Modeling Ice-Ocean-Ecosystem in the Bering-Chukchi-Beaufort Seas:

Using IPY (2007-2008), RUSALCA 2004 and 2009 measurements

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CILER
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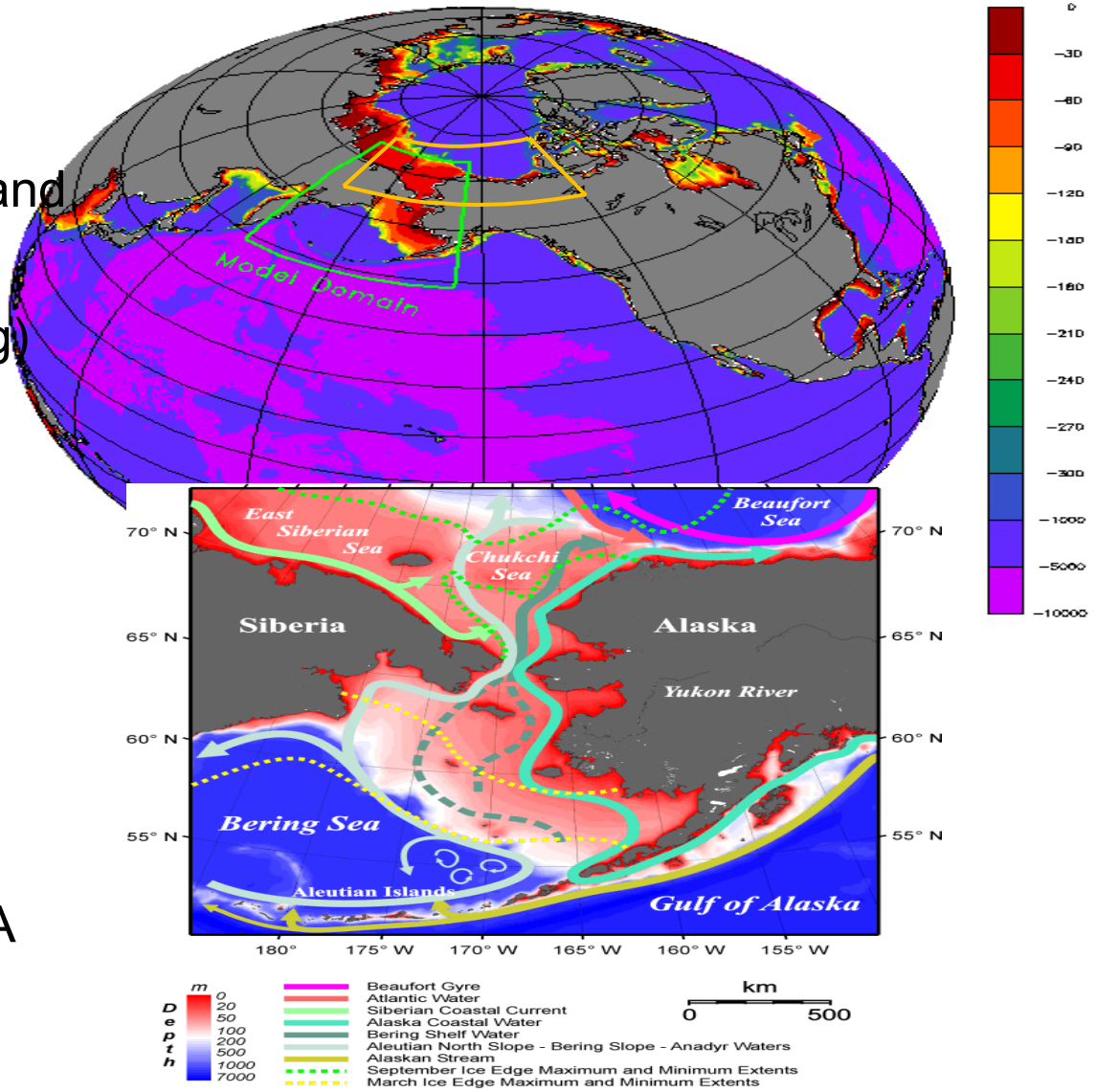
Modeling Bering-Chukchi Sea ice-ocean and ecosystem using CIOM

- CIOM with fully dynamics and thermodynamics, multiple category ice thickness (ridging)
- 3.8km and 21 level
- 6-hourly or daily forcing
- 3 configurations:

Bering Sea only (7-12km), Chukchi only (3.8km), Bering-Chukchi Sea (3.8-12km)

- Hypotheses test/RUSALCA synthesis
- Realistic simulation

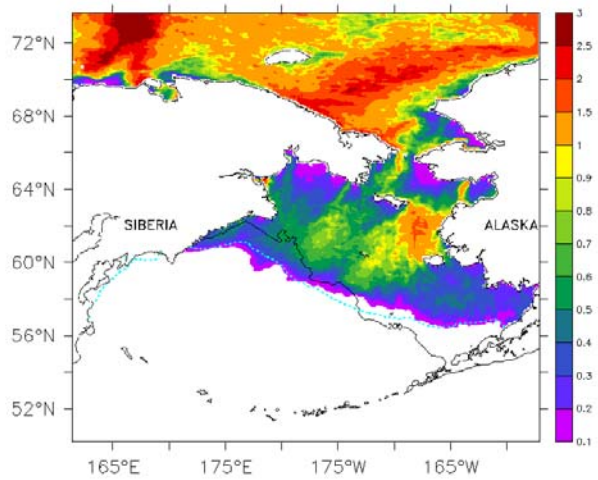


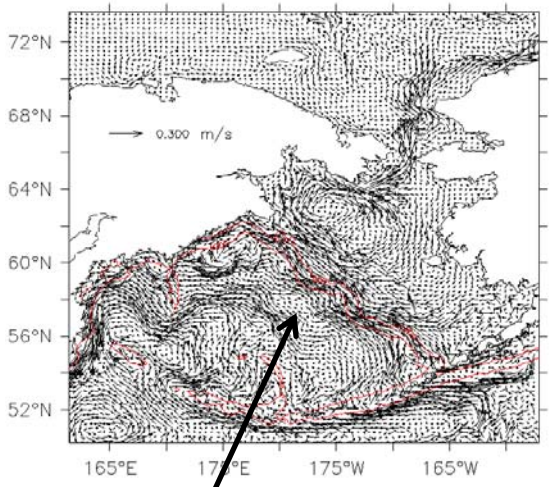
Modeling coastal circulation and T/S properties in the Chukchi Sea using CIOM: RUSALCA Years: 2004, 2009

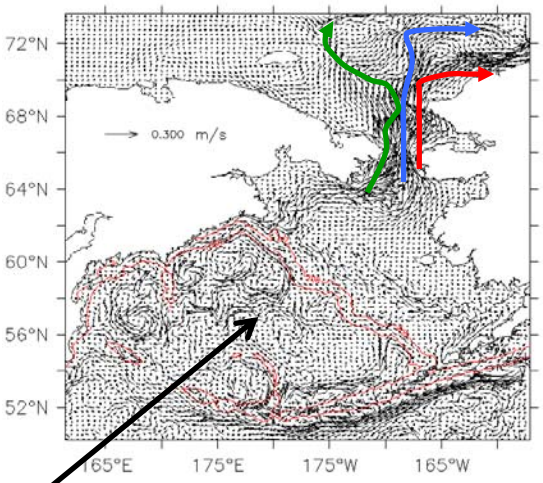
Wang et al. (submitted)

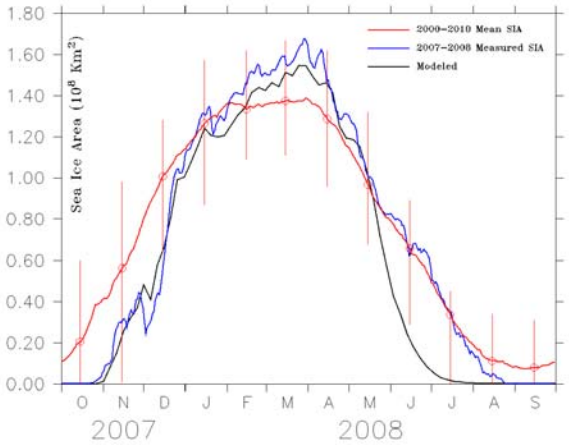
Coupled Ice-Ocean-Ecosystem Model in the Bering-Beaufort-Chukchi Seas (IPY)

Modeled ice thickness (3/08) surface current (3/08) surface current (7/08)



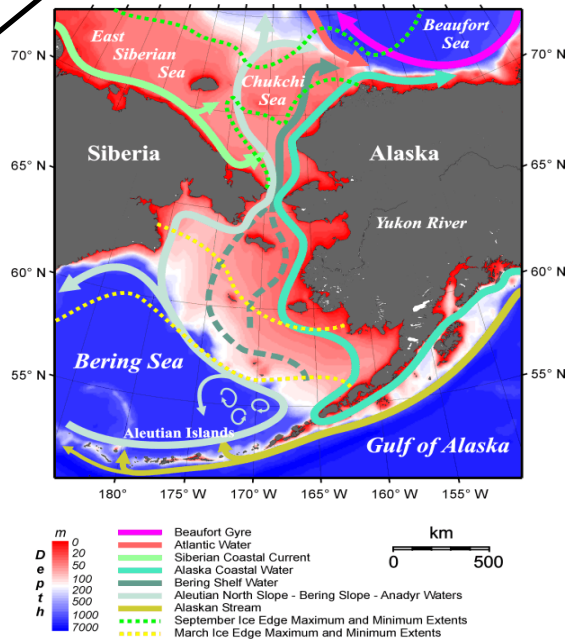






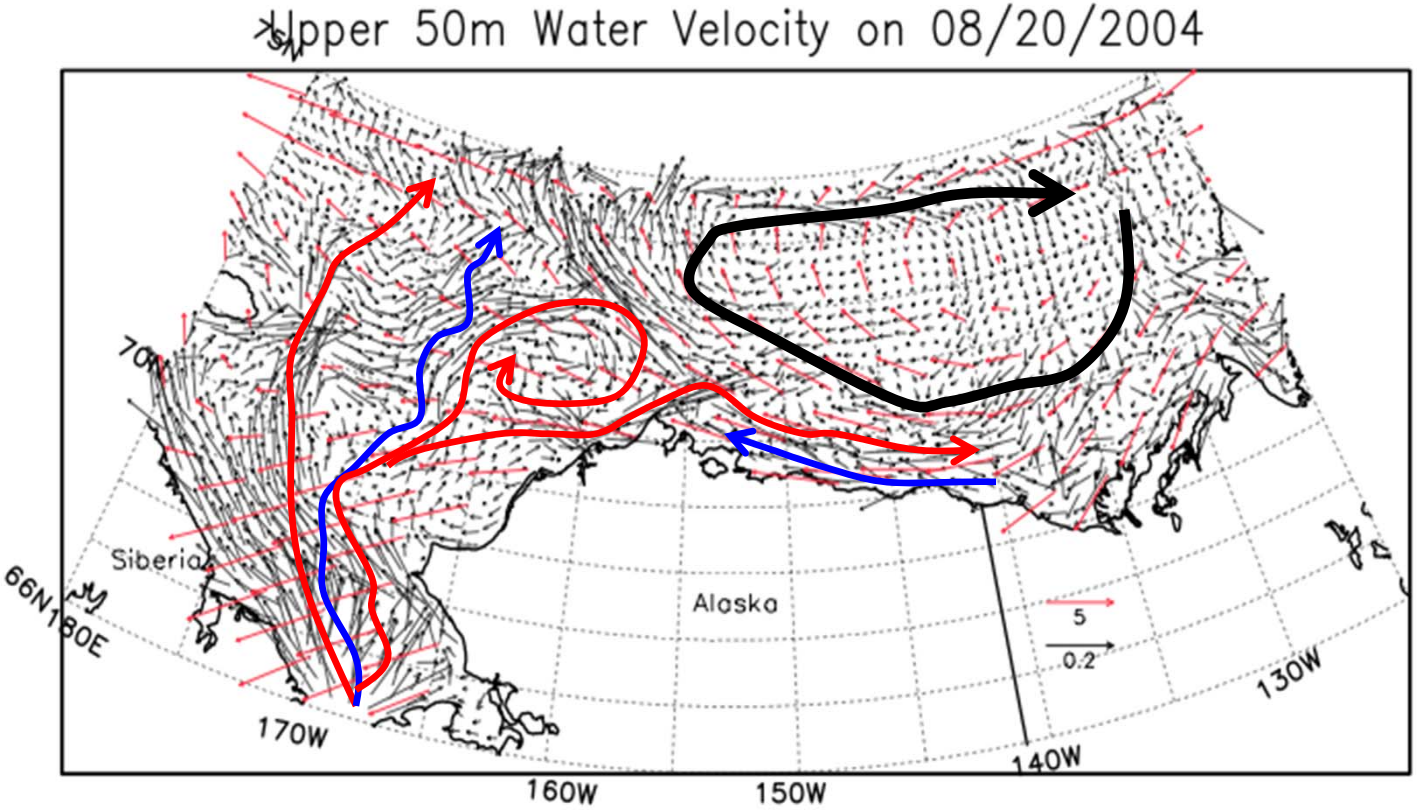
Few eddies

More eddies

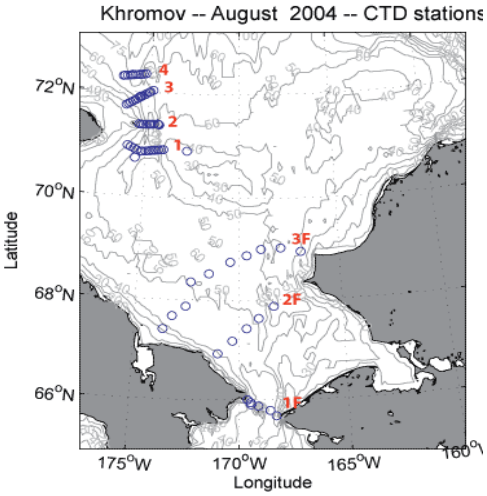


Simulated sea ice area (black line) and satellite-measured sea ice area (blue) over the entire Bering and Chukchi Seas for 2007-2008. The red line denotes the 11-year average area and the red vertical bars denote the maximum and minimum ice areas during 2000-2011. (Wang et al. 2013, JGR)

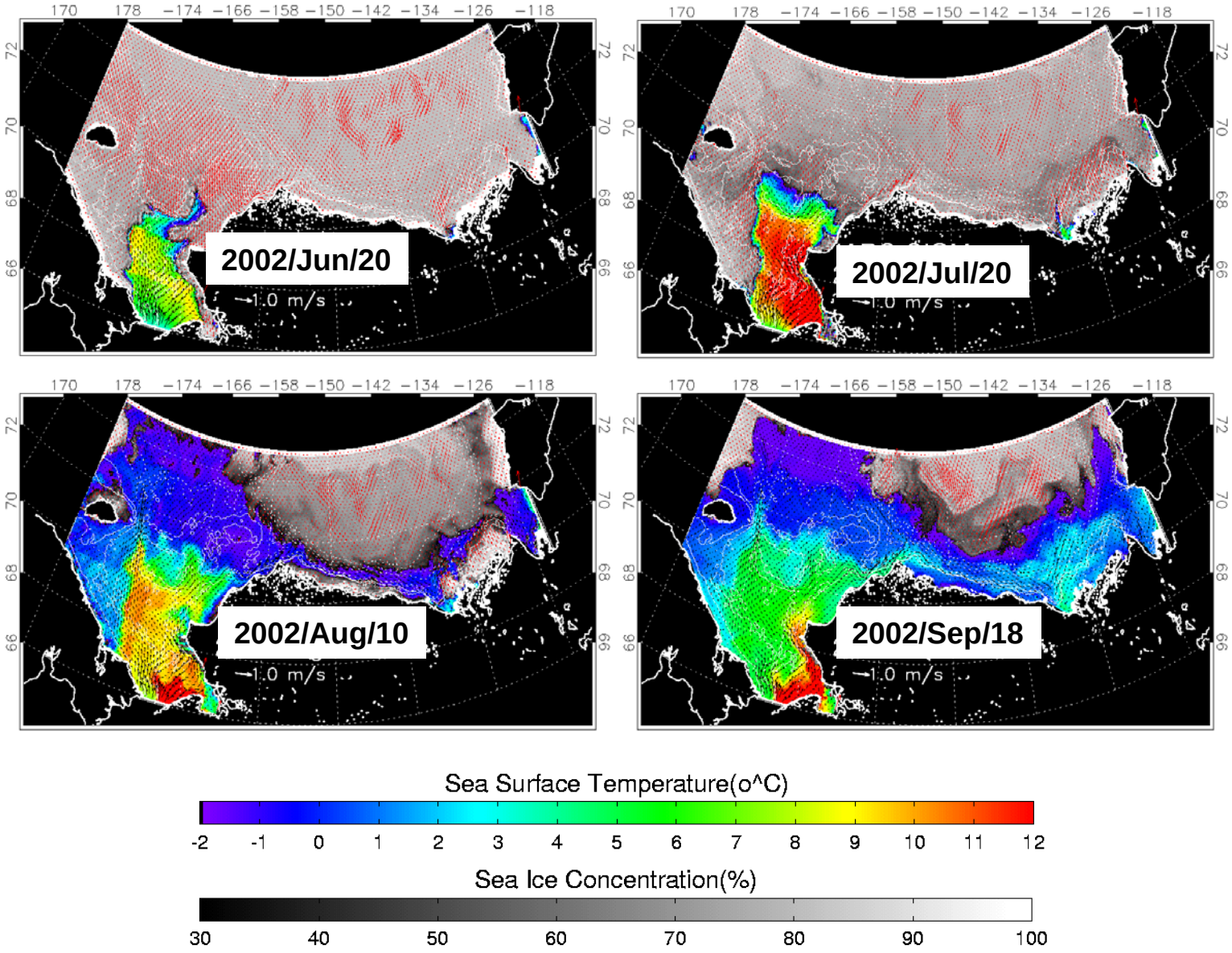
Verification of CIOM using 2004 RUSALCA Data (T) in the Bering-Beaufort-Chukchi Seas (work in progress)



RUSALCA
Aug 2004

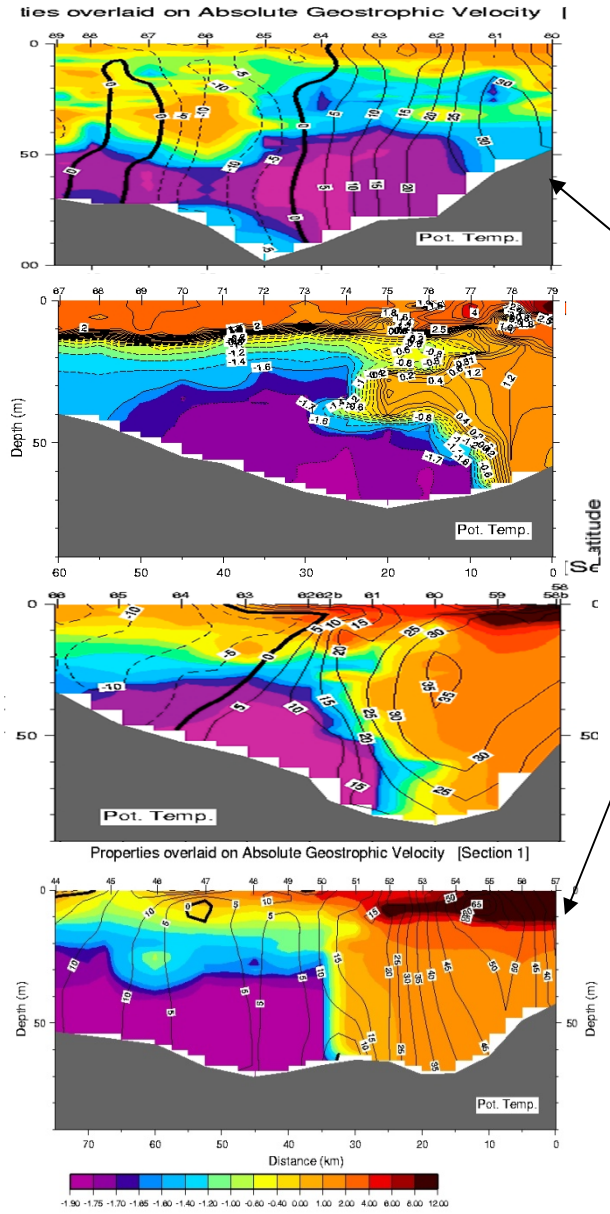


CIOM-simulated ice-ocean system

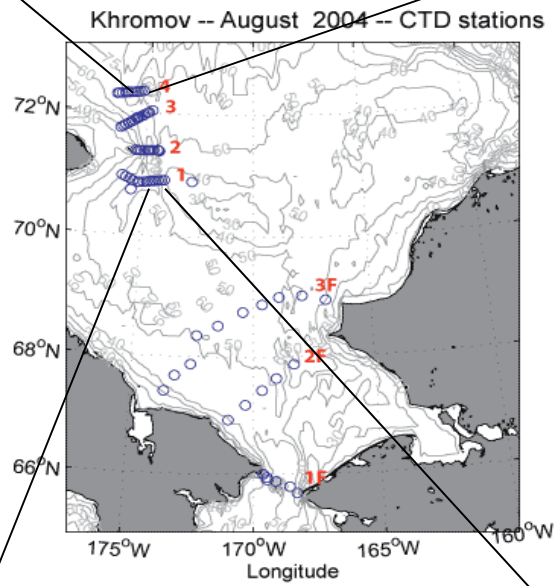


Verification of CIOM using 2004 RUSALCA Data (T&V) in the Bering-Beaufort-Chukchi Seas

