Ocean Colour

Contributions to Meeting
UN Sustainable Development Goals

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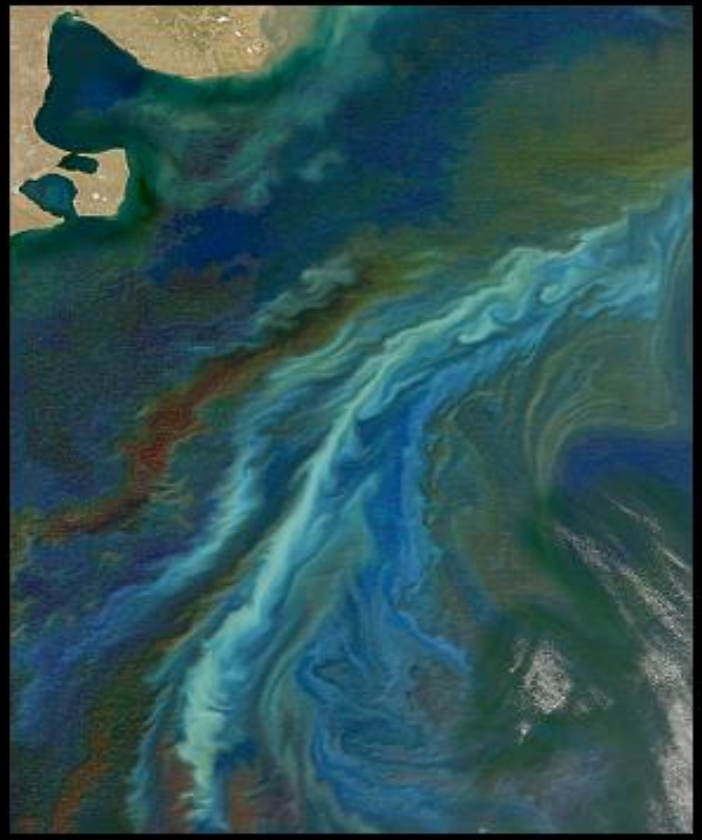
Barents Sea



Patagonian Shelf

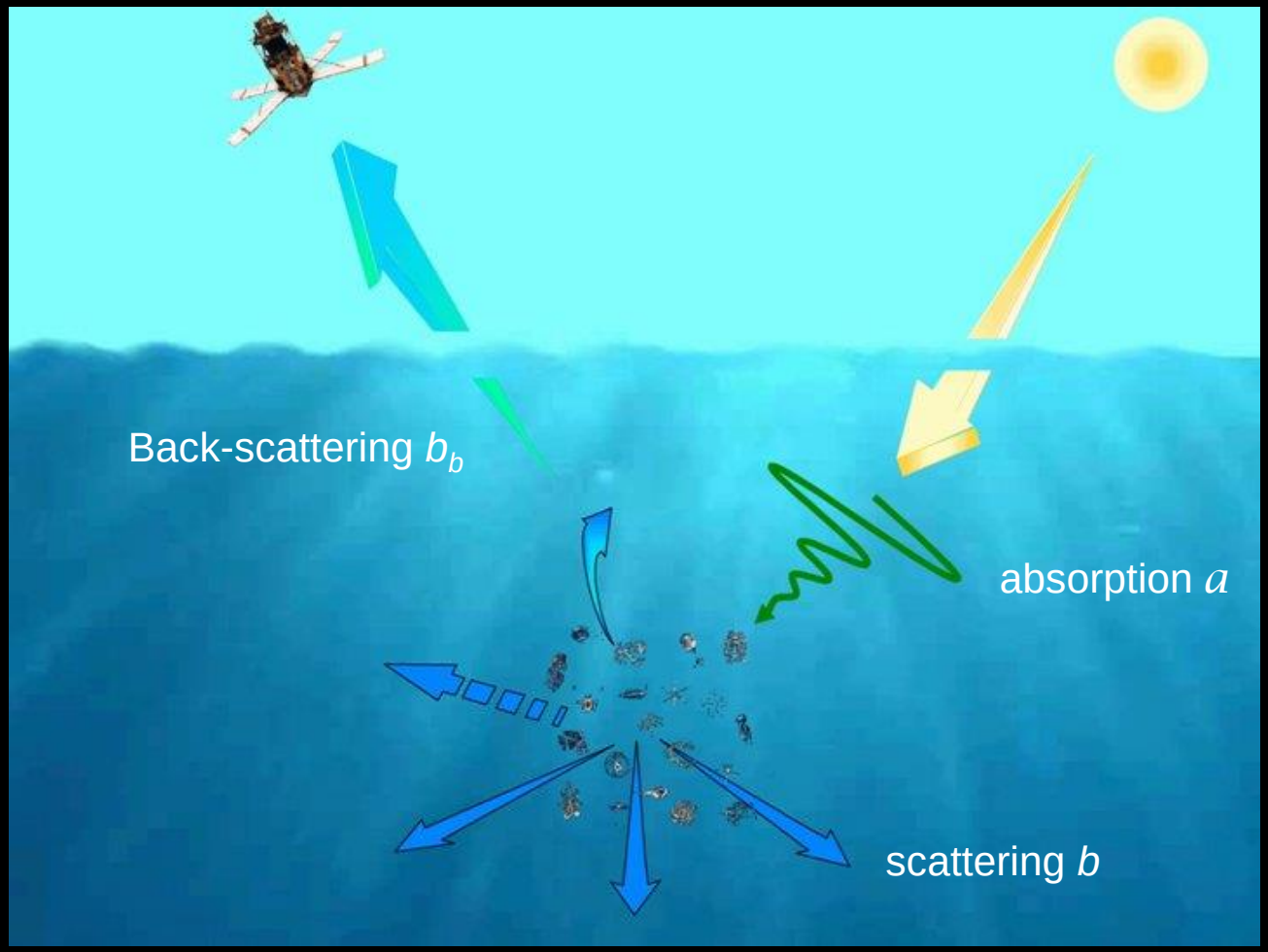
Colour of Aquatic Systems

as seen from ship at different times and places

From CEOS Report 2018, Images Courtesy CSIRO

- Everyday observation: colour of water changes with time and place
- What is responsible for these changes?
- Can we quantify the responsible agents?
- Why should we care?

Absorption and Scattering of Light in Water



Absorption and Scattering determine the fate of photons that penetrate into the ocean:

These processes depend on wavelength of light, and can be described by strict physical theory.

The water-leaving radiance (ocean colour signal) contains information on phytoplankton, suspended sediments, dissolved organic material and bottom type (in shallow waters). For scientific applications, these effects have to be quantified.

Optical properties of water and its constituents

Sea water and its principal constituents

Pure seawater

Particles

Phytoplankton

Non-algal

Dissolved matter

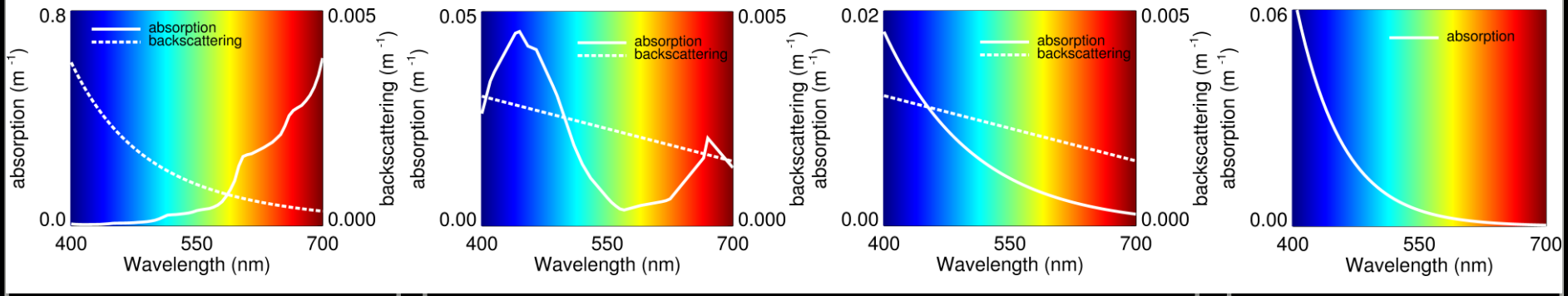
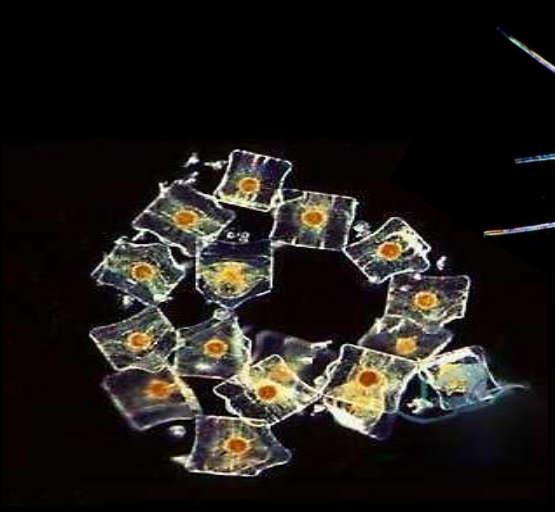


