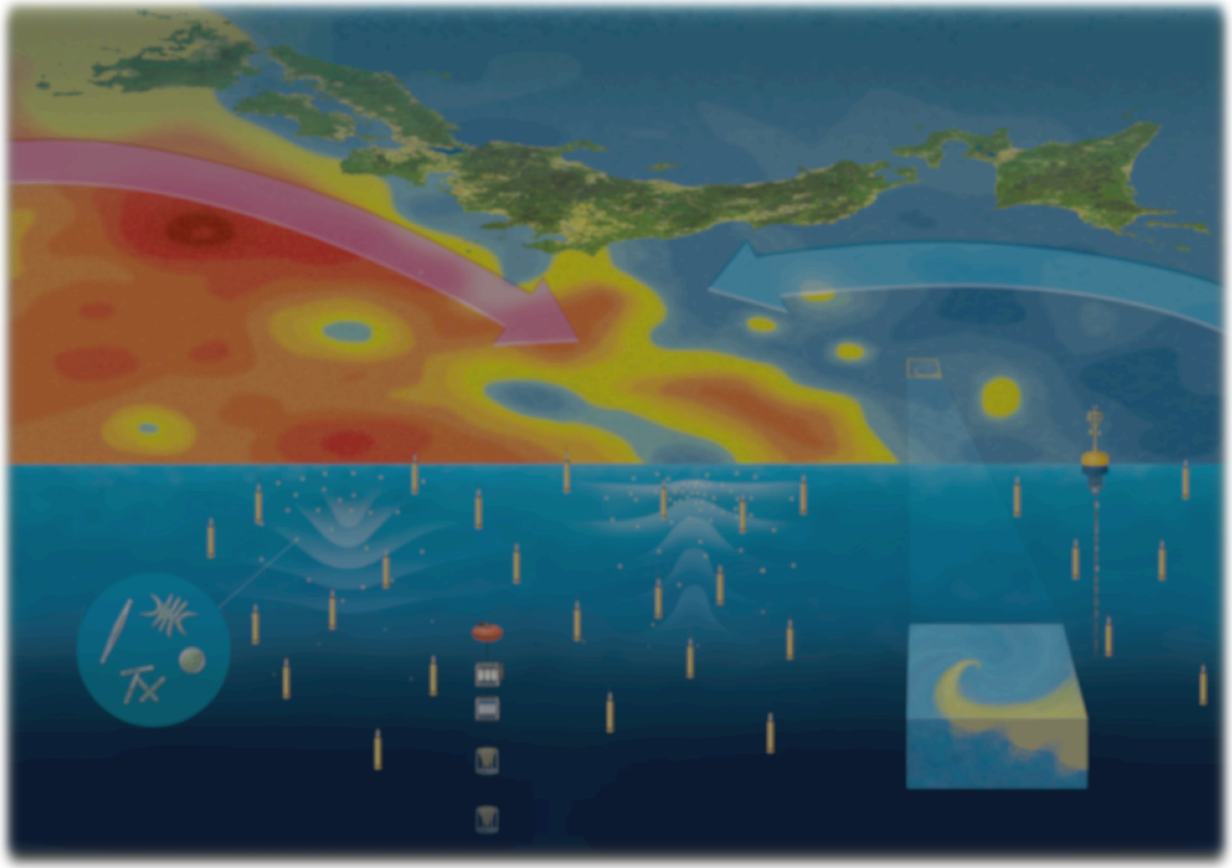
Biogeochemical processes observed in the Kuroshio recirculation gyre



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Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Objective of this talk

Introducing recent JAMSTEC's studies in the Kuroshio recirculation gyre

- S1 biogeochemical mooring (30^{o}N, 145^{o}E, oligotrophic condition) with shipboard measurements; 4 years conducted by Dr. Honda
- S1-INBOX (Western North Pacific Integrated Physical-Biogeochemical Ocean Observation Experiment, DO floats); summer 2011
- SeaGlider survey in 2014 Feb-May; 4 months in winter
- JAMSTEC's contribution to BGC Argo program

S1 mooring and shipboard surveys
February2010 →

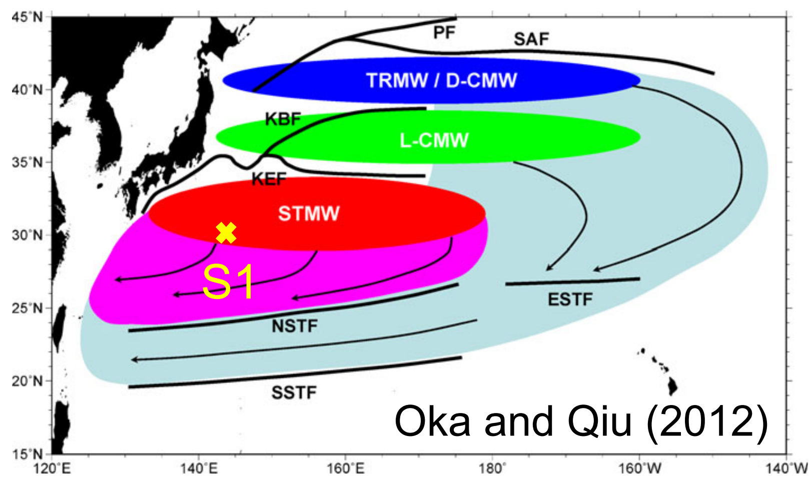
S1-INBOX (DO-floats)
July2011 →

SeaGlider
February 2014 →

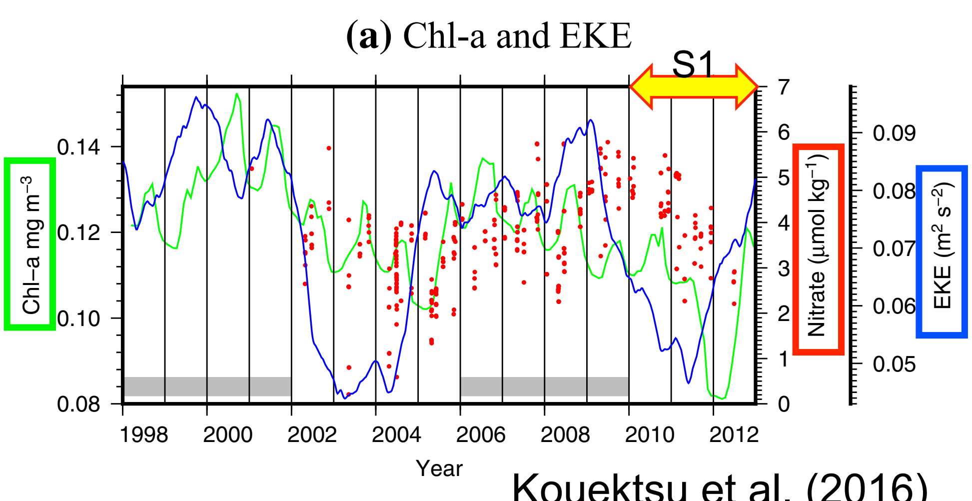
BGC Argo
April 2017 →

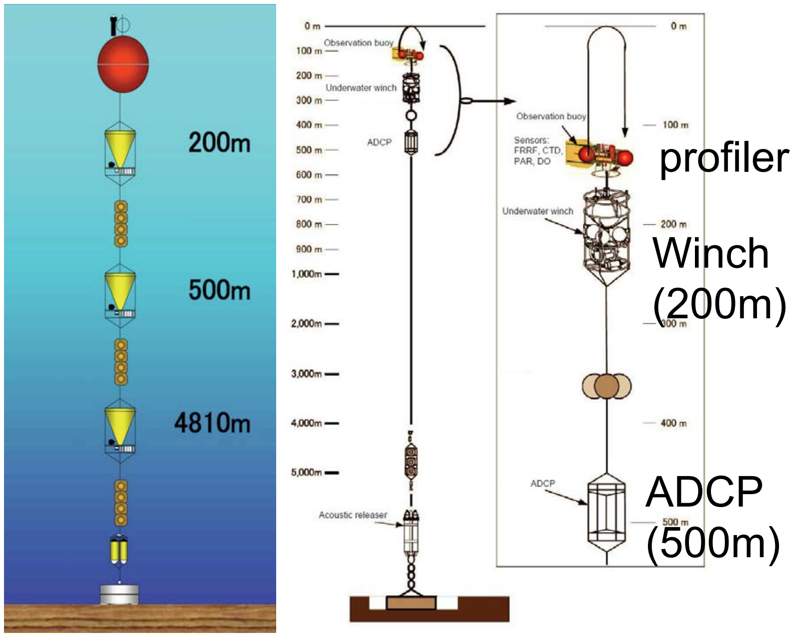
Analyzing data with **satellite products** (large spatial and temporal coverage)

