Formation-based evaluation of mesoscale eddy impacts on primary production in the North Pacific

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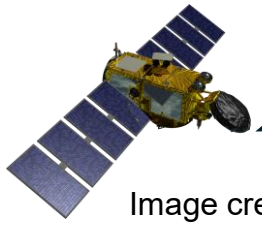
What Are Mesoscale Eddies?

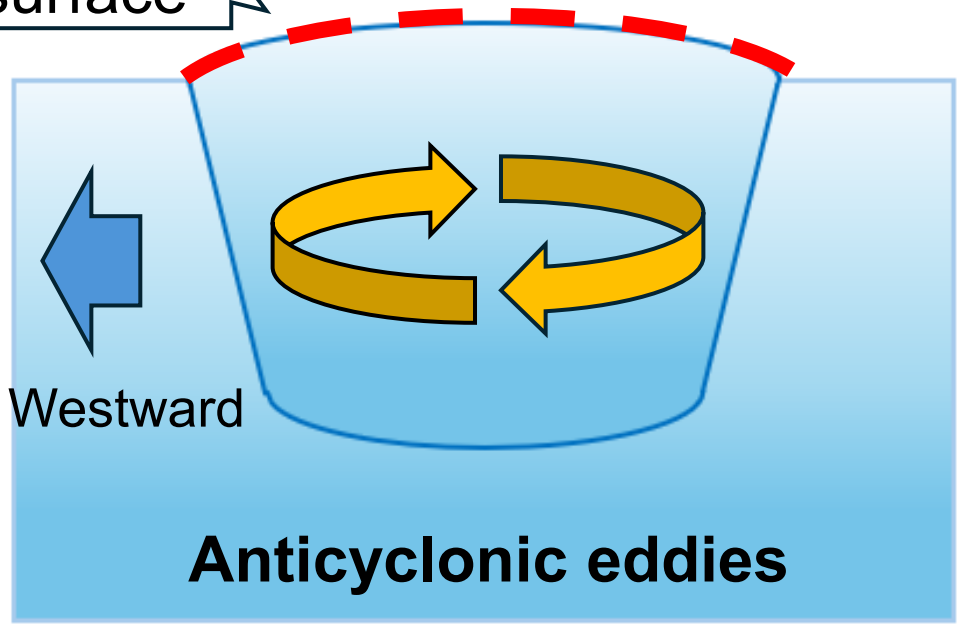


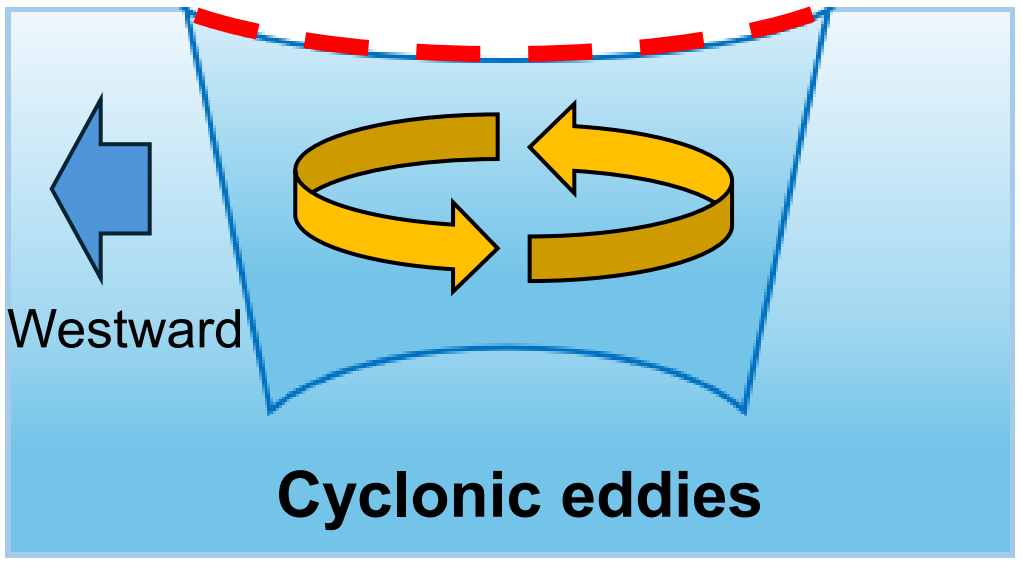
Tracking eddies with satellites

Image credit: NASA

Elevated sea surface

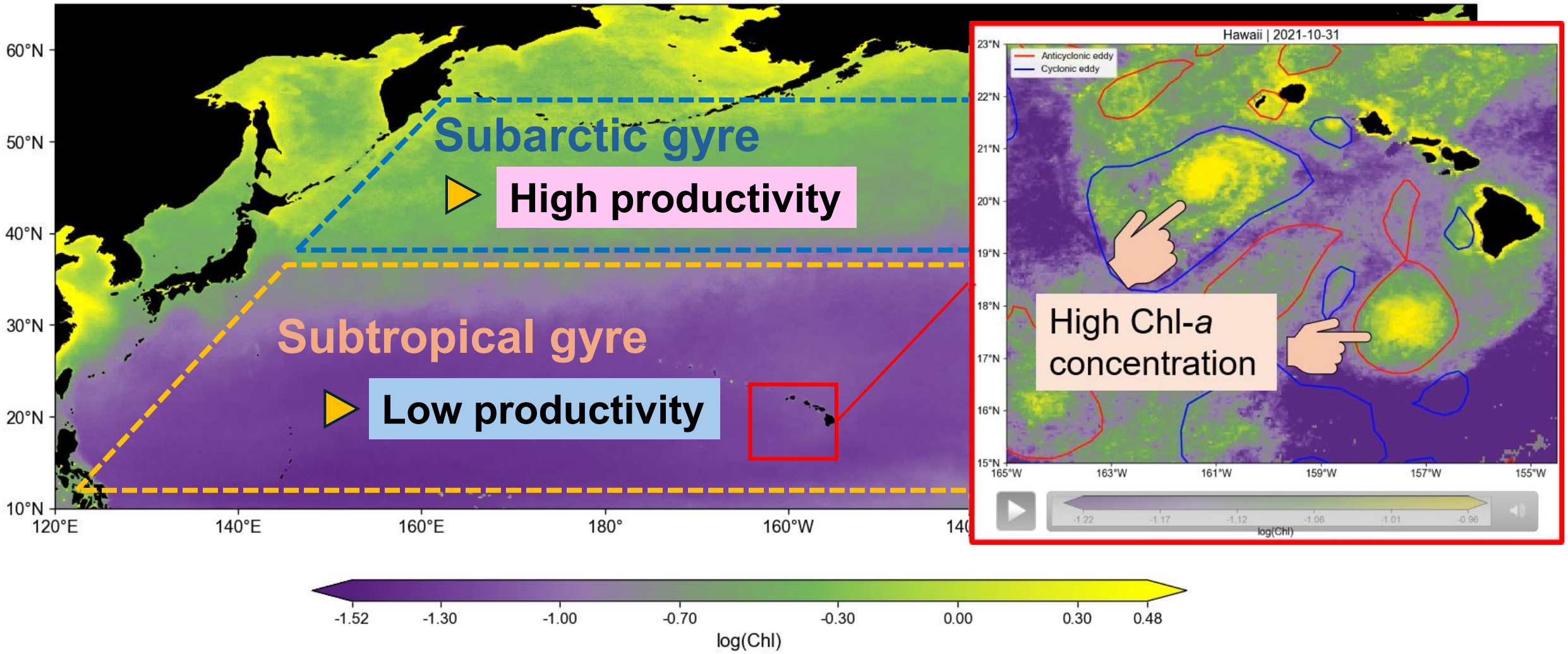
Depressed sea surface





✓ Horizontal Scale	10–100km
✓ Lifetime	Weeks–years
✓ Propagation	**Westward** (~ 1000s **km**) (Chelton et al. 2011)

