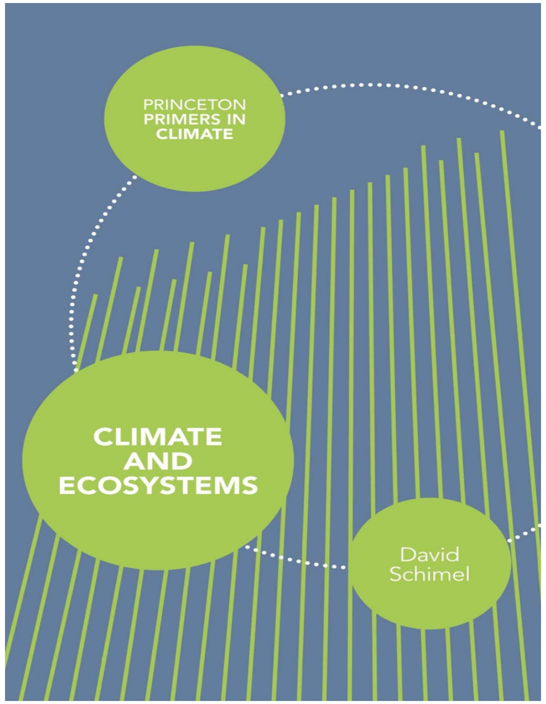
Chapter 3 Climate Controls over Ecosystems

&

Chapter 4 Ecosystem Feedbacks and Interactions with Climate



AOSC 680 – Yixin Wang

Outline

Core concepts in ecosystems

Interactions between ecosystems and the climate

Carbon stocks and fluxes due to ecosystems

Biomes

Classified according to the biota that live in it

Described in terms of the dominant photosynthetic organisms

Corresponds to patterns of precipitation, temperature, solar radiation (seasonality)

Terrestrial vs. Aquatic

Ecosystems

- Interactions between biota within the environment
- Many can make up a single biome

Habitats

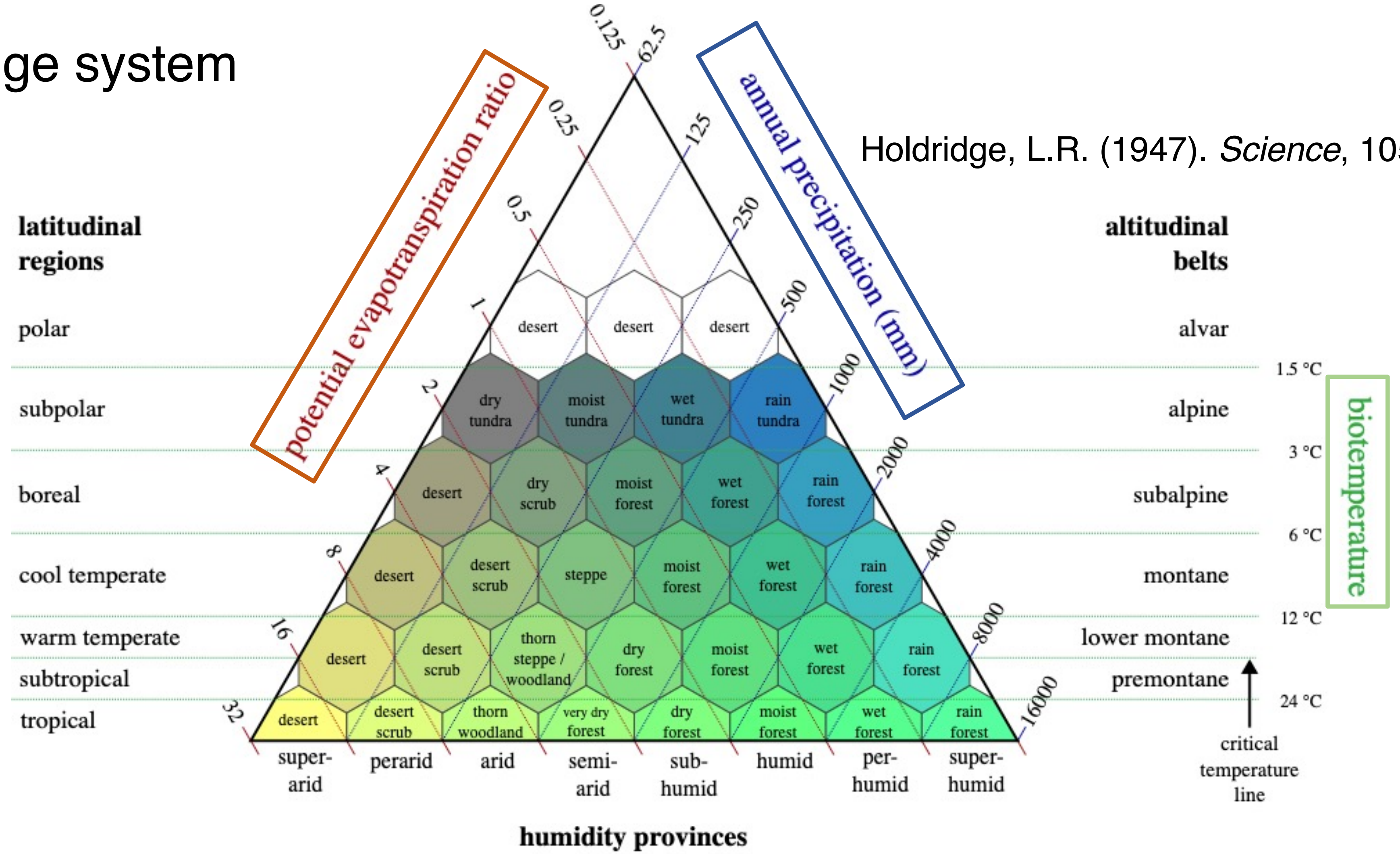
- Specific to a population or species
- The area in which that group lives

Terrestrial biomes

Holdridge system

PET
the amount of water that would be evaporated and transpired by a specific crop, soil or ecosystem if there were sufficient water available

PET ratio
relative to precipitation



Holdridge, L.R. (1947). *Science*, 105, 367–368.

https://en.wikipedia.org/wiki/Holdridge_life_zones

Aquatic biomes

Freshwater – rivers, streams, lakes, ponds, wetlands

Salinity

Marine – oceans and seas, estuaries

What is the difference?

https://www.necropsymanual.net/en/fish-groups/salmonids/

https://www.everythingreptiles.com/bearded-dragon/

https://www.greenhousegrower.com/crops/behold-the-magic-of-warm-season-grasses/

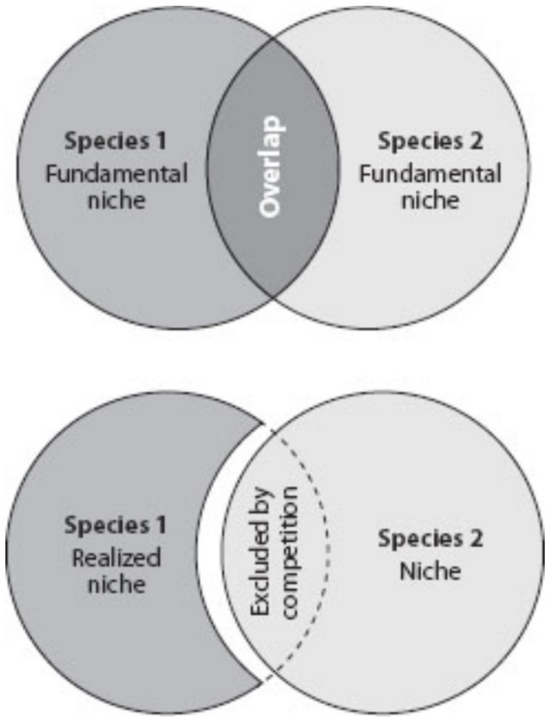
https://www.britannica.com/animal/coyote-mammal

https://www.allaboutbirds.org/guide/Swainsons_Thrush/id

Niche

Species ⟷ Specific environmental condition

How an organism or population **responds to / alters** the distribution of resources and competitors



Schimel, D. (2013). *Climate and Ecosystems*.

