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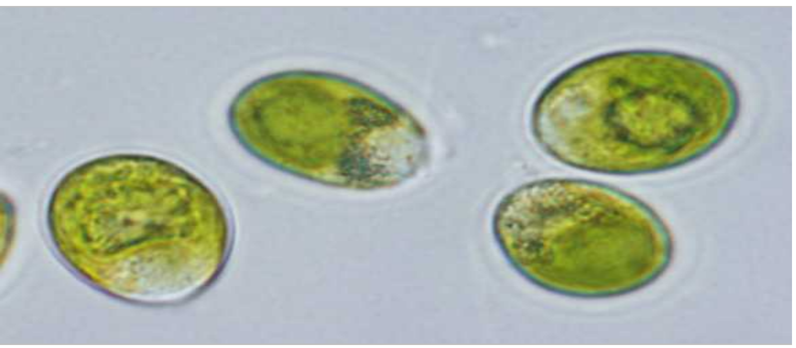

Computational Modeling of Algal Growth in Open Ponds

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Algal biofuels benefit the environment

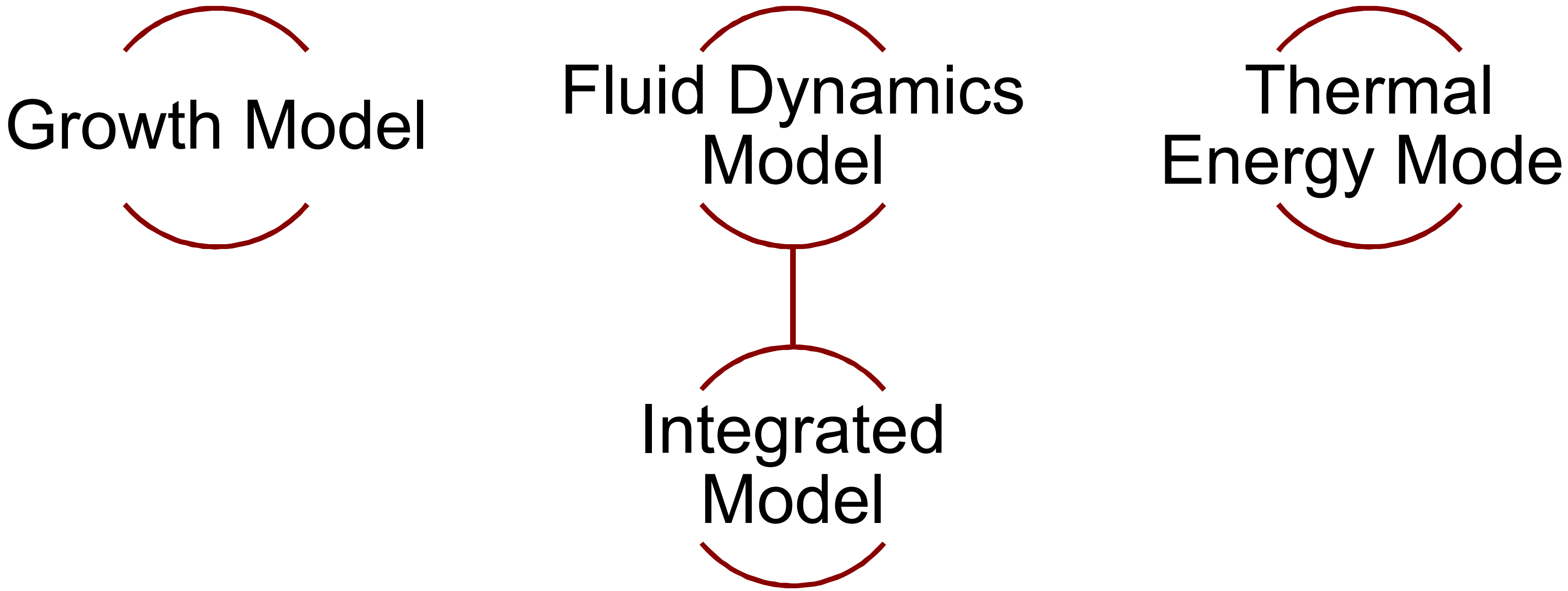
- Help meet the demand for alternative energy
- Grown on non-arable land
- Utilize wastewater
- Consume CO_2



