BGC-Argo Observations and Physical-Biogeochemical Modeling

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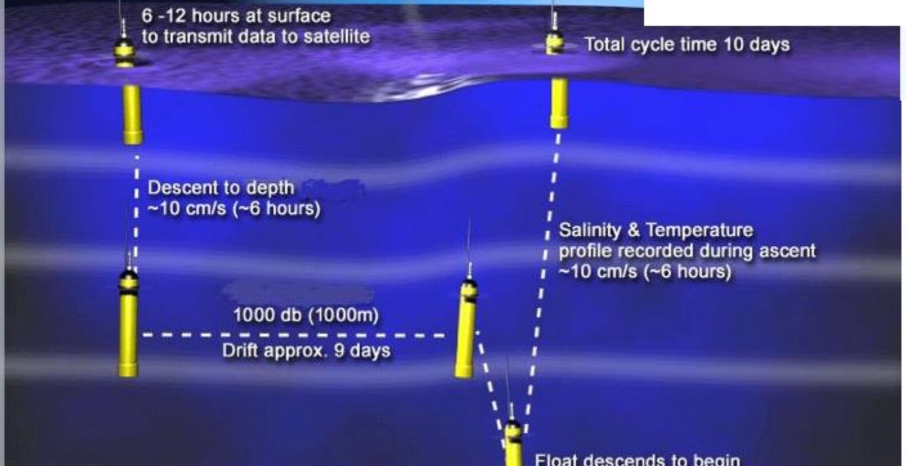
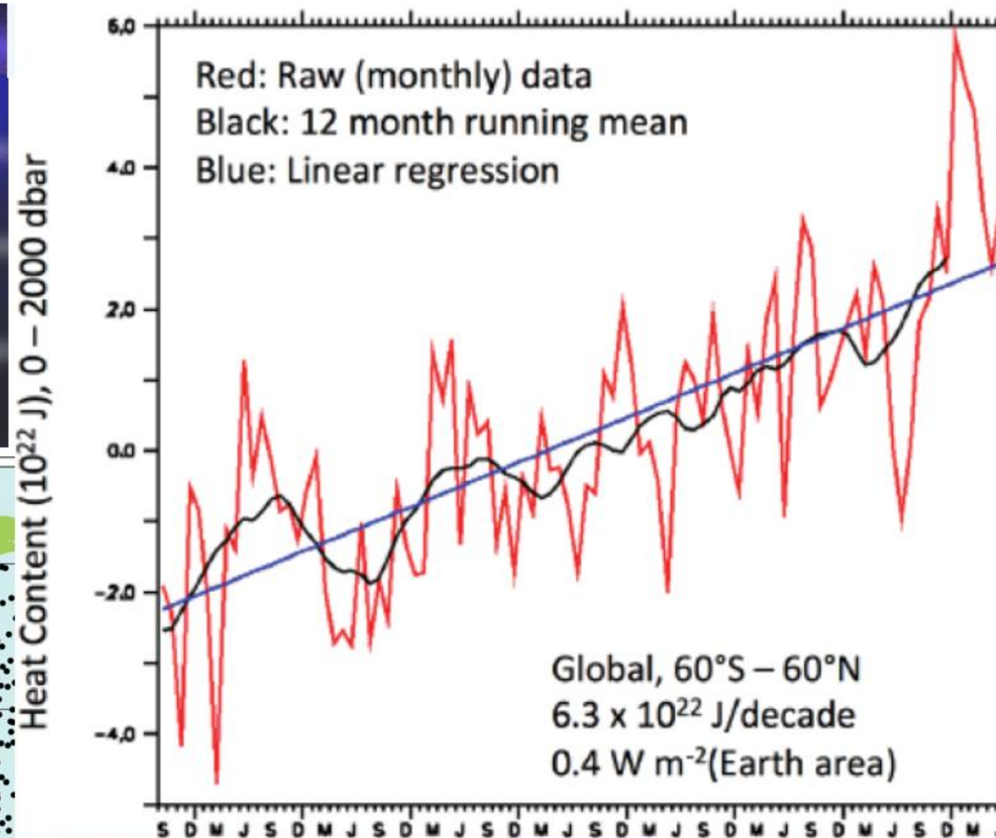
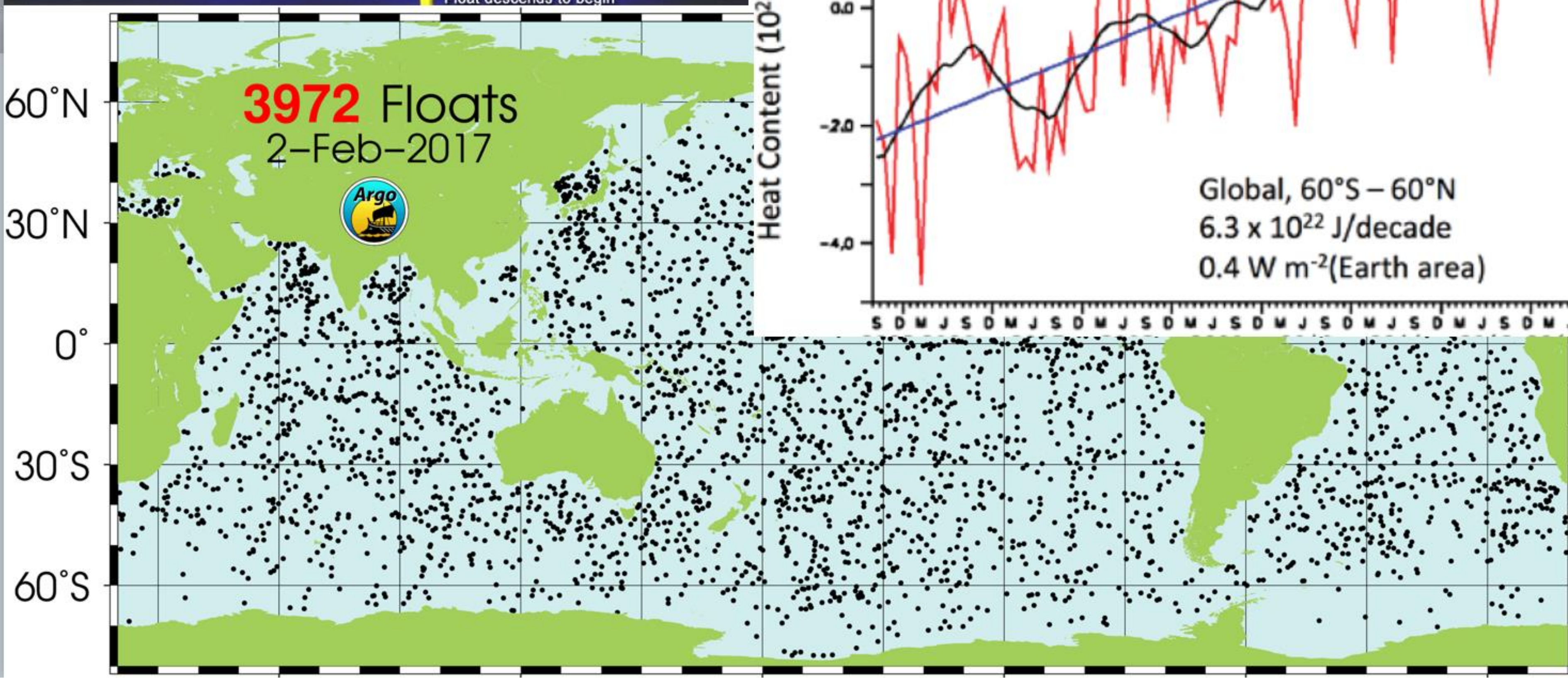
- BGC-Argo development (International and China)
- Two examples of using BGC-Argo
- Physical-biogeochemical modeling – two stories

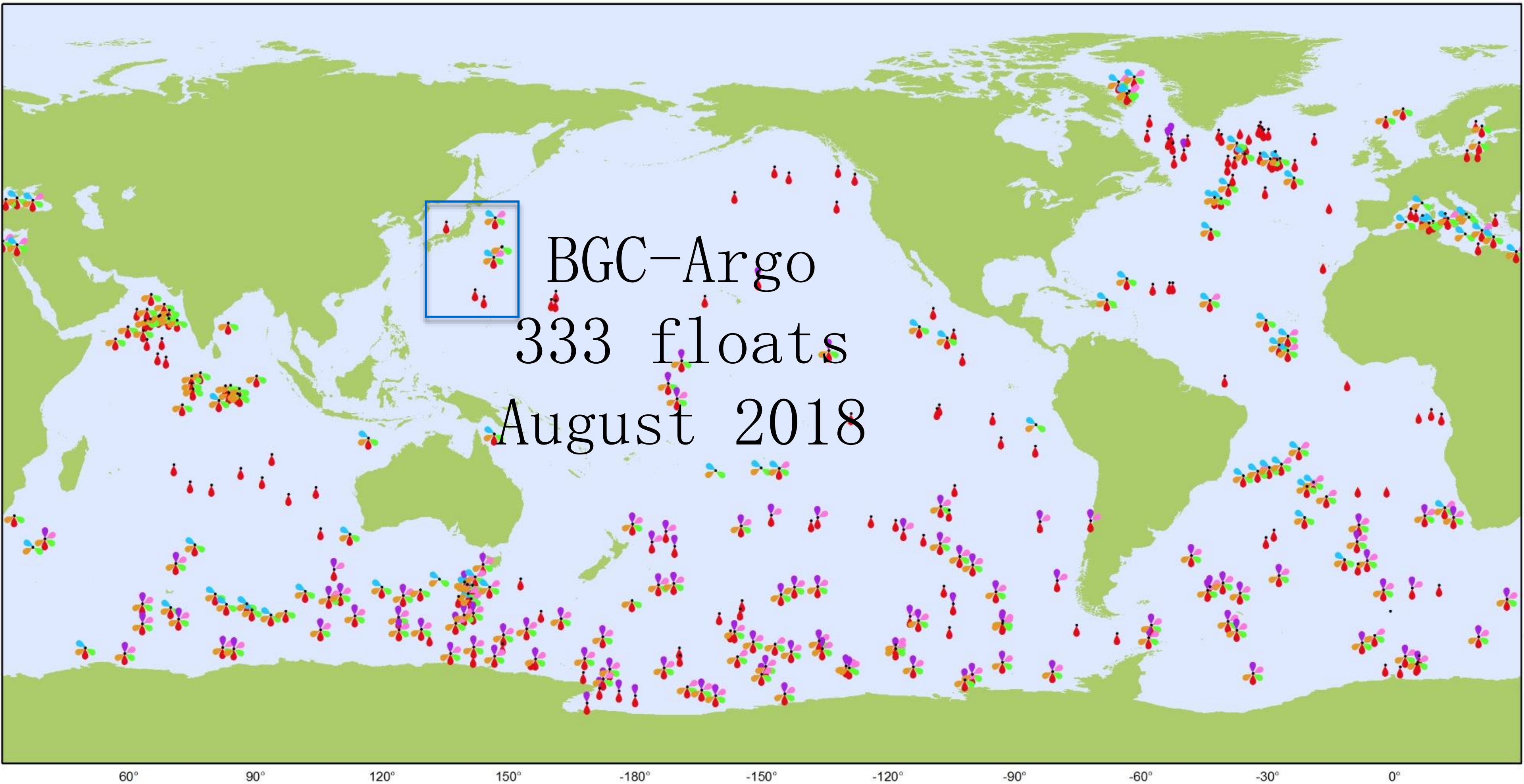
Global Argo Float Network

Goal: To document seasonal to decadal climate variability









Biogeochemical Argo **Sensor Types** **August 2018**

Latest location of operational floats (data distributed within the last 30 days)

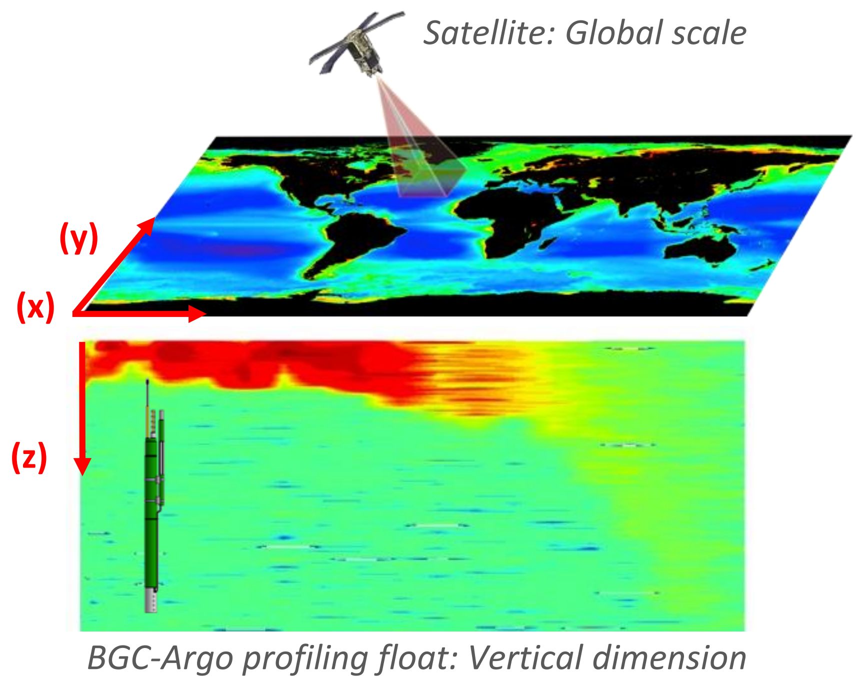
Operational Floats (333)
Suspended particles (209)
Downwelling irradiance (74)
pH (114)
Nitrate (132)
Chlorophyll a (210)
Oxygen (335)

Generated by www.jcommops.org, 05/09/2018

BGC-Argo must work in synergy with other components (especially satellite) of the global observing system

- **Floats and ocean color share key biogeochemical variables (matchups & validation):**
  - ✓ Chla
  - ✓ b_{bp} (POC)
  - ✓ Kd
  - ✓ CDOM

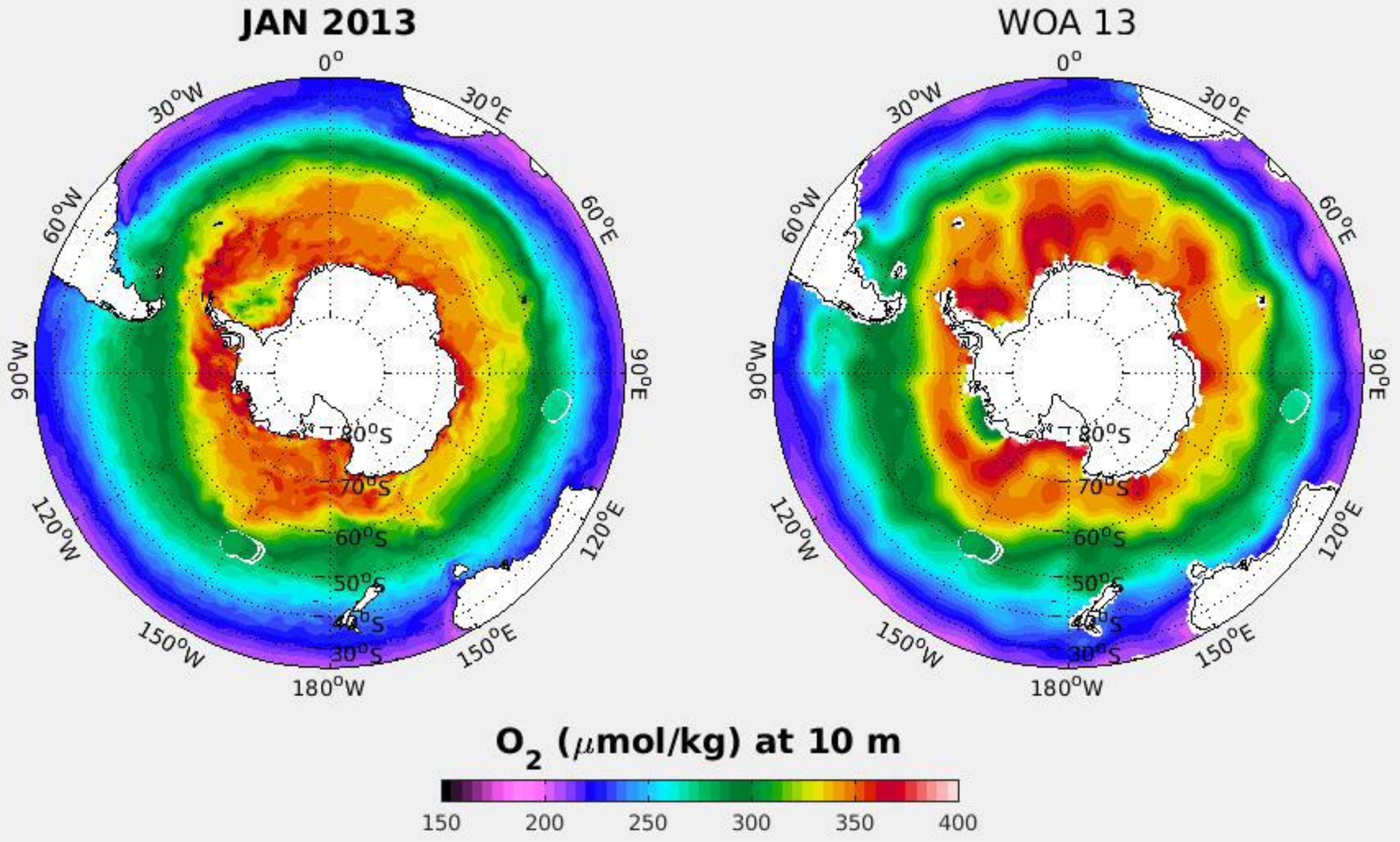
- **Benefits of a coupled approach:**
  - ✓ OC satellites "see" only the 1/5 of the euphotic layer => Profiling floats bring vertical dimension
  - ✓ Profiling floats bring observations under cloud cover or no light conditions
  - ✓ Remote sensing provides extrapolation to the global ocean



