Mesoscale Eddy Influence on Upper-Ocean Chlorophyll Variability in the South Indian Ocean

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Overview:

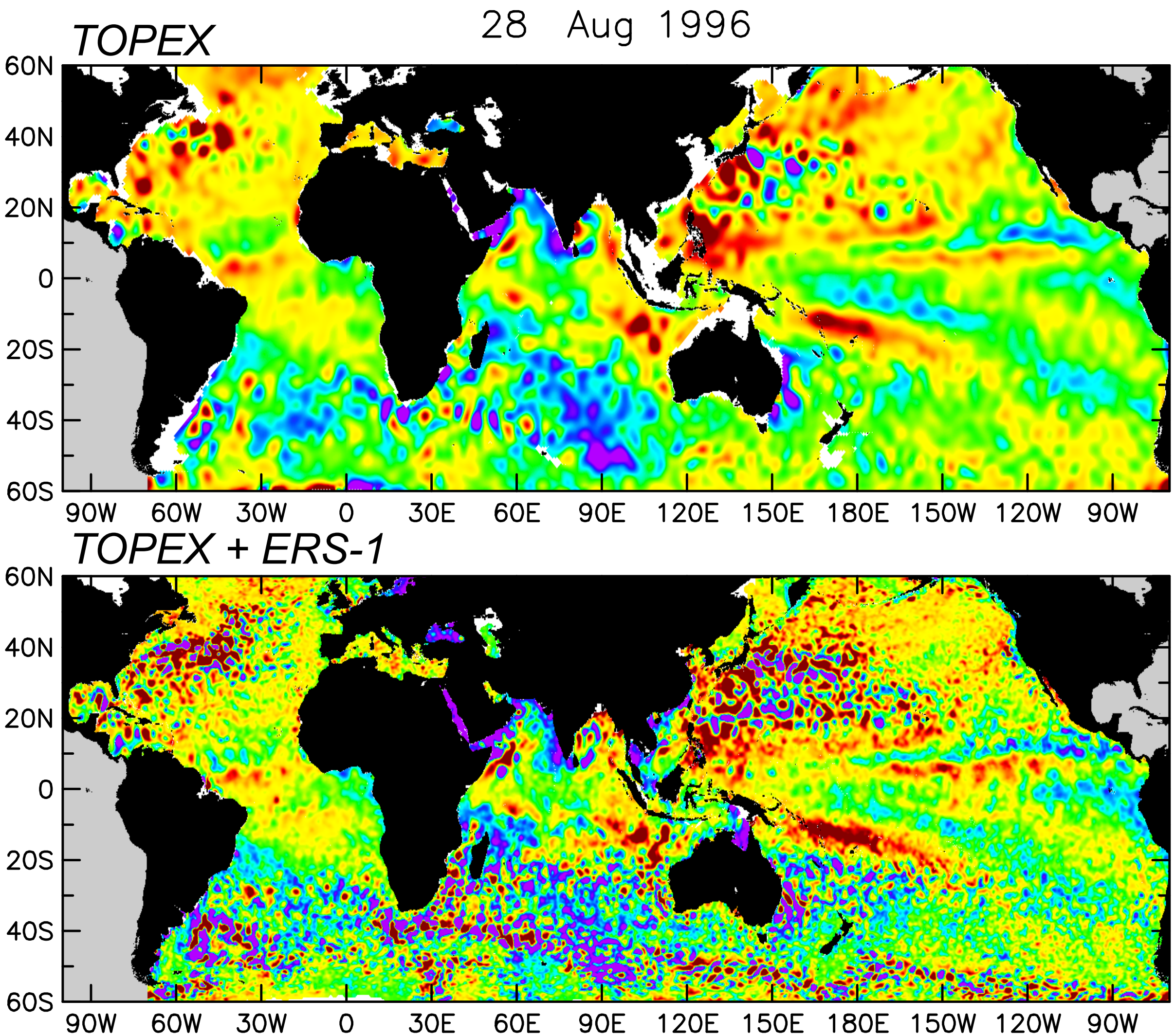
- Investigate physical-biological interaction in mesoscale eddies from a combination of 4 collocated satellite datasets:
  - *Altimeter measurements of SSH.*
  - *AMSR+AVHRR measurements of SST (Reynolds OI2 analyses).*
  - *QuikSCAT measurements of wind speed and wind stress.*
  - *SeaWiFS estimates of chlorophyll.*

- Determine the relative importance of eddy-induced Ekman pumping from:
  - *eddy-related SST influence on the wind stress field.*
  - *eddy-related surface current effects on the stress between the atmosphere and ocean.*

- Validate the conclusions from detailed analysis of eddies in the S. Indian Ocean.

* The results presented here are part of the PhD thesis by Peter Gaube

SSH from the TOPEX Altimeter Only and from the Merged Measurements from 2 Altimeters Produced by AVISO*



There are 2495 eddies in this representative map.

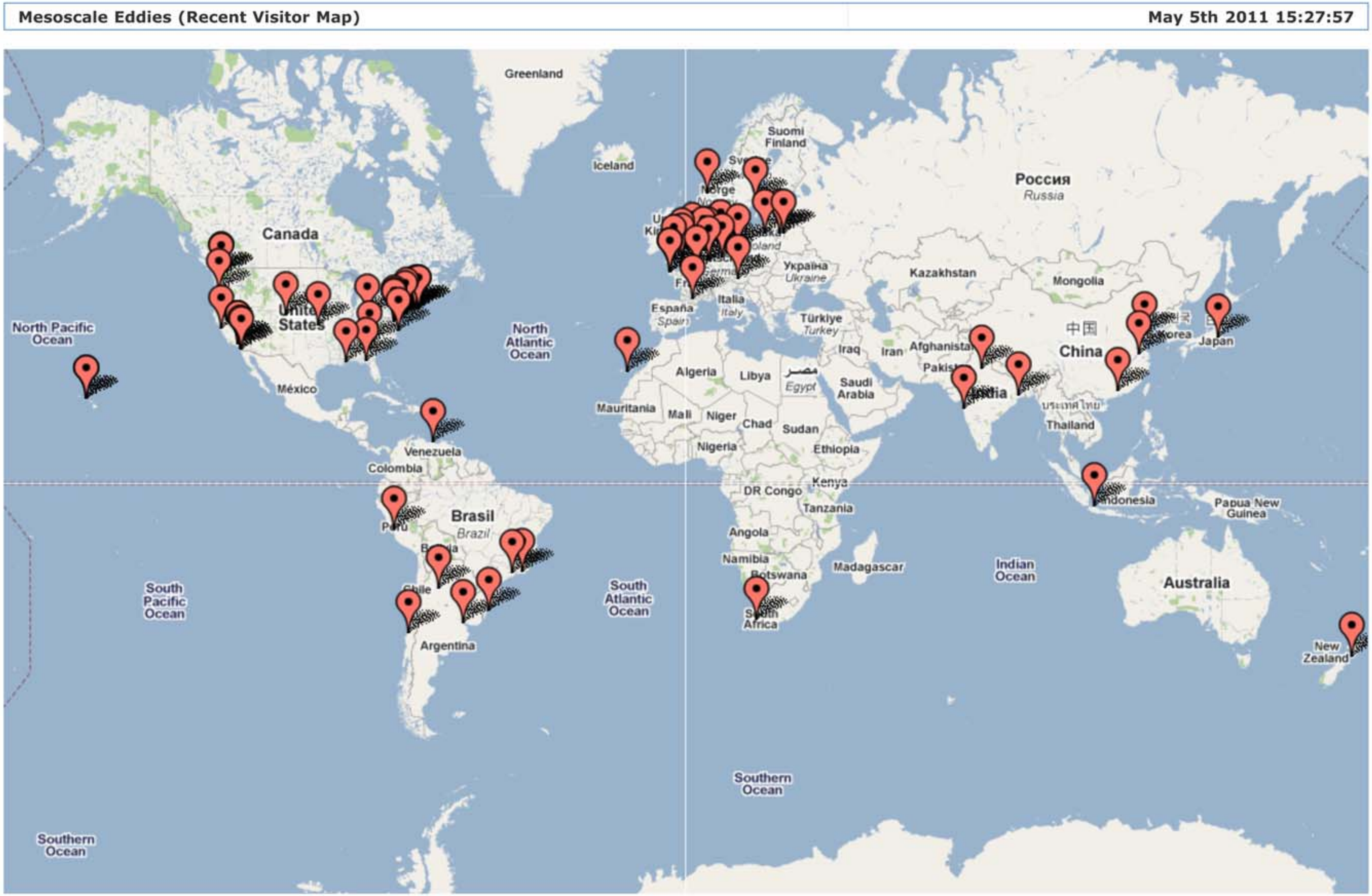
Globally over a 16-year data record, there are ~177,000 eddies.

Of these eddies, more than 52,000 were tracked for 12 weeks or longer.

* Ducet, N., P.-Y. Le Traon, G. Reverdin, 2000: Global high resolution mapping of ocean circulation from TOPEX/POSEIDON and ERS-1/2. *J. Geophys. Res.*, **105**, 19,477-19,498.

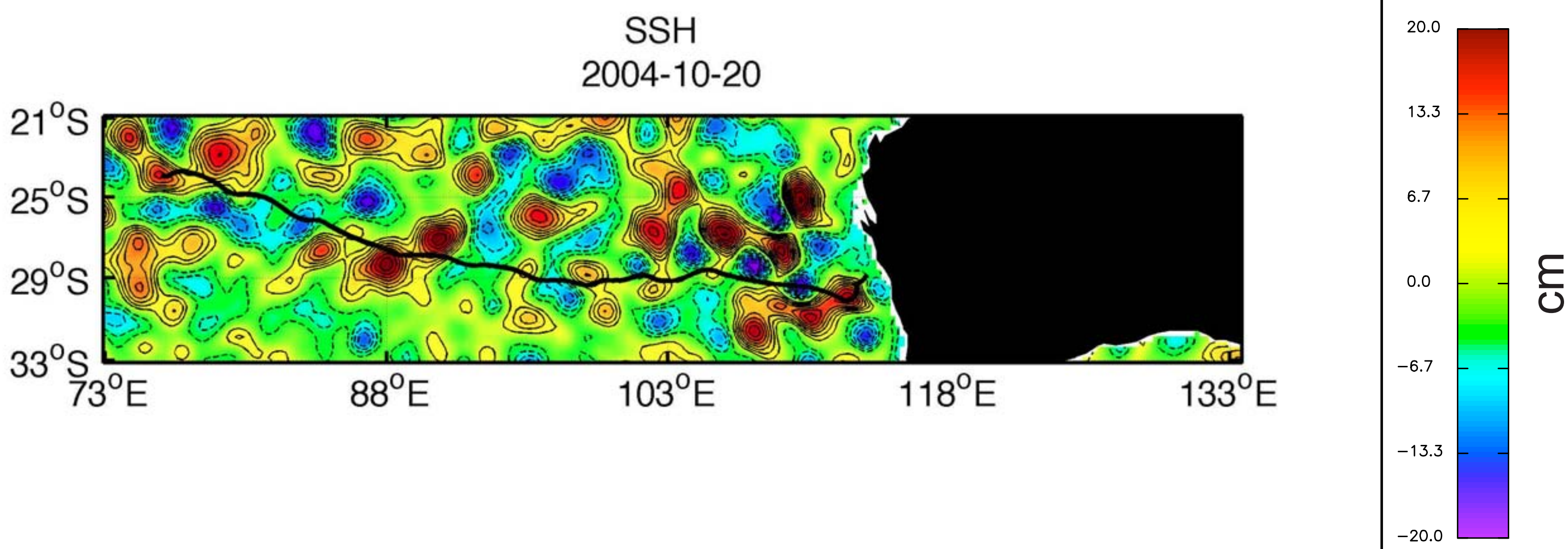
The trajectories of 177,000 eddies from October 1992 - December 2008 are available online at: http://cioss.coas.oregonstate.edu/eddies/

