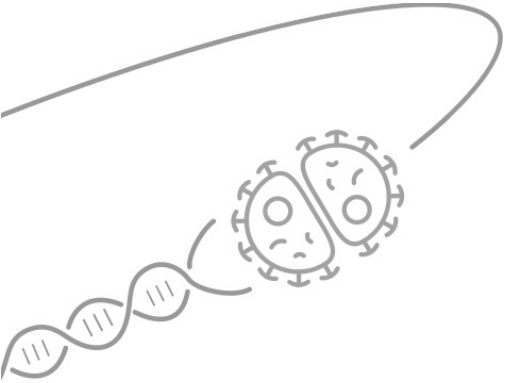
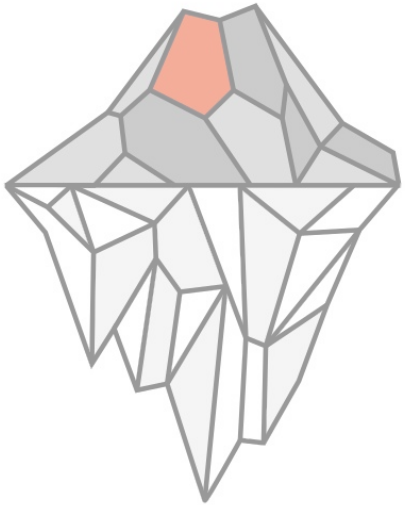


MICROBIAL METABOLISM AND PLANETARY HABITABILITY

GEOENGINEERING OUR CLIMATE



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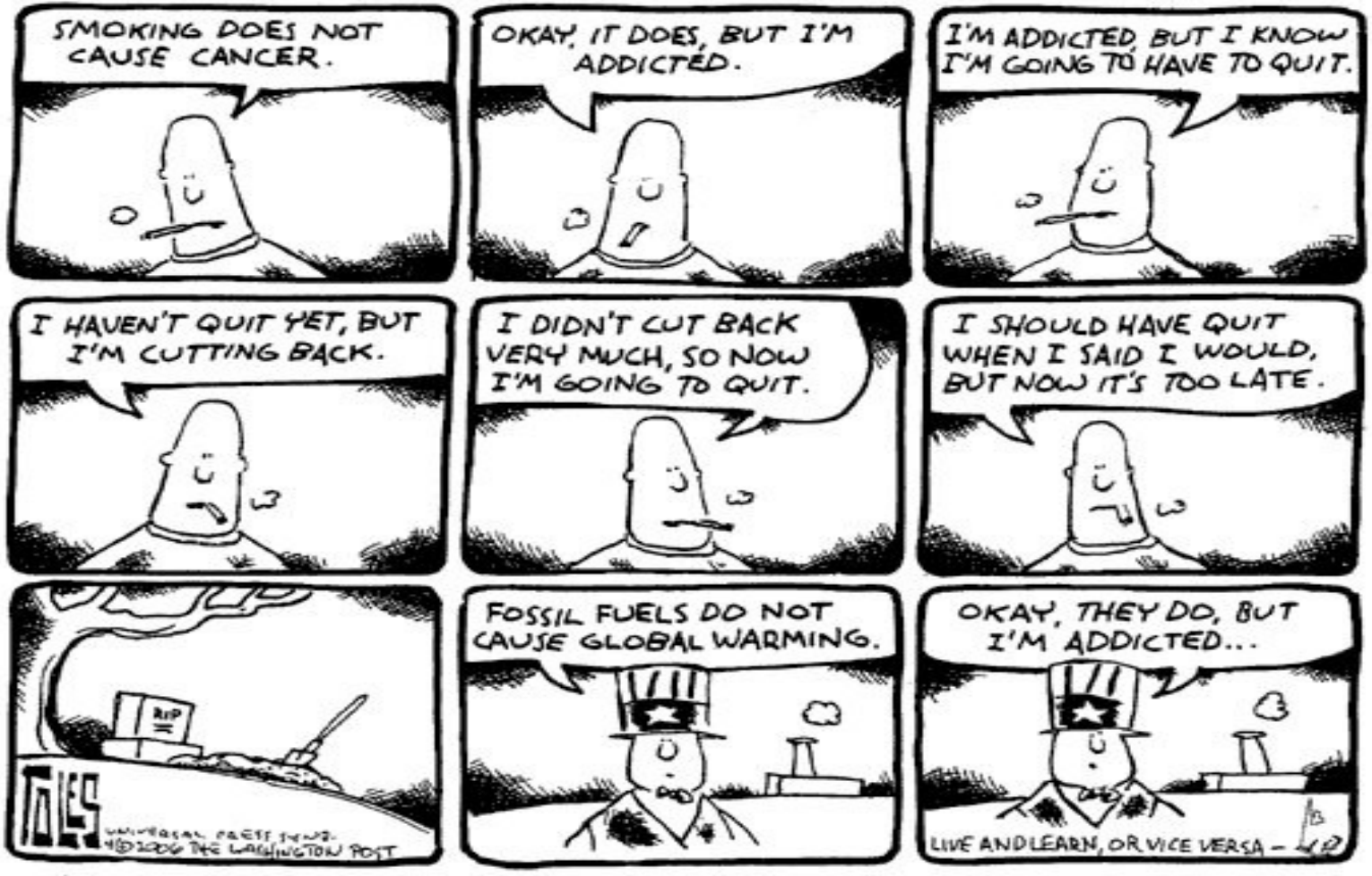
@donatogiovannelli

GIOVANNELLI LAB
UNIVERSITY OF NAPLES FEDERICO II

BIOLOGY OF EXTREME ENVIRONMENTS

DIPARTIMENTO DI BIOLOGIA


SMOKING DOES NOT CAUSE CANCER.
OKAY, IT DOES, BUT I'M ADDICTED.
I'M ADDICTED, BUT I KNOW I'M GOING TO HAVE TO QUIT.
I HAVEN'T QUIT YET, BUT I'M CUTTING BACK.
I DIDN'T CUT BACK VERY MUCH, SO NOW I'M GOING TO QUIT.
I SHOULD HAVE QUIT WHEN I SAID I WOULD, BUT NOW IT'S TOO LATE.
RIP
TOLES
FOSSIL FUELS DO NOT CAUSE GLOBAL WARMING.
OKAY, THEY DO, BUT I'M ADDICTED...
LIVE AND LEARN, OR VICE VERSA –
4-4-06

Climate Engineering: Geoengineering

Refers to actions deliberately taken in order to alter the natural functioning of processes that can directly or indirectly help with the mitigation of the climate ~~change~~ crisis, global warming and the increase of CO_2 in the atmosphere

Geoengineering is the deliberate modification of Earth's environment on a large scale "to suit human needs and promote habitability"

Over the years it has focused on different aspect of the issue, tacking the problem with different technological approach

These can be broadly divided in Solar Radiation Management and Carbon Sequestration

An incomplete history of Geoengineering

*In **1905** Arrhenius discussed a "virtuous circle" in which CO2 emissions would warm the climate, changing the northern limits of agriculture and enhancing productivity.*

Cloud seeding efforts started in 30s and 40s

*Modern concept goes back at least to **1945** in a meeting organized by John Von Neumann at Princeton on "deliberate modification of weather"*

***1953** Presidents Advisory Committee on weather control with focus on "rainmaking"*

***1955** in interview in Fortune magazine Von Neumann speculated that "Microscopic layers of colored matter spread on an icy surface, or in the atmosphere above one, could inhibit the reflection-radiation process, melt the ice, and change the local climate"*

An incomplete history of Geoengineering

*By **1970s** US gov spending $20M/yr on weather modification research. Substantial amounts also spent in USSR on this topic*

*Circa **1974**, it wascalculated that if global warming ever became a serious threat, we could counter it with just a few airplane flights a day in the stratosphere, burning sulfur to make aerosols that would reflect sunlight away*

1977 National Academy Report on Geoengineering

*Lamb, Hubert H. (**1971**). "Climate-Engineering Schemes to Meet a Climatic Emergency." Earth-Science Reviews said "an essential precaution is to wait until a scientific system for forecasting the behavior of the natural climate... has been devised and operated successfully for, perhaps, a hundred years"*

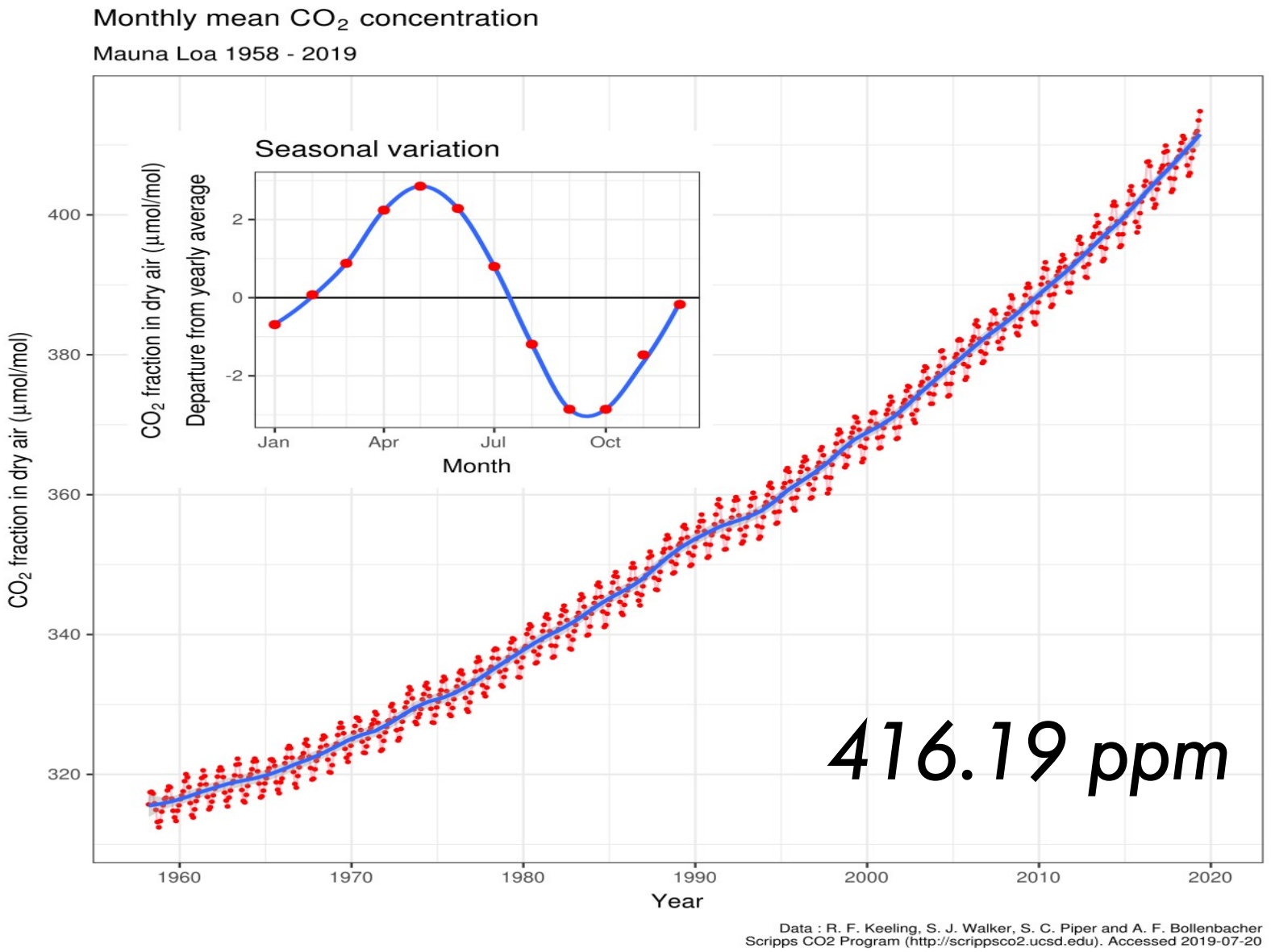
Keeling curve

*The **Keeling Curve** is a graph of the accumulation of carbon dioxide in the Earth's atmosphere based on continuous measurements taken at the Mauna Loa Observatory on the island of Hawaii from 1958 to the present day.*

