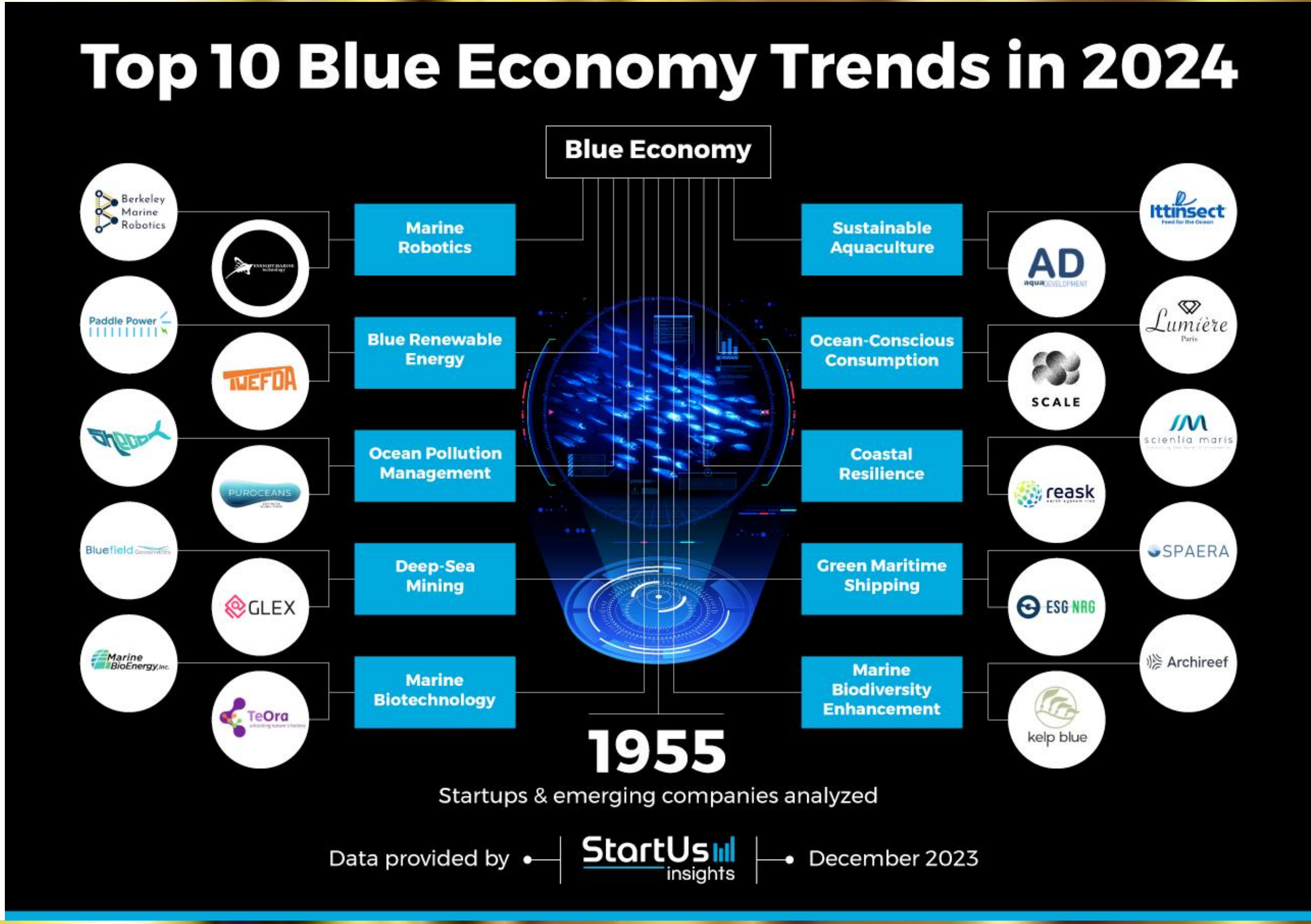
The Awesome Ocean

Ros Rickaby (rosr@earth.ox.ac.uk)
Department of Earth Sciences,
University of Oxford

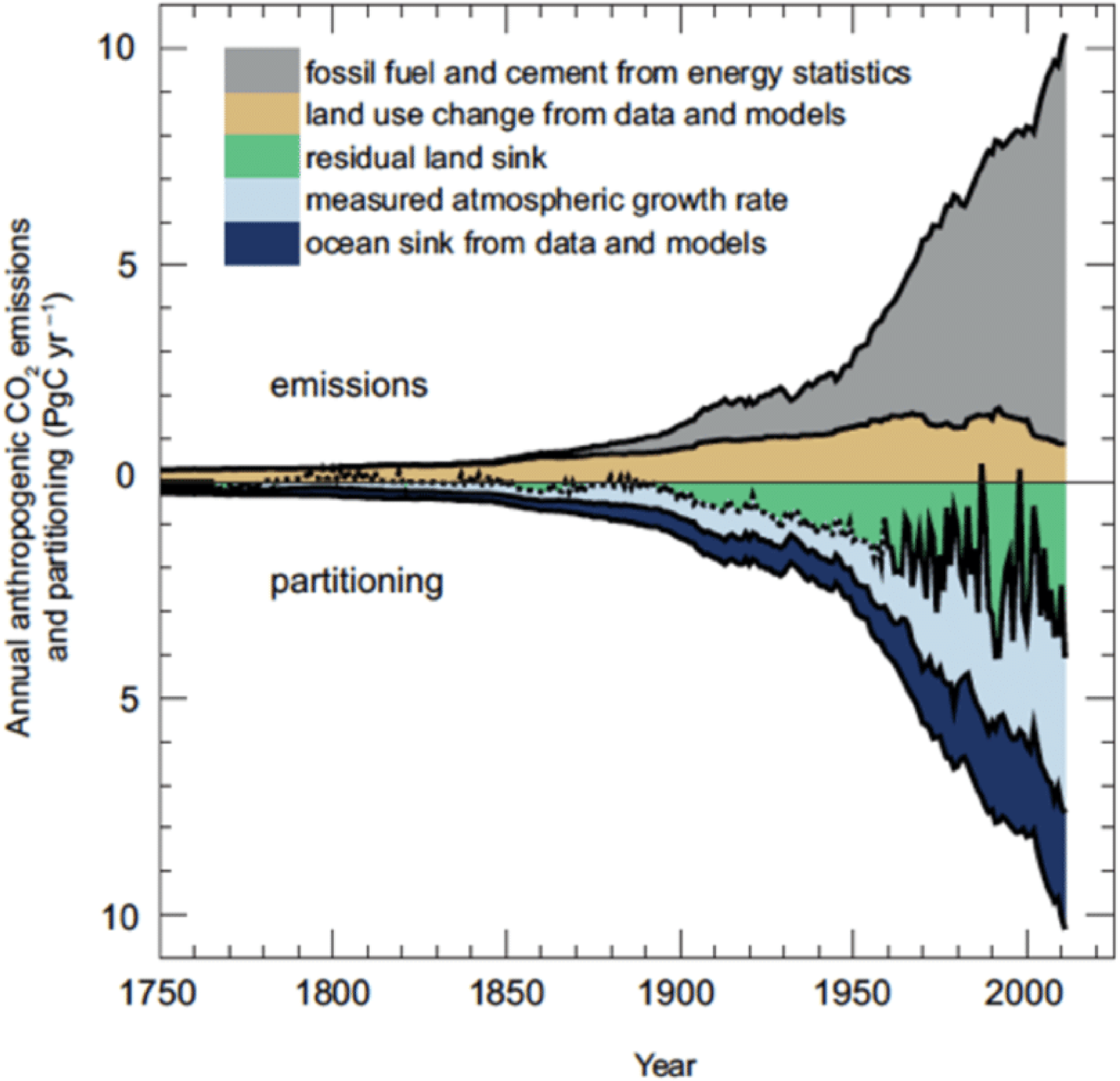
UNIVERSITY OF
OXFORD

The Awesome Ocean- liquid gold

- The worldwide ocean economy is valued at around **$1.5 trillion per year**, equivalent to the seventh largest economy in the world.
- The worldwide ocean economy is set to double by 2030 to $3 trillion.



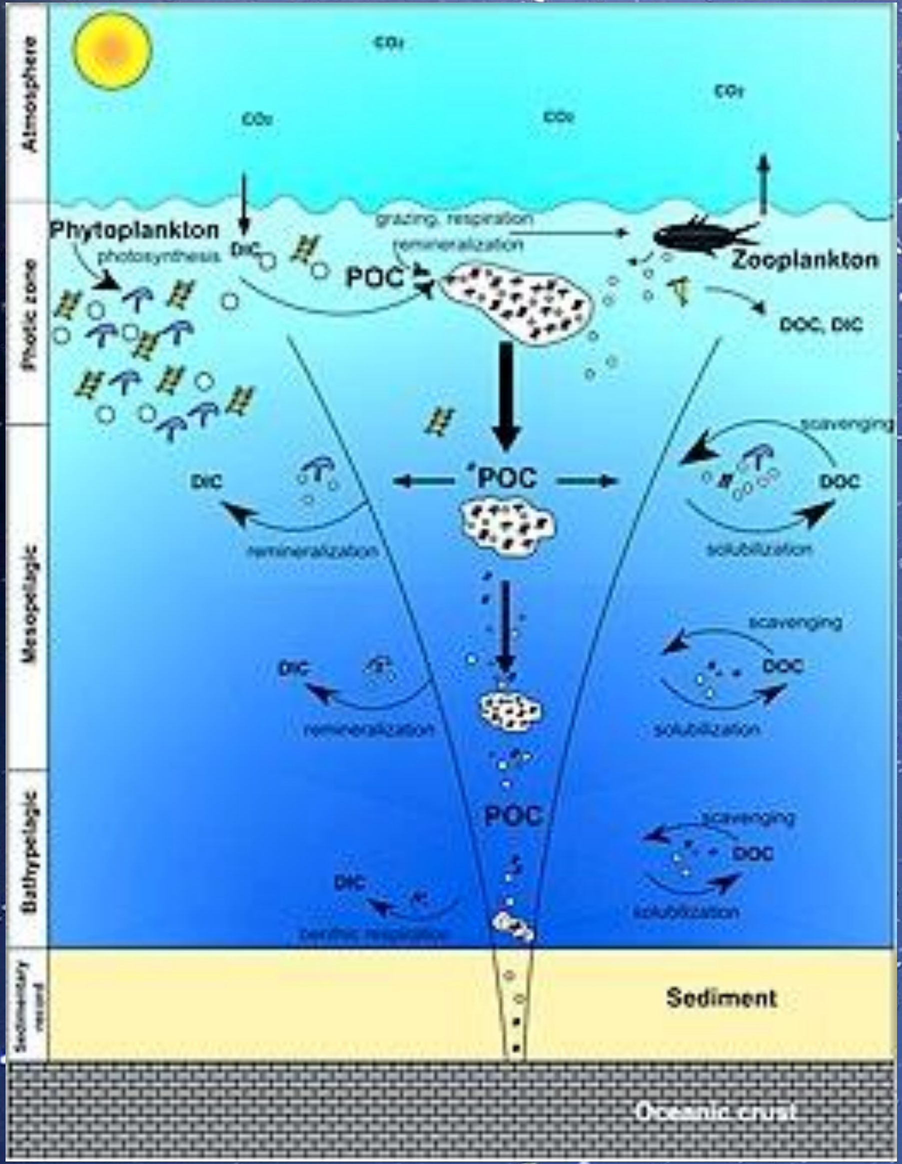
The Oceans- Currently a huge carbon sponge

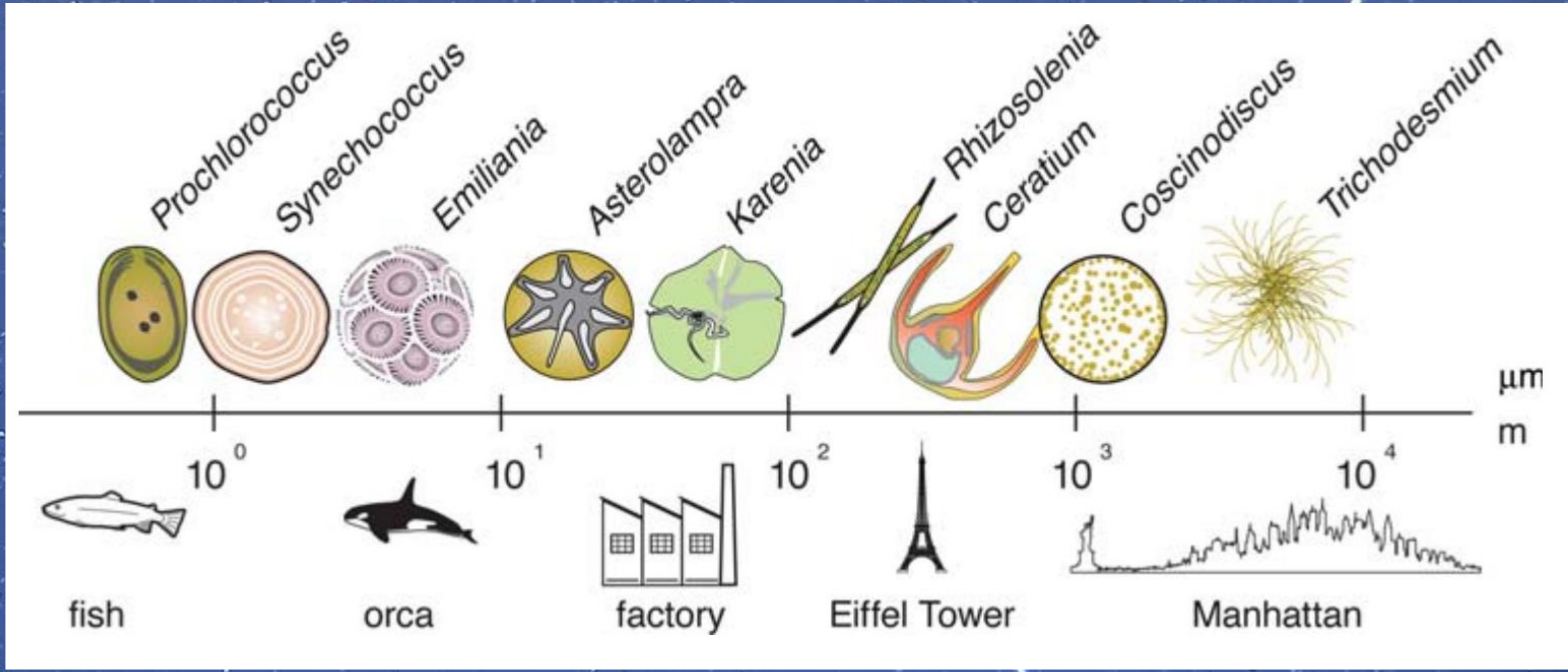


- The oceans take up emissions at a rate of about 2 GtC/yr so have absorbed 500 Gt from a total 1300 Gt emissions…**currently**
- 20kyrs ago, when mammoths roamed the planet the oceans stored an additional 900 GtC
- **All for free (in the context of C markets)**

The Power of the Plankton

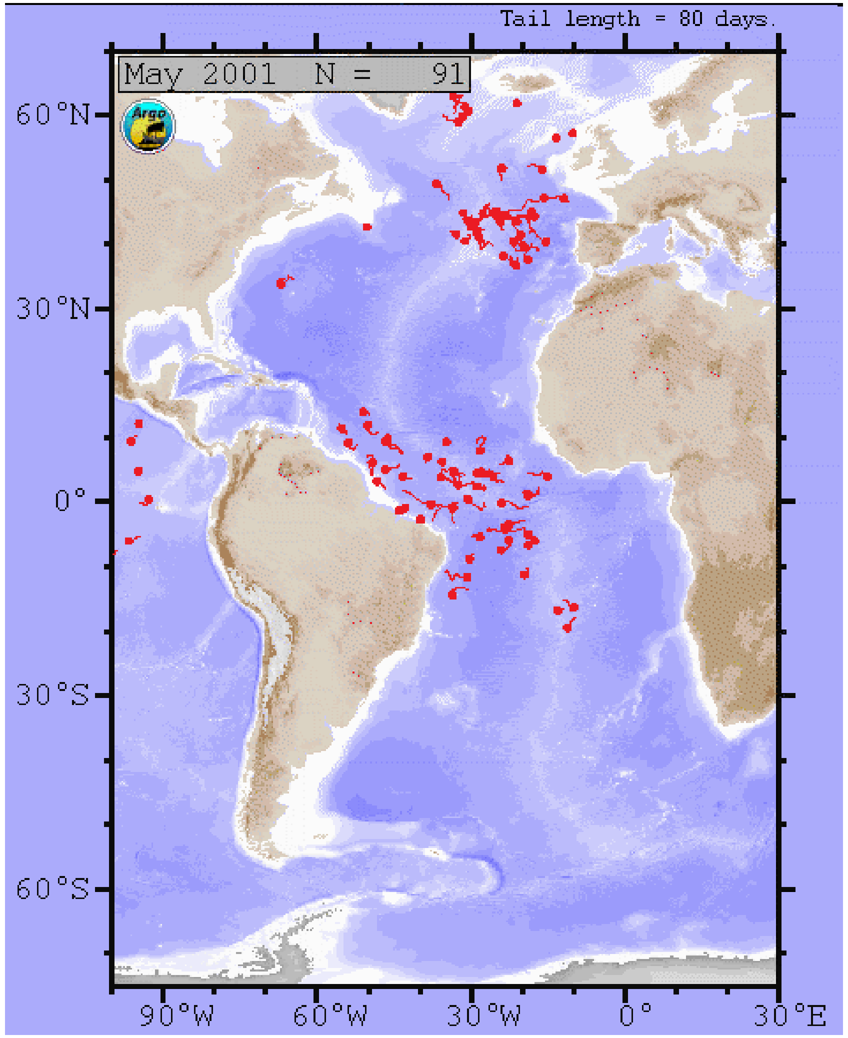
- Base of ecosystem productivity and 50-80% of global biodiversity
- Plankton are sentinels of change
- 5-12 PgC/yr

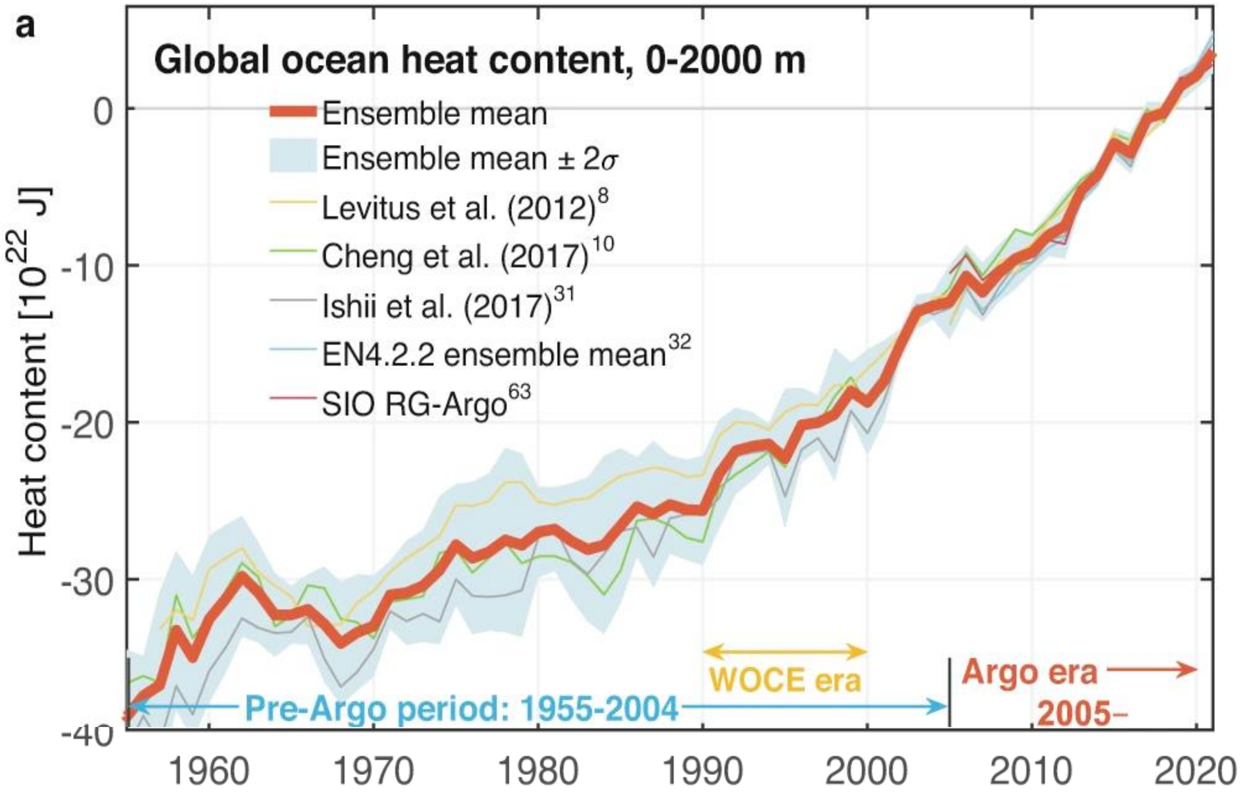




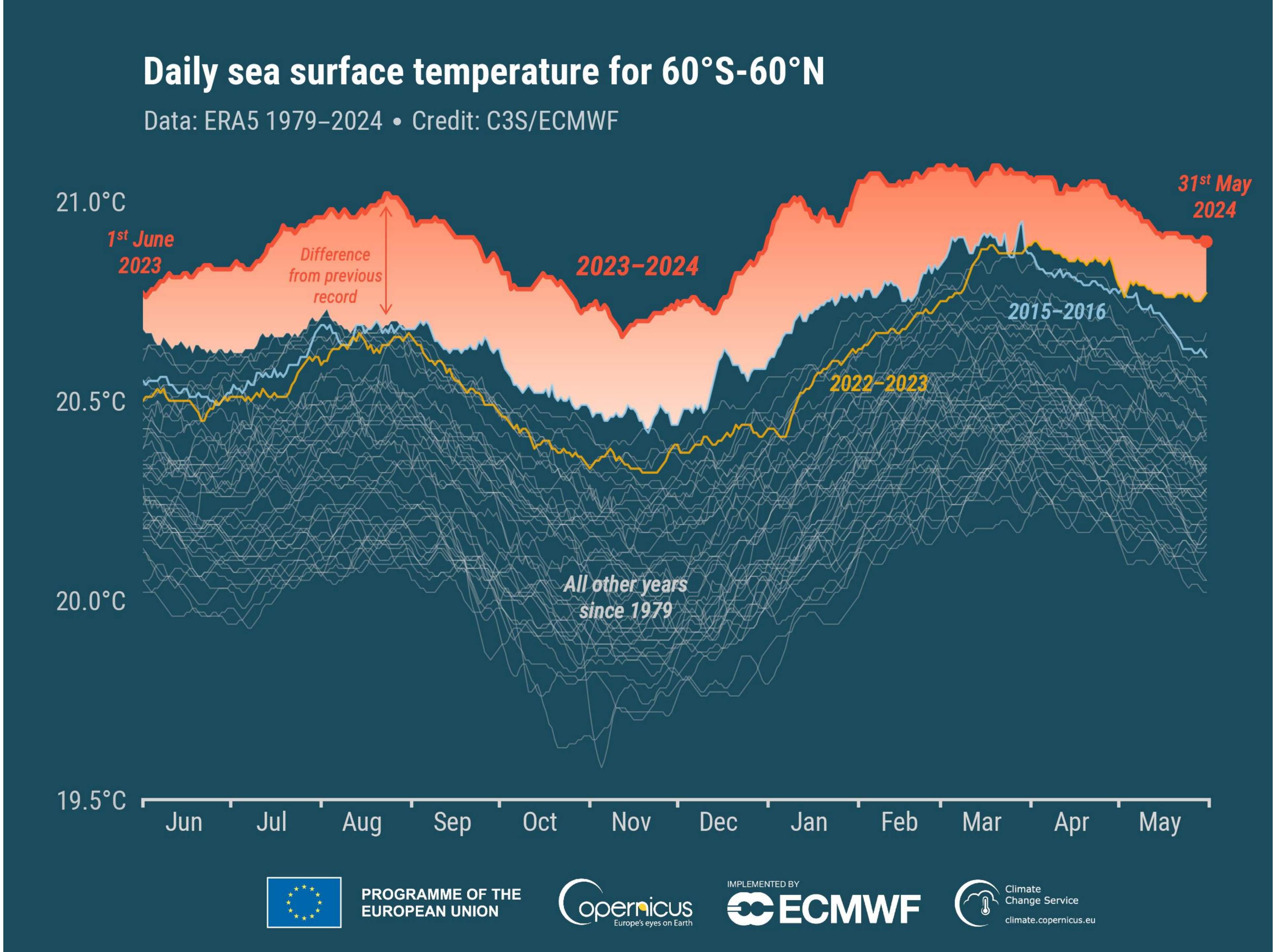
Finkel, Z.V., Beardall, J., Flynn, K.J., Quigg, A., Rees, T.A.V. and Raven, J.A., 2010. Phytoplankton in a changing world: cell size and elemental stoichiometry. *Journal of plankton research*, *32*(1), pp.119-137.

