A WATER MASS HISTORY OF THE SOUTHERN CALIFORNIA CURRENT SYSTEM

Steven Bograd¹, Isaac Schroeder², Michael Jacox¹

¹NOAA Southwest Fisheries Science Center, Monterey, CA
²Institute of Marine Sciences, University of California-Santa Cruz

Illustration by Fiona Morris
WATER MASS INFLUENCES ON THE CALIFORNIA CURRENT

SALINITY ON ISOPYCNALS

**Upper Thermocline**

- $\sigma_\theta = 25.8$
- $Z \sim 100-150 \text{ m}$

**Lower Thermocline**

- $\sigma_\theta = 26.5$
- $Z \sim 250-300 \text{ m}$
WATER MASS INFLUENCES ON THE CALIFORNIA CURRENT

Z ~ 100-150 M

Z ~ 250-300 M

SALINITY ON ISOPYCNALS

UPPER THERMOCLINE

LOWER THERMOCLINE

LINE 93
OBSERVED TRENDS IN PHYSICAL & BIOGEOCHEMICAL PROPERTIES

Bograd et al. (2015)

EFFECTS OF CLIMATE CHANGE ON THE WORLD’S OCEANS CONFERENCE JUNE 4-8TH, 2018     WASHINGTON, D.C.
OBSERVED TRENDS IN PHYSICAL & BIOGEOCHEMICAL PROPERTIES

Line 93 Mean Autumn Spiciness

Bograd et al. (2015)

Linear trend over 1984-2012

26.5

CUC

Bograd et al. (2015)
OBSERVED TRENDS IN PHYSICAL & BIOGEOCHEMICAL PROPERTIES

Bograd et al. (2015)

Line 93 Mean Autumn Spiciness

Line 93 Autumn Spiciness Trend

Linear trend over 1984-2012

Stn. 93.30 at \( \sigma_\theta = 26.5 \)

- \( O_2 \)
  - \( r = -0.59 \)

- \( NO_3 \)
  - \( r = 0.29 \)

- \( PO_4 \)
  - \( r = 0.46 \)

- \( Si(OH)_4 \)
  - \( r = -0.31 \)

- \( N:P \)
  - \( r = -0.39 \)

- \( Si:N \)
  - \( r = -0.50 \)

Bograd et al. (2015)
**OBSERVED TRENDS IN PHYSICAL & BIOGEOCHEMICAL PROPERTIES**

**σ₀ = 26.5**

Linear trend over 1984-2012

- **Oxygen** ↓
- **Nitrate** ↑
- **Phosphate** ↑
- **Silicate** ↑↓
- **N:P** ↓
- **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
WATER MASS INFLUENCES ON THE CALIFORNIA CURRENT

Thomson and Krassovski (2010)

Thomson and Krassovski (2010)
Pacific Subarctic Water (PSUW)
Pacific Equatorial Water (PEW)
Eastern North Pacific Central Water (ENPCW)

Thomson and Krassovski (2010)
## Water Mass Influences on the California Current

<table>
<thead>
<tr>
<th>Water Mass</th>
<th>Temperature</th>
<th>Salinity</th>
<th>Oxygen</th>
<th>Phosphate</th>
<th>Silicate</th>
<th>Nitrate</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PSUW&lt;sub&gt;deep&lt;/sub&gt;</strong></td>
<td>6.88</td>
<td>33.69</td>
<td>4.58</td>
<td>1.75</td>
<td>34.05</td>
<td>22.21</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>PSUW&lt;sub&gt;shal&lt;/sub&gt;</strong></td>
<td>7.75</td>
<td>32.80</td>
<td>6.24</td>
<td>1.16</td>
<td>14.81</td>
<td>10.33</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>PEW&lt;sub&gt;deep&lt;/sub&gt;</strong></td>
<td>9.47</td>
<td>34.68</td>
<td>0.42</td>
<td>2.73</td>
<td>39.72</td>
<td>36.41</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>PEW&lt;sub&gt;shal&lt;/sub&gt;</strong></td>
<td>13.41</td>
<td>34.85</td>
<td>1.06</td>
<td>2.04</td>
<td>22.06</td>
<td>28.38</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>ENPCW&lt;sub&gt;deep&lt;/sub&gt;</strong></td>
<td>12.89</td>
<td>34.18</td>
<td>4.94</td>
<td>0.66</td>
<td>9.85</td>
<td>7.58</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>ENPCW&lt;sub&gt;shal&lt;/sub&gt;</strong></td>
<td>18.77</td>
<td>34.87</td>
<td>5.32</td>
<td>0.14</td>
<td>3.87</td>
<td>0.25</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Pacific Subarctic Water (PSUW)
Pacific Equatorial Water (PEW)
Eastern North Pacific Central Water (ENPCW)
### Water Mass Influences on the California Current

