Biological and physical controls on the Kuroshio Extension oxygen cycle from an array of profiling floats

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SOCCOM

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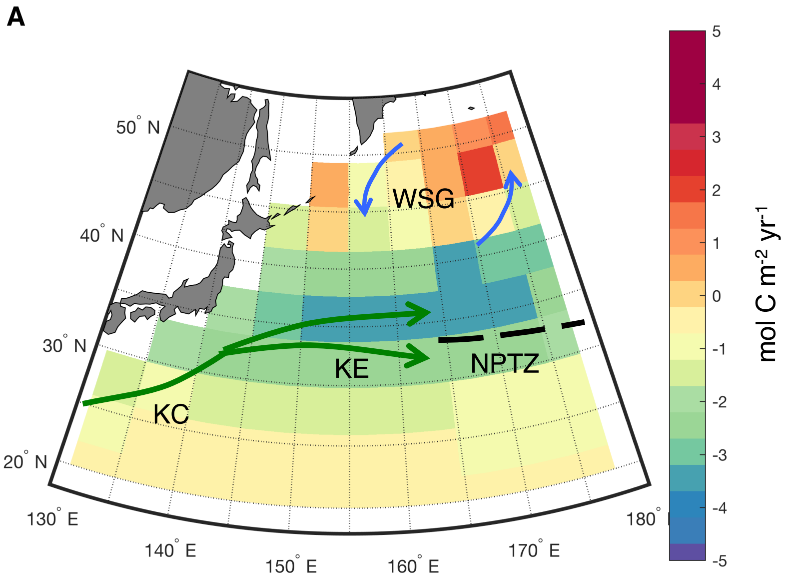
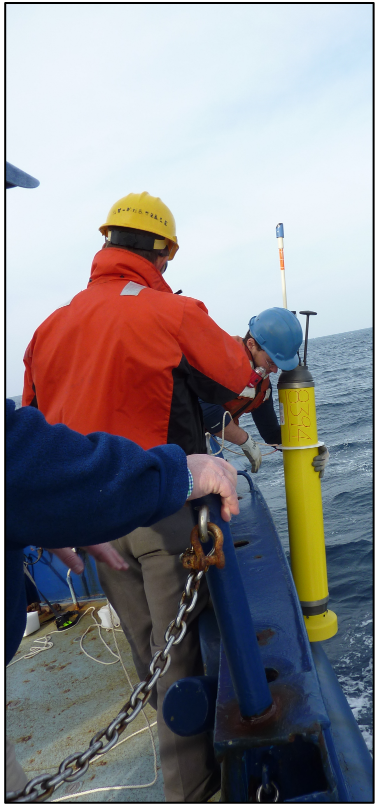
Motivation: Carbon uptake in the Western N. Pacific

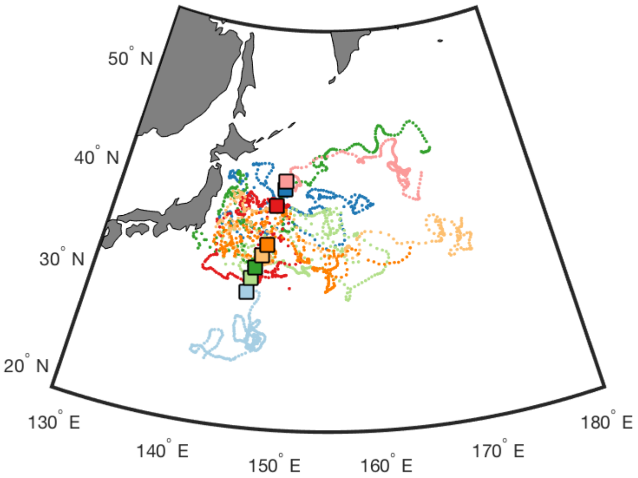


Takahashi et al. (2009)

- Kuroshio Extension is a large carbon sink
- Biological or physical control:
  - Ayers and Lozier (2012)
    -biology important, geostrophic divergence of DIC significant driver
  - Takahashi et al. (2009)
    -roughly equal biological and physical importance

