

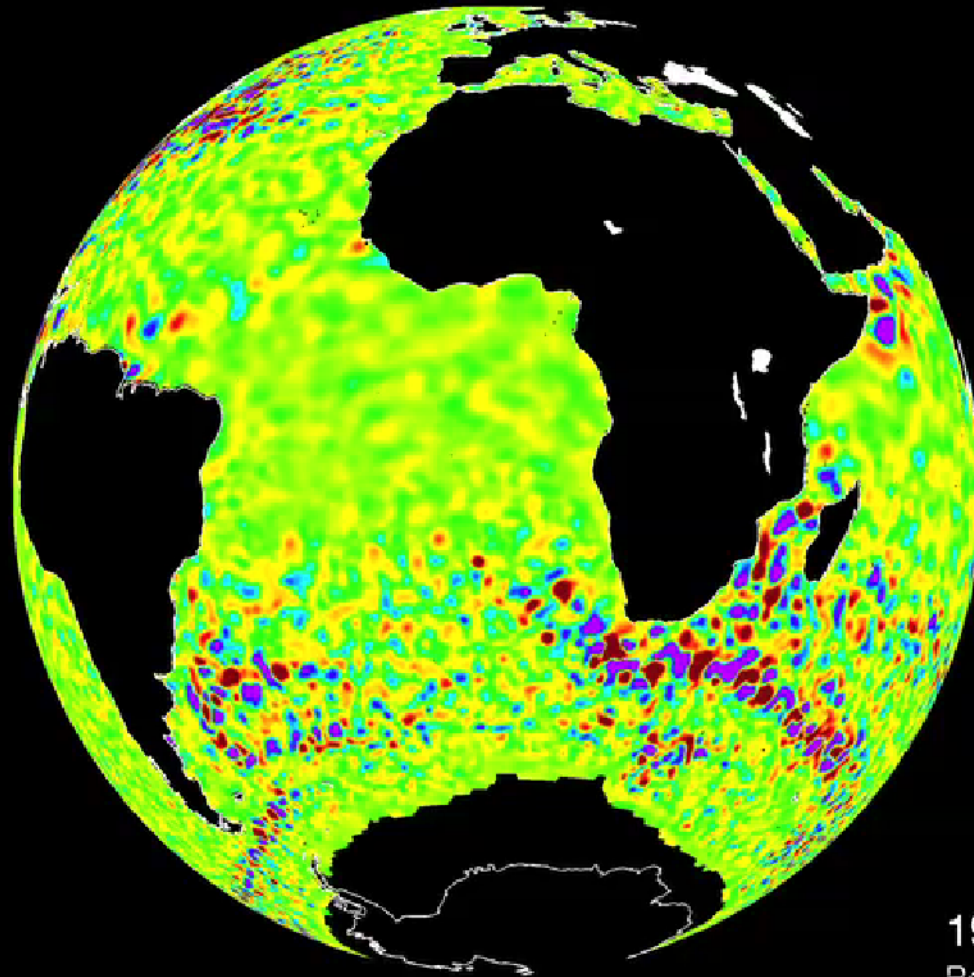
# Identifying the mechanism that dictate how sharks interact with (sub)mesoscale features

Peter Gaube  
Camrin Braun  
Alice Della Penna

Suomi-NPP/VIIRS 14 May 2015  
Georges Bank and Gulf Stream North Wall

# Nonlinear Mesoscale Eddies

SSH from the merged altimetry data with tracks of long-lived eddies (16 weeks and longer)



1992-10-14

Peter Gaube

[pgaube@whoi.edu](mailto:pgaube@whoi.edu)



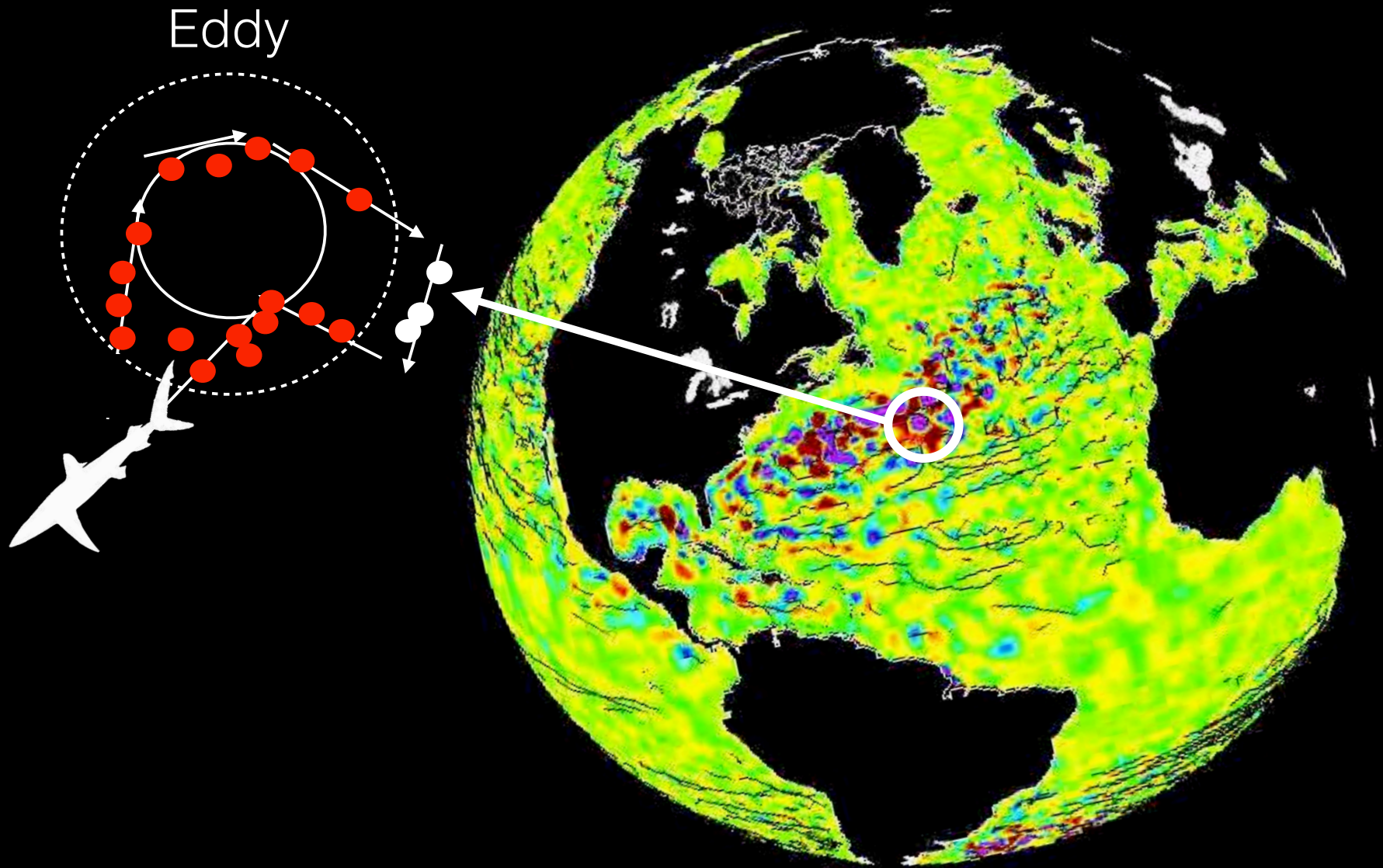


# The Use of Mesoscale Eddies by White Sharks

The tagging of white shark Lydia ([www.ocearch.org](http://www.ocearch.org))



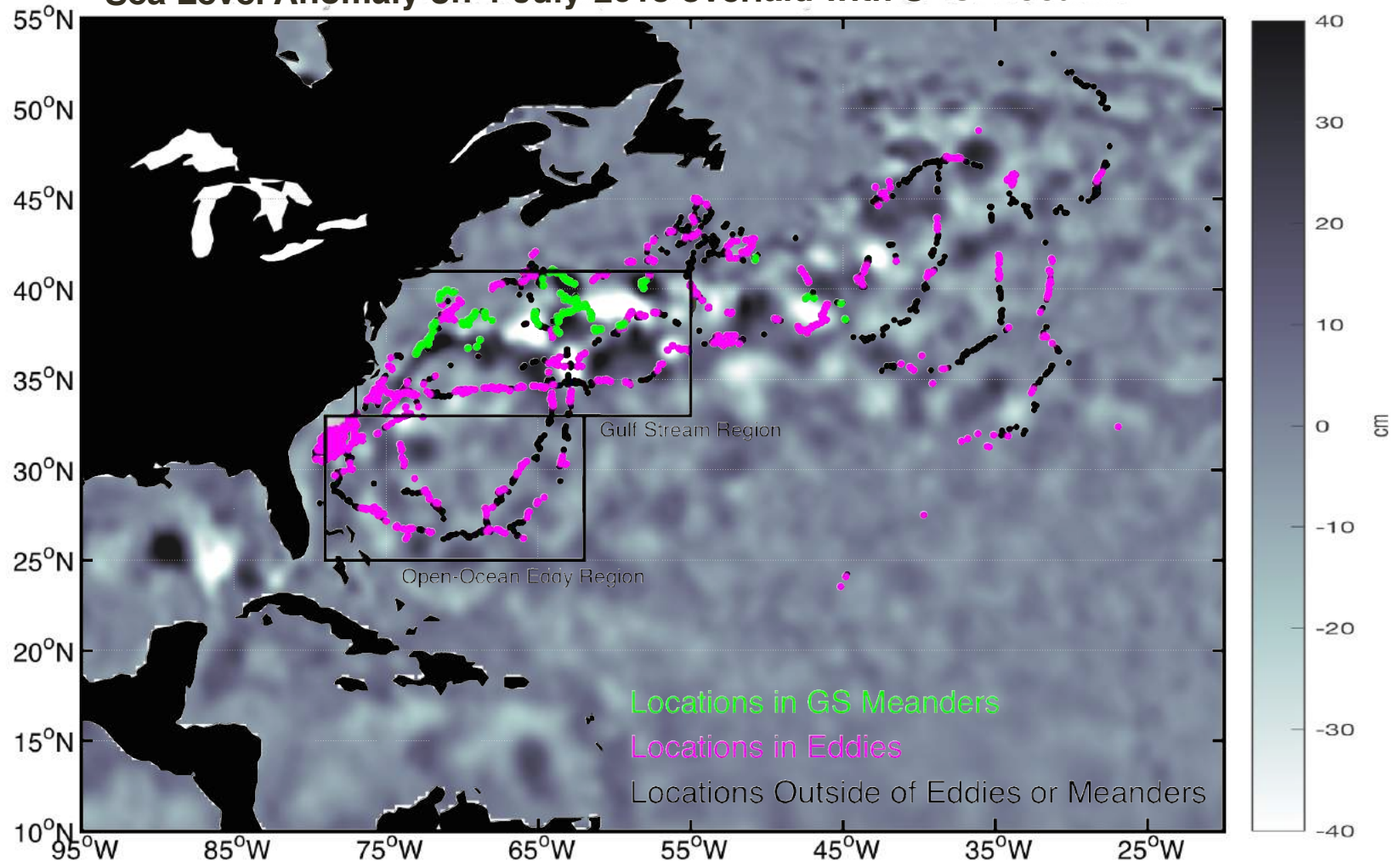
# Shark movements analyzed in eddy-centric coordinates





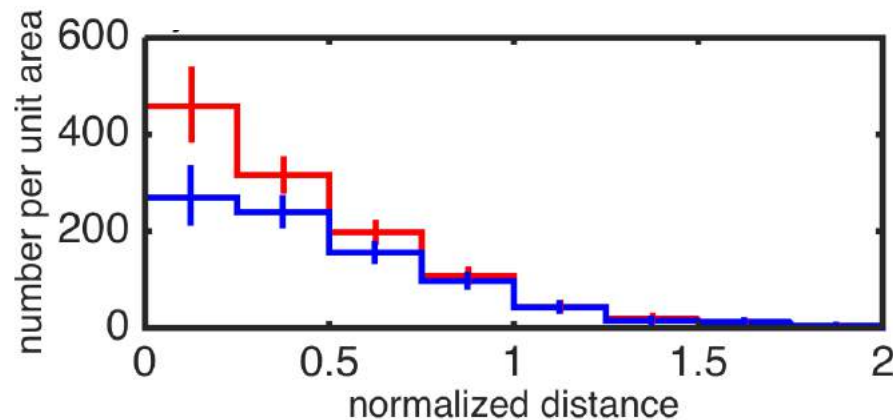
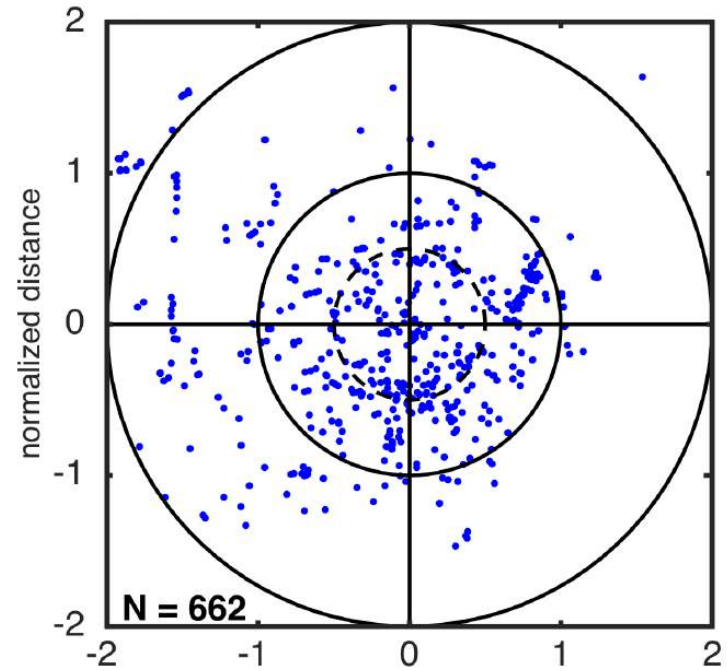
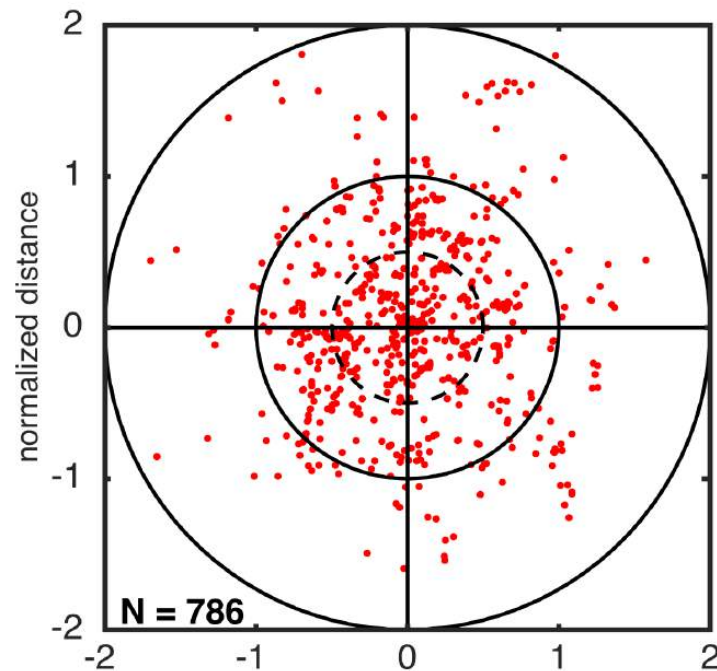
# White Shark SPOT Locations Collocated to Mesoscale Eddies and Meanders

Sea Level Anomaly on 4-July-2013 overlaid with SPOT locations



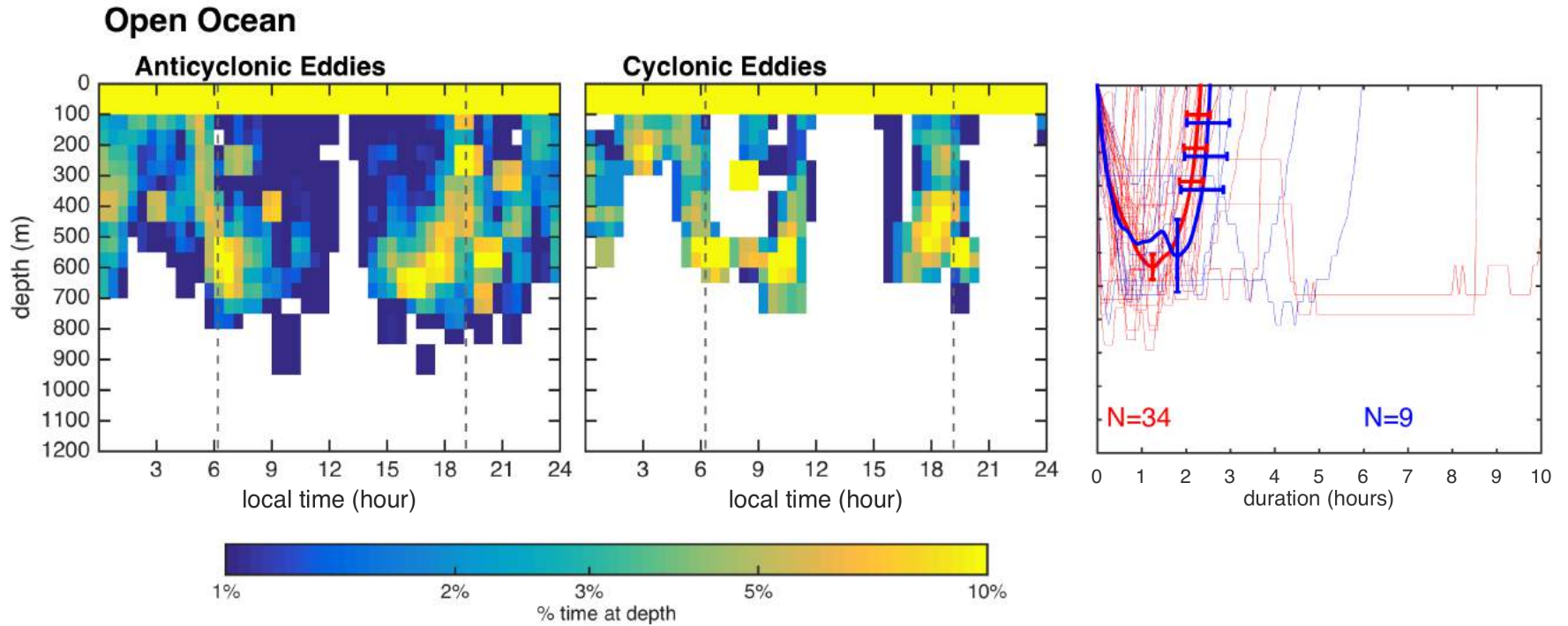
Gaube et al. 2018a

# Eddy-Centric Maps of White Shark Locations

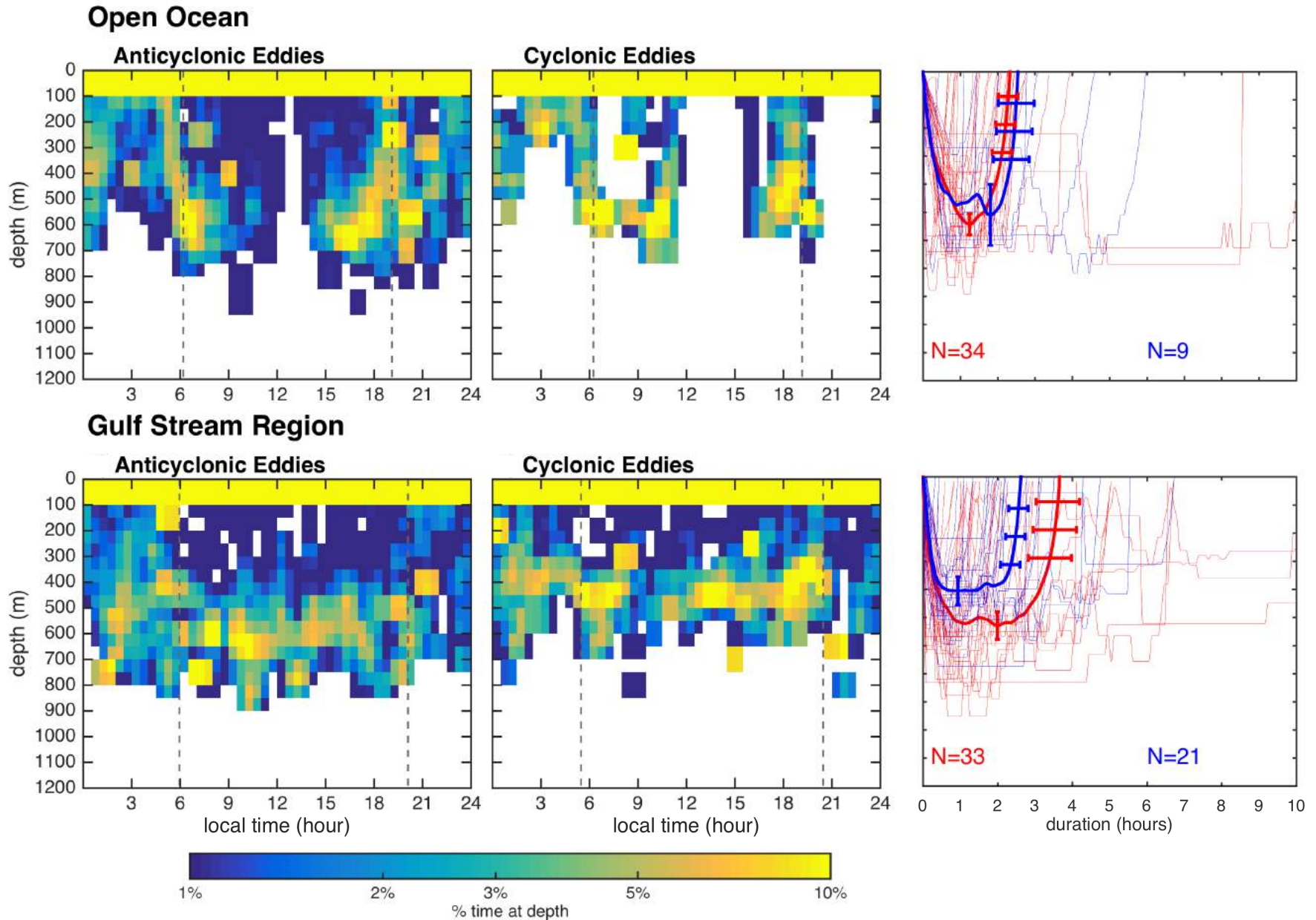




# Diving Behavior in Eddies



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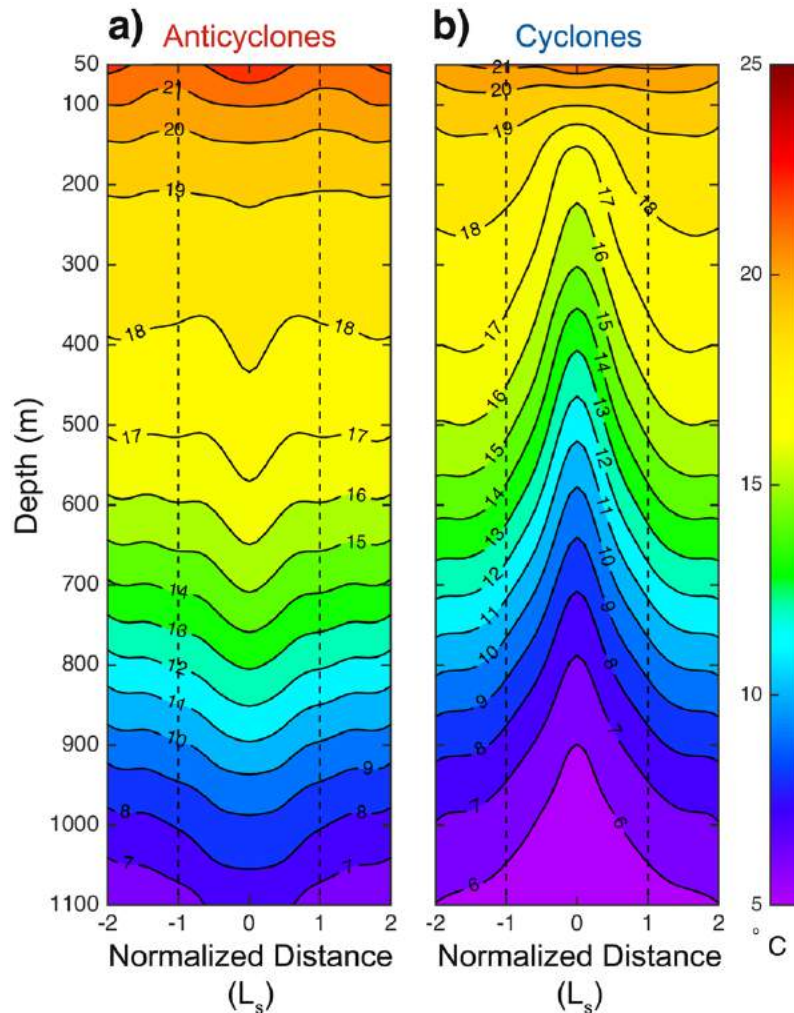




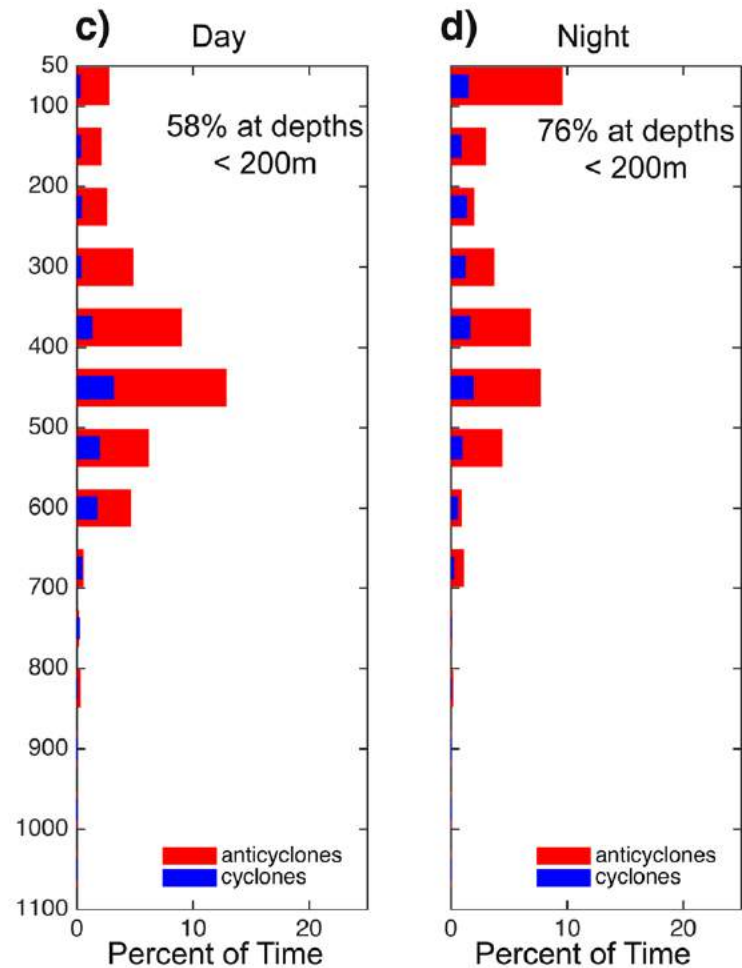
# More Time at Depth in Warm Anticyclones

