A Modified Coastal Upwelling Index Accounting for Non-Local Forcing

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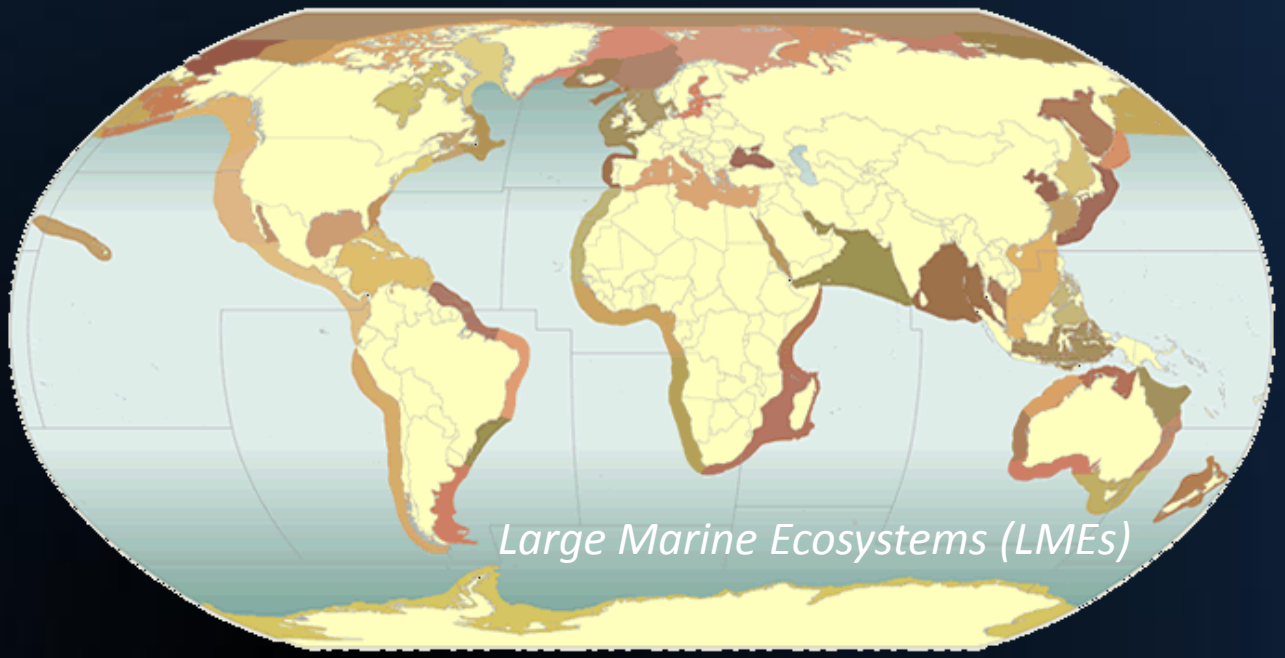
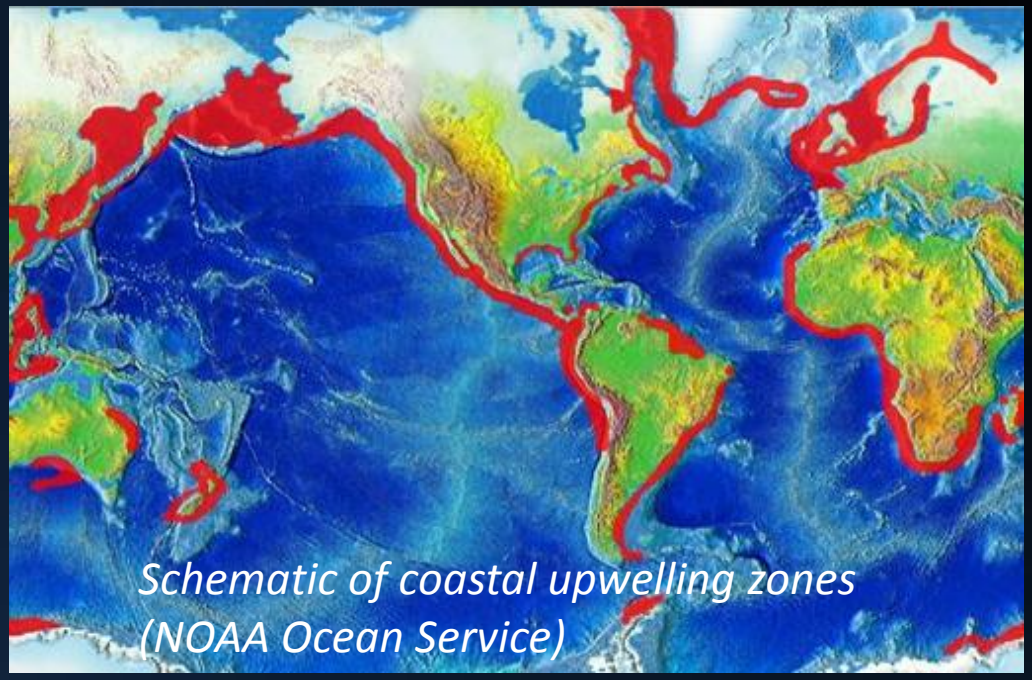
Coastal upwelling is critically important to marine ecosystems, coastal water quality, and carbon sequestration.



Large Marine Ecosystems (LMEs)



Schematic of coastal upwelling zones (NOAA Ocean Service)

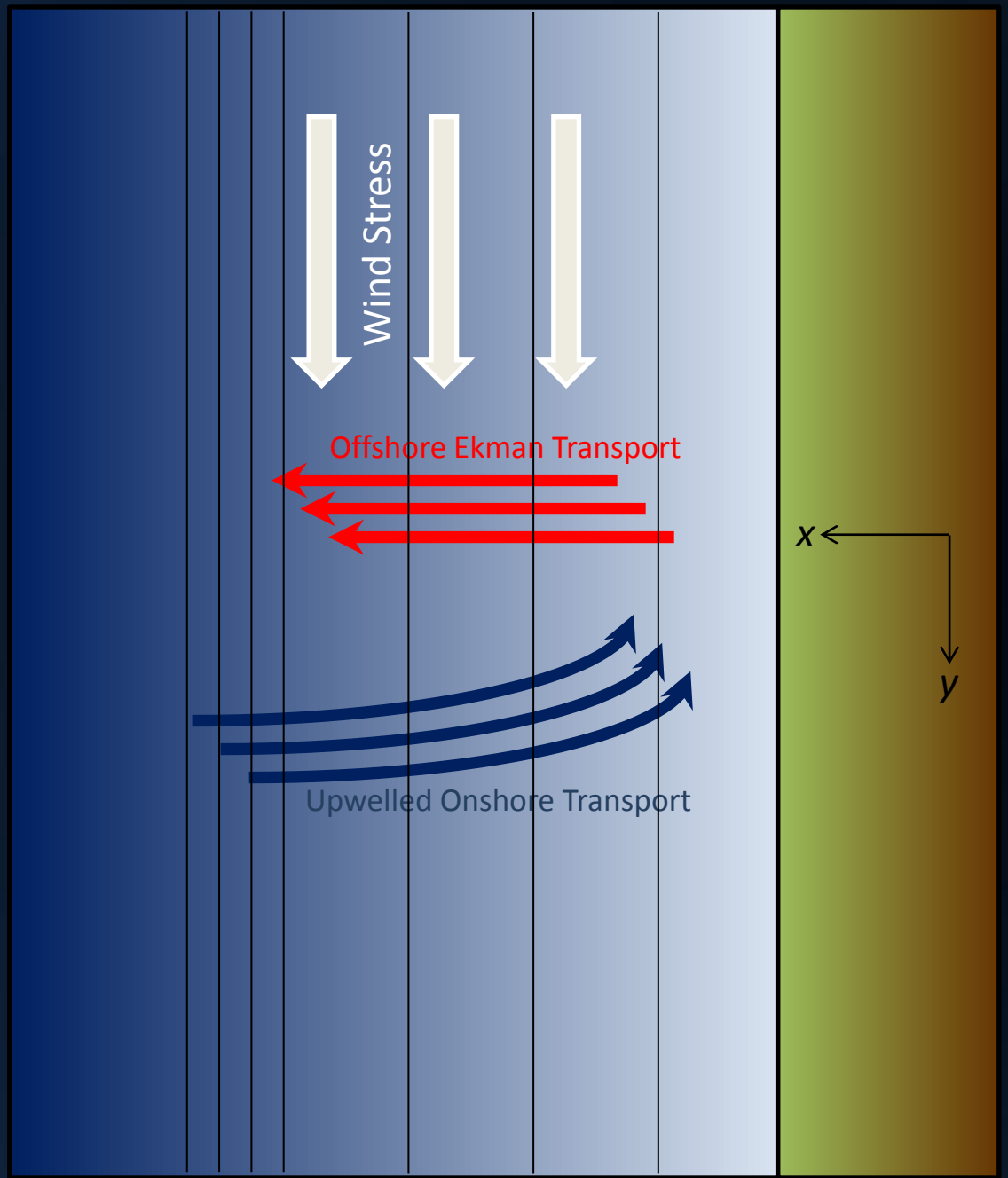
A number of upwelling zones are well known and studied, but coastal circulation in remote and sparsely observed regions is not well understood. Satellite scatterometers provide a wealth of data globally that can be used to infer coastal circulation including upwelling.