3D/4D Ocean Biogeochemistry

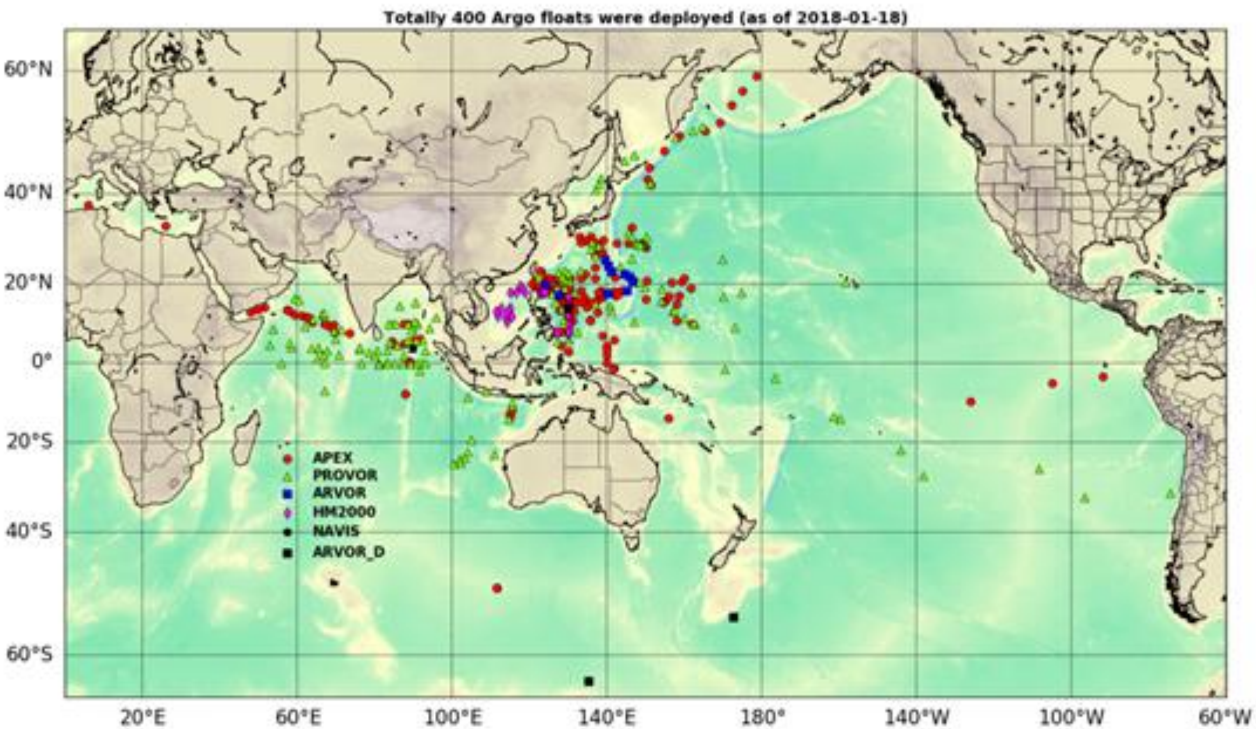
Biogeochemical Southern Ocean State Estimate (B-SOSE)
MITgcm + Biogeochemistry + Data Assimilation
(SOCCOM, 200+ BGC-Argo)

Courtesy of Matt Mazloff, Scripps Institution of Oceanography



China's contribution to Argo and BGC-Argo

The 410th Argo floats deployed in March 2018 by China Argo Project



China Argo Real-time Data Center

中国Argo实时资料中心

Hangzhou, China

Processing the BGC-Argo data

2014: **19** Bio-Argo floats with DO sensor, deployed by OUC in **Northwest Pacific**

2015: **6** Bio-Argo floats with DO sensor, deployed by OUC in the **Southern Ocean**

2017: **1** Bio-Argo float with DO, Chla, CDOM & backscattering in the **Southern Ocean**

2018: **7** Bio-Argo float with DO, Chla, backscattering, NO3, PAR in the **Northwest Pacific**

China Ongoing Argo and Bio-Argo Activities and Plans

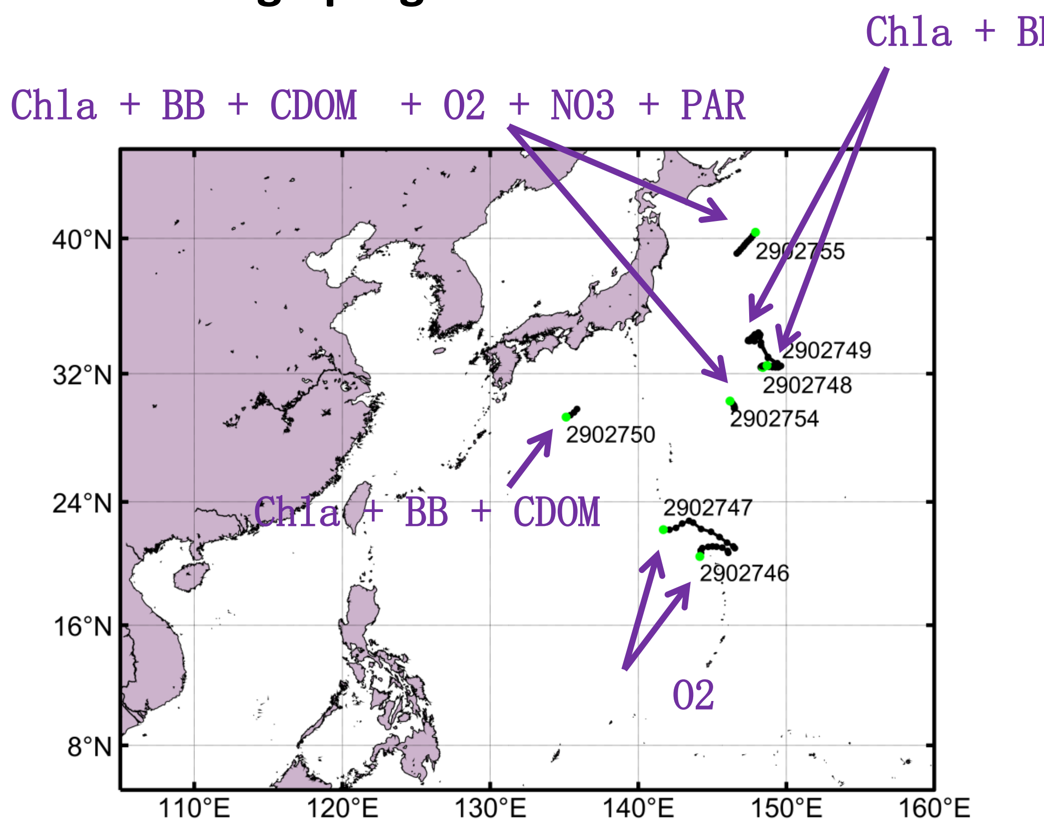
16 Bio-Argo for the Western Pacific 2018-2019

7 has been deployed during May-September 2018

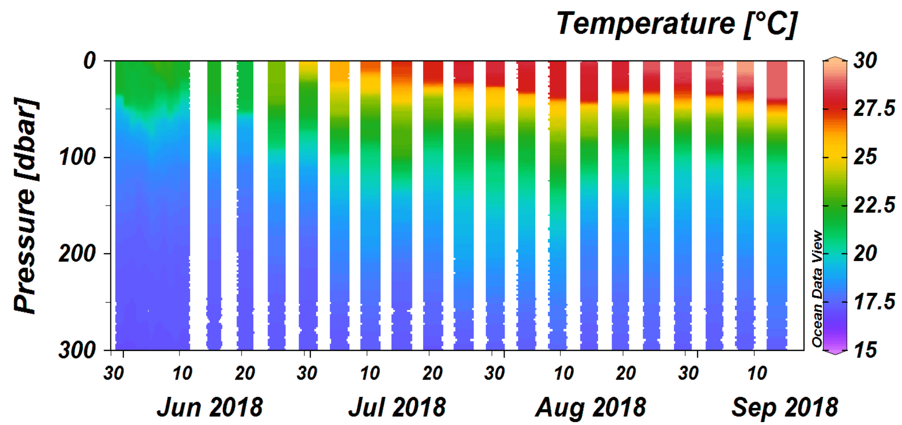
Name	WMO	Argo Type	Biogeochemical Sensors	Cycles	Deployment Time
siobio011	2902746	Provor CTS3	O2	12	May 2018
siobio012	2902747	Provor CTS3	O2	12	May 2018
siobio003	2902748	Provor CTS4	Chla + BB	30	May 2018
siobio004	2902749	Provor CTS4	Chla + BB	29	May 2018
siobio005	2902750	Provor CTS4	Chla + BB + CDOM	4	Sep. 2018
siobio009	2902754	Provor CTS4	Chla + BB + CDOM + O2 + NO3 + Irr.	15	Aug. 2018
siobio010	2902755	Provor CTS4	Chla + BB + CDOM + O2 + NO3 + Irr.	11	Sep. 2018

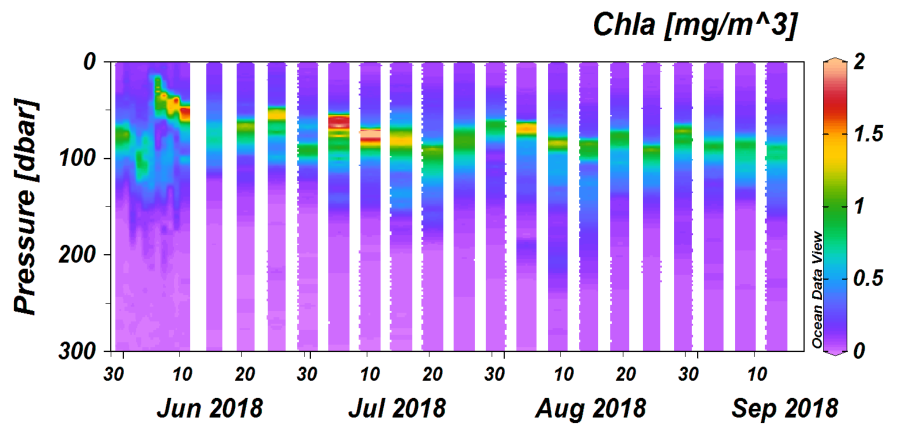
China Ongoing Argo and Bio-Argo Activities and Plans

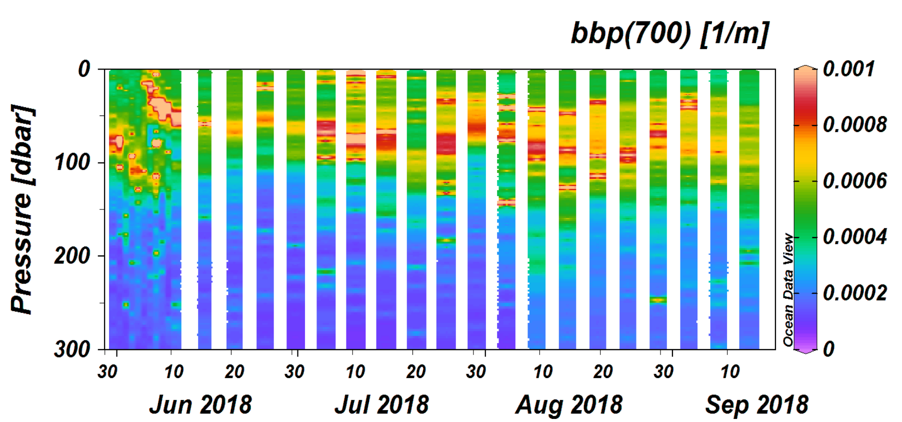
- ✓ **Start to build up an array of BGC-Argo in Western Pacific**
- ✓ **Total 16 floats will be deployed in NWP in the end of 2019**
- ✓ **All Data are contributed to international BGC-Argo program**
- ✓ **Real-time shared in Argo dataset**

