Validation of the Inherent Optical Properties of Seawater in the NASA-GISS Climate Model.

The City College of New York

National Aeronautics and Space Administration

Paul Lerner[1,2], Shabab Chowdhury[3] Anastasia Romanou[1]

1. Goddard Institute for Space Studies. 2. Department of Applied Physics and Applied Mathematics, Columbia University 3. City College of New York

Introduction

Inherent Optical Properties (IOPs) describe the absorption and scattering of radiation in seawater, and are critical in determining the amount of photosynthetically available radiation (PAR) for phytoplankton growth. While remote sensing products provide some information on IOPs at a global scale, models are necessary for understanding the processes and feedbacks that alter IOPs and PAR in present and future climate. Here, we present the validation of IOPs and oceanic PAR in the NASA-GISS climate model. Our model has 16 spectral bands in the wavelengths spanned by PAR, and simulates the absorption and backscatter properties of four phytoplankton functional types (diatoms, chlorophytes, cyanobacteria, and coccolithophores). We evaluate PAR and IOPs by leveraging remote-sensing data from MODIS-AQUA[1] and data on the vertical structure of PAR from BGC-ARGO[2]. We also evaluate our model's IOPs based on a compilation[3] of multiple datasets, including NOMAD, MAREDAT, and SEADATANET. To further elucidate the causes of IOP biases, we compile IOPs for different phytoplankton functional types (PFTs) from recent field and laboratory studies[4-9], and compare this compilation to the phytoplankton functional group IOPs currently used by the model. Future work will focus on leveraging this compilation of PFT-specific IOPs to improve both PAR and the optical properties of chlorophyll in the model.

Methods

The ocean radiative transfer scheme in NASA Ocean Biogeochemistry Model (NOBM)[10] uses the three-stream equations describing the underwater propagation of direct (E_d) diffuse (E_s), and upwelling radiation (E_u):

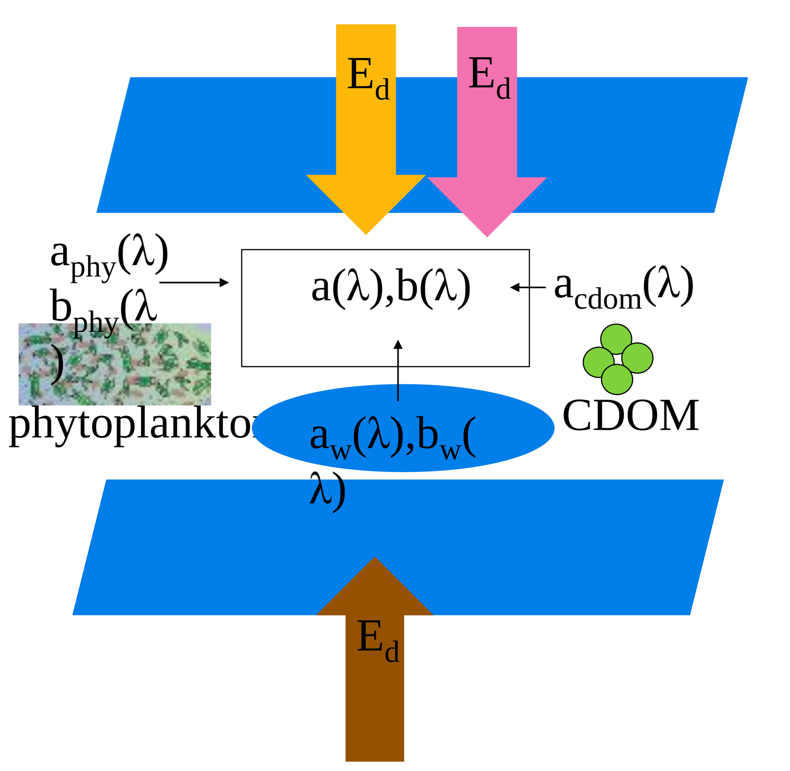

Fig. 1: Schematic of direct, diffuse, and upwelling radiation in a vertical oceanic layer in NOBM. Radiation encounters the optical constituents of seawater, including phytoplankton, CDOM, and water itself. Phytoplankton and water contribute to light scattering, while these properties and CDOM contribute to light absorption.