Figure from Bob Brewin

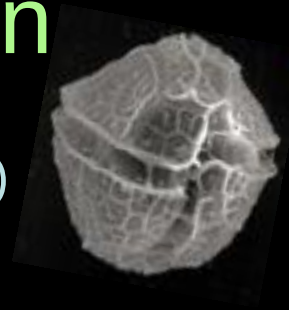
Ocean Colour: What controls it?

- Colour of the ocean contains latent information on the abundance of the marine microflora (phytoplankton)
- Invisible to the naked eye at close quarters, but huge collective impact visible from space.

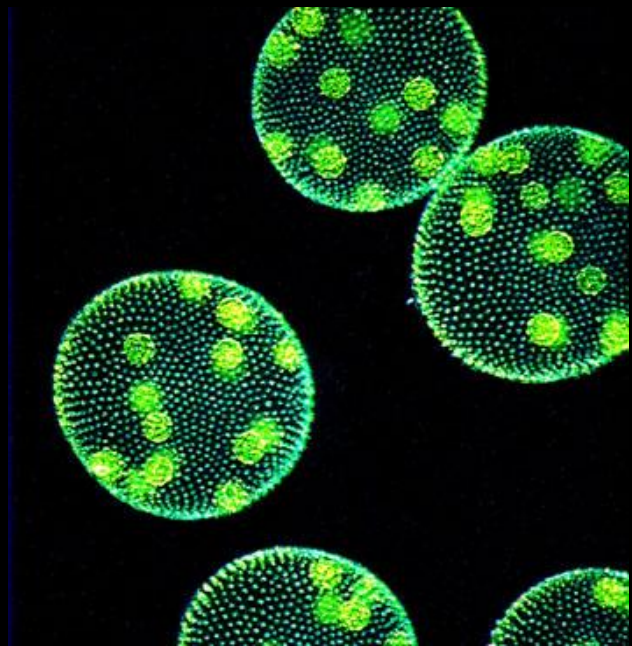


Phytoplankton bloom in the North Sea off the coast of Scotland. Image captured by ESA's MERIS sensor on 7 May 2008.

Some properties of phytoplankton

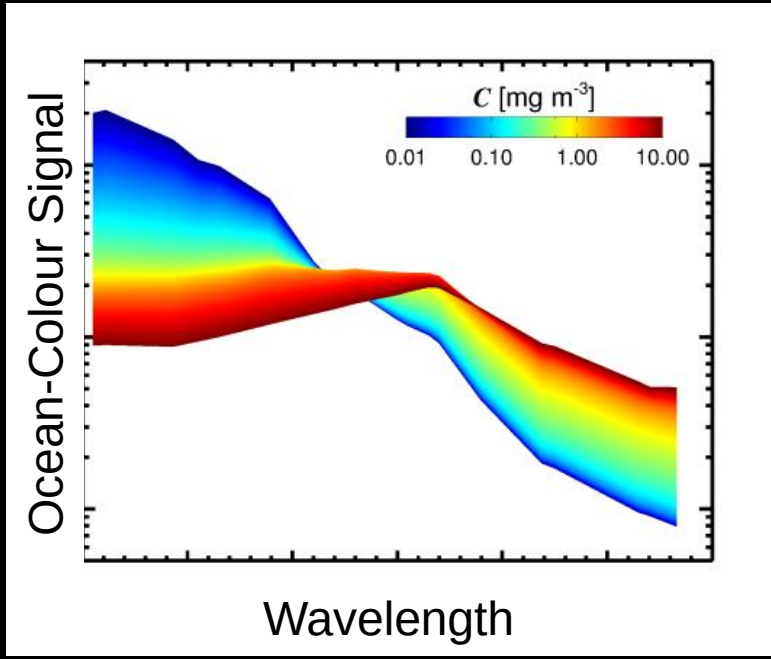


- Predominantly single-celled and microscopic (0.5 to 250μm)
- Green plants (chlorophyll pigments, photosynthesis)
- Mostly confined to the surface (illuminated) layer
- Ubiquitous and abundant (up to 10^5 cells ml^{-1})
- Control colour of water (detectable from space)
- Consume carbon dioxide
  (ocean carbon cycle, climate change)
- Collective metabolism enormous
  (50 x 10^9 tonnes per annum)
- Slightly negatively buoyant

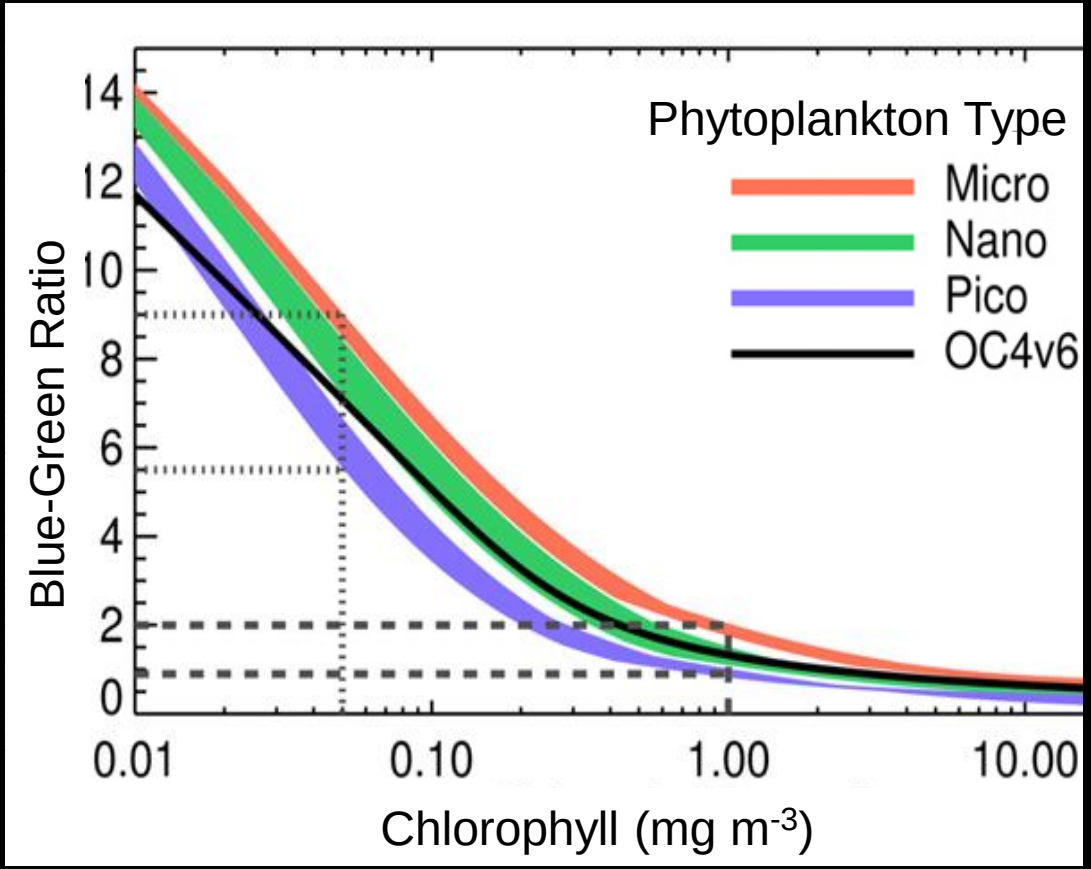


In the open ocean:

phytoplankton are the major independent factor responsible for changes in ocean colour



