

climate change initiative

OCEAN CARBON 4 CLIMATE



SCOPE



Salinity is critical for ocean carbon cycle and ocean acidification assessments (and climate policy!)

Jamie D. Shutler and Daniel J. Ford

Shuhba Sathyendranath, Gemma Kulk, Peter Land, Tom Bell, Peter Landschützer, Alizée Roobaert, Judith Hauck Sreeush Mohanan, Galen Mckinley, Amanda Fay, Thea Hatlen Heimdal, Marion Gehlen, Frederic Chevallier, David Woolf, Nicolas Gruber, Luke Gregor, Jean-Francois Piolle, Bertrand Chapron, Lucile Gultier.



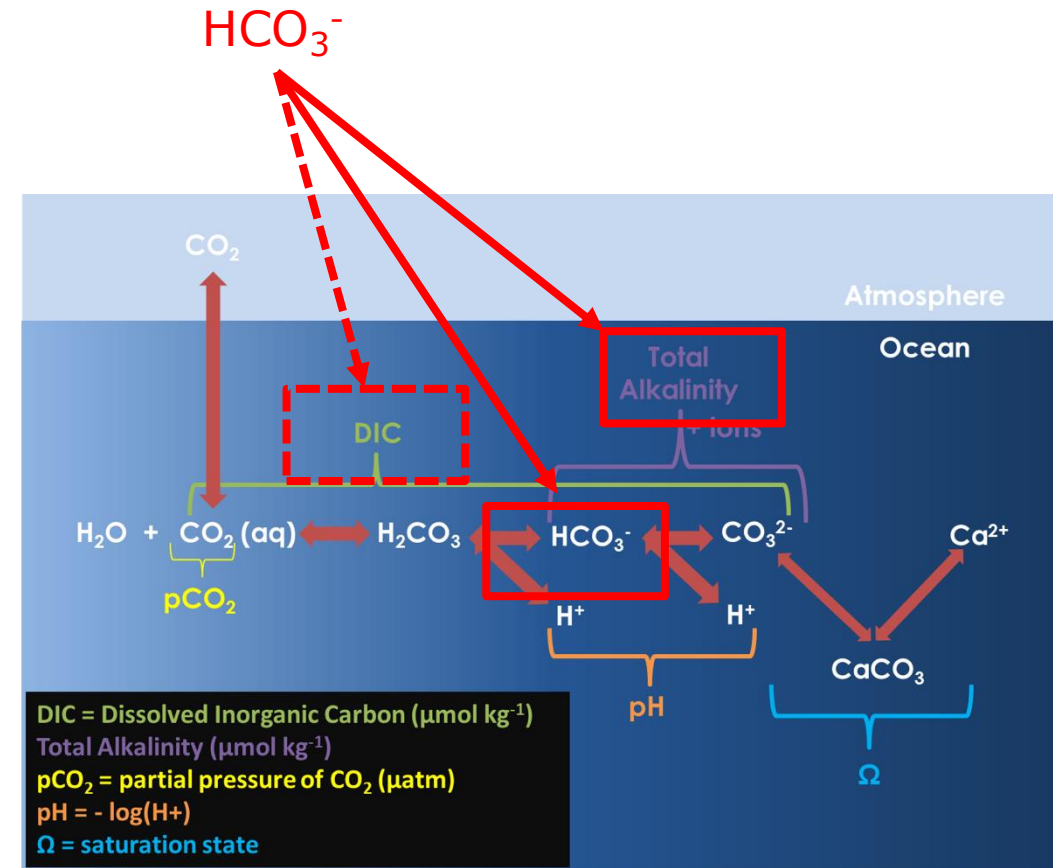
21/05/2026



Forchhammer's Principle

The **major ions** (>1mg/kg seawater) at S = 35.000 (from Pilson)

Ion	Formula	g/Kg	mmol/Kg
Sodium	Na ⁺	10.781	468.96
Magnesium	Mg ²⁺	1.284	52.83
Calcium	Ca ²⁺	0.4119	10.28
Potassium	K ⁺	0.399	10.21
Strontium	Sr ²⁺	0.00794	0.0906
Chloride	Cl ⁻	19.353	545.88
Sulfate	SO ₄ ²⁻	2.712	28.23
Bicarbonate	HCO₃⁻	0.126	2.06
Bromide	Br ⁻	0.067	0.844
Borate	H ₃ BO ₄ ⁻	0.0257	0.416
Fluoride	F ⁻	0.00130	0.068
Totals	11	35.169	1119.87



Carbonate chemistry

DIC covaries with SST and salinity

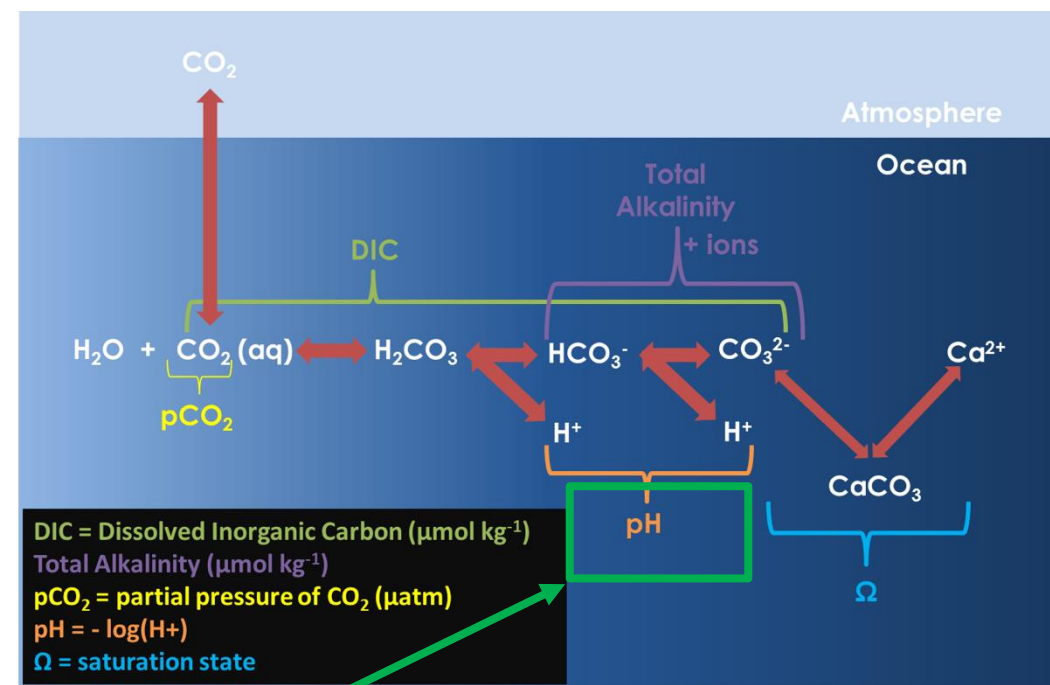
Stanford university lecture notes



Forchhammer's Principle

The **major ions** (>1mg/kg seawater) at S = 35.000 (from Pilson)

Ion	Formula	g/Kg	mmol/Kg
Sodium	Na ⁺	10.781	468.96
Magnesium	Mg ²⁺	1.284	52.83
Calcium	Ca ²⁺	0.4119	10.28
Potassium	K ⁺	0.399	10.21
Strontium	Sr ²⁺	0.00794	0.0906
Chloride	Cl ⁻	19.353	545.88
Sulfate	SO ₄ ²⁻	2.712	28.23
Bicarbonate	HCO ₃ ⁻	0.126	2.06
Bromide	Br ⁻	0.067	0.844
Borate	H ₃ BO ₄ ⁻	0.0257	0.416
Fluoride	F ⁻	0.00130	0.068
Totals	11	35.169	1119.87



Carbonate chemistry



Stanford university lecture notes



The ocean carbonate system



The oceanic carbonate system can be understood and probed through four key parameters: total alkalinity (A_T), total dissolved inorganic carbon (DIC or C_T), basity (pH), and fugacity or partial pressure of CO_2 ($f\text{CO}_2$ or $p\text{CO}_2$).



The ocean carbonate system

The oceanic carbonate system can be understood and probed through four key parameters: total alkalinity (A_T), total dissolved inorganic carbon (DIC or C_T), basity (pH), and fugacity or partial pressure of CO_2 ($f\text{CO}_2$ or $p\text{CO}_2$).

Knowledge of **any two of these parameters** is sufficient to **solve** the carbonate system equations **along with temperature and pressure** (due to thermodynamics).



The ocean carbonate system

The oceanic carbonate system can be understood and probed through four key parameters: total alkalinity (A_T), total dissolved inorganic carbon (DIC or C_T), basity (pH), and fugacity or partial pressure of CO_2 ($f\text{CO}_2$ or $p\text{CO}_2$).

Knowledge of **any two of these parameters** is sufficient to **solve** the carbonate system equations **along with temperature and pressure** (due to thermodynamics).

Salinity effects carbonate system calculation coefficients.



The ocean carbonate system

The oceanic carbonate system can be understood and probed through four key parameters: total alkalinity (A_T), total dissolved inorganic carbon (DIC or C_T), basity (pH), and fugacity or partial pressure of CO_2 ($f\text{CO}_2$ or $p\text{CO}_2$).

Knowledge of **any two of these parameters** is sufficient to **solve** the carbonate system equations **along with temperature and pressure** (due to thermodynamics).

Salinity effects carbonate system calculation coefficients.

Some pairs are more optimal than others.



The ocean carbonate system

The oceanic carbonate system can be understood and probed through four key parameters: total alkalinity (A_T), total dissolved inorganic carbon (DIC or C_T), basity (pH), and fugacity or partial pressure of CO_2 ($f\text{CO}_2$ or $p\text{CO}_2$).

Knowledge of **any two of these parameters** is sufficient to **solve** the carbonate system equations **along with temperature and pressure** (due to thermodynamics).

Salinity effects carbonate system calculation coefficients.

Some pairs are more optimal than others.

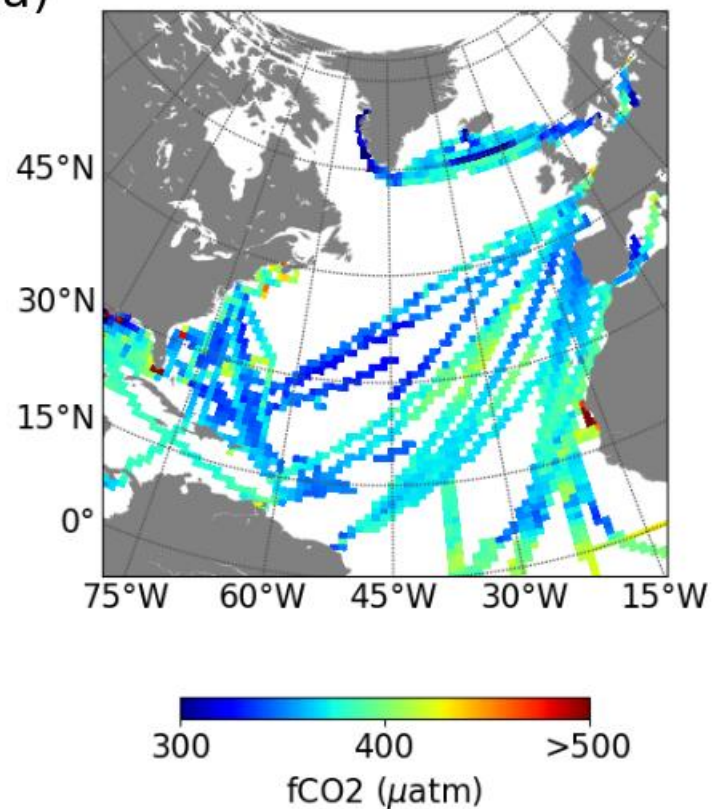
Relationship between different carbonate parameters is fundamentally driven by thermodynamics (salinity and temperature).



