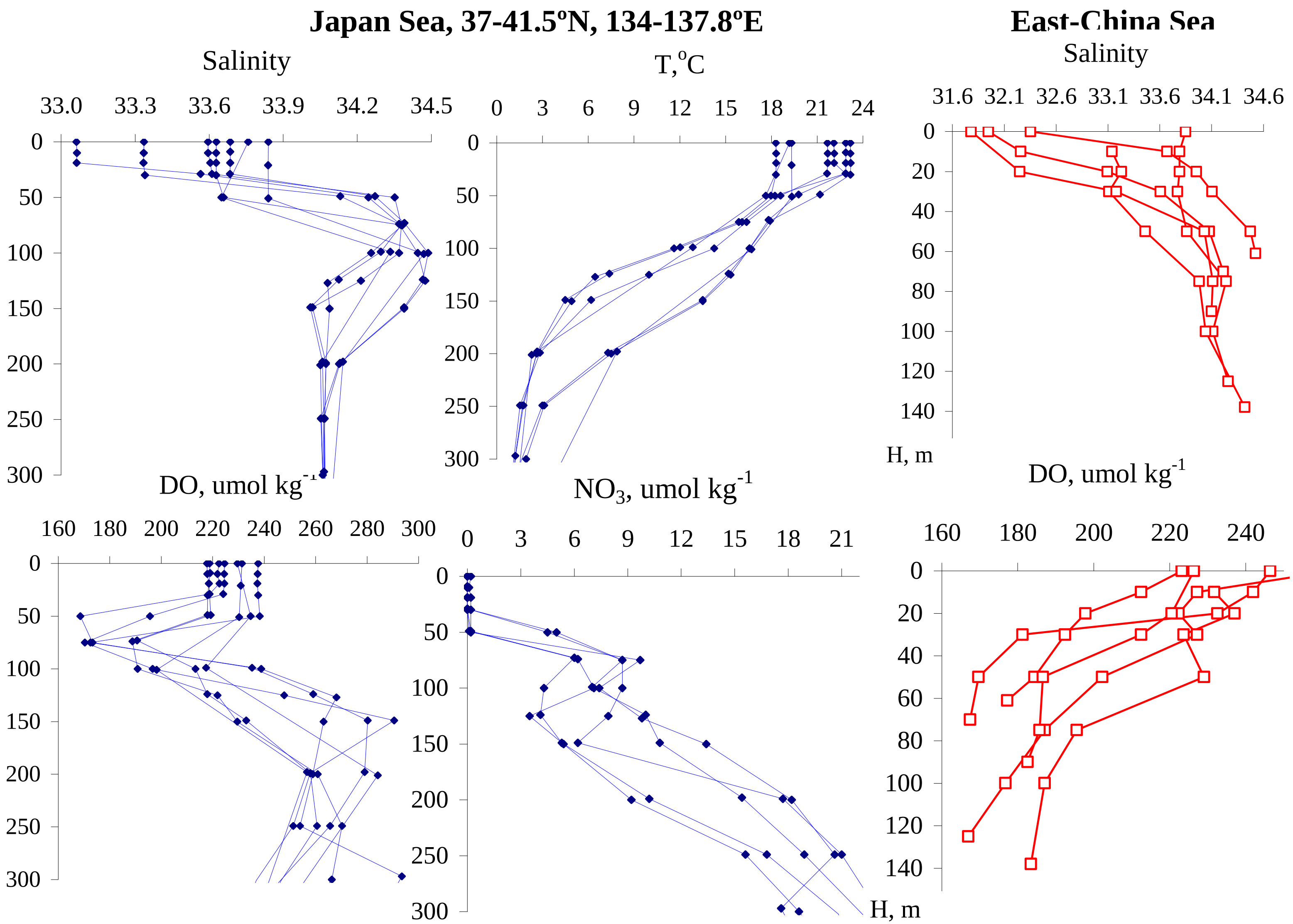
We studied temporal changes of physical and chemical environments (temperature, salinity, dissolved oxygen, nutrients) and chlorophyll-*a* concentration (Chl-*a*) in the central and southern Japan (or East) Sea (JES) in relation to the ocean climate variability. Our results demonstrate that the East China Sea (ECS) water transport through the Tsushima (or Korea) Strait is responsible for the year-to-year changes of the temperature, salinity, chemical parameters and Chl-*a* in the surface waters of the Japan Sea in fall. Enhanced water volume transport through the Tsushima Strait led to the dissolved oxygen (DO) depletion and increased stratification in the surface layer in pre-winter season is one of main reasons of the reducing DO and rising temperature in the intermediate and deep layers of the JES. Between 1978 and 2008 there was a tendency to decreased Chl-*a* at horizon of 50 m and increased Chl-*a* in the 0-30 m layer. The observed tendency in Chl-*a* vertical distribution and rising N:P ratio in the upper layer of JES are more likely to be due to increased inflow of the ECS coastal waters into the JES.



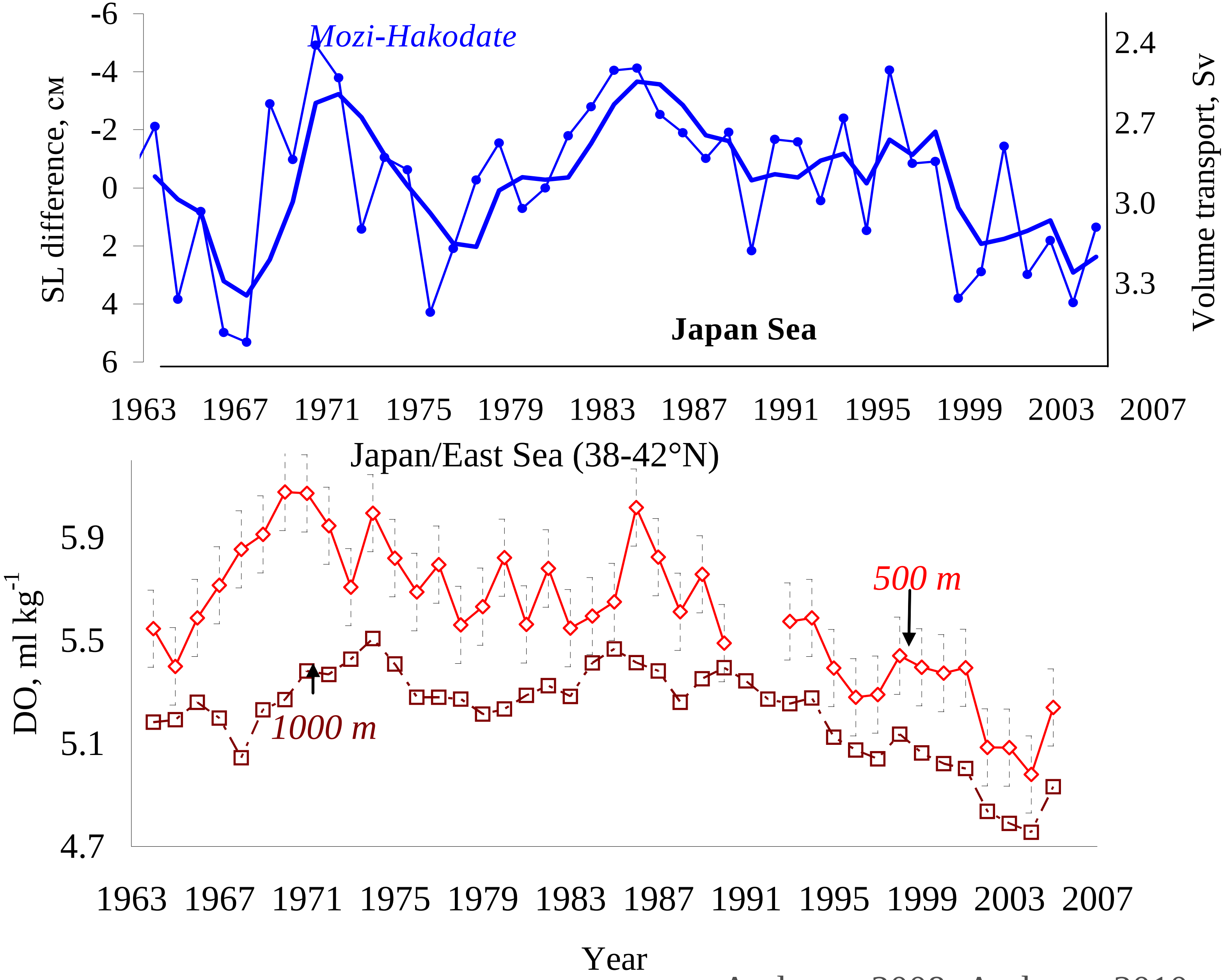
Japan/East Sea (38-42°N)
5.9
5.5
5.1
4.7
DO, ml kg-1
500 m
1000 m
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
Year

