Vulnerabilities and Thresholds in the Carbon-Climate-Human System

Mike Raupach, Pep Canadell

Global Carbon Project, Earth System Science Partnership

CSIRO Earth Observation Centre

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Aspiration and Outline

Aspiration of this talk

- Survey vulnerabilities in climate-carbon and carbon-climate-human system
- Seek common patterns
- Seek consistent measures of vulnerability
- Seek a Complex Adaptive System (CAS) perspective on vulnerability

Outline

- Defining vulnerability
- Vulnerability and climate
- Vulnerability and the carbon cycle
- Vulnerability and humans
- Synthesis

“Vulnerability” is a richly loaded word

Climate

- “Human impacts on the environment are now large enough that the climate system itself is **vulnerable** to human interference”

Carbon

- “Land and ocean carbon pools are **vulnerable** to increased CO_2 release as the climate warms, thus accelerating the warming”

Humans

- "Poor nations are the most **vulnerable** to climate change"

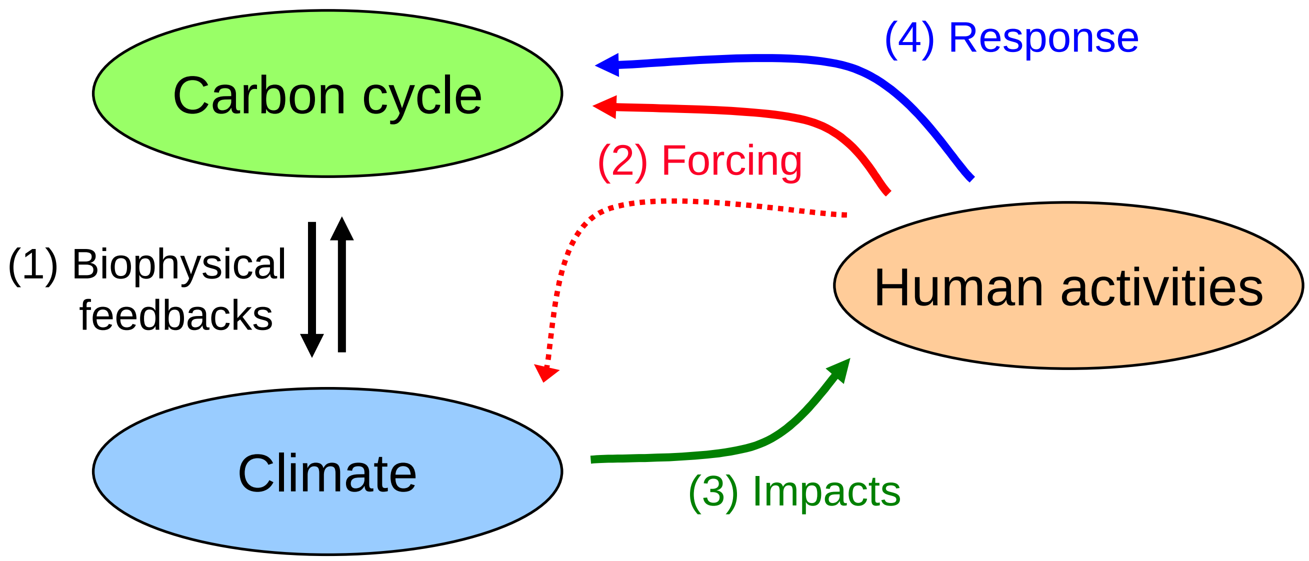
Defining vulnerability

- **Definition (Turner et al. 2003)**

  “Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor.”

- Thus we need to:
  - 1. Identify the system or system component
  - 2. Identify the forcing (hazard) and response (harm)
  - 3. Define a measure of "degree to which system is likely to experience harm"
  - 4. Apply this measure, act on result

Carbon-climate-human interactions



Vulnerability and Climate

- **Outline**
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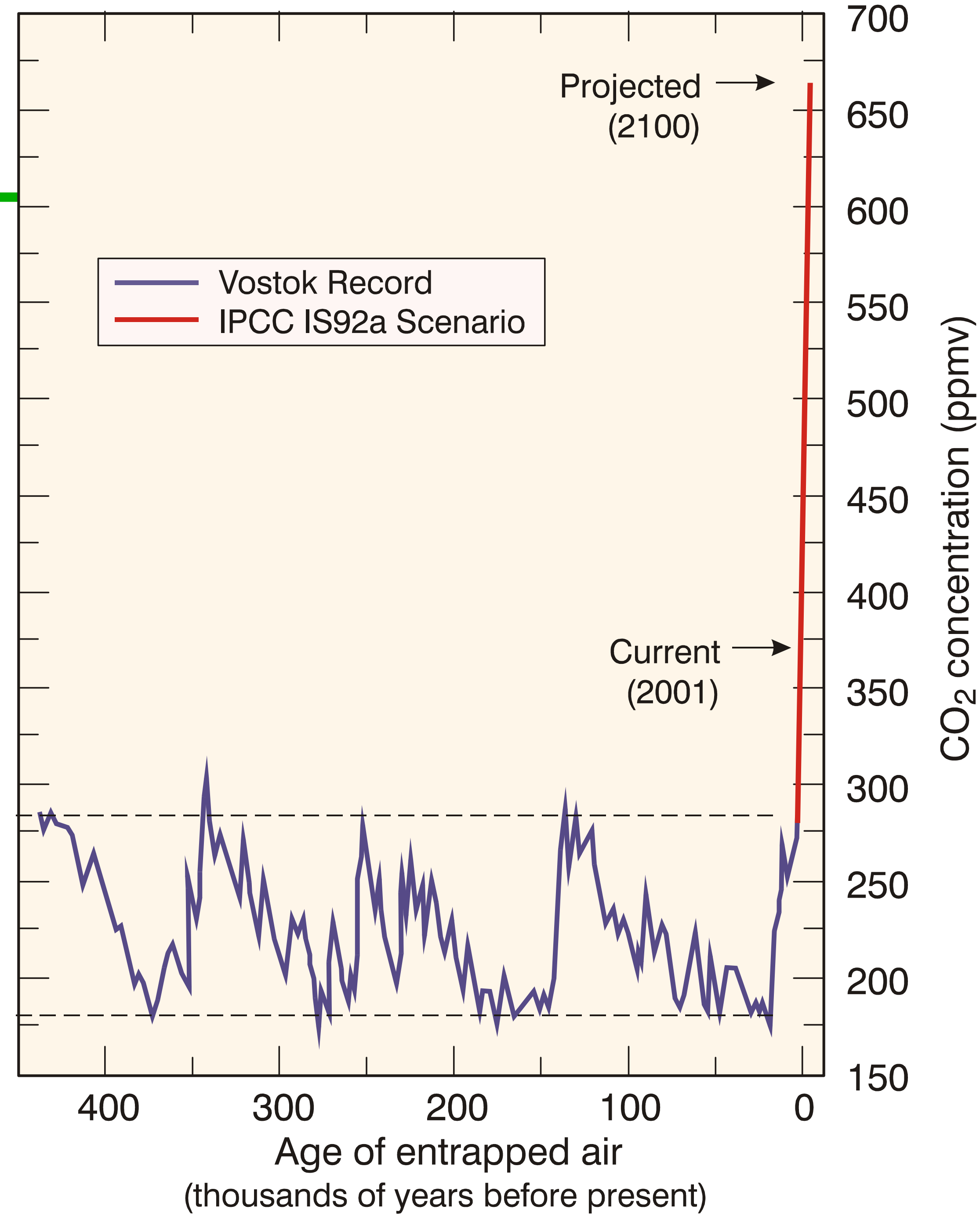
Atmospheric CO_2: past and future

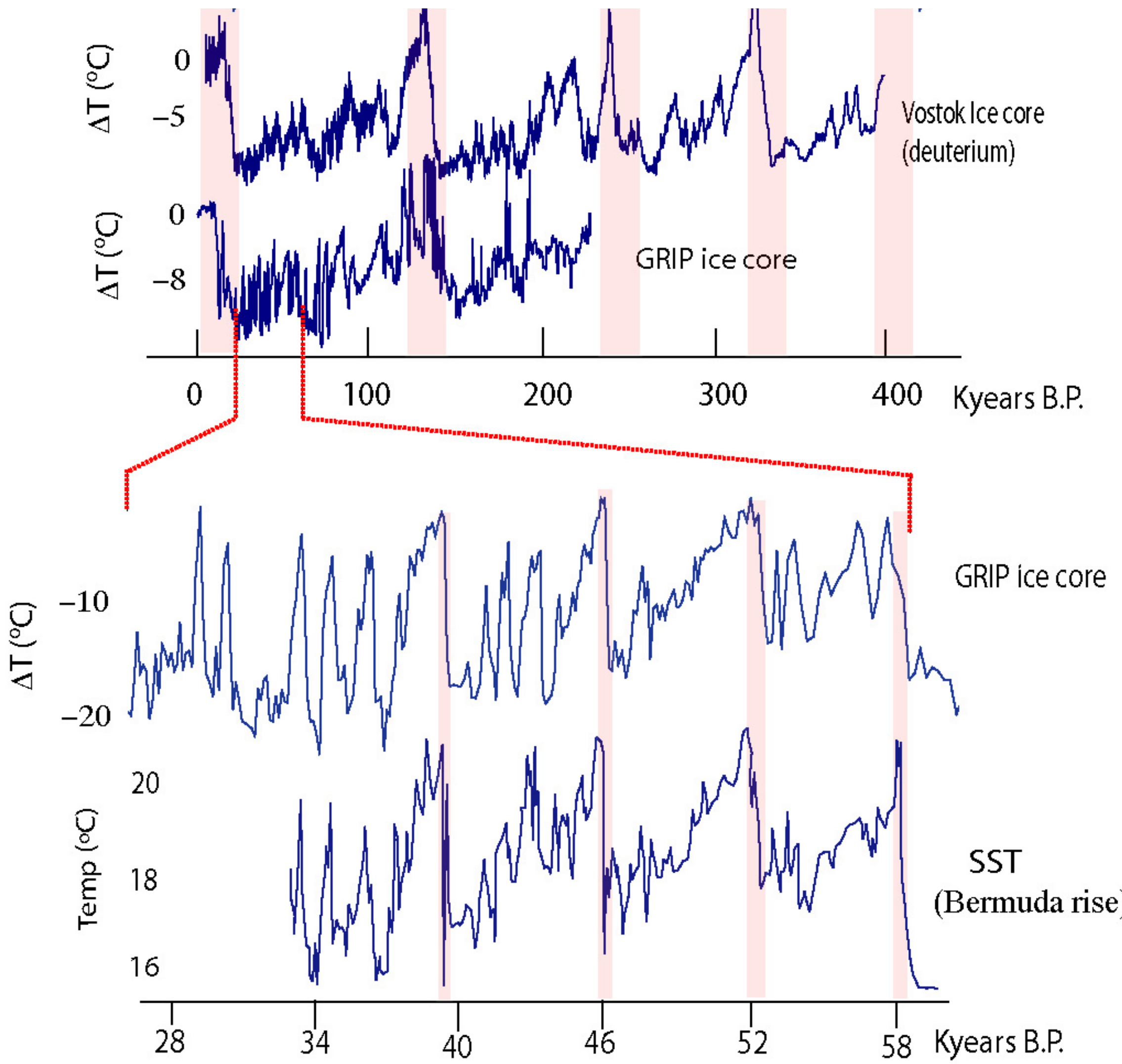
- Last 420,000 years: Vostok ice core record (blue)
- Last 100 years: Contemporary record (red)
- Next 100 years: IPCC BAU scenario (red)



