Time of Emergence for acidification and de-oxygenation in a water mass framework in the North Pacific

Keith Rodgers (Princeton University)
Maricela Coronado, Sarah Schlunegger (Princeton University)
Thomas Frölicher (ETH, Zurich, Switzerland)
Ivy Frenger (GEOMAR, Kiel, Germany)
Daisuke Sasano, Masao Ishii (JMR, MRI, Tsukuba, Japan)

Large initial condition ensemble runs first published in 2015 in Biogeosciences
1. Marine ecosystems provide multiple services of high economic/social value: (1) uptake of atmospheric CO$_2$, (2) primary protein source for 1 in 7 of the world’s population

2. Climate change will likely push the drivers of environments to which organisms are adapted outside the range of natural variability
   → Organisms can either adapt, migrate or go extinct

2. Potential drivers include:
   - Warming (SST)
   - Acidification ($\Omega_{arag}$)
   - Deoxygenation ($O_2$)
   - Perturbations to biological productivity (NPP)

4. On a global scale, changes in drivers are largely a consequence of increase in atmospheric CO$_2$ and associated climate change
Ocean warming, de-oxygenation and acidification

Global sea surface temperature

Global ocean O₂ inventory change

Global sea surface pH (-)

(Frölicher et al., 2016, submitted to Global Biogeochemical Cycles)
Challenge

• Detecting secular trends in drivers on local to regional scale is complicated by the presence of natural variability in the Earth System

• We apply Large Initial Condition Ensemble Simulations with GFDL’s ESM2M under historical/RCP8.5 pathways over 1950-2100 to consider emergence characteristics for ecosystem drivers
Model: GFDL ESM2M

- Coupled climate-carbon model GFDL ESM2M
- 2°-2.5° atmosphere; 0.3°-1° ocean
- Includes TOPAZv2 ocean biogeochemistry model
- Simulates mechanisms that control ocean carbon cycle and marine ecology
- TOPAZv2 considers three phytoplankton groups: small, large, diazotrophs

(Dunne et al. 2012, 2013)
Experimental design

- 30 ensemble members, with only minor perturbations to initial state for atmosphere/ocean/land/sea ice for January 1st, 1950
- Period 1950 – 2100 following historical/RCP85 GHG pathways
- 3+ million GAEA core-hours; 60 TB raw data
Decadal Apparent Oxygen Utilization (AOU) changes over North Pacific identified with Repeat Hydrographic measurements

Very large AOU changes near $\sigma_0=26.6$: Propagated from CMW outcrop region? Or associated with changes in circulation?

Deutsch et al. (2006)
Sasano et al. (2015): Considered O$_2$ trends using high-frequency repeat hydrography data along 165°E, also in a density framework.

High frequency measurements: can distinguish between timescales of variability, and reduce alias problems in characterizing decadal trends.

165°E Section spans Western EQPAC <-> subpolar North Pacific.
Sasano et al. (2015): Using DATA, identified linear trends in \(O_2\) along 165°E, and argued that this reflects natural decadal variability.

**Blue=deoxygenation**  
**Red=oxygenation**

Trends considered over 1987-2011
Consider ensemble mean zonal velocity, potential density, and $O_2$ along 165°E for GFDL’s ESM2M in 1990s

Useful to establish context for $O_2$:

Strongest zonal transport signal flanked on the northern side by low-$O_2$ waters below 150m in subpolar gyre and high-$O_2$ waters in the subtropical gyre
Here we use a 30-year trend window to define signal-to-noise over the recent historical period, and emergence is defined using a threshold of 67% confidence.

**Main Result:** At surface, $\Omega_{\text{arag}}$ emerges prior to other stressors (already emergent nearly everywhere), while $O_2$ inventories exhibit more complicated behavior.
How about emergence of $O_2$ on ocean interior density surface $\sigma_0=26.6$? using 25-year trend window with time interval 1987-2011 chosen by Sasano et al. (2015)

Relatively weak emergence over most of the global domain

Implications: trends over WOCE-CLIVAR era at this density can’t in general be distinguished from natural decadal variability
How about emergence of $\Omega_{\text{arag}}$ on ocean interior density surface $\sigma_0=26.6$? using 25-year trend window with time interval 1987-2011 chosen by Sasano et al. (2015)

Relatively strong emergence over much of the global domain

Nevertheless broad region downstream of Kuroshio Extension exhibits large variability;
Next consider emergence for both fields along 165°E over the same 25-year period considered by *Sasano et al. (2015)*, namely 1987-2011

Non-emergence of $O_2$ is evident viewed in both density and pressure coordinates.

For $\Omega_{\text{arag}}$, emergence throughout subtropical latitudes is more evident when shown in density space than in pressure space, and non-emergence of Kuroshio is more evident in pressure coordinate.
Conclusions

- For preliminary evaluation of de-oxygenation and acidification trends, both exhibit important regions where natural decadal variability complicates the task of trend detection.

- There is a hierarchy of emergence of these two potential ocean ecosystem drivers both globally and in the interior of the North Pacific, with $\Omega_{\text{arag}}$ emerging earliest, and $O_2$ emerging over significantly longer timescales.

- The results here underscore the critical importance of sustained multi-decadal observations of ocean biogeochemistry and ocean ecosystem drivers for trend detection;