A biological contribution to partial pressure of CO_2 in the western Arctic Ocean and Bering Sea

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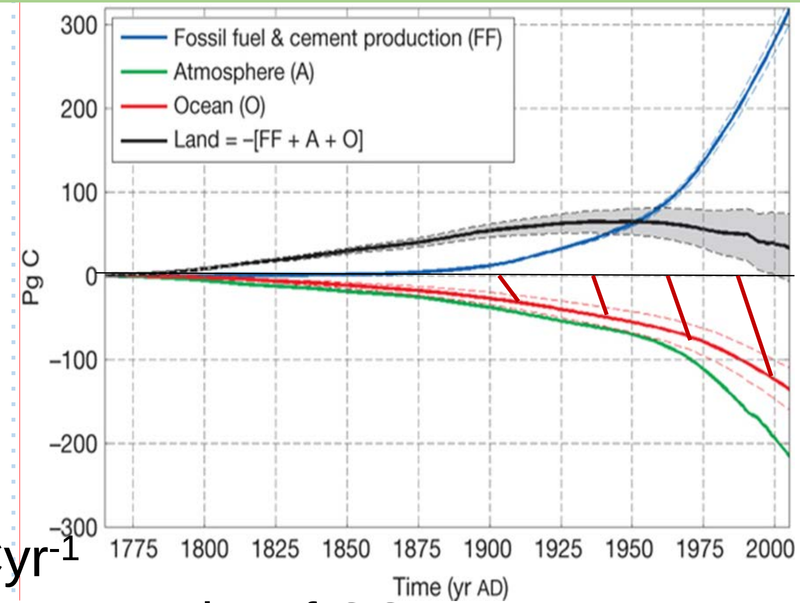
Air-sea CO_2 flux

The ocean plays a crucial role in mitigating effects of perturbation to the climate system, sequestering 20 to 35 % of anthropogenic CO_2 emissions (Khatiwala et al., 2009)



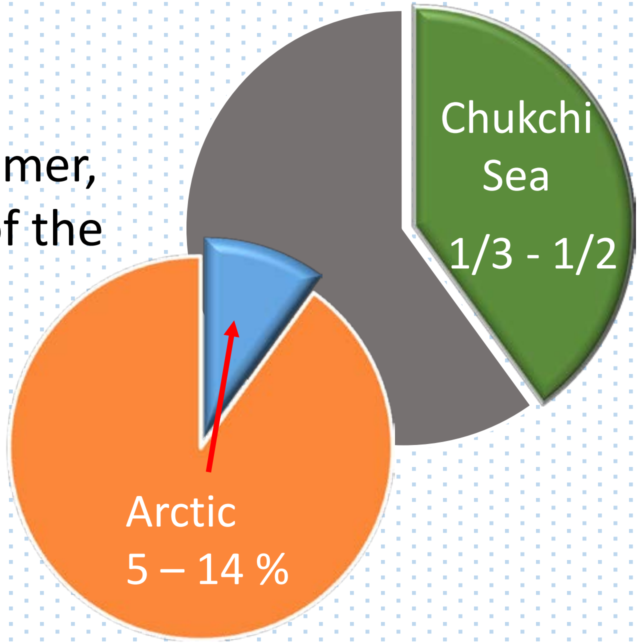
<Arctic Ocean>

Total sink of atmospheric CO_2 : 65-175 $TgCyr^{-1}$

- Contributing 5-14% to the global ocean's net uptake of CO_2 (Takahashi et al., 2002, 2009; Bates and Mathis, 2009)

Especially…

Chukchi Sea is a large ocean sink for CO_2 briefly in summer, sea ice-free period and contributes nearly 1/3 to 1/2 of the CO_2 sink in the Arctic (Bates et al., 2011a)



