High-quality dissolved oxygen baseline for ecosystem and variability studies

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S4: Deoxygenation in Global Ocean and Coastal Waters in Relation to Climate Change

Outline:

- Uncertainty of long-term O_2 high-quality baselines for climate variability assessment? Comparing *in situ* O_2 values derived from the World Ocean Atlas (WOA13) and the Global Ocean Data Analysis Project (GLODAP2).

- Sensor-based *in situ* O_2 data are a relatively new observing system: Could we use these data to complement O_2 chemical measurements?

Global Ocean Data Analysis Project (GLODAP) Bottle Data (version 2)

Olsen, A., R. M. Key, S. van Heuven, S. K. Lauvset, A. Velo, X. Lin, C. Schirnick, A. Kozyr, T. Tanhua, M. Hoppema, S. Jutterström, R. Steinfeldt, E. Jeansson, M. Ishii, F. F. Pérez & T. Suzuki. The Global Ocean Data Analysis Project version 2 (GLODAPv2) - an internally consistent data product for the world ocean, Earth System Science Data, 8, 297-323, 2016. doi:10.5194/essd-8-297-2016.

NOAA World Ocean Atlas 2013 (https://www.nodc.noaa.gov/OC5/woa13/pubwoa13.html)

- Garcia, H. E., R. A. Locarnini, T. P. Boyer, J. I. Antonov, O.K. Baranova, M.M. Zweng, J.R. Reagan, D.R. Johnson, 2014. World Ocean Atlas 2013, Volume 3: Dissolved Oxygen, Apparent Oxygen Utilization, and Oxygen Saturation. S. Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 75, 27 pp.

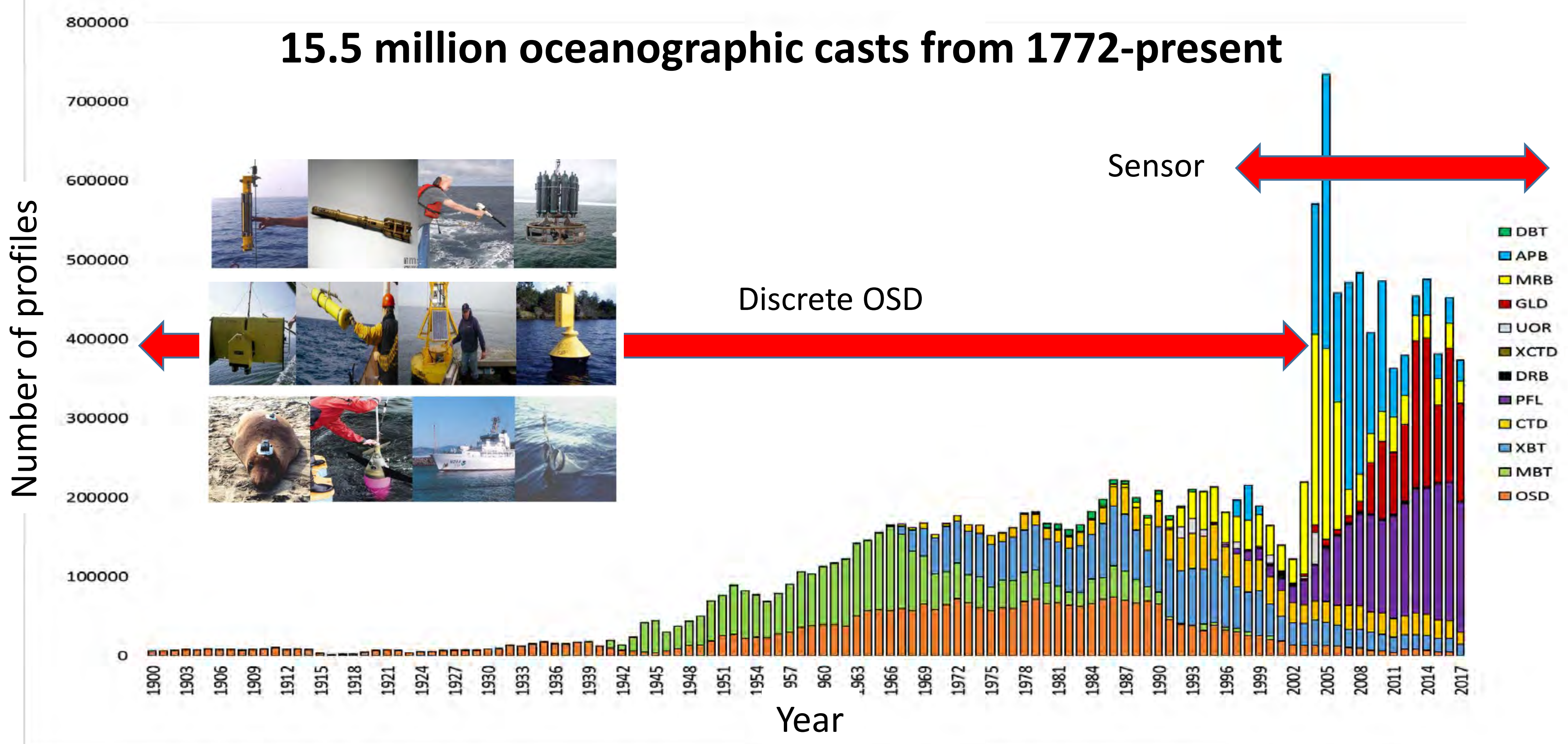
- Garcia, H. E., R. A. Locarnini, T. P. Boyer, J. I. Antonov, O.K. Baranova, M.M. Zweng, J.R. Reagan, D.R. Johnson, 2014. World Ocean Atlas 2013, Volume 4: Dissolved Inorganic Nutrients (phosphate, nitrate, silicate). S. Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 76, 25 pp.

- Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, H. E. Garcia, O. K. Baranova, M. M. Zweng, C. R. Paver, J. R. Reagan, D. R. Johnson, M. Hamilton, and D. Seidov, 2013. World Ocean Atlas 2013, Volume 1: Temperature. S. Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 73, 40 pp.

- Zweng, M.M, J.R. Reagan, J.I. Antonov, R.A. Locarnini, A.V. Mishonov, T.P. Boyer, H.E. Garcia, O.K. Baranova, D.R. Johnson, D.Seidov, M.M. Biddle, 2013. World Ocean Atlas 2013, Volume 2: Salinity. S. Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 74, 39 pp.