Computational modeling streamlines optimization

- Make cultivation more environmentally and economically feasible
- Account for a large number of variables
  - Algal strain
  - Environmental conditions
  - Pond design
  - Mixing
  - Geographic location
- Reduce experimentation cost and time

Components of an effective model



Growth Model

$$S_{algae} = K_{ag}\Phi_a - K_{ar}\Phi_a - K_{am}\Phi_a - \omega_a \frac{d\Phi_a}{dz} - \sum Z_\mu \Phi_{zoo} \frac{\sigma_a \Phi_a}{\sum \sigma_a \Phi_a + \sigma_{pom}\Phi_{lpom} + \sum \sigma_{zoo}\Phi_{zoo}}$$

$$K_{ag} = P_m \lambda_{temp} \lambda_{light} \lambda_{nutreints} \lambda_{pH}$$

$$\lambda_{temp} = \begin{cases} \exp\left(-K_1\left(T_{opt,1} - T\right)^2\right) & for\ T < T_{opt,1} \\ 1 & for\ T_{opt,1} \leq T \leq T_{opt,2} \\ \exp\left(-K_2\left(T - T_{opt,2}\right)^2\right) & for\ T_{opt,2} < T \end{cases}$$

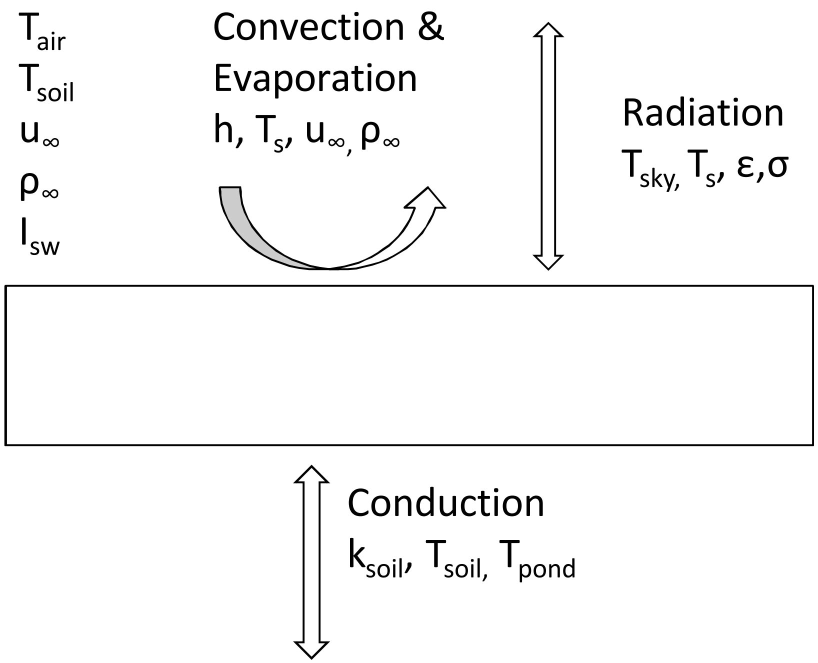
$$\lambda_{nutrients} = min\left(\left(\frac{\phi_n}{\phi_n + K_n}\right), \left(\frac{\phi_p}{\phi_p + K_p}\right), \left(\frac{\phi_c}{\phi_c + K_c}\right)\right)$$

$$\lambda_{light} = \left(\frac{I}{I_s} exp\left(-\frac{I}{I_s} + 1\right)\right)$$

