Climatological Seasonal Cycle of Global Ocean Oxygen, Heat and Apparent Oxygen Utilization Content Anomalies in the Surface Mixed Layer

Zhankun Wang[1], Hernan Garcia[2], Tim Boyer[3], James Reagan[4], and Just Cebrian[1]

[1]Mississippi State University
[2]NOAA/NODC
[3]NOAA/National Oceanographic Data Center
[4]ESSIC - University of Maryland

November 23, 2022

Abstract

Mean monthly climatological mixed layer depth (MLD) combined with temperature, dissolved oxygen, and apparent oxygen utilization (AOU) are used to produce global estimates of the seasonal variability of ocean heat content anomaly (OHCA), O_2 content anomaly (O2CA), and AOU content anomaly (ACA) in the surface mixed layer. Linear regression analyses show that the highest correlation occurs when O2CA lags OHCA by one month, whereas the highest correlation occurs when ACA lags OHCA by 2-3 months. The O2CA is negatively correlated, while the ACA is positively correlated with the OHCA in the mixed layer. The O2-heat ratio in the surface mixed layer is about -1.85 nmol/J in the subtropical and subpolar regions, which is on the same order of magnitude due to the O_2 solubility effect alone. The solubility effect is the primary driver for the seasonal cycle of the O_2 inventory in the mixed layer, and thus subject to changes in ocean warming. The 1-month lag between O2CA and OHCA suggests the O_2 inventory quickly responds to heat content changes on seasonal time scales due to strong mixing in the mixed layer. The 2-3 month lag between ACA and OHCA suggests oxygen changes through biological activities take a longer time following OHC changes in relation to physical changes through O_2 solubility. Our analysis indicates that the deoxygenation rate in the mixed layer, estimated from the regression analysis, is approximately -2.2 Tmol/year based on the O_2-heat ratio in the mid-latitudes, accounting for 6±2% of the global deoxygenation for the time period 1955-2019.

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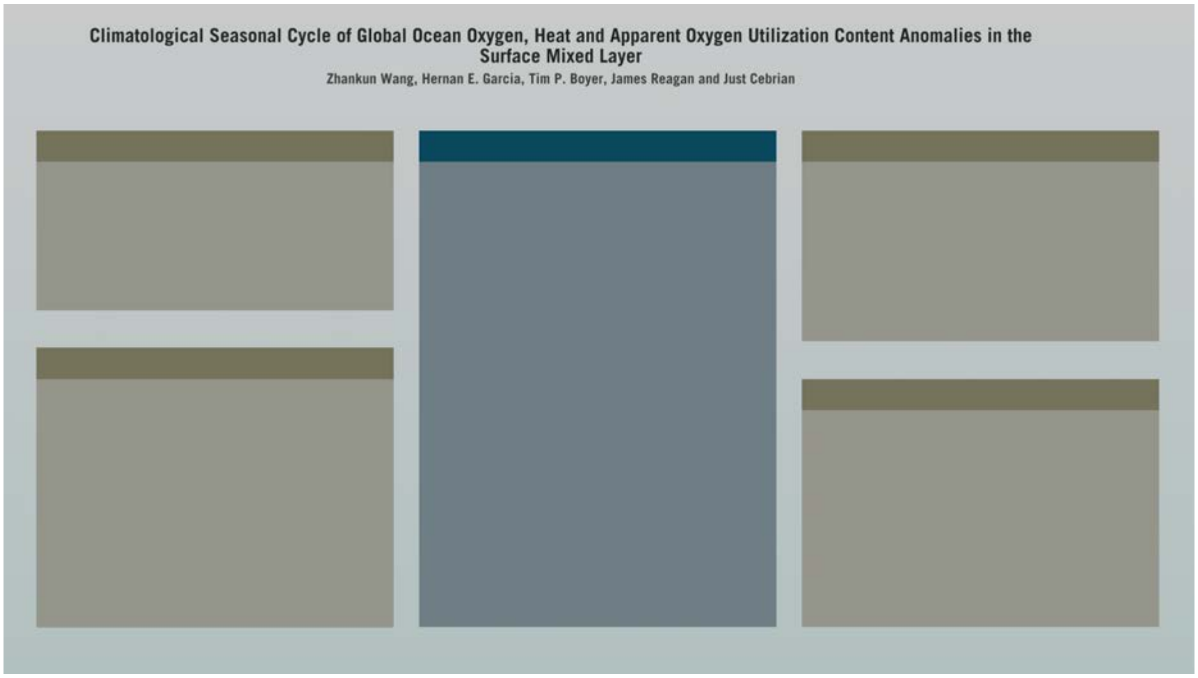

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DATA AND METHODS

World Ocean Atlas 2018 (WOA18)

The temperature, density, oxygen, and AOU data used in this analysis is from the World Ocean Atlas 2018 (WOA18) statistical and objectively analyzed field data on one-degree longitude/latitude grids (Locarnini et al., 2018; Garcia et al., 2018; Zweng et al., 2018).

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A 1°✕1° spatial latitude-longitude resolution global climatology of the mixed layer depth (MLD) based on individual profiles from World Ocean Database18 is constructed.

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$$O2CA = A\int_0^{mld} \Delta\, O_2\, \mathrm{d}z$$

where A is the area in m^2 of each 1°✕1° latitude-longitude grid box, ΔO_2 is the monthly minus the annual climatological value of dissolved oxygen, dz is half the distance between the next shallowest level and the current level plus half the distance between the next deepest level and the current level in the WOA (i.e., thickness of each depth layer), and *mld* is the surface mixed layer depth of the upper ocean.

