General introduction: terrestrial biosphere & the climate system

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Why are you/we interested in the Terrestrial Biosphere, and more specifically in its interactions with the atmosphere (and thereby with climate)?

Some Numbers

- ➔ **Energy Budget**
- ➔ **Water Cycle**
- ➔ **Carbon Cycle**
- ➔ **Expansion of Human Influence**
- ➔ **Human Appropriation of Net Primary Productivity**

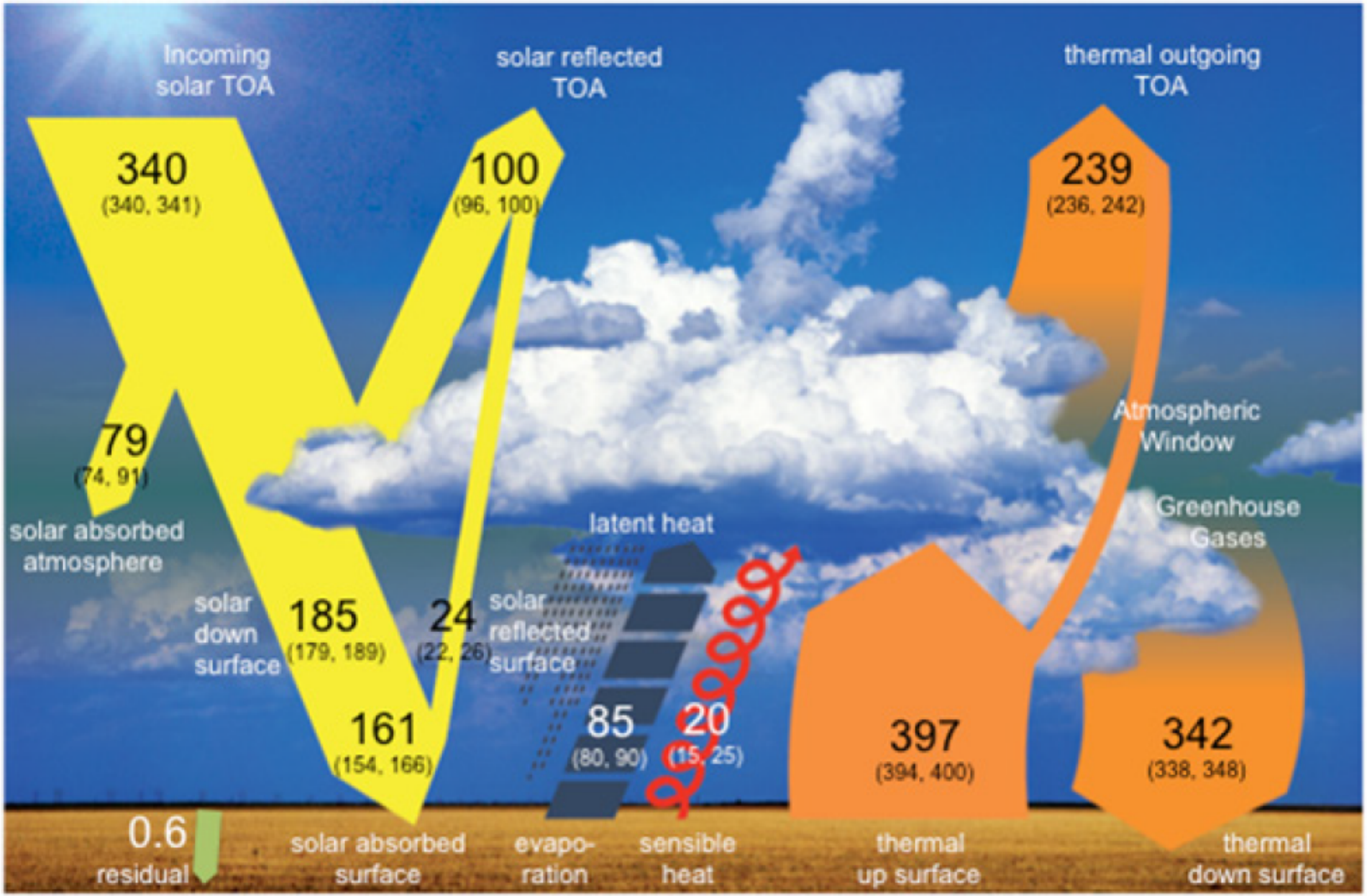
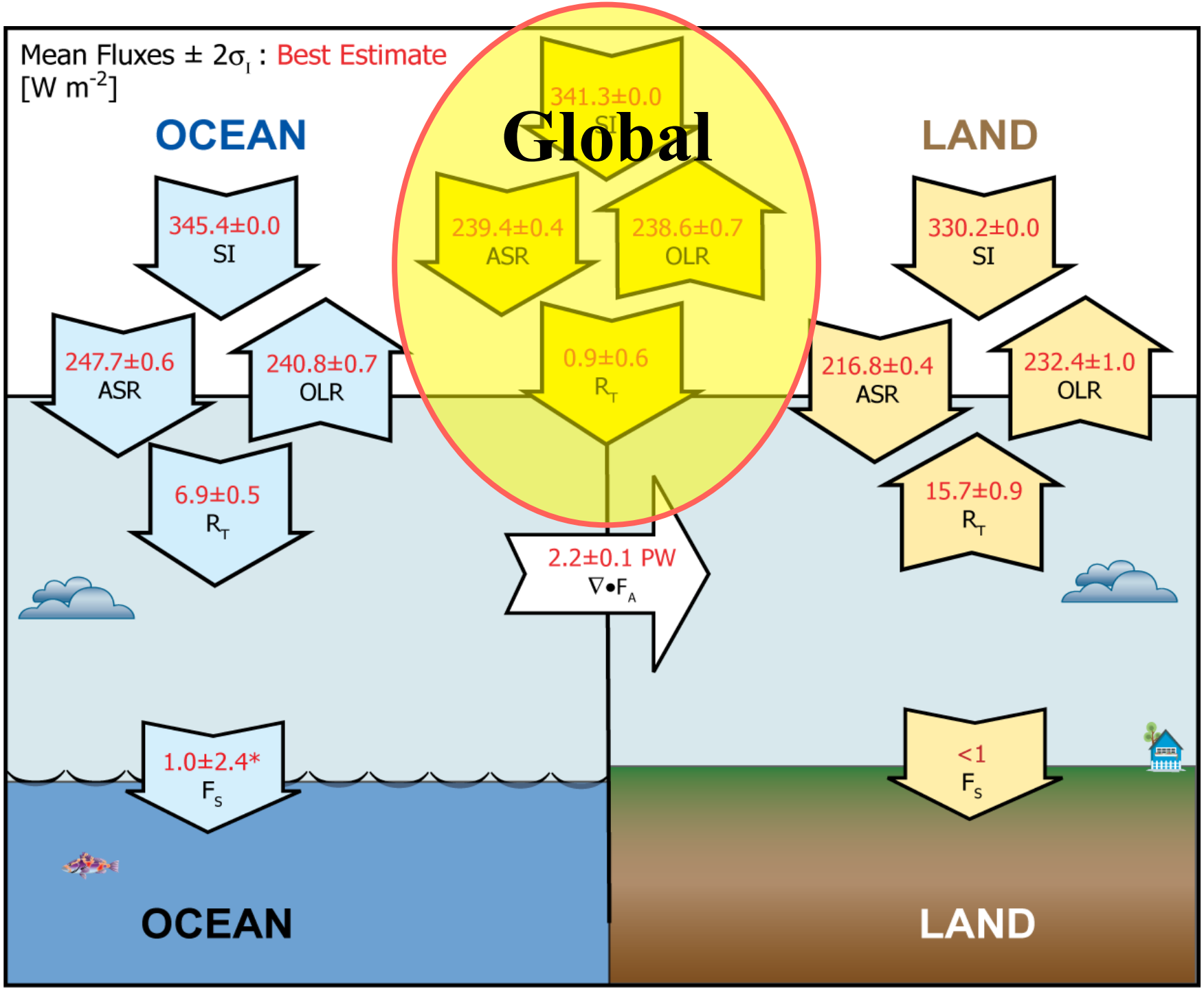


Figure 2.12: Global mean energy budget under present day climate conditions. Numbers state magnitudes of the individual energy flows in Wm^{-2}, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the radiative fluxes cover the range of values in line with observational constraints (based on Loeb et al., 2009; Stephens et al., in press; Trenberth and Fasullo, 2012; Wild et al., submitted).



* Values for the net flux into ocean are based on 1996-2003 values from Willis et al. (2004).

CERES period March 2000 to May 2004

Some Numbers

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The Global Water Cycle

Oki and Kanae, 2006

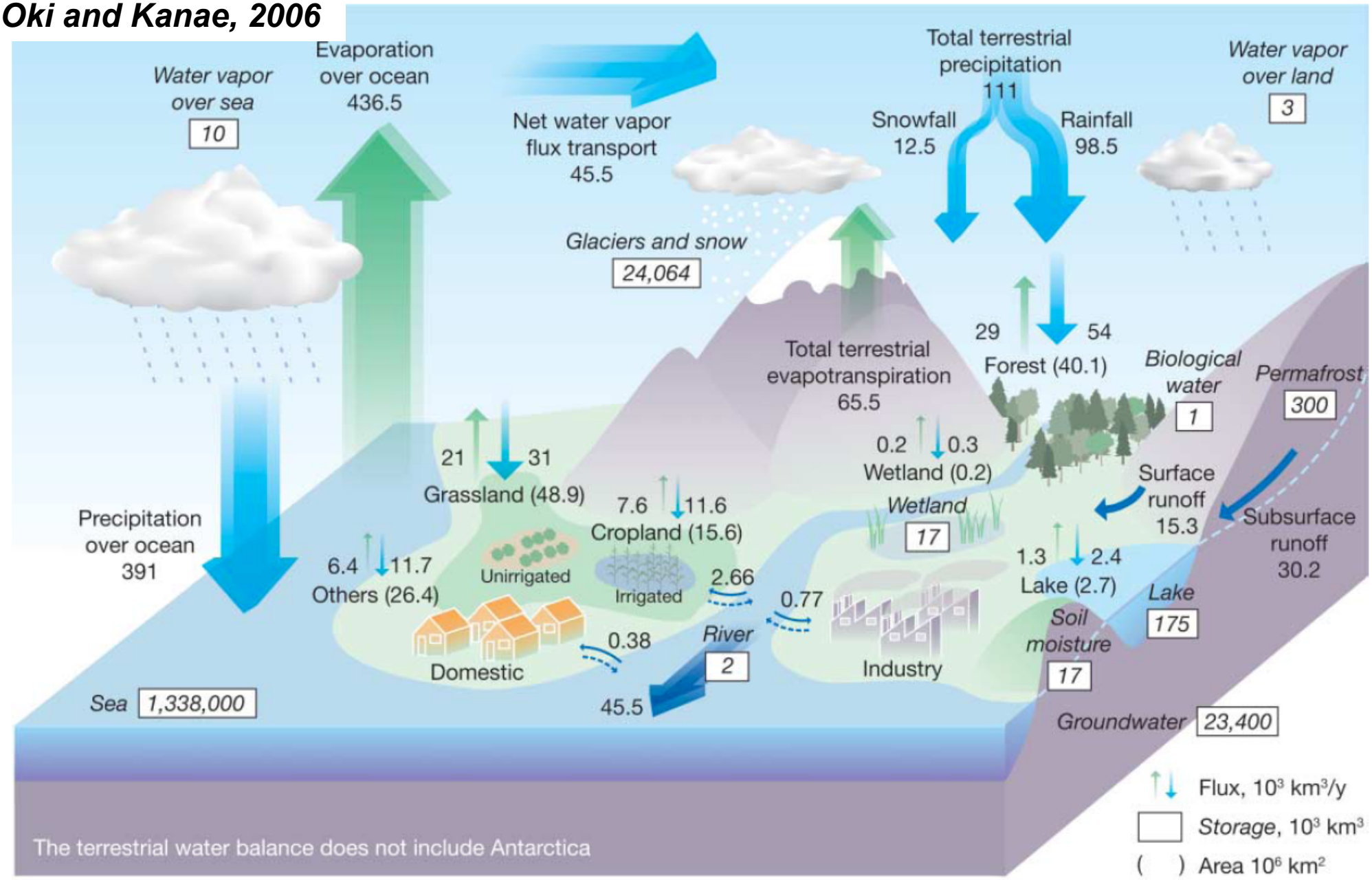
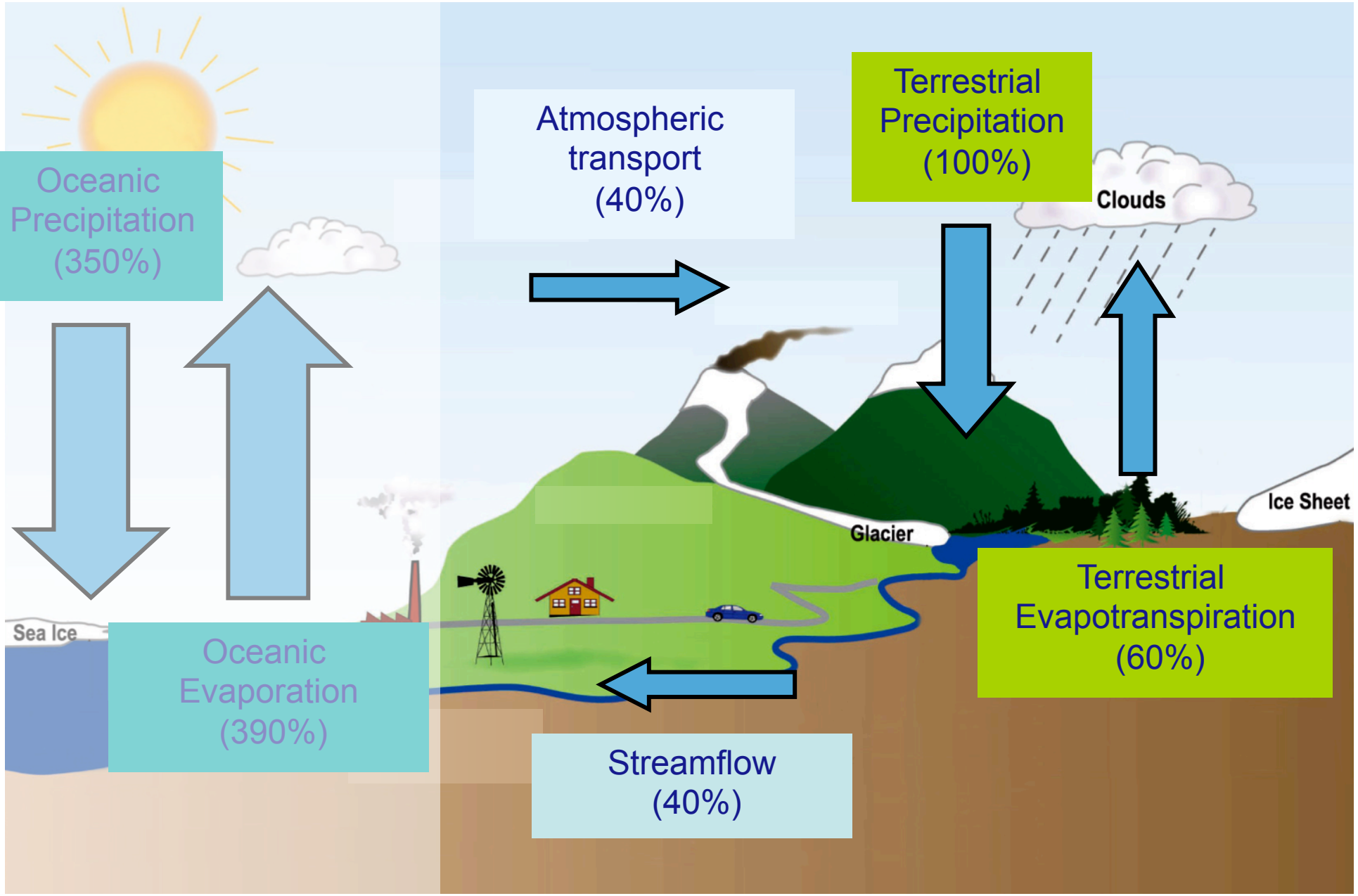


Fig. 1. Global hydrological fluxes (1000 km³/year) and storages (1000 km³) with natural and anthropogenic cycles are synthesized from various sources (*1*, *3–5*). Big vertical arrows show total annual precipitation and evapotranspiration over land and ocean (1000 km³/year), which include annual precipitation and evapotranspiration in major landscapes (1000 km³/year) presented by small vertical arrows; parentheses indicate area (million km²). The direct groundwater discharge, which is estimated to be about 10% of total river discharge globally (*6*), is included in river discharge.