Climate thresholds

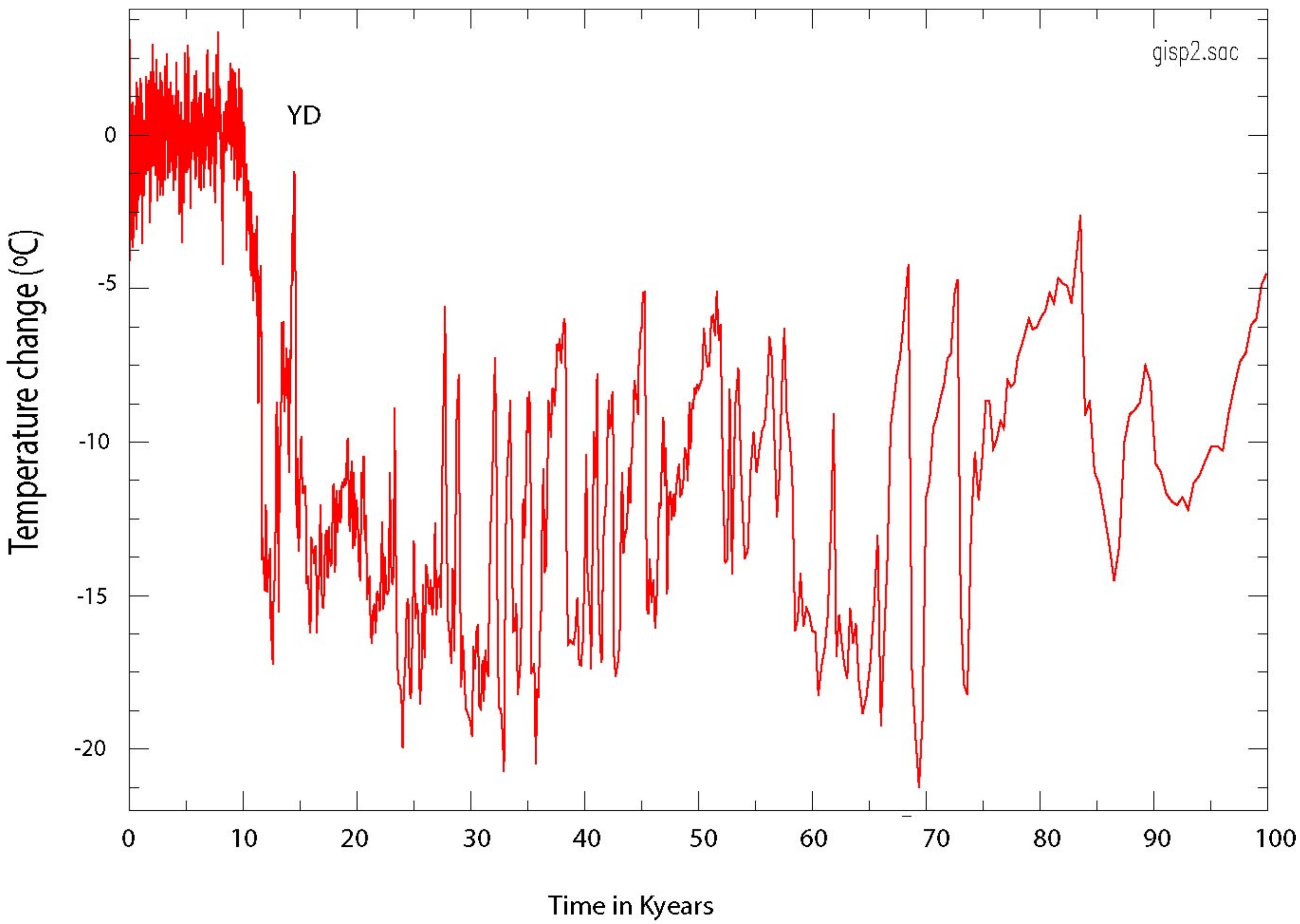
Ice-age temperature records:

- Vostok oscillations
  - Period around 100 ky
- Dansgaard-Oescher (DO) oscillations
  - Variable period, typically a few ky



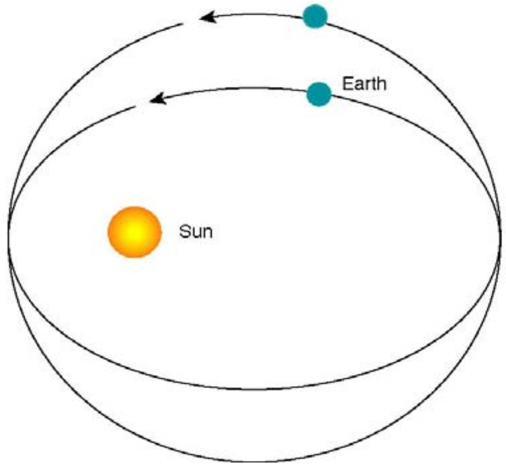
Simplified climate model for DO oscillations **(Rial 2005)**

