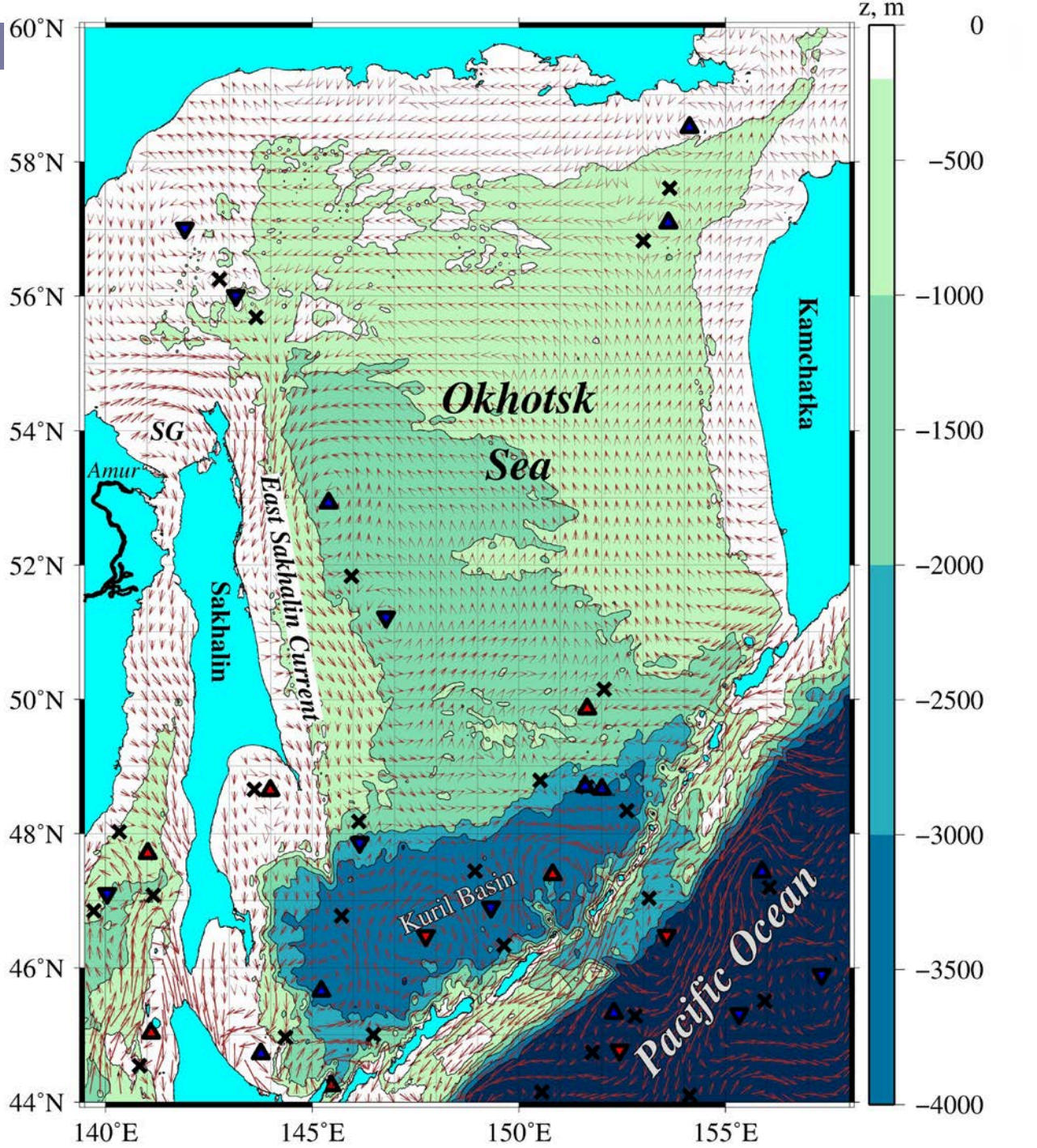
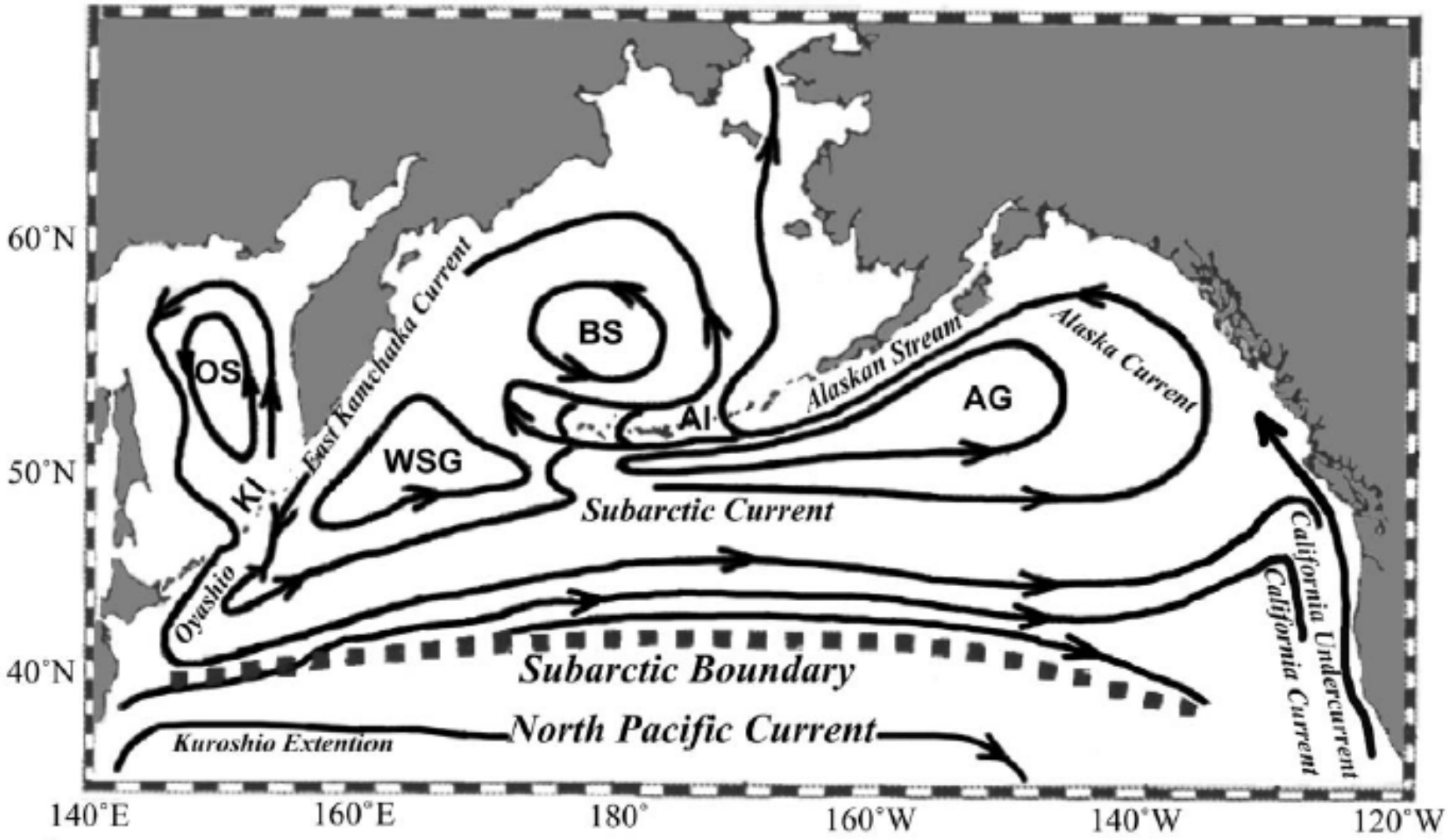
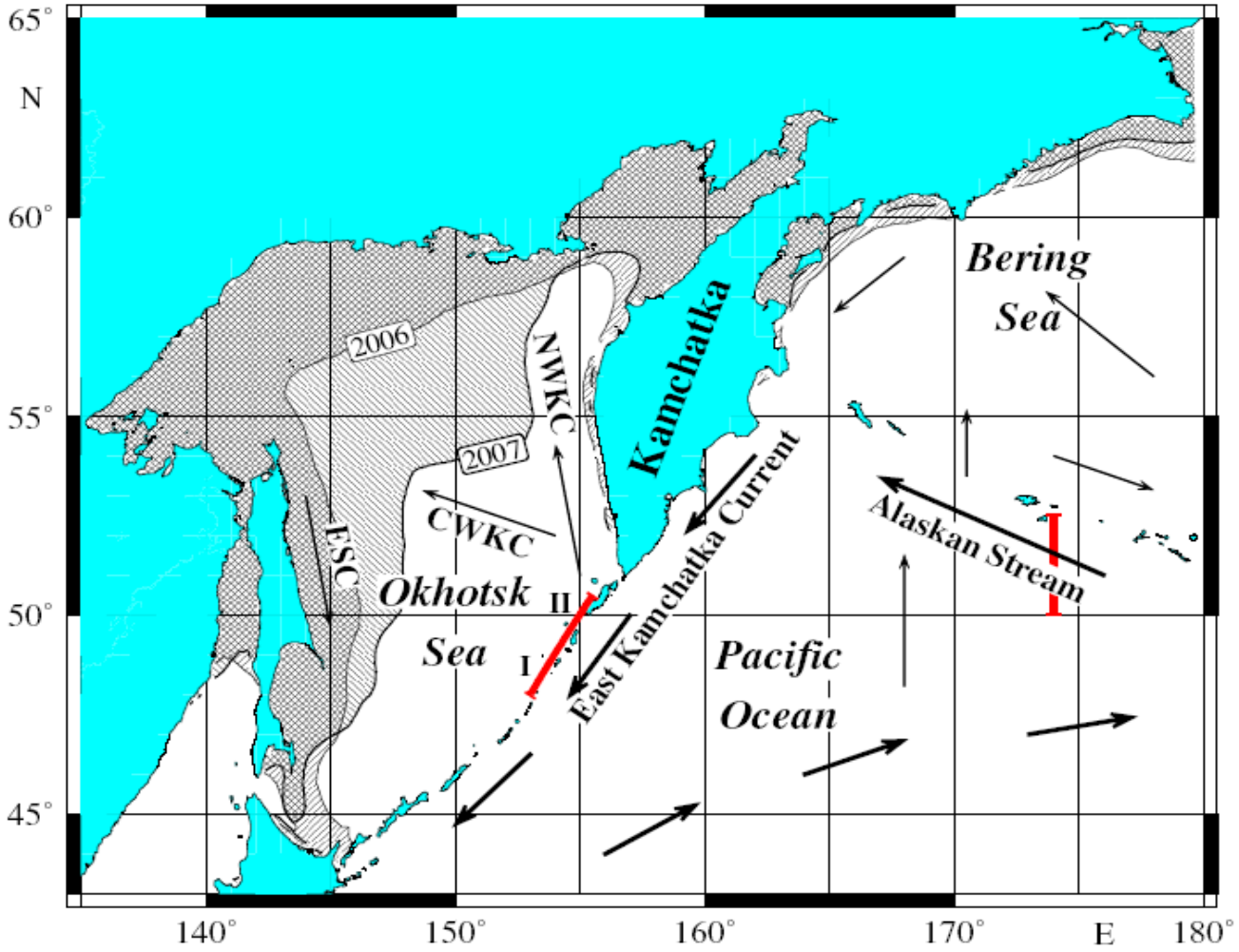
The seasonal and interannual variability of circulation in the eastern and western Okhotsk Sea and its impact on plankton biomass

Andrey G. Andreev, Sergey V. Prants, Maxim V. Budyansky and Michael Yu. Uleysky
V.I. Il'ichev ***Pacific Oceanological Institute, FEBRAS, 43 Baltiskaya St., Vladivostok***

AVISO, 1993-2015




60°N
50°N
40°N
140°E
160°E
180°
160°W
140°W
120°W
OS
BS
AI
AG
WSG
KI
East Kamchatka Current
Alaskan Stream
Alaska Current
Subarctic Current
Oyashio
Subarctic Boundary
North Pacific Current
Kuroshio Extention
California Undercurrent
California Current


65°
N
60°
55°
50°
45°
140°
150°
160°
170°
E
180°
2006
2007
NWKC
CWKC
ESC
Kamchatka
Bering
Sea
Okhotsk
Sea
II
I
East Kamchatka Current
Alaskan Stream
Pacific
Ocean

