Mechanisums of Mesoscale Physical/Biological Interaction

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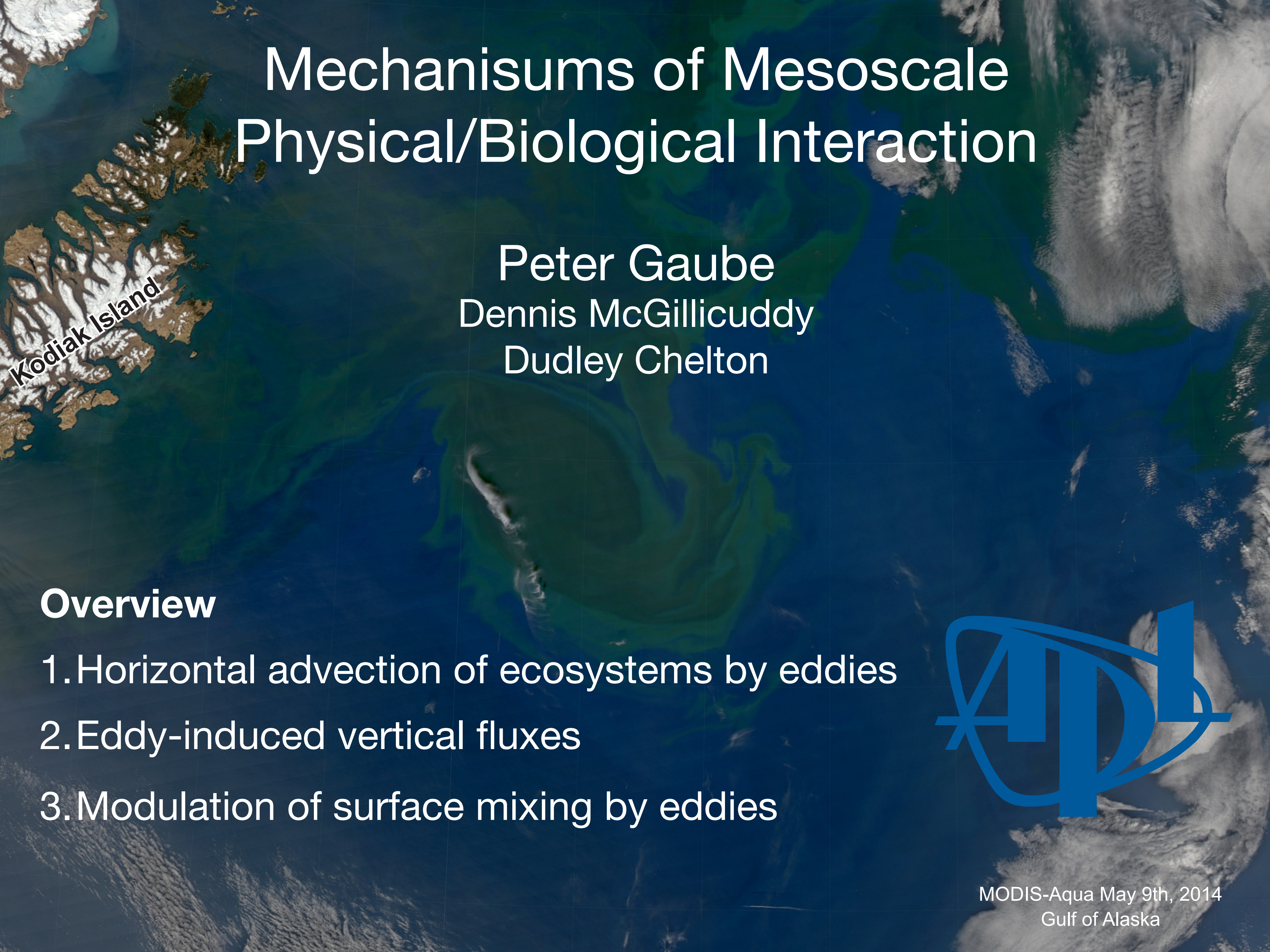
Overview

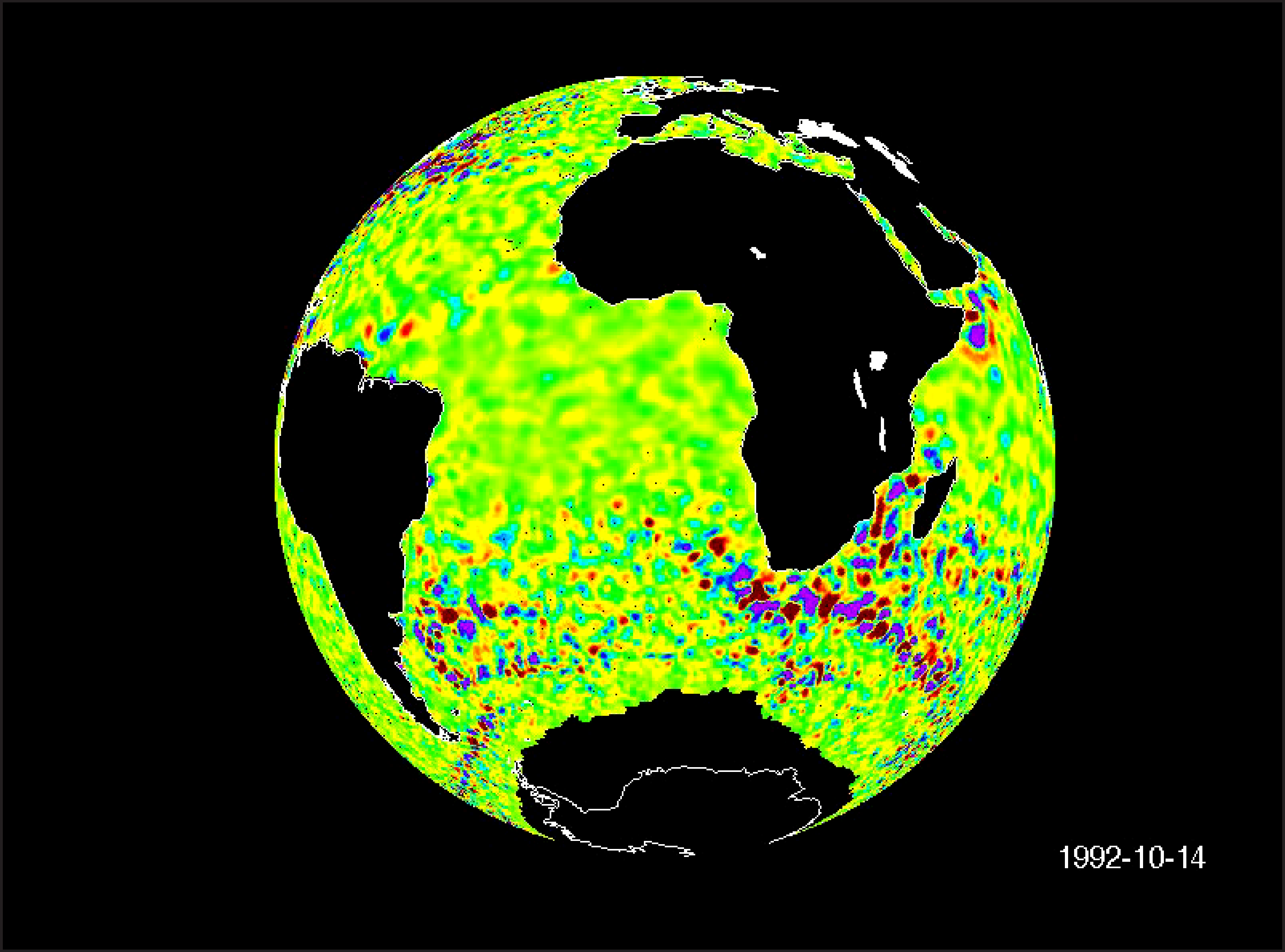
1. Horizontal advection of ecosystems by eddies
2. Eddy-induced vertical fluxes
3. Modulation of surface mixing by eddies



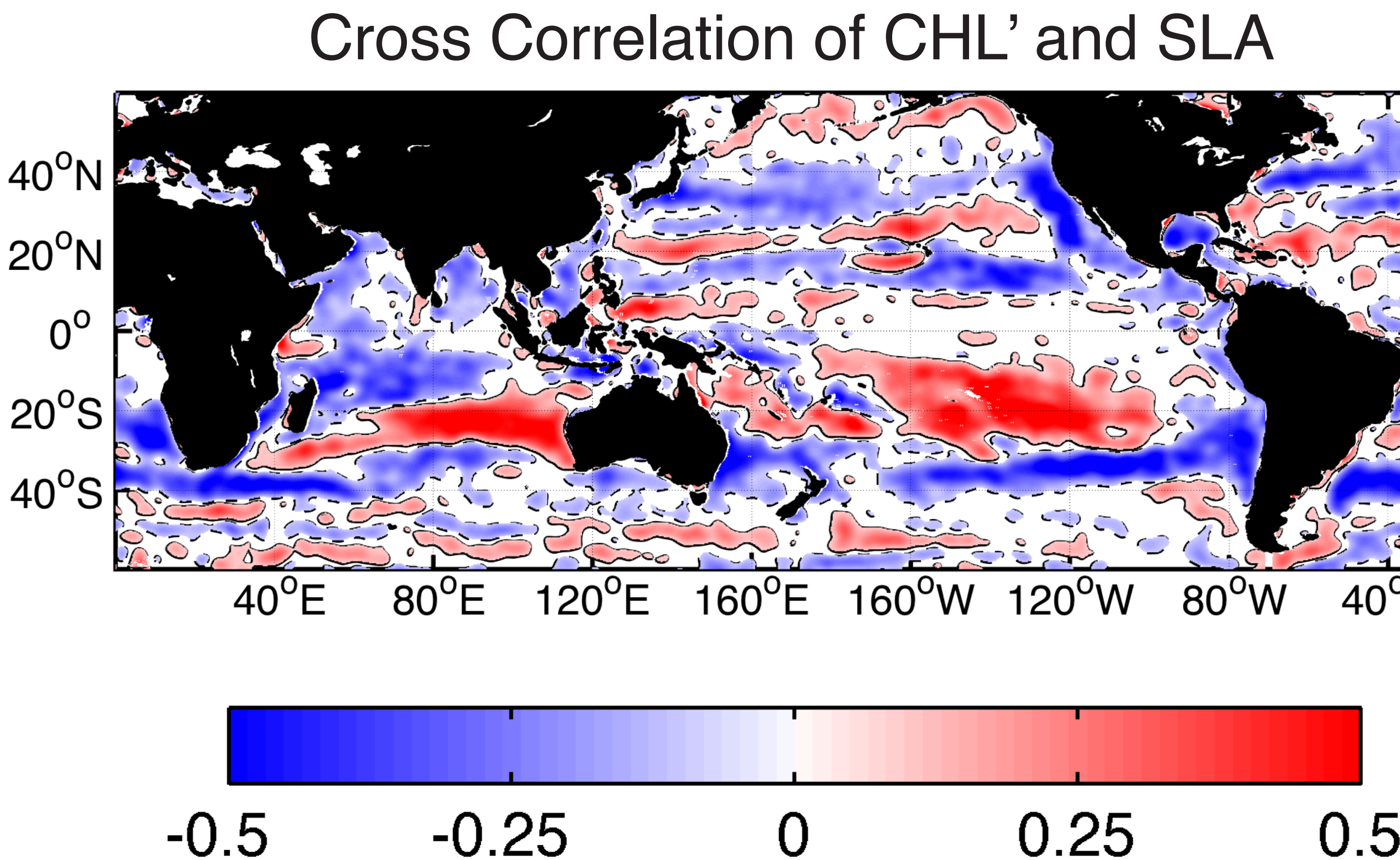
MODIS-Aqua May 9th, 2014
Gulf of Alaska

Observations of Nonlinear Mesoscale Eddies

SSH from the merged TOPEX and ERS-1/2 Data (Ducet *et al., 2000*)

