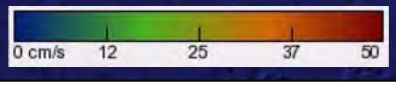
Sustained observations of mesoscale and submesoscale surface circulation off the U.S. West Coast

Sung Yong Kim[1,*], Eric Terrill[1], Bruce Cornuelle[1], Burt Jones[2], Libe Washburn[3], Mark Moline[4], Jeffrey Paduan[5], Toby Garfield[6], John L. Largier[7] Greg Crawford[8] and P. Michael Kosro[9]

[1]Scripps Institution of Oceanography
[2]University of Southern California
[3]University of California, Santa Barbara
[4]California Polytechnic State University
[5]Naval Postgraduate School
[6]San Francisco State University
[7]University of California, Davis
[8]Vancouver Island University, Canada
[9]Oregon State University

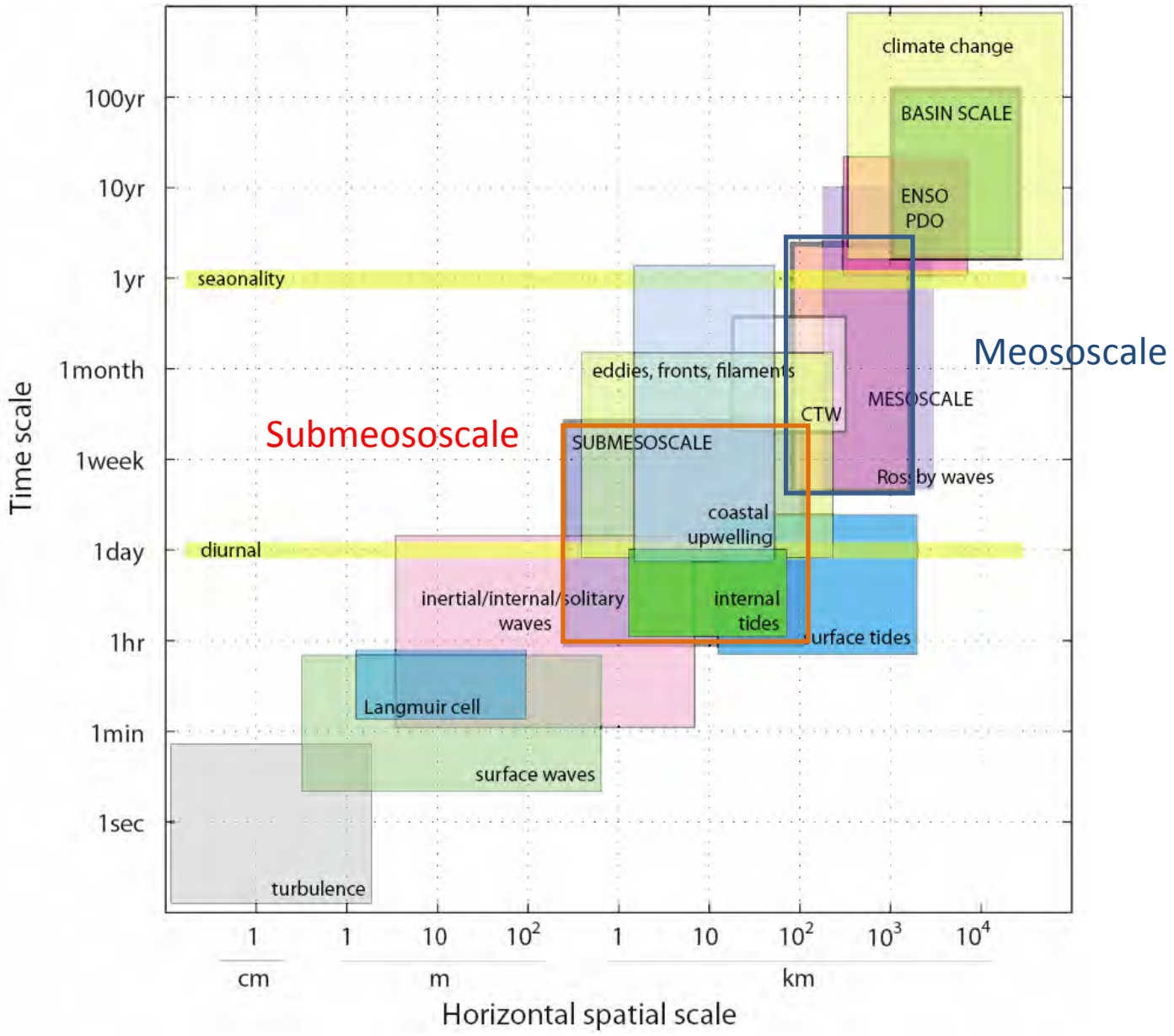
*syongkim@mpl.ucsd.edu
** The order of co-authors is geographically assigned.



Outline

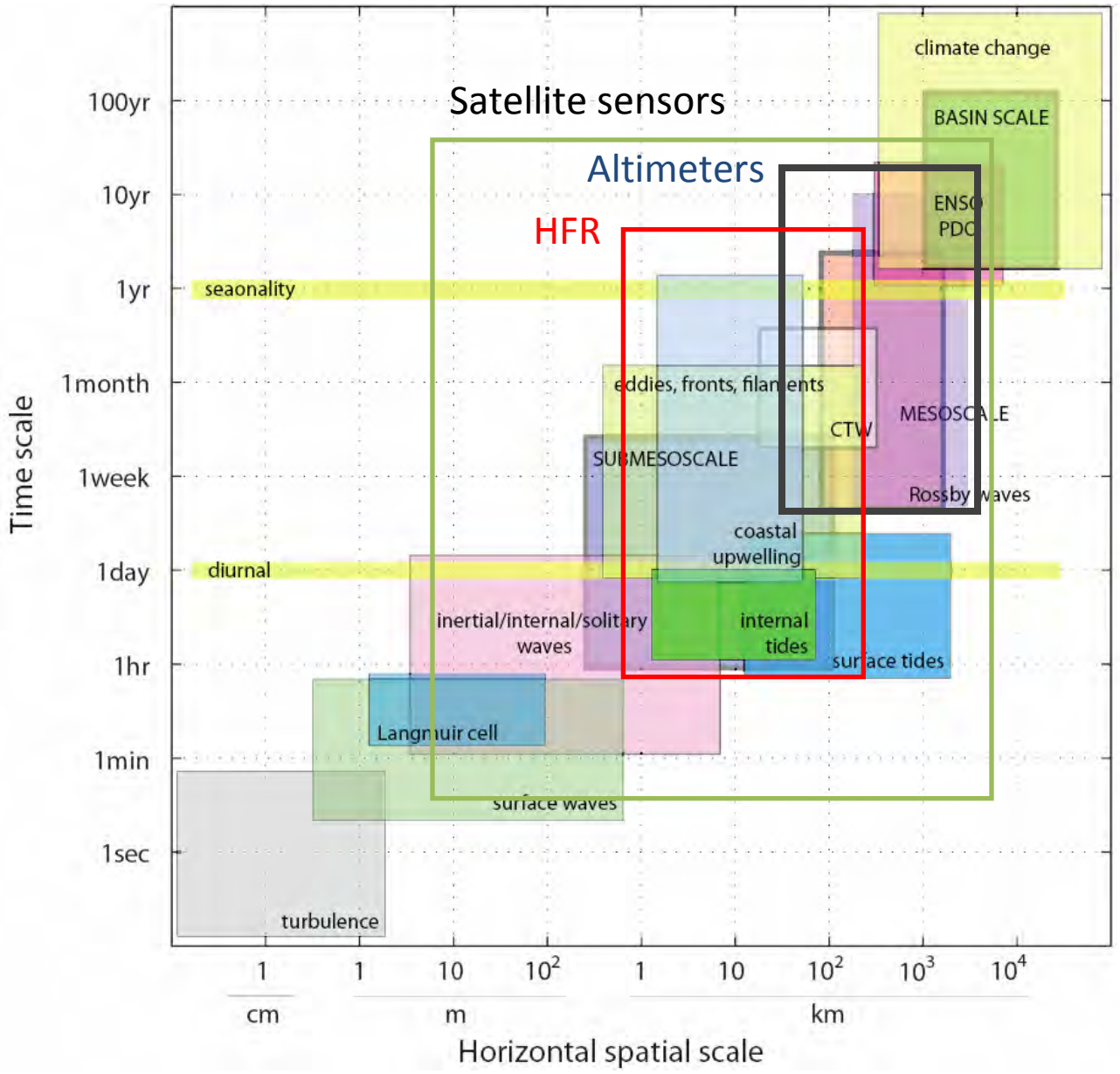
- Introduction
  - What's oceanic sub-meososcale and mesoscale?
  - Surface current measurement using high-frequency radar (as a part of coastal ocean observing system)
- Details of observed surface circulation
  - Driving forces of surface circulation
  - Low frequency signals trapped near the coast
  - Statistics of sub-meososcale edddies
  - Applications of surface transport model (e.g., river/outfall discharges and oil spill)
- Summary