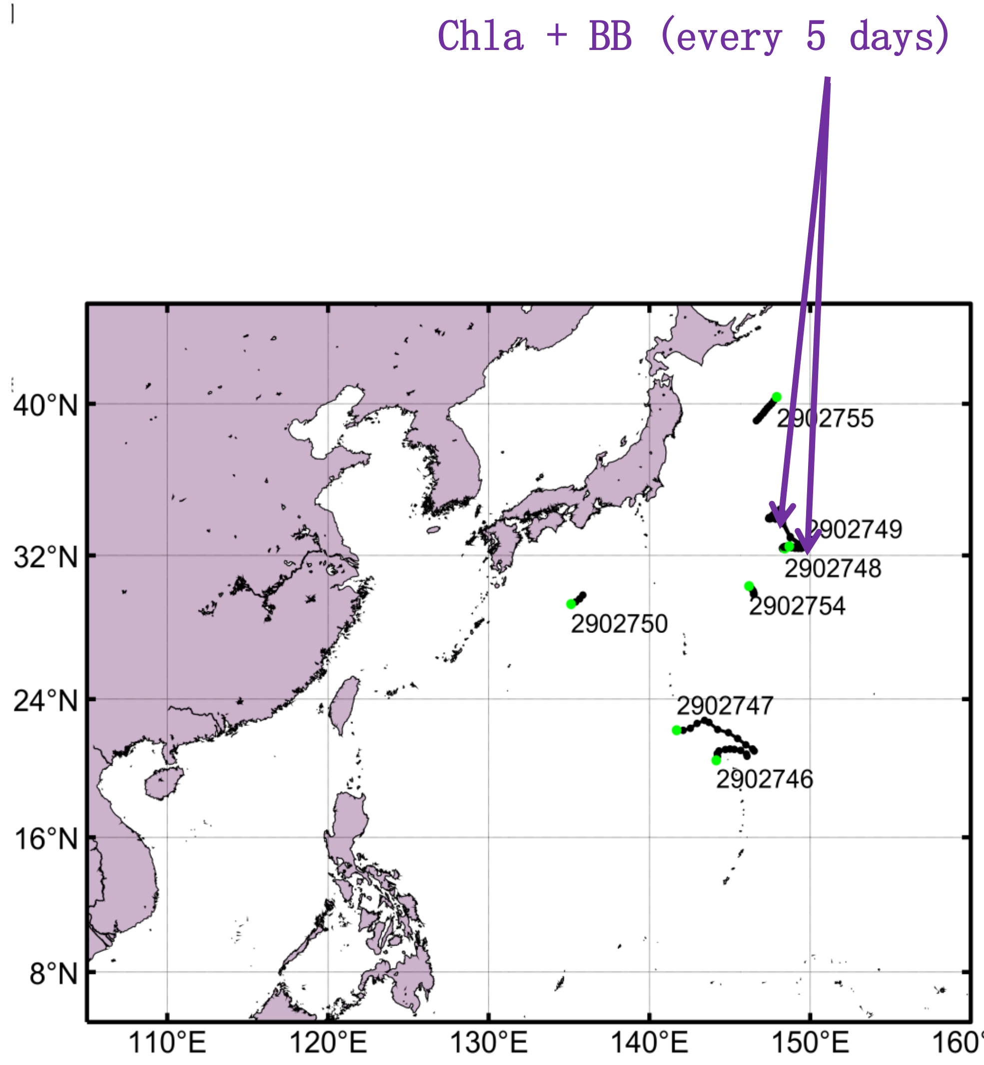


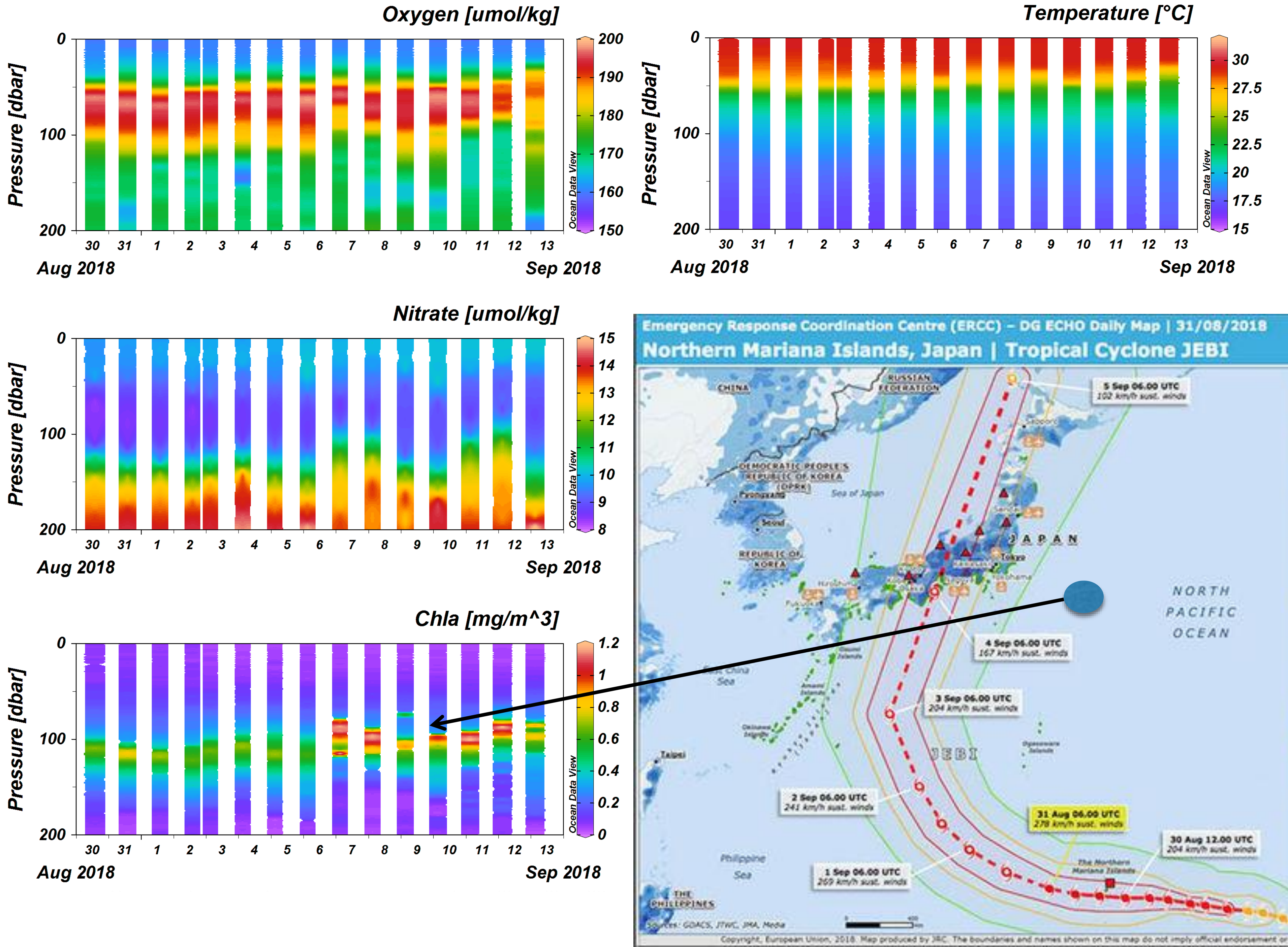
Real Time Data










Oxygen [umol/kg]
Pressure [dbar]
0
100
200
30 31 1 2 3 4 5 6 7 8 9 10 11 12 13
Aug 2018
Sep 2018
200 190 180 170 160 150
Ocean Data View
Temperature [°C]
Pressure [dbar]
0
100
200
30 31 1 2 3 4 5 6 7 8 9 10 11 12 13
Aug 2018
Sep 2018
30 27.5 25 22.5 20 17.5 15
Ocean Data View
Nitrate [umol/kg]
Pressure [dbar]
0
100
200
30 31 1 2 3 4 5 6 7 8 9 10 11 12 13
Aug 2018
Sep 2018
15 14 13 12 11 10 9 8
Ocean Data View
Chla [mg/m^3]
Pressure [dbar]
0
100
200
30 31 1 2 3 4 5 6 7 8 9 10 11 12 13
Aug 2018
Sep 2018
1.2 1 0.8 0.6 0.4 0.2 0
Ocean Data View
Emergency Response Coordination Centre (ERCC) – DG ECHO Daily Map | 31/08/2018
Northern Mariana Islands, Japan | Tropical Cyclone JEBI
CHINA
RUSSIAN FEDERATION
DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA (DPRK)
Pyongyang
Sea of Japan
Seoul
REPUBLIC OF KOREA
JAPAN
Tokyo
NORTH PACIFIC OCEAN
5 Sep 06.00 UTC
102 km/h sust. winds
4 Sep 06.00 UTC
167 km/h sust. winds
3 Sep 06.00 UTC
204 km/h sust. winds
2 Sep 06.00 UTC
241 km/h sust. winds
31 Aug 06.00 UTC
278 km/h sust. winds
30 Aug 12.00 UTC
204 km/h sust. winds
1 Sep 06.00 UTC
269 km/h sust. winds
JEBI
East China Sea
Philippine Sea
Taipei
THE PHILIPPINES
The Northern Mariana Islands
Sources: GDACS, JTWC, JMA, Media
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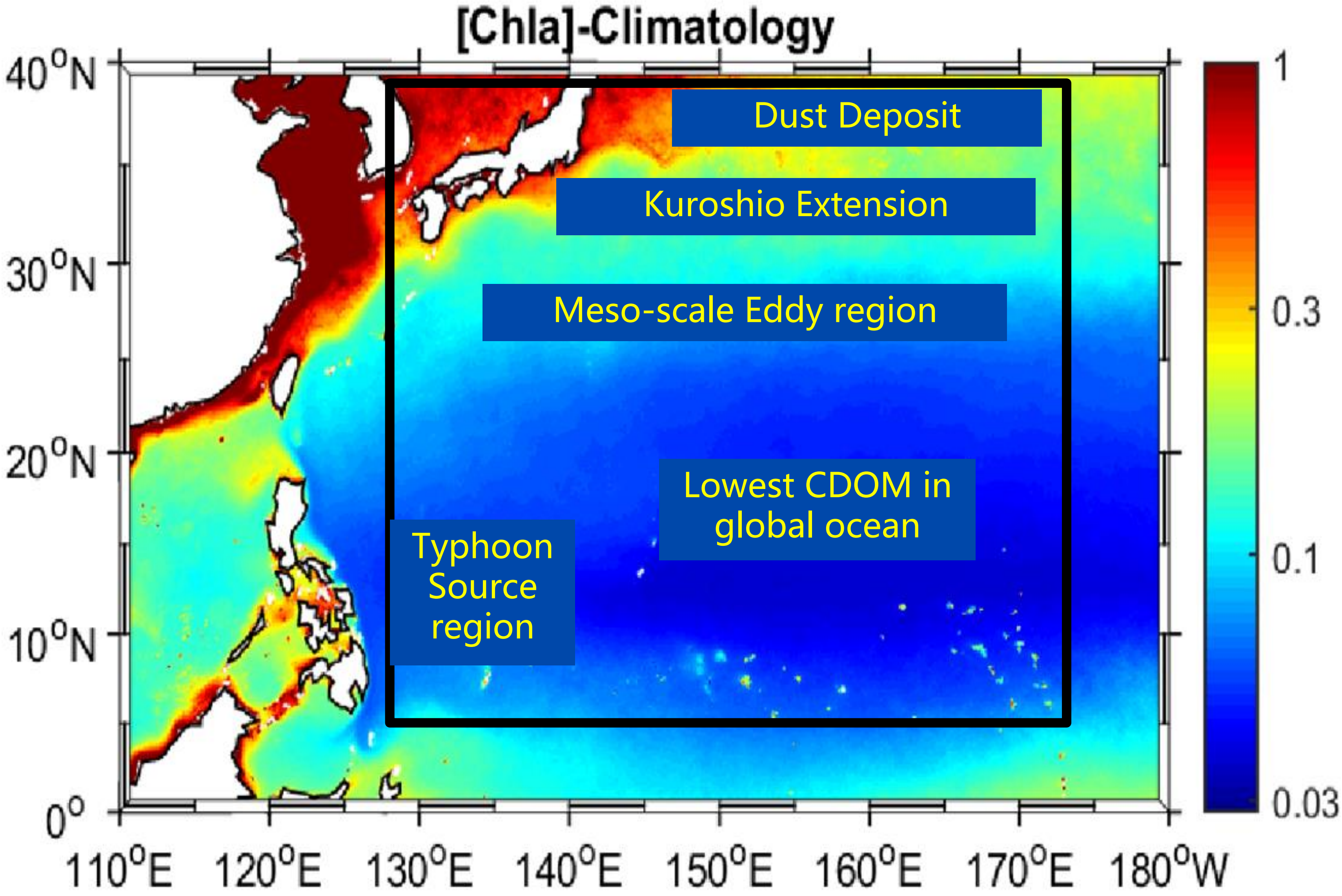
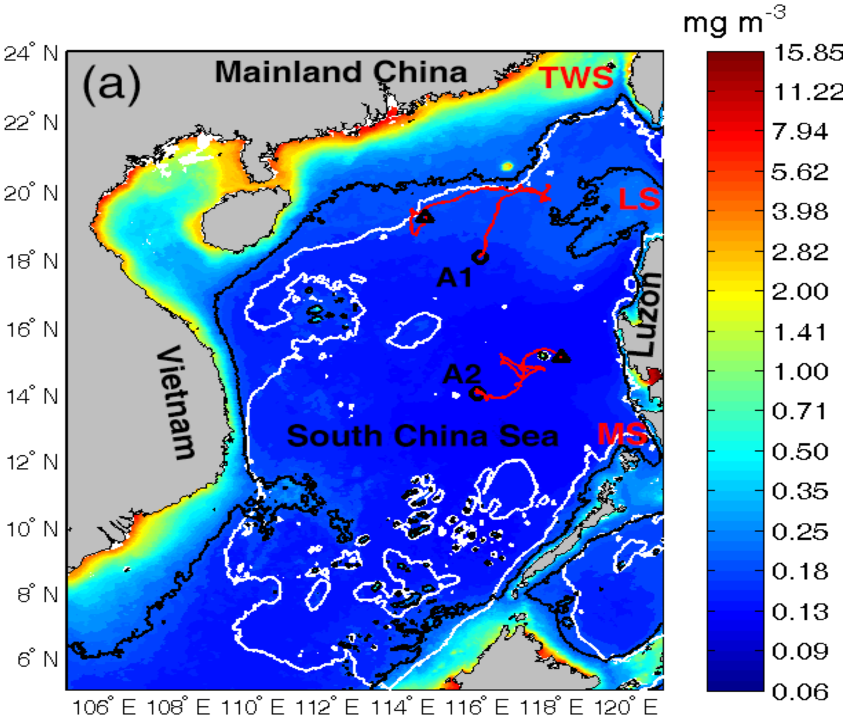
BGC-Argo observations and modeling for the Western Pacific Ocean

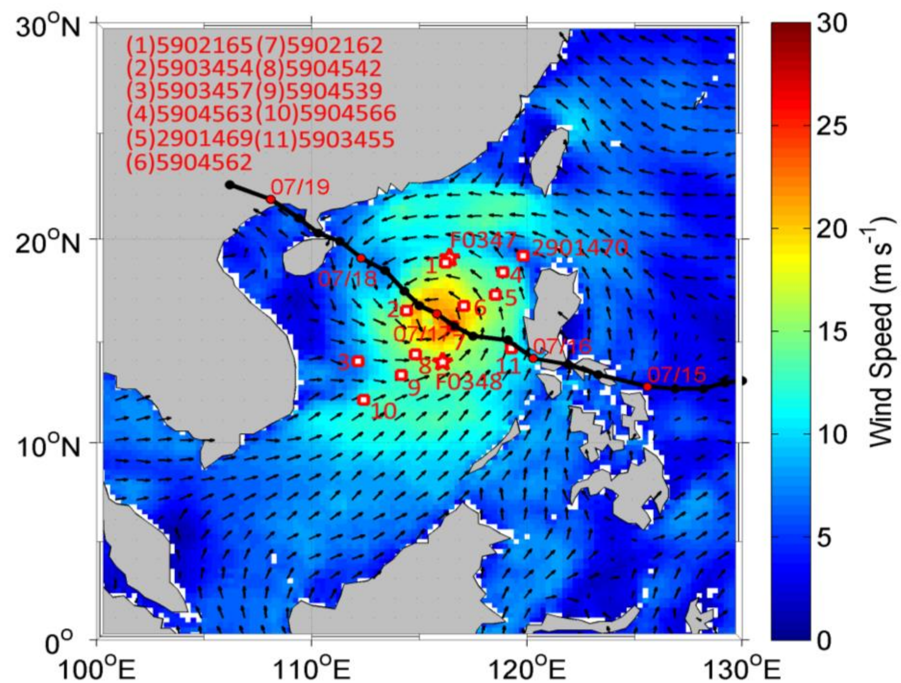


Two examples of using Bio-Argo in the South China Sea (SCS)

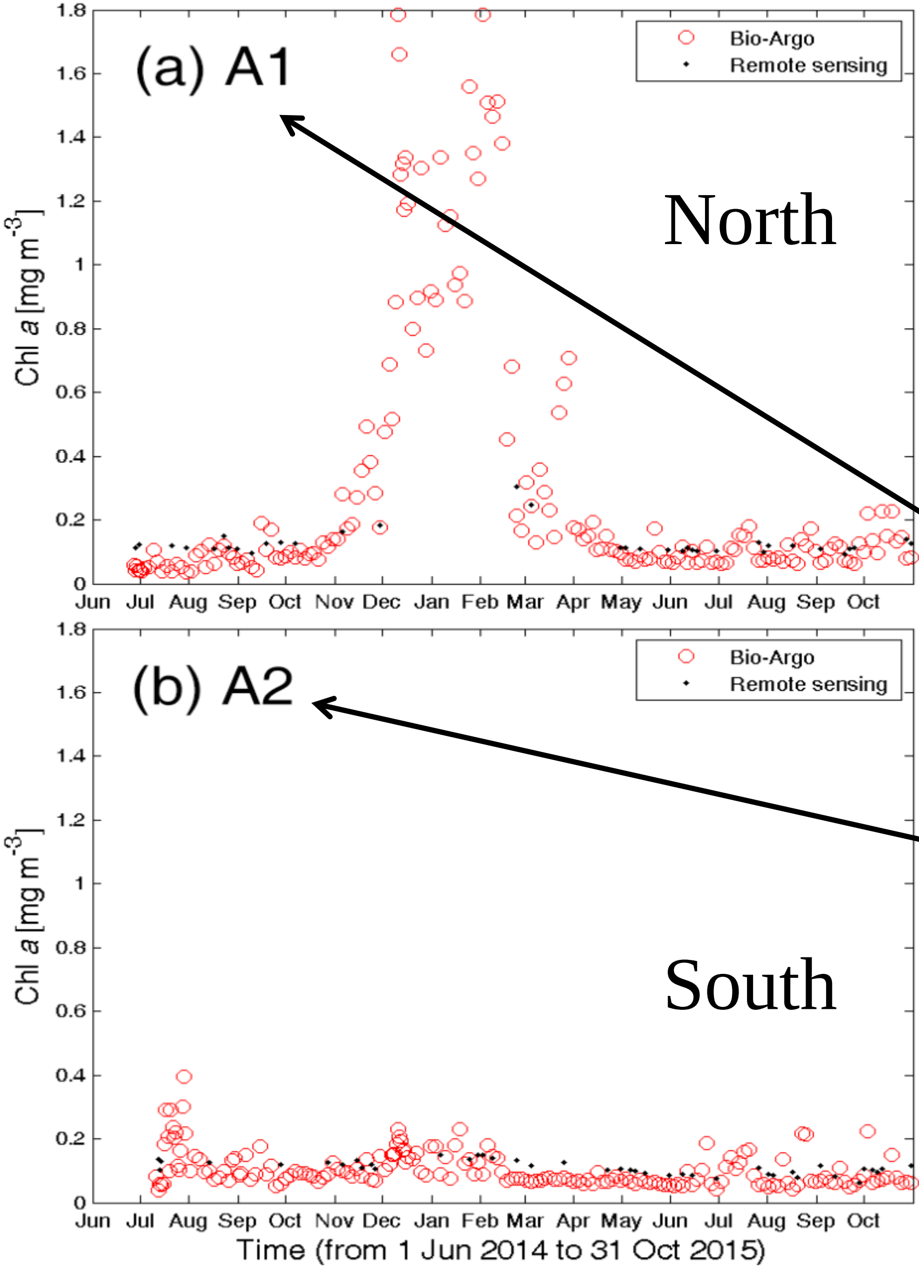
Chla seasonal cycle in SCS



Responses to typhoon in SCS



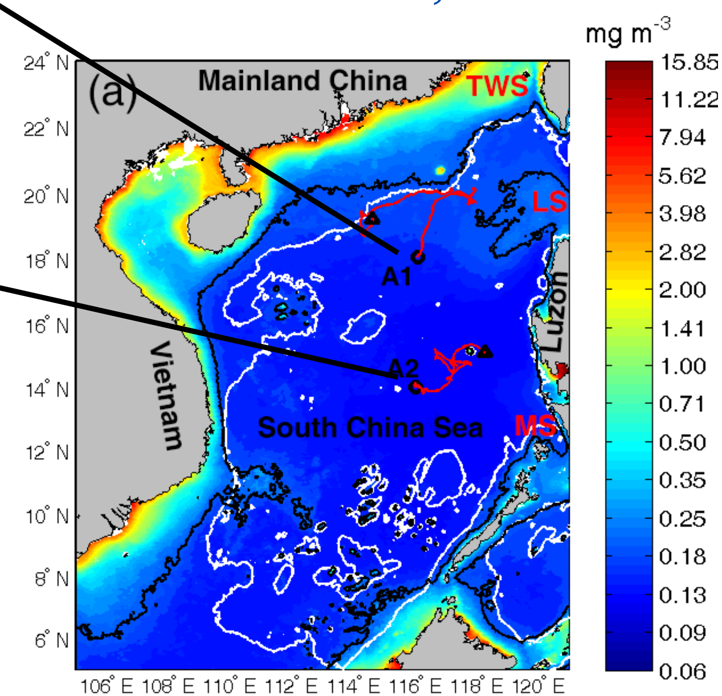
Chlorophyll *a* Observations and comparison with MODIS



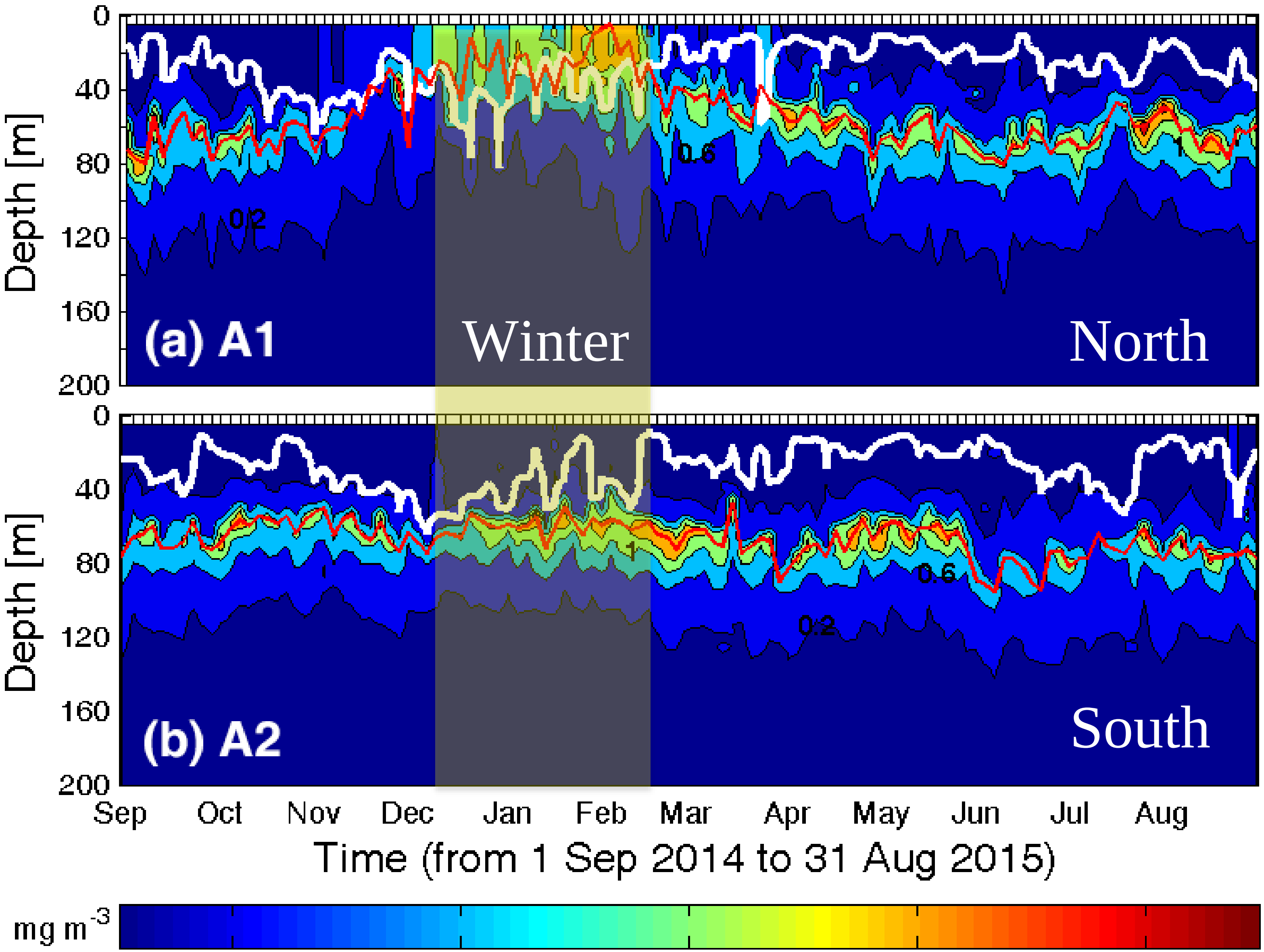
The mean absolute error is 0.043 mg m^{-3} (35 pairs) for A1, and 0.038 mg m^{-3} (41 pairs) for A2

The MODIS overestimated at low Chl *a* and missed most high Chl *a*, compared with Bio-Argo data.

