International Ocean Colour Science Meeting 2025

Advancing Global Ocean Colour Observations

1-4 December 2025 **Darmstadt, Germany**

Aquatic Carbon from Space

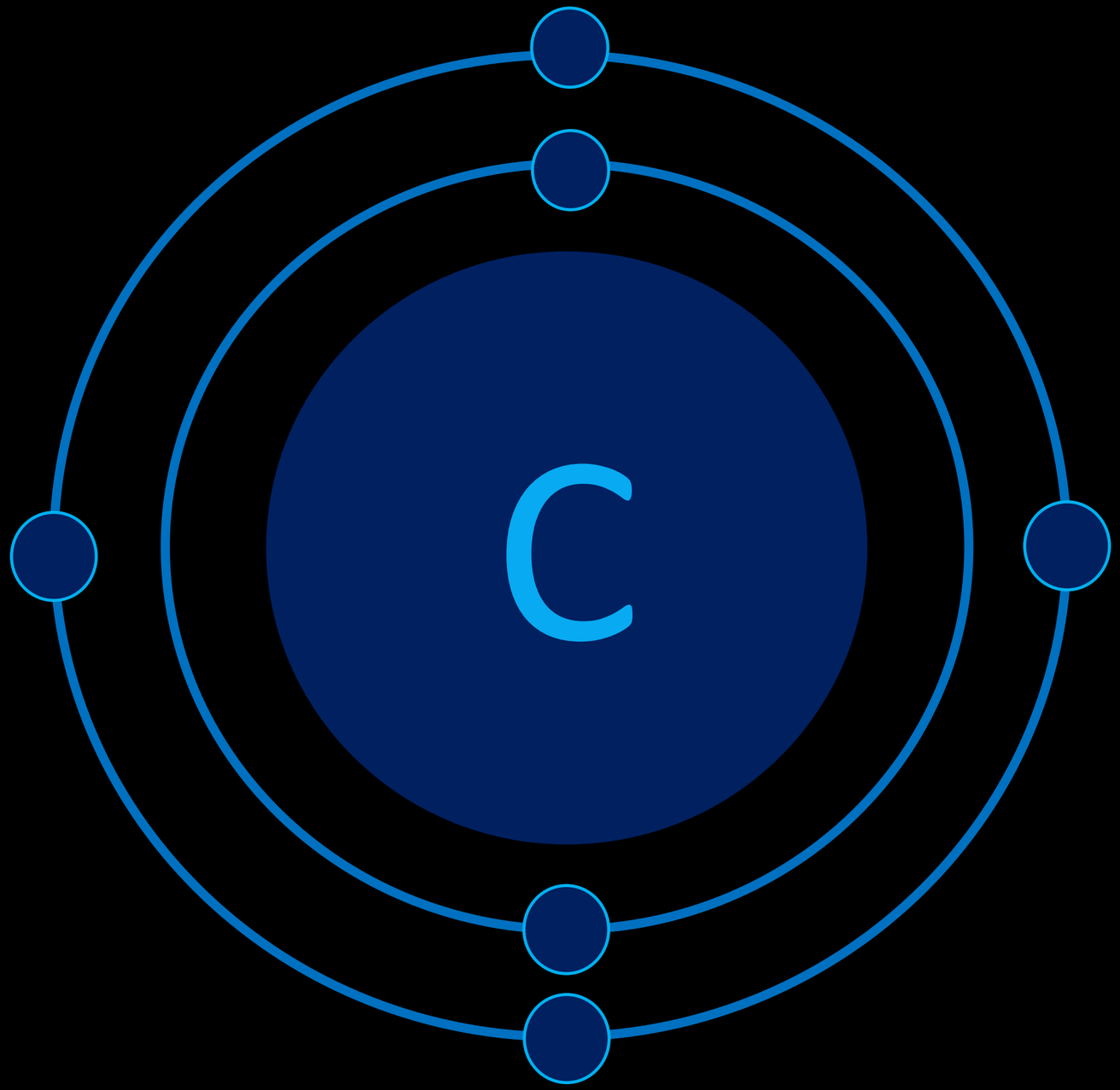
Bob Brewin

with contributions from: Jamie Shutler, Paula Bontempi, Robert Frouin, Cecile Rousseaux, Shubha Sathyendranath, Gemma Kulk, Bror Jönsson, Laura Lorenzini, Chuanmin Hu, Joaquim Goes, Aurea Ciotti, Dionysios Raitsos, Giorgio Dall'Olmo, Dan Ford, and many more

BREWTEK

University of Exeter

UK Research and Innovation



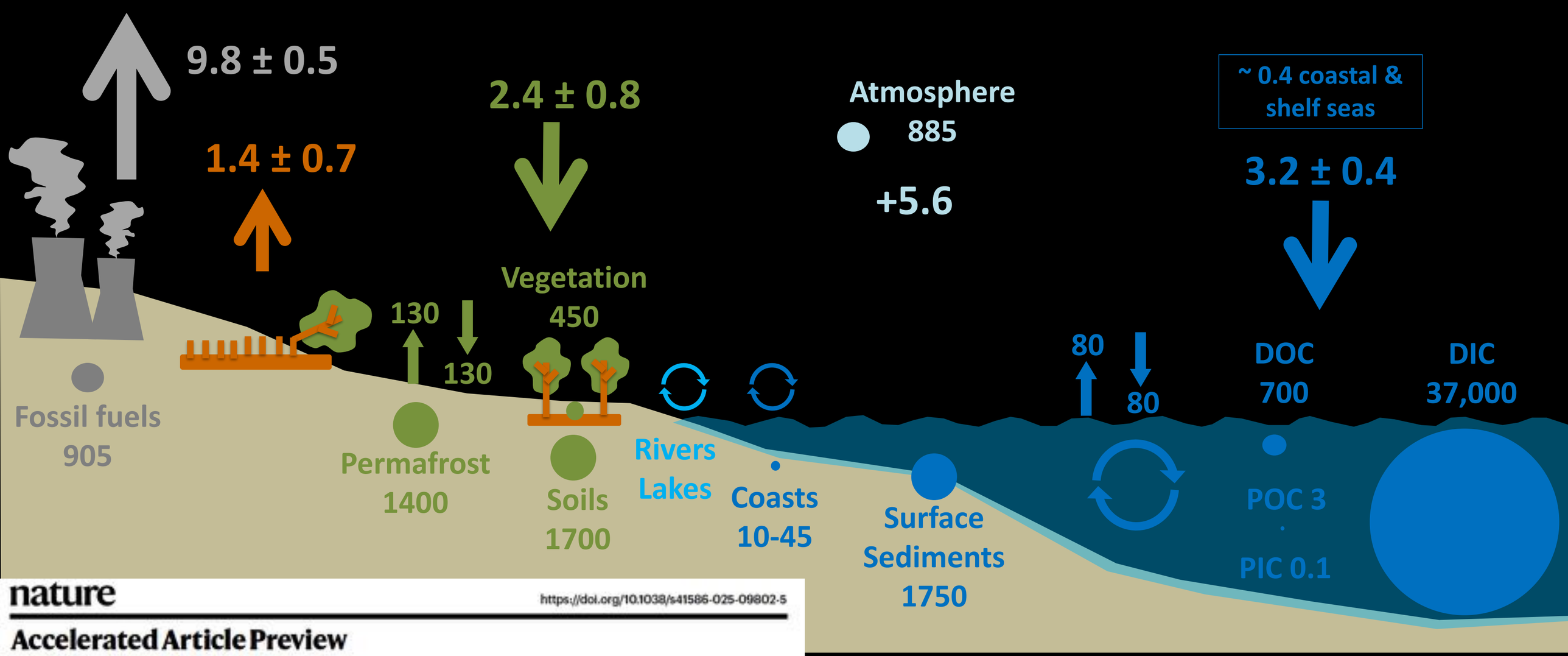
The most versatile element on Earth

Basis of all life

Fuels human civilization

Earth’s carbon cycle controls climate

How is Earth’s carbon cycle changing?



nature
https://doi.org/10.1038/s41586-025-09802-5
Accelerated Article Preview

Emerging climate impact on carbon sinks in a consolidated carbon budget

↑ Flux GtC y^{-1} (2014-2024 average) + Atmospheric increase GtC y^{-1}

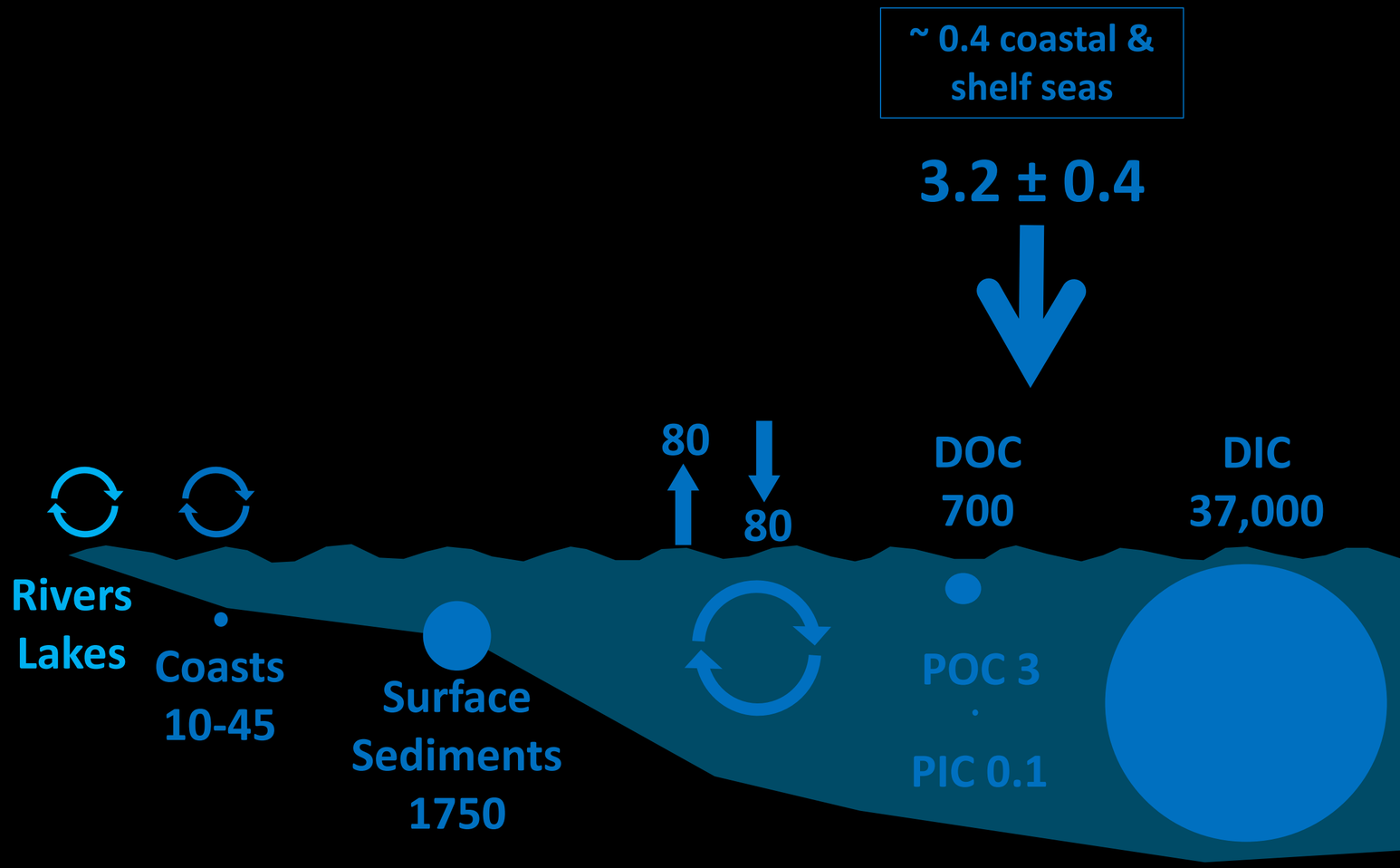
Friedlingstein et al. (2025) Global Carbon Budget 2025 https://doi.org/10.5194/essd-2025-659