Number of 1st-time visitors from 1 February 2011 to 5 May 2011: 752



Animation of SSH in the South Indian Ocean with the Trajectory of an Eddy Tracked for 31 Months

27 March 2002 - 20 October 2004

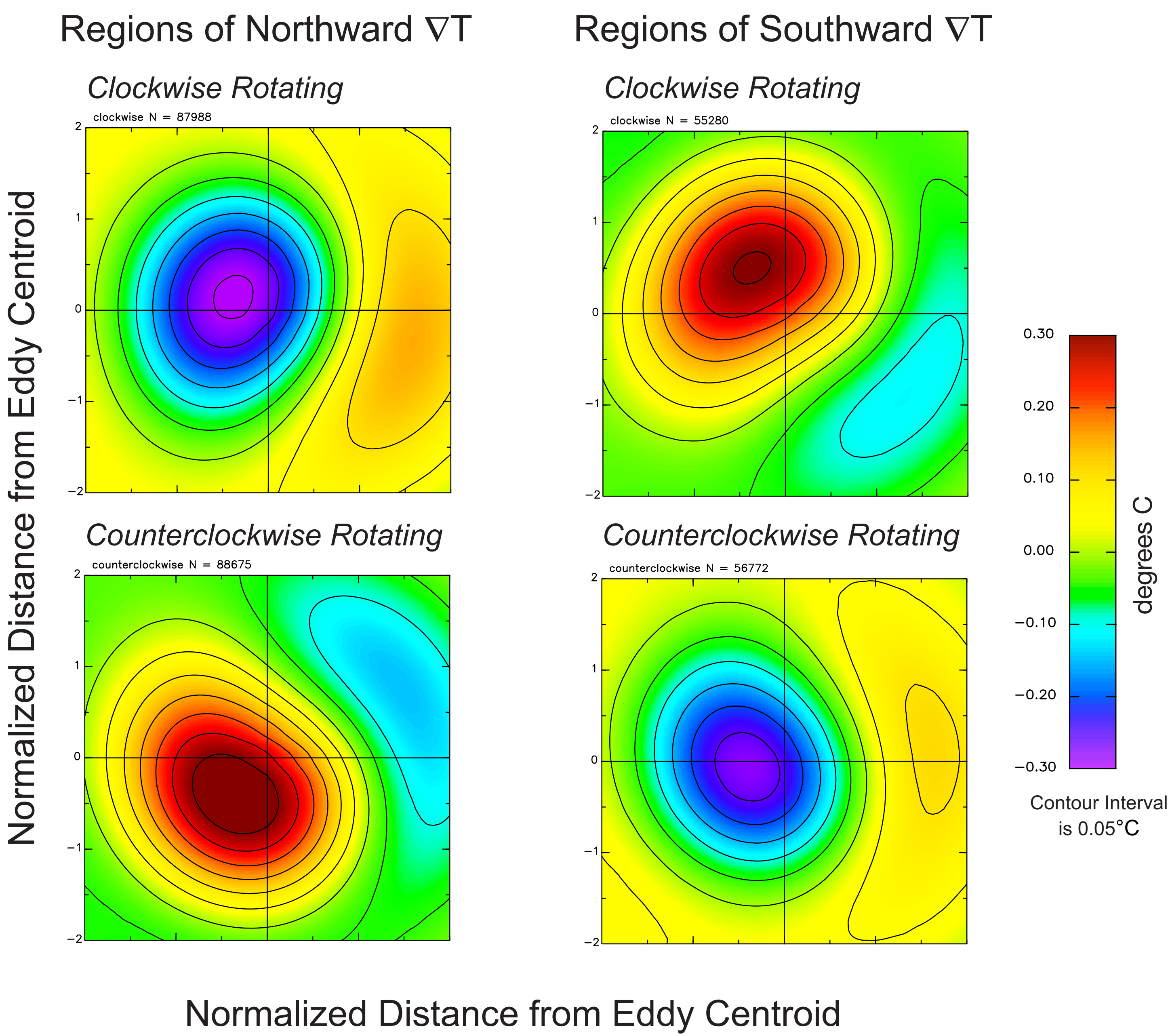


Procedure for Composite Averaging SST, Wind Speed and Wind Stress Curl in Eddy-Centric Coordinates: *Synergy Between 4 Complimentary Satellite Datasets*

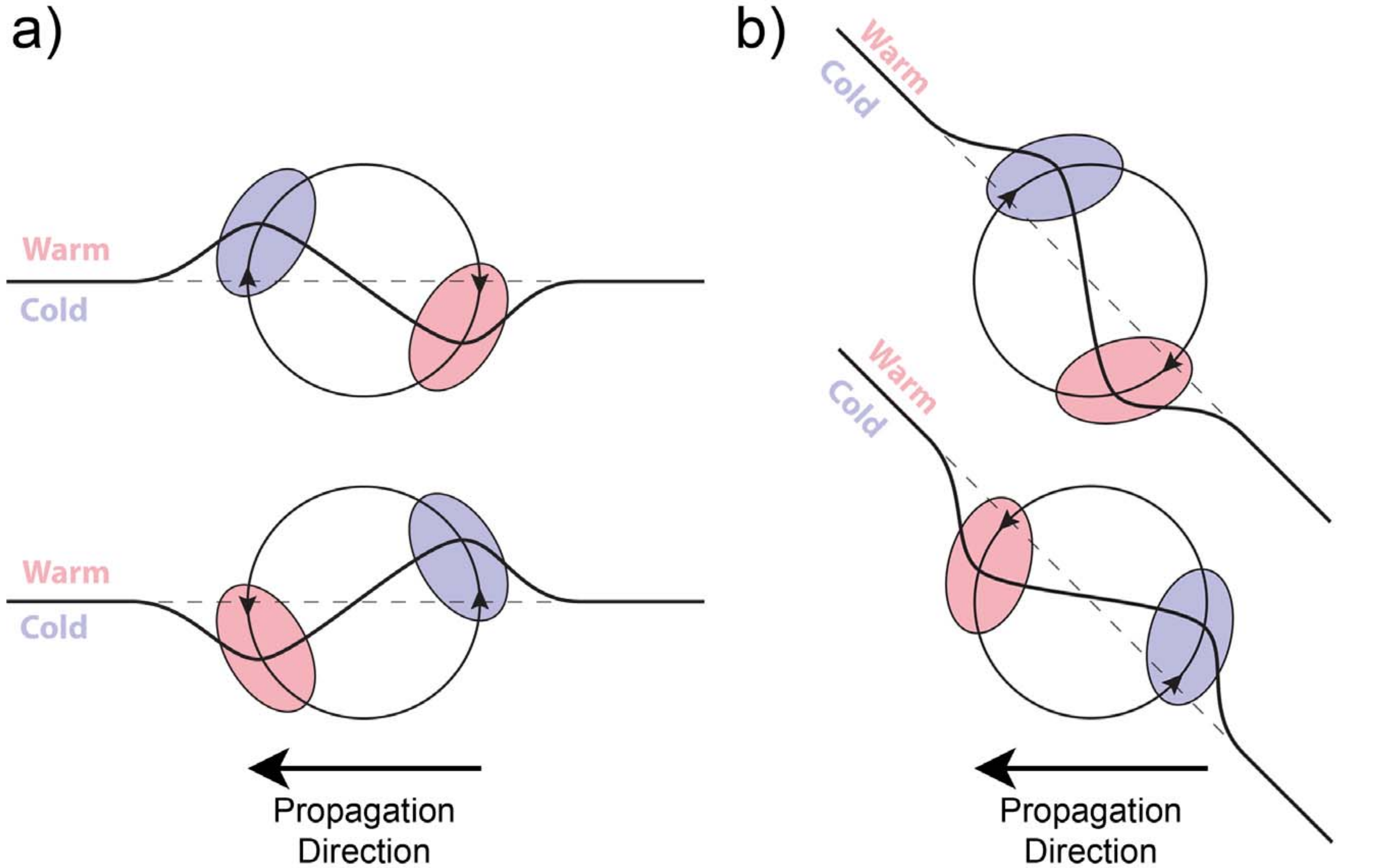
- Identify mesoscale eddies by altimetry from their SSH signatures.
- Composite average the other satellite datasets in an "eddy-centric" translating reference frame with $(\Delta x, \Delta y)$ coordinates relative to the eddy centroid normalized by the radius L_s of maximum rotational speed at each location along its trajectory.
  - *AMSR+AVHRR measurements of SST (Reynolds OI2 analyses).*
  - *QuikSCAT measurements of wind speed and wind stress.*
  - *SeaWiFS estimates of oceanic chlorophyll.*
- Because the dominant mechanism for eddy-induced SST variability is horizontal advection by the rotational velocity of the eddy, SST and wind speed must be composite averaged in a coordinate system that is rotated by an amount determined from the large-scale background SST gradient.

