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

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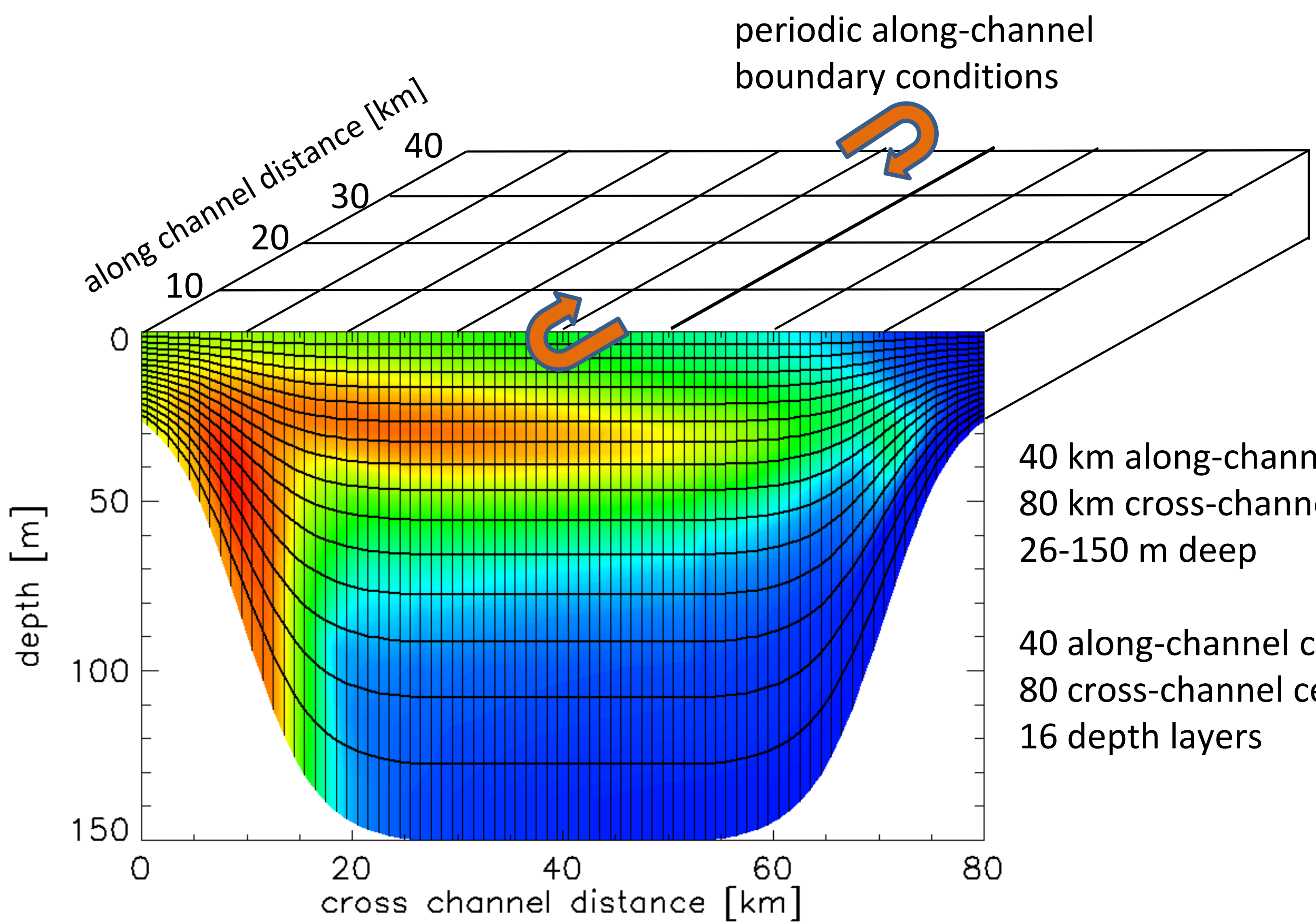
ROMS 3D Channel Geometry

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

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

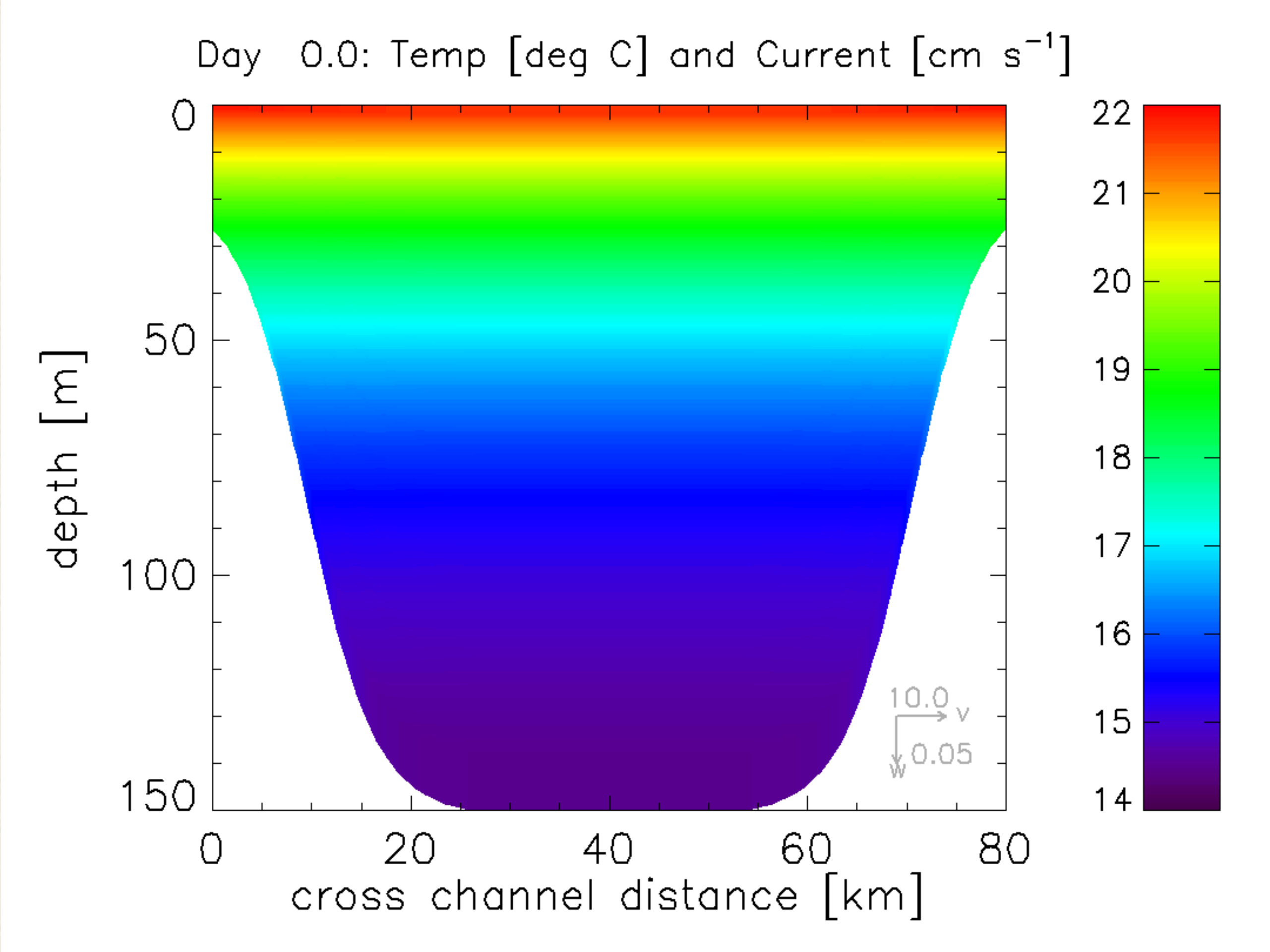
CM: medium Chl: max values of 1 or 2

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

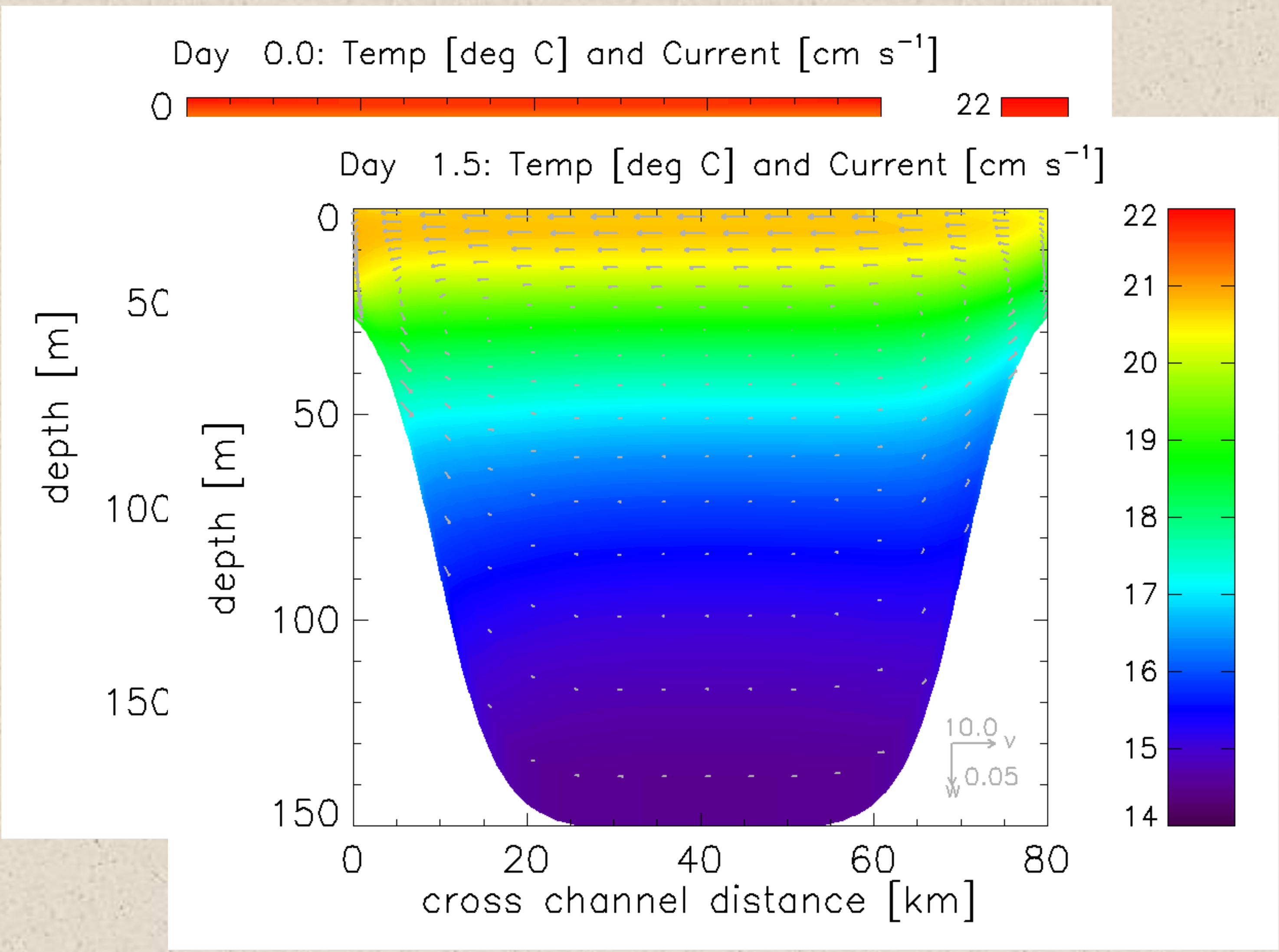
Runs we want to make (and file name ID) for each chlorophyll level (Cx = CH to start):

Run	Models	Comments
1	S1_H1_B1_Cx	this is the "old" way of doing everything (24 hour average light)
2	S2_H1_B1_Cx	diurnal light but analytic heating and biology equations
3	S2_H1_B2_Cx	diurnal light, Ecolight biology, but no feedback from biol to heating
4	S2_H2_B2_Cx	diurnal light, EcoLight biology, EcoLight heating,

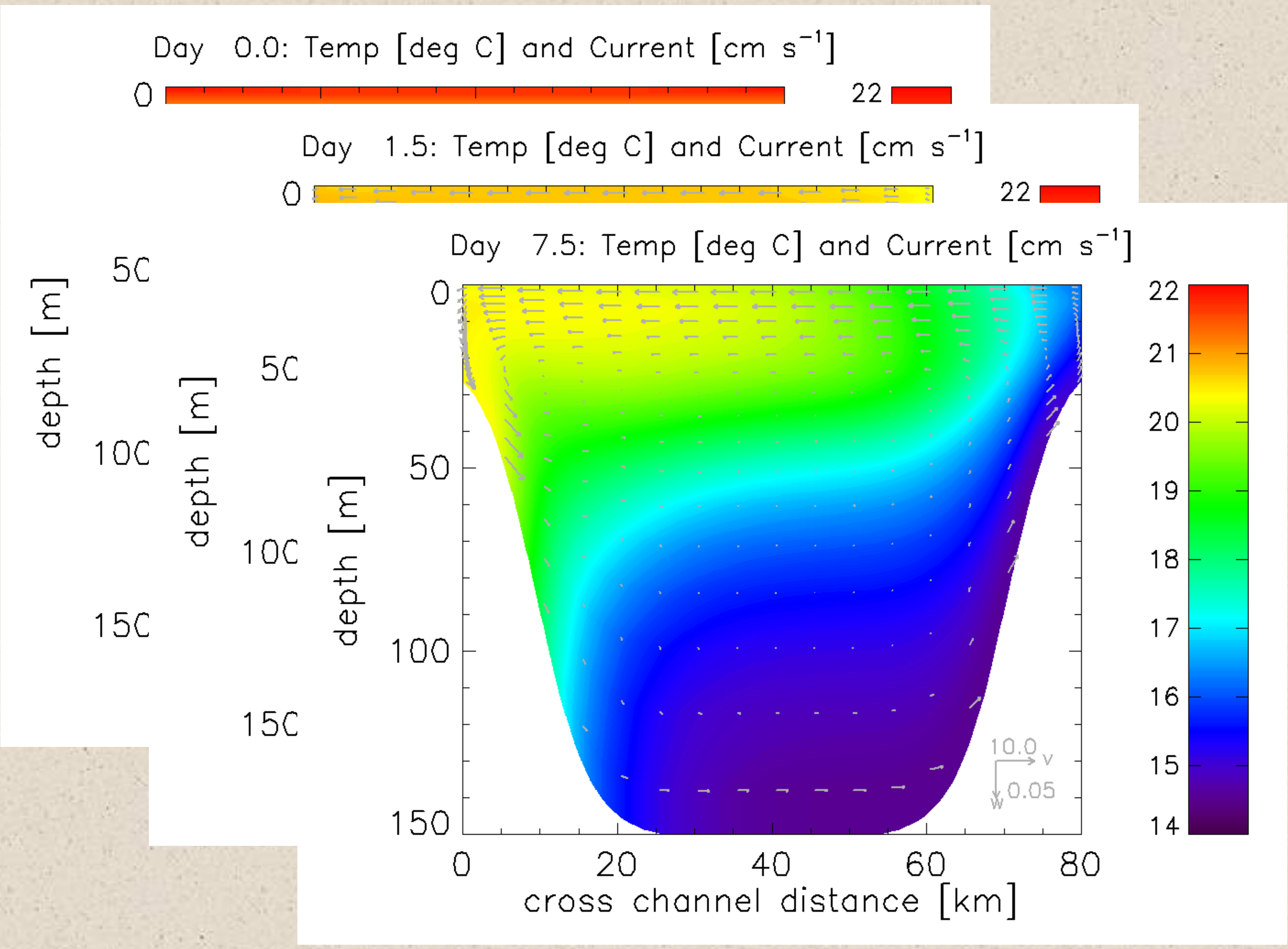
Example Sequence of Temperature & Current Cross-sections



