Recent reduction of dissolved oxygen in the North-western Pacific and Japan Sea

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• Precision of used sensors and data processing features
• Data for this presentation
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• Result of measurements in the Indian Ocean
• Conclusions
Equipment for measurements

Standard recent Oceanographic Equipment: CTD-Unit SBE-911+SBE32 sampler
Equipped with two sets of temperature-conductivity sets and oxygen sensors
Equipment for measurements II
### Accuracy of SBE sensors

<table>
<thead>
<tr>
<th></th>
<th>SBE-35</th>
<th>Temp. SBE-3+</th>
<th>Cond. SBE 4C</th>
<th>O$_2$ (SBE-43)</th>
<th>O$_2$ (RINKO-III)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depth measure</strong></td>
<td>to 6800 m</td>
<td>to 7000 m</td>
<td>to 7000 m</td>
<td>to 7000 m</td>
<td>To 7000</td>
</tr>
<tr>
<td><strong>Initial accuracy</strong></td>
<td>± 0.001 °C</td>
<td>0.001 °C</td>
<td>0.0003 S/m (0.001 psu)</td>
<td>2% saturation</td>
<td>±2%</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>0.001 °C per year</td>
<td>0.0002 °C/month</td>
<td>0.0003 S/m/mon. (0.001 psu/mon.)</td>
<td>0.5% per 1000 hours</td>
<td>±5% (1 month)</td>
</tr>
<tr>
<td><strong>Range:</strong></td>
<td>-5 to +35 °C</td>
<td>-5 to 35 °C</td>
<td>0 to 7 S/m</td>
<td>Until 120% surf. sat.</td>
<td>0-200%</td>
</tr>
</tbody>
</table>

- During the study of East Sea deep waters structure within long time it necessary to pay attention on basic characteristics of used sensors for CTD-unit.
SBEDataProcessing : simple case

- Preliminary processing (SBEdataprocessing software.)
  - Data conversion (binary->ascii)
  - Align CTD (time lag correction, optional for SBE911)
  - Cell Thermal Mass correction (correction for warming of sensor cells)
  - Filtering (get rid of noise, bad data)
  - Loop edit (exclusion of ship waving, fluctuations)
  - Bin averaging (averaging data by: pressure/depth/time)
Each SBE-sensor is individual. Its deformation can be corrected at depths more than 2000 m by the calibration using SBE-35 (platinum thermometer).

Usual calibration formula for this case:

\[ T_{cal} = T_{raw} - (C_0 + C_1 \times P) \]

- We used second sensors set (POI) for analysis due to the problem with the 1st one.
Temperature correction: with SBE35

After the 2012 Oparin-cruise, the SBE-unit of POI was calibrated in the USA. To obtain a final view of the data, new configuration files were used, and the drift of parameters was calculated. The temperature was corrected using the SBE35.

- Correction of temperature on sensitivity to pressure may cause a change of T value on ±0.003 C, which may be important during the study of climatic changes.
Salinity correction

- to obtain high accuracy it is not enough a standard SBE-processing procedures
- it is necessary to consider pressure effect for SBE conductivity sensor by calibration with data from sampling bottles (together with SBE 35 measurements)

• Correction may be defined using the following formula:

\[ C_{cal} = C - \left( \sum_{i=0}^{I} c_i \times C^i + \sum_{j=1}^{J} p_j \times P^j \right) \]
Salinity correction

JMA data of cruises of R/V “Keifu Maru” (blue line on map):


- During the cruise the Laboratory Salinometer was available onboard, which allowed one to make a calibration;

Laboratory Salinometer
Autosal 8400B

Table C.1.2. Conductivity Calibration Coefficient Summary.