<Bering Sea>

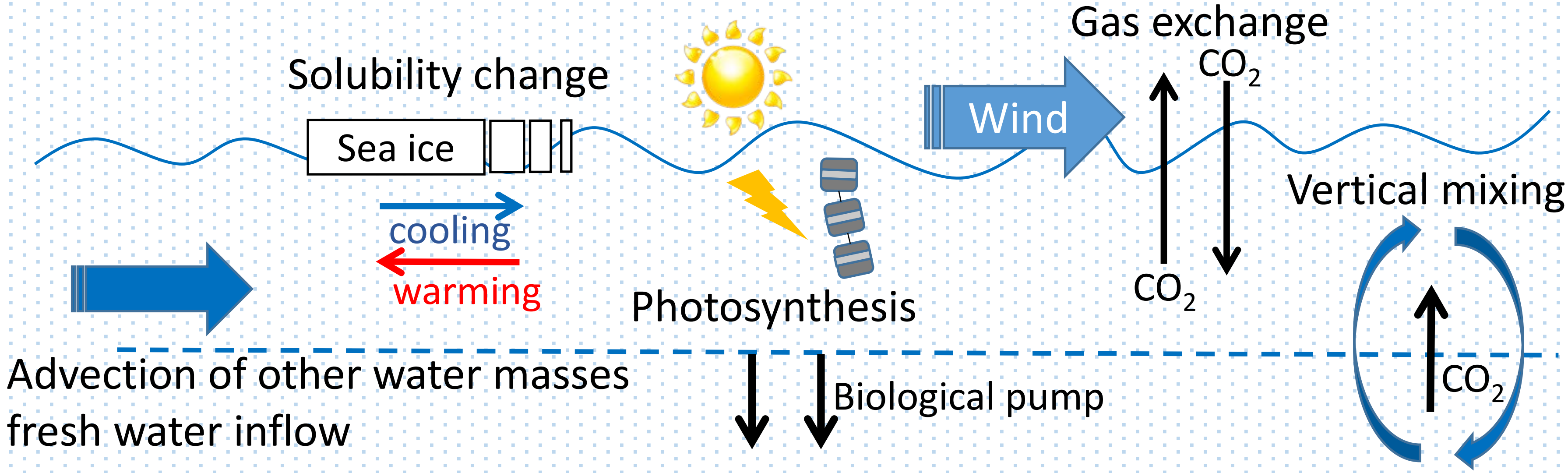
Bering sea shelf shift from neutral CO_2 sink/source status in spring to strong oceanic sink for CO_2 by summer (Bates et al., 2011a)

Mechanisms of CO_2 flux in seasonal ice zone

<u>Partial pressure of CO_2 (pCO_2) vary with</u>

1) Solubility change (temperature, salinity) → solubility pump
2) Vertical mixing (wind-induced, sea ice formation) → physical pump
3) Gas exchange at sea surface
4) Advection of other water masses and fresh water inflow
5) <u>Phytoplankton uptake</u> → biological pump

└→ Seasonally significant



Introduction

Rapid environmental change in the Arctic

Recent Arctic environment

- Increase in flesh and heat water flux depends on increasing Bering Strait throughflow (Woodgate et al., 2012)
- Reduction of sea ice area in summer and earlier retreat of sea ice
- Shift in timing of phytoplankton bloom and change in annual primary production (e.g. Brown and Arrigo, 2012; Ji et al., 2013, etc…)

Rapid environmental change in the Arctic Ocean

The Arctic marine carbon cycle will likely enter a high dynamic state in coming decades, with large uncertainties in the exchange of atmosphere-ocean CO_2 (Bates et al., 2011b)

Previous studies on pCO_2

There are many researches focusing on relationship between pCO_2 and physical processes

Ex) Murata and Takizawa, 2003; Hauri et al., 2013, etc...

However

Few studies have focused on relationship between pCO_2 and biological processes

⇒ Thus, little is known about how much biological processes affect pCO_2

It's important to clarify the biological contribution to pCO_2 for more understanding of air-sea CO_2 flux in the western Arctic and Bering Sea where environmental change is rapid

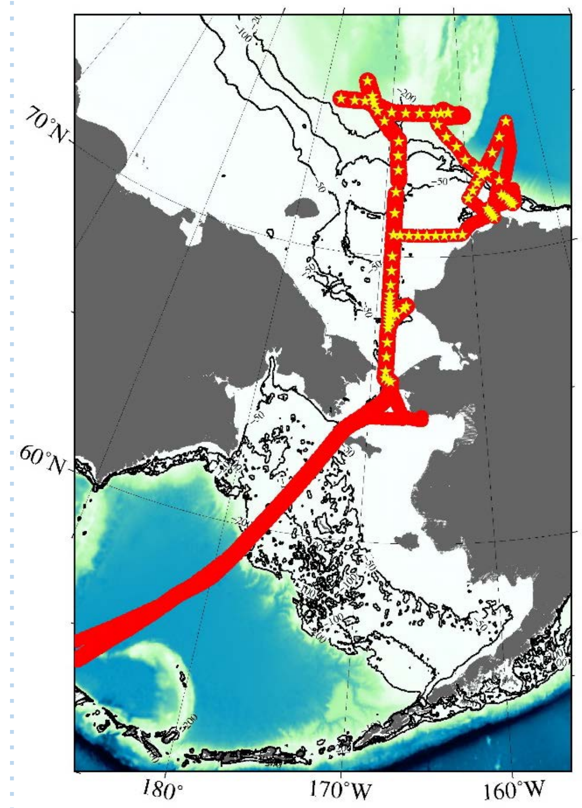
Objective

- To clarify biological contribution to *p*CO_2 in the western Arctic and Bering Sea