The absorption and backscatter coefficients are parameterized as:

- absorption: $a(\lambda) = a_{ph}(\lambda) + a_{cdom}(\lambda) + a_w(\lambda)$
- backscatter: $b(\lambda) = b_{ph}(\lambda) + b_w(\lambda)$
- $a_{ph}(\lambda) = \sum_{i=1}^{n} a_{P,i}(\lambda) P_i$, $b_{ph}(\lambda) = \sum_{i=1}^{n} b_{P,i}(\lambda) P_i$
- P_i: phytoplankton functional group (PFT) i, includes diatoms, chlorophytes, cyanobacteria, and coccolithophores (mg chl/m^3)

Where a_{Pi} are prescribed IOPs for each PFT.[11]

We use a pre-industrial spin-up of NOBM embedded in the coupled atmosphere-ocean model GISS-E2.1. The model is evaluated against chl and PAR from BGC-ARGO[2], and IOPs are evaluated against remote sensing products MODIS-AQUA[1] and a compilation of *in-situ* datasets[4-9].

Since IOPs primarily affect the vertical structure of PAR, we scale PAR from NOBM to limit the influence of biases in incoming shortwave radiation at the surface of the ocean:

$$PAR(z)^* = PAR(z)*PAR_{sf,obs}/ PAR_{sf}$$

Where PAR_{sf} is sea surface PAR from NOBM, and $PAR_{sf,obs}$ is sea surface PAR from BGC-ARGO.