S1 mooring: 2010 February - 2014 June



- S1 mooring: 30ºN, 145ºE
- Southern part of the Kuroshio recirculation gyre

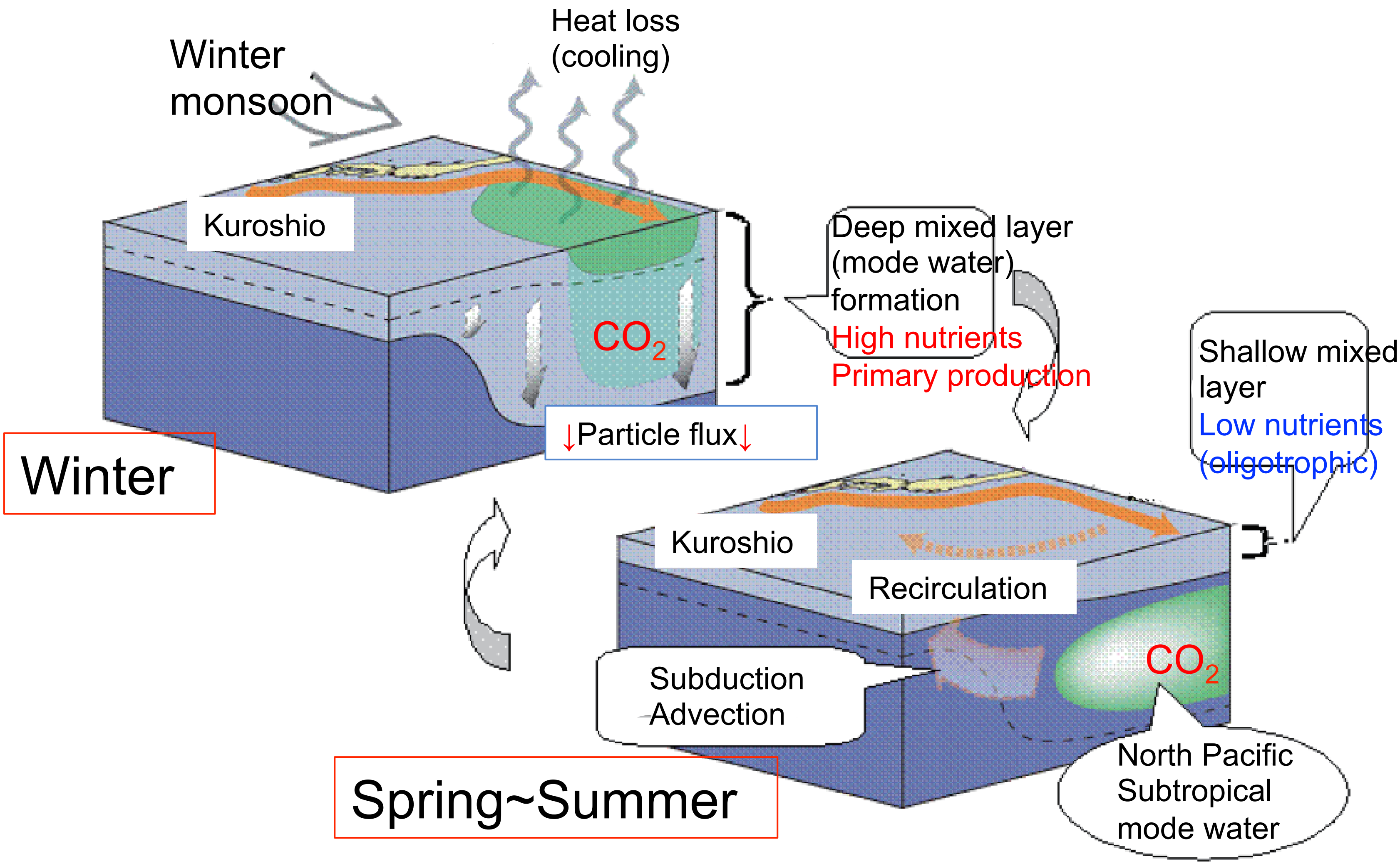




- Two moorings: Sediment trap and underwater buoy mooring
- Profiler was equipped with FRRF, PAR, CTD and DO

- S1 mooring was conducted when the Kuroshio was relatively stable
- Mixed layer was relatively deep in this period (not shown)

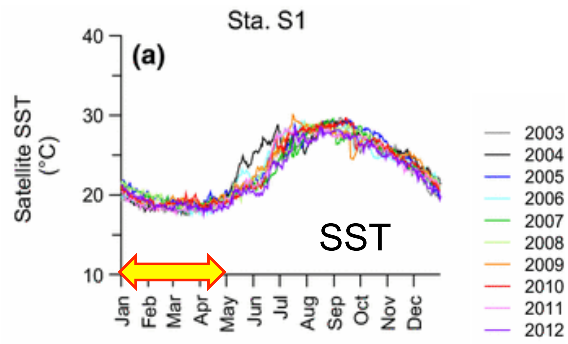
Schematic view of Kuroshio recirculation gyre: Mode water and carbon sink

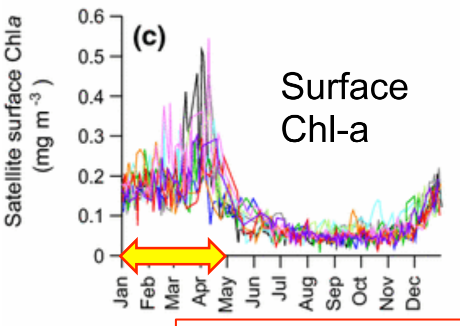


Biogeochemical <=> Physical processes

Figure is adapted from Japan Meteorology Agency web site

Seasonal variability at S1 mooring site: shipboard measurements





Fujiki et al. (2016)

Satellite data at S1

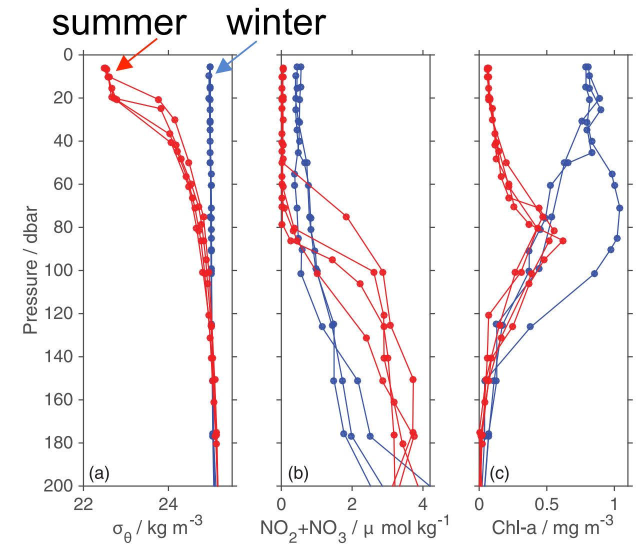
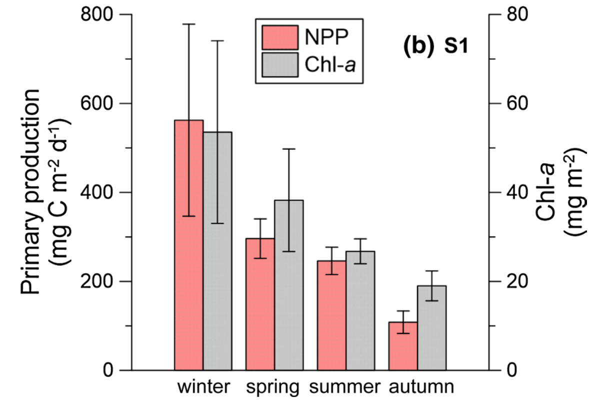


Figure 3. Vertical profiles of (a) potential density, σ_θ, (b) nutrients (nitrate and nitrite), and (c) chlorophyll *a* during MR11-02 (winter, blue lines) and MR 11-05 (summer, red lines) (see Table 1 for dates).