Temperature composites from Argo float profiles, diving depth from MiniPAT

Eddy Temperature  
Composite Averages



Time at Depth

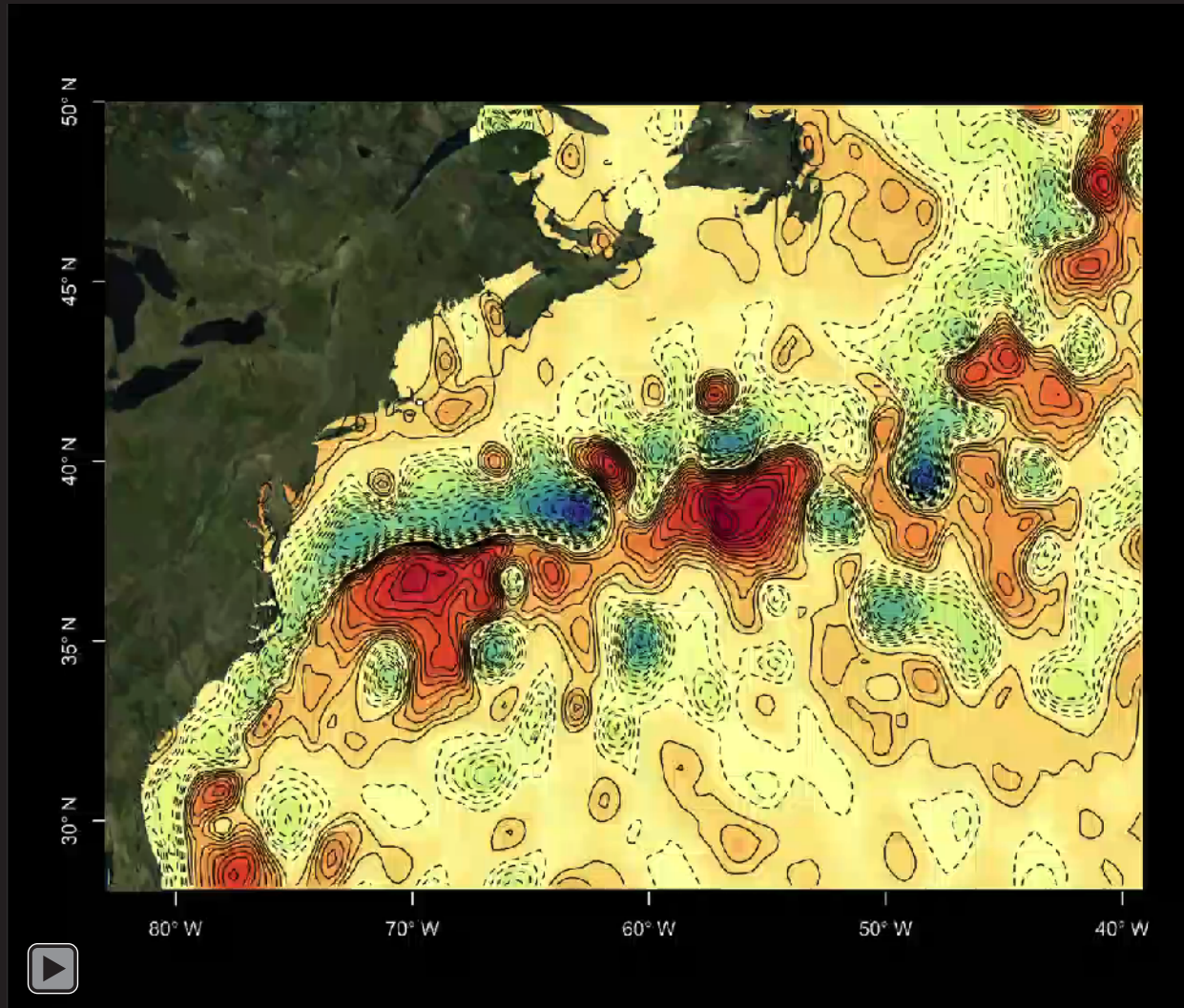






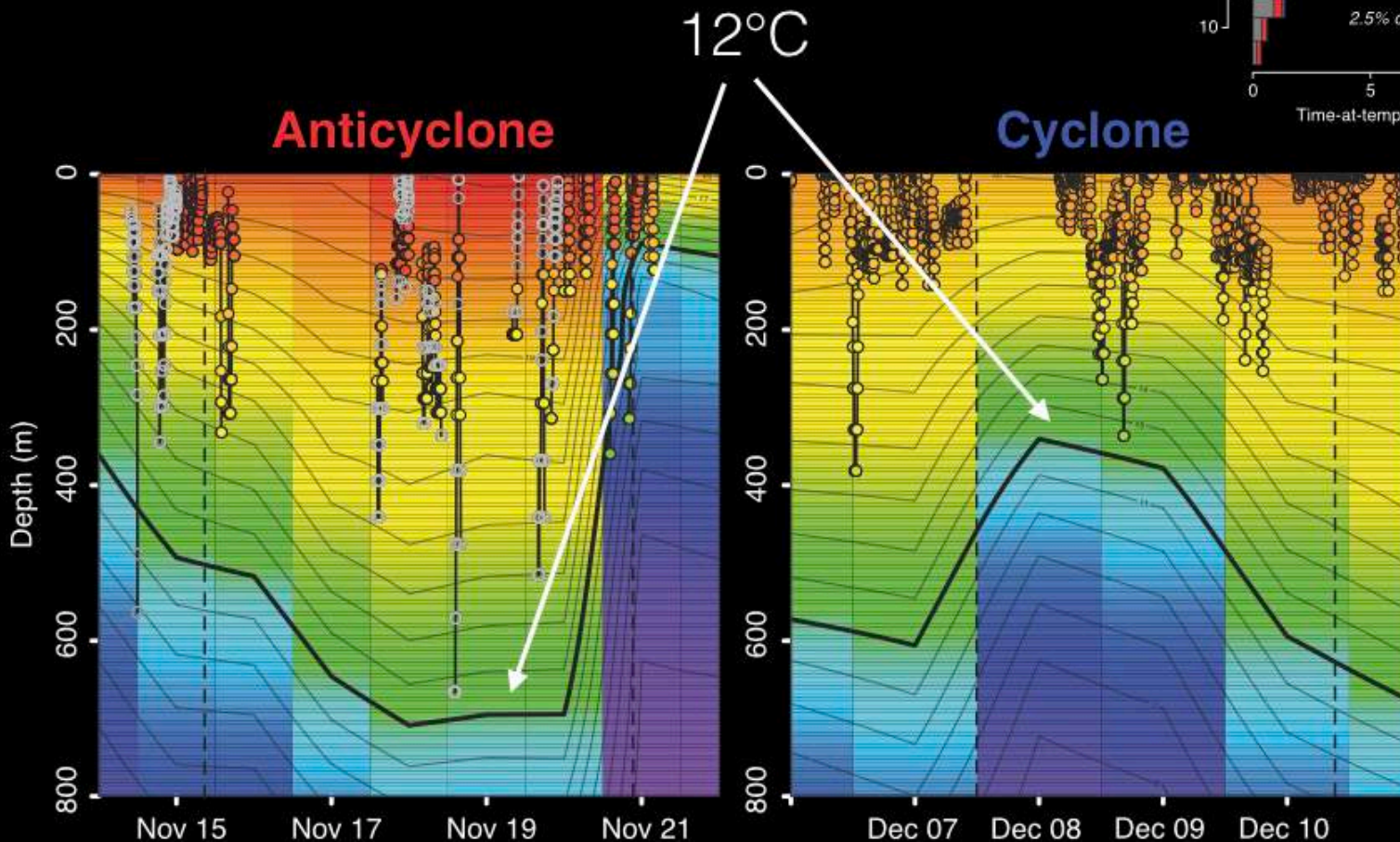
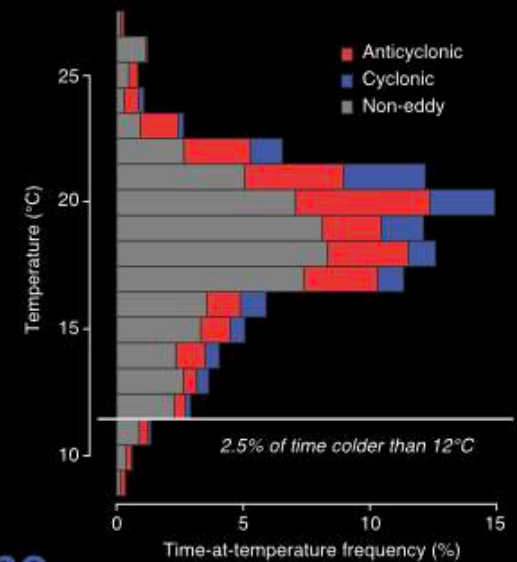


# Blue Shark “Oscar” interacting with mesoscale eddies and meanders in the Gulf Stream





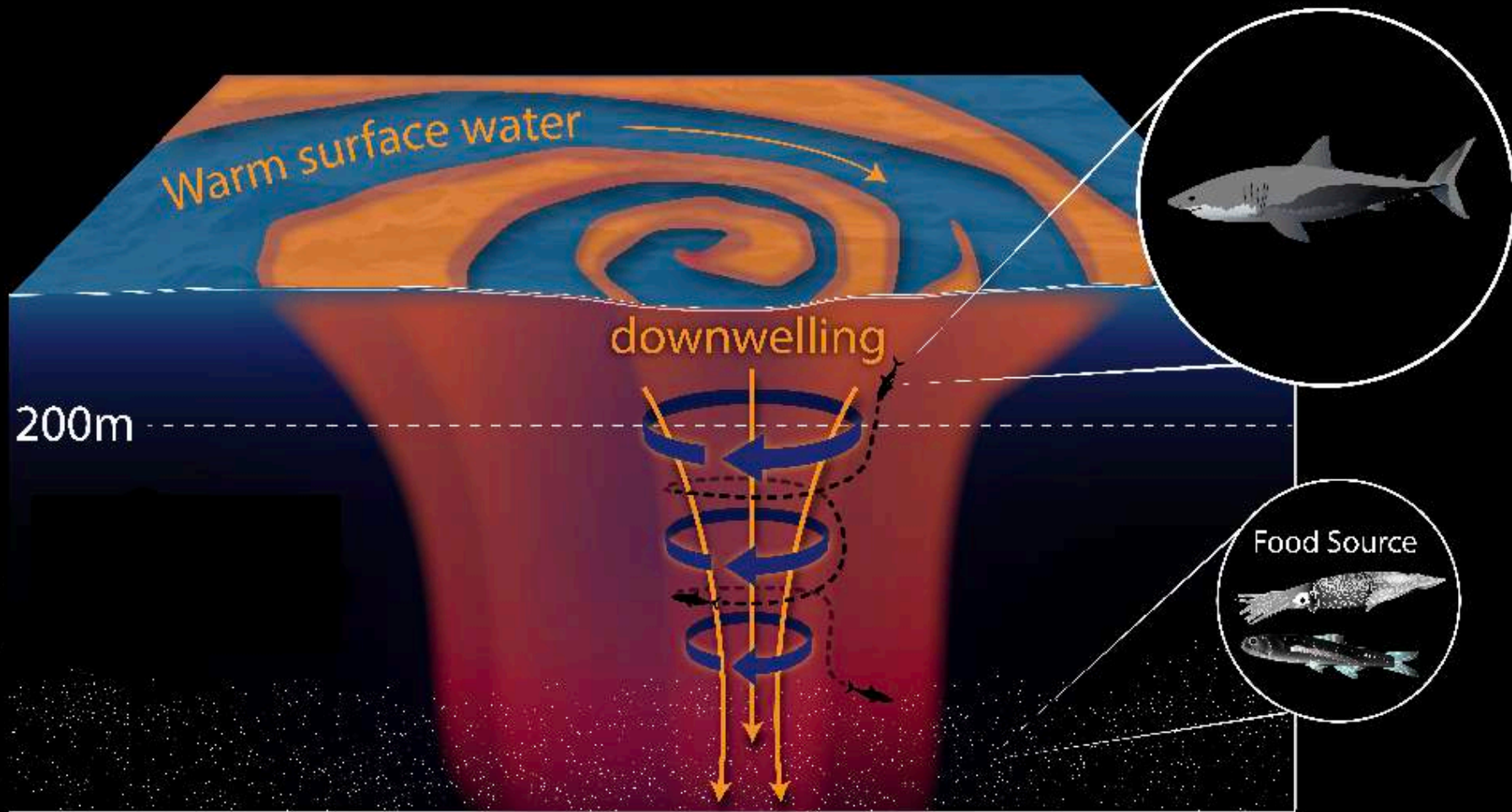
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Braun et al., (in prep)

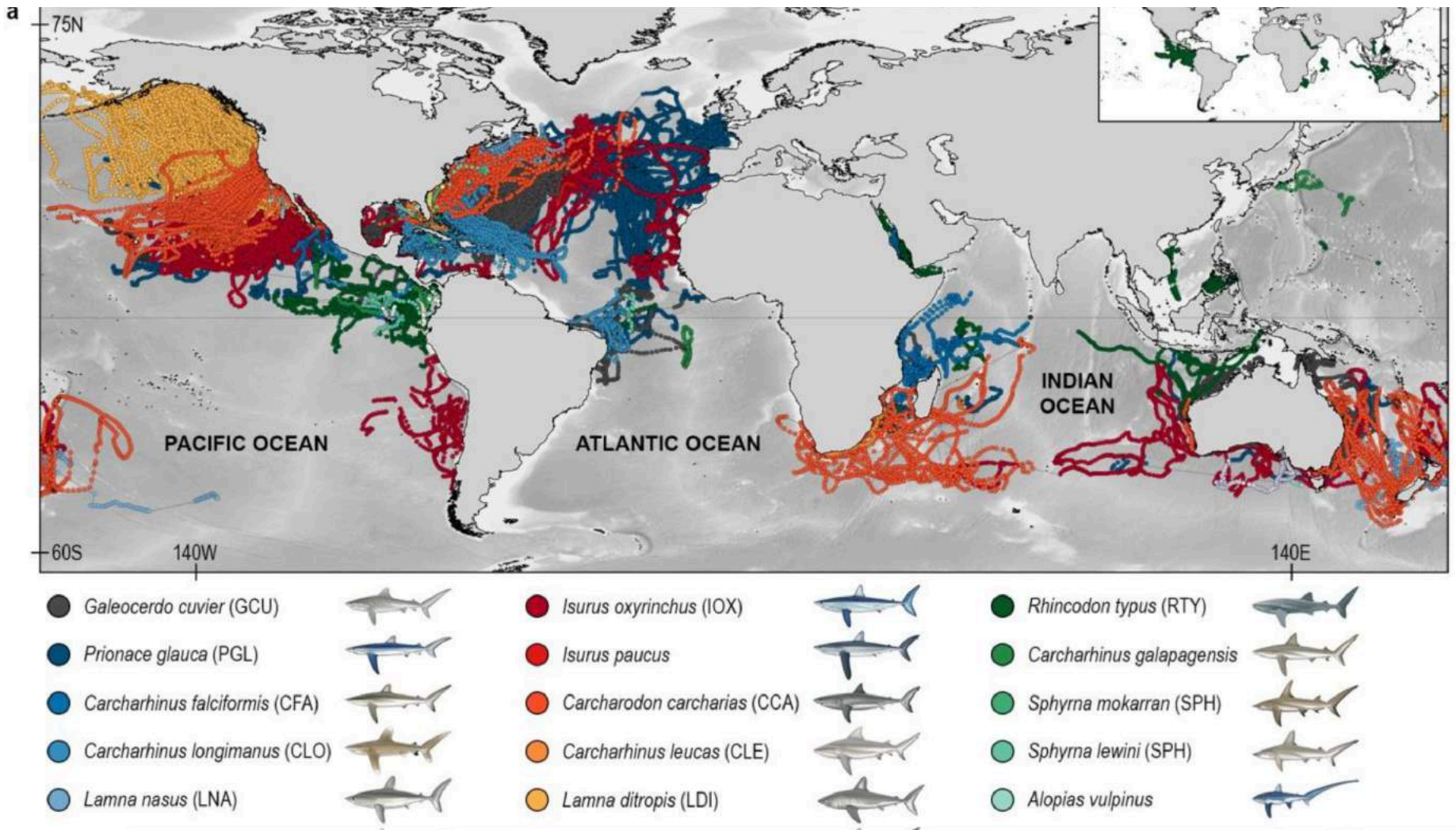


# Are Anticyclones Conduits to the Mesopelagic for Pelagic Predators?



# Coming soon from Global Shark Movement Project

<http://www.globalsharkmovement.org/>



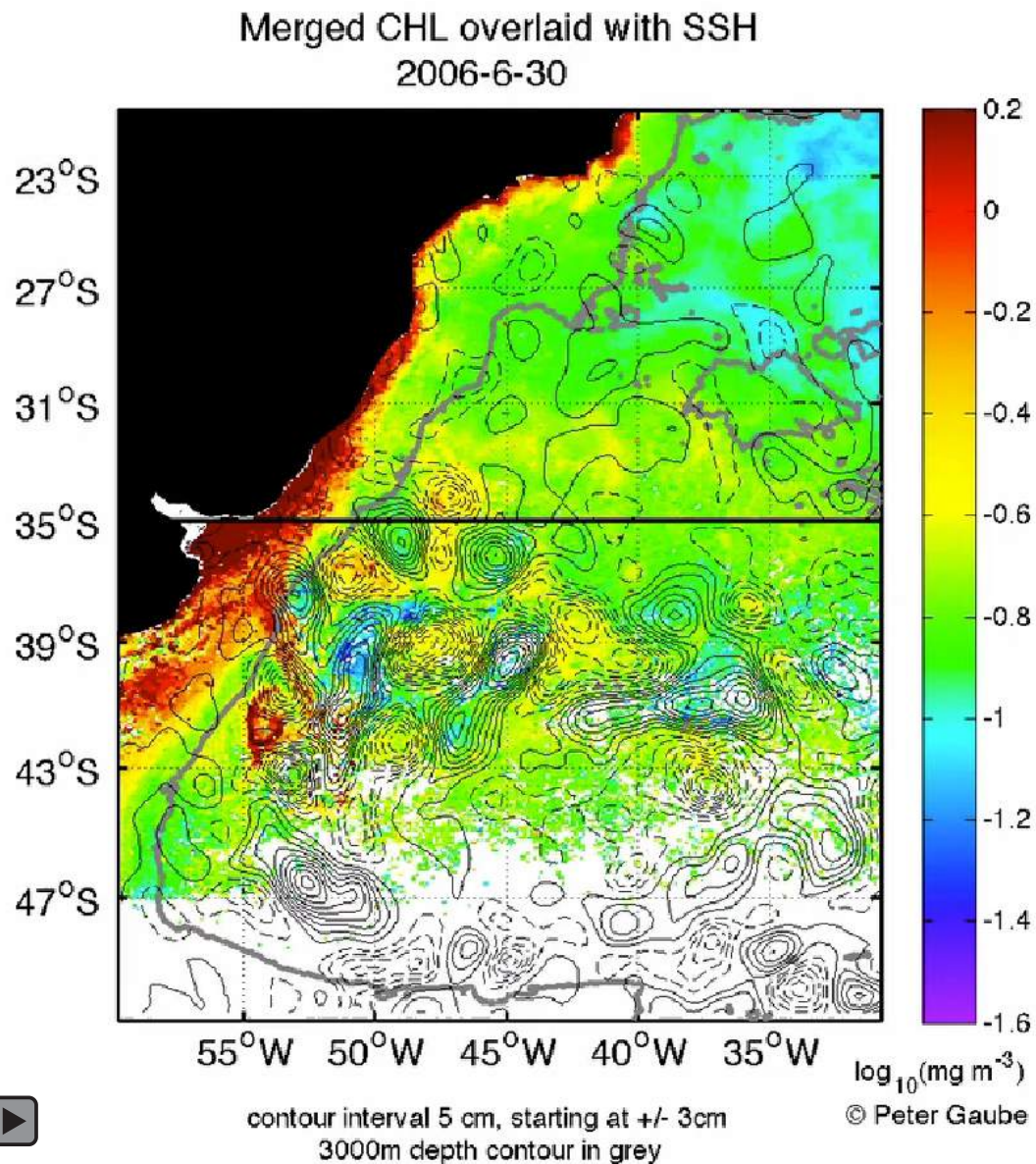
Peter Gaube

pgaube@apl.washington.edu



# Animation of Turtles, Eddies and CHL

$\log_{10}$  Chlorophyll-a from MODIS-Aqua, MERIS and SeaWiFS 2001-2008

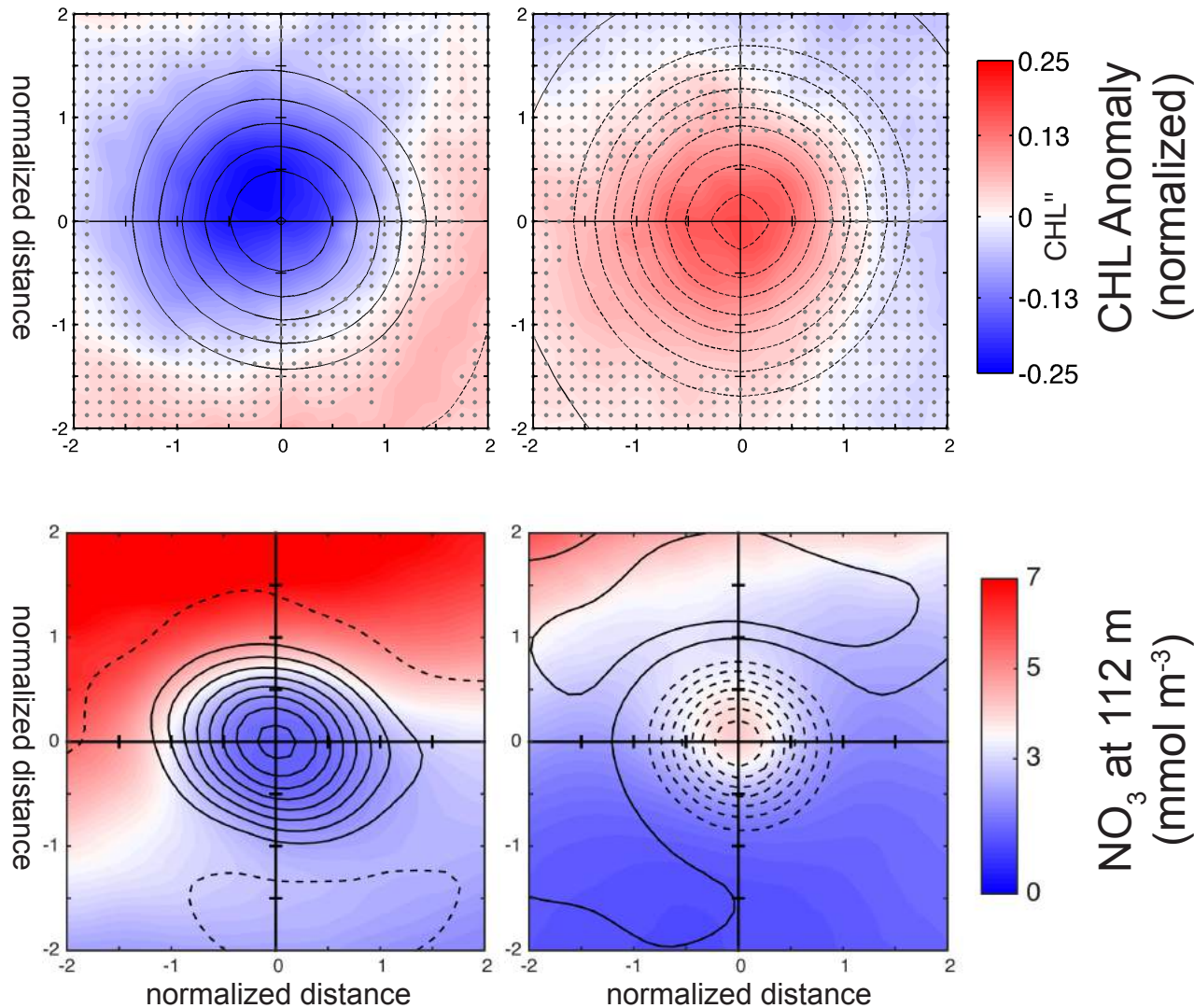




# Why do White Sharks Seek Out Anticyclones?

Anticyclones

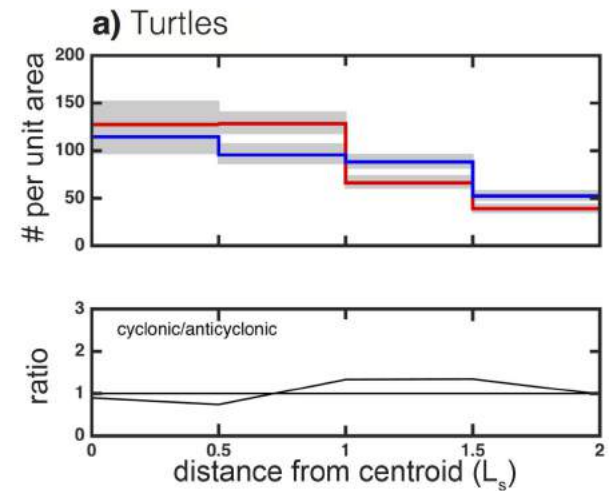
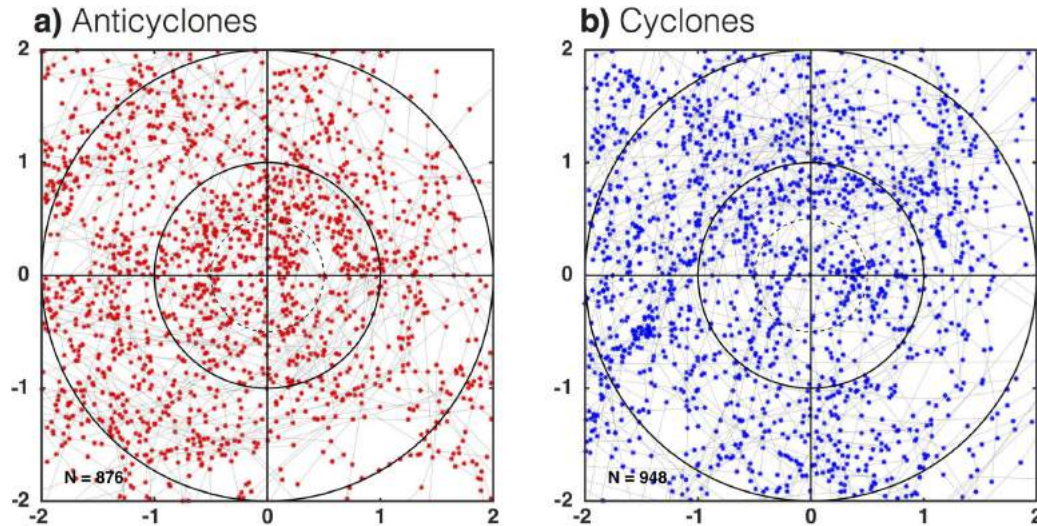
Cyclones