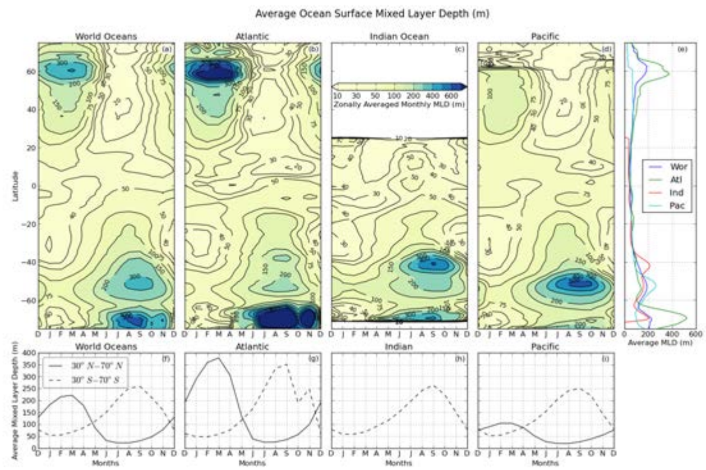
Heat Content Anomaly and AOU Content Anomaly

Monthly objectively analyzed temperature and Apparent Oxygen Utilization (AOU) from WOA18 are used to calculate the monthly heat and AOU content anomaly, respectively

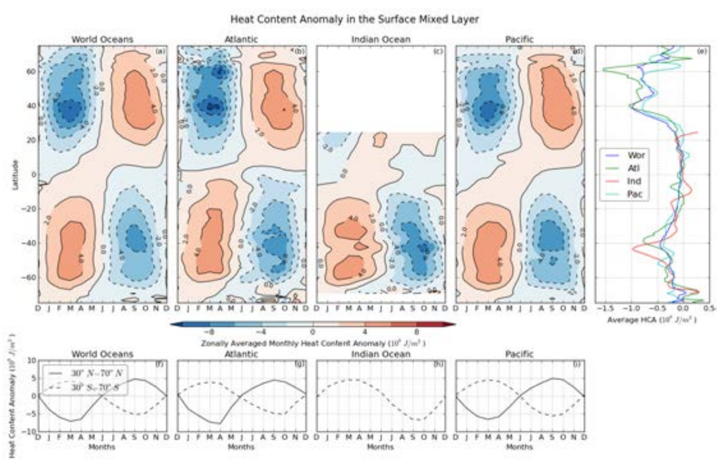
$$OHCA = A\int_0^{mld} \rho C_p \Delta T\, \mathrm{d}z$$

$$ACA = A\int_0^{mld} \Delta AOU\, \mathrm{d}z$$

ZONAL AND BASIN MIXED LAYER DEPTH AND HEAT CONTENT ANOMALIES



Average climatology of mixed layer depth (MLD) in meters. Zonally averaged monthly MLD for the (a) World, (b) Atlantic, (c) Indian, and (d) Pacific Ocean. Same colorbar is used for panels (a)-(d) as shown in (c). The contour lines are 10, 20, 30, 40 50, 75, 100, 150, 200, 300, 400, 500, 600 and 700m. (e) Average annual meridional MLD as a function of latitude for the World Ocean and the three major ocean basins. Zonally averaged monthly time series estimate of the mixed layer depth for the subtropics and mid-latitudes between 30° and 70° for both northern hemisphere (solid black) and southern hemisphere (dashed black) for (f) World, (g) Atlantic, (h) Indian and (i) Pacific Ocean, respectively.



Average climatology of ocean heat content anomaly (OHCA) in the surface mixed layer (108J/m^2). Zonally averaged monthly OHCA in the surface mixed layer for the (a) World, (b) Atlantic, (c) Indian, and (d) Pacific Ocean. Same colorbar used for panels (a)-(d) as shown below them. The OHCA at each 1°✕1° grid has been divided by the area of that grid to make the global and basin values comparable. The contour interval is 2.0108J/m2. (e) Average annual meridional OHCA as a function of latitude for the world ocean and the three major ocean basins. Monthly time series estimate of the OHCA for the subtropics and mid-latitudes between 30° and 70° for both northern hemisphere (solid black) and southern hemisphere (dashed black) for the (f) World, (g) Atlantic, (h) Indian and (i) Pacific Ocean, respectively.