Project Objectives:

- Develop a new global database of coastal upwelling indices from satellite scatterometer-derived wind products.

- Use this global product to examine spatio-temporal variability of upwelling/downwelling over Earth's coastal regions at multiple scales.

Idealized Coastal Upwelling

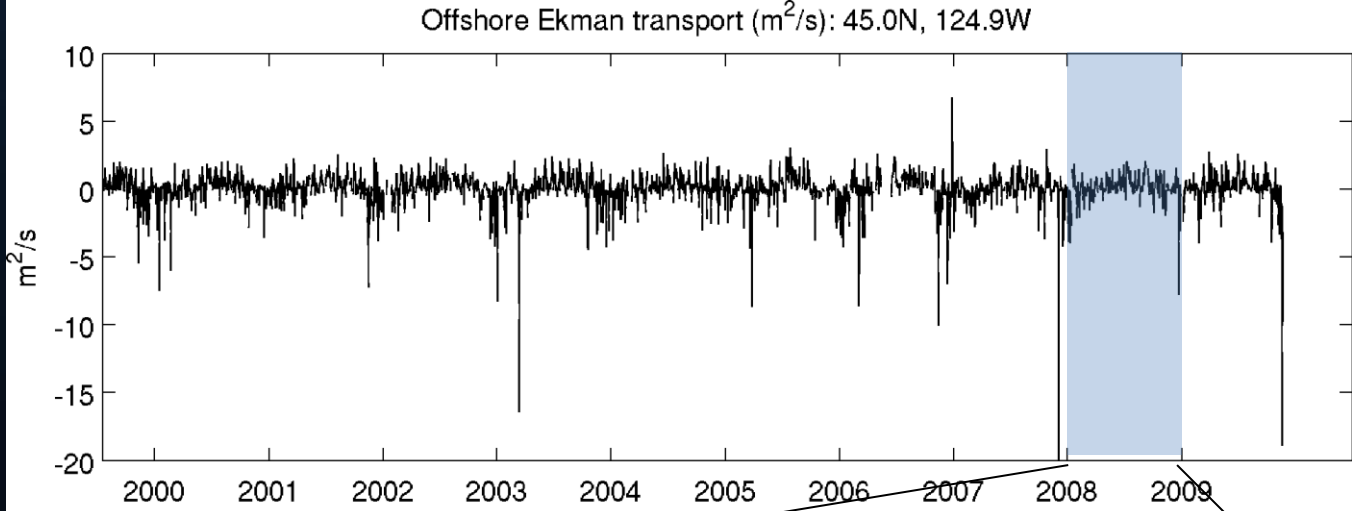


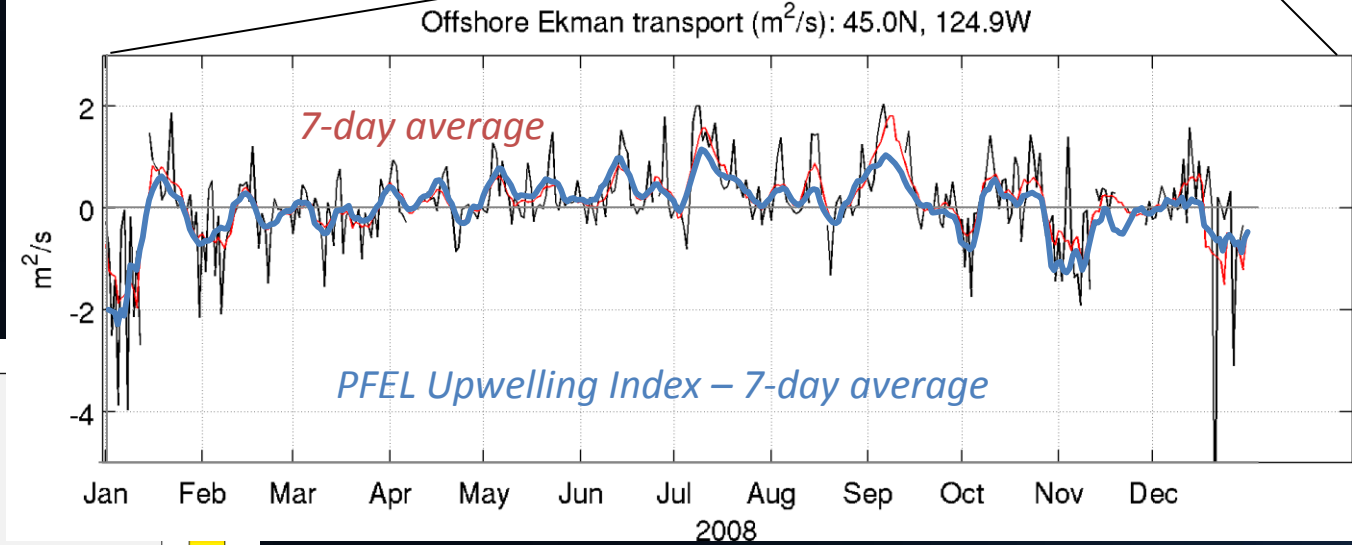
The offshore Ekman transport is

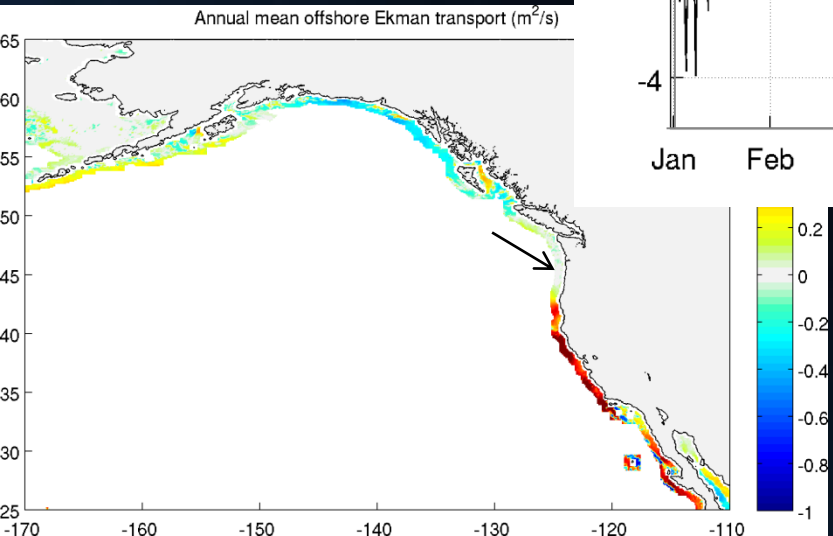
$$S_x = \frac{\tau_y}{\rho_0 f}$$

S_x is used as an upwelling Index.

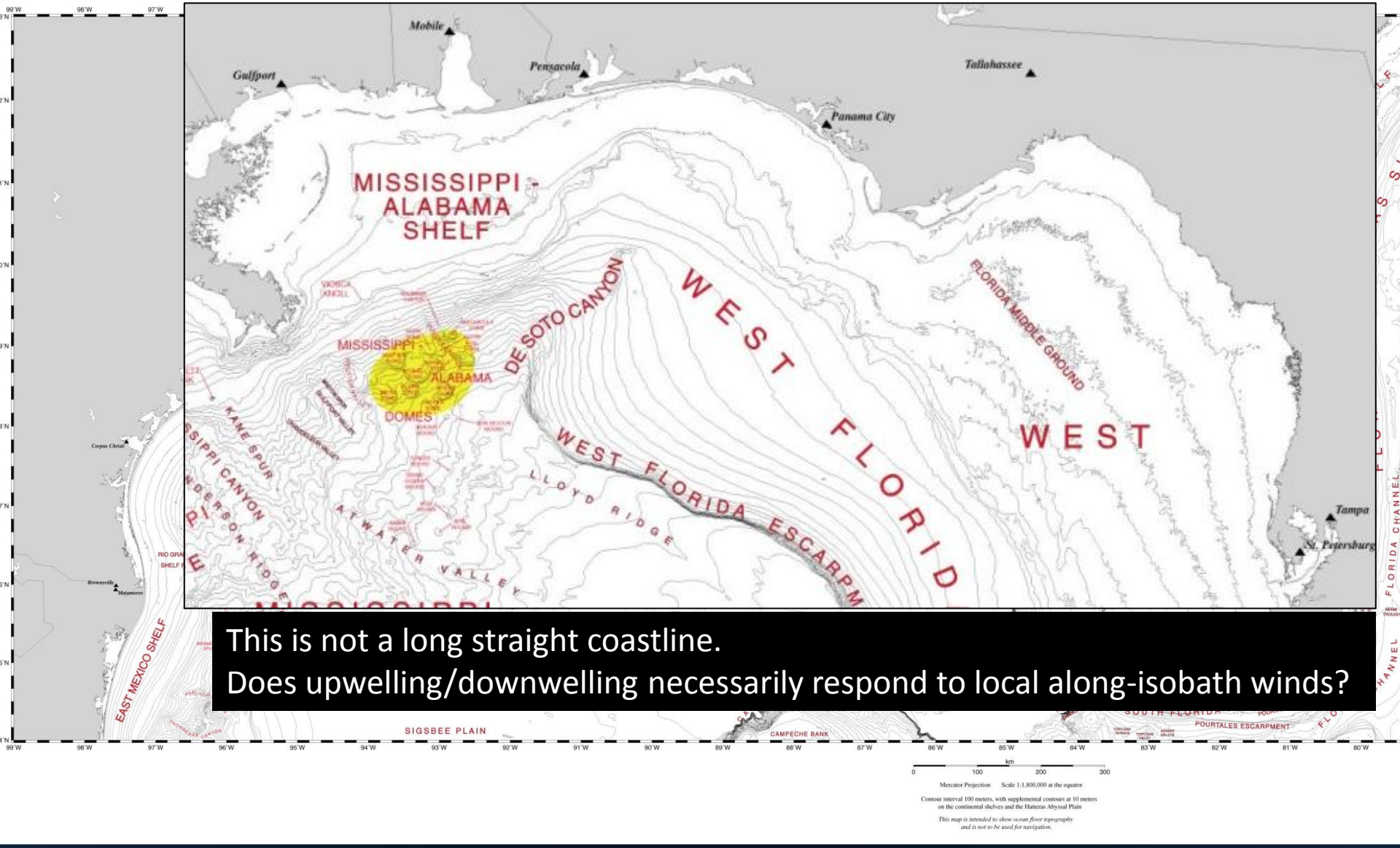
Classic Upwelling Indices from CCMP Winds