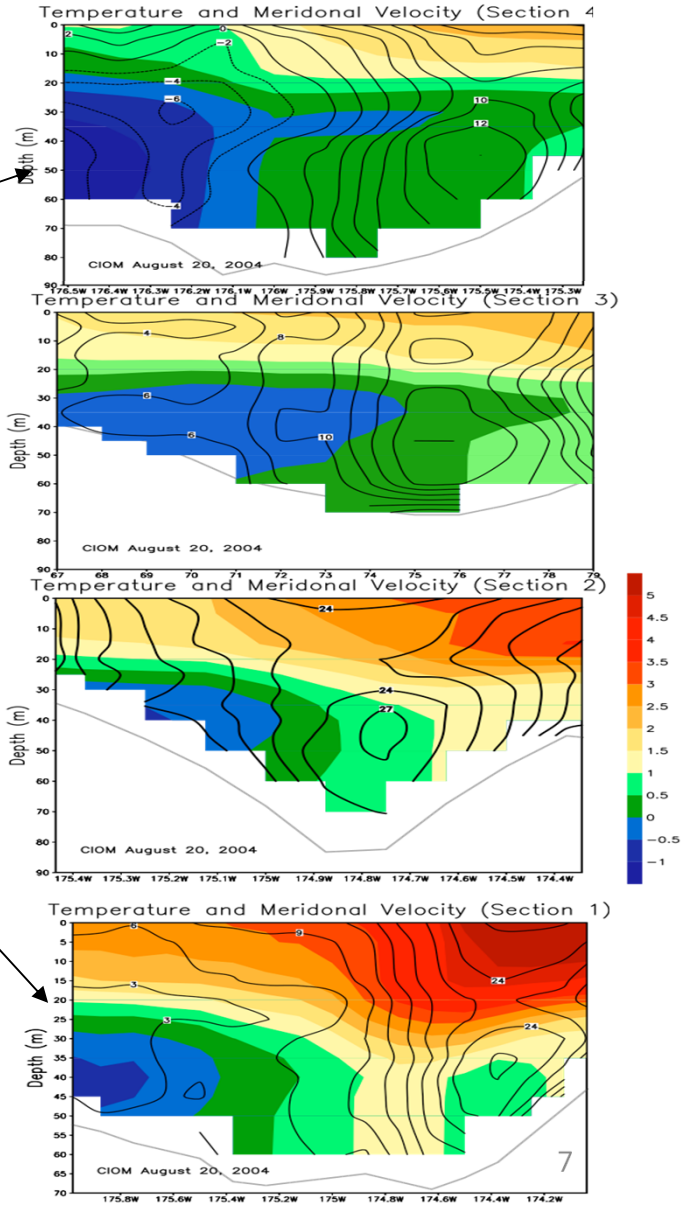
Observed (Pickart)



Aug 2004



CIOM-simulated (GLERL)

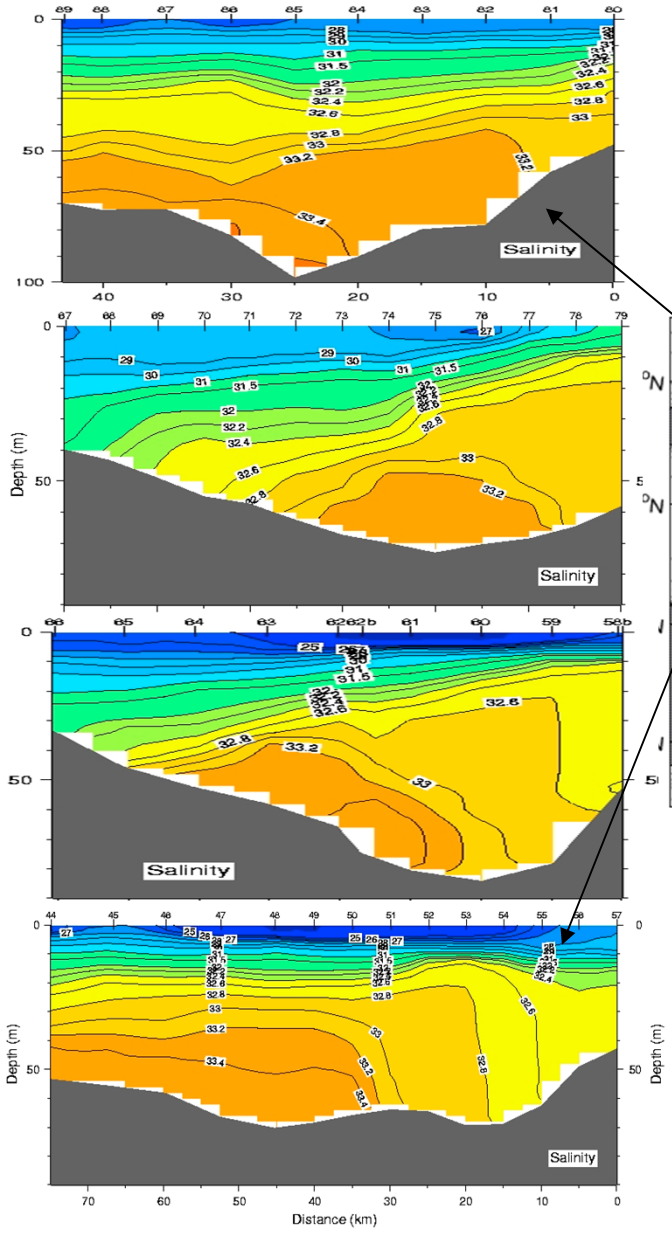


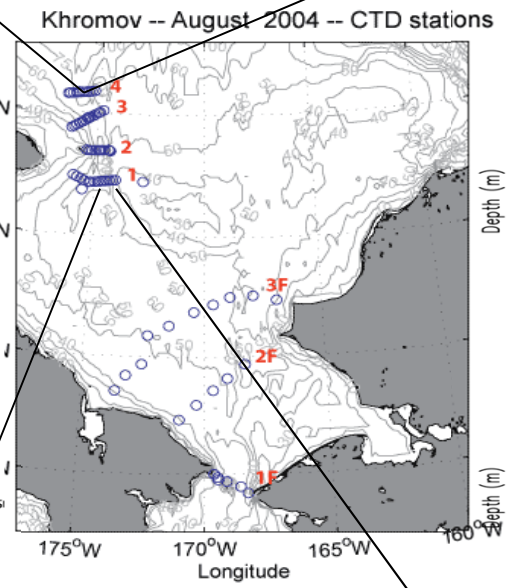
Verification of CIOM using 2004 RUSALCA Data (S) in the Bering-Beaufort-Chukchi Seas

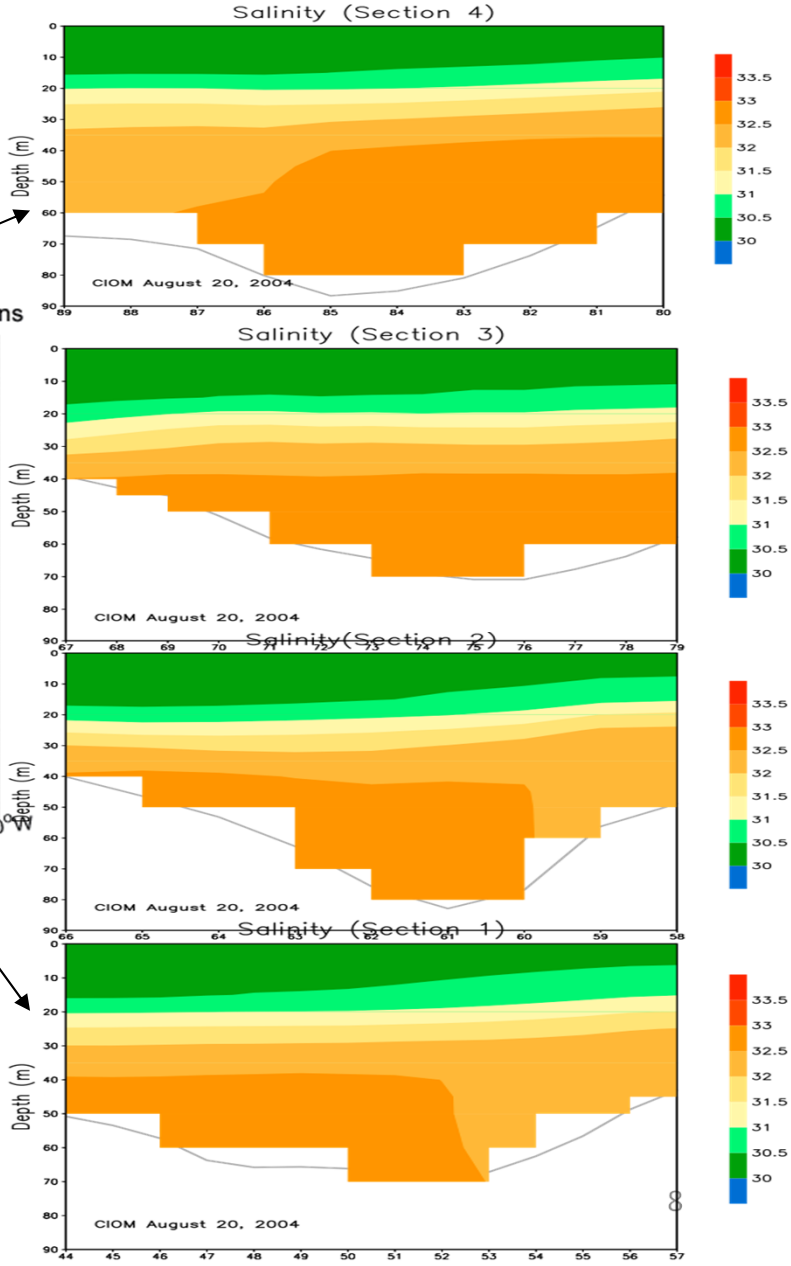
Observed (Pickart)

CIOM-simulated (GLERL)

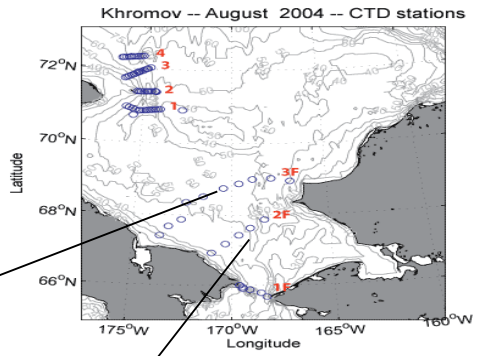
Aug 2004 (need tidal forcing)

