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Integrating *in situ* data and satellite ocean-colour towards improved estimation of marine autotrophic-carbon stock

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Outline

- Uncertainties in estimating autotrophic C stock
- Potential of bio-optical algorithms and data assimilation (DA) using long-term remote sensing (RS) data
- Ongoing works on bio-optical algorithm
- Ongoing works on DA for C biomass stocks.
- Sources of estimation uncertainties
- Future challenges

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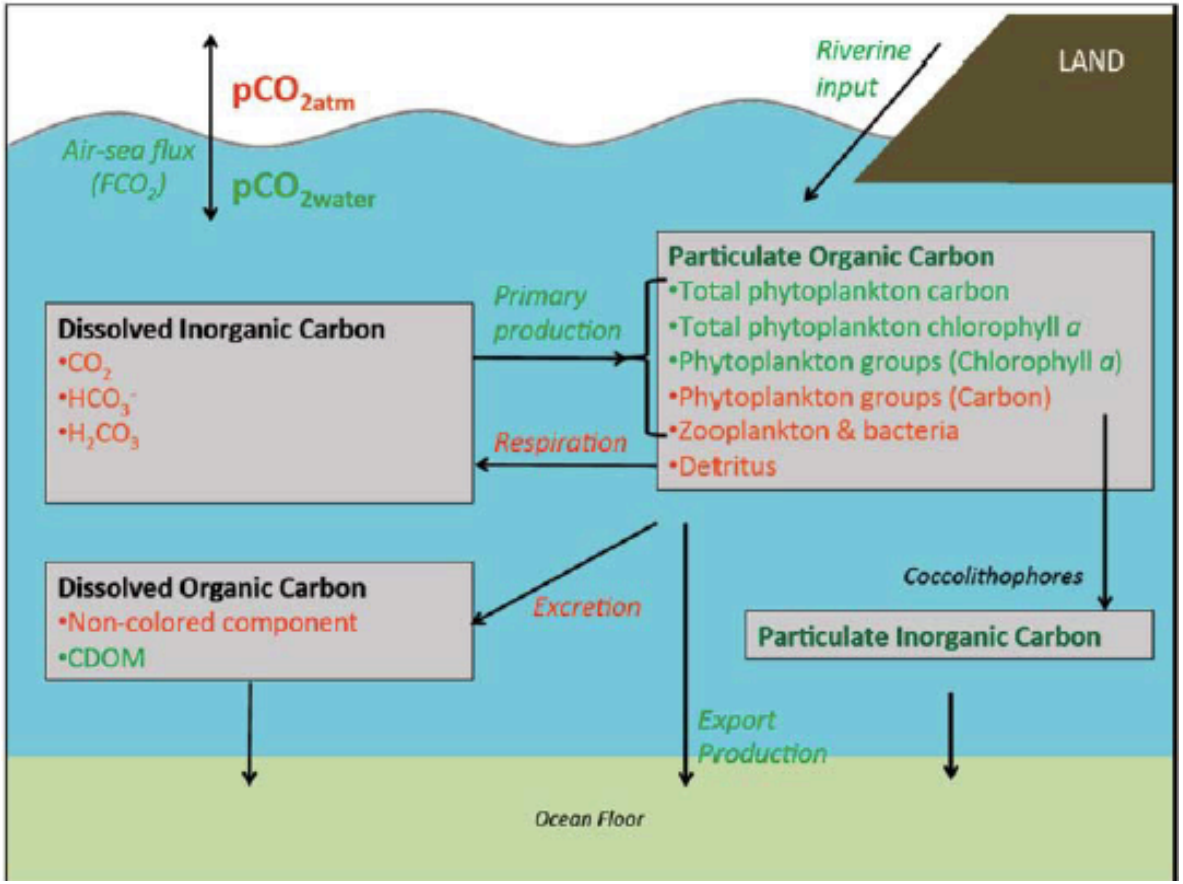
Autotrophic carbon: linking ocean and global climate



- Fixes ~ 50 GtC $year^{-1}$
- ~16 GtC $year^{-1}$ exported to ocean interior
- Global carbon cycle
- Oceanic biological pump
- Impact higher-trophic production

CEOS Strategy for Carbon Observation from Space 2014
Green- satellite-based methods available; Red- unavailable

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Autotrophic carbon: global estimates and uncertainties

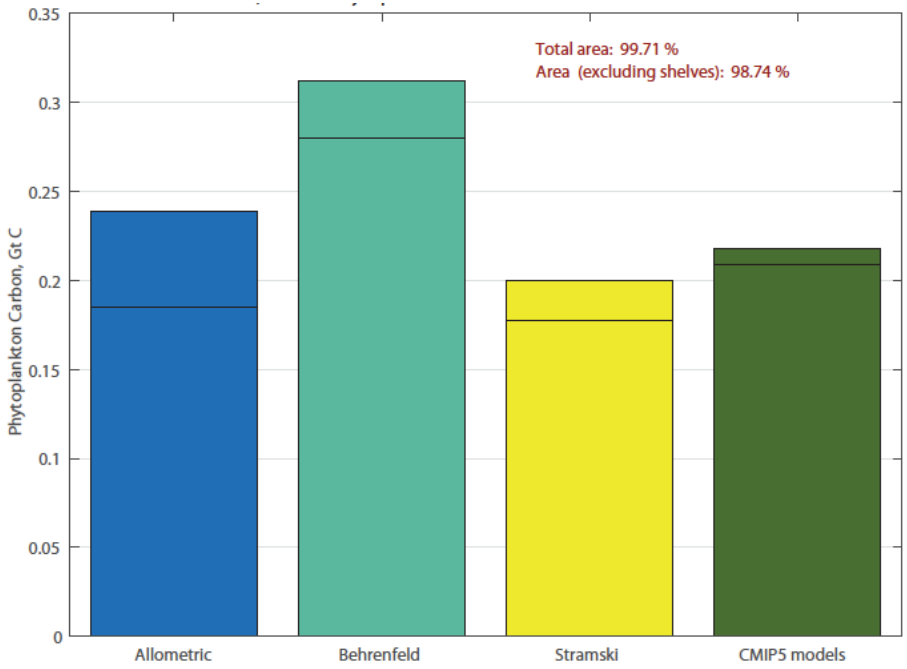

Fig source: Kostadinov et al. 2016

Phytoplankton carbon stock (GtC):