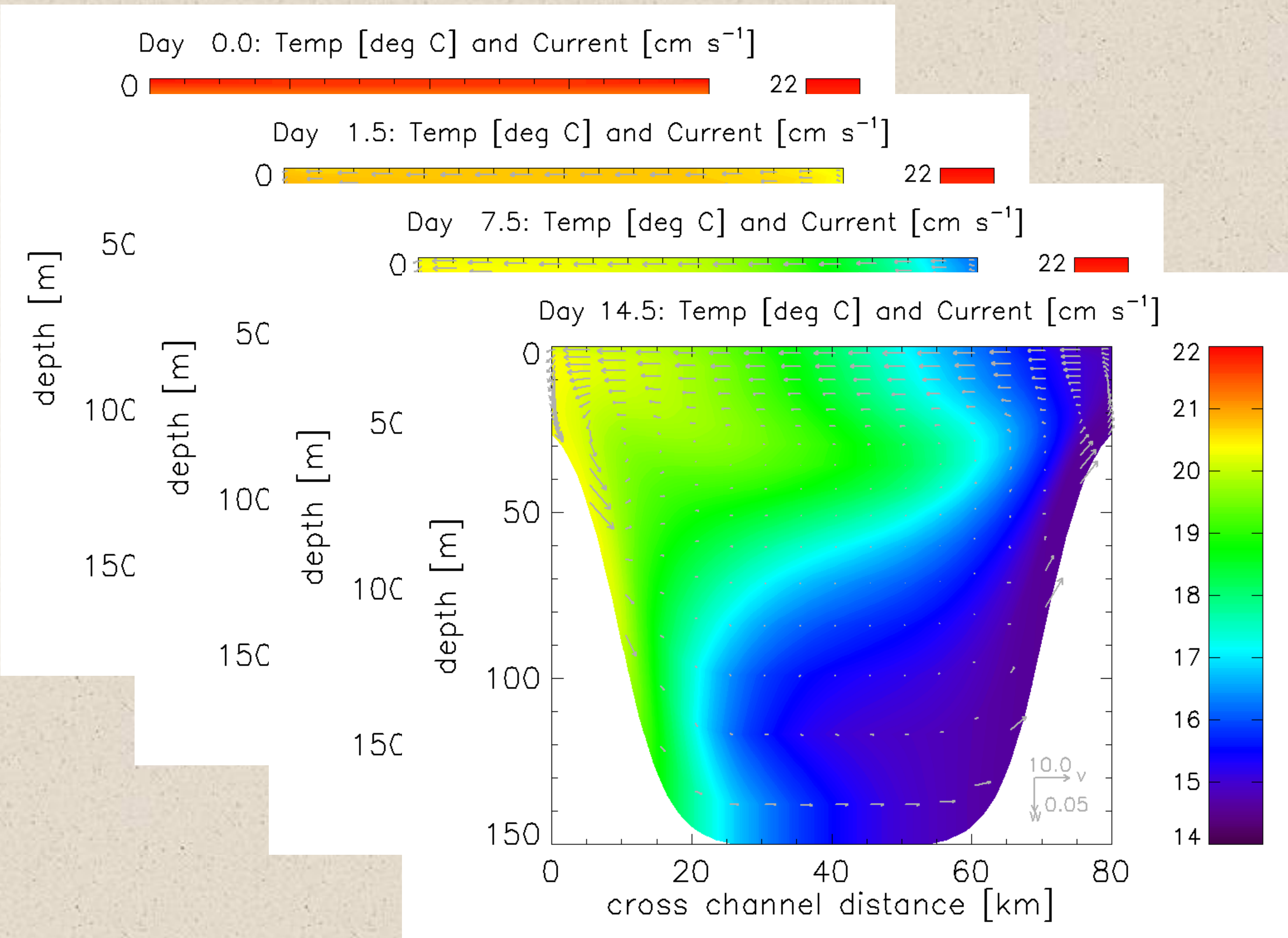
Example Sequence of Temperature & Current Cross-sections



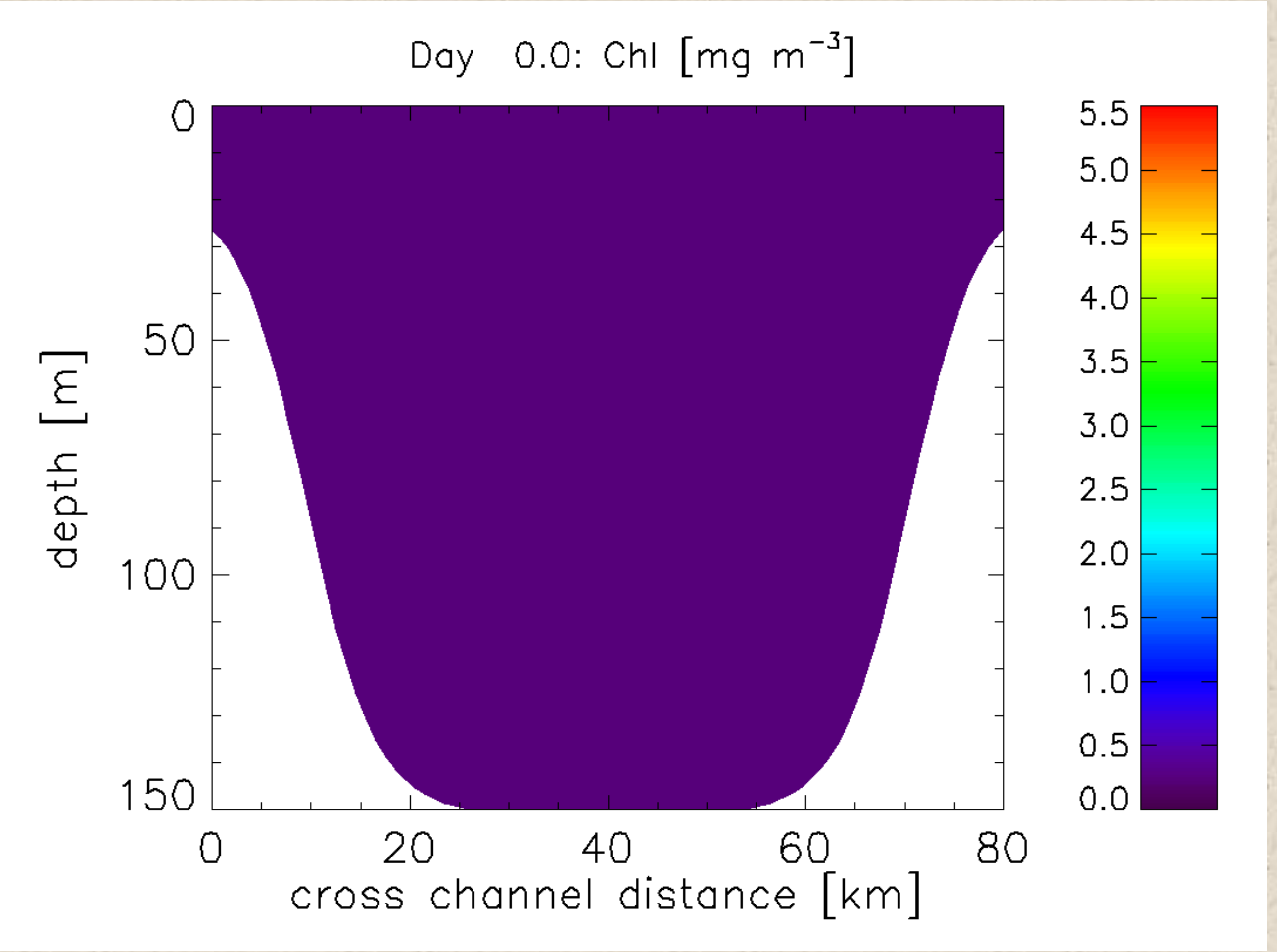
Example Sequence of Temperature & Current Cross-sections



