Physical and Biological Implications of Eddy Signatures

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Overview

I. Background
II. Data Sets
III. Eddy related enhanced seaward upwelling and filaments
IV. Summary
V. Further Applications

Lets think about the ‘complexity of the biophysical interactions that drive plankton distributions’

Vincent van Gogh (1889) The Starry Night

Jackson Pollock (1912-1956) Wild Beast

- What scales do you think of?.
- Physicist Jose Luis Aragon et. al (2006) note the mathematical structure of natural turbulence in relation to van Gogh’s works, e.g., like swirling skyline…
- Oceanographer/Mathematician Barry B. Cael relates biophysial interactions to Pollock’s small scales in Wild Beast.

https://www.us-ocb.org/new-satellites-paint-a-portrait-of-plankton-spatial-variability/

Background

- Wind driven upwelling

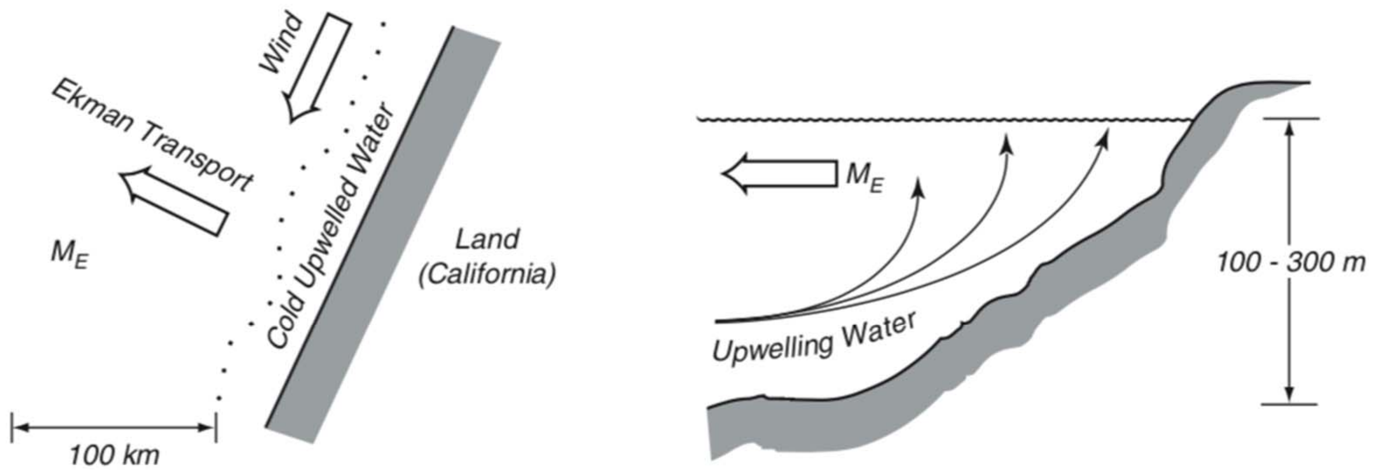
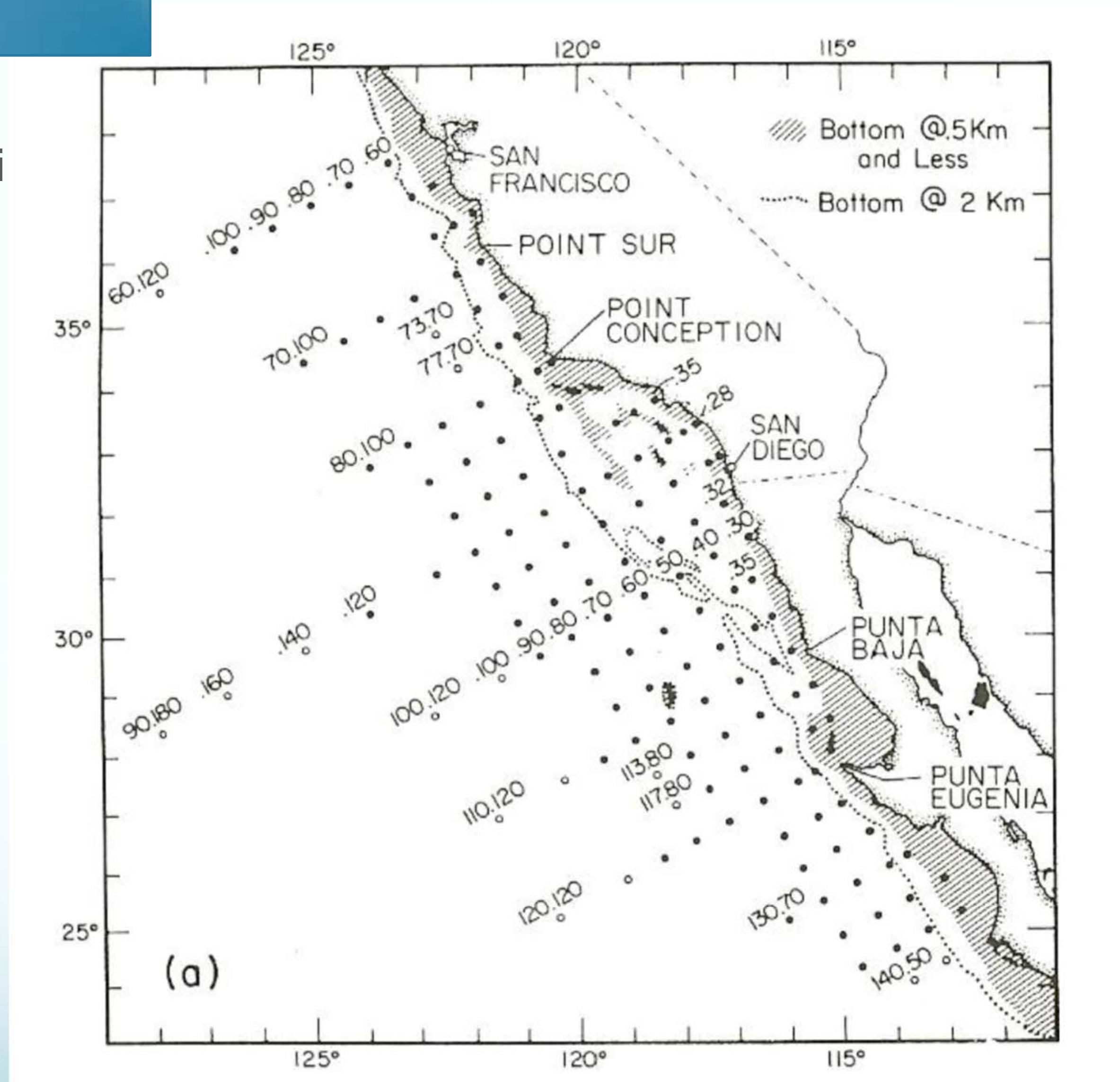


Figure 9.8 Sketch of Ekman transport along a coast leading to upwelling of cold water along the coast. **Left:** Plan view. North winds along a west coast in the northern hemisphere cause Ekman transports away from the shore. **Right:** Cross section. The water transported offshore must be replaced by water upwelling from below the mixed layer.

Steward (2009) Introduction to Physical Oceanography, p. 156.