The Oceans- a huge sponge of heat ~ 90% of our global warming





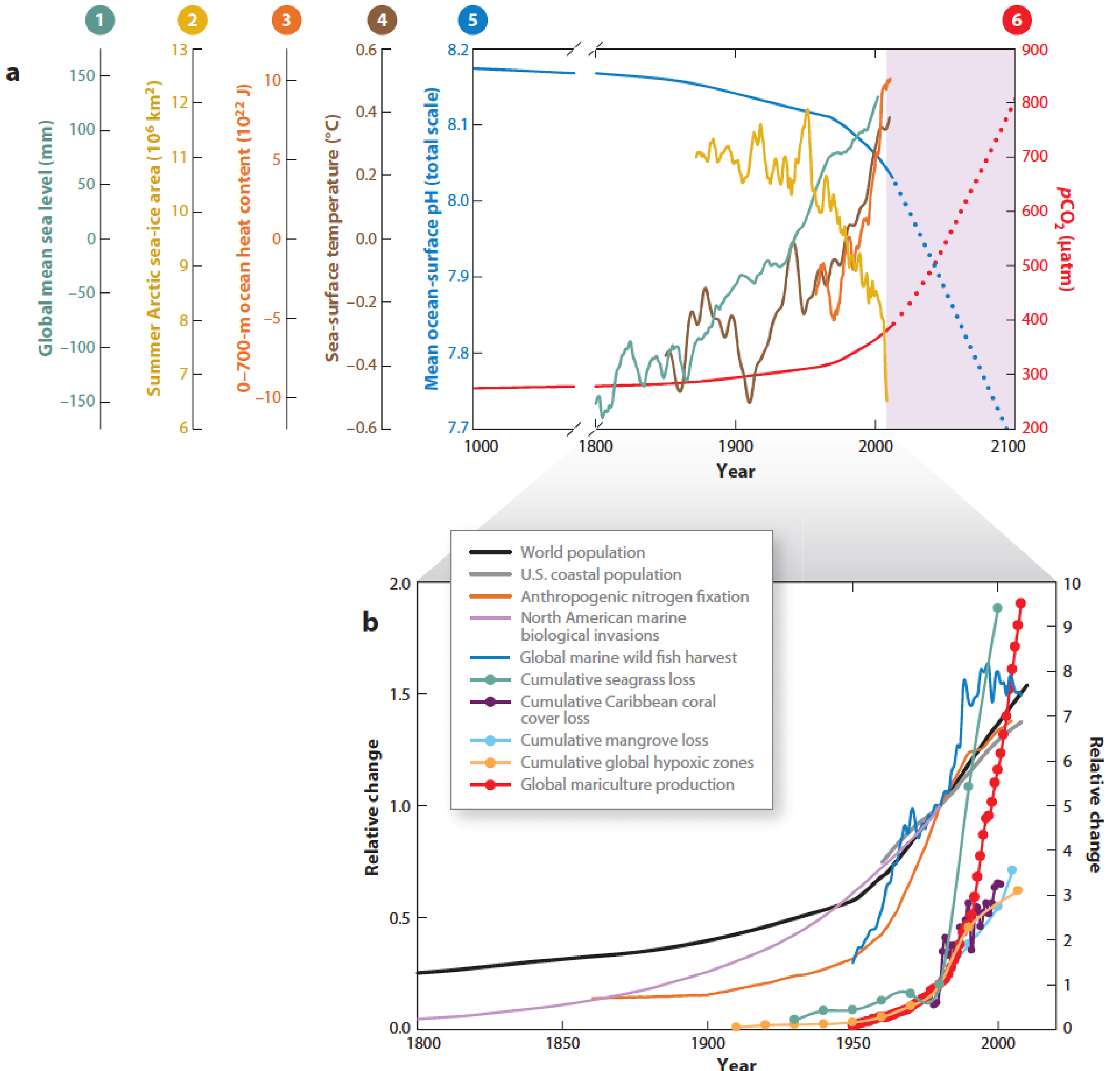
Argo Floats

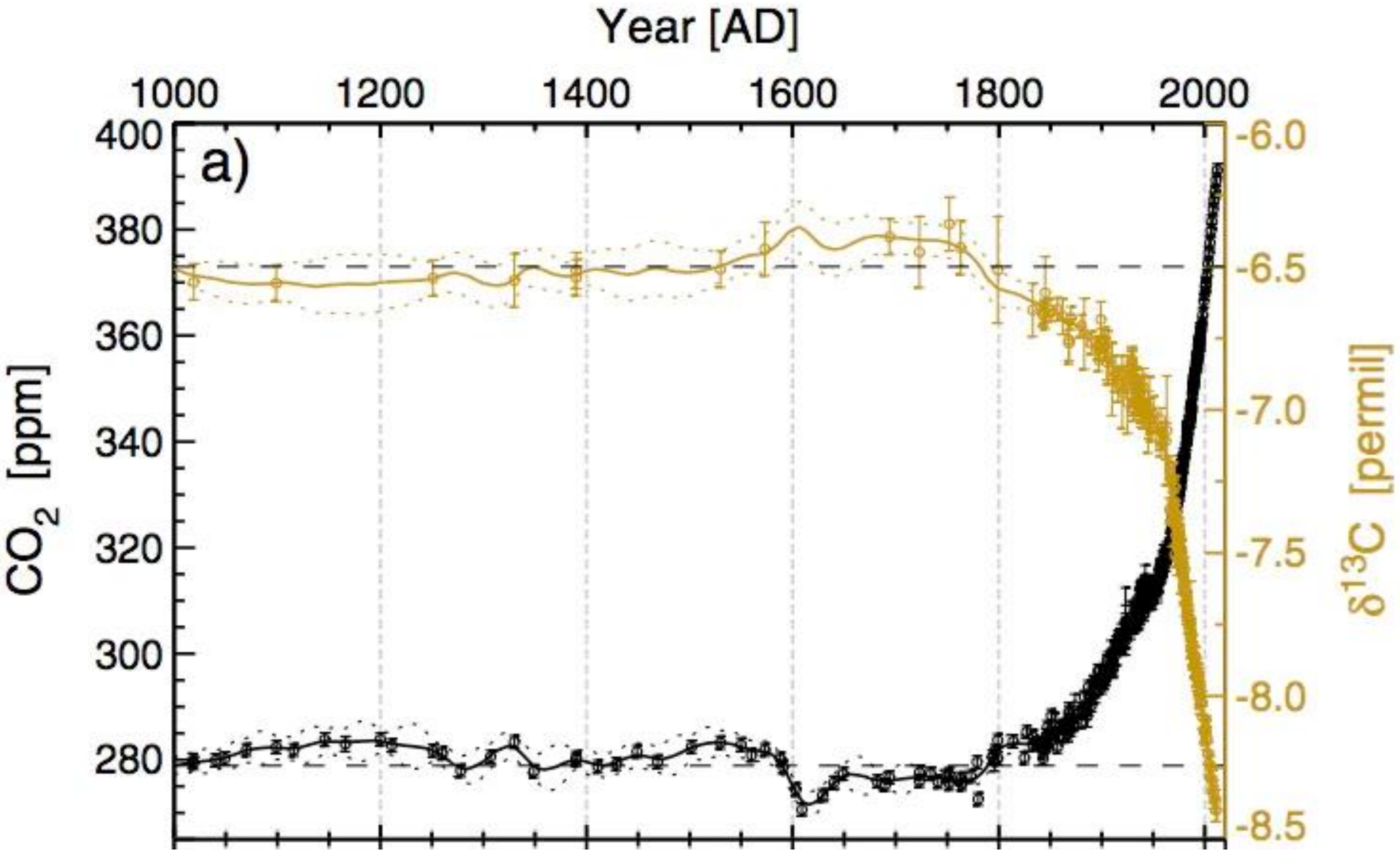


Daily sea surface temperature for 60°S-60°N
Data: ERA5 1979–2024 • Credit: C3S/ECMWF
21.0°C
20.5°C
20.0°C
19.5°C
1st June 2023
Difference from previous record
2023–2024
31st May 2024
2015–2016
2022–2023
All other years since 1979
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
PROGRAMME OF THE EUROPEAN UNION
Copernicus
Europe's eyes on Earth
IMPLEMENTED BY
ECMWF
Climate Change Service
climate.copernicus.eu

The altered Marine Environment

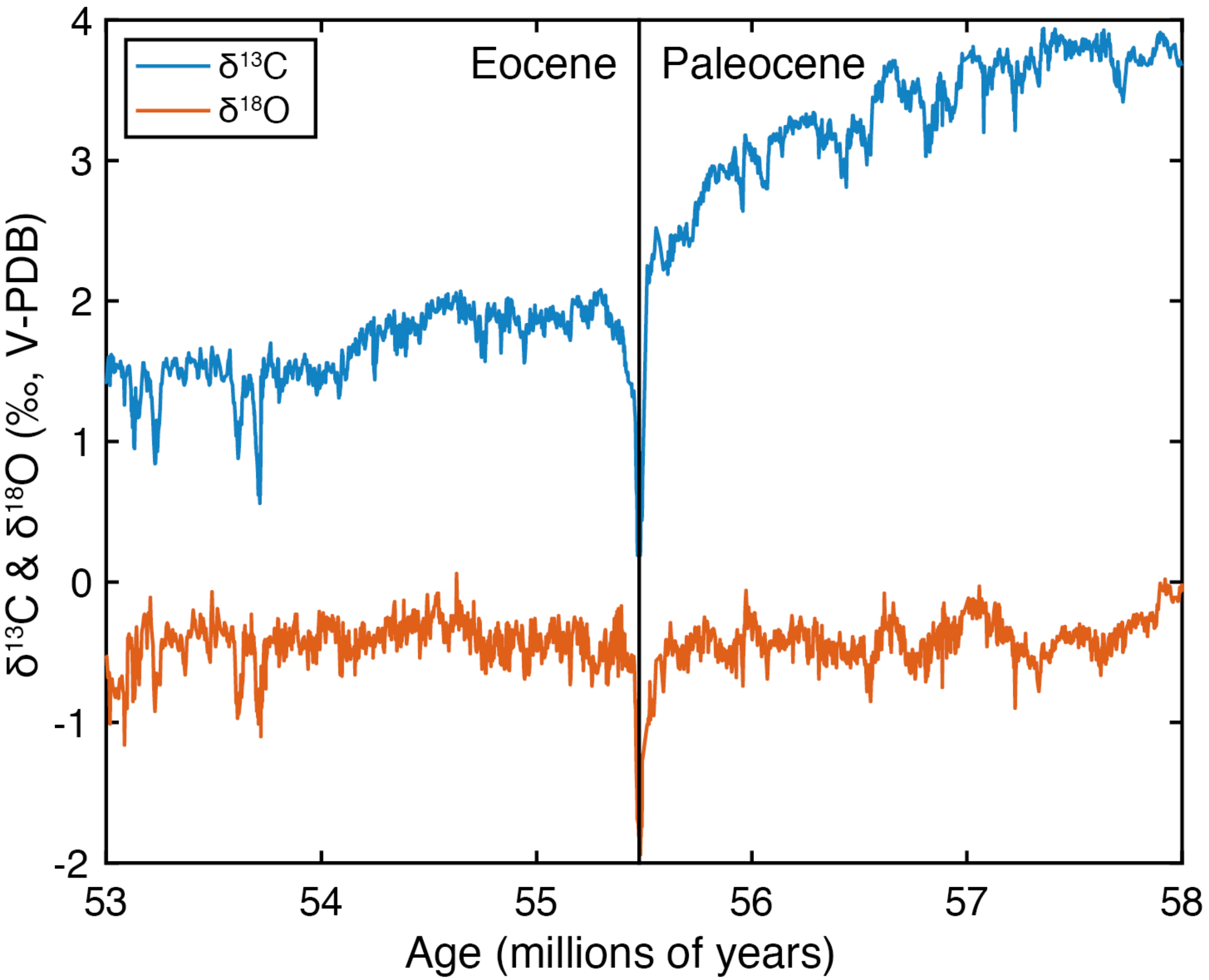
- Elevated CO2 (fertilization)
- pH- acidification
- Nutrients-stratification
- Oxygen-deoxygenation
- Temperature (P:R) (bleaching)
- Pollutants (including N2, plastics)
- Seasonal Change (mistimings: light and temperature)

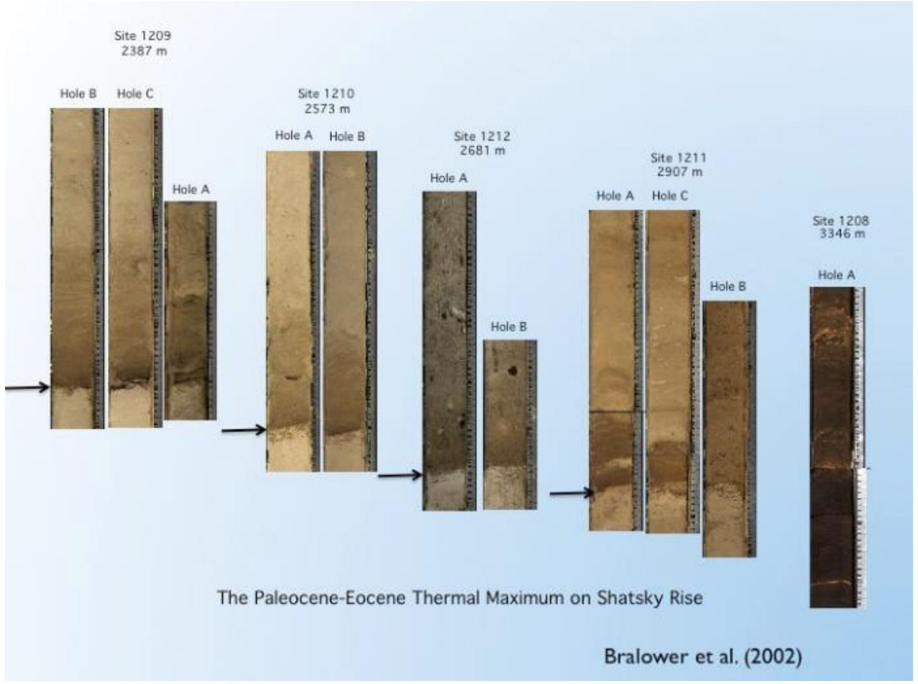




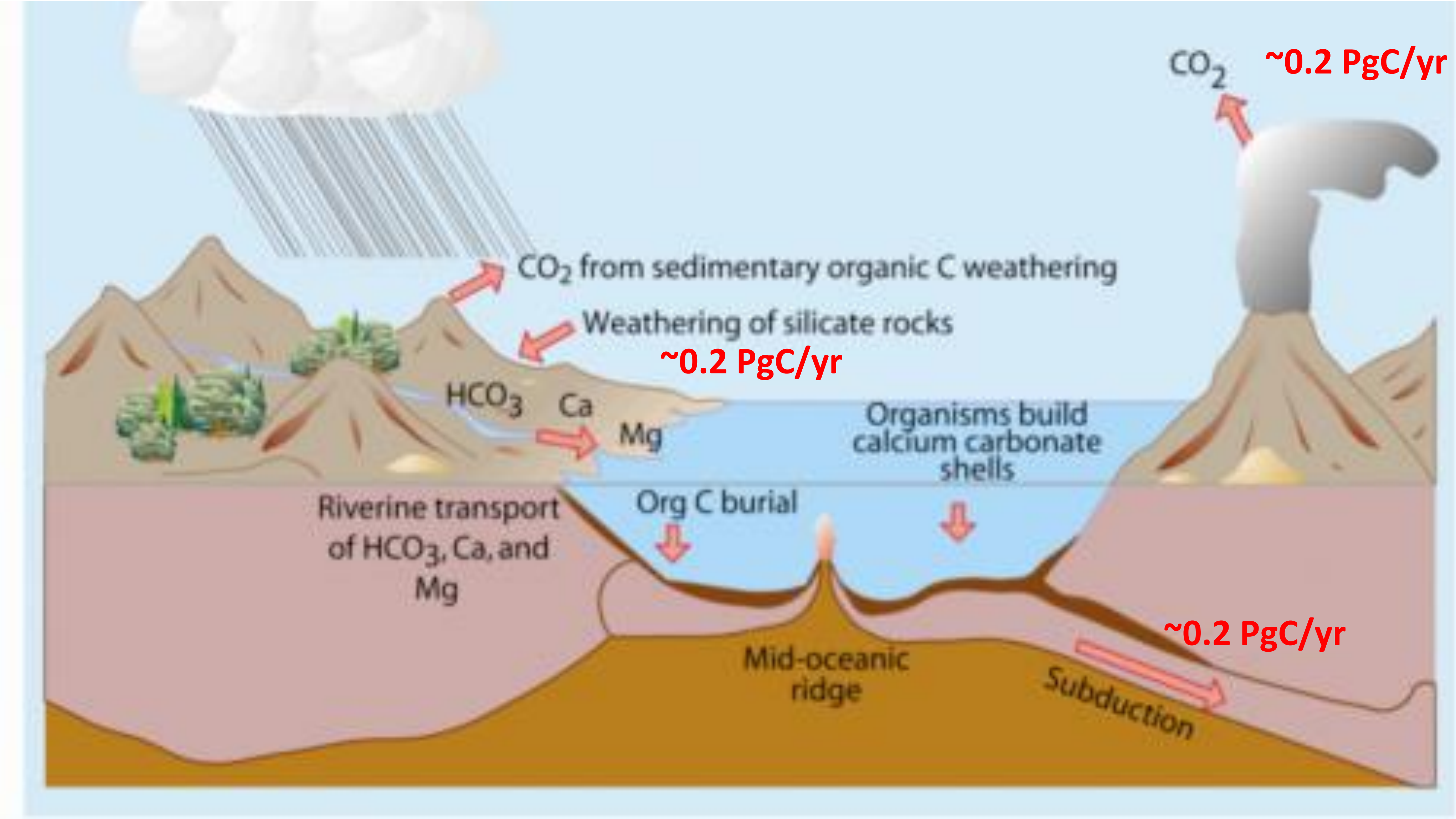
Year [AD]
1000
1200
1400
1600
1800
2000
a)
400
380
360
340
320
300
280
CO2 [ppm]
-6.0
-6.5
-7.0
-7.5
-8.0
-8.5
δ13C [permil]

PETM: 55800000yrs ago

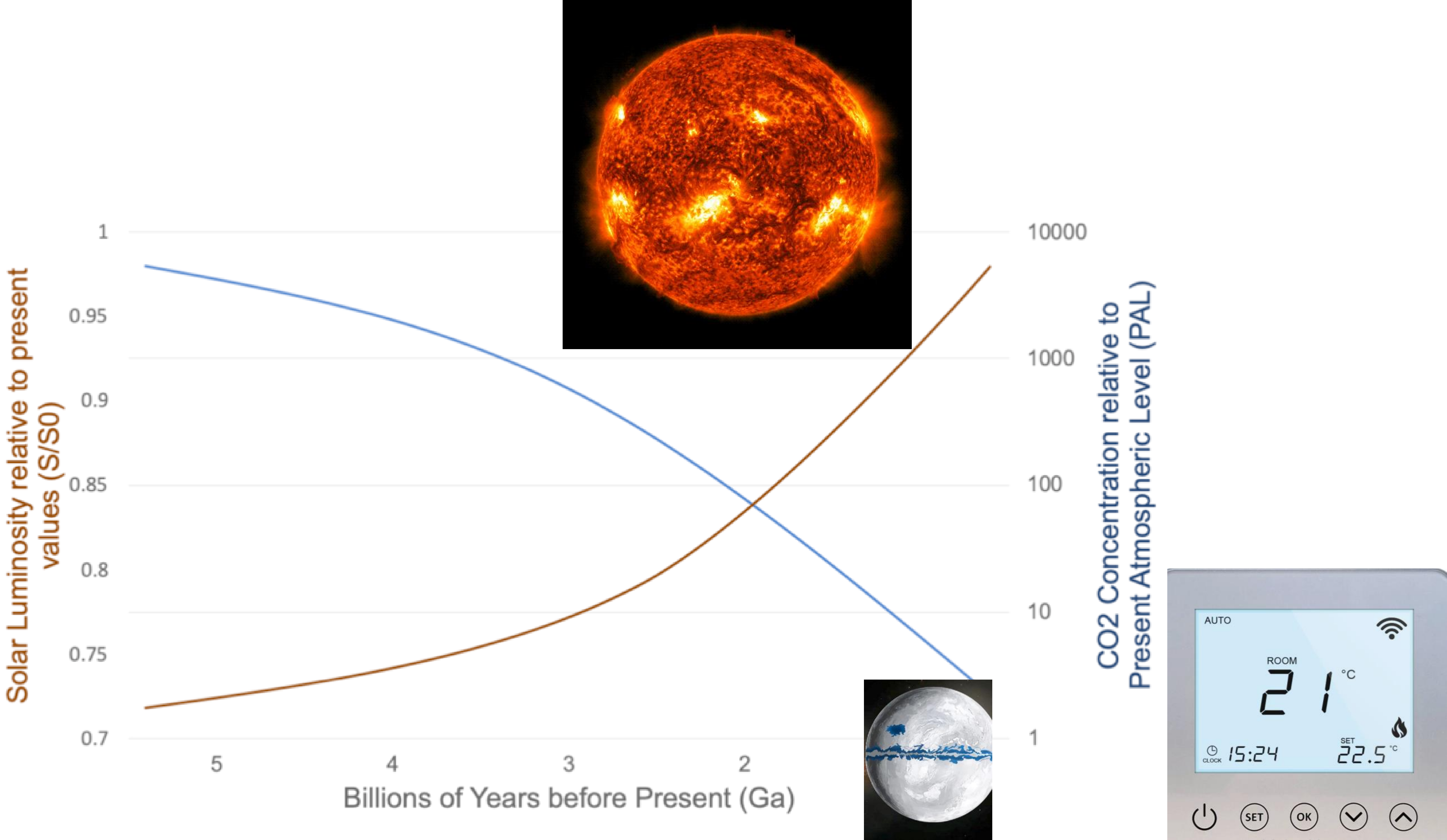




- 3000 PgC over 5000 years (0.6 PgC/yr or 2.4 $GtCO_2$/yr) emissions of CO_2
- 5-8 ^oC rise of global temperature
- Dissolved $CaCO_3$ in ocean sediments (acidification),
- Ocean Deoxygenation
- Increased weathering, increased Corg burial
- Timescale of recovery ~1-200000 years

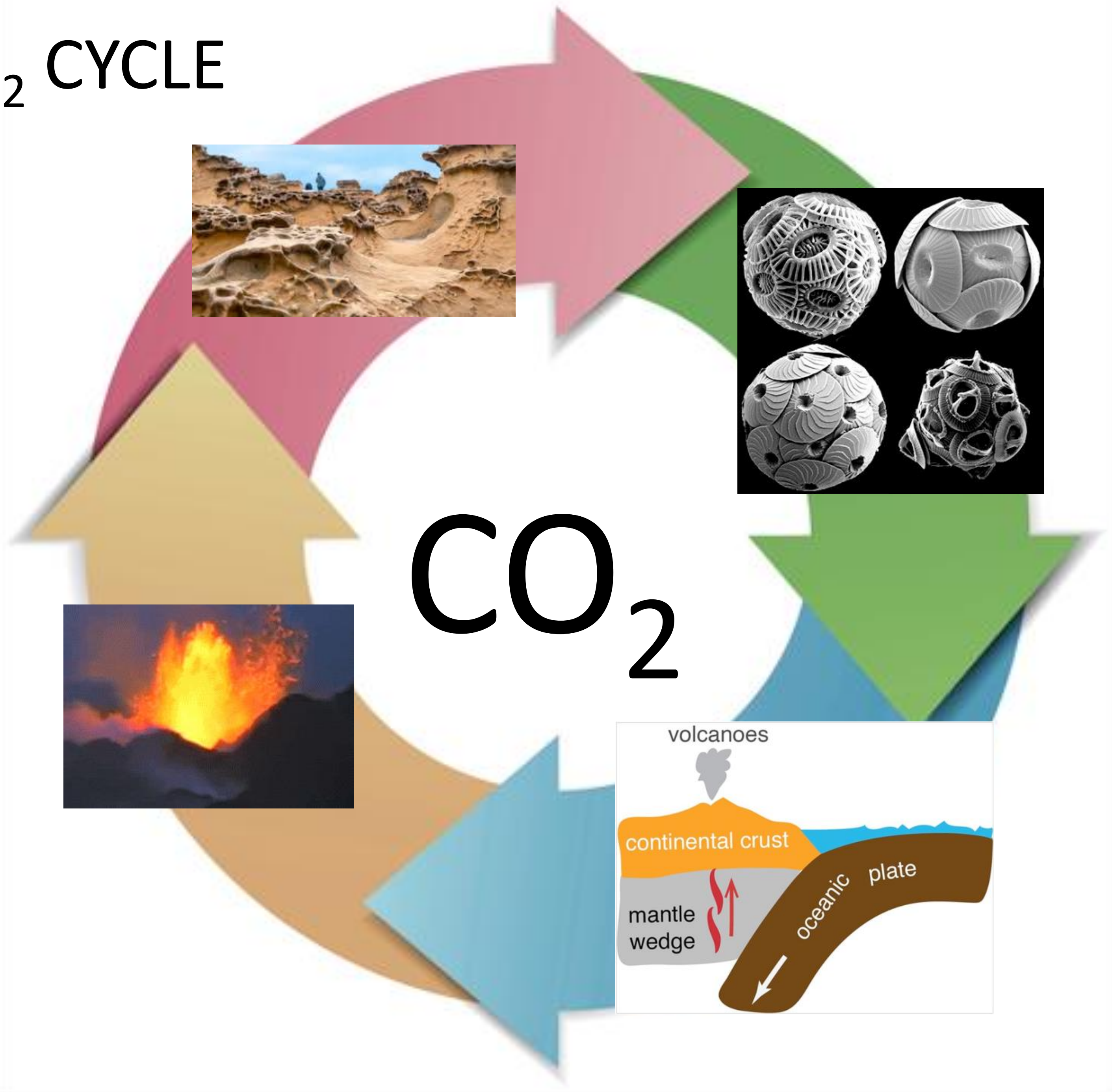


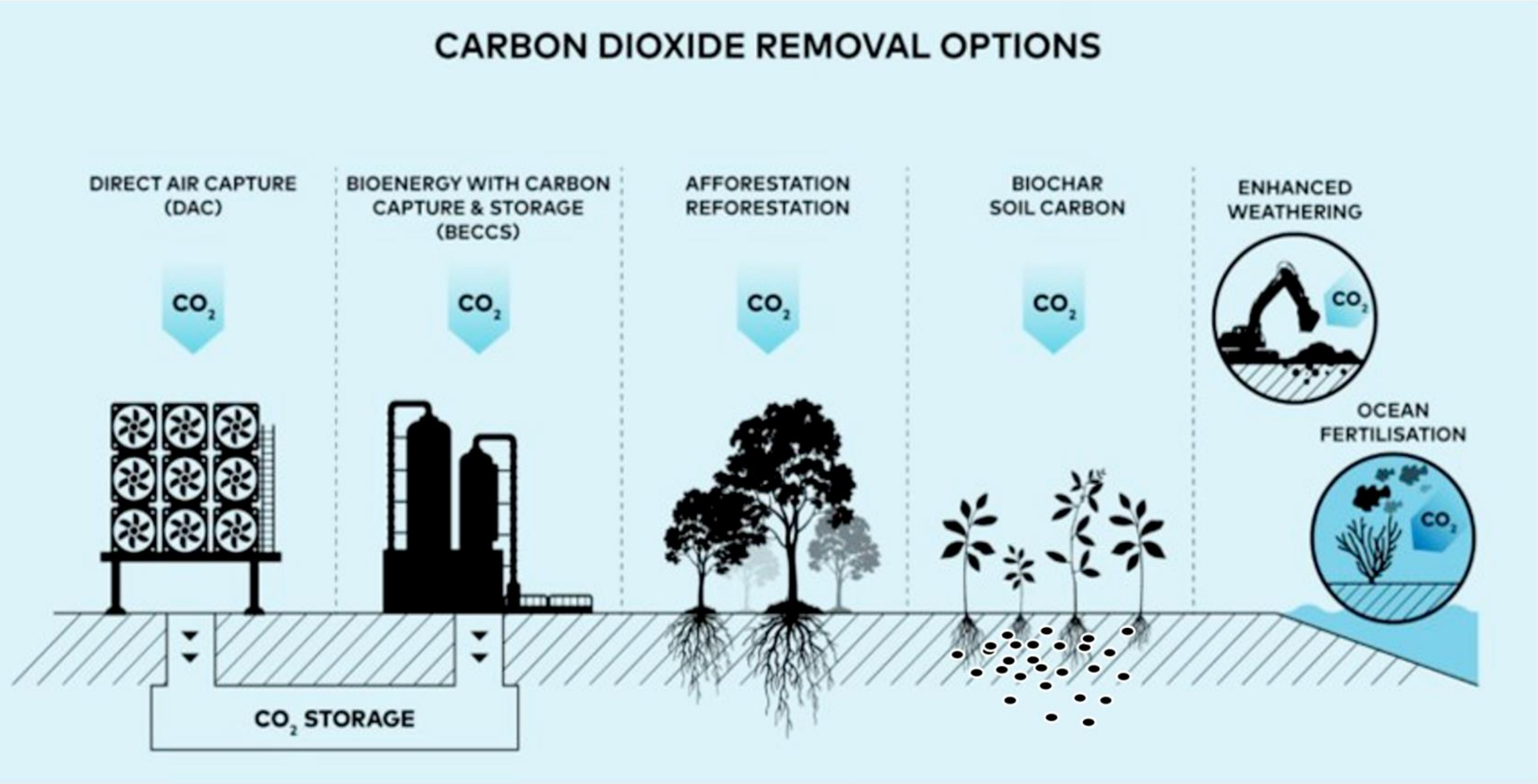
CO2
~0.2 PgC/yr
CO2 from sedimentary organic C weathering
Weathering of silicate rocks
~0.2 PgC/yr
HCO3
Ca
Mg
Organisms build calcium carbonate shells
Riverine transport of HCO3, Ca, and Mg
Org C burial
~0.2 PgC/yr
Mid-oceanic ridge
Subduction



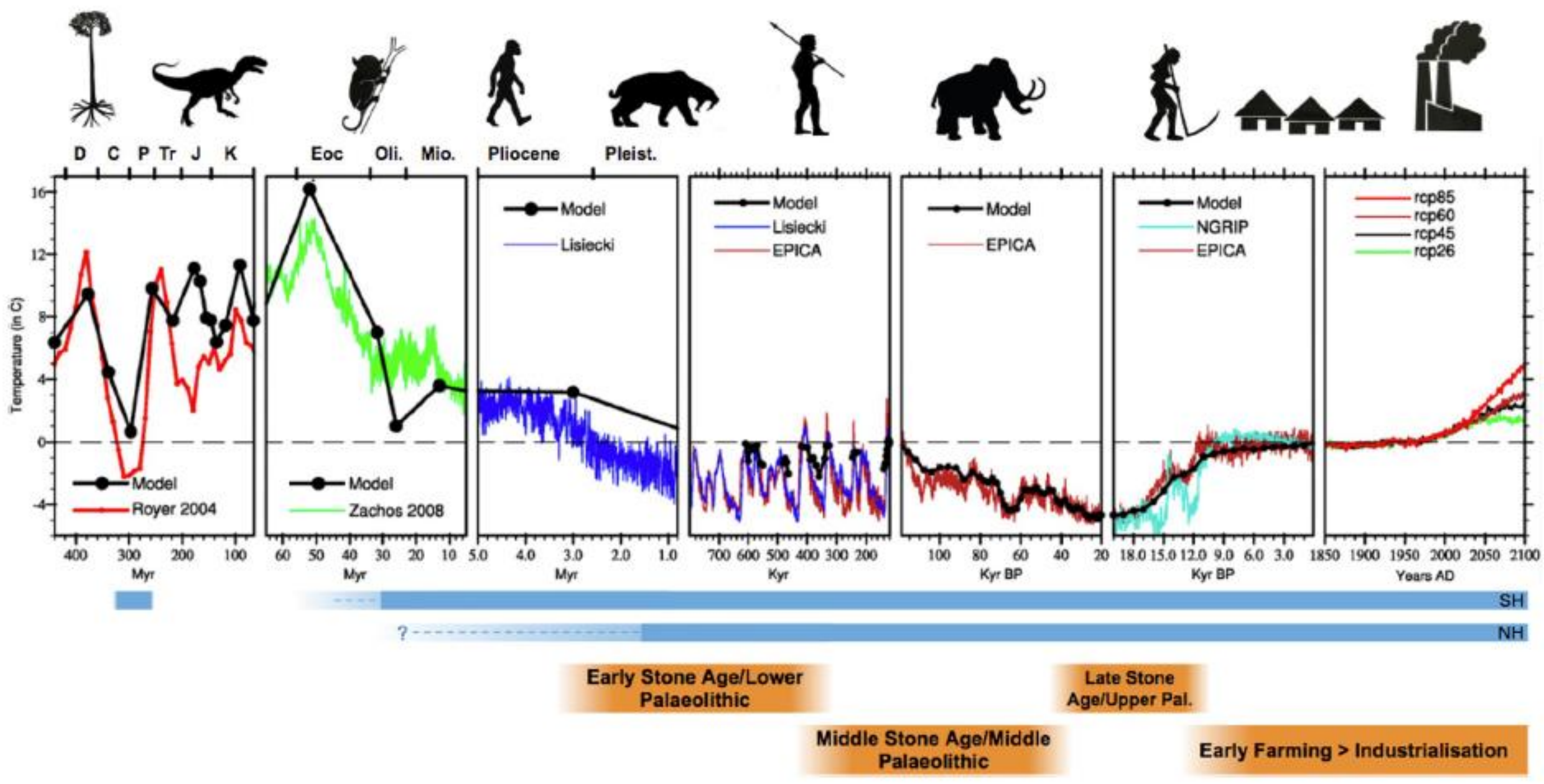
Solar Luminosity relative to present values (S/S0)
1
0.95
0.9
0.85
0.8
0.75
0.7
CO2 Concentration relative to Present Atmospheric Level (PAL)
10000
1000
100
10
1
5
4
3
2
Billions of Years before Present (Ga)
AUTO
ROOM
21 °C
CLOCK 15:24
SET 22.5 °C
SET
OK