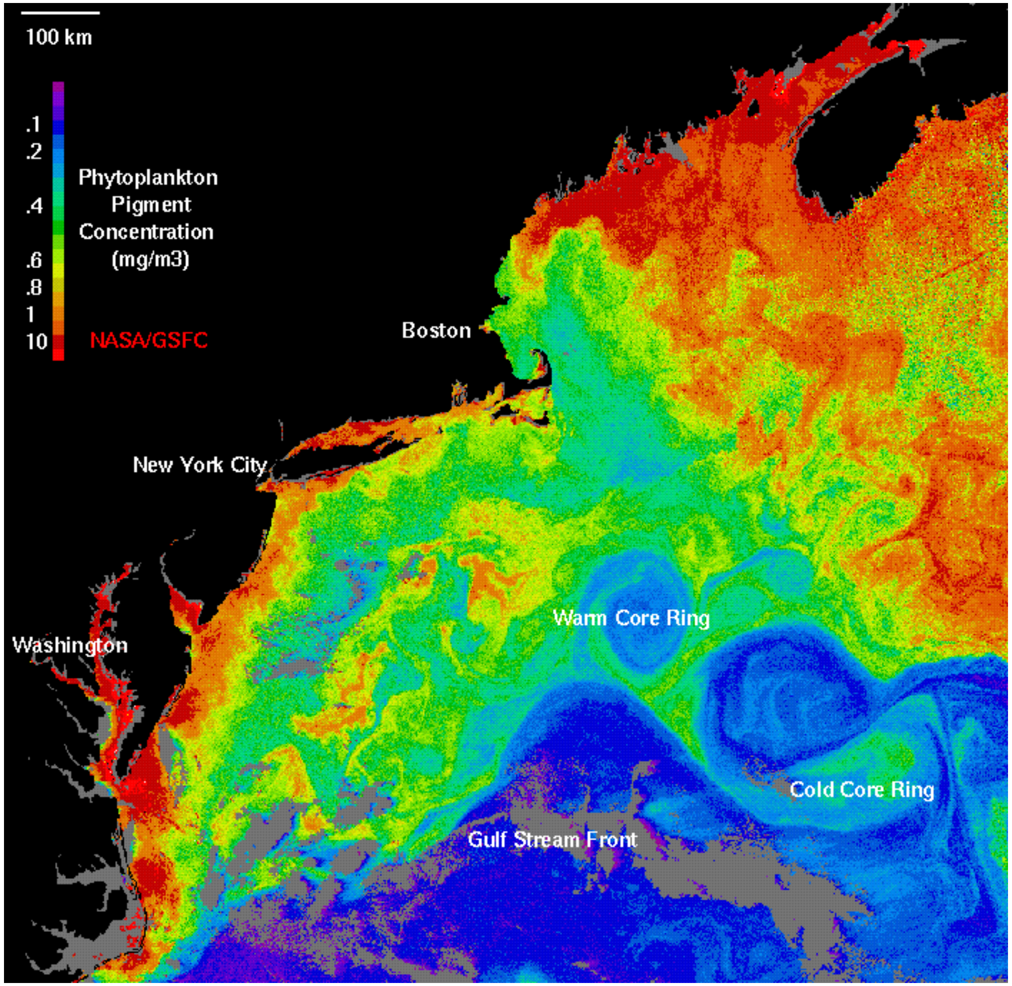


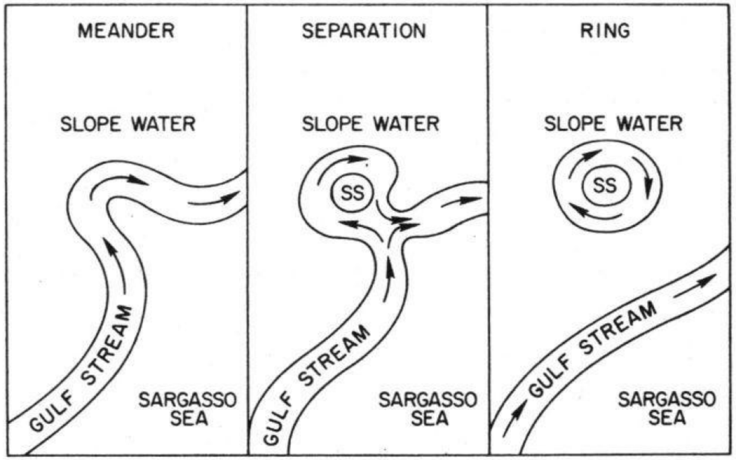
Exploring the Mechanisms Generating Observed Eddy Influence on Chlorophyll



Gaube *et al.*, 2014

Mechanisms of mesoscale physical-biological interaction: Trapped ecosystems



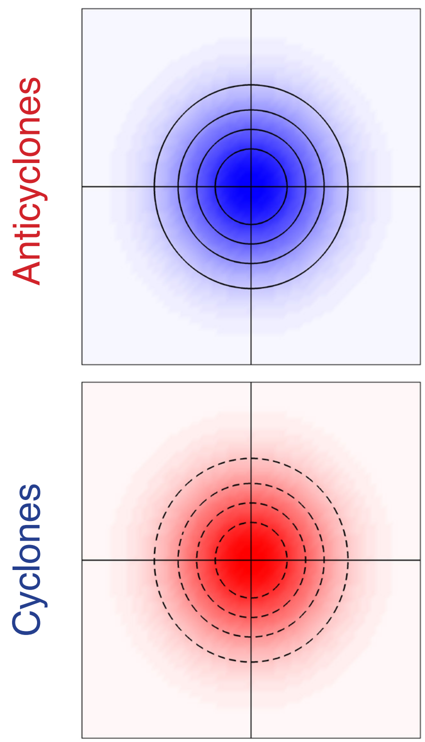


Warm Core Ring Executive Committee, 1982

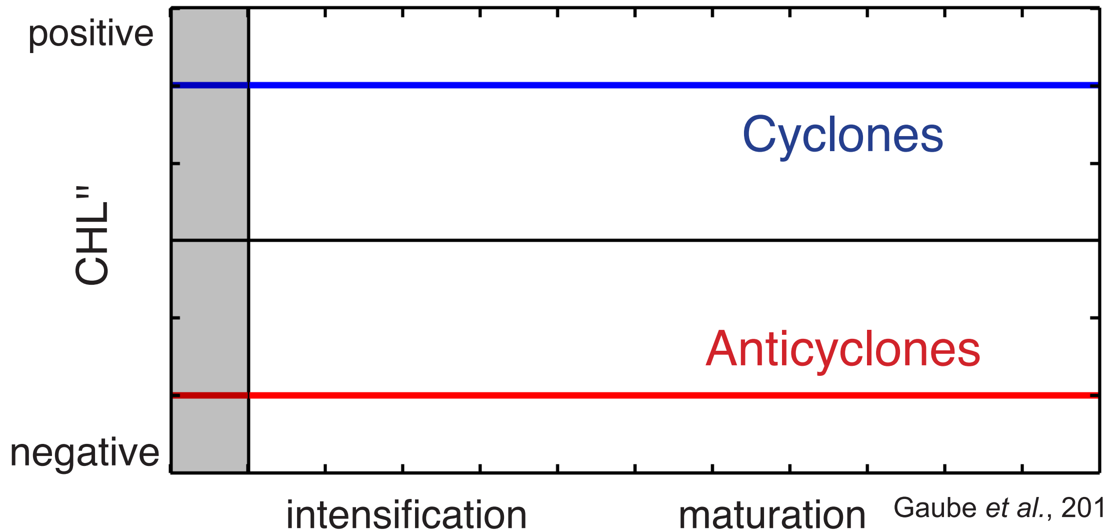
Mechanisms of Mesoscale Phys/Bio Interaction

Eddy Trapping

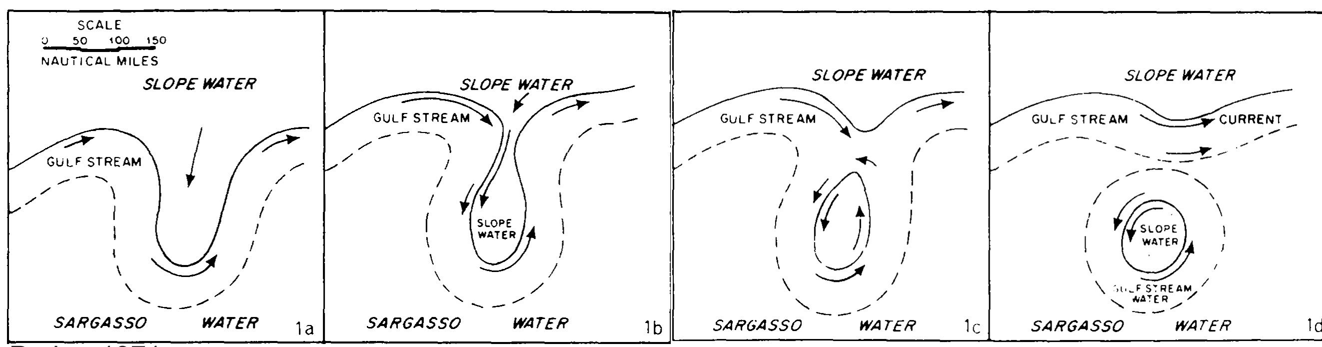
Idealized Composite Average



Idealized Composite Average
Time Series



Gaube *et al.*, 2014

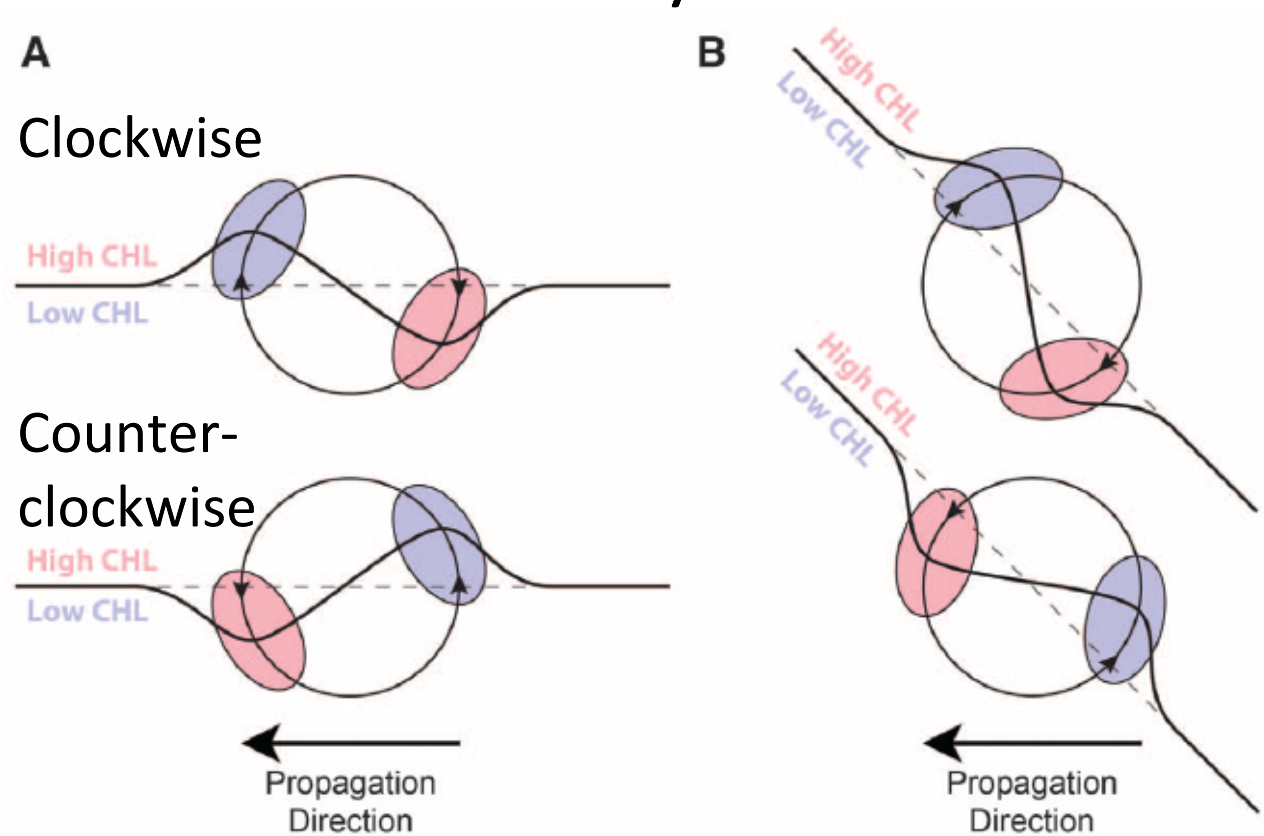


Parker 1971

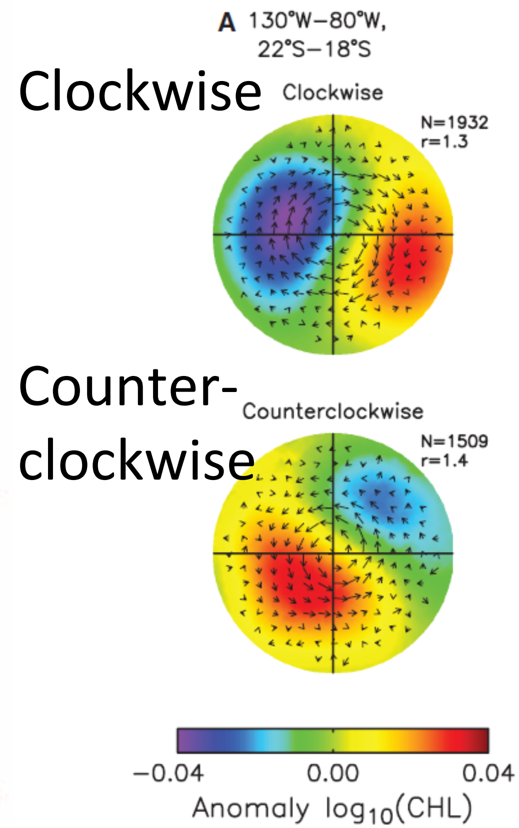
The sign of the CHL" resulting from the **trapping of CHL** is a function of the cross current CHL gradient.