Example Sequence of Temperature & Current Cross-sections

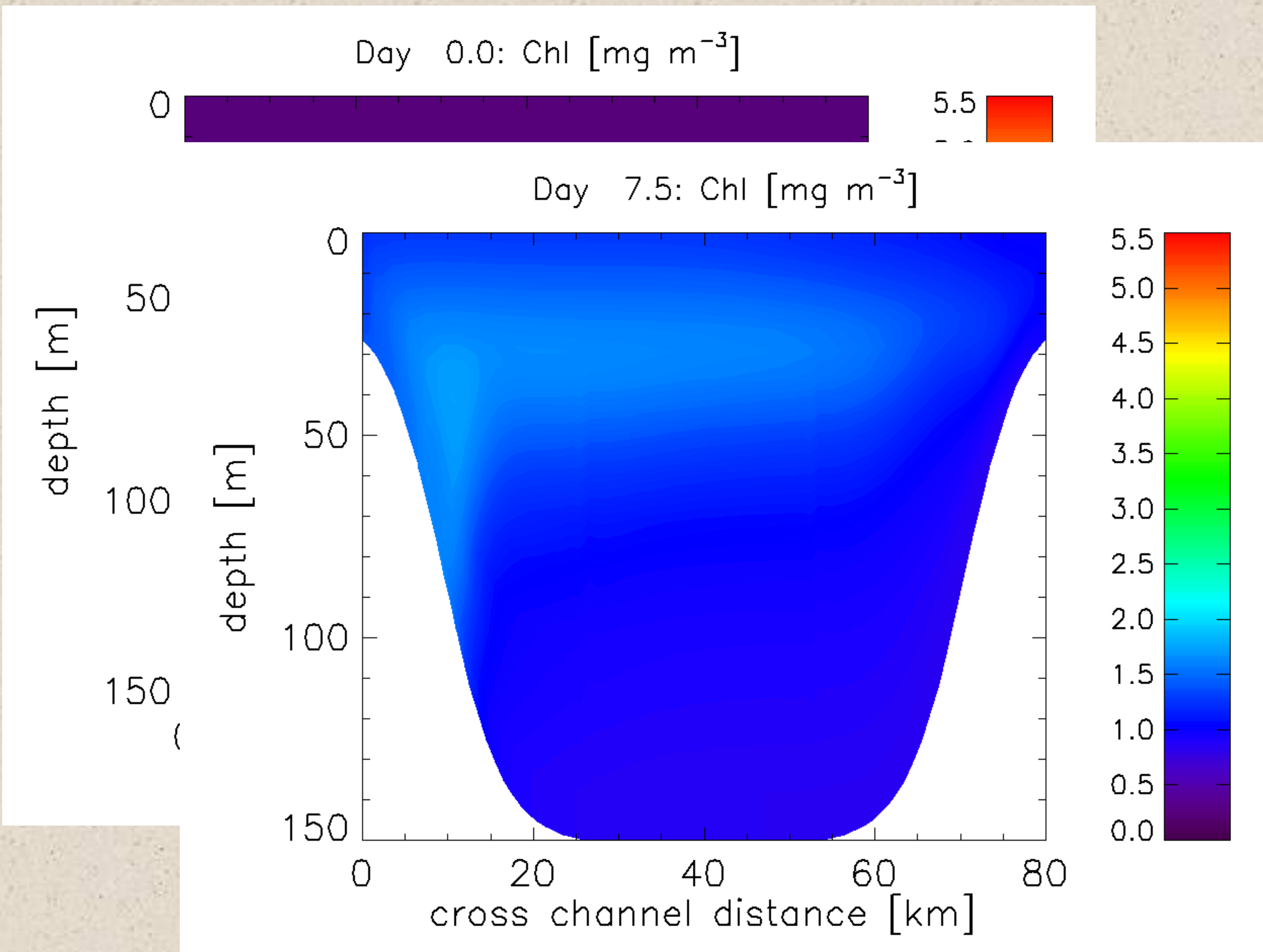


Example Sequence of Chlorophyll Cross-sections

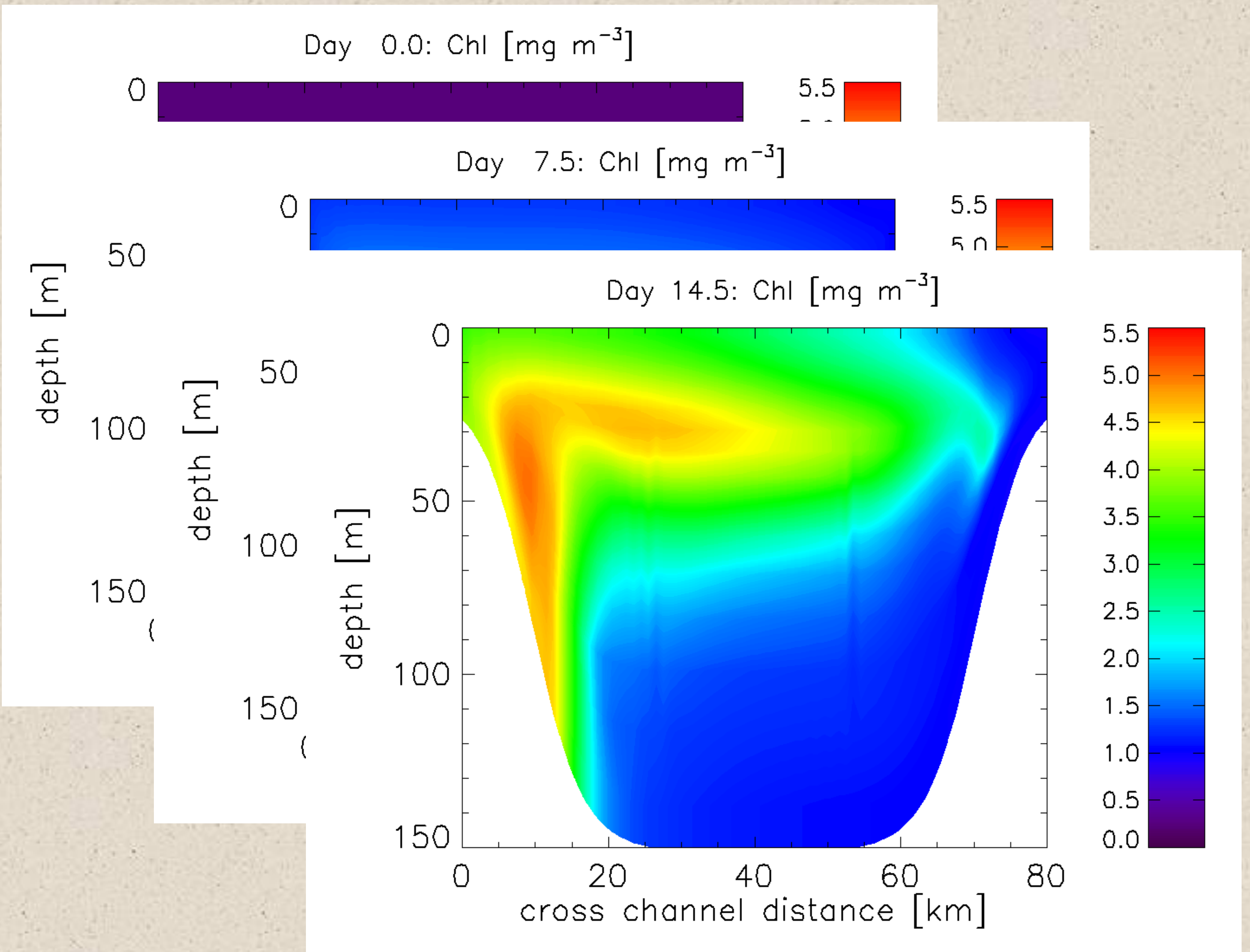


initial Chl = 0.25 mg m^{-3}

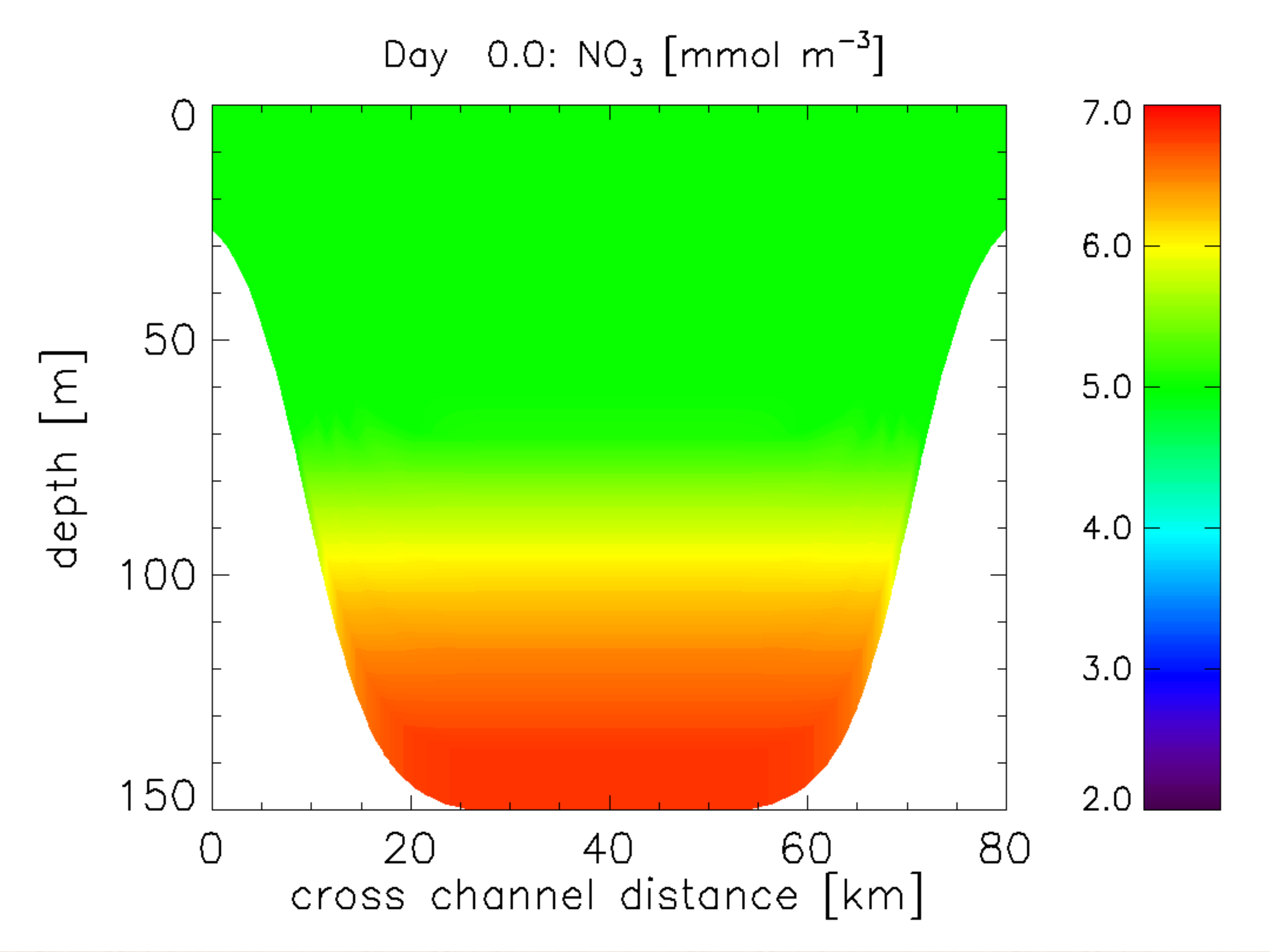
Example Sequence of Chlorophyll Cross-sections



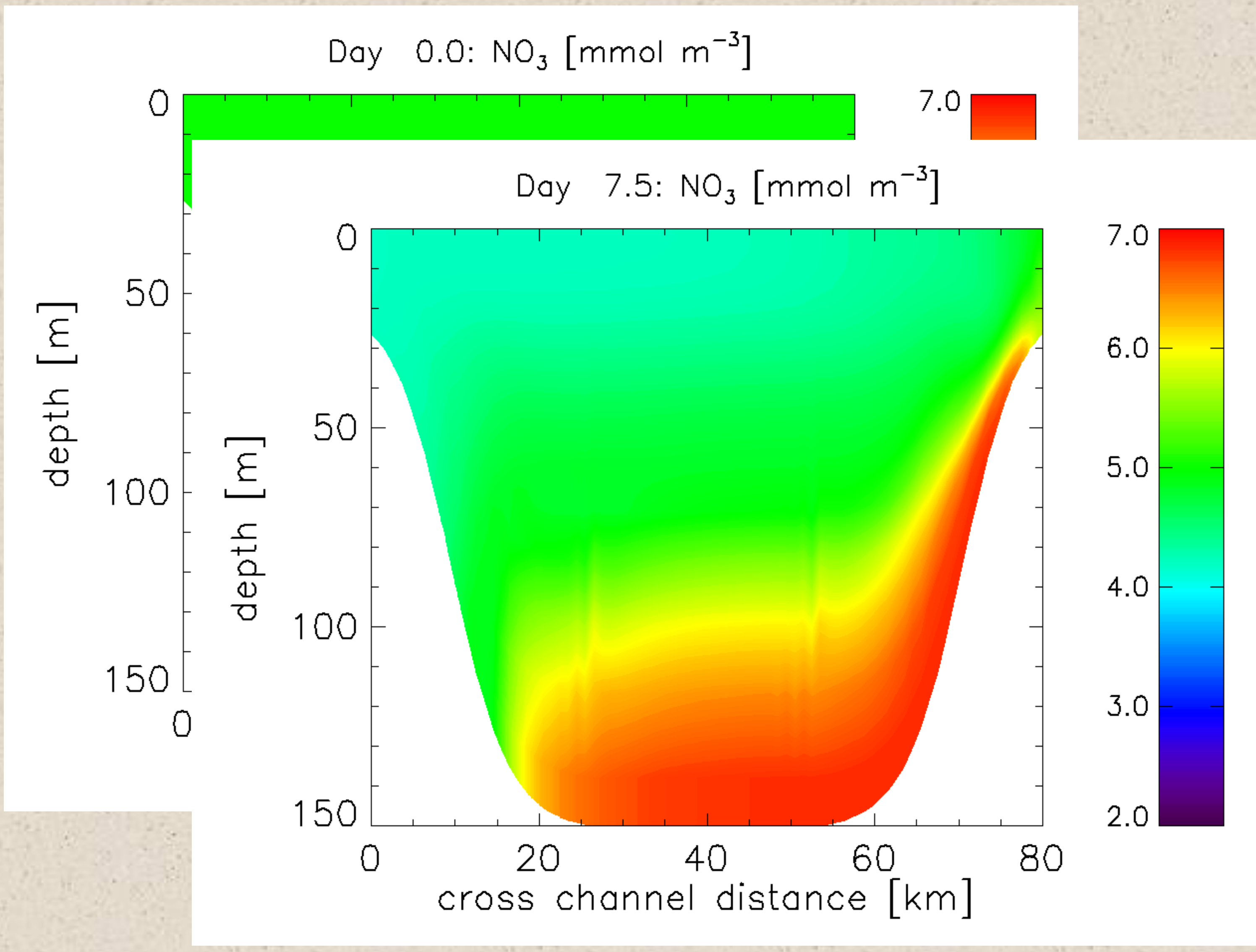
Example Sequence of Chlorophyll Cross-sections



