A Water Mass History of the southern California Current System

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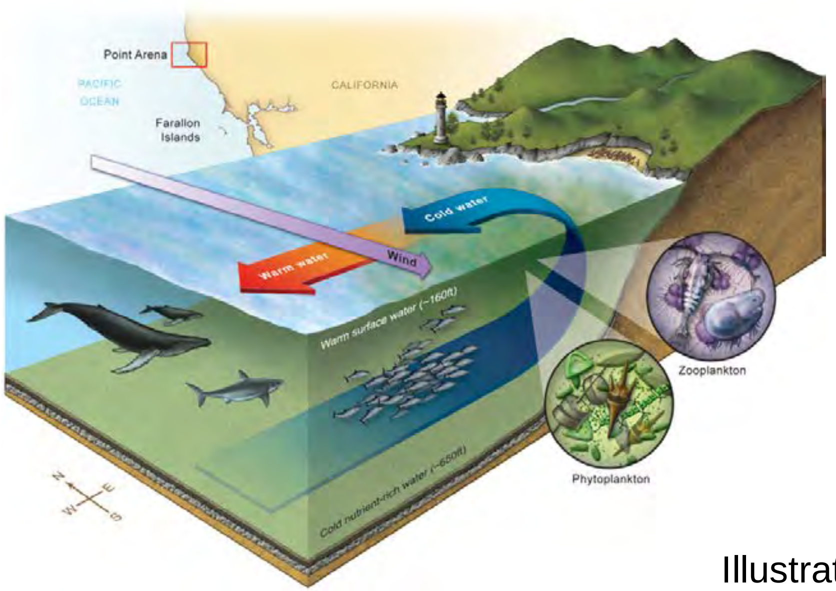
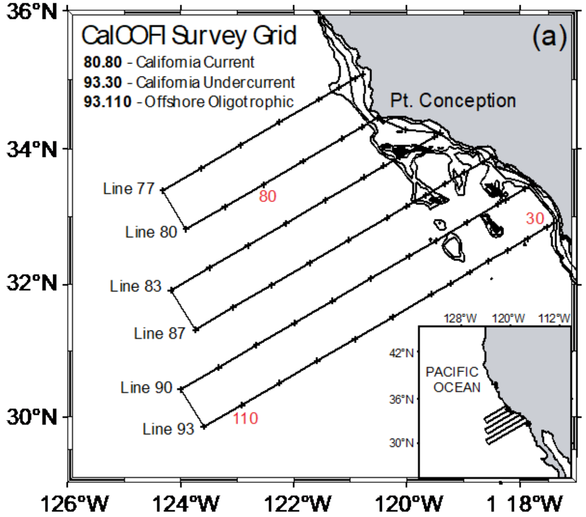
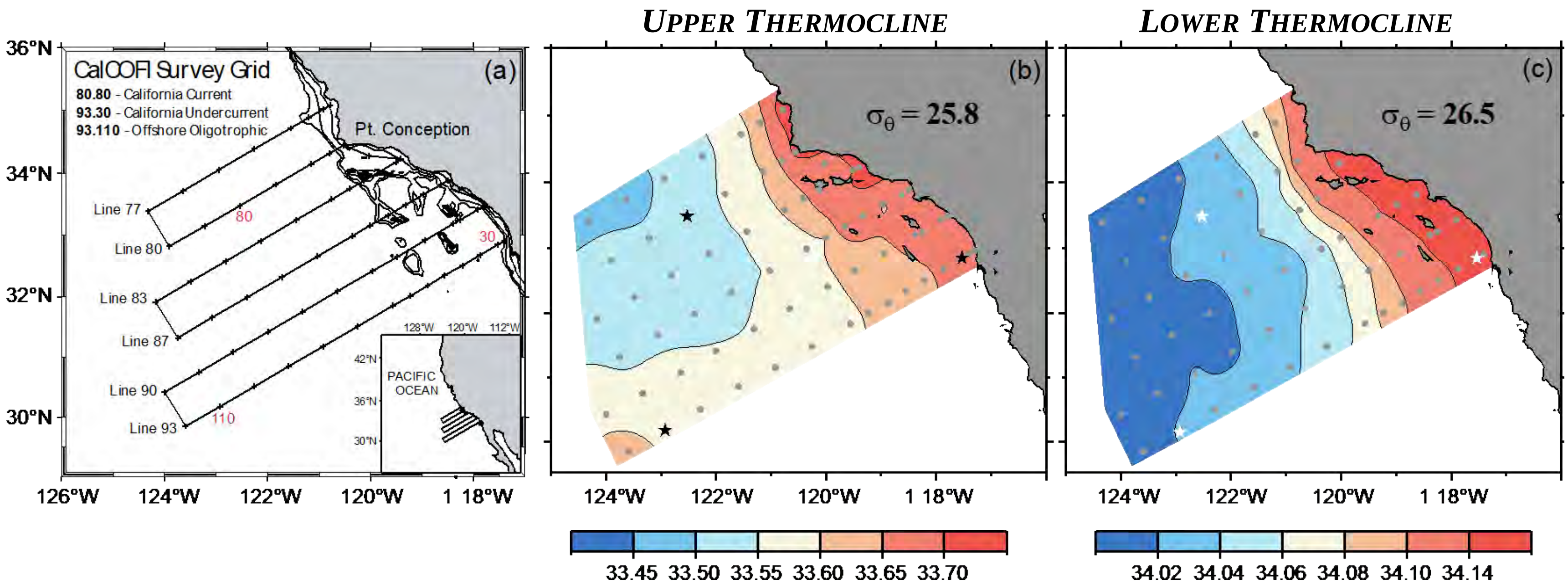


Illustration by Fiona Morris


CalCOFI Survey Grid
(a)
80.80 - California Current
93.30 - California Undercurrent
93.110 - Offshore Oligotrophic
Pt. Conception
Line 77
Line 80
Line 83
Line 87
Line 90
Line 93
80
30
110
36°N
34°N
32°N
30°N
126°W
124°W
122°W
120°W
1 18°W
128°W
120°W
112°W
42°N
36°N
30°N
PACIFIC OCEAN