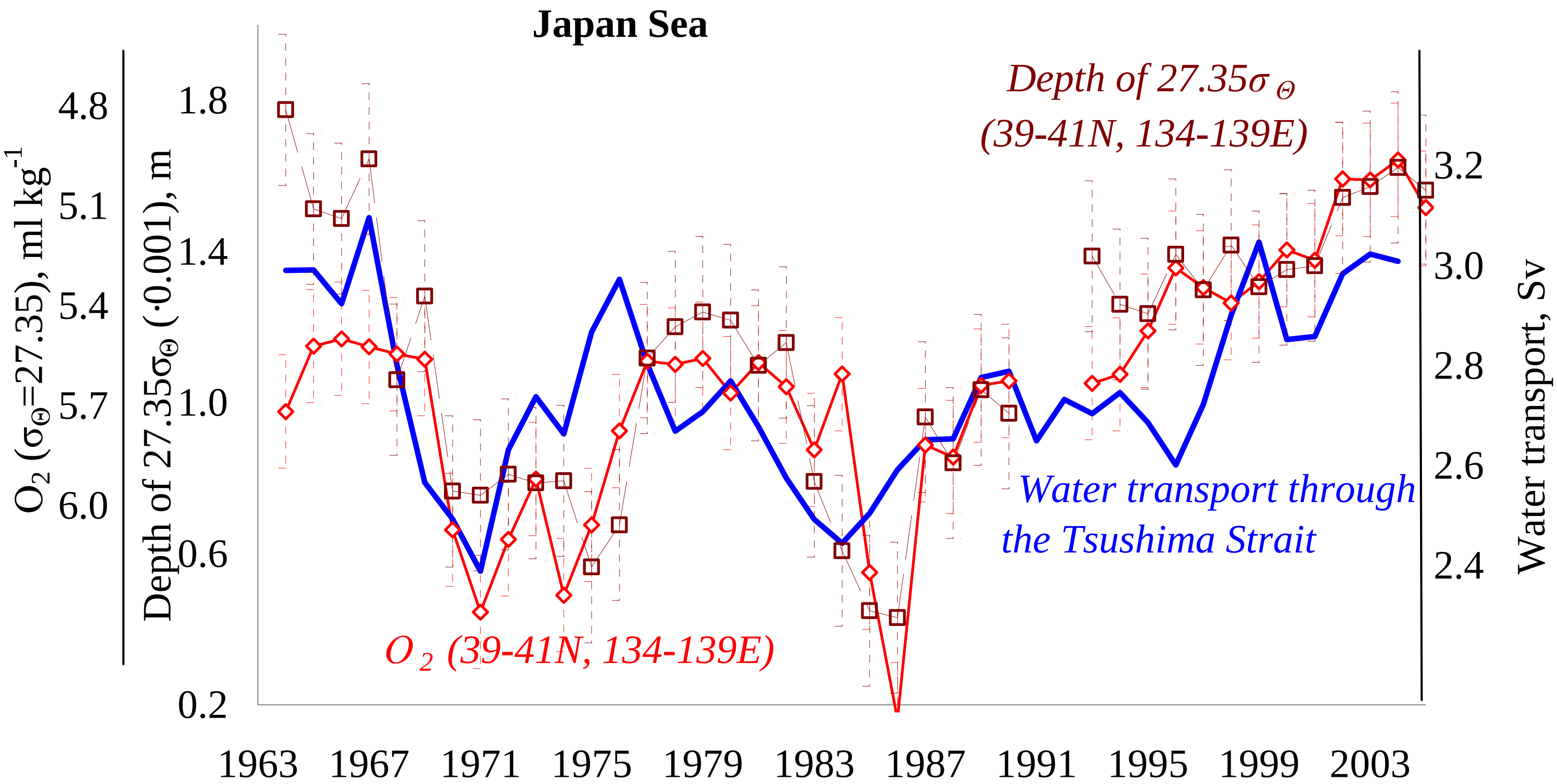
0.6
0.5
0.4
0.3
0.2
0.1
t0 C
500 m, 1000 m
38-42°N
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
Year




In July–October, the East China Sea waters flowing to the Sea of Japan through the Tsushima Strait are characterized by the considerable stratification due to the high temperature and low salinity in the subsurface water layer. In addition to the low-oxygen waters, the dissolved oxygen concentration decrease in the Japan Sea can be caused by the increase in the buoyancy flow from the East China Sea resulting in the stratification intensification and in the ventilation decrease of intermediate and deep waters of the Japan Sea.