1. Eddy Influence on SST and Wind Speed

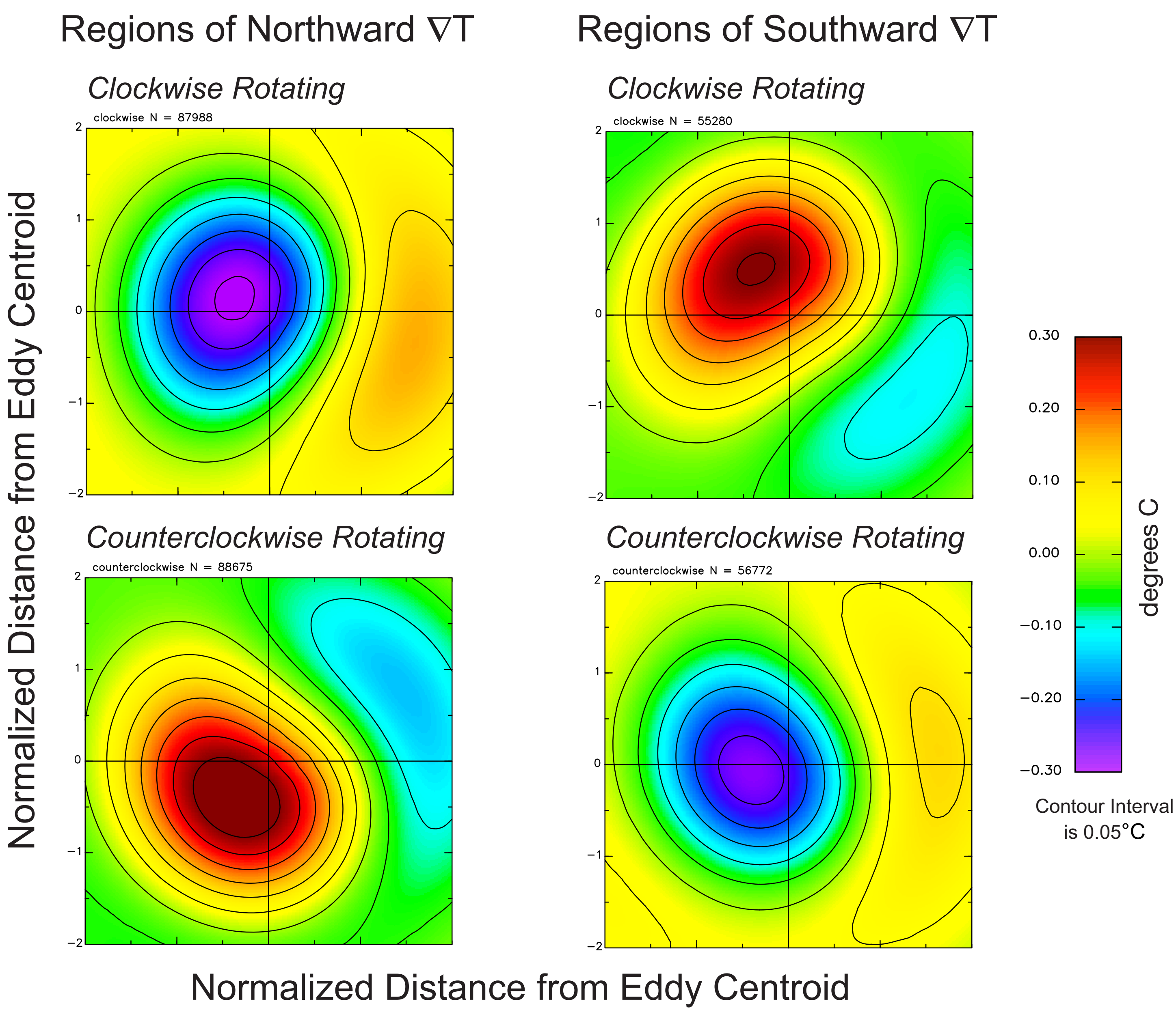
Global Composite Averages of SST in Eddy-Centric Coordinates



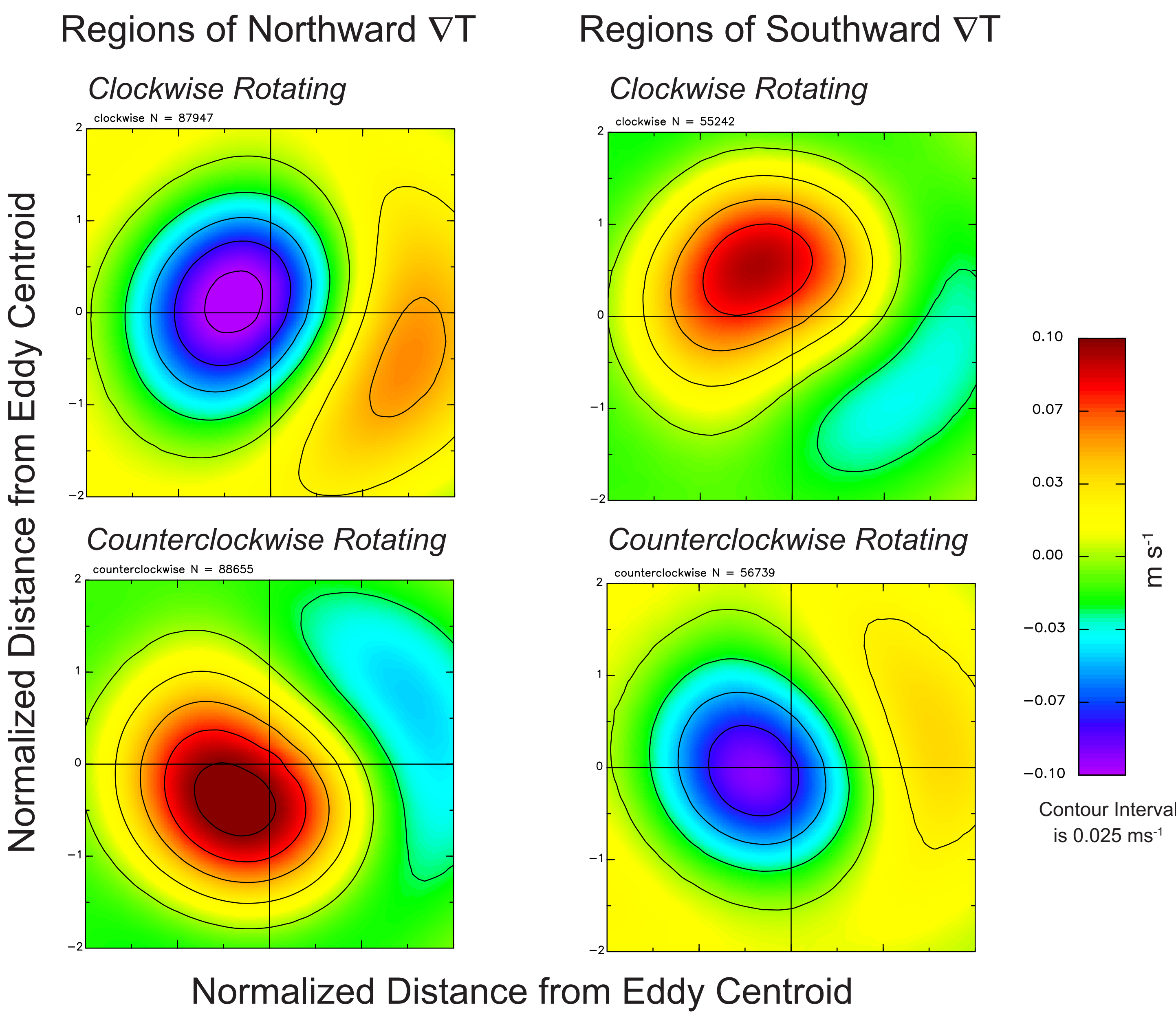
Schematic of Eddy Influence on SST Showing the Dependence on Rotational Sense and Large-Scale SST Gradient



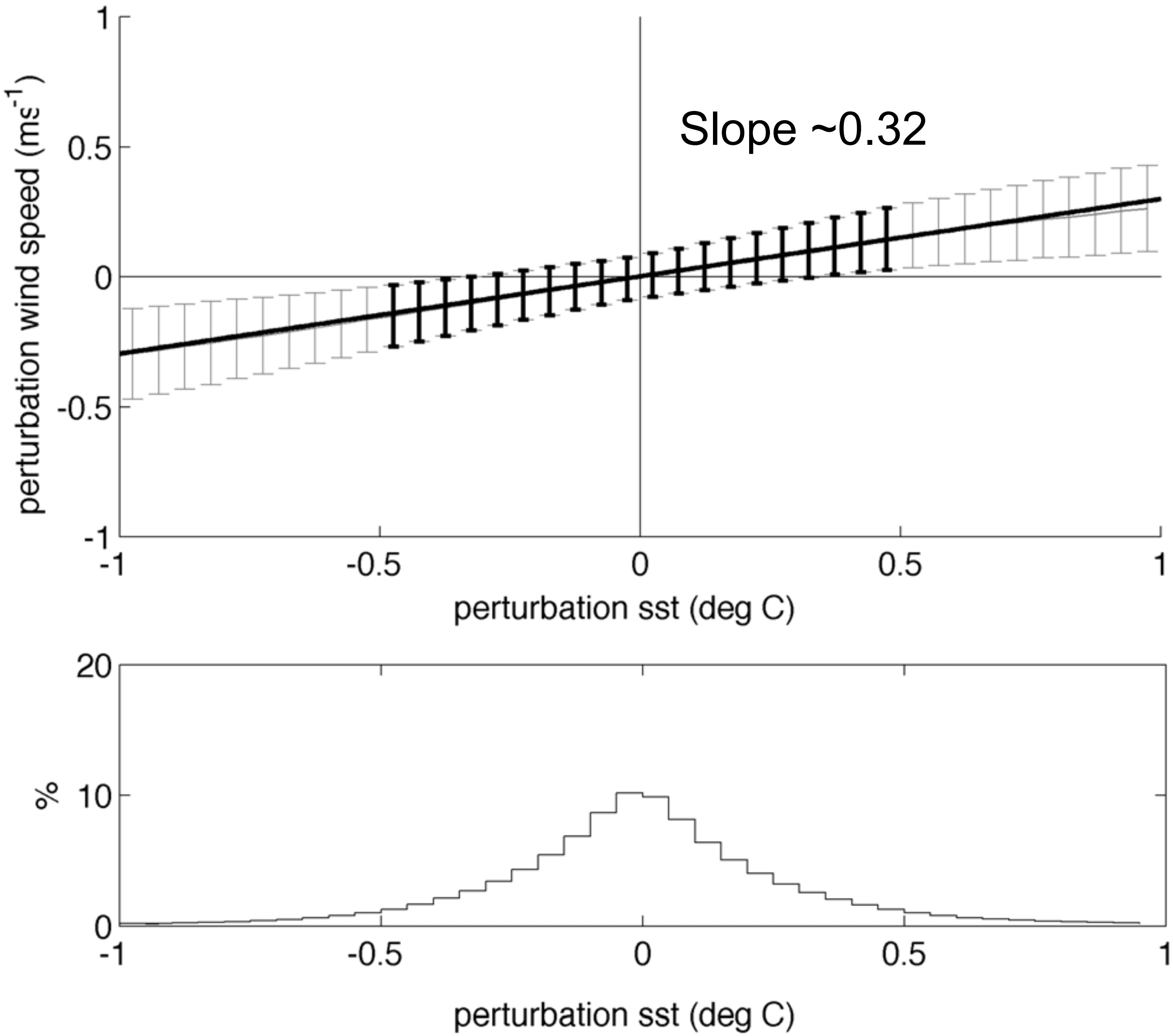
Global Composite Averages of SST in Eddy-Centric Coordinates