SALINITY ON ISOPYCNALS

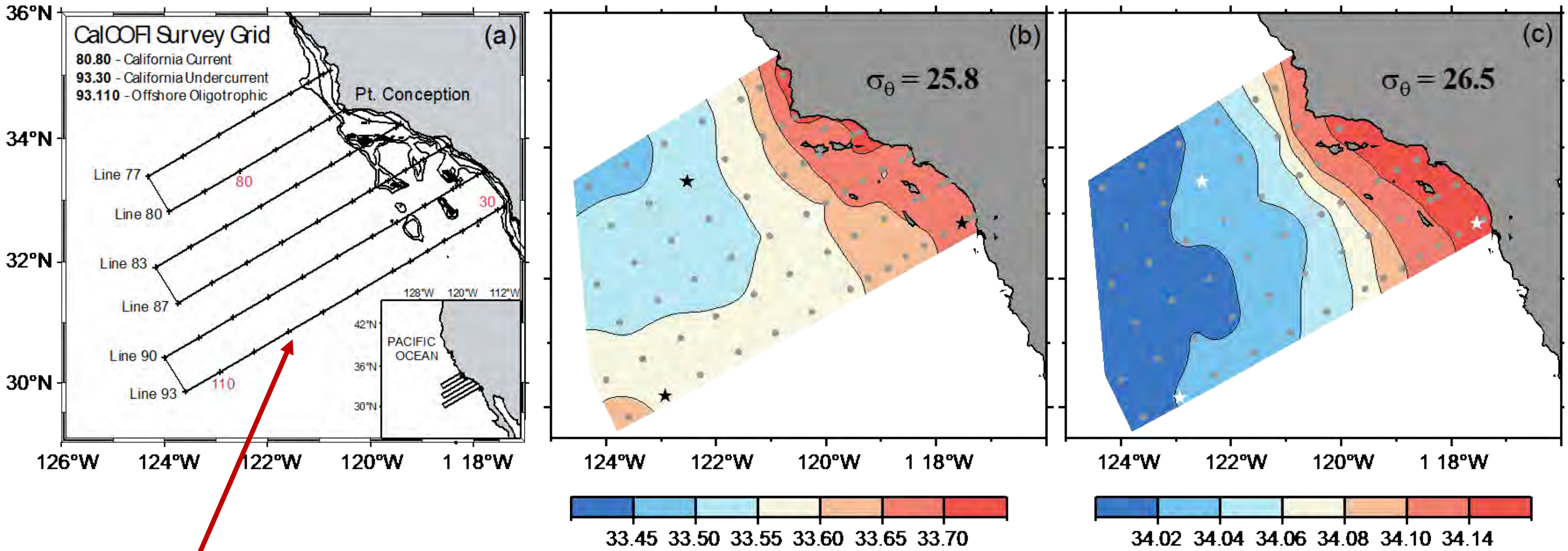


Z ~ 100-150 M

Z ~ 250-300 M

SALINITY ON ISOPYCNALS

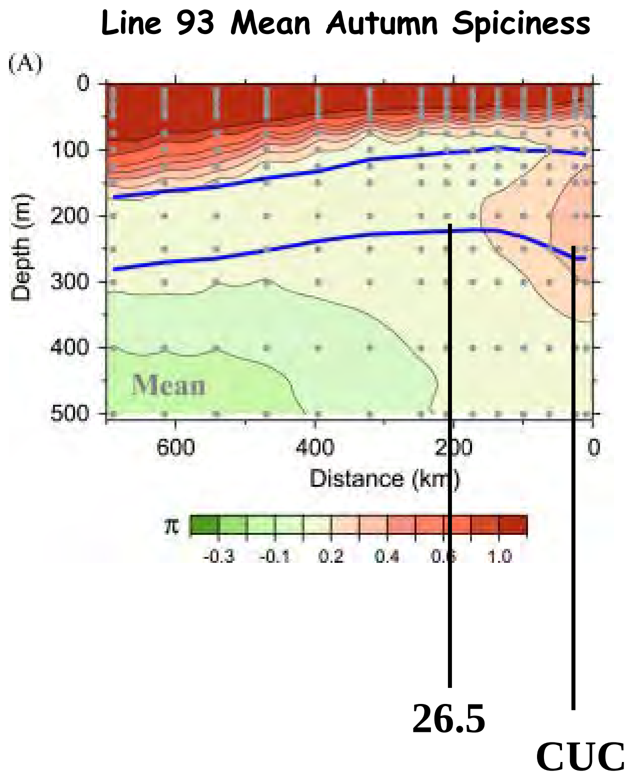
UPPER THERMOCLINE *LOWER THERMOCLINE*



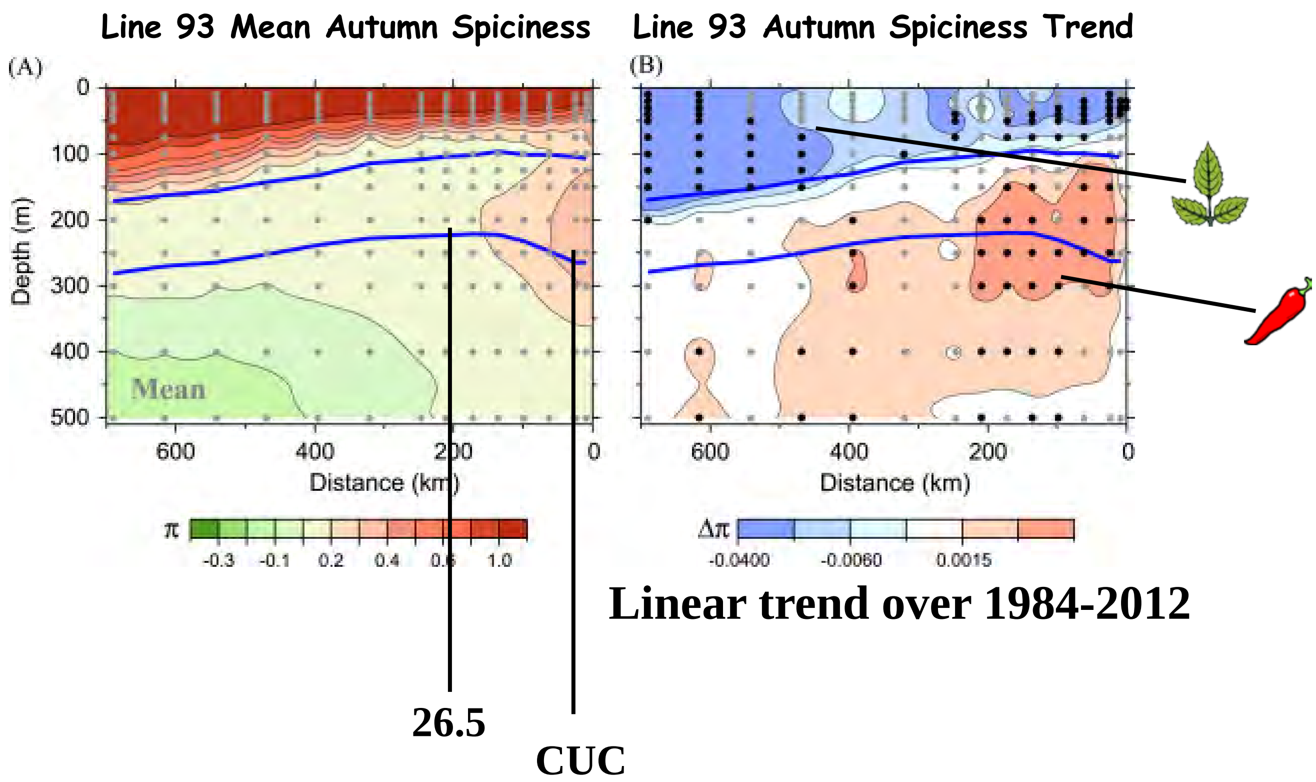
LINE 93

Z ~ 100-150 M

Z ~ 250-300 M



Bograd et al. (2015)



