Sustainability in Civil Engineering

III. Life and Climate

Term project logistics

- Project proposal due on Blackboard by Mar 14

  This should be an outline that includes
  - Topic
  - General approach
  - Data and methods to be used
  - Dissemination plan
  - Annotated bibliography (5-10 items and how each is relevant)
- After submitting the proposal, you must also schedule a meeting with me to discuss it – email me with your availability to set up a time

What is sustainability?

What are some manifestations of un***sustainability?***

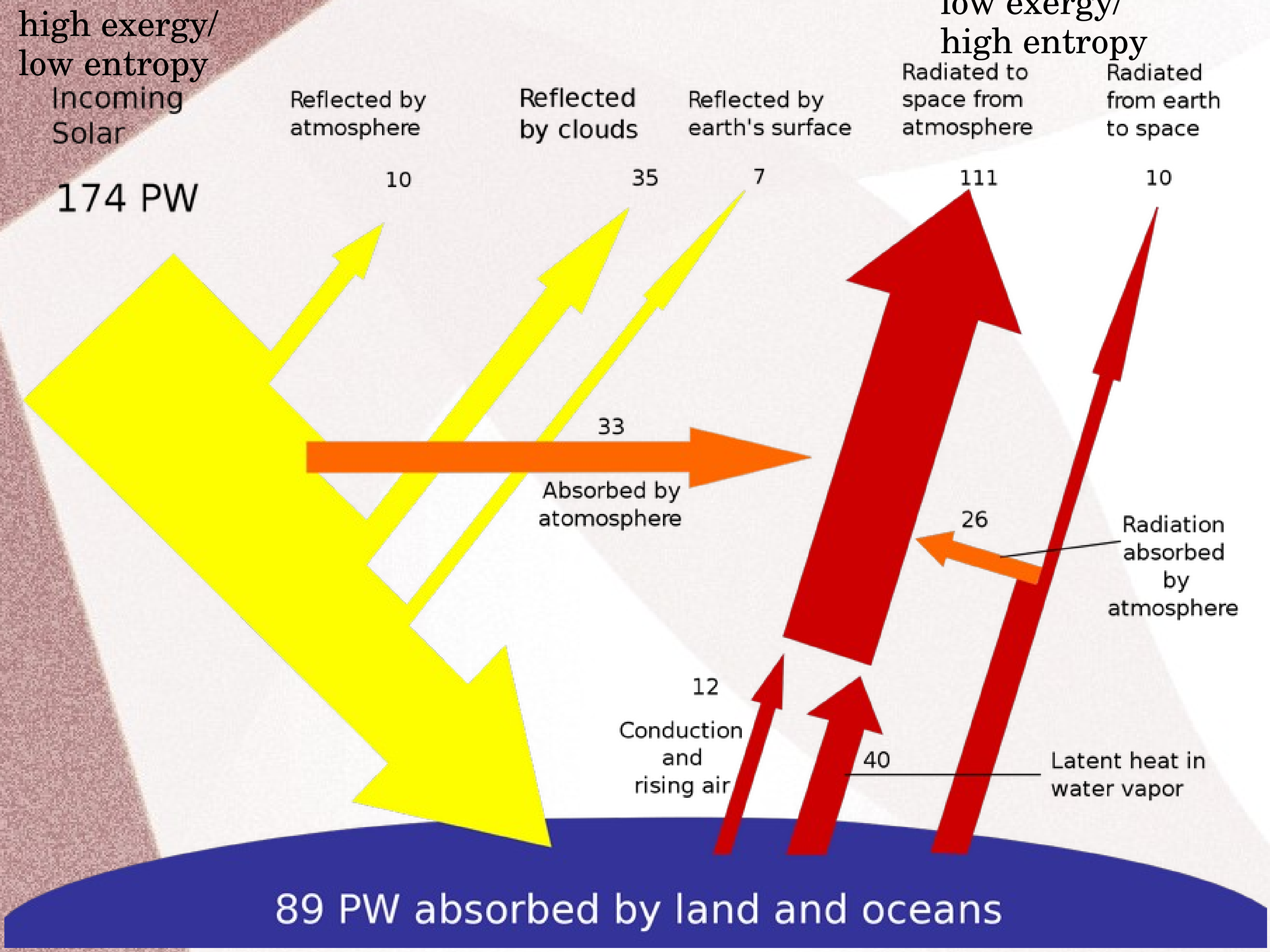
What is life?

- Are plants alive? Stars? Is there alien life?
- We can say that life-forms are highly organized and complex entities, enclosed yet open, that use ambient exergy to maintain themselves and grow/reproduce
- Collectively and over long periods of time, life is surprisingly powerful in shaping the planet's landscape and climate

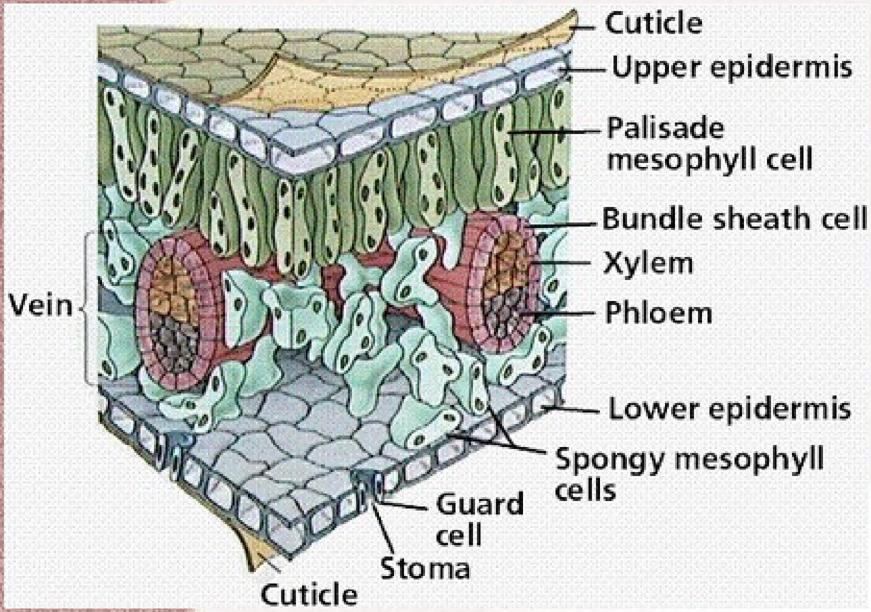
A living planet

How does the Earth show life's influence?

Earth's exergy source



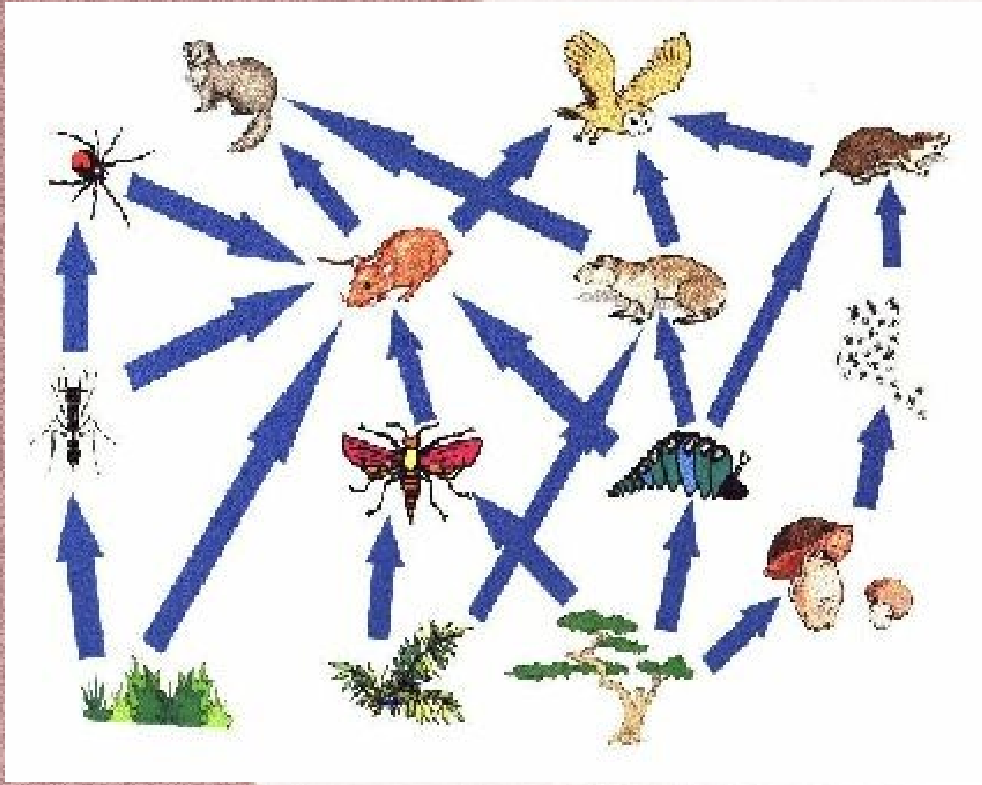
Plant primary production



$6H_2O + 6CO_2 + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2$

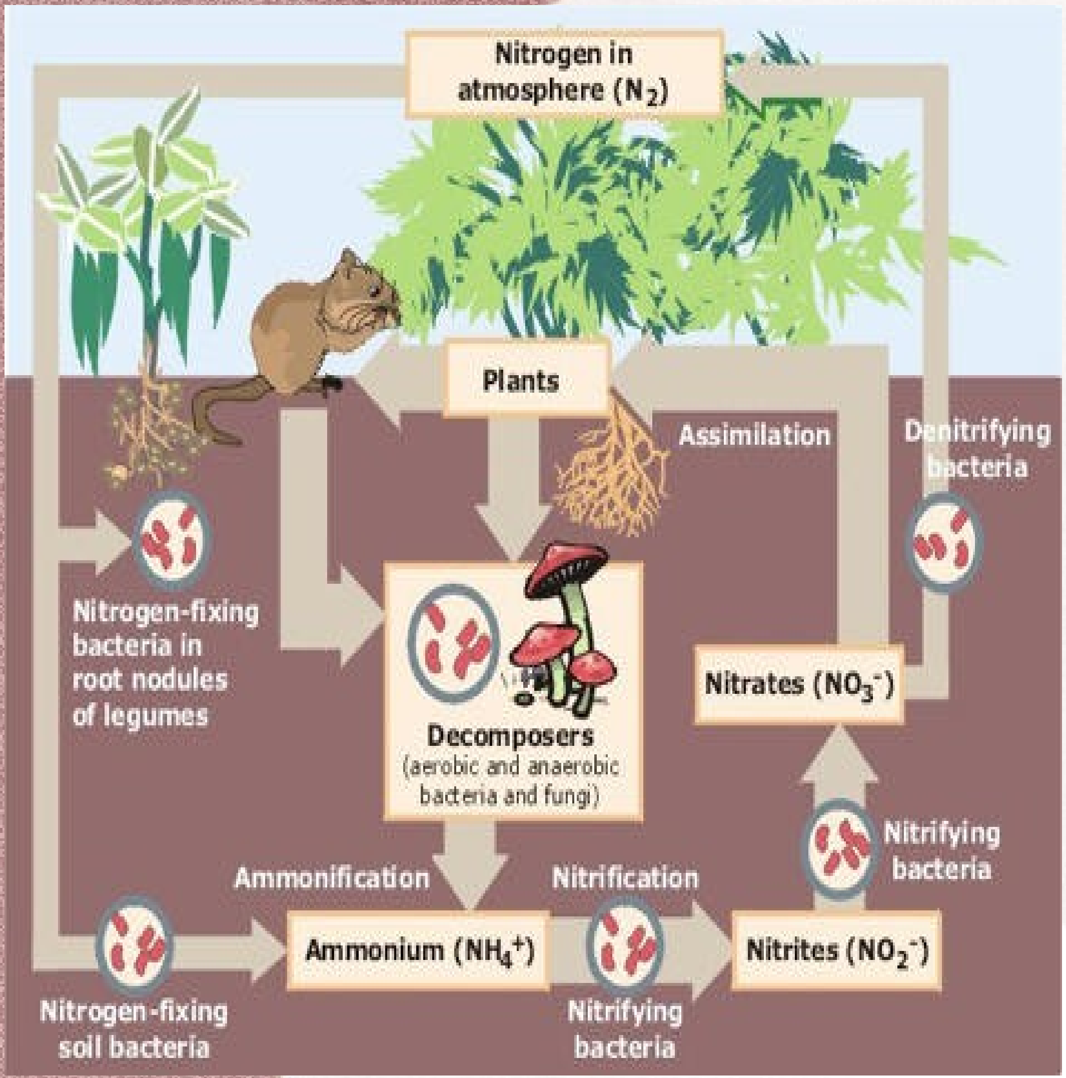
- What does photosynthesis require?
- Plants cover most of the feasible surface area, converting ~0.1% of incoming sunlight into chemical energy (100 TW, ~100 Pg C fixed / year); ~2% locally under good conditions
- Major impacts on surface and atmosphere

Food chains



- Millions of ways of life are carried on by specialized species
- Animals, fungi, and most bacteria feed on chemical exergy already fixed by plants
- Along the way, exergy is used up in maintenance and digestion; on the order of 10% of exergy used by prey is transmitted to predators
  - “Why big fierce animals are rare”

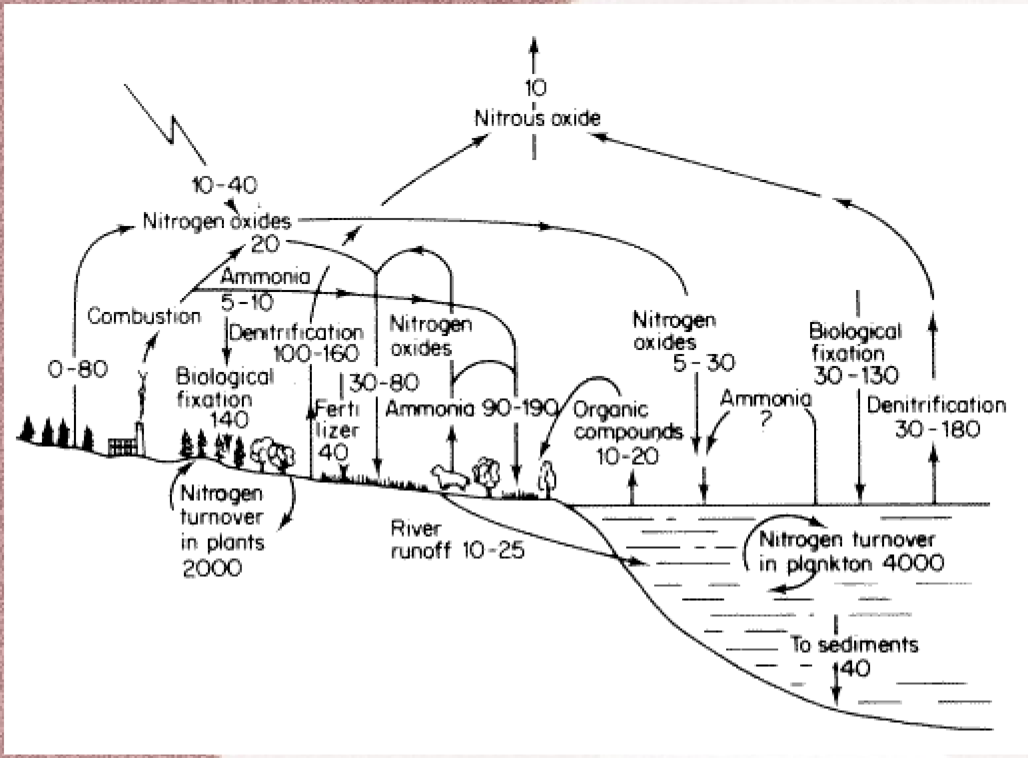
Nutrient cycles



- Elements that are scarce (e.g. N, P, Fe) tend to be recycled within ecosystems
- Fungi and other decomposers, as well as roots, help plants get needed minerals
- Matter is recycled, energy downcycled