LONG TERM CO_2 CYCLE

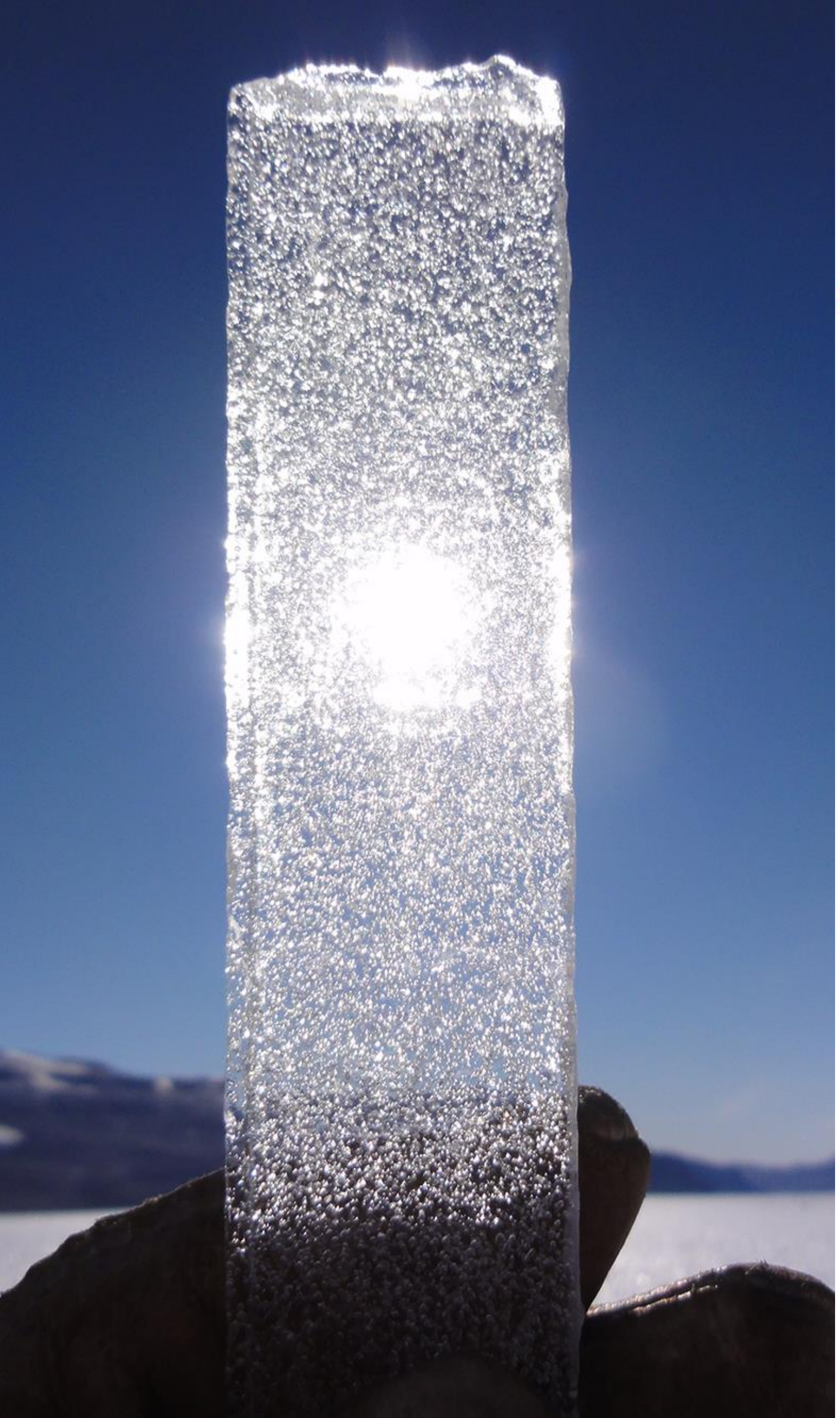




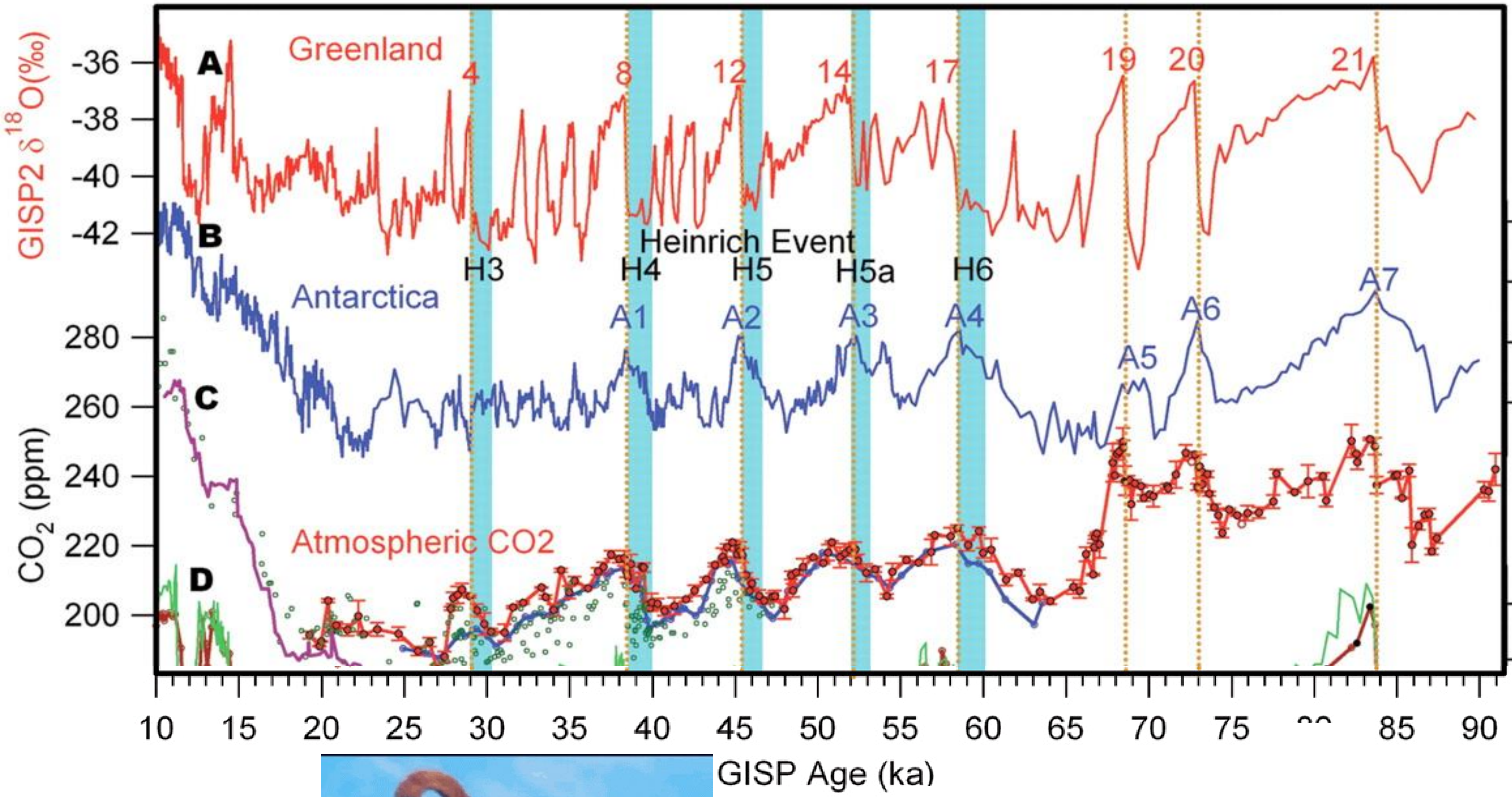
- Do the kinetics work?
- Can the sequestered C be measured?
- What are the unintended benefits? And consequences?
- What is the carbon/resource footprint of the technique itself?
- Who/What drives the C market?



D C P Tr J K
Eoc Oli. Mio.
Pliocene Pleist.
Temperature (in C)
Model
Royer 2004
Zachos 2008
Lisiecki
EPICA
NGRIP
rcp85
rcp60
rcp45
rcp26
Myr
Kyr
Kyr BP
Years AD
SH
NH
Early Stone Age/Lower Palaeolithic
Middle Stone Age/Middle Palaeolithic
Late Stone Age/Upper Pal.
Early Farming > Industrialisation



Ocean Carbon and Tipping Points



Ahn and Brooks, 2008

Environment

‘Literally off the charts’: global coral reef heat stress monitor forced to add new alerts as temperatures rise

Three new levels added by US Coral Reef Watch after ‘extreme’ unprecedented heat, with highest alert warning of ‘near complete mortality’

Graham Readfearn

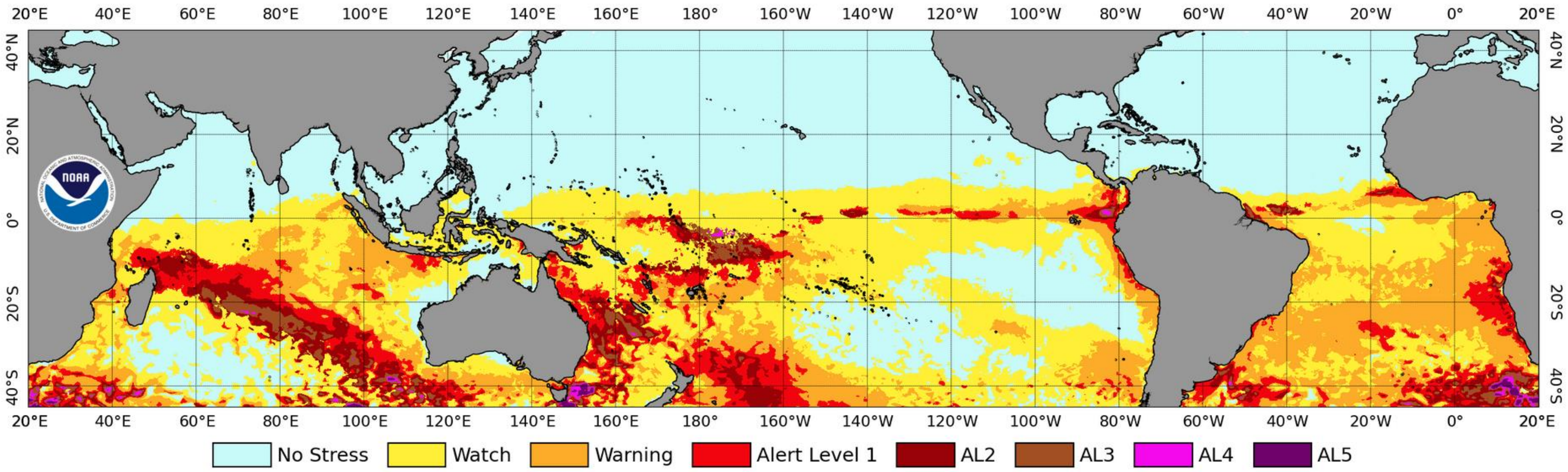
@readfearn

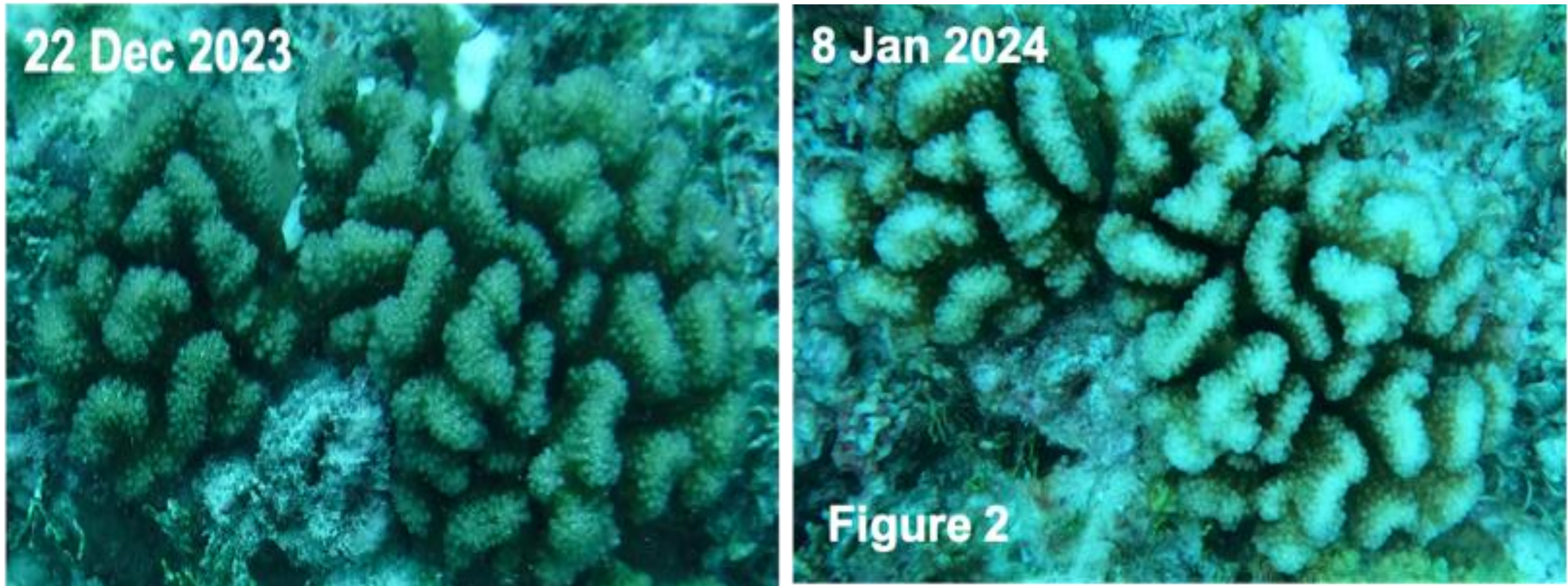
Wed 31 Jan 2024 14.00 GMT

Daily Global 5km Satellite Coral Bleaching Heat Stress Alert Area

(Version 3.1, released August 1, 2018)

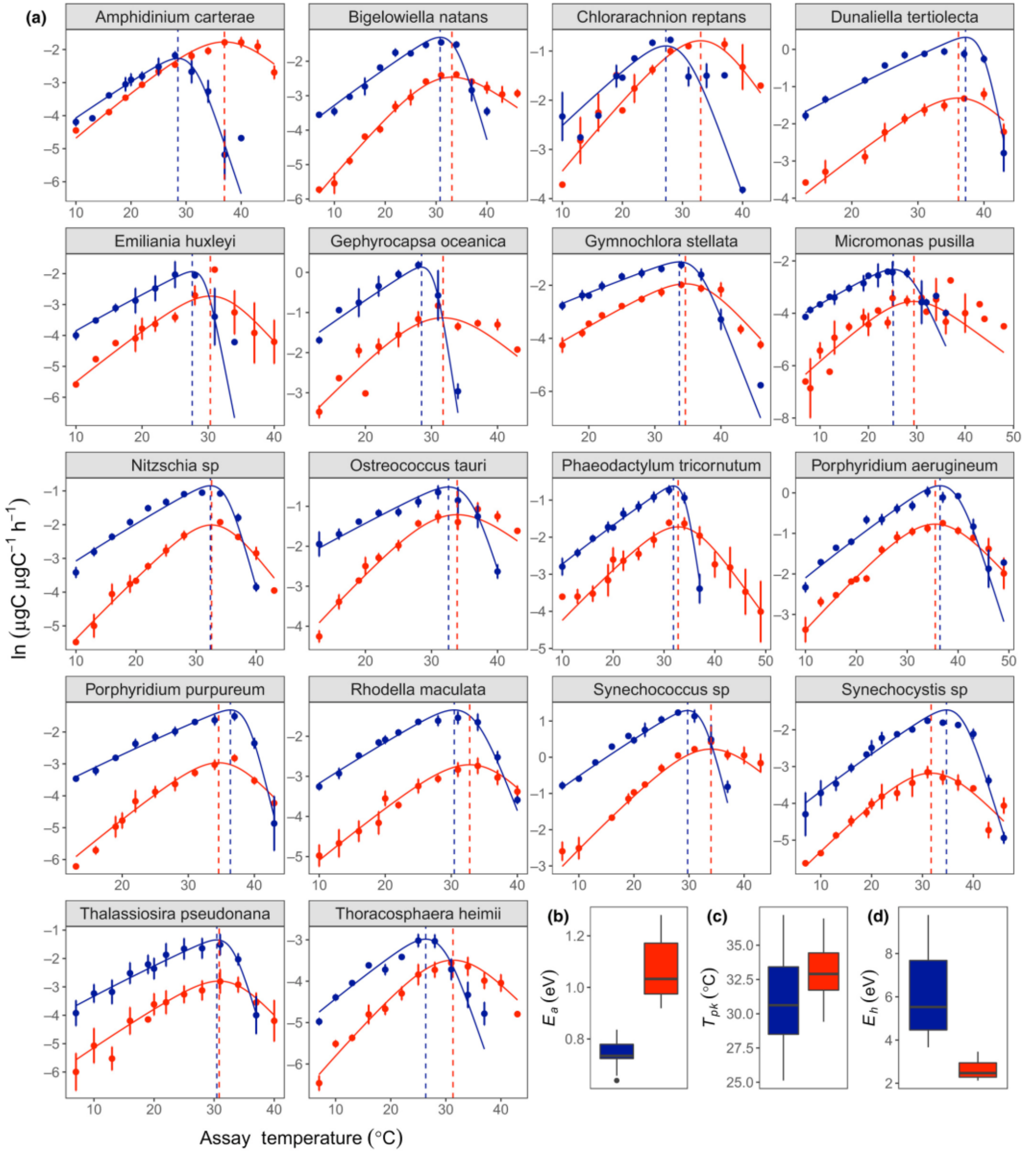
NOAA Coral Reef Watch Daily 5km Bleaching Alert Area 7-day Maximum (v3.1) 13 Feb 2024





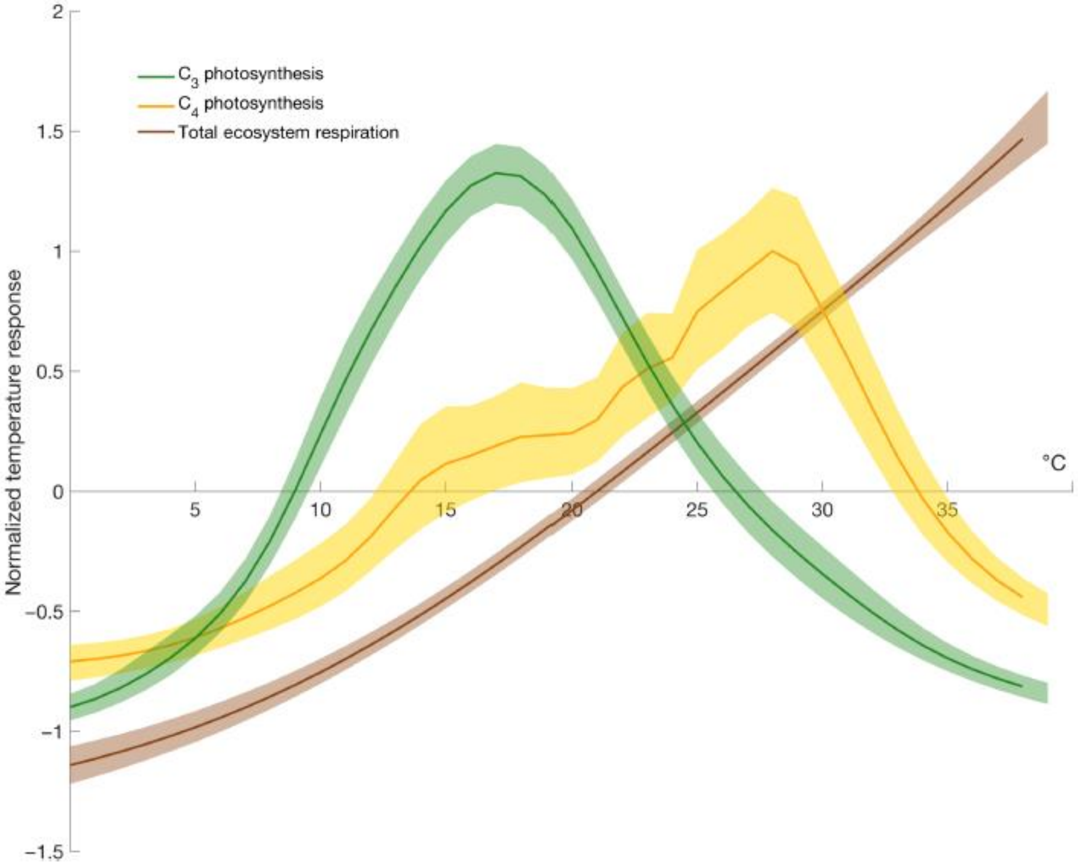
T tipping points of Photosynthesis versus Respiration (and C sink)

Barton et al., 2020

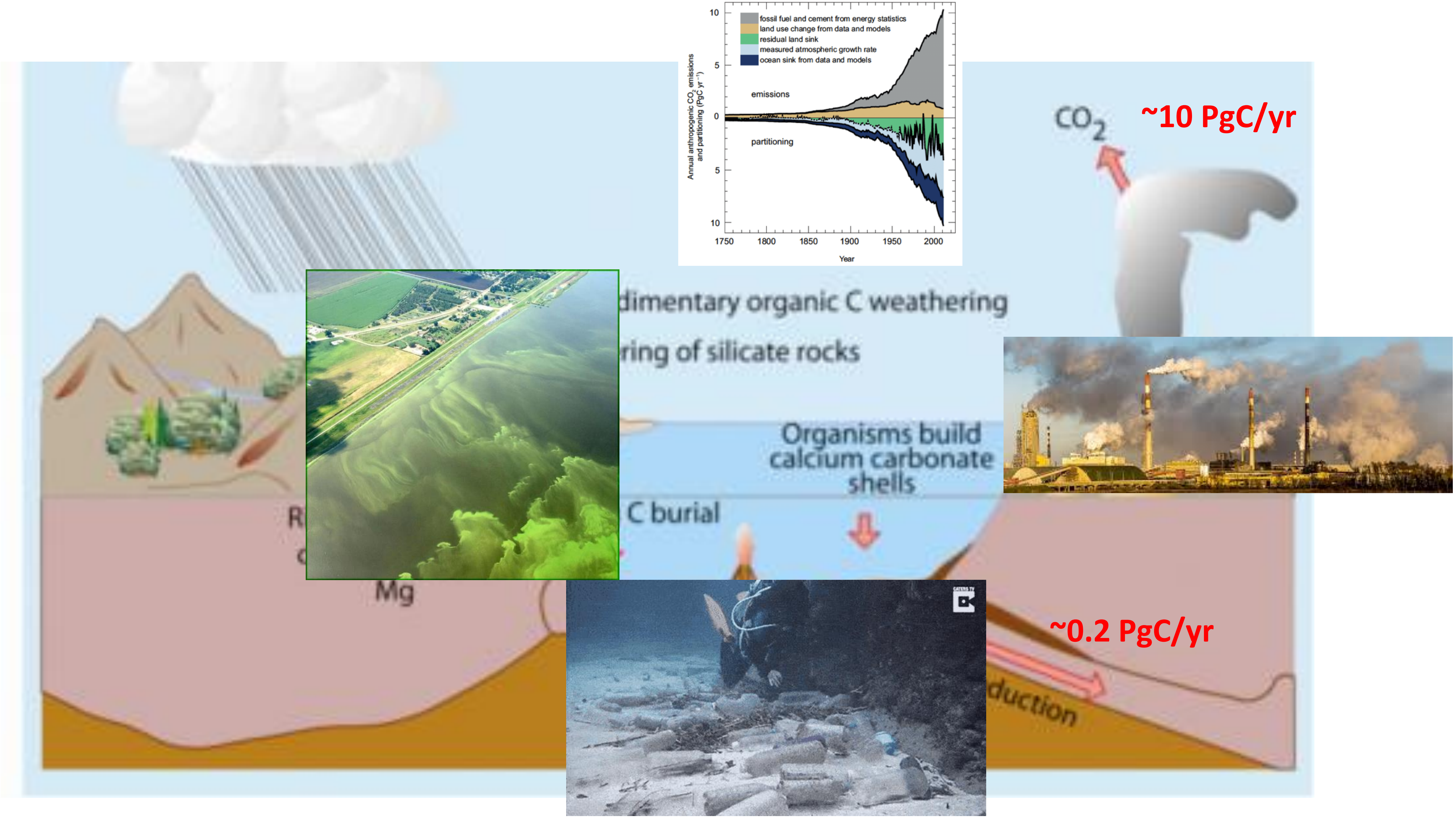


How close are we to the temperature tipping point of the terrestrial biosphere?

