Modelling of Systems for Sustainability

Nigel Goddard
David Sterratt

Newish course – we will be looking for your feedback and suggestions

Overview of today's lecture

- Introductory admin and schedule
- Motivation – why this is interesting
- Systems thinking and systems science
- Why computational modelling?

Online Materials

- https://opencourse.inf.ed.ac.uk/moss
  - All the course learning materials
    - Schedule, lectures, labs, tutorials, readings, etc
- Learn
  - Announcements
  - Piazza for discussions (see Tools->Piazza)
  - Coursework submission
  - Lecture recordings

Course structure in time

- Weeks 1-6: Concepts and modelling practice
  - 2 lectures (Mon/Wed), 1 discussion session (Fri)
  - 1 lab (Thu), 1 tutorial (Thu) – starting week 2
- Weeks 7-11: Group Project
  - Largely self-organised, with support
  - Modelling lab session (Thu)
  - Groups feedback/discussion (Fri)

Lecture Topics

- W1: Sustainability & systems thinking; Computer modelling
- W2: Analysing systems and formulating a model; Agent Based modelling
- W3: System Dynamics modelling; Model properties - emergence
- W4: Uncertainty, parameters, distributions; Communicating about models
- W5: Ecosystem models; Social system models
- W6: Integrated Assessment models; Project setup

Labs and Tutorials

- Weekly starting Week 2, on Thursday
- 1-hour (3 slots) tutorials to go over detailed examples in smallish groups
- 2-hour labs (2 slots) to learn about and practice running, constructing and evaluating models.

Group Projects

- Weeks 7-11
- 4 students per group
- Interdisciplinary
- Start organising in week 6
- Model and explore one or more systems relevant to sustainability

Assessment

- Coursework 1 (week 5, 50%)
  - Produce a design document for a published paper
  - Write a publicly accessible summary of the paper
- Coursework 2 (week 11, 50%)
  - Group project report co-written, individual attribution
  - Group project presentation/video

Motivation: Sustainability

- What is sustainability?
- An historical perspective
- Current situation and trajectory
- Goal: methods to understand interlinked system behaviour

Sustainability I: corporate ESG

- Environmental: preserve the natural environment over time, meeting present needs without compromising the availability of resources in the future.
- Social: inclusive societies, reduce inequality, and ensure long-term well-being for all people while preserving social cohesion and justice
- Governance: preserve and promote long-term economic well-being, balance between economic growth, resource efficiency, social equity and financial stability
- Goal: the organisation continues to thrive and grow


SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

Sustainability III: Our Approach

- *Systems underpinning human civilisation will continue to operate within ranges that permit civilisation to develop for the foreseeable future*
- Includes (but not limited to):
  - Climate (atmosphere and ocean) systems
  - Ecosystems across the planet
  - Sociotechnical systems – energy, transport, medical, educational, political, economic, ...

Non-sustainability in history

- Collapse brought on by system failures
  - Greenland Norse
  - Roman empire

Collapse I: Greenland Norse

- Underlying cause: climate change + globalisation
- Settled ~900-1400, up to 5,000 people
- Climate cooled – farming, travel ↓
- Elephant ivory edged out walrus tusk
- Didn't adapt

Globe graphic from Wikipedia here

Photo by Kumar Sriskanden

Collapse II: Western Roman empire

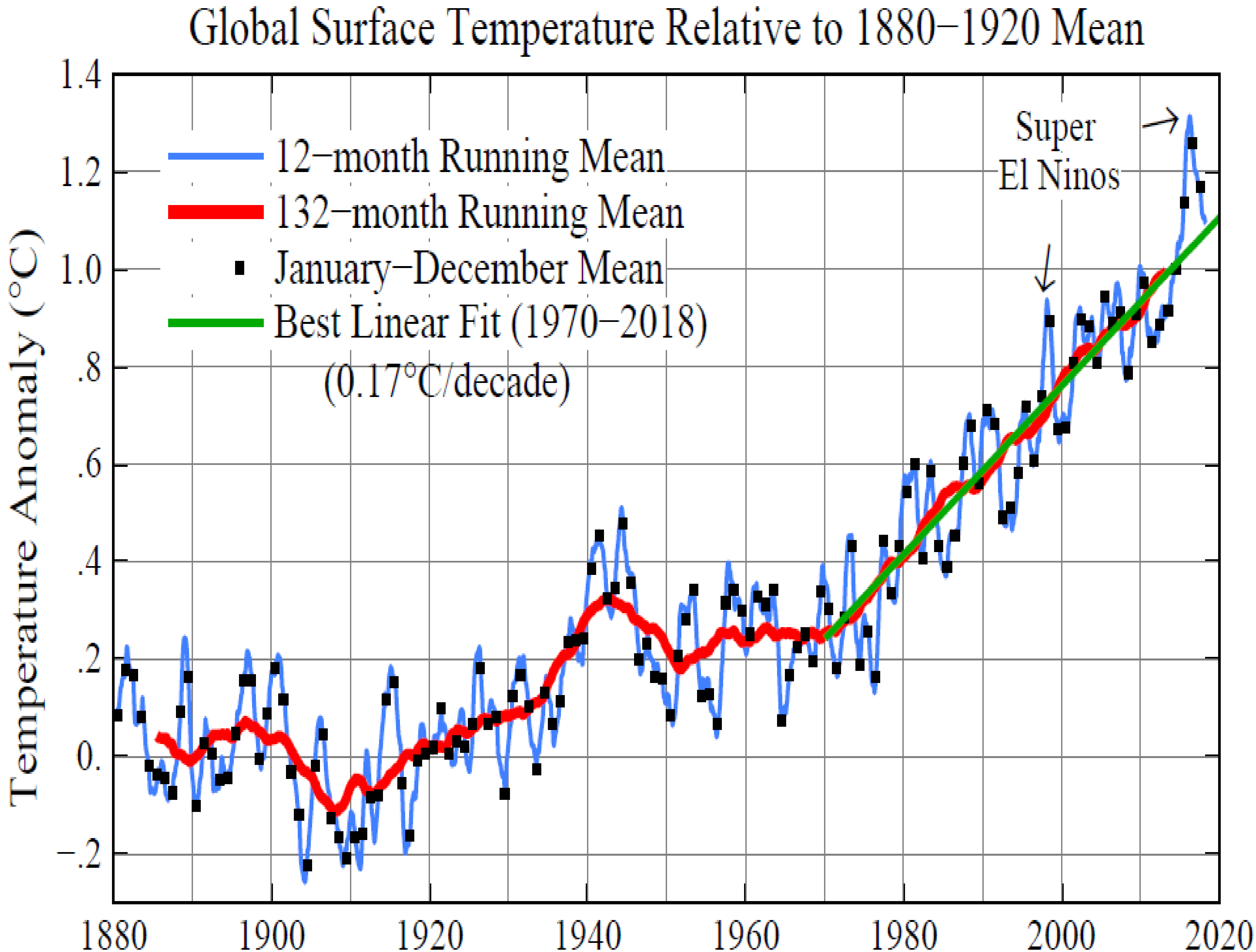
- Empire success based on growth
- Mediterranean-focused
- Systems
  - Military
  - Administrative
  - Agriculturual
- Overwhelmed by complexity