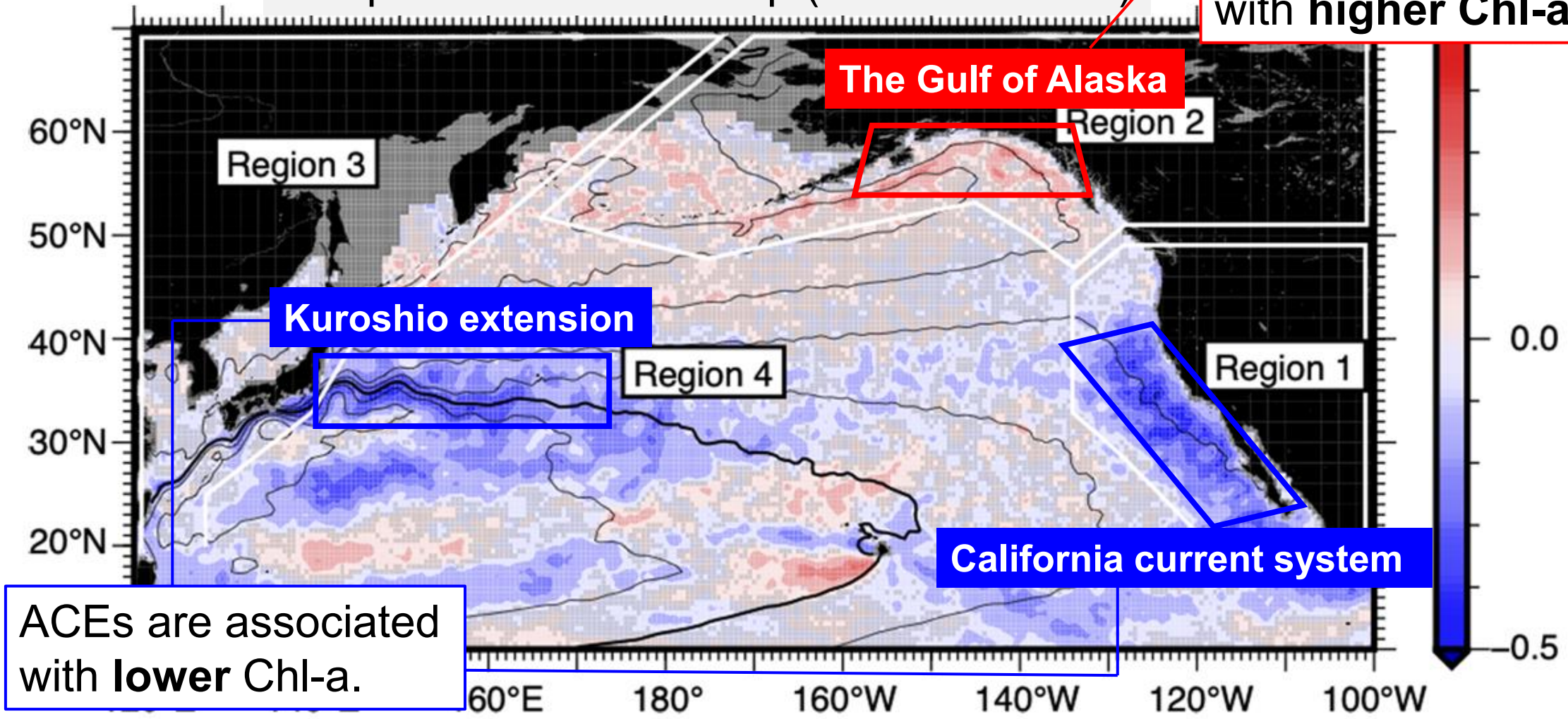
Annual mean Chlorophyll-a concentration (2021)



☛ Mesoscale eddies can strongly affect primary production

Temporal correlation map (SSHA vs Chl-a)

ACEs are associated with **higher Chl-a.**



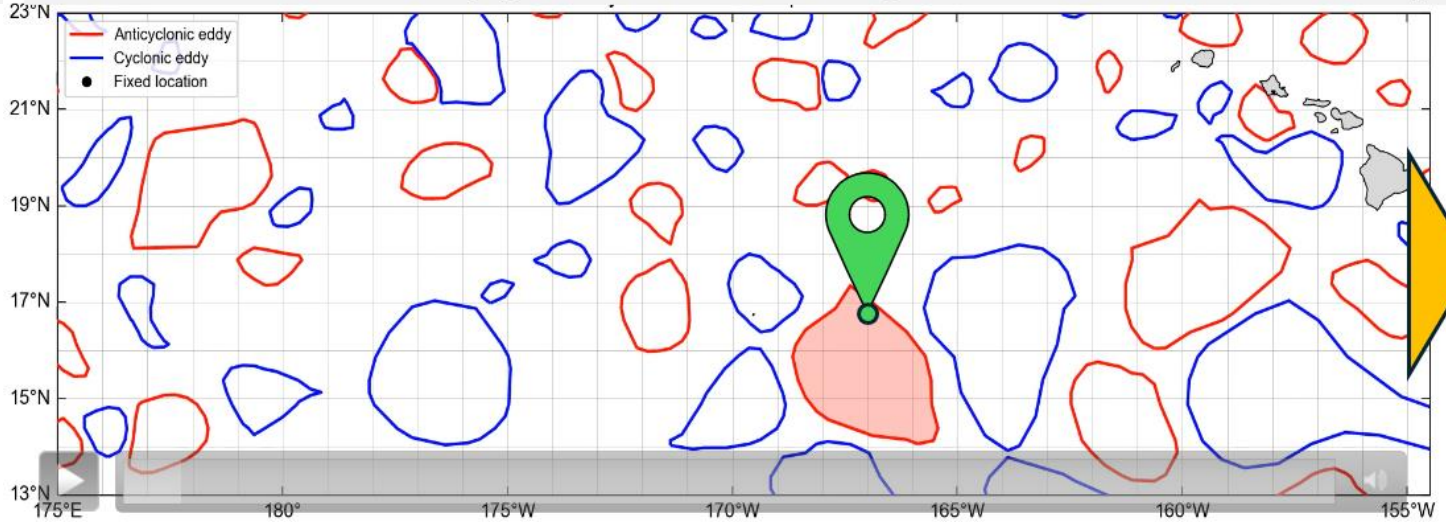
ACEs are associated with **lower** Chl-a.