Mechanisms of mesoscale physical-biological interaction: Eddy stirring

Theory



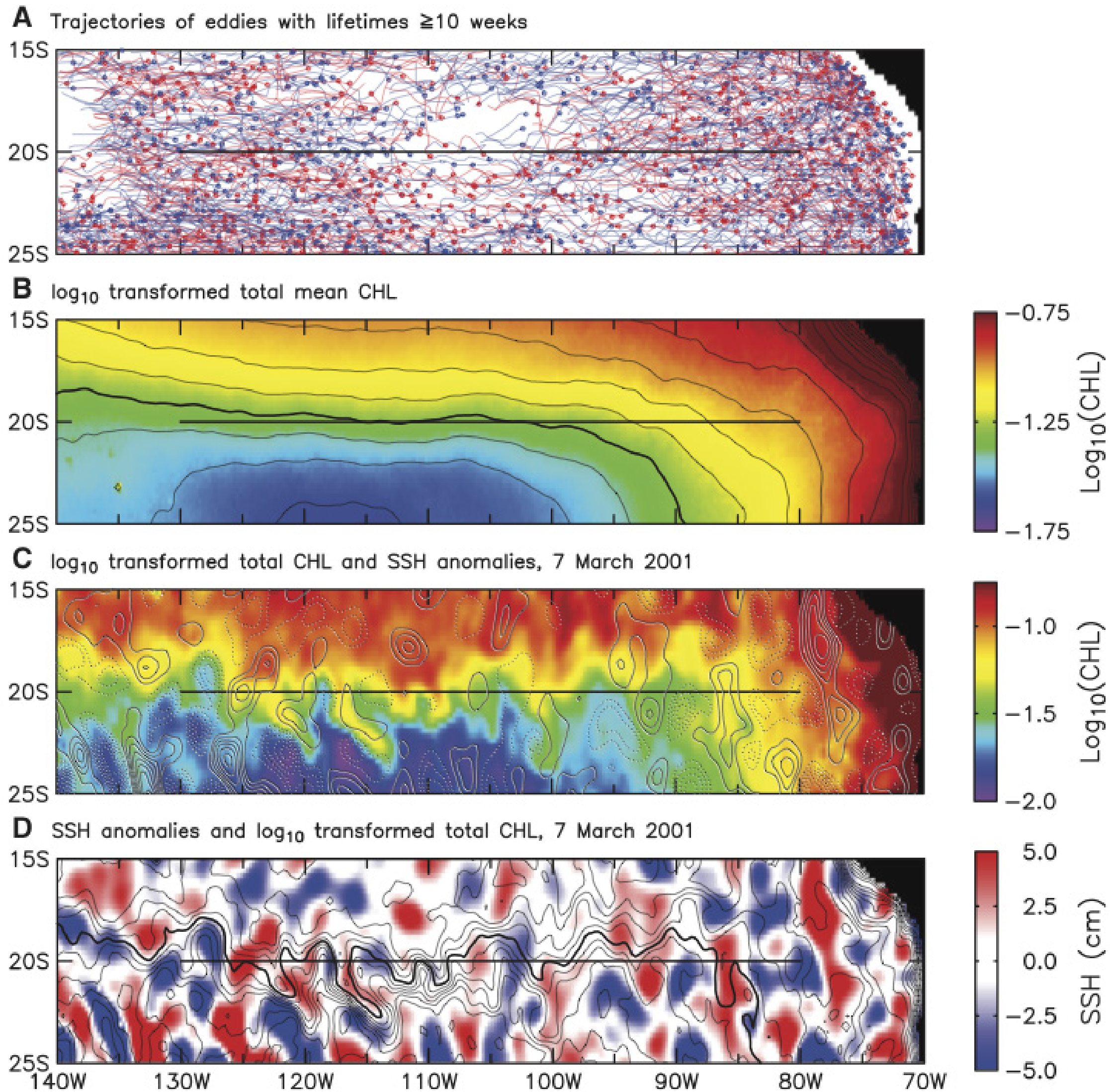
Observations



Chelton *et al.*, 2011a

Eddies of the South Pacific

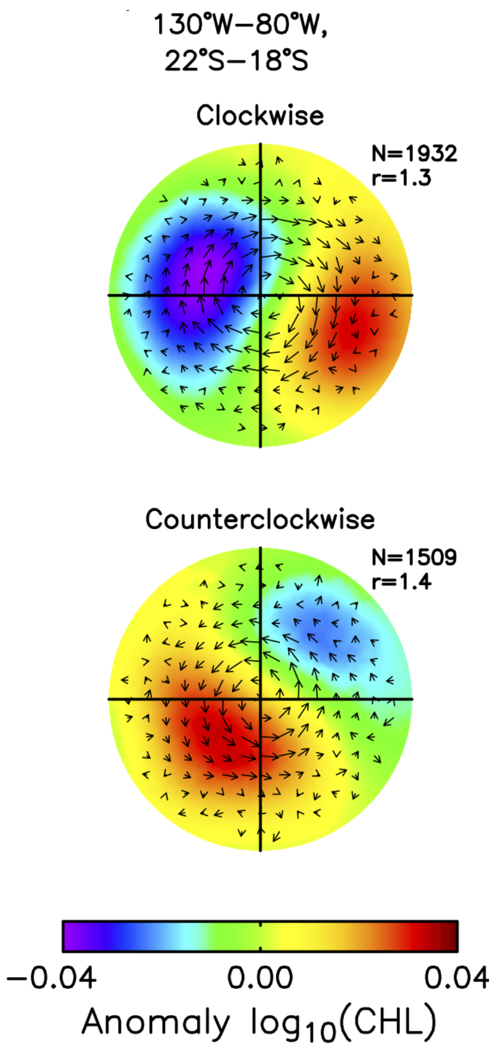
region investigated by Dandonneau et al., 2003; Killworth, 2004; Dandonneau et al., 2004 and Killworth et al., 2004



Chelton *et al.*, 2011a

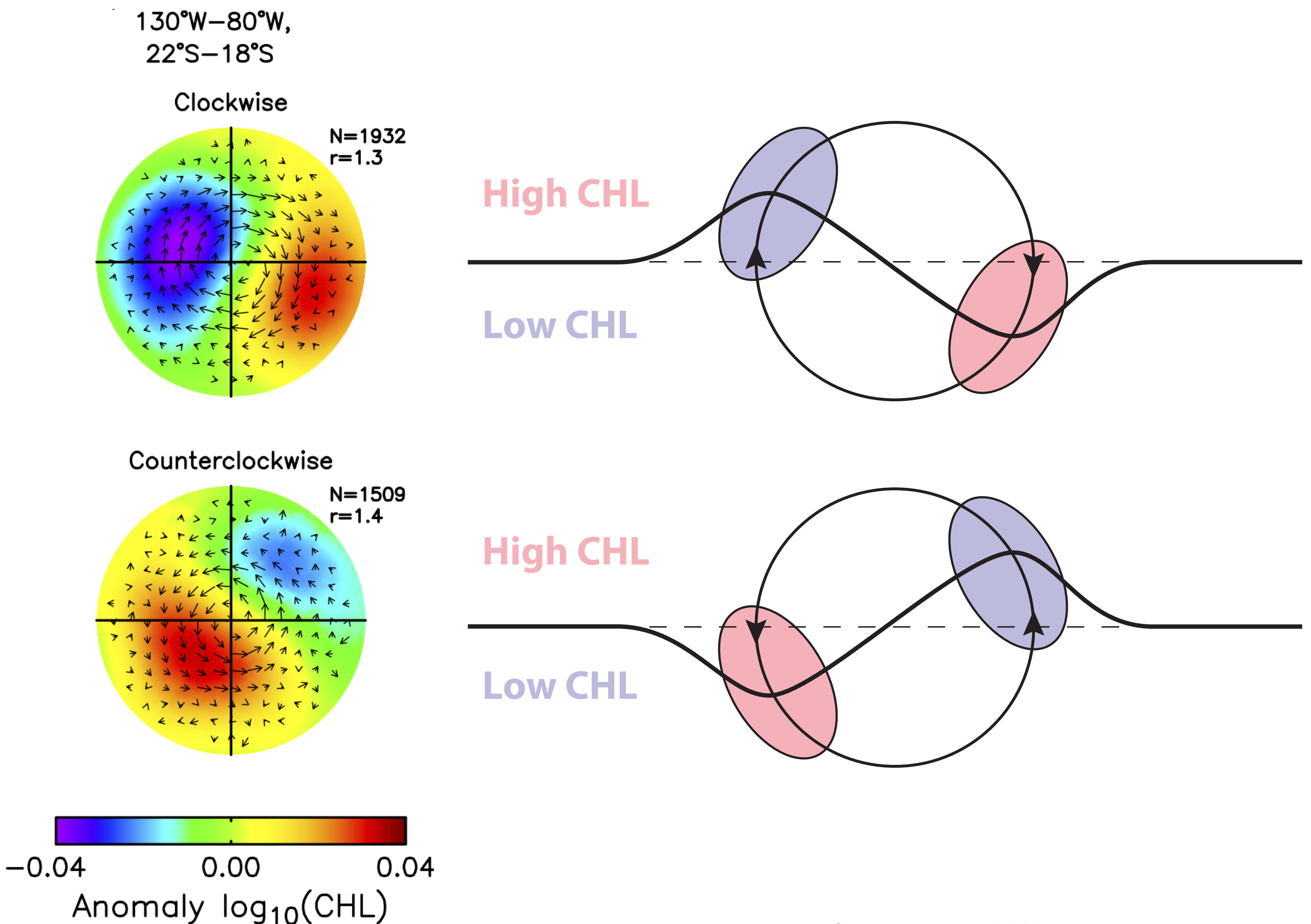
Eddy Composite Averages of Chlorophyll Anomaly