Katharyn A. Duffy[1,2]*, Christopher R. Schwalm[2,3], Vickery L. Arcus[4], George W. Koch[2], Liyin L. Liang[4,5], Louis A. Schipper[4]

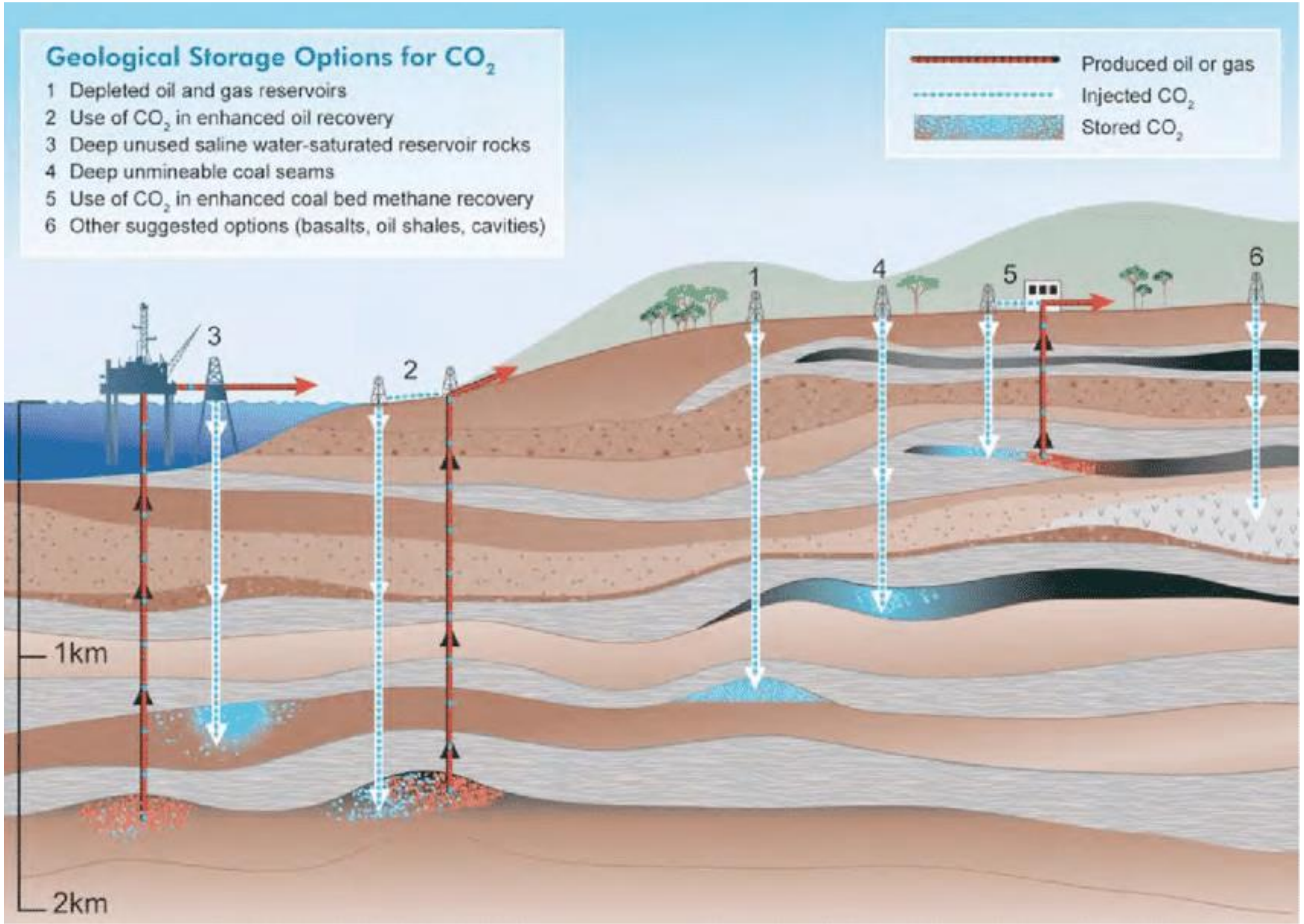


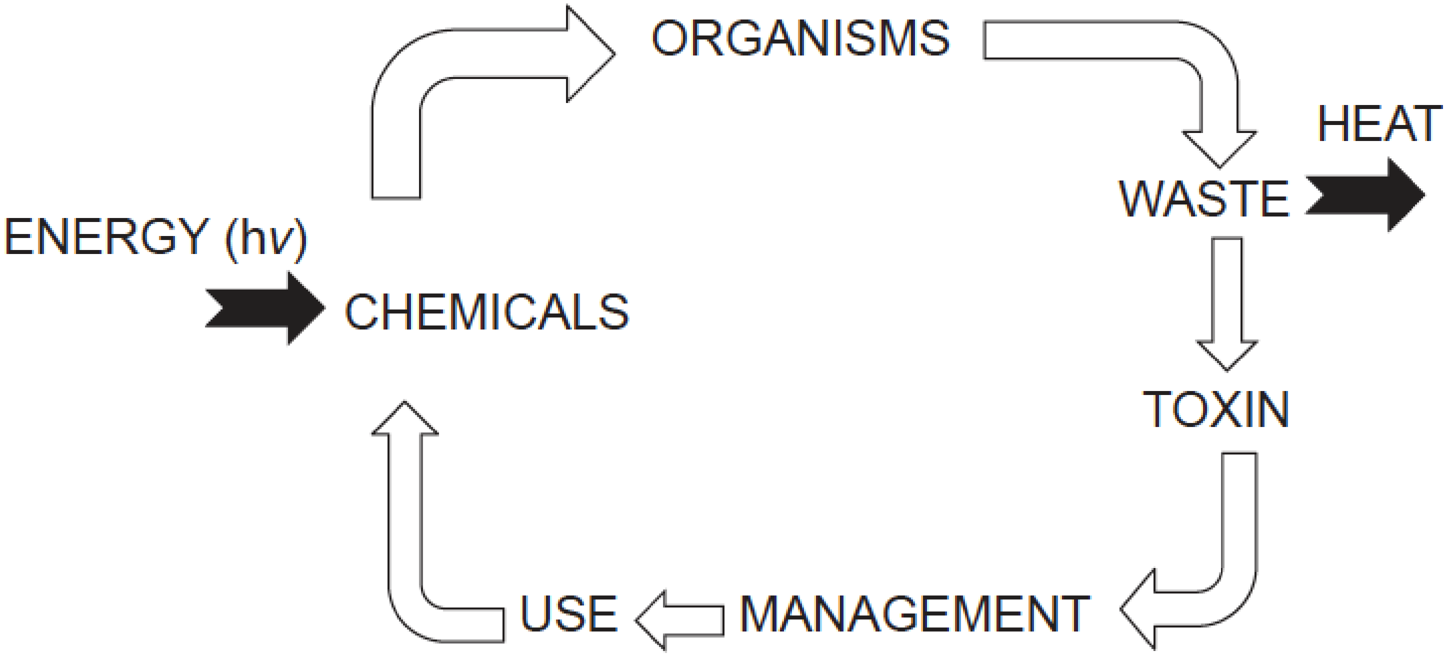
MAD: Move Adapt or Die

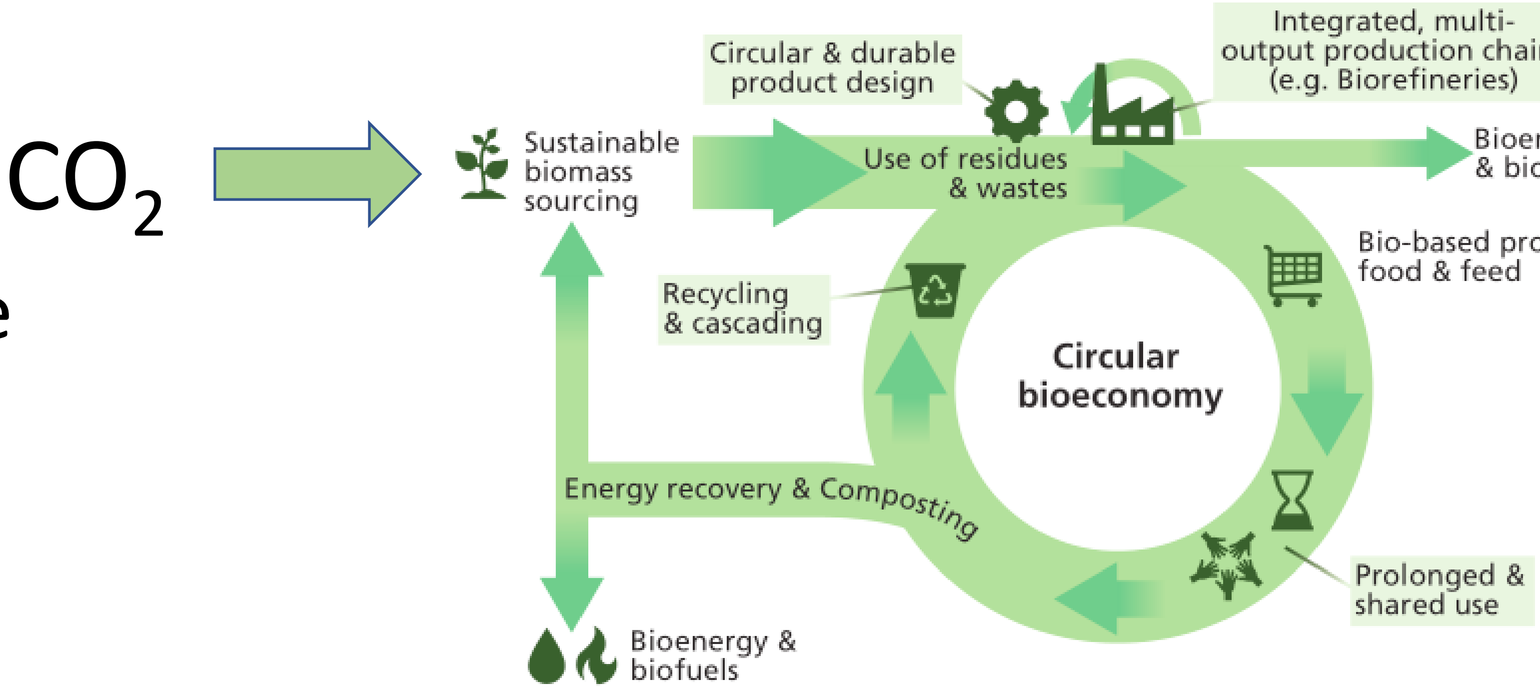


fossil fuel and cement from energy statistics
land use change from data and models
residual land sink
measured atmospheric growth rate
ocean sink from data and models
emissions
partitioning
Annual anthropogenic CO_2 emissions and partitioning ($PgC\ yr^{-1}$)
Year
10
5
0
5
10
1750
1800
1850
1900
1950
2000
CO_2
~10 PgC/yr
dimentary organic C weathering
ring of silicate rocks
Organisms build calcium carbonate shells
C burial
Mg
~0.2 PgC/yr
duction

Bung the CO_2 back where it came from…..

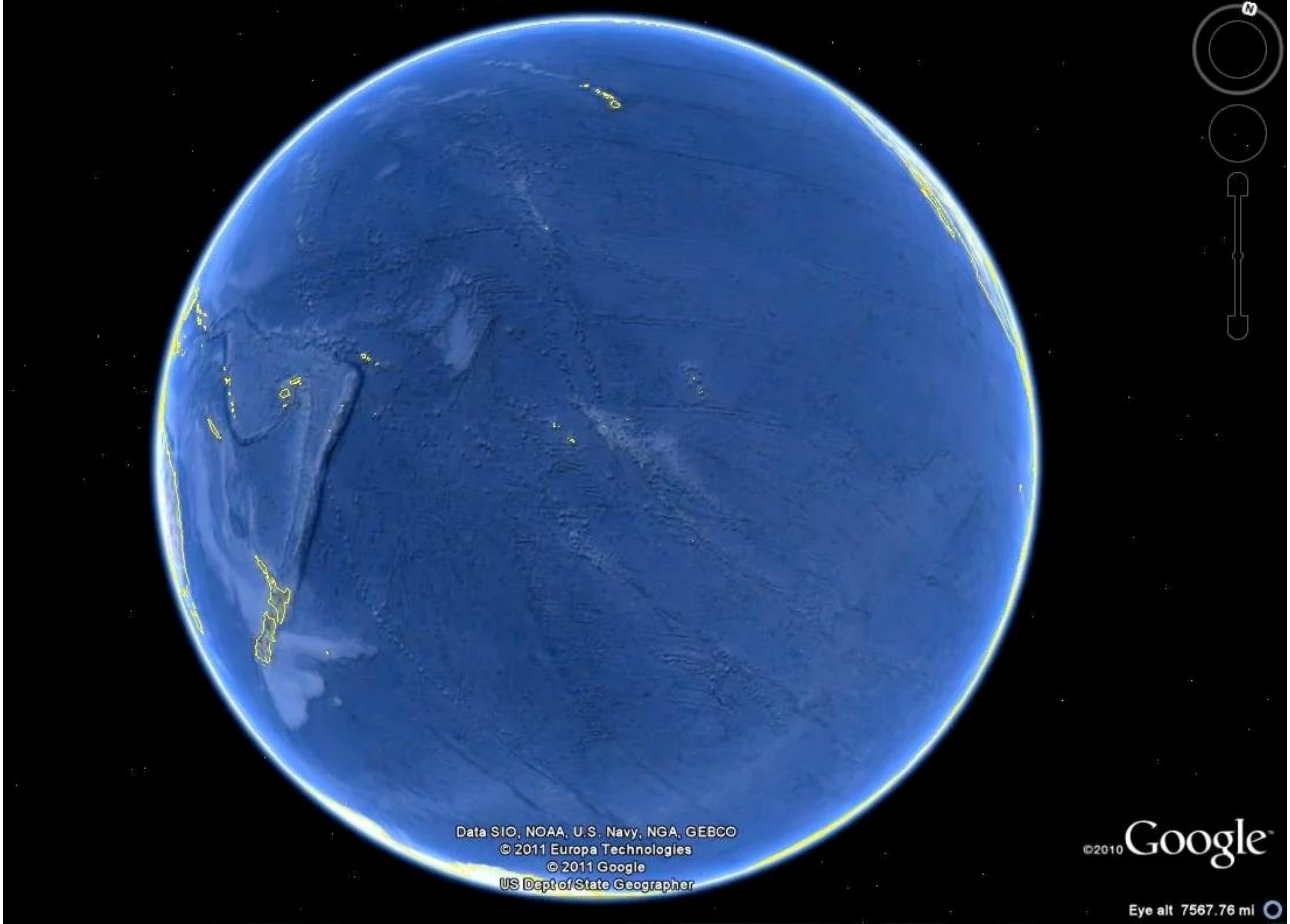




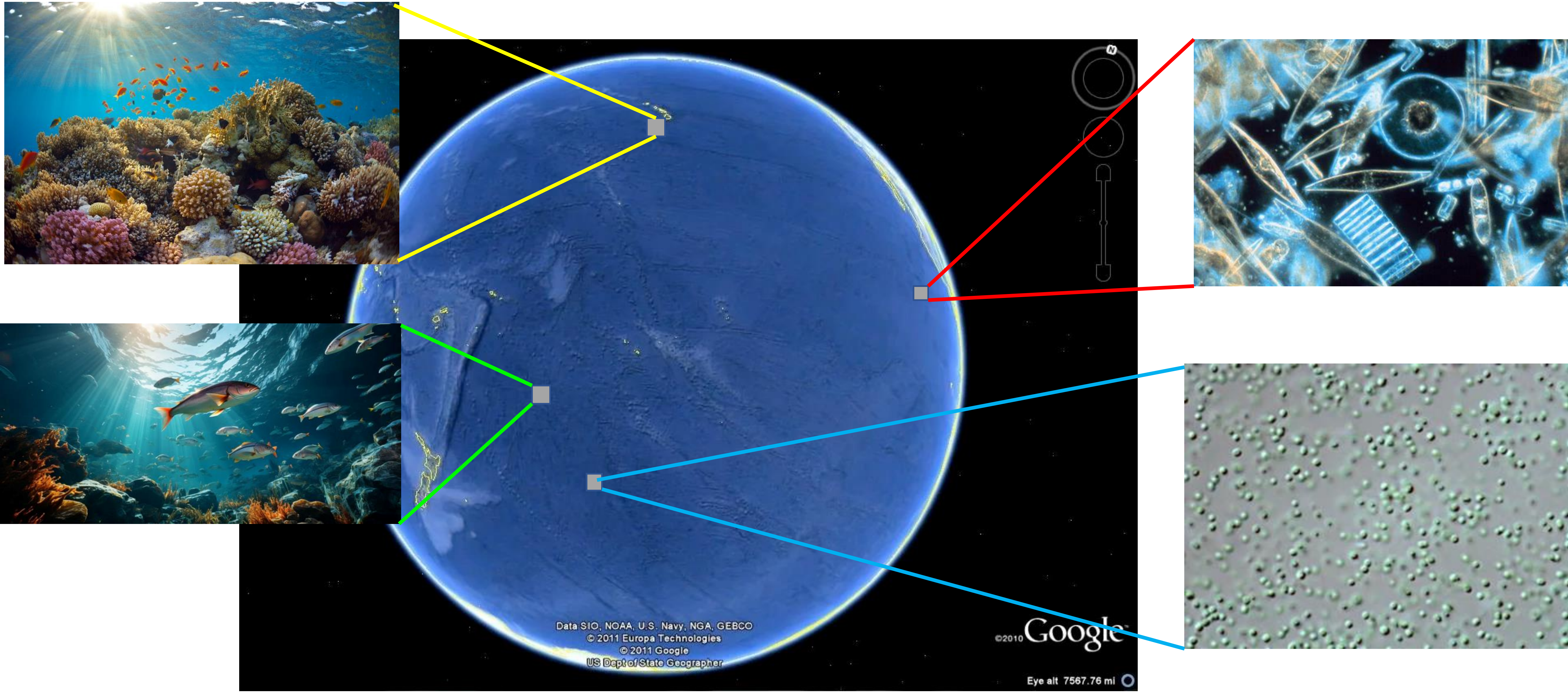


……and circularize the economy….

Stegmann, P., Londo, M., & Junginger, M. (2020). The Circular Bioeconomy: Its elements and role in European bioeconomy clusters. Resources, Conservation & Recycling: X, 100029. https://doi.org/10.1016/j.rcrx.2019.100029


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2011 Europa Technologies
© 2011 Google
US Dept of State Geographer
©2010 Google
Eye alt 7567.76 mi

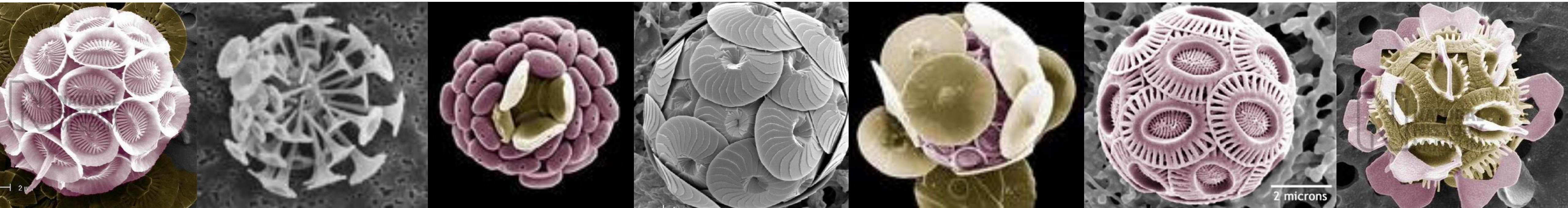
Google Ocean (real time who is living in each pixel)



Other search engines are available….

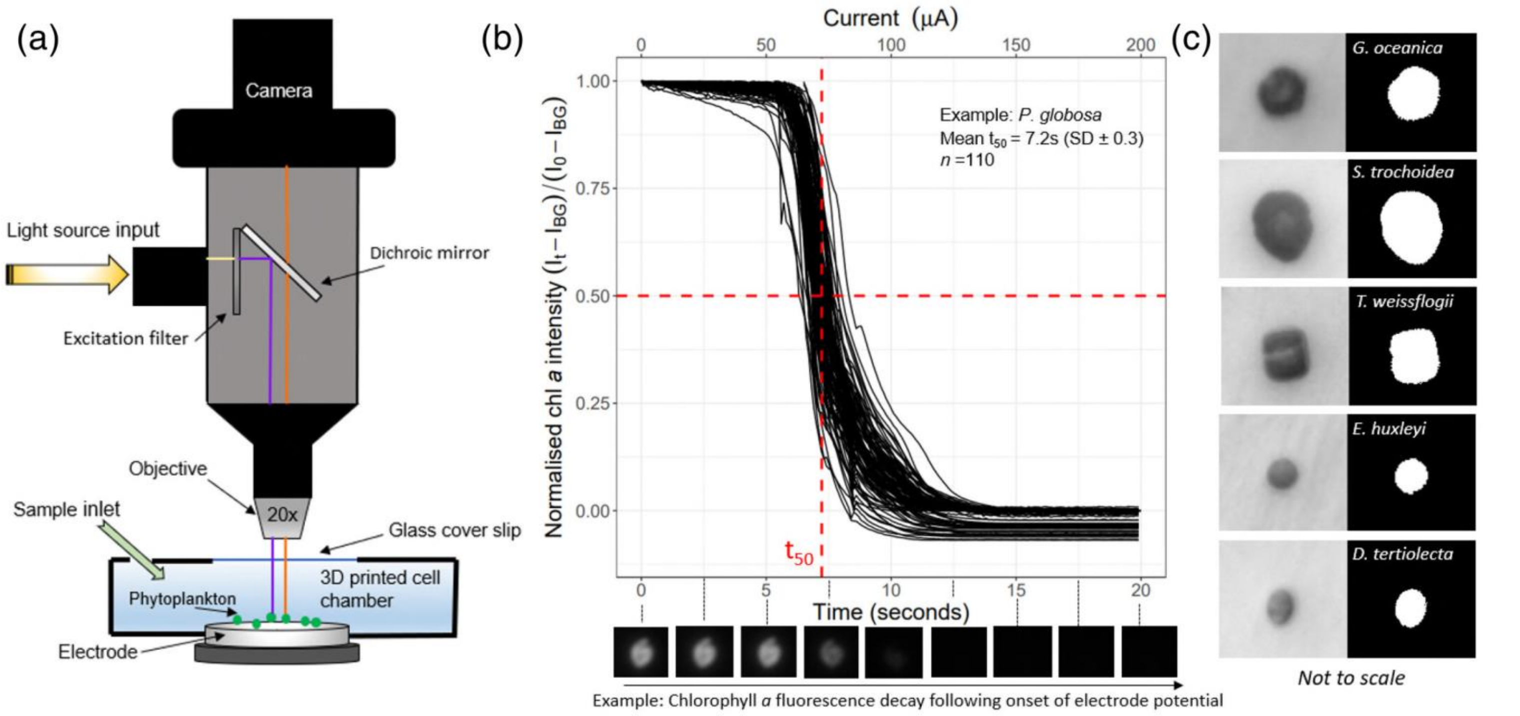
Google Ocean

- To introduce the world to the ocean
- Driver to map the diversity of the ocean comprehensively
- Invaluable data for plankton as monitors of climate and tipping points- the sentinels of the ocean
- Invaluable data for fisheries and macrofaunal conservation
- Baseline and disturbance data for all marine use
- Carbon/Biodiversity credits

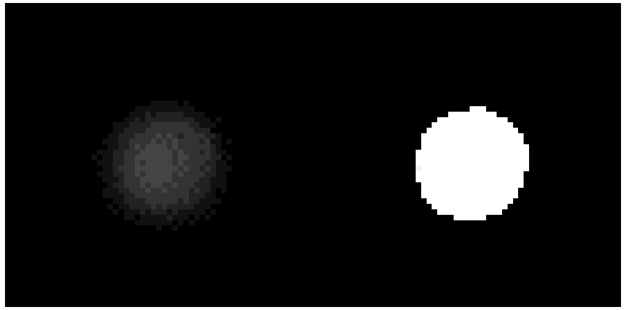


A plankton sensor (low cost/low power)

- We monitor the chlorophyll *a* fluorescence signal of living phytoplankton cells, and measure the decay of this signal in response to electrochemically driven oxidative stress



Taken from Barton *et al*., 2023, *Limnology and Oceanography: Methods*



Applying a potential to seawater sample does two things:

- H^+ ions generated, creating acidic conditions = dissolution of $CaCO_3$
- Oxygen radicals (or reactive oxygen species) are created (e.g. hydroxyl radicals, OH)

= oxidative destruction of Chlorophyll a

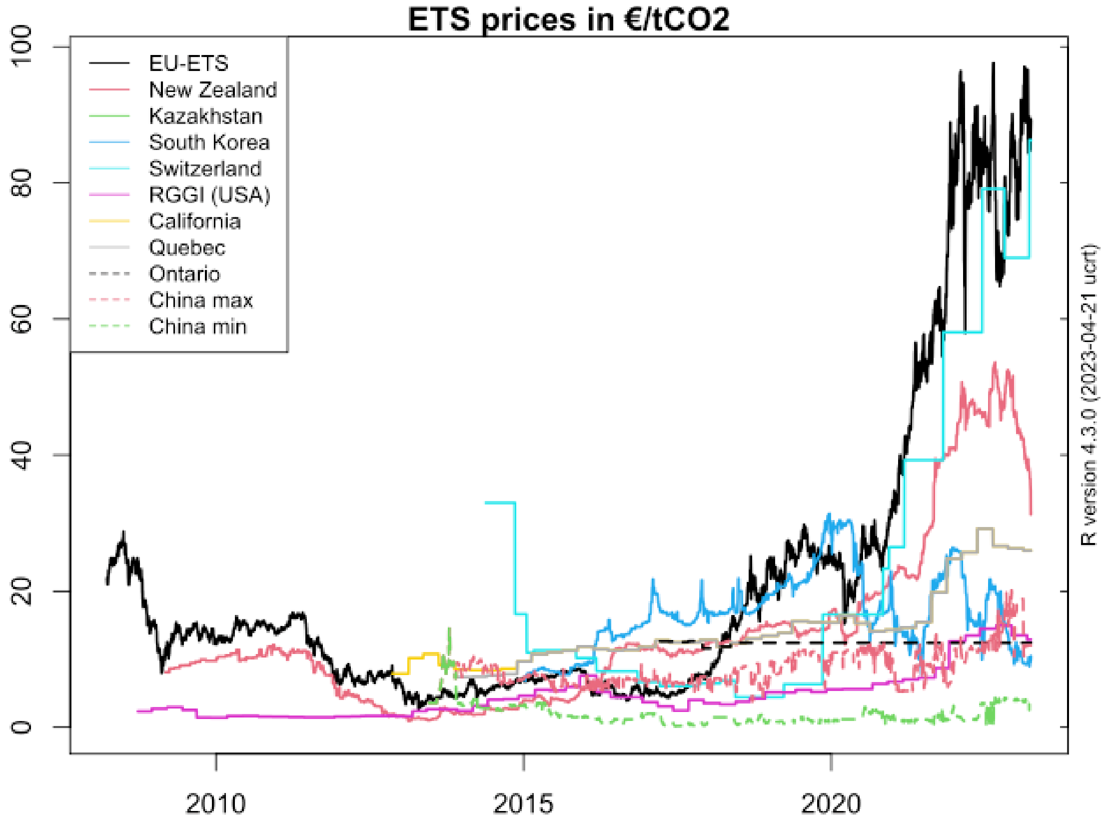
Liquid Gold

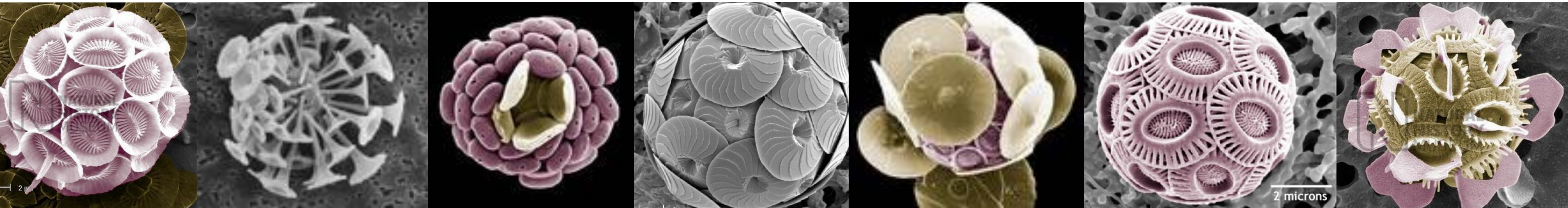
How do we protect the valuable sea….
A huge sponge of our carbon and heat -all done for free
The poor ocean accumulates waste- it sits right in the mix
We must circularise flows; slow inputs- there is no quick fix

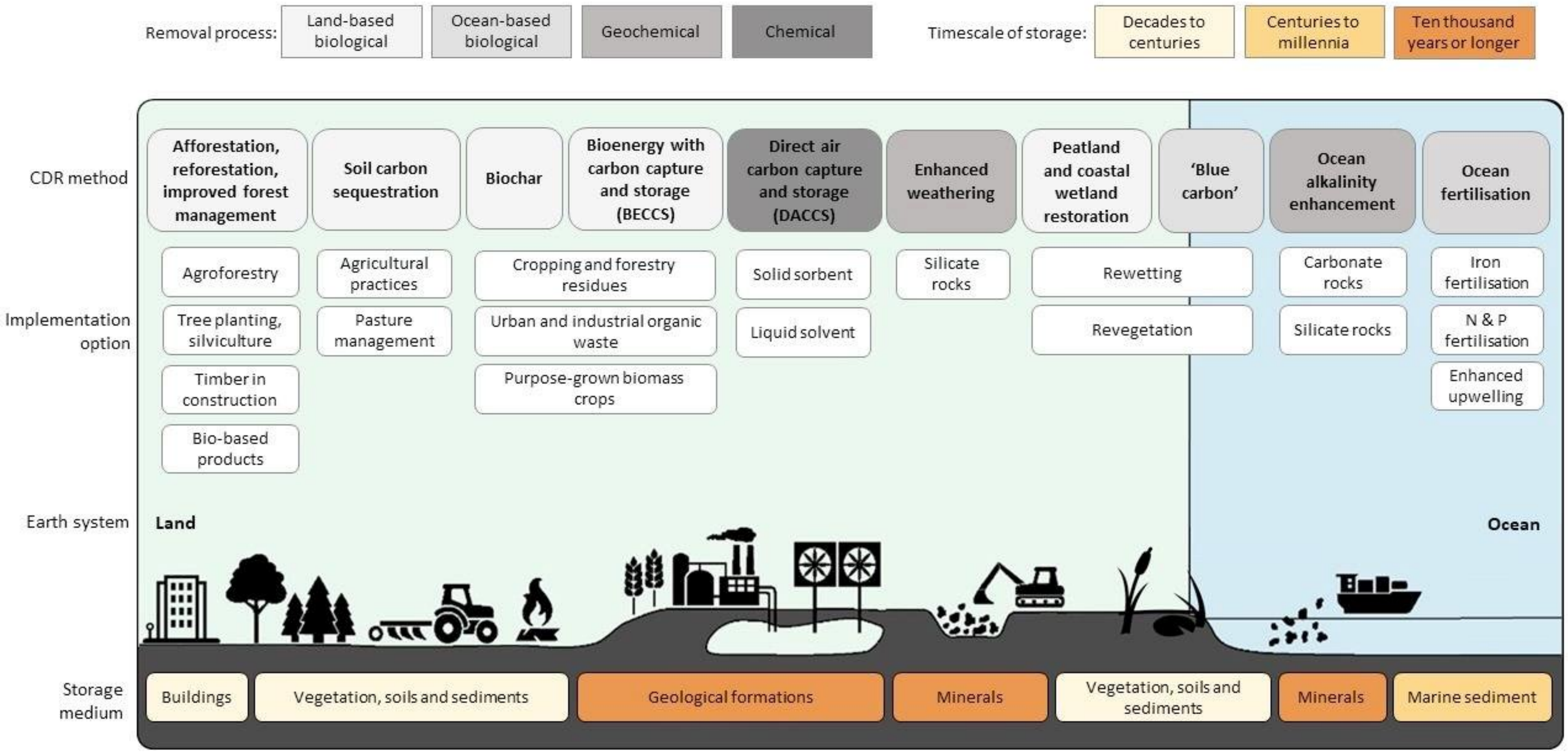
No doubt there is gold in them thar seas,
Marine robots, green transport, renewable energies
New food, new life, awesome blue opportunities
But each of these uses splashes a disruptive bomb
Across the network of life and marine carbon
And these must be real time charted, valued and controlled
Before we can turn the blue one gold