Ocean profile data in the World Ocean Database (WOD) by year and probe type

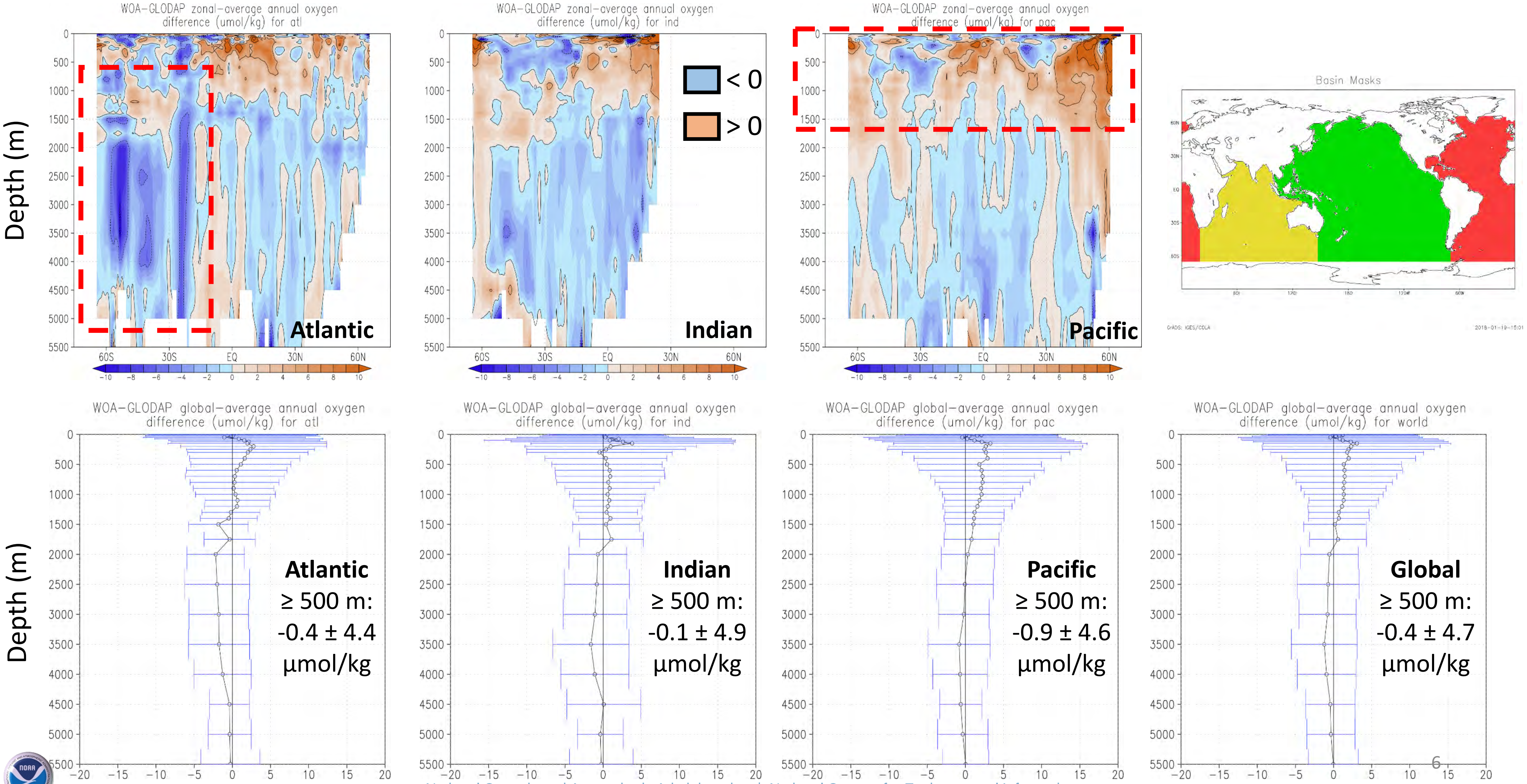
https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html



WOA-GLODAP basin-scale zonal difference (60°S-60°N)

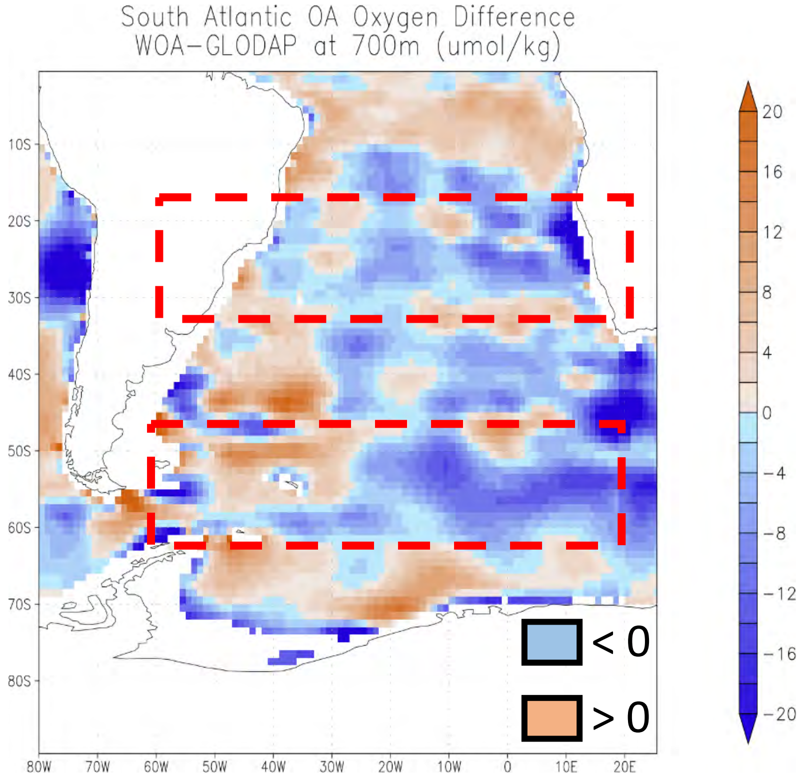
		WOA-GLODAP average difference ± average standard deviation			
Variable	**Depth range (m)**	**Atlantic**	**Pacific**	**Indian**	**Global**
Phosphate (µmol/kg)	0-500	0.02 ± 0.11	0.01 ± 0.13	-0.01 ± 0.12	0.01 ± 0.12
	500-5500	-0.01 ± 0.05	-0.02 ± 0.07	-0.02 ± 0.08	-0.02 ± 0.07
Nitrate+Nitrite (µmol/kg)	0-500	0.02 ± 1.60	-0.20 ± 1.87	-0.34 ± 1.69	0.18 ± 1.78
	500-5500	-0.16 ± 0.70	-0.23 ± 1.02	-0.24 ± 0.98	-0.22 ± 0.95
Silicate (µmol/kg)	0-500	0.1 ± 3.1	1.0 ± 3.5	0.9 ± 3.9	0.8 ± 3.6
	500-5500	-0.5 ± 2.7	0.8 ± 4.1	-0.2 ± 3.9	-0.3 ± 3.8
Oxygen (µmol/kg)	0-500	1.1 ± 9.8	1.8 ± 11.5	0.9 ± 10.6	1.4 ± 10.9
	500-5500	-0.4 ± 4.4	0.9 ± 4.6	0.1 ± 4.9	0.4 ± 4.7
Temperature (°C)	0-500	-0.256 ± -0.928	-0.224 ± -0.945	-0.212 ± -0.856	-0.229 ± 0.927
	500-5500	-0.001 ± 0.154	0.005 ± 0.153	0.002 ± 0.163	0.003 ± 0.160
Salinity	0-500	-0.007 ± 0.141	0.000 ± 0.120	-0.016 ± 0.122	-0.005 ± 0.127
	500-5500	0.001 ± 0.019	-0.001 ± 0.012	0.002 ± 0.017	0.000 ± 0.015

WOA-GLODAP O_2 (μmol/kg) basin-scale zonal differences (60°S-60°N)

