Satellite Observations of Eddy-Induced Ekman Pumping

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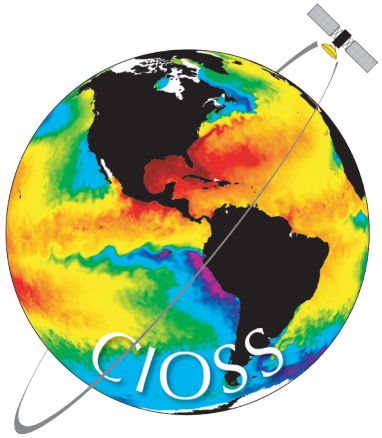
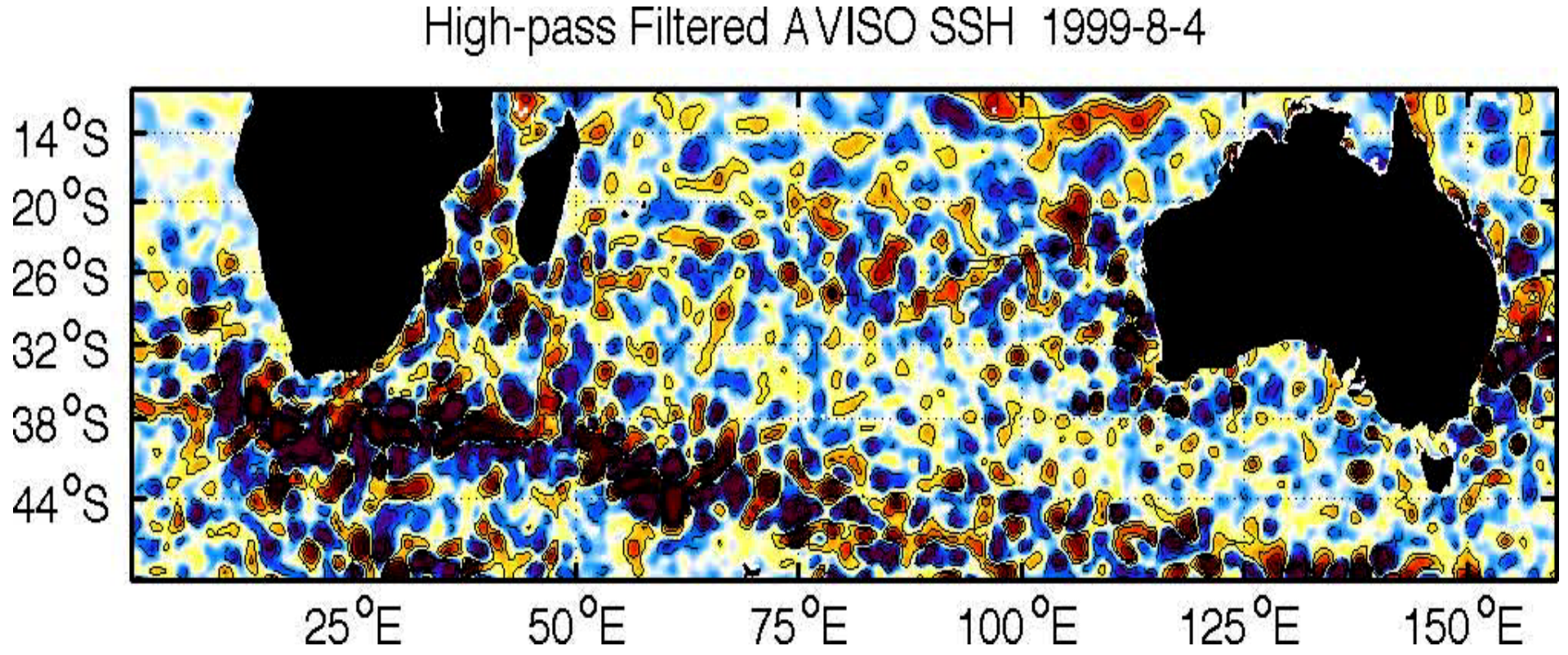


Ekman Pumping in Eddy Interiors*

1. Observations of mesoscale ocean eddies
2. What is eddy-induced Ekman pumping?
(Martin and Richards, 2001; McGillicuddy *et al.*, 2007)
3. Can we observe a biological response to this upwelling?

*as identified by the automated eddy tracking procedure of Chelton *et al.*, 2010

