Progress on Multiparameter Eddy Tracking: Biogeochemical and Biophysical Applications

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NOAA CoastWatch Seminar

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Overview of Eddy Tracking

Overview of Eddy Tracking

- Inputs:
  - NOAA Radar Altimetry Database System (RADS) NRT Altimetry 0.25° x 0.25° daily grids (Sea Level Anomalies (SLA), U, V)
  - NOAA Geo-Polar Blended NRT L4 Analysis 0.083° x 0.083° daily grids (night SST)
  - NOAA MSL12 NRT VIIRS multi-sensor ocean color DINEOF gap-filled analysis 0.083° x 0.083° daily grids (Chl-a)
  - SMAP JPL V5.0 interpolated 0.25° x 0.25° daily grids (SSS)
- Uses a closed-contour eddy tracking method adapted from Chaigneau et al. (2008, 2009) and Pegliasco et al., (2015)
- Trajectories considered valid if eddy tracking run for 100+ days, calculated using a cost-function:

$$CF_{e_{1,}e_2} = \sqrt{\left(\frac{\Delta R - \overline{\Delta R}}{\sigma_{\Delta R}}\right)^2 + \left(\frac{\Delta A - \overline{\Delta A}}{\sigma_{\Delta A}}\right)^2 + \left(\frac{\Delta EKE - \overline{\Delta EKE}}{\sigma_{\Delta EKE}}\right)^2}$$

- Threshold free but a threshold can be applied if desired
- Available from August 2019-present
- Observation based in entirety, does not require model input

Variables Tracked

- Date/time
- Overall eddy coordinates
- Observation number
- Eddy trajectory
- Eddy contours
- Eddy area
- Amplitude
- Radius
- Mean speed
- Mean vorticity
- Vorticity at center
- Normalized vorticity at center
- Mean EKE
- Mean straining deformation rate
- Mean shearing deformation rate
- Mean Okubo-Weiss parameter
- U inside eddy
- V inside eddy
- Mean SST
- Mean SSS
- Mean Ocean Color Chl-a
- Mean MESI

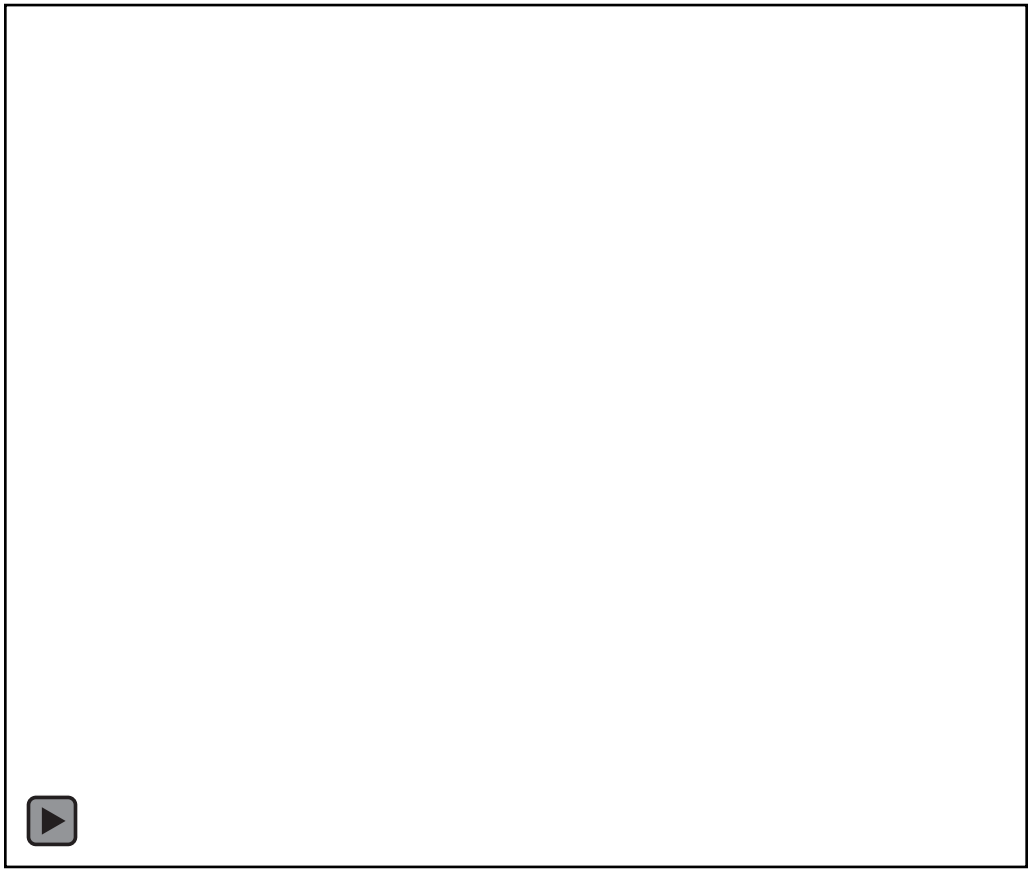
Multiparameter Eddy Significance Index

Multiparameter Eddy Significance Index (MESI)

Normalized index of multiparameter eddy variability that describes the potential impact of a given eddy on mixed layer dynamics and nutrient pumping

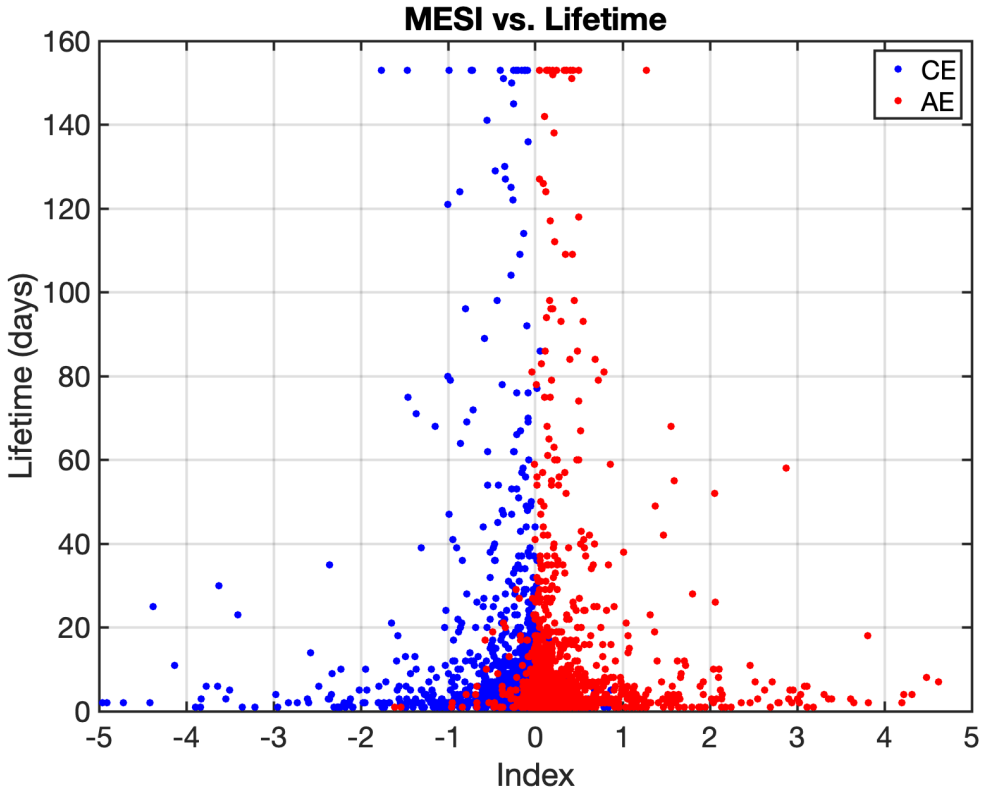
$$MESI = Z_{SLA} * abs(Z_{SST}) * abs(Z_{SSS}) * abs(Z_{Chla}) * abs(\log_{10}(Z_{EKE}))$$

$$Z_{var} = \frac{var - \overline{var}}{\sigma_{var}}$$



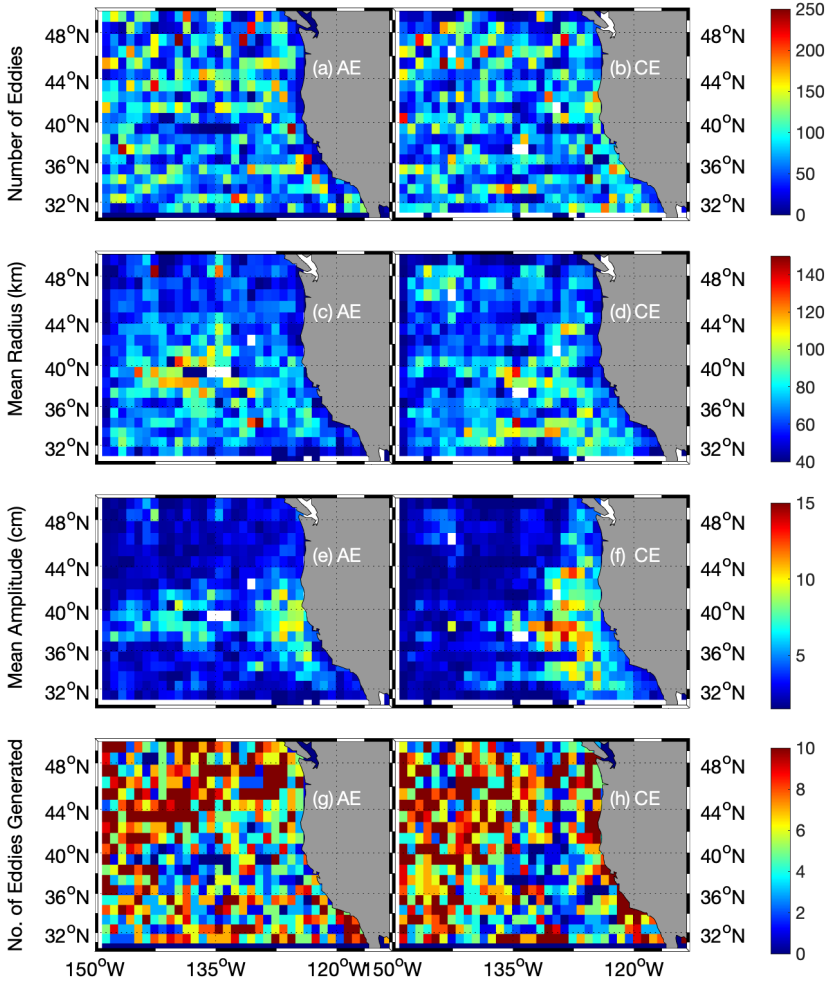
Why threshold free?

