Distributions of pCO_2 and their decadal changes in the Bering Sea

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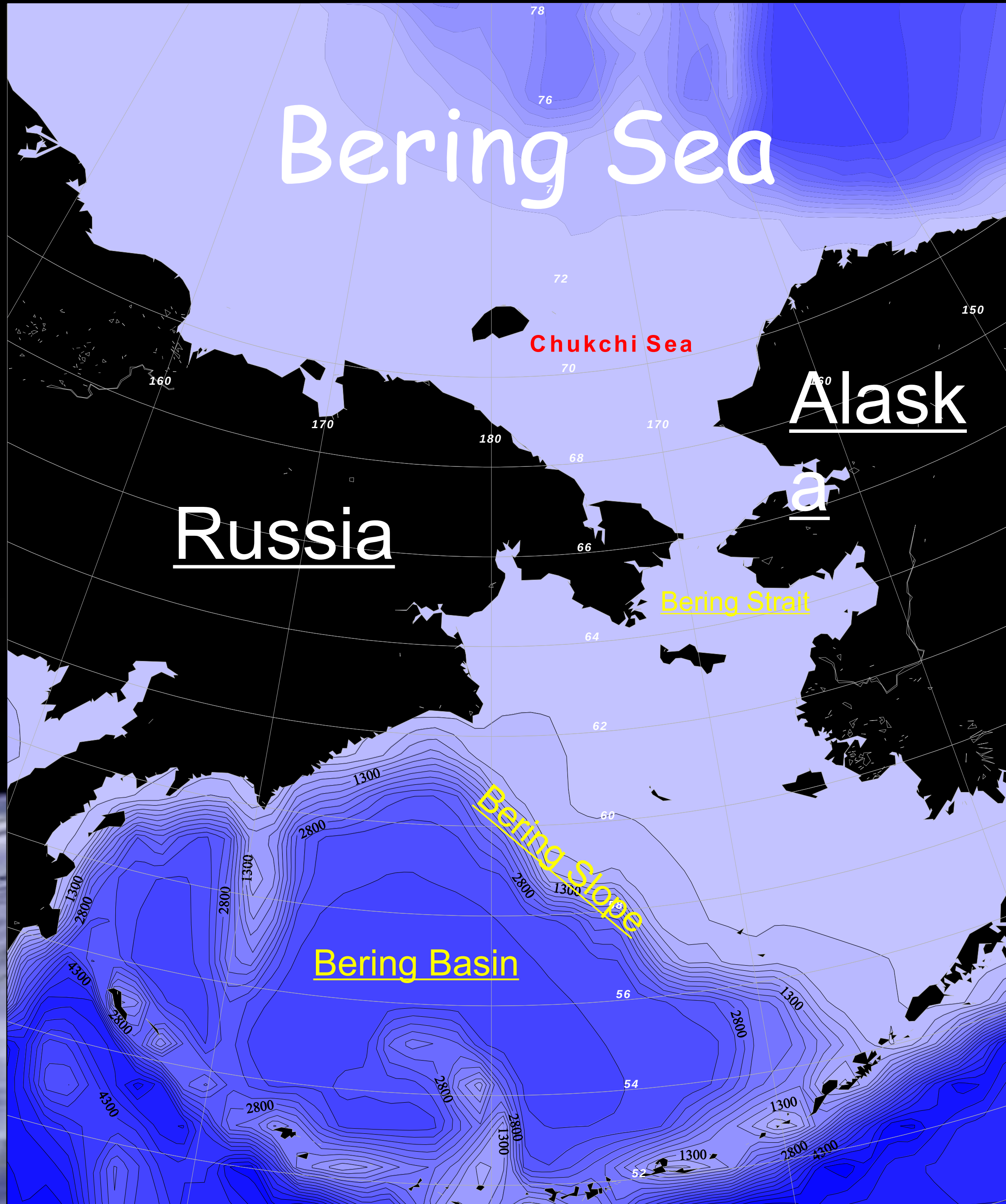
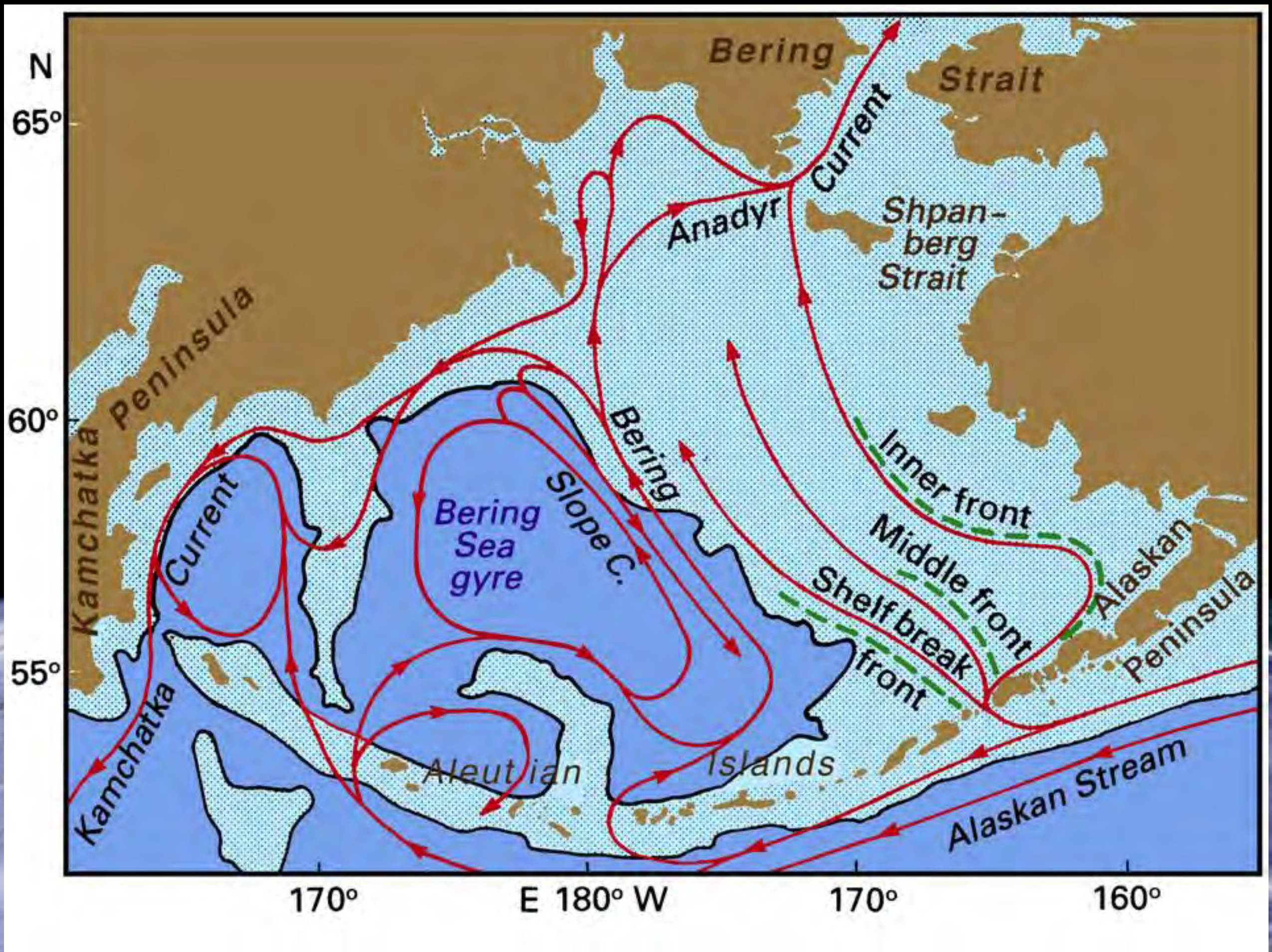
OUTLINES

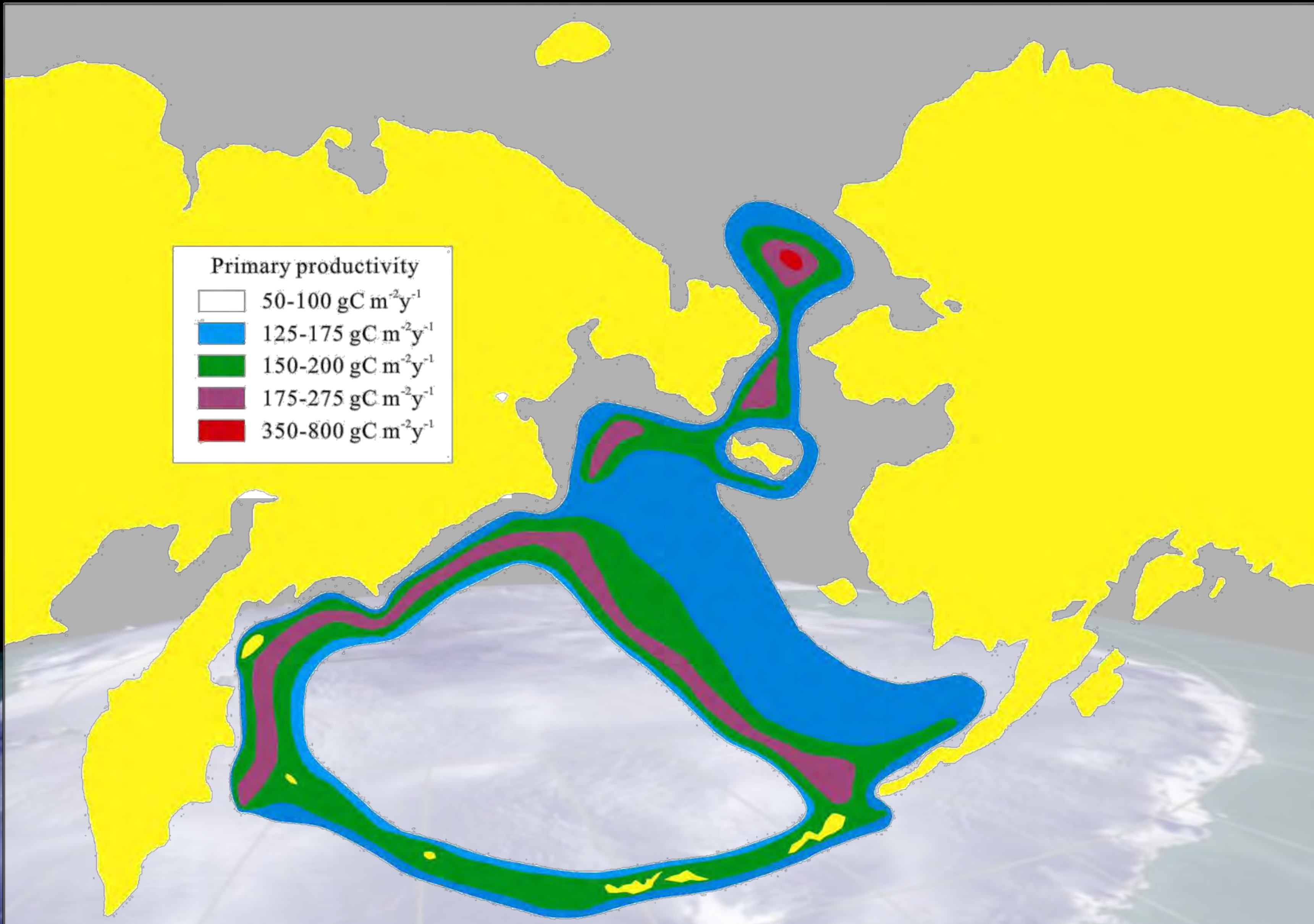
- Geographic and Methods
- Distinct pCO_2 zones in the Bering Sea and their control
- Decadal change of the Bering Sea carbon sink (from 1999 to 2012)
- Conclusion


Bering Sea
Chukchi Sea
Alask
a
Russia
Bering Strait
Bering Slope
Bering Basin

Circulations in the Bering Sea

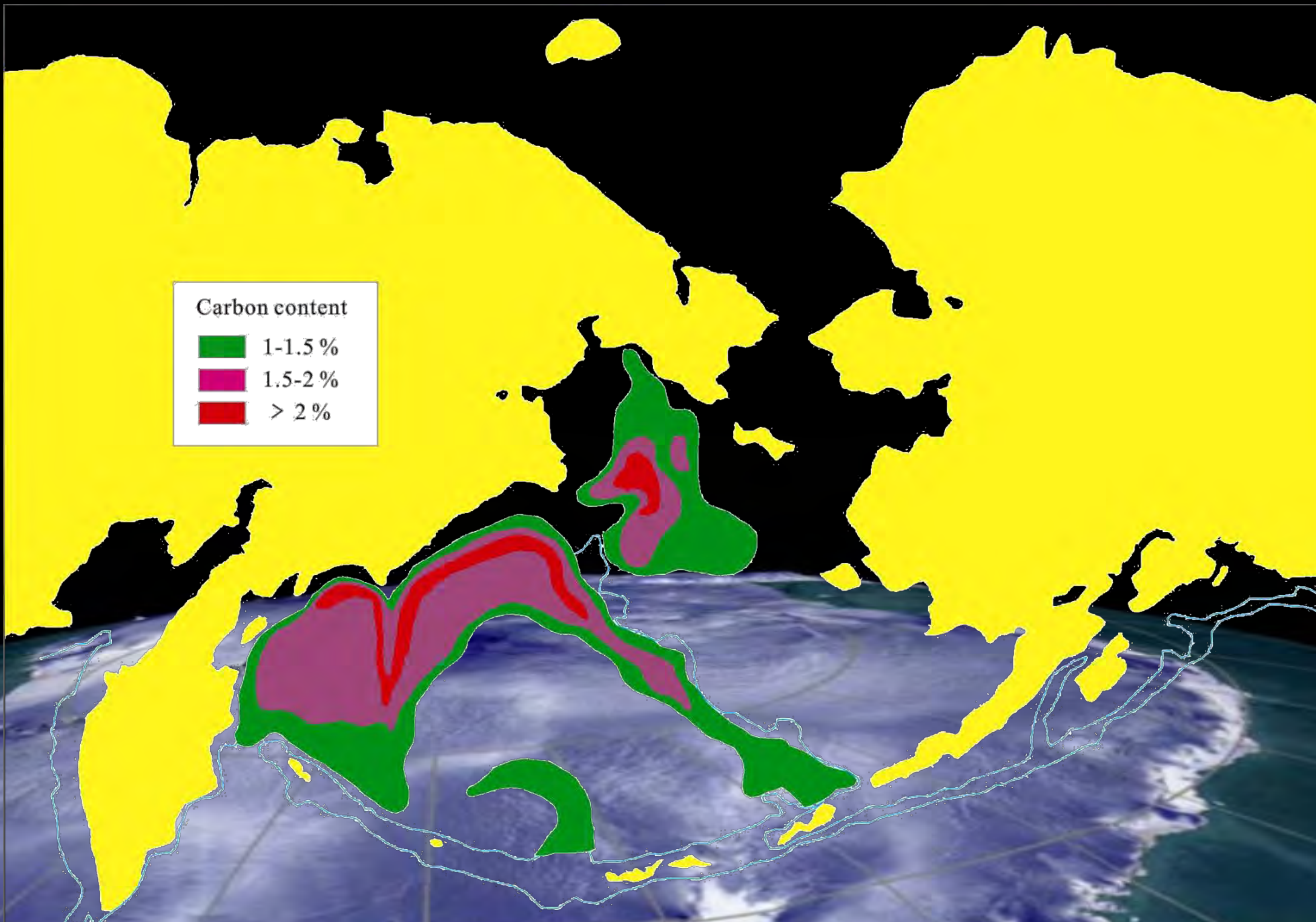


Bering Sea Green Belt



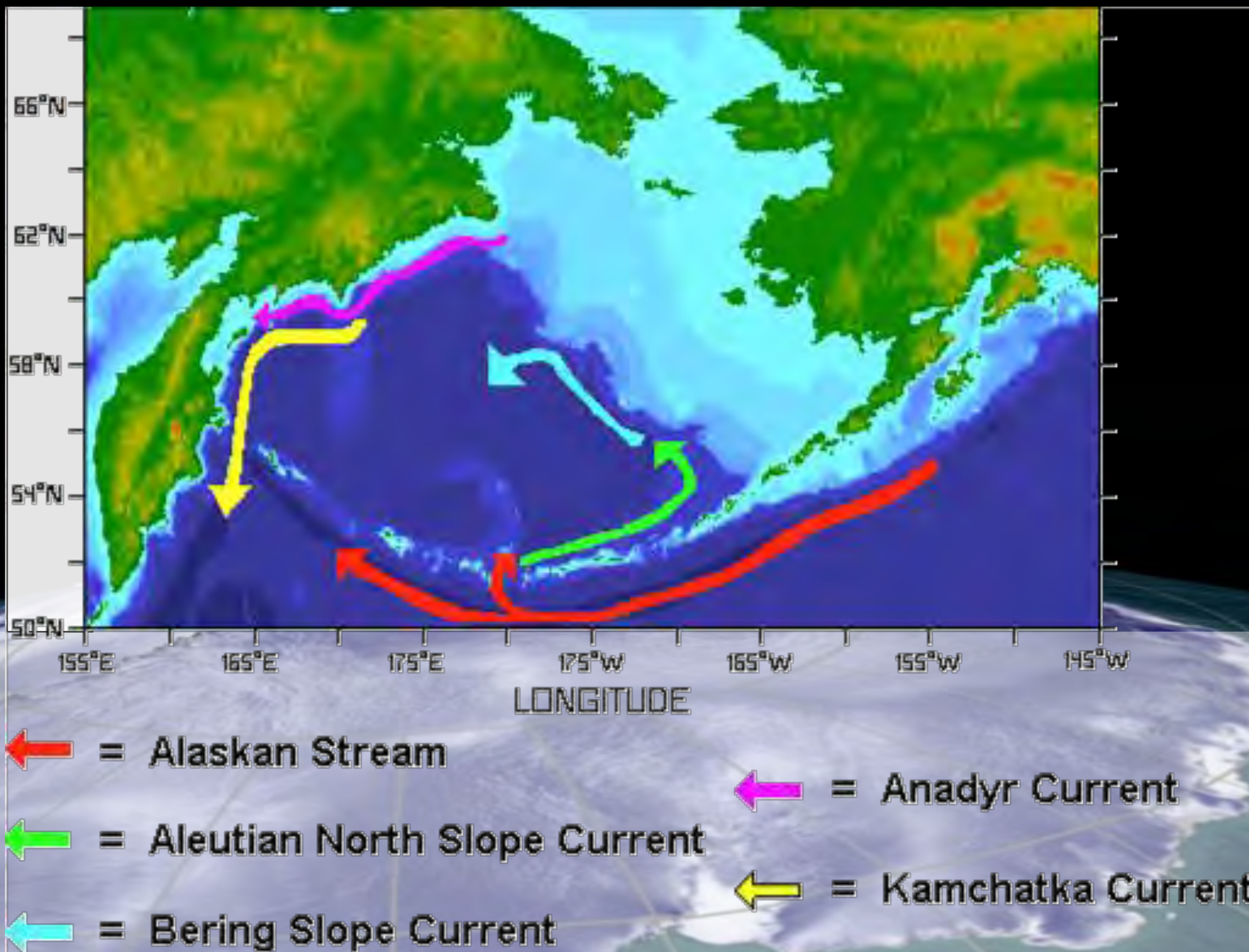
Generalized pattern of primary productivity in the Bering Sea (redrawn from Springer et al., 1996)

Carbon content in surface sediments



Carbon content in surface sediments of the Bering Sea (redrawn from Springer et al., 1996)

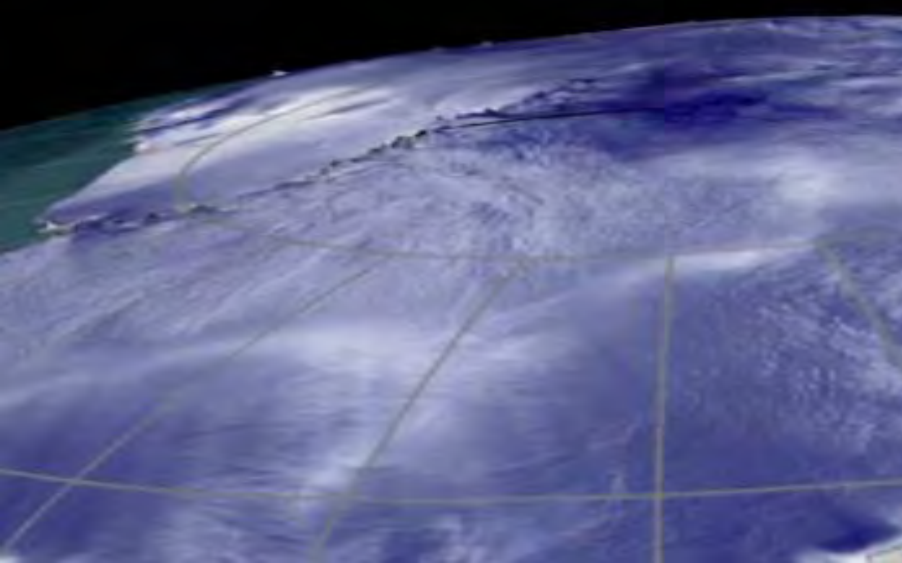
Schematic diagram of major currents in the Bering Sea