Vertical Structure of PAR and Chlorophyll

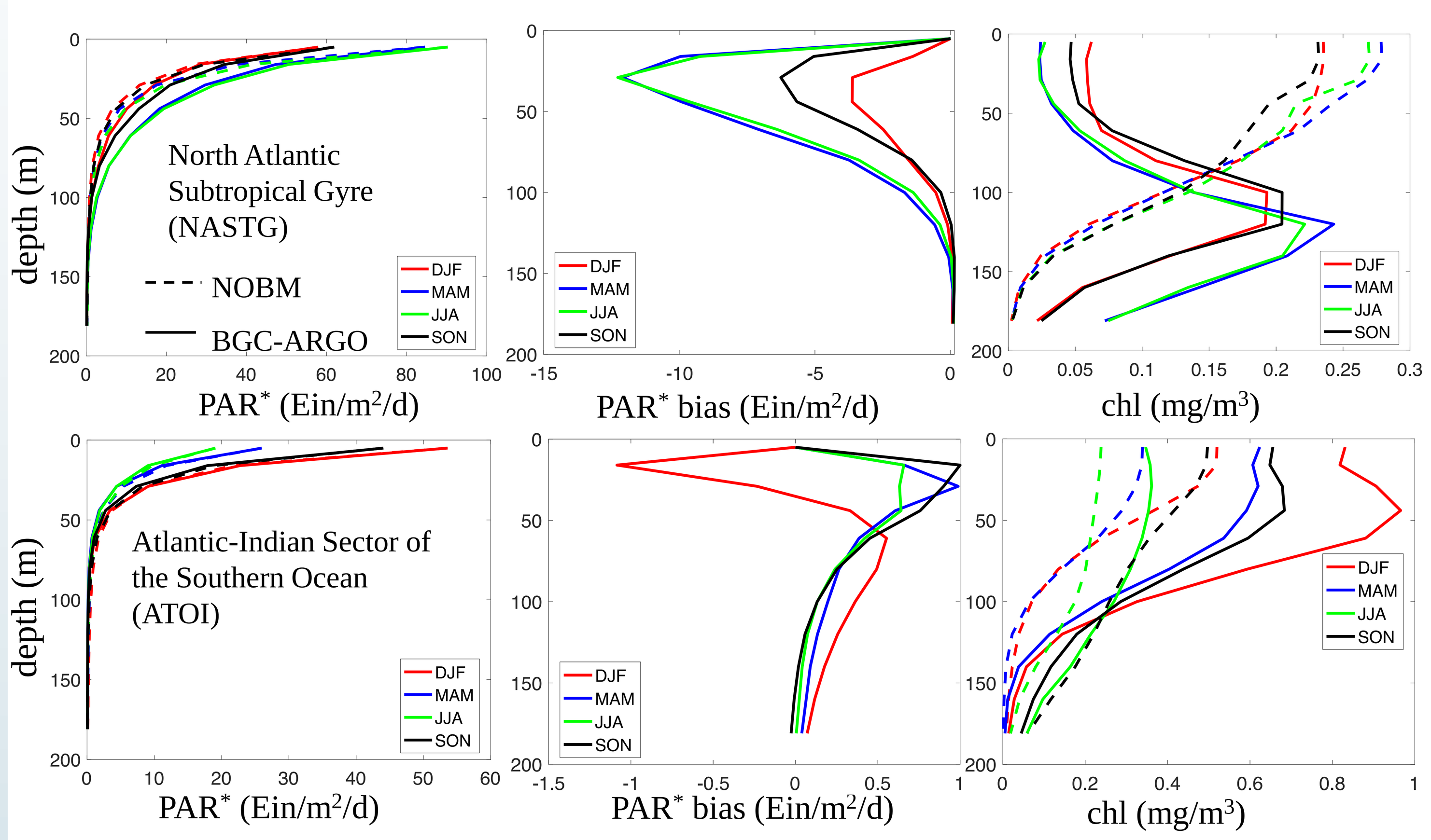

Fig. 2: In the NASTG (see maps below), the model overestimates chlorophyll concentration in the upper 100 m, likely leading to an overestimation PAR attenuation. However, in the ATOI, the model's PAR closely agrees with BGC-ARGO despite underestimating chlorophyll. This could be due to compensating biases in CDOM absorption, or overestimation of a_{phy} (see panel to the bottom right).