Background

- Well known CalCalfi in situ data
- Feature-Oriented Regional Modeling System (FORMS)



Gangopadhyay, Avijit; Lermusiaux, Pierre F.J.; Rosenfeld, Leslie; Robinson, Allan R.; Calado, Leandro; Kim, Hyun Sook; Leslie, Wayne G. and Haley, Patrick J 2011: The California Current System: A Multiscale Overview and the Development of a FeatureOriented Regional Modeling System (FORMS).” Dynamics of Atmospheres and Oceans 52, no. 1–2: 131–169

Background

- The eddy upwelling mechanism for adjacent eddies of opposite sign (McGillcuddy et. al, 1998)

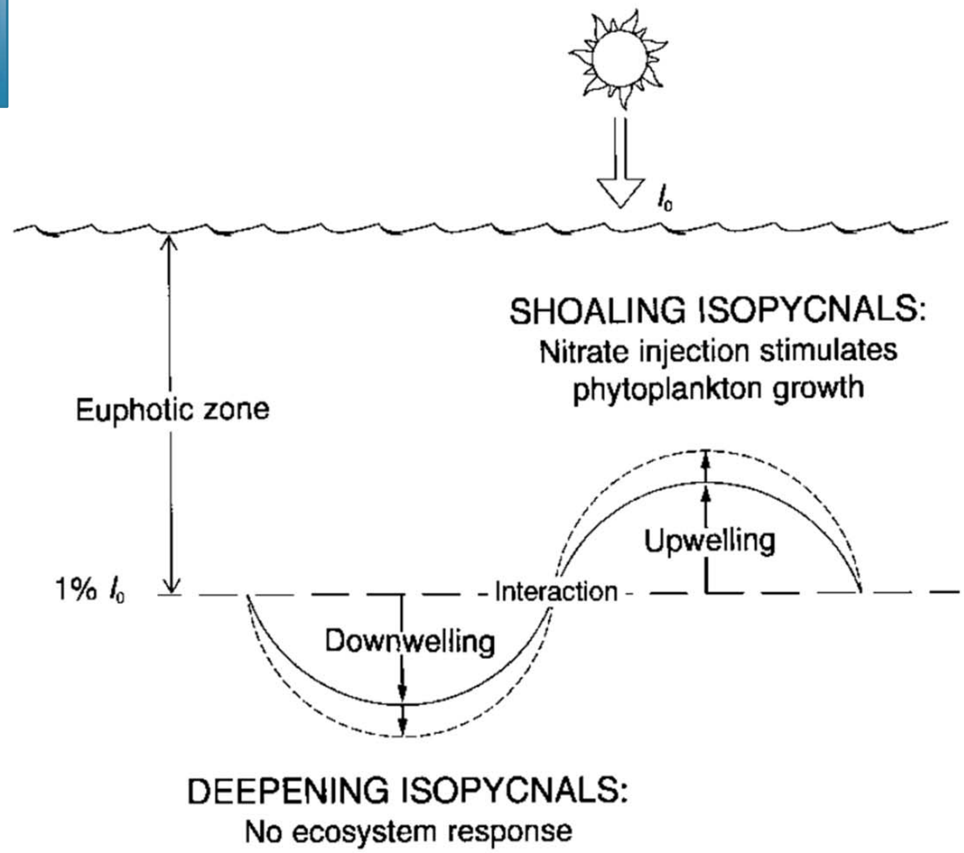
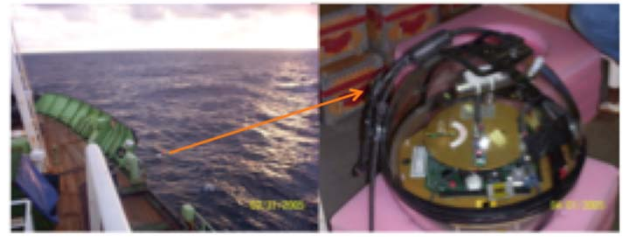


Figure 1 A schematic representation of the eddy upwelling mechanism. The solid line depicts the vertical deflection of an individual isopycnal caused by the presence of two adjacent eddies of opposite sign. The dashed line indicates how the isopycnal might be subsequently perturbed by interaction of the two eddies. I_0 represents incident solar radiation, and 1% I_0 the base of the euphotic zone.

D. J. McGillicuddy Jr, A. R. Robinson, D. A. Siegel, H. W. Jannasch§, R. Johnsonk, T. D. Dickey, J. McNeil, A. F. Michaels, and A. H. Knapk, Influence of mesoscale eddies on new production in the Sargasso Sea, Nature, Vol 394, 1998.

Background

- Eddy signatures from in situ data show both baroclinic (steric) and mass load height components (Baker-Yeboah et al 2010)

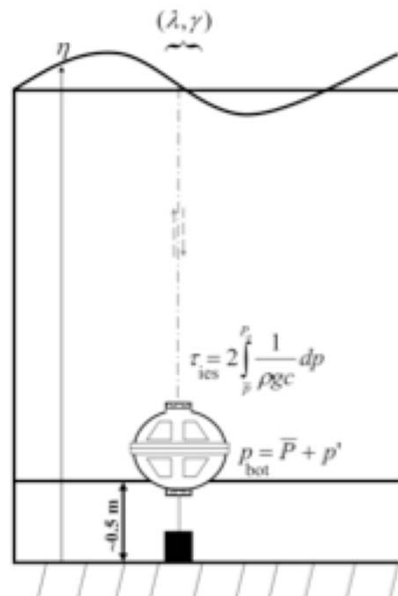


$$\eta'_{PIES} = \eta' - \eta_{IB} = \eta'_{bt} + \eta'_{bc}.$$

Sea surface height from PIES

$$\eta' - \eta_{IB} + H = \int_{P_a}^{\overline{P}} \frac{1}{\rho g}\, dp + \int_{\overline{P}}^{p_{bot}} \frac{1}{\rho g}\, dp,$$

$$= \frac{1}{g} \int_{P_a}^{\overline{P}} [\alpha(35, 0, p) + \delta]\, dp + \frac{(p_{bot} - \overline{P})}{\rho_b g}$$



Baker-Yeboah, S., D. A. Byrne, and D. R. Watts. … Basin: Baroclinic and Deep Barotropic Eddy Vari… doi:10.1029/2010JC006236, 2010. http://www.ag…