Non-sustainability in history

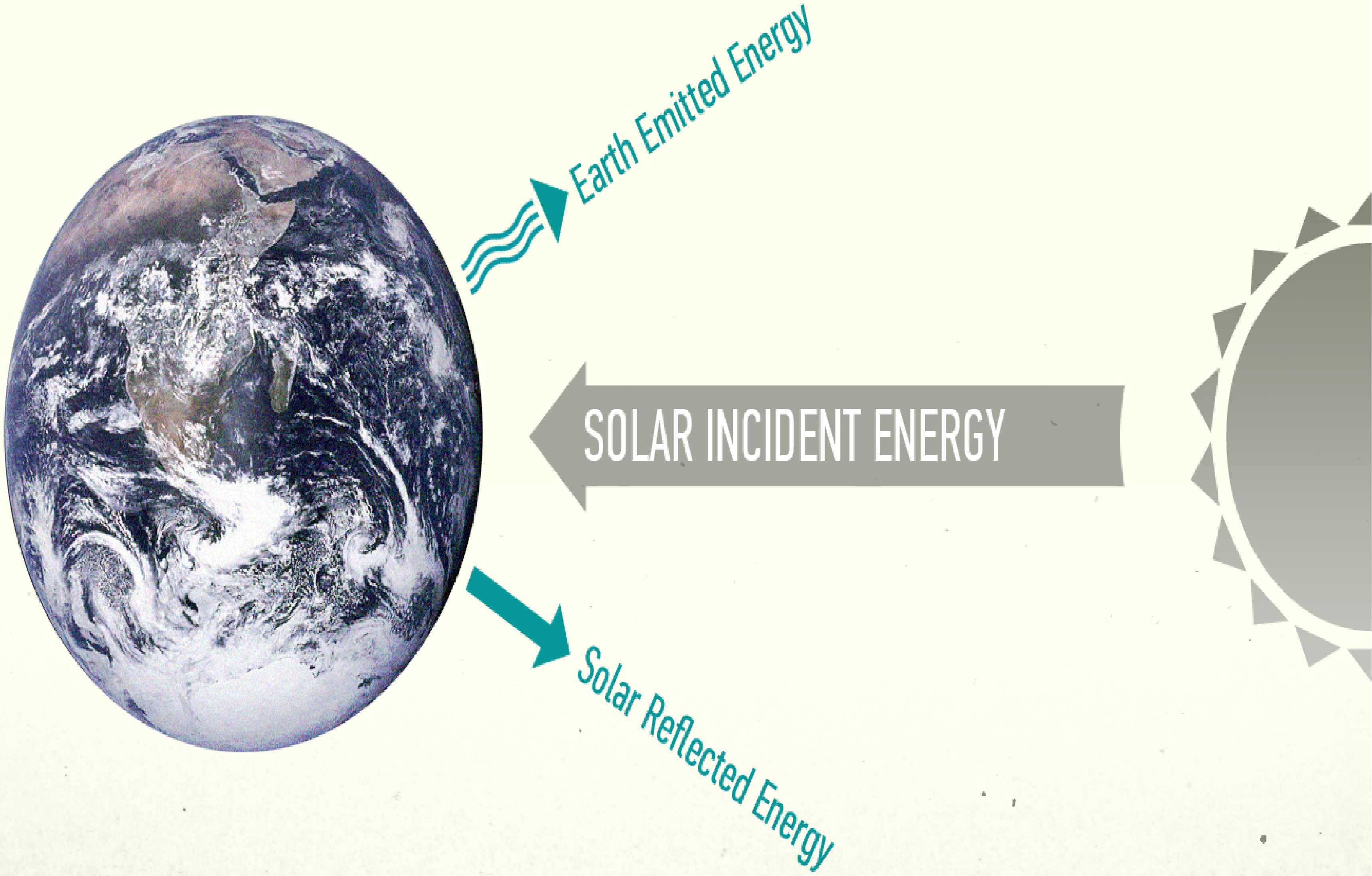
- Collapse brought on by system failures
  - Greenland Norse
  - Roman empire
- Complex, interacting systems