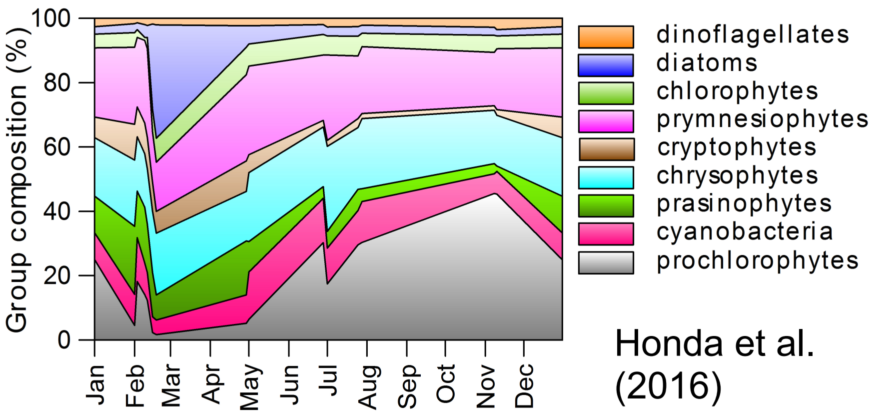
CTD bottle samples

Inoue et al.(2016)



Matsumoto et al. (2016)

Primary production from 24h on-deck incubations

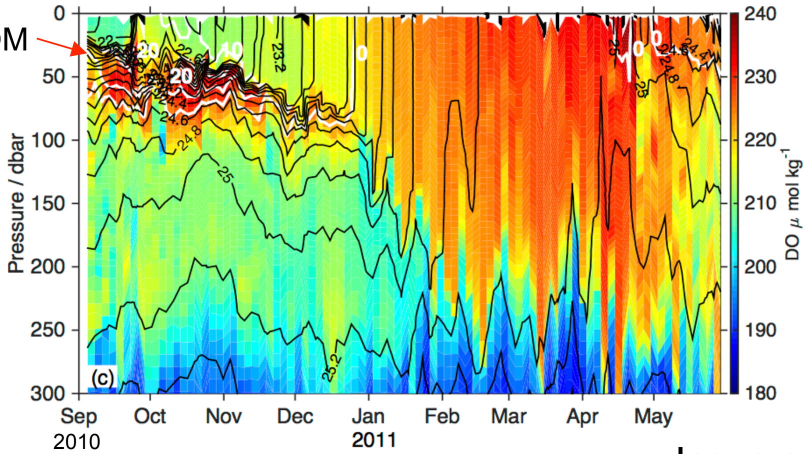


phytoplankton composition (CHEMTAX analysis)

Honda et al. (2016)
Fujiki et al. (2016)

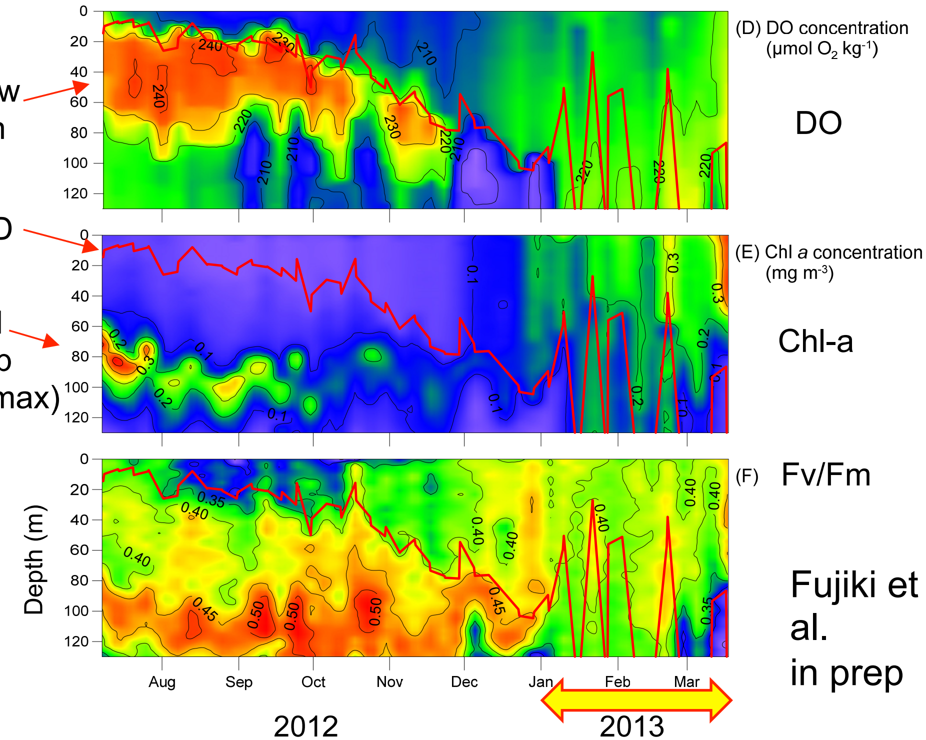
- Deep mixed layer in winter
- Higher nutrients and chl-a, primary production in winter cruises
- Deep chl-a maximum (DCM) at the top of nutrientcline in summer
- Diatoms increased in winter
- *Prochlorococcus* increased in summer

Seasonal variability at S1 mooring site



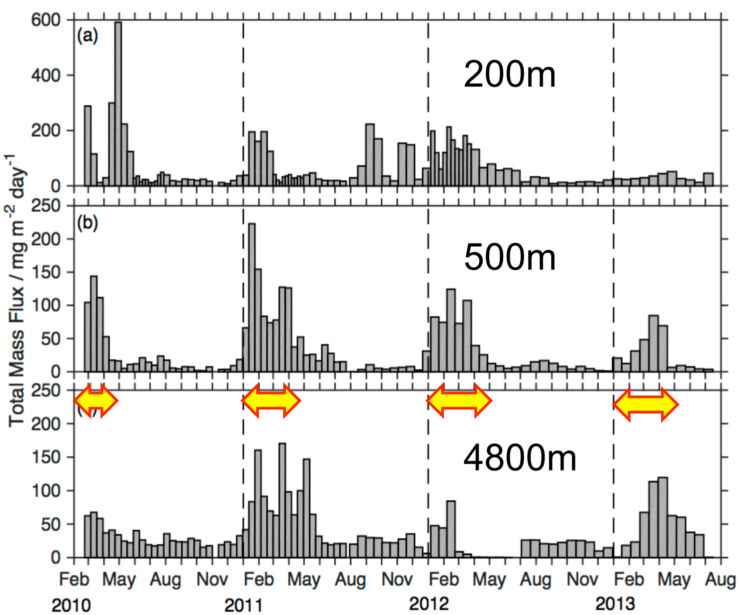
DO from one float

Inoue and Kouketsu (2016)



Fujiki et al. in prep

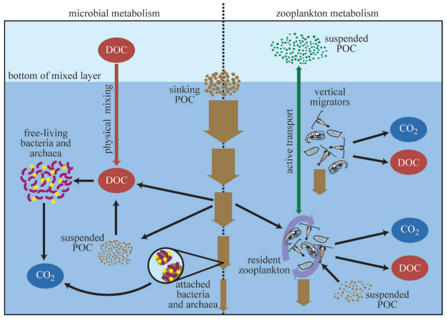
Pop-up profiler



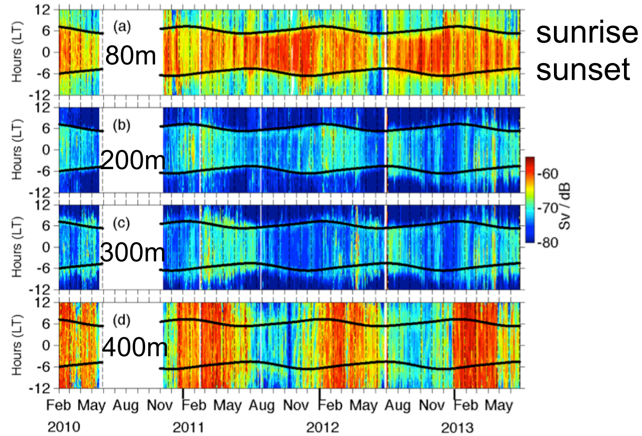
Sediment trap

- High DO was confined in seasonal thermocline in summer and entrained during winter deep ML formation
- Low Chl-a in early winter (December)
- Chl-a, DO, and Fv/Fm increased when MLD reached to the top of nutrientcline
- Total mass flux increased in winter