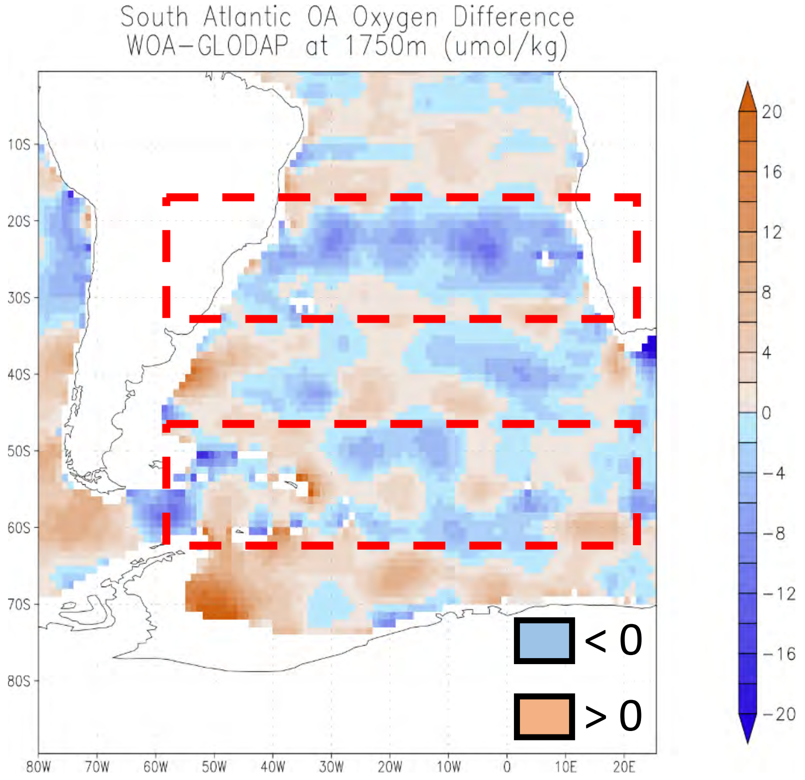


South Atlantic regional WOA-GLODAP O_2 differences (µmol/kg)

