RESPIRATION IN THE GULF OF MAINE INFERRED FROM CLIMATOLOGIES OF DISSOLVED OXYGEN AND PRIMARY PRODUCTION

R. Najjar[1], J. Siewert[1], and J. O'Reilly[2]

1. MOTIVATION

- Respiration is a central process in marine biogeochemical cycles but is extremely difficult to measure directly.
- Dissolved oxygen concentration is sensitive to primary production and respiration.
- Dissolved oxygen and primary production have been measured extensively in seawater, and the latter can be estimated with remote sensing.

OBJECTIVE: To use climatologies of dissolved oxygen and primary production (*PP*) to estimate respiration (*R*) and net community production (*NCP* = *PP* – *R*) in the Central Gulf of Maine.

APPROACH: Construct a 1-D mass balance model for the oxygen anomaly (ΔO_2, the departure from saturation) that includes the processes of gas exchange, diffusion, entrainment, primary production and respiration.

2. OBSERVATIONS

- Dissolved oxygen concentration ($[O_2]$), temperature (*T*) and salinity (*S*) measurements at standard depth levels were obtained from the World Ocean Atlas 2005 of the National Oceanographic Data Center.
- $\Delta[O_2] = [O_2] - [O_2]_{sat}(T,S)$, where $[O_2]_{sat}$ is computed following Garcia and Gordon (1992).
- Two-harmonic fits were made to *T* and $\Delta[O_2]$, (Figure 1) and then cubic splines were made in the vertical.
- Mixed layer depth (*H*) computed using a 0.5° C criterion. Mean annual cycle (not shown) has February maximum of 146 m and July minimum of 6 m.
- Climatological monthly wind speeds were obtained from the National Buoy Data Center from a buoy (#44005) in the Gulf of Maine (1978-2001). Gas exchange velocity (k_w) was computed using Wanninkhof's (1992) formulation for long-term winds.
- Integrated *PP* estimates are from the VGPM2A model (Figure 2), which is the VGPM model (Behrenfeld and Falkowski, 1997) with a modified *T* sensitivity and an accounting of bottom depth. VGPM2A uses chlorophyll and light from SeaWiFS and *T* from AVHRR. *PP* profiles generated using attenuation coefficient for PAR.

Figure 1. Observed (left, ^{14}C-based from MARMAP program) and satellite-based (right, VGPM2A) primary production in the Mid Atlantic Bight and Gulf of Maine.

- Good, broad-scale agreement between *in situ* and satellite-based primary production

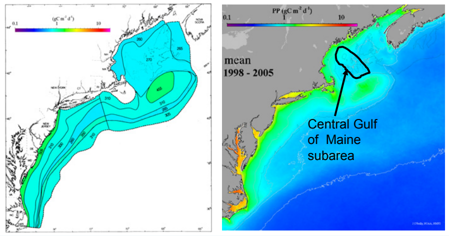


Figure 2. Observations and two-harmonic fit to temperature and O_2 anomaly at 10 m depth.

- These fits are typical of those at other depths. Unflagged NODC data were used, but outliers suggest further cleaning may be needed.

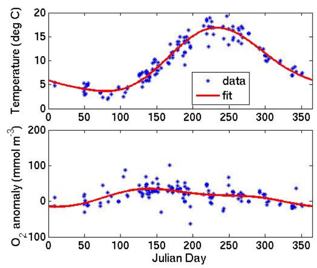
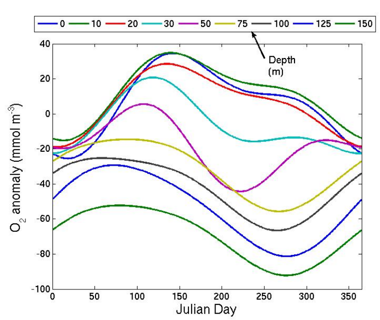


Figure 3. Two-harmonic fits to O_2 anomaly at all standard depths between 0 and 150 m.

- Annual cycles are typical of those seen in open ocean (Najjar and Keeling, 1997), but are stronger. Note how phase shifts between 20 and 75 m.
- These cycles reflect the seasonality of photosynthesis, respiration, and ventilation.