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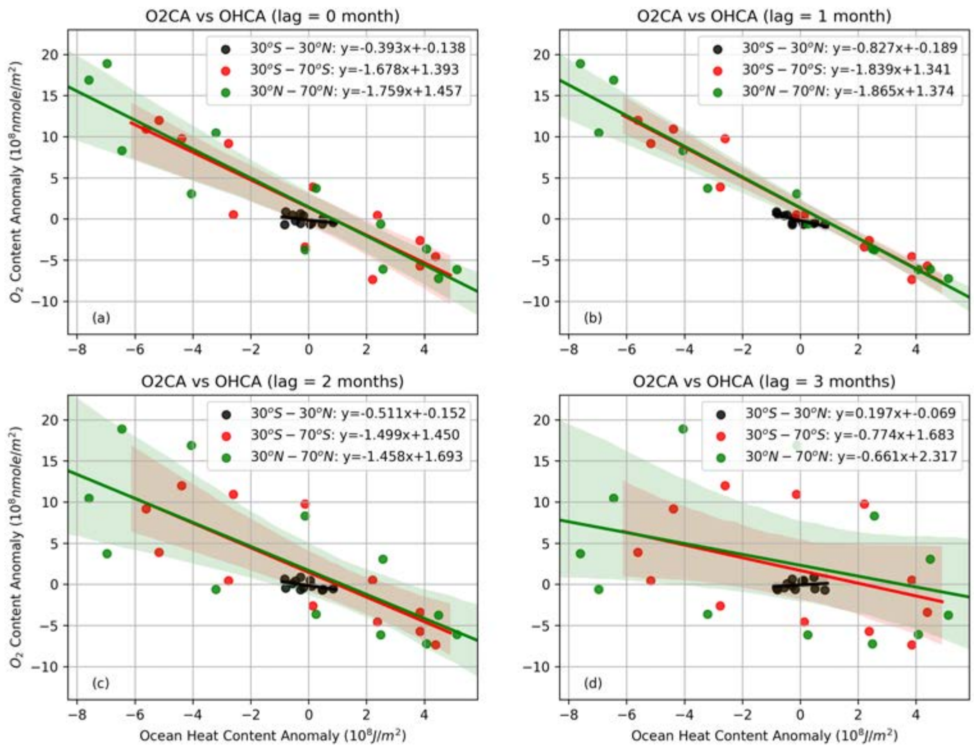
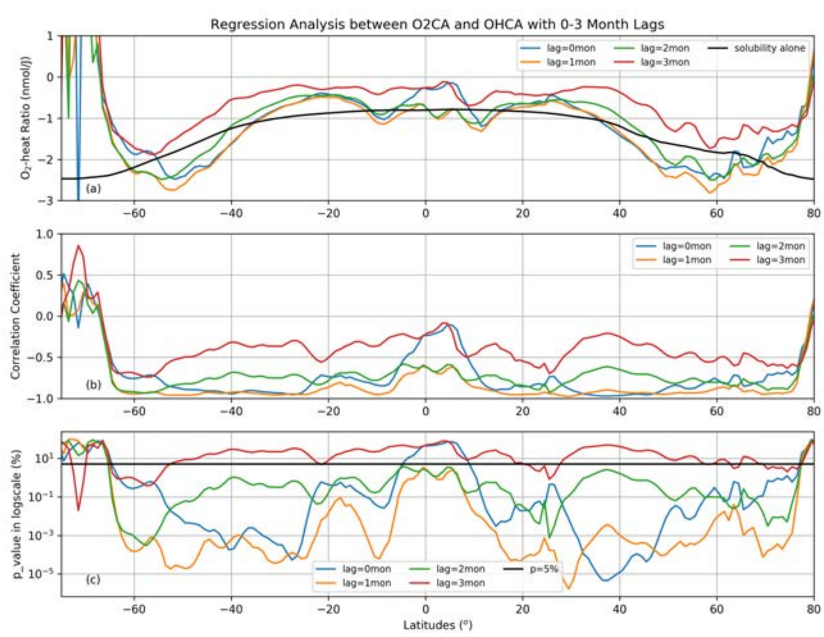
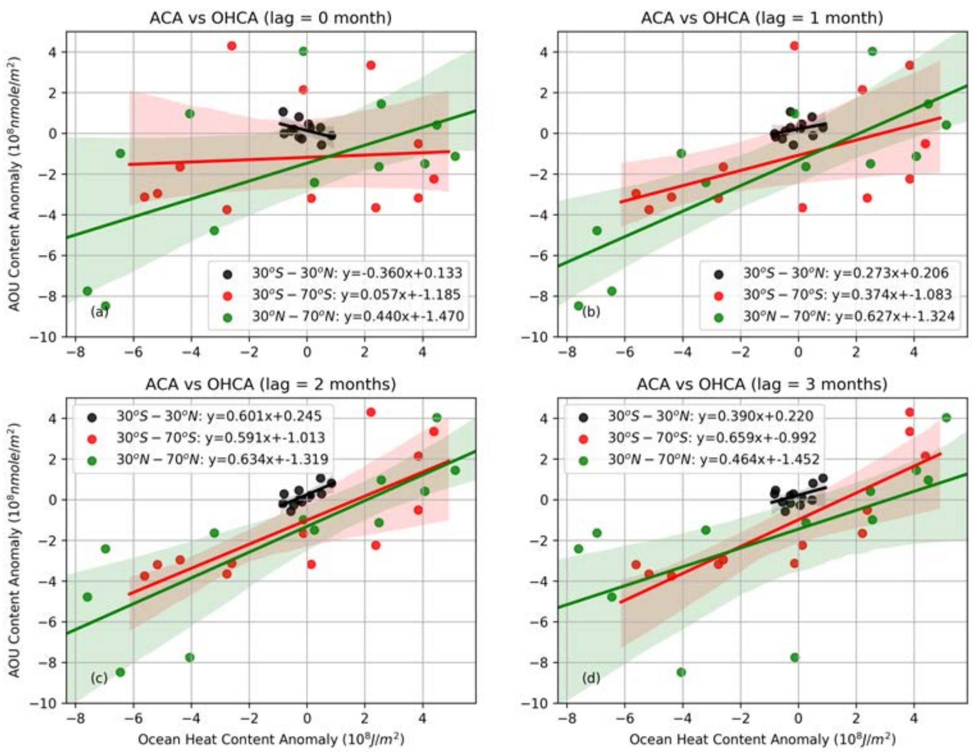


Lagged linear regression analysis on the monthly heat content anomaly as the dependent variable and corresponding monthly average O_2 content anomaly as the independent variable within three latitudinal bands : 30°N-70°N (green), 30°S- 30°N (black), and 30°S-70°S (red) to determine the relationship between OHCA and O2CA. The straight solid lines show the best fit lines and the shadow regions represent the 95% confidence interval for the fitted regression line. The fitted linear equations for the latitudinal band are shown in the legend. Lagged regression is utilized to examine the lag effect. (a) no lag (0-month); (b) 1-month lag; (c) 2-month lag; and (d) 3-month lag.



The lagged regression analysis between O2CA and OHCA along latitudes. (a) The O_2-heat ratio (slope of the lagged linear regression relationship) along latitudes with lags from 0 month to 3 months. The black solid line represents the solubility effect alone line. (b) Correlation coefficient along latitudes for the 0-3 month lagged regression analysis. (c) p-value in log scale along latitudes for the 0-3 month lagged regression analysis.