Animation of Mesoscale Ocean Eddies

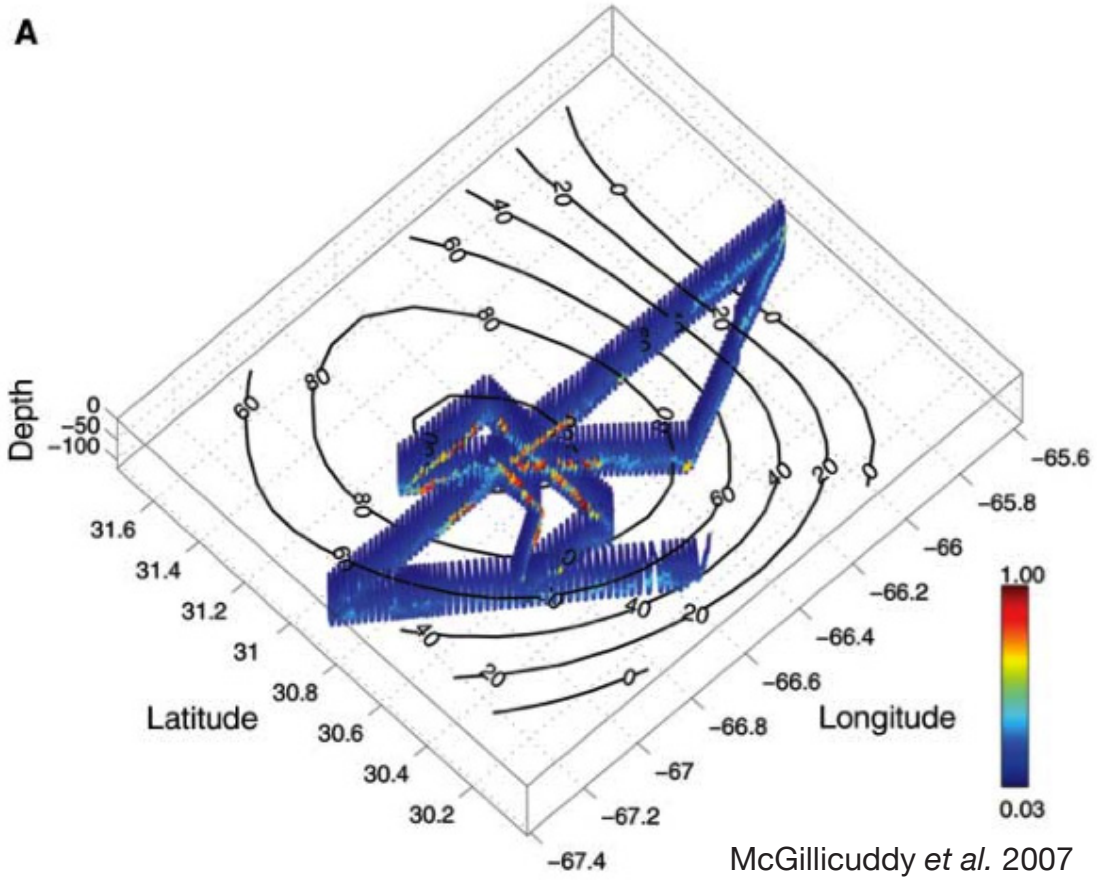


Why are Mesoscale Eddies Important?

- Mesoscale eddies are **ubiquitous** features of the World's oceans.
- It has been estimated that the **kinetic energy** due to **mesoscale** processes is an **order of magnitude greater** than that due to large scale ocean currents (Richardson 1983).
- Eddies provide a significant portion of the **meridional heat flux** in the ocean (Qiu and Chen 2005, Roemmich and Gilson 2001).
- Nutrient input to the euphotic zone due to **mesoscale eddies** has been cited as one of the mechanisms providing the "**missing nitrogen source**" responsible for the midlatitude spring blooms of phytoplankton (McGillicuddy *et al.* 1998).

Eddy-Induced Ekman Pumping

Eddy/wind interaction (first described by Martin and Richards in 2001) was invoked to explain the **anomalous phytoplankton bloom** observed during an intensive ship survey of a **mode-water anticyclonic eddy** in the North Atlantic.
(McGillicuddy et al. 2007)



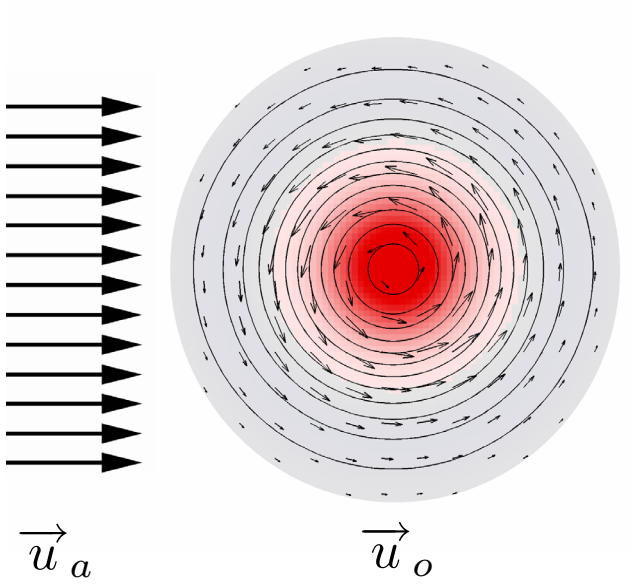
McGillicuddy *et al.* 2007

Eddy-Induced Ekman Pumping

Eddies can induce Ekman pumping in a uniform wind field.

How it works:

Eddy Vorticity



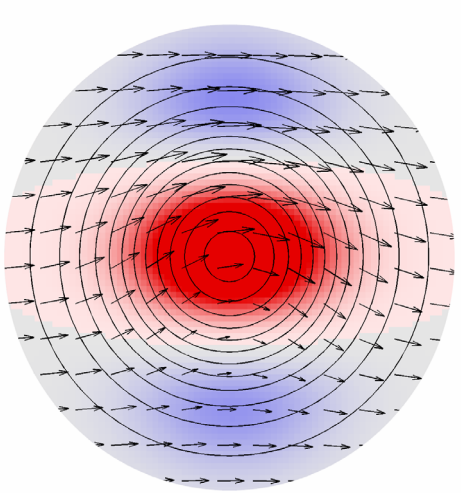
$\vec{u}_a$ $\vec{u}_o$

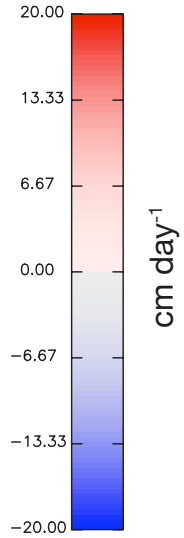
$$\vec{\tau} = \rho C_D |u_{rel}| \vec{u}_{rel}$$

