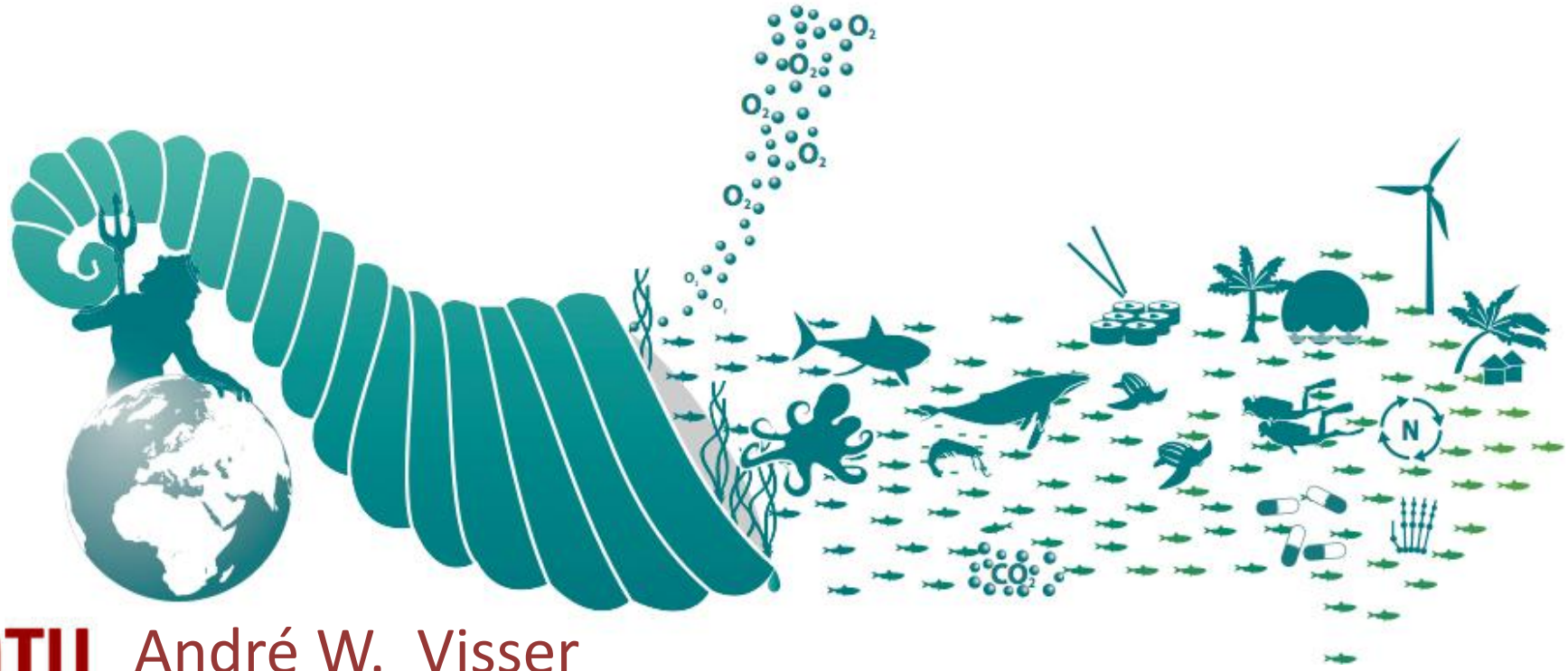
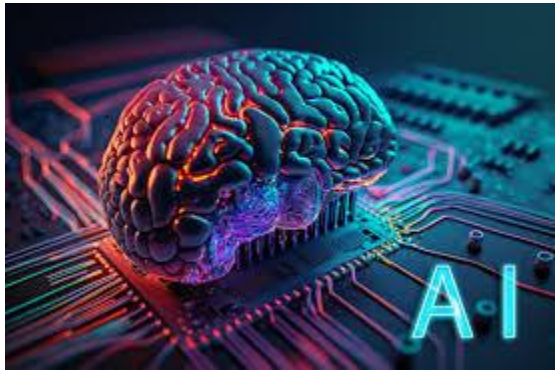
The biological carbon pump: sequestration, turnover and residence times



André W. Visser
Professor of Physical Oceanography
National Institute of Aquatic Resources, DTU

Ocean-ICU
BioEcoOcean
ECOTIP

European Marine Board IOPAN Sopot Oct 2025



What is Carbon Sequestration ?

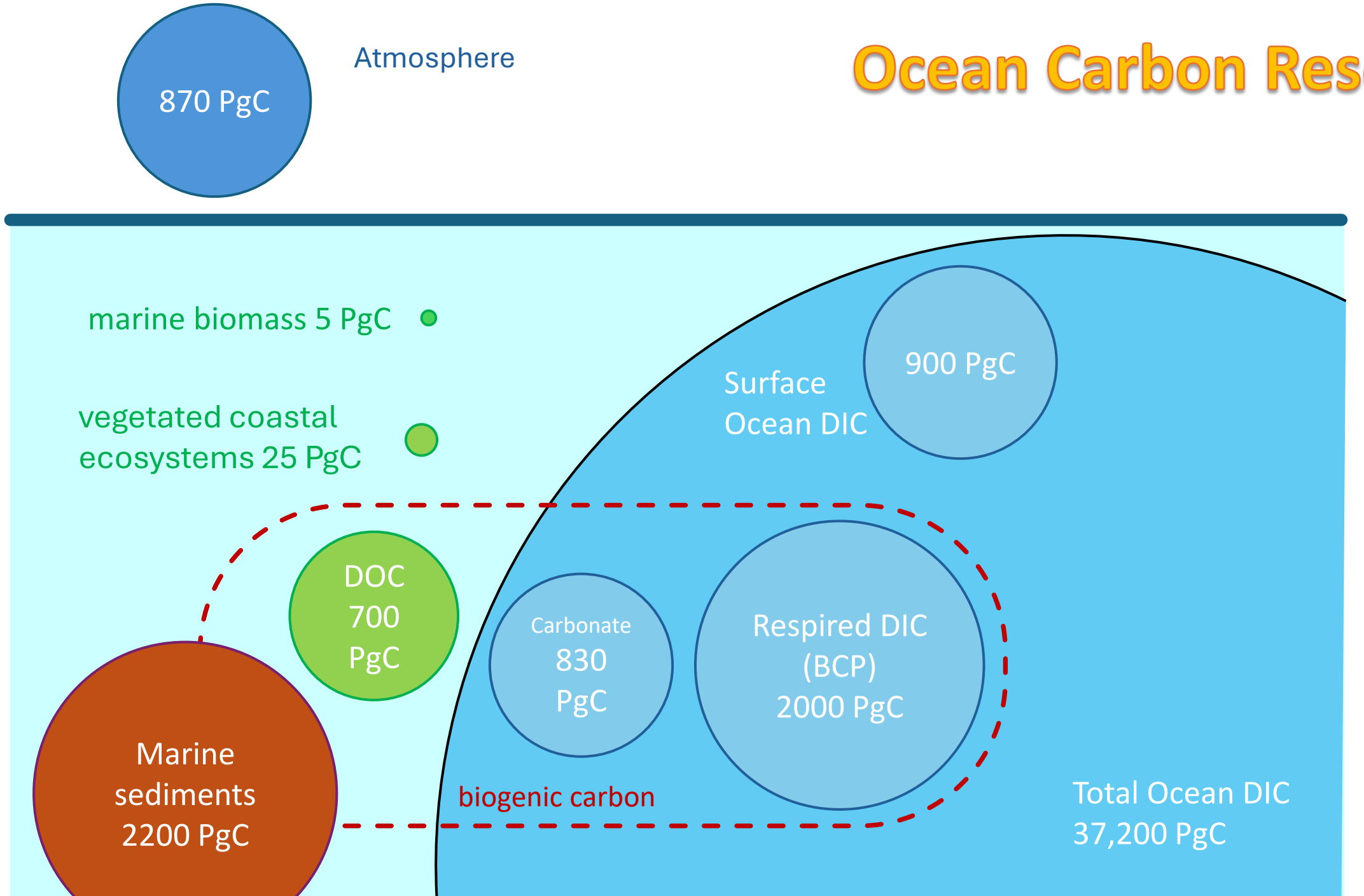
Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide (CO_2). It's a key strategy for mitigating climate change by reducing the amount of CO_2 in the atmosphere, which is a major greenhouse gas contributing to global warming.