Land-Surfaces significantly contribute to the Global Water Cycle

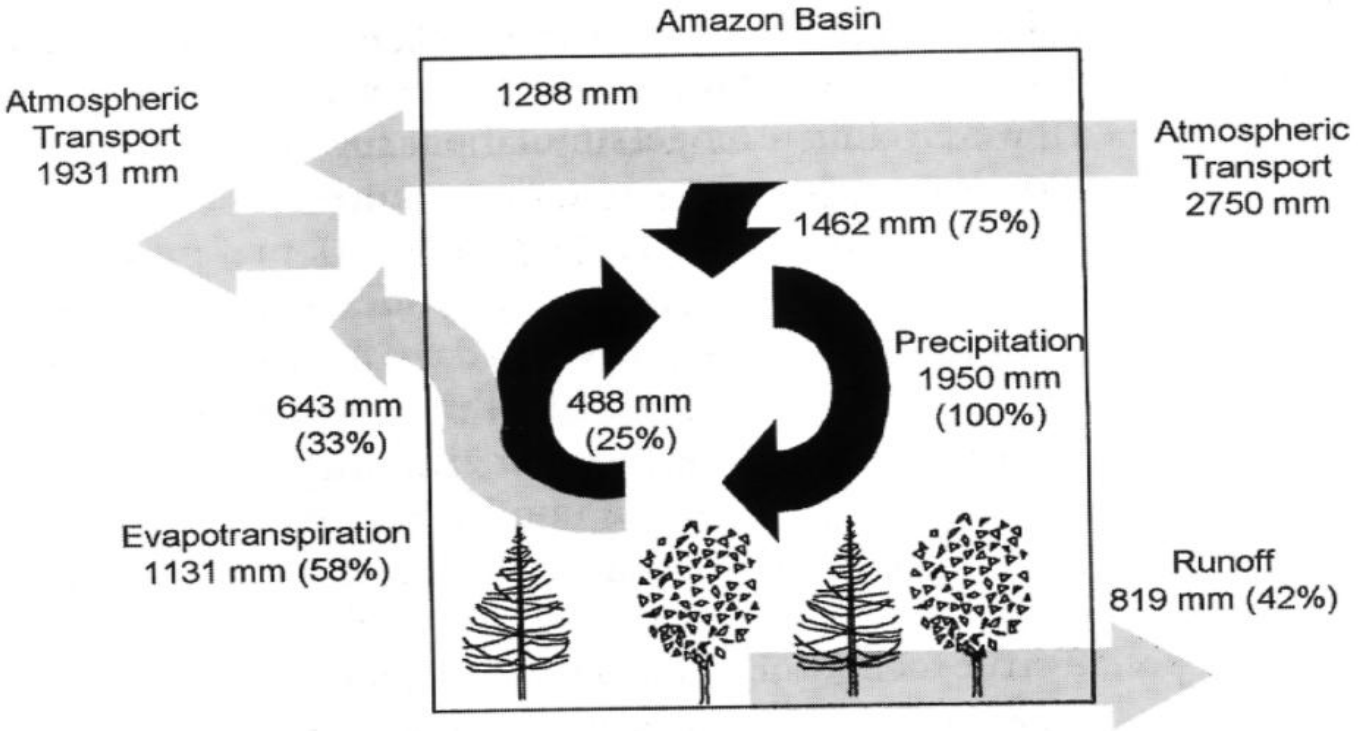


(Flux estimates: Oki and Kanae, Science 2006)

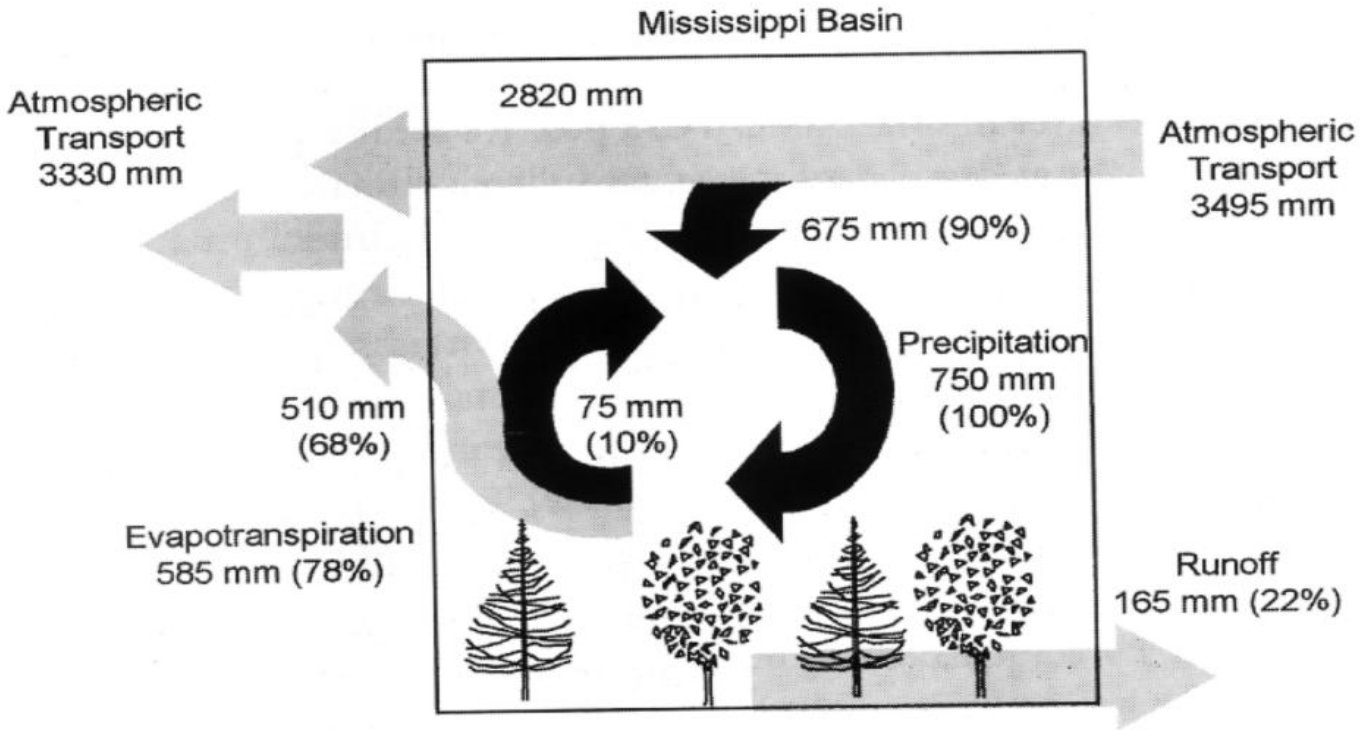
Courtesy of Sonia Seneviratne

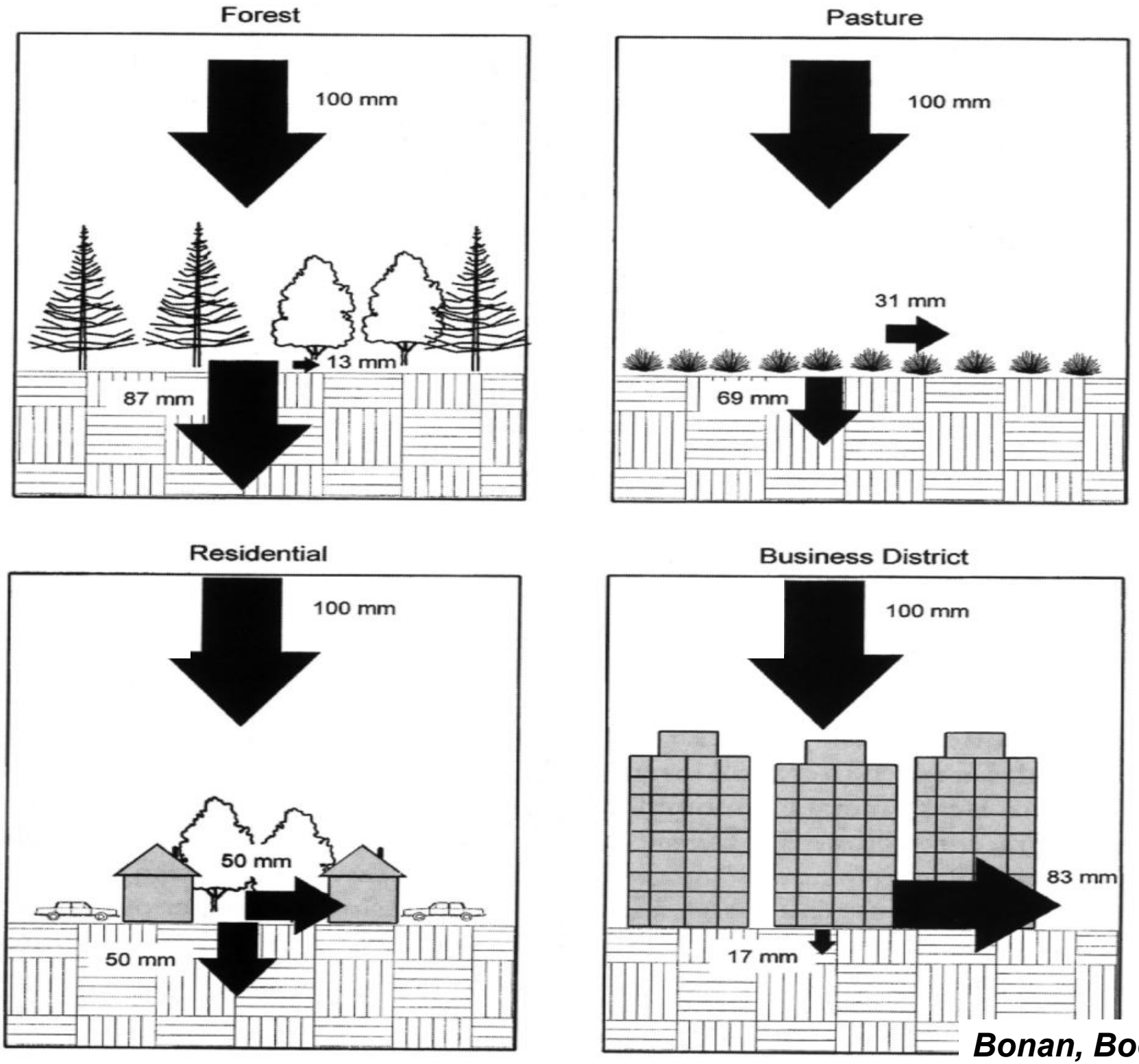
Bonan, Book - 2004

Amazon Basin



Mississipi Basin





Bonan, Book - 2004

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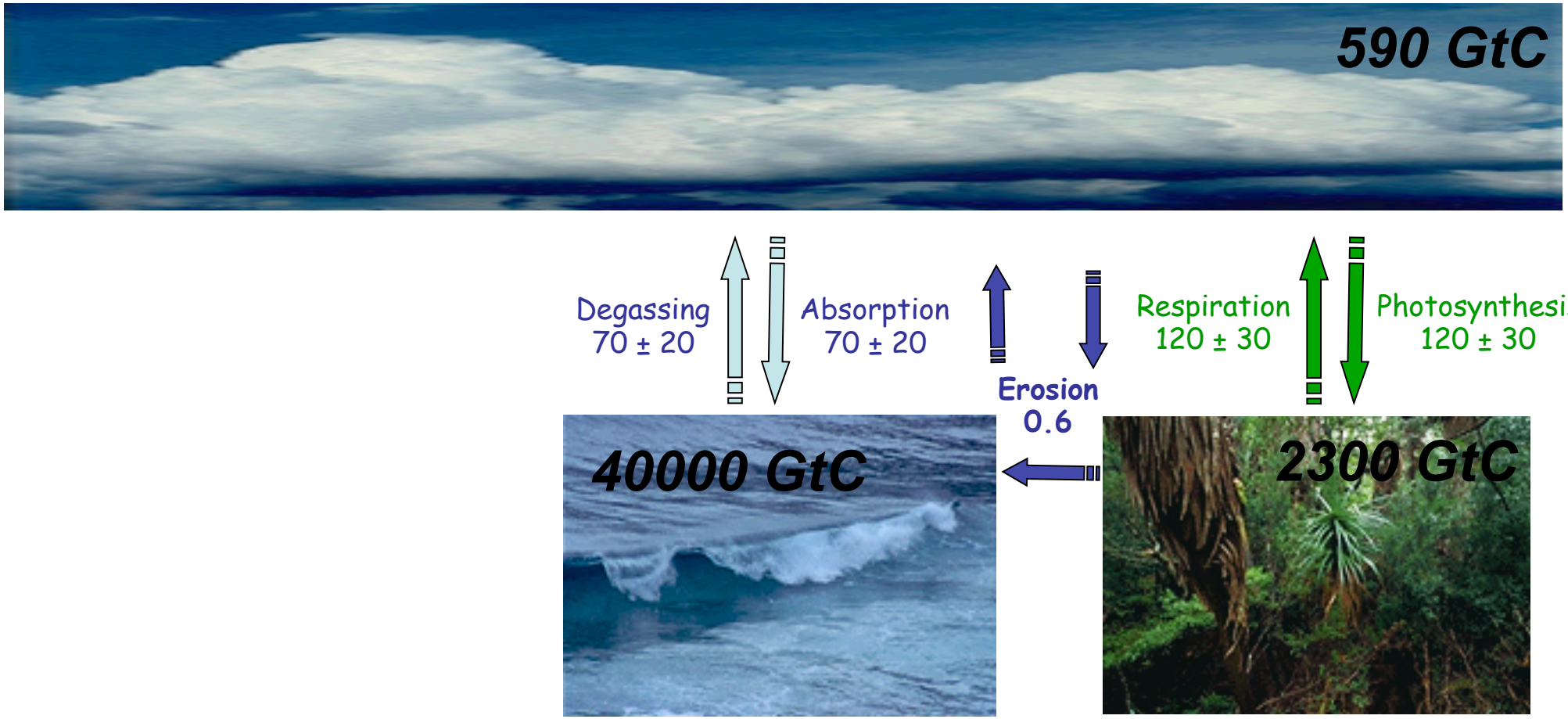
- ➔ Human Appropriation of Net Primary Productivity

CO_2 «natural» budget expressed in GtC year^{-1} (1 GtC = 10^{15}gC)



Annual Pre-Industrial Fluxes

Mean Stocks per reservoir

Source : IPCC-TAR

Le bilan global actuel du CO_2 en GtC an^{-1} (1 GtC = 10^{15}gC)

Fossil Source

Degassing 70+20

Absorption 70+20+1.7

Erosion 0.6

Respiration 120

Photosynthesis 120+1.4

Annual Fluxes for the ~1990s

Mean Stocks per reservoir

Source : IPCC-TAR

Le bilan global actuel du CO_2 en GtC an^{-1} (1 GtC = 10^{15}gC)