Signs of unsustainability now

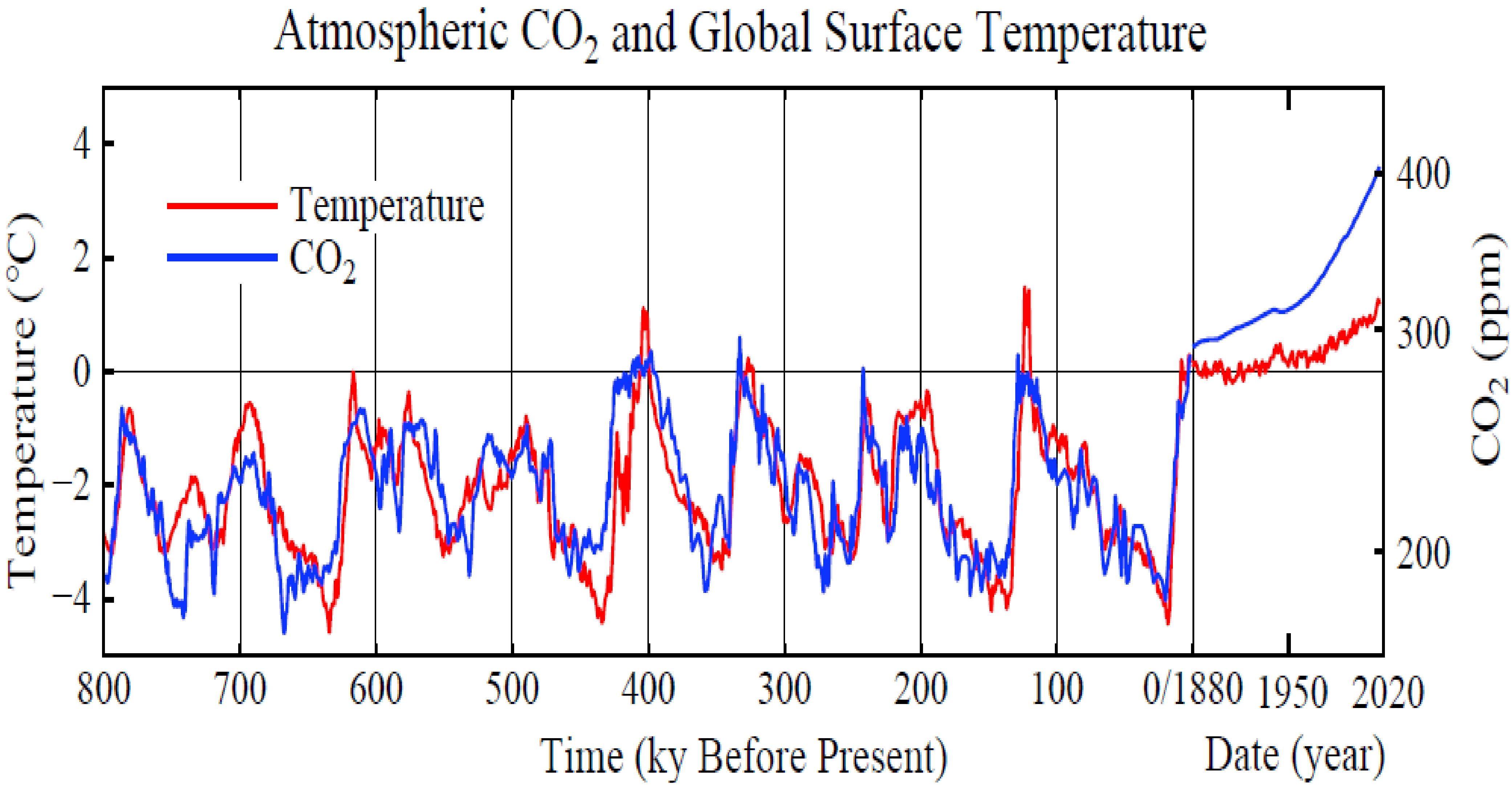
- Climate data (James Hansen)
- Climate tipping points
- Eco/social system stress
- Energy stress



Slide from James Hansen presentation (2018)



Slide from [James Hansen presentation] (2018)

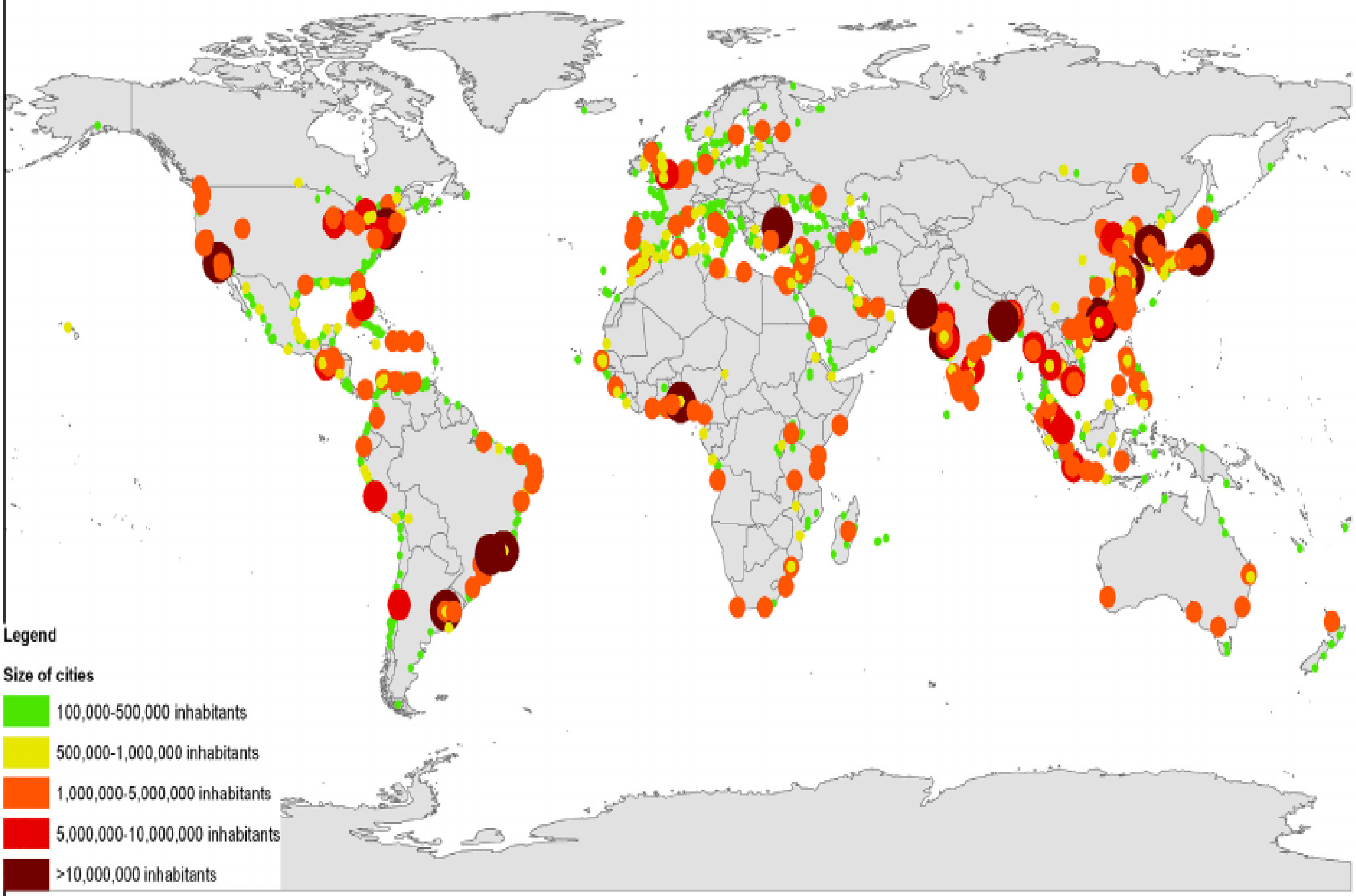


Note that the time scale for the past century has been expanded. A logarithmic scale is used for CO_2 because climate forcing and temperature change increase with the logarithm of CO_2.

Paleo global surface temperature change is from ocean core data of Zachos *et al.* (*Nature* 451, 279-283, 2008) via equations of Hansen *et al.* (*Phil. Trans. Roy. Soc. A*, 371, 20120294, 2013).