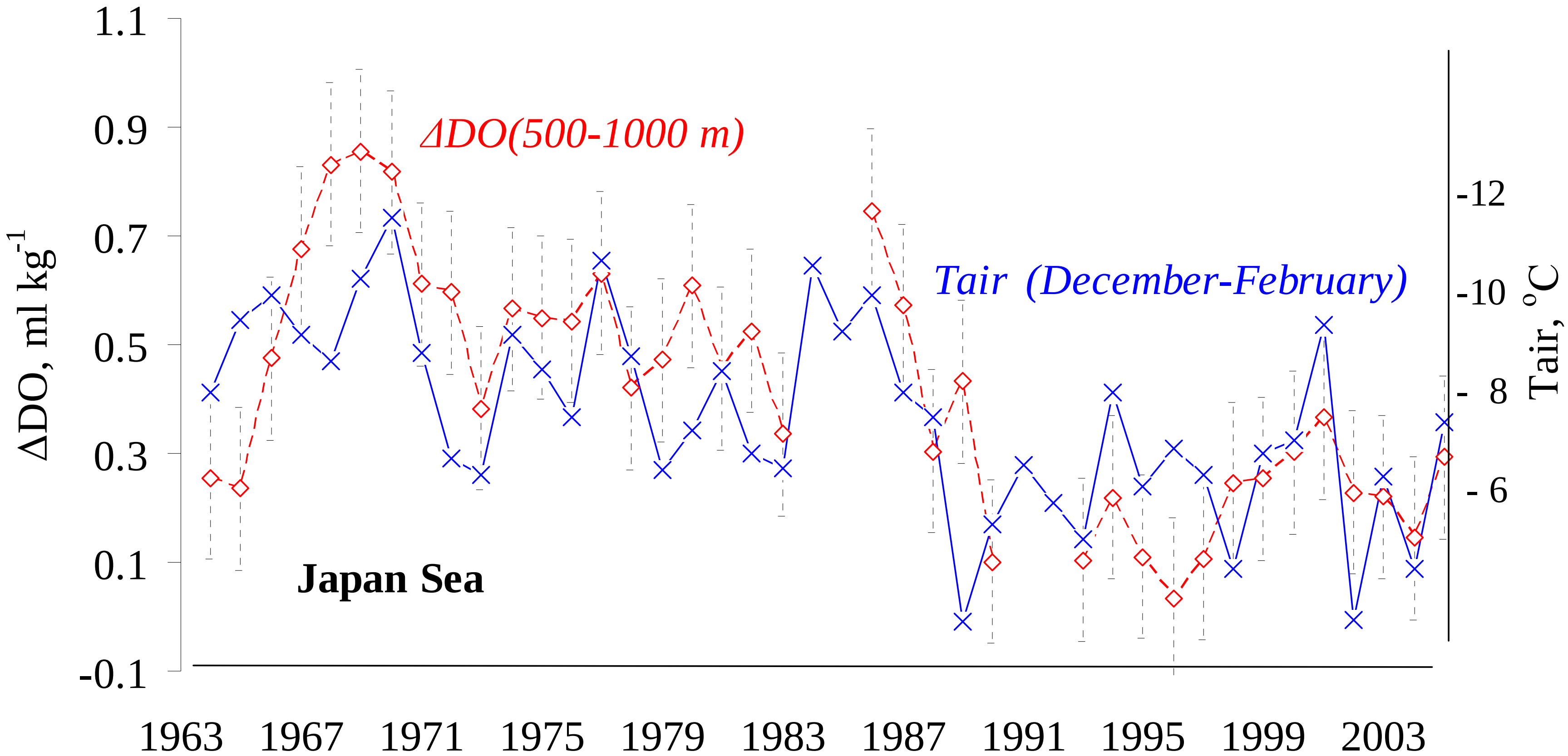



Andreev, 2008; Andreev, 2010

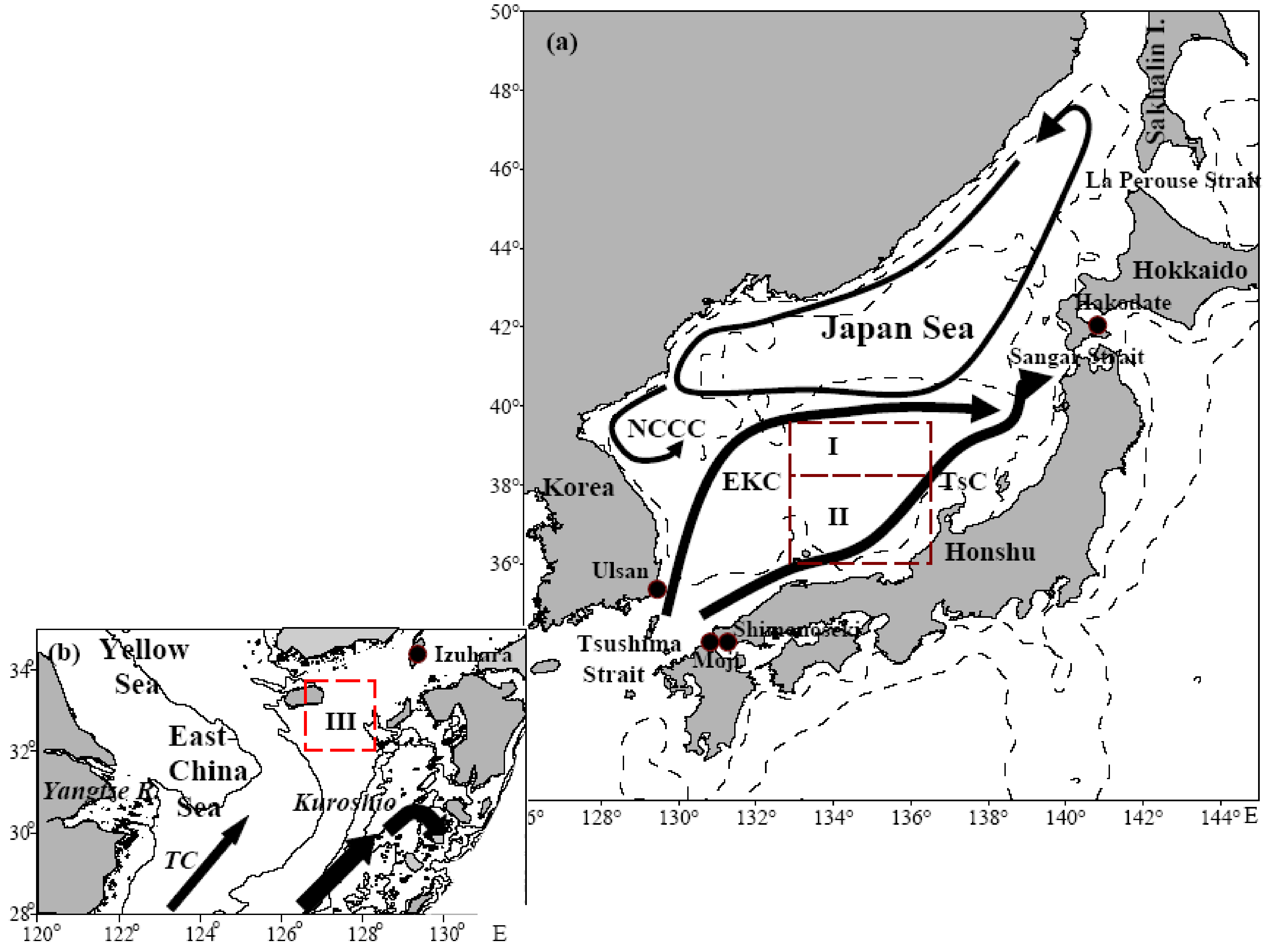



**(1964-2005, r=0.57, r= -0.63)**

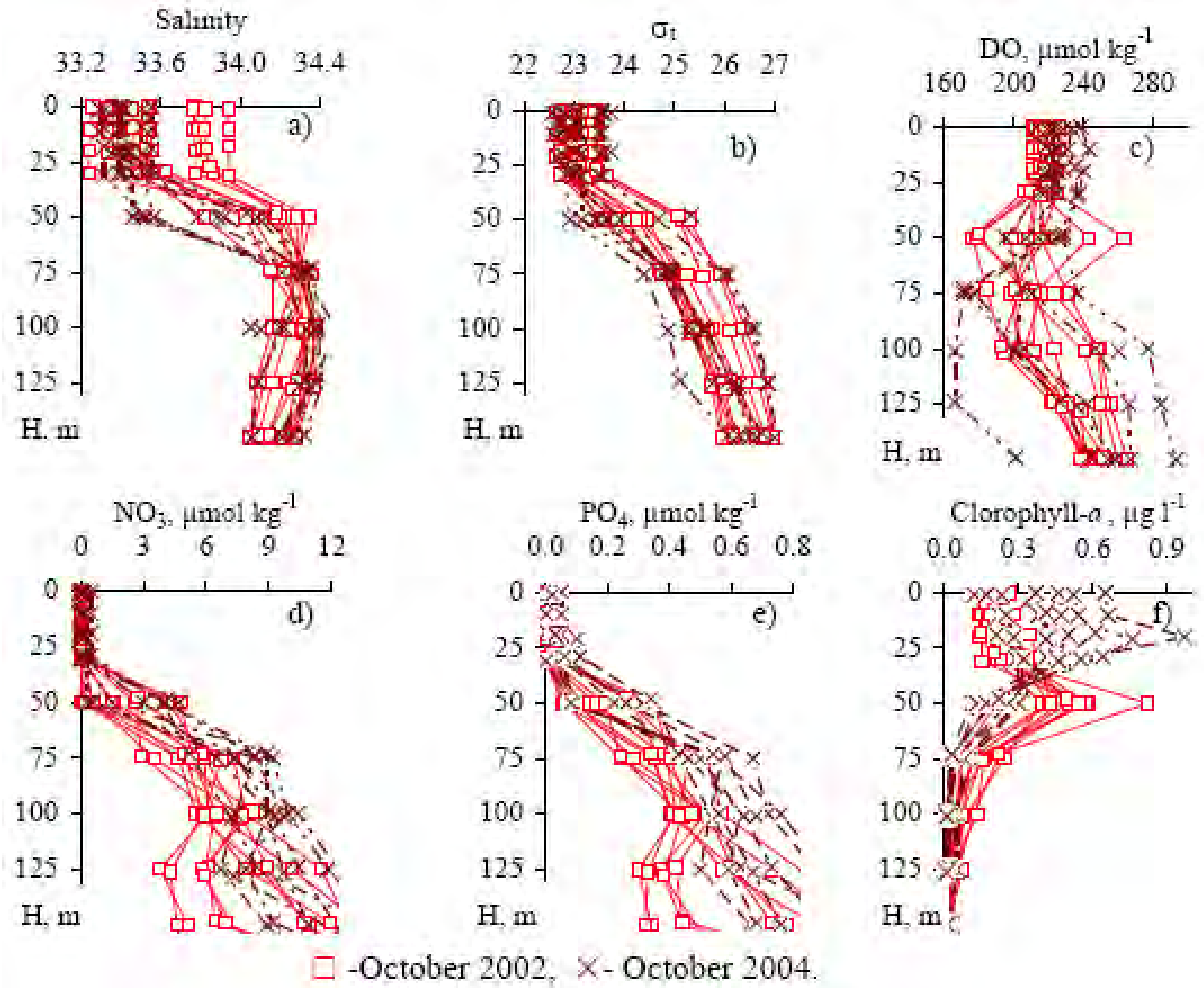
Andreev, 2008; Andreev, 2010



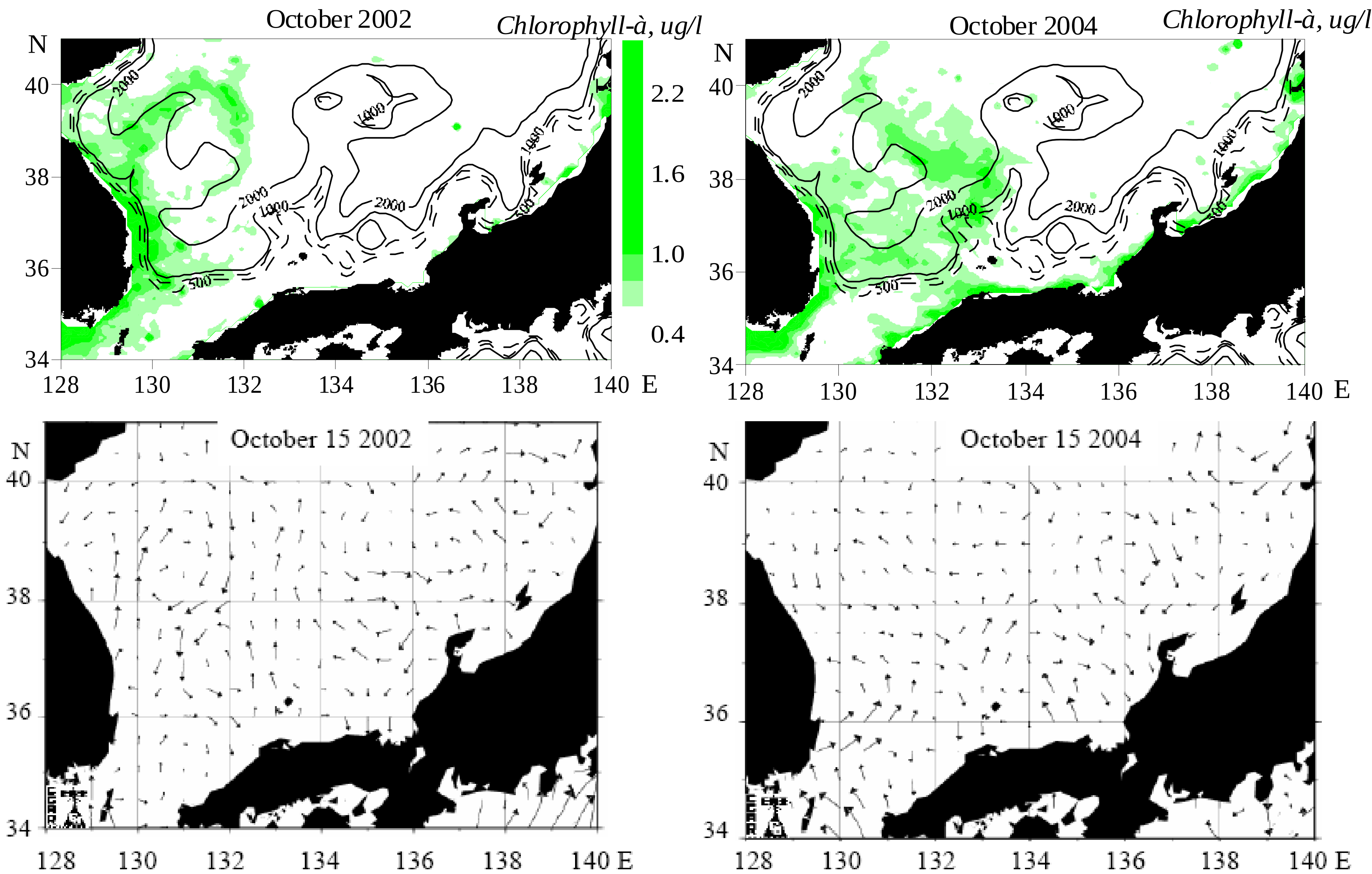

Andreev, 2008; Andreev, 2010



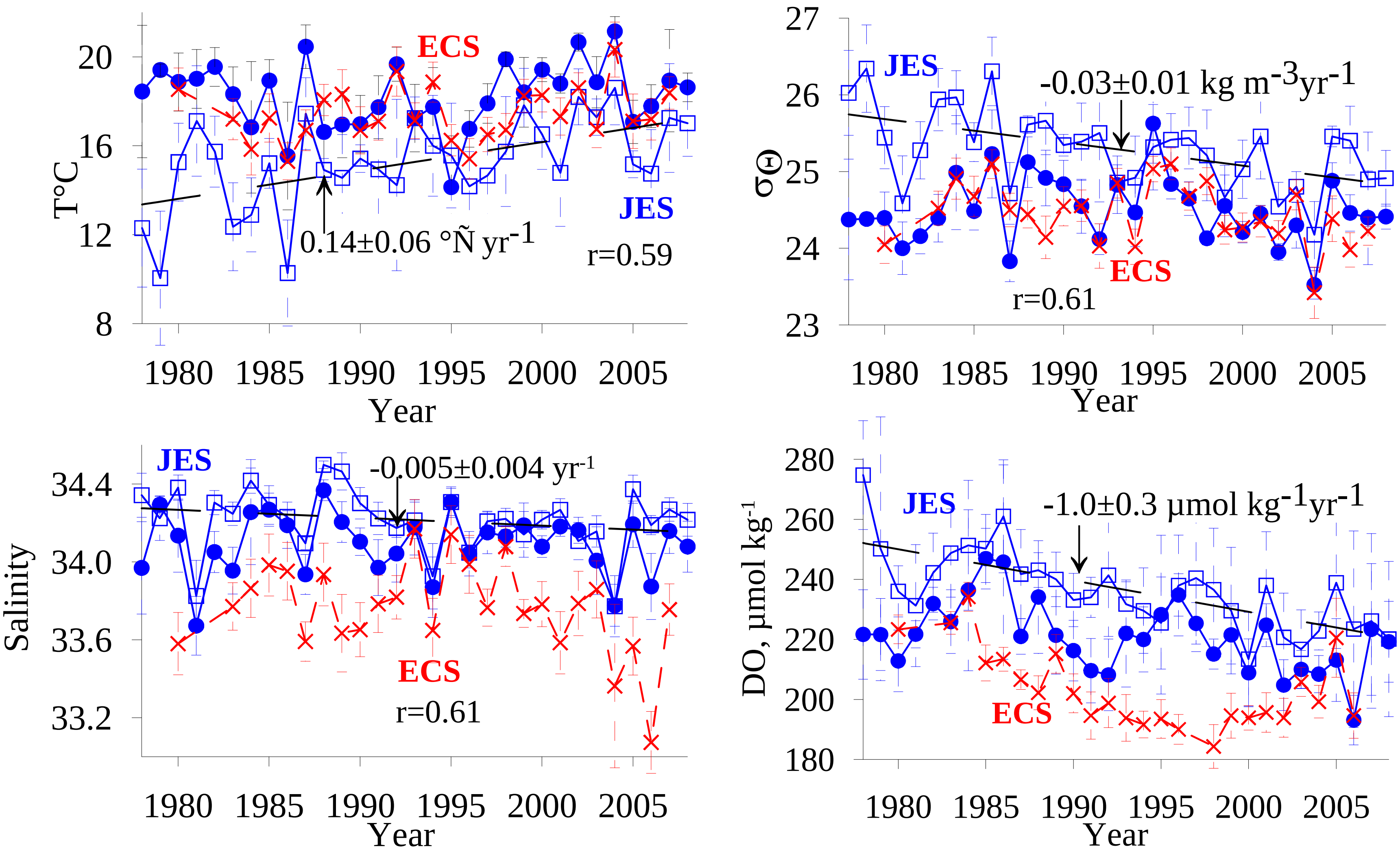
(a)
Sakhalin I.
La Perouse Strait
Hokkaido
Hakodate
Japan Sea