Fundamental role of Earth observation data



(a)



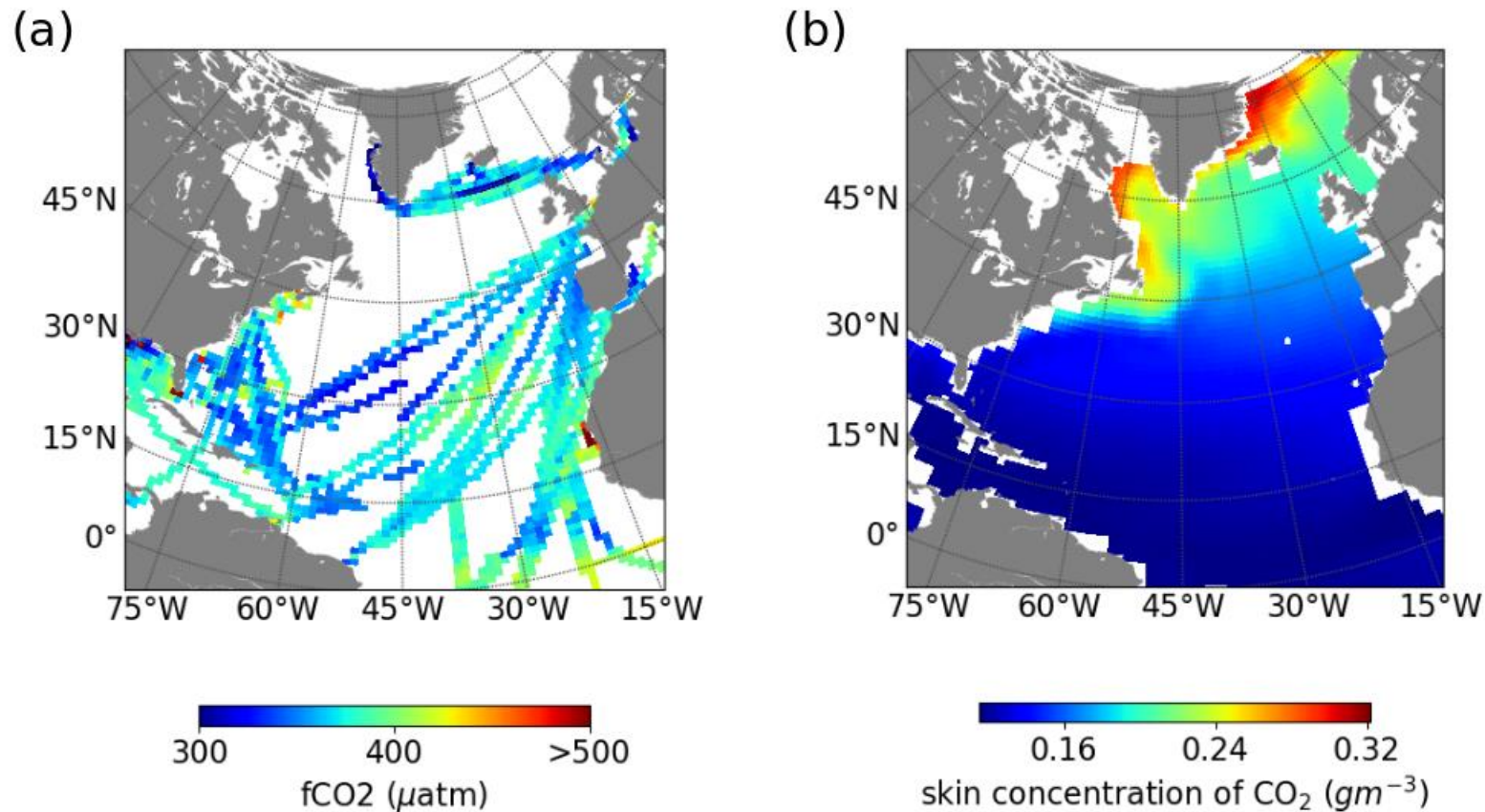
Shutler *et al.*, (2020), *FEC*.

Satellite salinity, temperature, sea-sate, ocean colour and land area in synergy with machine learning and AI.





Fundamental role of Earth observation data



Shutler *et al.*, (2020), *FEC*.

Satellite salinity, temperature, sea-sate, ocean colour and land area in synergy with machine learning and AI.

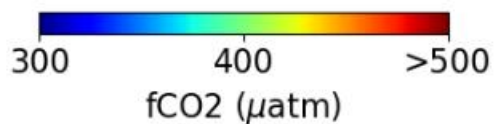
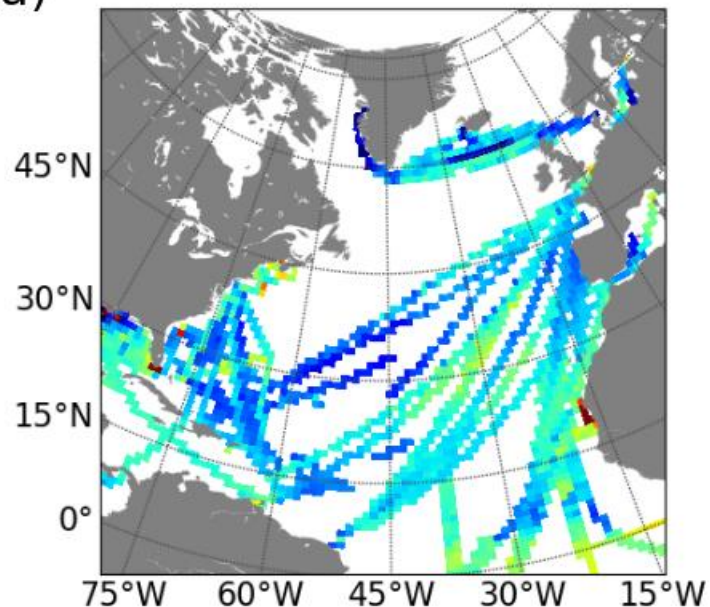




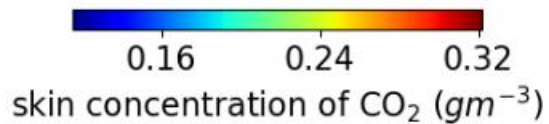
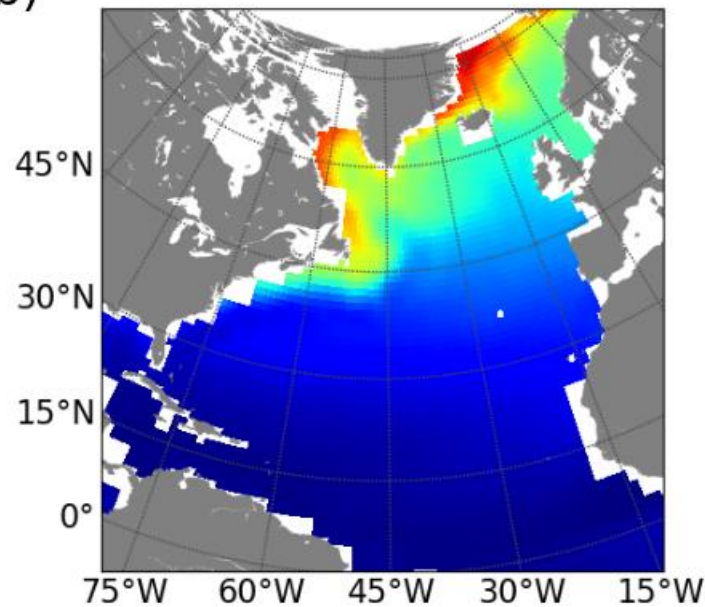
Fundamental role of Earth observation data



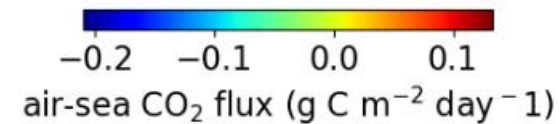
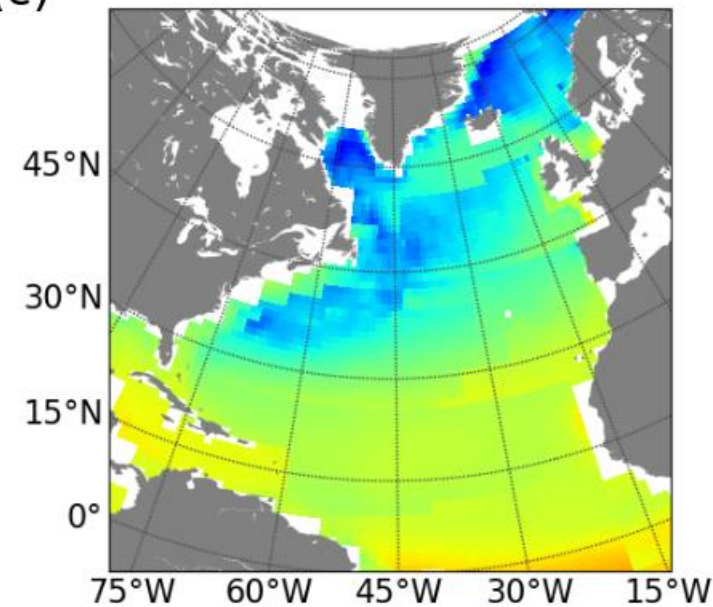
(a)



(b)



(c)



Shutler *et al.*, (2020), *FEC*.

Satellite salinity, temperature, sea-sate, ocean colour and land area in synergy with machine learning and AI.

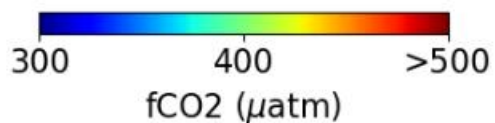
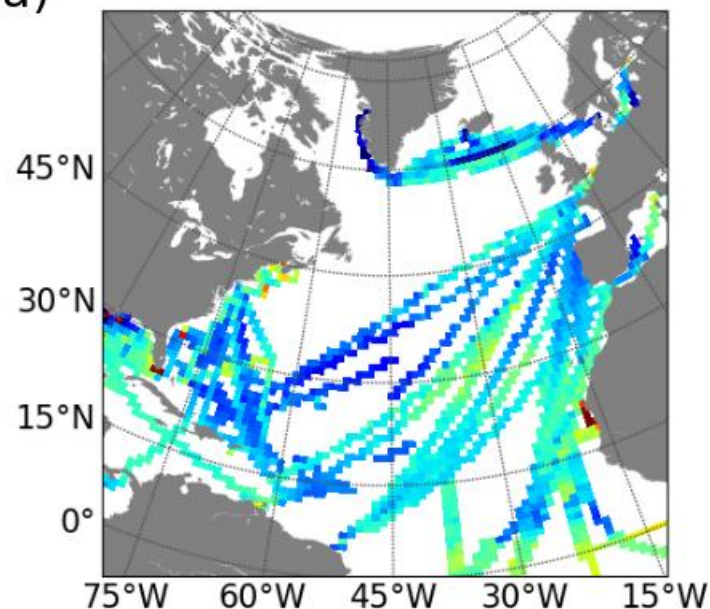




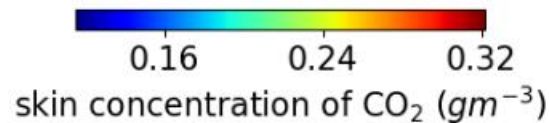
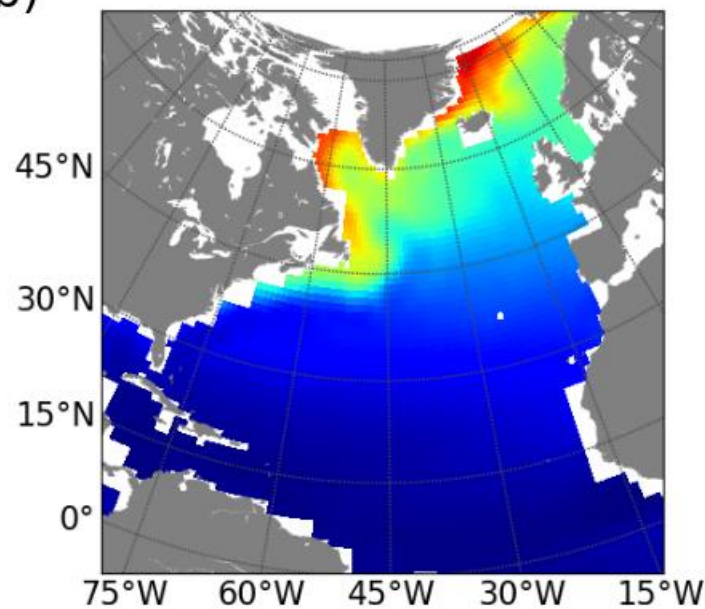
Fundamental role of Earth observation data



