에너지인력양성사업

Ocean Systems Engineering

KAIST

A description of T/S and oxygen variability off southern California using regional- and global-scale climate indices

Sung Yong Kim

Division of Ocean Systems Engineering
School of Mechanical, Aerospace & Systems Engineering
Korea Advanced Institute of Science and Technology (KAIST)

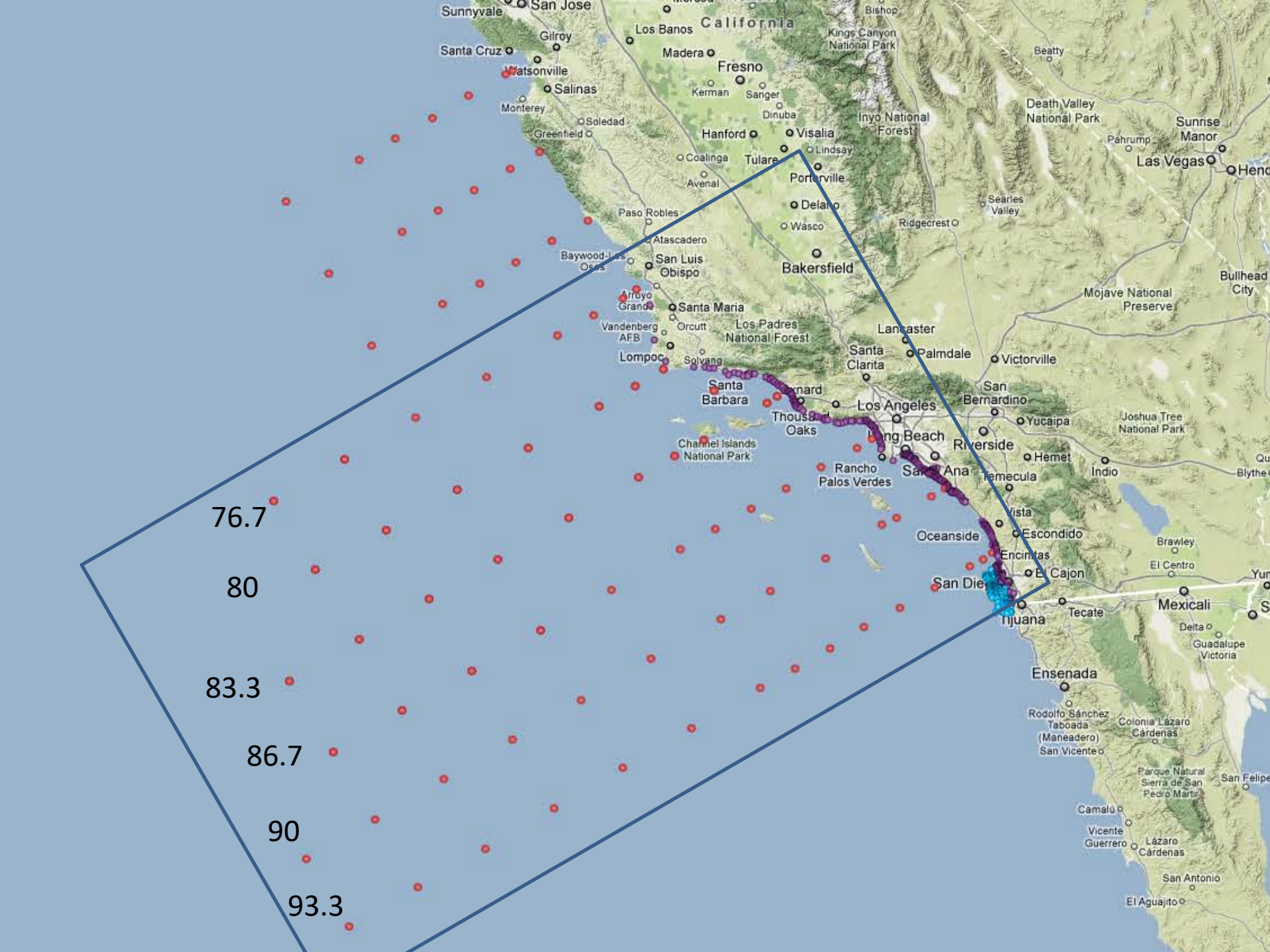
Bruce Cornuelle

CASPO, Scripps Institution of Oceanography

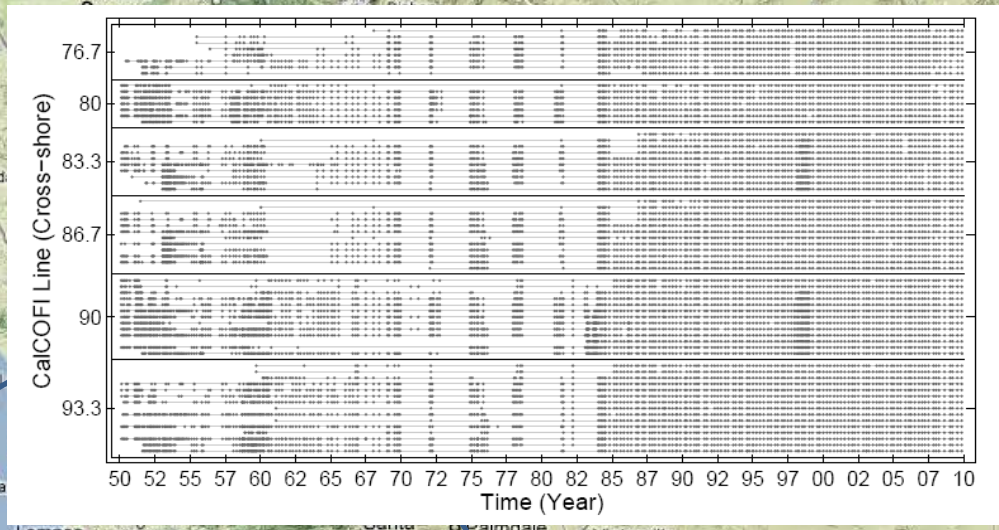
Southern California Coastal Ocean Observing System

Outline

- Data sets and motivation
- Examples of analysis
- Data analysis
- Vertical sections of T/S/Oxygen
- Horizontal presentation of Temperature (Seasonality only)
- Summary

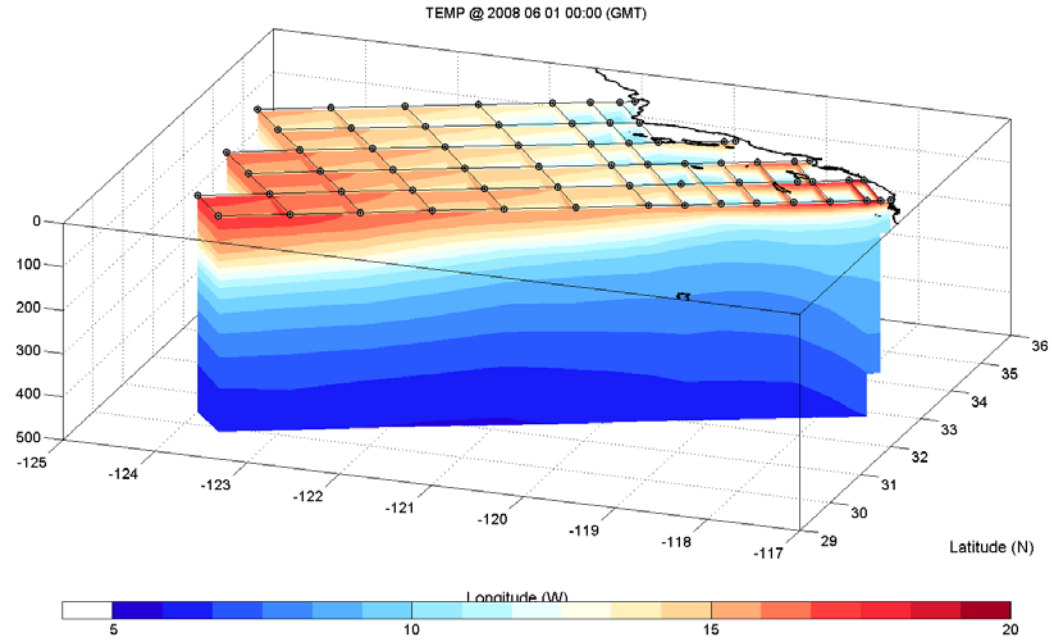

76.7
80
83.3
86.7
90
93.3
Sunnyvale
San Jose
California
Gilroy
Los Banos
Santa Cruz
Madera
Fresno
Watsonville
Salinas
Kerman
Sanger
Monterey
Dinuba
Soledad
Greenfield
Hanford
Visalia
Lindsay
Coalinga
Tulare
Avenal
Porterville
Delano
Wasco
Paso Robles
Atascadero
Baywood-Los Osos
San Luis Obispo
Bakersfield
Arroyo Grande
Santa Maria
Vandenberg AFB
Orcutt
Los Padres National Forest
Lompoc
Solvang
Santa Barbara
Thousand Oaks
Channel Islands National Park
Los Angeles
Santa Clarita
Lancaster
Palmdale
Victorville
San Bernardino
Yucaipa
Long Beach
Riverside
Hemet
Rancho Palos Verdes
Santa Ana
Temecula
Indio
Oceanside
Escondido
Encinitas
El Cajon
San Diego
Tijuana
Tecate
Mexicali
Brawley
El Centro
Ensenada
Rodolfo Sánchez Taboada (Maneadero)
San Vicente
Colonia Lázaro Cárdenas
Parque Natural Sierra de San Pedro Mártir
Camalú
Vicente Guerrero
Lázaro Cárdenas
San Antonio
El Aguajito
Death Valley National Park
Inyo National Forest
Kings Canyon National Park
Bishop
Beatty
Pahrump
Las Vegas
Sunrise Manor
Searles Valley
Ridgecrest
Mojave National Preserve
Bullhead City
Joshua Tree National Park
Blythe
Delta
Guadalupe Victoria

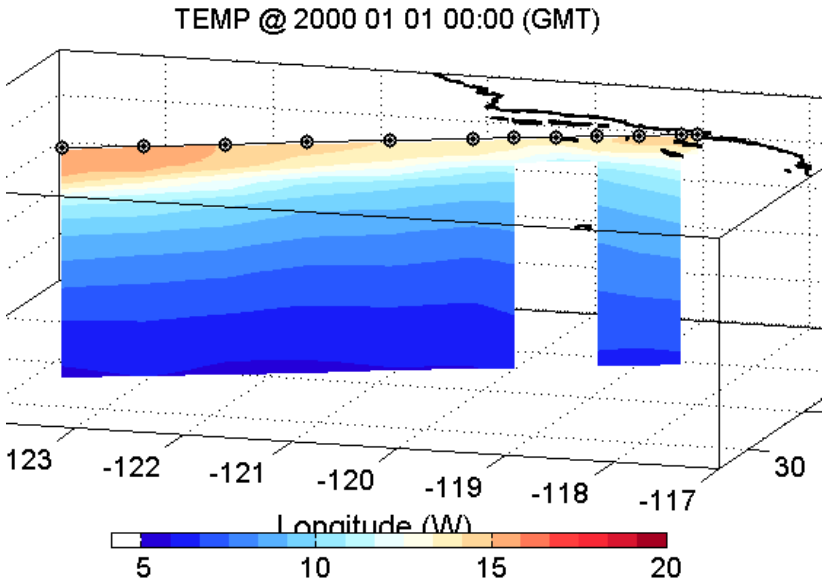
- Historical Data
  - Quarterly California Cooperative Oceanic Fisheries Investigations (CalCOFI) CTD data (1950 – 2009).
  - Monthly CTD samplings at local discharge and outfalls off southern California (Bight Water Quality, Point Loma Ocean Outfall, and South Bay Ocean Outfall; 1990 – 2009).