Global Composite Averages of Wind Speed in Eddy-Centric Coordinates

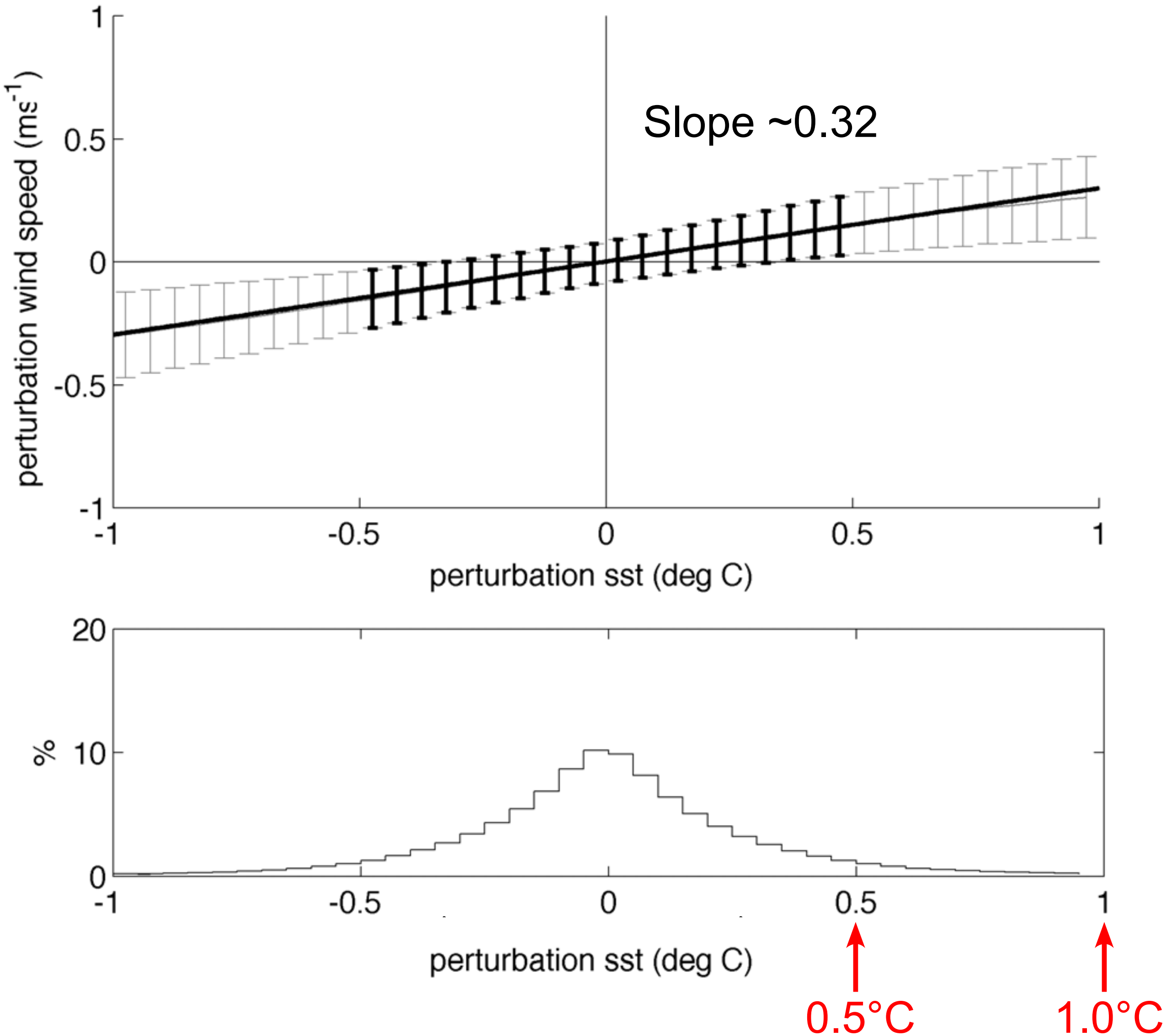


Coupling Coefficient Between Wind Speed and SST over Globally Distributed Mesoscale Eddies

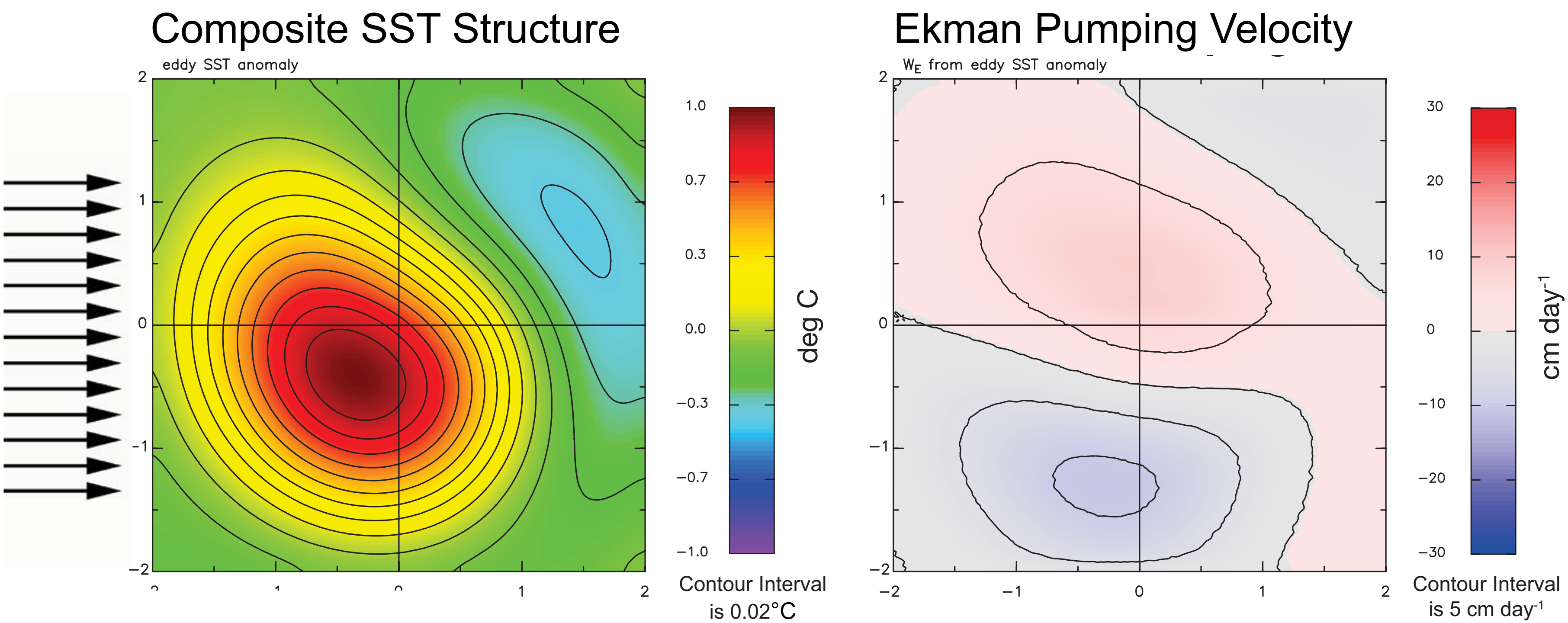


2. Ekman Pumping from Eddy-Related SST Influence on Wind Speed

Coupling Coefficient Between Wind Speed and SST over Globally Distributed Mesoscale Eddies



Ekman Pumping from Eddy Perturbations of SST
for Westerly Winds Over a 1.0°C SST Anomaly