- Falkowski et al. (1998) → 1.0
- Le Quéré et al. (2005) → 0.78
- Behrenfeld et al. (2005) →0.32
- Stramski et al. (2008) → 0.2
- CMIP5 models mean → 0.22
- Kostadinov et al. (2016) → 0.24

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The key: connecting RS Chl to *in situ* phytoplankton C

- Chl – standard variable from RS, index of biomass
- C – base currency for ecosystem models, biomass
- Conversion of C to Chl interfaces the two
- But C:Chl ratio not constant
- Source of uncertainty in phytoplankton-C estimate
- Consistent parameterization of C:Chl required
- C:Chl relates to maximum phytoplankton growth rate

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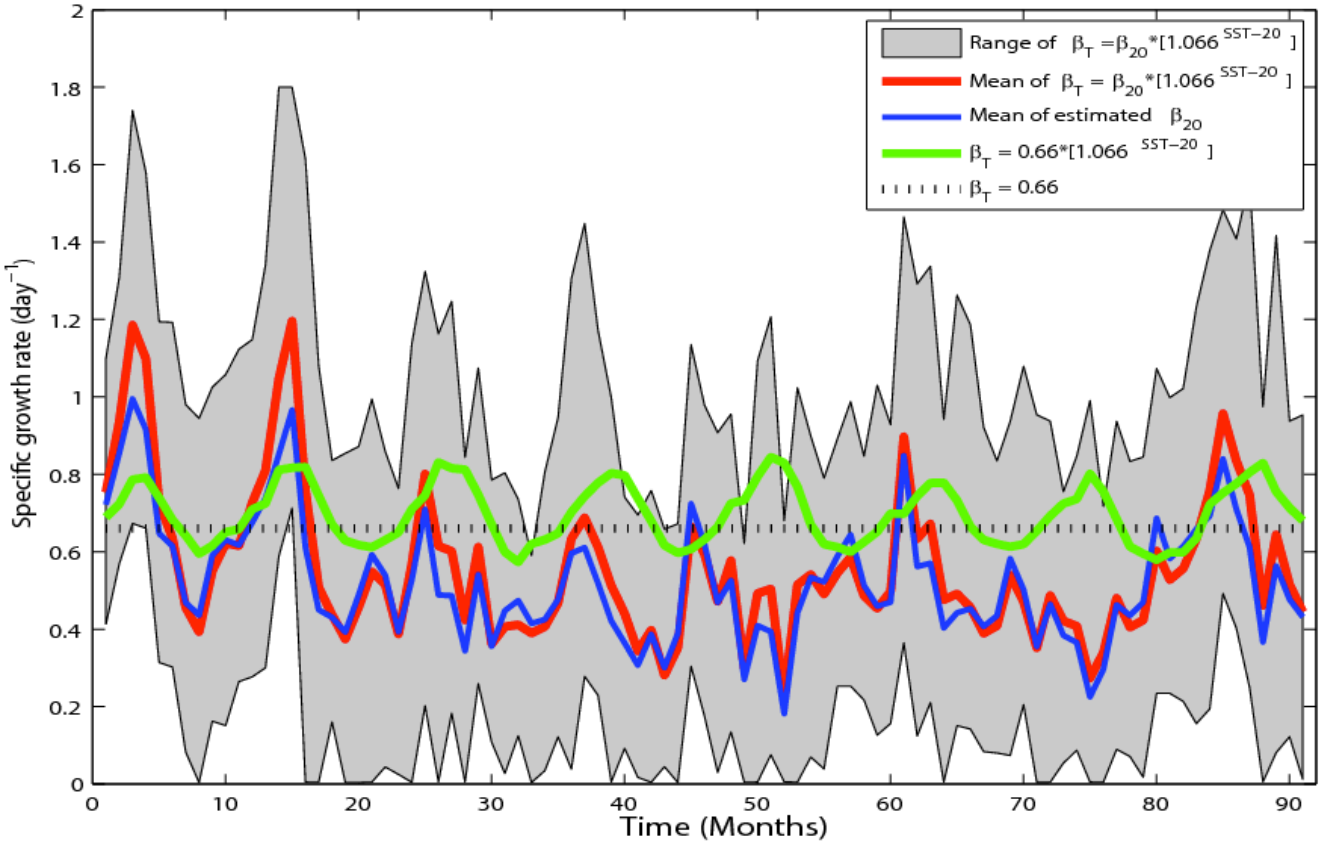
Time-varying phytoplankton growth rate



- NPZ-type model
- MODIS Chl 2002-2010
- Canary Island area
- Data assimilation: dual state-parameter estimation using EnKF