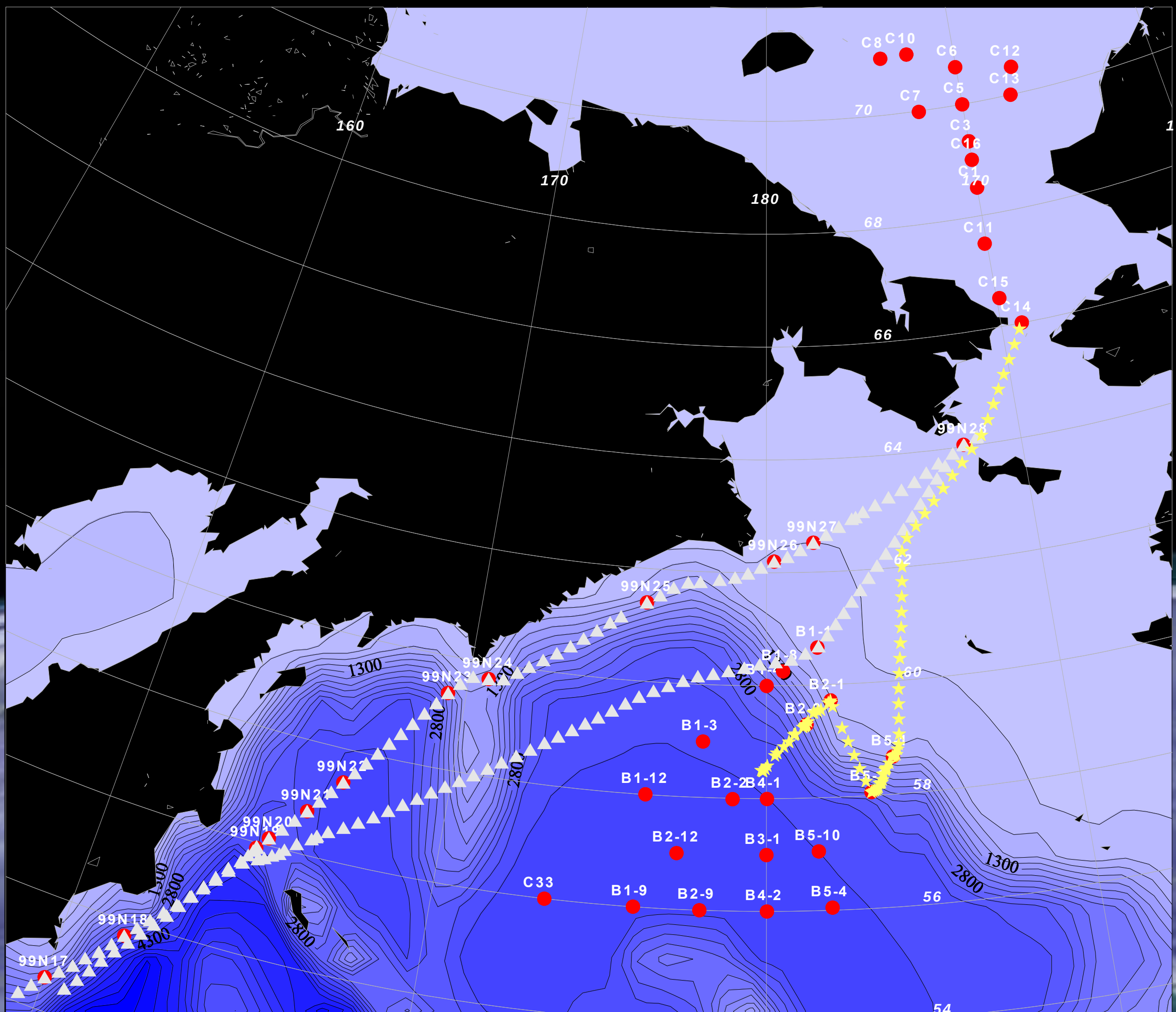
Underway pCO_2 observation

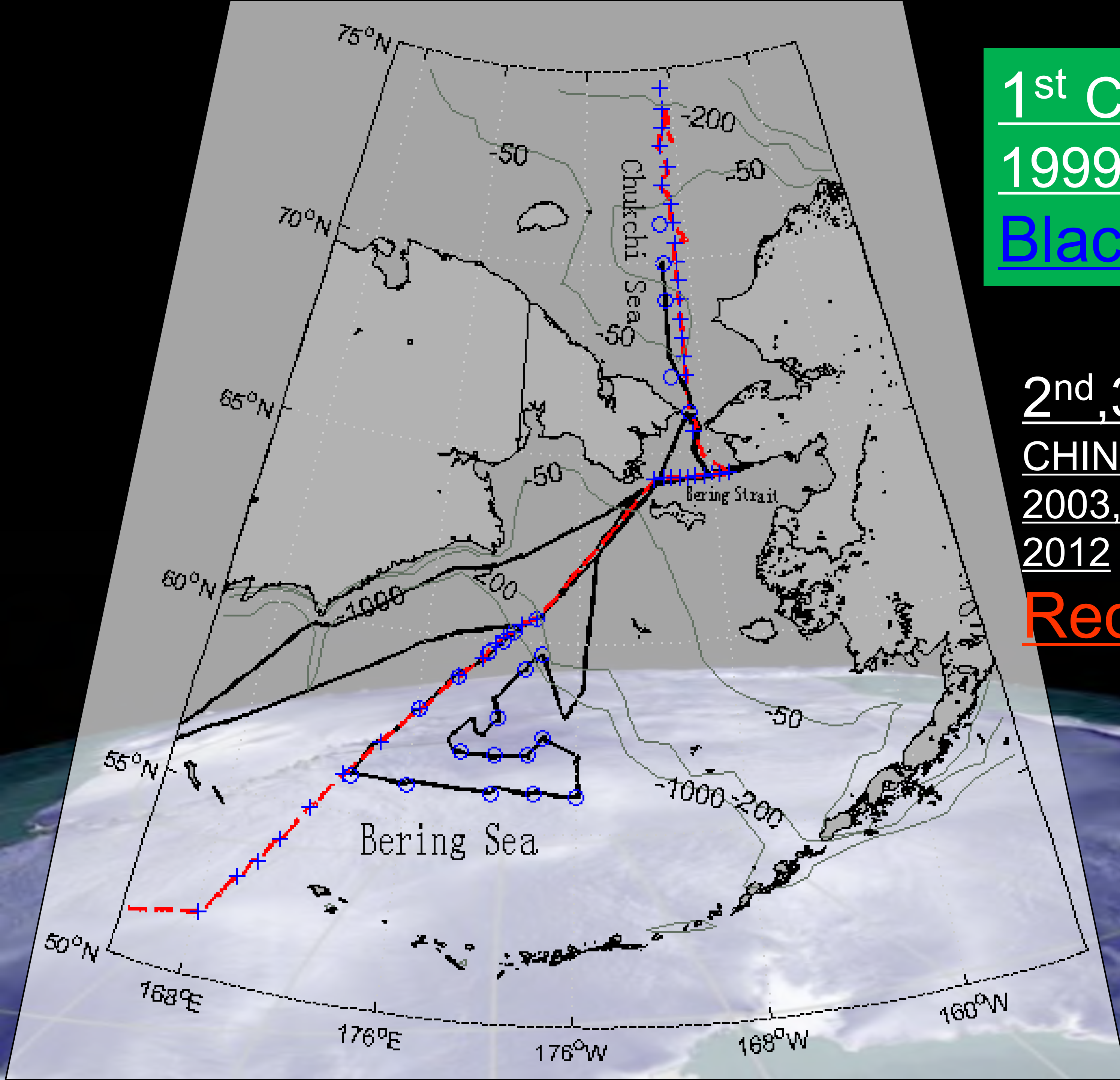
•CO_2 system Measurements in situ

CO2 parameters



CHINARE-1999

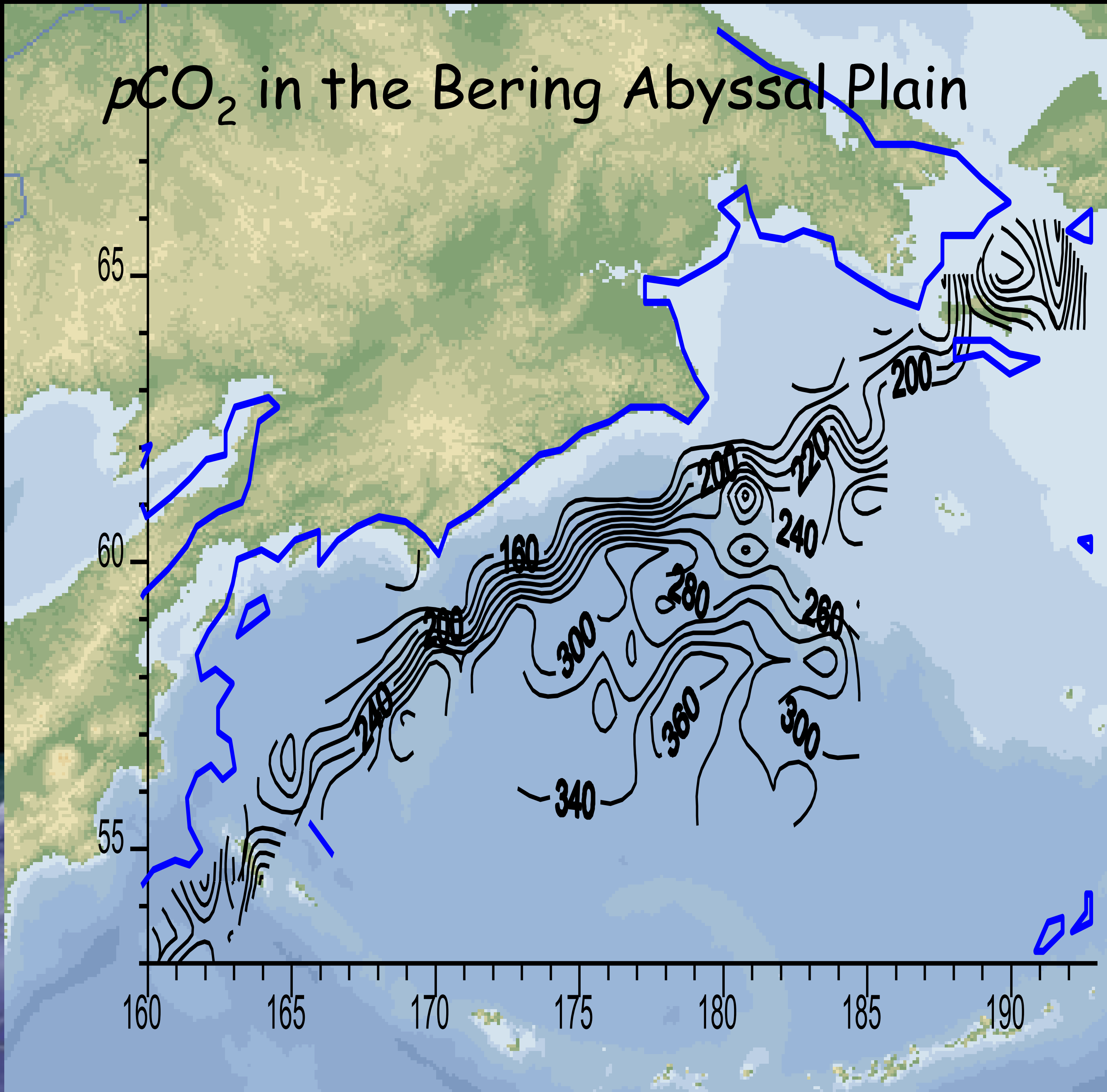




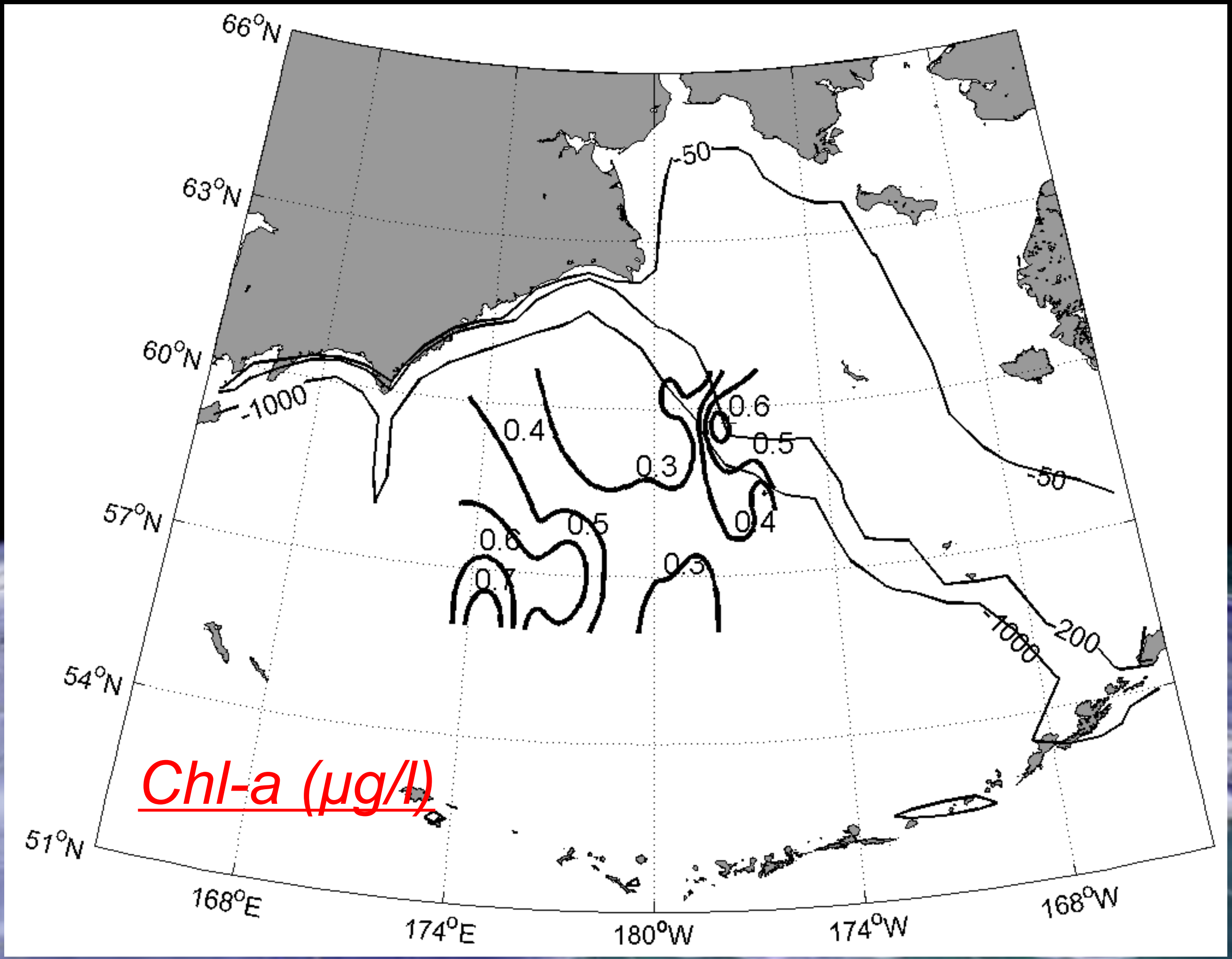
1st CHINARE
1999.7～9
Black Line

2nd,3rd,4th & 5th
CHINARE cruises
2003, 2008, 2010, 2012
Red line

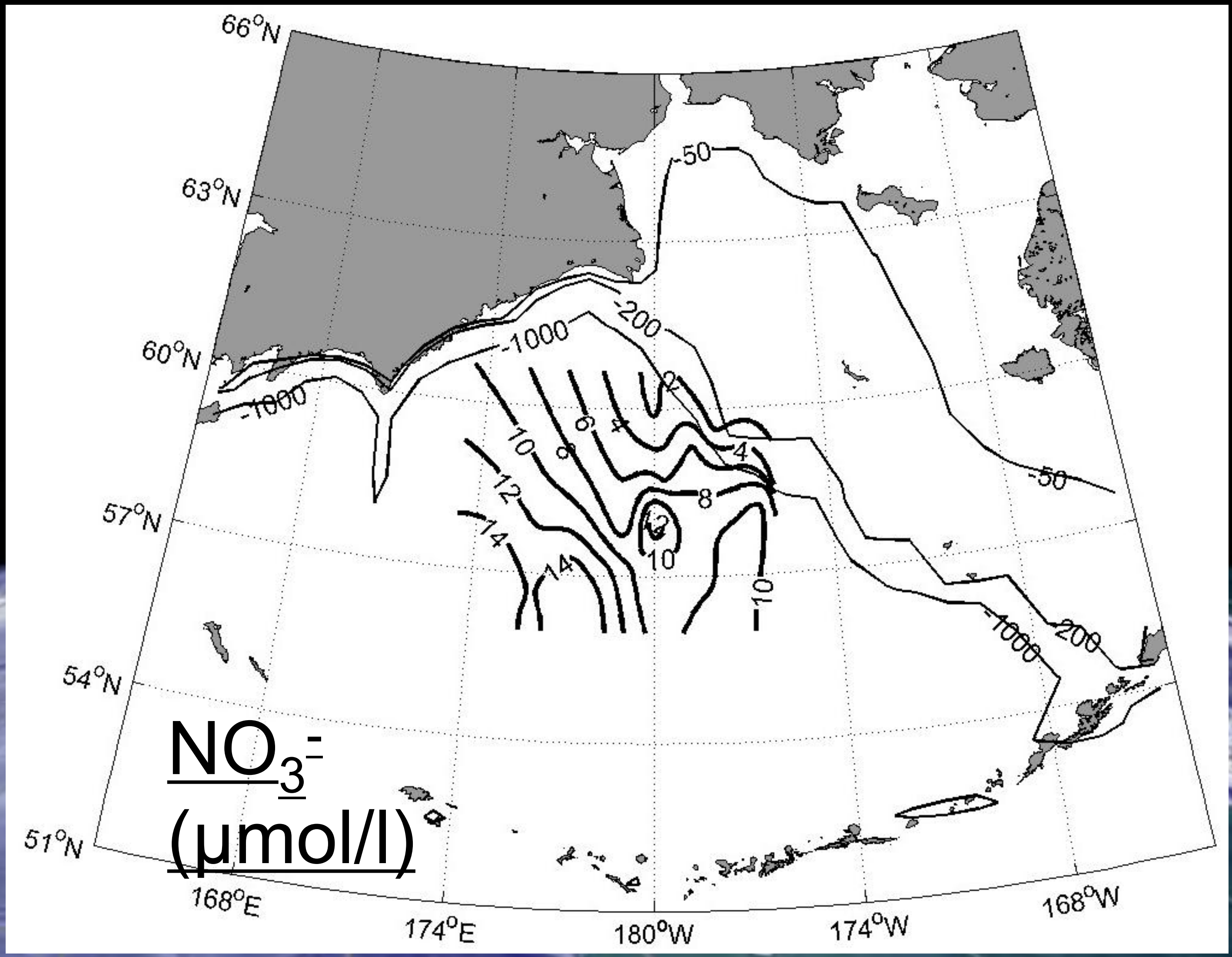
pCO_2 in the Bering Abyssal Plain



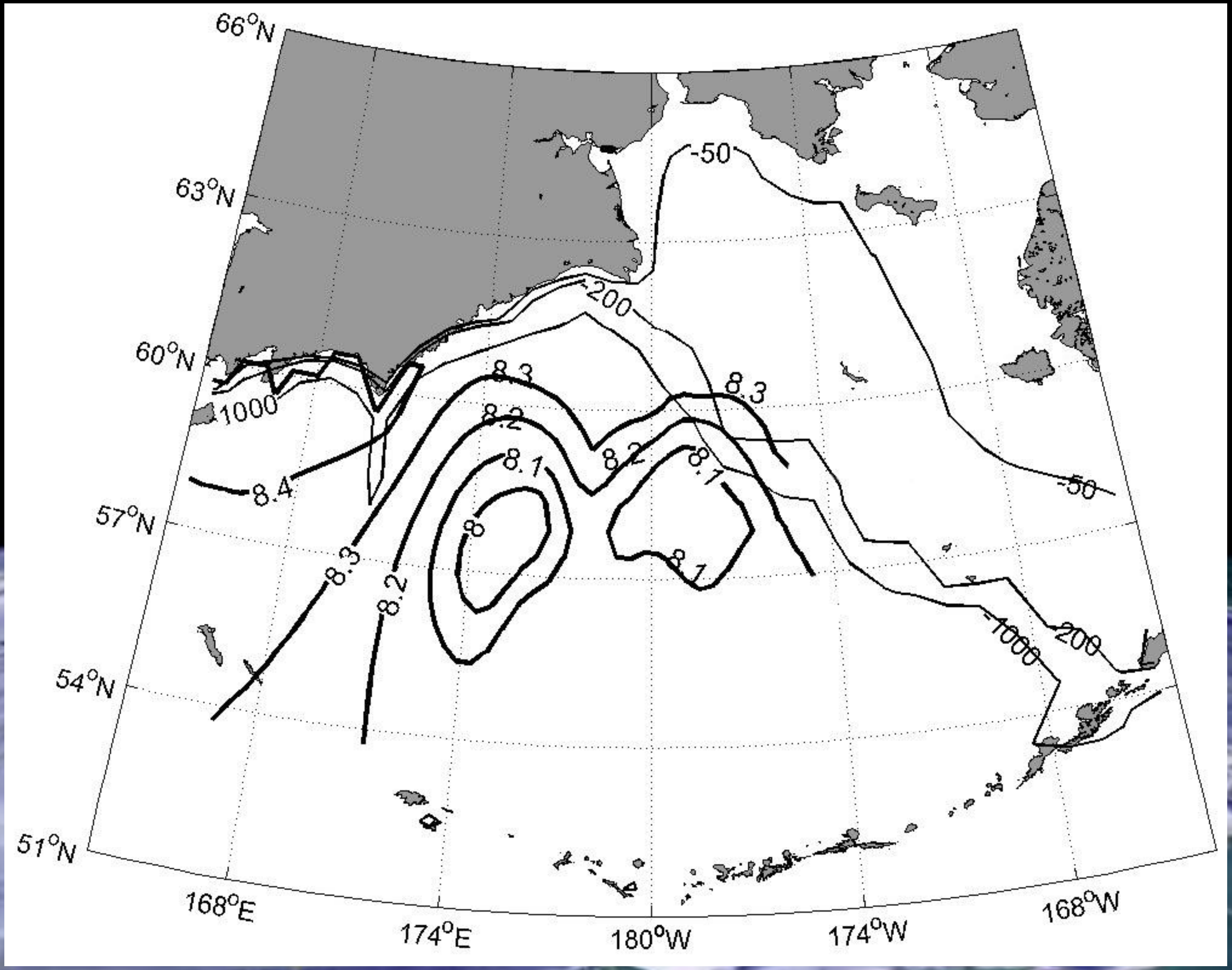
Bering Sea Chl-a



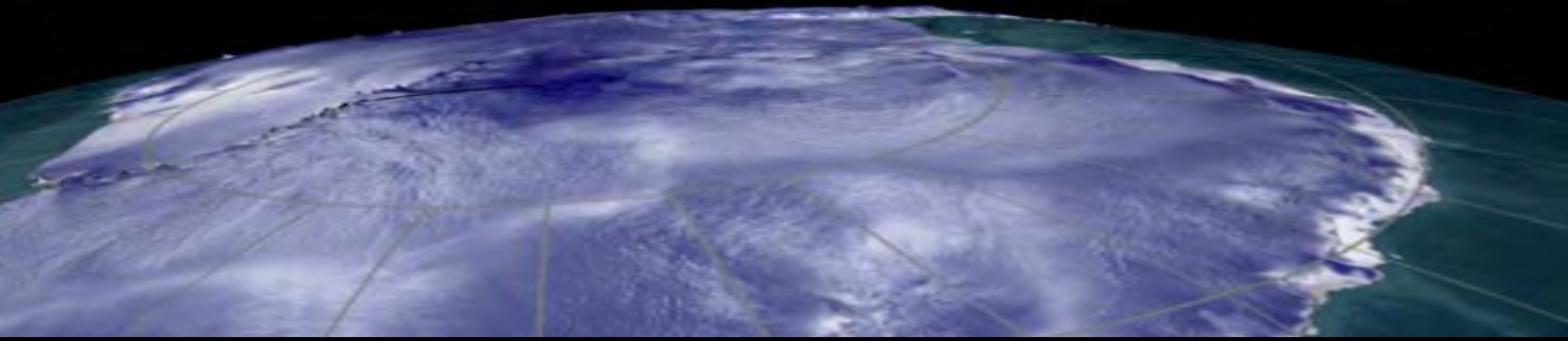
Bering Sea Nutrients (NO_3^-)