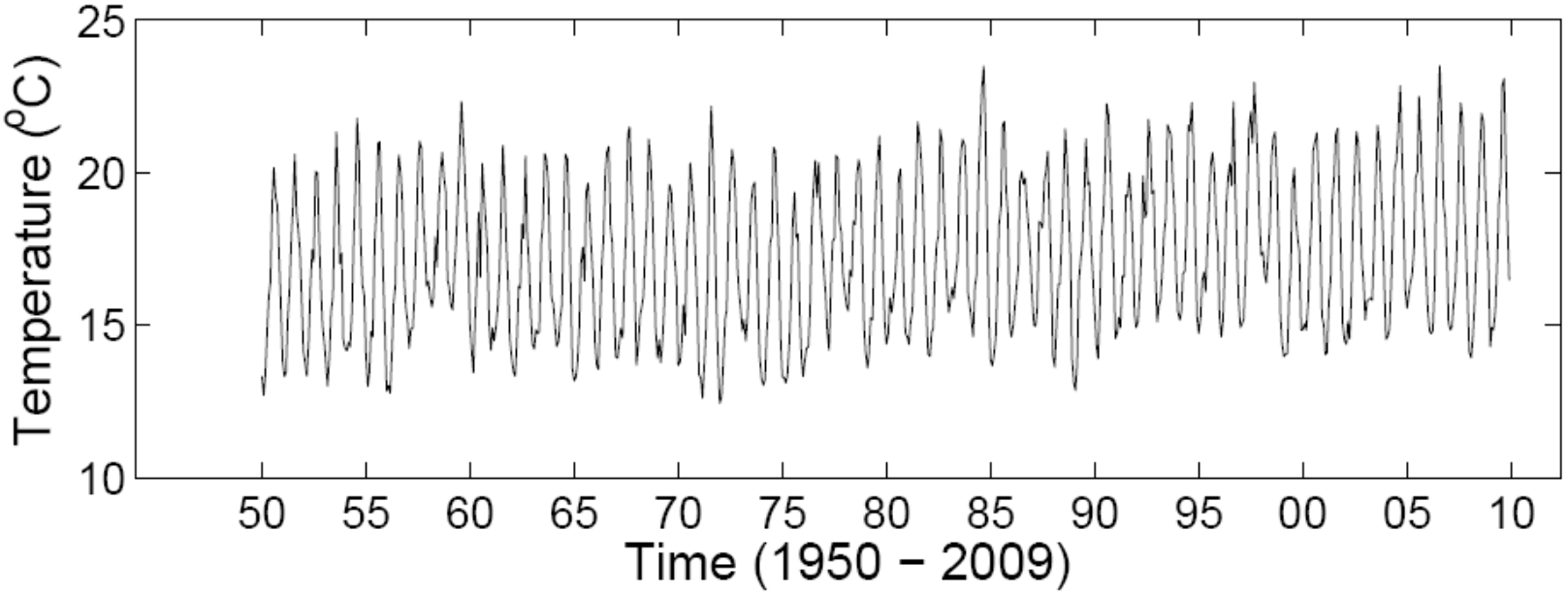
Motivation

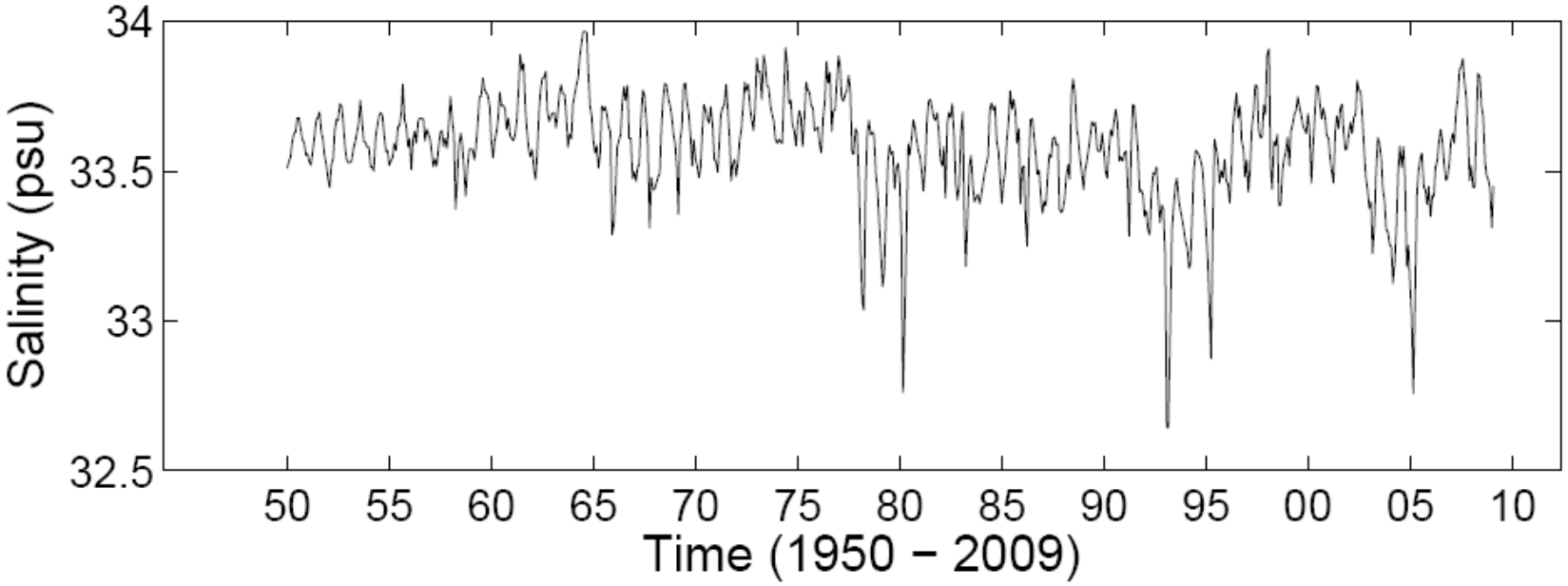
- Partitioning of historical data into seasonality, components coherent with regional and global climate indices.
- How much variance is explained by each term?
- Deriving climatology and reconstructing three-dimensional (x,y,z) time series (t).
- Detecting potential climate signals from coastal observations.



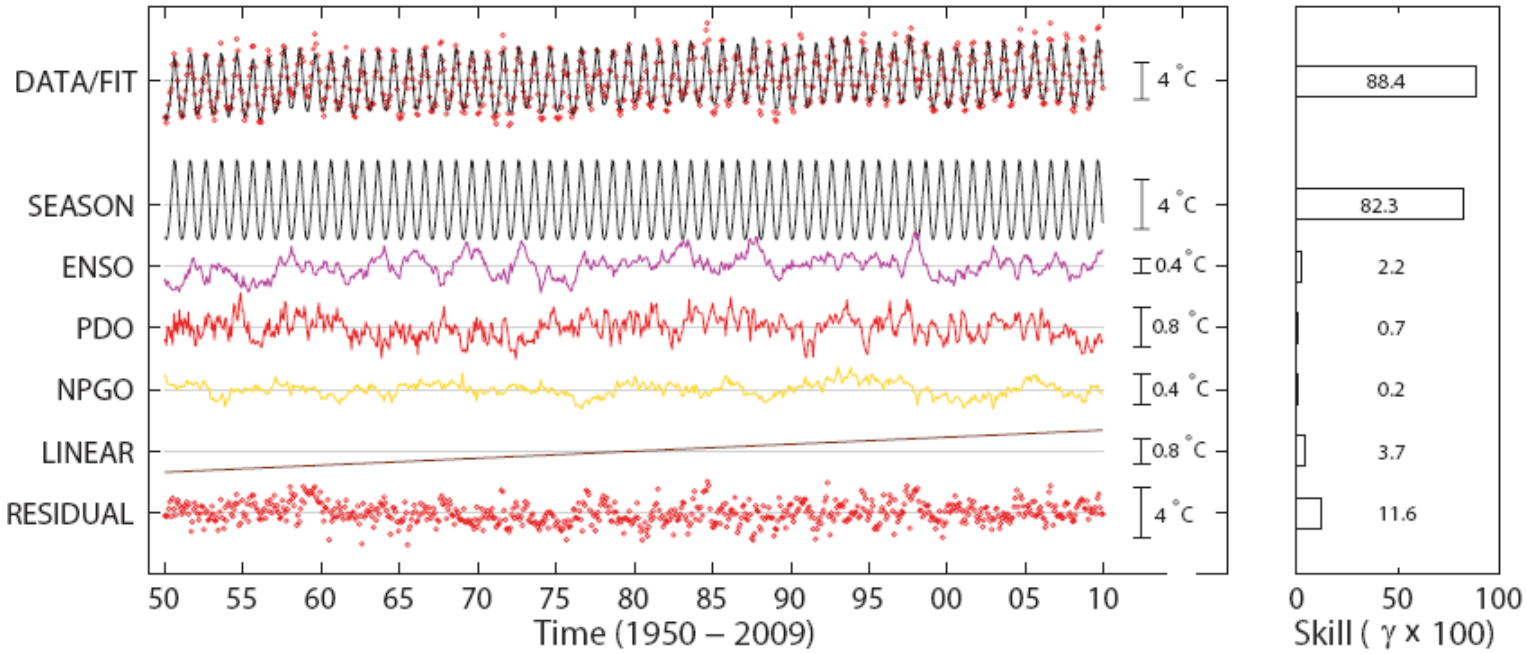


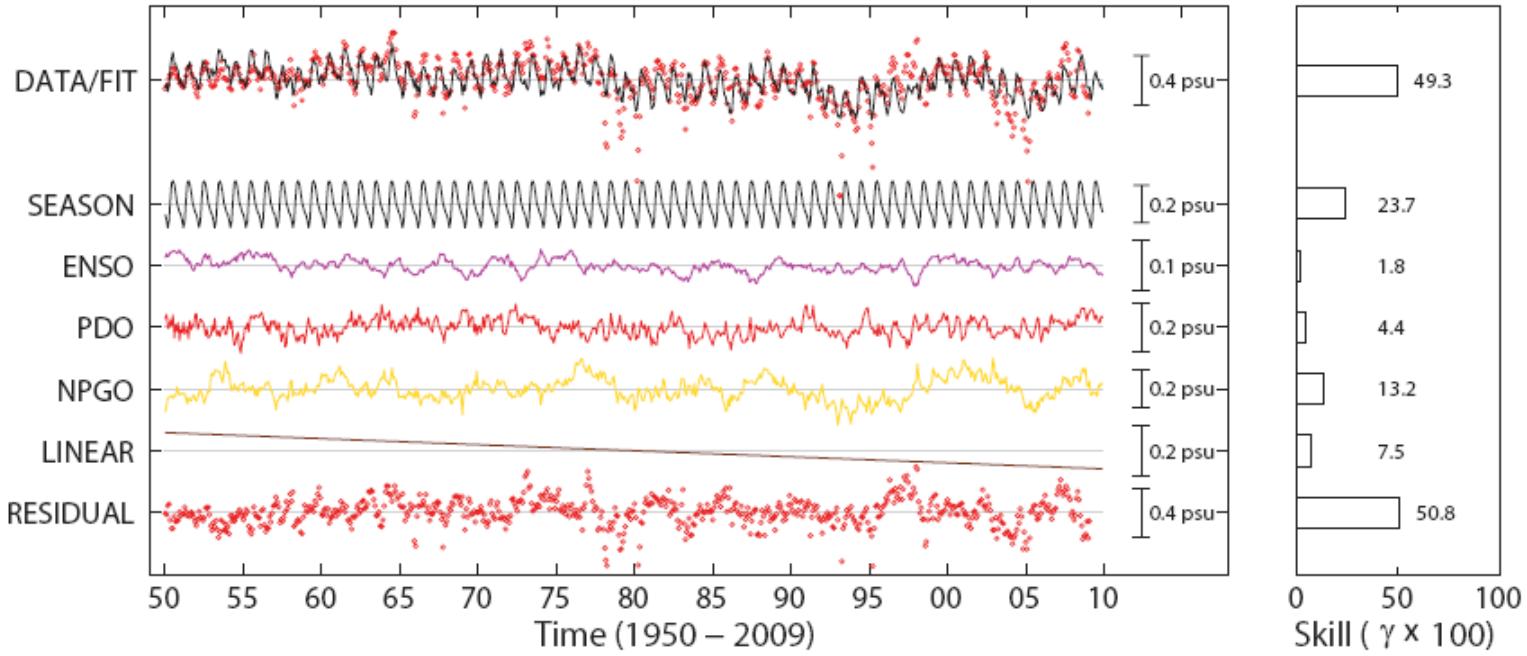
Time series of temperature and salinity at SIO Pier