Roy et al. (2012) Journal of Marine Systems

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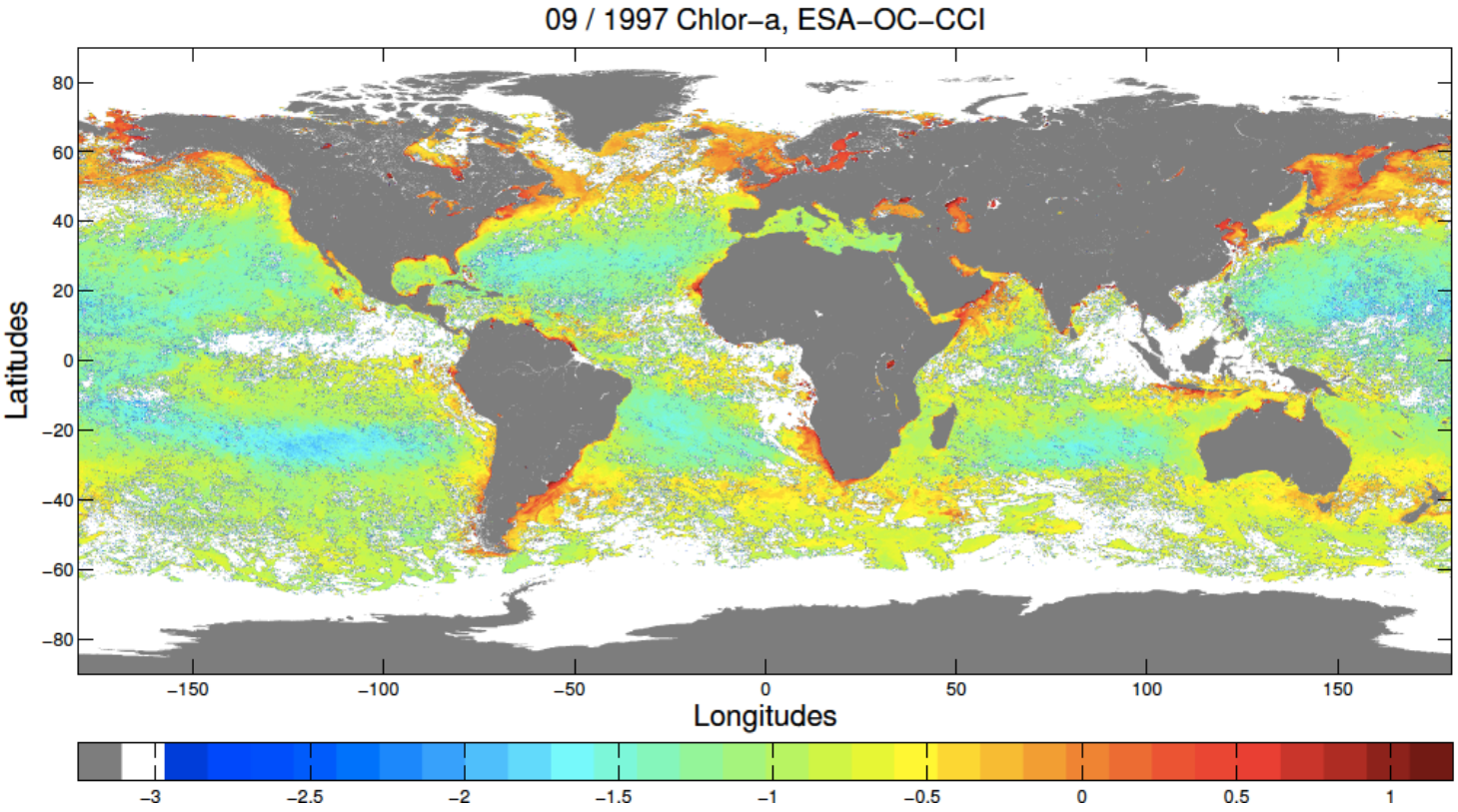
16-Year long Chl series from ocean colour: e.g., OC-CCI



Data source:
https://www.oceancolour.org

Phytoplankton C: integrating *in situ* and RS data

Approaches:

- **Develop bio-optical algorithm using multi-spectral signals from ocean colour**
- Incorporate ocean colour data into 'ecosystem models' e.g., through data assimilation

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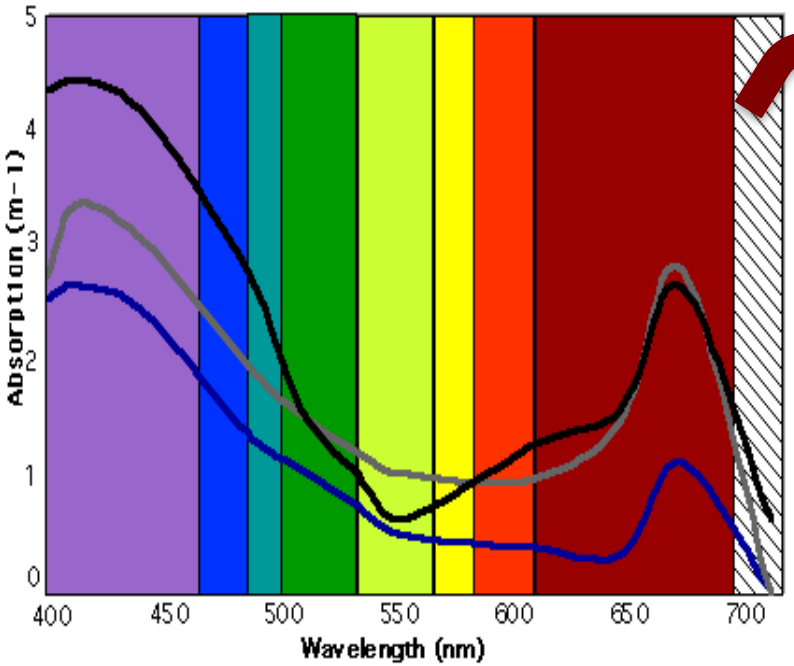
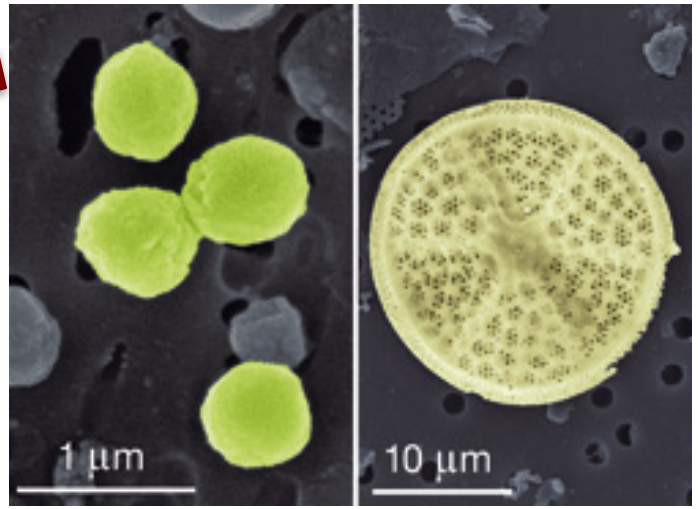
Bio-optical algorithm: optics to phytoplankton size