eddies along 20°S section



Eddy Composite Averages of Chlorophyll Anomaly

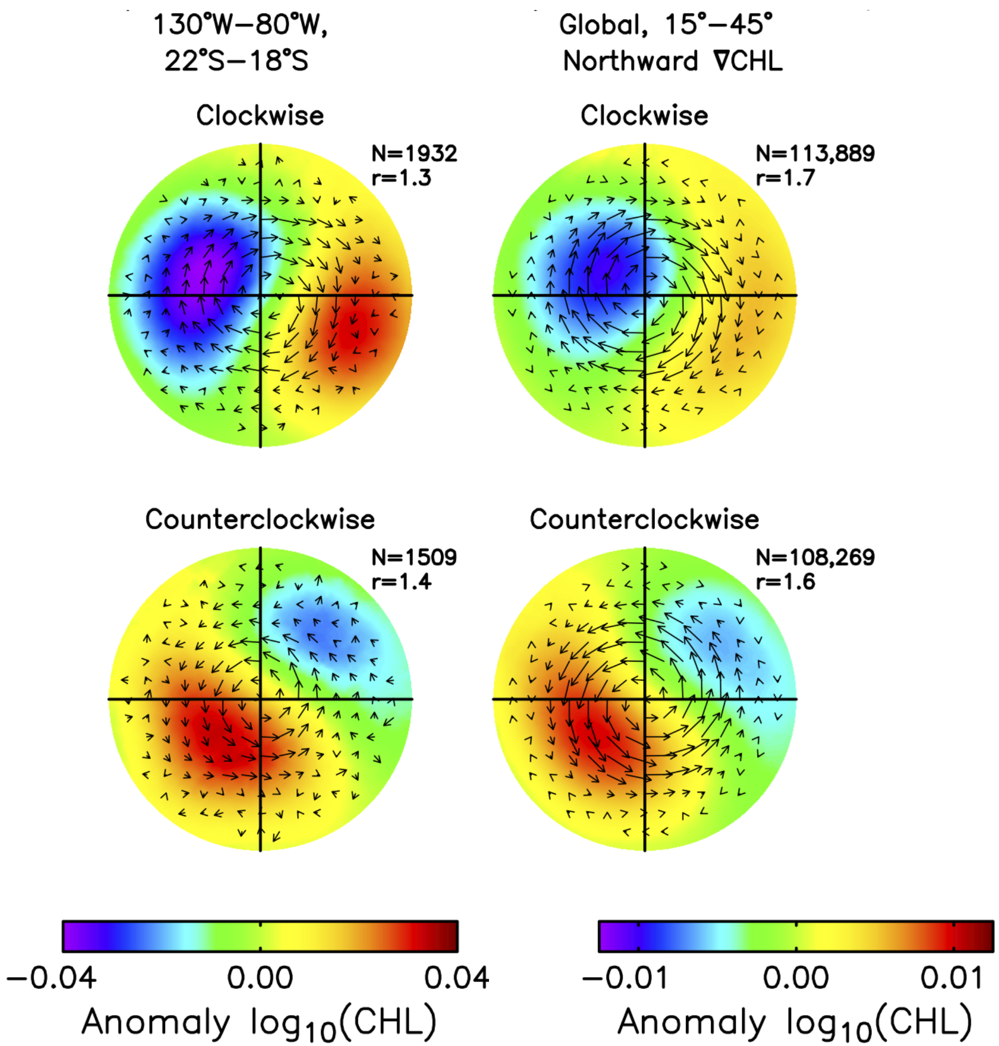
eddies along 20°S section



Chelton *et al.*, 2011a

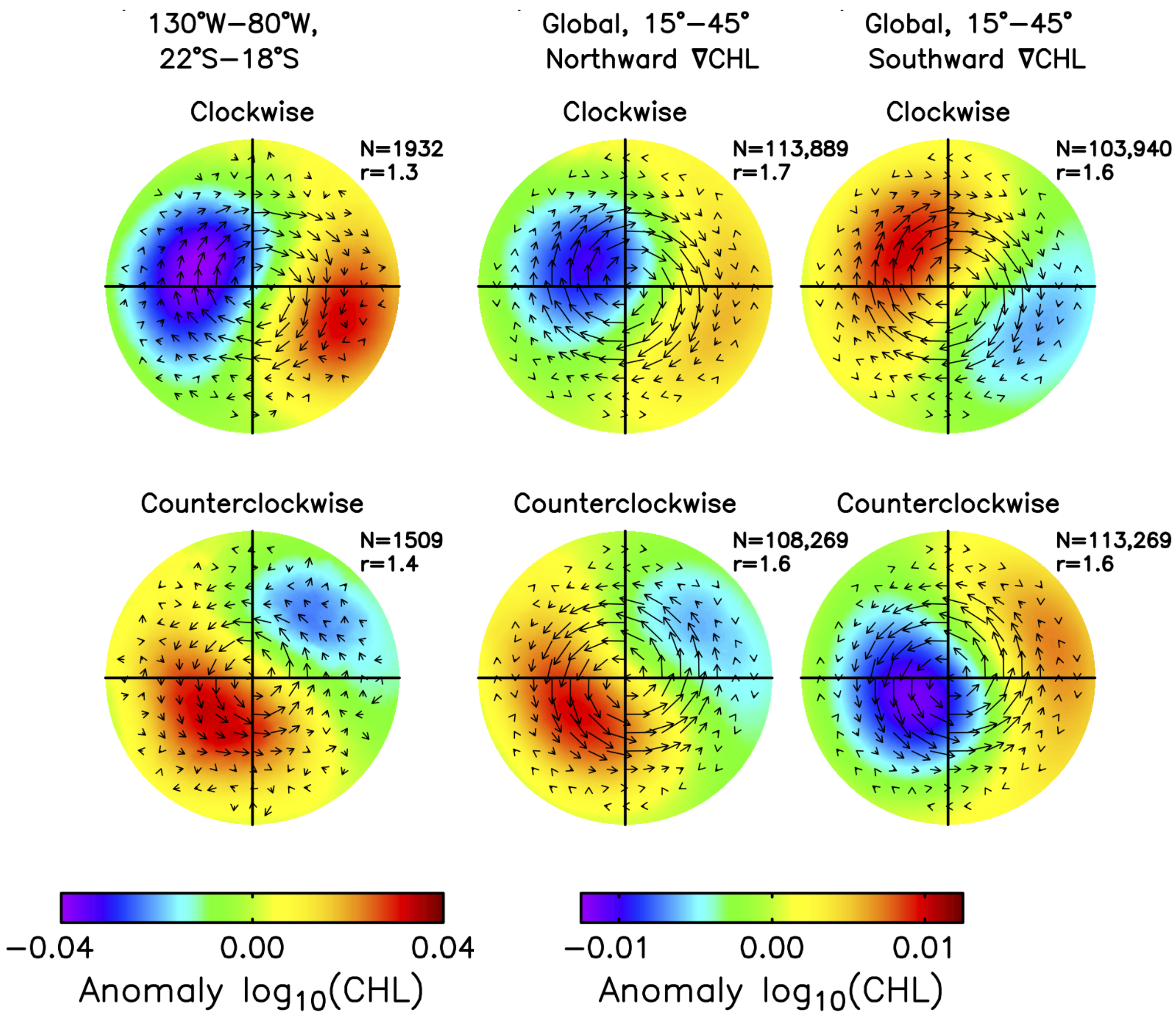
Global Composites of Chlorophyll Anomaly

northward CHL gradient



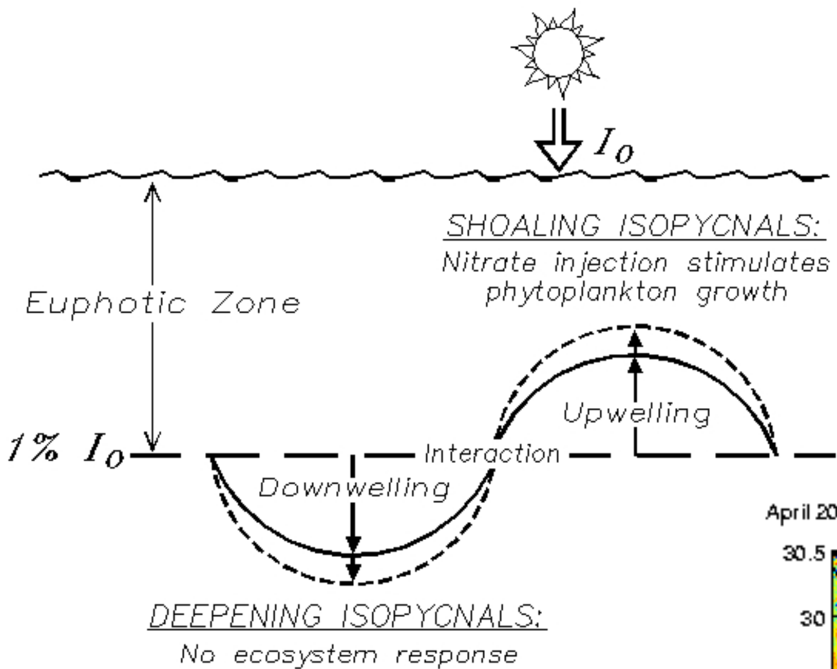
Global Composite of Chlorophyll Anomaly

northward and southward CHL gradient

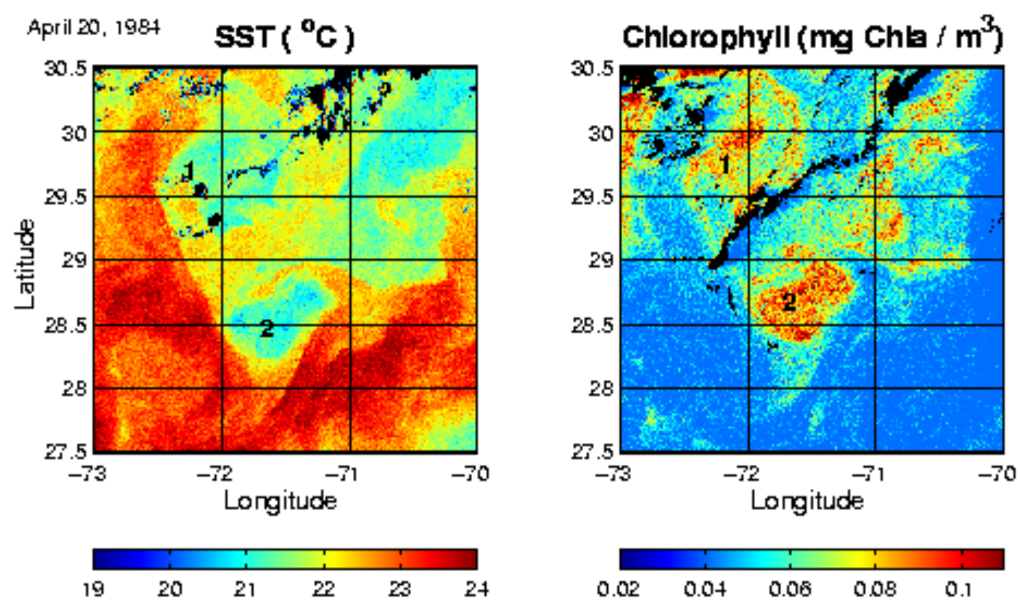


Chelton *et al.*, 2011a

Mechanisms of mesoscale physical-biological interaction: Eddy formation / intensification

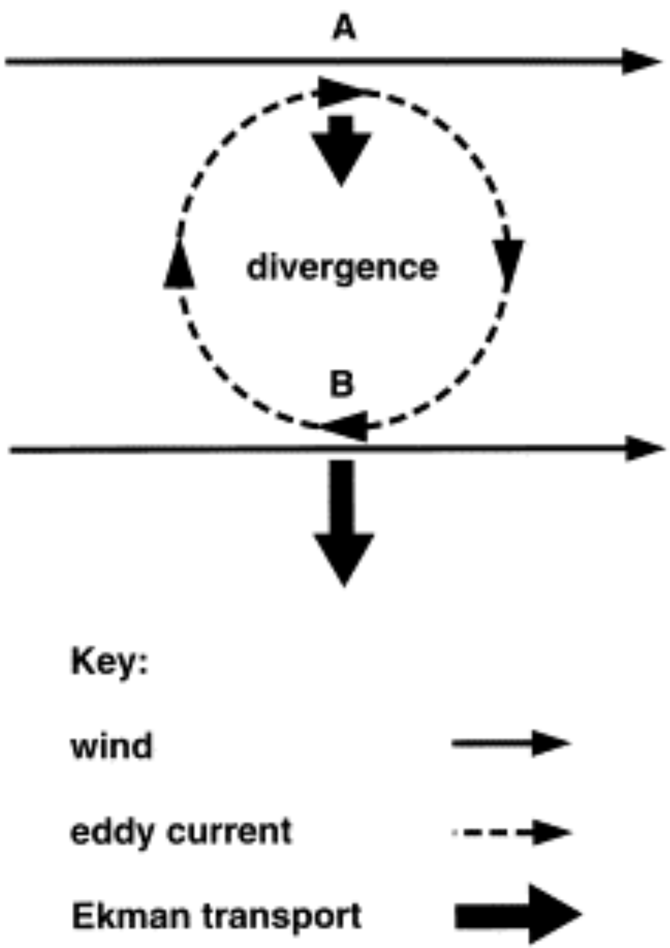


McGillicuddy and Robinson, 1997

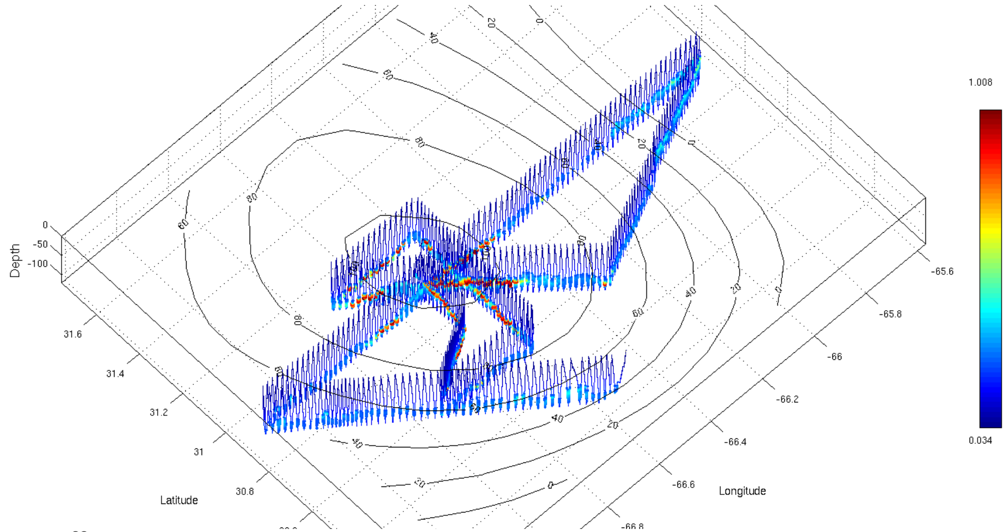


McGillicuddy et al., 2001

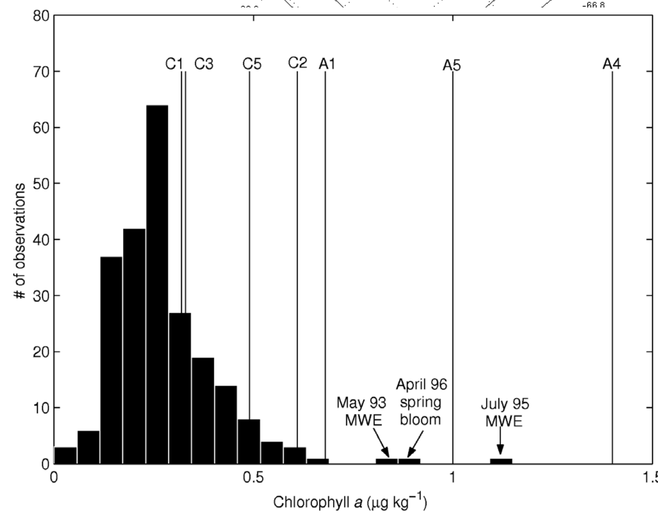
Mechanisms of mesoscale physical-biological interaction: Eddy-induced Ekman pumping