Oceanic processes in time and spatial scales



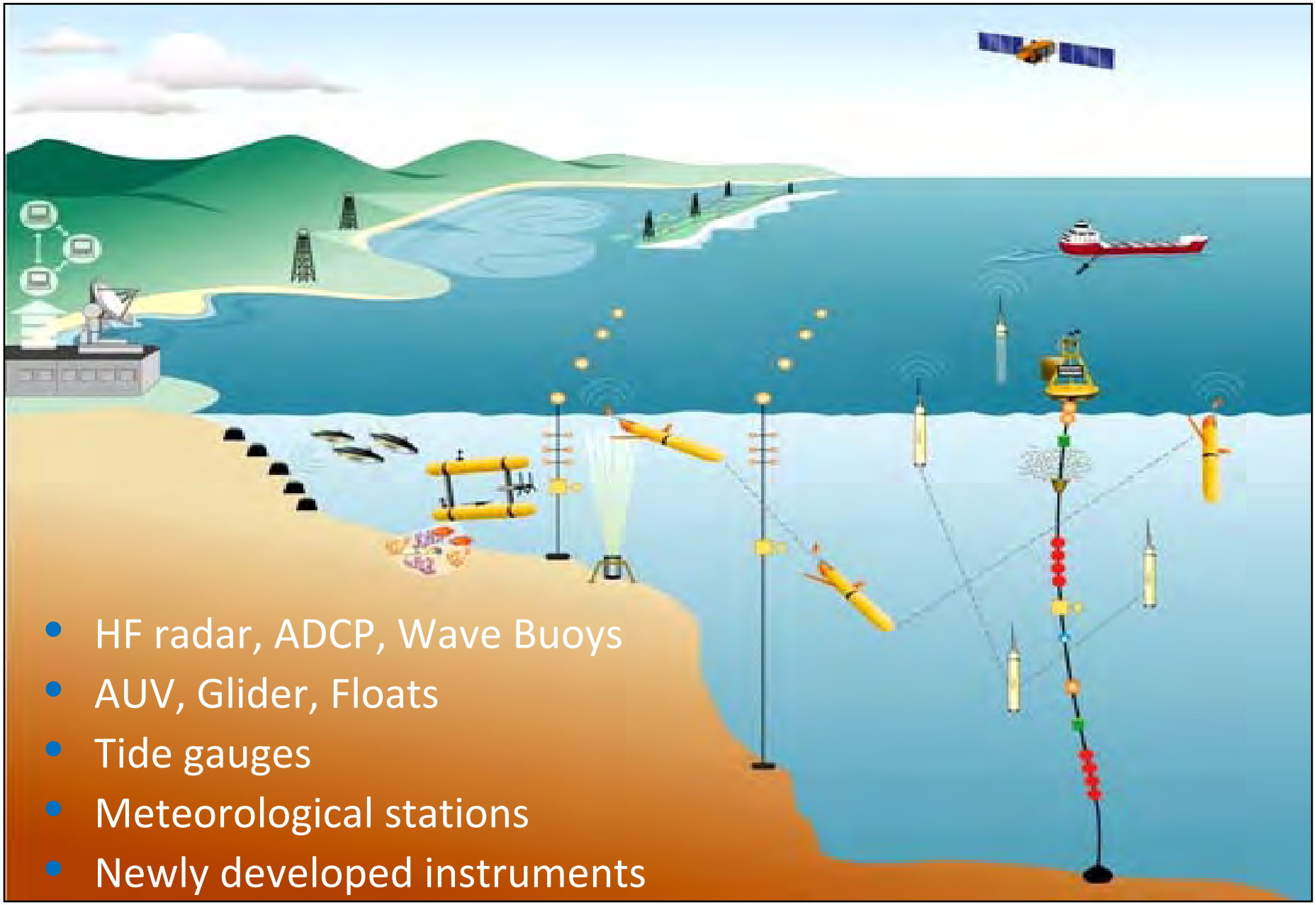
(Chelton 2001, Dickey *et al*, RG 2006)

Oceanic processes in time and spatial scales



(Chelton 2001, Dickey *et al*, RG 2006)

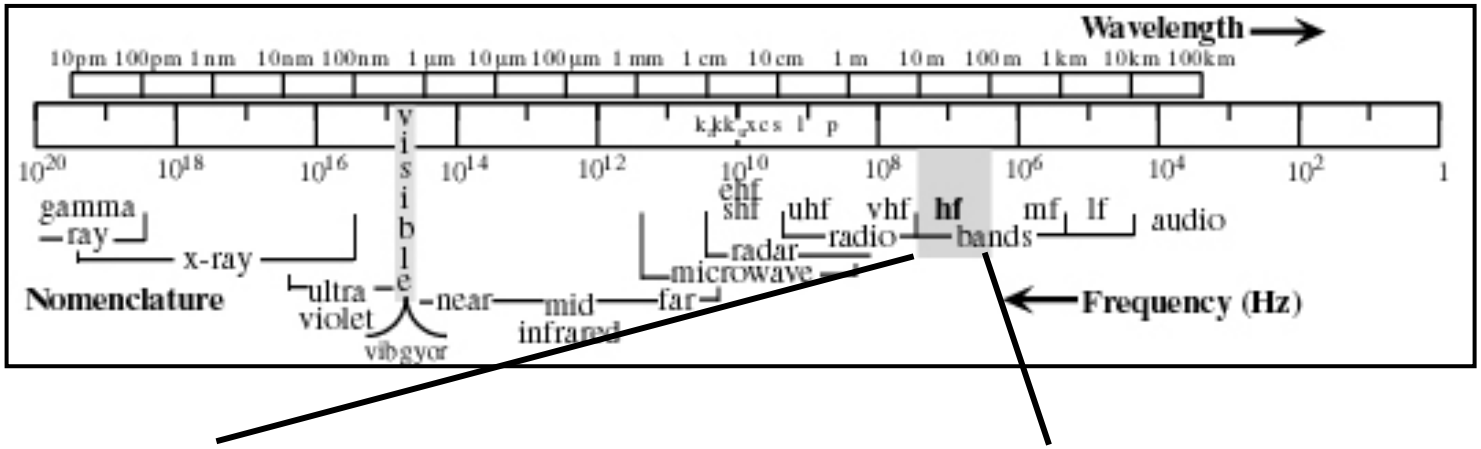
Coastal Ocean Observing System (COOS)



- HF radar, ADCP, Wave Buoys
- AUV, Glider, Floats
- Tide gauges
- Meteorological stations
- Newly developed instruments

http://www.imos.org.au/

Radio signals used in high-frequency radar



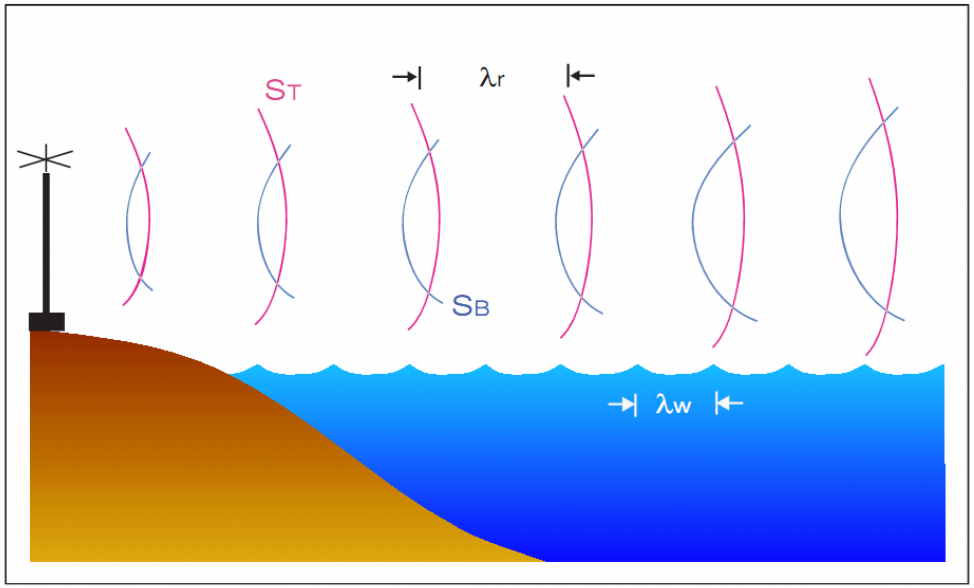
3-30 MHz (between AM radio and TV)

Wavelength (λ_r) : 10 ~ 100 (m)