3. MODEL

- Mean annual cycle, 1-dimensional. Separate equations for the mixed layer and below. The mixed layer equation is:

$$H\frac{d\Delta[O_2]_{ml}}{dt} = PP_I - R_I - F_S + F_B + E$$

- $\Delta[O_2]_{ml}$ = mixed layer average $\Delta[O_2]$.
- PP_I and R_I are *PP* and *R* integrated over *H*.
- F_s = upward flux of oxygen across the ocean surface, $k_w\Delta[O_2]_{sfc}$.
- F_B = upward diffusive flux of ΔO_2 across mixed layer base using a diffusivity K_z of 1 cm^2 s^{-1}.
- *E* = entrainment flux of ΔO_2, computed from observed change in *H* and difference in concentration between water in mixed layer and entrained water.

- Below the mixed layer:

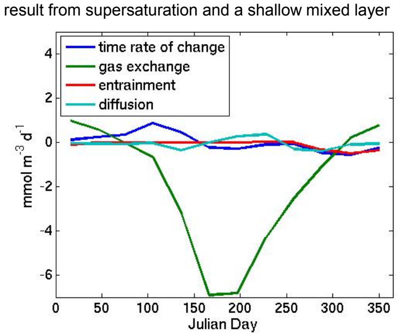
$$\frac{\partial\Delta[O_2]}{\partial t} = PP - R + \frac{\partial}{\partial z}\left(K_z\frac{\partial\Delta[O_2]}{\partial z}\right)$$

- We make estimates of all of the terms in the above equations, except respiration, which is determined by difference.

4. RESULTS

Figure 4. Mixed layer physical processes

- Positive values are sources to mixed layer.
- Air-sea exchange dominates over other transport processes.
- Large negative values due to gas exchange in summer result from supersaturation and a shallow mixed layer



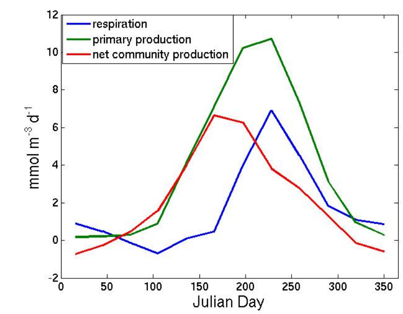
ACKNOWLEDGMENTS

This research is a component of The USECoS (US Eastern Continental Shelf Carbon Cycling) Project, which is supported by the National Aeronautics and Space Administration Interdisciplinary Science Program.

[1]The Pennsylvania State University najjar@meteo.psu.edu; [2]NOAA/NMFS Narragansett Lab Jay.O'Reilly@noaa.gov

Figure 5. Mixed layer biological processes

- Respiration lags primary production; net community production leads both.
- From *NCP*, mixed layer is autotrophic March-November and heterotrophic December-February.



- Annual, integrated mixed layer budget (mol O_2 m^{-2}):

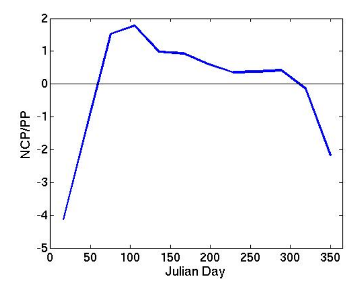
PP = 19.4

R = 13.6

NCP = 5.8

- *NCP/PP* = 0.30

Figure 6. Ratio of NCP to PP in mixed layer



- Analogous to an *f*-ratio.
- Negative values reflect net heterotrophy. Values greater than one not realistic—maybe *PP* in spring is too low? Declining values over the summer reflect increased recycling.

Budget averaged between mixed layer base and 150 m.

- In mol O_2 m^{-2} yr^{-1}: *R* = 4.0, *PP* = 0.7, Diffusion = -0.5, $d\Delta O_2/dt$ = -2.8.
- Dominant balance between time rate of change and respiration
- Respiration below mixed layer accounts for about 2/3 of mixed layer *NCP*

5. FUTURE WORK

- Uncertainty estimates
- Include thermal impact on ΔO_2
- Use OPAL primary production
- Extend to other subareas on shelf

REFERENCES

Behrenfeld, M.J. and P.G. Falkowski (1997), Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnol. Oceanogr.*, 42:1-20.

Garcia, H. E., and L. I. Gordon (1992), Oxygen solubility in seawater: Better fitting equations, *Limnol. Oceanogr.*, 37:1307-1312.

Najjar, R. G., and R. F. Keeling (1997), Analysis of the mean annual cycle of the dissolved oxygen anomaly in the World Ocean, *J. Mar. Res.*, 55:117-151.

Wanninkhof, R., 1992, Relationship between wind speed and gas exchange over the ocean. *J. Geophys. Res.*, 97:7373-7382.