Climate–ecosystem modeling

Assumptions:

Parameterizations:

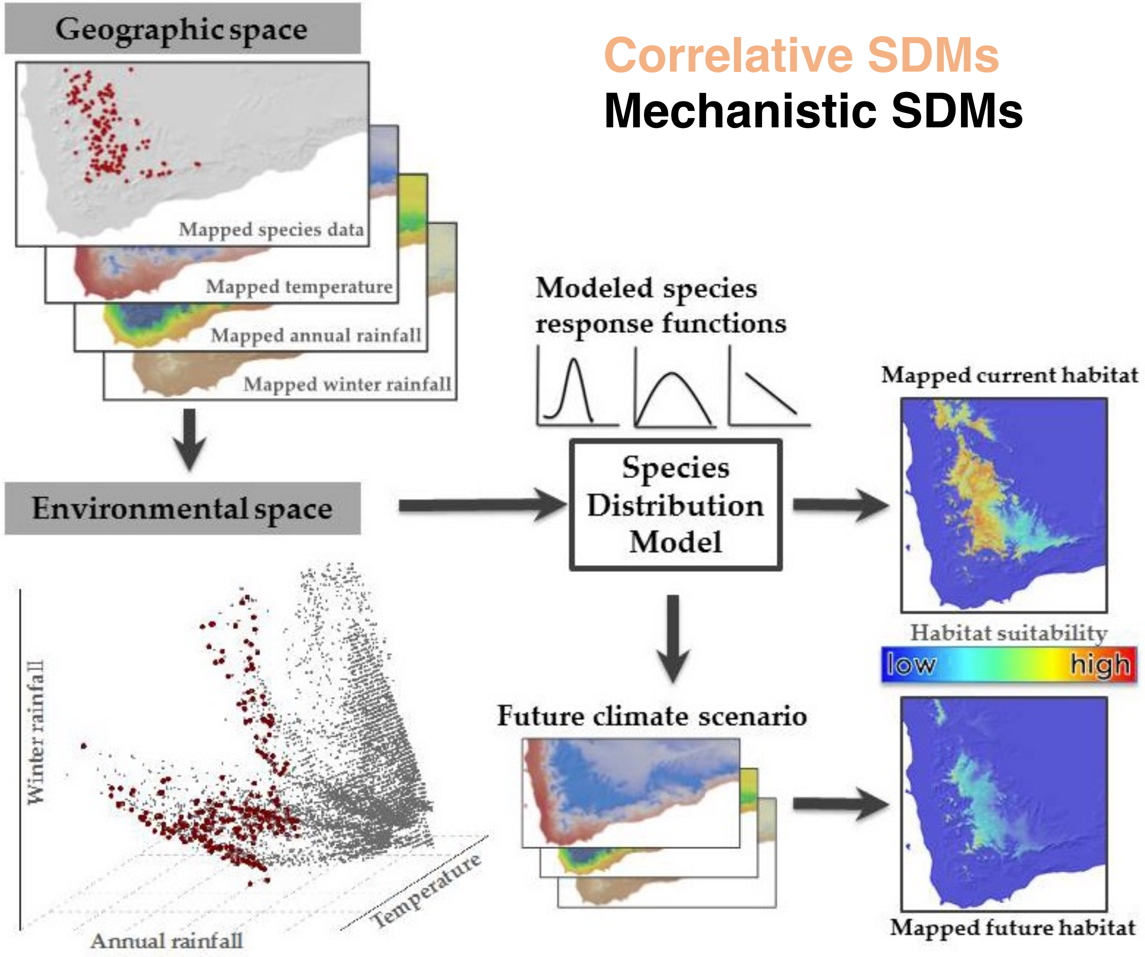
- ✓ Spatial covariance of biomes, communities, organisms and climate
- ✓ Additional biogeochemical constraints, especially for the marine system
- ✓ Physiological parameters vs. Distributional information

Comments on equilibrium

Marine system

Terrestrial system

Species Distribution Models (SDMs)



Correlative SDMs

Mechanistic SDMs

Species Distribution Models

"predict first, assemble later"

$$\begin{array}{c} \\ Site_1 \\ Site_2 \\ Site_3 \\ \ldots \\ Site_j \end{array}\left[\begin{array}{c} Spp_1 \\ 0 \\ 1 \\ 1 \\ \ldots \\ 1 \end{array}\right] = f\left\{ \begin{array}{c} \\ Site_1 \\ Site_2 \\ Site_3 \\ \ldots \\ Site_j \end{array}\left[\begin{array}{cccccc} Env_1 & Env_2 & Env_3 & \ldots & Env_k \\ 23.4 & 545.5 & 0.64 & \ldots & 4.1 \\ 22.1 & 89.0 & 0.22 & \ldots & 8.0 \\ 24.9 & 439.5 & 0.61 & \ldots & 3.4 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 25.3 & 321.7 & 0.88 & \ldots & 3.9 \end{array}\right] \right\}$$

Profile techniques

- BIOCLIM
- DOMAIN …

Regression-based techniques

- Generalized linear model (GLM)
- Generalized additive model (GAM)
- Multivariate adaptive regression splines (MARS) …

Machine learning techniques

- Artificial neural networks (ANN)
- Random forest (RF)
- Support vector machine (SVM)
- XGBoost (XGB) …

Maguire, K.C., et al. (2016). *Proc. R. Soc. B*, 283: 20152817.

https://www.umces.edu/comparison-species-and-community-level-models-across-novel-climates-and-communities

Applications of SDMs

Niche tracking:

- Species follow limiting environmental boundaries through geographic space to remain in a favorable climatic space
- Occurs when a local population in unfavorable climate conditions becomes extinct, or when individuals colonize sites in newly favorable climates
- SDMs predict how niche tracking evolves, providing insights for species conservation

Discovering limiting factors of species:

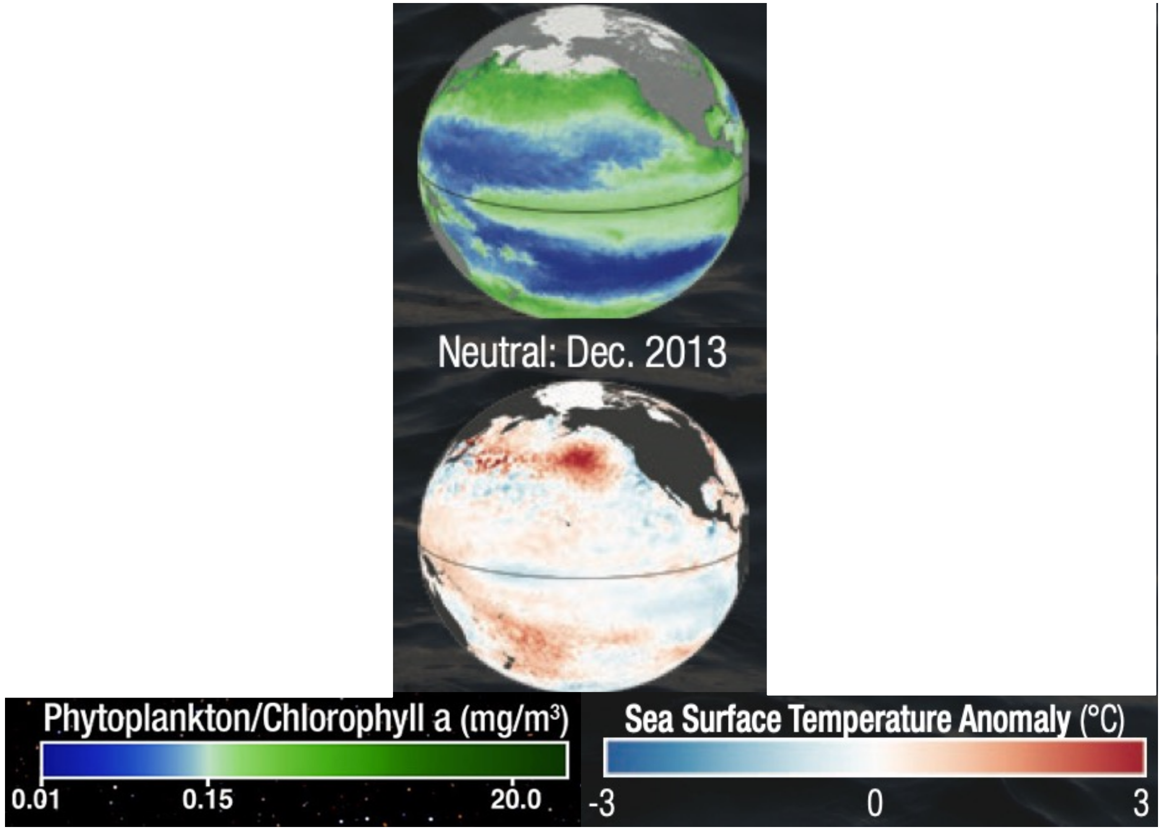
Consider a terrestrial animal species

Ultimate driving factor?

Effects of climate variability

If there is a(n) El Niño / La Niña event, how will species react / interact …?

Consider **phytoplankton** in the Pacific



https://eospso.nasa.gov/sites/default/files/publications/OceanColor_508.pdf

Effects of climate change

If temperature is rising, how will species react / interact …?