http://serc.si.edu/labs/phytoplankton/primer/components_phyto.aspx

Absorption spectra of phytoplankton in the visible wavelengths

Cell size



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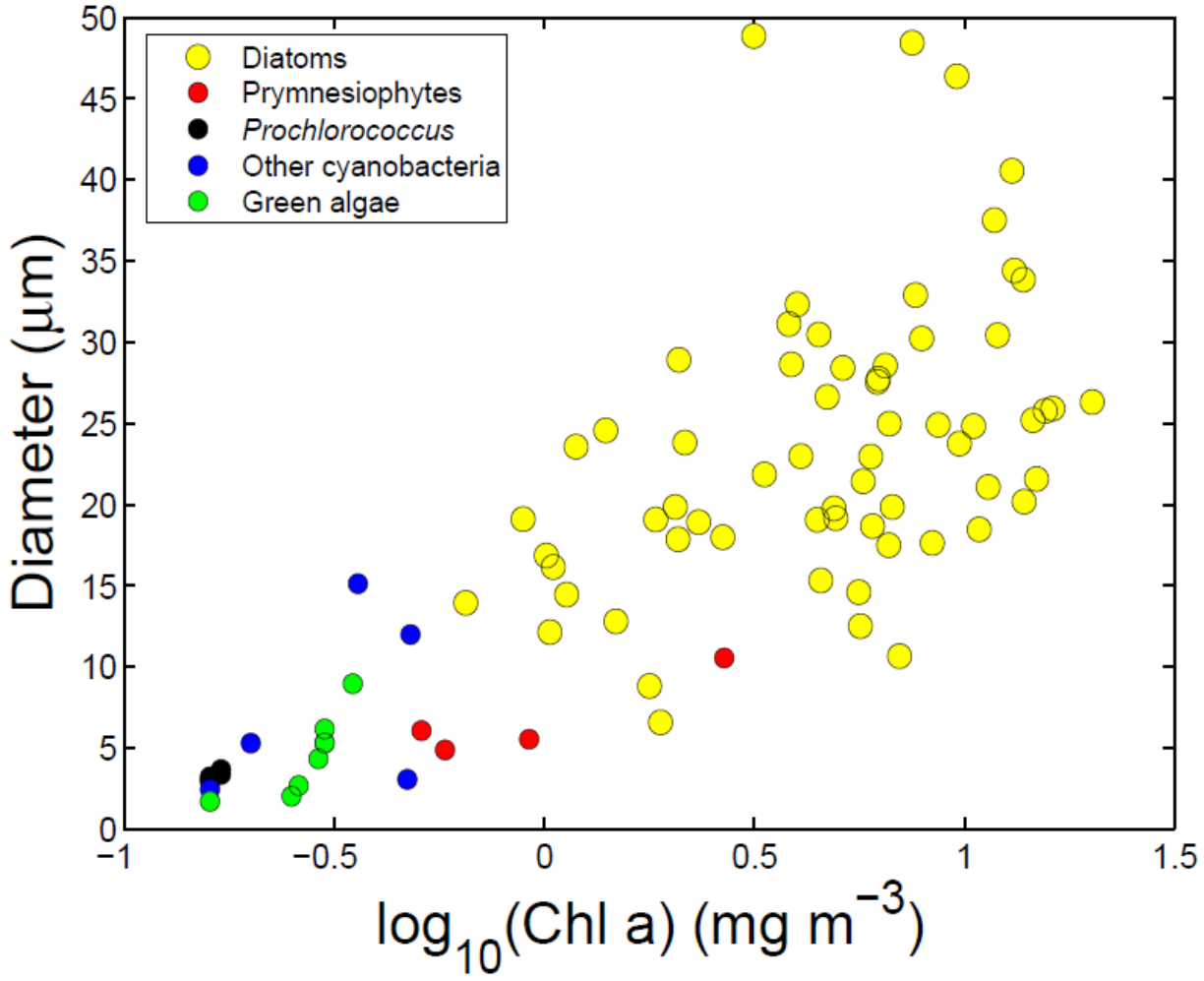
In situ PFT data and bio-optically-derived cell size