Fossil → Source

Degassing 70+20 ⇅ Absorption 70+20+1.7

Erosion 0.6

Respiration 120 ⇅ Photosynthesis 120+1.4

Annual Fluxes for the ~1990s

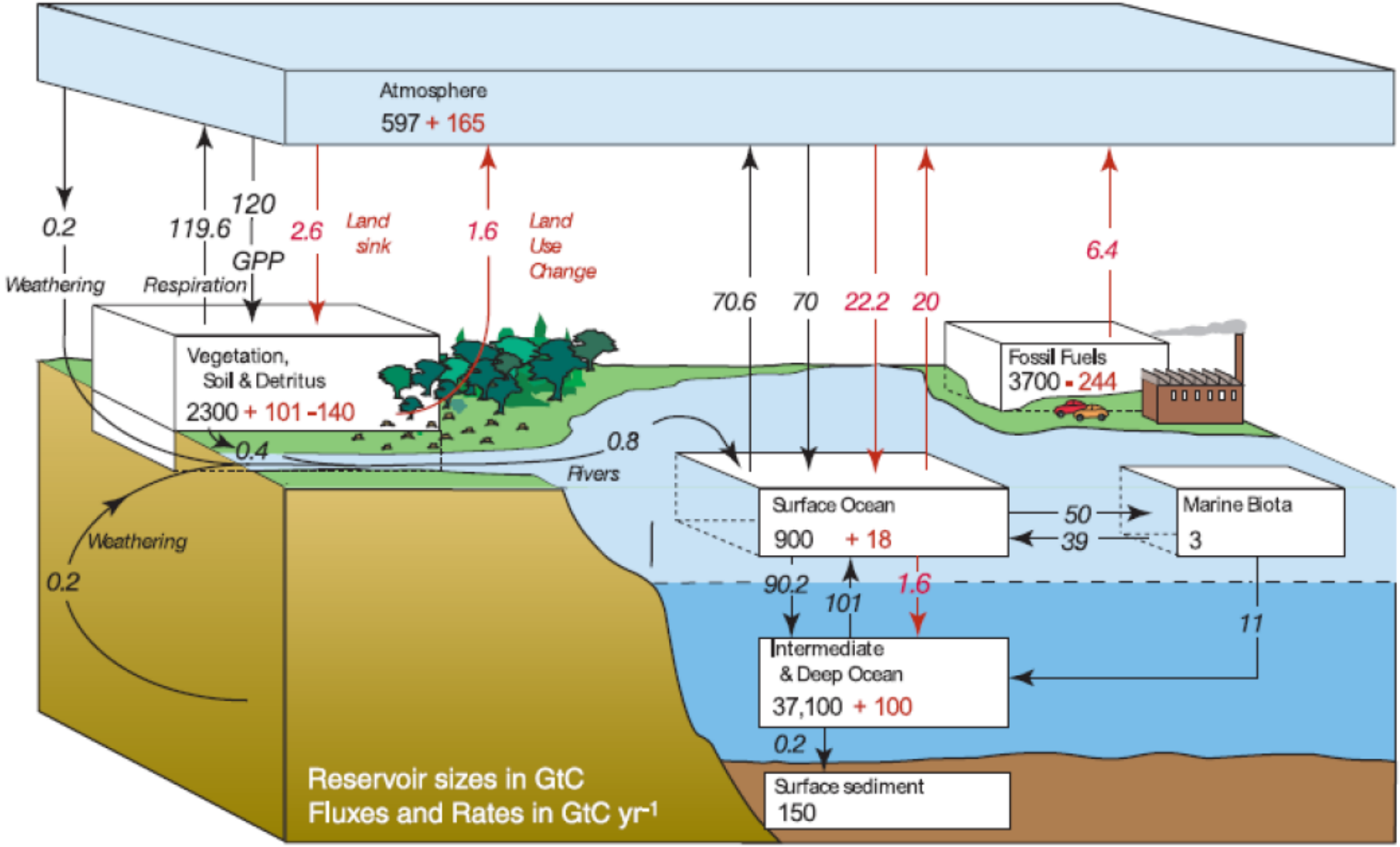
Mean Stocks per reservoir

Source : IPCC-TAR

Land-Use Changes

+

Global Carbon Cycle



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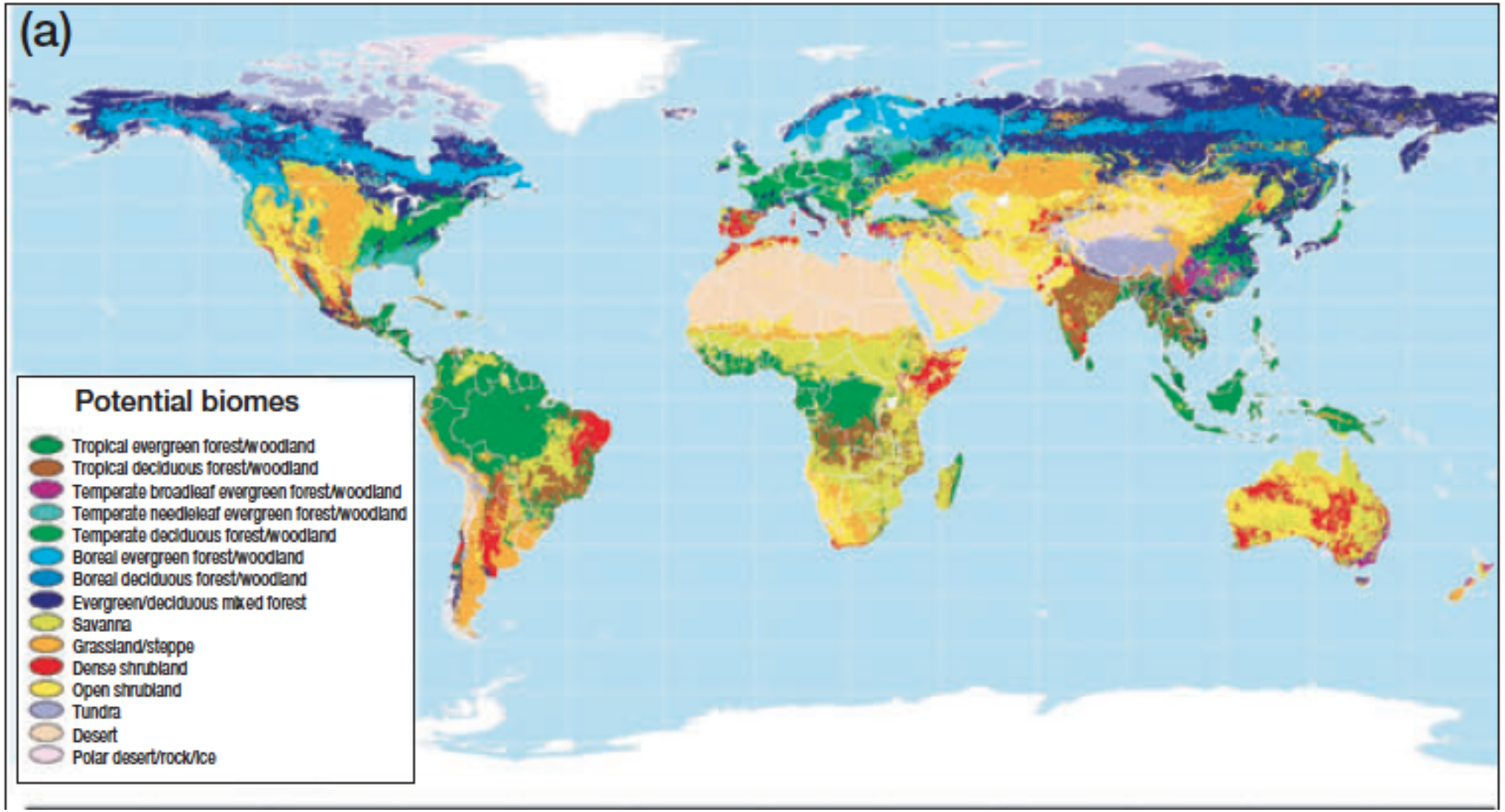
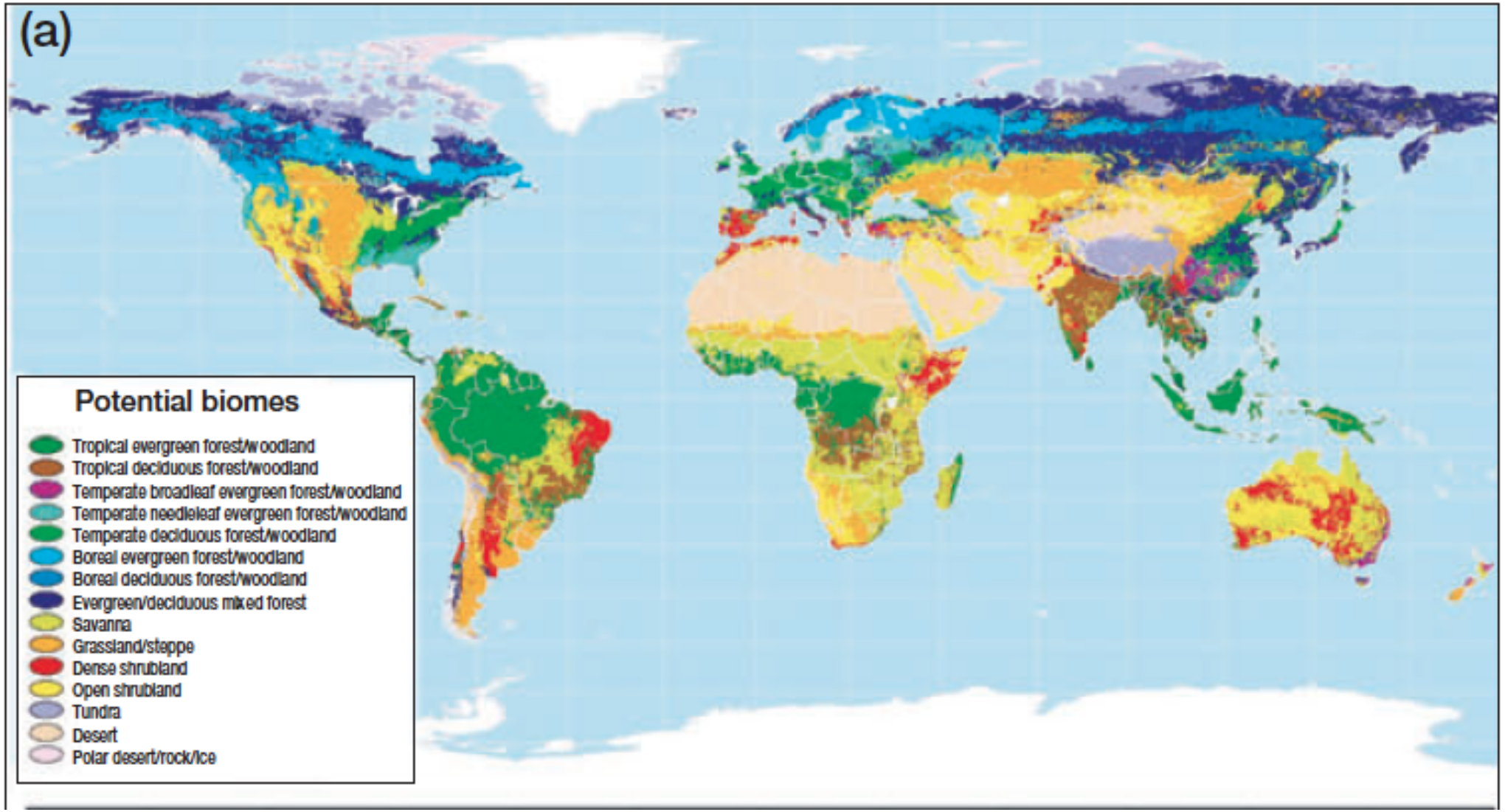
Potential Vegetation Distribution



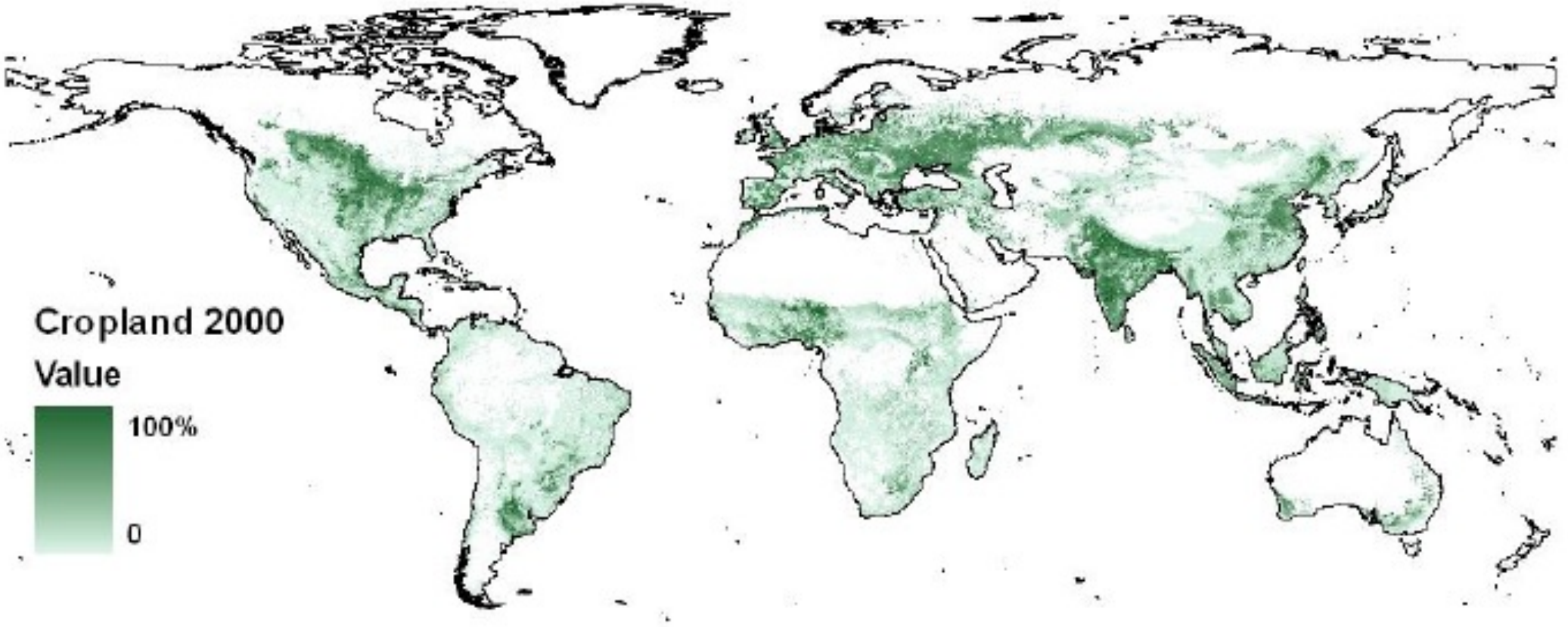
Ramankutty *et al.*

Potential Vegetation Distribution



BUT, nowadays,
~47 millions of km^2 are occupied by Man
~40% of land surfaces

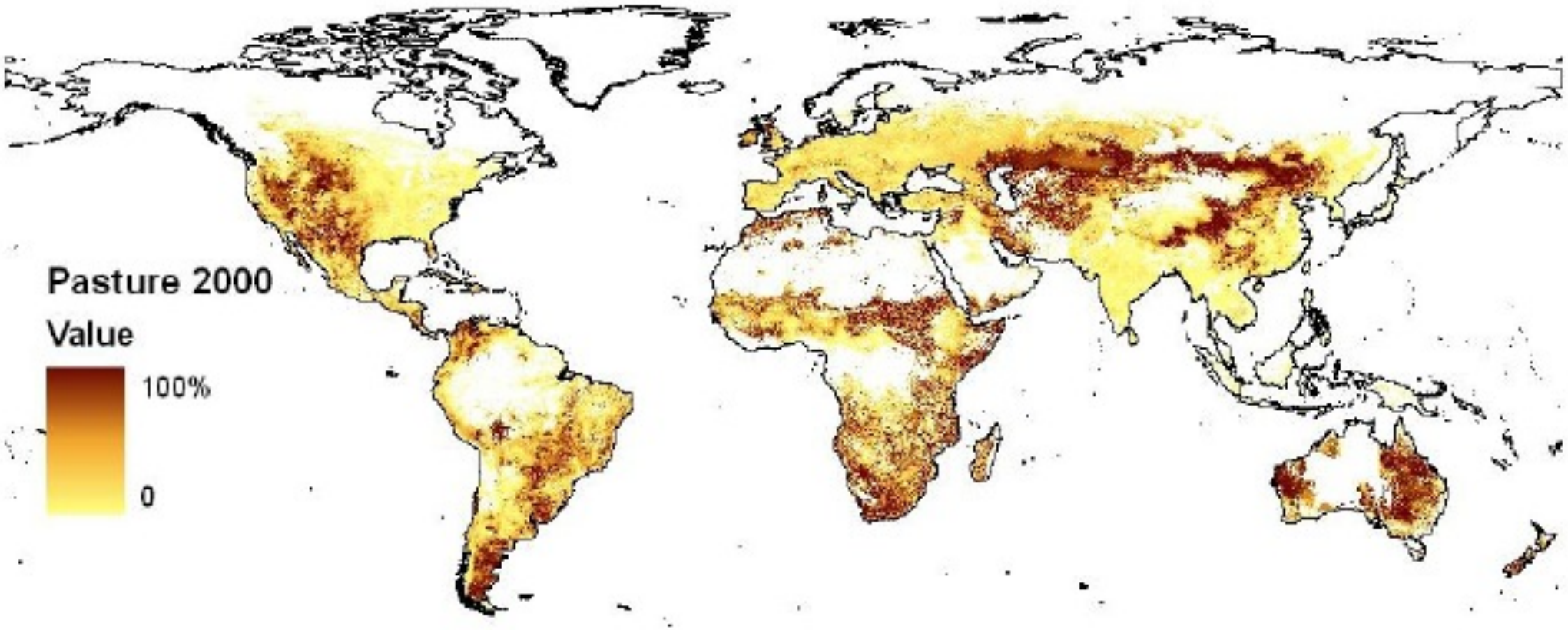
Expansion of Crop Areas
(percent of a grid-cell)



~15 millions of km^2

Ramankutty *et al.*

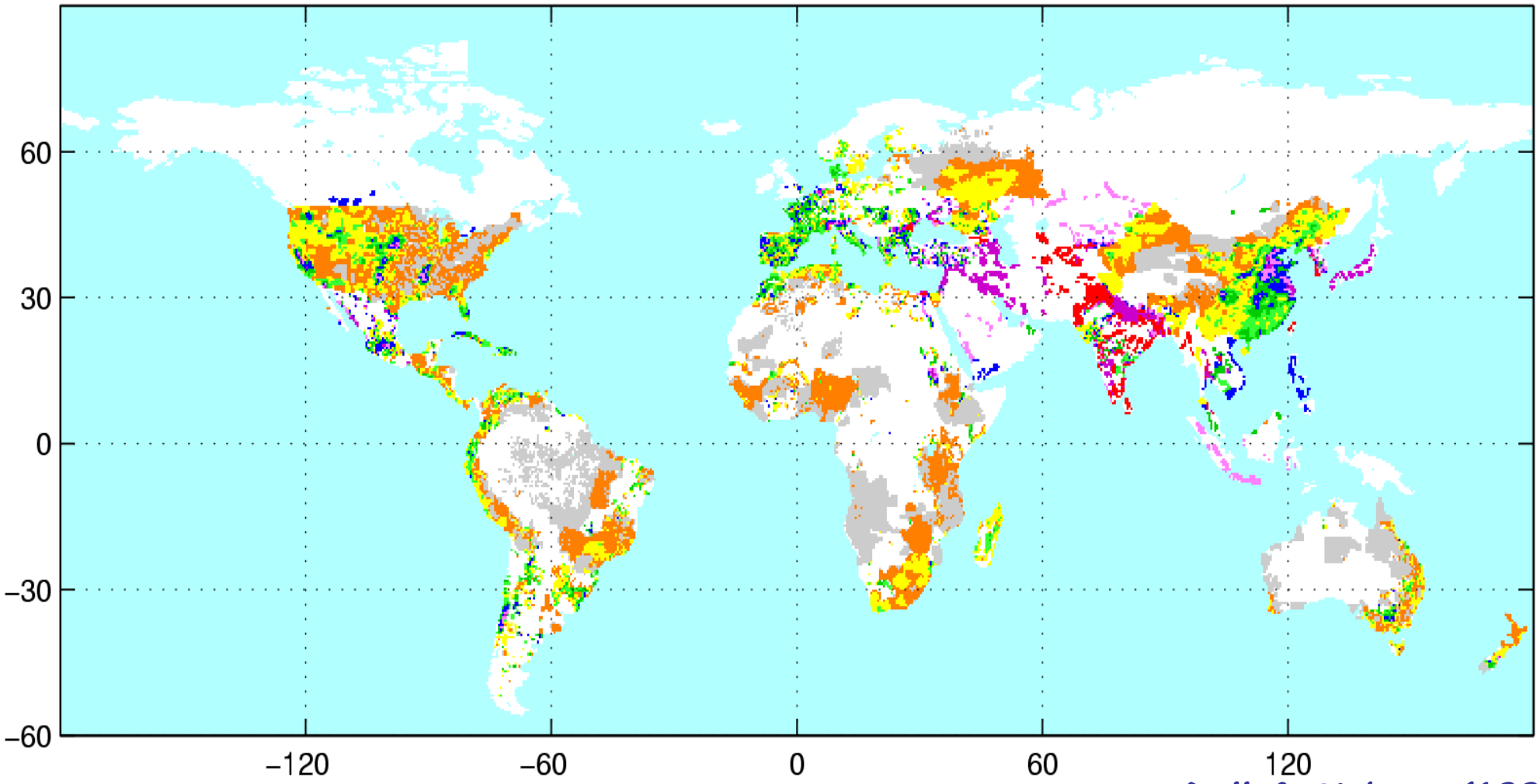
Pasture Expansion
(percent of a grid-cell)