Deployment of modified Argo-oxygen floats

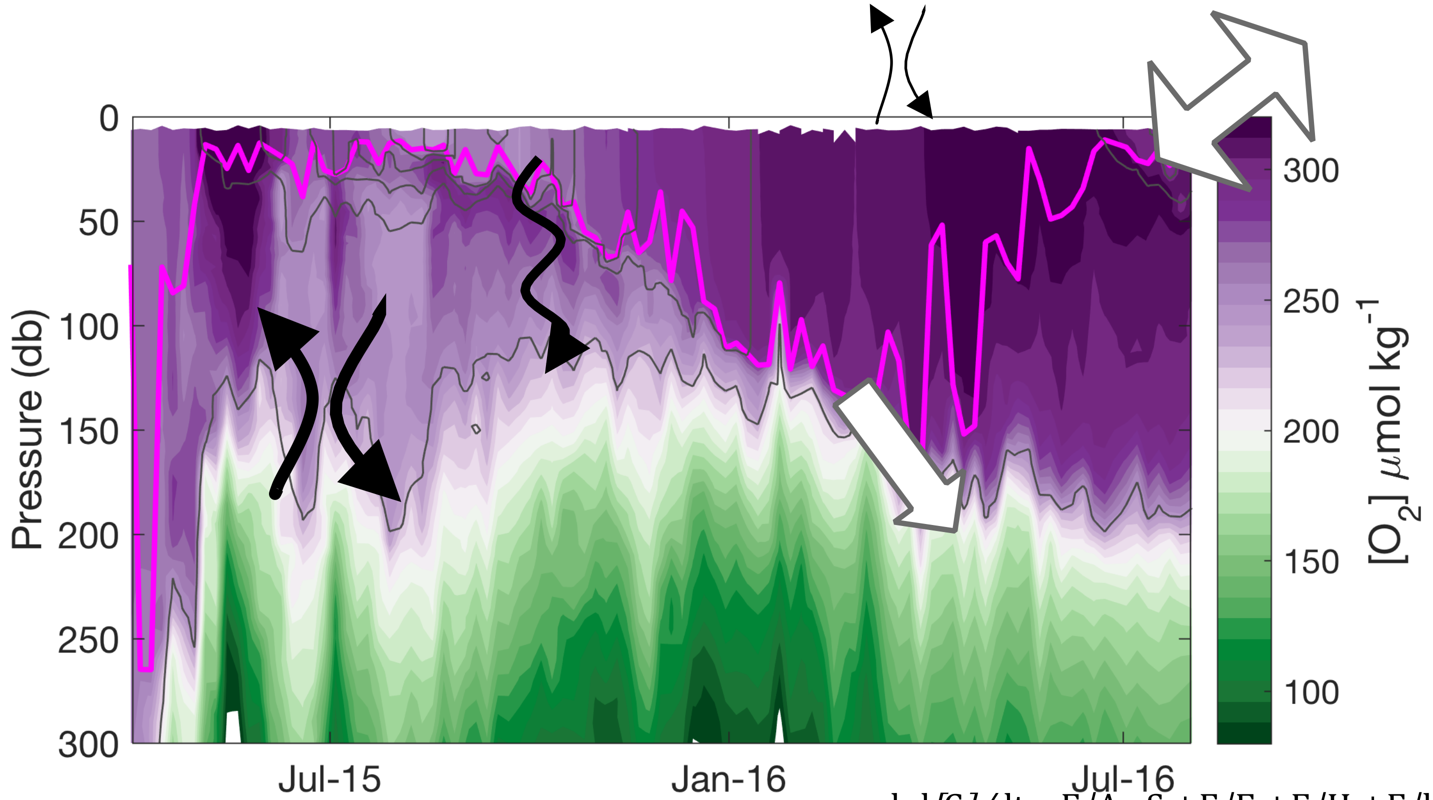




- Designed and deployed Argo oxygen floats capable of air calibration
  - Critical for estimating the air-sea flux of oxygen
- Goal: to constrain the impact of biological carbon export on the Kuroshio Extension carbon uptake

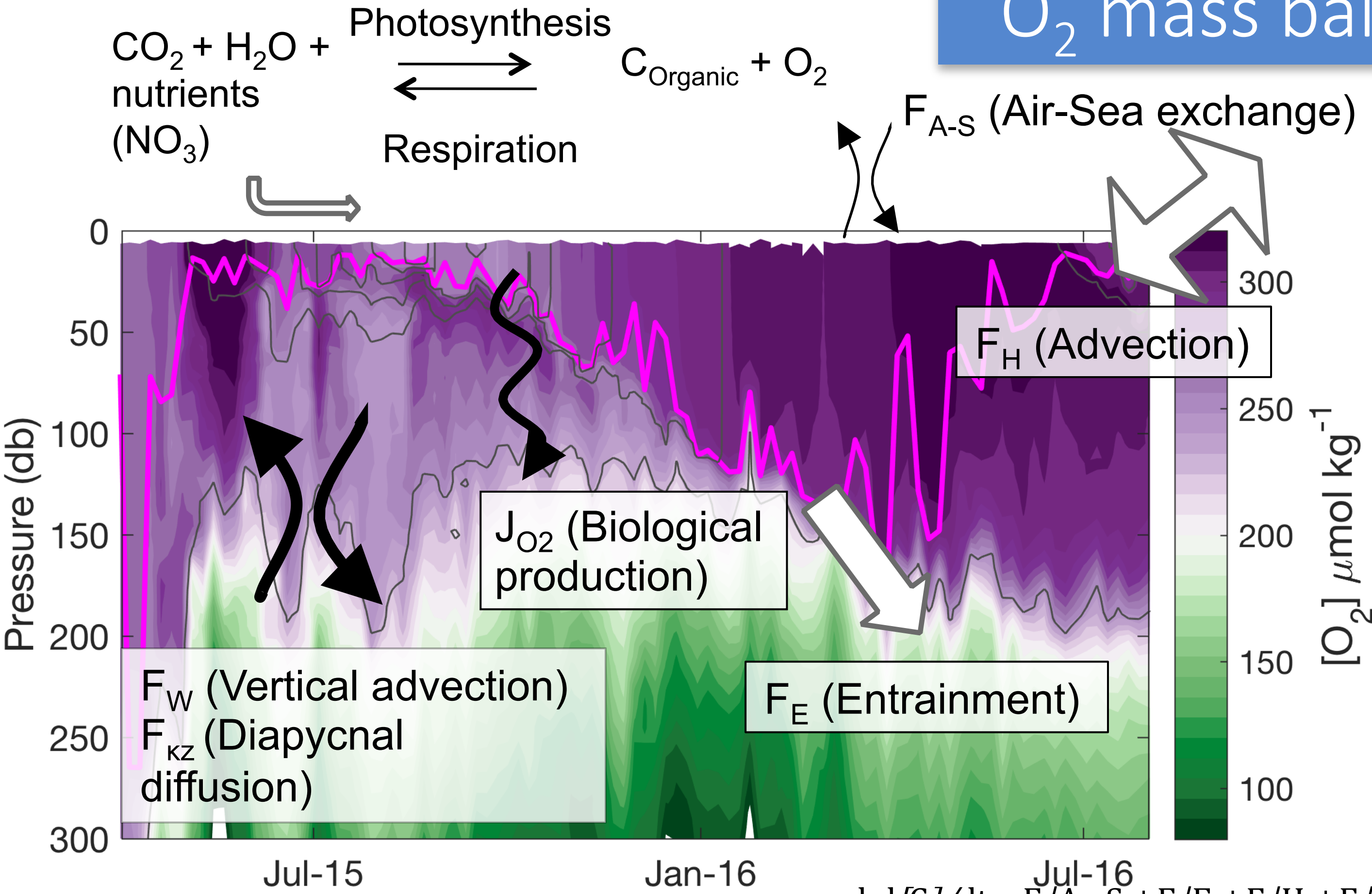
Bushinsky et al. (2016)