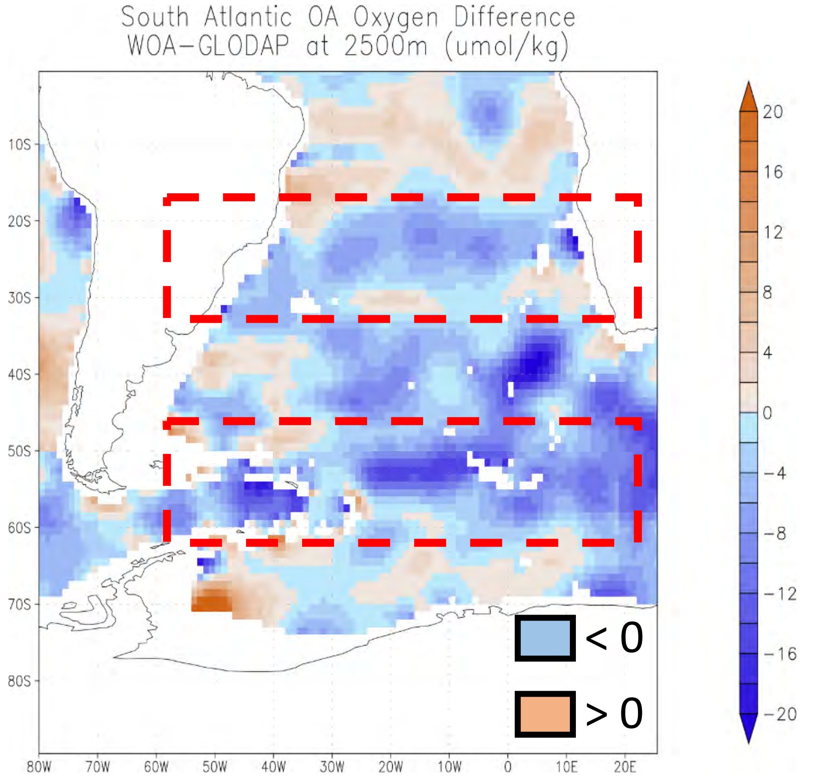
700 m

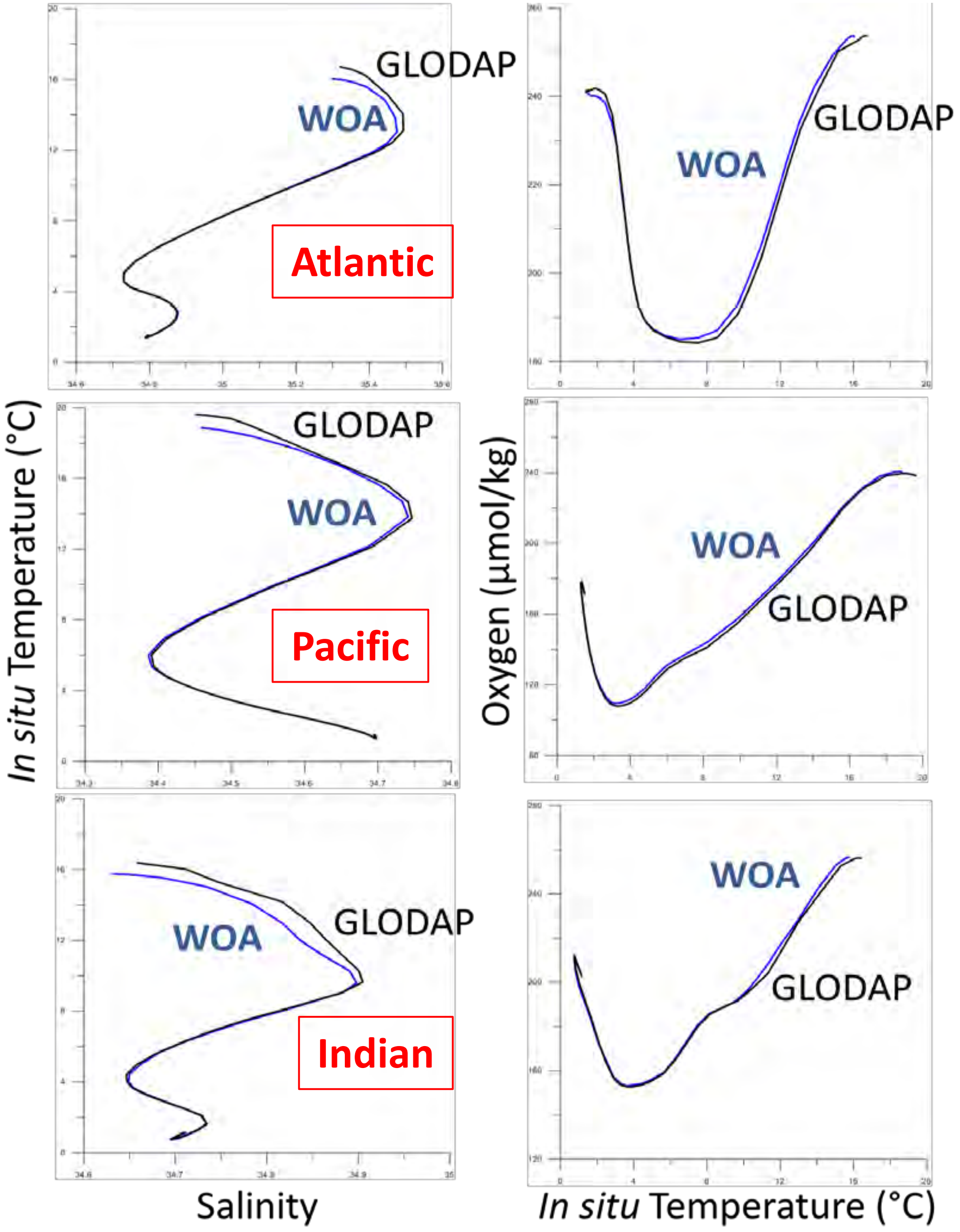


1750 m



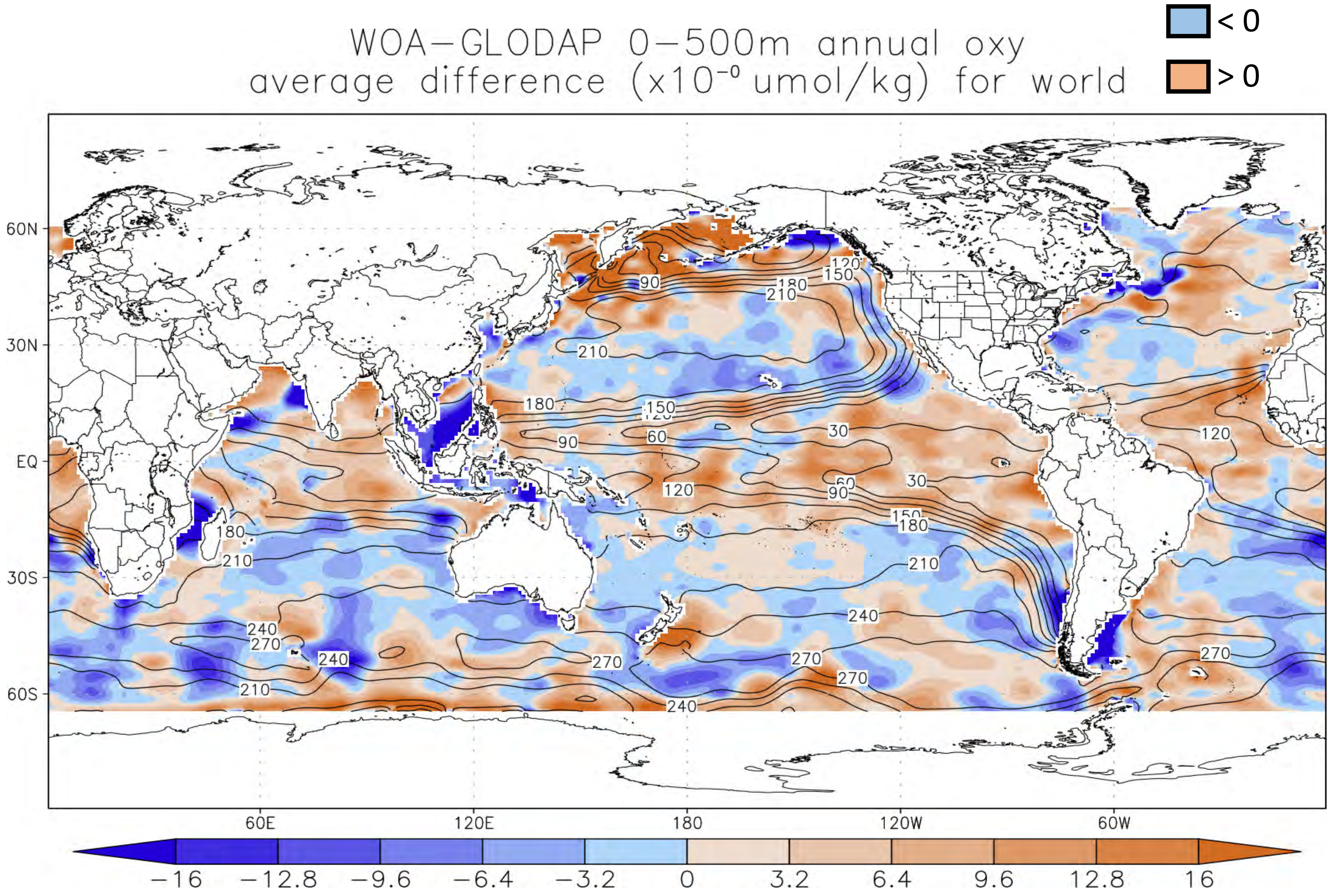
2500 m





GLODAP2 is relatively saltier, warmer, and lower in O_2 when compared to WOA for near surface and thermocline waters warmer than about 4°C depending on basin.

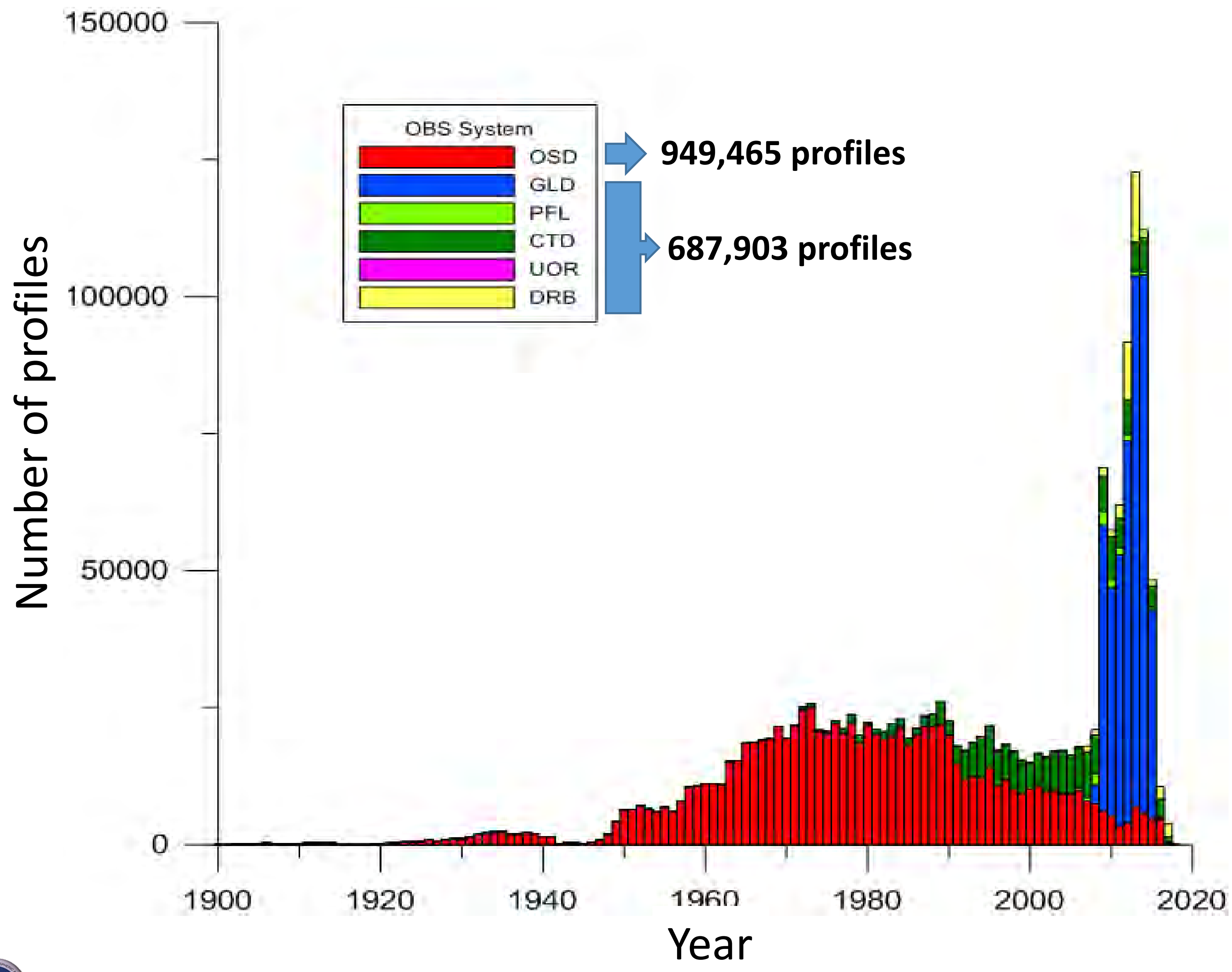
O_2 in situ data	GLODAP2	WOA 2018
Observations	688,477	4,945,707
Profiles	45,306	877,400
Time coverage	1972-2013	1955-2017
Variability fields (1°x1°)	Annual	Annual, seasonal, monthly
Depth levels	33	102
Grid size	1-degree	1-degree