- Ice-core temperatures in Greenland

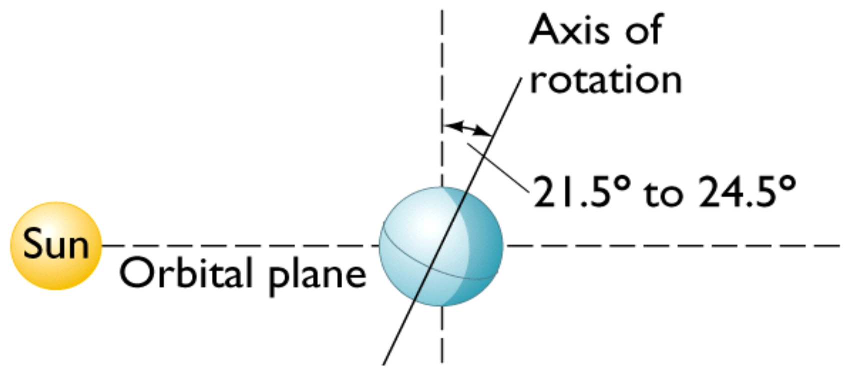


The Milenkovich cycles

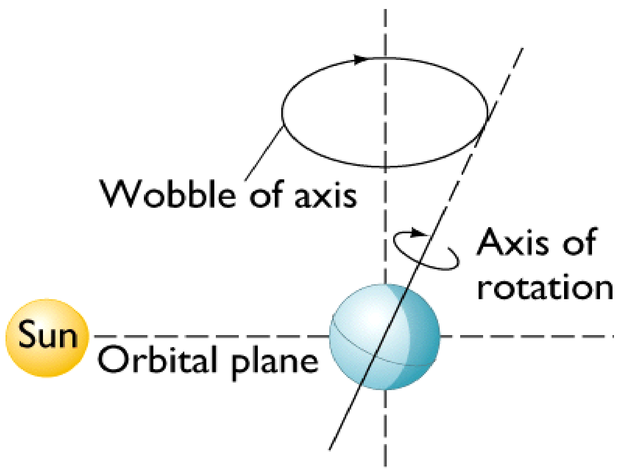
Eccentricity
41,000 years



Tilt or obliquity
41,000 years

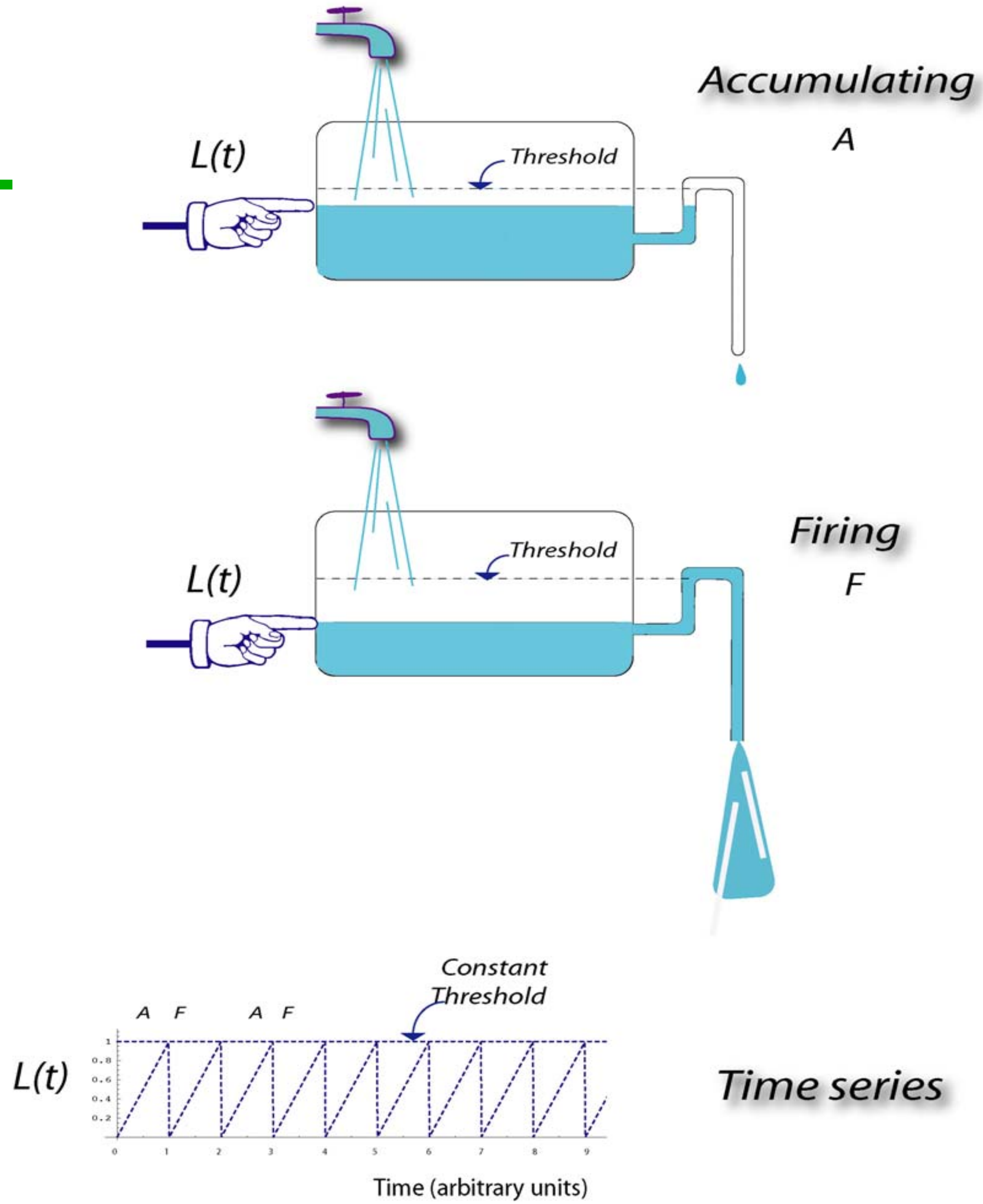


Precession of the equinoxes
23,000 years



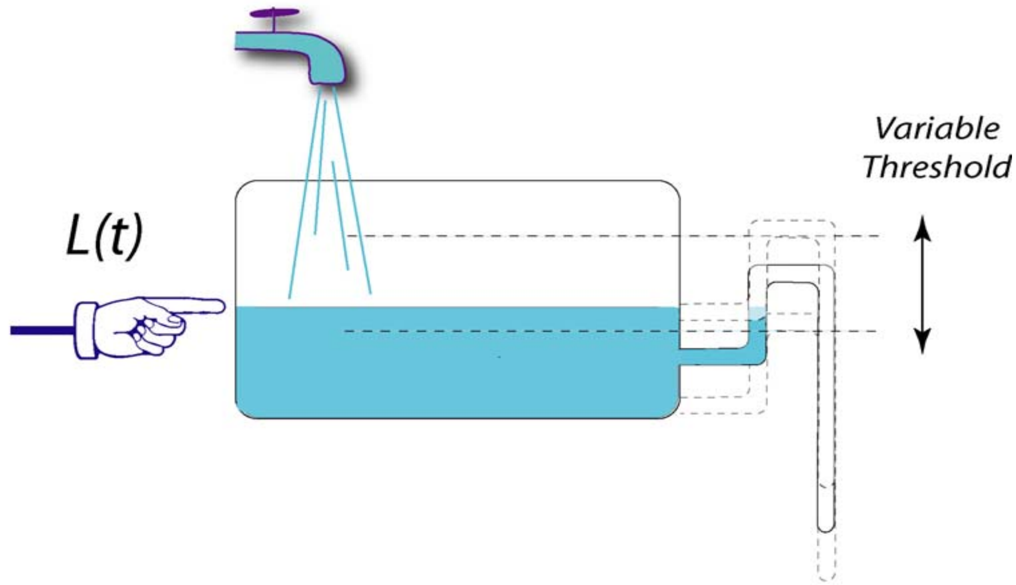
Thresholds in the climate system

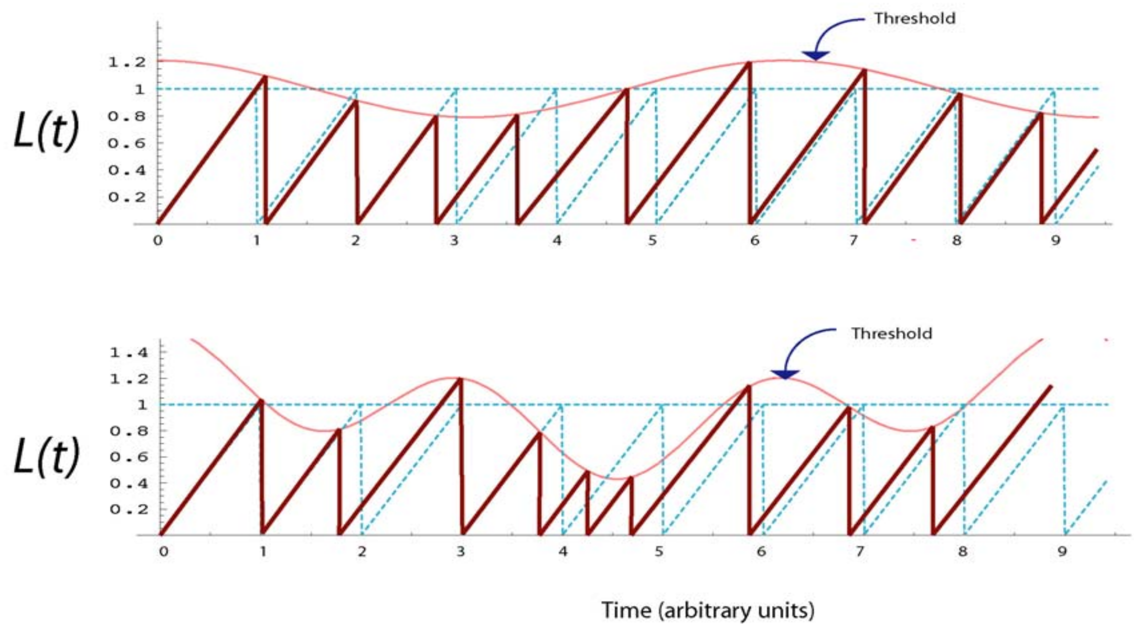
- **Astable oscillator**
  - Mechanism for generating a sawtooth waveform
  - No external forcing required to trigger threhold event



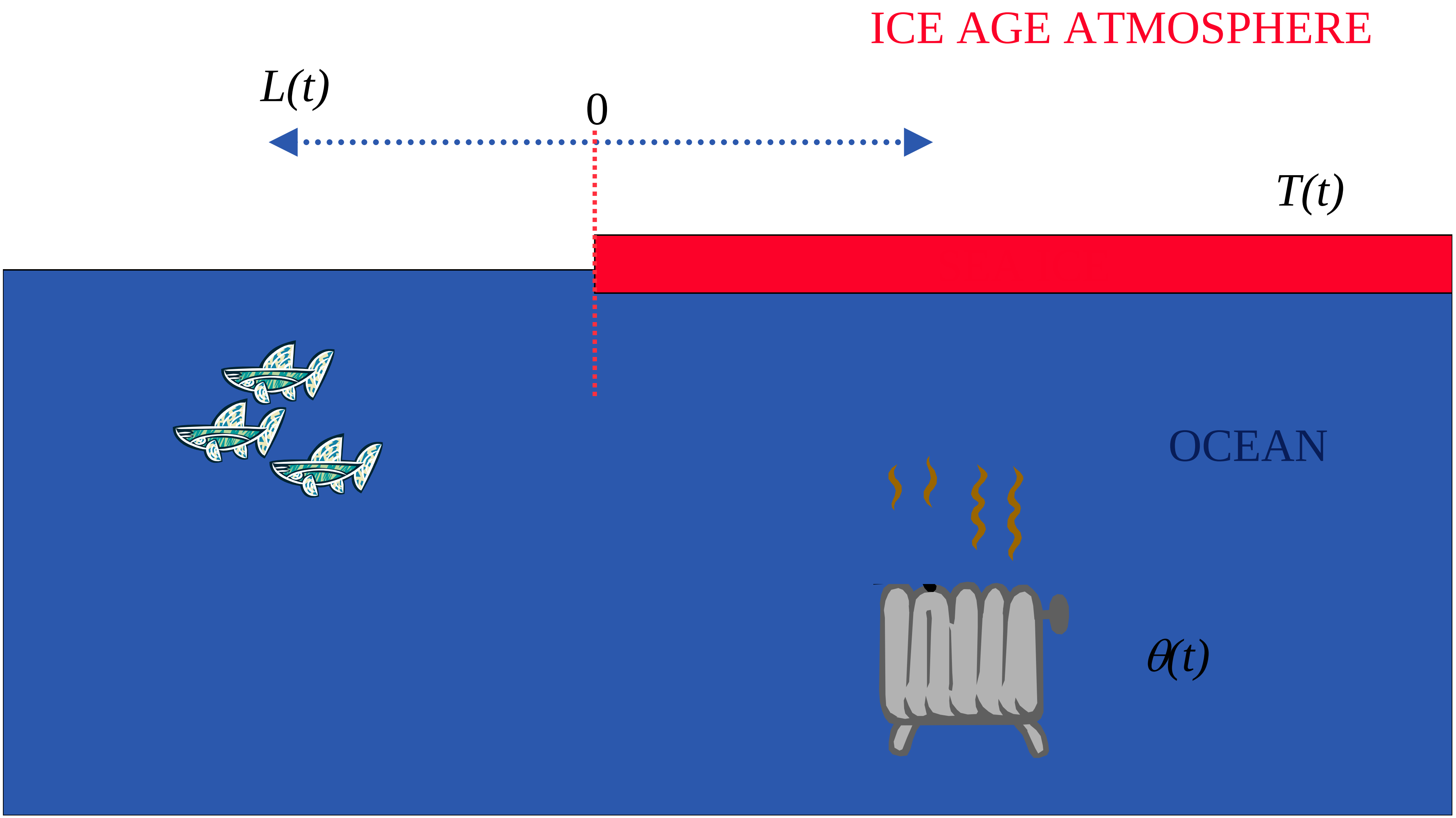
Thresholds in the climate system

- **Frequency modulation of astable oscillator**
  - External (Milenkovich) forcing changes the frequency of threhold events