- AVISO+ eddy atlases filter out all eddies that are low amplitude (0.4 cm NRT and 1-45 cm DT) and short lived (10 days NRT and 28 days DT)
- Our system keeps those eddies
  - Important for air-sea interactions, local weather → feeds back into oceanic systems
  - Play a role in ocean circulation
  - Still impact upper ocean processes and ecosystem dynamics
  - Impact nutrient cycling and water quality
  - Does result in some false eddies
  - Thresholds can easily be imposed by end users



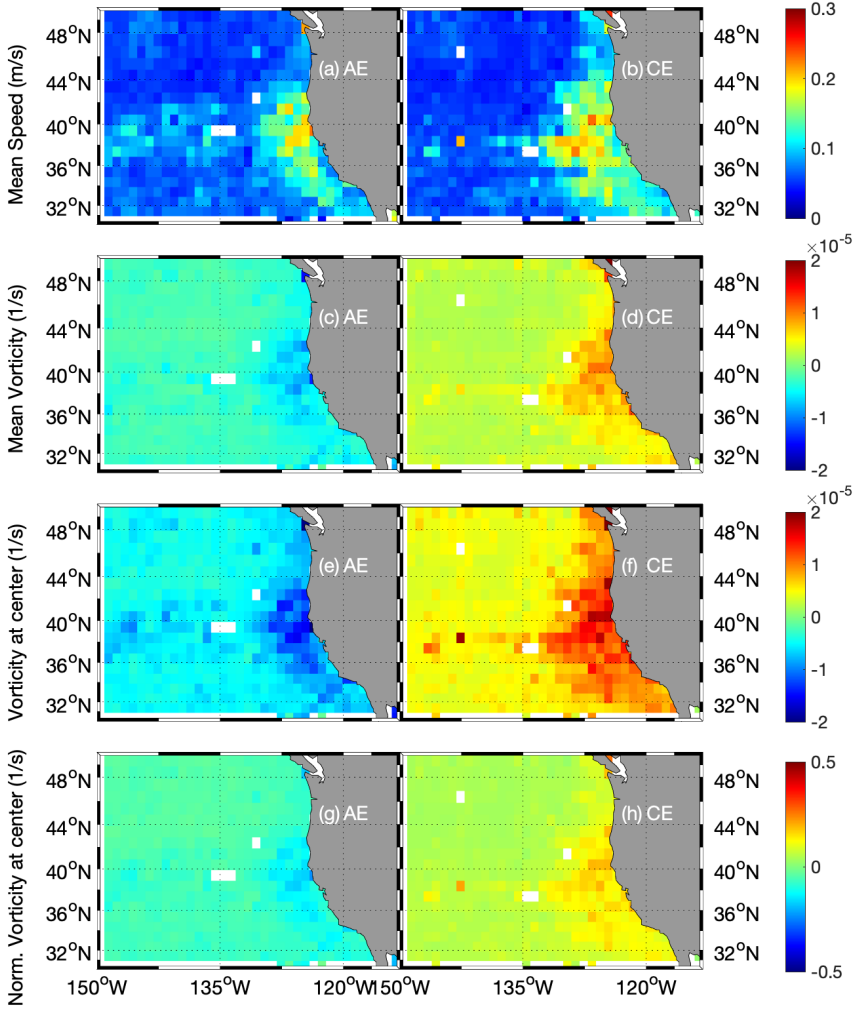
Eddy Characteristics in the California Current System

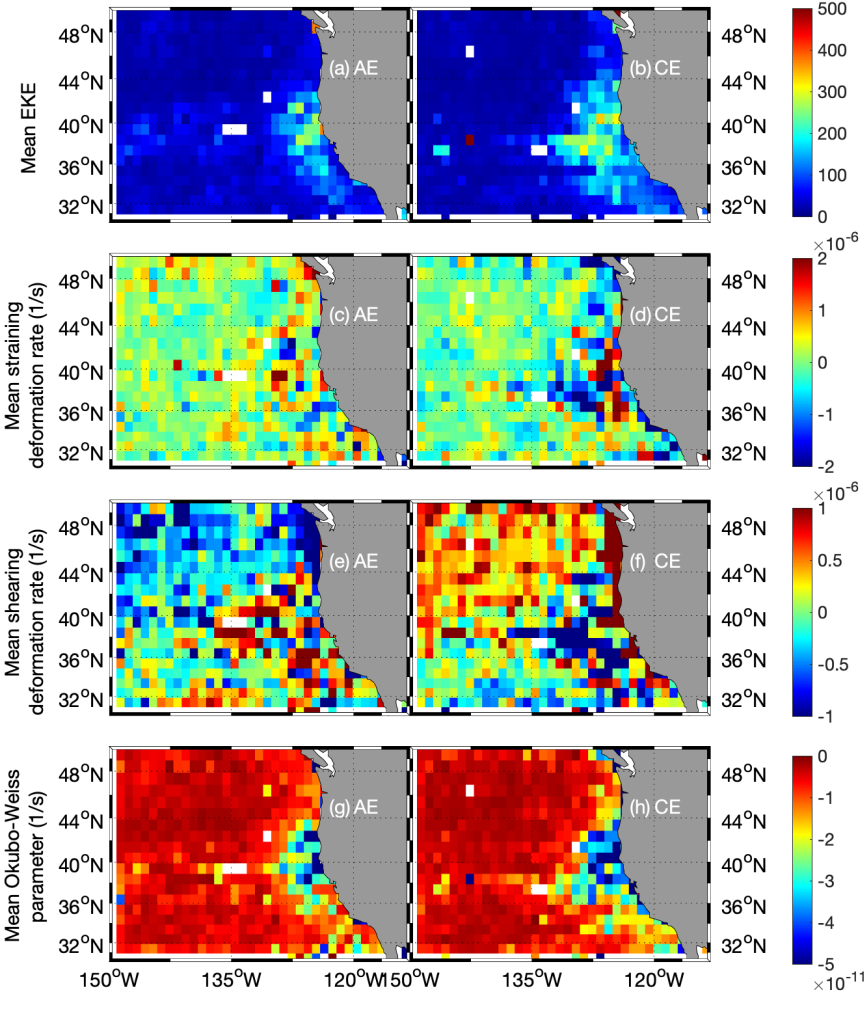
Eddy Characteristics



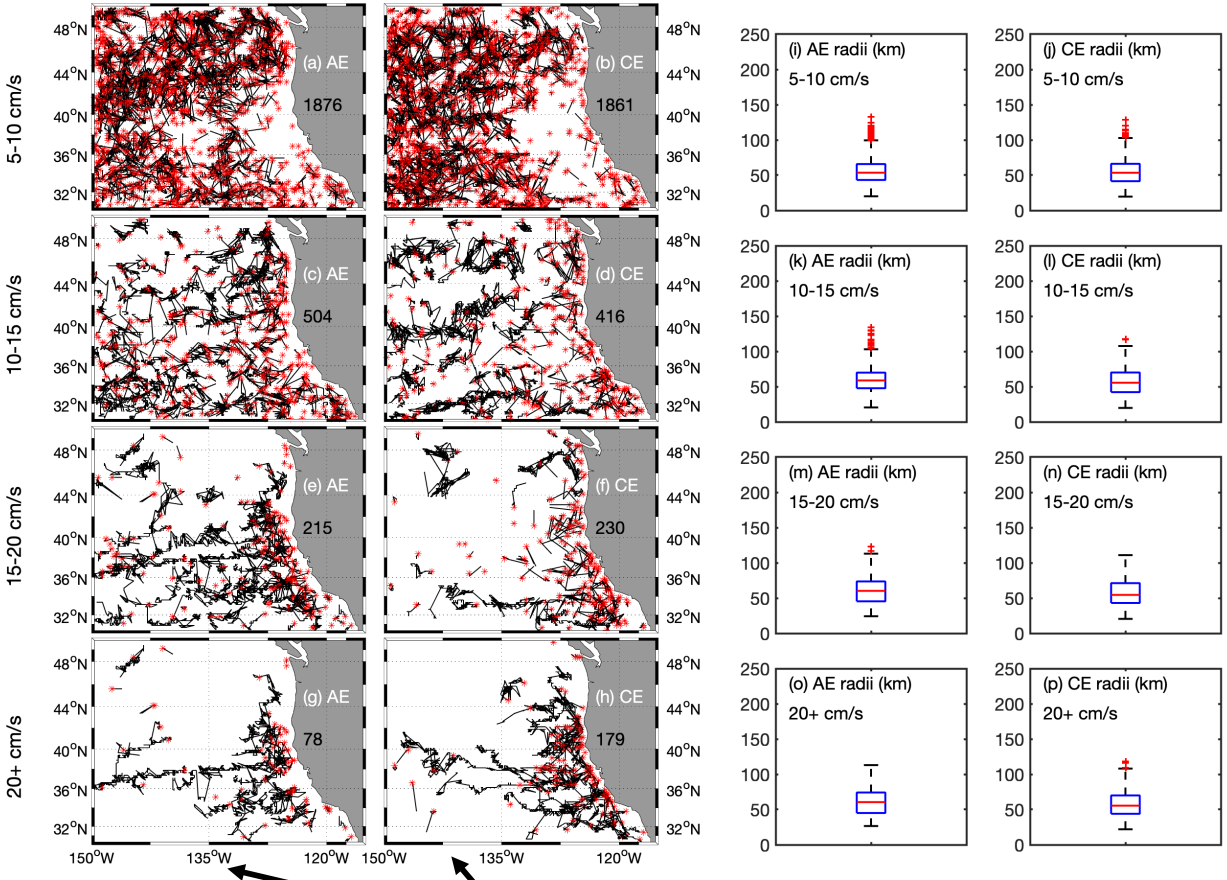
- Eddy characteristics for August 1, 2019 – August 1, 2021
- Eddies sorted into anticyclonic (AE) and cyclonic (CE) eddies
- Resulting eddy characteristics shown in 1° bins (4 grid points per bin)
- Distribution of characteristics highlights regional differences (Radius, No. of eddies generated) and location of California Current (Amplitude)
- Consistent with literature