(Kouketsu et al. 2015; Ueno et al. 2023)

Correlation measures covariability (≠ magnitude of Chl-a change)

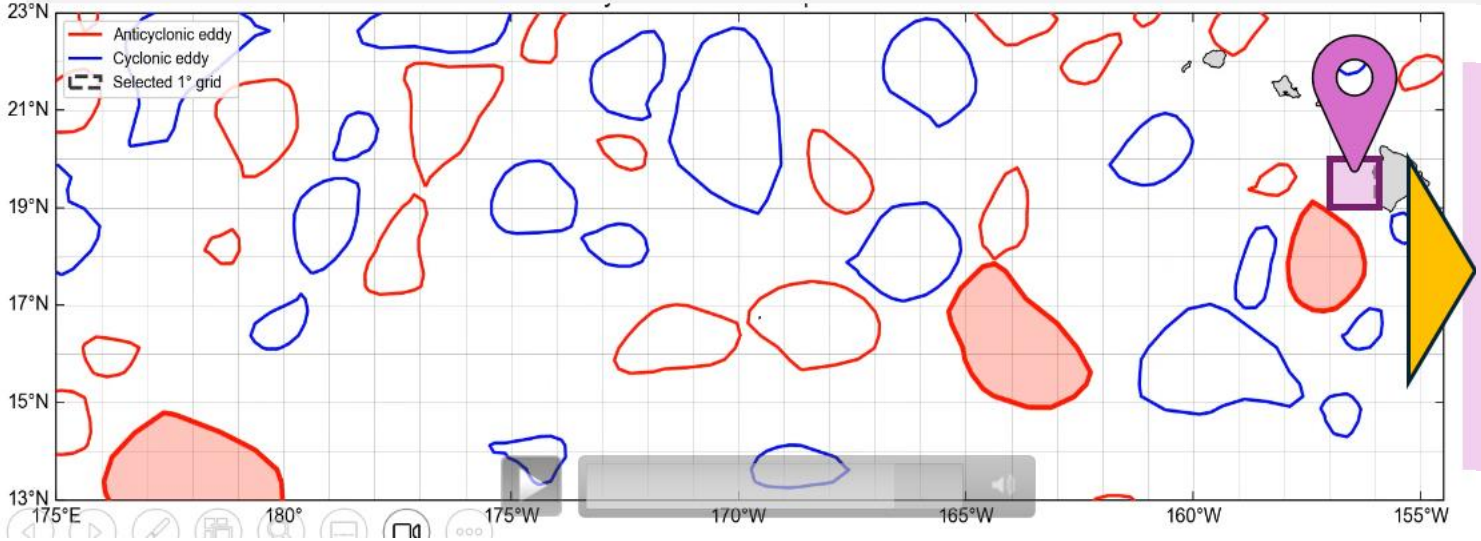
Two Complementary Approaches

Conventional approach ▶ **Eddy-location-based perspective**



- Focuses on fixed locations.
- Evaluates the impacts of eddies passing through each location.
- <u>Where do eddies affect primary production?</u>

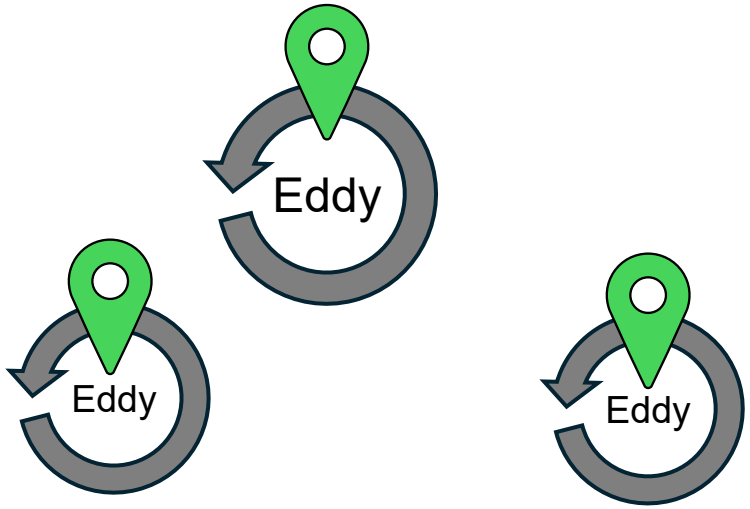
Our new approach ▶ **Eddy-formation-based perspective**

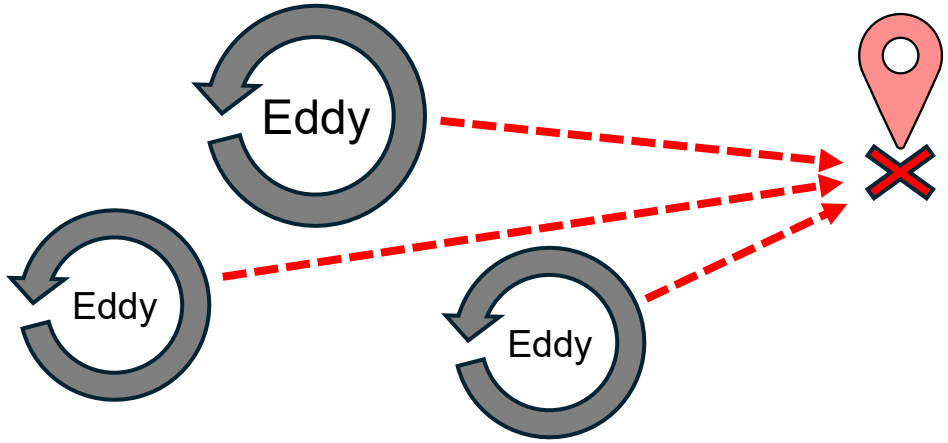


- Tracks eddies from their formation regions.
- Assigns impacts along their paths to their formation sites.
- <u>Where do influential eddies form?</u>

We use an **eddy-formation-based approach** to identify the eddy formation regions with large impacts on primary production.

Perspective	Eddy-**location**-based	Eddy-**formation**-based
Focus	Current location of eddies	Eddy-formation sites
Key Question	Where do eddies strongly affect primary production?	Where do eddies with large impacts on primary production form?