In-situ and satellite data

Cruise data

R/V “*Mirai*” Arctic Cruise, 2012 (MR12-E03)
3rd Sep. – 17th Oct., 2012



In-situ and satellite data

- Partial pressure of CO_2 (pCO_2)
- Sea Surface Temperature (SST)
- Sea Surface Salinity (SSS)
- Chlorophyll a concentration (Chl.a)

} In-situ Data (Underway)

- Mean wind speed
- Open water period

} Physical

- Mean primary productivity } Biological

Physical, Biological → Reanalysis & satellite data

- Total Alkalinity(TA), Salinity(Sal), Dissolved Inorganic Carbon(DIC)
  → CTD bottle sampling data

Data sampling and processing

pCO_2[μatm], SSS[psu], SST[℃] and Chl.a[mg m^{-3}]

1st step: Seawater was pumped up from 4.5m below the sea surface.
p*CO$_2$**: Cavity Ring-Down Spectroscopy (CRDS), and ***SSS; SST; Chl.a: Continuous sea surface water monitoring system

Open water period (OP) [days]

Satellite derived sea ice concentration (SIC), SSMI/DMSP, 25km, Daily

The period from onset of ice retreat to observed day

→ The day that SIC is first below 10%

Primary Productivity [mg C m^{-2} d^{-1}]

Satellite derived a_{ph}(443), E_0, Z_{eu}, MODIS/Aqua, 9km, Daily

Calculated by the algorithm using phytoplankton light absorption coefficient ($a_{ph}(\lambda)$) (Hirawake et al., 2011) and optimized by a parameter in Arctic region

Wind speed [m s^{-1}]

NCEP/North American Regional Reanalysis(NARR) , Wind speed at 10m above sea level, 32km 3 hours

Cluster analysis

pCO_2 & environmental parameters

SST

SSS

Chl.a

Open water period (OP)

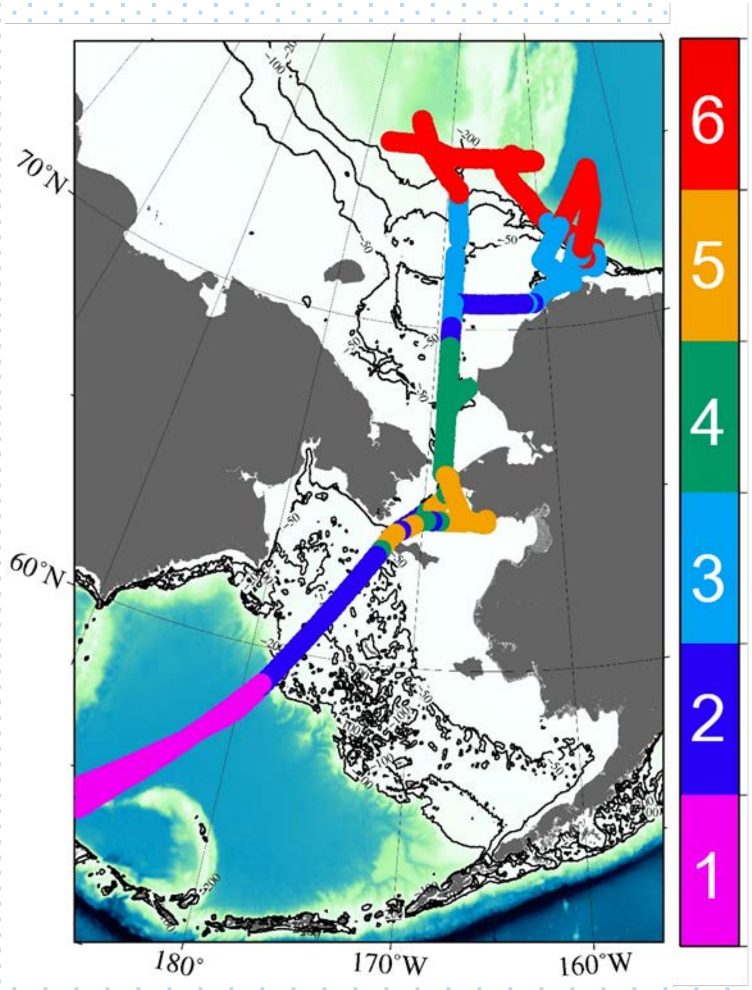
Mean wind speed during OP

Mean primary productivity during OP

$\Delta pCO_2(pCO_{2sea} - pCO_{2air})$

Normalized : $\dfrac{(X - \bar{x})}{\sigma}$

Classified into 6 regions



1. Bering sea basin
2. Northern Bering & central Chukchi Sea
3. Northern shelf of Chukchi Sea
4. Southern Chukchi Sea
5. Southern Bering Strait
6. Northern Chukchi Sea (basin & slope)