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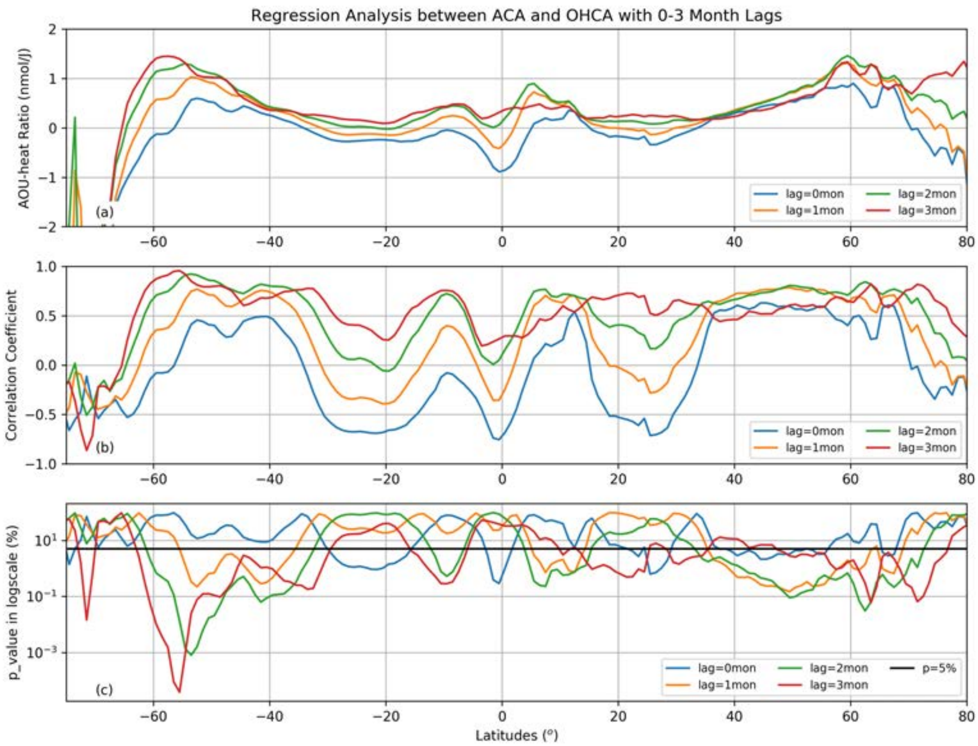

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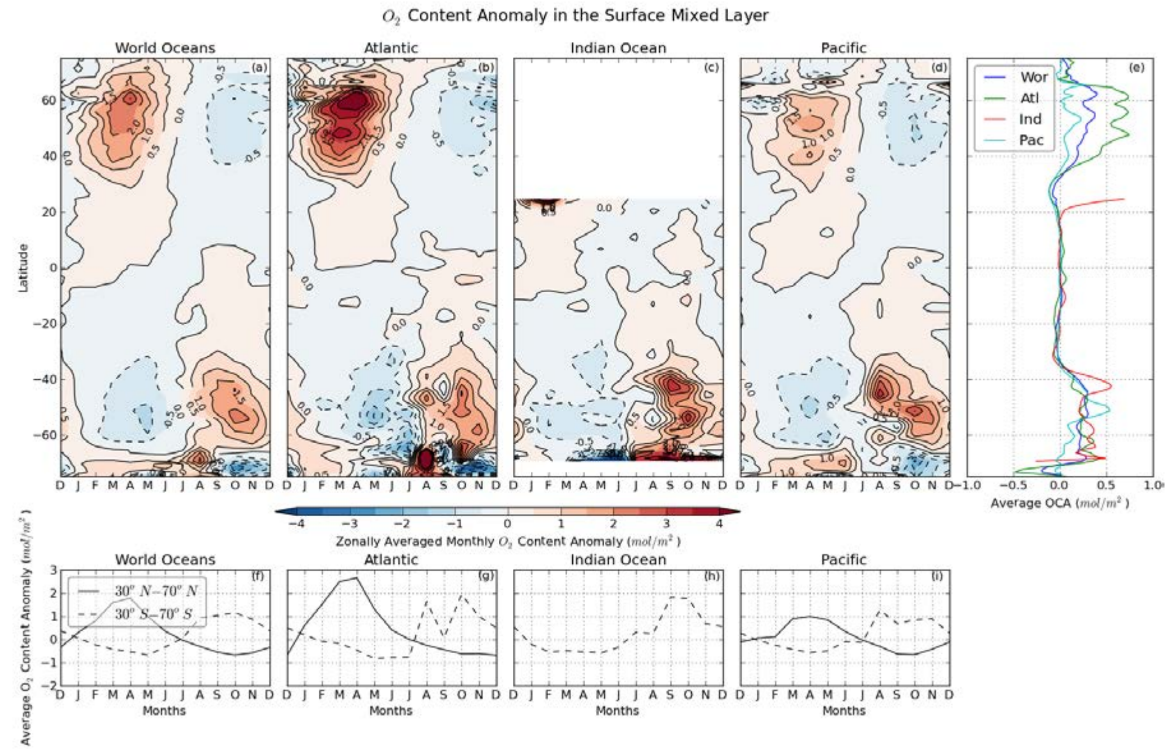
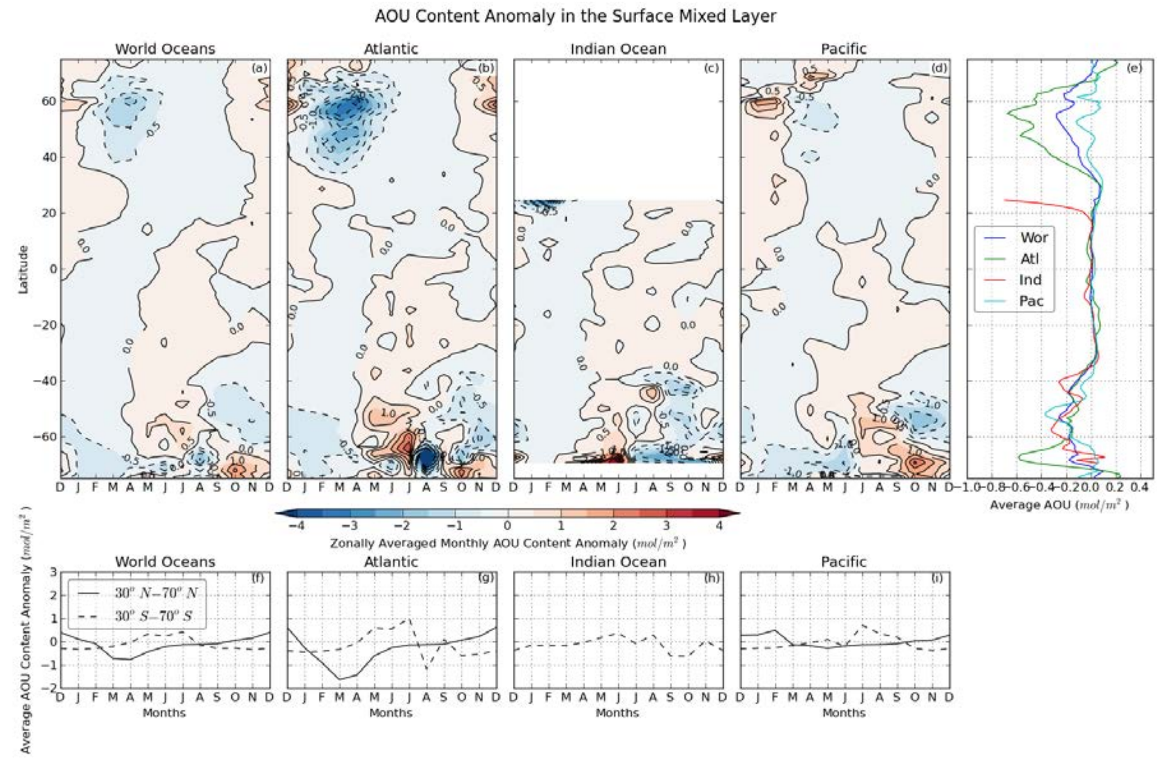
ZONAL AND BASIN OXYGEN CONTENT AND AOU CONTENT ANOMALIES