30% anthropogenic CO_2 uptake

Largest reservoir of active carbon of Earth

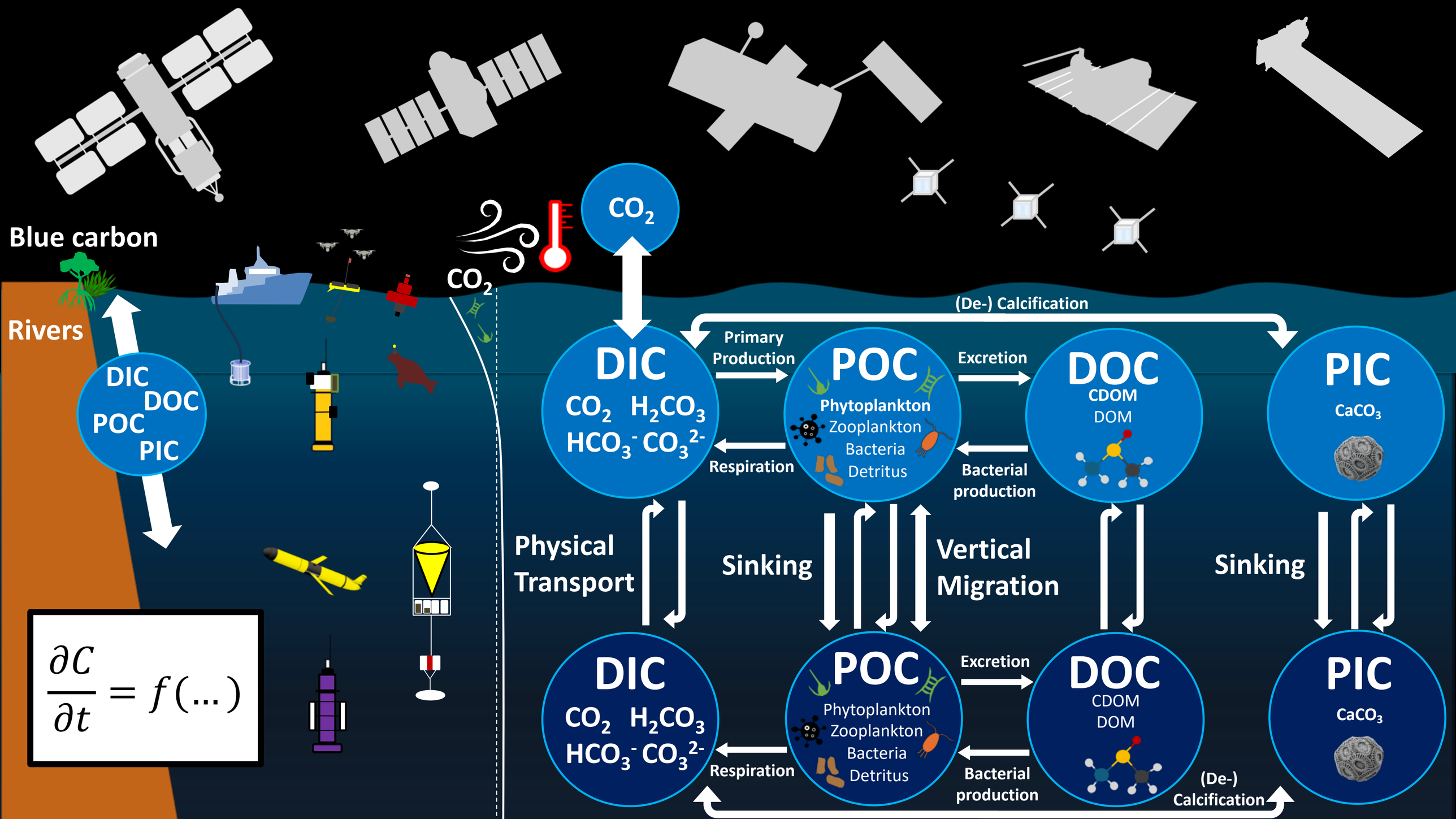
50% of planetary photosynthesis

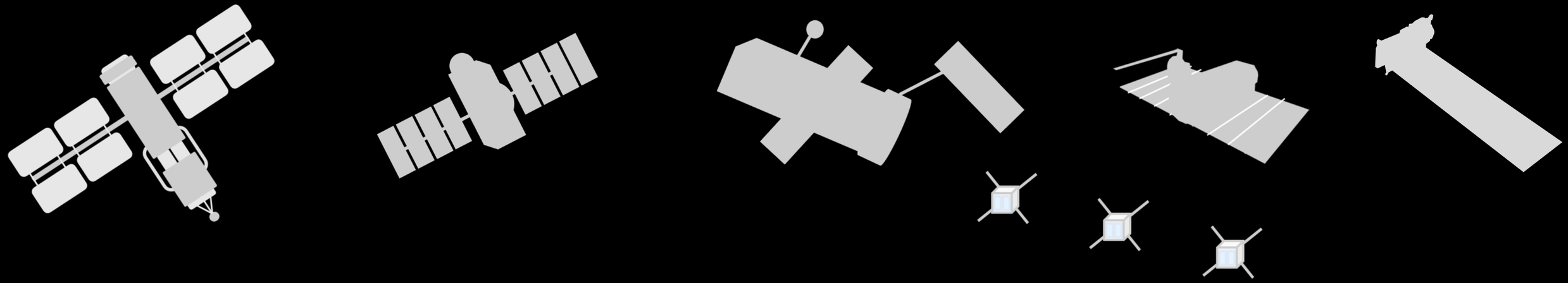
One of the two main observational constraints on budget calculations



Monitoring aquatic carbon is essential

Friedlingstein et al. (2025) Global Carbon Budget 2025 https://doi.org/10.5194/essd-2025-659


Blue carbon
Rivers
DIC
DOC
POC
PIC
CO_2
CO_2
$\frac{\partial C}{\partial t} = f(\ldots)$
DIC
CO_2 H_2CO_3
HCO_3^- CO_3^{2-}
Primary Production
POC
Phytoplankton
Zooplankton
Bacteria
Detritus
Excretion
DOC
CDOM
DOM
PIC
$CaCO_3$
(De-) Calcification
Respiration
Bacterial production
Physical Transport
Sinking
Vertical Migration
Sinking
DIC
CO_2 H_2CO_3
HCO_3^- CO_3^{2-}
POC
Phytoplankton
Zooplankton
Bacteria
Detritus
Excretion
DOC
CDOM
DOM
PIC
$CaCO_3$
Respiration
Bacterial production
(De-) Calcification



Satellites will address critical science priorities for quantifying ocean carbon

Jamie D Shutler[1*], Rik Wanninkhof[2], Philip D Nightingale[3], David K Woolf[4], Dorothee CE Bakker[5], Andy Watson[6], Ian Ashton[1], Thomas Holding[1], Bertrand Chapron[7], Yves Quilfen[7], Chris Fairall[8], Ute Schuster[6], Masakatsu Nakajima[9], and Craig J Donlon[10]

Sensing the ocean biological carbon pump from space: A review of capabilities, concepts, research gaps and future developments

Robert J.W. Brewin [a,b,*], Shubha Sathyendranath [b,c], Trevor Platt [b], Heather Bouman [d], Stefano Ciavatta [b,c], Giorgio Dall'Olmo [b,c], James Dingle [b], Steve Groom [b], Bror Jönsson [b], Tihomir S. Kostadinov [e], Gemma Kulk [b], Marko Laine [f], Victor Martínez-Vicente [b], Stella Psarra [g], Dionysios E. Raitsos [h], Katherine Richardson [i], Marie-Hélène Rio [j], Cécile S. Rousseaux [k,l], Joe Salisbury [m], Jamie D. Shutler [a], Peter Walker [b]

ANNUAL REVIEWS

Annual Review of Marine Science

Quantifying the Ocean's Biological Pump and Its Carbon Cycle Impacts on Global Scales

David A. Siegel,[1] Timothy DeVries,[1] Ivona Cetinić,[2,3] and Kelsey M. Bisson[4]

EARTH-SCIENCE REVIEWS

Earth-Science Reviews

Supports open access

Aquatic Carbon Roadmap

CEOS

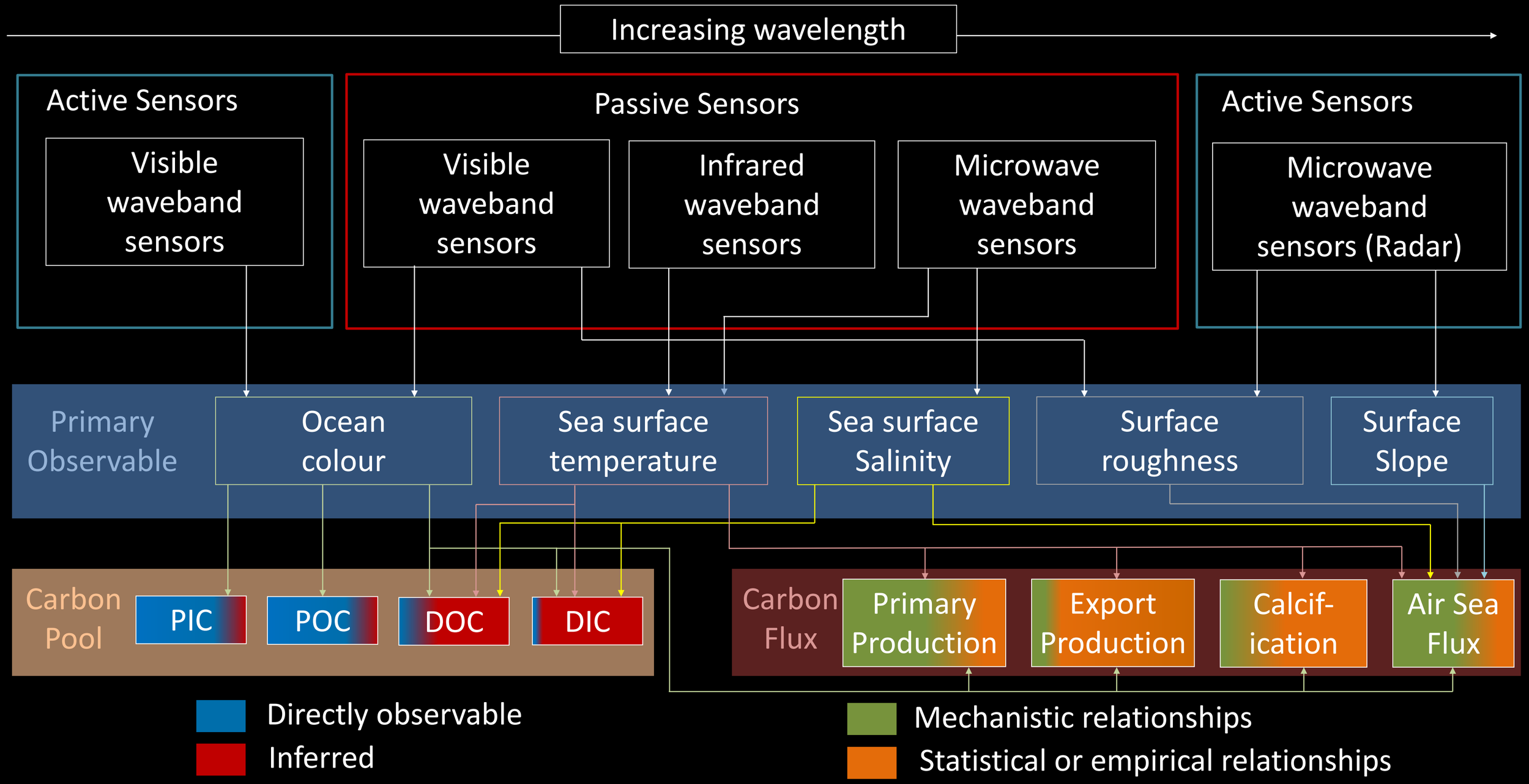
Committee on Earth Observation Satellites