Carbon sequestration is the process of capturing atmospheric carbon dioxide (CO_2) and storing it to prevent it from contributing to climate change

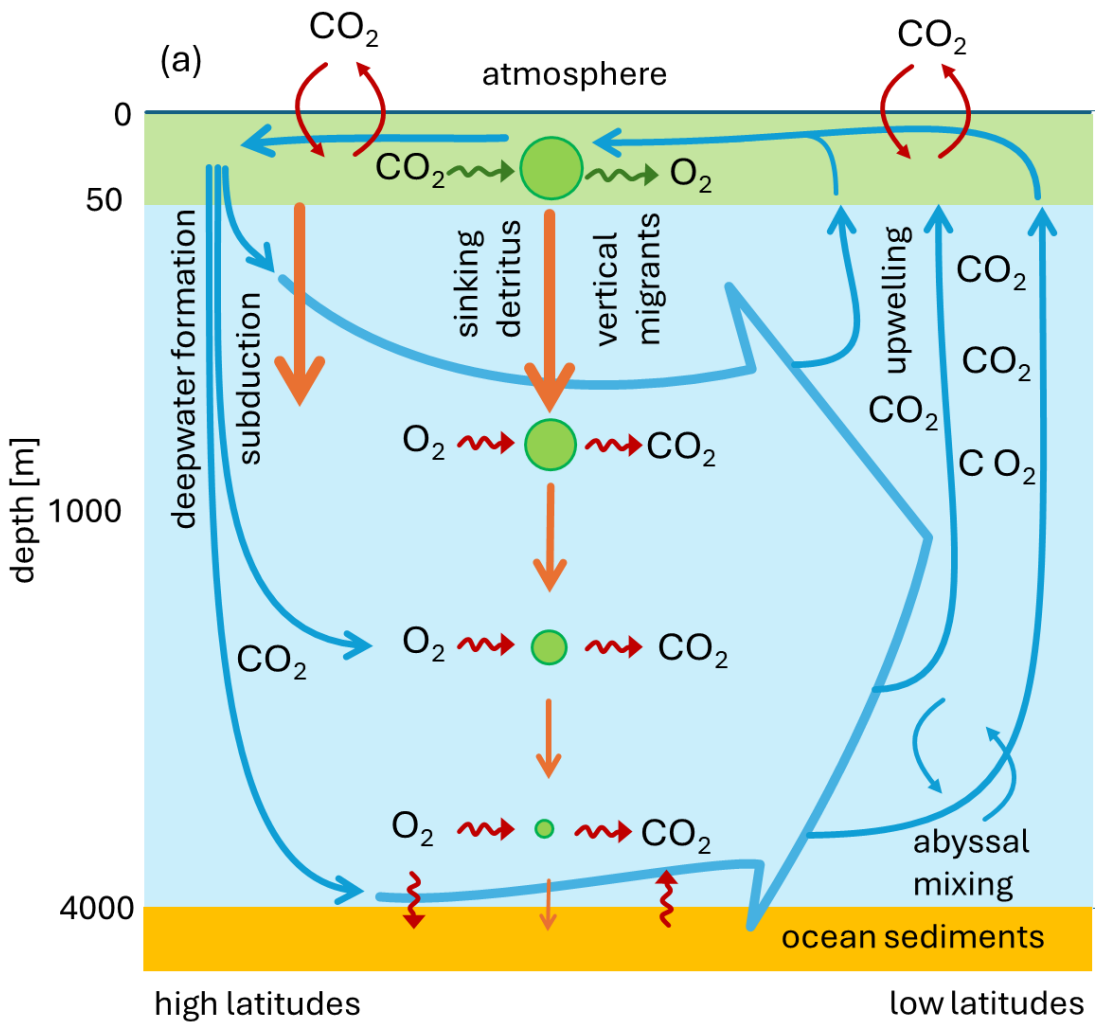
Carbon sequestration is the process of capturing carbon dioxide from the atmosphere and storing it long-term in natural sinks or through technological means, helping to reduce greenhouse gases and mitigate climate change.