Redfield ratio: C:N:P – 106:16:1
Liebig's law of the minimum

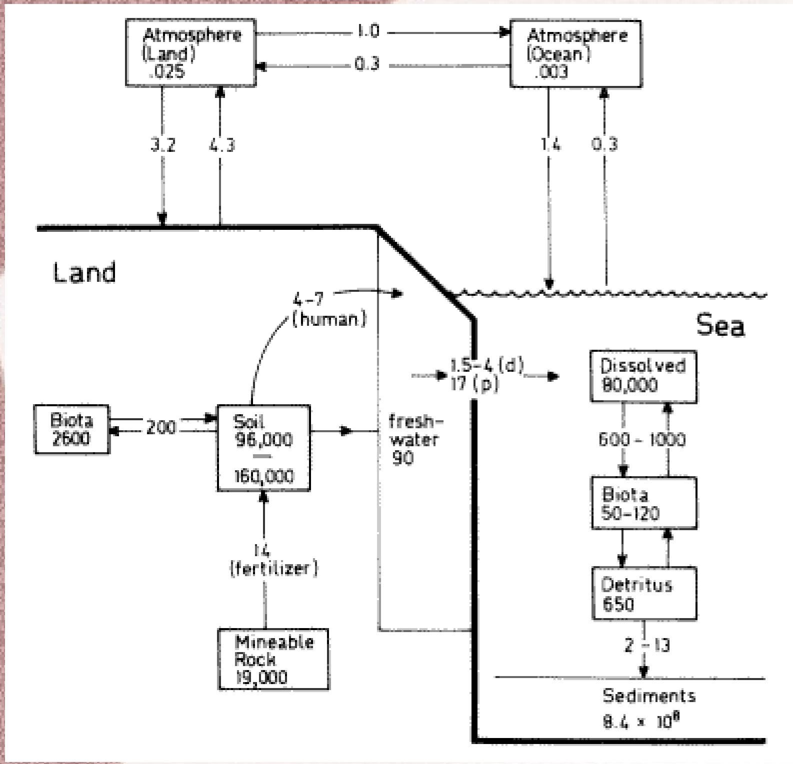
Global nitrogen flows



Tg N / year

- Nitrogen is needed for proteins and other biomolecules
- Most nitrogen is in the atmosphere as N_2
- Nitrogen is converted biologically (and industrially) between phases & many different forms

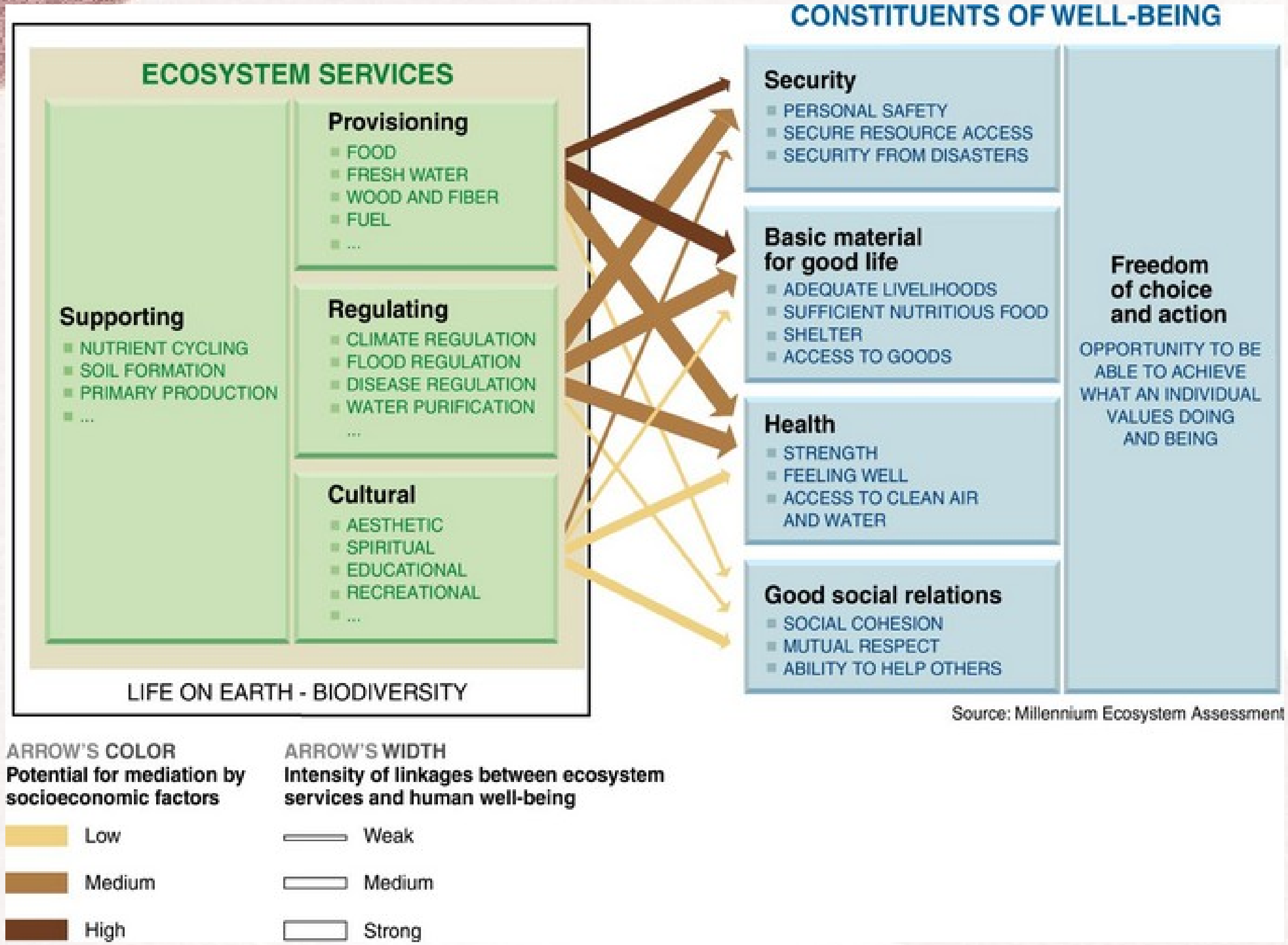
Global phosphorus flows and stocks



Tg P (per year)

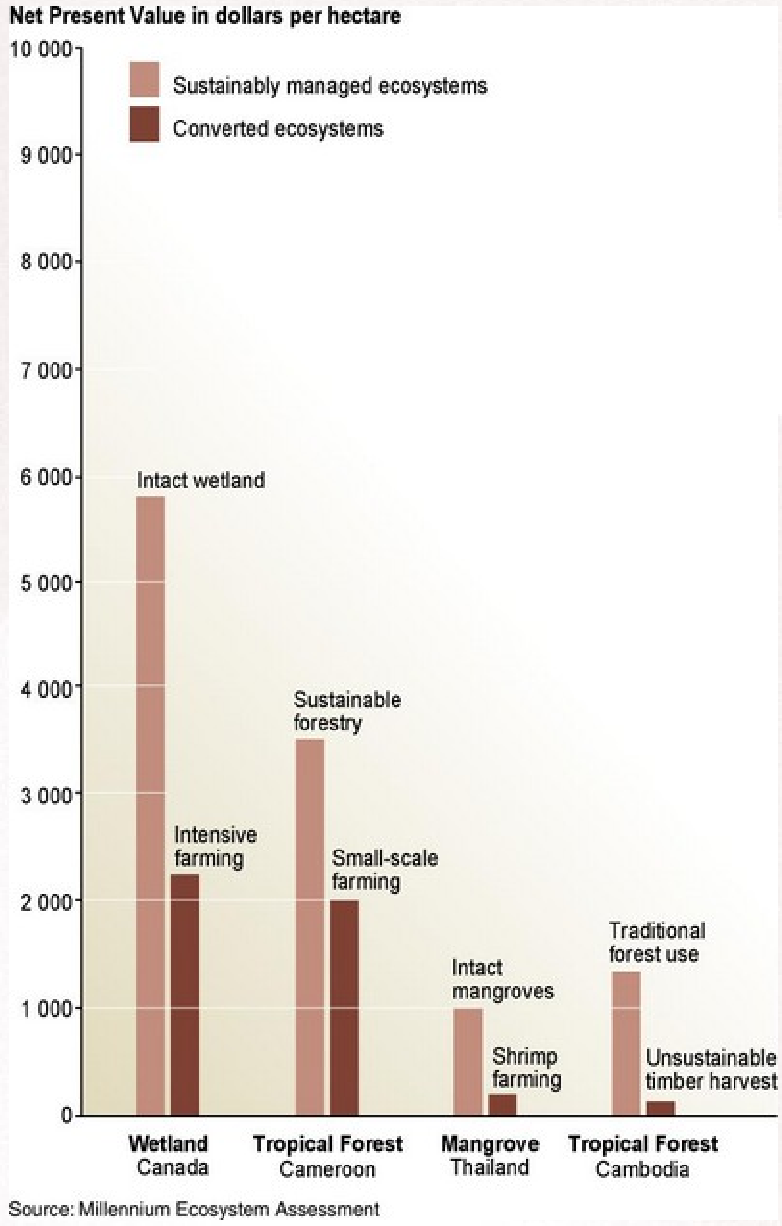
- Needed for many critical biomoelcules (including DNA)
- No significant gas form
- Land loses dissolved phosphorus to ocean, ocean to sediments; only new source is weathering of bedrock
- Common limiting nutrient; heavily recycled

Ecosystem services

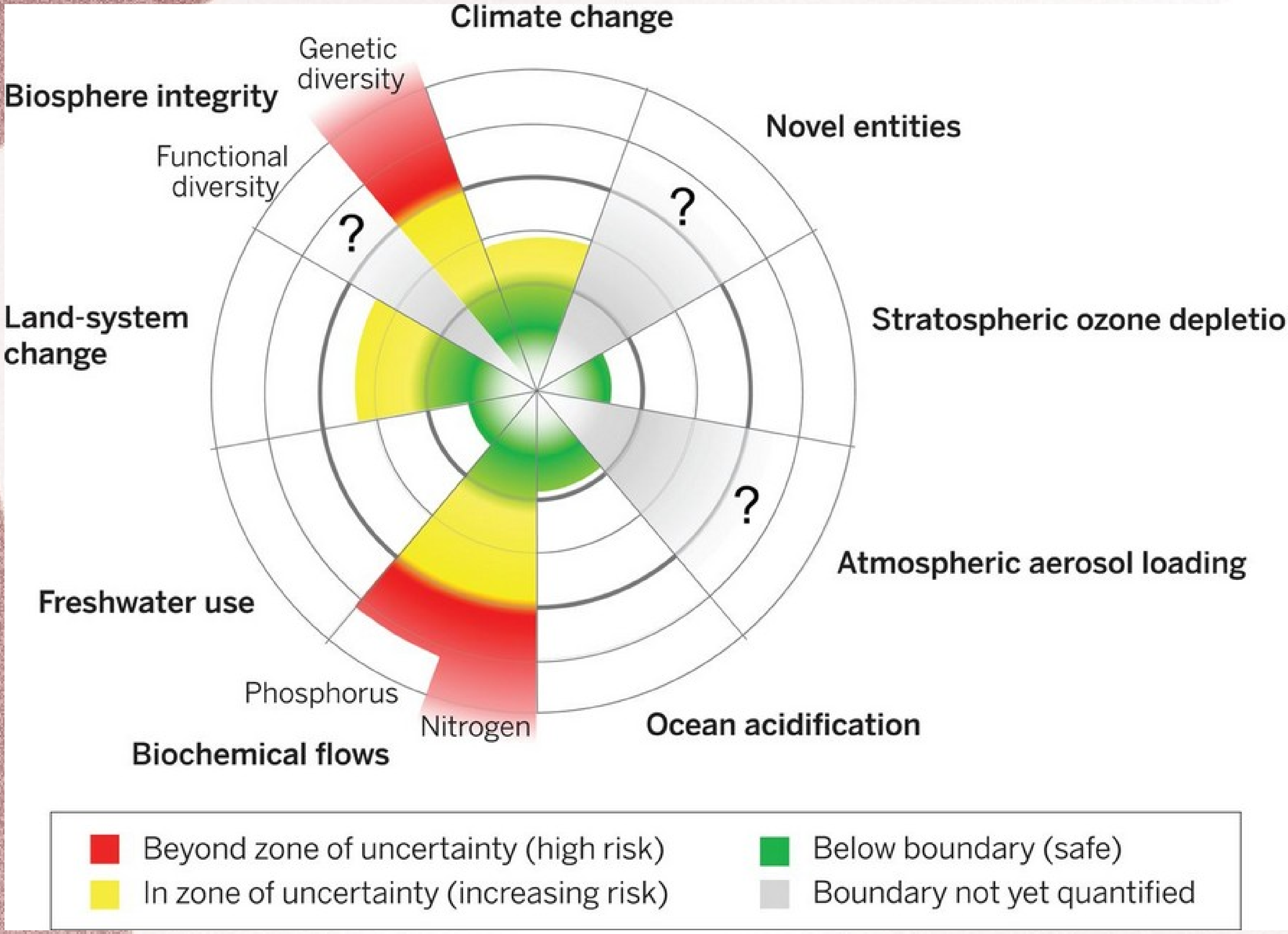


An attempt to convince economists (etc.) of the value of ecology (Millennium Ecosystem Assessment)