Dewar and Flierl, 1987
Martin and Richards, 2001



Fluorescence
µg Chl *a* L^{-1}



BATS Chl a 1988-2003

McGillicuddy et al., 2007

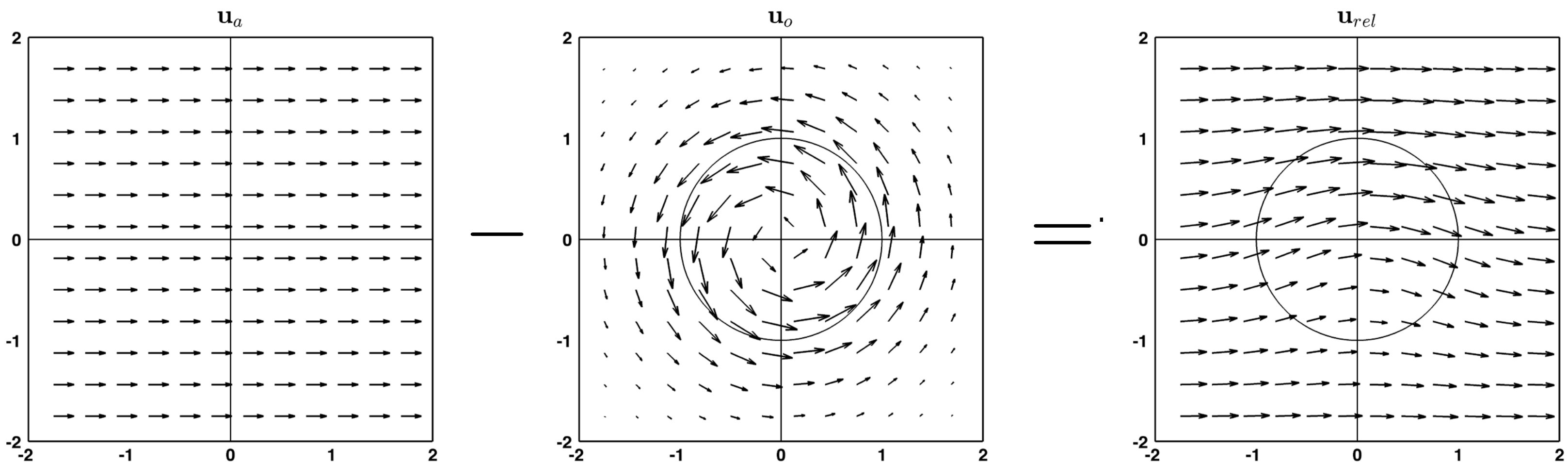
Surface Current-Induced Ekman Pumping

How it works:

- The surface currents of eddies impart a curl in the relative wind.

Dewar and Flier, 1987; Martin and Richards, 2001

Wind **Eddy Surface Currents** **Relative Wind**



$$\mathbf{u}_{rel} = \mathbf{u}_a - \mathbf{u}_o$$

$$\boldsymbol{\tau} = \rho_a C_D \mathbf{u}_{rel} |\mathbf{u}_{rel}|$$

$$W_{tot} = \frac{1}{\rho_o} \nabla \times \left(\frac{\boldsymbol{\tau}}{(f + \zeta)} \right)$$

Surface Current-Induced Ekman Pumping

$$
\begin{aligned}
W_{tot} &= \frac{1}{\rho_o} \nabla \times \left(\frac{\boldsymbol{\tau}}{(f+\zeta)} \right) \\
&= \frac{1}{\rho_o} \left[\frac{\nabla \times \boldsymbol{\tau}}{f+\zeta} - \frac{\boldsymbol{\tau} \times \nabla \zeta}{(f+\zeta)^2} - \frac{\boldsymbol{\tau} \times \nabla f}{(f+\zeta)^2} \right] \\
&= \underbrace{\frac{\nabla \times \boldsymbol{\tau}}{\rho_o (f+\zeta)}}_{\mathrm{W_c}} - \underbrace{\frac{1}{\rho_o (f+\zeta)^2} \left(\tau^y \frac{\partial \zeta}{\partial x} - \tau^x \frac{\partial \zeta}{\partial y} \right)}_{\mathrm{W}_\zeta} + \underbrace{\frac{\beta \tau^x}{\rho_o (f+\zeta)^2}}_{\mathrm{W}_\beta}
\end{aligned}
$$

- Surface current-induced Ekman pumping
- Dominant term at scale ≥O(100 km)

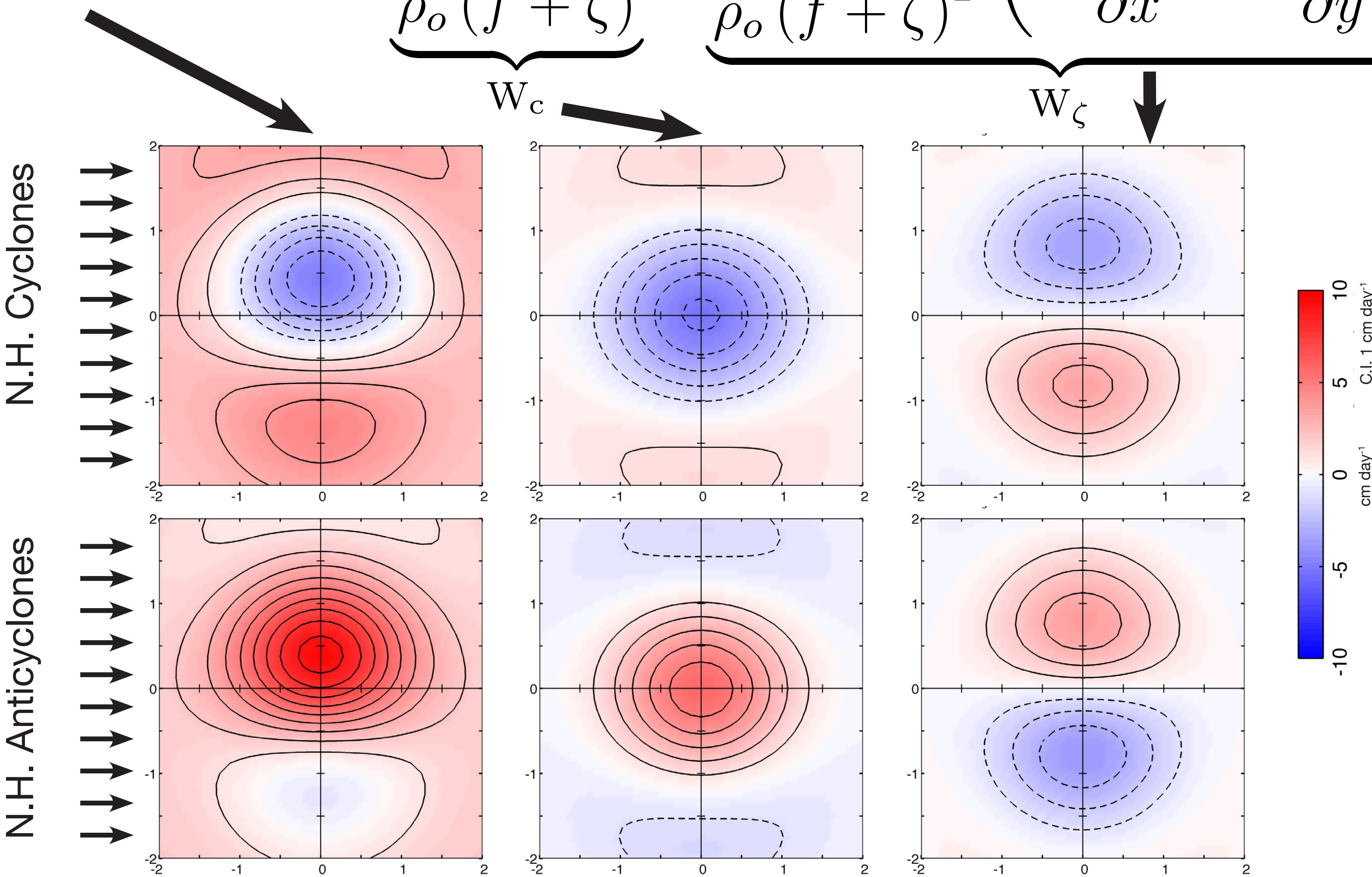
- Vorticity gradient-induced Ekman pumping
- Dominant term at scale ~ O(10 km)

-"Beta" Ekman pumping
- Negligeable at scale < O(100 km)

Gaube *et al.*, (2015)

Surface Current-Induced Ekman Pumping

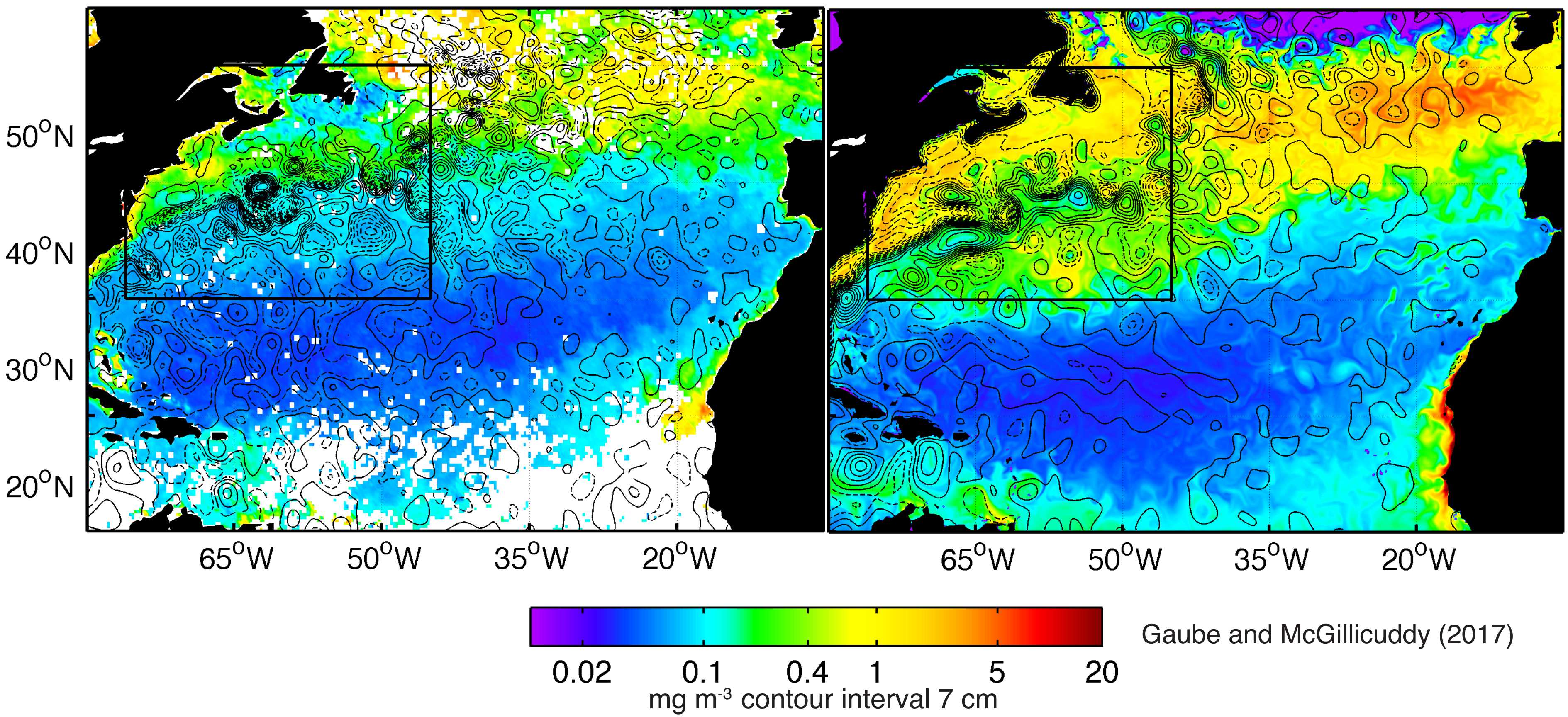
$$W_{tot} = \underbrace{\frac{\nabla \times \boldsymbol{\tau}}{\rho_o (f + \zeta)}}_{W_c} - \underbrace{\frac{1}{\rho_o (f + \zeta)^2} \left(\tau^y \frac{\partial \zeta}{\partial x} - \tau^x \frac{\partial \zeta}{\partial y} \right)}_{W_\zeta}$$