O_2 mass balance



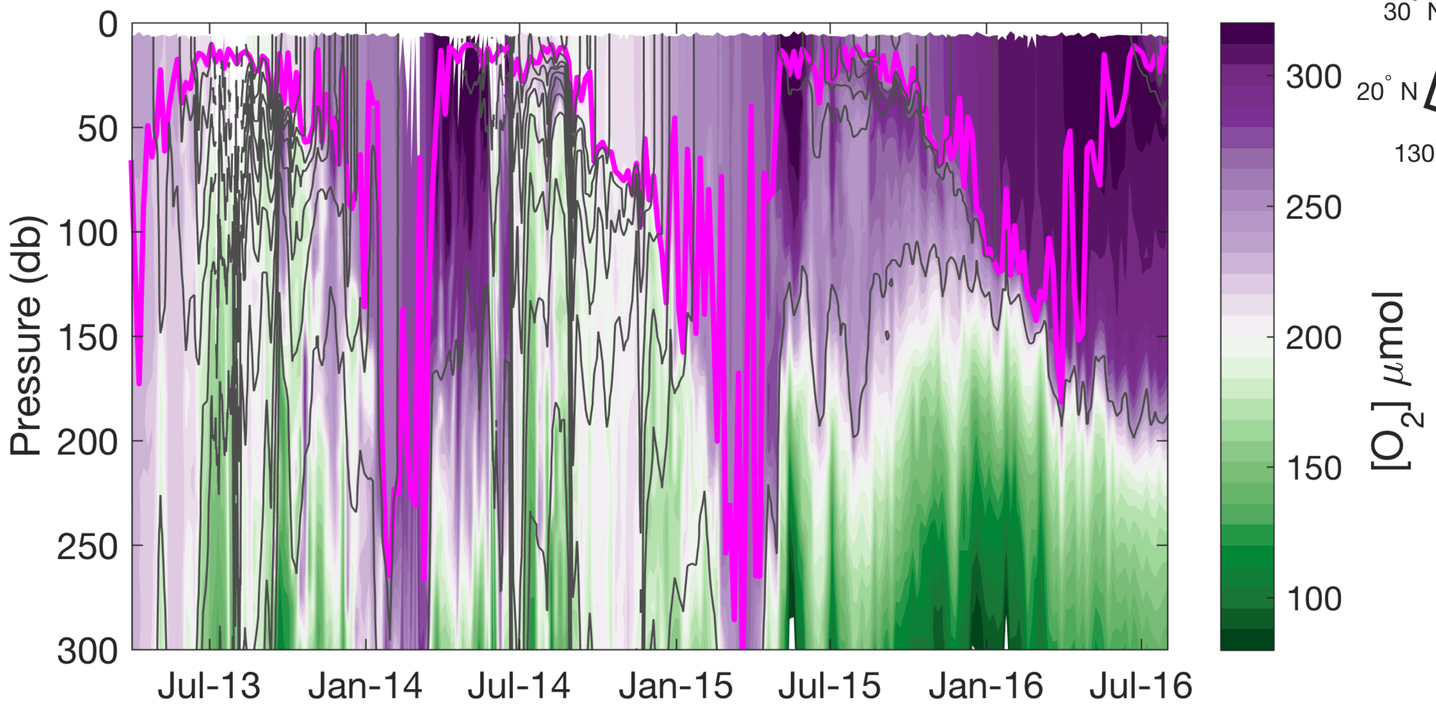
$$h\,d[C]/dt = F_{A-S} + F_E + F_H + F_{kz} + F_W + F_J$$

