Light in the ocean: Illuminating links between water clarity and upper ocean heating

Grace Kim
NASA Goddard Space Flight Center
grace.e.kim@nasa.gov

Figure 1. This satellite image of the Chesapeake Bay shows various river inputs. Brown water indicates high levels of colored dissolved organic matter, while green water suggests high concentrations of phytoplankton.

Introduction

Sunlight is a major source of ocean heating. Light in water decreases approximately exponentially with increasing depth, and the vertical profile is represented by the following relationship:

$$I(\lambda,z) \approx I(\lambda,0)\, e^{-k_d(\lambda)\, z}$$, where I is irradiance and k_d is the attenuation coefficient

The vertical structure of solar heating in the upper ocean depends on the concentrations of materials in the water (e.g. phytoplankton, detritus, organic material). Expected future increases in precipitation are likely to bring more riverine inputs into estuaries, eventually making their way out into the ocean. The following studies improve the calculations of water clarity in ocean circulation-ecosystem models, with the aim of better representing the observed environment. These investigations demonstrate how changing concentrations of light-attenuating materials affect temperature and upper ocean processes.

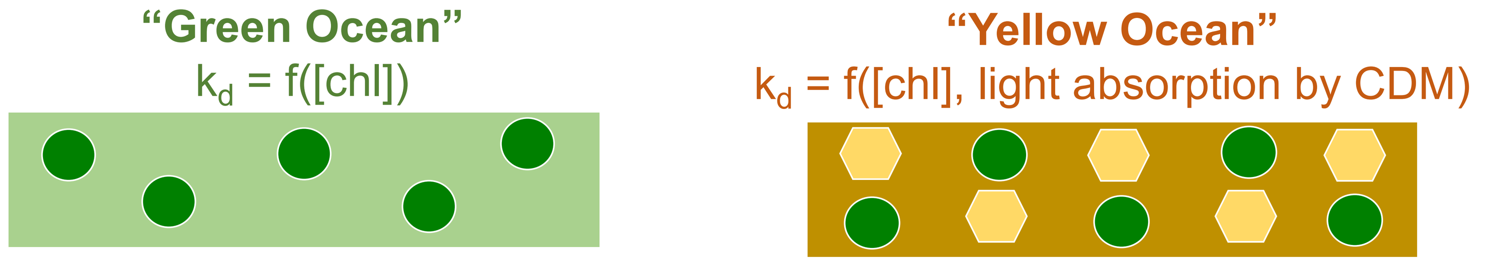
Study 1. Including colored detrital matter in a coupled global climate model

Model: GFDL CM2Mc, coupled ocean-atmosphere climate model
Collaborators: Anand Gnanadesikan and Marie-Aude Pradal (JHU), Carlos Del Castillo (NASA-GSFC)
Spatial extent: Global
Time scale: 100s of years

Motivation

In global climate models, the attenuation coefficient for light in water, k_d, is commonly calculated as a varying function of chlorophyll concentration. However, colored detrital matter (CDM) does not always co-vary with [chl].

Experimental setup



Results

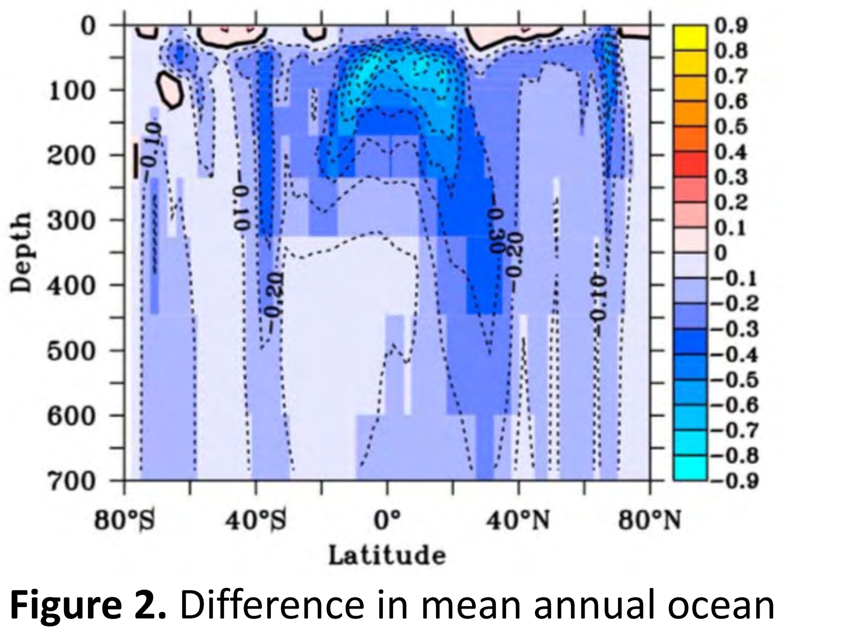


Figure 2. Difference in mean annual ocean temperature for the upper 700m of the Atlantic Ocean. "Yellow Ocean" minus "Green Ocean". Average of final 100 years. Overall, colder waters in the upper 700m in the "Yellow Ocean" run.