$$\lambda_{pH} = \frac{[H^+]}{[H^+] + k_{OH} + [H^+]^2/k_H}$$

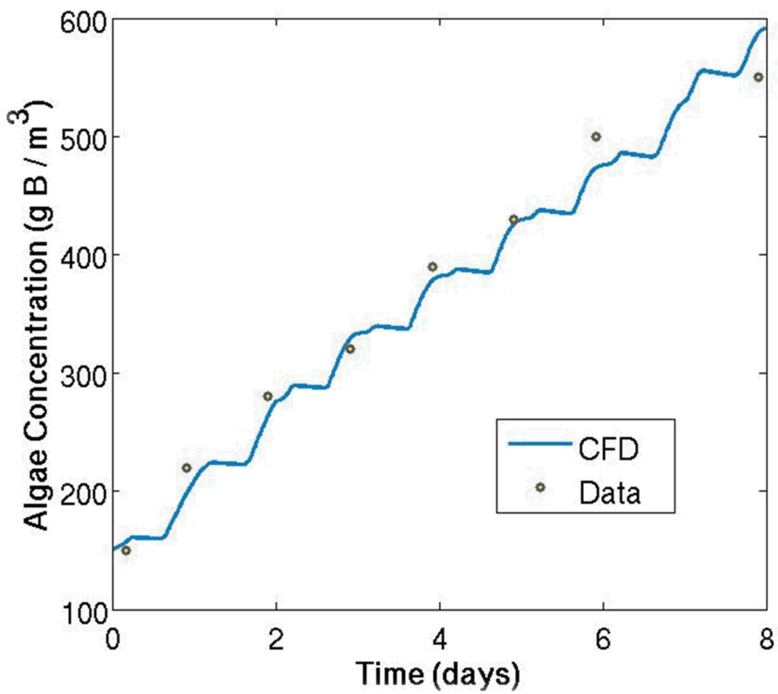
Energy Model

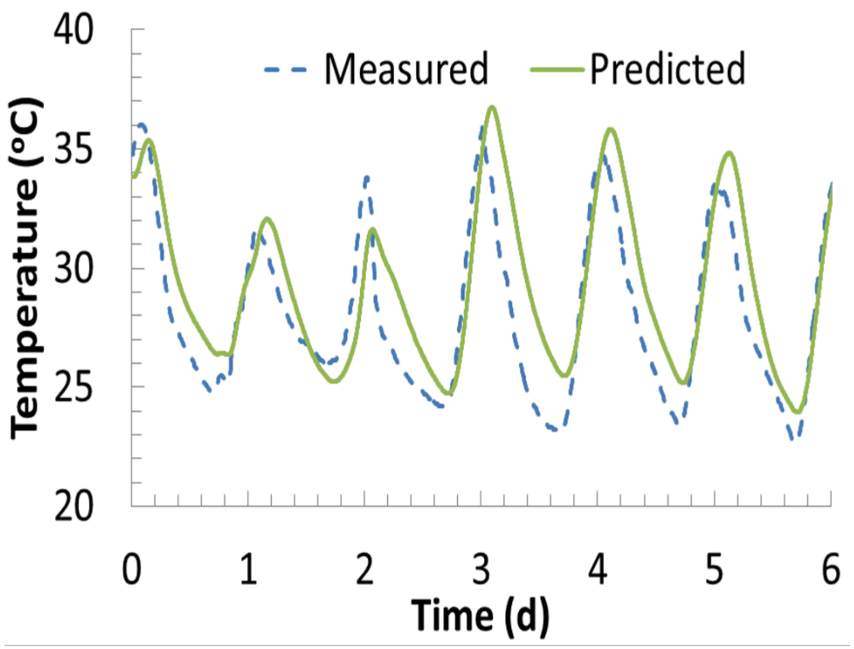
- $q"_{lw} = \varepsilon\sigma(T_{sky}^4 - T_{surface}^4)$
- $q"_{conv} = \bar{h}(T_\infty - T_s)$
- $q"_{evap} = h_{fg} h_m (\rho_{sat} - \rho_\infty)$
- $q"_{cond} = k\left(T_{pond} - T_{soil}\right)$
- $q"_{sw}$, from weather data