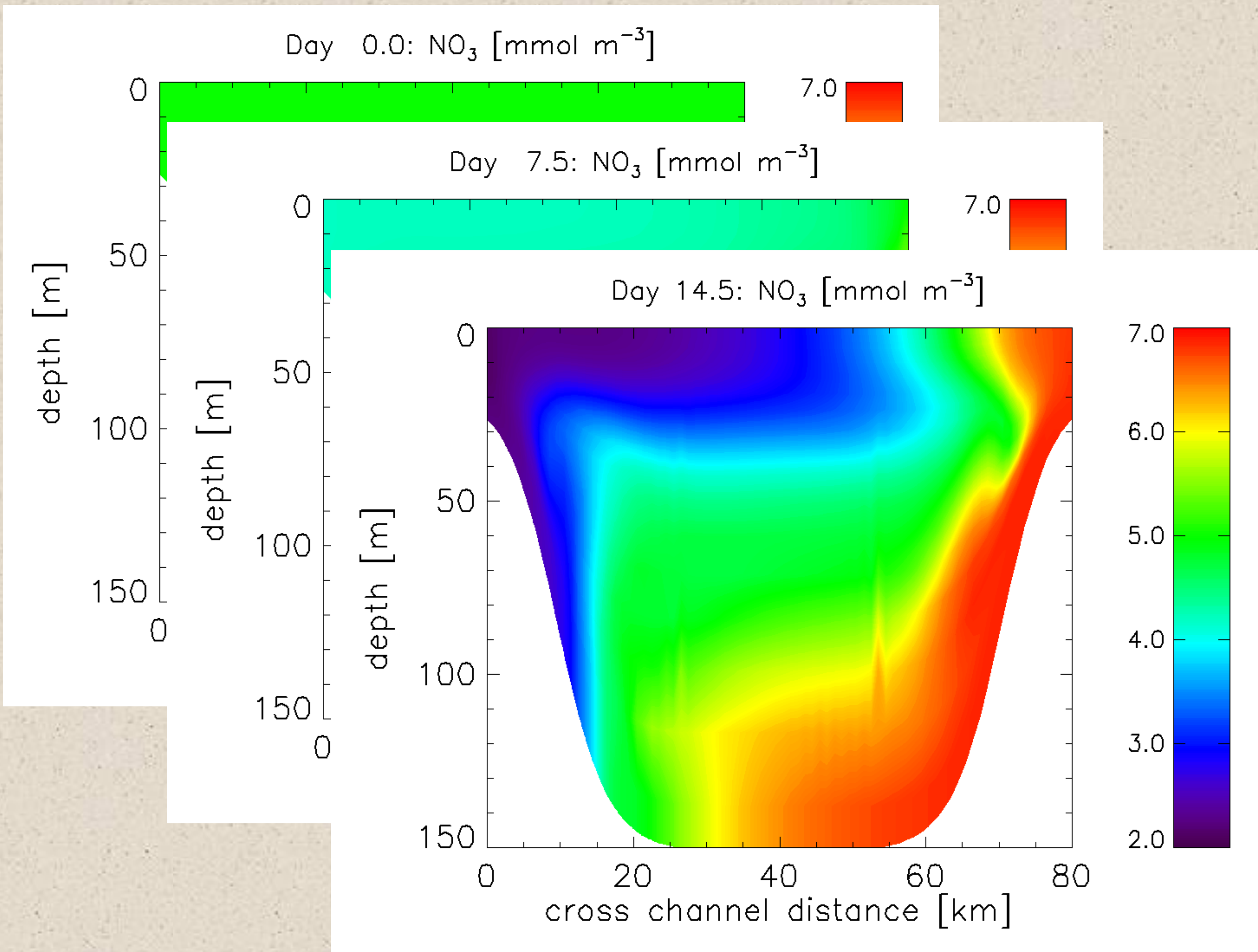
Example Sequence of NO_3 Cross-sections

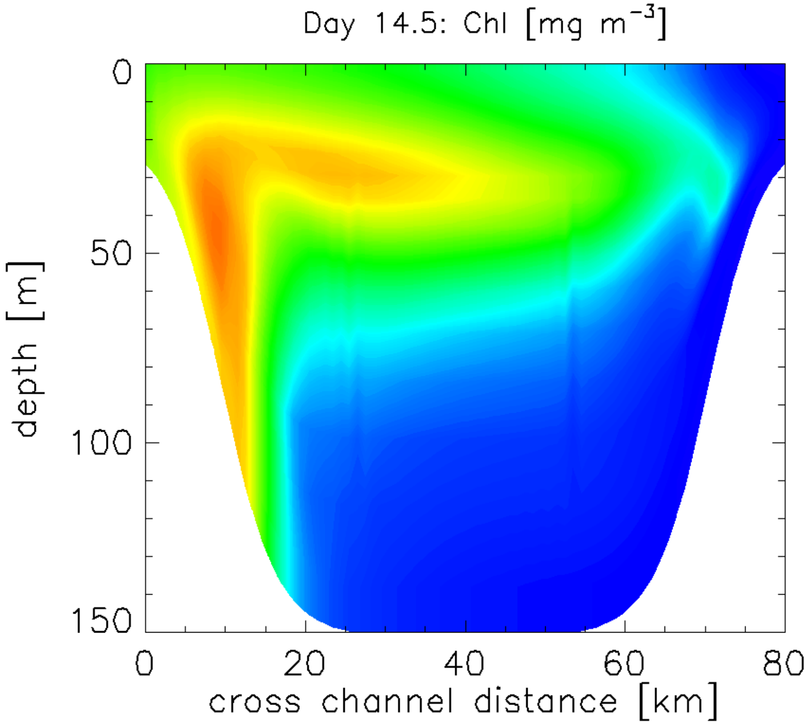


Example Sequence of NO_3 Cross-sections



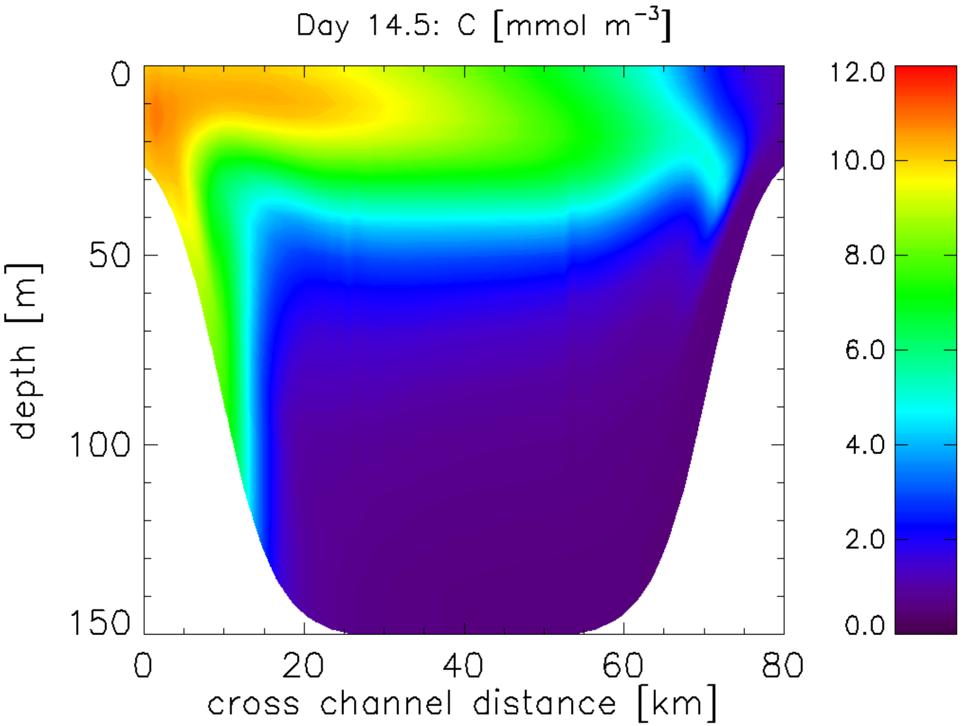
Example Sequence of NO_3 Cross-sections



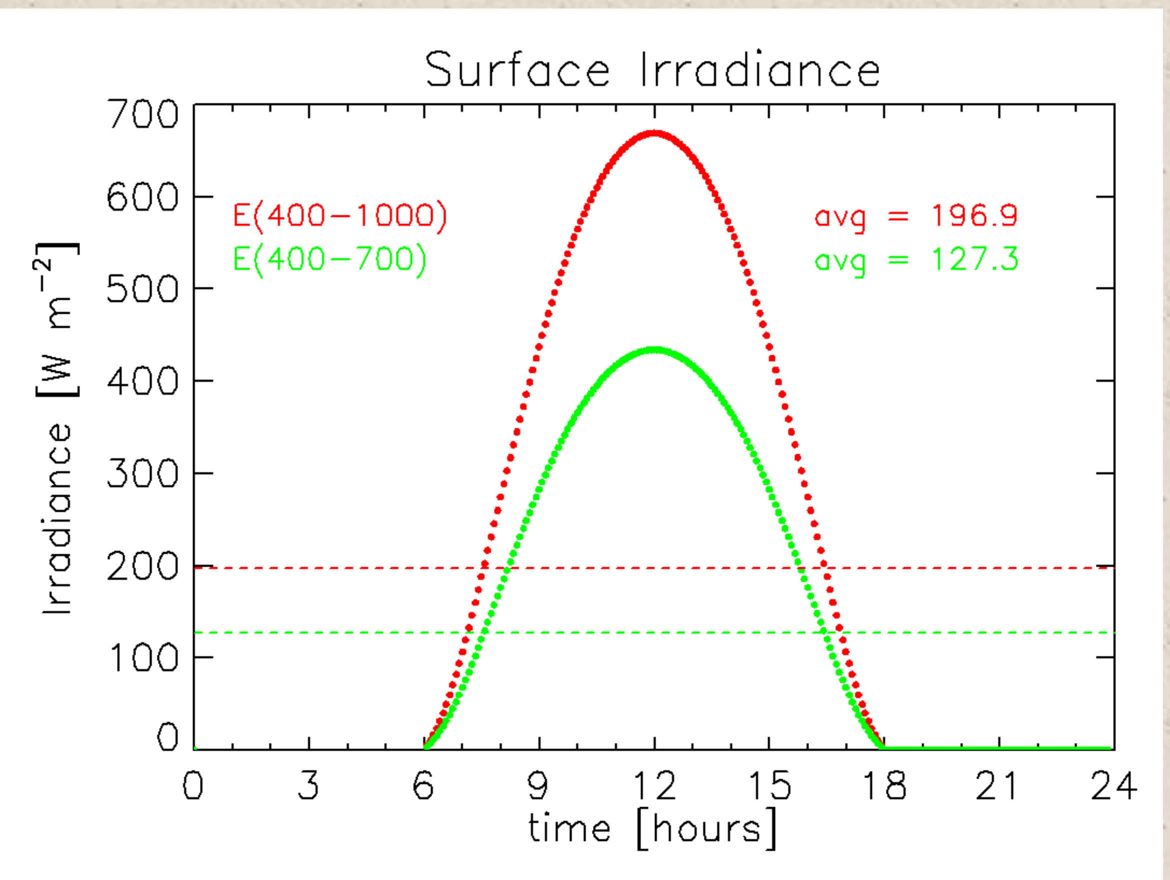


Note that Chlorophyll and Carbon do not have exactly the same spatial pattern

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?

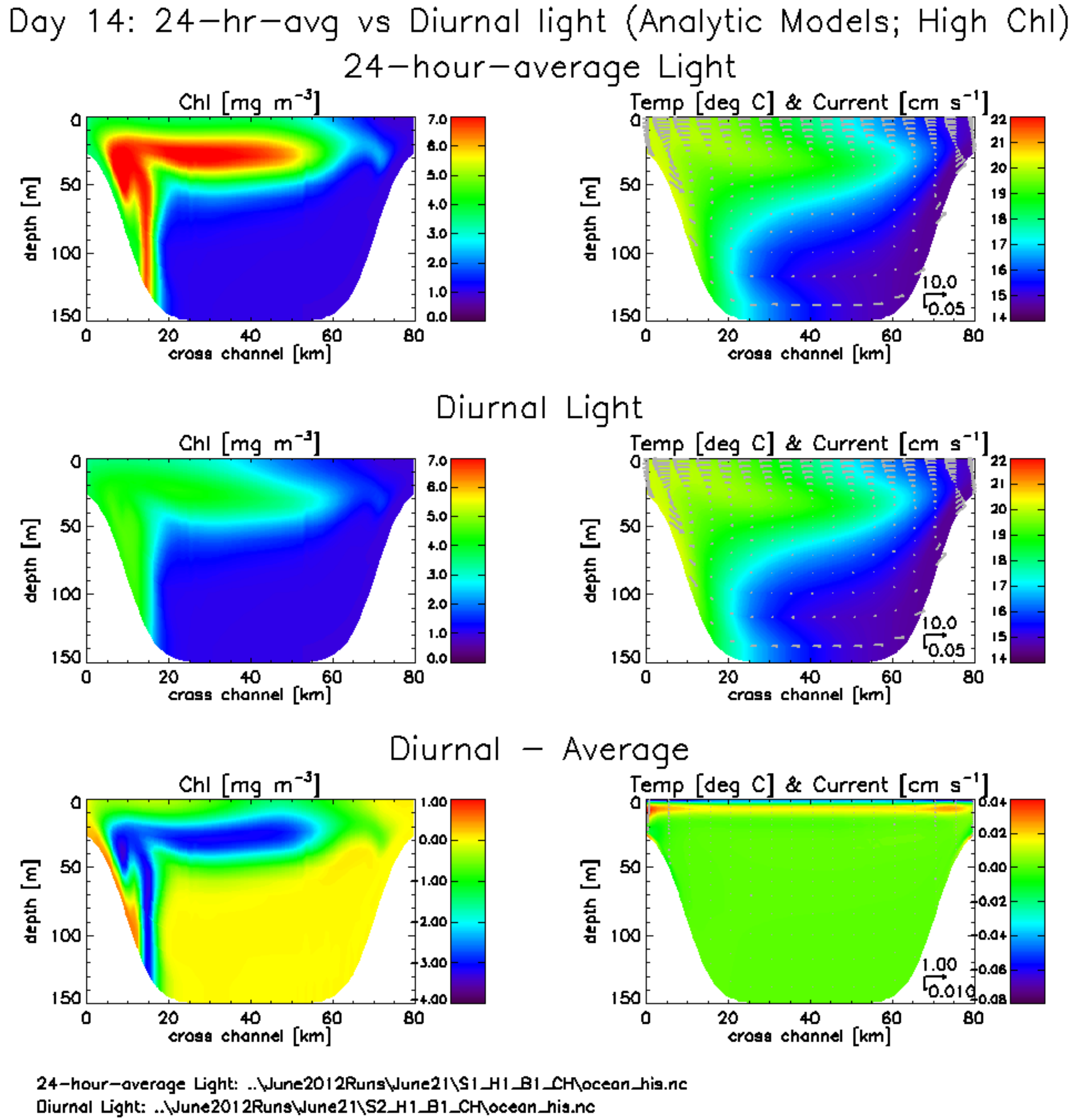


Note: For this sky (30% overcast), the ratio of E(400-700)/E(400-1000) is 0.65, not the commonly used 0.46.

• 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

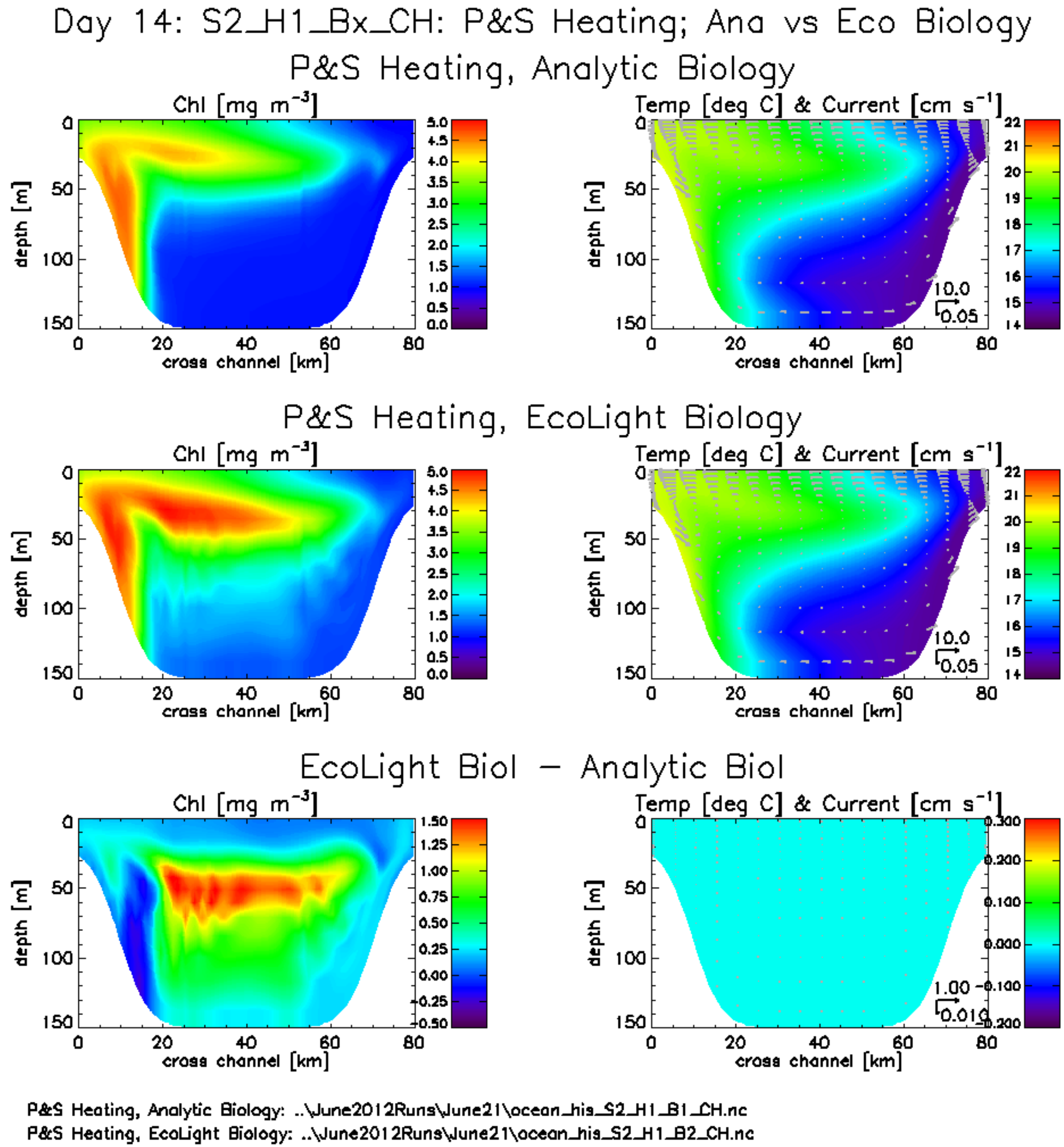


- Same heating
- Different biology
- Biology affects E(400-700) but not heating.

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

- High Chl case.

- The biology changes because of the different PAR(z)