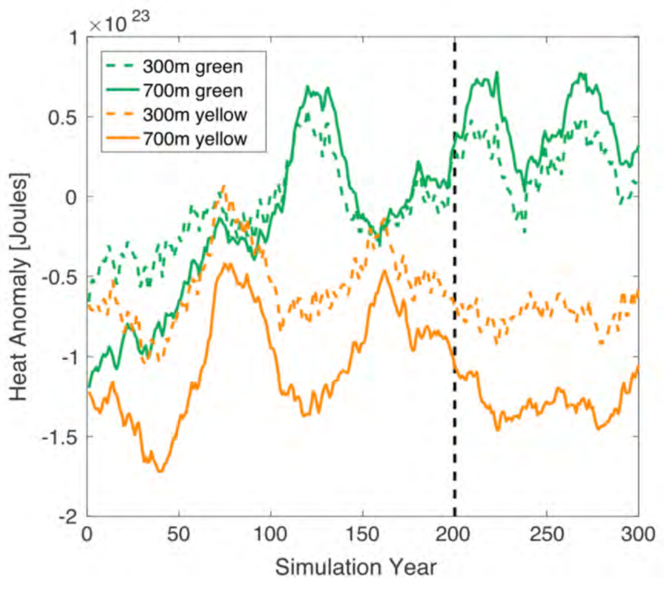


Figure 3. Annually averaged ocean heat content anomaly for the upper 300 and 700 m. Anomaly calculated with respect to average of the Green Ocean simulation. Lower heat content in the "Yellow Ocean" run.

Study & Figures Reference: Kim, Grace E., et al. "Upper ocean cooling in a coupled climate model due to light attenuation by yellowing materials." *Geophysical Research Letters* 45.12 (2018): 6134-6140.

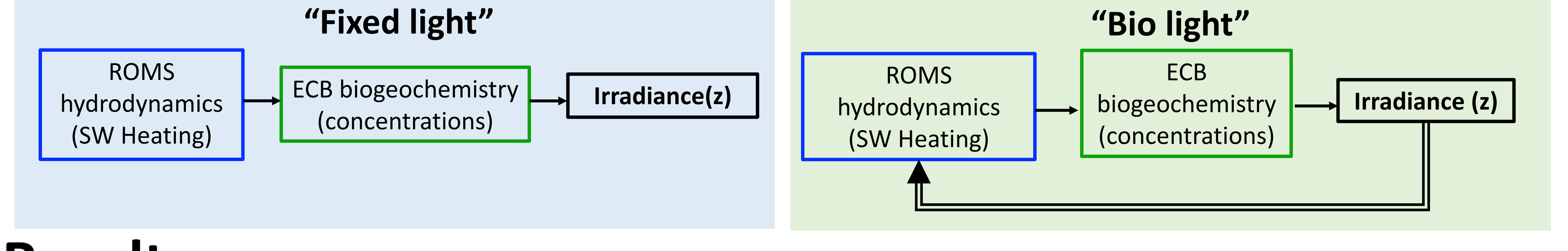
Study 2. Varying light attenuation in the physical calculations of an estuarine model

Model: ChesROMS-ECB, ocean forced with NARR atmospheric data
Collaborators: Pierre St-Laurent and Marjy Friedrichs (VIMS), Antonio Mannino (NASA-GSFC)
Spatial extent: Chesapeake Bay
Time: 2001-2005

Motivation

In the ROMS modeling system, the light calculations for solar heating are independent of the biogeochemistry. The default configuration is a constant attenuation coefficient, k_d, which is not representative of the natural environment.