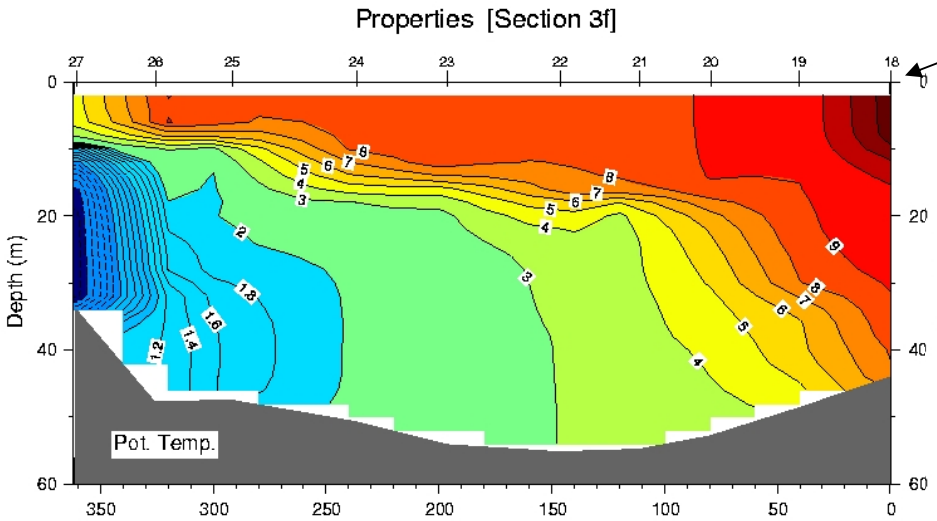


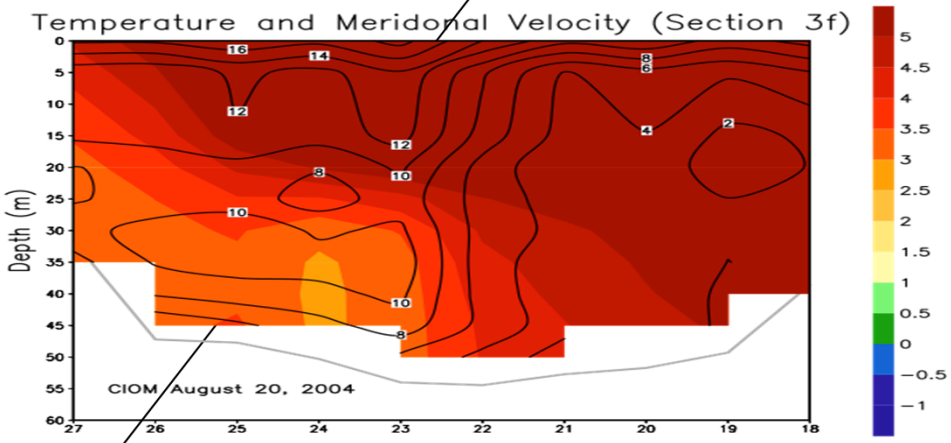


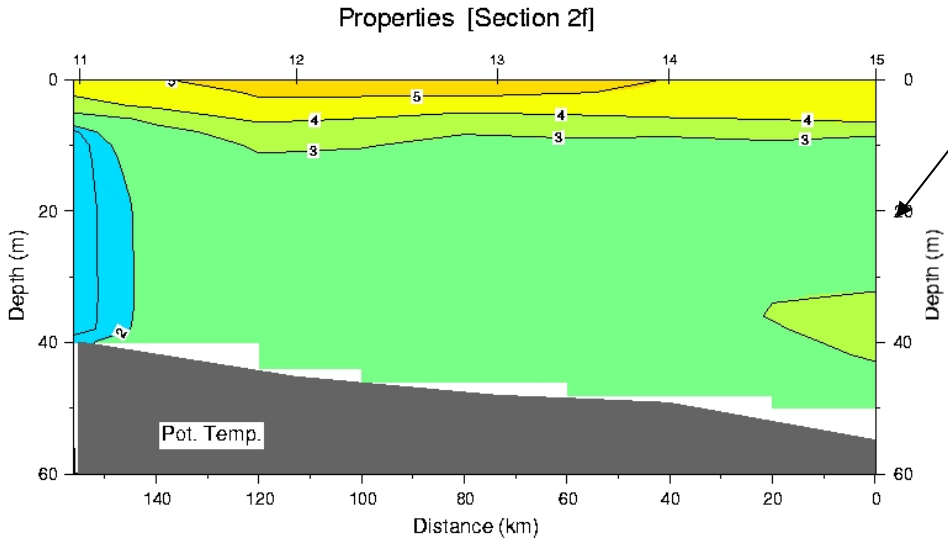


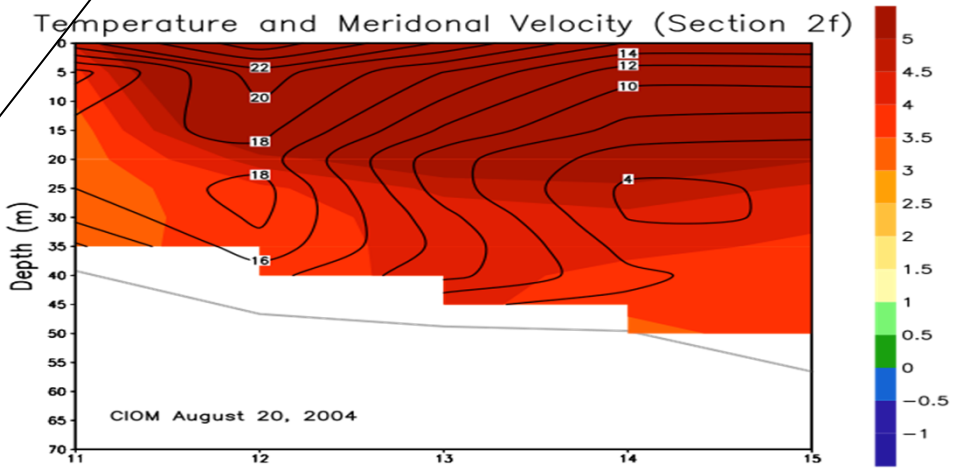
Southern Chukchi Sea



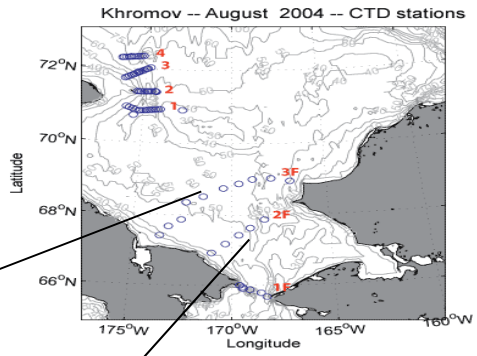


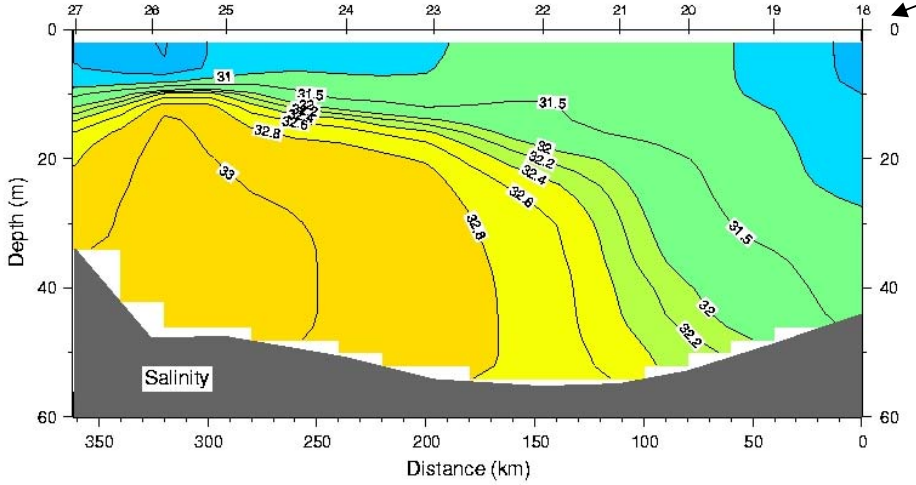


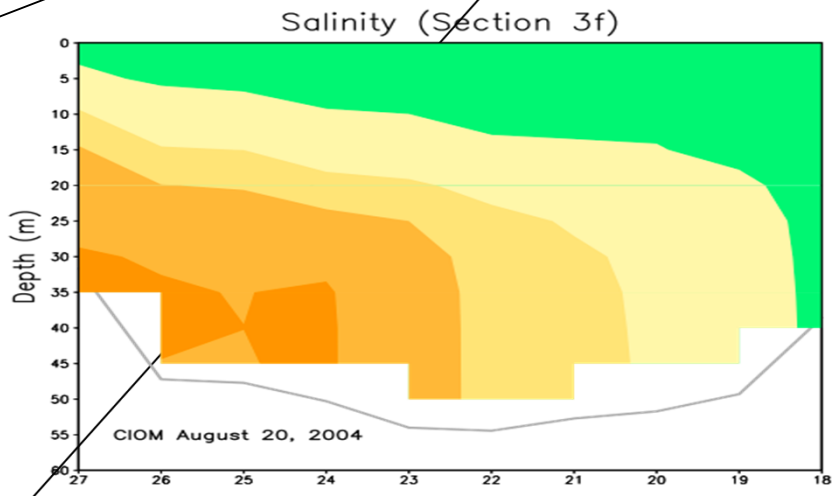


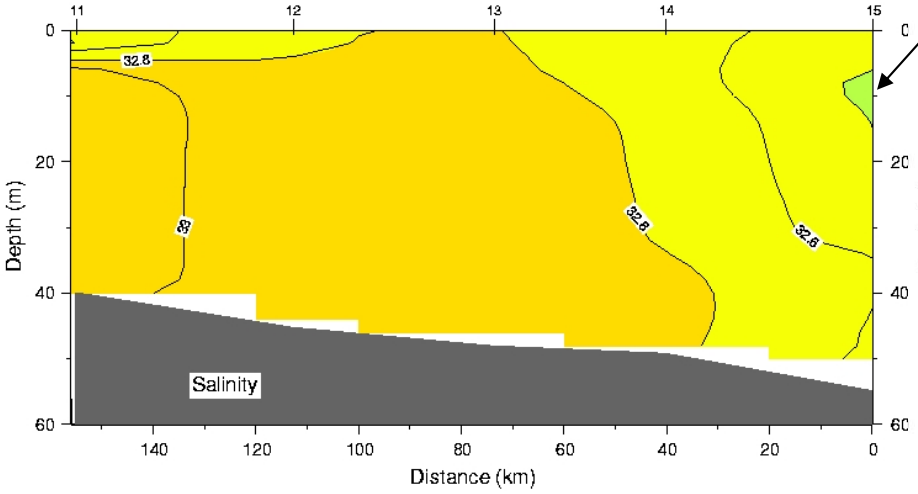


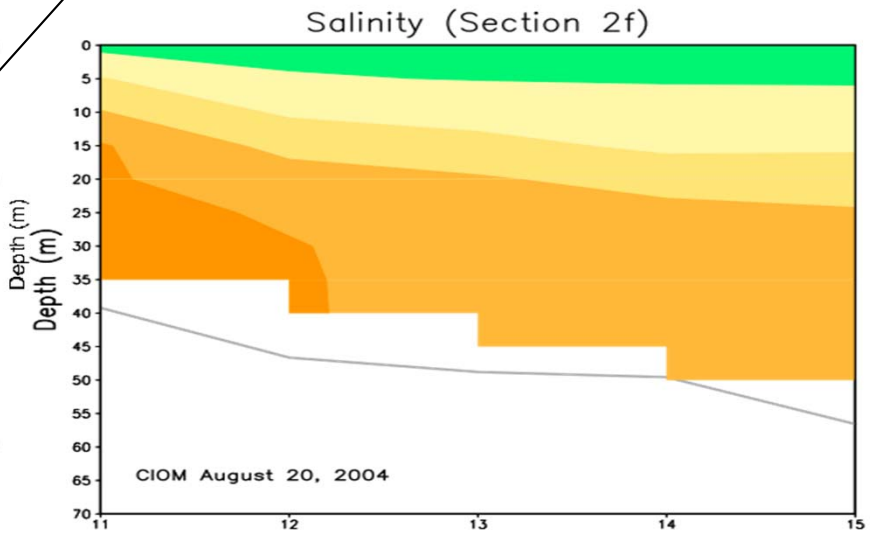
Southern Chukchi Sea: S



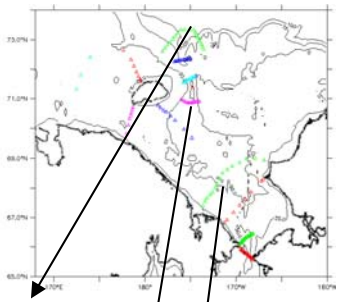




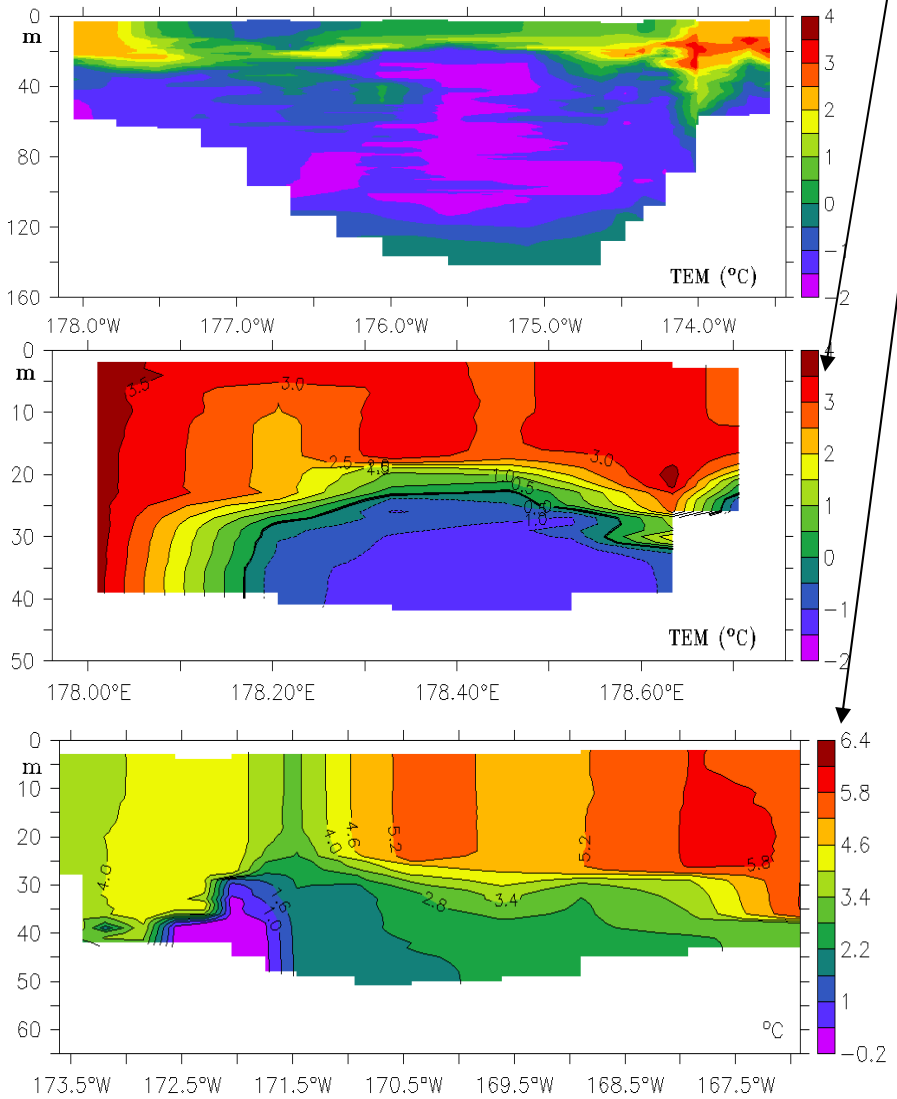




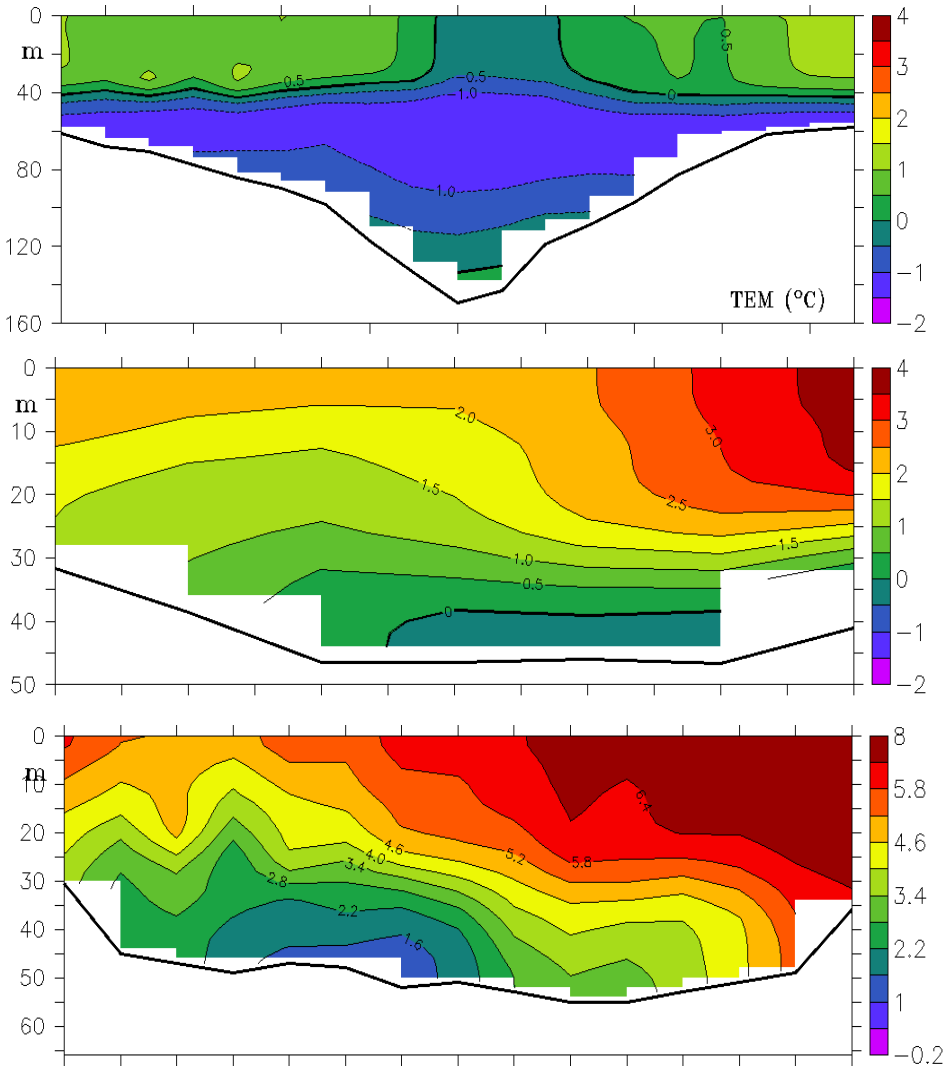
Verification of CIOM using 2009 RUSALCA Data (T) in the Beaufort-Chukchi Seas

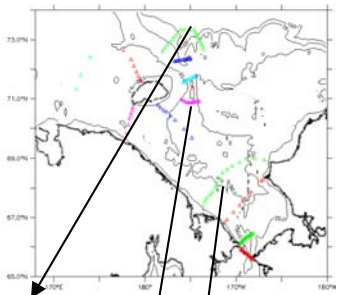


RUSALCA-observed temperature (Pickard and others)

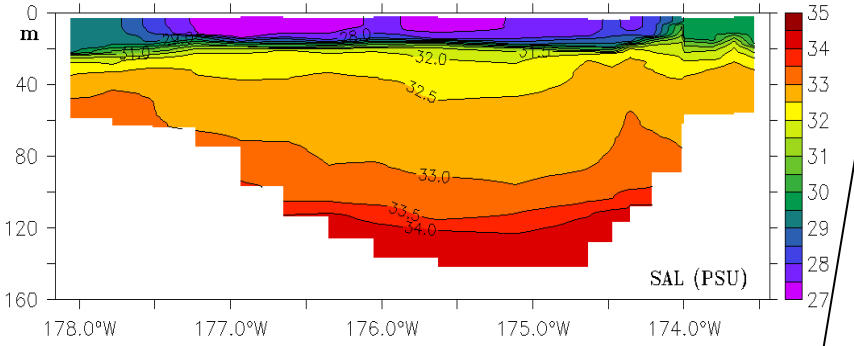


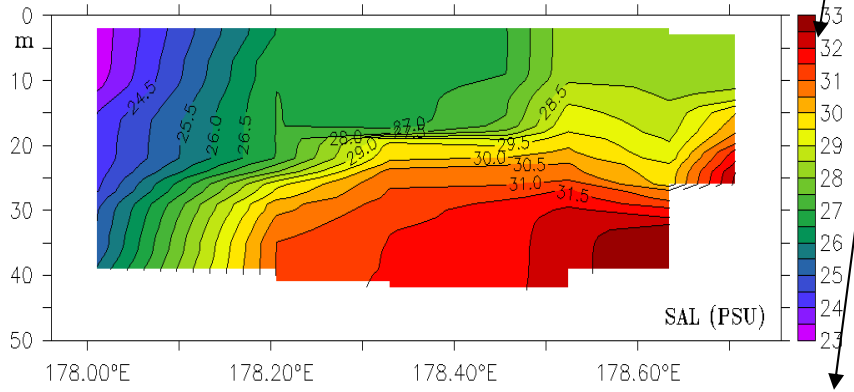
CIOM-simulated temperature (GLERL)

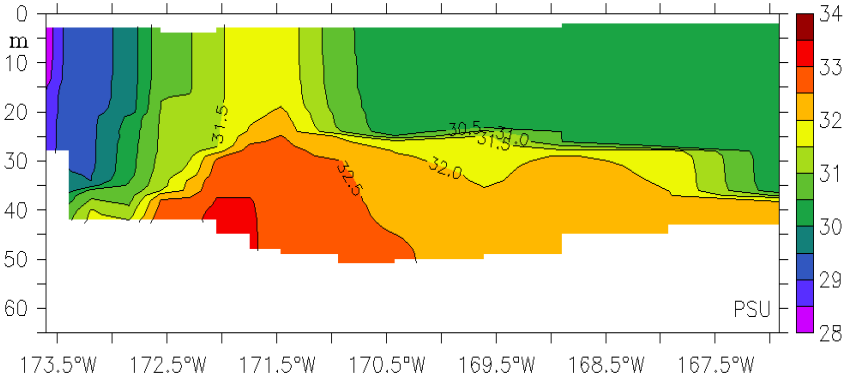




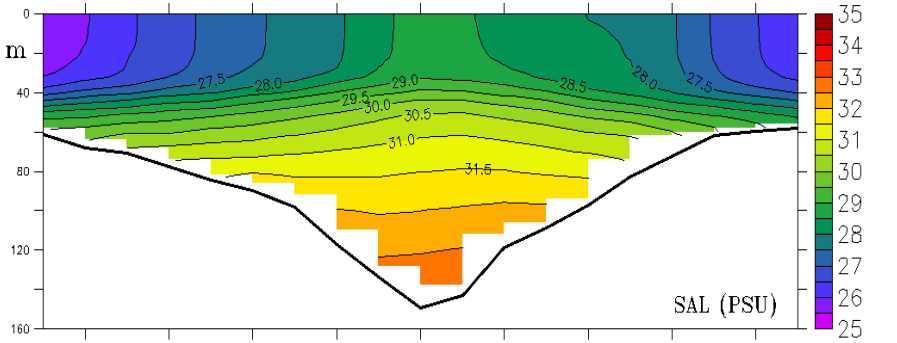
Observed salinity

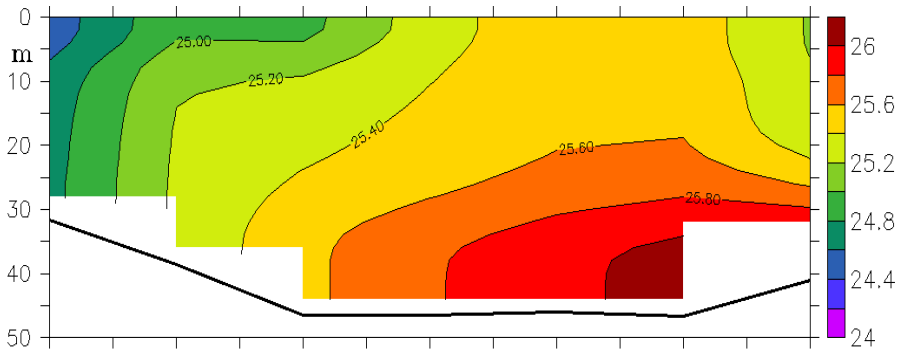


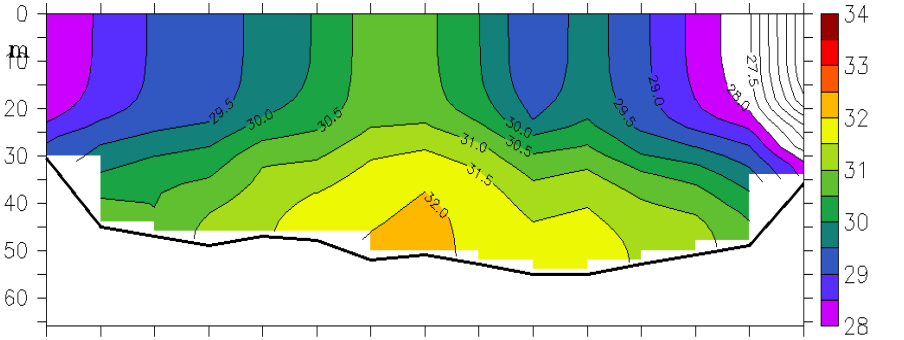




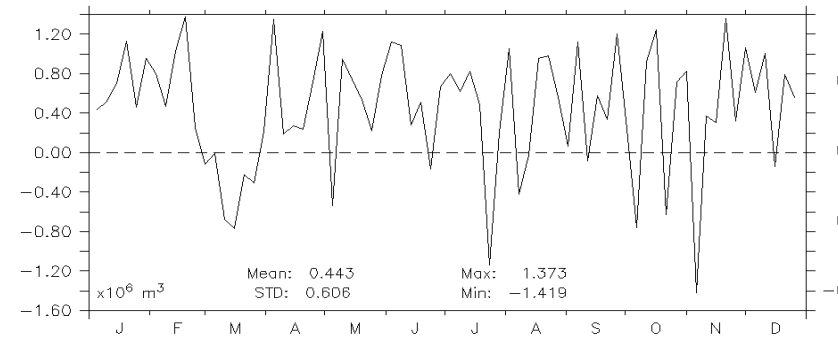
Simulated salinity

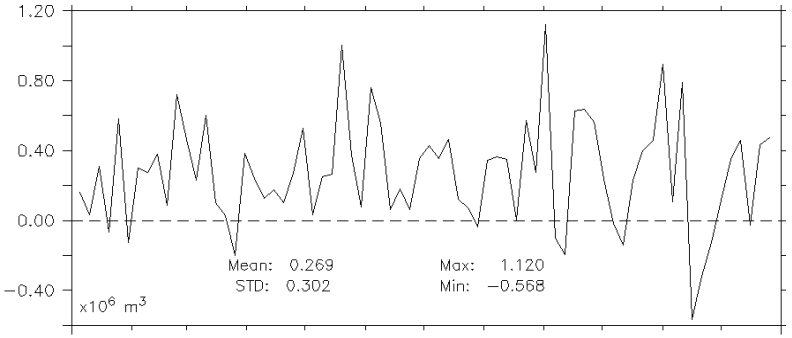


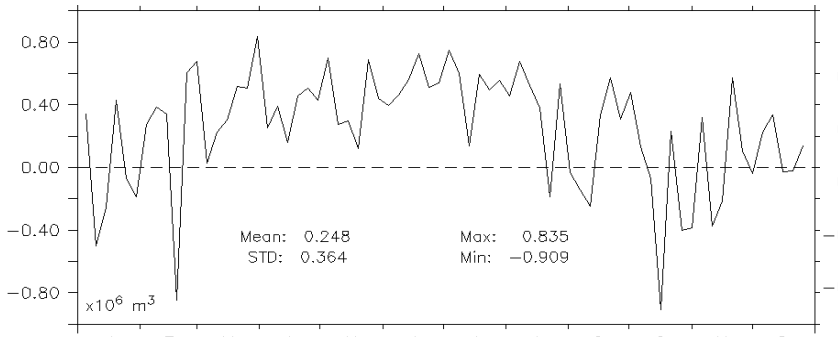


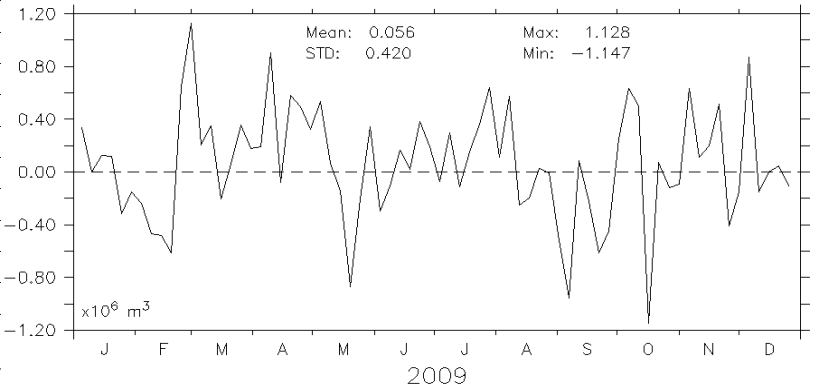


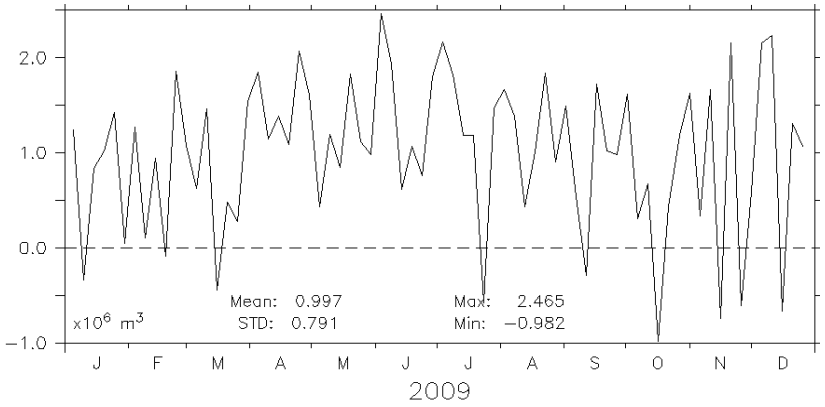
Volume Transport through Five Straits











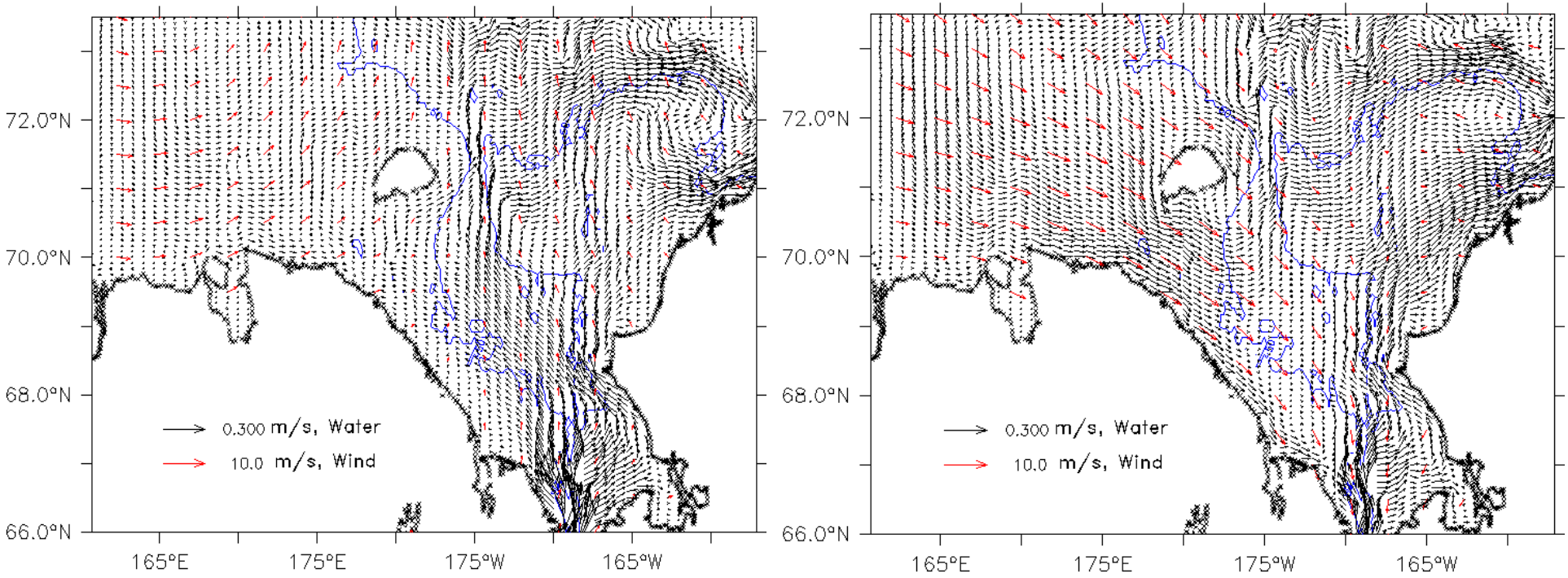
2009 Transport through

Barrow Canyon **Central Channel**

Herald Valley **Long Island Strait**

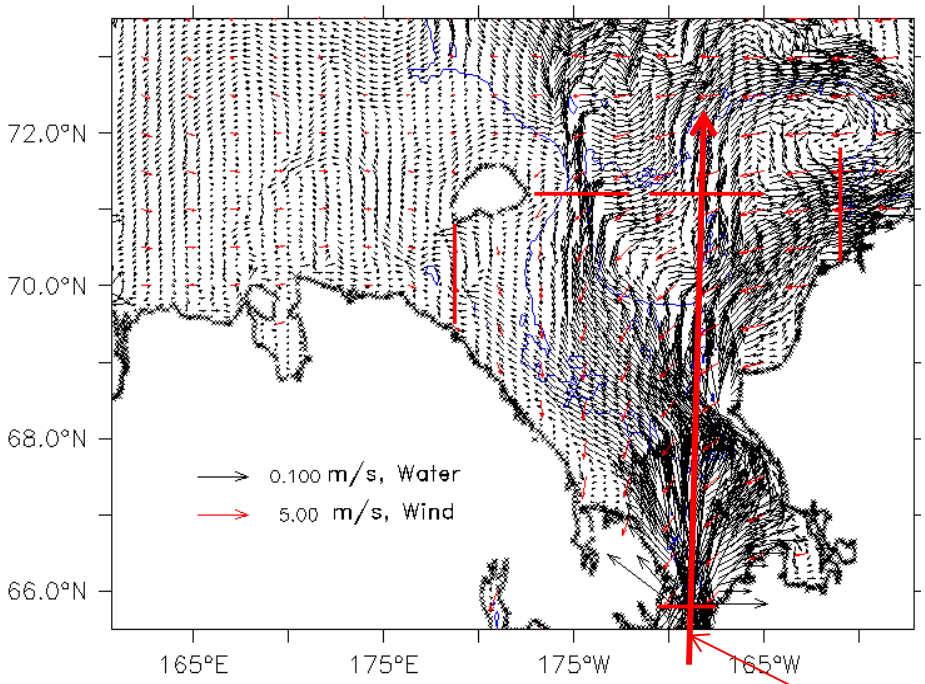
Bering Strait.