Sangar Strait
NCCC
I
EKC
TsC
Korea
II
Honshu
Ulsan
Tsushima Strait
Moji
Shimonoseki
(b)
Yellow Sea
Izuhara
III
East China Sea
Yangtze R.
Kuroshio
TC



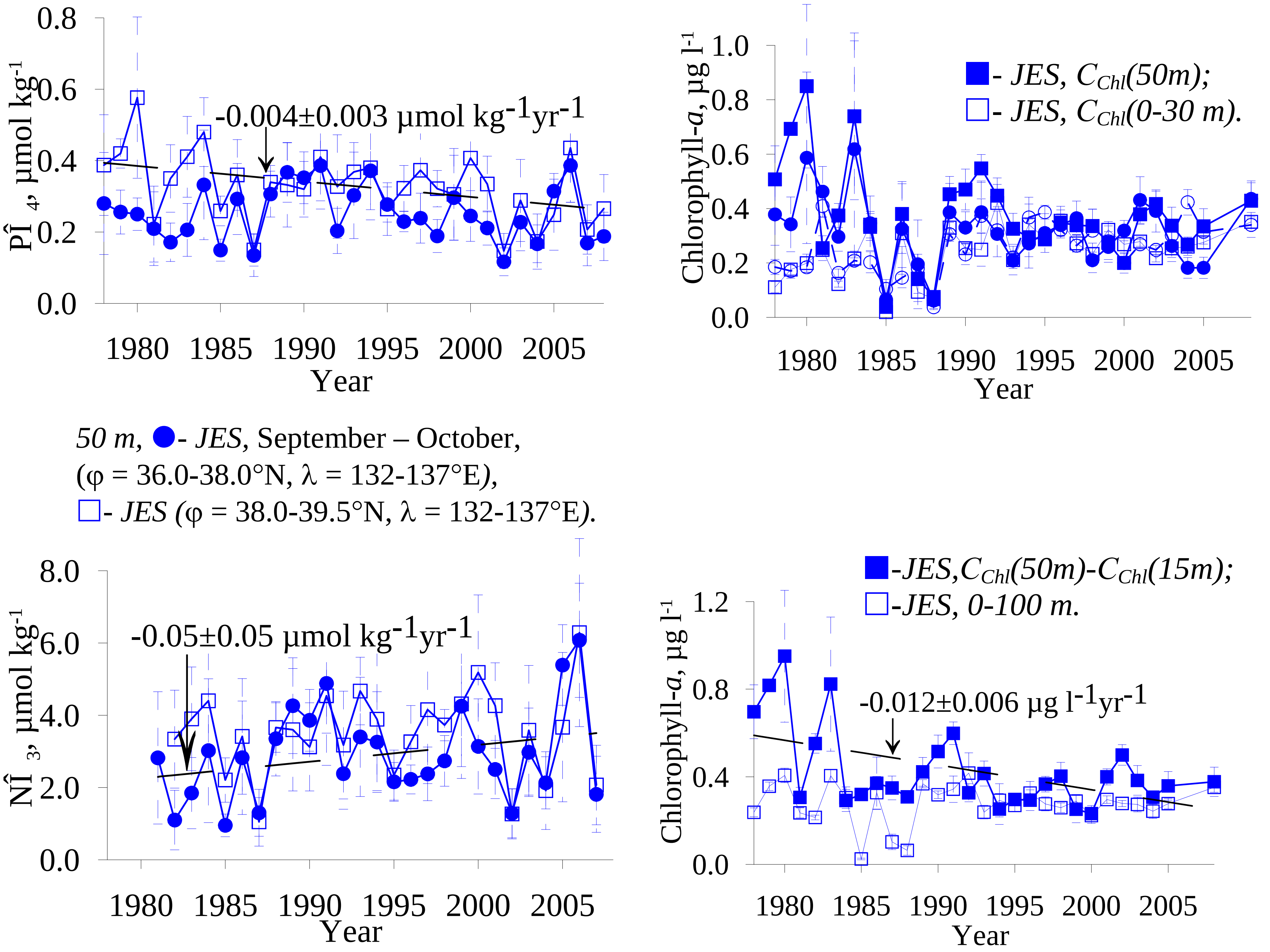

**Vertical distribution of salinity (a), relative density (b), dissolved oxygen (c), nitrate (d), phosphate (e) and chlorophyll (f) concentration in the Japan (East) Sea (36.0-39.5°N, 132-137°E).**



