Spatially and temporally coherent transport structures in the Central California offshore Wind Energy Area

Leah Hoogstra*, Emmett Ehrnstein**, Ryan K. Walter**, Paul Choboter*

*Mathematics Department, California Polytechnic State University, San Luis Obispo, CA, USA
**Physics Department, California Polytechnic State University, San Luis Obispo, CA, USA

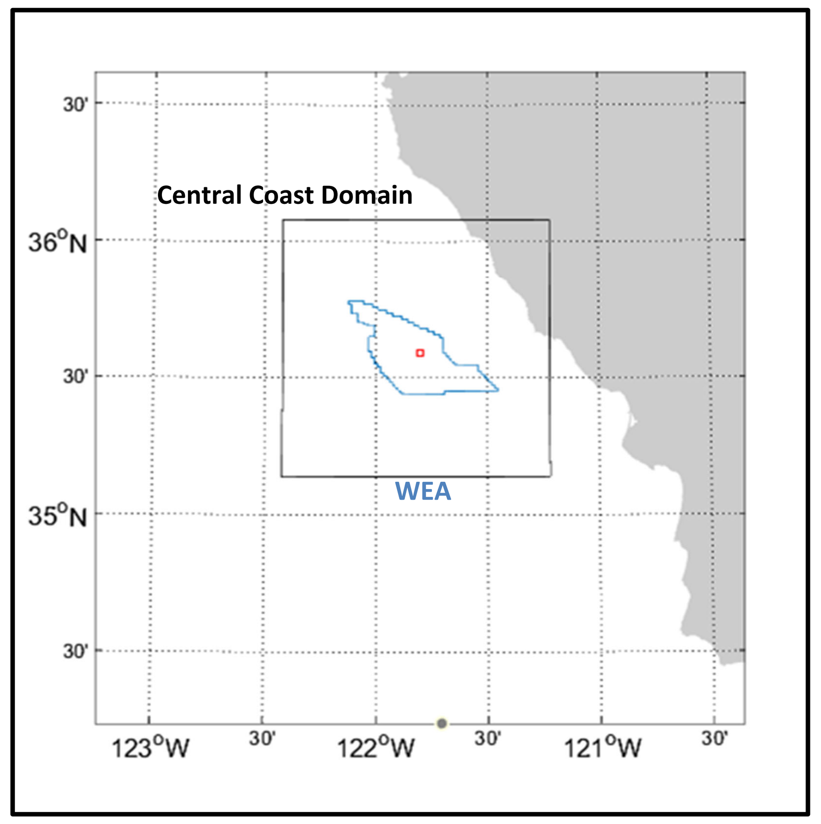
1.Background

- In an effort to combat the growing climate crisis, the Bureau of Ocean Energy Management held the first ever lease sale off the California coast in the Morro Bay Wind Energy Area (WEA) for offshore wind energy development.
- Thus, there is a need to understand complex spatiotemporal patterns in the ocean circulation and transport processes in this region, with implications for the local ecosystem and pollutant spill response.

- We use surface current vectors obtained using high frequency radar (HFR) stations along the California coast hourly with 6km resolution to characterize the currents in this region.
- Moreover, we analyze the flow using Lagrangian coherent structures (LCSs), a recently developed technique to identify material patterns in transport phenomena.
- We detect LCSs in the WEA to highlight fluid transport systems. LCS analysis could be used to predict potential environmental impacts of the wind farm (e.g. oil spills, animal migration).