Zhang, Wang, Chai, and Qiu
JGR, 2016



Subsurface Chlorophyll Maximum (SCM)



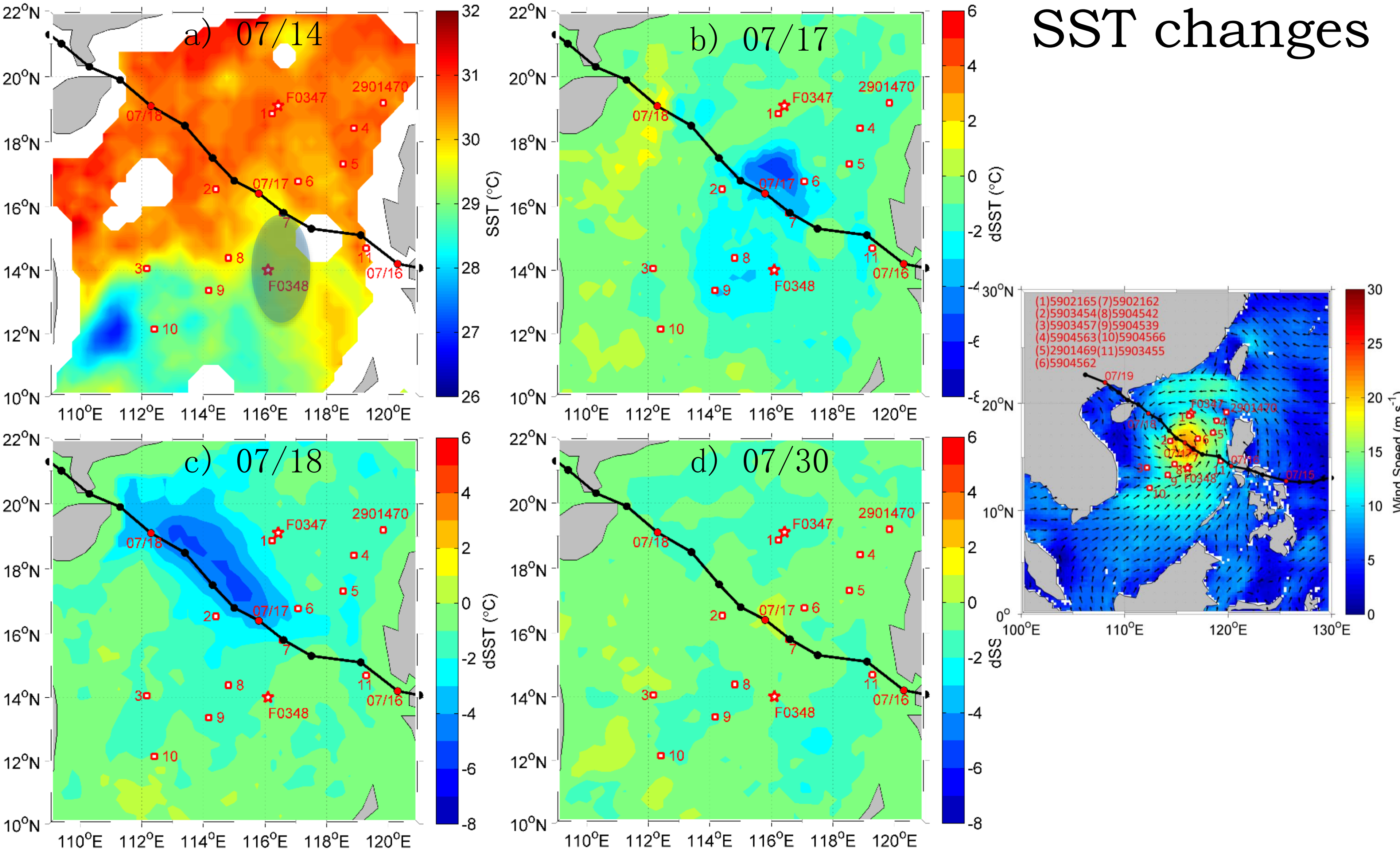
The SCM depth varied between 48 m and 96 m, and its annual mean was 67.4 m.

Zhang, Wang, Chai, and Qiu

JGR, 2016

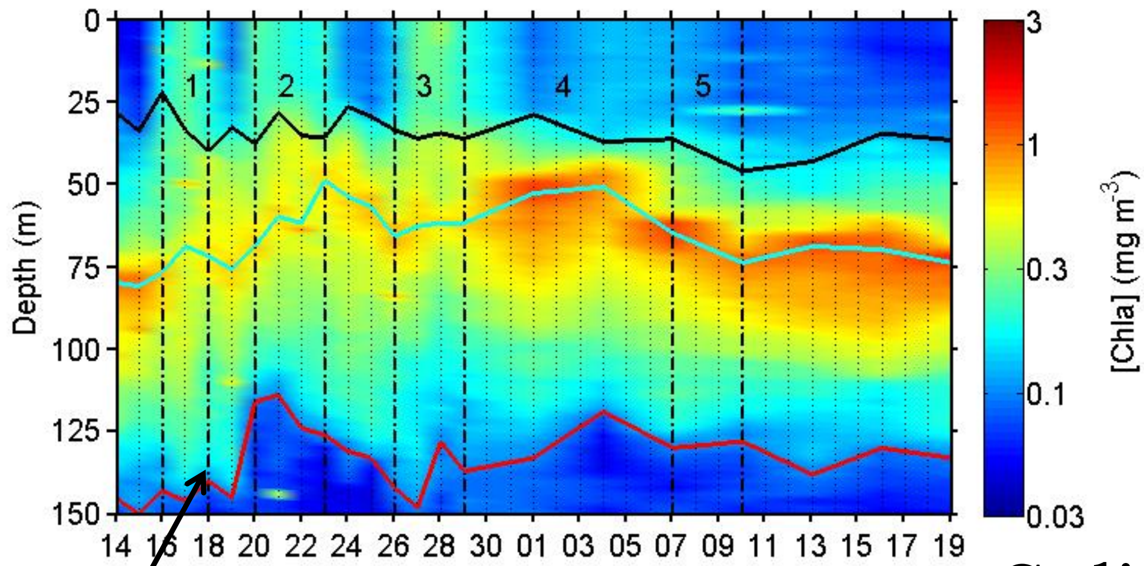
Response to Typhoon Rammasun (July 2014)

SST changes

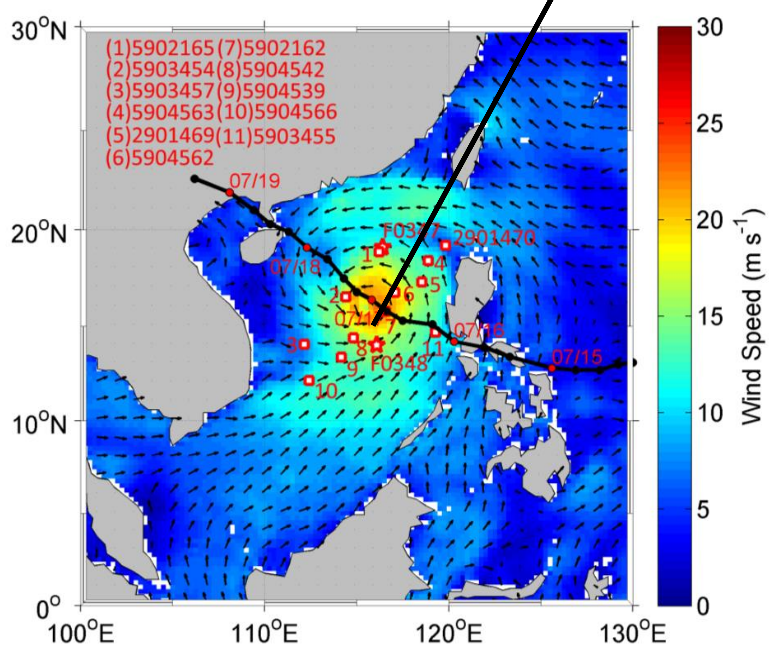


Bio-Argo F348 time series (left side 200km）

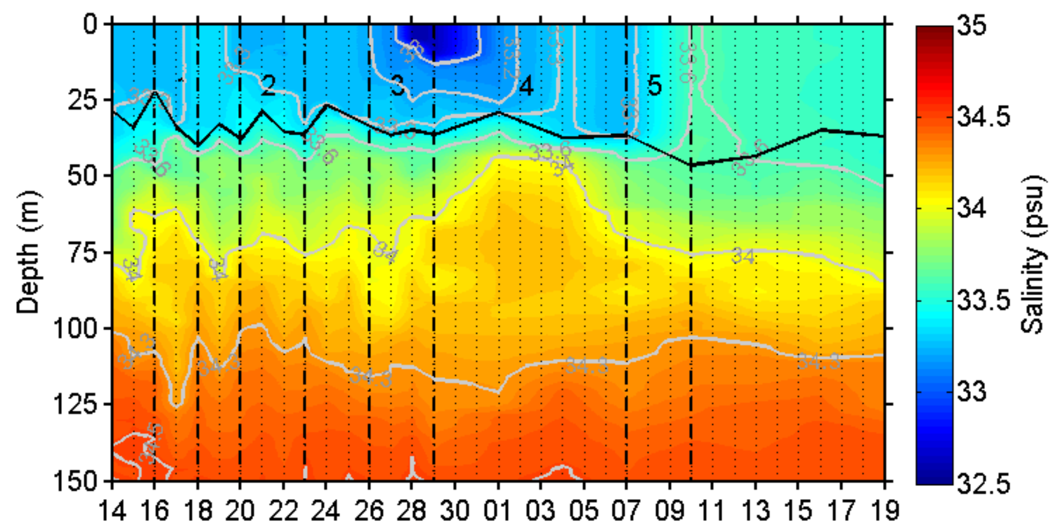
Chlorophyll

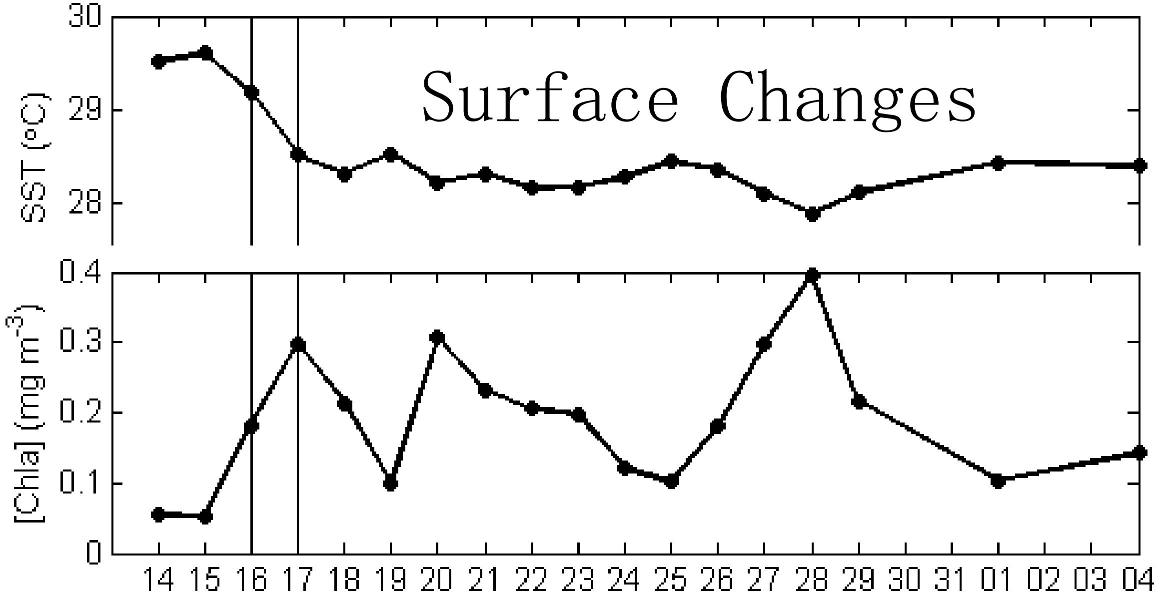


Qiu and Wang, Xing and Chai (in prep.)



Salinity

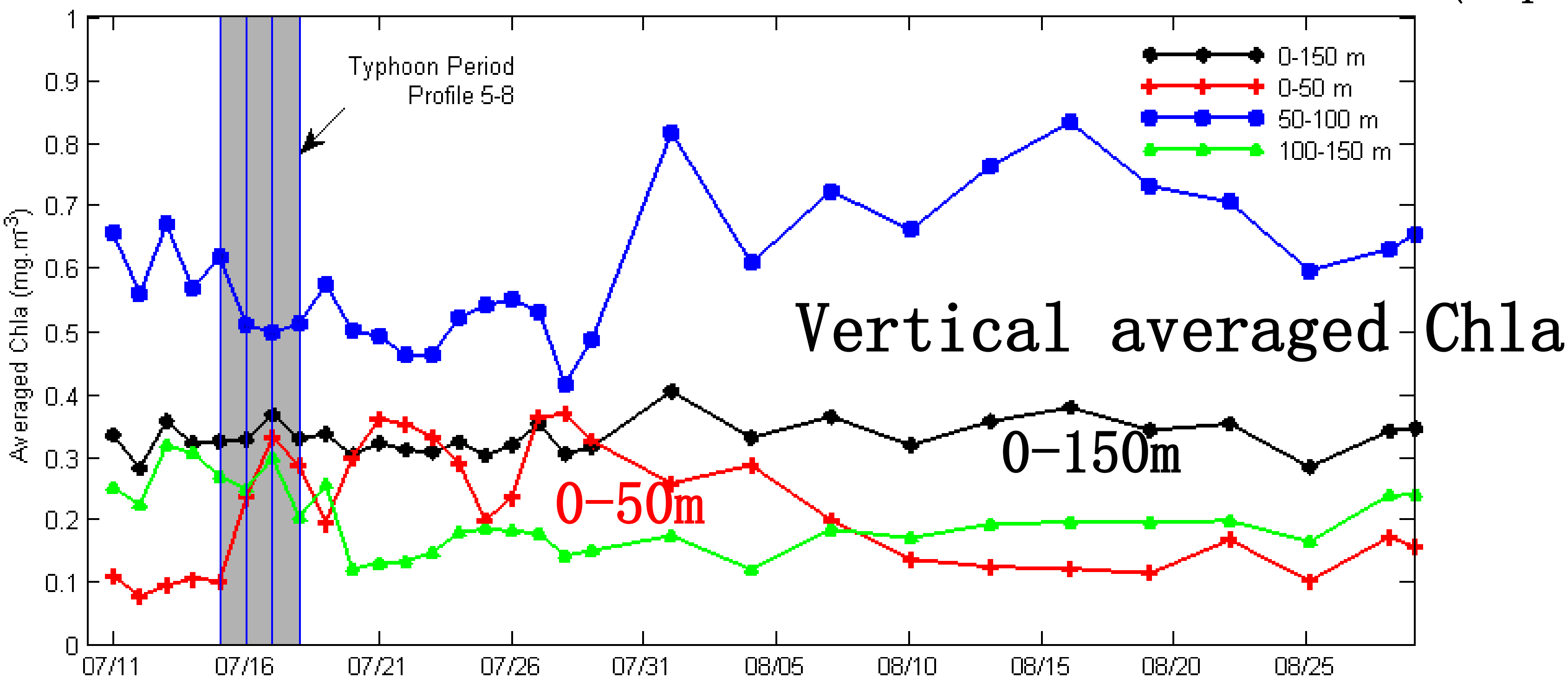




SST

Surface Chla

Qiu, Wang,
Xing and Chai
(in prep.)