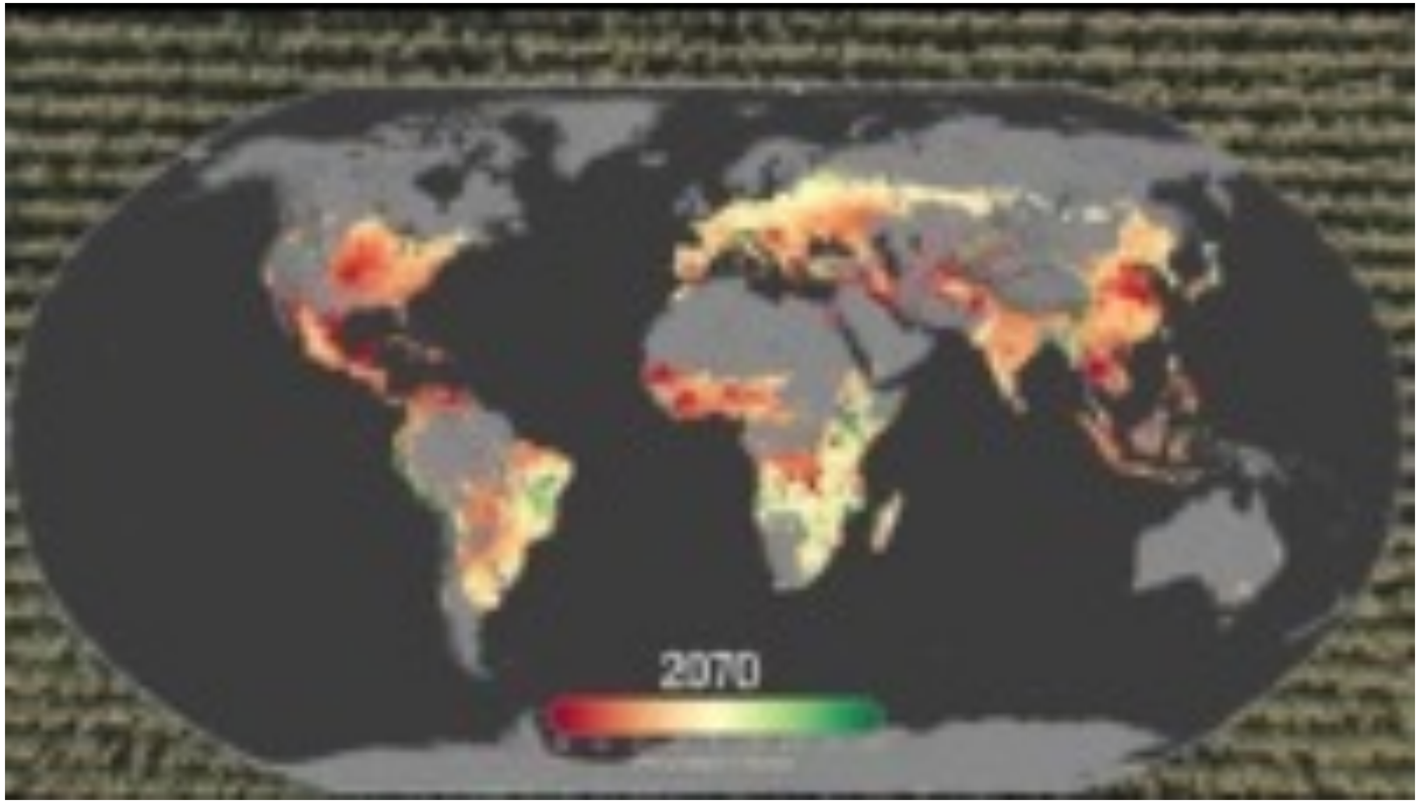
Consider a **beetle–whitebark pine** system

https://brooklyneagle.com/articles/2019/08/01/asian-longhorned-beetles/

Effects of climate change

If temperature is rising, how will species react / interact …?

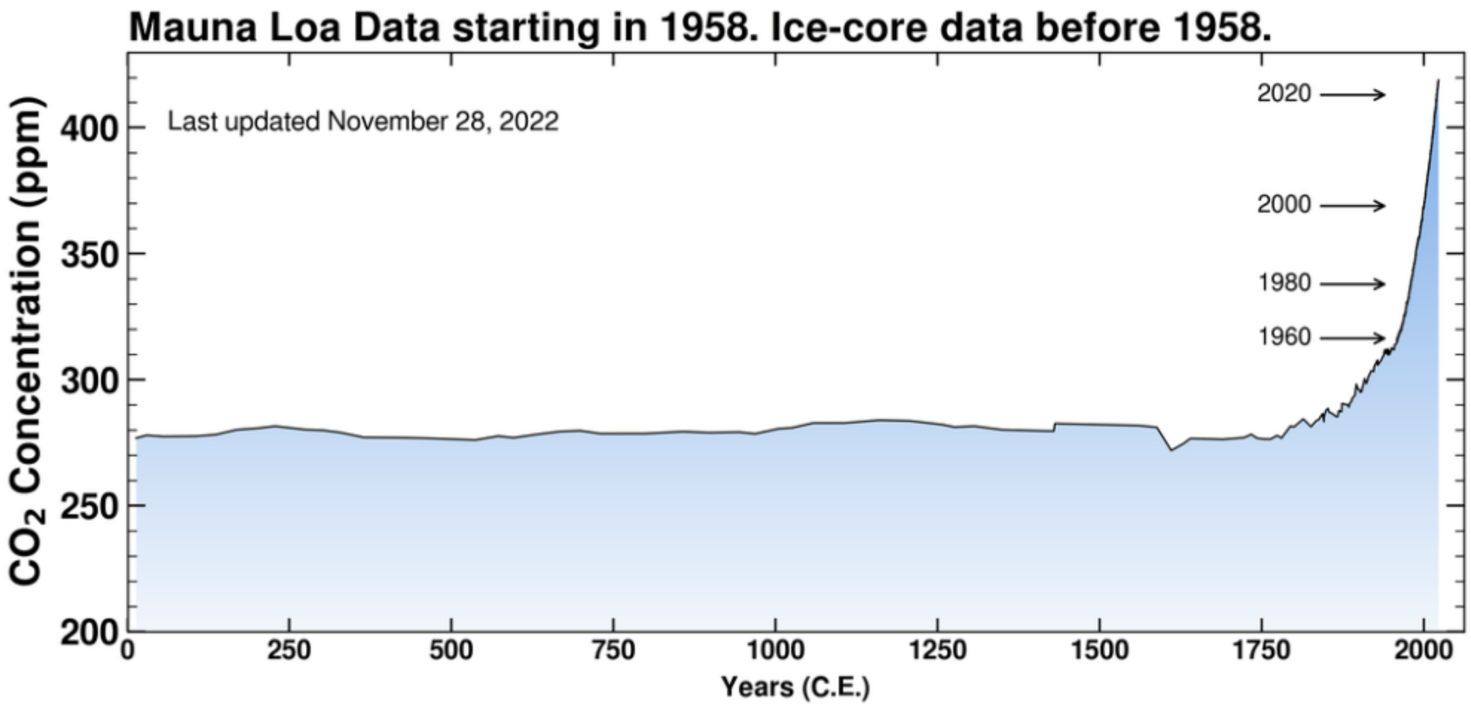
Consider **crop growth** / agricultural production



https://youtu.be/-NZIvvhGIR0 Jagermeyr, J., et al. (2021). *Nat. Food*, 2, 873–885.
Kumar, V., et al. (2017). *J. Pharm. Innov.*, 6 (9), 70–79.

Carbon cycle

How can we ascertain that the rise in CO_2 is due to anthropogenic emissions?



