Oceanic mesoscale eddies as revealed by Lagrangian coherent structures

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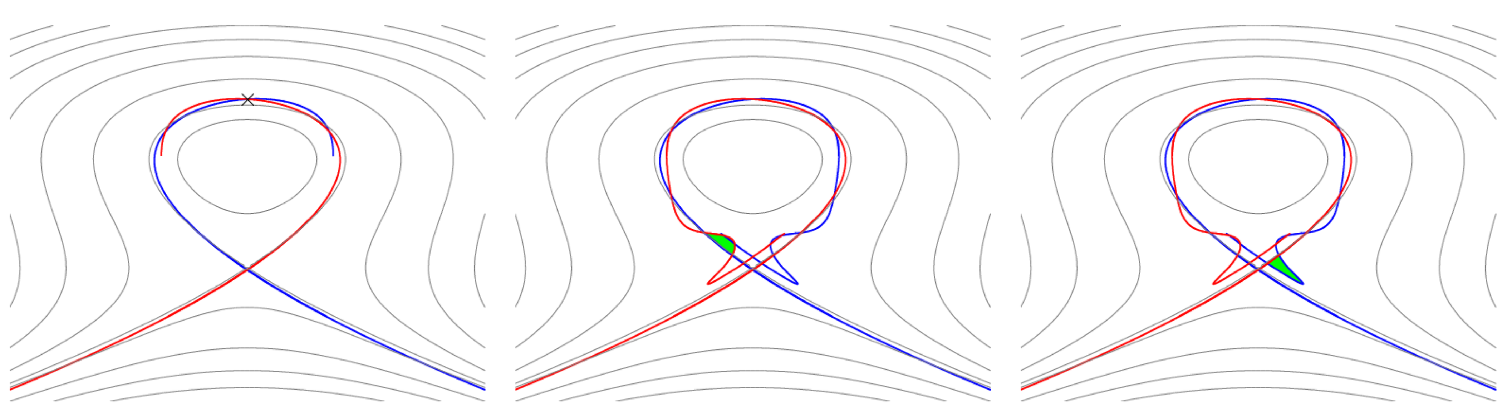
Motivation, outline and data

- Common Eulerian picture is that transport by mesoscale oceanic eddies is effected largely by the trapping and subsequent translation of water slugs inside eddies that can be defined as the regions enclosed by sea height (streamfunction) contours.
- Recognizing Lagrangian nature of transport notion and using dynamical systems tools, we:
  - ▷ demonstrate feasibility of revealing *Lagrangian coherent structures* (LCSs) to unambiguously identify and track eddies;
  - ▷ provide evidence that above picture is generally not valid;
  - ▷ discuss viability of using LCSs to produce quantitative transport estimates.
- Employed in analysis are coarse-grained altimetry-derived surface velocities and satellite-tracked drogue drifter trajectories.