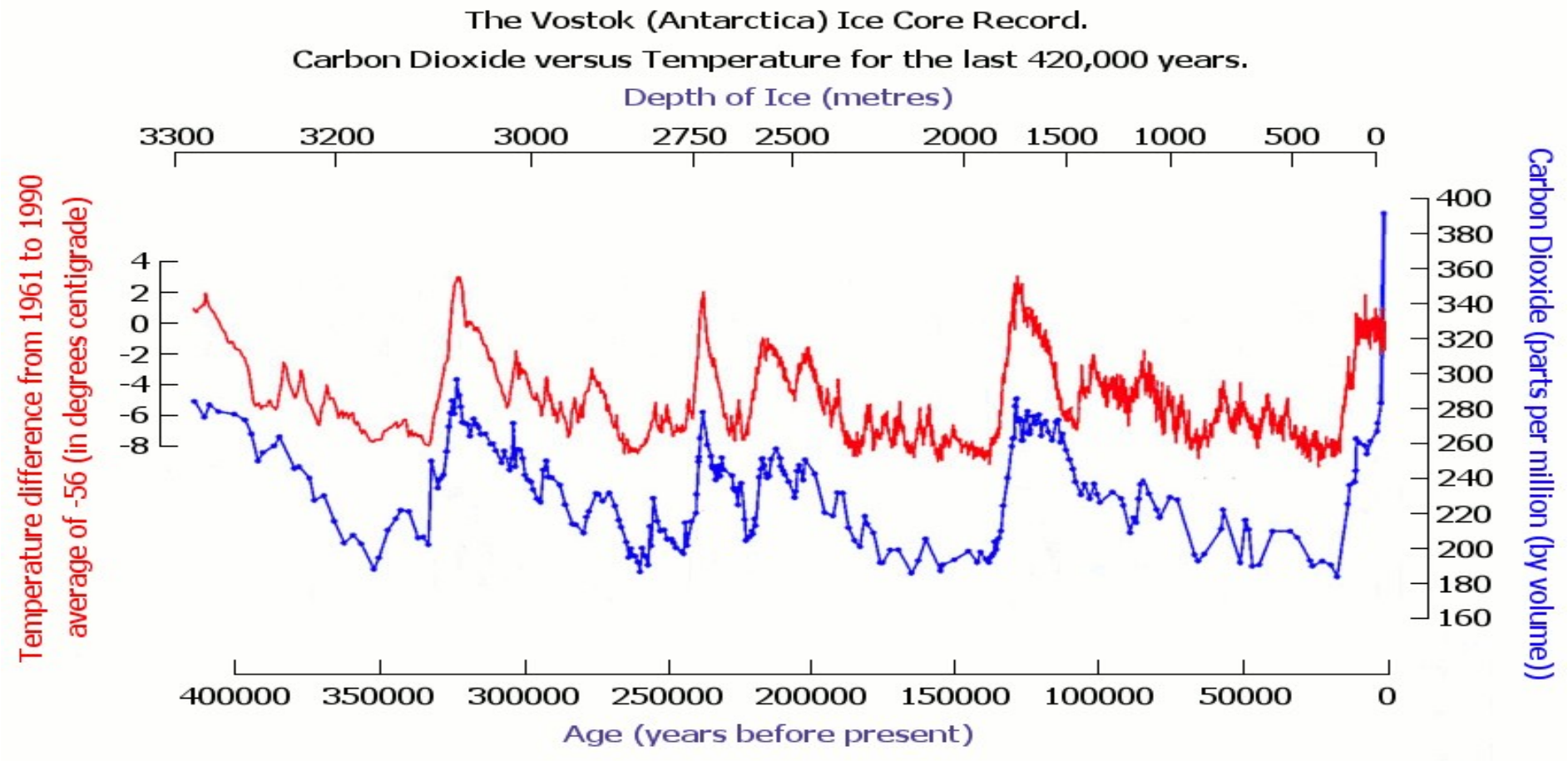
The curve is named for the scientist Charles David Keeling, who started the monitoring program and supervised it until his death in 2005.

Keeling's measurements showed the first significant evidence of rapidly increasing carbon dioxide levels in the atmosphere.

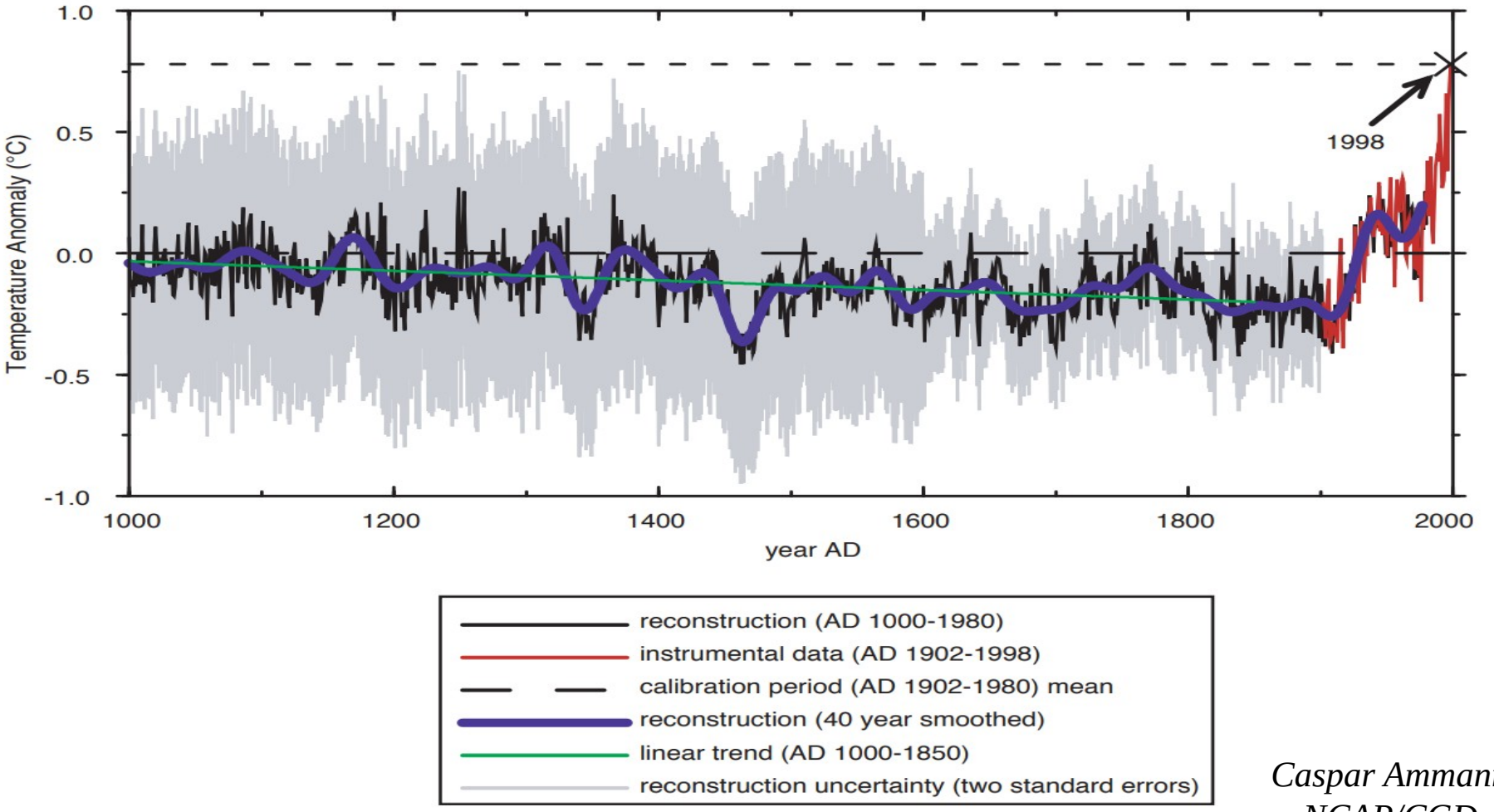
Many scientists credit the Keeling curve with first bringing the world's attention to the current increase of carbon dioxide in the atmosphere.


Monthly mean CO_2 concentration
Mauna Loa 1958 - 2019
Seasonal variation
CO_2 fraction in dry air (µmol/mol)
Departure from yearly average
2
0
-2
Jan
Apr
Jul
Oct
Month
CO_2 fraction in dry air (µmol/mol)
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
Year
416.19 ppm
Data : R. F. Keeling, S. J. Walker, S. C. Piper and A. F. Bollenbacher
Scripps CO2 Program (http://scrippsco2.ucsd.edu). Accessed 2019-07-20