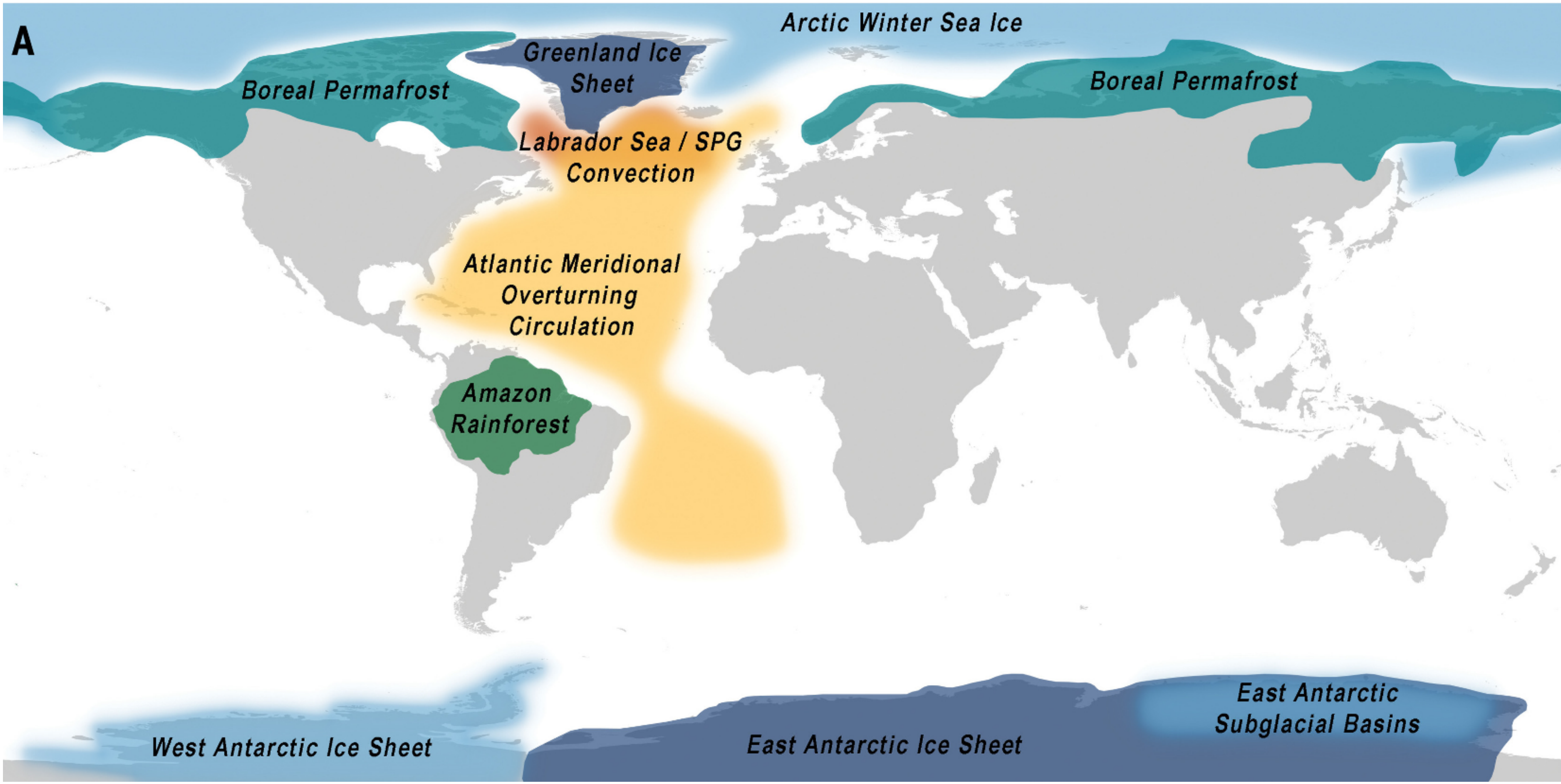
Slide from James Hansen presentation (2018)

More than half of the world's largest cities are on the coastline.



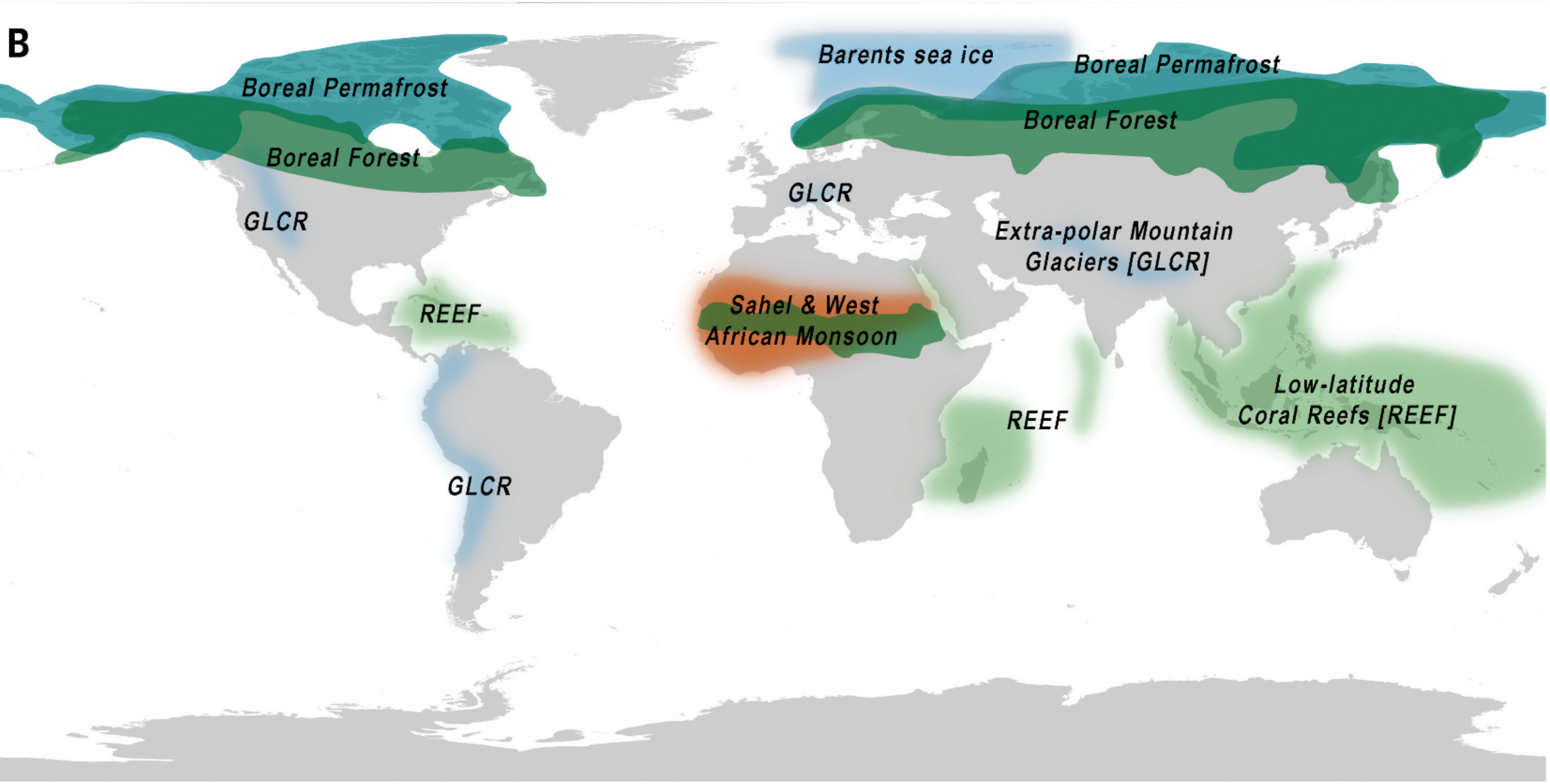
Slide from [James Hansen presentation](#) (2018)

