→ ESA ADVANCED OCEAN SYNERGY TRAINING COURSE 2019

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Marine Organic Carbon from Space

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European Commission · Copernicus Europe's eyes on Earth · EUMETSAT

Who am I?

Dr Hayley Evers-King

Currently: Marine Applications Expert at EUMETSAT (user support and training for Copernicus marine data S-3 (J-3, S-6 + CMs)).

Previously: Developing marine applications of EO (Ocean colour and synergy)

- Cal/Val and algorithm development
- Sensitivity of reflectance to particles (size, structure, PFTs)
- HABs and coastal biotoxins, Heat fluxes
- Model validation
- **Ocean carbon**

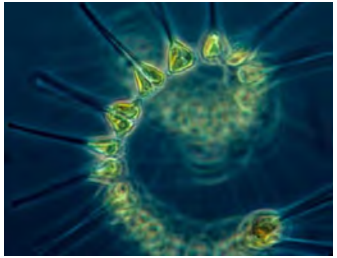
Aims of this lecture

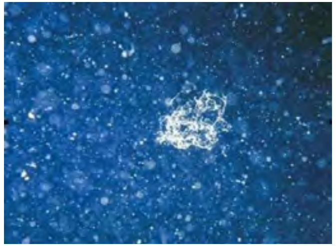
OBJ-1: Understand the major dynamics of marine organic carbon pools, and why it is important to monitor them.

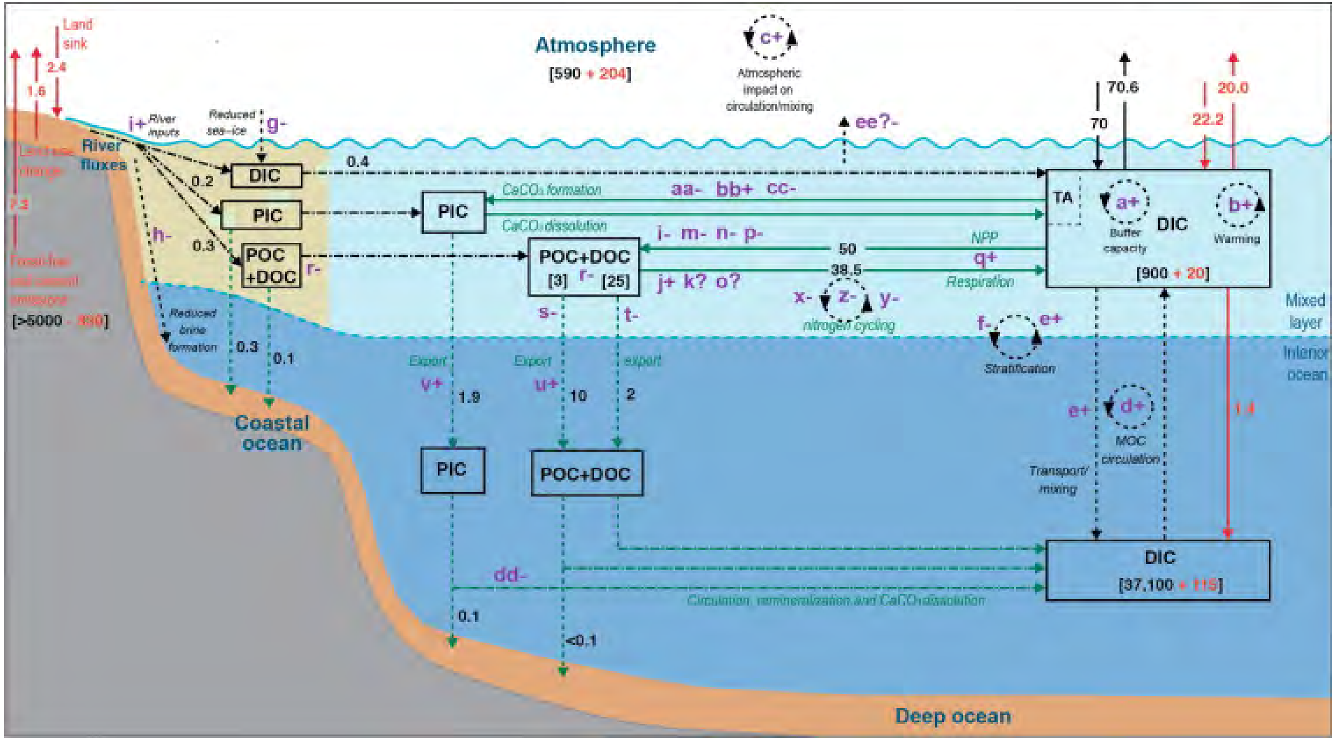
OBJ-2: Understand how satellite sensors can allow us to observe the marine organic carbon pools, current limitations and future research directions.

OBJ-3: Show how satellite data fits in to a wider ocean observing system for conducting research on marine carbon pools.

What is marine organic carbon?







Dissolved Organic Carbon (DOC)

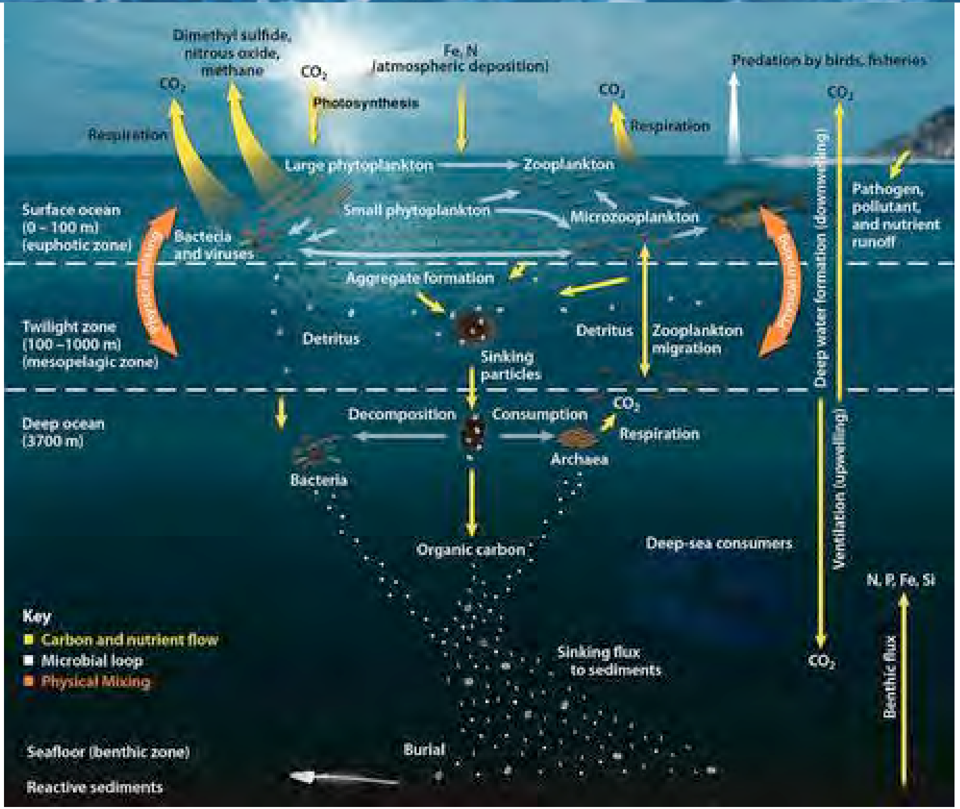
- Major reservoir of active Carbon (estimates between 600-700 PgC)
- Major role in physical transport of carbon from surface to depth, and in metabolism of heterotrophs.
- Sources:
  - Land drainage (allochthonous – distance)
  - Released by plankton (autochthonous - indigenous)
- Classified by reactivity (refractory or labile)
  - Different roles in ocean biogeochemistry.
    - Labile (transient (hr-day) smaller)
    - Refractory (slow cycle – up to 40,000 yrs)