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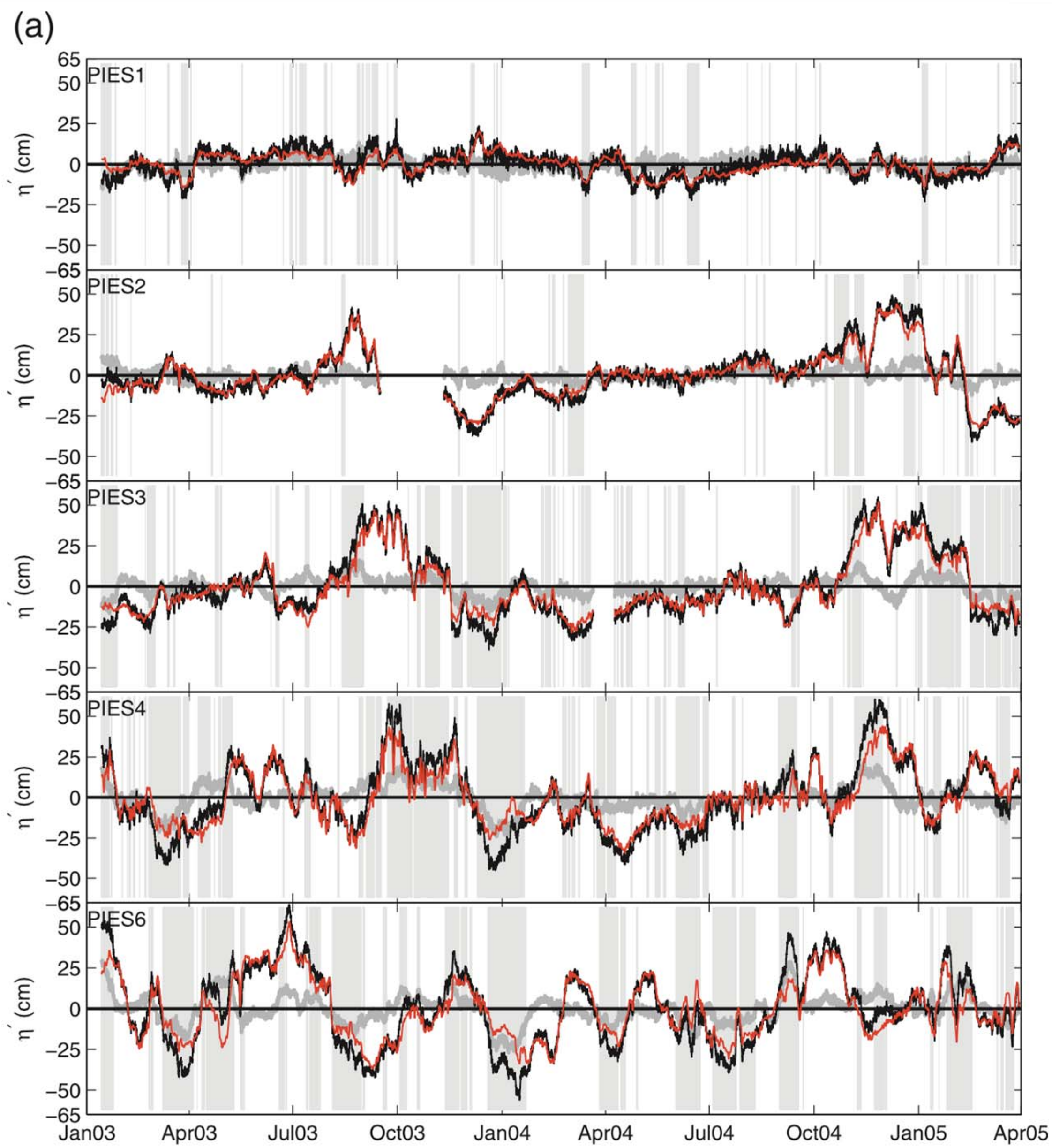

FIG. 3. (a) SSH variability from PIES sites: η'_{bt} (gray), η'_{bc} (red), and η'_{PIES} (black). The red curve is often close to the black curve. The shaded regions highlight times during which η'_{bt} can influence the total sea level variability, when $^{\dagger}R_{bt} \geq 0.25$ and $|\eta'_{PIES}| \geq 15$ cm. (b) As in (a), but for sites 7–12.

Baker-Yeboah, S., D. A. Byrne, and D. F
Basin: Baroclinic and Deep Barotropic E
doi:10.1029/2010JC006236, 2010. http:

Background

- Using the strong correlation between altimeter and in situ pressure sensor–equipped inverted echo sounder (PIES) data, an analysis is done using current altimeter data in conjunction with Visible Infrared Imaging Radiometer Suite (VIIRS; on board S-NPP and NOAA-20) Ocean Color and Sea Surface Temperature data to gain further insight into the physical and biological implications of mesoscale eddies associated with Agulhas rings off of South Africa.
- A comparison is done with the California Current system, another major upwelling regime in the World Ocean,
- to assess the the relationship of slope eddies in upwelling regions to open ocean eddy signatures.

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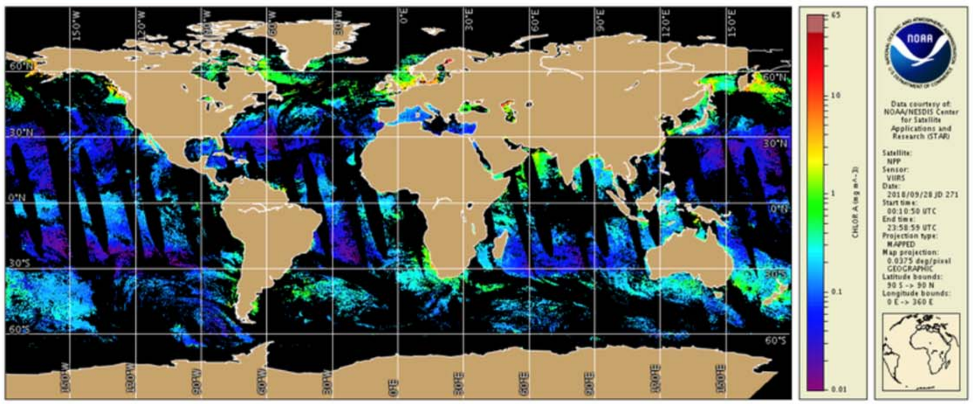
Data Sets Used

NOAA MSL12 Ocean Color - Science Quality - VIIRS SNPP

Satellite Data Products / Ocean Color (Chlorophyll, radiances, etc.) / Science quality / NOAA MSL12 Ocean Color - Science Quality - VIIRS SNPP

Updated: December 18, 2018

Data Access | Description | Information | Documentation



Level 2 VIIRS Ocean Color produced by NOAA/STAR Ocean Color Team through NOAA Multi-Sensor Level 1 to Level 2 processing system (MSL12) using an improved calibration for the satellite data record (OC-SDR, which is Level 1b).

The current VIIRS science quality collection, released in CoastWatch as of 07 August 2017, is produced from MSL12 v1.2* using OC-SDR v04.

Ocean Color satellite sensors measure visible light at specific wavelengths which leaves the surface of the ocean and arrives at the top of the atmosphere where the sensor is located. nL_W, can be calculated. nL_Ws are used to derive other ocean properties such as the concentration of chlorophyll-*a* (chlor-a, chlora, or sometimes chl , which is the green pigment responsible for photosynthesis and therefore and indicator of the amount of phytoplankton biomass in the ocean water) and the coefficients for attenuation of downwelling irradiance (K_d(PAR) and K_d(490) which are related to water clarity).

The ocean color datasets described here are from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor aboard the Suomi-NPP satellite (SNPP) which was launched in November 2011. The VIIRS SNPP ocean color science quality collection differ in several ways from the near real-time products (Table 1).

*Note that the metadata in the NetCDF files show v1.20 from the beginning of the collection (2 Jan. 2012) up tthrough 24 April 2017 and v1.21 from 25 April 2017 forward. This version change did not affect retrieval values for the standard products served by CoastWatch.

- Daily
- 750 m resolution

https://coastwatch.noaa.gov/cw/satellite-data-products/ocean-color/science-quality/viirs-snpp.html

Data Sets Used

OAA Submit

the Help Desk:

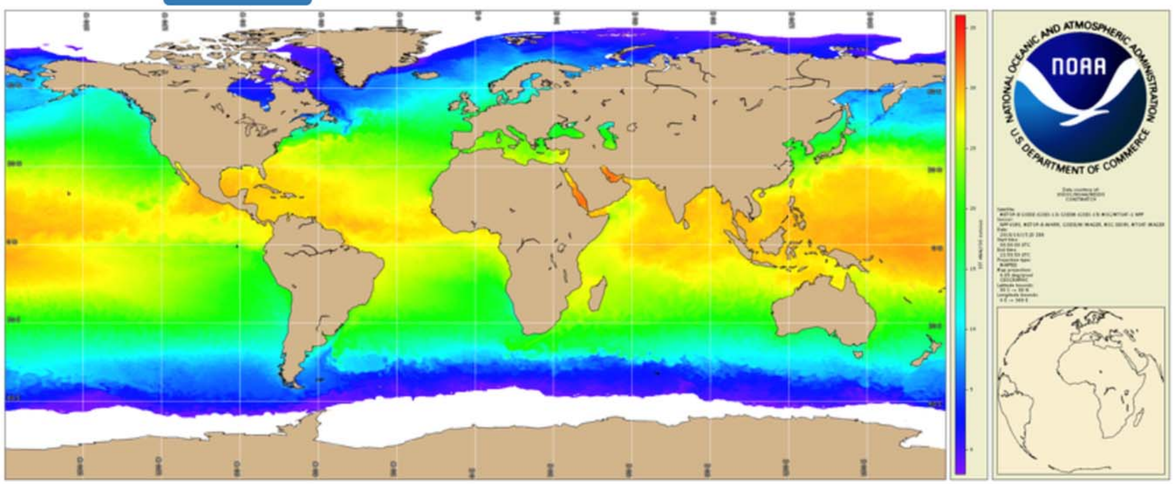
Email | (301) 683-3335

NOAA Geo-Polar Blended Global Level 4

Satellite Data Products / Sea Surface Temperature / NOAA Geo-Polar Blended Global Level 4