Eddy Characteristics





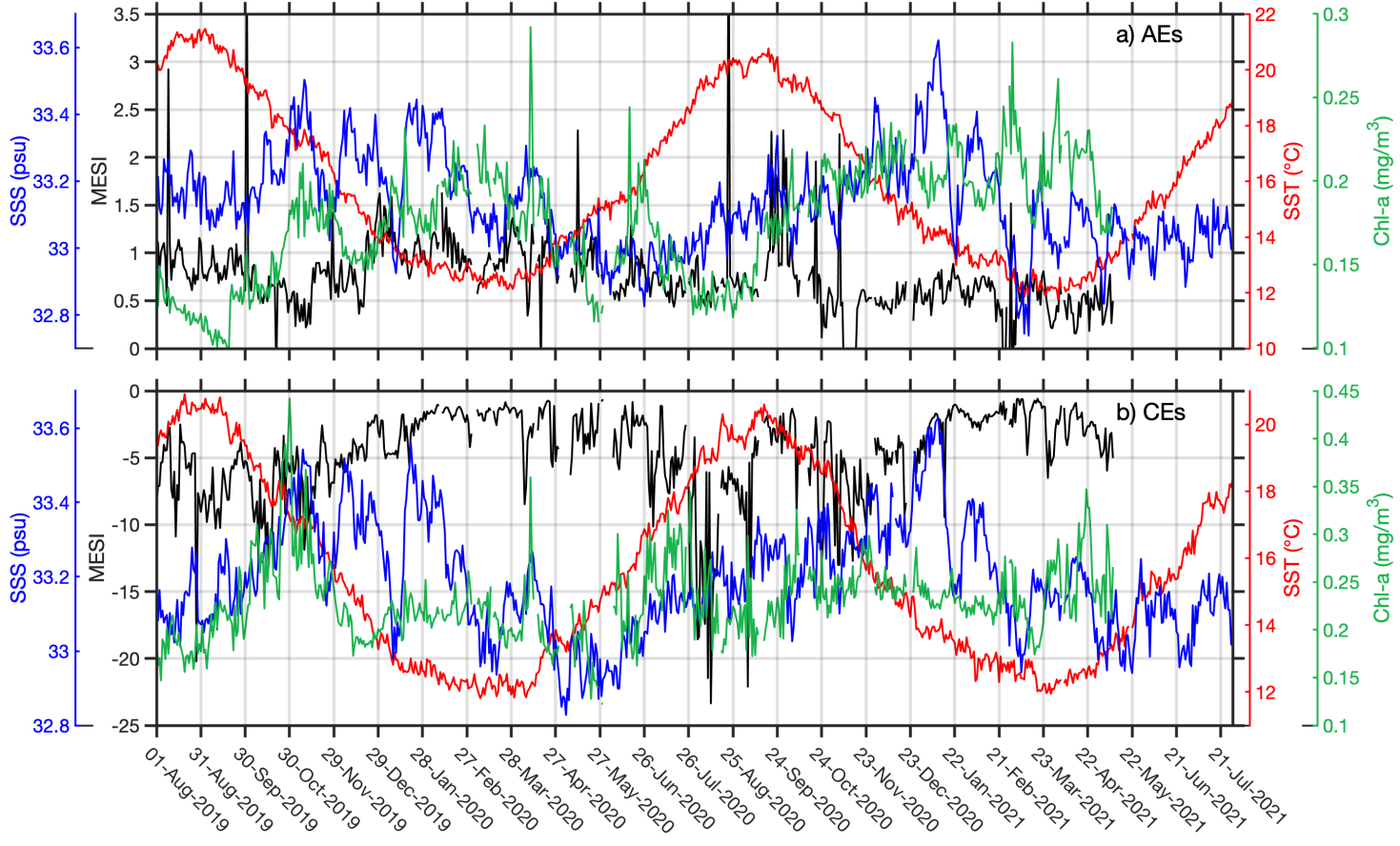
Eddy Trajectories



Cross-shelf transport!

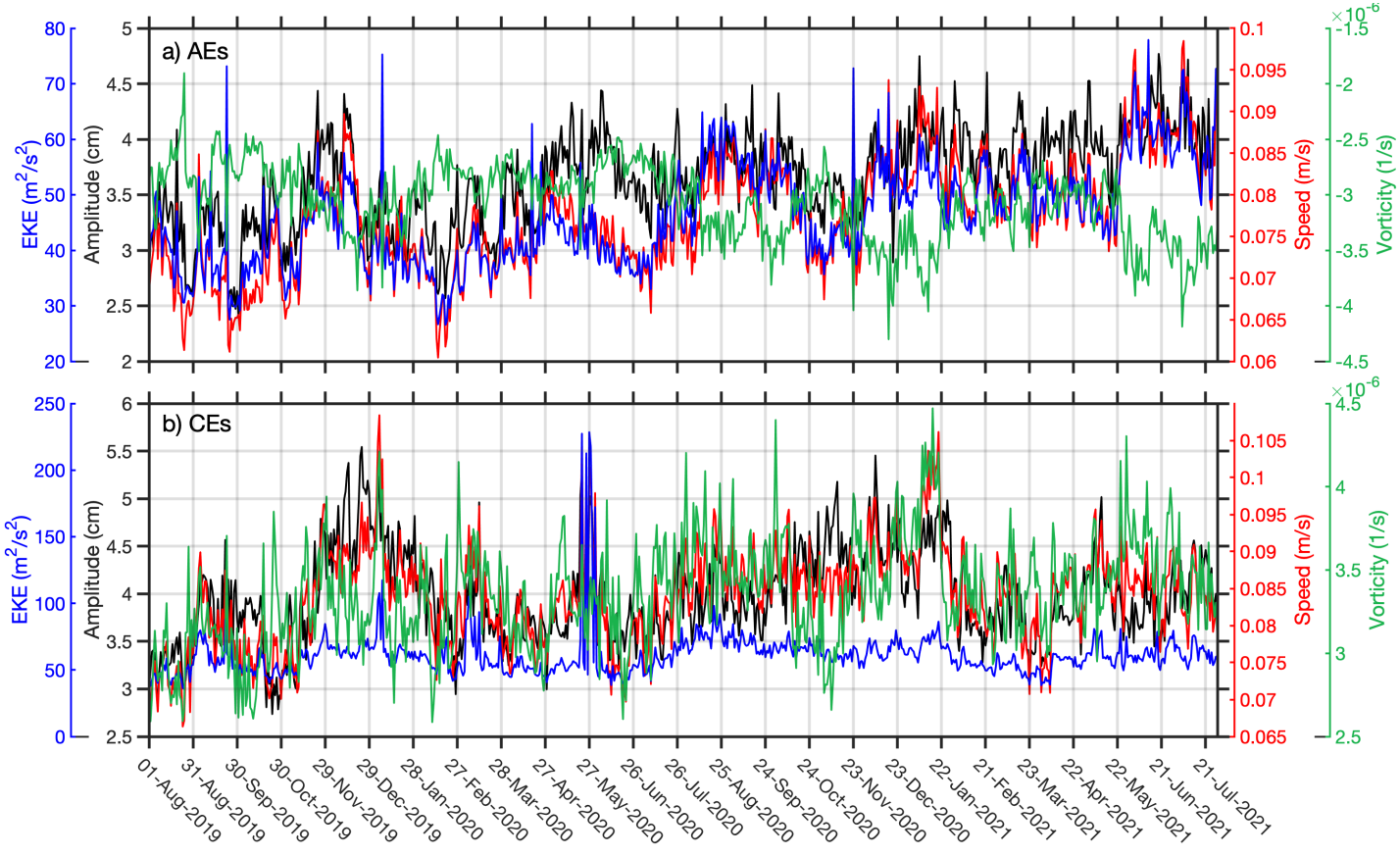
- Eddy trajectories plotted in bins based on eddy speed (5-10 cm/s, 10-15 cm/s, 15-20 cm/s, and 20+ cm/s)
- **Numbers in black** indicate number of eddies shown in the category
- **Red stars** are point of eddy genesis, **black lines are** the trajectories
- **Box plots** show corresponding distribution of eddy radii (km) in each category
- Trajectories and related statistics can be filtered and analyzed according to any parameter