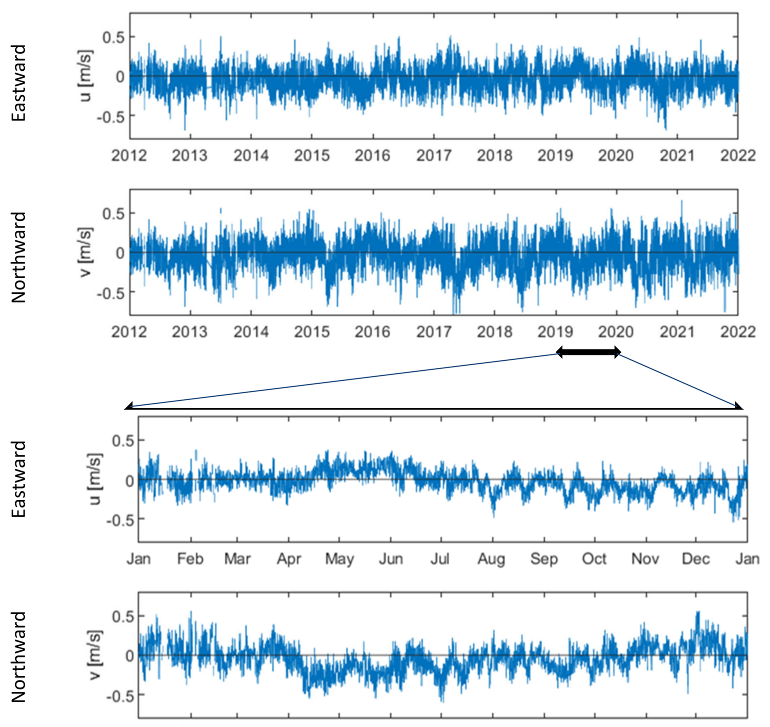
2. High Frequency Radar (HFR) Data Analysis

A.Central Coast Domain and Wind Energy Area (WEA)

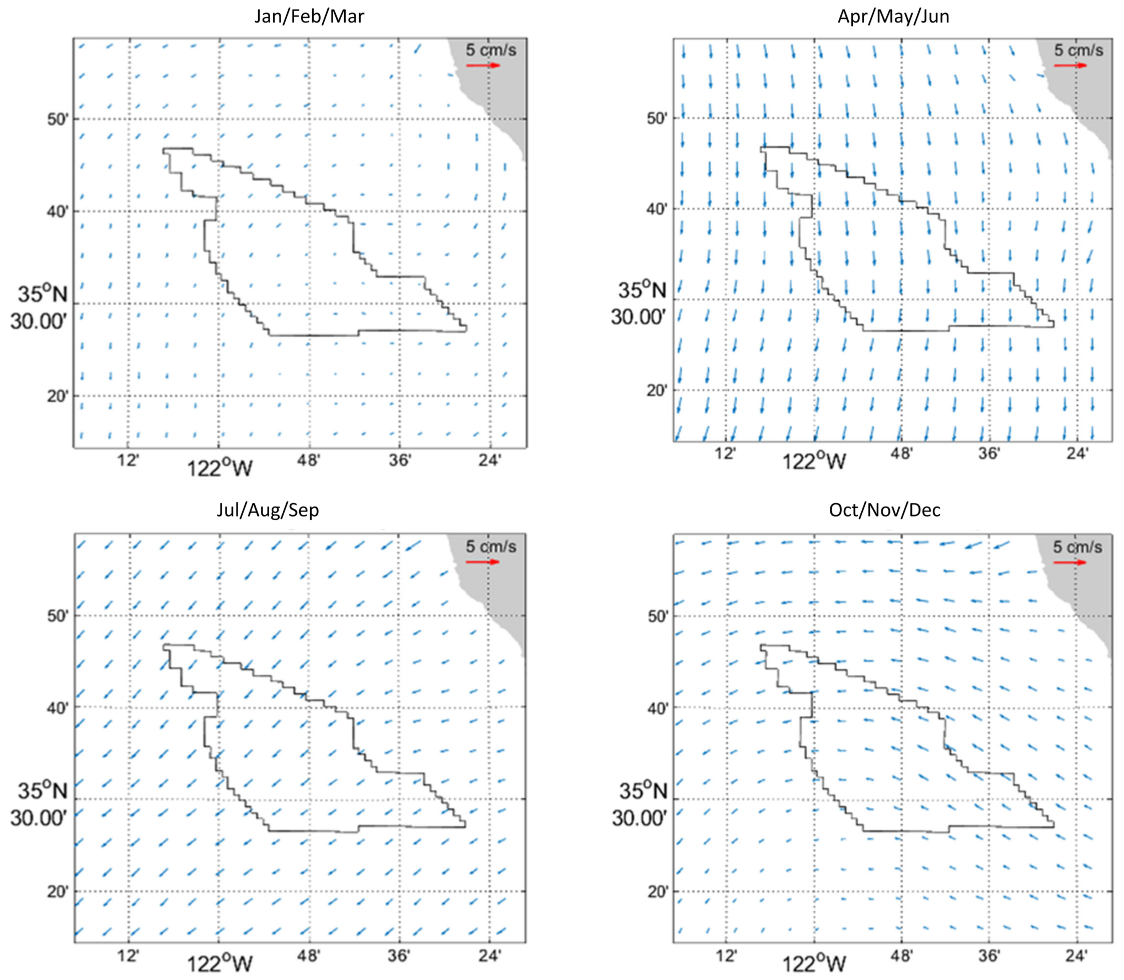


B. Single Point Temporal Variability

Eastward (u) and northward (v) velocity components at one point (red dot on left map) from 2012 to 2022 (top) and a single year in 2019 (bottom)