<table>
<thead>
<tr>
<th>N/</th>
<th>Num</th>
<th>(c_0) (mS/m)</th>
<th>(c_1)</th>
<th>(c_2) (mS/m)</th>
<th>(p_1) (mS/μbar)</th>
<th>(p_2) (mS/m/μbar²)</th>
<th>Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3670</td>
<td>1274</td>
<td>1.5107e-3</td>
<td>-7.4144e-5</td>
<td>0.0000e-0</td>
<td>6.6856e-7</td>
<td>-8.3866e-11</td>
<td>Stn. 1 – 67</td>
</tr>
<tr>
<td>3670</td>
<td>308</td>
<td>2.2680e-3</td>
<td>-8.0696e-5</td>
<td>0.0000e-0</td>
<td>-1.2437e-8</td>
<td>0.5038e-11</td>
<td>Stn. 68 – 83,</td>
</tr>
<tr>
<td>3670</td>
<td>698</td>
<td>1.0048e-3</td>
<td>-7.6991e-5</td>
<td>0.0000e-0</td>
<td>3.9031e-7</td>
<td>-4.2466e-11</td>
<td>Stn. 84 – 107</td>
</tr>
<tr>
<td>3670</td>
<td>698</td>
<td>1.0048e-3</td>
<td>-7.6991e-5</td>
<td>0.0000e-0</td>
<td>3.9031e-7</td>
<td>-4.2466e-11</td>
<td>Stn. 84 – 107</td>
</tr>
<tr>
<td>2849</td>
<td>2195</td>
<td>2.1693e-3</td>
<td>-5.5359e-5</td>
<td>0.0000e-0</td>
<td>8.3709e-7</td>
<td>7.6495e-11</td>
<td>Stn. 1 124</td>
</tr>
</tbody>
</table>
Mysterious Deep Salinity Minimum

- Due to polynomial equation of second order sometimes slope and curl is not correctly obtained for intermediate and deep waters of JES
Dissolved Oxygen Measurements

SBE 43 – O₂ sensor with polarographic membrane

\[
O_2 = S_{oc} \cdot \left( V + V_{off} + \tau_{20} \cdot e^{(D_1 \cdot p + D_2 \cdot (T - 20))} \cdot \frac{dV}{dt} \right) \\
\cdot O_{sat} \cdot (1 + A \cdot T + B \cdot T^2 + C \cdot T^3) \cdot e^{\left[ (E \cdot p) / (273.15 + T) \right]} 
\]

Ref: Uchida et al.


Rinko III – O₂ sensor with optical sensor

\[
\begin{align*}
P_0 &= 1.0 + c_4 \times t \\
P_c &= c_5 + c_6 \times v + c_7 \times T + c_8 \times T \times v \\
K_{sv} &= c_1 + c_2 \times t + c_3 \times t^2 \\
coef &= (1.0 + c_9 \times P / 1000)^{3/3} \\
[O_2] &= \left( \frac{P_0 \cdot P_c}{P_c - 1.0} \right) / K_{sv} \times coef
\end{align*}
\]
Comparatively with the SBE43 RinkolIII has a temporal drift which is not similar for different cruises.
This cause us to use only 30% of obtained data for calibration in the La66 cruise.
According with this the RinkolIII sensors needs to be inspected and controlled during the further cruises.
Observations areas of joint works/used Data

R/V “Professor Gagarinsky”, 2009-2015

-La 63, Jul- Sep 2013  La 76, Jul-Aug 2017

-Historical dataset from eWOCE:
North-Western Pacific;
Indian Ocean;
GOOS Regions

- EuroGOOS
- BS-GOOS
- MedGOOS
- GOOS AFRICA
- IO-GOOS
- NEAR-GOOS
- Iocaribe-GOOS
- SEA-GOOS
- PI-GOOS
- GRASP

The Global Ocean Observing System
Objectives for project:
- JES is semi-enclosed basin with the stable hydrographic structure e.g. cool deep water with the salinity and oxygene anomalies within the intermediate waters;
- The monitoring of these parameters gives a key for understanding of global warming the World Ocean;
- The main idea is to compare the temperature, salinity and oxygene observations made within the close locations which allow to suggest about data quality and compatibility of measurements made independently by the JMA and POI;
Data error assessment by NEAR-GOOS data