- 30°S
- 10 ms^{-1} wind speed
- 1° SST perturbation

$$U'_{wind} = \alpha \; SST'$$

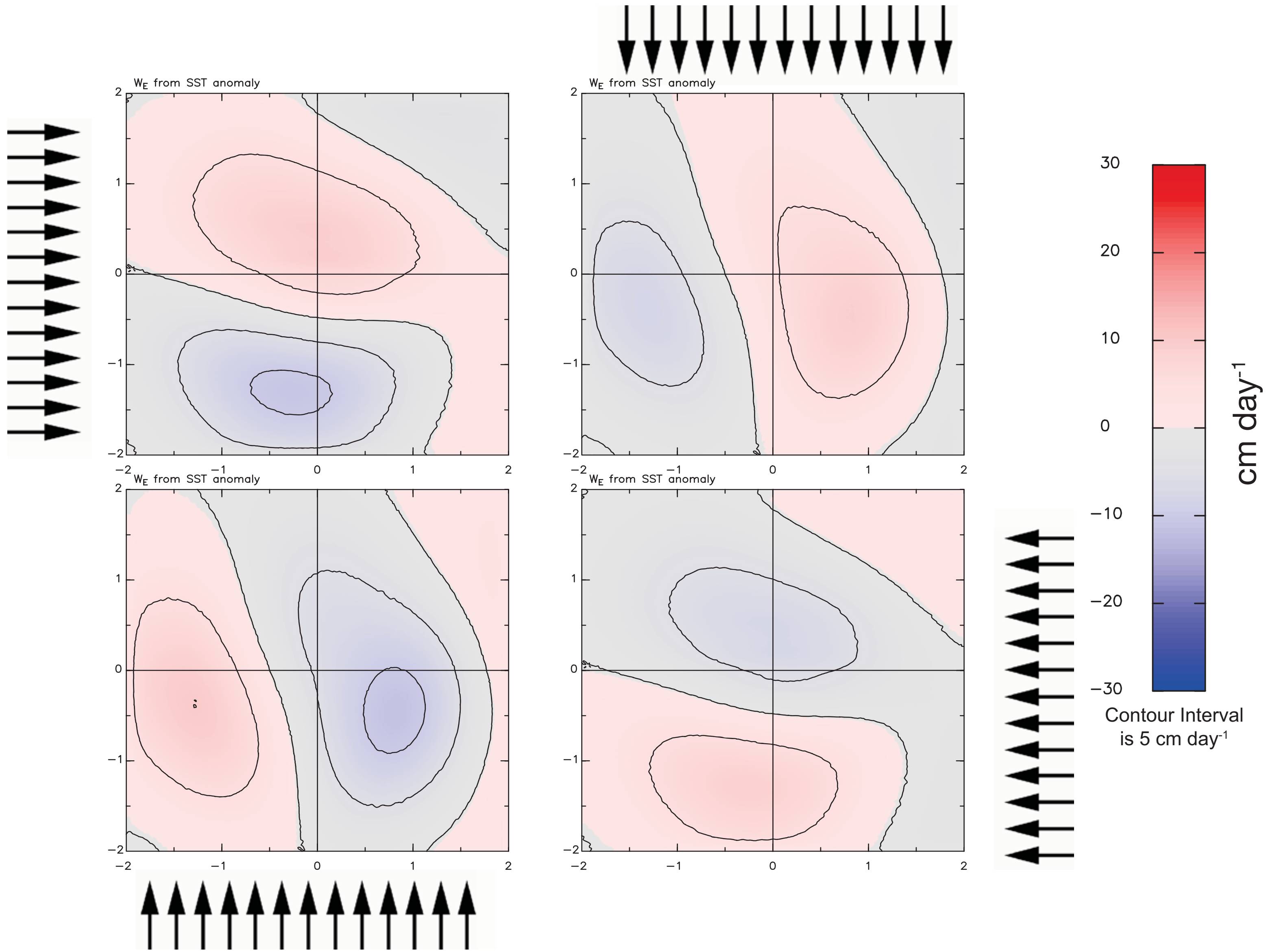
$$\alpha = 0.32$$

$$\vec{\tau} = \rho \, C_D \, |\vec{u}| \, \vec{u}$$

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

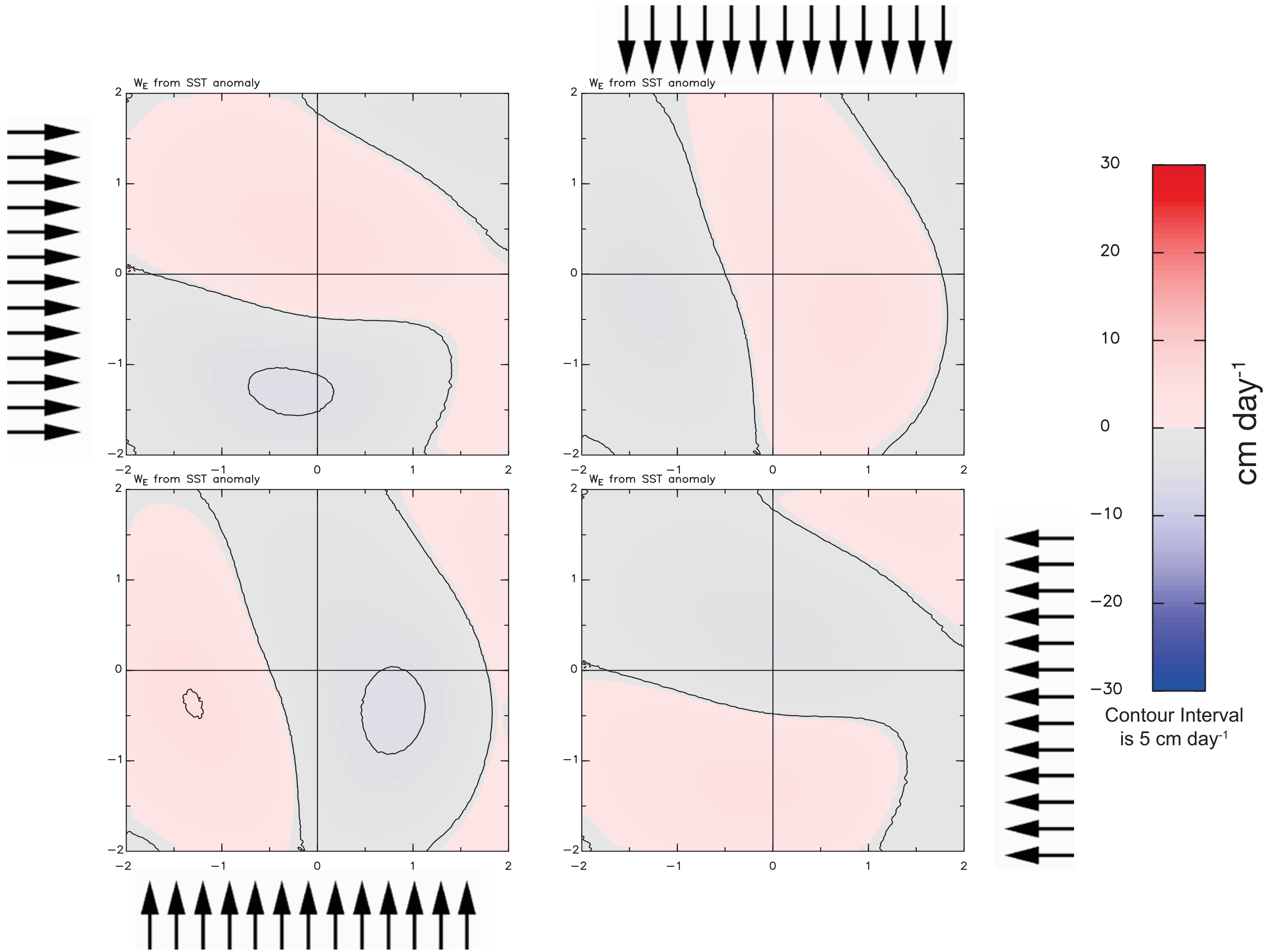
Ekman Pumping from Eddy Perturbations of SST

for Winds from Various Directions Over a 1.0°C SST Anomaly



Ekman Pumping from Eddy Perturbations of SST

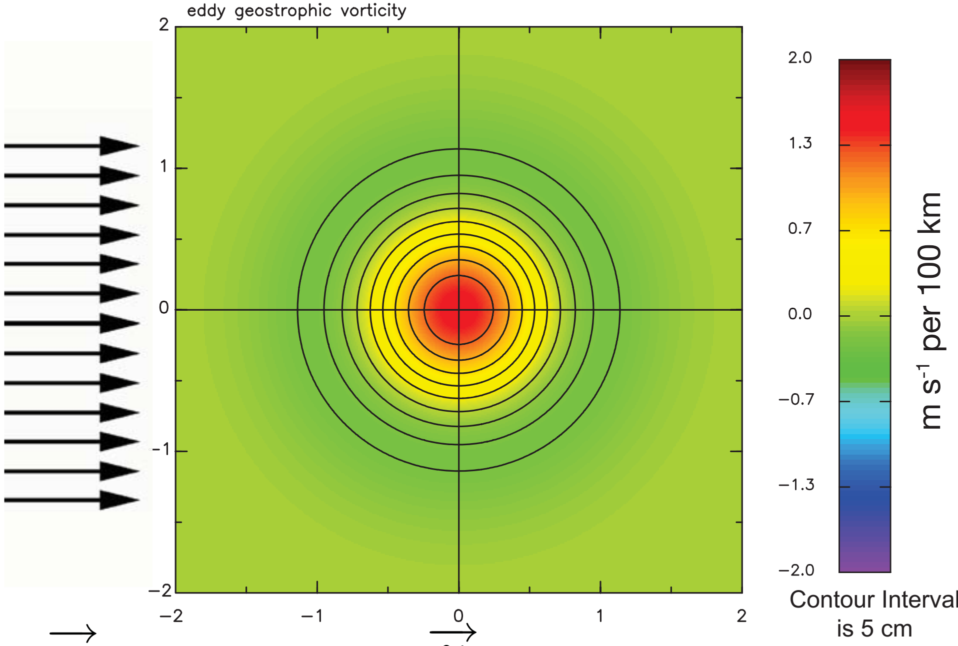
for Winds from Various Directions Over a 0.5°C SST Anomaly