Sea Surface Absorption and Backscatter

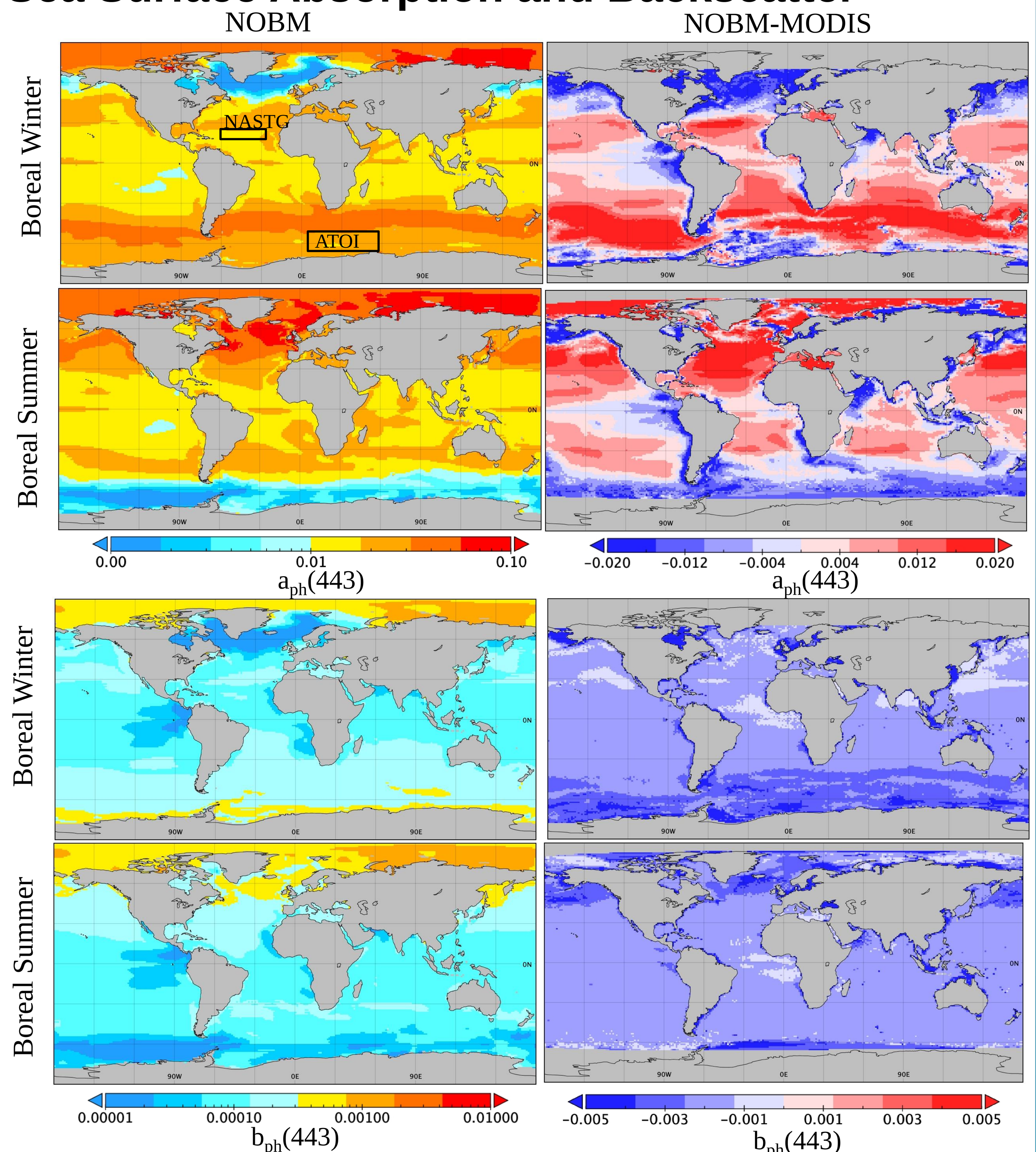

Fig. 3: Absorption and Backscatter coefficients for phytoplankton at 443 nm in NOBM and MODIS-AQUA. Absorption is generally overestimated by the model, except at high latitudes in summer. Backscatter is largely underestimated by NOBM; likely due to missing contributions from particulates.