Transport reversals are caused by Pacific Arctic pressure head + wind forcing



August September

Depth-averaged currents in the Chukchi Sea 2009



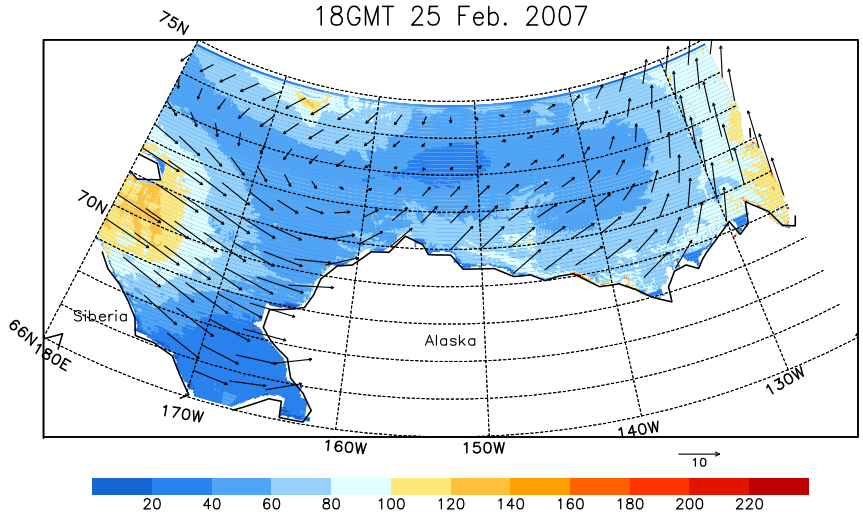
Pacific Arctic pressure head
+ Wind forcing
➔ Transport reversals

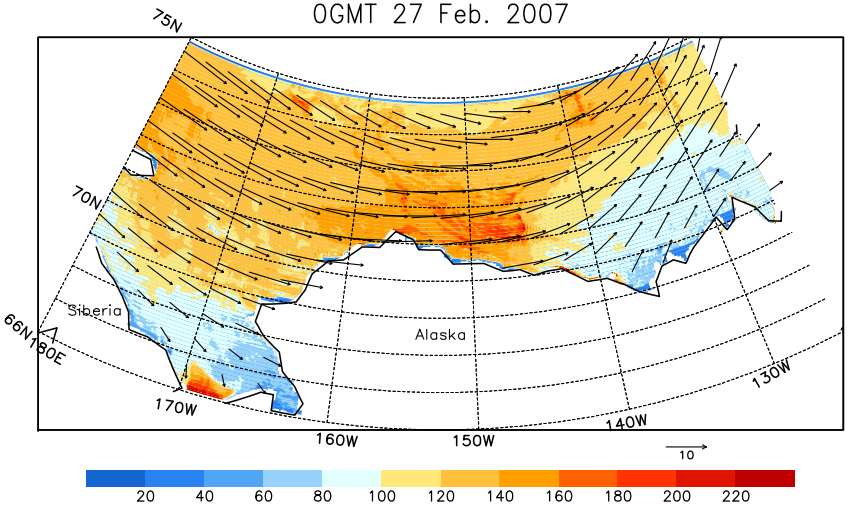
Table: Water transports in the Chukchi Sea in 2009, positive and negative values denote flowing into and out of Chukchi Sea, respectively.

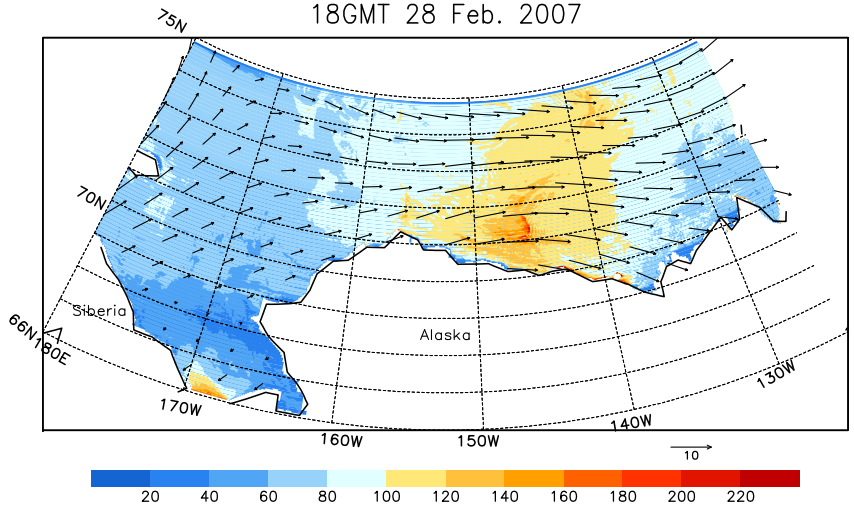
Unit: Sv	Mean	STD	Mean /STD	Max	Min	|Max| /|Min|	Observations
Barrow Canyon	0.44	0.61	0.73	1.37	-1.42 (westward)	0.97	0.45 (Itoh et al. 2013)
Central Channel	0.27	0.30	0.89	1.12	-0.57 (southward)	**1.97**	0.2 ± 0.1 (Weingartner et al. 2005)
Herald Canyon	0.25	0.36	0.68	0.84	-0.91 (southward)	0.92	0.1-0.3 (Woodgate et al. 2005)
Long Strait	0.06	0.42	**0.13**	1.13	-1.15 (eastward)	0.98	
Bering Strait	1.00	0.79	**1.26**	2.47	-0.98 (southward)	**2.51**	0.8 ± 0.2 (Woodgate et al. 2006)

Modeling ice-ocean system response to storm passage in the Beaufort Sea using CIOM

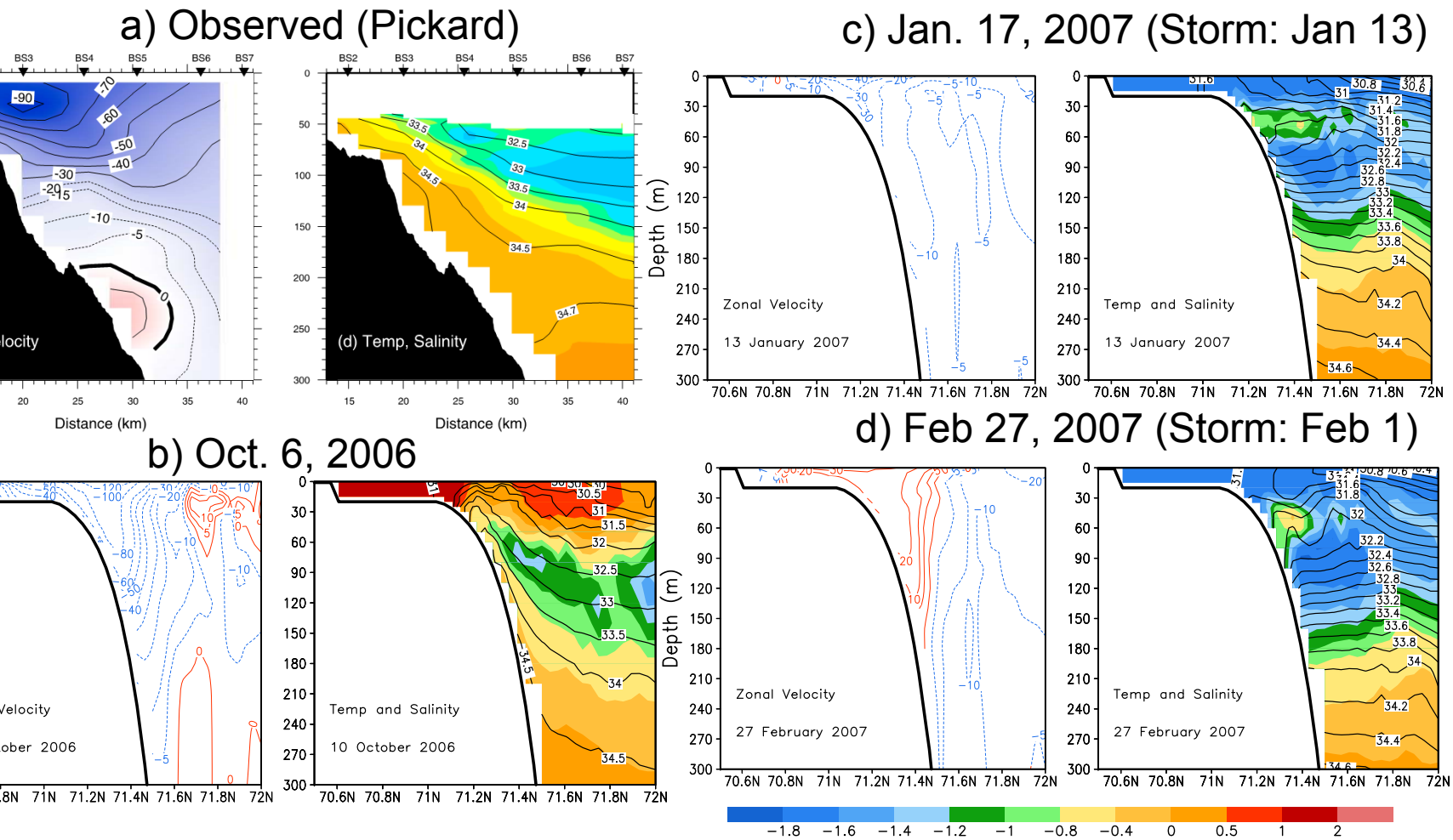
Bai et al. (2015, Deep Sea Res, II)

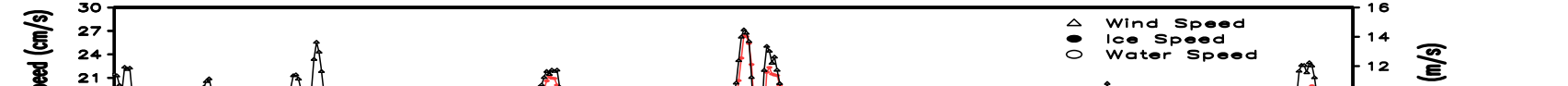


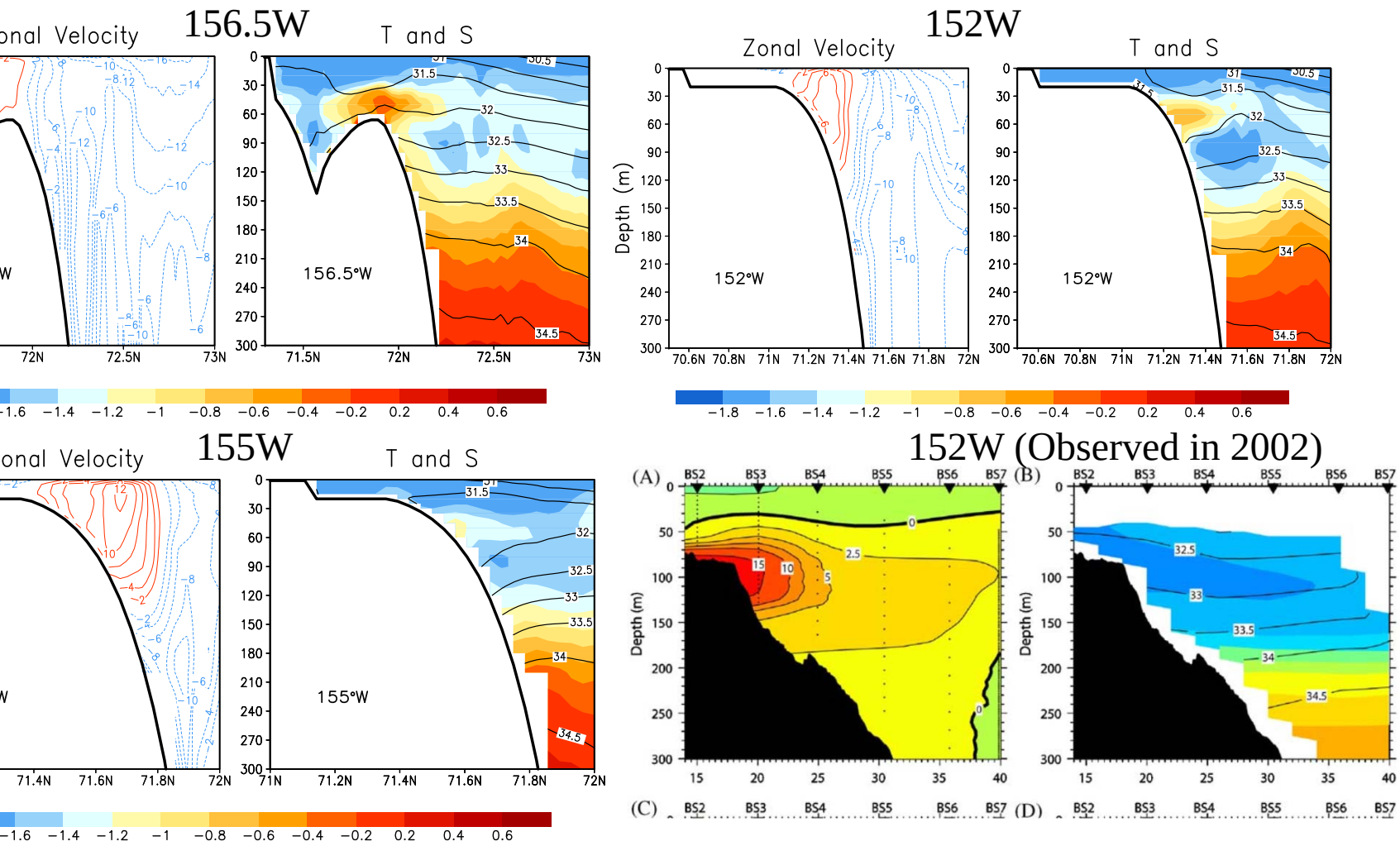




Calculated net surface heat flux (W/m^2, positive upward) with wind vectors overlain during the passage of the cyclone on 25-27 February 2007.


a) Observed (Pickard)
c) Jan. 17, 2007 (Storm: Jan 13)
b) Oct. 6, 2006
d) Feb 27, 2007 (Storm: Feb 1)
BS3 BS4 BS5 BS6 BS7
BS2 BS3 BS4 BS5 BS6 BS7
Distance (km)
(d) Temp, Salinity
Depth (m)
Zonal Velocity
13 January 2007
Temp and Salinity
13 January 2007
Zonal Velocity
27 February 2007
Temp and Salinity
27 February 2007
Temp and Salinity
10 October 2006
70.6N 70.8N 71N 71.2N 71.4N 71.6N 71.8N 72N
−1.8 −1.6 −1.4 −1.2 −1 −0.8 −0.4 0 0.5 1 2

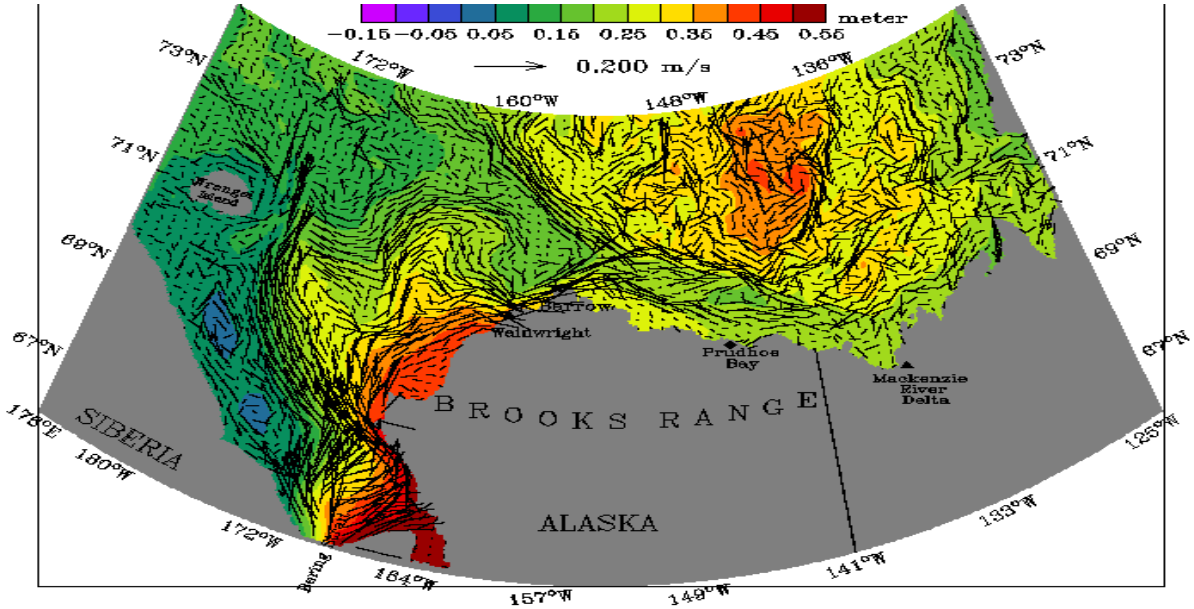

Wind Speed
Ice Speed
Water Speed
(m/s)



d vertical sections of winter mean zonal velocity (contour, unit: cm/s) and
ure (shaded) and salinity (black line) along 156.5W, 155W and 152W

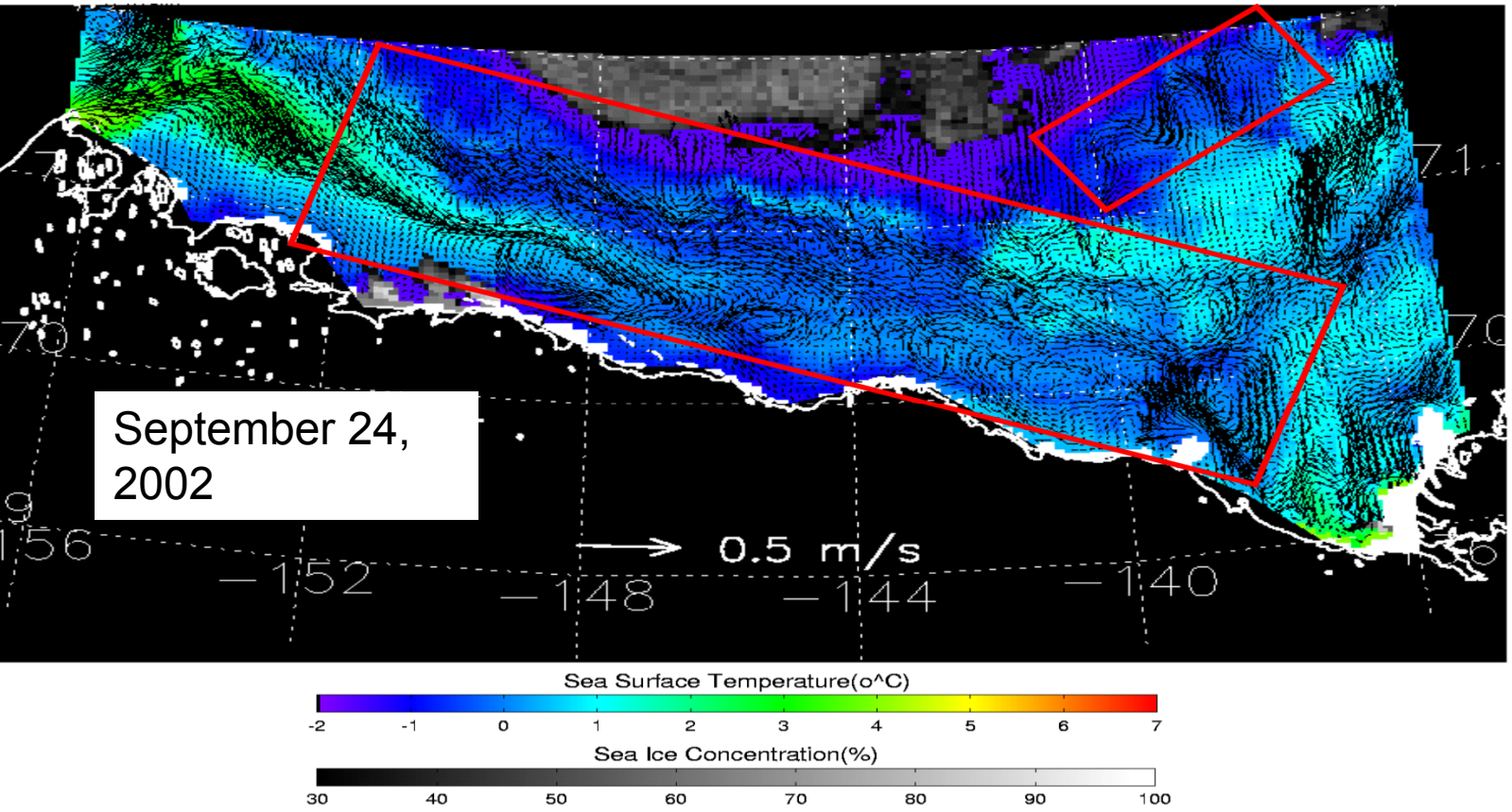
odeling coastal circulation and landfast ice in the Beaufort Sea using CIOM

ang et al. (2014, JGR)