The value of plankton to the UK

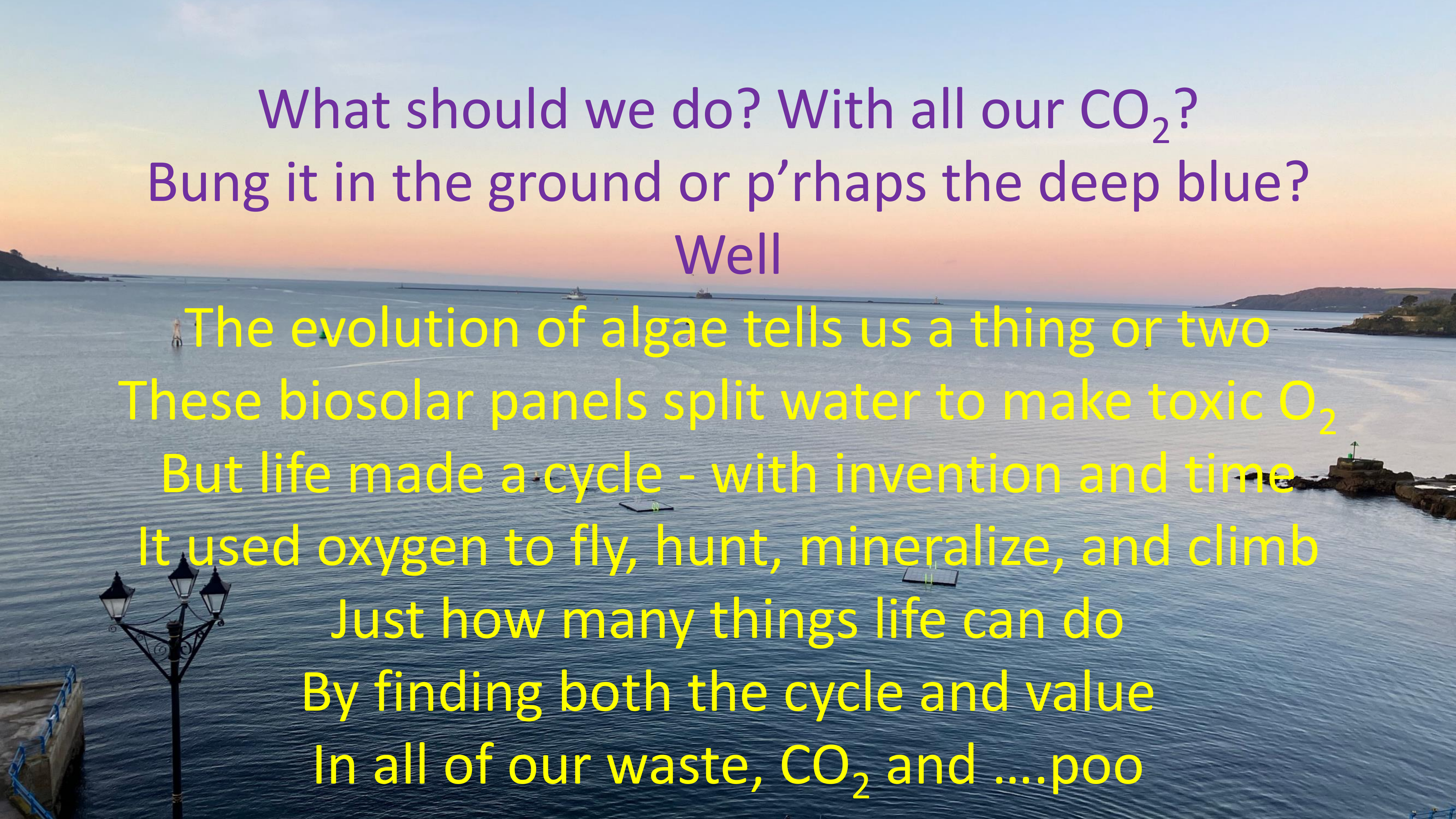
- The UK has stewardship of around 7 665 586 km^2 of neighbouring sea bed including *OTCD*
- UK’s exclusive economic zone (EEZ) the fifth largest in the world
- 2% of the world’s ocean surface (Pro rata component of the Bio Pump admittedly imperfect: 100-240 MtC/yr (£7.4-17.8 billion)
- Biotech resources of the plankton are currently underexplored



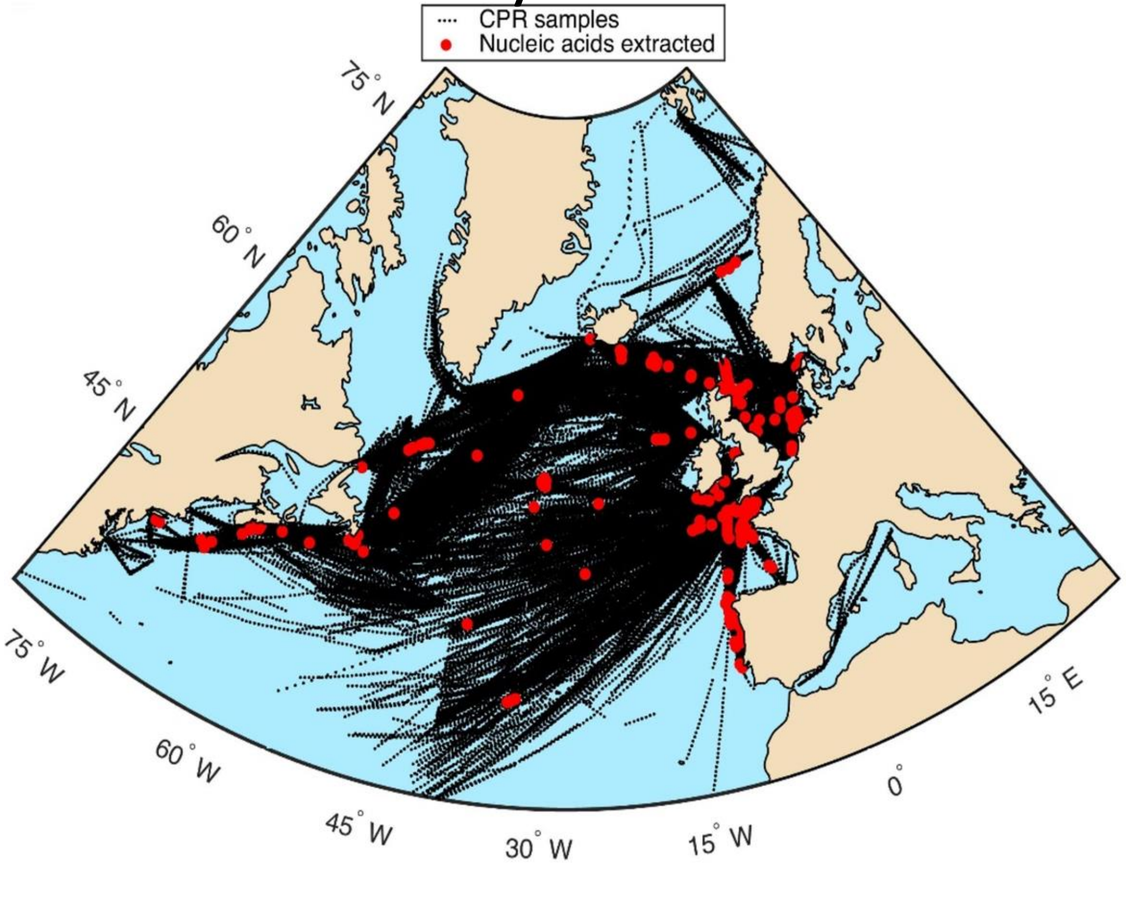




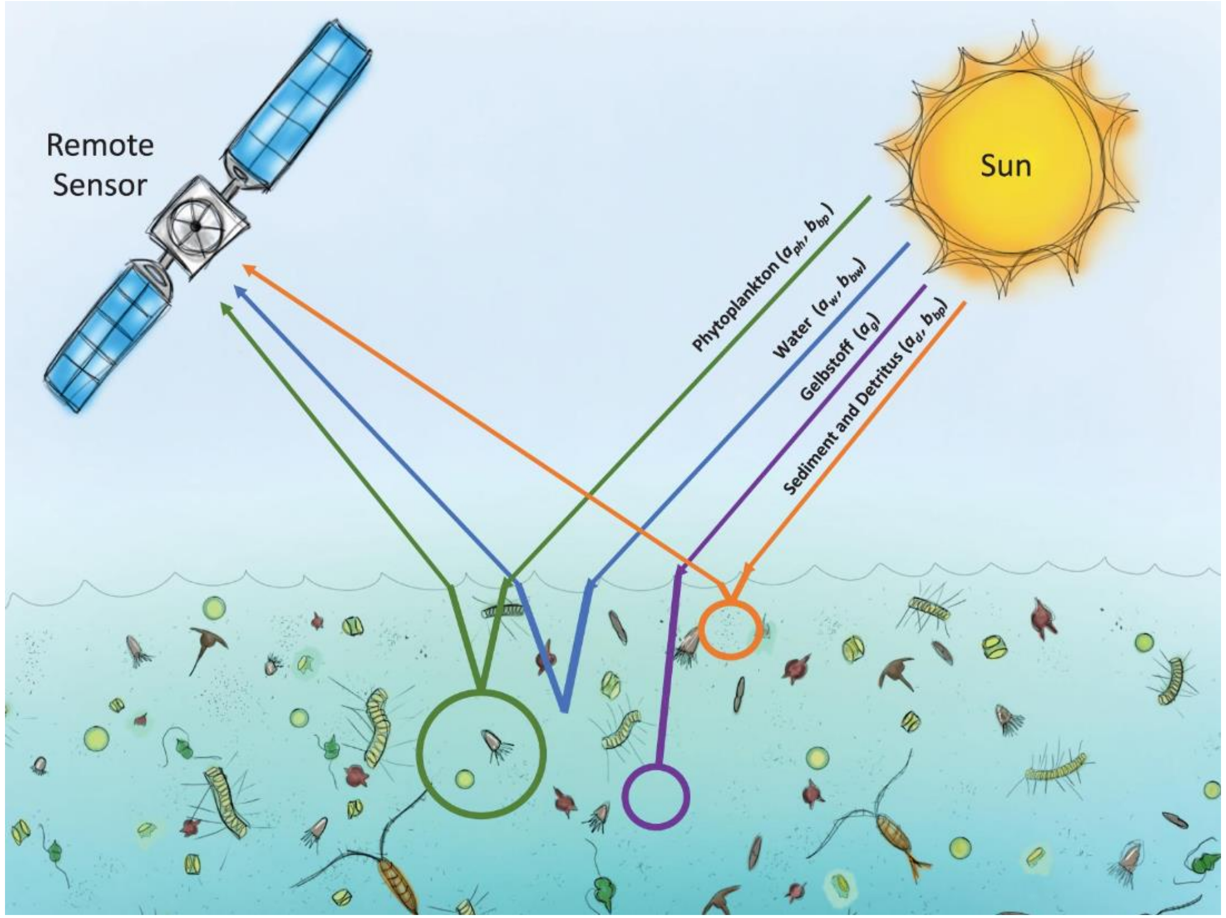
Removal process:
Land-based biological
Ocean-based biological
Geochemical
Chemical
Timescale of storage:
Decades to centuries
Centuries to millennia
Ten thousand years or longer
CDR method
Afforestation, reforestation, improved forest management
Soil carbon sequestration
Biochar
Bioenergy with carbon capture and storage (BECCS)
Direct air carbon capture and storage (DACCS)
Enhanced weathering
Peatland and coastal wetland restoration
'Blue carbon'
Ocean alkalinity enhancement
Ocean fertilisation
Implementation option
Agroforestry
Tree planting, silviculture
Timber in construction
Bio-based products
Agricultural practices
Pasture management
Cropping and forestry residues
Urban and industrial organic waste
Purpose-grown biomass crops
Solid sorbent
Liquid solvent
Silicate rocks
Rewetting
Revegetation
Carbonate rocks
Silicate rocks
Iron fertilisation
N & P fertilisation
Enhanced upwelling
Earth system
Land
Ocean
Storage medium
Buildings
Vegetation, soils and sediments
Geological formations
Minerals
Vegetation, soils and sediments
Minerals
Marine sediment


What should we do? With all our CO_2?
Bung it in the ground or p'rhaps the deep blue?
Well
The evolution of algae tells us a thing or two
These biosolar panels split water to make toxic O_2
But life made a cycle - with invention and time
It used oxygen to fly, hunt, mineralize, and climb
Just how many things life can do
By finding both the cycle and value
In all of our waste, CO_2 and ....poo

The CPR Survey - since 1931

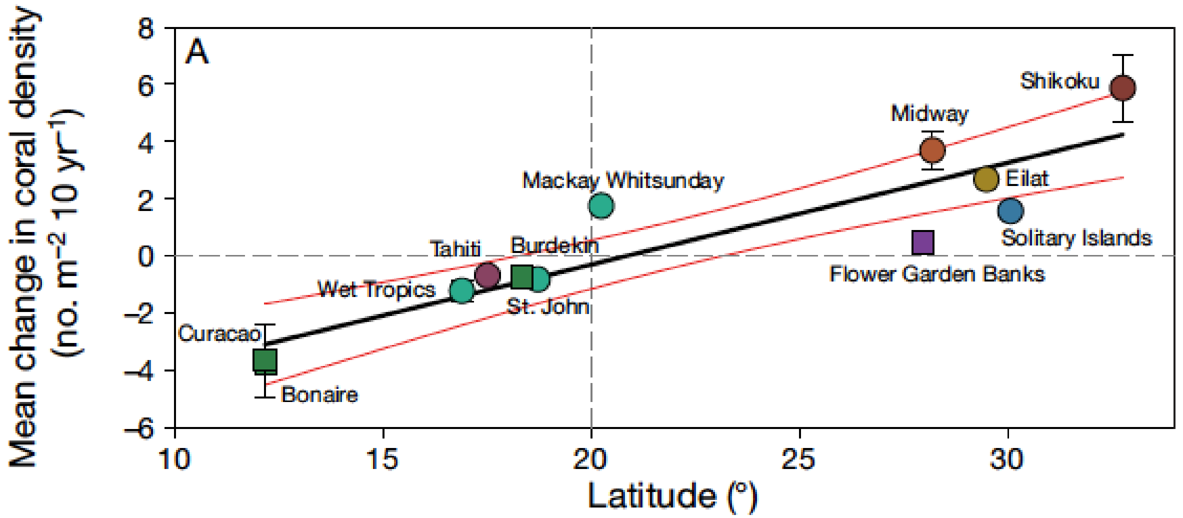


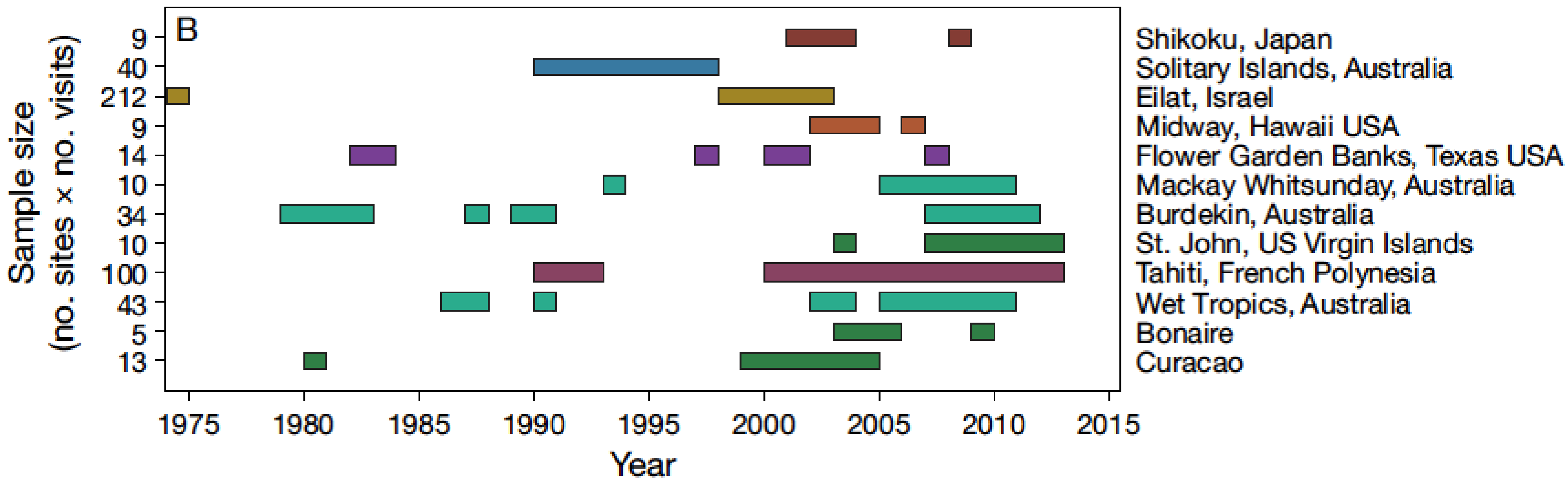
Satellites Since 1978



- Need integration of different methods (and new technologies) to capture biodiversity of the communities, to quantify abundance of different phytoplankton species/functional groups and their impact on flux of carbon

Coral bleaching....but some hope...





FEATURE ARTICLE

Global biogeography of coral recruitment: tropical decline and subtropical increase

N. N. Price[1,*], S. Muko[2], L. Legendre[3], R. Steneck[4], M. J. H. van Oppen[5,6], R. Albright[5,7,18], P. Ang Jr.[8], R. C. Carpenter[9], A. P. Y. Chui[8], T.-Y. Fan[10], R. D. Gates[11], S. Harii[12], H. Kitano[13], H. Kurihara[14], S. Mitarai[15], J. L. Padilla-Gamiño[16], K. Sakai[12], G. Suzuki[17], P. J. Edmunds[9]

Tropicalisation of the subtropics...

Carbon versus biodiversity?

ARTICLE

https://doi.org/10.1038/s43247-022-00625-0 OPEN

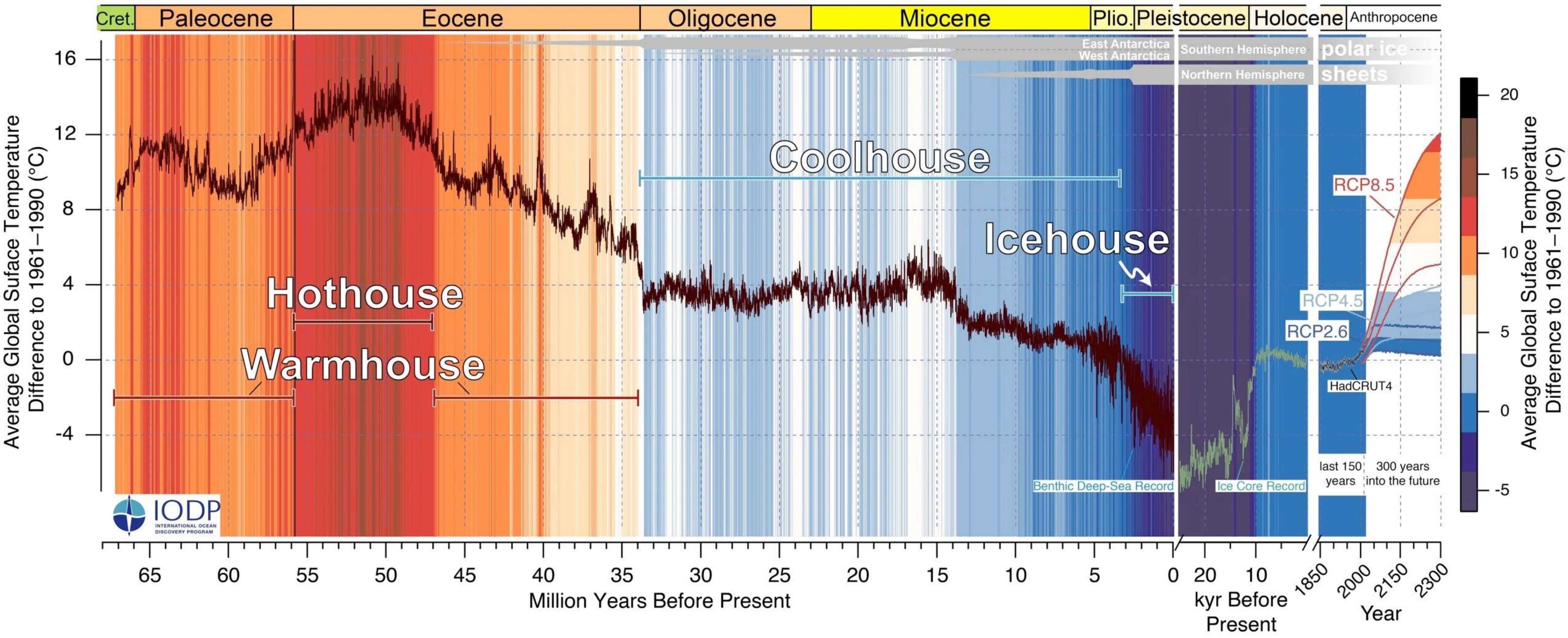
Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea

Ute Daewel[1✉], Naveed Akhtar[1], Nils Christiansen[1] & Corinna Schrum[1,2]

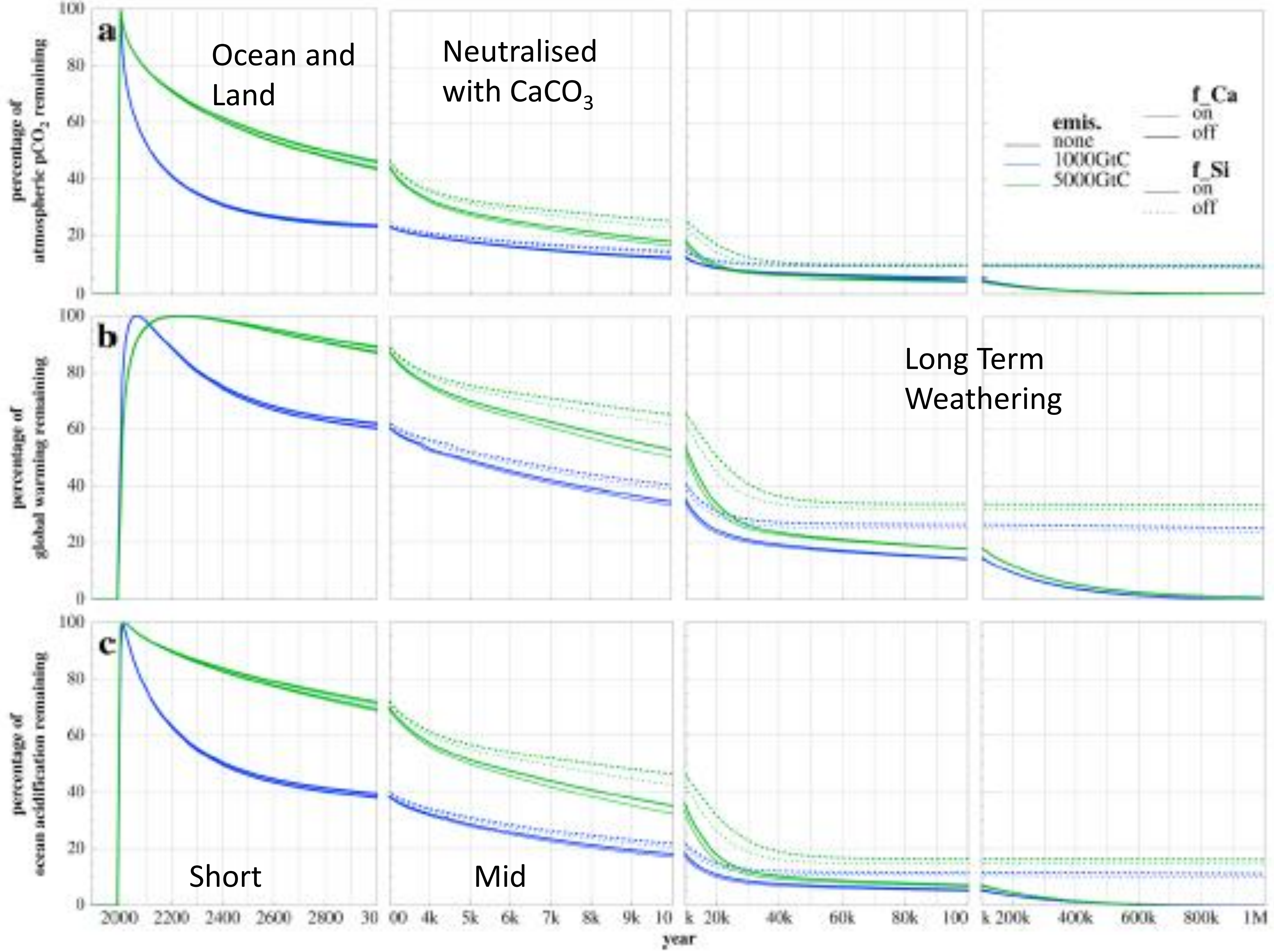
Clean Energy +

Carbon Pump +

Benthic Biodiversity -

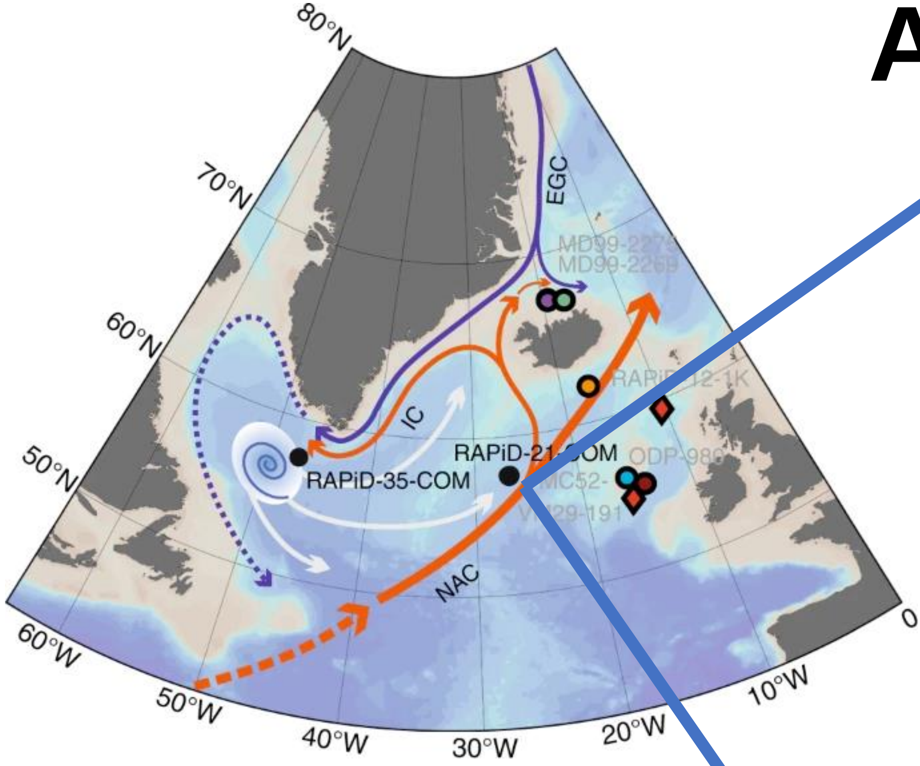


Cret.
Paleocene
Eocene
Oligocene
Miocene
Plio.
Pleistocene
Holocene
Anthropocene
East Antarctica
West Antarctica
Southern Hemisphere
Northern Hemisphere
polar ice sheets
Coolhouse
Icehouse
Hothouse
Warmhouse
RCP8.5
RCP4.5
RCP2.6
HadCRUT4
Benthic Deep-Sea Record
Ice Core Record
last 150 years
300 years into the future
Average Global Suface Temperature Difference to 1961–1990 (°C)
Million Years Before Present
kyr Before Present
Year
IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