Average climatology of O_2 content anomaly (O2CA) in the surface mixed layer (mol/m^2). Zonally averaged monthly O2CA in the surface mixed layer for the (a) World, (b) Atlantic, (c) Indian, and (d) Pacific Ocean. Same colorbar used for panels (a)-(d) as shown below them. The O_2 content anomaly at each 1°×1° grid has been divided by the area of that grid to make the global and basin values comparable. The contour interval is 0.5 mol/m^2. (e) Average annual meridional O2CA as a function of latitude for the world ocean and the three major ocean basins. Monthly time series estimate of the O2CA for the subtropics and mid-latitudes between 30° and 70° for both northern hemisphere (solid black) and southern hemisphere (dashed black) for the (f) World, (g) Atlantic, (h) Indian and (i) Pacific Ocean, respectively.



Average climatology of apparent oxygen utilization (AOU) content anomaly in the surface mixed layer (mol/m^2). Zonally averaged monthly AOU content anomaly in the surface mixed layer for the (a) World, (b) Atlantic, (c) Indian Ocean, and (d) Pacific Ocean. Same colorbar used for panels (a)-(d) as shown below them. The AOU content anomaly at each 1°✕1° grid has been divided by the area of that grid to make the global and basin values comparable. The contour interval is 0.5 mol/m^2. (e) Average annual meridional AOU content anomaly as a function of latitude for the world ocean and the three major ocean basins. Monthly time series estimate of the AOU content anomaly for the subtropics and mid-latitudes between 30° and 70° for both northern hemisphere (solid black) and southern hemisphere (dashed black) for the (f) World, (g) Atlantic, (h) Indian and (i) Pacific Ocean, respectively.

CONCLUSIONS

- The large-scale seasonal cycle of global ocean oxygen anomaly and AOU content anomaly in the surface mixed layer are related to the seasonal cycle of the heat content anomaly in the mixed layer.
- Increases (decreases) in heat content in the mixed layer leads to decreases (increases) in O2 content. The response time is about one month.
- The heat content increase (decrease) in the mixed layer likely leads to an increase (decrease) in AOU content. The time lag between ACA and OHCA is about 2-3 months.
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Acknowledgments

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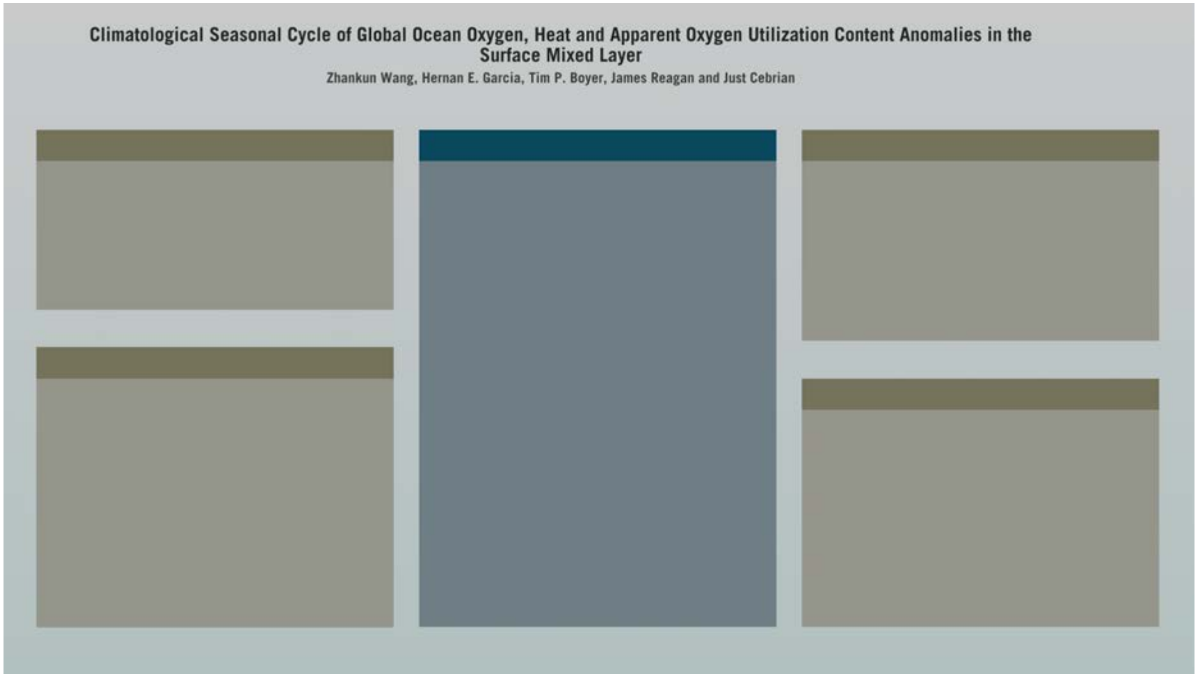