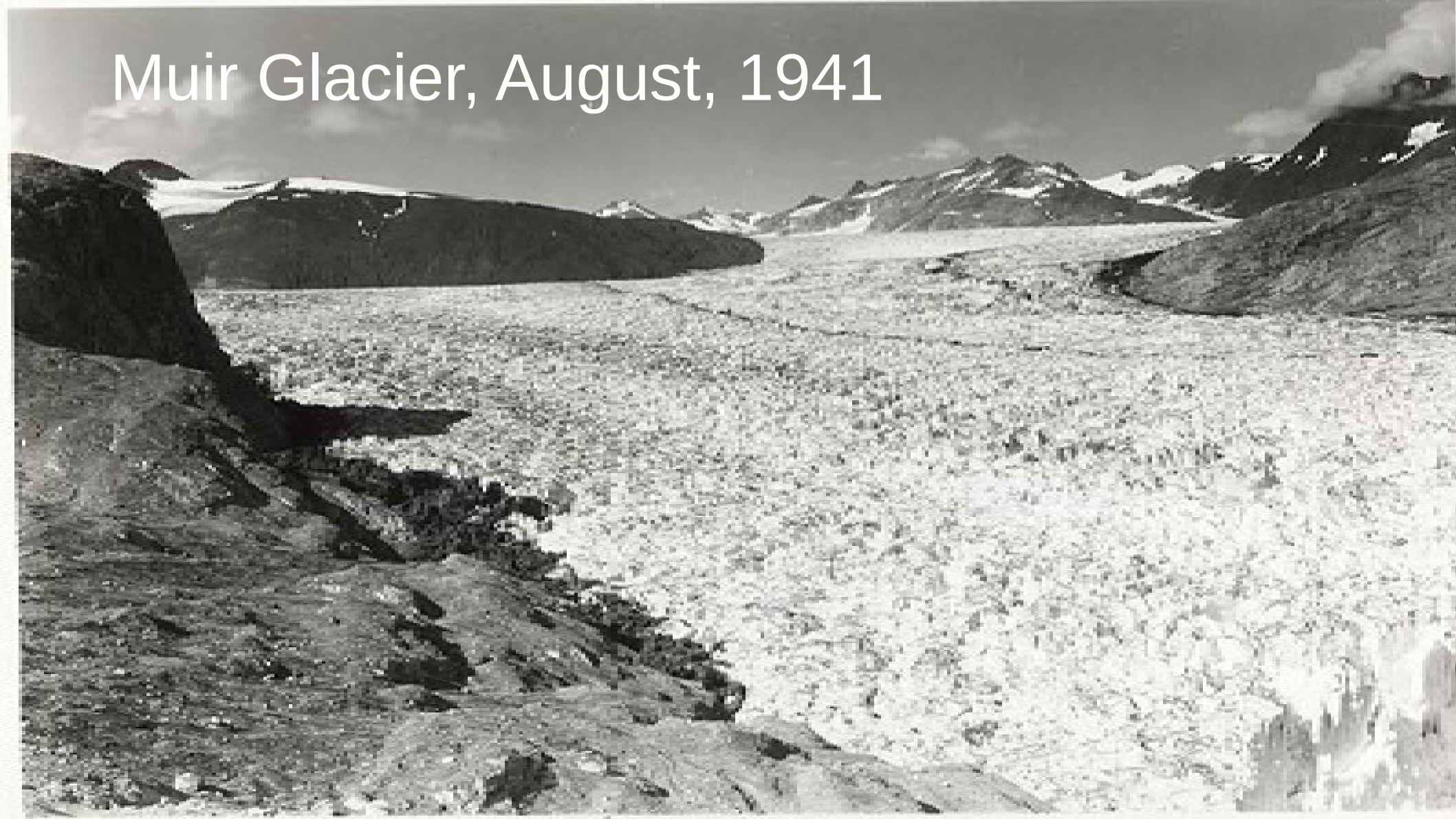
CO2 – Temperature correlations



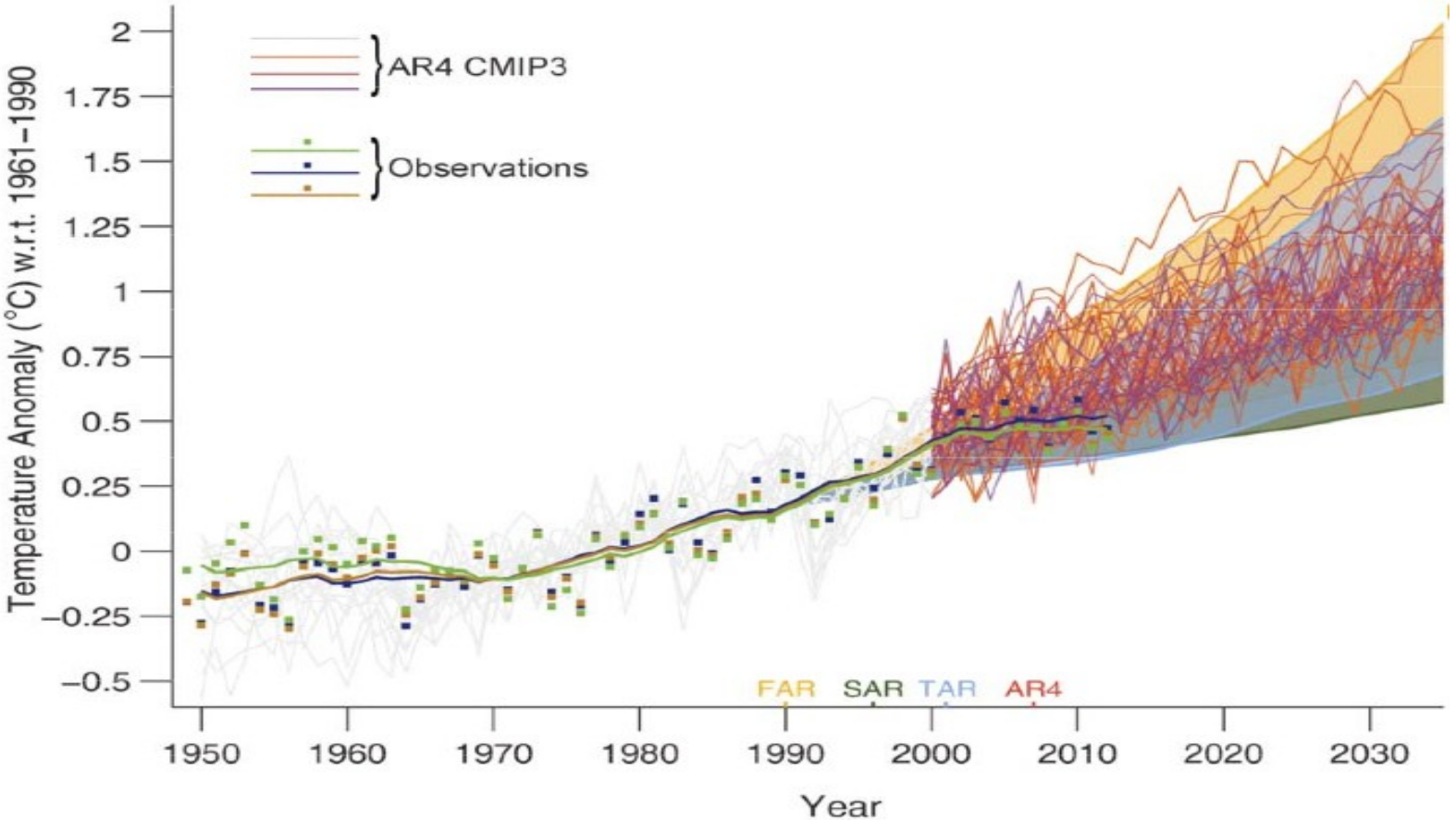
The Last Millenium



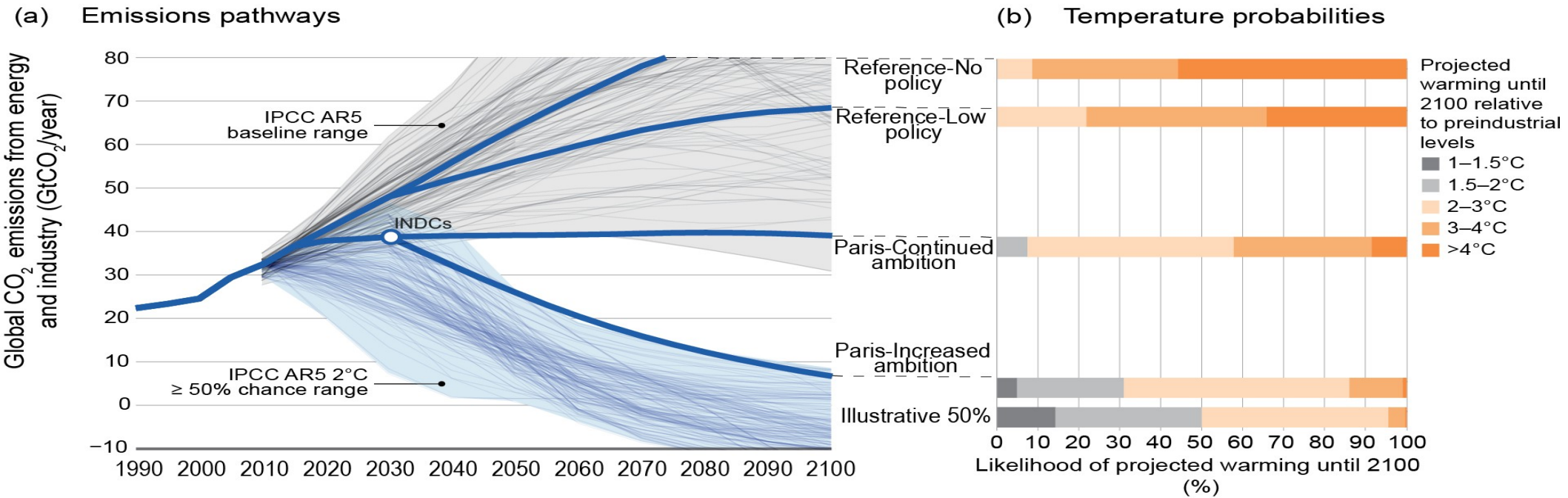
Caspar Ammann
NCAR/CGD


Muir Glacier, August, 1941


Muir Glacier, August, 2004



2013 Intergovernmental Panel on Climate Change (IPCC) report



Wikipedia, Global CO2 emissions and probabilistic temperature outcomes of different policies

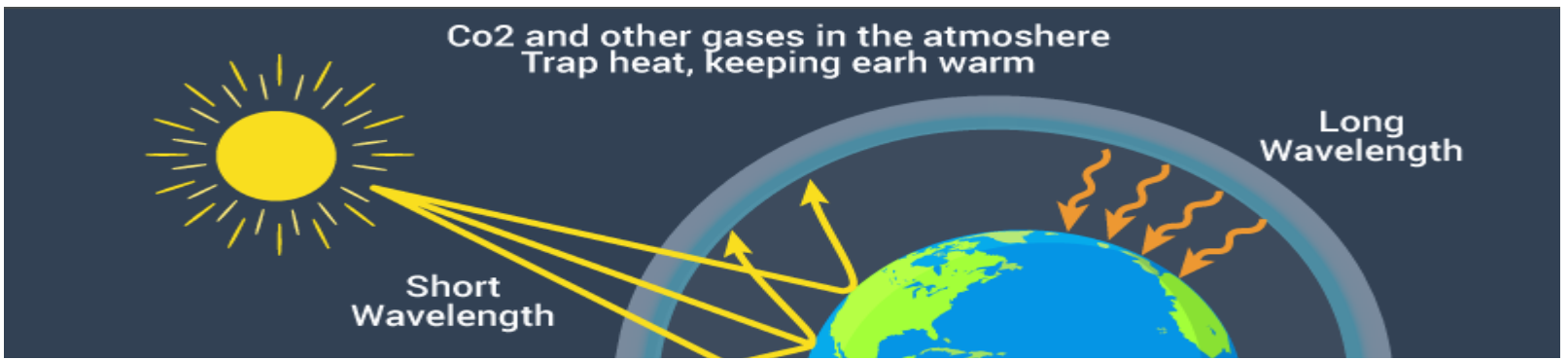
Geoengineering what?

Key concept: Greenhouse effect

The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere.

If a planet's atmosphere contains radiatively active gases (i.e., greenhouse gases) they will radiate energy in all directions. Part of this radiation is directed towards the surface, warming it.

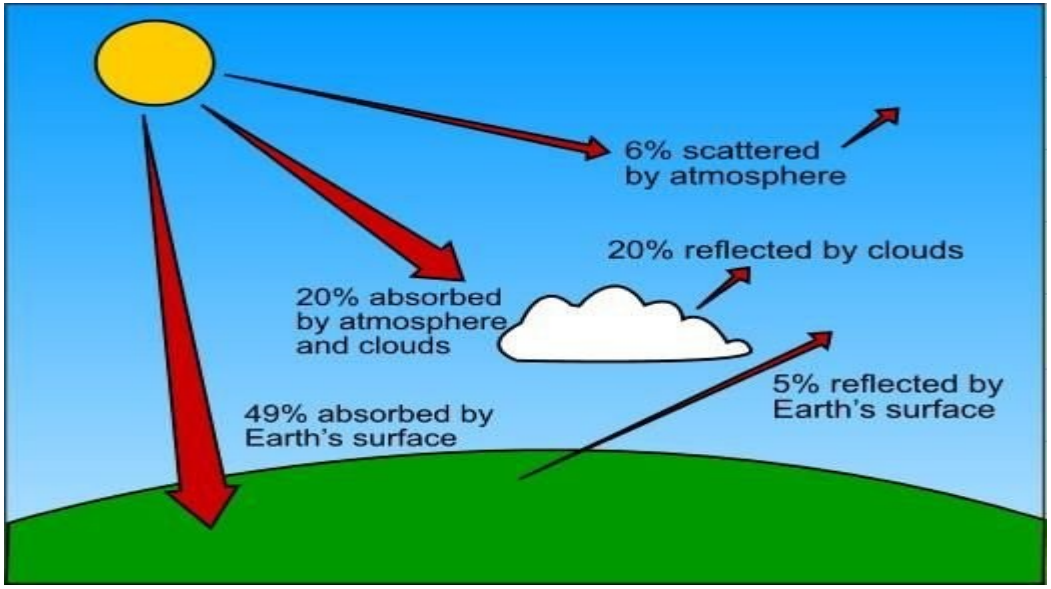
Earth's natural greenhouse effect is critical to supporting life.



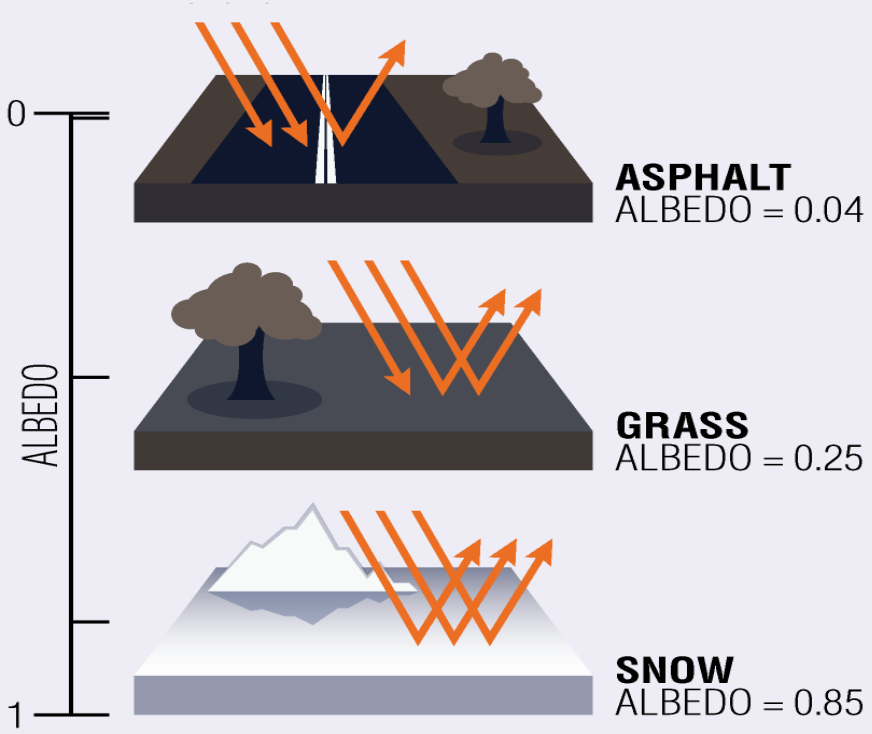
Key concept: Albedo

Albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation received by an astronomical body (e.g. a planet like Earth).

It is dimensionless and measured on a scale from 0 (corresponding to a black body that absorbs all incident radiation) to 1 (corresponding to a body that reflects all incident radiation).



WORD OF THE WEEK | ALBEDO



A measure (between zero and one) of the amount of light reflected off of a surface.

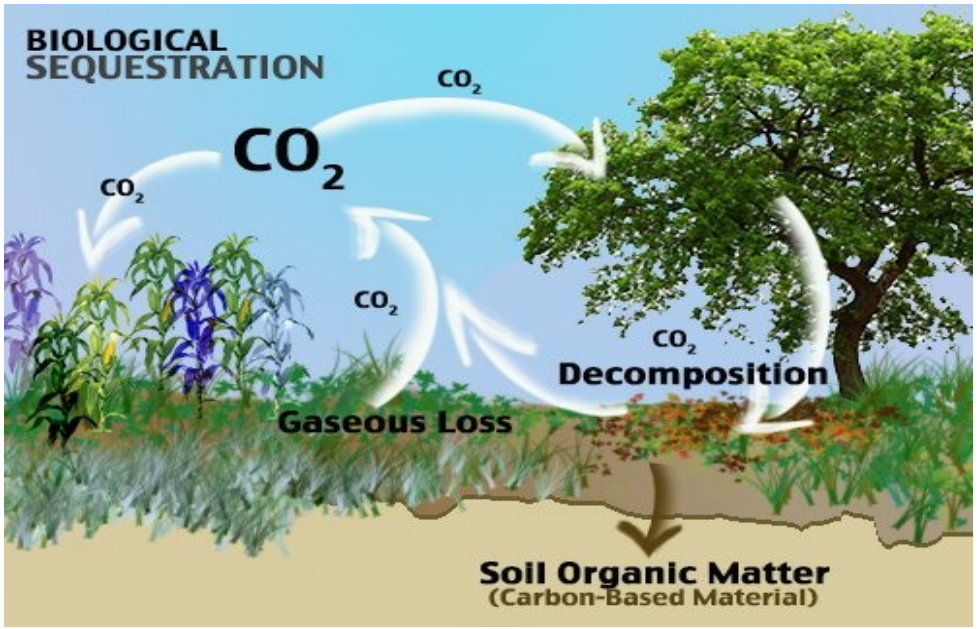
Objects like dark asphalt and Bennu have a low albedo. Objects like ice and snow have a high albedo.