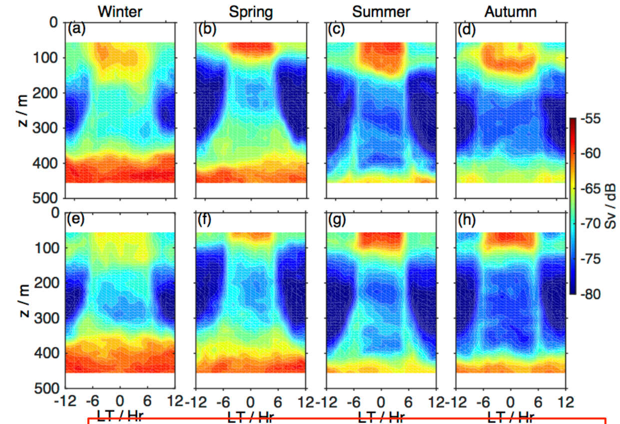
Zoo plankton behavior at S1 mooring site (ADCP)



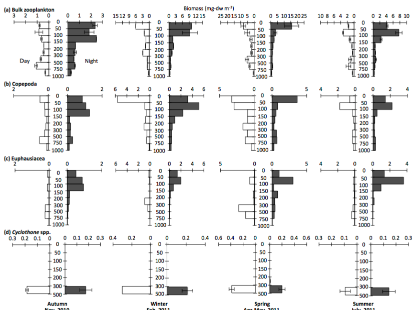
Steinberg et al. (2008)



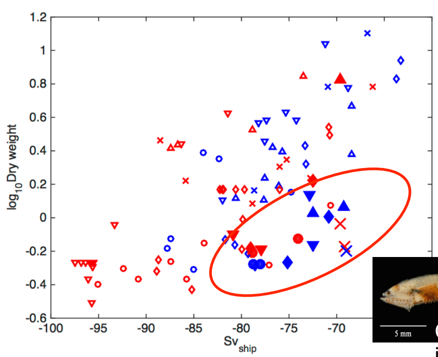
Diurnal and seasonal variability (BS at each level)

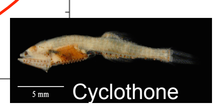


Seasonal composite in new and full moon (LT=0 is midnight)



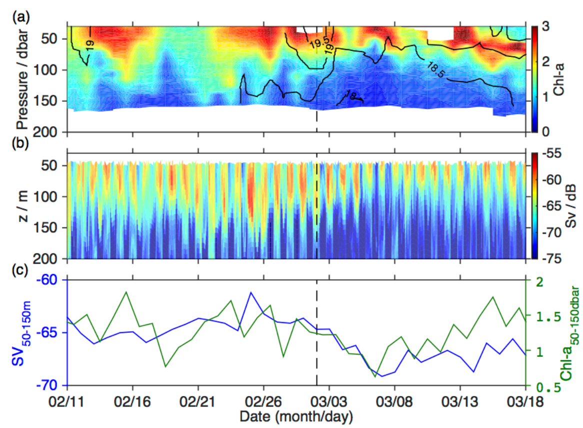
Net sampling (4 seasons)



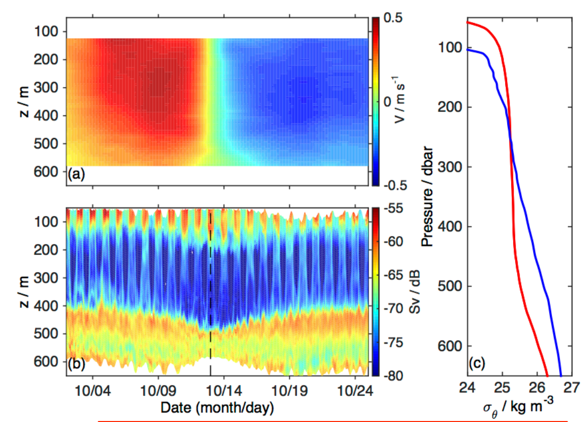


in mid depth

Biomass vs back scatter (BS)



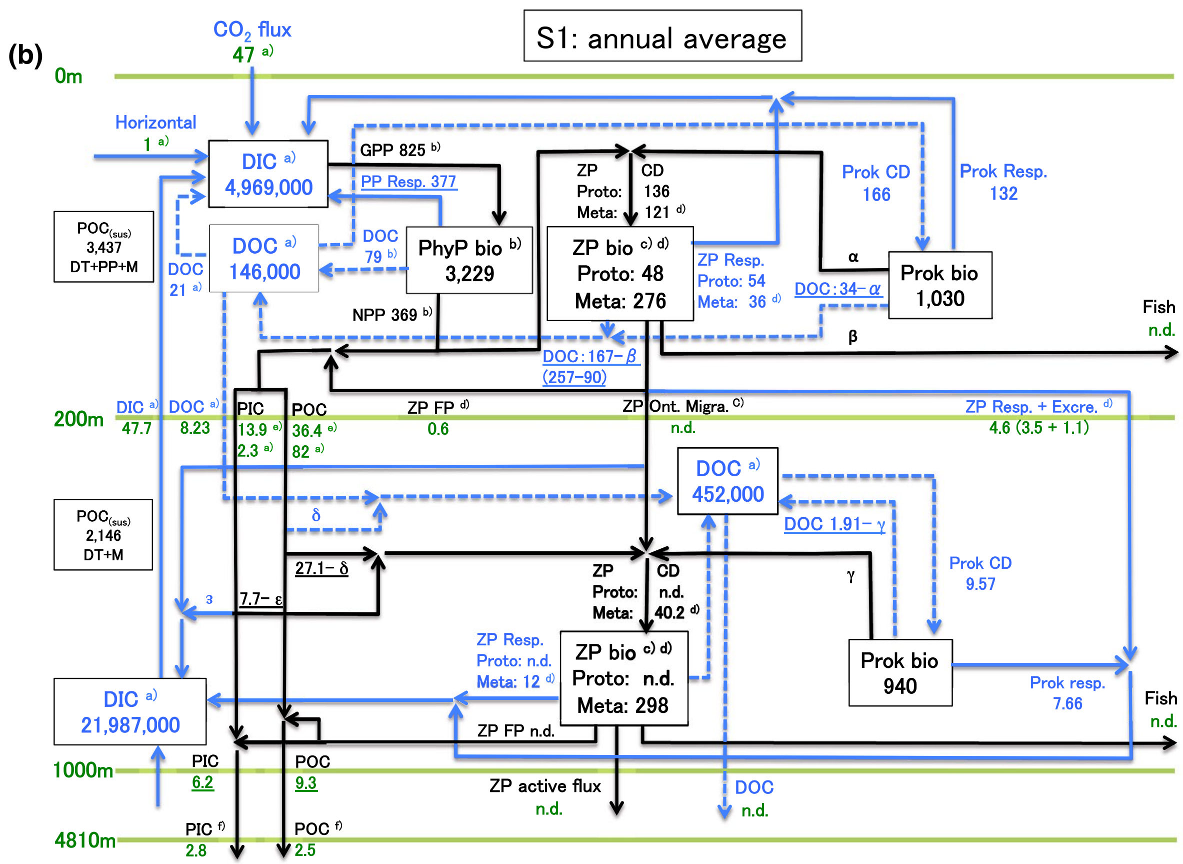
High BS in winter mixed layer



Less BS in an anticyclonic eddy

Inoue et al. (2016), Kitamura et al. (2016)

Carbon budget at S1

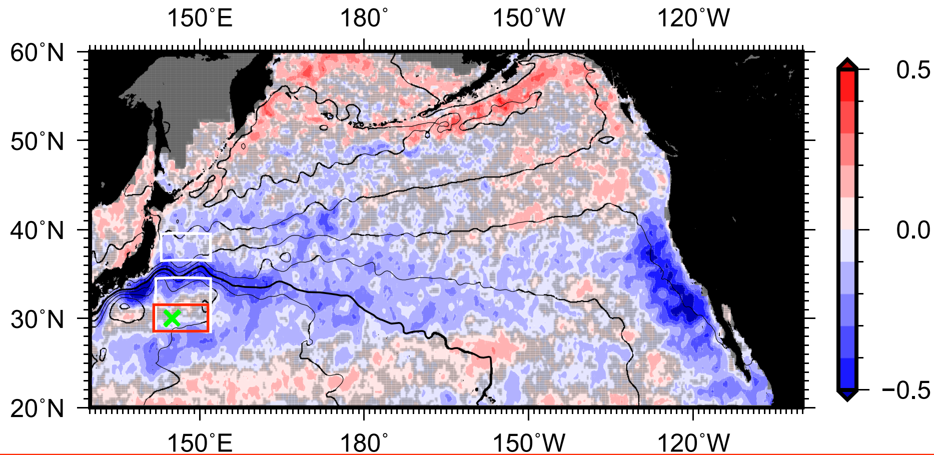


Honda et al. (2017)