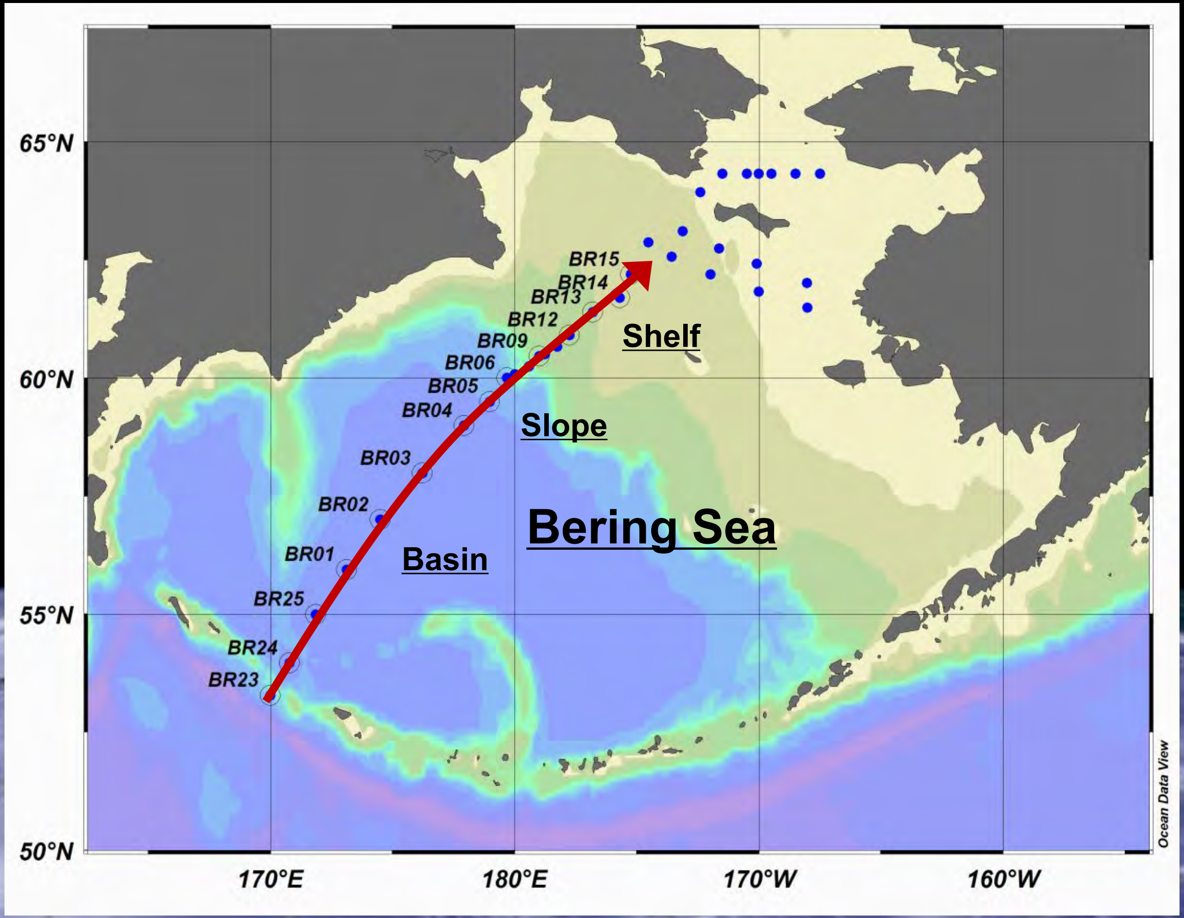
Bering Sea pH

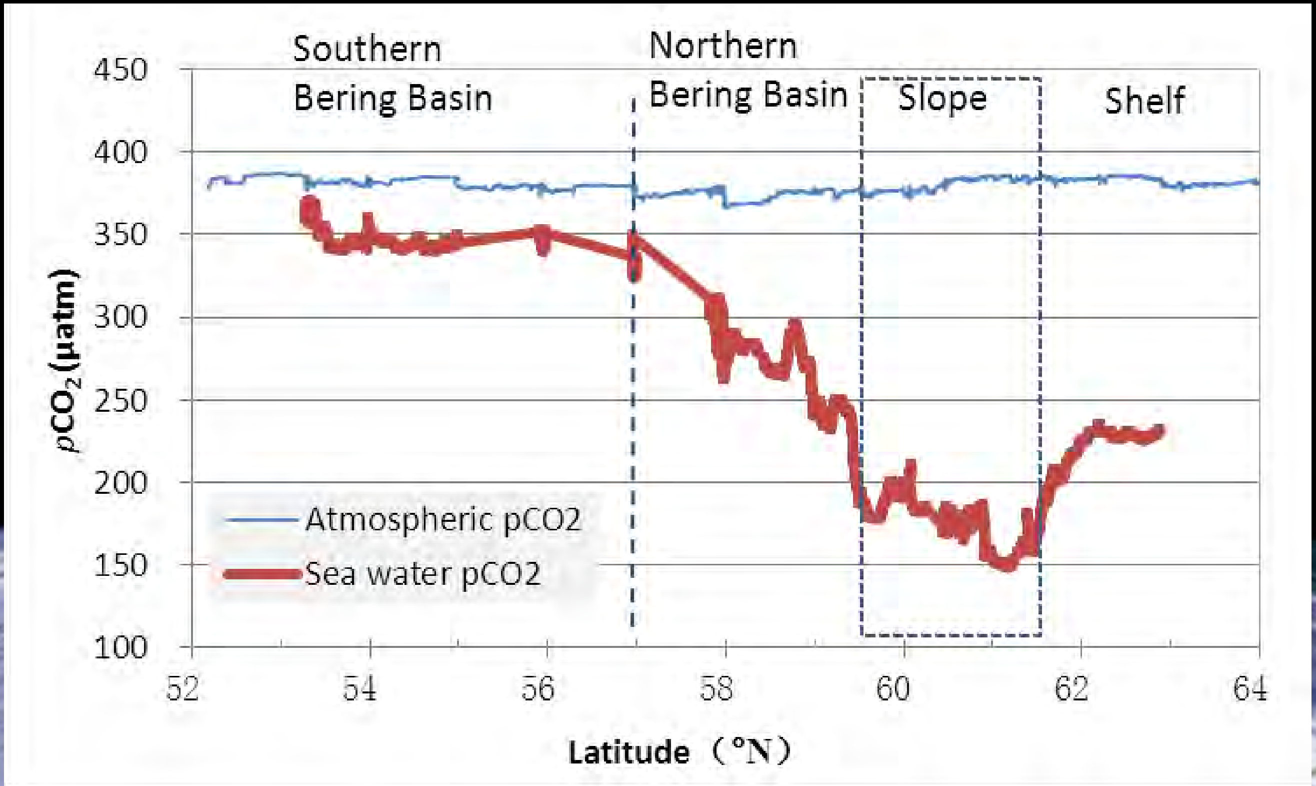


Distinct pCO_2 zones in the Bering Sea and their control



Sampling Locations



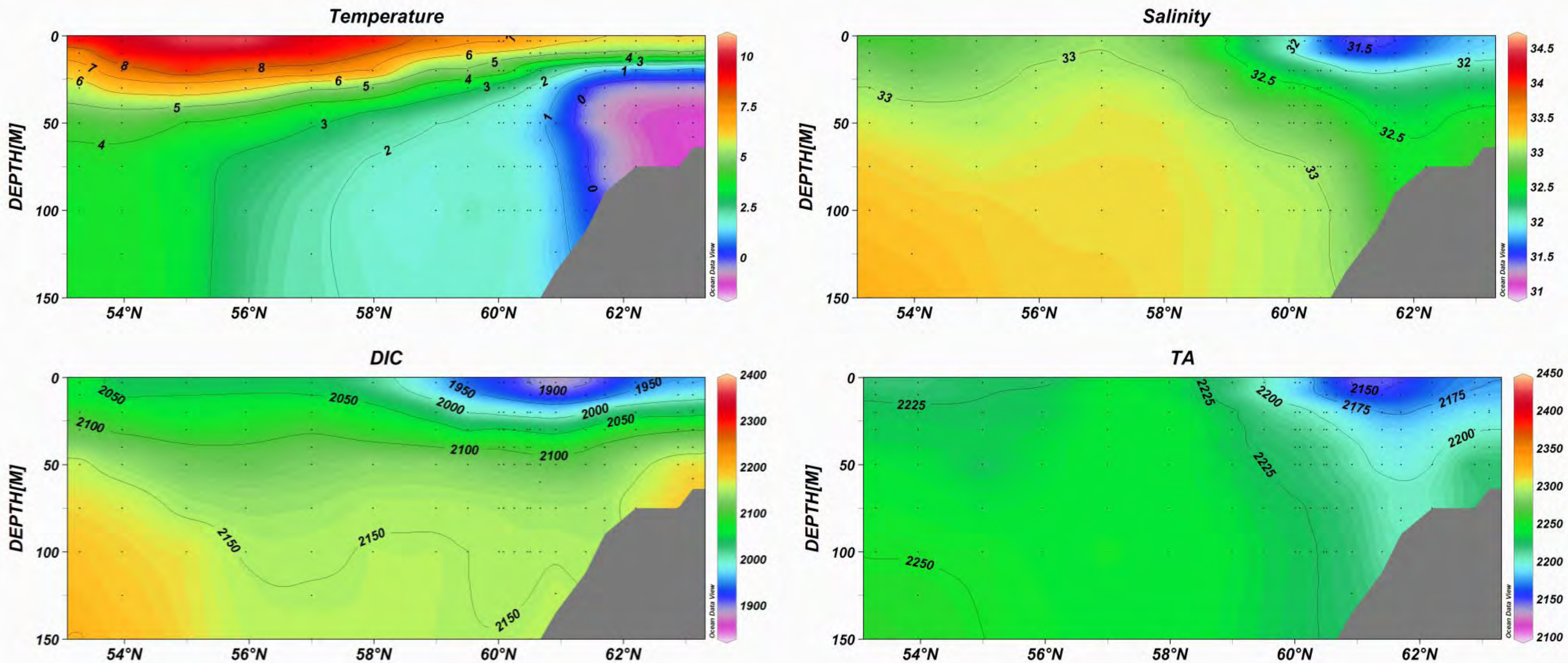


Latitudinal distribution of pCO_2 (μatm) along transect BR

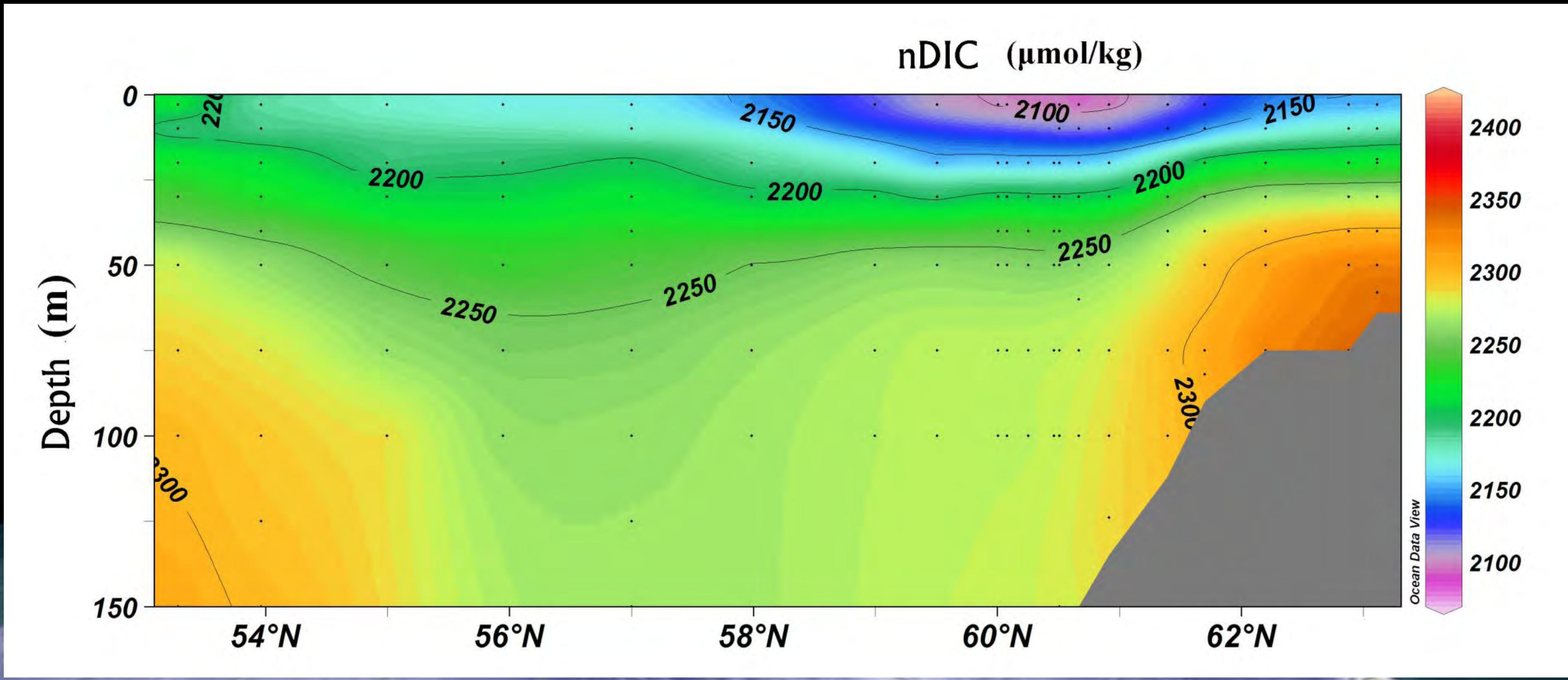
Processes ⇨ CO_2 Uptake

Process	Proxy		Change	pCO_2	Cause
Warming	temperature	T	↗	↗	Decreasing the solubility of CO_2
Bio production	Nutrients	NO_3^-	↘	↘	Bio production consume DIC
Organism decomposing	Nutrients	NO_3^-	↗	↗	Release the inorganic carbon
Carbonate deposit	Alkalinity	TA	↘	↗	in proportion of 2 : 1 diluted TA and TCO_2
Carbonate dissolve	Alkalinity	TA	↗	↘	Reverse process
Air-sea Exchange（Air→sea）	time	Time	↗	↗	

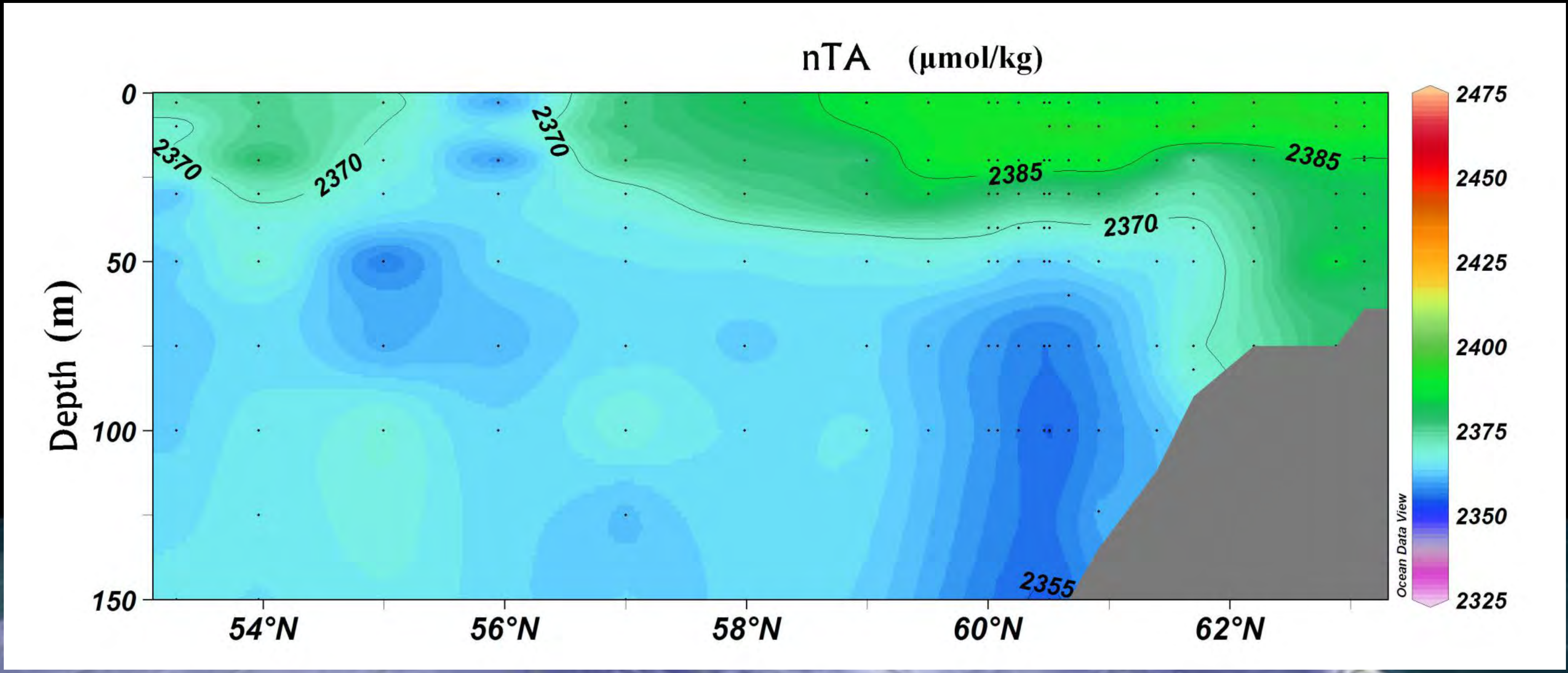
T, S, TA, DIC


Temperature
Salinity
DIC
TA
DEPTH[M]
54°N
56°N
58°N
60°N
62°N
Ocean Data View

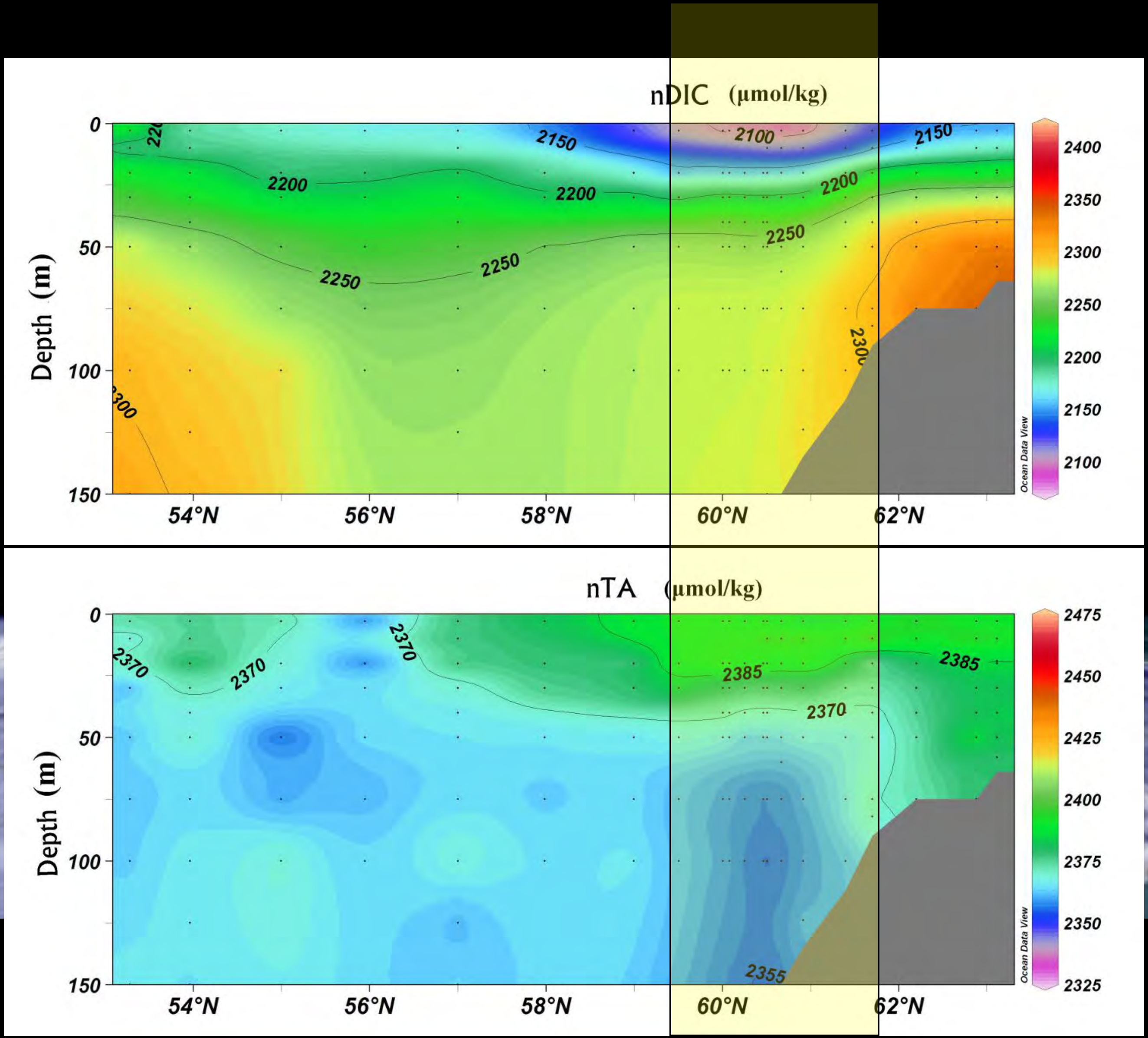
normalized DIC



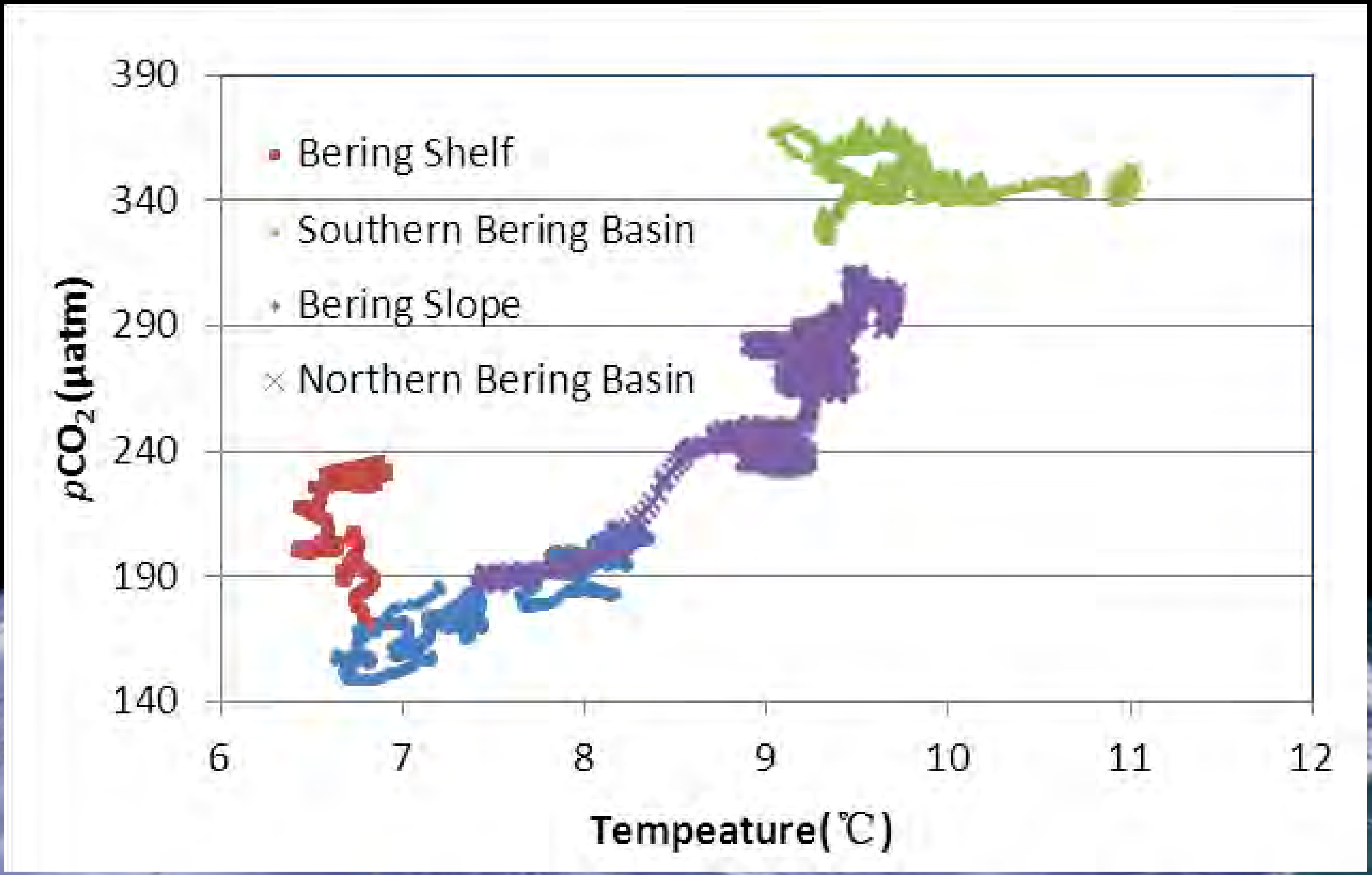
normalized TA



Biological Control on BSC

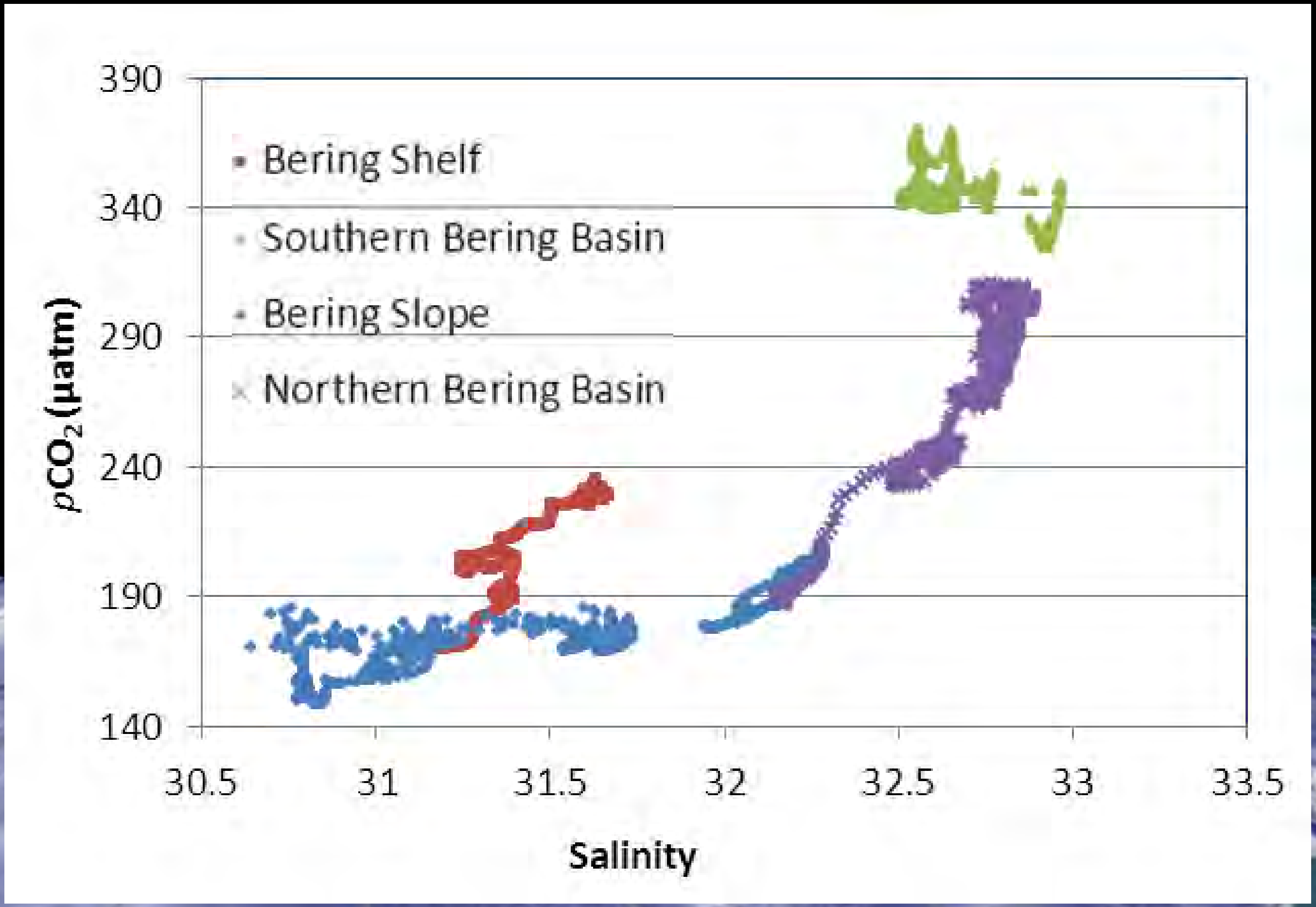


pCO_2~SST



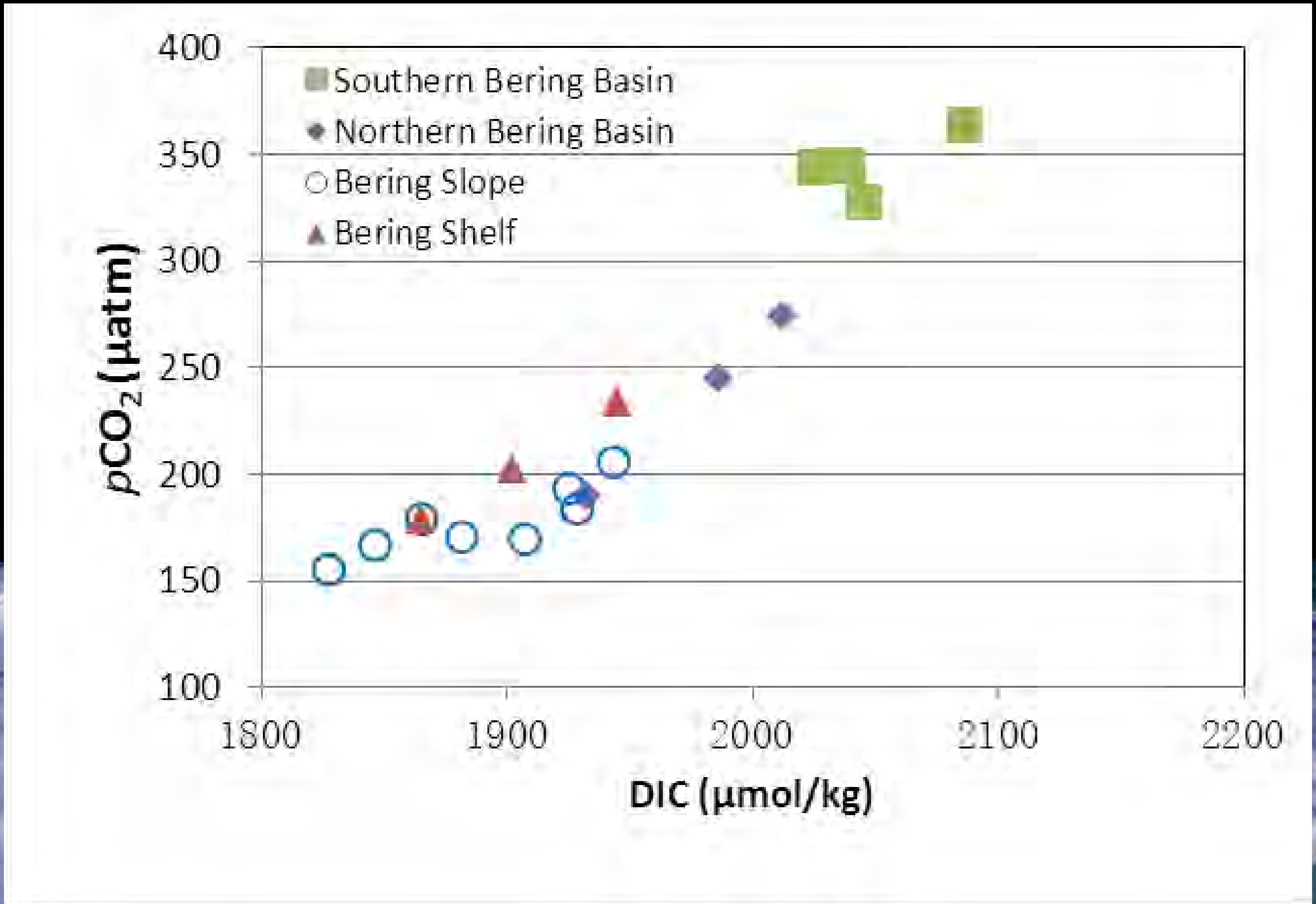
390
340
290
240
190
140
Bering Shelf
Southern Bering Basin
Bering Slope
Northern Bering Basin
pCO2 (μatm)
6
7
8
9
10
11
12
Tempeature(℃)