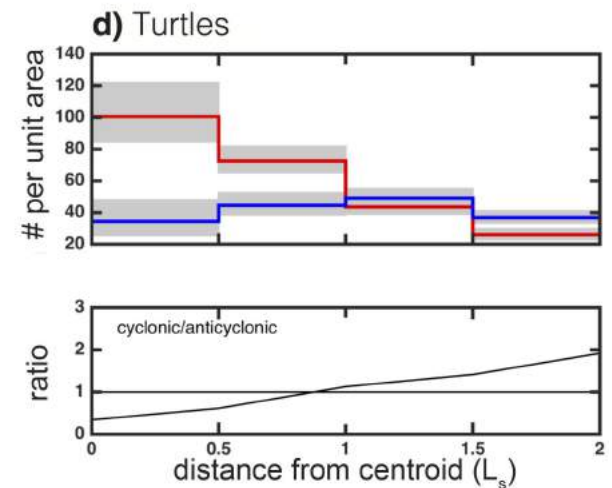
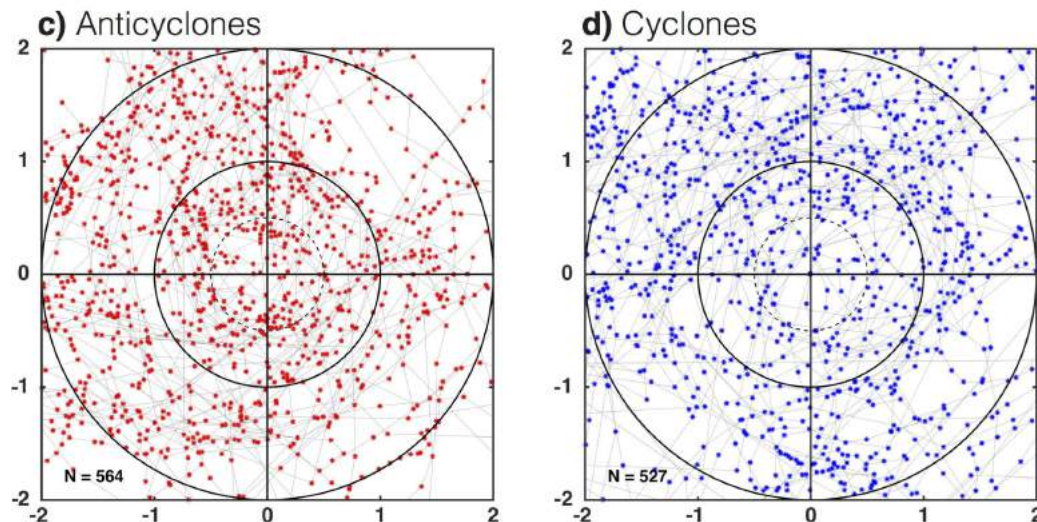
Gulf Stream  
Anticyclones:

- Negative near-surface anomalies CHL.
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# Eddy Centric Analysis of Turtle Movement

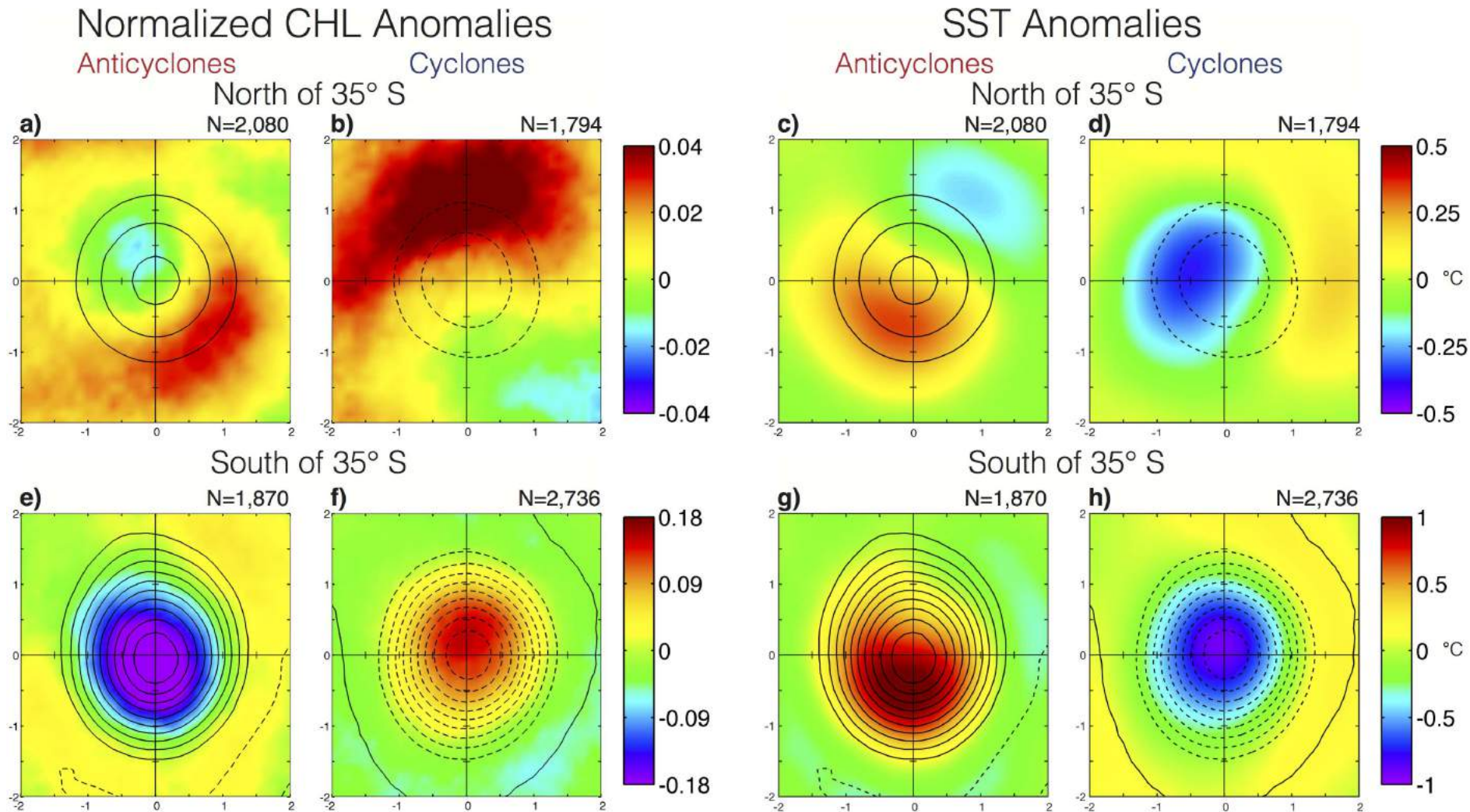


## Turtle Location South of 35° S

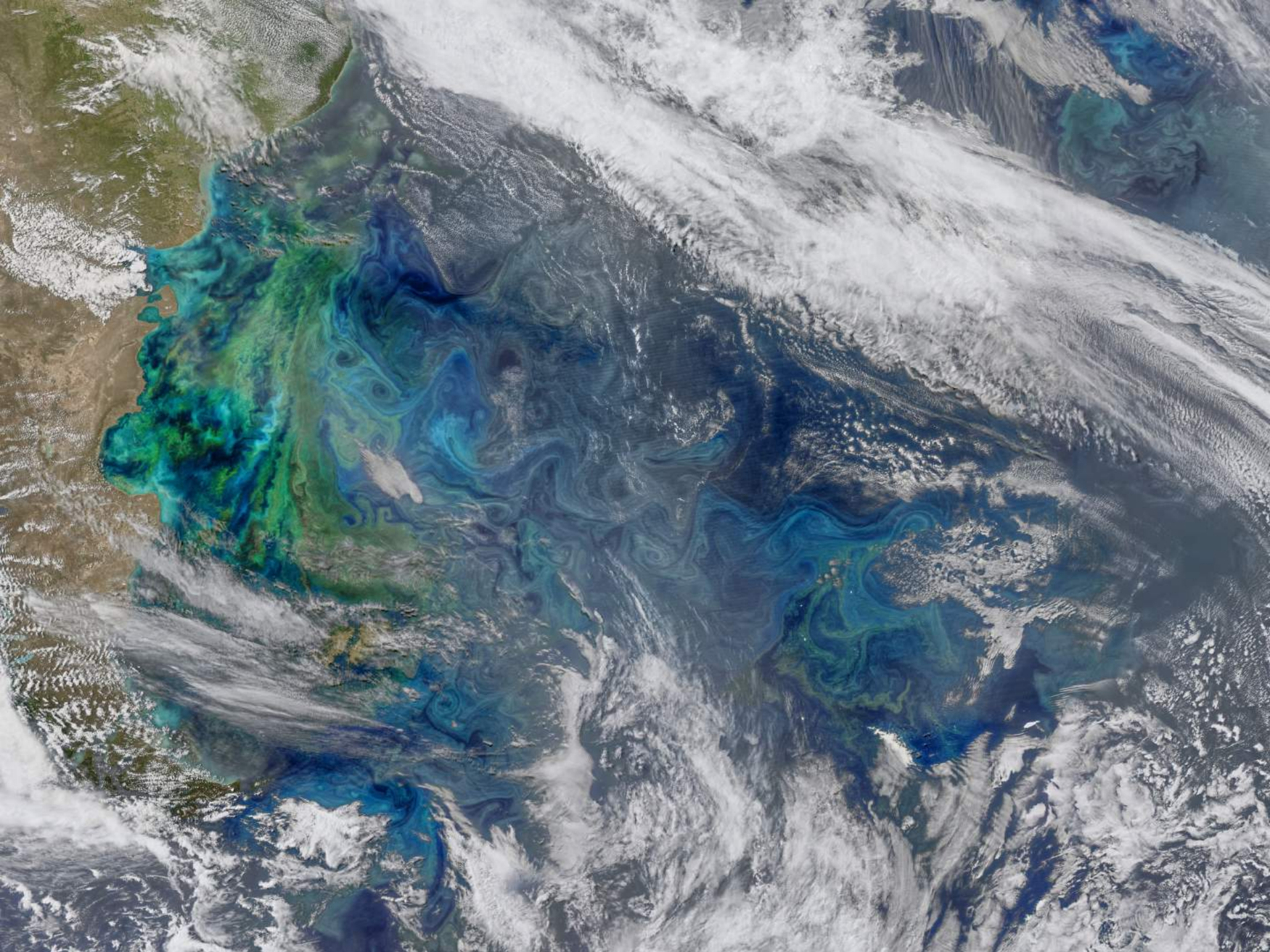




# Why do Juvenile Loggerheads Prefer Anticyclones?

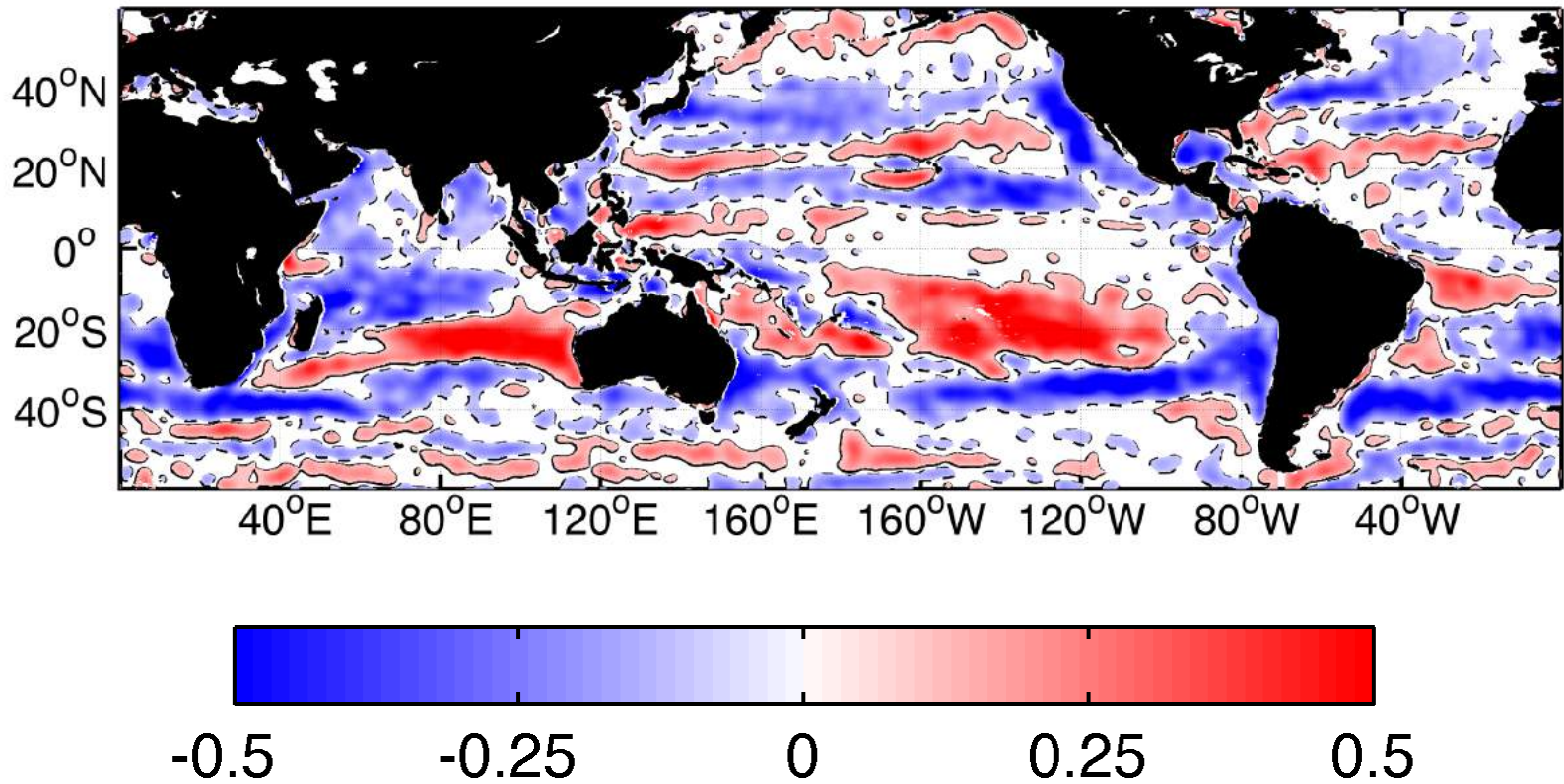






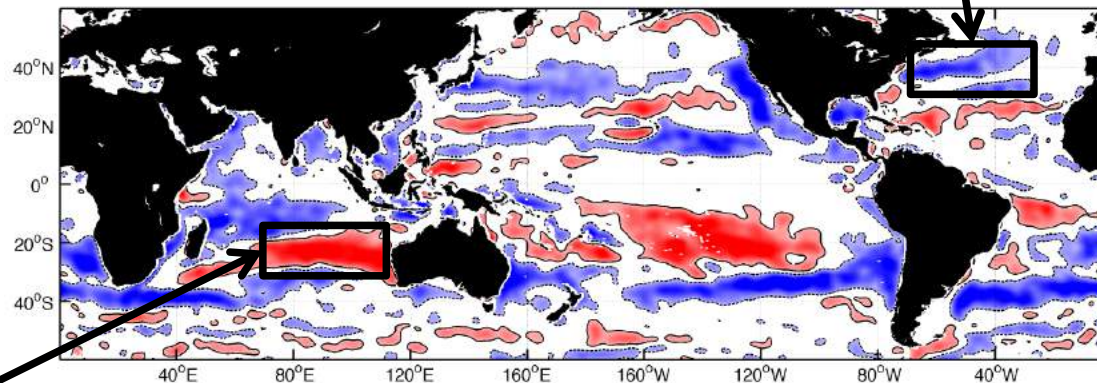
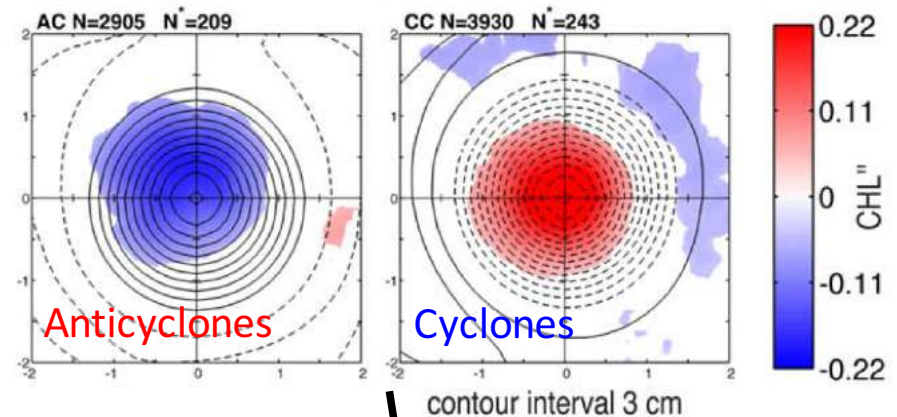


## Cross Correlation of CHL' and SSH

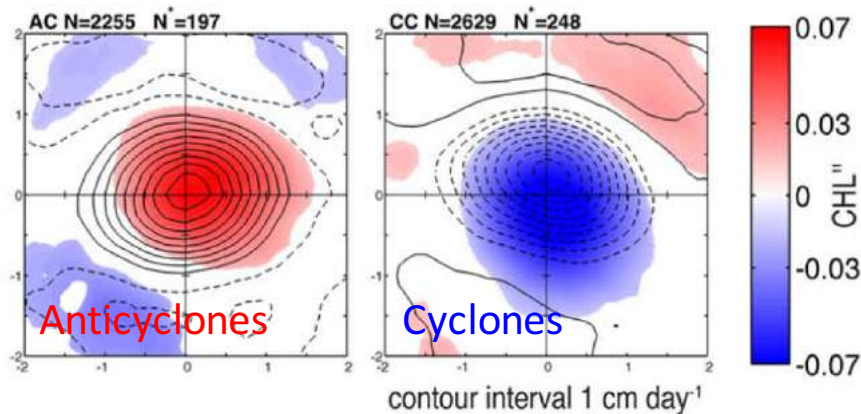


# SSH – CHL correlation and eddy-centric composites

a) Gulf Stream Eddies (Year Round)

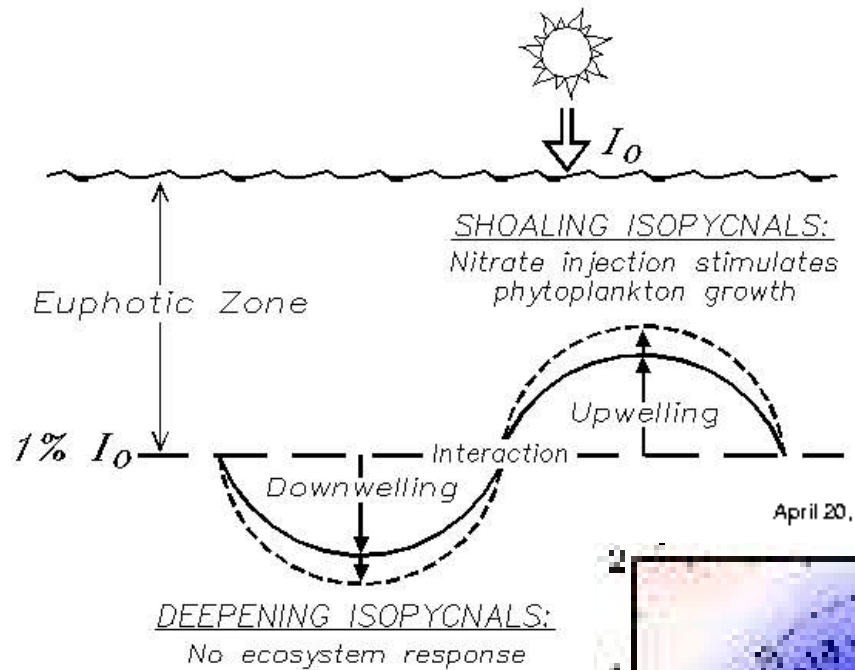


e) South Indian Ocean Eddies (May-October)



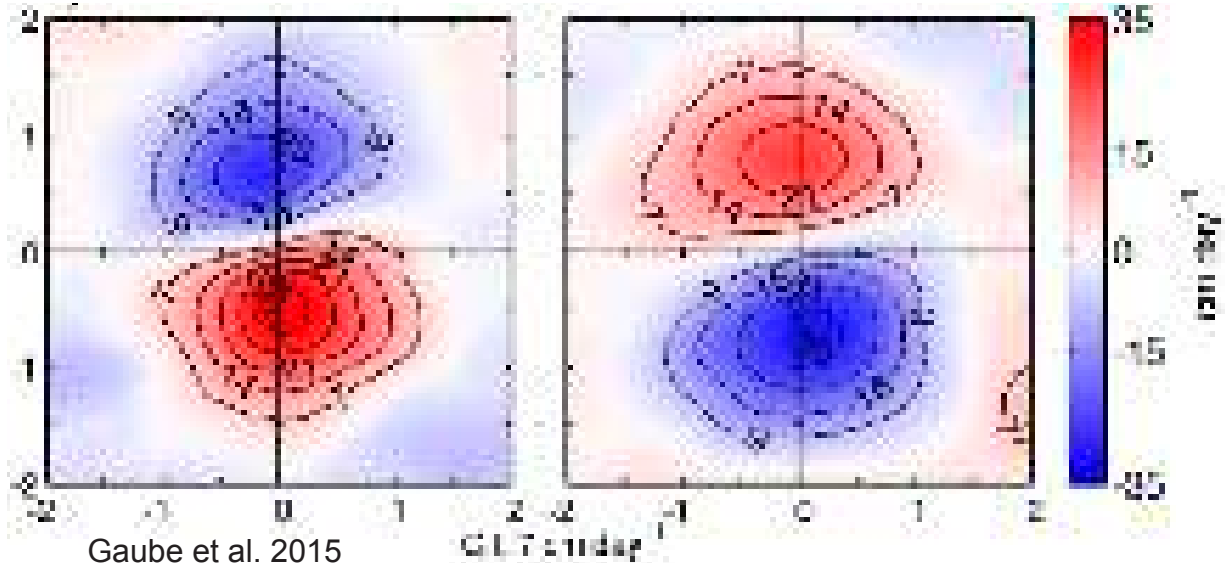
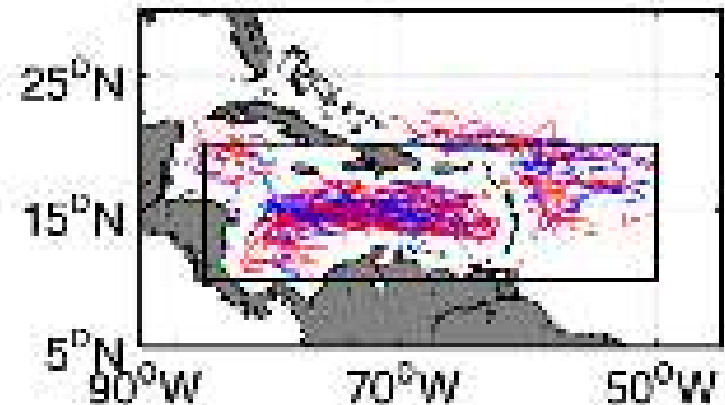