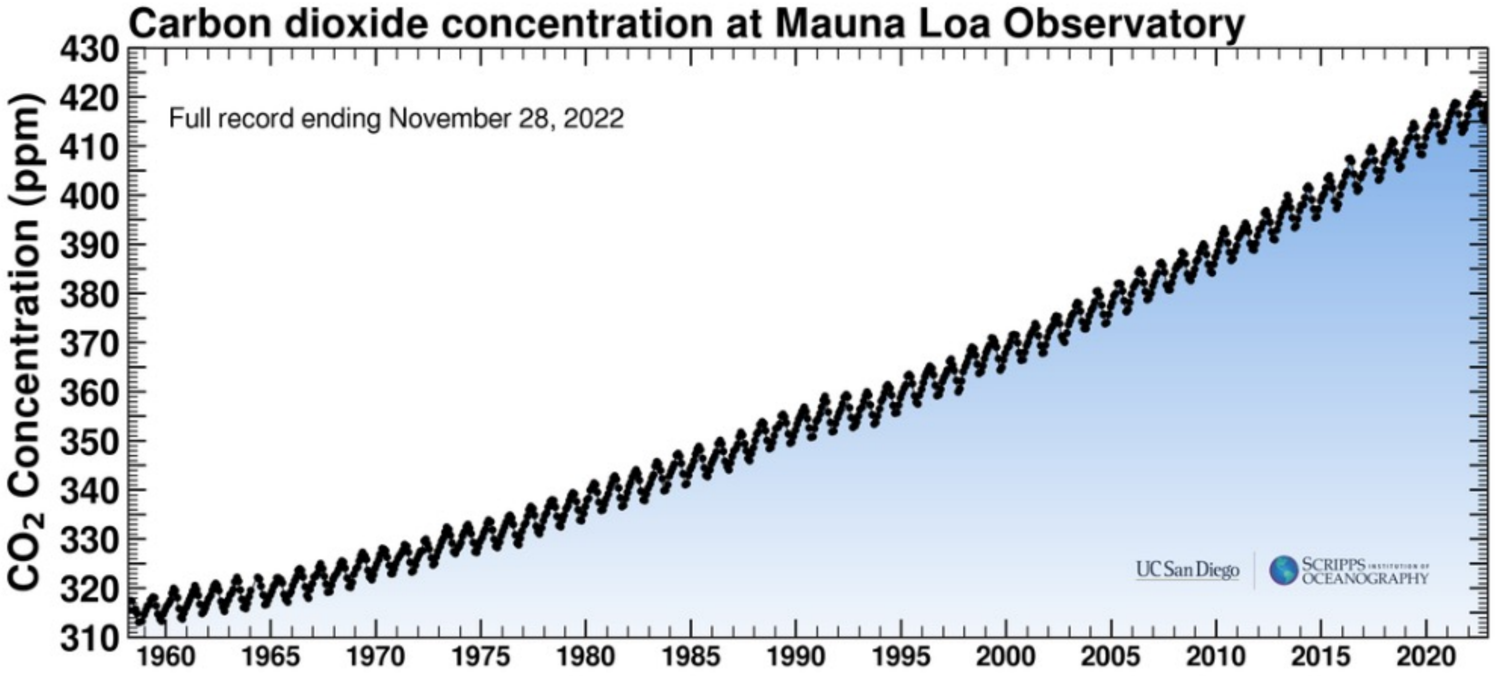
https://keelingcurve.ucsd.edu

How does CO_2 rise relate to the biosphere?

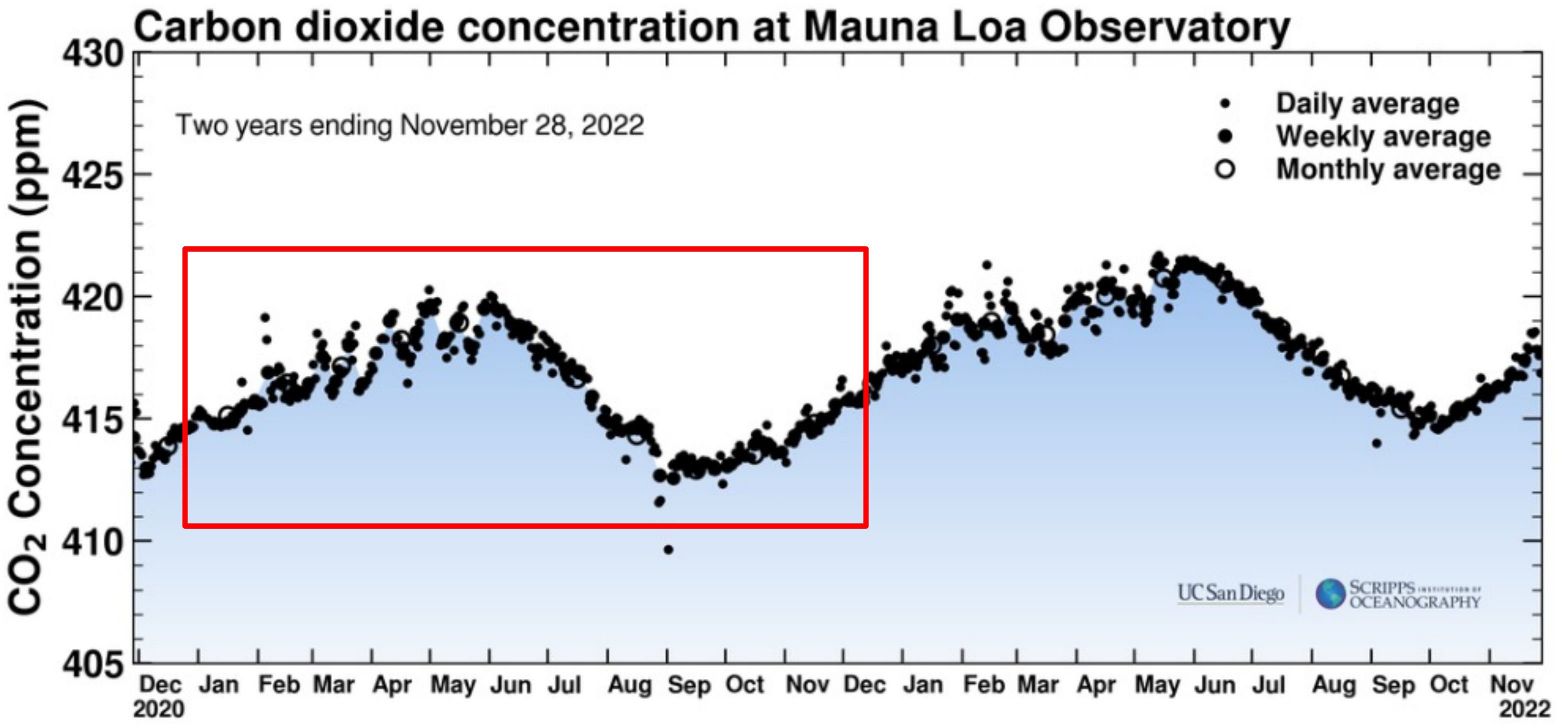
Carbon cycle

What can we see?

Why does this happen?