Varying cell size of taxonomic groups captured by bio-optical algorithm

Roy et al. 2011, Royal Society Interface

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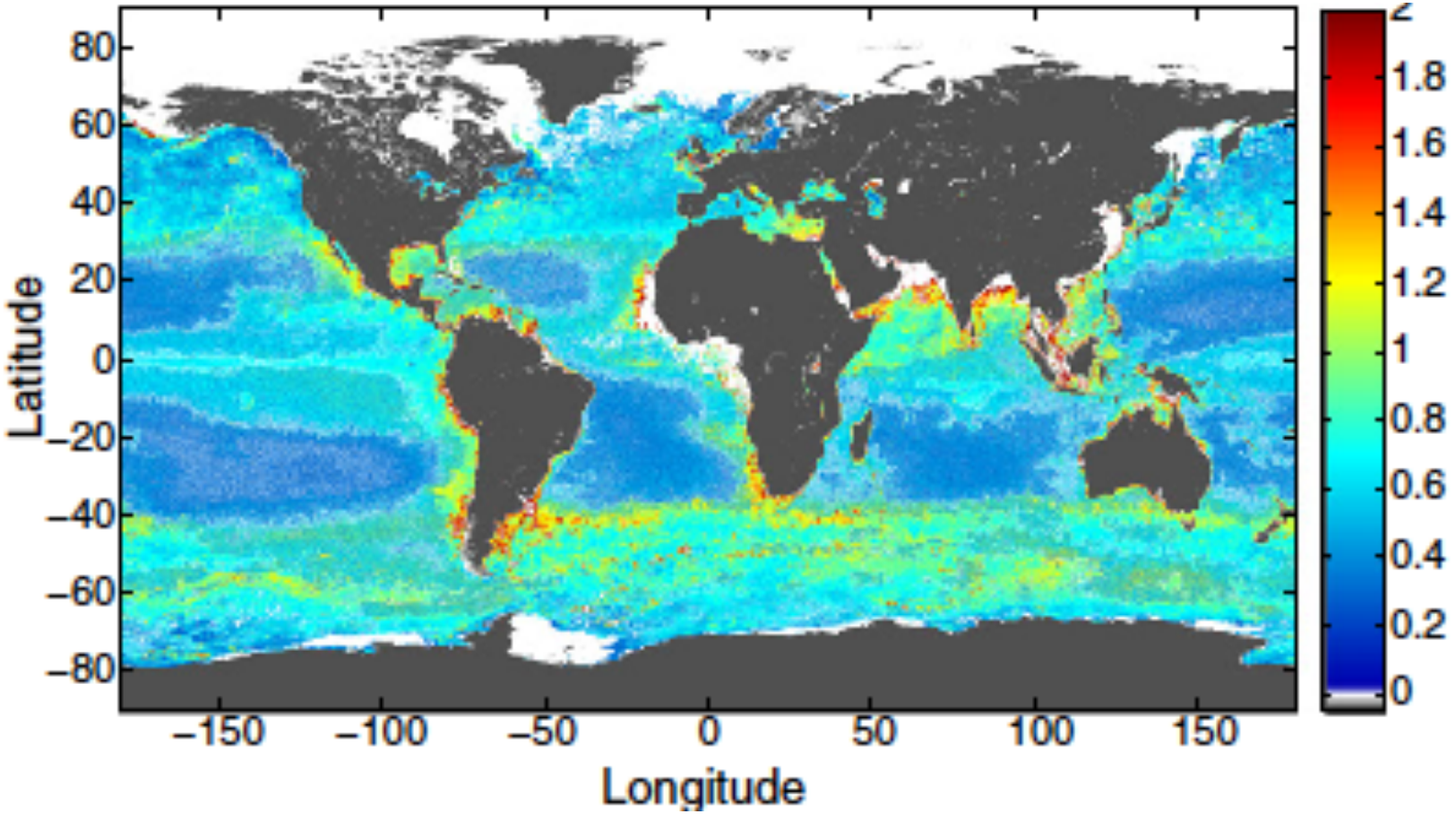
Applying bio-optical algorithm to ocean colour

Average size of phytoplankton cells (in micro-m)