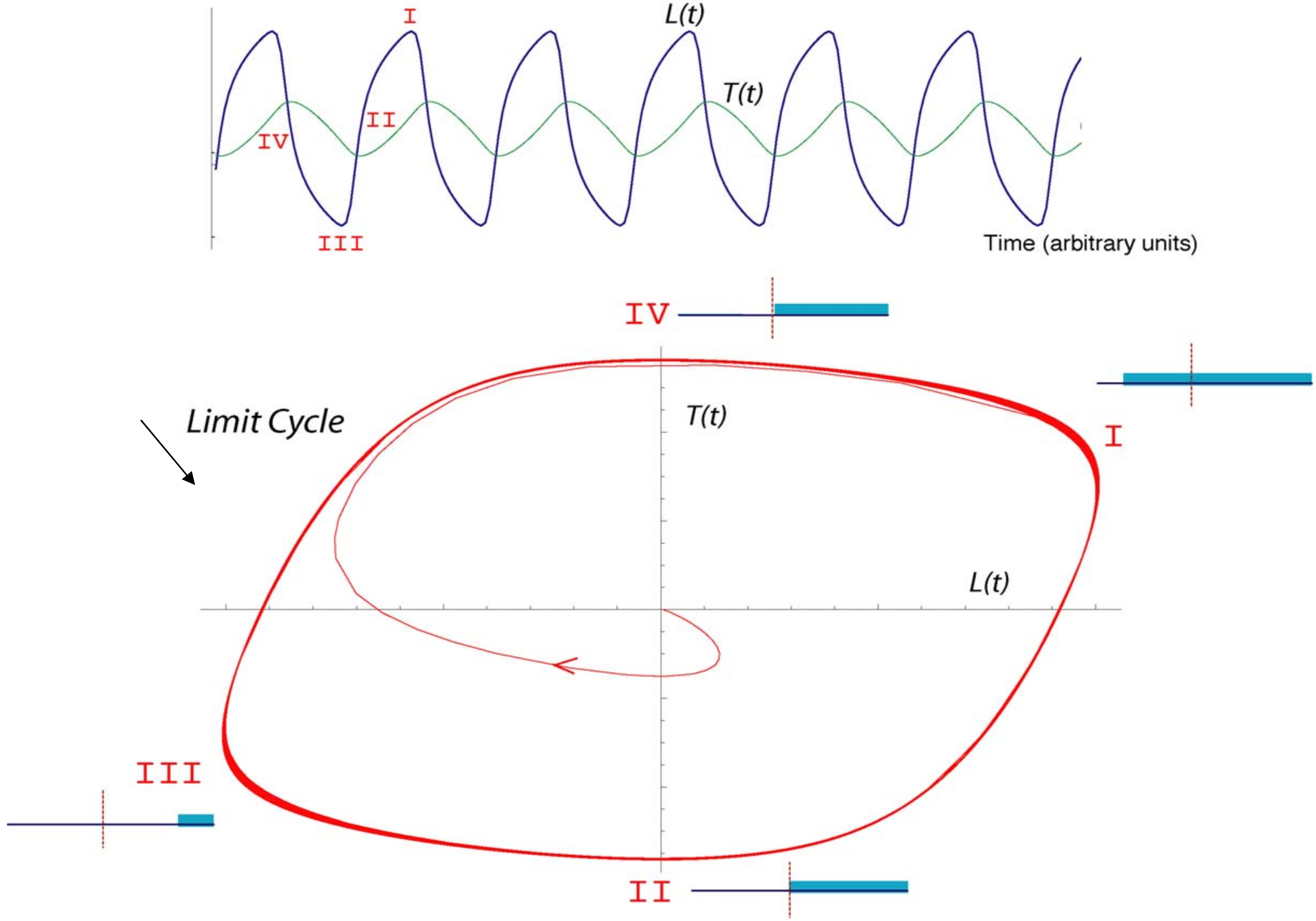




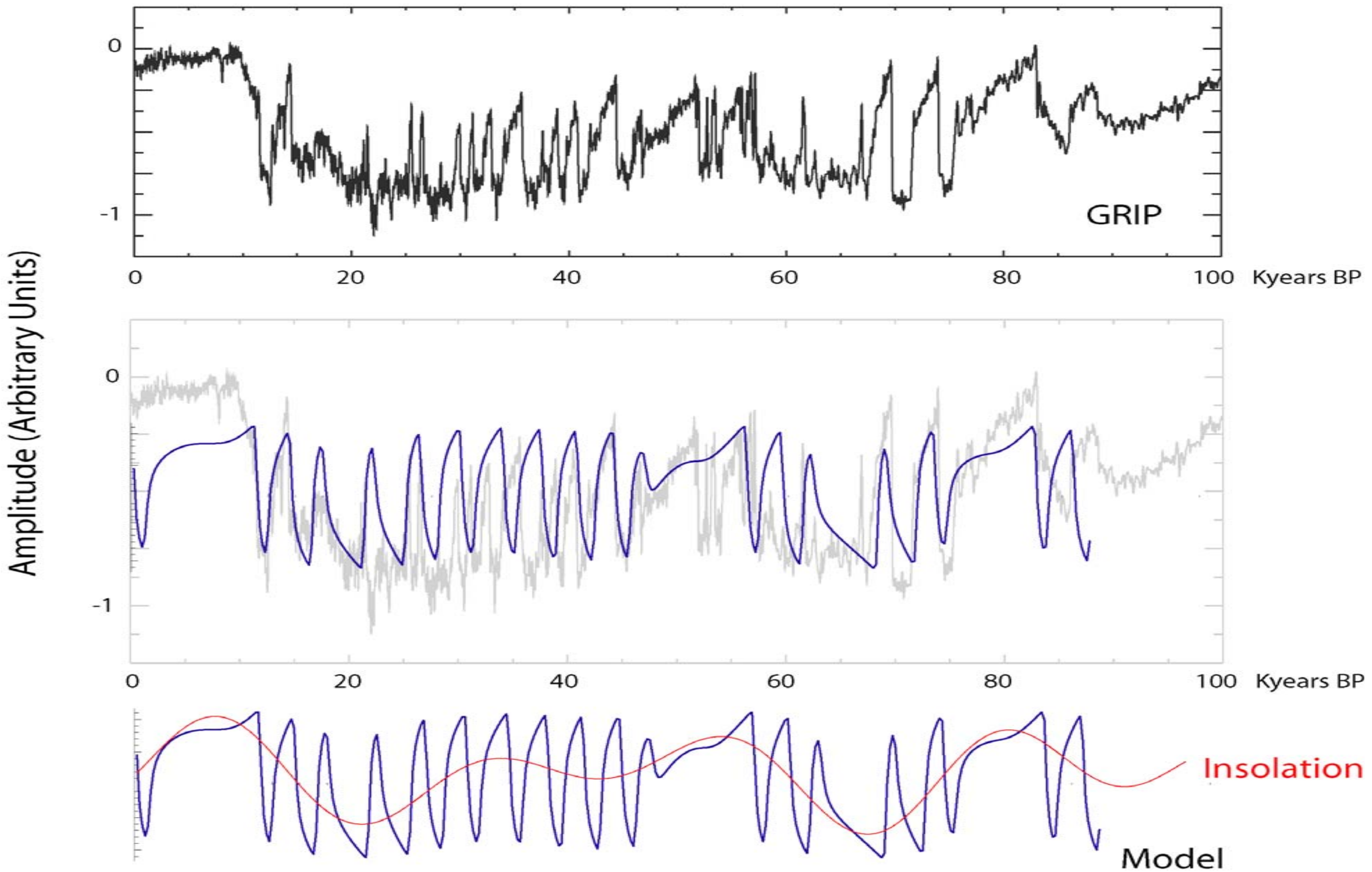
The Saltzmann nonlinear thermal oscillator



Self-sustained relaxation oscillation of the Saltzmann nonlinear thermal oscillator



Simplified climate model for DO oscillations **(Rial 2005)**



Vulnerability and climate

- The planetary climate of Earth is dynamic: abrupt changes are the norm
- Changes typically have a threshold-like character (fast warming, slow cooling)
- Thresholds are driven by a combination of self-organisation and external forcing
  - Self-organisation (endogenous drivers)
    - Ice, oceans, CO2, dust, plants
    - Vulcanism-carbonate cycle
    - Continental drift
  - External forcing (exogenous drivers)
    - Orbital forcing
    - Meteorites
- ---
- Climate thresholds imply **vulnerabilities** for ecosystems and the biosphere
- Within a wide envelope of change, the Earth System is remarkably **resilient**

