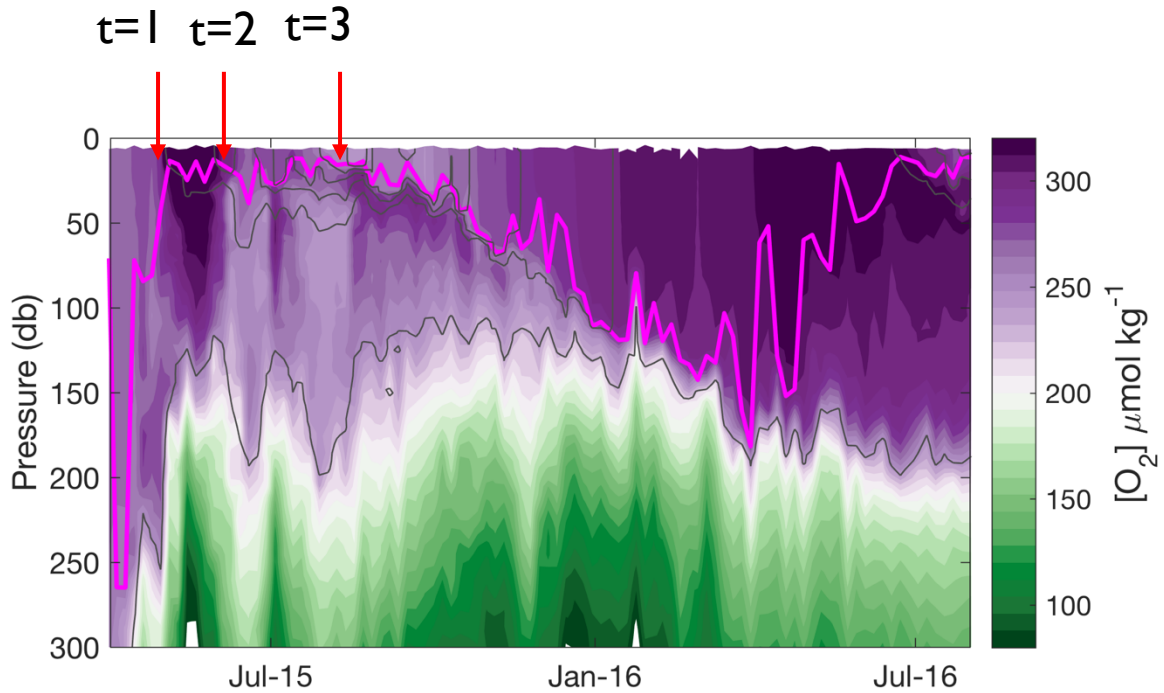


1. (From class):

You sample the mixed layer at three points in time ($t=1, 2, 3$):

$$\rho = 1000 \text{ kg m}^{-3}$$



Sample	Time (days)	SST (°C)	$[O_2]_{\text{sat}}$ ($\mu\text{mol kg}^{-1}$)	MLD (m)	Case 1 - $[O_2]_{\text{ML}}$ ($\mu\text{mol kg}^{-1}$)	Case 2 - $[O_2]_{\text{ML}}$ ($\mu\text{mol kg}^{-1}$)	F_{bio} ($\text{mmol O}_2 \text{ m}^{-2} \text{ d}^{-1}$)
1	0	15	250	70	250	250	-----
2	10	21	220	20	?	320	?
3	20	27	200	20	?	240	?

a. (Case 1) If there were no biology and the gas transfer coefficient were constant at 4 m d^{-1} , what would you expect the mixed layer oxygen concentration to be in the second and third samples?

b. (Case 2) You run your Winkler titrations and find the actual oxygen concentrations listed for Case 2. Realizing there actually was a spring bloom occurring, you decide to calculate the biological flux of oxygen in the mixed layer. Assume no biological flux at the time of sample 1. The flux calculated for sample 2 should be the average biological flux between samples 1 and 2, etc.