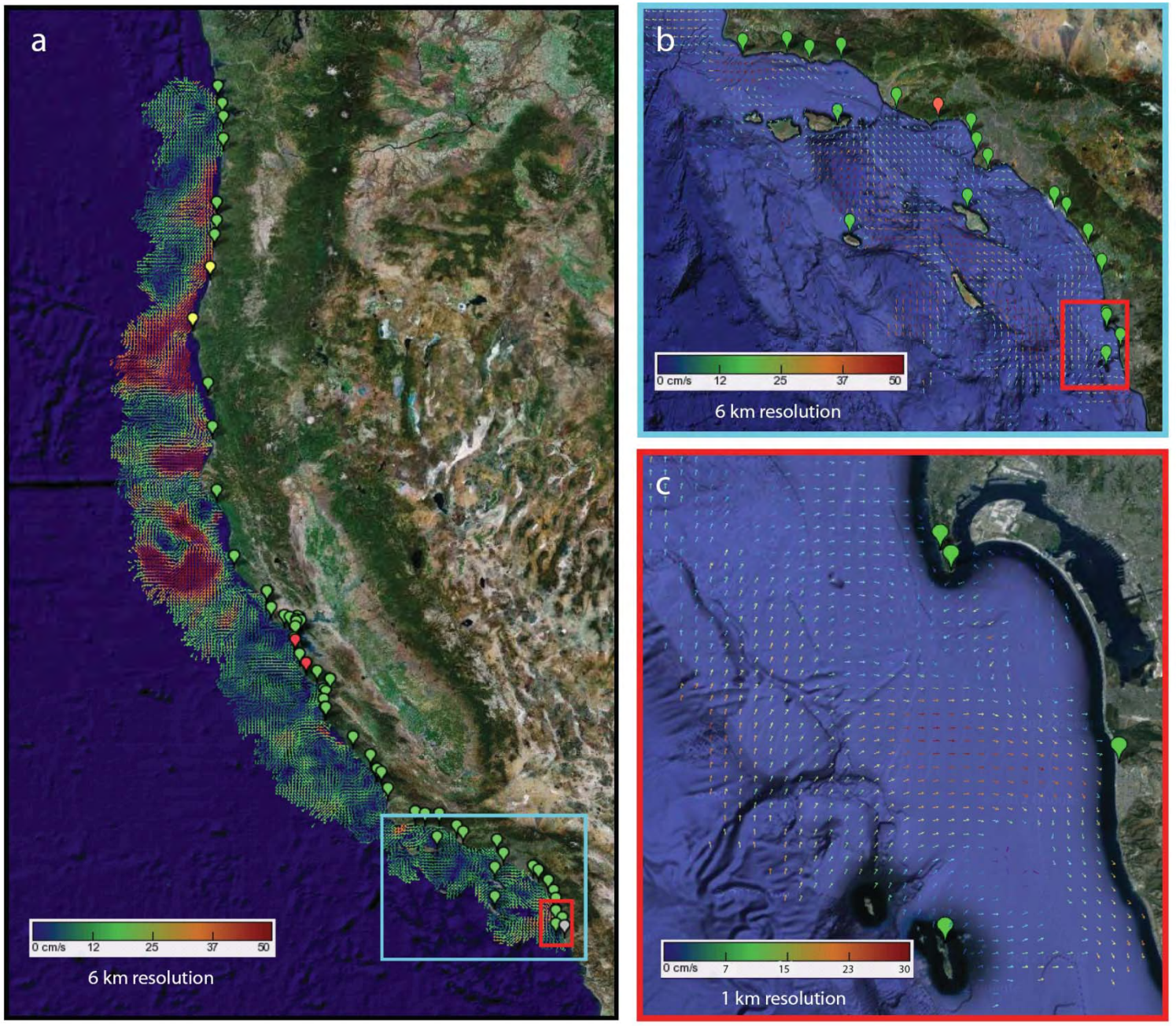
Bragg backscattering

When the radar signals are backscattered in phase,

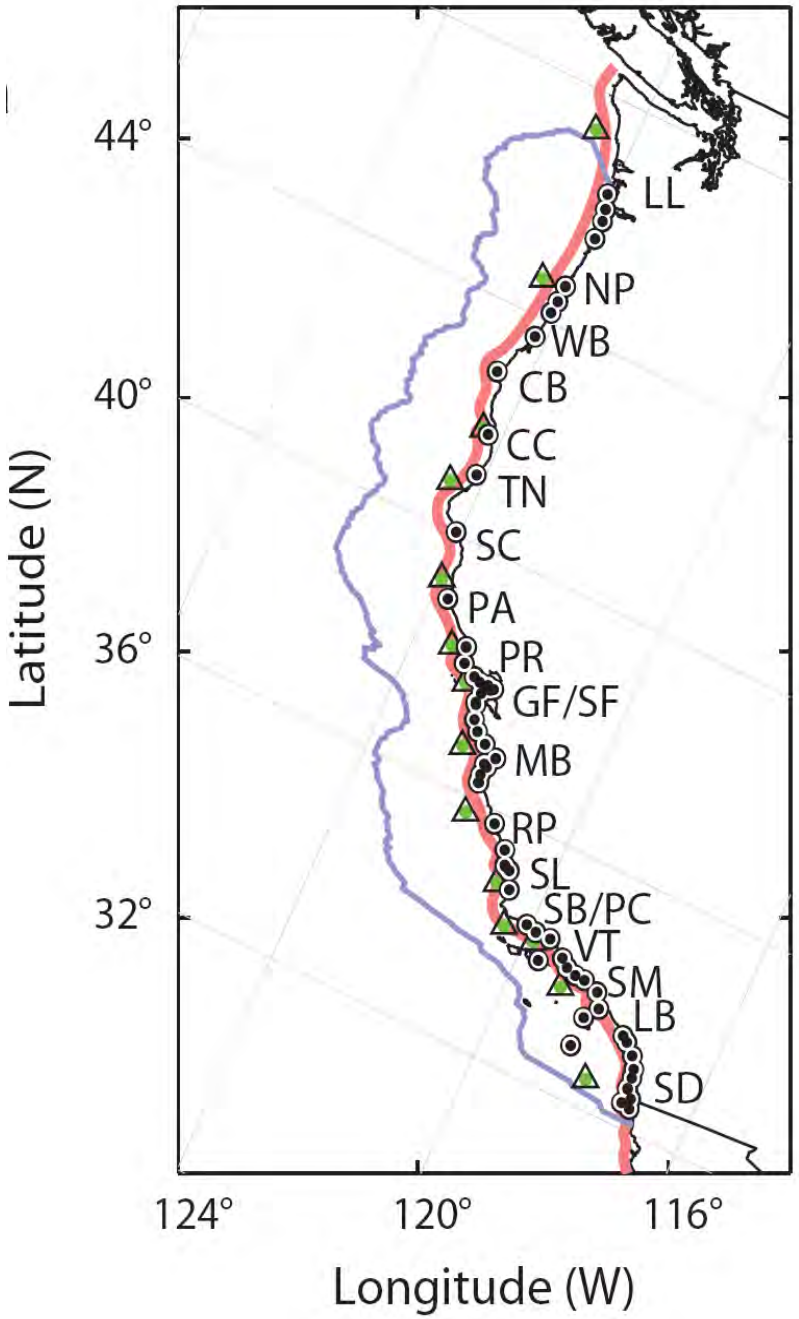
$$\lambda_w = \lambda_r / 2$$

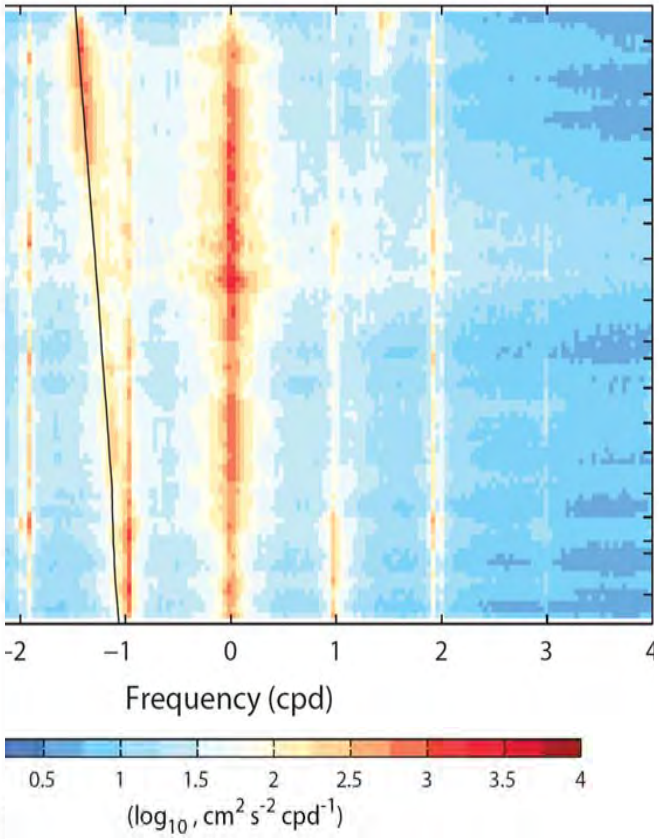


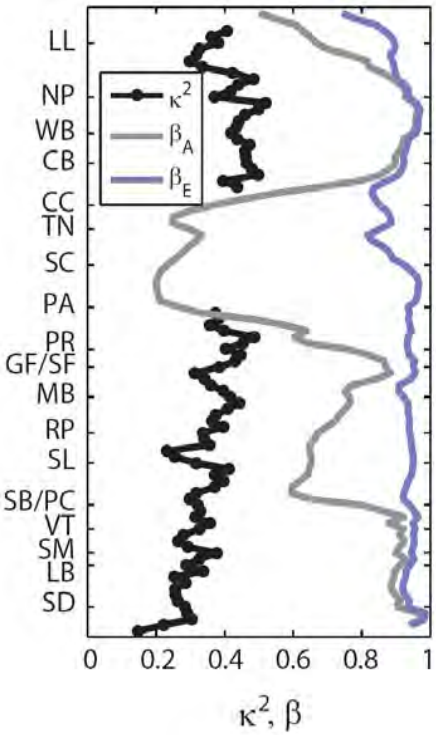
HFR surface current maps off the USWC (Cascade maps)



Variance of surface currents (alongshore view)