Estimation method of biological contribution

Water mass analysis

$$f_{Bering} + f_{River} + f_{Ice} = 1$$

$$f_{Bering}\, S_{Bering} + f_{River}\, S_{River} + f_{Ice}\, S_{Ice} = S$$

$$f_{Bering}\, TA_{Bering} + f_{River}\, TA_{River} + f_{Ice}\, TA_{Ice} = TA$$

(Yamamoto-Kawai et al., 2005)

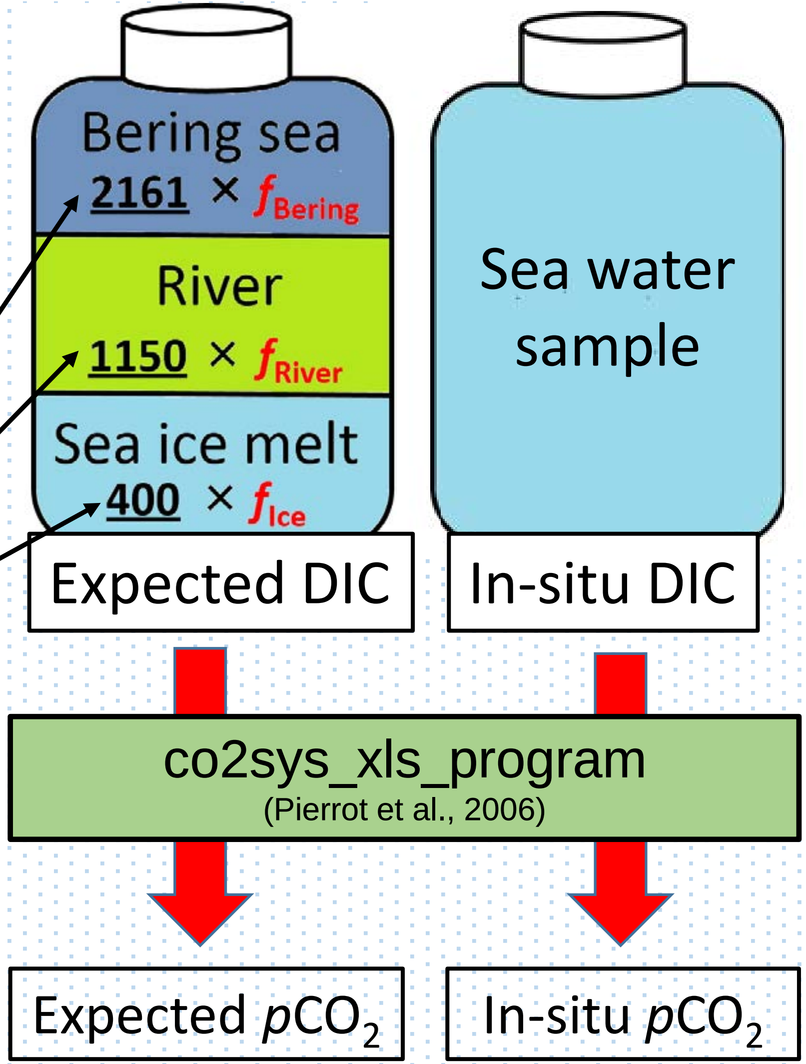
※ *S*, *TA* are measured value

End-member (Cai et al., 2010)	End-member value		
	Sal. [psu]	TA [μmol kg^{-1}]	DIC [μmol kg-1]
Bering Sea water	33.218	2257.9	2161
River water	0	1100	1150
Sea ice melt water	5	450	400

evaluated 3-component fraction of end-members (f_{Bering}, f_{River}, f_{Ice})