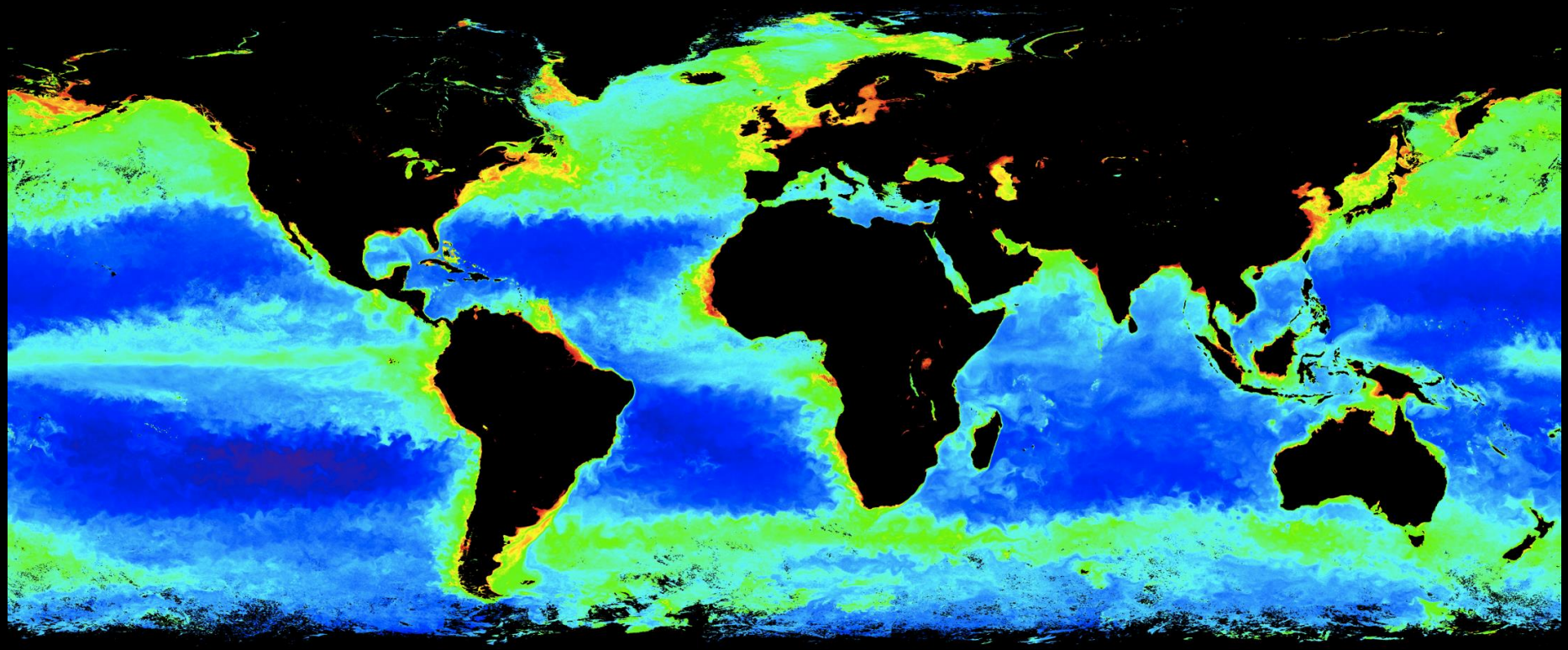
From Bob Brewin



Sathyendranath et al. 2017

Theoretical considerations and empirical evidence underpin algorithms for estimating chlorophyll concentration and the contributions of major phytoplankton types to the total concentration.

Chlorophyll concentration mapped from ocean-colour sensors in space
Merged Product



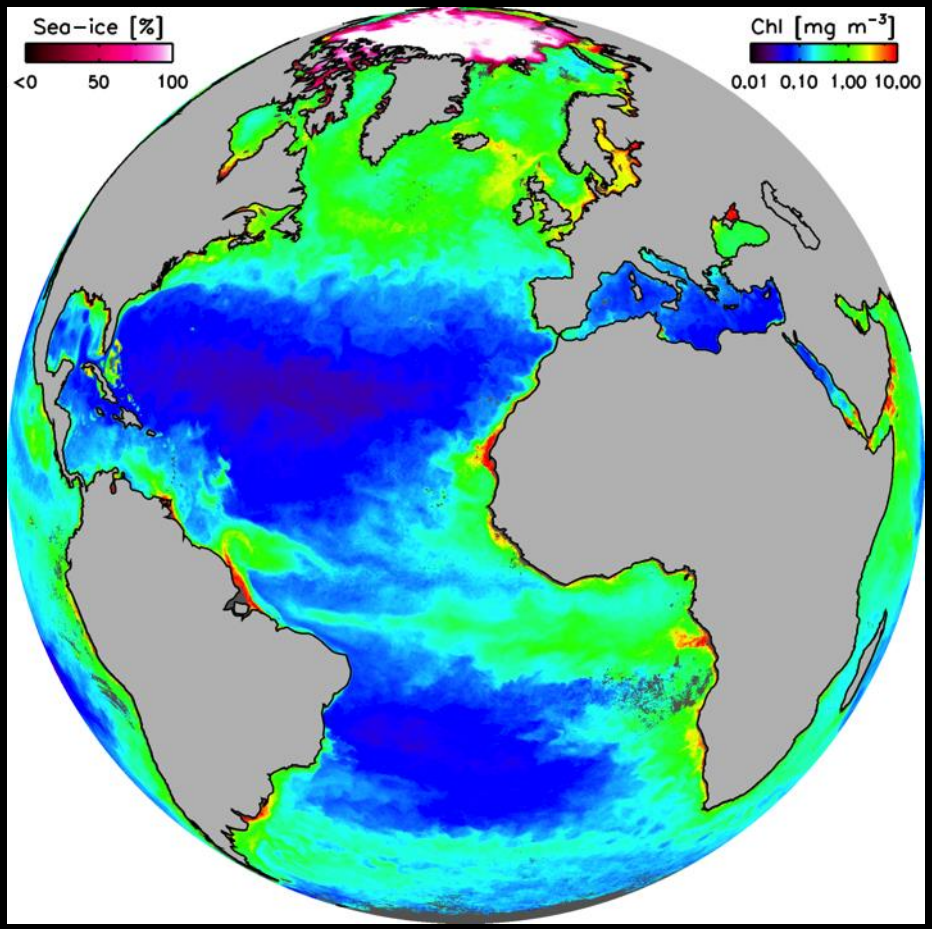
ESA OC-CCI V3

Ocean Colour for UN Sustainable Development Goals

The 16 SDGs are an expression of intergovernmental aspirations to make a better global society. Ocean colour is useful, and is being used, in helping meet the goals and the associated targets.