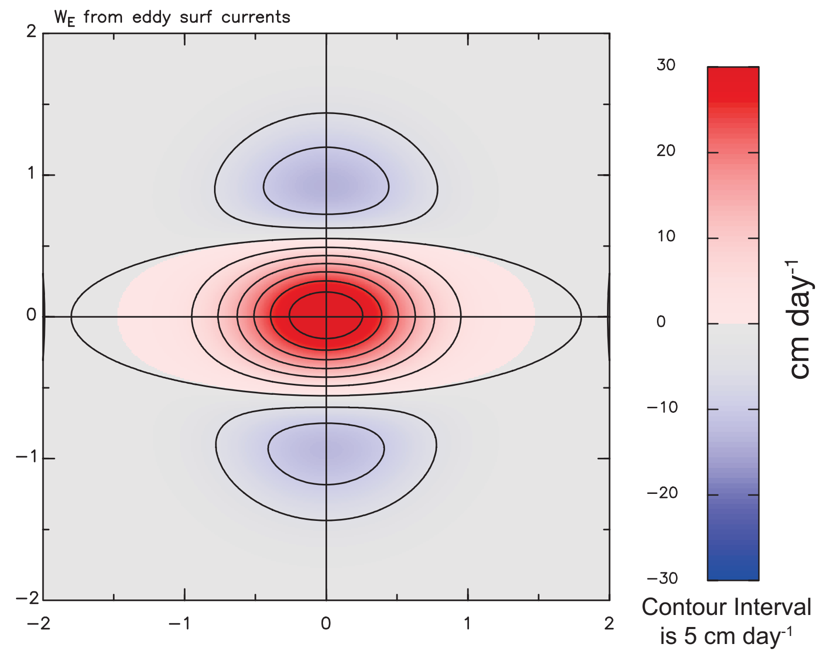


3. Ekman Pumping from Eddy Surface Currents for an Idealized Gaussian Eddy

Ekman Pumping from Eddy Surface Currents

for an Idealized Gaussian Eddy and Westerly Winds





$\overrightarrow{u}_a$ $\overrightarrow{u}_o$

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

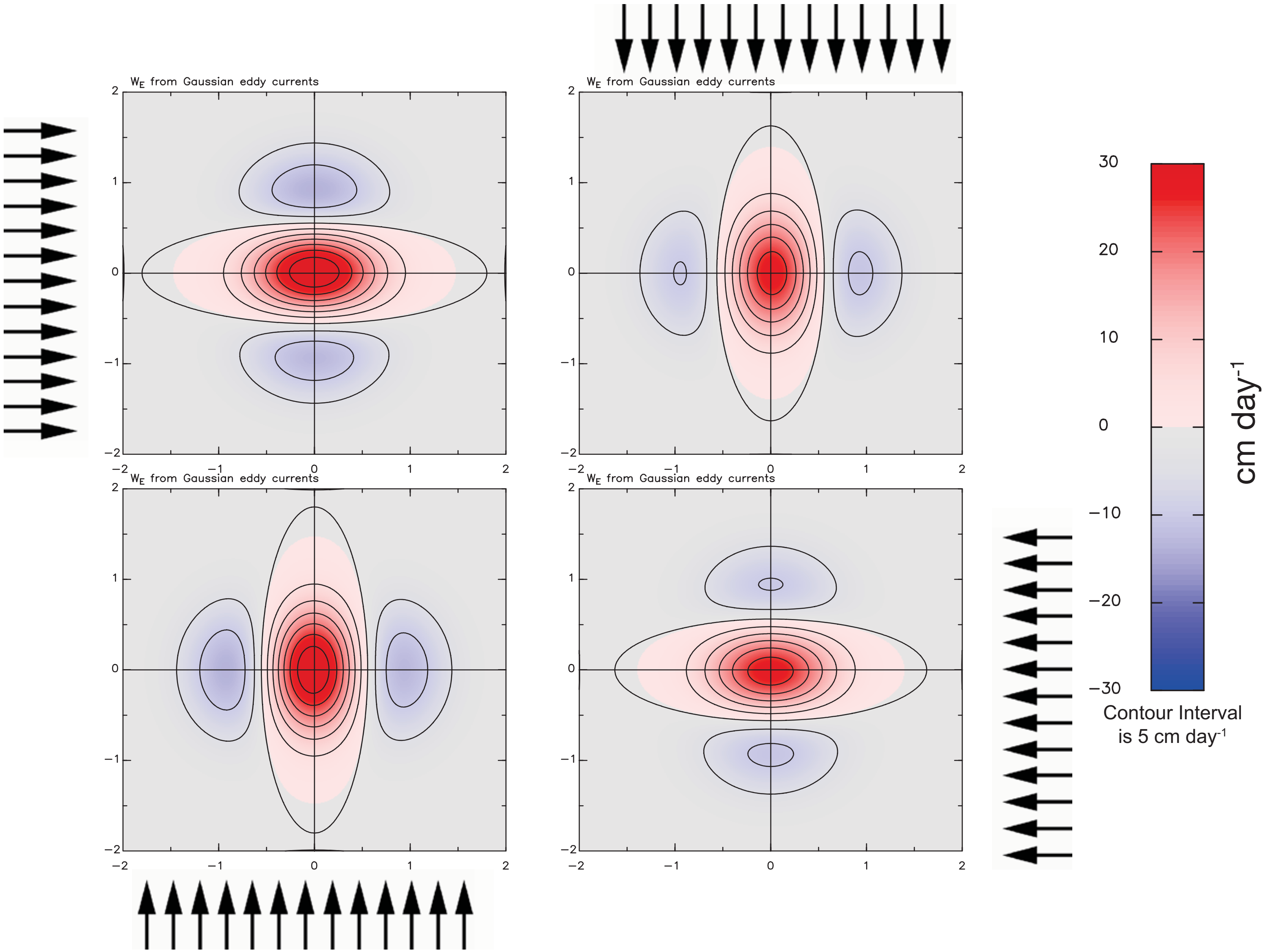
$$\overrightarrow{u}_{rel} = \overrightarrow{u}_a - \overrightarrow{u}_o$$

- 30°S
- 20 cm amp.
- 10 ms^{-1} wind
- Max current 40 cm s^{-1}

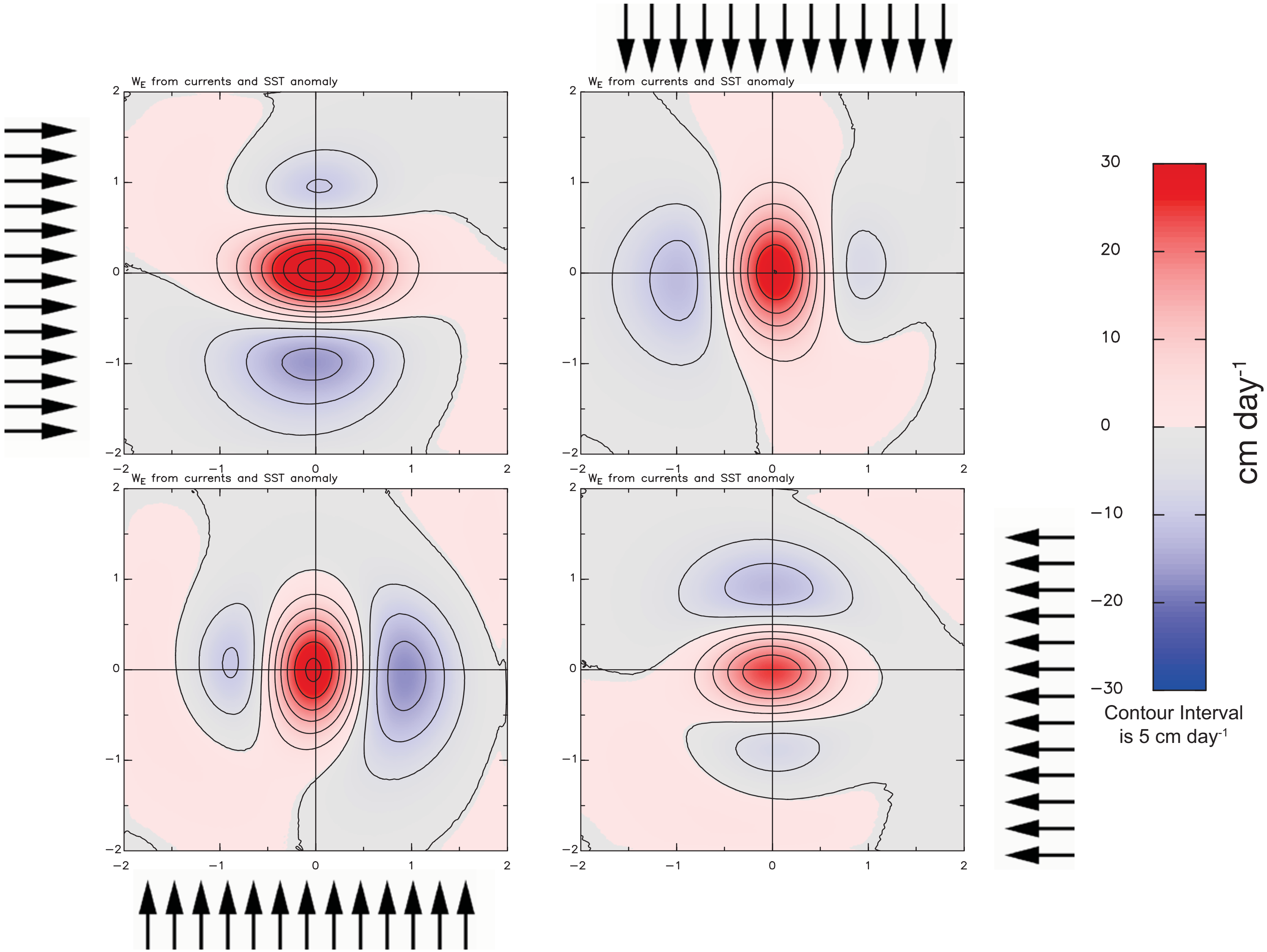
$$W_E = \frac{1}{\rho f} \nabla \times \overrightarrow{\tau}$$

Ekman Pumping from Eddy Surface Currents

for an Idealized Gaussian Eddy and Winds from Various Directions

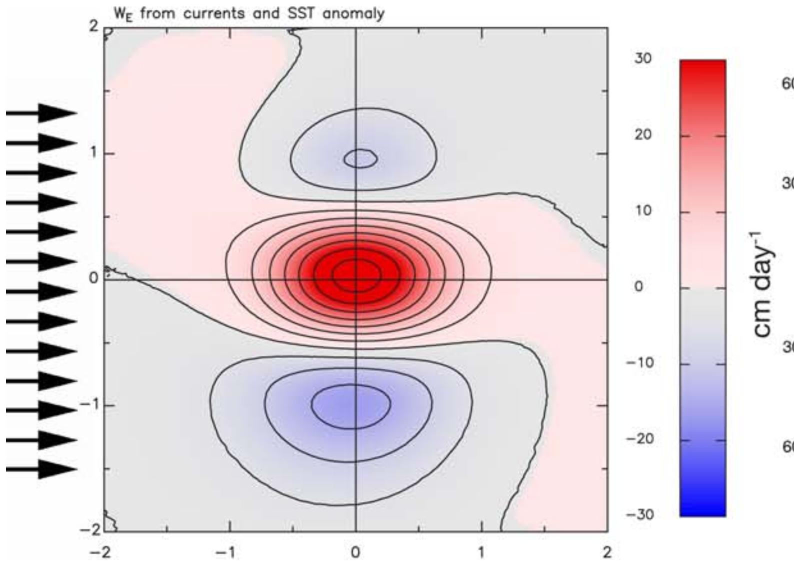


Ekman Pumping from Eddy Surface Currents and SST Combined
for Winds from Various Directions Over a 0.5°C SST Anomaly



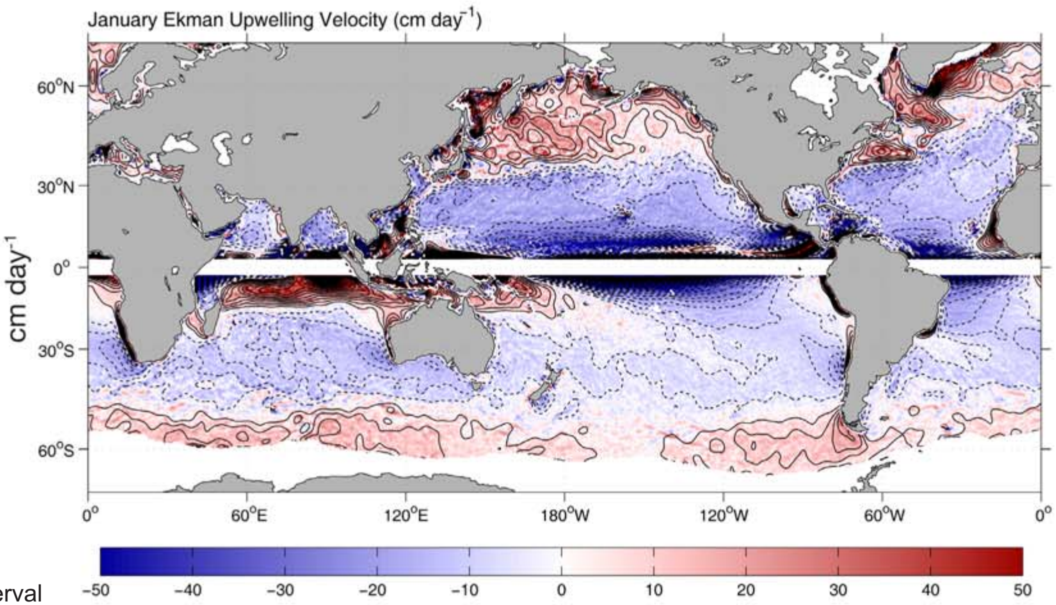
How does this eddy-induced Ekman pumping compare with Ekman pumping associated with the large-scale wind field?