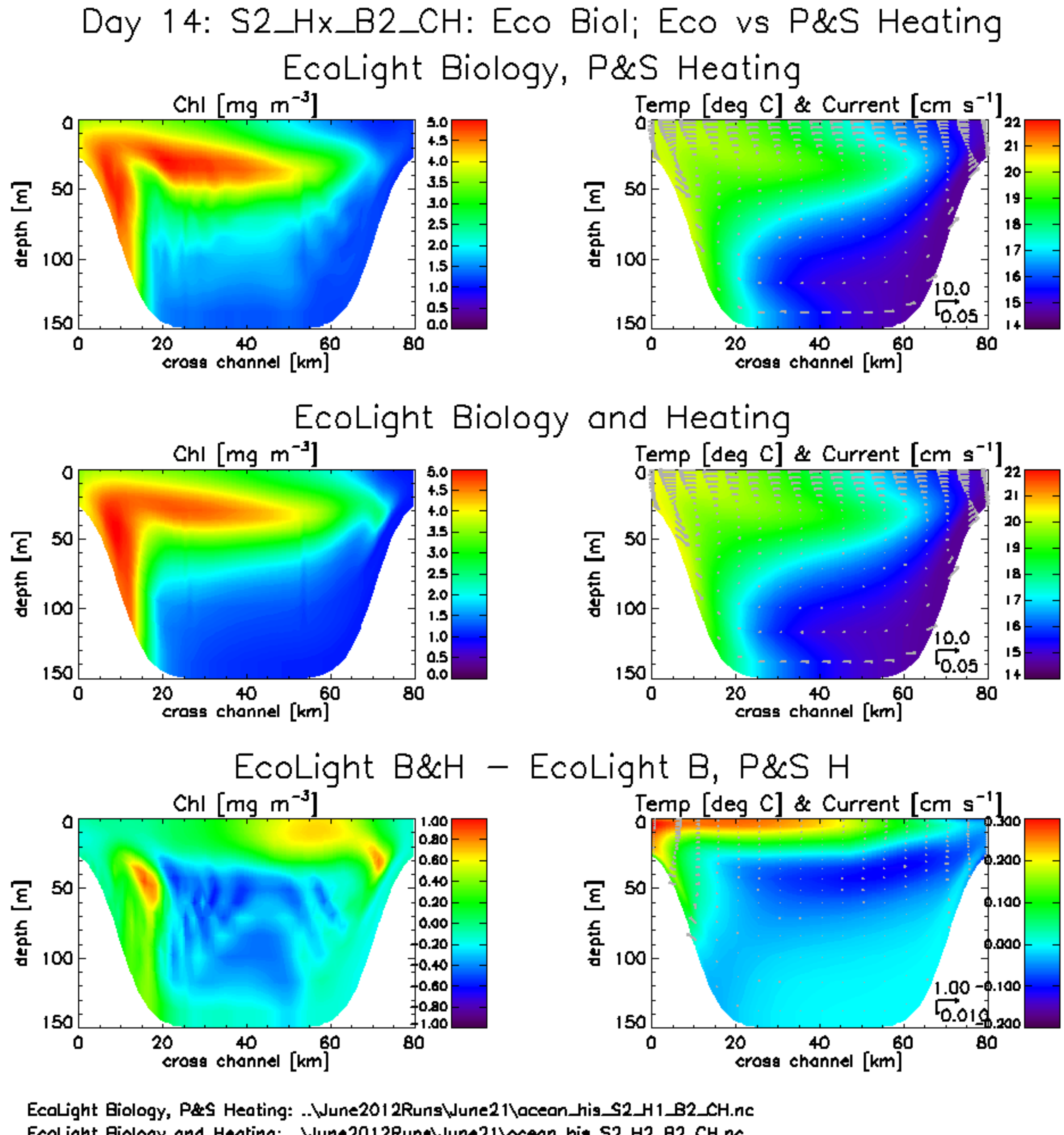
- Same biology
- Different heating

- 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

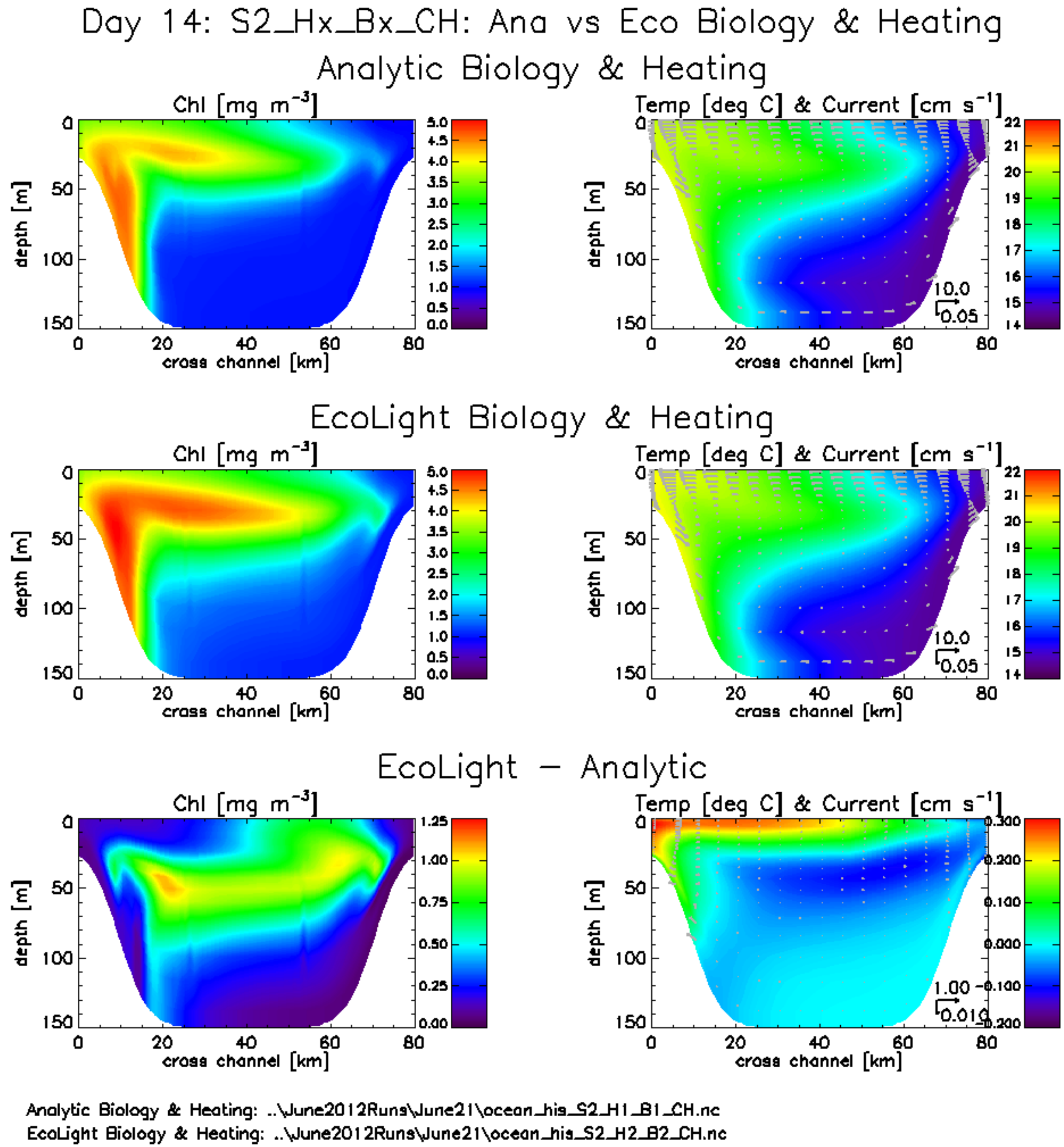


- Different biology
- Different heating
- No coupling between biology and heating vs full coupling (biology affects heating and heating affects biology)

- Analytic biology & heating vs EcoLight Biology & heating

- High Chl case

- Biology and heating are significantly different

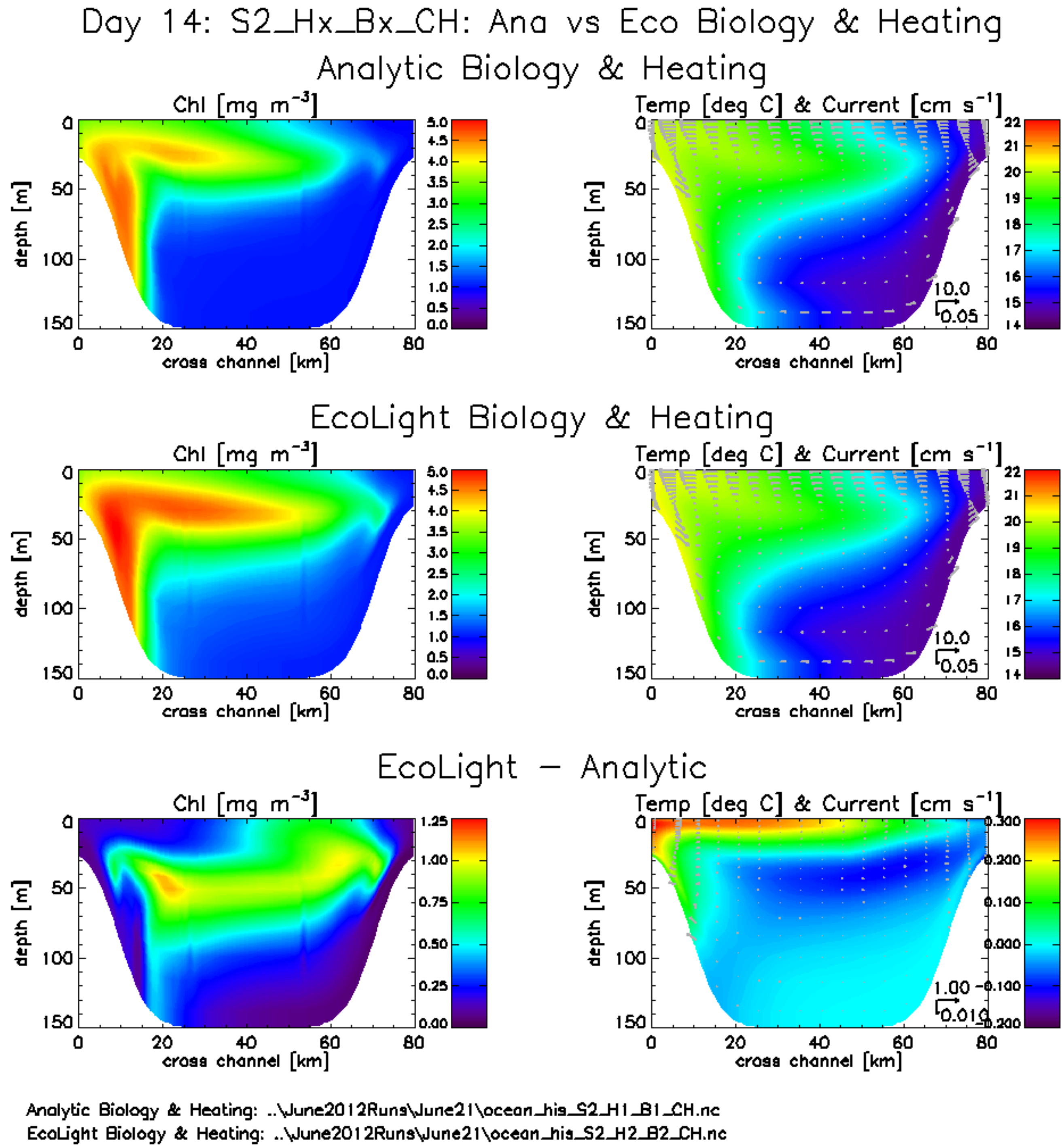


• What is the computational cost of using EcoLight?

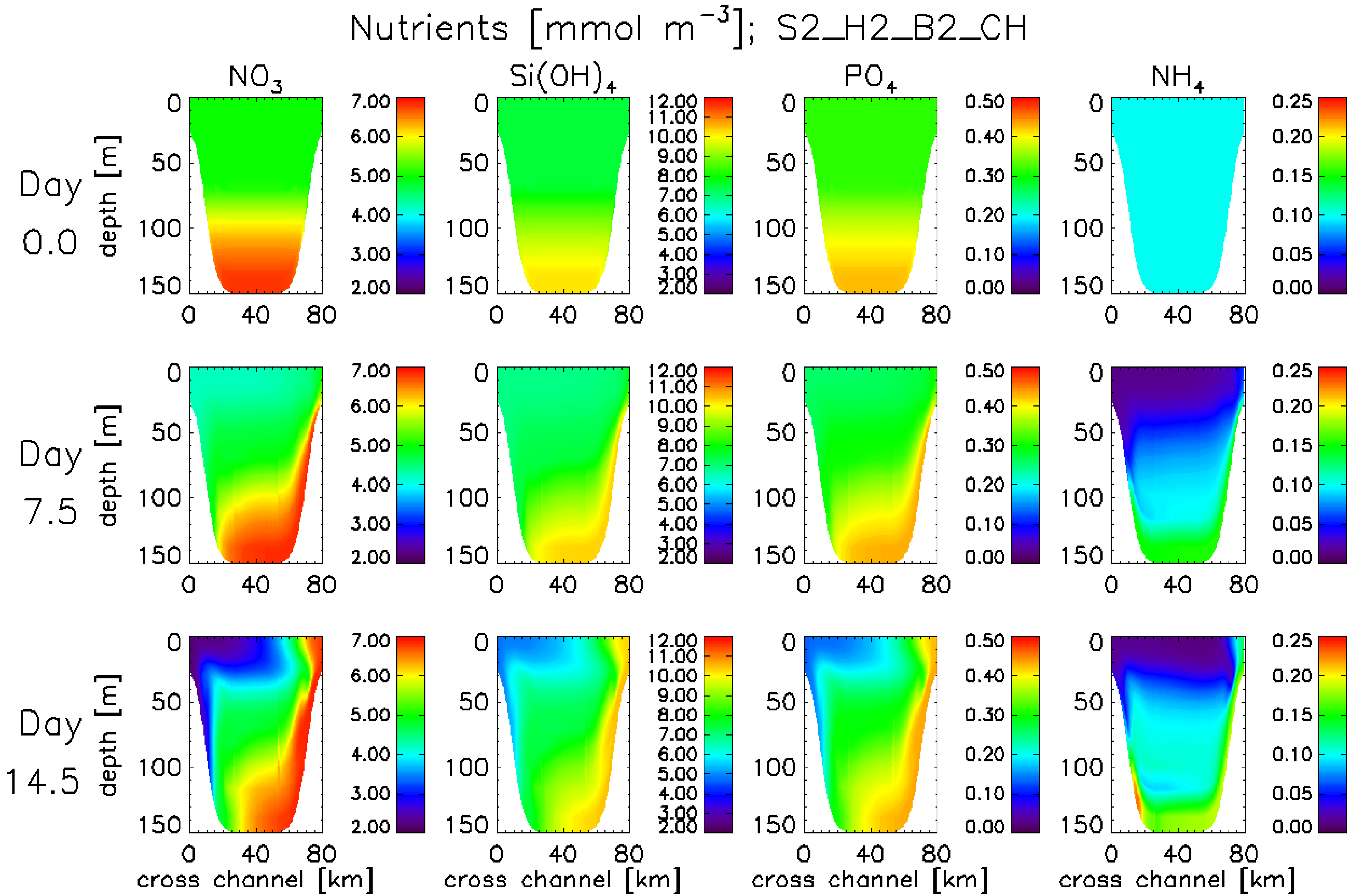
• 143 minutes total run time (1 processor) for Analytic biology and heating

• 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



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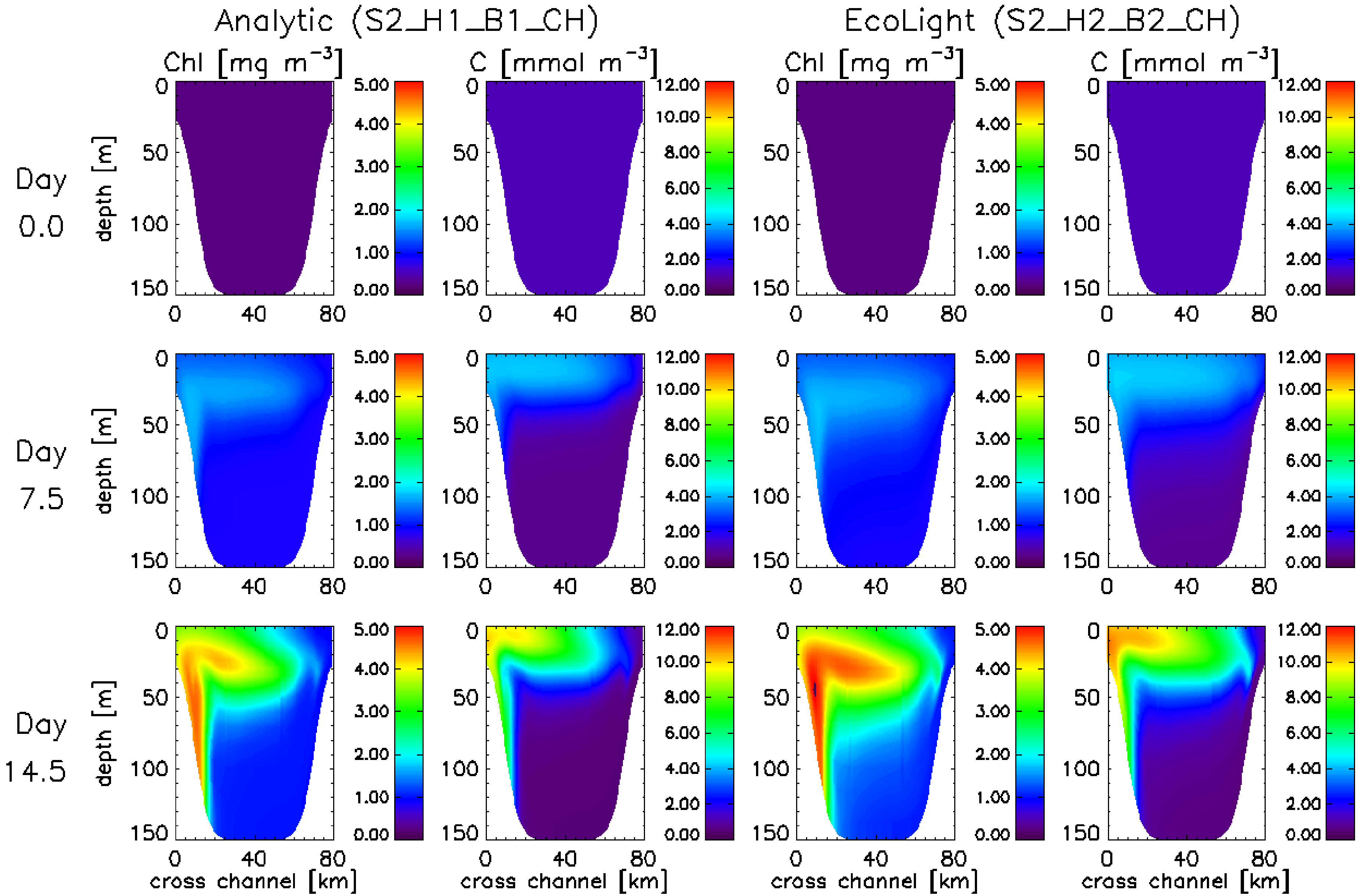
Chl and Carbon, Analytic vs EcoLight for high Chl run



File Left: ..\June2012Runs\June21\ocean_his_S2_H1_B1_CH.nc
File Right: ..\June2012Runs\June21\ocean_his_S2_H2_B2_CH.nc

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.