Special issue

Aquatic carbon stocks and fluxes: The big picture from remote sensing

Last update 22 April 2023

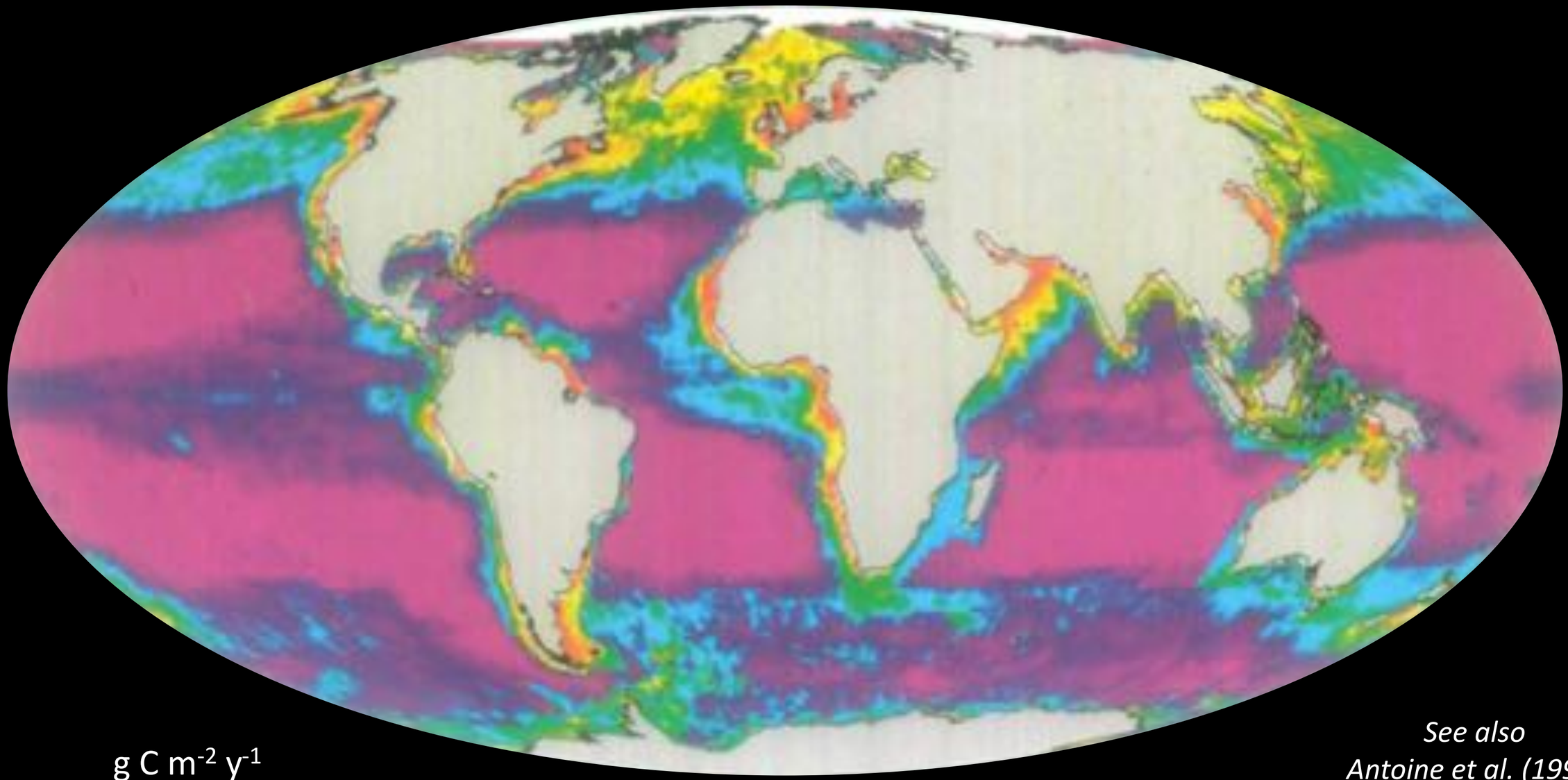
Aquatic landscapes contribute 99% of the habitable space on Earth. In these watery realms, microscopic and macroscopic organisms conduct half of the biosphere's photosynthesis, physical and -chemical processes remove billions of tons of carbon dioxide from the atmosphere, and complex food webs both produce and consume climate-sensitive compounds, some of which are transported into deep reaches of the ocean while others can enter the atmosphere to influence a variety of processes. In recent decades, our understanding of carbon cycling, biogeochemistry, ecology, and interactions of global aquatic systems with the atmosphere has greatly improved through observations using airborne and satellite remote sensing systems. With these observations, we have realized a revolution in our quantitative assessment of carbon stocks and fluxes in aquatic systems. While a rich scientific literature exists detailing these advances, we lack a compiled synthesis of developments, findings, and future directions that is accessible both to researchers in aquatic sciences and the broader scientific community. The synthesis manuscripts in this collection summarize our current understanding of carbon stocks and fluxes in aquatic systems, and explore directions for future advancements, with a particular focus on globally relevant topics that rely on the use of remote sensing data, including integration with in-situ measurements and models. This



Inspired by Robinson (2004) Measuring the Oceans from Space

How satellite data has transformed understanding of ocean carbon cycling

Global Ocean Primary Production



g C m^{-2} y^{-1}

75 120 226 498 800

See also
Antoine et al. (1996)
Behrenfeld & Falkowski (1997)