2. Consider a two-layer ocean box model with no river or burial terms and the conditions set below. In all calculations assume a density of 1025 kg m^{-3} .

$$[\text{PO}_4^{3-}]_{\text{deep}} = 2.2 \text{ } \mu\text{mol/kg}$$

$$[\text{PO}_4^{3-}]_{\text{surface}} = 1.0 \text{ } \mu\text{mol/kg}$$

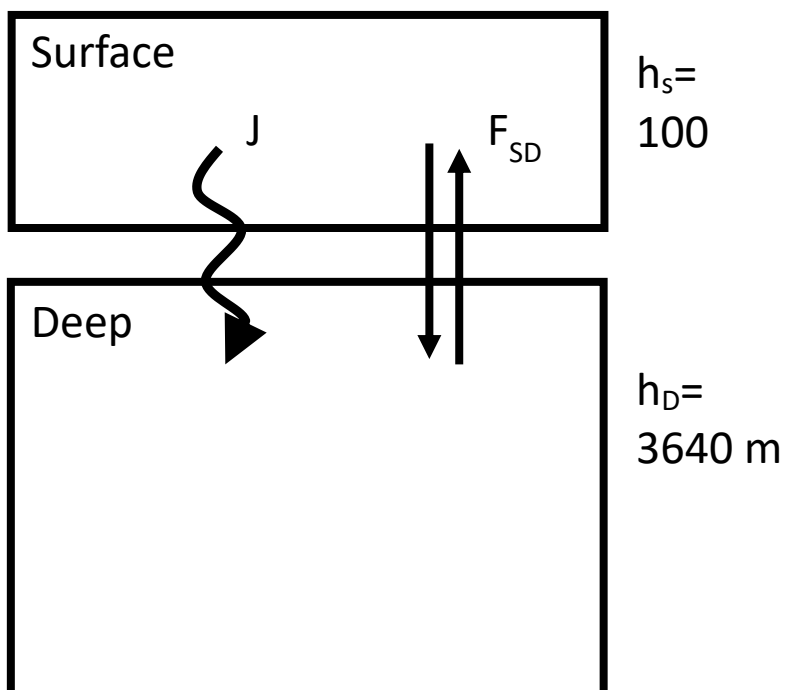
$$[\text{O}_2]_{\text{surface}} = 275 \text{ } \mu\text{mol/kg (the saturation value)}$$

P:N:C:O₂ ratio in particles is 1:16:106:-154

$$\text{Total ocean area} = 3.6 \times 10^{14} \text{ m}^2$$

All particles are respired in the deep ocean.

- Calculate the particulate flux (J) in units of phosphate and carbon given a mixing velocity (F_{SD}) of 3.5 m y^{-1} .
- Calculate the steady state oxygen concentration in the deep ocean.
- If the mixing velocity were 15% smaller, but the amount and composition of the particle flux were the same as part a and b, find $[\text{PO}_4^{3-}]_{\text{surface}}$ and $[\text{O}_2]_{\text{deep}}$ (you can assume that deep phosphate stays the same).
- Using the initial conditions (i.e. no reduction in the mixing velocity), assume that now 1% of the particulate flux is permanently buried into the sediments of the deep box each year. Add the burial flux to your diagram and write out your new mass balance equations. Calculate and plot $[\text{PO}_4^{3-}]_{\text{surface}}$, $[\text{PO}_4^{3-}]_{\text{deep}}$, and $[\text{O}_2]_{\text{deep}}$, over time until a steady state is reached.
- What has happened as the system comes to a new steady state? What are the final conditions?



3. While considering your two-box model, you realize a fundamental difference between the two-box model and the real ocean. Phosphate concentrations in the ocean are closer to 0 $\mu\text{mol/kg}$ than 1 $\mu\text{mol/kg}$! After recovering from realizing the carelessness of your instructor, you decide to recalculate the particle flux and deep oxygen concentration given a realistic $[\text{PO}_4^{3-}]_{\text{surface}} = 0 \mu\text{mol/kg}$ (assuming no deep burial).

a.) What is the new $[\text{O}_2]_{\text{deep}}$?

b.) Is this value realistic? If not, what is a fundamental problem with our model? Consider how deep water is actually formed in the surface ocean and how that matches the surface distributions of nutrients that we have considered in class and in the text.