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

scatterometers measure $\vec{u}_{rel}$

Ekman Pumping





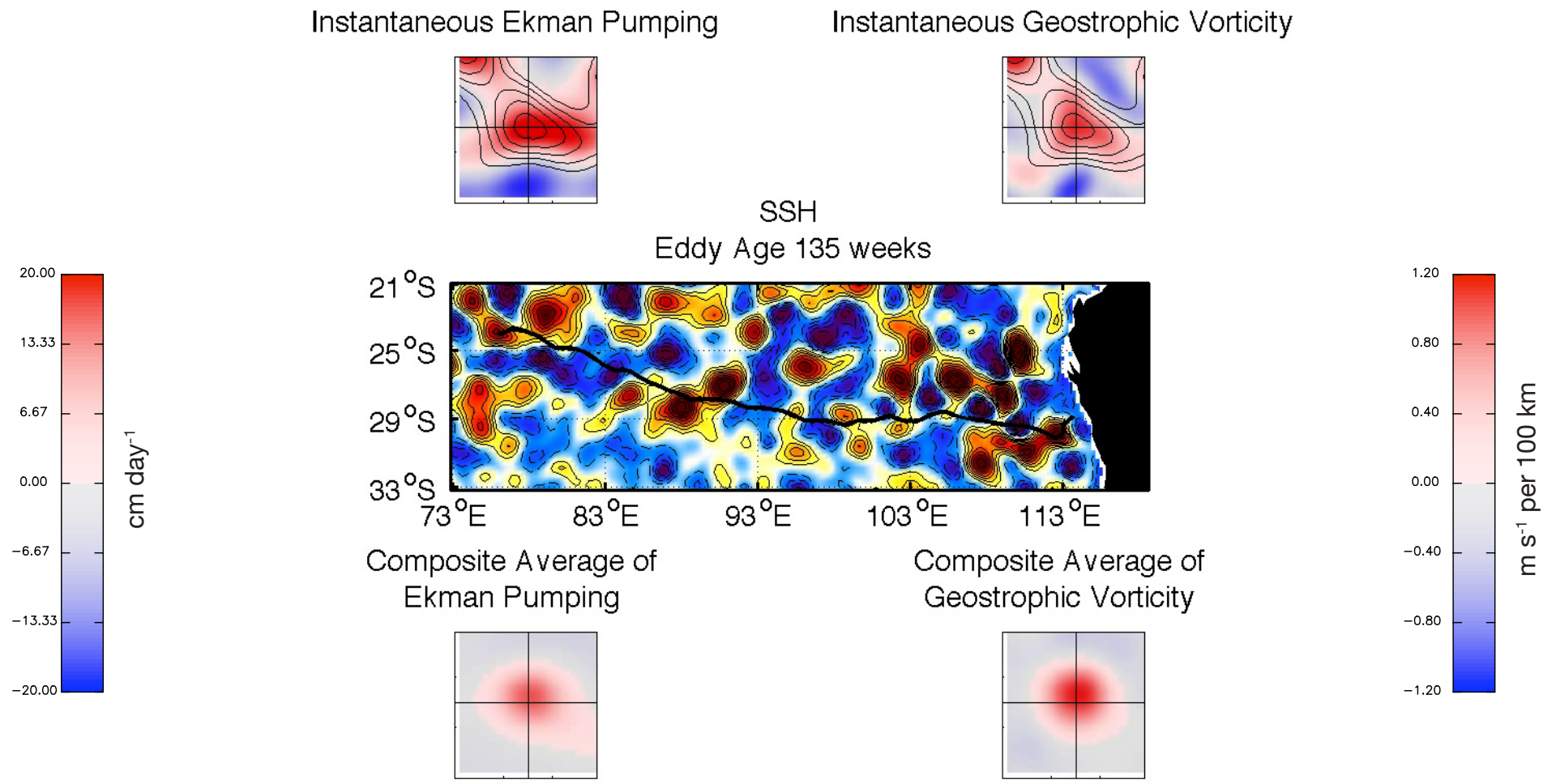
$$W_E = \frac{1}{\rho f} \nabla \times \vec{\tau}$$