O_2 concentration averaged difference (µmol/kg)

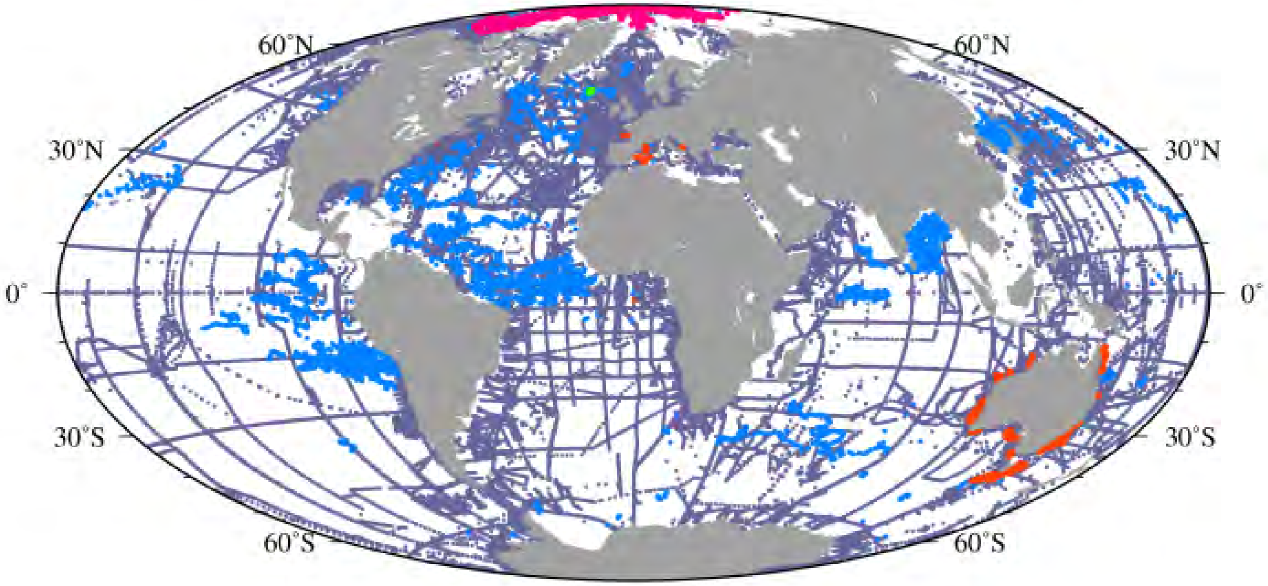
Contours are mean O_2 values 0-500 m.

A local |10 µmol/kg| O_2 difference represent as much as 30% magnitude of the observed signal



Impact of O_2 Observing Systems:

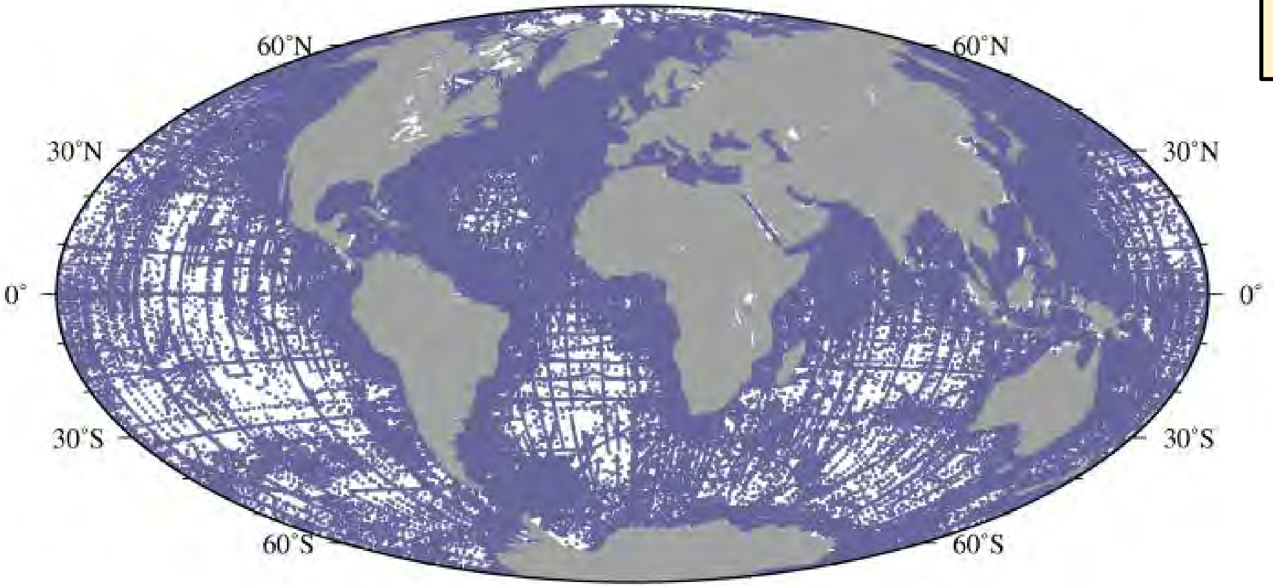
Sensor-based O_2 *in situ* data are becoming increasingly abundant and likely will have greater temporal and spatial coverage than OSD.



O_2 Sensor Data (687,903 profiles)

- = Drifting Buoys (37,812 profiles)
- = Undulating Oceanographic Recorder (361 profiles)
- =Glider Data (450,084 profiles)
- =Profiling Float (12,216 profiles)
- =Conductivity-Temperature-Depth (187,430 profiles)

O_2 measurements in the NCEI World Ocean Database (WOD) as a function of observing system as of May 2018



O_2 Chemical Data (949,465 profiles)

- = Ocean Station data (Discrete measurements)

Profile Analysis to identify profiles with systematic depth offsets (approximately parallel profiles)

Independent O_2 profiles with ~covariance and ~normal population

$x_1, \ldots, x_n$ with n_1 measurements and $y_1, \ldots, y_n$ with n_2 measurements