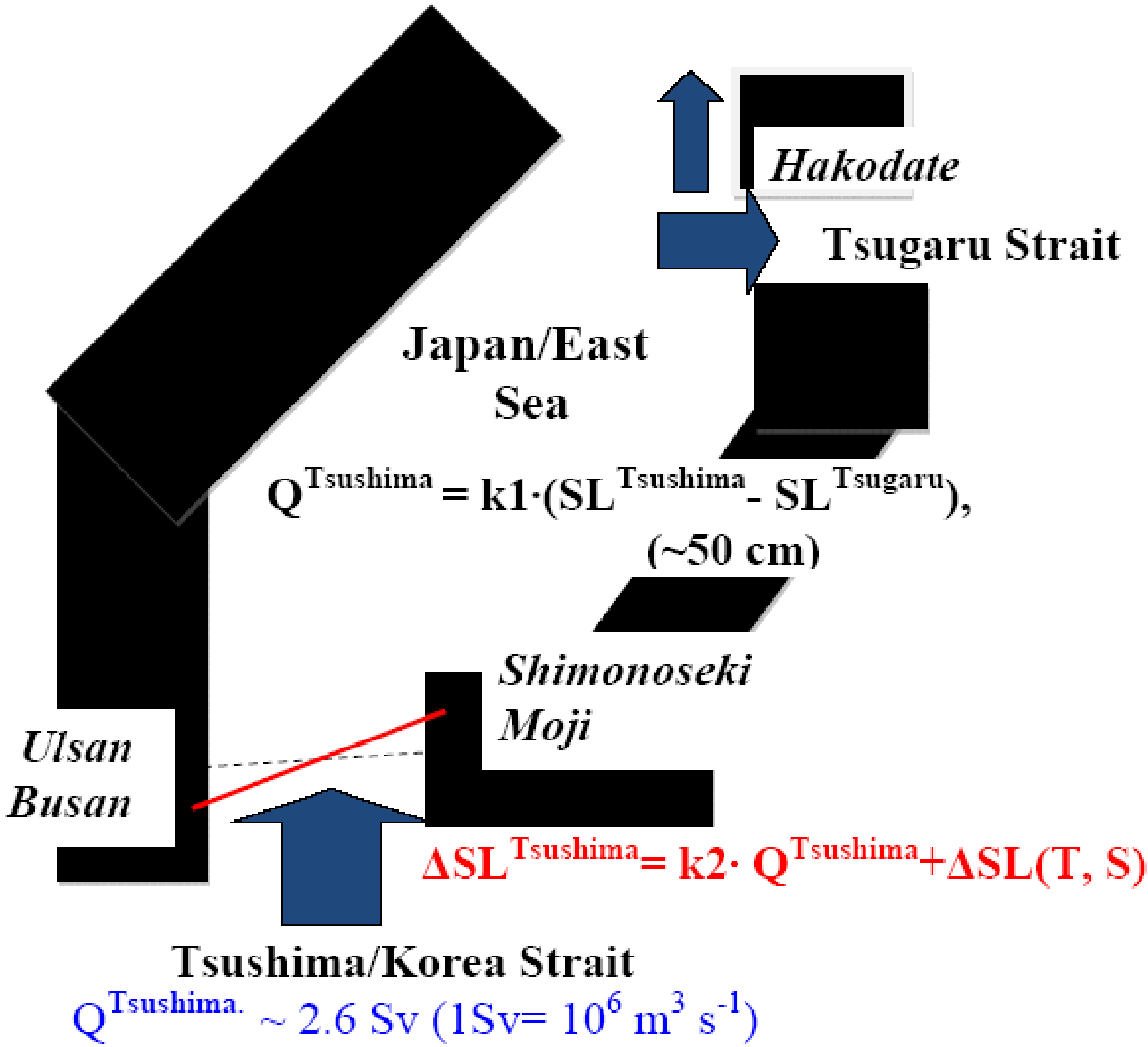

**Monthly composites of the chlorophyll-*a* concentration (SeaWiFS data) and relative geostrophic velocities (http://argo.colorado.edu/~realtime/gifs_tmp/global_vel) for October 2002 and October 2004.**



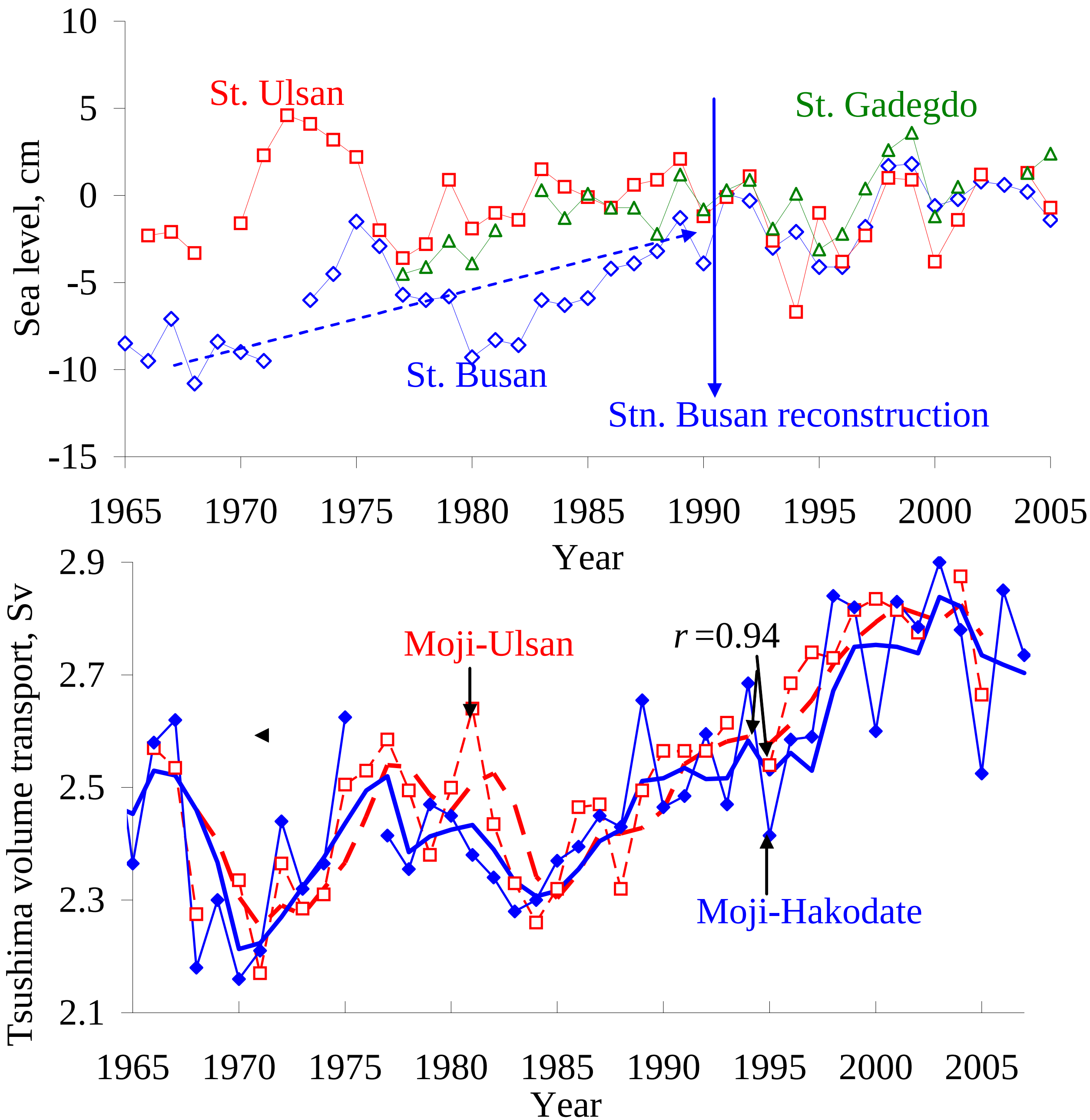

*50 m*, ● - *Jap. Sea*, September – October (φ = 36.0-38.0°N, λ = 132-137°E*)*,
□ - *Jap. Sea (*φ = 38.0-39.5°N, λ = 132-137°E*);*
× - *East- China Sea*, August (φ = 32.0-33.5°N, λ = 126-128°E).