Wind speed 7 m s^{-1}

Max eddy velocity ~ 30 cm s^{-1}

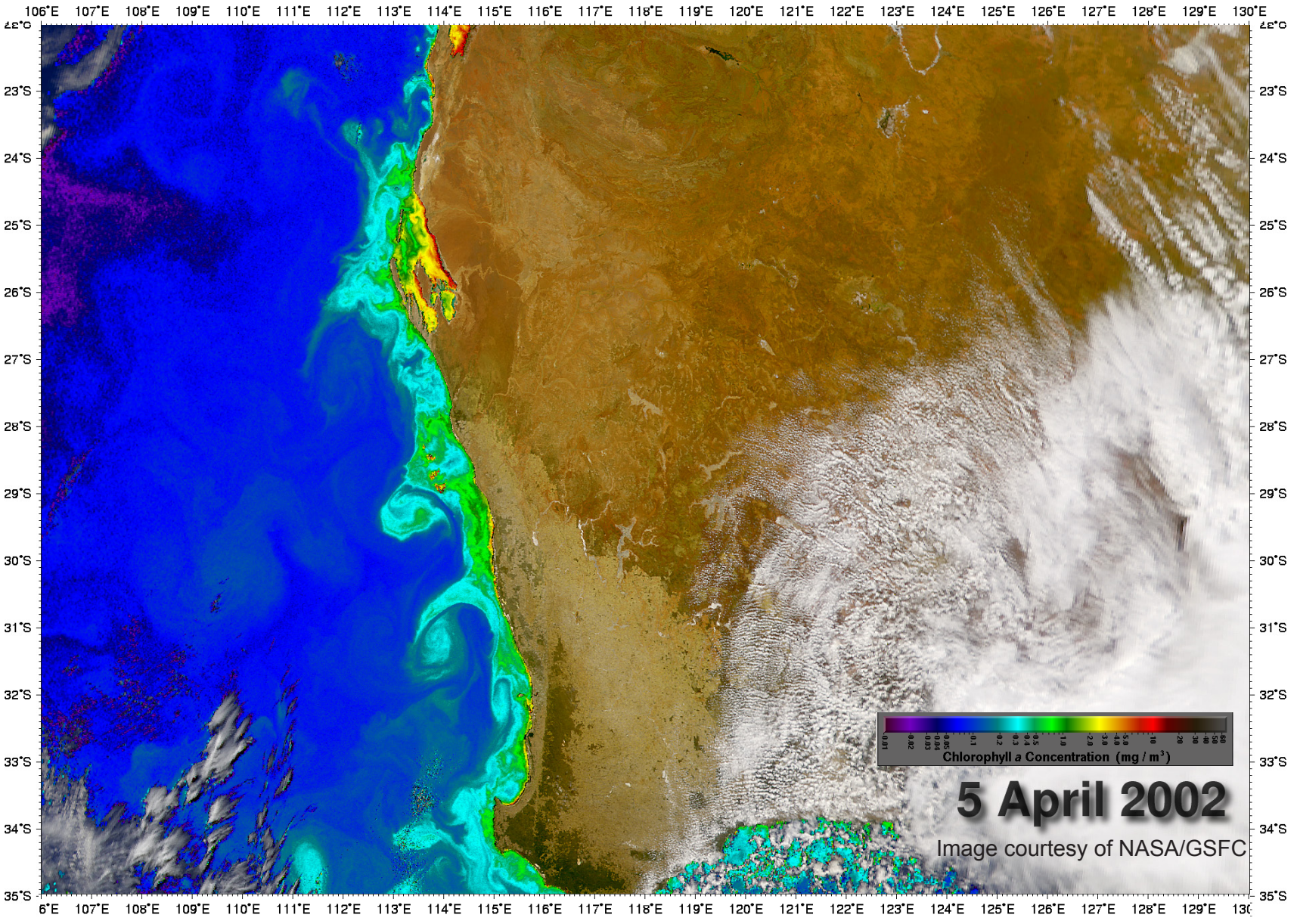
Case Study: Indian Ocean Anticyclone

6x6 high-pass filtered vorticity and Ekman pumping

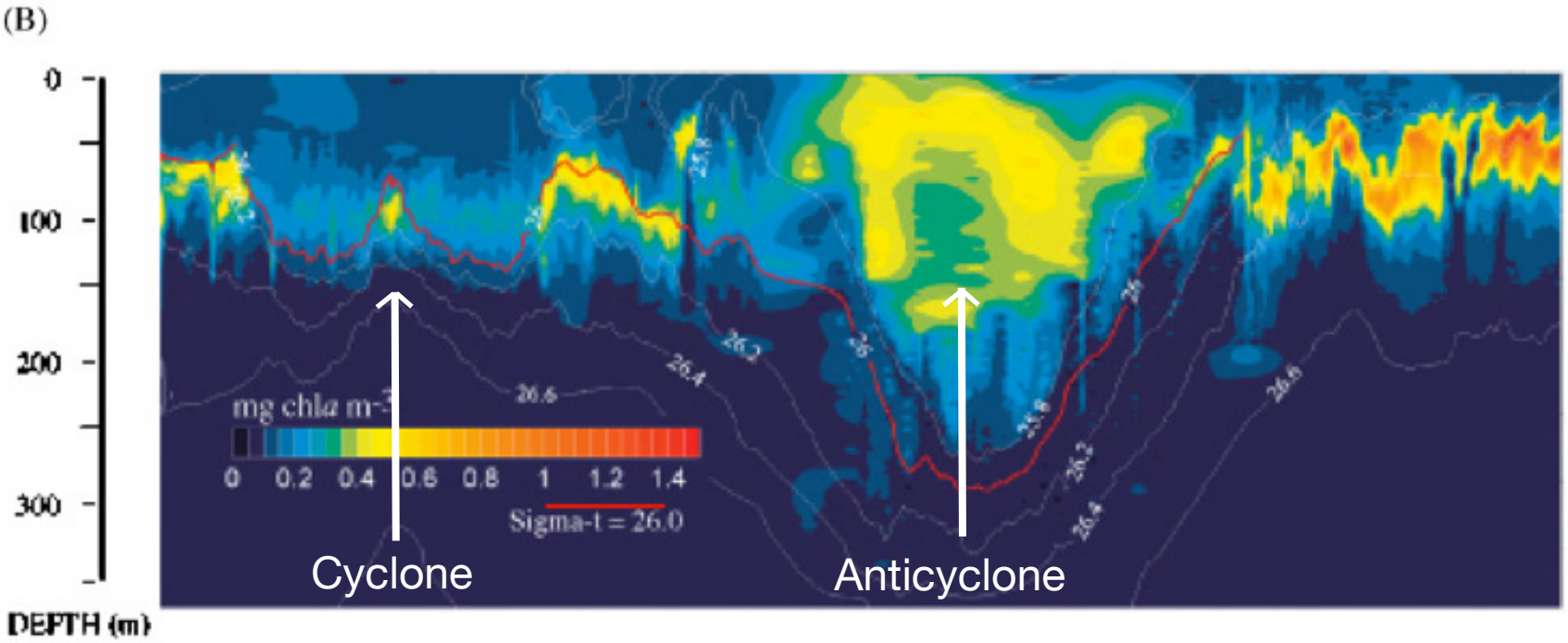


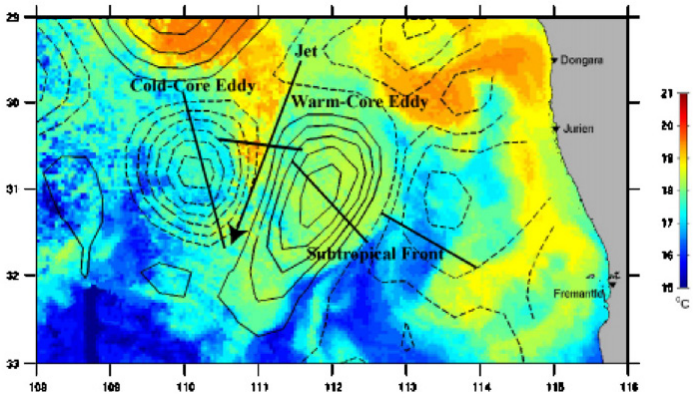
Elevated CHL in Leeuwin Current Anticyclones