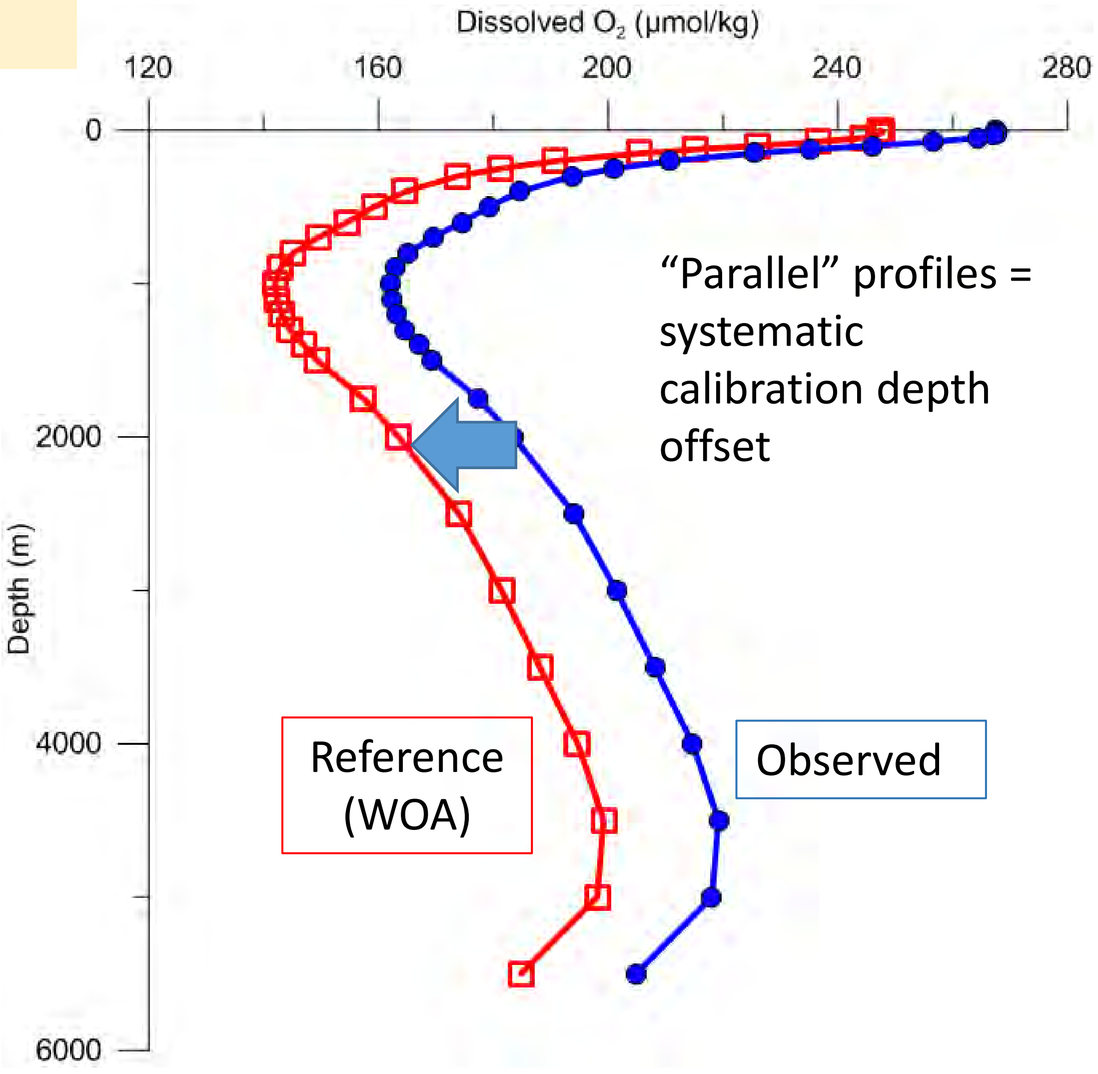
Test metric statistic (ellipse):

$$T^2 = [C(\overline{X} - \overline{Y})]' \left[\left(\frac{1}{n_1} + \frac{1}{n_2} \right) C S_p C' \right]^{-1} [C(\overline{X} - \overline{Y})] \leq d^2$$

Where C is a contrast matrix, S_p is a pooled covariance matrix, and d^2 is given by

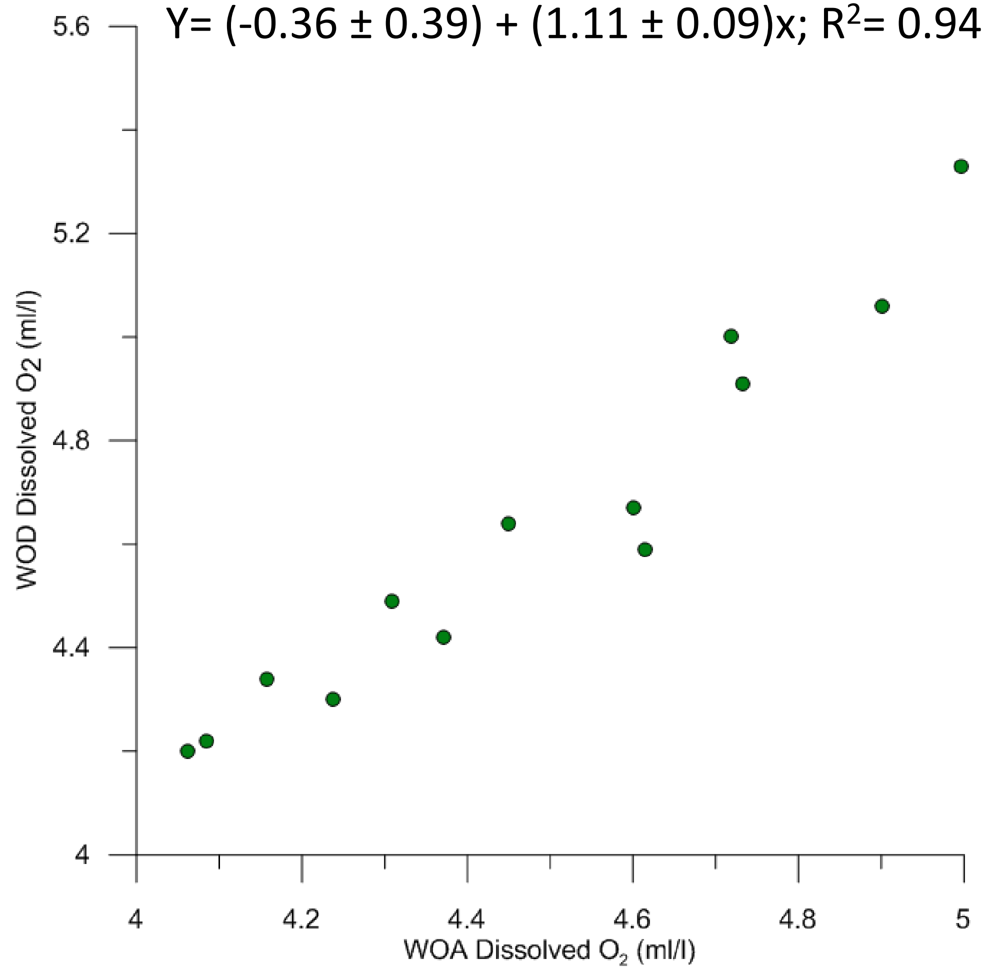
$$d^2 = \left[\frac{(n_1 + n_2 - 2)(p-1)}{n_1 + n_2 - p} \right] F_{p-1, n_1+n_2-p}(\alpha)$$