Particulate Organic Carbon (POC)

- Relatively small pool (0.43 Pg C in sunlit ocean, 2.28 Pg C over 200m)
- But responsible for large and important fluxes including to DOC and DIC pools.
- Both marine and terrestrial origins.
- Subcomponents:
  - Terrigenous particles (source on land)
  - Phytoplankton
  - Detrital particles

Why do we care?

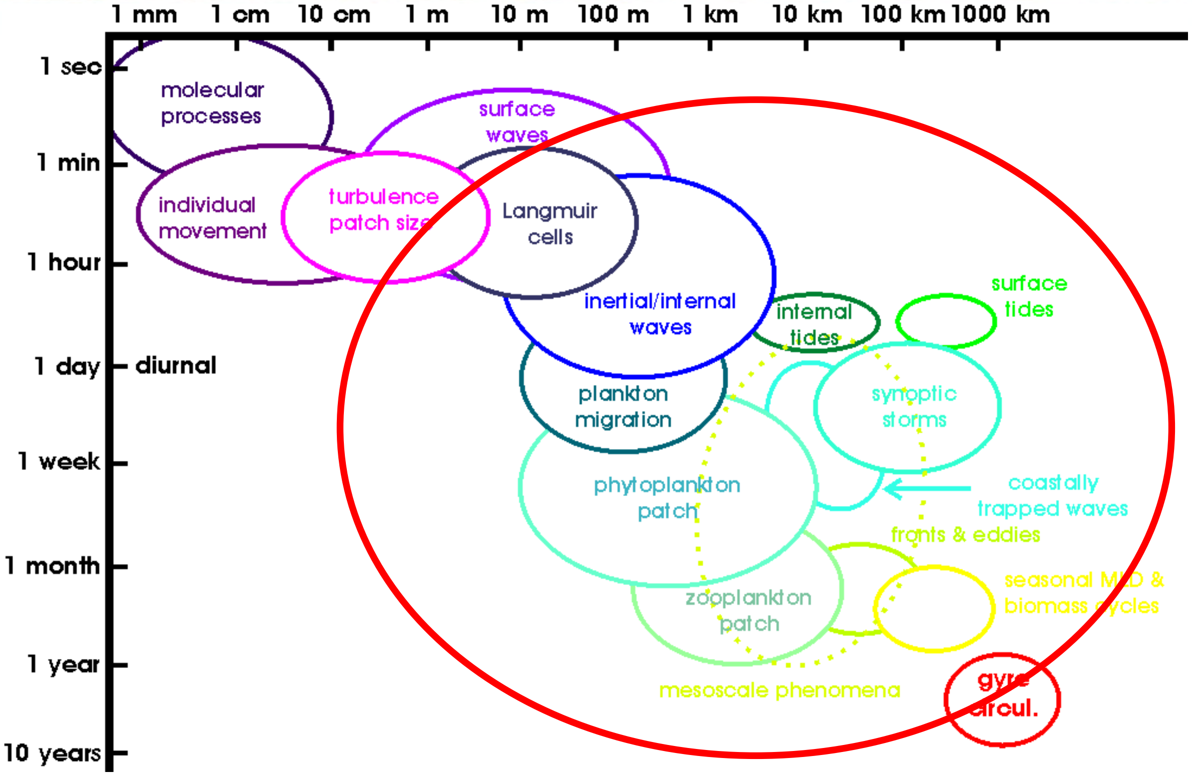
- Involved in key Earth system processes:
  - Primary production in the oceans
    - Key connection to ecosystem status
    - Connection to fisheries
  - Ocean role in global carbon cycle
    - Physical pump
    - Biological pump
    - Climate Change



What do we need to know?

- Where is it?
- What type is it?
- How much is there?
- How is it changing over time?
- How sure are we?

....Earth Observation data (especially when used in synergy) can provide options to address these requirements.



Is marine organic carbon 'visible' from space?

Fundamental question(s):

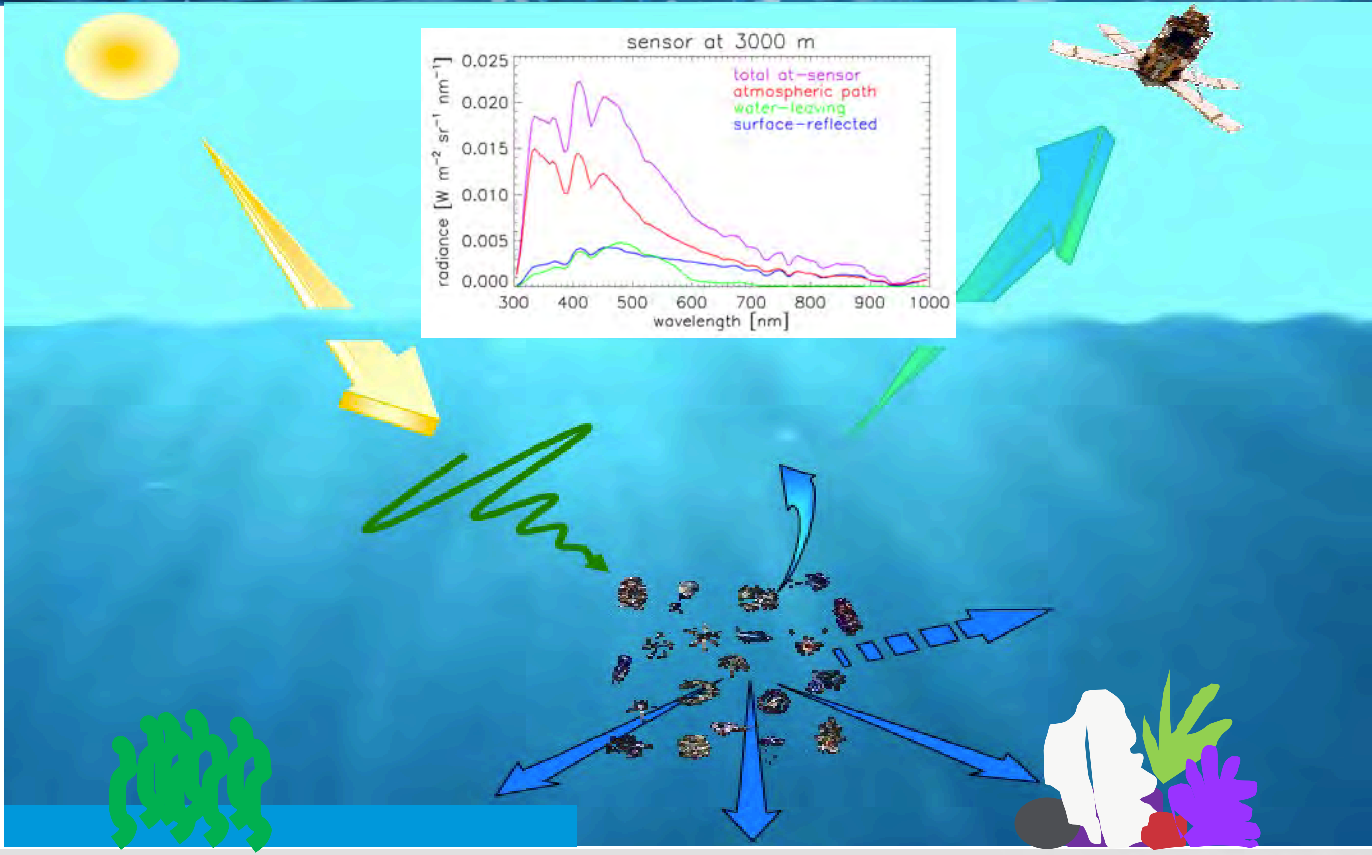
Does marine organic carbon have some kind of signal we can detect using EO methods?