# Vertical Exchange Forced by Eddy Dynamics



McGillicuddy and Robinson, 1997

a) Caribbean Sea Eddies

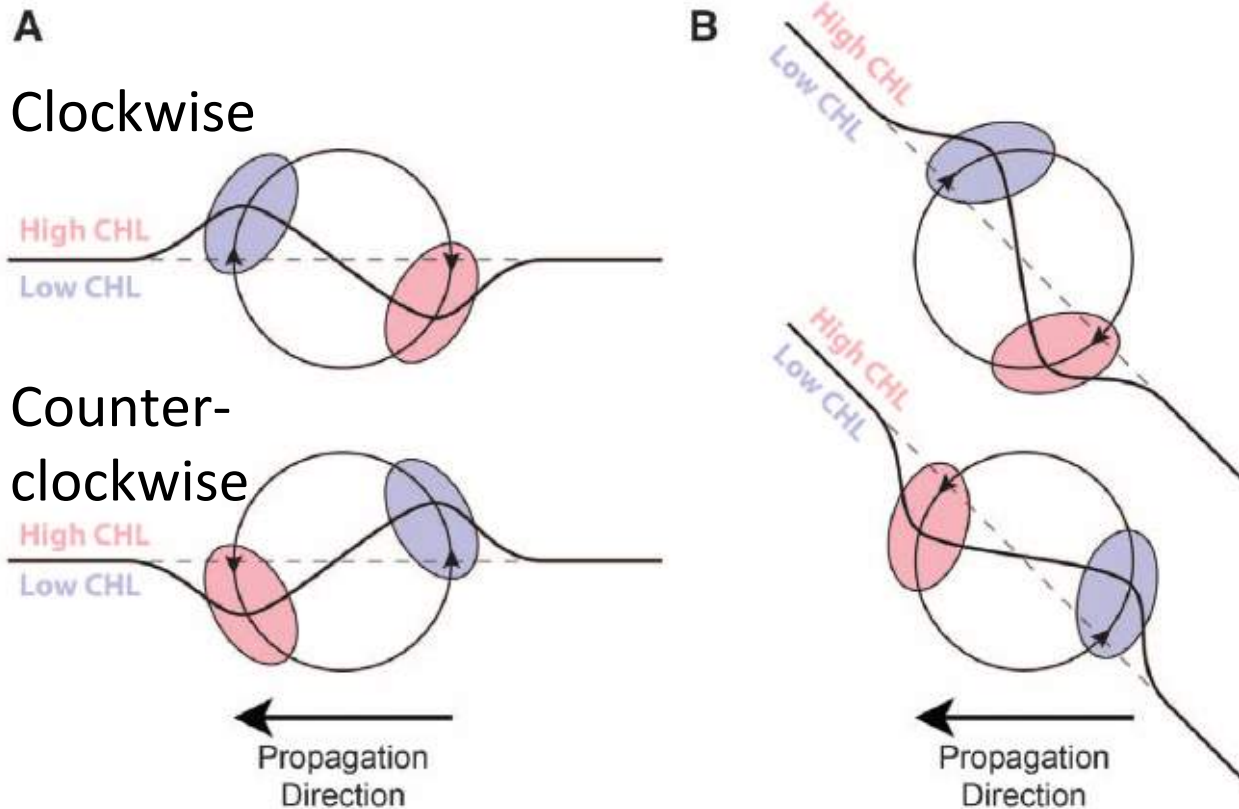


Gaube et al. 2015

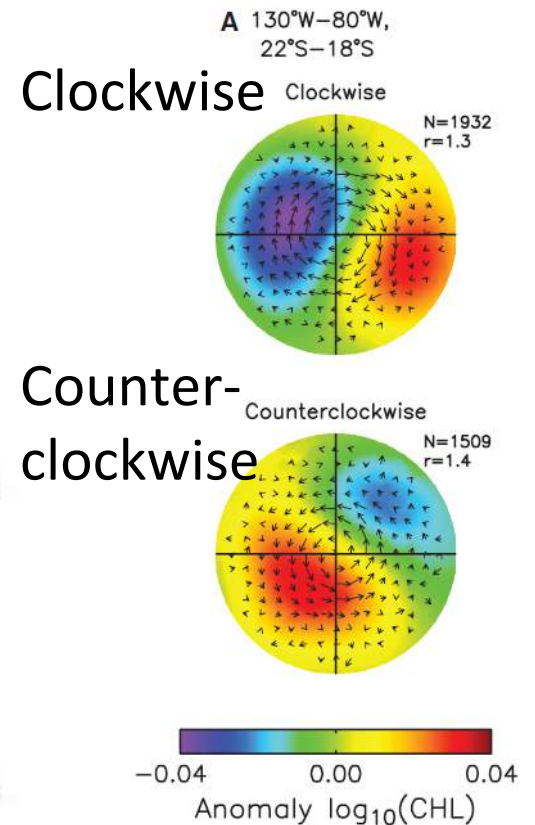
# Eddy Stirring

Observations reveal this to be the globally dominant mechanism

## Theory

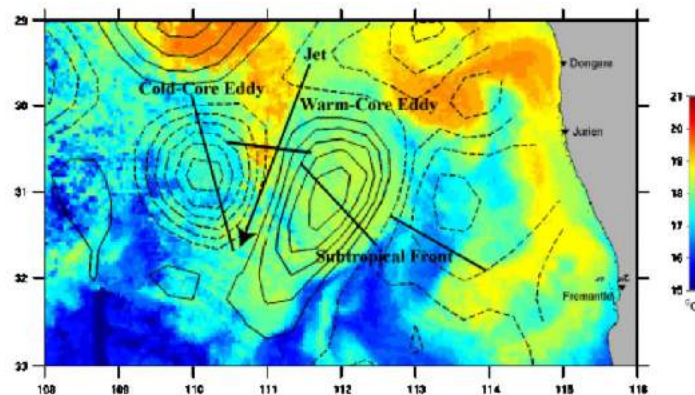
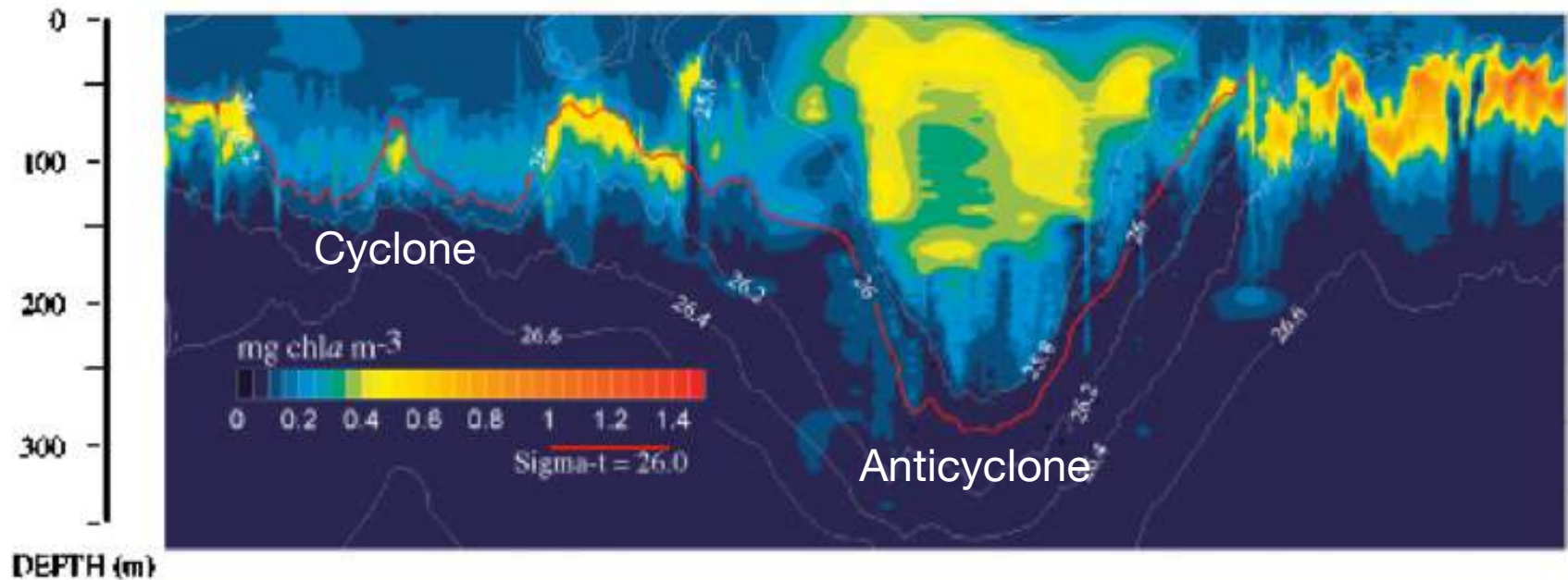


## Observations



# Eddies Modulate Mixed Layer Depth

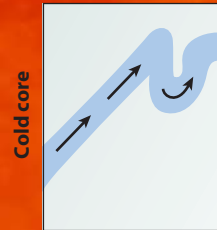
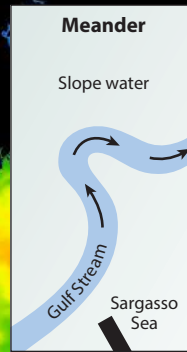
Pelagic predators spend a significant amount of time in the mixed layer



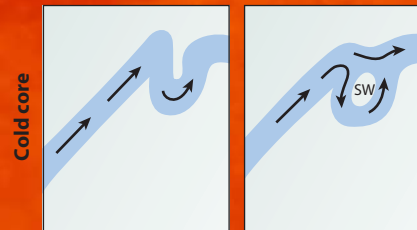
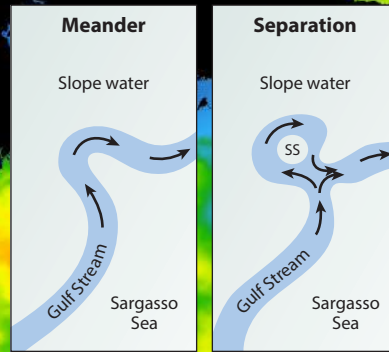
Waite *et al.* (2007b)  
figure 5, b and c



# Trapping of Pelagic Ecosystems in Mesoscale Eddies

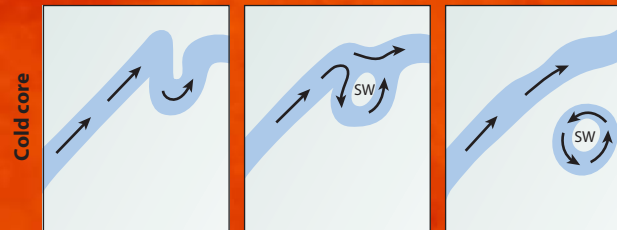
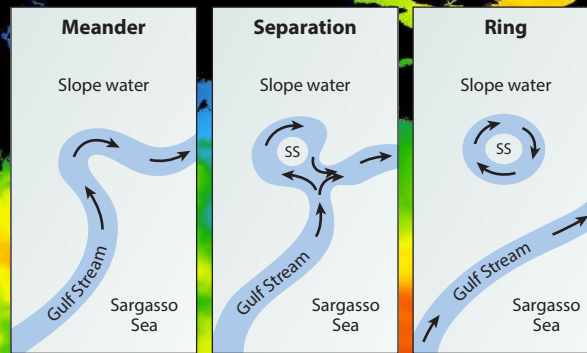


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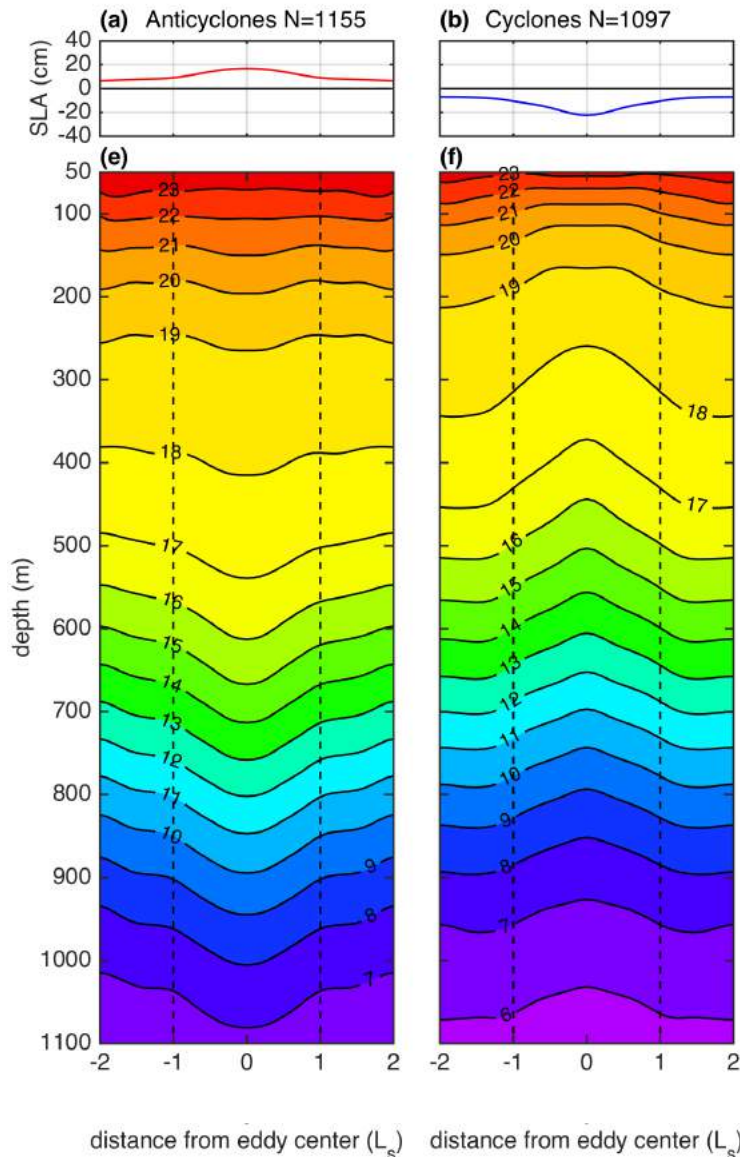
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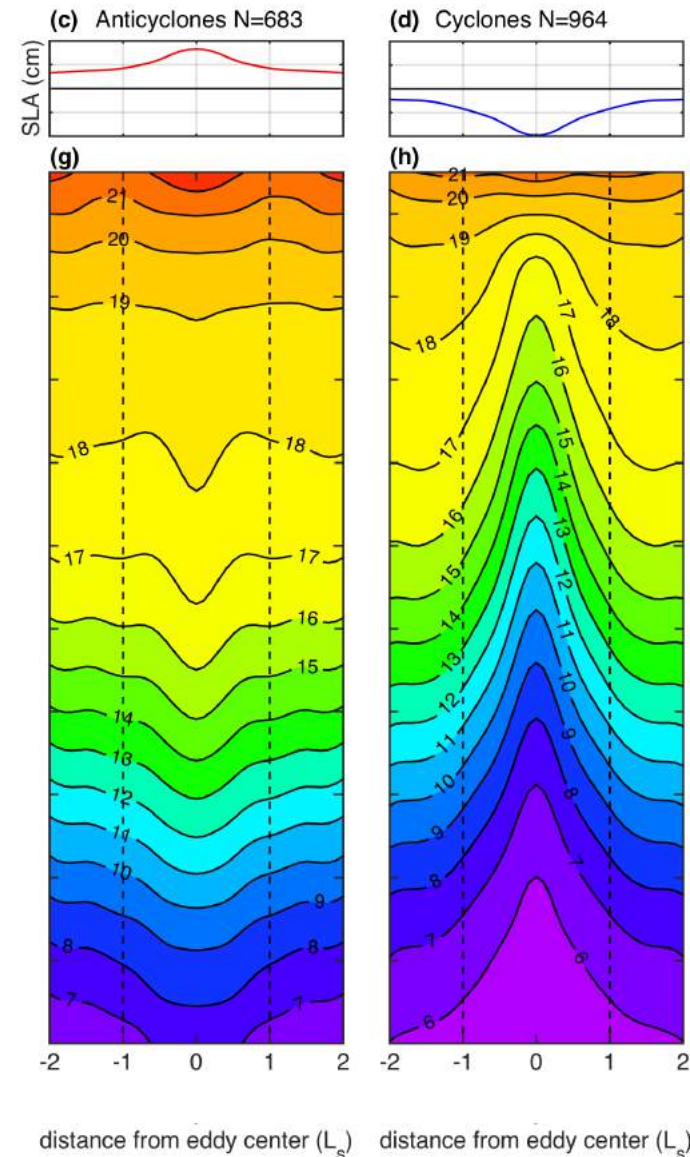
# Eddy Temperature Composites

Computed from Argo float profiles collocated with the interiors of eddies

## Open Ocean Eddies

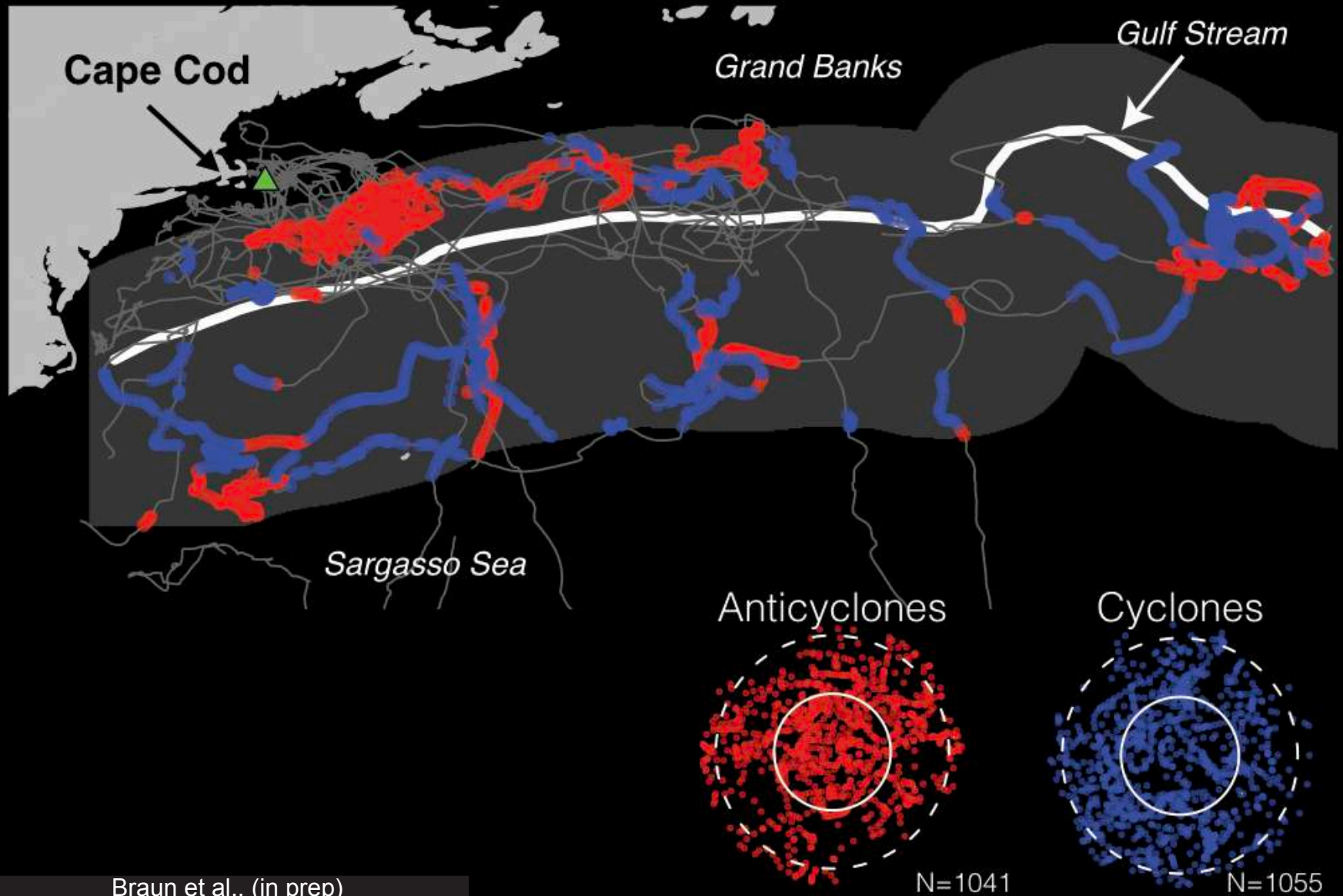


## Gulf Stream Region Eddies





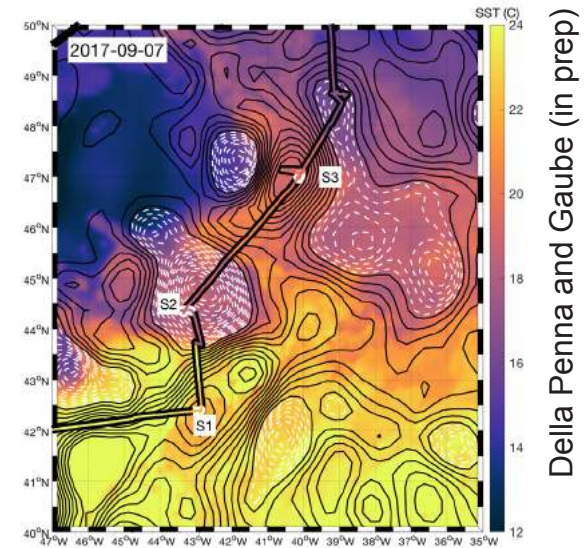
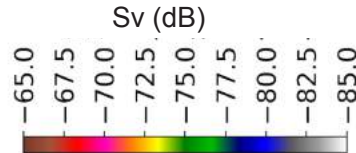
# Blue sharks regularly interact with Gulf Stream eddies



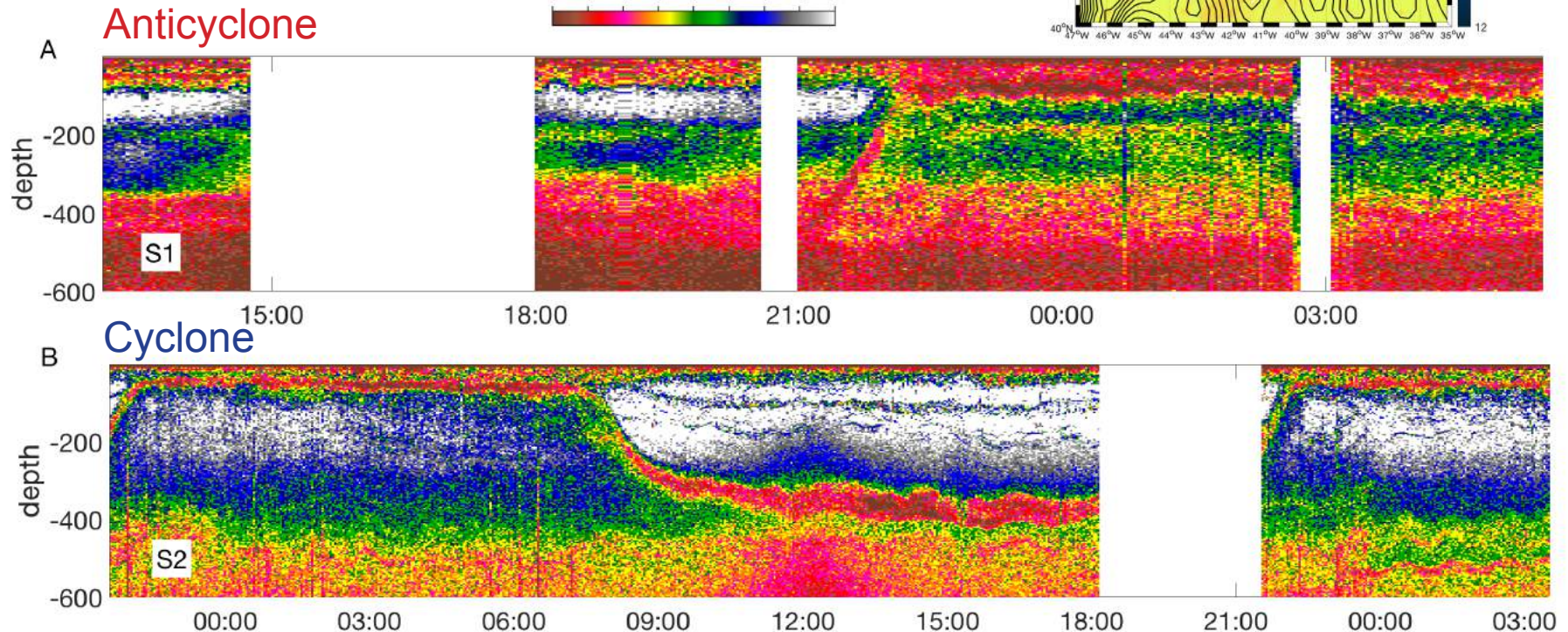
# Eddies Affect Deep Scattering Layers

Eddies separated by only 200 km

- Eddies modulate both the magnitude of mesopelagic backscattering and the characteristics of the DVM
- Mesopelagic acoustic backscatter is inversely correlated with surface chlorophyll-a

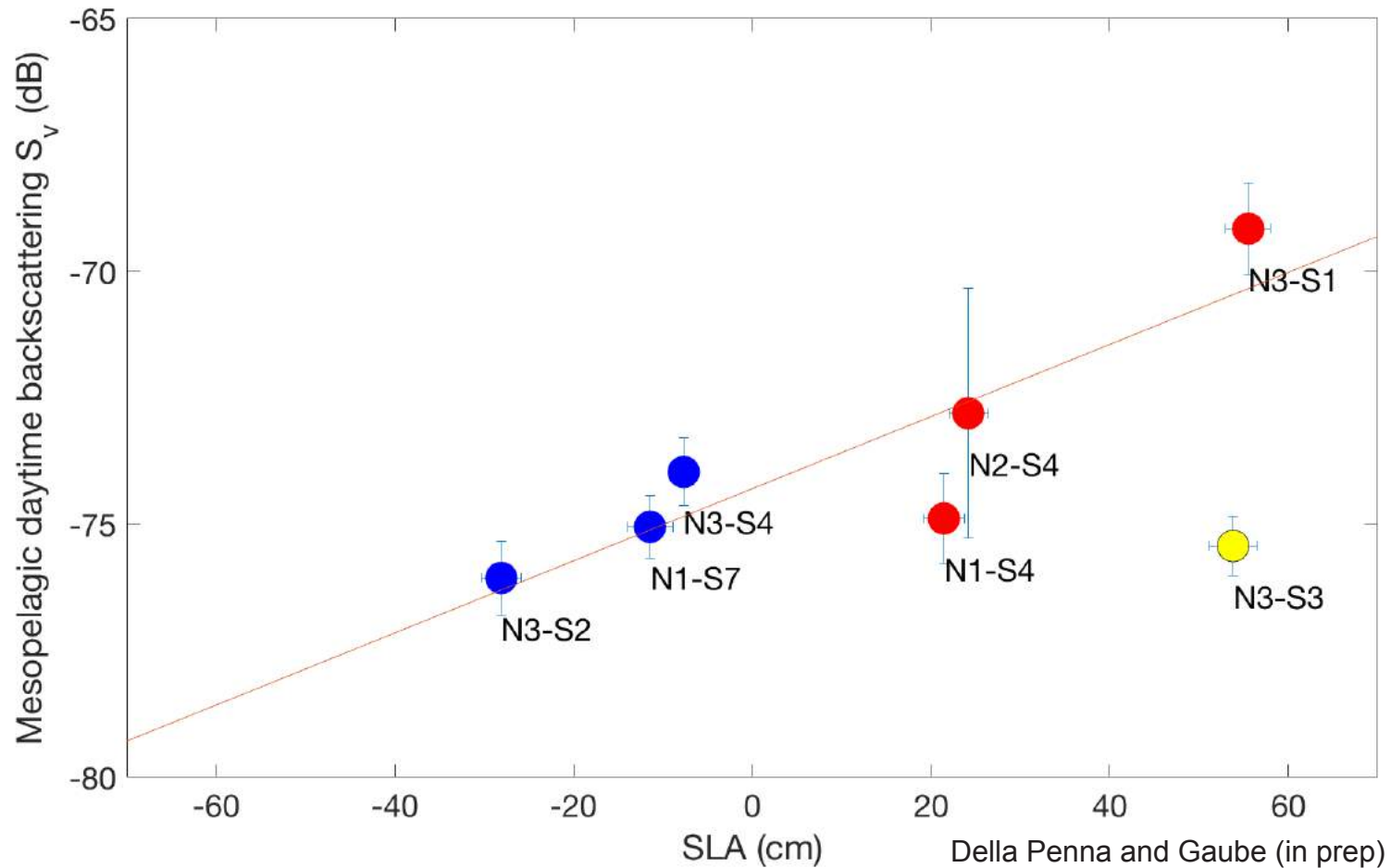


Della Penna and Gaube (in prep)