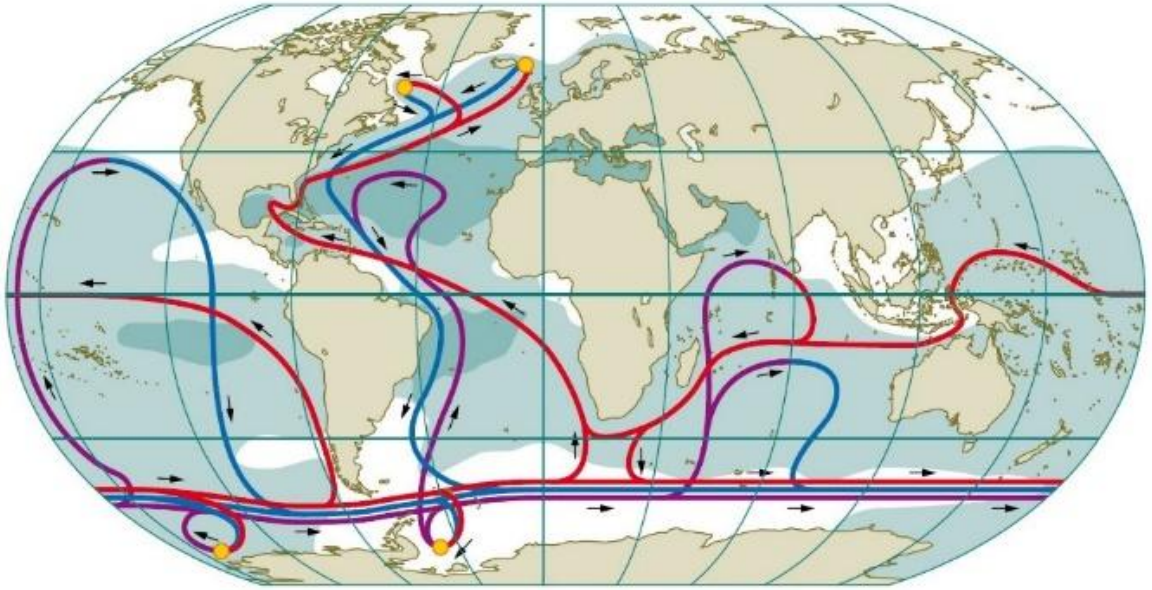
Carbon sequestration = offset to offset anthropogenic emissions

Ocean Carbon Reservoirs



Oceanic carbon pumps and circulation





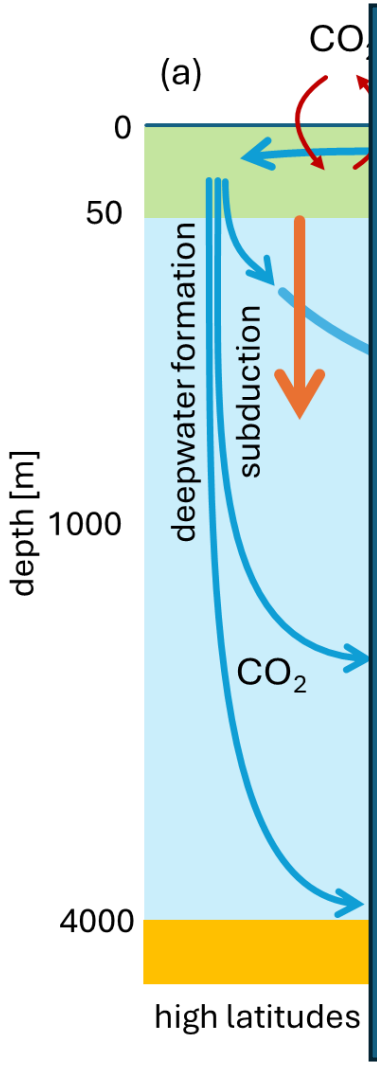
Global Overturning Circulation

Global Ocean Production Estimate: 50 PgC / year

Global Export Estimate : 10 PgC / year

In near steady state for the last 10,000 years:
what goes in is very nearly balanced by what goes out
export flux ≈ out gassing

Residence time



How long does respired carbon stay in the oceans before it is outgassed back to the atmosphere

Mean residence time:

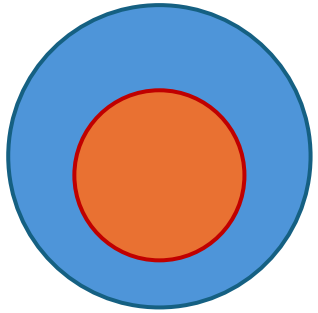
T = 2000 PgC / 10 PgC/year = 200 years

Depth of respiration matters: deeper => longer

Reservoir dynamics: steady state after t > 3 x T after which flux in = flux out

PgC / year

Ocean Carbon Reservoirs



Atmosphere total 870 PgC

Anthropogenic 280 PgC

marine biomass 5 PgC

vegetated coastal ecosystems 25 PgC

Surface Ocean DIC

900 PgC

Anthropogenic DIC (surface) 25 PgC

DOC 700 PgC

Carbonate 830 PgC

Respired DIC (BCP) 2000 PgC

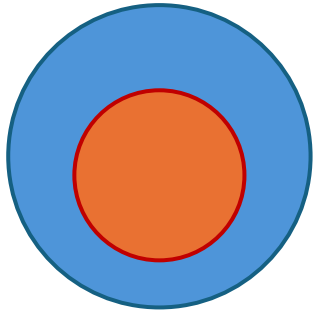
Anthropogenic DIC (subsurface) 160 PgC

Marine sediments 2200 PgC

biogenic carbon

Total Ocean DIC 37,200 PgC

Ocean Carbon Reservoirs



Atmosphere total 870 PgC

Anthropogenic 280 PgC

Within the bounds of uncertainty, <u>all</u> of the carbon taken up by the world's oceans can be attributed to physics and chemistry

There is little evidence to that biological processes, in terms of either biomass or the biological carbon pump has played any role. (less than 1% of current emissions)

urface
cean DIC

900 PgC

Anthropogenic
DIC (surface)
25 PgC

DOC
700
PgC

Carbonate
830
PgC

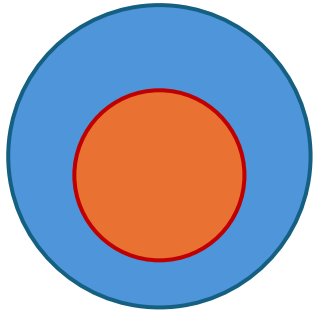
Respired DIC
(BCP)
2000 PgC

Anthropogenic
DIC (subsurface)
160 PgC

Marine
sediments
2200 PgC

biogenic carbon

Total Ocean DIC
37,200 PgC



Atmosphere total 870 PgC

Anthropogenic 280 PgC

Ocean Carbon Reservoirs

Within the bounds of uncertainty, <u>all</u> of the carbon taken up by the world's oceans can be attributed to physics and chemistry

There is little evidence to that biological processes, in terms of either biomass or the biological carbon pump has played any role. (less than 1% of current emissions)

Yet the literature (and media) is full of claims that the biological carbon pump and other blue carbon habitats sequester carbon.