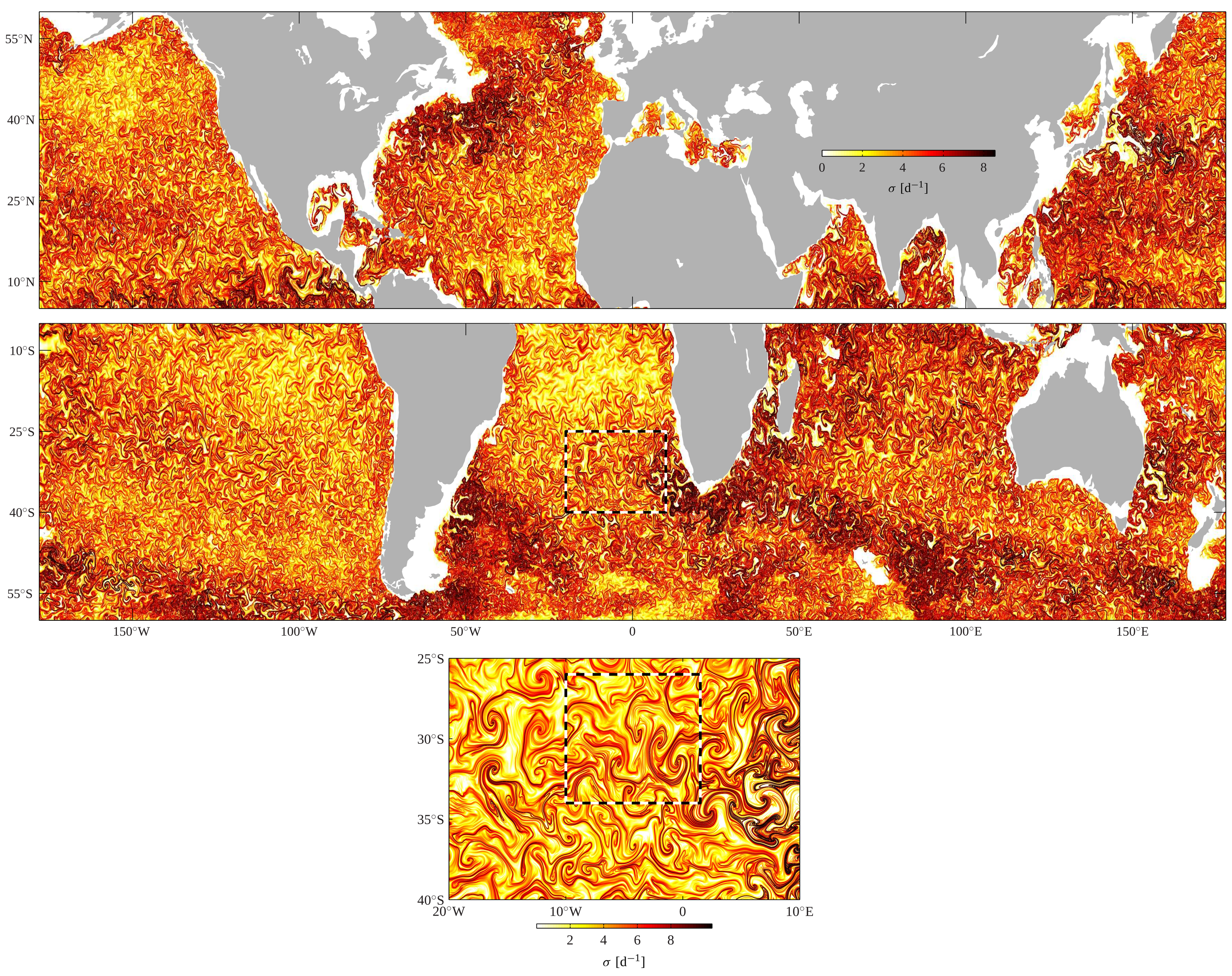
LCSs: definition, implications, and identification

- Distinguished material curves in unsteady flows such that passive particles straddling them either repel or attract at a maximum rate in forward time.
- Delineate boundary between fluid domains with distinct advection properties
  - ▷ allow objective (frame-independent) eddy boundary definition.
- Attracting and repelling LCSs transversely intersect many times defining "lobes" that retain fluid over time
  - ▷ deformation over time controls eddy–ambient fluid exchange.
- Can be identified as ridges in *finite-time Lyapunov exponent* fields.