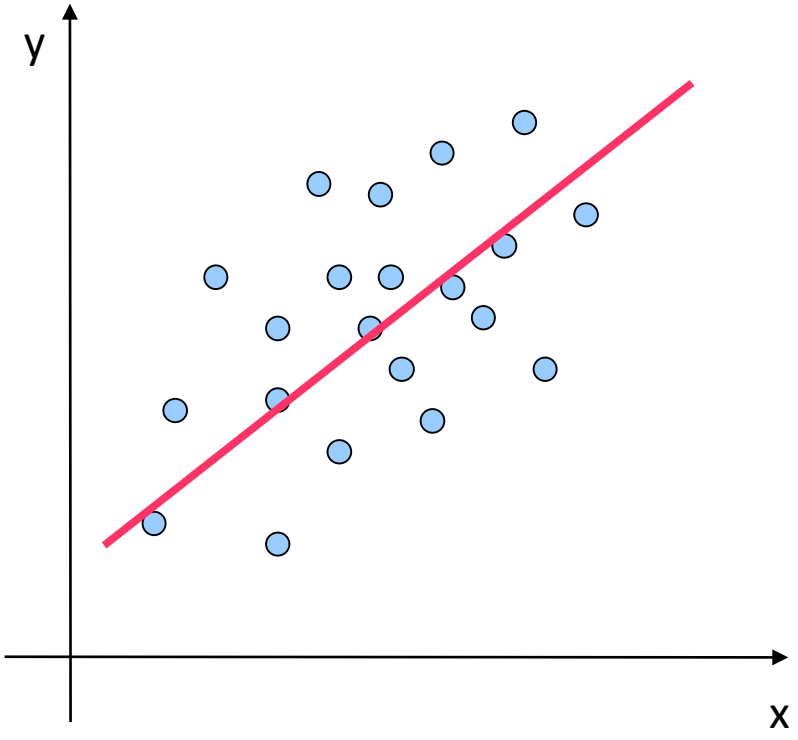


Examples (SIO temperature and salinity) of decomposition





Linear regression



$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix} = \begin{bmatrix} x_1 & 1 \\ x_2 & 1 \\ \vdots & \vdots \\ x_n & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix}$$

$$\mathbf{d} = \mathbf{G}\,\mathbf{m}$$

d: Data (observations)
G: Basis functions
m: Regression coefficients

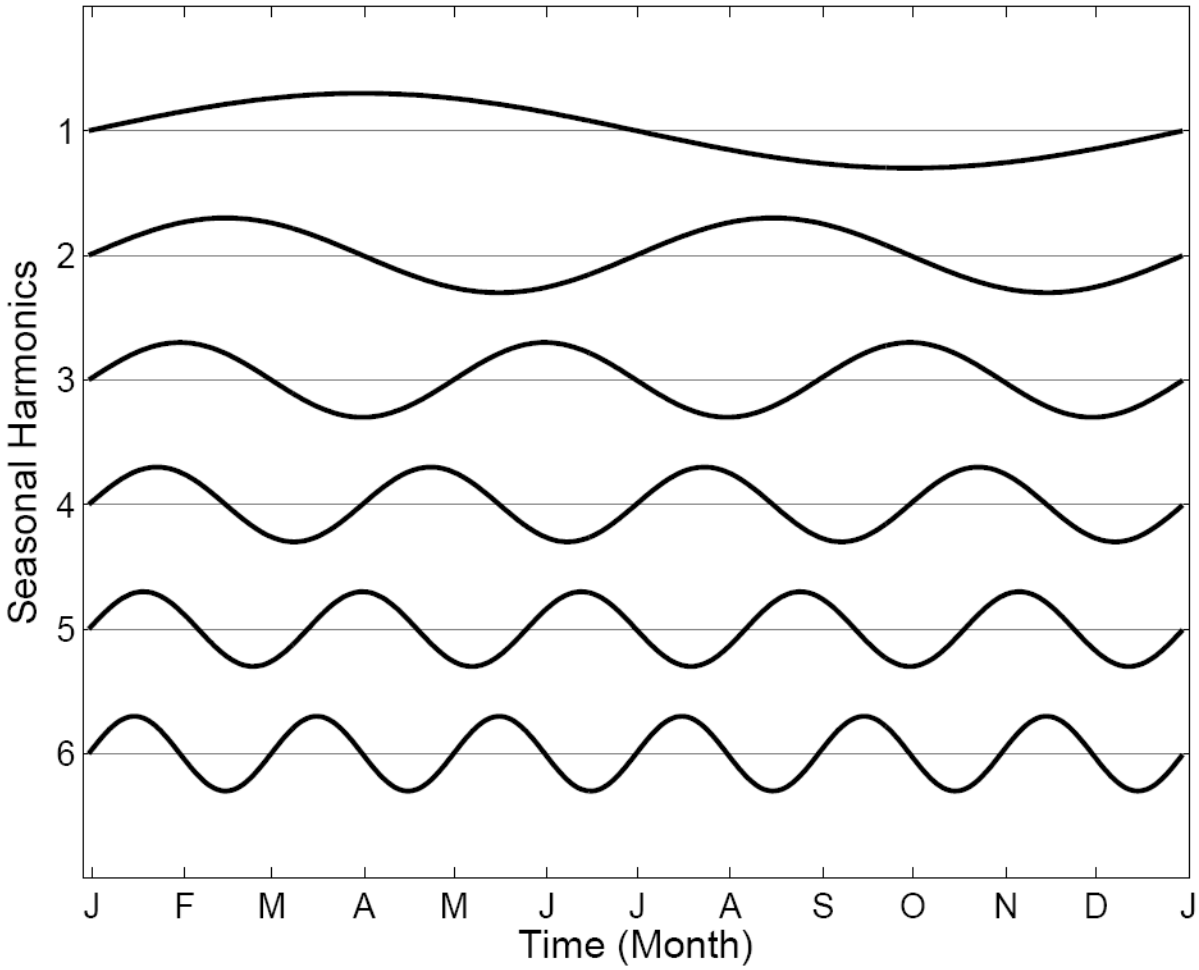
- Least-squares fit for unevenly sampled time series

$$\begin{aligned} \hat{\mathbf{m}} &= \mathbf{P}\mathbf{G}^{\dagger}\left(\mathbf{G}\mathbf{P}\mathbf{G}^{\dagger} + \mathbf{R}\right)^{-1}\mathbf{d}, \\ &= \left(\mathbf{G}^{\dagger}\mathbf{R}^{-1}\mathbf{G} + \mathbf{P}^{-1}\right)^{-1}\mathbf{G}^{\dagger}\mathbf{R}^{-1}\mathbf{d}, \end{aligned}$$

P: model covariance
R: error covariance

Regression basis

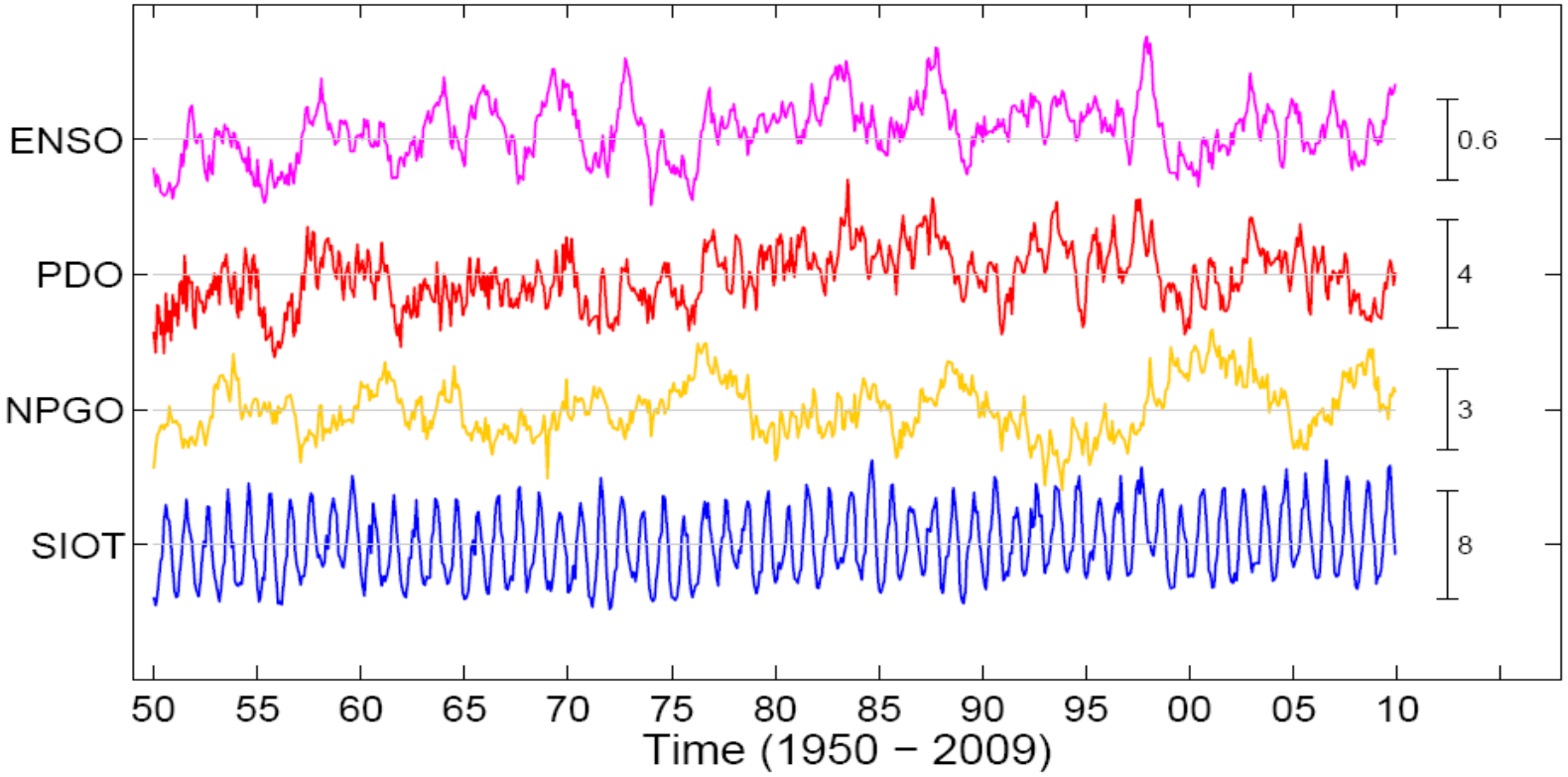
- SA1 – SA6 (6 harmonics of seasonality)



- T = 365.2425 days
- T/2 = 182.6718 days
- T/3 = 121.7812 days
- T/4 = 91.3559 days
- T/5 = 73.0687 days
- T/6 = 60.8906 days

Regression basis

- SA1 – SA6 (6 harmonics of seasonality)
- ENSO: El-nino Southern Ocean Oscillation (1900-2009)
- PDO (Pacific Decadal Oscillation): 1st mode of North Pacific SST (1900-2009)
- NPGO (North Pacific Gyre Oscillation): 2nd mode of northeastern Pacific SSHAs + SST (1950-2009)
- SIOT: Scripps Pier Temperature (1916-2009)
- Linear trend



Data decomposition

- Decomposition of time series (multivariate regression)

$$d(t) = d_{\mathrm{S}}(t) + d_{\mathrm{C}}(t) + d_{\mathrm{F}}(t) + d_{\mathrm{R}}(t),$$

  - Seasonality with six harmonics (SA1, SA2, …, and SA6).
  - Climate indices (ENSO, PDO, NPGO, and SIOT).
  - Polynomials (mean and linear trend)
- Scientific Successive orthogonalization
  - As climate indicate are coherent each other, there is ambiguity in partition of variance.
  - In a given order of basis functions, a basis function is orthogonalized by basis functions above that in sequentially.
  - Seasonality → ENSO → linear trend → PDO → NPGO → SIOT
  - Caveat: Orthogonalized basis functions are not the same as the original ones

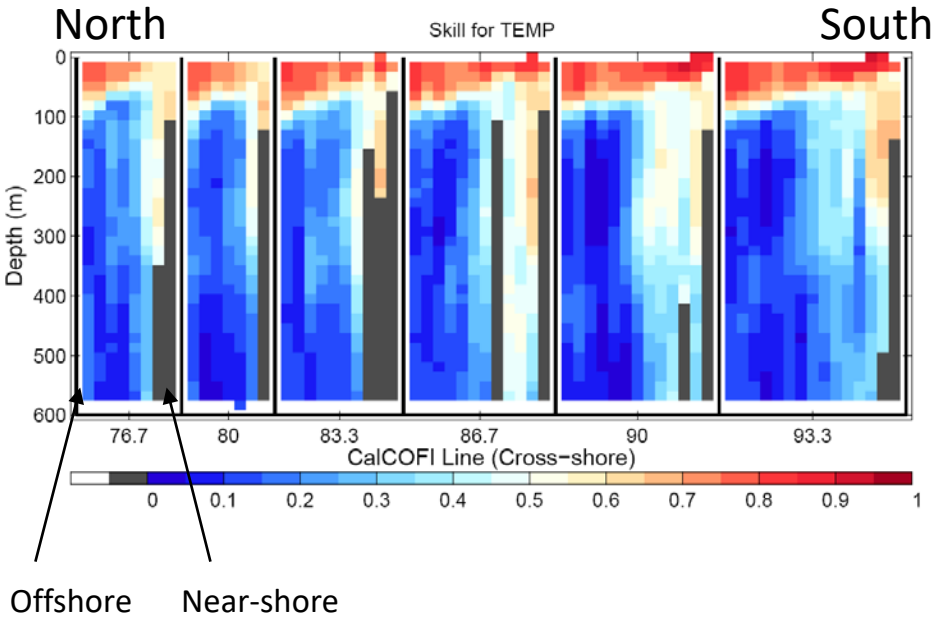
Correlation before orthogonalization

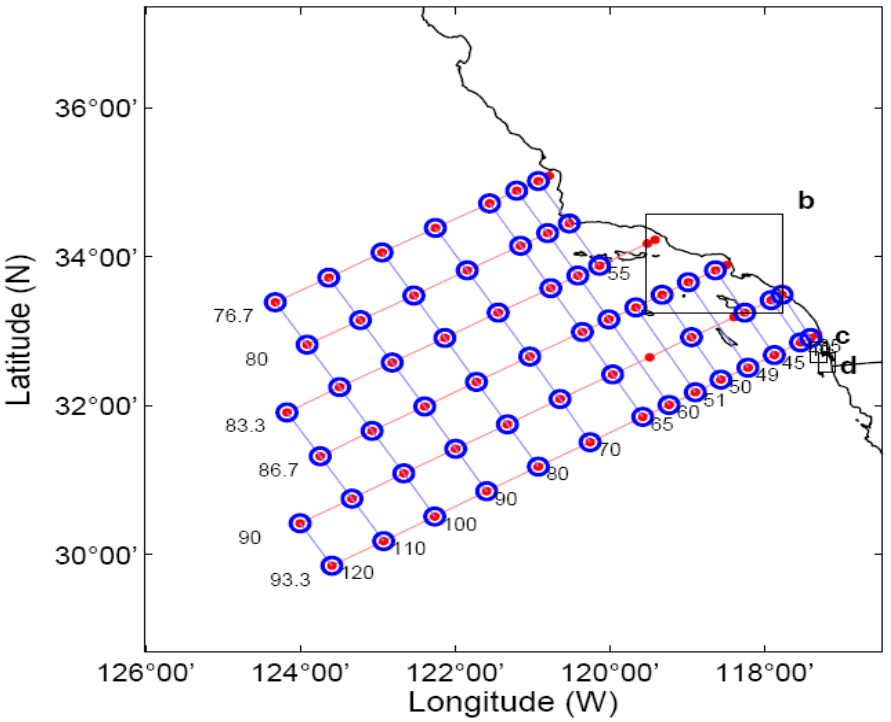
	ENSO	PDO	NPGO	SIOT
ENSO				
PDO	0.58			
NPGO	-0.18	-0.09		
SIOT	0.21	0.20	-0.02	