Longhurst et al. (1995) *https://doi.org/10.1093/plankt/17.6.1245*

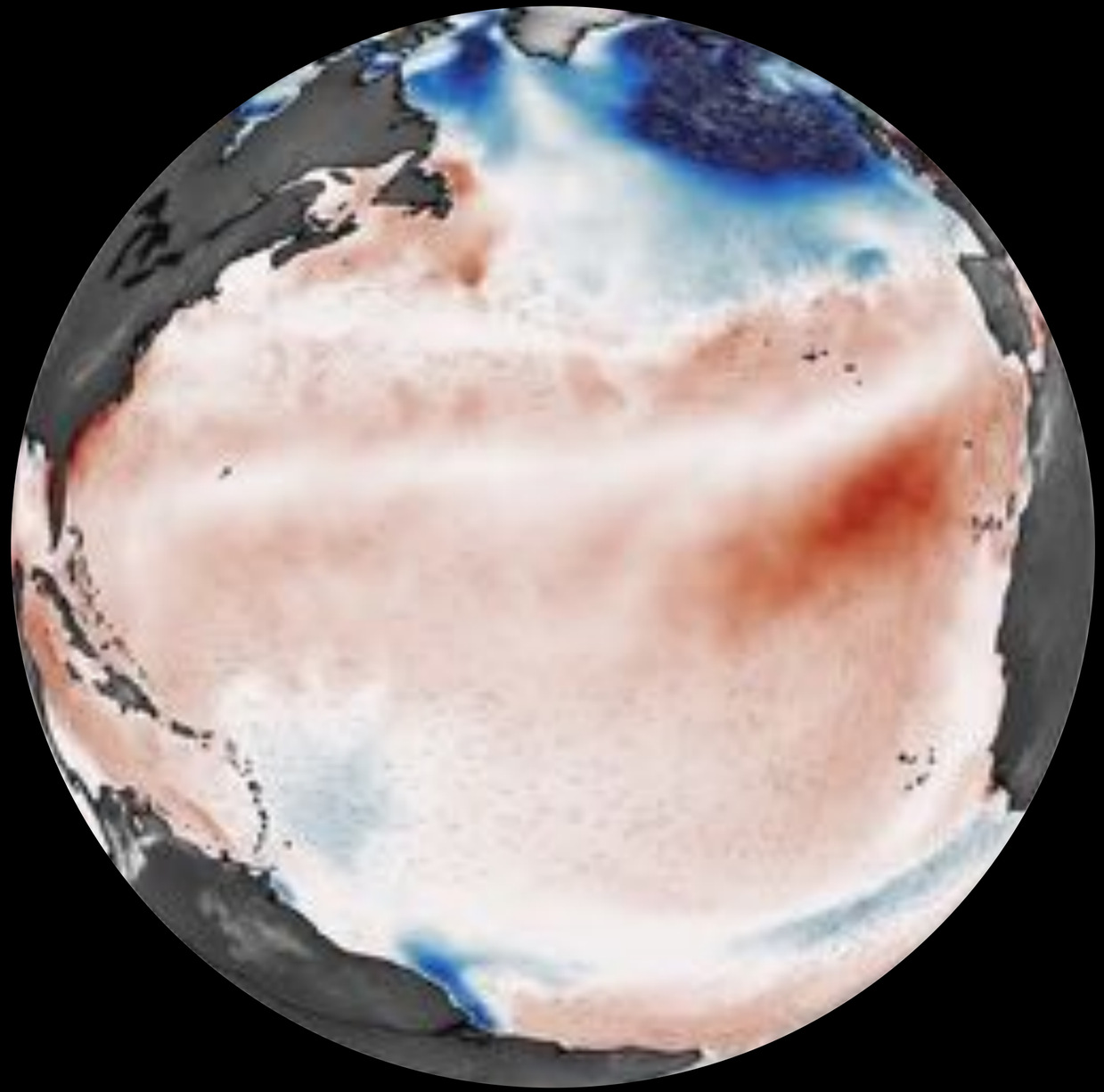
Air-Sea CO_2 flux

mmol C m^{-2} d^{-1}

15

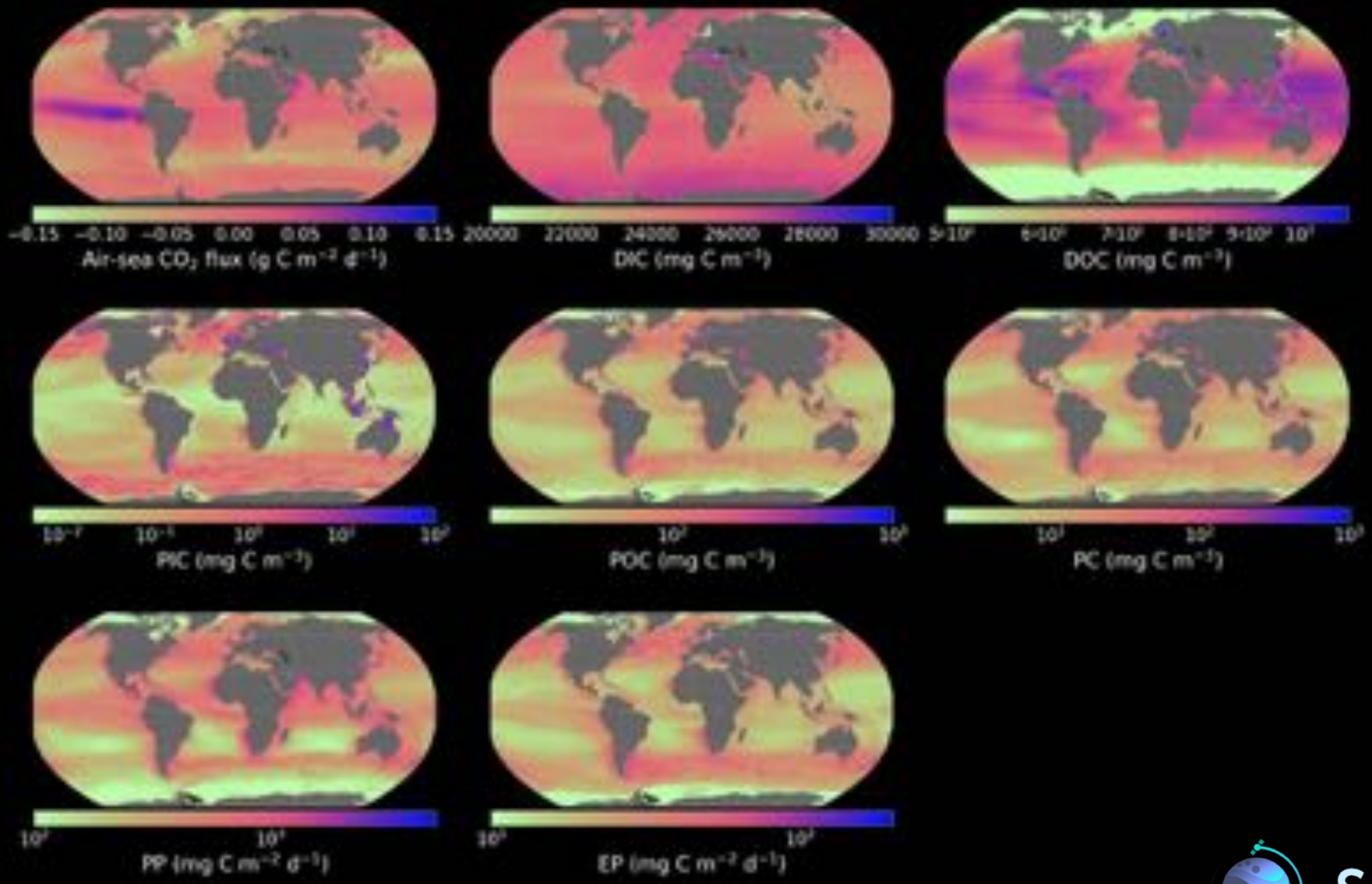
0

-15



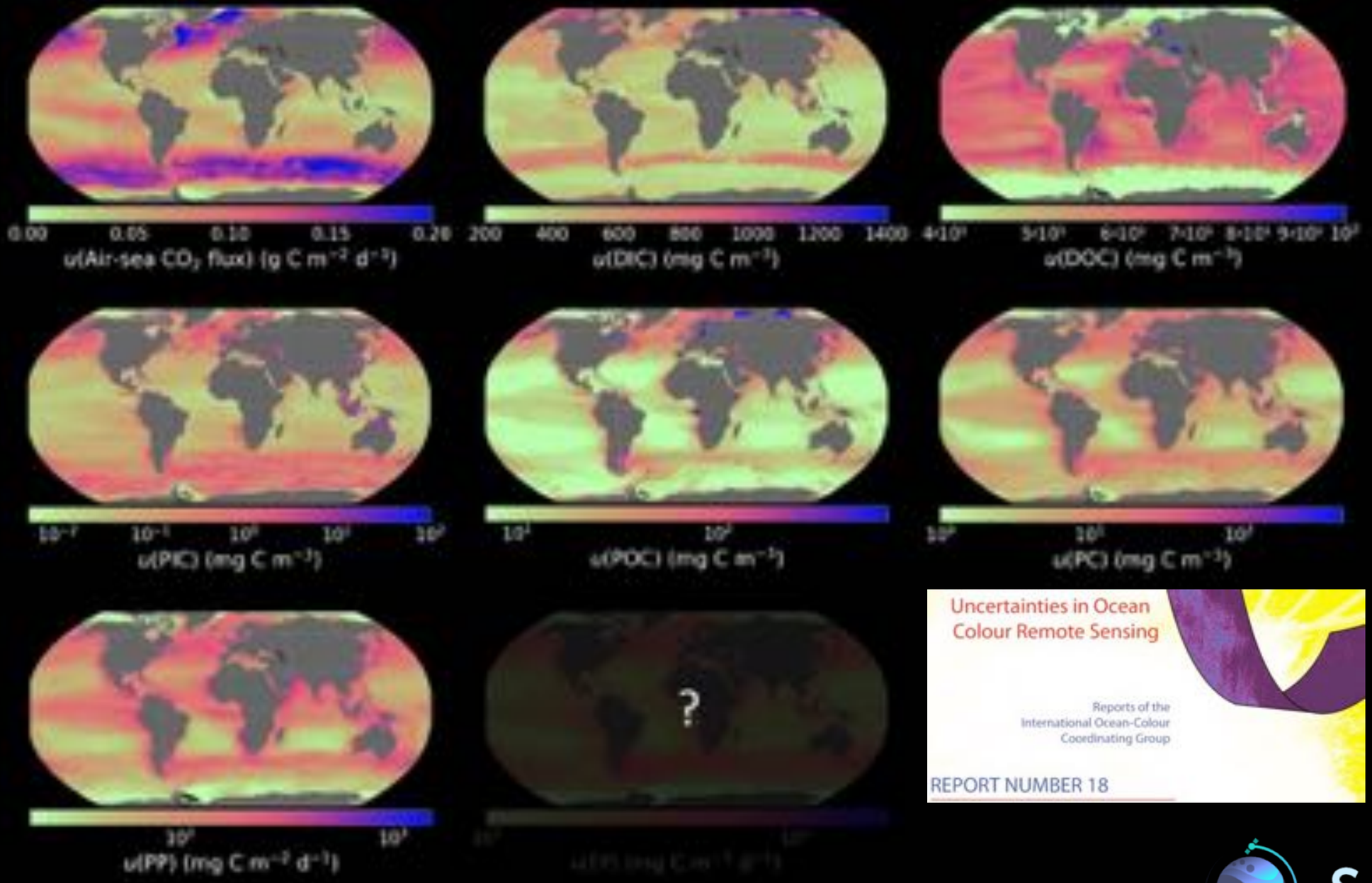
Gregor et al. (2024) *https://doi.org/10.1029/2024GB008127*

Where are we now?



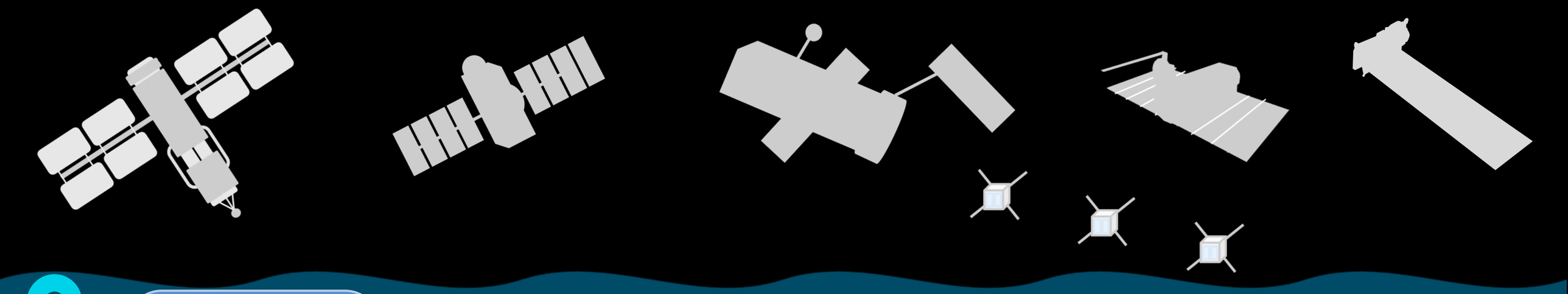
Kulk et al. (2025) Ocean Carbon from Space 2nd Workshop