What to believe ?

nature communications

Explore content · About the journal · Publish with us

nature › nature communications › articles › article

Article | Open access | Published: 08 September 2024

Antarctic krill sequester similar amounts of carbon to key coastal blue carbon habitats

nature geoscience

Explore content · About the journal · Publi

nature › nature geoscience › articles › article

Article | Published: 05 August 2019

Important contribution of macroalgae to oceanic carbon sequestration

nature geoscience

Explore content · About the journal · Publish with us

nature › nature geoscience › progress article › article

Progress Article | Published: 12 September 2016

Substantial role of macroalgae in marine carbon sequestration

nature

Explore content · About the journal · Publish with us

nature › review articles › article

Review | Published: 17 April 2019

Multi-faceted particle pumps drive carbon sequestration in the ocean

PNAS

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

nature geoscience

Explore content · About the journal · P

nature › nature geoscience › articles › article

Article | Published: 27 November 2023

Century-scale carbon sequestration flux throughout the ocean by the biological pump

nature communications

Explore content · About the journal · Publish with us

nature › nature communications › articles › article

Article | Open access | Published: 11 April 2023

Carbon sequestration by multiple biological pump pathways in a coastal upwelling biome

nature communications

Explore content · About the journal · Publish with us

nature › nature communications › articles › article

Article | Published: 31 March 2015

Marine sequestration of carbon in bacterial metabolites

Ocean “Sequestration Rate”

Marine Science Community general usage

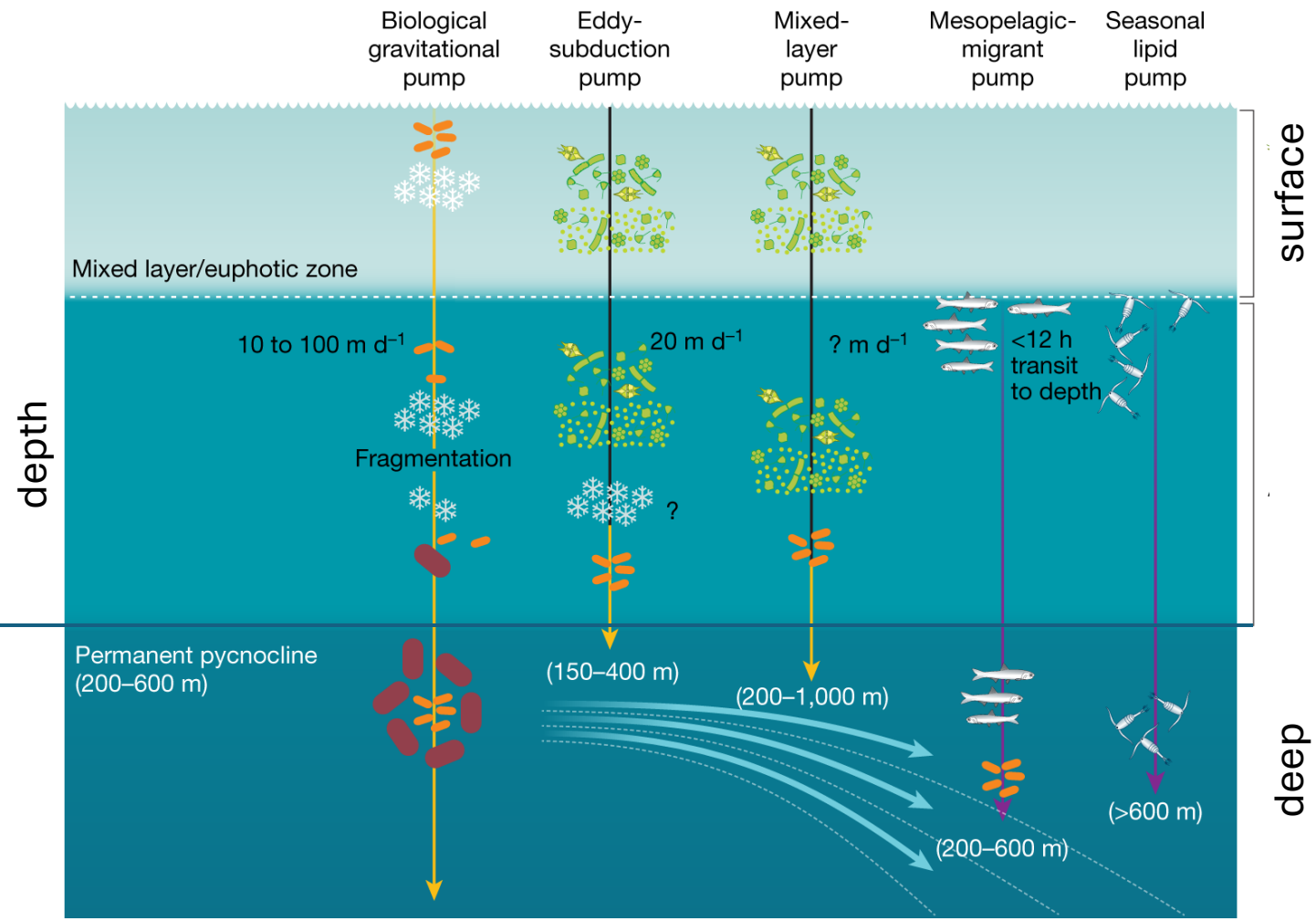
Carbon sequestration is removing carbon out of contact with the atmosphere for more than 100 years

atmosphere CO_2

“sequestration rate”

Residence time less than 100 years

Residence time more than 100 years



Ocean “Sequestration Rate”

Marine Science Community general usage

Carbon sequestration is removing carbon out of contact with the atmosphere for more than 100 years