C. Seasonal Current Averages



3. Lagrangian Coherent Structures

A.Definition

- Lagrangian coherent structures (LCSs) are "the hidden skeletons of fluid flows." [1] They organize transport processes in the ocean.
- LCSs are lines in a fluid flow which have an outsized impact on the fluid particles around them. Fluid flux across an LCS is negligible, so these structures act as transport barriers.
- Repelling and attracting LCSs are analogous to the stable and unstable manifolds (respectively) of a classic saddle point (pictured below). As a fluid parcel approaches the unstable manifold, it is stretched out along it and does not cross it. Similarly, the fluid parcel is repelled by the stable manifold.

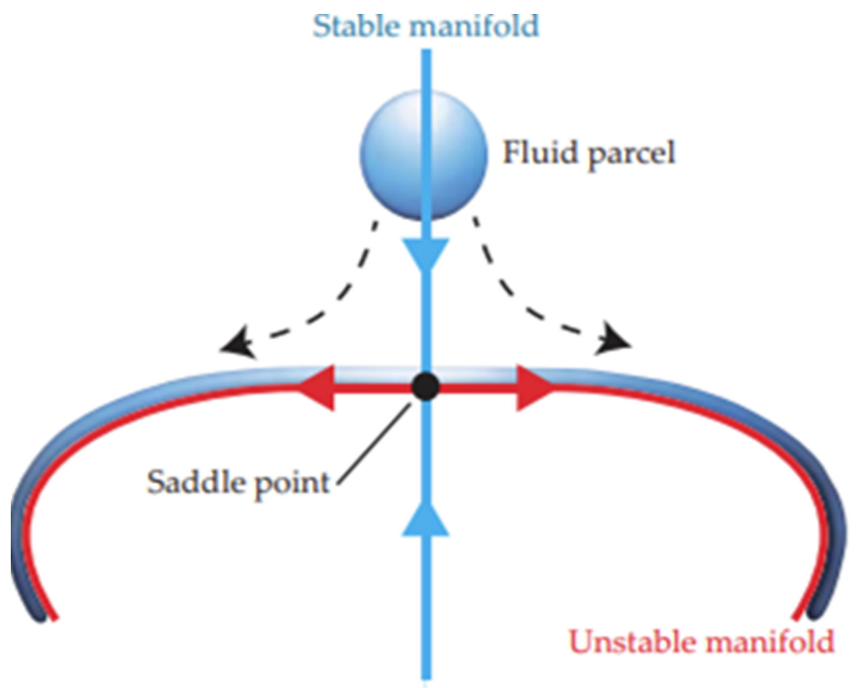


Image: Peacock and Haller 2013 [1]