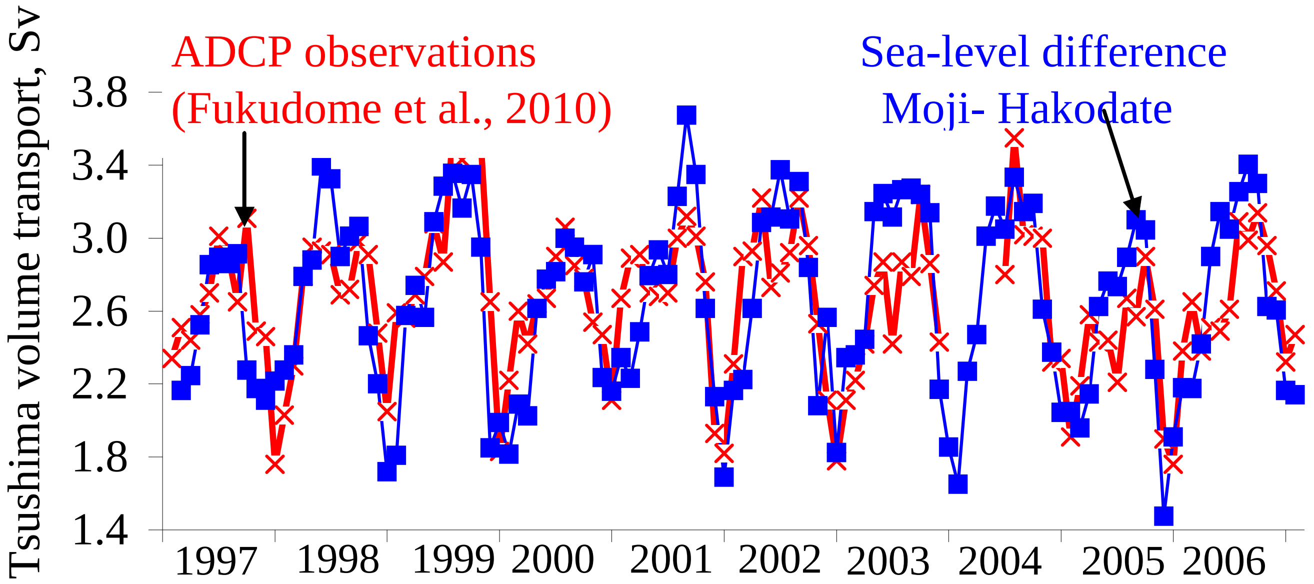


0.8
0.6
0.4
0.2
0.0
PÎ 4, µmol kg-1
-0.004±0.003 µmol kg-1yr-1
1980 1985 1990 1995 2000 2005
Year
1.0
0.8
0.6
0.4
0.2
0.0
Chlorophyll-a, µg l-1
■- JES, C_Chl(50m);
□- JES, C_Chl(0-30 m).
1980 1985 1990 1995 2000 2005
Year
50 m, ●- JES, September – October,
(φ = 36.0-38.0°N, λ = 132-137°E),
□- JES (φ = 38.0-39.5°N, λ = 132-137°E).
8.0
6.0
4.0
2.0
0.0
NÎ 3, µmol kg-1
-0.05±0.05 µmol kg-1yr-1
1980 1985 1990 1995 2000 2005
Year
■-JES,C_Chl(50m)-C_Chl(15m);
□-JES, 0-100 m.
1.2
0.8
0.4
0.0
Chlorophyll-a, µg l-1
-0.012±0.006 µg l-1yr-1
1980 1985 1990 1995 2000 2005
Year



Hakodate
Tsugaru Strait
Japan/East Sea
Q^Tsushima = k1·(SL^Tsushima - SL^Tsugaru),
(~50 cm)
Shimonoseki
Moji
Ulsan
Busan
ΔSL^Tsushima = k2· Q^Tsushima + ΔSL(T, S)
Tsushima/Korea Strait
Q^Tsushima ~ 2.6 Sv (1Sv= 10^6 m^3 s^-1)


St. Ulsan
St. Gadegdo
St. Busan
Stn. Busan reconstruction
Sea level, cm
10
5
0
-5
-10
-15
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
Tsushima volume transport, Sv
2.9
2.7
2.5
2.3
2.1
Moji-Ulsan
r =0.94
Moji-Hakodate
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

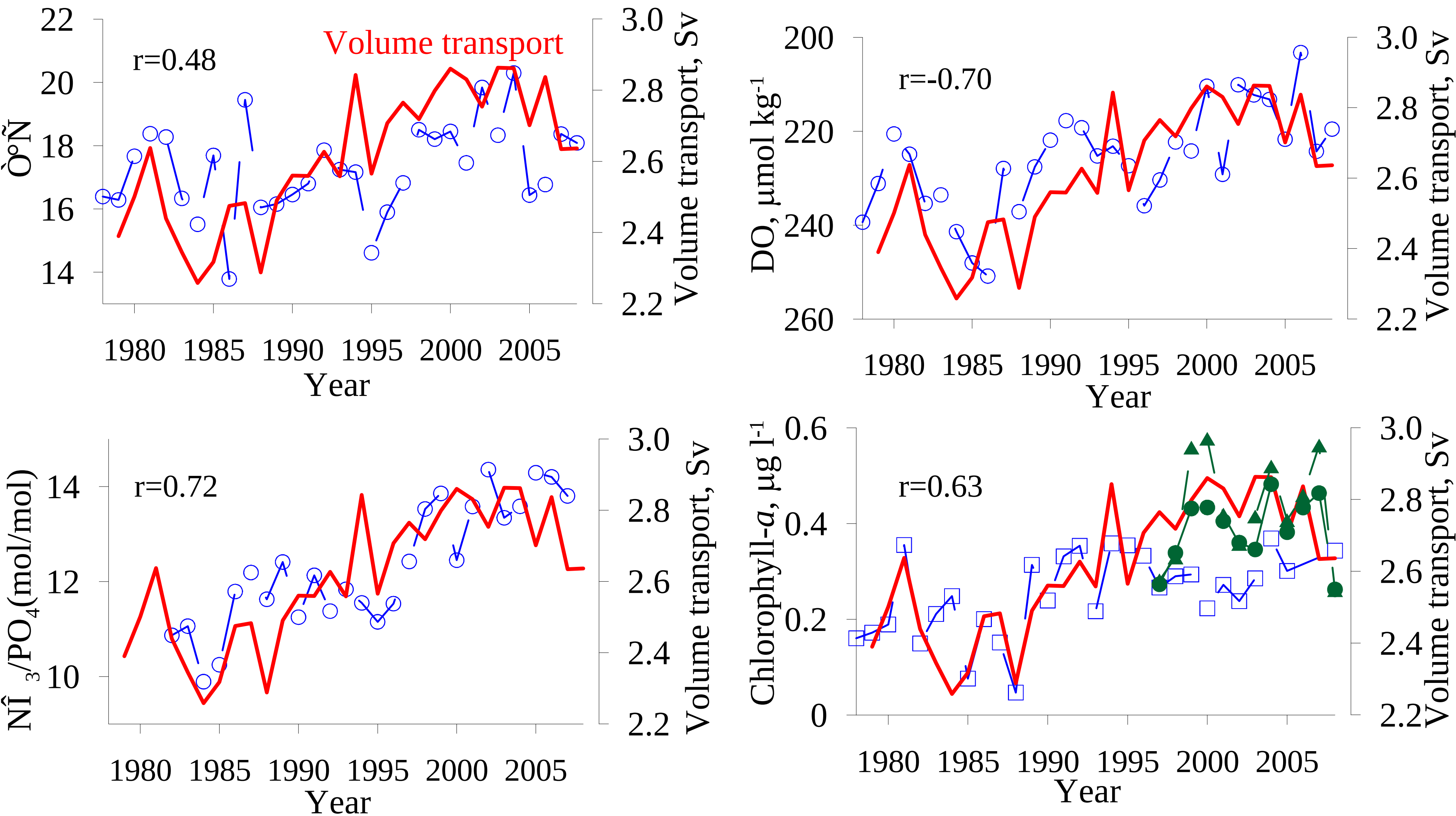



$$Q^{Tsushima} = 0.05 \cdot (SL^{Moji} - SL^{Ulsan}) + 2.94, \quad (1)$$

$$Q^{Tsushima} = 0.05 \cdot (SL^{Moji} - SL^{Hakodate}) + 2.24. \quad (2)$$

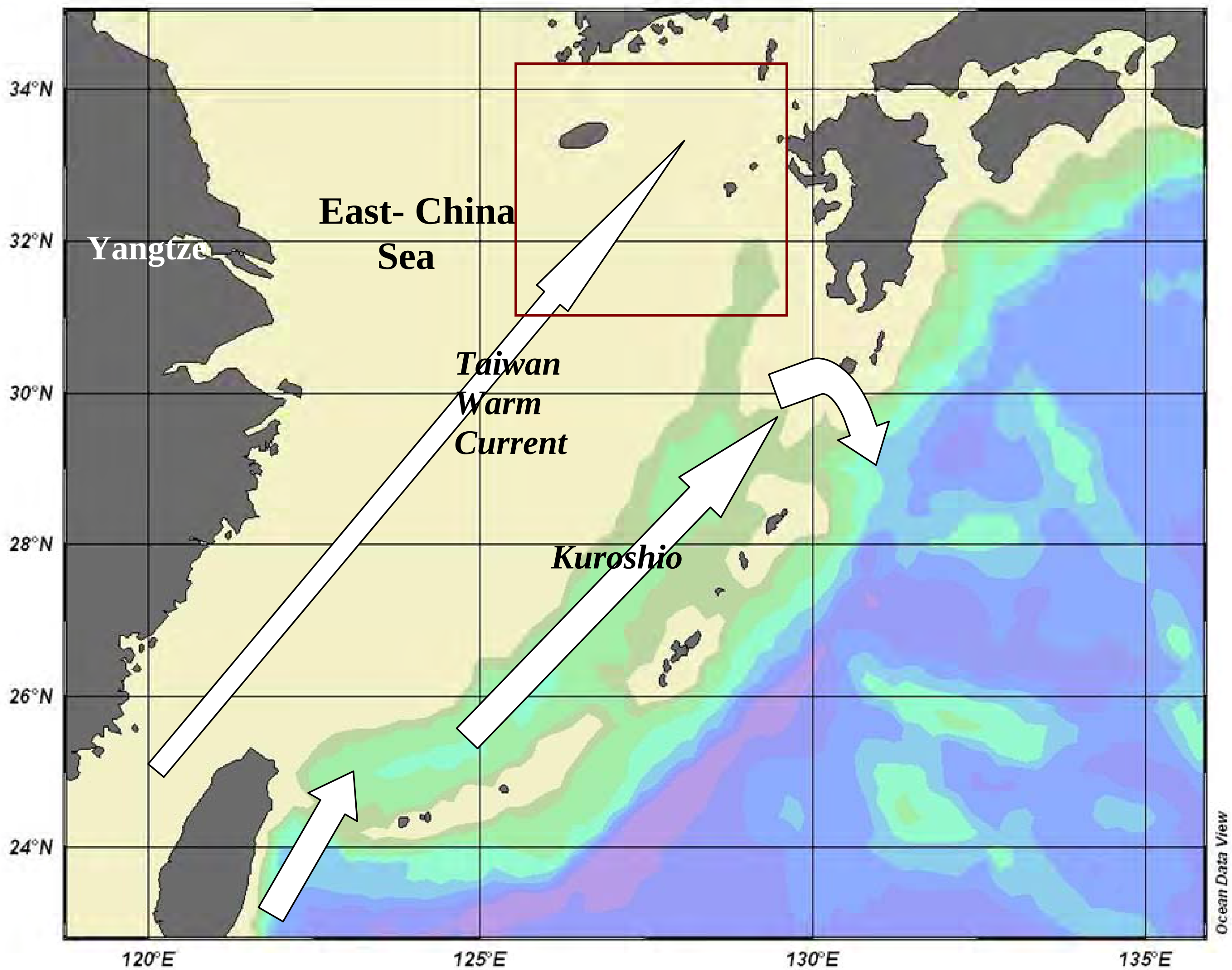
The water volume transport through the western part of the Tsushima Strait ($Q^{WestTsushima}$, Sv) was computed by using the sea level difference between Izuhara (Tsushima Island) and Ulsan stations ($SL^{Izuhara}$-$SL^{Ulsan}$, cm) and ADCP measurements in the western Tsushima channel (Fukudome et al., 2010):