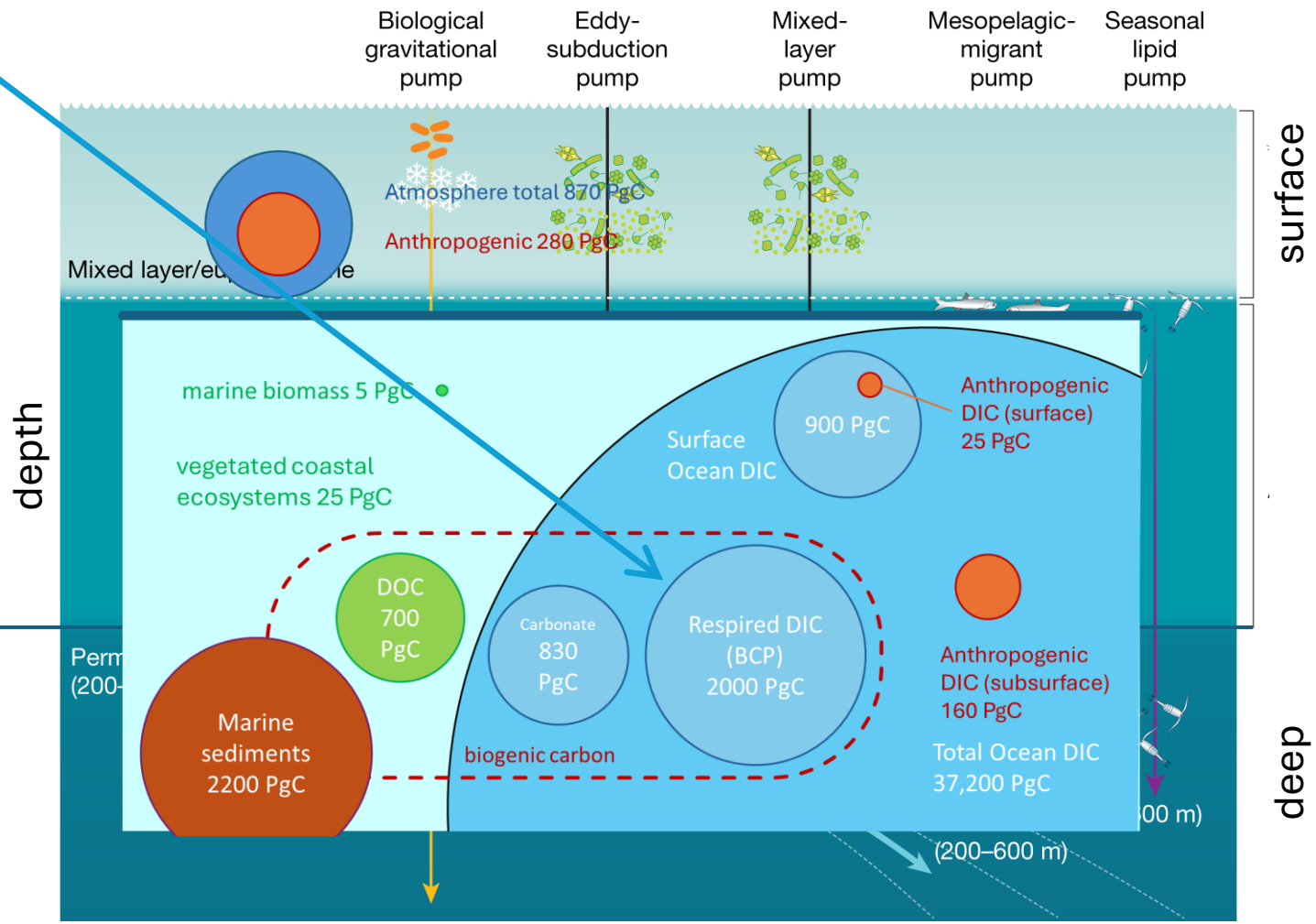
But this does NOT necessarily change the size of any off these bubbles

atmosphere CO_2

“sequestration rate”

Residence time less than 100 years

Residence time more than 100 years



Ocean “Sequestration Rate”

Marine Science Community general usage

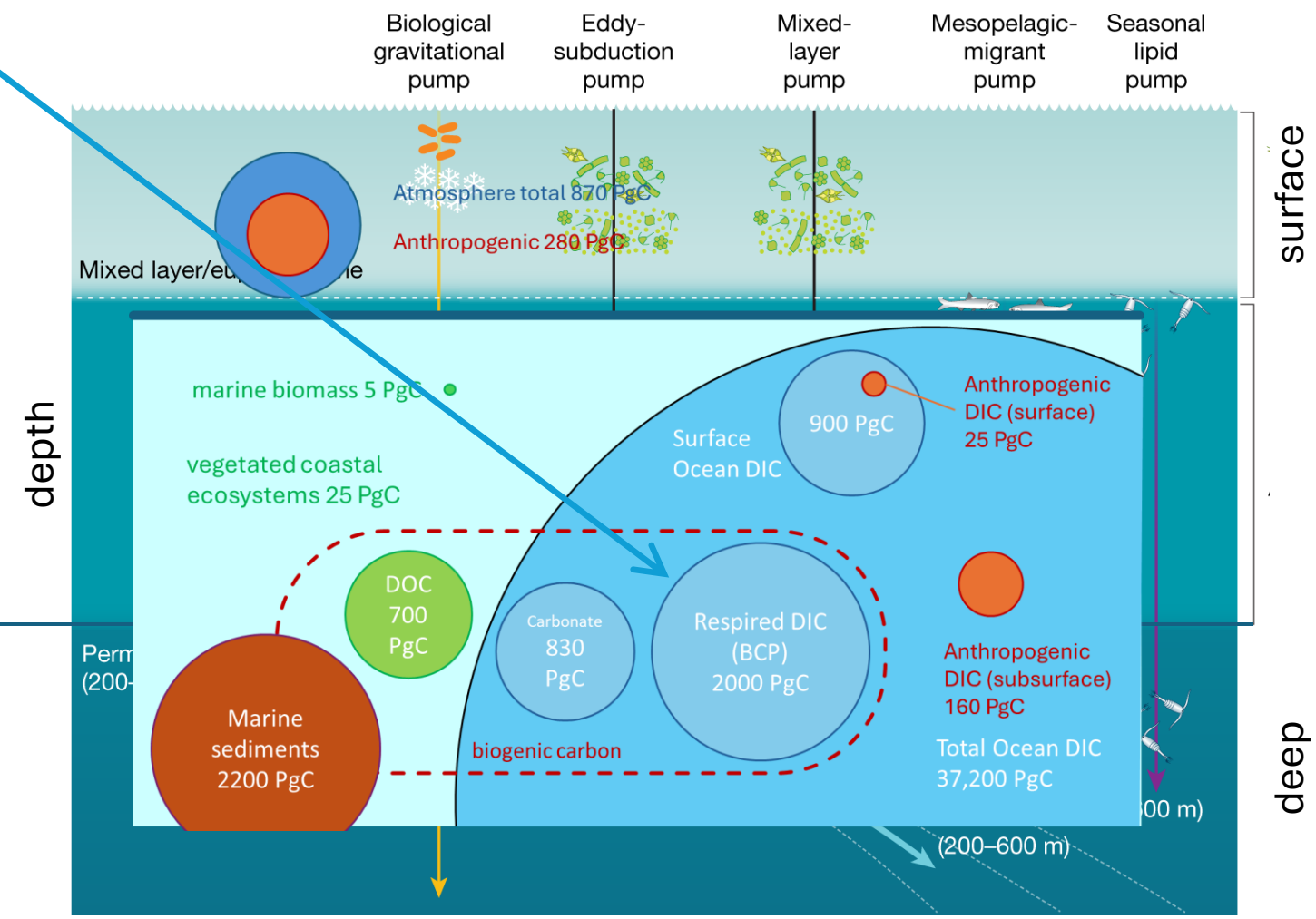
Carbon sequestration is removing carbon out of contact with the atmosphere for more than 100 years