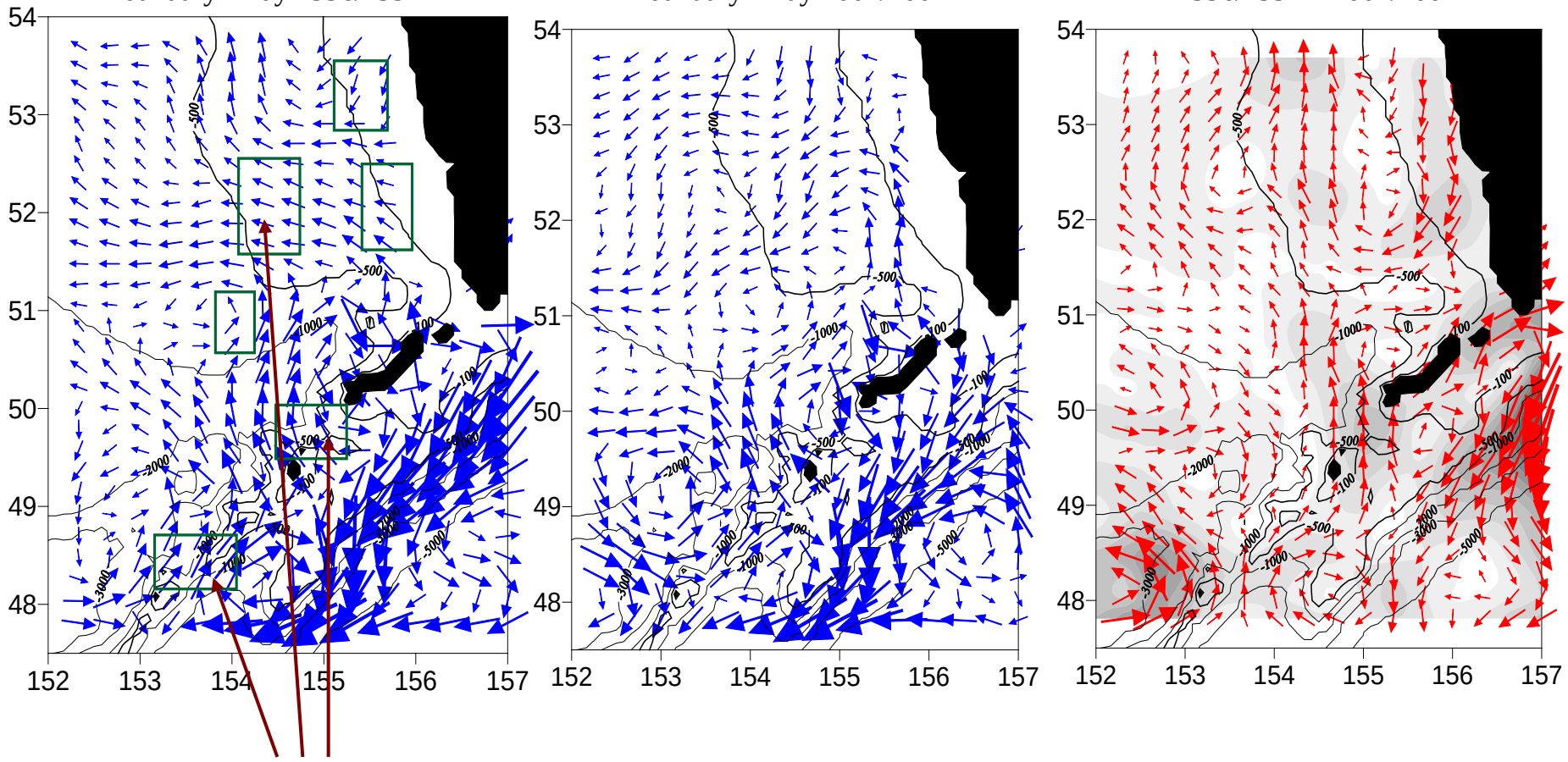
Enhanced Alaskan Stream flow

January- May 1996/1997

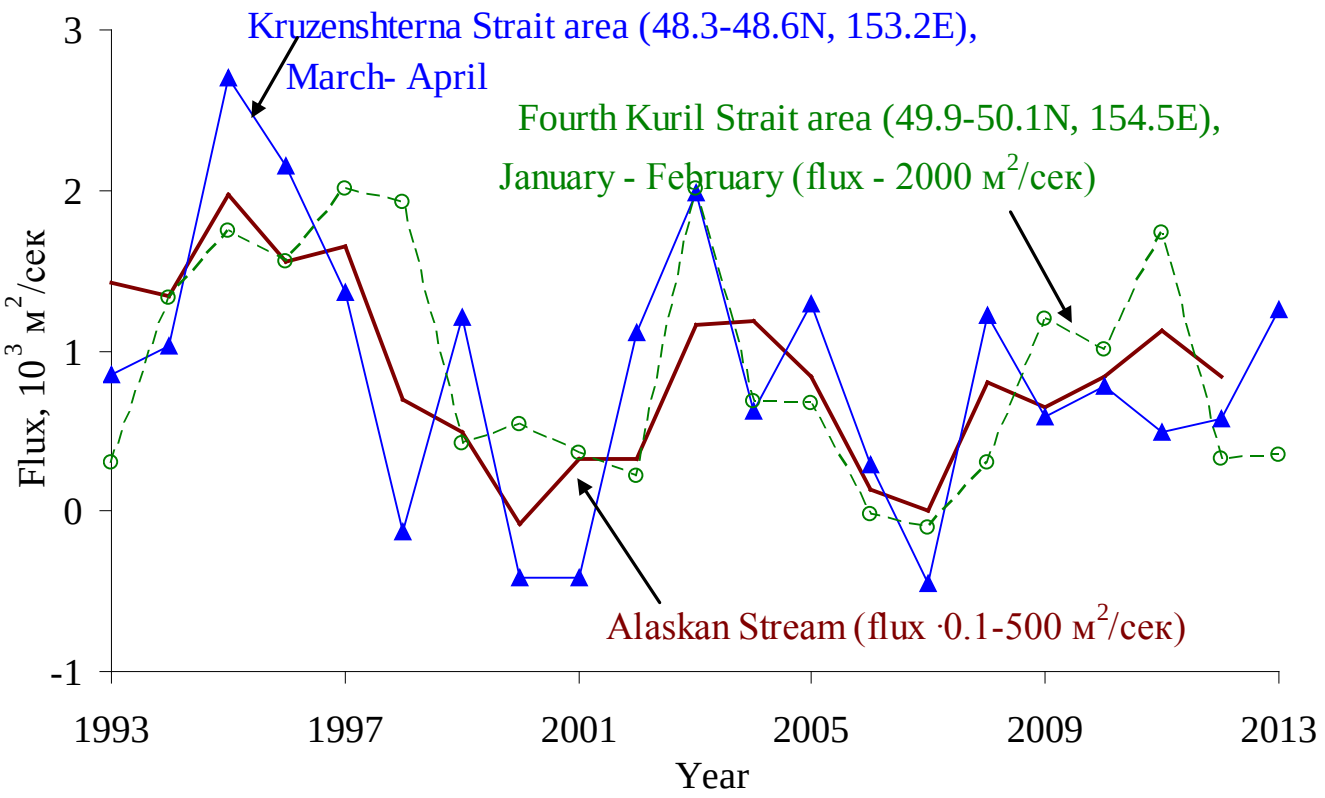
Weak Alaskan Stream flow

January- May 2001/2002

1996/1997 – 2001/2002

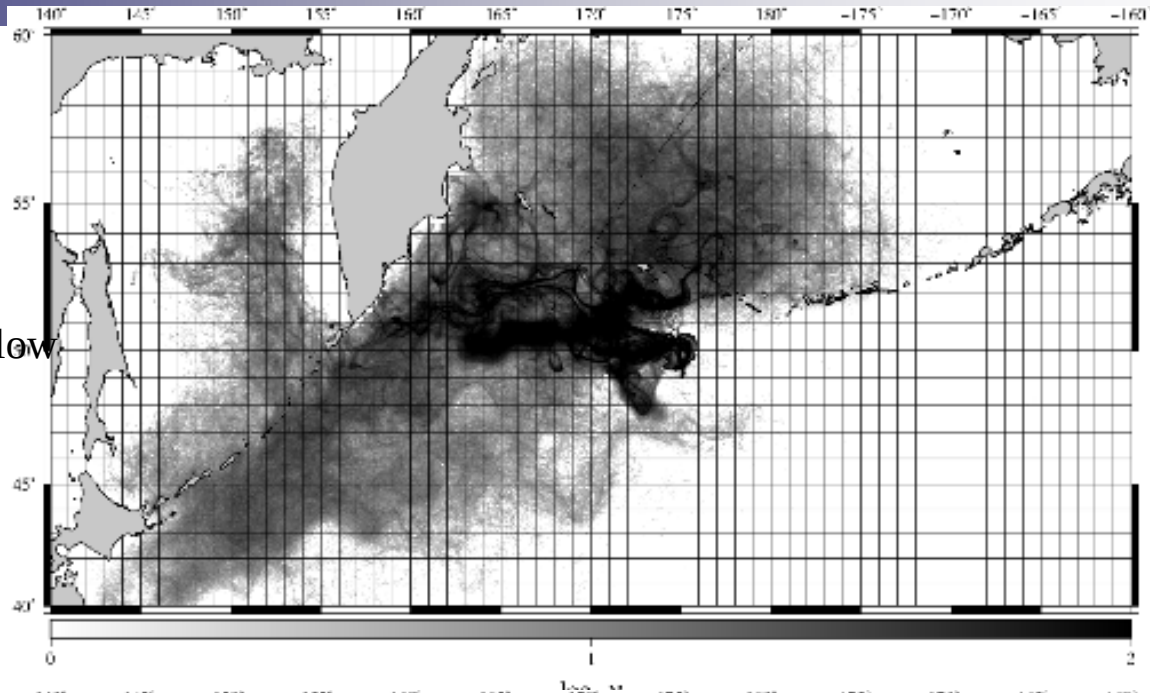


Regions where correlation coefficients between the meridional fluxes and the Alaskan Stream flux are higher than 0.6 (1993 – 2015).


Kruzenshterna Strait area (48.3-48.6N, 153.2E),
March- April
Fourth Kuril Strait area (49.9-50.1N, 154.5E),
January - February (flux - 2000 м2/сек)
Alaskan Stream (flux ·0.1-500 м2/сек)
Flux, 10^3 м^2/сек
Year
3
2
1
0
-1
1993
1997
2001
2005
2009
2013