SeaWiFS True Color with Chlorophyll-a Overlaid



Transect of an Anticyclone and Cyclone in the Leeuwin Current





Waite *et al.* (2007b) figure 5, b and c

Elevated CHL in Leeuwin Current Anticyclones

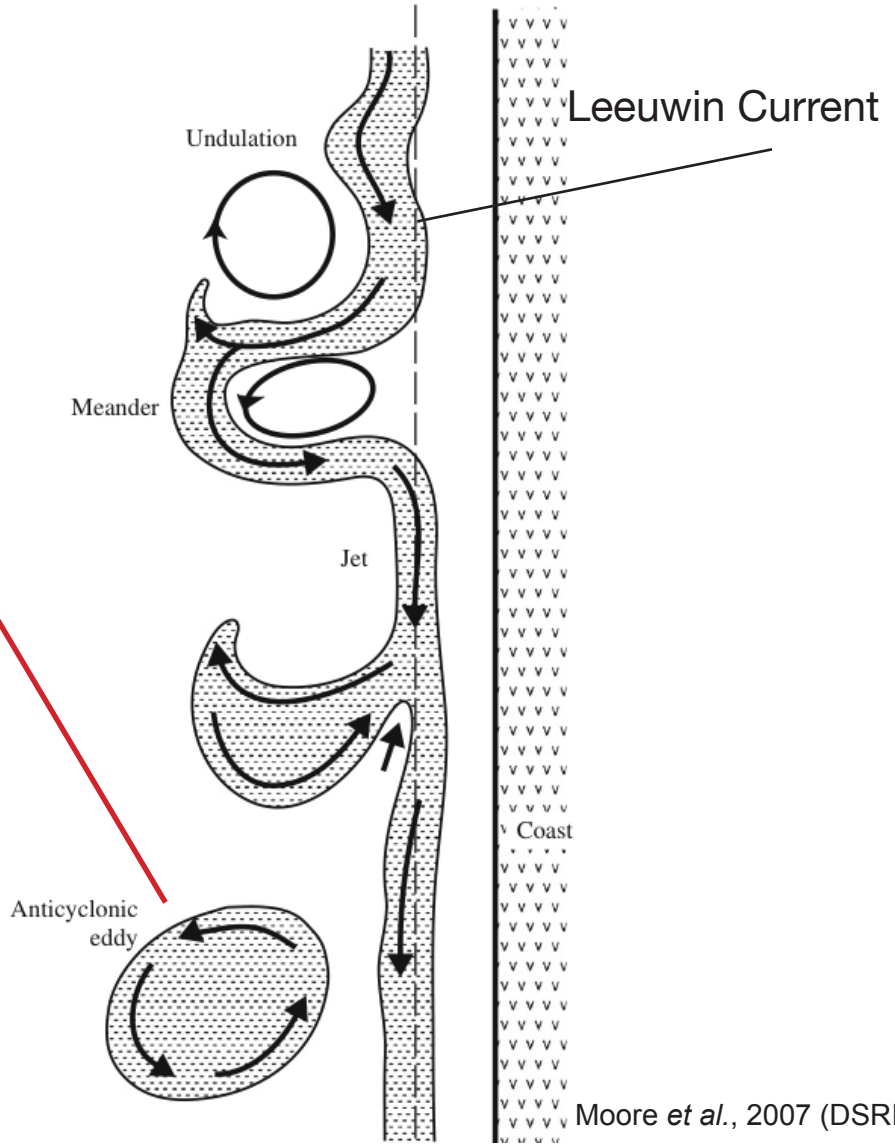
The Leeuwin Current:
An anomalously poleward flowing eastern boundary current system

Relatively nutrient "rich" shelf water is preferentially entrained into anticyclones during formation (Pearce & Griffiths, 1991).

Blooms can still be observed more than a year after their formation.

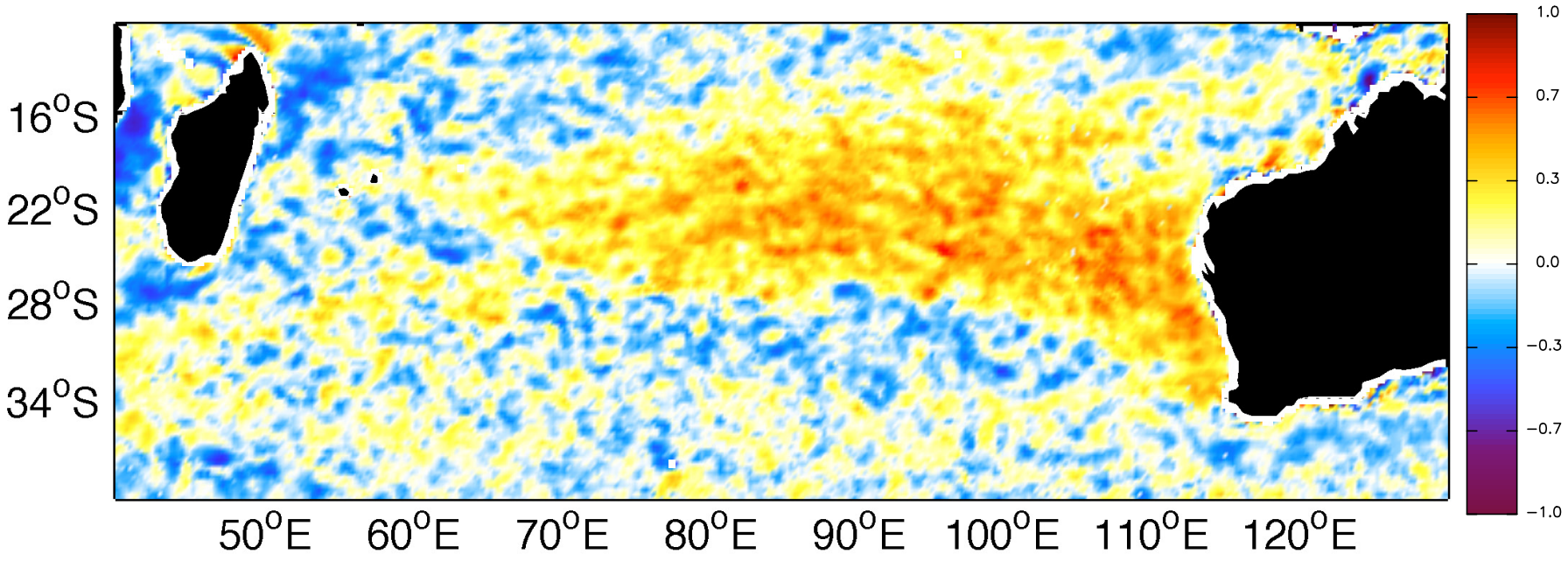
How are these blooms sustained??

Possibly through eddy-induced Ekman pumping



Moore *et al.*, 2007 (DSRII)