Key concept: Biological Sequestration

Biological sequestration is the is the ***capture and storage*** *of the atmospheric greenhouse gas carbon dioxide by biological processes*

This may be by increased ***primary productivity*** *(reforestation, biological carbon pump) or by* ***preventive measures*** *(avoid deforestation)*

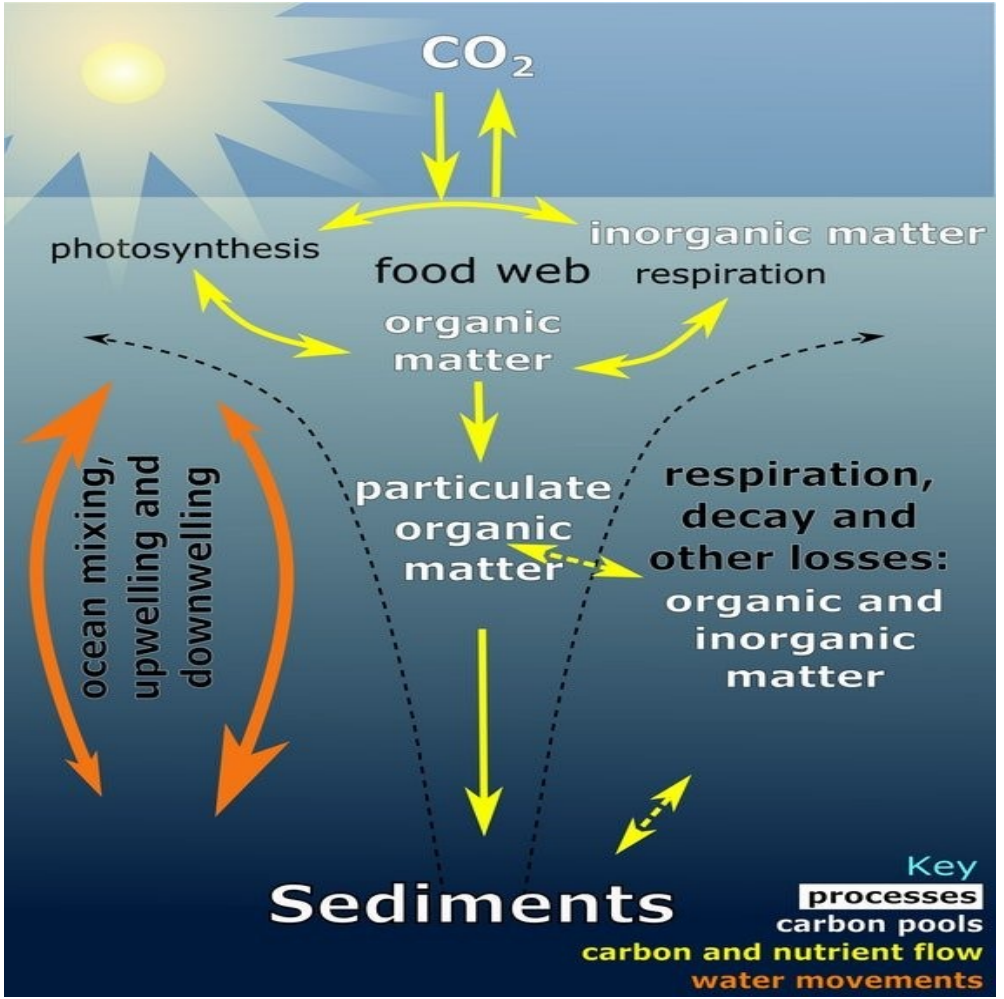
Storage can be achieved in different ways, such as through ***burrial*** *or* ***immobilization*** *in refractory fractions of organic matter*



Key concept: Biological Carbon Pump

The biological pump, in its simplest form, is the ocean's biologically driven sequestration of carbon from the atmosphere to the ocean interior and seafloor sediments

It is the part of the oceanic carbon cycle responsible for the sequestering organic matter formed mainly by phytoplankton during photosynthesis (soft-tissue pump), as well as the cycling of calcium carbonate ($CaCO_3$) formed into shells by certain organisms such as plankton and mollusks (carbonate pump)



Key concept: Carbonation of Rocks

Carbon, in the form of CO2 can be removed from the atmosphere by chemical processes, and stored in ***stable carbonate mineral*** *forms. This process is known as 'carbon sequestration by mineral carbonation' or mineral sequestration.*

The process involves reacting carbon dioxide with abundantly available metal oxides–either magnesium oxide (MgO) or calcium oxide (CaO)–to ***form stable carbonates****.*

These reactions are exothermic and ***occur naturally*** *(e.g., the weathering of rock over geologic time periods).*

Some rocks are ***more prone to carbonation****, and therefore are primary target for carbon storage studies*

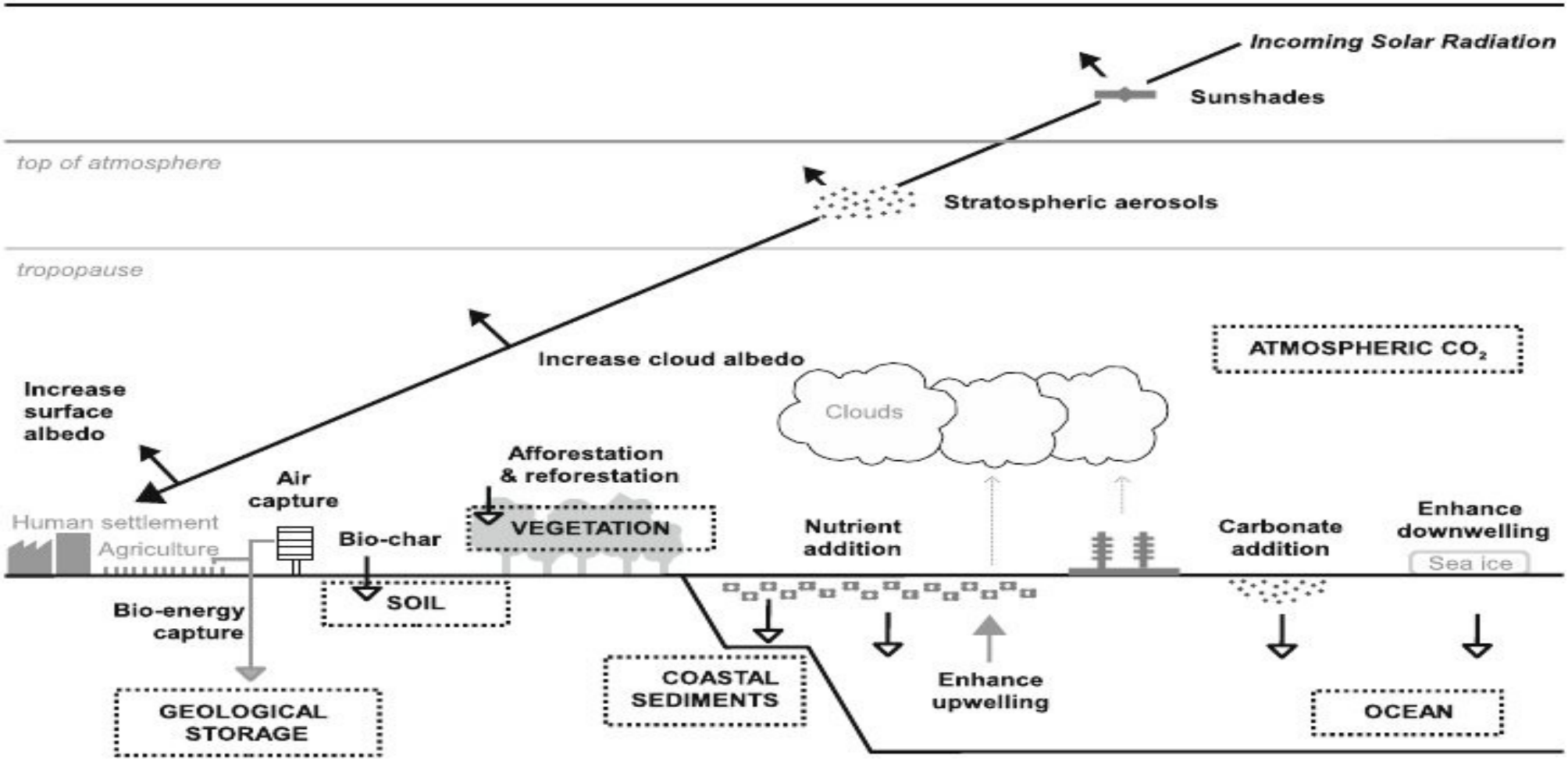
Geoengineering: (some) technologies

Solar Radiation management

- *Space mirrors (Wood, Angel)*
- *Seeding stratocumulus clouds (Aerosols)*
- *Sulfur particles: high altitude injections*
- *Sulfur particles: volcanoes*

Carbon Sequestration

- *Ocean Carbon Pump*
- *Carbonation of Rocks*



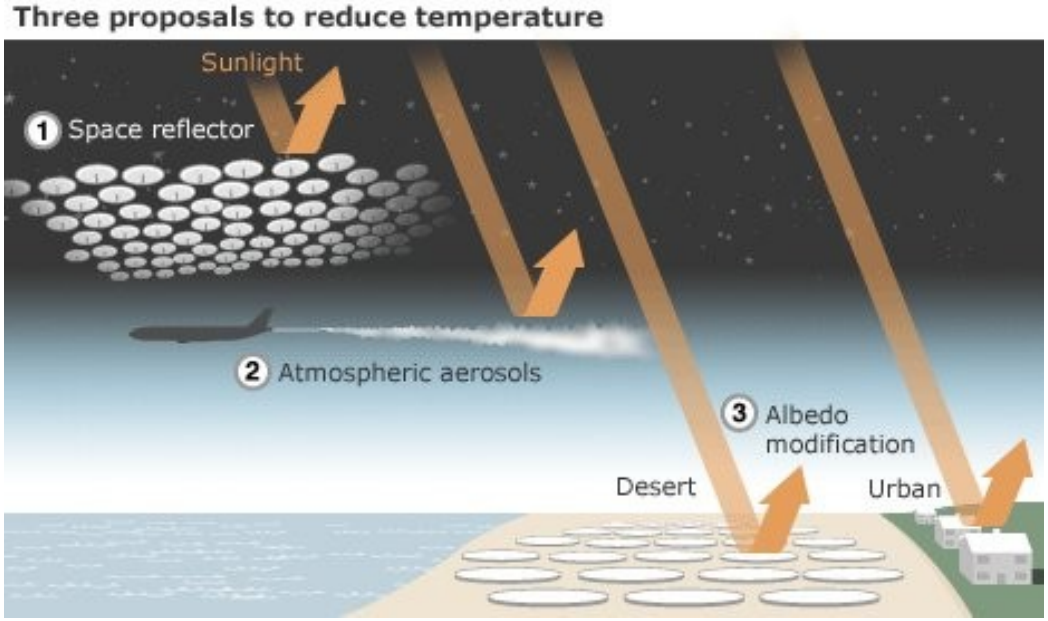
Vaughan and Lenton, 2011 *Climatic change*

Solar Radiation Management

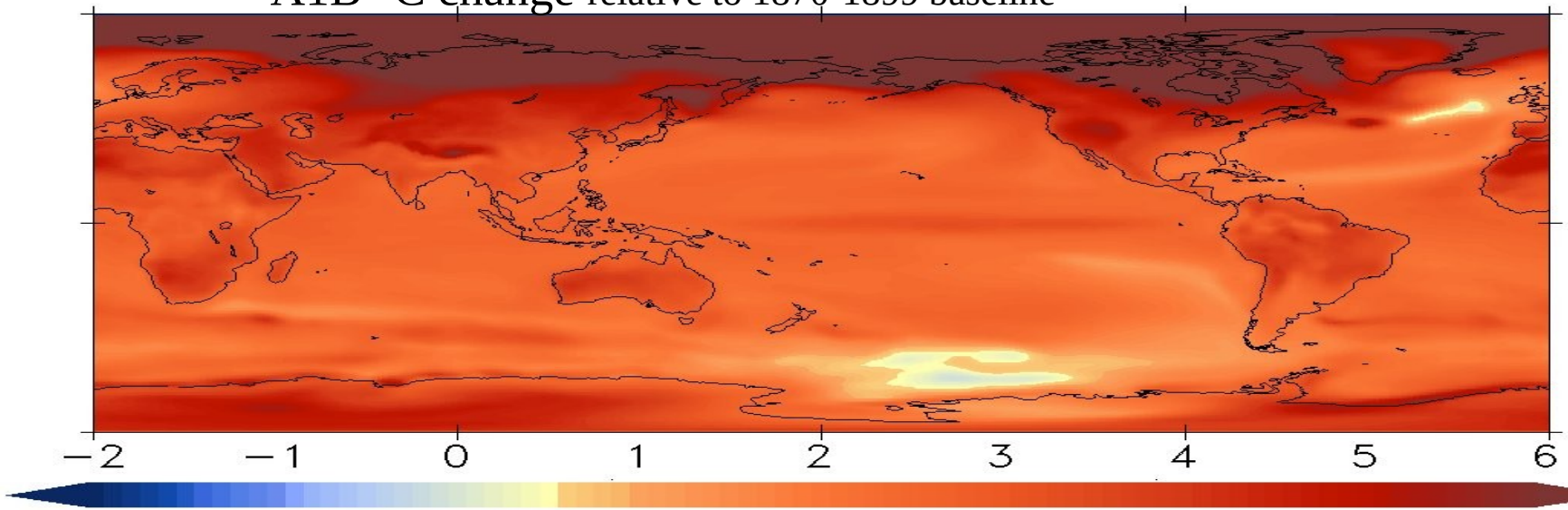
Solar Radiation Management

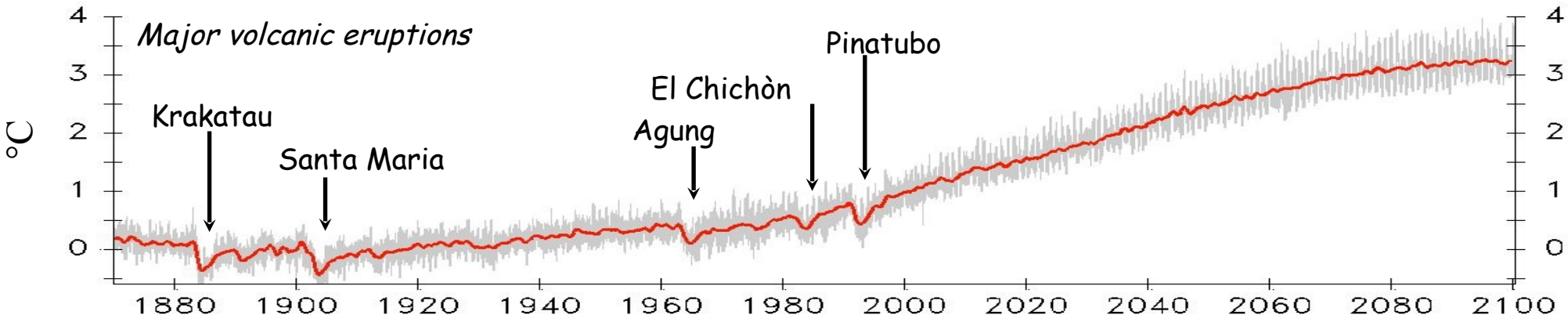
Solar Radiation management

- *Space mirrors (Wood, Angel)*
- *Seeding stratocumulus clouds (Aerosols)*
- *Sulfur particles: high altitude injections*
- *Sulfur particles: volcanoes*
- *Albedo modifications*