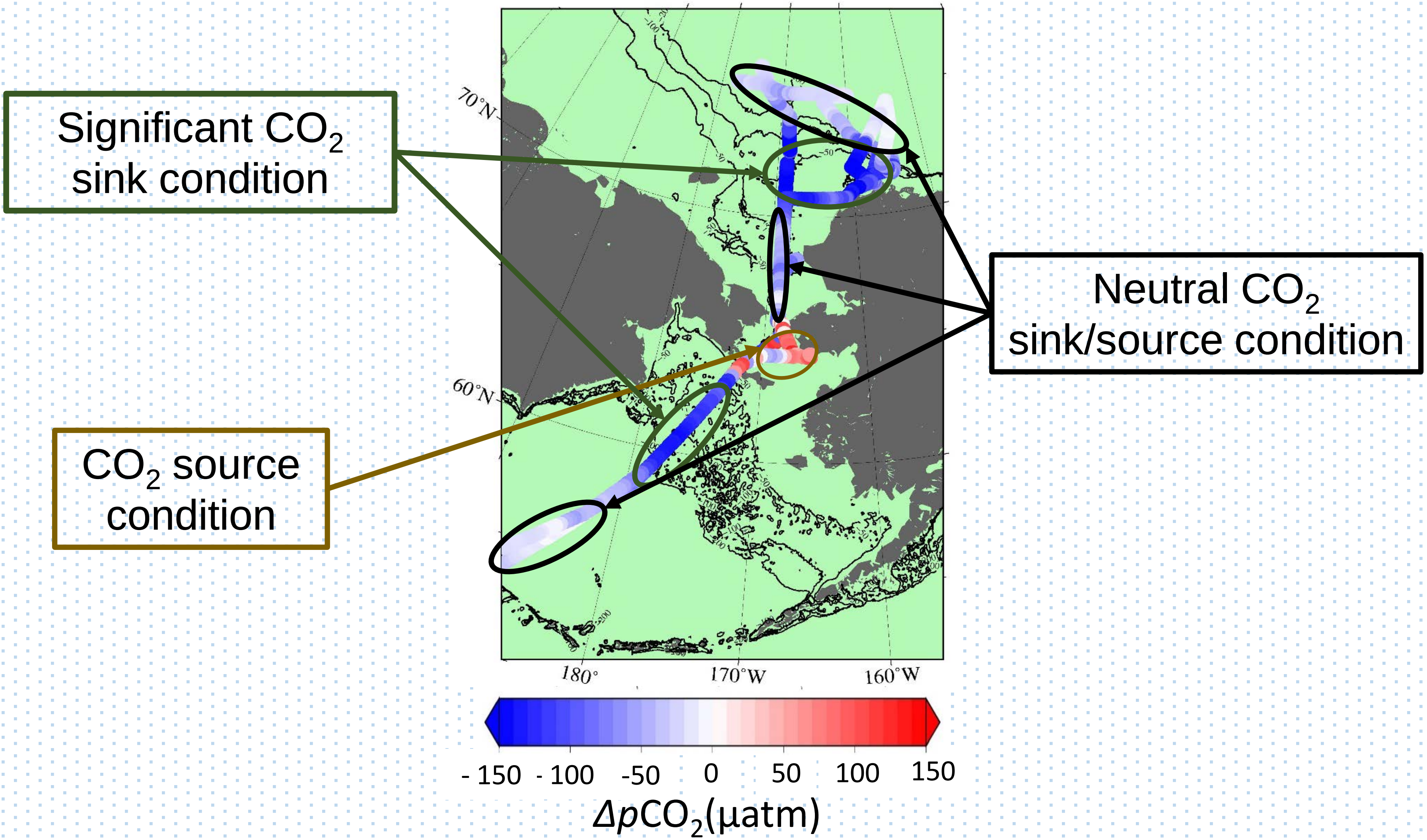
※This analysis is not available in south of Bering Strait due to no CTD sampling data

Expected (from water mass analysis) V.S. in-situ (sea water sample)