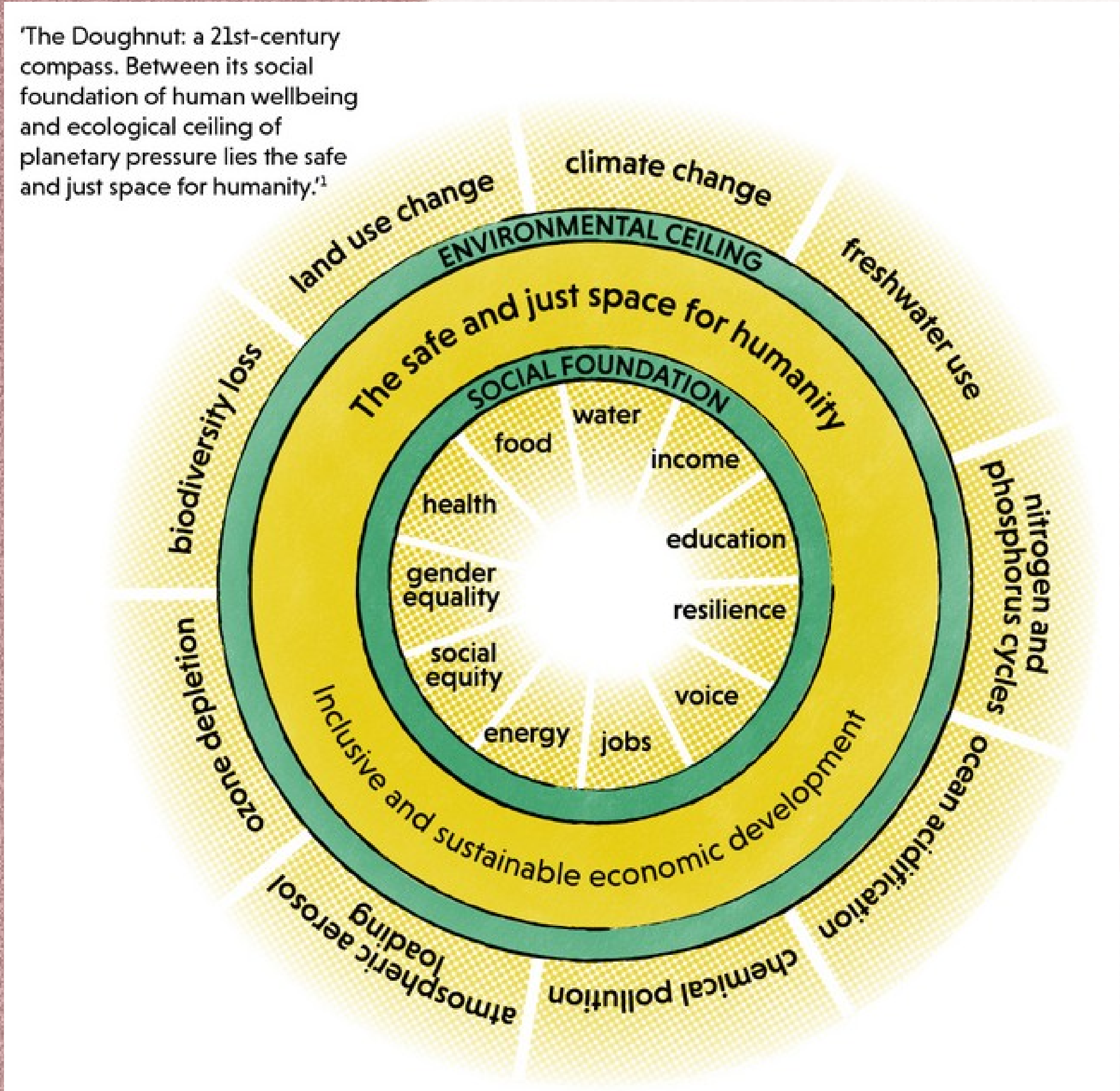
Natural ecosystems as wealth

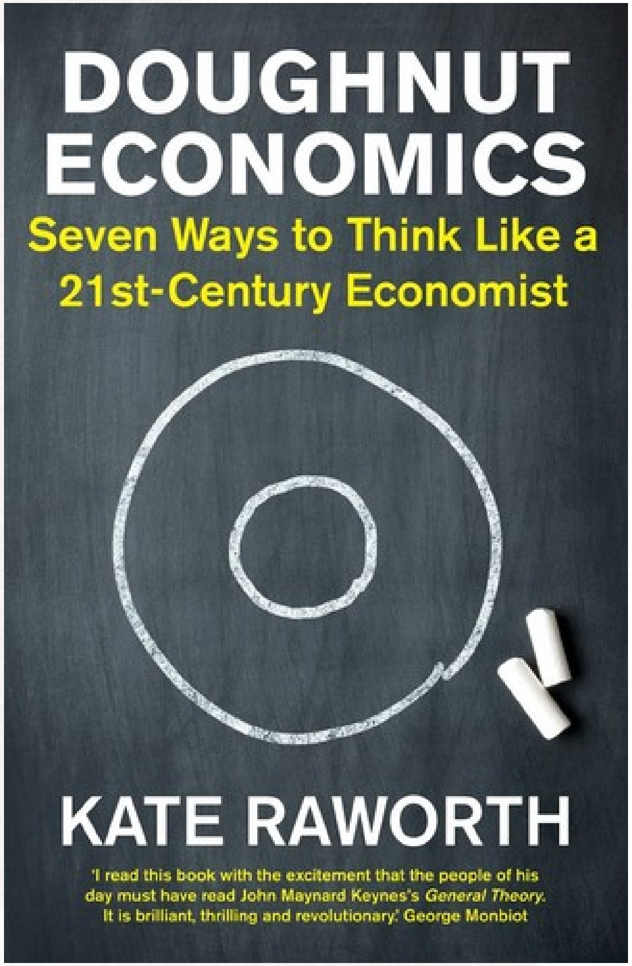


Planetary boundaries



Doughnut development



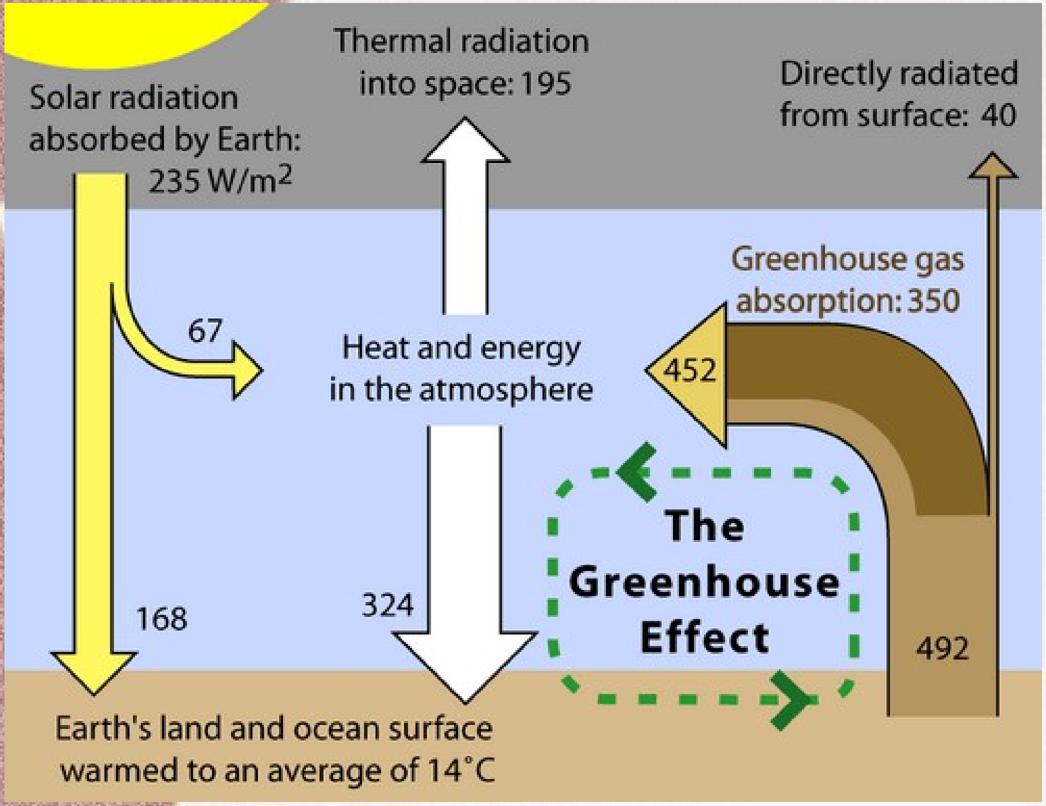


Laws of ecology (Barry Commoner)

- Everything is Connected to Everything Else.
- Everything Must Go Somewhere.
- Nature Knows Best.
- There Is No Such Thing as a Free Lunch.

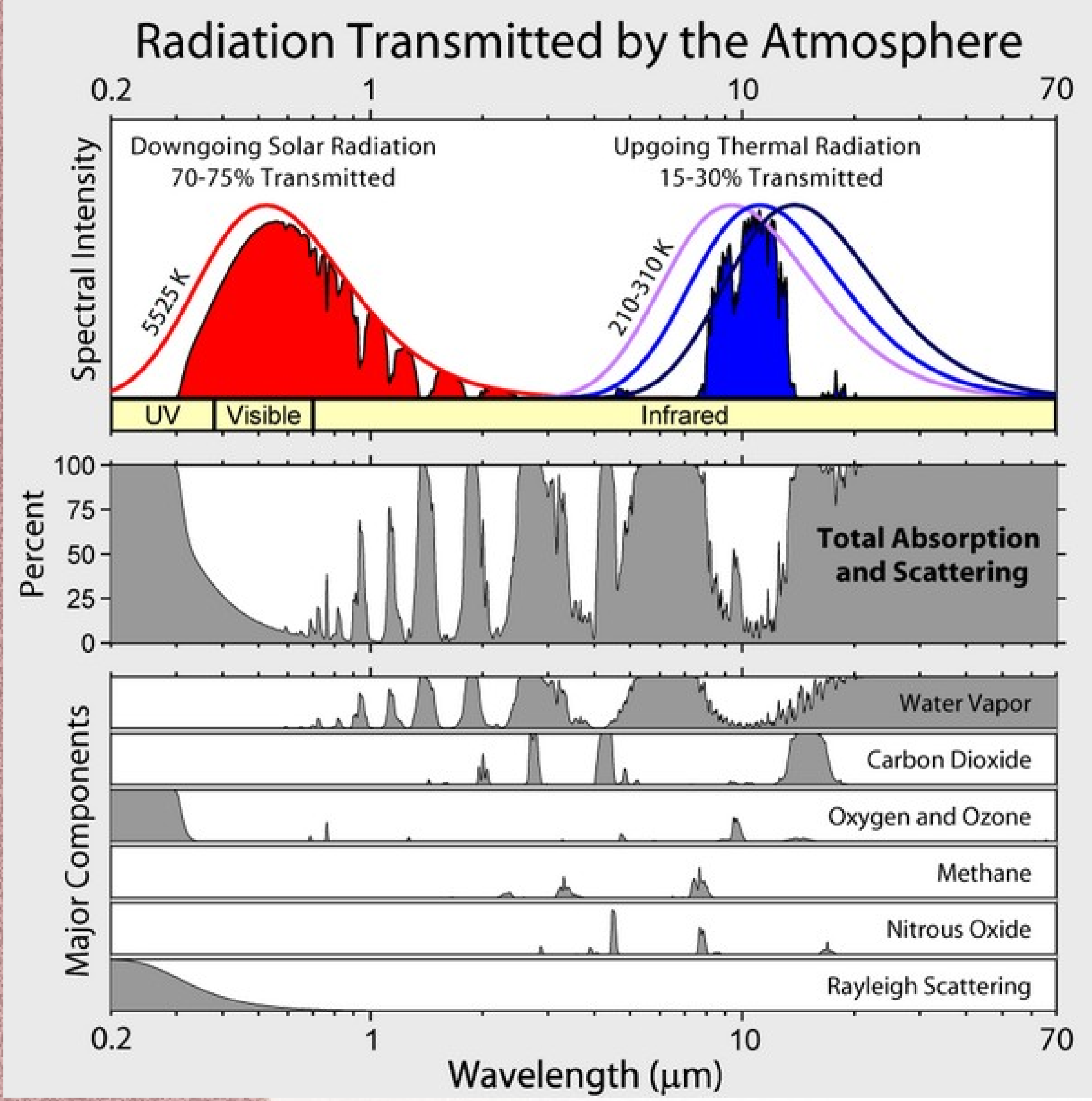
- Complex: Unintended consequences and backfires are common (e.g. pesticides, fire suppression)
  - You can never do just one thing

The greenhouse effect



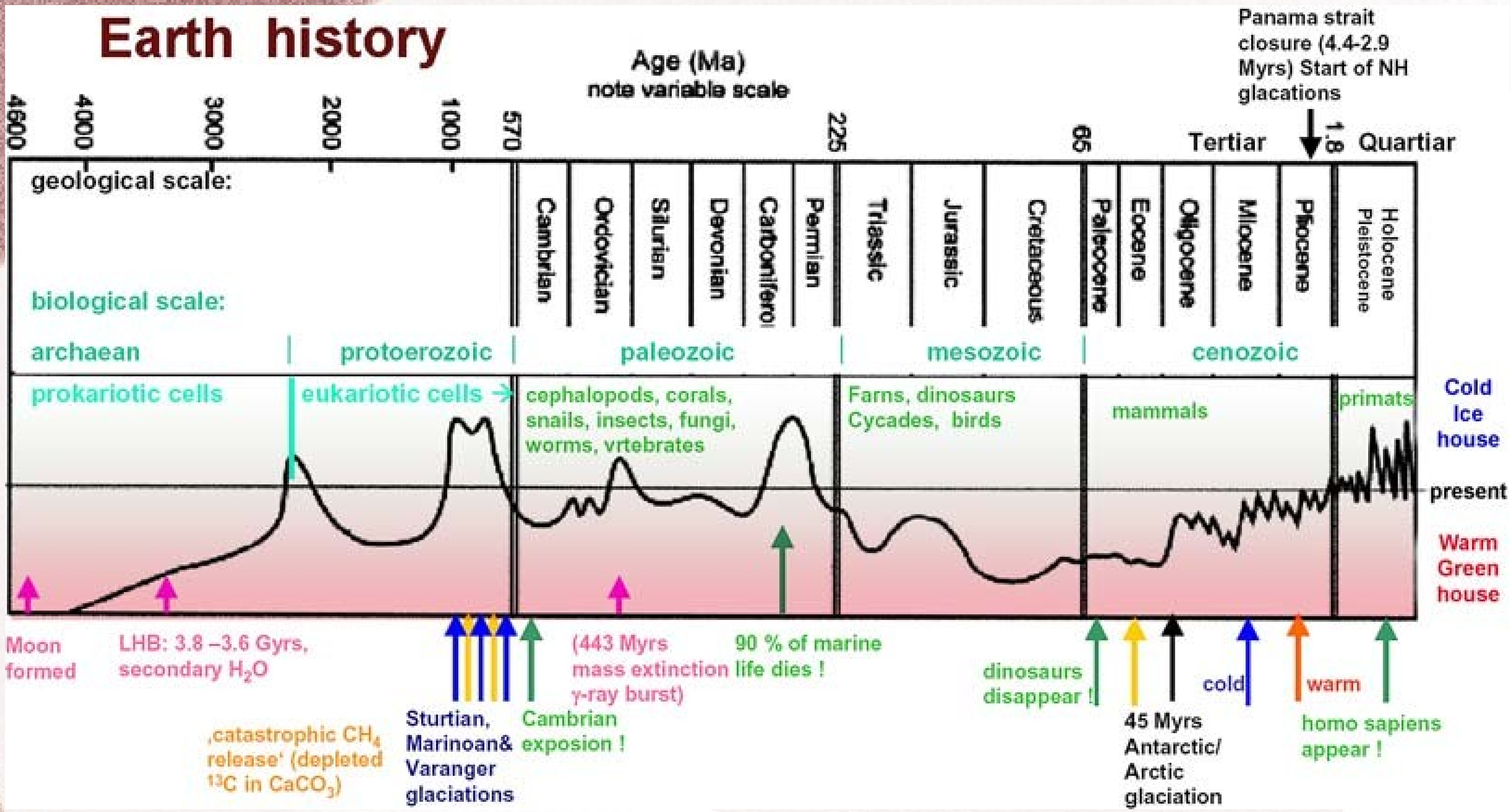
- The amount of sunlight the earth absorbs can be balanced by radiation at a blackbody temperature of 255 K. Why is our average surface temperature 288 K?
- Greenhouse gases act like insulation that reduces (radiative) heat transfer between the earth and space