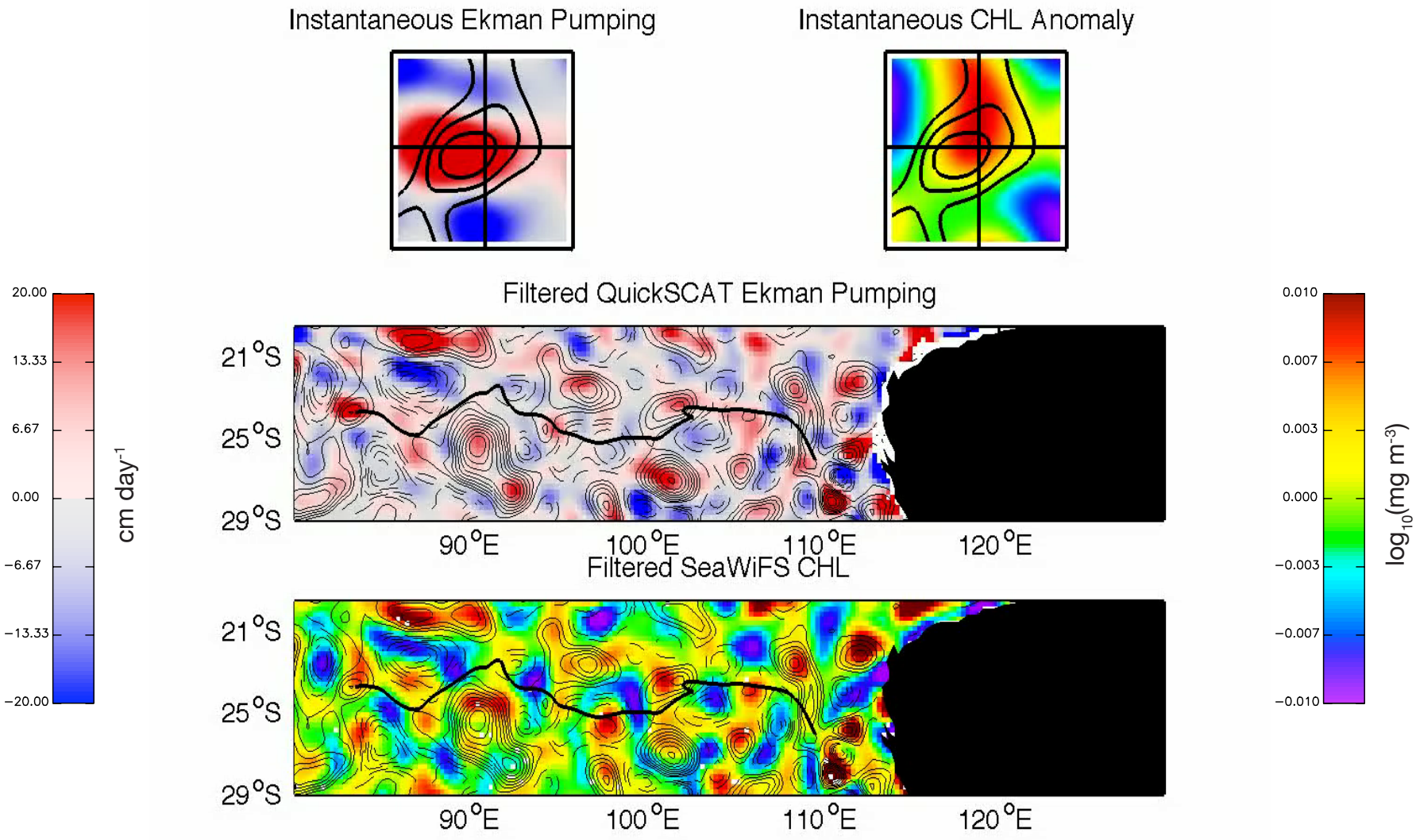
Correlation between Eddy-induced Ekman Pumping and Chlorophyll Anomalies



Measurements masked to only include observations within eddies. Both fields have been high-pass filtered.