Surface Chlorophyll and Sea Level Anomalies in the North Atlantic Ocean

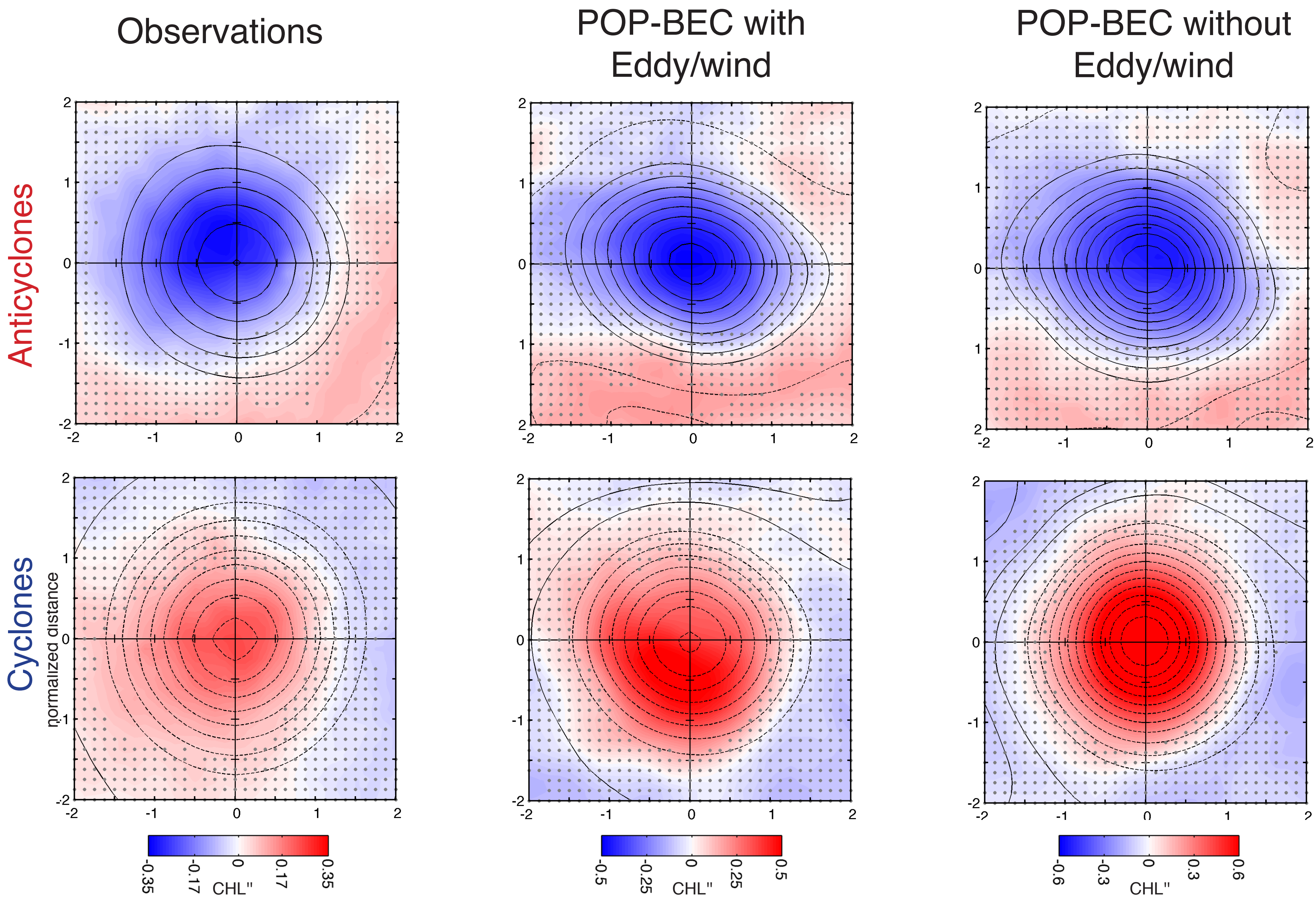
SeaWiFS $\log_{10}$(CHL) and AVISO SLA
June 6th, 1998

BEC $\log_{10}$(CHL) at surface and POP SLA
June 14th



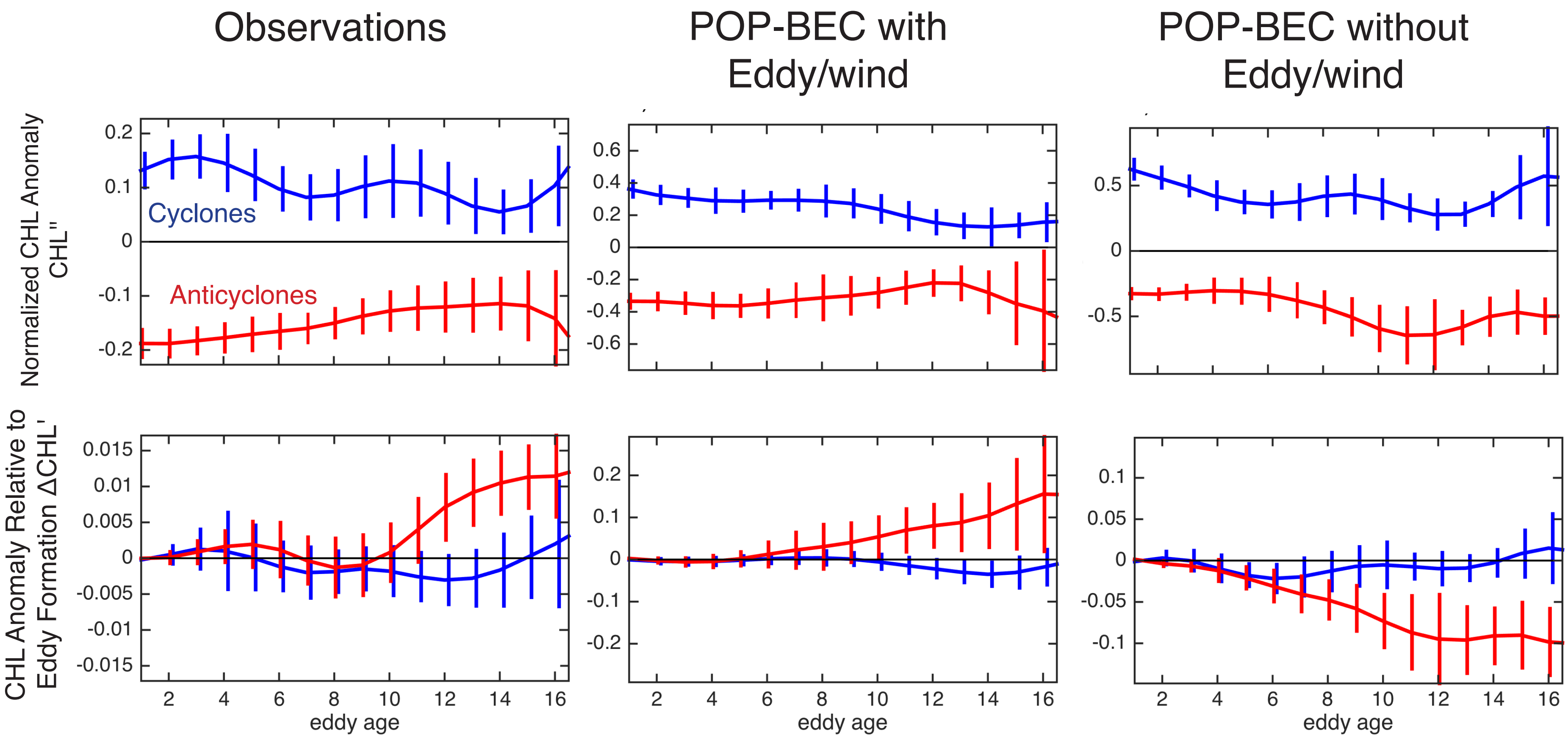
BEC=**B**iogeochemical **Ec**osystem Model: 3-phytoplankton types and 1-zooplankton.
Limiting nutrients nitrate (NO_3), ammonium (NH_4), phosphate (PO_4), iron (Fe), and silicate (SiO_3).

Composite Averages of CHL Anomalies in Westward Propagating Eddies



The Evolution of CHL in Gulf Stream Eddies

CHL anomalies averaged within the interiors of eddies as a function of time since eddy formation

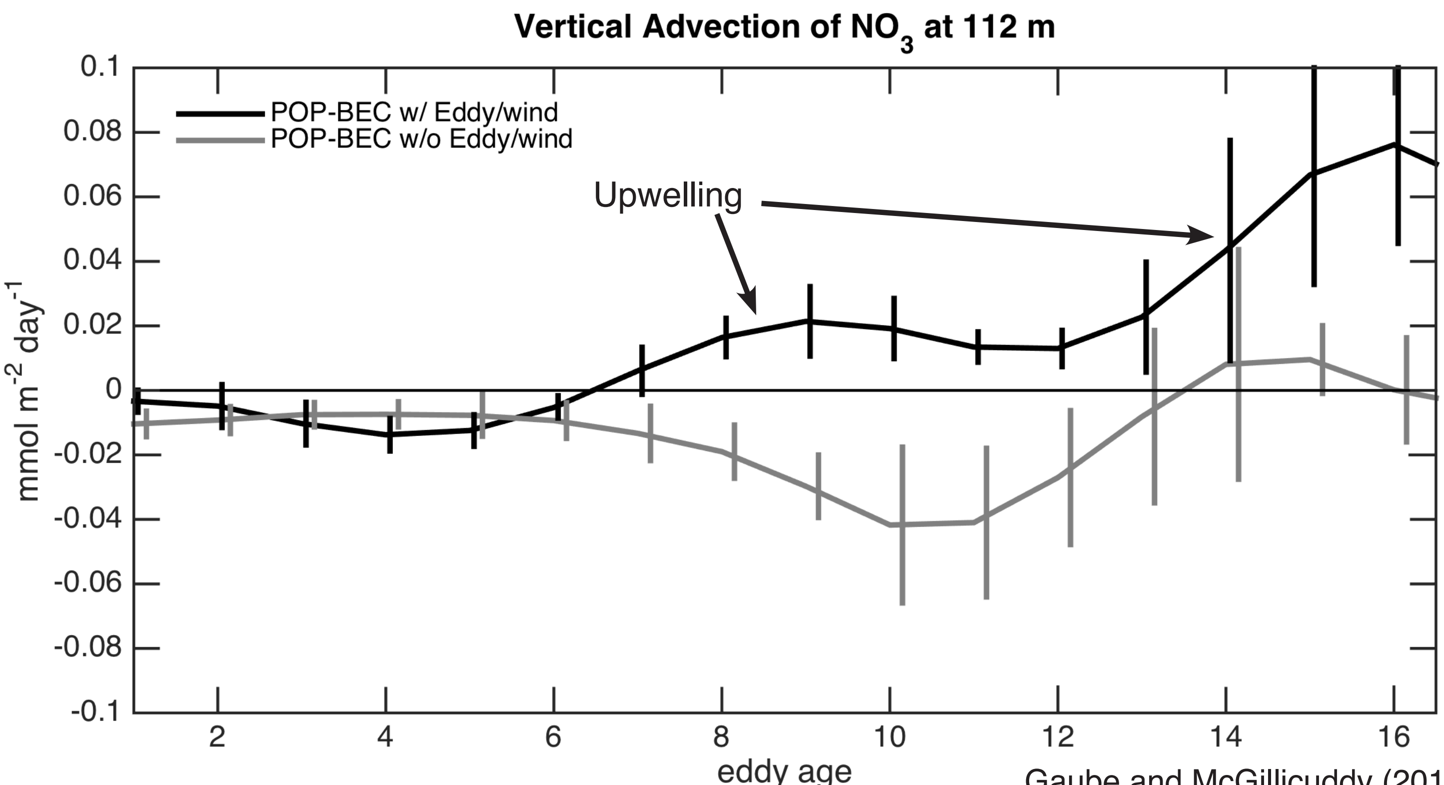


$$\Delta CHL'(x,y,t) = CHL'(x,y,t) - CHL'(x,y,t_0)$$
$$= [CHL(x,y,t) - \langle CHL(x,y,t)\rangle] - [CHL(x,y,t_0) - \langle CHL(x,y,t_0)\rangle]$$

Gaube and McGillicuddy (2017)