Vulnerability and the carbon cycle

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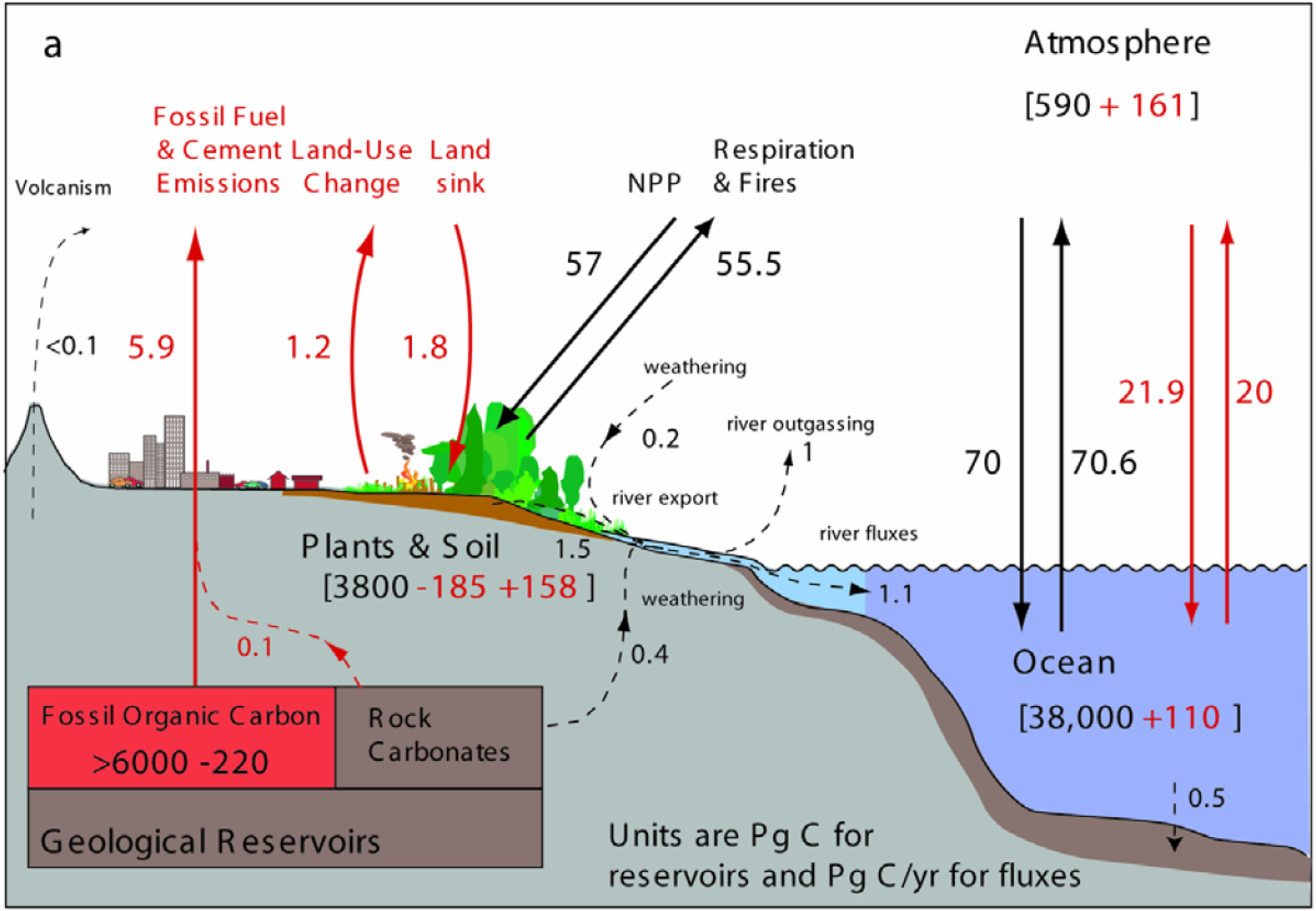
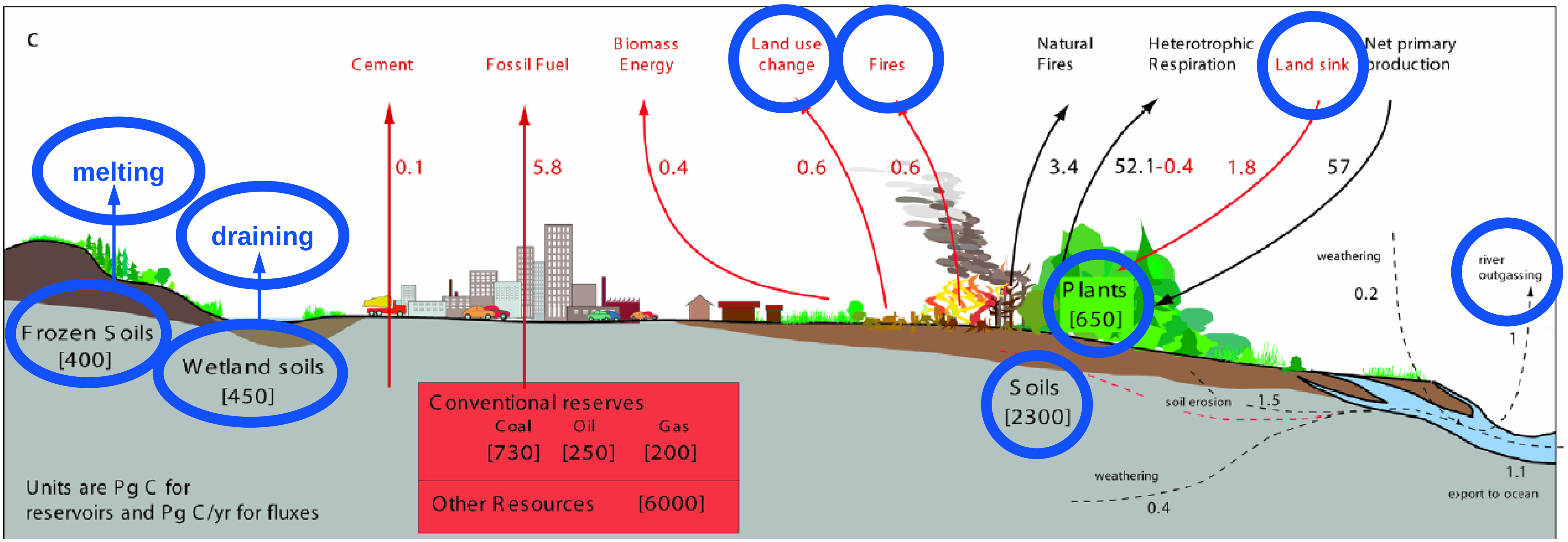


The current carbon cycle (Sabine et al 2004)

Field CB, Raupach MR (eds.) (2004) The Global Carbon Cycle: Integrating Humans, Climate and the Natural World. Island Press, Washington D.C. 526 pp.

Vulnerability of terrestrial biogenic carbon

Pre-human
Current perturbations
Future perturbations



The current carbon cycle: detail for land (Sabine et al 2004)

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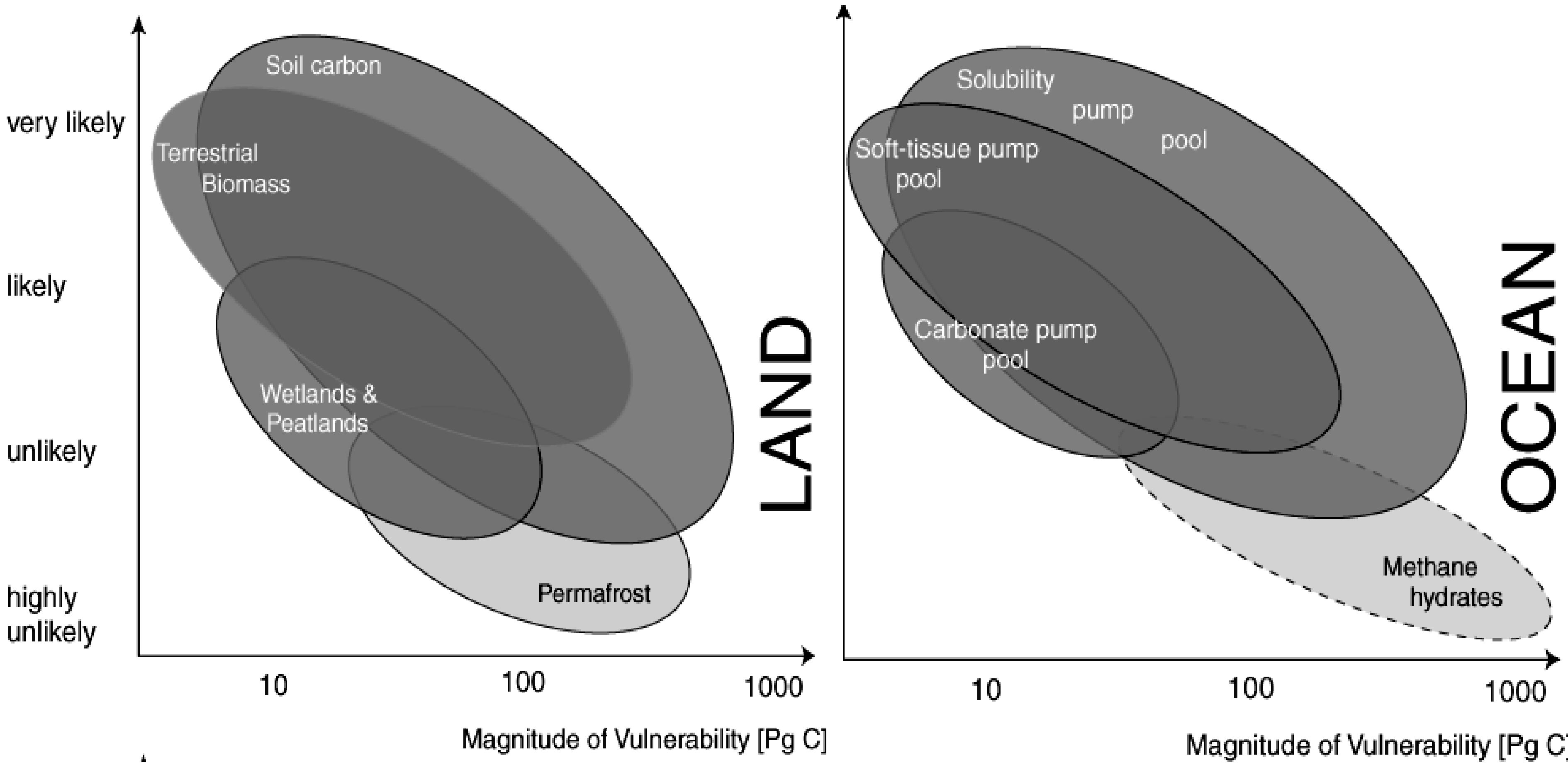
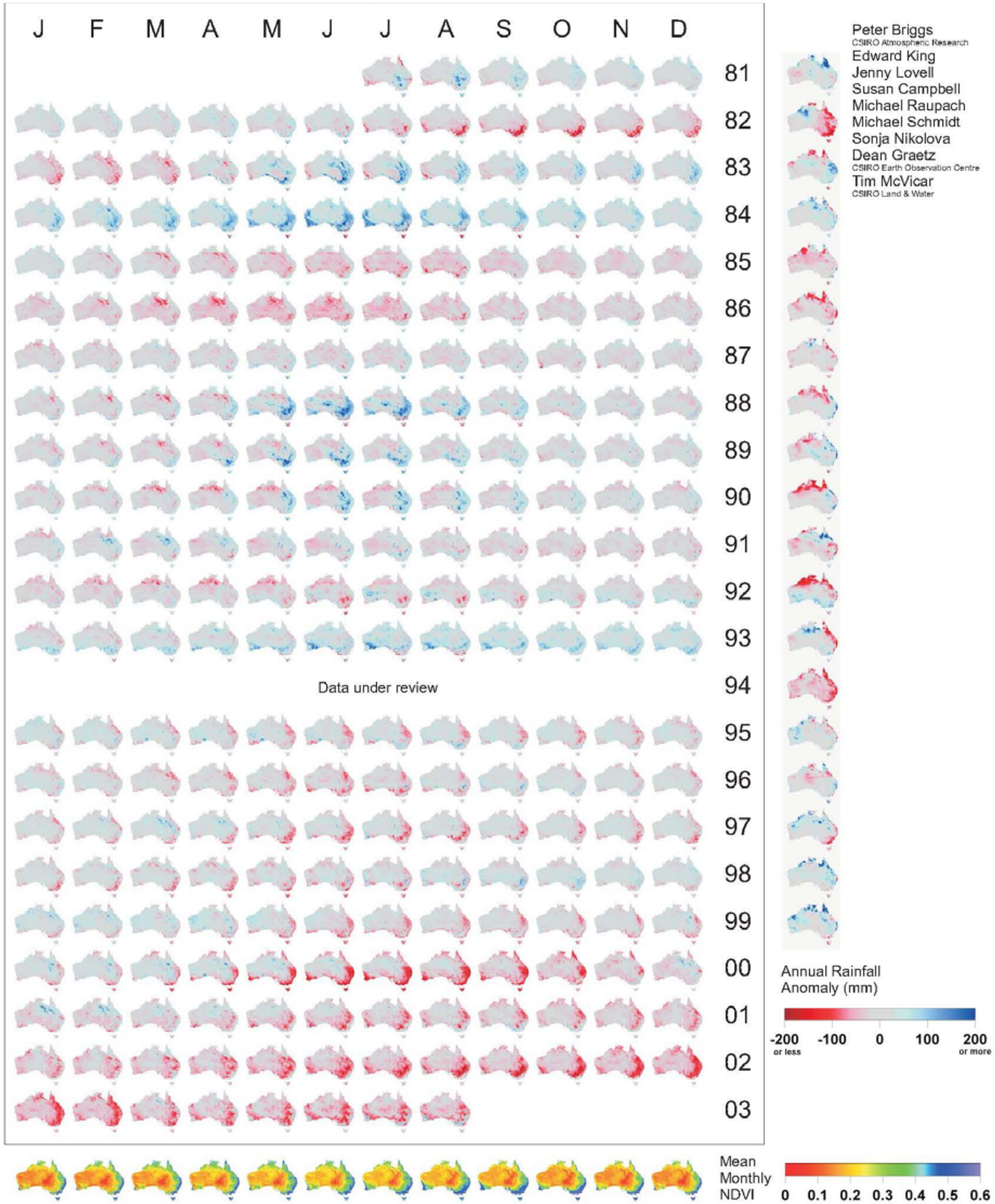
Vulnerable land and ocean carbon pools, 2000-2100