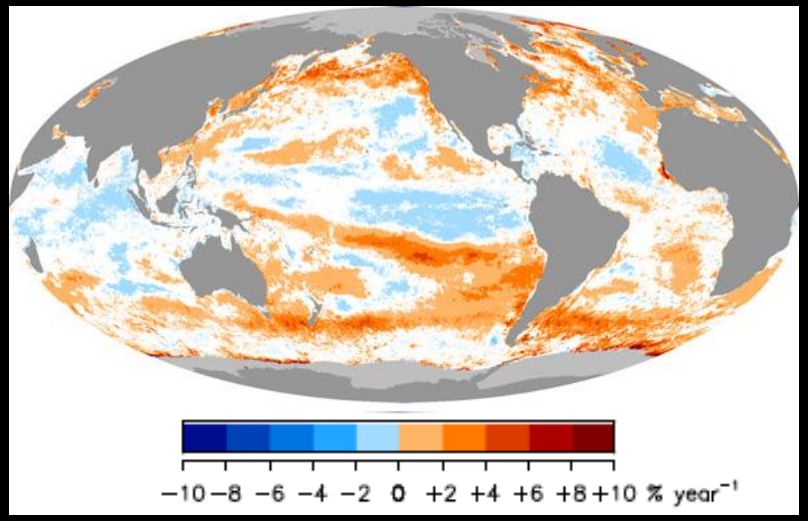
Relevant SDG	What can ocean colour do?
SDG 2: Zero Hunger	Responsible fisheries and aquaculture
SDG 3: Good Health	Food quality, water-borne diseases
SDG 6: Clean Water	Water quality
SDG 13: Climate Action	Essential Climate Variable, Biophysical dynamics, Carbon cycle
SDG 14: Life Below Water	Marine biodiversity, Marine food web

Ocean Colour and Climate

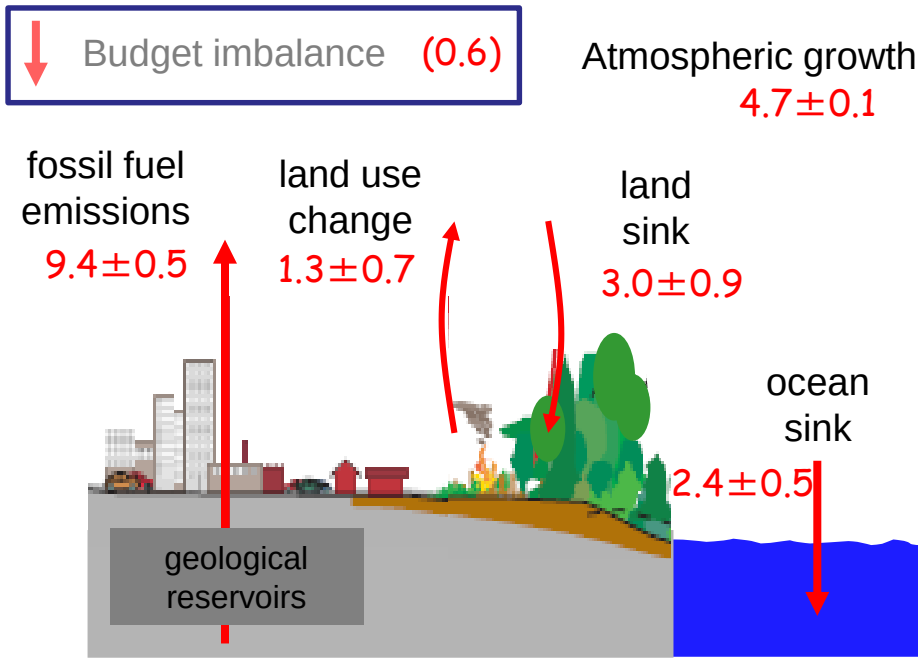


OC-CCI product

- Water-leaving radiance and chlorophyll concentration are recognized as Essential Climate Variables
- The Green component of the Blue Planet
- Phytoplankton are highly vulnerable to changes in environmental conditions
- Marine equivalent of the canary in the coal mine
- Part of ESA's Climate Change Initiative: Goal to create long time series, detect changes and trends

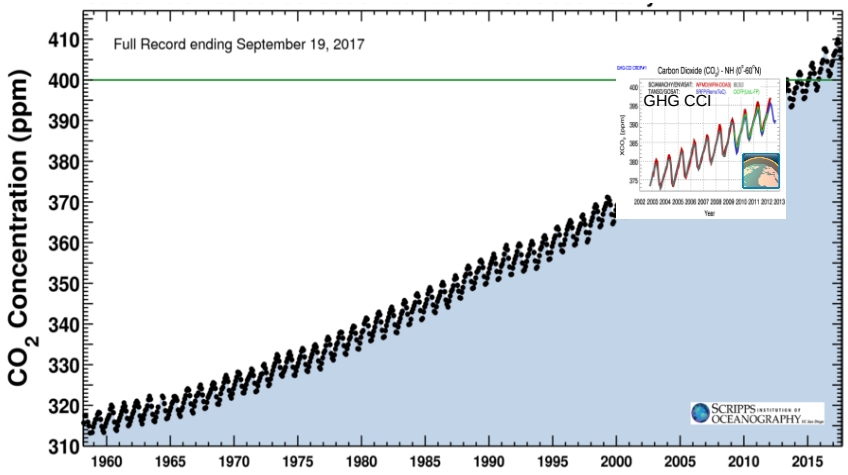


2007-2016 Earth Carbon budget (GtC y^{-1})



Source: Le Quéré et al. (2018)

Latest CO2 Reading, 3 Dec. 2018: 409 ppm
Carbon dioxide concentration at Mauna Loa Observatory



Pools and Fluxes of Carbon in the Ocean

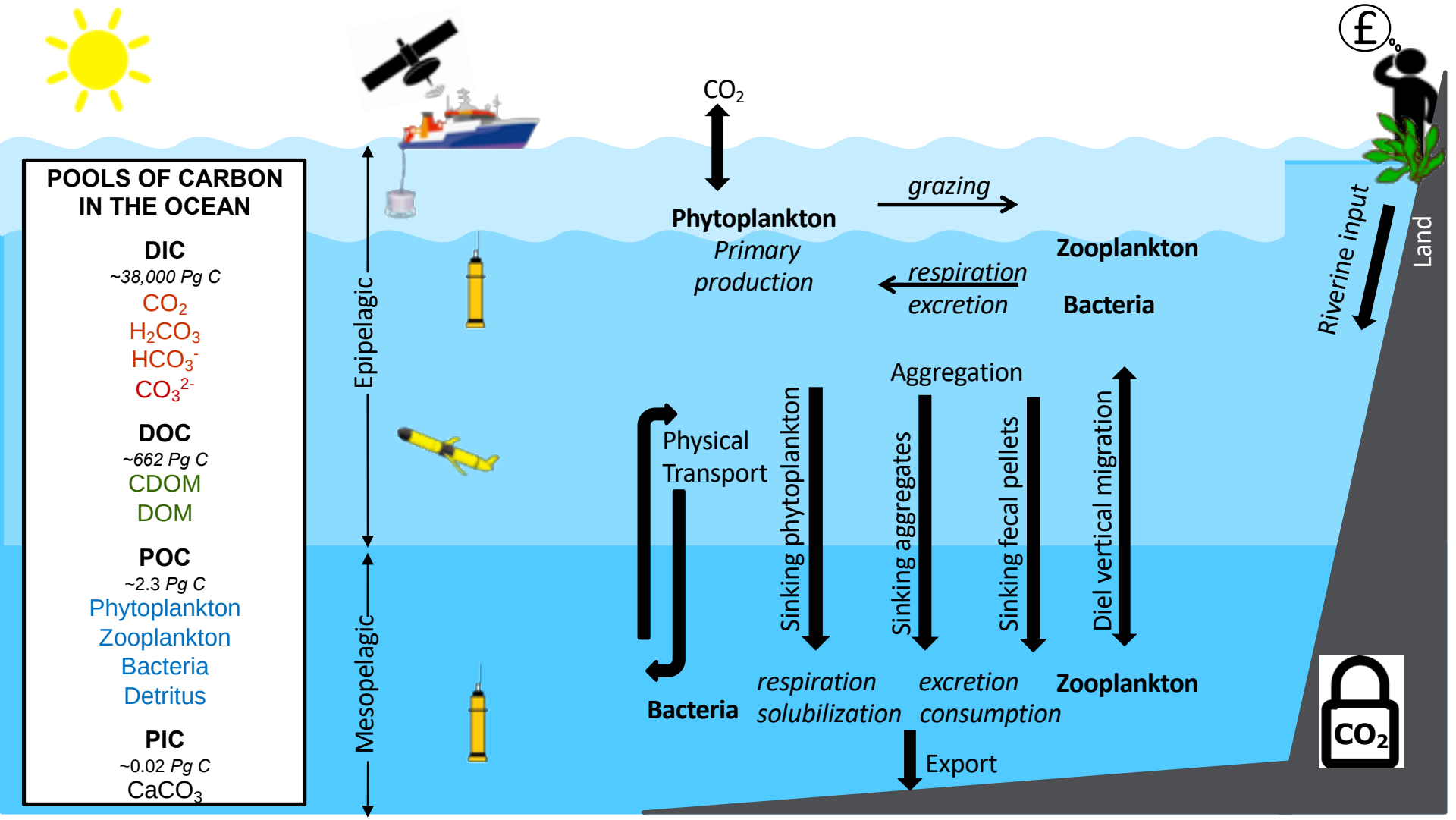
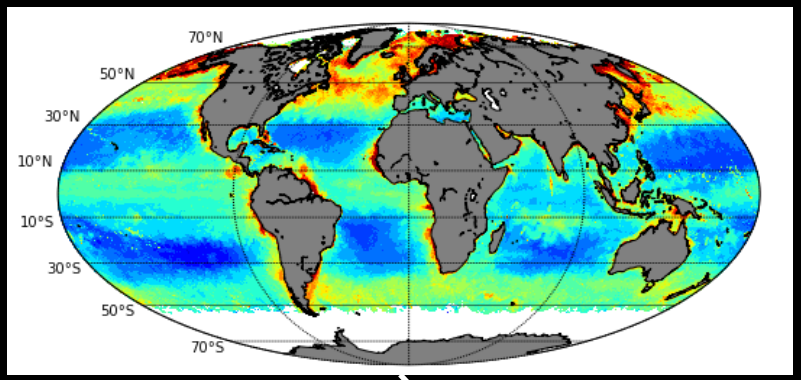