Updated: December 18, 2018

Data Access | **Description** | Information | Documentation



The National Oceanic and Atmospheric Administration's (NOAA) office of National Environmental Satellite Data and Services (NESDIS) now generates a daily 0.05° (~5km) global high resolution satellite-based sea surface temperature (SST) analyses on an operational basis. The new analysis combines SST data from U.S, Japanese and European geostationary infrared imagers, and low-earth orbiting infrared (U.S. and European) SST data, into a single high-resolution 5-km product - this grid spacing was chosen to allow the resolution to approach the Nyquist sampling criterion for the mid-latitude Rossby radius (~20 km), in order to preserve mesoscale oceanographic features such as eddies and frontal meanders. The input SST data themselves are also processed in-house via the Geo-SST Bayesian and physical retrieval approach (GOES-E/W, Meteosat-10), and, for polar-orbiting and Himawari-8, the Advanced Clear Sky Processor for Oceans (ACSPO).

- Daily
- 0.05° (~5km) global resolution

https://coastwatch.noaa.gov/cw/satellite-data-products/sea-surface-temperature/sea-surface-temperature-near-real-time-geopolar-blended.html

Data Sets Used

Submit

lelp Desk:

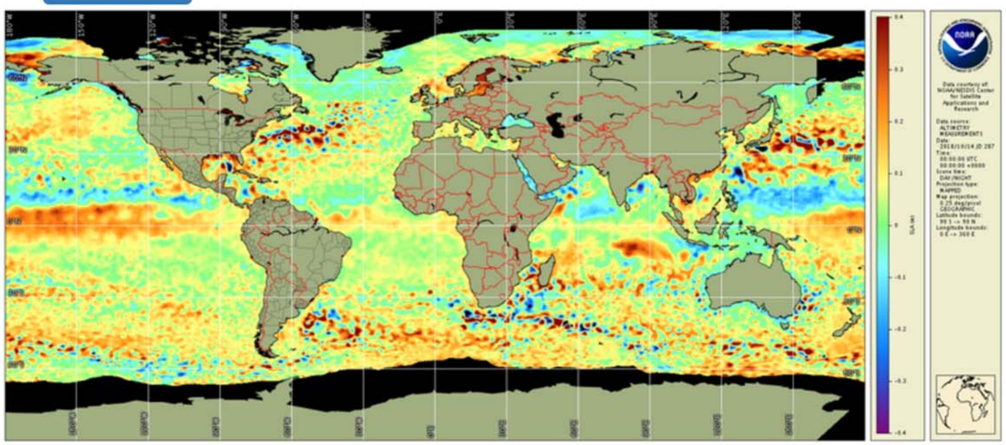
3335

Optimal interpolation Level-3 sea level anomalies composite from multiple altimeter missions

Satellite Data Products / Sea Surface Height / Optimal interpolation Level-3 sea level anomalies composite from multiple altimeter missio

Updated: December 18, 2018

Data Access | Description | Information | Documentation



The NOAA Laboratory for Satellite Altimetry's (LSA) sea surface height team produces 0.25-degree longitude/latitude Level-3 sea level anomaly (SLA) daily datasets by applying optimal interpolation to along-track satellite observations over the global ocean from a constellation of radar altimeter missions. Theses grids are produced with near-real time (3-5 hour latency) data.

The altimetry data are from RADS (http://rads.tudelft.nl/rads/rads.shtml), the Radar Altimetry Database System, first developed at Delft University of Technology, now also at the NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The RADS data for each mission is updated with state of the art corrections for tides, atmospheric path delay, etc. Because they are all computed consistently between the various missions, this avoids the possibility of introducing biases and drifts because of the different implementation of the various corrections by different agencies. The goals of RADS are to provide a homogenous dataset of sea level anomalies, wave heights, and wind speeds, along with database selection and analysis tools.

- Daily,
- 0.25° resolution
-

https://coastwatch.noaa.gov/cw/satellite-data-products/sea-surface-height/optimal-interpolation-level-3-sea-level-anomalies-from-multiple-altimeter-missions.html

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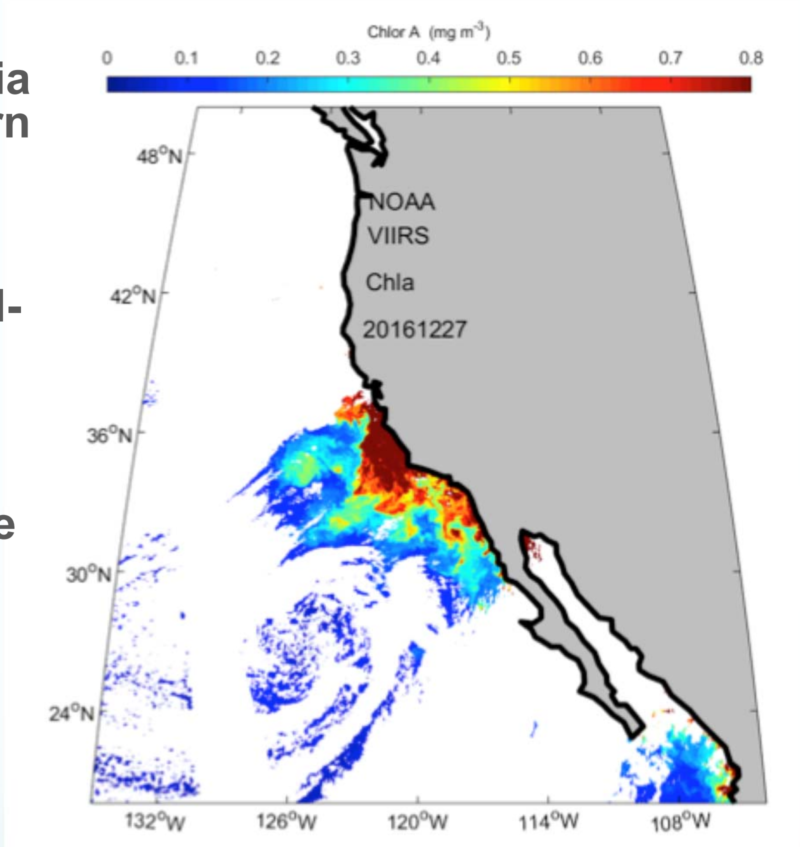
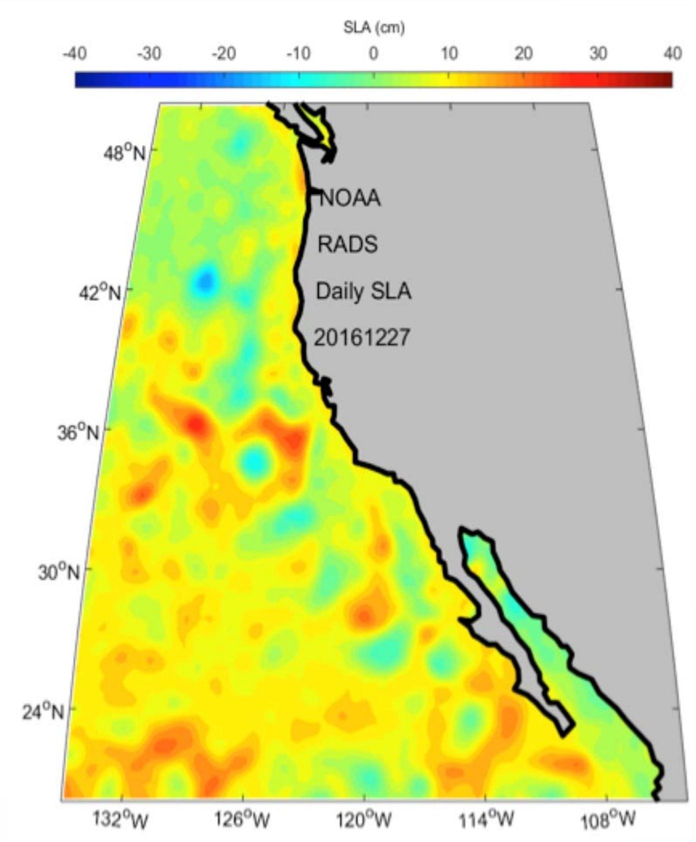
Chl-a Filaments and Eddies near deep slope