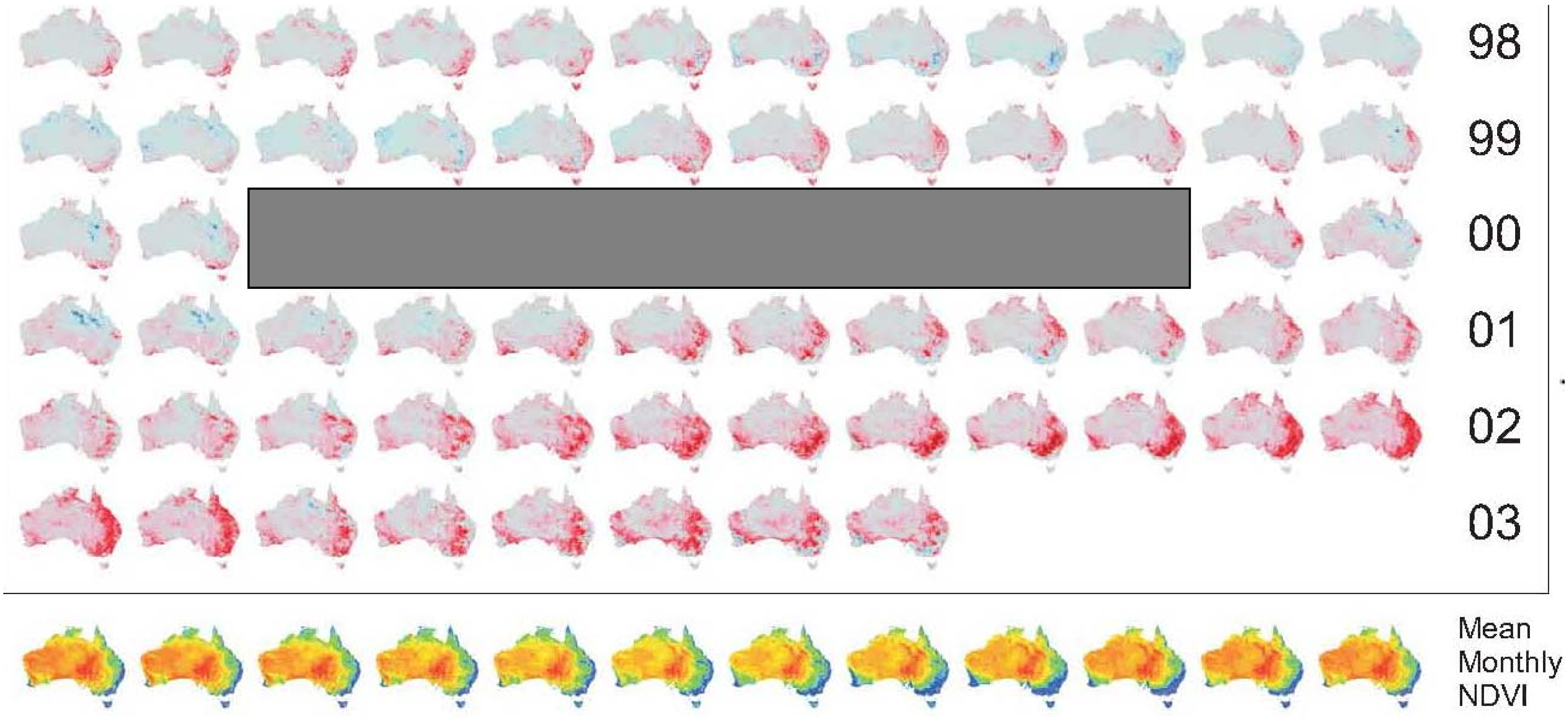
Gruber et al. (2004, SCOPE-GCP)

Drought and warming => loss of vegetation C

- **Australian continent: AVHRR-NDVI anomaly 1981-2003**
- Current version (Oct 2003) uses EOC "B-PAL" archive of AVHRR data
- 5 km, 8-11 day composites
- Still to incorporate:
  - Atmos correction
  - BRDF correction
  - 1-km data



Drought and warming => loss of vegetation C



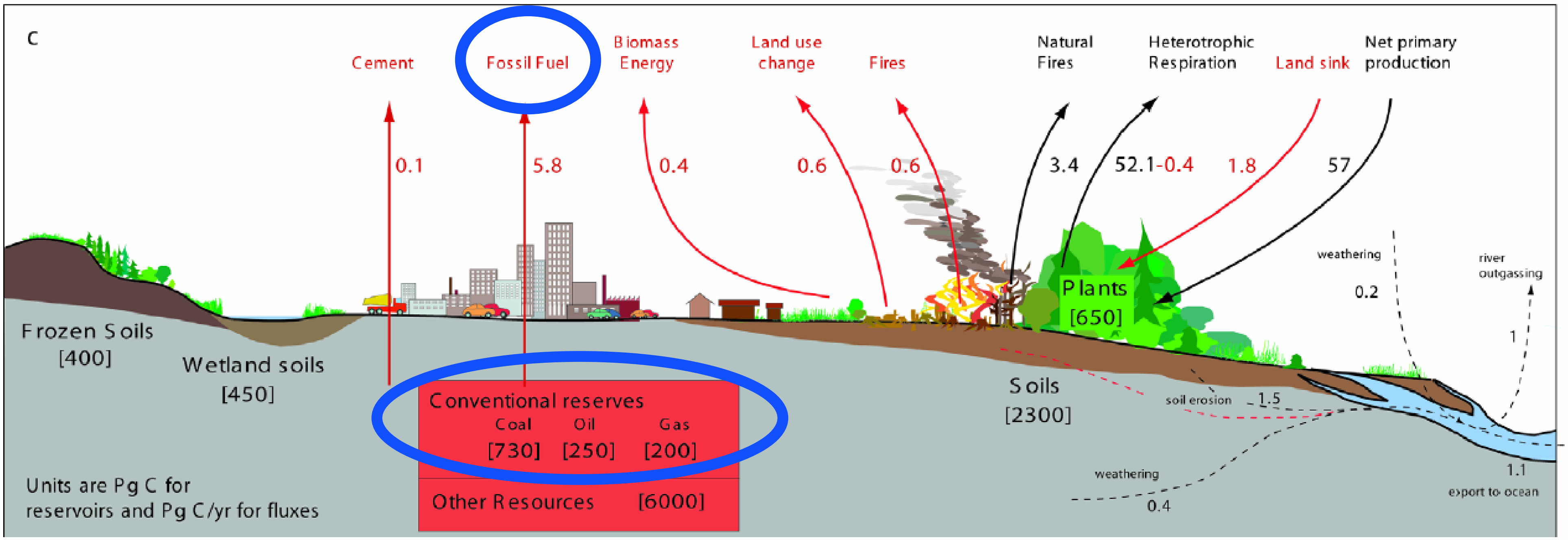
- AVHRR-NDVI anomaly 1998-2003 (part of a series 1981-present)