Does it interact with the incident light field?

Are there other things that do, that could be used as a proxy?

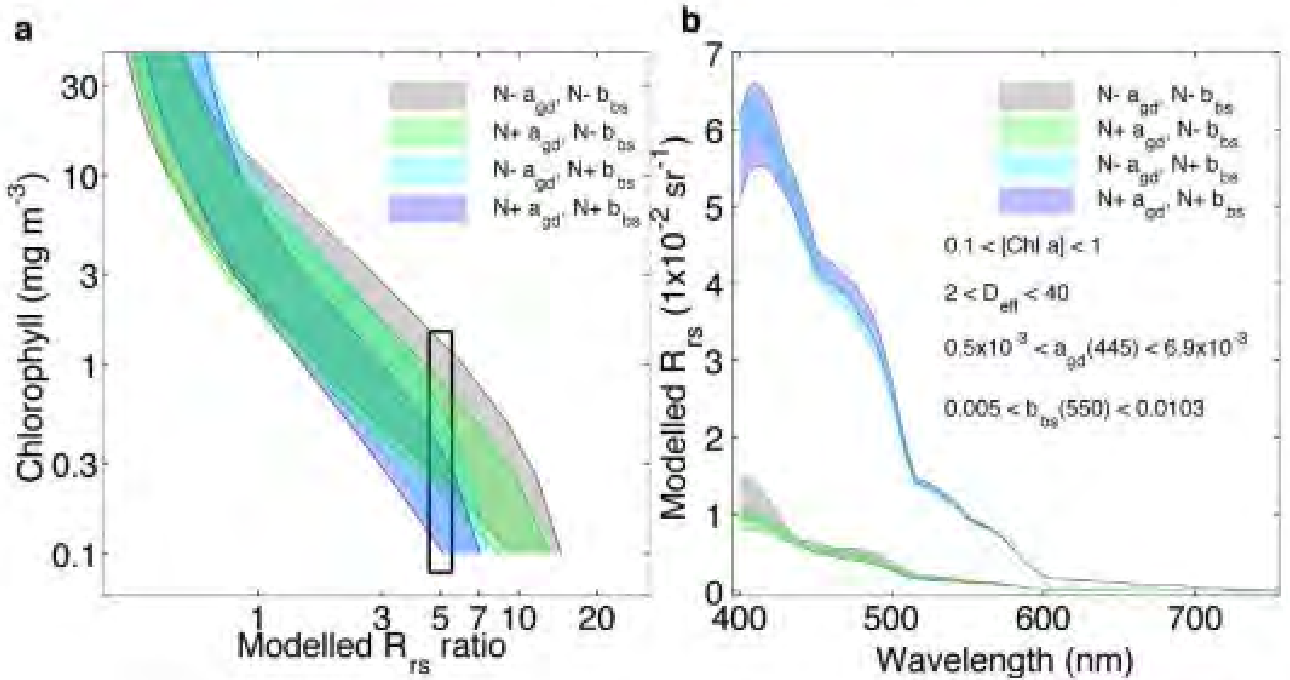
Some notes on the use of ocean colour data

- Measuring reflected light which is a combination of all processes going on in water (a and b)
- Challenges:
  - A. Correction
  - Distinguishing components



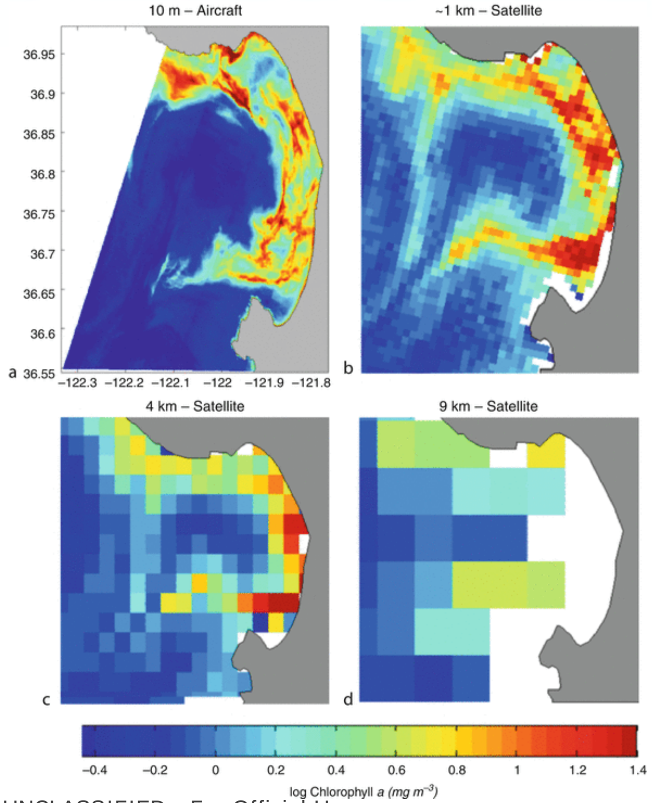
The challenges of ambiguity

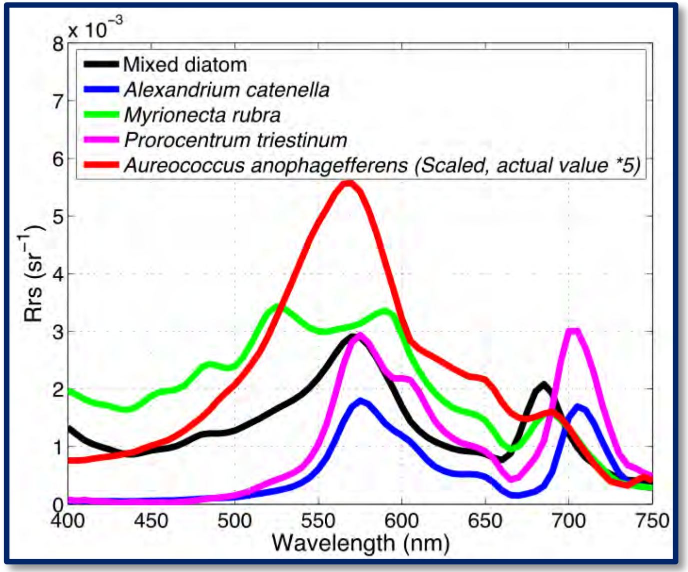
The challenges of ambiguity



Evers-King et al., 2014

Which satellites/products?