Previous experimental validation

- 2D model
- Experimental data from ASU

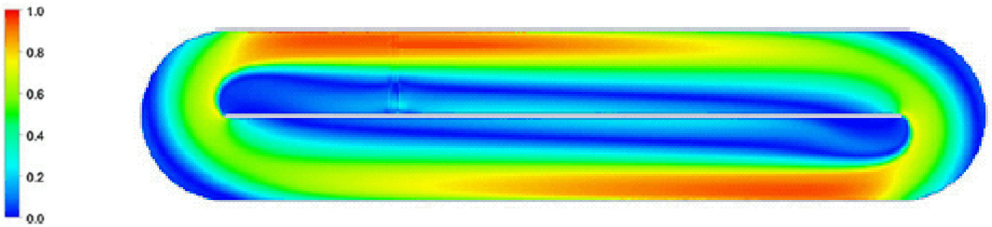


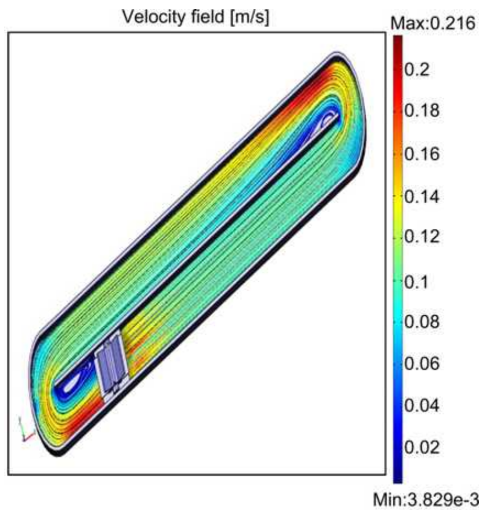


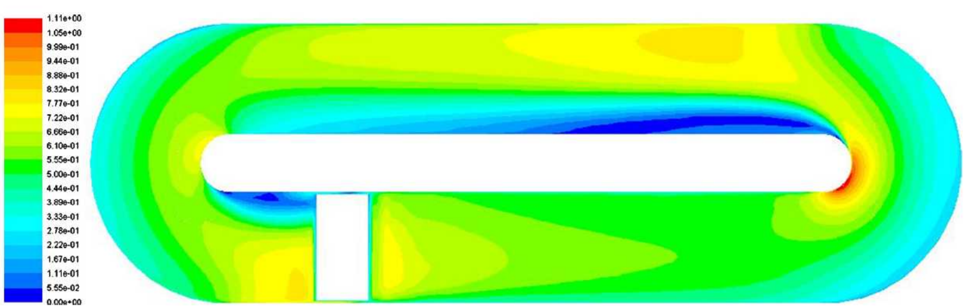
Design and operation of ponds can affect algal growth

- Commercial ponds are typically mixed by paddle wheels and 180^{o} bends
- Fluid dynamics affect algal growth
  - Species transport
  - Thermal energy transport
  - Exposure to solar irradiation

Assumptions for modeling paddle wheels





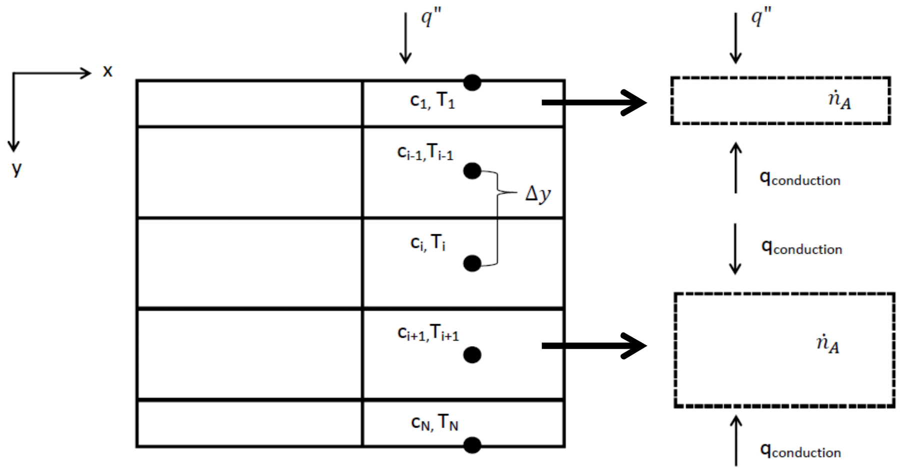


- Momentum Source
  - Liffman et al. 2013
- Inlet/ Outlet
  - Hadiyanto et al. 2013
- Movable Mesh
  - Hreiz et al. 2014