SCOPE



Kulk et al. (2025) Ocean Carbon from Space 2nd Workshop

SCOPE



Phytoplankton Turnover Time 3.3 days

Primary Production 24 GtC y^{-1}

Photosynthesis $H_2O + CO_2 \rightarrow CH_2O + O_2$

0.22 GtC Phyto-Carbon

0.98 GtC Detritus

0.13 GtC Picoplankton

Total POC 1.2 GtC

15 GtC DOC

1.0 GtC labile

14 GtC Semi-refractive

Excretion Transformation Accumulation

0.06 GtC Nanoplankton

Calcification $Ca^{2+} + 2HCO^{-}_3 \rightarrow CaCO_3 + CO_2 + H_2O$

0.06 GtC PIC

0.03 GtC Microplankton

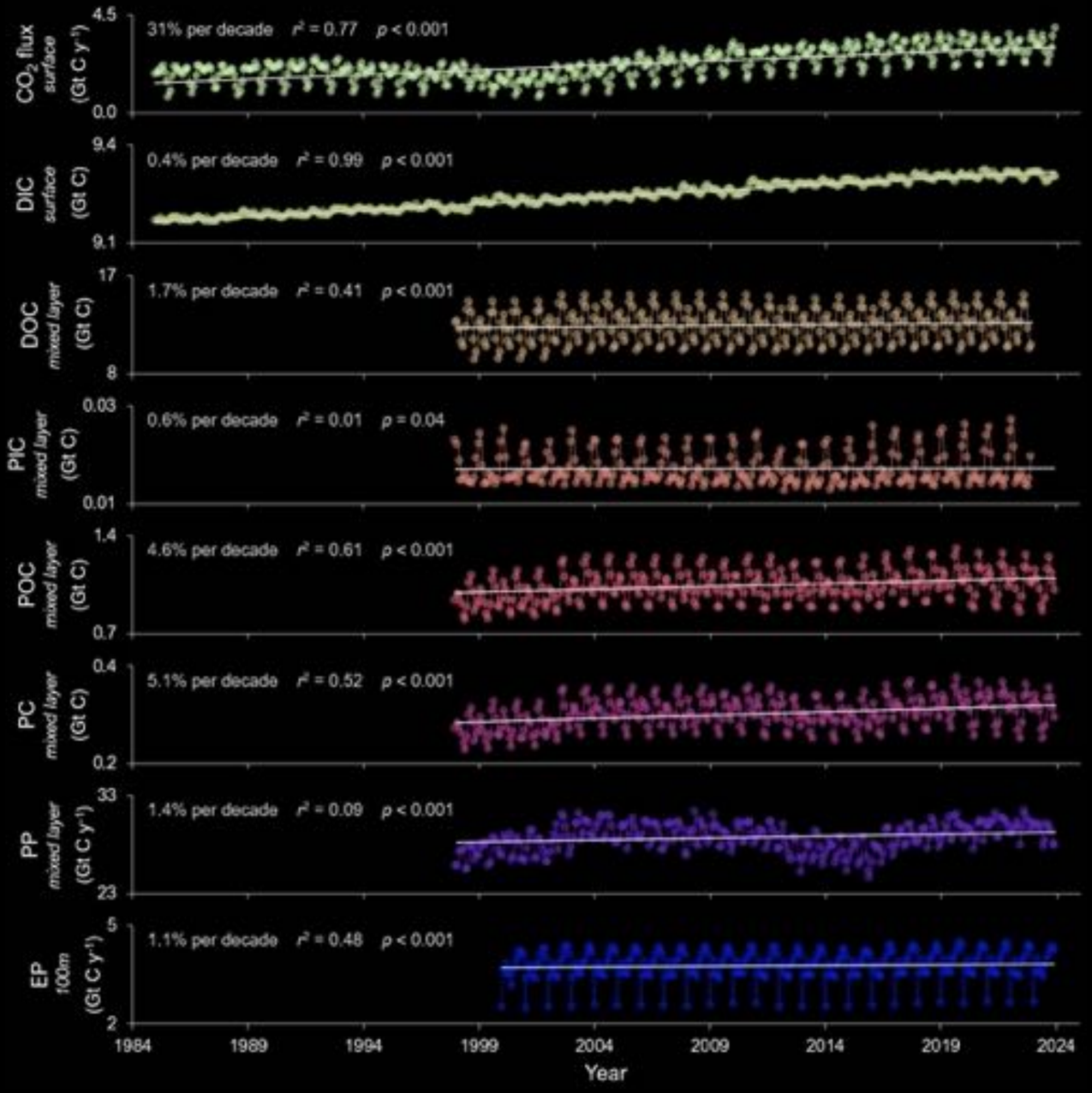
Mixed layer depth

Particle Export 2-9 GtC y^{-1}

Sathyendranath et al. (In Prep)

What next?

Continued investment in climate data records



Journal of Remote Sensing
A SCIENCE PARTNER JOURNAL

RESEARCH ARTICLE

Cross-Satellite Atmospheric Correction for Consistent Remote Sensing Reflectance from Multiple Ocean Color Satellites: Concept and Demonstrations

Zhongping Lee[1*†], Tianhao Wang[1†], Longteng Zhao[1], Daosheng Wang[1], Xiaomin Ye[2], Shaoling Shang[1], and Xiaolong Yu[1*]

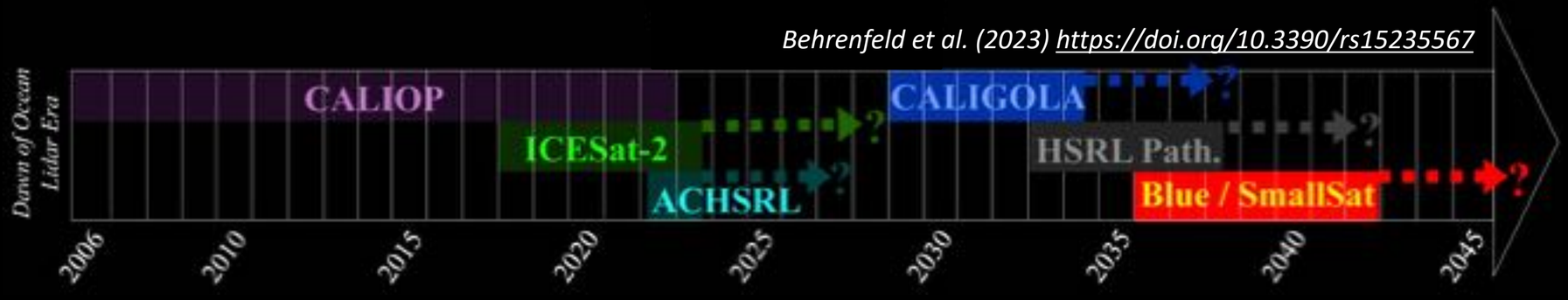
IOCCG
International Ocean Colour Coordinating Group

New Task force – Harmonizing Global Ocean Colour for Long-Term Climate and Ecosystem monitoring