Climate Tipping Points I



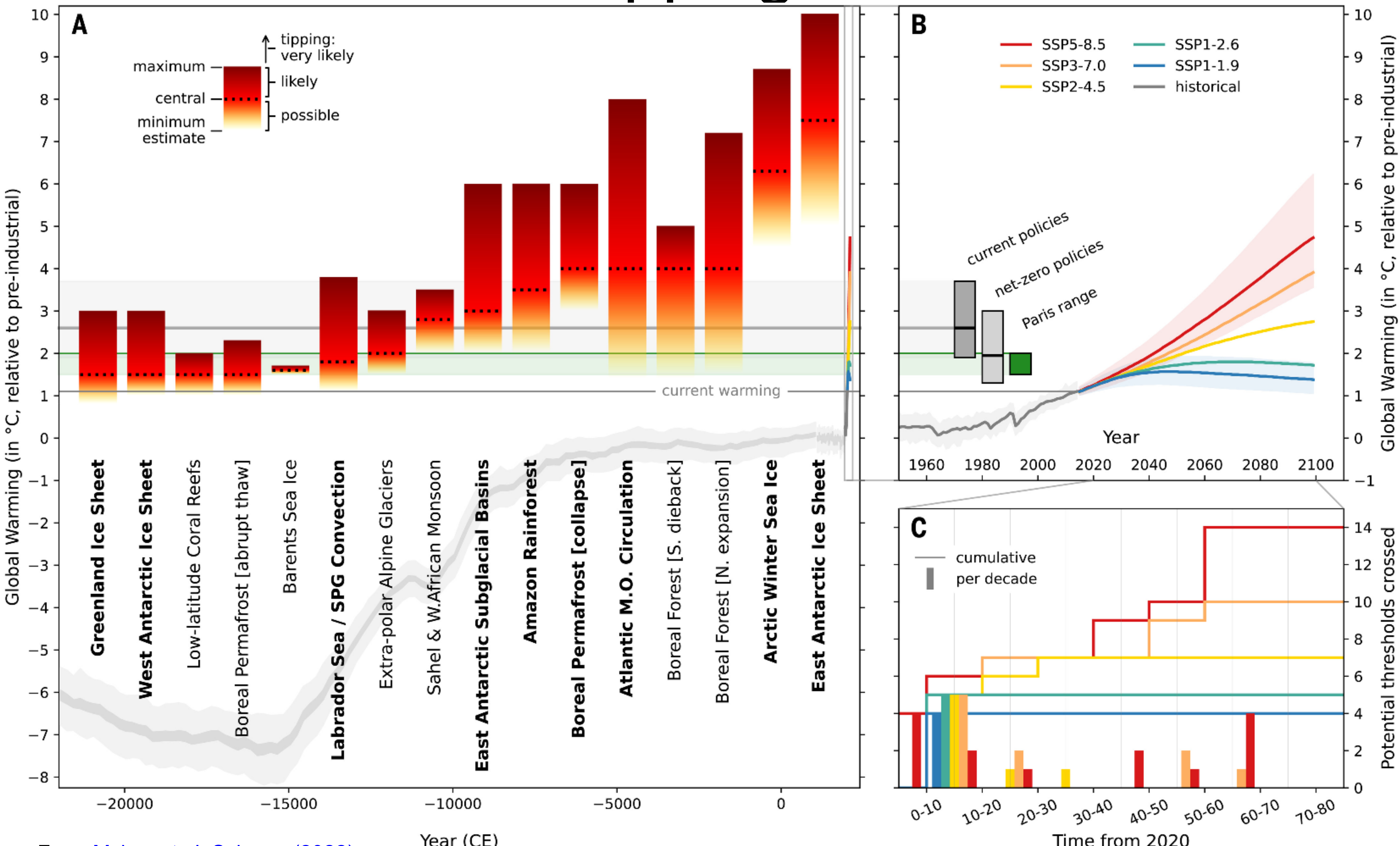
From [Mckay et al, Science (2022)]