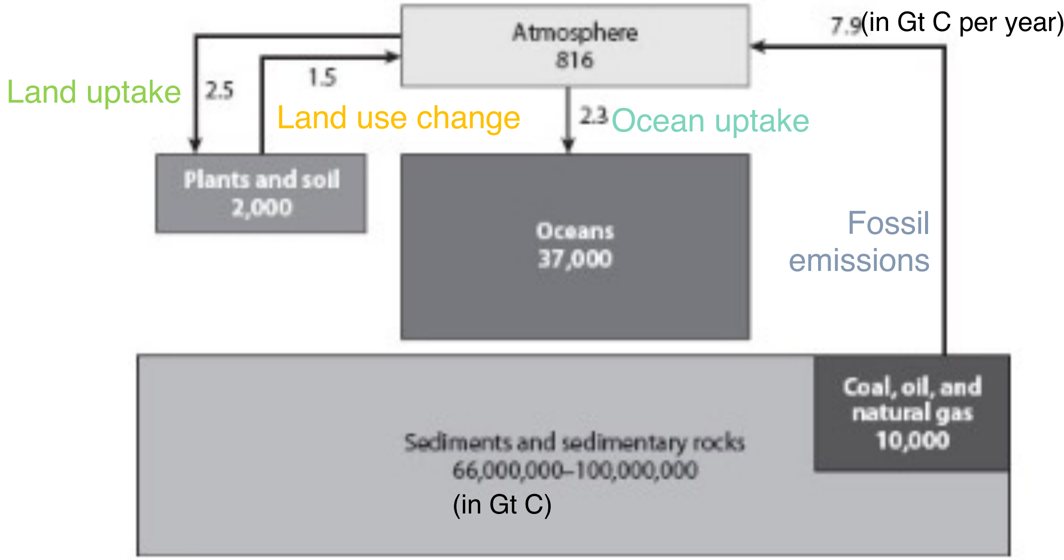


https://keelingcurve.ucsd.edu

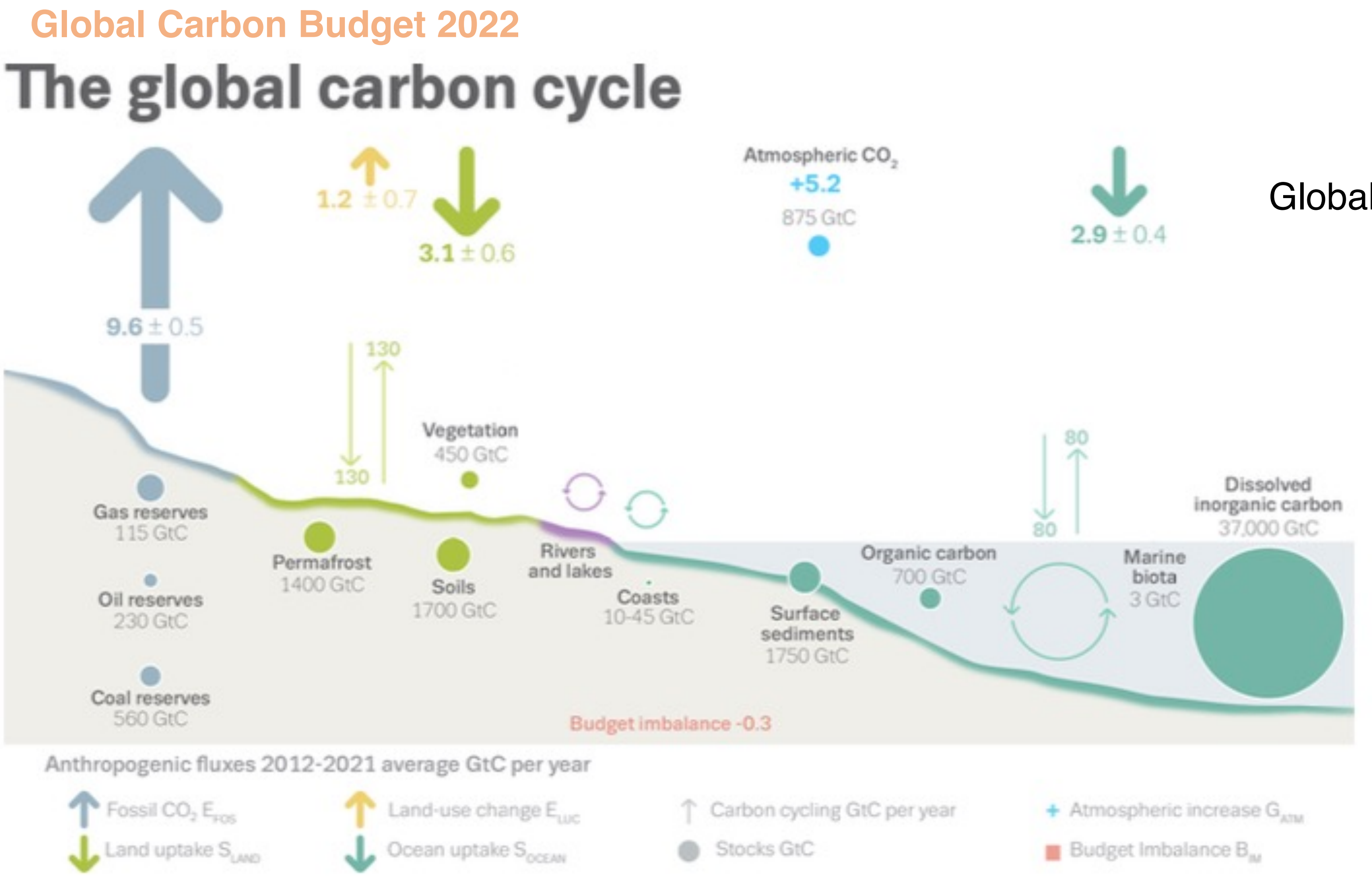


Breathing of the Earth

Carbon budget



Global Carbon Project 2011, cited by Schimel, D. (2013).



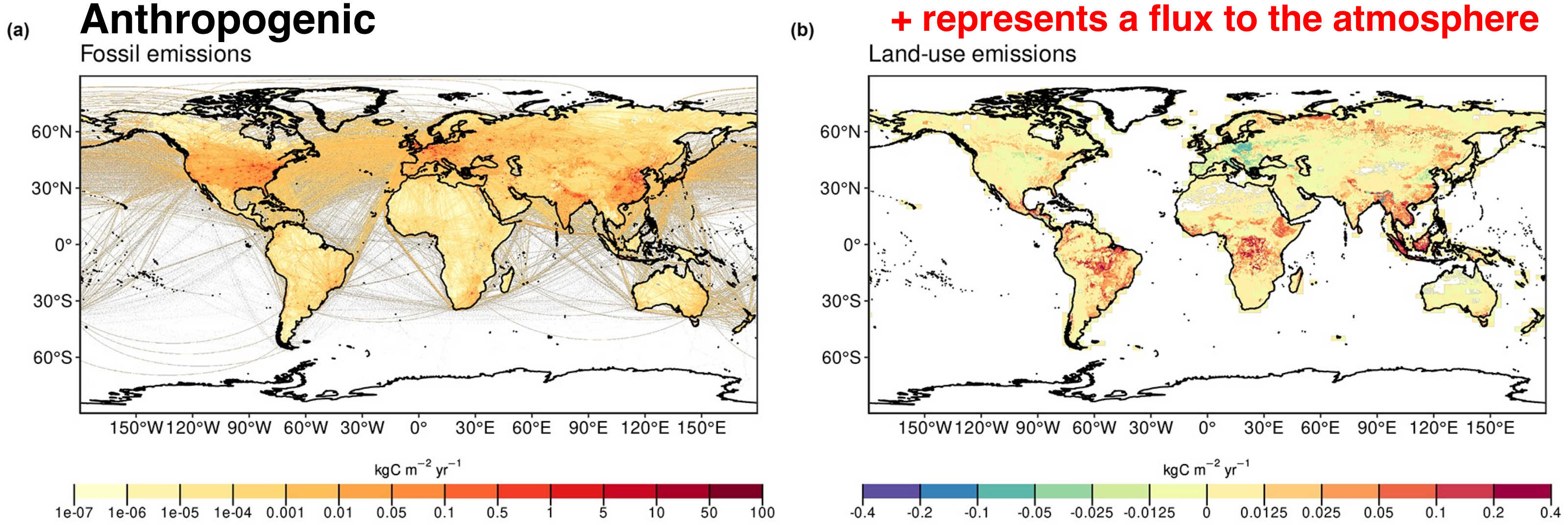
Friedlingstein, P., et al. (2022). *Earth Syst. Sci. Data*, 14, 4811–4900.

Carbon budget

Over 2012–2021

Anthropogenic

+ represents a flux to the atmosphere



What constitute these emissions?

What are the spatial patterns of these sinks (+ / –)?

Friedlingstein, P., et al. (2022). *Earth Syst. Sci. Data*, 14, 4811–4900.

Ocean CO_2 uptake

The ocean captures twice as much carbon dioxide as previously thought

By Sara Rigby Published: 07th April, 2020 at 10:05

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Without the ocean's 'biological carbon pump', atmospheric carbon levels would be much higher.

- The oceans' 'biological pump' is capturing even more carbon dioxide than previously thought, a study finds.
- Phytoplankton on the surface of the ocean absorb carbon dioxide, and are eaten by zooplankton, carrying the CO_2 deeper into the ocean.
- The levels of CO_2 in the atmosphere would be much higher if not for the biological carbon pump.

Buesseler K.O., et al. (2020). *PNAS*, 117 (18), 9679–9687.
https://www.sciencefocus.com/news/the-ocean-captures-twice-as-much-carbon-dioxide-as-previously-thought/

The *biological pump* in the oceans[3]

In temperate and high latitudes there is a peak each spring in ocean biological activity. During the winter, water rich in nutrients is transferred from deep water to levels near the surface. As sunlight increases in the spring an explosive growth of the plankton population occurs, known as the 'spring bloom'. Pictures of ocean colour taken from satellites demonstrate dramatically where this is happening.

Plankton are small plants (phytoplankton) and animals (zooplankton) that live in the surface waters of the ocean; they range in size between about 0.001 mm across and the size of typical insects on land. Herbivorous zooplankton graze on phytoplankton; carnivorous zooplankton eat herbivorous zooplankton. Plant and animal debris from these living systems sinks in the ocean. While sinking, some decomposes and returns to the water as nutrients, some (perhaps about 1%) reaches the deep ocean or the ocean floor, where it is lost to the carbon cycle for hundreds, thousands or even millions of years. The net effect of the 'biological pump' is to move carbon from the surface waters to lower levels in the ocean. As the amount of carbon in the surface waters is reduced, more carbon dioxide from the atmosphere can be drawn down to restore the surface equilibrium. It is thought that the 'biological pump' has remained substantially constant in its operation during the last century unaffected by the increase in carbon dioxide.

