**Biofouling Modeling**

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# Physical Dynamics

Methodology mostly follows Kooi 2017. Biofouling causes particles to “yoyo” sort of related to euphotic depth.

A close up of a device

Description automatically generated

­Her model relates the number of attached algae particles (*A*) which affect the density/size of the plastic particle, and thus the vertical hydrodynamics (settling velocity). Here we focus on A.

*A* is changed in time by 4 factors (Kooi, eq 11):

1. Collision of algae with plastic particles
2. Light and temperature limited growth
3. Grazing mortality
4. Respiration

## 1: Collision of algae with plastic particles

Collision frequency depend on some dynamics, specifically Brownian motion, settling velocity, and shear. No external datasets needed.

Notably, collision frequency also depends on concentration of algae in the water column, for which there are no data. This gets tricky. We want an accurate idea of the concentration of algae at any grid point. Kooi uses chlorophyll A concentration as a proxy and relates the two by constant carbon ratios. We will do the same.

### Vertical Profiles of Chlorophyll A

Getting chlorophyll A concentration vertical profiles is challenging. Kooi references Uitz 2006, which really goes hard into extrapolating vertical profiles from surface concentrations. Keys: distinguishes between “mixed” (mixed layer > euphotic depth) and “stratified” areas (mixed layer < euphotic depth), different parameterization for each. For both, multiple fits are done for different levels of surface concentration, so there’s a fat table of hard-coded parameters. The following figure shows concentration depth profiles for stratified (S) waters, in 9 categories of surface concentration. Euphotic depth is also shown.

A close up of a map

Description automatically generated

Compare the above profiles to the following profiles for mixed waters (M):

A close up of a map

Description automatically generated

There is a significant difference between these two profiles for a given concentration class. To distinguish, we compare euphotic depth (calculated from surface chlorophyll concentration) with mixed layer depth (MLD). To calculate MLD, I suggest we use the simple “threshold method,” either in density or in temperature (see Thompson 2003, section 2a). We will likely want an estimate of the mixed layer depth anyways, for the sake of computing turbulent mixing of plastic particles, which should vary seasonally with the variation of the mixed layer (quite a strong seasonal variation). So, perhaps this could be cached internally per time-step.

I suggest we use both profiles; no parameters are provided for mixed water profiles, but the author describes them as “constant then linear,” which is apparent in the graph. We distinguish between 2 cases using MLD and euphotic depth:

Case 1: stratified waters. Use same method as Kooi.

Case 2: well mixed waters: constant concentration from surface to euphotic depth. Then, linear decrease to mixed layer depth. This takes into account the mixing in euphotic zone, and assumes mixing as the only mechanism which brings chlorophyll a below euphotic zone.

Case 1 ensures that we accurately capture the interesting near-surface concentration profile in calm waters. Case 2 ensures that we take into account conditions where case 1 breaks down, which could be a lot of the time; euphotic depth is less than 100m, but MLD can be much lower, especially in subtropical winters. See following Figure from Tjiputra 2012 of mixed layer depth seasonality:

A screenshot of a computer

Description automatically generated

We should also remember that HYCOM has been demonstrated to overestimate the mixed layer depth, should this depth turn out to govern the plastic dynamics we observe.

## 2: Light and Temperature Limited Growth

Algae growth is well modeled as a function of light and temperature. Kooi cites Bernard 2012, which is pretty bang on, really accurate. Ultimately the data needed is, obviously, temperature, which we can have from HYCOM, and light. Light is a bit more complicated; to get light intensity at an arbitrary z, you need light intensity at the surface and the average concentration of algae in the euphotic zone. Below euphotic depth, light is just zero, so model only has to work above euphotic depth. This concentration could be integrated from the calculated vertical profiles, but I recommend it be estimated as surface concentration / euphotic depth.

## 3: Mortality

This is modeled as constant, 39% population dieoff per day, due to grazing. Pretty basic. Comes from oceanic grazing mortality in Calbet 2004. That paper, in table 1, offers other values based on region: Oceanic (.39), Coastal (.40), Estuarine (.53), Tropical (.50), Temperate (.41), and Polar (.16). We might want to use all these, as our model, unlike Kooi’s, ought to take regional variation into account, and the above values vary quite significantly. We’ll need to look into Calbet’s regional definitions.

## 4: Respiration

Somewhat difficult to find an explanation for this term and its sign! Perhaps it is “common knowledge,” but I didn’t know. Here, from Béchet 2013:

Endogenous respiration: Photosynthesis generates chemical energy in the form of ATP, NADPH, and organic material. Endogenous respiration includes the consumption of chemical energy at day time and the consumption of organic material at night time.

Algal productivity: Rate of net biomass production expressed as the difference of the rate of photosynthesis minus the rate of endogenous respiration.

So, essentially, it’s metabolic activity, which consumes organic material and thus decreases the number of algae over time. As long as they’re alive, they’re consuming themselves, so below euphotic zone, this will lead to a die-off in addition to grazing mortality.

Kooi models respiration using a constant respiration rate, and a dependence on temperature which appears to be an “industry standard” relation between metabolic activity and temperature, dating way back to seminal papers in the 70s. Good enough for me, though I never found the justification for Kooi’s parameter value in the citation trail. Would like to re-investigate.

# Computational Considerations

## Data Product Tree

Algae Flux

Respiration

Mortality

Algae Collisions

Growth

Algae Concentration(z)

Region

Light(z)

Ave. Algae Concentration

Mixed Layer Depth

Density(z)

## Data Sources

1. Chl A Surface Concentration
   1. NASA NEO – 8-day or month 2002-2019. If we are interested in seasonality, we could composite a single average year and use that as forcing. If not, average everything and force.
2. Salinity
   1. HYCOM
3. Temperature
   1. HYCOM
4. Surface Light
   1. Data is available, but better to use simple model.
   2. We can use the geometry of the earth/sun interaction to derive light intensity for any lat/lon/time. This will give us accurate shape in time, but not sure about accuracy of magnitude. We’ll have to calibrate somehow to observations, or match somehow (use Kooi’s assumptions?)
5. Lat/lon
   1. Internal, on particle

## Complexity

The following complexity analysis is for a single particle. Naively, everything scales linearly with number of particles, unless we can be clever (recommended ☺).

1. Algae Collisions
   1. p from z: eval polynomial, constant time
   2. rho from p, S, T: also polynomial, constant time
   3. MLD from threshold method: downward search, will scale with vertical resolution, should be very fast as solution is in top several layers. O(vert res)
   4. Chl a concentration & z: parameterized, constant time
   5. Collisions from kernel + concentration: constant
   6. Total: O(constant \* vertical resolution)
2. Growth
   1. Chl a ave concentration: estimated by surface concentration/euphotic depth, constant time.
   2. Surface light intensity: function of lat/lon/time, constant time
   3. Combine a. and b.: constant time
   4. Total: constant time
3. Mortality
   1. Identify region from lat/lon: constant time
   2. Calculate mortality: constant time
   3. Total: constant time
4. Respiration
   1. Constant time

Overall complexity comments:

Everything should be constant regardless of grid spacing, except for MLD estimation, but this should be insignificant, as it’s a search, and result should be in first couple layers. Also, MLD might already be cached from hydrodynamics, making total time complexity constant.

The whole thing naively scales linearly to number of particles. Caching could improve this dramatically if we expect many particles to share grid elements.