pCO_2～SSS



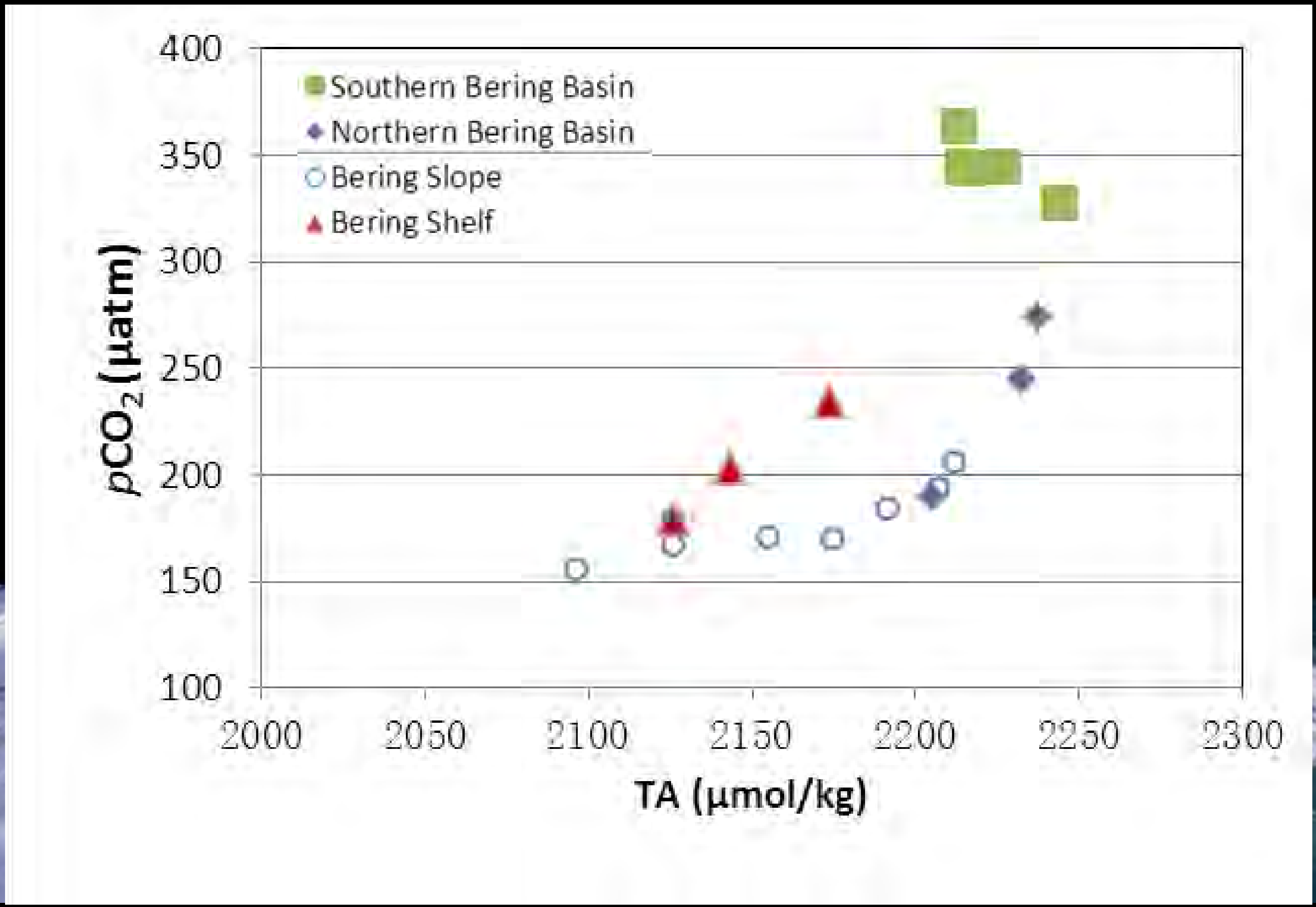
390
340
290
240
190
140
Bering Shelf
Southern Bering Basin
Bering Slope
Northern Bering Basin
pCO2 (μatm)
30.5
31
31.5
32
32.5
33
33.5
Salinity

pCO_2～DIC

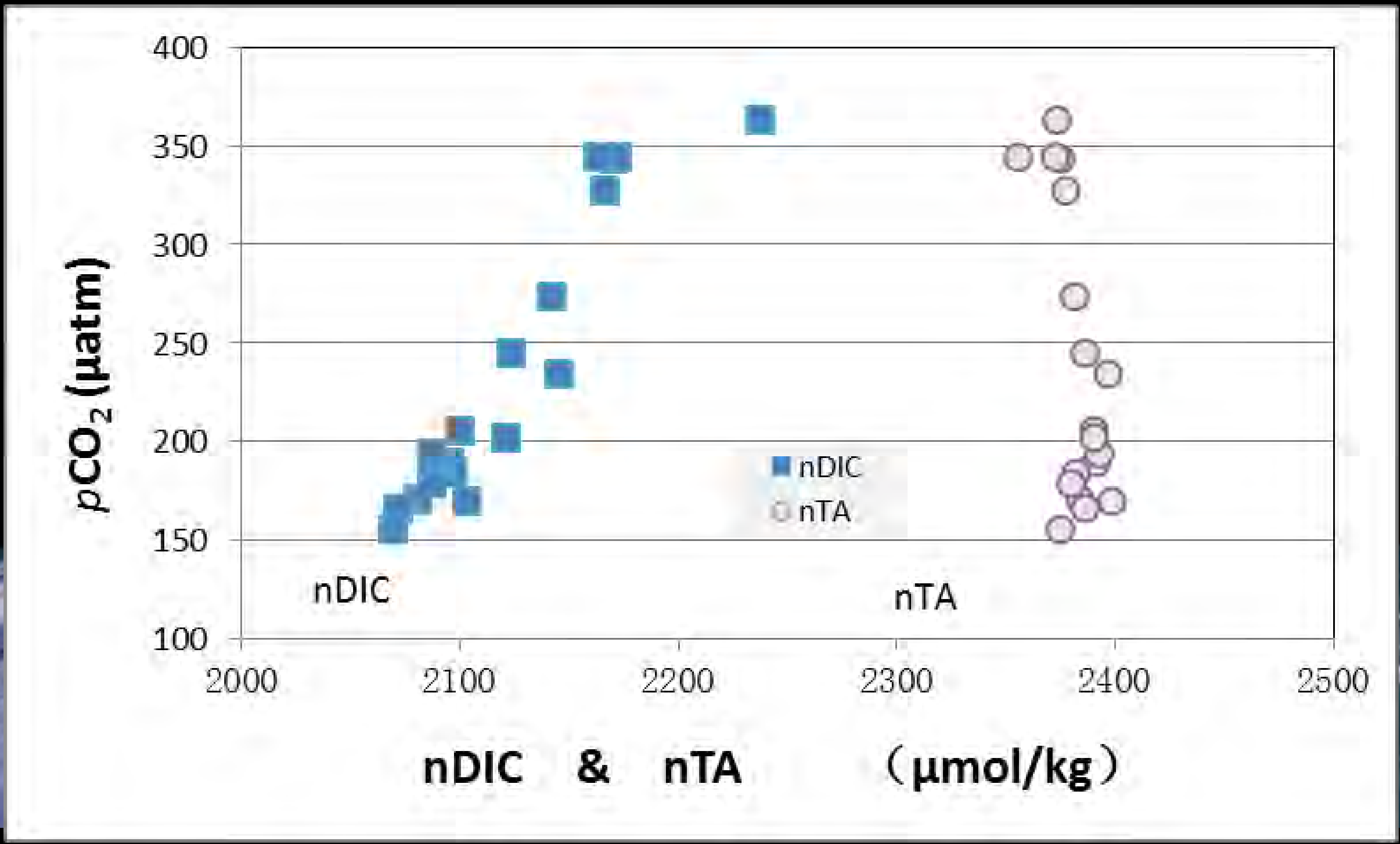


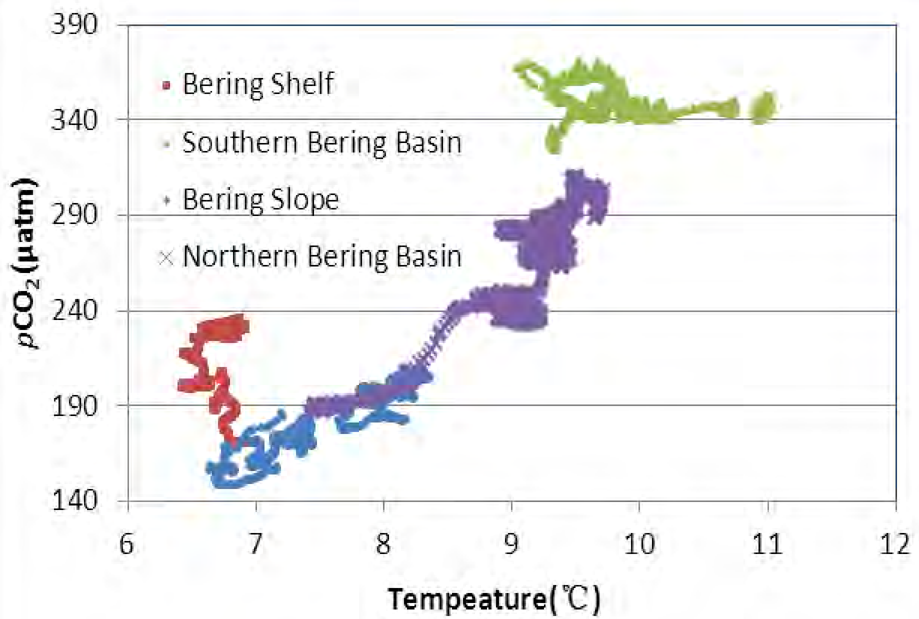
Southern Bering Basin
Northern Bering Basin
Bering Slope
Bering Shelf
400
350
300
250
200
150
100
1800
1900
2000
2100
2200
pCO$_2$ (µatm)
DIC (µmol/kg)

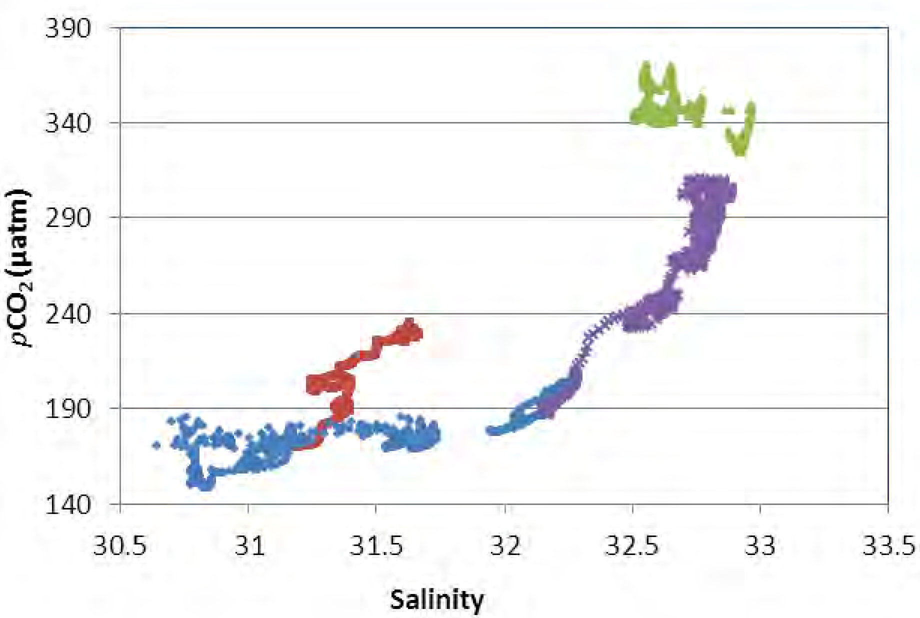
pCO$_2$～TA


Southern Bering Basin
Northern Bering Basin
Bering Slope
Bering Shelf
400
350
300
250
200
150
100
pCO$_2$ (μatm)
2000
2050
2100
2150
2200
2250
2300
TA (μmol/kg)

pCO_2～(nTA & nDIC)

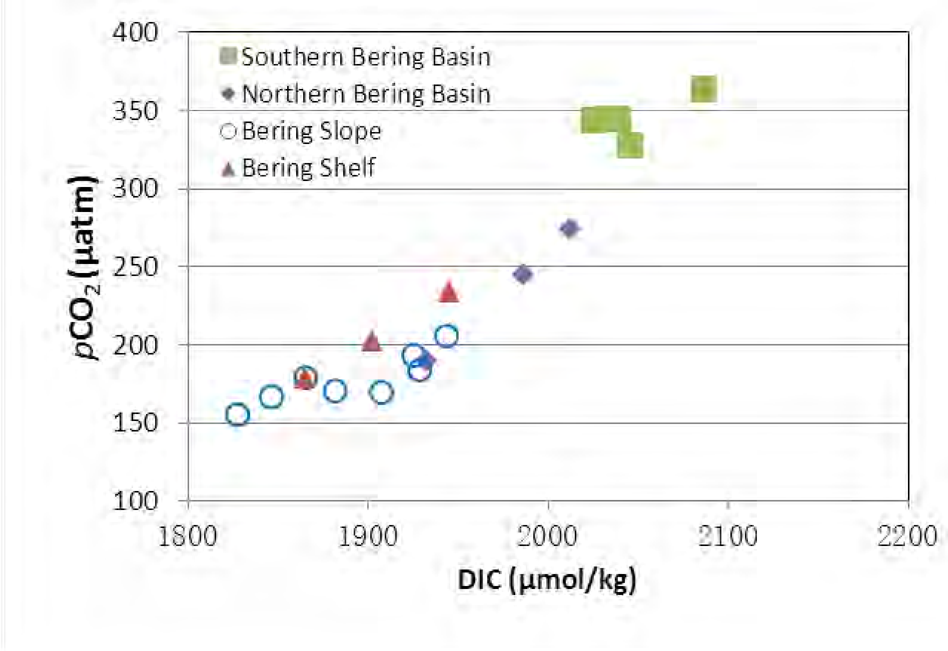


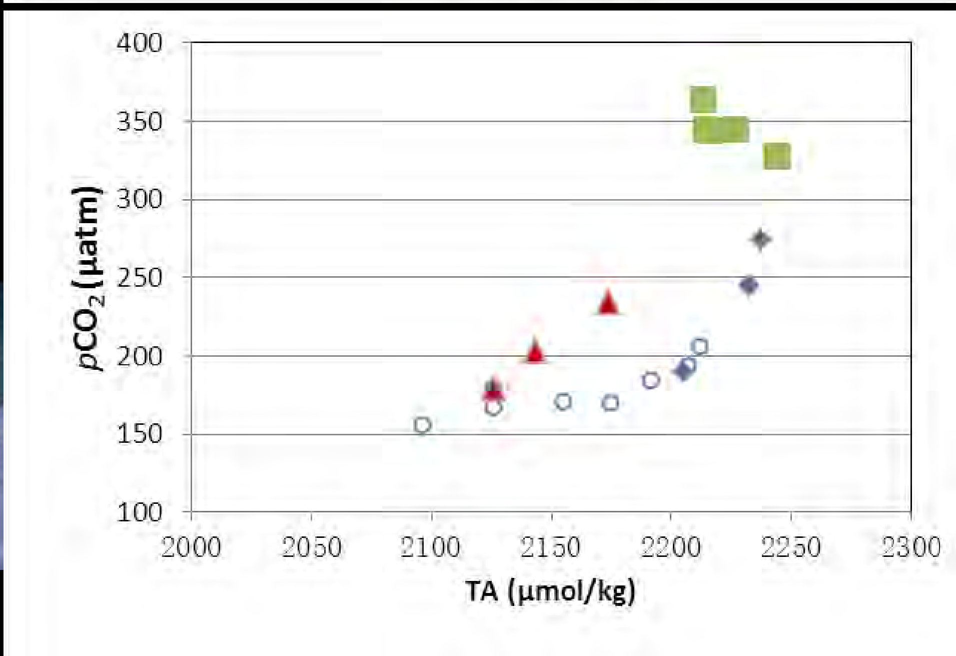




Controlling Factors

Regions	T	S	
Southern Basin	×	×	
Northern Basin	√	√	mixing
Slope	√	×	
Shelf	×	√	

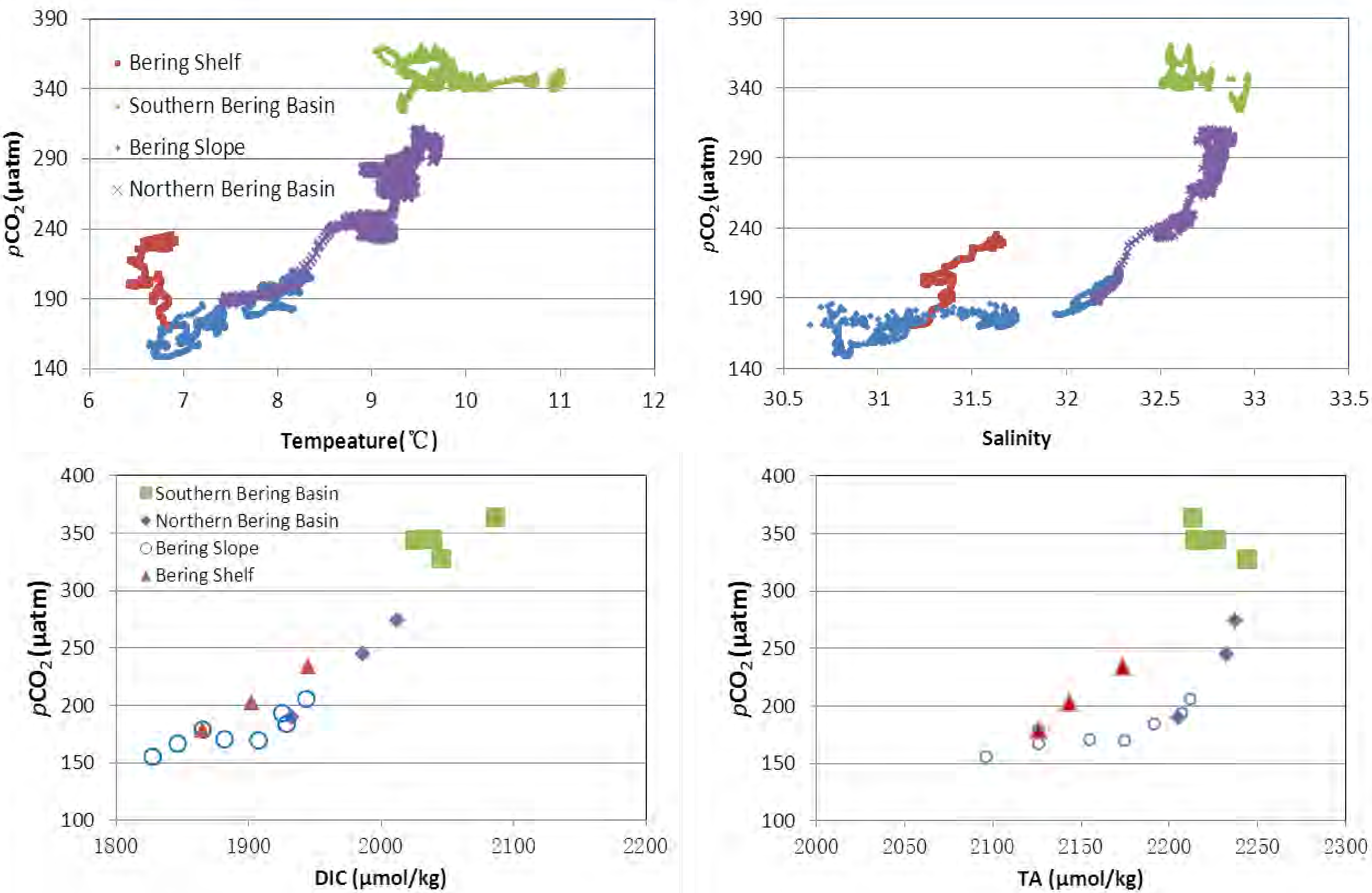




Controlling Factors

Region	TA	DIC	nDIC	
S-Basin	×	×	×	
N-Basin	×	√	√	mixing
Slope	×	×	√	
Shelf	√	√	√	

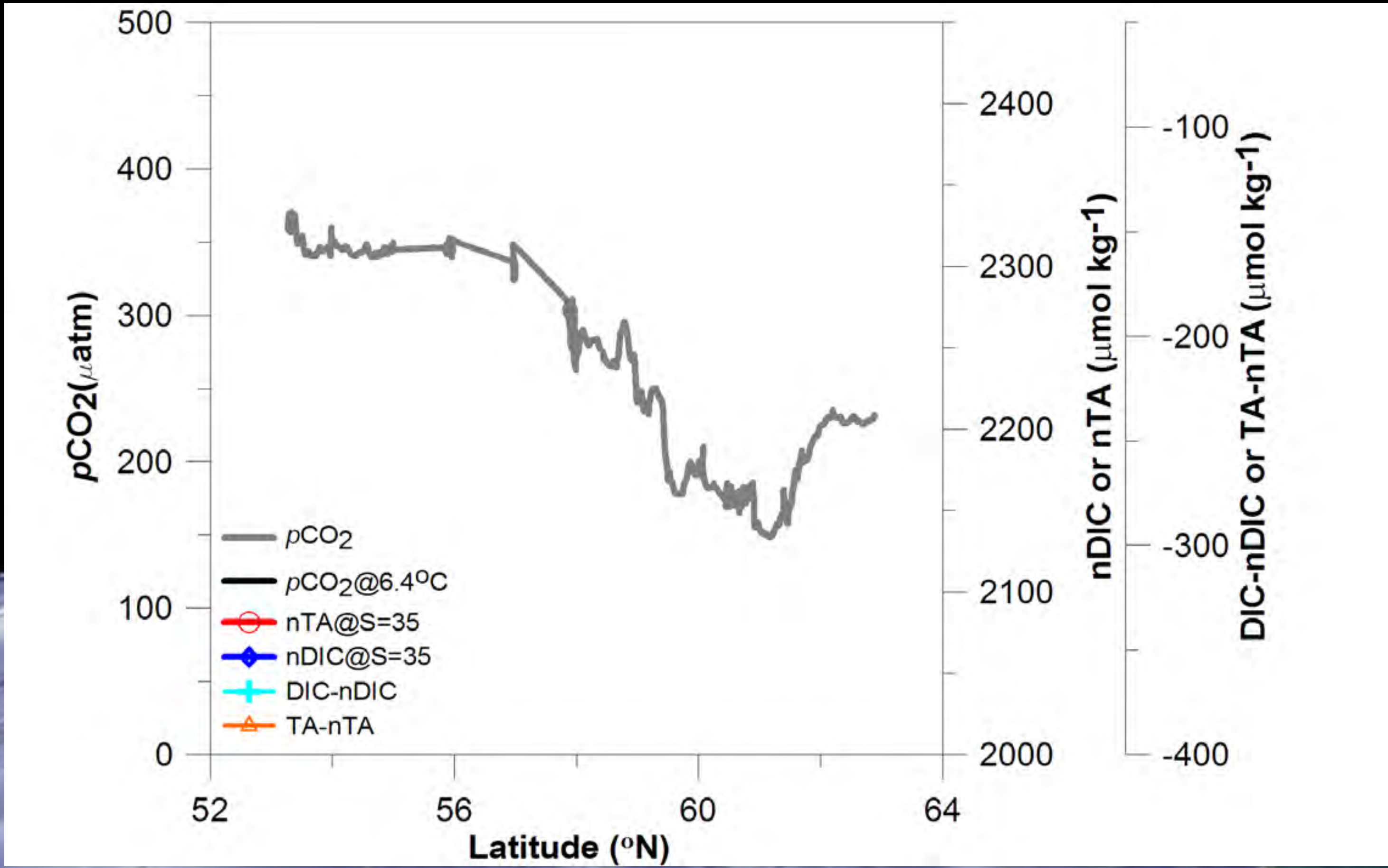
Controlling Factors



pCO_2 and air-sea CO_2 fluxes in the Bering Sea

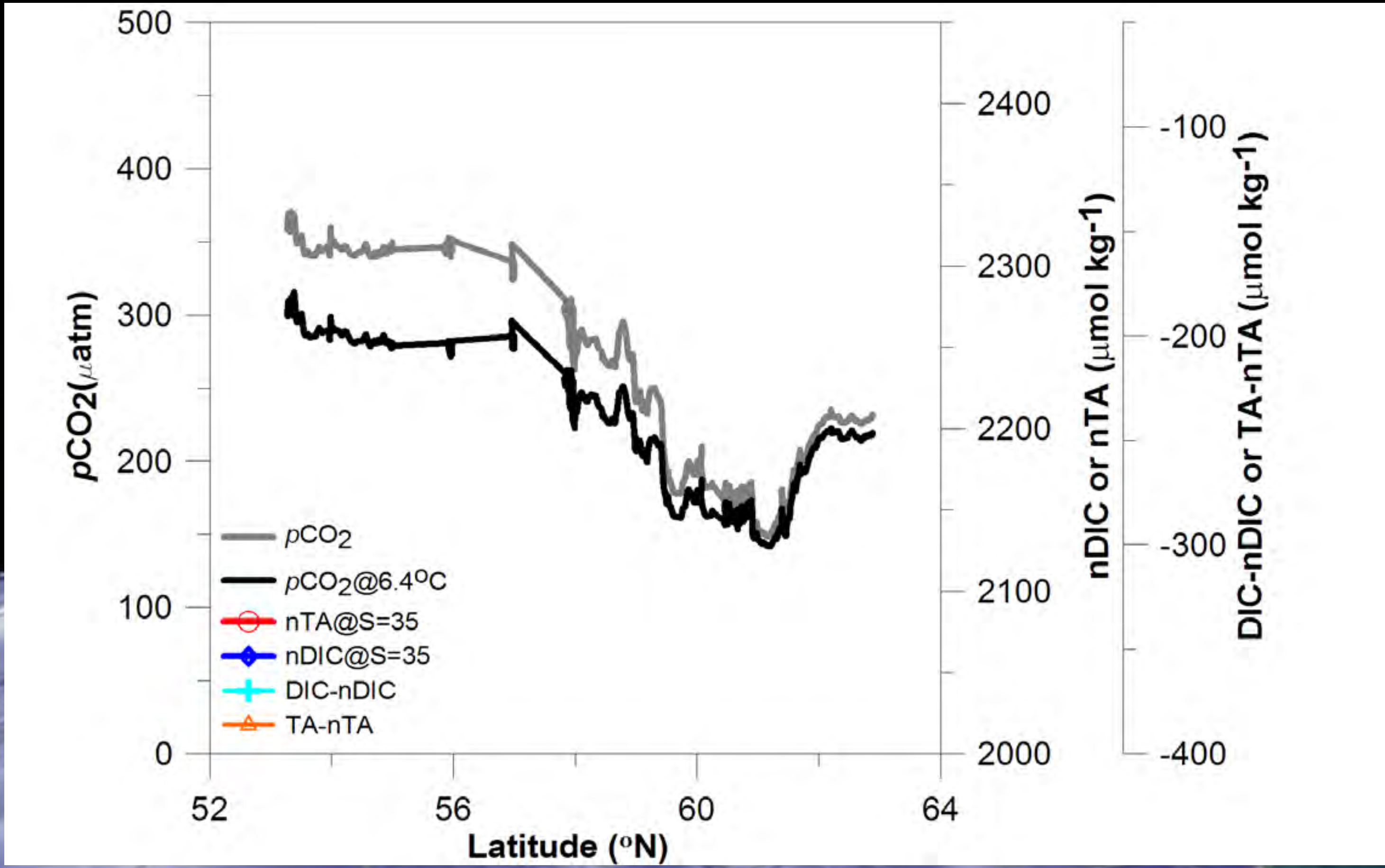
Regions	Averaged pCO_2sw (μatm)	Air pCO_2 (μatm)	Wind speed (m s^{-1})	CO_2 fluxes (mmol m^{-2} d^{-1})
Southern Basin (53-57° N)	348	379	6	-2.9
Northern Basin (57-59.5° N)	274	379	6	-9.8
Slope (59.5-61.5° N)	181.2	379	6	-18.7
Shelf (61.5-63° N)	220.7	379	6	-15.0