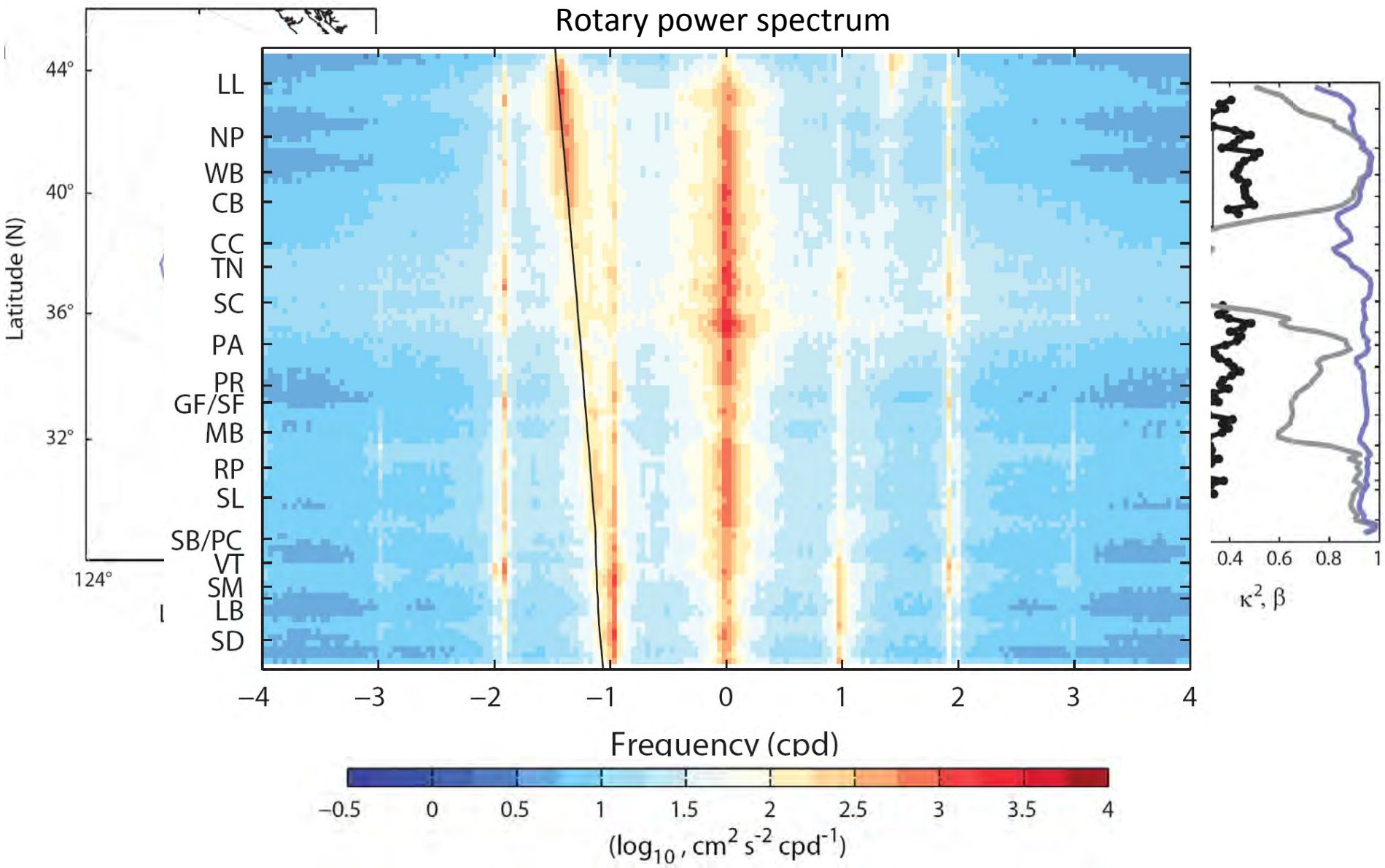






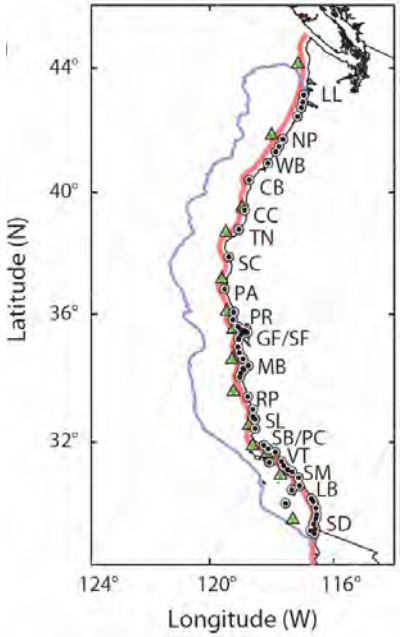
- 61 HFRs, 14 NDBC wind buoys hourly observations (2007 to 2008)
- Effective spatial coverage (blue; 6 km) and coastline axis (red; 25 km apart from shoreline)

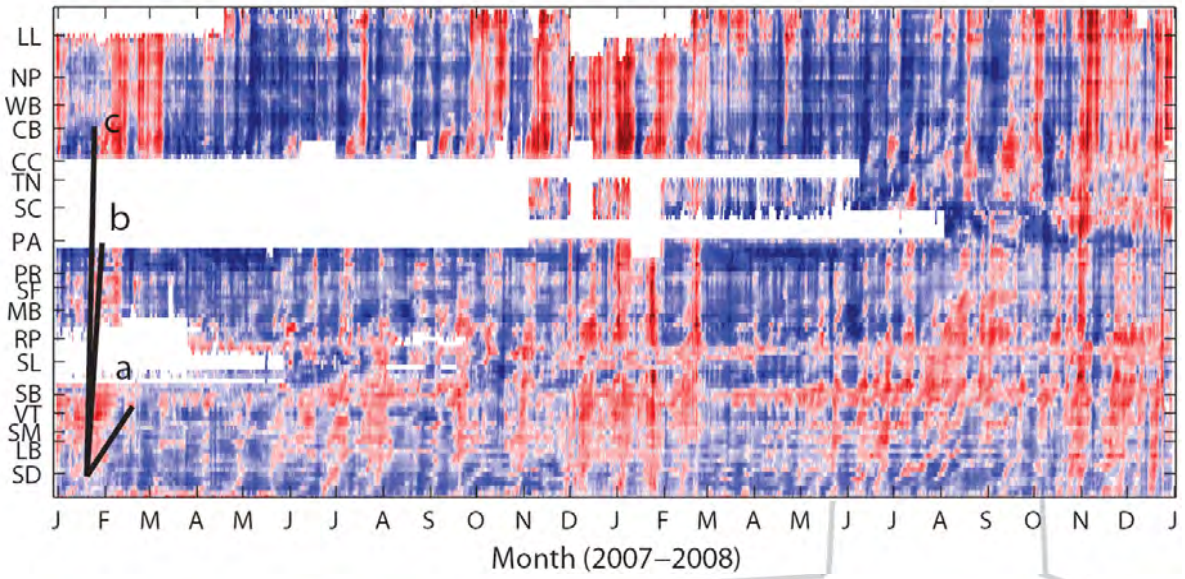
Variance of surface currents (alongshore view)

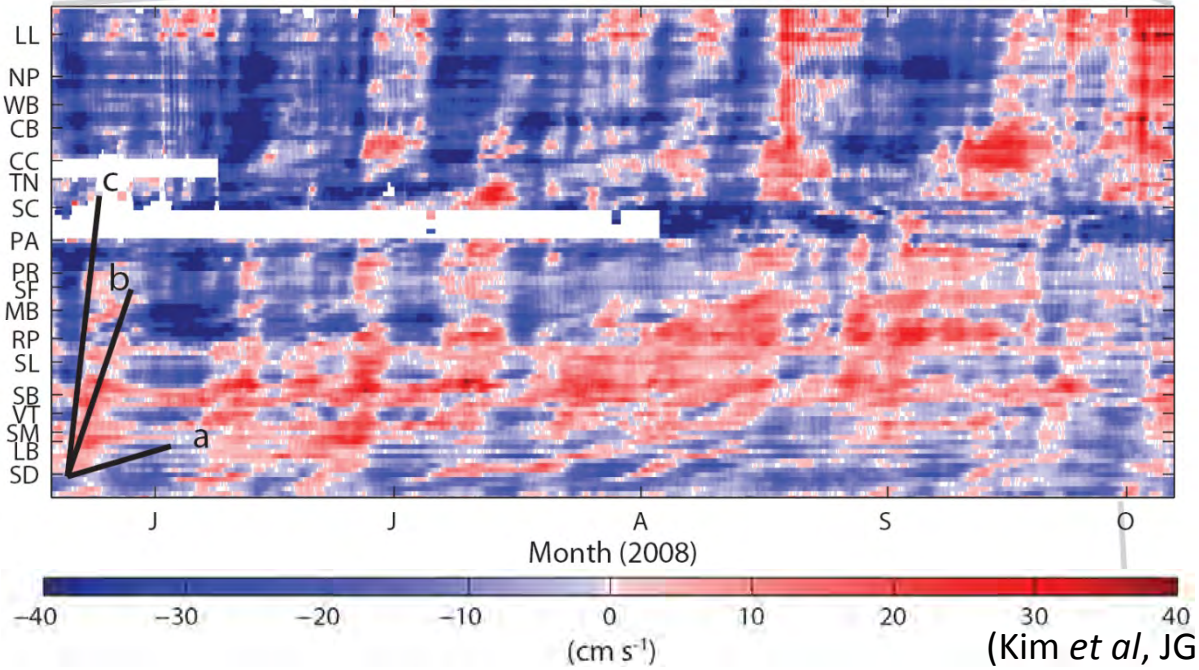


- Variance coherent with tides, wind, low frequency signals, and Coriolis force.
- Regional noise levels