Goals to implement and validate the computational model

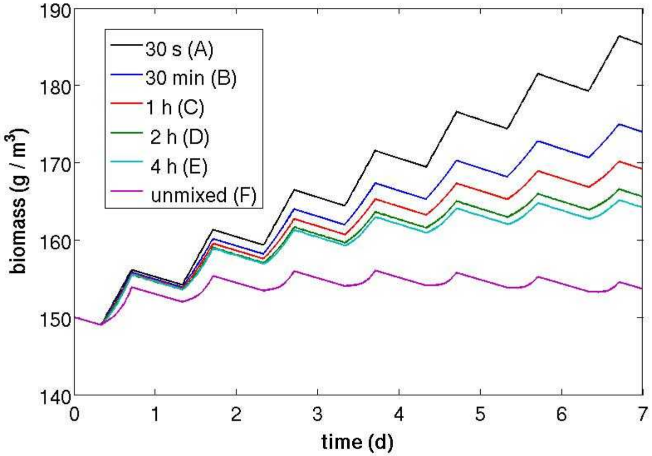
- Determine if computational growth models can capture the effects of mixing
- Quantify the effect of model assumptions on computational growth models
  - Compare 2D unmixed 2D repeating boundary, 3D momentum source, and 3D inlet/ outlet models
- Compare computational results with experimental data
  - Data from the ATP^3 project
  - 1000 L ponds
  - Mesa, AZ
  - Nannochloropsis *oceanica*

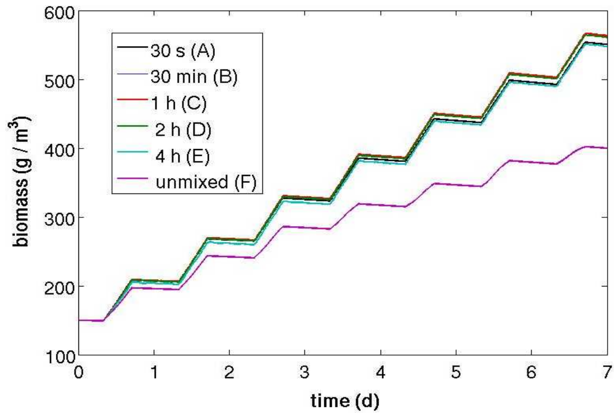
Finite difference mixing model

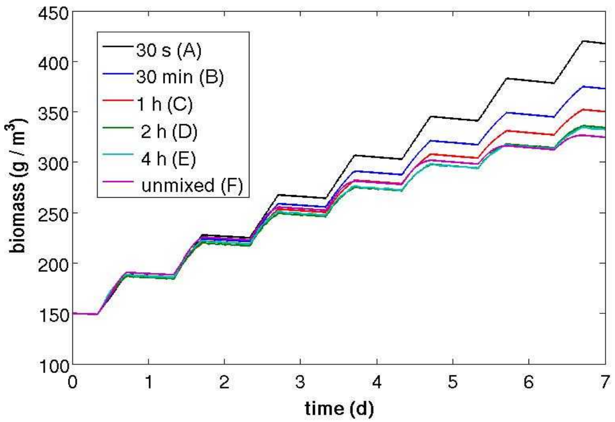


	Low	Medium	High
Temperature [C]	12 ± 2	22 ± 2	32± 2
Intensity [W m^{-2}]	300	600	900
Mixing time	30 s (A)	30 min (B)	1 h (C)
Mixing time	2 h (D)	4 h (E)	unmixed (F)