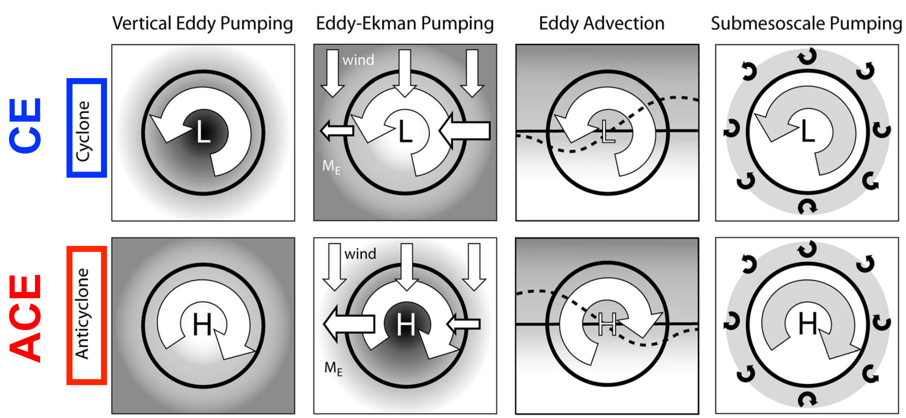
- Honda et al. (2017) estimated the annual-average carbon budget at S1 mooring site from the seasonal shipboard measurements and sediment trap mooring
- CO_2 influx at surface is large, productivity in euphotic zone is large, but export ratio at 5000m is small
- The budget is not closed because of horizontal advection etc. (1D view)
- Effects of intermittent physical events such as eddies and typhoons are not

Eddies around S1 mooring

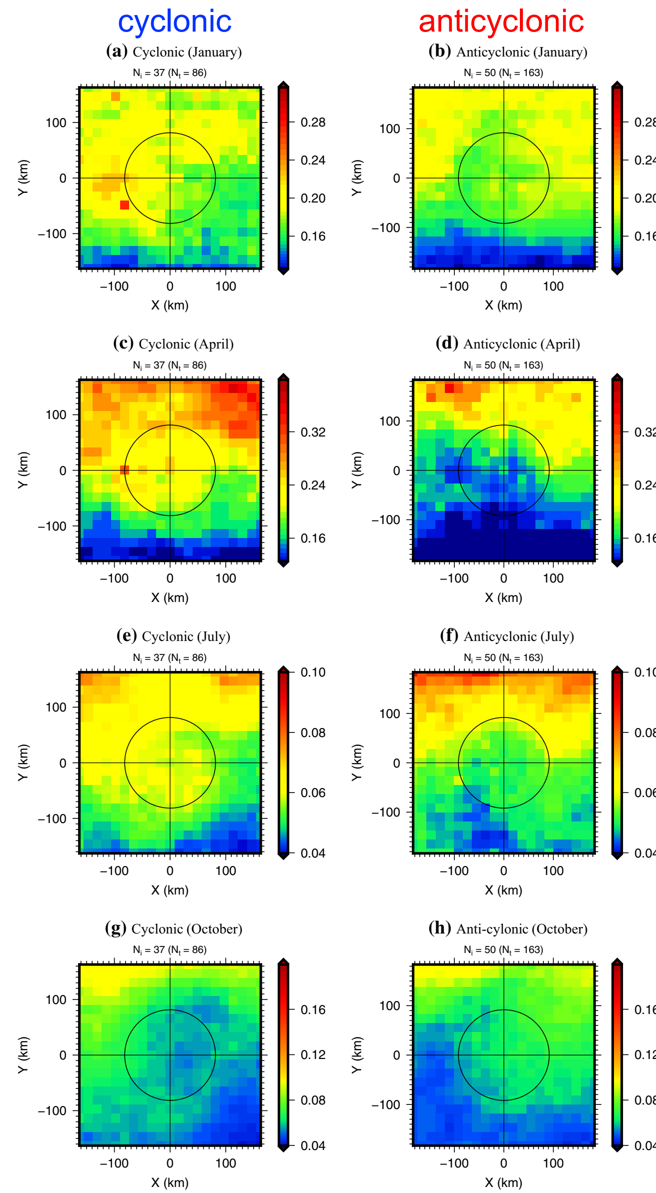
Kouketsu et al. (2016)



- Correlation between 300 days high-passed SSHA and surface chl-a anomaly (seasonal variability was removed)
- Higher negative correlation near Kuroshio
- Low correlation around S1 mooring site

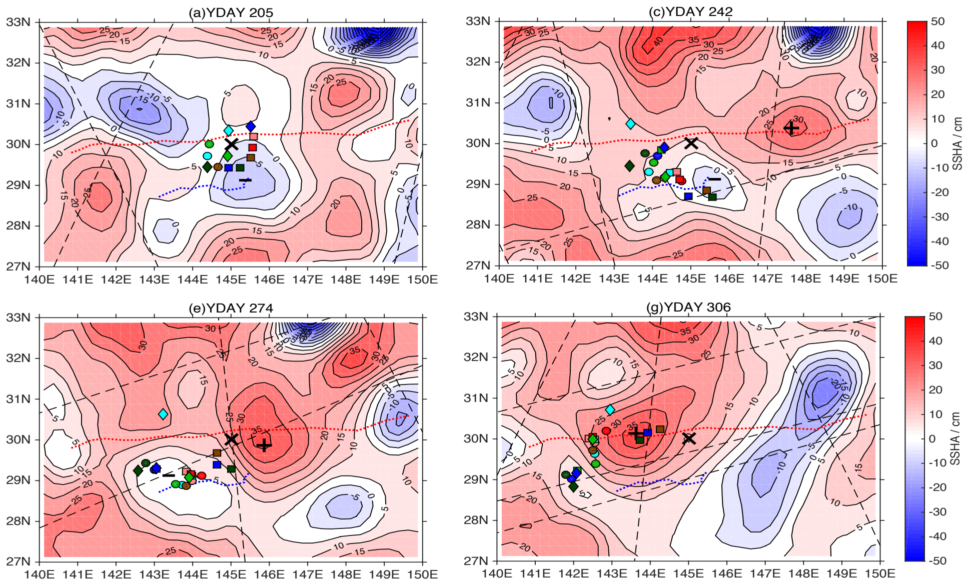


Schematic of eddy effects:
Black=high chl-a (Siegel et al. 2011)

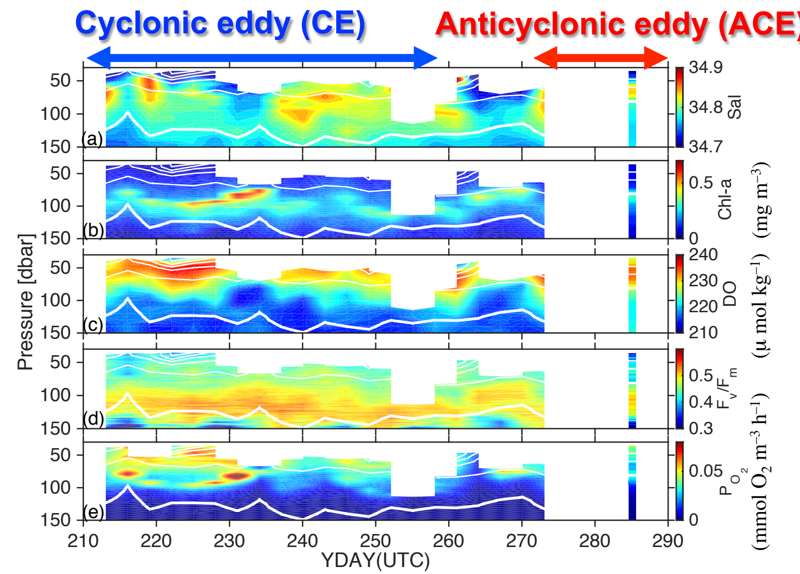


Eddy composite of surface chl-a around S1:
- Eddy advection might be important on surface
- There is a seasonality possibly due to ML deepening and seasonal thermocline