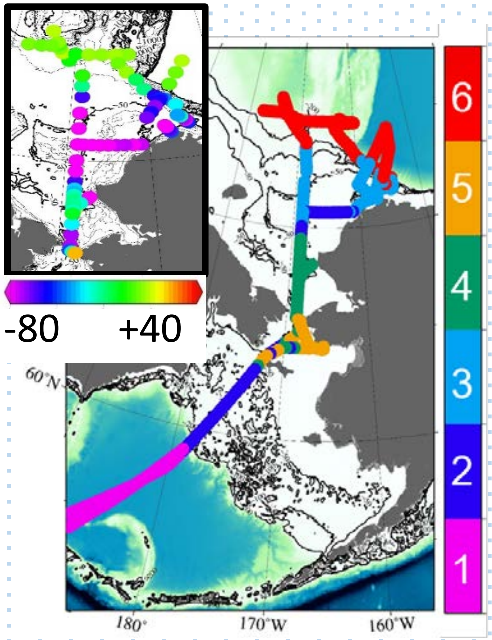
Spatial distribution of ΔpCO_2

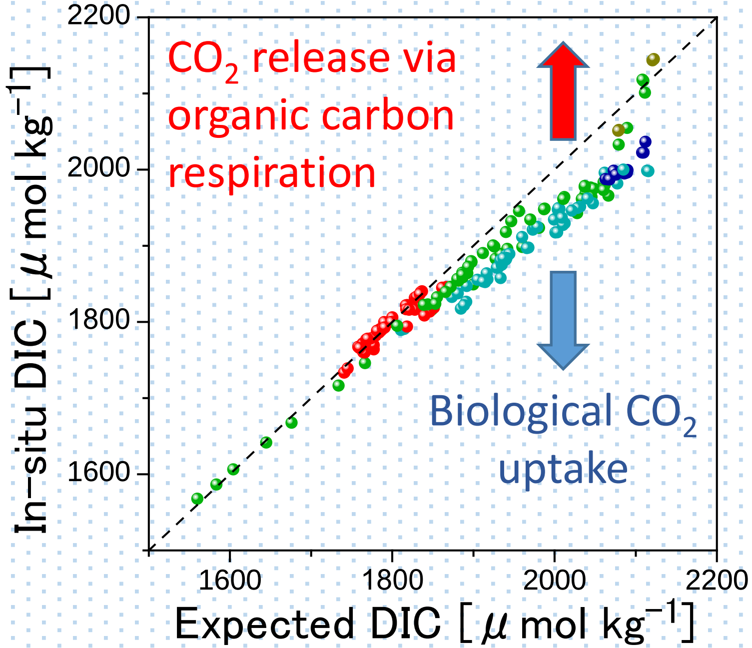
- Most regions had CO_2 sink condition except southern Bering strait
- Spatial variability of ΔpCO_2 was significant ($-200 < \Delta pCO_2 < 160$)

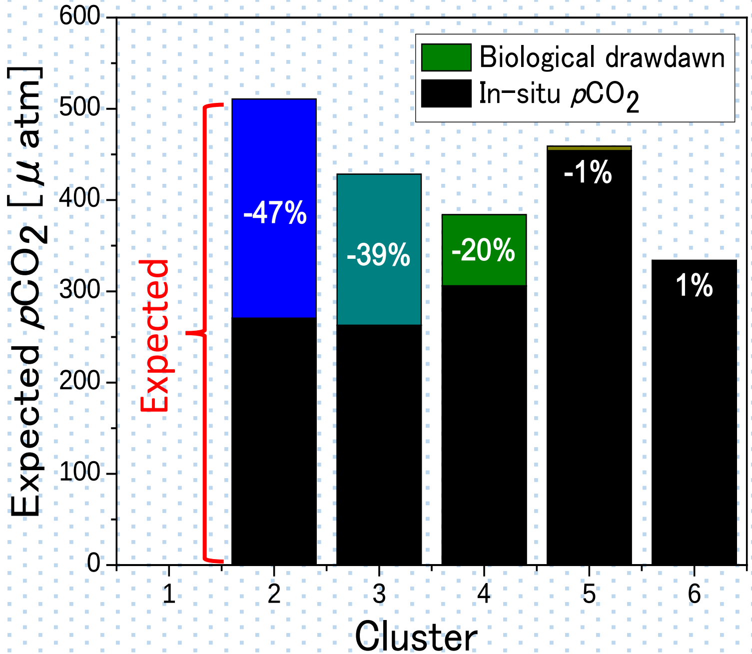


Biological contribution

- Northern & central shelf of Chukchi Sea (Cluster 2, 3)
  ⇒ Large biological contribution: 47%(2.6), 39%(8)
- Southern Chukchi Sea (Cluster 4)
  ⇒ Not so large biological contribution: 20%(24)
- Southern Bering Strait and northern Chukchi Sea (Cluster 5, 6)
  ⇒ No biological contribution: 1%(39), 0%(12)







The feature of ΔpCO_2 in the Arctic

Significant low ΔpCO_2 region

② Northern Bering & central Chukchi Sea

⇒ ΔpCO_2 : -131(39) μatm, 47%

- Relatively high mean primary productivity (702 mg C m^{-2} d^{-1})

± Relatively weak wind (5.55 m s^{-1})

± Less stratification (f_{sim}=1%)