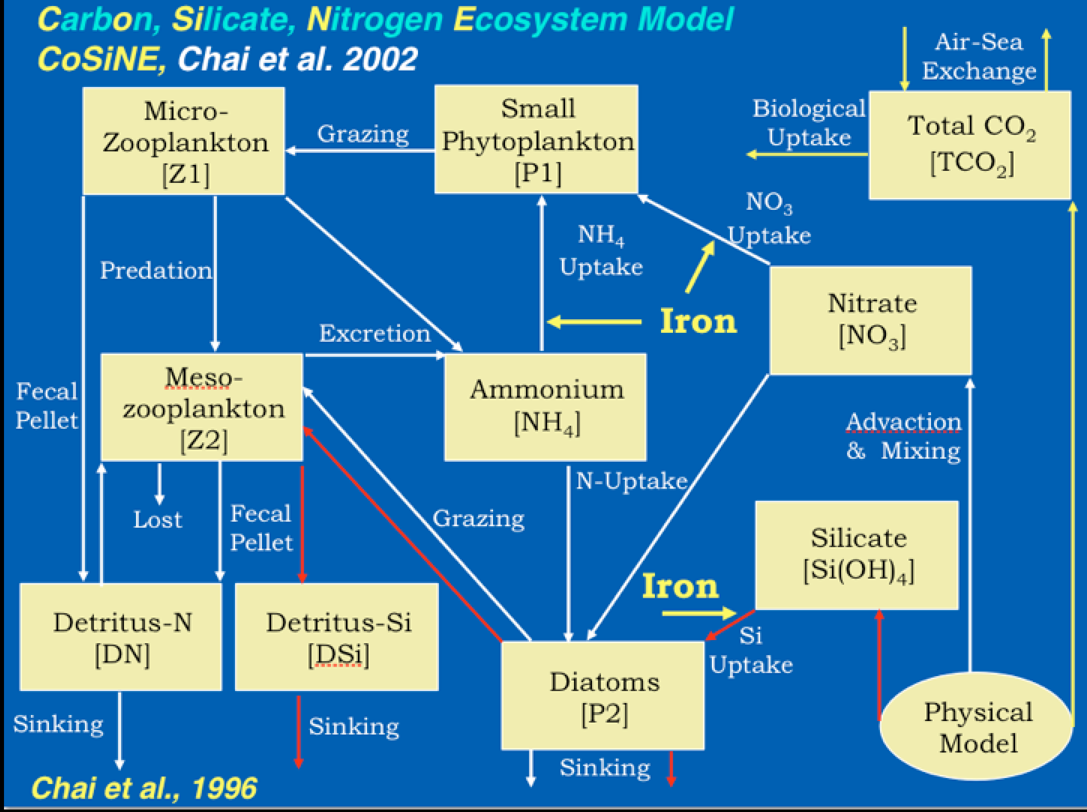
Physical-Biogeochemical Modeling ROMS-CoSiNE

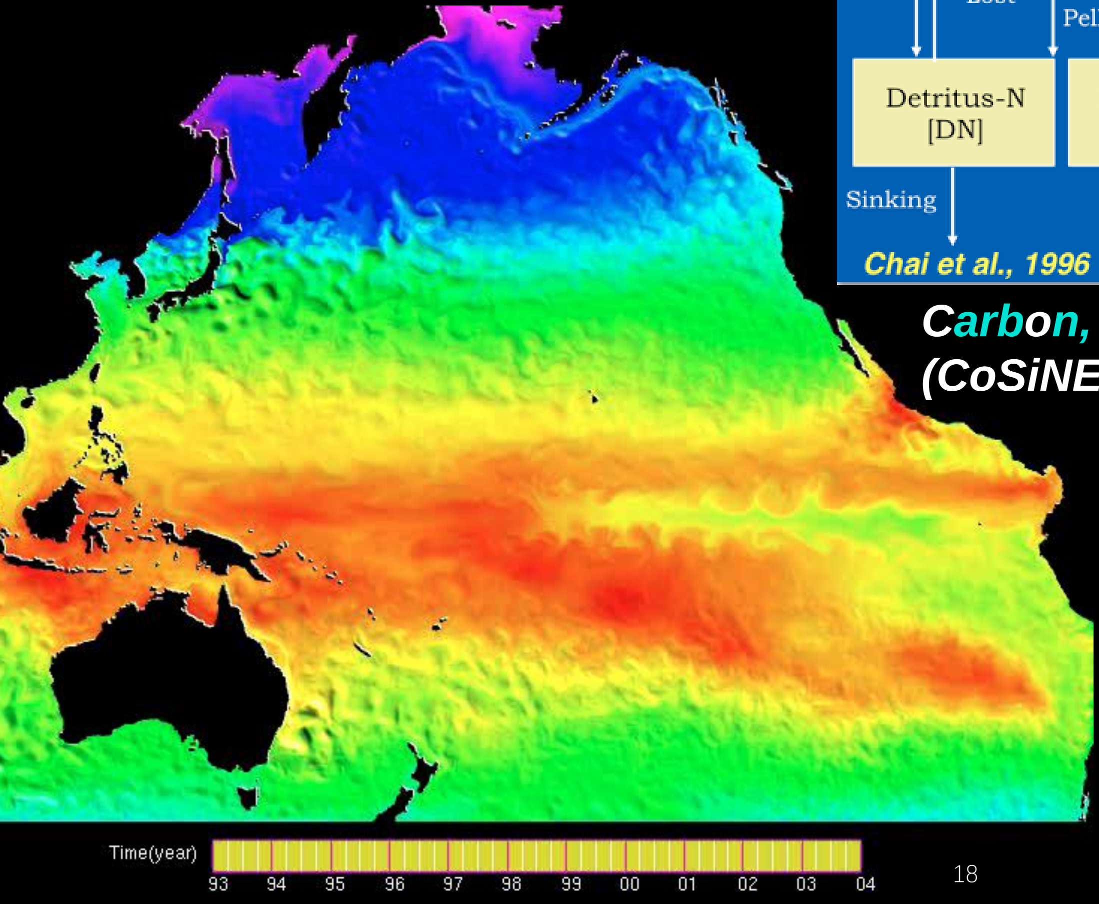
Regional Ocean Model System (ROMS)

Carbon, Silicate, Nitrogen Ecosystem Model (CoSiNE)

1/8 deg. (7-12km), 1/2 deg. (50km)

1991-2017, 1958-2017





Carbon, Silicate, Nitrogen Ecosystem Model (CoSiNE-13)

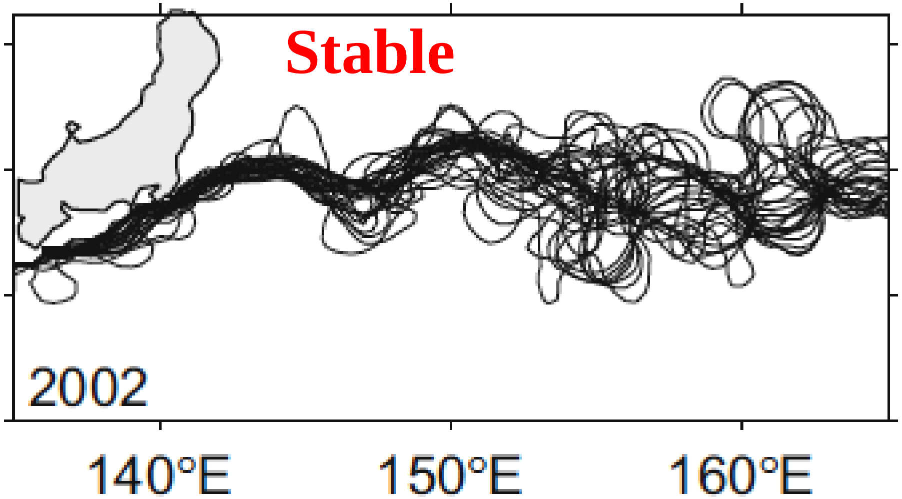
(Chai et al., 2002, 2003, 2007, 2009; Fujii and Chai, 2007; Liu and Chai, 2009; Xiu and Chai, 2011, Palacz et al., 2011, Xu et al., 2013, Xiu and Chai, 2013, 2014, Guo et al., 2014; 2015; Zhou et al., 2017; Liu et al, 2018)

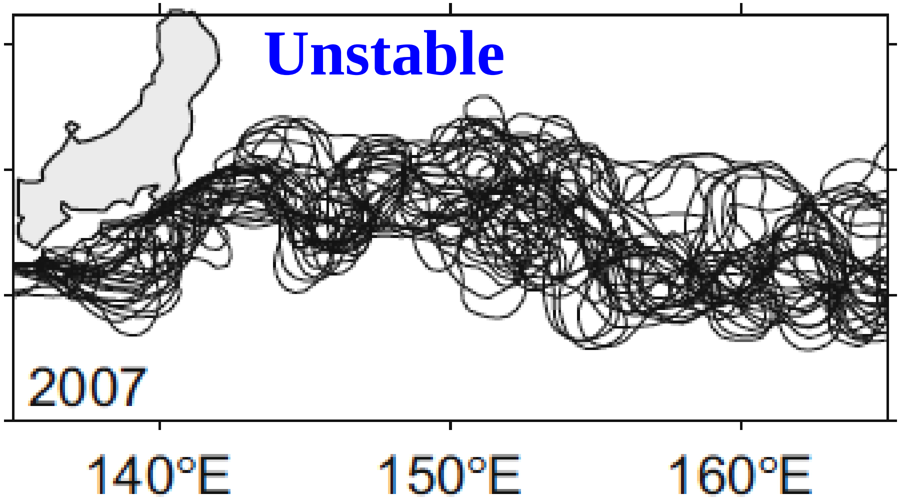
Two Stories

#1: Remote impact on decadal variability of nutrients and biomass in the Kuroshio Extension
(Lin and Chai et al., 2014, Lin and Chai et al., submitting)

#2: Long-Term Trend of Oceanic Surface Carbon in the Northwestern Pacific Ocean from 1958 to 2017
(Xiu and Chai, 2014; Ji and Chai et al., submitting)

Stable and Unstable State of Kuroshio Extension (KE)





KE intense and northerly zonal mean path and a well-defined southern recirculation gyre.

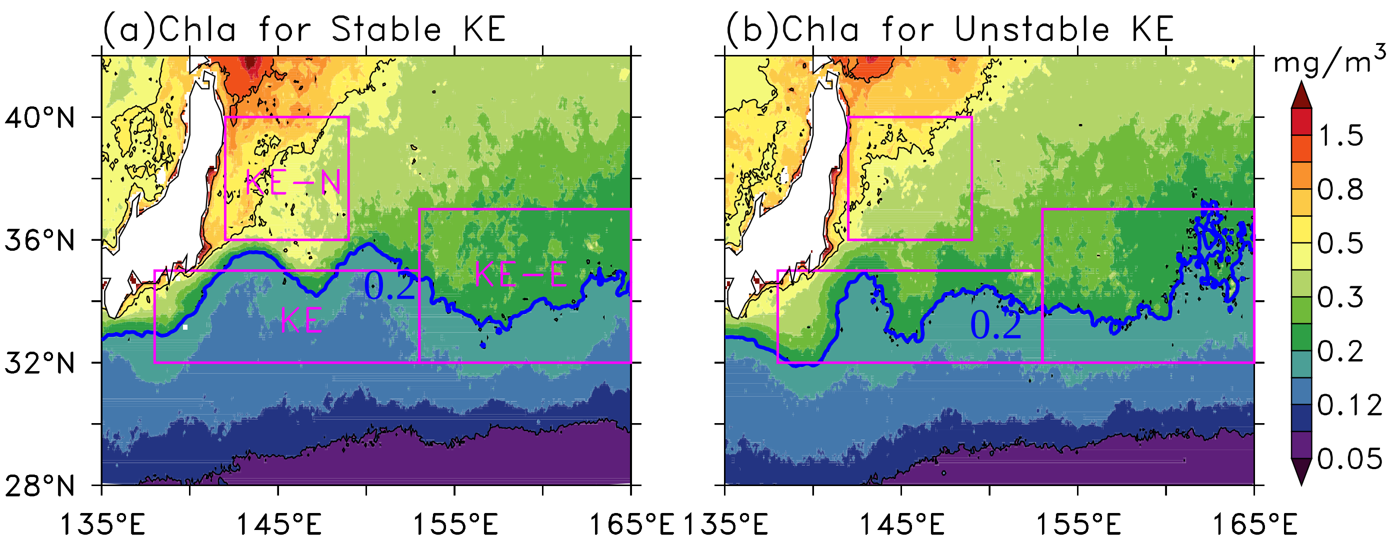
Periods: 10/1992–06/1995, 01/2002-12/2004, 2011-2016

KE jet had a reduced eastward transport and a more southerly flow path.

Periods: 07/1995–12/2001, 01/2005-12/2009

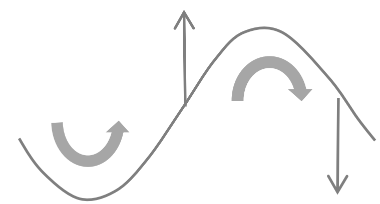
Qiu and Chen 2010; Qiu et al, 2018

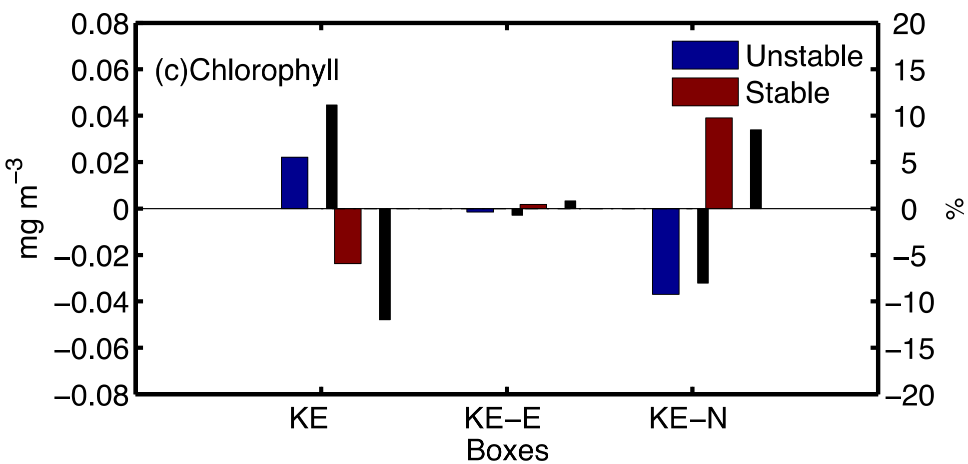
Chl interannual and decadal variation in KE



Rossby Waves

3-4 yr lag



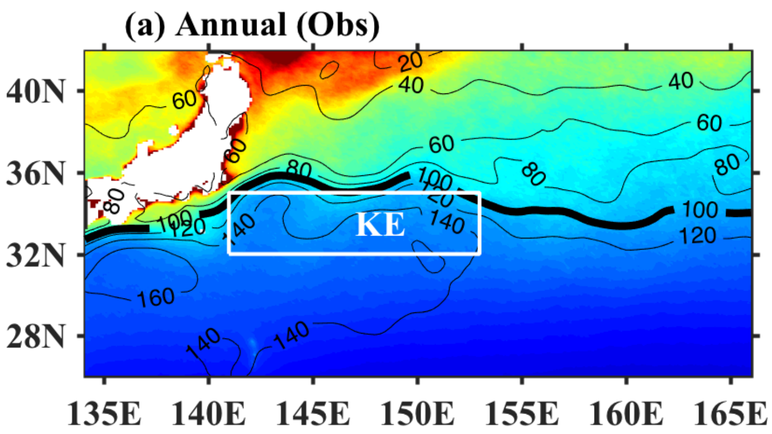


Chl decreased as KE is stable

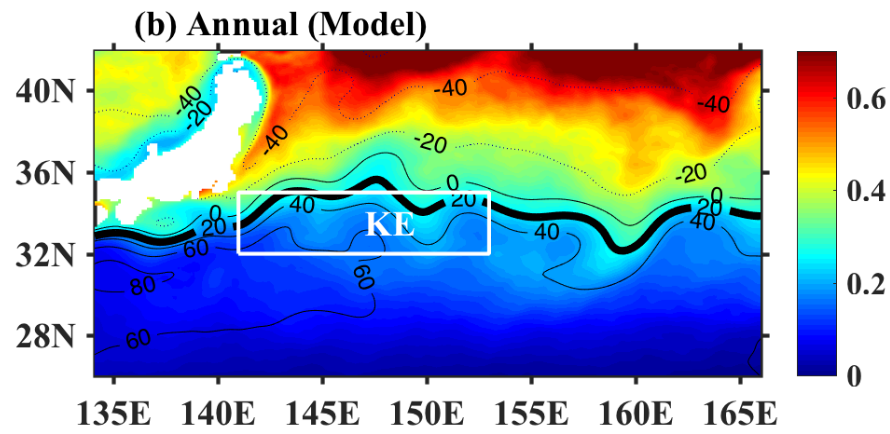
Lin and Chai et al., JGR-Oceans, 2014

Evaluation (ROMS-CoSiNE Model)

Annual Chl (color) and SSHA (contour)