Correlation after orthogonalization

	ENSO	PDO	NPGO	SIOT
ENSO				
PDO	-0.05			
NPGO	0.07	-0.00		
SIOT	-0.09	0.00	0.00	

Presentation of cross-shore transects





Total skill:

$$\kappa^2 = 1 - \frac{\left\langle \left(d - \hat{d}\right)^2 \right\rangle}{\langle d^2 \rangle}$$

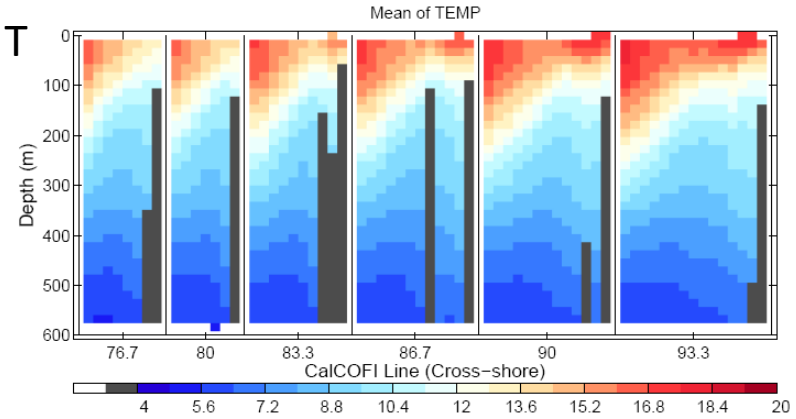
Individual skill:

$$\kappa_l^2 = 1 - \frac{\langle (d - d_l)^2 \rangle}{\langle d^2 \rangle}$$

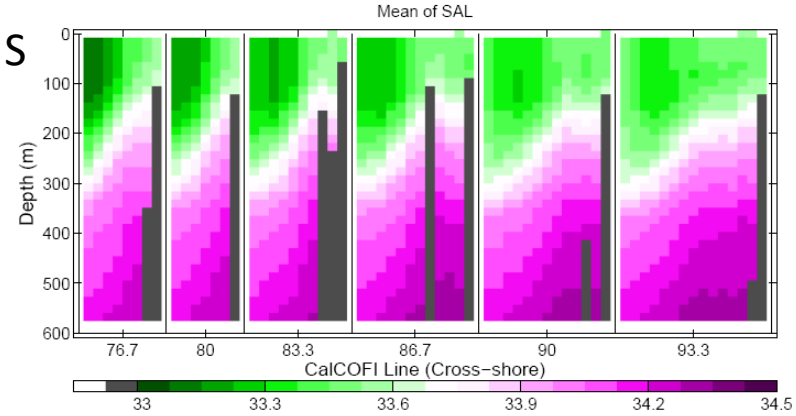
for CalCOFI transects of T/S/Oxygen; sigma-t

Mean of T/S/Oxygen

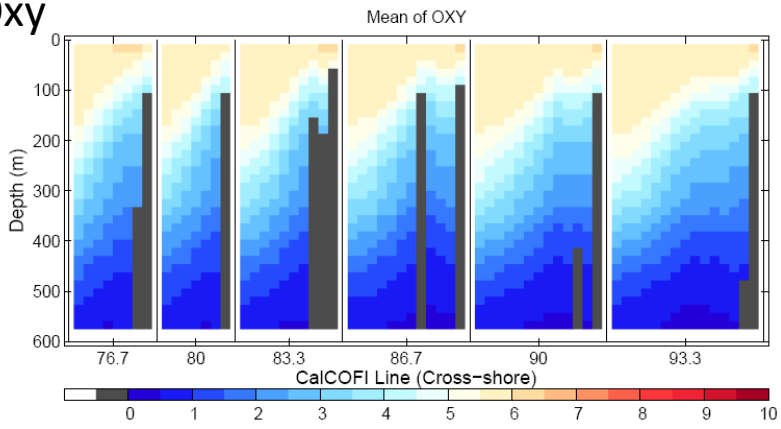
T



S



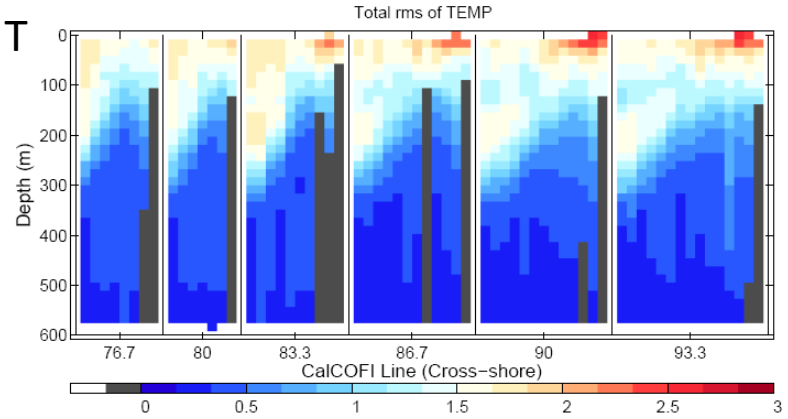
Oxy



- California Current (CC) and California Under Current (CUC)
  - CC: cool, fresh, oxygen and nutrient-rich water coming from northeastern Pacific.
  - CUC: warm, salty, oxygen poor, nutrient-rich water originating from northeastern eq. Pacific
  - Southward slope: onshore currents
- Salinity minimum offshore in upper 100 m (due to SE horizontal advection); maximum nearshore below 500 m
- Oxygen minimum neashore with depth; similar tilting

RMS of T/S/Oxygen

T



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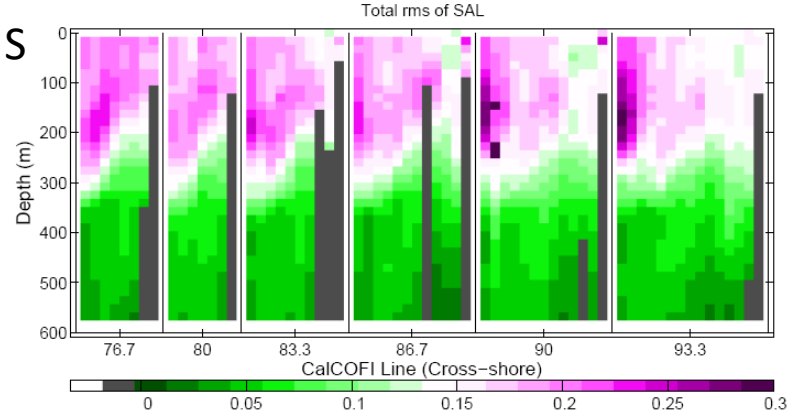

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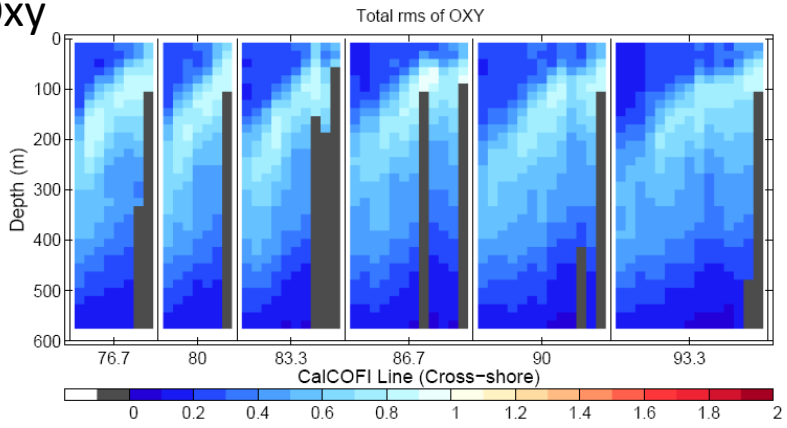
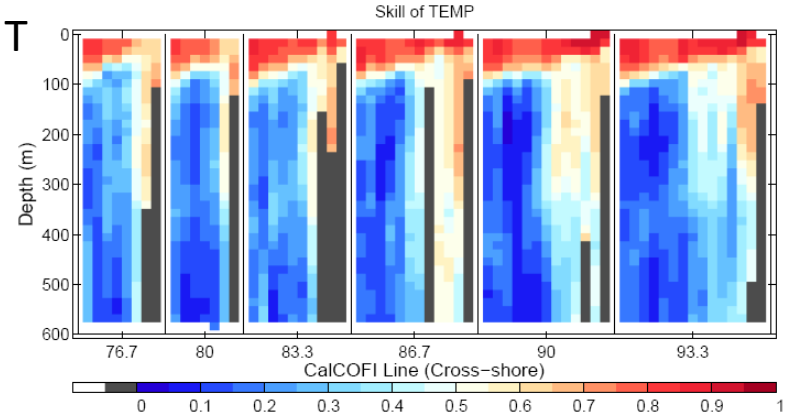


- Surface and subsurface high rms of temperature (surface heating and cooling; thermocline displacement at 100-150 m)
- Offshore salinity higher rms than nearshore (CC vs CUC); freshwater inputs nearshore by rivers
- Subsurface oxygen rms (similar to thermocline variability)

Skill of regression of T/S/Oxygen

T



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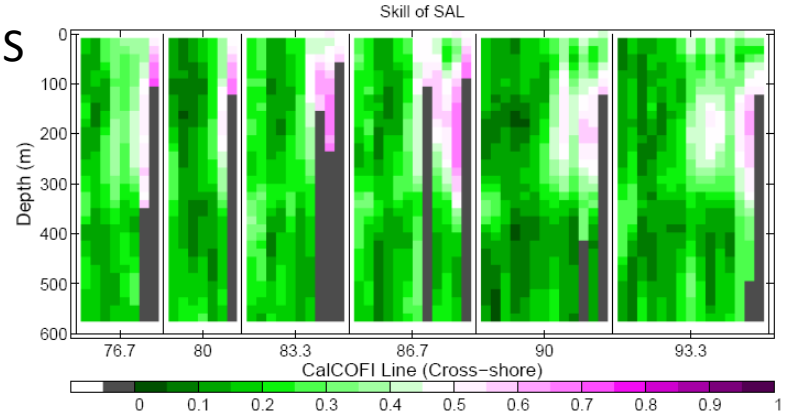
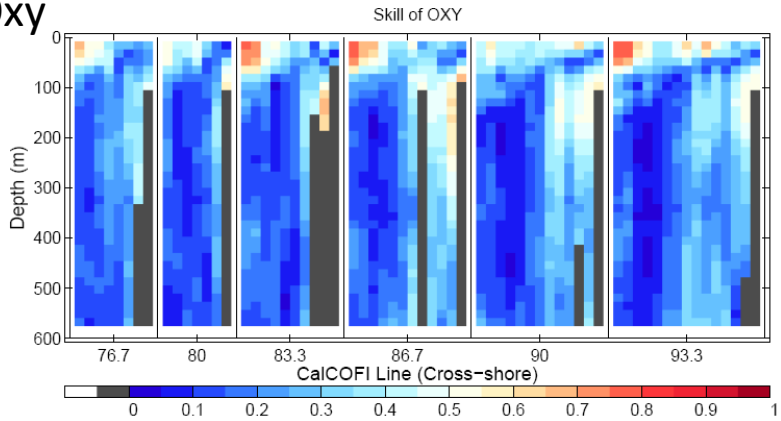


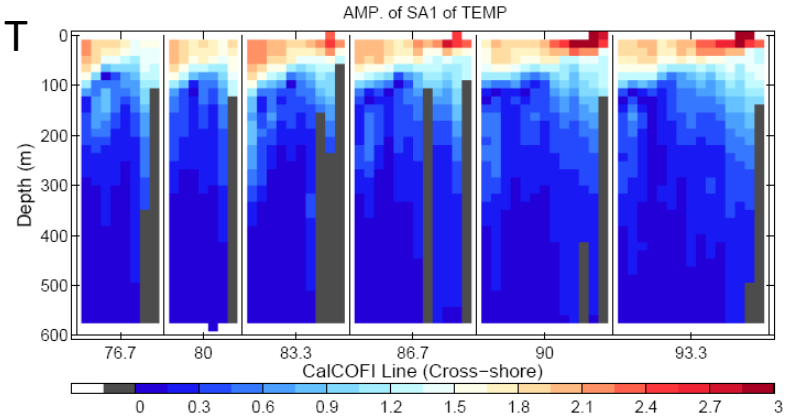
Oxy



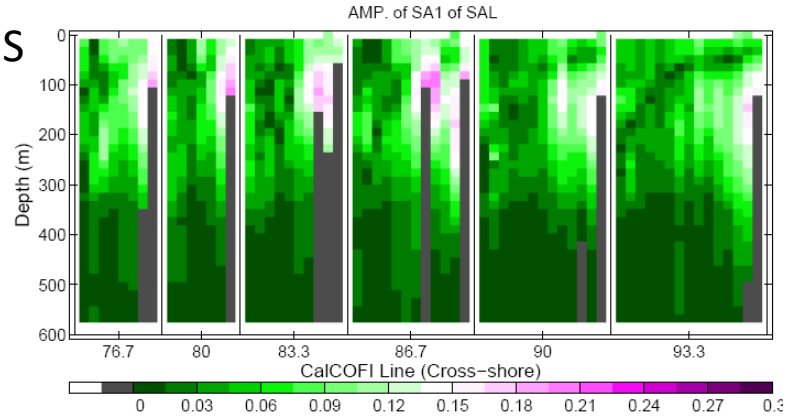
- How much variance can be explained by this regression.
- Significant skill (T) near the surface due to seasonal variability of heating/cooling; basis functions derived from surface observations.
- Small skill offshore 100m below variability of T and S (eddy- and wave-driven processes and surface-forced displacements; Miller et al 1998)
- High skill on salinity for very near coast regions .
- Relatively high skill on oxygen for offshore and very near coast regions (due to seasonal variability).