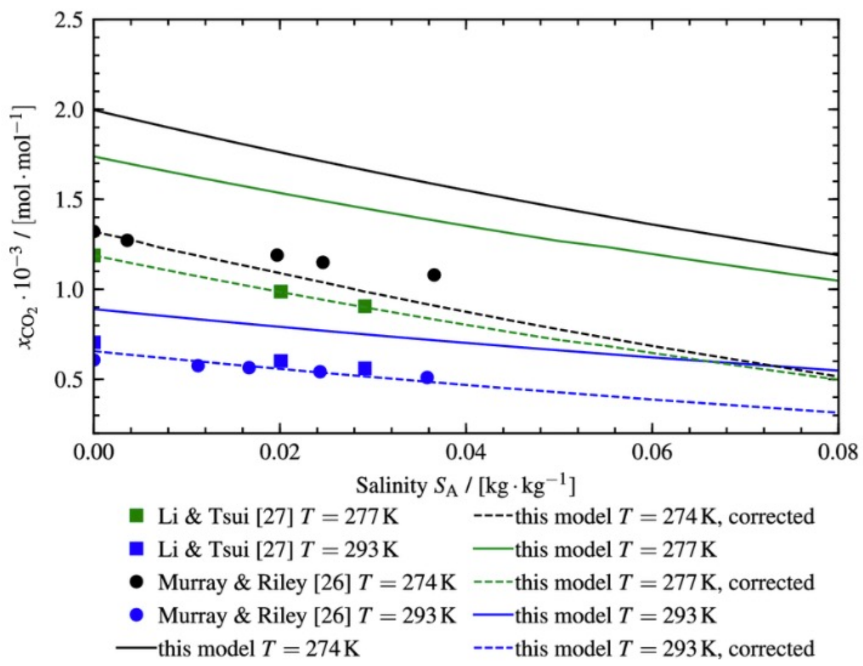
Evidence of the importance of the 'biological pump' comes from the palaeoclimate record from ice cores (see Chapter 4). One of the constituents from the atmosphere trapped in bubbles in the ice is the gas methyl sulphonic acid, which originates from decaying ocean plankton; its concentration is therefore an indicator of plankton activity. As the global temperature began to increase when the last ice age receded nearly 20 000 years ago and as the carbon dioxide in the atmosphere began to increase (Figure 4.9), the methyl sulphonic acid concentration decreased. An interesting link is thereby provided between the carbon dioxide in the atmosphere and marine biological activity. During the cold periods of the ice ages, enhanced biological activity in the ocean could have been responsible for maintaining the atmospheric carbon dioxide at a lower level of concentration – the 'biological pump' was having an effect.

There is some evidence from the palaeo record of the biological activity in the ocean being stimulated by the presence of iron-containing dust blown over the oceans from the land surface. This has led to some proposals in recent years to enhance the 'biological pump' through artificially introducing iron over suitable parts of the ocean. While an interesting idea, it seems from careful studies that even a very large-scale operation would not have a large practical effect.

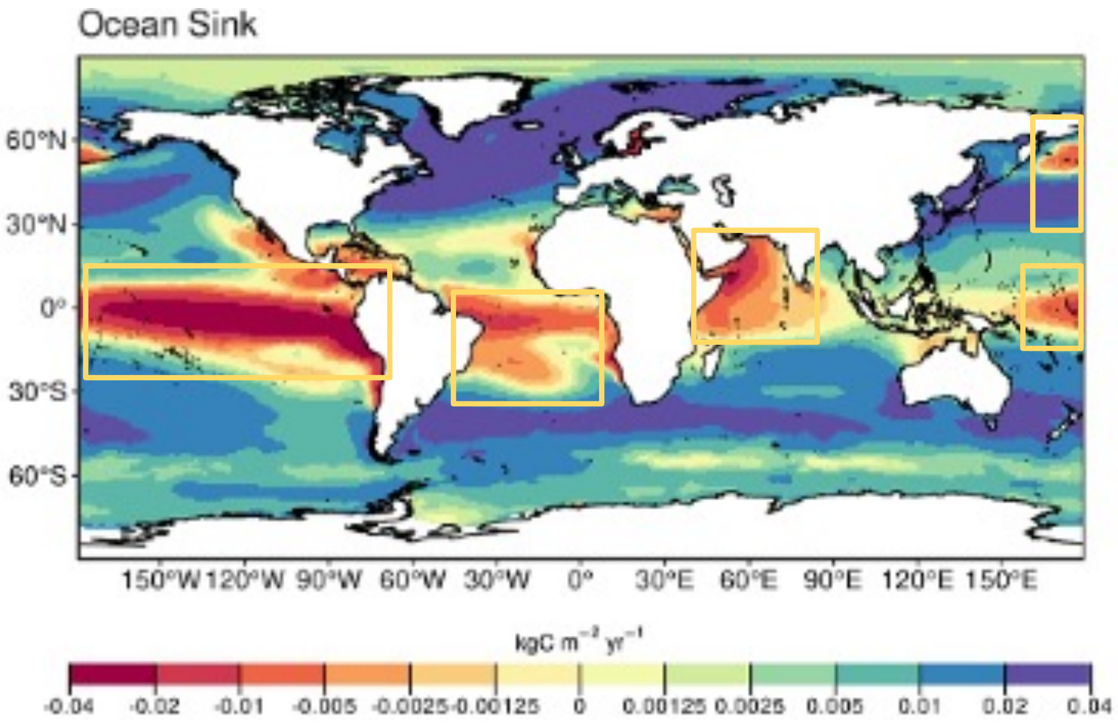
The question then remains as to why the ice ages were periods of greater marine biological activity than the warm periods in between. One possible contributing process is suggested by considering what happens in winter as nutrients are fed into the upper ocean ready for the spring bloom of biological activity. When there is less atmospheric carbon dioxide, cooling by radiation from the surface of the ocean increases. Since convection in the upper layers of the ocean is driven by cooling at the surface, increased cooling results in a greater depth of the mixed layer near the top of the ocean where all the biological activity occurs. This is an example of a positive biological feedback; a greater depth of layer means more plankton growth.[4]

