Oxygen Content Decadal Variability in the Upper North Pacific

Hernan E. Garcia, Tim P. Boyer, Syd Levitus, John Antonov, and Ricardo A. Locarnini

NOAA/NODC Ocean Climate Laboratory
1315 East–West Highway
Silver Spring, MD 20910
Hernan.Garcia@noaa.gov
http://www.nodc.noaa.gov/OCL/

PICES 13th [October, 2004]

S8: The impacts of climate change on the carbon cycle in the North Pacific
OUTLINE

• Methods
• Estimates of decadal O\textsubscript{2} variability
• Seasonal vs. decadal variability scales
• O\textsubscript{2}/AOU/Heat decadal variability/trends
• Summary
METHODS


- Objective analysis on 5- and 10-year composite periods on a 1° grid, global (seasons removed).

- Estimate inventories & trends (0-100 m case)

\[
OC = A \int_{z_1}^{z_2} \Delta O_2 \, dz
\]

NOAA/NODC/Ocean Climate Laboratory/H. Garcia
<table>
<thead>
<tr>
<th>Location</th>
<th>Time span (years)</th>
<th>Depth range (m)</th>
<th>$\Delta O_2$ (µmol/kg)</th>
<th>$\Delta AOU$ (µmol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. Atlantic (24.5°N section)</td>
<td>1981-1992</td>
<td>800-2200</td>
<td>-3 to -7</td>
<td></td>
</tr>
<tr>
<td>N. Pacific (basin mean)</td>
<td>1972s-1990s</td>
<td>1000-1750</td>
<td></td>
<td>-4</td>
</tr>
<tr>
<td>N. Pacific (22°-44°N)</td>
<td>1980-1997</td>
<td>100-600</td>
<td>-9 to -20</td>
<td></td>
</tr>
<tr>
<td>N. Pacific (48°-60°N)</td>
<td>1950-2000</td>
<td>50-900</td>
<td></td>
<td>+5 to +25</td>
</tr>
<tr>
<td>S. Pacific (28°S section)</td>
<td>1967-1995</td>
<td>800-1200</td>
<td>-5 to -8</td>
<td></td>
</tr>
<tr>
<td>S. Indian (32°S section)</td>
<td>1962-1997</td>
<td>300-800</td>
<td>-7 to -8</td>
<td>+3</td>
</tr>
<tr>
<td>S. Indian (32°S section)</td>
<td></td>
<td>2500-4000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern Ocean (50°-60°S)</td>
<td>1965-1995</td>
<td>&gt; 400</td>
<td>-5 to -15</td>
<td></td>
</tr>
</tbody>
</table>

5-year composites

10-year composites

Oxygen content

$10^{19}$ µmol

0-100 m layer

$(70^\circ S-70^\circ N)$

Pacific Basin Case
Seasonal vs. Decadal Variability Scales?
Amplitude of annual harmonic zonally integrated monthly O$_2$ anomaly content ($10^{15}$ µmol/m) in the Pacific Basin

Garcia et al. 2004, submitted
Amplitude of annual harmonic of monthly $O_2$ anomaly content

Amplitude of annual harmonic of monthly AOU anomaly content

Garcia et al. 2004, submitted

Figure 6. Amplitude per unit area of the annual harmonic for the 0-100 m depth of the monthly content of (a) $O_2$ and (b) AOU. The nominal contour interval is 1 mol m$^{-2}$. NOAA/NODC/Ocean Climate Laboratory/H. Garcia
Pacific Basin Decadal/Seasonal O$_2$ Scale Comparison

Decadal

Seasonal

Range: $\sim 2 \times 10^{19}$ µmol

Range: $\sim 4 \times 10^{19}$ µmol

Year

Month

NOAA/NODC/Ocean Climate Laboratory/H. Garcia
Surface $\Delta O_2$/heat slope seasonal

$\sim 5.7$ nmol/J

$\partial O_2/H$ (1 mol month$^{-1}$ w$^{-1}$ $\sim 385.8$ nmol J$^{-1}$)

Corrections: O$_S$, skin-temperature, msl atmospheric pressure, sea-ice

Garcia and Keeling [2001]
O_2, AOU, Heat

decadal-scale

Variability

Are trends constant?
Pacific Basin: Heat and O₂ content [0-100 m; 1955-1998]

NOAA/NODC/Ocean Climate Laboratory/H. Garcia
### O$_2$-to-Heat ratios (nmol/J); [nmol=$10^{-9}$ mol]