Eddy Characteristics



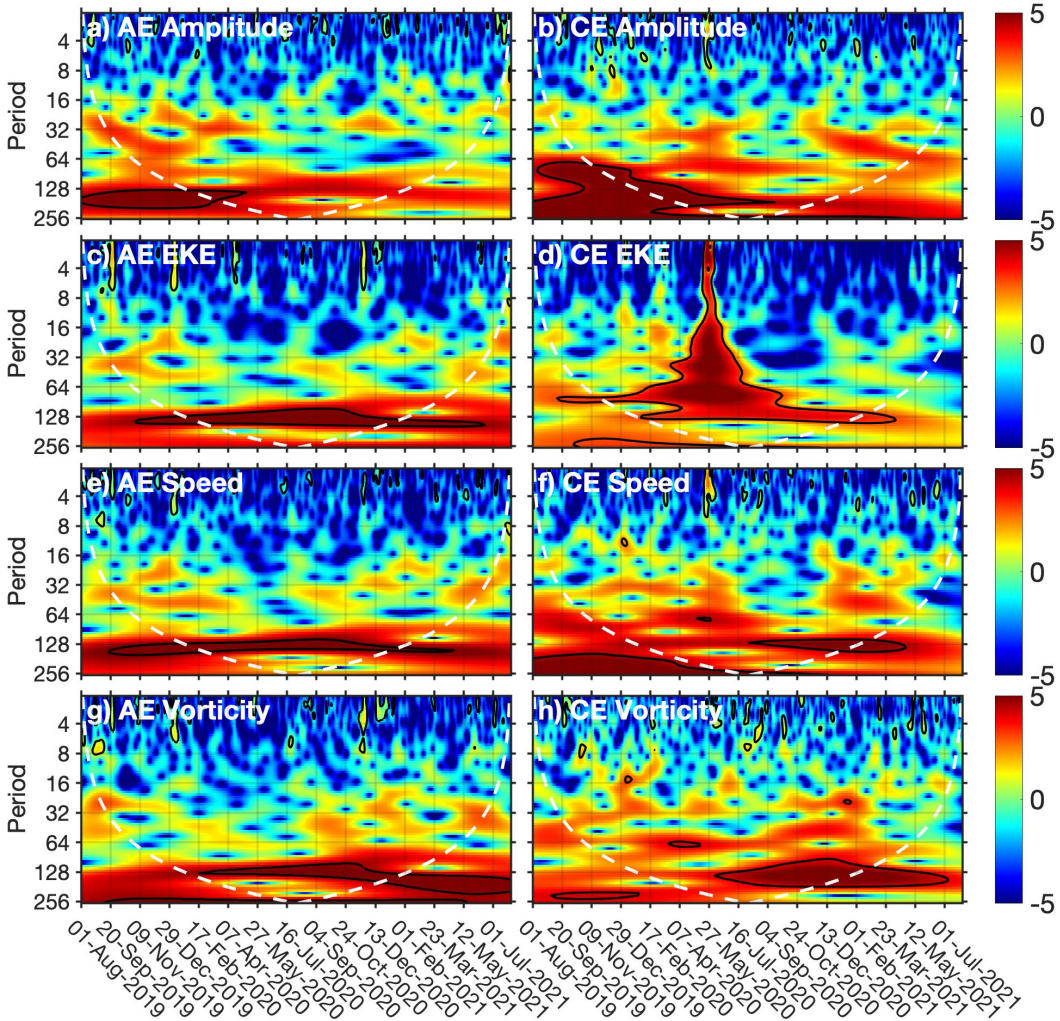
Daily time series of **mean MESI**, **mean SSS** (psu), **mean SST** (°C), and **mean Chl-a** (mg/m^3) averaged across the research area (210-260°W, 10-55°N) for a) AEs and b) CEs from August 1, 2019-August 1, 2021.

Eddy Characteristics



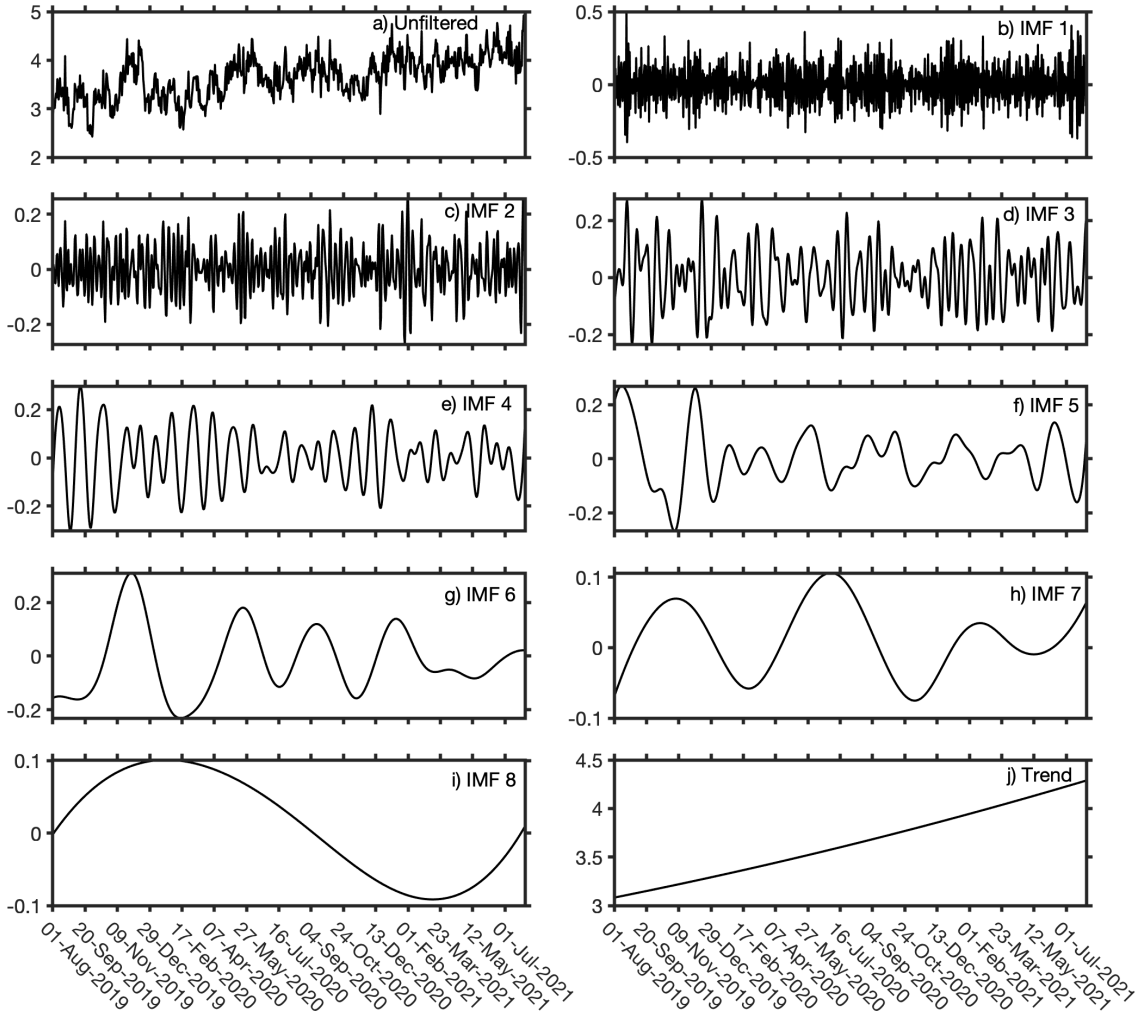
Daily time series of **eddy amplitude** (cm), **mean EKE** (m^2/s^2), **mean speed** (m/s), and **mean vorticity** (1/s) averaged across the research area (210-260°W, 10-55°N) for a) AEs and b) CEs from August 1, 2019-August 1, 2021.

Eddy Characteristics



- Wavelet analysis of daily anticyclonic (left) and cyclonic (right) eddy time series of (a,b) mean amplitude, (c,d) mean EKE, (e,f) mean speed, and (g,h) mean vorticity.
- Shaded values are in normalized units of statistical power.
- **White dashed lines** indicate the cone of influence, outside of which edge effects become significant.
- **Black solid contours** indicate regions in time-frequency space that are statistically significant with 95% confidence.