Mixing affect on algal growth



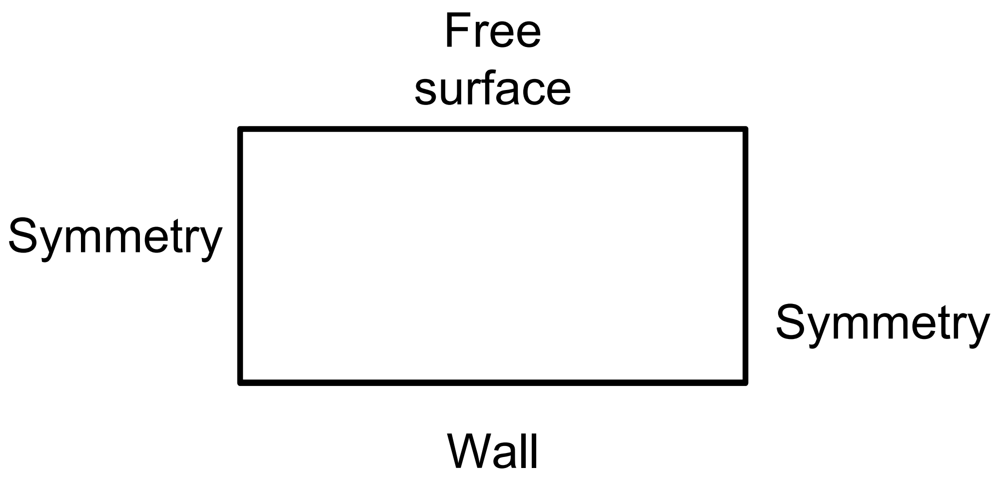




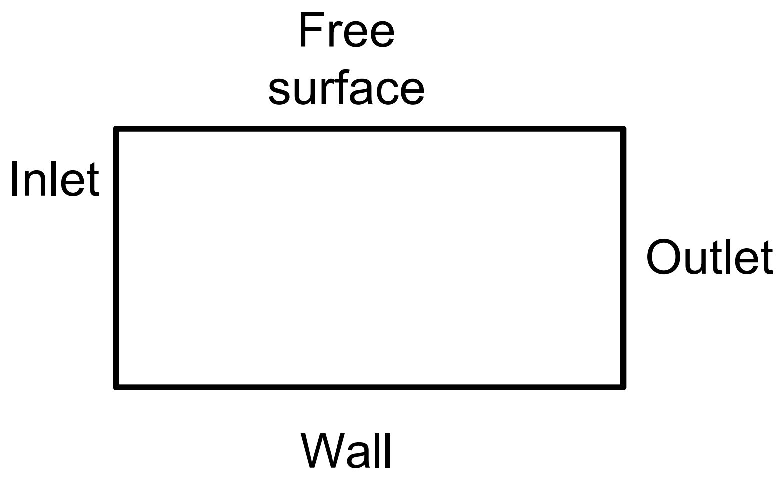
Biomass concentration as a function of time with both temperature and light held at low, medium, and high levels, respectively for ease of visualization.