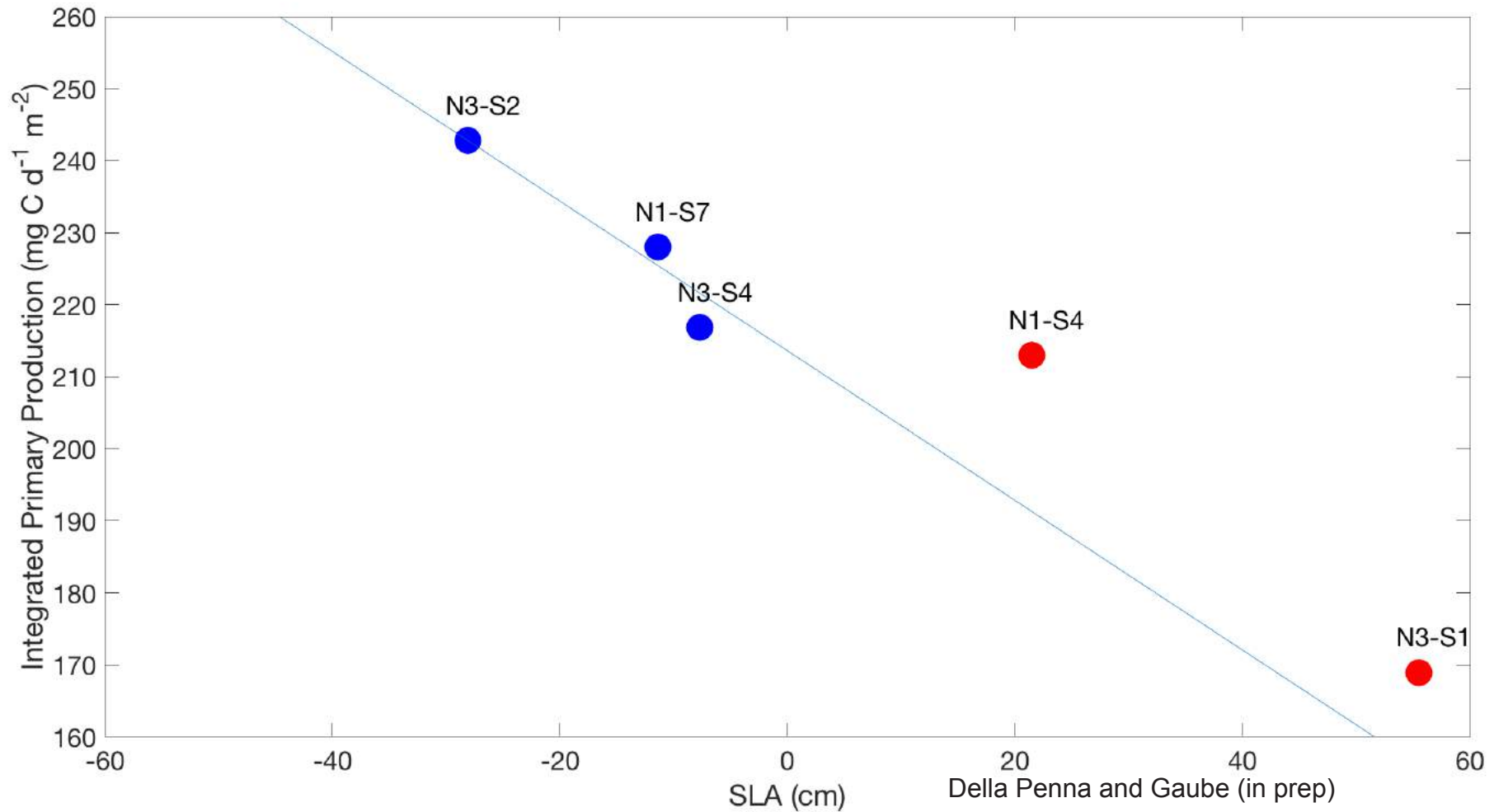




# Mesopelagic Backscattering is Elevated in Anticyclones in the North Atlantic

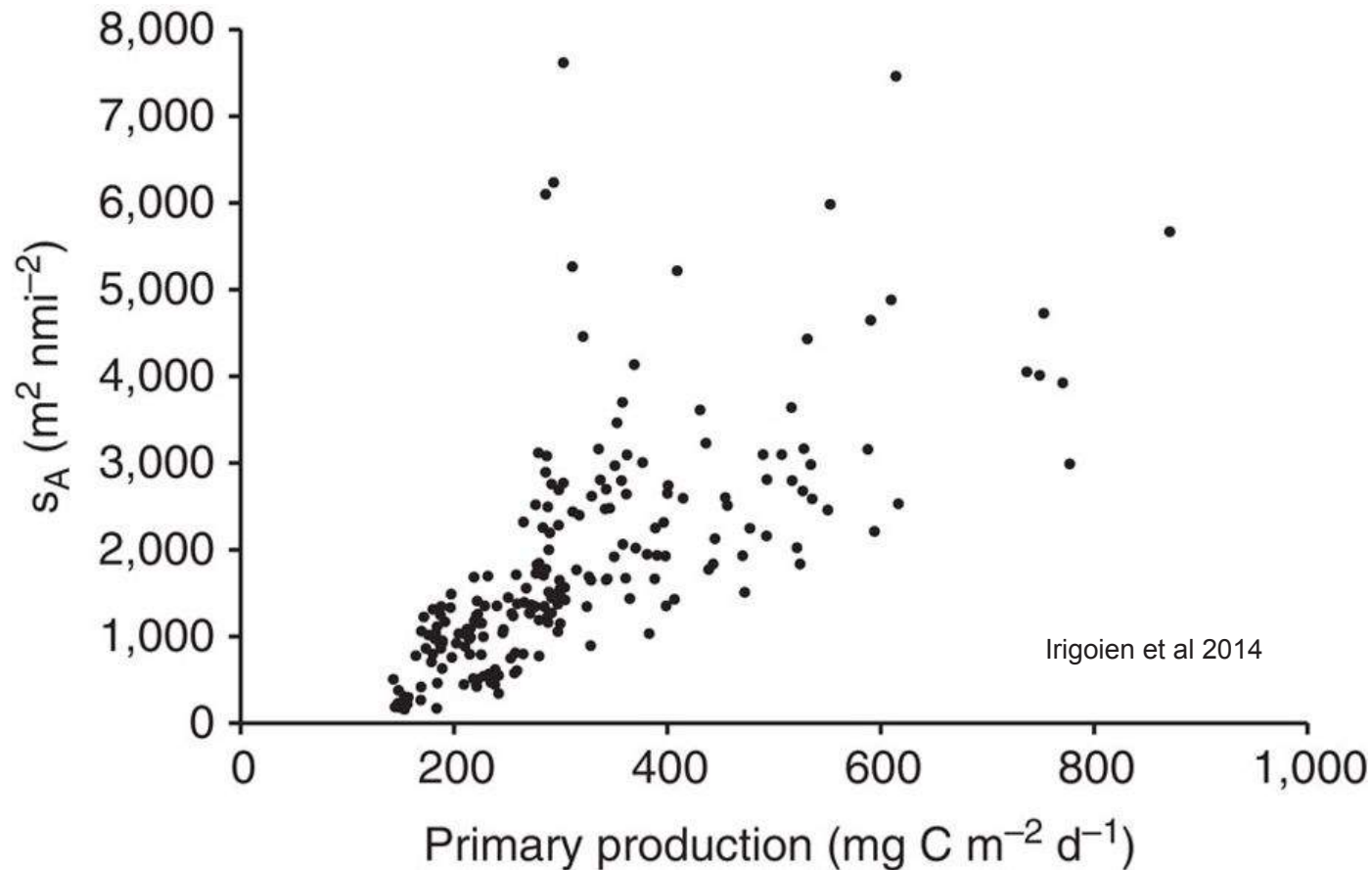


# Mesopelagic Backscattering is Inversely Correlated with Primary Production in these Eddies





# Primary Production and Mesopelagic Backscattering are Correlated at the Global Scale



# Summary and Conclusions

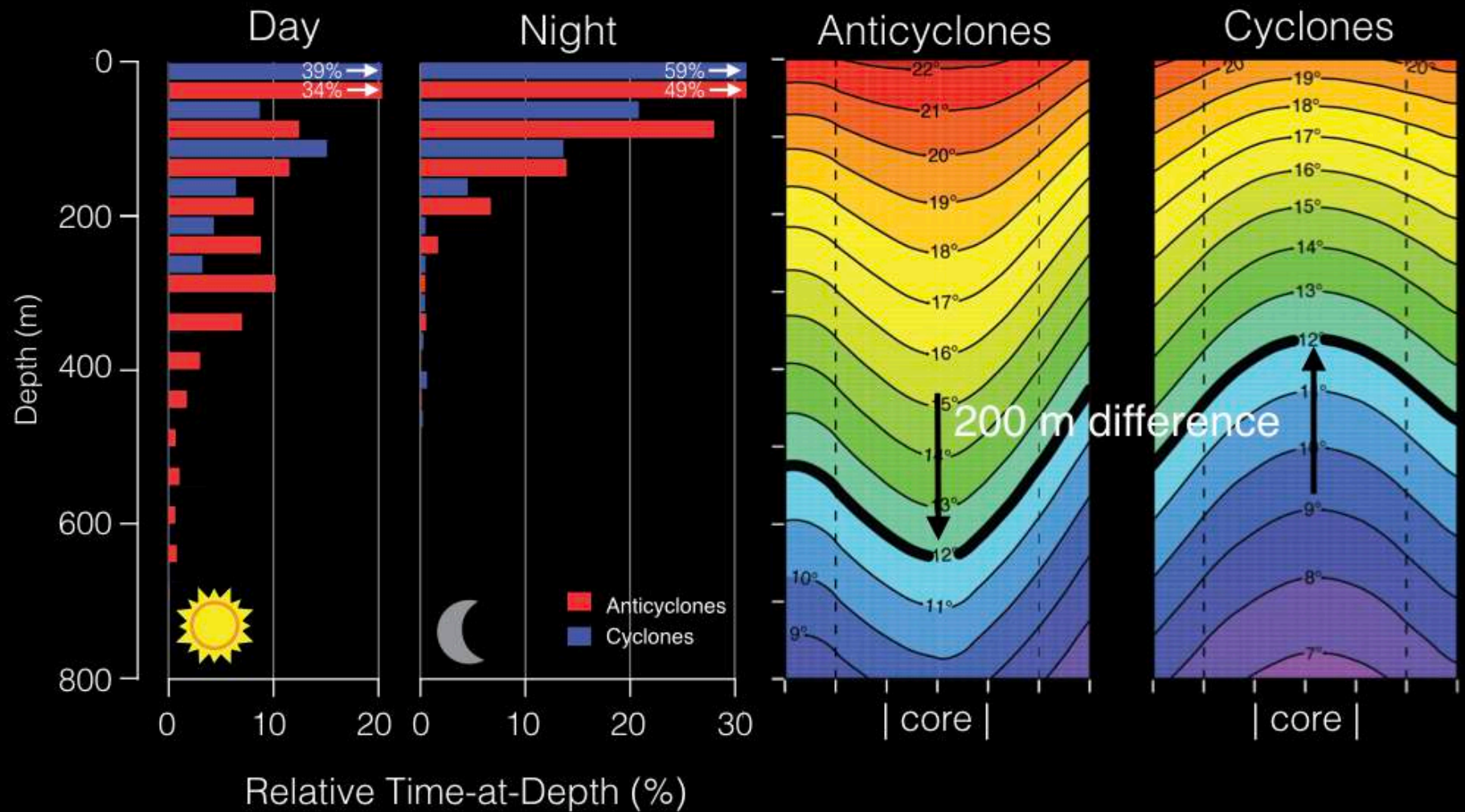
- Our research indicates that pelagic sharks and turtles preferentially occupy the cores of anticyclonic eddies.
  - Turtles in the Southern BMC seek out warm-core anticyclones
  - White sharks in the North Atlantic conduct longer dives into the mesopelagic in warm-core anticyclones
  - Blue sharks prefer anticyclones in the North Atlantic and exploit the larger strata enveloped by the 12 deg C isotherm in warm-core anticyclones\*.

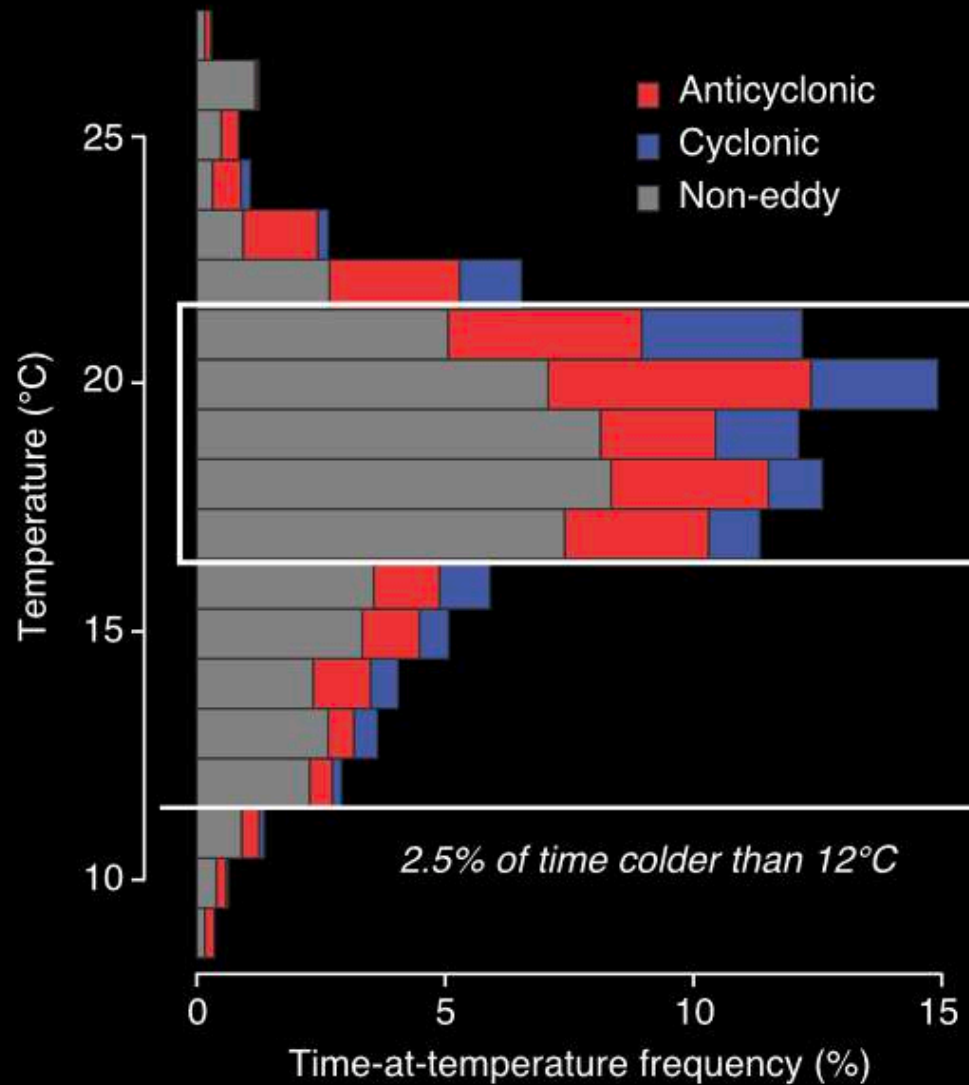
The observed preference of anticyclones by white sharks could be the result of a simple calculus of energetic demands:

- (1) White sharks regulate their internal temperature and anticyclones in the North Atlantic are generally associated with positive sub-surface temperature anomalies;
- (2) foraging dives might be more successful in anticyclones as a result of elevated mesopelagic fish and squid biomass when compared to cyclones.



# Diel vertical migration in eddies suggests foraging at depth





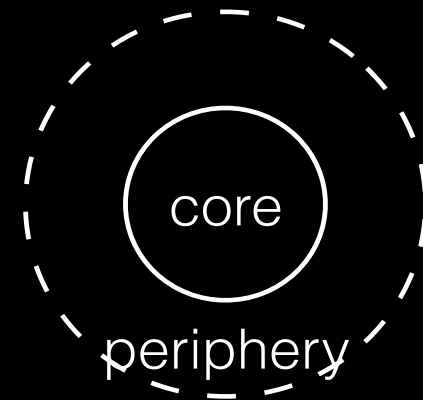
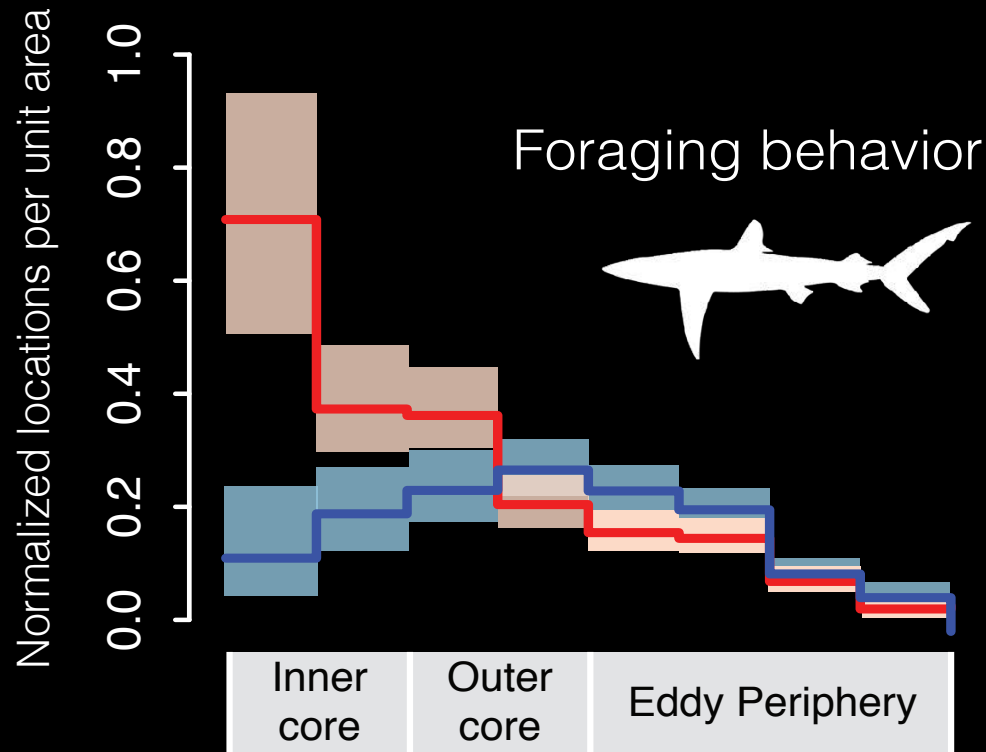
preferred thermal envelope?

tolerable

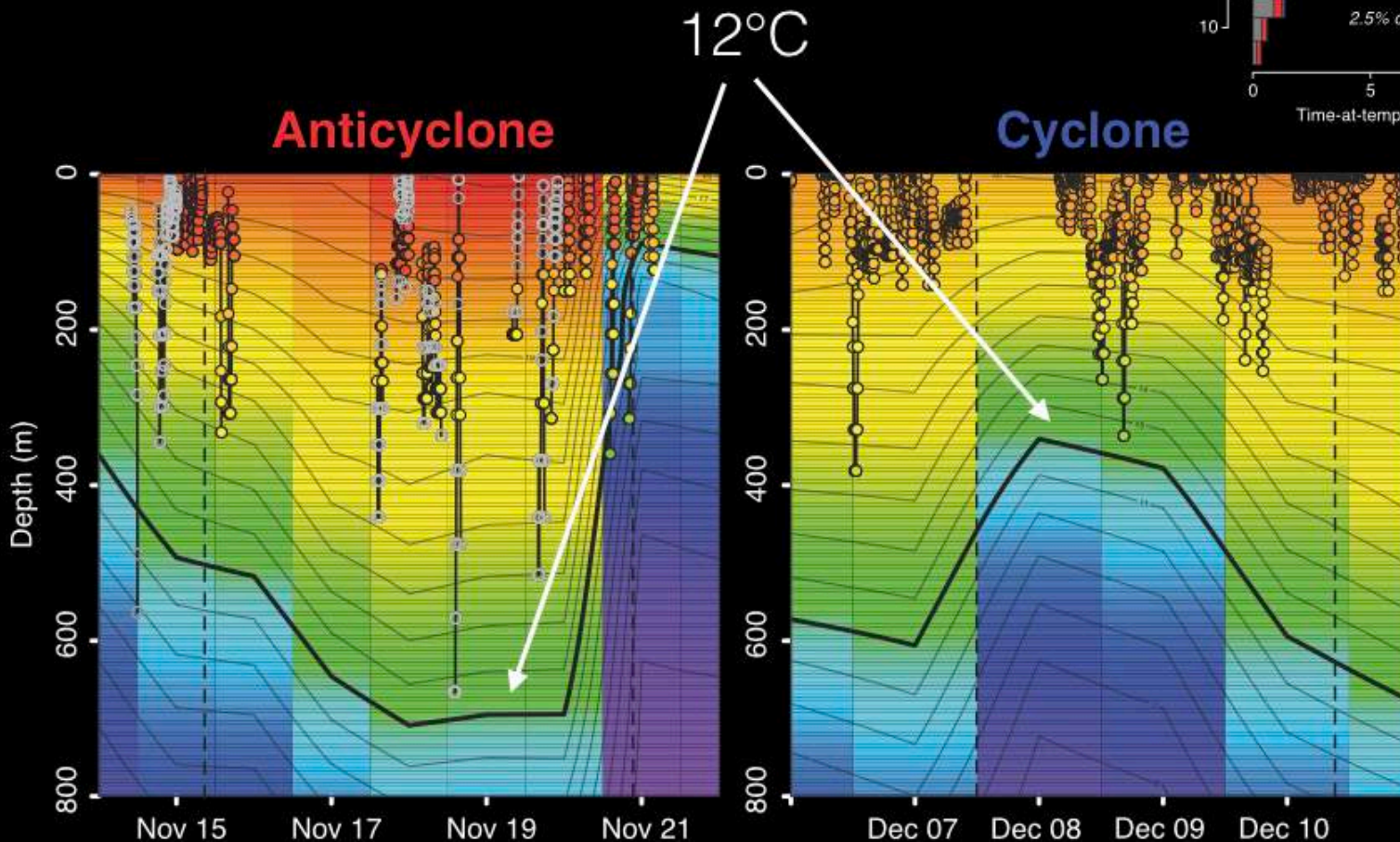
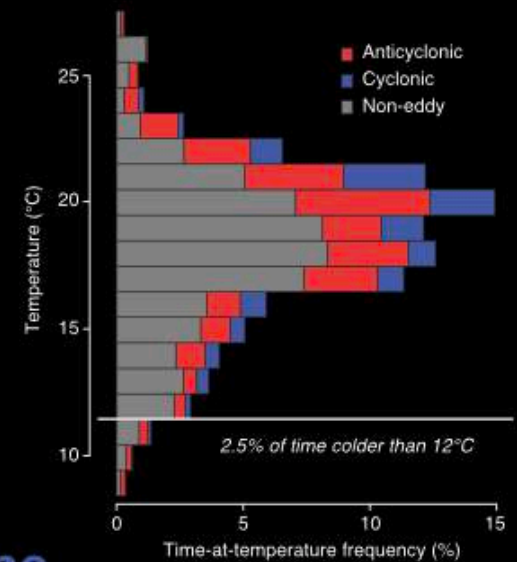
avoid?



# Sharks prefer cores of anticyclones

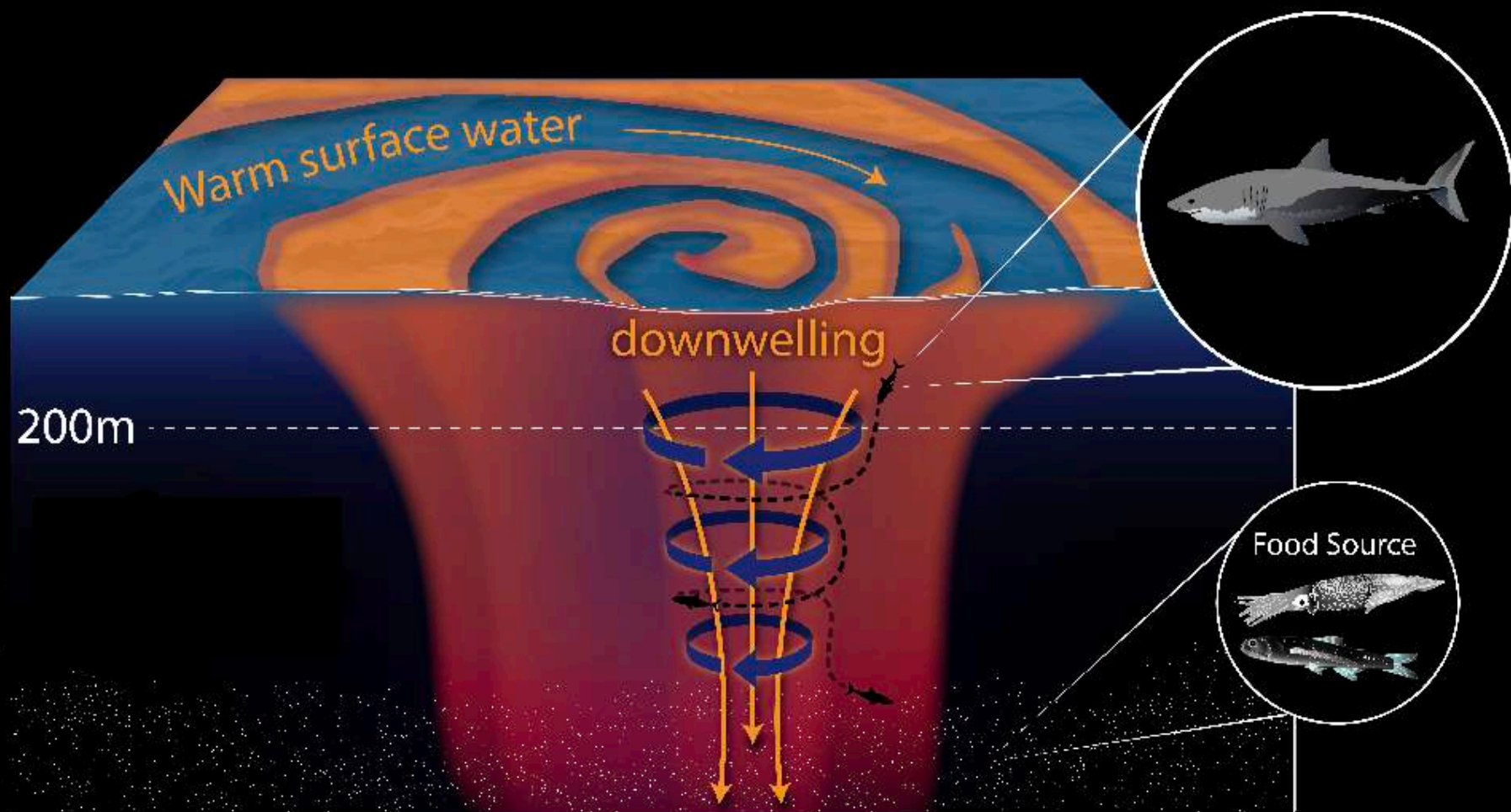


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Braun et al., (in prep)