Seasonal amplitudes of T/S/Oxygen

T



S



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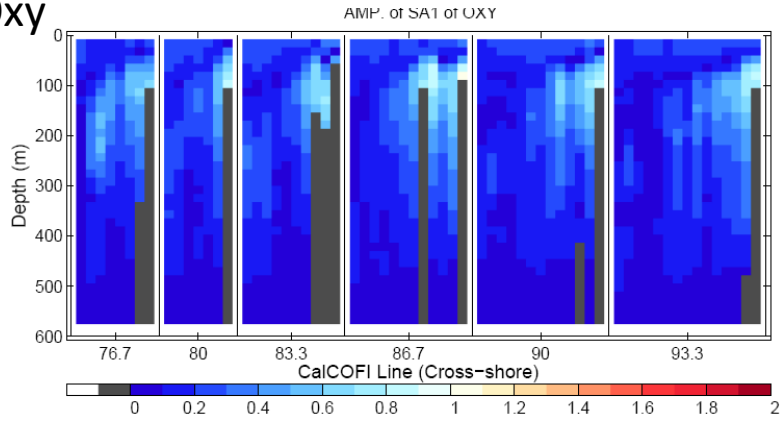
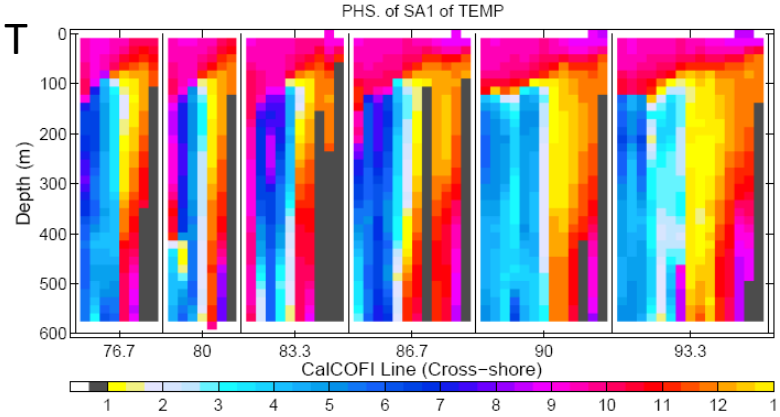


- SA1 dominancy in the upper 100 m (T)
- Offshore subsurface water has weak seasonal coastal upwelling (so, mesoscale variability or climate influence)
- Nearshore mid-depth; nearcoast (S/Oxy); due to seasonal upwelling influence

Seasonal phases of T/S/Oxygen

T



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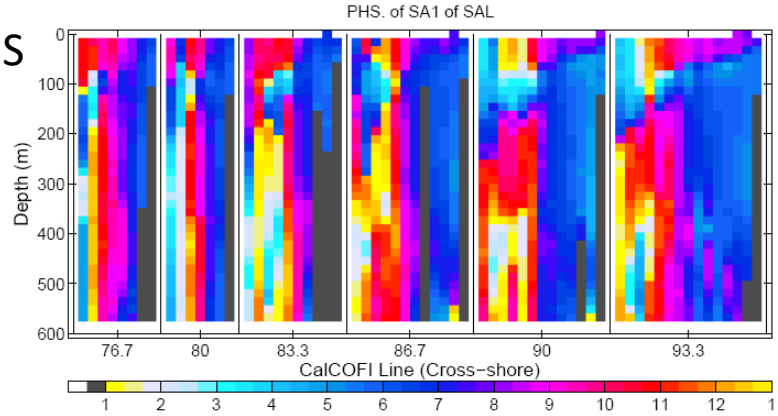

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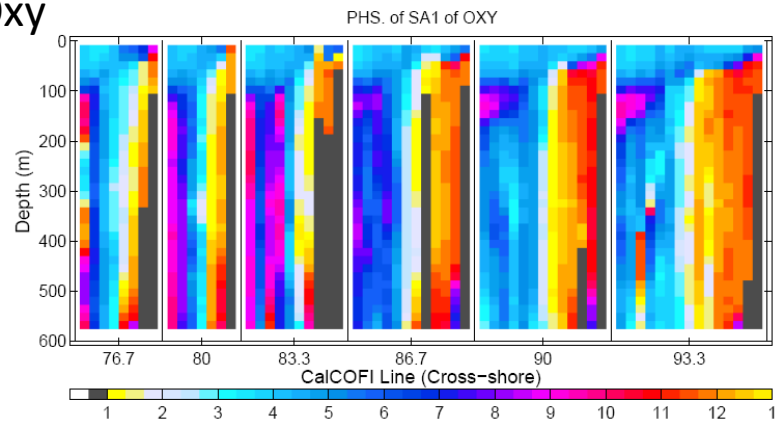
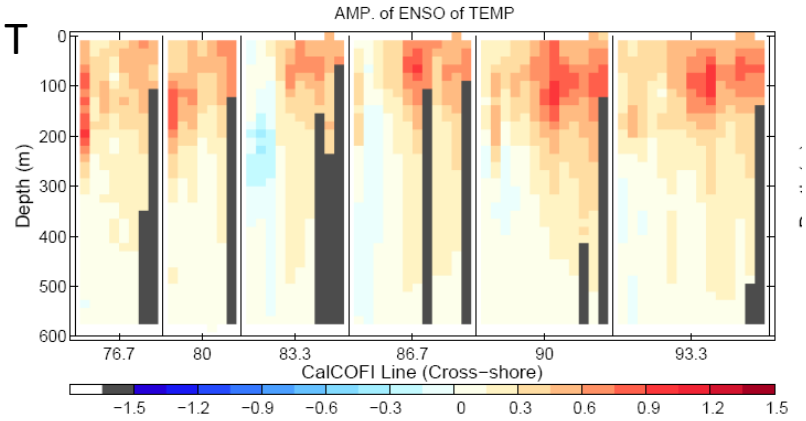


- Maximum of surface T and Oxygen appear on September (seasonal surface heating/cooling) and May (supersaturation due to phtosynthesis+net heating), respectively.
- Cold/salty offshore (CC); warm/fresh nearshore (CUC) during winter
- Seasonal subsurface phase propagation (T) – offshore propagation of seasonal Rossby wave (1-2 km/day)

ENSO amplitudes of T/S/Oxygen

T



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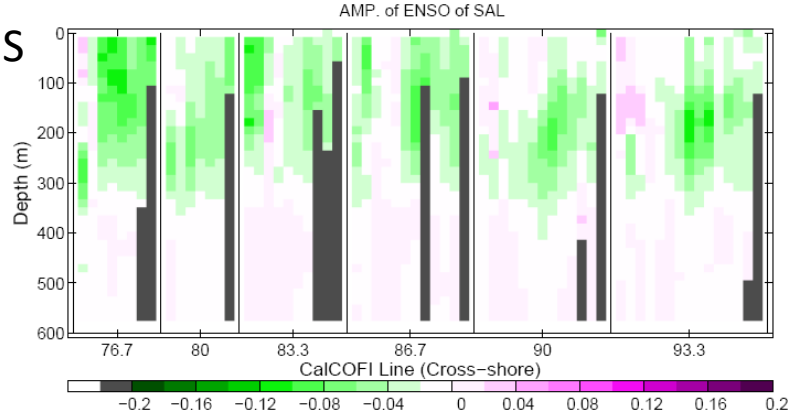

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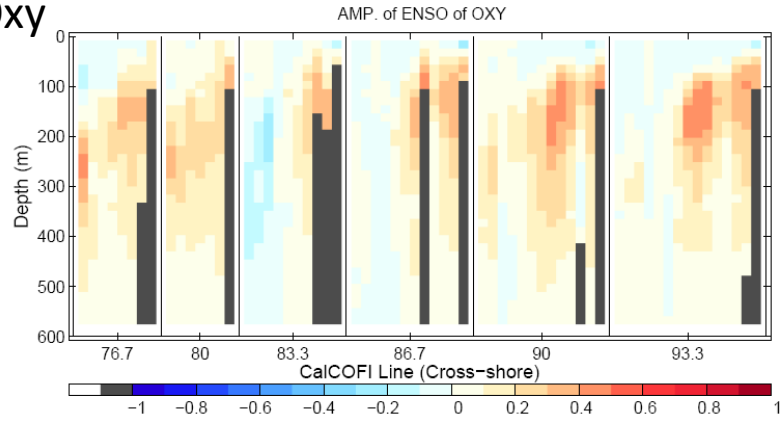
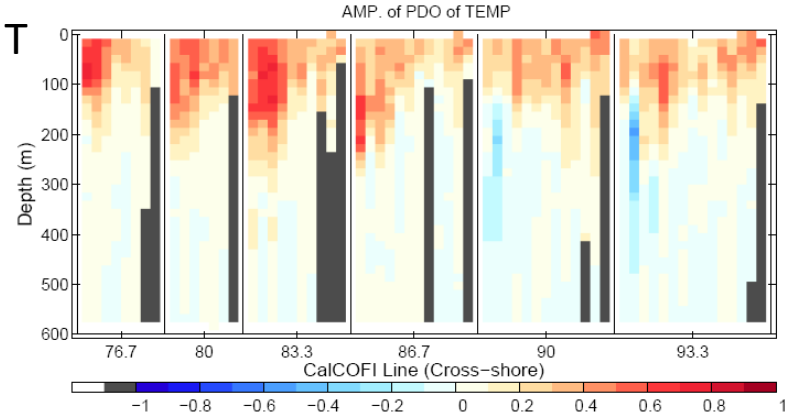


- Upper 200m nearshore (T+)
  - ENSO signals; coastally trapped waves or advection of coastally-trapped CUC
- Upper 200m nearshore (S-; weak)
- Between 100 m and 300 m (Oxy+); weakly negative upper 100 m (Oxy-);

PDO amplitudes of T/S/Oxygen

T



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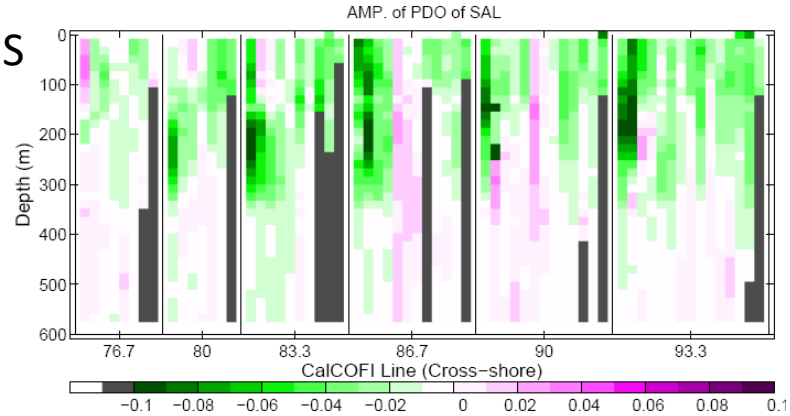
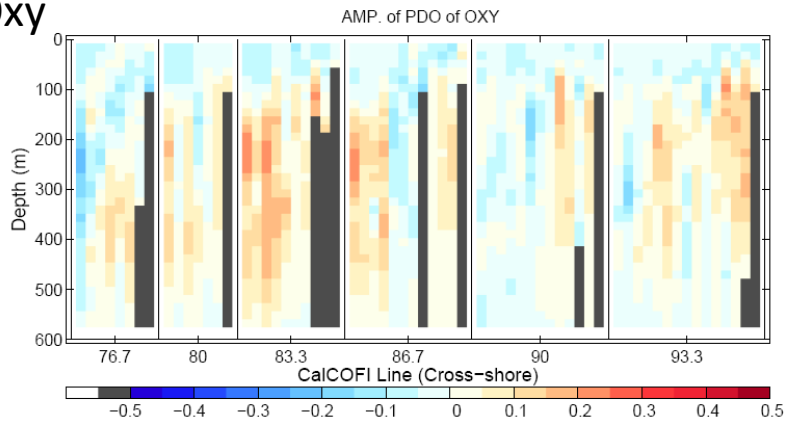