 ~32 millions of km^2

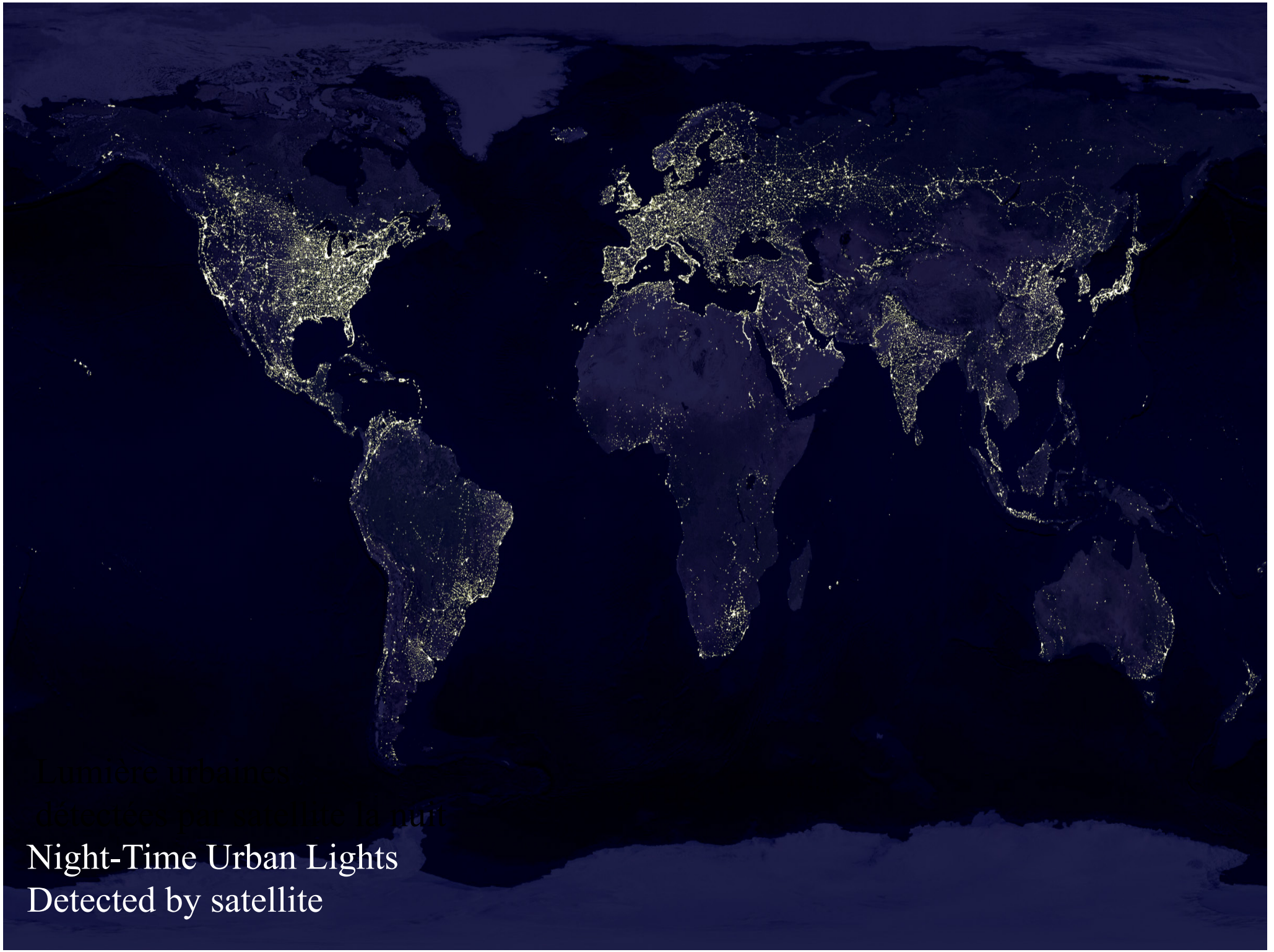
Ramankutty *et al.*

Expansion of Areas equiped for irrigation



Döll & Siebert (1999)

< 0.1	5 – 10	35 – 50	Percentage land
0.1 – 1	10 – 20	50 – 75	equiped
1 – 5	20 – 35	75 –100	for irrigation


Lumière urbaines
détectées par satellite la nuit
Night-Time Urban Lights
Detected by satellite

Heat Source to be added to the atmosphere

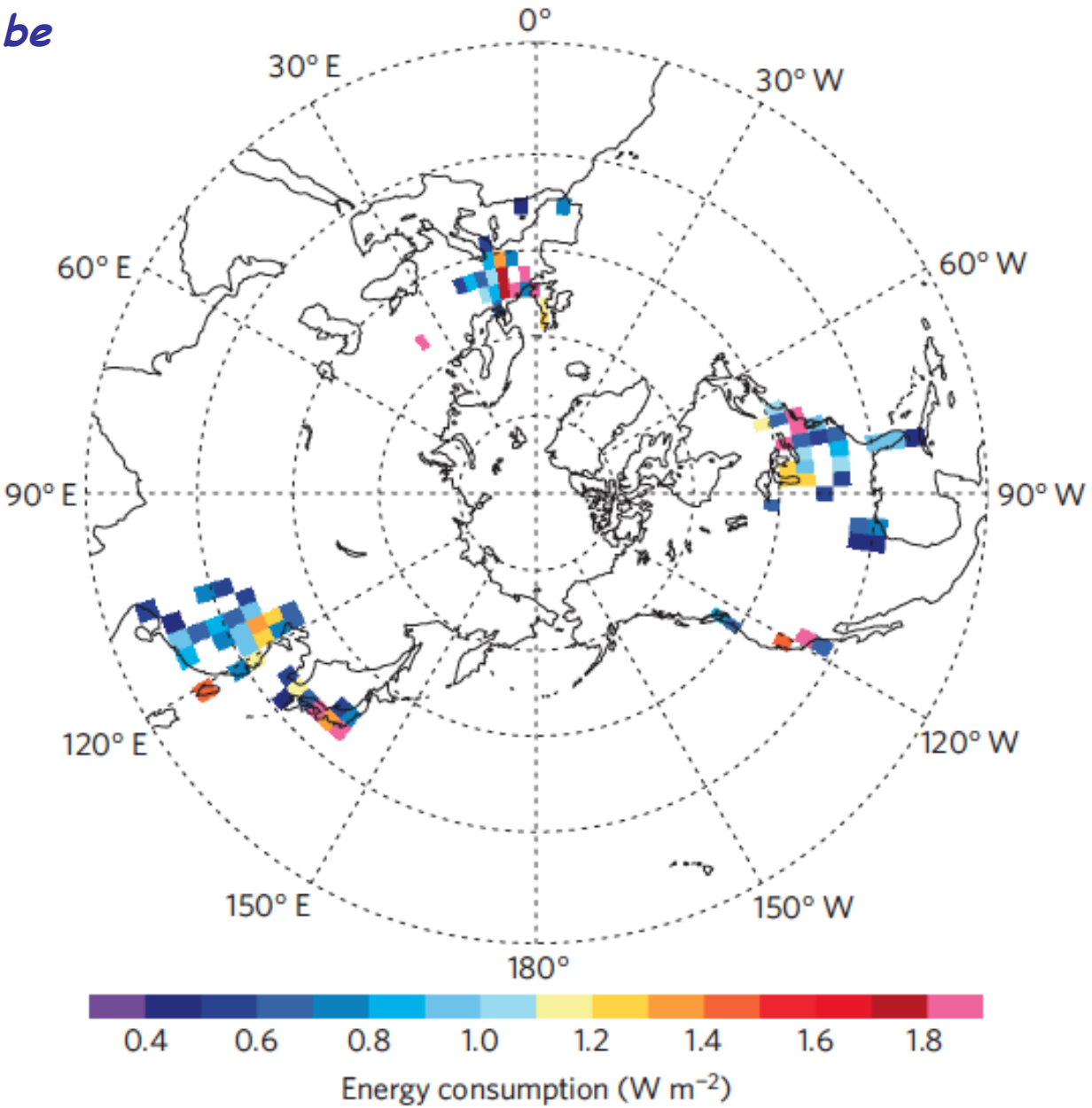


Figure 1 | Locations and area-averaged energy consumption of the 86 model grid points used in the perturbation runs. Each value is obtained by dividing the total estimated energy-use by the area represented by the model grid point.

Zhang et al. (2013)

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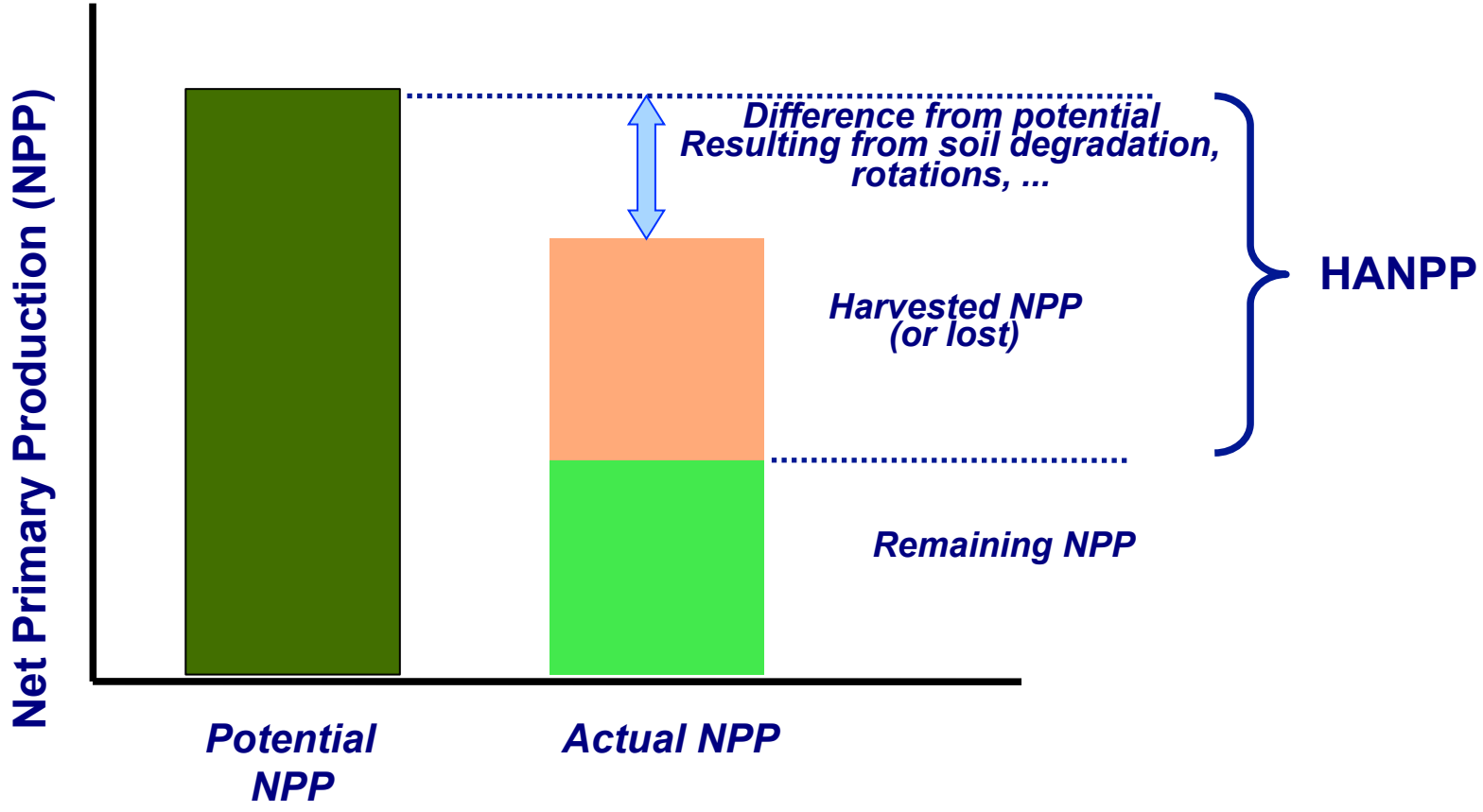
Human appropriation of net primary production (HANPP), the aggregate impact of land use on biomass available each year in ecosystems, is a prominent measure of the human domination of the biosphere.

We found an aggregate global HANPP value of 15.6 Pg C/yr or 23.8% of potential net primary productivity, of which 53% was contributed by harvest, 40% by land-use-induced productivity changes, and 7% by human-induced fires.

This is a remarkable impact on the biosphere caused by just one species.

Today Men harvest ~40% of the total Net Primary Productivity Produced on land

HANPP = Human Appropriation of Net Primary Production



Erb et al. 2009

HANPP

(in % of Potential NPP)

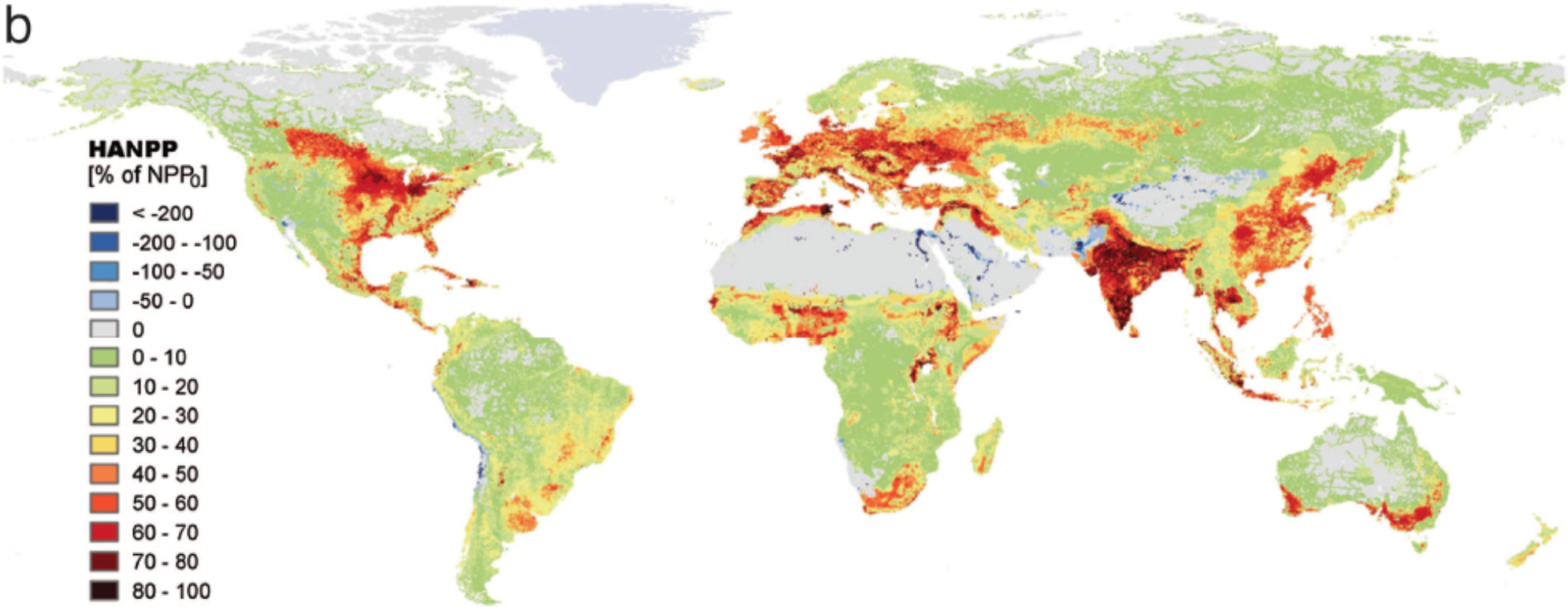


Fig. 1. Maps of the human appropriation of net primary production (HANPP), excluding human-induced fires. (*a*) Land-use-induced reductions in NPP as a percentage of NPP_0. (*b*) Total HANPP as a percentage of NPP_0. Blue (negative values) indicates increases of NPP_{act} (*a*) or NPP_t (*b*) over NPP_0, green and yellow indicate low HANPP, and red to dark colors indicate medium to high HANPP.