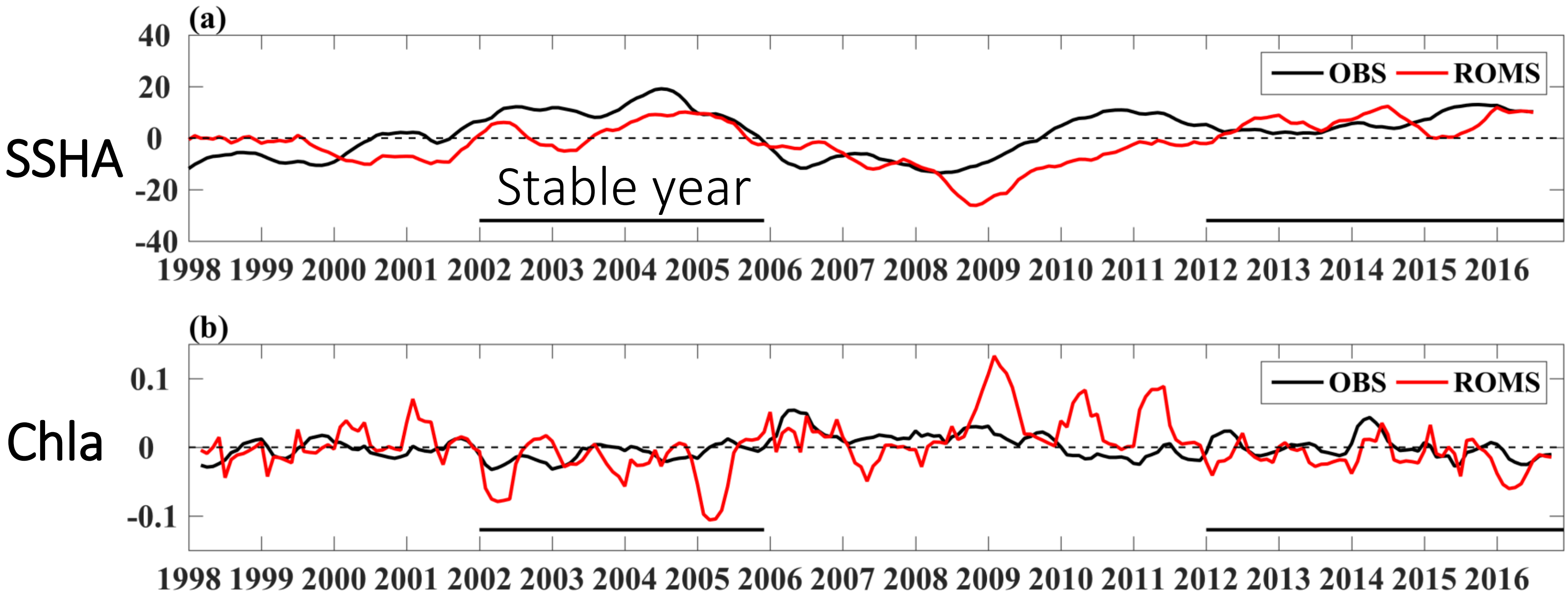
Observations



Model Results

The ROMS-CoSiNE model can capture the main surface Chl and SSH/SSHA features as observed

Decadal variation of SSHA and Chla in the KE region

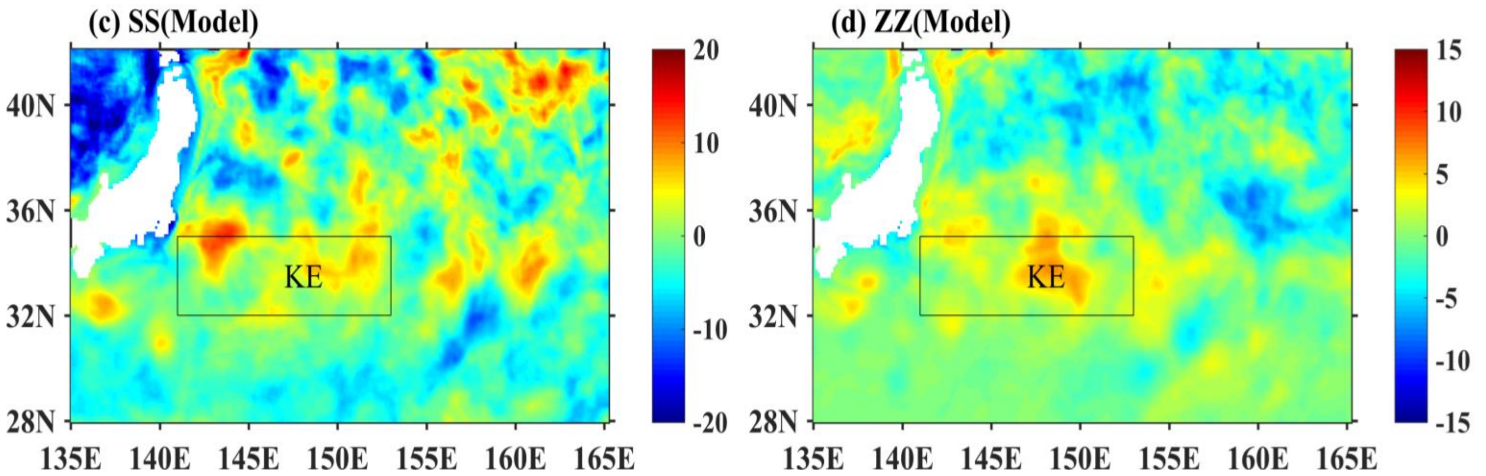


Corr $_{chl}$ = 0.53

ROMS-CoSiNE can also simulate the interannual/decadal variation of Chl

Modeled phytoplankton and zooplankton biomass changes

unstable - stable



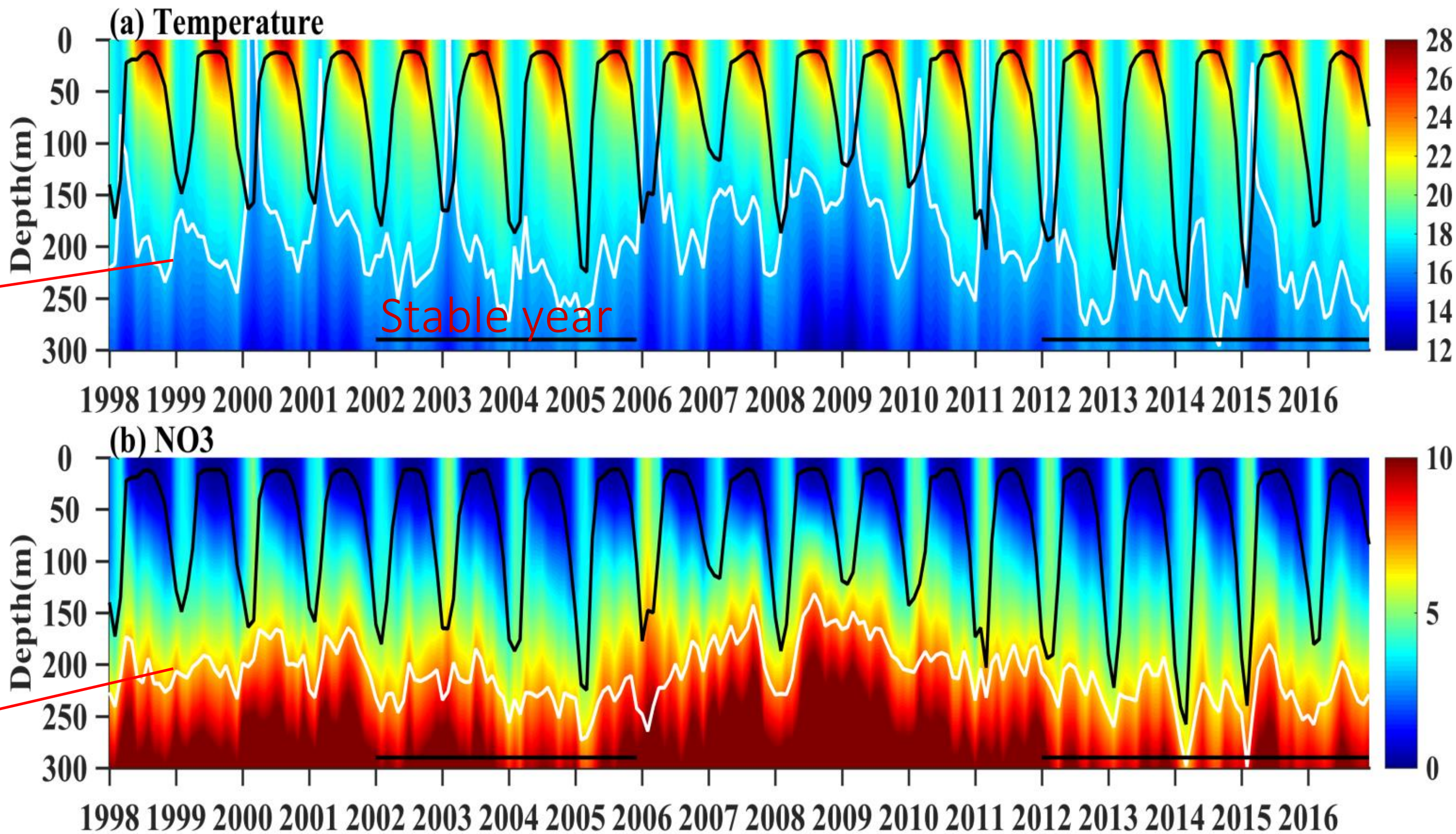
Upper 100m phytoplankton

Upper 100m zooplankton

Themocline and nutricline detph

Temperature

D17



NO_3

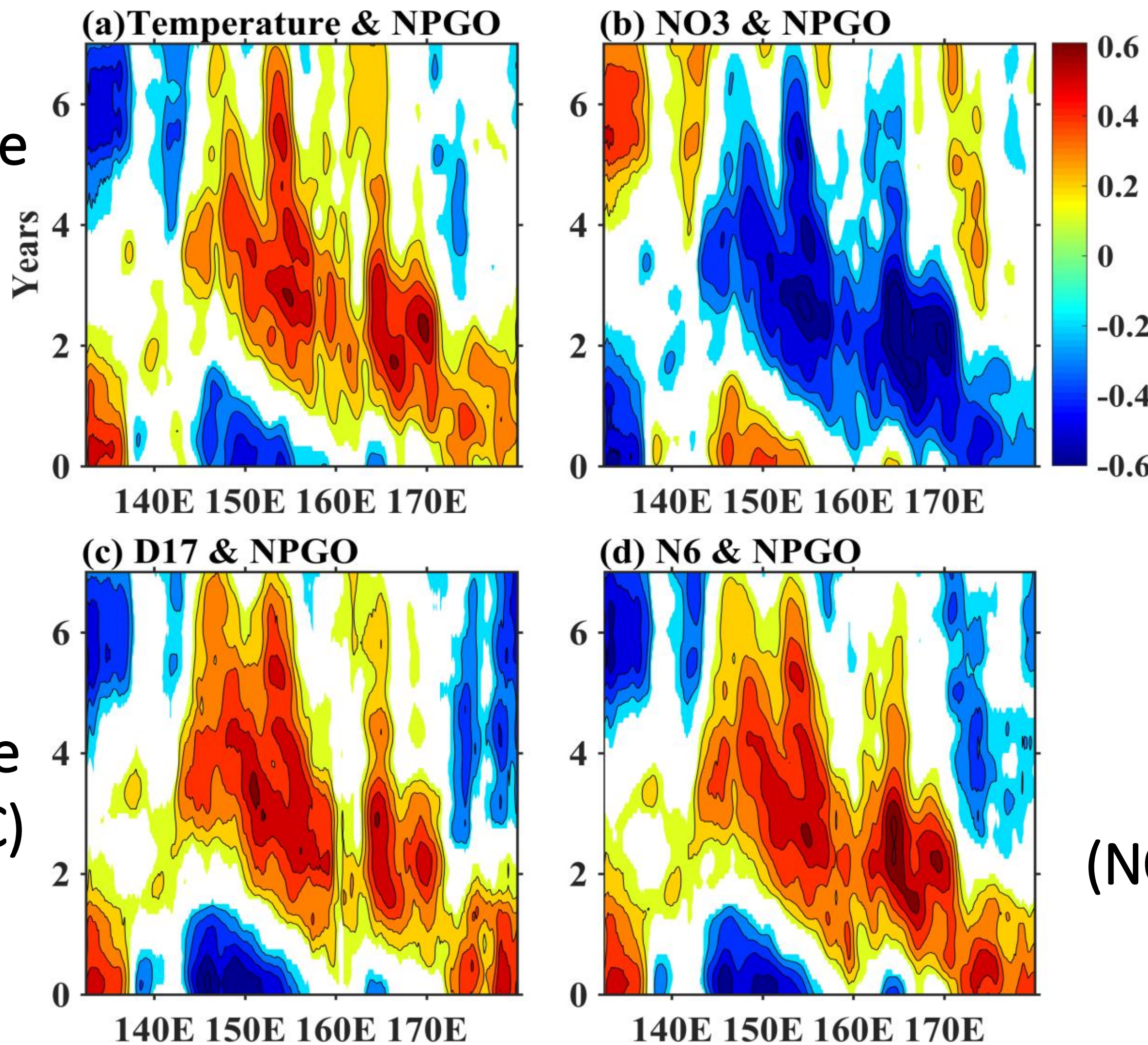
N6

Black line: mixed layer depth (MLD)

Lead correlation by NPGO

Temperature at 200m

NO$_3$ at 200m

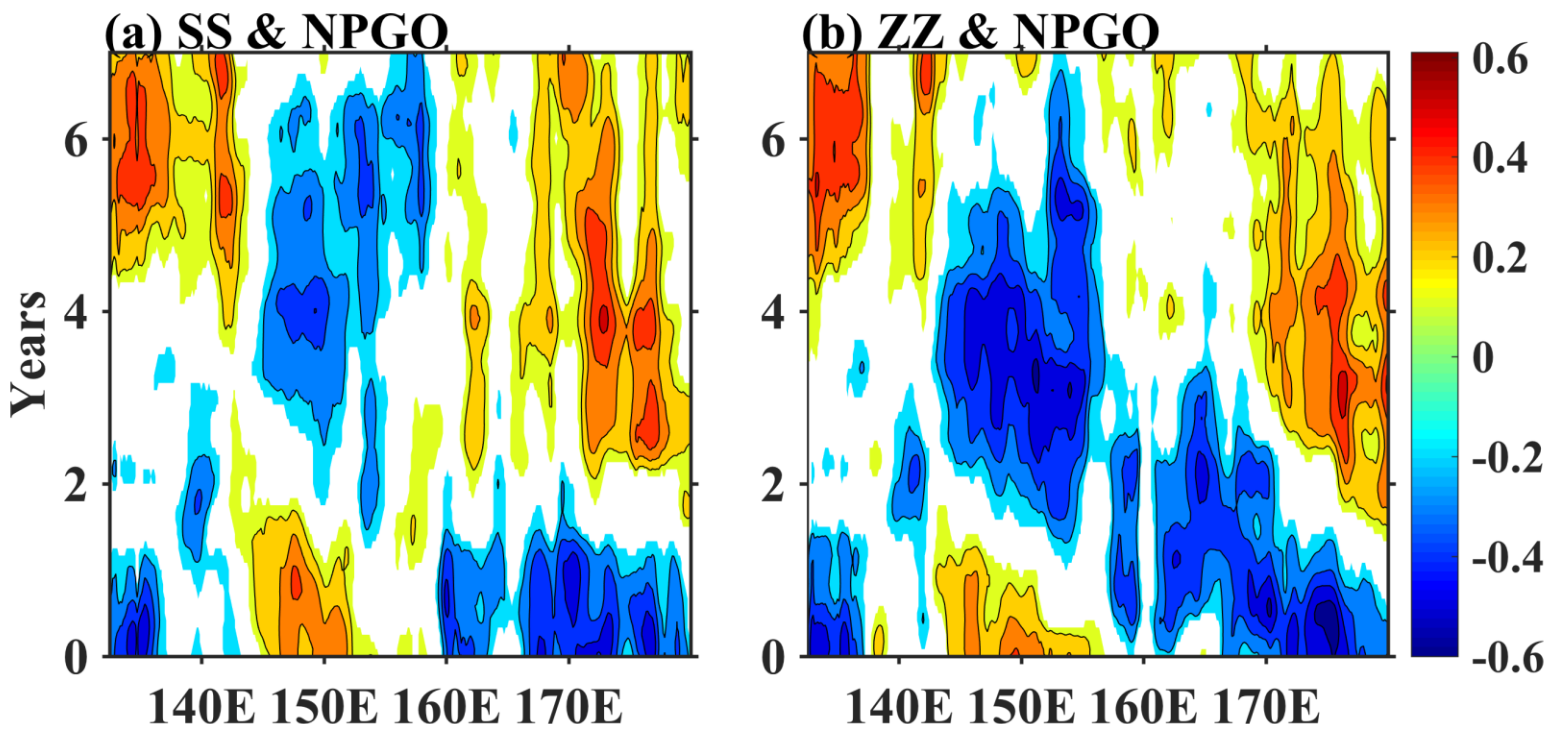


Thermocline Depth (17^{o}C)

Nutricline Depth (NO_3=6 mmol/m^3)

Correlations with subsurface variables are higher and more coherent at zonal direction than that at surface

Lead correlation by NPGO



Upper 100m phytoplankton

Upper 100m zooplankton

Correlation is higher and more coherent at zonal direction for zooplankton than phytoplankton

Summary for story #1

- Interannual variation of biological processes in KE region are influenced by the remote perturbations, not the local winds.
- The remote modulation of NPGO not only impacts on the surface but also the thermocline or nutricline depth.
- During stable (unstable) years, thermocline deepen (lift), upper layer nutrients decrease (increase), result in plankton biomass decrease (increase).
- One possibility is to predict the interannual/decadal variation of plankton biomass in the KE using NPGO index.