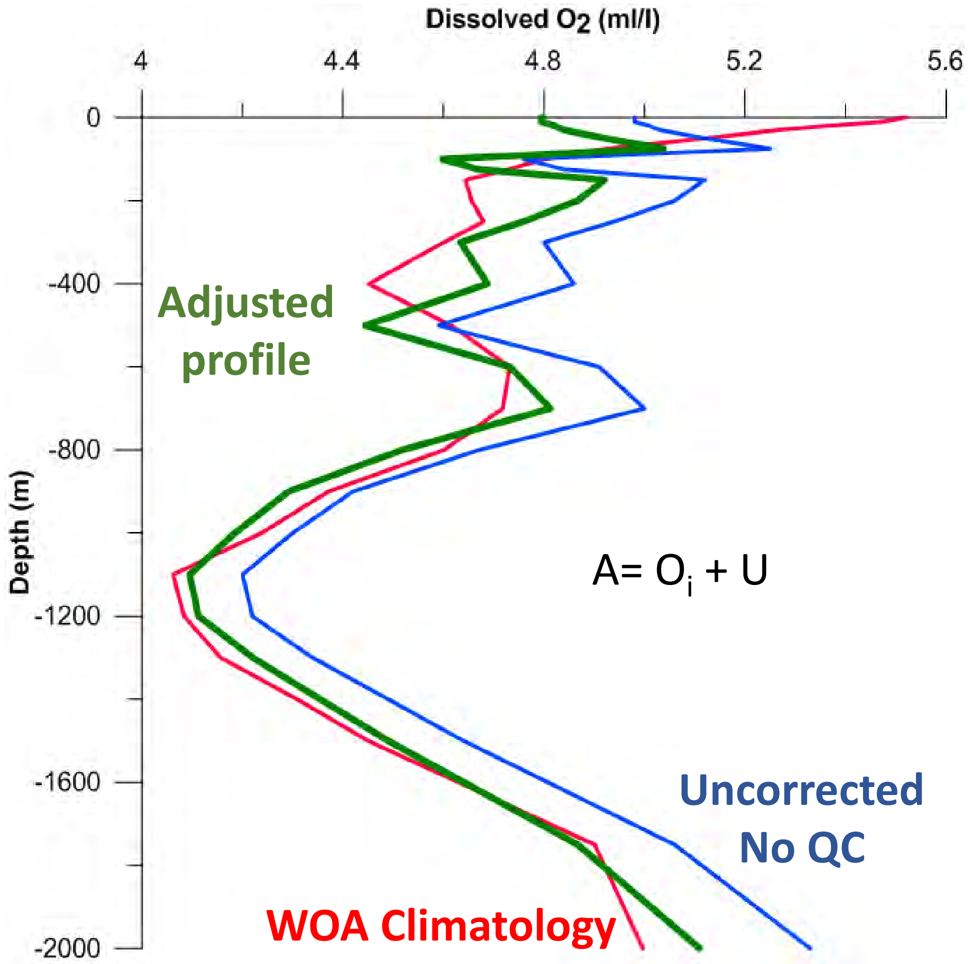
Assumption: Systematic depth offsets represent sensor calibration issues (Type I/II errors)



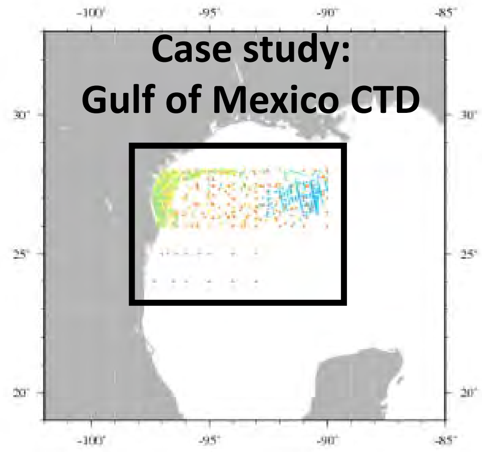
LSR Adjusting systematic CTD O_2 profile depth offsets

Example for data with $0.8 < r^2 < 1.2$; Z > 500 m depth
$Y= (-0.36 \pm 0.39) + (1.11 \pm 0.09)x$; $R^2= 0.94$