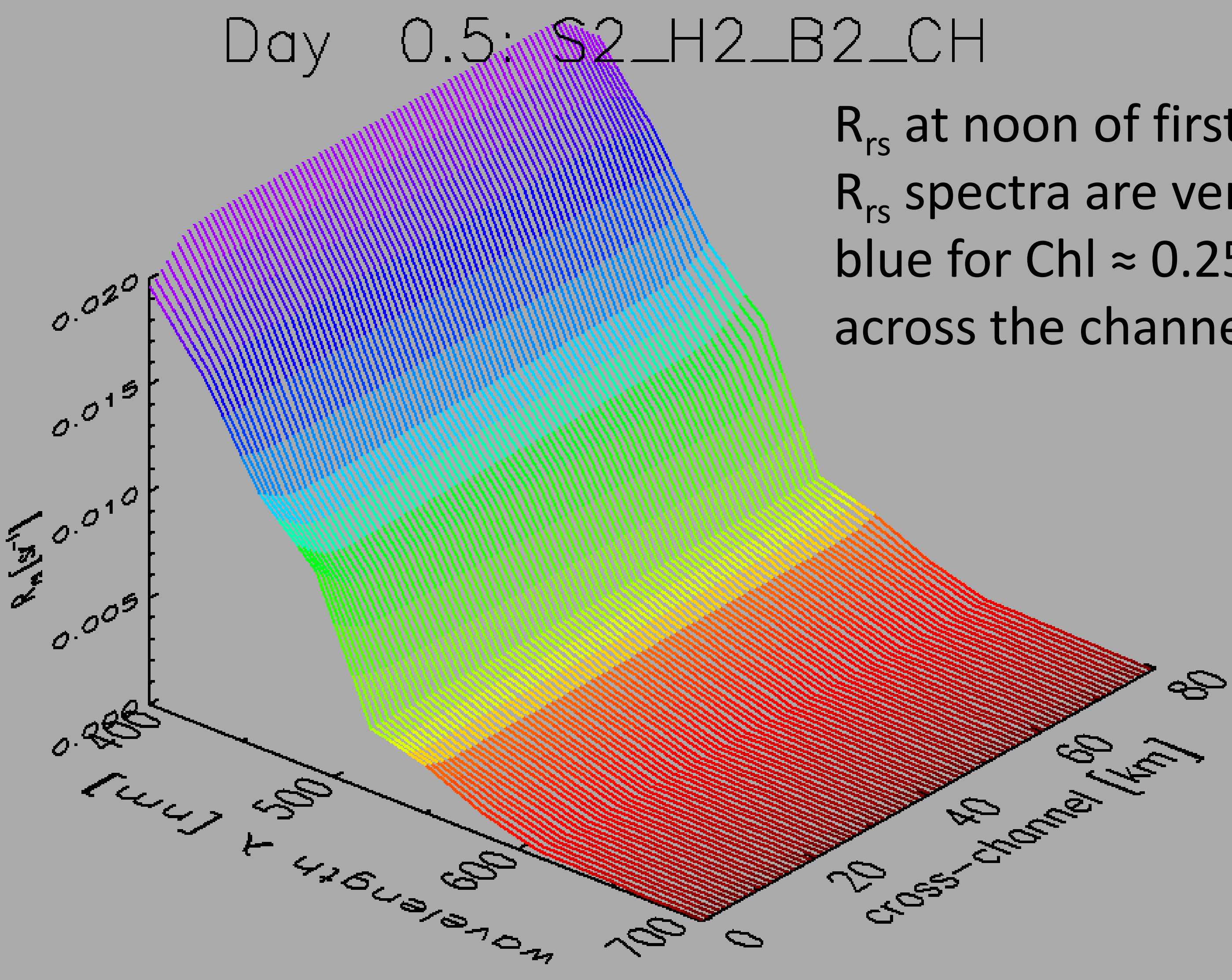
- EcoLight output includes $R_{rs}(\lambda)$, $E_d(z, \lambda)$, $E_u(z, \lambda)$, $L_u(z, \lambda)$, which are not available from simple light models. These quantities can be used to validate ecosystem predictions using remote sensing or in-water data from moorings, gliders, etc.

- 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

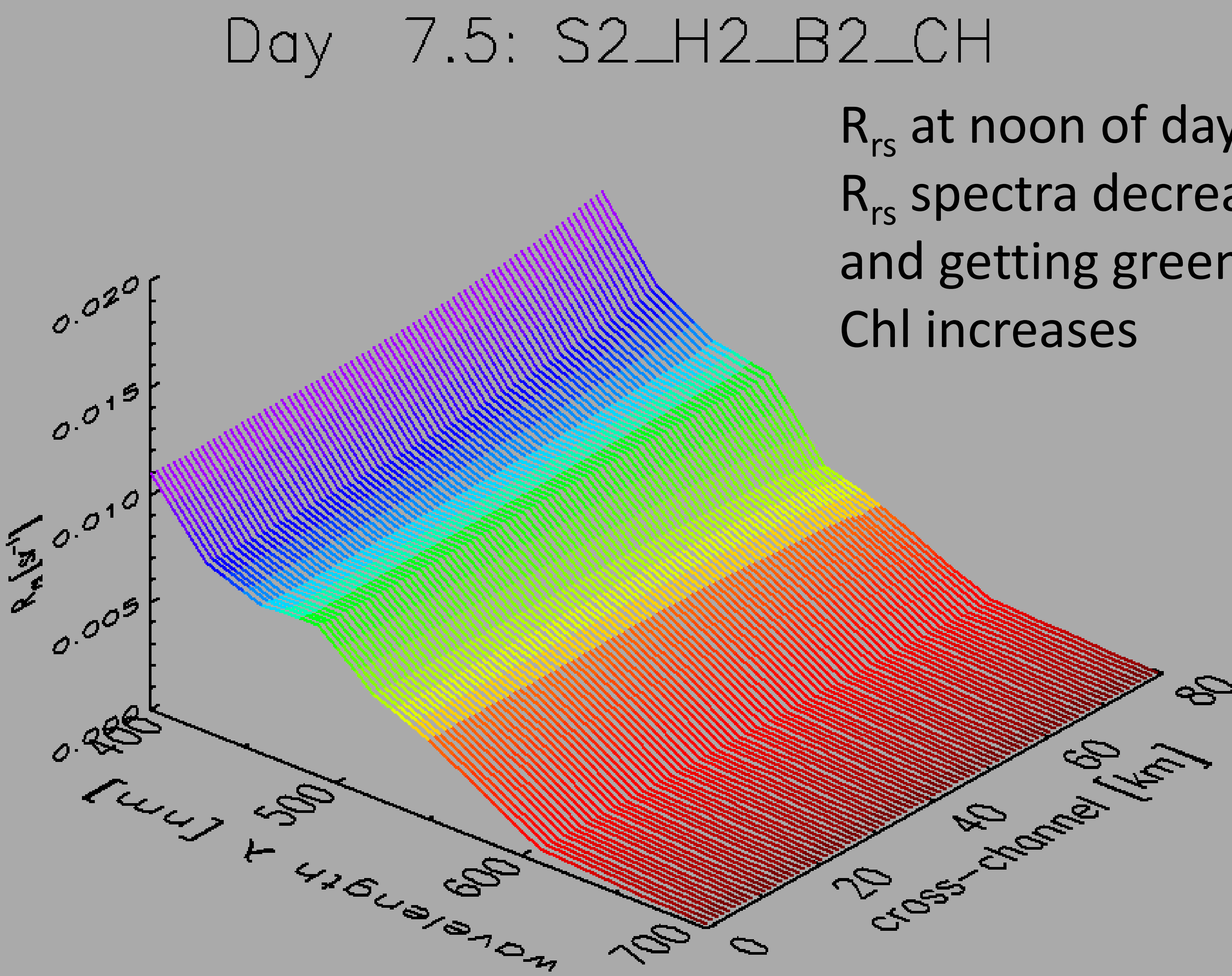
- EcoLight is valid for all waters: Case 1 or Case 2, shallow or deep

Evolution of $R_{rs}(\lambda)$ Across the Channel



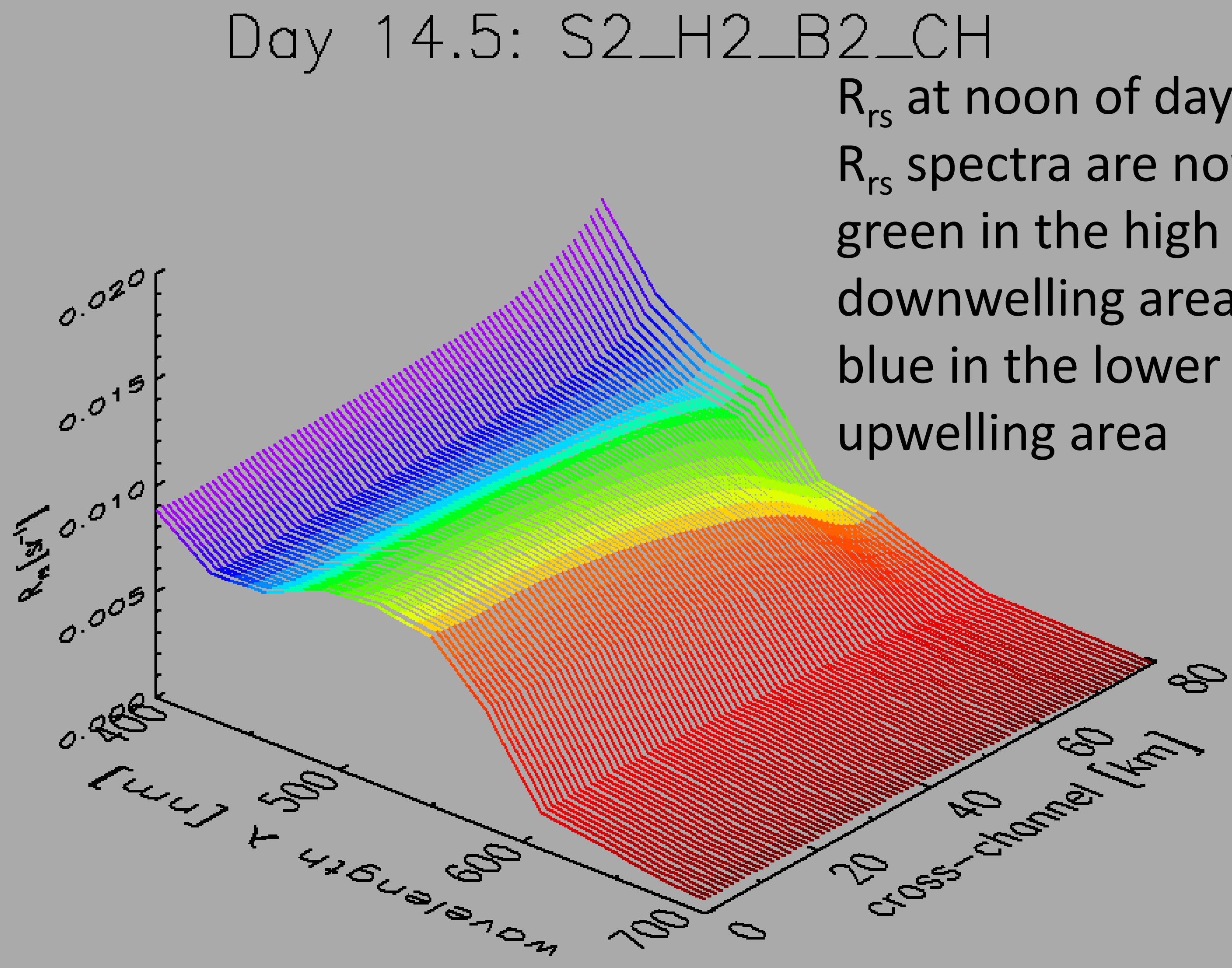
R_{rs} at noon of first day: R_{rs} spectra are very blue for Chl ≈ 0.25 across the channel

Evolution of $R_{rs}(\lambda)$ Across the Channel



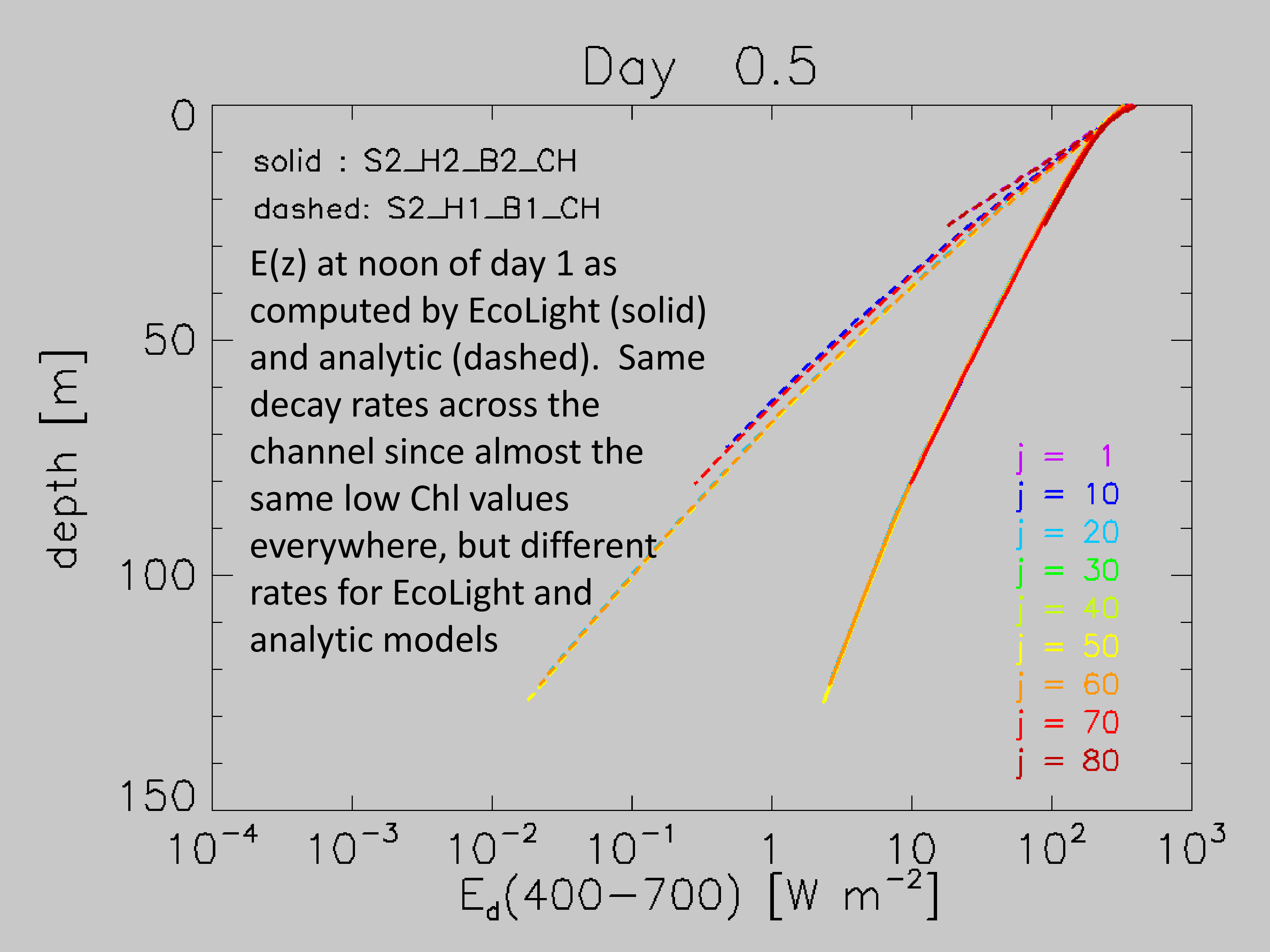
R_{rs} at noon of day 7:
R_{rs} spectra decreasing and getting greener as Chl increases