Two Stories

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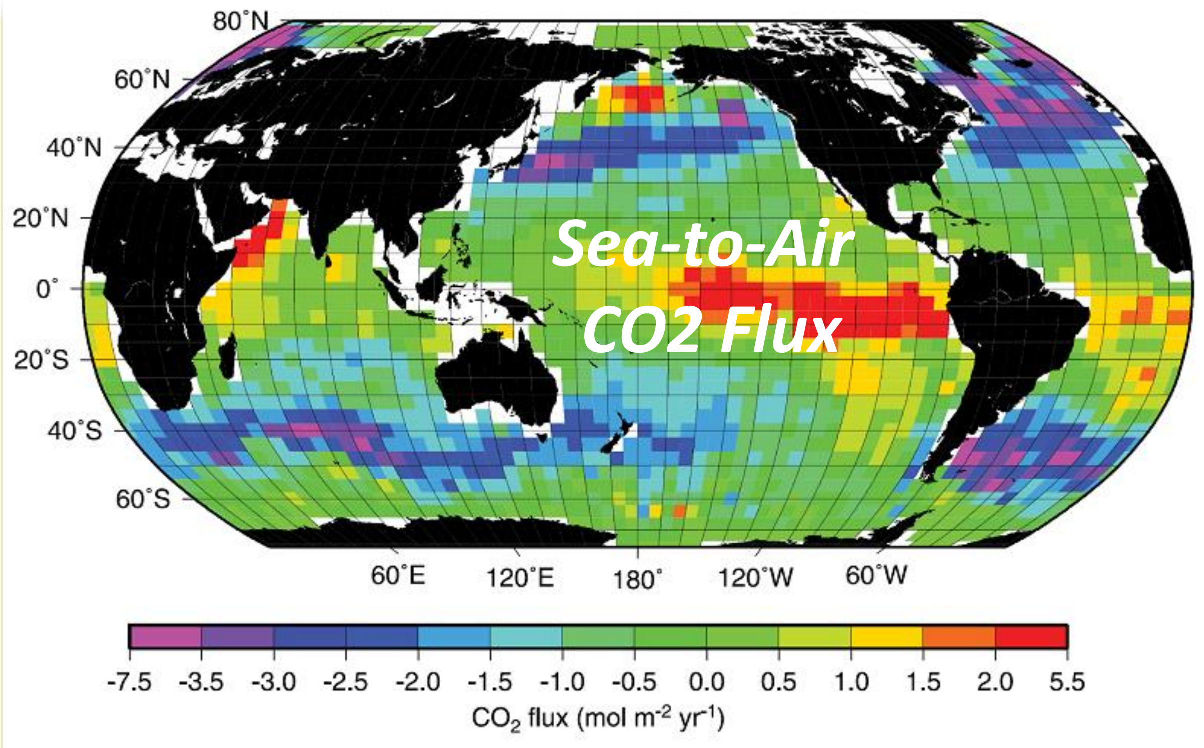
#2: Long-Term Trend of Oceanic Surface Carbon in the Northwestern Pacific Ocean from 1958 to 2017
(Xiu and Chai, 2014; Ji and Chai et al., submitting)

Fate of anthropogenic CO_2 emissions (2005-2014 average)

8.6±0.4 GtC/yr 92%



Sources **+**

of all other flux components

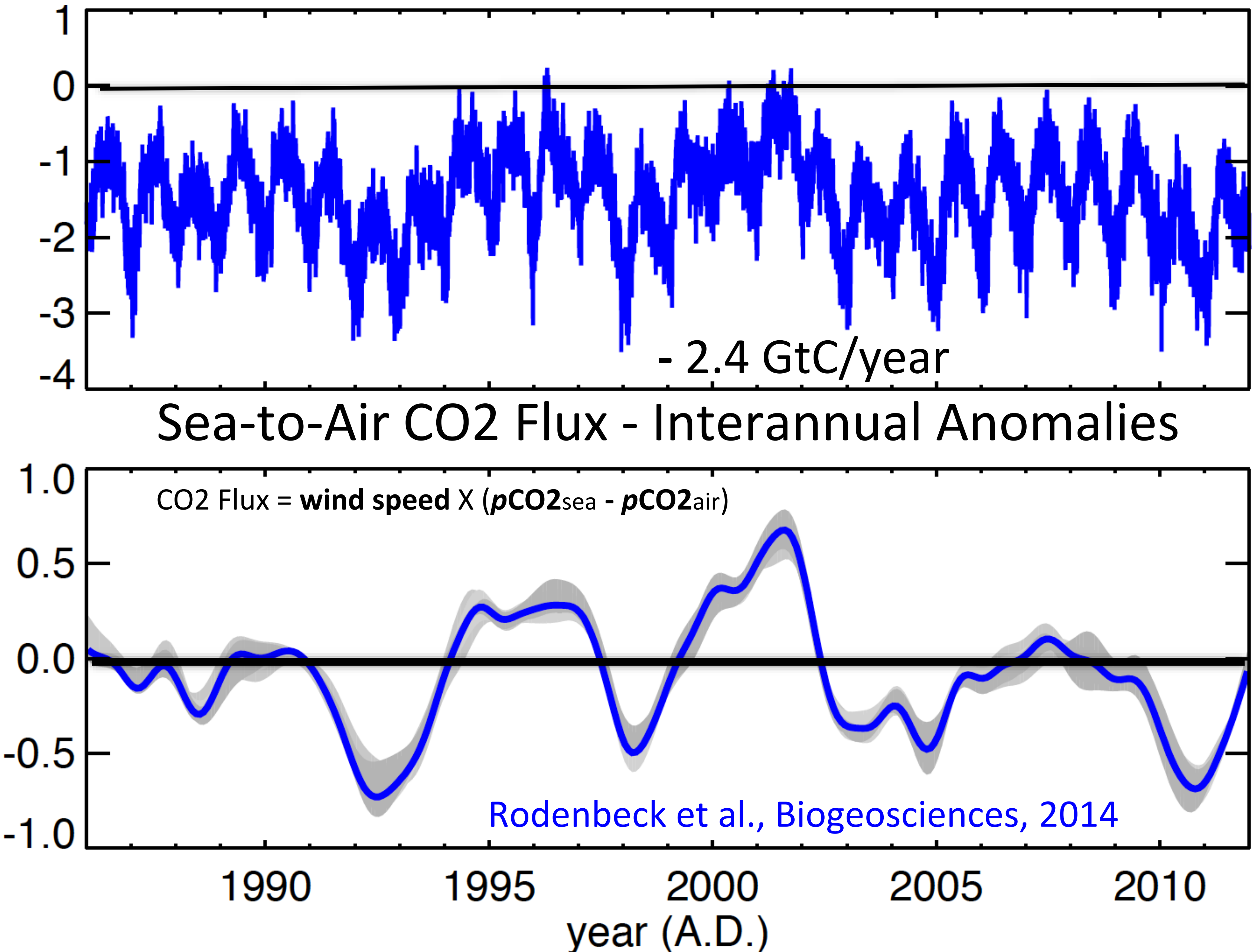
0.8±0.5 GtC/yr 8%

28%

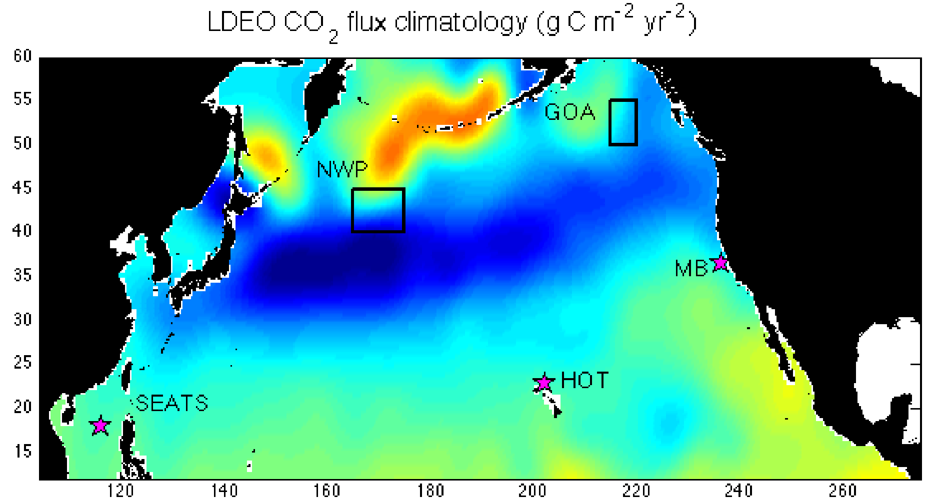
2.6±0.8 GtC/yr

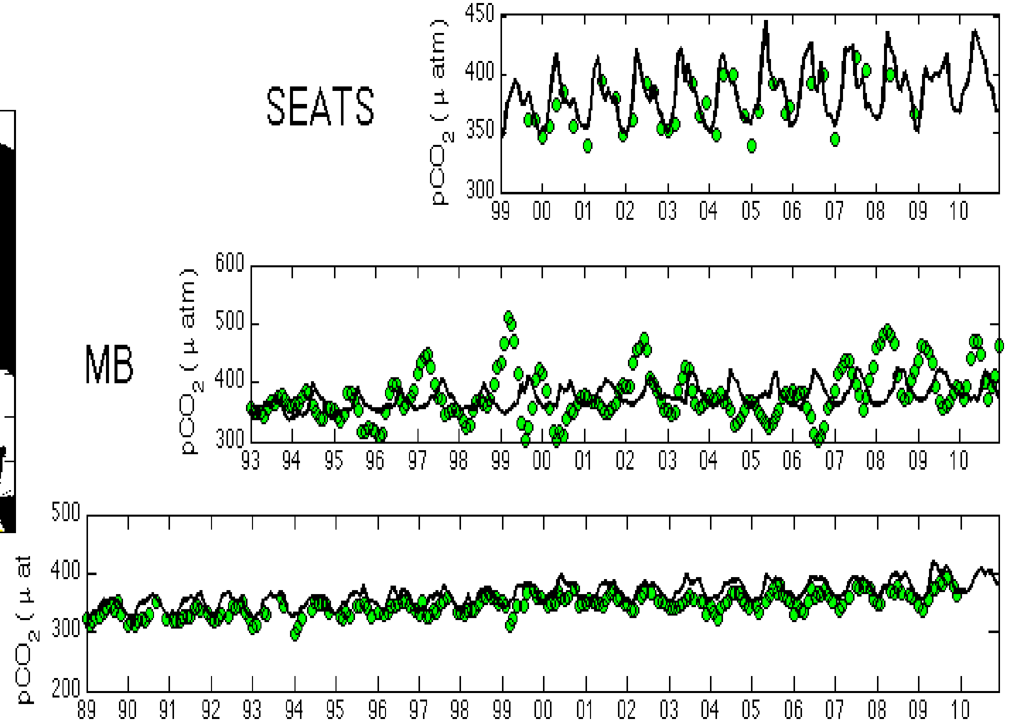
Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2015; Global Carbon Budget 2015

Global Sea-to-Air CO2 Flux



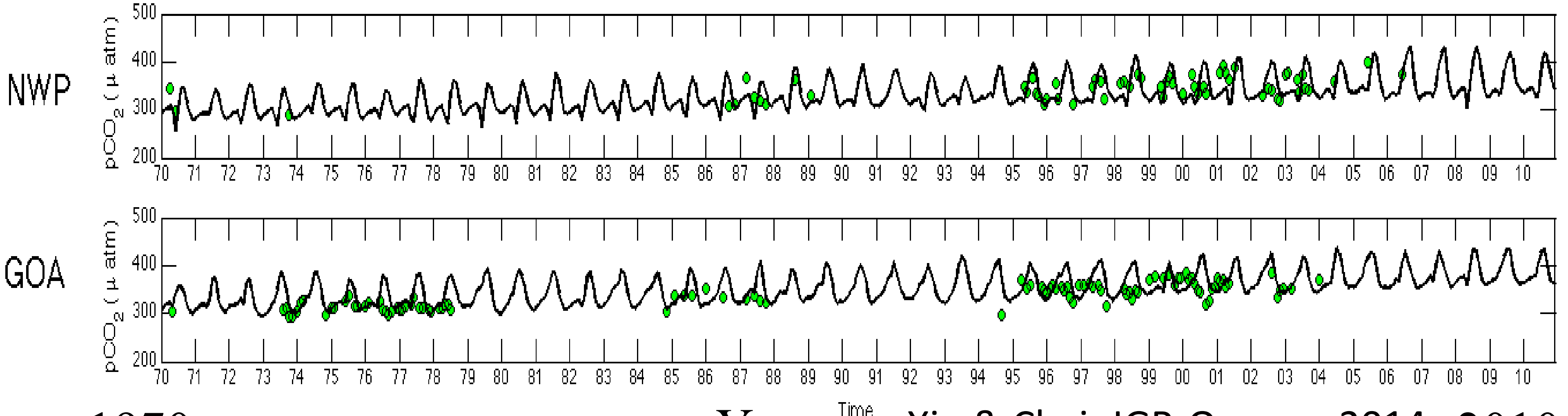
Sea Surface pCO_2





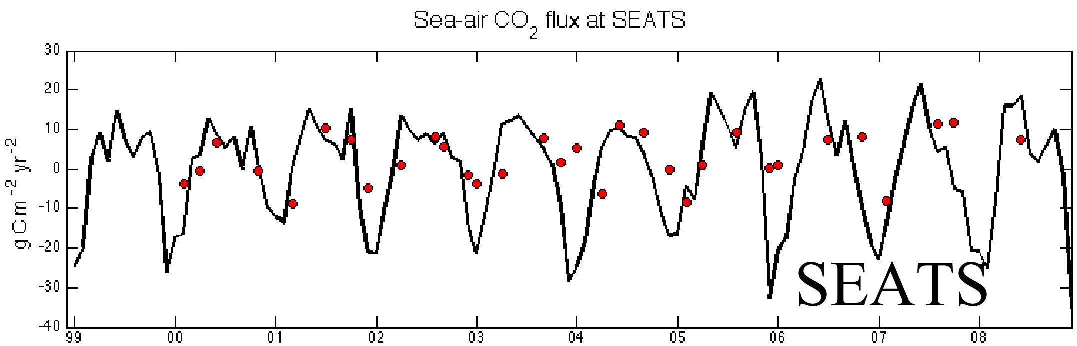
Seasonal cycle is largest

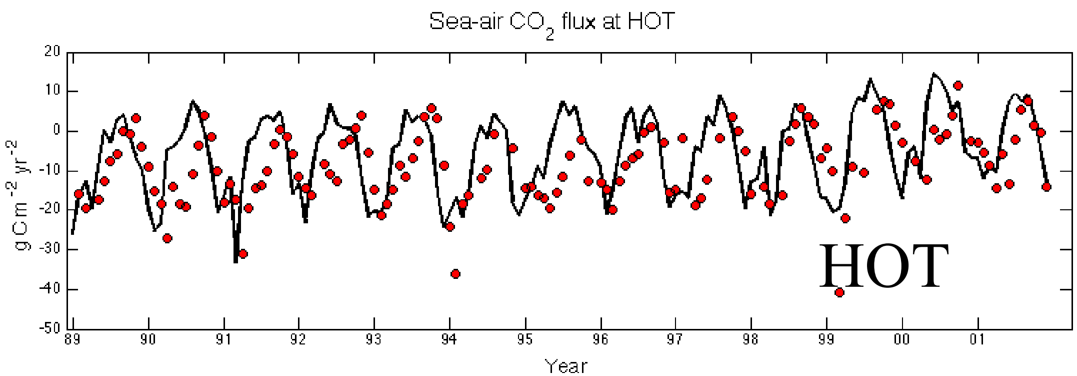
Anthropogenic trend is 1-2 ppm/year

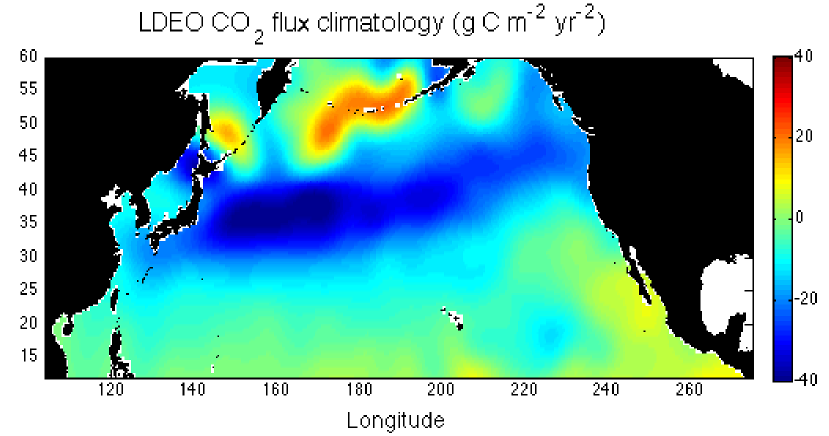


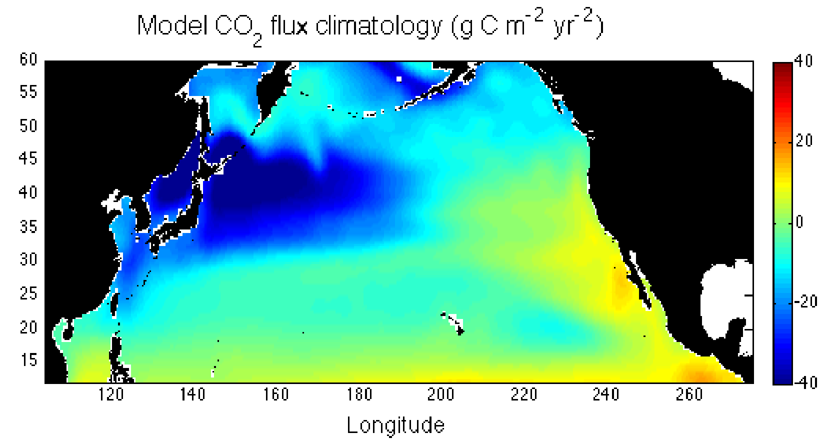
1970 Year Xiu & Chai, JGR-Oceans, 2014 2010