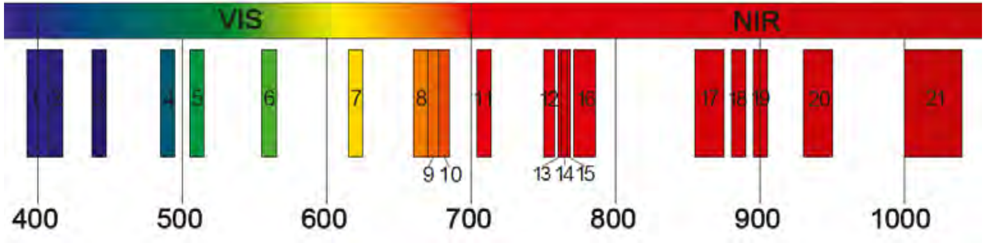




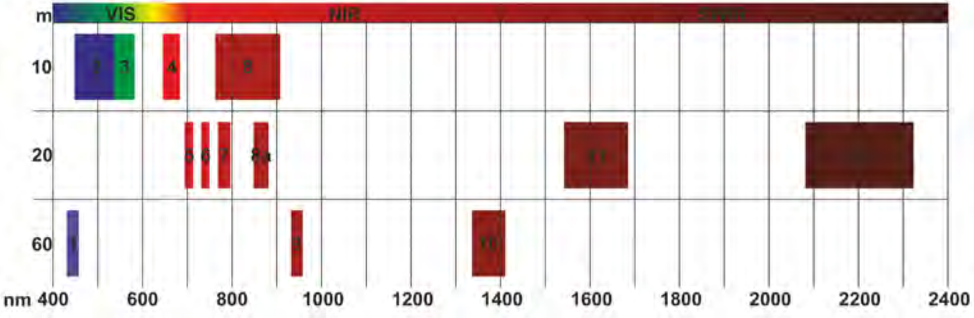
RESOLUTION, RESOLUTION…. SENSITIVITY!

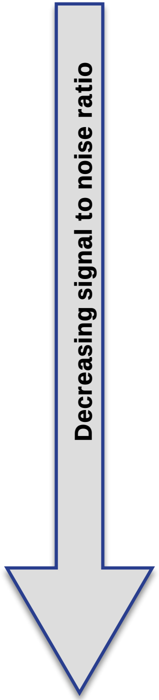
Which satellites/products?

Sentinel-3 OLCI:



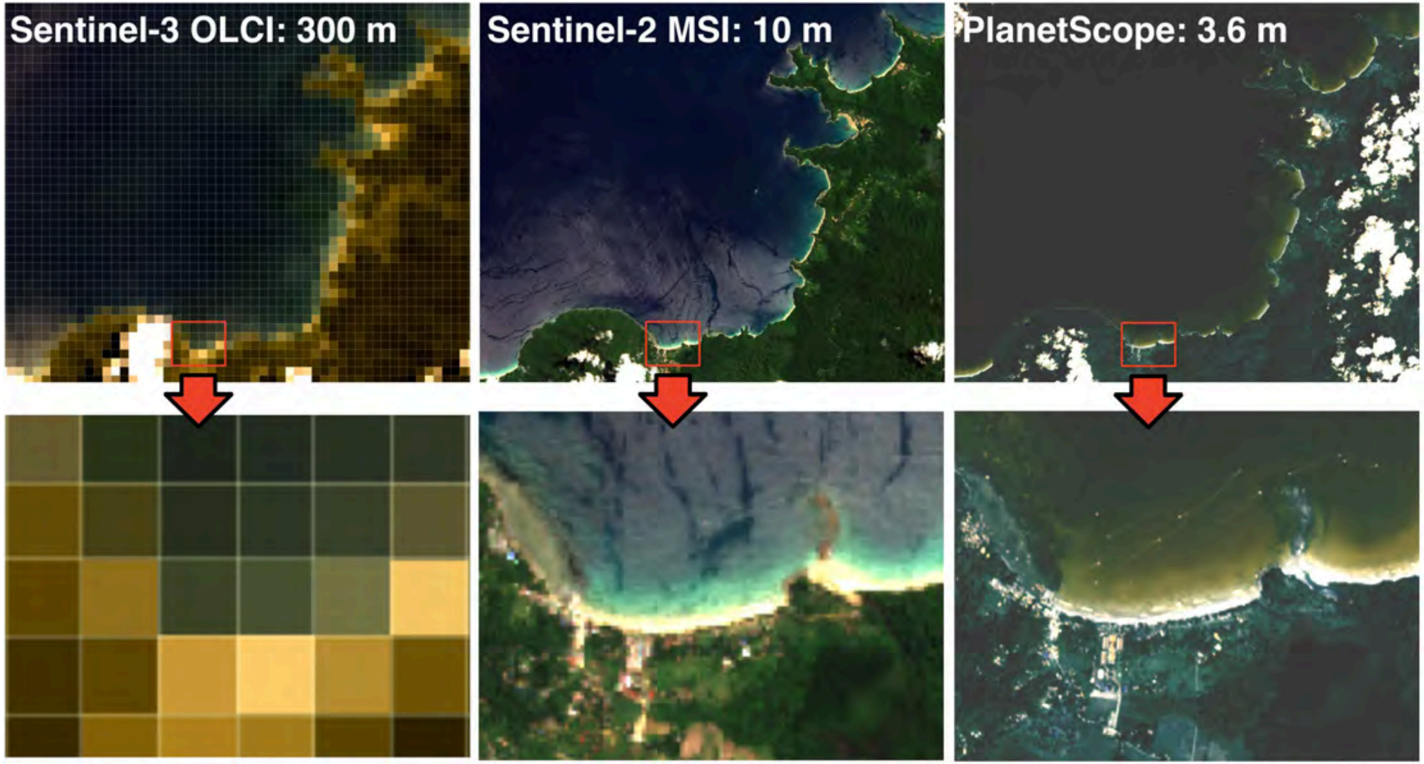
Sentinel-2 MSI:



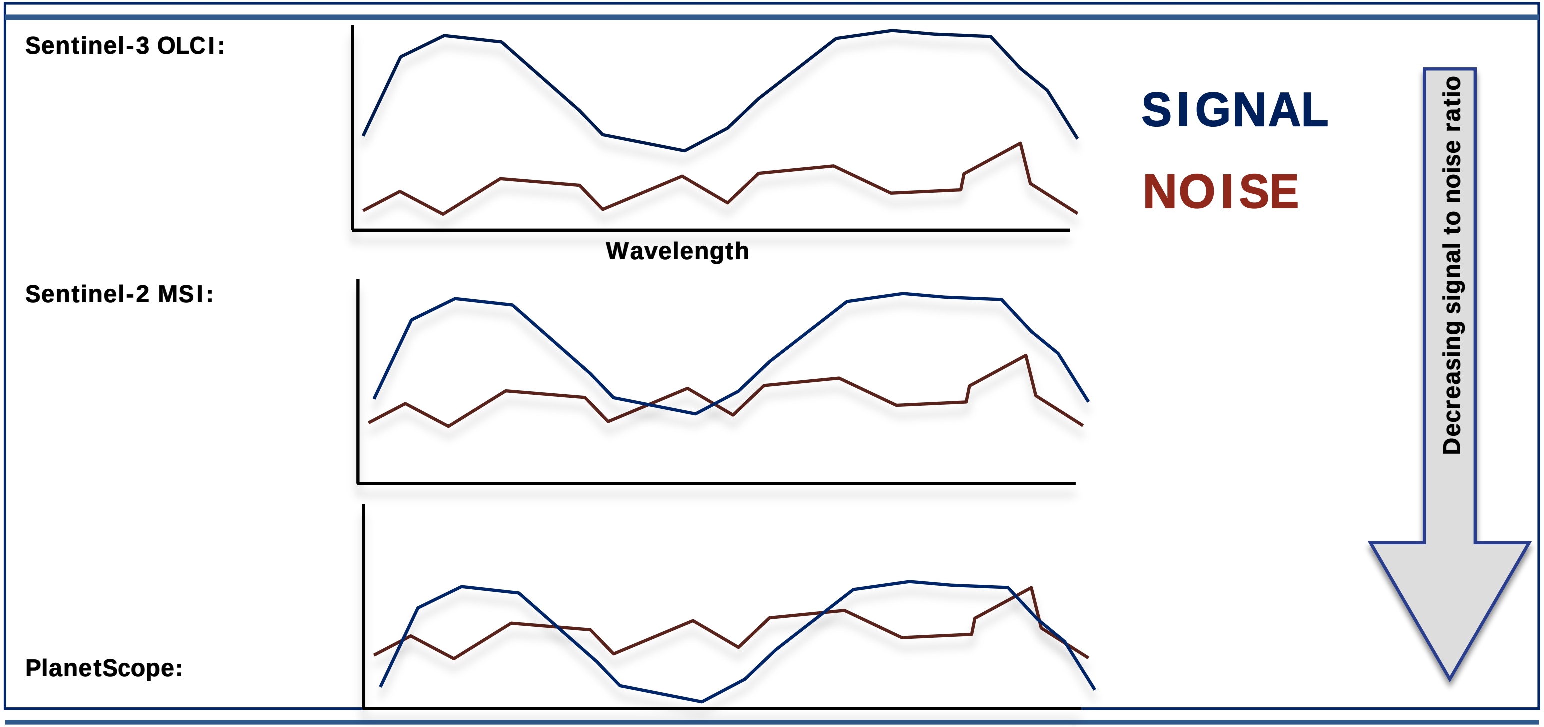


PlanetScope: Red, Green, Blue, (1 x NIR)

Which satellites/products?

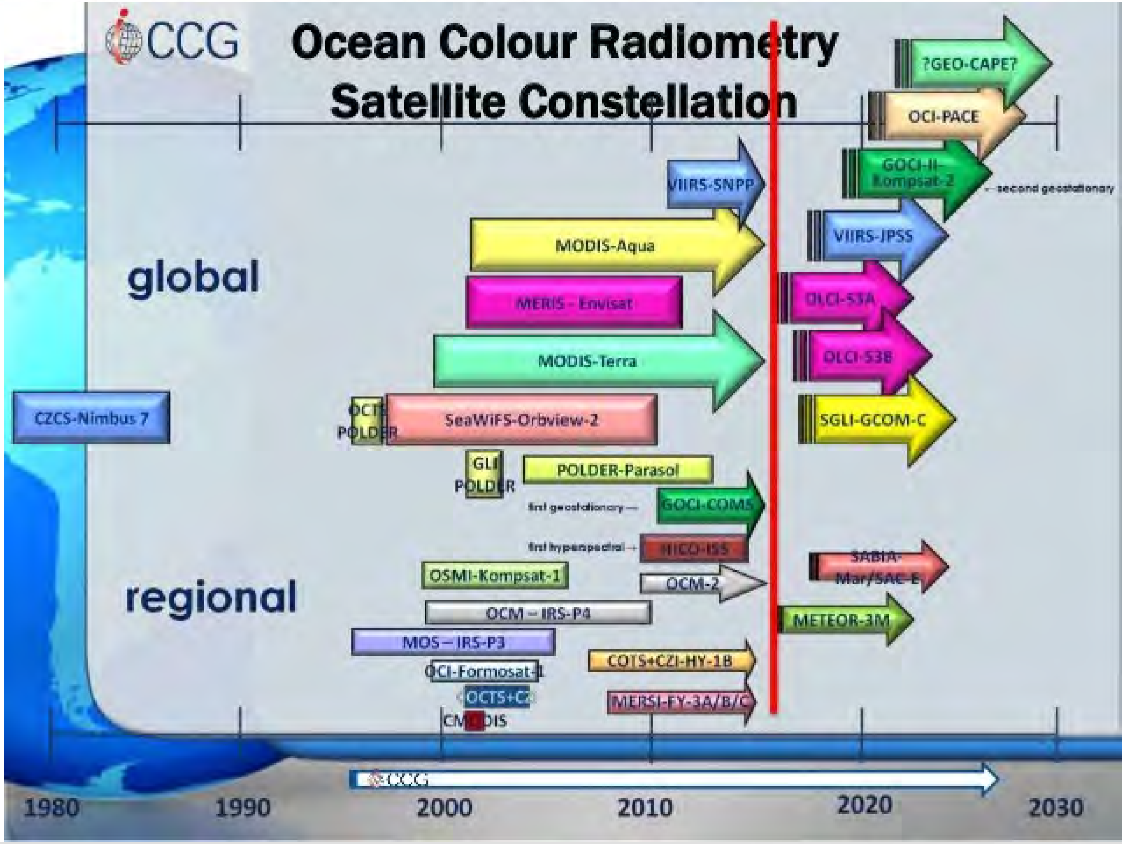


Which satellites/products?



Which satellites/products?

- Many, many satellites!
- Different characteristics
- Continuity is a problem
- Growing development of multi-sensor products (L3,L4) e.g. OC-CCI and CMEMS



Is marine organic carbon ‘visible’ from space?