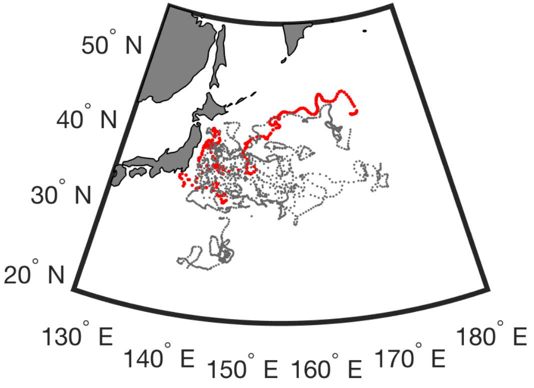
O_2 mass balance



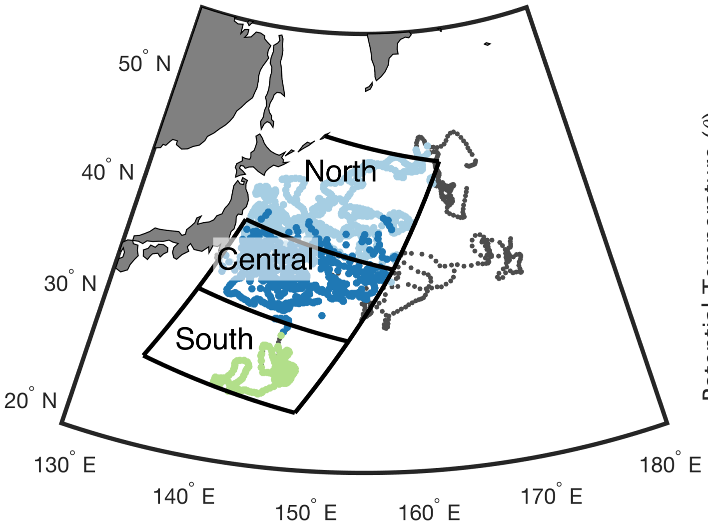
$$h\,d[C]/dt = F_{A-S} + F_E + F_H + F_{kz} + F_W + F_J$$

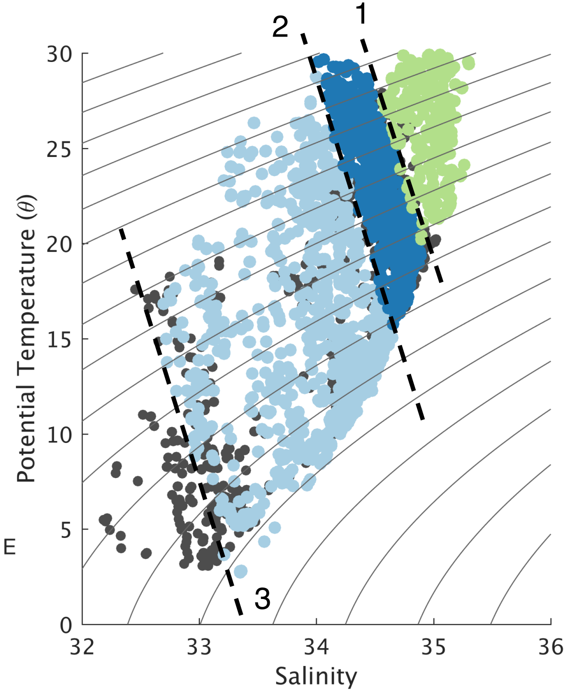
KE region: strong horizontal advection and fronts





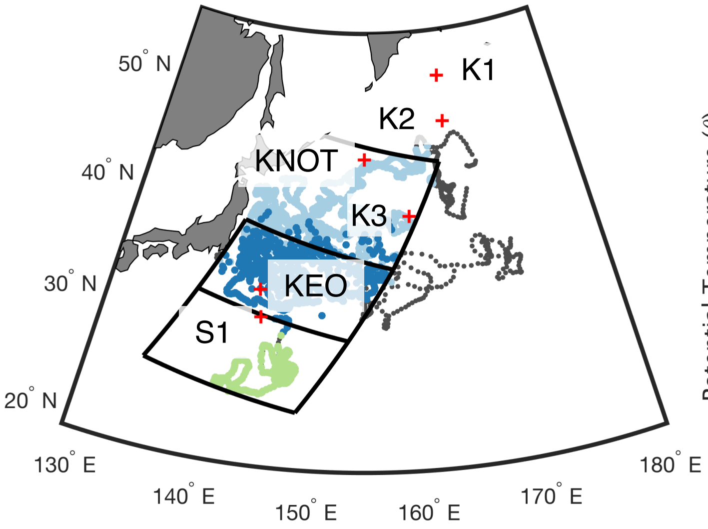
Separating float profiles by TS and location

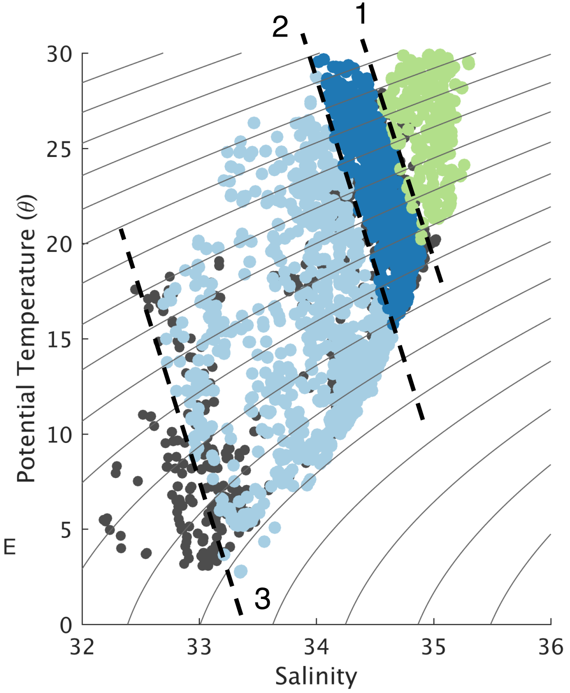




- Simple geographic boundaries ignore seasonal movement of Kuroshio Extension
- Surface Temperature-Salinity relationships help identify and separate water masses