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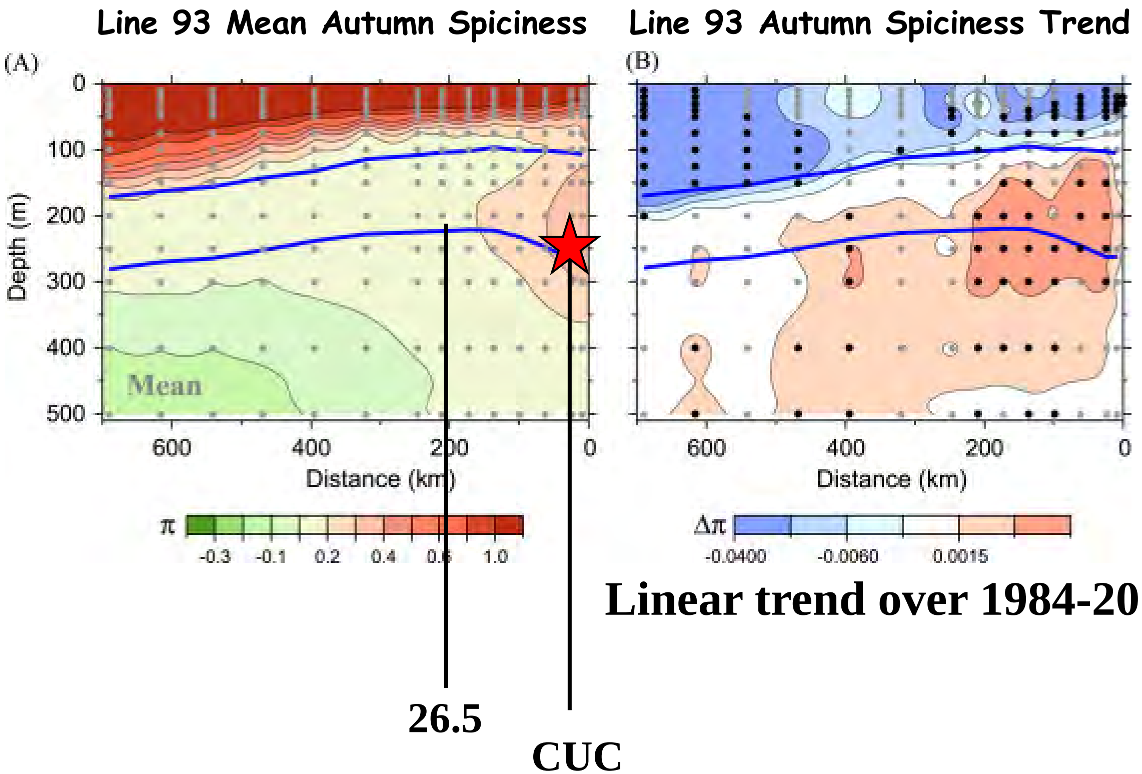
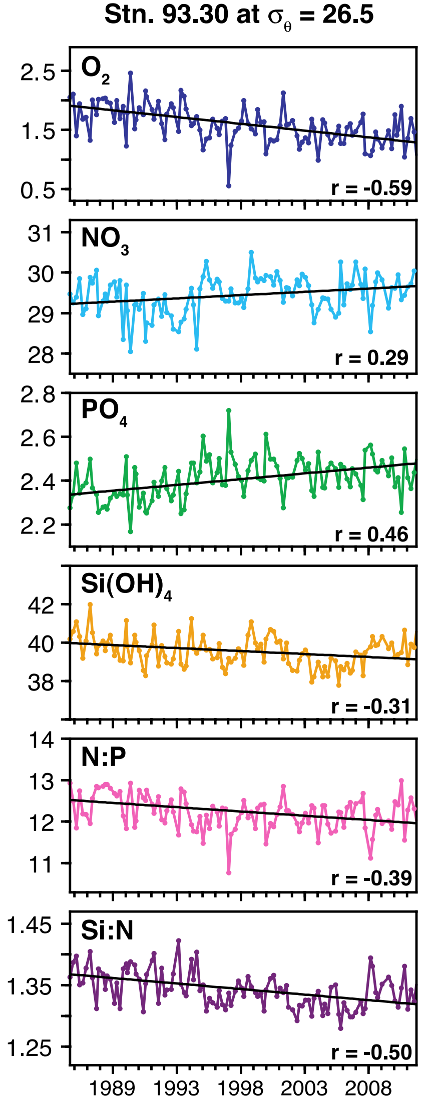


Linear trend over 1984-2012



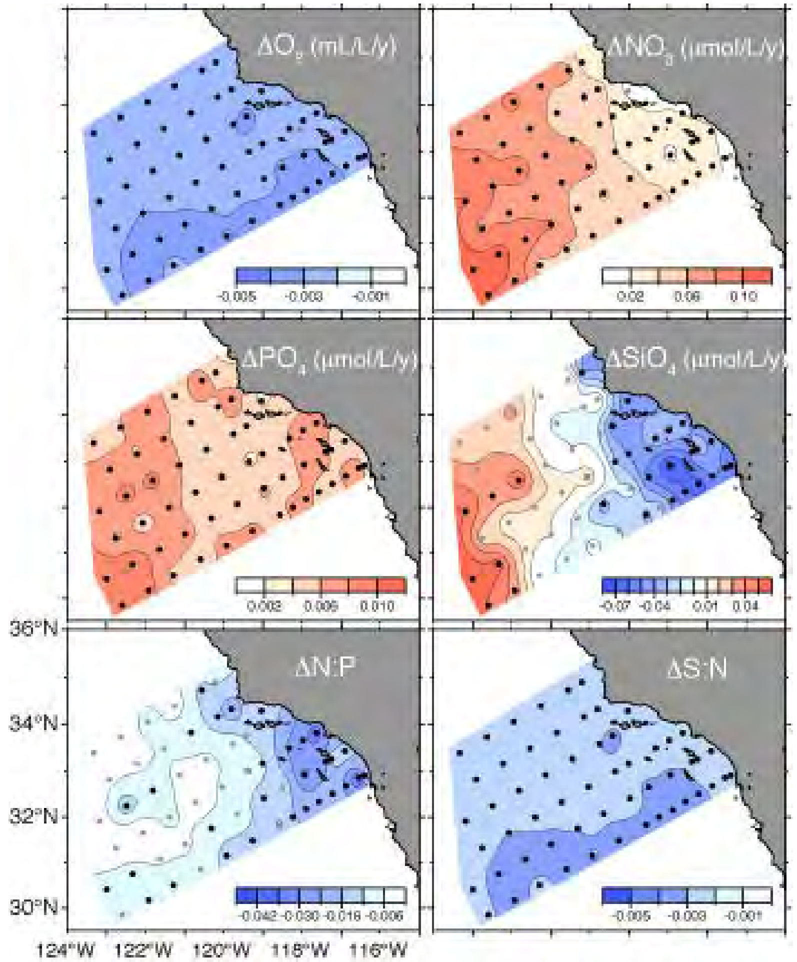
Bograd et al. (2015)

$\sigma_\theta = 26.5$

Oxygen ⇩

Phosphate ⇧

N:P ⇩



Linear trend over 1984-2012

Nitrate ⇧

Silicate ⇧⇩

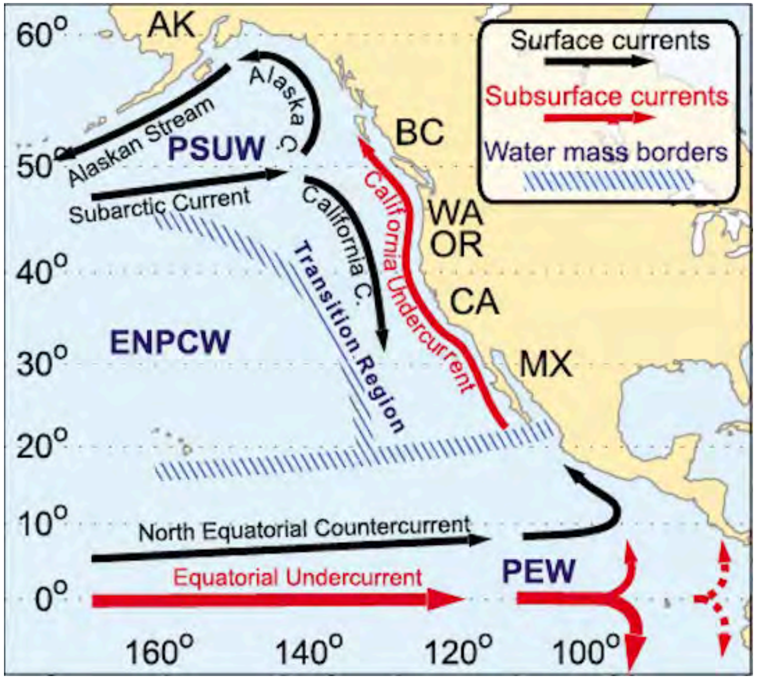
S:N ⇩

Bograd et al. (2015)