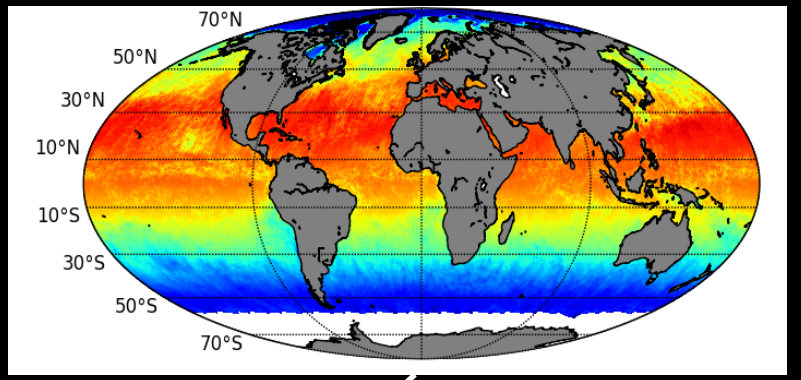
Figure Courtesy Bob Brewin

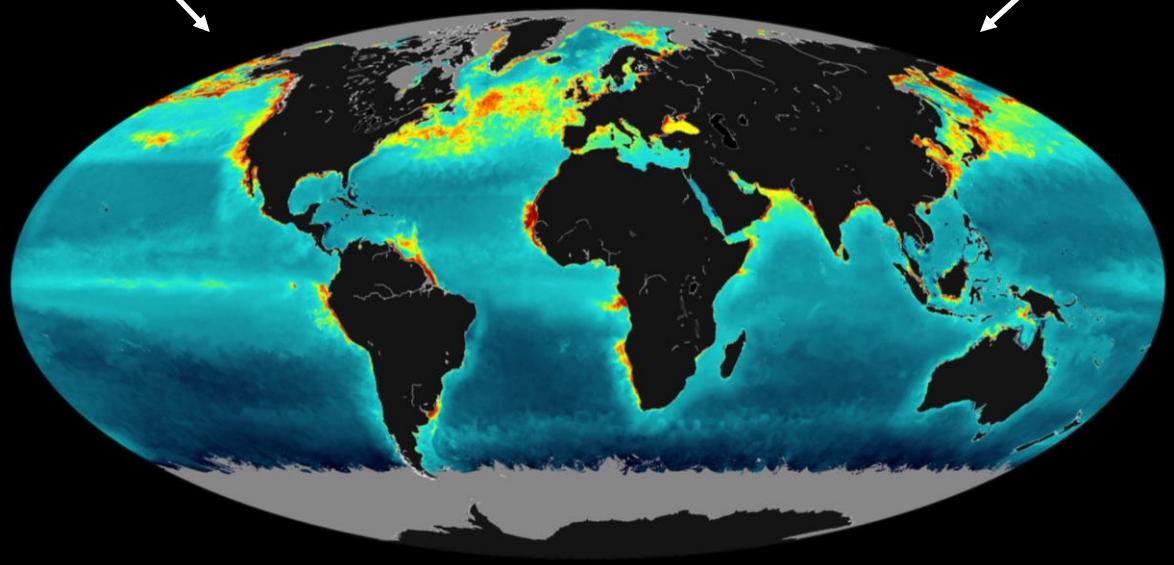
Marine Primary Production from Space

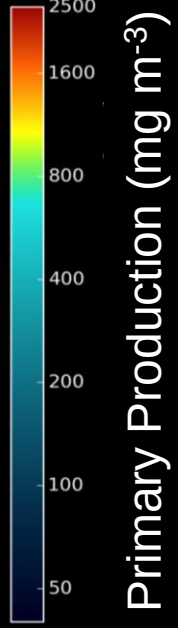
ESA OC-CCI CHL-A



ESA PAR PRODUCT

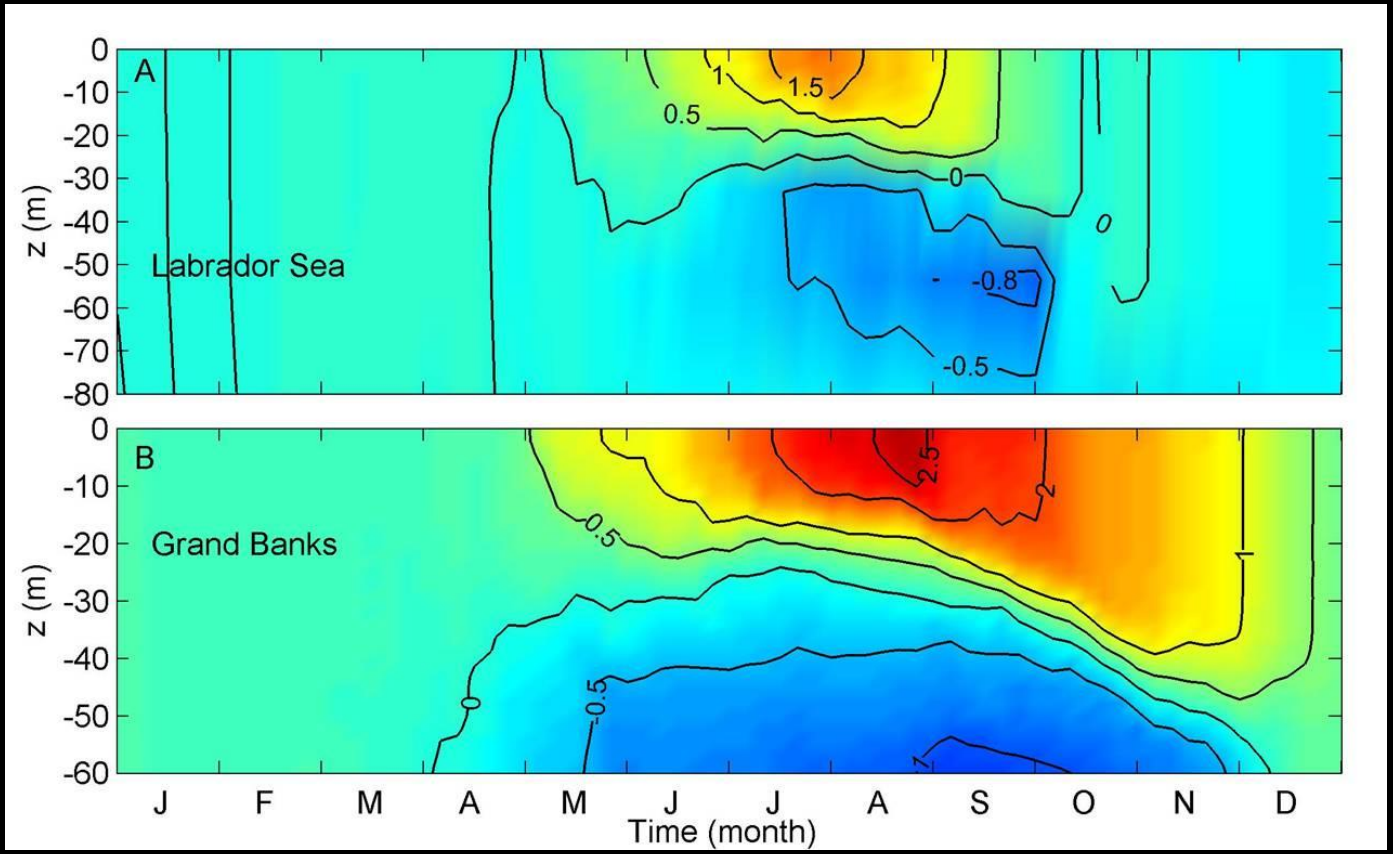






Annual marine primary production is ~50GT per annum

Biologically-induced temperature differences in the ocean



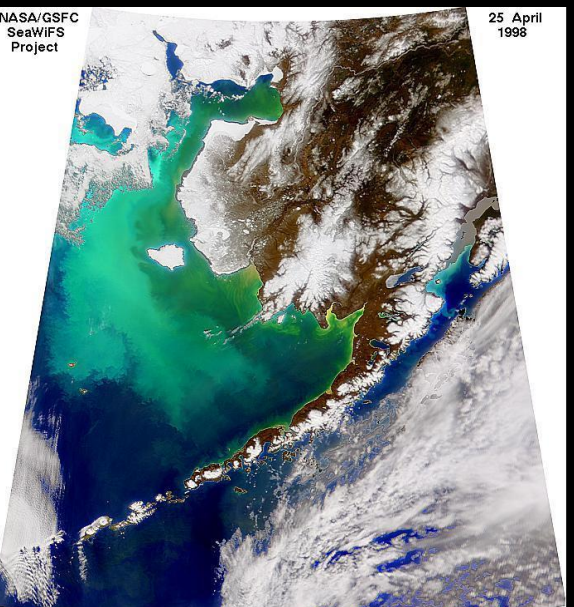
Wu *et al.* (2007)

In the Arabian Sea, biological heating may reach more than 1°C per month (Sathyendranath et al., 1991)

Coupling between light and chlorophyll and related feedbacks should be an ingredient of Earth System studies in the context of climate change.

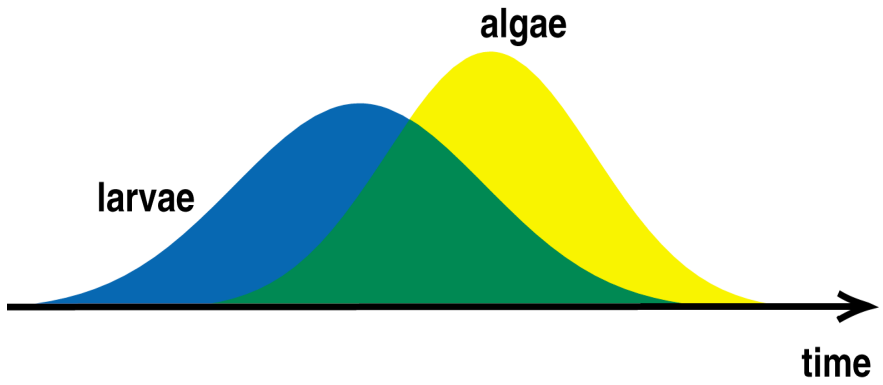
Fisheries Applications of EO include:

- Harvest Fisheries