Separating float profiles by TS and location





- Simple geographic boundaries ignore seasonal movement of Kuroshio Extension
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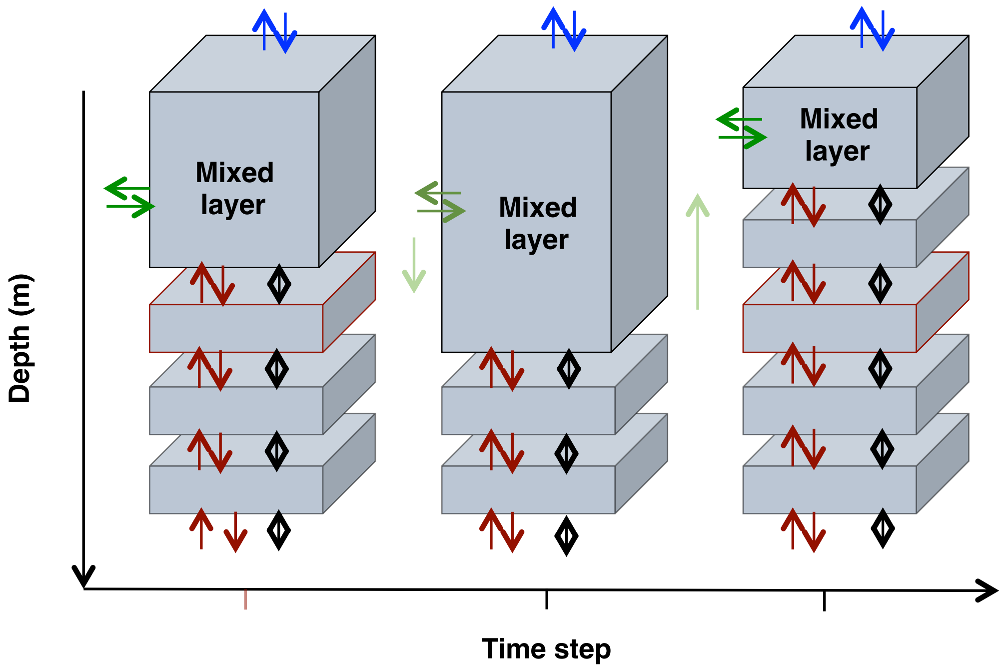
KE upper ocean gas model



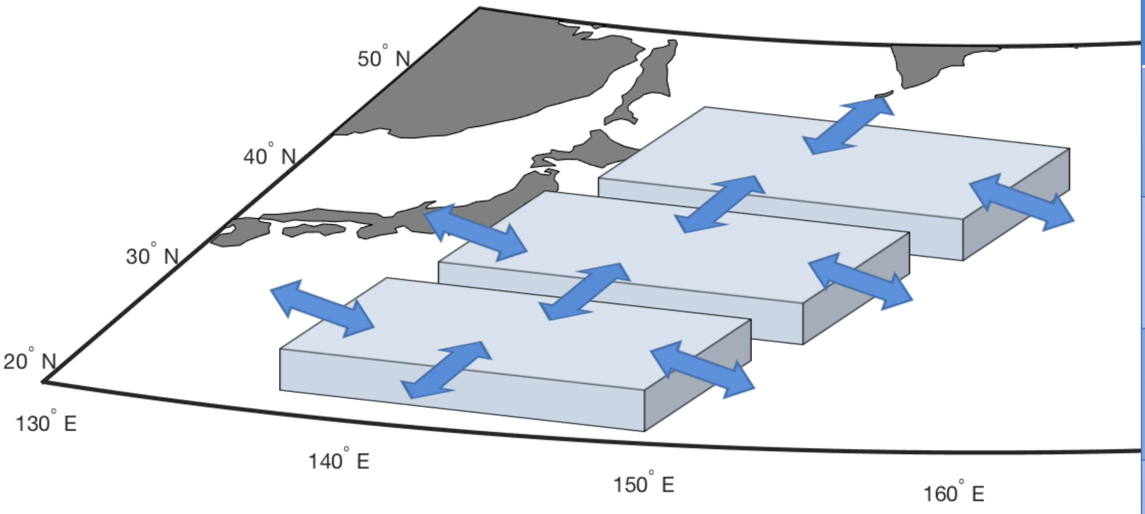
$F_{A\text{-}S}$: Gas exchange
F_E: Entrainment/shoaling
F_{kz}: Diapycnal diffusion
F_W: Vertical advection
F_H: Horizontal advection

Calculates expected oxygen in the absence of biology.
Temperature and Salinity from float data, sub mixed layer boxes ~10 m