eddy boundary **eddy–ambient fluid exchange**

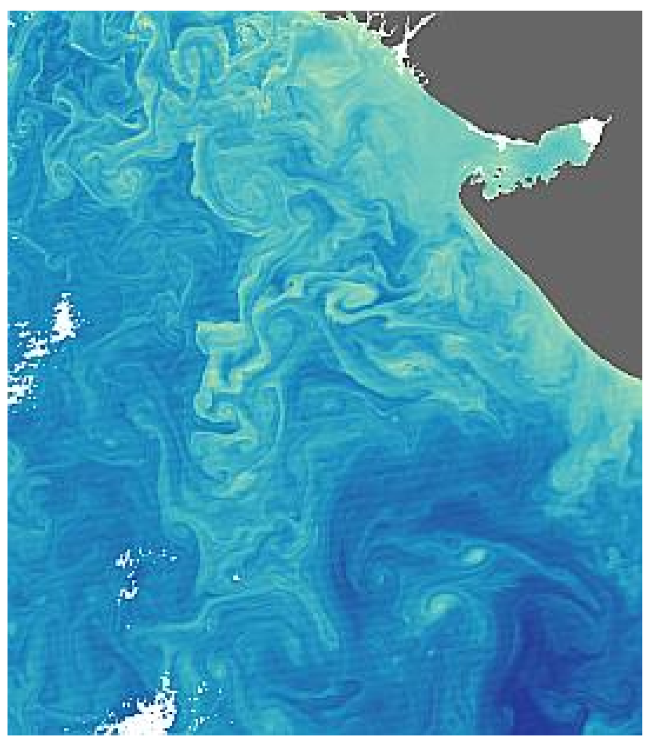


Typical global backward-time FTLE field snapshot



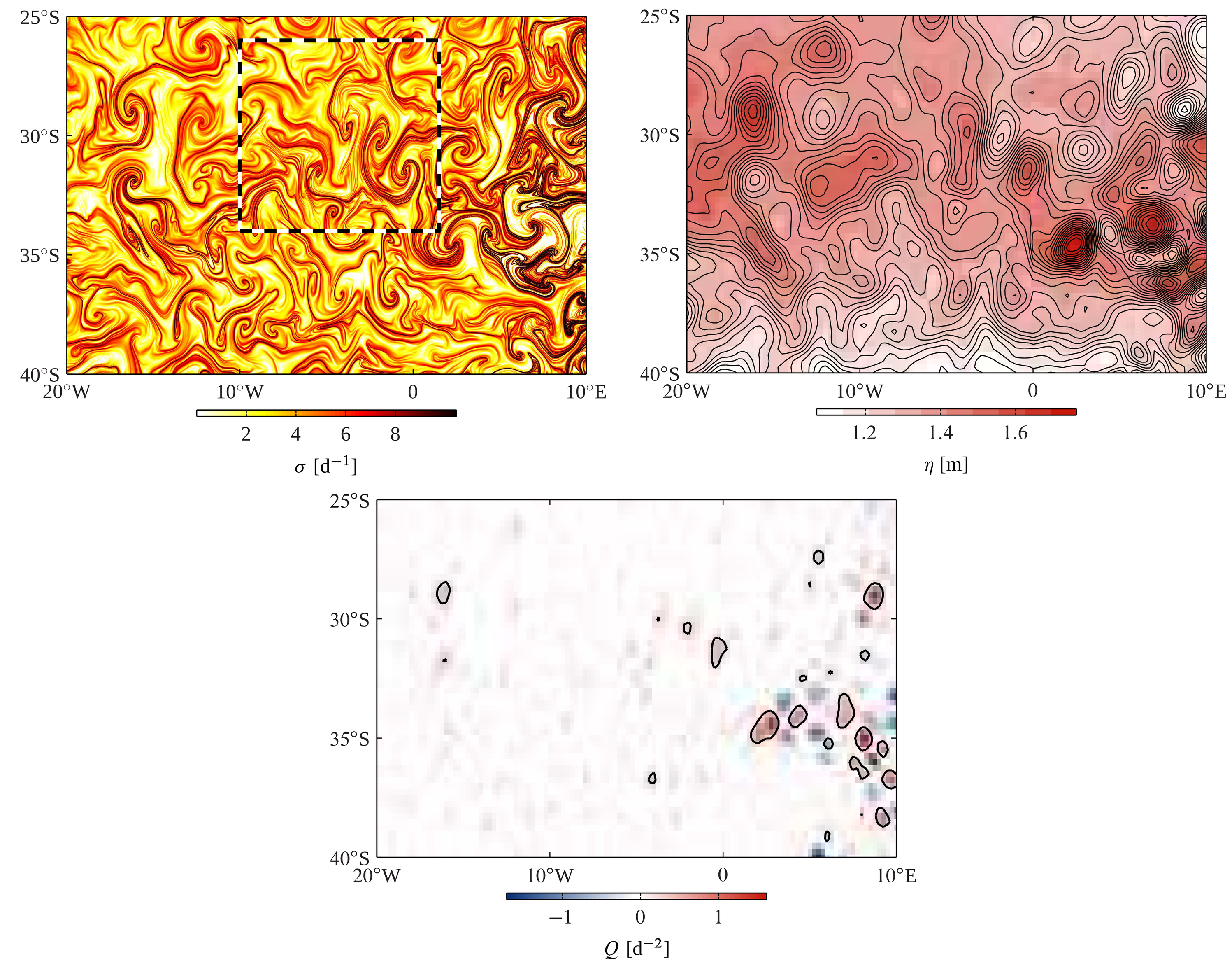
Close inspection reveals with unprecedented detail a very rich variety of (attracting) LCSs. These include spiral-like LCSs or distorted monopolar (cyclonic or anticyclonic) eddies, and mushroom-like LCSs or distorted dipolar (cyclonic and anticyclonic) eddies.