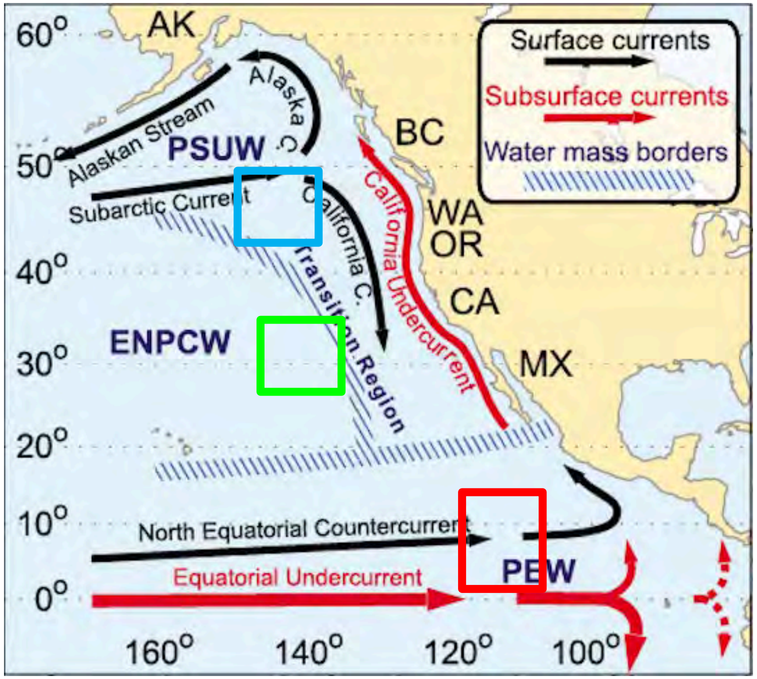
OBJECTIVES

- QUANTIFY WATER MASS CONTRIBUTIONS TO SOUTHERN CALIFORNIA CURRENT
- INVESTIGATE SPATIAL AND TEMPORAL VARIABILITY
  - LOW-FREQUENCY VARIABILITY (TRENDS OR CHANGE POINTS)
  - EFFECTS OF EL NIÑO – LA NIÑA
- INFER MECHANISMS OF BIOGEOCHEMICAL CHANGES IN CALCOFI DATA
  - CHANGES AT SOURCE? ALONG ADVECTIVE PATHWAY? LOCALLY?
- CLIMATE CHANGE IMPACTS

PRELIMINARY RESULTS

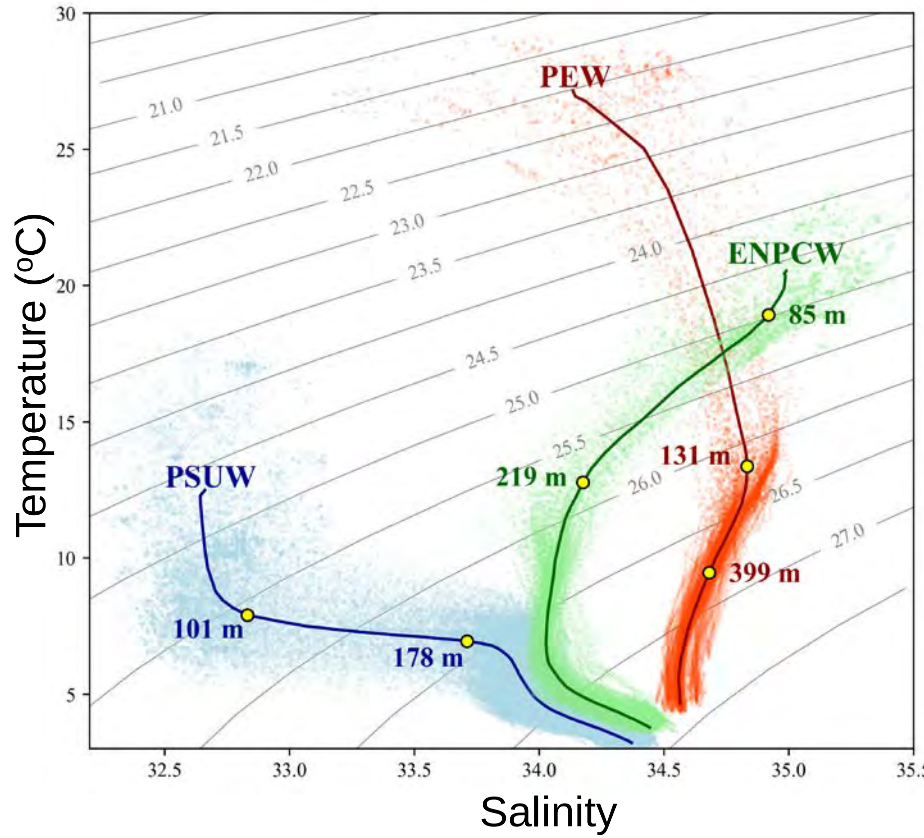


Thomson and Krassovski (2010)



Thomson and Krassovski (2010)

World Ocean Database, 1984-2016



Pacific Subarctic Water (PSUW)

Pacfic Equatorial Water (PEW)

Eastern North Pacific Central Water (ENPCW)

	$PSUW_{deep}$	$PSUW_{shal}$	PEW_{deep}	PEW_{shal}	$ENPCW_{deep}$	$ENPCW_{shal}$
	PSUW 26.4	PSUW 25.6	PEW 26.8	PEW 26.2	ENPCW 25.8	ENPCW 25.0
Temperature	6.88	7.75	9.47	13.41	12.89	18.77
Salinity	33.69	32.80	34.68	34.85	34.18	34.87
Oxygen	4.58	6.24	0.42	1.06	4.94	5.32
Phosphate	1.75	1.16	2.73	2.04	0.66	0.14
Silicate	34.05	14.81	39.72	22.06	9.85	3.87
Nitrate	22.21	10.33	36.41	28.38	7.58	0.25
Mass	1.00	1.00	1.00	1.00	1.00	1.00

Pacific Subarctic Water (PSUW)
Pacfic Equatorial Water (PEW)
Eastern North Pacific Central Water (ENPCW)

Water Mass Influences on the California Current

	$PSUW_{deep}$ PSUW 26.4	$PSUW_{shal}$ PSUW 25.6	PEW_{deep} PEW 26.8	PEW_{shal} PEW 26.2	$ENPCW_{deep}$ ENPCW 25.8	$ENPCW_{shal}$ ENPCW 25.0
Temperature	6.88 Low	7.75	9.47	13.41	12.89 High	18.77
Salinity	33.69 Low	32.80	34.68 High	34.85	34.18	34.87
Oxygen	4.58 High	6.24	0.42 Low	1.06	4.94	5.32
Phosphate	1.75	1.16	2.73	2.04	0.66	0.14
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Mass	1.00	1.00	1.00	1.00	1.00	1.00

Pacific Subarctic Water (PSUW)
Pacfic Equatorial Water (PEW)
Eastern North Pacific Central Water (ENPCW)

SIX WATER MASSES: **(PEW, PSUW, ENPCW; UPPER AND DEEP)**

SIX VARIABLES: **T, S, O_2, NO_3, PO_4, SiO_4**

SIX EQUATIONS + CONSERVATION OF MASS

SOLVE FOR % EACH WATER MASS IN **CALCOFI** DOMAIN [1984-2017]

Tomczak and Large (1989)