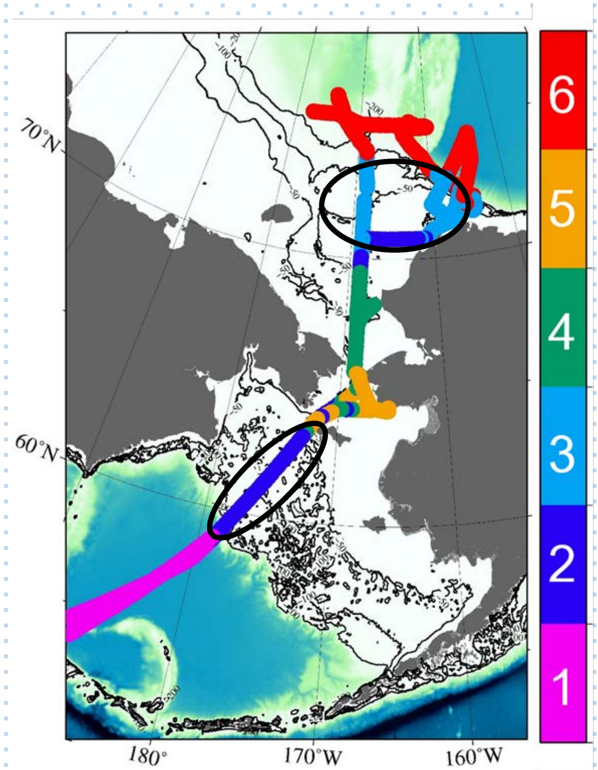
③ Northern shelf of Chukchi Sea

⇒ ΔpCO_2 : -109(39) μatm, 39%

- Relatively high Chl.a (0.9 mg m^{-3})

± Relatively weak wind (5.04 m s^{-1})

± Less stratification(f_{sim}= 8%)



Cluster	Chl.a Median(IQR)	mean_PP Median(IQR)	mean_wind Median(IQR)
Cluster1	0.60(0.44)	605(94)	7.33(0.21)
Cluster2	0.53(0.50)	702(155)	5.55(0.60)
Cluster3	0.90(0.50)	450(124)	5.04(0.55)
Cluster4	1.40(0.95)	807(67)	6.46(0.29)
Cluster5	0.55(0.43)	624(139)	5.59(0.45)
Cluster6	0.09(0.04)	382(170)	5.52(0.34)

In-situ biological pump and/or advection of low pCO_2 water after blooming allowed significant CO_2 sink condition in these regions

The feature of ΔpCO_2 in the Arctic

Neutral ΔpCO_2 region

④ Southern Chukchi Sea

⇒ ΔpCO_2 : -57(33) μatm, 20%

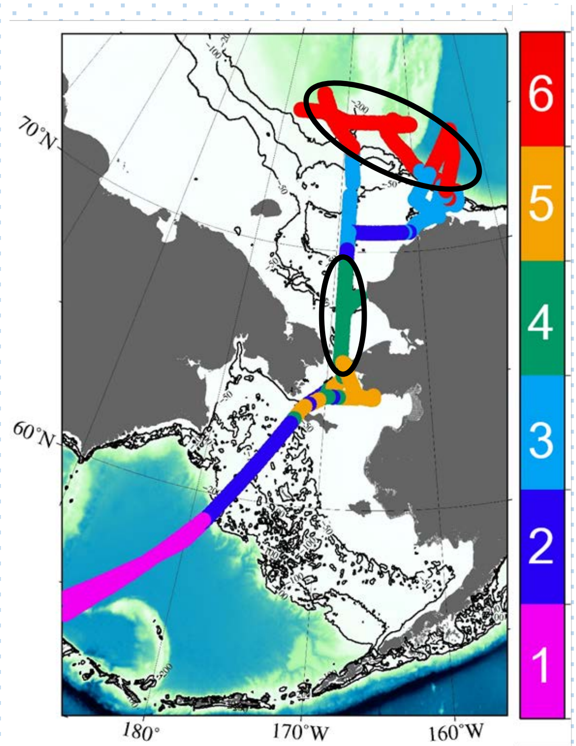
- \- High primary productivity (807 mg C m^{-2} d^{-1})
- \- High chl.a (1.40 mg m^{-3})
- \+ Significant stratification by sea ice melt water (f_{SIM} = 10%)
- \+ Relatively strong wind (6.46 m s^{-1})

⑥ Northern Chukchi Sea

⇒ ΔpCO_2 : -23(13) μatm, -1%

- ± Low primary productivity (382 mg C m^{-2} d^{-1})
- ± Low Chl.a (0.09 mg m^{-3})
- \+ Significant stratification by sea ice melt water (f_{SIM} = 16%)

Shallow mixed layer depth and strong stratification by sea ice melted-water allowed relatively quick re-equilibration with atmosphere (Cai et al., 2010)