Absorption spectra from *in-situ* datasets

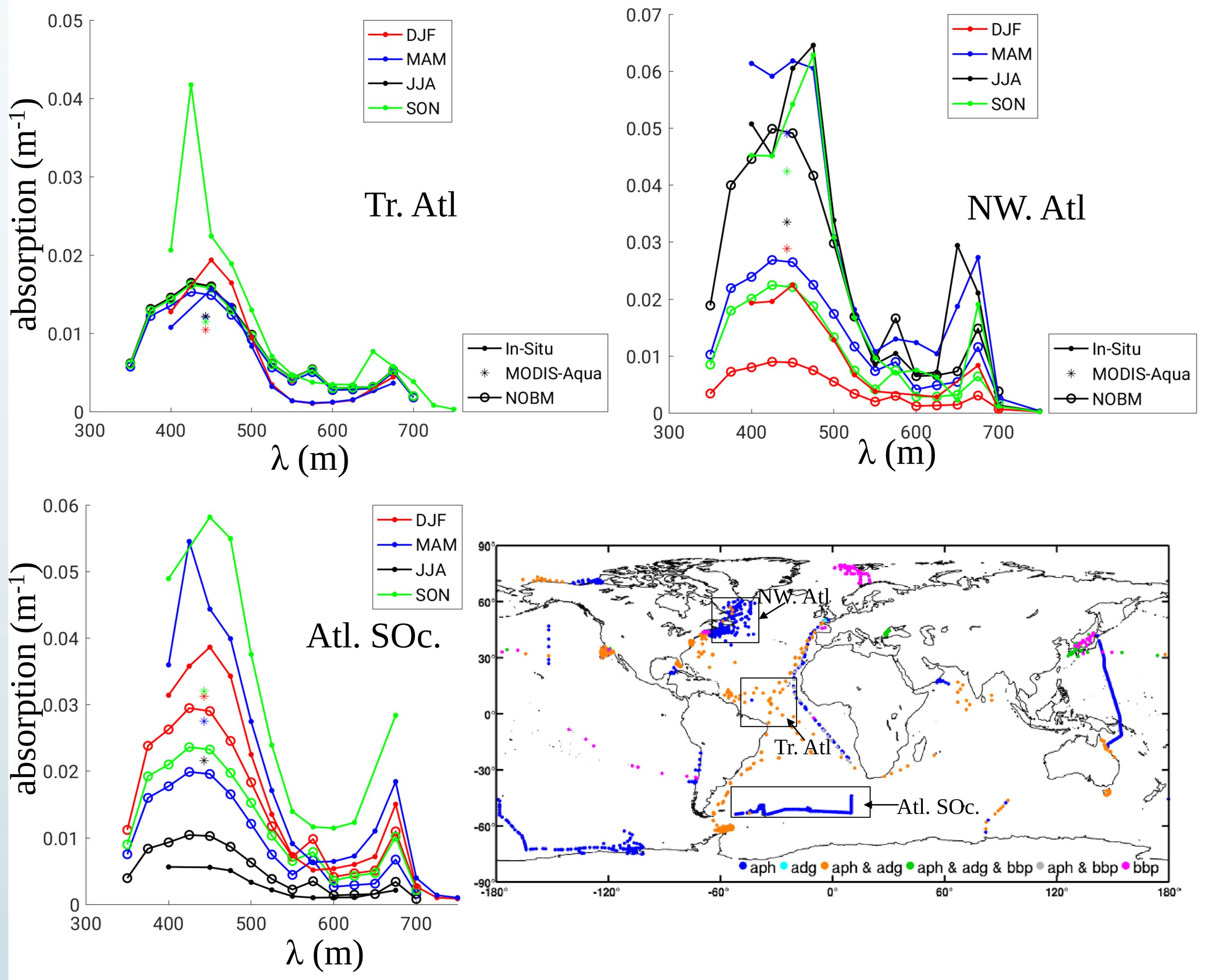

Fig. 4: *In-situ* absorption spectra in distinct oceanographic regimes show peaks near 443 and 683 nm that are much larger than the peaks in NOBM. At 443 nm, peaks from *in-situ* data are generally larger than $a_{ph}(443)$ derived from MODIS-AQUA. Thus model bias direction and magnitude depends on both region and data source. In the map[3], black boxes show the regions in which the *in-situ* data are average to generate the, and colored dots show locations where data were collected. Only "aph" (phytoplankton absorption) is considered here.