A1B °C change relative to 1870-1899 baseline





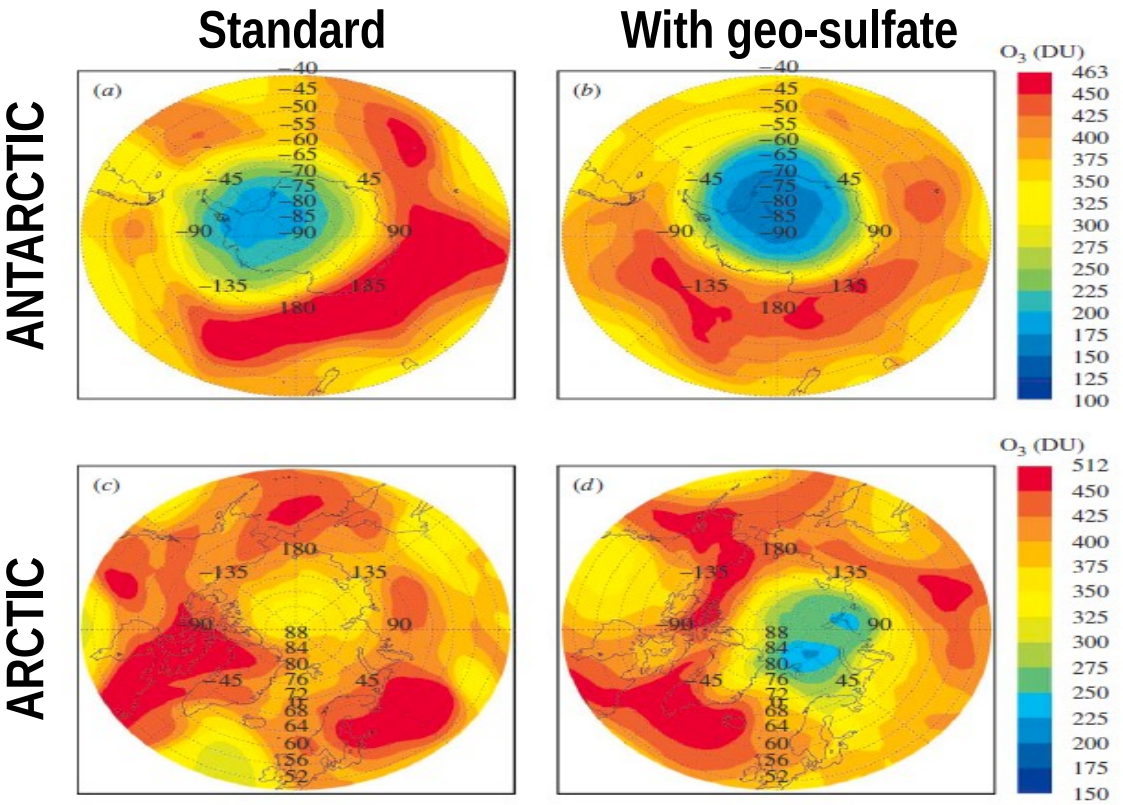
Global average surface temperature (relative to 1870-1899 mean)

Impact on stratospheric ozone

Sulphate aerosols provide surfaces on which chemical reactions leading to ozone loss take place. They also lead to the increased formation of PSCs

Worsening of stratospheric ozone depletion:

- *substantial increase in Arctic ozone depletion especially during cold winters*
- *delay of 30-70 years in recovery of Antactic ozone layer*



2025 ozone simulations

Tilmes et al, 2008 Science

Rasch et al, 2008 Phil. Trans. R. Soc. A

Boundary layer cloud seeding

Deliberate introduction of Could Condensation Nuclei (CCN) to enhance the droplet concentration in low-level clouds increasing Cloud Albedo & Longevity - i.e. a cooling effect

This geoengineering approach may be considered an analogue to Natural droplet creation at ocean surface

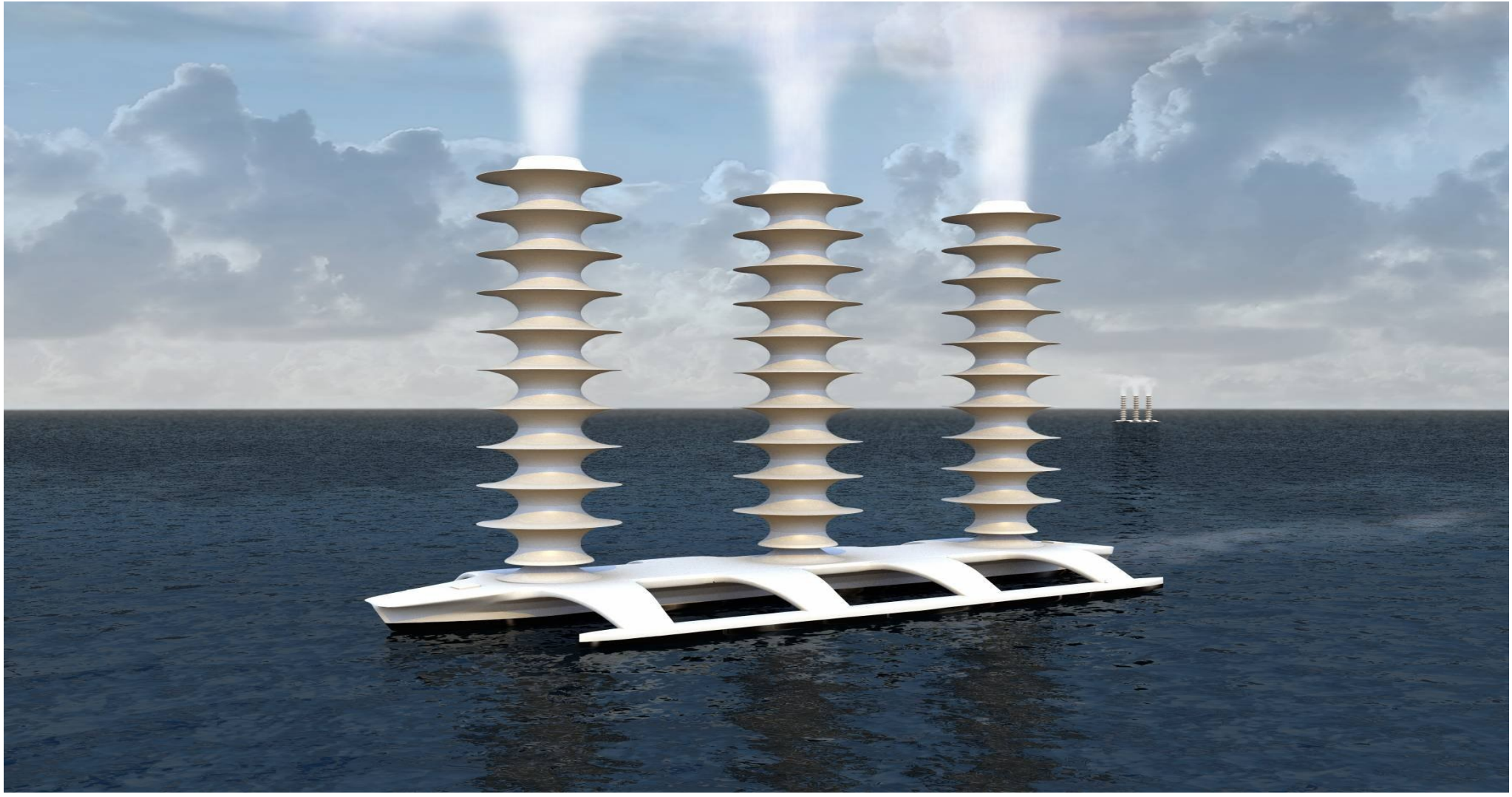
Bubble-bursting, white-capping NaCl droplets effective CCN

Ship tracks, fires, industrial pollution sources CO2 doubling compensated by (Slingo, 1990):

120% increase in droplet concentrations

40% decrease in effective radius

12% increase in oceanic cloud cover



Carbon Sequestration

Carbon Sequestration

Also known as "carbon capture", is a geoengineering technique for the long-term storage of carbon dioxide (or other forms of carbon) for the mitigation of global warming

Carbon sequestration generally assume two different things: carbon capture and carbon storage.

The efficiency of the capture and the time for which it can be stored influence the effectiveness of this geoengineering approach

Carbon can be sequestered:

- *Industrially*
- *In plants and soil "terrestrial sequestration"*
- *Deep in ocean "ocean sequestration"*
- *Underground "geological sequestration"*

Terrestrial Carbon Sequestration

Terrestrial Carbon Sequestration

The process through which CO2 from the atmosphere is absorbed naturally through photosynthesis and stored as carbon in biomass and soils.

Tropical deforestation is responsible for 20% of world's annual CO2 emissions, though offset by uptake of atmospheric CO2 by forests and agriculture

Ways to reduce greenhouse gases:

- avoiding emissions by maintaining existing carbon storage in trees and soils

- increasing carbon storage by tree planting or conversion from conventional to conservation tillage practices on agricultural lands

Carbon accumulation eventually reaches saturation point where additional sequestration is no longer possible (when trees reach maturity, or when the organic matter in soils builds back up to original levels before losses occurred)

After saturation, the trees or agricultural practices still need to be sustained to maintain the accumulated carbon and prevent subsequent losses of carbon back to the atmosphere

Geological Sequestration

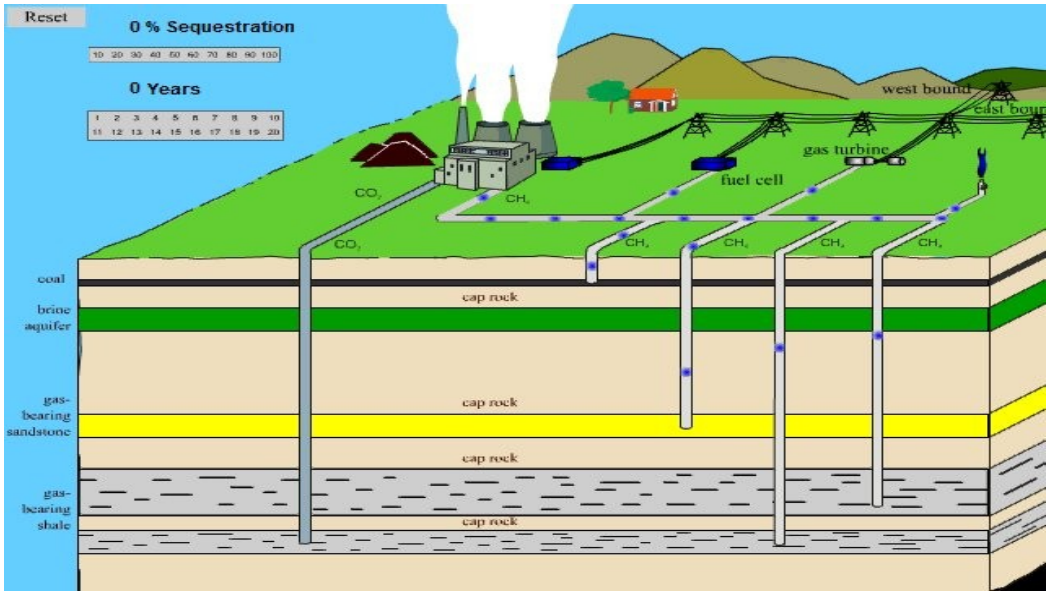
Midwest Geological Sequestration Consortium (Illinois)

Geological Sequestration

Storing of CO2 underground in rock formations able to retain large amounts of CO2 over a long time period

Held in small pore spaces, often in location that have held oil and natural gas for millions of years, as a supercritical fluid

Alternatively, can be directly bound to rocks as carbonate



Ocean Sequestration

Ocean Sequestration

Carbon is naturally stored in the ocean via two pumps, the **ocean carbonate buffer** *(solubility of CO2) and the* **biological carbon pump** *(photosynthesis)*

In the ocean carbonate buffer, dissolved carbon dioxide from the atmosphere is in equilibrium with seawater concentrations of carbonic acid and bicarbonate

Dissolution of additional CO2 means a drop in pH of seawater, leading to ocean acidification

In the biological carbon pump, CO2 is used by photosynthetic organisms and in carbonate used for body parts