Experimental setup



Results

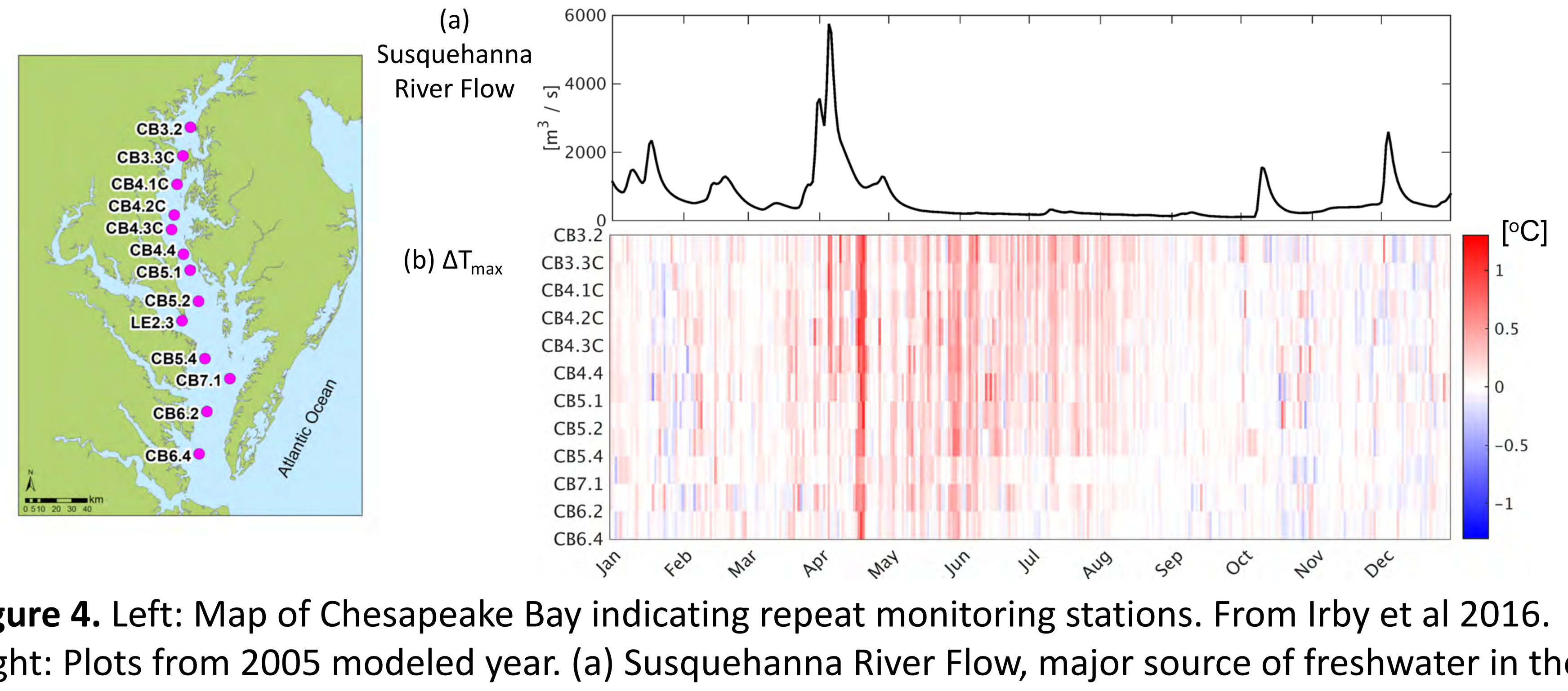


Figure 4. Left: Map of Chesapeake Bay indicating repeat monitoring stations. From Irby et al 2016. Right: Plots from 2005 modeled year. (a) Susquehanna River Flow, major source of freshwater in the Bay. (b) Change in maximum surface temperature at stations shown on left. "Bio light" minus "Fixed light". Increased maximum temperatures when biogeochemistry is accounted for in solar heating calculations.

ChesROMS ECB Model Reference: Da, Fei, Marjorie AM Friedrichs, and Pierre St-Laurent. "Impacts of atmospheric nitrogen deposition and coastal nitrogen fluxes on oxygen concentrations in Chesapeake Bay." *Journal of Geophysical Research: Oceans* 123.7 (2018): 5004-5025.

Conclusions and Future Work

In model runs with decreased water clarity, water below the mixed layer is colder and the integrated heat content is lower. The effect on average surface temperatures is small, but there is more temperature variability associated with concentrating solar heating near the surface. How do climate-driven light attenuation changes in an estuary affect the ocean, and vice versa? Future studies with a nested estuary-shelf model can improve our understanding of this interaction.

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