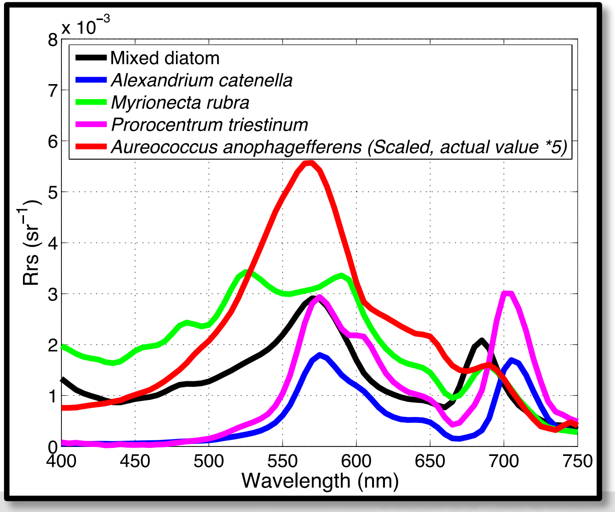
- What characteristics does DOC have that we can measure?
  - No ensemble signature (☹)
  - Coloured dissolved organic matter does have a distinctive absorption (*a*) spectrum (though often also combined with particulate detritus)
  - How easy is it to link absorption with concentration?
  - Can we separate sources/types?

Color caused by dissolved matter: tannins

Is marine organic carbon 'visible' from space?

- What characteristics does POC have that we can measure?
  - All about particles:
    - C_p, B_p, b_{bp}, and a all affected by particle abundance, as well as size, shape, and structure.
  - Some sub-components of POC have distinctive characteristics themselves:
    - Phytoplankton:
      - Chlorophyll linked with abundance
      - *a* and b_b affected by size, structure, shape.
  - But some don't (or we aren't sure!)

Color caused by suspended material: sediment



- Huge body of work developing methods for MOC measurement, since early days of most EO techniques.
- Some single data type (e.g. ocean colour, but often using multiple variables).
- See Jamie's earlier lecture for pCO_2, DIC and PIC but note the links between the pools!

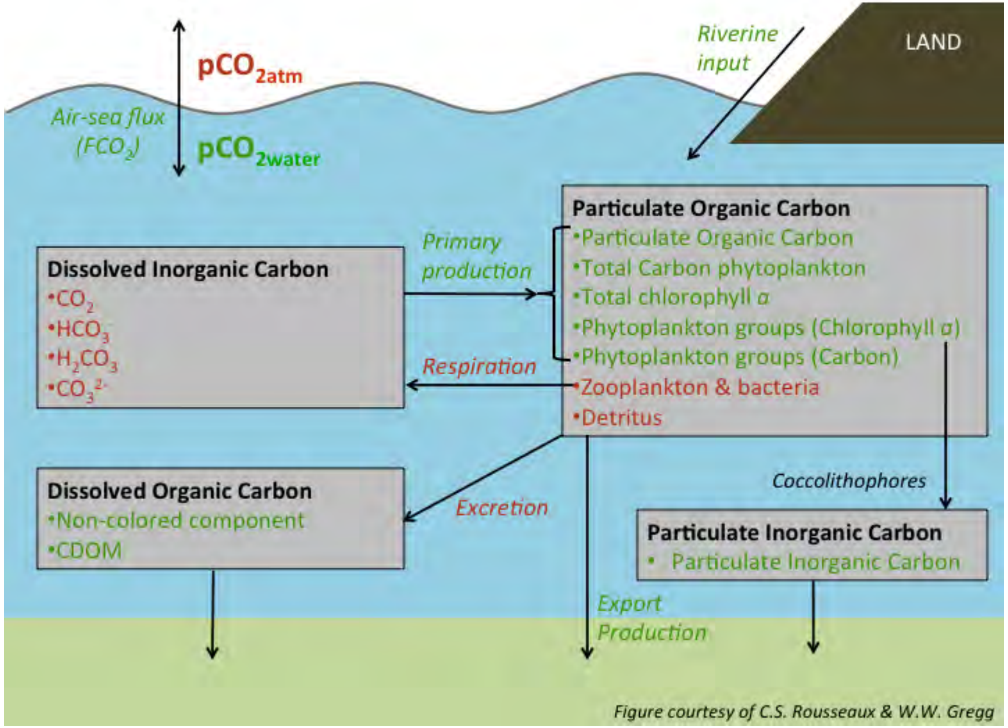
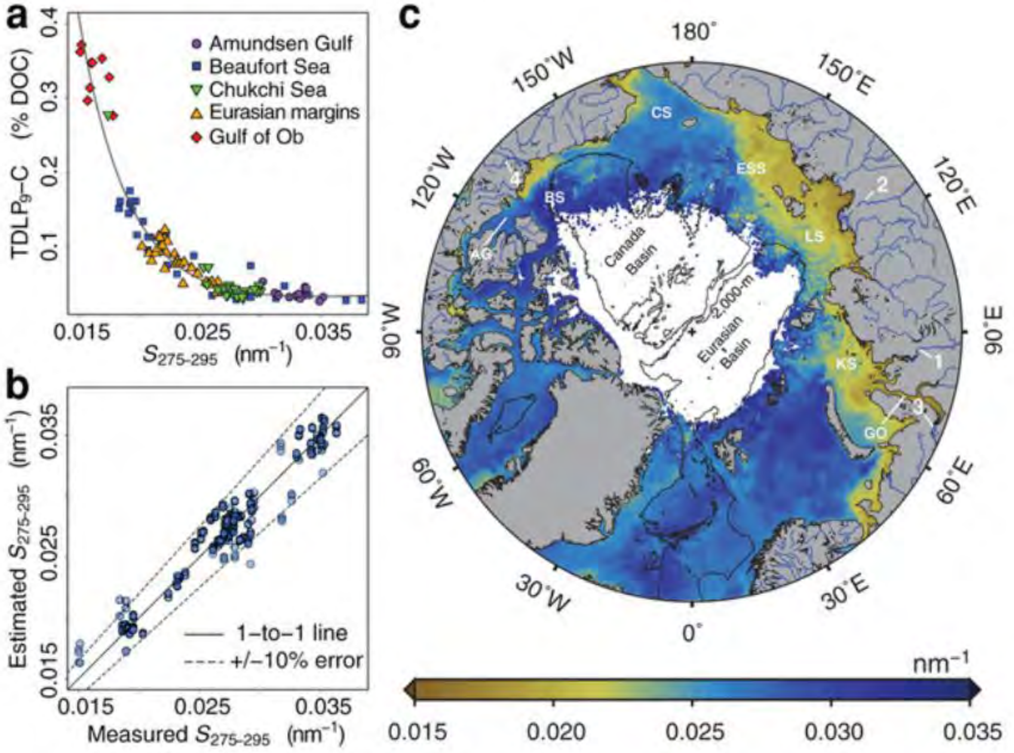


Figure courtesy of C.S. Rousseaux & W.W. Gregg

EO approaches - DOC

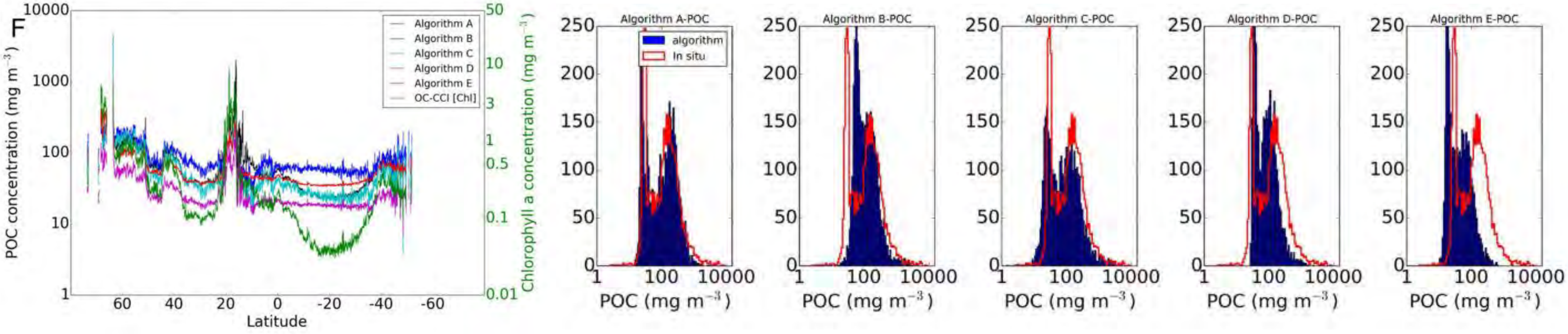
- Empirical relationships between absorption from CDOM (including slopes of spectra).
- Proportionality in the open ocean (?)
- Links with salinity
- Highly regionally variable.