Eddy Characteristics



- EEMD analysis of daily anticyclonic eddy time series of amplitude (cm), separated into individual intrinsic mode functions (IMFs), the original time series, and the remaining trend.
- Can identify dominant modes of periodicity within the eddy time series (seasonal, intraseasonal)
- Significant overall trend → increase of almost 1.5 cm in just 2 years in the California Current System

Eddy Impact and MESI

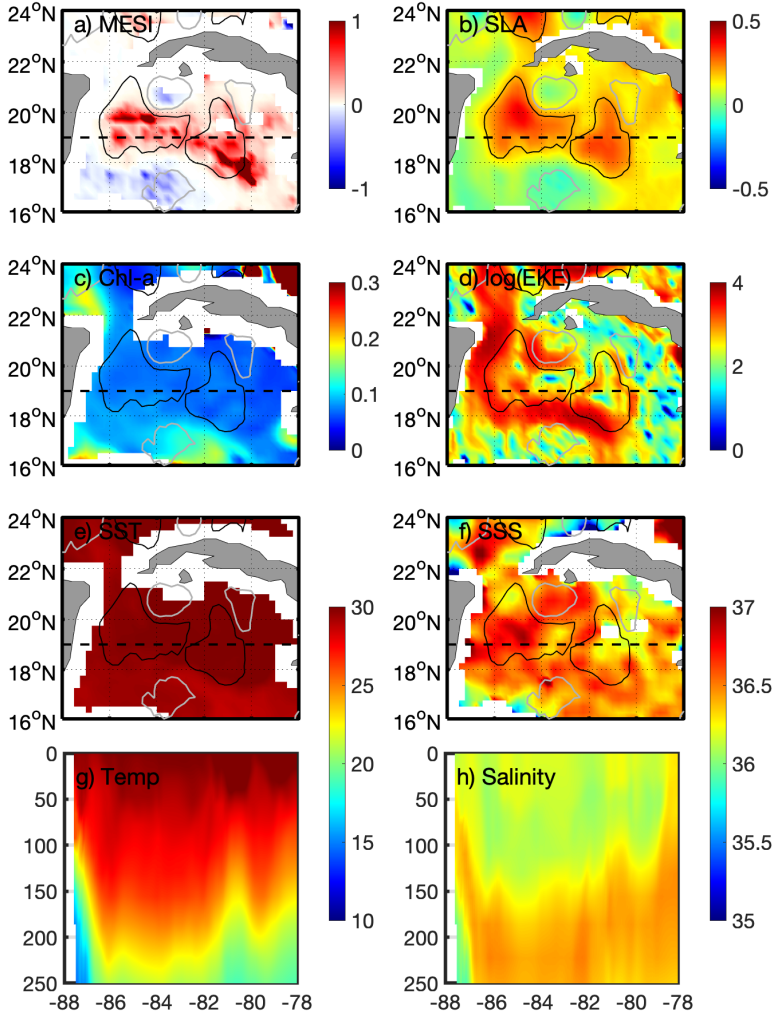






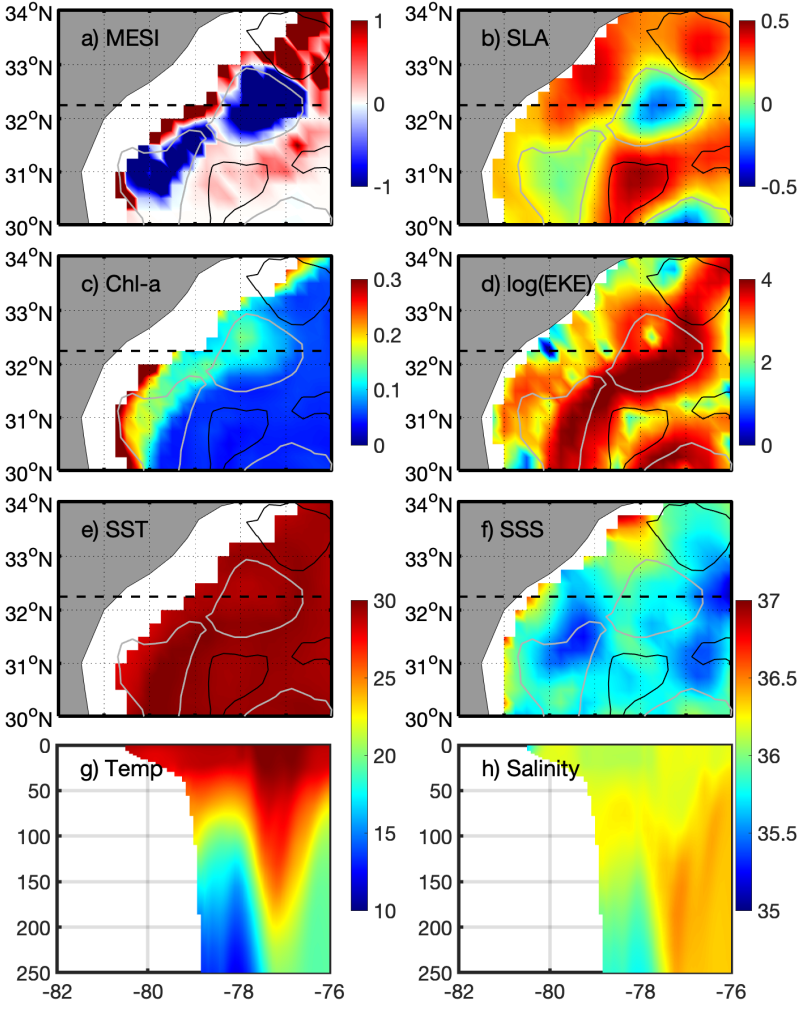


Eddy Impact



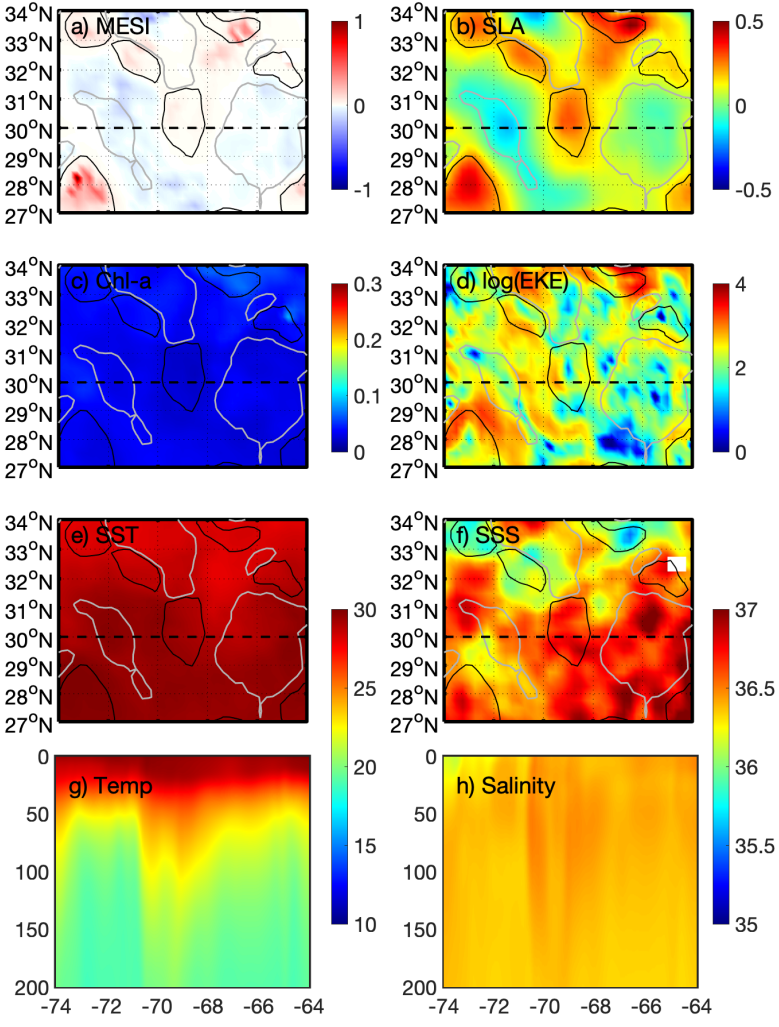
- MESI, SLA, Chl-a, EKE, SST, and SST from satellite observations overlaid with eddy contours in the Caribbean Sea
- NEMO ocean model temperature and salinity transects
- Transect (black dashed line) across two eddies with **high positive MESI** values
- High positive MESI eddies have a strong impact on the upper ocean down to 250 m depth

Eddy Impact



- MESI, SLA, Chl-a, EKE, SST, and SST from satellite observations overlaid with eddy contours off the South Carolina coast
- NEMO ocean model temperature and salinity transects
- Transect (black dashed line) through one eddy with a **high negative MESI** value
- High negative MESI eddies have a strong impact on the upper ocean down to 200 m depth

Eddy Impact



- MESI, SLA, Chl-a, EKE, SST, and SST from satellite observations overlaid with eddy contours off the US East Coast
- NEMO ocean model temperature and salinity transects
- Transect (black dashed line) across three eddies with **low MESI values**
- Low MESI eddies do **not** have as strong an impact on the upper ocean even when the apparent eddy seems strong (depth, energetics, productivity)

Eddies and Biogeochemical Processes in the California Current System









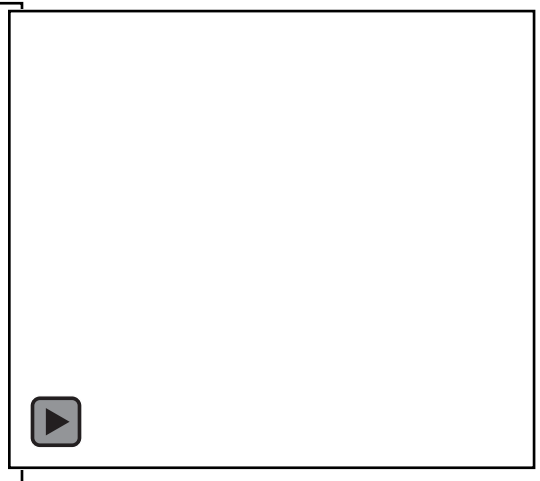
Biogeochemical Cycles and Eddies



- **Anticyclonic** and **cyclonic** contours overlaid on MESI and contributing variables
- Most high MESI values correspond to eddies with elevated productivity, high EKE, and high amplitude SLA
- Highest impact eddies found near the coast in region with highest eddy speeds, deformation rates, OW parameters