In the California Current Eastern Boundary System,

- **chlorophyll-a filaments and blobs along the shelf-slope region were also strongly associated with cyclones,**
- **especially during peak upwelling periods.**





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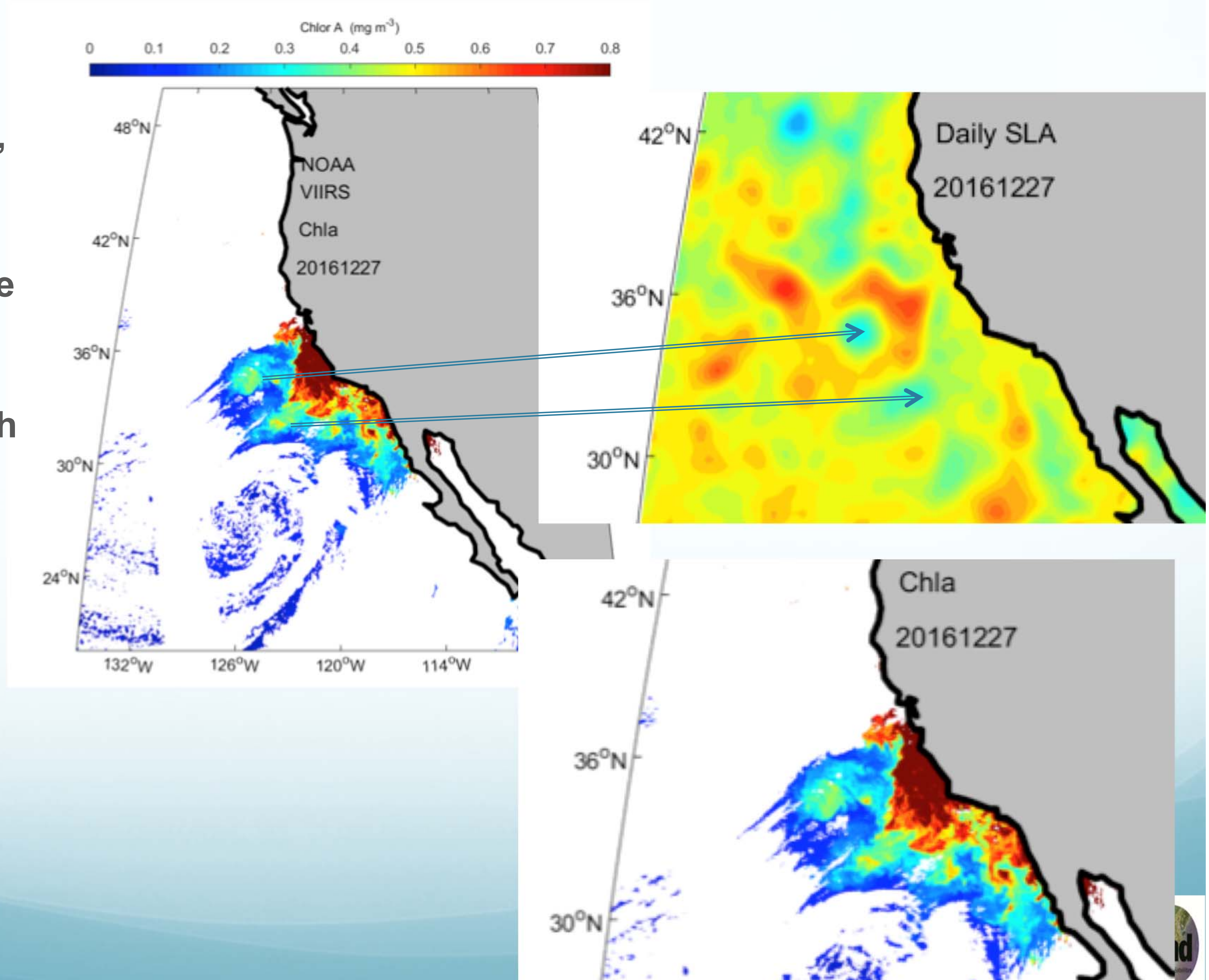

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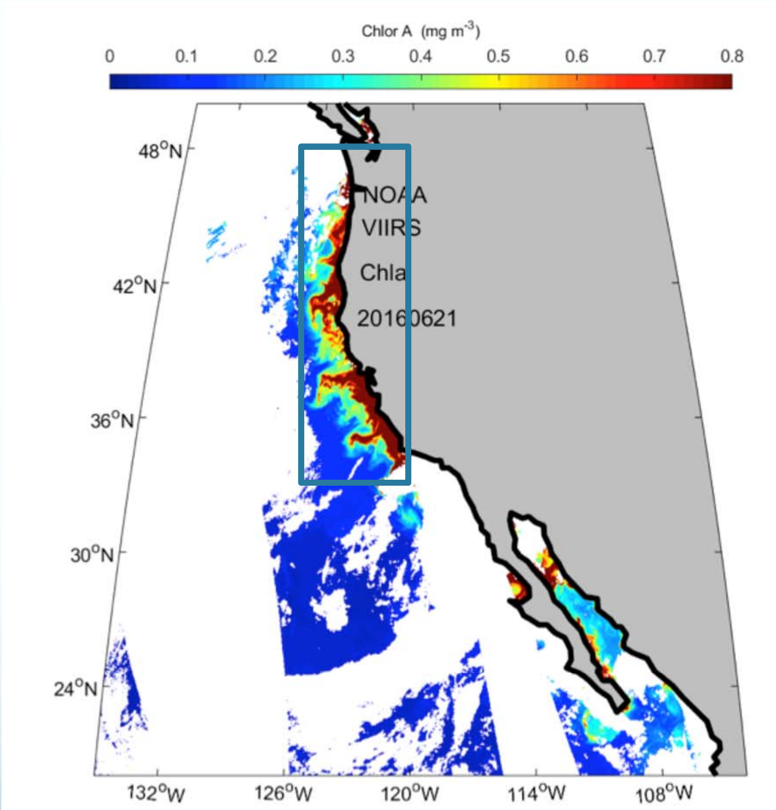