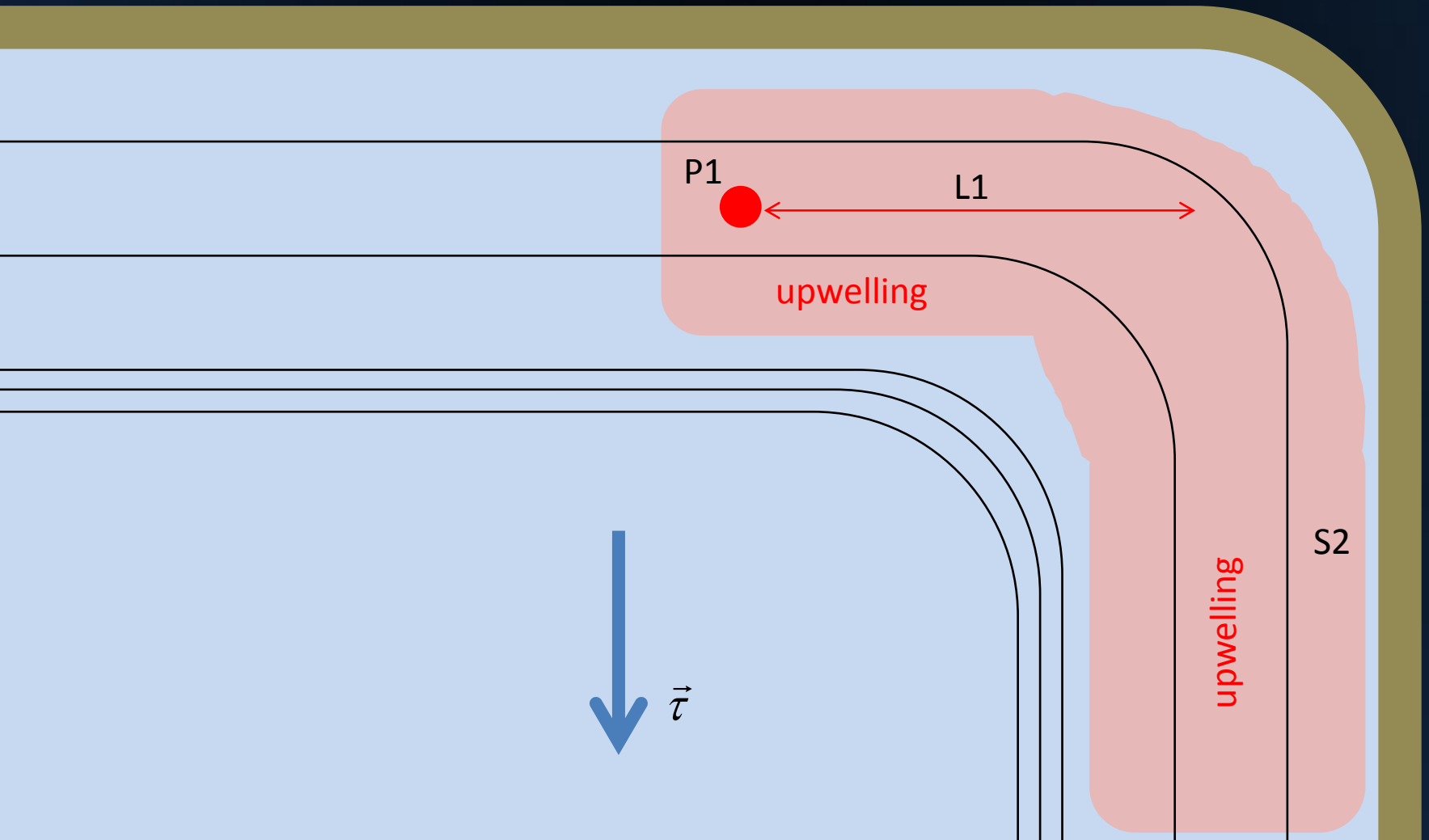


Wind-Induced Upwelling on a Shelf with Complex Geometry

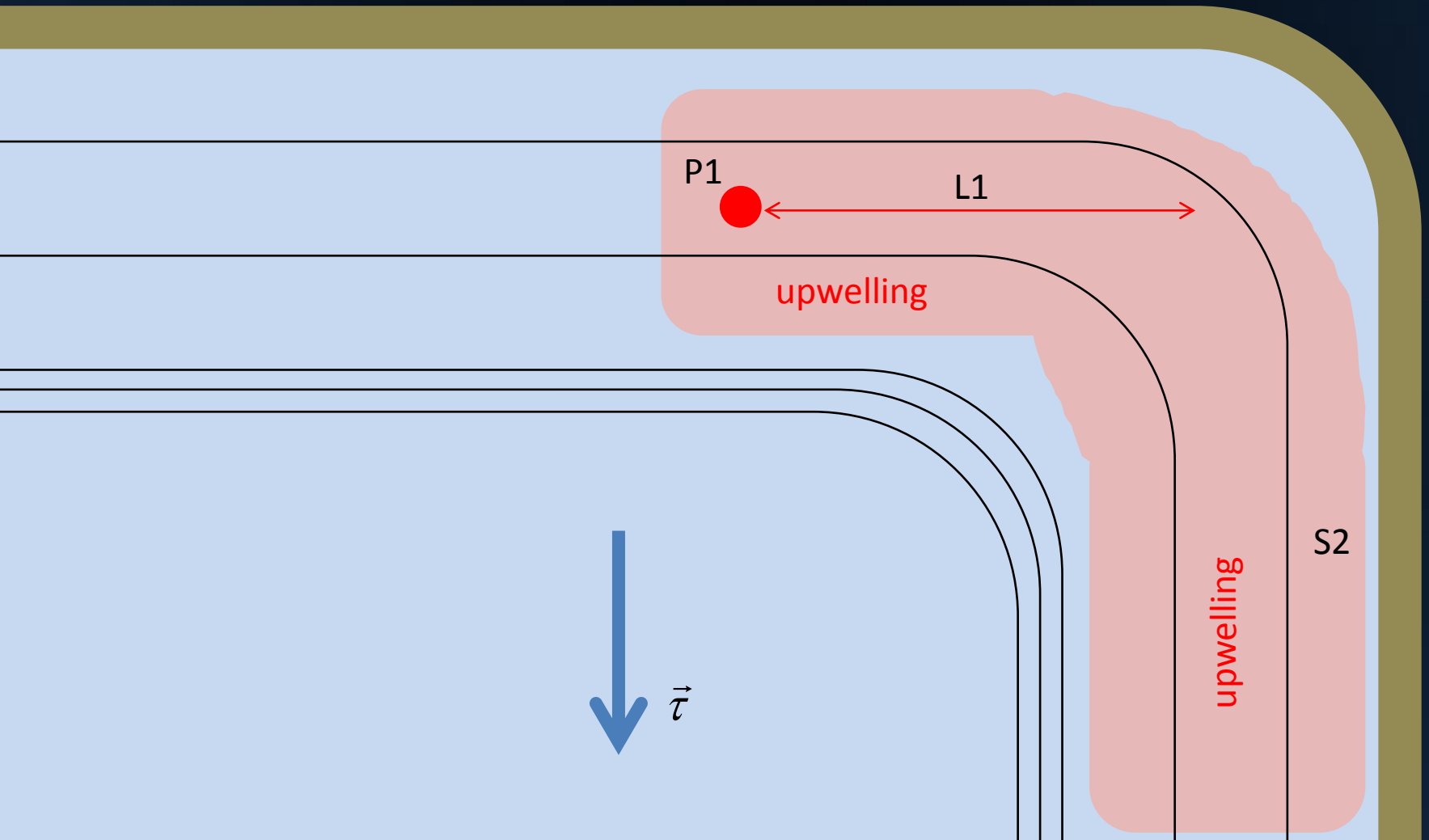


This is not a long straight coastline.
Does upwelling/downwelling necessarily respond to local along-isobath winds?