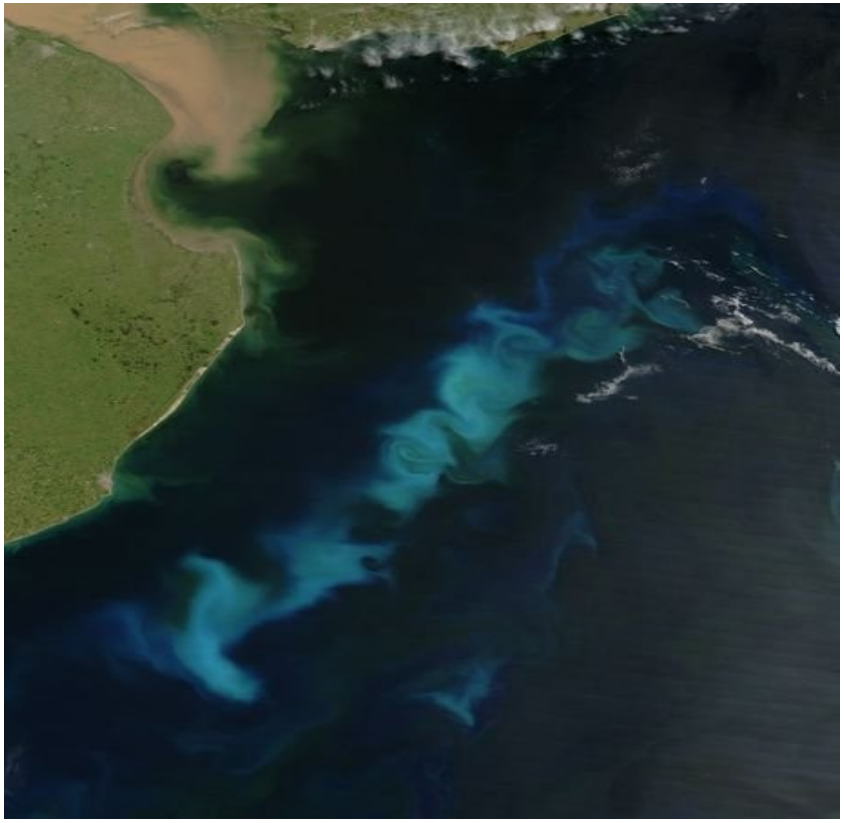
Carbon Sequestration: Ocean

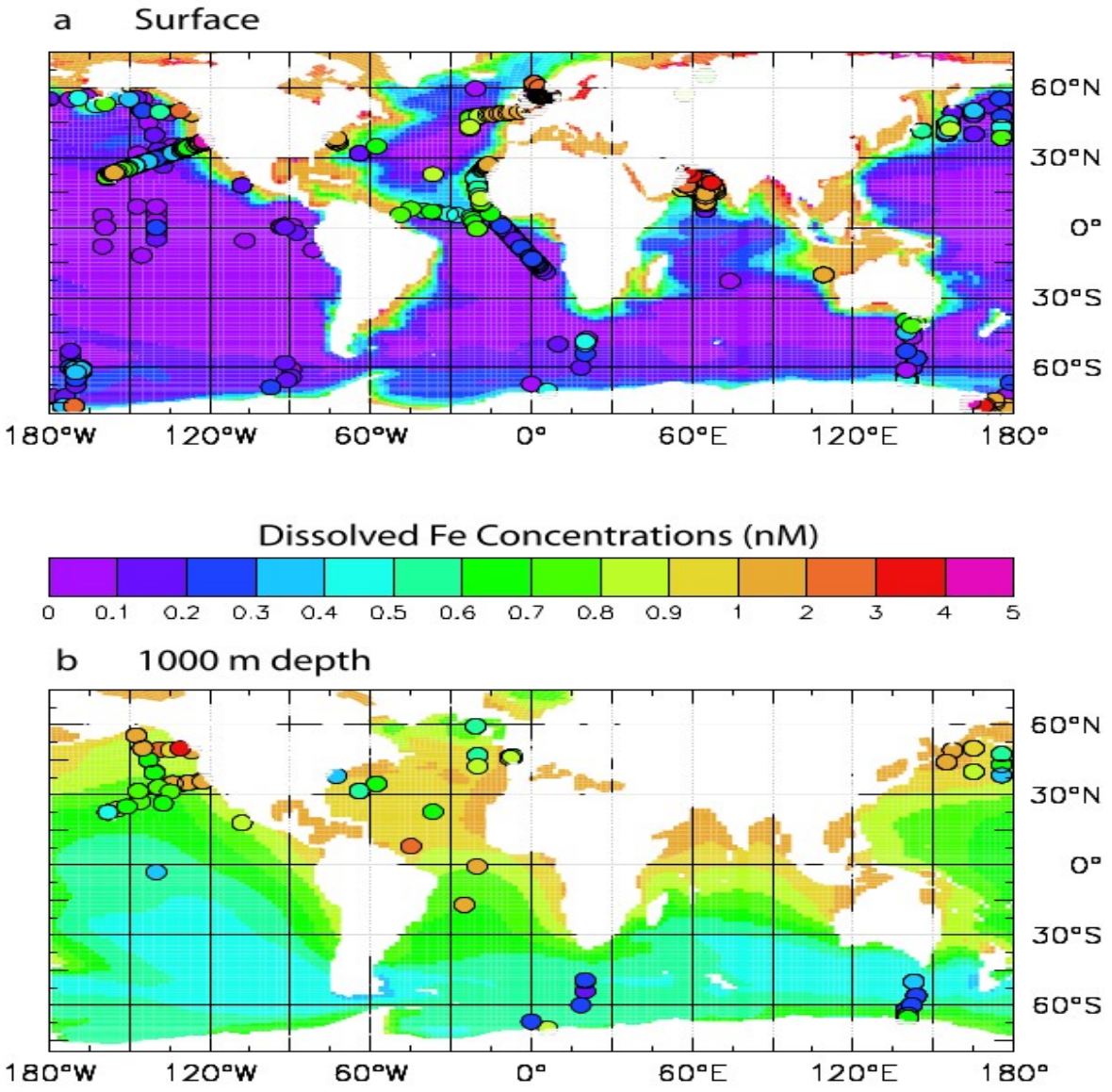
Primary Productivity in the Ocean

Primary productivity is limited in the ocean by the penetration of the ***solar radiation****,* ***nutrient*** *availability and* ***iron*** *concentrations*

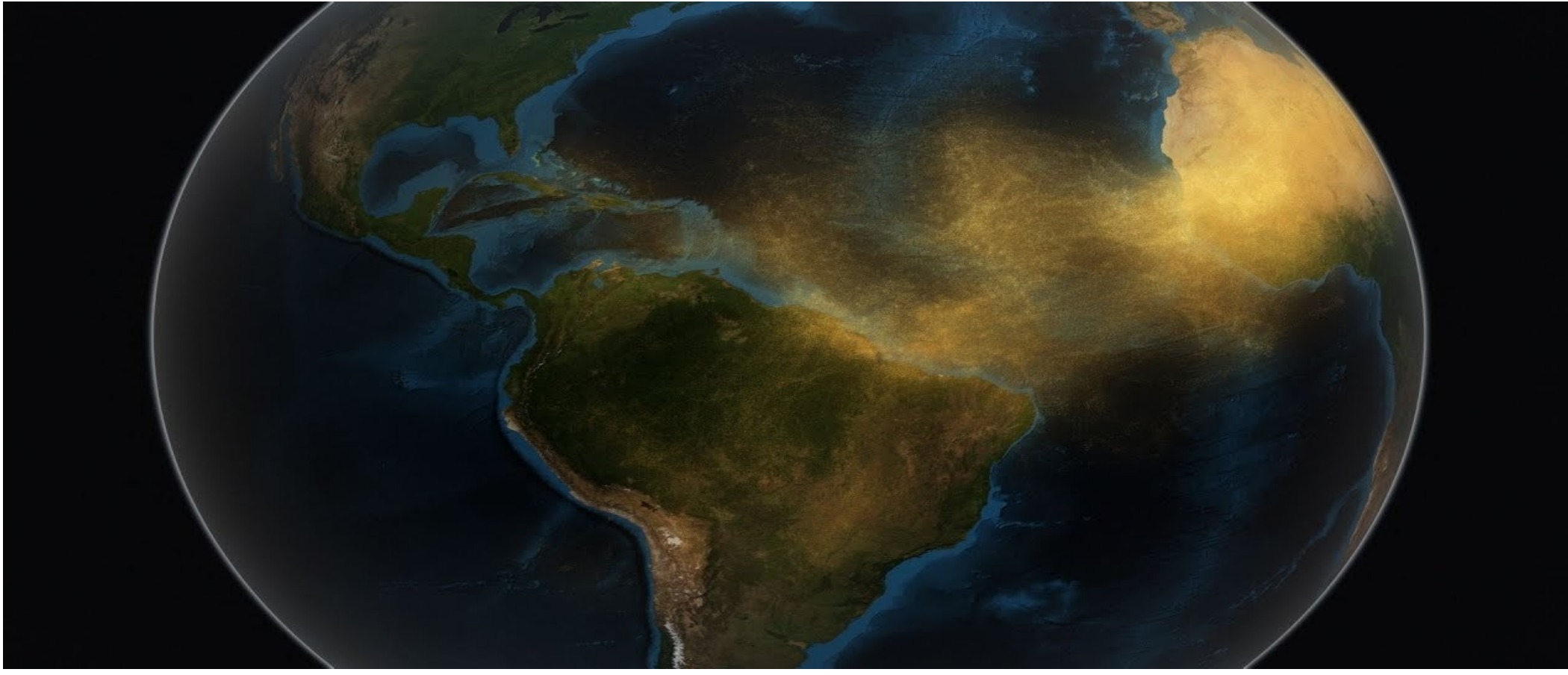
Besides photosynthesis, plankton that ***generate calcium or silica carbonate*** *skeletons, such as diatoms, coccolithophores and foraminifera, account for most direct carbon sequestration*

When these organisms die 20-30% of their carbonate skeletons ***sink to the seafloor*** *and get buried in sediments*

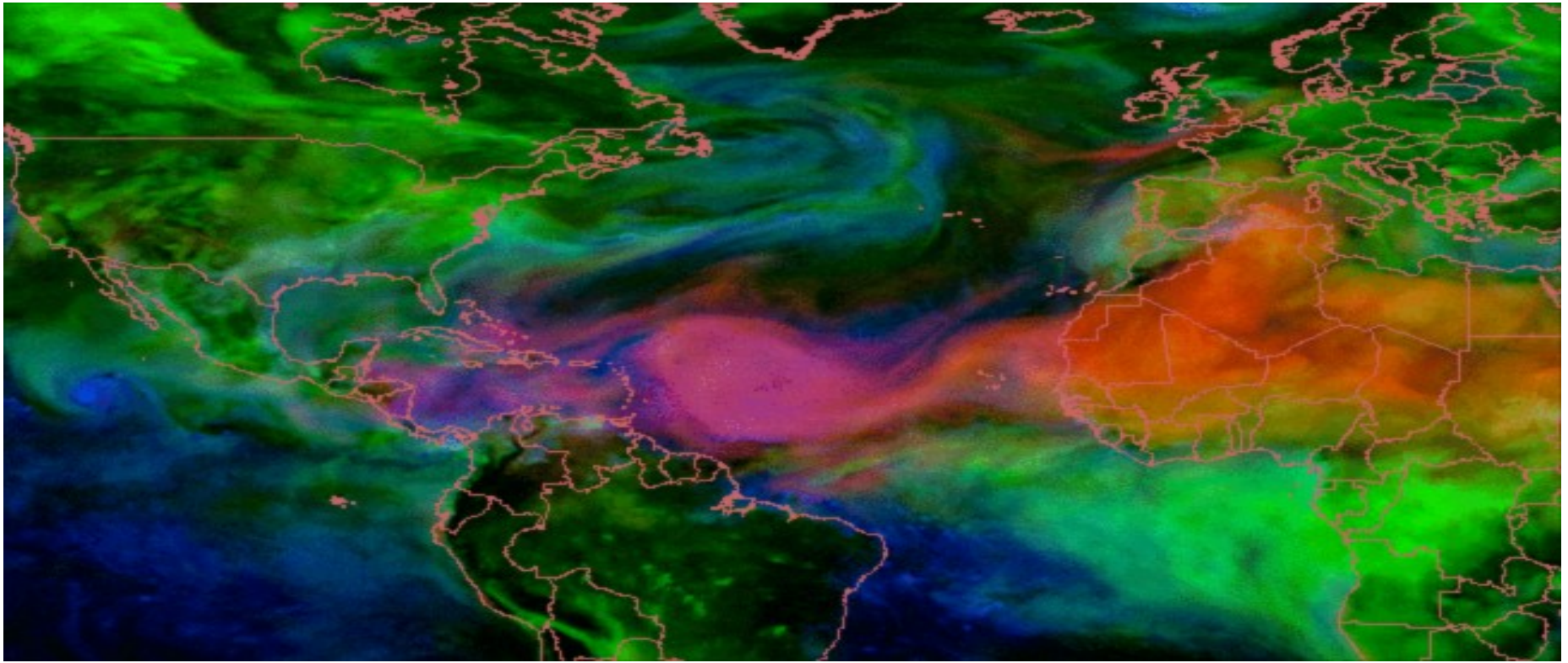



a Surface
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°
Dissolved Fe Concentrations (nM)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 2 3 4 5
b 1000 m depth
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°

Natural Iron Fertilization



Natural Iron Fertilization



"Give me a few oil tankers full of iron, and I'll give you an ice age."