IOP compilation for PFTs

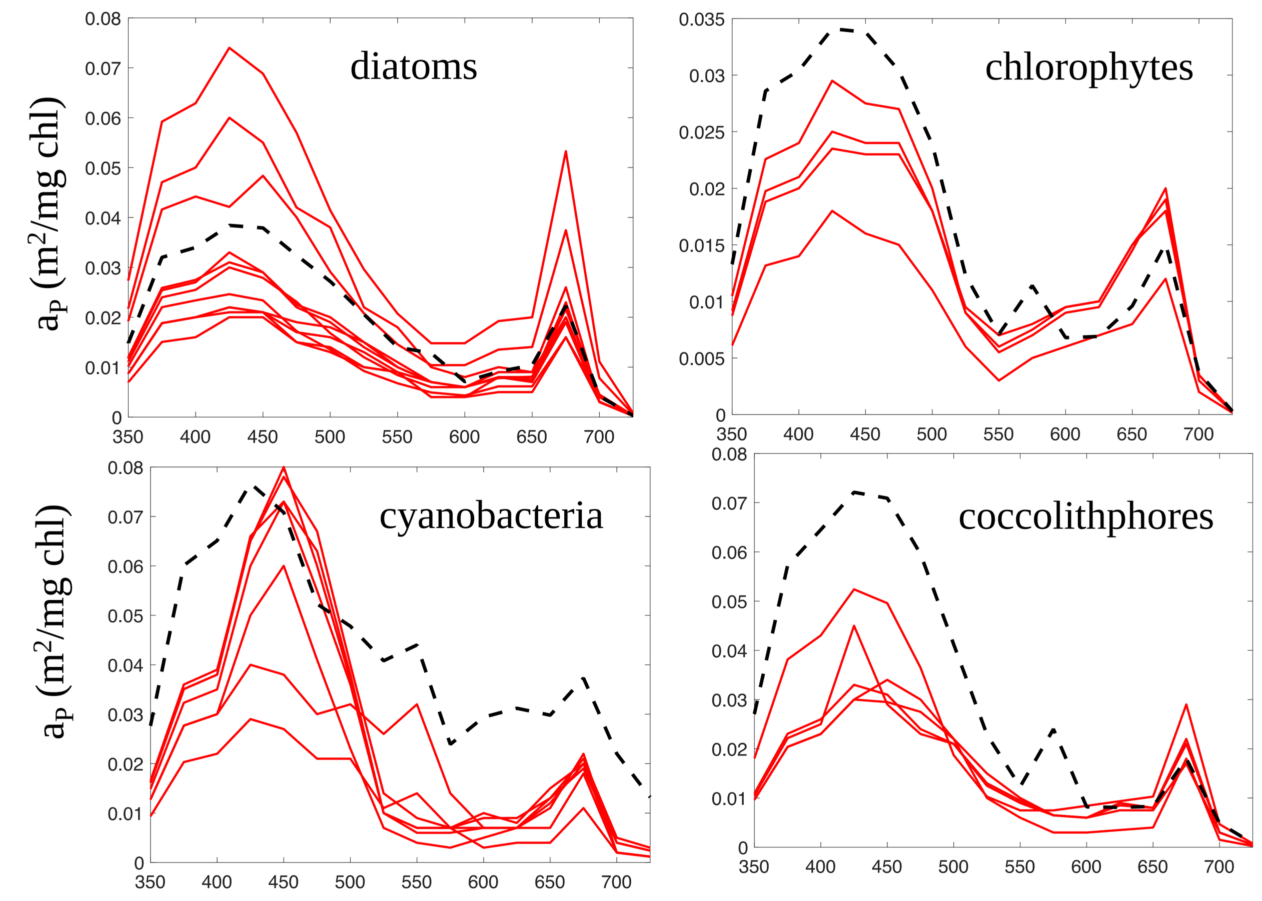

Fig. 5. For all PFTs except diatoms, peaks in chl-normalized absorption near 443 nm are smaller in NOBM than from incubation[4-7] and *in-situ*[8,9] studies (the peaks are also shifted in the case of cyanobacteria).

Conclusions/Outlook

- NOBM overestimates absorption at mid and low latitude and underestimates absorption at high latitudes.
- Overestimation of absorption and underestimation of PAR at mid and low latitudes can be attributed to the model having too much chlorophyll and having prescribed PFT-specific IOPs that are too high. The cause of high-latitude biases remains unclear and a subject of future investigation.
- Large discrepancies between remote sensing and *in-situ* absorption spectra complicate validation of NOBM's IOPs.

Contact

email: paul.lerner@nasa.gov
Phone: 213-678-5546

Funding:

NASA Office of STEM Engagement (OSTEM), the Minority University and Education Project (MUREP), and the New York Space Grant (NYSG)

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