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AGU FALL MEETING
Online Everywhere | 1–17 December 2020

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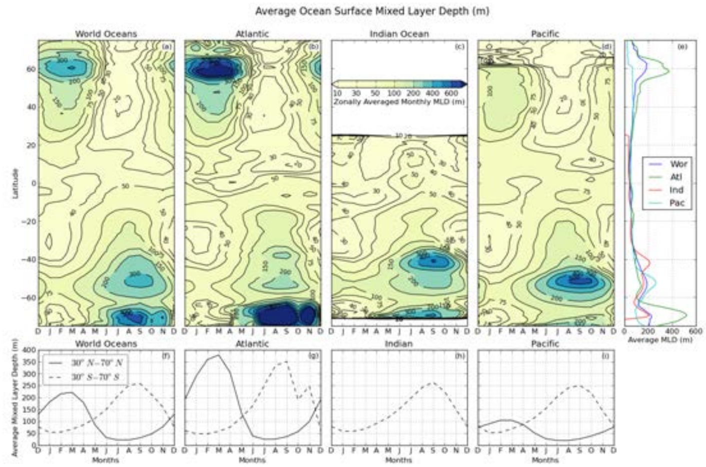

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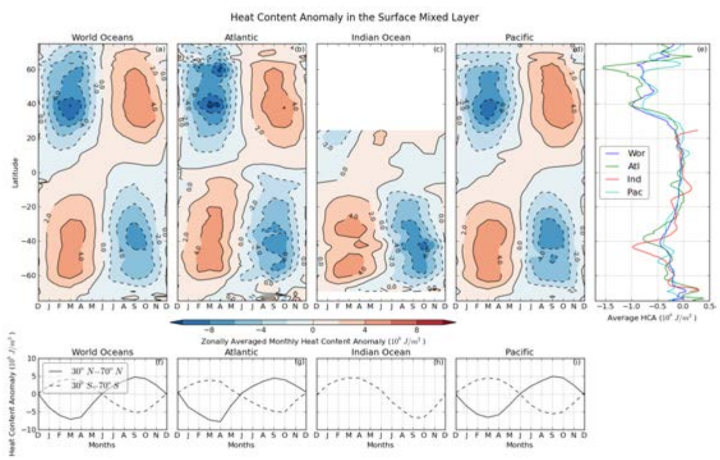

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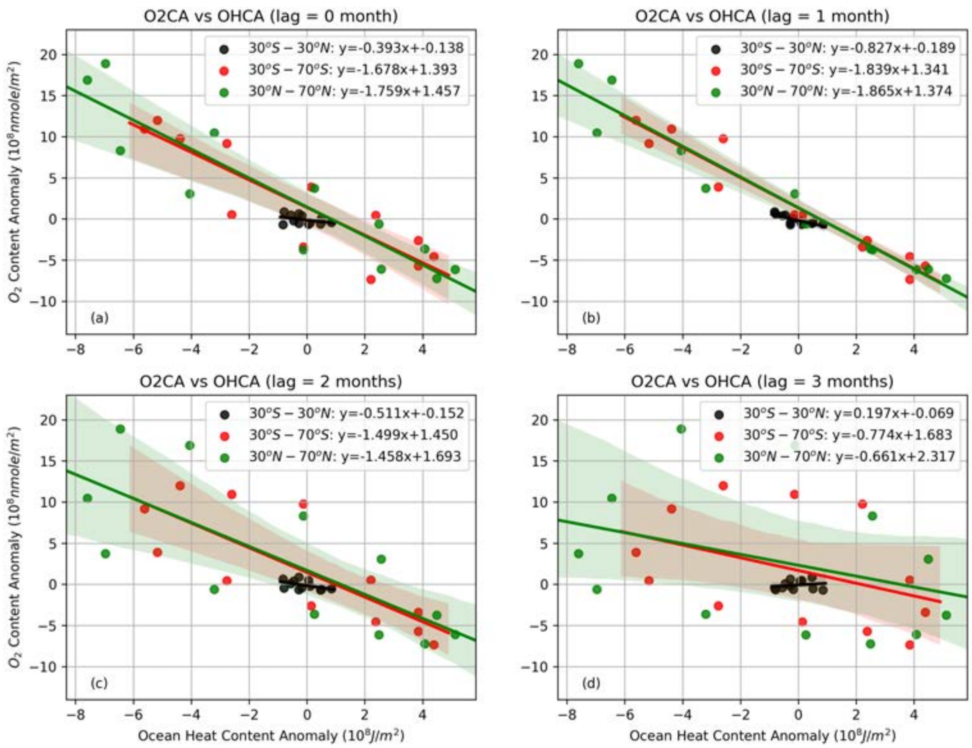