Six Water Masses: **(PEW, PSUW, ENPCW; Upper and Deep)**

Six Variables: **T, S, O_2, NO_3, PO_4, SiO_4**

Six Equations + Conservation of Mass

Solve for % each Water Mass in **CalCOFI** Domain [1984-2017]

$$X_{PEWu}T_{PEWu} + \ldots + X_{NPCWd}T_{NPCWd} + 0 = T_{OBS} + R_T$$

$$X_{PEWu}S_{PEWu} + \ldots + X_{NPCWd}S_{NPCWd} + 0 = S_{OBS} + R_S$$

$$X_{PEWu}O_{2,PEWu} + \ldots + X_{NPCWd}O_{2,NPCWd} - r_{O/P}\,\Delta P = O_{2,OBS} + R_{O2}$$

$$X_{PEWu}PO_{4,PEWu} + \ldots + X_{NPCWd}PO_{4,NPCWd} + \Delta P = PO_{4,OBS} + R_{PO4}$$

$$X_{PEWu}NO_{3,PEWu} + \ldots + X_{NPCWd}NO_{3,NPCWd} + r_{N/P}\,\Delta P = NO_{3,OBS} + R_{NO3}$$

$$X_{PEWu}SiO_{4,PEWu} + \ldots + X_{NPCWd}SiO_{4,NPCWd} + r_{Si/P}\,\Delta P = SiO_{4,OBS} + R_{SiO4}$$

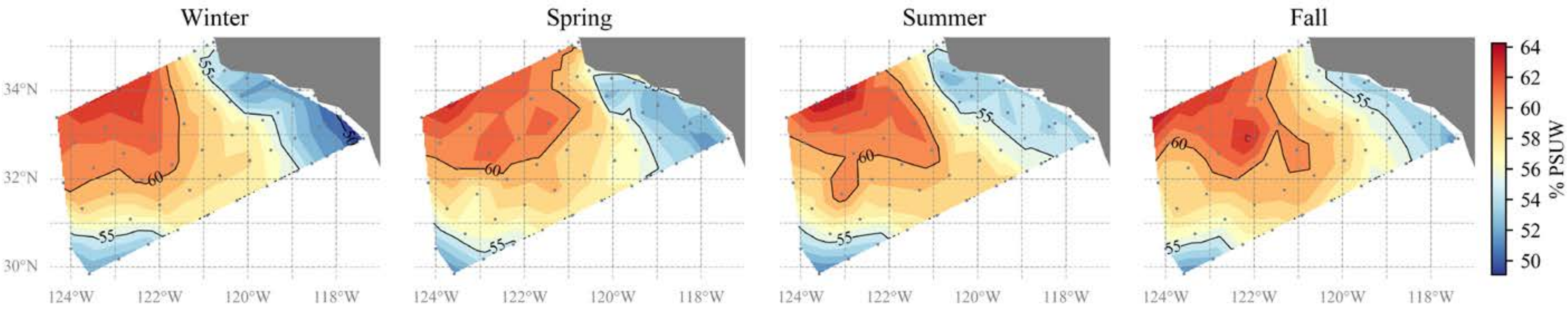
$$X_{PEWu} + X_{PSUWu} + X_{NPCWu} + X_{PEWd} + X_{PSUWd} + X_{NPCWd} = 1 + R_{\Sigma}$$

http://omp.geomar.de/node3.html

Tomczak and Large (1989)

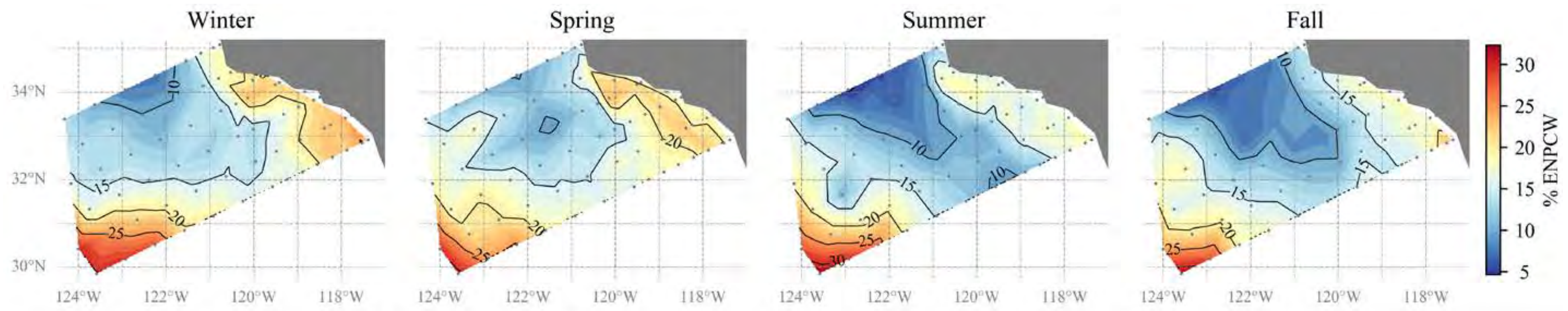
Seasonal Mean PSUW Contribution in Upper Thermocline

%PSUW in CalCOFI domain at $\sigma_\theta = 25.8$



- Seasonal mean PSUW contributions in upper thermocline
- Waters at this level are 55-60% PSUW throughout
- High PSUW offshore - influx of California Current; low inshore
- Weak seasonality; minimum inshore PSUW contribution in winter

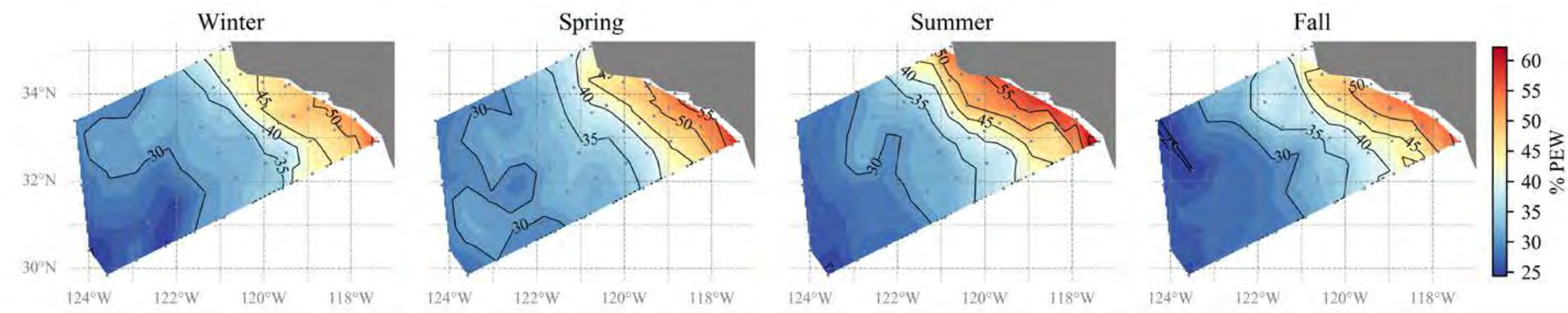
%ENPCW IN CALCOFI DOMAIN AT $\sigma_\theta = 25.8$



- SEASONAL MEAN ENPCW CONTRIBUTIONS IN UPPER THERMOCLINE
- WATERS AT THIS LEVEL ARE ONLY 5-15% EPNCW
- HIGHEST EPNCW IN SOUTHWEST CORNER AND INSHORE (ENTRAINED IN POLEWARD FLOW)