  - economies of fuel and time
- Fisheries Management
  - intelligence on ecosystem fluctuations and effect on future states of exploited stocks
- Aquaculture Industry
  - carrying capacity, harmful algal blooms
- Protection of Species at Risk
  - exclusion zones and reduction of by-catch

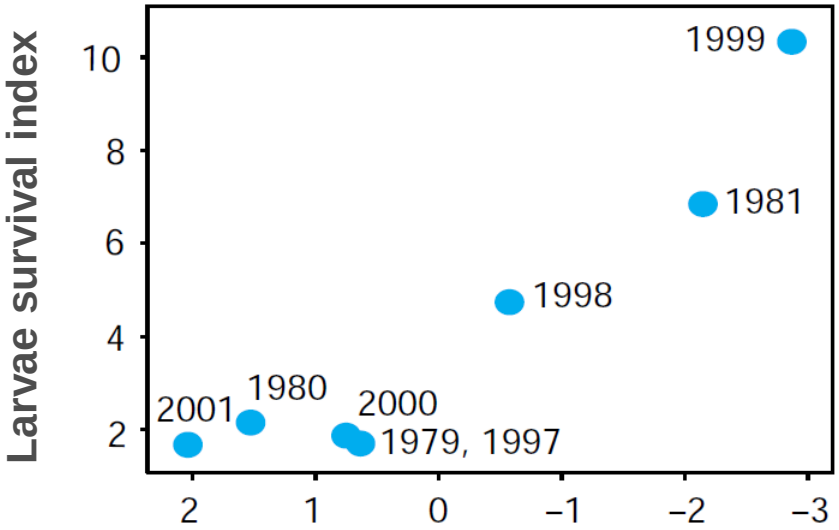


- Marine Protected Areas & Vulnerable Marine Ecosystems
  - delineation of these
- Ecosystem Health and Ecosystem Services
  - monitoring health, evaluating services
- High Seas Governance
  - international governance strategy, ecosystem delineation, straddling stocks

Survival of Haddock Larvae as Function of Timing of Spring Bloom Peak



Scotia Shelf



Where number of haddock larvae and biomass of phytoplankton overlap, larvae have food supply adequate for survival