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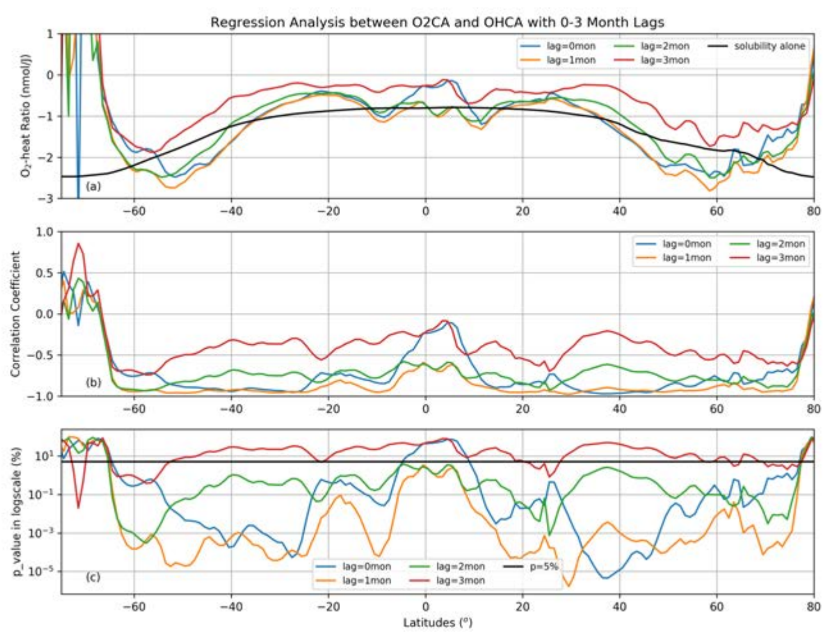

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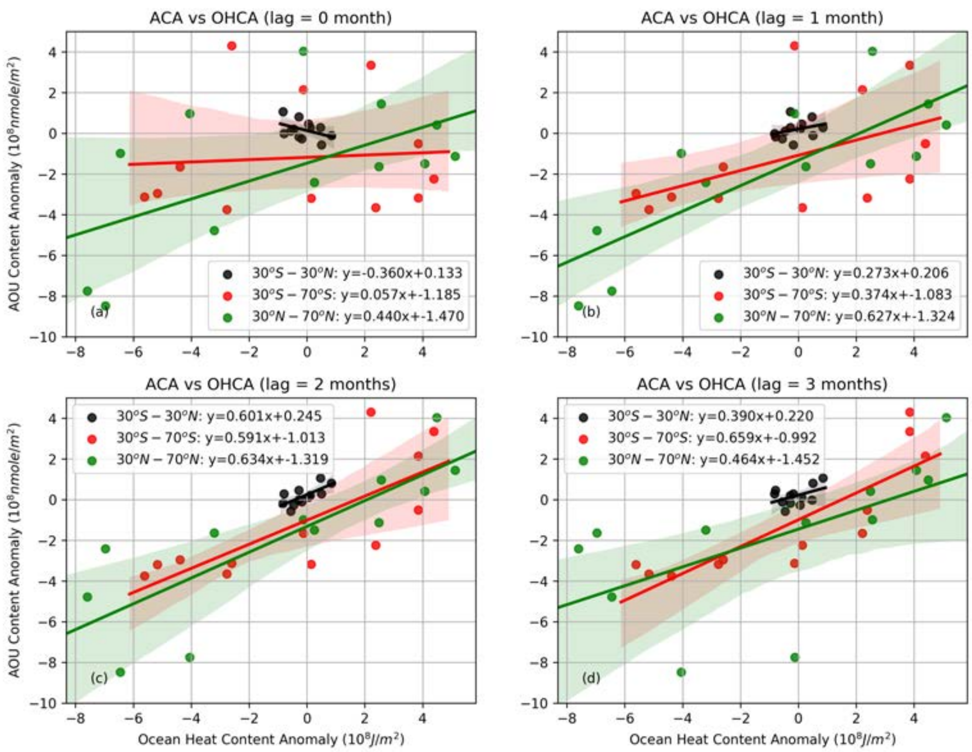

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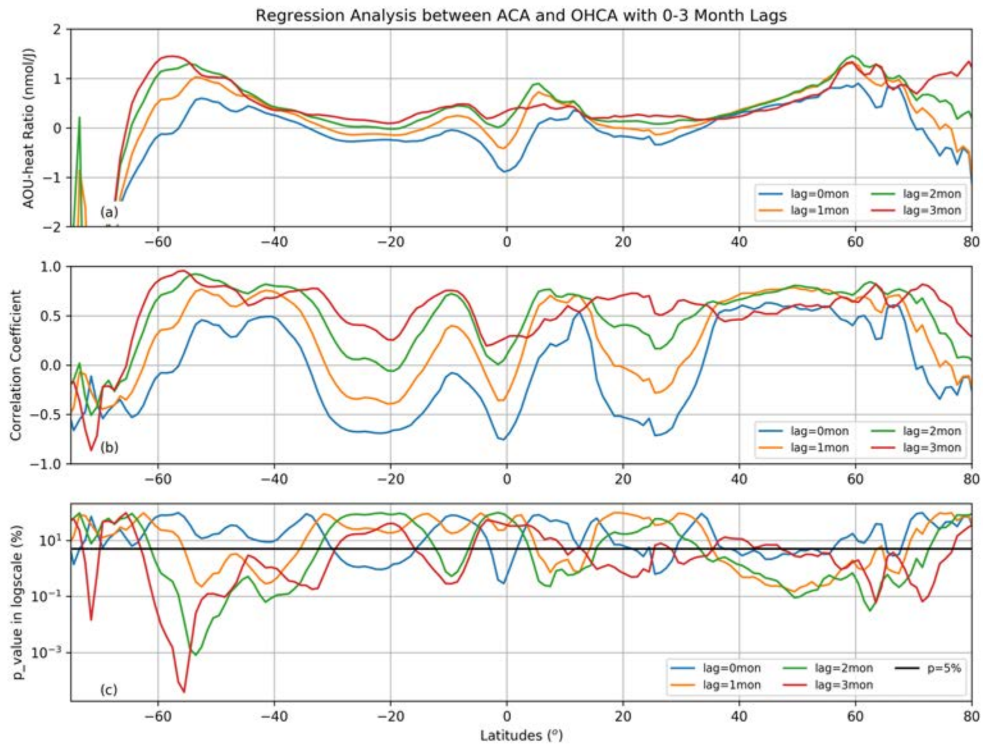