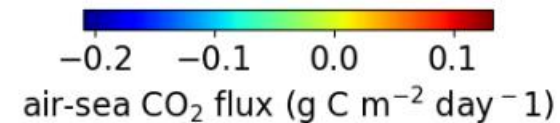
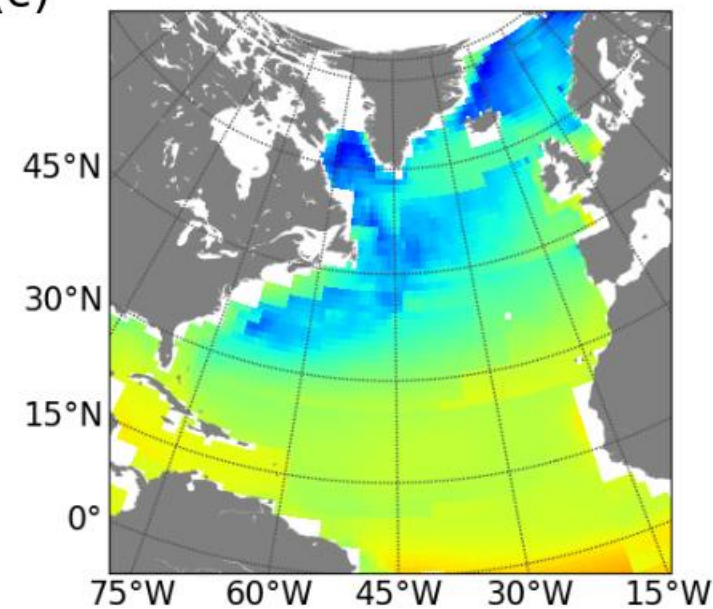
(a)



(b)



(c)



Shutler *et al.*, (2020), *FEC*.

Satellite salinity, temperature, sea-sate, ocean colour and land area in synergy with machine learning and AI.

Example is pCO₂ (or fCO₂), same is possible for A_T

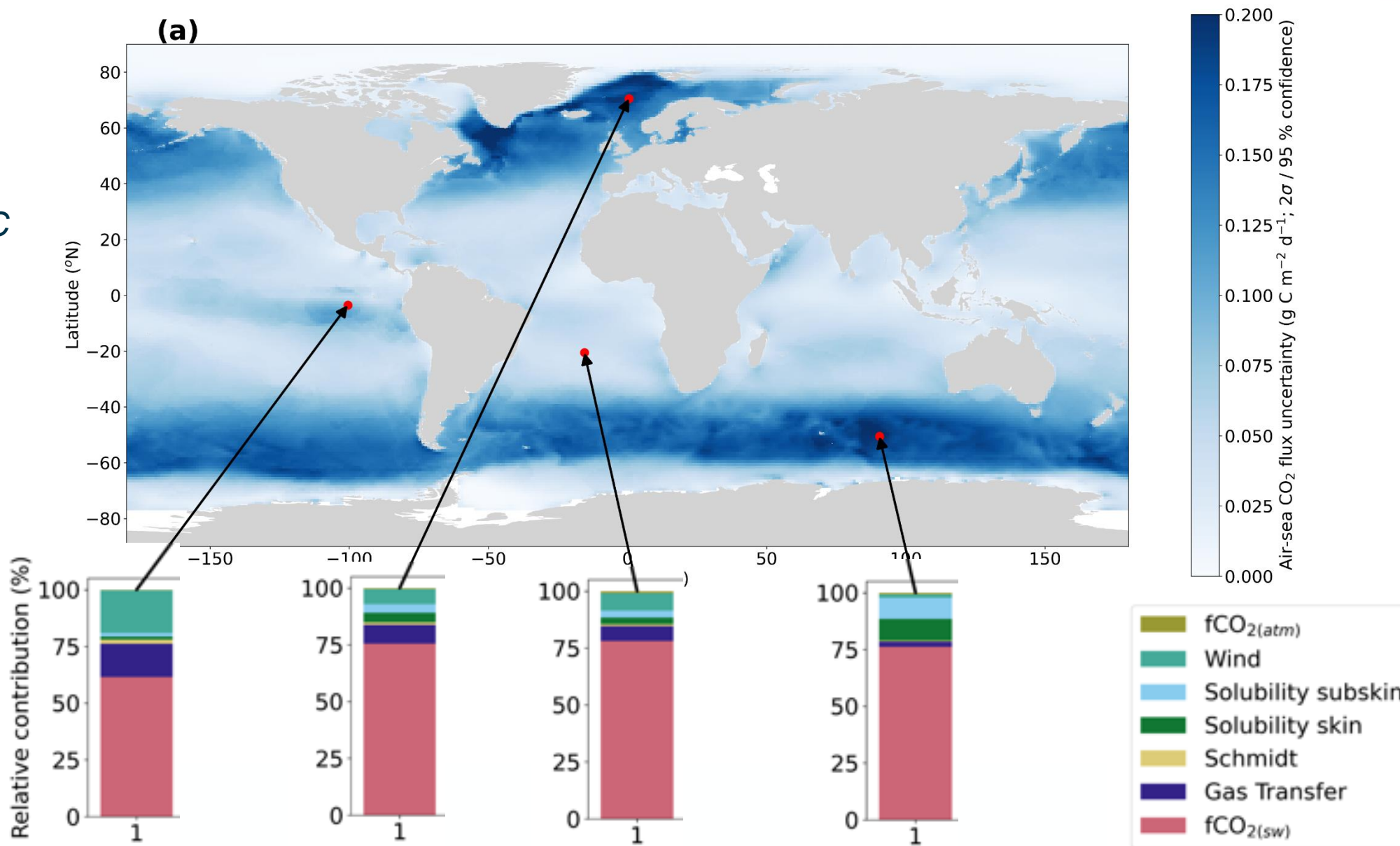




Per pixel uncertainties



Ford *et al.*
(2024), *GBC*





Constraining the whole system

1. Exploitation of as many Climate Data Records as possible:

Ocean Colour CCI

SST CCI

Land cover CCI

Salinity CCI

Sea ice CCI (via OSI-SAF)



SCOPE

2. Exploit multiple constraints on the system e.g., Gregor and Gruber (2021), *ESSD*.

3. Propagation of uncertainties.

Ford *et al.* (2024), *GBC*.





Constraining the whole system



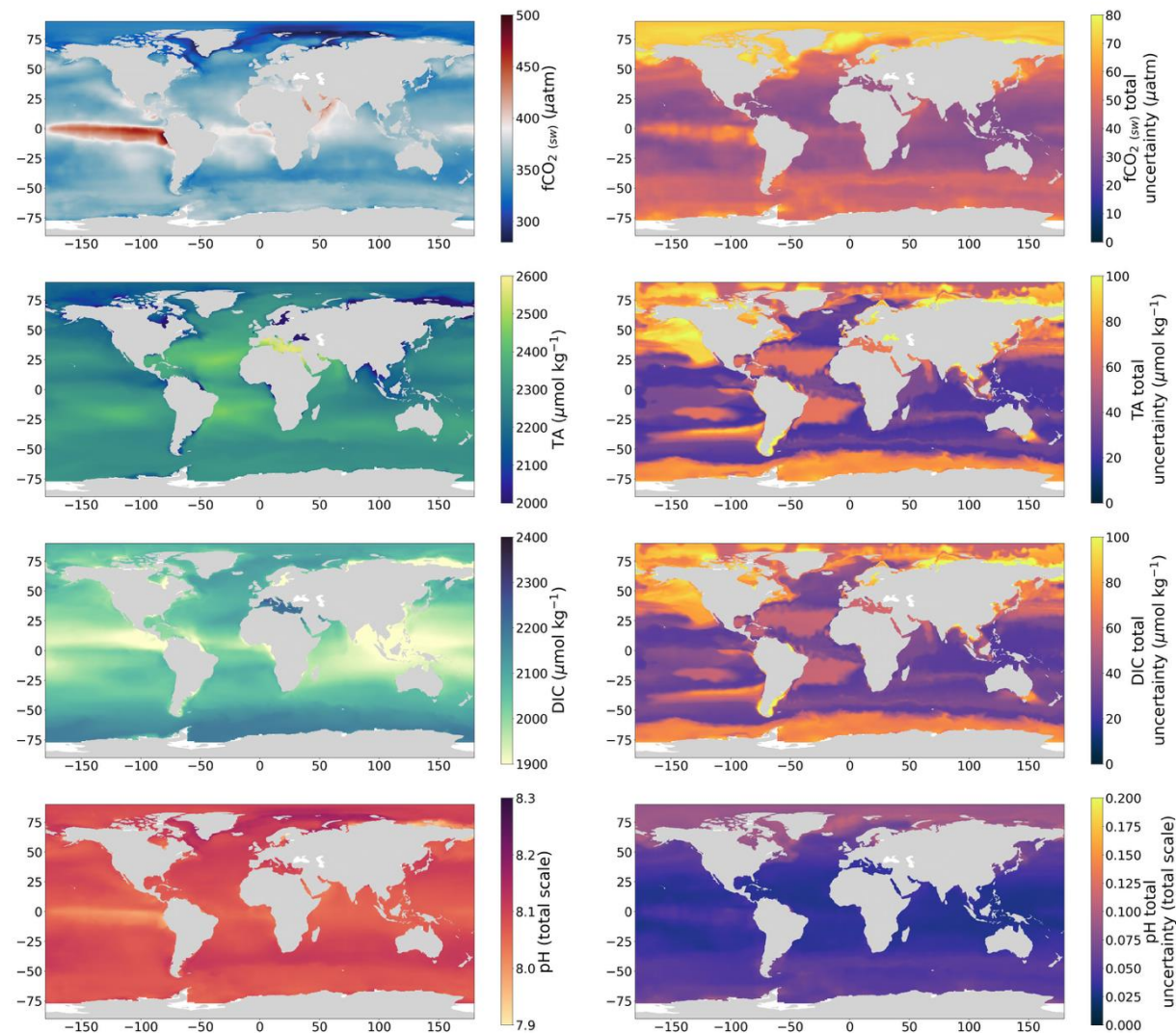
1. Exploitation of as many Climate Data Records as possible:

- Ocean Colour CCI
- SST CCI
- Land cover CCI
- Salinity CCI
- Sea ice CCI (via OSI-SAF)



2. Exploit multiple constraints on the system e.g., Gregor and Gruber (2021), *ESSD*.

3. Propagation of uncertainties.
Ford *et al.* (2024), *GBC*.





Guiding regional management



#OceanAcidificationStripes

HOME

FAQ

CLIMATE STRIPES

ETH zürich

<https://oceanacidificationstripes.info>

Select Region

Class

Basins

Ocean

Global Ocean

Information

Region	Global Ocean Basin
Date Range	1982-2022
Data Source	OceanSODA-ETHZ
Creator	Nicolas Gruber & Luke Gregor
Licensor	ETH Zürich
License	