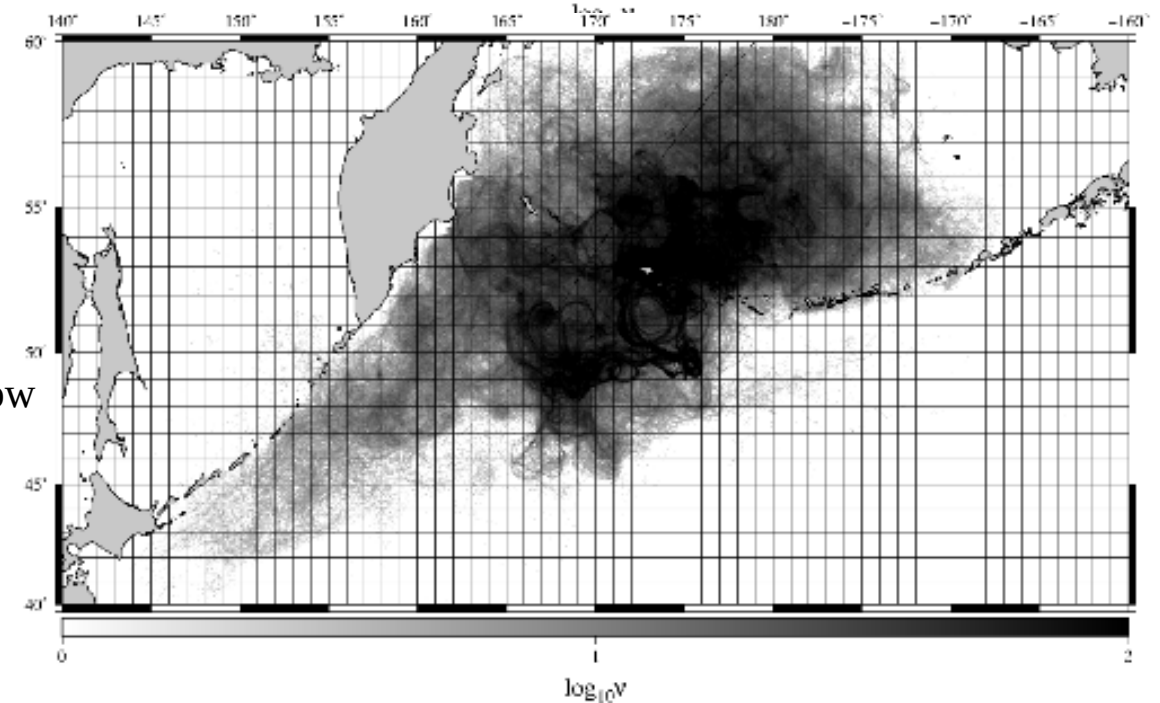
March 1996

Enhanced Alaskan Stream flow



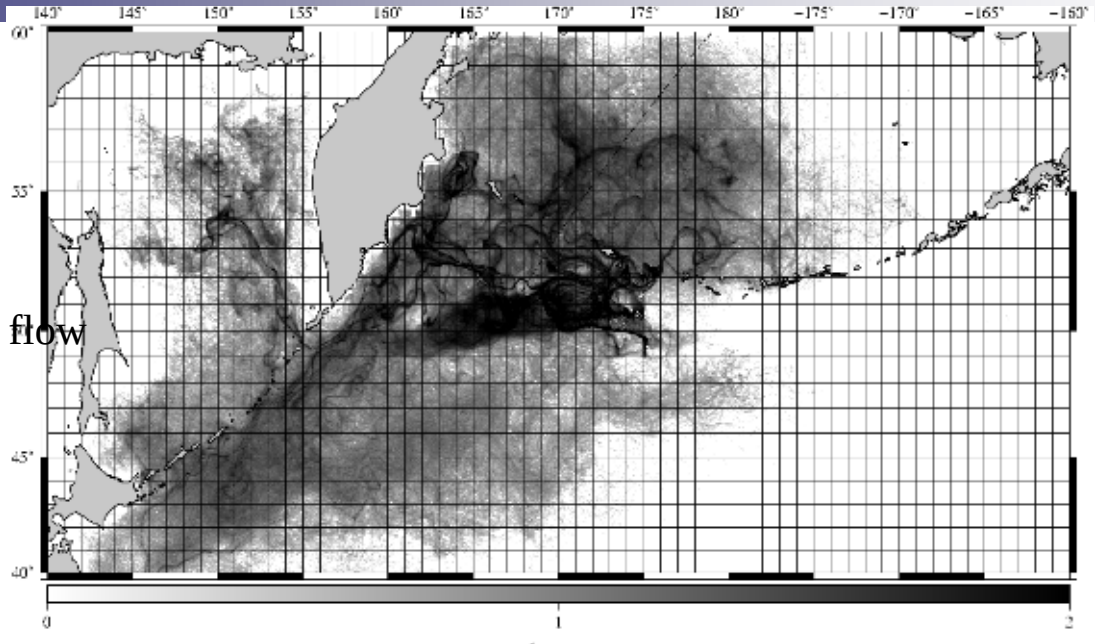
March 2000

Weak Alaskan Stream flow



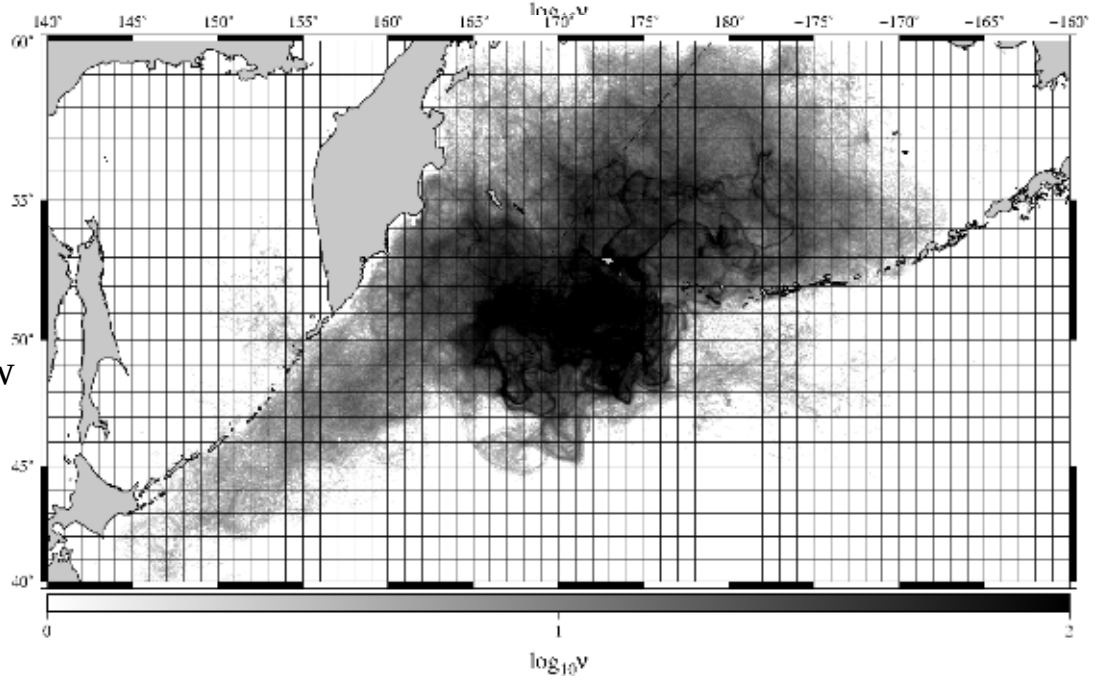
August 1996

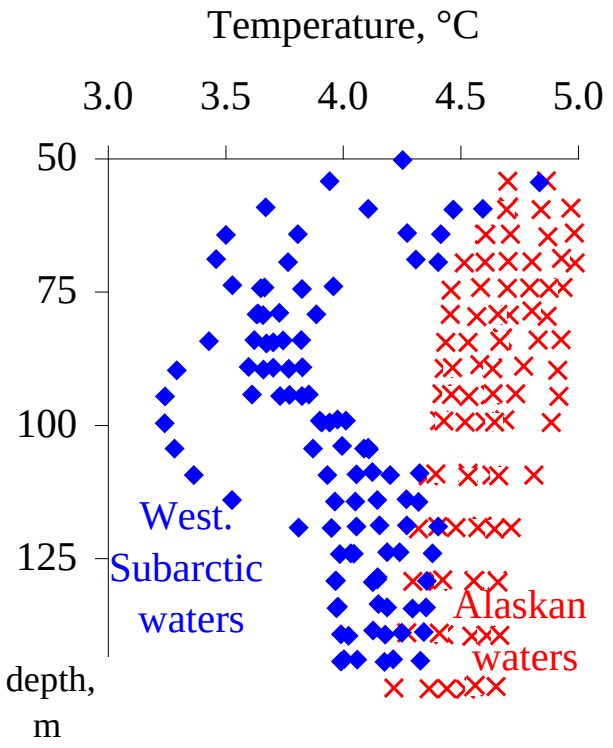
Enhanced Alaskan Stream flow

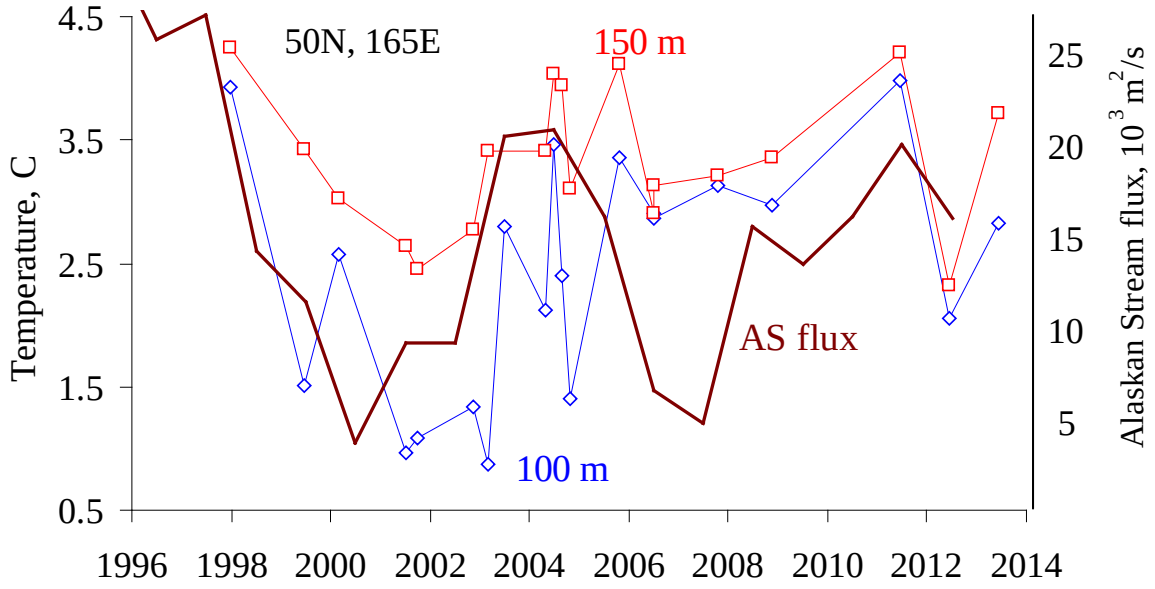


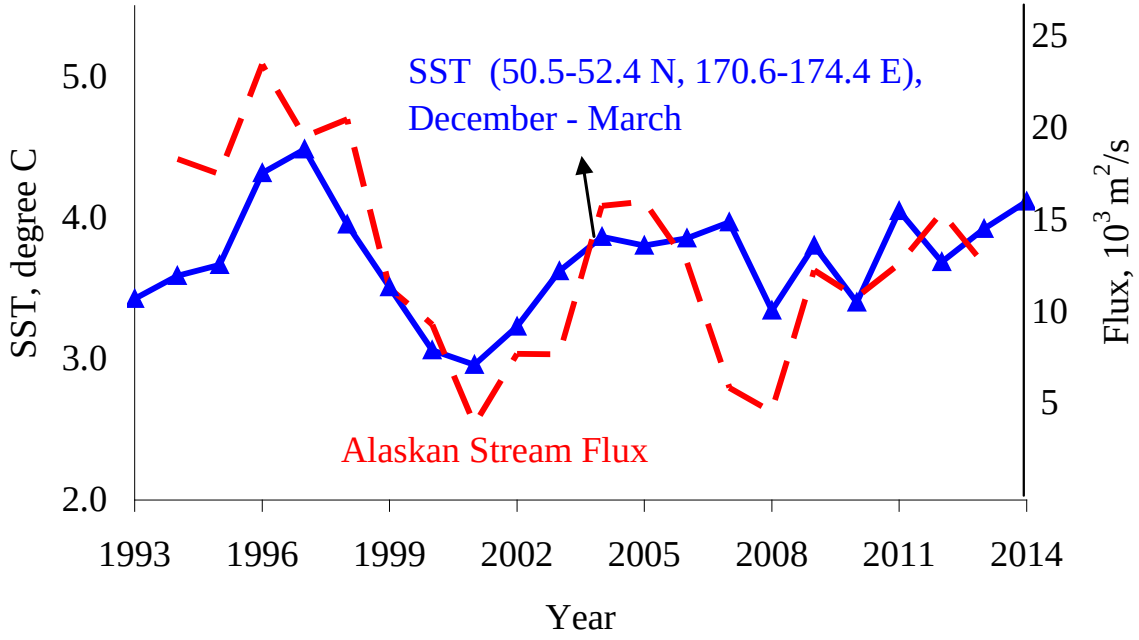
August 2000

Weak Alaskan Stream flow

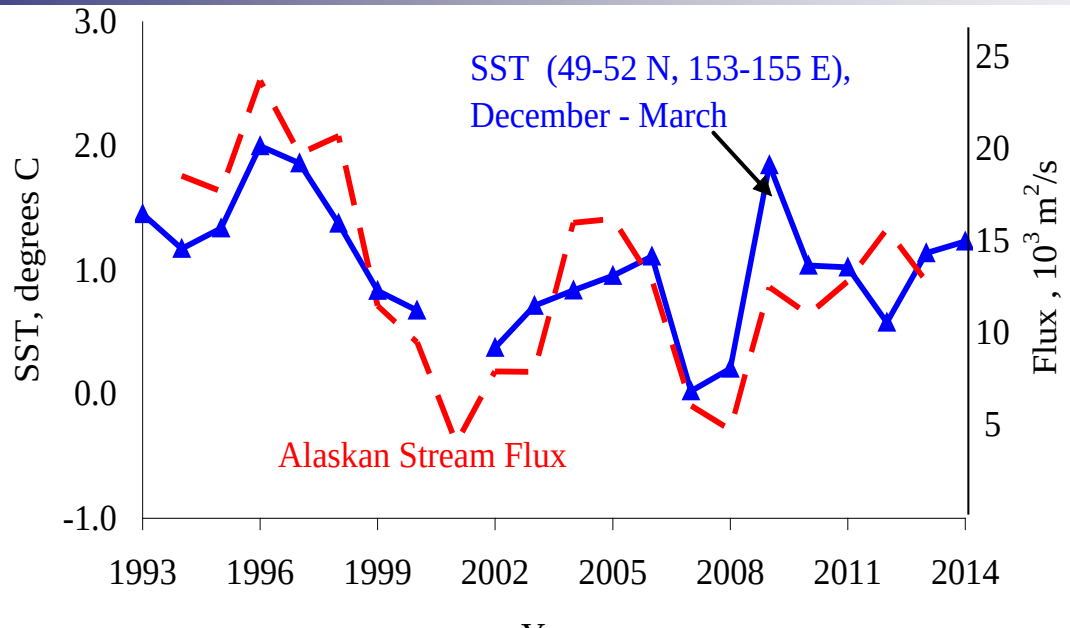


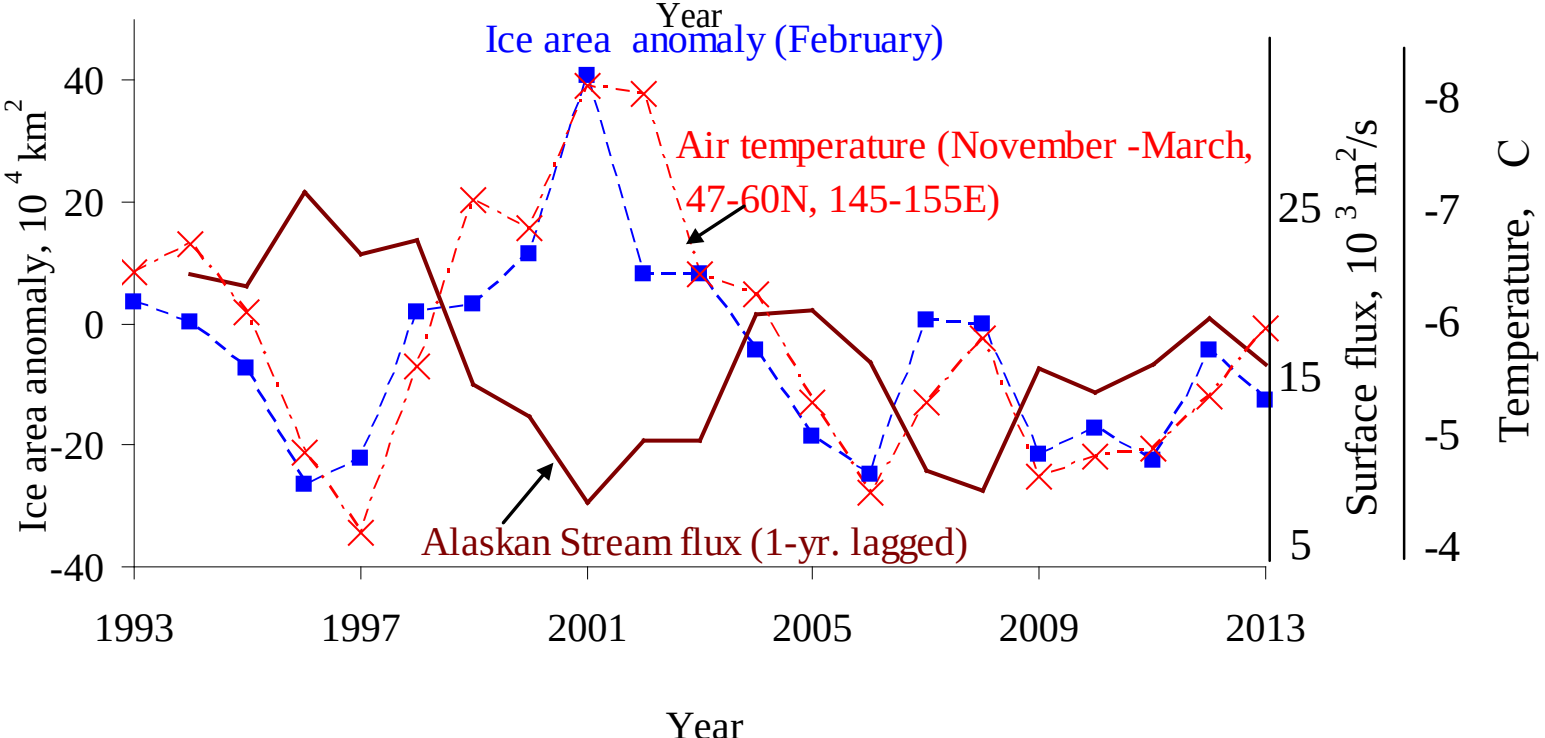

Temperature, °C
3.0
3.5
4.0
4.5
5.0
50
75
100
125
depth, m
West. Subarctic waters
Alaskan waters