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



Normalized Distance from Eddy Centroid

Contour Interval is 5 cm day^{-1}



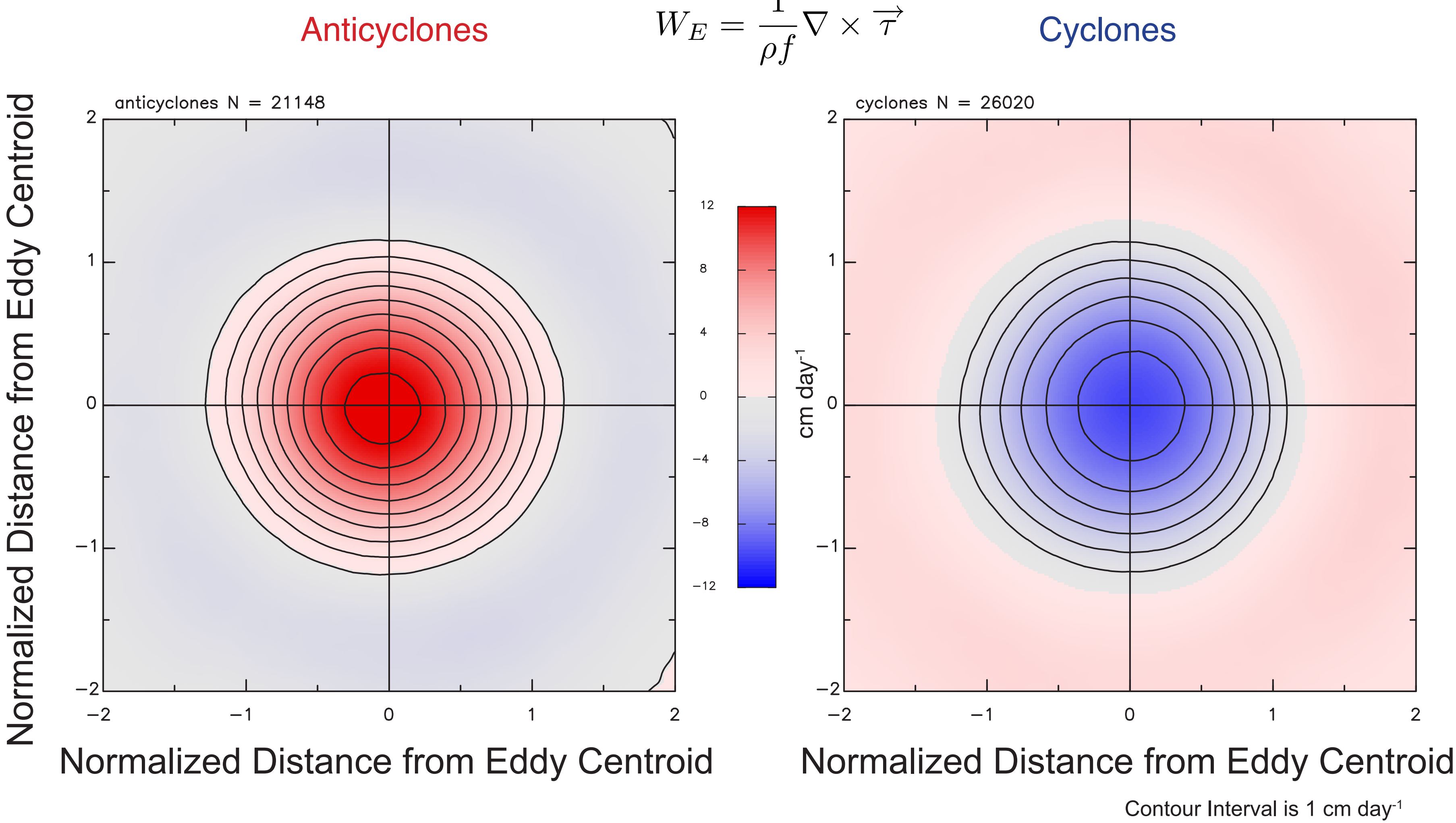
Risien and Chelton, 2008

Eddy-induced Ekman pumping is an Order-1 Perturbation of the Ekman pumping associated with the large-scale wind field.

4. Is the previous Ekman pumping for an idealized Gaussian eddy observed in the QuikSCAT data?

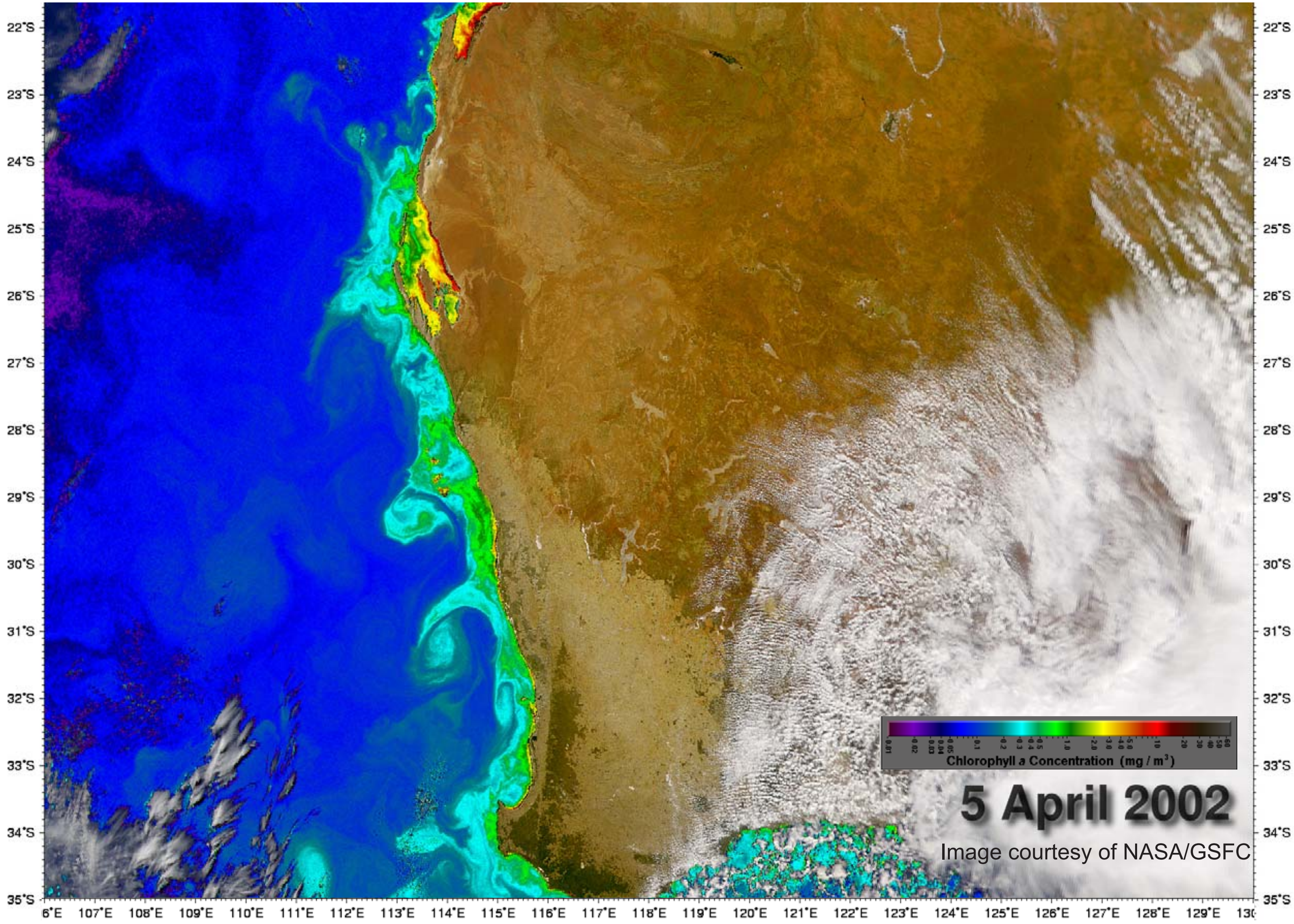
Global Composite Averages of Ekman Pumping from the Wind Stress Curl in Eddy-Centric Coordinates

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



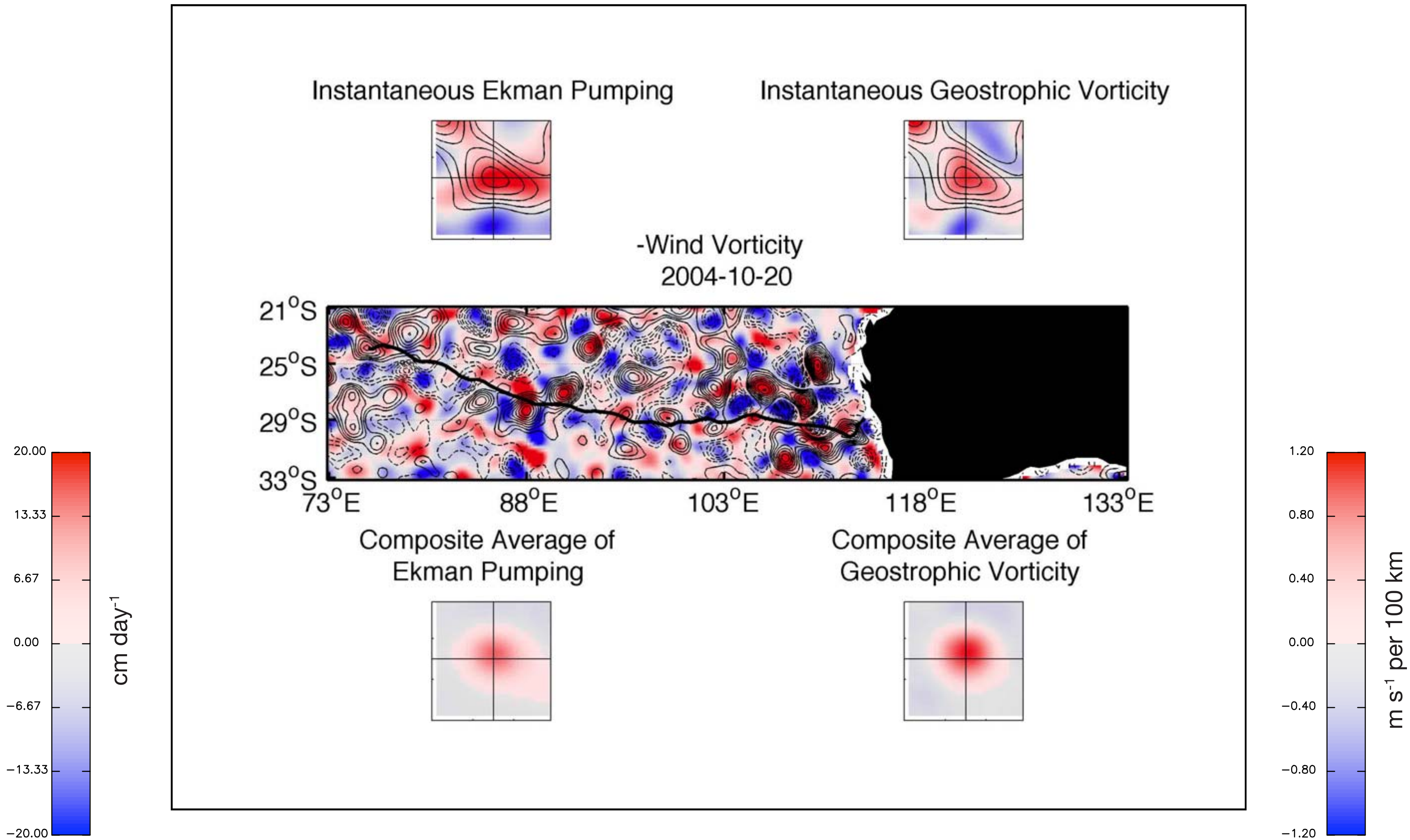
The tripole pattern that occurs for any particular wind direction becomes a blurred ring in composite averages over a wide range of wind directions.