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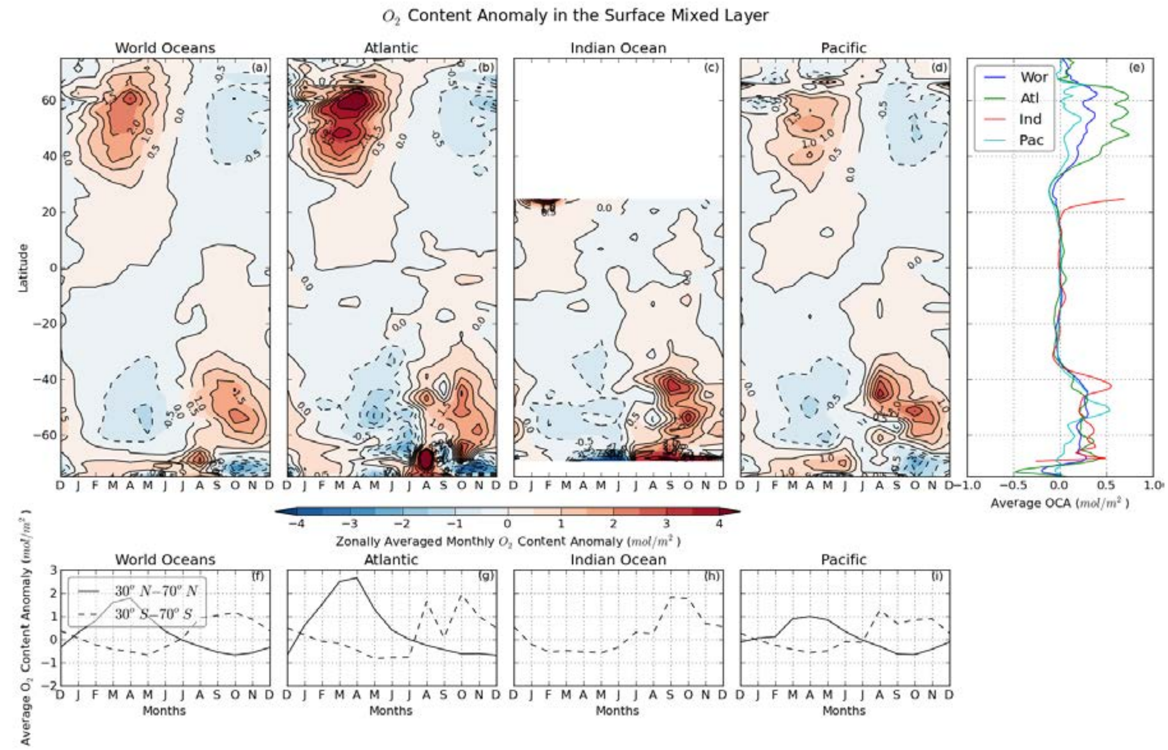

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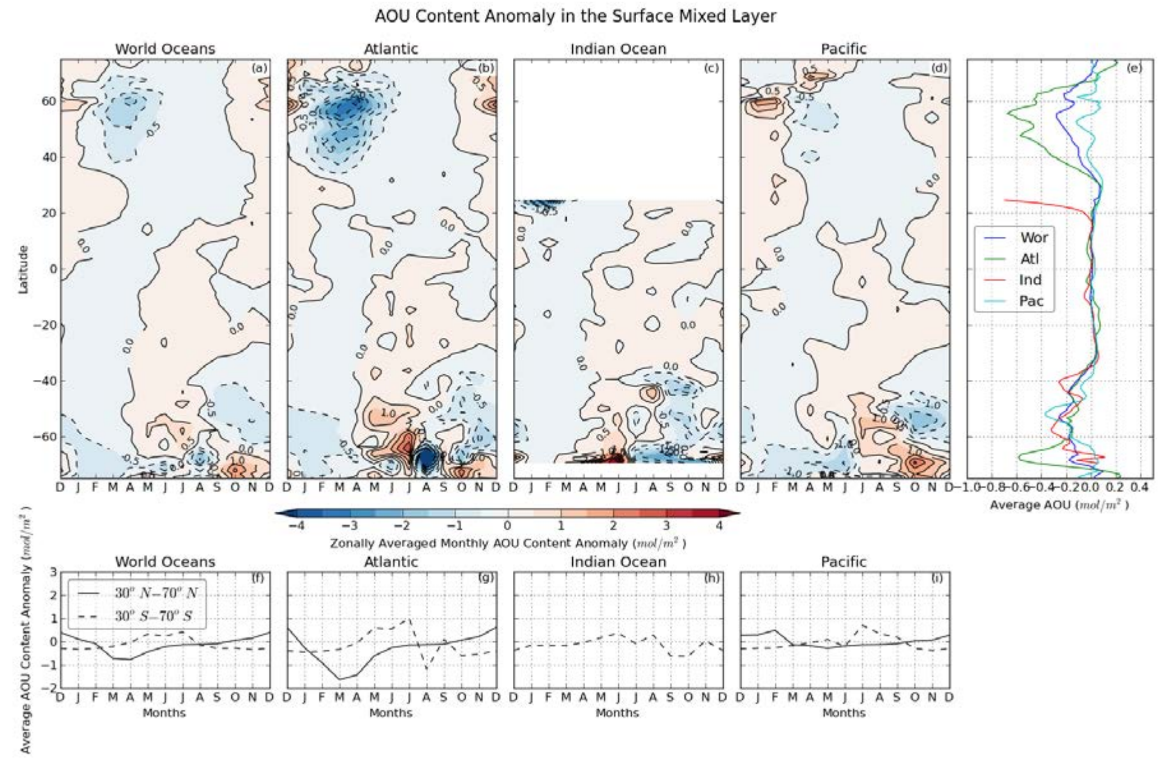

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