Roy et al. 2013, Remote Sensing of Environment

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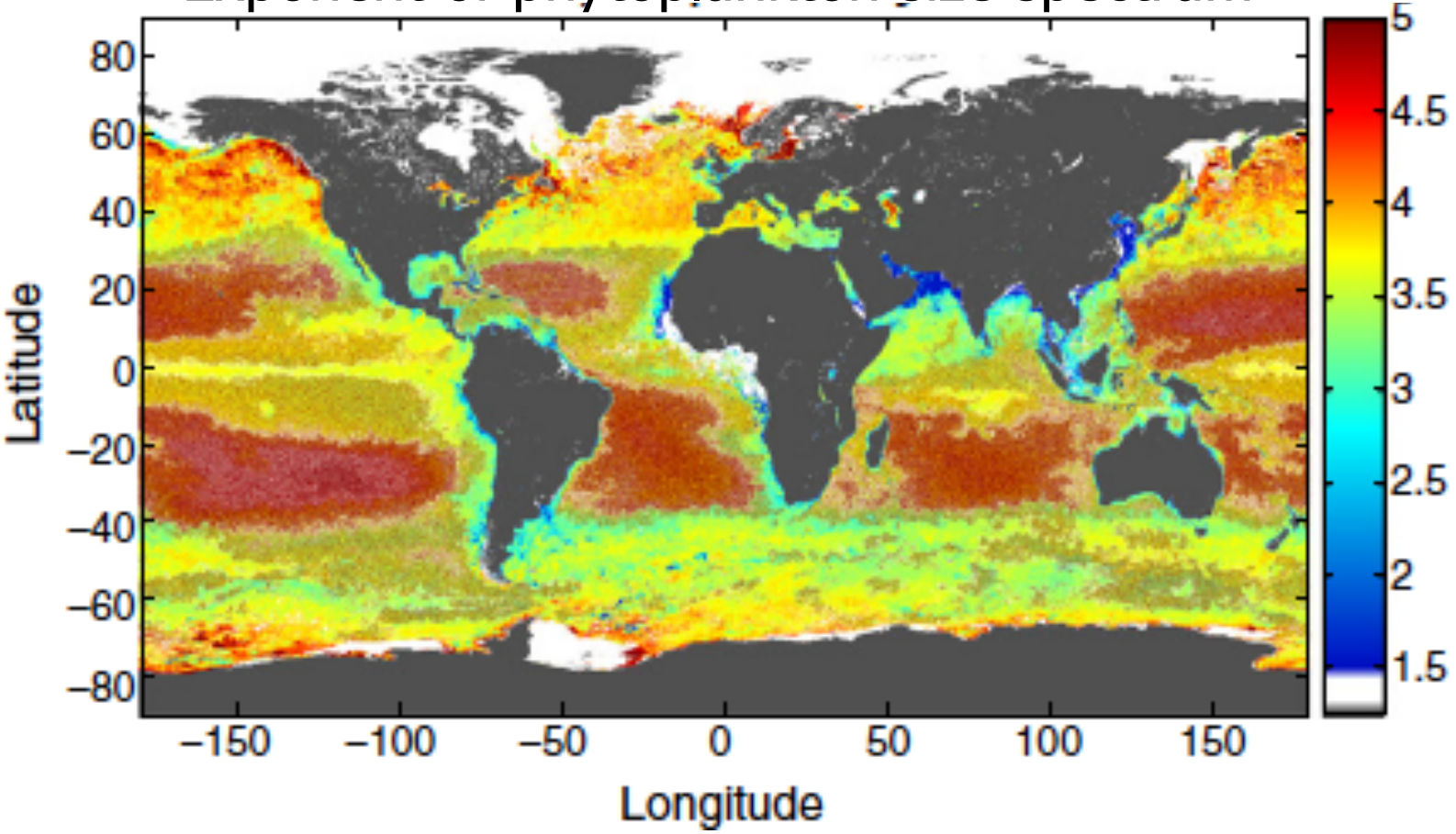
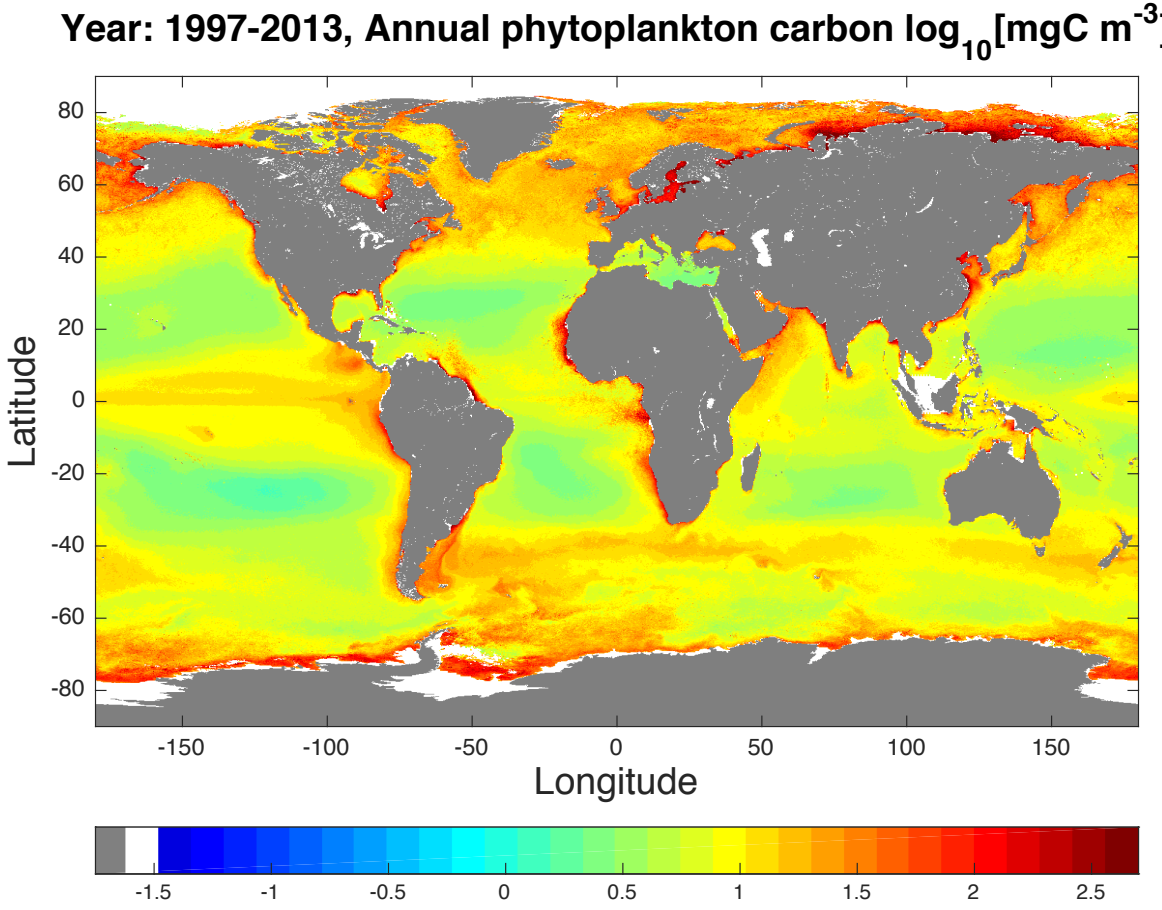
Applying bio-optical algorithm to ocean colour