Wind-driven coastal pressure anomalies propagate in the downcoast direction as coastally trapped waves. Their structure is modified by local wind along their propagation characteristics.

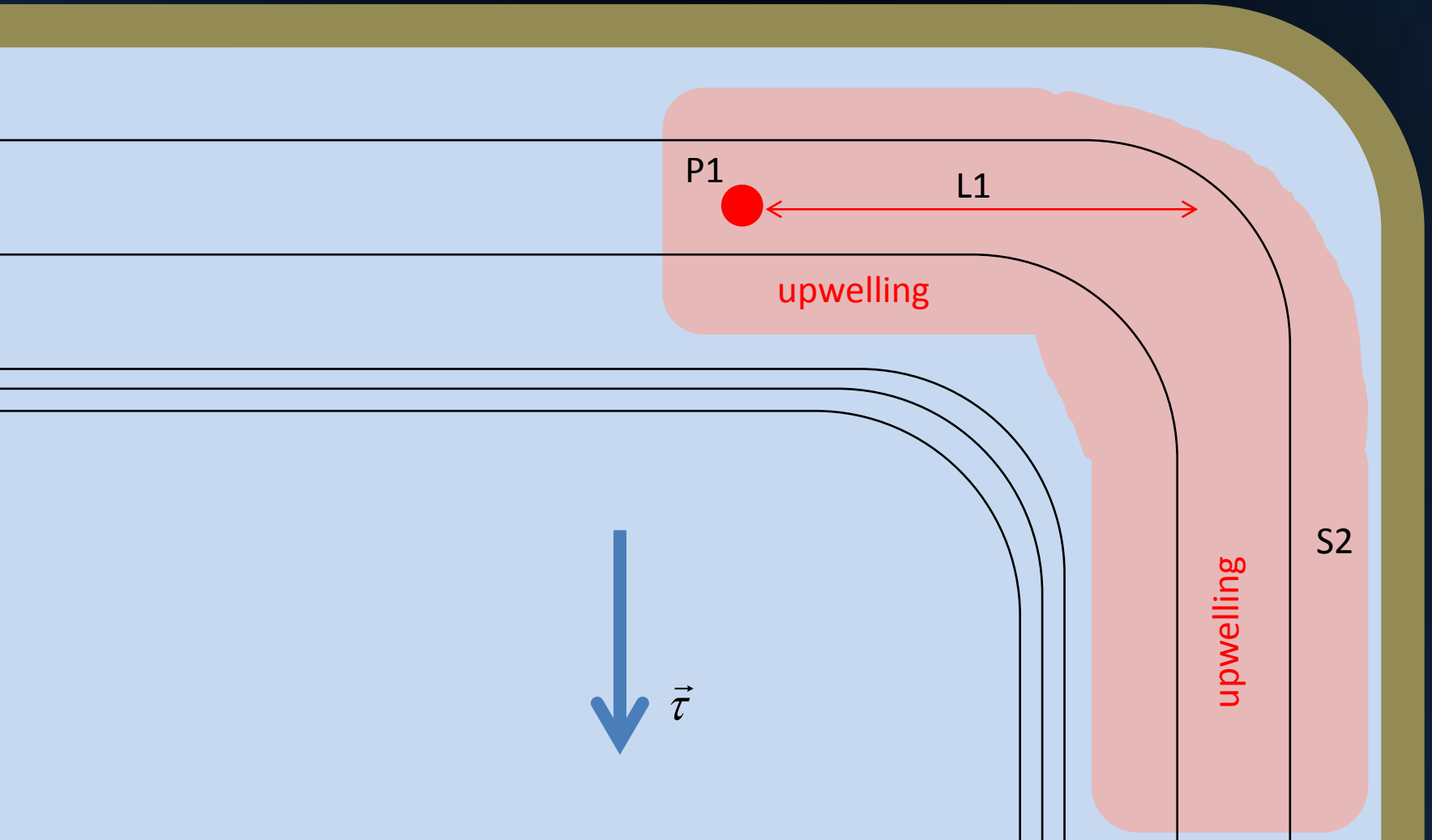


In this example, the upwelling signal generated along coastline segment S2 propagates toward point P1. P1 experiences upwelling by wind-forced motion along coastline S2 (beginning at some time lag L1/c after the onset of winds), even though the winds are not parallel to the coast at P1.



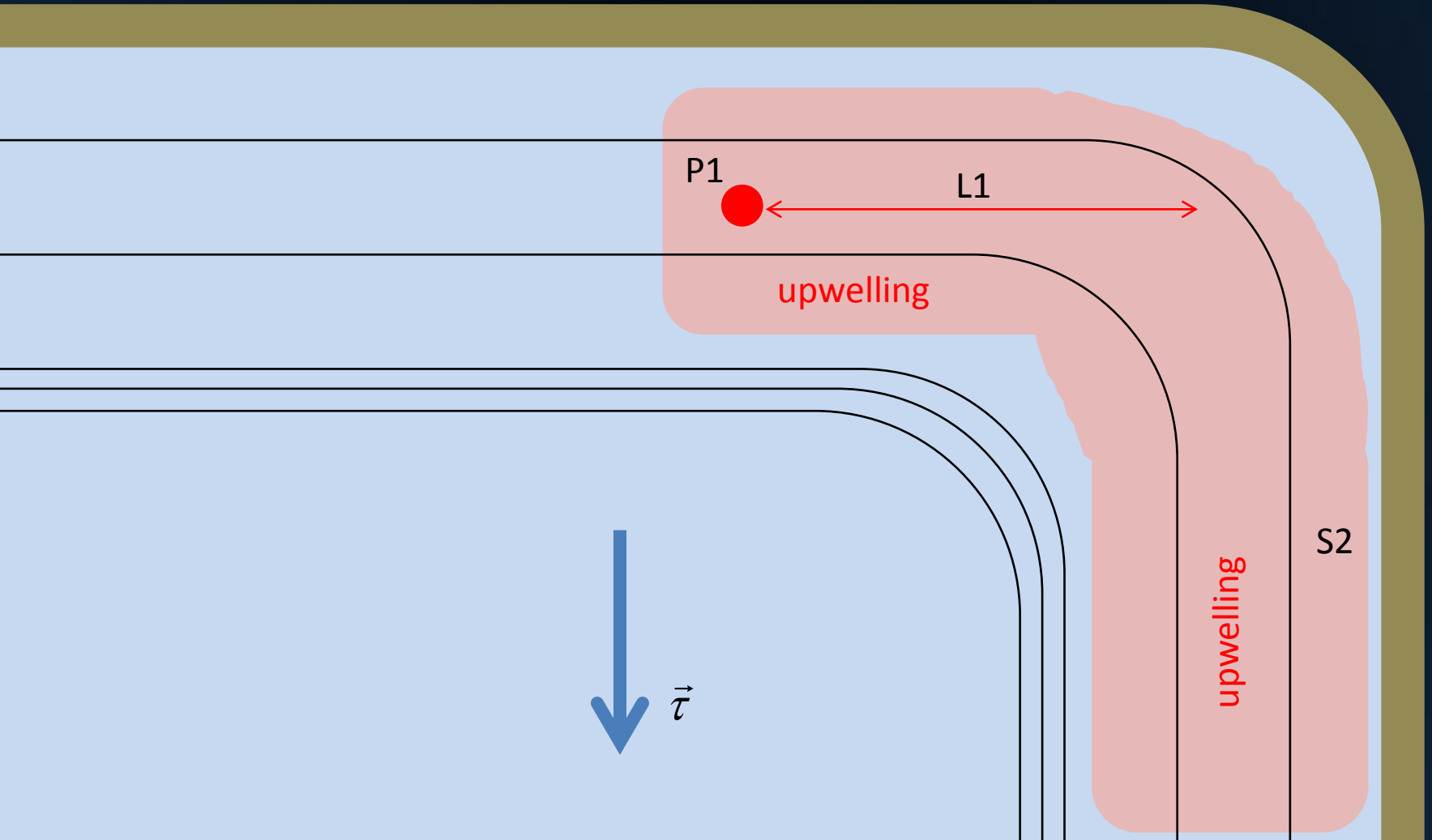
The upwelling response at P1 may be approximately inferred from the *local wind* with lag > L1/c if along-coast length scales (~L1) are small compared to spatial scales of the wind field.

For the west Florida shelf, c~8.2 m/s, (30km/hr) (Mitchum and Clarke, 1986).
If L1=300km, the lag would be ~10 hours, or shorter than the Ekman spin-up time scale of a pendulum day.