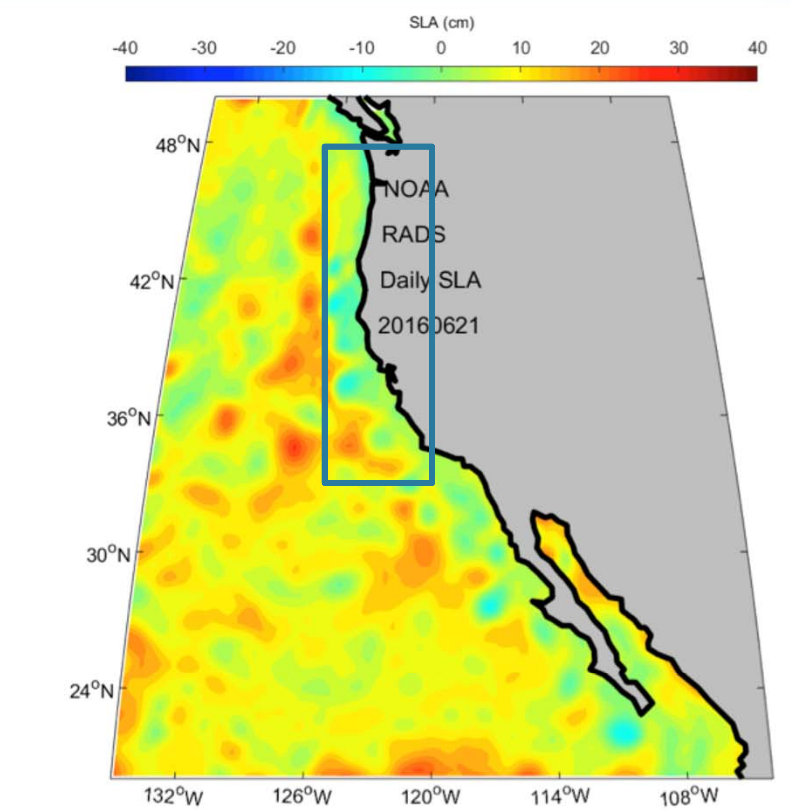

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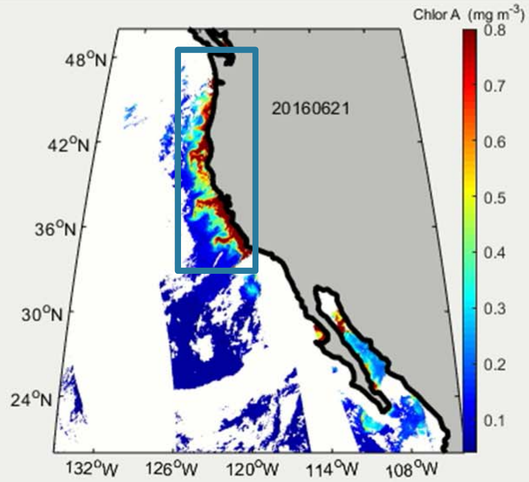
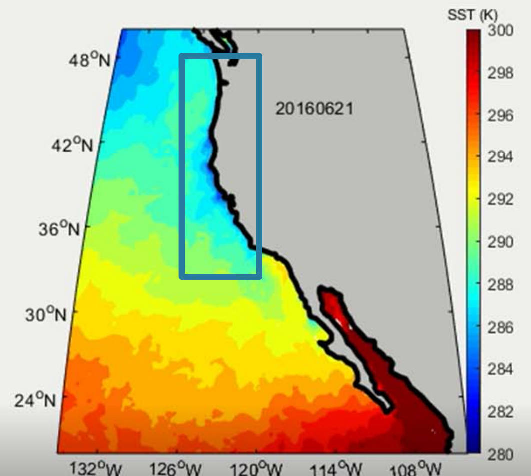
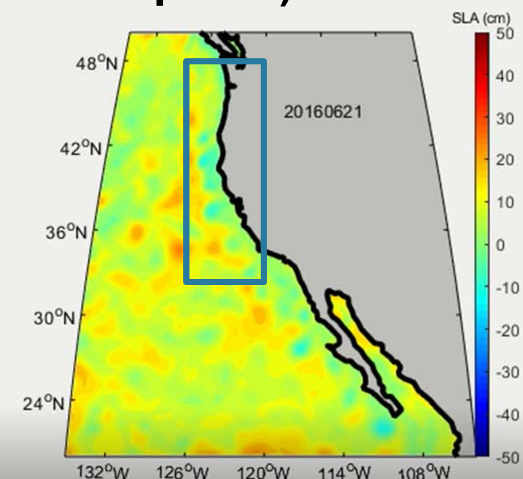
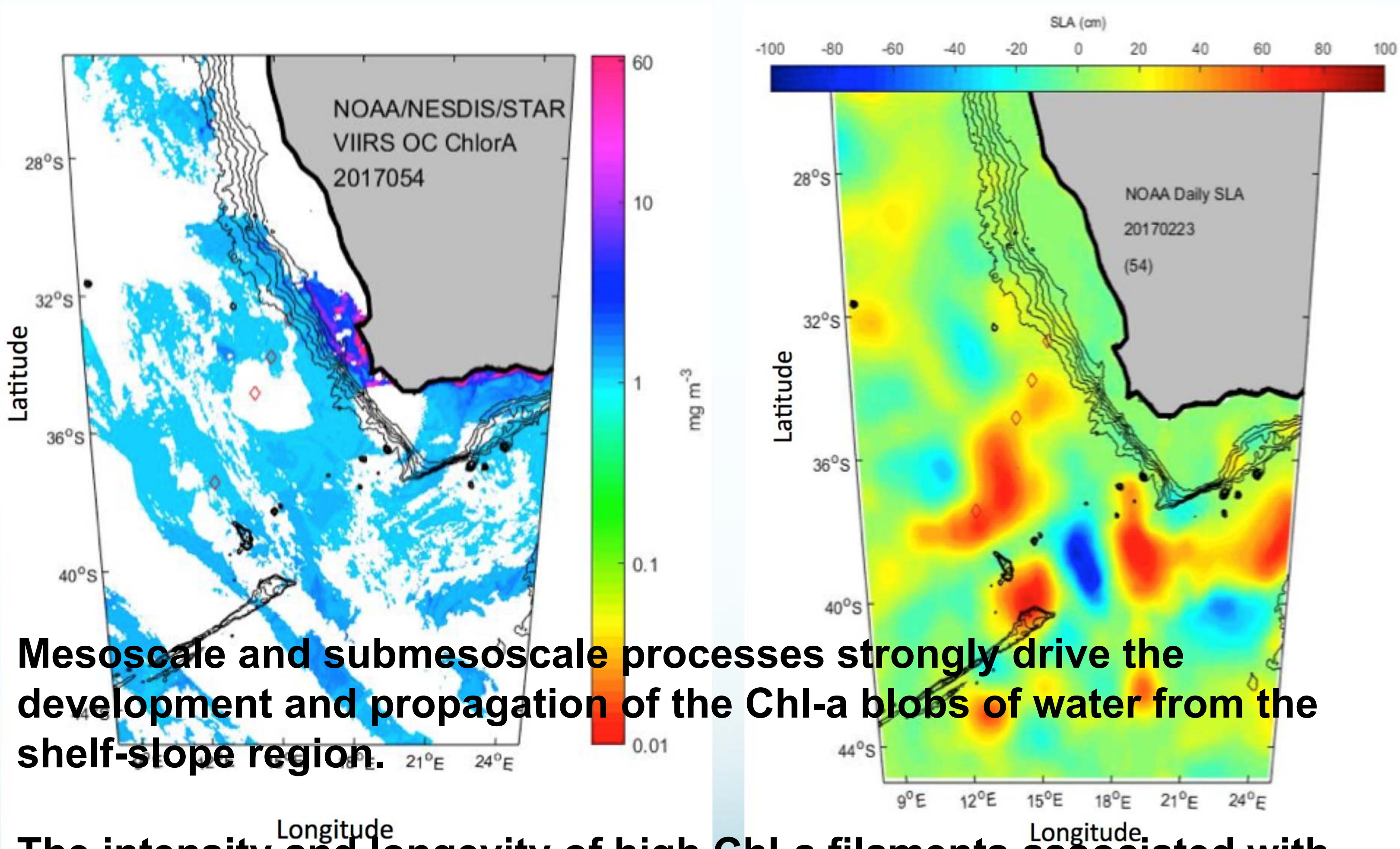