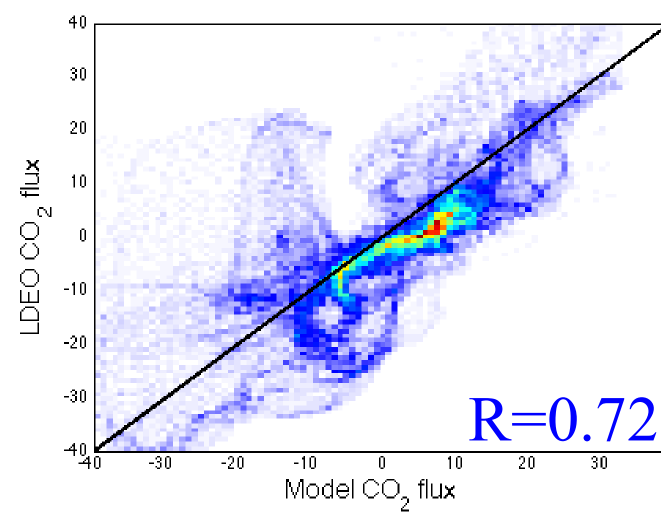
Sea-to-Air CO_2 flux











SEATS: -0.14 g C m^{-2} yr^{-1}

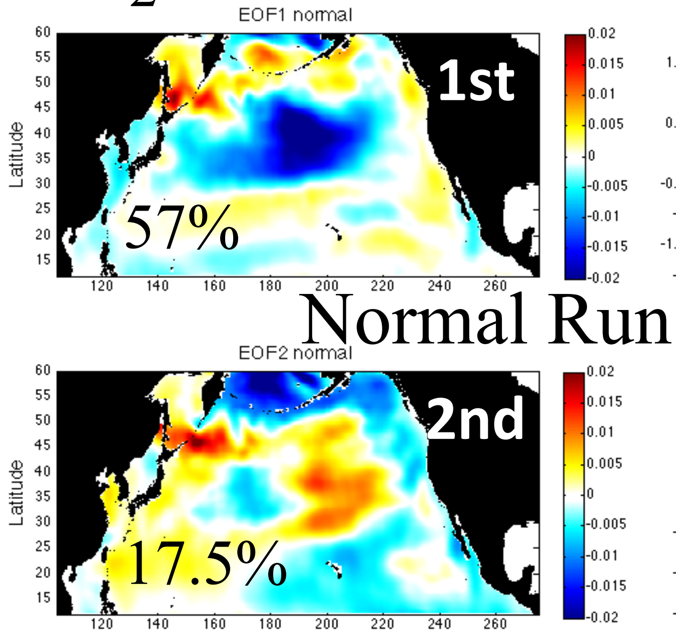
MB: 4.6 g C m^{-2} yr^{-1}

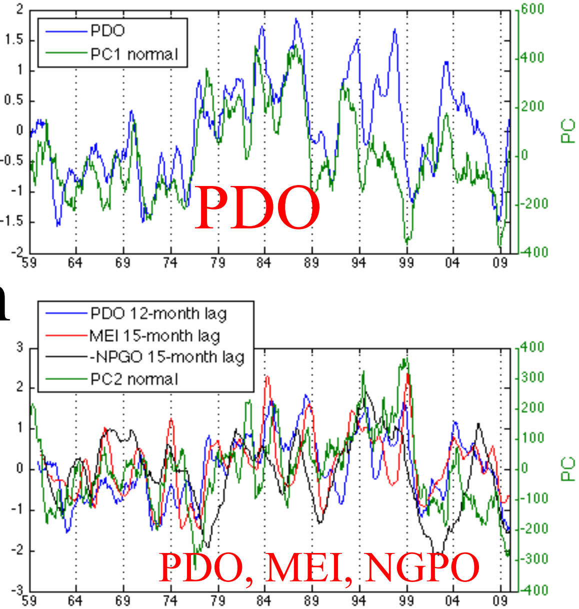
HOT: -5 g C m^{-2} yr^{-1}

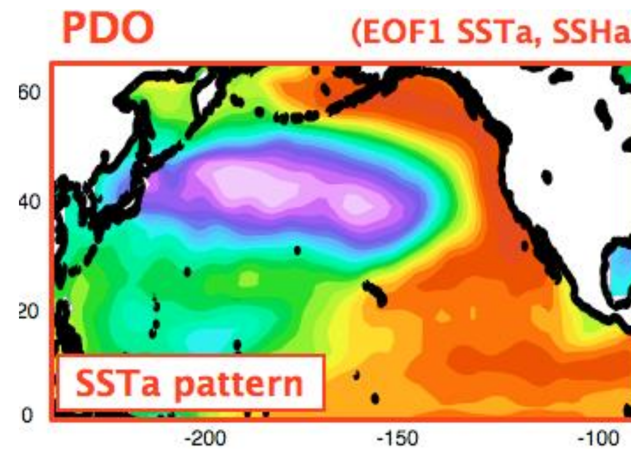
Integrated North PACIFIC (ocean sink):

-0.57 Pg C yr^{-1}

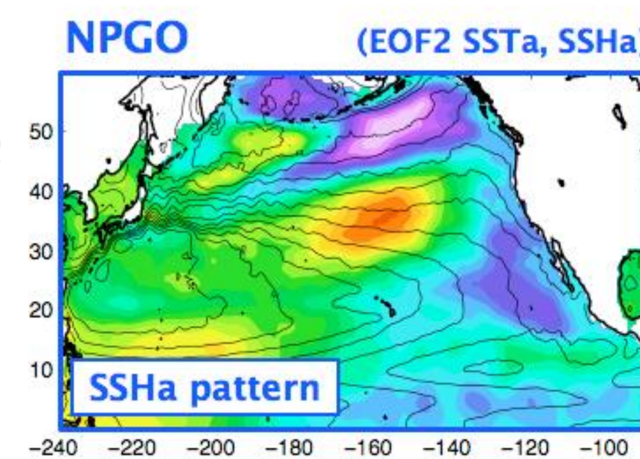
CO_2 flux Interannual and decadal variability







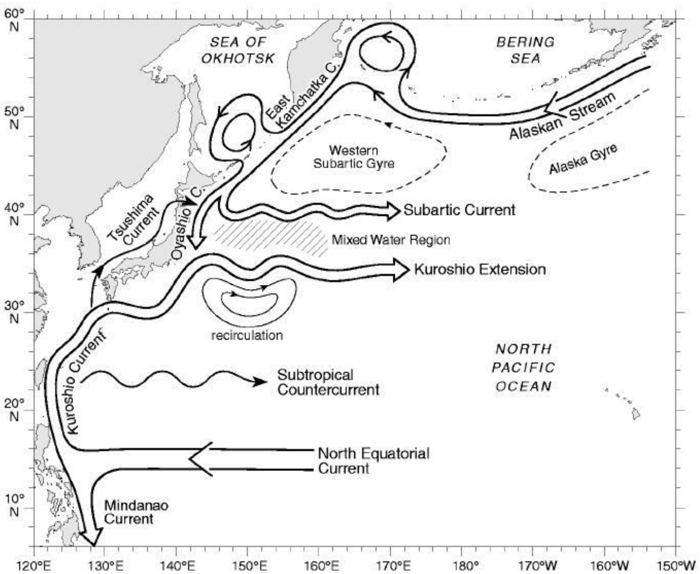
Correlation/Lags	PC1 normal run (**57%** variance)	PC2 normal run (**18%** variance)
PDO	**0.77/0**	**0.62/12**
MEI	**0.53/0**	**0.59/15**
NPGO		**-0.51/15**



Xiu & Chai, JGR-Oceans, 2014

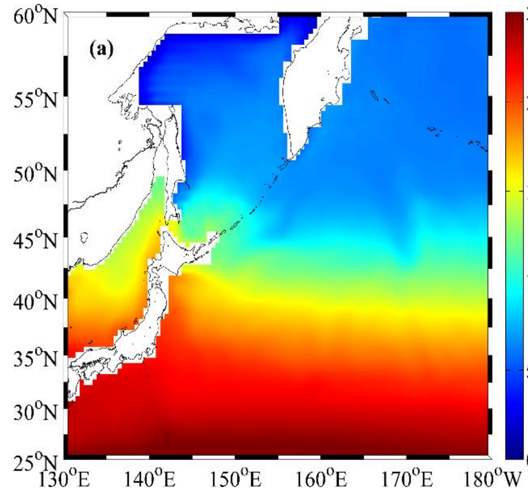
Carbon Cycle in the Northwest Pacific

Complex physical dynamics with various water mass formations;

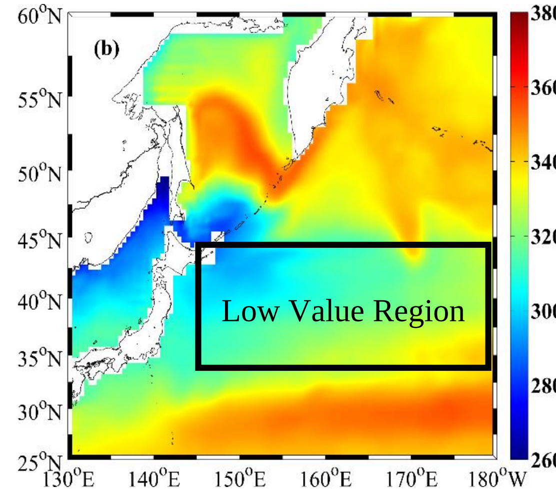


Current systems, Qiu (2001)

Annual SST



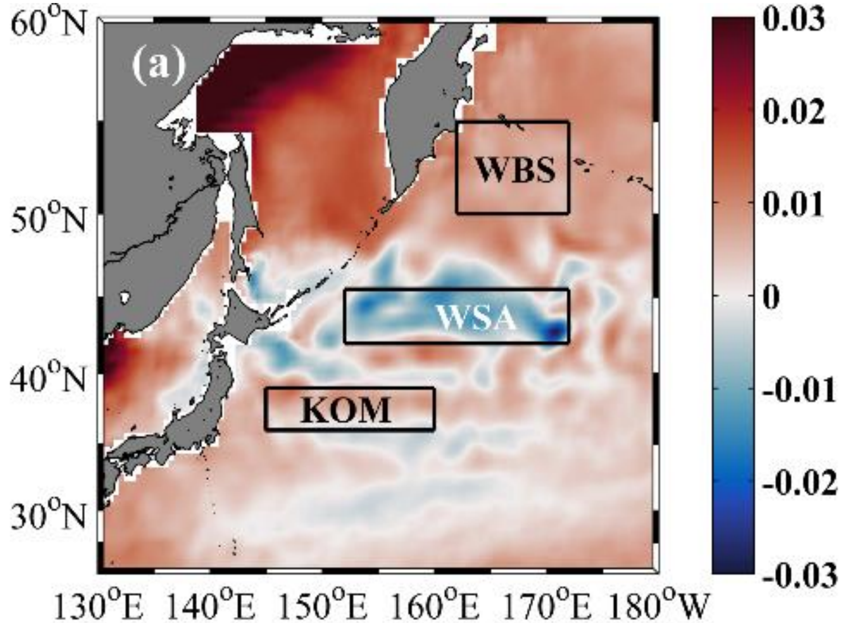
Annual pCO_2



At the annual timescale, the NWP acts an important sink, estimated with a net uptake value of 0.50 Pg-C per year.

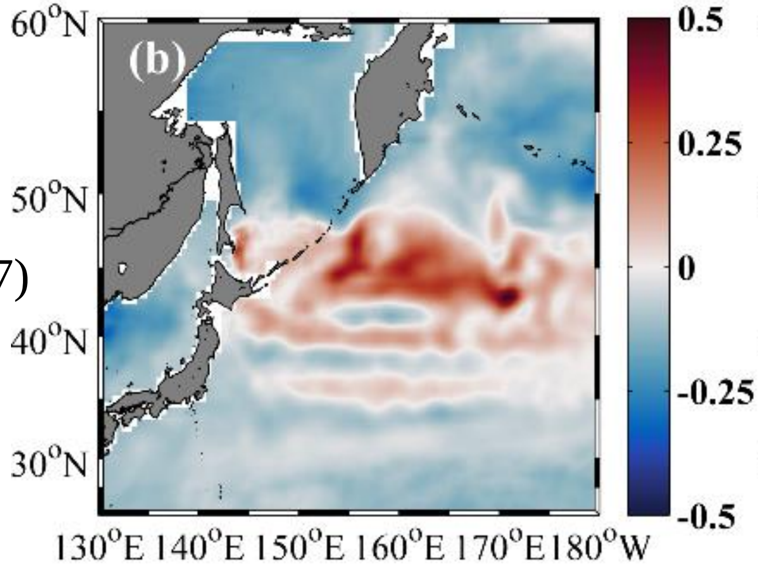
At the seasonal timescale, sink in winter, source in summer (Xiu and Chai, 2014).

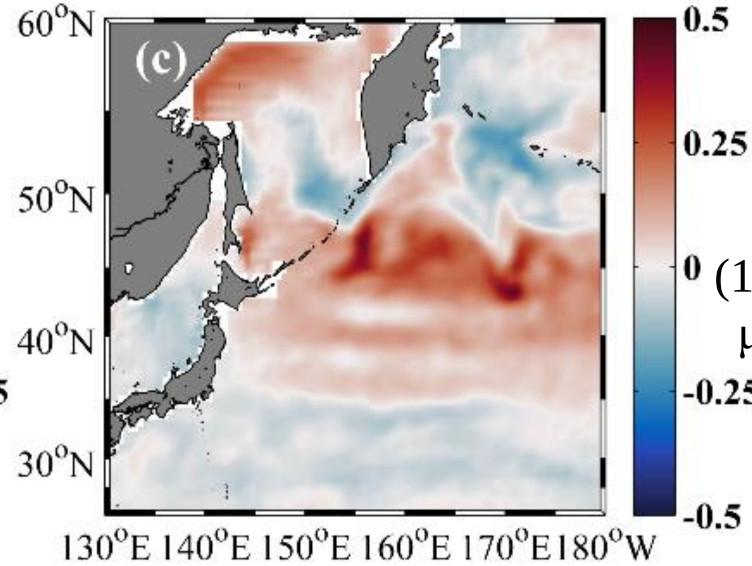
Spatial Distribution of Long-term Trends (SST, TCO_2, and pCO_2)



Rate of
SST change
(1958-2017)
°C/year

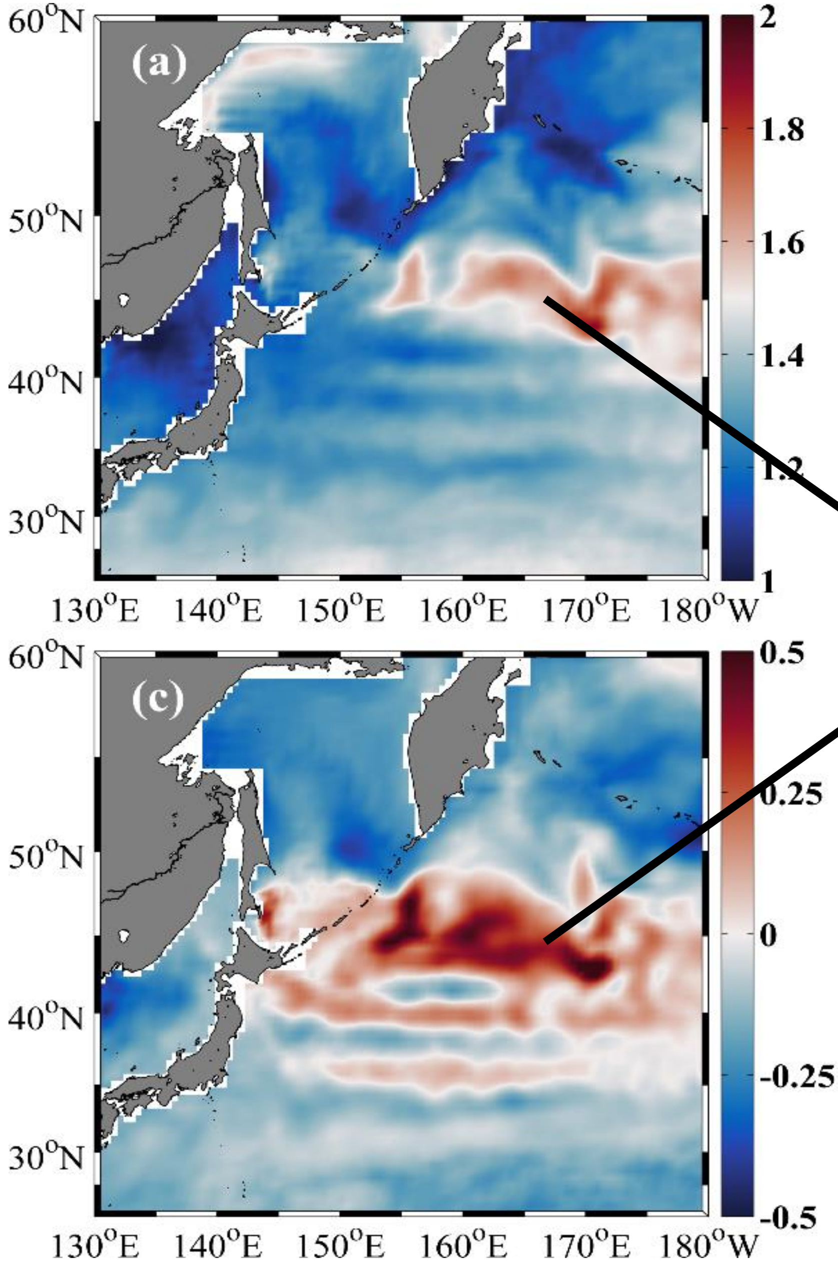
Rate of
TCO_2
change
(1958-2017)
mmol/m^3
/year





Rate of
pCO_2
change
(1958-2017)
µatm/year

SST and TCO2 as drivers for the long-term trend of pCO2 changes



pCO_2 change due to SST change: 6-9%

The largest change is in the Western Subarctic Region

pCO_2 change due to TCO_2 change: 85-88%

Summary for story #2

- At seasonal time scale, temperature plays a key role in determining surface pCO_2, biological processes modulate carbon cycle in upper ocean
- Interannual variation of pCO_2 and air-sea CO_2 flux in the Northwest Pacific Ocean are closely controlled by physical processes (PDO, NGPO).
- Temperature decreased in the Western Subarctic region during the past 60 years (1958-2017), but TCO_2 increased which leads to increase of pCO_2.
- The entire Northwestern Pacific Ocean likely will continue to enhance ocean’s uptake of anthropogentic CO_2 due to global warming.

BGC-Argo Observations and Physical-Biogeochemical Modeling

Prof. Fei CHAI (柴扉）
Second Institute of Oceanography, China
University of Maine, USA

- BGC-Argo development (International and China)
- Two examples of using BGC-Argo
- Physical-Biogeochemical modeling – two stories

1. BGC-Argo provide key information for physical and biogoechemical processes, especially on meso-scale and event-scale
2. Combining remote sensing, BGC-Argo, and physical-biogeochemical modeling provide 4-dimensional state estimates of marine ecosystems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