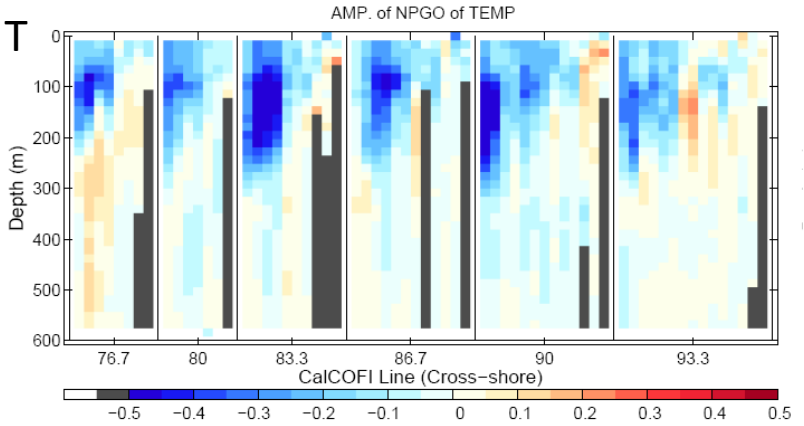
Oxy



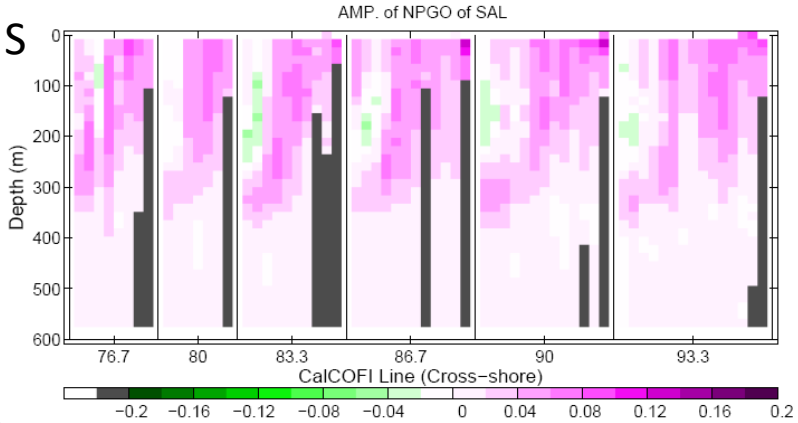
- Offshore upper T (+) subsurface T (-)
  - ENSO-removed PDO; may be basin-mode effects on the boundary current
- Offshore enhanced S (-)
- Subsurface oxygen (+)

NPGO amplitudes of T/S/Oxygen

T



S



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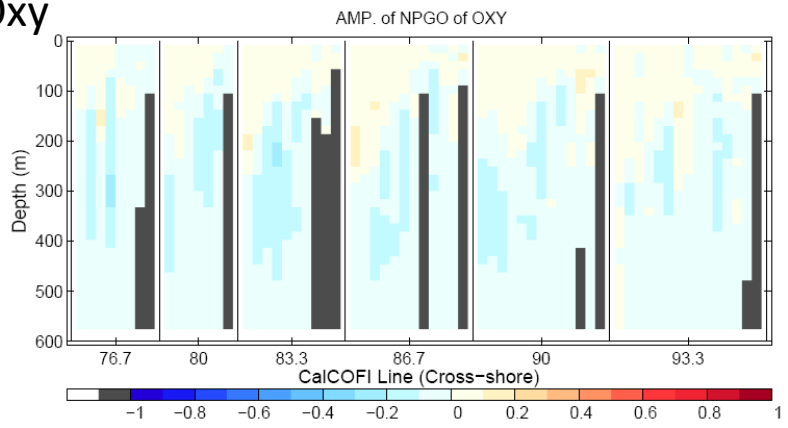
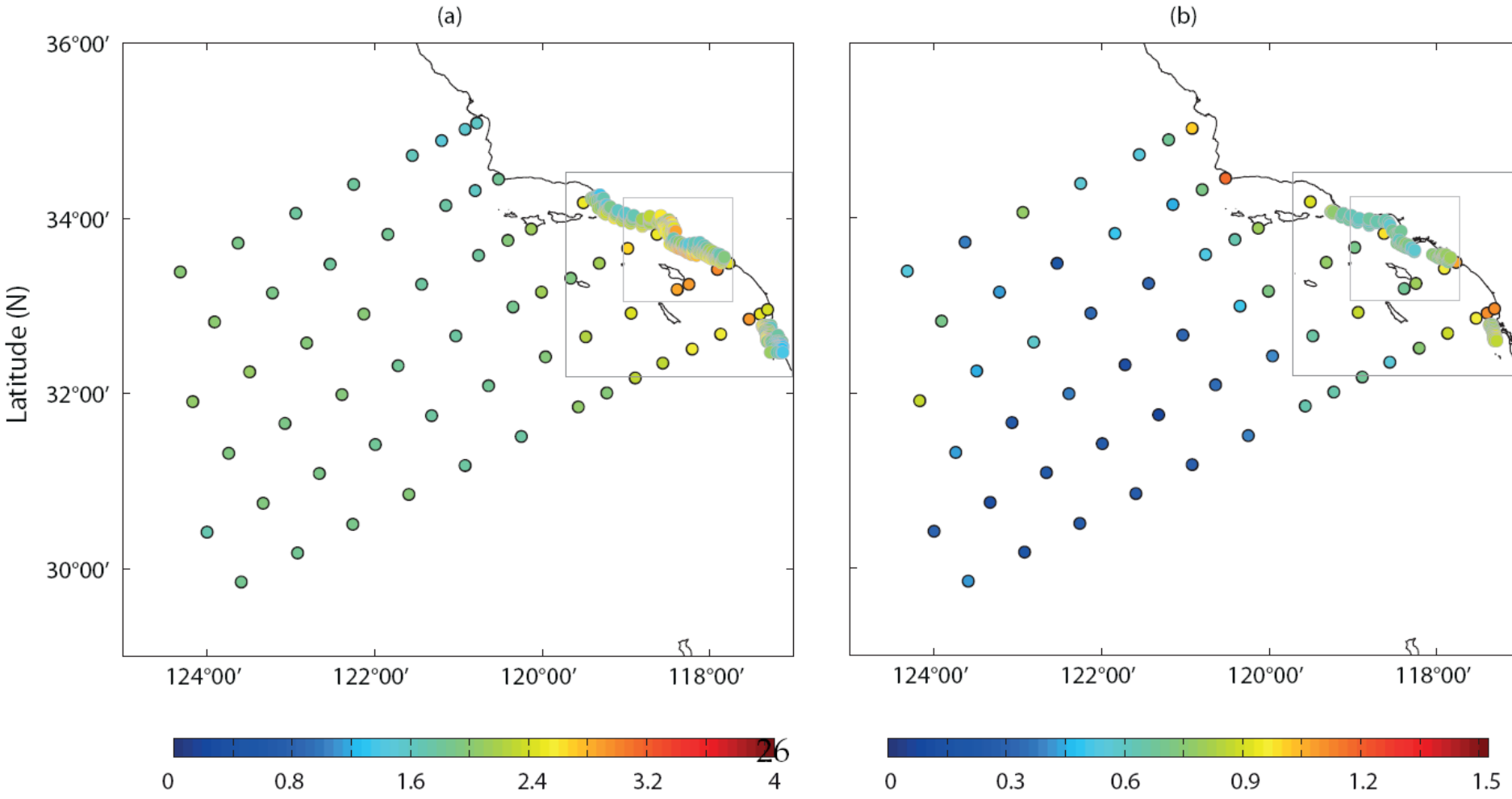
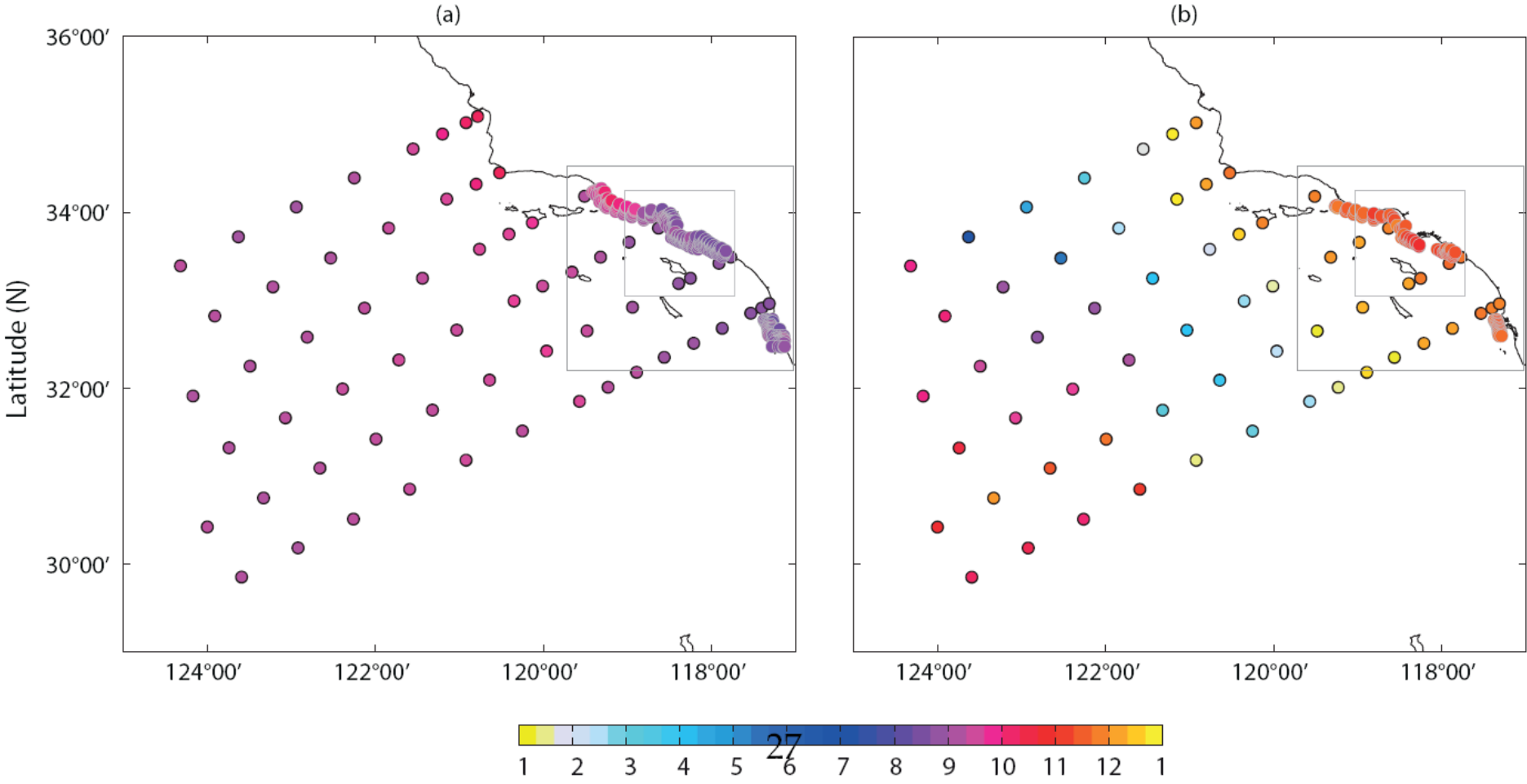


- Offshore T (-) in upper 200 m
- Nearcoast surface and offshore subsurface S (+)
  - An effective regression basis of S in SCB
- Offshore (+) and subsurface (-) of Oxy amplitudes