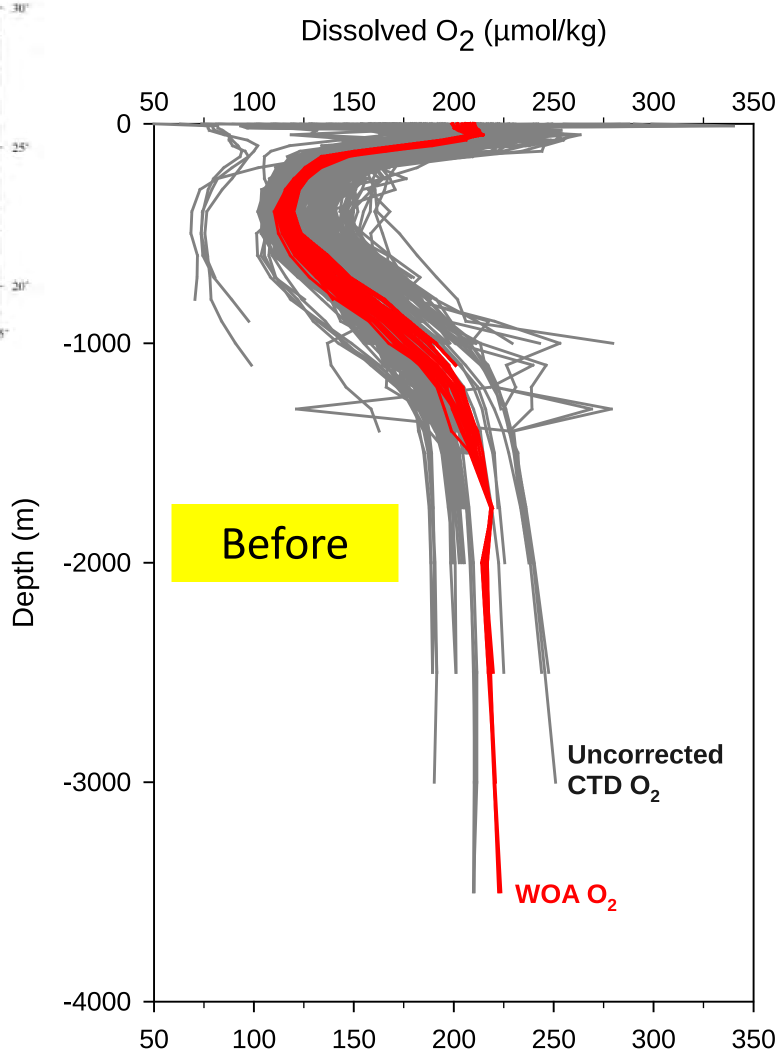


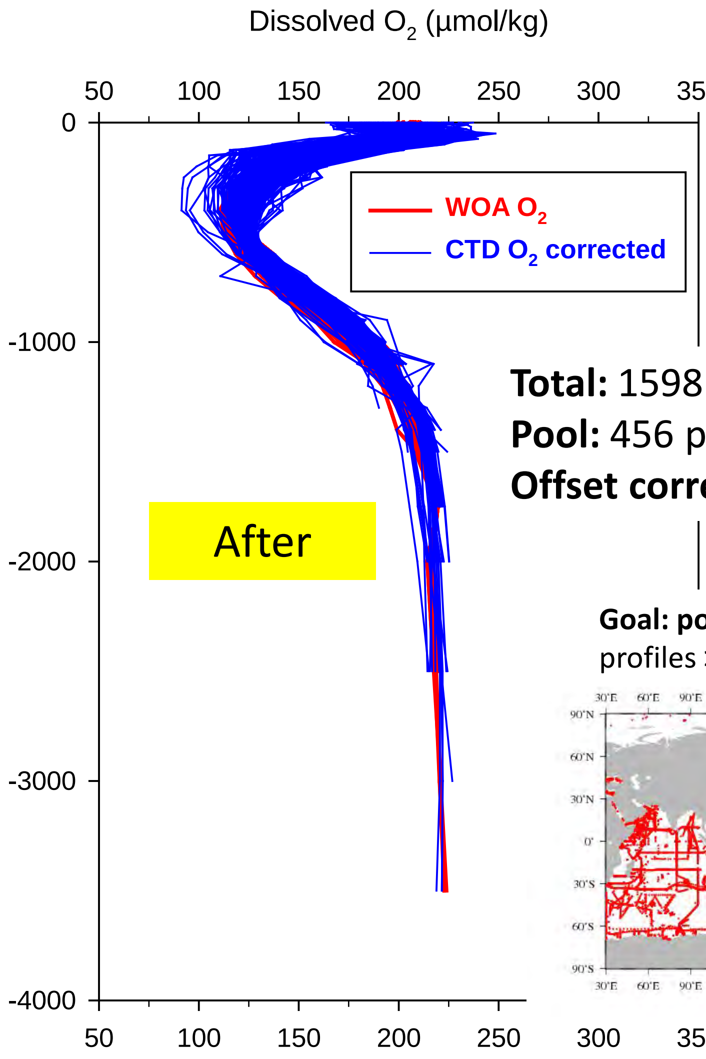


Integrating WOD *in situ* data with sensor-based O_2 data for WOA: Statistical calibration of systematic depth offsets with uncertainties



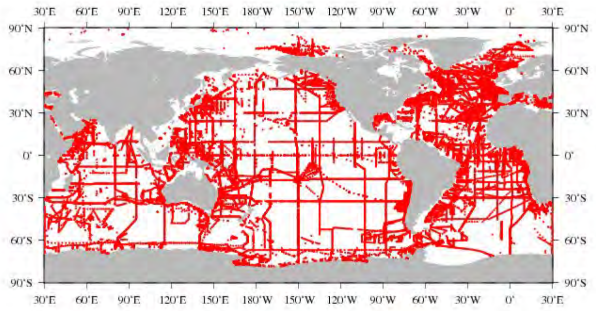
1598 Profiles with O_2 (456 profiles > 500 m)





Total: 1598 Profiles
Pool: 456 profiles > 500 m
Offset corrected: 258 profiles (~57%)

Goal: pool WOD CTD O2: 66,405 profiles > 500 m depth



Summary

Part I

- WOA13 and GLODAP2 O_2 deep basin fields are in agreement within long-term O_2 measurement uncertainty (< 1 µmol/kg) and do not show significant systematic depth offsets.

- Significant measurable O_2 differences exists at the local and regional level as a function of depth. These differences could be attributed to near surface seasonal bias, longer time scales variability (thermocline), and data coverage differences. WOA O_2 has greater spatial and temporal coverage than GLODAP.

Part II

- The number of sensor based O_2 measurements have increased significantly in the past few years. The addition of Bio ARGO and other emergent observing systems will greatly increase the spatial and temporal coverage of more traditional O_2 chemical measurements.

- Carefully quality controlled O_2 sensor data could complement existing *in situ* based climatologies along with well documented corrections. WOA2018 will include separate climatologies, one for *in situ* and another for *in situ* + sensor (*e.g.*, CTD, BIO-ARGO, Gliders, *etc*).

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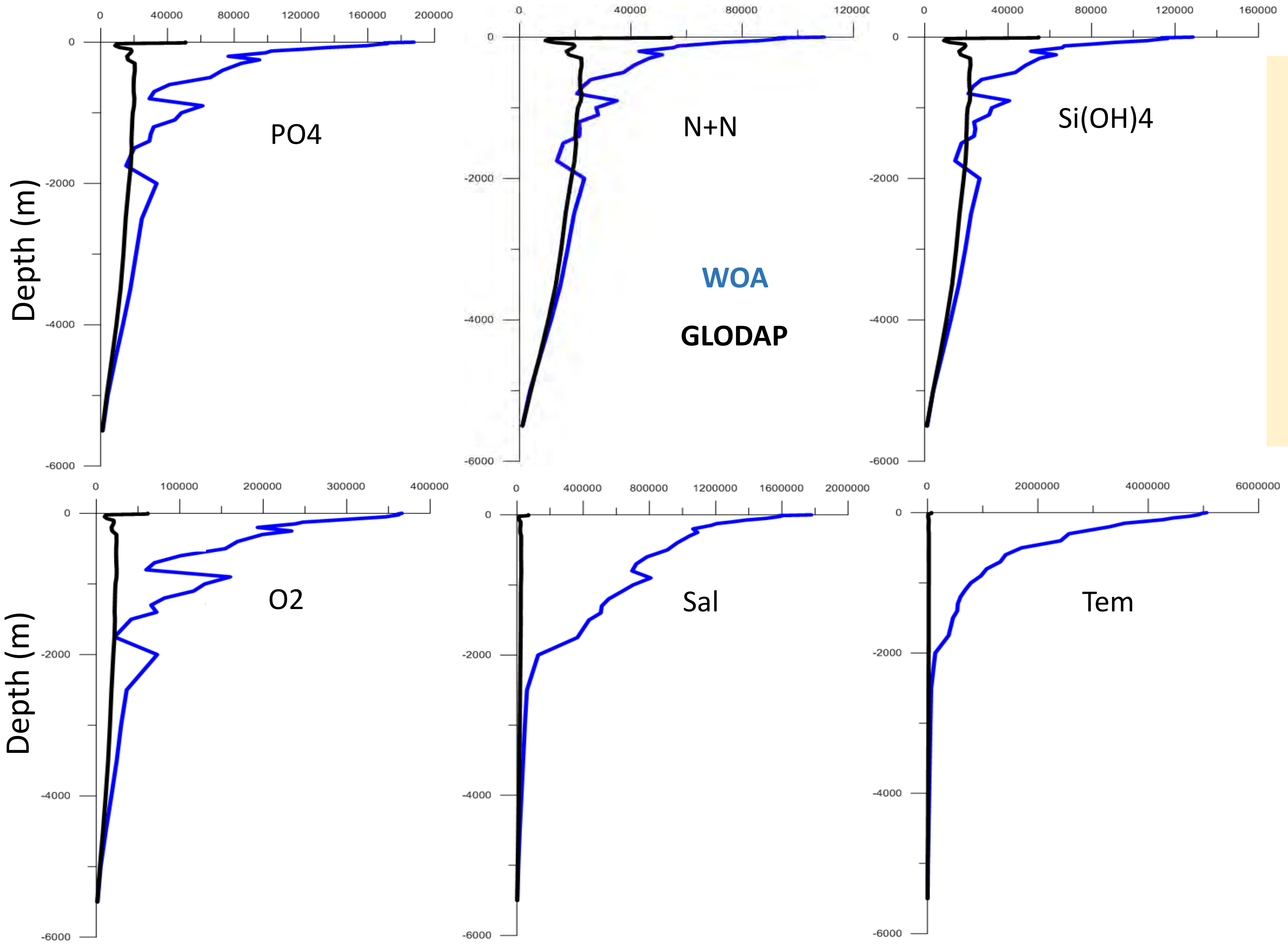

Number of observations available in WOA and GLODAP (60°S-60°N)