But this does NOT change the size of any off these bubbles

… it could just as likely be only the turnover rate of a long-lived carbon reservoir …

Residence time less than 100 years

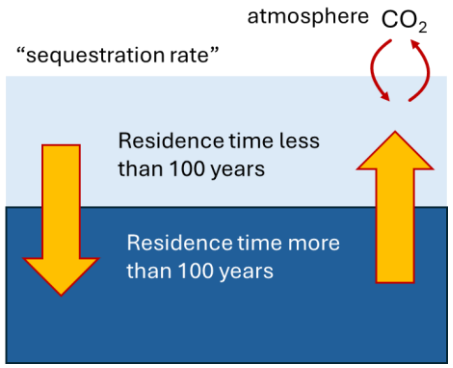
Residence time more than 100 years



Ocean "Sequestration Rate"

Sequestered carbon defined as "carbon stored out of contact with the atmosphere for more than 100 years" (AR4 2007)

Carbon sequestration is removing carbon out of contact with the atmosphere for more than 100 years



Carbon sequestration is not necessarily "the process of storing carbon out of contact with the atmosphere for more than 100 years"

This does not preclude that the carbon so stored is simply replacing carbon that has already been in the reservoir for more than 100 years and is now leaking out.
A necessary but not sufficient condition.

Carbon sequestration defined as "the process of increasing the carbon content of a reservoir/pool other than the atmosphere"

Are any bubbles getting bigger?

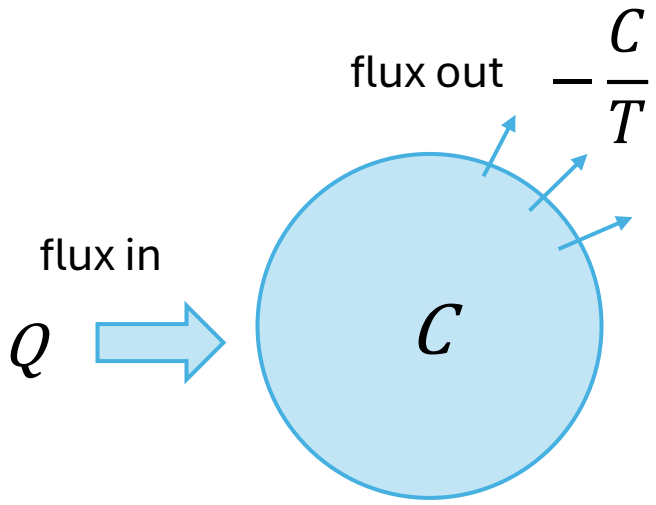
(IPCC AR4 2007 Glossary to WG2, https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg2-app-1.pdf).

Ocean "Sequestration Rate"

P Reservoir life time: How long the reservoir has existed or is expected to exist. (persistence)

F Time sale of perturbation in conditions

T Residence time. how long material stays in the reservoir before leaking out.



$$P > T > F$$

$$C = Q\,T$$

near steady state

$$\frac{dC}{dt} = T\frac{dQ}{dt} + Q\frac{dT}{dt}$$

The reservoir expands (i.e. C is sequestered *sensu* offset) when either the flux in increases or the resisence time increases

Can we detect a Carbon Sequestration Rate for the BCP?