Haberl et al. 2007

Terrestrial Biosphere & Climate

Brief summary of various interactions

Reichstein et al., ileaps 2011

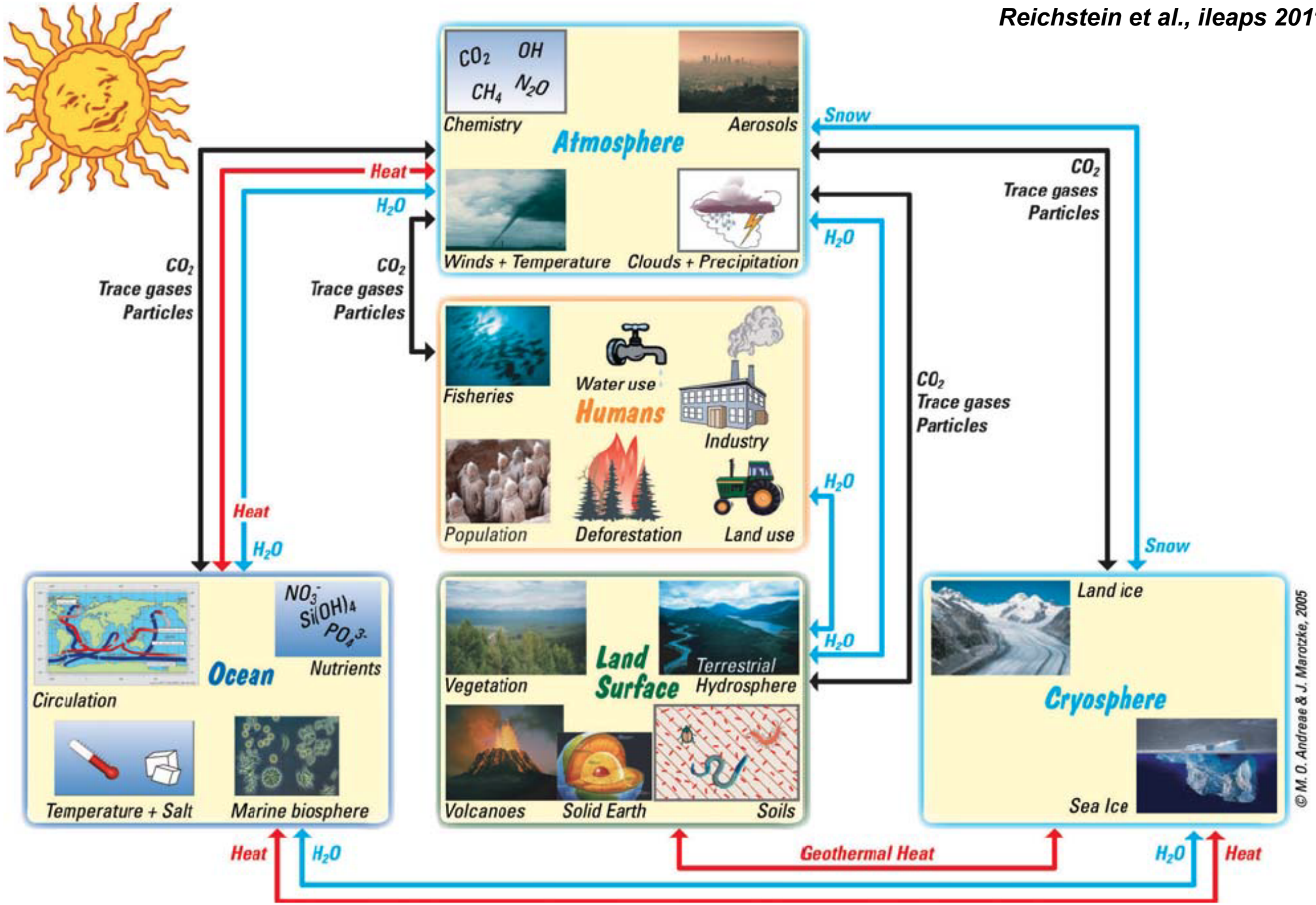


Figure 1. View on the Earth System with its subsystems and their interactions (from [22]).

Guenther et al., ileaps 2011

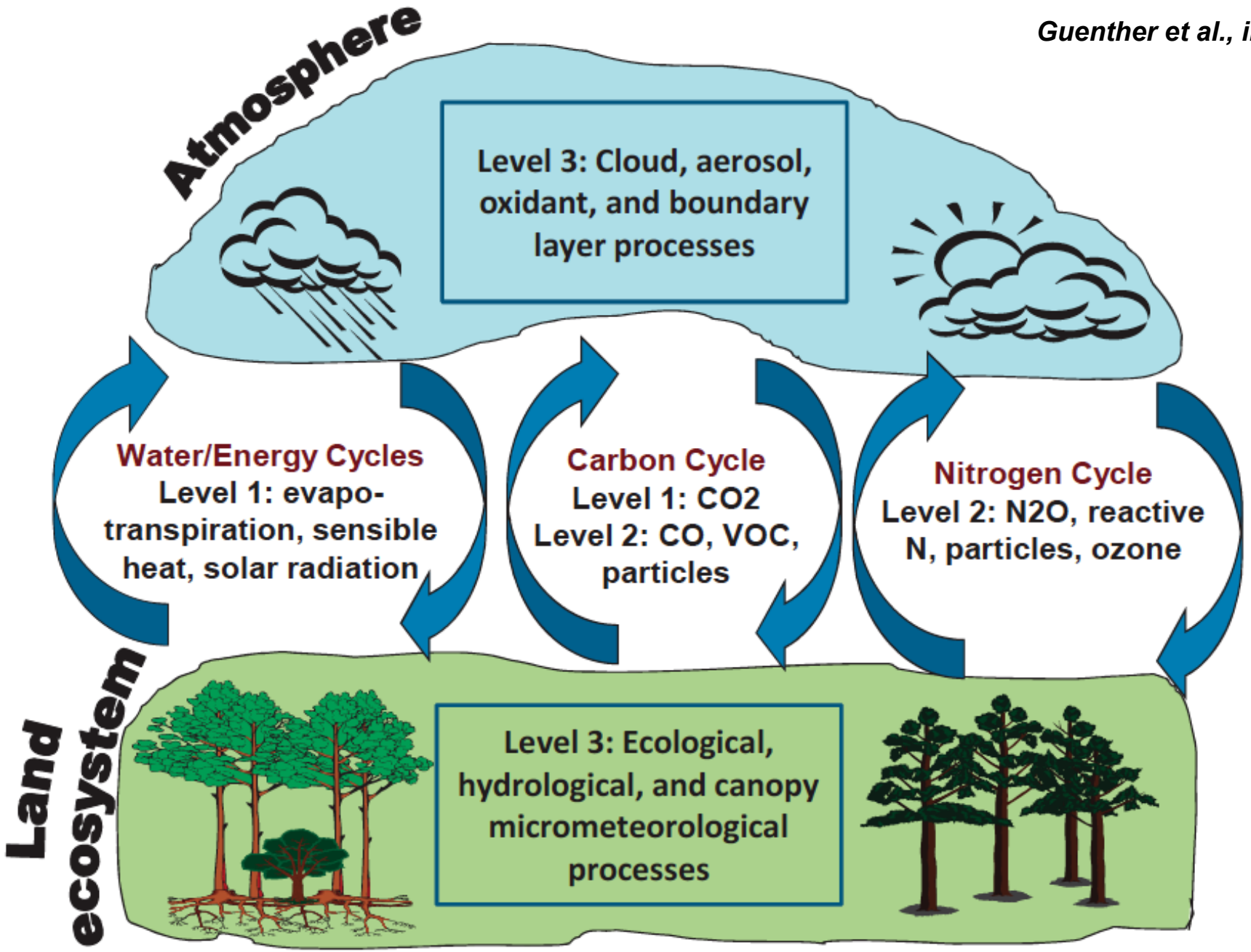
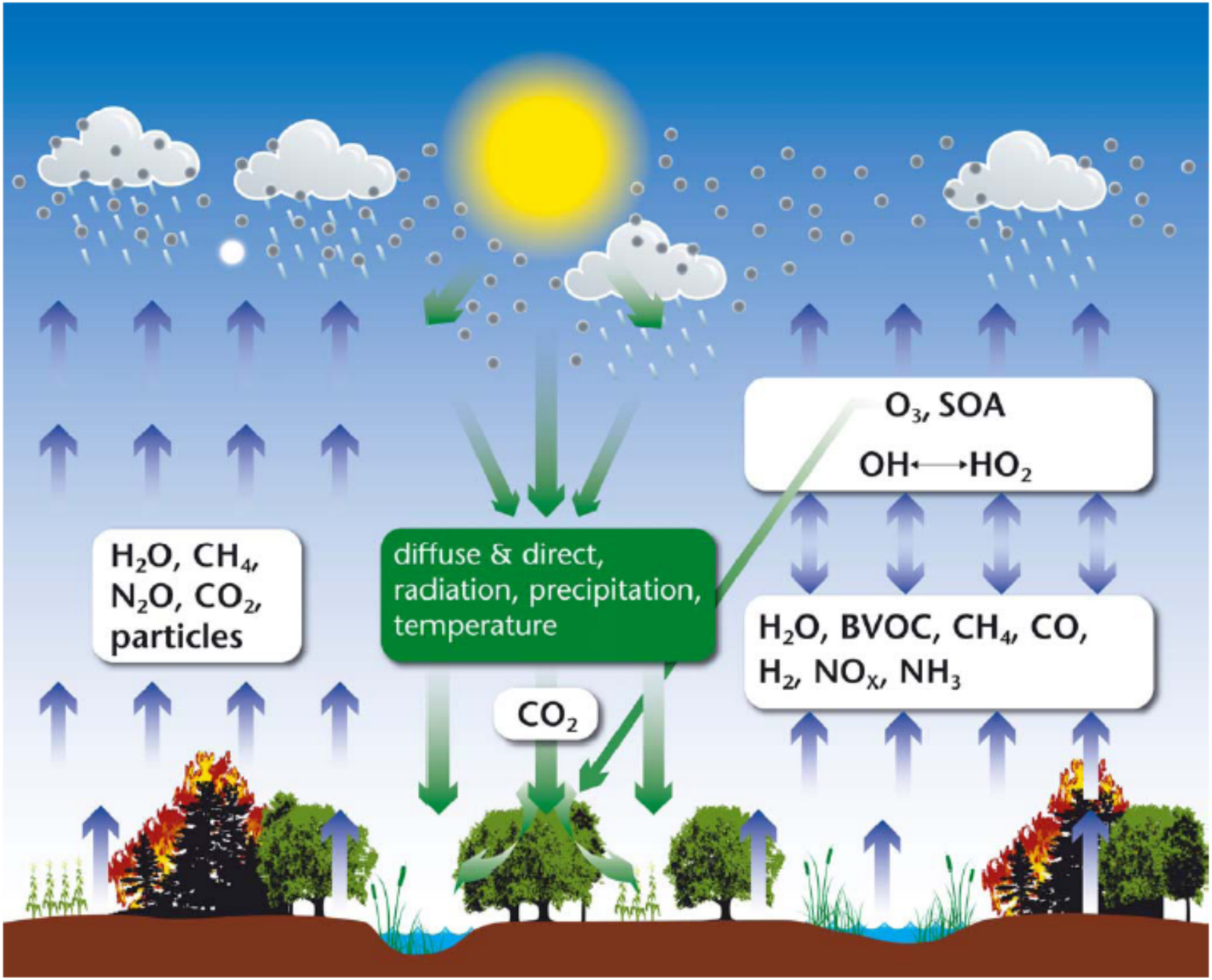


Figure 1. Schematic of land ecosystem–atmosphere interactions and hierarchal observational levels that include basic fluxes (level 1), advanced fluxes (level 2) and comprehensive measurements at "flagship sites" (level 3).

Some Processes that are being implemented now



Arneth et al. 2010

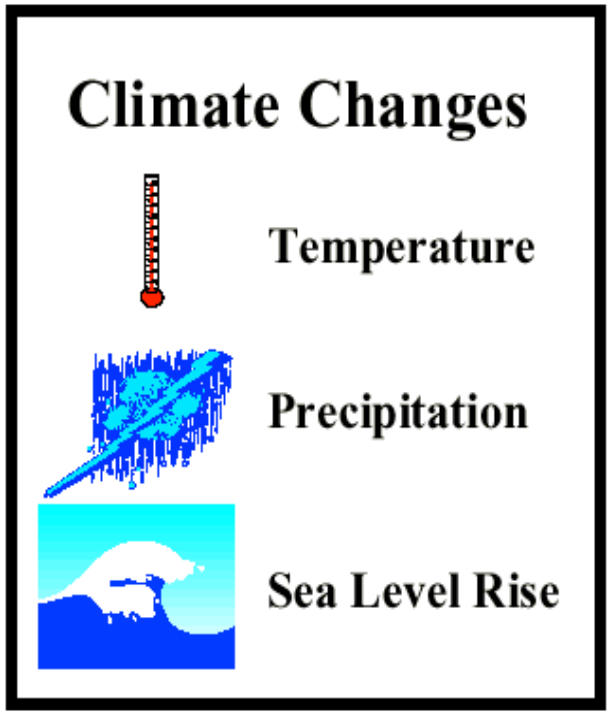
Some Processes that may be needed in our models

What is important

for decision making?

At what spatial scale?

Potential Climate Change Impacts



Health Impacts

Weather-related Mortality
Infectious Diseases
Air Quality-Respiratory Illnesses

Agriculture Impacts

Crop yields
Irrigation demands

Forest Impacts

Change in forest composition
Shift geographic range of forests
Forest Health and Productivity

Water Resource Impacts

Changes in water supply
Water quality
Increased Competition for water

Impacts on Coastal Areas

Erosion of beaches
Inundate coastal lands
Costs to defend coastal communities

Species and Natural Areas

Shift in ecological zones
Loss of habitat and species

EPA

Do we need to account for impacts of land-uses on climate before taking a decision on land-planning?

Strategies for land uses

Effects on climate

An example of intimate links: the water cycle

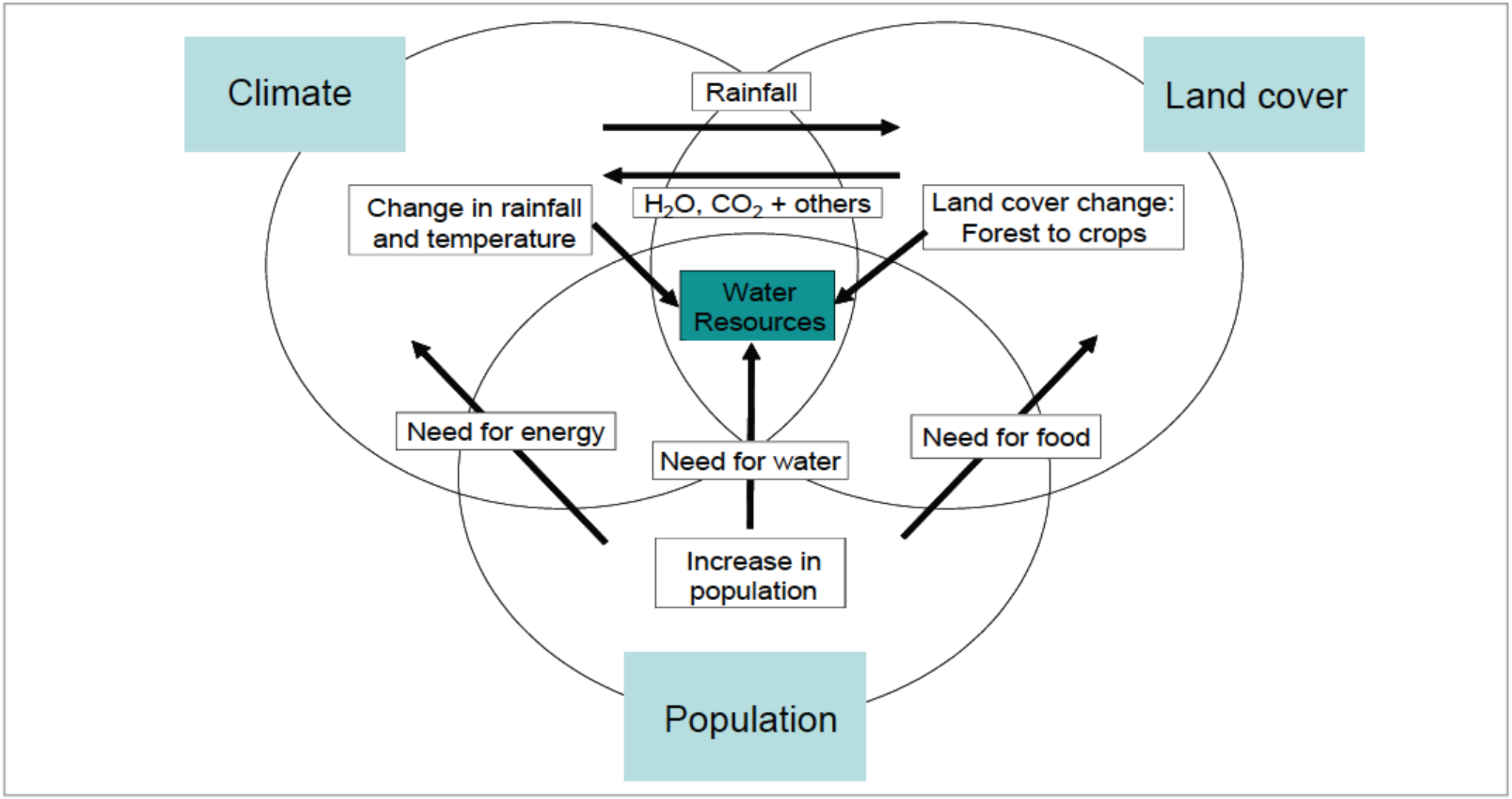
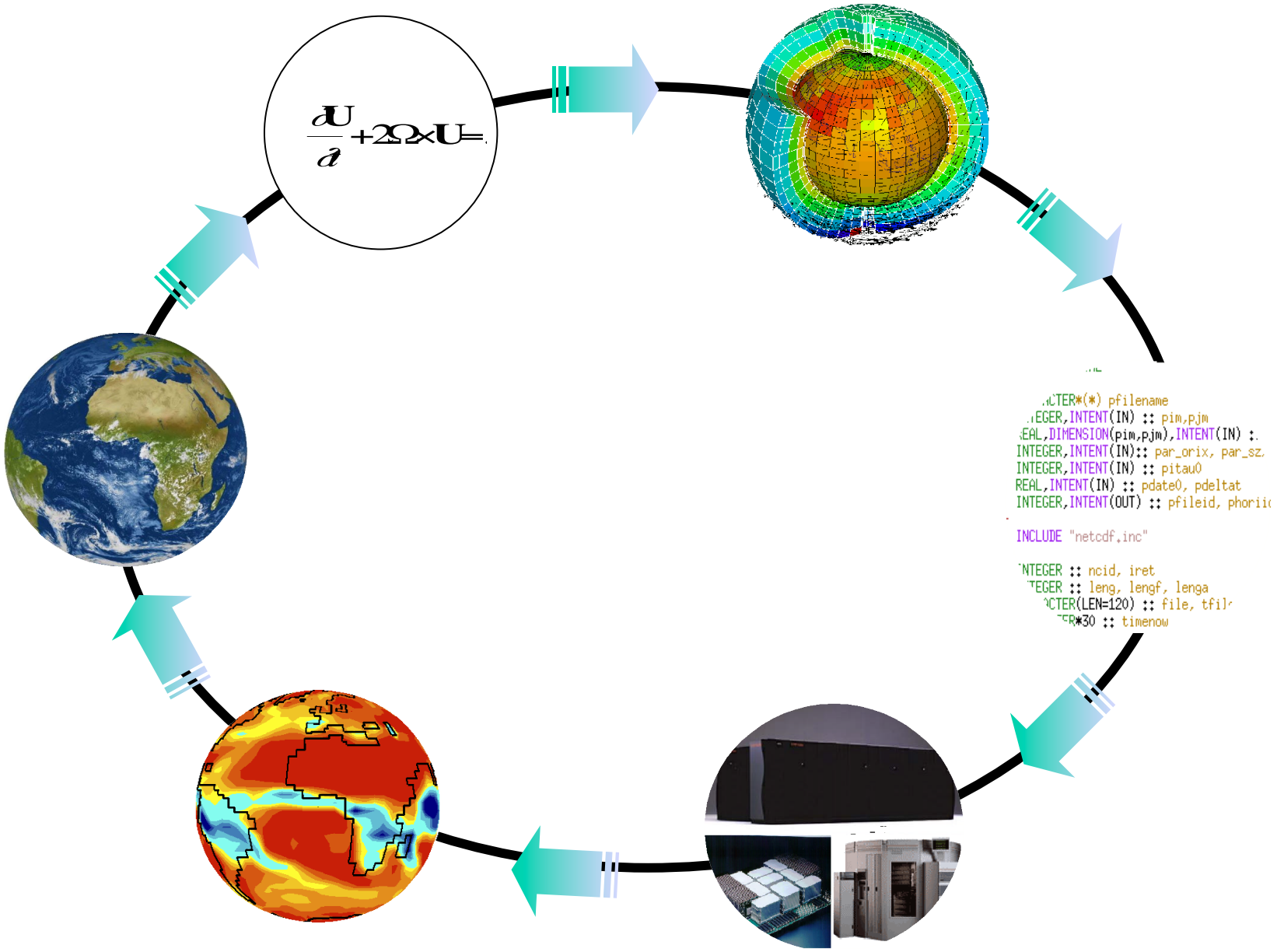