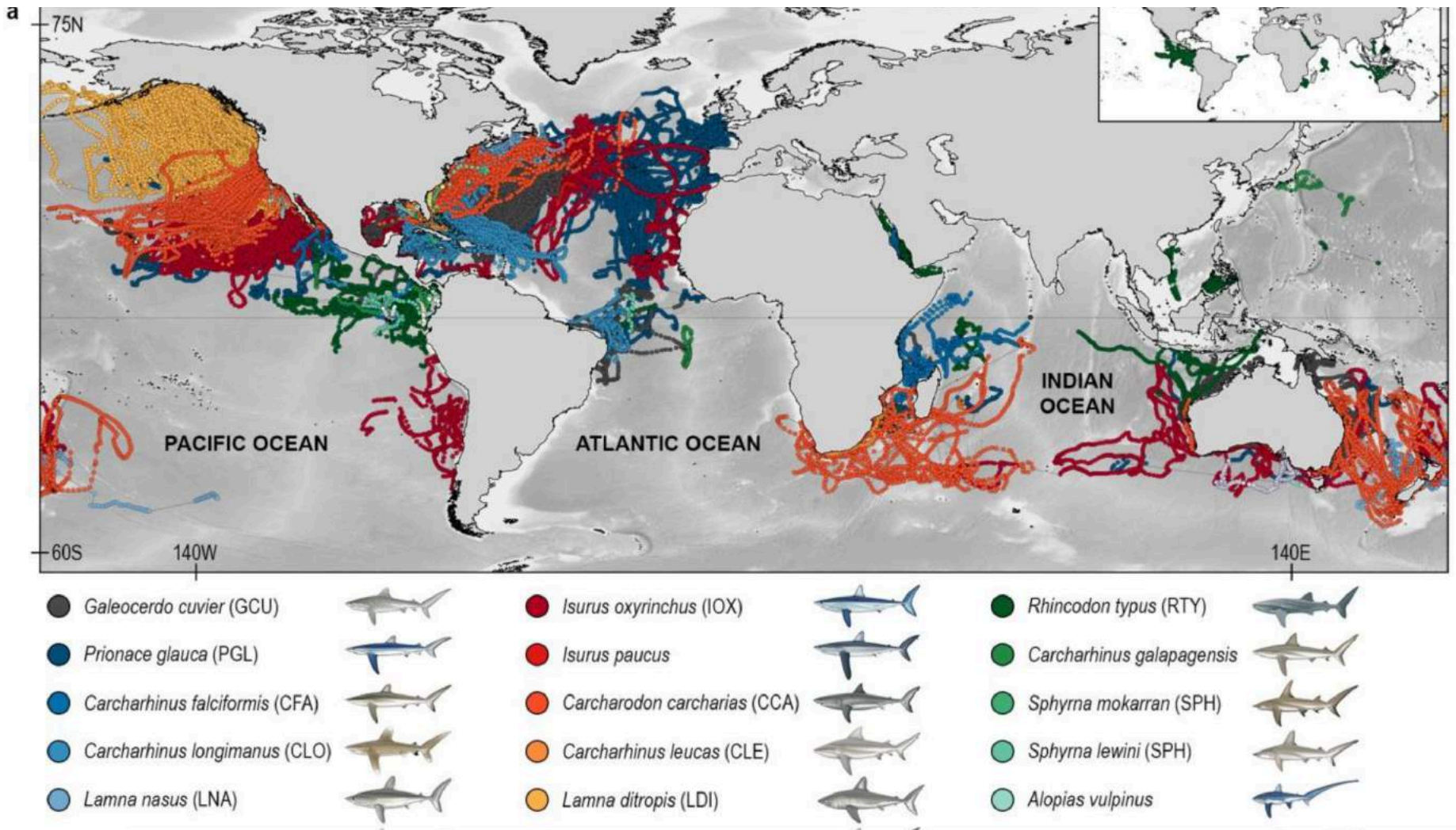
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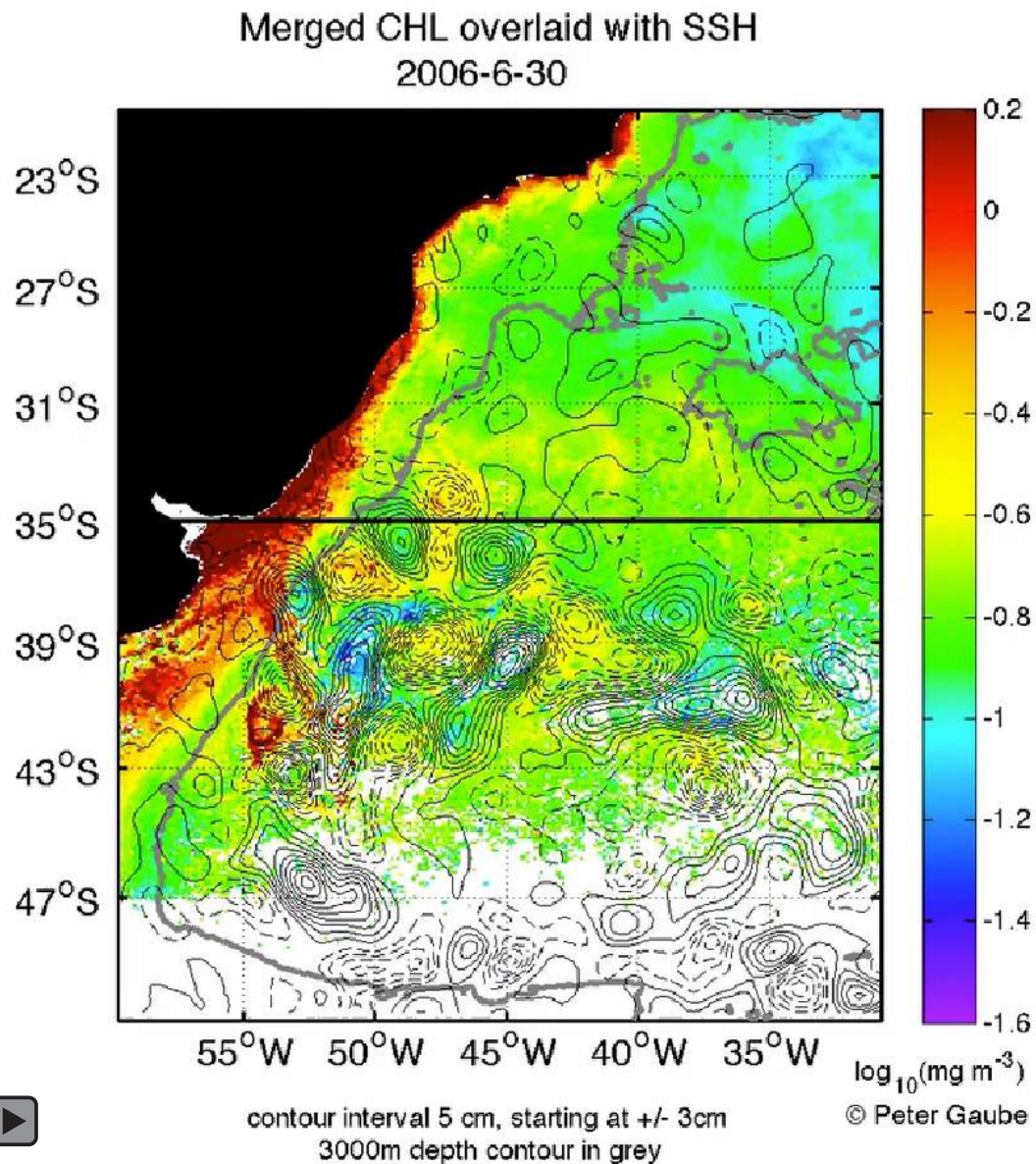


Peter Gaube

pgaube@apl.washington.edu

# Animation of Turtles, Eddies and CHL

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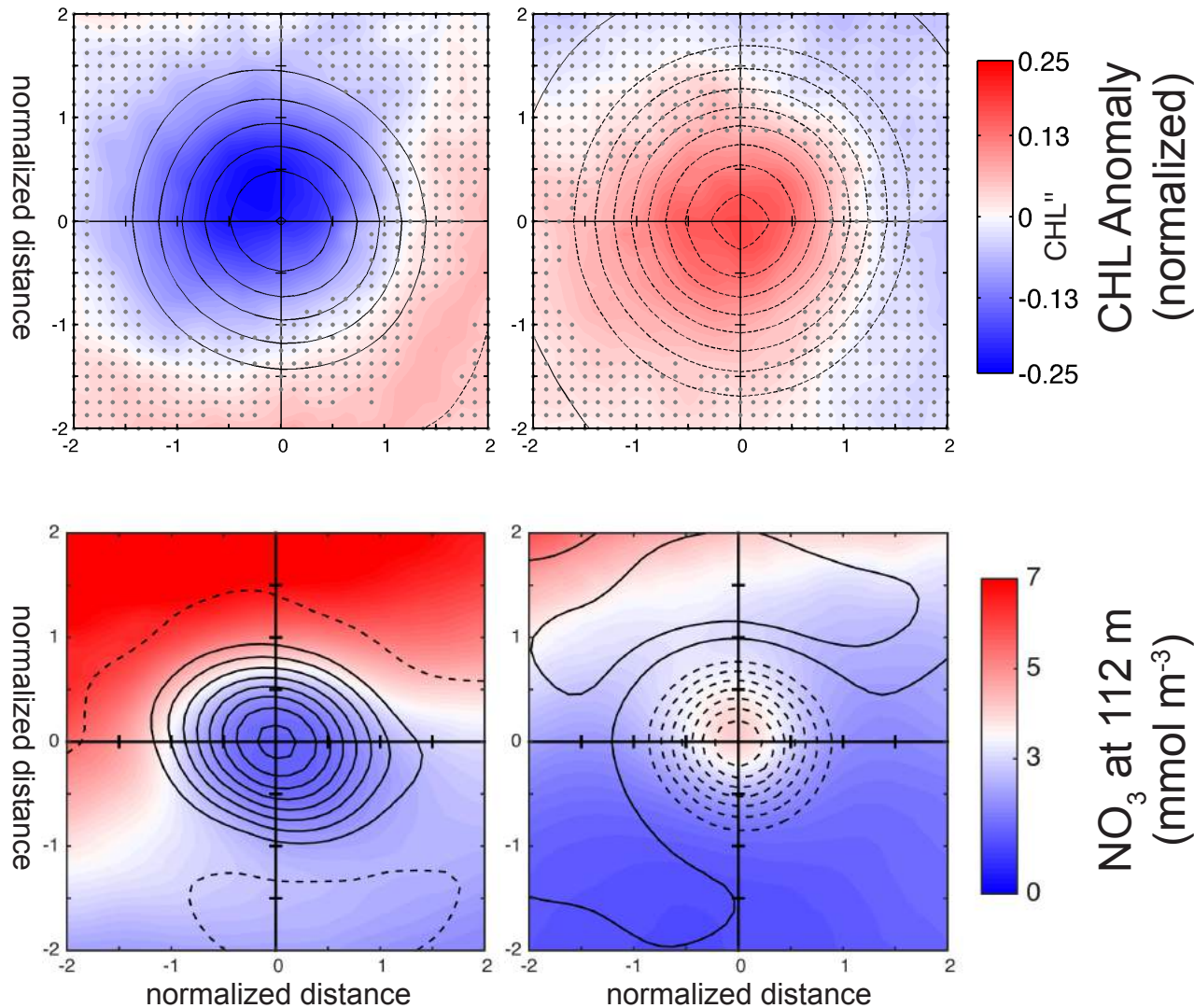




# Why do White Sharks Seek Out Anticyclones?

Anticyclones

Cyclones

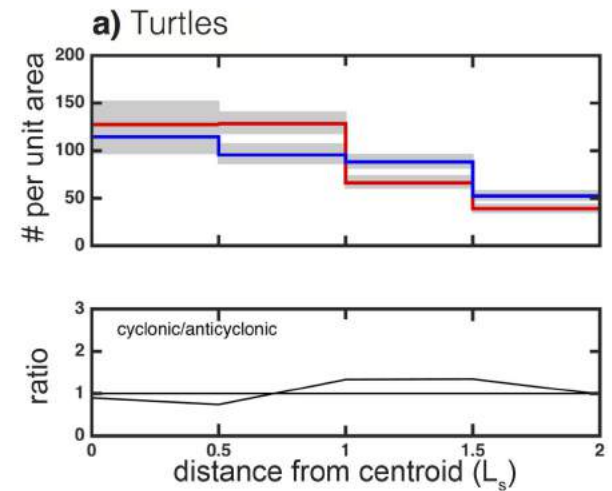
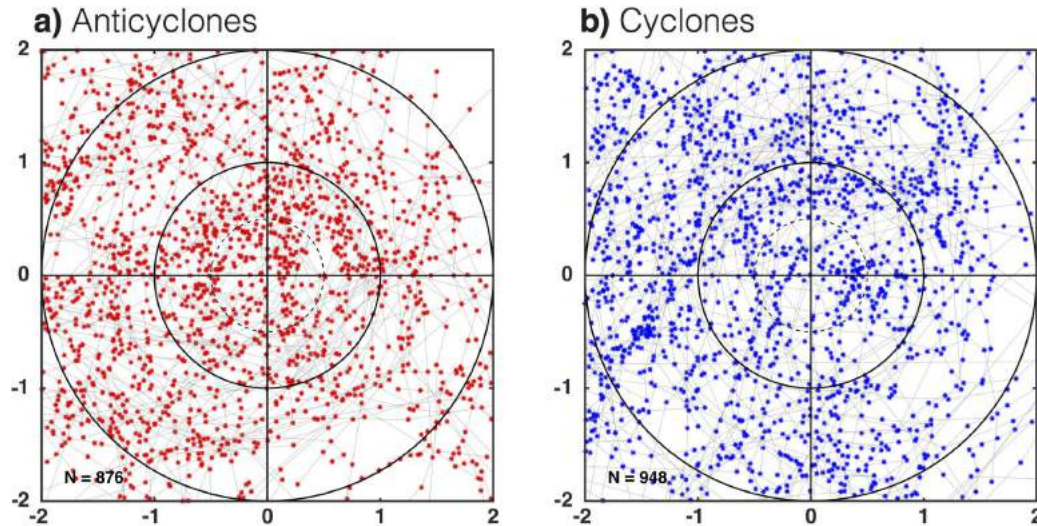


Gulf Stream  
Anticyclones:

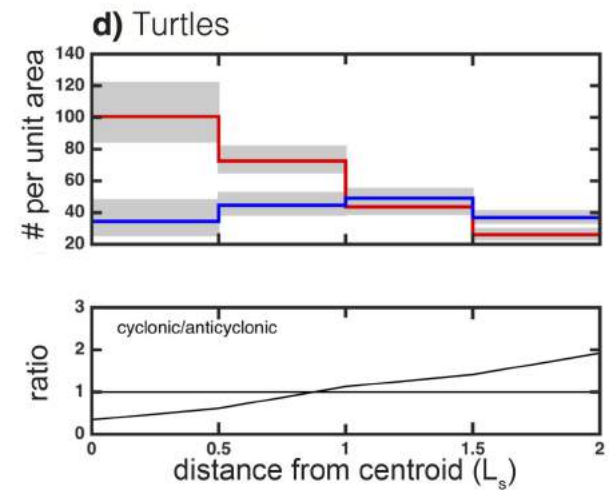
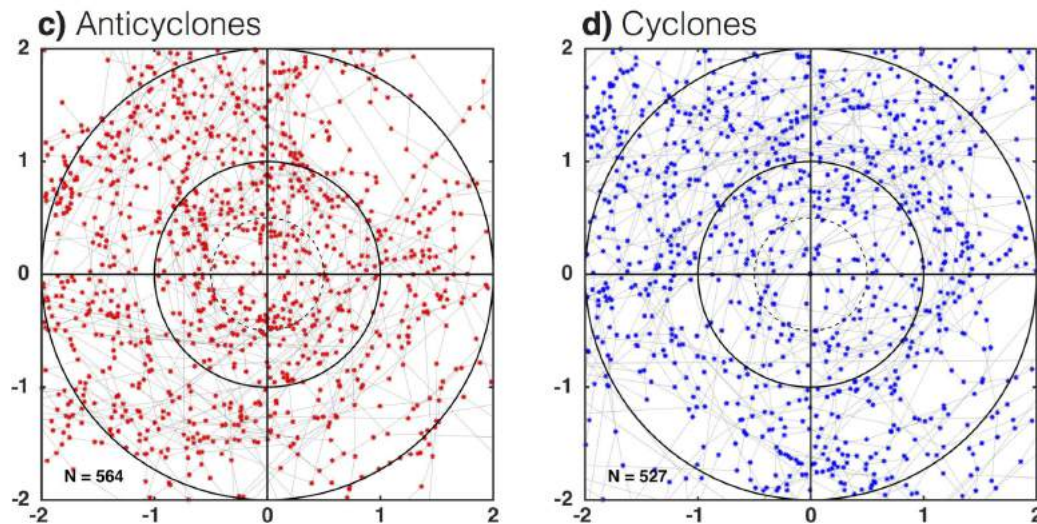
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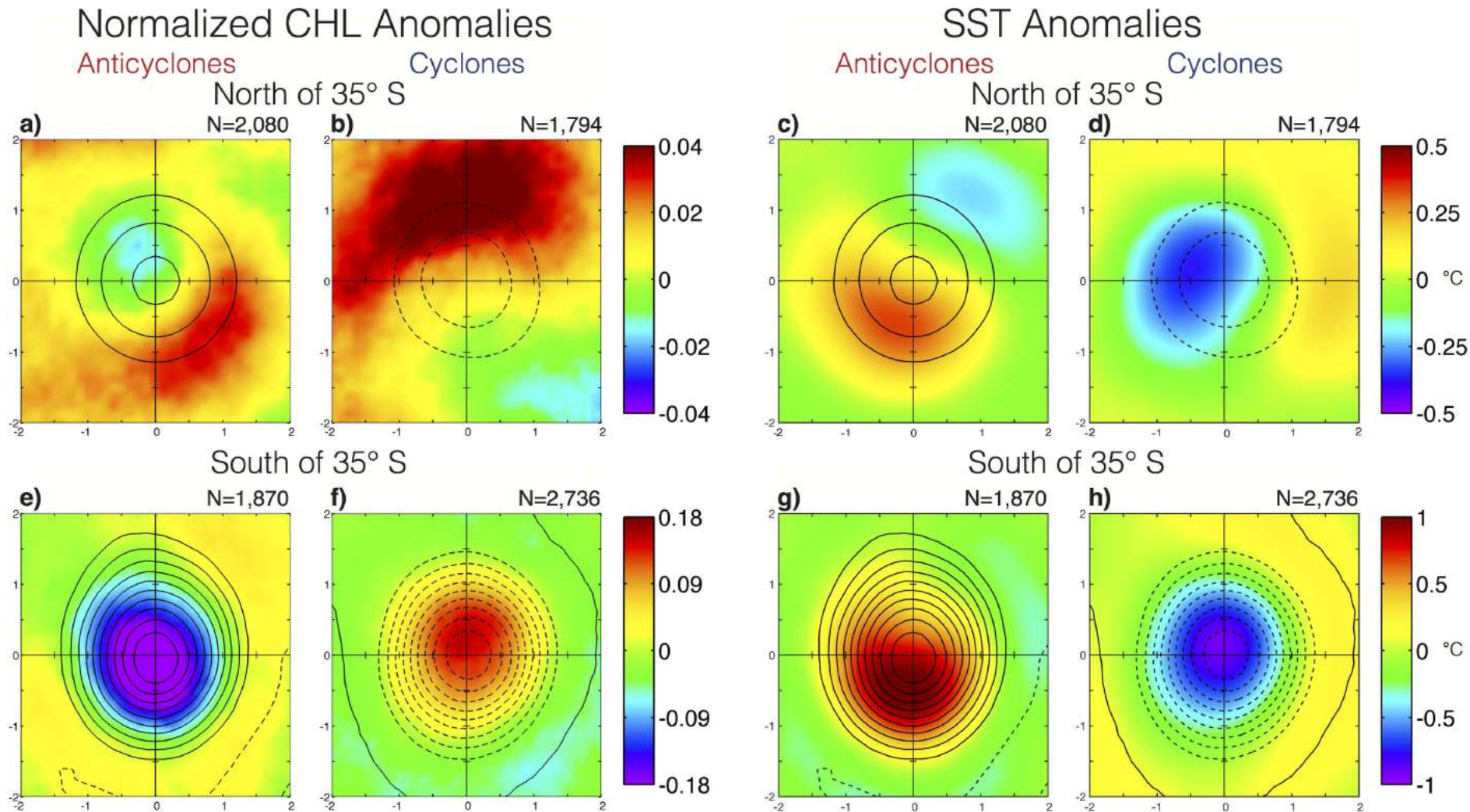
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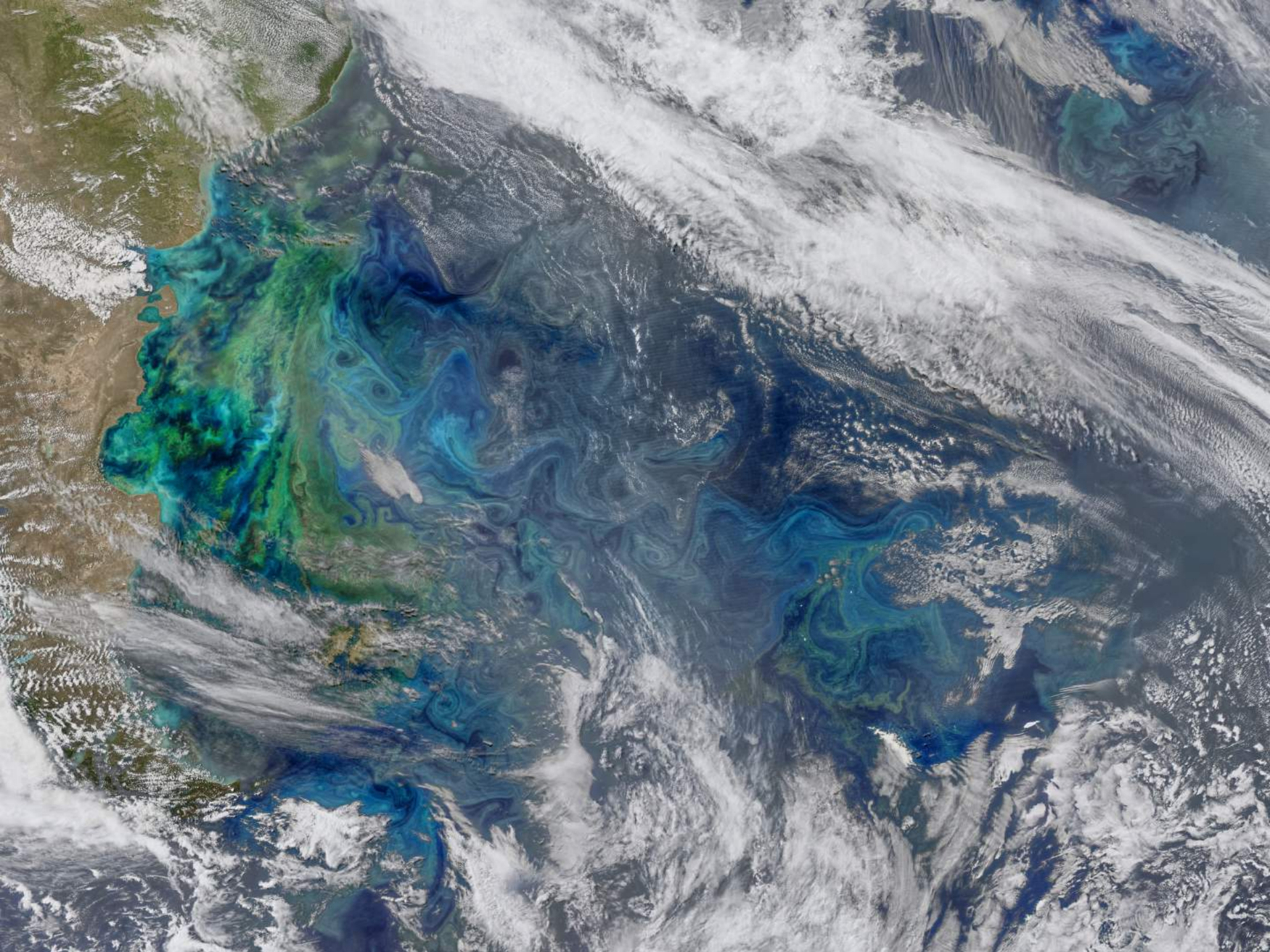


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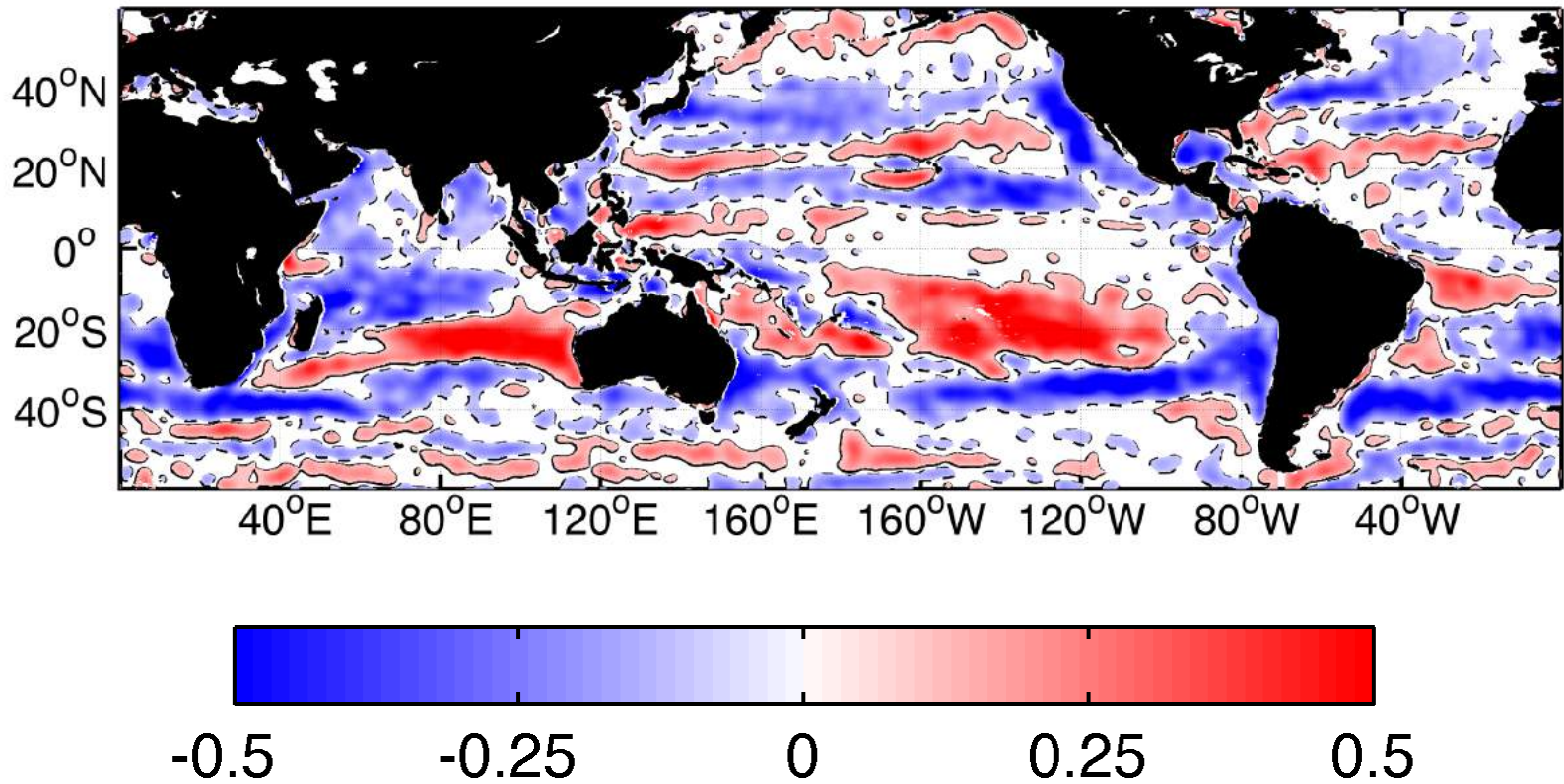
Gaube et al. 2017