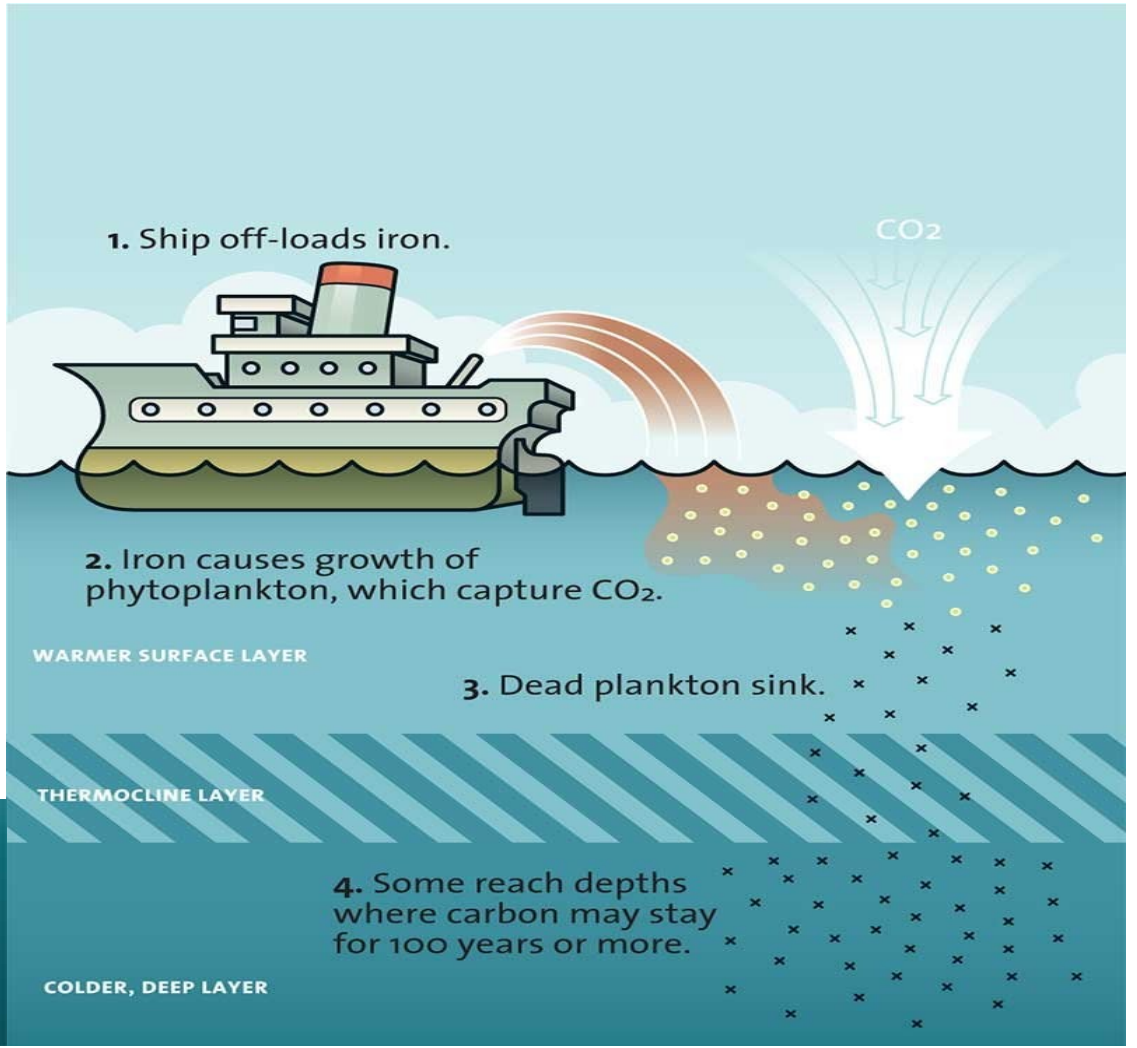
– John Martin, WHOI Scientist

Iron Fertilization

Iron fertilization refers to the release of iron in the ocean to ***stimulate primary productivity***

Increased primary productivity should lead to the ***increase of exports*** *to the seafloor with resulting increased carbon sequestration*

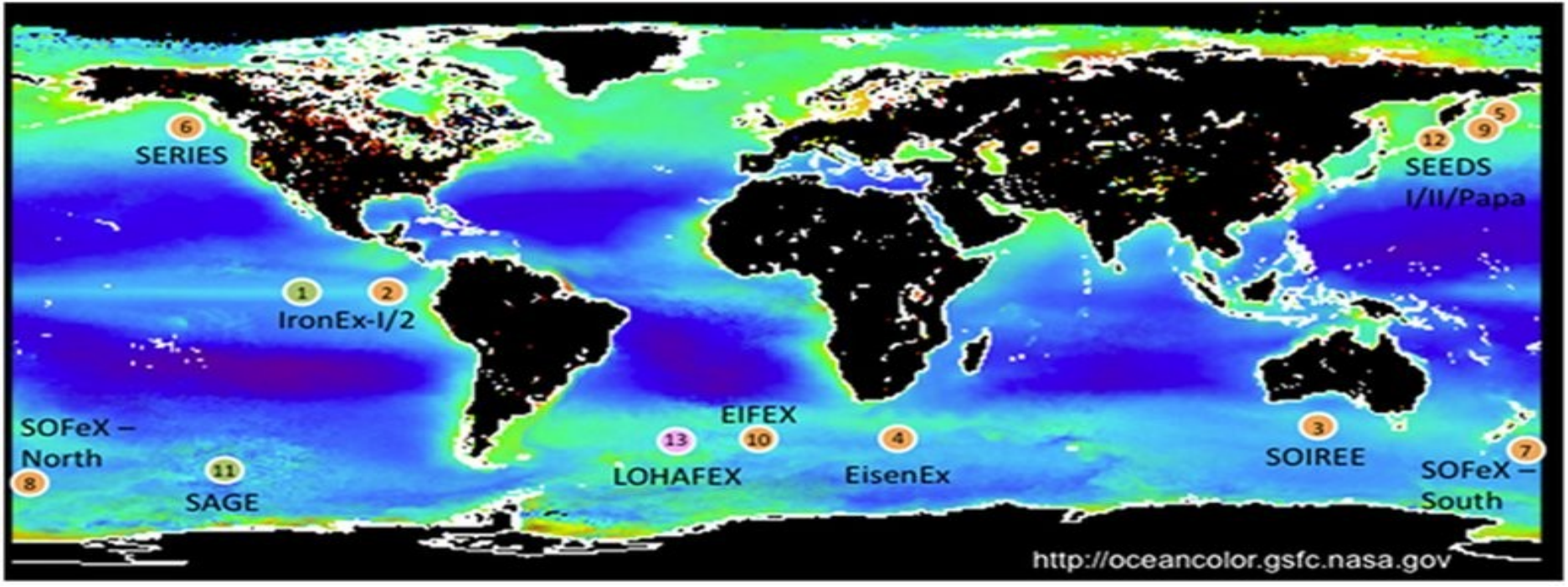
Increased sedimentation rates due to higher exports should ensure ***long term burial*** *of the sequestered carbon*



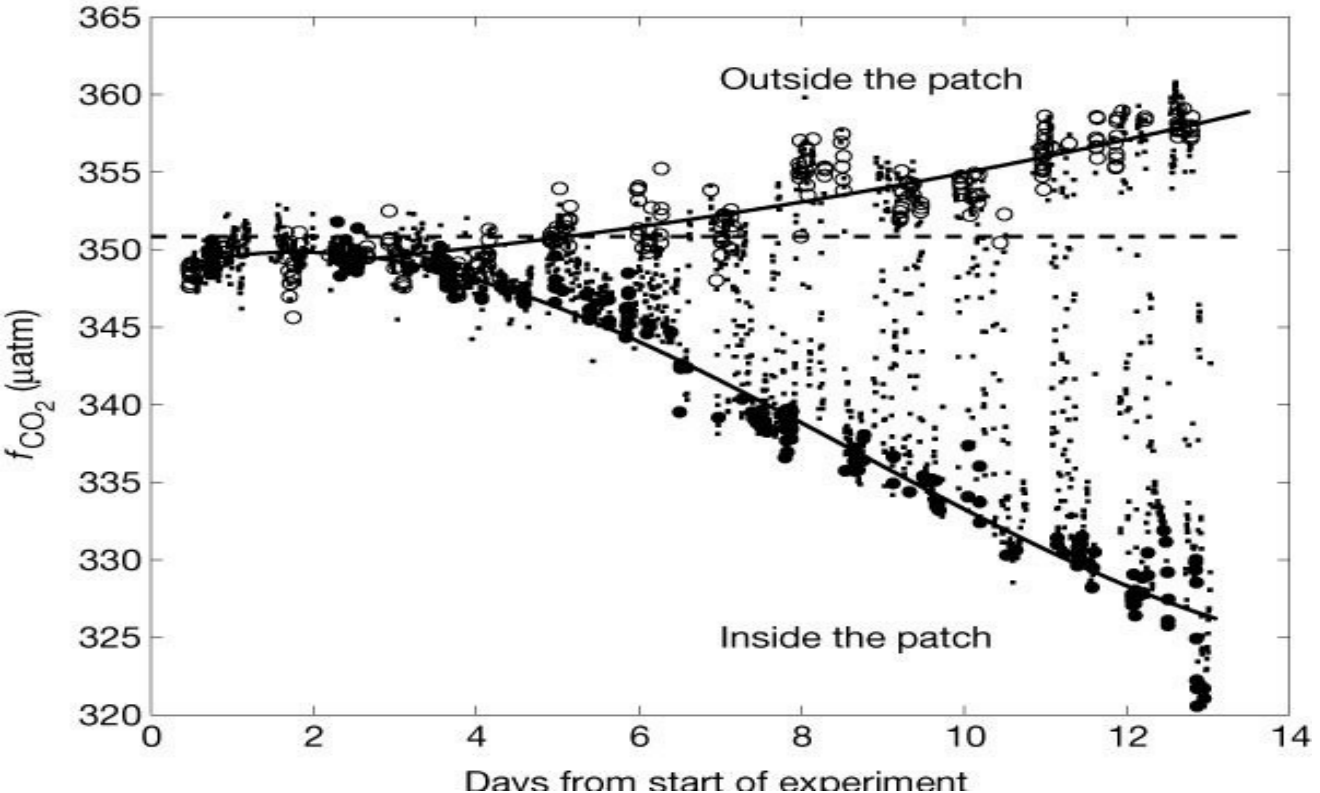
The Fantasy:
Plankton populations rebound to historic levels, reviving fisheries and sequestering vast amounts of carbon.

The Fear:
Iron leads to the depletion of deep-water oxygen, alters food chain, and promotes toxic species; CO_2 soon resurfaces.

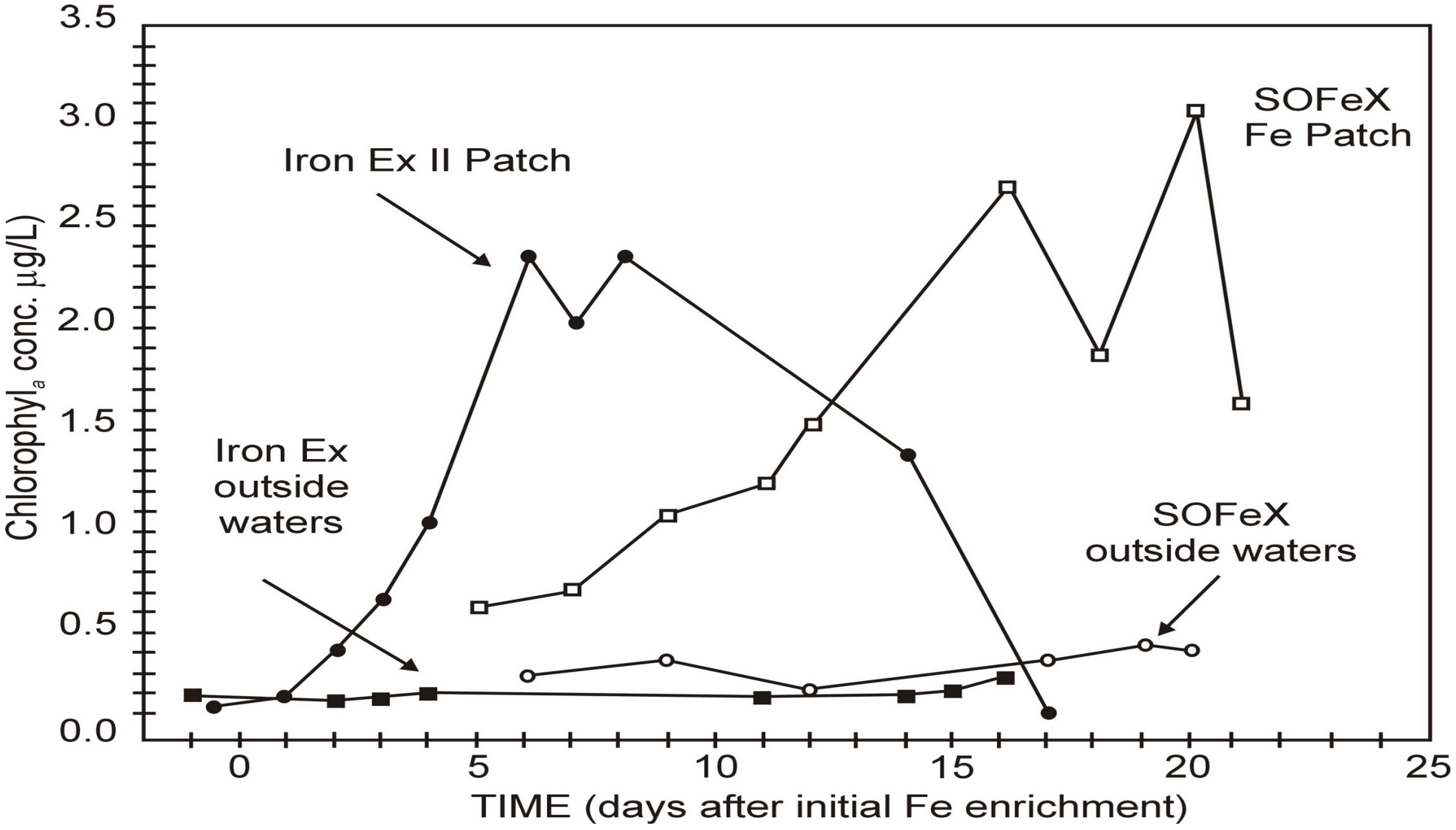
Iron Fertilization



Quantifiable reduction in atmospheric CO_2 in "patches" of iron fertilization. SOFEX Experiment