50N, 165E
150 m
100 m
AS flux
Temperature, C
Alaskan Stream flux, 10^3 m^2/s
4.5
3.5
2.5
1.5
0.5
25
20
15
10
5
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014


SST (50.5-52.4 N, 170.6-174.4 E),
December - March
Alaskan Stream Flux
SST, degree C
Flux, 10^3 m^2/s
5.0
4.0
3.0
2.0
25
20
15
10
5
1993
1996
1999
2002
2005
2008
2011
2014
Year

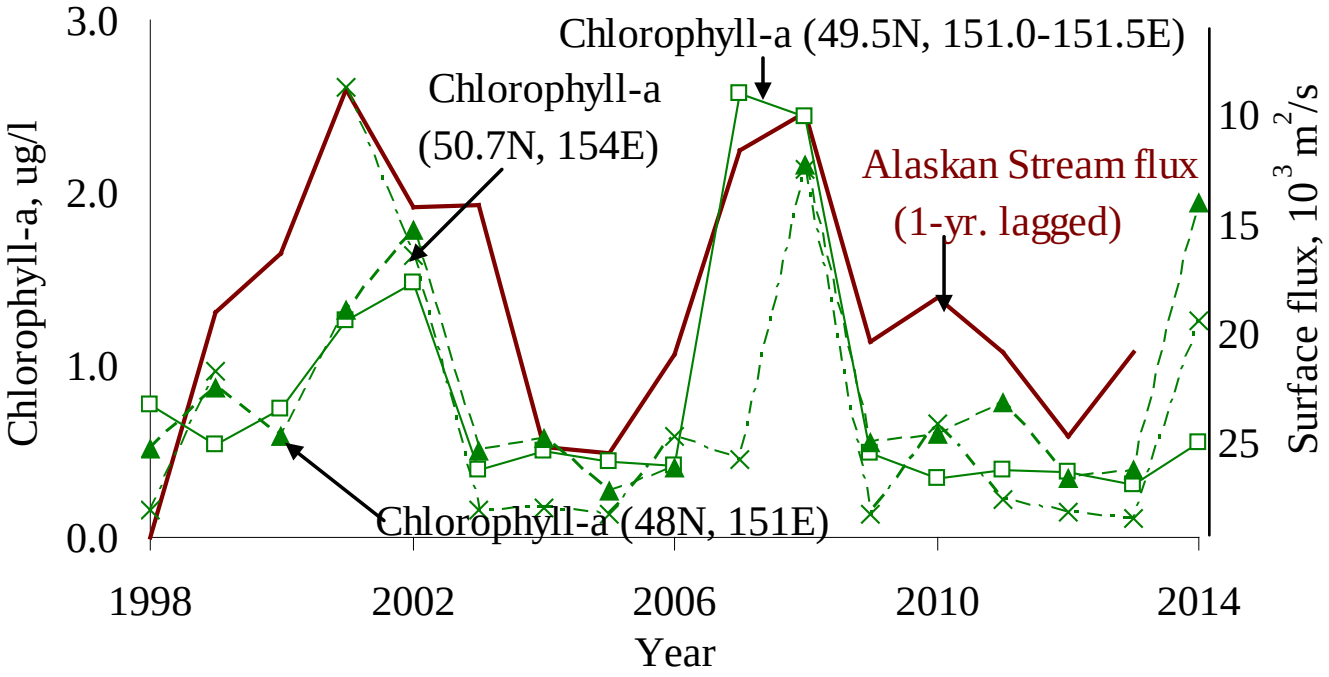
Western Okhotsk Sea



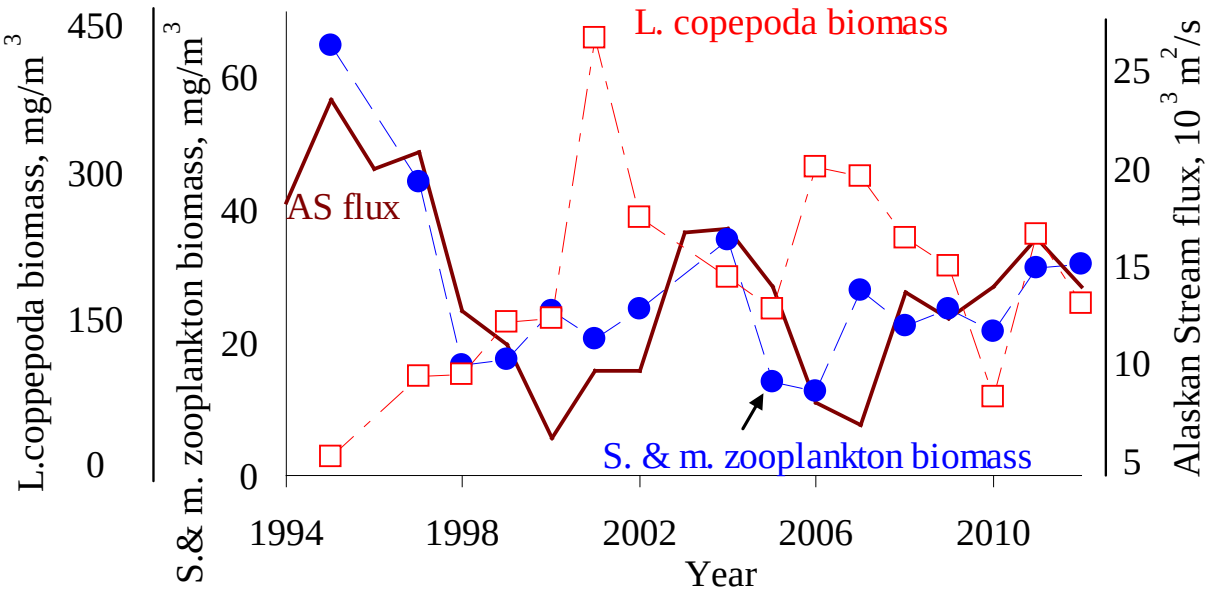


Western Okhotsk Sea

Satellite chlorophyll , May

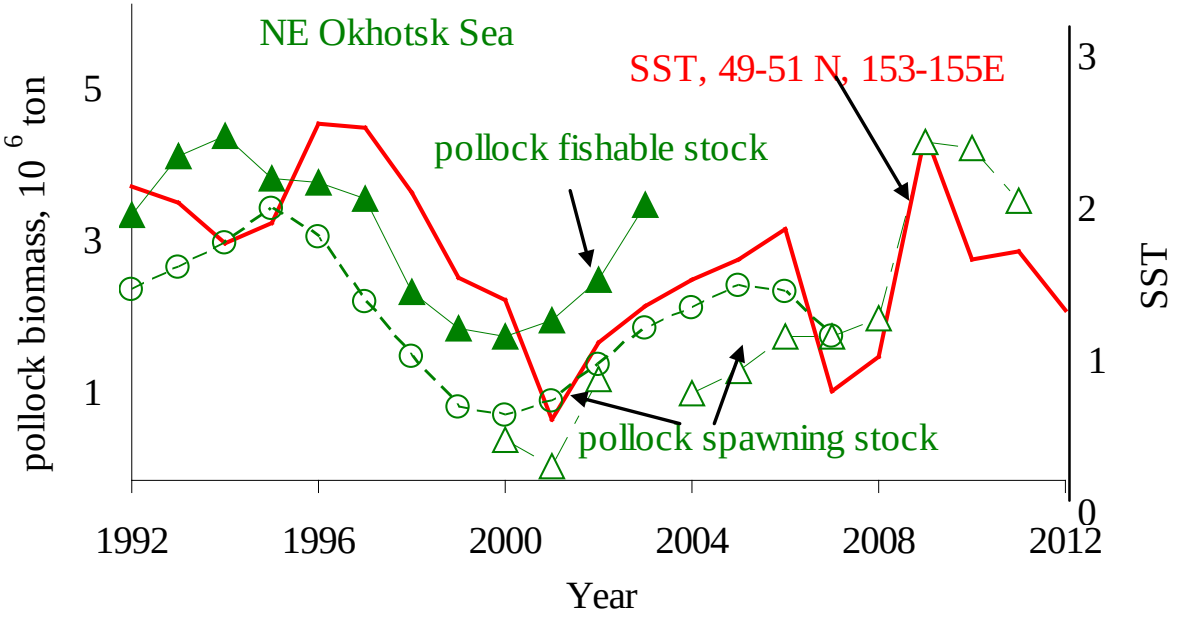


Zooplankton data:Volkov, 2013

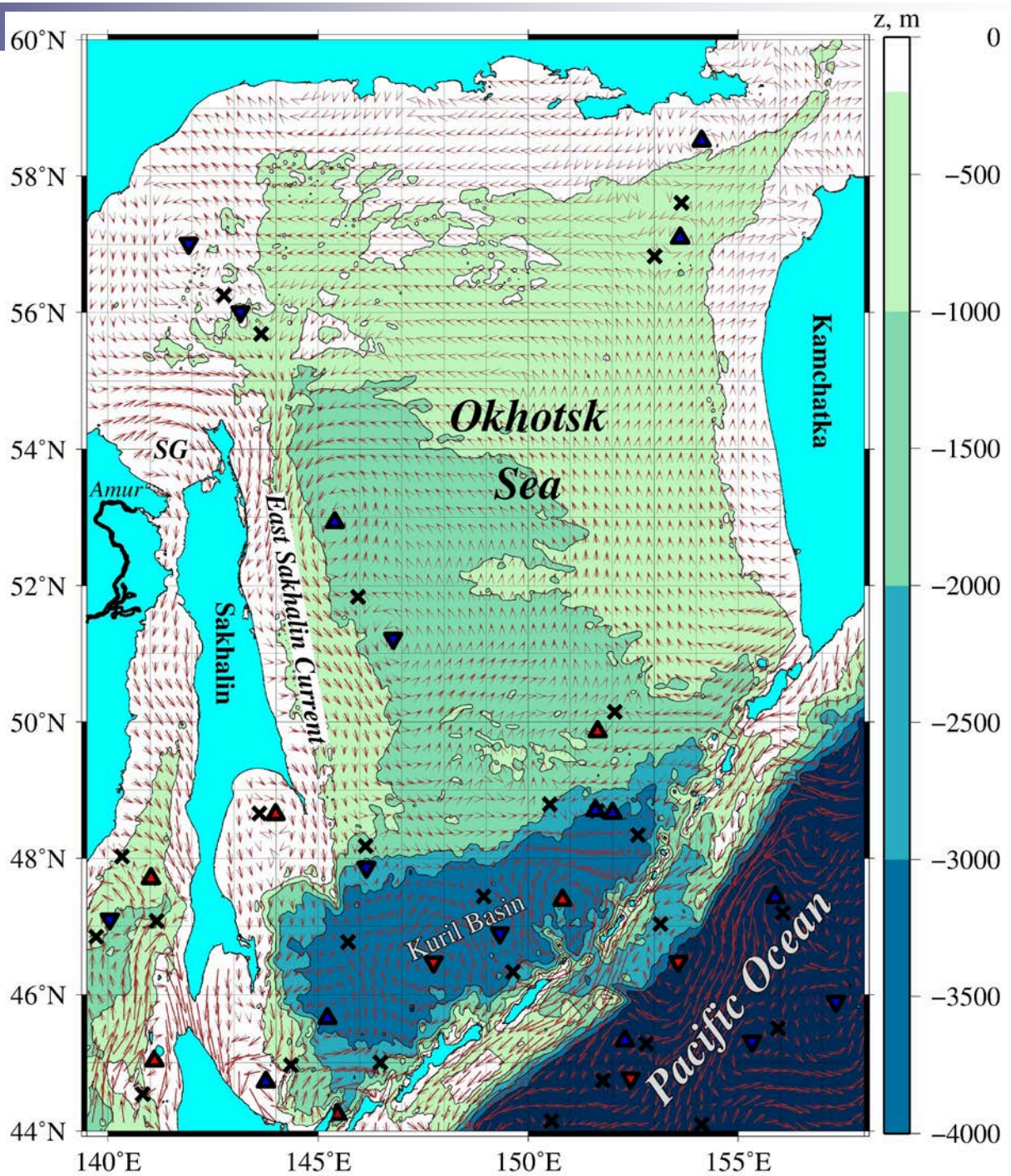


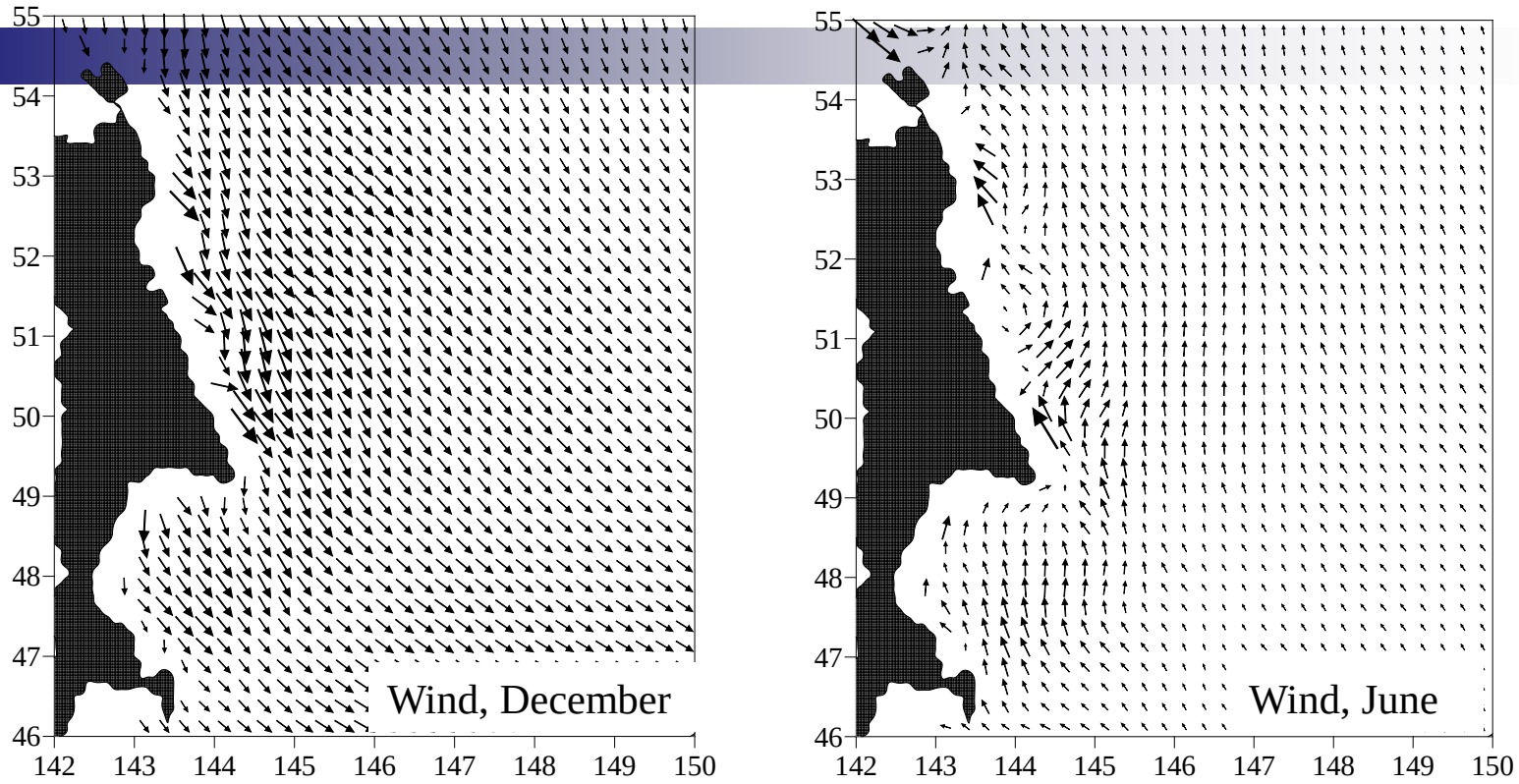
NW Okhotsk Sea

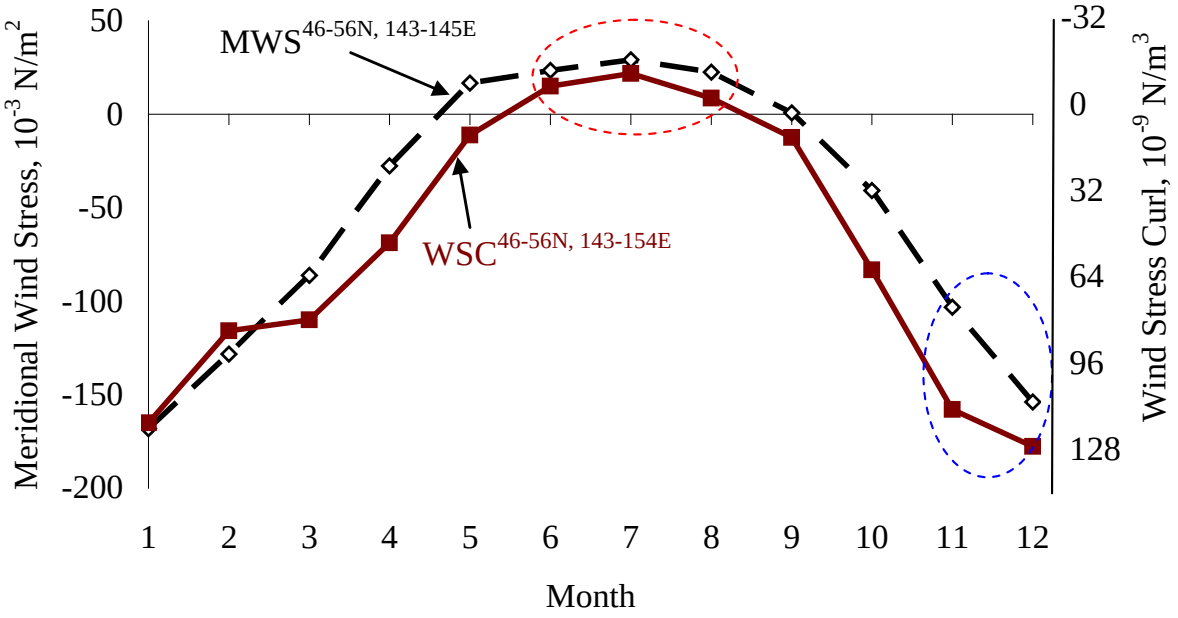
Walleye pollock data: Kotenev, Bulatov, 2009; Ovsyannikov et al., 2013



AVISO, 1993-2015

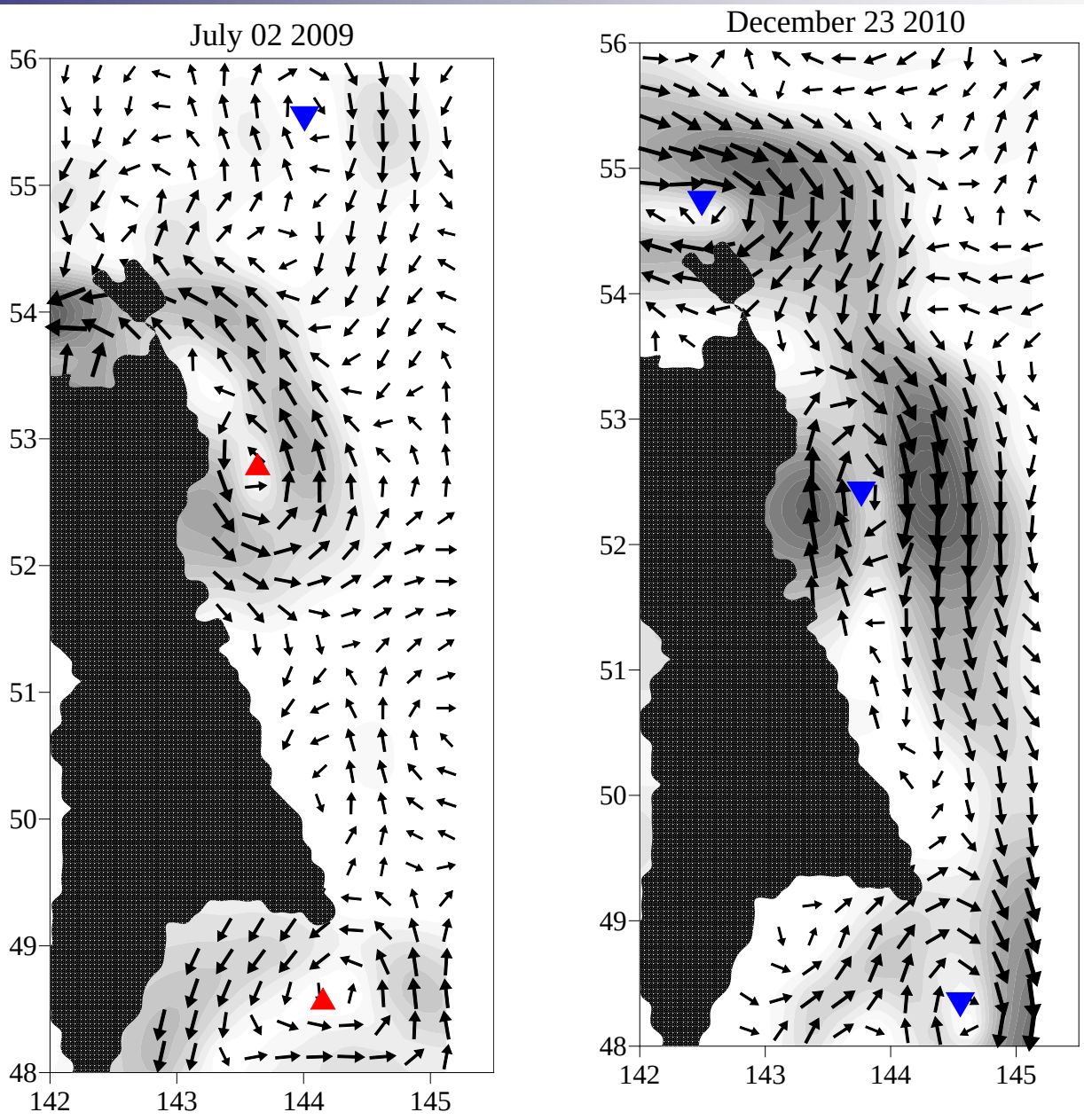



Wind, December
Wind, June

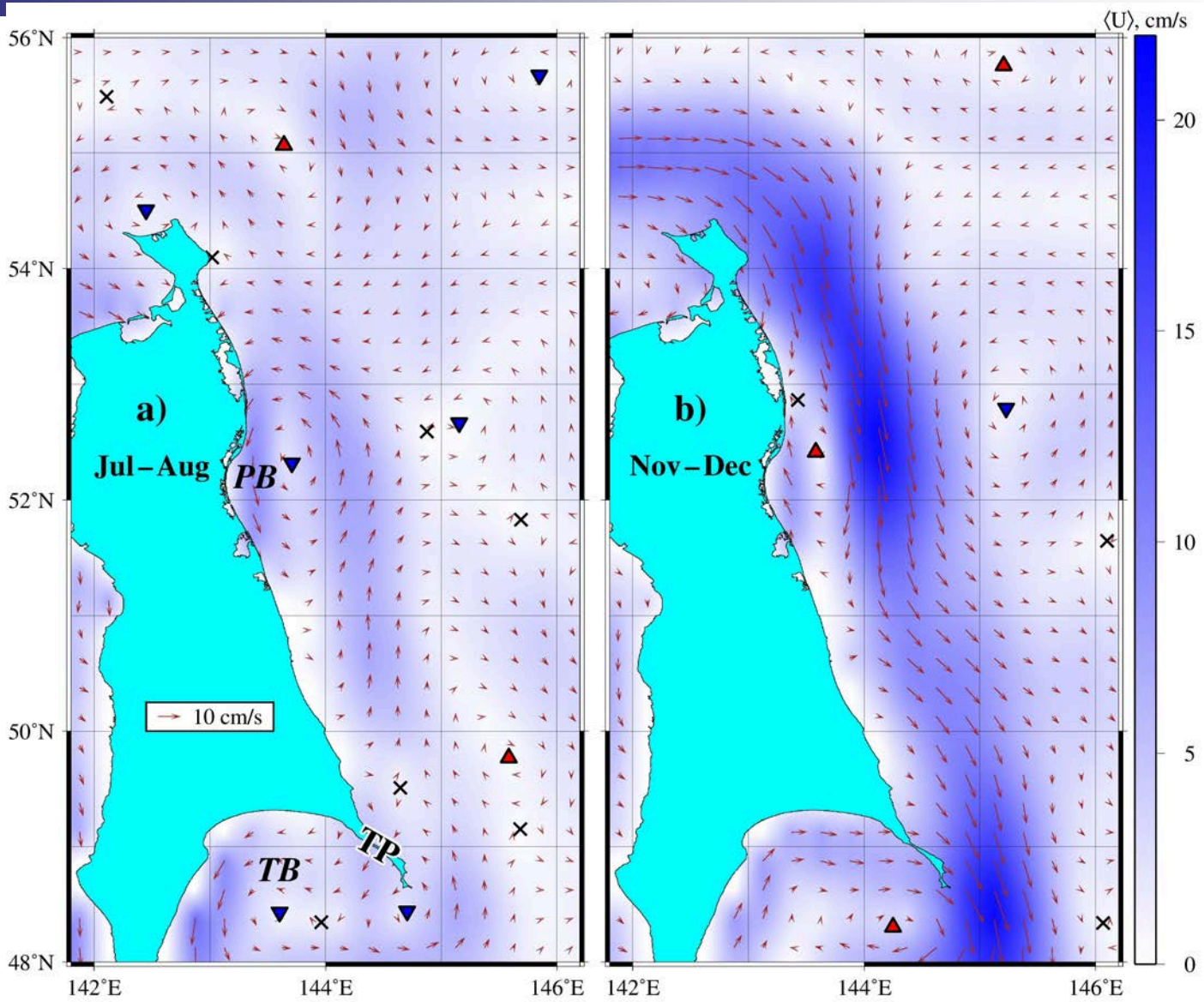

MWS46-56N, 143-145E
WSC46-56N, 143-154E
Meridional Wind Stress, 10-3 N/m2
Wind Stress Curl, 10-9 N/m3
Month

Ohshima et al. (2004) have demonstrated that the computed Sverdrup transport (by using the wind stress curl data) and the observed southward ESC transport (53N, July 1998–January 2000) exhibit large seasonal variations with a maximum in winter and a minimum in summer. They assumed that the main part (the shelf-slope core) of the ESC can be regarded as the western boundary current of the wind-driven cyclonic gyre. The lack of the observed northward transport of the ESC across 53N in summer of 1999 during the period of the negative (anticyclonic) wind stress curl was explained by an importance of the annually mean wind stress curl for the southward flow of the ESC in summer. Ebuchi (2006) has studied the seasonal and interannual variations in the ESC and its relation to wind stress and wind stress curl fields in the OS using ten-year (1992-2002) records of the sea level anomaly observed by the TOPEX/POSEIDON altimeter. He concluded that the southward flow of the ESC is strong in winter and almost disappears in summer.