Chlorophyll-a filaments (upper left) and blobs along the shelf-slope region were also strongly associated with cyclones (lower right) and cold slope water filaments (lower left). (View Loop File)





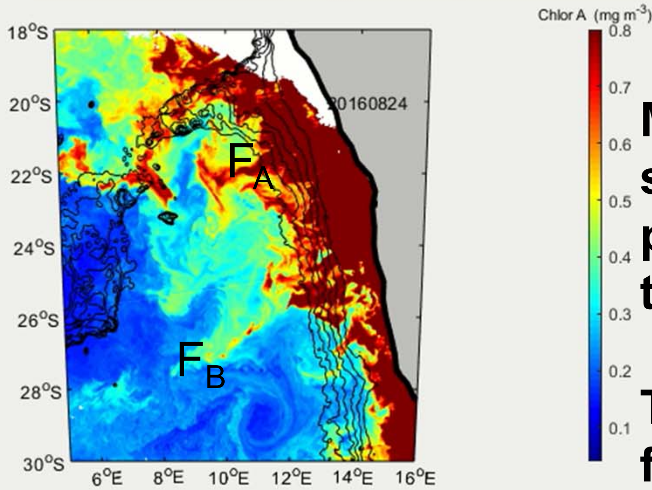
Chl-a Filaments and Eddies near deep slope



Mesoscale and submesoscale processes strongly drive the development and propagation of the Chl-a blobs of water from the shelf-slope region.

The intensity and longevity of high Chl-a filaments associated with the Benguela upwelling system are strongly related to deep ARs and their remnant eddy parts.

Chl-a Filaments and Eddies near deep slope



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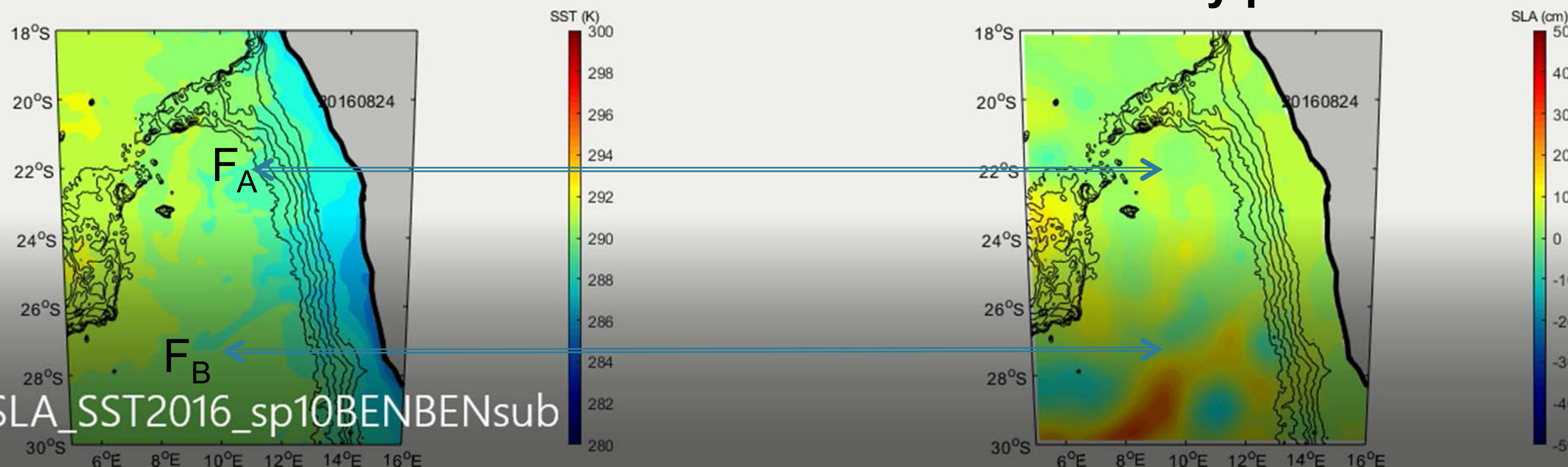

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Summary Points

- The ocean dynamic signal of cyclonic and anticyclonic eddies are equally important in both the California and Benguela Eastern Boundary Upwelling Systems at enhancing the seaward component of upwelling as observed over a 3-year period of 2015 to 2017.
- In the California Upwelling regions, large filament extended 200 km to 500 km from the deep slope (1000 m isobar) with variable width: broader near the shelf slope (80 to 160 km) and narrowing seaward (30 to 20 km), lasting on average up to 4 weeks in SST and OC, occurring off and on through out each year.
- Smaller filaments were just as ubiquitous but with scales near the shelf slope of 80 to 100 km and narrowing seaward to 30 to 20 km.
- Most filaments terminated in cyclonic curl based on OC data, showing strong cyclonic tendency or a T shape bridge indicating positive and negative vorticity.
- Cyclones were the primary carriers of the rich Chlorophyll-a signals.

Summary Points

- Sea surface height variability in conjunction with ocean color imagery show ARs and their split eddy parts act as a driver of long cross-slope high Chl-a filament formations in the Benguela Upwelling System;
- Benguela High Chl-a filaments and Agulhas eddy slope events occur more often than previously thought given the rich eddy field of the region and the consistent observation in satellite altimeter data that some ring parts follow the deep 3000 meter isobath away from the main (west-northwest) pathway of the ring corridor.
- This shelf-slope branch of the ring corridor provides a connection between the biologically active upwelling region and the open ocean, as western boundary current eddies influence an eastern boundary upwelling regime at sub- and mesoscales.