Where this is not so, larvae are vulnerable to death by starvation

Hjort-Cushing match-mismatch hypothesis

Platt et al., 2003

Kerala Floods 2018

6 Feb. 2018
Landsat 8 data

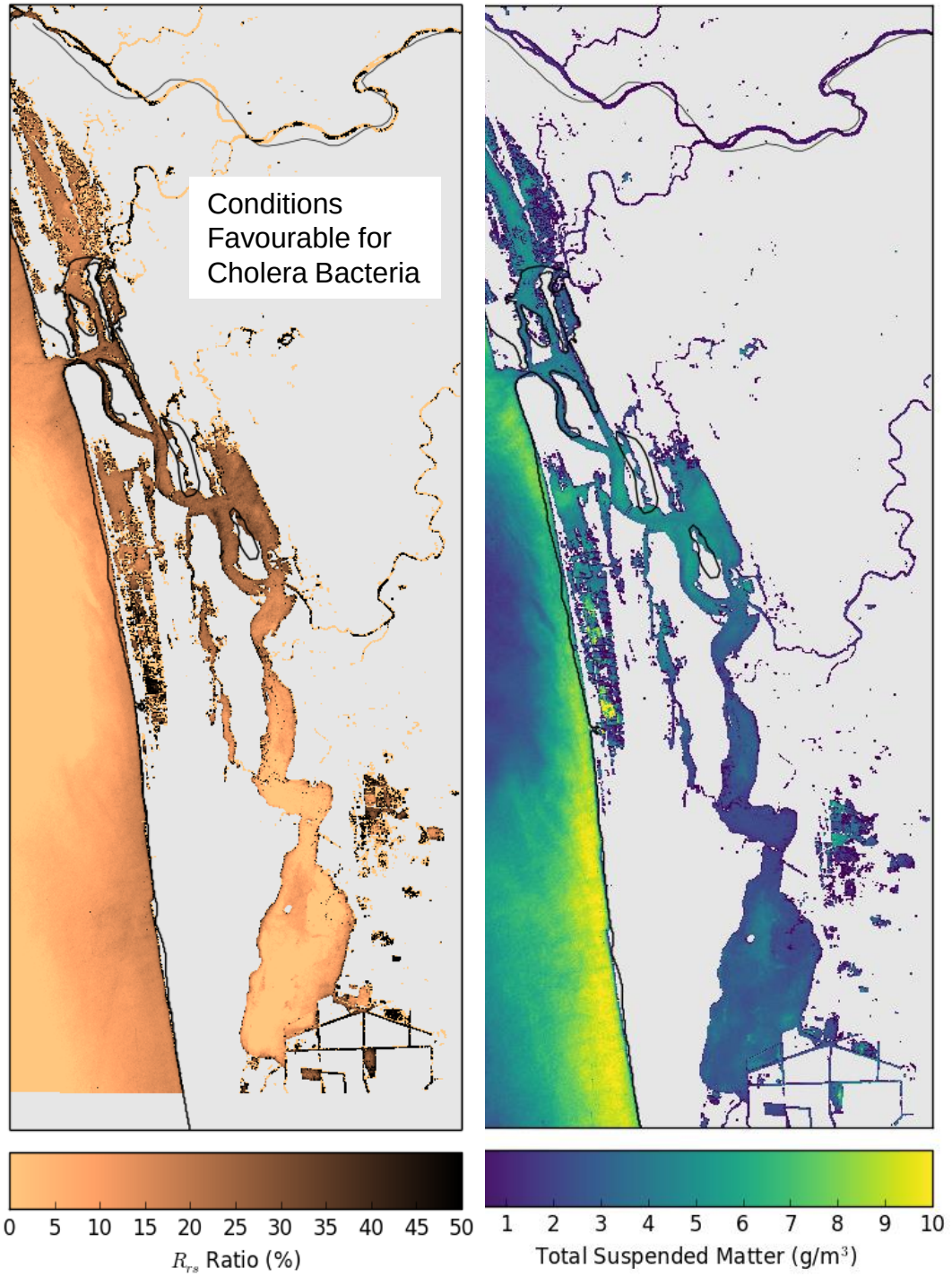
22 Aug. 2018
Sentinel 2 data

- A million people displaced
- Death toll of ~400
- Massive destruction of infrastructure
- Huge economic costs, loss to ecosystems
- Threat of water-borne diseases
- Flood mapping key to relief operations
- Beleaguered government and people looked to satellites for information

Images from *Hindustan Times* 28 August 2018

SDG 6: Clean Water

- Ocean colour is just as useful in lakes as in the ocean
- SDG Target: “By 2020, protect and restore water-related ecosystems, including …., wetlands, rivers, aquifers and lakes”
- Bacteria responsible for diseases such as cholera contaminate water used for drinking and bathing, a reality aggravated by poor sanitation and by flooding
- Ocean colour (chlorophyll concentration) has been shown to be a good predictor of the abundance of the bacterium responsible for cholera
- Ocean colour being explored to develop geo-referenced risk maps for cholera outbreaks

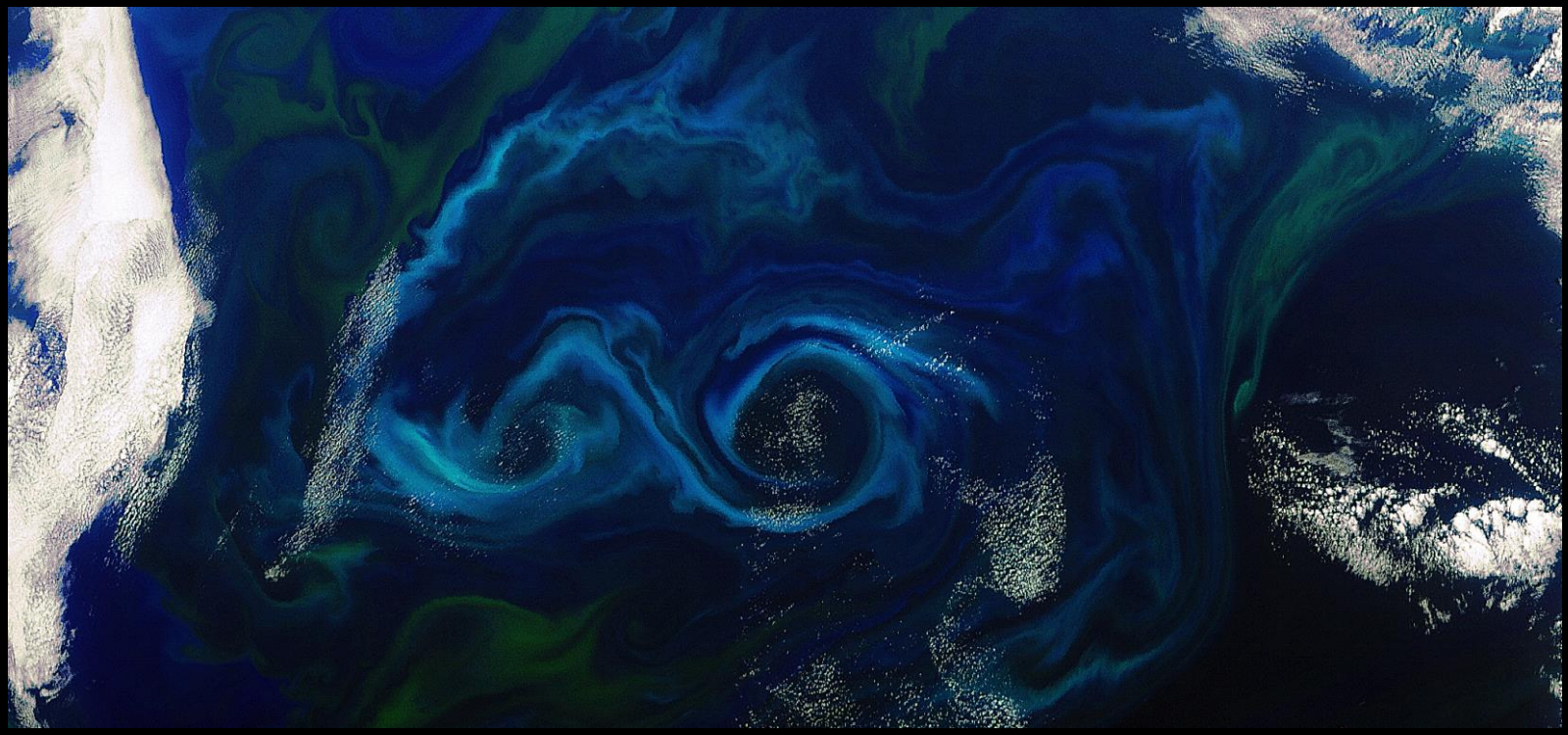


Colour: where Light meets Life

Colour of the ocean tells us where and how the life-giving light is coupled to the ocean microflora. The more green the colour, the stronger the coupling.

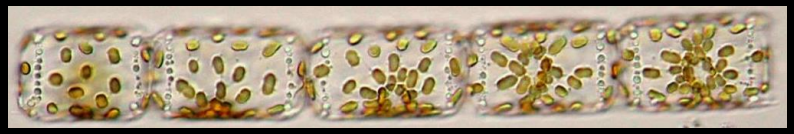
It is the most fundamental phenomenon in the pelagic ecosystem: without it, the pelagic ocean would be sterile.

We can monitor this coupling through remote sensing. An ocean-colour image maps the strength of coupling between the ecosystem and its energy source.