- Talley at al. 2004
- Cruise La58 R/V Akademik M.A. Lavrentyev”, Ga56 R/V “Professor Gagarinsky”, Op44 R/V “Akademik Oparin”
- R/V “Keifu Maru”
  - Ga56 St028 – 19/Jun/12
  - Op44 St033 – 24/Oct/12
  - KM-3141 – 30/Oct/12
  - KM-3169 – 4/Nov/12

La58-st98 (raw): 196 (calibrated 1000m-bottom): 210

<table>
<thead>
<tr>
<th>Talley:</th>
<th>Ga56 st028</th>
<th>Op44 st033</th>
<th>KM-3169</th>
<th>KM-3141</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talley:</td>
<td>0.064</td>
<td>34.068</td>
<td>0.068</td>
<td>34.068</td>
</tr>
<tr>
<td>La58-st98 (calibrated):</td>
<td>196</td>
<td>195</td>
<td>210</td>
<td></td>
</tr>
</tbody>
</table>
Calibrated data comparison (2009-2015)
Observations in the Japan sea

Finally were defined:
- Temperature corrected in the same manner for the last 5 years essentially increases;
- The temperature growth is not regular from year to year;
- The salinity minimum is stable within the frames of instrument sensitivity;
- The oxygen in the deep layer has some variations and now is lower than 3 years before;
Studies in the North-western Pacific

-For result validation the WOCE atlas have been used:
-Research Vessel R/V John Vickers (NOAA Pacific Marine Environmental Laboratory (PMEL), USA, Chief Scientist - John L. Bullister, bullister@pmel.noaa.gov, Leg 2: 16 August- 15 September 1992)

Measurements:
Oxygen                          J. Bullister    PMEL bullister@pmel.noaa.gov
nutrients                       K. Fanning      USF KAF@MSL1.Marine.USF.edu
O2 by the hydrochemical analysis

- The profiles measured 20 years ago and in our cruises have good matched to each other;
- During this cruise we have used new type of optical sensor for oxygen measurements;
O2 decreasing for last 3-4 years in the Japan Sea and North-Western Pacific

Essential fact for the Japan Sea that Θ is continuing slightly increasing, while the deep waters lose their DO, via advection from east to west of Japan Basin;

At the same time OMZ values in the North-Western Pacific become critical:

2013:
- Winkler: 13 uMol/kg;
- RincolIII: 8 uMol/kg;

2016:
- Winkler: No data;
- RincolIII: 2-3 uMol/kg(!!!);

1992:
- Winkler: over 20 uMol/kg
Meanwhile in the Indian Ocean....

The Indian Ocean – is very unstudied place for last 50 years. Recently the 2nd International Indian Ocean Expedition (IIOE-2) has started by the SCOR.
Features of 90°E

Profiles of oxygen content, obtained during the ABP42 cruise (bottom right), and correspondent to eWOCE data from 1995 and 2007, but the content is lower on 20% than 22 years ago, and about ~15% than 10 years ago.
Sub-surface oxygen concentrations averaged between 200m and 600m from World Ocean Atlas 2009 (µmol per kg) (by Maciej Telszewski and Laurent Bopp)

Light and dark red stripes indicate waters with O$_2$ <100 µmol per kg and O$_2$ <20 µmol per kg respectively.
Conclusions

• As the result of NEAR-GOOS activity our team has a chance to make our CTD-unit well calibrated and make measurements in the far geographic locations of one sea and two oceans (well, actually more than one sea – but the subject of this report is our activity within the frames of international cooperation)

• The measurements gave unexpected results which is not good matched to the model output for study deoxygenation but probable they should be taken into account due to used methods and obtained results;

• Most of the works described here at the beginning was not supported by any grants and was like a third-party works within the frames of other big projects, but finally we talk about serious things which (we hope) might be the interesting for the whole scientific society;
Thank you for your attention!

СПАСИБО!

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