**Pacific Subarctic Water (PSUW)**

**Pacific Equatorial Water (PEW)**

**Eastern North Pacific Central Water (ENPCW)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PSUW deep</th>
<th>PSUW shal</th>
<th>PEW deep</th>
<th>PEW shal</th>
<th>ENPCW deep</th>
<th>ENPCW shal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>6.88 Low</td>
<td>7.75 Low</td>
<td>9.47 High</td>
<td>13.41 High</td>
<td>12.89 High</td>
<td>18.77 High</td>
</tr>
<tr>
<td>Salinity</td>
<td>33.69 Low</td>
<td>32.80 Low</td>
<td>34.68 High</td>
<td>34.85 High</td>
<td>34.18 High</td>
<td>34.87 High</td>
</tr>
<tr>
<td>Oxygen</td>
<td>4.58 High</td>
<td>6.24 High</td>
<td>0.42 Low</td>
<td>1.06 Low</td>
<td>4.94 Low</td>
<td>5.32 Low</td>
</tr>
<tr>
<td>Phosphate</td>
<td>1.75</td>
<td>1.16</td>
<td>2.73</td>
<td>2.04</td>
<td>0.66</td>
<td>0.14</td>
</tr>
<tr>
<td>Silicate</td>
<td>34.05</td>
<td>14.81</td>
<td>39.72</td>
<td>22.06</td>
<td>9.85</td>
<td>3.87</td>
</tr>
<tr>
<td>Nitrate</td>
<td>22.21</td>
<td>10.33</td>
<td>36.41 High</td>
<td>28.38 Low</td>
<td>7.56 Low</td>
<td>0.25 Low</td>
</tr>
<tr>
<td>Mass</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Six Water Masses: (PEW, PSUW, ENPCW; Upper and Deep)

Six Variables: T, S, O₂, NO₃, PO₄, SiO₄

Six Equations + Conservation of Mass

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

Tomczak and Large (1989)
**EXTENDED OPTIMUM MULTIPARAMETER ANALYSIS (OMP)**

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

**SIX VARIABLES:** T, S, O₂, NO₃, PO₄, SiO₄

**SIX EQUATIONS + CONSERVATION OF MASS**

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

\[
\begin{align*}
X_{PEWu}T_{PEWu} + \ldots + X_{NPCWd}T_{NPCWd} + 0 &= T_{OBS} + R_T \\
X_{PEWu}S_{PEWu} + \ldots + X_{NPCWd}S_{NPCWd} + 0 &= S_{OBS} + R_S \\
X_{PEWu}O_{2,PEWu} + \ldots + X_{NPCWd}O_{2,NPCWd} - r_{O/P} \Delta P &= O_{2,OBS} + R_{O2} \\
X_{PEWu}PO_{4,PEWu} + \ldots + X_{NPCWd}PO_{4,NPCWd} + \Delta P &= PO_{4,OBS} + R_{PO4} \\
X_{PEWu}NO_{3,PEWu} + \ldots + X_{NPCWd}NO_{3,NPCWd} + r_{N/P} \Delta P &= NO_{3,OBS} + R_{NO3} \\
X_{PEWu}SiO_{4,PEWu} + \ldots + X_{NPCWd}SiO_{4,NPCWd} + r_{Si/P} \Delta P &= SiO_{4,OBS} + R_{SiO4} \\
X_{PEWu} + X_{PSUWu} + X_{NPCWu} + X_{PEWd} + X_{PSUWd} + X_{NPCWd} &= 1 + R_\Sigma
\end{align*}
\]

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

Tomczak and Large (1989)
%\text{PSUW} \text{ 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
%\textbf{ENPCW} in \textbf{CalCOFI} domain at $\sigma_\theta = 25.8$

- \textbf{Seasonal mean ENPCW contributions in upper thermocline}
- \textbf{Waters} at this level are \textbf{only} 5-15\% \textbf{ENPCW}
- \textbf{Highest ENPCW} in south\textbf{west corner and inshore} (entrained in poleward flow)
%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)
TRENDS IN SOURCE WATER CONTRIBUTIONS: PSUW AT 80.80

CALCOFI STATION 80.80 (CALIFORNIA CURRENT)

- Time-depth plot of PSUW at Station 80.80
- Seasonal variability in surface layer
- High PSUW contribution around $\sigma_\theta = 25.8$ (CC)
- Strong interannual variability in upper 200 m in quantity of PSUW & depth structure
**TRENDS IN SOURCE WATER CONTRIBUTIONS: PEW AT 93.30**

**CALCOFI STATION 93.30 (CALIFORNIA UNDERCURRENT)**

- Time-depth plot of PEW at station 93.30
- Highest PEW contribution around $\sigma_0 = 26.5$ (CUC)
- Strong interannual variability: trend/shift to higher PEW
- Higher PEW contribution in El Niño years (stronger CUC)

$\sigma_0 = 26.5$
WINTER Z AND \textbf{PSUW} IN CALCOFI DOMIAN AT $\sigma_\theta = 25.8$

- **Mean Upper Thermocline Depth**, \textbf{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** $\sigma_\theta = 26.5$

- **Mean lower thermocline depth, PEW contribution during El Niño, La Niña**
- **Higher PEW contribution inshore during El Niño** (stronger CUC), less during La Niña
WATER MASS CHANGES ASSOCIATED WITH ENSO EVENTS

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

- **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**
WATER MASS CHANGES ASSOCIATED WITH ENSO EVENTS

%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?
Optimum Multiparameter Analysis (OMP) is a useful tool for characterizing water masses.
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.
Changes in nutrient content of source waters …?

Changes in stratification …?

Increased hypoxia and ocean acidification …?

Plasticity of species dependent on coastal upwelling …?

Jacox et al. (2015)