$$h\,d[C]/dt = F_{A-S} + F_E + F_H + F_{kz} + F_W + F_J$$

modified from Bushinsky and Emerson, 2015

KE upper ocean gas model – regional view



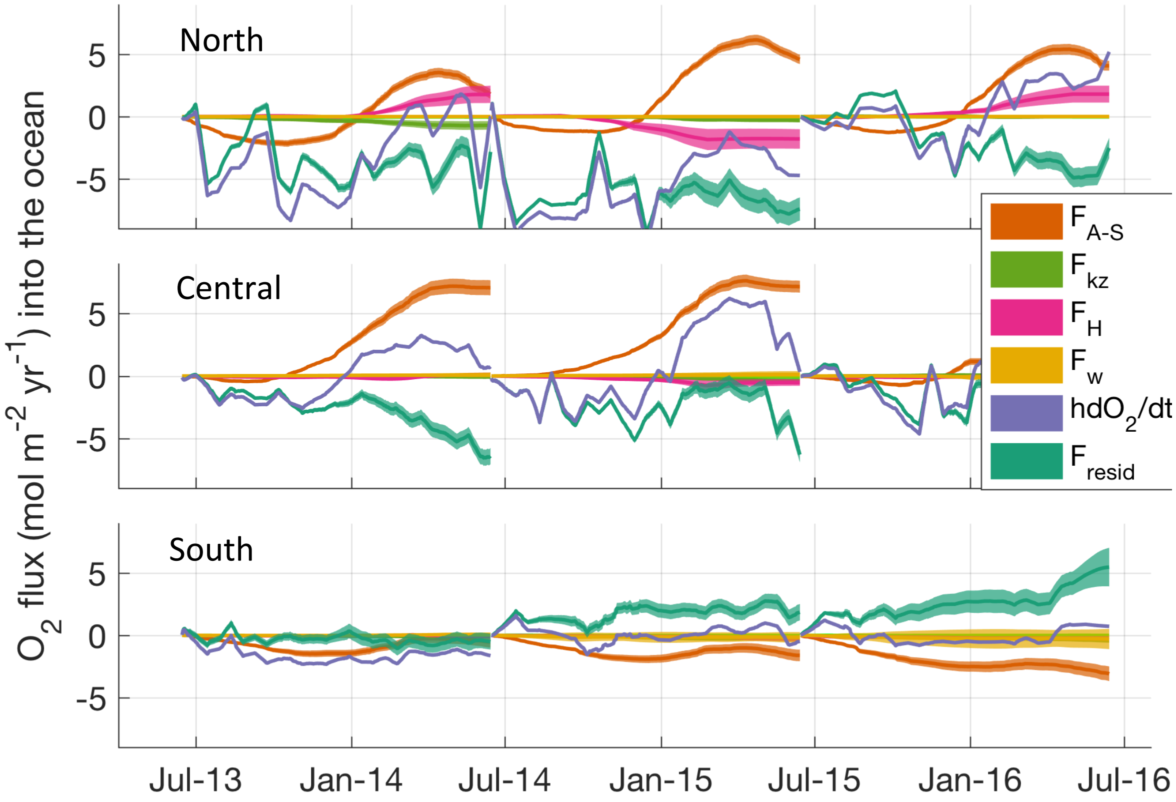
- Profiles averaged along density surfaces
- Model extends below deepest wintertime mixed layers
- Annual fluxes integrated to depth of wintertime mixed layer for each year

Term	Oxygen fluxes
$F_{A\text{-}S}$ Gas exchange	Liang '13, tuned to wintertime Ocean Station Papa N_2, ASCAT winds
F_E Entrain./shoaling	Float SST/Sal (de Boyer Montégut 2004) and Δ[C]/dz
F_{kz} Diapycnal diffusion	Deep $_{KZ} = 10^{-5}\ m^2\ s^{-1}$; ML $_{KZ}$ from Cronin et al. (2015); Float measured Δ[C]/dz
F_W Vertical advection	Ekman pumping, calculated from ASCAT winds
F_H Horizontal Advection	AVISO Geostrophic Velocities, Ekman transport from ASCAT winds
	Horizontal % O_2 gradients from other boxes, World Ocean Atlas

Model Flux calculations

Term	Oxygen fluxes
$F_{A\text{-}S}$ Gas exchange	Liang '13, tuned to wintertime Ocean Station Papa N_2
F_E Entrainment/ shoaling	Float SST/Sal (de Boyer Montégut 2004) and Δ[C]/dz
F_{kz} Diapycnal diffusion	Deep $K_z = 10^{-5}$ m^2 s^{-1}; ML $K_z = 10_{-4}$ m^2 s^{-1}; Float measured Δ[C]/dz
F_W Vertical advection	Ekman pumping, calculated from ASCAT winds
F_H Horizontal Advection	AVISO Geostrophic Velocities, Ekman transport from ASCAT winds
	[illegible]

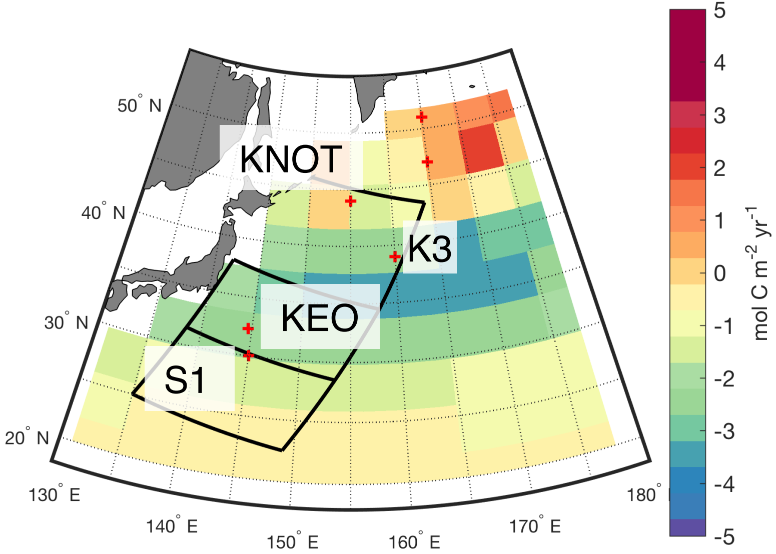
Dominant model term: gas exchange



mol O_2 m^{-2} yr^{-1}

Mean flux	North	Central	South
dO2/dt	0.2	0.5	-0.5
$F_{A\text{-}S}$	**3.5**	**7.1**	**-1.7**
F_{kz}	-0.3	-0.2	-0.3
F_H	0.6	-0.2	-0.2
F_W	0	0.1	-0.1
F_{resid}	**-4.3**	**-6.4**	**2.3**