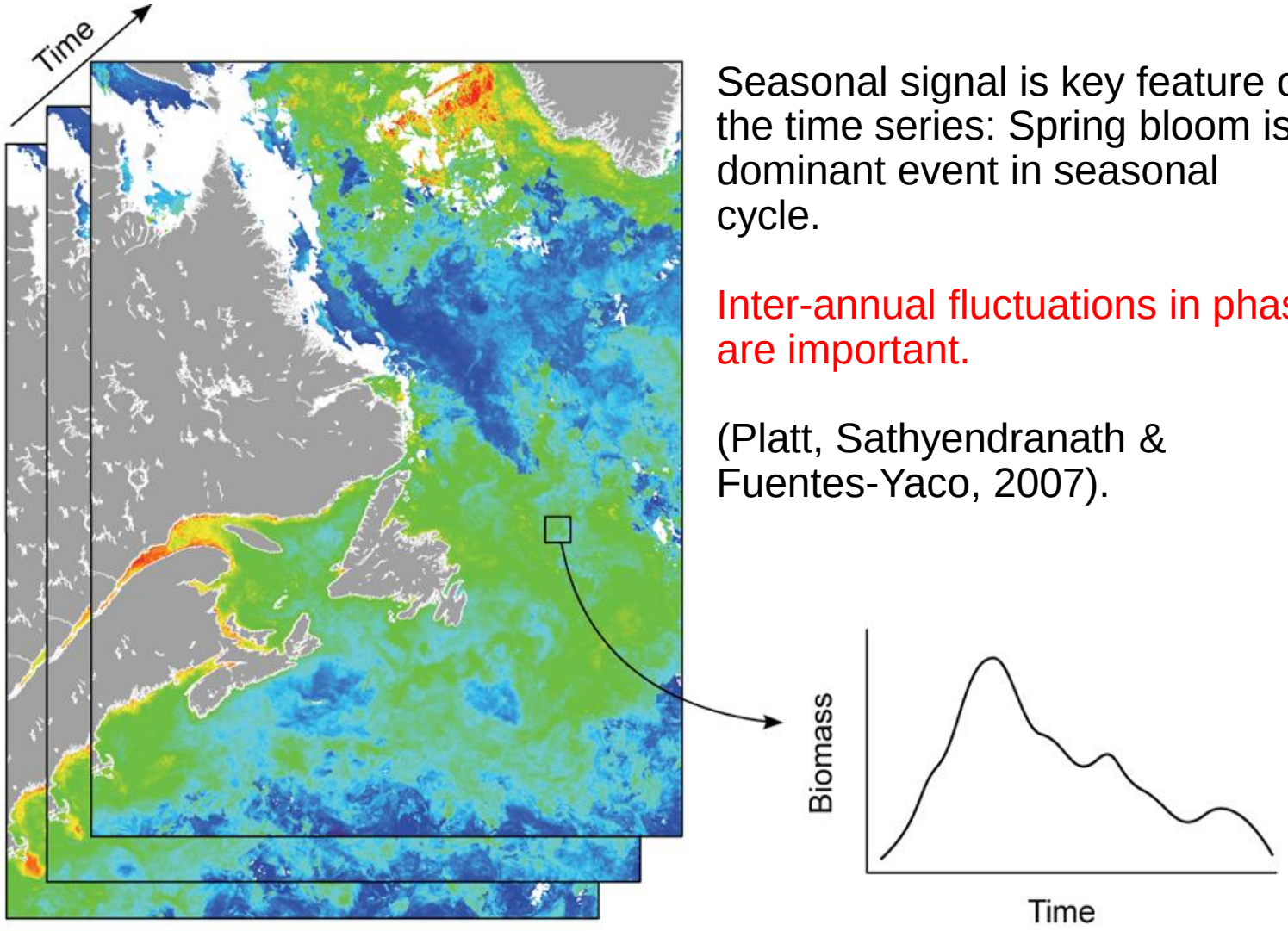


“Kennt man die Eigenfarbe eines Sees, so kennt man auch seine übrigen Eigenschaften”—if you know the color of a lake, you also know its other characteristics – A. Thienemann 1925

THIENEMANN, A. 1925. Inland waters of central Europe. E. Schweizbart’sche Verlagsbuchshandlung. Cited in Tranvik et al. (2009) Limnology and Oceanography



Construction of time series possible at any chosen scale of spatial averaging



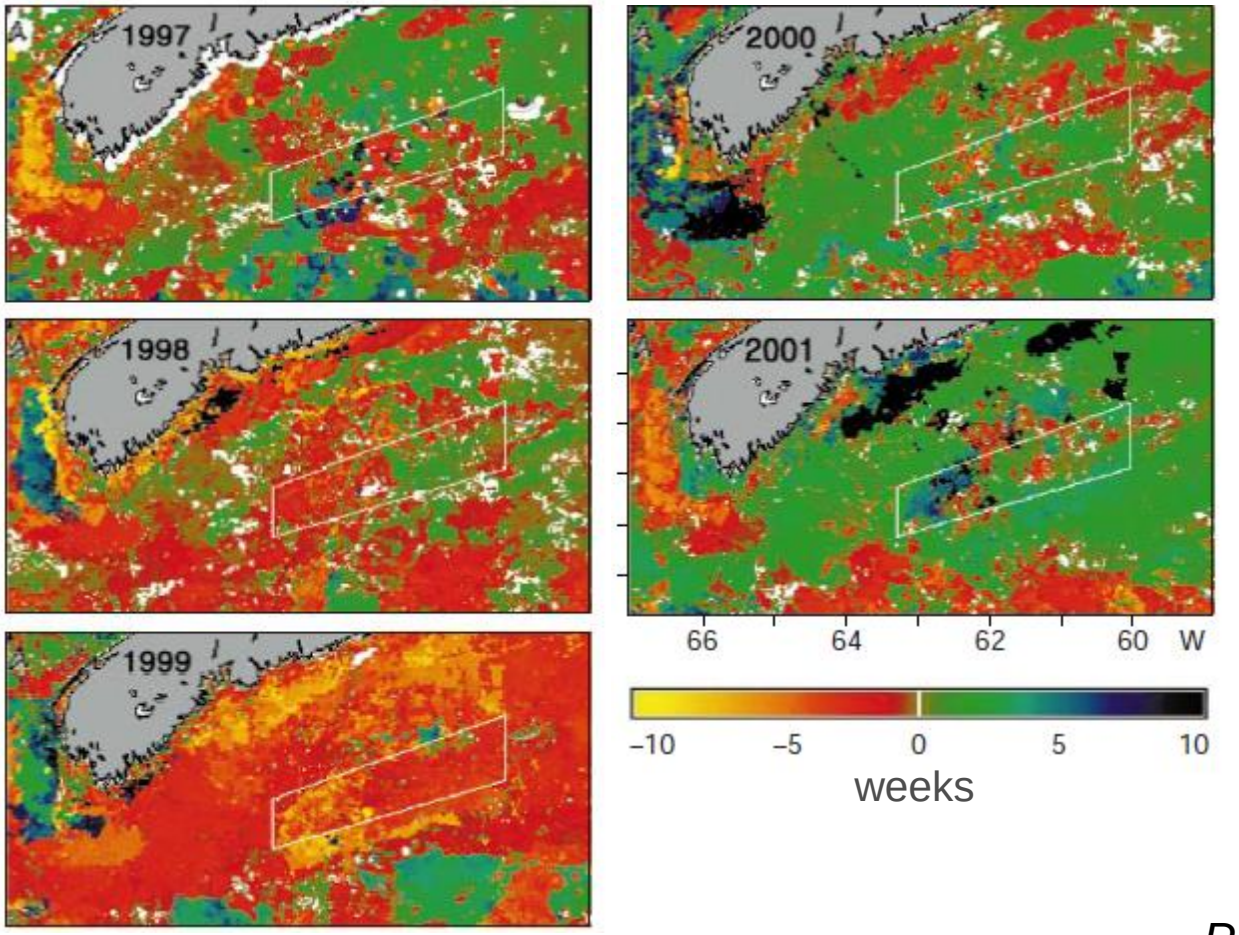
Seasonal signal is key feature of the time series: Spring bloom is dominant event in seasonal cycle.

Inter-annual fluctuations in phase are important.

(Platt, Sathyendranath & Fuentes-Yaco, 2007).

Phytoplankton phenology and Haddock larval recruitment

Anomalies in the timing phytoplankton spring bloom peak



Platt et al., 2003