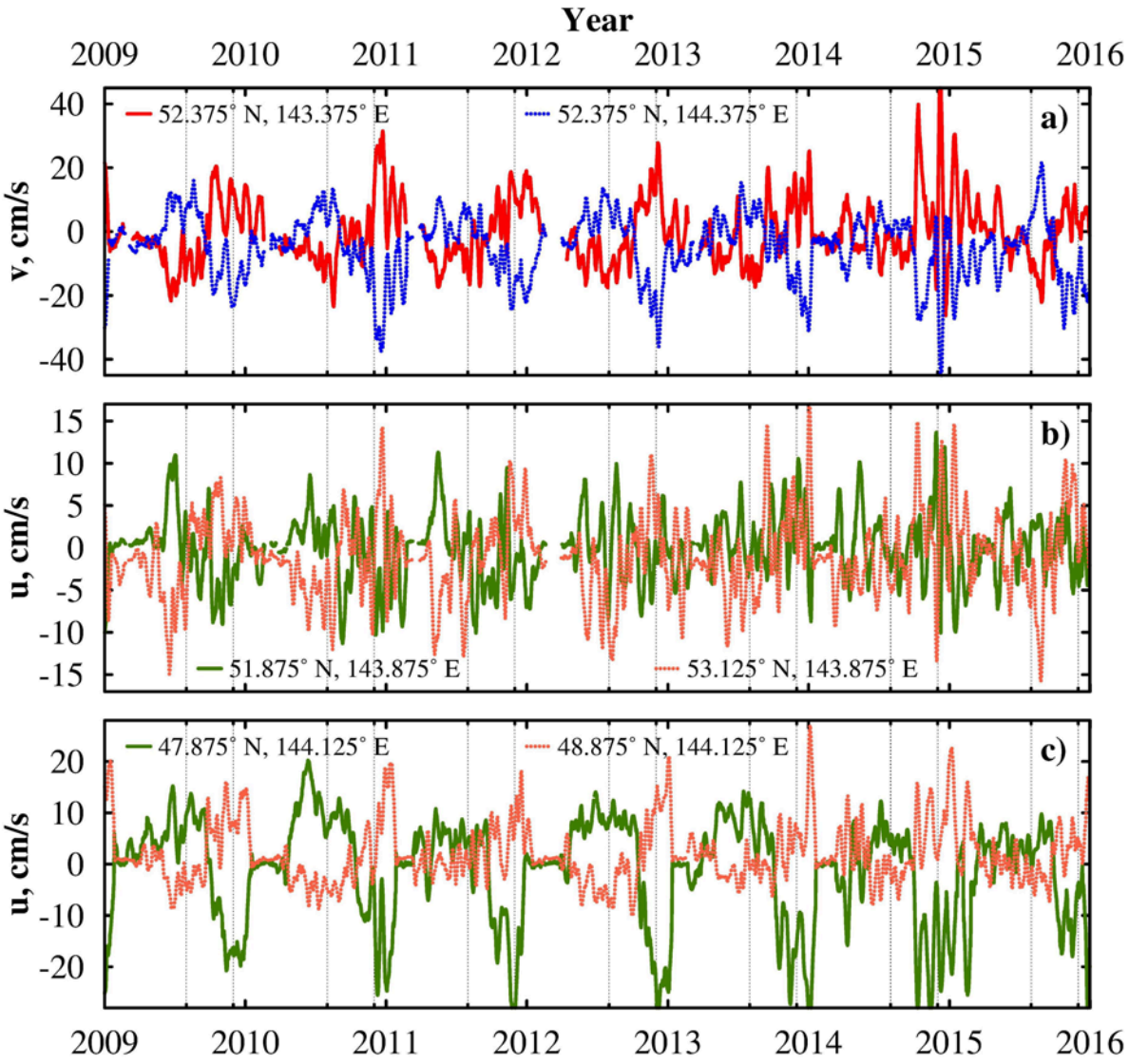
Using the CTD data collected in summer 1994, Verkhunov (1997) revealed the mesoscale cyclonic circulation off the northeastern Sakhalin and the **northward** transport of the ESC along the slope and the southward transport along the shelf. The **northward** flow in the surface layer of the northeastern Sakhalin shelf (52.5N) during August and first decade of September and strong southward flow during the second and third decades of September 1997 and 1998 was shown by Kochergin et al. (mooring data). The existence of the **northeastward and northwestward currents** along the East Sakhalin slope (51.5N) in summer 2009 and 2010 has been shown by Kusailo et al. using the mooring data.