Subinertial alongshore surface currents



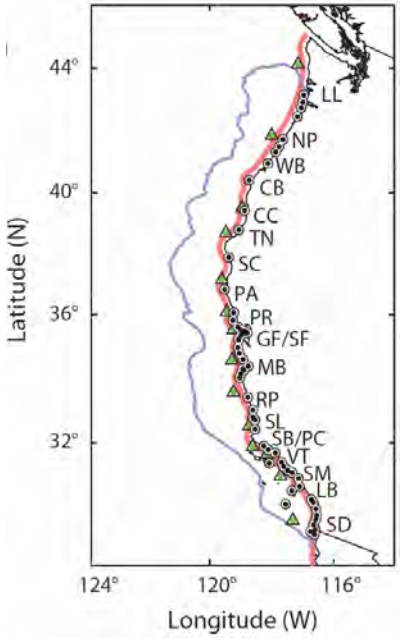


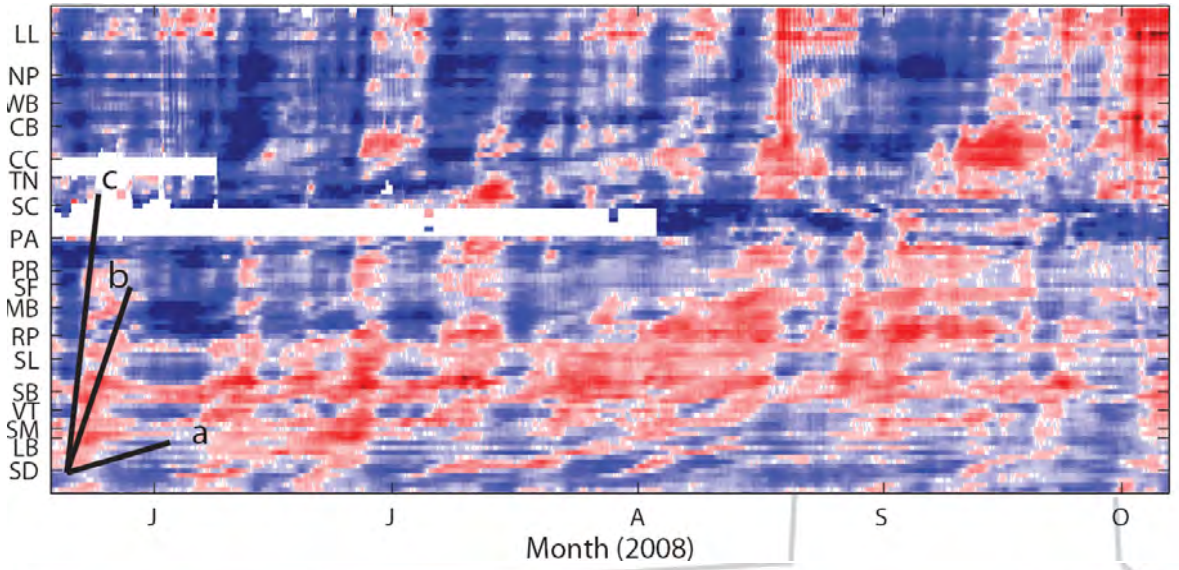


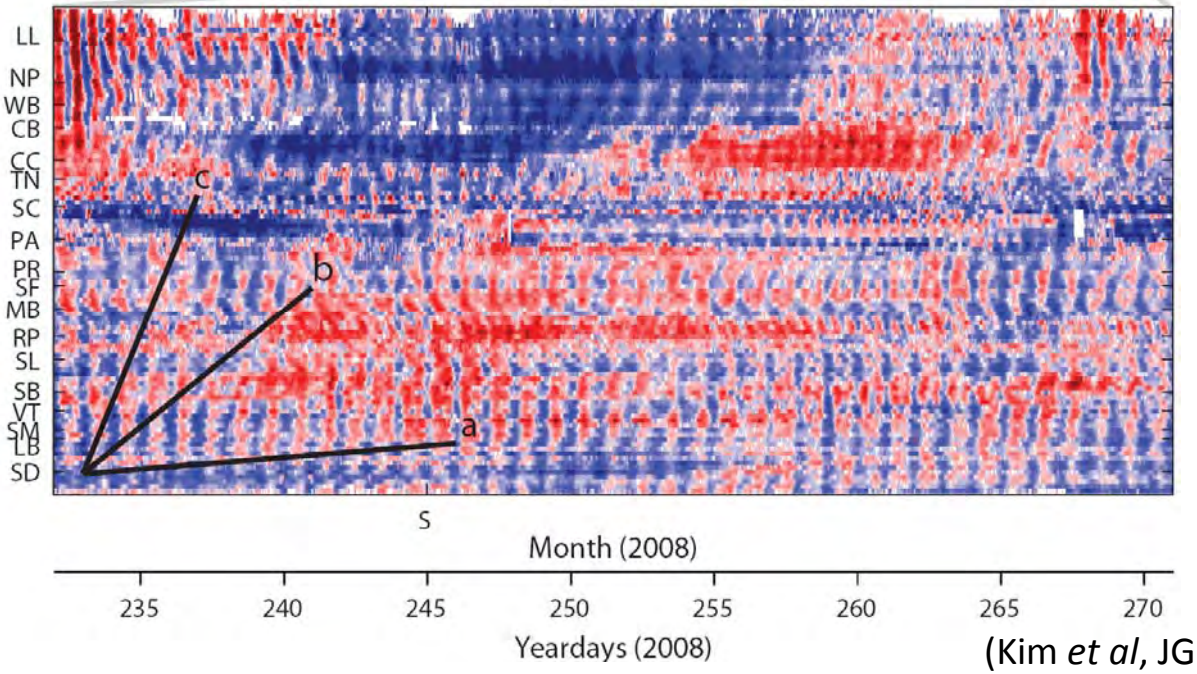
- Rotated currents following the shoreline
- Daily averaged alongshore surface currents.
- Seasonal California Currents.
- Phase speeds of 10 and 100 – 300 km/day
- Slower mode feature is found in southern CA

(Kim *et al*, JGR 2011)

Sub-inertial alongshore surface currents (zoom-in)



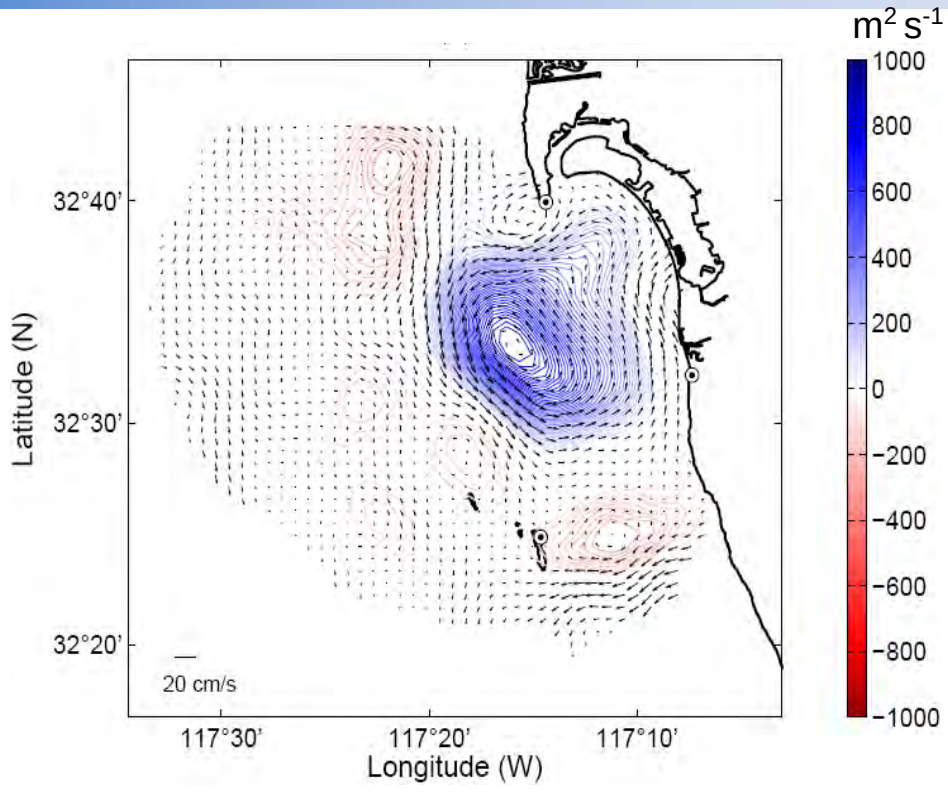


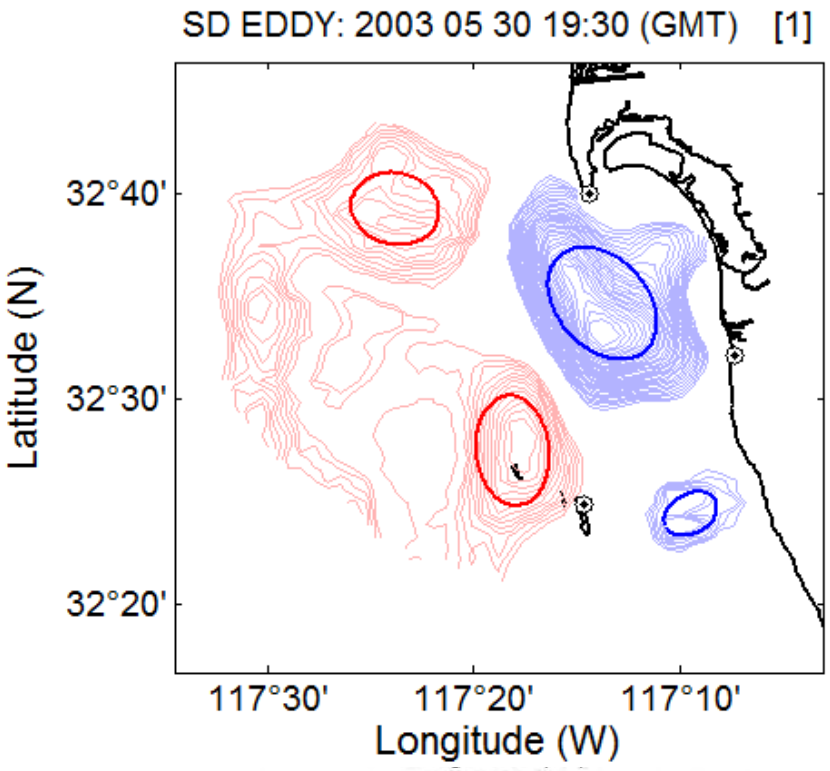


- Hourly alongshore surface currents.
- High-frequency structure coherent with diurnal wind and tides.
- Poleward progression of convergence front.