pCO_2



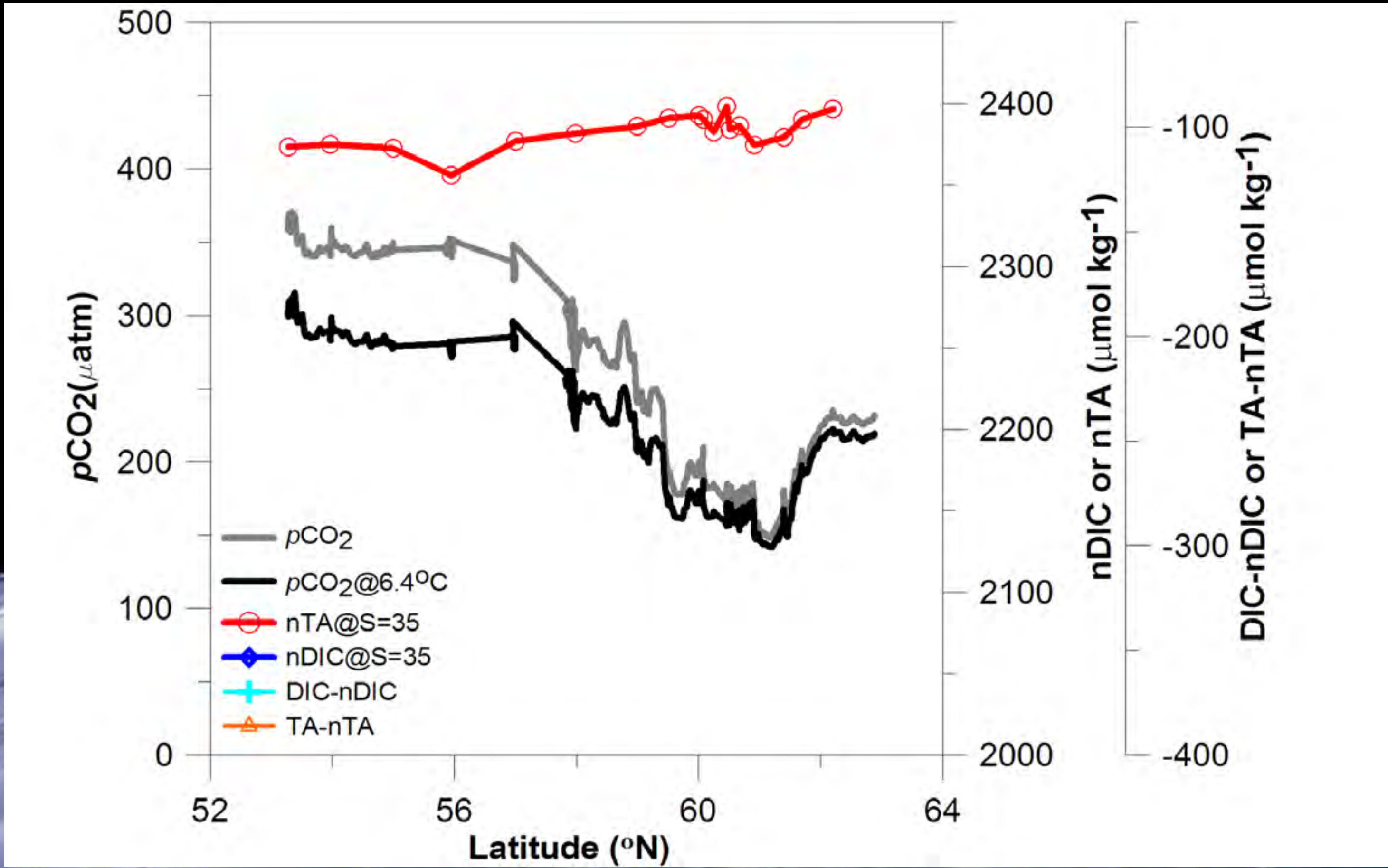
500
400
300
200
100
0
pCO2(μatm)
2400
2300
2200
2100
2000
nDIC or nTA (μmol kg-1)
-100
-200
-300
-400
DIC-nDIC or TA-nTA (μmol kg-1)
52
56
60
64
Latitude (oN)
pCO2
pCO2@6.4oC
nTA@S=35
nDIC@S=35
DIC-nDIC
TA-nTA

pCO_2 @6.4°C



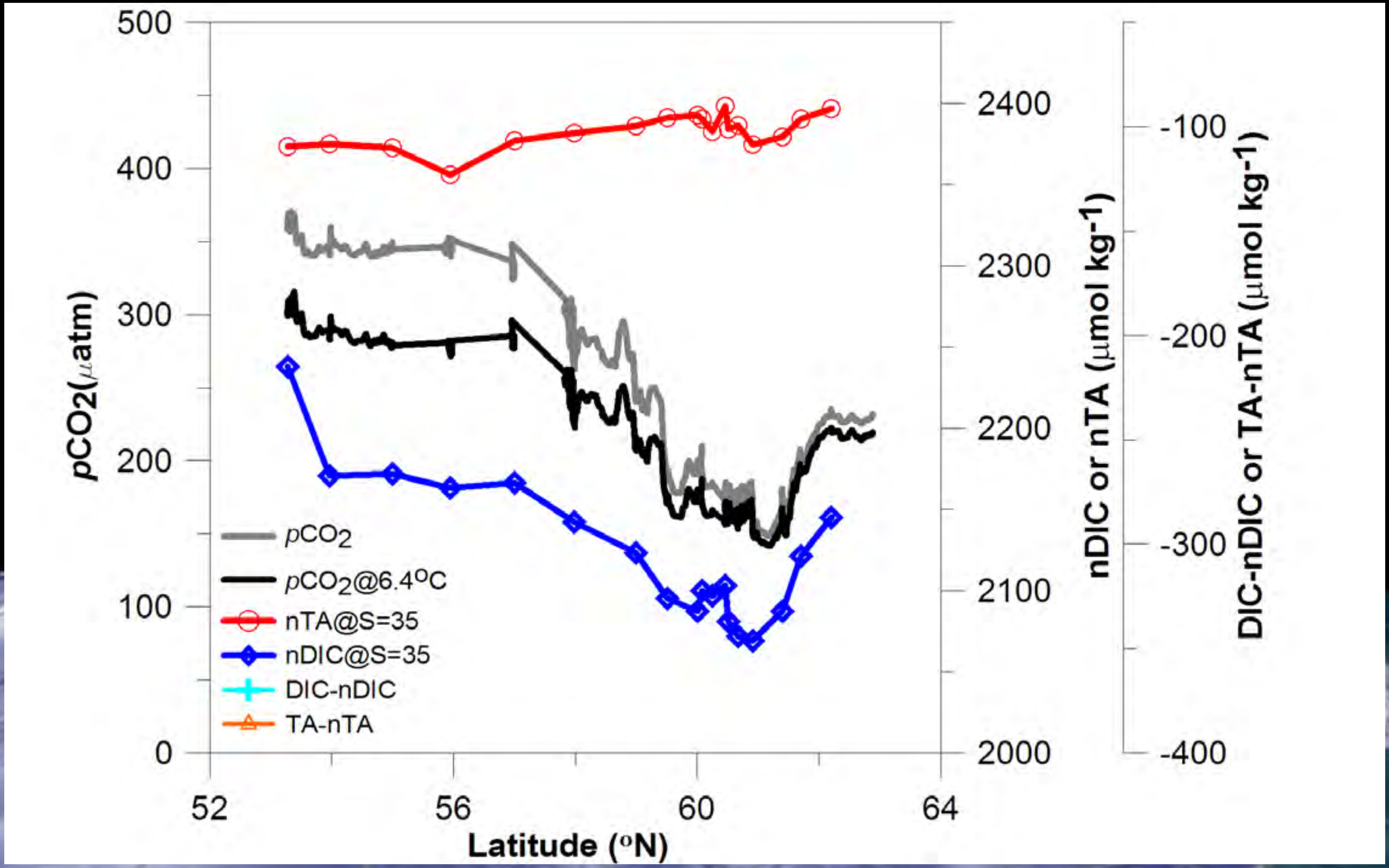
500
400
300
200
100
0
pCO2(μatm)
2400
2300
2200
2100
2000
nDIC or nTA (μmol kg-1)
-100
-200
-300
-400
DIC-nDIC or TA-nTA (μmol kg-1)
52
56
60
64
Latitude (°N)
pCO2
pCO2@6.4°C
nTA@S=35
nDIC@S=35
DIC-nDIC
TA-nTA

nTA @S=35



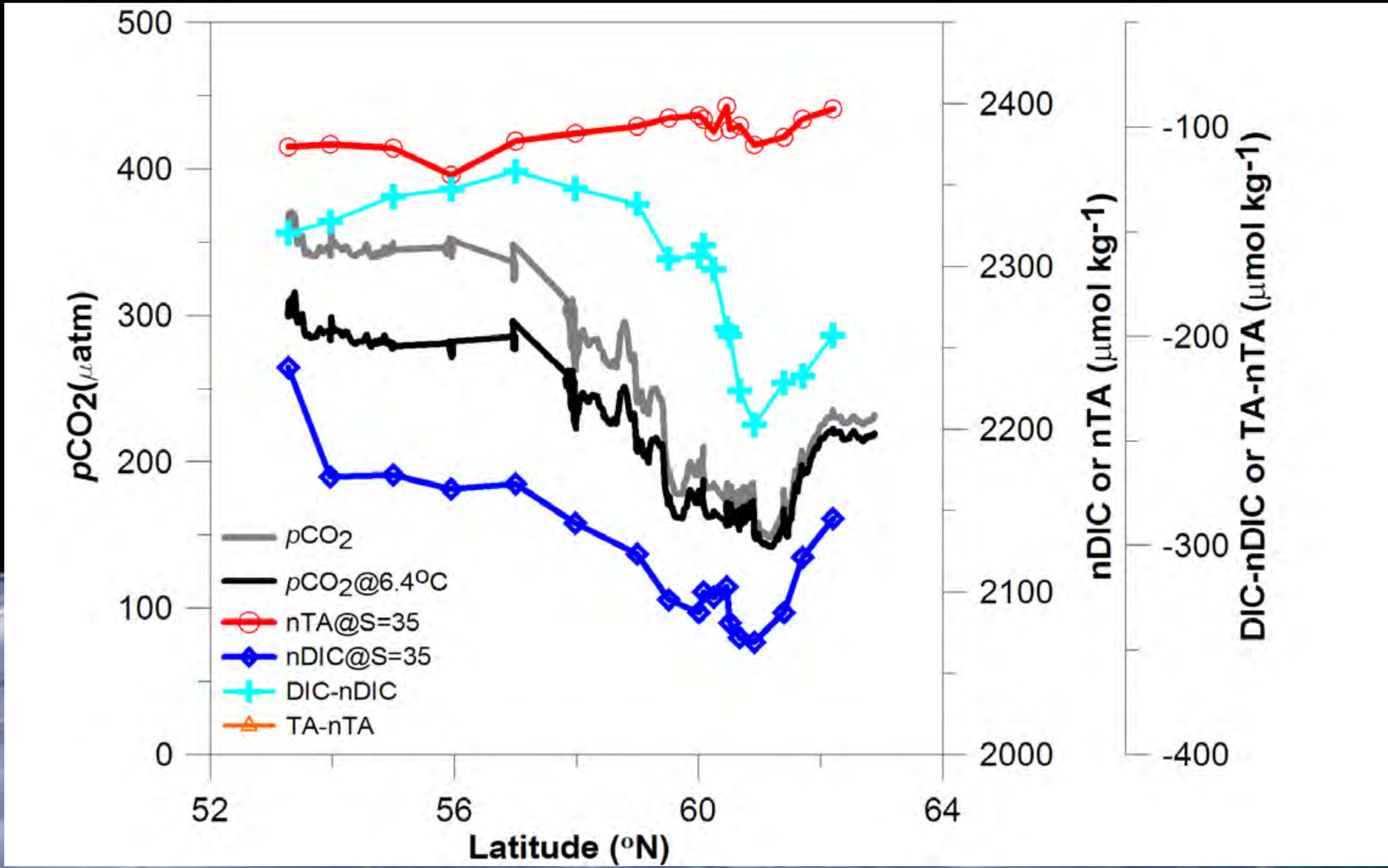
500
400
300
200
100
0
pCO2(μatm)
2400
2300
2200
2100
2000
nDIC or nTA (μmol kg^{-1})
-100
-200
-300
-400
DIC-nDIC or TA-nTA (μmol kg^{-1})
52
56
60
64
Latitude (°N)
pCO$_2$
pCO$_2$@6.4°C
nTA@S=35
nDIC@S=35
DIC-nDIC
TA-nTA

nDIC@S=35



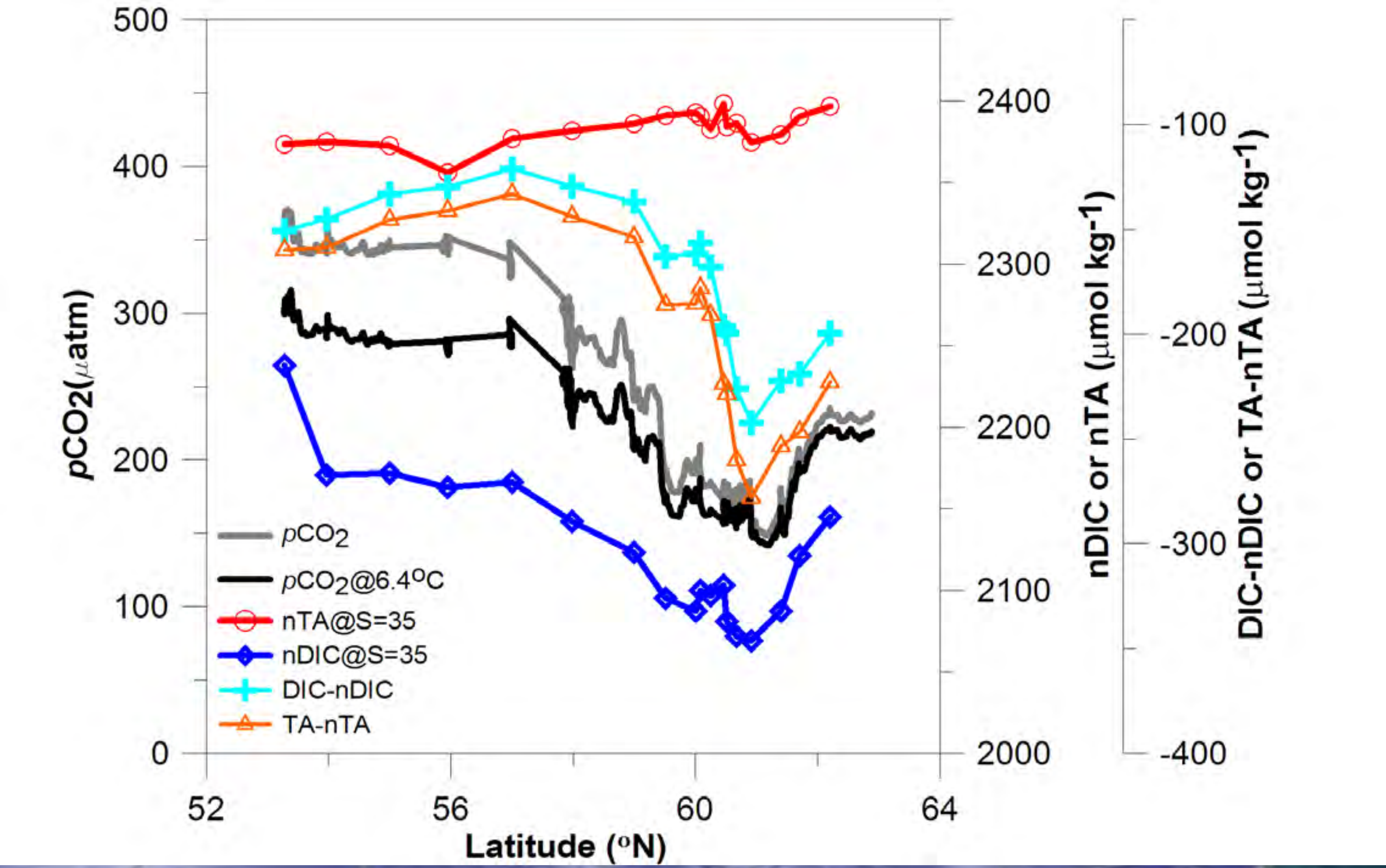
500
400
300
200
100
0
pCO2(μatm)
2400
2300
2200
2100
2000
nDIC or nTA (μmol kg^{-1})
-100
-200
-300
-400
DIC-nDIC or TA-nTA (μmol kg^{-1})
52
56
60
64
Latitude (°N)
pCO2
pCO2@6.4°C
nTA@S=35
nDIC@S=35
DIC-nDIC
TA-nTA

DIC -nDIC



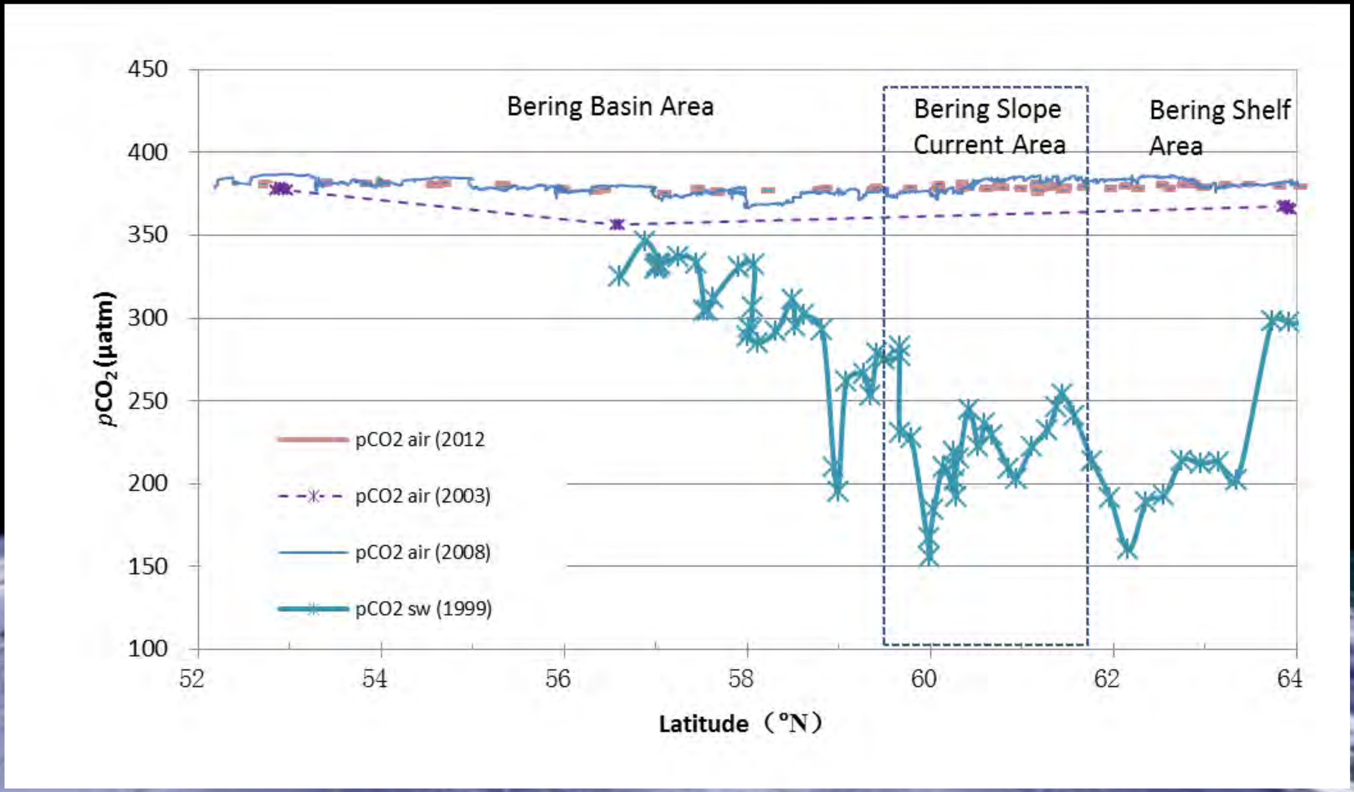
500
400
300
200
100
0
pCO2(μatm)
2400
2300
2200
2100
2000
nDIC or nTA (μmol kg-1)
-100
-200
-300
-400
DIC-nDIC or TA-nTA (μmol kg-1)
52
56
60
64
Latitude (oN)
pCO2
pCO2@6.4oC
nTA@S=35
nDIC@S=35
DIC-nDIC
TA-nTA

TA - nTA



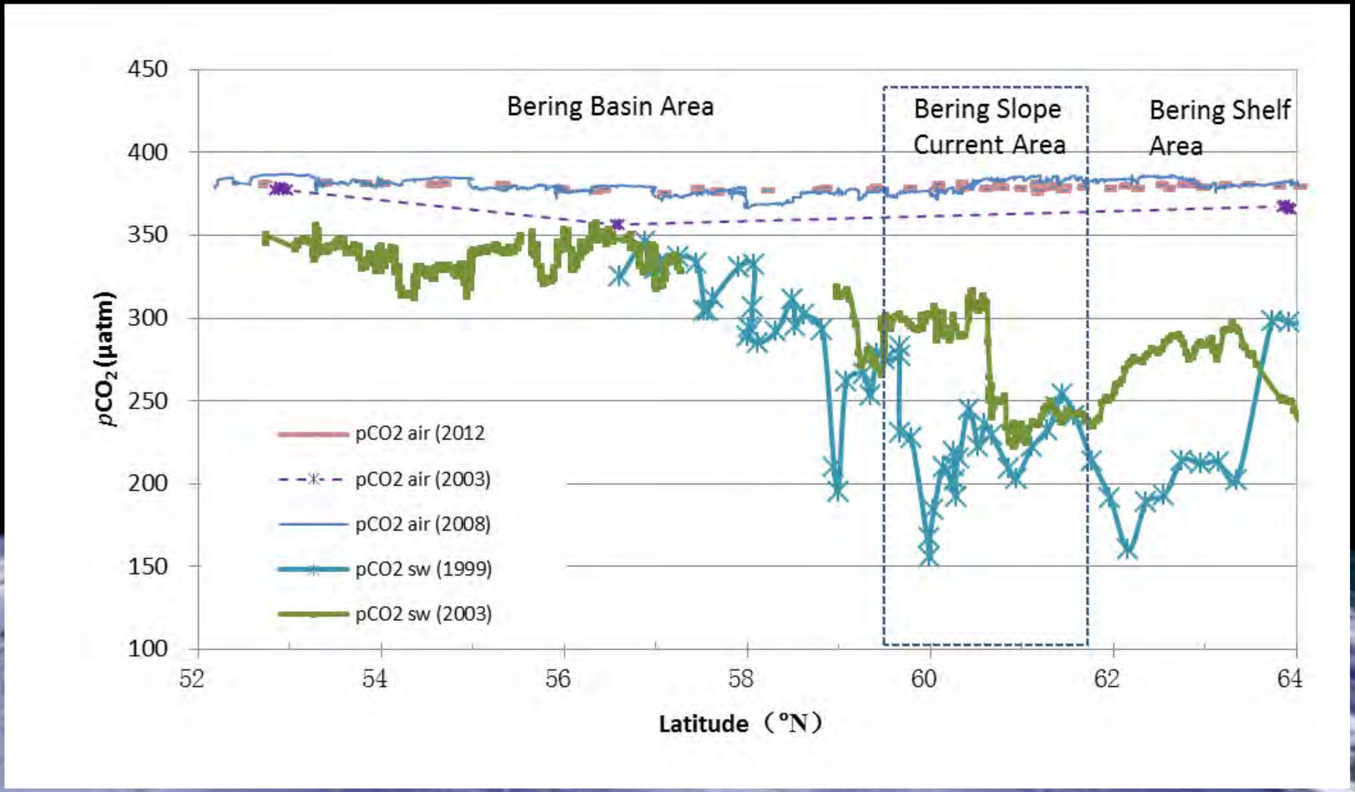
500
400
300
200
100
0
pCO2(µatm)
52
56
60
64
Latitude (°N)
2400
2300
2200
2100
2000
nDIC or nTA (µmol kg-1)
-100
-200
-300
-400
DIC-nDIC or TA-nTA (µmol kg-1)
pCO2
pCO2@6.4°C
nTA@S=35
nDIC@S=35
DIC-nDIC
TA-nTA

