THE INFLUENCE OF GULF STREAM MEANDERS AND EDDIES ON CHLOROPHYLL: SYNTHESIS OF SATELLITE OBSERVATIONS AND EDDY-RESOLVING MODELS

Satellite Observations and Eddy-Resolving Models

The influence of Gulf Stream meanders and eddies on near surface chlorophyll (CHL) is investigated by analyzing satellite observations of sea surface height (SLA) from CLS/AVISO and CHL anomalies from SeaWiFS (Fig. 1a). Eddy resolving (1/10°) physical/biological models (POP-BEC, see Anderson *et al.* [2011] for details and Fig. 1b) are used to help interpret the observed influence of eddies and meanders on CHL.

Two different simulations were conducted, one with the standard surface stress formulation:

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

and one in which the stress is computed as the difference between air and ocean surface velocities $\mathbf{u}_{air}$ and $\mathbf{u}_{sea}$:

$$\boldsymbol{\tau} = \rho_a C_D (\mathbf{u}_{air} - \mathbf{u}_{sea}) |\mathbf{u}_{air} - \mathbf{u}_{sea}|,$$

where ρ_a is the density of air and C_D the drag coefficient.

Coherent mesoscale structures are identified as closed contours of SLA following the method described in detail in Appendix B of Chelton *et al.* (2011).

Definition of CHL Anomalies

CHL anomalies (CHL') are defined as:

$$CHL' = CHL - \langle CHL \rangle, \quad (1)$$

where $\langle CHL \rangle$ is the spatially smoothed CHL field. Normalized CHL anomalies (CHL'') are defined as:

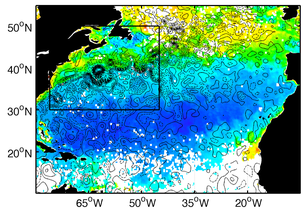
$$CHL'' = CHL' / \overline{CHL}, \quad (2)$$

where $\overline{CHL}$ is the time-averaged background CHL field. CHL anomalies relative to the formation of eddies and meanders ($\Delta CHL'$) are defined as;

$$\Delta CHL' = CHL'(k) - CHL'(k=1), \quad (3)$$

where $CHL'(k)$ is eddy-centric CHL' at week k.

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



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

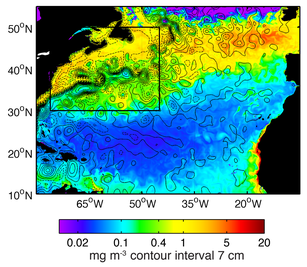


Figure 1: Maps of near-surface CHL overlaid with contours of SLA

Mechanisms of Biological-Physical Interaction at the Mesoscale (Gaube *et al.*, 2014)

a) Eddy Stirring generates dipoles of CHL'' as a result of the azimuthal advection of CHL around the peripheries of eddies and meanders. CHL' is expected to be positive in anticyclones and negative in cyclones (Fig. 2a).

b) Trapping of CHL generates monopoles of negative and positive CHL'' in anticyclones and cyclones, respectively. CHL' is expected to be effectively invariant in time (Fig. 2b).

c) Eddy intensification generates monopoles of negative and positive CHL'' in anticyclones and cyclones, respectively. CHL' is expected to increase in cyclones and decrease in anticyclones (Fig. 2c).

d) Eddy/wind interaction, also know as **eddy-induced Ekman pumping**, generates monopoles of positive and negative CHL'' in anticyclones and cyclones, respectively. CHL' is expected to increase in anticyclones and decrease in cyclones (Fig. 2d).

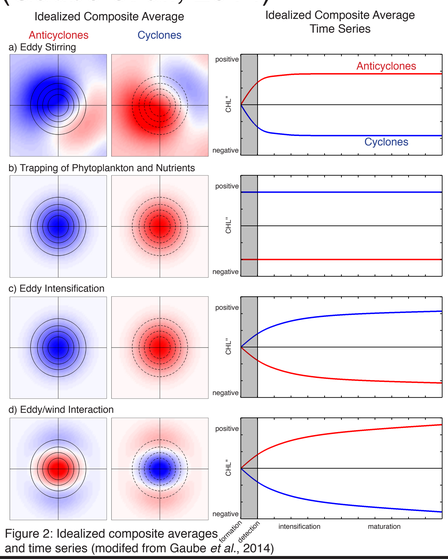


Figure 2: Idealized composite averages and time series (modifed from Gaube *et al.*, 2014)

Regional Analysis

Gulf Stream meanders and eddies are defined as eastward and westward propagating features, respectively, with lifetimes greater than 3 weeks. The spatial distribution of meanders and eddies in the two simulations are qualitatively similar to observations (Figs. 3a, c and e), however the simulations appear to have produced fewer eddies.