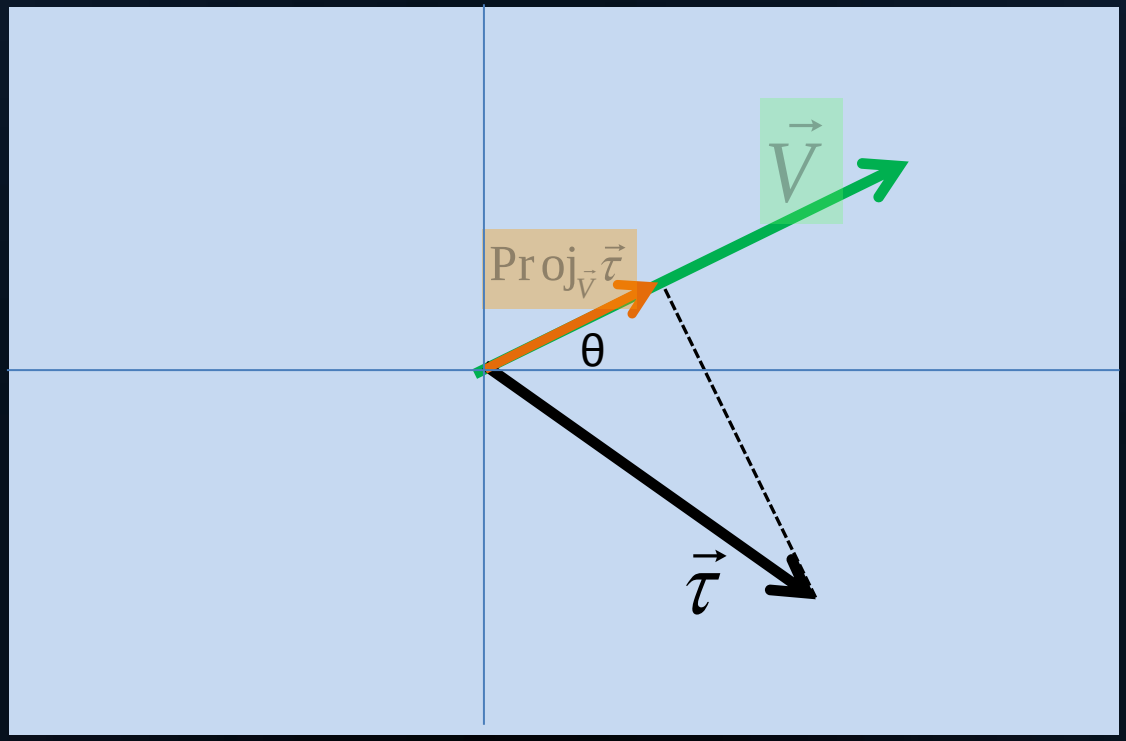


The upwelling/downwelling response at P1 will not be approximated by the wind component parallel with the local isobaths, but rather the component along a rotated vector influenced by the orientation of coastline segment S2.

To estimate the rotation of the vector onto which the local wind stress should be projected for inferring local upwelling/downwelling, numerical model results are analyzed.



A Modified Upwelling Index



For each coastal point:

1. Project τ onto the vector V rotating through all angles. Here, τ is backward averaged over a 24-hour period

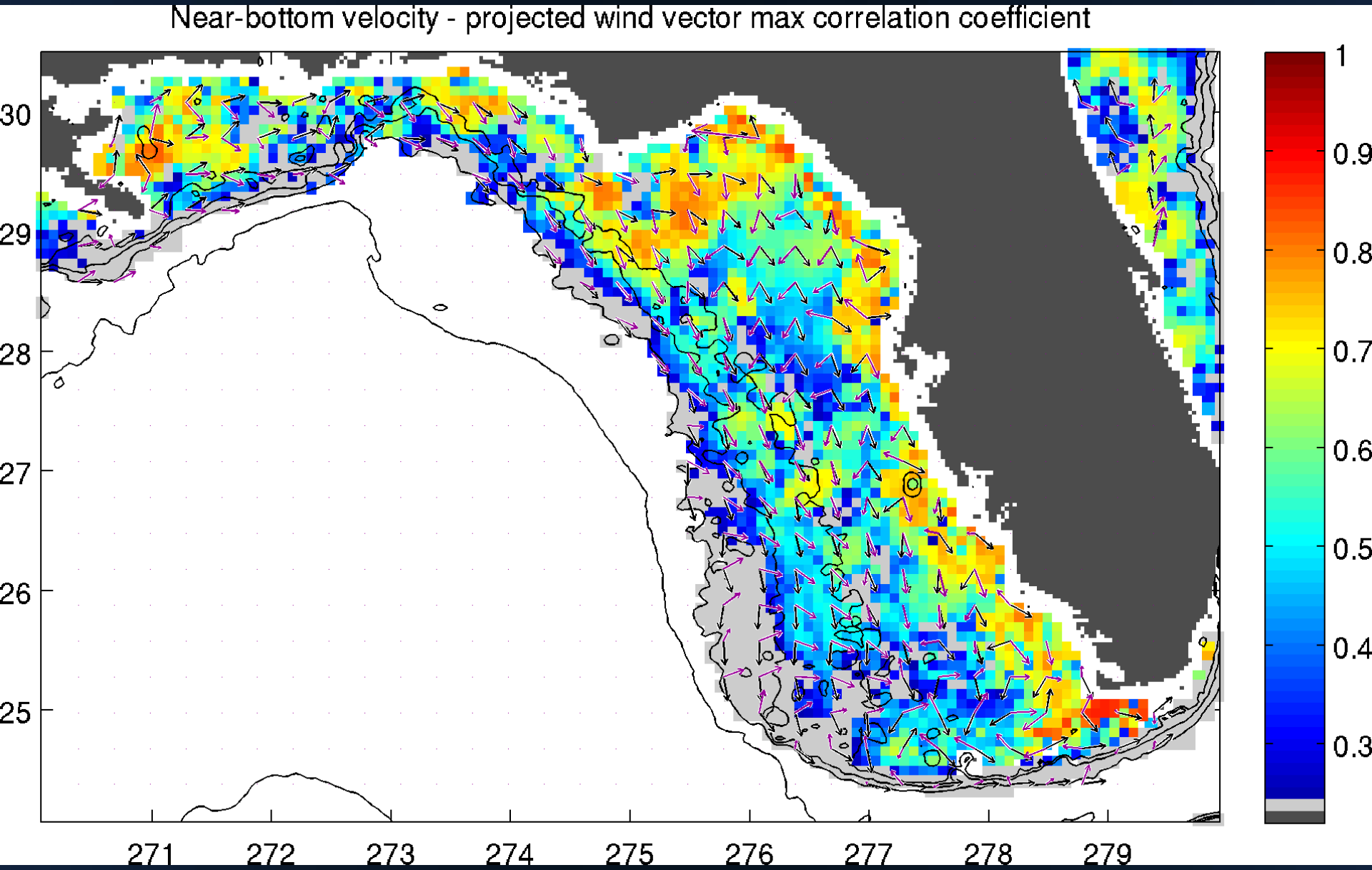
2. For each angle, compute correlation between the projected (filtered or lagged) wind stress time series and the near-bottom cross-isobath ocean velocity component.

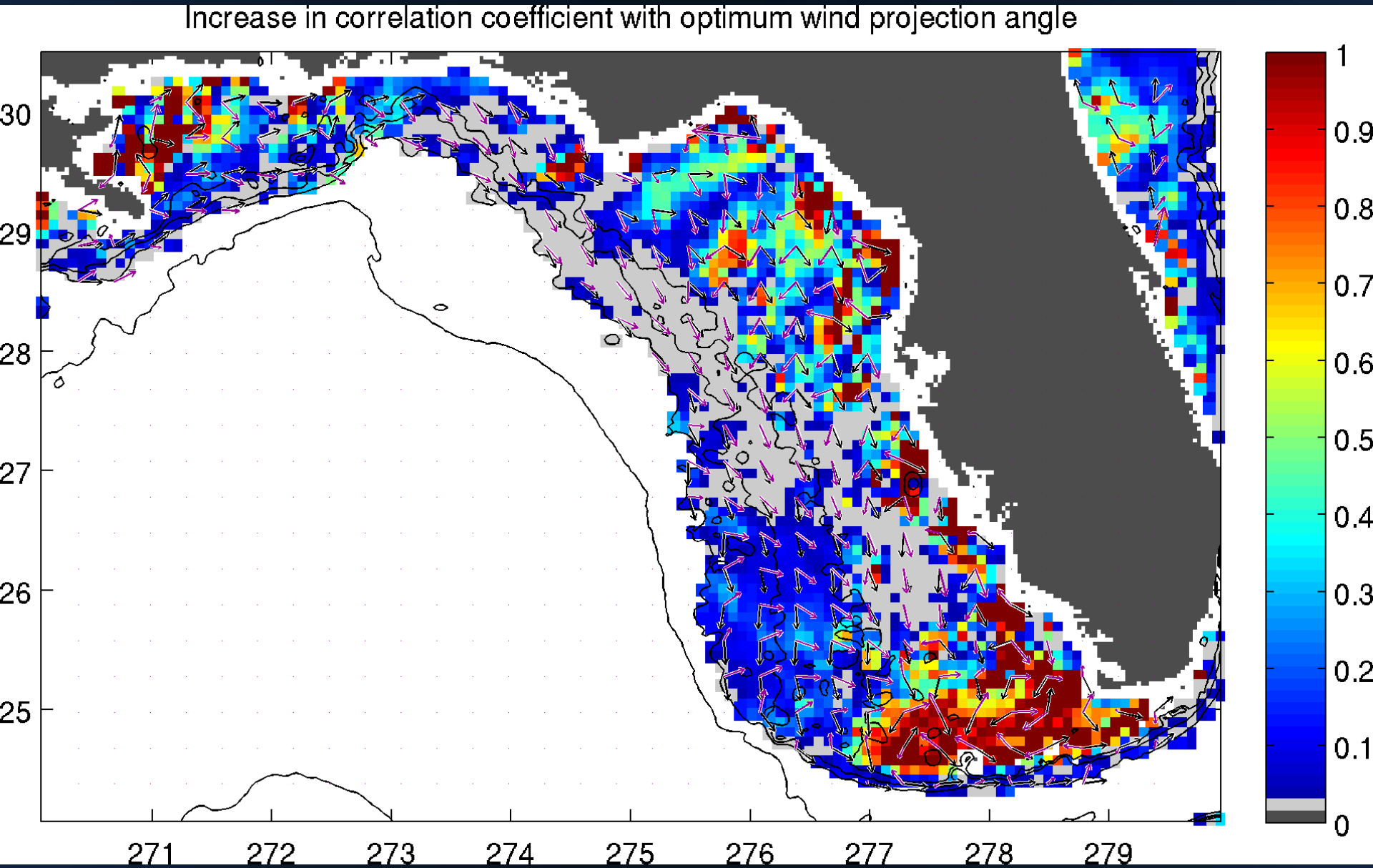
3. Determine the rotation angle of maximum correlation