(Kim *et al*, JGR 2011)

Eddy detection on HFR surface currents





- Streamlines (nearly closed polygons) are identified with winding angle method.
- Co-centered streamlines are fitted into an ellipse.
- If the center of ellipses in consecutive time steps is within a drifting range (e.g., 1.5 km) with the same rotation, ellipses are considered as a part of an eddy time series. The length of time series is called as persistency

(Kim, CSR 2011)

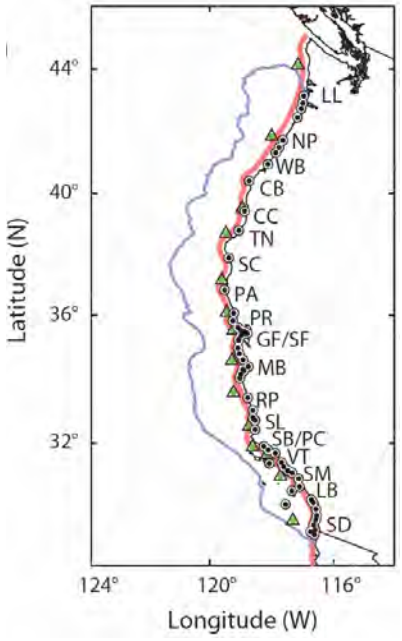
Demography of sub-mesoscale eddies

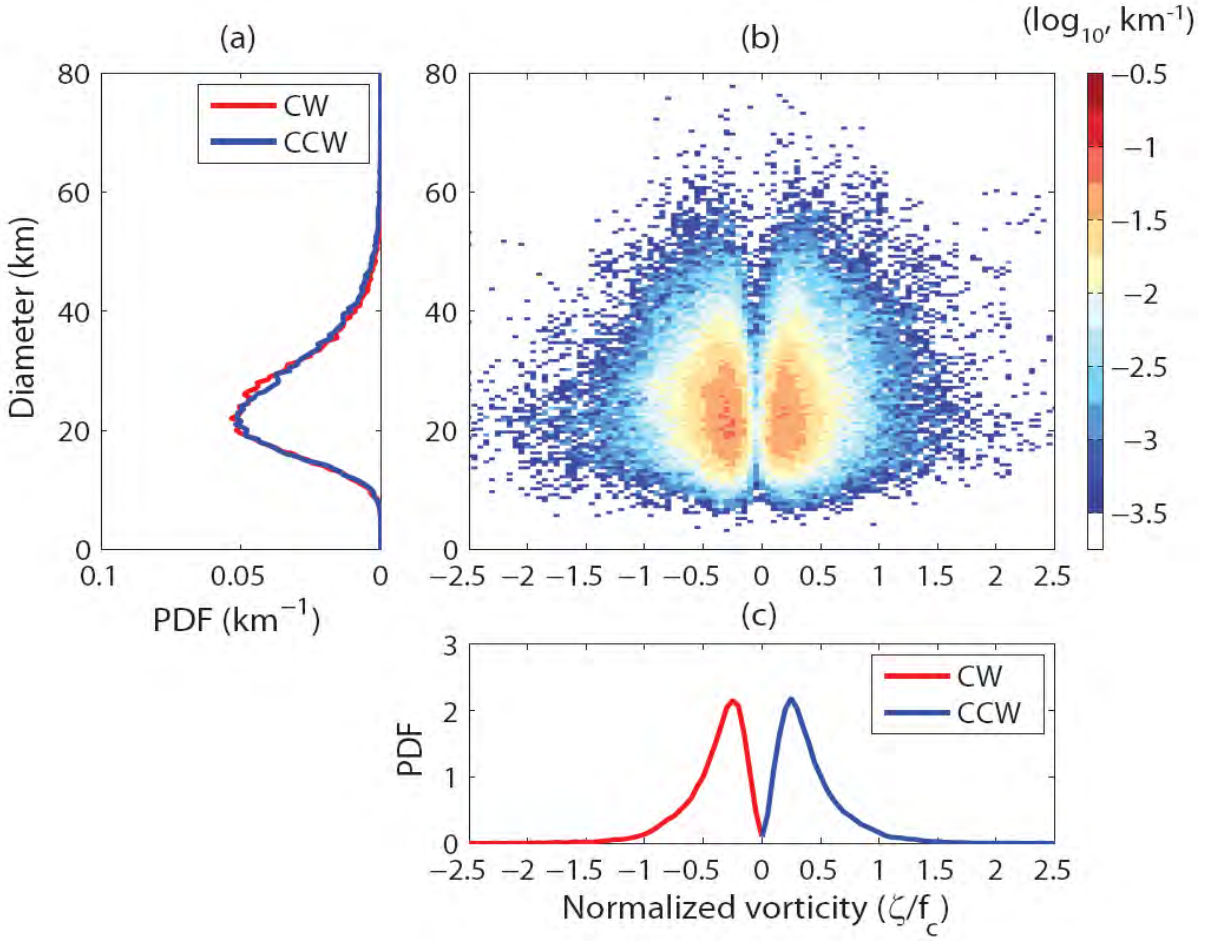
Using flow geometry of the stream functions.

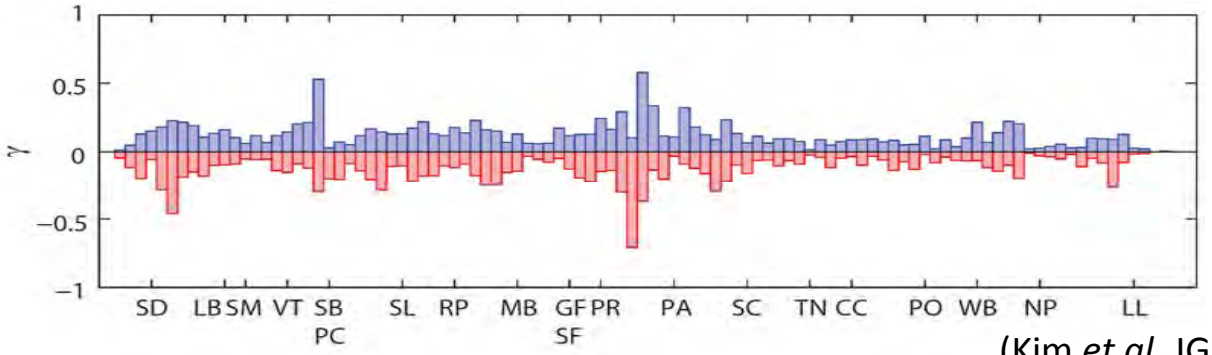
A cluster of streamlines is fitted with an ellipse. (Kim CSR, 2010)

Vorticity at the center of eddies.

About 2200 eddies for each rotation are identified (at least two days persistence).