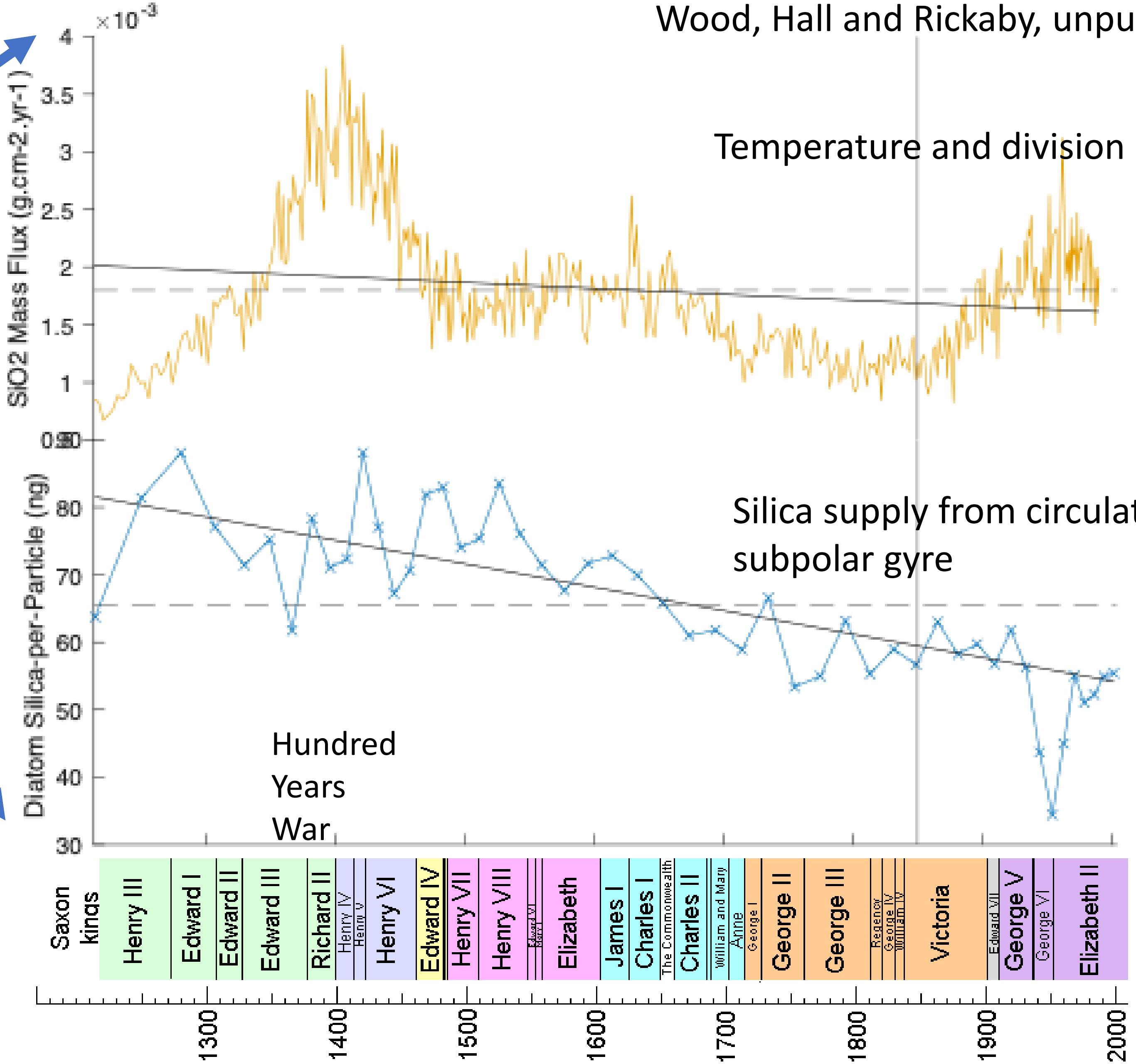


Colbourn et al., 2015

A Variable Biological Pump



Wood, Hall and Rickaby, unpublished



Move, Adapt or Die (MAD)

i) PETM extinctions benthic forams and polward range shifts in dinos, mammals, reptiles, plants and high community turnover
ii) >4oC cooler EO boundary, extinction many European terrestrial mammals and globally marine invertebrates
iii)Late Mio cooling, thermophilous plants shifted southwards and finally went extinct

iv) More than half of cool temperature Euroepan tree genera did not survive glacial cycles starting end Pliocene
v) An adaptive mutation of heamoglobin enabled mammoths to tolerate v low Ts at high latitude
vi) More than 70& megafauna in the Americas and Australia and 40% in Eurasia underwent extinction (5-10 ka) but climate or human?
vii) Plants in N. America migrated northwards between 450 and 2200 km in <10kyrs under a warming of 5oC

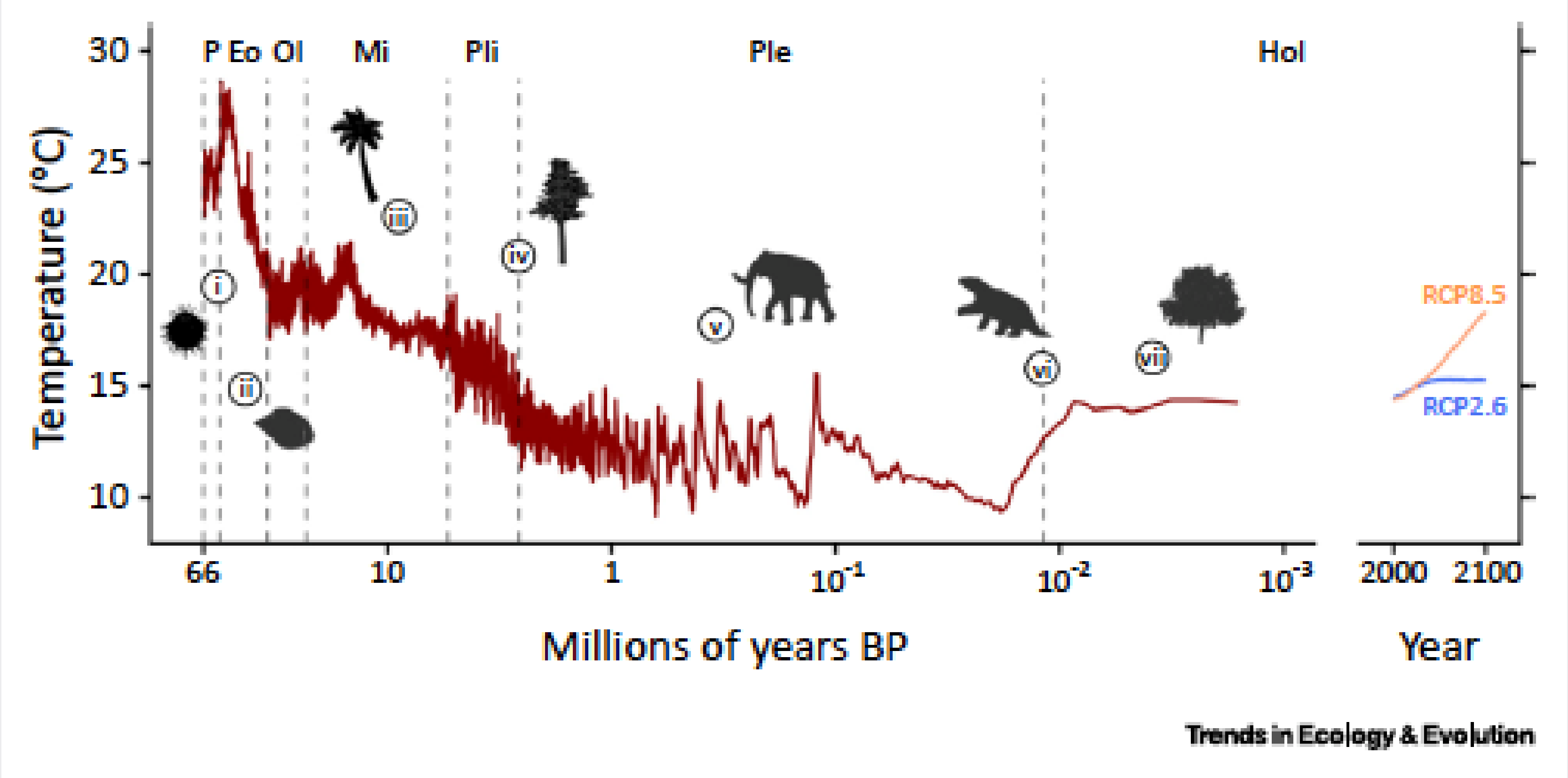
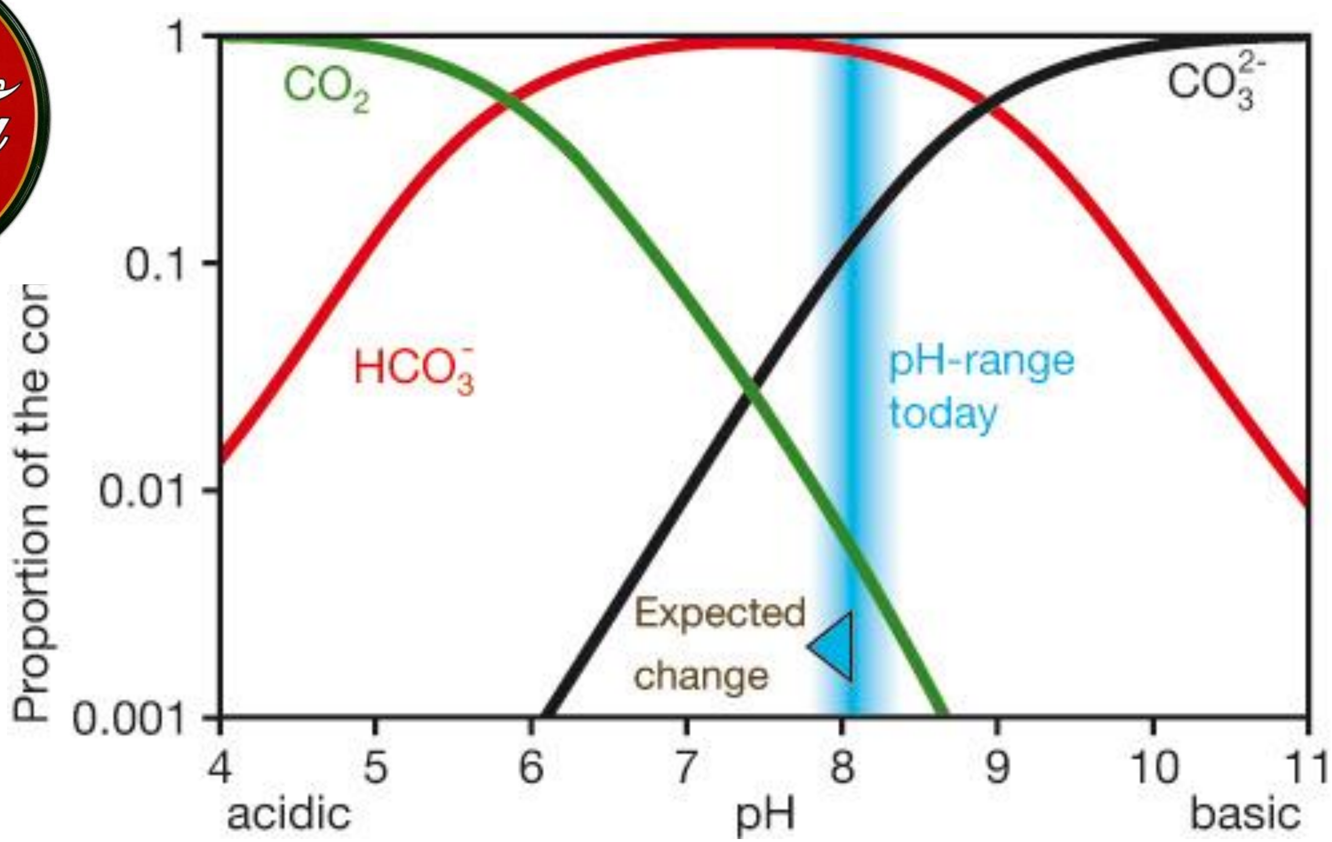


Figure I. Future Climate Forcing will Surpass those of the Previous Several Million Years [2]. Abbreviations: Eo, Eocene, Hol, Holocene; Mi, Miocene, Ol, Oligocene, P, Palaeocene, Pli, Pliocene, Ple, Pleistocene.

CO_2 (acid) + CO_3^{2-} (alkali) + H_2O = $2HCO_3^-$



CO_2 used for photosynthesis

CO_3^{2-} used for calcification ($CaCO_3$)

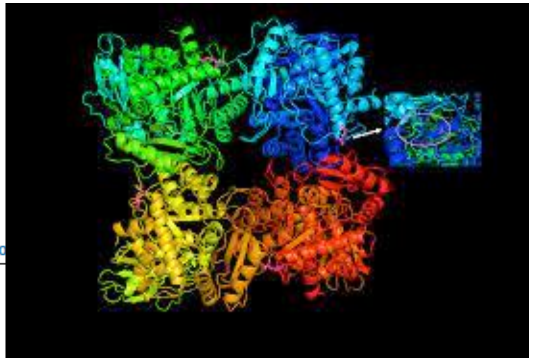
CO_2 Fertilisation

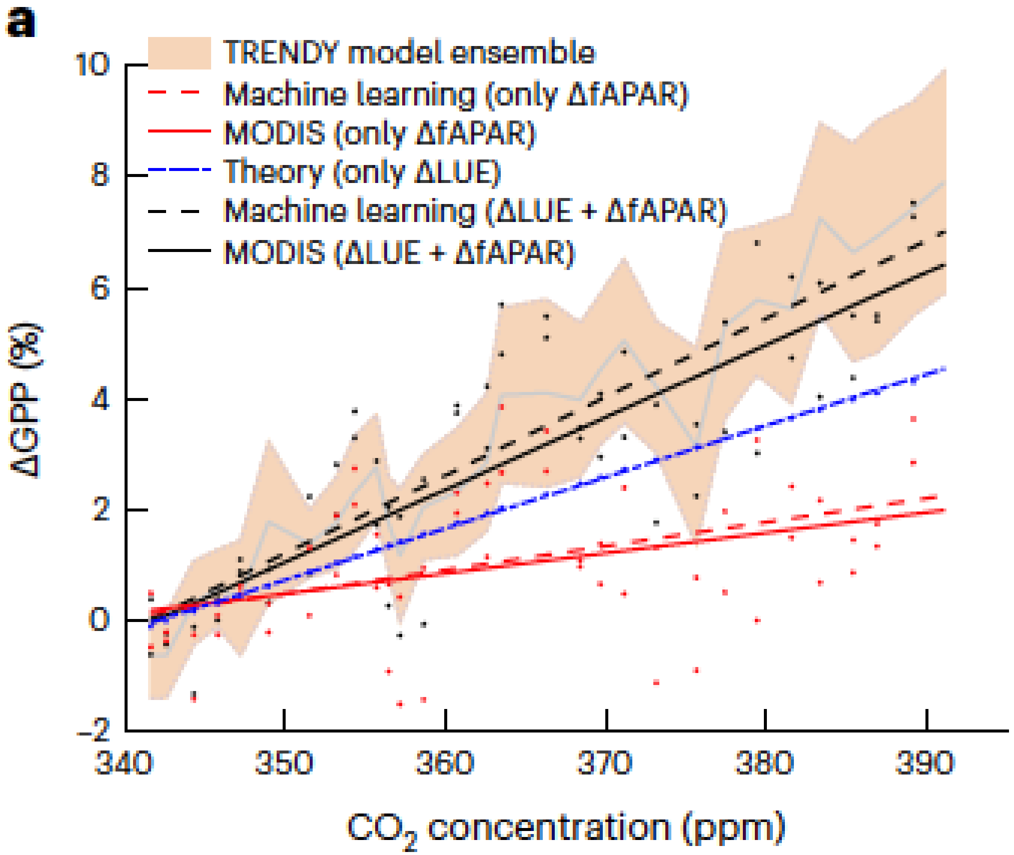
nature climate change

Article

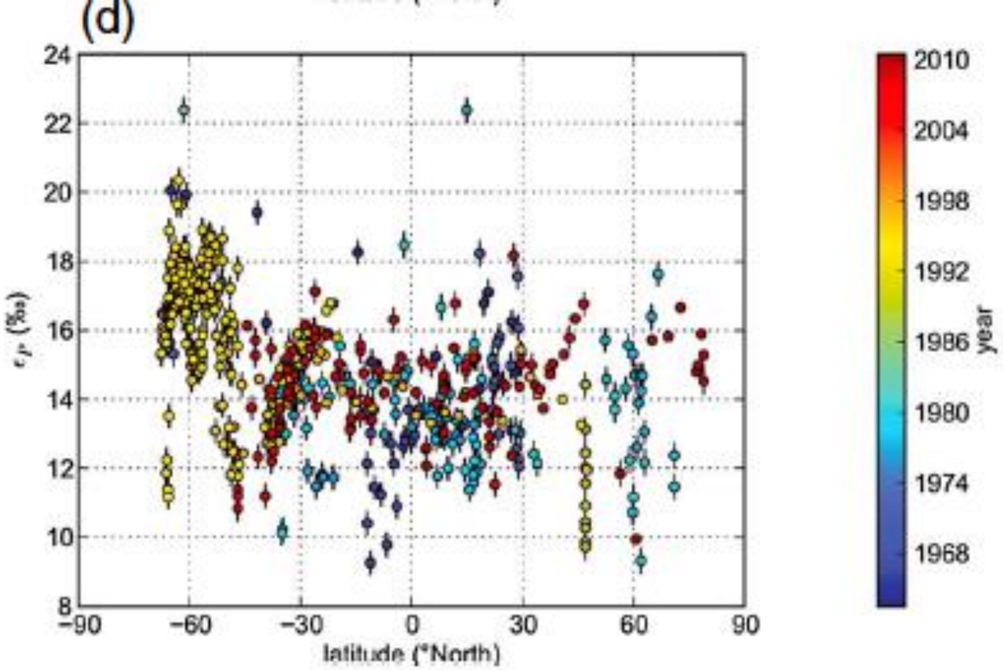
https://doi.org/10.1038/s41558-023-0

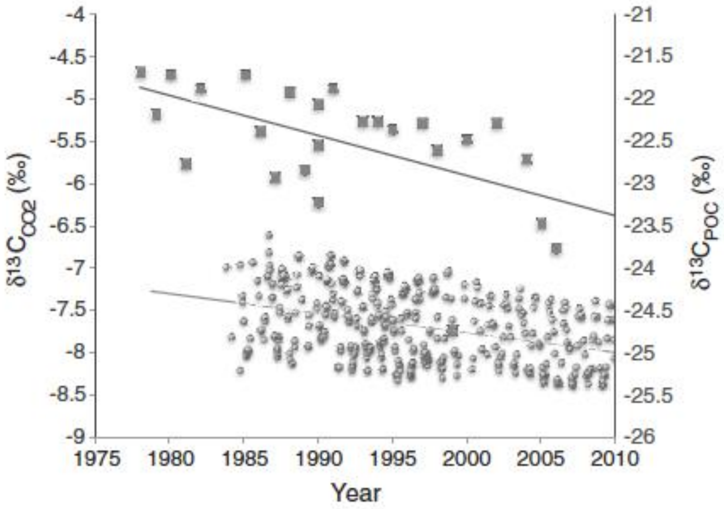
A constraint on historic growth in global photosynthesis due to rising CO_2





Land





Marine

Evidence for changes in carbon isotopic fractionation by phytoplankton between 1960 and 2010

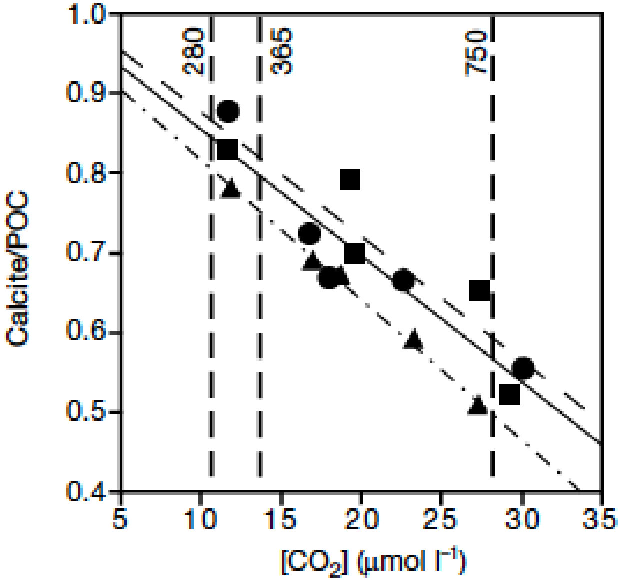
J. N. Young,[1,2] J. Bruggeman,[1] R. E. M. Rickaby,[1] J. Erez,[3] and M. Conte[4]

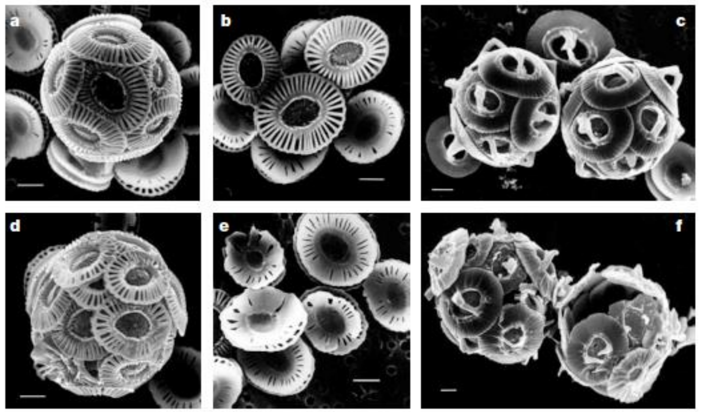
Ocean Acidification

Or higher…………..?

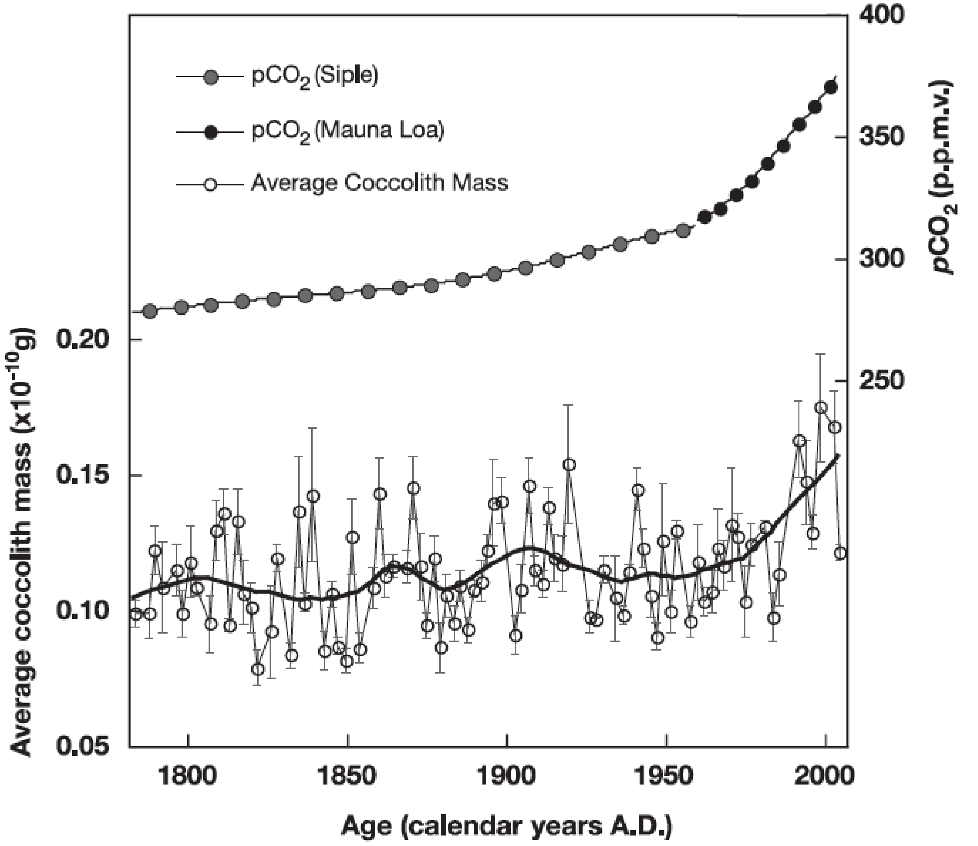
Reduced calcification of marine plankton in response to increased atmospheric CO_2

Ulf Riebesell *, Ingrid Zondervan*, Björn Rost*, Philippe D. Tortell†, Richard E. Zeebe*‡ & François M. M. Morel†





Lower calcification………..?



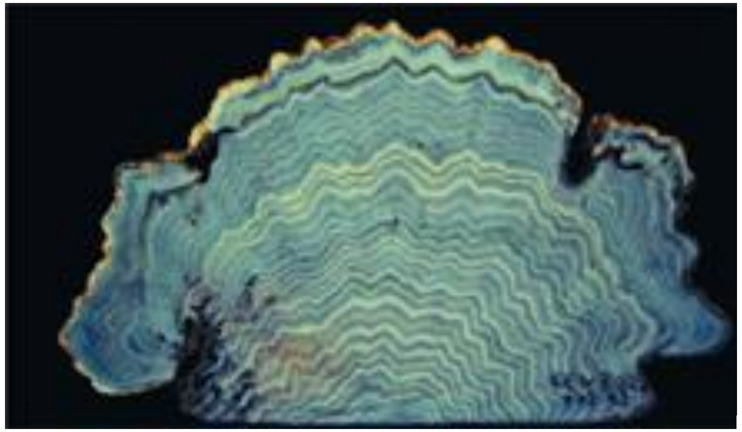
Phytoplankton Calcification in a High-CO_2 World

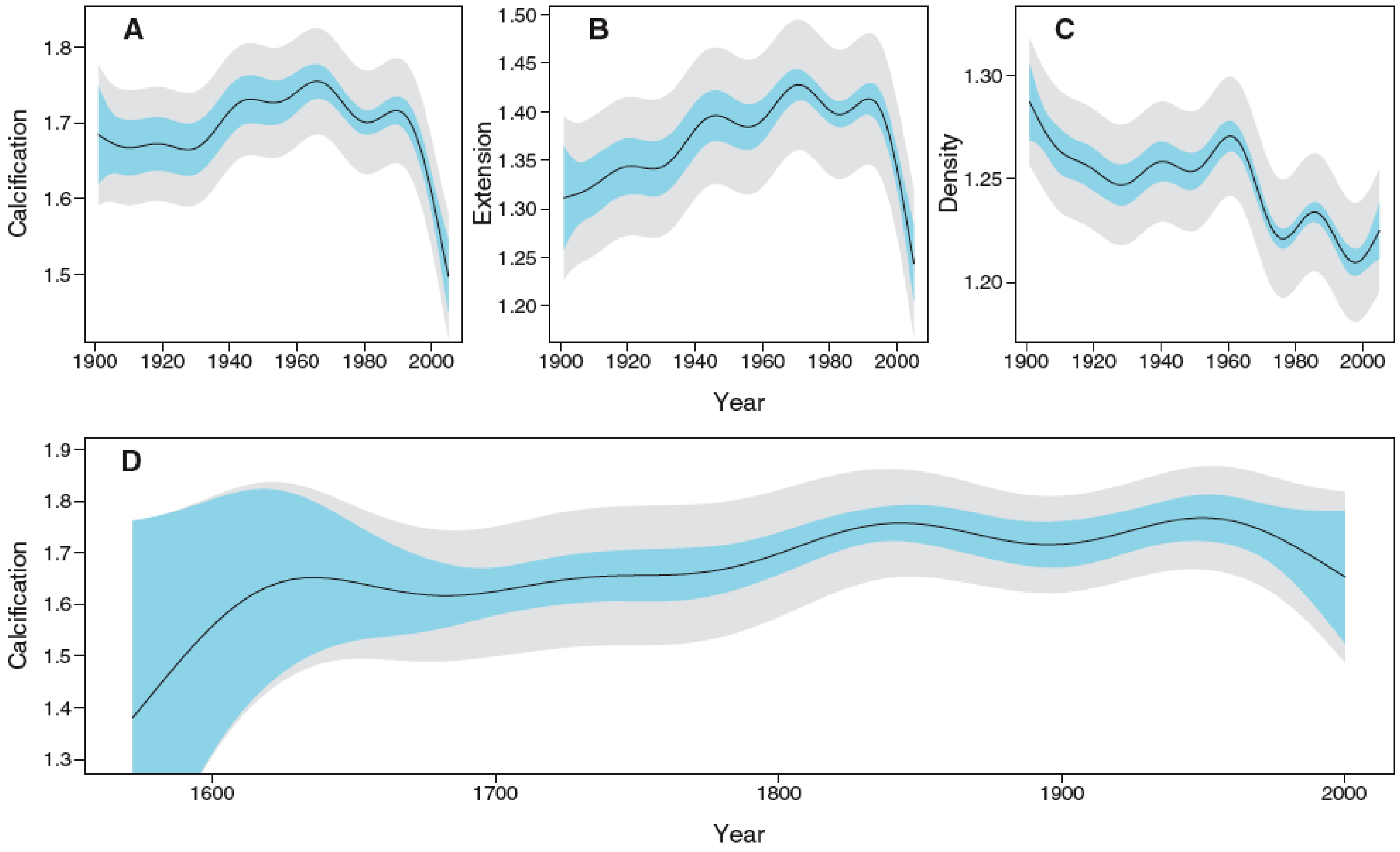
M. Debora Iglesias-Rodriguez,[1*] Paul R. Halloran,[2*] Rosalind E. M. Rickaby,[2] Ian R. Hall,[3] Elena Colmenero-Hidalgo,[3†] John R. Gittins,[1] Darryl R. H. Green,[1] Toby Tyrrell,[1] Samantha J. Gibbs,[1] Peter von Dassow,[4] Eric Rehm,[5] E. Virginia Armbrust,[5] Karin P. Boessenkool[3]

De'Ath et al., 2009

Declining Coral Calcification on the Great Barrier Reef

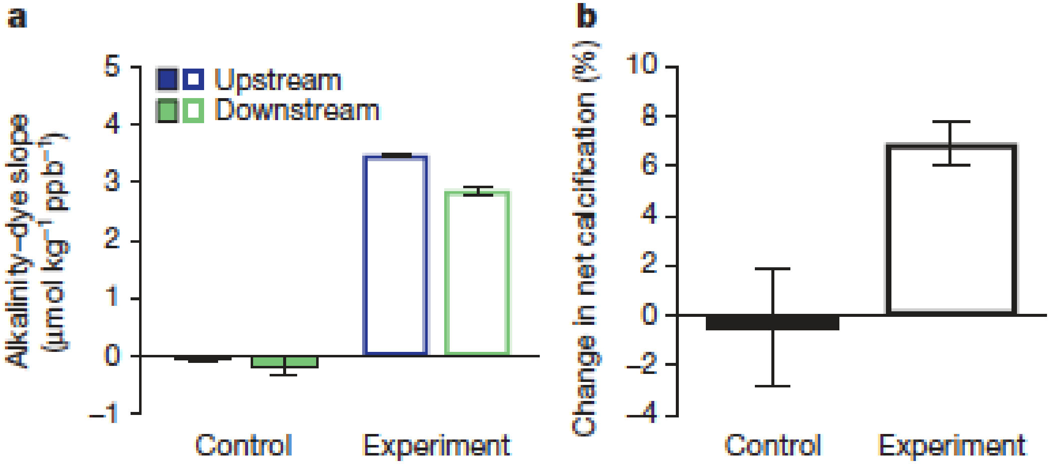
Glenn De'ath,* Janice M. Lough, Katharina E. Fabricius





Reversal of ocean acidification enhances net coral reef calcification

Rebecca Albright[1], Lilian Caldeira[1], Jessica Hosfelt[2], Lester Kwiatkowski[1], Jana K. Maclaren[1,3], Benjamin M. Mason[4], Yana Nebuchina[1], Aaron Ninokawa[2], Julia Pongratz[1,5], Katharine L. Ricke[1,6], Tanya Rivlin[7,8], Kenneth Schneider[1,9], Marine Sesboüé[1], Kathryn Shamberger[10,11], Jacob Silverman[12], Kennedy Wolfe[13], Kai Zhu[1,14,15] & Ken Caldeira[1]

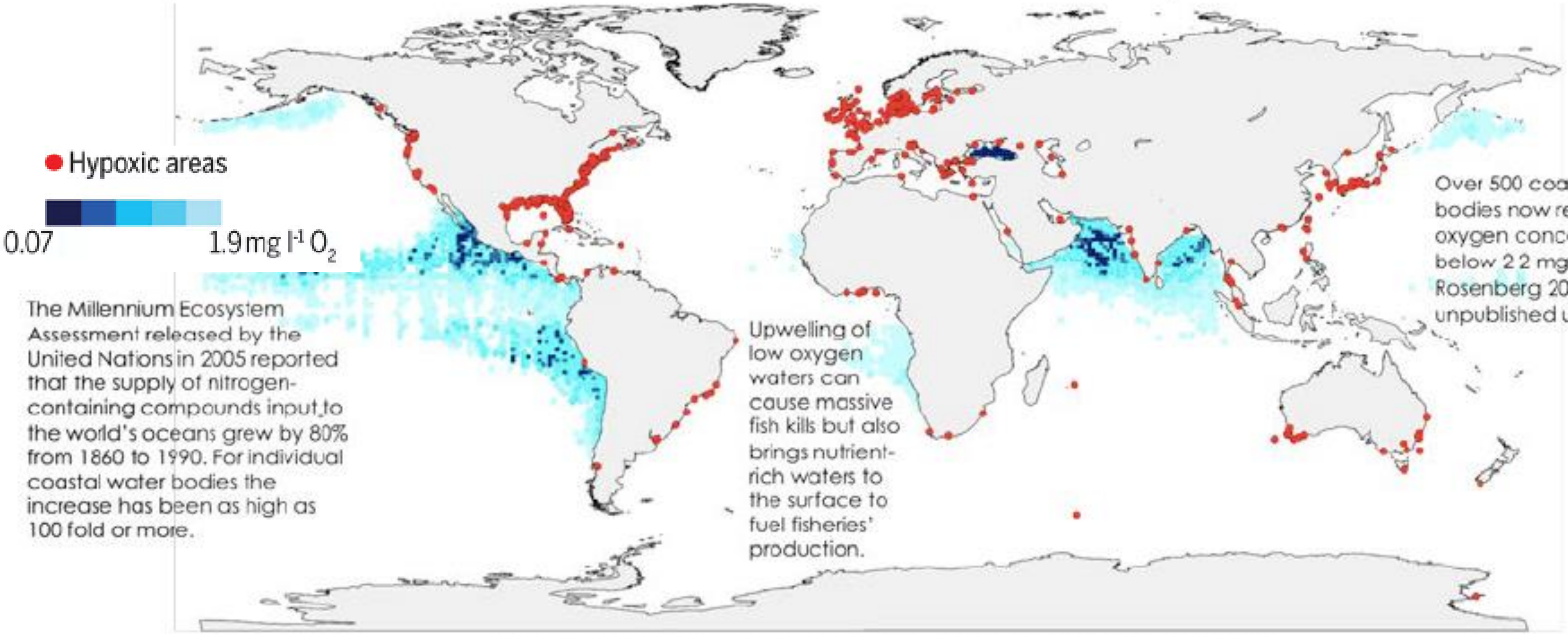


Certainly impacts on coral reef calcification

Ocean Deoxygenation

During the past 50 years, the area of low oxygen water in the open ocean has increased by 4.5 million km^2.[1] The world's oceans are now losing approximately 1 gigaton of oxygen each year (Keeling and Garcia 2002).