Energy balance and greenhouse gases



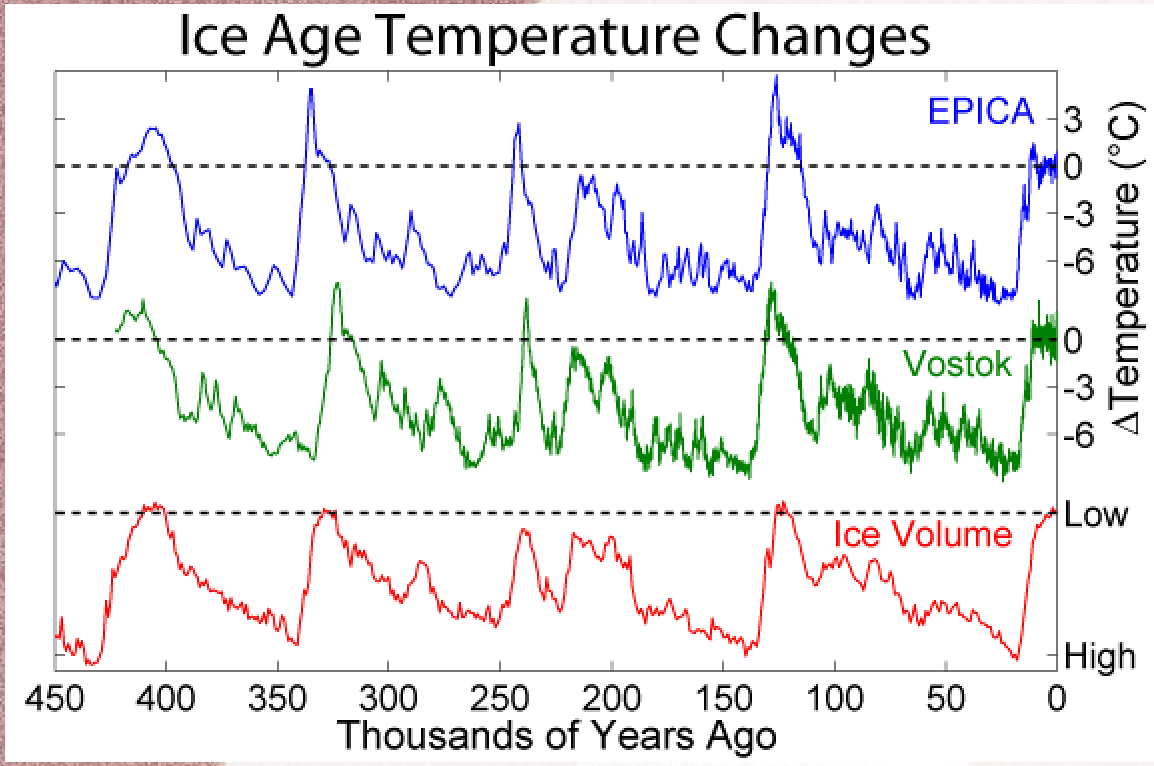
- Because of life, 99% of the atmosphere is O_2, N_2, and Ar, which don't absorb IR light; most other molecules, notably H_2O and CO_2, do
- Without life, the atmosphere would be mostly CO_2 and possibly H_2O

Climate history



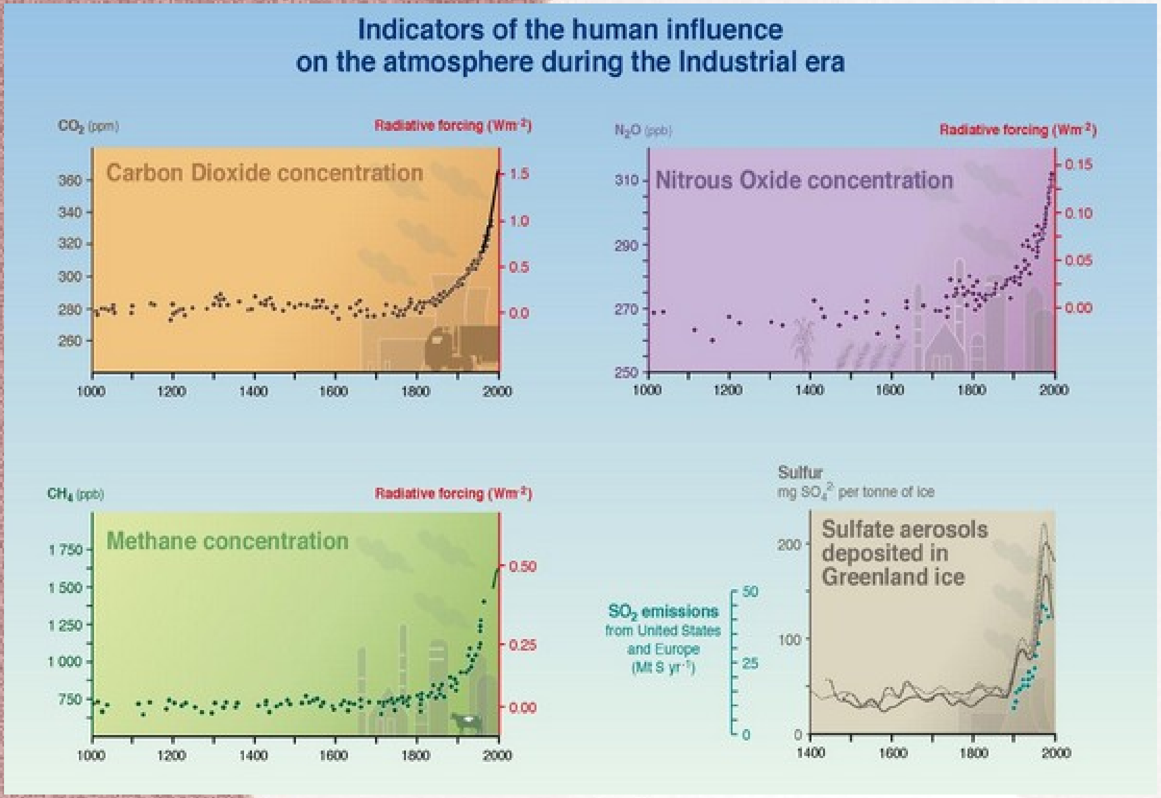
- Although the sun has brightened ~40% since earth formed, we haven't gotten warmer
- Probable reason: CO_2 removal by photosynthesis

Climate since people (last million years)



- Mostly ice ages (5 K colder, big ice sheets), separated by interglacials
- Positive temperature-GHG feedback (CO_2 concentrations ~190 ppm in cold, ~270 ppm in warm periods)
- Interglacial for last 12,000 years: very stable temperatures, GHG levels, and sea level

GHG concentrations since 1800

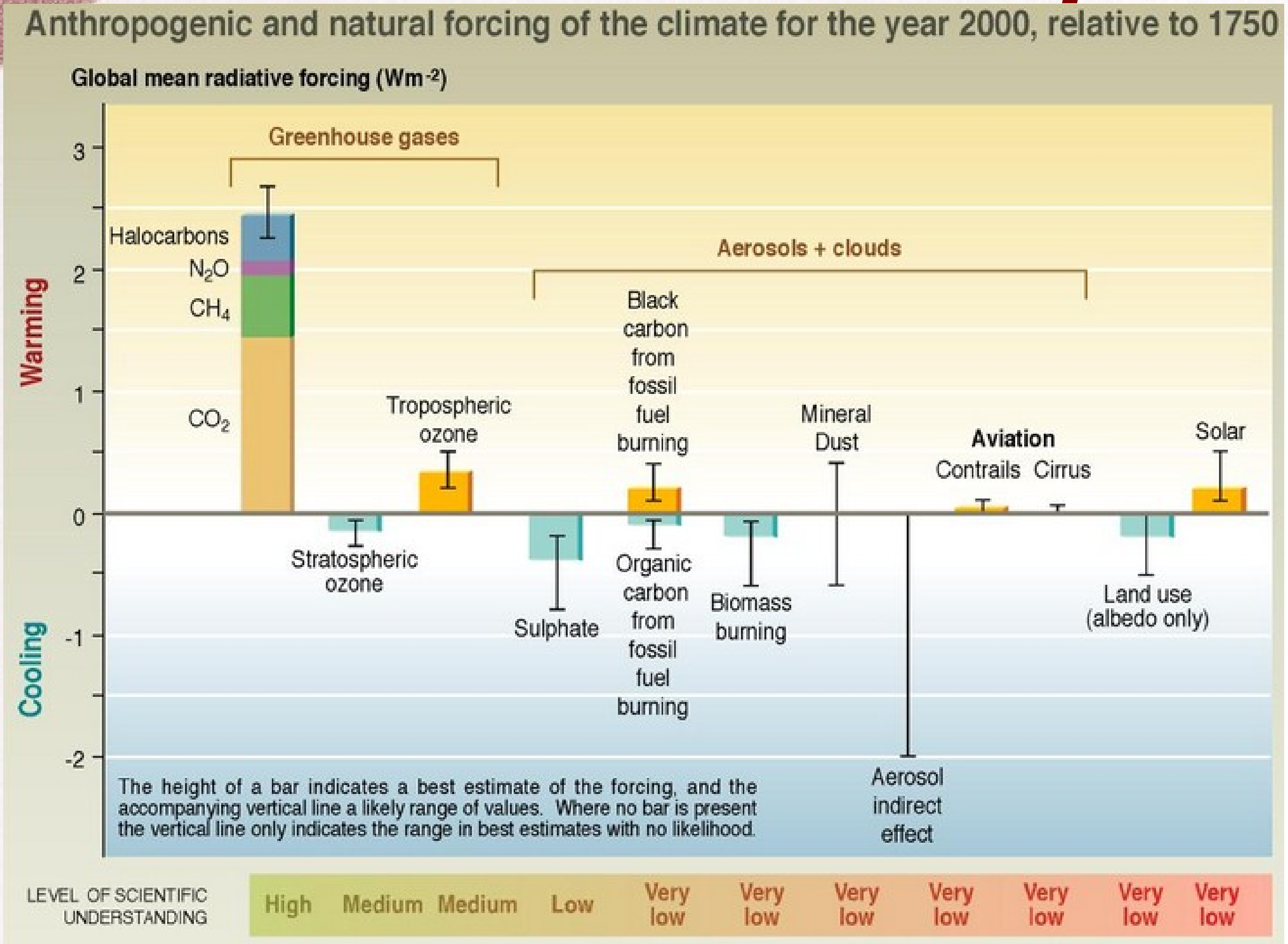


- CO_2: 280 → 420 ppm
  - Fossil fuel burning
  - Secondary: forest burning, lime
- CH_4: 750 → 1900 ppb
  - Paddy cultivation
  - Cow digestion
  - Fossil fuel use
  - Landfills, reservoirs
- N_2O: 270 → 330 ppb
  - N Fertilizer
- CFCs etc. (new)

Global warming potential

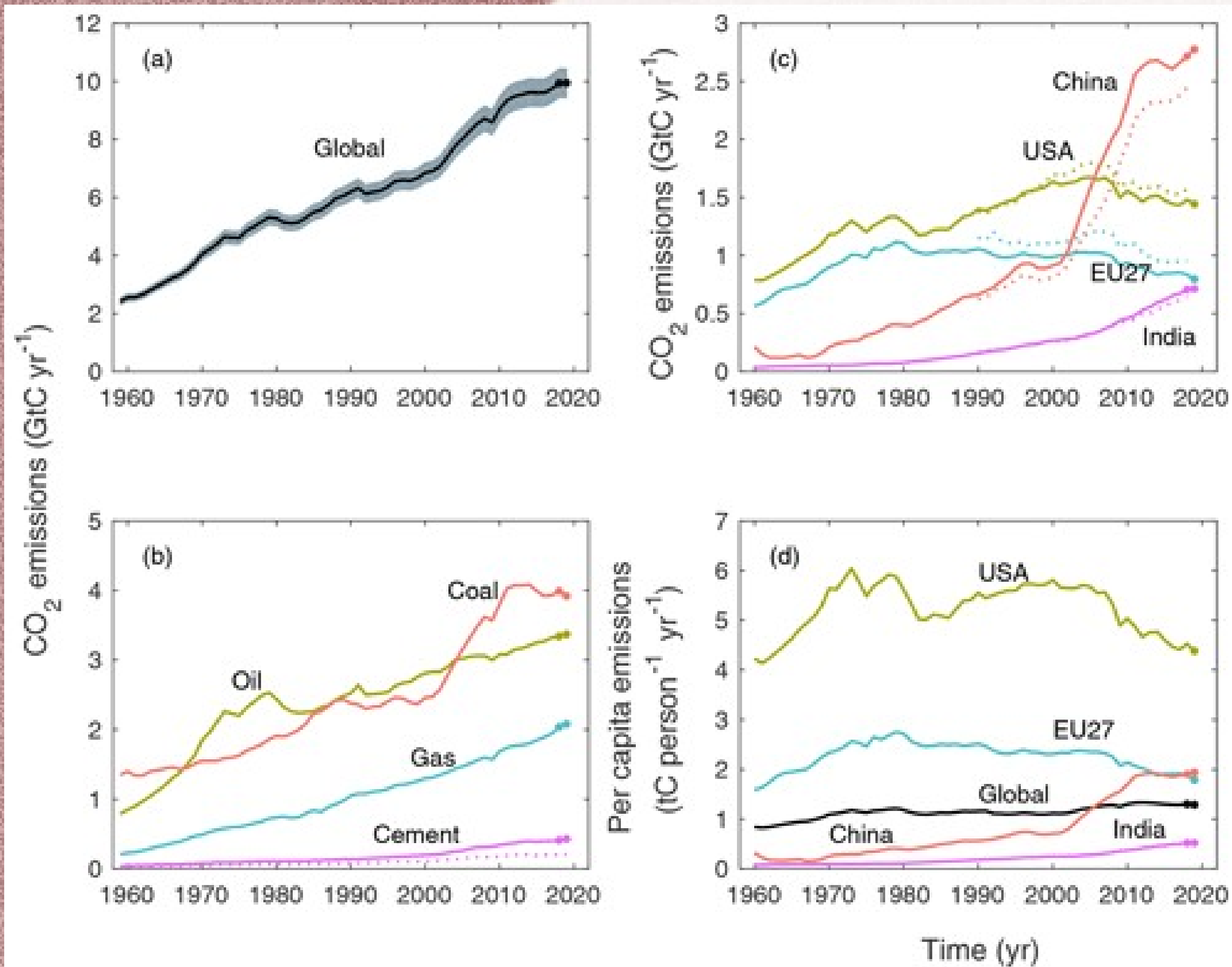
- The contribution of a release of a mole of a given gas to greenhouse warming, relative to that of CO_2 (which has GWP = 1)
- Depends on the starting atmospheric composition and on the timeframe (100-year GWP is usually quoted)
- Some values (IPCC): CH_4: 25, N_2O: 298, CFC-12: 10,900