The response of the phytoplankton community to mesoscale eddies and meanders can be inferred from cross correlation of the SLA structure of eddies and their CHL'. Observations in the Gulf Stream region reveal predominantly **negative cross correlation** (Fig. 3b), that suggests cyclonic features (with negative SLA) are associated with enhanced CHL (positive CHL') and anticyclonic features (positive SLA) are associated with suppressed CHL (negative CHL'). The cross correlation in both simulations is also predominantly negative in the Gulf Stream region, but with slightly larger spatial extent (Figs. 3d and f).

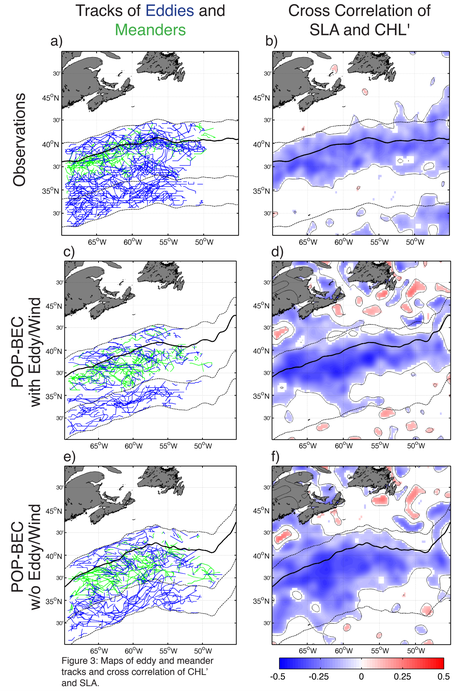


Figure 3: Maps of eddy and meander tracks and cross correlation of CHL' and SLA.

References

Anderson, L. A., D. J. McGillicuddy, M. E. Maltrud, I. D. Lima, and S. C. Doney (2011), Impact of eddy/wind interaction on eddy demographics and phytoplankton community structure in a model of the North Atlantic Ocean, Dynamics of Atmospheres and Oceans, 52, 80–94.

Chelton, D. B., M. G. Schlax, and R. M. Samelson (2011), Global observations of nonlinear mesoscale eddies, Progress in Oceanography, 91(2), 167--216.

Gaube, P., D. J. McGillicuddy Jr, D. B. Chelton, M. J. Behrenfeld, P. Strutton. Regional variations in the influence of mesoscale eddies on near-surface chlorophyll. Journal of Geophysical Research - Oceans, submitted.

Eddy-Centric Analysis

Composite averages of eastward propagating meanders consist of monopoles of negative and positive normalized CHL anomaly (CHL'') in anticyclonic and cyclonic meanders, respectively (Fig. 4a). The spatial structure of CHL'' in the simulations is quite similar to observations, but larger in magnitude (Figs. 4c and e). Composite averages of CHL'' in westward propagating eddies consist primarily of monopoles of negative and positive CHL'' in anticyclonic and cyclonic eddies, respectively (Figs 4b). Both simulations generate eddies with similar composite averages of CHL'' (Figs. 4d and f).

Time series of CHL'' in observed and simulated anticyclonic and cyclonic meanders remain significantly negative and positive, respectively, during the first 8 weeks of the meander's lifetime (Figs. 5a, d and h). Observed cyclonic meanders exhibit a significant positive trend in CHL'' (Fig. 5a). The simulation including eddy/wind interaction reproduces this trend in cyclonic meanders (Fig. 5d).

The observed evolution of CHL in westward propagating eddies is characterized by significantly negative CHL'' in anticyclones and positive CHL'' in cyclones (Fig. 5b). Time series of CHL' relative to eddy formation (ΔCHL') are used to elucidate trends in CHL during eddy maturation. A significant increase in ΔCHL' within anticyclonic eddies is observed (Fig. 5c), likely a result of upwelling from eddy/wind interaction. The influence of eddy/wind interaction on CHL within Gulf Stream eddies is substantiated by the different temporal trends in ΔCHL' between the two simulations. In the model with eddy/wind interaction, ΔCHL' increases after week 6 (Fig. 5f), which is similar to observed ΔCHL' (Fig. 5c). In the simulation including eddy/wind interaction, there is also an upward trend in the flux of nitrate into the euphotic zone of anticyclones (Fig. 5g). These positive trends in ΔCHL' and the flux of nitrate in anticyclones are not observed in the simulation without eddy/wind interaction (Figs. 5j and k).