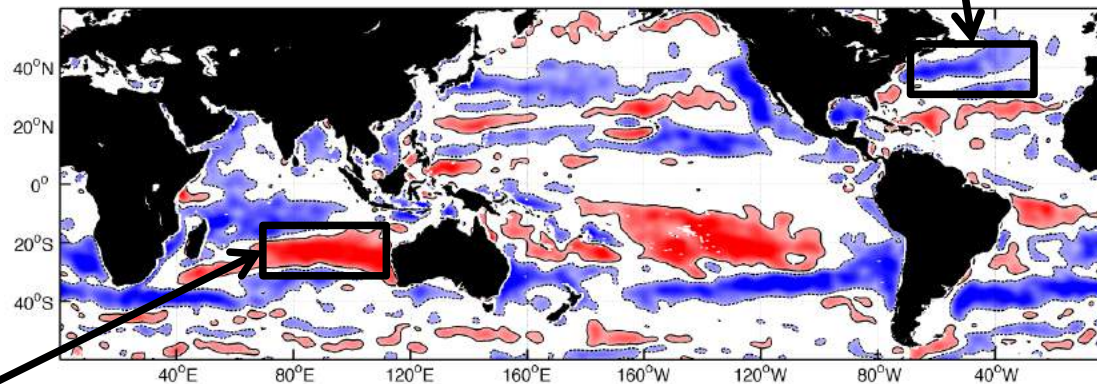
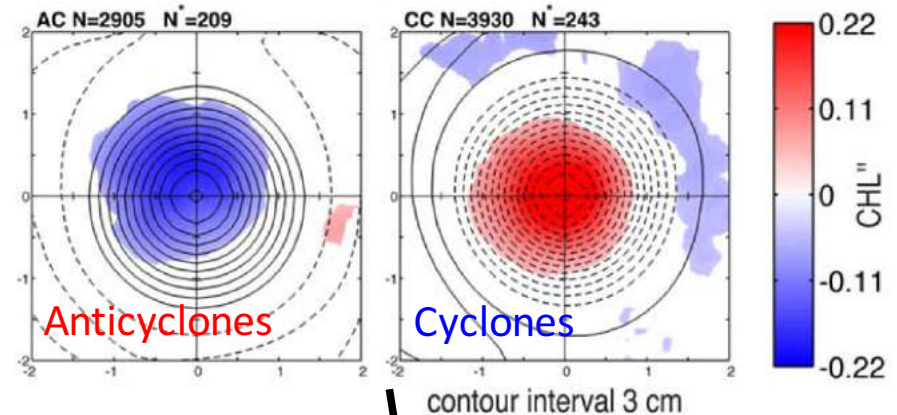


## Cross Correlation of CHL' and SSH

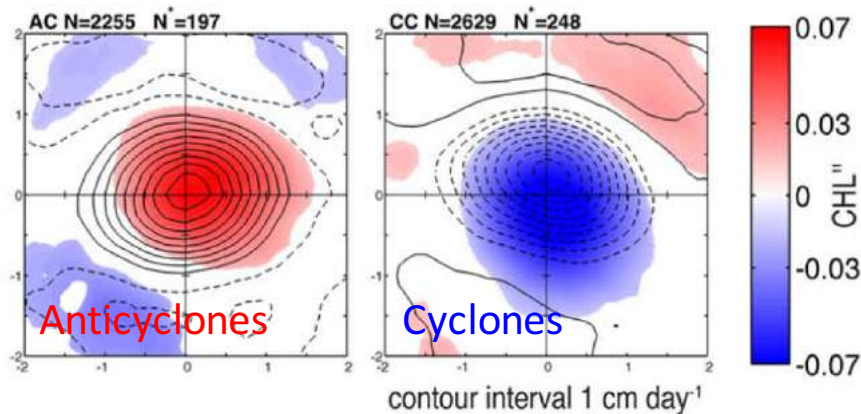


# SSH – CHL correlation and eddy-centric composites

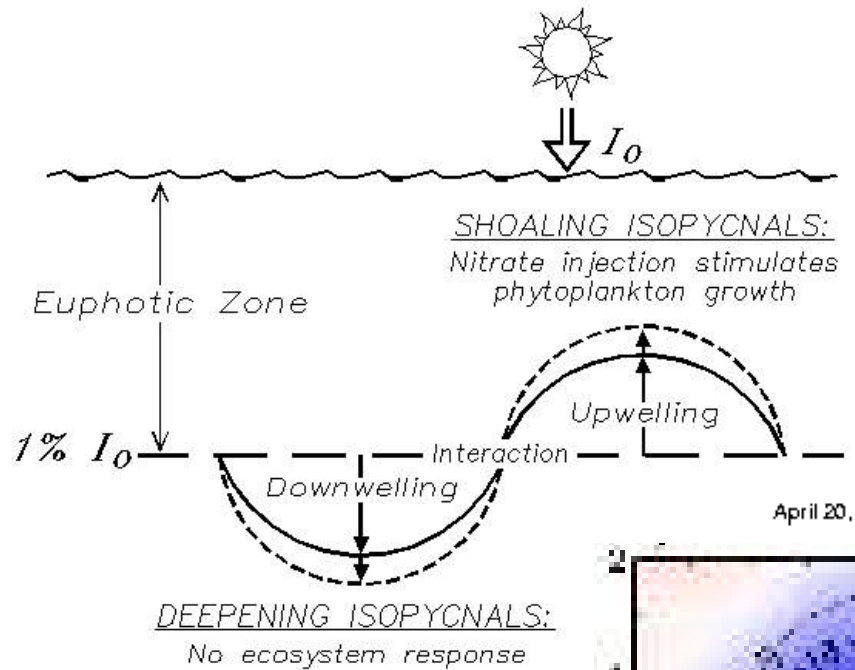
a) Gulf Stream Eddies (Year Round)



e) South Indian Ocean Eddies (May-October)

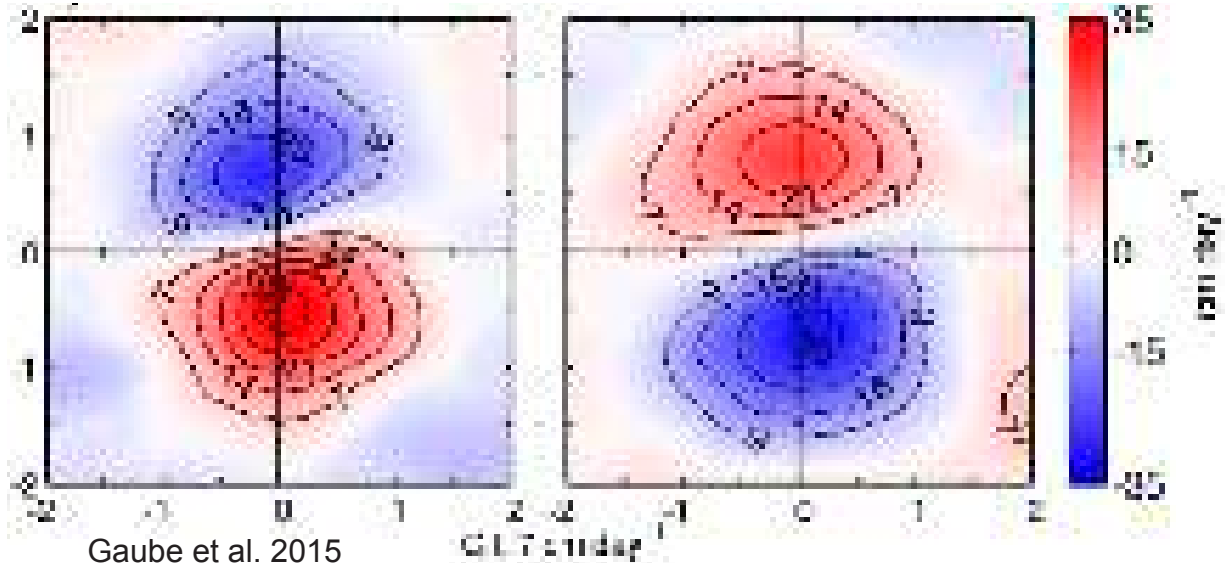
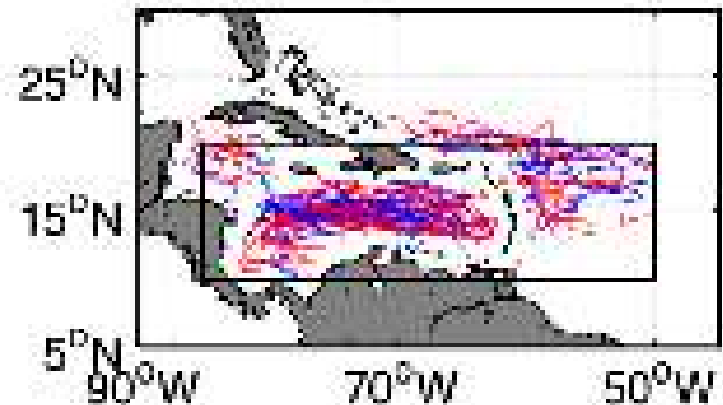


# Vertical Exchange Forced by Eddy Dynamics



McGillicuddy and Robinson, 1997

a) Caribbean Sea Eddies



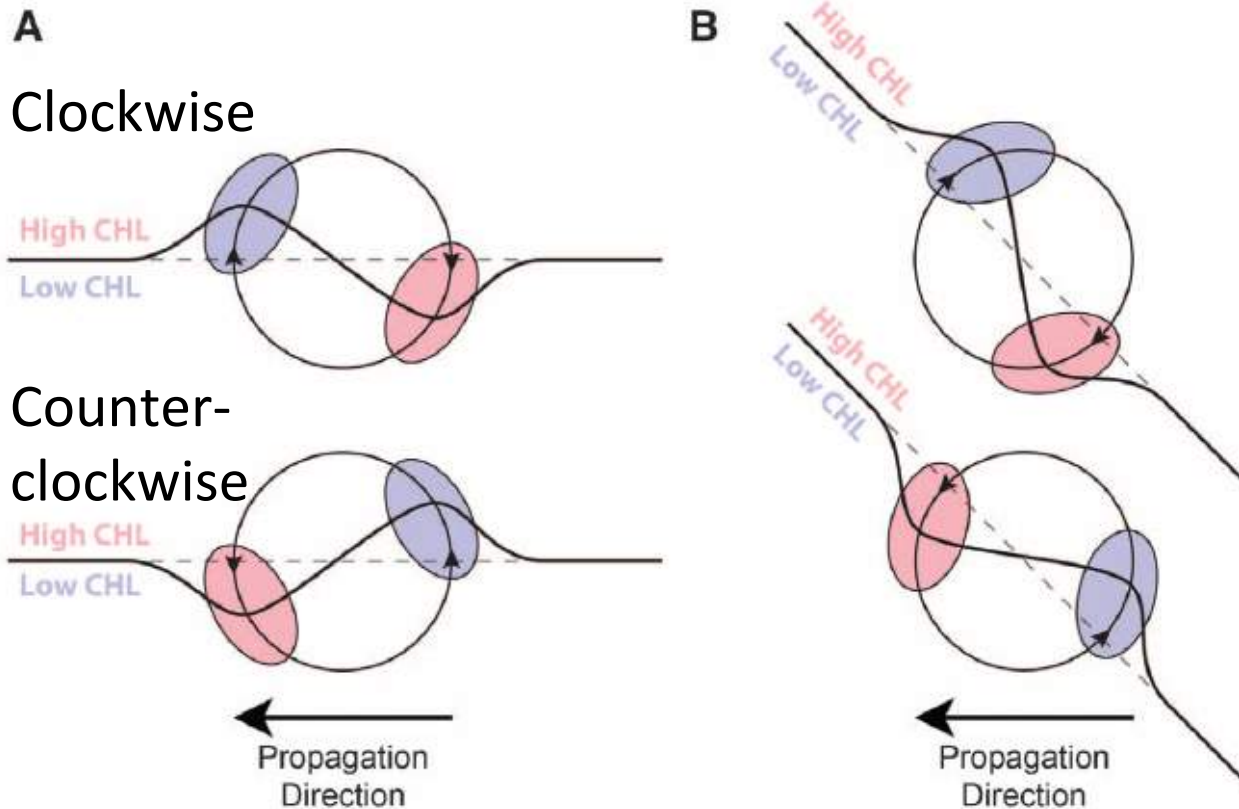
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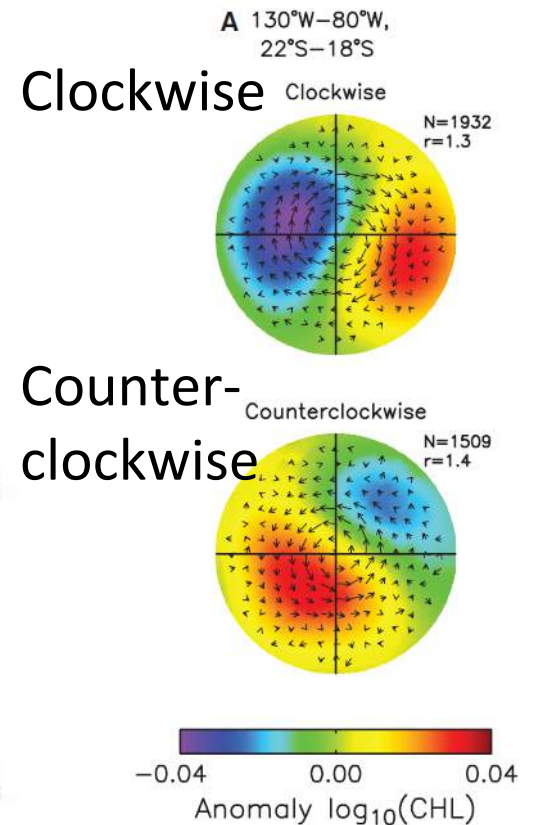
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Observations reveal this to be the globally dominant mechanism

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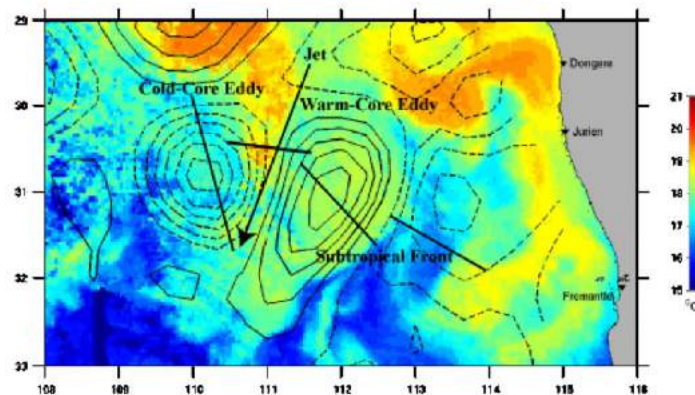
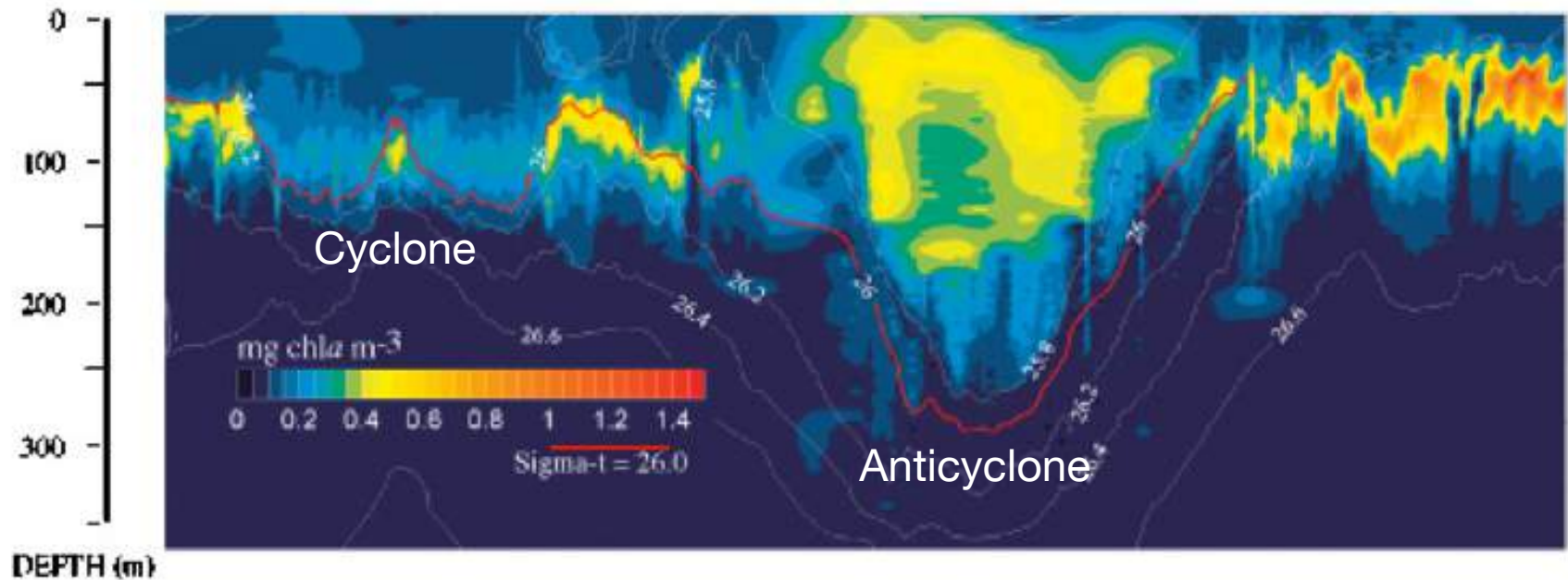


## Observations



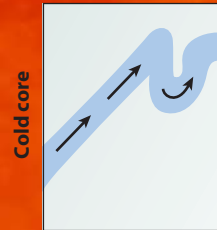
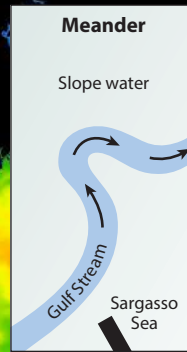
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Pelagic predators spend a significant amount of time in the mixed layer



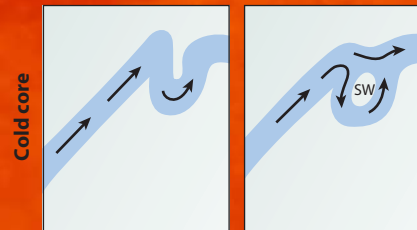
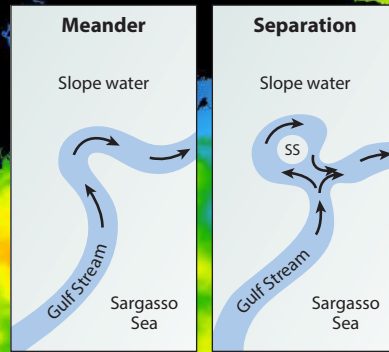
Waite *et al.* (2007b)  
figure 5, b and c

# Trapping of Pelagic Ecosystems in Mesoscale Eddies

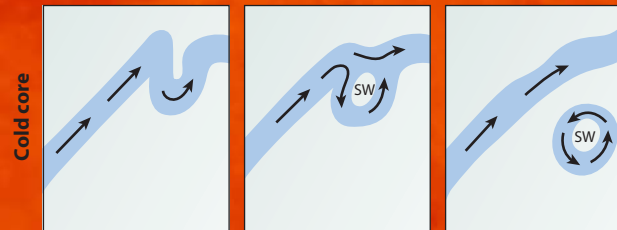
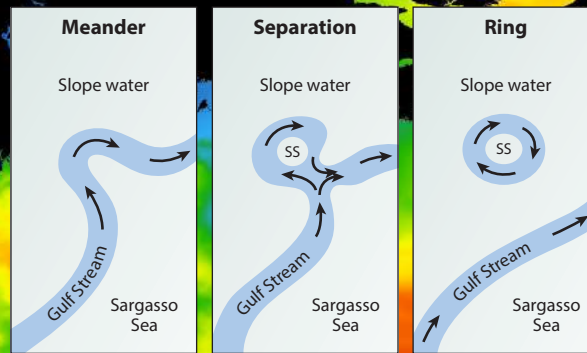




# Trapping of Pelagic Ecosystems in Mesoscale Eddies



# Trapping of Pelagic Ecosystems in Mesoscale Eddies

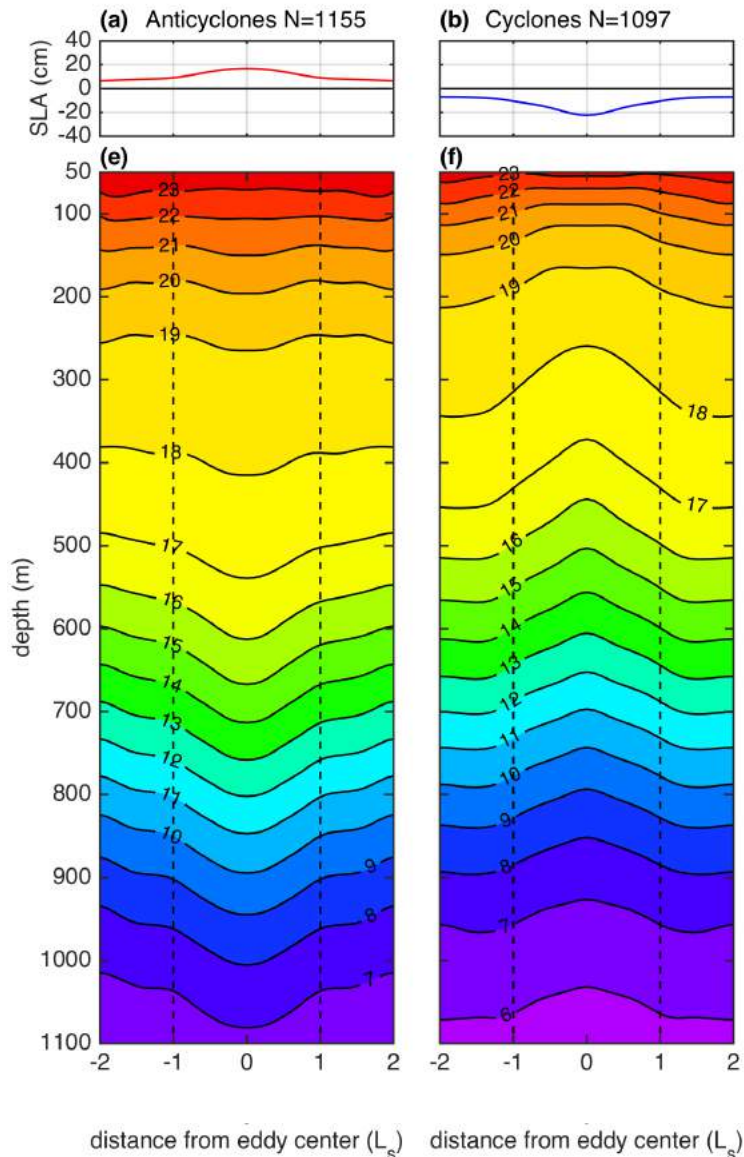




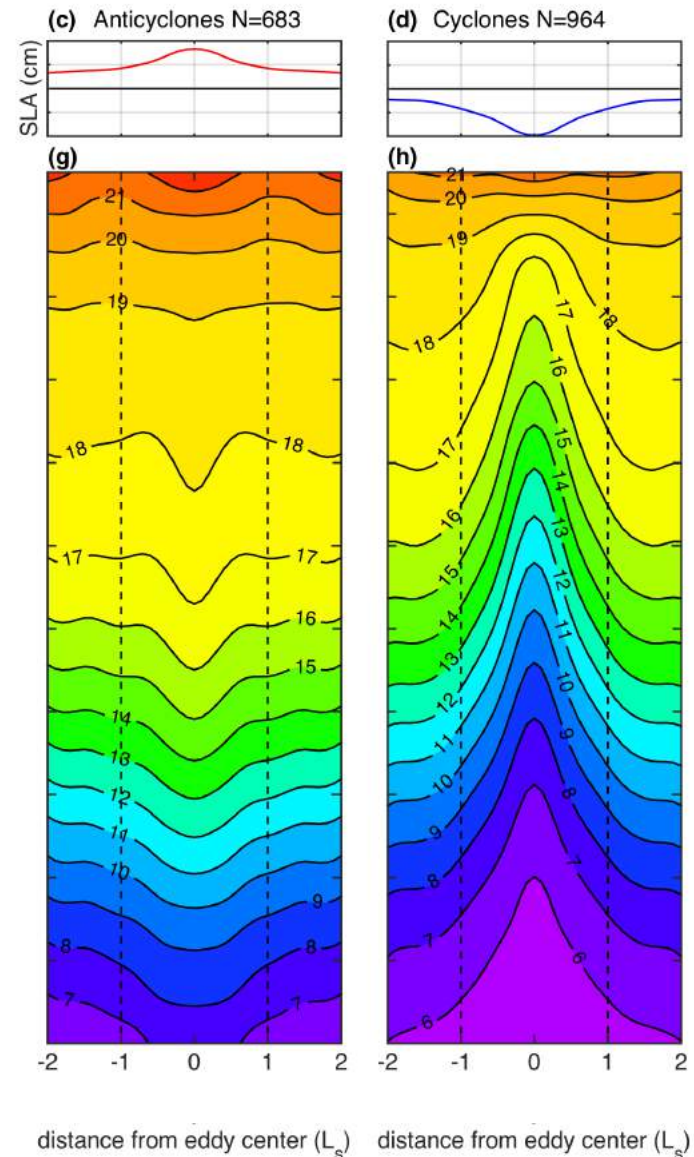
# Eddy Temperature Composites

Computed from Argo float profiles collocated with the interiors of eddies

## Open Ocean Eddies

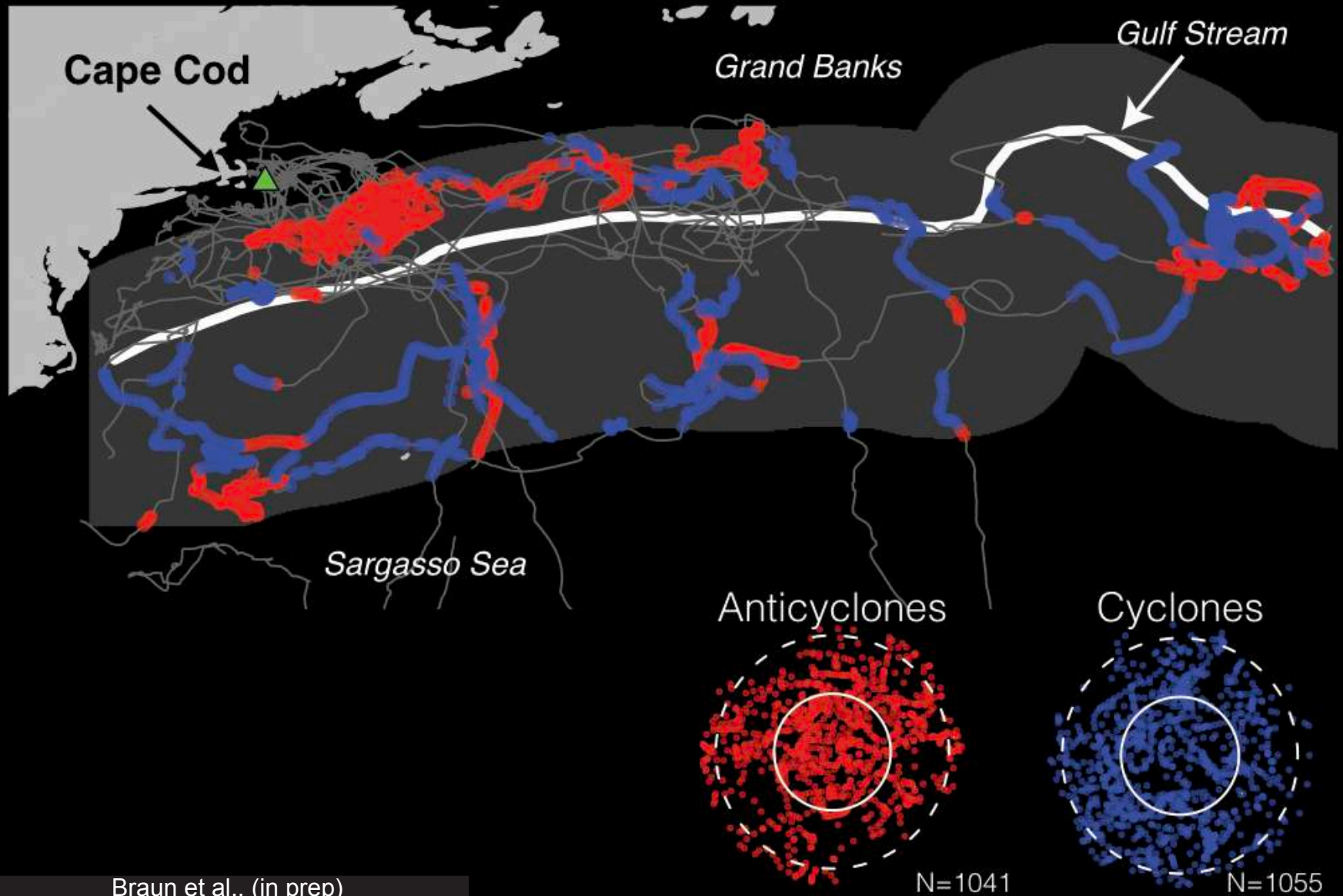


## Gulf Stream Region Eddies





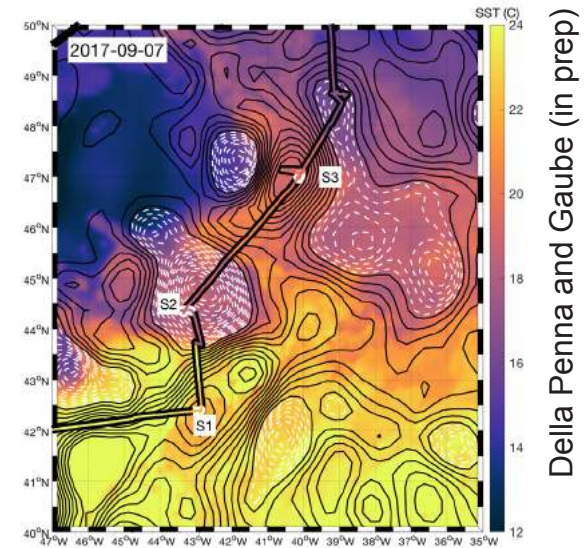
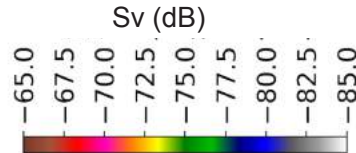
# Blue sharks regularly interact with Gulf Stream eddies