Factors affecting earth's temperature



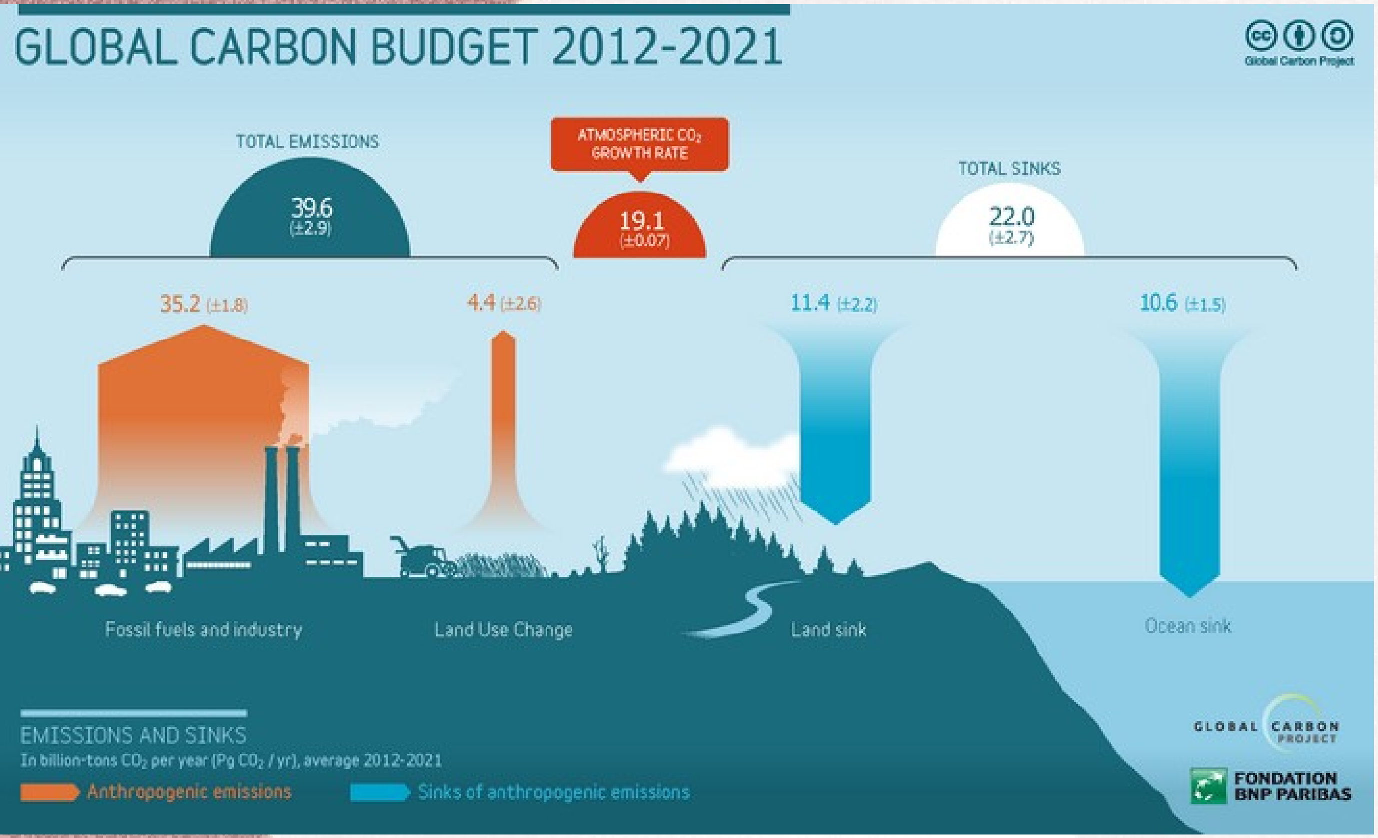
Net radiative forcing from human impacts is around 1.5 W m^{-2}, on the order of 1% of sun intensity

Carbon dioxide buildup



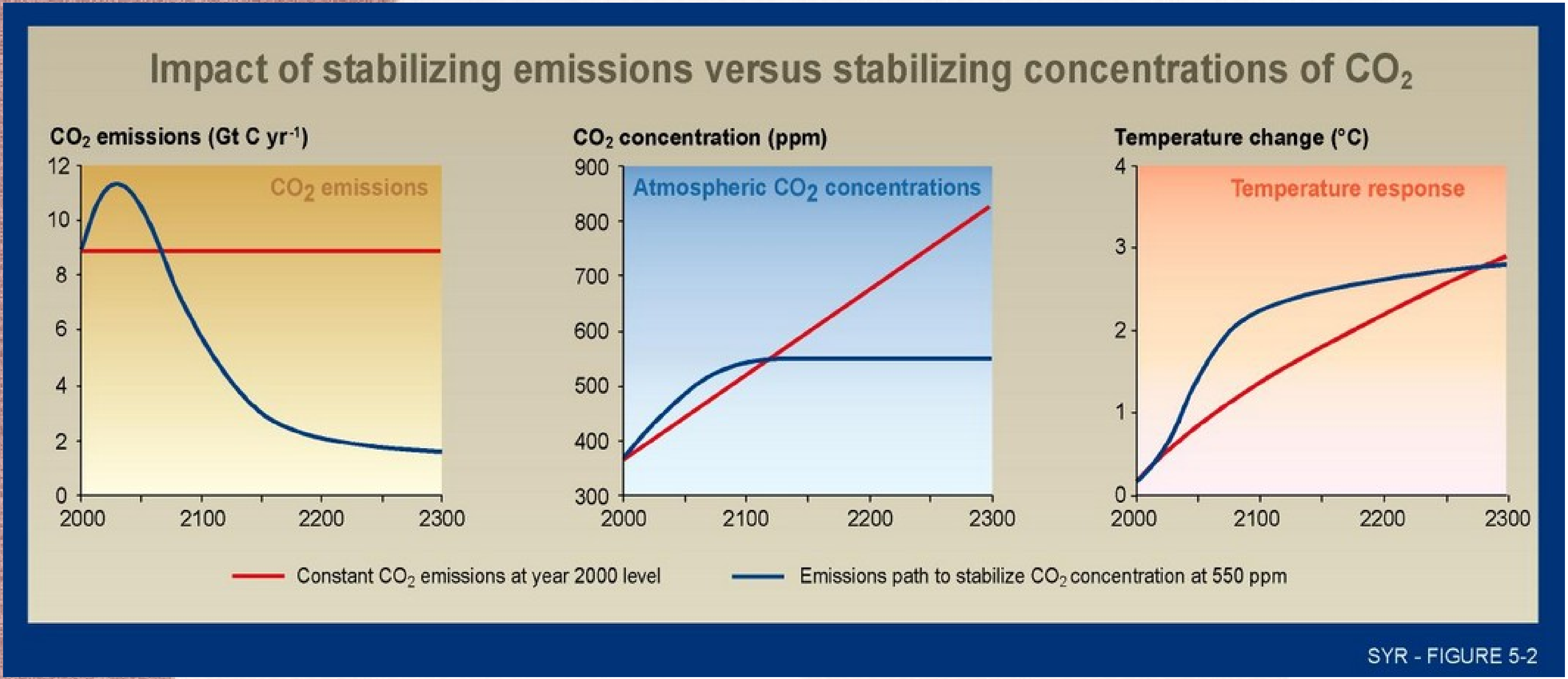
- Emissions: 10 Pg C / y [37 Pg CO_2]; 1.2 ton per person per y (USA: 4; EU: 1.7; China: 1.9; India: 0.5)
- 2.1 Pg C = 1 ppm atm. CO_2 → yearly emissions are >1% of what's in entire atmosphere

Fossil carbon release



- Over centuries, 75% of emissions will dissolve in the ocean
- Geological reactions are much slower (thousands of years)
- Currently, atmospheric concentration is increasing by 2.5 ppm (0.6%) / year

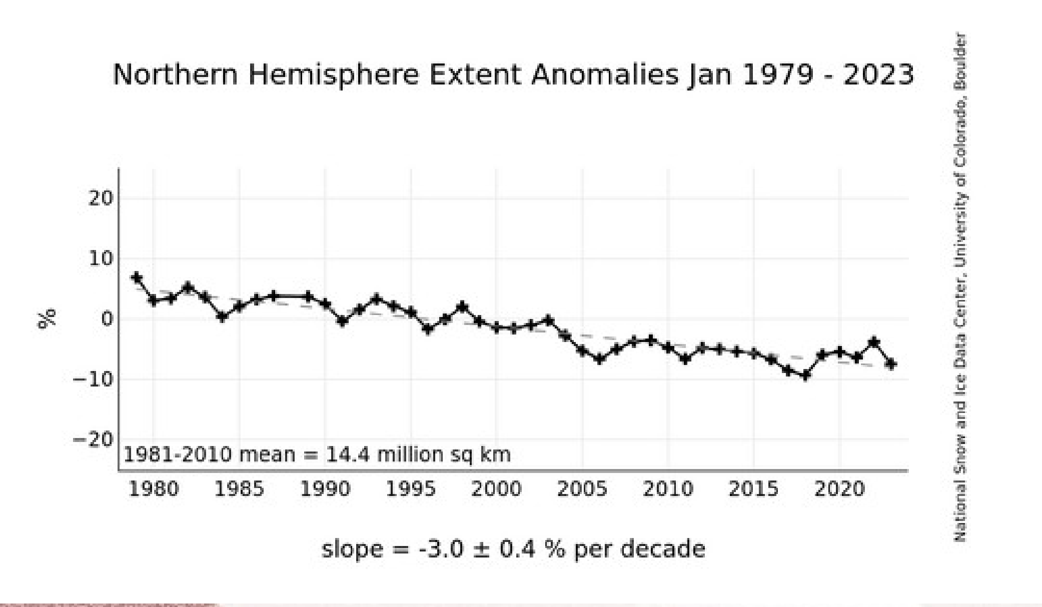
Emissions vs. concentrations

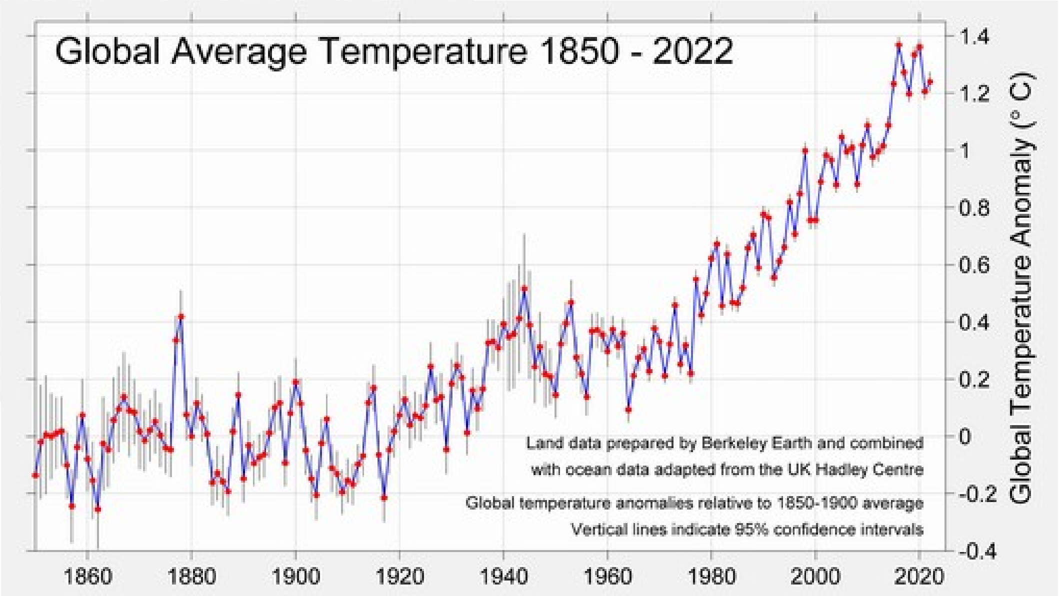


To stabilize or reduce atmospheric CO_2, need ***zero*** emissions (stabilizing/reducing *emissions* not enough)