Fichot et al., 2013

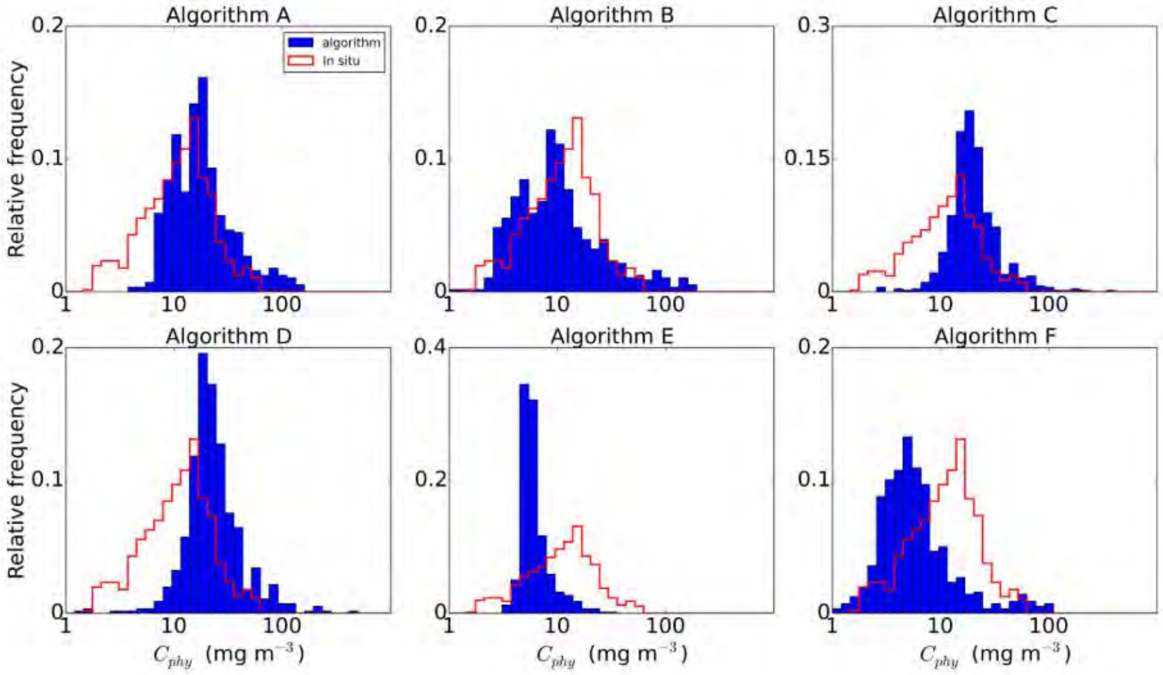
EO approaches - POC

- R_{rs} based – Stramski et al, 2008 (in NASA processing)
- b_{bp} based – Stramski et al., 2008
- b_{bp} and Chl based - Loisel et al., 2002
- $K_d(490)$ and Chl based – Gardner et al., 2006

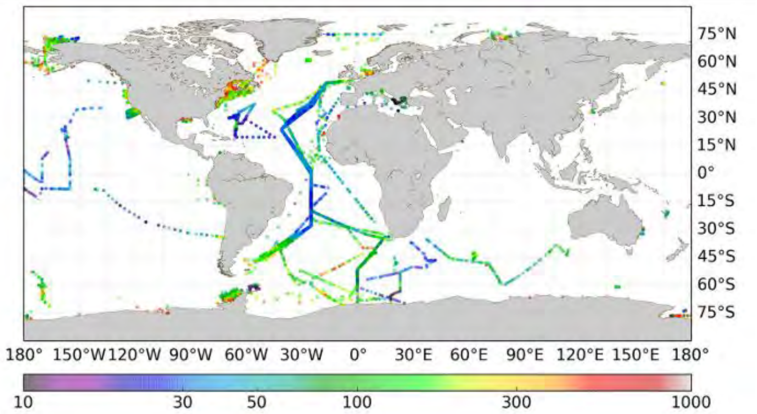


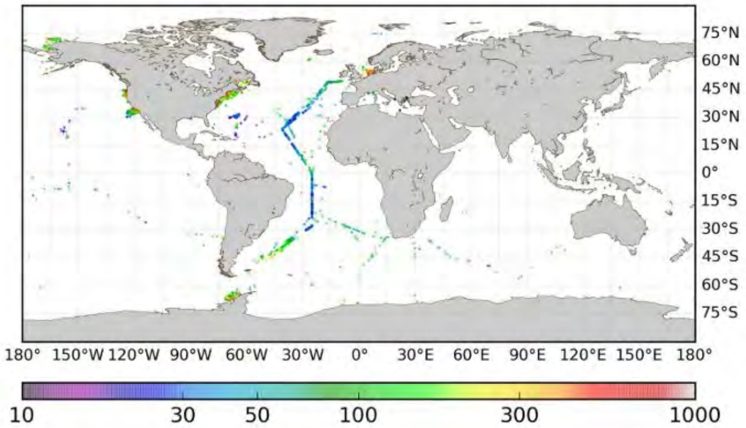
EO approaches – Phytoplankton carbon

- Chlorophyll-a based
- Backscattering based
- Allometric: Absorption and backscattering, include some parameterisation of size structure



- **In situ data**
  - Essential for understanding of underlying processes that make EO of marine organic carbon possible
  - Variable in terms of:
    - Reliability and relevance of methods
    - Temporal and spatial coverage.