STRIPES

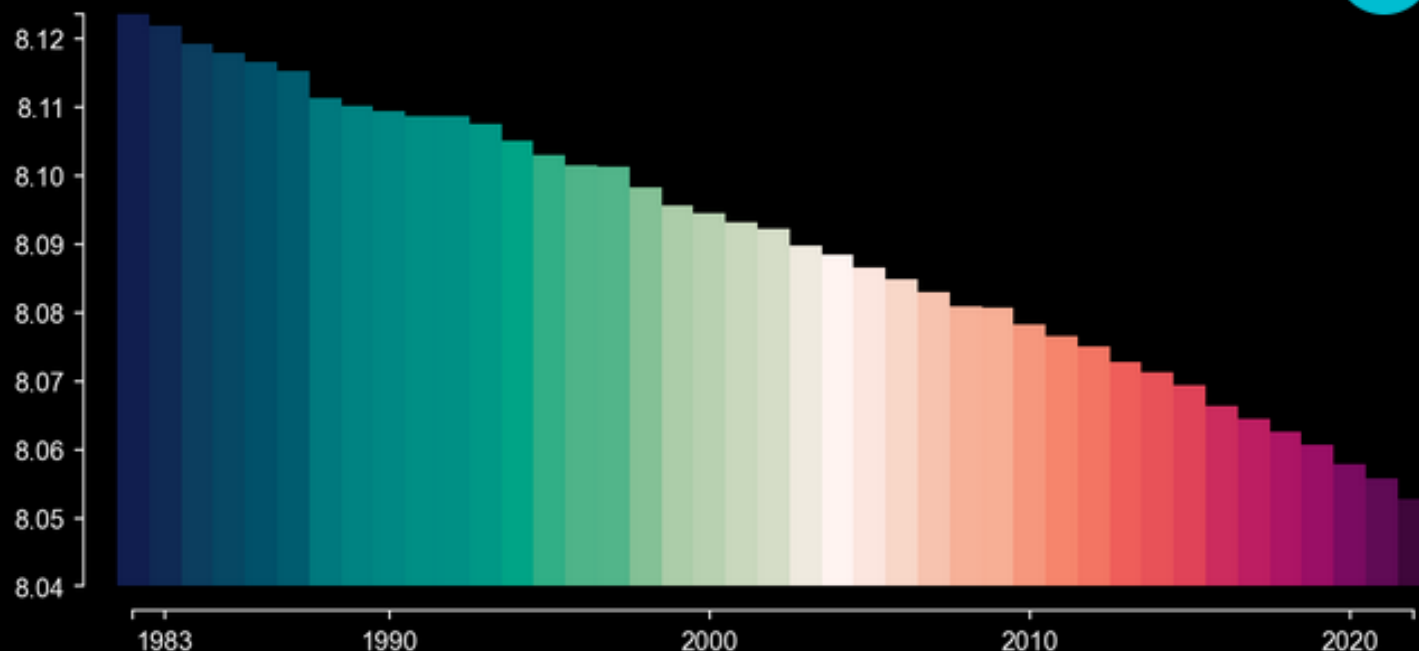
LABELLED STRIPES

BARS

BARS WITH SCALE

pH in the Global Ocean

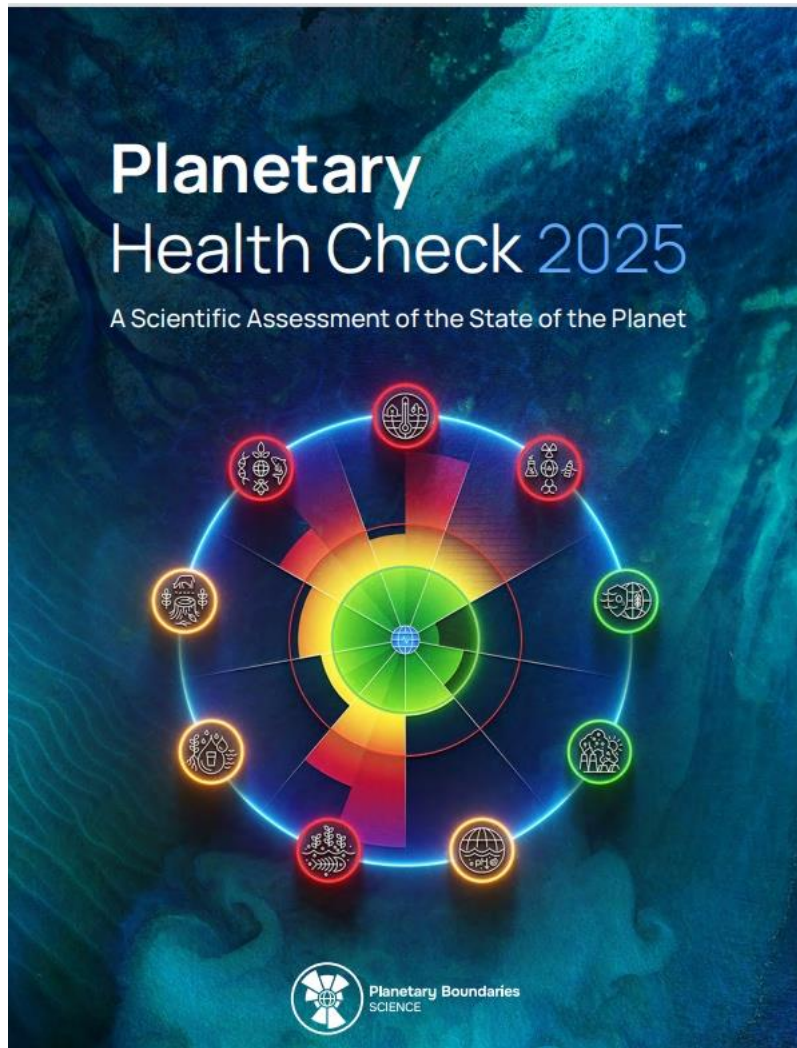
A 0.071 decrease in pH from 1982 to 2022 represents an 18% increase in acidity

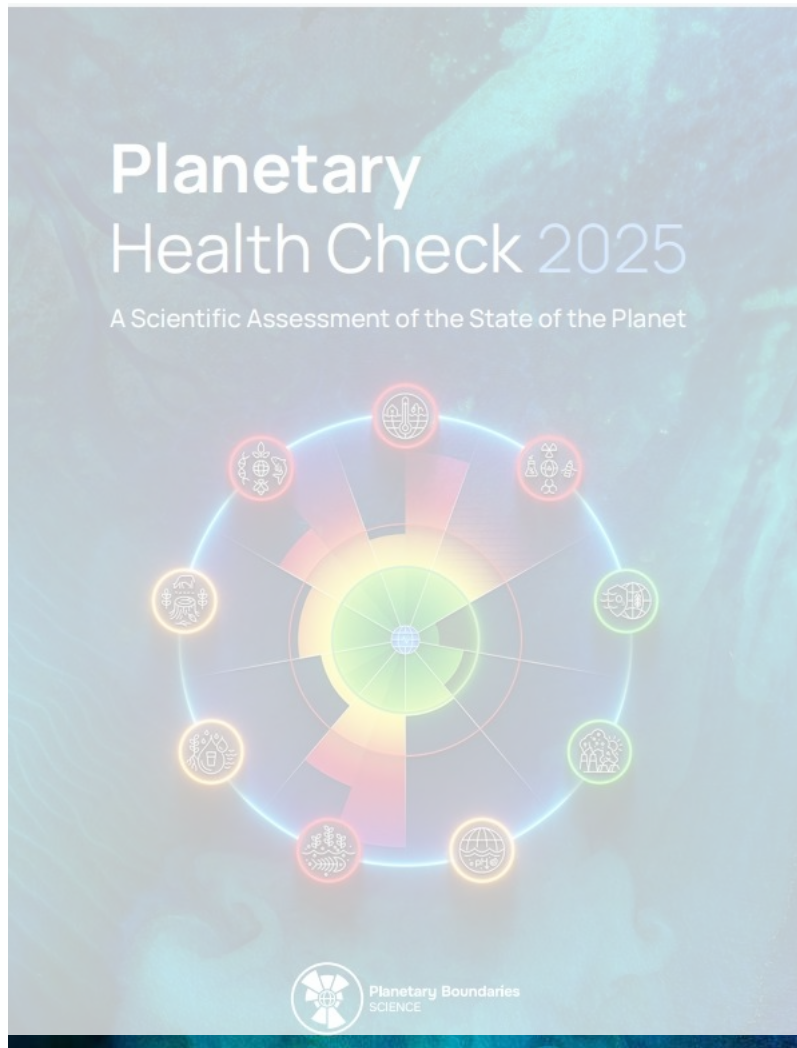


Aragonite saturation pH



Planetary Health Check (Boundary) Assessment





4. Planetary Boundary Information Sheets

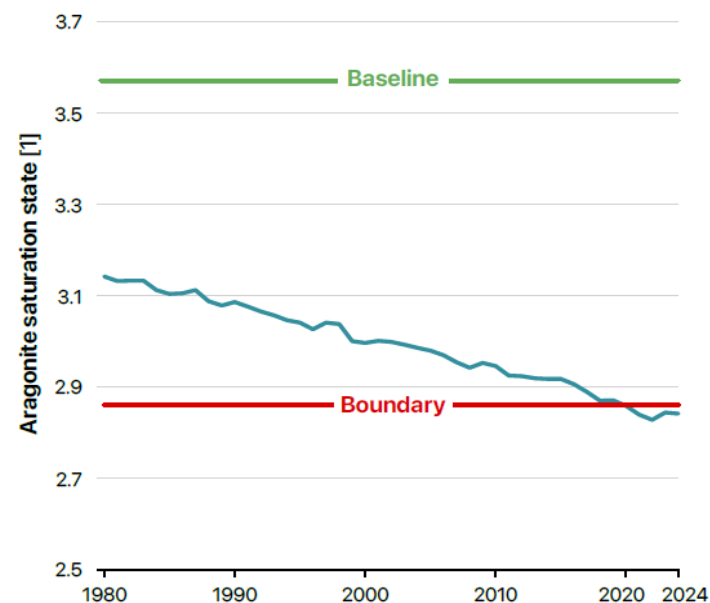
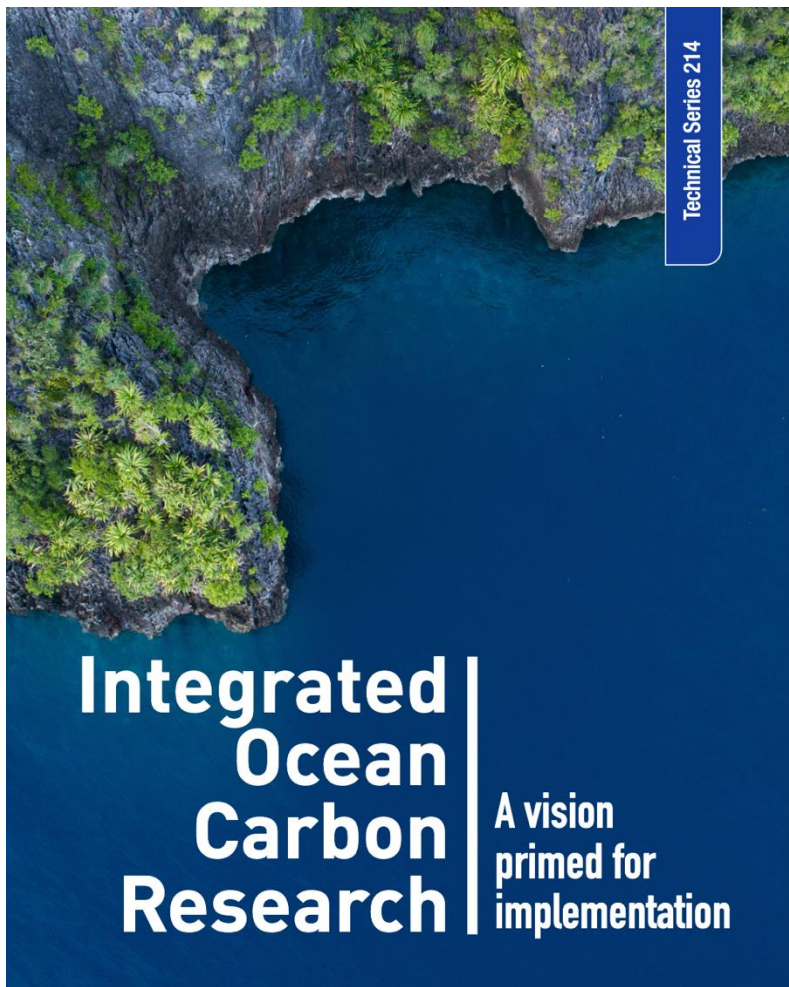


FIGURE 39 - Ocean Acidification has transgressed its Planetary Boundary. This figure shows how the global surface aragonite saturation state has changed over time (based on UExp-FNN-U data).³⁵⁵ It has declined significantly in recent decades and has now breached the Planetary Boundary. The baseline (green line) is a revised estimate of the pre-industrial aragonite saturation state around the year 1750, based on Jiang et al. (2023)³⁵⁴. Because it is higher than previous estimates, the revised Planetary Boundary (set at 80% of the pre-industrial state; red line) is also higher – meaning today’s ocean is even further from its pre-industrial state than previously thought.

Key takeaway: Ocean acidification has gone beyond safe limits, increasingly endangering marine ecosystems.