$$Q^{WestTsushima} = 0.05 \cdot (SL^{Izuhara} - SL^{Ulsan}) + 1.65. \quad (3)$$

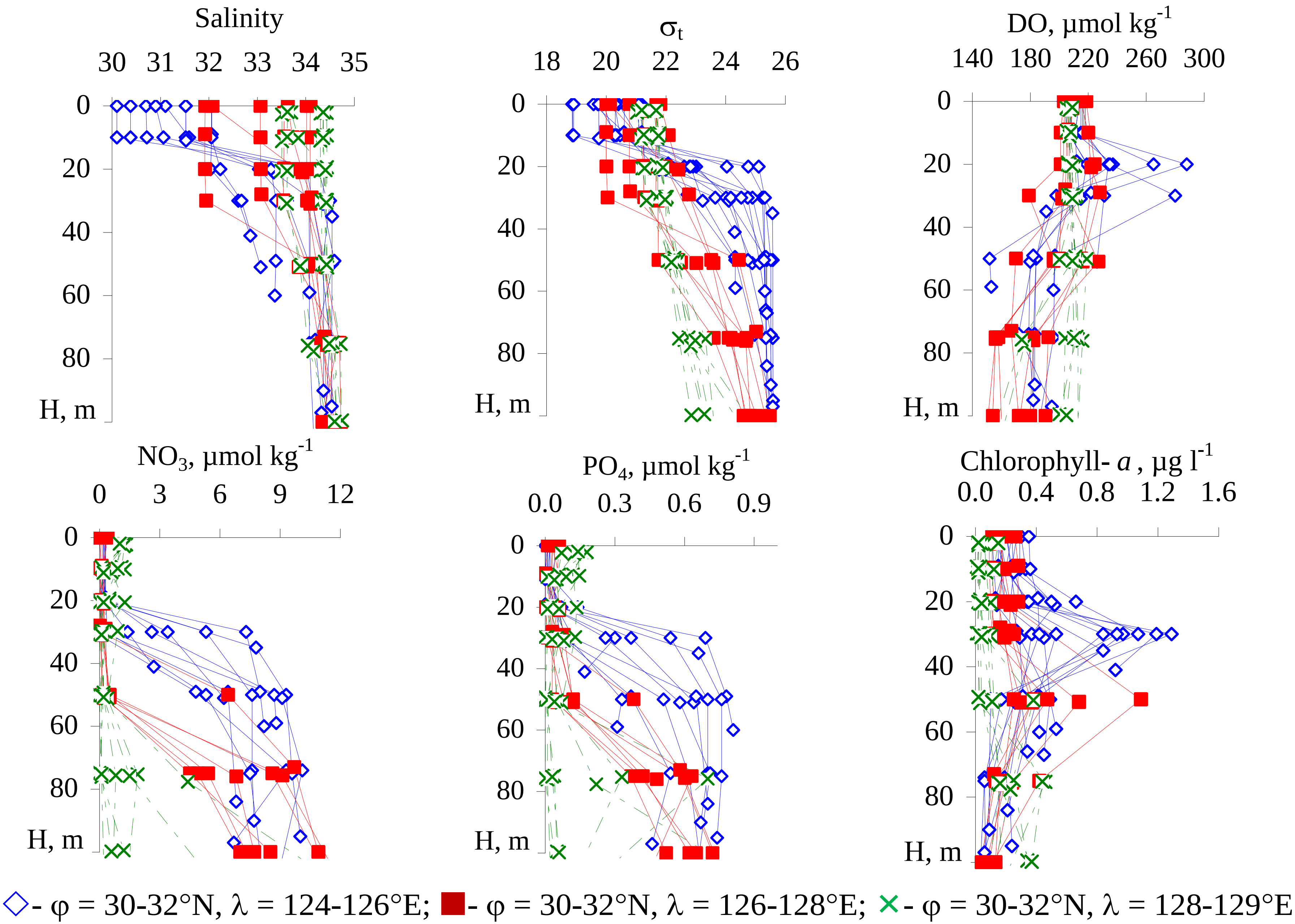



50 m, JES, September – October,
φ = 36.0-39.5°N, λ = 132-137°E.

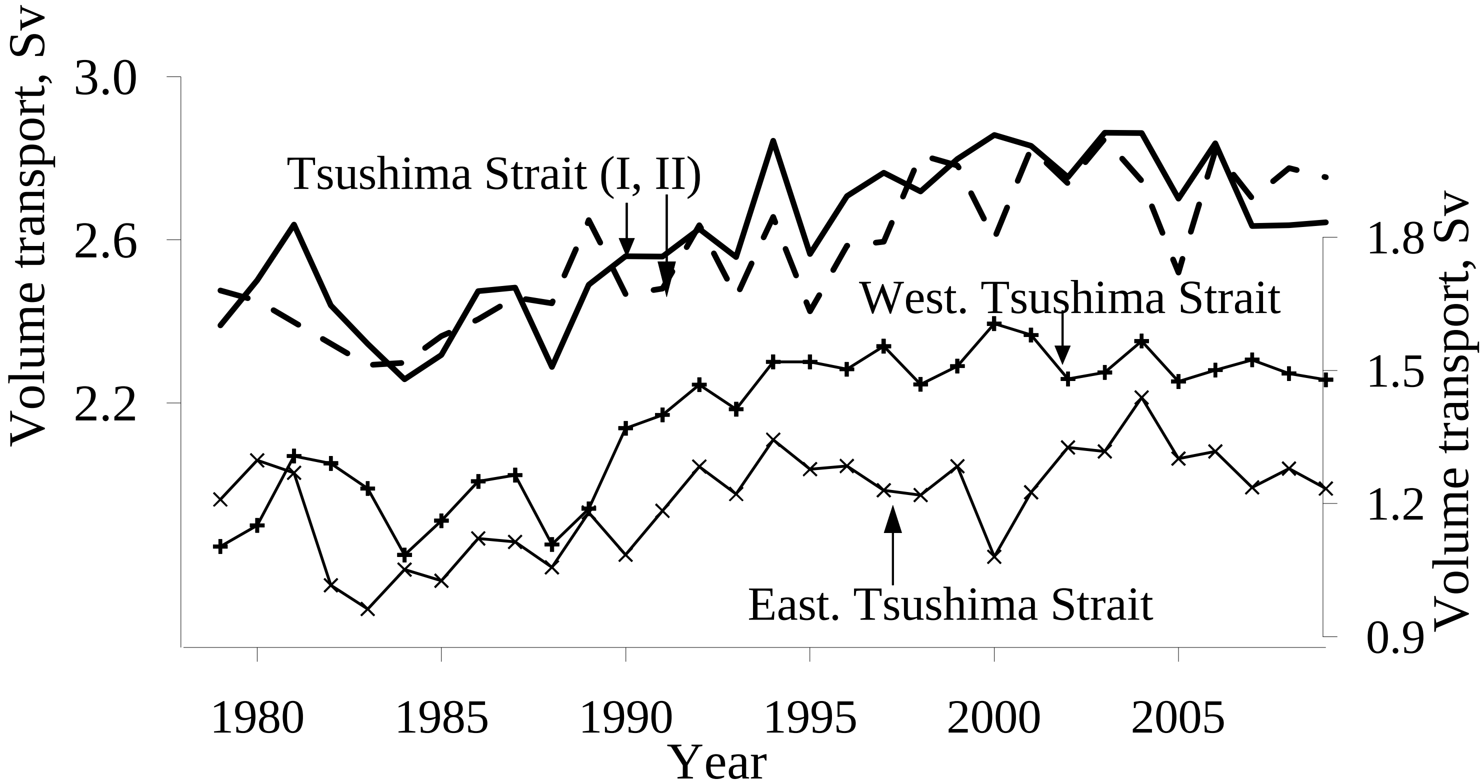
□- *in situ*, 0-30 m (φ = 36.0-39.5°N, λ = 132-137°E),
▲- SeaWiFS (φ = 36.5-39.1°N, λ = 133.5-134.5°E),
●- SeaWiFS, φ = 36.5-39.1°N, λ = 134.5-136.0°E).