A Modified Upwelling Index

- Lower water column (near-bottom) velocity time series are extracted from the Global Hybrid Coordinate Ocean Model (HYCOM) 1992-2012 hindcast simulation for each near-coastal grid point.
- Time series of 3-hourly CFSR wind stresses that force the model are also extracted.
- The correlation analysis is performed on the near-bottom velocity and time series of wind stress projected onto the rotating vector.
- The rotation angle corresponding to maximum correlation is computed.
- The CCMP wind stress time series are then projected onto the angle of maximum correlation at each grid point to produce modified upwelling indices.

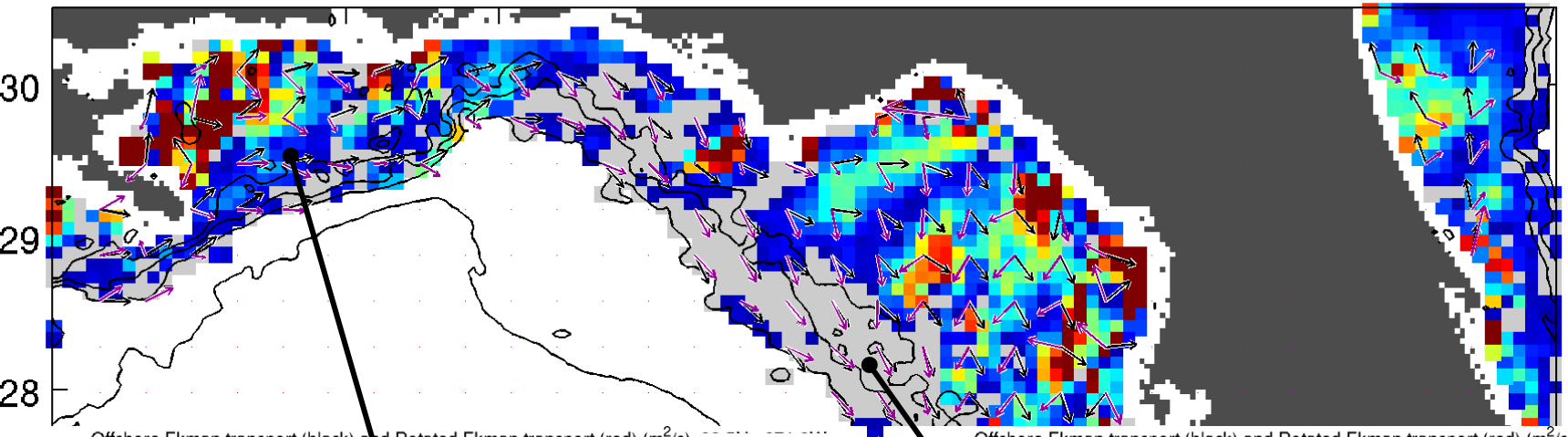
Northeastern Gulf of Mexico Example



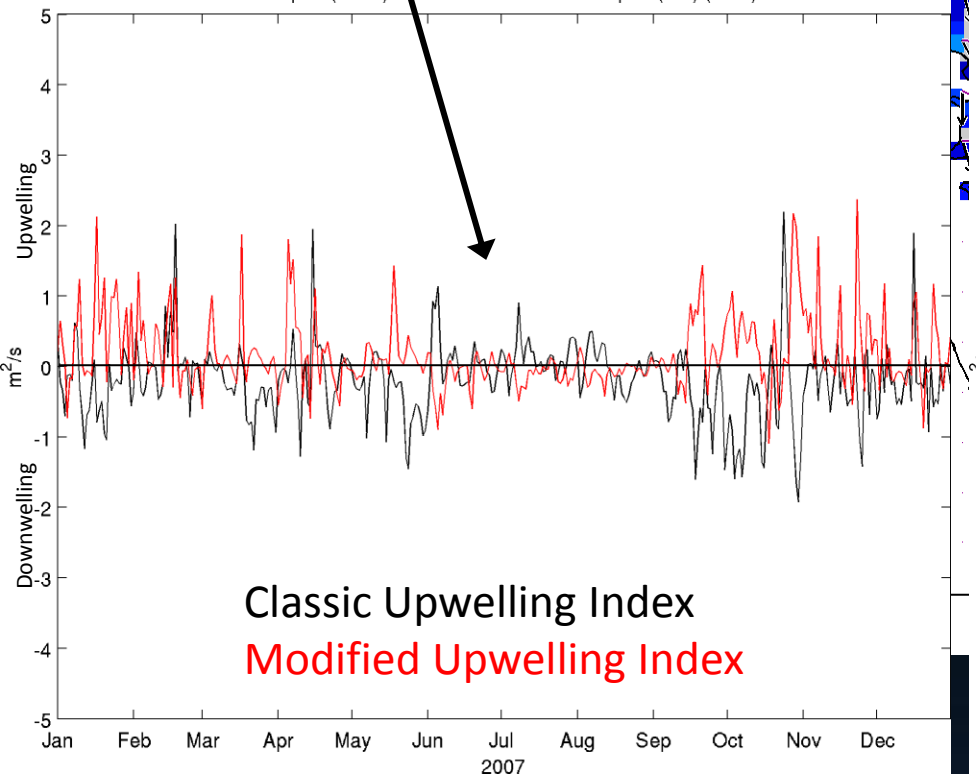

Increase in correlation coefficient with optimum wind projection angle
30
29
28
27
26
25
271
272
273
274
275
276
277
278
279
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Modified Upwelling Indices

Increase in correlation coefficient with optimum wind projection angle



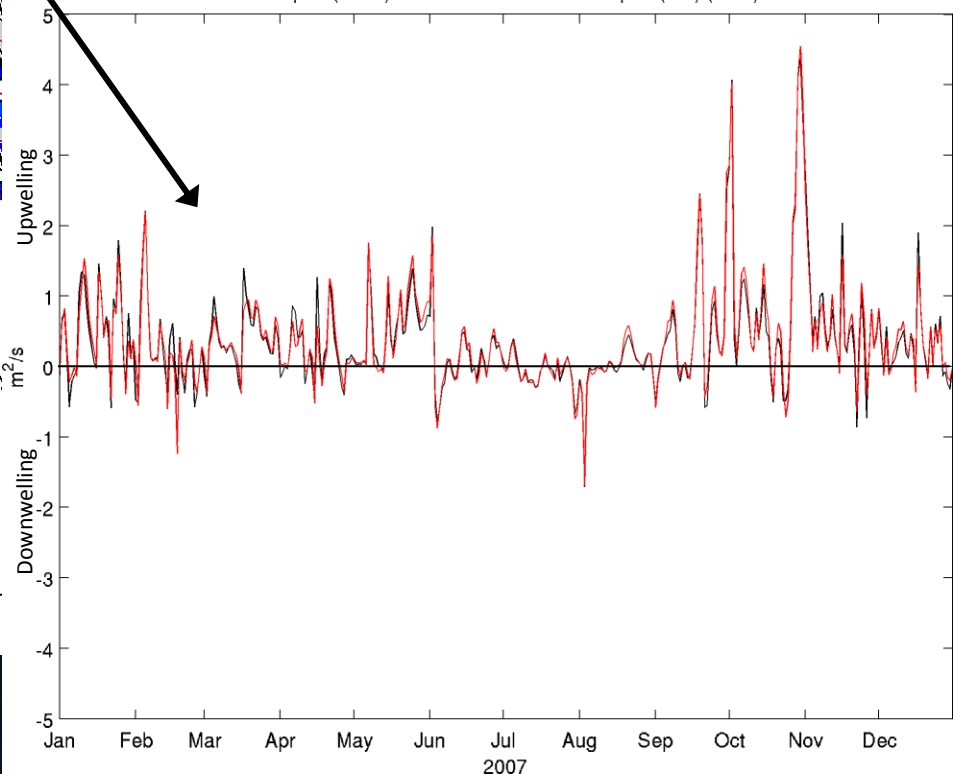
Offshore Ekman transport (black) and Rotated Ekman transport (red) (m^2/s)