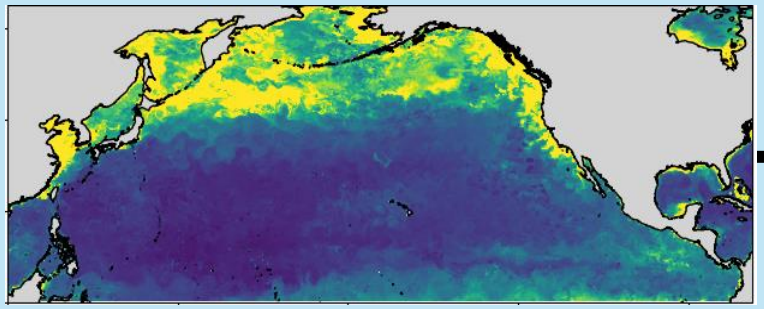
- Period: **2003/1/1−2020/12/31**
- Region: **North Pacific** (10˚−65˚N, 120˚E−85˚W)

➢ **Eddy tracking**: META3.2 DT (AVISO+)
- Eddies detected from spatially filtered absolute dynamic topography (ADT).
- Daily trajectories and eddy properties: polarity, location, radius, and amplitude.

➢ **Net primary production (NPP)**: Ocean Productivity (Oregon State University)
- **NPP: Net carbon fixation by phytoplankton**
- Based on the Vertically Generalized Production Model (VGPM) (Behrenfeld and Falkowski, 1997)
- 1/12˚ spatial, 8-day temporal resolution

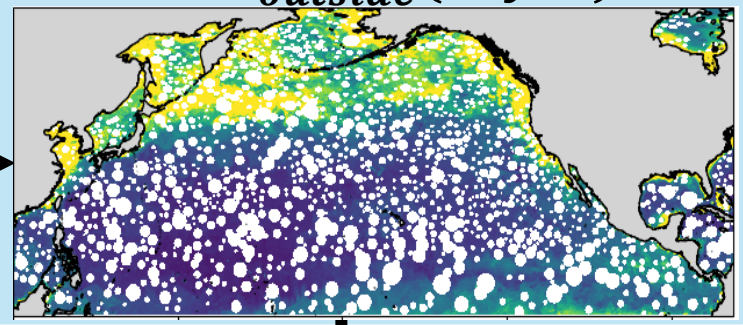
Eddy-associated NPP Anomaly (NPPA)

$NPP\ (x, y, t)$



Remove NPP inside eddies

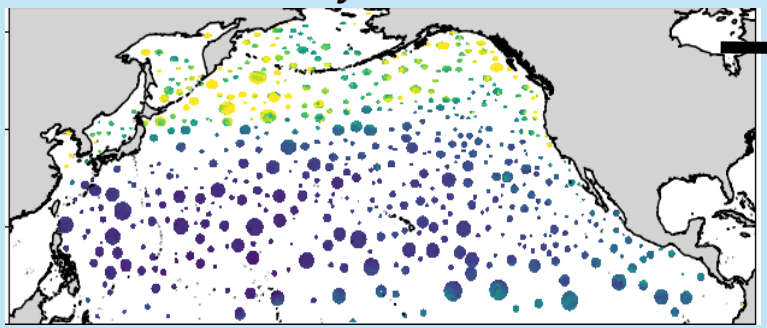
$NPP_{outside}(x, y, t)$



Extract NPP inside eddies

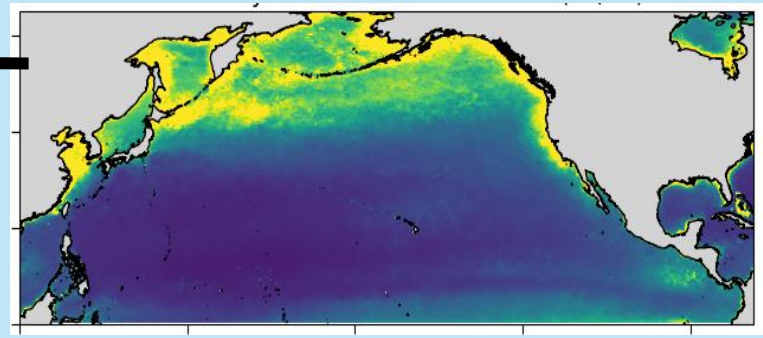
Climatological mean for the same dates(d)

$NPP_{eddy}\ (x, y, t)$

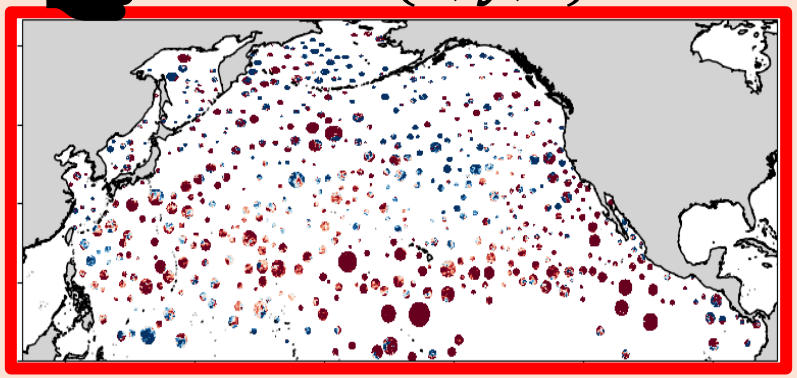


Difference from the climatology

$NPP_{clim}\ (x, y, d)$



$NPPA\ (x, y, t)$



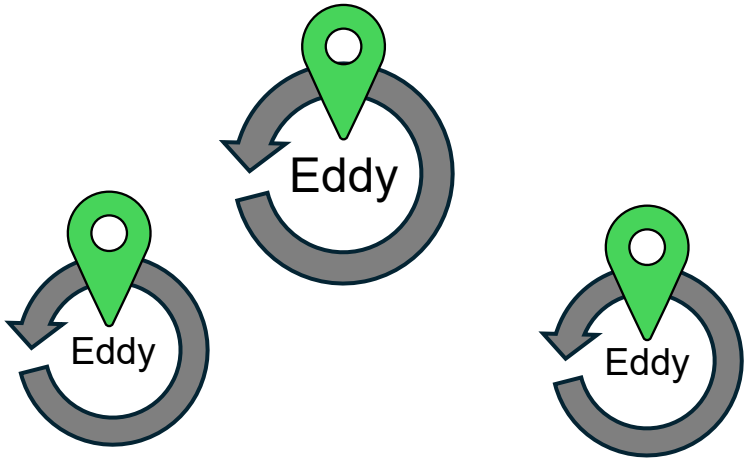
Eddy-associated NPP Anomaly (NPPA)