Global warming so far

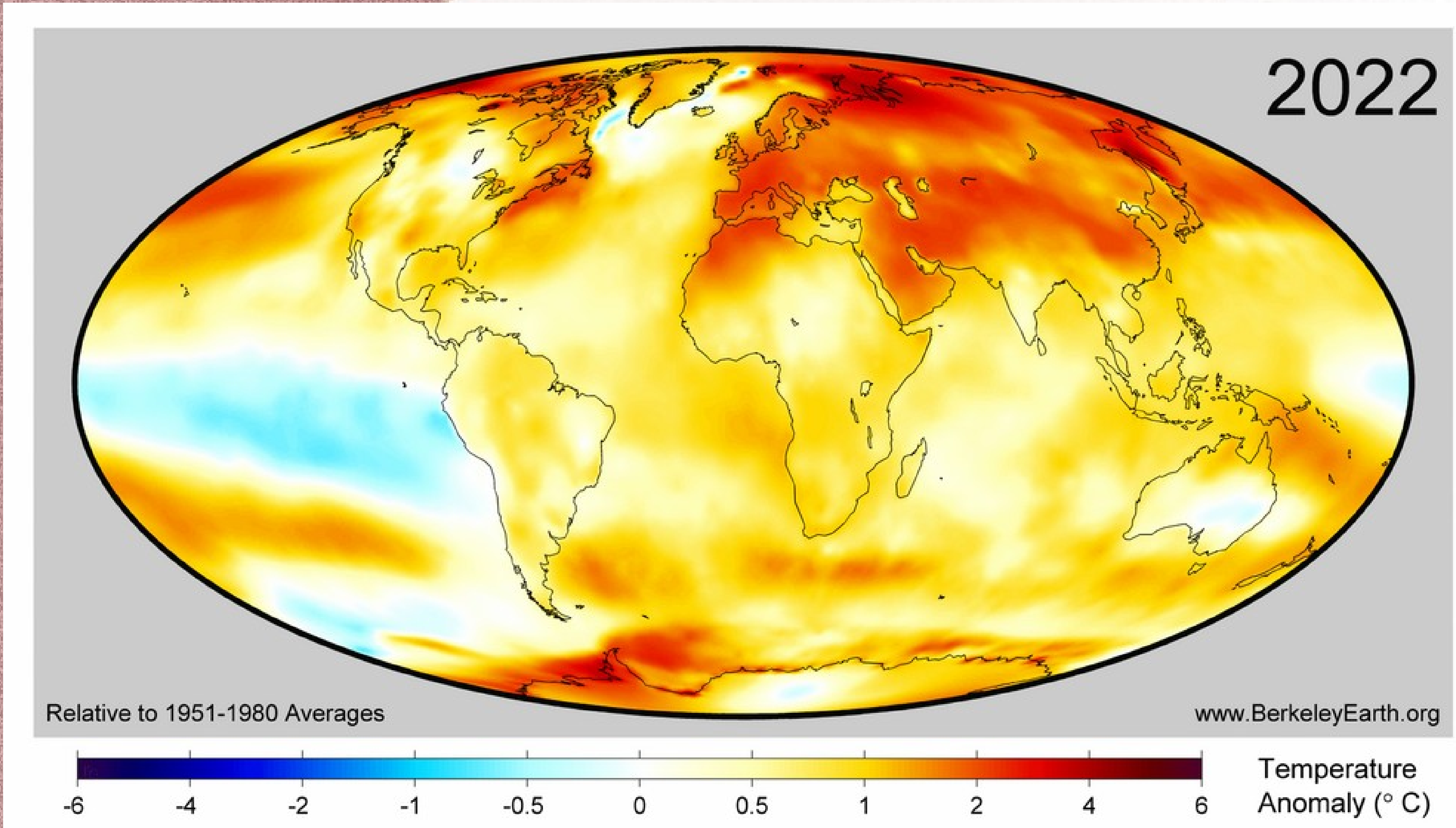
Sea ice





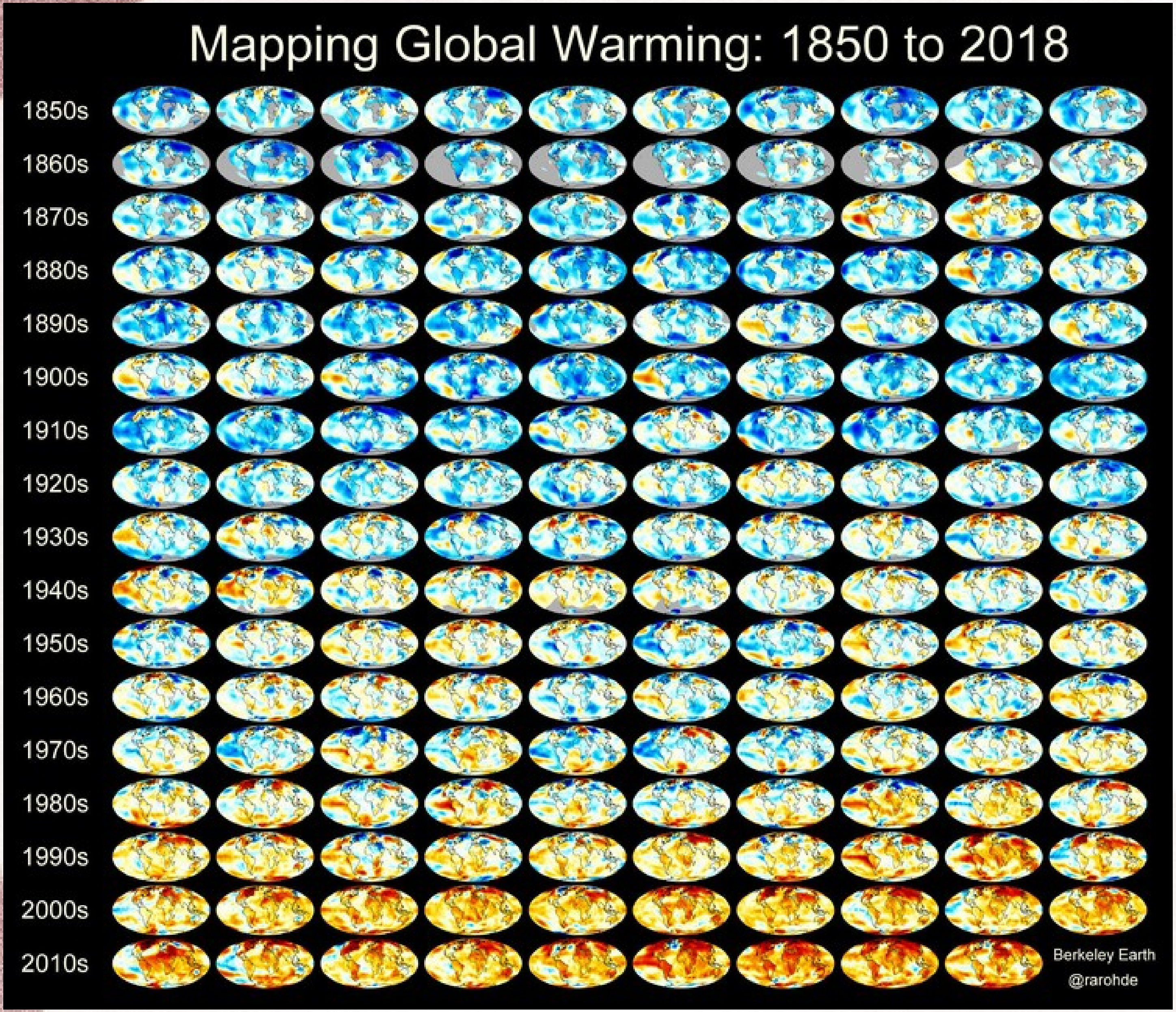
- Heating is similar to climate model simulations
- Arctic sea ice melt is faster than models

Warming just about everywhere

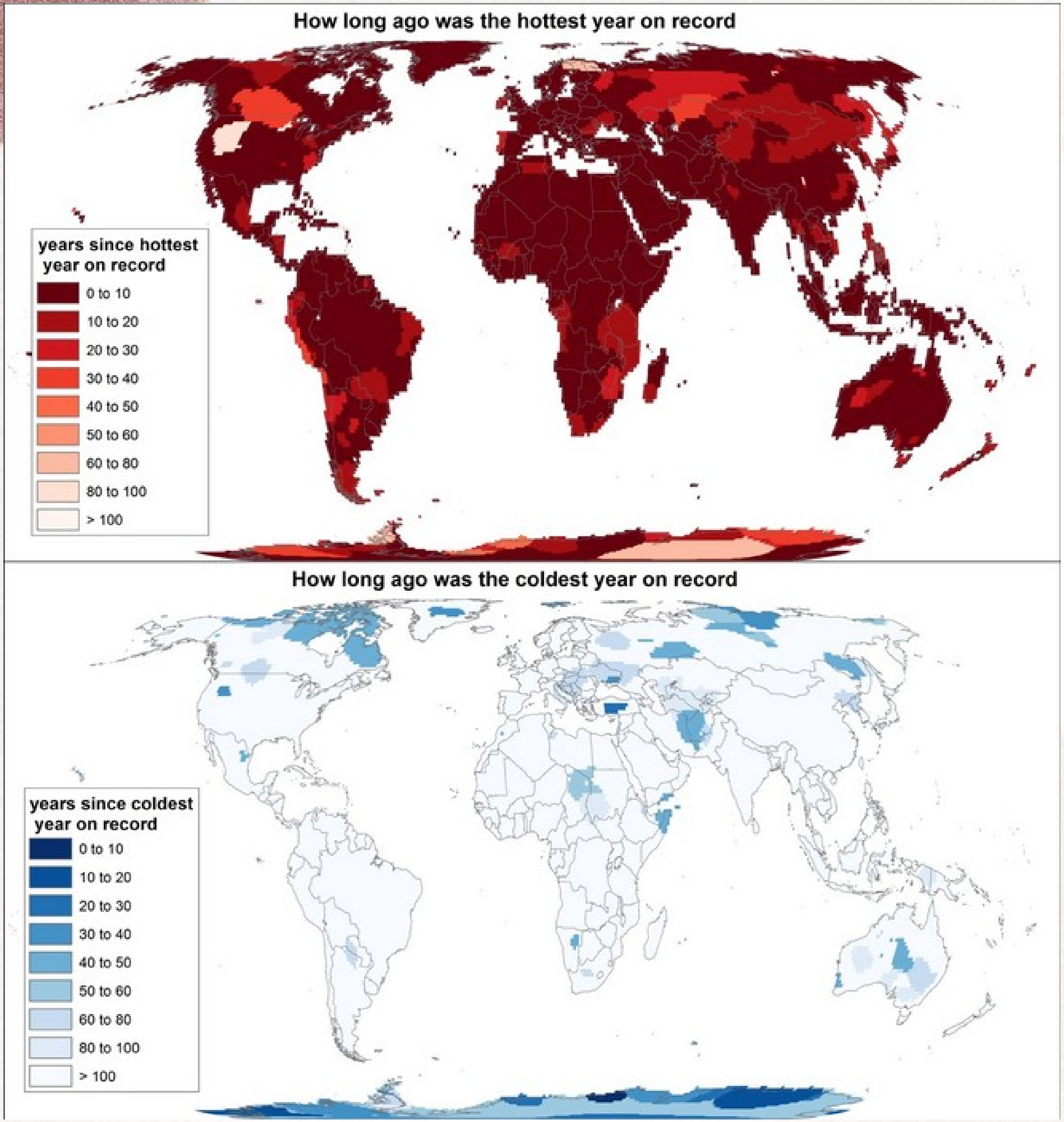


- The planet's average surface temperature has risen about 1.2 K (2 °F) since the late 19th century (1.8 K for land temperature)

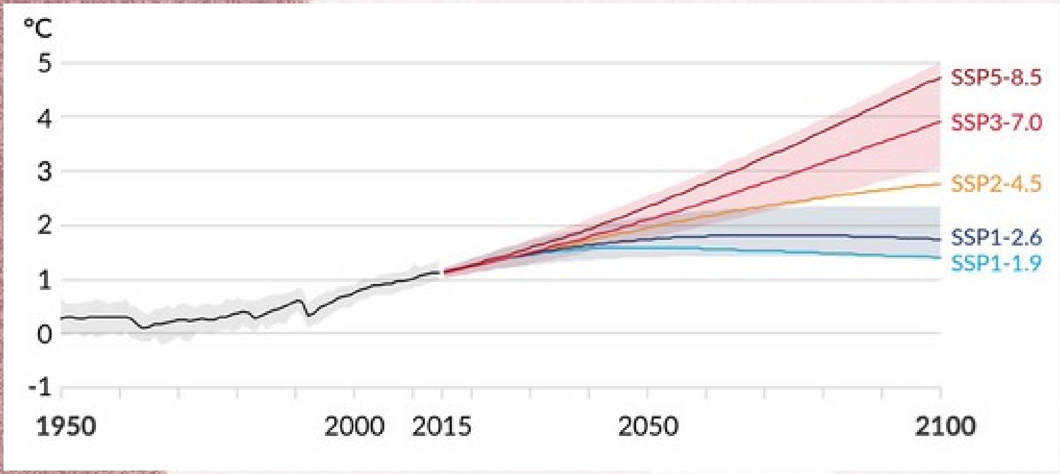
Local long-term temperatures

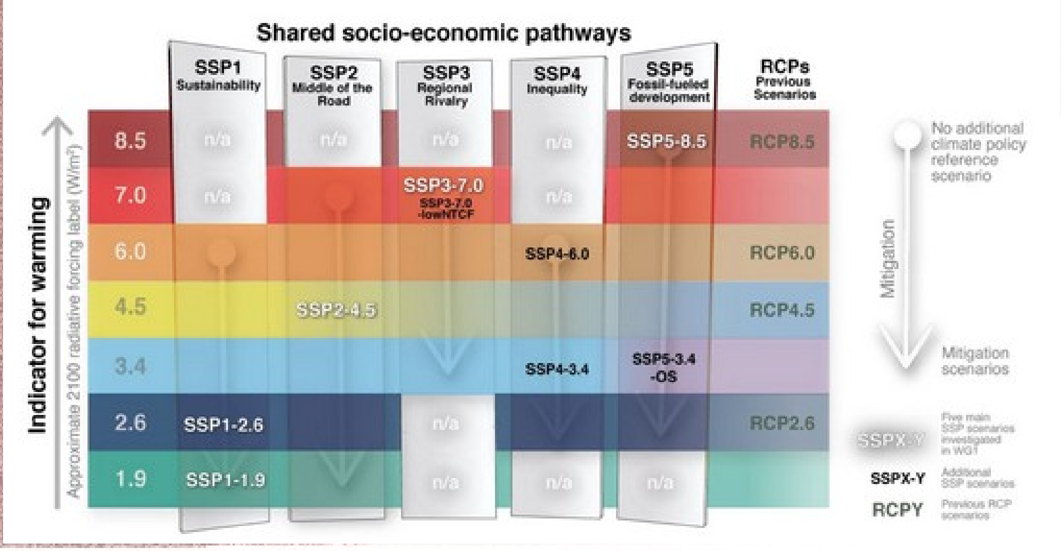


New warmest years



“Very likely” (IPCC) climate changes





- ≥ 1 K more warming (depending on emissions and feedbacks)
- Ocean acidification
- Faster evaporation
- More intense rain
- Continued melting of glaciers, ice caps, and sea ice; sea level rise

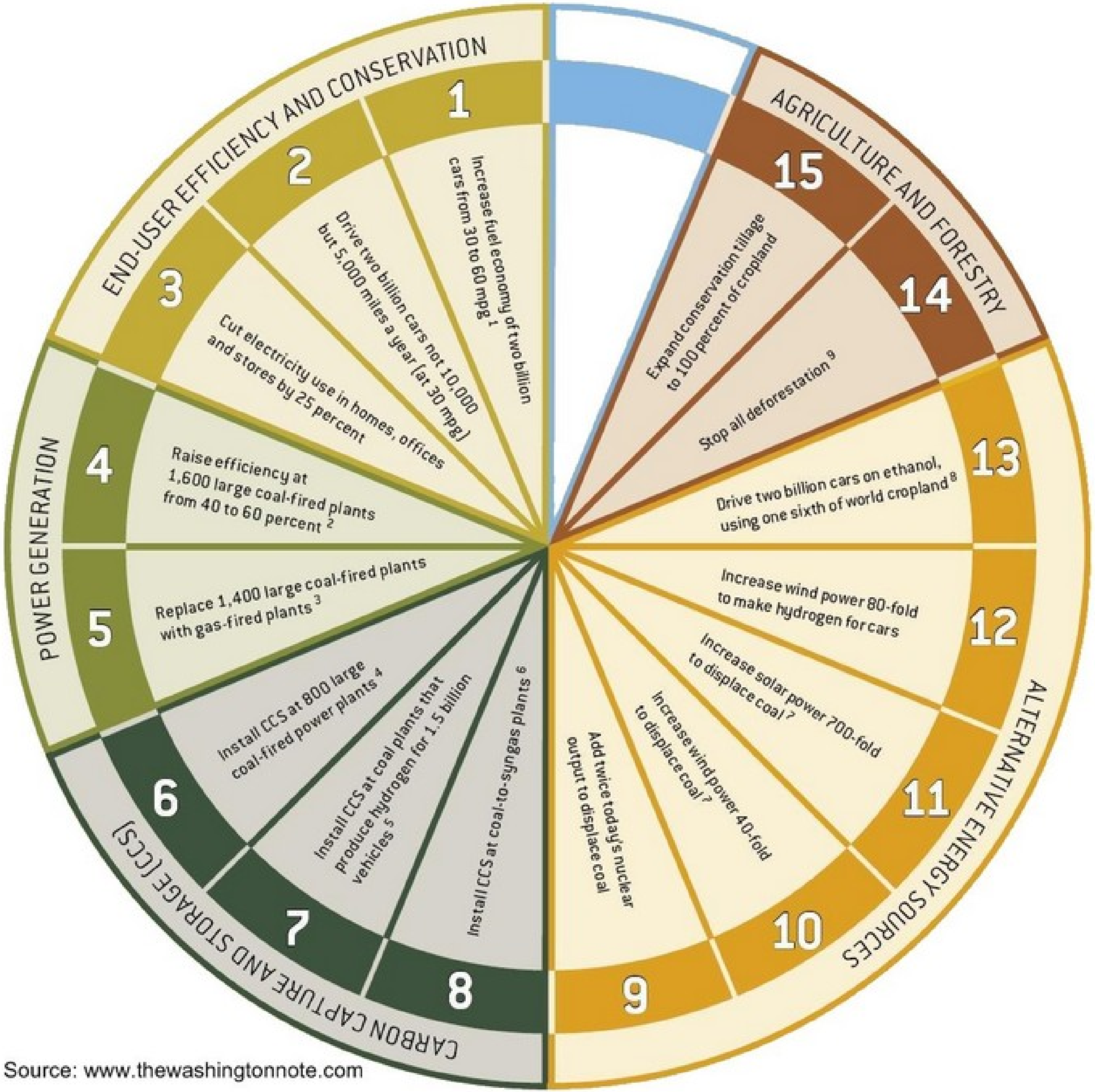
Climate feedbacks introduce many unknowns