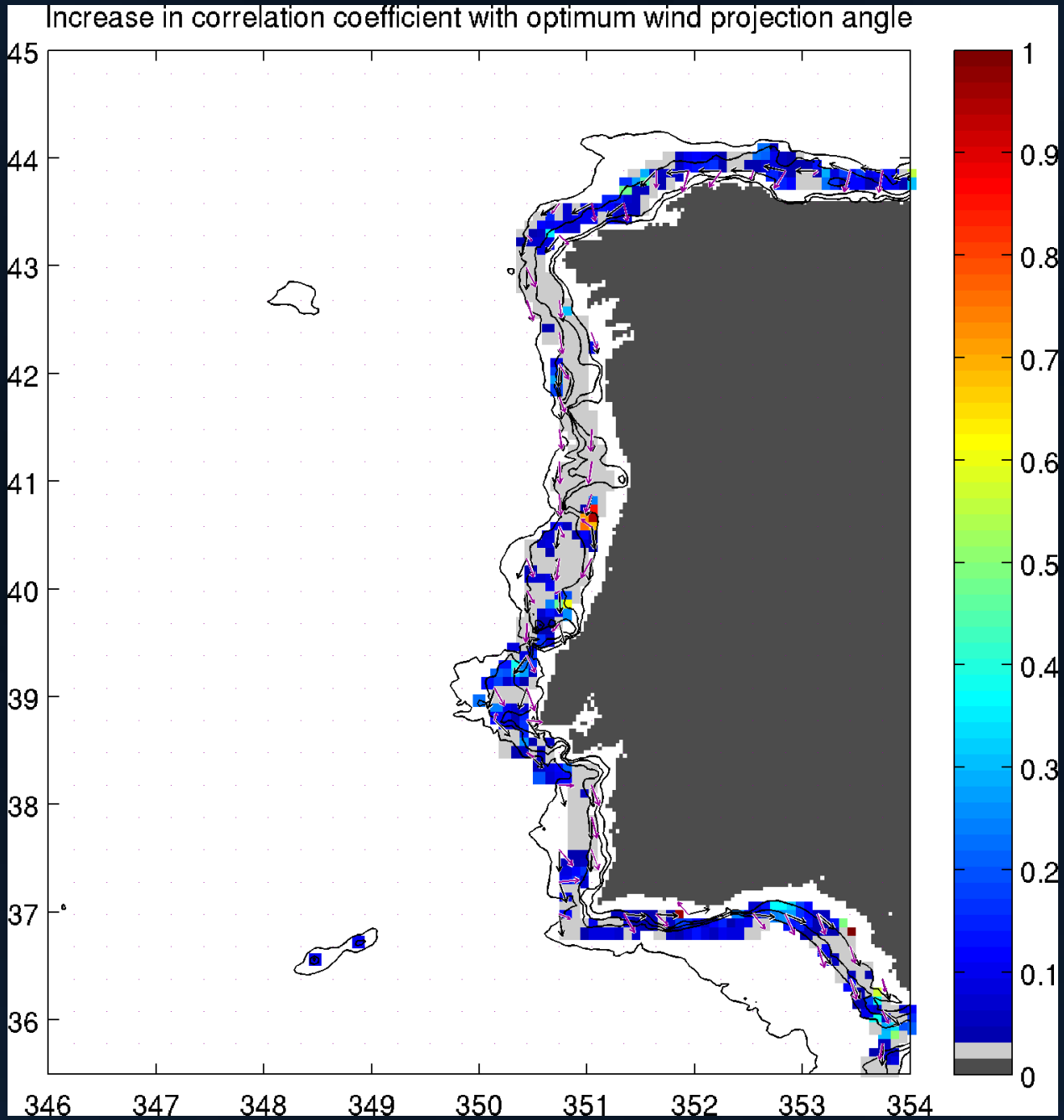
Classic Upwelling Index

Modified Upwelling Index

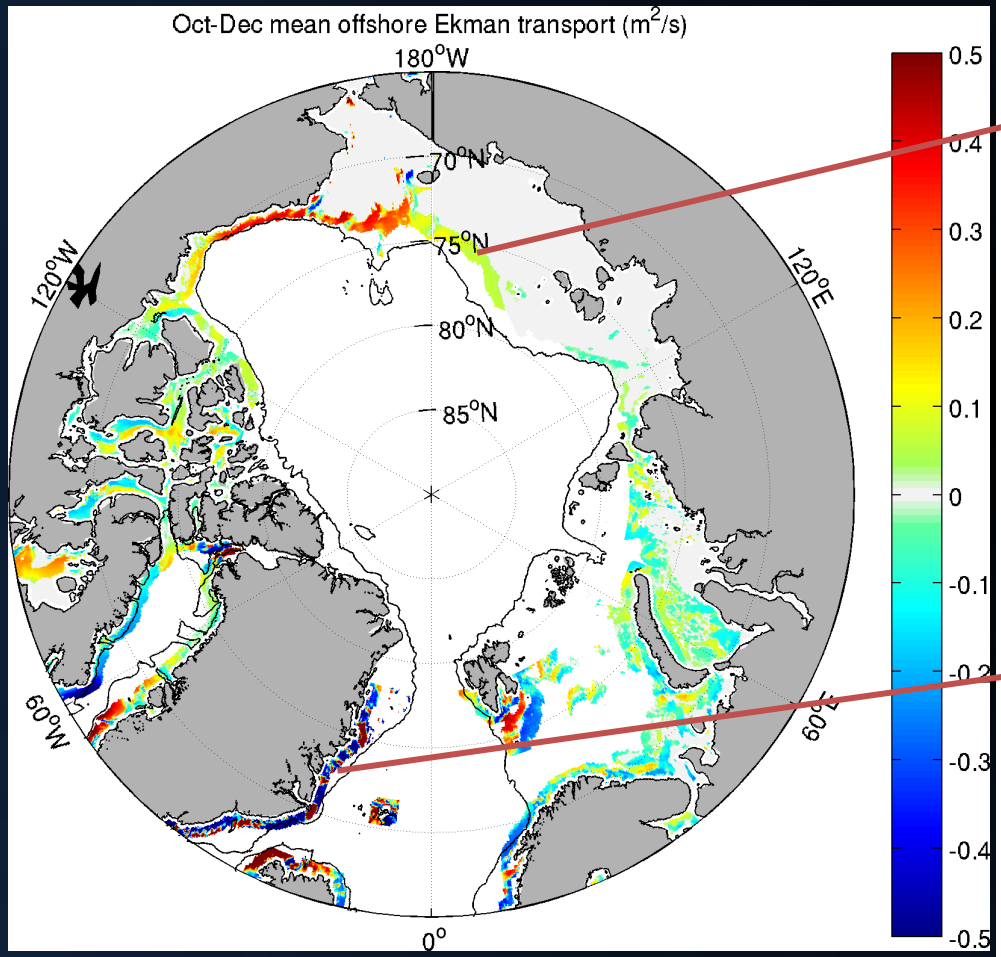
Offshore Ekman transport (black) and Rotated Ekman transport (red) (m^2/s)