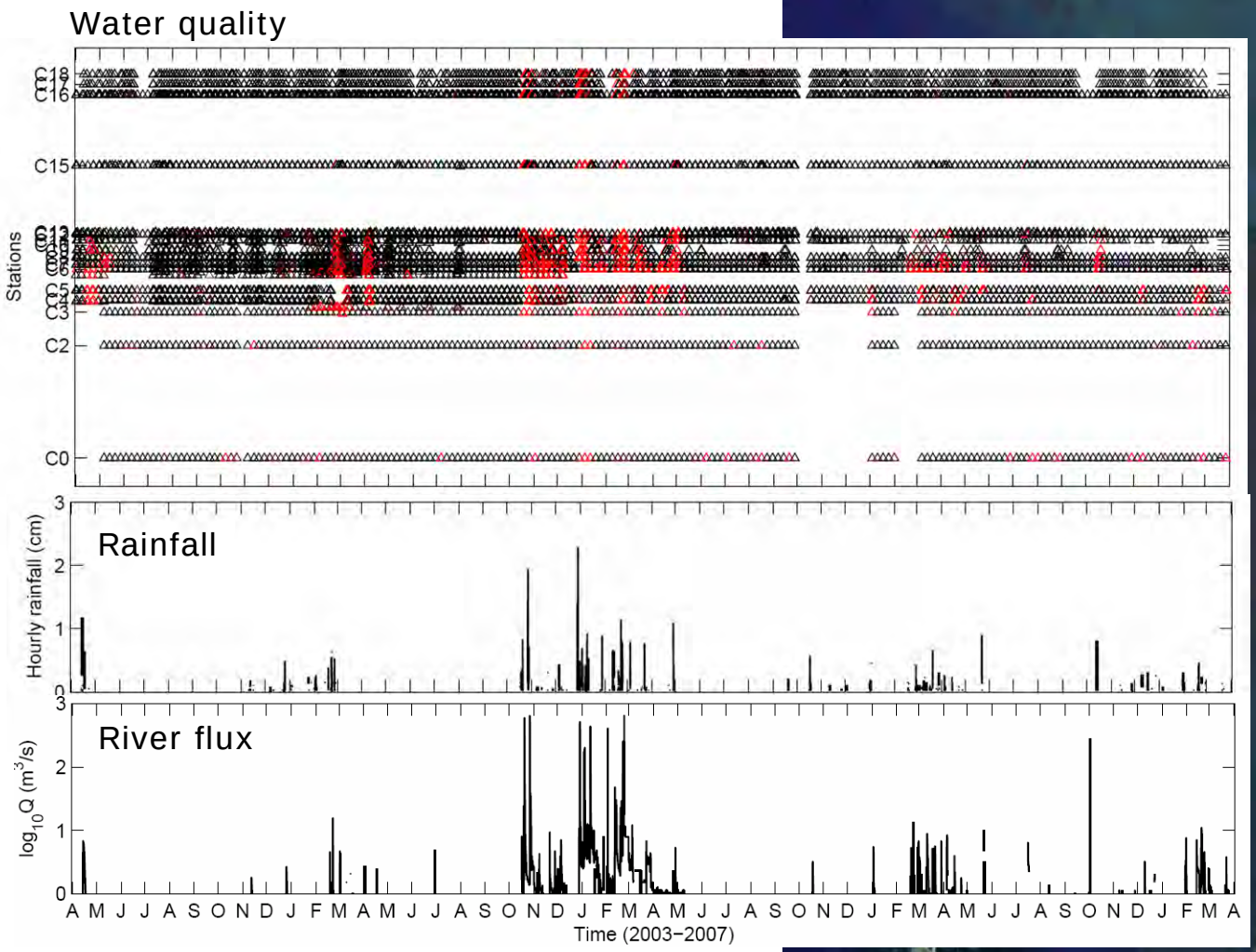


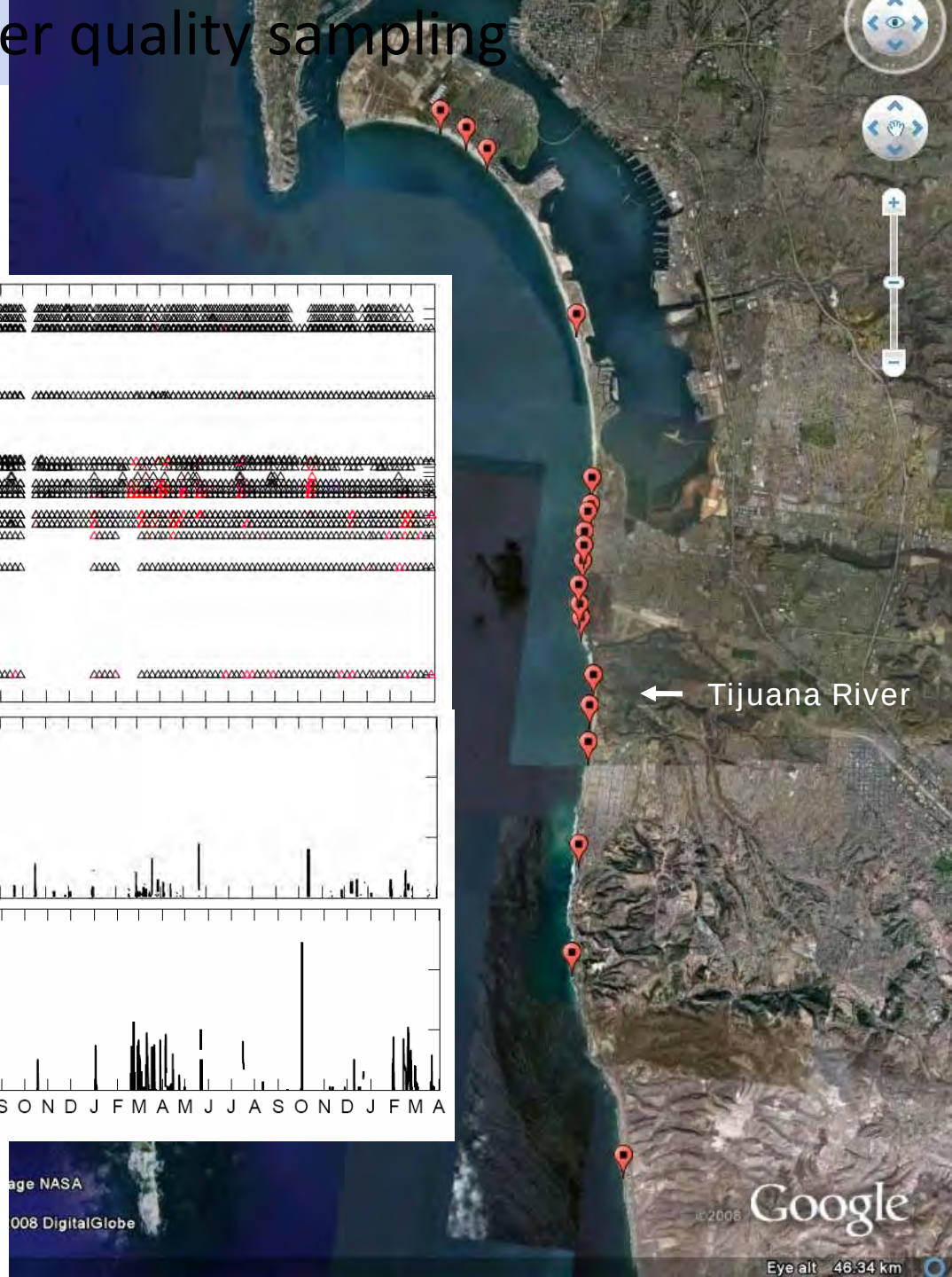




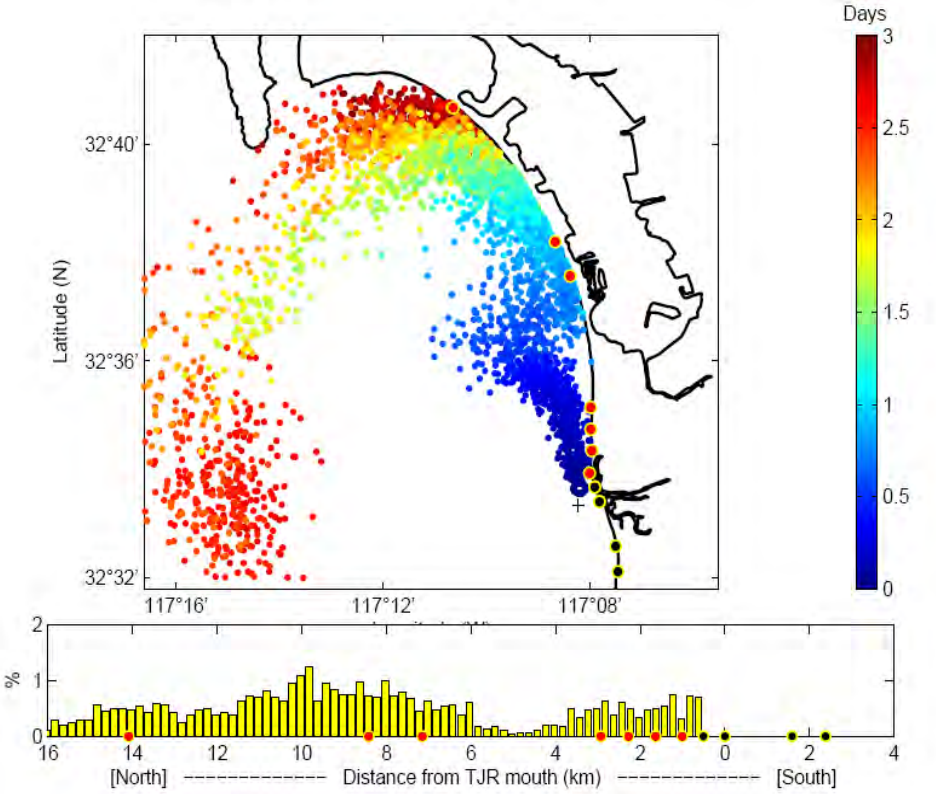
(Kim *et al*, JGR 2011)

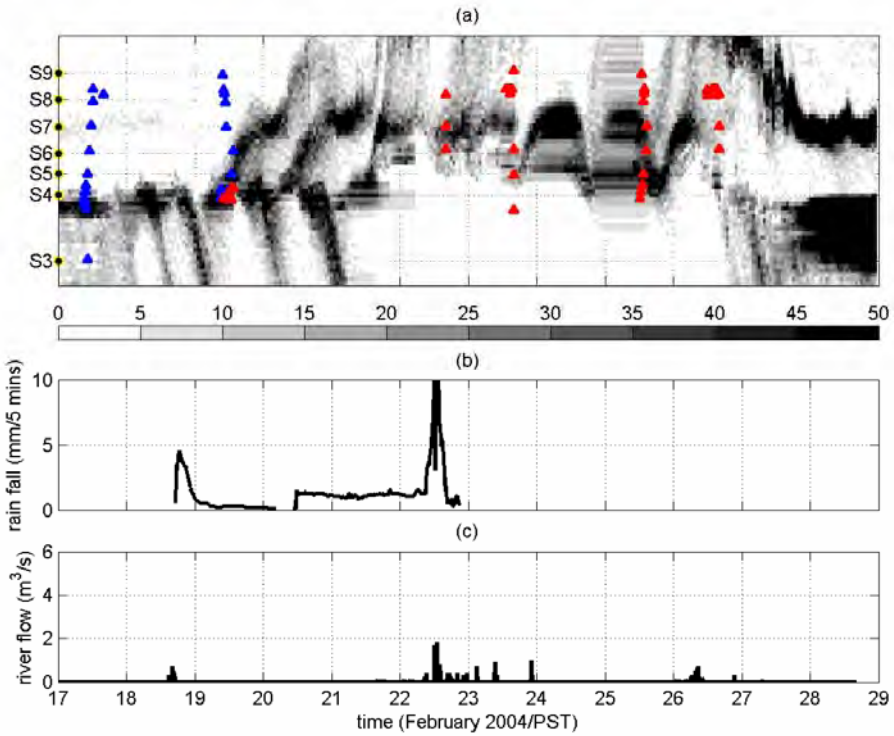
San Diego shoreline water quality sampling