Climate Tipping Points II



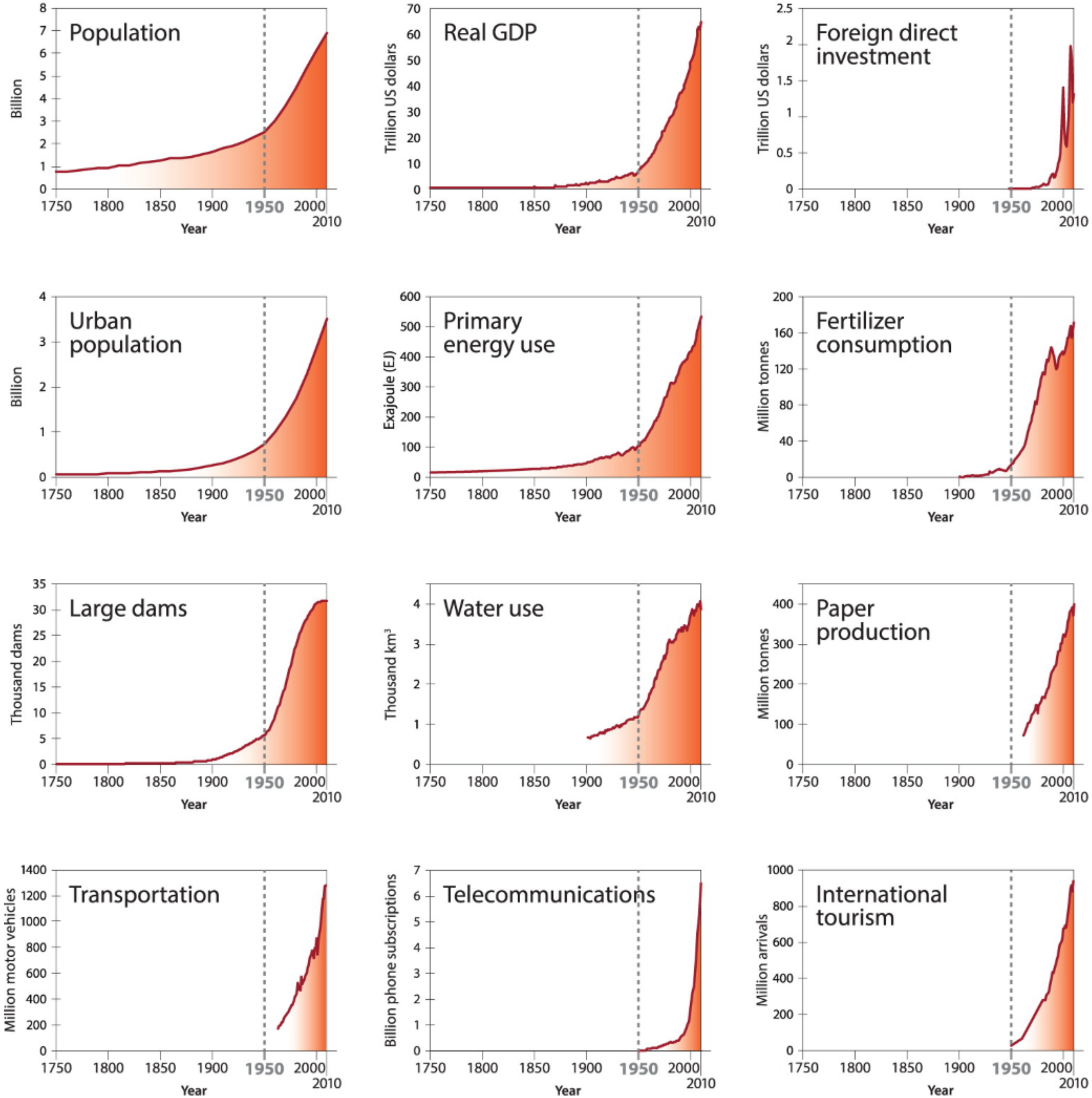
From [Mckay et al, Science (2022)]

Climate Tipping Points III



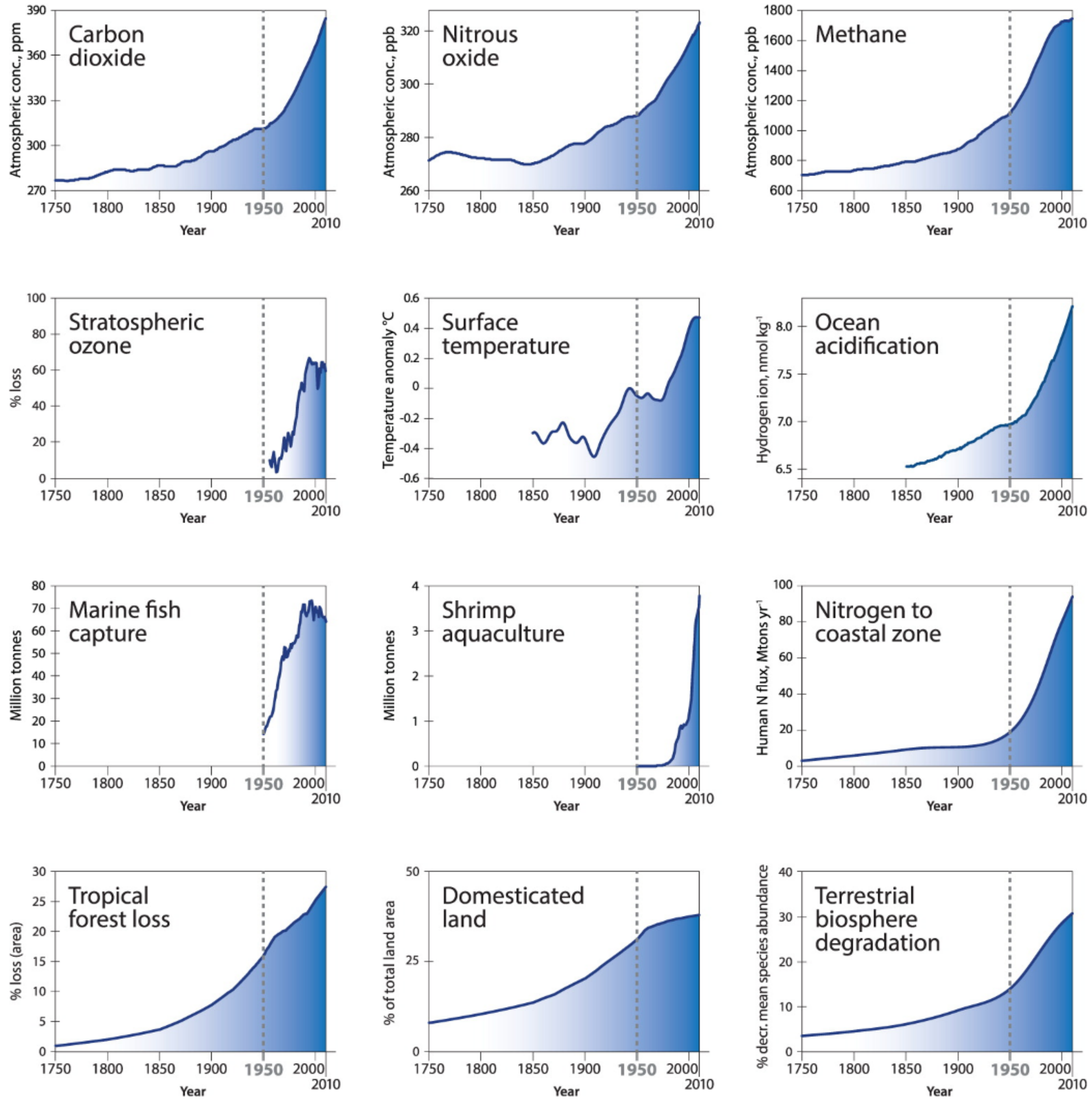
From [Mckay et al, Science (2022)]

Socio-economic trends



From Steffen et al, Anthropocene Review (2015)

Earth system trends



From Steffen et al, Anthropocene Review (2015)

Sustainability now: Energy

- We need to get off fossils fuels asap
  - Climate effects
  - Getting harder to access
- But: currently still critical for food system, transport system, heavy machinery, plastics, constructing a new energy infrastructure, and use still increasing.
- We don’t have good replacements
  - Energy dense
  - Storable
  - High temperature
  - Easily transportable

Five Horsemen of the Energy Transition

(from Michael Leibreich)

- Economic system - $130 trillion
- Electrical system - grid distribution upgrade
- Mining system – 5x; diesel needed?
- Political system – do voters care enough?
- Social system – powerful delayers?