The Baltic Sea has the largest coastal water hypoxic zone. In 2011 the area of water with dissolved oxygen concentrations <2 mg L^{-1} was nearly 80,000 km^2. (Carstensen et al. 2014).



The Millennium Ecosystem Assessment released by the United Nations in 2005 reported that the supply of nitrogen-containing compounds input to the world's oceans grew by 80% from 1860 to 1990. For individual coastal water bodies the increase has been as high as 100 fold or more.

Upwelling of low oxygen waters can cause massive fish kills but also brings nutrient-rich waters to the surface to fuel fisheries' production.

Over 500 coastal water bodies now report dissolved oxygen concentrations below 2.2 mg L^{-1} (Diaz and Rosenberg 2008 and Diaz unpublished update).

Deoxygenation alters the goods and services delivered by marine ecosystems to humans. Services reduced can include food production through and aquaculture, climate regulation, nutrient cycling and resilience

[1]The estimate is for 200 m – a slightly shallower depth than shown on this map.

Declining oxygen in the global ocea and coastal waters

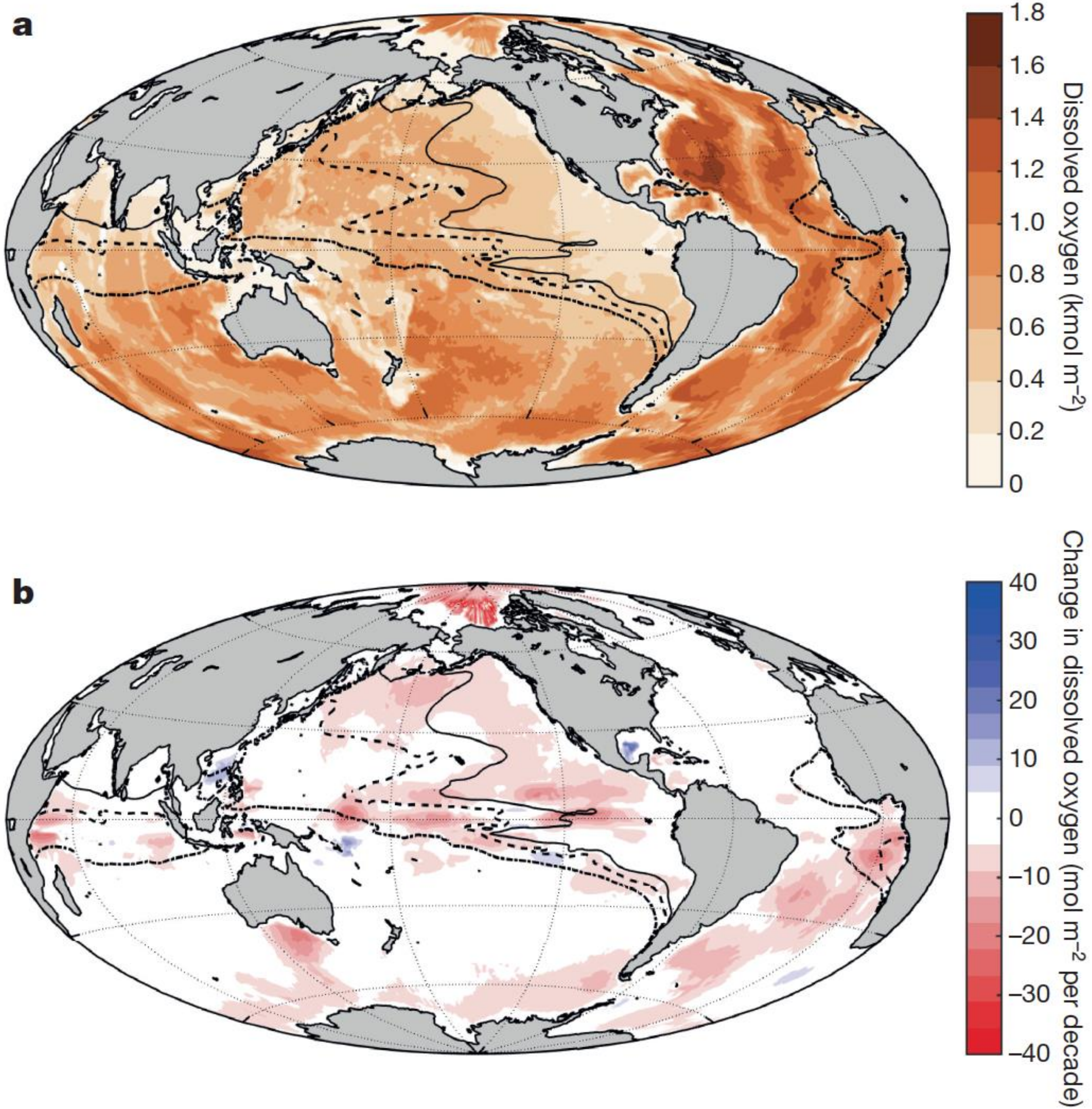
Denise Breitburg,* Lisa A. Levin, Andreas Oschlies, Marilaure Grégoire,

Observable trends

Table 1 | Oxygen content and change per basin

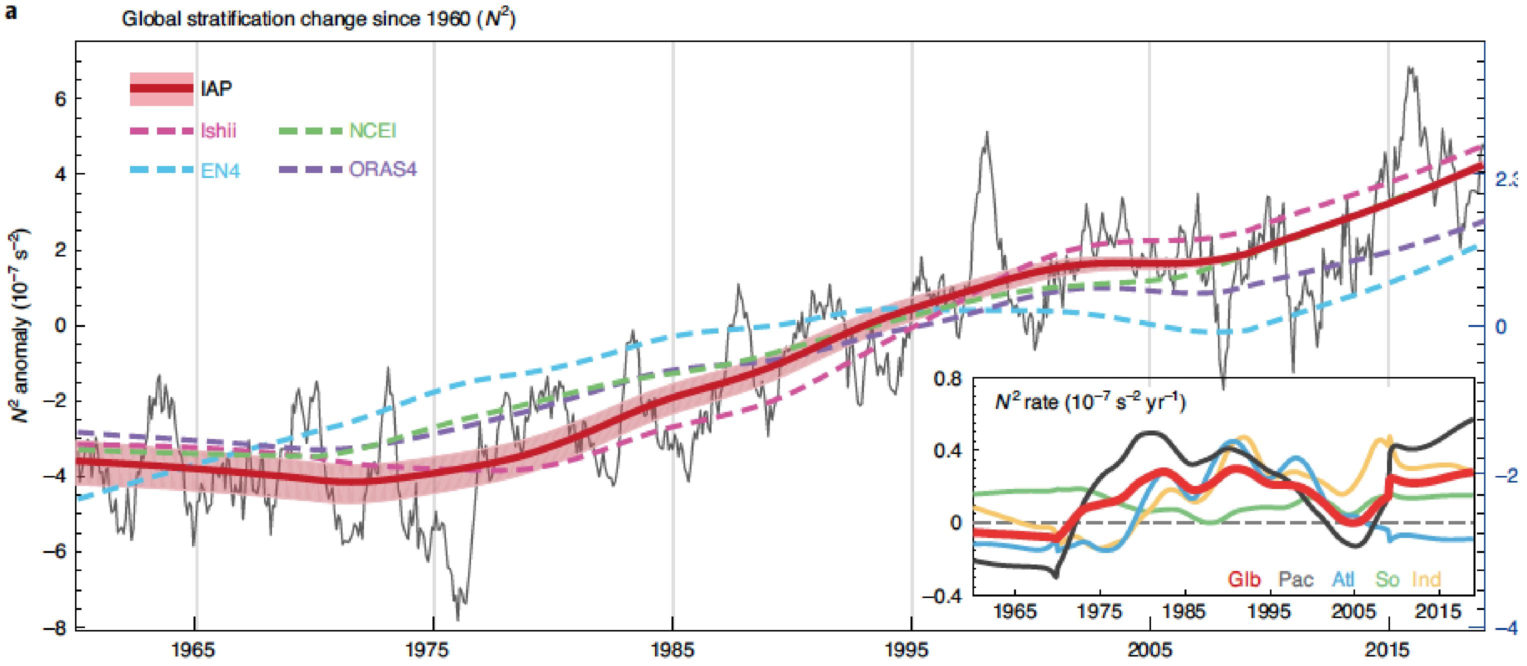
Basin	Oxygen content (Pmol)	Oxygen change (Tmol per decade)	Change as percentage of global change	Volume as percentage of global ocean volume
Arctic Ocean	4.7±0.2	−73±30	7.6±3.1	1.2
North Atlantic	26.9±0.1	−9±19	0.9±1.9	8.5
Equatorial Atlantic	15.9±0.0	−72±20	7.5±2.1	5.7
South Atlantic	22.4±0.1	−119±27	12.4±2.8	7.8
North Pacific	24.5±0.1	−173±40	18.0±4.2	16.3
Equatorial Pacific	25.5±0.4	−210±125	21.9±13.0	16.3
South Pacific	33.1±0.1	−71±37	7.4±3.9	14.3
Equatorial Indian Ocean	10.7±0.1	−55±49	5.7±5.1	6.6
South Indian Ocean	26.1±0.1	−27±34	2.8±3.5	10.2
Southern Ocean	37.6±0.1	−152±47	15.8±4.9	13.1
Total	**227.4±1.1**	**−961±429**	**100**	**100**

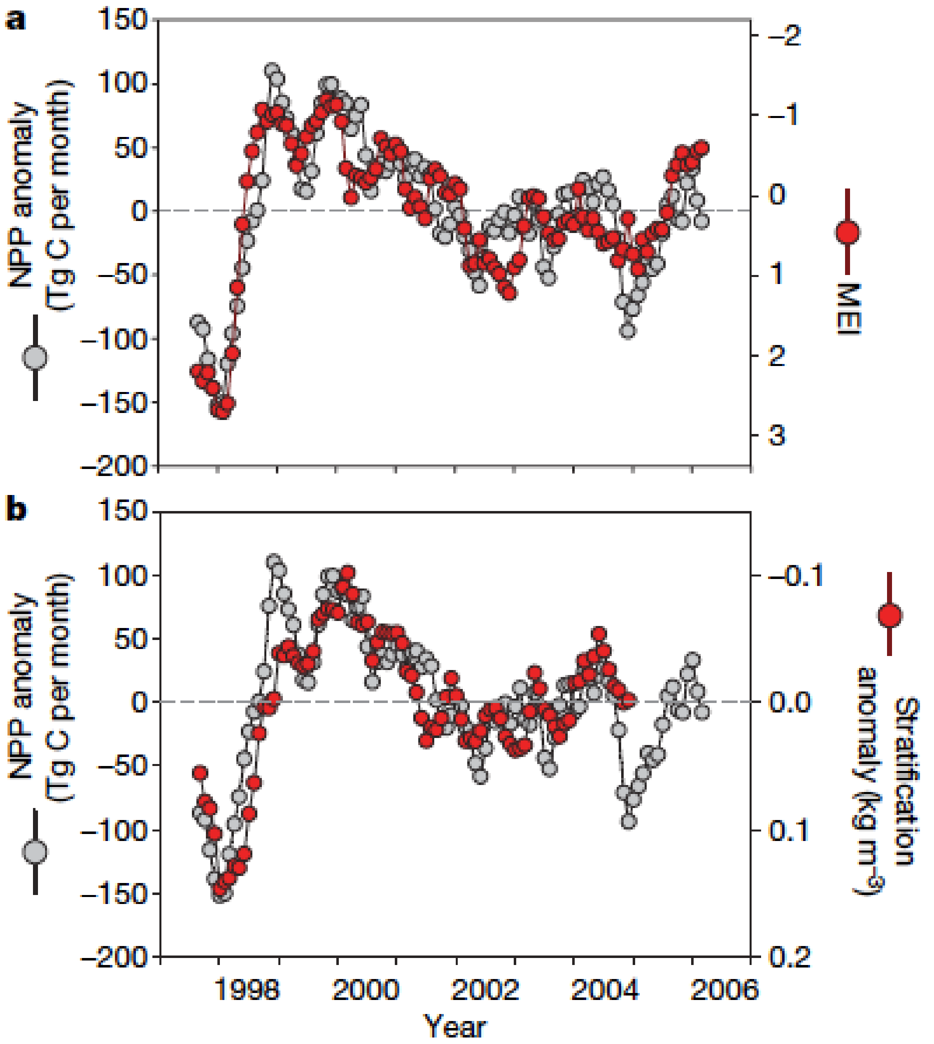
Trends that are more significant than two standard errors are marked in light grey. See Extended Data Table 1 for an extended version of this table.



Increasing ocean stratification over the past half-century

Guancheng Li[1,2,3], Lijing Cheng[1,2,3] ✉, Jiang Zhu[1,2,3] ✉, Kevin E. Trenberth[4], Michael E. Mann[5] and John P. Abraham[6]





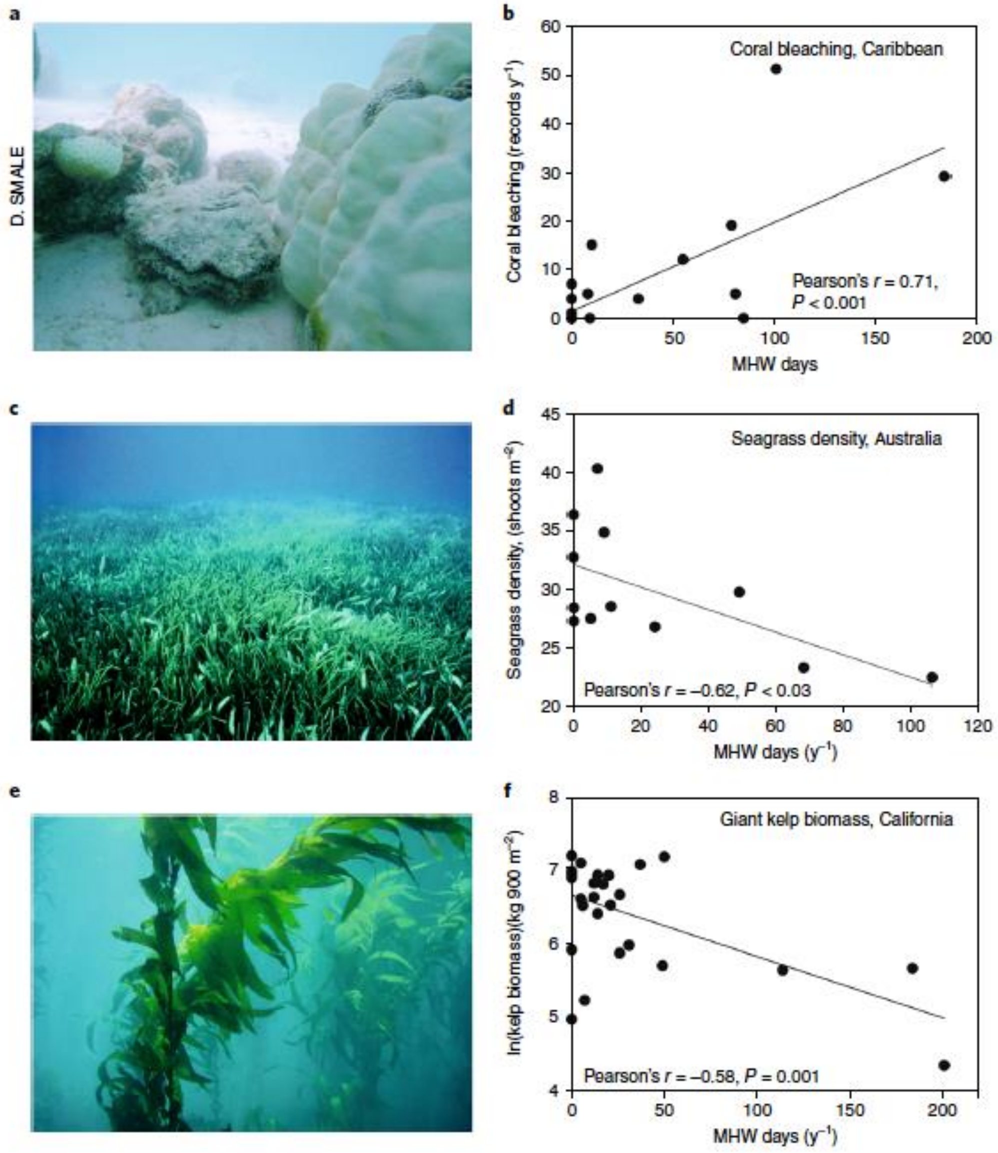
Climate-driven trends in contemporary ocean productivity

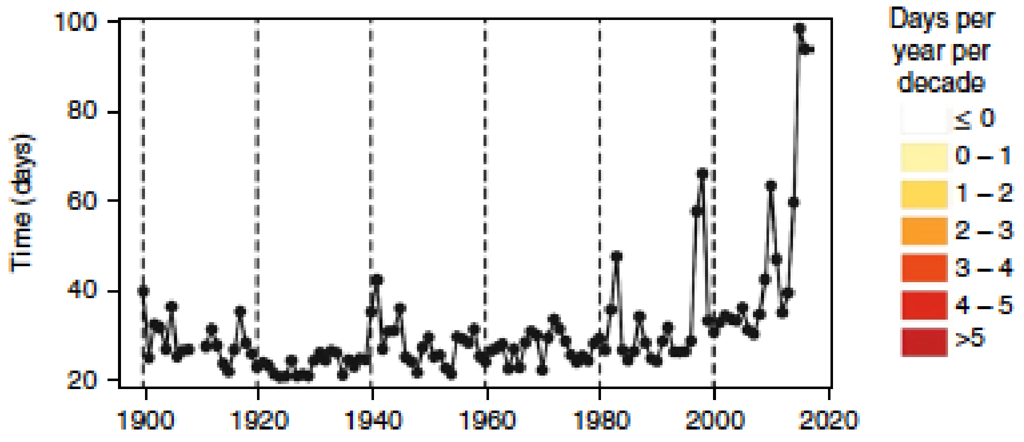
Michael J. Behrenfeld[1], Robert T. O'Malley[1], David A. Siegel[3], Charles R. McClain[4], Jorge L. Sarmiento[5], Gene C. Feldman[4], Allen J. Milligan[1], Paul G. Falkowski[6], Ricardo M. Letelier[2] & Emmanuel S. Boss[7]

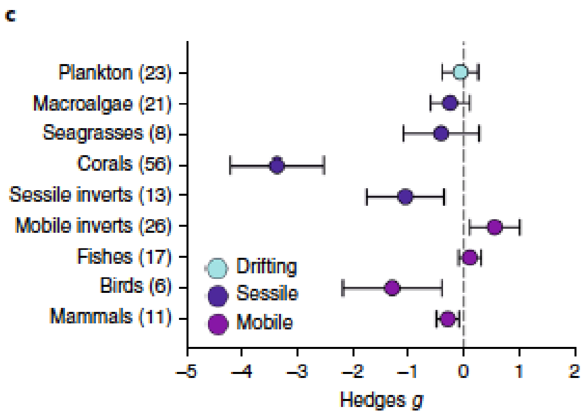
Marine Heatwaves

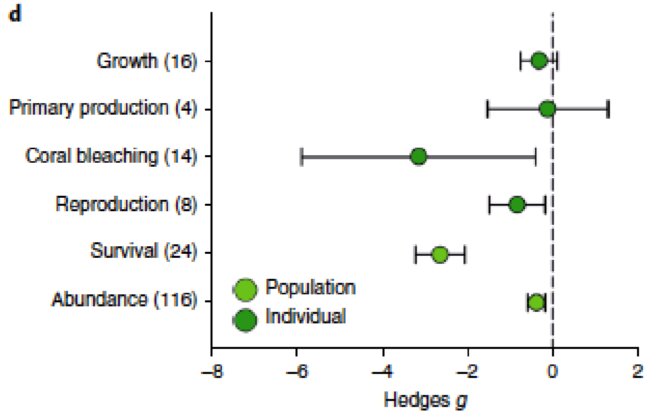
LETTERS
https://doi.org/10.1038/s41558-019-0412-1
nature climate change

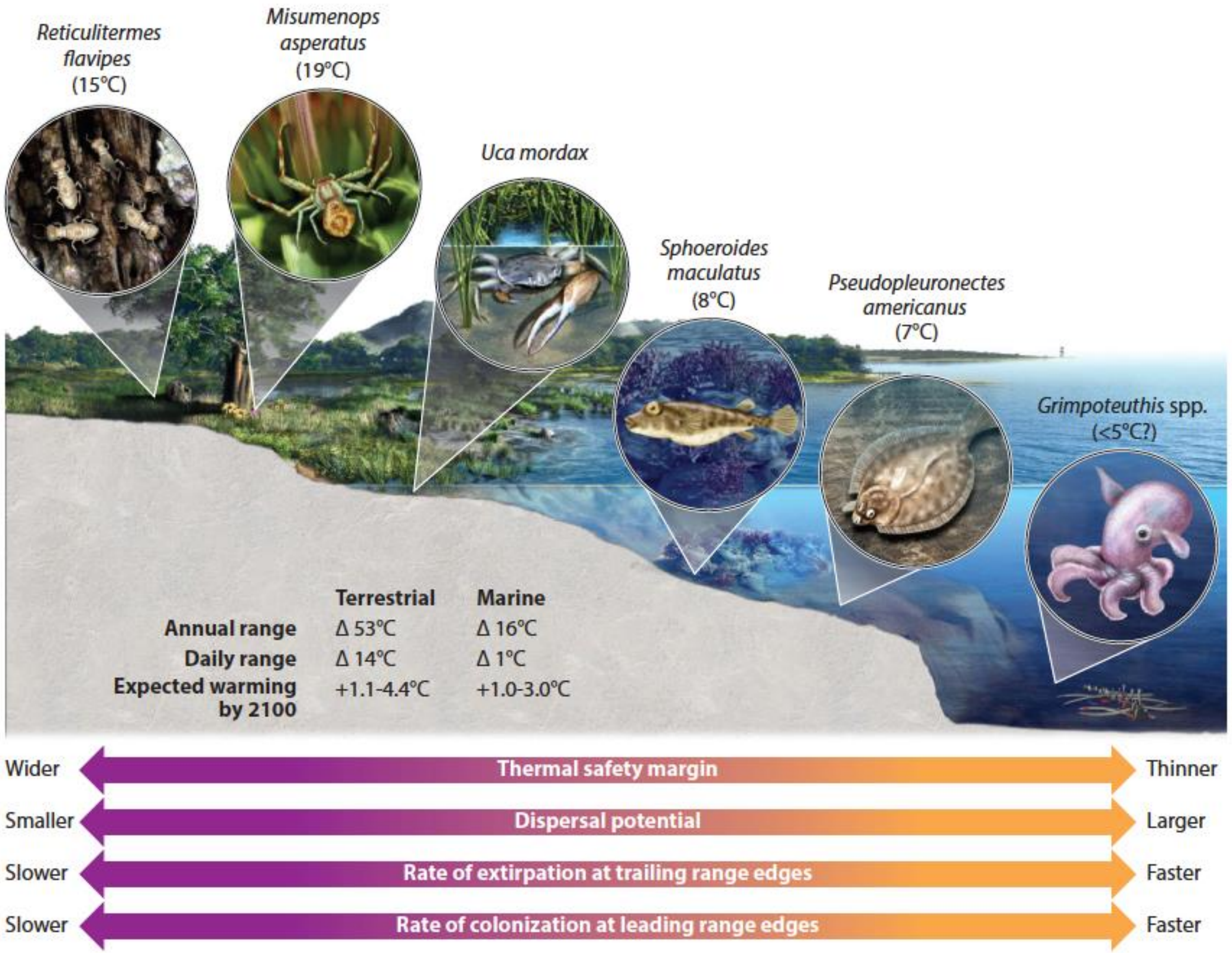
Marine heatwaves threaten global biodiversity and the provision of ecosystem services







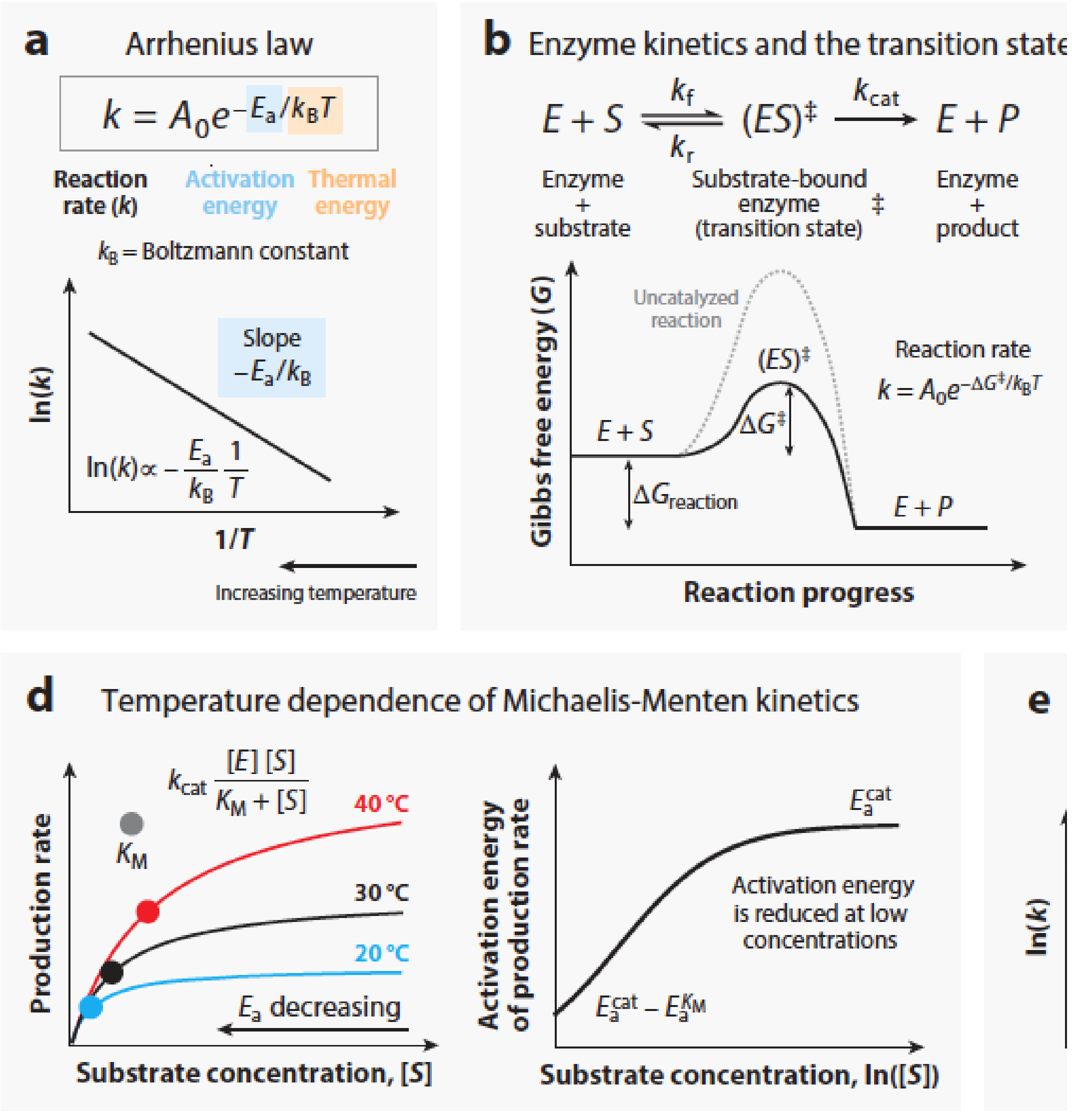




gure 6

comparative view of climate change vulnerability from terrestrial to marine ecosystems. Representative species are shown with th ermal safety margins. The thermal safety margin is a relative (not absolute) proxy for the amount of warming an organism can lerate. Lower annual and daily temperature variation in the ocean has left many marine species less evolutionarily conditioned to th climate warming, which is reflected in narrower safety margins. These vulnerabilities are exacerbated by reduced access to ther fuges in the ocean. The numbers at the bottom show the average annual and daily range of temperatures from local monitoring tions, as well as the expected warming by 2100. The examples here are drawn from the east coast of North America, including ather stations and oceanographic buoys in South Carolina. Illustration by N.R. Fuller of Sayo-Art LLC.