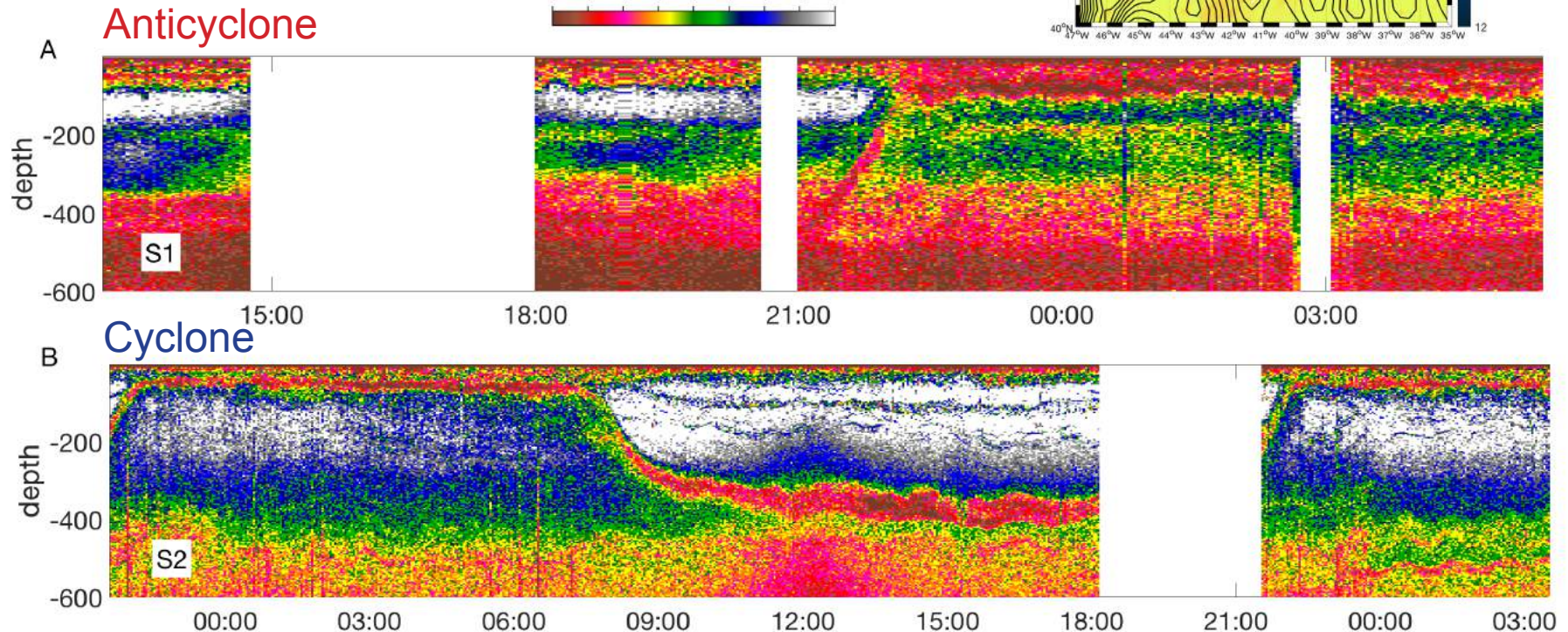
# Eddies Affect Deep Scattering Layers

Eddies separated by only 200 km

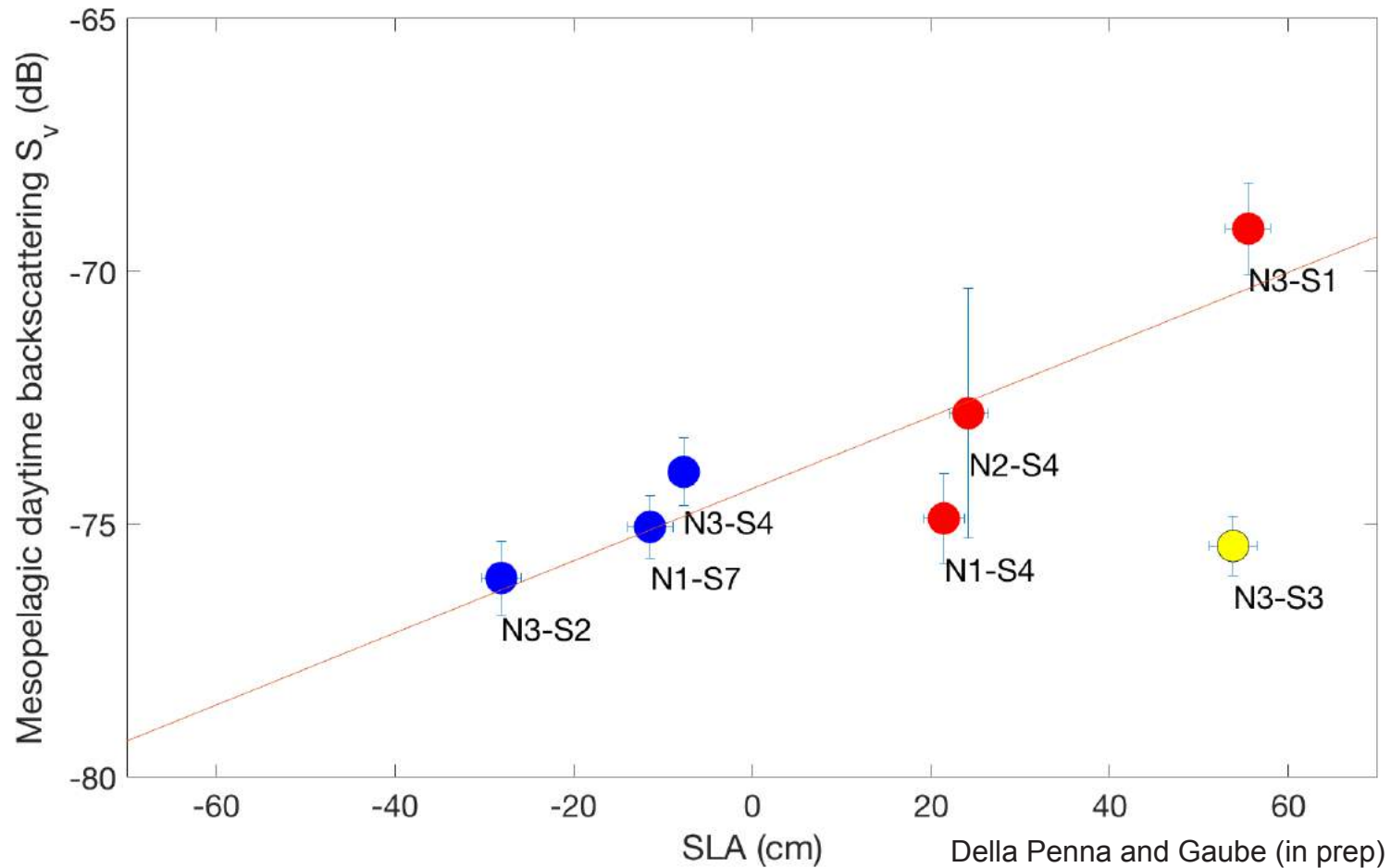
- Eddies modulate both the magnitude of mesopelagic backscattering and the characteristics of the DVM
- Mesopelagic acoustic backscatter is inversely correlated with surface chlorophyll-a



Della Penna and Gaube (in prep)

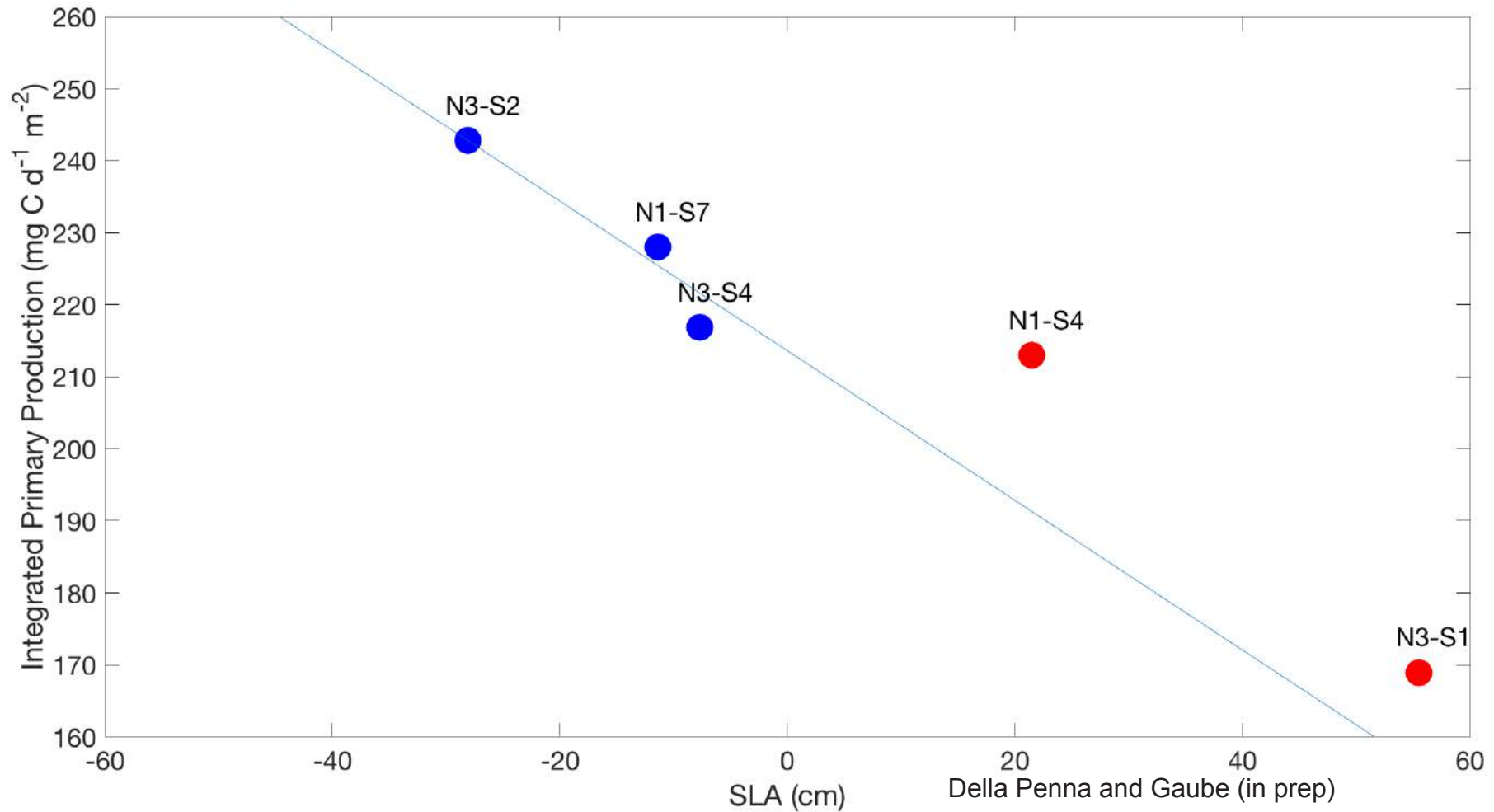


# Mesopelagic Backscattering is Elevated in Anticyclones in the North Atlantic

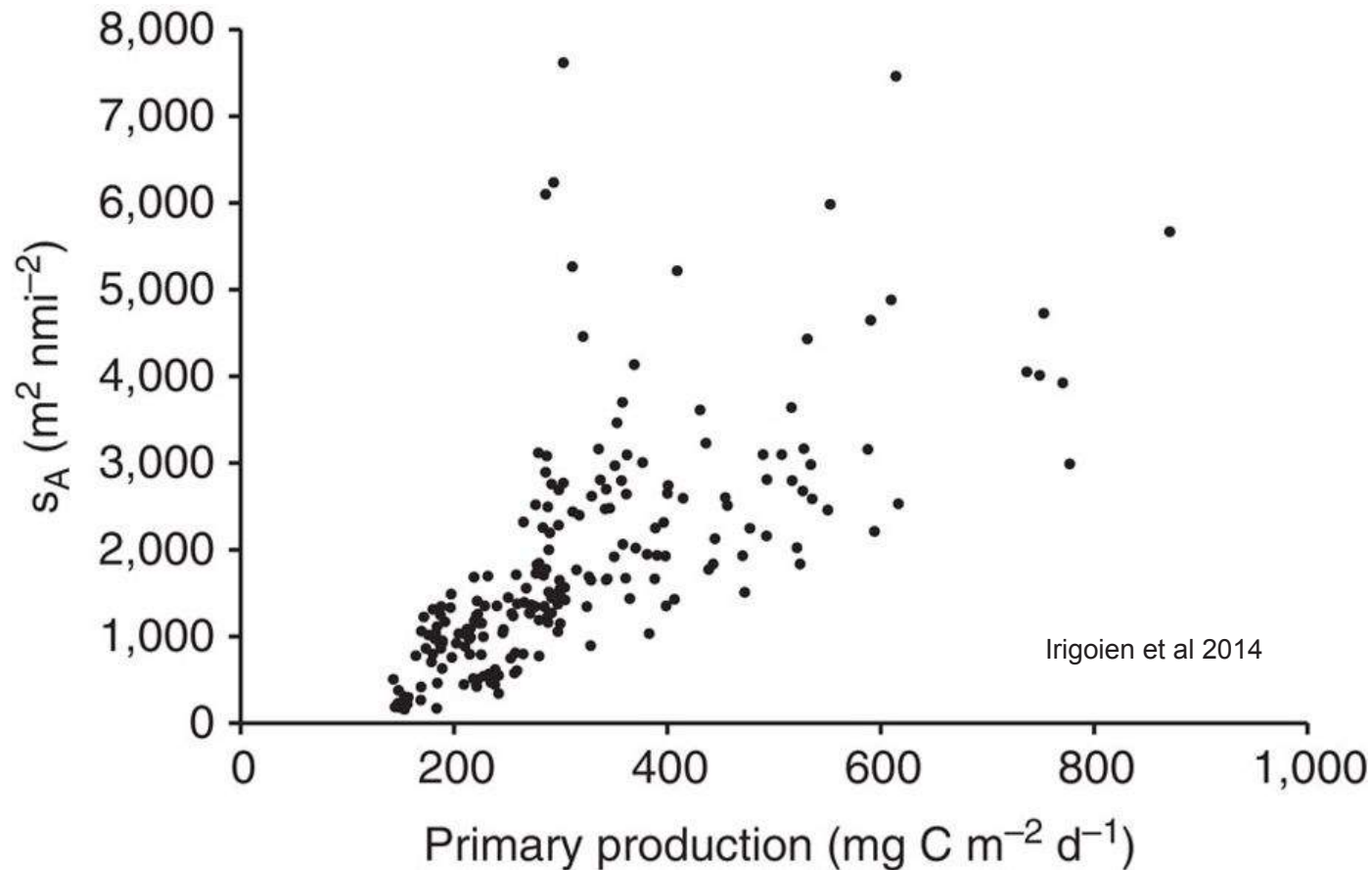




# Mesopelagic Backscattering is Inversely Correlated with Primary Production in these Eddies



# Primary Production and Mesopelagic Backscattering are Correlated at the Global Scale



# Summary and Conclusions

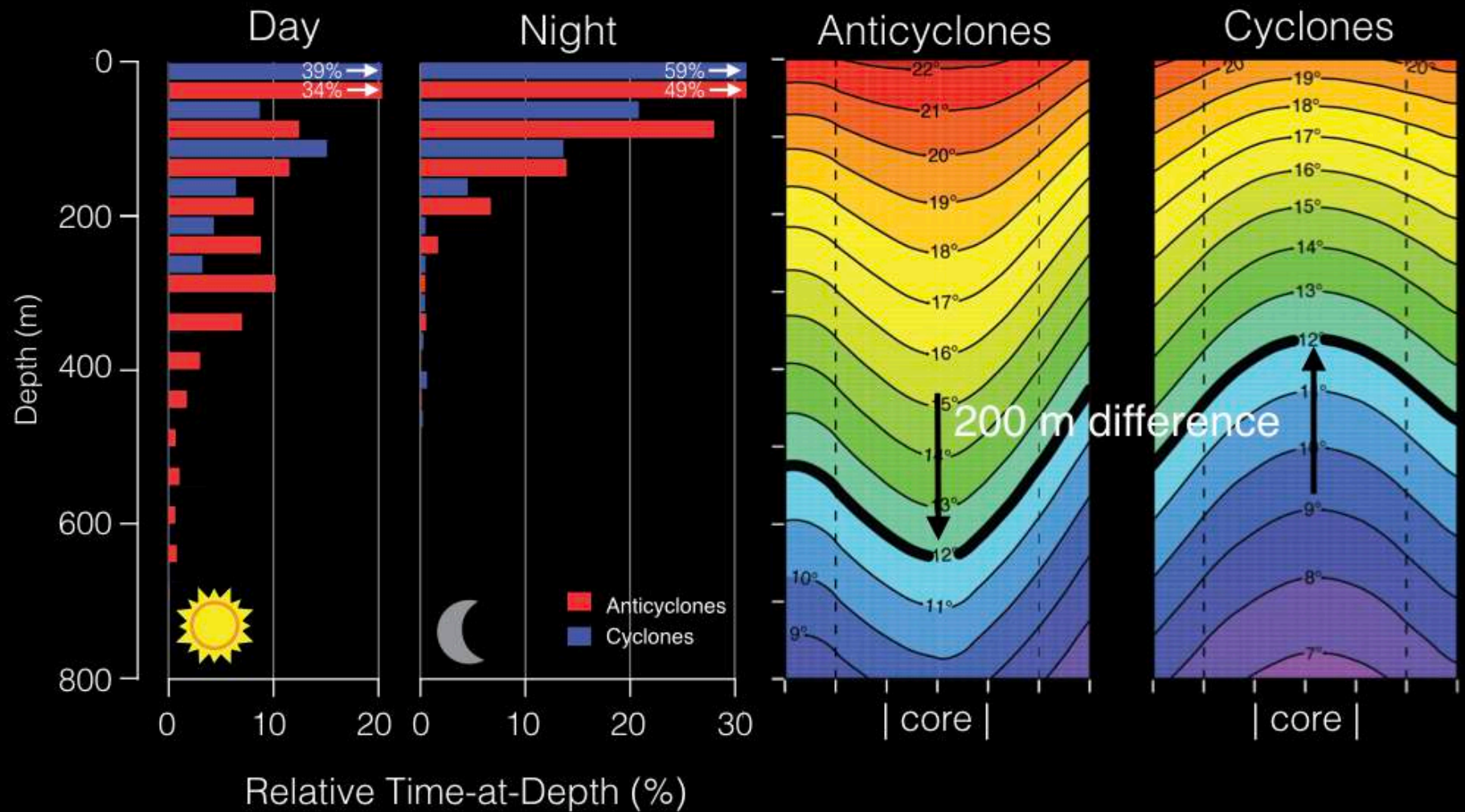
- Our research indicates that pelagic sharks and turtles preferentially occupy the cores of anticyclonic eddies.
  - Turtles in the Southern BMC seek out warm-core anticyclones
  - White sharks in the North Atlantic conduct longer dives into the mesopelagic in warm-core anticyclones
  - Blue sharks prefer anticyclones in the North Atlantic and exploit the larger strata enveloped by the 12 deg C isotherm in warm-core anticyclones\*.

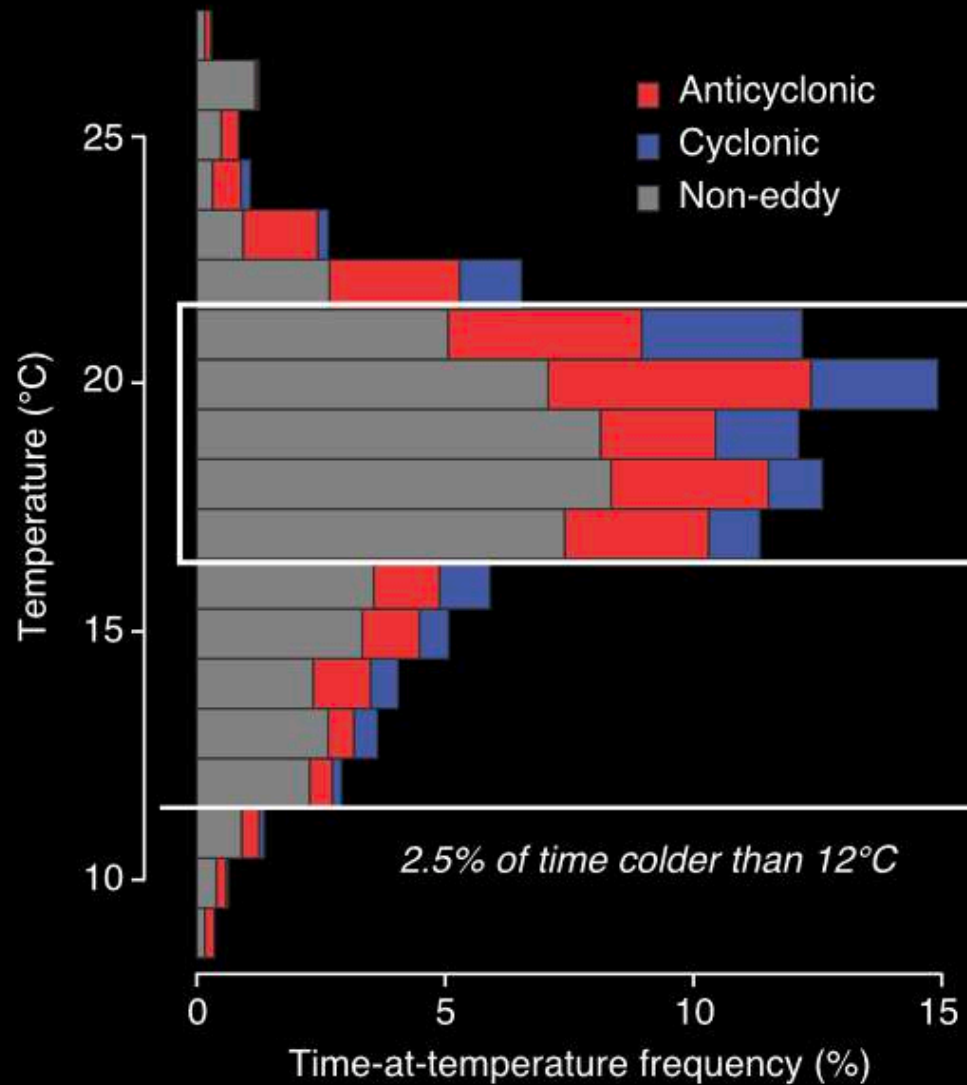
The observed preference of anticyclones by white sharks could be the result of a simple calculus of energetic demands:

- (1) White sharks regulate their internal temperature and anticyclones in the North Atlantic are generally associated with positive sub-surface temperature anomalies;
- (2) foraging dives might be more successful in anticyclones as a result of elevated mesopelagic fish and squid biomass when compared to cyclones.



# Diel vertical migration in eddies suggests foraging at depth





preferred thermal envelope?

tolerable

avoid?