Improved Ocean Ecosystem Predictions
via Improved Light Calculations
II. Example Results

Curtis Mobley
Sequoia Scientific, Inc.

Fei Chai and Peng Xiu
University of Maine

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ROMS 3D Channel Geometry

Example simulations of an idealized upwelling-downwelling system

- 40 km along-channel
- 80 km cross-channel
- 26-150 m deep
- 40 along-channel cells
- 80 cross-channel cells
- 16 depth layers

periodic along-channel boundary conditions
Simulation Options

We have 2 sky conditions:

S1: 24 hour average sky irradiance (obtained from the diurnal RADTRAN values of S2 runs)

S2: diurnal sky irradiance with above-surface irradiance computed by RADTRAN

We have 2 in-water heating profiles:

H1: use Paulson & Simpson in-water attenuation model

H2: use EcoLight in-water attenuation (400-1000 nm)

We have 2 in-water biology profiles:

B1: use original CoSiNE in-water attenuation model

B2: use Ecolight in-water attenuation (400-700 nm)

We have 3 chlorophyll levels (or maybe just low and high to start):

CL: low Chl: max Chl value <0.5 mg/m3

CM: medium Chl: max values of 1 or 2

CH: high Chl: max Chl ~5 mg/m3

Runs we want to make (and file name ID) for each chlorophyll level (Cx = CH to start):

<table>
<thead>
<tr>
<th>Run</th>
<th>Models</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1_H1_B1_Cx</td>
<td>this is the “old” way of doing everything (24 hour average light)</td>
</tr>
<tr>
<td>2</td>
<td>S2_H1_B1_Cx</td>
<td>diurnal light but analytic heating and biology equations</td>
</tr>
<tr>
<td>3</td>
<td>S2_H1_B2_Cx</td>
<td>diurnal light, Ecolight biology, but no feedback from biol to heating</td>
</tr>
<tr>
<td>4</td>
<td>S2_H2_B2_Cx</td>
<td>diurnal light, EcoLight biology, EcoLight heating,</td>
</tr>
</tbody>
</table>
Example Sequence of Temperature & Current Cross-sections
Example Sequence of Temperature & Current Cross-sections
Example Sequence of Temperature & Current Cross-sections

Day 0.0: Temp [deg C] and Current [cm s$^{-1}$]

Day 1.5: Temp [deg C] and Current [cm s$^{-1}$]

Day 7.5: Temp [deg C] and Current [cm s$^{-1}$]
Example Sequence of Temperature & Current Cross-sections
Example Sequence of Chlorophyll Cross-sections

initial Chl = 0.25 mg m$^{-3}$
Example Sequence of Chlorophyll Cross-sections
Example Sequence of Chlorophyll Cross-sections
Example Sequence of NO$_3$ Cross-sections
Example Sequence of NO$_3$ Cross-sections
Example Sequence of $\text{NO}_3$ Cross-sections

Day 0.0: $\text{NO}_3$ [mmol m$^{-3}$]

Day 7.5: $\text{NO}_3$ [mmol m$^{-3}$]

Day 14.5: $\text{NO}_3$ [mmol m$^{-3}$]
Note that Chlorophyll and Carbon do not have exactly the same spatial pattern.

C:Chl ratio varies with light conditions and nutrients. Photosynthesis in this case is light, temp & nutrient driven. In this case, Chl/cell is higher at lower light (at depth) due to photoadaptation.
Question: Does it matter if you use the 24-hour-average irradiance vs. diurnal irradiance to heat water and grow phytoplankton?

Note: For this sky (30% overcast), the ratio of $E(400-700)/E(400-1000)$ is 0.65, not the commonly used 0.46.
- Daily-average vs diurnal incident irradiance
- Analytic biology and heating models

- High Chl case
- Radtran diurnal sky irradiances
- 24-hr averages from Radtran values

The heating isn’t much different, but the biology is much different because of how photosynthesis responds to the P-E curve
• Same heating
• Different biology
• Biology affects E(400-700) but not heating.

• Pauson and Simpson for heating
• Analytic vs Ecolight for biology.

• High Chl case.

• The biology changes because of the different PAR(z)
• Same biology
• Different heating

• Ecolight for biology
• Paulson and Simpson vs EcoLight for heating.

• High Chl case
• Heating changes because EcoLight E(z, 400-1000) responds to changing IOP(z), P&S doesn’t

• The biology changes because the different heating changes the upper ocean mixing
• Different biology
• Different heating
• No coupling between biology and heating vs full coupling (biology affects heating and heating affects biology)

• Analytic biology & heating vs EcoLight Biology & heating

• High Chl case

• Biology and heating are significantly different
• What is the computational cost of using EcoLight?

• 143 minutes total run time (1 processor) for Analytic biology and heating

• 170 minutes total run time (1 processor) for EcoLight biology and heating

• Only a 19% increase to do light right
Nutrients for the high Chl run

Nutrients [mmol m$^{-3}$]; S2_H2_B2_CH

Day 0.0

Day 7.5

Day 14.5

File: June2012Runs\June21\ocean_his_S2_H2_B2_CH.nc
Chl and Carbon, Analytic vs EcoLight for high Chl run

Note: Fixing C is the first level of ecosystem response; Chl is not the true measure of phytoplankton biomass
Other EcoLight-S Advantages

Even for runs where the individual analytic $E(400-700)$ and $E(400-1000)$ light models give good results, there are other advantages to using EcoLight.