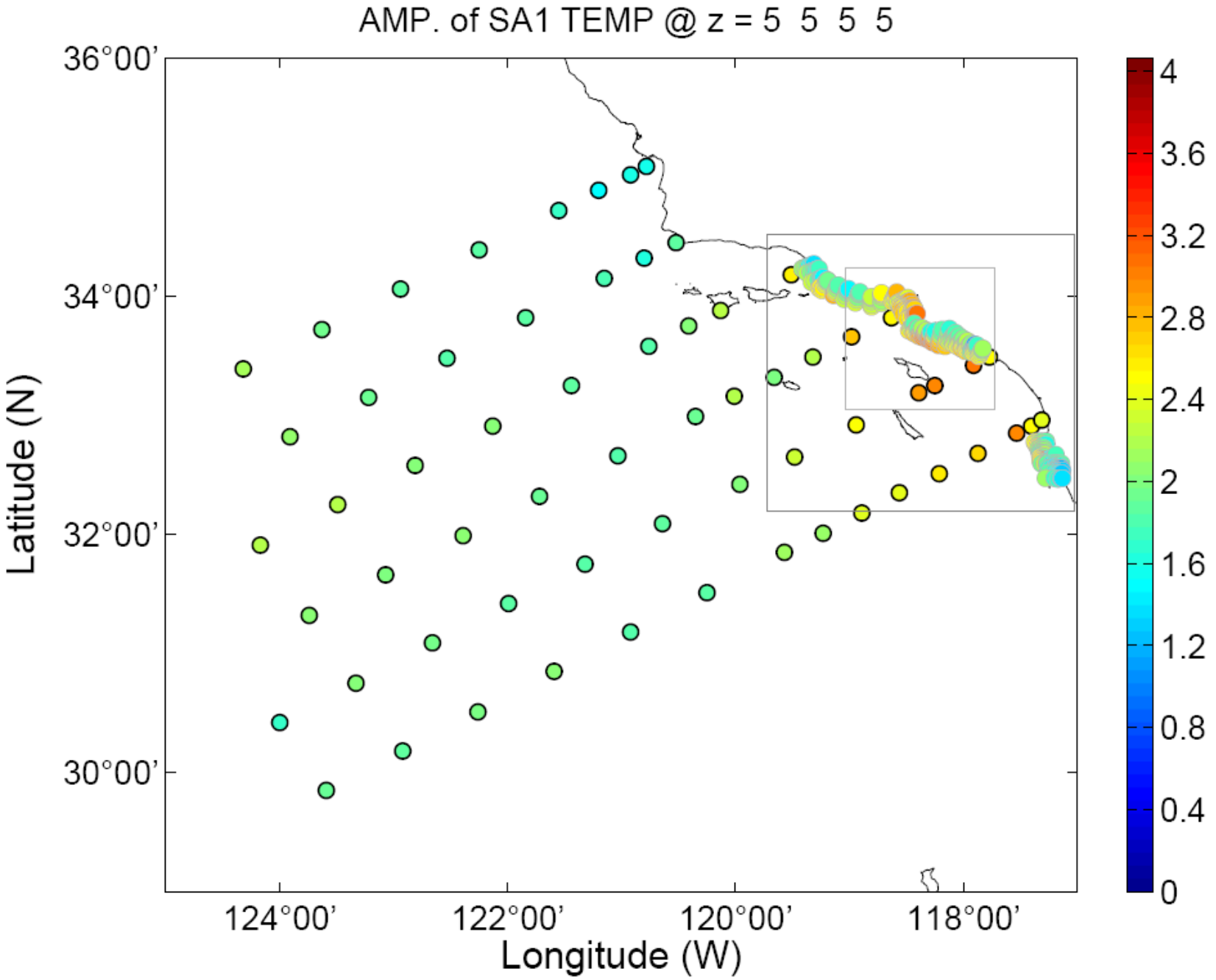
Seasonal (SA1) amplitudes of temperature at z=5, 70 m



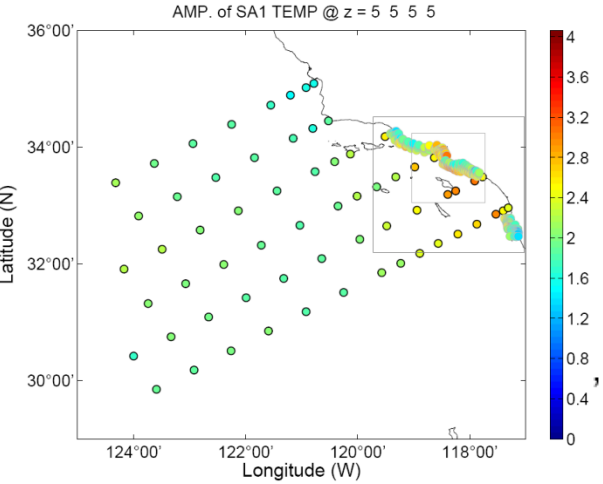
Seasonal (SA1) amplitudes of temperature at z=5, 70 m

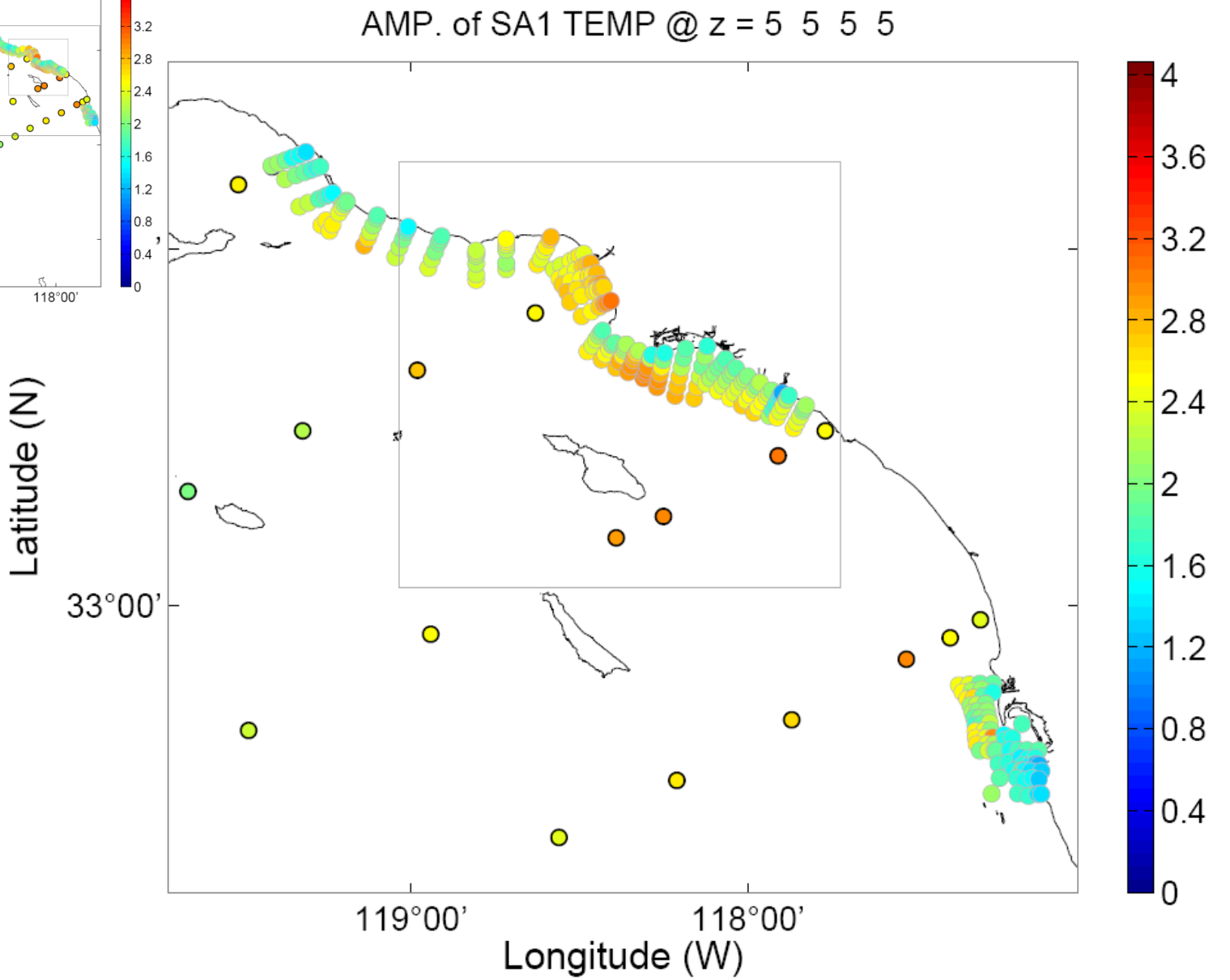


Seasonal (SA1) amplitudes of surface temperature

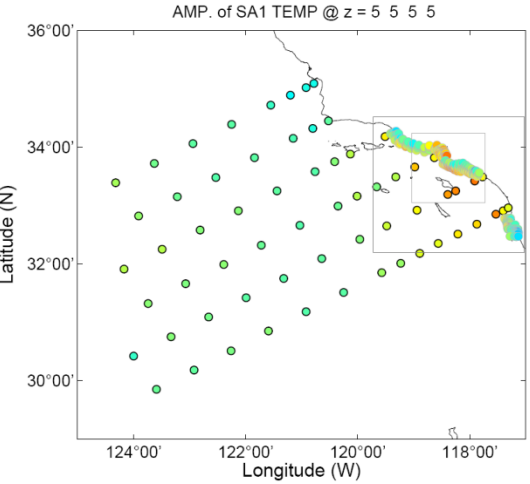


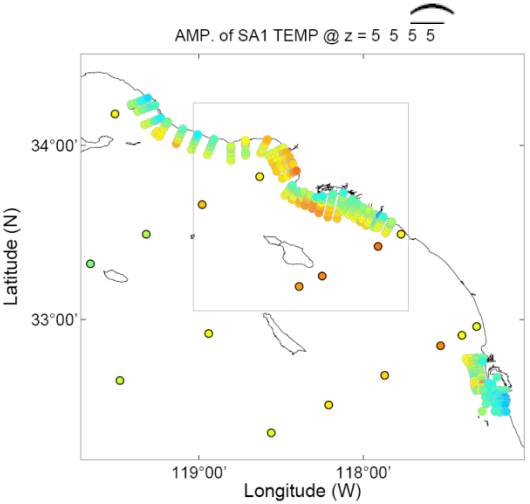
Seasonal (SA1) amplitudes of surface temperature