Evolution of $R_{rs}(\lambda)$ Across the Channel

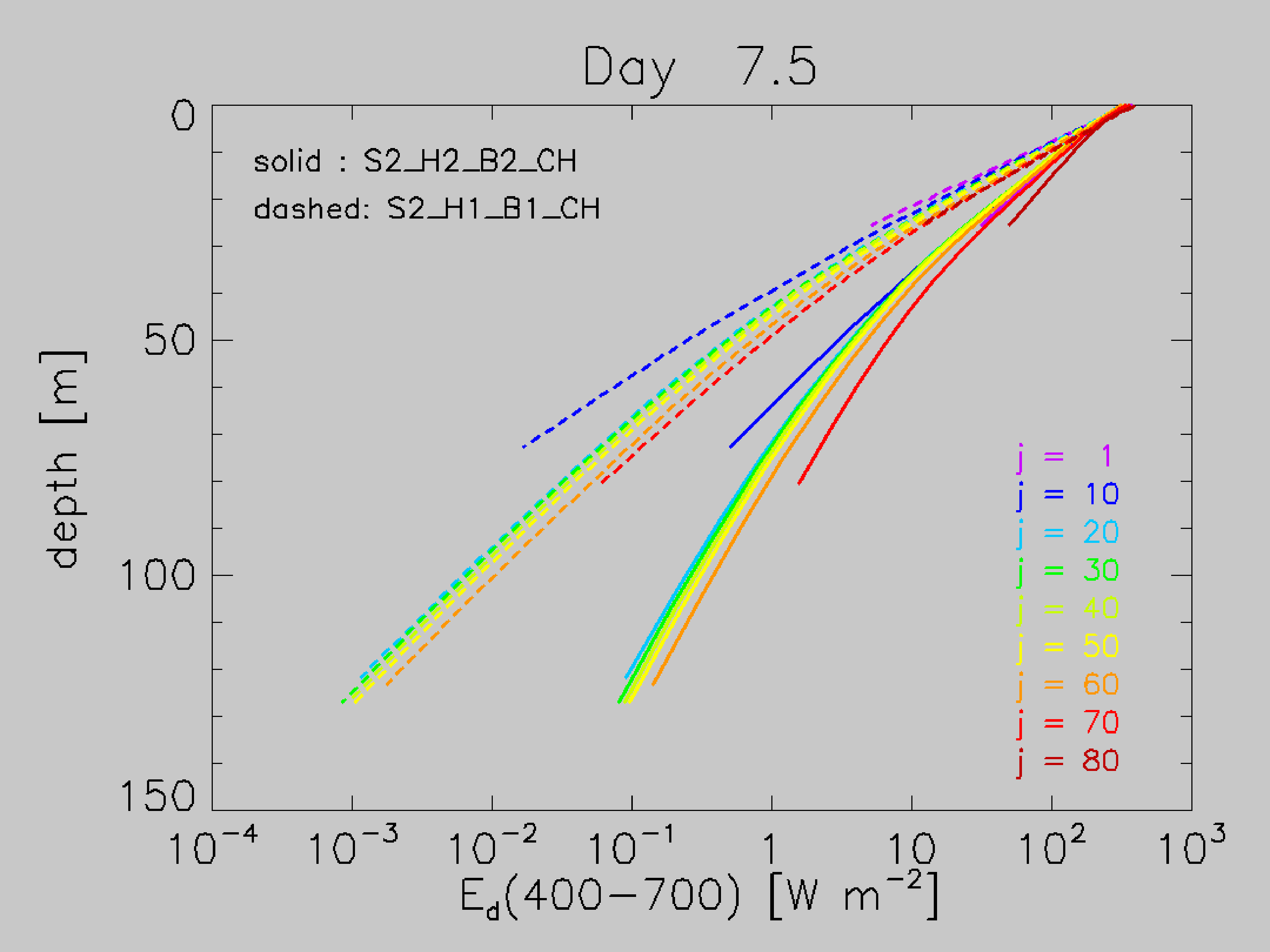


R_{rs} at noon of day 14: R_{rs} spectra are now green in the high Chl downwelling area, still blue in the lower Chl upwelling area

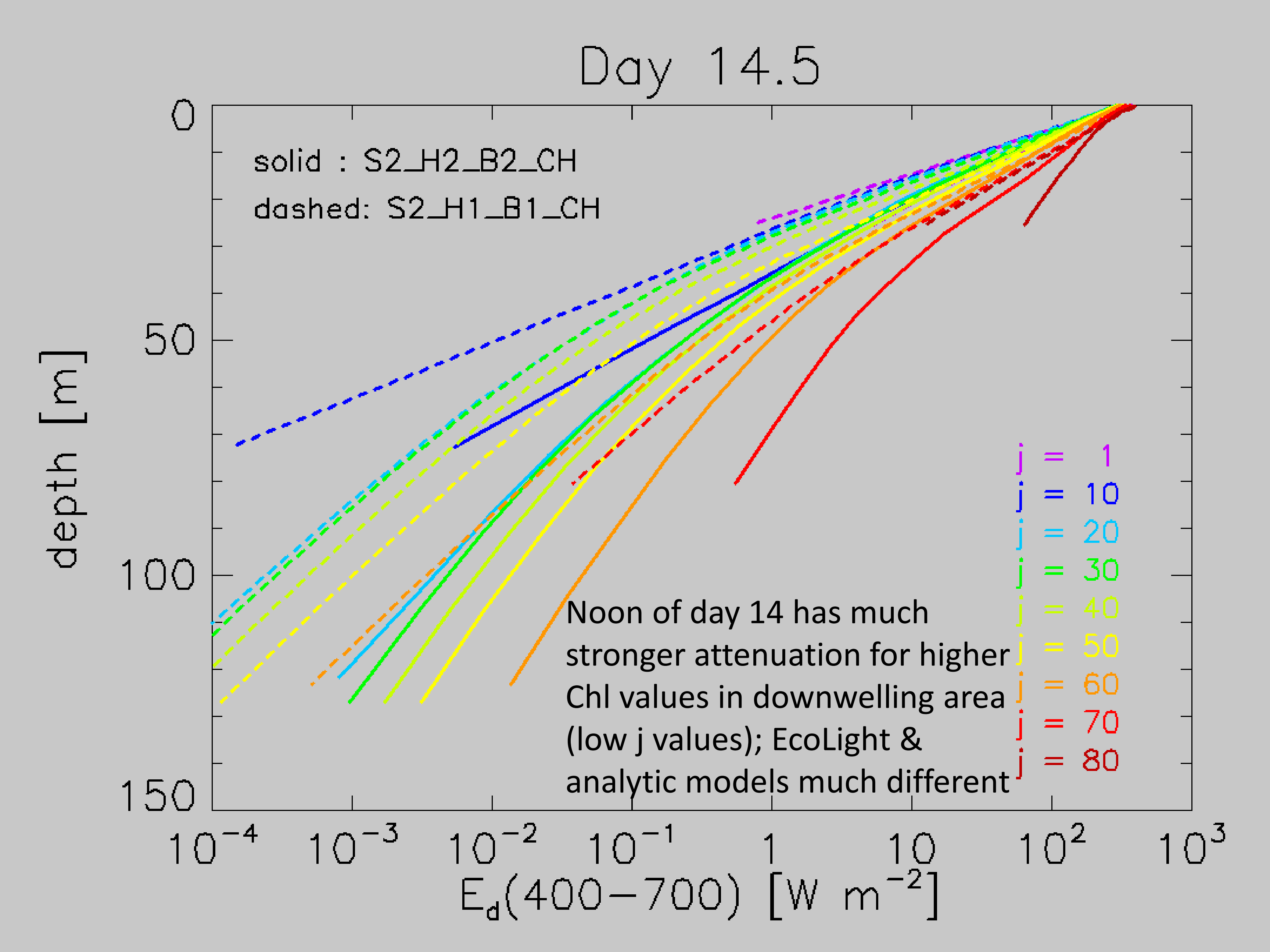
Evolution of E_d Across the Channel



Evolution of E_d Across the Channel



Evolution of E_d Across the Channel

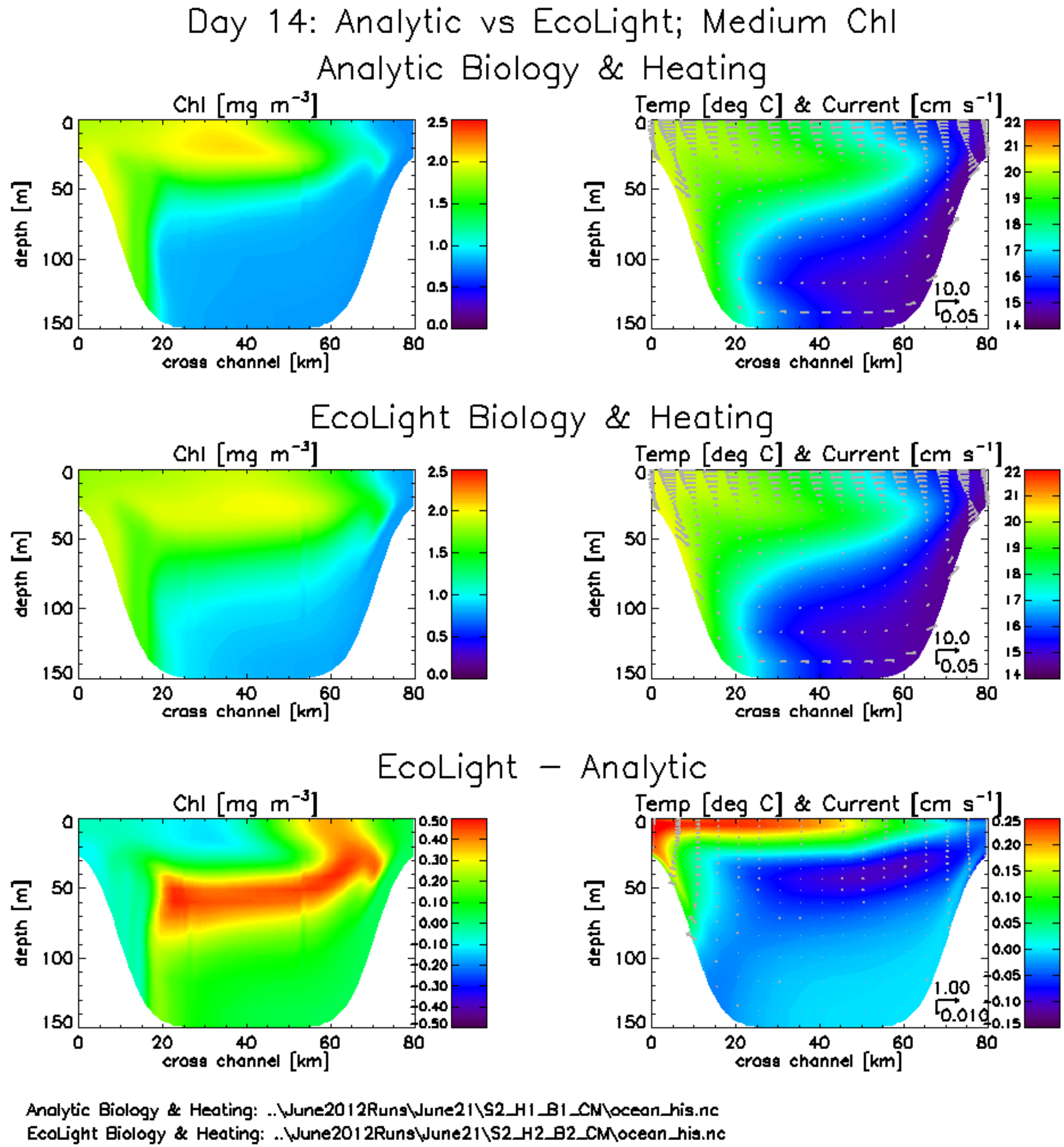


• Different ecosystem conditions (nutrient utilization rates, grazing rates, etc.) leading to medium Chl values

• 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.