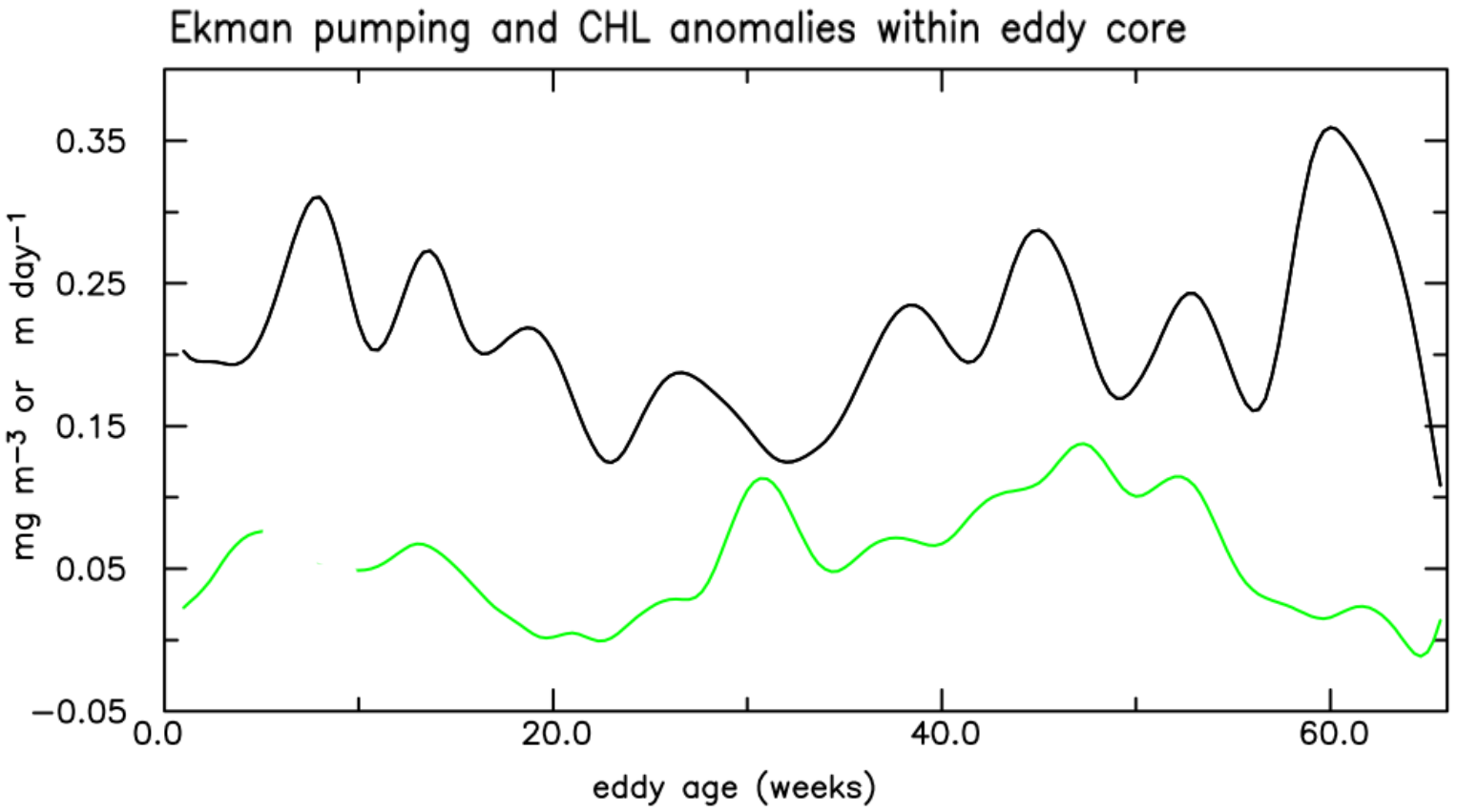
Case Study: Leeuwin Current Anticyclone

SeaWiFS CHL and QuickSCAT Ekman pumping



Case Study: Leeuwin Current Anticyclone

SeaWiFS CHL in green and QuickSCAT Ekman pumping in black



Leeuwin Current Eddies Composite Averages

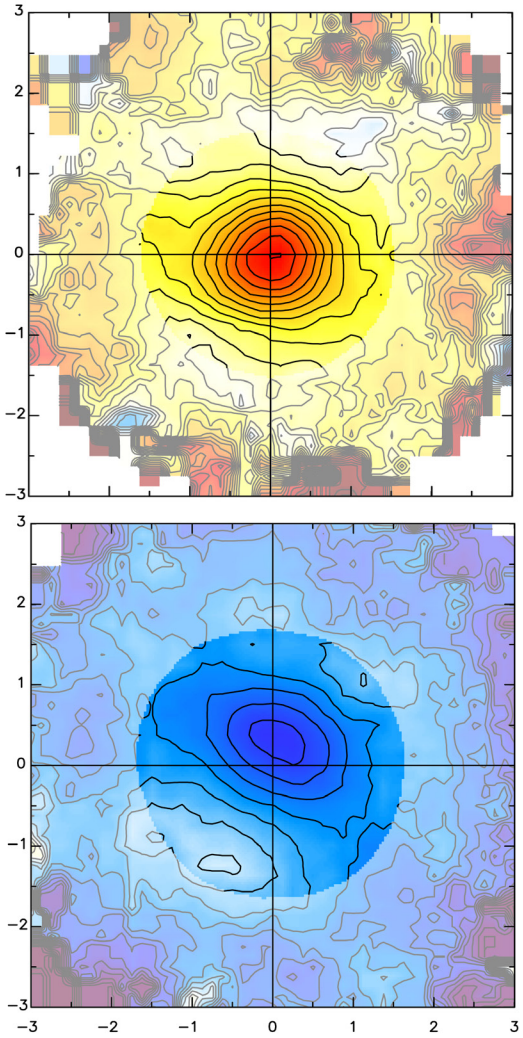
21-day composites at 7-day intervals

Horizontally Normalized

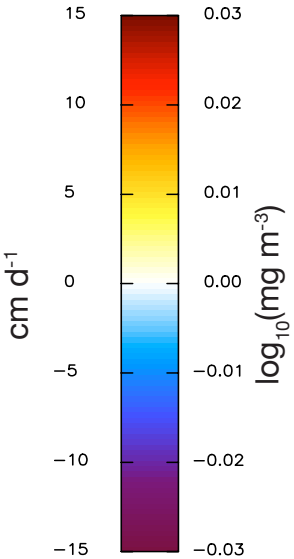
QuickSCAT Ekman Pumping

SeaWiFS CHL Anomaly

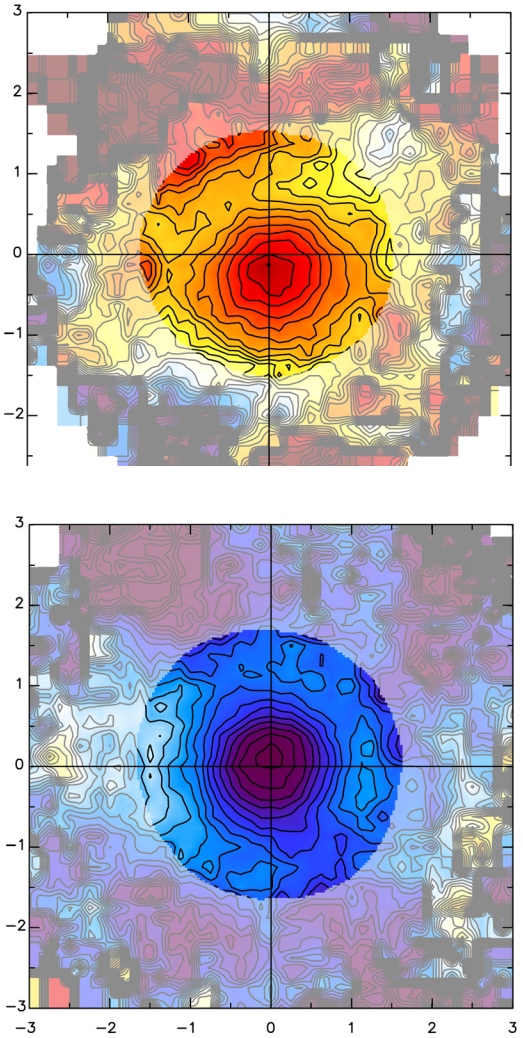
normalized distance from eddy centroid



Anticyclones

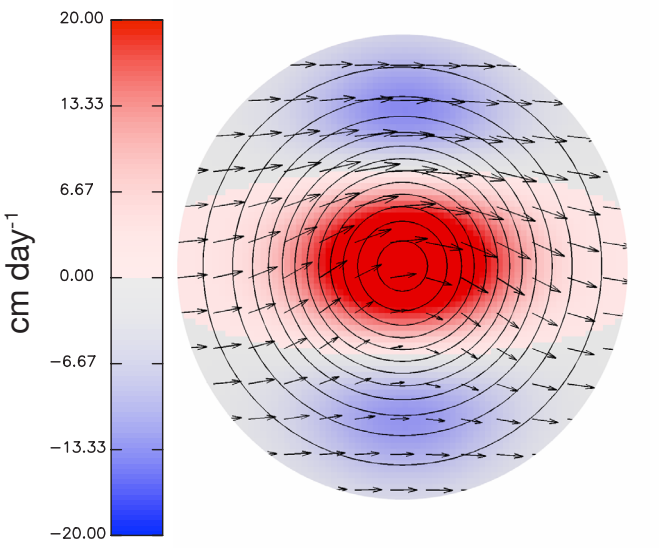


Cyclones



Comparison of Eddy-Induced Ekman Pumping with Ekman Pumping by the Large-Scale Wind