Temperature effects at the level of the enzyme/cell



Enzymes reduce the Activation energy of a reaction for biological temperatures and so enhance the rate

Temperature speeds up the rate of the reaction and provides more thermal energy

But enzymes have thermal limits: the rate is catalyzed to an optima until the enzyme loses structure/denatures

Membrane fluidity is also strongly T-dependent

Annual Review of Biophysics

The Effects of Temperature on Cellular Physiology

Benjamin D. Knapp[1] and Kerwyn Casey Huang[1,2,3,4]

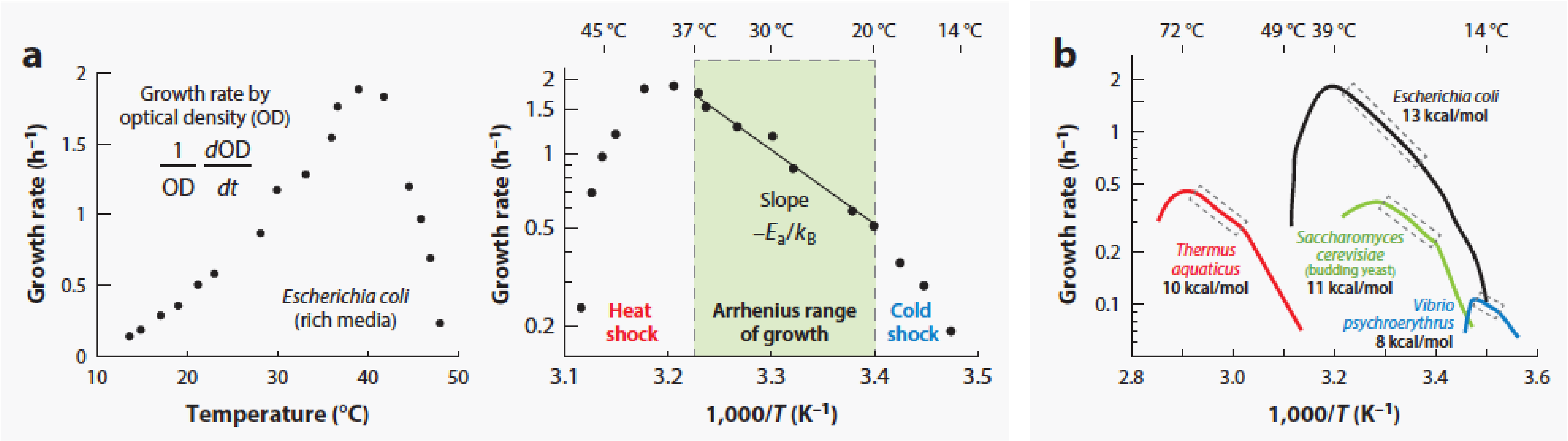
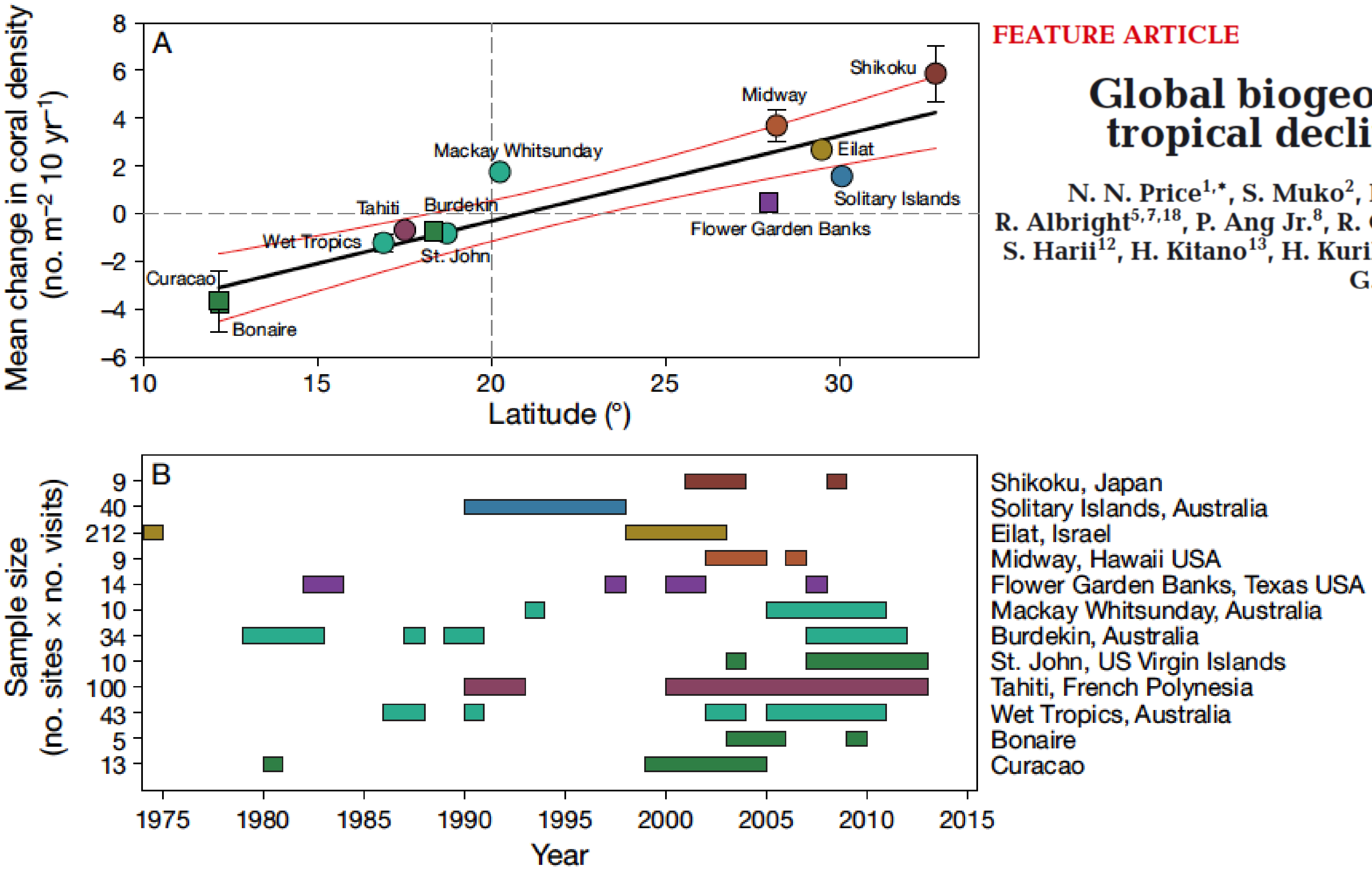


Figure 2

Cellular growth rates obey species-specific Arrhenius laws. (*a*) Growth rates of *Escherichia coli* in rich medium were measured at various temperatures (*left*). An Arrhenius plot [log(growth rate) versus $1/T$] reveals a range of temperatures (20–37°C) over which the data are approximately linear, a so-called Arrhenius range (*right*). Temperatures above and below the Arrhenius range produce a heat- and cold-shock response, respectively. Data from Reference 54. (*b*) Bacterial and eukaryotic species possess Arrhenius ranges (*dotted boxes*)

Coral bleaching….but some hope…



FEATURE ARTICLE

Global biogeography of coral recruitment: tropical decline and subtropical increase

N. N. Price[1,*], S. Muko[2], L. Legendre[3], R. Steneck[4], M. J. H. van Oppen[5,6], R. Albright[5,7,18], P. Ang Jr.[8], R. C. Carpenter[9], A. P. Y. Chui[8], T.-Y. Fan[10], R. D. Gates[11], S. Harii[12], H. Kitano[13], H. Kurihara[14], S. Mitarai[15], J. L. Padilla-Gamiño[16], K. Sakai[12], G. Suzuki[17], P. J. Edmunds[9]

Tropicalisation of the subtropics…

Climate Change at the level of the organism/ecosystem

- Latitudinal Migration
- Ecosystem Restructure
- Phenological mismatch

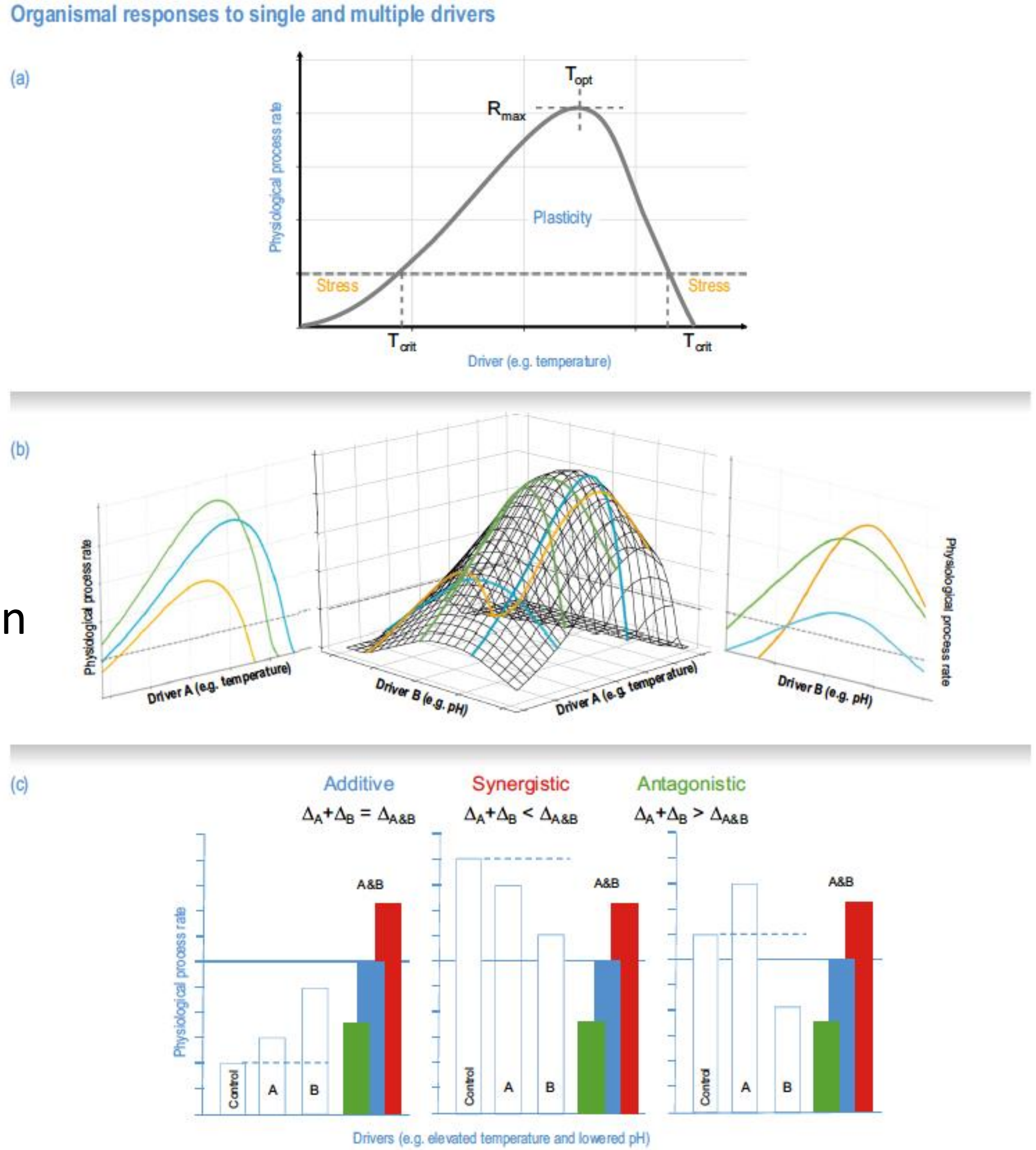
Organism Impacts realized through Niches

The response curve for one driver can depend on other drivers (e.g. T and pH)

Impacts of multiple drivers can be additive, synertistic, or ntagonistic ie cumulative effect is equal to, larger than or smaller than the sumof the individual effects

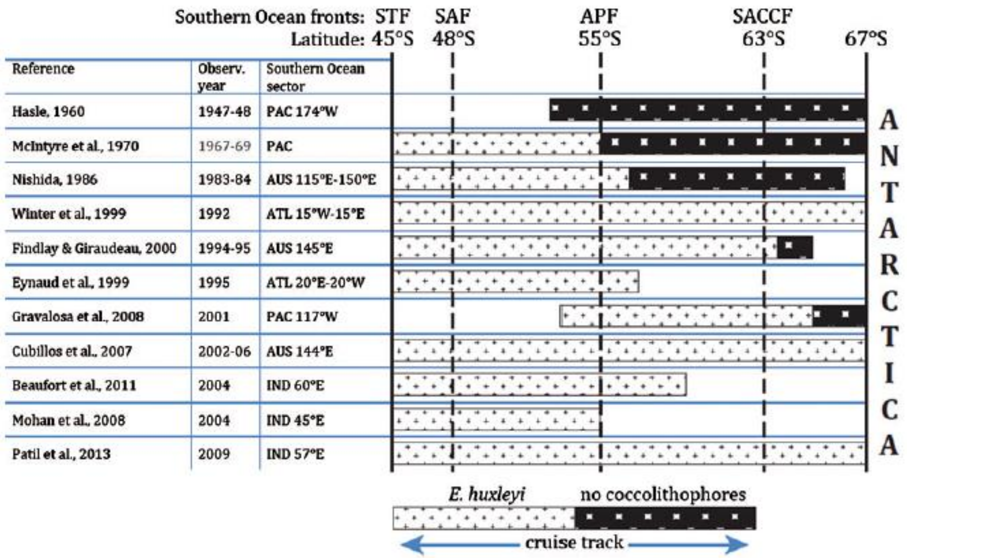
But modelling latitudinal range based on niche alone neglects biotic interactions, evolutionary change and dispersal ability

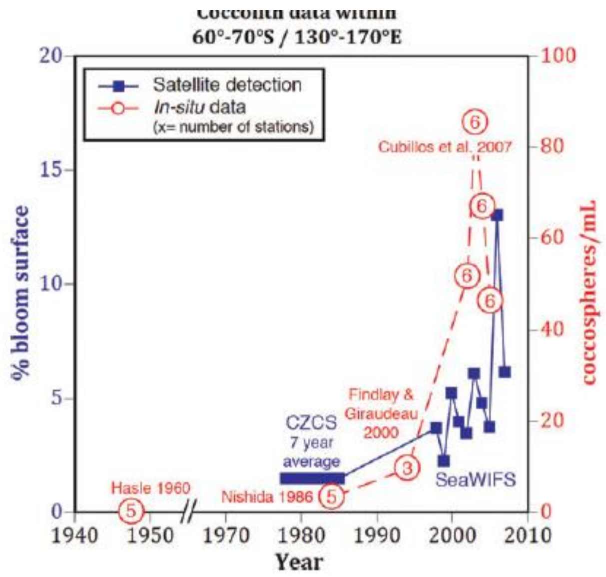
IPCC



Latitudinal Shifts

- Help species maintain their niche
- But unless other dependent/ant species move concurrently leads to changes in ecosystem structure
- Can run out of thermal room (either poleward, with depth or with altitude)





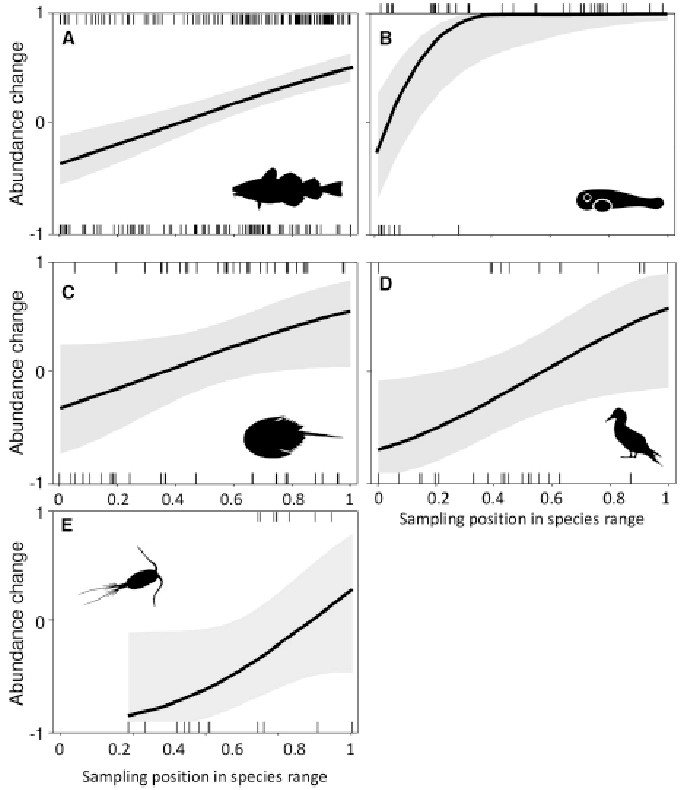
Poleward expansion of the coccolithophore *Emiliania huxleyi*

AMOS WINTER[1]*, JORIJNTJE HENDERIKS[2], LUC BEAUFORT[3], ROSALIND E. M. RICKABY[4] AND CHRISTOPHER W.

Current Biology

Climate Change Drives Poleward Increases and Equatorward Declines in Marine Species

range of species. Our results show that abundance increases have been most prominent where sampling has taken place at the poleward side of species ranges, and abundance declines have been most prominent where sampling has taken place at the equatorward side of species ranges. These data pro-



Phenology mismatch

Climate change: Seasonal shifts causing 'chaos' for UK nature

27 December 2023

Climate

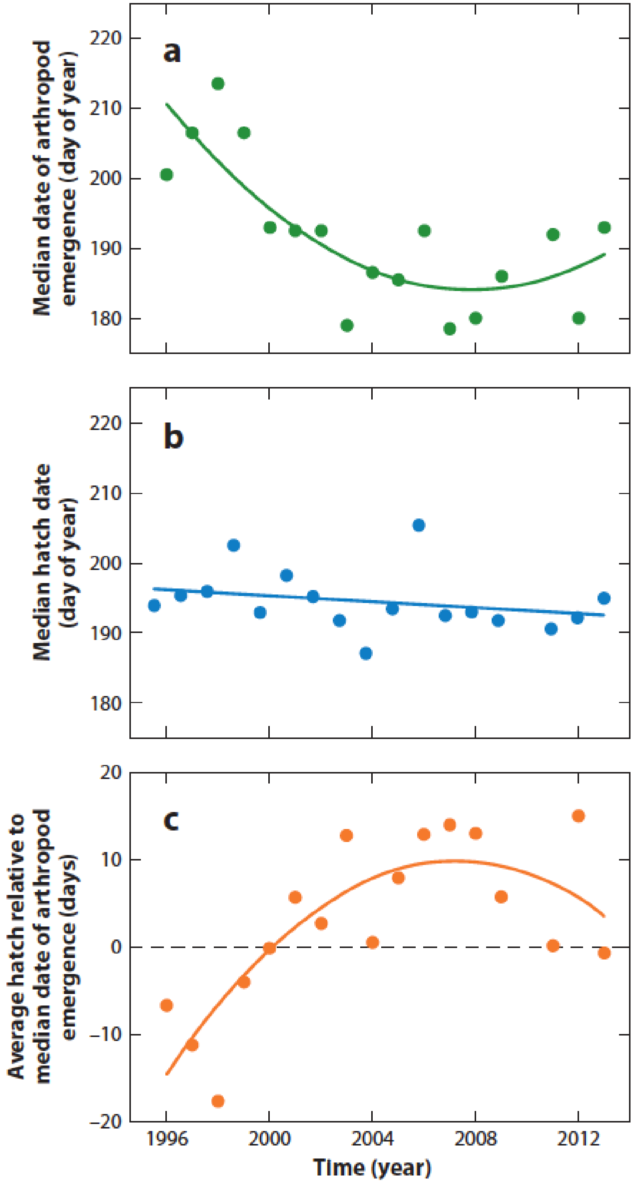
Changing seasons are affecting the reproductive cycle of animals like red deer

Warm temperatures have prompted some shrubs to come into bloom early, making them susceptible to sudden cold snaps - affecting pollinators, and the birds that feed on their seeds (and Ros' pear tree).

The UK's most iconic tree, the oak, could be particularly hard hit ….Cold snaps are getting shorter- often doesn't leave enough time to kill off diseases.
-the oak processionary moth, which has been steadily migrating northwards, whose caterpillars infest oak trees, thrive in these shorter cold spells making the oaks more vulnerable to attack from other parasites,…

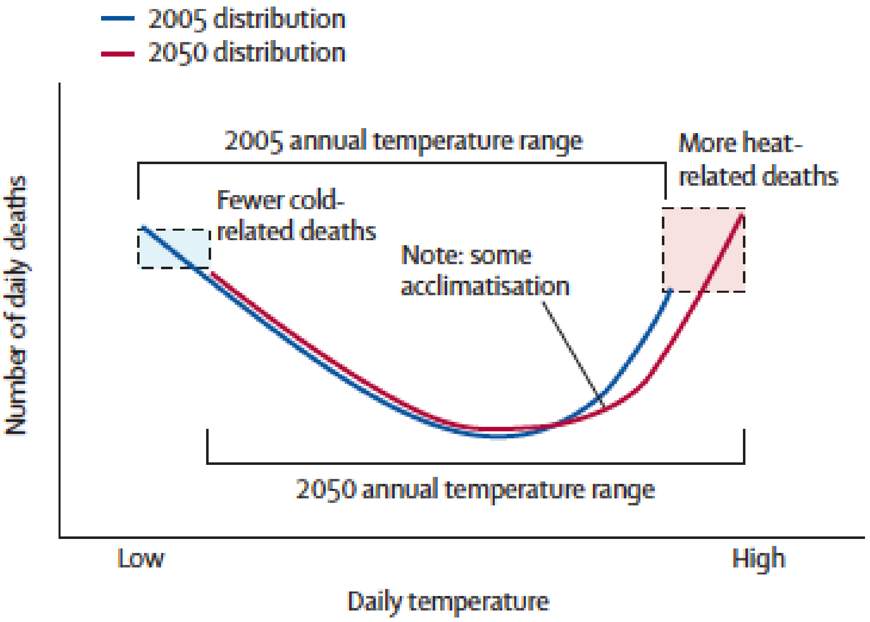
Warmer winters also impact heathlands allowing the heather beetle to kill off huge areas of heather. Animals which hibernate, like dormice, are especially threatened. They emerge from their winter sleep earlier and can quickly use up their vital remaining stores of energy.

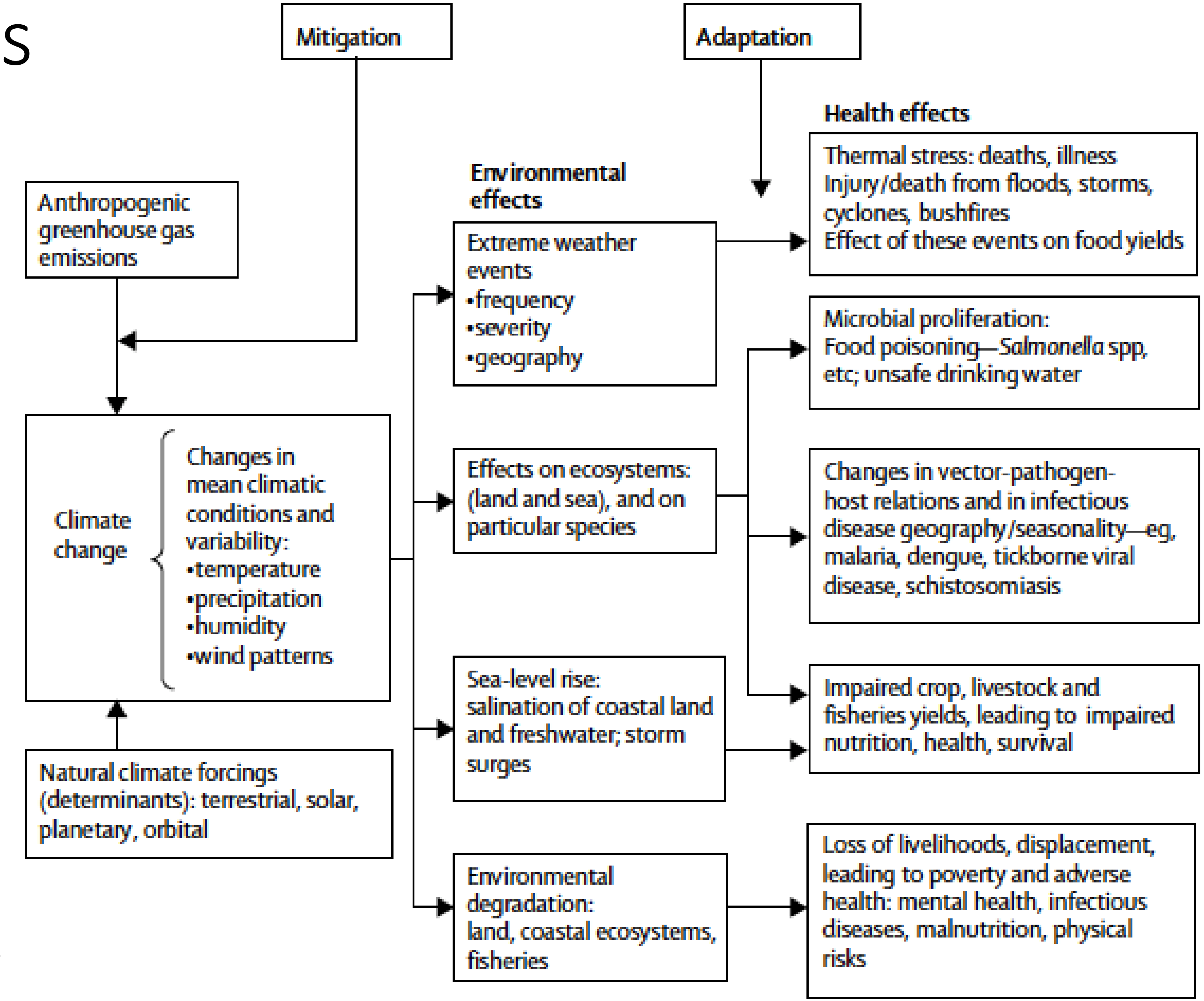
Greenland Duckling hatching and insect mismatch



Impact on Humans

- Disease
- Fire
- Sealevel rise (displacement)
- Food/Agriculture
- Heat Stress





Human Interventions: Unintended Consequences