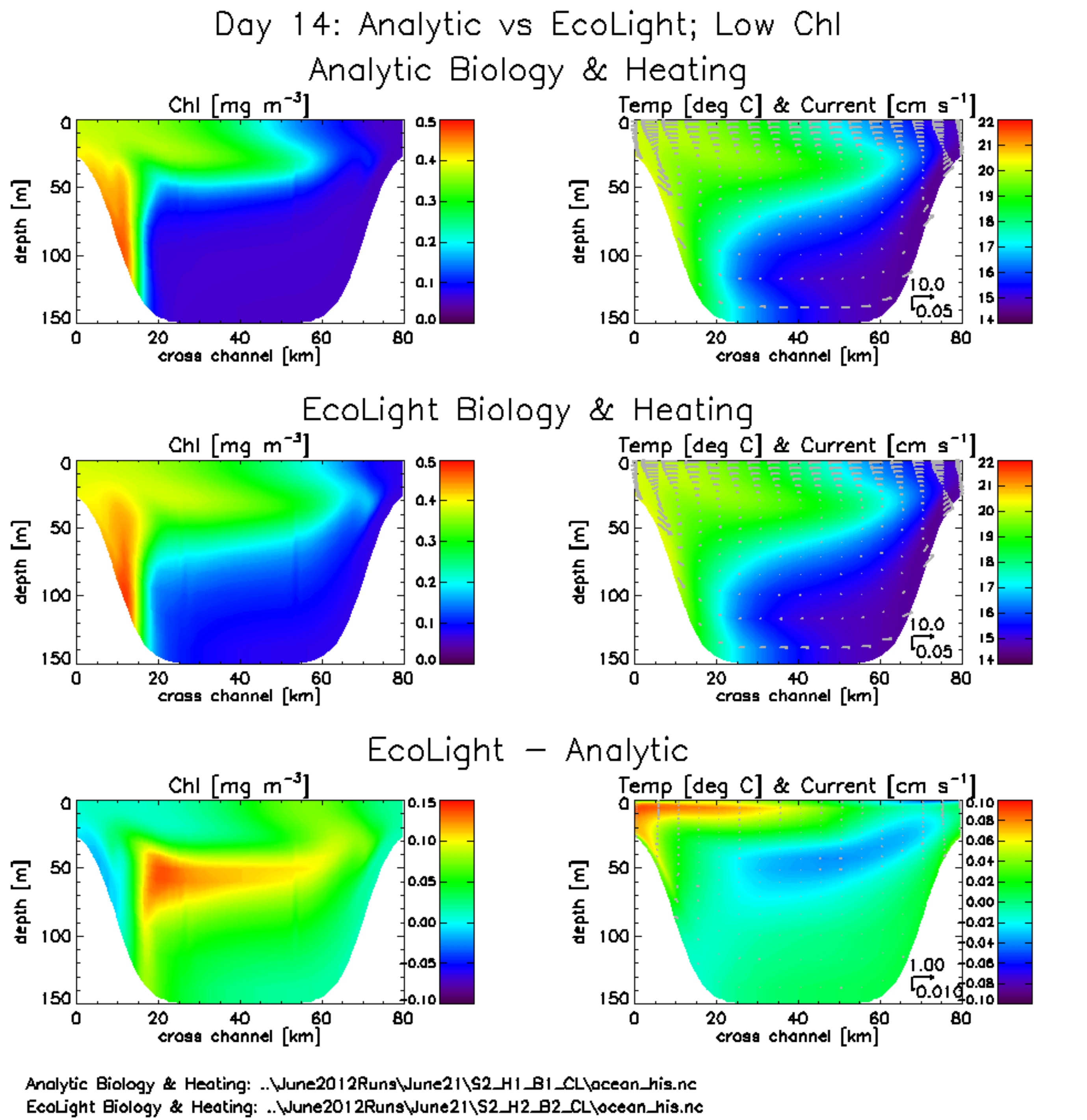


- Different ecosystem conditions (nutrient utilization rates, grazing rates, etc.) leading to low Chl values

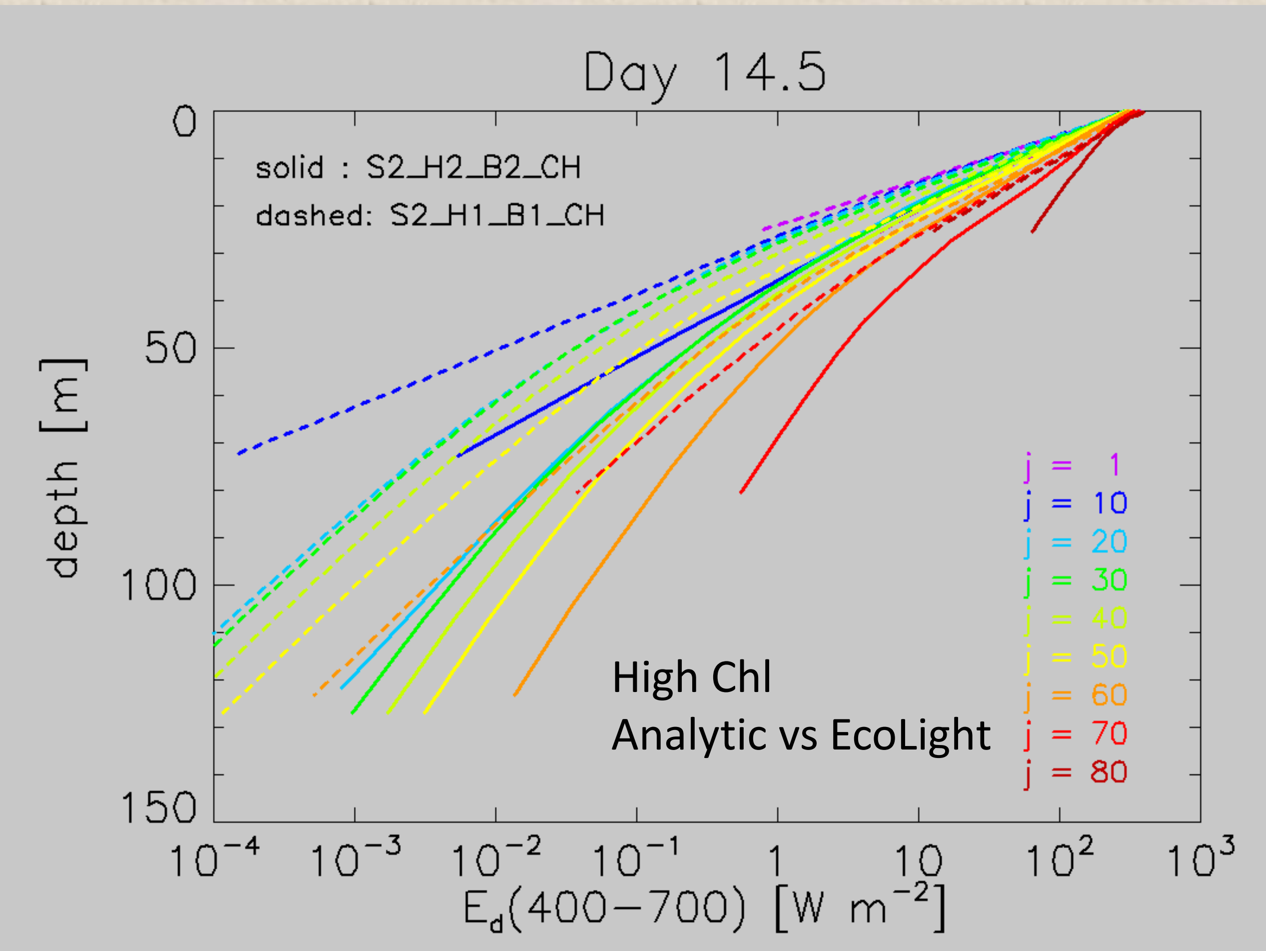
- Analytic light vs. Ecolight

- LowChl run

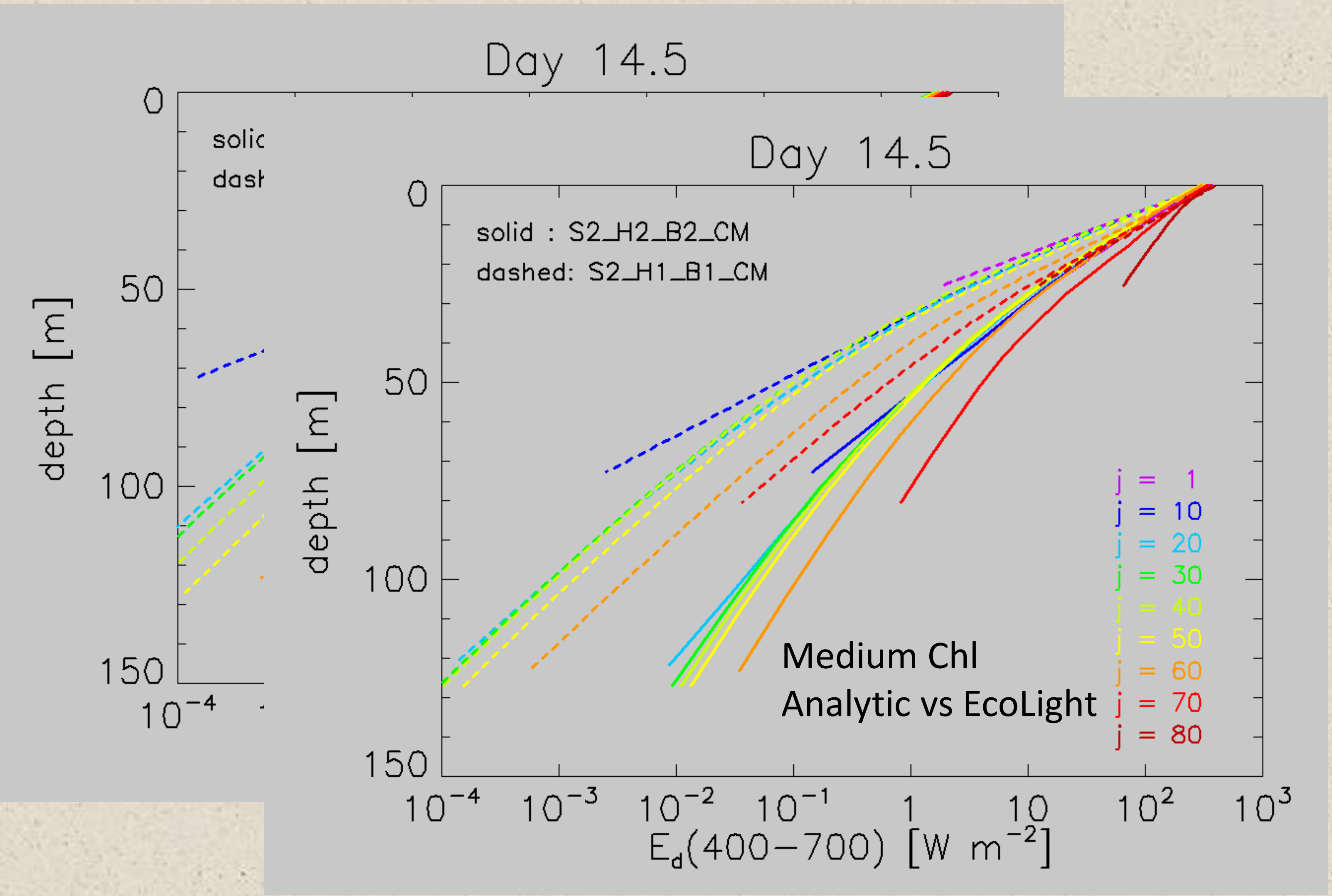
- The patterns are somewhat different but the conclusion is the same: proper incorporation of light significantly affects both heating and biology.



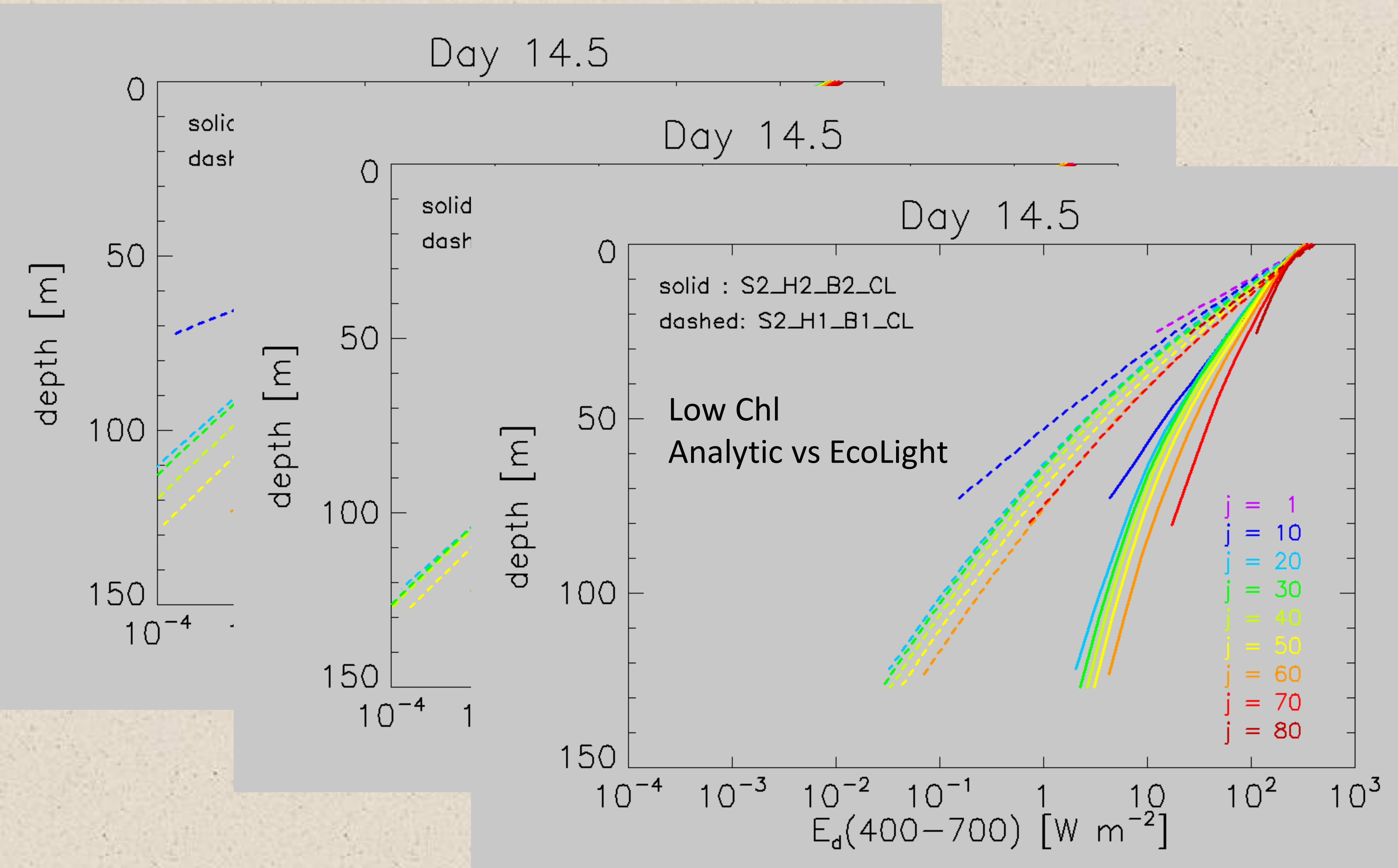
E_d Across the Channel for High, Med, Low Chl



E_d Across the Channel for High, Med, Low Chl



E_d Across the Channel for High, Med, Low Chl



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.

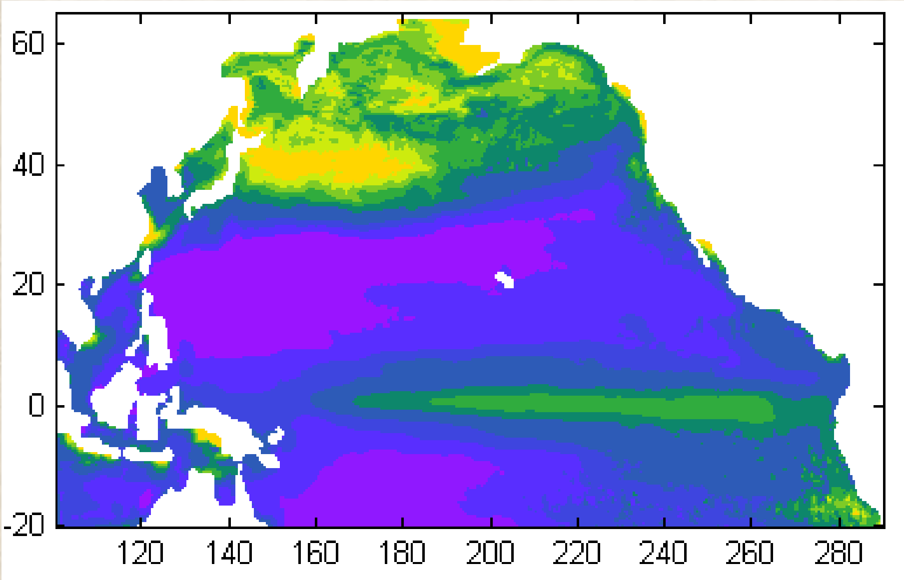
Looking to the Future

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

Either way, life is good!

If not funded:
Curt retires and goes kayaking



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