Exponent of phytoplankton size spectrum



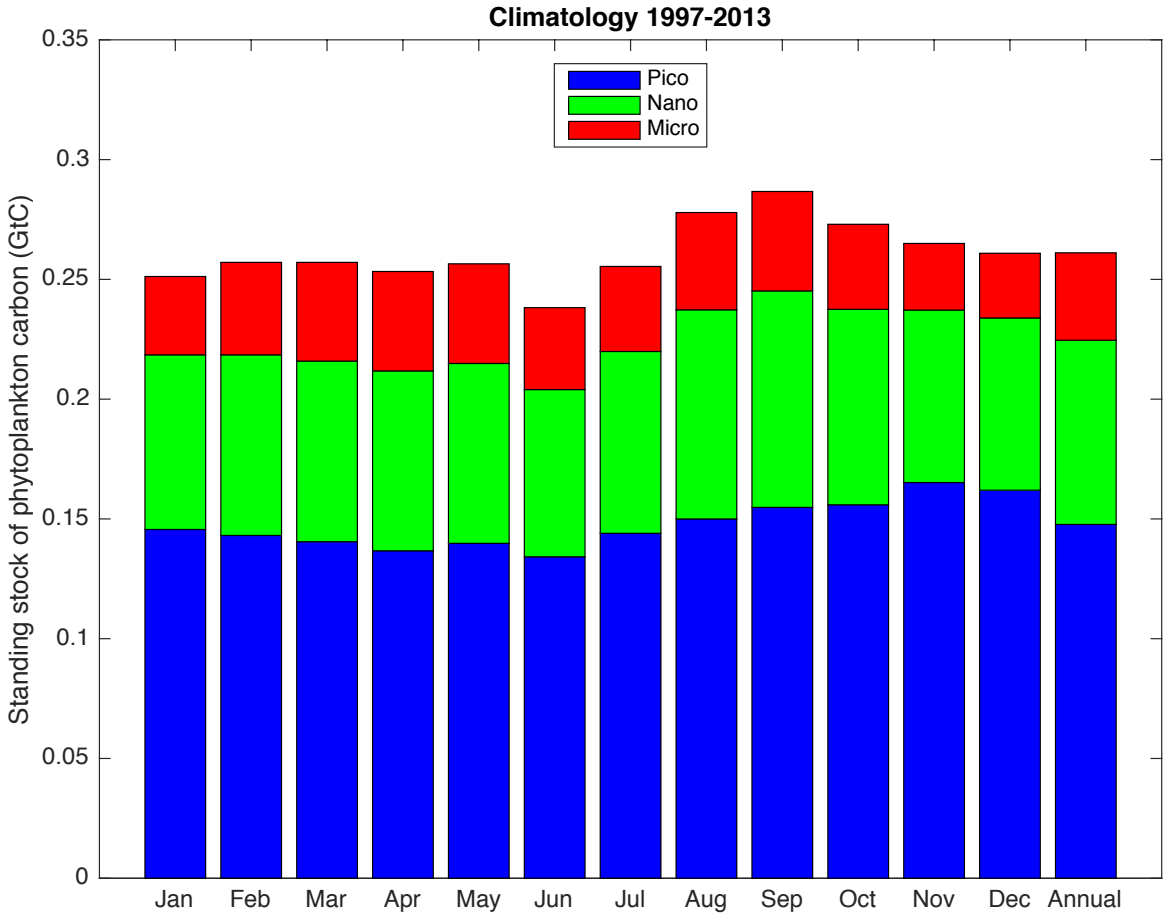
Roy et al. 2013, Remote Sensing of Environment

Bio-optical algorithm to compute autotrophic C



Roy et al. 2016 (in review) Remote Sensing of Environment

Bio-optically-derived autotrophic C in 3 size classes



Roy et al. 2016 (in review) Remote Sensing of Environment

Phytoplankton C: integrating *in situ* and RS data

Approaches:

- Develop bio-optical algorithms using multi-spectral signals from ocean colour
- **Incorporate ocean colour data into 'ecosystem models' through data assimilation**