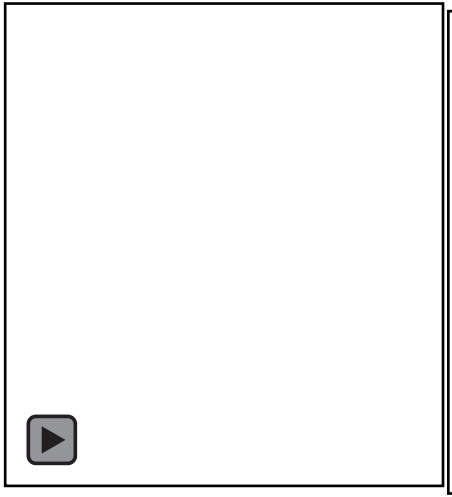
Biogeochemical Cycles and Eddies

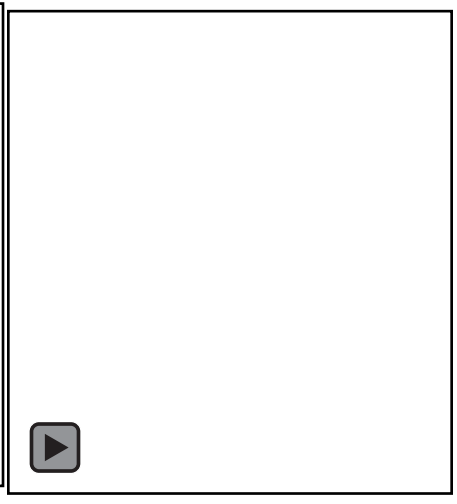


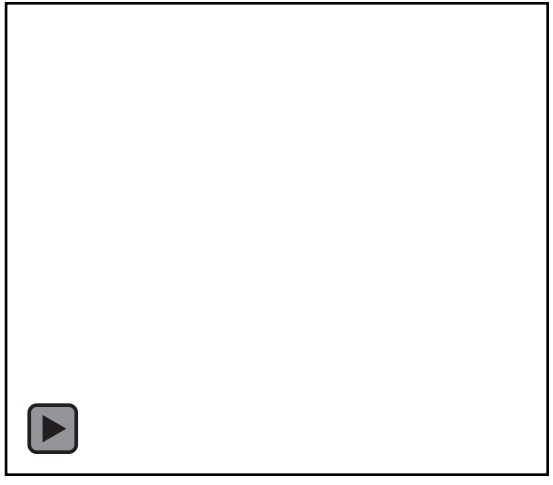


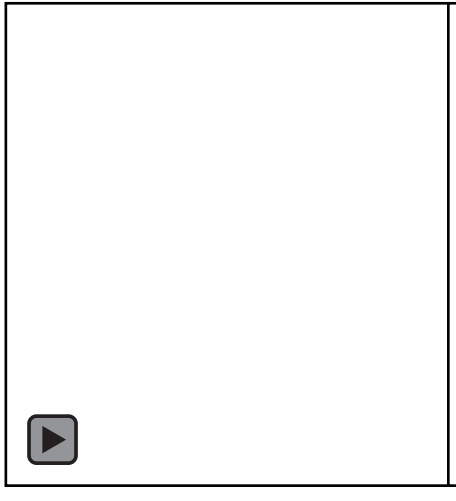
- Near coastal agreement most pronounced
- Inverse relationship between MESI and BGC variables
- Eddies contours used in conjunction with MESI can help better understand biogeochemical processes in mesoscale eddies using satellite observations and eddy tracking

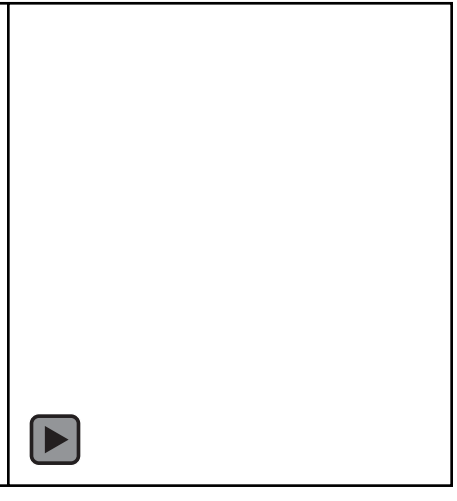
Biogeochemical Cycles and Eddies





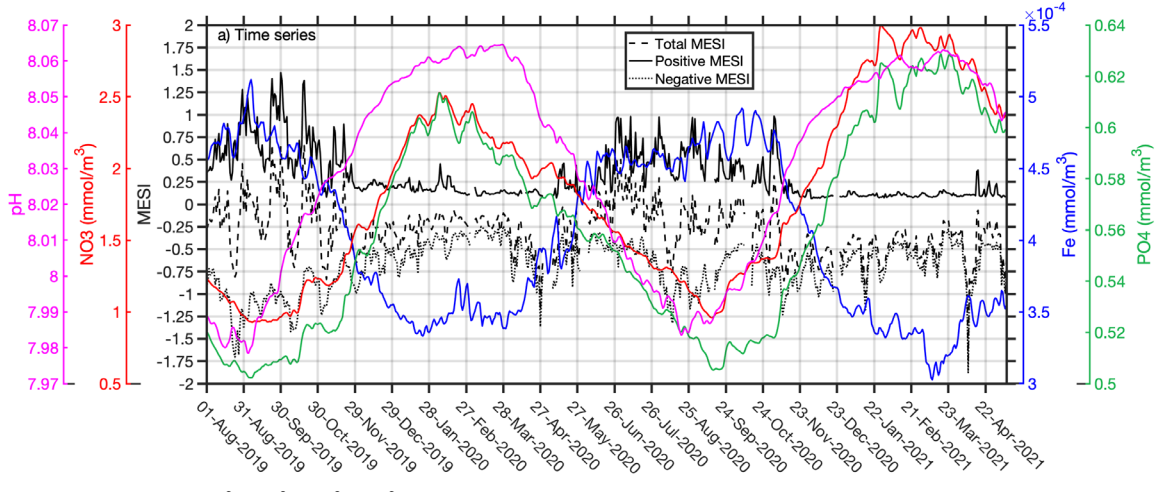


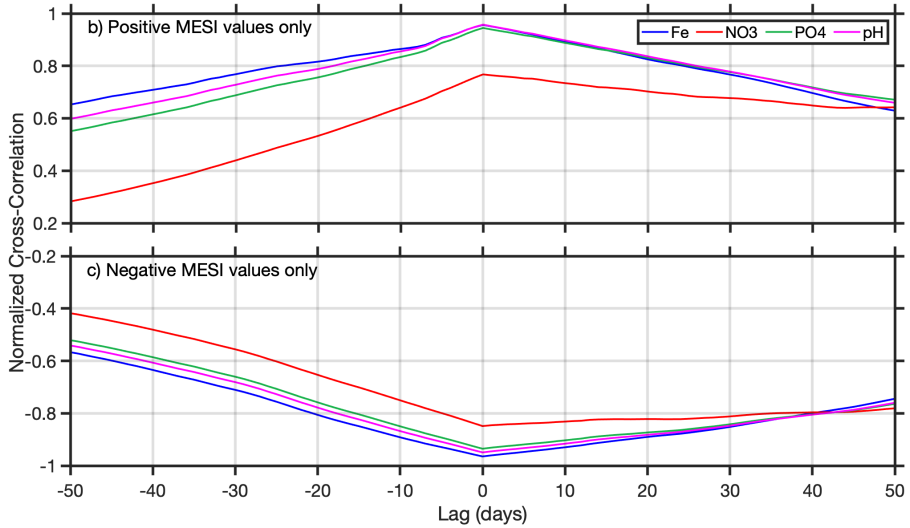




- Depth transects through a strong AE (left) and CE (right) with high MESI values
- Biogeochemical signal penetrates to depth, upwelling visible in CE
- Multiparameter eddy tracking can help identify high impact eddies and monitor their characteristics and trajectories
- MESI serves as a useful first glance for potential eddy impact

Biogeochemical Cycles and Eddies





- Up to 97% cross-correlation with no lag between MESI and Fe for the California Current System
- Nitrate has the lowest correlation through time of all the BGC variables tested
- Suggests that MESI can be used as a NRT indicator of biogeochemical activity and can be used to monitor systems using observations rather than model output
- Total and negative MESI values (CEs) vary more closely with BGC variables than positive MESI values (AEs)
  - Consistent with eddy activity in California Current System

Summary


NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE


GLOBAL SCIENCE & TECHNOLOGY, INC.


CoastWatch.
noaa.gov


NOAA
Laboratory for Satellite Altimetry
NOAA·NESDIS·STAR

Summary

- Multiparameter eddy tracking allows for user-friendly analysis of NRT eddies in the California Current System and beyond

- MESI can be used in concert with eddy tracking to rapidly identify eddies that may have strong biogeochemical and biophysical impacts, with applications across numerous fields of oceanography for both operational uses and research

- Multiparameter eddy tracking is presently an experimental regional product for NOAA CoastWatch, but will soon be global

Questions?