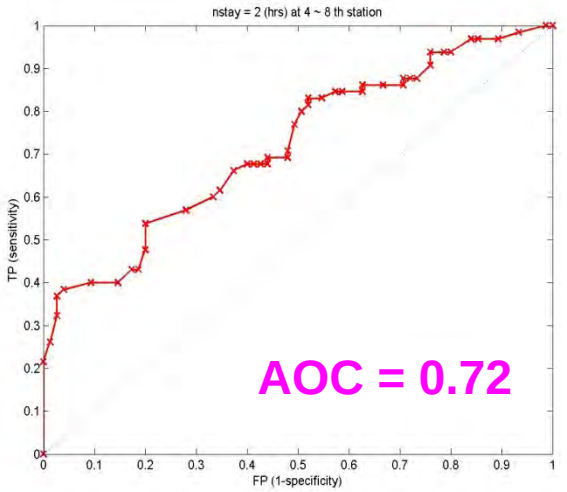


Lagrangian particle track model



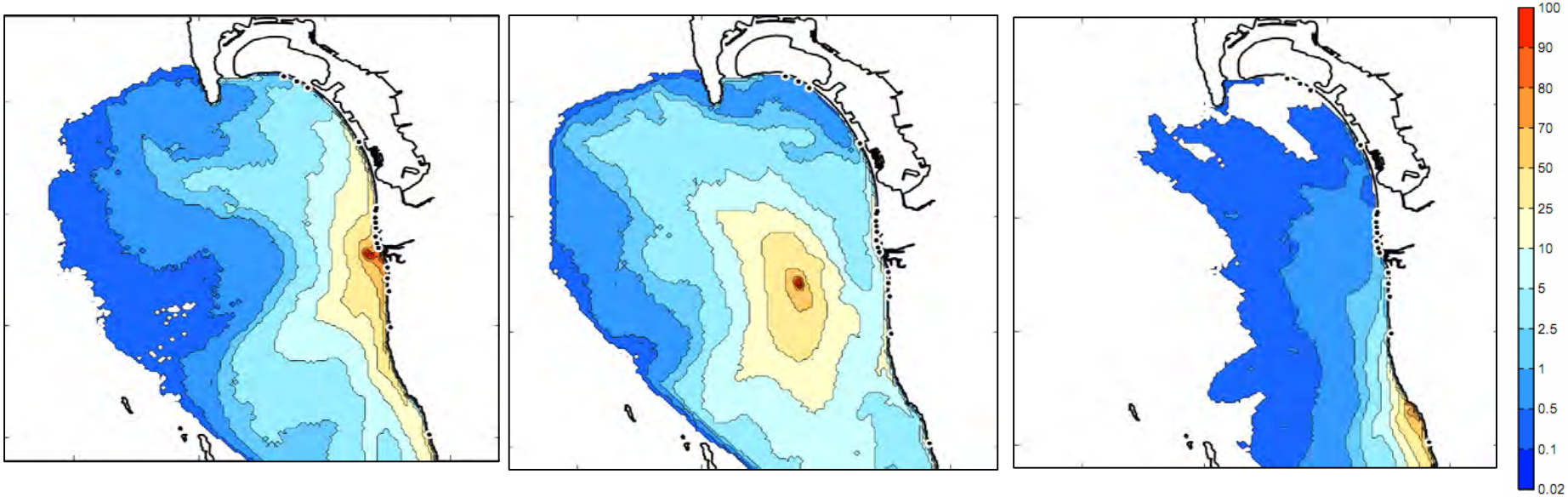


- Objectively mapped surface currents
- Forward time integration
- Particle concentrations vs. water quality samplings
- ROC (Receiver Operating Characteristics) analysis



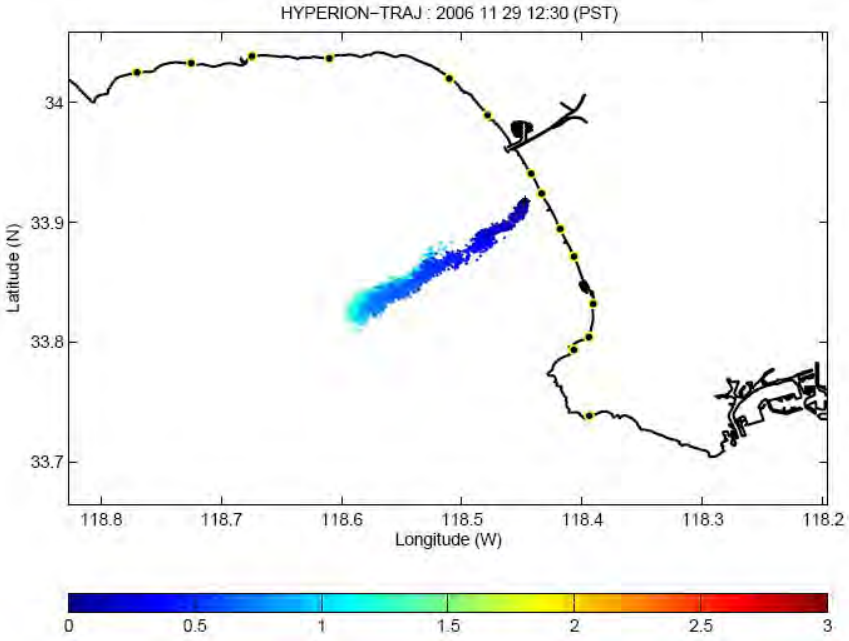
Exposure map (2D PDF)

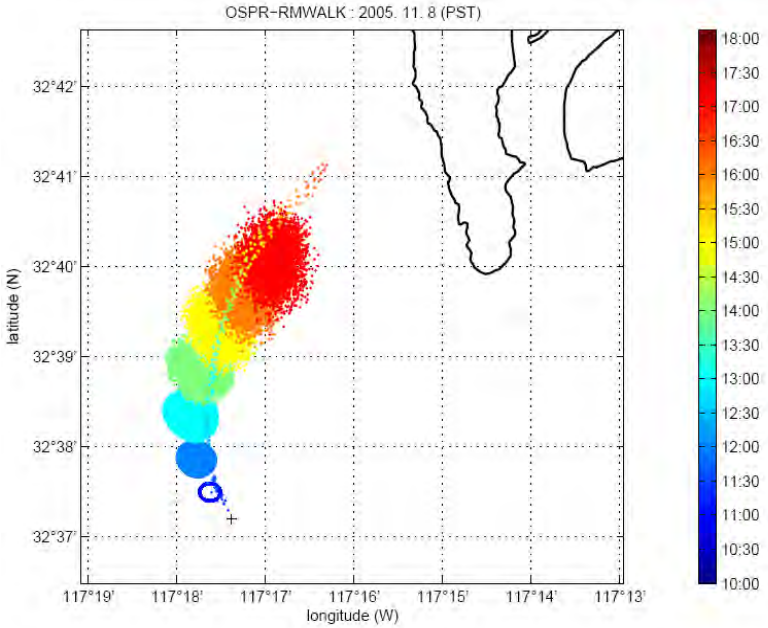
Sources	Location		Discharge type	Flow rate ($m^3 s^{-1}$ (MGD))
	Longitude (W)	Latitude (N)		
TJR	32.5556	117.1369	Wet season	~ 2.9 (66)
SBO	32.5373	117.1835	Plume surfacing	~ 0.9 (20)
PBD	32.4336	117.1100	Continuous	1–1.5 (22–35)

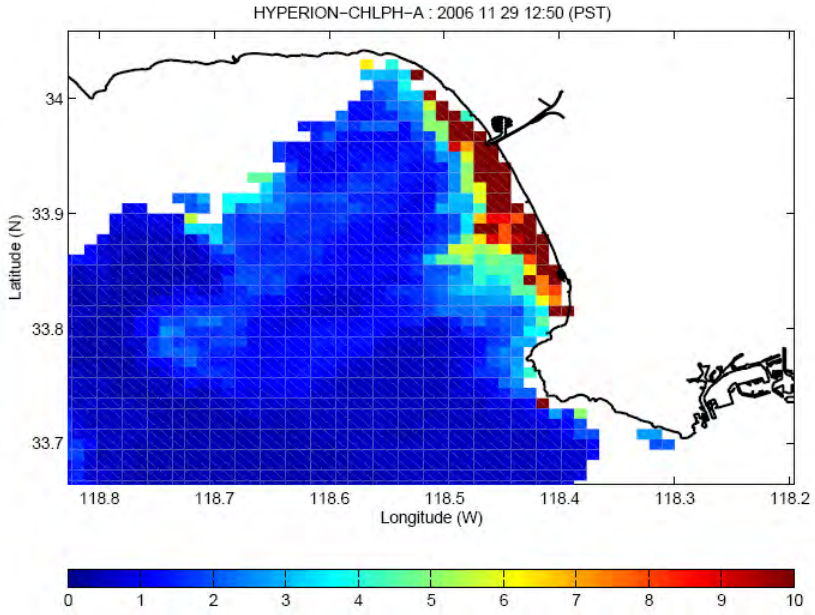


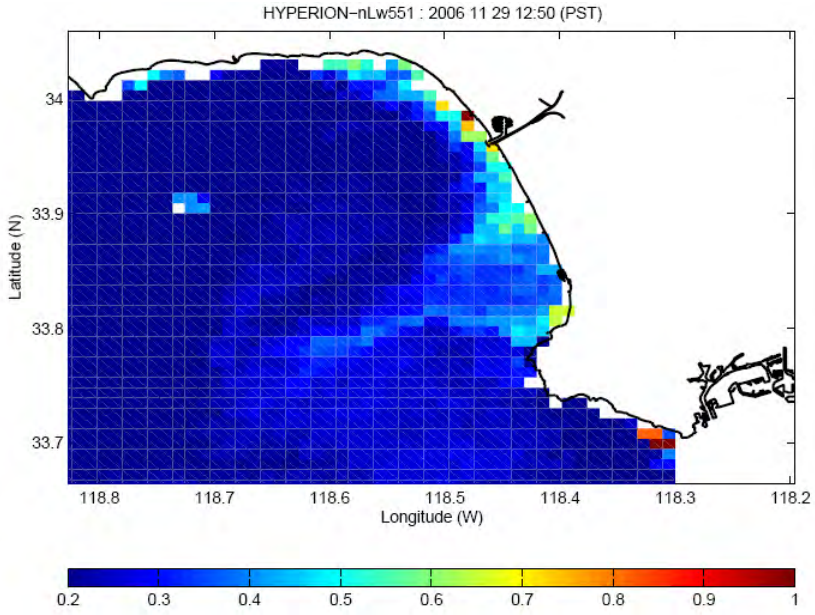
Exposure map normalized by # of particles at the source location.
(when each source is active)

Hyperion Discharge & oil spill experiment









Summary

- The operational USWC HFR network as a backbone of regional coastal ocean observing system (ROOS) provides the detailed aspects of coastal surface circulation and ocean dynamics at a resolution (km in space and hourly in time) of never before resolved.
- Observed surface currents contain responses to the low frequency, tides, wind forcing, and Earth rotation.
- HFR observations can be a useful resource to study surface circulation, eddies and interaction of energy at submesoscale, and ocean state estimates and can provide various environmental applications.