Vertical Nitrate Advection in Gulf Stream Eddies

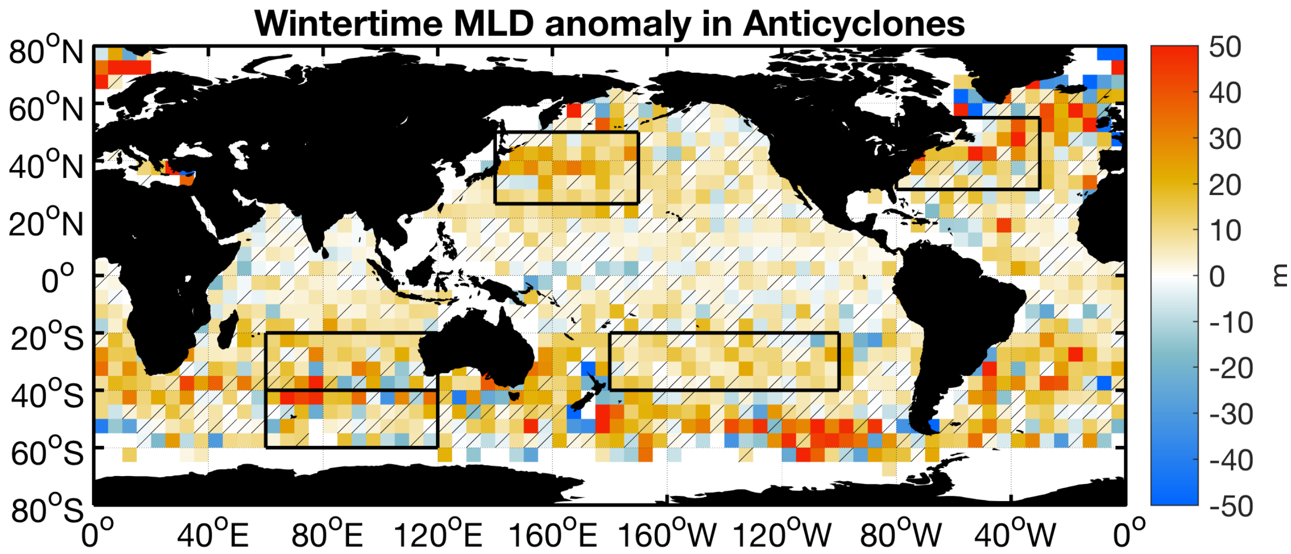
From the POP-BEC solution

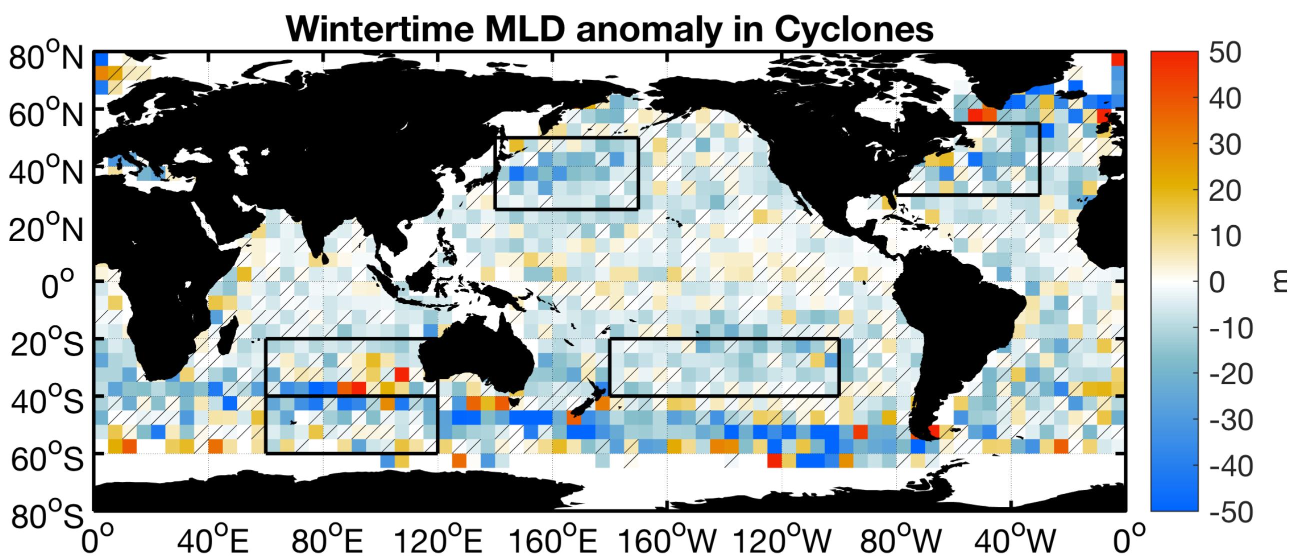


Gaube and McGillicuddy (2017)

- Upwelling of NO_3 begins at week 7 and becomes signficant at week 8 in model that includes eddy-induced Ekman pumping.
- The CHL response starts at at week 6-7, but does not become signififant until week 11 (15 days later).

Eddy-mediated MLD modulations

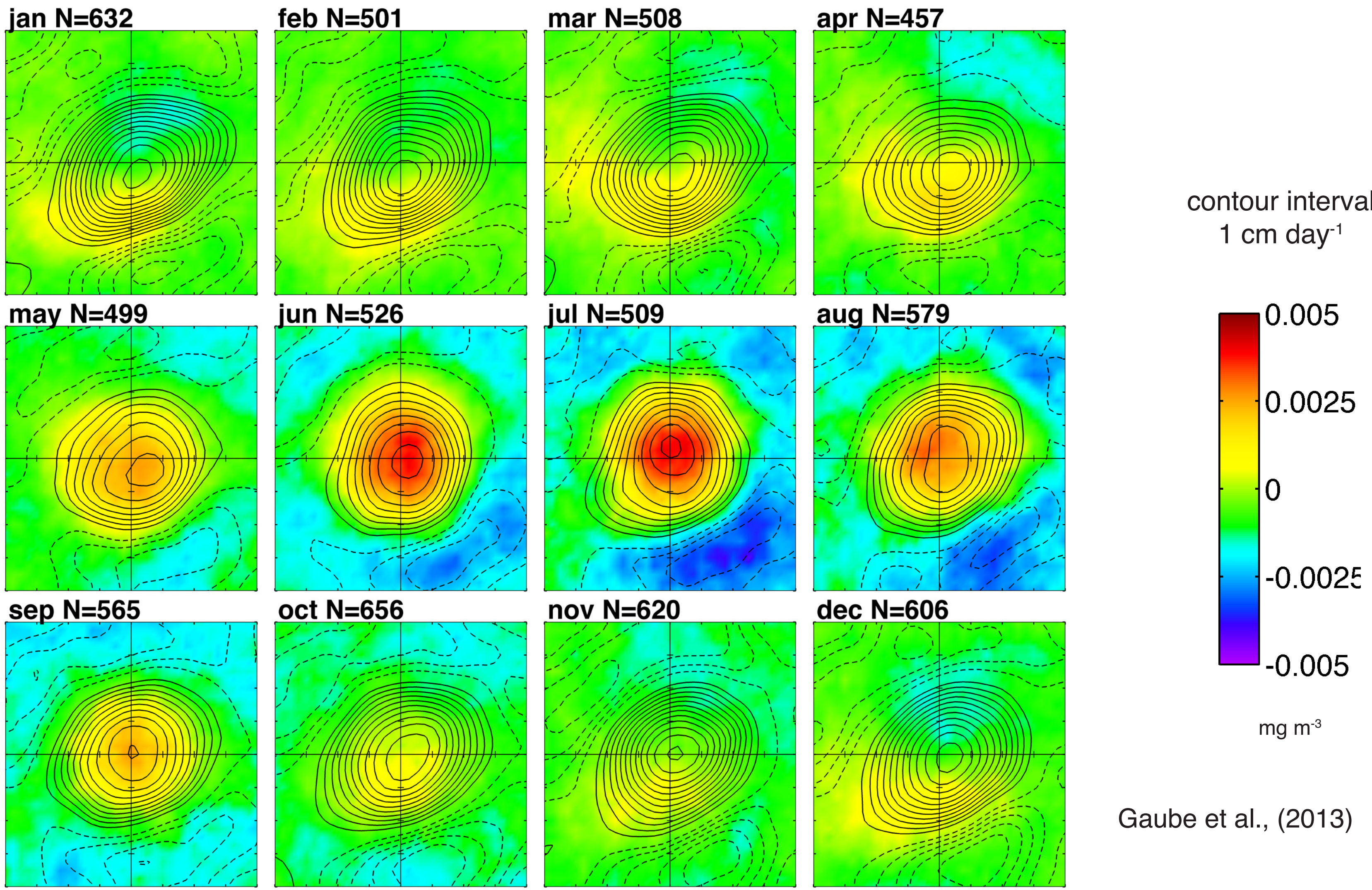




Gaube et al., (in prep)

Composite Averaged Chlorophyll Anomalies by Month

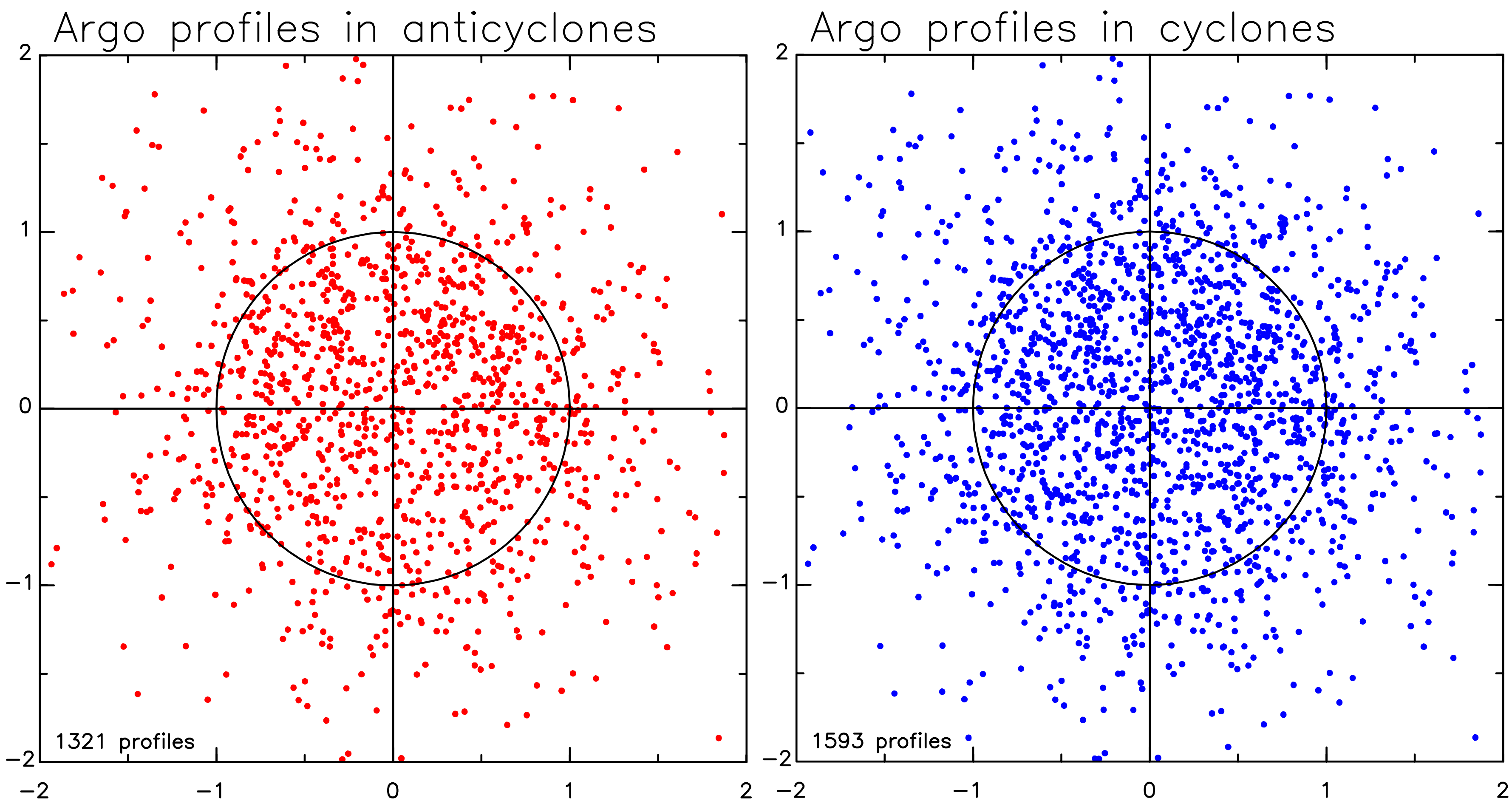
filtered SeaWiFS chlorophyll with contours of QuikSCAT Ekman pumping (anticyclones)



What is driving the seasonality of CHL anomalies in the interiors of South Indian Ocean anticyclones?