- EcoLight output includes $R_{rs}(\lambda)$, $E_d(z, \lambda)$, $E_u(z, \lambda)$, $L_u(z, \lambda)$, which are not available from simple light models. These quantities can be used to validate ecosystem predictions using remote sensing or in-water data from moorings, gliders, etc.

- EcoLight $R_{rs}(\lambda)$ allows for model validation by direct comparison with measured $R_{rs}(\lambda)$, without the intermediate step of converting satellite $R_{rs}(\lambda)$ to chlorophyll for comparison with predicted chl.

- EcoLight $E(400-1000)$ gives consistent light for both heating and biology and couples biology and hydrodynamics.

- EcoLight is valid for all waters: Case 1 or Case 2, shallow or deep.
Evolution of $R_{rs}(\lambda)$ Across the Channel

Day 0.5: S2_H2_B2_CH

$R_{rs}$ at noon of first day:
$R_{rs}$ spectra are very blue for Chl $\approx 0.25$ across the channel
Evolution of $R_{rs}(\lambda)$ Across the Channel

Day 7.5: S2_H2_B2_CH

$R_{rs}$ at noon of day 7:
$R_{rs}$ spectra decreasing and getting greener as Chl increases
Evolution of $R_{rs}(\lambda)$ Across the Channel

Day 14.5: S2_H2_B2_CH

$R_{rs}$ at noon of day 14: $R_{rs}$ spectra are now green in the high Chl downwelling area, still blue in the lower Chl upwelling area.
Evolution of $E_d$ Across the Channel

$E(z)$ at noon of day 1 as computed by EcoLight (solid) and analytic (dashed). Same decay rates across the channel since almost the same low Chl values everywhere, but different rates for EcoLight and analytic models.
Evolution of $E_d$ Across the Channel

Day 7.5

solid: S2_H2_B2_CH

dashed: S2_H1_B1_CH

$E_d(400-700)$ [W m$^{-2}$]
Evolution of $E_d$ Across the Channel

Noon of day 14 has much stronger attenuation for higher Chl values in downwelling area (low $j$ values); EcoLight & analytic models much different

$E_d(400-700) \text{ [W m}^{-2}\text{]}$
• Different ecosystem conditions (nutrient utilization rates, grazing rates, etc.) leading to medium Chl values

• Analytic light vs. Ecolight

• Medium Chl run

• The patterns are somewhat different but the conclusion is the same: proper incorporation of light significantly affects both heating and biology.
• Different ecosystem conditions (nutrient utilization rates, grazing rates, etc.) leading to low Chl values

• Analytic light vs. Ecolight

• LowChl run

• The patterns are somewhat different but the conclusion is the same: proper incorporation of light significantly affects both heating and biology.
Ed Across the Channel for High, Med, Low Chl

Day 14.5

depth [m]

solid: S2_H2_B2_CH
dashed: S2_H1_B1_CH

High Chl
Analytic vs EcoLight

j = 1
j = 10
j = 20
j = 30
j = 40
j = 50
j = 60
j = 70
j = 80

$E_d(400-700) \ [\text{W m}^{-2}]$
$E_d$ Across the Channel for High, Med, Low Chl

Day 14.5

- solid: S2_H2_B2_CM
- dashed: S2_H1_B1_CM

Medium Chl
Analytic vs EcoLight
$E_d$ Across the Channel for High, Med, Low Chl

Day 14.5

Low Chl
Analytic vs EcoLight

solid: S2_H2_B2_CL
dashed: S2_H1_B1_CL
Conclusions

• Use of accurate light calculations makes significant differences in upper-ocean heating, hence in upper ocean stratification and circulation, for a wide range of conditions.

• Use of accurate light calculations makes significant differences in biological constituent concentrations and ecosystem evolution, for a wide range of conditions.

• Use of accurate light calculations increases total run times by only a few tens of percent. There is no longer any excuse for not doing accurate light calculations. Do Light Right!
Acknowledgement

• The development of EcoLight-S and the work presented here were funded by the U.S. Office of Naval Research Ocean Biology and Optics Program via contracts to Curtis Mobley and Fei Chai.

• That program was closed down in 2011. It was good while it lasted.
Looking to the Future

We have a proposal for continued work in review by the NASA Ocean Biogeochemistry Program.

If funded:
We use ROMS-CoSiNE-EcoLight for Pacific Ocean studies.

If not funded:
Curt retires and goes kayaking.

Either way, life is good!

Dodecanese Islands, Greece
Lava Falls, Grand Canyon

Lava Falls is the largest runnable rapid in North America (class V)
Lava Falls, Grand Canyon
Lava Falls, Grand Canyon
Lava Falls, Grand Canyon
Lava Falls, Grand Canyon