$$NPPA(x,y,t) = NPP_{eddy}(x,y,t) - NPP_{clim}(x,y,d)$$

Eddy-associated NPPA = NPP inside eddies − Outside-eddy climatology

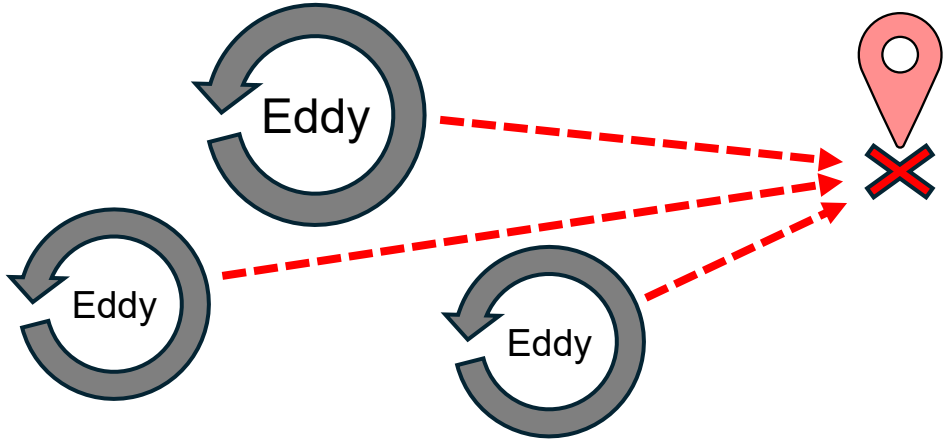
Eddy-location-based

Sum NPPA at each grid cell where eddies are observed

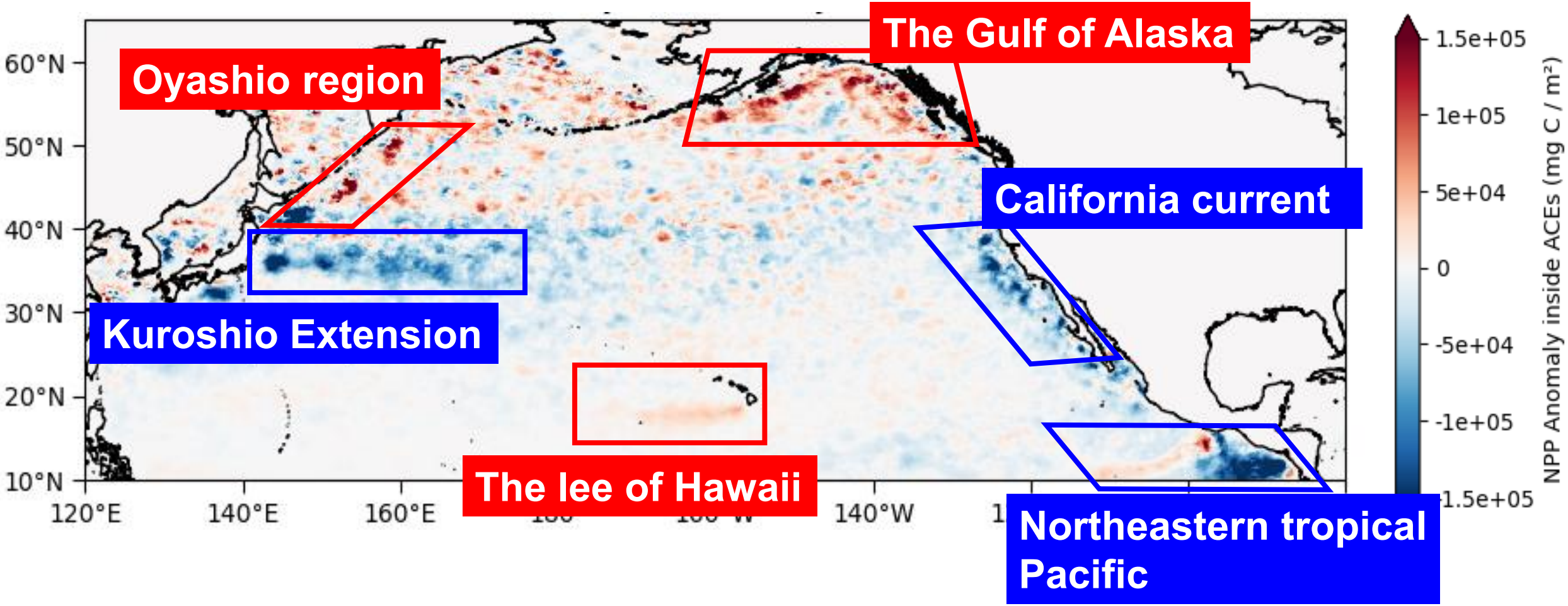


Eddy-formation-based

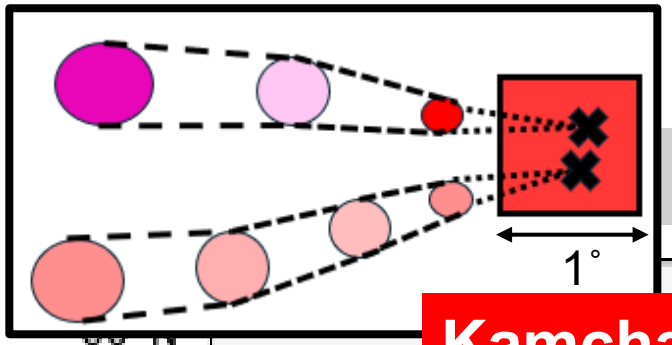
Assign NPPA of each eddy track to its formation site



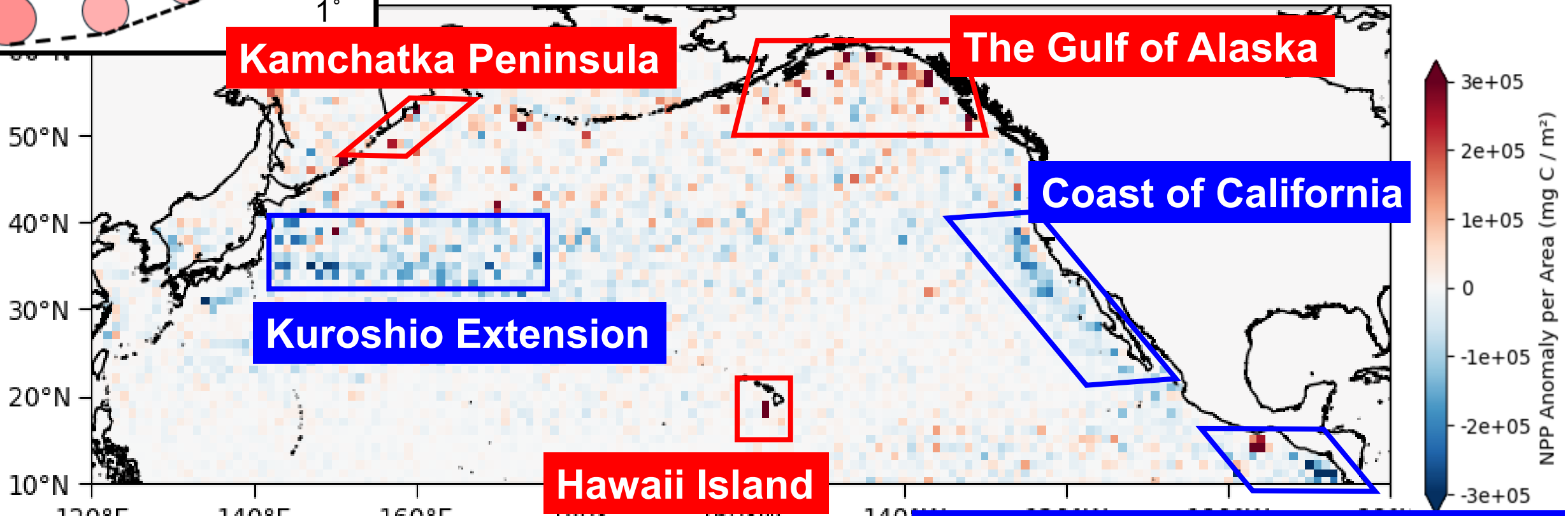
Total eddy-**location**-based impacts (2003-2020, ACEs)



Where do influential eddies form?