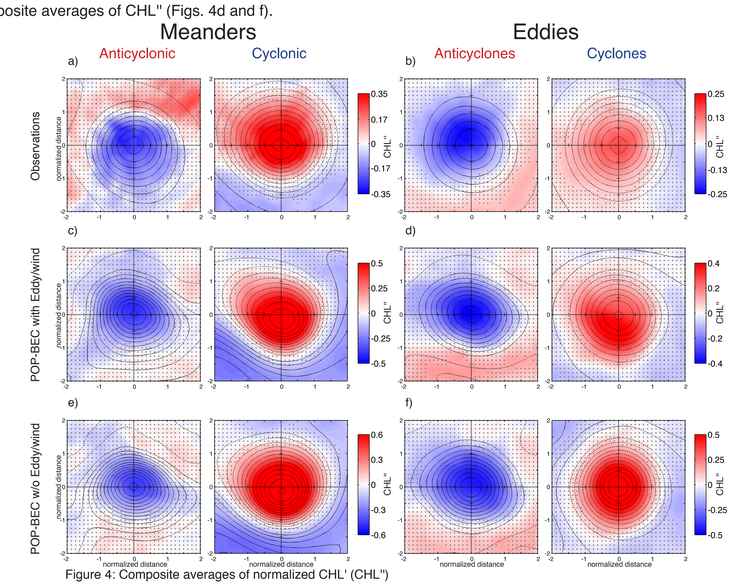


Figure 4: Composite averages of normalized CHL' (CHL'')

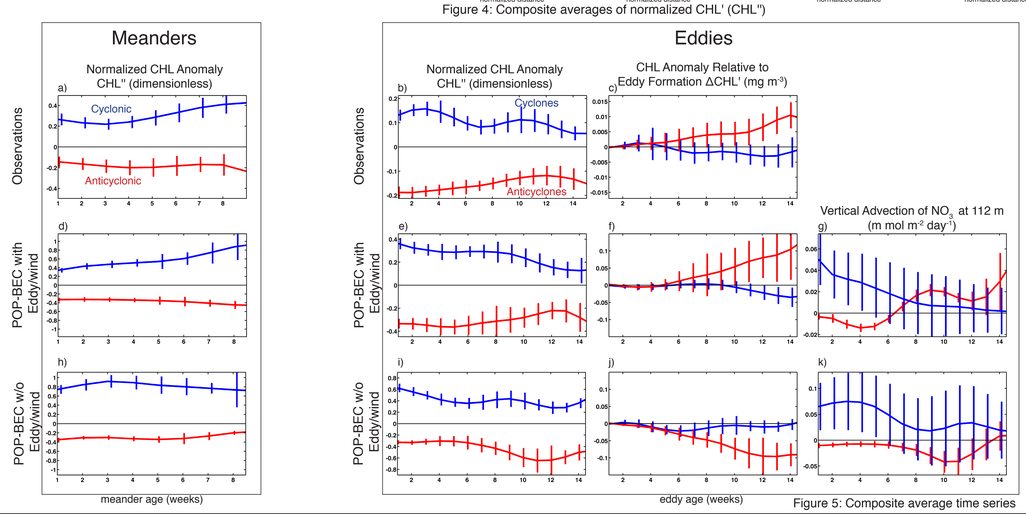


Figure 5: Composite average time series

Key Results

- The CHL anomalies (CHL') of Gulf Stream meanders are consistent with the horizontal transport and subsequent trapping of phytoplankton.
- Cyclonic Gulf Stream eddies trap water with elevated phytoplankton concentrations. Positive CHL' decays as cyclones mature.
- Anticyclonic Gulf Stream eddies trap water with suppressed phytoplankton concentrations. CHL' in anticyclones is observed to increase as the eddies mature.
- The CHL' in simulated anticyclones increases as eddies mature in response to the upwelling of nutrients by eddy/wind interaction.

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