Harness recent and emerging satellites

PACE

Behrenfeld et al. (2023) https://doi.org/10.3390/rs15235567



GLIMR

EnMAP

EU | ESA chime COPERNICUS

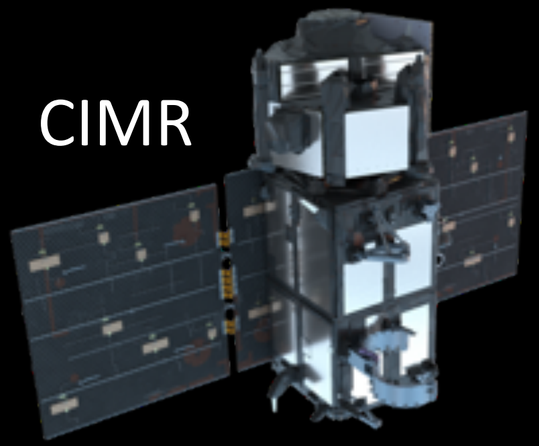
ESA | JAXA earthcare

SATÉLITE DE APLICACIONES BASADAS EN LA INFORMACIÓN AMBIENTAL DEL MAR SABIA-Mar CONAE - ARGENTINA

SWOT

GOCI-II

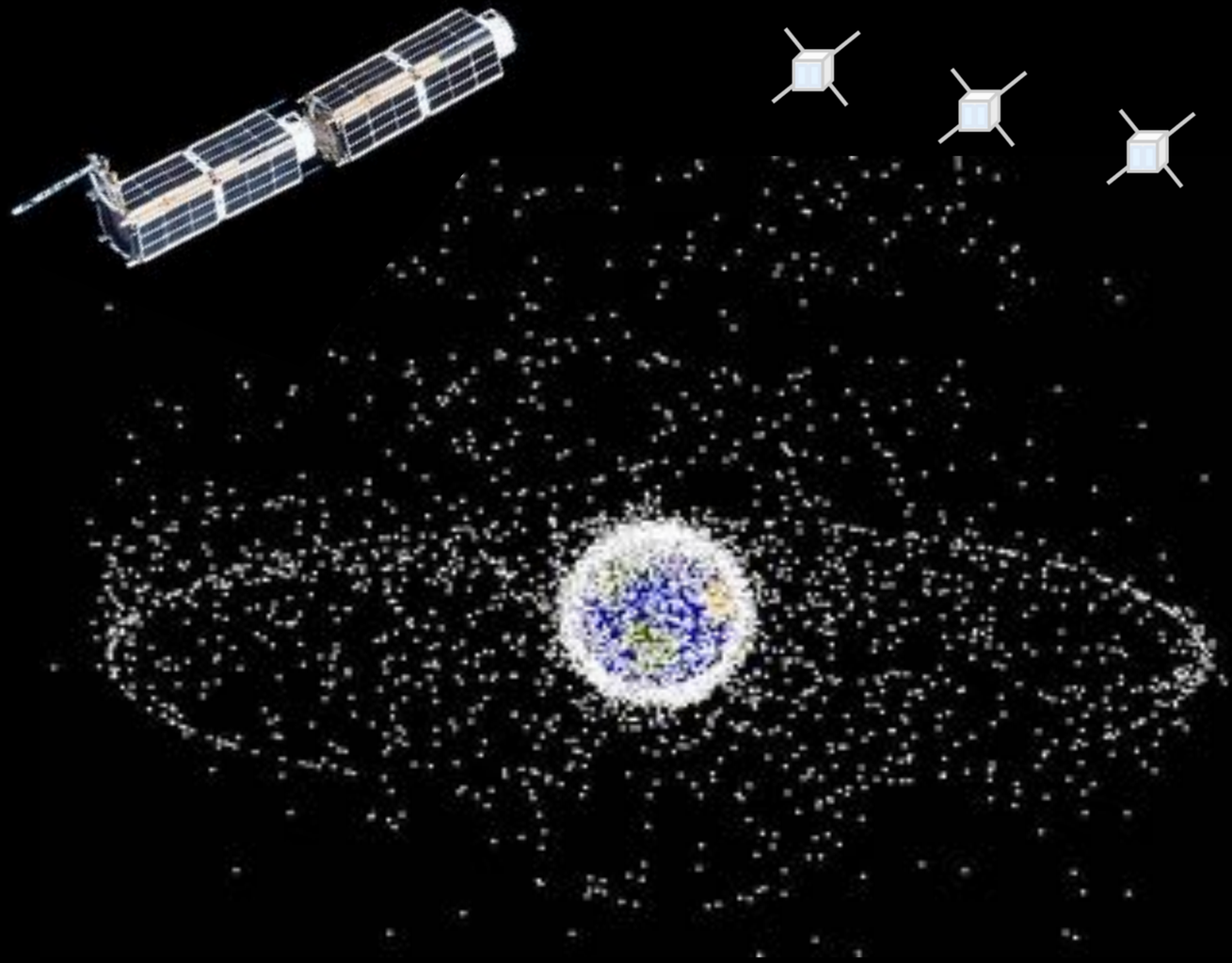
CIMR



CO2M

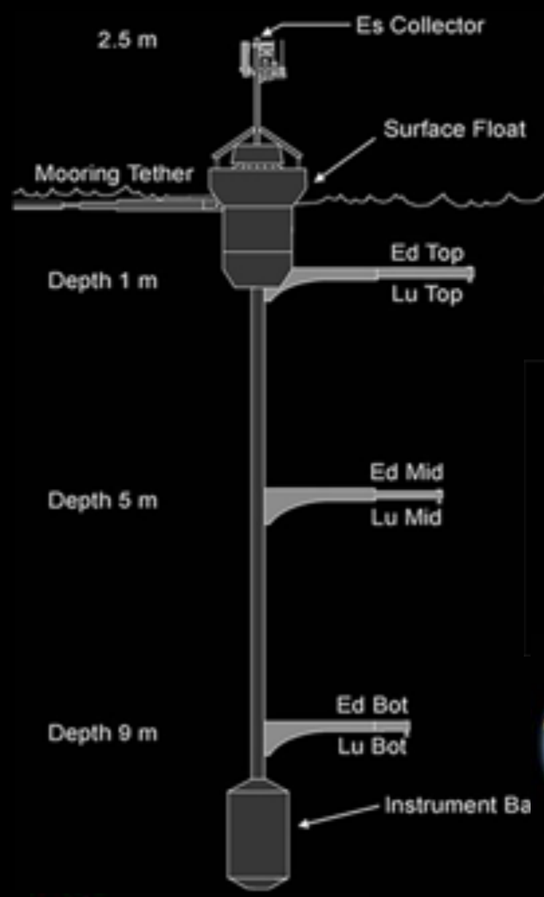
Small and commercial satellites

Bresnahan et al. (2024)
https://doi.org/10.1038/s41597-024-04076-4



Martellato et al. (2022)
https://doi.org/10.3390/rs14092066

Cal/Val of primary observables



fiducial reference measurements for satellite ocean colour

FRM4STS

FRM4ALT

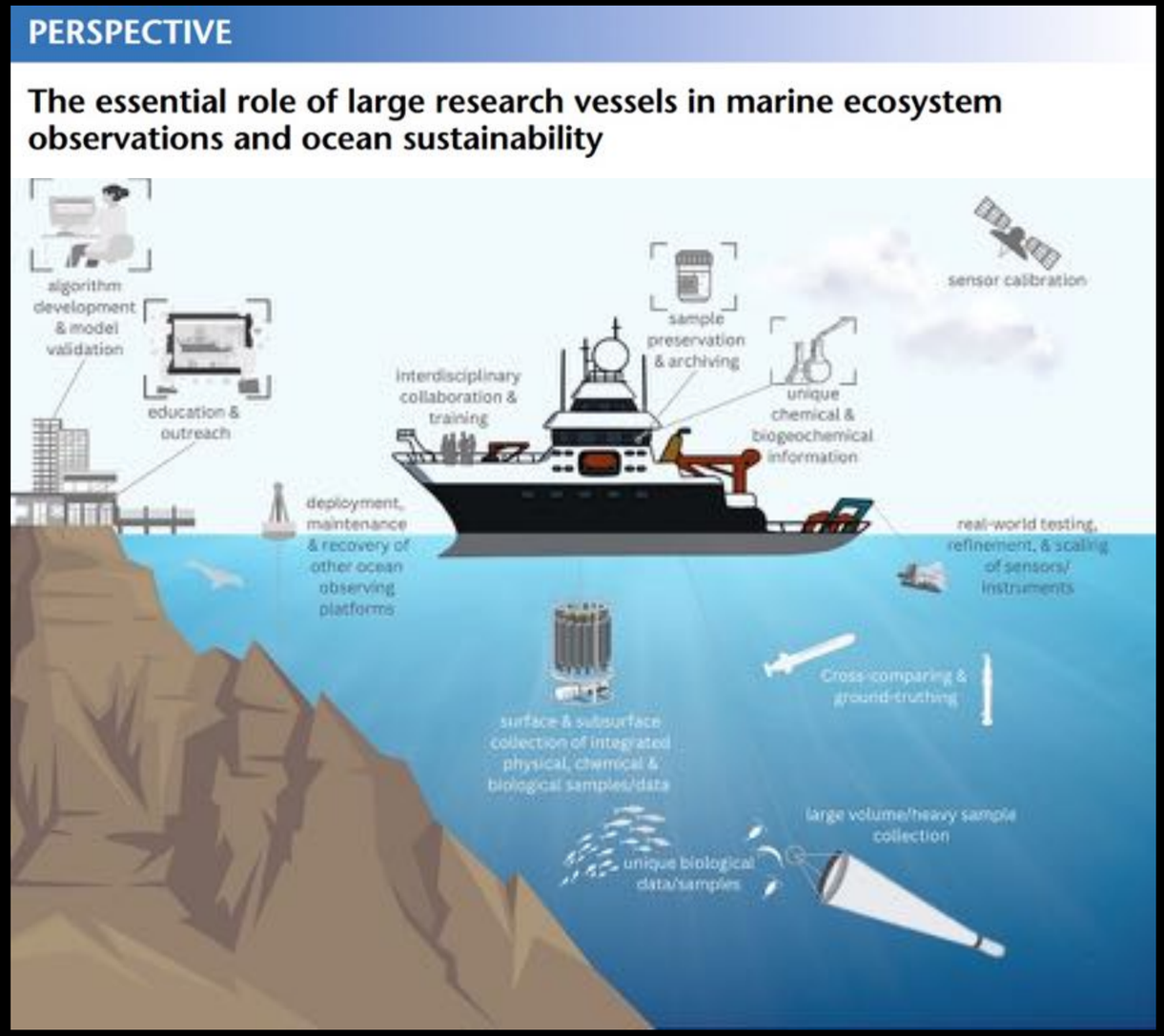
CEOS Committee on Earth Observation Satellites

OCR-VC

iCCG International Ocean Colour Coordinating Group

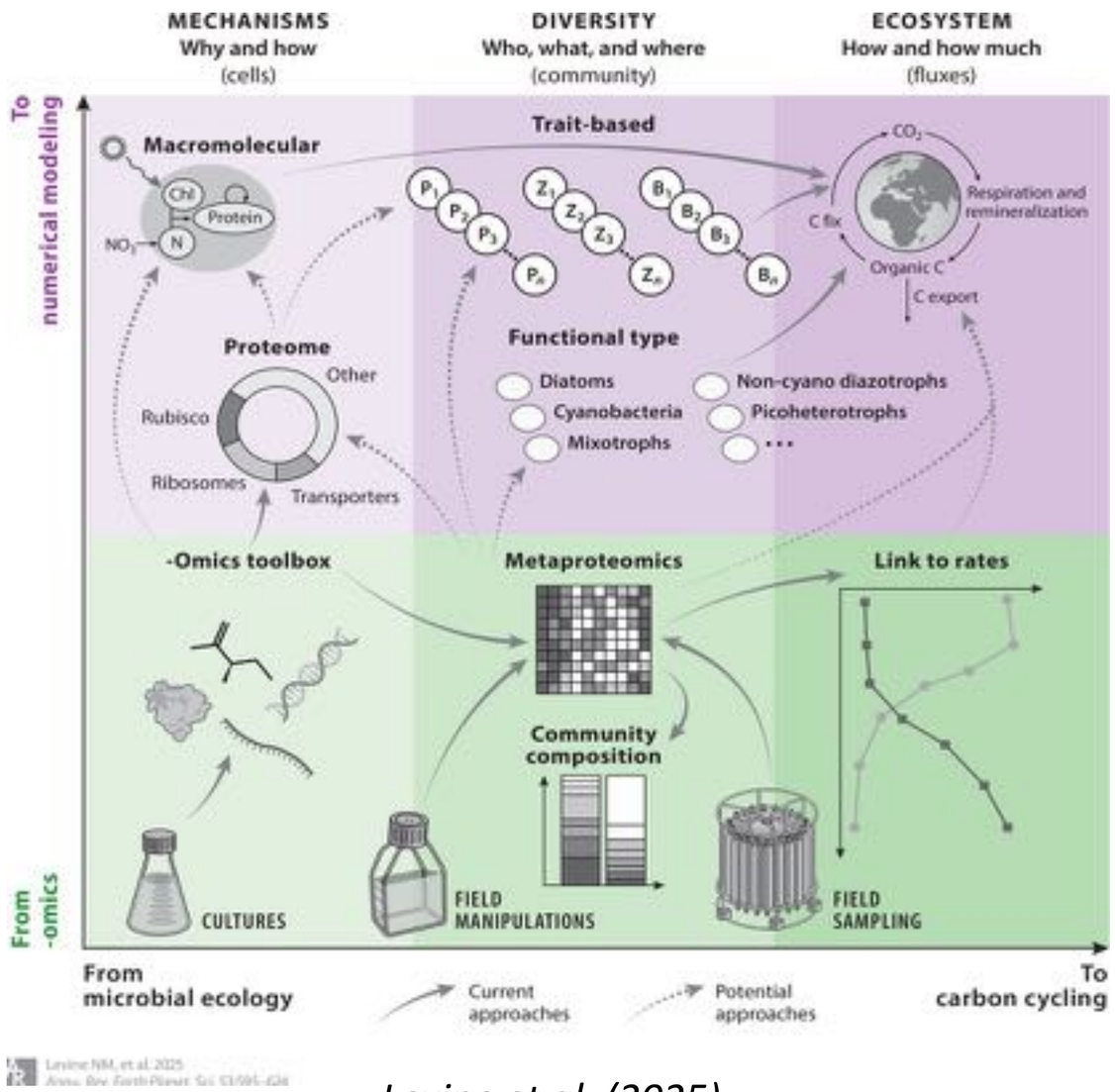
Zibordi et al. (2025) *https://doi.org/10.1175/BAMS-D-24-0085.1*

Essential role of ships



Satterthwaite et al. (2025) *https://doi.org/10.1002/lno.70110*

Insight from emerging methods



Levine et al. (2025)

https://doi.org/10.1146/annurev-earth-040523-020630

Citizen Science and affordable monitoring

PHILOSOPHICAL TRANSACTIONS A

frontiers | Frontiers in Remote Sensing

Superyachts could support satellite ocean colour validation

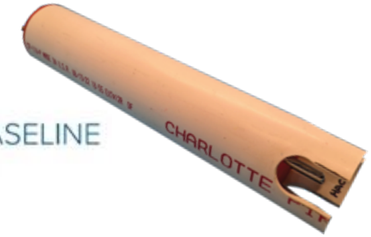
Sailing through the southern seas of air–sea CO_2 flux uncertainty

Peter Landschützer[1,2,†], Toste Tanhua[3,†], Jacqueline Behncke[2,4] and Lydia Keppler[5]