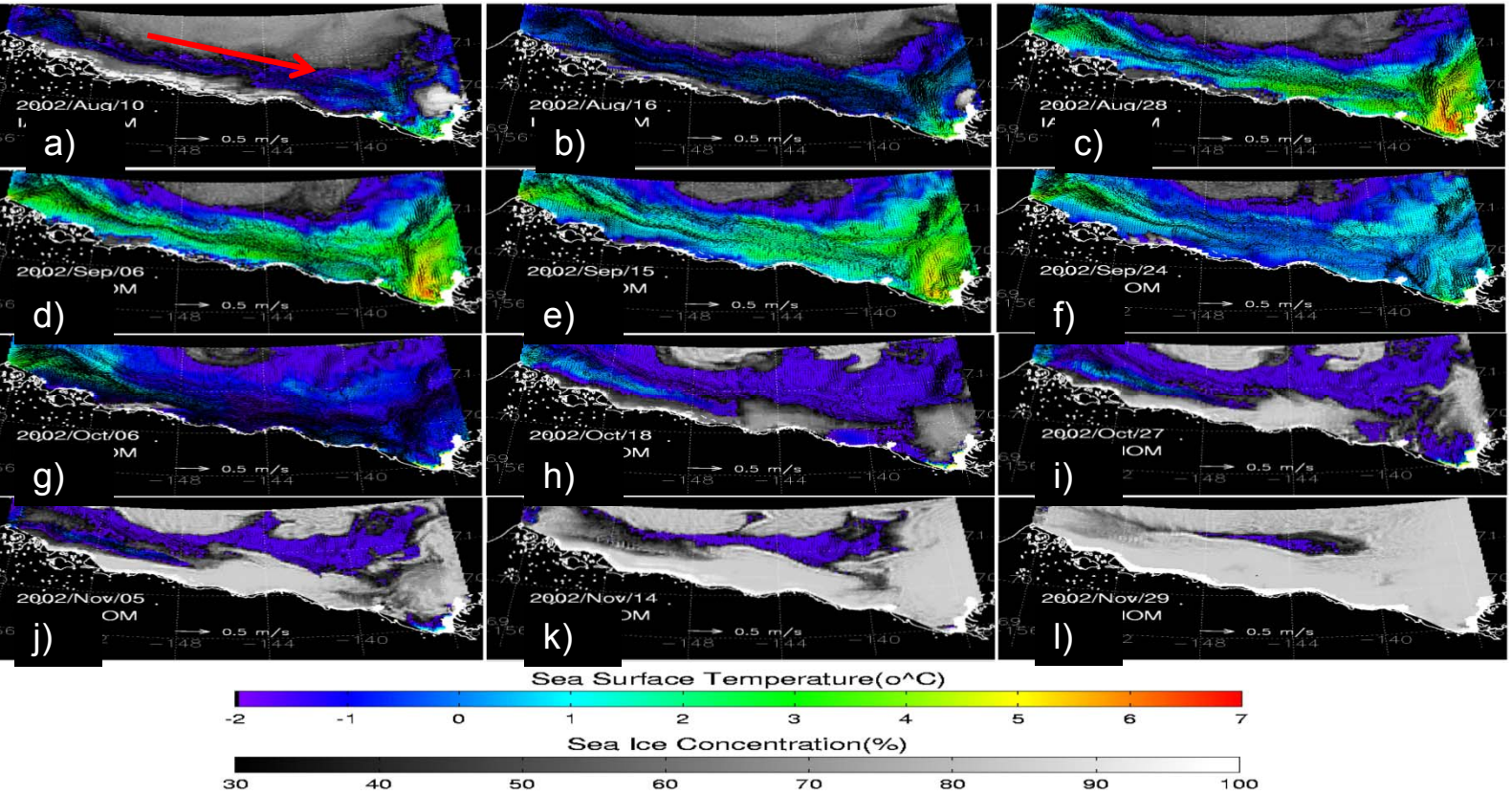


Sea Surface Elevation and Circulation

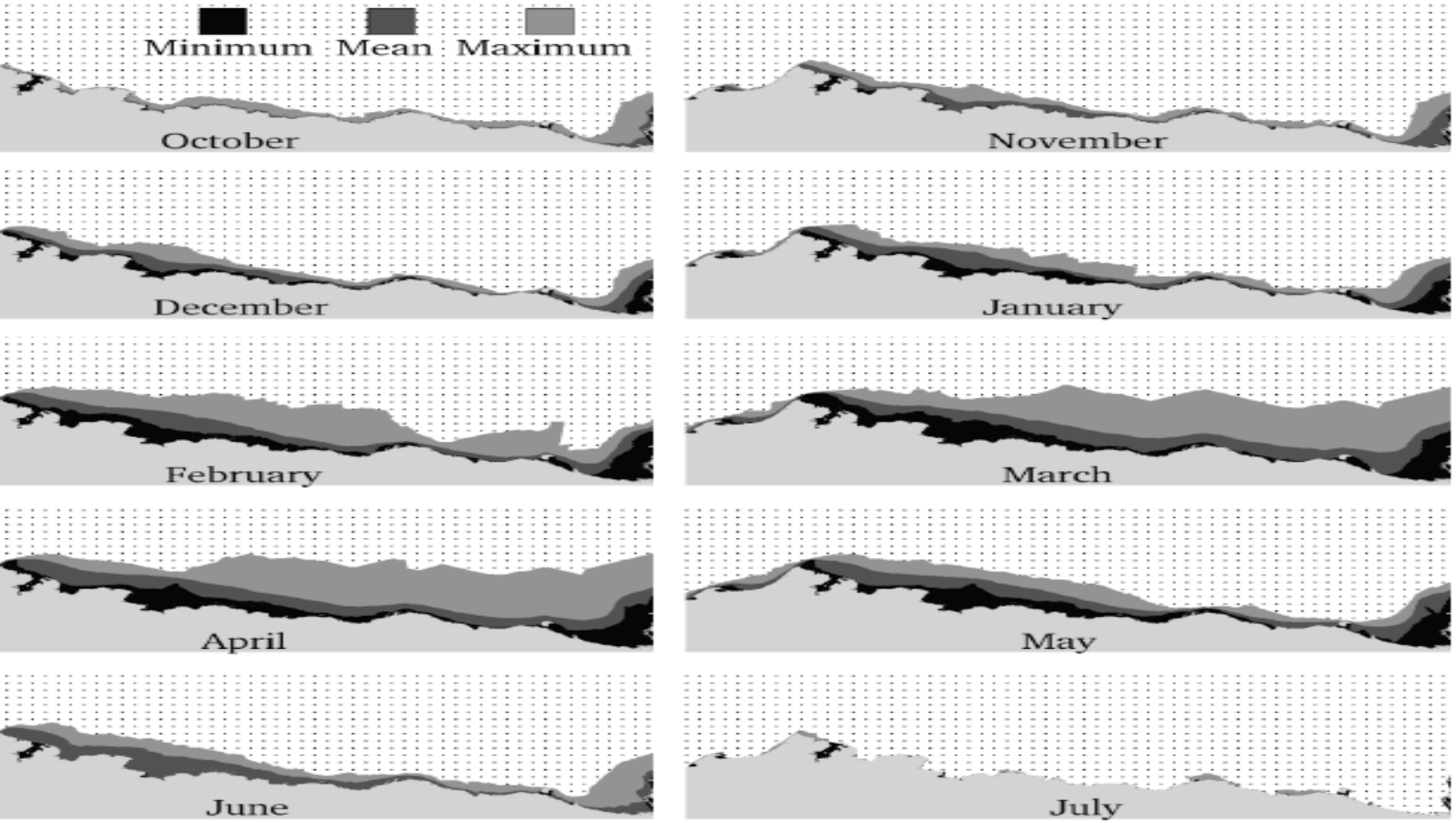
2. Model-simulated upmost 50-m averaged ocean velocity and sea surface height
tion in color with units of meters) on July 10, 2002, consistent with the schematic
circulation pattern (Fig. 1).

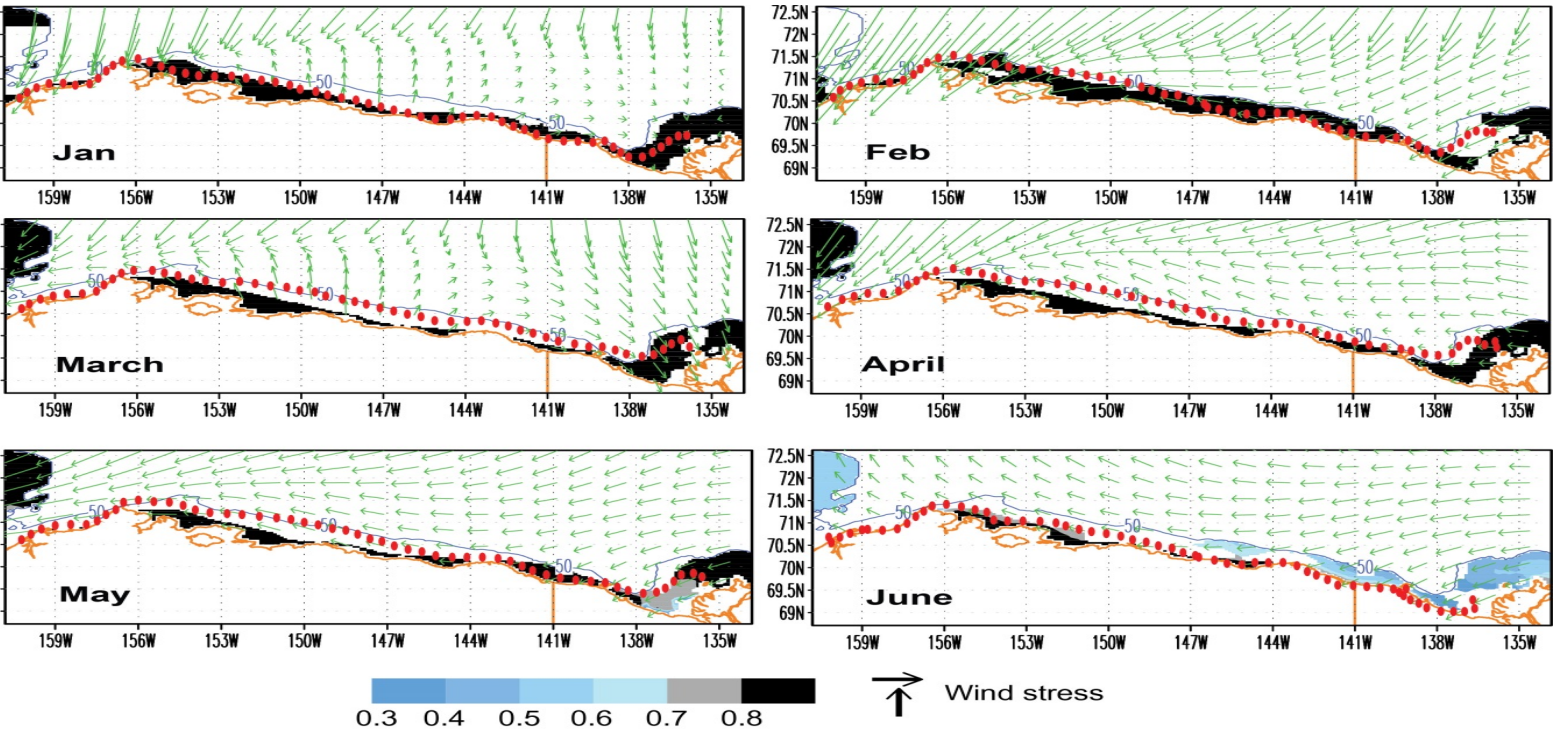


all-scale meso-scale eddies (~20-30km) are caused by baroclinic
ability with Interaction of negative sloping topography (Ikeda 1983-theory;
ng and Ikeda 1997-confirm the theory): Favoring anti-cyclones



. Sea ice cover and ocean circulation in the Beaufort Sea coastal area on (from left a) August 10th, b) August 16th, c) August 28th, d) September 6th, e) September 15th,

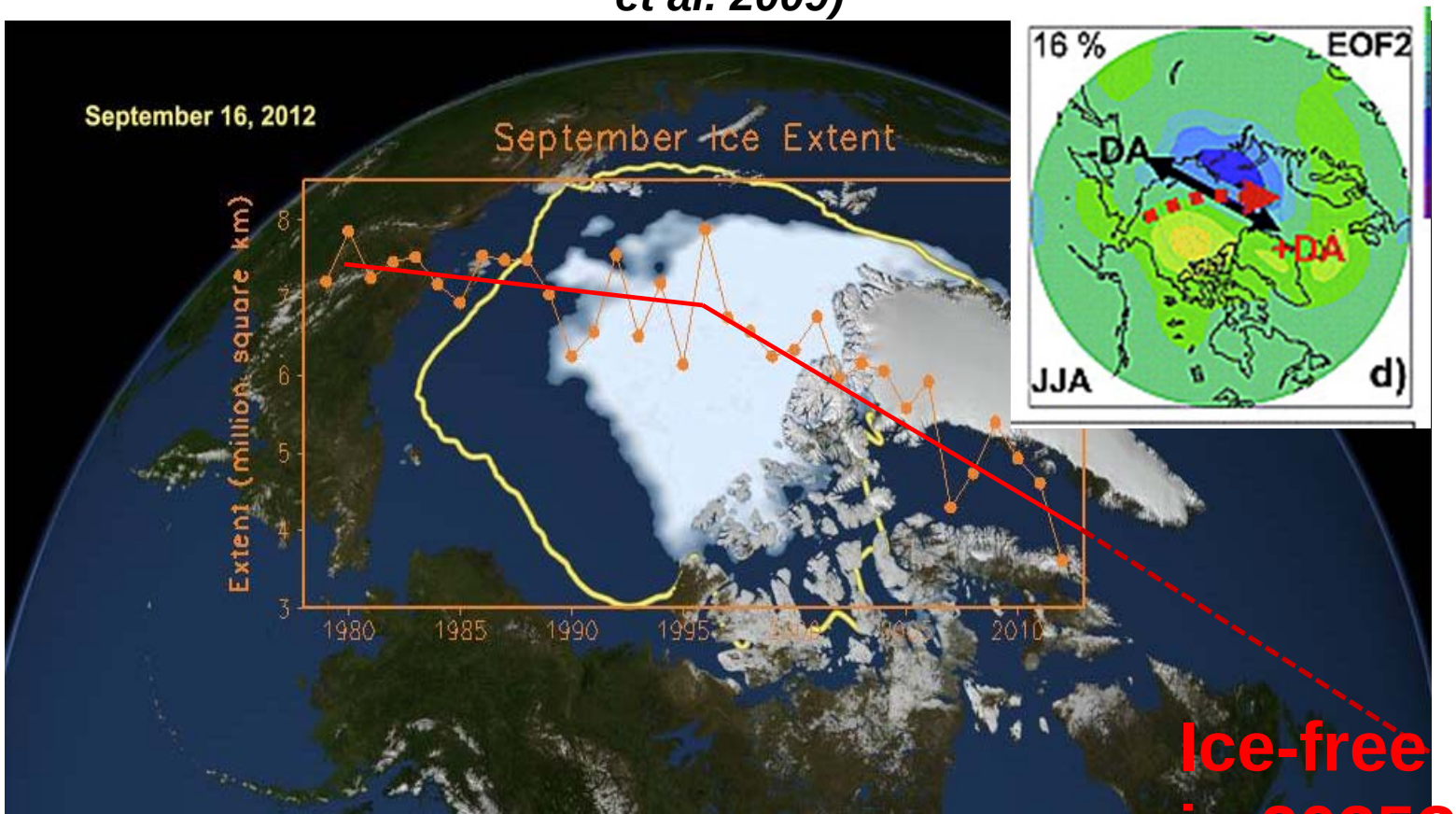

Minimum
Mean
Maximum
October
November
December
January
February
March
April
May
June
July

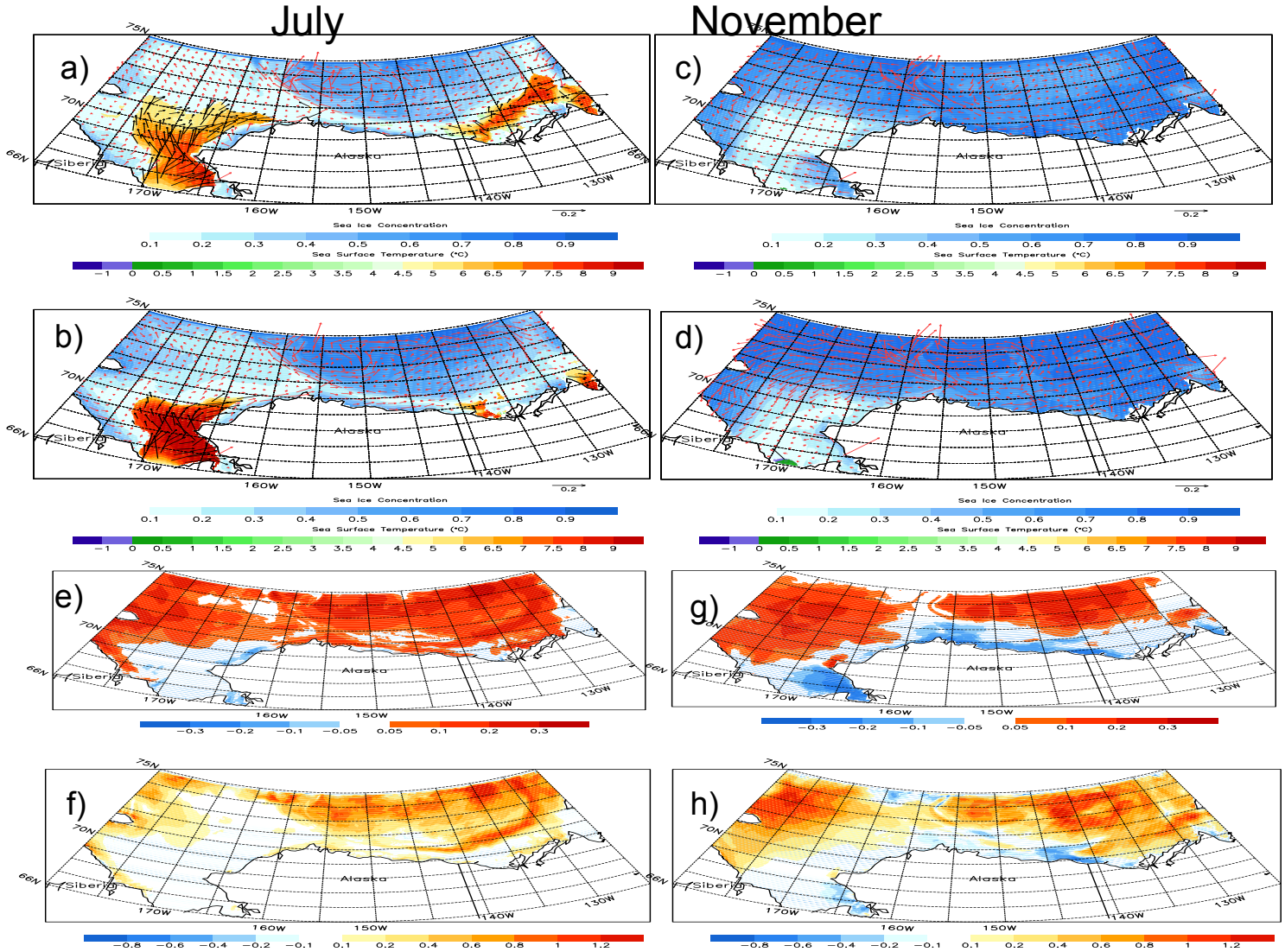


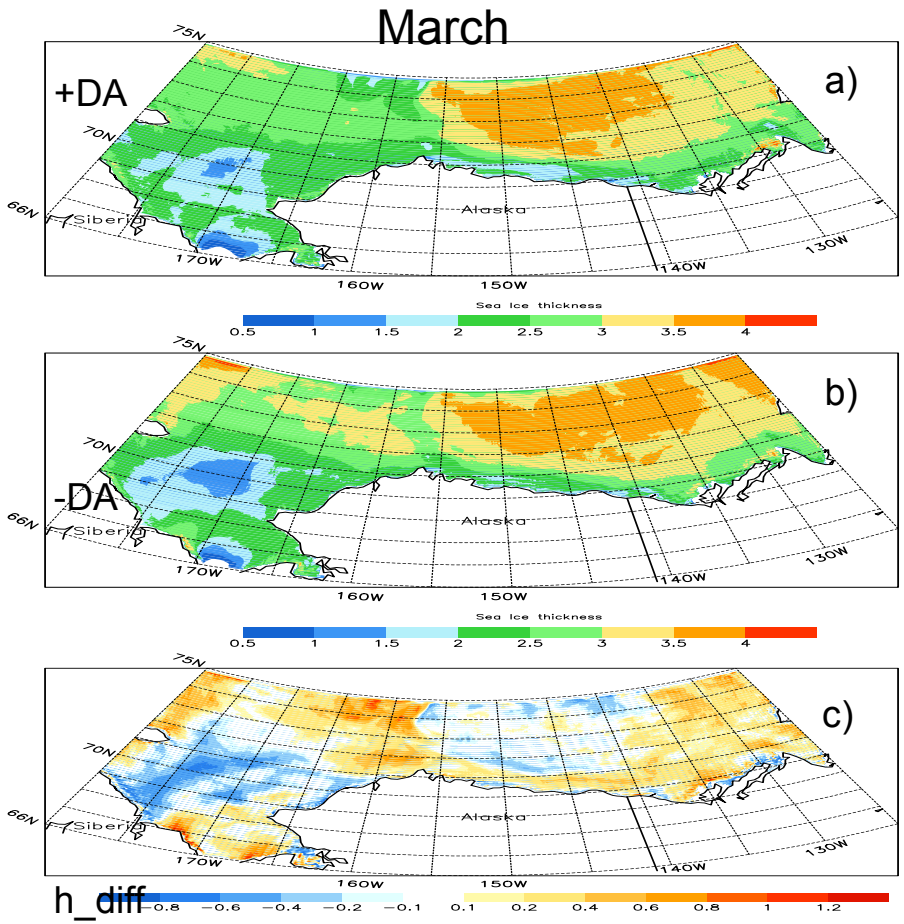
e 10. The CIOM-simulated January to June climatological landfast ice extent (from 1996-2004, black shaded)