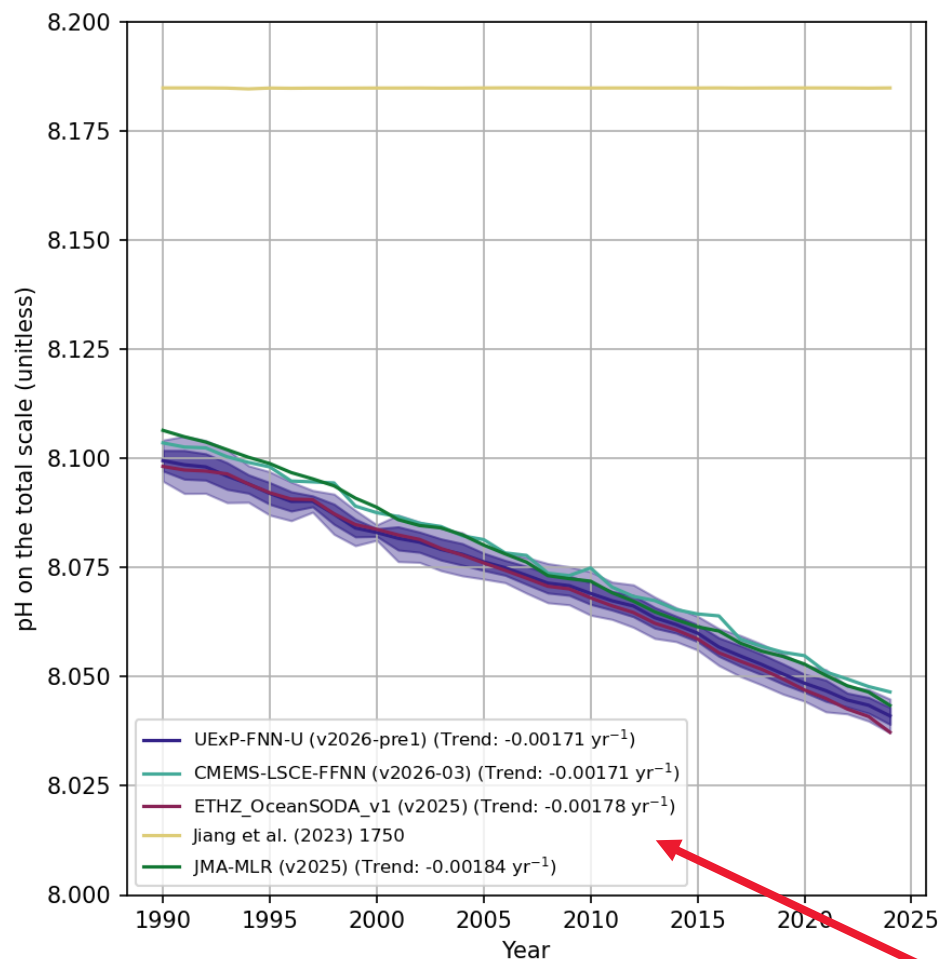


Satellite Earth observation for ocean physics, biology and the carbonate system are included.

UNESCO (2026), IOC Technical Series 214, IOC/2026/TS/214 Rev
<https://doi.org/10.71245/FULK2623>



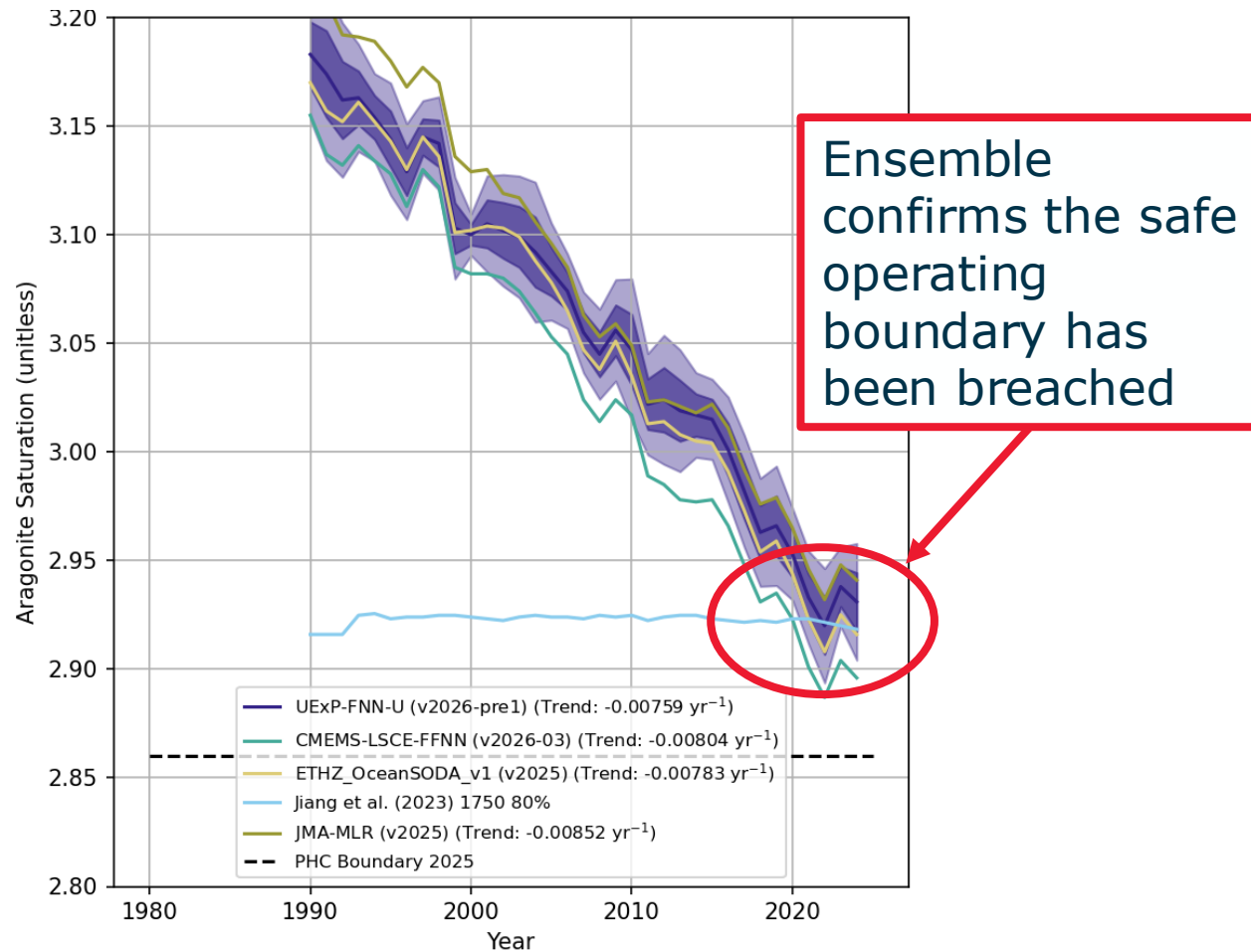
Planetary Health Check 2026 (& IPCC AR7 draft)



Gradient in pH is near identical to the result from in situ estimates of long-term decline. Consistency across all four datasets. 0.017 to 0.018 decade⁻¹.

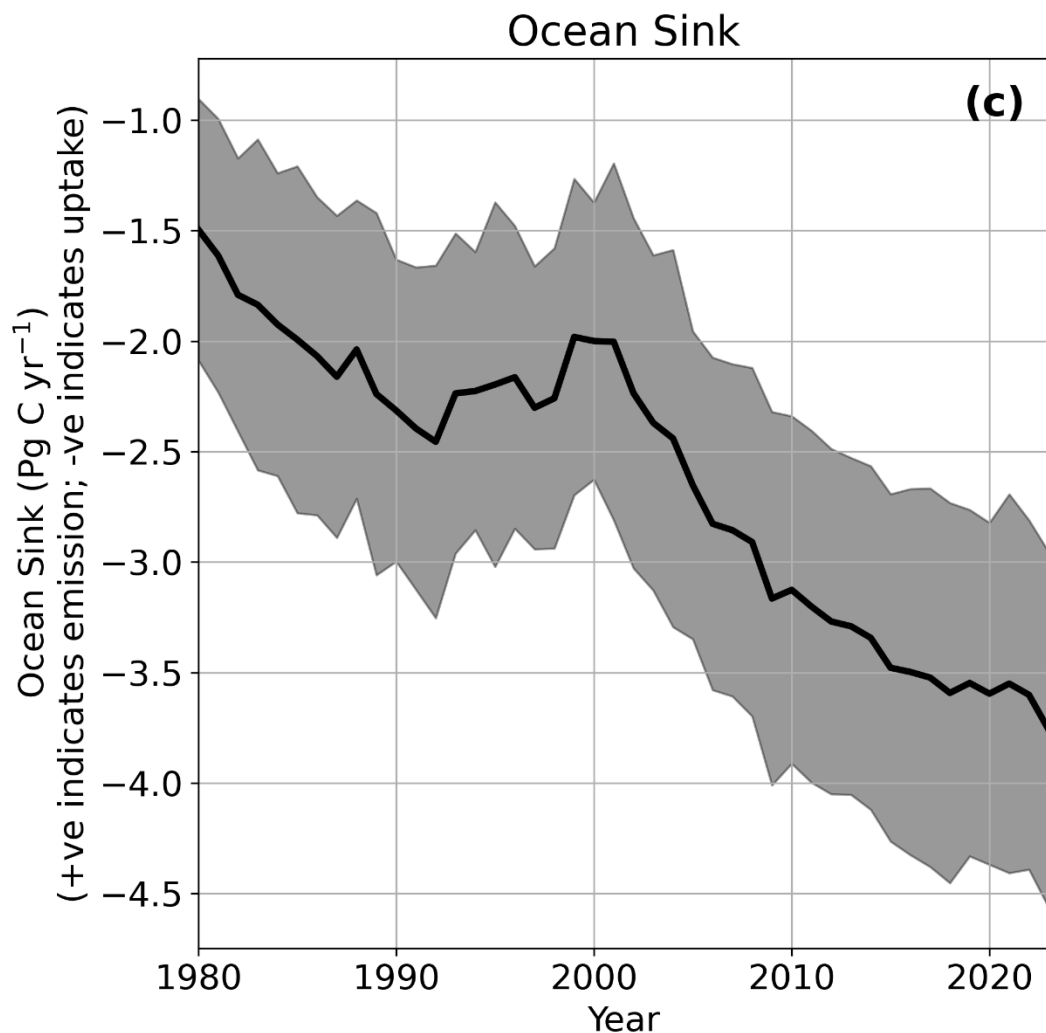


Planetary Health Check 2026 (& IPCC AR7 draft)