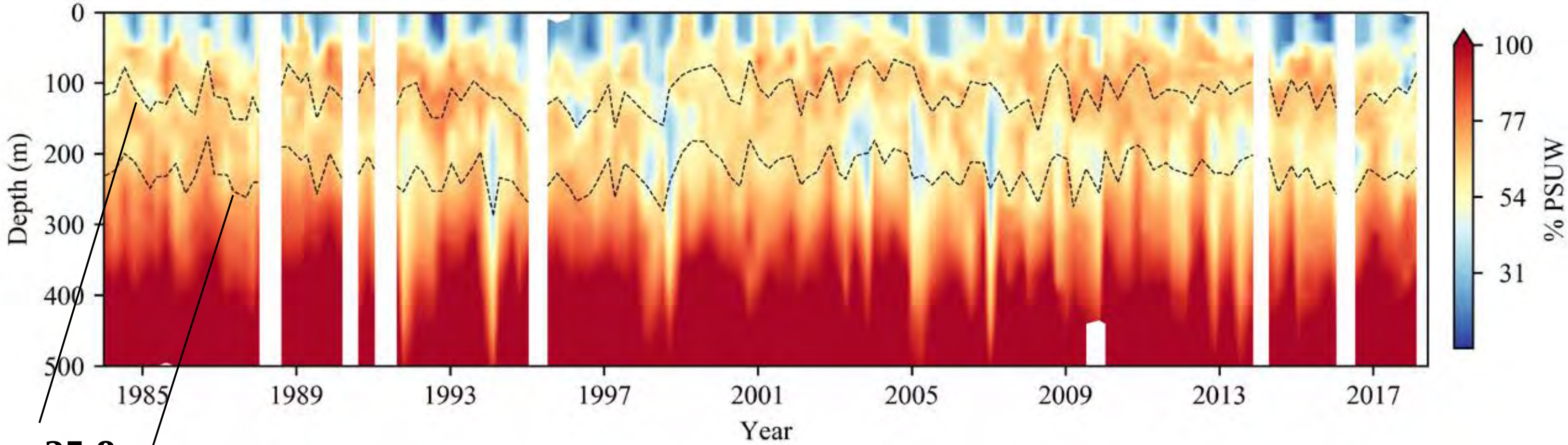
Seasonal Mean PEW Contribution in Lower Thermocline

%PEW in CalCOFI domain at $\sigma_\theta = 26.5$



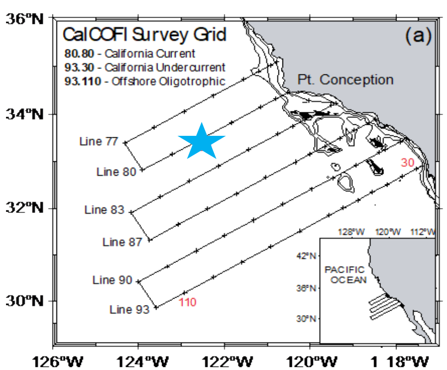
- Seasonal mean PEW contributions in lower thermocline
- Strong cross-shore gradient in distribution of PEW
- 50-60% PEW contribution in nearshore region
- Strong seasonality – more PEW in summer-fall (strong CUC)

CalCOFI Station 80.80 (California Current)



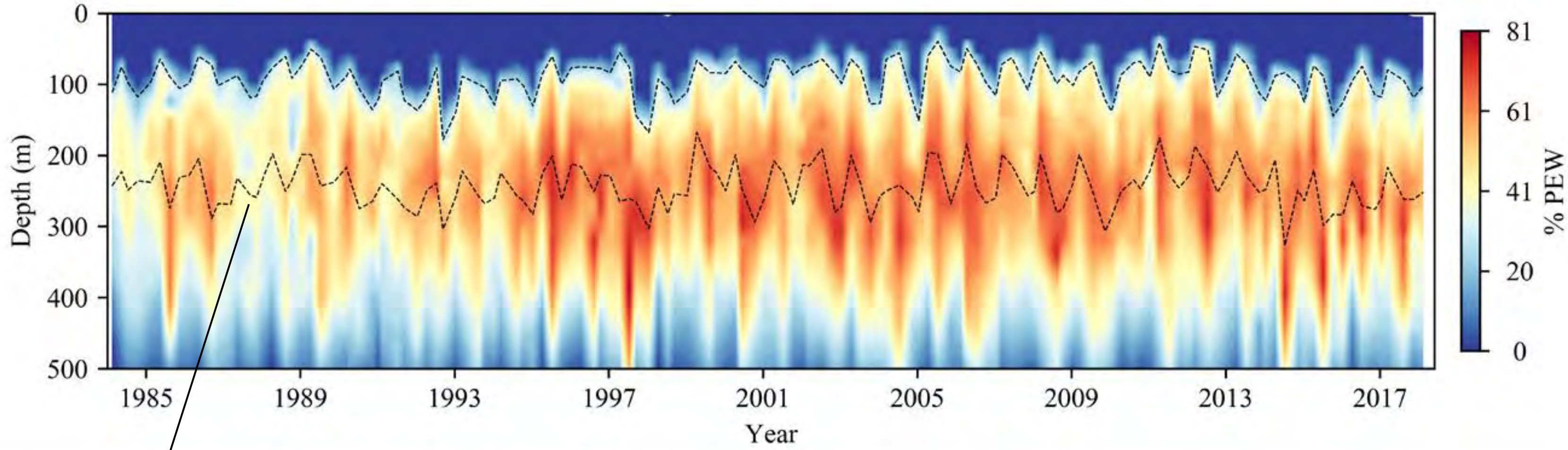
σ_θ = 25.8

σ_θ = 26.5

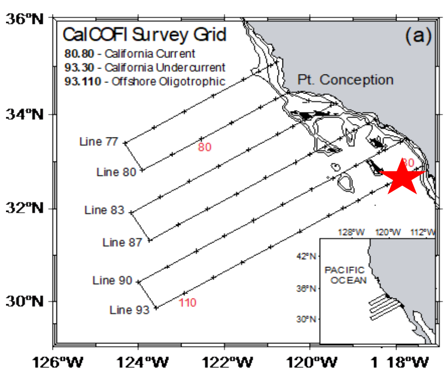


- Time-Depth plot of PSUW at Station 80.80
- Seasonal variability in surface layer
- High PSUW contribution around σ_θ = 25.8 (CC)
- Strong interannual variability in upper 200 m in quantity of PSUW & depth structure

CalCOFI Station 93.30 (California Undercurrent)

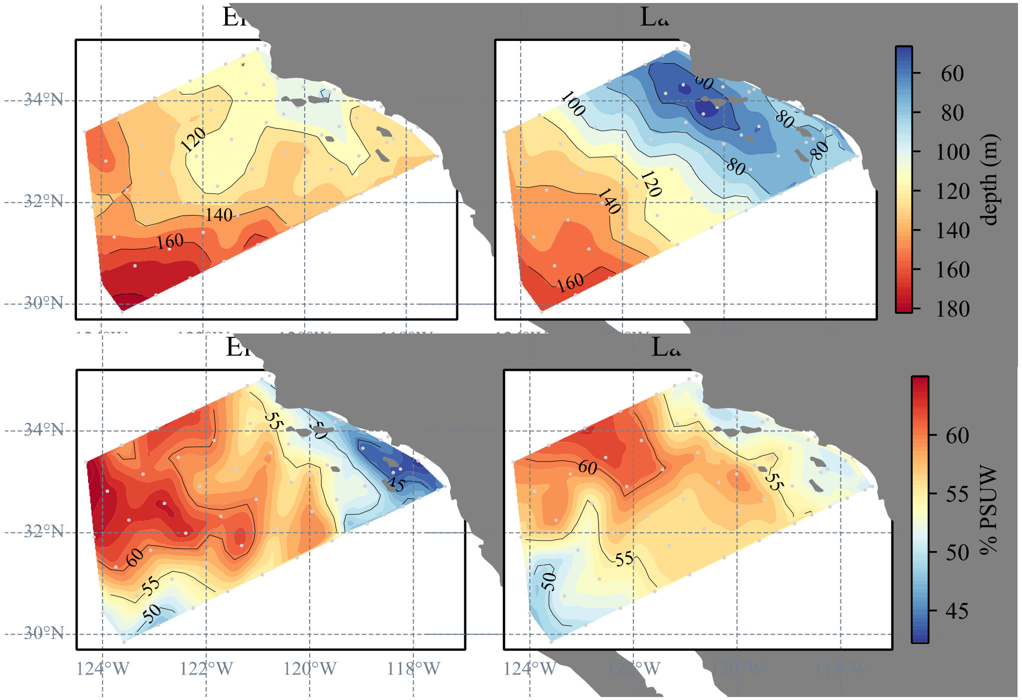


$\sigma_\theta = 26.5$



- Time-Depth plot of PEW at Station 93.30
- Highest PEW contribution around $\sigma_\theta = 26.5$ (CUC)
- Strong interannual variability: trend/shift to higher PEW
- Higher PEW contribution in El Niño years (stronger CUC)