We can do it, but it needs concerted, sustained effort.

Sustainable Systems

- Sustainability has been a problem in the past
- It looks like it’s a much bigger problem now
- Historical examples and current models show: slow changes in *system* parameters *can* induce sudden changes in *system* behaviour
- Key word throughout: ***system***

Principles of System Science

(synthesized from Meadows 2008 and Mobus & Kalton 2015)

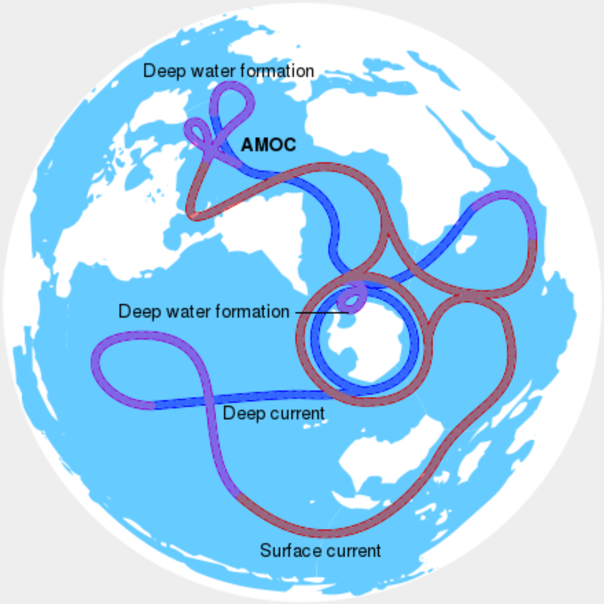
A system is more than the sum of its parts, in these ways:

1) Set of *processes* in structural and functional/purposeful hierarchies
2) Networks of *relations* amongst *components*
3) *Dynamic* over multiple temporal and organisational scales
4) Embedded in supersystems and composed of subsystems
5) Bounded according to the questions being asked
6) Can exhibit adaptability, resilience, goals, evolution

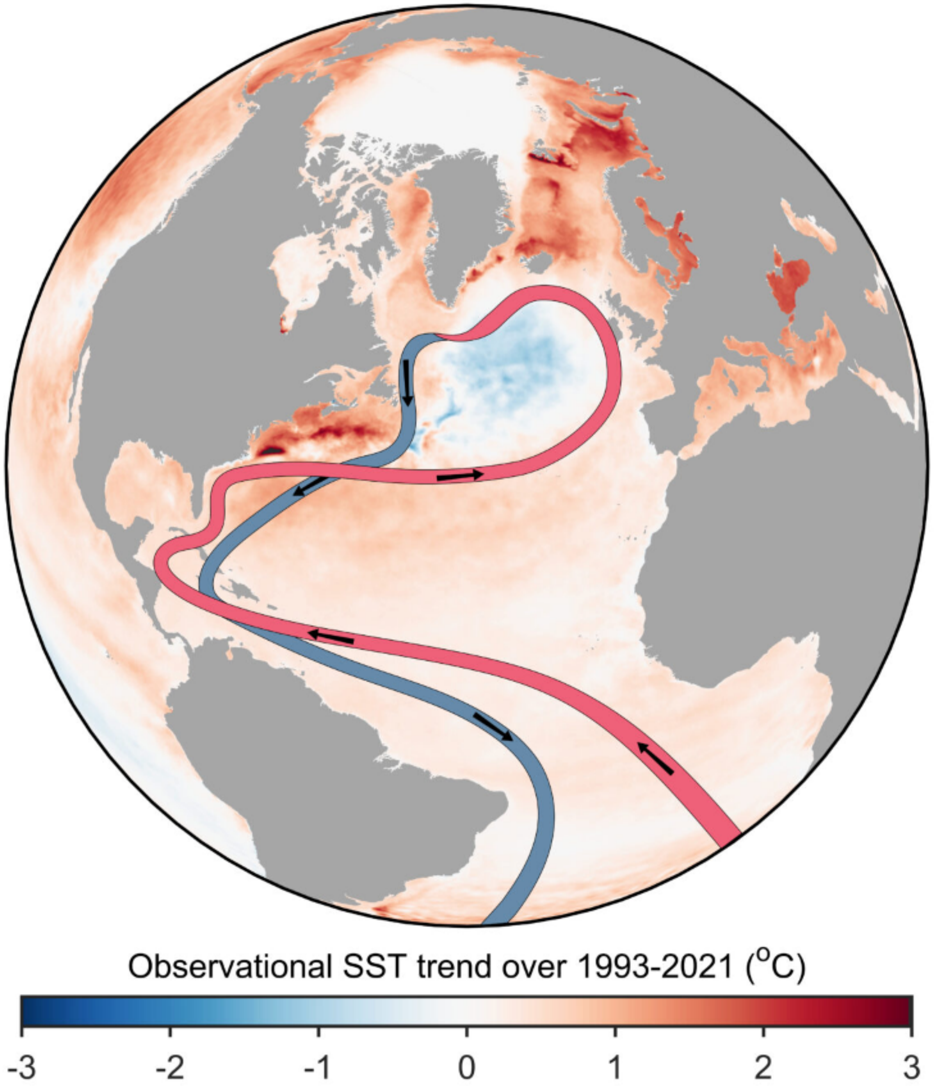
Example Systems

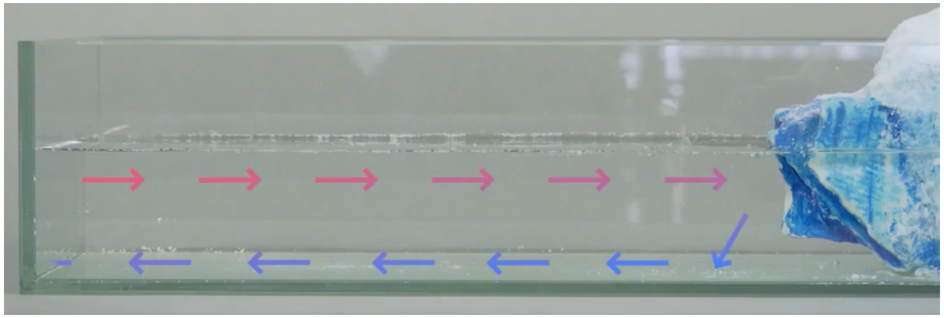
- AMOC
  - Atlantic Meridional Overturning Circulation
- Tree
- University