July, 1999



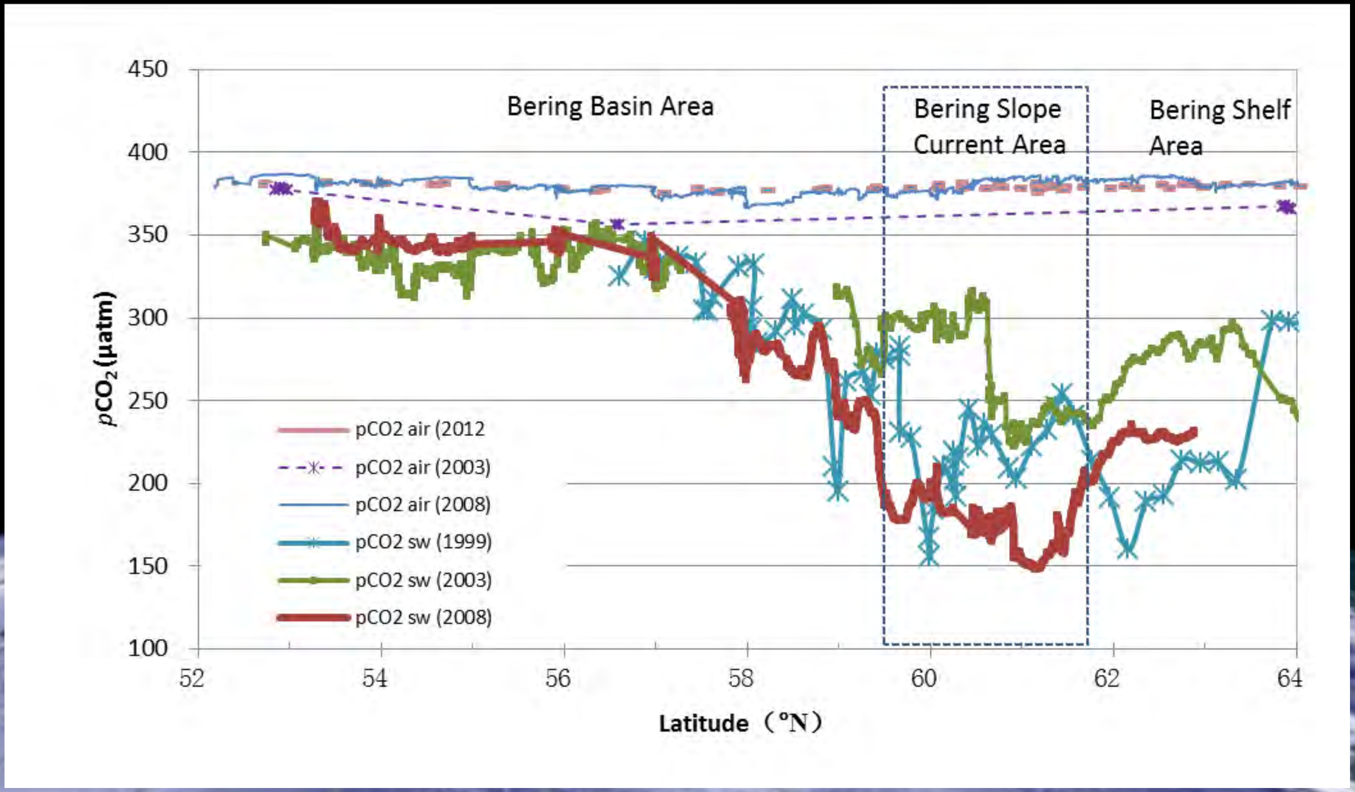
450
400
350
300
250
200
150
100
52
54
56
58
60
62
64
Bering Basin Area
Bering Slope
Current Area
Bering Shelf
Area
pCO2 air (2012
pCO2 air (2003)
pCO2 air (2008)
pCO2 sw (1999)
pCO2 (μatm)
Latitude （°N）

July, 2003



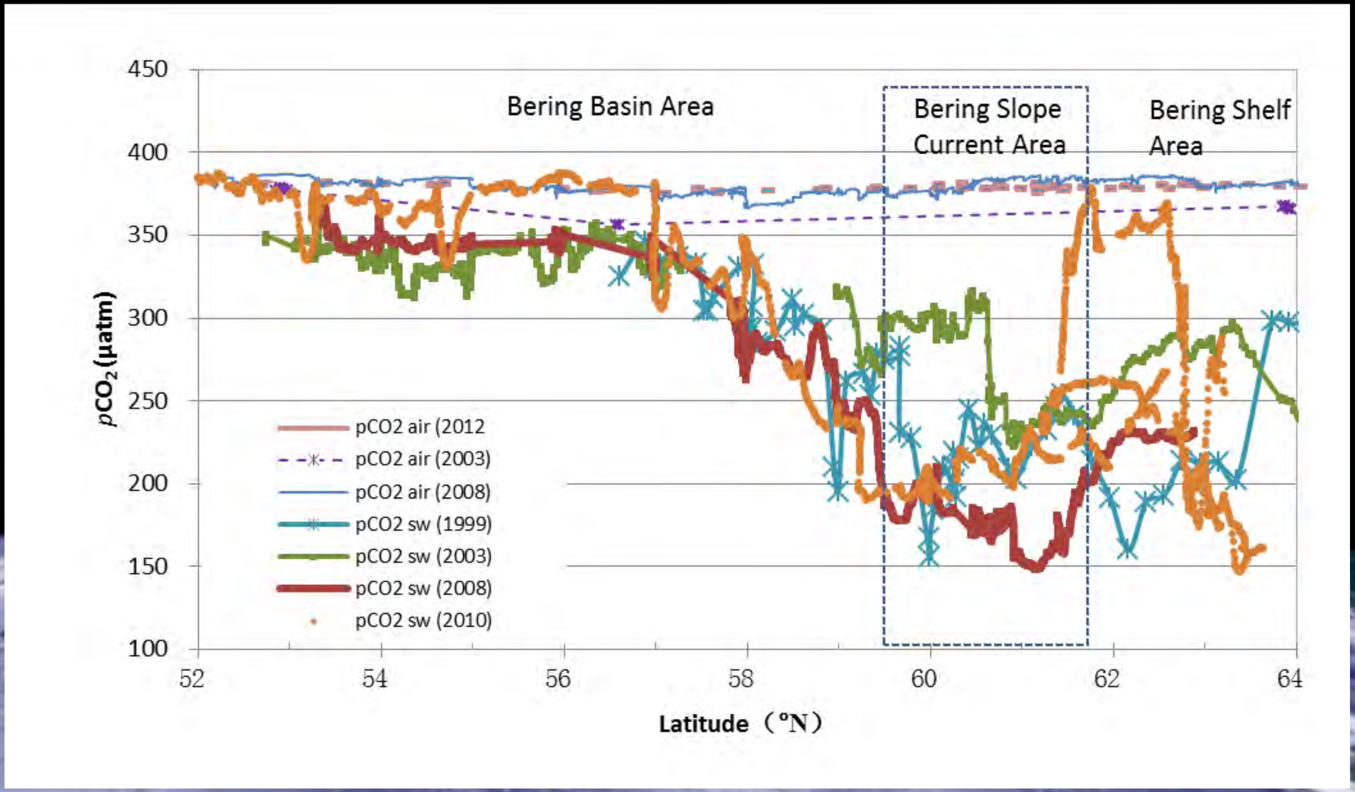
450
400
350
300
250
200
150
100
pCO2 (µatm)
Bering Basin Area
Bering Slope
Current Area
Bering Shelf
Area
pCO2 air (2012
pCO2 air (2003)
pCO2 air (2008)
pCO2 sw (1999)
pCO2 sw (2003)
52
54
56
58
60
62
64
Latitude （°N）

July, 2008

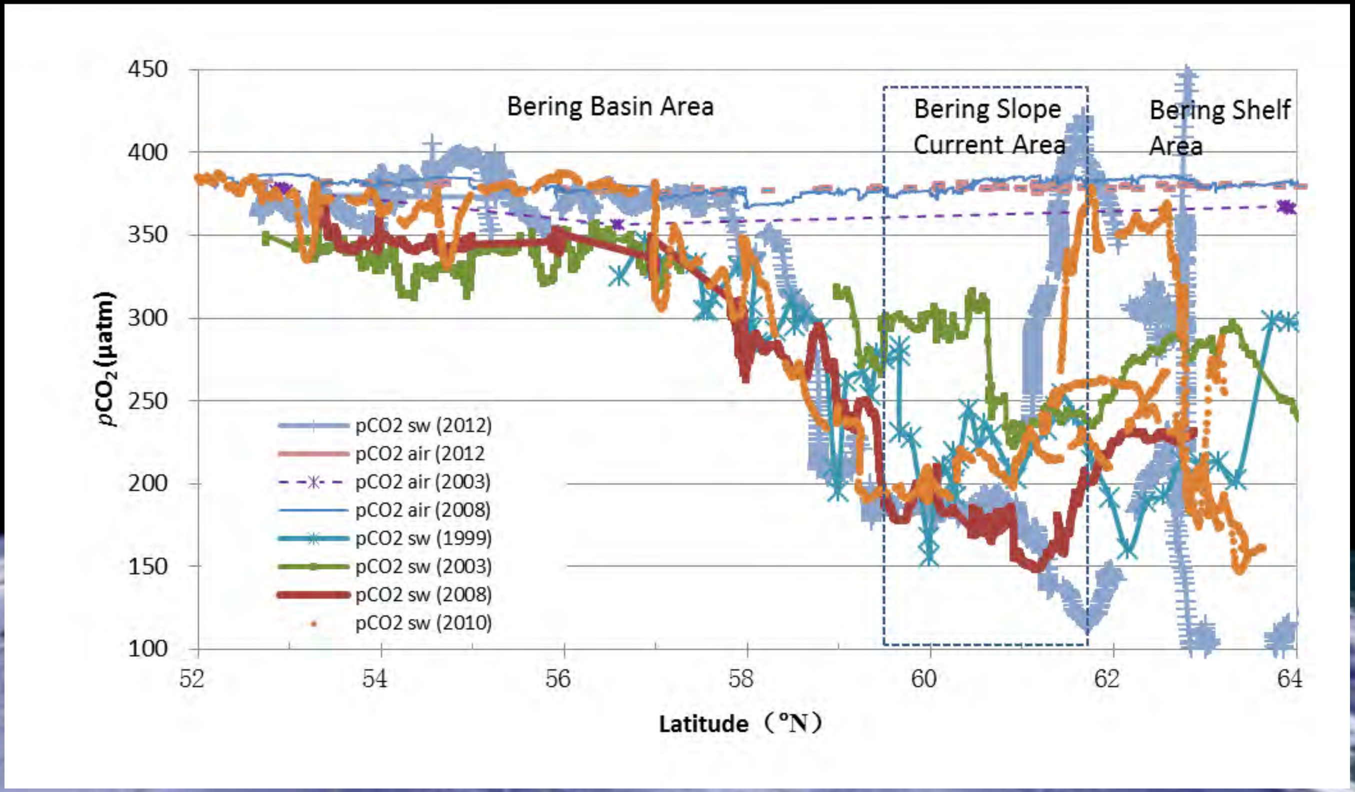


Bering Basin Area
Bering Slope Current Area
Bering Shelf Area
450
400
350
300
250
200
150
100
pCO_2 (µatm)
52
54
56
58
60
62
64
Latitude （°N）
pCO2 air (2012
pCO2 air (2003)
pCO2 air (2008)
pCO2 sw (1999)
pCO2 sw (2003)
pCO2 sw (2008)

July, 2010

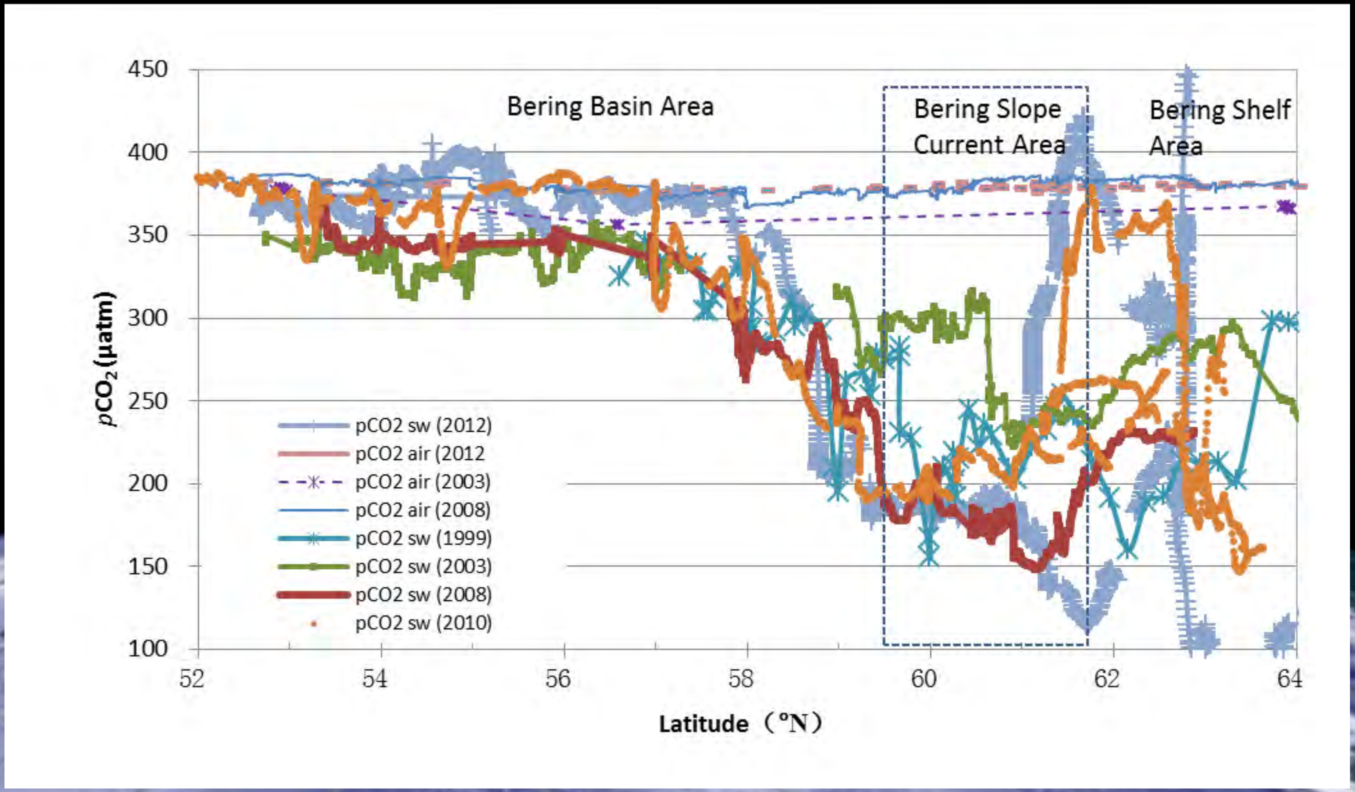

450
400
350
300
250
200
150
100
Bering Basin Area
Bering Slope Current Area
Bering Shelf Area
pCO2 air (2012
pCO2 air (2003)
pCO2 air (2008)
pCO2 sw (1999)
pCO2 sw (2003)
pCO2 sw (2008)
pCO2 sw (2010)
pCO2 (µatm)
52
54
56
58
60
62
64
Latitude （°N）

July, 2012



Bering Basin Area
Bering Slope Current Area
Bering Shelf Area
pCO$_2$ (μatm)
450
400
350
300
250
200
150
100
52
54
56
58
60
62
64
Latitude （°N）
pCO2 sw (2012)
pCO2 air (2012
pCO2 air (2003)
pCO2 air (2008)
pCO2 sw (1999)
pCO2 sw (2003)
pCO2 sw (2008)
pCO2 sw (2010)

Bering Sea Summer carbon sink, 1999 - 2012



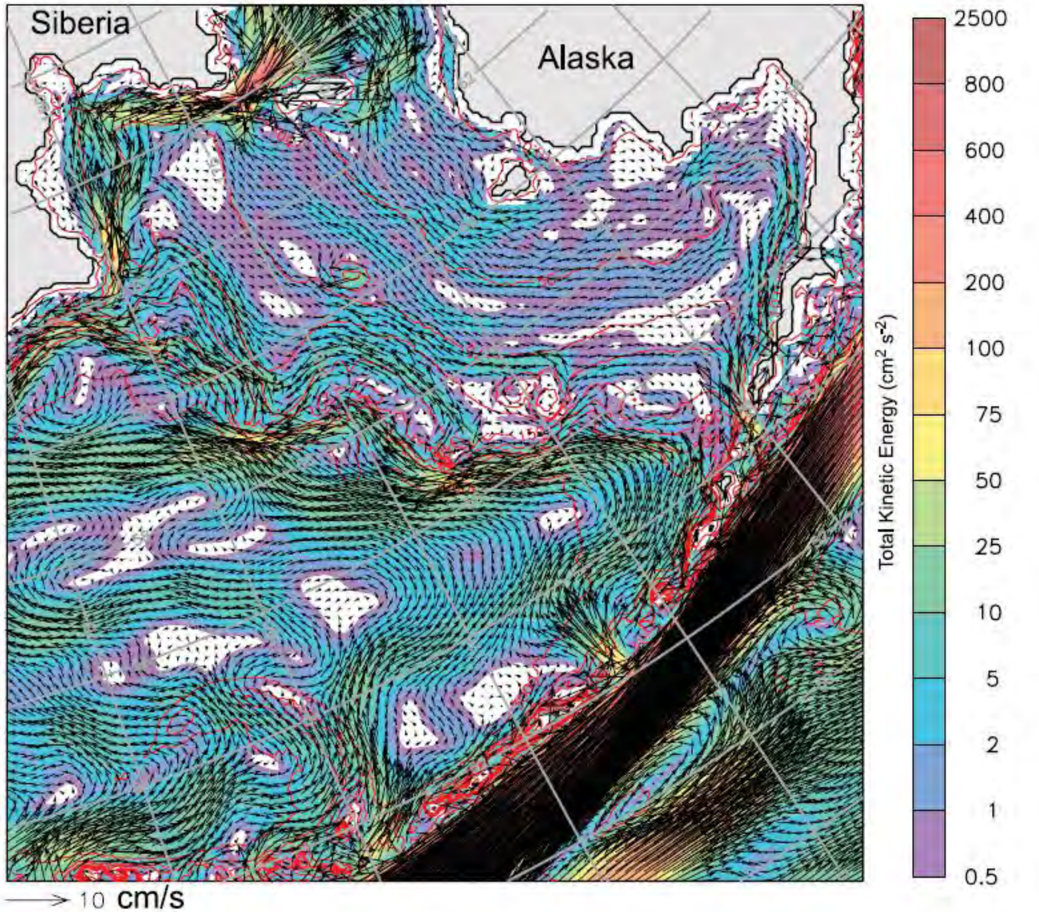


Fig. 1. Twenty-six-year (1979–2004) mean 0–220 m circulation and total kinetic energy. Every second vector is shown.

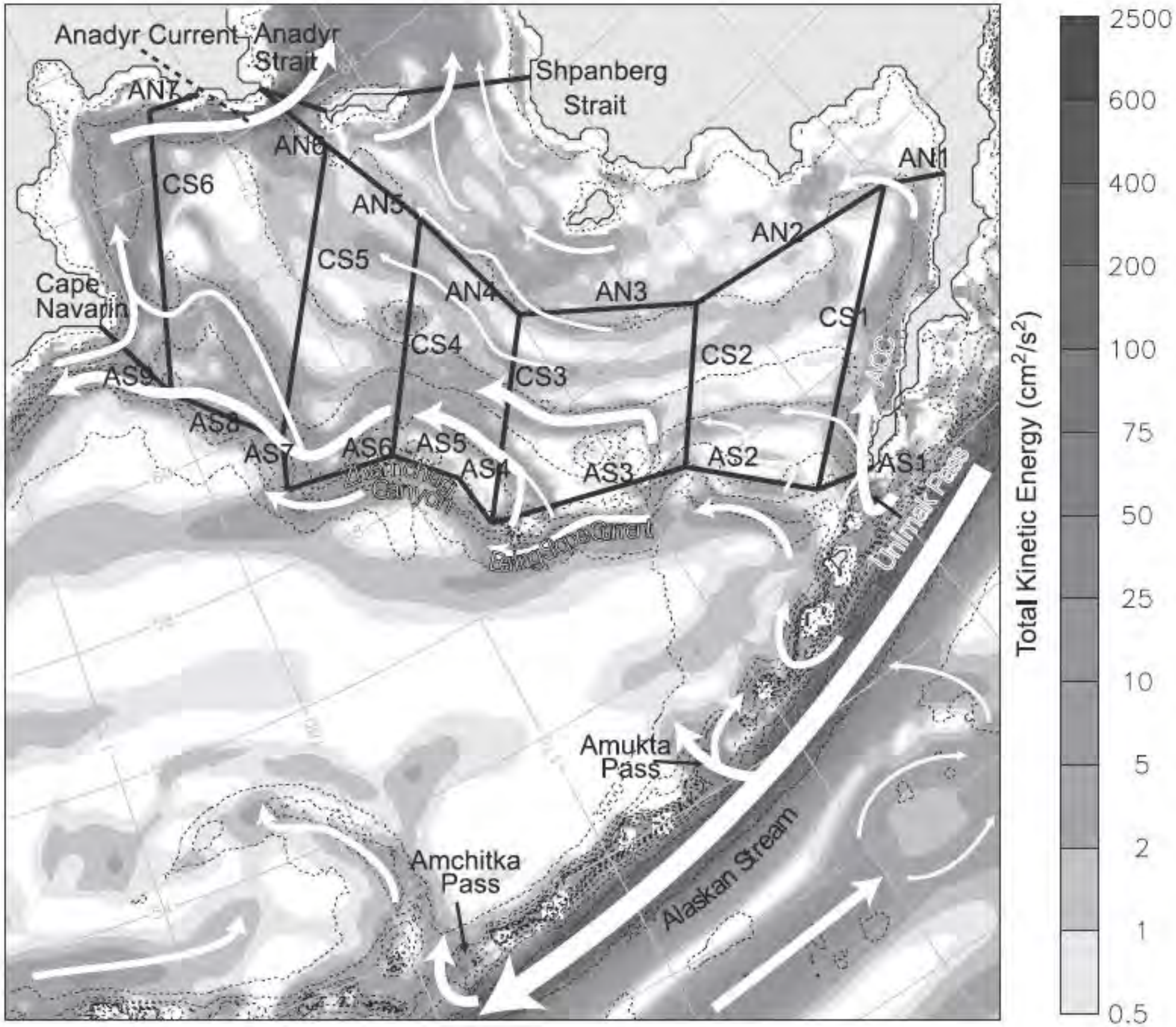
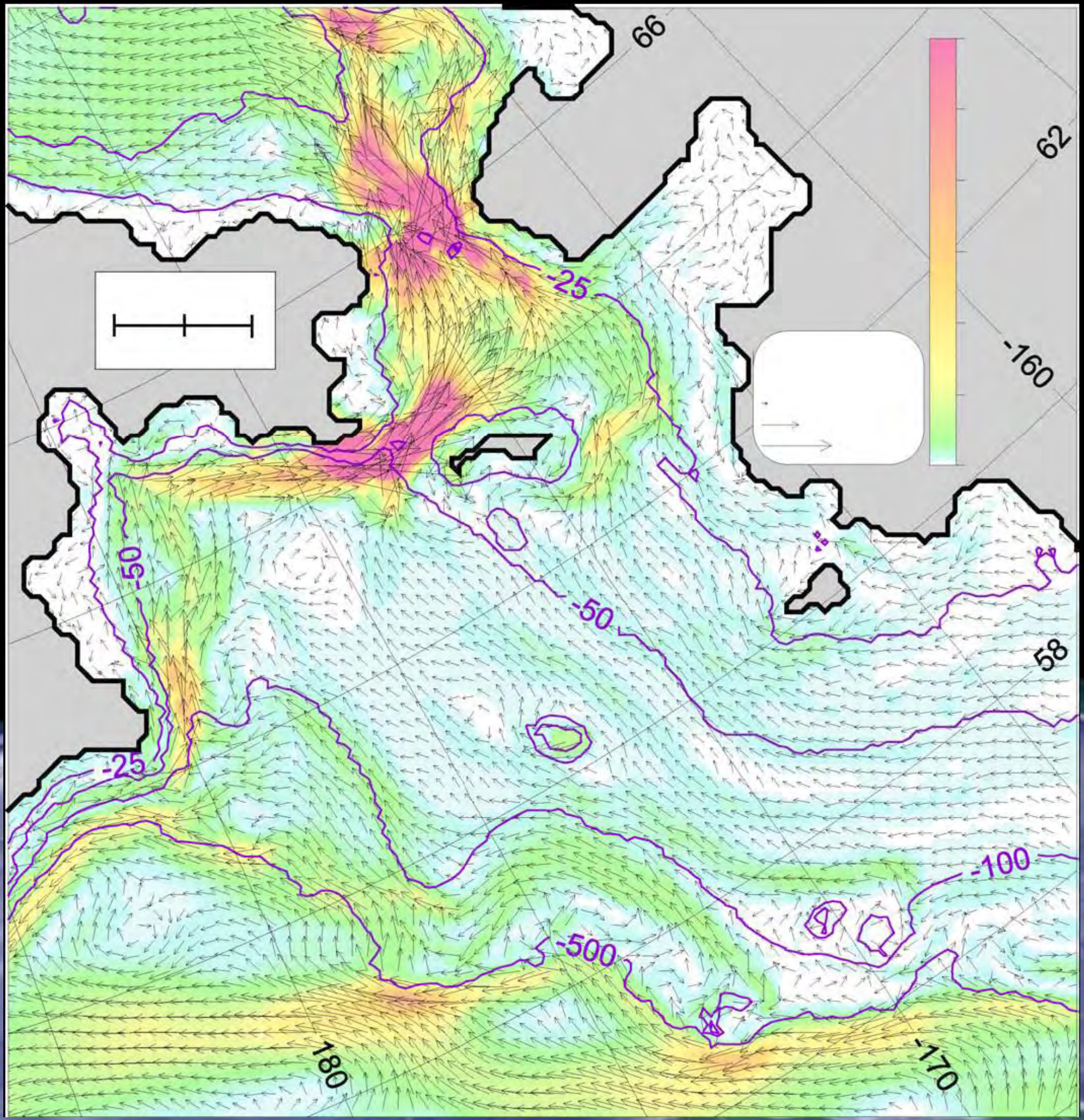
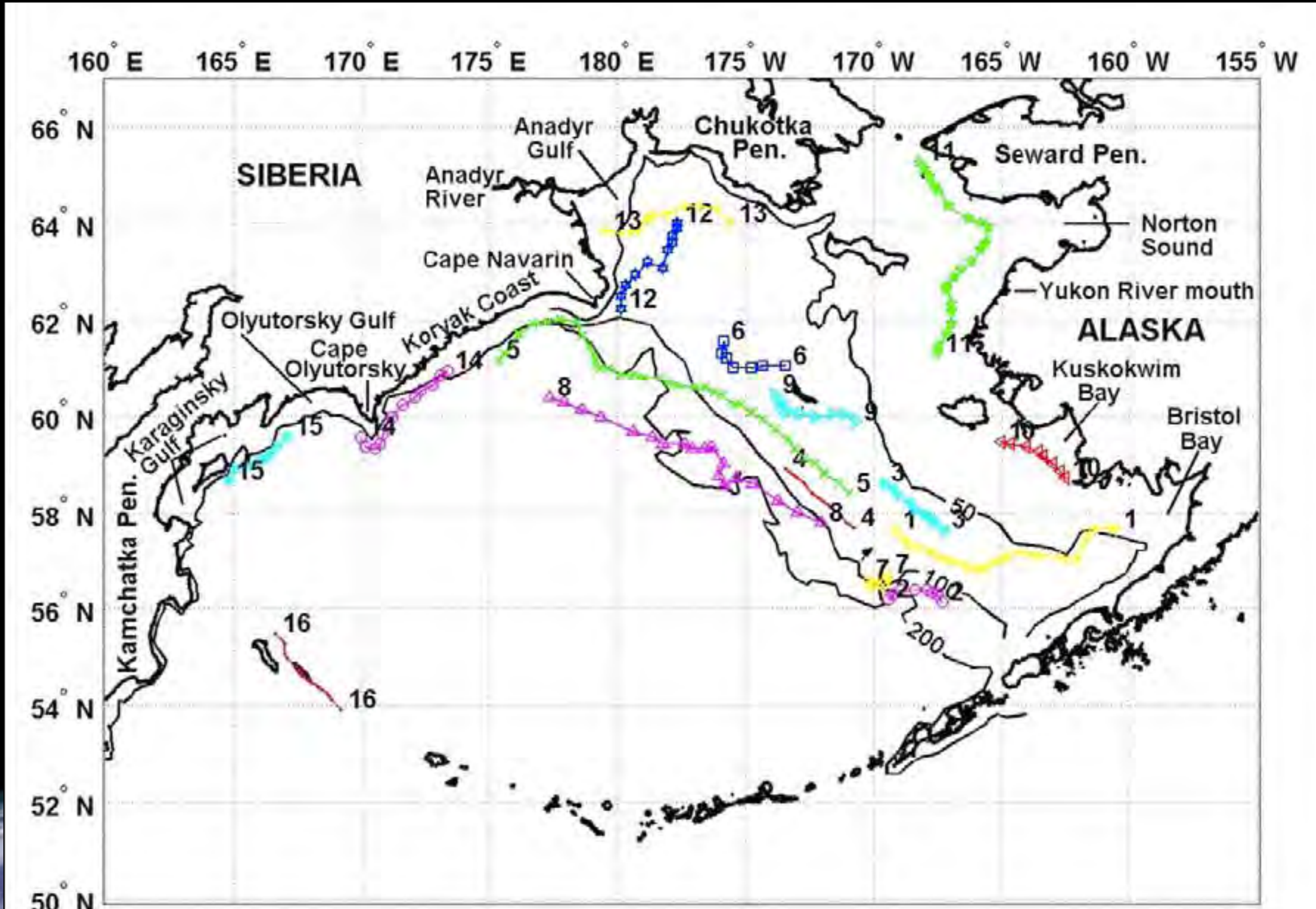


Fig. 2. Schematic circulation (0–220 m) and total kinetic energy based on Fig. 1. The locations of model cross-sections and names are included.

the BSC appears to be more a system of eddies rather than a continuous current, which emphasizes the need for a fully eddy-resolving, basin-wide model to represent its complex dynamics.