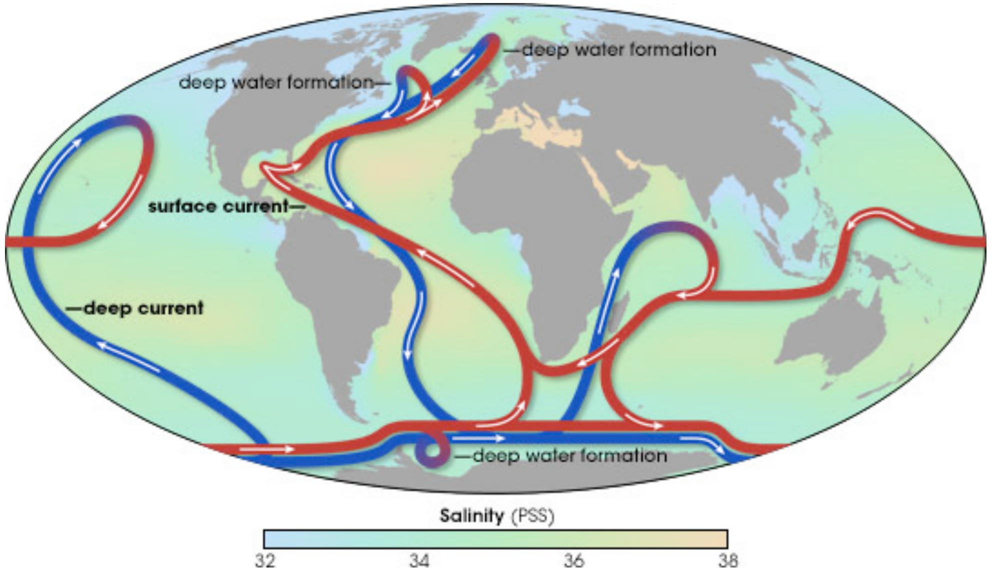
Houghton, J. (2015). *Global Warming.*

Ocean CO_2 outgassing



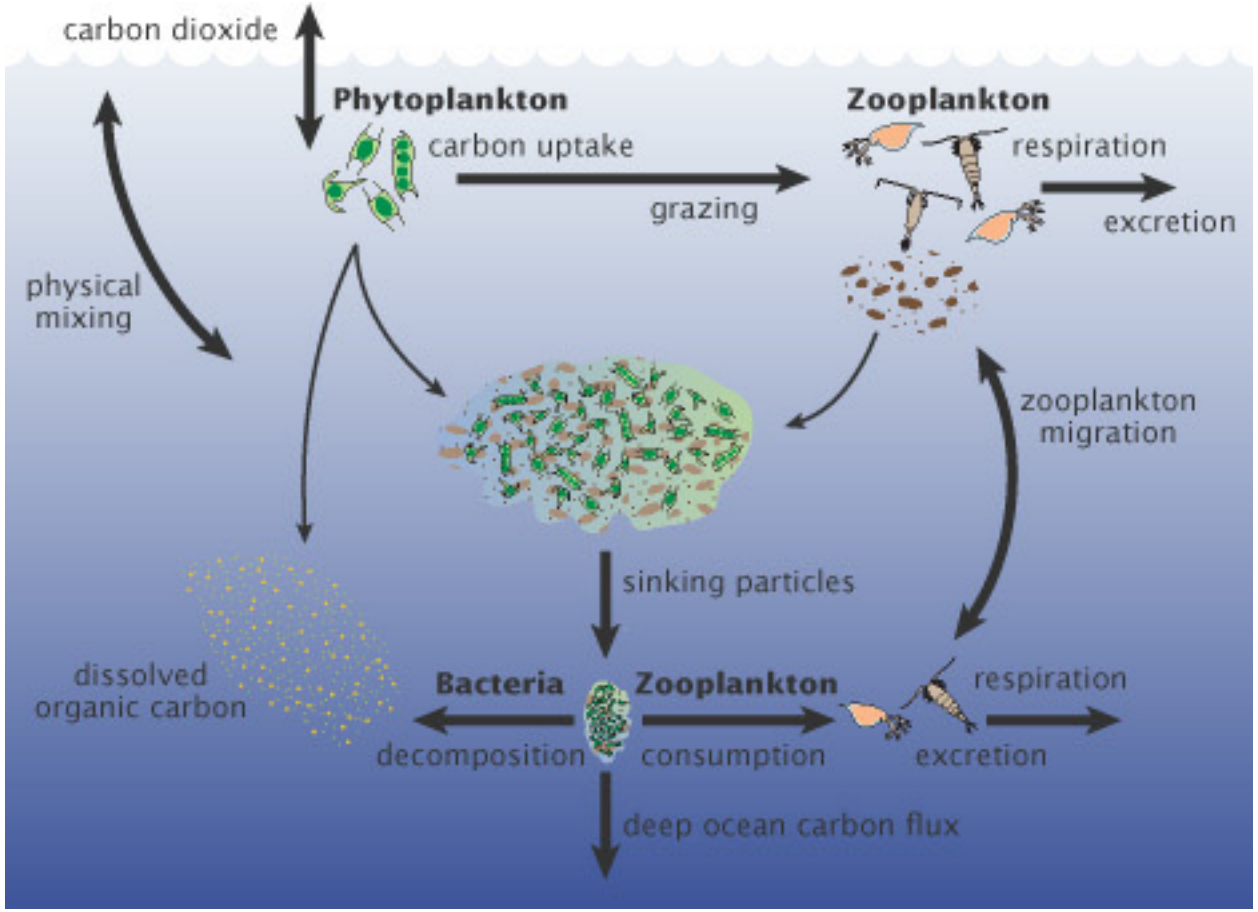
Semrau, B., et al. (2022). *Int. J. Thermophys.*, 43 (3).





https://earthobservatory.nasa.gov/features/Paleoclimatology_Evidence/paleoclimatology_evidence_2.php