THE OpenCTD

A LOW-COST, OPEN-SOURCE CTD FOR COLLECTING BASELINE OCEANOGRAPHIC DATA IN COASTAL WATERS

By Andrew Thaler, S. Kersey Sturdivant, Russell Y. Neches, and J. Jacob Levenson

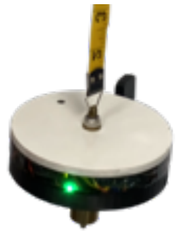


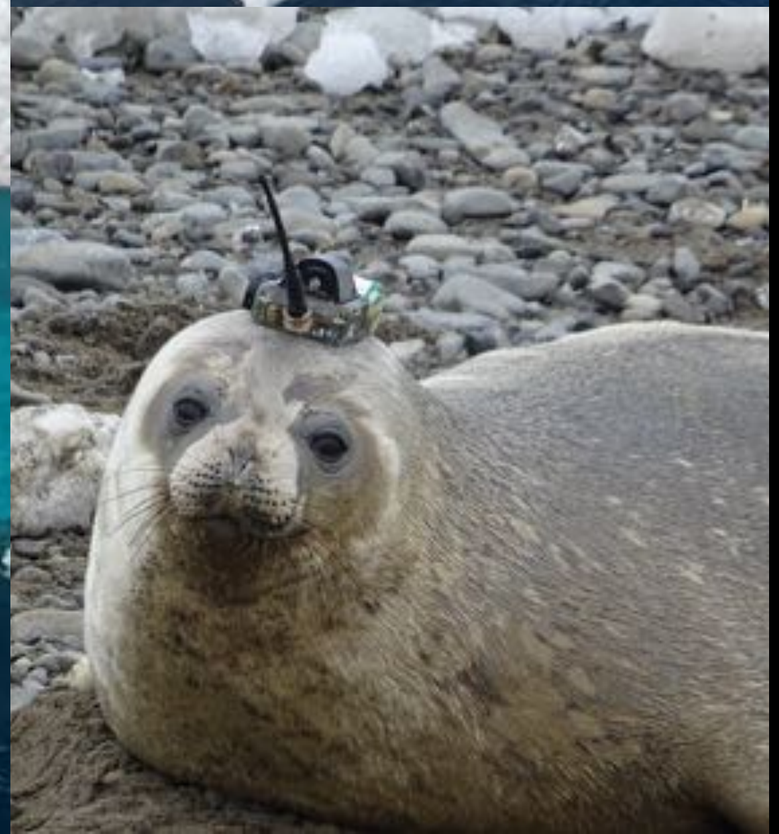
LIMNOLOGY and OCEANOGRAPHY: METHODS

ASLO

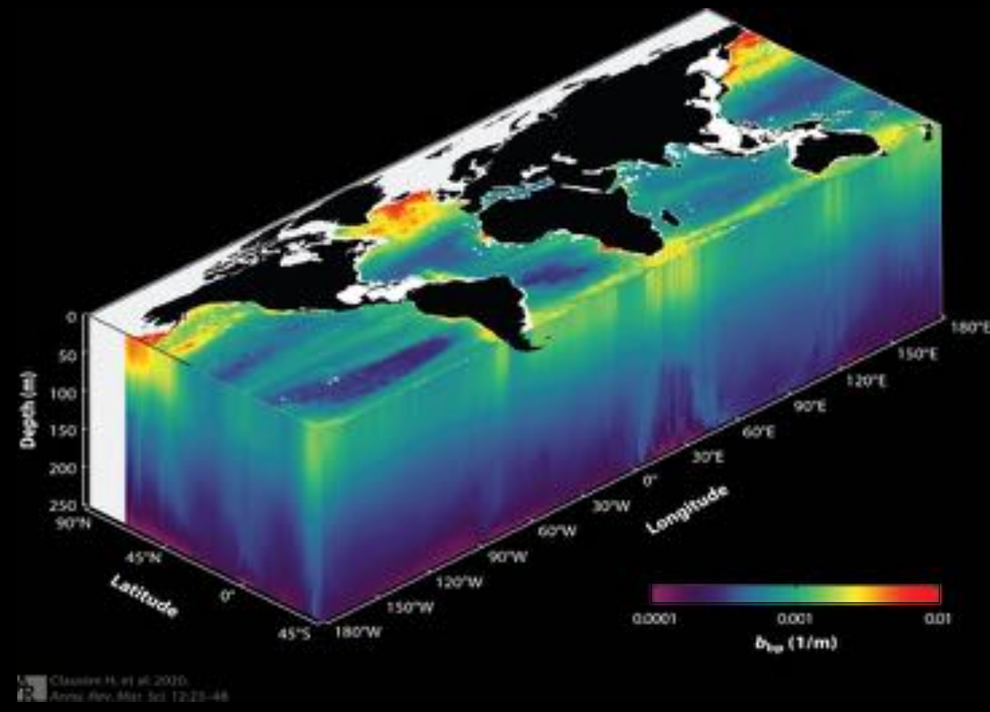
Limnol. Oceanogr.: Methods 22, 2024, 507–526
© 2024 The Author(s). *Limnology and Oceanography: Methods* published by Wiley Periodicals LLC on behalf of Association for the Sciences of Limnology and Oceanography.
doi: 10.1002/lom3.10624

Lab on a Secchi disk: A prototype open-source profiling package for low-cost monitoring in aquatic environments





Bellacicco et al. (2024) *https://doi.org/10.1175/JTECH-D- 23-0161.1*



Claustre et al. (2020)
https://doi.org/10.1146/annurev-marine-010419-010956

Towards a fully coupled, multi-platform carbon observing system

Global Ocean Observing System

Moltmann et al. (2019) https://doi.org/10.3389/fmars.2019.00291
Claustre et al. (2021) https://doi.org/10.3389/fmars.2021.780052

Support the next generation of ocean carbon and Earth system models

Eos

SUPPORT EOS

A Leap Toward Next-Generation Ocean Models

GPU-optimized ocean modeling achieves decade-long simulations in a day, enabling mesoscale-resolving climate simulations that open new opportunities for long-term planning in a changing climate.

Silvestri et al. (2025)
https://doi.org/10.1029/2024MS004465

nature ecology & evolution

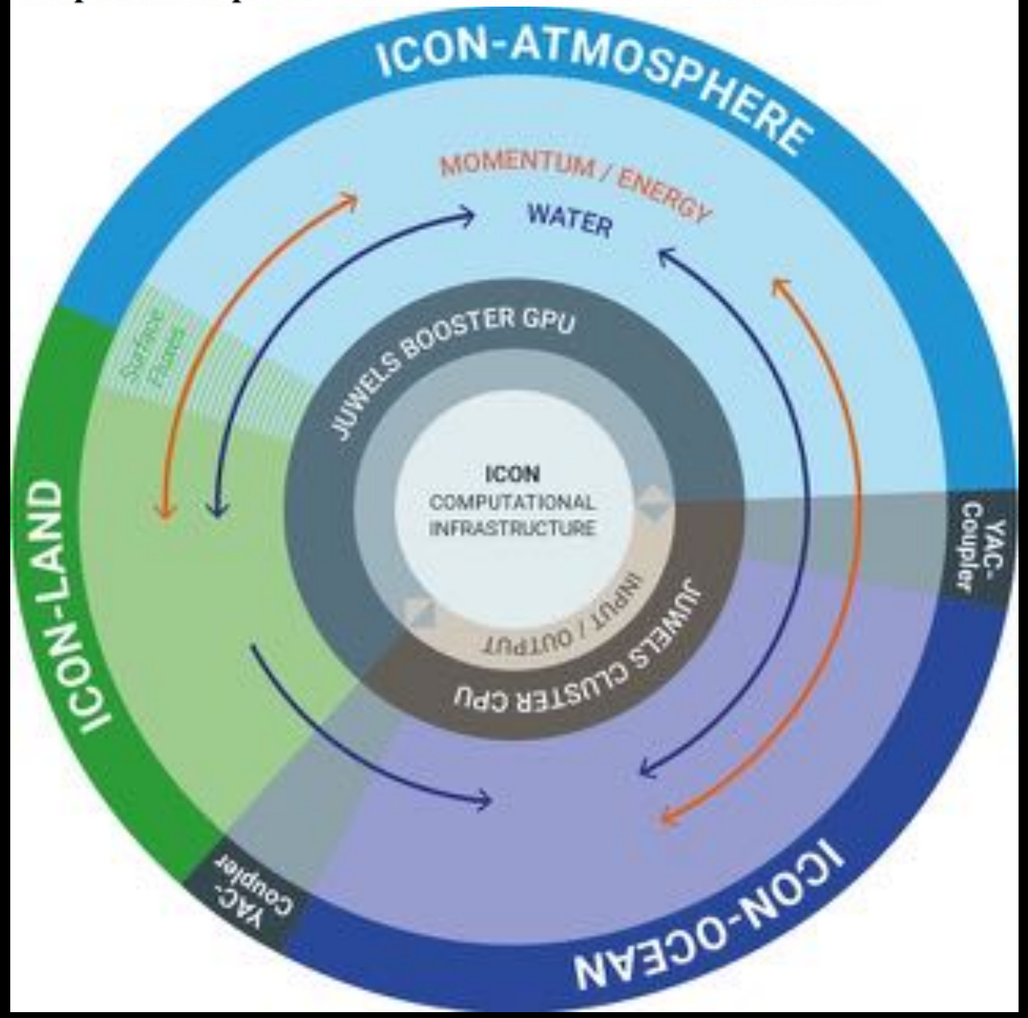
Perspective

https://doi.org/10.1038/s41559-025-02788-3

More realistic plankton simulation models will improve projections of ocean ecosystem responses to global change

Flynn et al. (2025)
https://doi.org/10.1038/s41559-025-02788-3

Earth system modeling on modular supercomputing architecture: coupled atmosphere–ocean simulations with ICON 2.6.6-rc



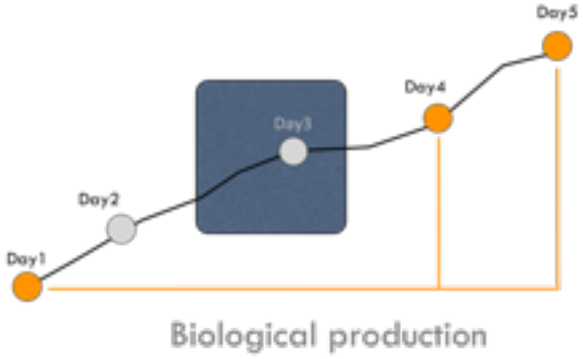
Bishnoi et al. (2024)
https://doi.org/10.5194/gmd-17-261-2024

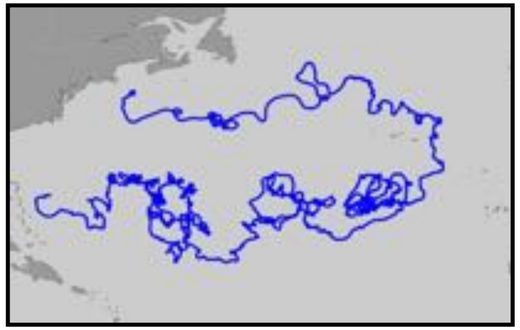
UNSCEO (2022)

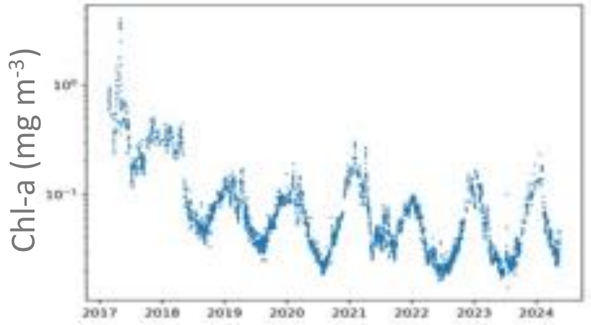
Findable Accessible Interoperable Reusable