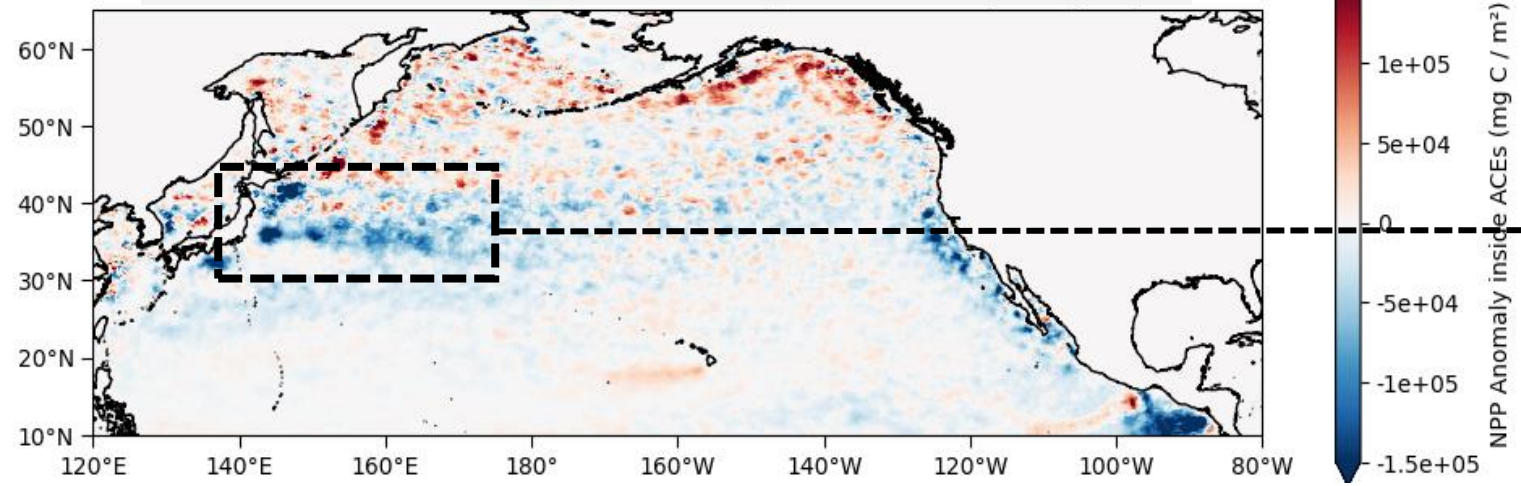


Total eddy-**formation**-based impacts (2003-2020, ACEs)

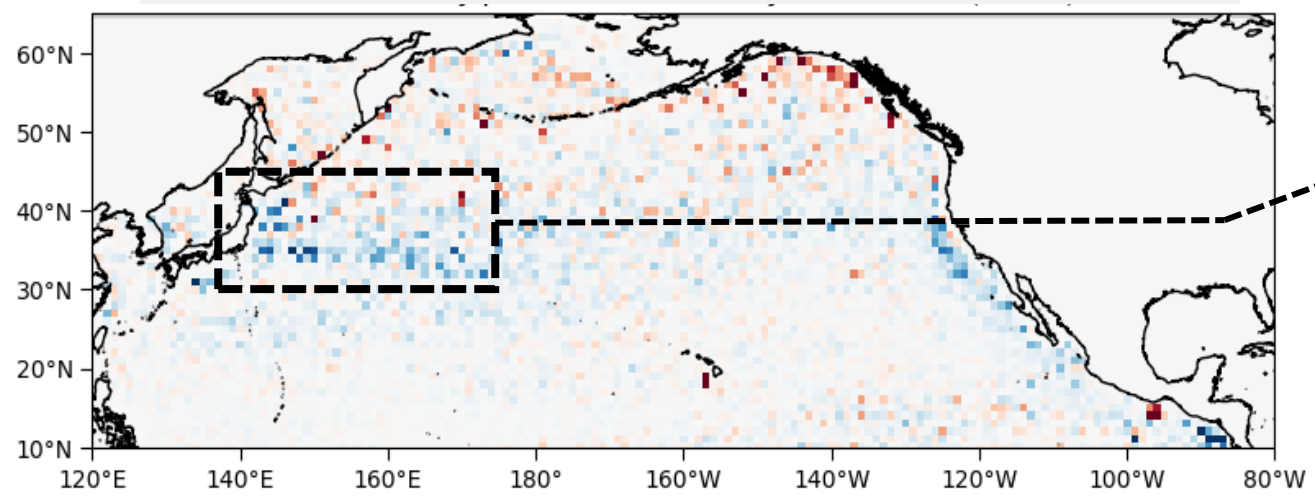


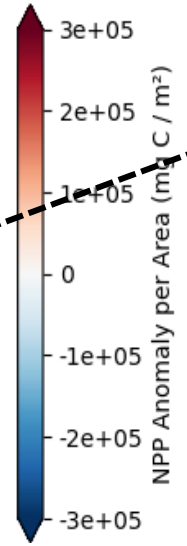
Comparison of Two Approaches (1)

Eddy-location-based impacts (ACEs)