Heather Roman-Stork: heather.roman-stork@noaa.gov

Collaborators: Eric Leuliette, Deirdre Byrne

Extra Slides









Background

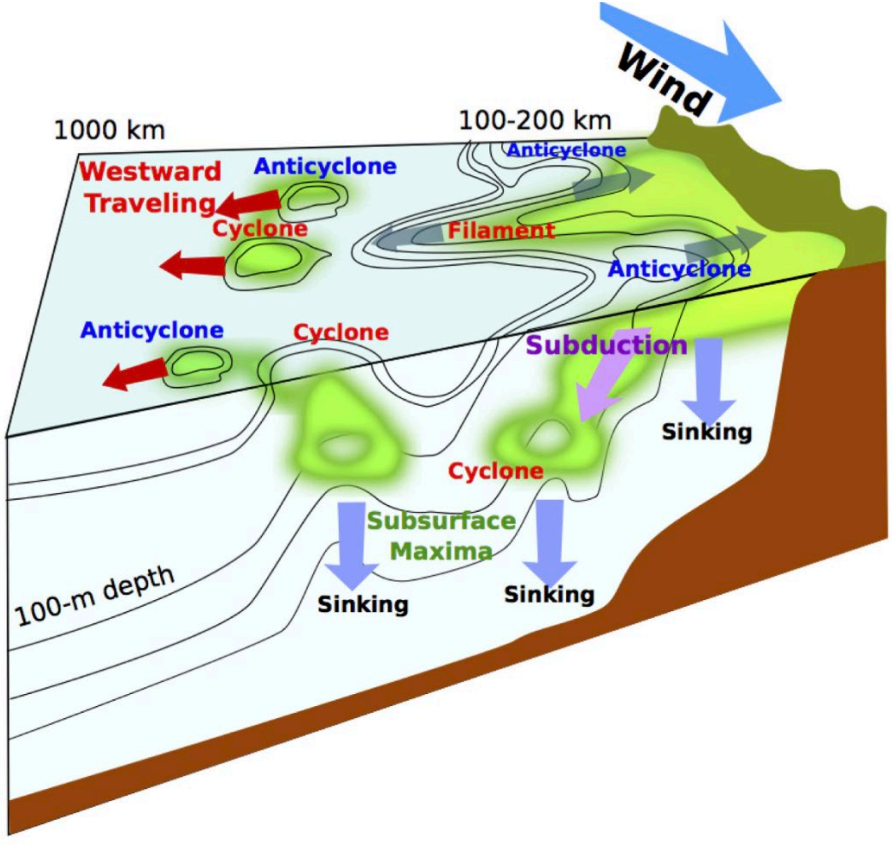


Figure 15. Schematic diagram summarizing the dynamics of offshore transport of organic carbon in the California Current System as diagnosed by our model simulation. After being formed in the upwelled waters, a substantial fraction of the organic matter is transported offshore, first by filaments that protrude across the coastal upwelling front, which tends to act as a barrier for offshore transport. Much of the organic matter is subducted at the fronts associated with the filaments. From there, the organic matter is readily transported further offshore by westward propagating eddies, which form at an offshore distance of about 100–200 km. Most of the initial offshore transport in summer occurs by cyclonic eddies, largely reflecting their generation at the tip of the filaments. The organic carbon in the cyclonic eddies is then stirred and entrained also into anticyclonic eddies, which travel west as well. The eddy fluxes dominate the transport in the region 200–800 km from the shore.

- Cross-shelf transport of organic matter and biogeochemical/biophysical properties by mesoscale eddies is a critical part of biogeochemical and biophysical cycling in the California Current System

- Tracking these eddies and their biophysical properties can provide a valuable tool for ecosystem, water quality, biophysical, and biogeochemical studies, among others.

(Nagai et al., 2015)

Comparison to AVISO+ Products

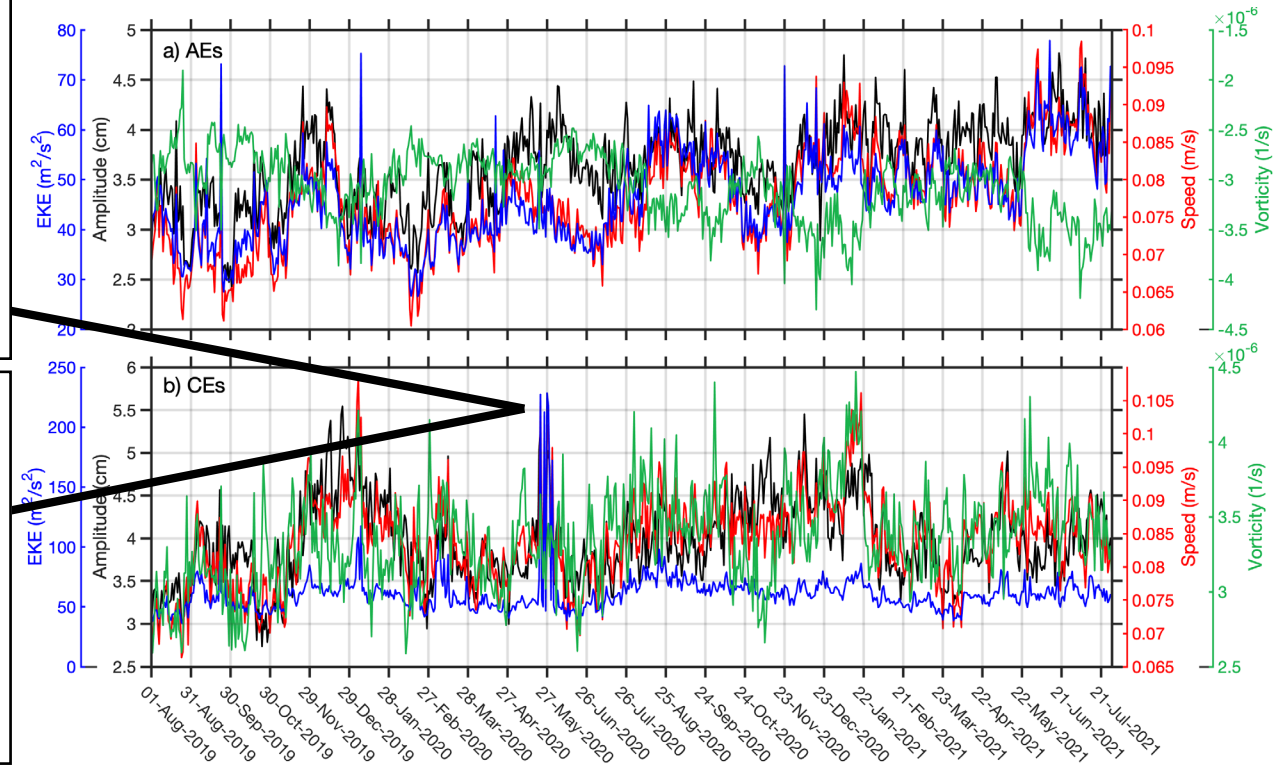
AVISO+

- NRT (2018-present) and DT (1993-2020) products
- Based on CMEMS NRT ADT grid and C3S Delayed Time SLA grid
- 83.5N-83.5S coverage
- Uses Chelton et al. (DT) and Py Eddy Tracker (NRT) algorithms
- One (NRT) and at least one (DT) extrema per eddy
- 0.4 cm (NRT) and 1-45 cm (DT) amplitude threshold
- Minimum eddy lifetime of 10 days (NRT) and 28 days (DT)
- Updated daily with 15-day latency (NRT) and annually (DT)
- Only provides eddy location, timing, amplitude, radius, and contour

NOAA

- Can be run both NRT (2018-present) and DT (2018-present)
- Based on NOAA RADS SLA and U/V grids, with multiparameter additions
- 60N-60S latitudinal coverage
- Uses modified Chaigneau et al., (2008, 2009)/Pegliasco et al., (2015) algorithm
- One extrema per eddy
- Amplitude threshold free
- No minimum eddy lifetime
- Product latency will be dependent on gridded product availability
- Multiparameter, provides full eddy analysis along with eddy location, timing, amplitude, radius, and contour