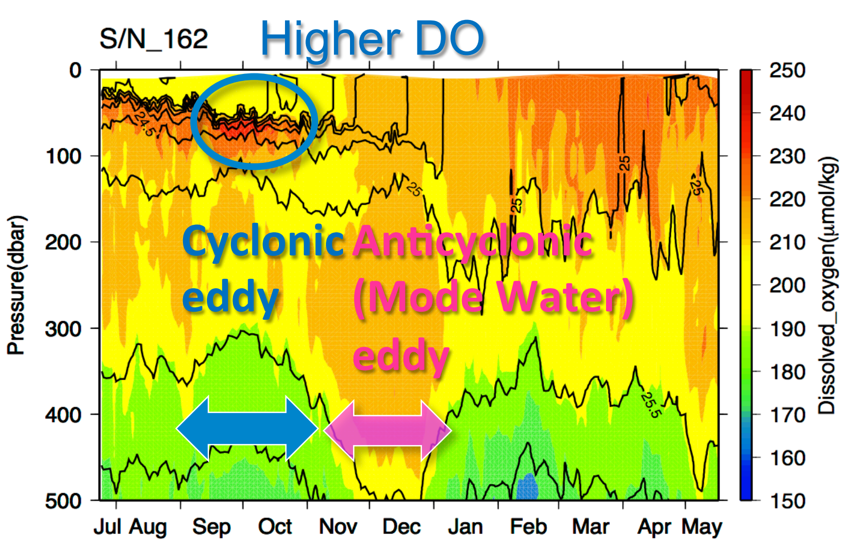
S1-INBOX in summer 2011:eddy effects in subsurface



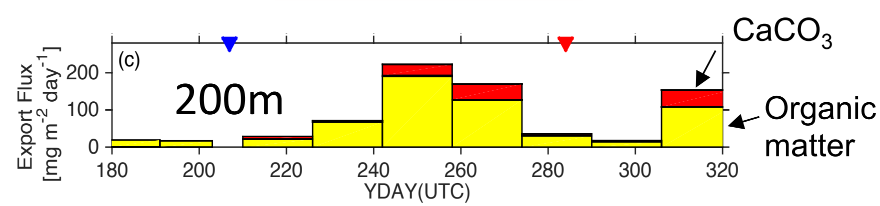
SSHA and float positions



Pop-up profiler



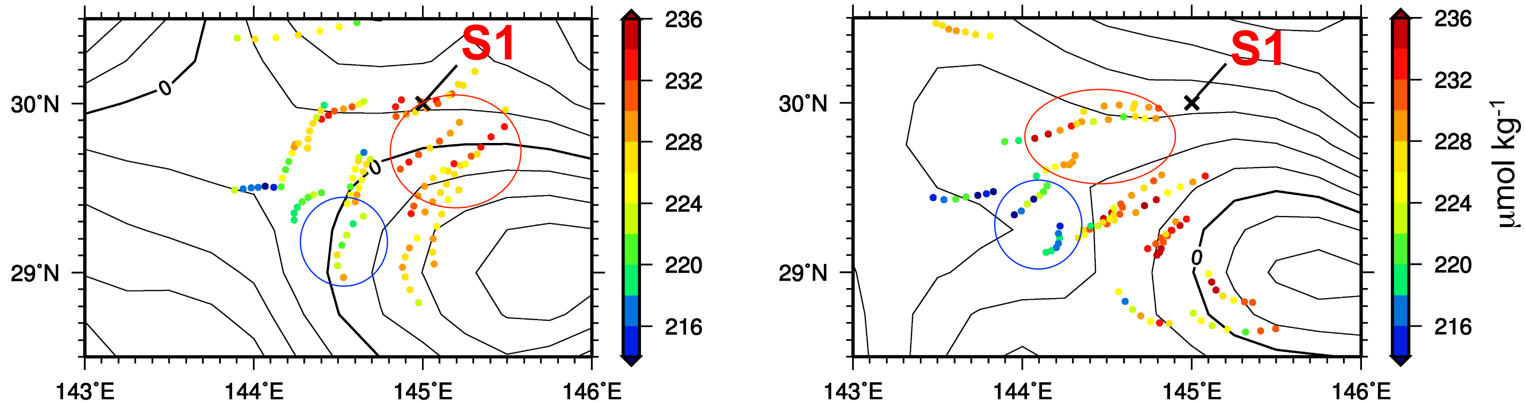
DO time series observed by one float



Sediment trap mooring

- CE and ACE passed by S1
- Patchy high S, chl-a, DO distribution along with isopycnal heaving during CE
- Mooring was tilted during ACE
- Total mass flux increased in CE

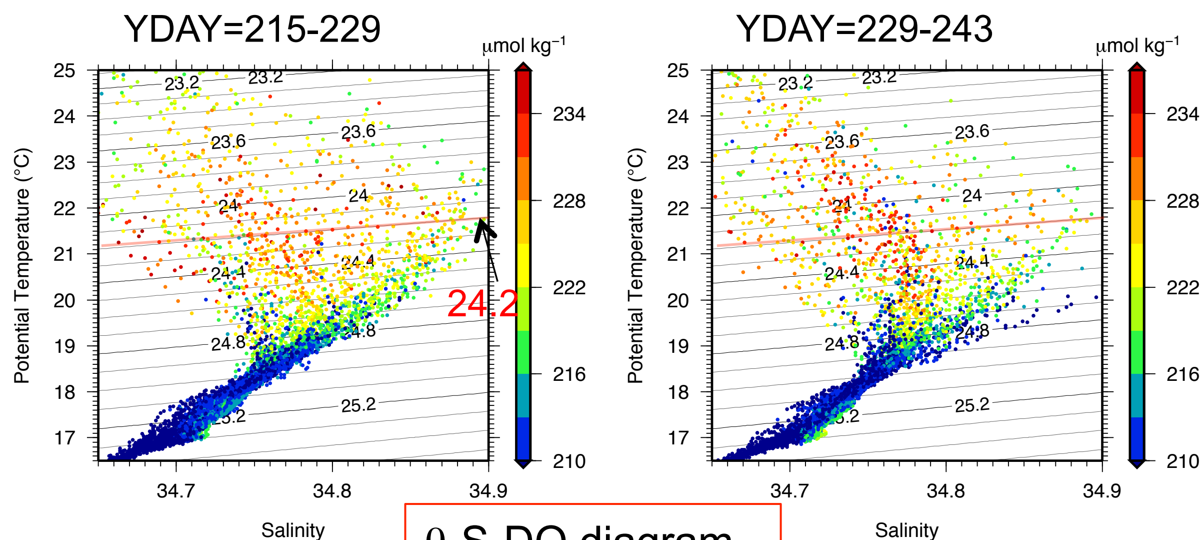
The cyclonic eddy observed by floats



YDAY=215-229

DO on 24.2 σ_θ surface (SOM)