[Question 4 is not required - Can be submitted for extra credit]

4. To try to fix your issue, let's separate the surface ocean into a high-latitude and a low-latitude box. Instead of a general mixing term we will now use an overturning circulation "T" and a high latitude/deep mixing term (F_{hd}).

$$[\text{PO}_4^{3-}]_{\text{deep}} = 2.2 \mu\text{mol/kg}$$

$$[\text{PO}_4^{3-}]_{\text{H}} = 1.3 \mu\text{mol/kg}$$

$$[\text{PO}_4^{3-}]_{\text{L}} = 0 \mu\text{mol/kg}$$

$$[\text{O}_2]_{\text{L}} = 275 \mu\text{mol/kg}$$

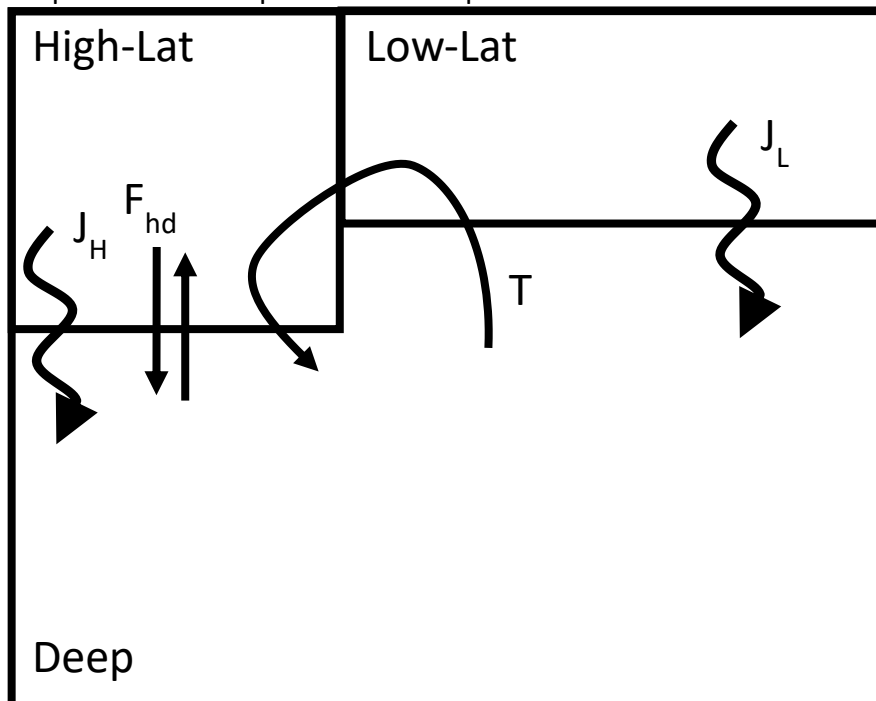
$$[\text{O}_2]_{\text{H}} = 316 \mu\text{mol/kg}$$

$$F_{hd} = 1.26 \times 10^{15} \text{ m}^3 \text{ y}^{-1}$$

$$T = 8 \times 10^{14} \text{ m}^3 \text{ y}^{-1}$$

P:N:C:O₂ ratio in particles is 1:16:106:-154

All particles are respired in the deep ocean.



- a.) Write out the mass budget for the three boxes and solve for the deep box $[O_2]_{\text{deep}}$
- b.) Plot the deep oxygen concentration as a function of high-latitude phosphate concentrations (between 0 and a max of $2.3 \mu\text{mol/kg}$).
- c.) How do you expect that changes in high-latitude nutrient utilization would therefore impact ocean biogeochemistry? What are the implications for the carbon and oxygen cycles?