ANCP estimates in the KE

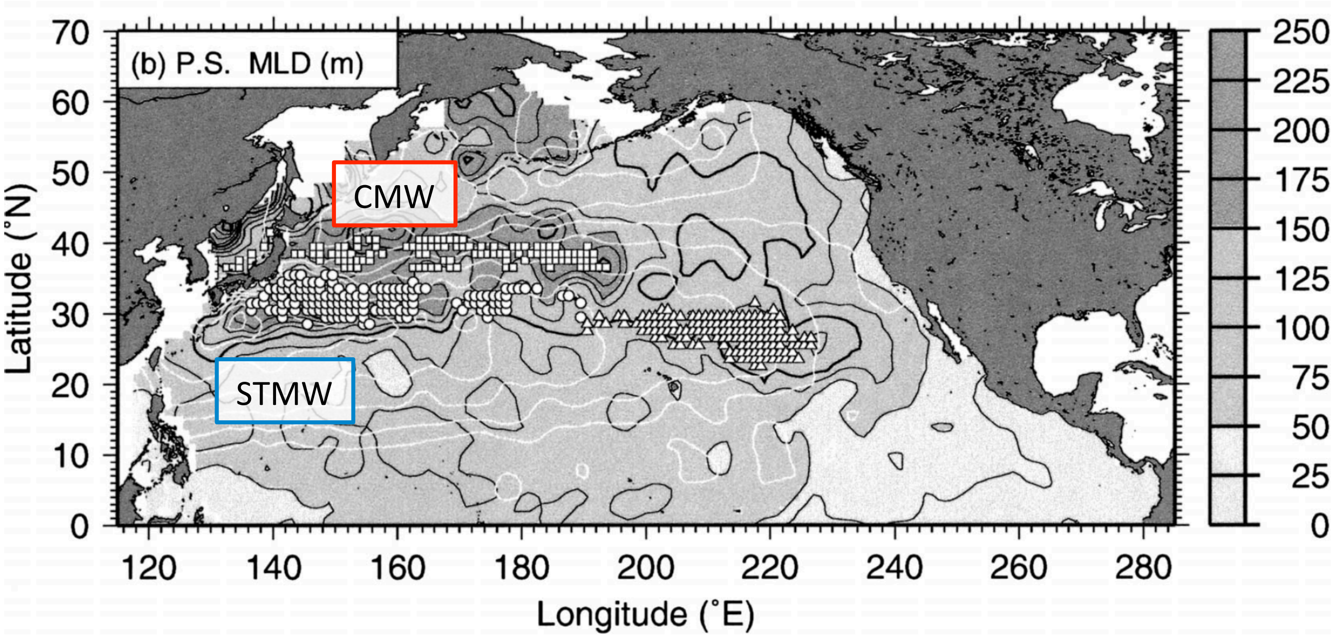


mol C m^{-2} yr^{-1}	North	Central	South
This study (integrated to base of winter ML)	~0	~0	~1.6 ± 2
Other studies (base of WML)	0.5 ± 0.7[1]	-	2.2 ± 0.3[4], 2.8 ± 0.5[5]
Other studies (Surface/ML)	~2[3]	7 ± 3[2], ~1.5[3]	-

[1]Palevsky and Quay (2017), Palevsky et al. (2016)
[2]Fassbender et al. (2017)
[3]Yasanuka et al. (2013)
[4]Yang et al. (2017)
[5]Wakita et al. (2016)

Mode water formation in the Western North Pacific

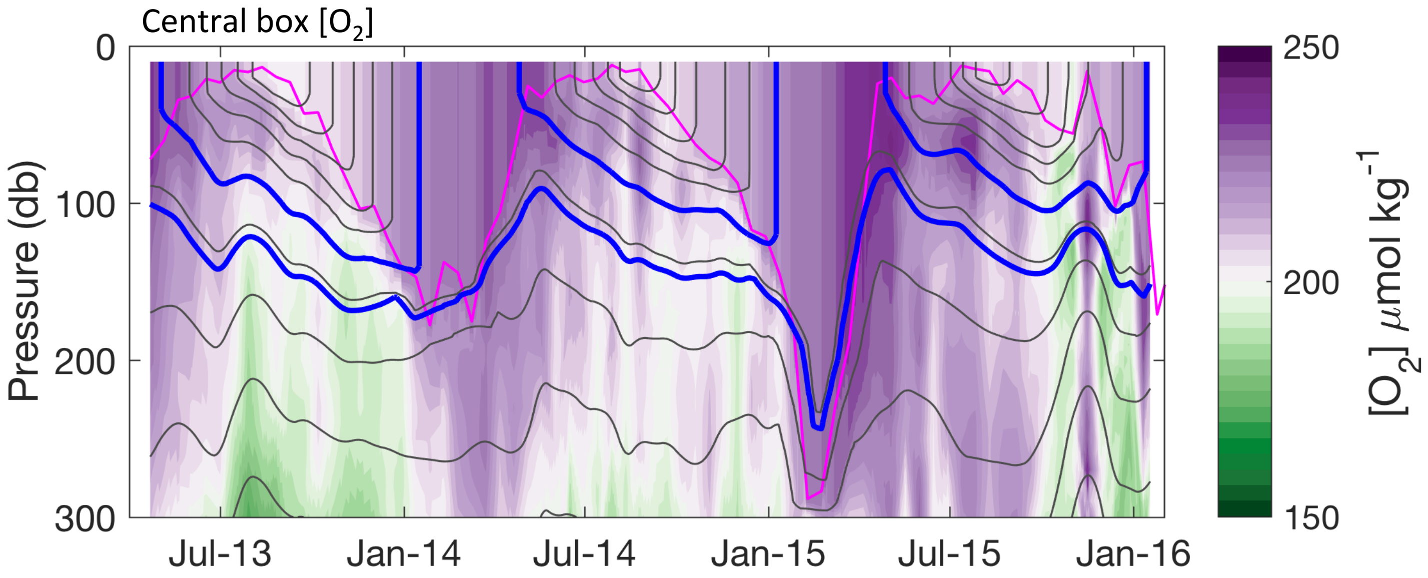
$$h d[C]/dt = F_A - S + F_E + F_H + F_{kz} + FW + F_J$$