2D Models

Unmixed

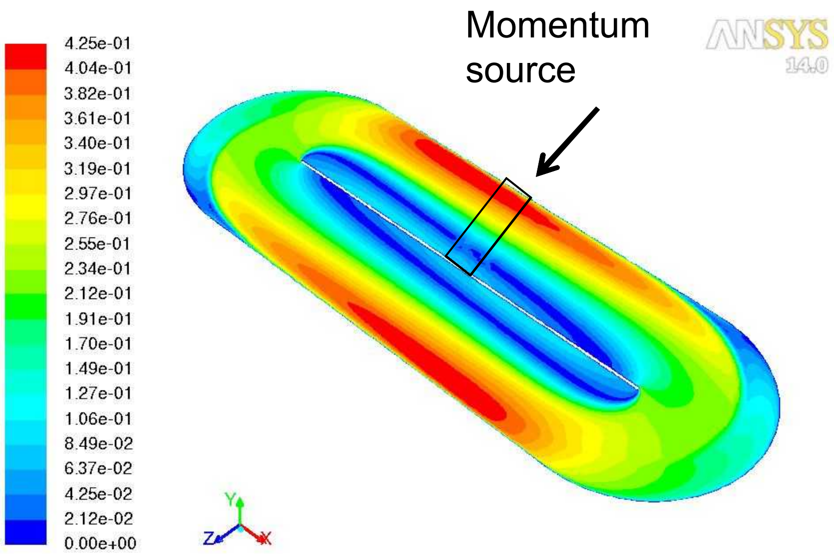


Repeating Boundary



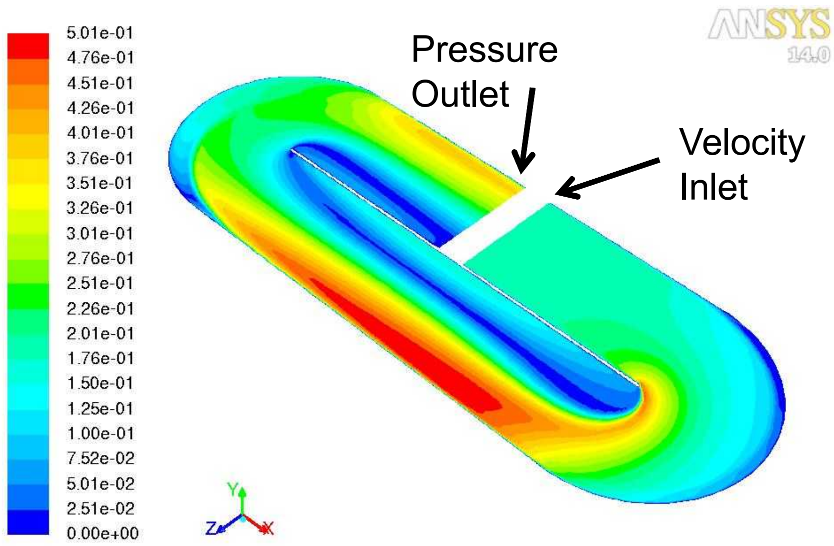
3D Models

Momentum Source



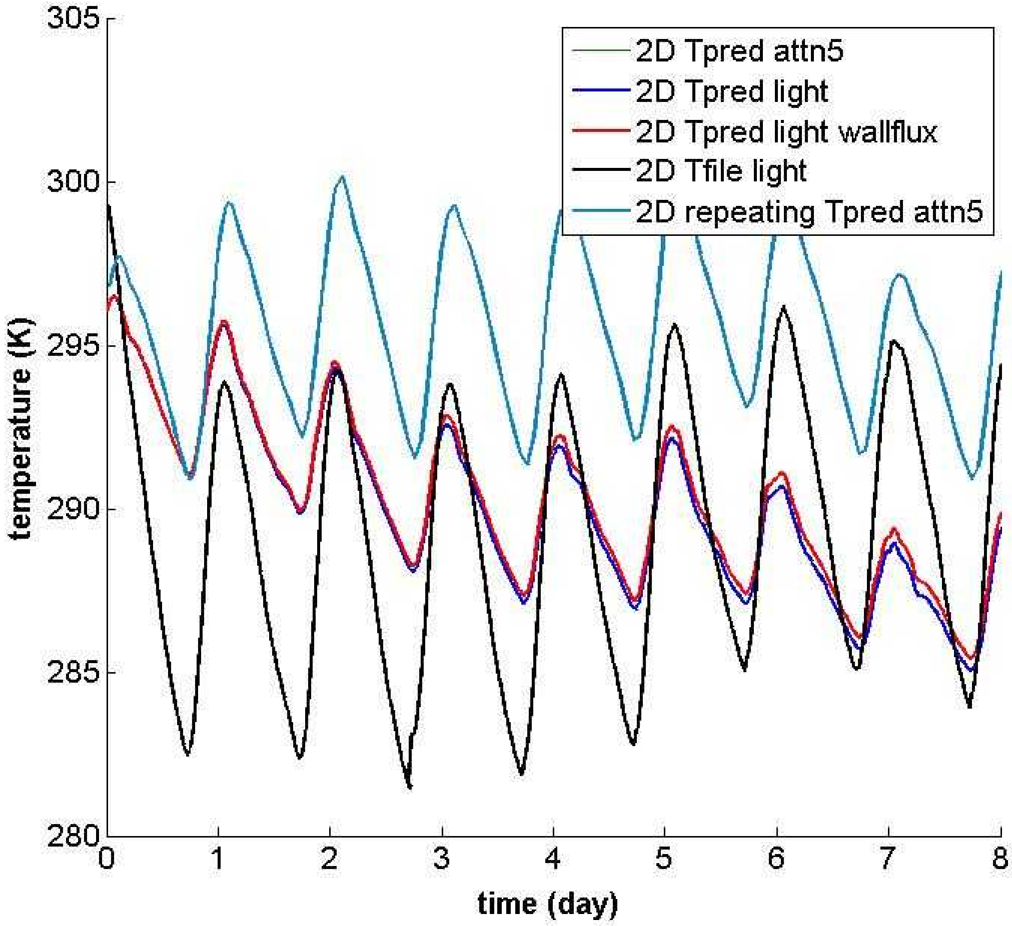
Velocity magnitude at the pond surface (m s^{-1})