66
62
-160
58
180
-170
-25
-50
-50
-25
-100
-500



Twenty-three-year mean velocity averaged over the upper 50 m. Twenty-five percent of vectors are shown. Color shading represents the total kinetic energy (cm2 s[1]2) calculated as 0.5*(u2+v2).

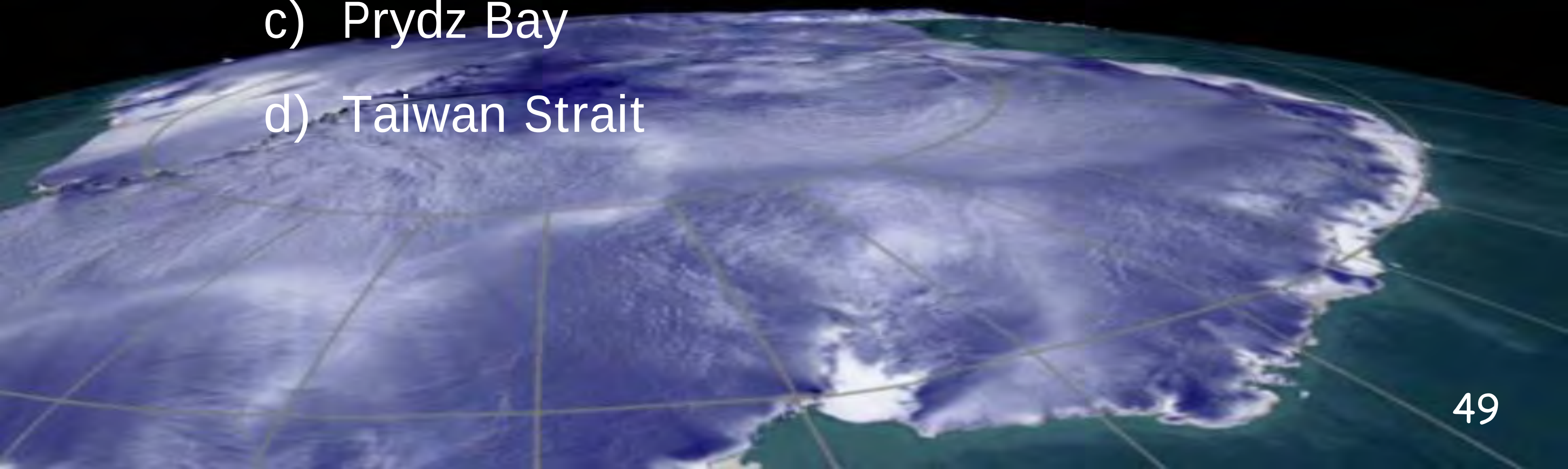
Compared with the other Sea Areas

a) the Southern Ocean

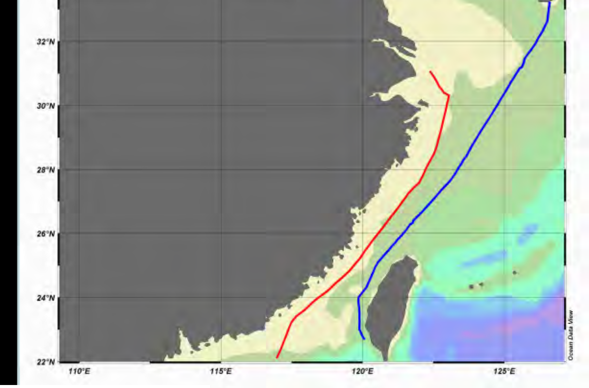
b) the Western Arctic Ocean

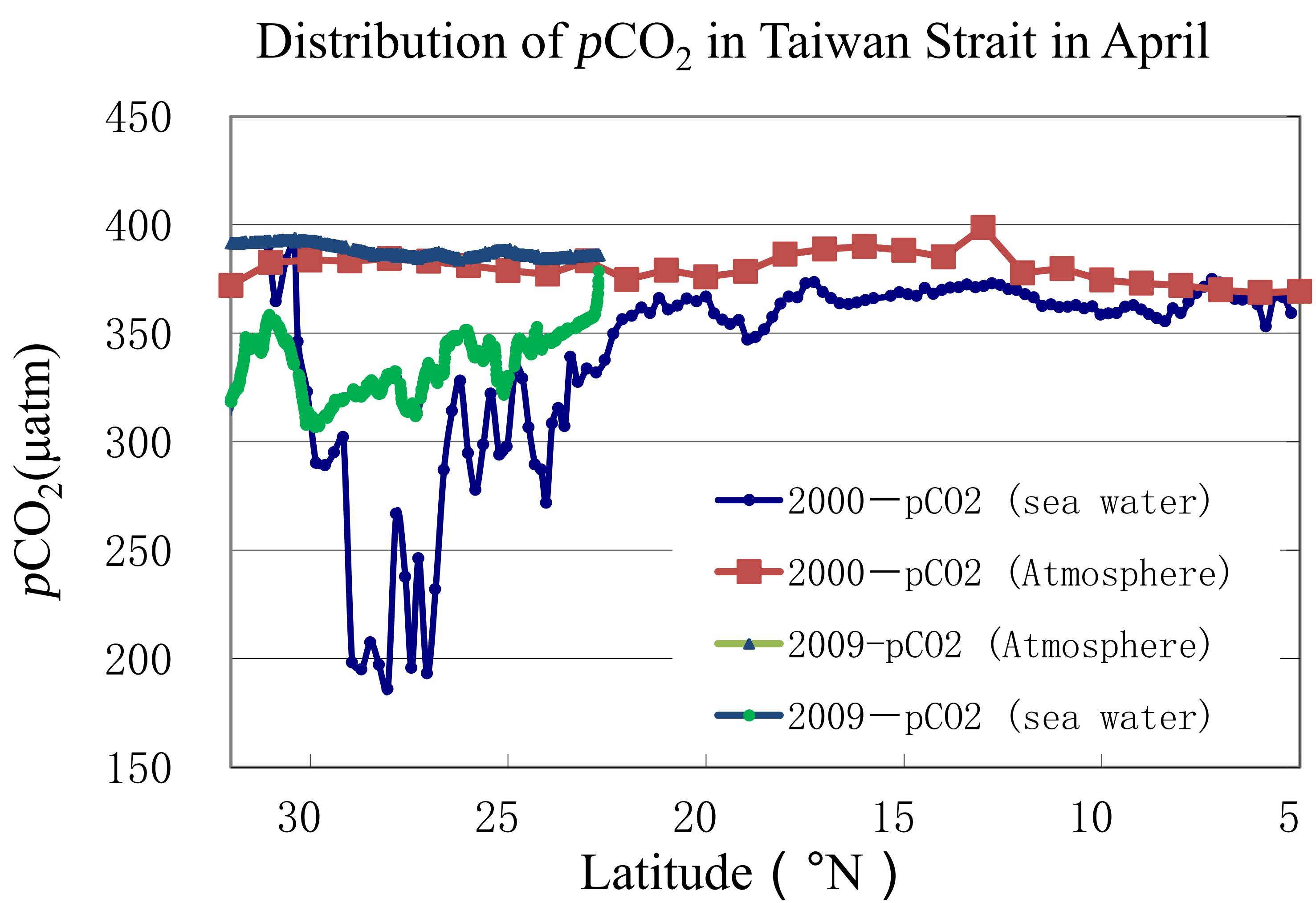
c) Prydz Bay

d) Taiwan Strait

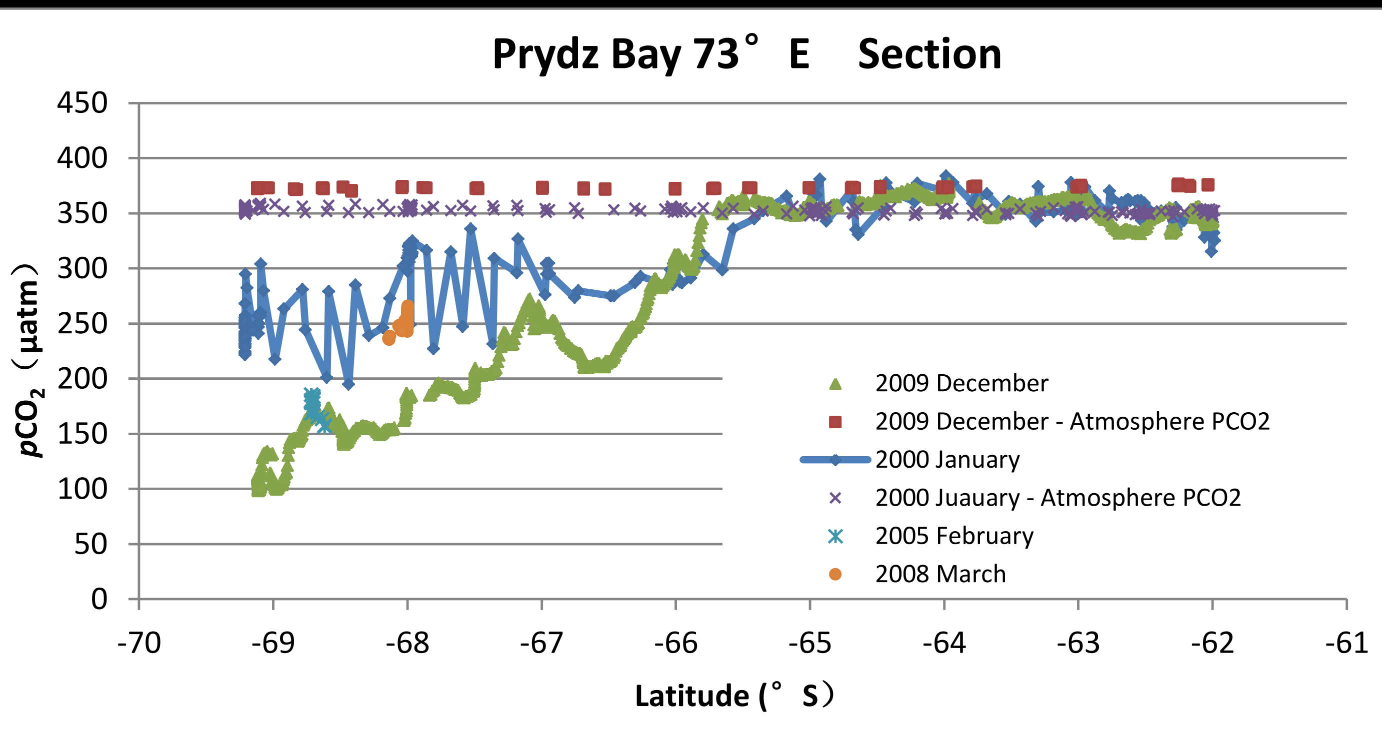


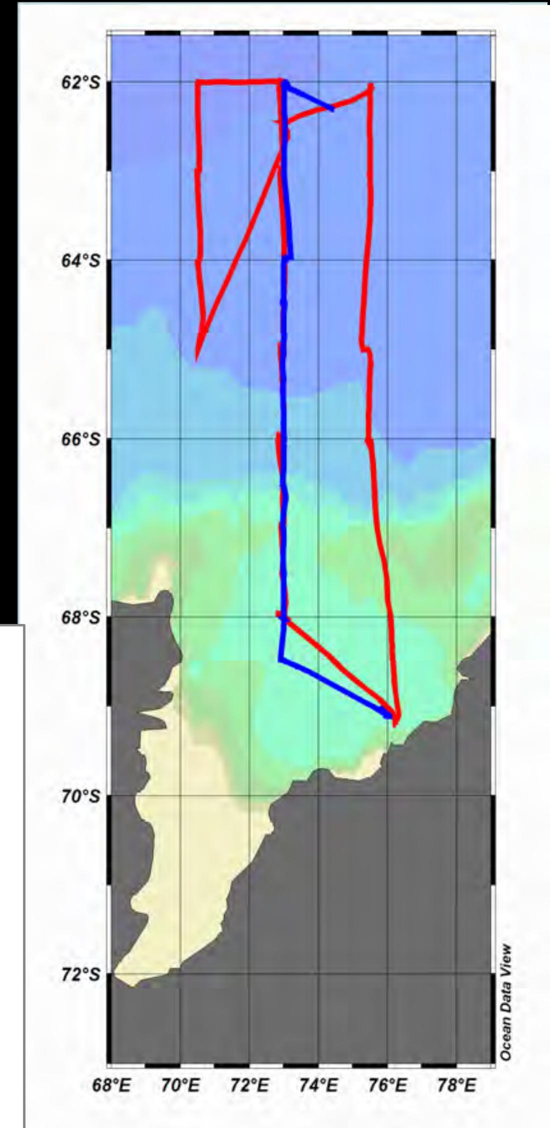
Taiwan & East China Sea
2000 VS. 2009



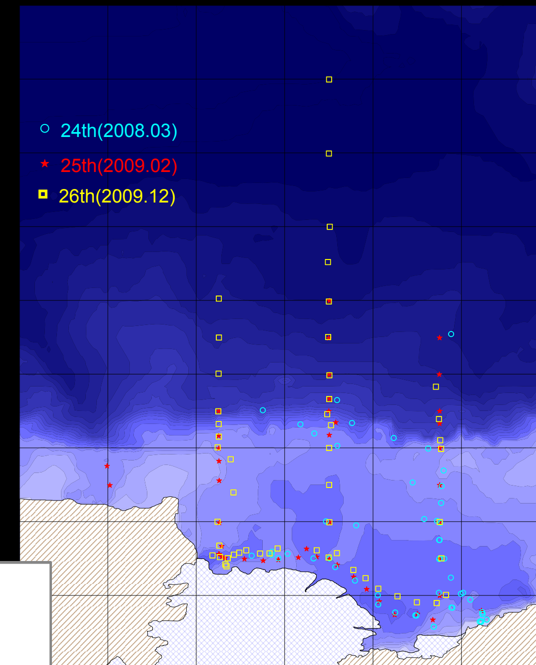


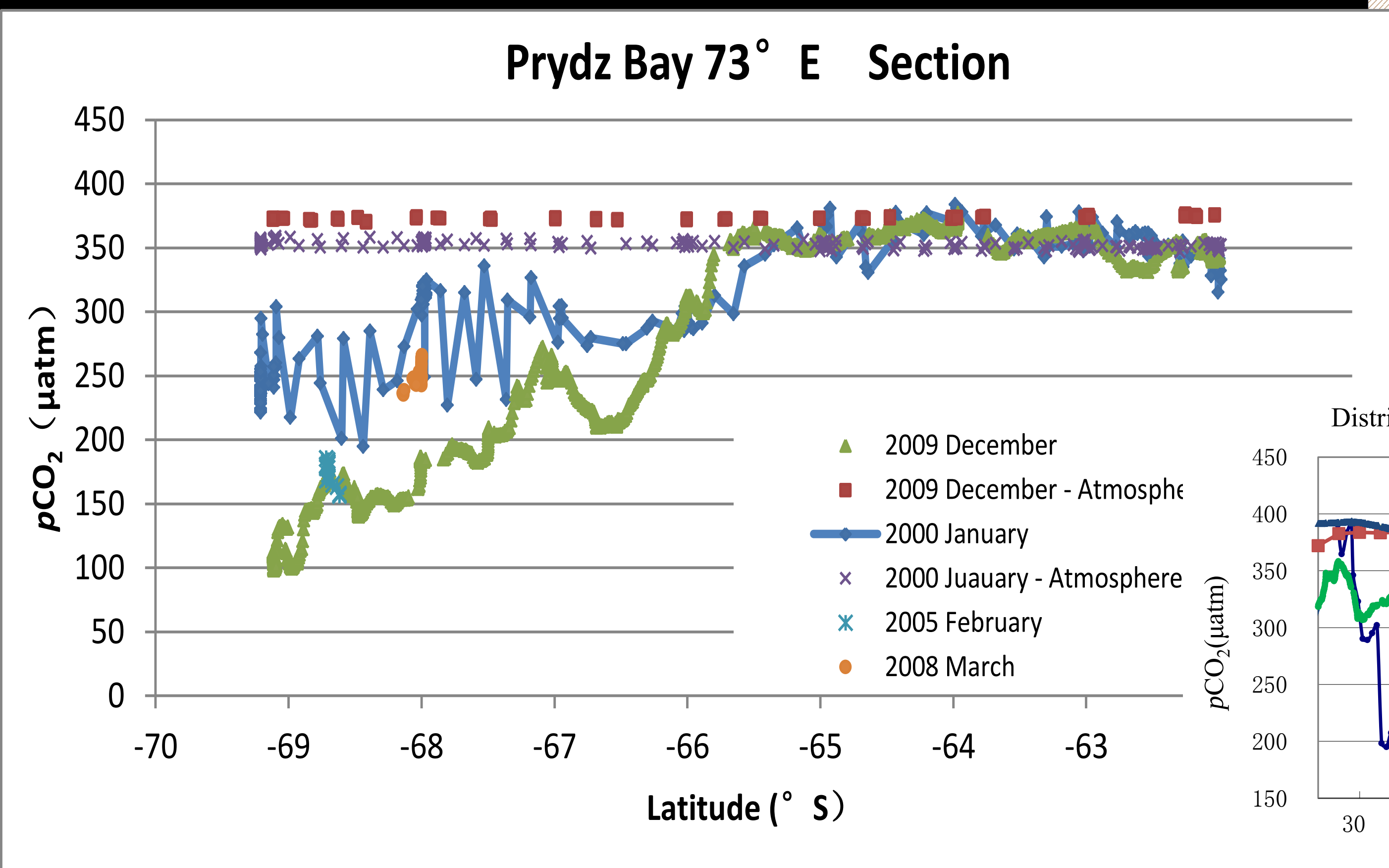
Prydz Bay - P3 section（73° E）

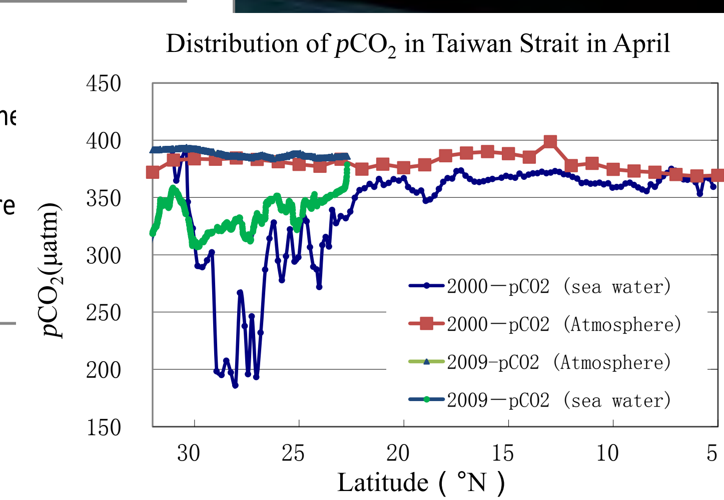




Prydz Bay
P3 Section（73° E）







Distribution of pCO_2 in the Prydz Bay

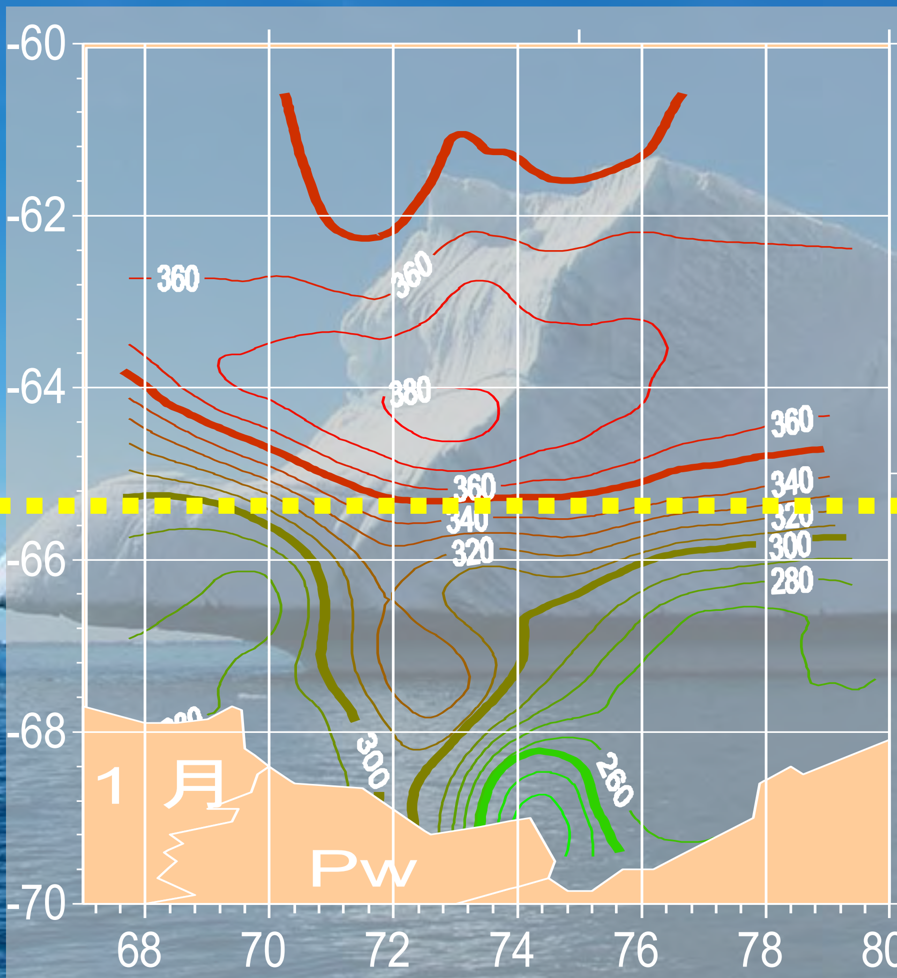
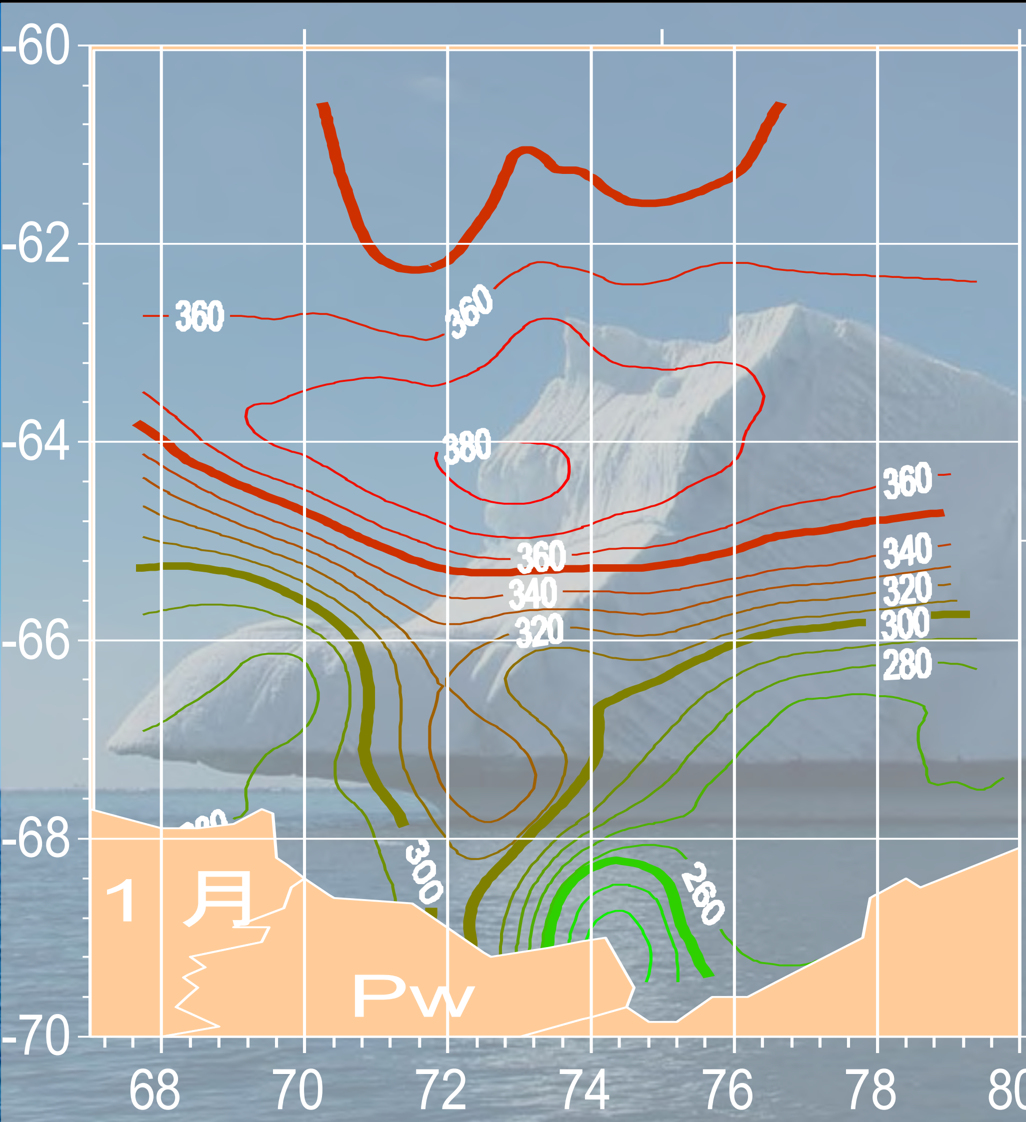