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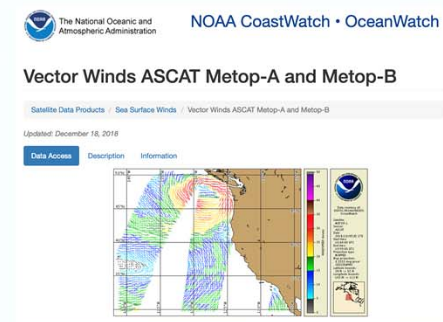
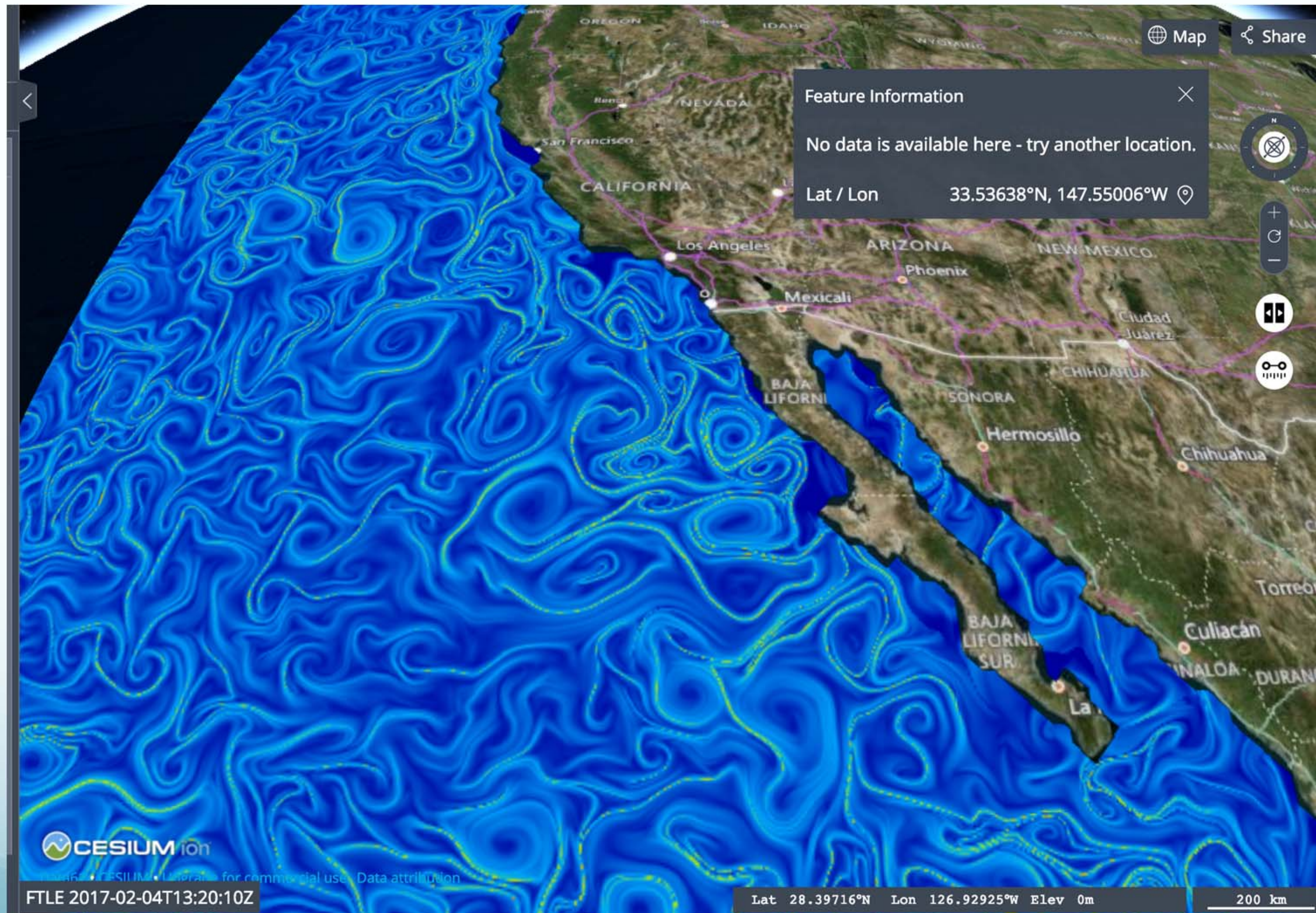
Further Applications (Ongoing)



- Add Winds from SAR or ASCAT Metop (A,B)
- Complete Overlay Fields
  - Sea Level Anomaly Velocity Vectors on SST
  - Sea Level Anomaly contours onto Ocean Color
    - NOTE: Physical and biological signatures in satellite data convey deep Agulhas Rings acting on the slope initially as deep as 3000 meters often precede high Chlorophyll-a and K490 cross-slope filament formation and blobs of high Chl-a water.
    - Cross-sensor analysis of sea surface height anomaly and ocean color chlorophyll satellite data show strong agreement in both regions of study and that biological inferences can be made from the combination of altimeter and OC data.
    - Dynamic features in the SLA field complement the cloudy OC Chl-a fields.

Further Applications (Ongoing)

- Complete Finite Time Lyapunov Exponent Maps



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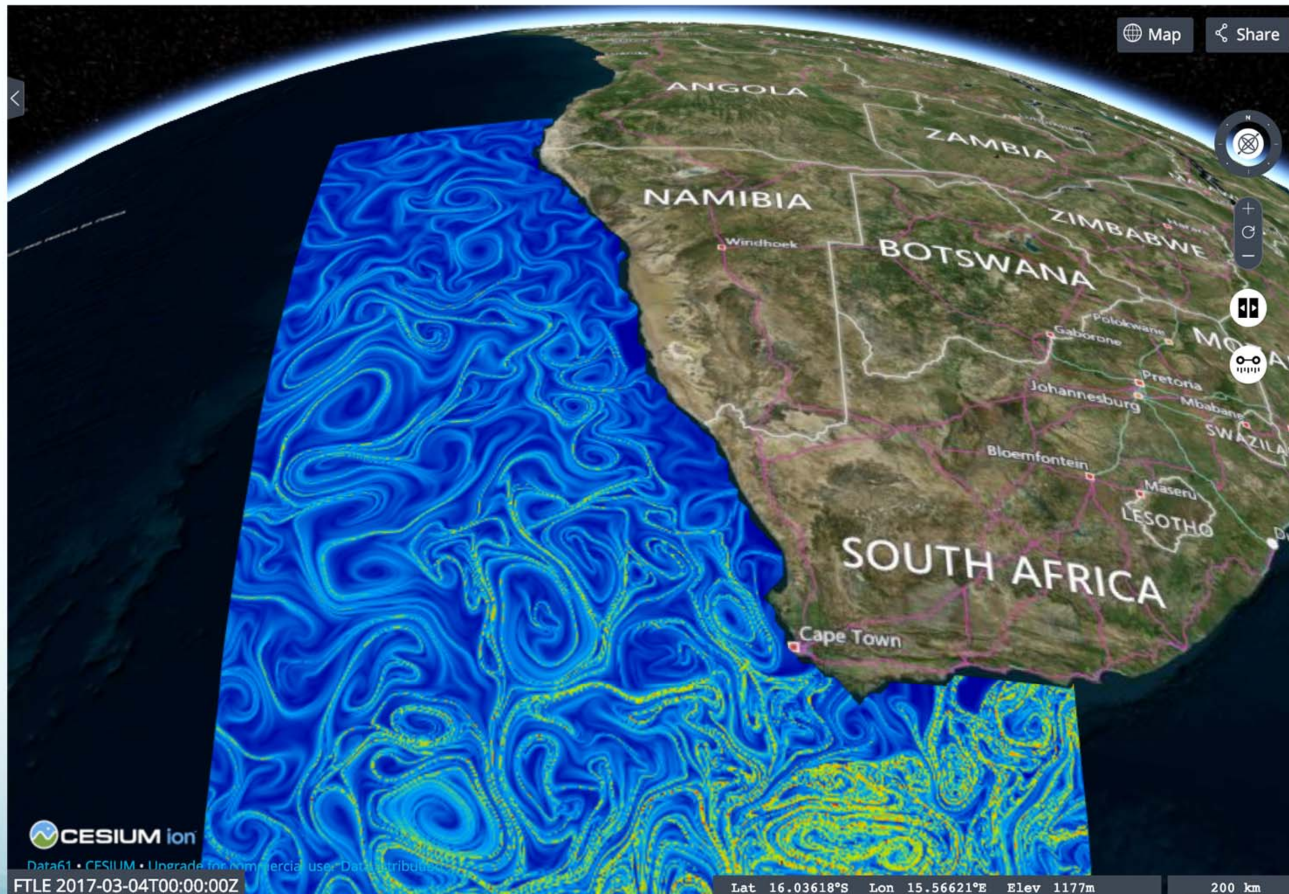

Jose Luis Aragon et. al (2006)

Vincent van Gogh (1889) The Starry Night

Barry B. Cael

Jackson Pollock (1912-1956) Wild Beast

The study of biophysical interactions

- **that drive plankton distributions**
- **is multifaceted and an ongoing study…**

Thank You