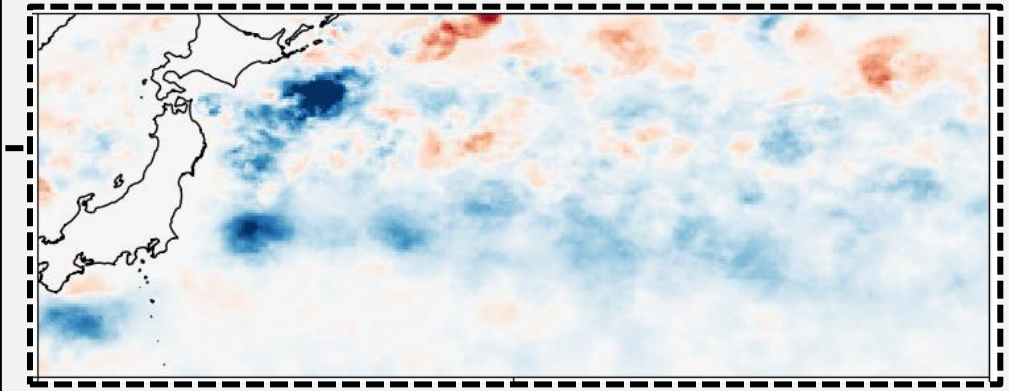


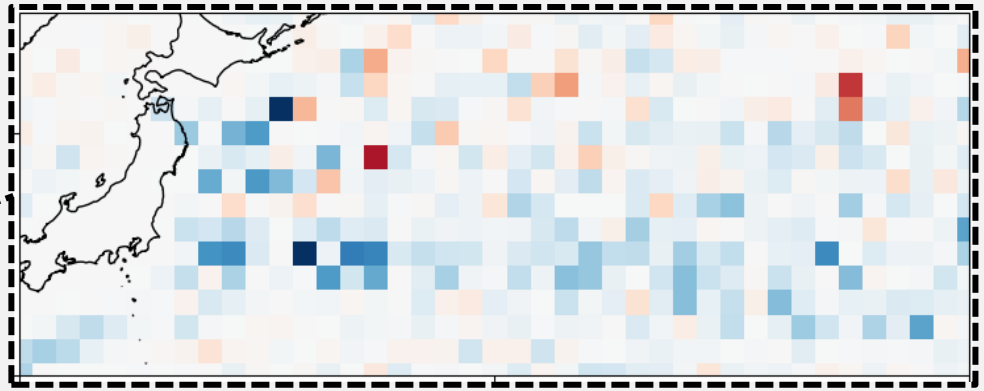
Eddy-formation-based impacts (ACEs)





Kuroshio Extension

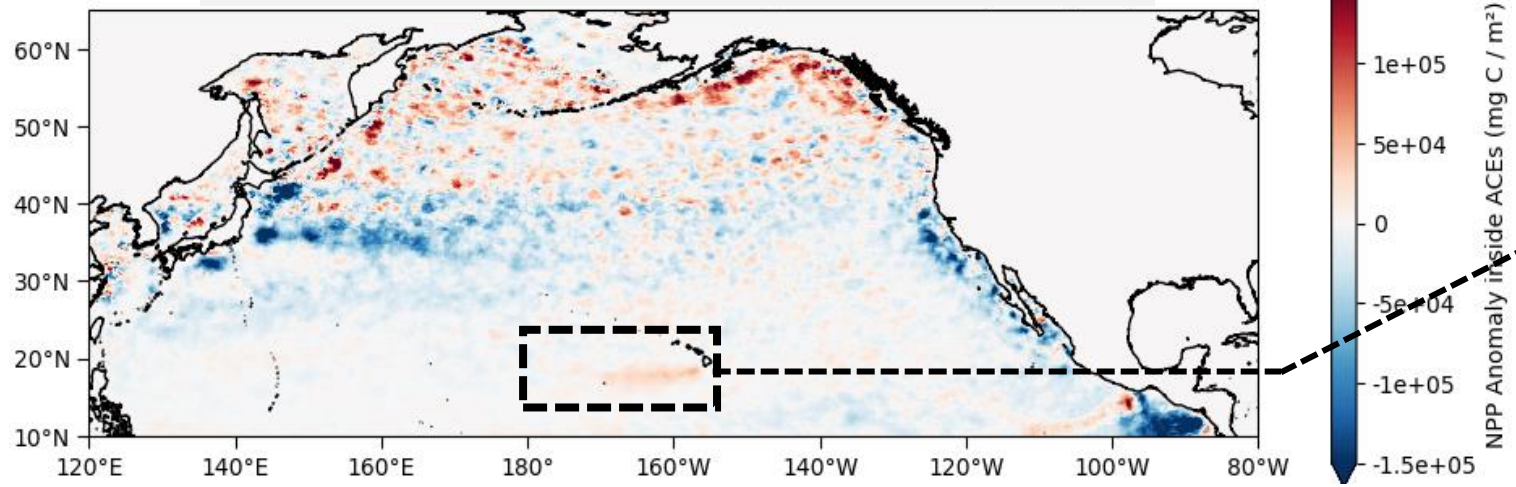




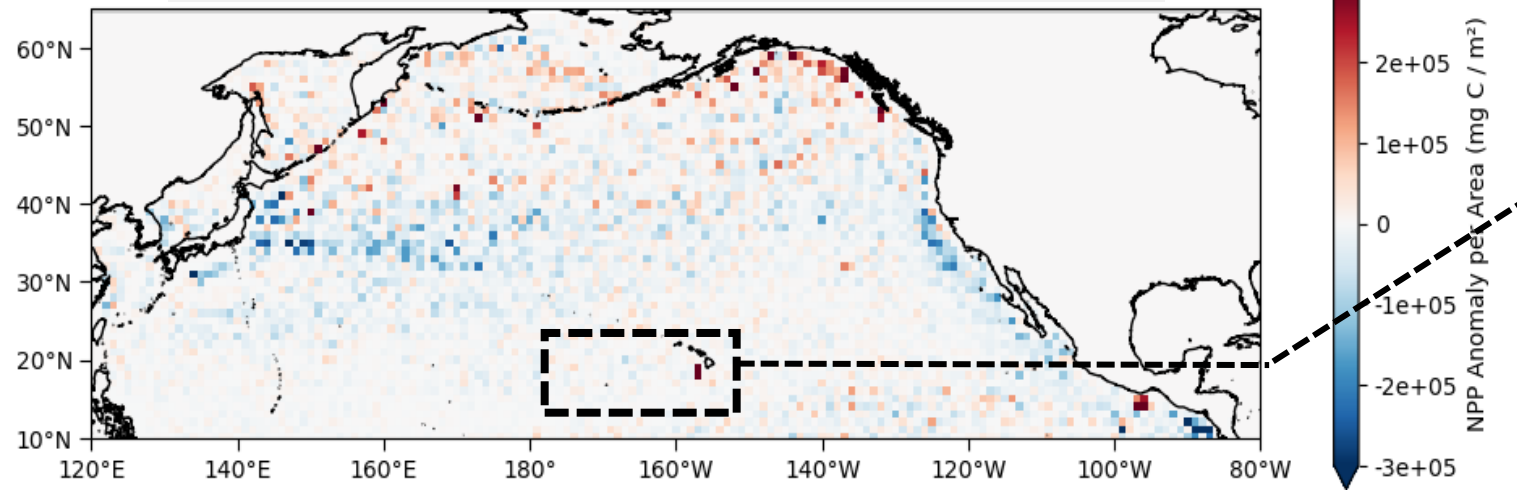
➢ Eddies have large impacts "only" near their formation sites.