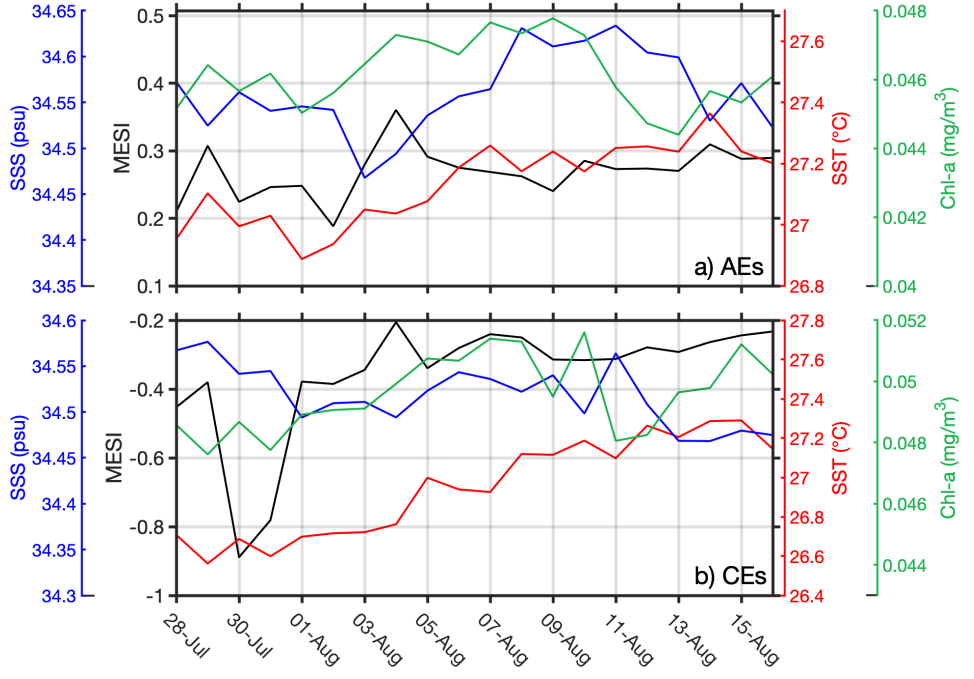
Eddy Characteristics



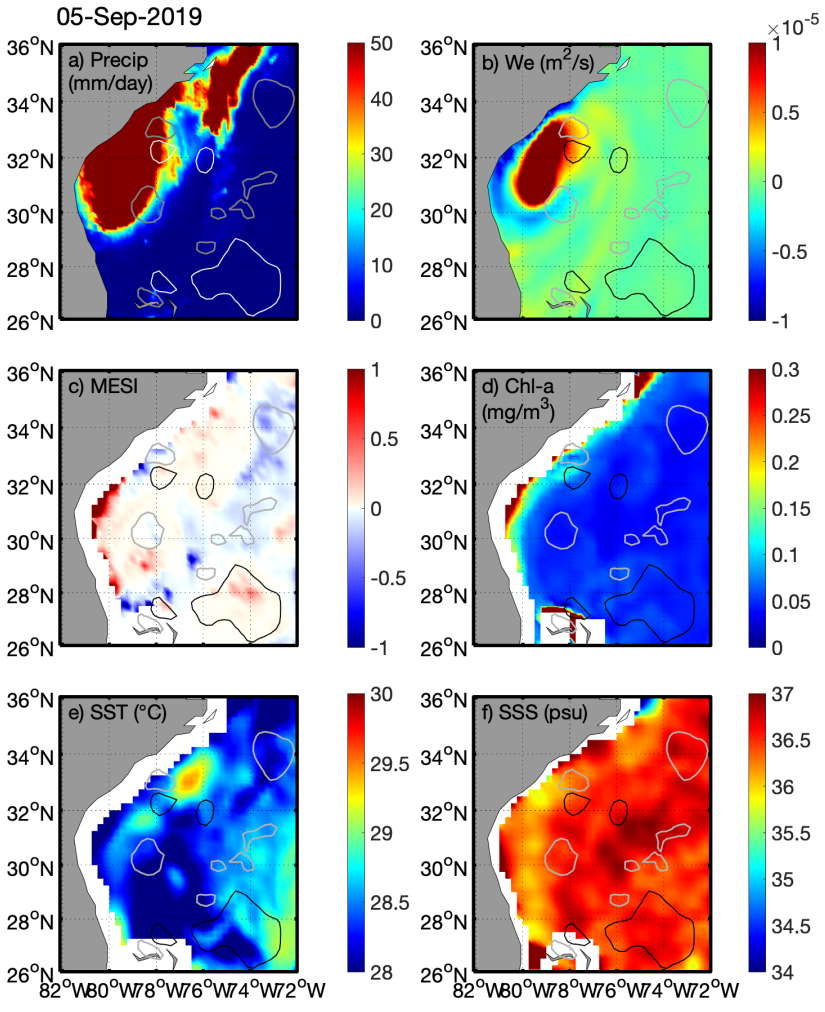
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Applications of Eddy Tracking

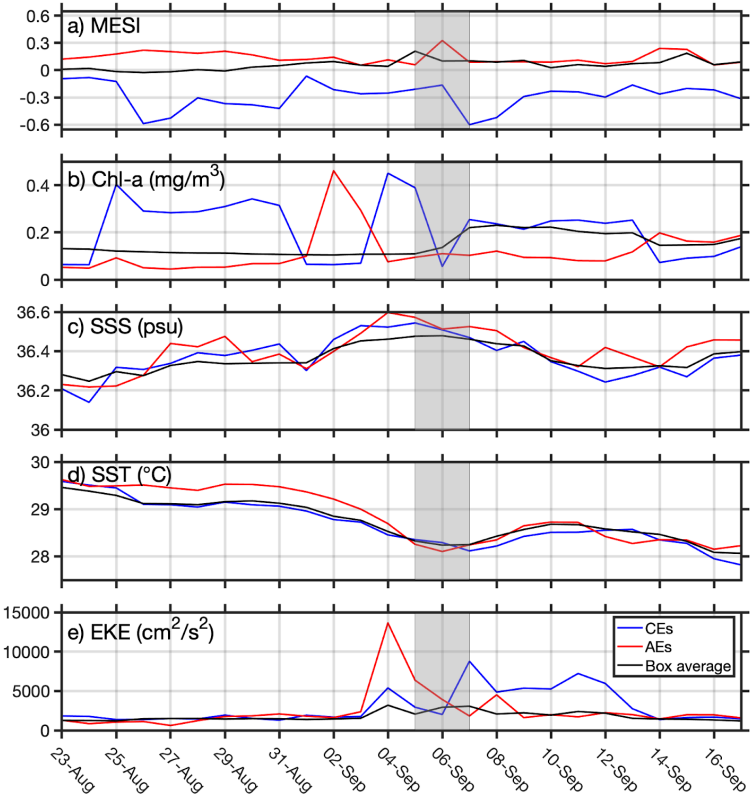
- Hurricane Erick (July 30-August 5, 2019)
- (Left): Satellite observations and eddy contours
- (Right): Time series of mean eddy properties



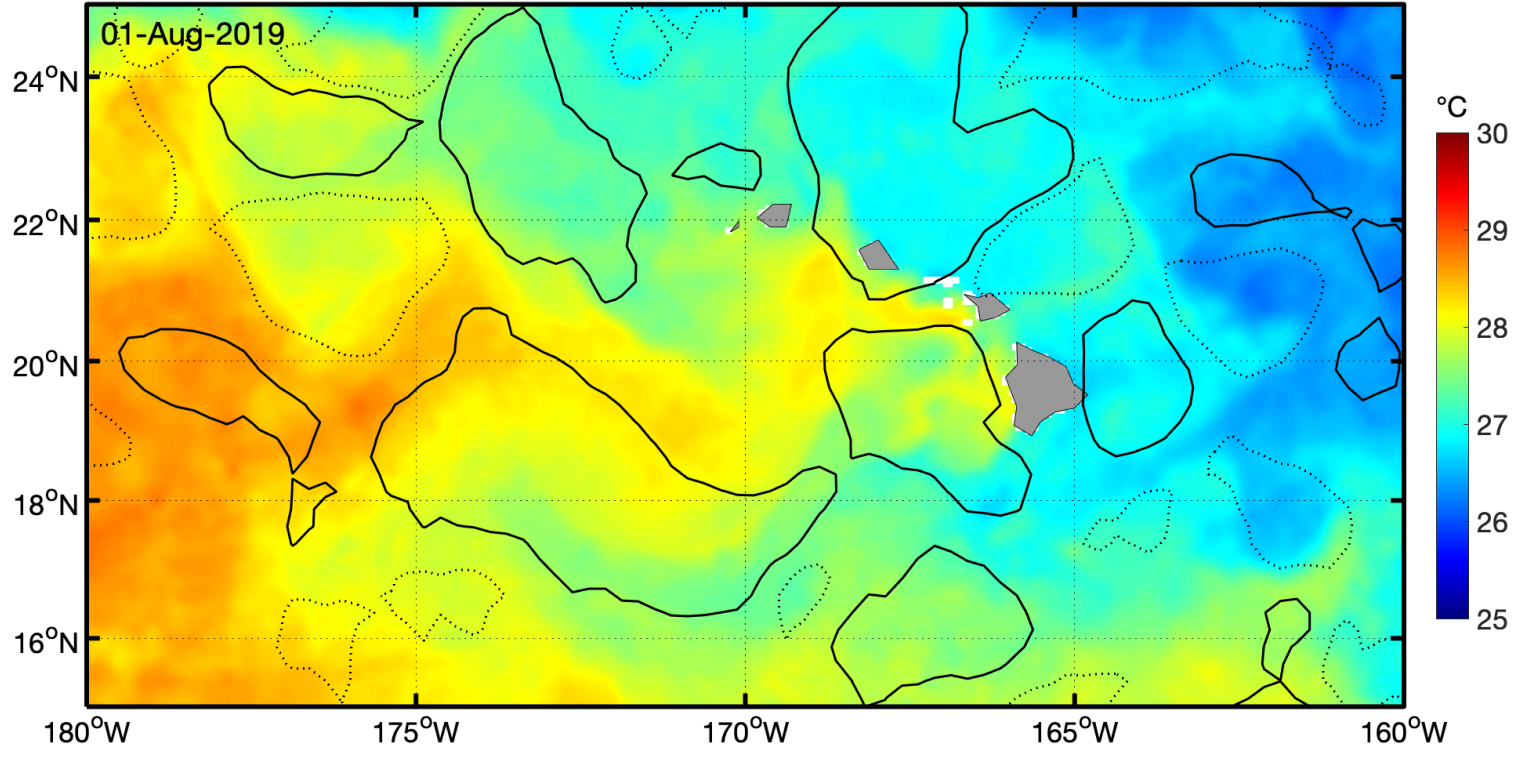
Applications of Eddy Tracking



- Hurricane Dorian (Aug 26-Sep 9, 2019)
- (Left): Satellite observations and eddy contours
- (Right): Time series of mean eddy properties



Applications of Eddy Tracking



- Geopolar SSTs overlaid with eddy contours (anticyclonic = solid; cyclonic = dashed)
- Eddy contours and SSTs reasonably well collocated even though unrelated datasets