Using the ocean constraint on GLOBAL carbon



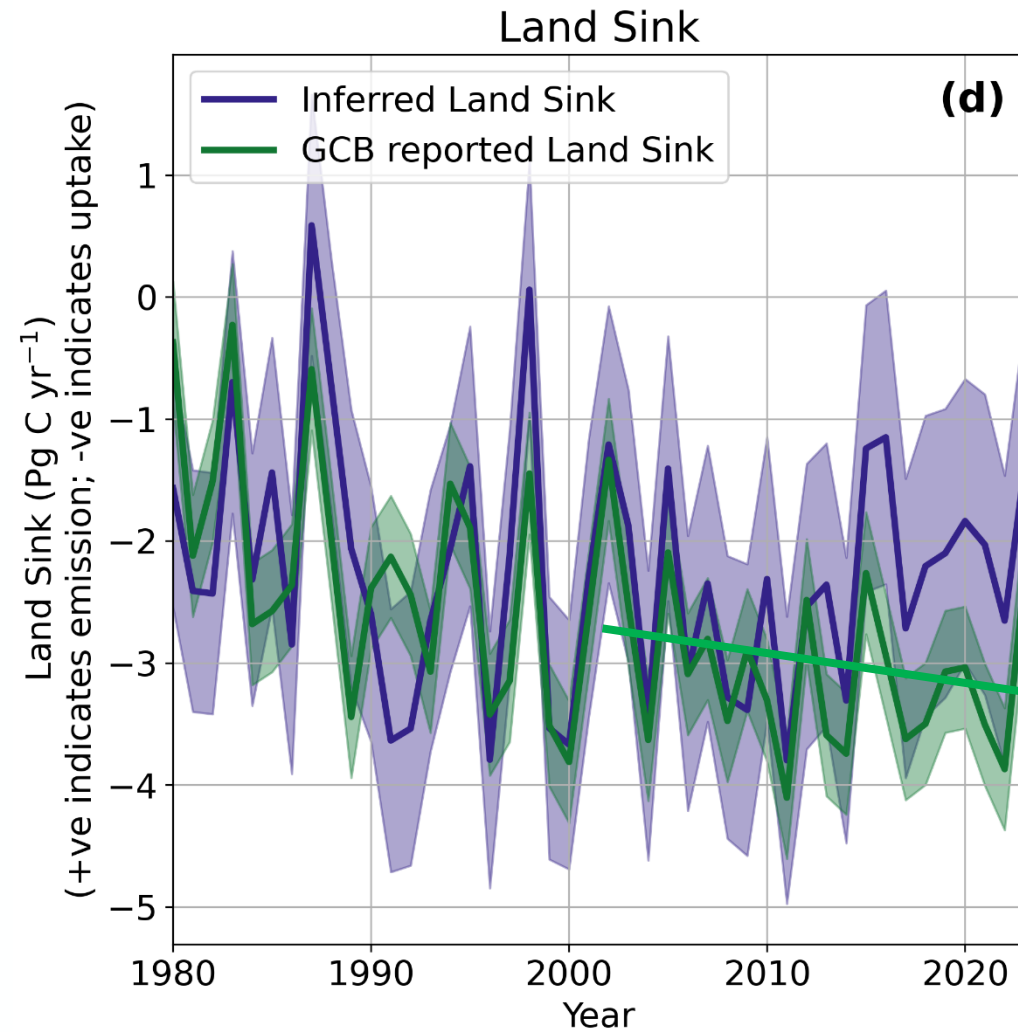
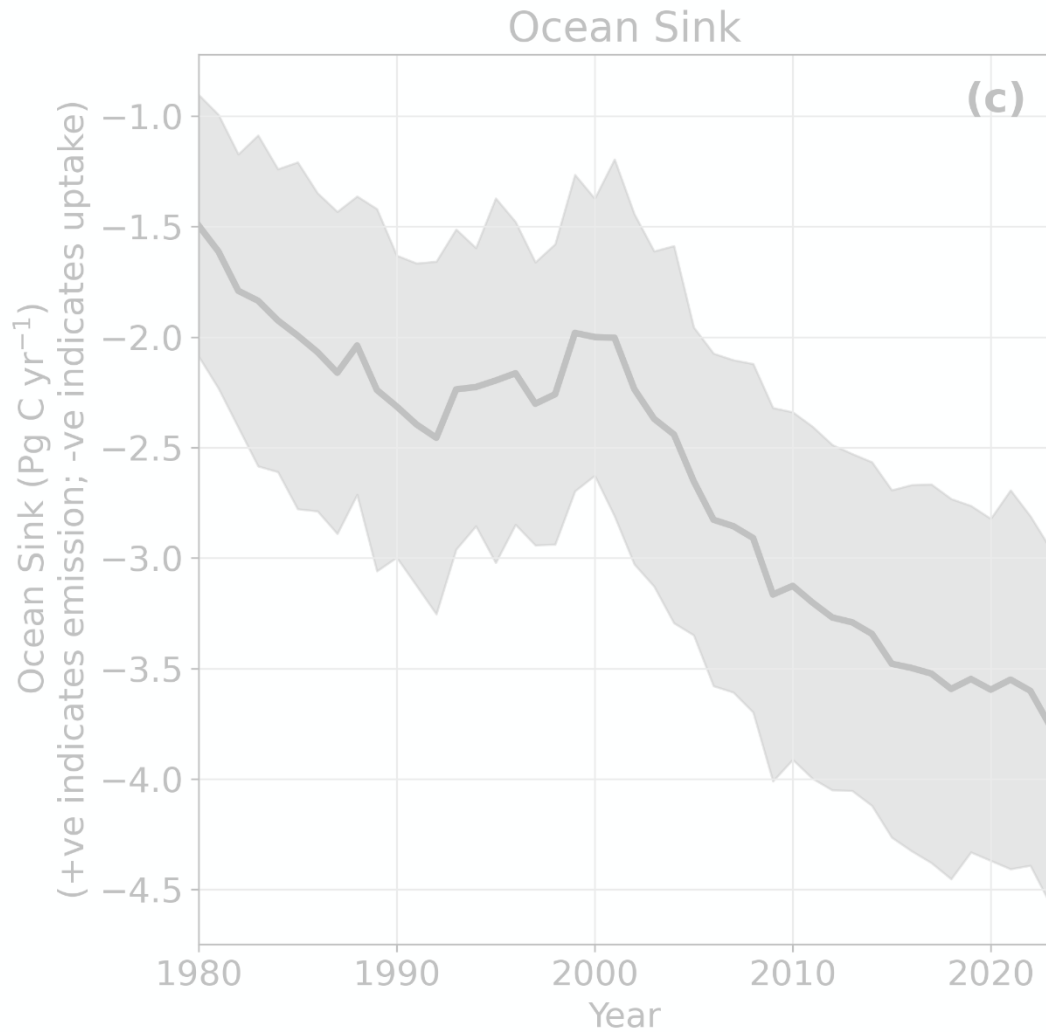
Global carbon Budget (GCB) provided to guide policy decisions on reducing emissions.

Data provided for annual GCB assessments



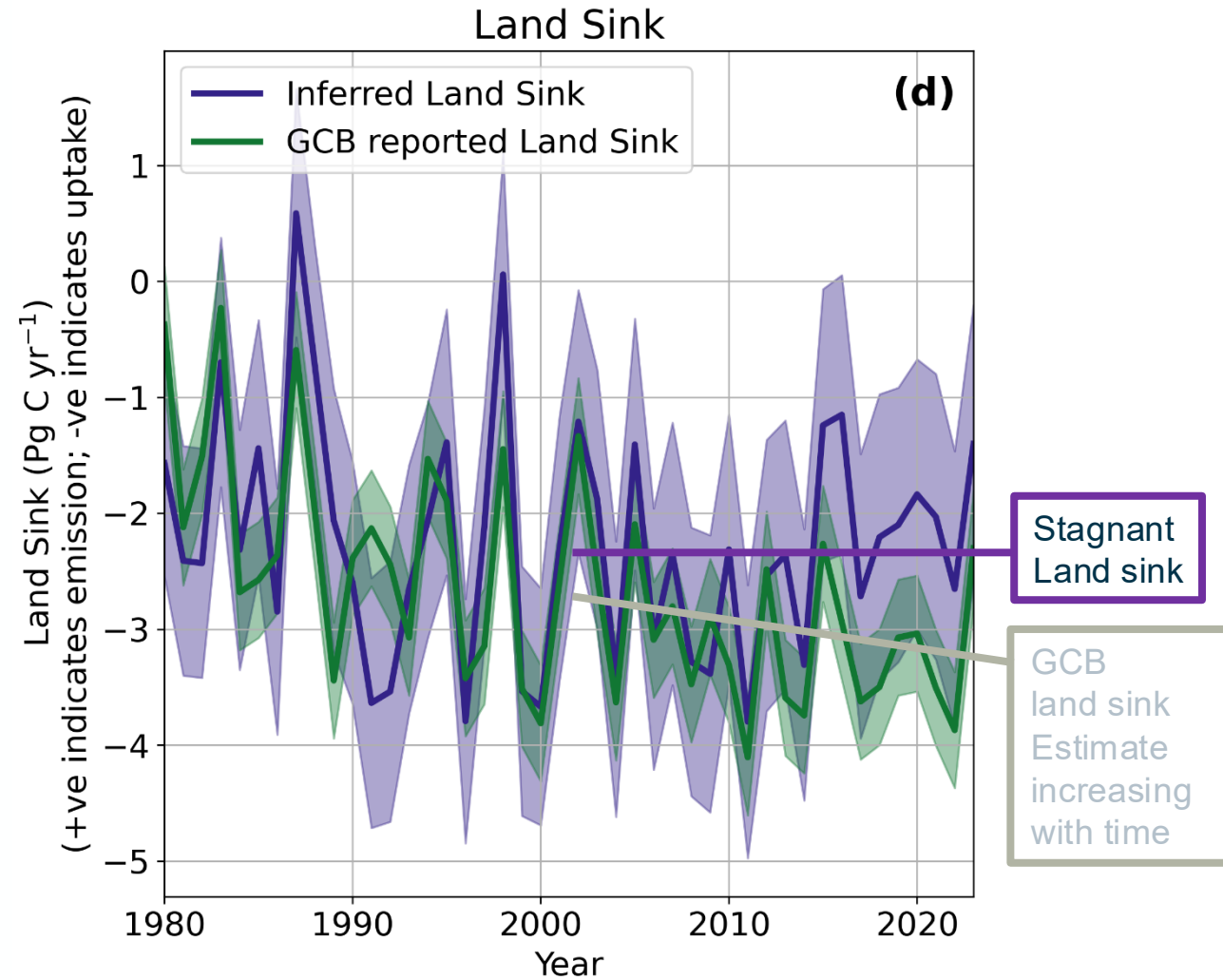
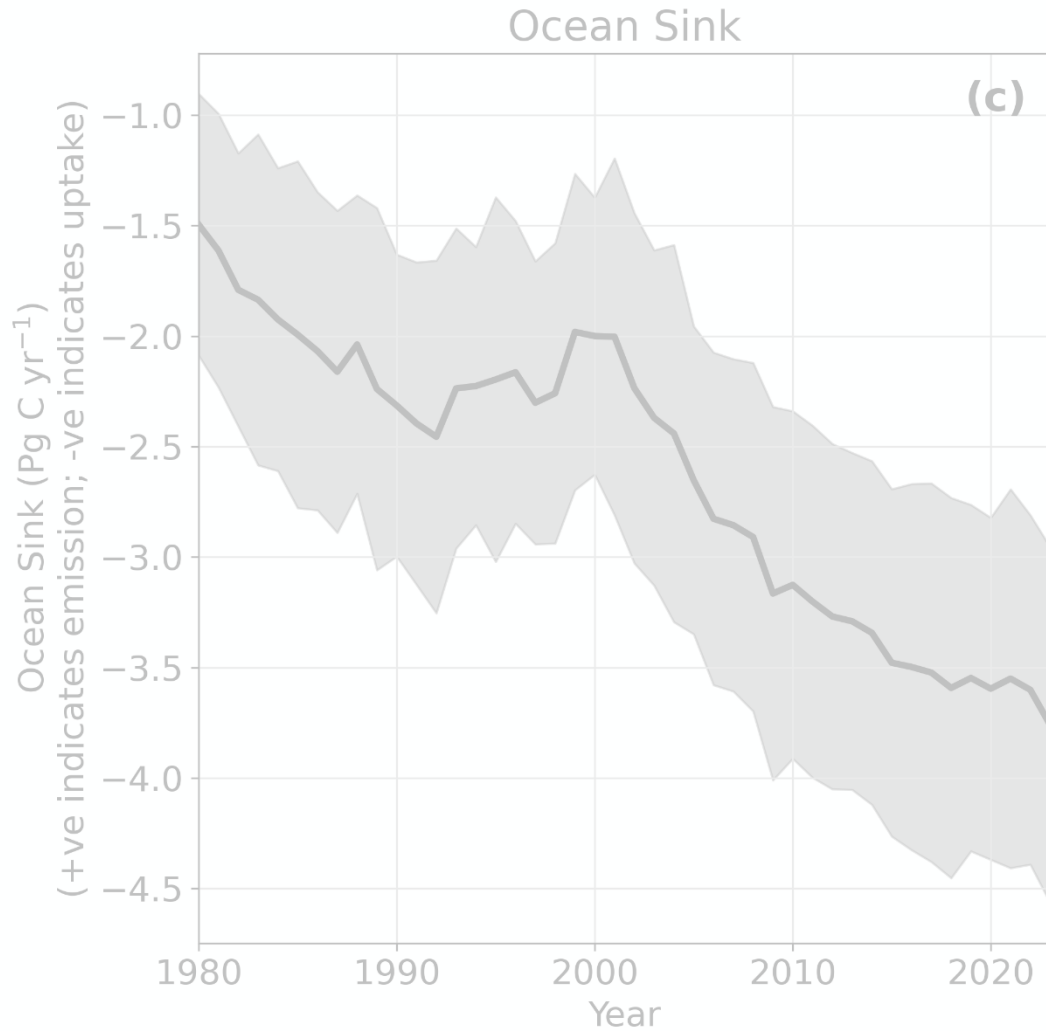