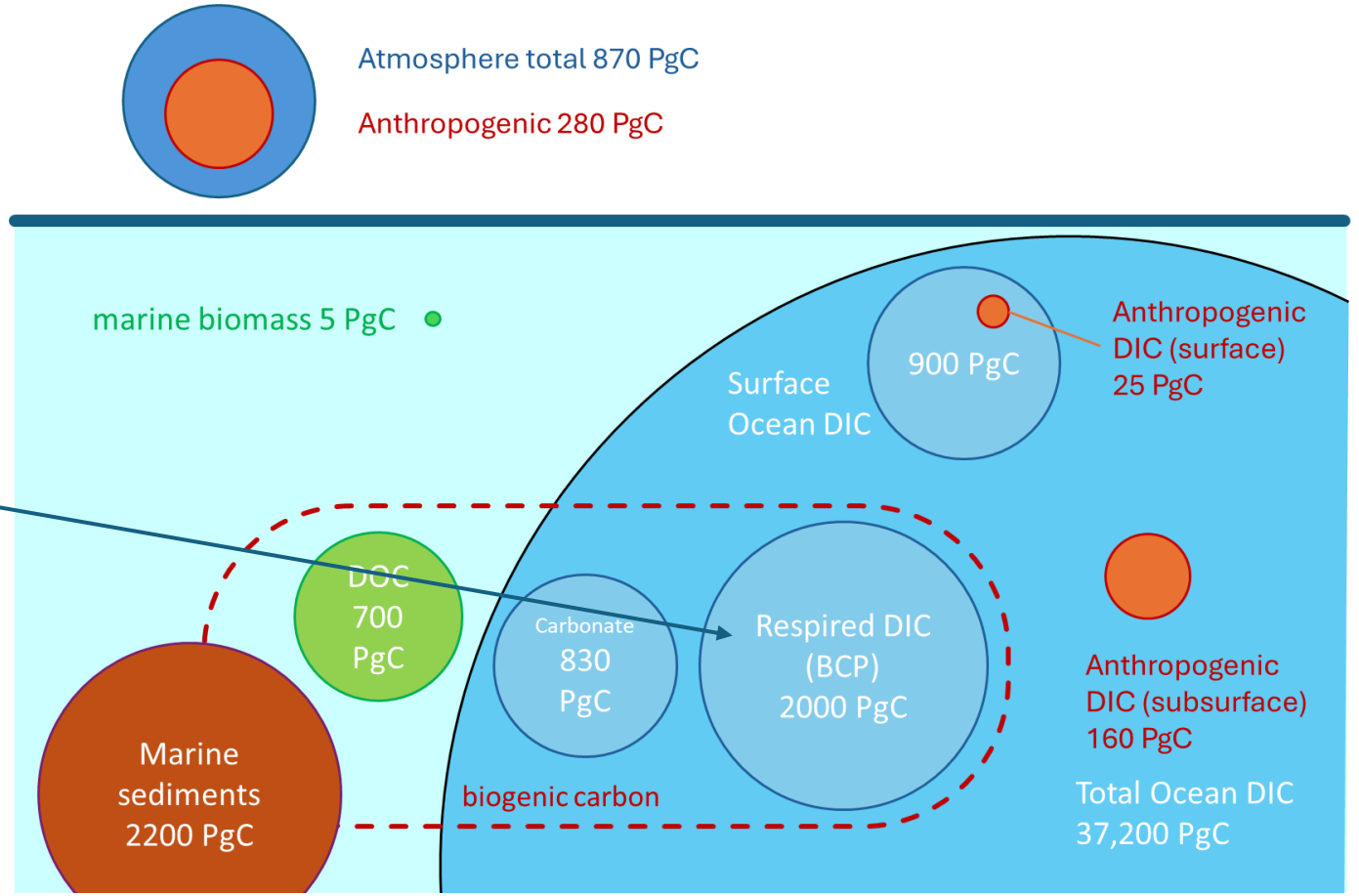
The oxygen constraint

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 78H_2O + 18H^+ \underset{\text{resp}}{\overset{\text{photo}}{\rightleftharpoons}} \{C_{106}H_{175}O_{42}N_{16}P_1\} + 150O_2$$

... as the flip side of the biological carbon pump... can be used to estimate changes in sequestered DIC reservoir...

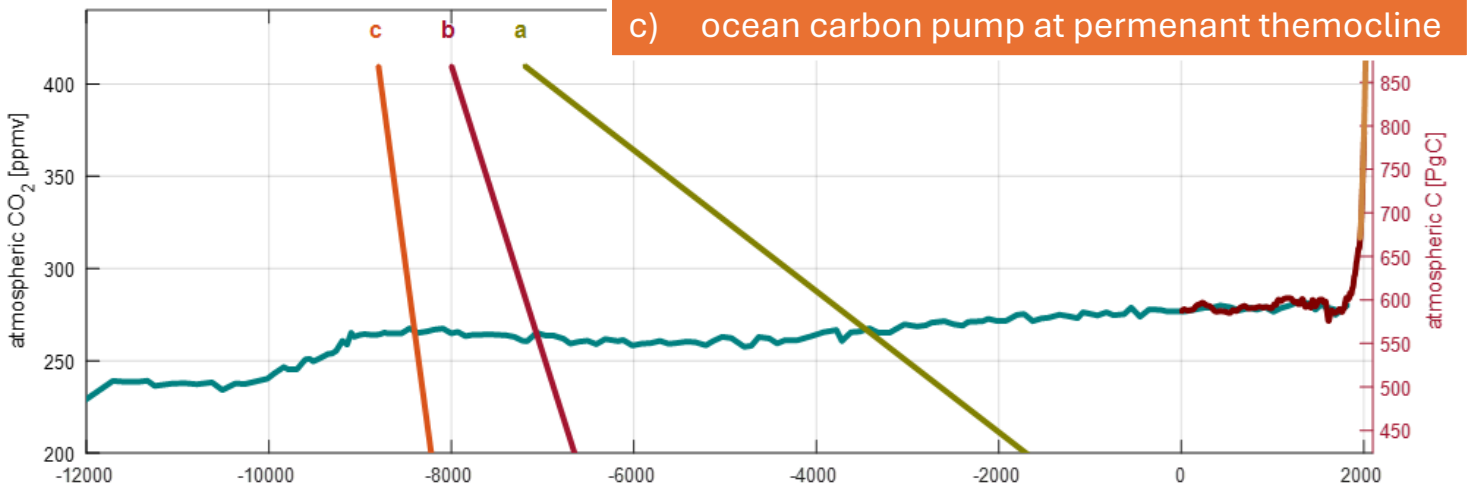
Observed increase in oxygen demand suggests increase in DIC reservoir of 0.1 PgC / year... the rate at which this bubble increases

Put into context < 1% of present emissions.



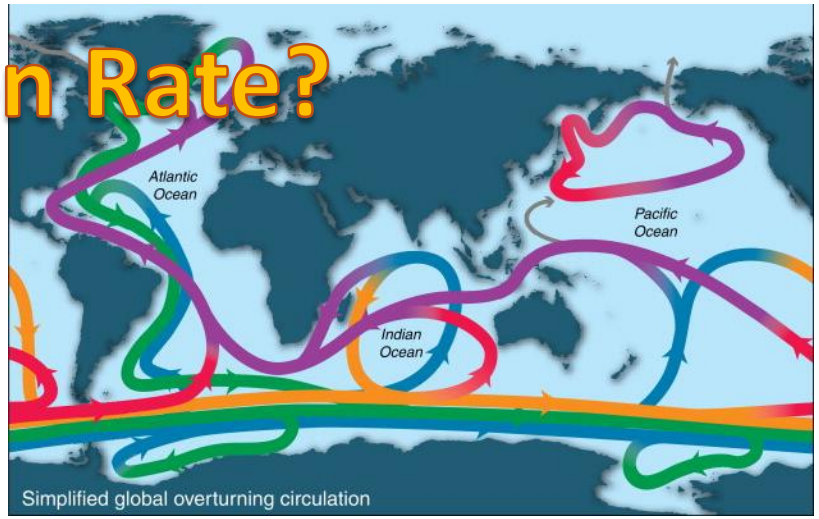
Can we detect a Carbon Sequestration Rate?
The Holocene constraint

a) vegetated coastal ecosystems
b) ocean carbon pump @ 100 m
c) ocean carbon pump at permenant themocline