<table>
<thead>
<tr>
<th>Basin (0-100m)</th>
<th>1955-1998</th>
<th>1985-1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific (70°S-70°N)</td>
<td>0.22</td>
<td>-19.7</td>
</tr>
<tr>
<td>North Pacific (0°-70°N)</td>
<td>0.30</td>
<td>-4.7</td>
</tr>
<tr>
<td>North Pacific (20°-70N)</td>
<td>-0.32</td>
<td>-1.8</td>
</tr>
<tr>
<td>South Pacific (0°-70°S)</td>
<td>0.17</td>
<td>2.3</td>
</tr>
<tr>
<td>South Pacific (20°-70S)</td>
<td>-0.17</td>
<td>-20.4</td>
</tr>
</tbody>
</table>

NOAA/NODC/Ocean Climate Laboratory/H. Garcia
Zonally integrated $O_2$/AOU/$O^-$ ($10^{19}$ µmol) and heat ($10^{20}$ J) content of the 0 to 100 m depth layer for the North Pacific Basin (20°S-70°N). $O^-$ calculated as AOU+$O_2$ content. Note different contour intervals (CI) and color scales.
Linear correlation zonally integrated content

\(\text{O}_2\)

\(\text{Heat}\)

\(\text{AOU}\)

(1955-1998)

Linear correlation coefficient of \(\text{O}_2\) (top), heat (middle), and AOU (bottom) content trend at each layer for the 1955-1998 period. Contour interval is 0.25.
O₂ content linear correlation

Heat content linear correlation

AOU content linear correlation

Linear correlation
Pentads (1985-1998)

NOAA/NODC/Ocean Climate Laboratory/H. Garcia
**O₂ content**

Heat content

AOU content

0-100 m layer

Pentads

1955/59

To

1996/1999

NOAA/NODC/Ocean Climate Laboratory/H. Garcia
Global Ocean O$_2$ content anomaly

(0-100 m; 10$^{19}$ µmol)
Summary

Decadal $O_2$ variability:
- Peak-to-peak $\sim 1/2$ of seasonal
- Measurable and spatially coherent
- Trends are dependent on time period
- Regionally complicated (e.g., tropical Pacific)
- Non-lag heat-to-$O_2$ trends are weak (timing?)
- Observation-validated decadal-resolving model is needed
Time series of N+N, chlorophyll, temperature and O₂ from **CalCOFI** (32°N, 120°W) and **BATS** (in purple). Data are averaged over the 10 to 80 m depth layer.
**NO OCEAN O₂ SINK/SOURCE**

Change in CO₂ (ppm)

350 355 360 365 370 375 380

-80

Change in O₂/N₂ (per meg)

-280

-240

-200

-160

-120

-80

1991

Change due to fossil fuel combustion

1999

Land biotic uptake

Ocean CO₂ uptake

Atmospheric O₂ decrease

Land sink = 1.7 ± 0.6 Pg C/yr

Oceanic sink = 1.5 ± 0.4 Pg C/yr

**OCEAN O₂ SOURCE**

Change in CO₂ (ppm)

350 355 360 365 370 375 380

-80

Change in O₂/N₂ (per meg)

-280

-240

-200

-160

-120

-80

1991

Change due to fossil fuel combustion

1999

O₂ outgassing

Land sink = 0.9 Pg C/yr

Oceanic sink = 2.3 Pg C/yr

After Keeling et al. [1996]  
After Manning [2000]
Examples of number of O$_2$ observations in each 1° grid square at 50 m depth [WOD01]

1955-1957: 22,230 obs
1960-1964: 31,359 obs
1970-1974: 47,144 obs
1980-1984: 44,824 obs
1990-1994: 25,770 obs
1994-1998: 15,200 obs
O$_2$ sampling errors for different pentads & depths

O$_2$ long-term precision (deep N. Pacific & N. Atlantic [1972-1996]):
± 1.0-2.2 µmol/kg
[e.g. Saunders, 1986; Gouretski and Jancke, 1996; WOCE, 1994; Garcia and Keeling, 2001; Garcia et al. 1998; Johnson et al. 2000]

Std Error for N > 50; all basins
[1955-1962]: ± 2-4 µmol/kg
[1978-1977]: ± 1-3 µmol/kg
[1993-1997]: ± 1-2 µmol/kg
No systematic or proportional errors assumed

NOAA/NODC/Ocean Climate Laboratory/H. Garcia