AMOC



[Wikipedia link to browser animation]





From Grist

Set of processes in structural and functional/purposeful hierarchies

- AMOC
  - Heat transport
  - Ocean mixing
- Tree
  - Growth and propagation
  - Absorb carbon dioxide CO_2 and produce oxygen O_2
- University
  - Student education (teaching)
  - New knowledge (research)

Network of relations amongst components

- AMOC
  - Components: Bodies of water
  - Relations: Ocean mixing
- Tree
  - Components: roots, trunk, branches, leaves, flowers, cambium, bark, ...
  - Relations: water flow, nutrient flow, photosynthesis, structure, ...
- University
  - Components: students, academics, administrators, buildings, IT systems, policies
  - Relations: teaching, supporting, assessing, managing, using,...

Dynamic over multiple temporal and organisational scales

- AMOC
  - Temporal: Surface winds (d), upwelling (ky)
  - Organisational: up/downwelling (100m), inter-ocean transport (10000m)
- Tree
  - Temporal: daily, seasonal, annual, lifetime
  - organisational: sub-cellular, cellular, leaf/flower/bud/twig, trunk/branches
- University
  - Temporal: day, week, semester, year, program
  - Organisational: tutorial group, class, research lab/institute, school, college, ...

Embedded in supersystems and composed of subsystems

- AMOC
  - Super: thermohaline, earth oceans/atmosphere, solar system
  - Sub: tropical and polar gyres, specific currents, ocean boundaries, ...
- Tree
  - Super: forest, region, continent, ...
  - Sub: cellular, root-exchange, photosynthesis, cambium, ...
- University
  - Super: community/city, education system, ...
  - Sub: teaching, research, administration, HR, finance, ...

Bounded according to the questions being asked

- AMOC
  - Hurricane formation: specific spatial focus, multi-year period
  - Climate change: worldwide focus, multi-decadal period
- Tree
  - Disease spread: single/small number of trees, seasonal
  - Climate change: forests/regions, decadal
- University
  - Research contribution: focus on research components/relations, decadal trends
  - Financial stability: whole-organisation, yearly

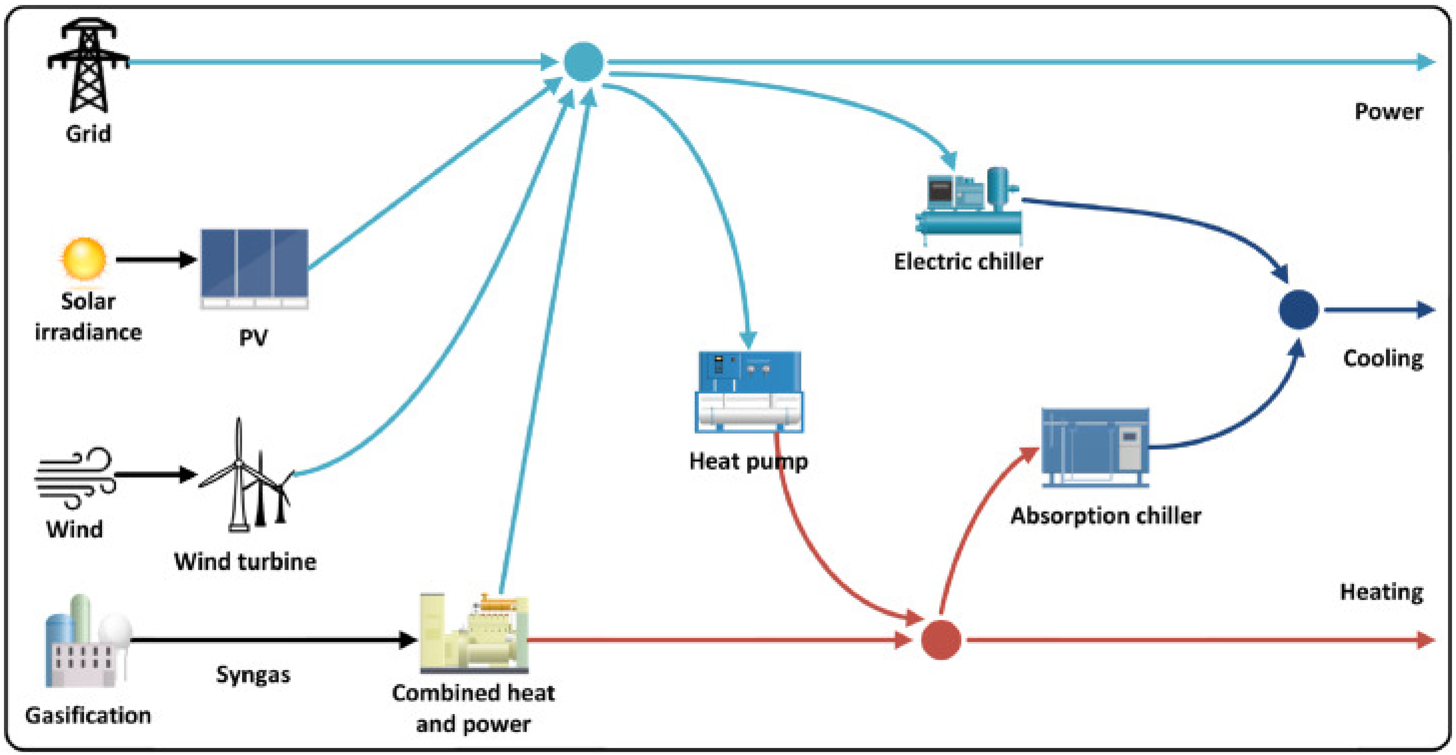
Can exhibit adaptability, resilience, goals, evolution

- AMOC
  - Bistable, heat/nutrient transport
- Tree
  - Grows towards light, fights pests/disease, reproduction, life stages
- University
  - Respond to challenges, mechanisms to cope with difficulties, mission statement, policy/structure revision

Why Computational Modelling I?

Verbal: “The electrical energy system relies on generation by gas-fired power stations, wind-turbines and nuclear plant. Gas varies from 0-95%, wind from 0-95% and nuclear 5-10%, depending on weather and maintenance conditions.”

Why Computational Modelling II?



From Liu et al, Applied Energy 2 (2021): https://doi.org/10.1016/j.adapen.2021.100024