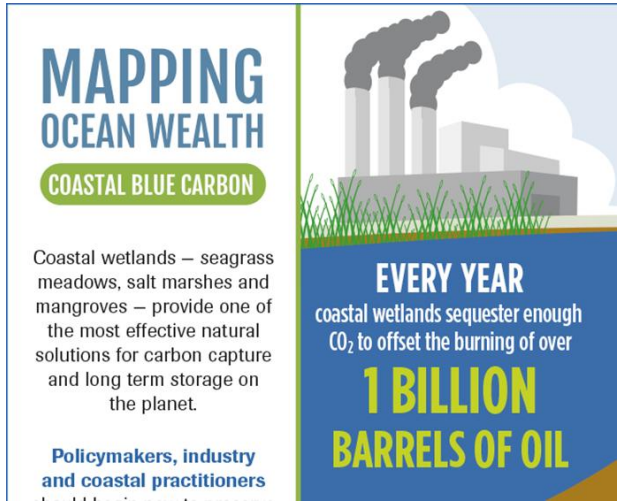


Had the rates reported in the literature been in operation during the Holocene, then the entire atmosphere would have been stripped of CO_2 in a few 1000 years, leading to a snowball earth climate. These estimates cannot be actual sequestration rates.
Rather they are turnover rates : what goes in comes out again.

Seriously questions validity of valorization of biological carbon pump and blue carbon.



We are engaged in a political debate concerning climate action where the term “sequestration” carries a lot or weight.



There are clear instances where the science has been mis-interpreted in the political arena.

There are also clear instances where the sciences have perpetrated their own unguarded abuse.

ARTICLES
https://doi.org/10.1038/s41558-021-01089-4
nature climate change
Check for updates

OPEN

The blue carbon wealth of nations

Christine Bertram[1], Martin Quaas[2], Thorsten B. H. Reusch[3], Athanasios T. Vafeidis[4], Claudia Wolff[4] and Wilfried Rickels[1]

Article
https://doi.org/10.1038/s41558-025-02295-0

Global distribution, quantification and valuation of the biological carbon pump

Received: 26 December 2023
Accepted: 21 February 2025

F. Berzaghi[1], Jérôme Pinti[2,3], Olivier Aumont[4], Olivier Maury[5], Thomas Cosimano[6] & Mary S. Wisz[1,7]

With issues such as nature-based solutions and marine CO_2 removal high on the agenda, it is vital that we, the scientific community use transparent language least they confuse not only the political debate but also outselves.

Thank you for your attention

GORDON AND BETTY MOORE FOUNDATION

SIMONS FOUNDATION

ECOTIP

BioEcoOcean

SEA-QUESTER

Ocean-ICU

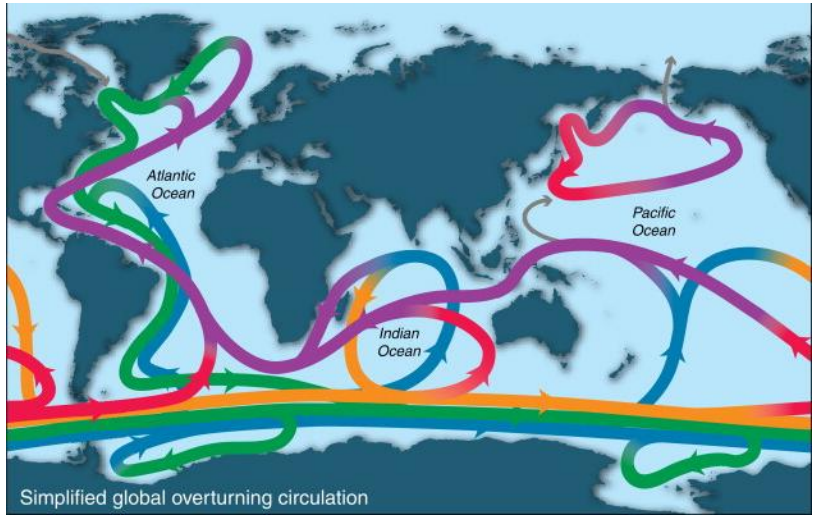
Visser, A.W. (2025), Sequestration by the biological carbon pump: Do we really know what we are talking about?. Limnol. Oceanogr. Lett. https://doi.org/10.1002/lol2.70053

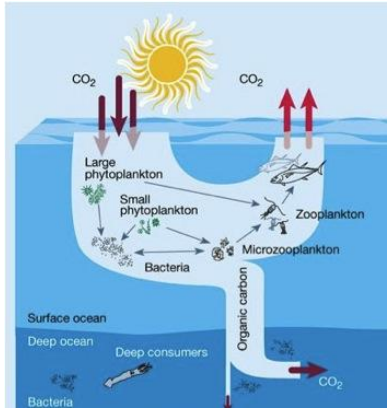
Co-funded by the European Union

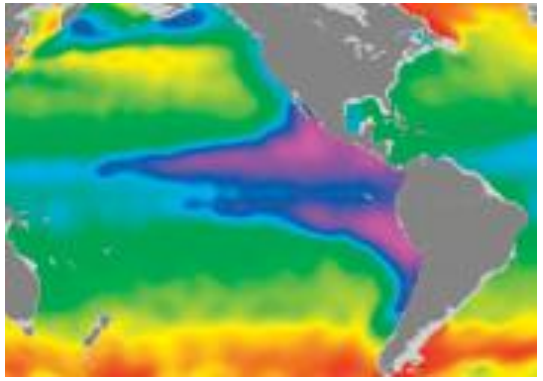
UK Research and Innovation

This work was funded by the European Union under grant agreement no. 101083922 (OceanICU) and UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant number 10054454, 10063673, 10064020, 10059241, 10079684, 10059012, 10048179]. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101136480 (SEA-Quester)







BioEcocean

Funded by the European Union

Partners

UPPSALA UNIVERSITET

DTU

EuroGOOS European Global Ocean Observing System

UNIVERSITÀ DI PISA

unesco Intergovernmental Oceanographic Commission

GOOS The Global Ocean Observing System

OBIS OCEAN BIODIVERSITY INFORMATION SYSTEM

ciimar Centro Interdisciplinar de Investigação Marinha e Ambiental

Institute of Oceanology Polish Academy of Sciences

MERCATOR OCEAN INTERNATIONAL

AIR CENTRE

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.