Using the ocean constraint on GLOBAL carbon





Using the ocean constraint on GLOBAL carbon

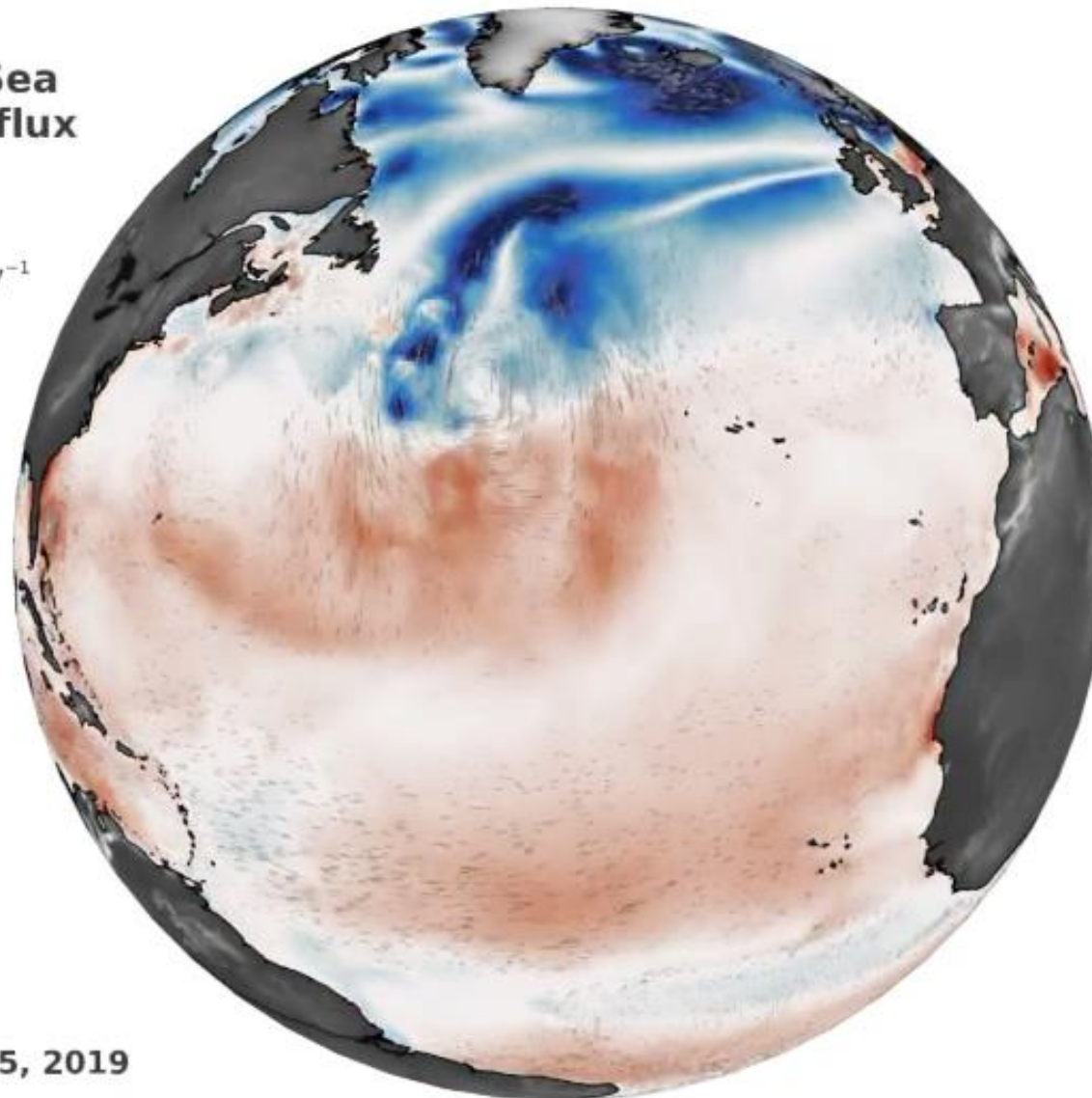
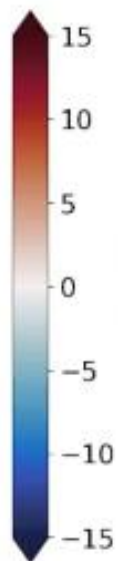




Can we have higher resolution analyses?

Air-Sea
CO₂ flux

mmol C
m⁻² day⁻¹



Sep 15, 2019

8 day, 0.25
degree

Gregor, Shutler,
Gruber (2025), *GBC*.



Salinity is important



Salinity understanding, expertise, and advances in sensing (in situ and in space) are critical for supporting ocean carbon assessments.

Advances Funded by:

European Space Agency (ESA OceanFlux, Pathfinders-OA, OceanSODA, OceanHealth, SCOPE, OC4C)
European Commission (OceanICU, UKRI)
Convex Seascape Survey





Salinity is important



Salinity understanding, expertise, and advances in sensing (in situ and in space) are critical to enable ocean carbon assessments.

These global carbon assessments are now being used to guide regional (e.g., US and Canadian west coast, European OSPAR) and international policy (e.g., IPCC, PHC, GCB).

Advances Funded by:

European Space Agency (ESA OceanFlux, Pathfinders-OA, OceanSODA, OceanHealth, SCOPE, OC4C)
European Commission (OceanICU, UKRI)
Convex Seascape Survey





Salinity is important



Salinity understanding, expertise, and advances in sensing (in situ and in space) are critical to enable ocean carbon assessments.

These global carbon assessments are now being used to guide regional (e.g., US and Canadian west coast, European OSPAR) and international policy (e.g., IPCC, PHC, GCB).

More advances are possible.

Advances Funded by:

European Space Agency (ESA OceanFlux, Pathfinders-OA, OceanSODA, OceanHealth, SCOPE, OC4C)
European Commission (OceanICU, UKRI)
Convex Seascape Survey





Salinity is important



Salinity understanding, expertise, and advances in sensing (in situ and in space) are critical to enable ocean carbon assessments.

These global carbon assessments are now being used to guide regional (e.g., US and Canadian west coast, European OSPAR) and international policy (e.g., IPCC, PHC, GCB).

More advances are possible.

Shutler *et al.*, (2024), *ESR*.

Advances Funded by:


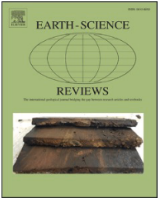
European Space Agency (ESA OceanFlux, Pathfinders-OA, OceanSODA, OceanHealth, SCOPE, OC4C)
European Commission (OceanICU, UKRI)
Convex Seascape Survey

Earth-Science Reviews 250 (2024) 104682

Contents lists available at [ScienceDirect](#)


Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

The increasing importance of satellite observations to assess the ocean carbon sink and ocean acidification

Jamie D. Shutler^{a,*}, Nicolas Gruber^b, Helen S. Findlay^c, Peter E. Land^c, Luke Gregor^b,





Salinity is important



Salinity understanding, expertise, and advances in sensing (in situ and in space) are critical to enable ocean carbon assessments.

These global carbon assessments are now being used to guide regional (e.g., US and Canadian west coast, European OSPAR) and international (e.g., PHC, GCB).

Ford *et al.*, (2025), *ERC*.

More advances are possible.

Shutler *et al.*, (2024), *ESR*.

Advances Funded by:

European Space Agency (ESA OceanFlux, Pathfinders-OA, OceanSODA, OceanHealth, SCOPE, OC4C)
European Commission (OceanICU, UKRI)
Convex Seascape Survey

ENVIRONMENTAL RESEARCH COMMUNICATIONS



LETTER • OPEN ACCESS

Regionally different marine heatwave ocean carbon sink responses are consistent with carbonate understanding

Daniel J Ford*, Sayooj P Nair, Kate Oglethorpe and Jamie D Shutler

Published 21 November 2025 • © 2025 The Author(s). Published by IOP Publishing Ltd

[Environmental Research Communications, Volume 7, Number 11](#)

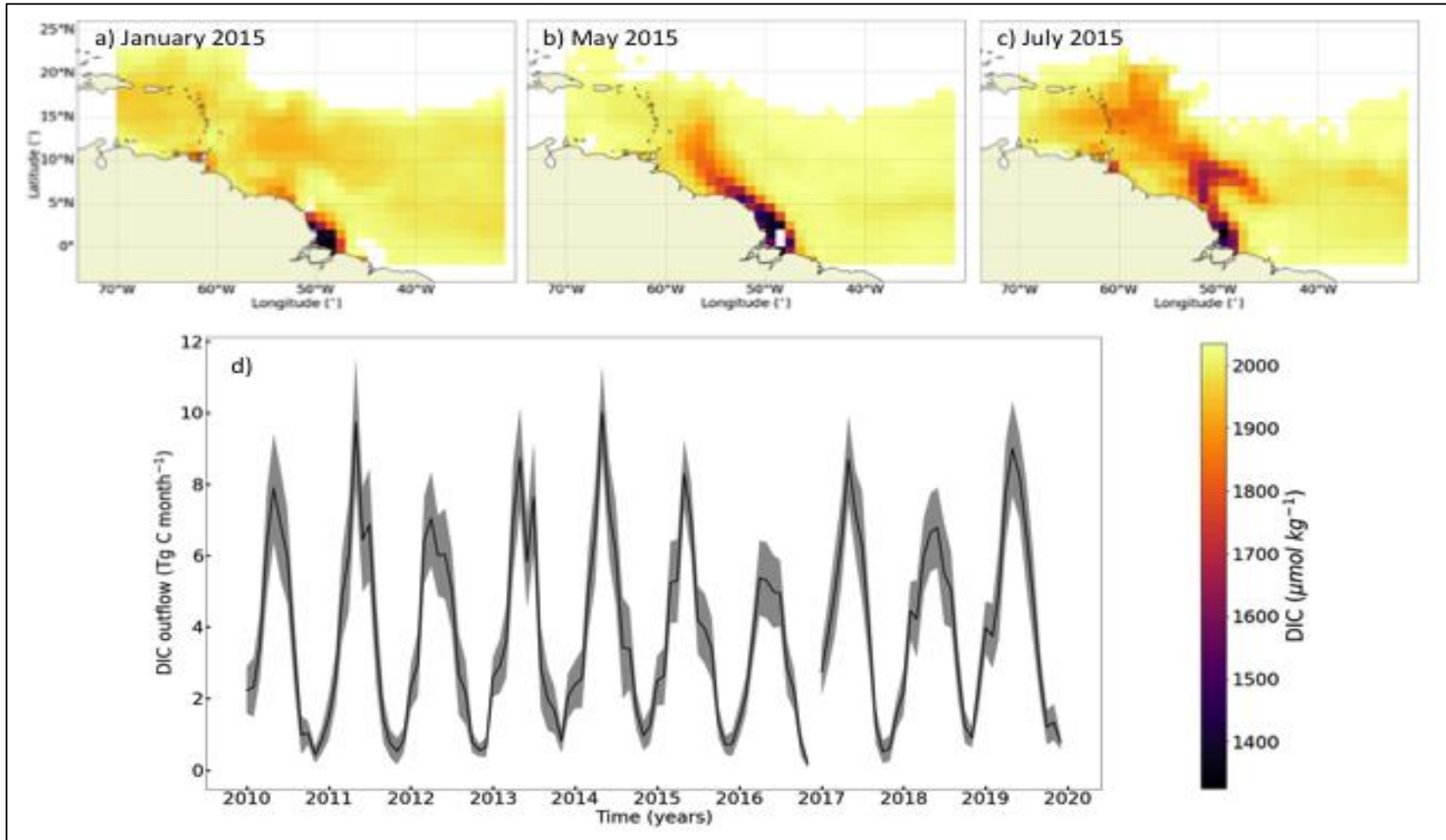
Citation Daniel J Ford *et al* 2025 *Environ. Res. Commun.* 7 111009