Winter Z and %PSUW in CalCOFI domain at $\sigma_\theta = 25.8$



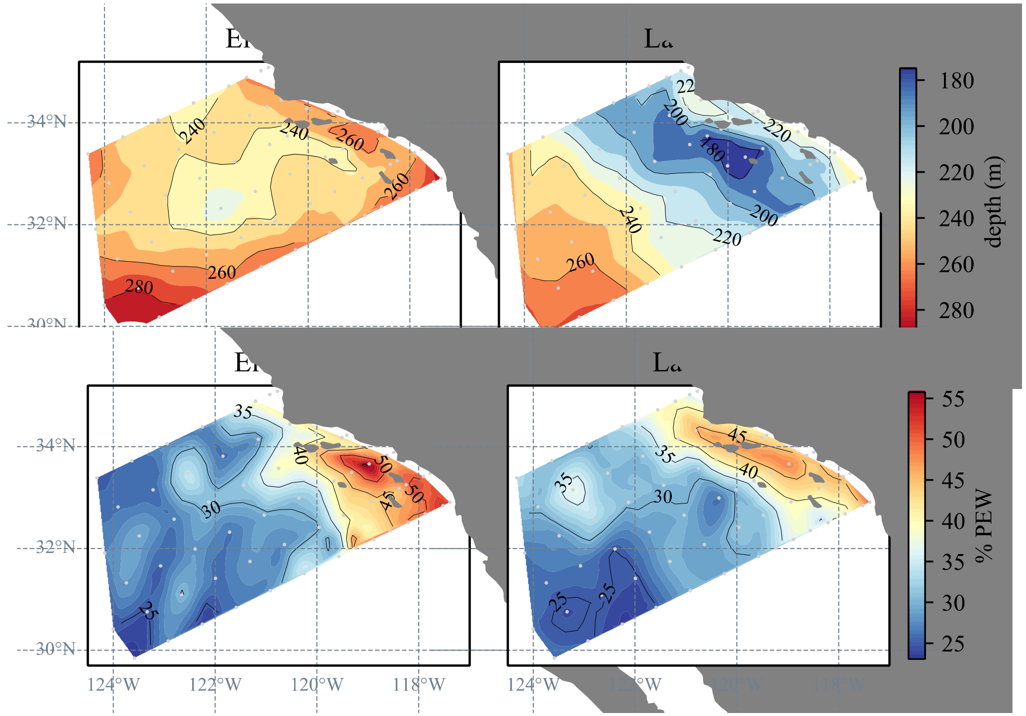
Depth

%PSUW

- Mean upper thermocline depth, PSUW contribution during El Niño, La Niña
- Higher PSUW contribution offshore, lower inshore during El Niño
- High PSUW content within California Current core during La Niña

WATER MASS CHANGES ASSOCIATED WITH ENSO EVENTS

WINTER Z AND %PEW IN CALCOFI DOMAIN AT σ_θ = 26.5

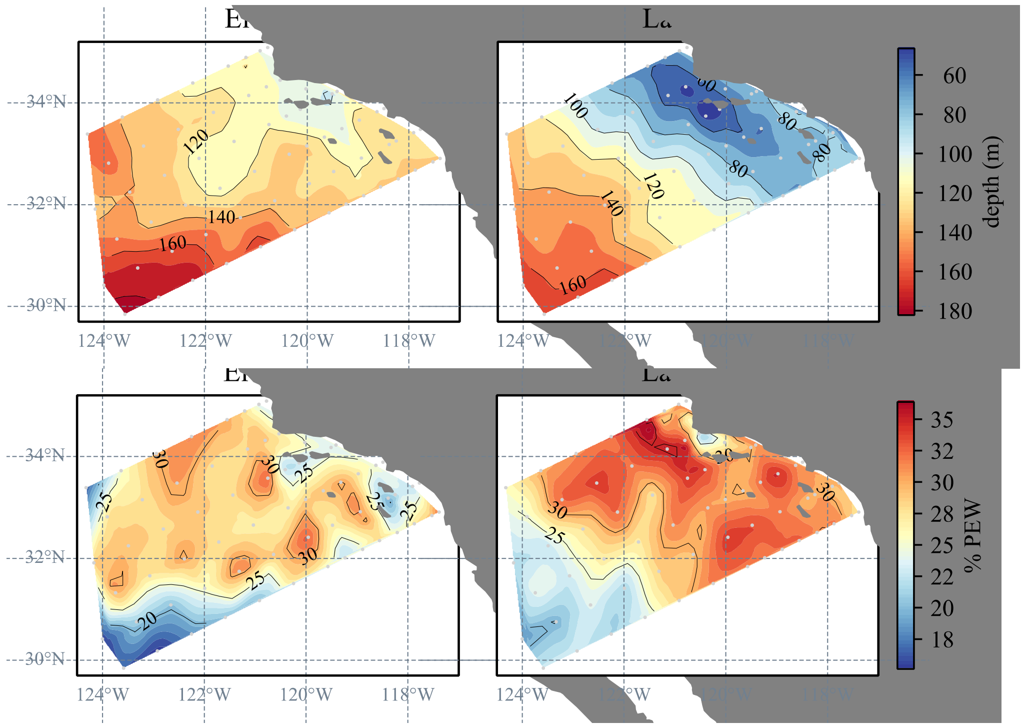


DEPTH

%PEW

- MEAN <u>LOWER</u> THERMOCLINE DEPTH, PEW CONTRIBUTION DURING EL NIÑO, LA NIÑA
- <u>HIGHER PEW</u> CONTRIBUTION INSHORE <u>DURING EL NIÑO</u> (STRONGER CUC), LESS DURING LA NIÑA