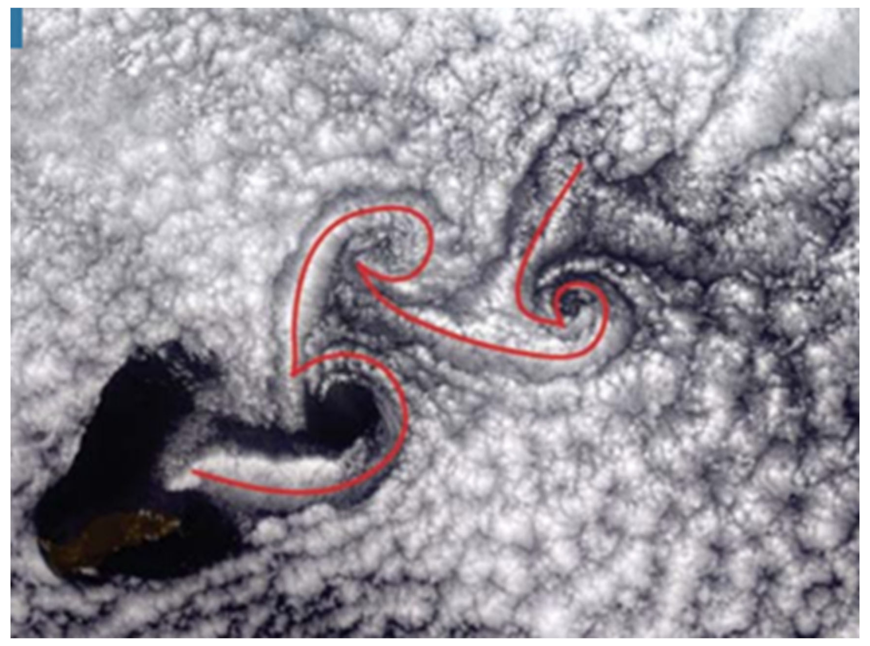


Image: Peacock and Haller 2013 [1]

B. Calculation

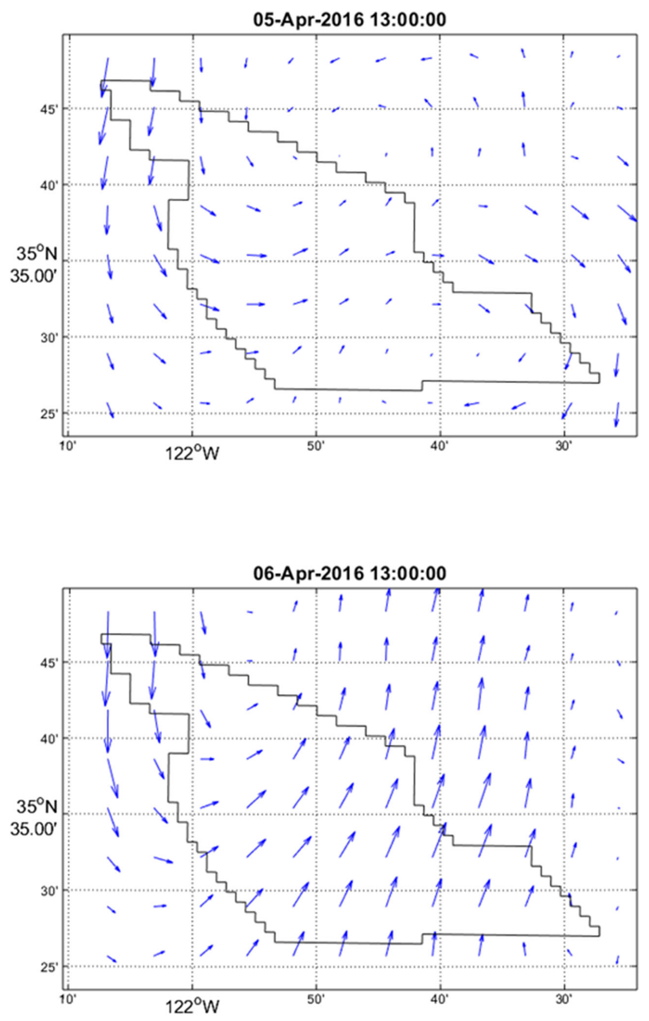
- We first integrate the flow map $F_{t_0}^t(x_0)$ from initial time t_0 to time t for each initial position $\boldsymbol{x_0} = [x_0, y_0]$ across the WEA using the HFR velocity data.
- We then calculate the eigenvalues $\lambda_1 < \lambda_2$ and eigenvectors ξ_1, ξ_2 of the right Cauchy-Green strain tensor for each point in the grid $\boldsymbol{x_0}$

$$C_{t_0}^t(x_0) = \left[\nabla F_{t_0}^t(x_0)\right]^T \nabla F_{t_0}^t(x_0)$$

- The orbits of the eigenvector fields satisfy a variational problem involving the averaged shear functional using parameterized material lines *r(s)*. LCSs are trajectories of the differential equations