Phytoplankton



https://earthobservatory.nasa.gov/features/Phytoplankton

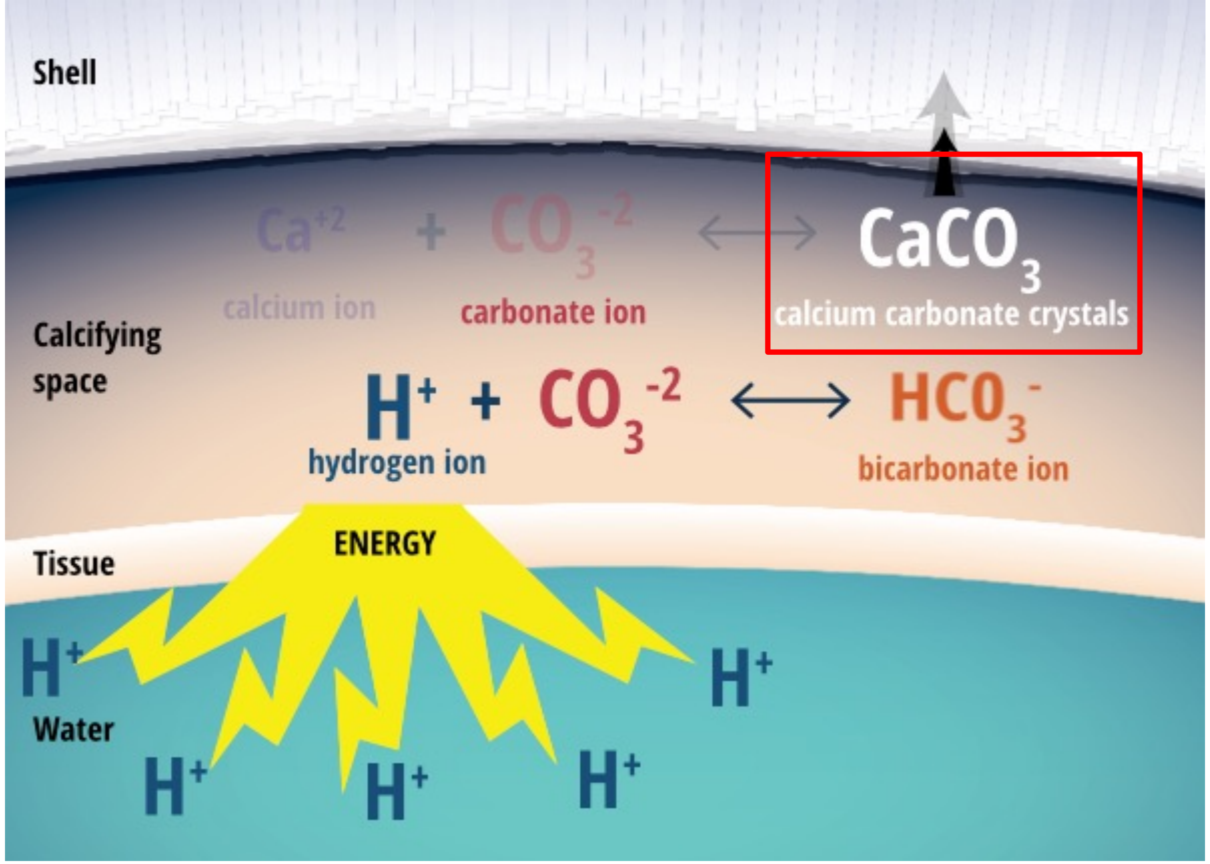
Anthropogenic CO_2 emissions

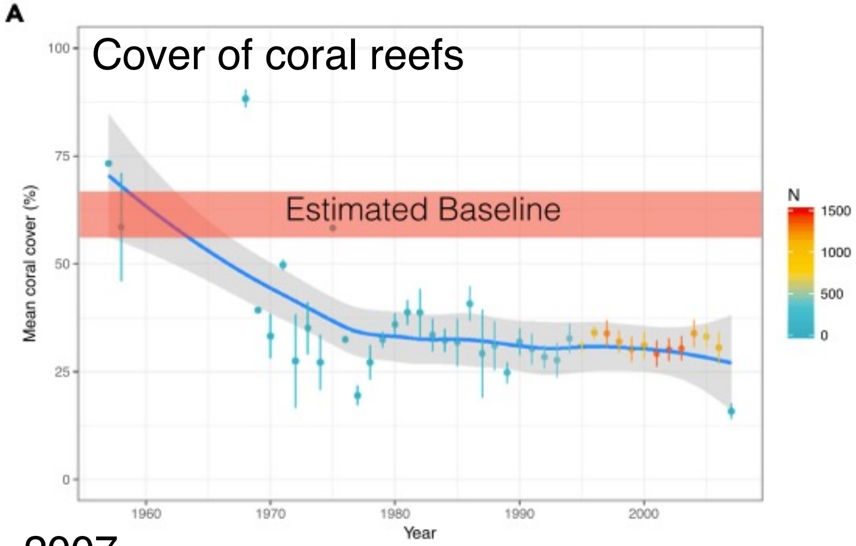
Global warming

Productivity

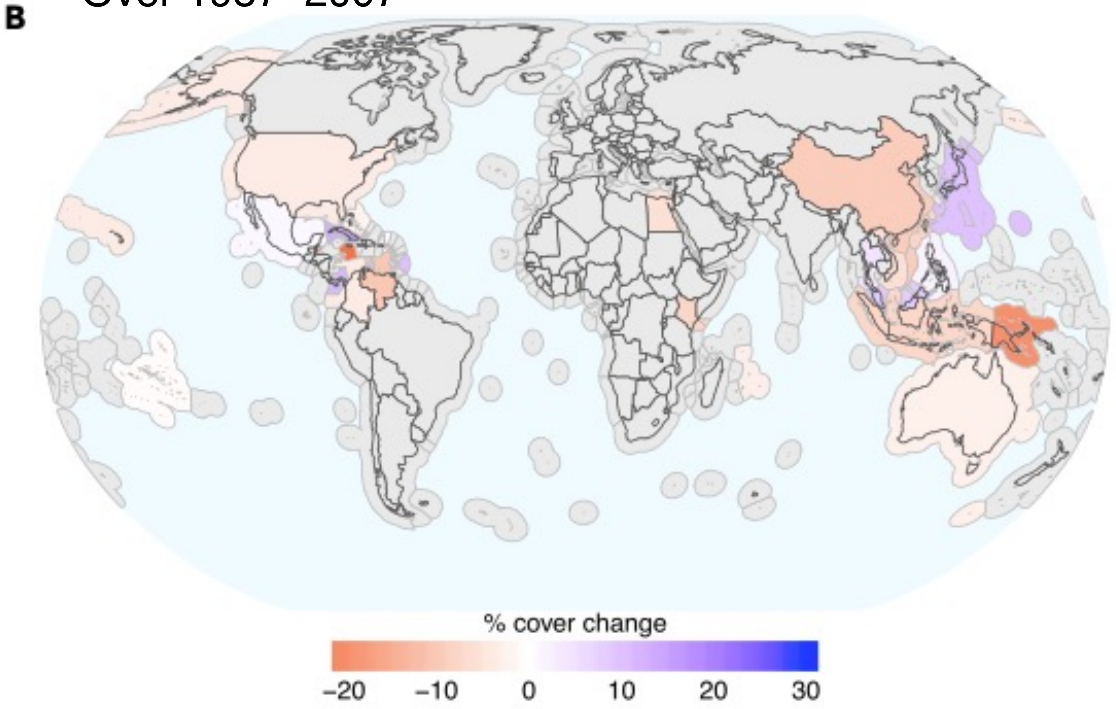
Ocean acidification

Threat to shellfish and corals





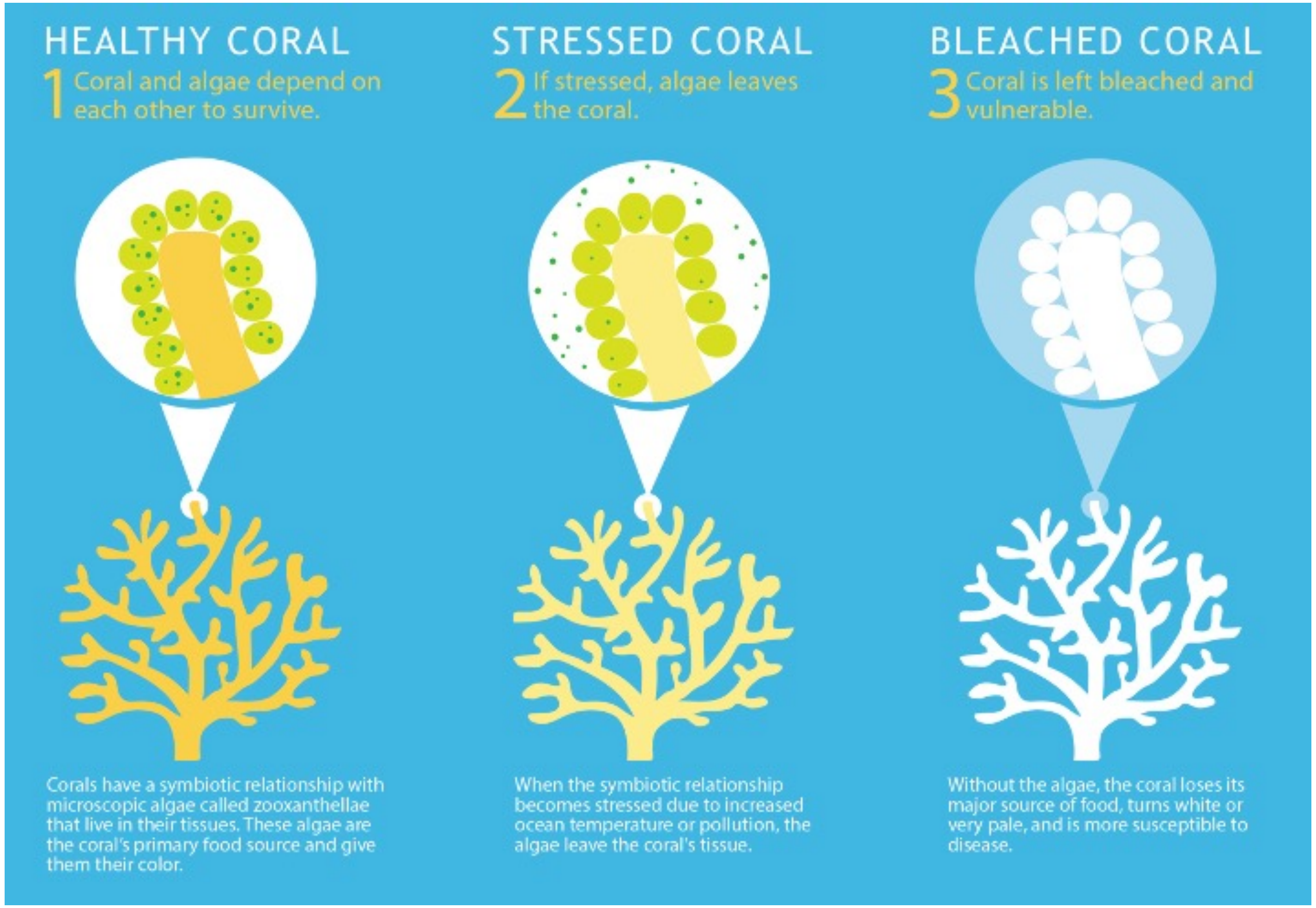
Over 1957–2007



Eddy, T.D., et al. (2021). *One Earth*, 4, 1278–1285.

https://www.whoi.edu/multimedia/carbon-dioxide-shell-building-and-ocean-acidification/

Coral bleaching

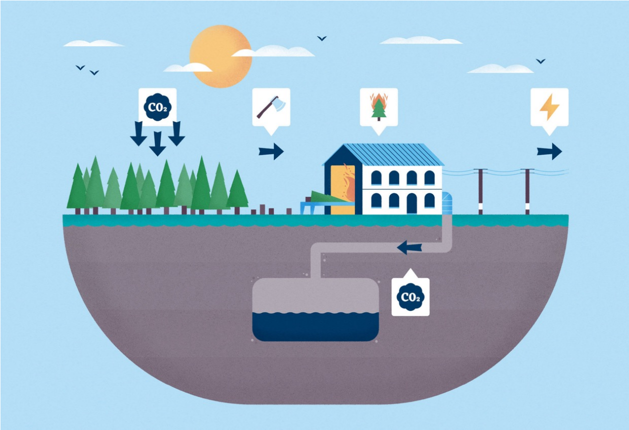


https://oceanservice.noaa.gov/facts/coral_bleach.html

What can we do?

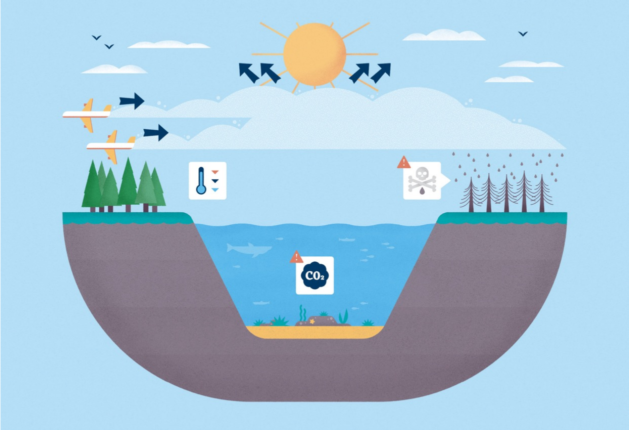
Geoengineering

Earth Systems viewpoint



Direct carbon capture

- May take effect but require huge amount of electricity production



Stratospheric aerosol injection

- Does not address acidification because CO2 emissions continue
- May disrupt stratospheric ozone (sulphate aerosols)

On the land

Environmental science

Atmospheric CO_2 removed by rock weathering

Johannes Lehmann & Angela Possinger

Large-scale removal of carbon dioxide from the atmosphere might be achieved through enhanced rock weathering. It now seems that this approach is as promising as other strategies, in terms of cost and CO_2-removal potential. See p.242

Lehmann, J., Possinger, A. (2020). *Nature*, 583, 204–205.

In the ocean

Mitigating the atmospheric CO_2 increase and ocean acidification by adding limestone powder to upwelling regions

L. D. D. Harvey[1]

Received 5 June 2007; revised 18 December 2007; accepted 5 February 2008; published 23 April 2008.

and supersaturation in these regions as well. Geographically optimal application of 4 billion t of $CaCO_3$ a^{-1} (0.48 Gt C a^{-1}) could induce absorption of atmospheric CO_2 at a rate of 600 Mt CO_2 a^{-1} after 50 years, 900 Mt CO_2 a^{-1} after 100 years, and 1050 Mt CO_2 a^{-1} after 200 years.

Harvey, L.D.D. (2008). *J. Geophys. Res.*, 113, C04028

https://chinadialogue.net/en/climate/geoengineering-how-to-stop-global-warming-most-controversial-solutions-explained/