DOI 10.1088/2515-7620/ae15e0





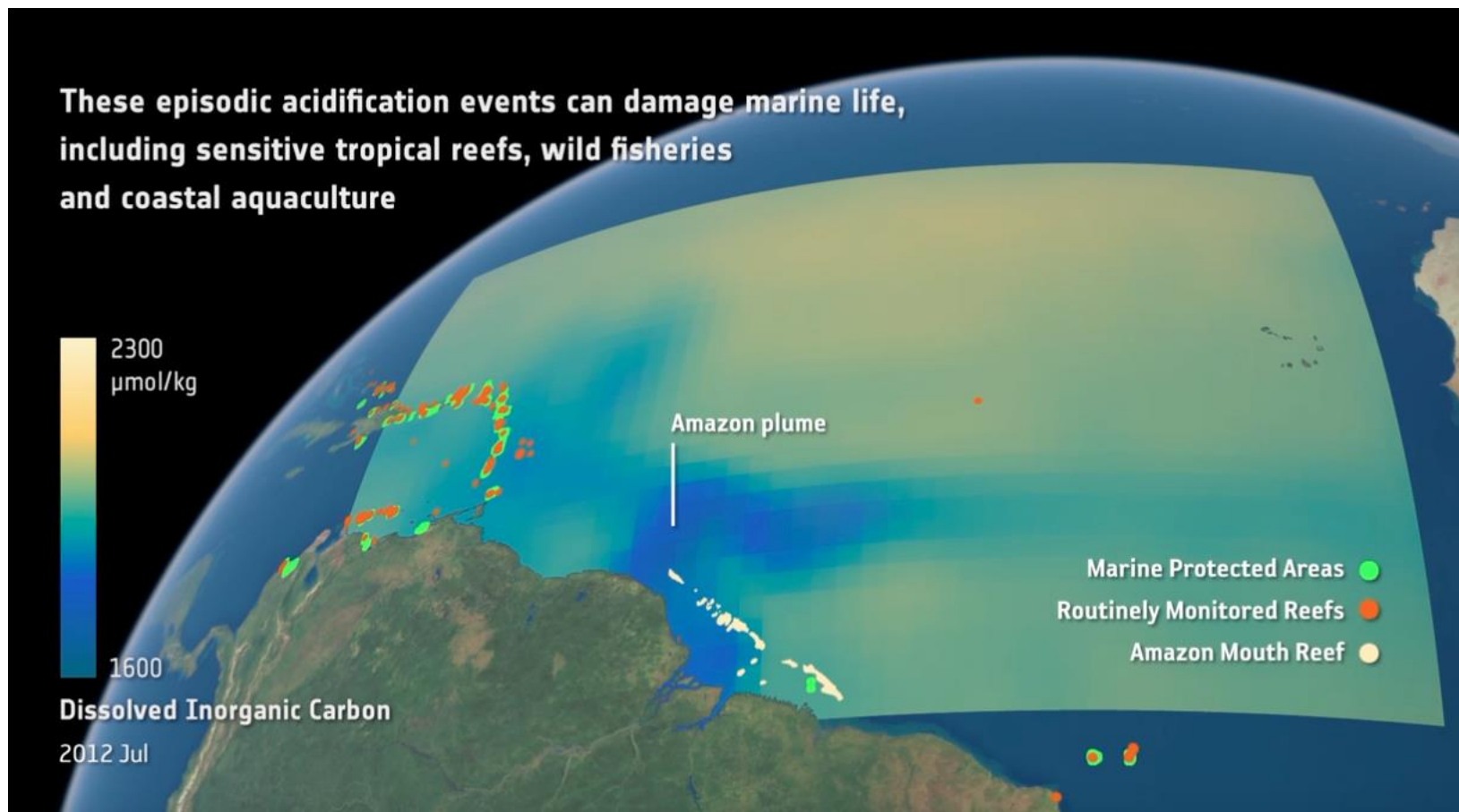
Spare slides



Sims *et al.*, (2023), *ESSD*.



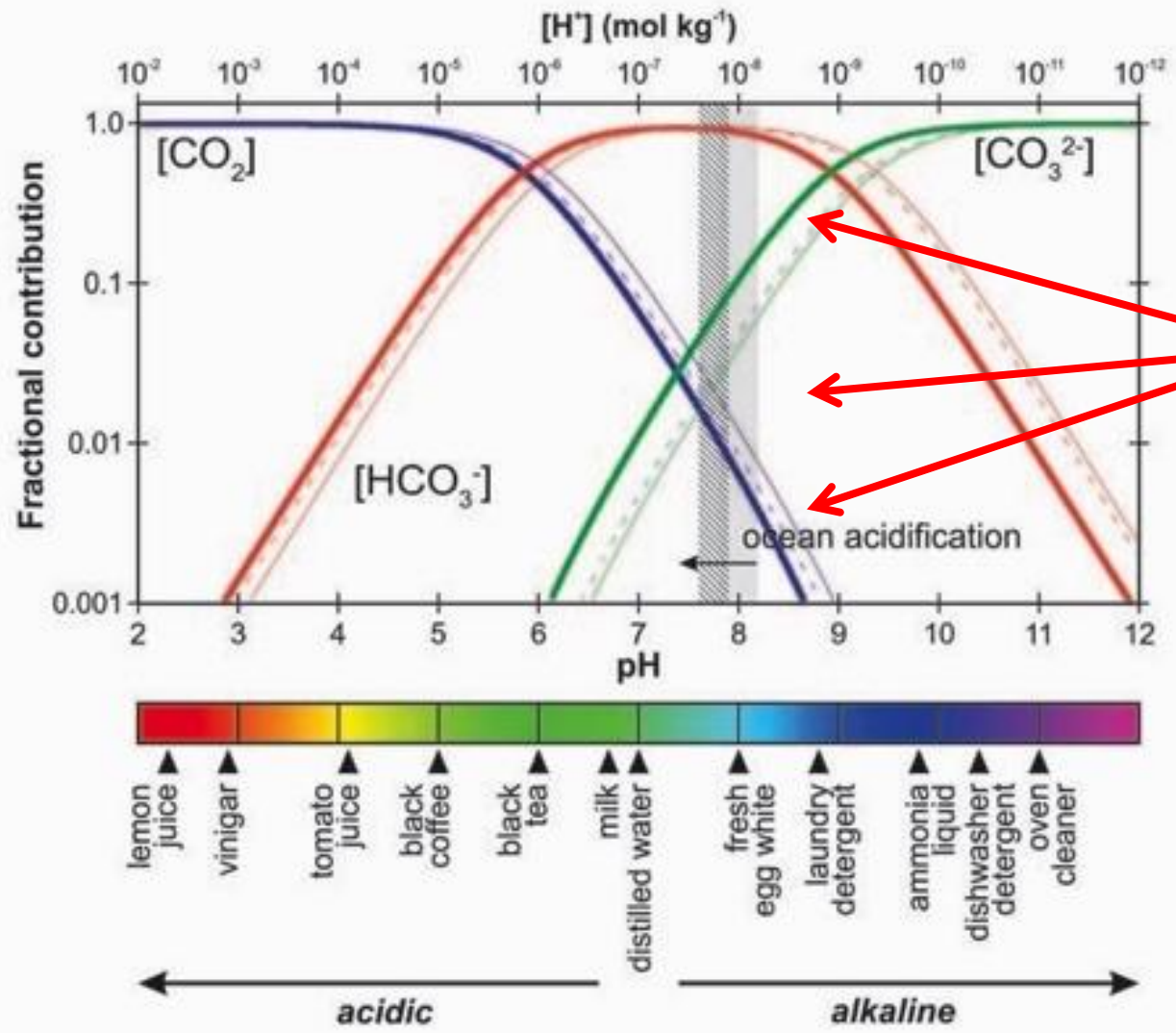
Space observations for supporting



https://www.esa.int/Applications/Observing_the_Earth/SMOS/Space_is_key_to_monitoring_ocean_acidification



Linkages between carbonate species



At typical surface seawater pH of 8.2, the speciation among $[CO_2]$, $[HCO_3^-]$, and $[CO_3^{2-}]$ is 0.5%, 89%, and 10.5%, respectively (but this is temperature, pressure and salinity dependent).

Therefore, most of the dissolved CO_2 in the oceans is in the form of $[HCO_3^-]$ (bicarbonate) and not in the form of $[CO_2]$.

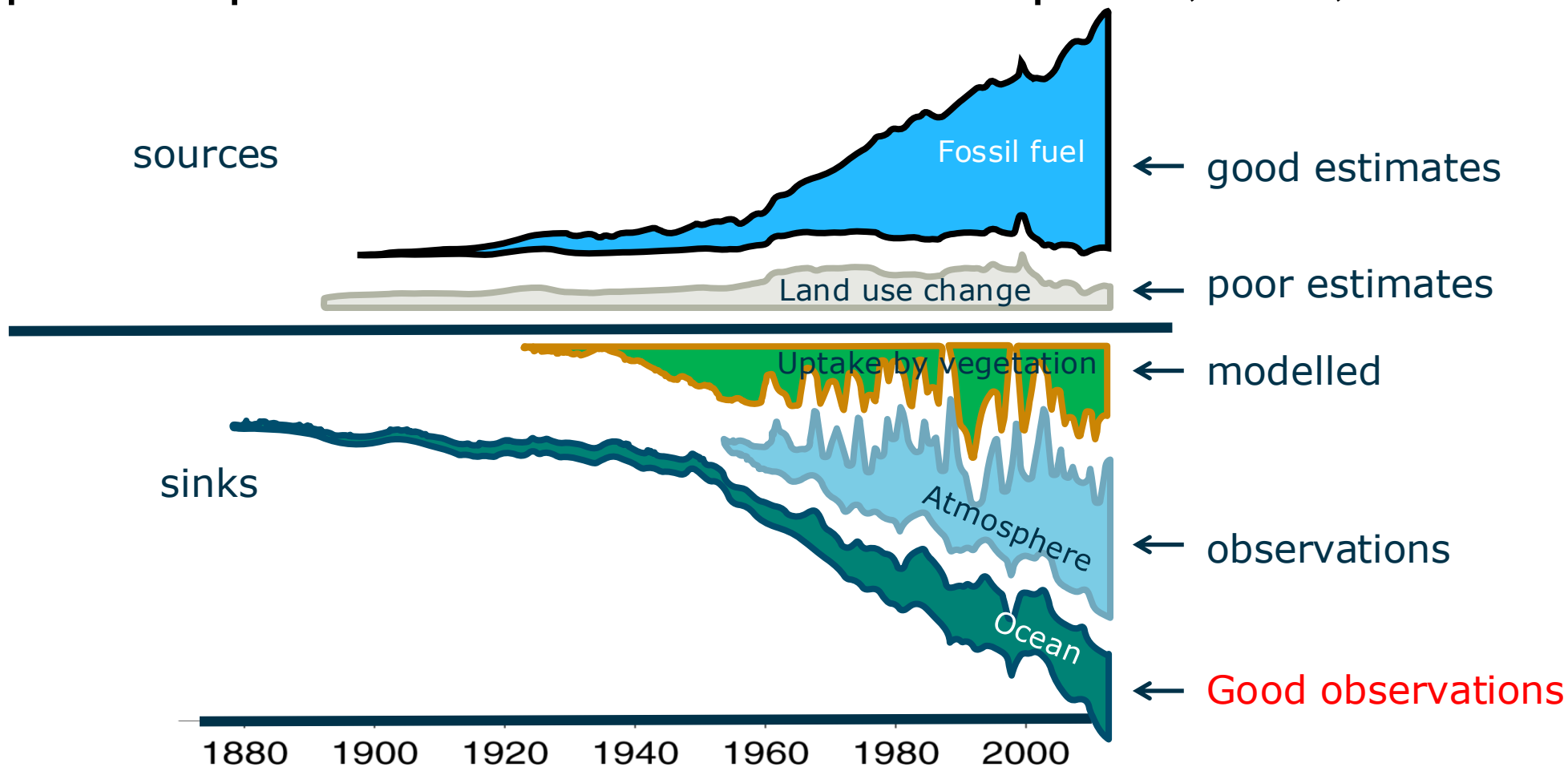
Eunice
Foote
1856



Discovered the properties
of green house gases



How uptake is partitioned between the atmosphere, land, and ocean



Ocean data and observations are a key constraint on global carbon budgets