Chlorophyll concentration from MODIS-Aqua satellite

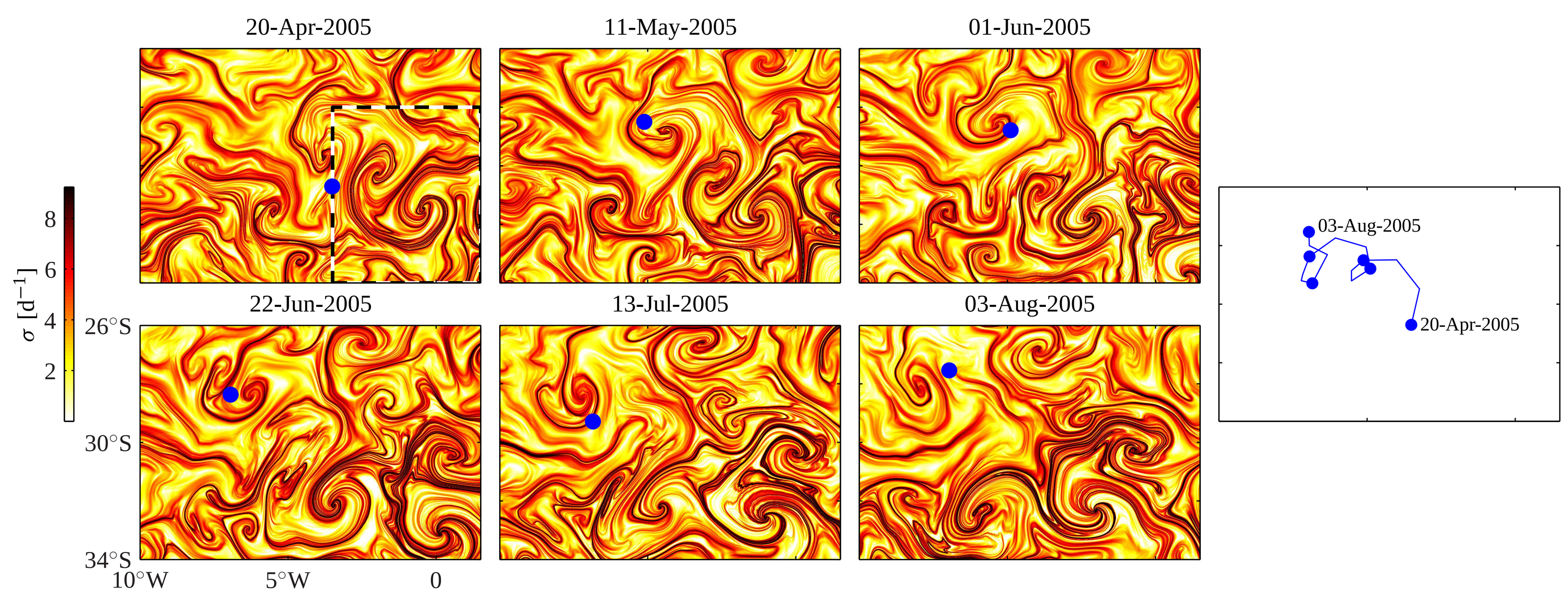


Note presence of qualitatively similar features as in above FTLE plot.