- A warmer atmosphere can hold more water vapor, amplifying greenhouse warming
- Land and open water absorb more sunlight than ice (albedo feedback)
- Clouds cover has a big impact on radiation budget – not clear how clouds will change
- Under drought/fire, plant C could be released as more CO_2
- Methane hydrates in Arctic ocean floors could sublimate
- Ice sheets disintegrate by flowing (not completely melting) – no good models
- *The response of the earth system (especially life) to large disturbance is unpredictable*

Mitigation of global warming

- To reduce emissions:
  - Stop burning fossil fuels (alternative energy sources)
  - Reduce forest burning
- To increase CO_2 fixing/absorption:
  - Sequestration of combustion products: much talked about, but not actually happening (may not be practical – thermodynamic difficulties)
  - Pyrolysis of biomass into char (slow to decay in soil)
- Policies: carbon tax, or cap (C emission rations)
  - Note that net emissions must go to zero
  - Need long-term effort in many countries, cf. 350.org

Example policies: Socolow and Pacala's "stabilization wedges"



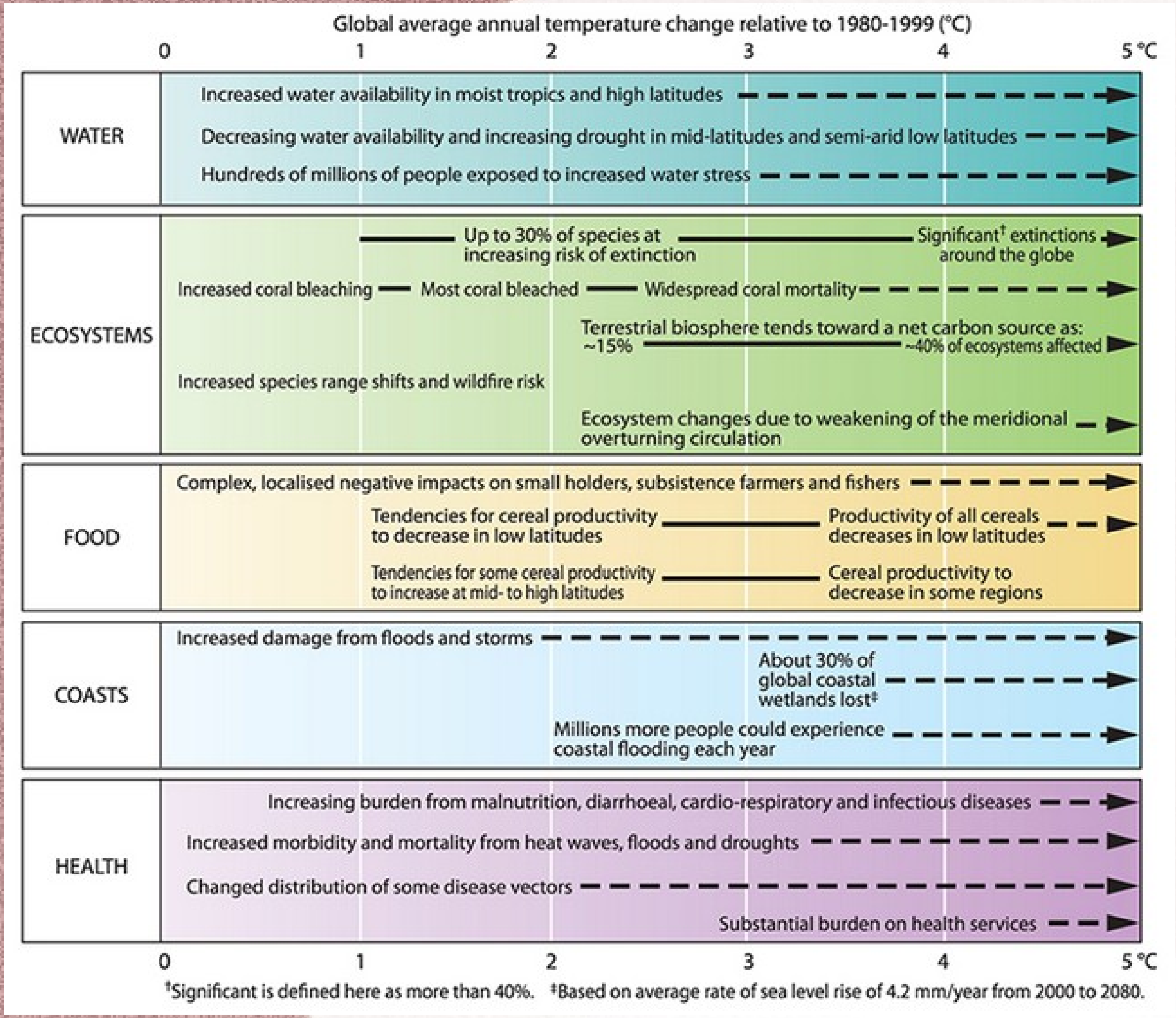
Source: www.thewashingtonnote.com

- Climate stabilization with near-present energy use rates will require major changes and large investments
- On the plus side, these changes will have other benefits (e.g. security, health)

Geoengineering: Science fiction brought to earth

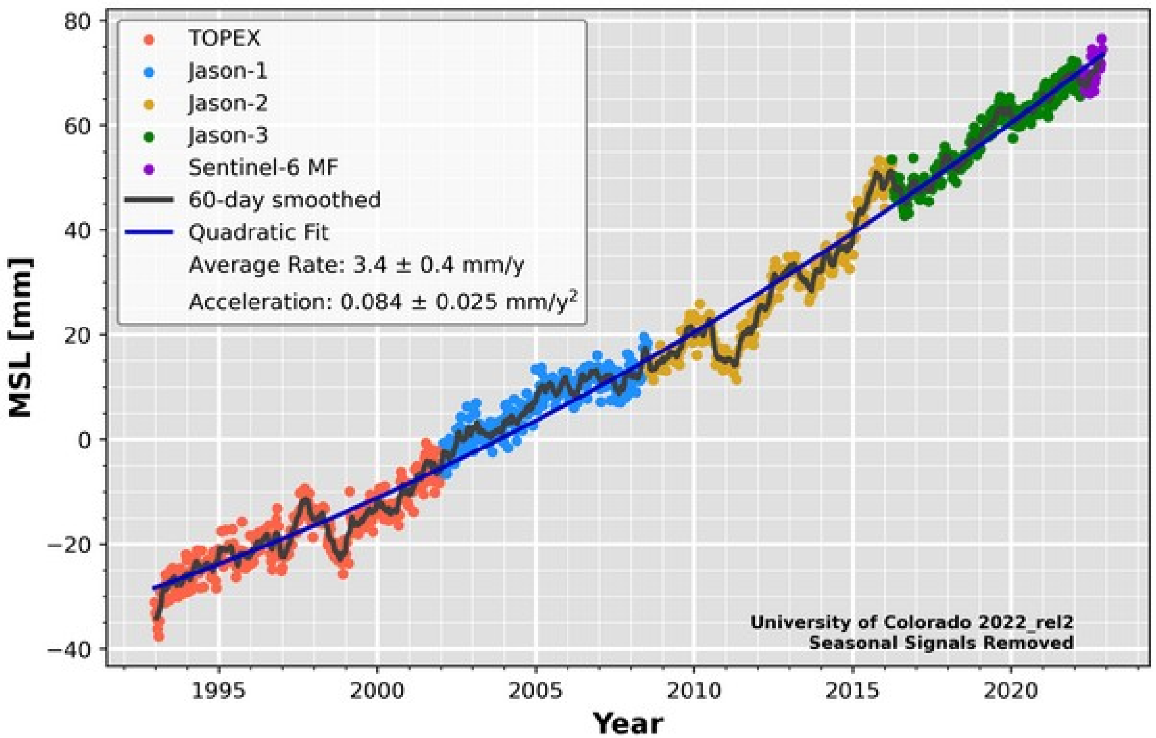
- Speculative ideas for cooling the earth
  - Place sulfuric acid in the stratosphere to maintain a permanent planetary haze
  - Spray ocean water into the air to make clouds more reflective
  - Mix ocean water to bring cold, nutrient-rich water to surface
  - Launch many pieces of aluminum foil into earth orbit to deflect some sunlight
- None has been shown to be feasible; each elicits many concerns about side effects

Impacts of climate change on people



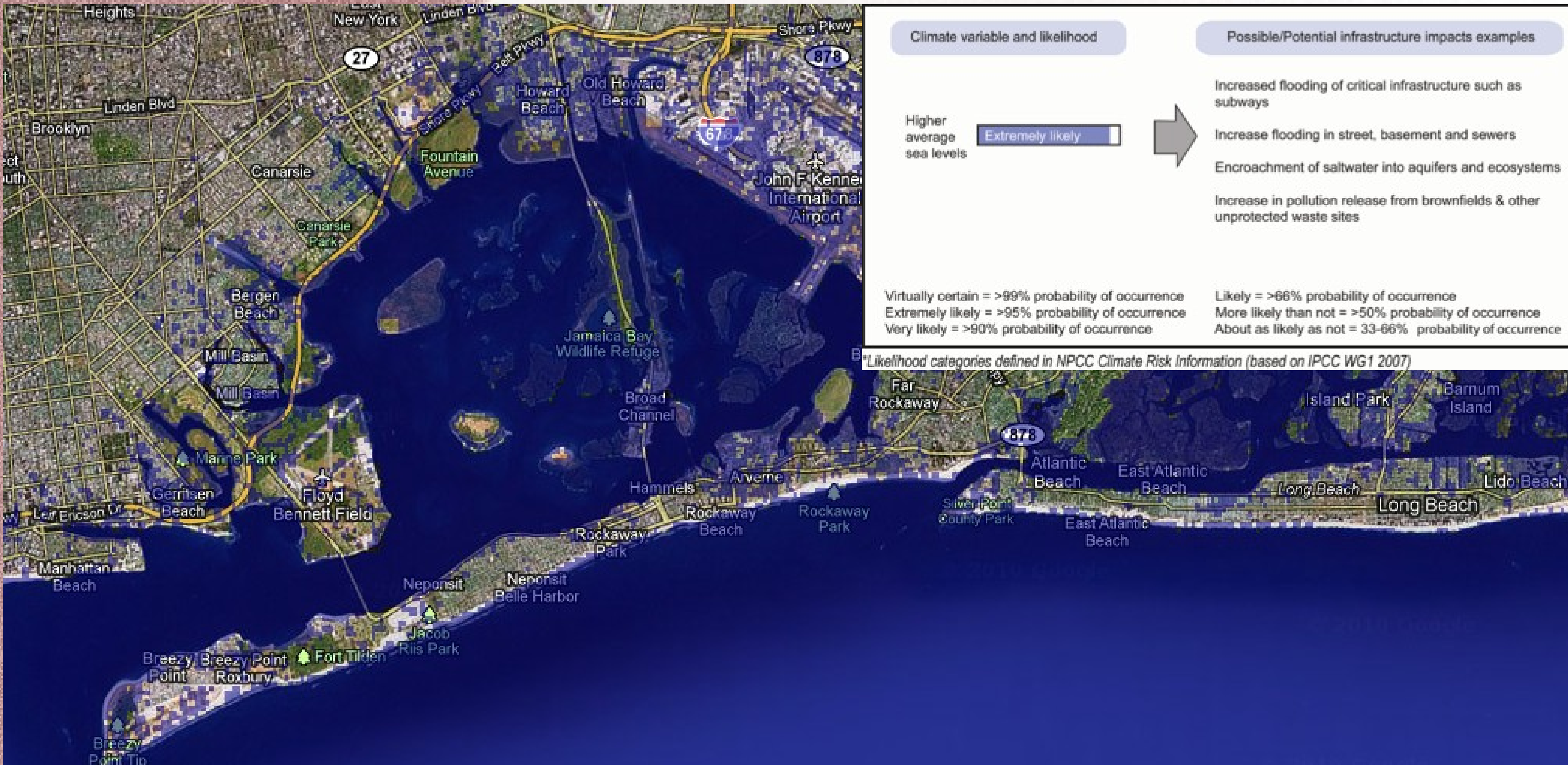
- Heat and drought will make crop failure more likely in warm climates
- Coastal cities may be flooded (cf. Houston); Bangladesh has ~15 million people within 1 m of sea level

Sea level rise



- Globally, accelerated from 2 to 4 mm/y since 1990s
- About 6 mm/y around NY

Adapting to global warming in NYC



Cf.

New York City Panel on Climate Change 2019 Report

Spreading flood zones

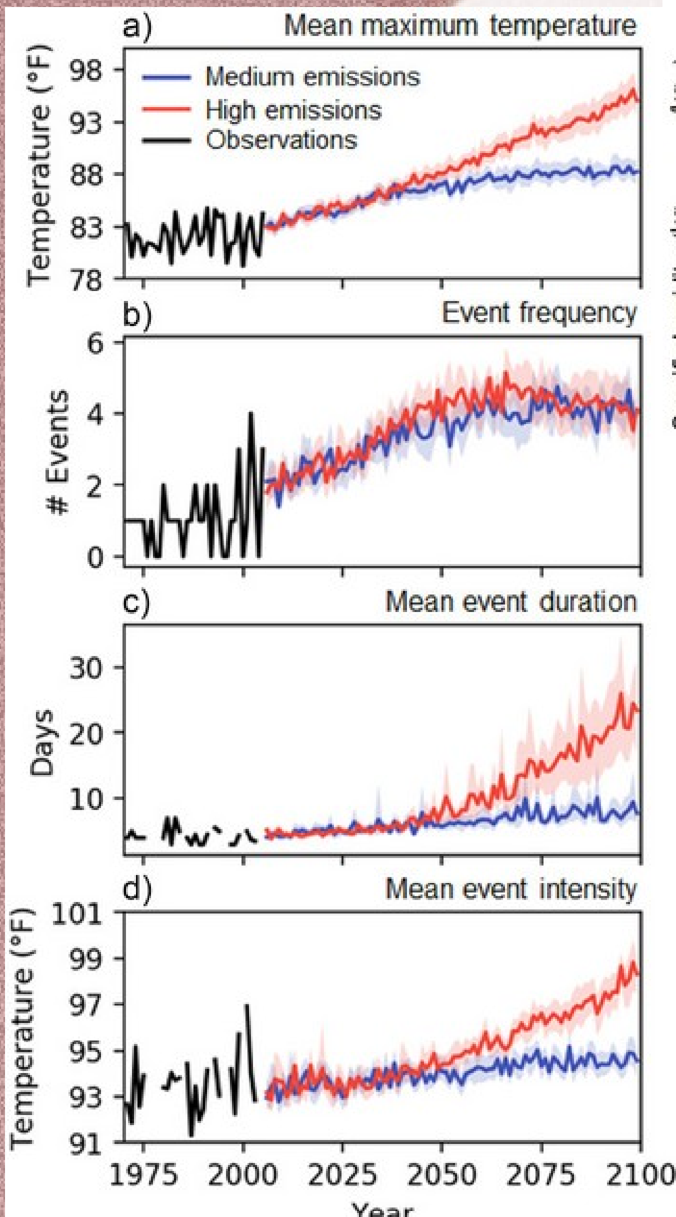
0.6-2 m sea level rise possible for 2020-2100