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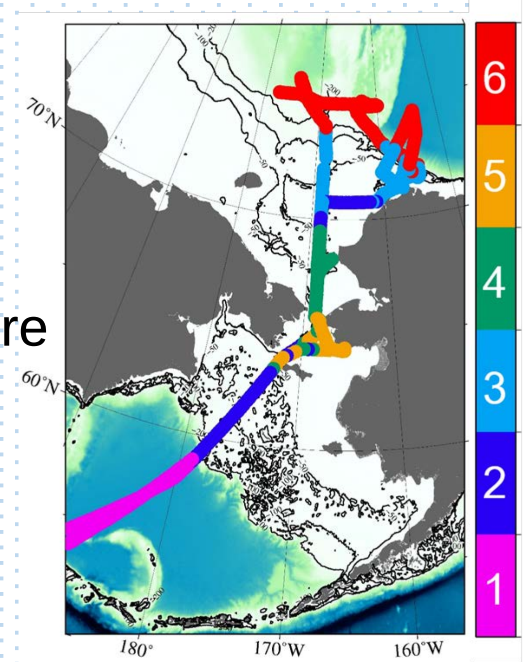
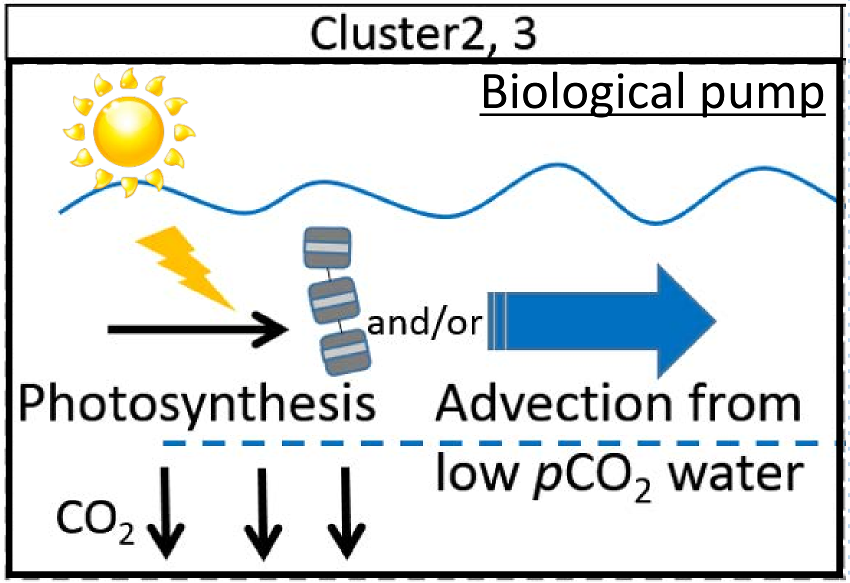
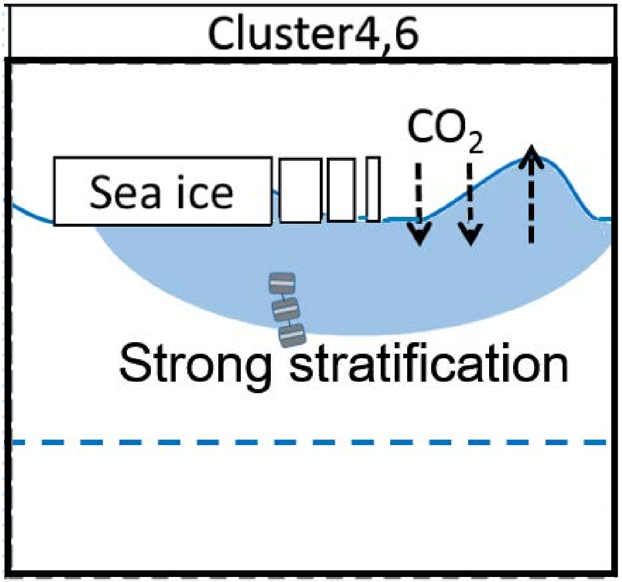
Conclusion

- The northern Bering, central & northern shelf of Chukchi Sea (Cluster2, 3) had significant CO_2 sink condition and <u>biological CO_2 uptake largely contributed to pCO_2.</u>
- The southern & northern Chukchi Sea (Cluster4, 6) where strongly stratified by sea ice melt water had relatively neutral CO_2 sink/source condition, and <u>biological contribution to pCO_2 was not so large or nothing</u>







If further sea ice reduction and earlier ice retreat will occur(e.g. IPCC AR5; Brown and Arrigo, 2012), and annual net primary productivity will increase (e.g. Arrigo et al, 2008; Pabi et al, 2008);

two possible scenarios are expected

- CO_2 sink will be enhanced in the region where primary productivity increase

- strong and broad stratification may occur by further sea ice reduction and earlier ice retreat, and allow relatively quick re-equilibration with atmosphere and prevent CO_2 uptake from atmosphere to the ocean.


Thank you
for your attention