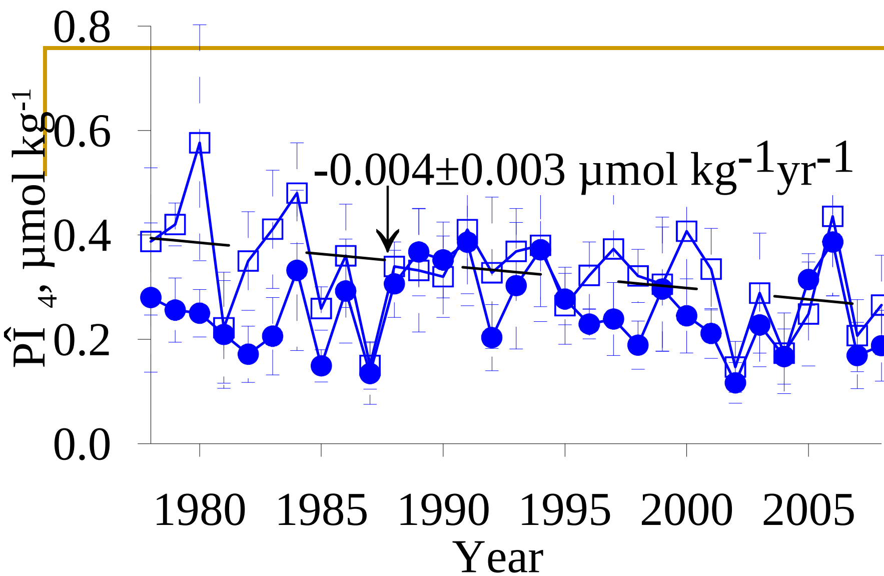
East- China
Sea
Yangtze
Taiwan
Warm
Current
Kuroshio
34°N
32°N
30°N
28°N
26°N
24°N
120°E
125°E
130°E
135°E
Ocean Data View

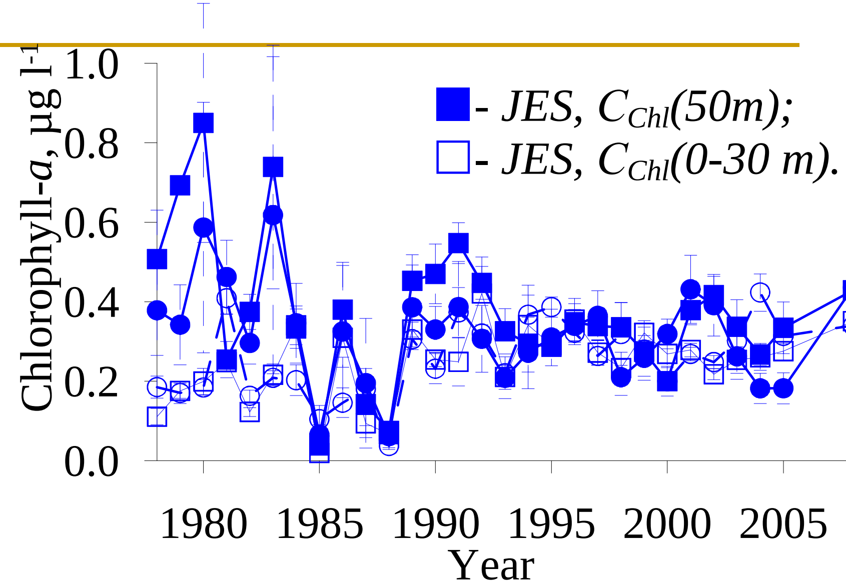



East-China Sea (August 1988, August 2006)

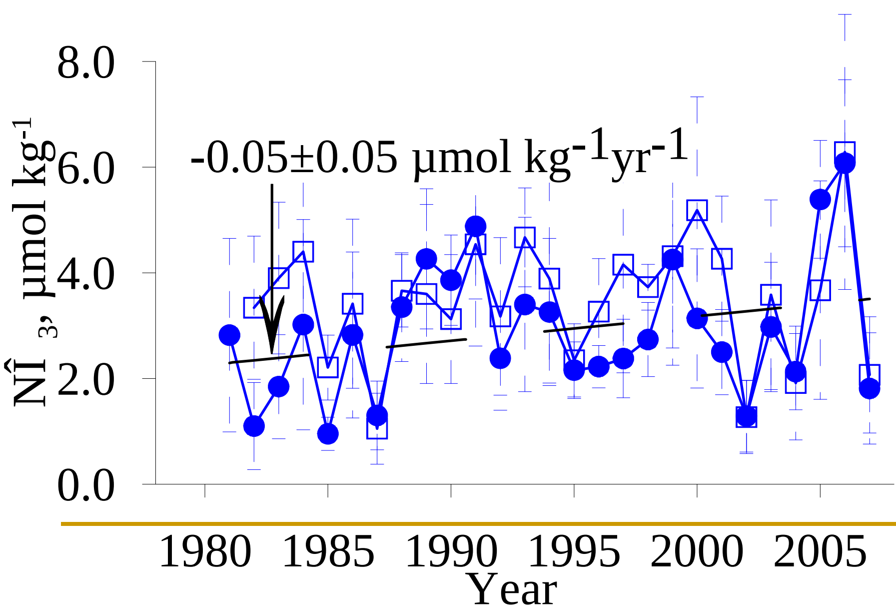


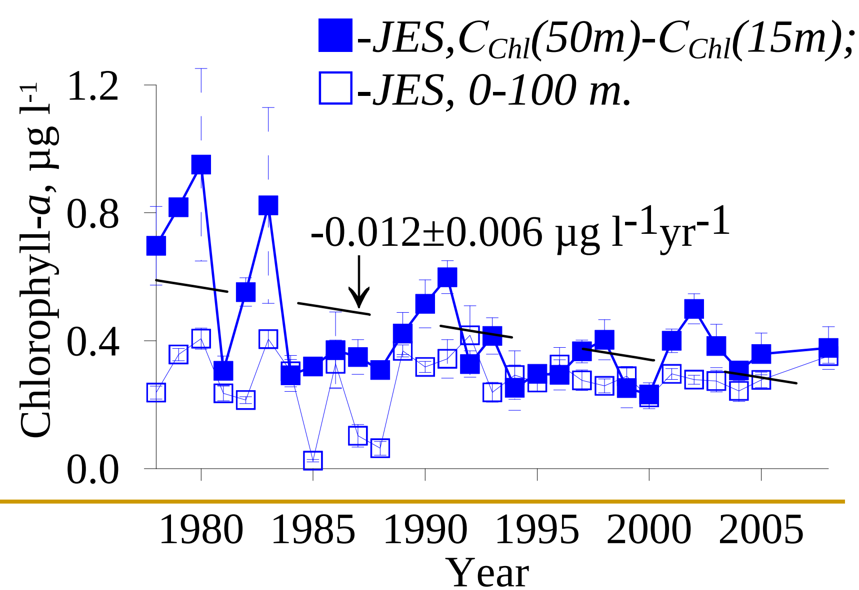
Volume transport, Sv
3.0
2.6
2.2
Tsushima Strait (I, II)
West. Tsushima Strait
East. Tsushima Strait
1.8
1.5
1.2
0.9
Volume transport, Sv
1980
1985
1990
1995
2000
2005
Year




*50 m*, ● - *JES*, September – October,
(φ = 36.0-38.0°N, λ = 132-137°E),
□ - *JES* (φ = 38.0-39.5°N, λ = 132-137°E).



**SUMMARY**

Between 1978 and 2008 in the central JES in fall the temperatures show an increasing trend (0.14± 0.06°C year$^{-1}$) at horizon of 50 m. Salinities exhibited descending trends with an annual rate of -0.005± 0.004 ($\alpha$= 0.10) year$^{-1}$. Time series surface water densities markedly increased (-0.03± 0.01 kg m$^{-3}$ year$^{-1}$), suggesting an intensification of the upper water column stratification.

In the upper layer of the central and southern JES the DO concentrations was reduced with an annual rate of -1.0 ± 0.3 µmol kg$^{-1}$ year$^{-1}$. The phosphate (P) concentration exhibited decreasing trend with an annual rate of -0.004± 0.003 µmol kg$^{-1}$ year$^{-1}$. In the southern JES the concentrations of nitrate (N) were increasing (0.05 ± 0.05 µmol kg$^{-1}$ year$^{-1}$). During the observation period (1978-2008) in the central and southern JES the N:P ratio increased at annual rates of 0.15 ±0.03 year$^{-1}$.

The increasing trends of seawater temperature and N: P ratio and the decreasing trends of DO and P concentrations in the central and southern JES in fall were consistent with those in the adjacent sea areas, i.e. the Yellow Sea and East China Sea. The trend of ascending N:P ratio in the JES attributed to both the decrease in P concentration and the increase in N in seawater of the ECS.

The year-to-year variability of the temperature, salinity and relative density in the southern JES in September-October were related to those in the northern ECS in August. Correlations of the year-to-year variability in the regionally averaged temperature, N:P ratio, DO and chl-*a* with the annual volume transport through the Tsushima Strait reveal that an advection of the ECS waters contributed to the variability of the pre-winter environmental conditions and chl-*a* concentration in the upper waters of the central and southern JES.

The increased inflow of high temperature and low oxygen ECS waters and the decreased photosynthetic rate of phytoplankton resulted in the descending trend of DO at horizon of 50 m in central and southern JES. The increased water transport through the western part of the Tsushima Strait probably brought more inner shelf ECS waters into JES (with more shallow subsurface chl-*a* maximum than in the central and outer shelf waters of the ECS) and thereby led to the decreased chl-*a* concentration at horizon of 50 m and its increase in 0-30 m layer.