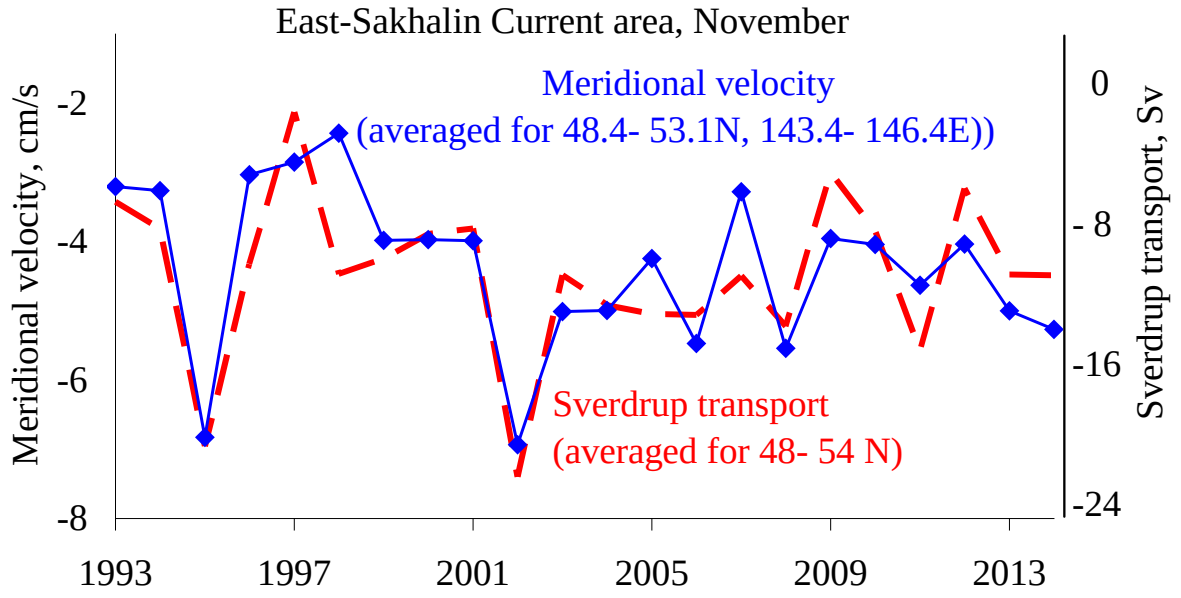

July 02 2009
December 23 2010
56
55
54
53
52
51
50
49
48
142
143
144
145

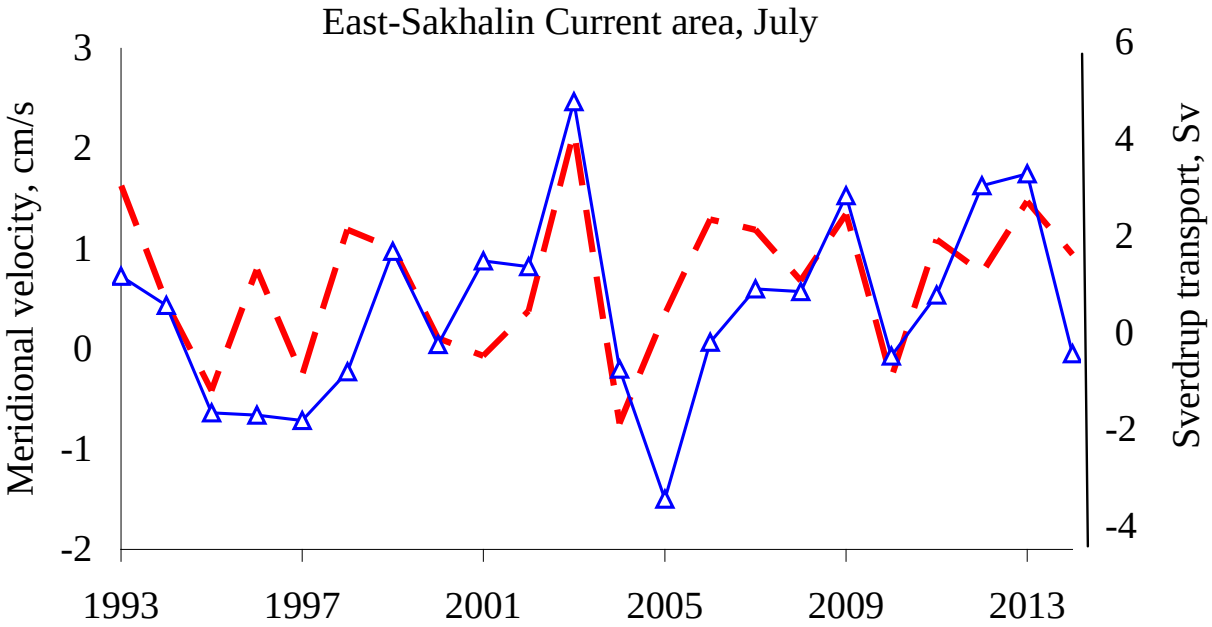
AVISO data

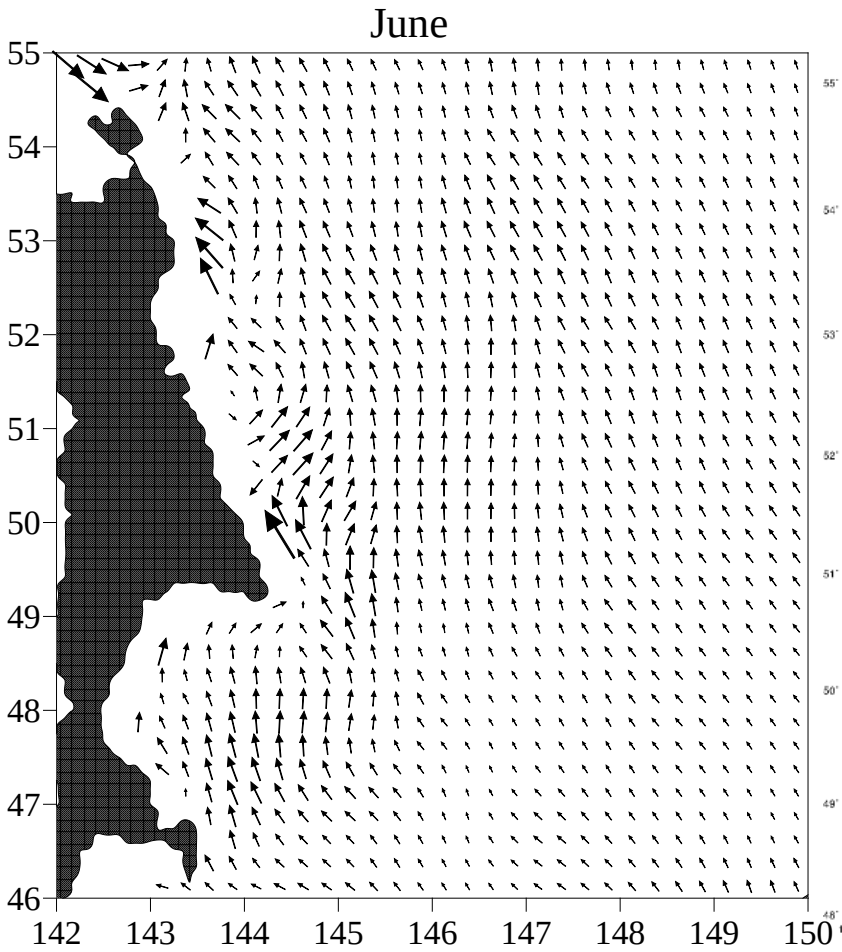


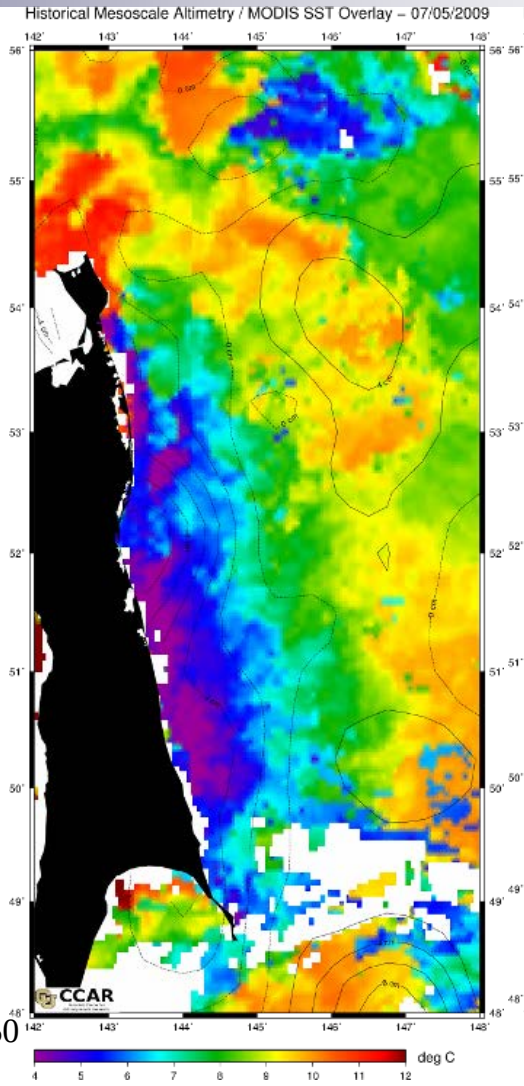
AVISO, 1993-2015

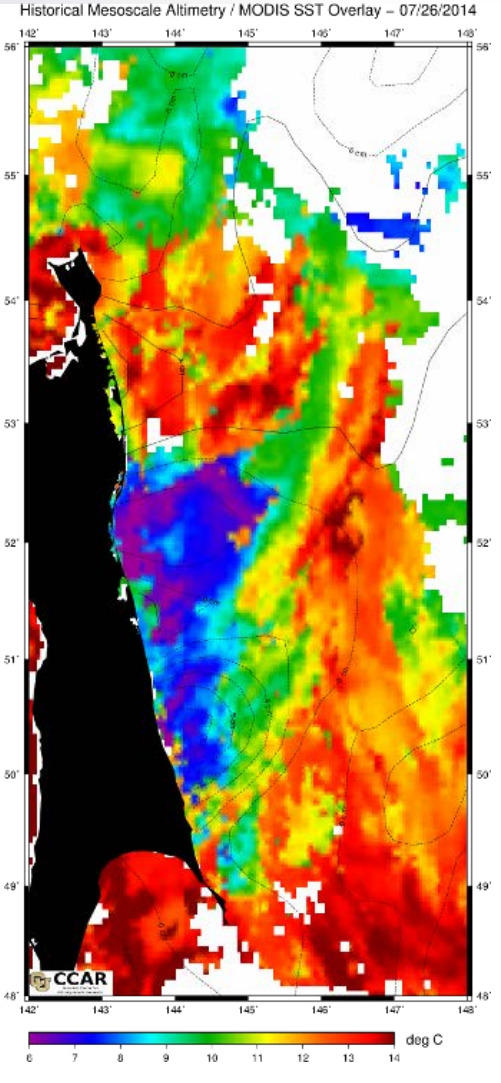

Year
2009
2010
2011
2012
2013
2014
2015
2016
52.375° N, 143.375° E
52.375° N, 144.375° E
a)
v, cm/s
40
20
0
-20
-40
b)
u, cm/s
15
10
5
0
-5
-10
-15
51.875° N, 143.875° E
53.125° N, 143.875° E
c)
47.875° N, 144.125° E
48.875° N, 144.125° E


East-Sakhalin Current area, November
Meridional velocity
(averaged for 48.4- 53.1N, 143.4- 146.4E))
Sverdrup transport
(averaged for 48- 54 N)
Meridional velocity, cm/s
Sverdrup transport, Sv
-2
-4
-6
-8
0
- 8
-16
-24
1993
1997
2001
2005
2009
2013

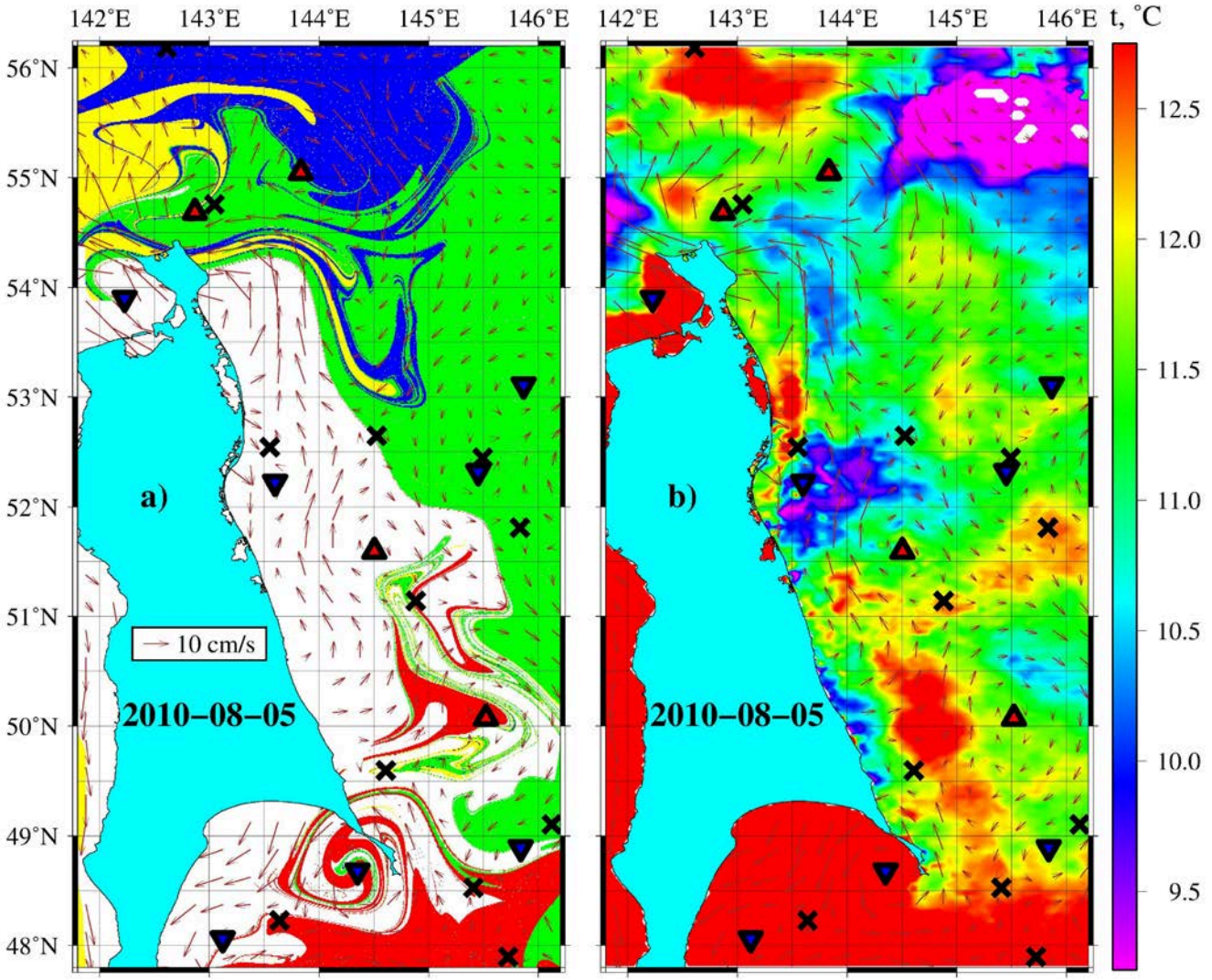

East-Sakhalin Current area, July
Meridional velocity, cm/s
Sverdrup transport, Sv
3
2
1
0
-1
-2
6
4
2
0
-2
-4
1993
1997
2001
2005
2009
2013