Regional Analysis: Eddies in the South Indian Ocean that Form in the Leeuwin Current off the West Coast of Australia



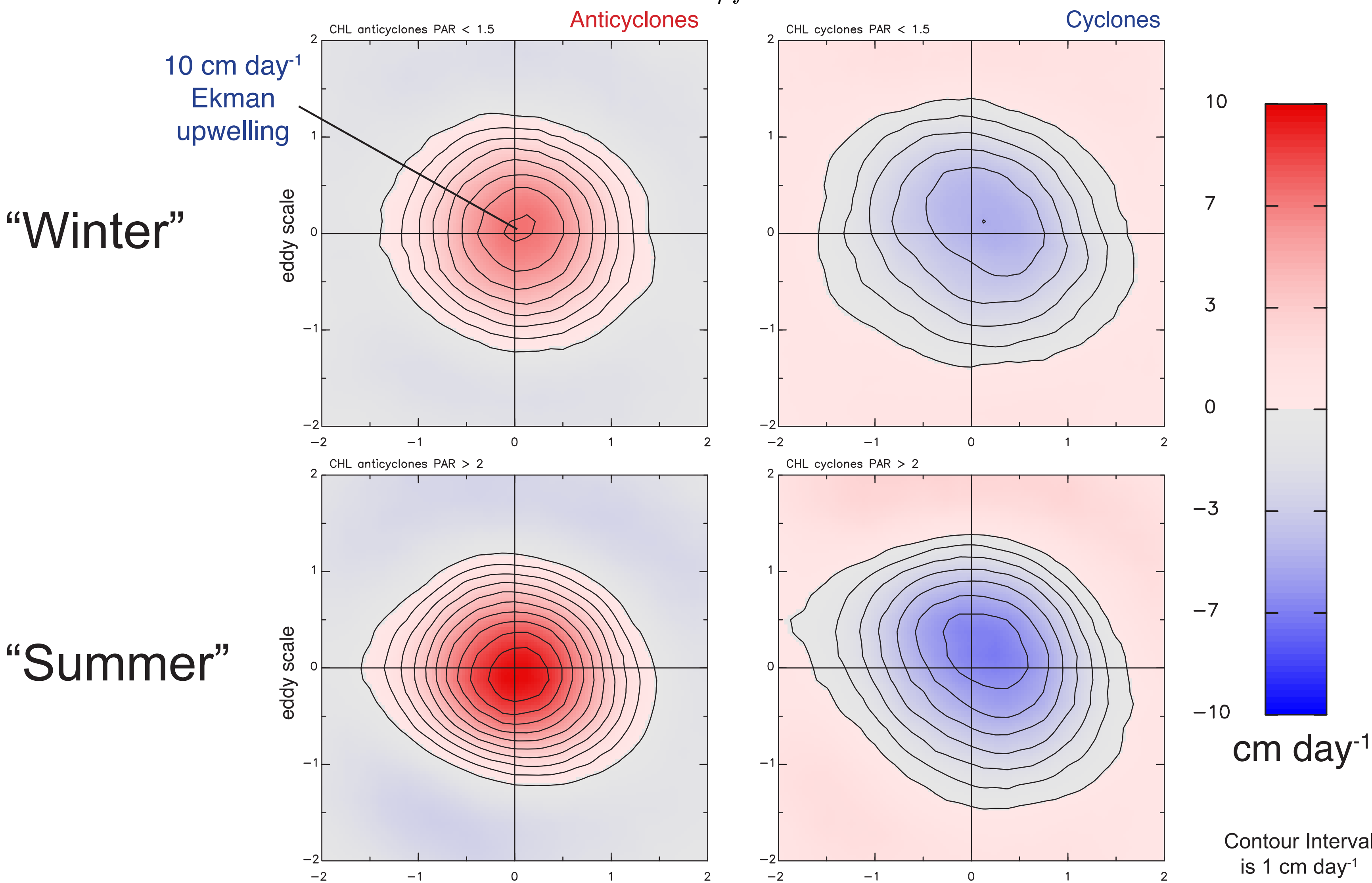
Animation of Ekman Pumping in the South Indian Ocean with SSH Contours and the Trajectory of an Eddy Tracked for 31 Months

27 March 2002 - 20 October 2004



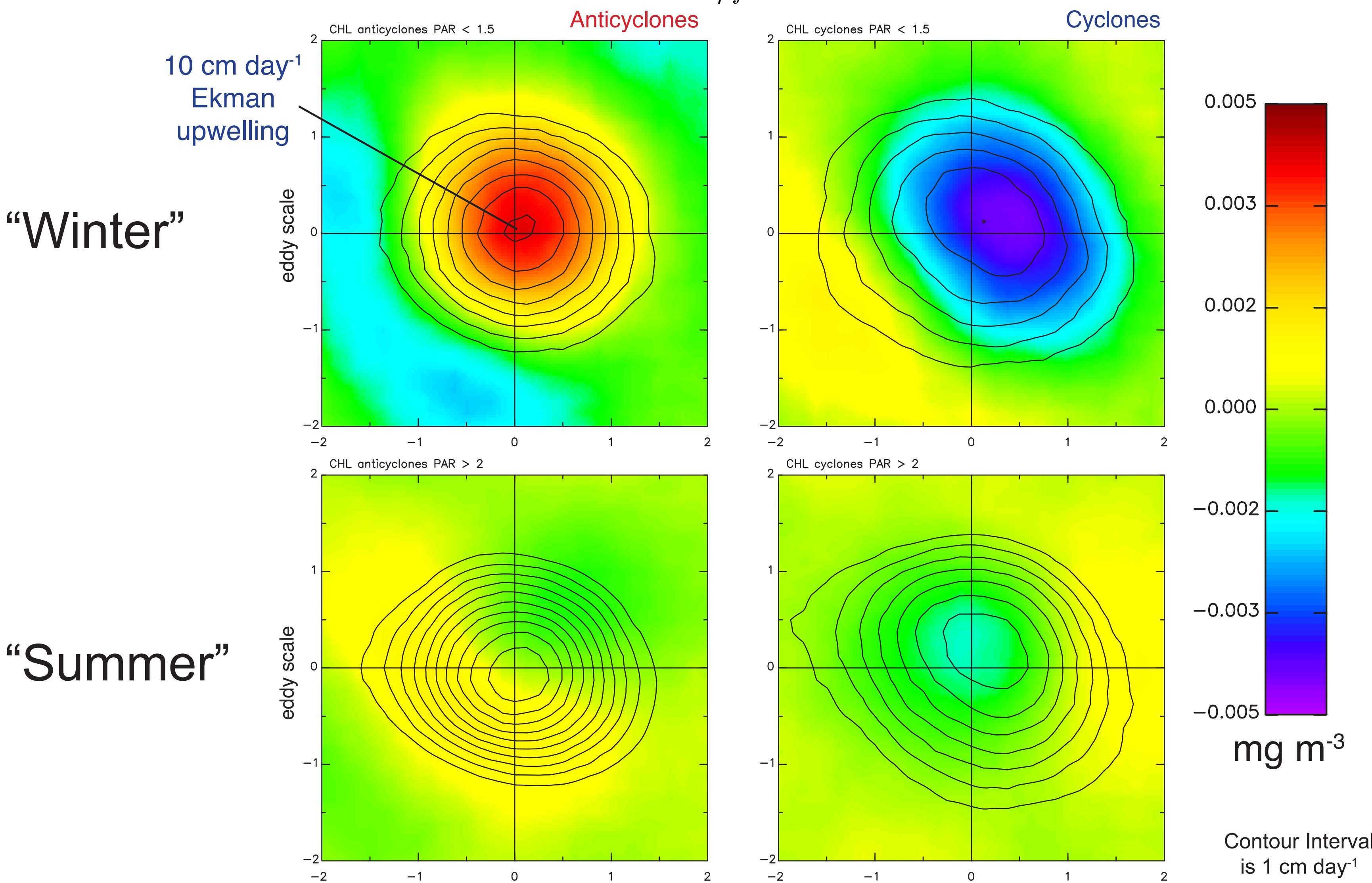
South Indian Ocean Composite Averages of Ekman Pumping from the Wind Stress Curl in Eddy-Centric Coordinates

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



South Indian Ocean Composite Averages of Chlorophyll in Eddy-Centric Coordinates

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



Conclusions

- The availability of a decade of overlapping data records from multiple satellite sensors is allowing synergistic analyses of complex processes.
- The collocation of 4 satellite datasets to the interiors of mesoscale eddies in this study has shown that:

  1) *Eddy-induced SST variability consists of advection by the azimuthal velocity of the eddies that depends on the rotational sense of the eddy and the direction of the background SST gradient.*

  2) *These SST anomalies generate surface wind speed anomalies that are consistent with the coupling previously found between SST and wind speed along meandering SST fronts.*

  3) *The structure of these SST-induced wind speed perturbations results in wind stress curl and associated Ekman pumping anomalies over the eddy interiors.*

  4) *This SST-induced Ekman pumping is secondary to the Ekman pumping associated with eddy surface currents.*
     - *The latter is an O(1) perturbation of the background Ekman pumping associated with the large-scale wind field.*

  5) *Ekman pumping over anticyclones appears to sustain blooms of phytoplankton within the cores of eddies in the Indian Ocean during wintertime.*
     - *The reason that this is limited to wintertime is not yet fully understood.*