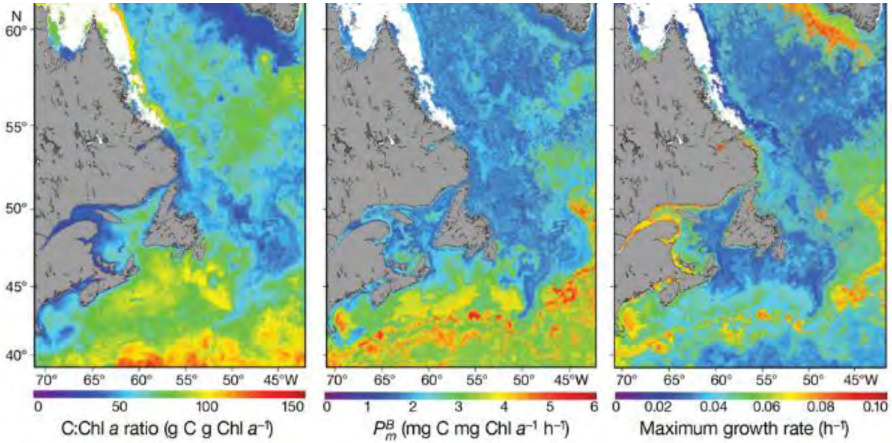


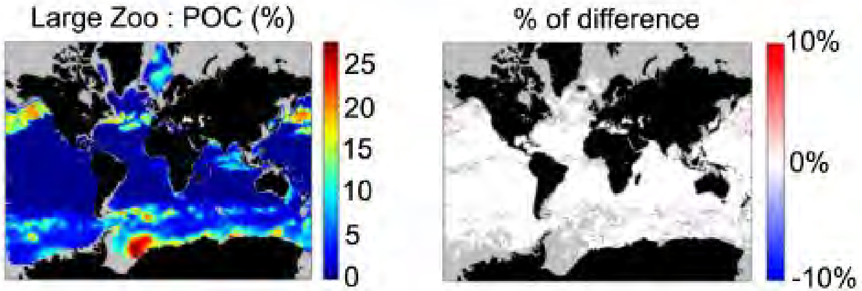


Combining EO data with other methods

Modelling:

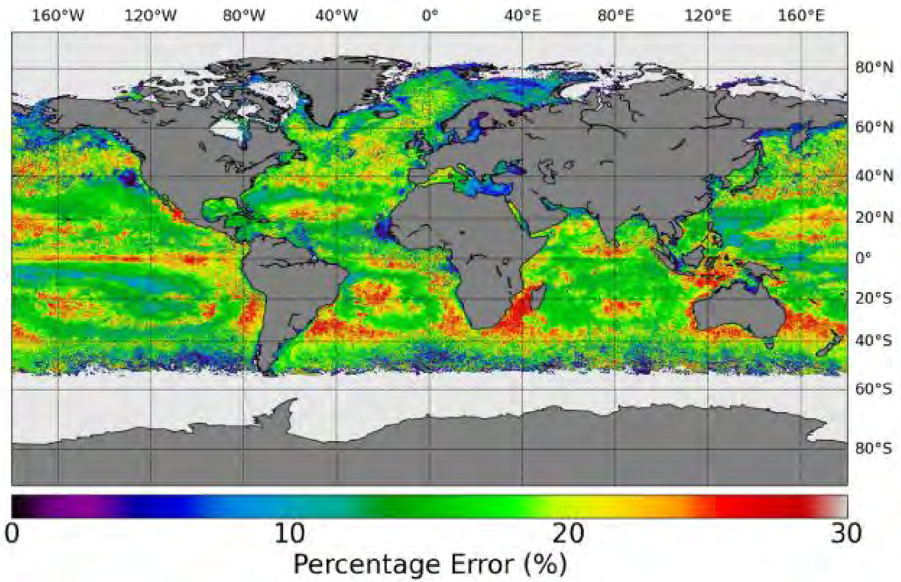
- EO can help validate models
- Essential approach for:
  - Developing mechanistic understanding
  - Considering future changes
  - Extending what EO can tell us:
    - Assimilation
    - PP, C:CHL, export





Errors and uncertainty in marine organic carbon measurements from EO

- Topic of increasing relevance across EO, especially as we move towards operational approaches and use in decision making.
- Modellers particularly need this for assimilation.
- HOW?
    - Best practice: GUM
    - Other options:
        - Assign errors based on water class approaches (ESA-OCCCI approach)



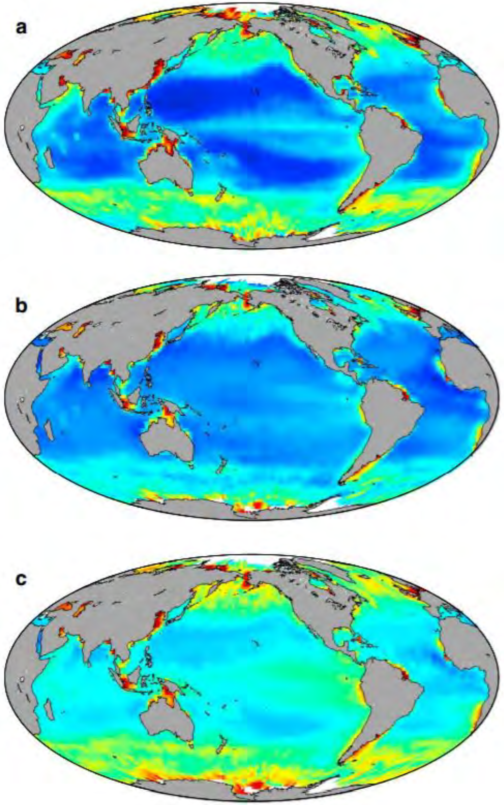
Which data to choose?

- L1: For complex waters where limitation is atmospheric correction
- L2: For high spatial and temporal resolution application e.g. looking at dynamic coastal environments
- L3: When you need a time series (and don’t have the challenges above!), or when you need to combine data sets.
- L4: Great for model assimilation and complex statistical analysis (gaps!)

NOTE: not all variables you need will be available everywhere ☹

The future of marine organic carbon and EO

- New products/variables:
  - IOPs
- New EO methods:
  - LIDAR
  - Hyperspectral
- New algorithm approaches:
  - Machine learning
- New synergy options:
  - Atmospheric composition
  - Beyond EO:
    - Model assimilation



Behrenfeld et al., 2013

Key points

- Much information about marine organic carbon can be obtained from EO.
- Primarily focused around optical methods (visible ocean colour)
- Subject to all constraints:
    - Atmospheric correction
    - Sensor/product selection
    - Ambiguity of the ocean colour inverse problem
- Methods using R_{rs}, IOPs, and geophysical products.
- Can potentially combine with salinity and other EO sources.
- Many future research directions and a major priority for future missions.

Acknowledgements

- Much of my own understanding, and much of work shown here was a result of the ESA Pools of Carbon Project (Science Exploitation ofOperational Missions (SEOM) following Contract: 4000113692/15/I-LG)
- Collaborators on that project and subsequent papers – notably Dariusz Stramski and Hubert Loisel.
- EUMETSAT for funding my participation today.
- Copernicus for data in subsequent practical

OBJ-1: Understand which ocean remote sensing data can be used for making estimates of ocean organic carbon pools.

OBJ-2: Work with a variety of current data sources in Python and apply and compare different algorithms.

What are we working with?

- Jupyter notebook – Marine_Organic_Carbon_OTC2019_HEK
- Uses:
    - OLCI data (Sentinel-3)
    - Suggested further applications for Copernicus Marine service Chlorophyll data (based on OC-CCI processing).
- Demonstration of notebook, then time for you to try and run it, adapt it if you like, and ask questions.
- Additional challenges (for now or later) – in Jupyter notebook.