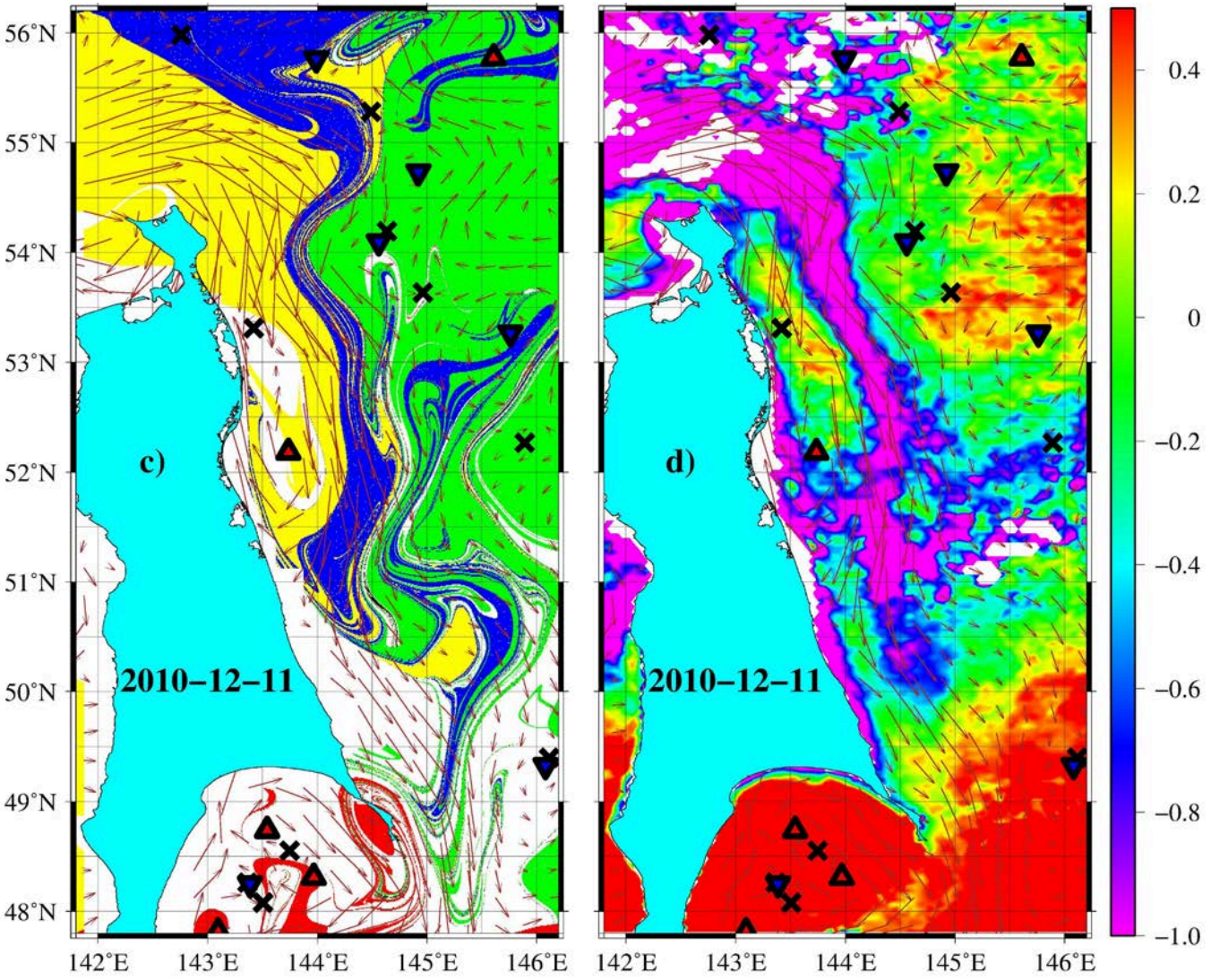


SST, July 2009, July 2014



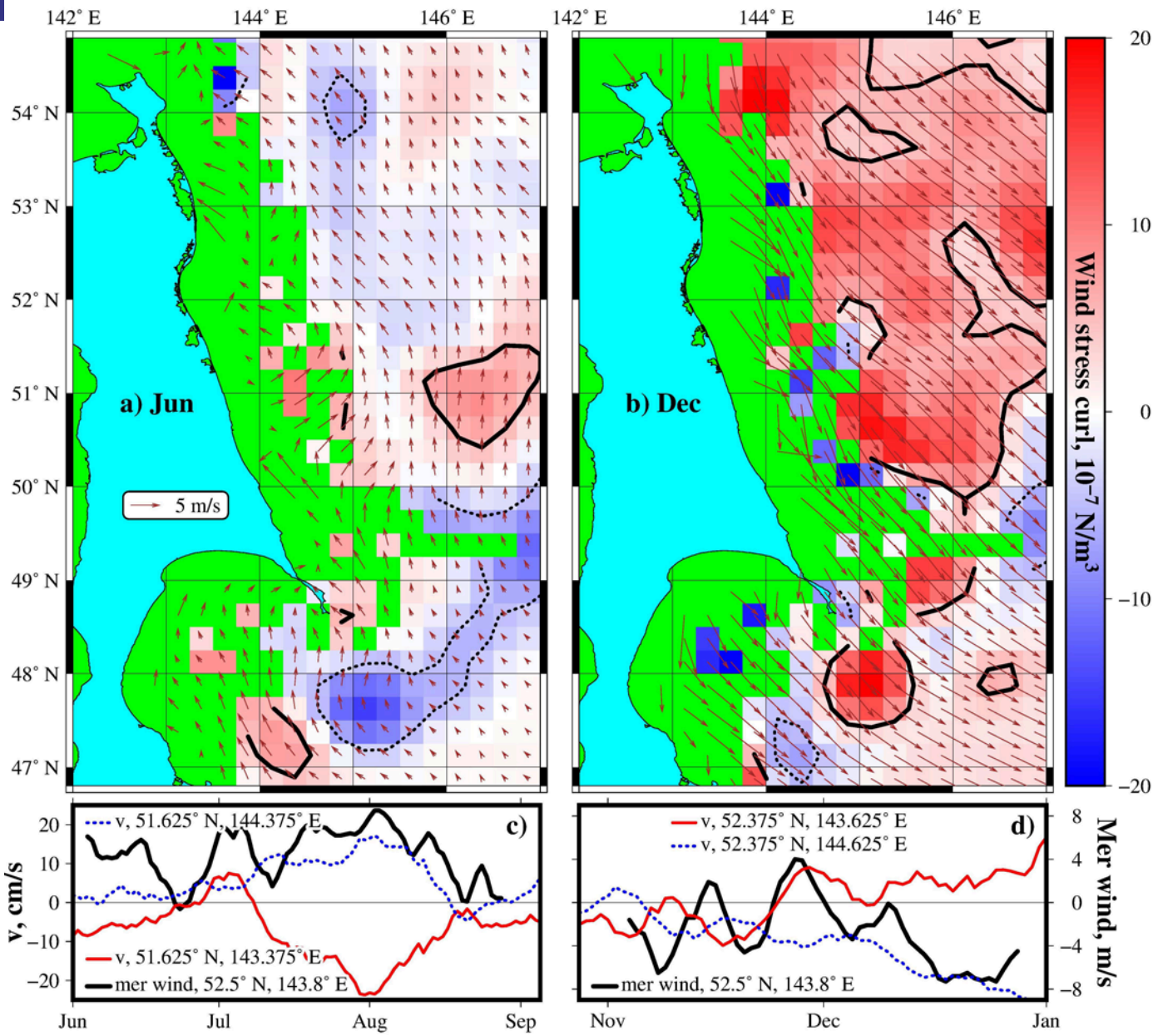
Lagrangian map

SST

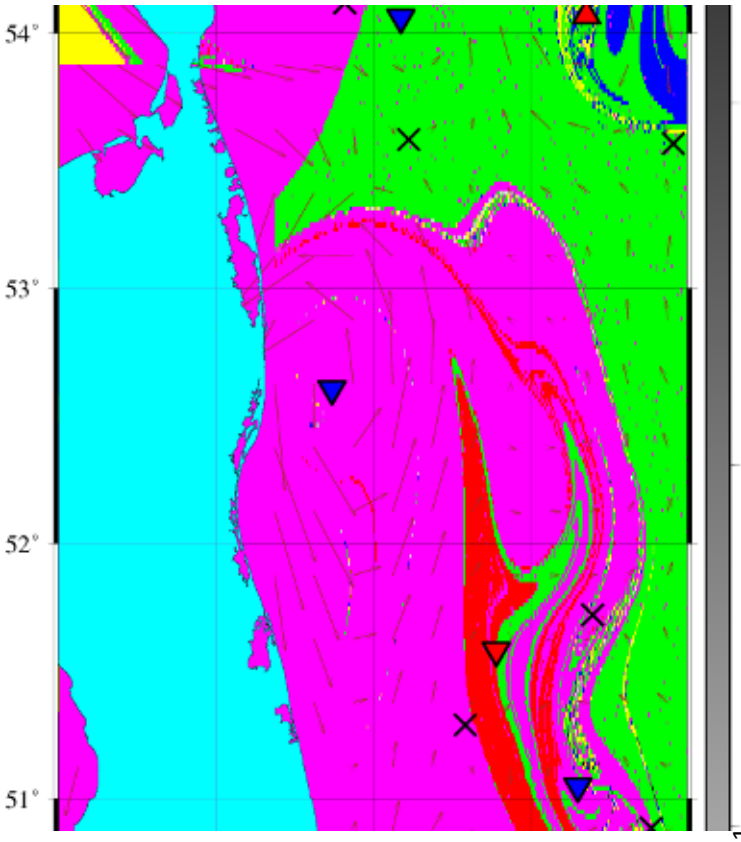


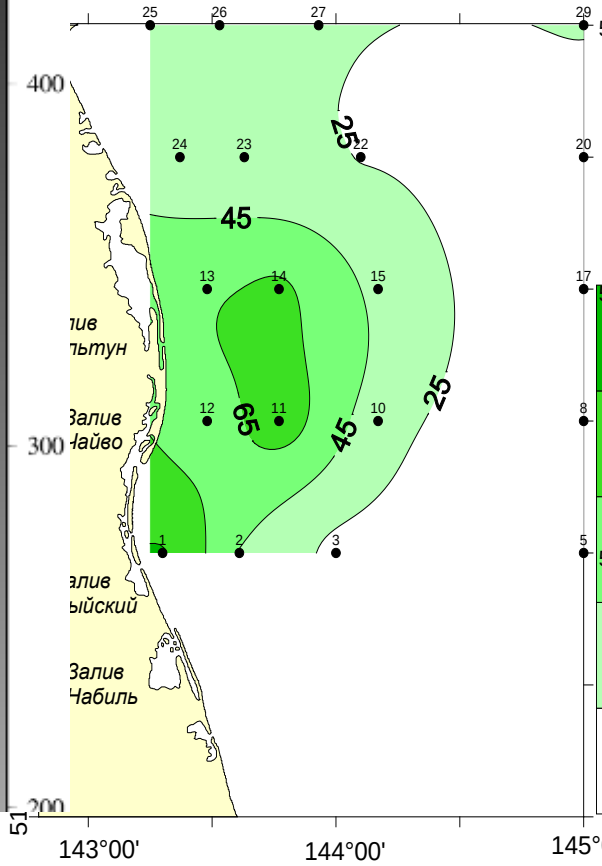
Lagrangian map

SST

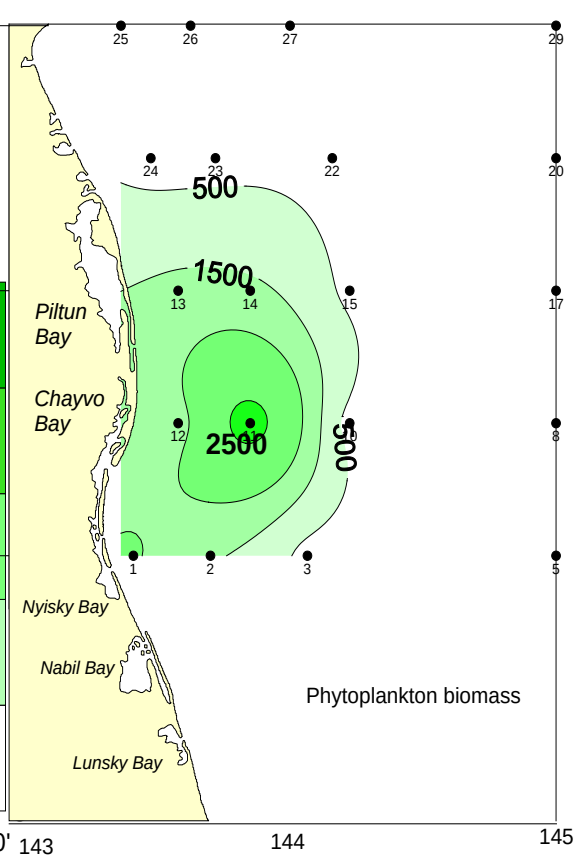

142° E
144° E
146° E
54° N
53° N
52° N
51° N
50° N
49° N
48° N
47° N
a) Jun
5 m/s
b) Dec
Wind stress curl, 10⁻⁷ N/m³
20
10
0
−10
−20
c)
v, 51.625° N, 144.375° E
v, 51.625° N, 143.375° E
mer wind, 52.5° N, 143.8° E
v, cm/s
Jun
Jul
Aug
Sep
d)
v, 52.375° N, 143.625° E
v, 52.375° N, 144.625° E
mer wind, 52.5° N, 143.8° E
Mer wind, m/s
Nov
Dec
Jan

Belan et al. Oceanographical and hydrobiological investigations along north east Sakhalin Island in summer 2003.

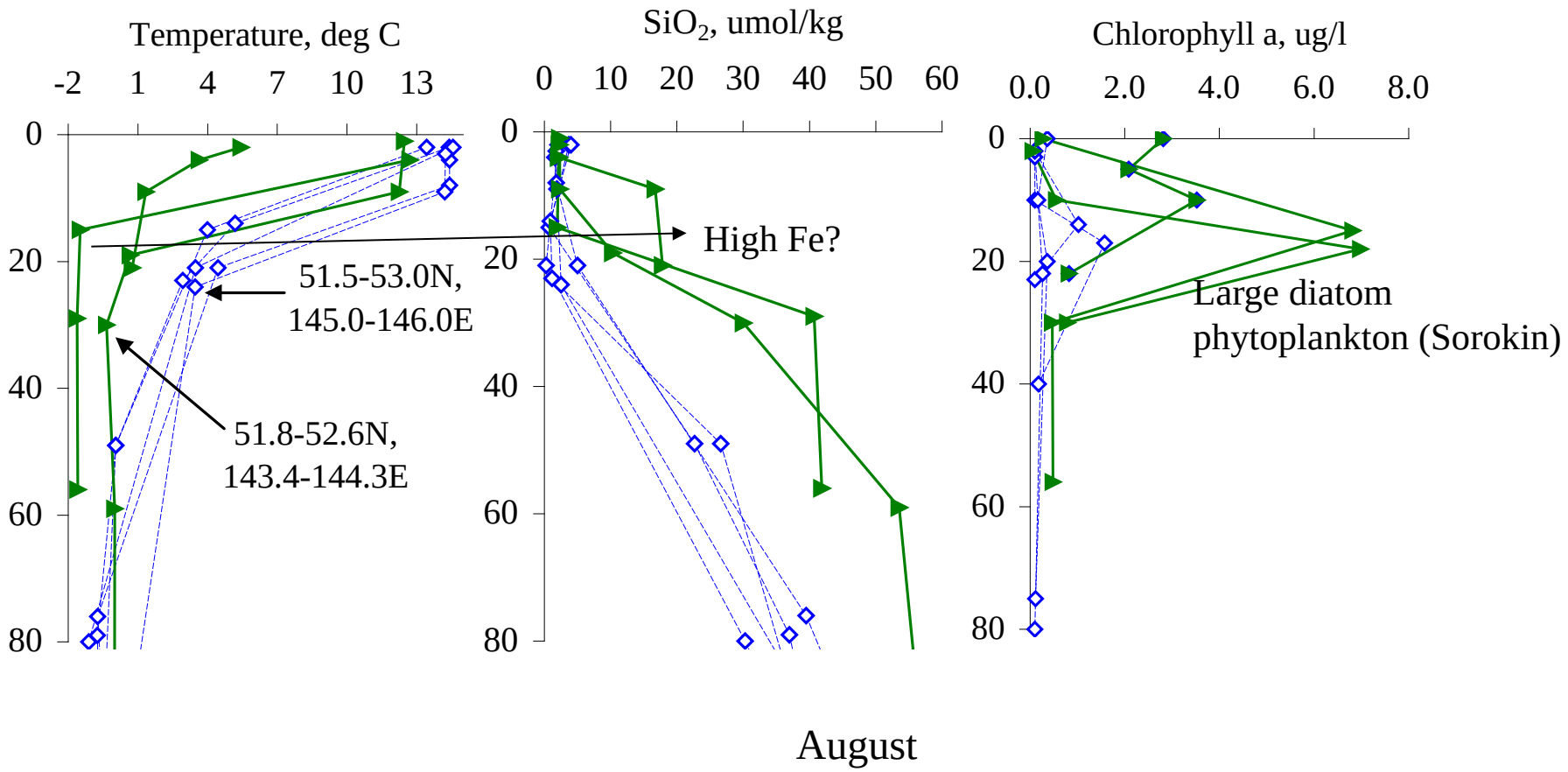




Chlorophyll-a concentration, (depth integrated, mg/m2)



Phytoplankton biomass, (mg/m3)


Temperature, deg C
-2 1 4 7 10 13
SiO_2, umol/kg
0 10 20 30 40 50 60
Chlorophyll a, ug/l
0.0 2.0 4.0 6.0 8.0
0
20
40
60
80
High Fe?
51.5-53.0N,
145.0-146.0E
51.8-52.6N,
143.4-144.3E
Large diatom
phytoplankton (Sorokin)

August

Summary

The seasonal and interannual variability of circulation in the eastern and western Okhotsk Sea has been investigated using AVISO velocity field and oceanographic data for the period from 1993 to 2015. Year-to-year changes of the Alaskan Stream surface flow, forming the northern boundary of the western subarctic gyre in Pacific Ocean, impact dynamics of water and plankton biomass in the eastern Okhotsk Sea. An intensification/weakening of the Alaskan Stream current leads to increased/decreased fluxes in the areas of the Krusenstern and Fourth Kuril Straits connected the Okhotsk Sea with the Pacific Ocean. Enhance of the Alaskan Stream flux is accompanied by an increase in water temperature and biomass of small- and medium-sized zooplankton and decreasing ice area and biomass of large-sized zooplankton in the eastern Okhotsk Sea. In the East-Sakhalin Current region, the coastal upwelling forcing by northward winds and positive wind stress curl along the Sakhalin coast in summer lead to the mesoscale cyclone formation. An inflow of low salinity waters from the Sakhalin Bay driving by southward winds and negative wind stress curl along the Sakhalin coast during fall and winter result in the mesoscale anticyclone generation. The mesoscale cyclones support the high biological productivity at the eastern Sakhalin shelf in July-August.