Argo Float Profiles within South Indian Ocean Eddies

Argo profiles from which MLD seasonal cycles are calculated

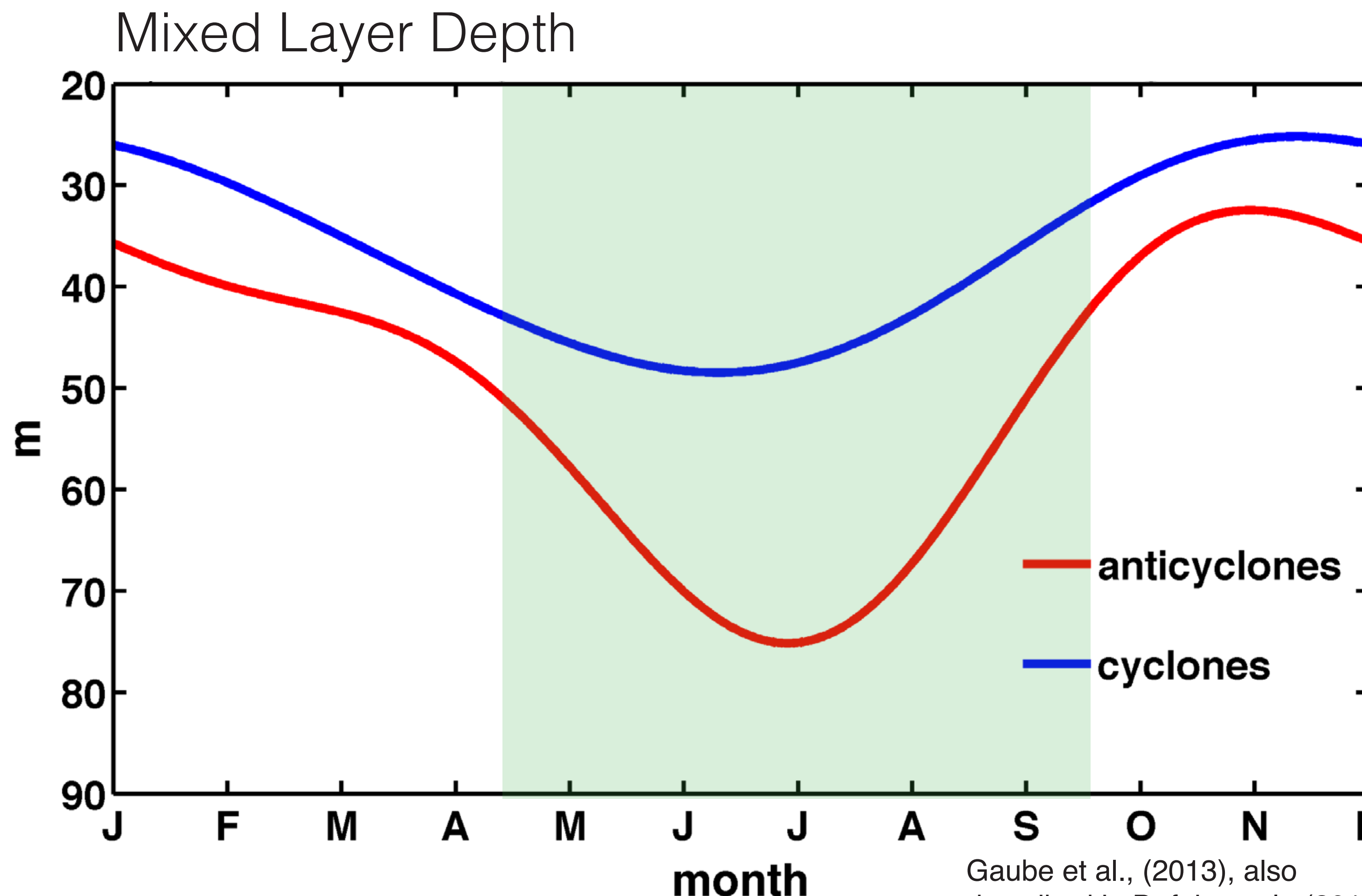


Seasonal cycles of MLD are calculated from the above profiles as a function of eddy polarity.

Seasonal Cycle of Mixed Layer Depth in Eddies

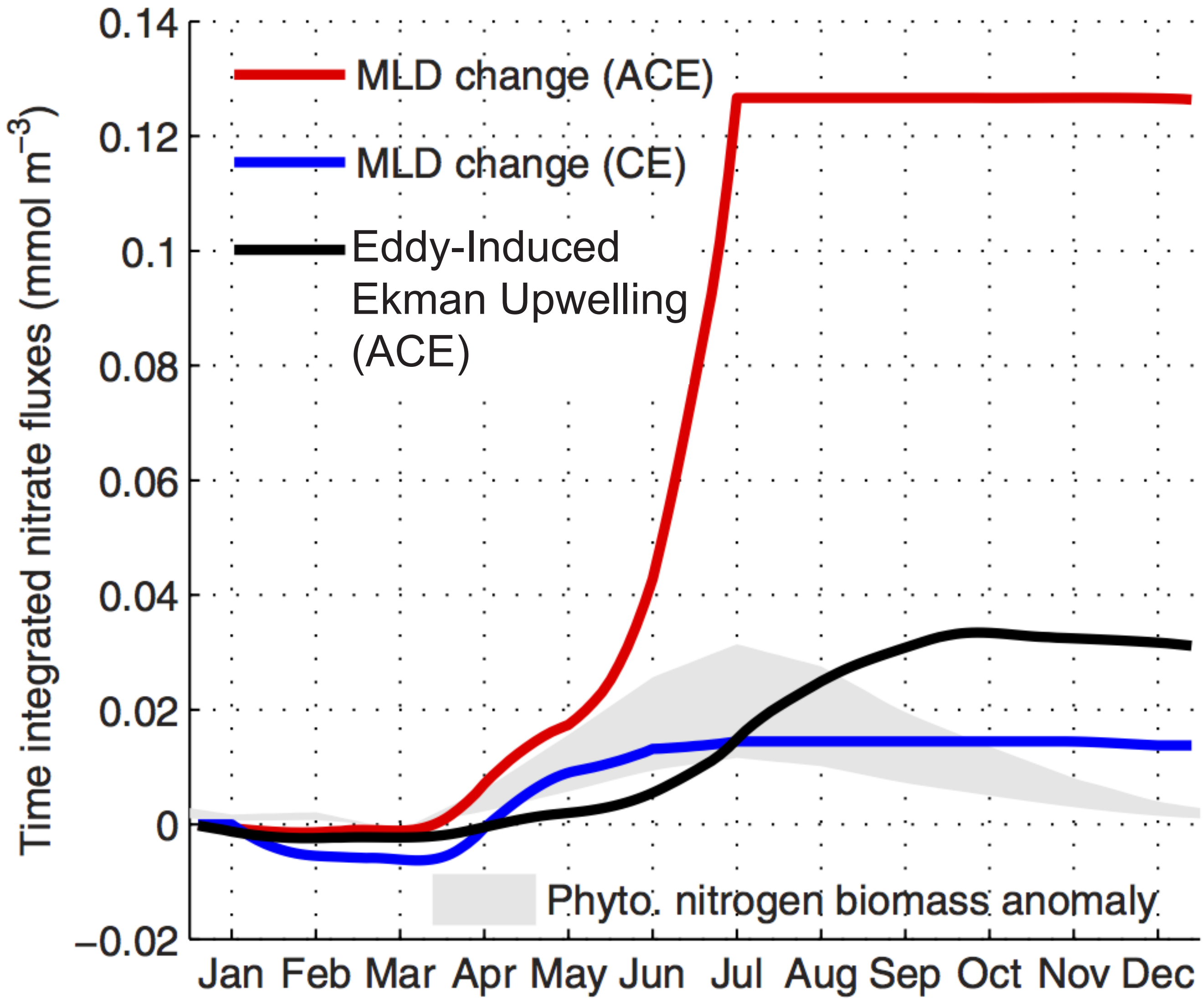
MLD from Argo float profiles

(Holte and Talley, 2009, http://mixedlayer.ucsd.edu/)



Gaube et al., (2013), also described in Dufois et al., (2014)

Integrated Nitrate Flux
Resulting from Deeper Mixing in Anticyclones



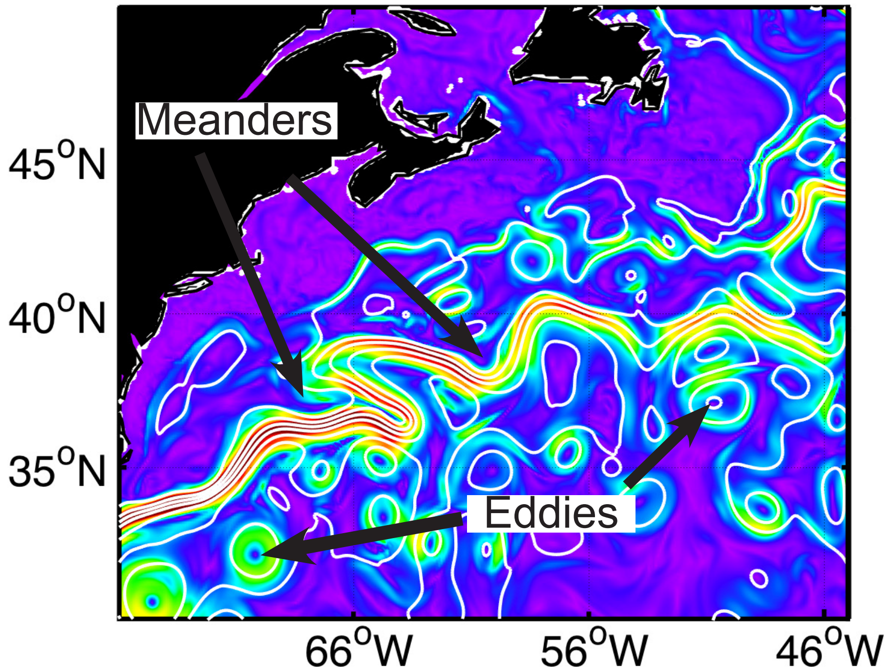
Dufois et al., (2014)

Summary and Conclusions

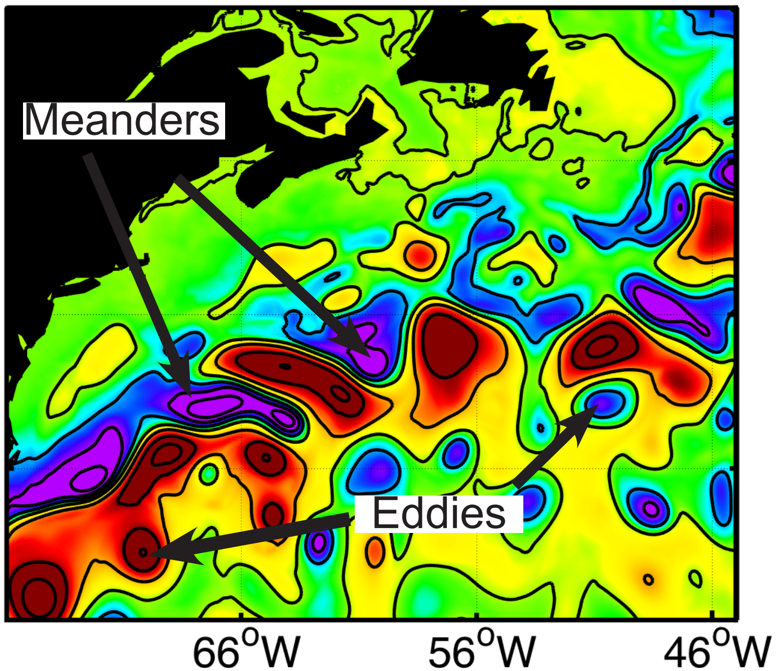
- Mechanisum of mesoscale physical/biological interaction can be classifed as:
    1. The advection ecosystmes and nutrients horizontally
    2. Vertical fluxes of ecosystems and nutrients
    3. Eddy-induced pertibation of near-surface mixing
-
- Globally, eddy stiring dominates the observed impact of eddies on CHL
- Our anaysis reveals that multiple mesoscale mechanisusm inflaunce the observed response of CHL to eddies in a given region
- By combining satellite and in situ observations, we are now able to estiamted the eddy-impact on near-surface mixing

Differentiating Eddies and Meanders in the Gulf Stream Region

Current Speed and
Total Sea Surface Height



Sea Level Anomaly



- Coherent mesoscale structures are identified and tracked in fields of sea level anomaly.
- Meanders appear as closed contours in sea level anomaly
- The propagation direction of meanders and eddies are used to differentiate them.