Comparison of Two Approaches (2)

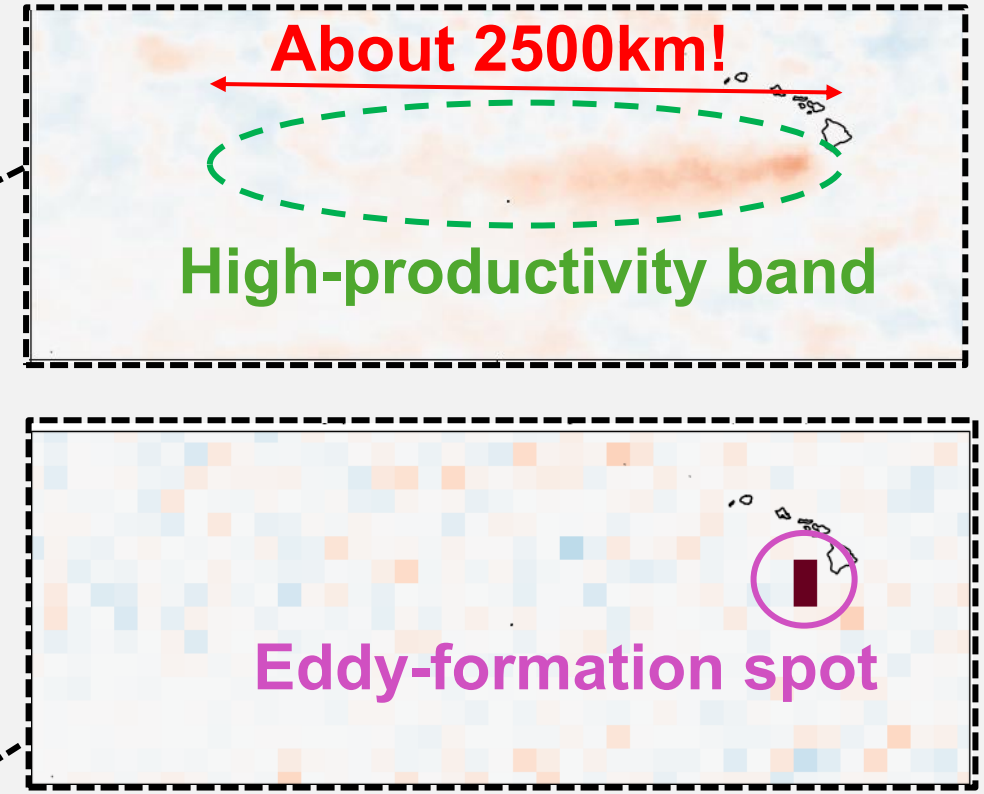
Eddy-location-based impacts (ACEs)



Eddy-formation-based impacts (ACEs)



The lee of Hawaii

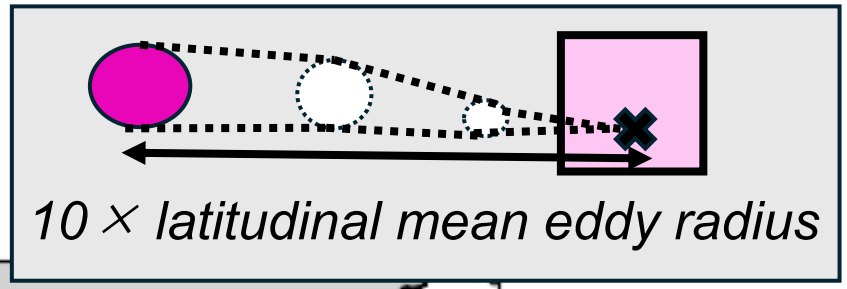


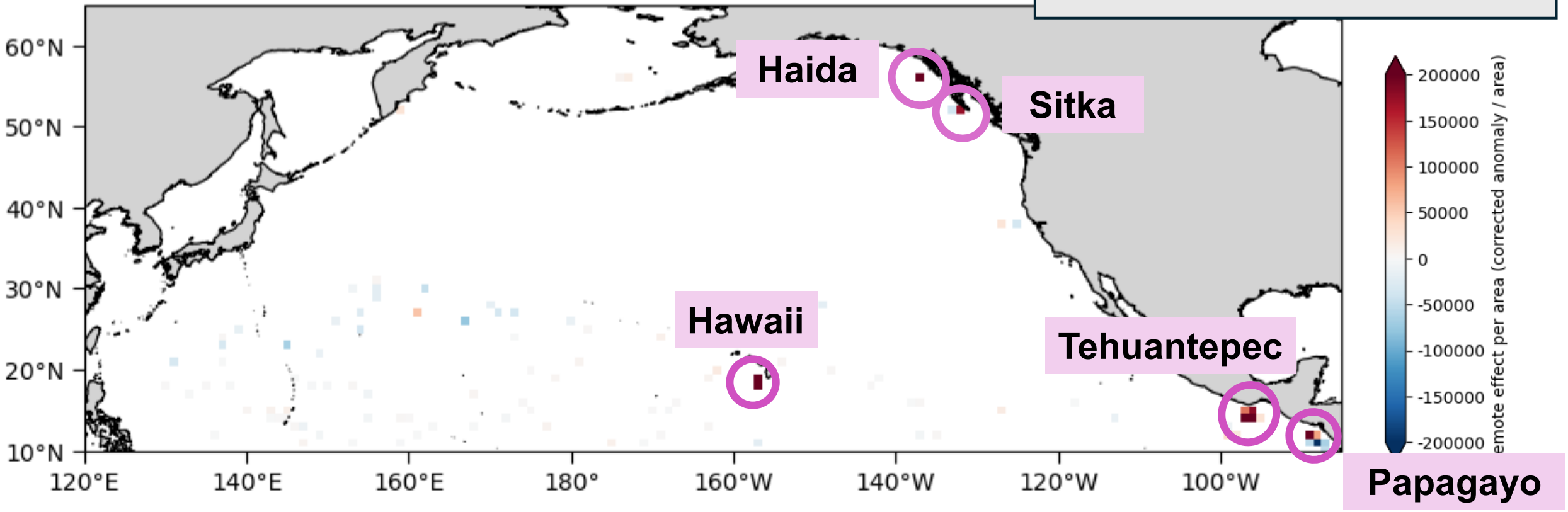
- Eddies affect NPP even far from their formation sites.

Eddy Impacts Far from Their Formation Sites

Formation-based NPP variability (ACEs)

Distances > 10 × latitudinal mean eddy radius





These regions are hotspots where long-lived eddies continue to influence NPP far from their formation sites.

We quantified eddy impacts on NPP using an **eddy-formation-based approach**.

We identified formation hotspots of anticyclonic eddies with large NPP impacts near **Kamchatka**, in the **Gulf of Alaska** and **Kuroshio Extension**, **west of Hawaii**, and off **California** and **Central America**.

Anticyclonic eddies originating near **Haida, Sitka, Hawaii, Tehuantepec, and Papagayo** continue to have substantial impacts on NPP **far from their formation sites**.

Our approach does not quantify the contributions of individual processes to each eddy's impact on NPP.