&D: Arctic Dipole Anomaly (DA) is the major forcir to accelerate Arctic summer sea ice decline

is the 2nd EOF mode of Sea Level Pressure Anomaly north of 70N *(Wang et al. 2009)*




July
November
+DA
-DA
C_diff
h_diff
a)
b)
c)
d)
e)
f)
g)
h)
Alaska
Siberia
75N
70N
66N
170W
160W
150W
140W
130W
Sea Ice Concentration
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Sea Surface Temperature (°C)
−1 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 6 6.5 7 7.5 8 9
−0.3 −0.2 −0.1 −0.05 0.05 0.1 0.2 0.3
−0.8 −0.6 −0.4 −0.2 −0.1 0.1 0.2 0.4 0.6 0.8 1 1.2



13. Composite sea ice thickness (in meters) composite mean in the Beaufort and Chukchi seas in March during +DA –DA (b) phases, simulated by the CIOM. h_diff denotes the sea ice thickness difference between the -DA (b) and

Summary

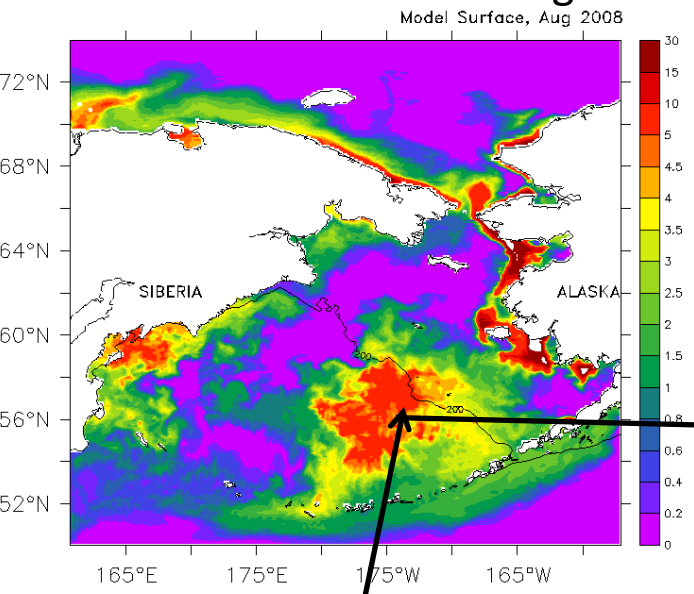
- CIOM is capable of simulating sea ice and ocean in the Arctic
- CIOM is coupled to the NPZD model
- CIOM captures some landfast ice features, but lack of anchoring process
- CIOM can be used to simulate ice-ocean system response to storms

odeling ice-ocean-ecosystem in the Bering and Chukchi Seas using CIOM: RUSALCA Years: 2007-2010

ang et al. (2013, JGR), Hu et al. (in prep)

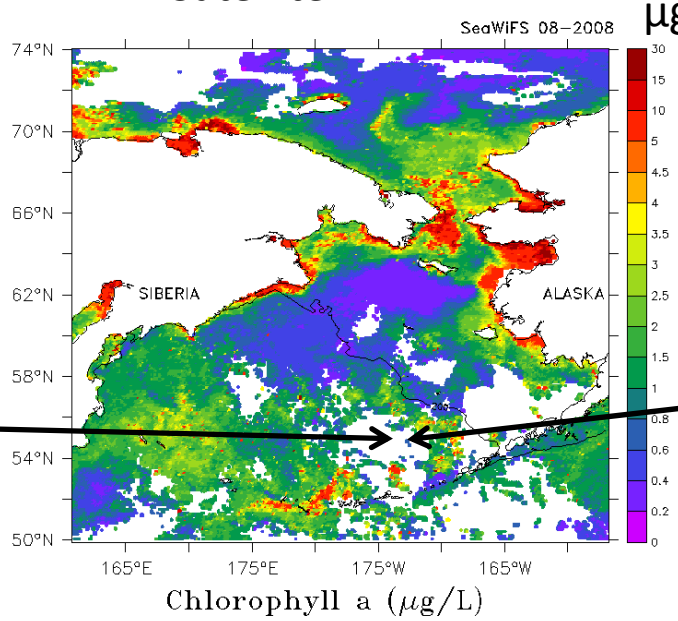
Coupled Ice-Ocean-Ecosystem Model in the Bering-Beaufort-Chukchi Seas (IPY)

Modeled August 2008



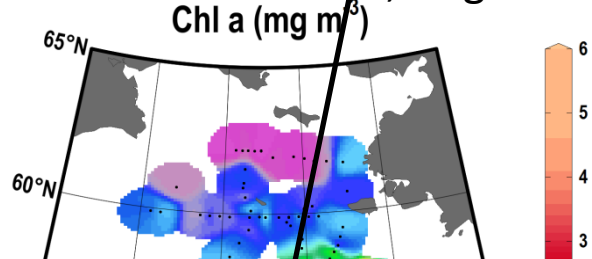
Satellite

µg/L

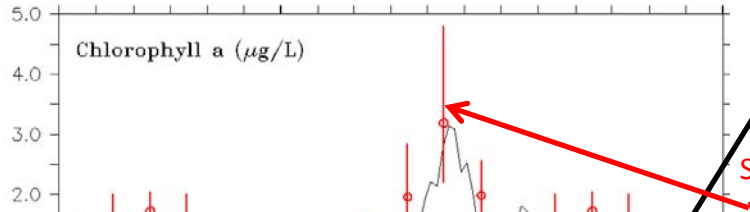


Cloud cover

In situ measurement, August 2008

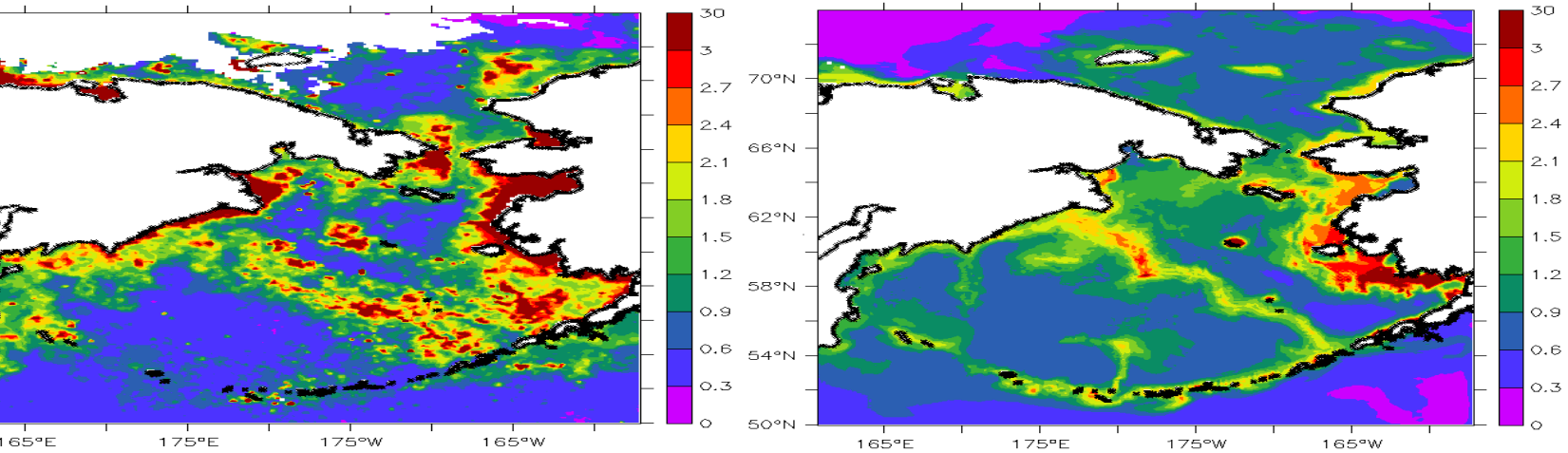


Seasonal variation 2007-2008



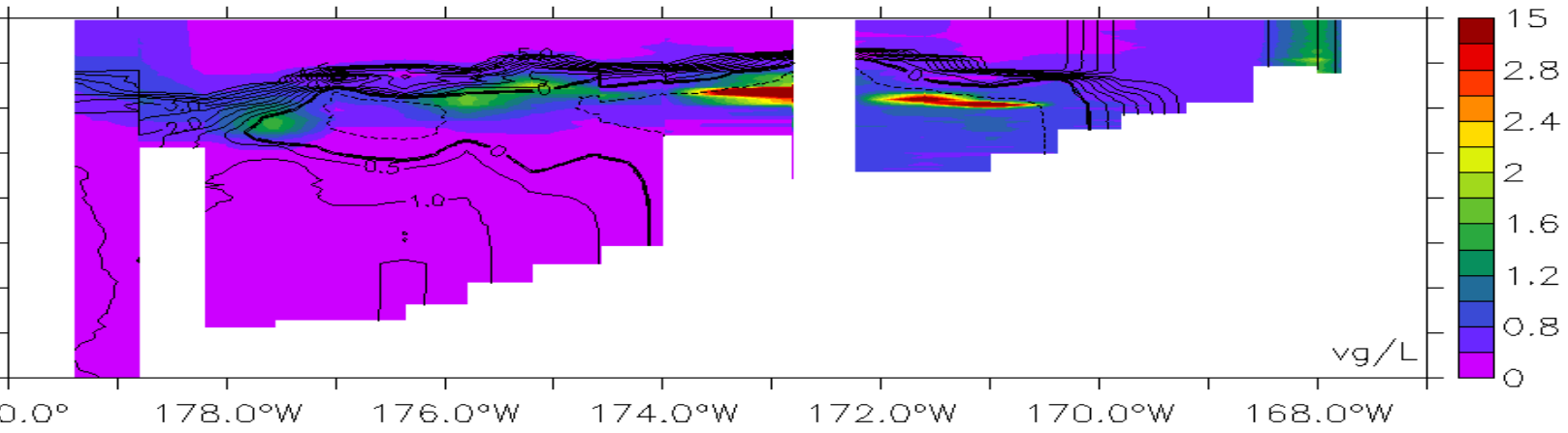
Modeled

Satellite-measured with max-min

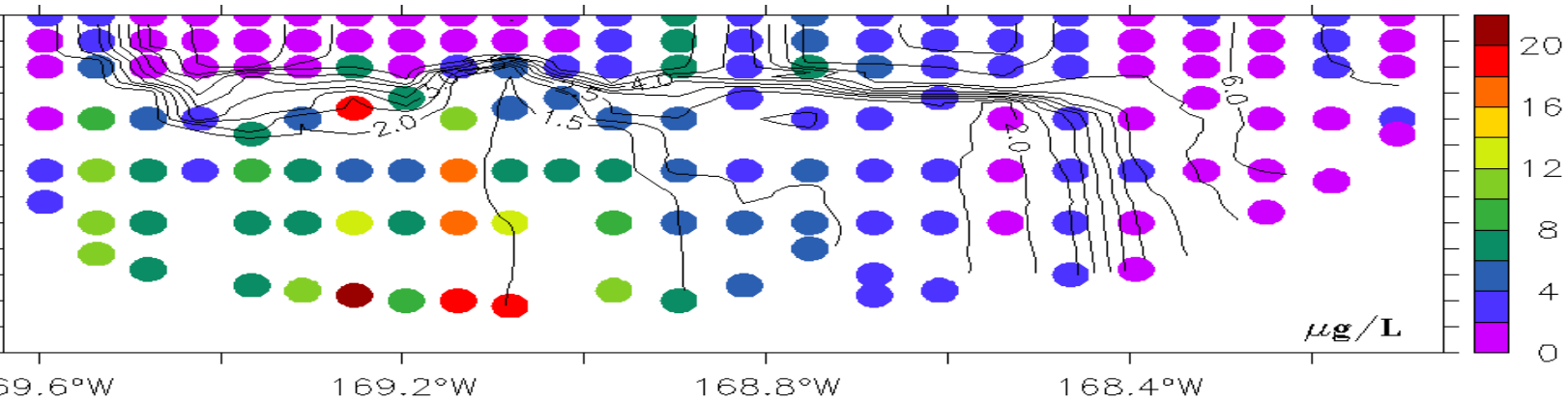


re 2. (a) Observed average (May-Sep 2009, SeaWiFS. The other part of year
t included because of sea ice cover and lacking of SeaWiFS data) surface
rophyll a. (b) Simulated average (May-Sep 2009) surface Chlorophyll a. Oct-
are not included due to lack of satellite data, lot of area was covered by sea ice.

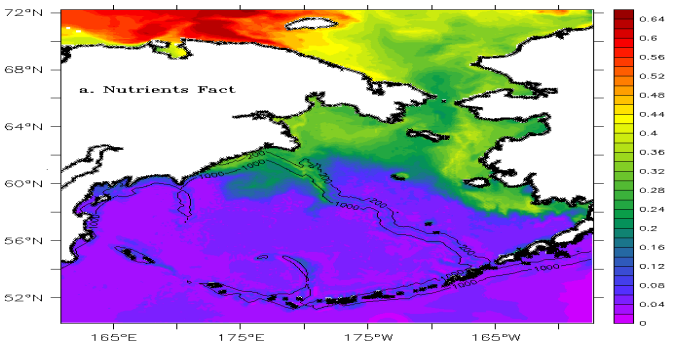
Observed subsurface max chl-a

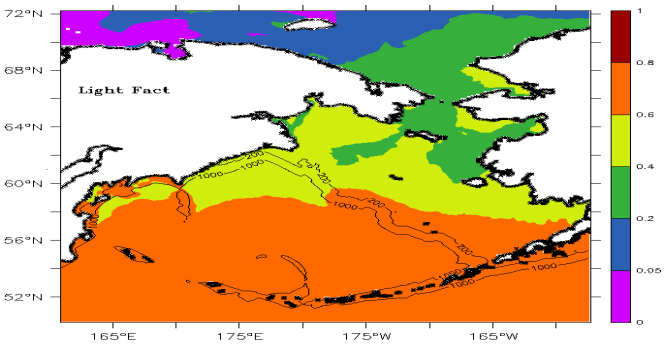


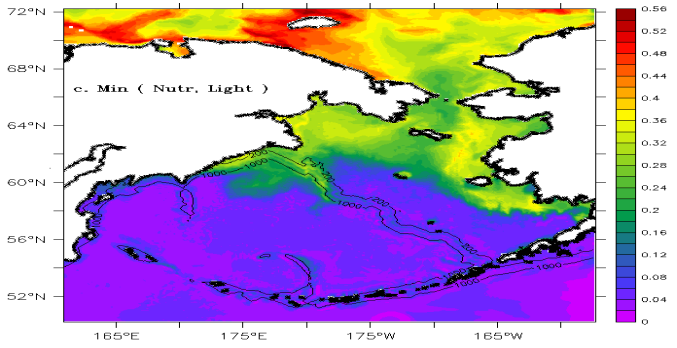
e 3. Measured Chlorophyll a (µg/L, color filled) and temperature (°C,
our lines) from Aug. 2008-cruise.

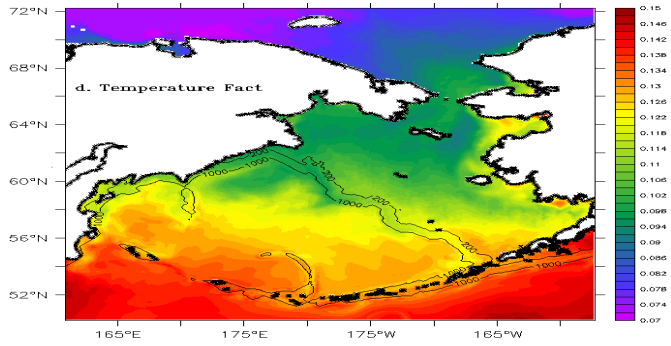


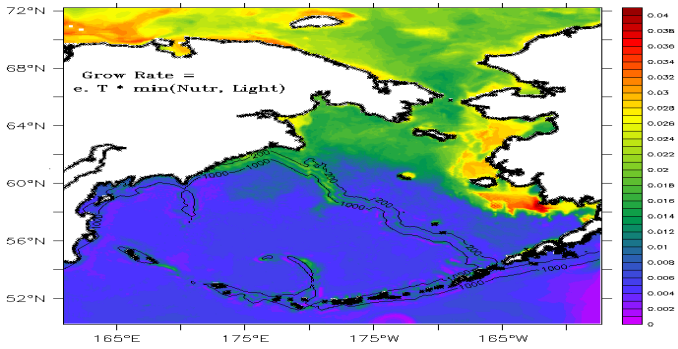
e 4. Chlorophyll a in color and temperature in contour of section AL (see e 1 for location), Sep. 2009, RUSALCA cruise.