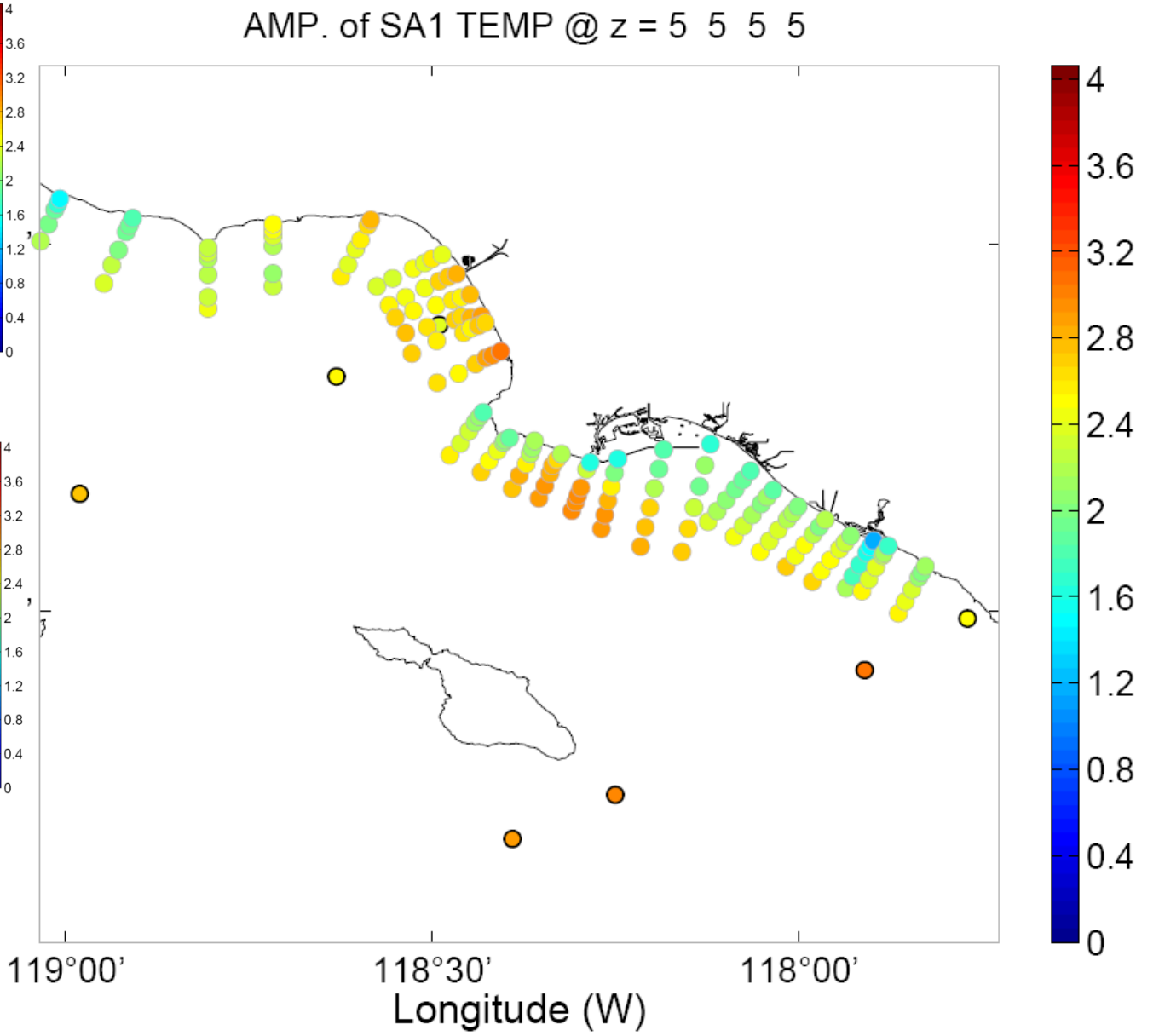




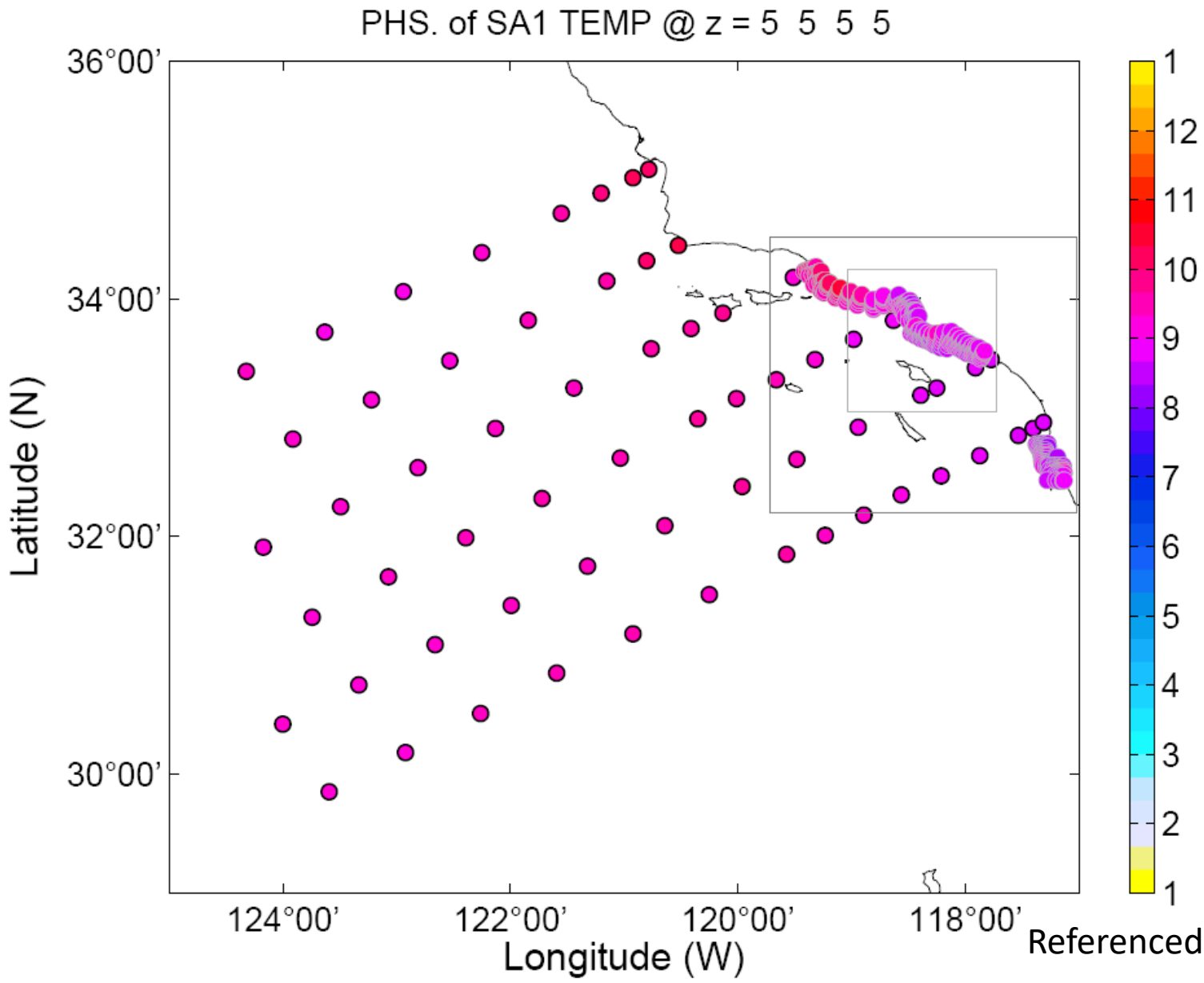
Seasonal (SA1) amplitudes of surface temperature





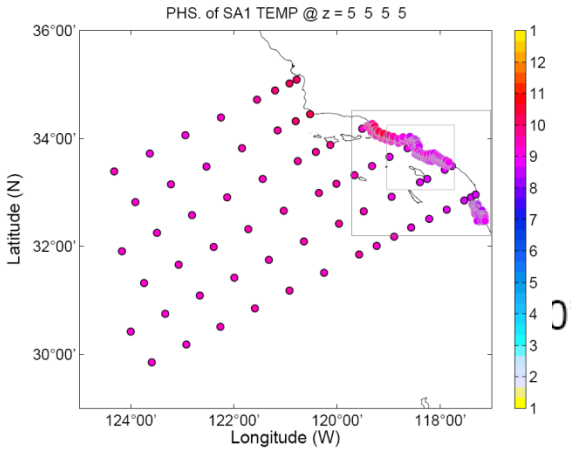


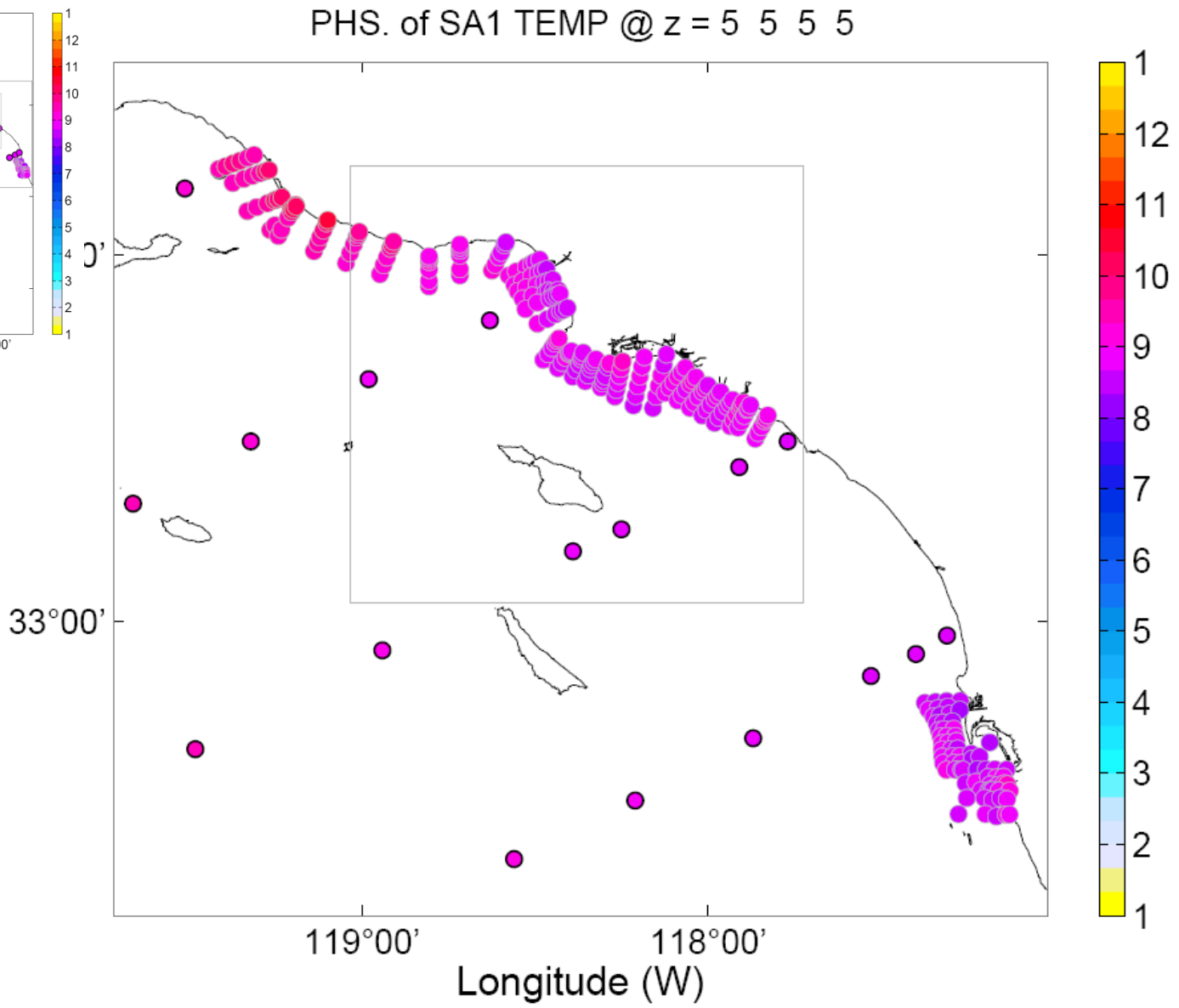
Seasonal (SA1) phases of surface temperature



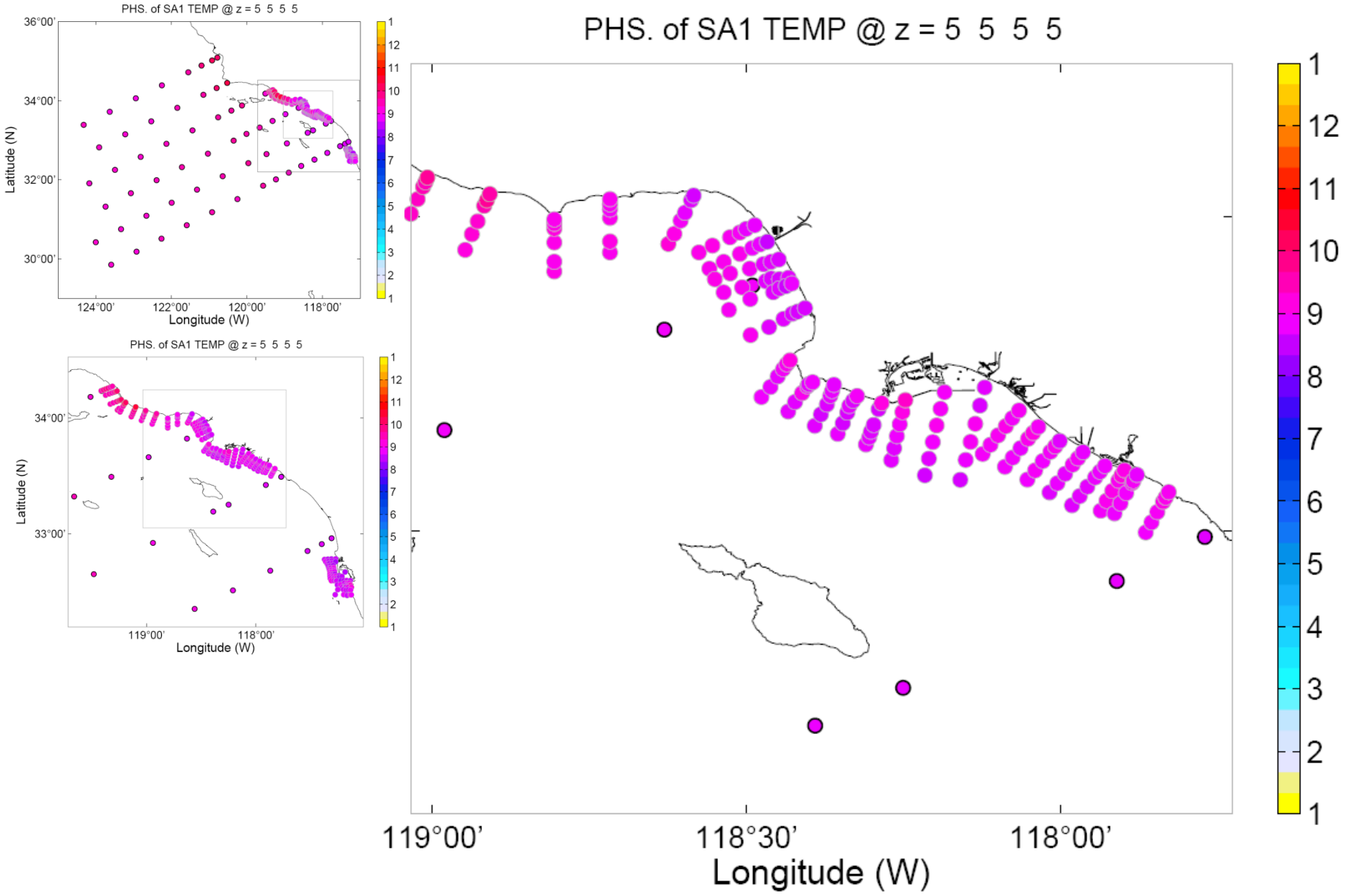
Referenced to JAN 1

Seasonal (SA1) phases of surface temperature





Seasonal (SA1) phases of surface temperature



Summary

- Multivariate regression analysis of CTD data
- Partitioning of historical coastal observations into seasonality, climate indices-coherent components (, and linear trend).
- Successive orthogonalization was implemented for coherent basis functions.
- Temperature and salinity are fitted with SA1, SA2, ENSO, linear trend, PDO, NPGO, and SIOT.
- Regional circulation is explained by regional and climate indices-coherent spatial structure.