Watson et al, 2000 Nature

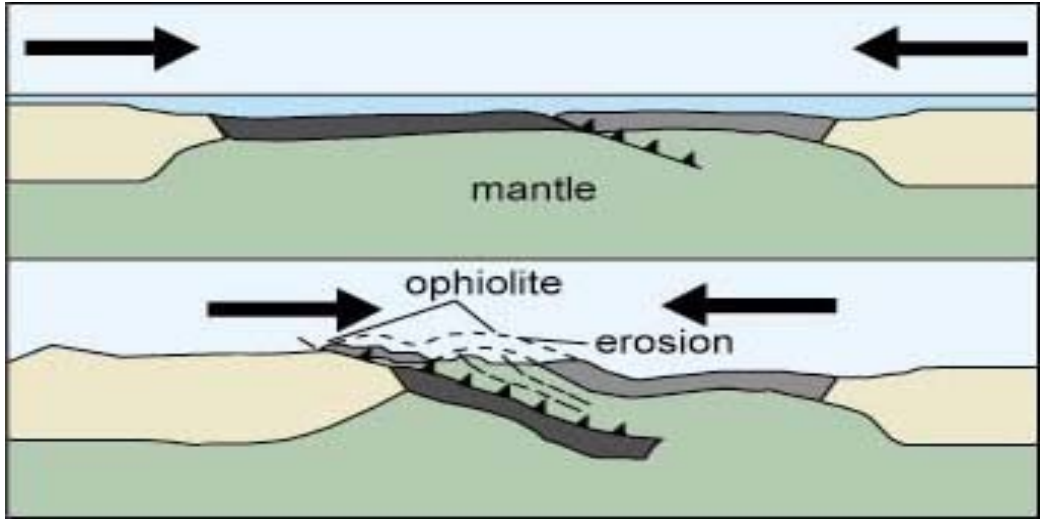

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Chlorophyl$_a$ conc. µg/L)
0
5
10
15
20
25
TIME (days after initial Fe enrichment)
Iron Ex II Patch
SOFeX
Fe Patch
Iron Ex
outside
waters
SOFeX
outside waters

Carbon Sequestration: Underground

Natural Carbon Sequestration

An ophiolite is a section of the Earth's oceanic crust and the underlying upper mantle that has been uplifted and exposed above sea level and often emplaced onto continental crustal rocks

Made of mantle rocks (peridotite) rich in iron and magnesium, they react with water and CO2, sequestering carbon into carbonate



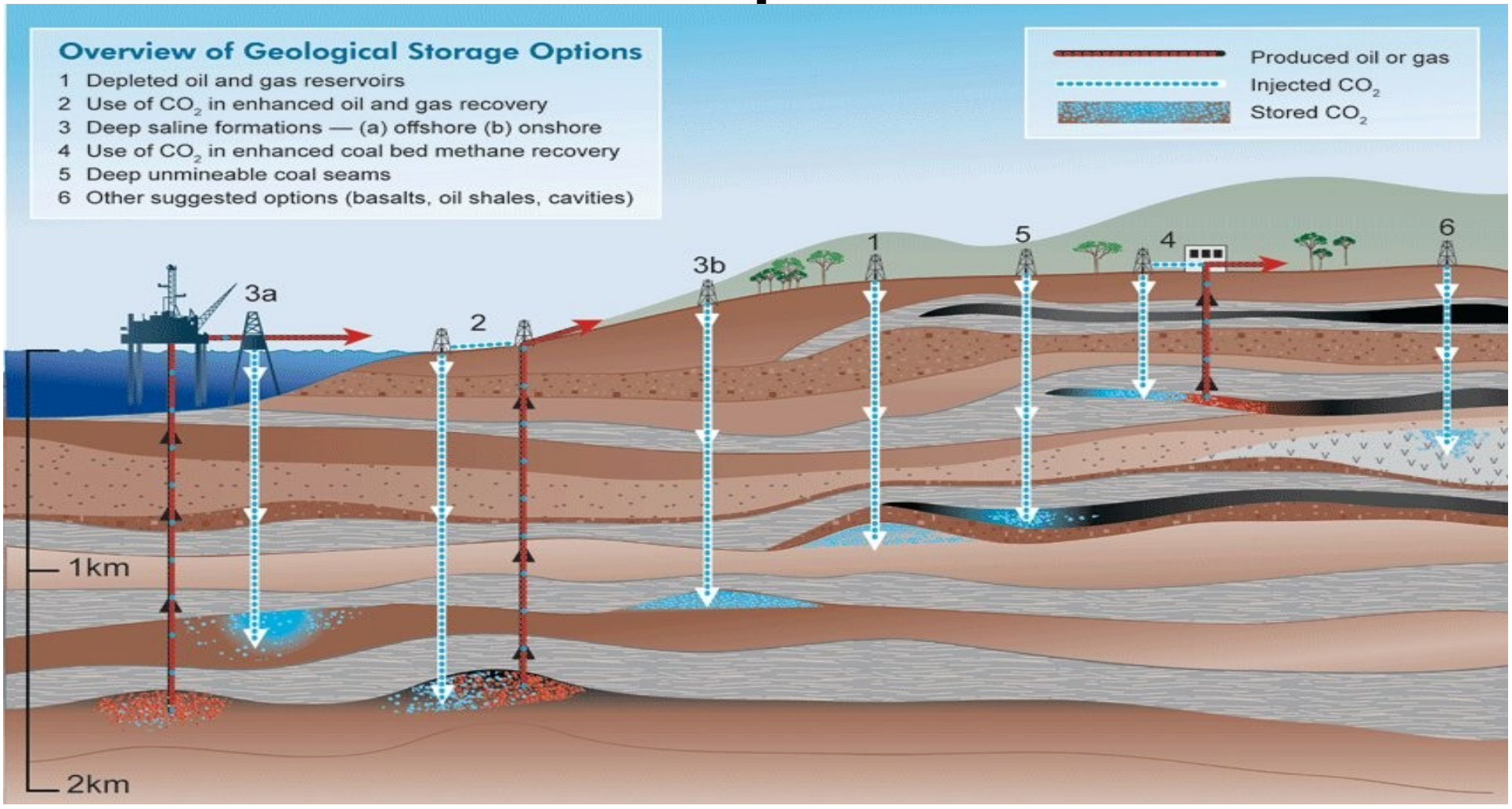
Manmade Carbon Sequestration

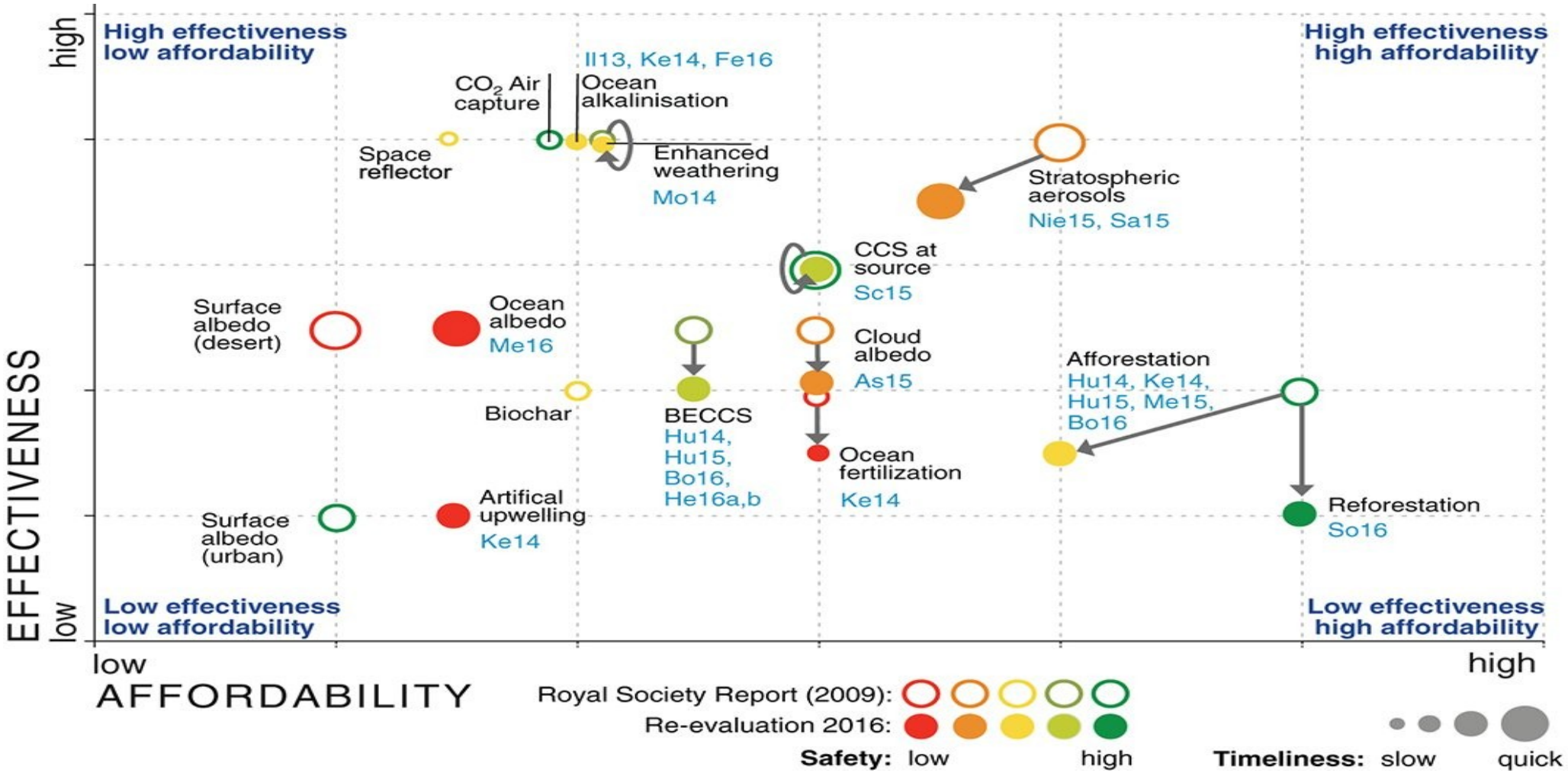
Geological sequestration refers to the storage of CO2 underground in depleted oil and gas reservoirs, saline formations, or deep, un-minable coal beds

Once CO2 is captured from a gas or coal-fired power plant, it would be compressed to ≈100 bar so that it would be a supercritical fluid. In this fluid form, the CO2 would be easy to transport via pipeline to the place of storage.

The CO2 would then be injected deep underground, typically around 1 km, where it would be stable for hundreds to millions of years.

Carbon Sequestration





Research for assessment of Climate Engineering: The German Research Foundation's Priority Program SPP 1689

Geoengineering: Ethical and Practical Concerns

Geoengineering should be considered a ***mitigation strategy****, and not a solution to the problem*

Long-term man-made forcing acting on climate and planet stability ***need to be removed*** *before any geoengineering strategy becomes sustainable*

Costs and scale *at which the geoengineering effort need to be undertaken are enormous, and may not make it a viable approach*

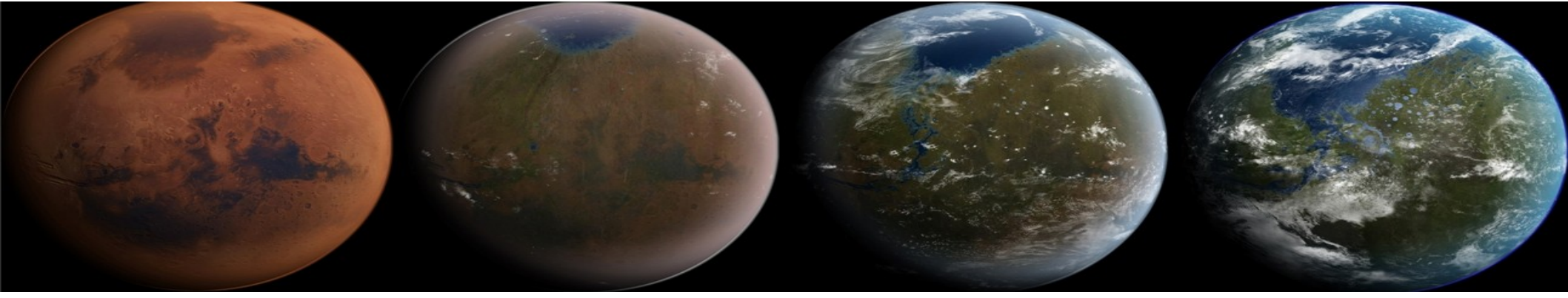
Tinkering with planetary scale feedback through ecosystem or processes engineering might have ***unwanted/unforeseen cascading effects***

Geoengineering: not just this planet

Geoengineering concept can also be applied to ***extraterrestrial planets***

In this case they are often collectively referred to as ***Terraforming***

A number of project exists for example on the possible terraforming of Mars



This week read

Watson, A.J., and others. 2000. **Effect of iron supply on Southern Ocean CO2 uptake and implications for glacial atmospheric CO2.** Nature 407: 730 – 733

Herkewitz, W. 2015. **Here's How We'll Terraform Mars With Microbes.** Popular Mechanics, *https://bit.ly/2xOGiSG*