Suga et al. (2004)

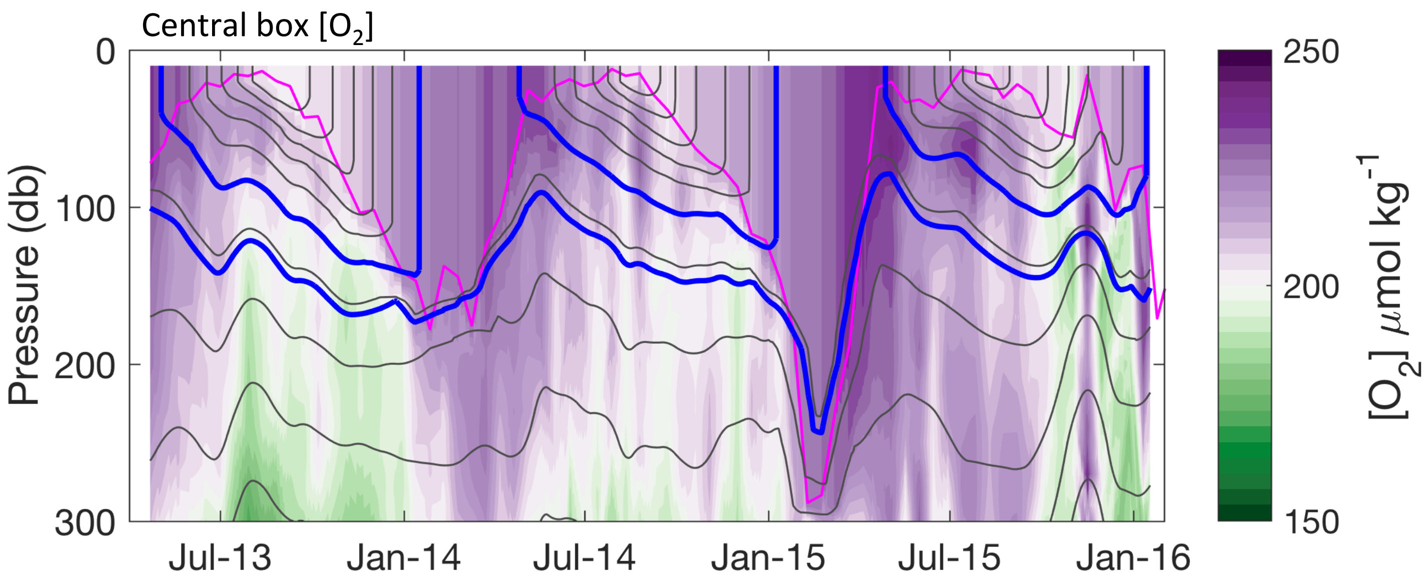
- North box: CMW
- Central box: STMW formation region

Mode water formation in the Western North Pacific



STMW: 25< $\boldsymbol{\sigma_\theta}$ < 25.6

Mode water formation in the Western North Pacific

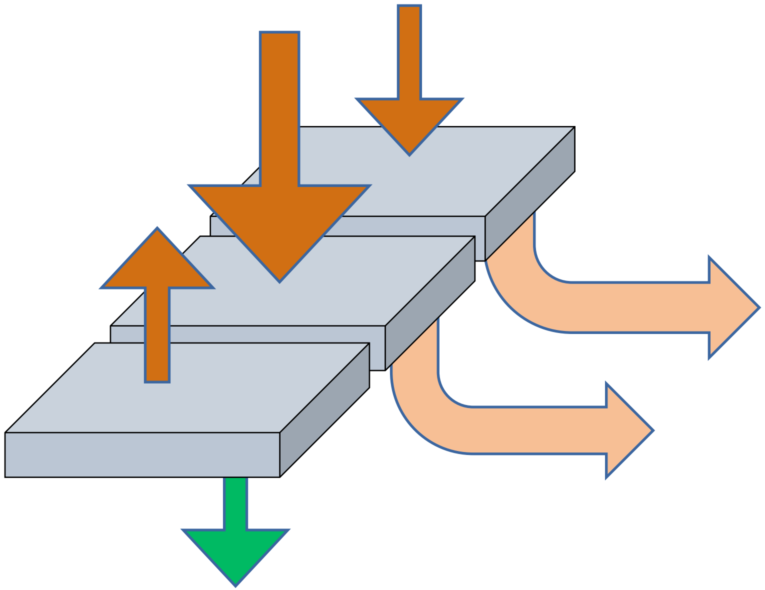


STMW: 25< σ_θ < 25.6

Mode water formation needed to remove residual oxygen flux

	This study (Sv)	Suga et al. 2008 (Sv)
North (CMW)	6.1-6.8	~6.5
Central (STMW)	6.8-7.3	~4

KE upper ocean O_2 budget - Conclusions



- North/Central boxes: little evidence for strong biological control on air-sea exchange
- Primary driver of oxygen uptake – solubility changes, air-sea exchange, removed by mode water formation
- Large area integration of float data enables interpretation of psuedo-langranian profilers in a highly advective region

$$h\,d[C]/dt = F_{A-S} + F_E + F_H + F_{kz} + FW + F_J + FMW$$