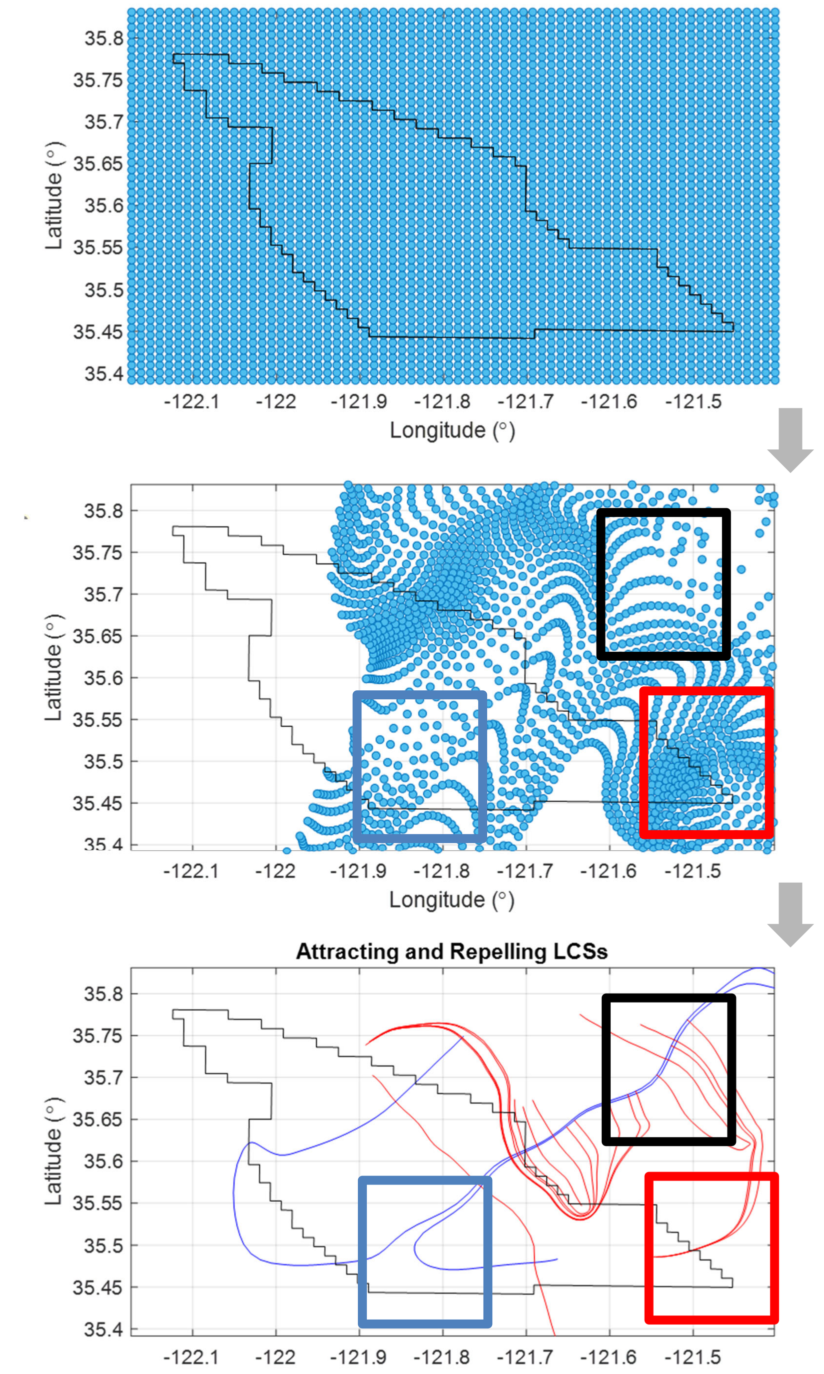
$r' = \xi_1(r)$ for repelling LCSs
$r' = \xi_2(r)$ for attracting LCSs

C. Example Velocity Field Snapshot in WEA



Velocity field in the WEA 24 hours apart. Top chart is the start time for LCS calculations shown right.

D. Computed LCSs in WEA



Grid of particles over the WEA at the initial start time

Final locations of particles after 48 hours highlighting movement by the changing velocity field

LCSs calculated over the full 48 hours using the particle trajectories

Attracting LCSs
Repelling LCSs
Saddle Point

4. Future Work

- Quantify interannual variability in surface current patterns and drivers of this variability
- Detect mesoscale ocean eddies using HFR data and by implementing elliptic LCSs
- Quantify attracting and repelling LCSs in the WEA over various time scales using different integration times and across different seasons and events
- Correlate LCSs with spatial patterns in sea surface temperature and chlorophyll using satellite products
- Link LCS results with ecosystem vulnerability in the WEA such as marine mammal patterns and potential pollutant spill response

References

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