CCG International Ocean Colour Coordinating Group

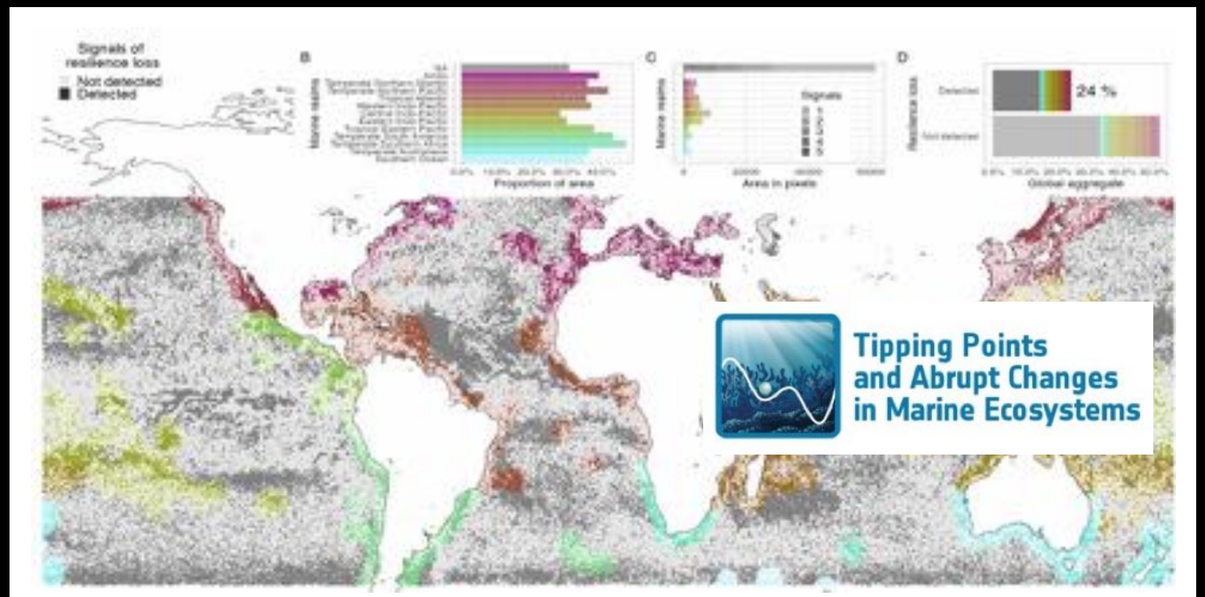
Advance approaches to using satellite data for carbon research







Jönsson et al. (2009)
https://doi.org/10.1080/01431160802558758



Rocha (2022)
https://doi.org/10.1088/1748-9326/ac73a8

nature communications

Article

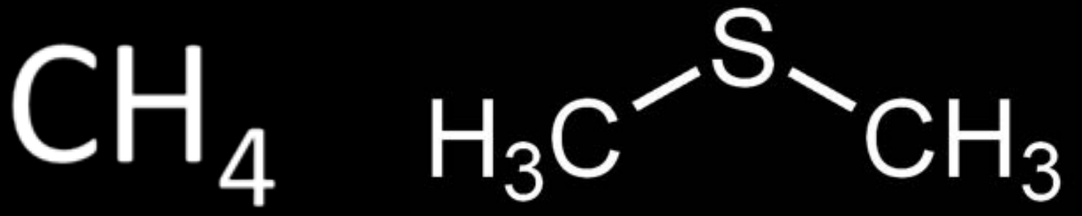
https://doi.org/10.1038/s41467-025-62363-z

The oceanic physical injection pump of organic carbon

Received: 7 August 2024

Accepted: 18 July 2025

Marco Bellacicco[1], Salvatore Marullo[1], Giorgio Dall'Olmo[2], Daniele Iudicone[3] & Bruno Buongiorno Nardelli[4]



Improved fundamental understanding

Seasonal copepod lipid pump promotes carbon sequestration in the deep North Atlantic

Sigrún Huld Jónasdóttir[a,1], André W. Visser[a,b], Katherine Richardson[c], and Michael R. Heath[d]

CARBON CYCLE

Major role of particle fragmentation in regulating biological sequestration of CO_2 by the oceans

Nathan Briggs[1,2]*, Giorgio Dall'Olmo[3,4], Hervé Claustre[2]

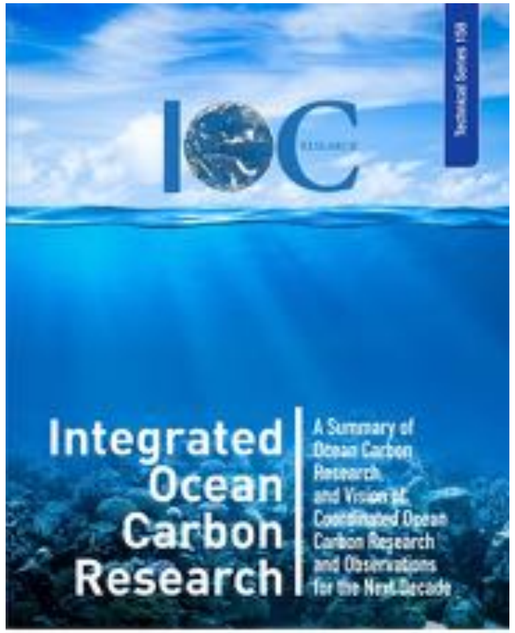
OCEANOGRAPHY

Eddy-driven subduction exports particulate organic carbon from the spring bloom

Melissa M. Omand,[1]* Eric A. D'Asaro,[2] Craig M. Lee,[2] Mary Jane Perry,[3] Nathan Briggs,[3] Ivona Cetinić,[3] Amala Mahadevan[1]†

Substantial energy input to the mesopelagic ecosystem from the seasonal mixed-layer pump

Giorgio Dall'Olmo[1,2,3]*, James Dingle[1], Luca Polimene[1], Robert J. W. Brewin[1,2] and Hervé Claustre[4]



Chapter III. Fundamental and Emerging Research Questions

Article

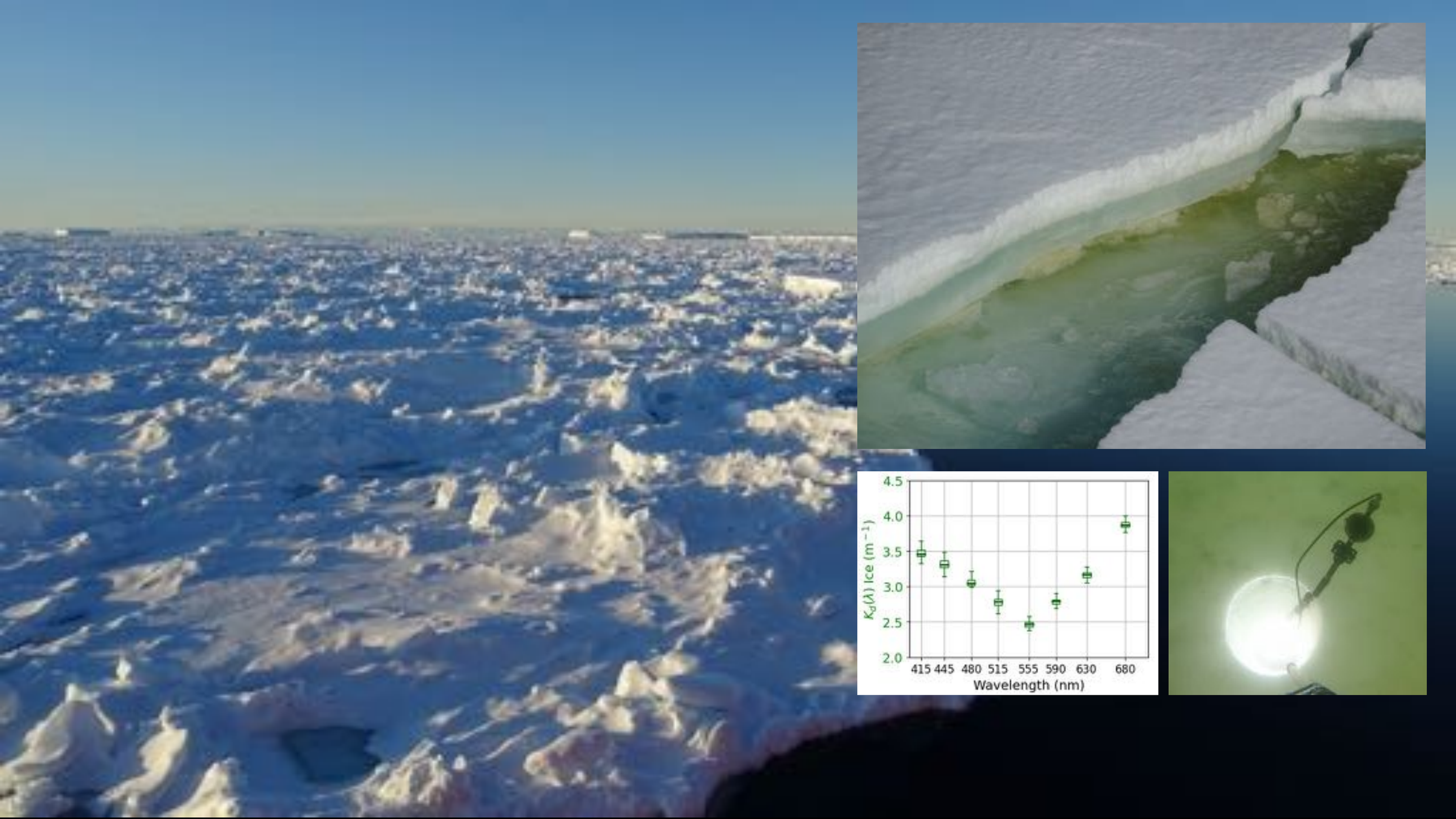
Widespread phytoplankton blooms triggered by 2019–2020 Australian wildfires

https://doi.org/10.1038/s41586-021-03805-8
Received: 25 August 2020
Accepted: 5 July 2021

Weiyi Tang[1,9,10], Joan Llort[2,3,10], Jakob Weis[1,4], Morgane M. G. Perron[5], Sara Basart[6], Zuchuan Li[1,7], Shubha Sathyendranath[8], Thomas Jackson[8], Estrella Sanz Rodriguez[5], Bernadette C. Proemse[5], Andrew R. Bowie[3,6], Christina Schallenberg[3,6], Peter G. Strutton[3,4], Richard Matear[6] & Nicolas Cassar[1]

An exceptional phytoplankton bloom in the southeast Madagascar Sea driven by African dust deposition

John A. Gittings[a], Giorgio Dall'Olmo[b], Weiyi Tang[c], Joan Llort[d], Fatma Jebri[e], Eleni Livanou[a], Francesco Nencioli[f], Sofia Darmaraki[a], Iason Theodorou[a], Robert J. W. Brewin[g], Meric Srokosz[e], Nicolas Cassar[h,*] and Dionysios E. Raitsos[a,*]



4.5
4.0
3.5
3.0
2.5
2.0
$K_d(\lambda)$ Ice (m^{-1})
415 445 480 515 555 590 630 680
Wavelength (nm)

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Thank you!

Questions

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