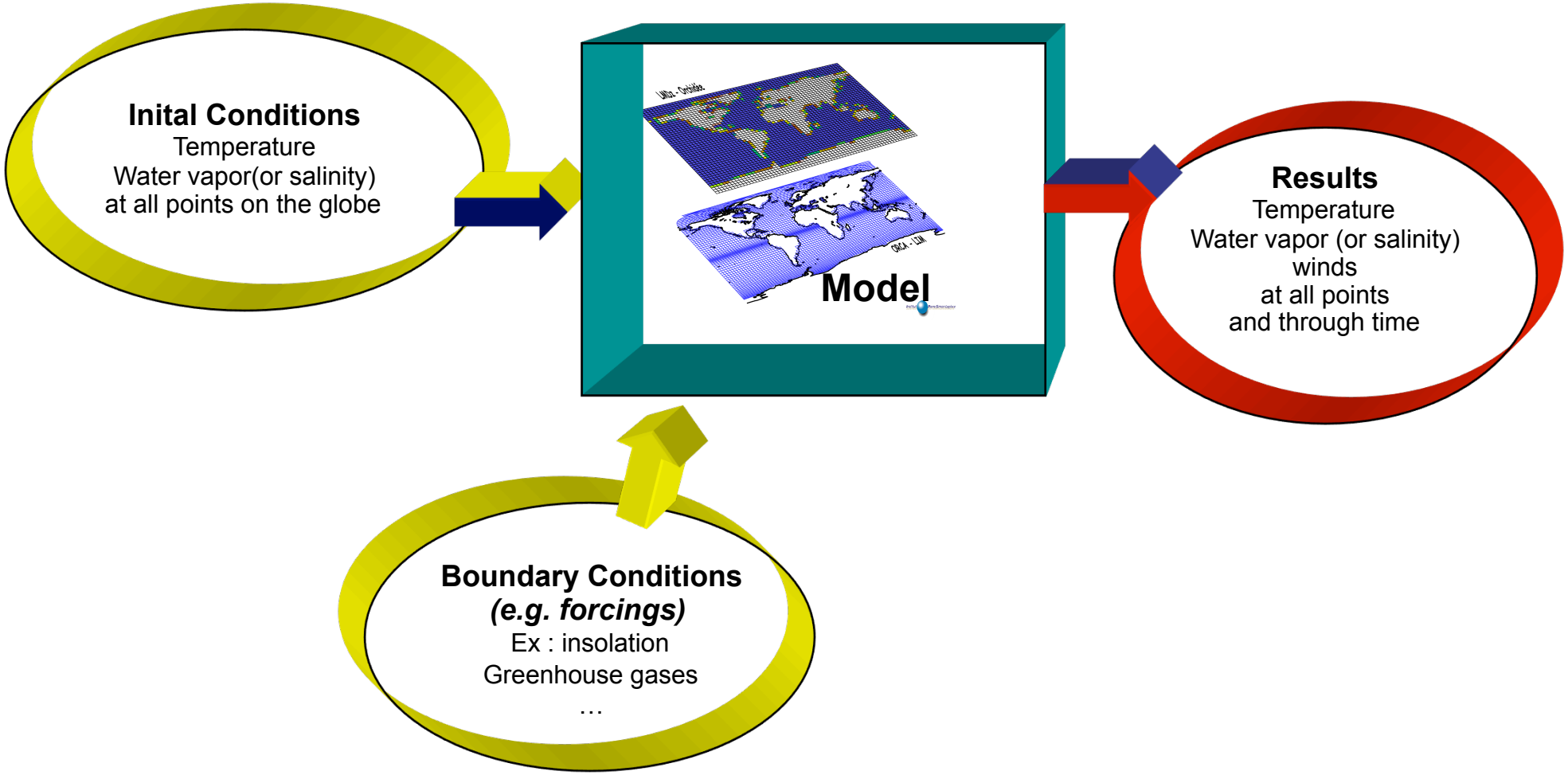
Figure 1. Drivers of global change and feedbacks to the global water cycle.

Some of our Main Tools: Models

How do we construct a model?



How do we run a climate simulation?