Inlet/ Outlet

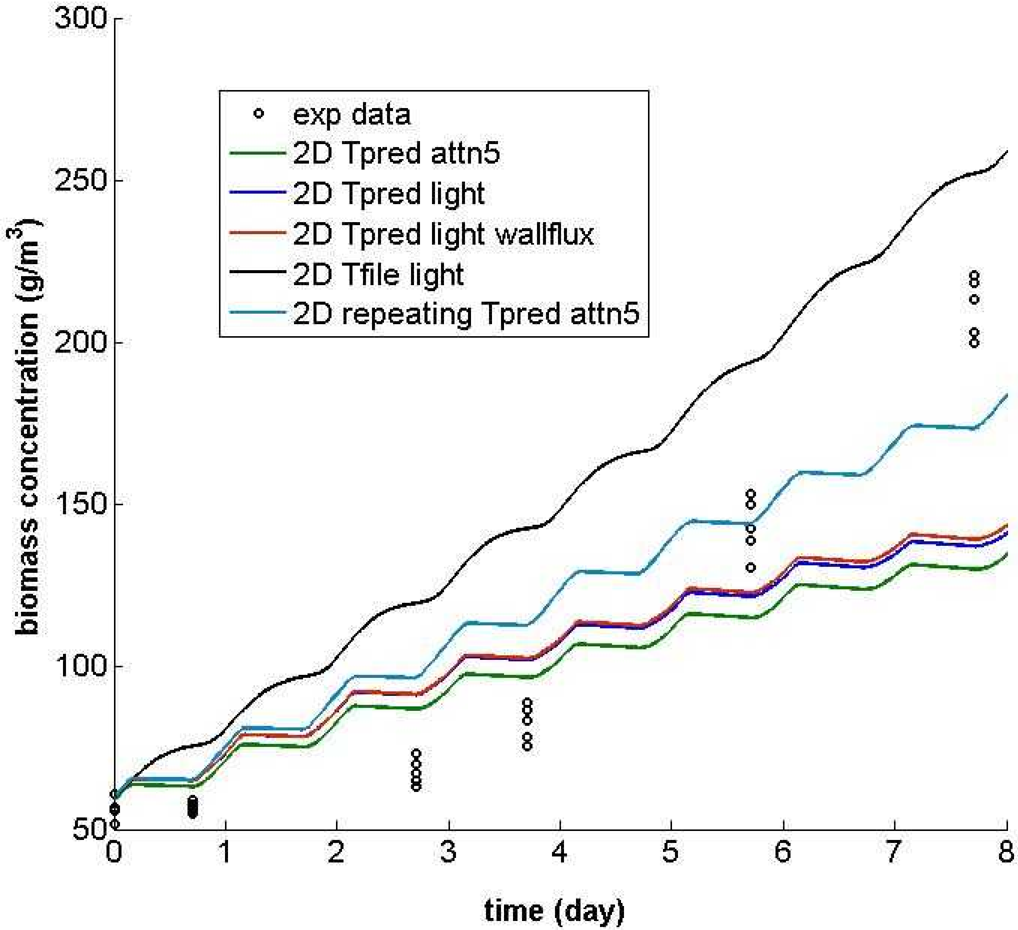


Velocity magnitude at the pond surface (m s^{-1})

Pond Temperature



Biomass Concentration



Conclusions

- Computational modeling is an effective tool in modeling and optimizing algal growth
- 2D models give good results for large ponds
- 3D models are most likely needed to model detailed hydrodynamic and temperature effects in small or well mixed ponds