Attracting LCSs, η and Q

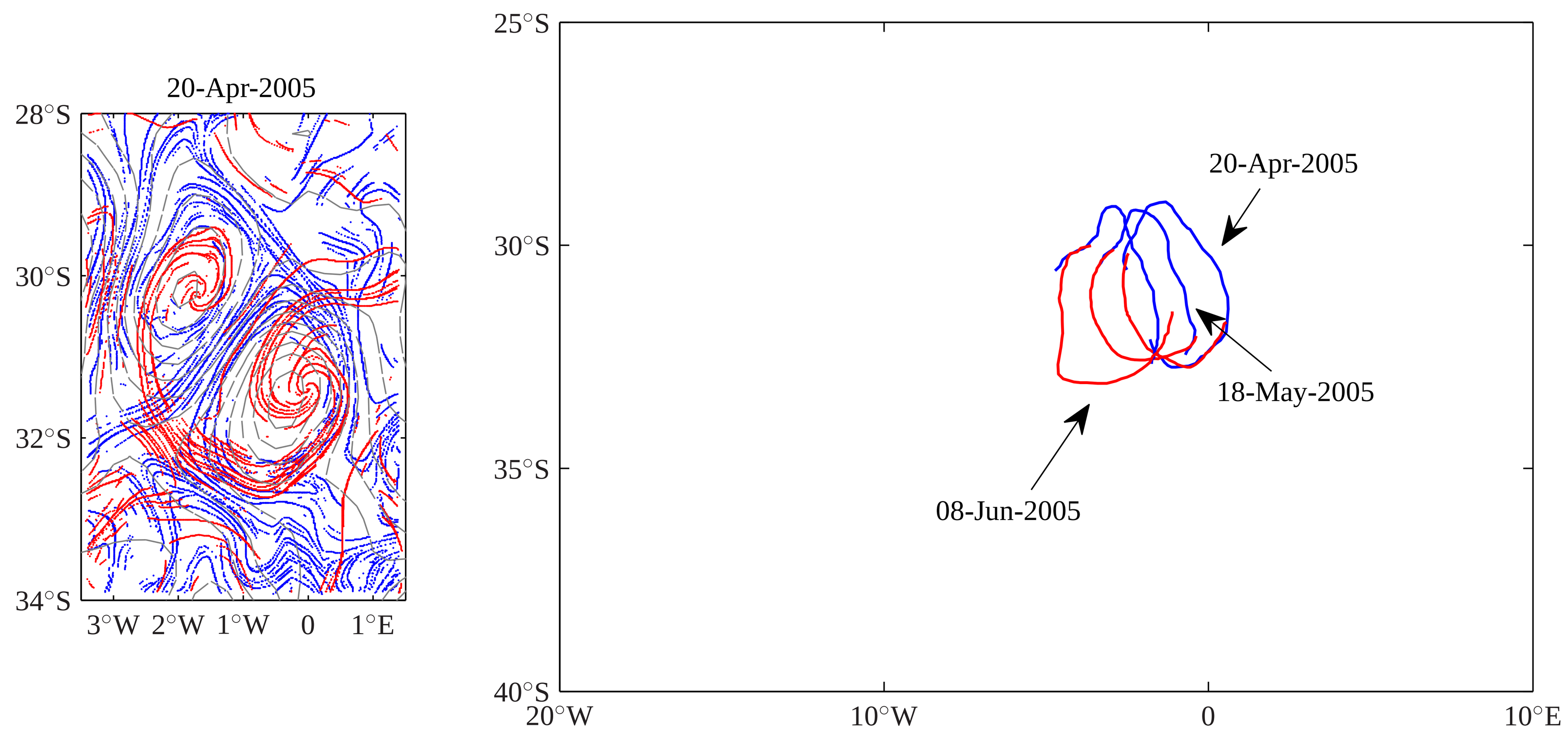


Comparison with observed drifter trajectory



- The drifter closely follows the pathway indicated by the LCS (approaches but does not cross the LCS as it continually deforms).
- Provides strong support to our LCS calculation.
- Given coarseness of velocity data, also suggests nonlocal dynamics.

Tracking the evolution of a dipolar eddy



- Up to intersection points, attracting and repelling LCSs delineate dipole boundary, which can be tracked over time.
- Highly intricate LCS "tangle" indicates intense exchange with ambient water: common Eulerian picture does not apply.

Conclusions and future directions

- LCSs can be feasibly extracted from altimetry-derived surface currents.
- Common Eulerian picture of transport is generally not valid.
- Correct transport estimation must account for fluid particle motion information carried by LCSs.
- By revealing LCSs we are seeking to estimate:
  - ▷ extent of the eddy–ambient water exchange;
  - ▷ water fraction transported by eddies preserving its characteristics;
  - ▷ distance traveled across world oceans.

  Critical to correctly assess role of eddies in interbasin and regional exchanges.

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Reference

Beron-Vera, F. J., M. J. Olascoaga and G. J. Goni (2008). Oceanic mesoscale vortices as revealed by Lagrangian coherent structures. *Geophys. Res. Lett.* 35, L12603.