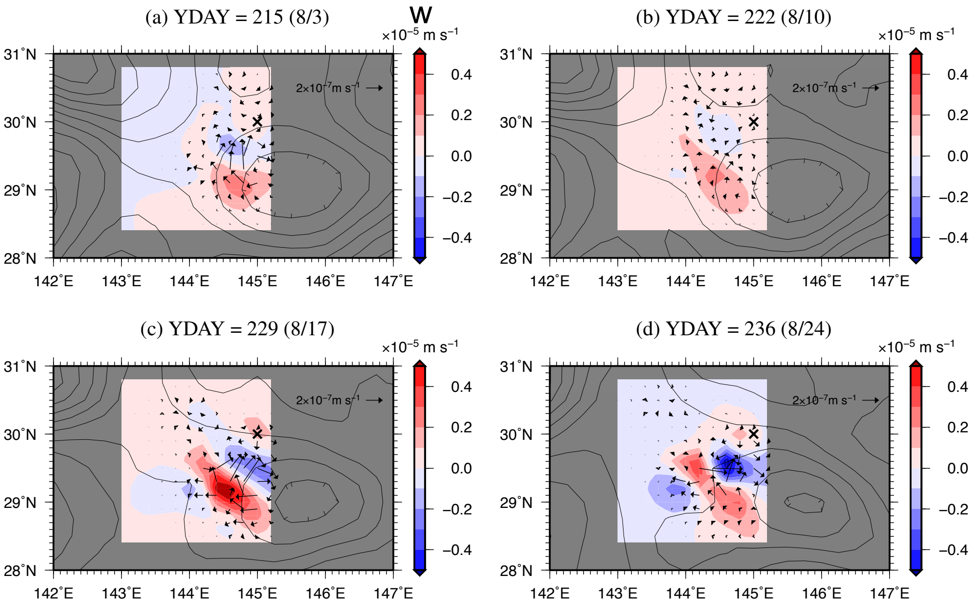
YDAY=229-243



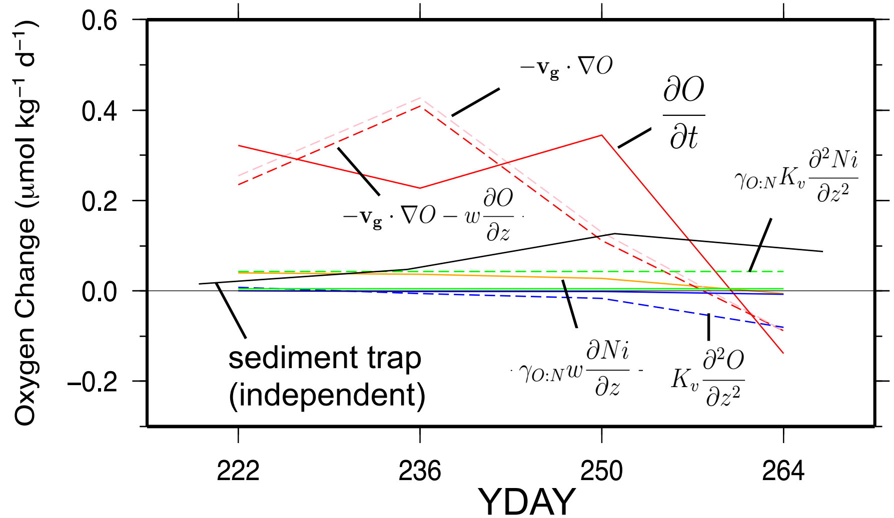
θ-S-DO diagram

- During this period, floats mainly existed in the northwestern corner of CE
- There was narrow bands (~20–40 km) structures of high and low oxygen
- Salinity had a large scatter below the SOM, indicating different origins of water

Vertical and ageostrophic flows below the SOM estimated from ω-equation in QG framework from interpolated fields



Vertical and ageostrophic velocity on 24.7 σ_θ

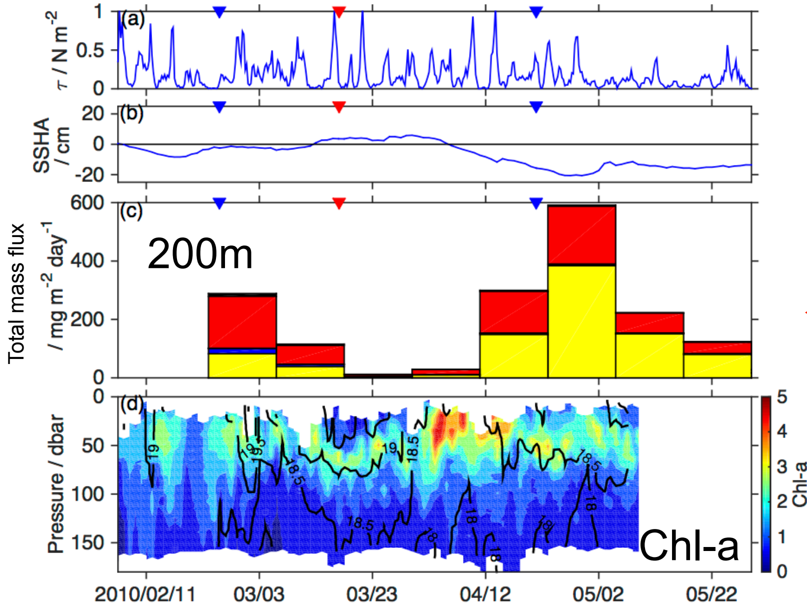


$$\frac{\partial O}{\partial t} = -\mathbf{v_g}\cdot\nabla O - w\frac{\partial O}{\partial z} + K_v\frac{\partial^2 O}{\partial z^2} + \gamma_{O:N} w\frac{\partial Ni}{\partial z} + \gamma_{O:N} K_v\frac{\partial^2 Ni}{\partial z^2}$$

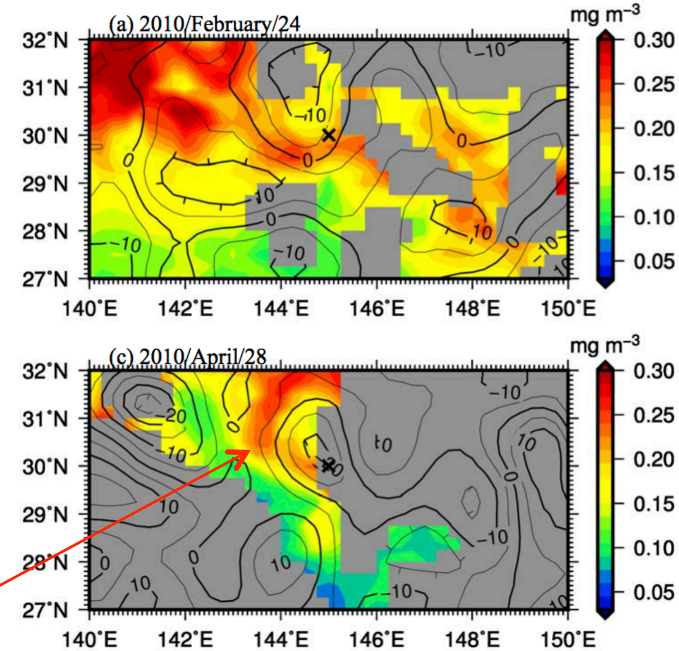
DO budget (comparison for each term)

- Upwelling and downwelling were alternatively occurred around the northwestern side of the eddy with horizontal scales of 20-40 km
- Small scale wiggling of density front created this spatial pattern, consistent with the large scatter in θ-S diagram (advection of different water mass)
- Tendency term of DO was similar pattern and magnitude as the advection term
- Production term due to nutrient transports explained a part of DO increase

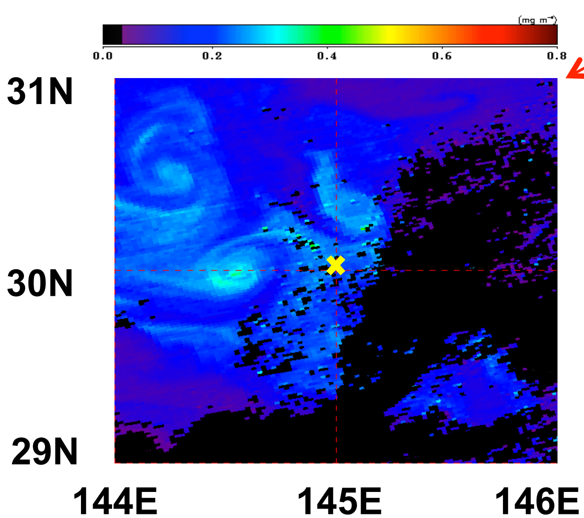
Eddies in winter



Winter mixed layer formation and restratification in 2010

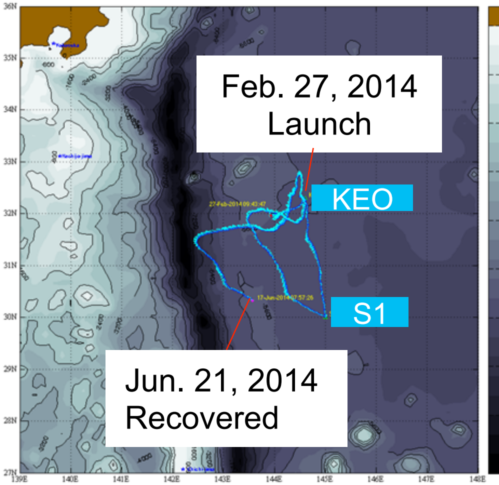


Satellite Chl-a + SSHA

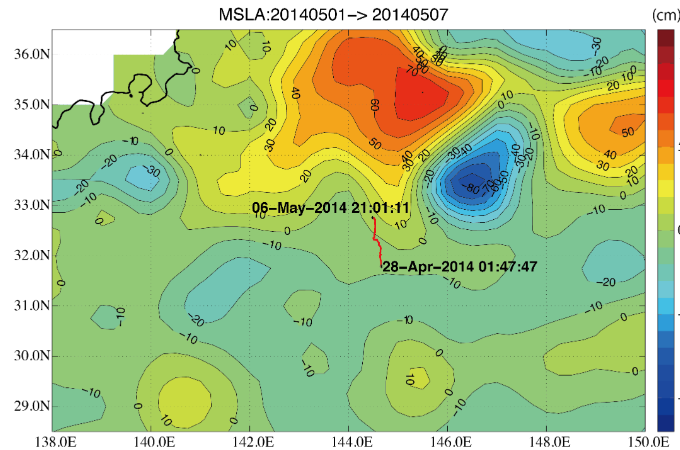


- Restratification due to CE before March 3
- Less total mass flux during ACE
- High chl-a in transient ACE to CE in early April
- Higher mass flux in end of April when CE passed
- Submeso(?) eddy was observed at the edge of the cyclonic eddy on 2010/4/26 MODIS Chl-a (high resolution)
- Mixed layer eddies?