  Peter Briggs, Edward King, Jenny Lovell, Susan Campbell, Michael Raupach


Canberra, 18 January 2003

Vulnerability of fossil carbon pools

Pre-human
Current perturbations
Future perturbations



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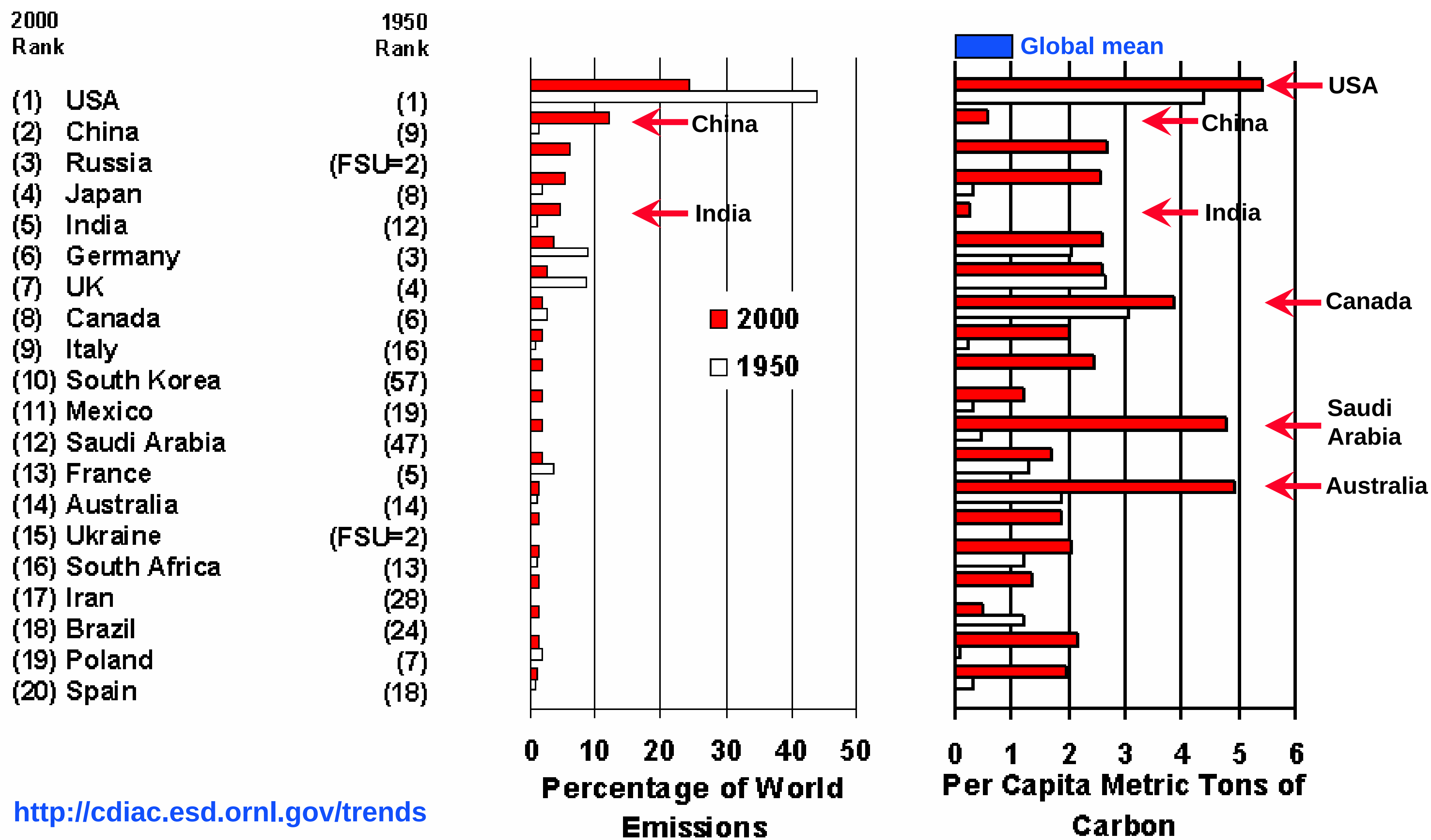
Trends in national carbon emissions (1950 to 2000)



http://cdiac.esd.ornl.gov/trends

Vulnerability and human systems

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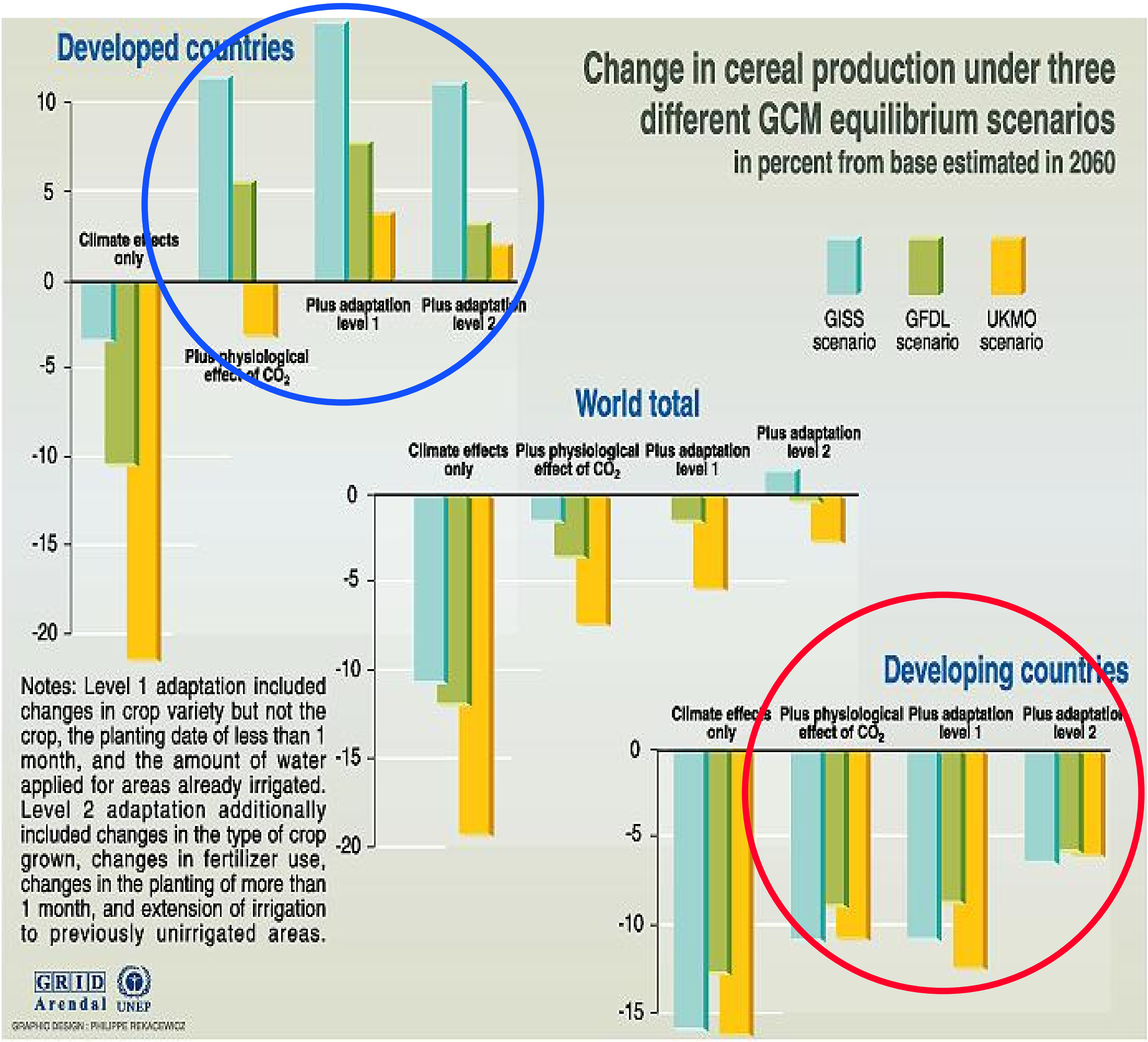
Food

- Food supplies in **less developed countries** are more badly affected by climate change than those in **developed countries**

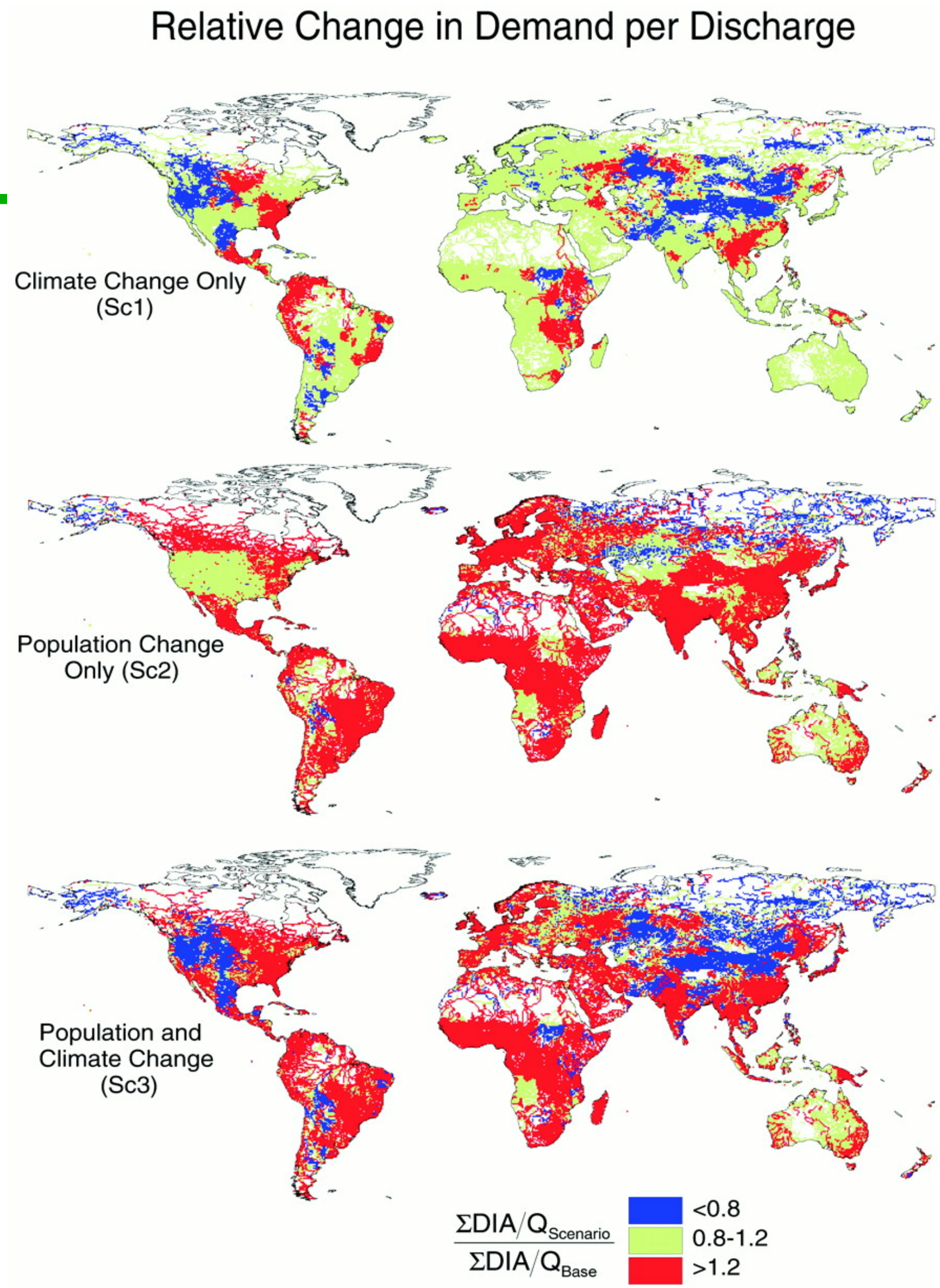


Source: Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

IPCC 1995

Water

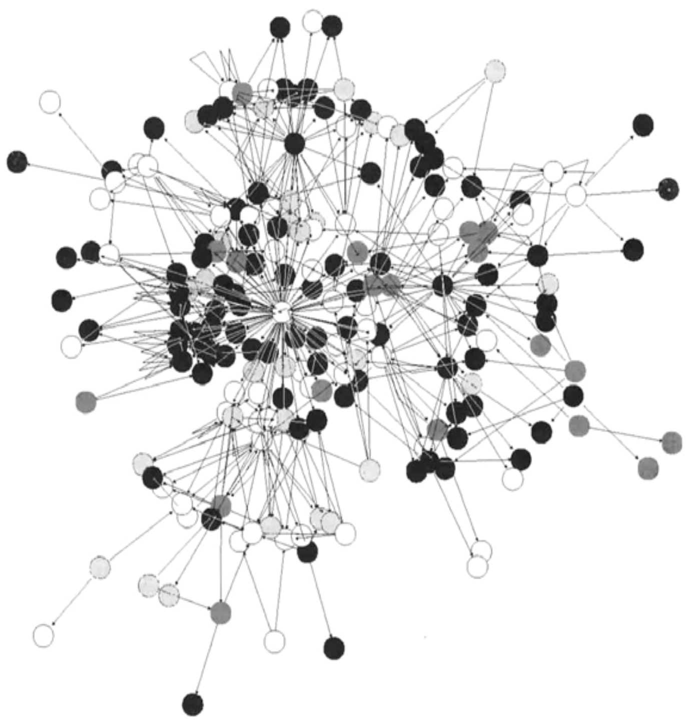
- Effects of climate change on water supply are variable, but tend to be more severe in less developed countries (Africa, Central America) than in developed countries
- Population changes will amplify this imbalance



Vörösmarty et al 2000, Science

Vulnerability of networks: individuals matter

Influence network for development of Montreal Protocol



Key

- TEAP member from government
- TEAP member from NGO
- TEAP member from academia
- TEAP member from industry

Direction of arrows: Nominator ←——— Influencer
There is no significance to the length of arrows.