图 4　观测区Pw 的分布

outside of the bay

inside of the bay



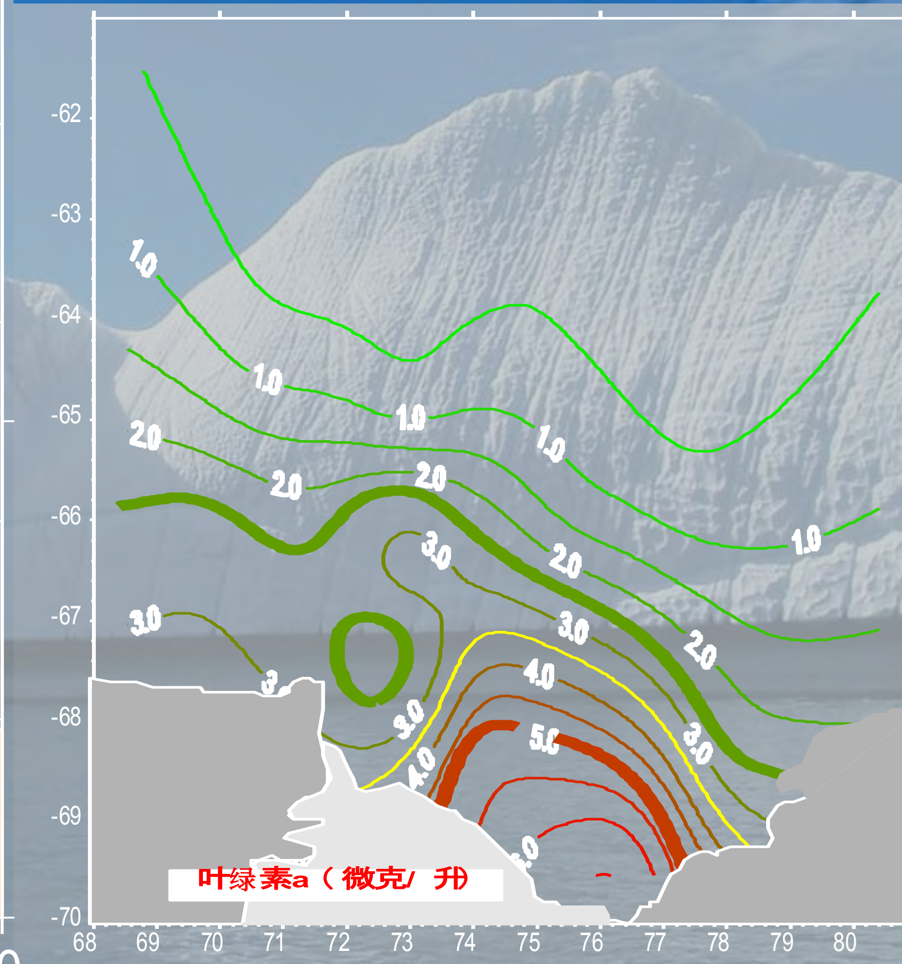
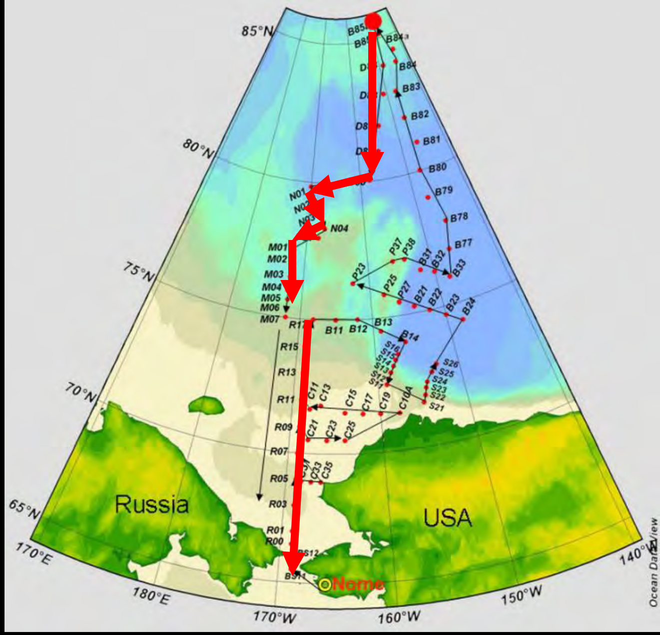
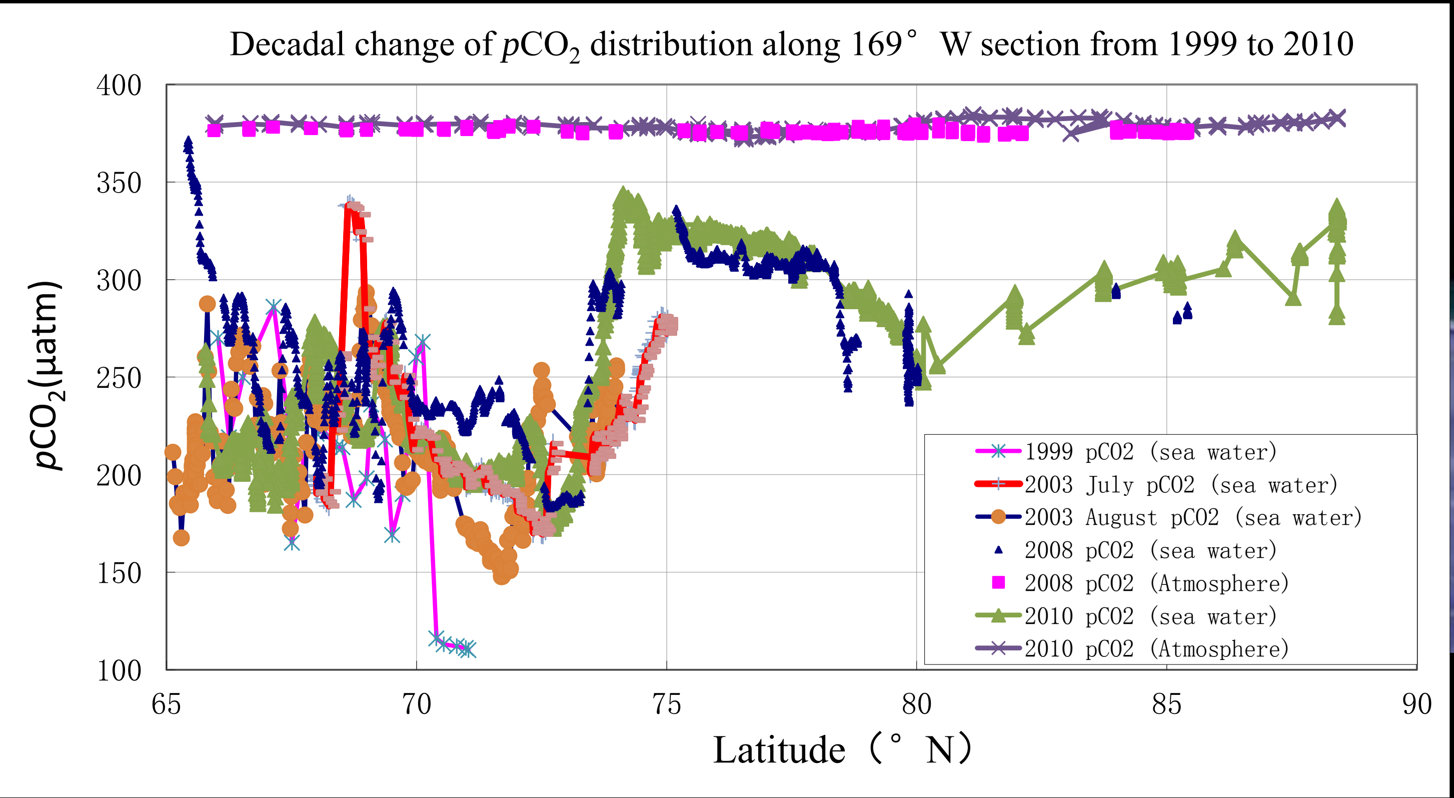


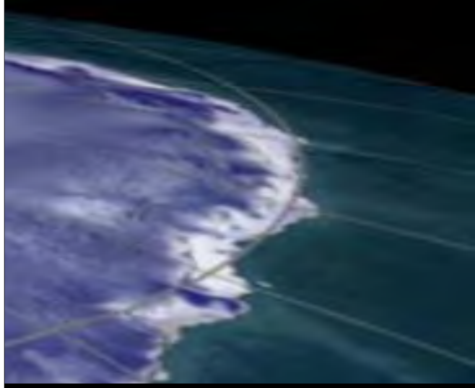
图 4 观测区Pw 的分布

图7 观测区叶绿a 的平面分布

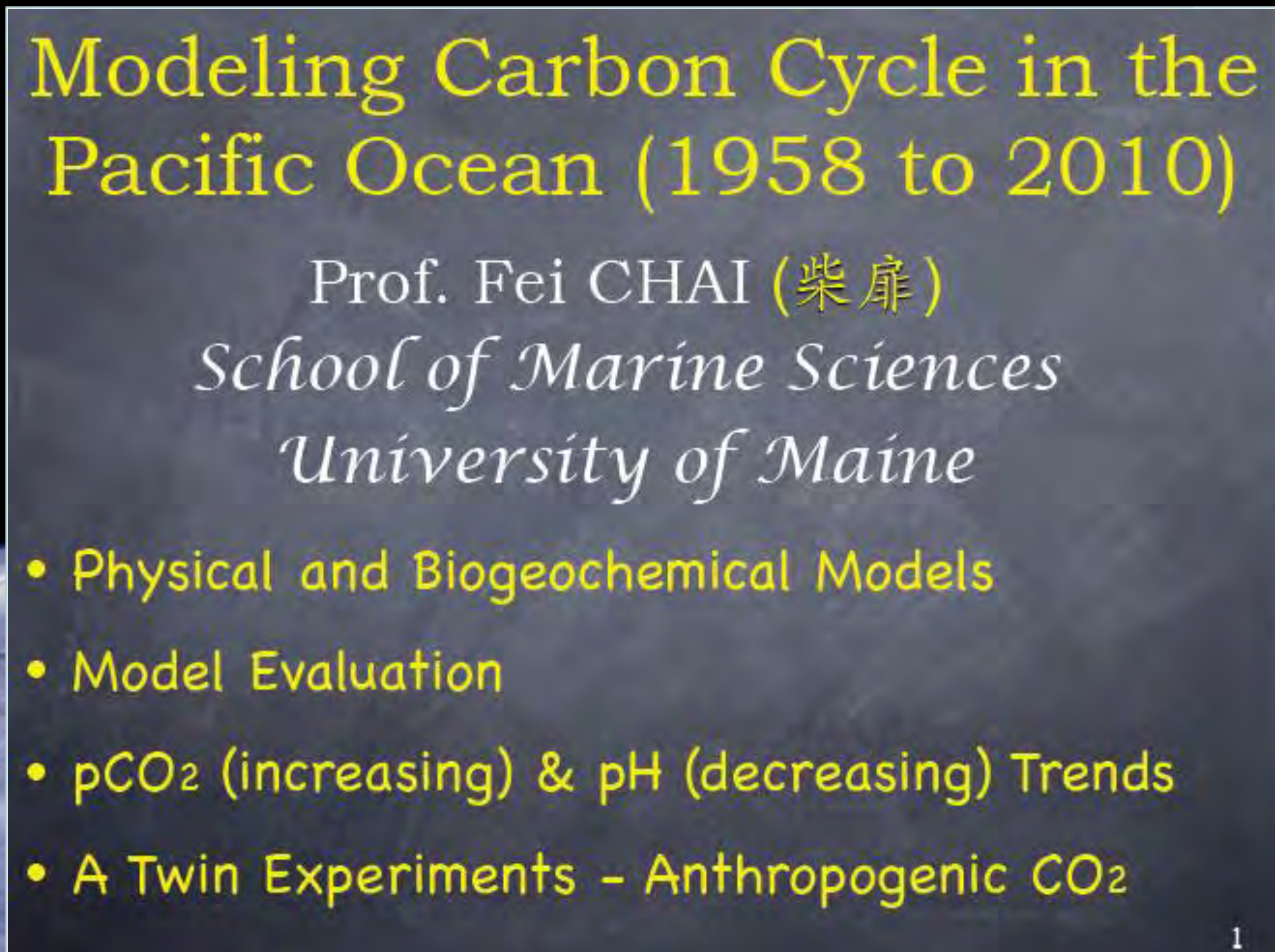
pCO_2 along 169° W section in the Western Arctic Ocean





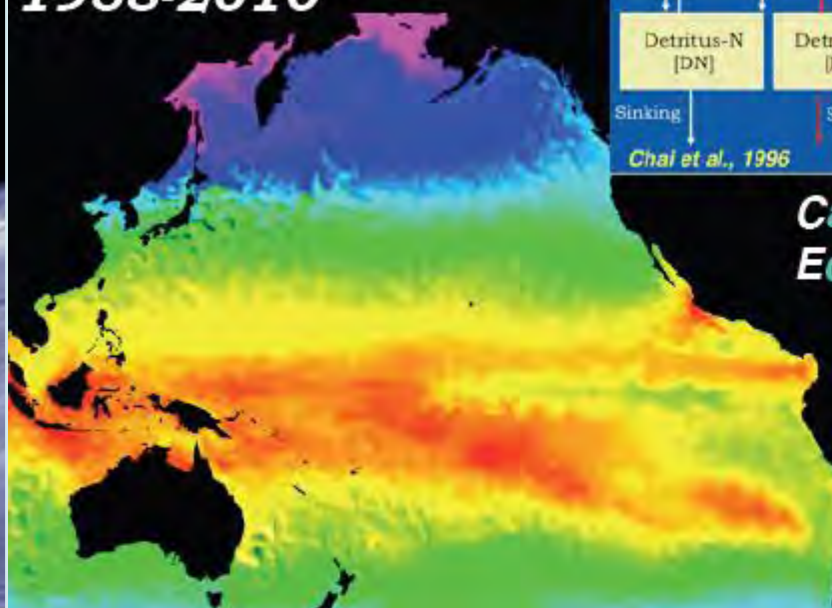


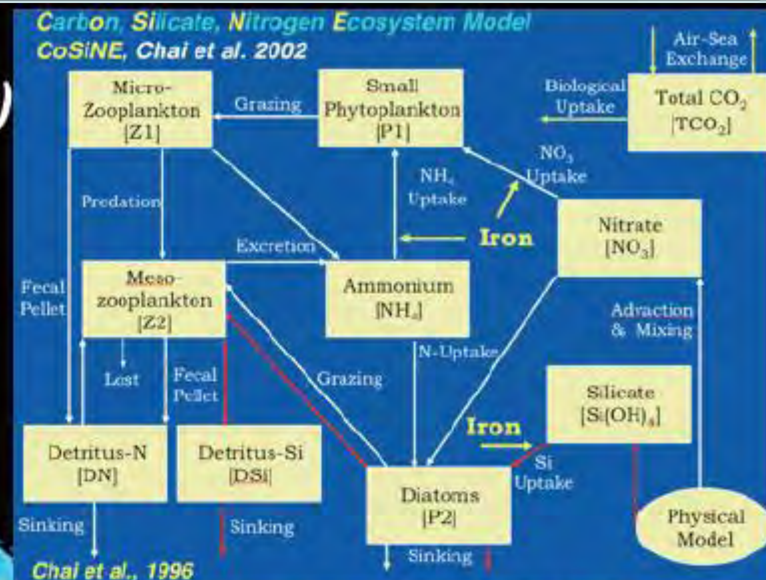
Compared with the modeling results



Regional Ocean Model System (ROMS)
1/8 deg. (~12km)
1990-2010

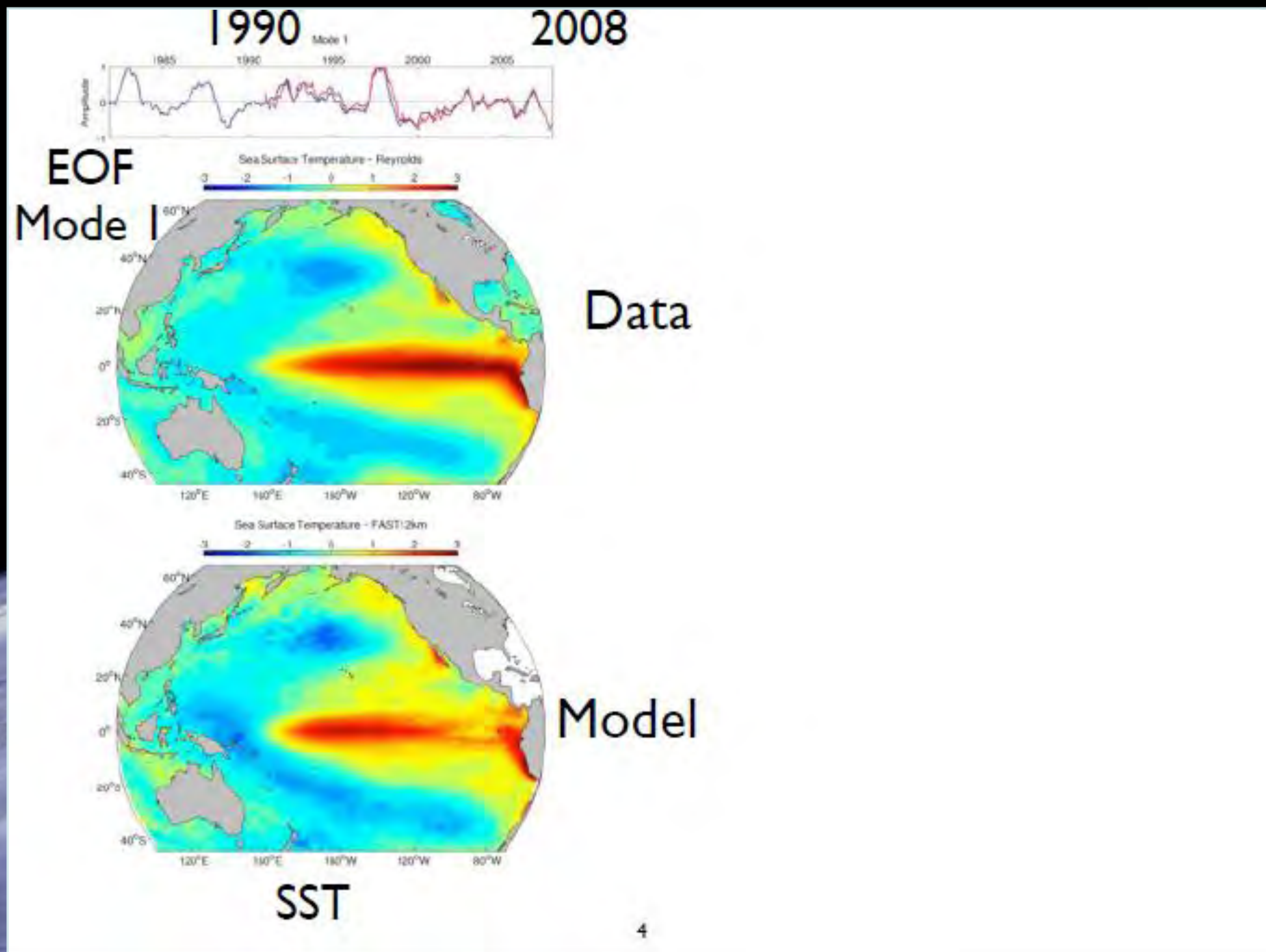
or 1/2 deg. (~50km)
1958-2010



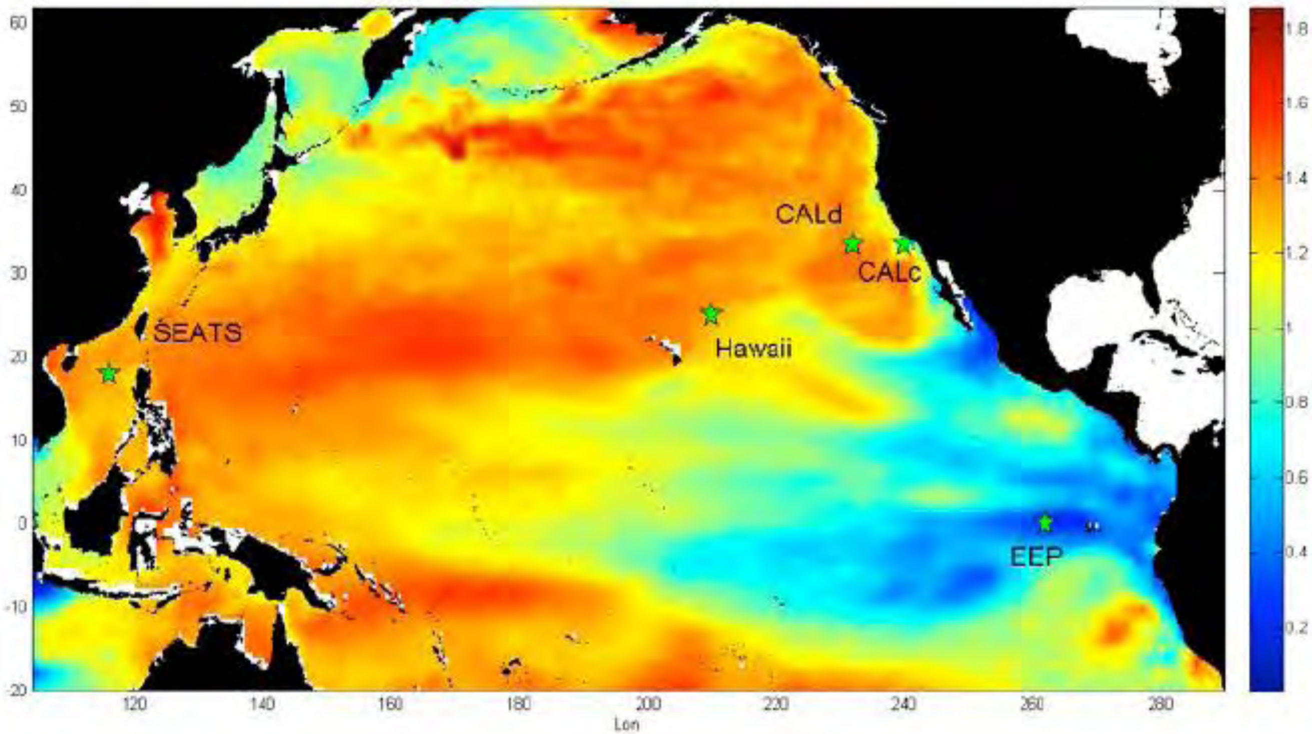


Carbon, Silicate, Nitrogen Ecosystem Model (CoSiNE)

(Chai et al., 2002, 2003, 2007, 2009; Fujii and Chai, 2007; Liu and Chai, 2009; Xiu and Chai, 2011, Palacz et al., 2011)


1990
2008
Mode 1
1985
1990
1995
2000
2005
EOF
Mode 1
Sea Surface Temperature - Reynolds
Data
Sea Surface Temperature - FAST:2km
Model
SST
4

Increasing trend of sea surface pCO_2 (ppm/year)

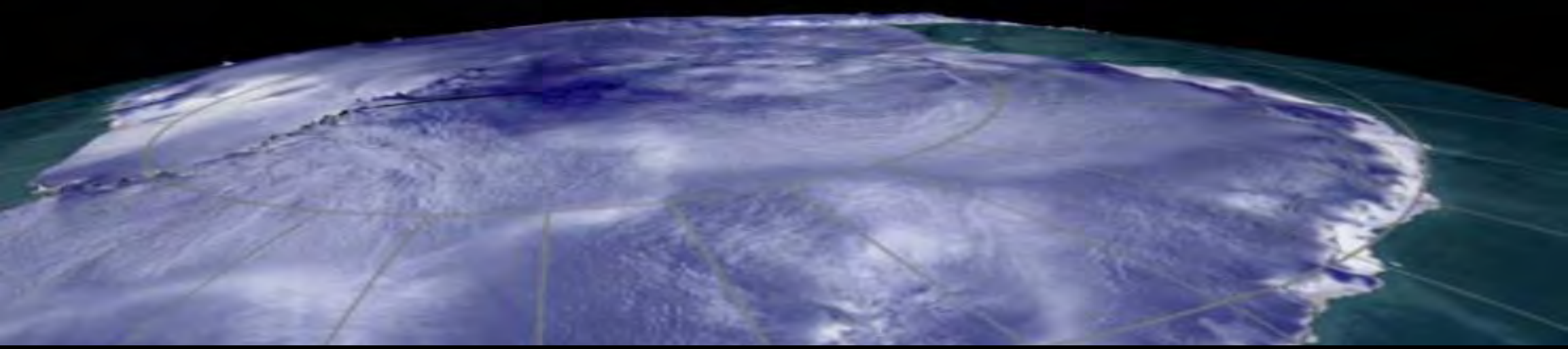


Conclusion (1)

1. Sea water pCO_2 along transect BR changed dramatically. The main reason of higher pCO_2 in the Southern Bering Basin is well-mixed water masses with higher temperature, higher DIC and TA.
2. The water masses in the slope were significantly different from those of other regions in the Bering Sea, with obvious lower temperature, fresher, lower DIC and TA, leading to lower pCO_2 in the surface seawater.
3. The Bering Sea is a net sink for atmospheric CO_2.

Conclusion (2)

4. Compared with other typical sea areas, Bering Sea's summer carbon sink remains unchanged at large
5. Observation results unexpected coordinate with the modeling result, but the regime still need to be discussed.



Acknowledgments

NSFC

CHINARE
Teams

R/V Xuelong
Captain and
all crew


Thank You!