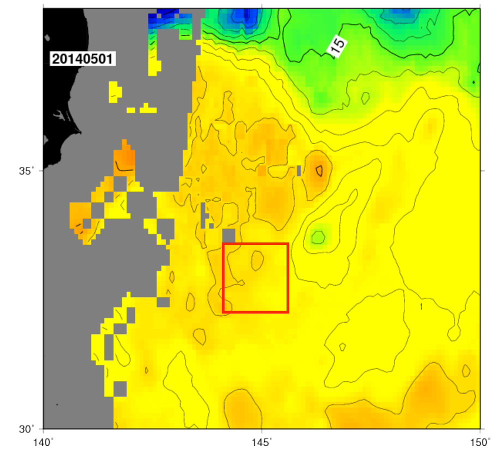
SeaGlider deployments in winter 2014



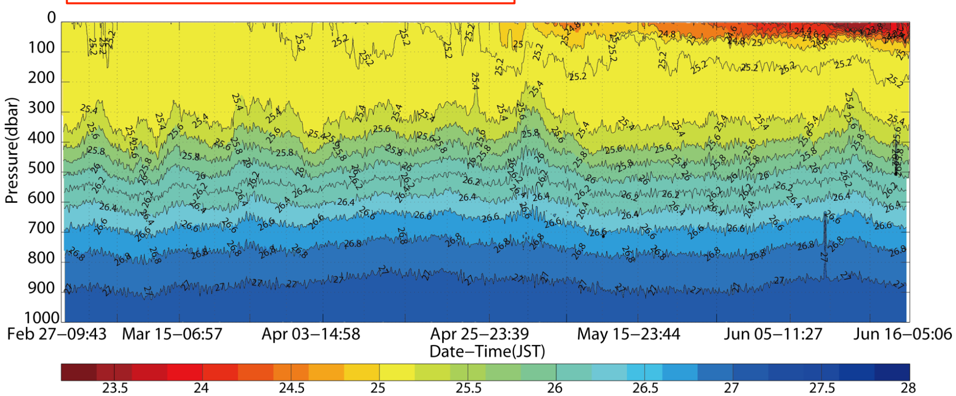
SeaGlider trajectory



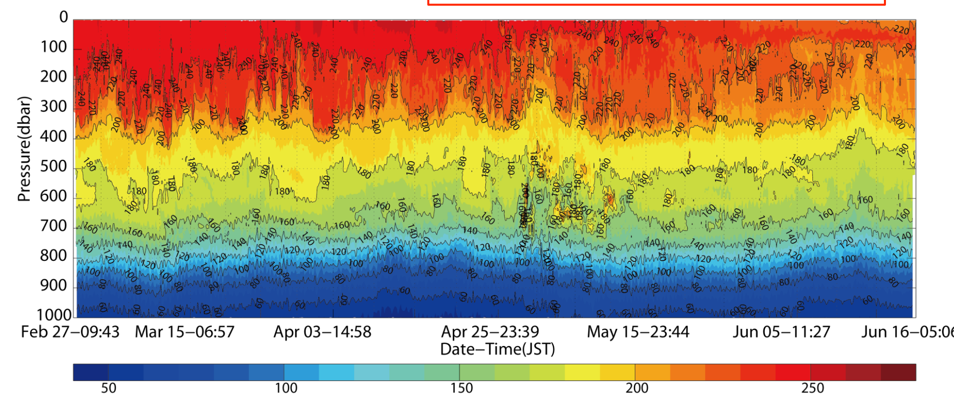
SSHA (2014/May/1-7)



Daily SST on May 01 (AMSR2&Windsat)



Time series of σ_θ



Time series of DO

- SeaGlider was at the edge of the ACE around May 1st when the surface mixed layer started to be restratified and many high and low oxygen patches were observed

Summary (BGC around S1 mooring site)

Seasonality

- Higher production in late winter and early spring
- Summer and fall: Seasonal thermocline and oligotrophic condition in euphotic zone

Eddies and mixing

- Eddies are important in both summer and winter
- ADCP observed near-inertial motions after storms and typhoons (not shown)
- There was no direct turbulence measurement during S1 project

Not well studied in this observational program: Fate of carbon

- Relation to the large scale circulation (subduction, advection, and obduction)
- Temporal changes of BGC properties in the mode water (mixing, respiration, nutrient recycling…)

Connecting process studies to a big picture
=> BGC Argo project

JAMSTEC's contributions to BGC Argo project (deployments between 2017April-2018March)

BGC Apex (T,S,P,DO,Chl-a,bb=back scatter)

	North Pacific	1

BGC Navis (T,S,P,DO,NO^{3-},Chl-a,bb)

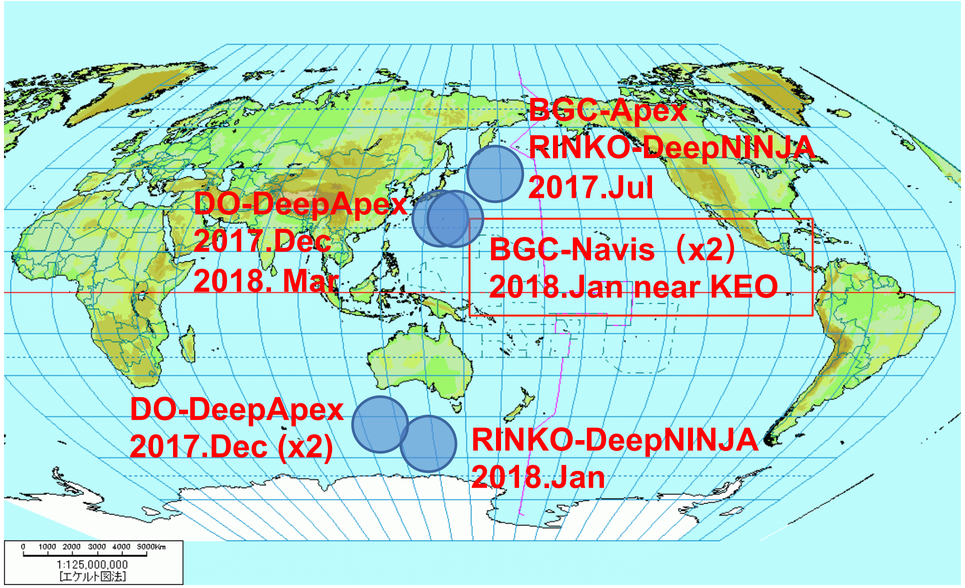
	North Pacific (near KEO)	2

DO-Deep Apex (T,S,P,DO)

	North Pacific	2
	South Indian	2

Rinko-Deep NINJA (T,S,P, DO) 1

	North Pacific	2
	Southern Ocean	1



BGC Argo floats

TWR
BGC APEX
SBE41 CTD, Aanderaa Optode4330, Wetlab Chl-a, bb, CDOM
・2000dbar

SBE
BGC Navis
SBE41 CTD, SBE63 Oxygen, Wetlab Chl-a,bb,CDOM, Satlantic Deep SUNA
・2000dbar

TWR
DO-Deep APEX
・SBE61 CTD, Aanderaa Optode4831 or JFE RINKO AROD-FT
・6000dbar

Tsurumi
Rinko-Deep NINJA
・SBE41 CTD, JFE RINKO AROD-FT
・4000dbar