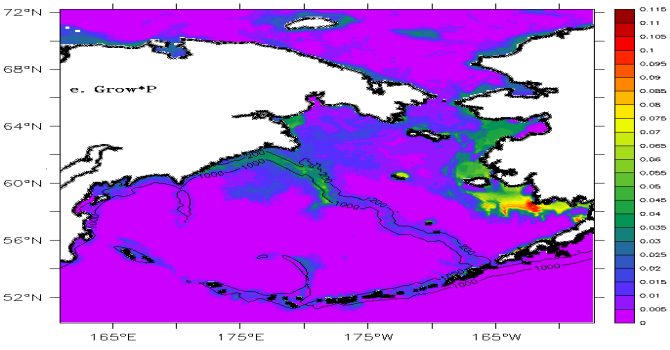

a. Nutrients Fact
72°N
68°N
64°N
60°N
56°N
52°N
165°E
175°E
175°W
165°W

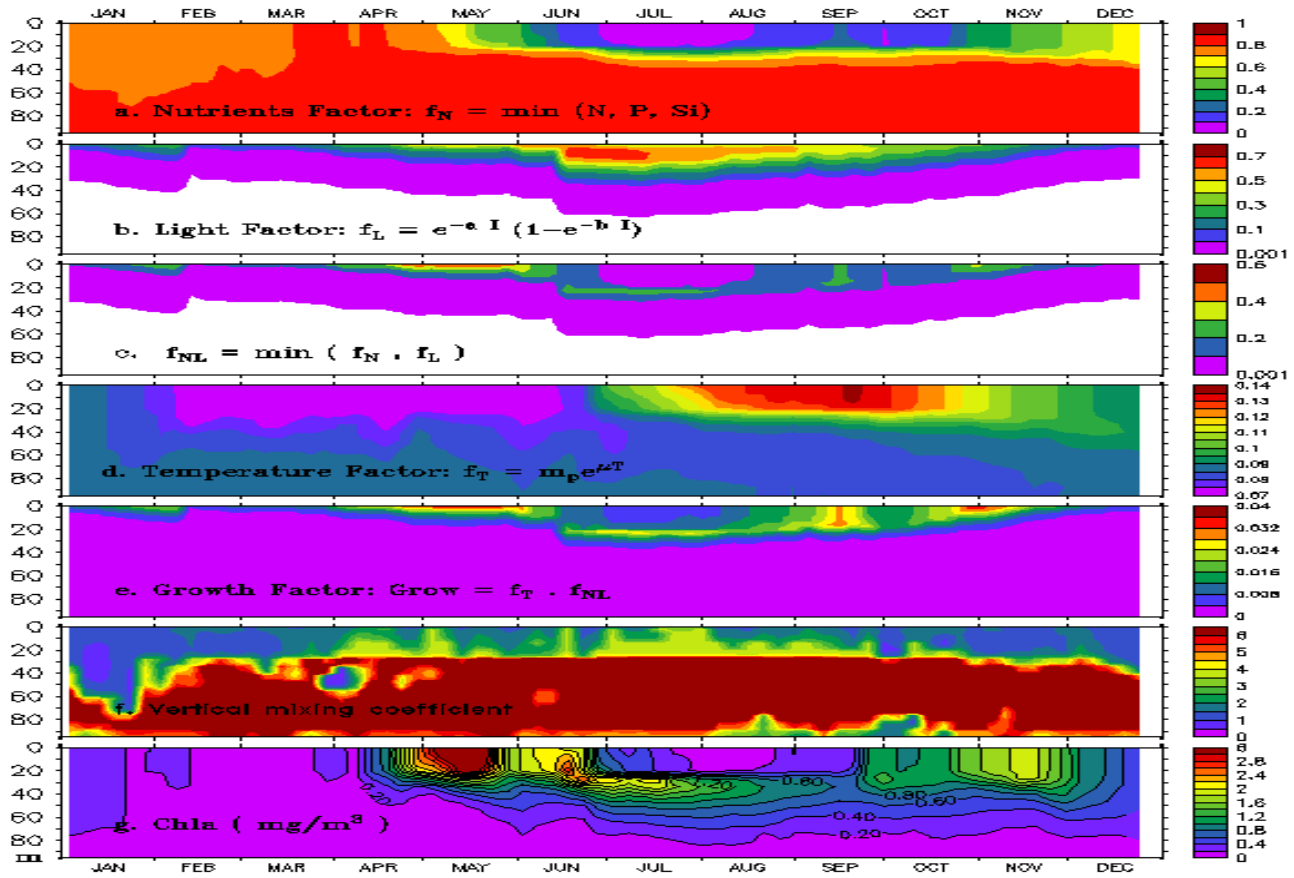

Light Fact
72°N
68°N
64°N
60°N
56°N
52°N
165°E
175°E
175°W
165°W

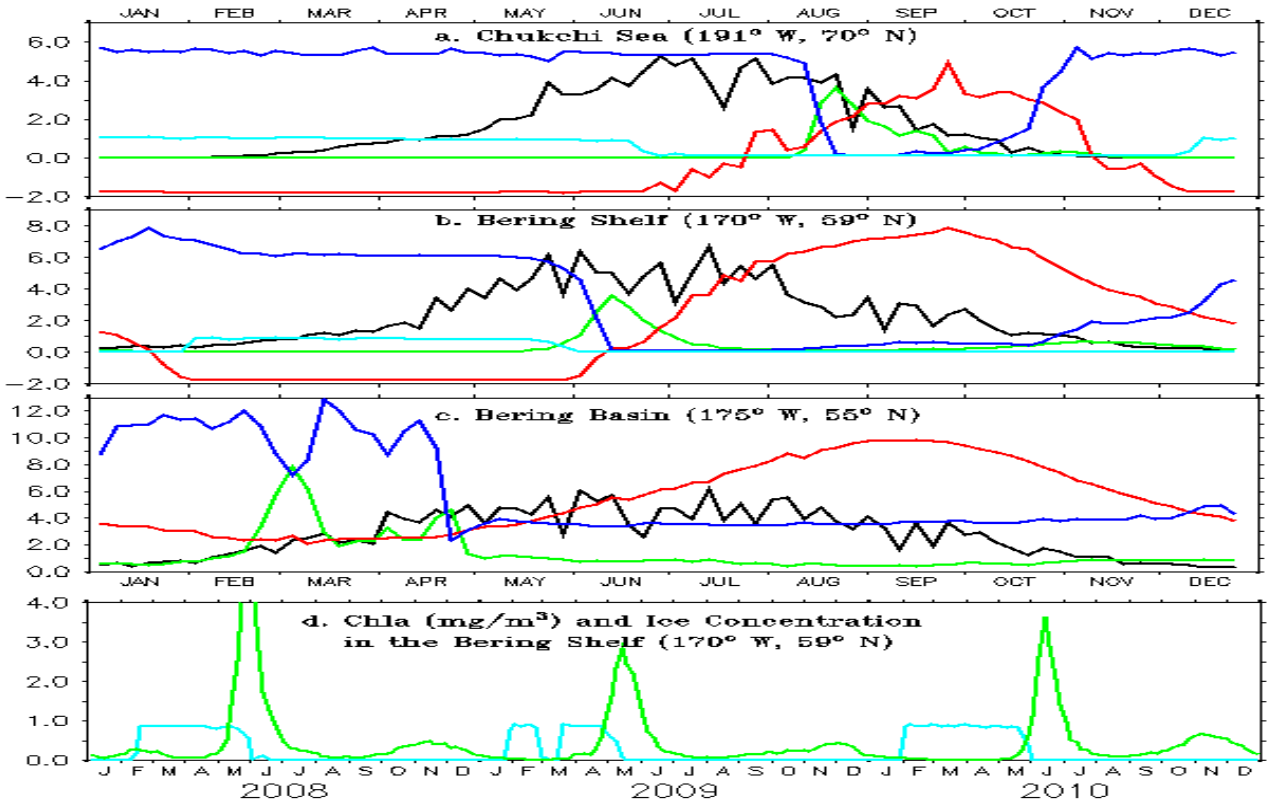

c. Min (Nutr, Light)
72°N
68°N
64°N
60°N
56°N
52°N
165°E
175°E
175°W
165°W


d. Temperature Fact
72°N
68°N
64°N
60°N
56°N
52°N
165°E
175°E
175°W
165°W

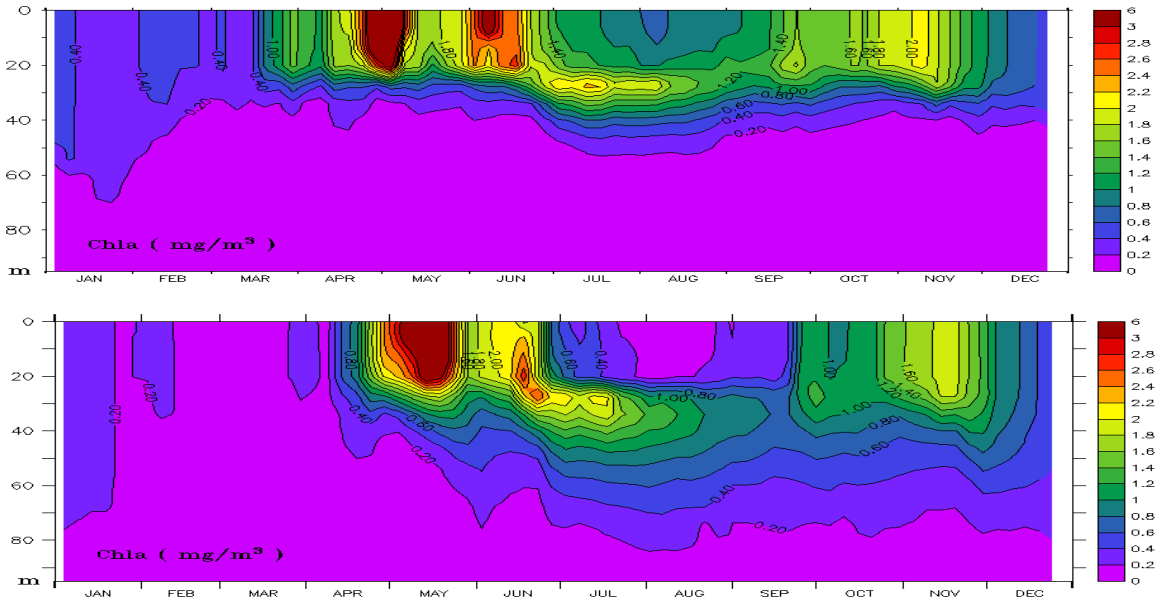

Grow Rate =
e. T * min(Nutr, Light)
72°N
68°N
64°N
60°N
56°N
52°N
165°E
175°E
175°W
165°W


e. Grow*P
72°N
68°N
64°N
60°N
56°N
52°N
165°E
175°E
175°W
165°W


JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
0
20
40
60
80
m
a. Nutrients Factor: f_N = min (N, P, Si)
b. Light Factor: $f_L = e^{-a\,I}\,(1-e^{-b\,I})$
c. f_{NL} = min (f_N , f_L)
d. Temperature Factor: $f_T = m_p e^{\mu T}$
e. Growth Factor: Grow = f_T . f_{NL}
f. Vertical mixing coefficient
g. Chla (mg/m^3)
0.20
0.40
0.60
0.80
1
0.8
0.6
0.4
0.2
0
0.7
0.5
0.3
0.1
0.001
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.04
0.032
0.024
0.016
0.008
8
5
4
3
2
1
2.8
2.4
1.6
1.2



e 7. Spatial difference of bloom timing, short wave radiation in black,
rature in red, Chlorophyll a in green, nitrate in blue, and sea ice concentration
t blue. (a) In Chukchi Sea (191 °W, 70 °N), (b) in Bering Shelf (170 °W, 59 °N),
Bering Basin (175 °W, 55 °N), and (d) Chlorophyll a and sea ice concentration



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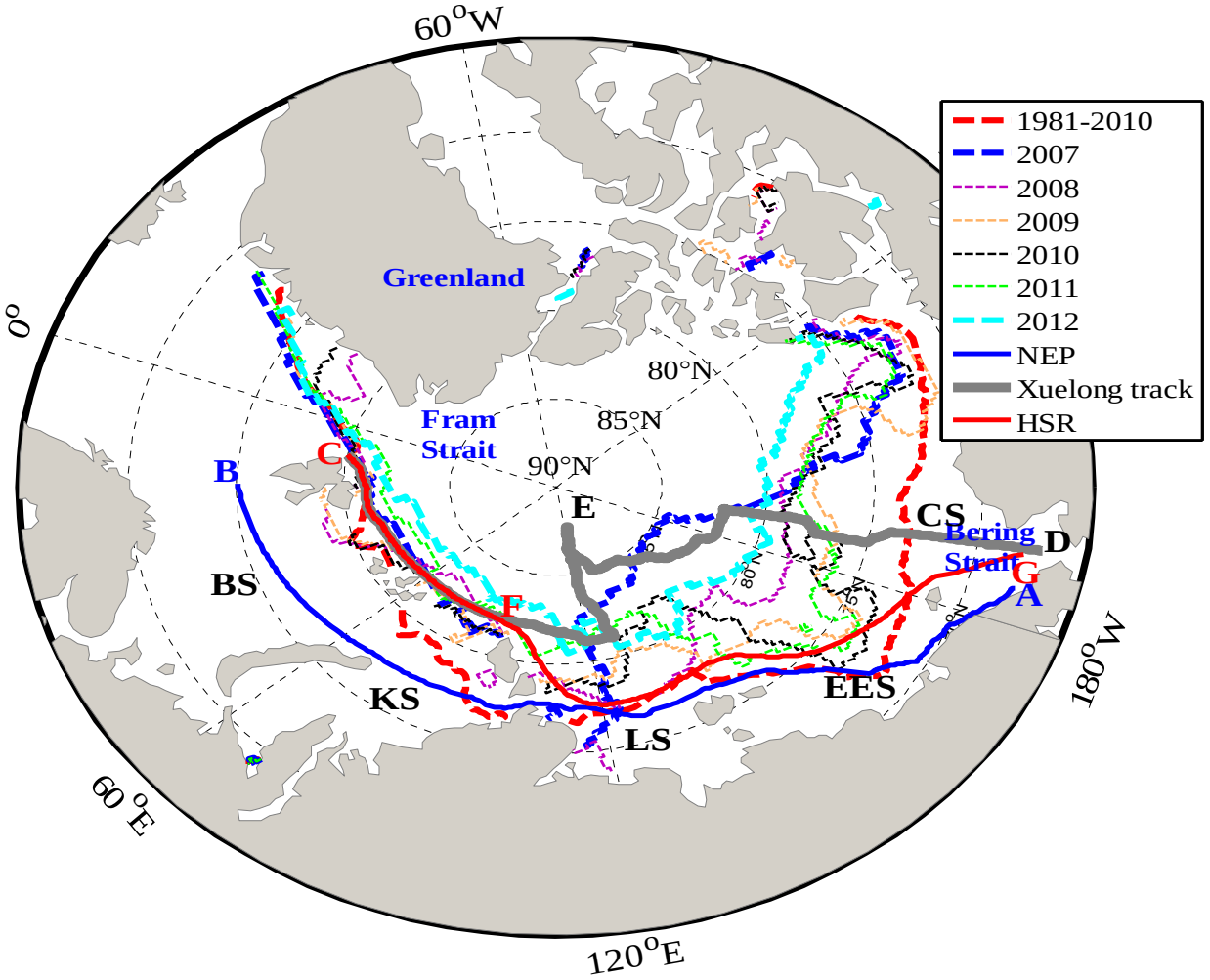
Bering Basin (175 °W, 55 °N), and (d) Chlorophyll a and sea ice concentration

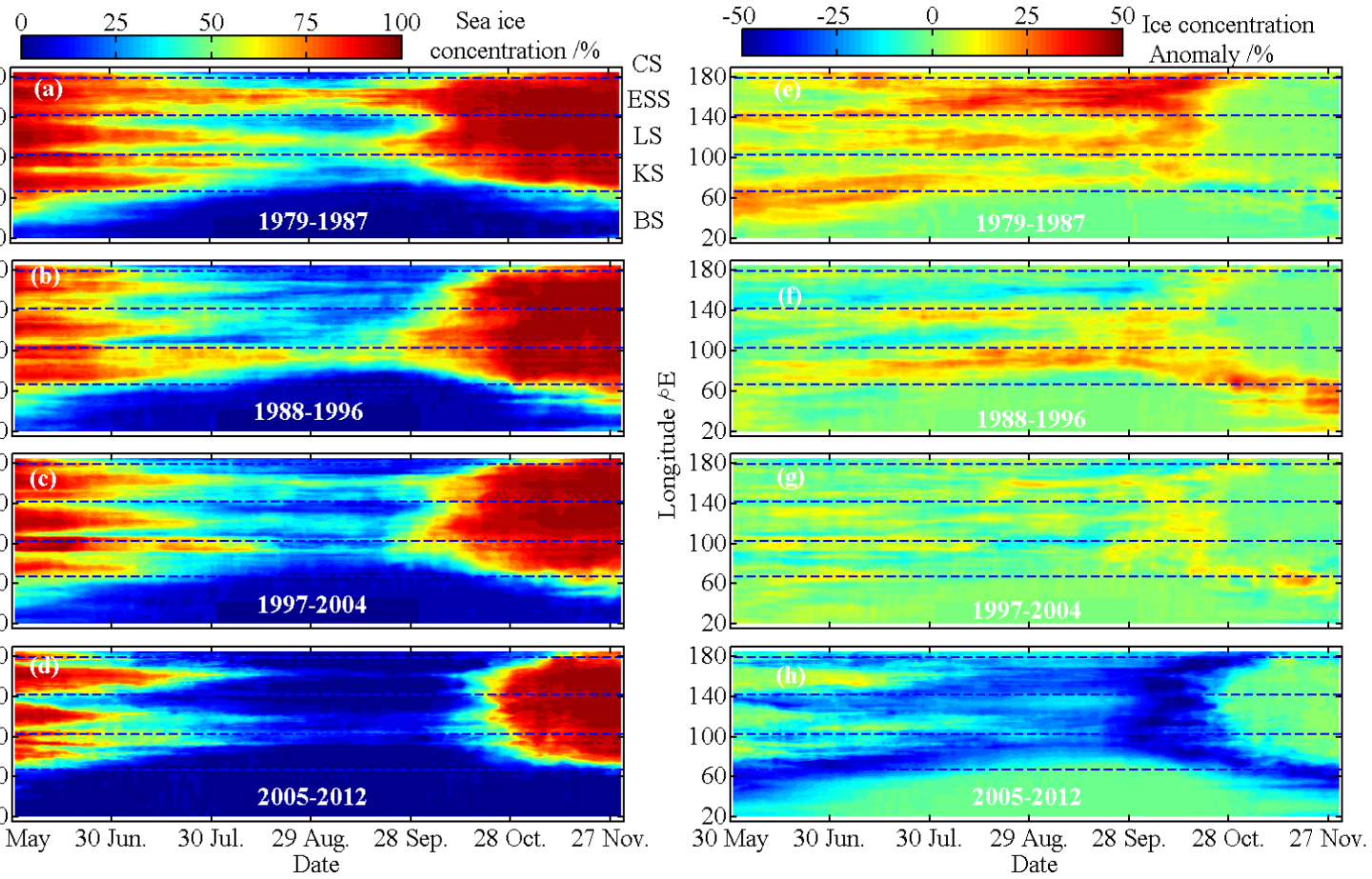
anges in sea ice along the Arctic Northeast Passage since 1979: Results from remote sensing data

, R. J. Wang et al. (CRST, 2015)
llaborated with Polar Research Institute of China-PRIC)

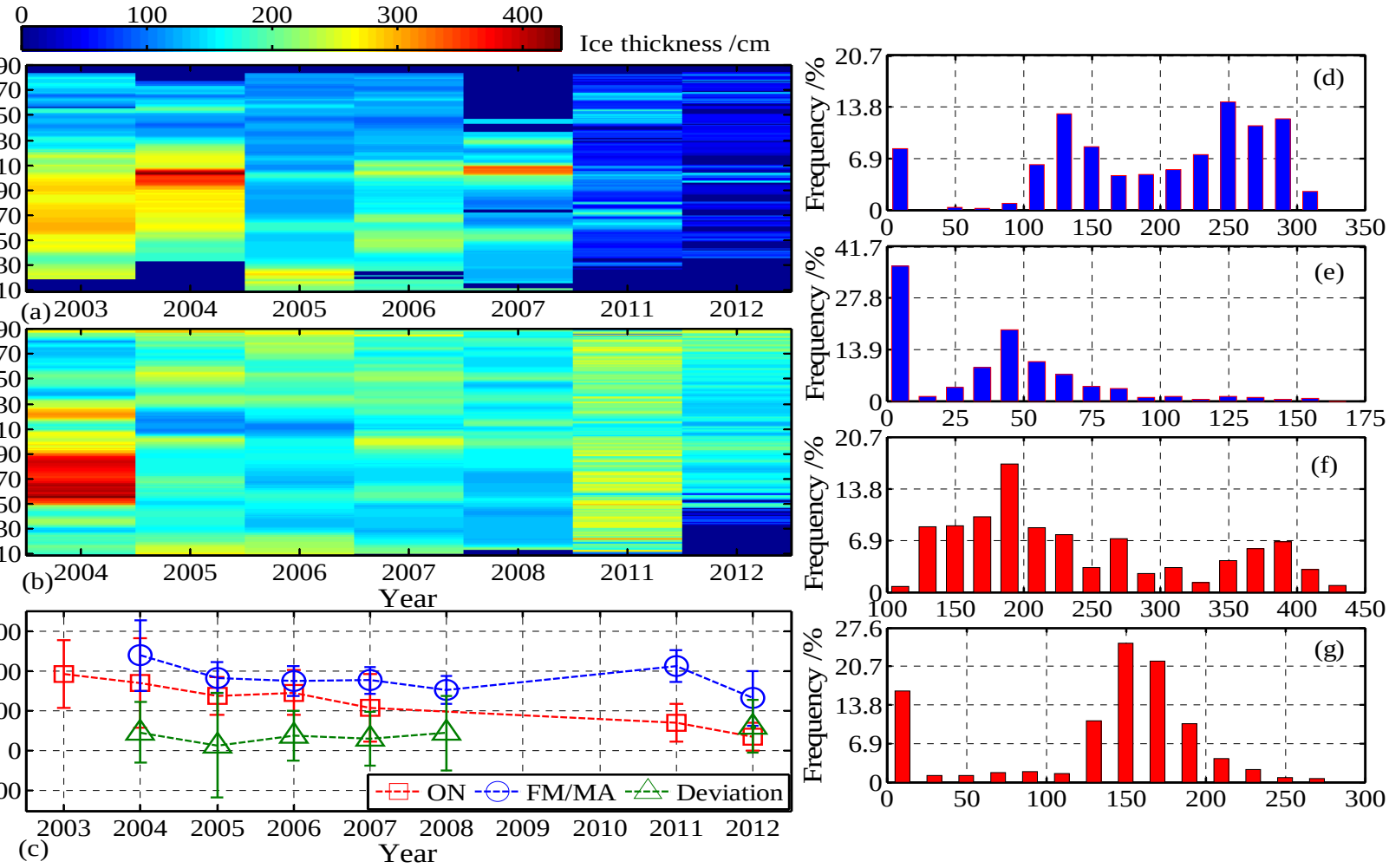
NEP and HSR



SMI-derived Arctic sea ice edges in September averaged from 1981 to 2010 and those


0 25 50 75 100
Sea ice concentration /%
-50 -25 0 25 50
Ice concentration Anomaly /%
CS
ESS
LS
KS
BS
(a)
1979-1987
(b)
1988-1996
(c)
1997-2004
(d)
2005-2012
(e)
(f)
(g)
(h)
180 140 100 60 20
Longitude /°E
30 May 30 Jun. 30 Jul. 29 Aug. 28 Sep. 28 Oct. 27 Nov.
Date

Ice thickness distribution



AO/DA vs open period in NEP

	Chukchi	East Siberian	Laptev	Kara	Barents
AO_w vs. Open period	n.s.	0.41*	n.s.	n.s.	n.s.
AO_sp vs. Open period	n.s.	0.49**	n.s.	n.s.	n.s.
AO_su vs.Open period	n.s.	n.s.	n.s.	-0.46**	n.s.
AO_a vs. Open period	n.s.	n.s.	n.s.	n.s.	n.s.
DA_w vs. Open period	n.s.	n.s.	n.s.	n.s.	n.s.
DA_sp vs. Open period	n.s.	0.49**	0.34*	n.s.	n.s.
DA_su vs.Open period	0.42*	0.49**	0.63***	0.63****	n.s.
DA_a vs. Open period	n.s.	0.49**	0.34*	n.s.	n.s.

tatistical relationship of seasonal average AO/DA indices and the open period defined by 50% ice

Future plan: 2016-2020

orking on progress:

Arctic-CIOM

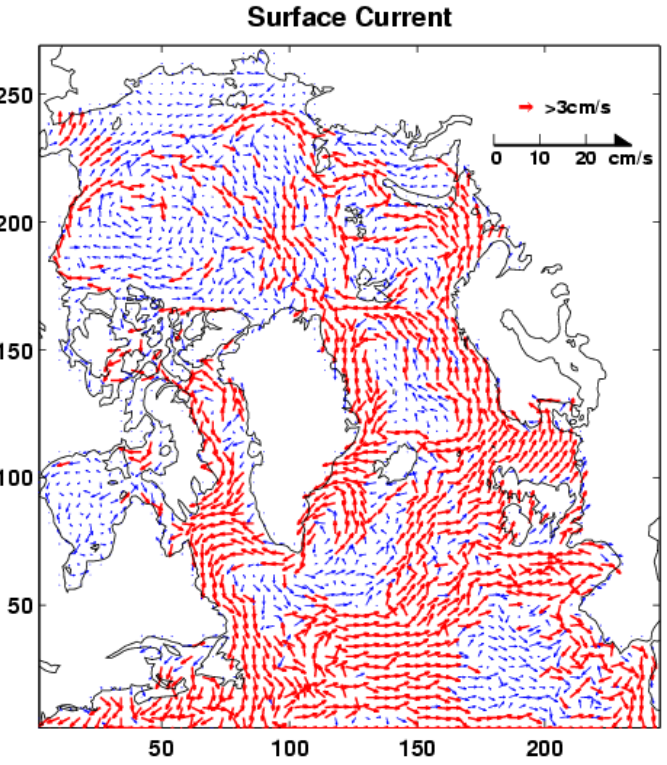
Arctic-FVCOMice

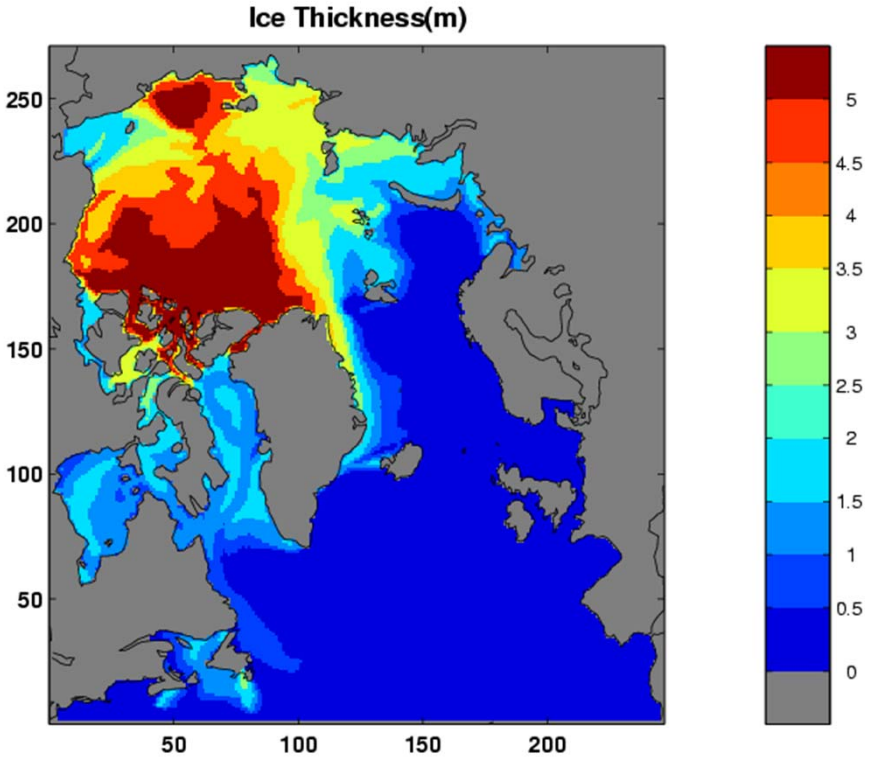
Arctic-CIOM+npzd

Arctic-FVCOMice+npzd

Arctic-CIOM

Wang, Liu, et al. (2005, JO), Long et al. (2012, JC)

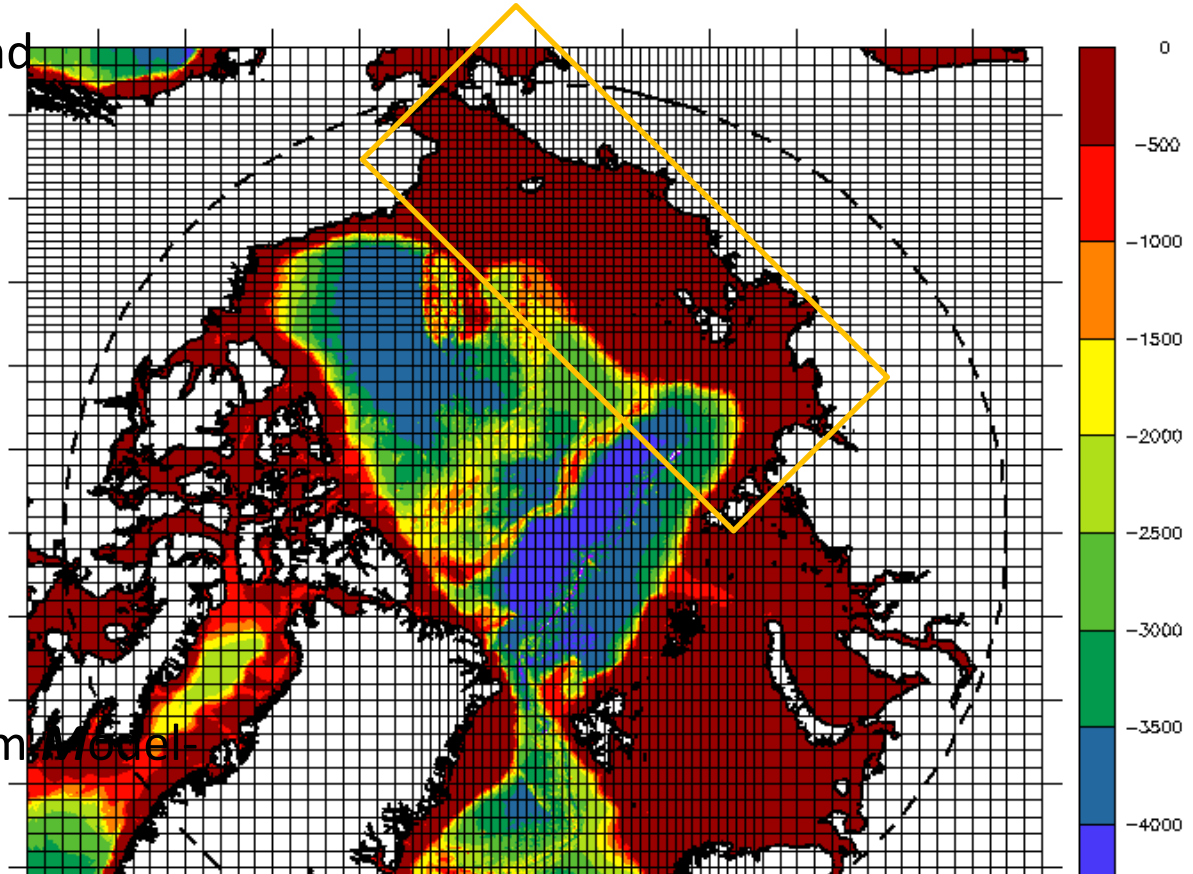


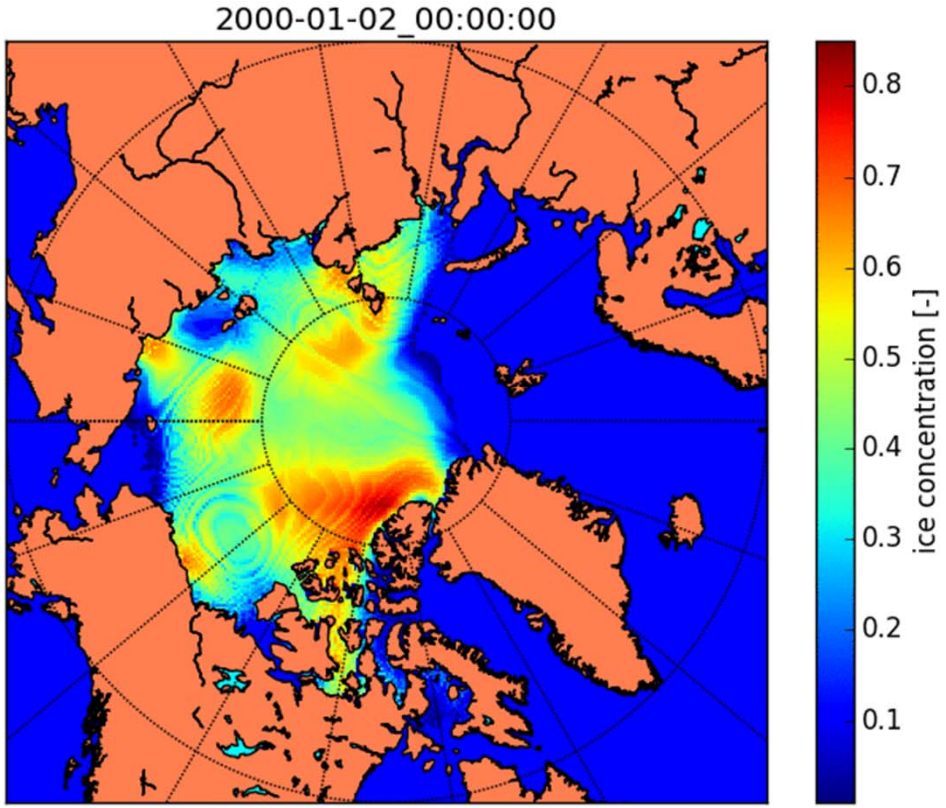


he CIOM-simulated climatological Arctic Ocean surface current (left) and ice

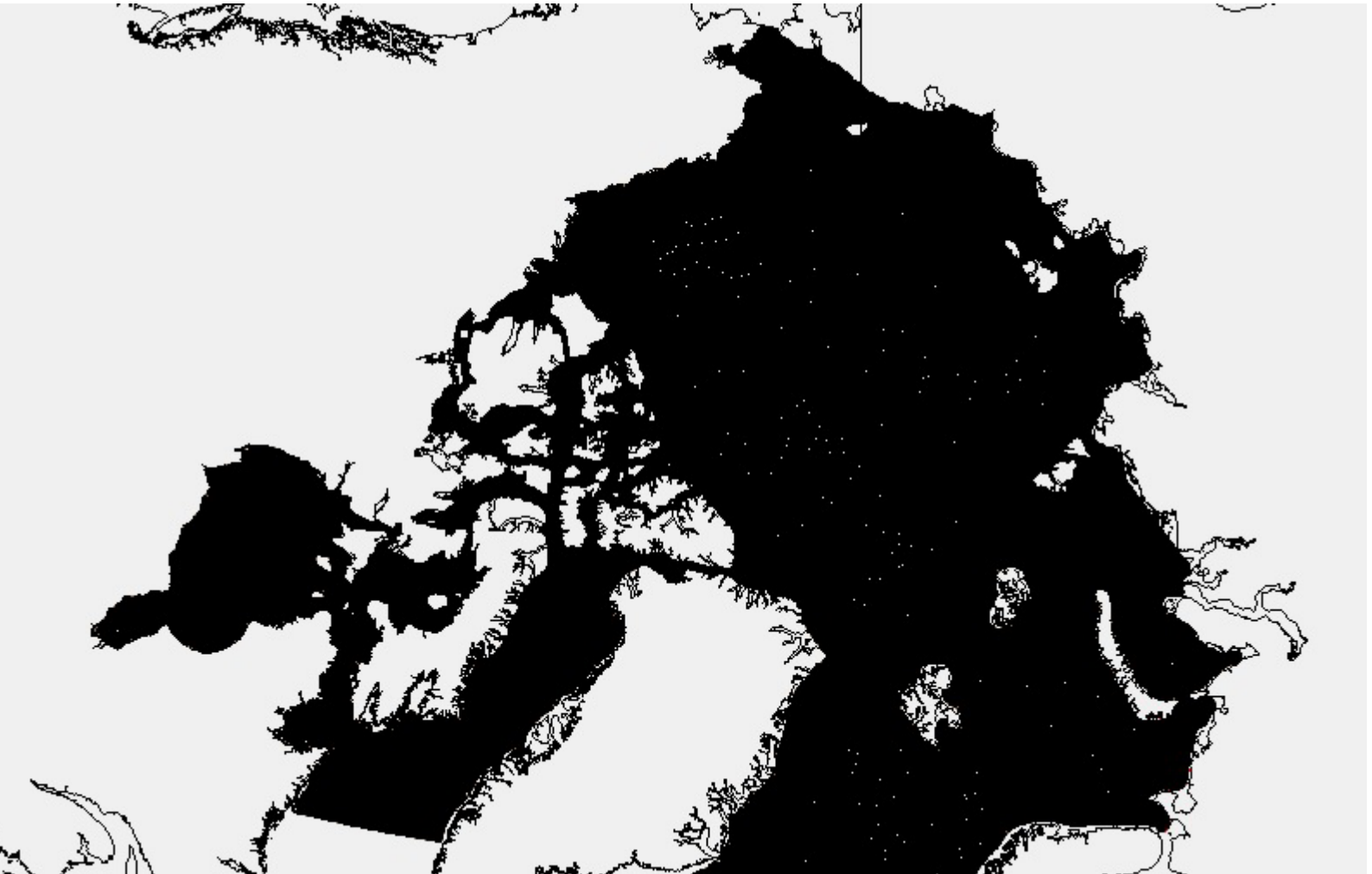
Proposed New Configuration for RUSALCA's Northward Expansion, 2015-2020 (Arctic-CIOM)

M with fully dynamics and
dynamics, multiple
y ice thickness (ridging)
2km in ESS/elsewhere
vel
urly or daily forcing
otheses test/RUSALCA
nesis
stic simulation
oM—***Ph***ysical-***Eco***system ***M***odel-
O



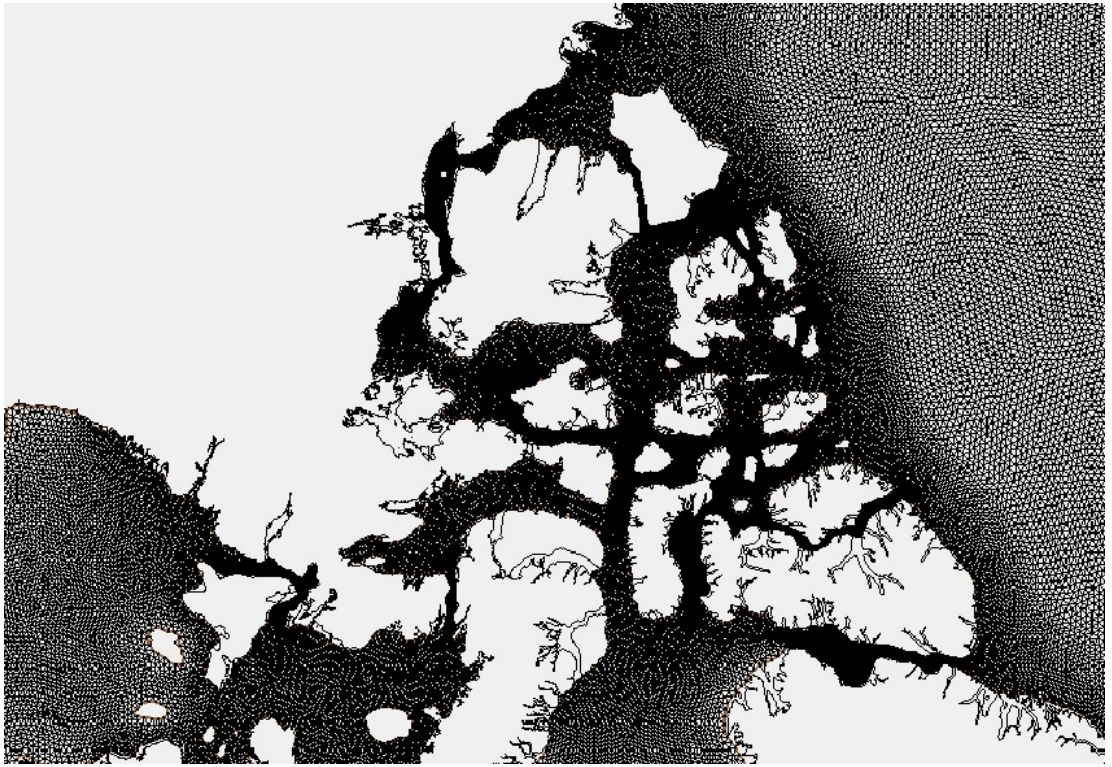

2000-01-02_00:00:00
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
ice concentration [-]

ERL Proposes to Development of Arctic Unstructured-Grid Models Enhanced Predictive Capabilities for NOAA Arctic Initiative



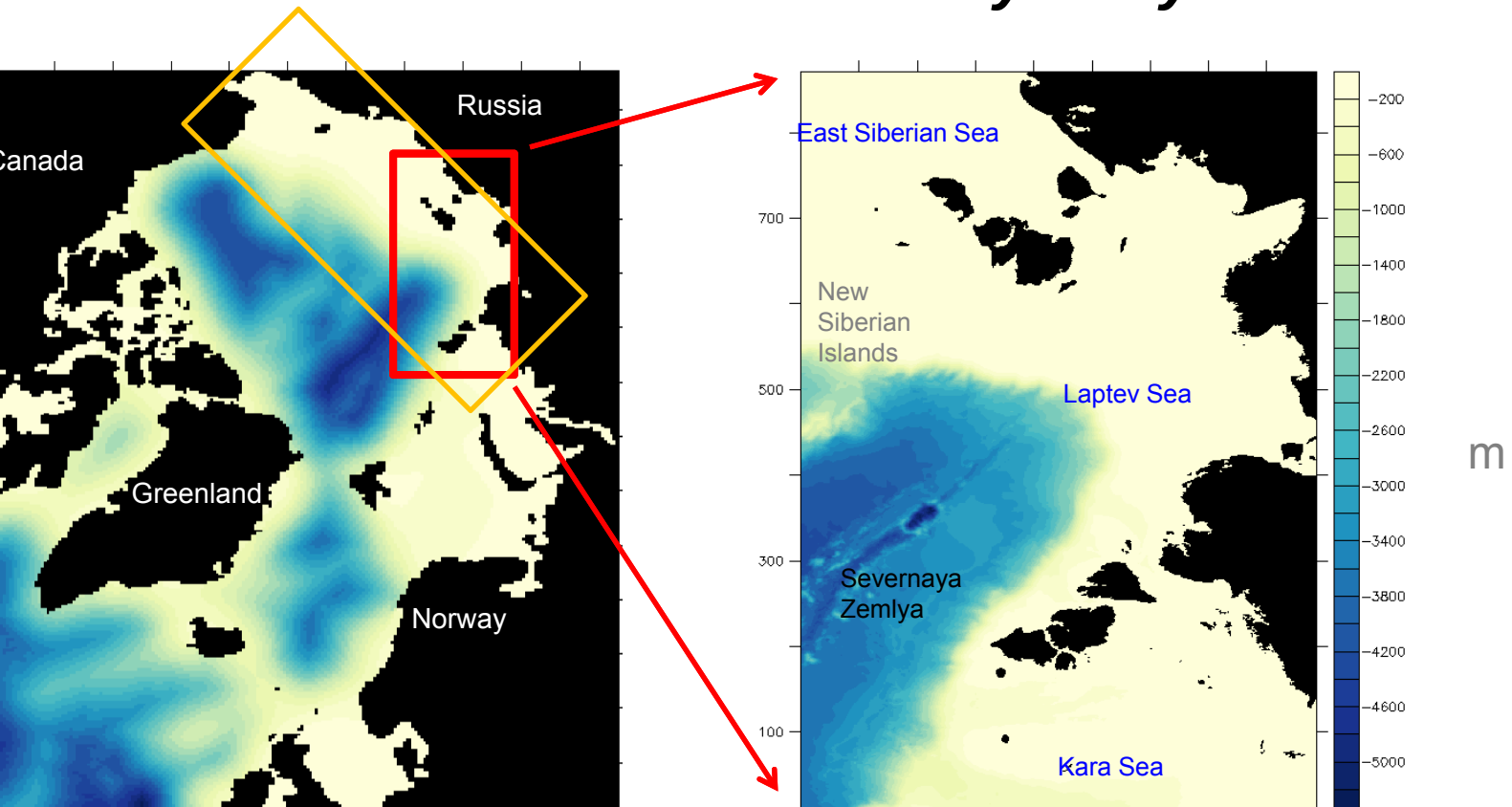
Working on Arctic-FVCOMice, 2015-2020

OM with fully dynamics and
dynamics, multiple
y ice thickness (ridging)
2km in ESS/elsewhere
vel
urly or daily forcing
otheses test/RUSALCA
nesis
stic simulation
oM—***Ph***ysical-***Eco***system
el-NPZD



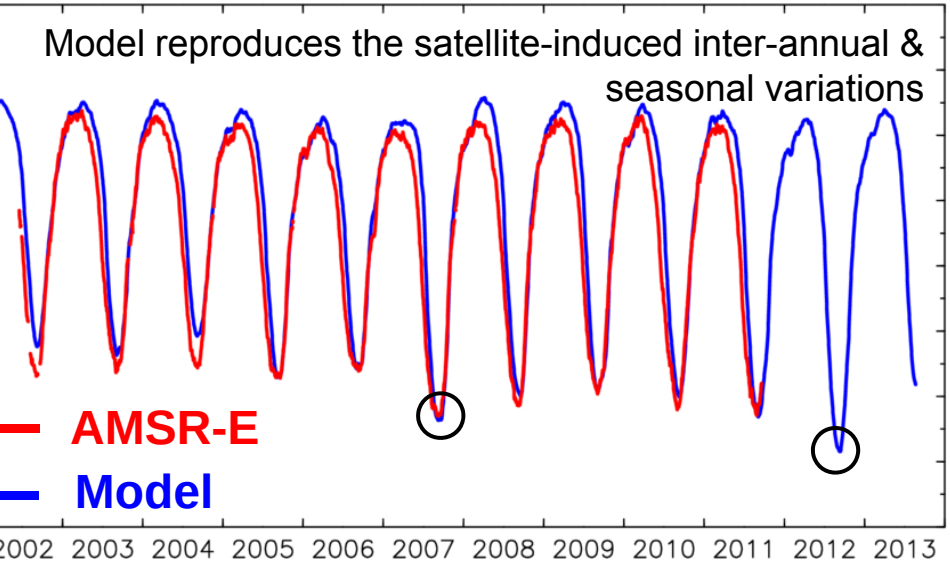
n Resolution Regional Model
Short-term Predictions (Yamaguchi)

putational Domain and Model Bathymetry

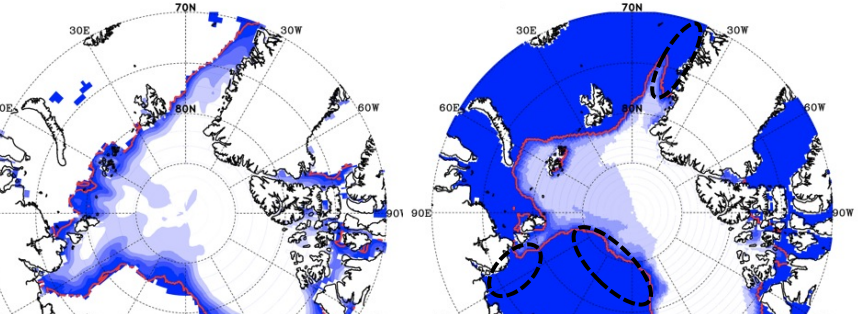


roducibility of the whole Arctic Ocean model

Daily time series of total ice area (km^2) from AMSR-E and model in the Arctic Ocean



September mean sea-ice concentration (%) in 2007 from AMSR-E (left) and Model (right)



Sea-ice draft (m)