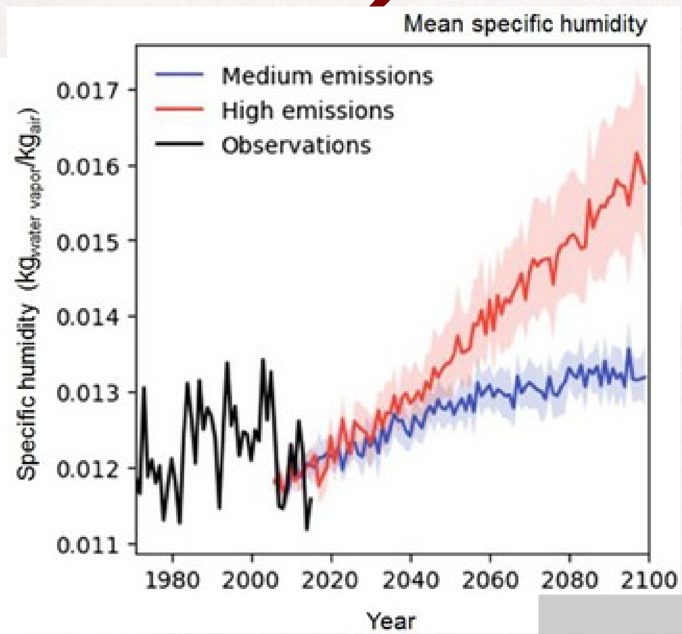
2020s

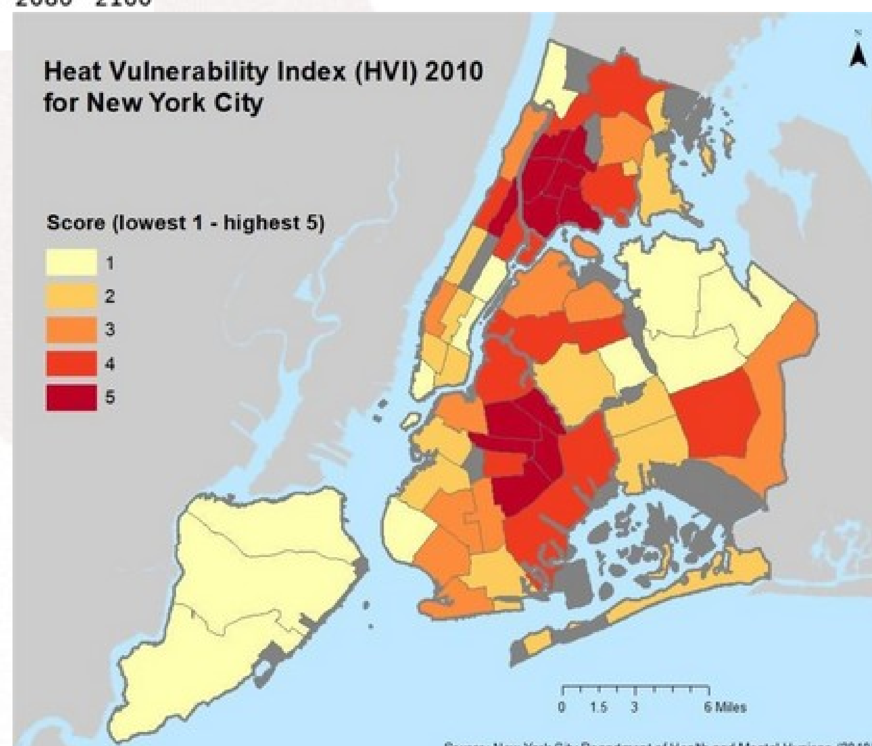
2100

NYC DCP
Flood Hazard Maps
(2017)

Heat (esp. humid) is a direct concern



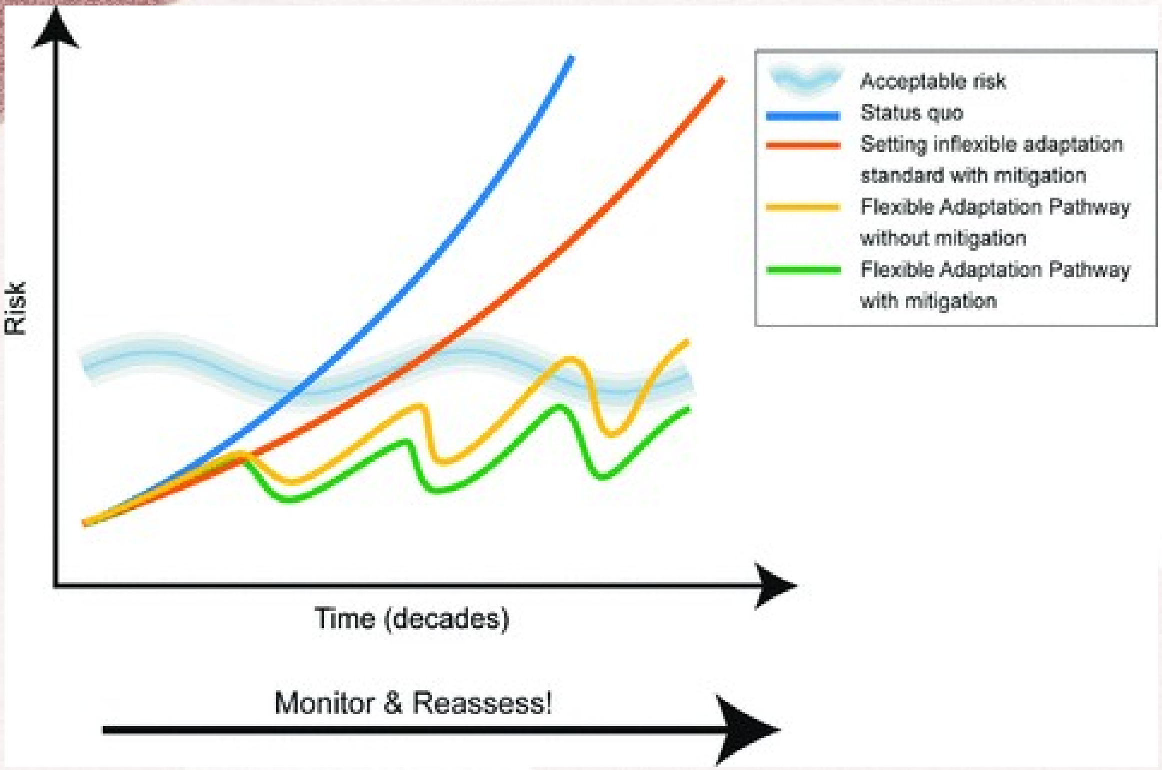




The proposed process

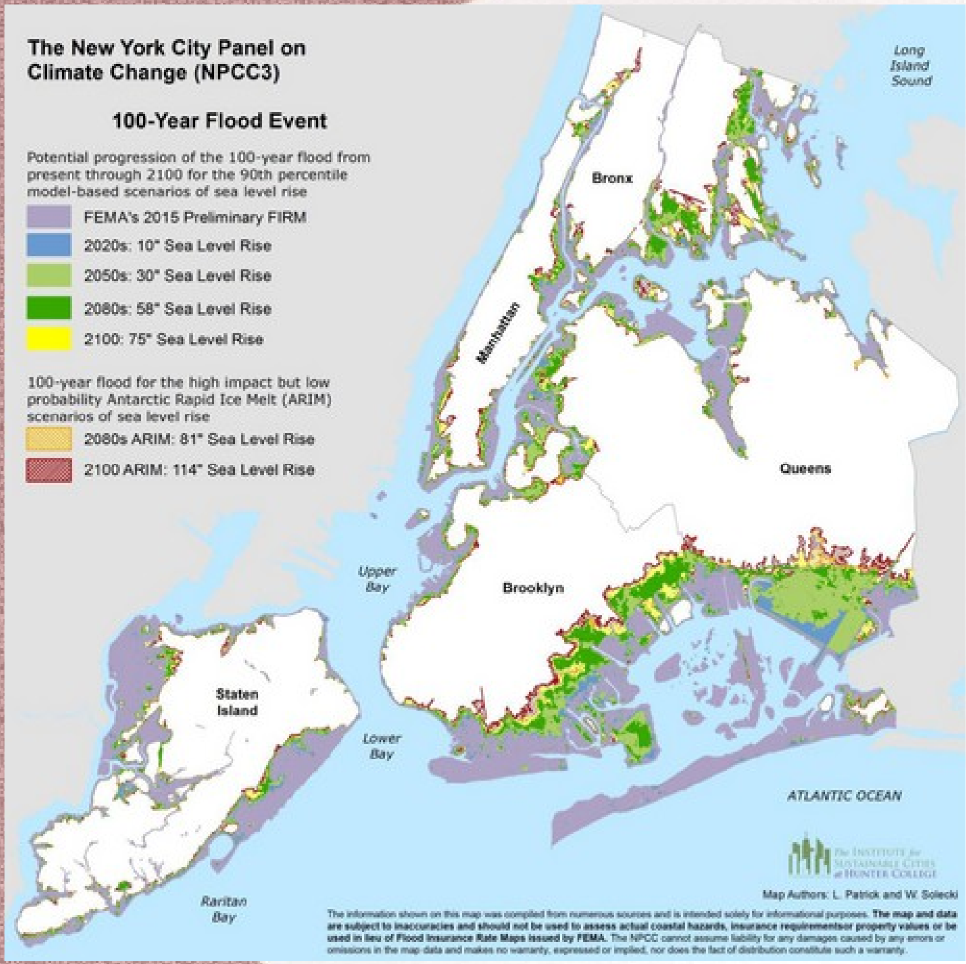
- Adaptation Assessment Steps:
  - Identify current and future climate hazards
  - Conduct inventory of infrastructure and assets
  - Characterize risk of climate change on infrastructure
  - Develop initial adaptation strategies
  - Identify opportunities for coordination
  - Link strategies to capital and rehabilitation cycles
  - Prepare and implement adaptation plans
  - Monitor and reassess

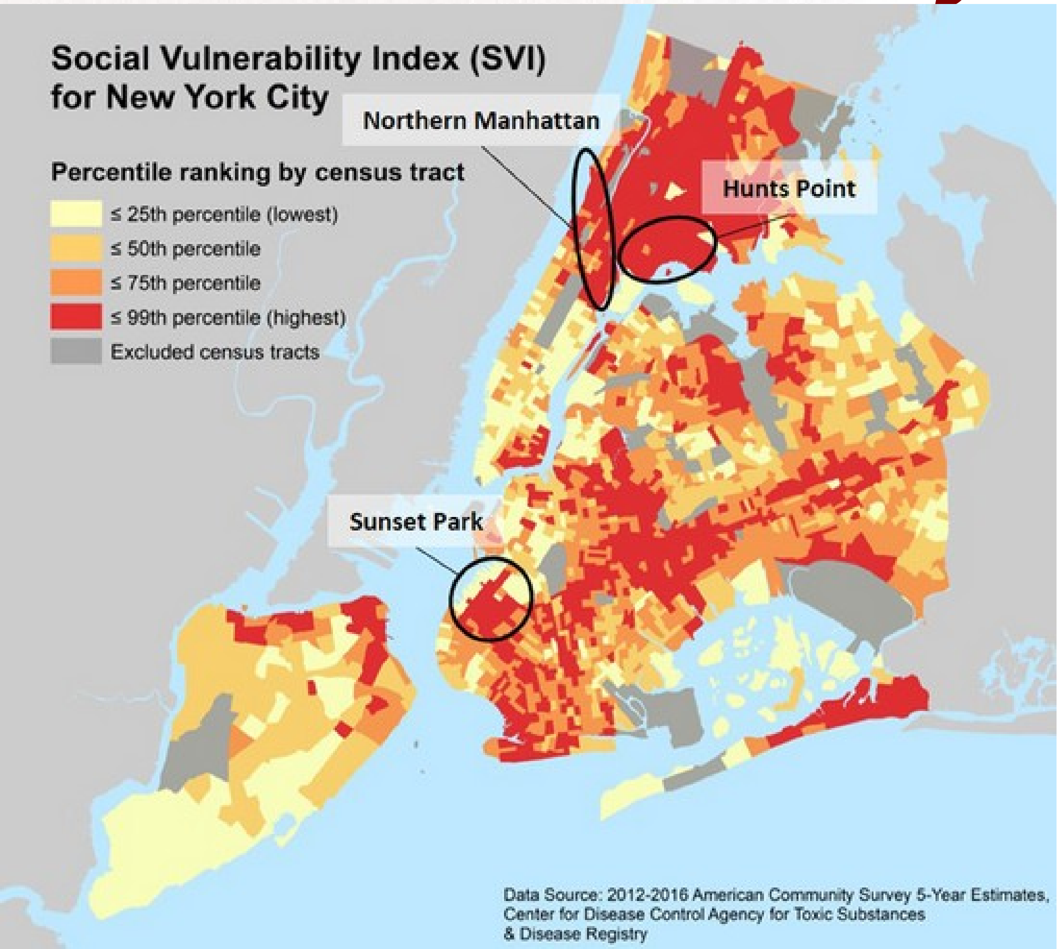
Flexibility and resilience



Since the impacts of climate change can’t be precisely forecast, we should plan to periodically re-evaluate plans in light of new developments

Differences in physical and social vulnerability





The SVI utilizes 15 indicators categorized into four themes: socioeconomic status, household composition and disability, minority status and language, and housing and transportation. NPCC3 community case study neighborhoods are circled.

Recommendations to the City

- Risks identified as
  - Heat and heat waves
  - Sea level rise and storm surge
  - Droughts and floods
- Have ongoing climate monitoring and an advisory panel
- Revise codes and regulations to address climate impacts
- Work with the insurance industry

Not answered: Is there enough investment in foreseeable needs? Will there be enough lead time to wait and see?

Can NYC be flood-proofed?

- “The potential 30-foot storm surge* accompanying a Category 3 hurricane would flood large swaths of south Brooklyn, parts of Queens, Staten Island, and Manhattan below Canal Street ... floodwater might pour into the city's tunnels and subway system ... The city's wastewater treatment plants ... could back up, sending raw sewage into basements and bathrooms citywide.” (2006)
- Dutch engineers have conceptualized a barrier across the Verrazano Narrows – price tag: $6.5 billion
- Other cities have such barriers, usually built *after* major floods

*Sandy: ~9 ft.

After Sandy, smaller projects are underway

- Rendering of planned promenade and 20' seawall in SE Staten Island, Ft Wadsworth to Oakwood Beach; $600 million, 2025

A spectrum of possible adaptation responses

Coastal adaptation (IPCC CZMS, 1990)	Adaptation objectives (Klein and Tol, 1997)	Adaptation responses (after Cooper et al., 2002; Defra, 2001)	Example
		Advance the line	Land claim; empoldering Estuary closure
Protect	Increased robustness	Hold the line	Dyke; beach nourishment
Accommodate	Increased flexibility		'Flood proof' buildings Floating agricultural systems
Retreat	Enhanced adaptability	Retreat the line	Managed realignment
		Limited intervention	Ad hoc seawall
		No intervention	Monitoring only
	Reversing maladaptive trends	Sustainable adaptation	Wetland restoration
	Improved awareness and preparedness	Community-focussed adaptation	Flood hazard mapping; flood warnings

"We're going to have to do something," [Stony Brook University oceanography professor Malcolm] Bowman said. "Or else you retreat, and that's inconceivable. How are you going to retreat from New York City?"

How do we engineer resilient infrastructure?

Can we design structures that will serve people well under not only global warming but also resource depletion, social change, and natural and human-made disasters?