Figure 7.1a ***Connections in the 1994 Technology and Economic Assessment Panel (TEAP): with Steve Andersen***

Source: authors' survey

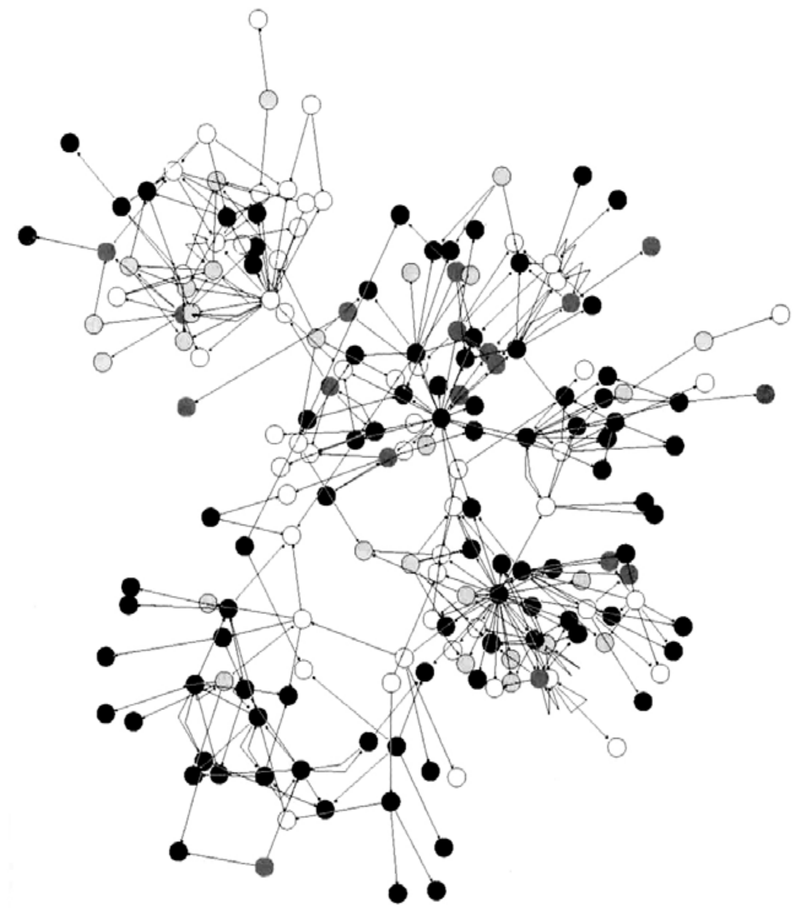


Figure 7.1b ***Connections in the 1994 Technology and Economic Assessment Panel (TEAP): without Steve Andersen***

Source: authors' survey

Canan & Reichman 2002,
Ozone Connections: Expert Networks in Global Environmental Governance

Synthesis

- **Outline**
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Quantifying and coping with vulnerability

- Quantifying vulnerability
  - Vulnerability = **[Cost of harm]** x **Prob(harm)**

    = **[Cost of harm]** x **Prob(harm, given hazard) x Prob(hazard)**

- Coping with vulnerability: reduce vulnerability by
  - **Reducing probability of harm, by reducing the stress (mitigation)**
  - **Reducing cost of harm, by reducing the impact (adaptation)**

- The problem of transferred harm:
  - Spatial transfer: In climate change, the main generators of stress are not the same people as those experiencing most of the harm
  - Temporal transfer: There is a time delay between the stress and the harm
  - => Low incentives for mitigation

Complex Adaptive Systems: vulnerability and resilience

- Attributes defining a Complex Adaptive System (CAS)
  - Hierarchy: system consists of components interacting by (fairly) simple rules
  - Self-organisation: internally generated, not externally imposed
  - Evolutionary emergence: organised system behaviour evolves in time, allowing complexity (information content) to increase
  - Adaptive capacity: system has the capability to survive
    - its own autonomous cycles and thresholds,
    - changes in external conditions
- **An evolving CAS is both resilient and vulnerable**
- Dynamics inducing vulnerability in a CAS:
  - thresholds, regime shifts, bifurcations, limit cycles, chaos
- These system-wide phenomena can lead to:
  - system collapse (without or with recovery)
  - collapse of a component (without or with recovery)

Human-biosphere interaction as a dynamical system

A two-equation model

- State variables: B(t) = biomass
  H(t) = human population

- Equations:

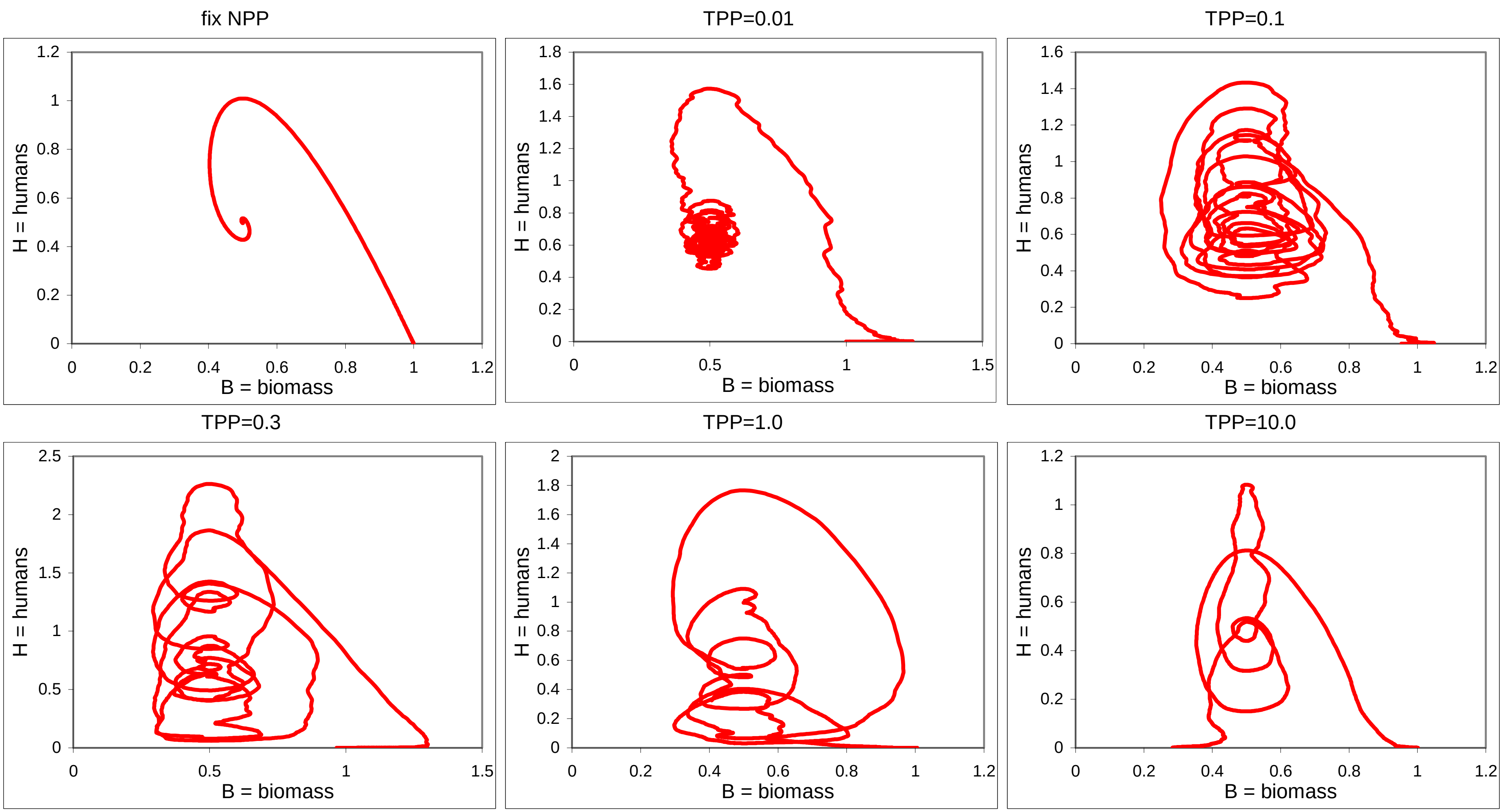
$$\frac{dB}{dt} = \underbrace{P}_{\text{Primary production of biomass}} - \underbrace{kB}_{\text{Respiration of biomass}} - \underbrace{E}_{\text{Extraction of biomass by humans}} ; \qquad \frac{dH}{dt} = \underbrace{g}_{\text{Population growth rate}} \left(\underbrace{E - mH}_{\text{Surplus in biomass extraction}} \right)$$

- Model for extraction of biomass by humans: $\boxed{E = cBH}$

  - more humans extract more biospheric resource
  - each human extracts more as *B* increases (*B* is surrogate for quality of life)

Human-biosphere interaction as a dynamical system

Trajectories on a (*B,H*) plane with random climate variability in production



Random primary production: log-Markovian, sd = 0.5, varying time scale

Human-biosphere interaction as a dynamical system

Trajectories on a (*B*,*H*) plane for 6 scenarios