WINTER Z AND %PEW IN CALCOFI DOMAIN AT $\sigma_\theta = 25.8$

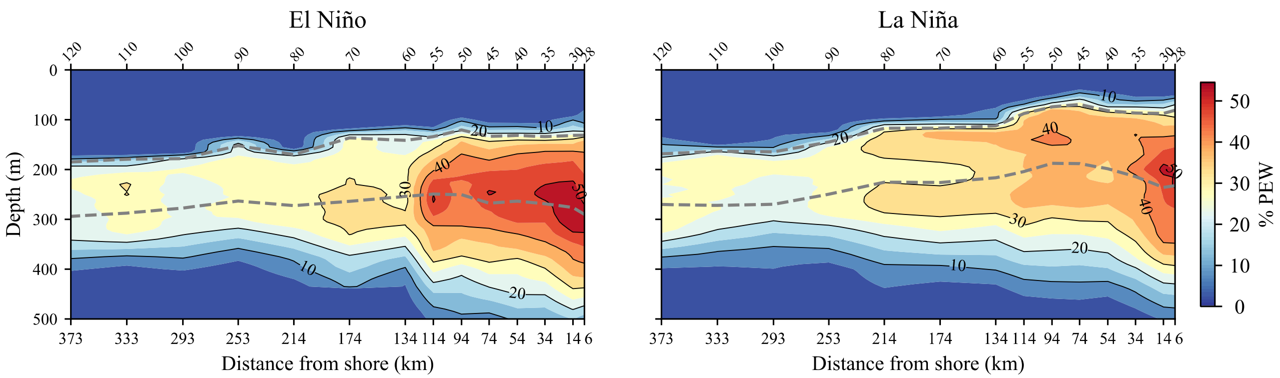


DEPTH

%PEW

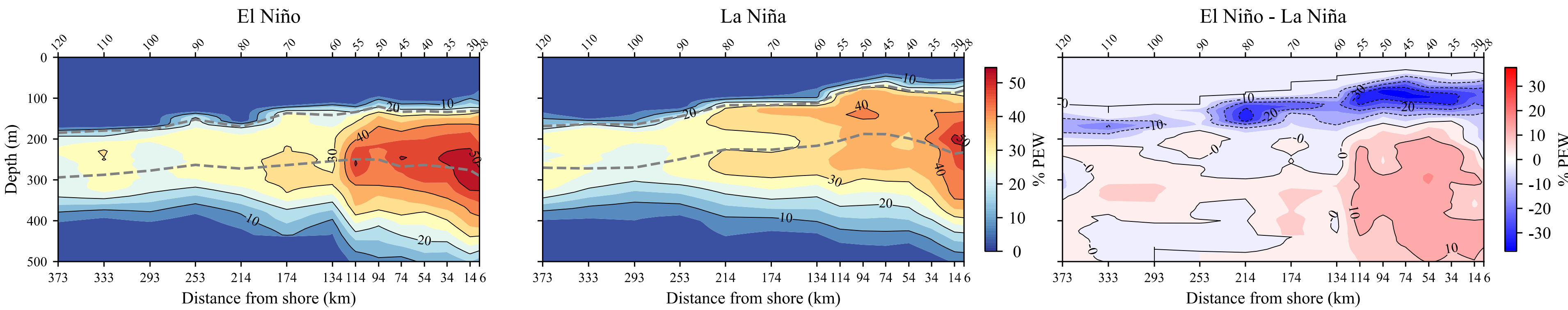
- MEAN UPPER THERMOCLINE DEPTH, PEW CONTRIBUTION DURING EL NIÑO, LA NIÑA
- HIGHER PEW CONTRIBUTION DURING LA NIÑA, BUT ISOPYCNAL MUCH SHALLOWER
- ALTHOUGH WEAKER PEW CONTRIBUTION DURING LA NIÑA, HAVE MORE PEW IN UPPER WATER COLUMN

%PEW IN CALCOFI DOMAIN ALONG LINE 93



- LINE 93 SECTIONS, PEW CONTRIBUTION DURING EL NIÑO, LA NIÑA
- SIGNIFICANTLY HIGHER PEW CONTRIBUTION DURING EL NIÑO
- VERTICAL DISTRIBUTION OF PEW DIFFERENT IN EL NIÑO VS. LA NIÑA

%PEW IN CALCOFI DOMAIN ALONG LINE 93



- DIFFERENCE IN PEW CONTRIBUTION DURING EL NIÑO VS. LA NIÑA
- HIGHER PEW CONTENT DURING LA NIÑA IN UPPER THERMOCLINE
- STRONGER UPWELLING DURING LA NIÑA SUPPLIES UPPER LAYERS WITH ENHANCED PEW CONTRIBUTION – STRONGER BIOLOGICAL IMPACT?

SUMMARY

- OPTIMUM MULTIPARAMETER ANALYSIS (OMP) IS A USEFUL TOOL FOR CHARACTERIZING WATER MASSES

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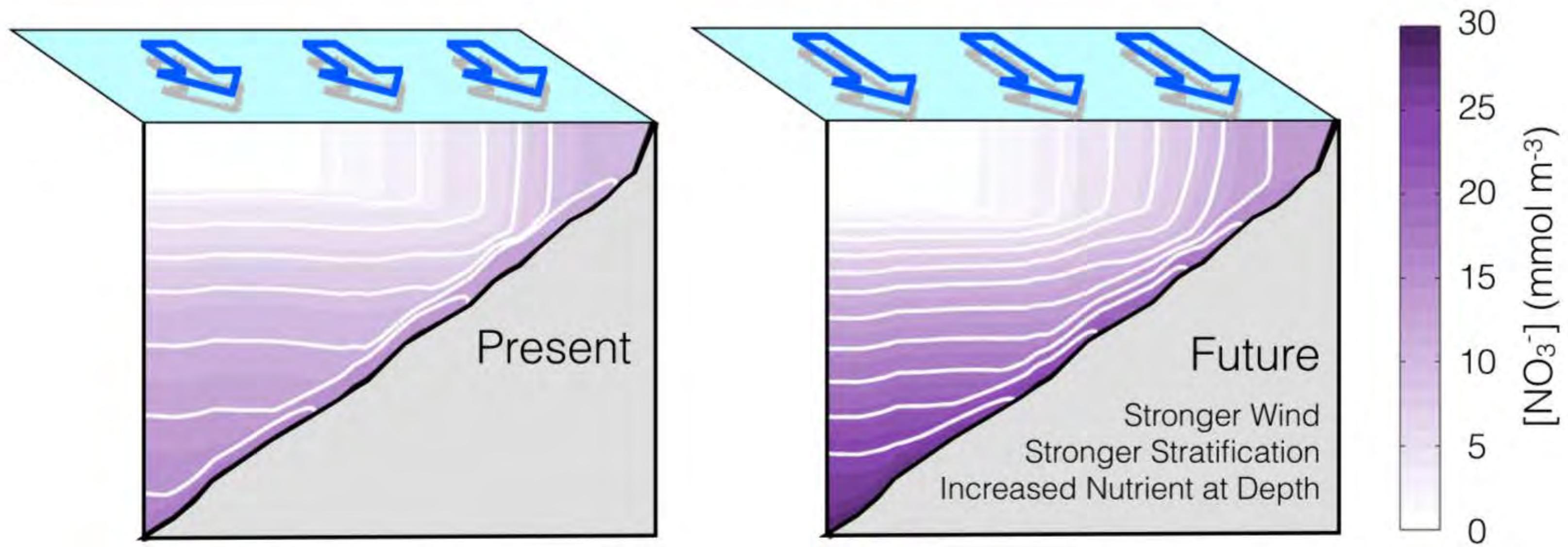
- OPTIMUM MULTIPARAMETER ANALYSIS (OMP) IS A USEFUL TOOL FOR CHARACTERIZING WATER MASSES
- LOW FREQUENCY VARIABILITY IN WATER MASS CONTRIBUTIONS IN SOUTHERN CALIFORNIA CURRENT
    - TREND TOWARDS A STRONGER UNDERCURRENT/PEW INFLUENCE
    - STRONGER UNDERCURRENT/PEW INFLUENCE DURING EL NIÑO EVENTS
    - STRONGER UPWELLING DURING LA NIÑA TAPS NUTRIENT-RICH PEW MORE EFFECTIVELY
    - WATER MASS TRANSFORMATION ALONG ADVECTIVE PATHWAY (NOT SHOWN)

Summary

- Optimum Multiparameter Analysis (OMP) is a useful tool for characterizing water masses
- Low frequency variability in water mass contributions in southern California Current
  - Trend towards a stronger Undercurrent/PEW influence
  - Stronger Undercurrent/PEW influence during El Niño events
  - Stronger upwelling during La Niña taps nutrient-rich PEW more effectively
  - Water mass transformation along advective pathway (not shown)
- Future work:
  - Upwelling source depth vs. Undercurrent location & strength
  - Biological implications of different water mass distributions



Jacox et al. (2015)

- Changes in nutrient content of source waters …?
- Changes in stratification …?
- Increased hypoxia and ocean acidification …?
- Plasticity of species dependent on coastal upwelling …?

QUESTIONS?