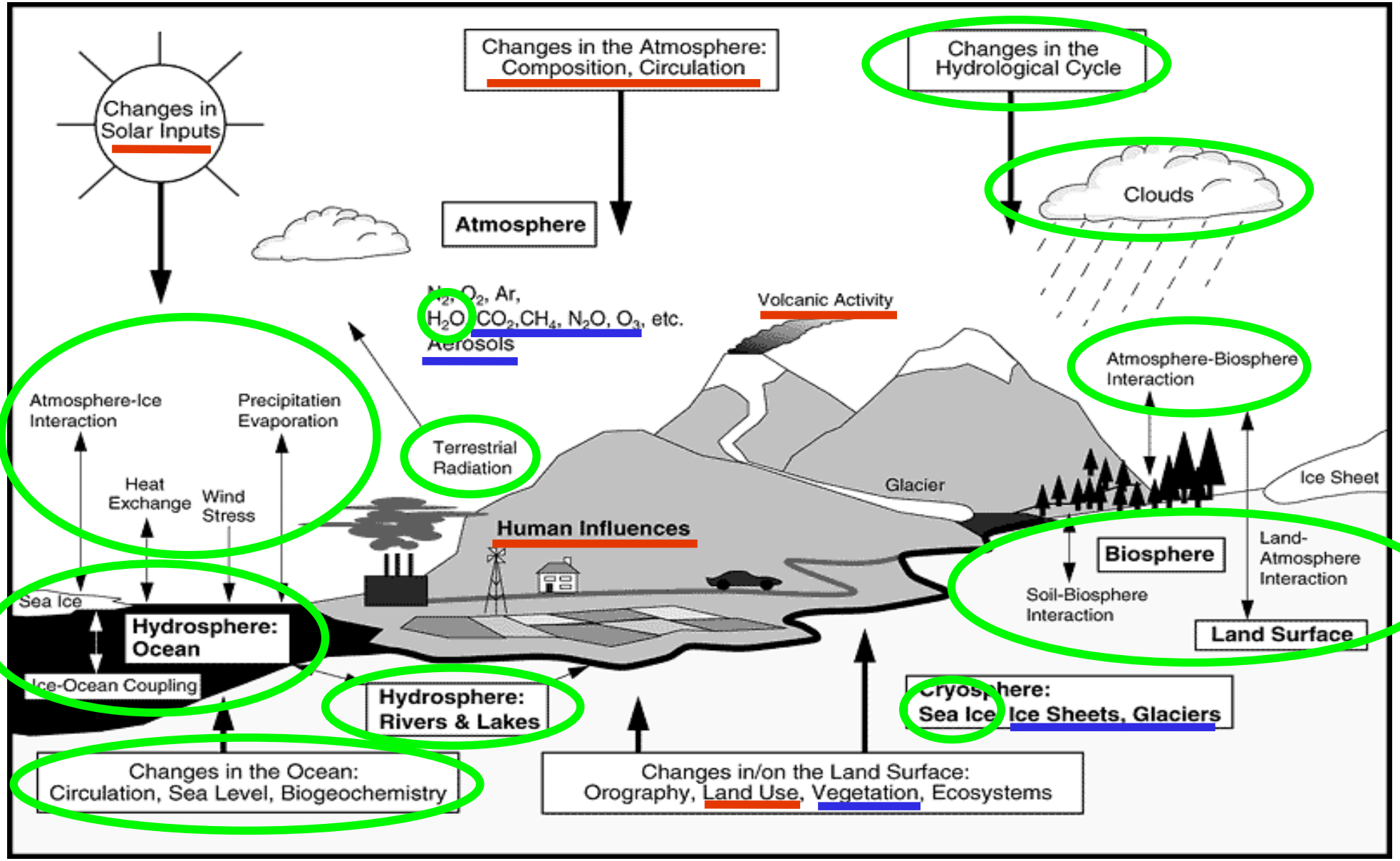


Reference (Control) Simulation

Perturbed Simulation

➔ *Boundary Conditions are changed for example*

Climate processes we account for



Forcings

Forcings or Feedbacks

Calculated

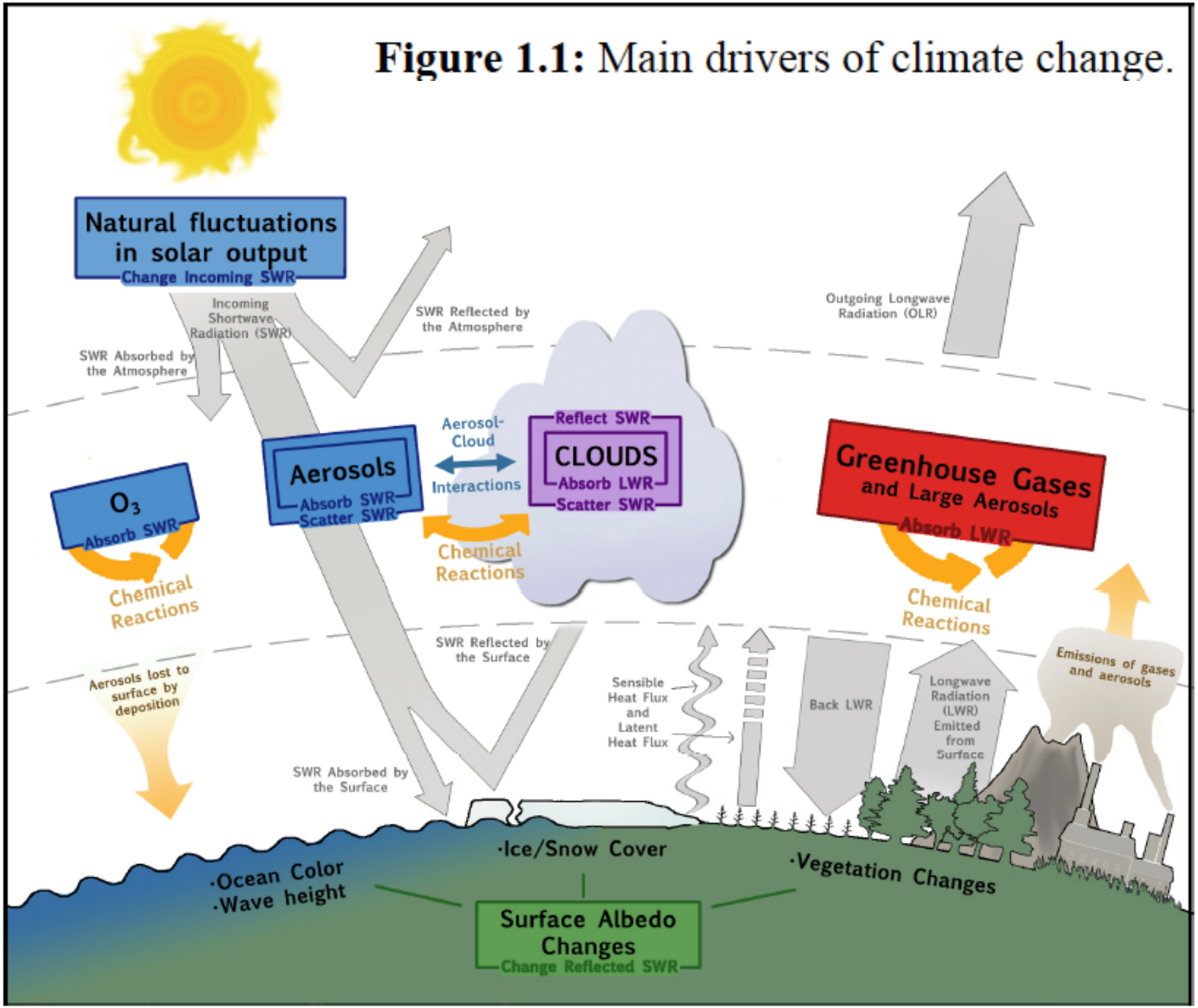
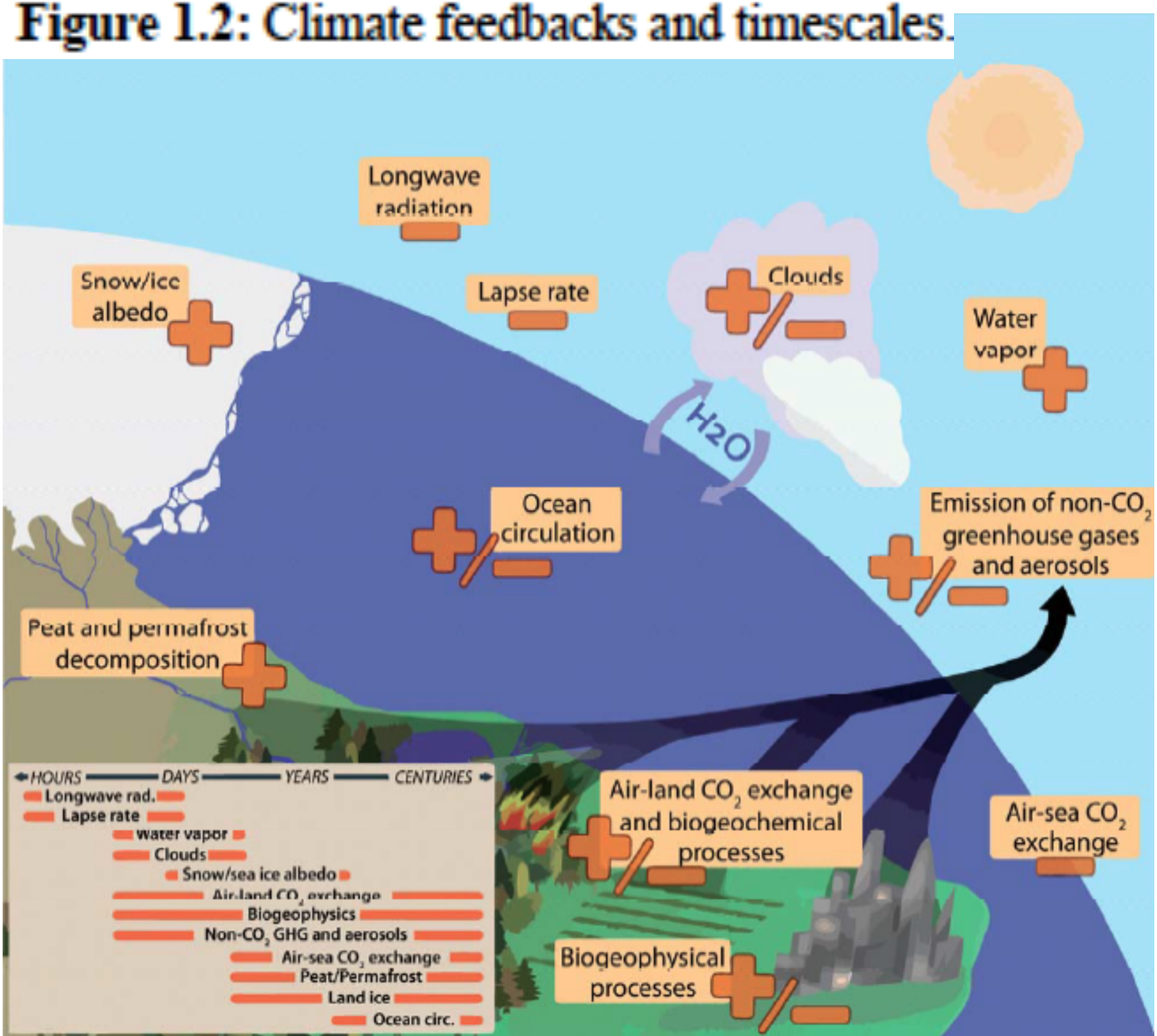
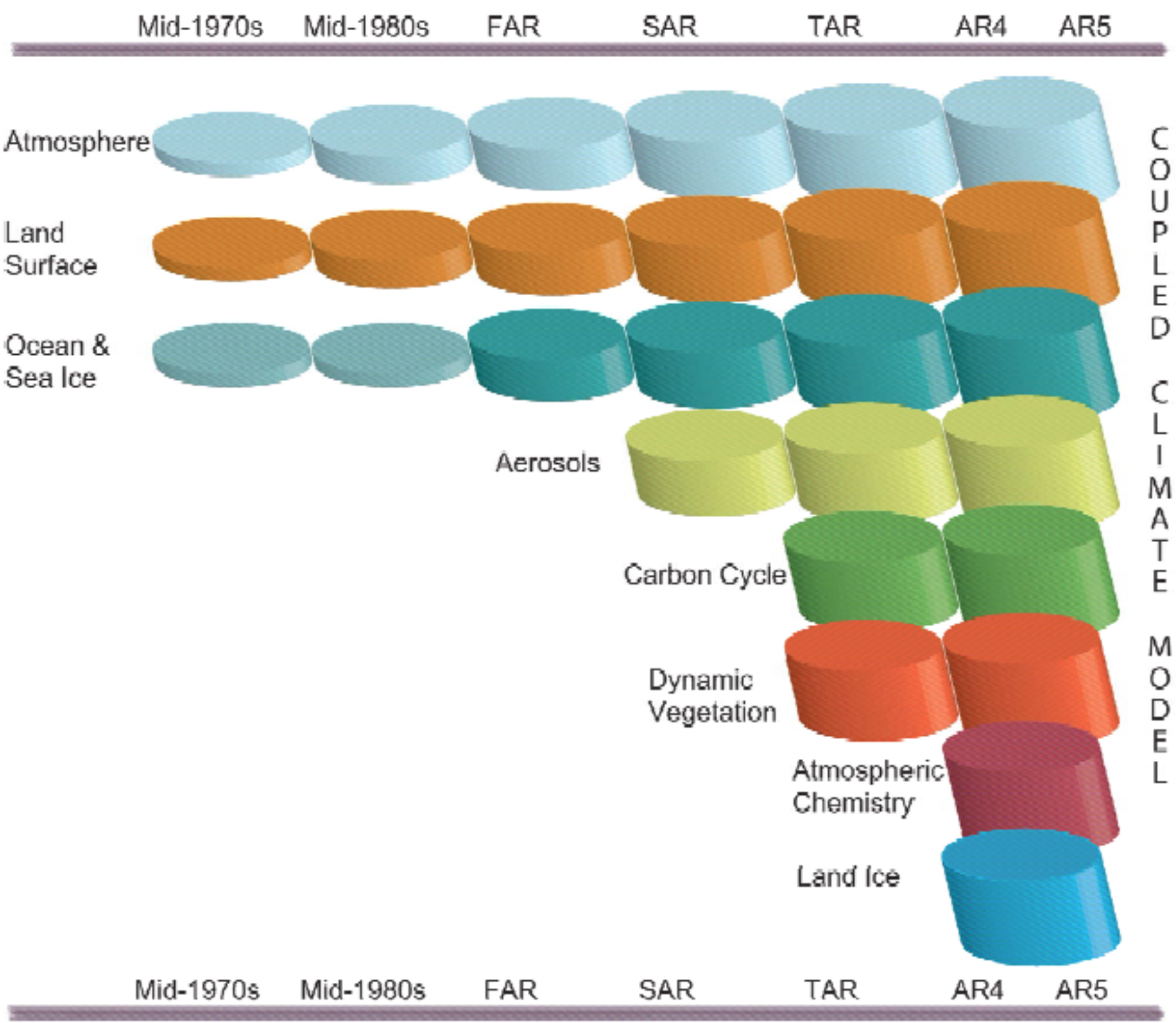
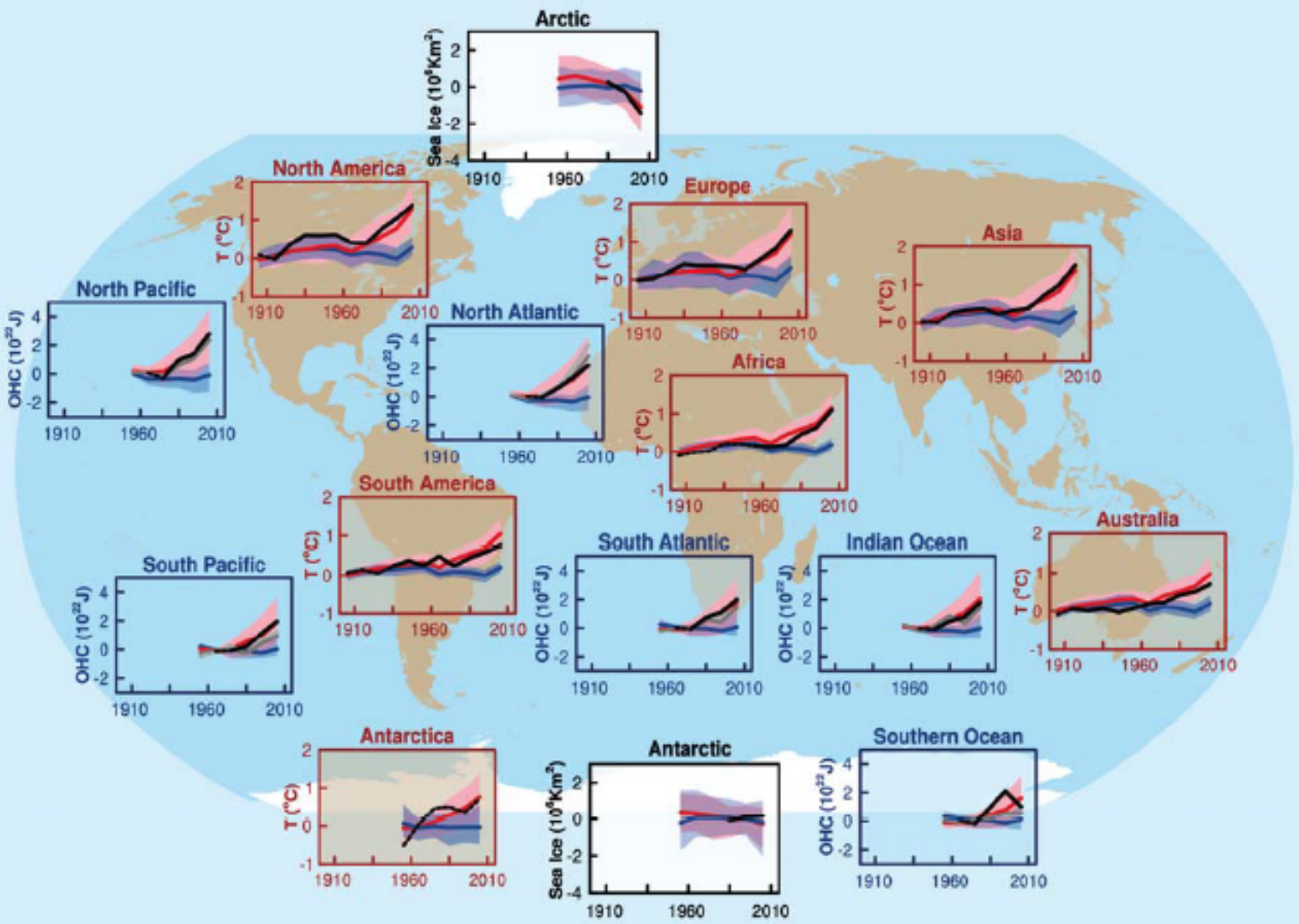


Figure 1.1: Main drivers of climate change.
Natural fluctuations in solar output
Change Incoming SWR
Incoming Shortwave Radiation (SWR)
SWR Absorbed by the Atmosphere
SWR Reflected by the Atmosphere
Outgoing Longwave Radiation (OLR)
Aerosol-Cloud Interactions
Reflect SWR
CLOUDS
Absorb LWR
Scatter SWR
Aerosols
Absorb SWR
Scatter SWR
O3
Absorb SWR
Chemical Reactions
Chemical Reactions
Greenhouse Gases and Large Aerosols
Absorb LWR
Chemical Reactions
SWR Reflected by the Surface
Aerosols lost to surface by deposition
Sensible Heat Flux and Latent Heat Flux
Back LWR
Longwave Radiation (LWR) Emitted from Surface
Emissions of gases and aerosols
SWR Absorbed by the Surface
·Ocean Color
·Wave height
·Ice/Snow Cover
·Vegetation Changes
Surface Albedo Changes
Change Reflected SWR

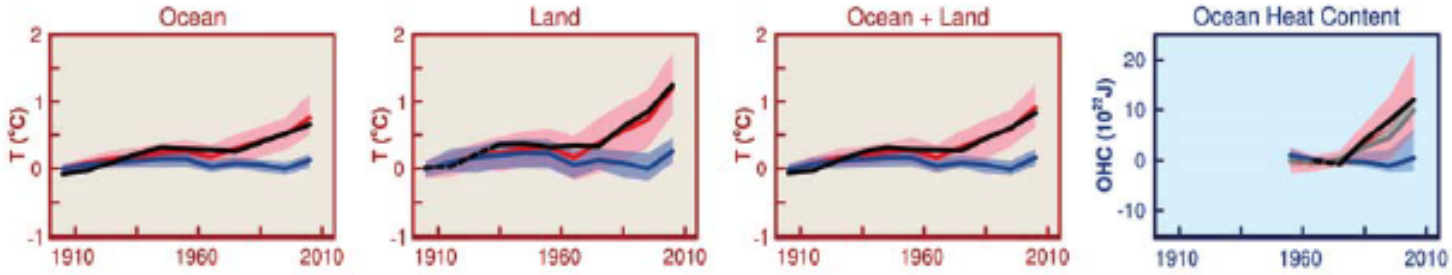
Figure 1.2: Climate feedbacks and timescales.




Mid-1970s
Mid-1980s
FAR
SAR
TAR
AR4
AR5
Atmosphere
Land Surface
Ocean & Sea Ice
Aerosols
Carbon Cycle
Dynamic Vegetation
Atmospheric Chemistry
Land Ice
COUPLED CLIMATE MODEL
Mid-1970s
Mid-1980s
FAR
SAR
TAR
AR4
AR5



Global

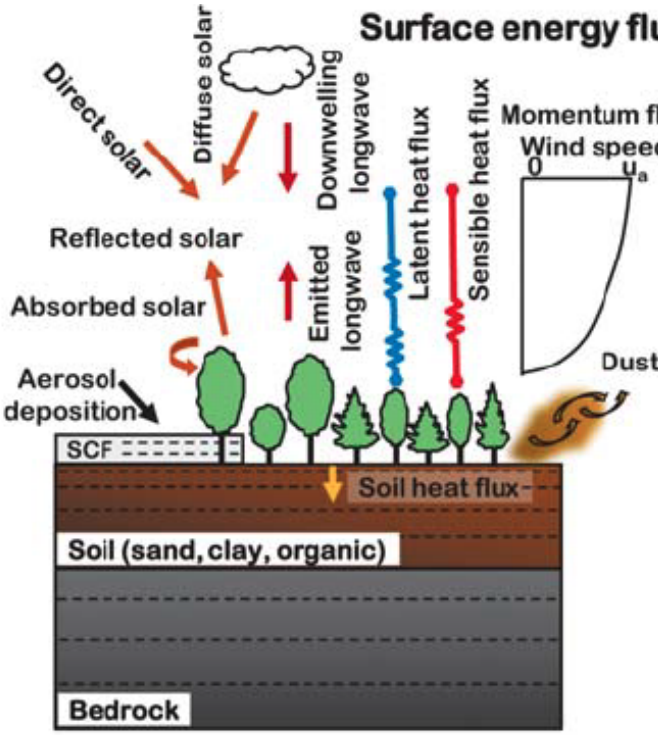


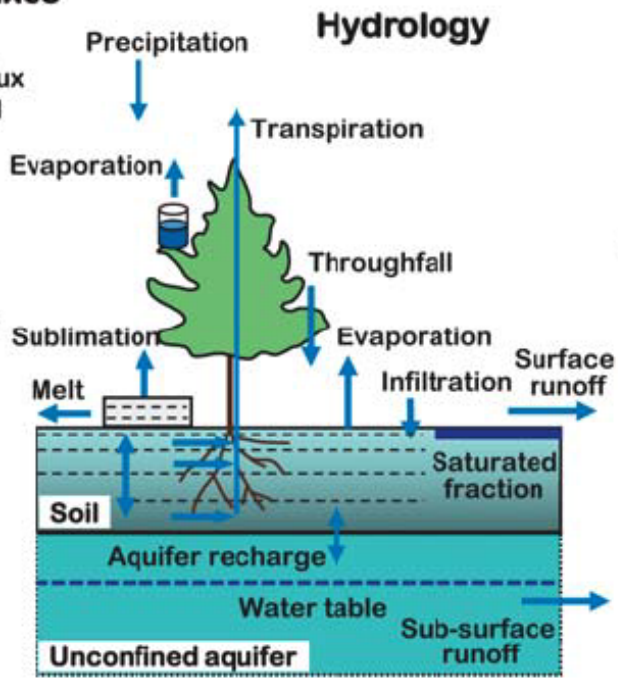
Observations

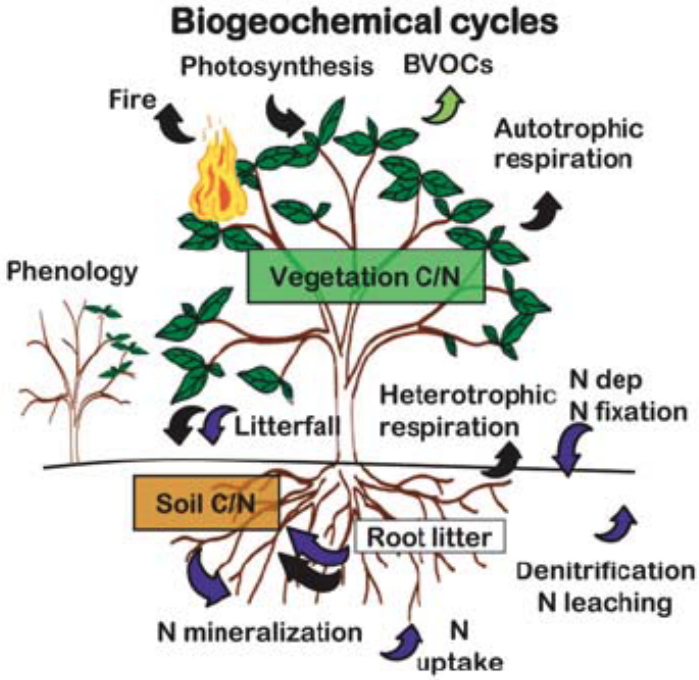
Models using only natural forcings

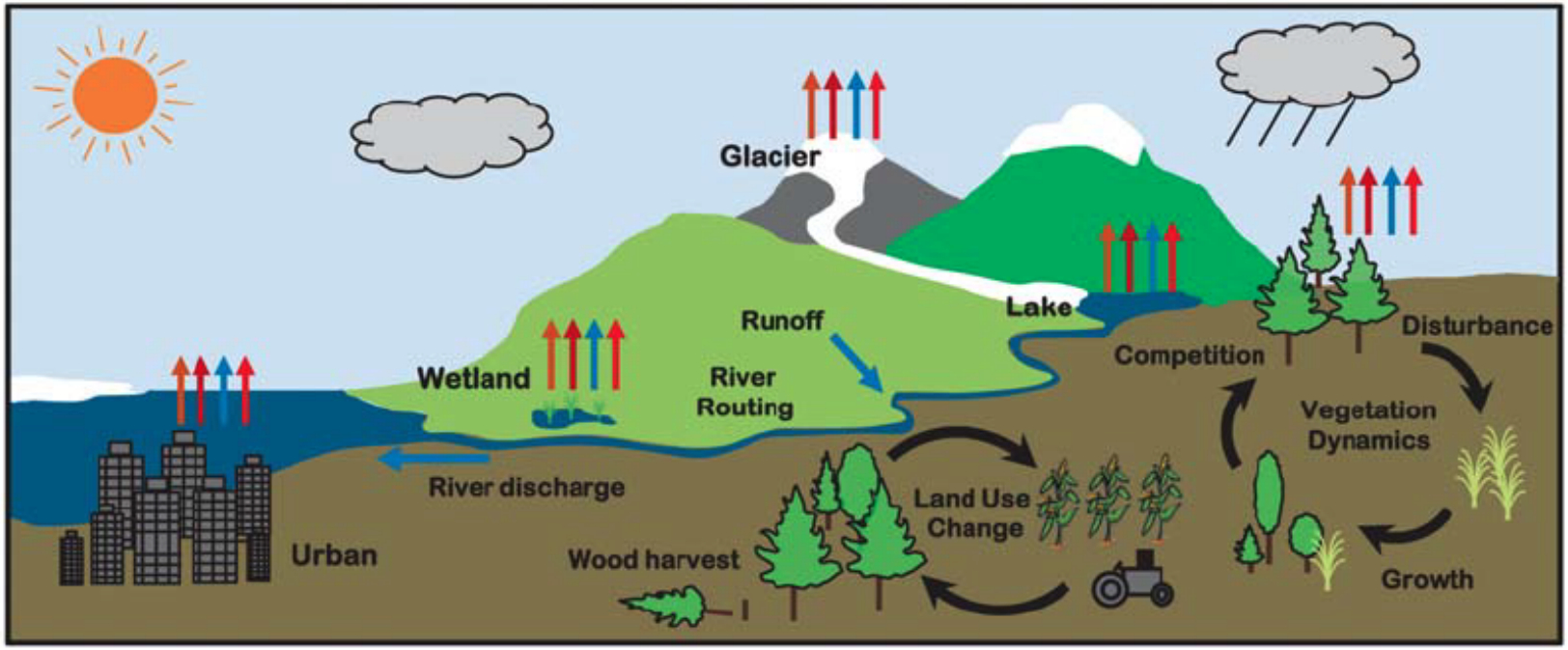
Models using both natural and anthropogenic forcings