Eddy-Induced Ekman Pumping

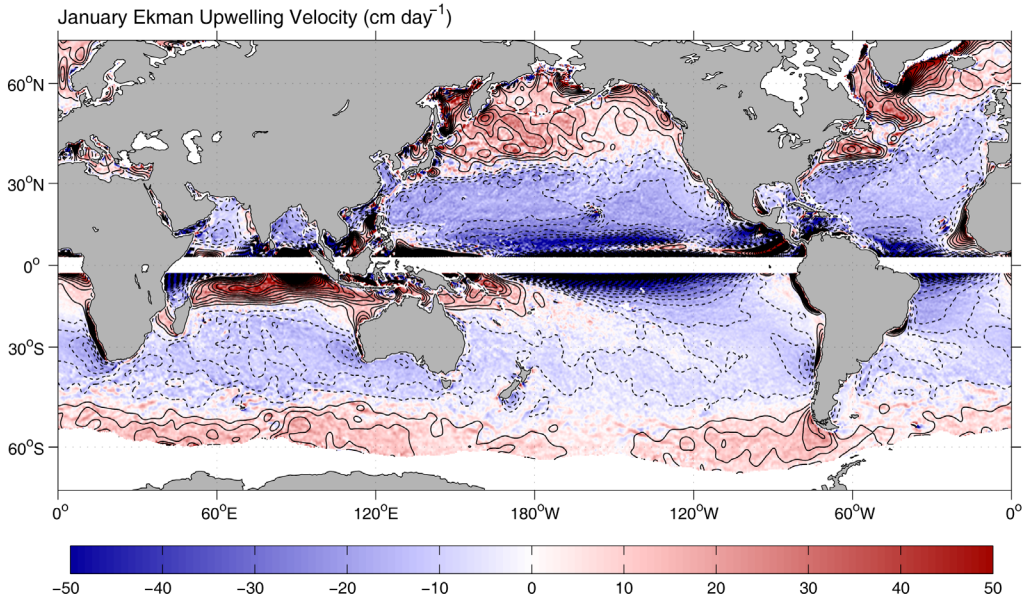


Wind speed 7 m s^{-1}

Max eddy velocity ~ 30 cm s^{-1}

Ekman Pumping at core of eddy ~ 25 cm d^{-1}

Large-Scale Ekman Pumping



Risien and Chelton, 2008

Summary and Conclusions

Global Results

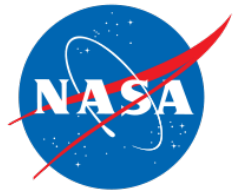
- The surface circulation of mesoscale eddies can be observed in scatterometer wind vorticity fields.

- Eddy-induced Ekman pumping is O(1) perturbation of the mean basin scale wind stress curl induced upwelling.

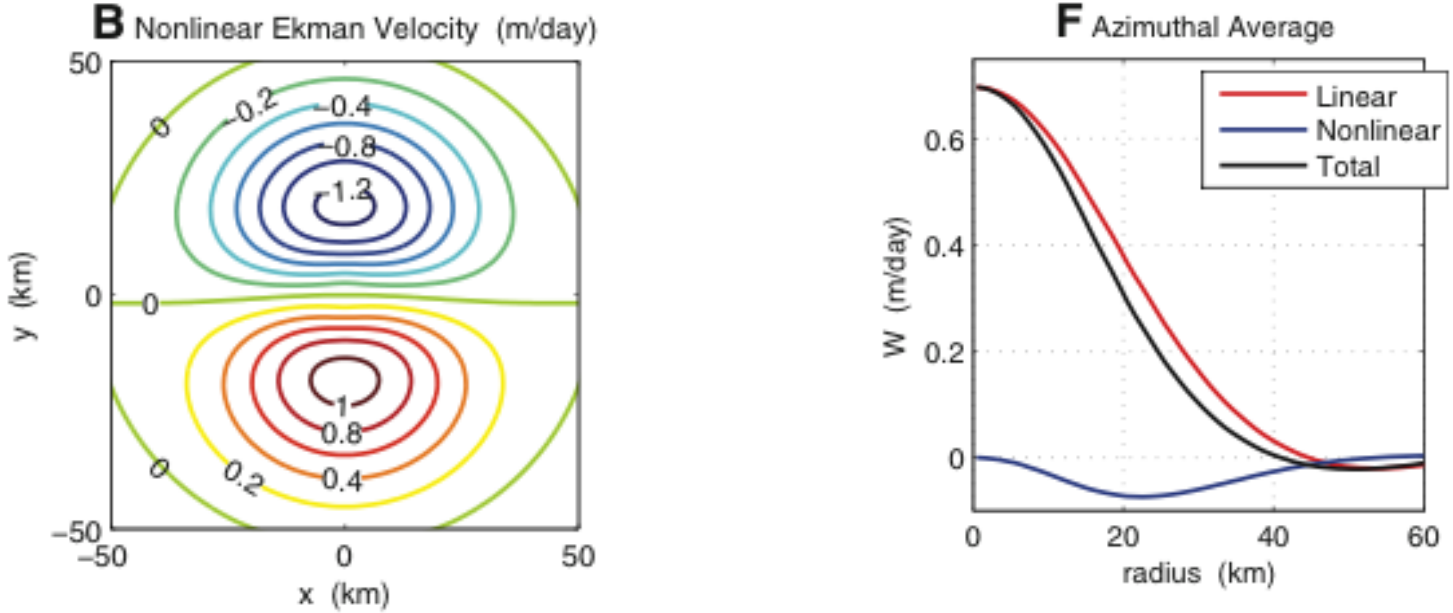
Leeuwin Current Eddies

- High correlation along with the collocation of positive CHL anomalies with upward pumping velocities at the core of anticyclonic eddies suggest that CHL blooms within Leeuwin Current anticyclones could be sustained by eddy-induced Ekman pumping.

- High CHL values within eddies could be due to photoacclimation by phytoplankton. Thus, further investigation into the phytoplankton carbon biomass and CHL:C of these eddies is required.



Nonlinear Eddy-Induced Ekman Pumping



Water parcel would be upwelled 2m before being downwelled again

McGillicuddy *et al.* 2008