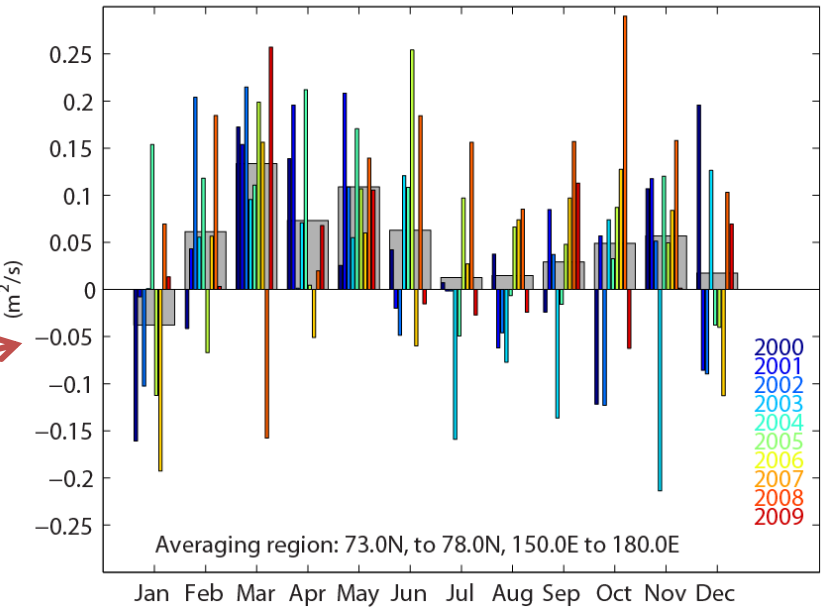


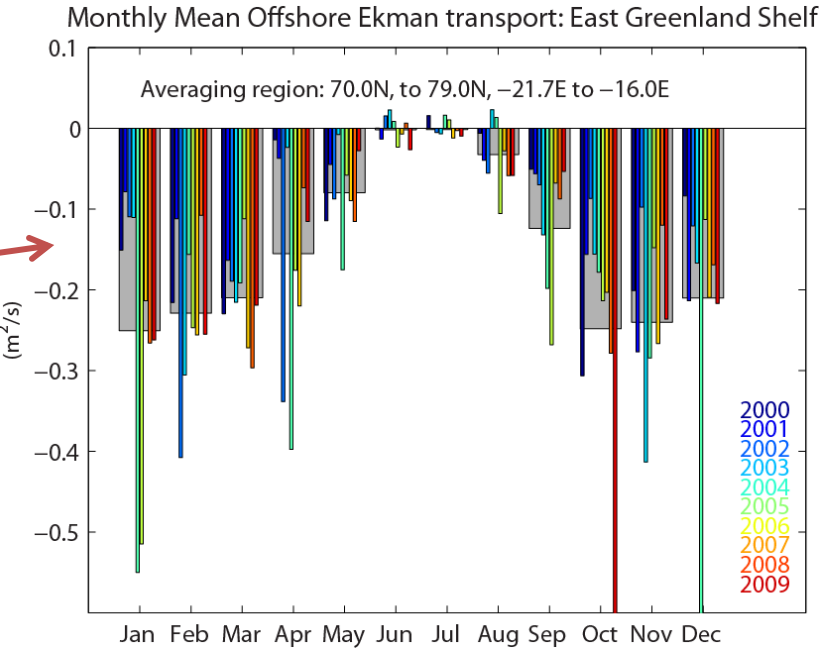
Iberian Peninsula Example



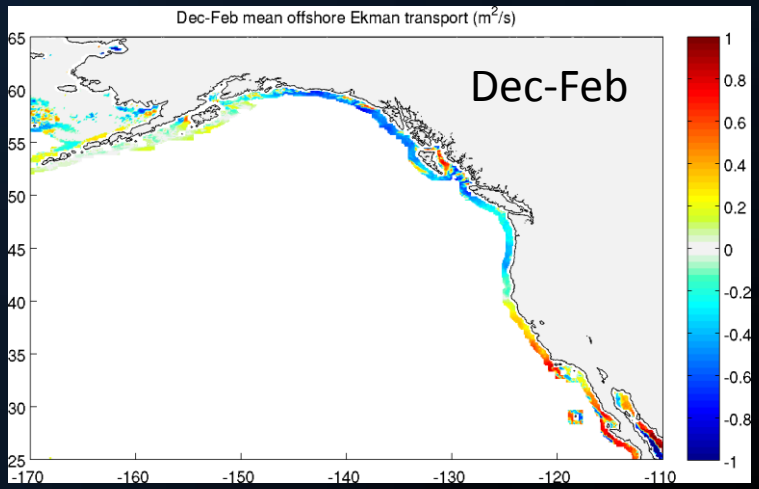
Seasonal and Interannual Variability

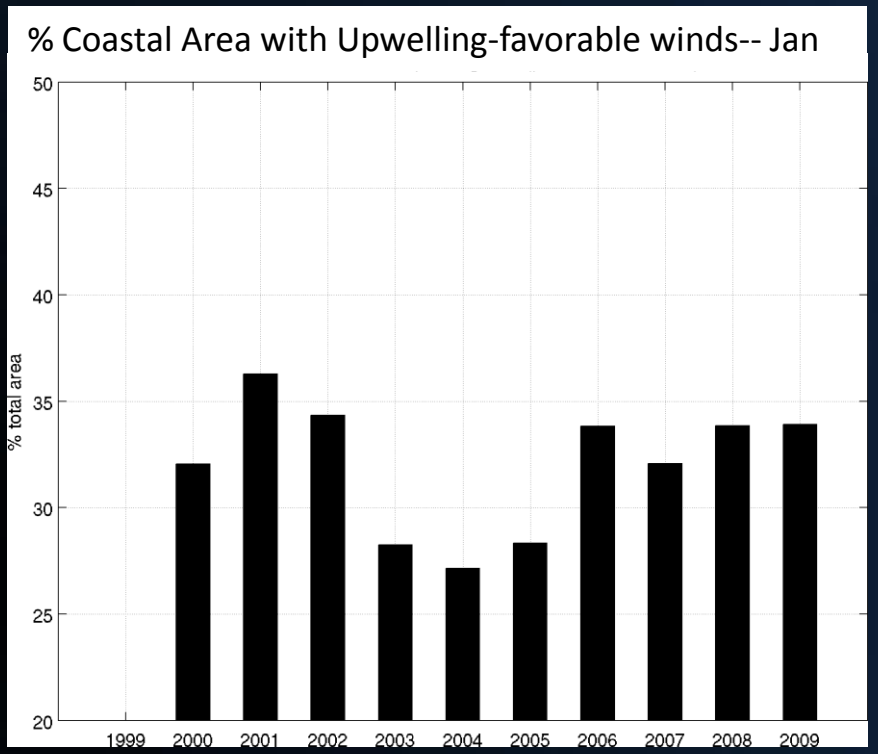


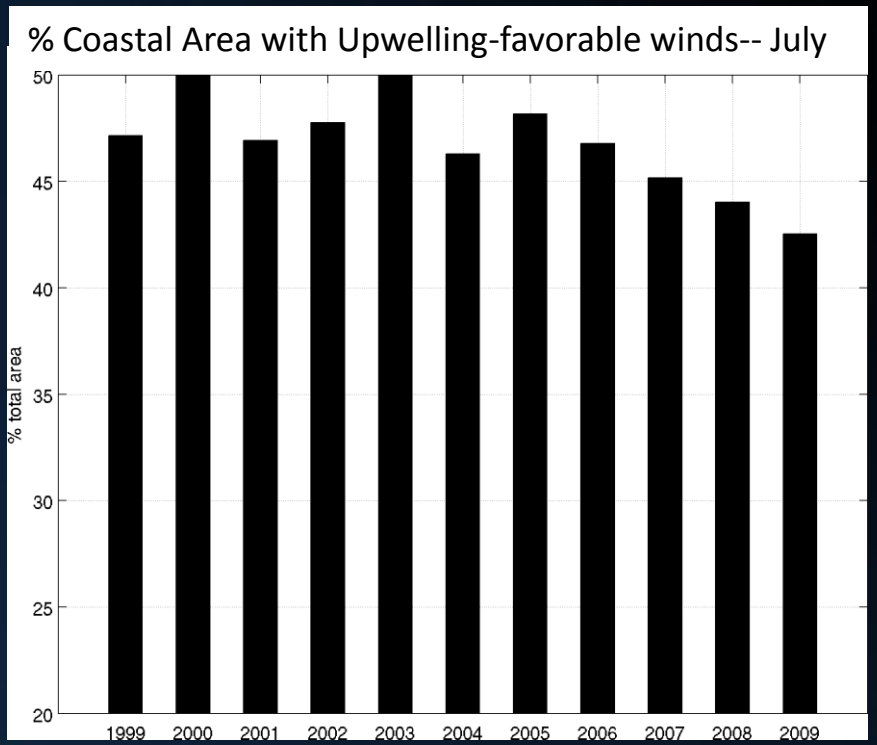


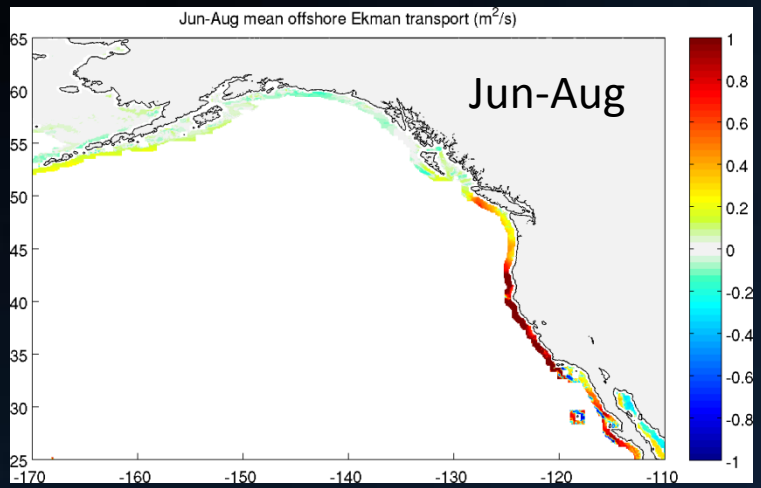


Interannual Variability: Area of upwelling-favorable winds









Summary

- A new method is developed to improve the applicability of wind-derived coastal upwelling indices in regions of complex coastline geometry.
  - Wind direction most related to near-bottom cross-shelf velocity
  - Correlation between local winds and upwelling/downwelling

- Satellite wind products (e.g., CCMP) are used to produce a > decade-long database of daily upwelling indices for the world's coastal regions, including poorly sampled or remote regions.

- Analysis of the database reveals spatio-temporal variability of coastal upwelling at many scales.

- Following assessment with historic in situ observations, the modified upwelling index database will be made available via web-based analysis tools.