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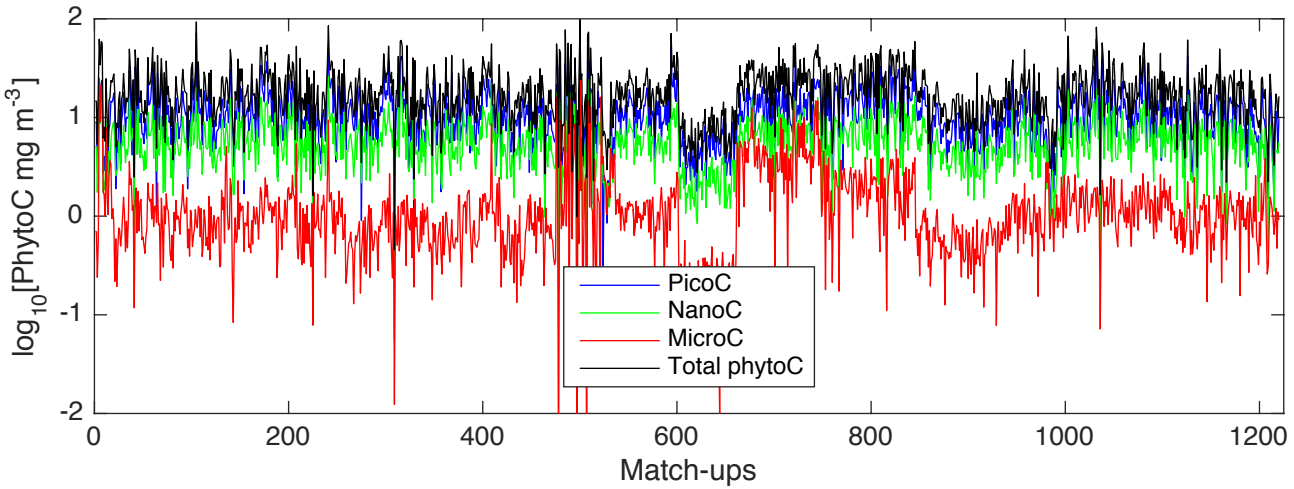
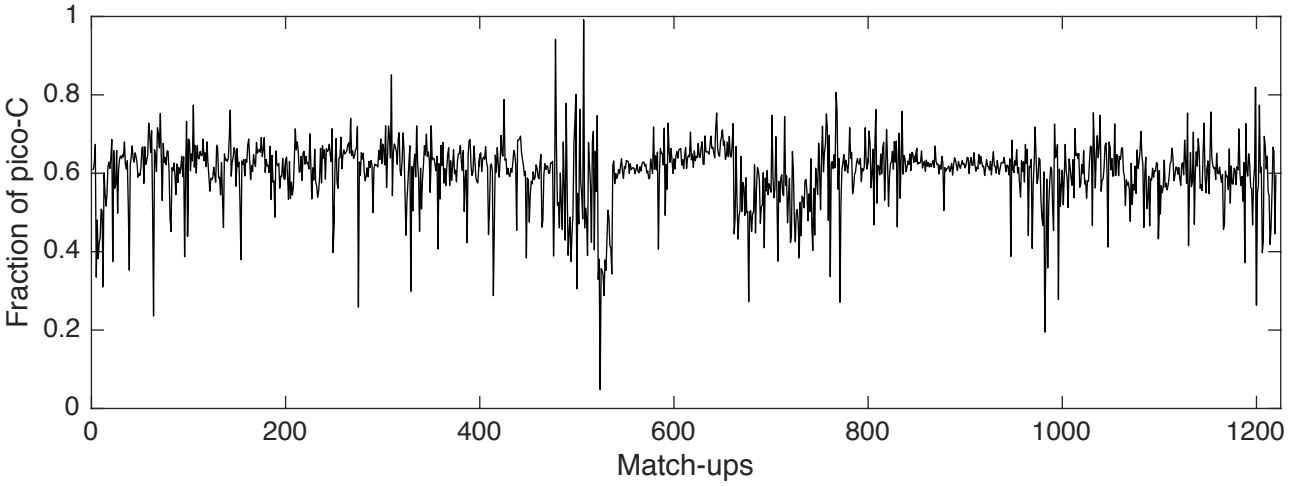
PSC and total phytoplankton C for match-up points





Roy et al., in preparation

Way forward to improve phytoplankton C estimation

- Inter-comparison of phytoplankton C estimates from various methods against *in situ* data:
  - POC-based,
  - PSD-based,
  - absorption-based
  - and DA-based.

  (Ongoing through ESA-POCO)

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Future challenges-1: Uncertainties in RS inputs

- Variety of RS products, multiple satellites sensors
- Reliability of the merged products
- Uncertainty budgets often unavailable
- Some uncertainties OC-CCI processing quantified, not used widely
- Data on coastal ocean still less reliable
- Bio-optical algorithms target open oceans

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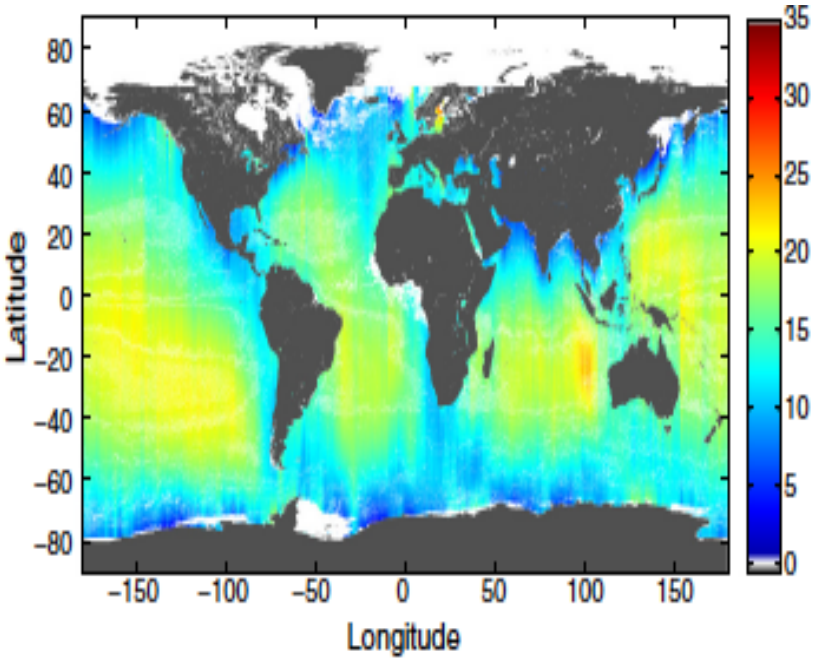
Future challenges-2: Uncertainties in model selection

- Not all bio-optical models estimate the effects of uncertainties in input variables
- BGC models formulations differ from each other
- Inputs from physiological models (e.g., Geider models) often not included

Uncertainty % in Micro-PSC



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Future challenges-3: Issues with *in situ* data

- *In situ* pico-C values were not directly measured, Pico-C assumed C-per cell values
- Unavailability of *in situ* phytoplankton C in other PSCs, making appropriate validation difficult
- Unavailability of *in situ* phytoplankton total C (POC is available)
- *In situ* bio-optical data (e.g. absorption phytoplankton) limited

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Take-home messages

- Uncertainties in phytoplankton C estimates are higher that those for POC or PP
- Bio-optical algorithm and DA to OBGC can provide independent estimates of PSC-C from ocean colour
- Improving the quality and consistency of ocean colour data required to reduce uncertainties
- Validation data for phytoplankton C still insufficient
- More *in situ* data on phytoplankton C, PSC, and bio-optical variables are required (bio-argo?)

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