Terrestrial Processes we account for

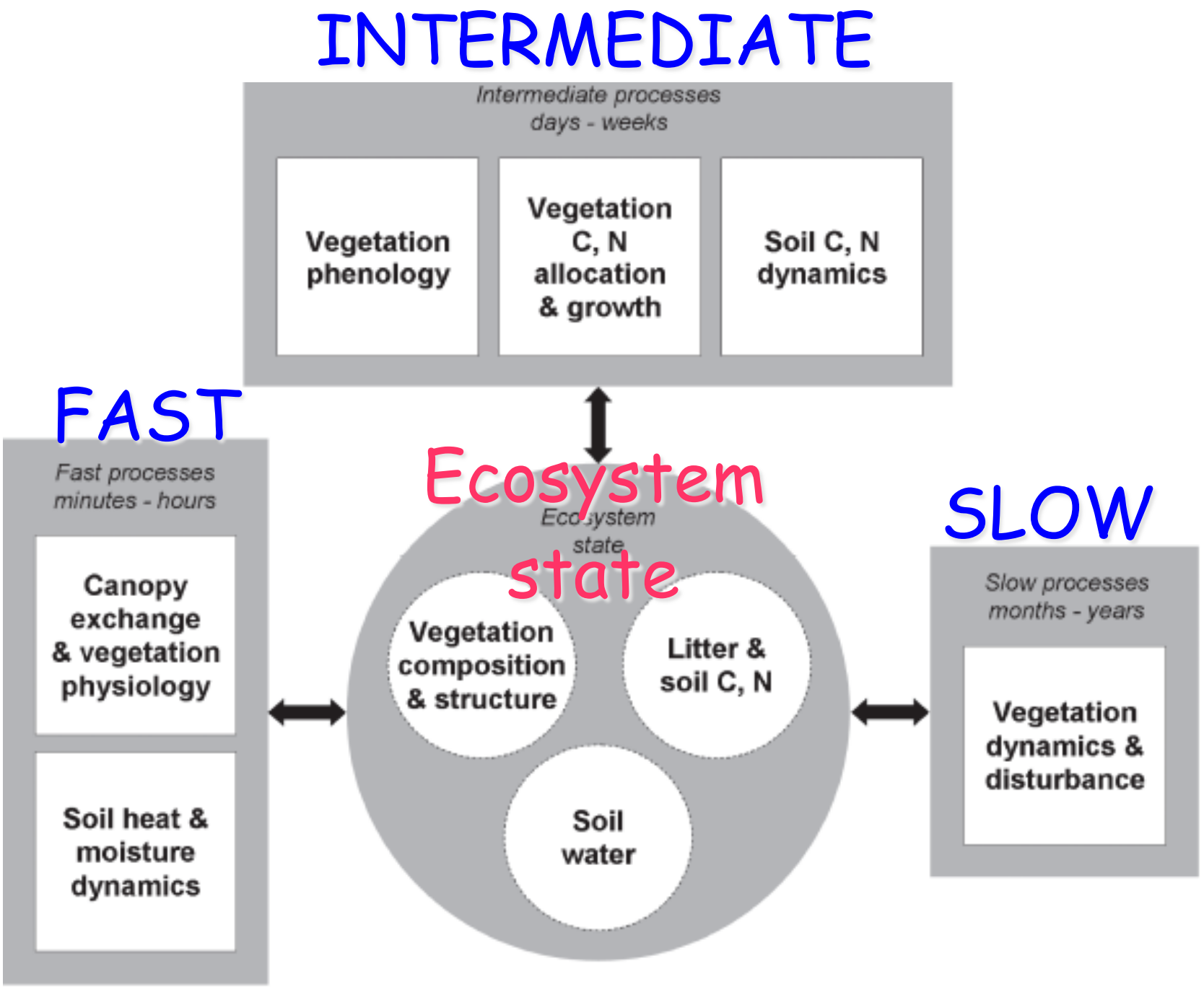




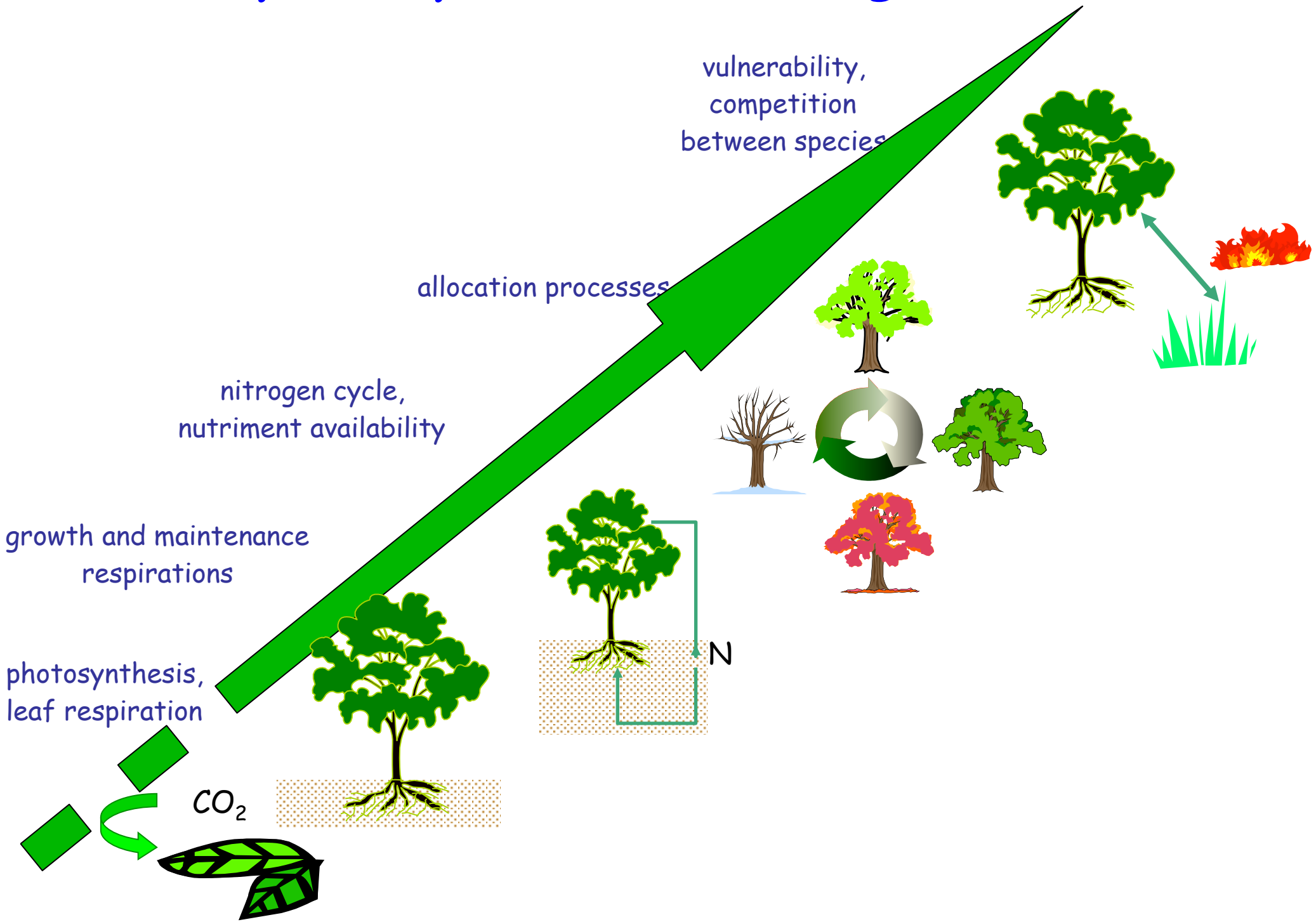




DGVMs = Dynamic Global Vegetation Models

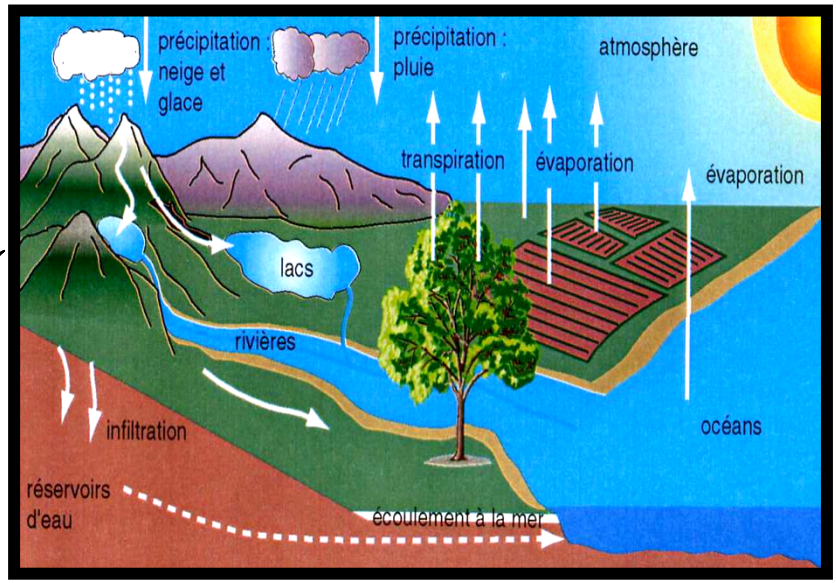


example of processes, through time-scales



example of processes, through spatial-scales

Watershed outflow



Soil-plant water budget

interception loss

transpiration

leaf transpiration

infiltration

runoff

What are Biosphere Models used for ?

PREDICT

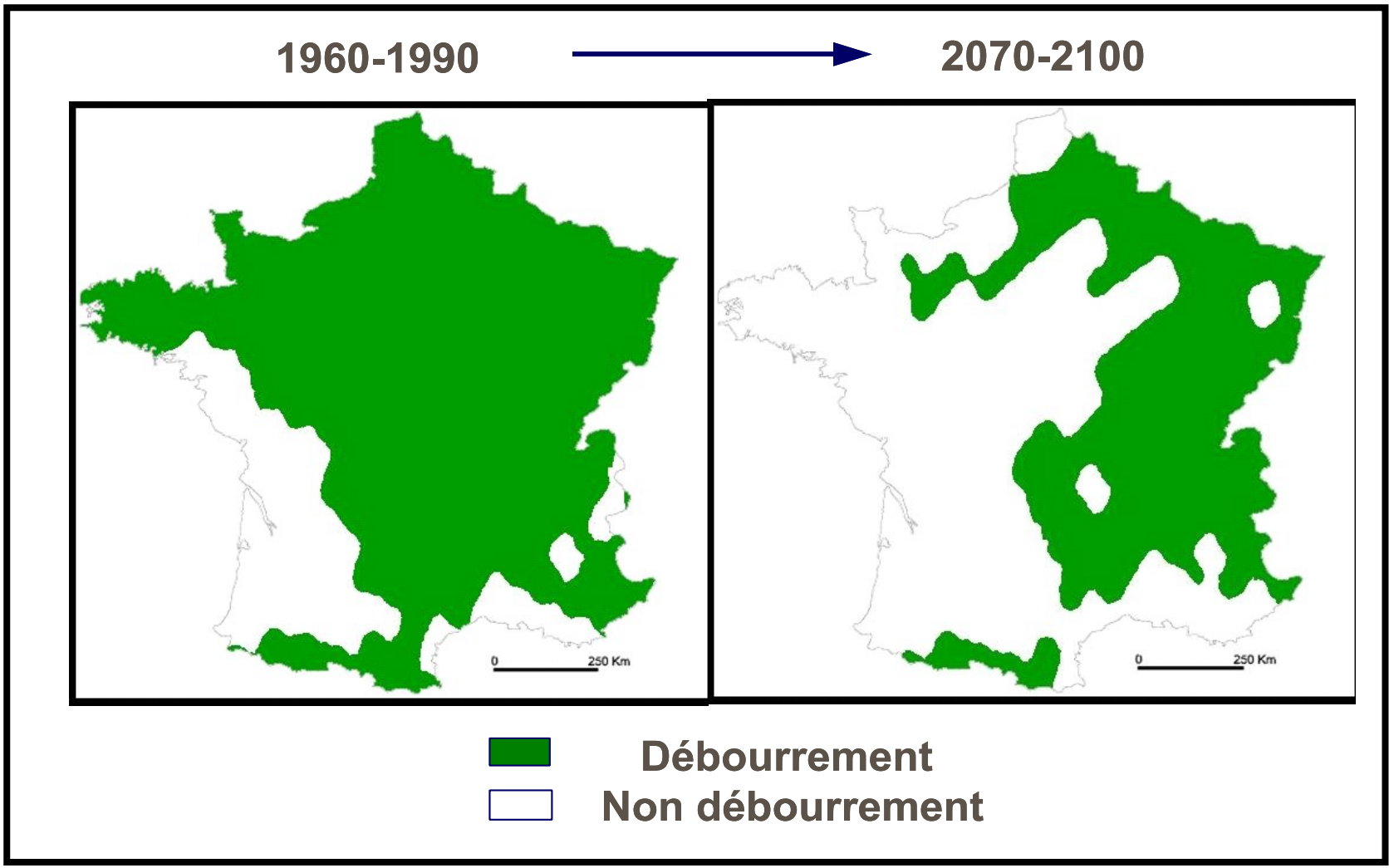
for example:

the impacts of climate change on:

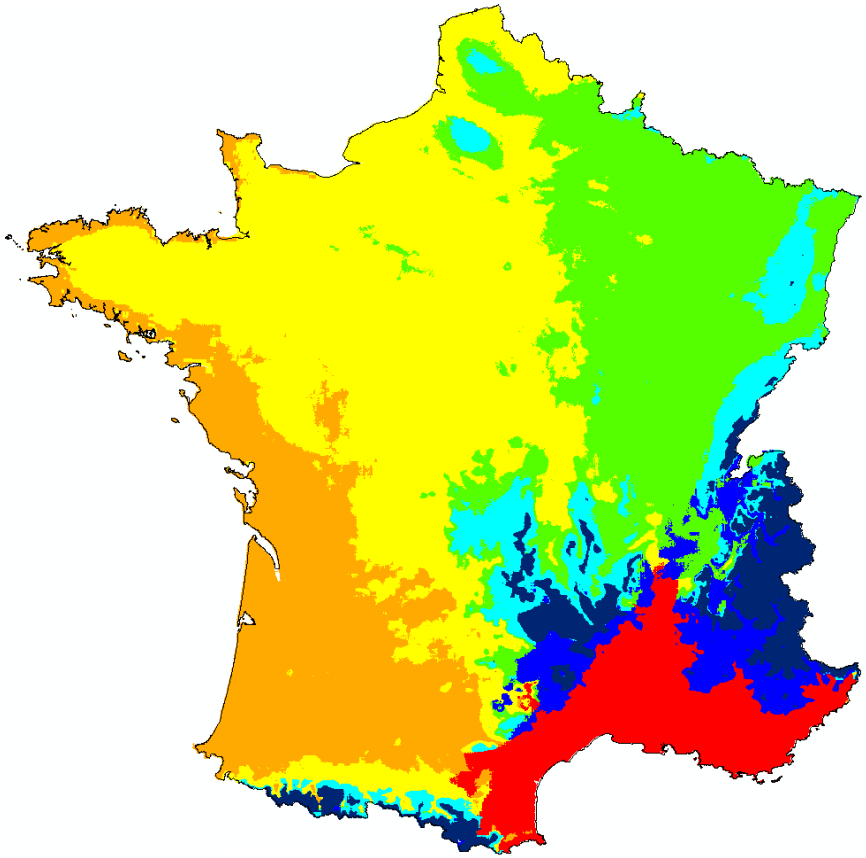
- water resources,
- the biospheric sink of CO_2,
- productivity,
- regional and global changes in vegetation distribution,
- …

Climate Impact on the distribution of Spruce

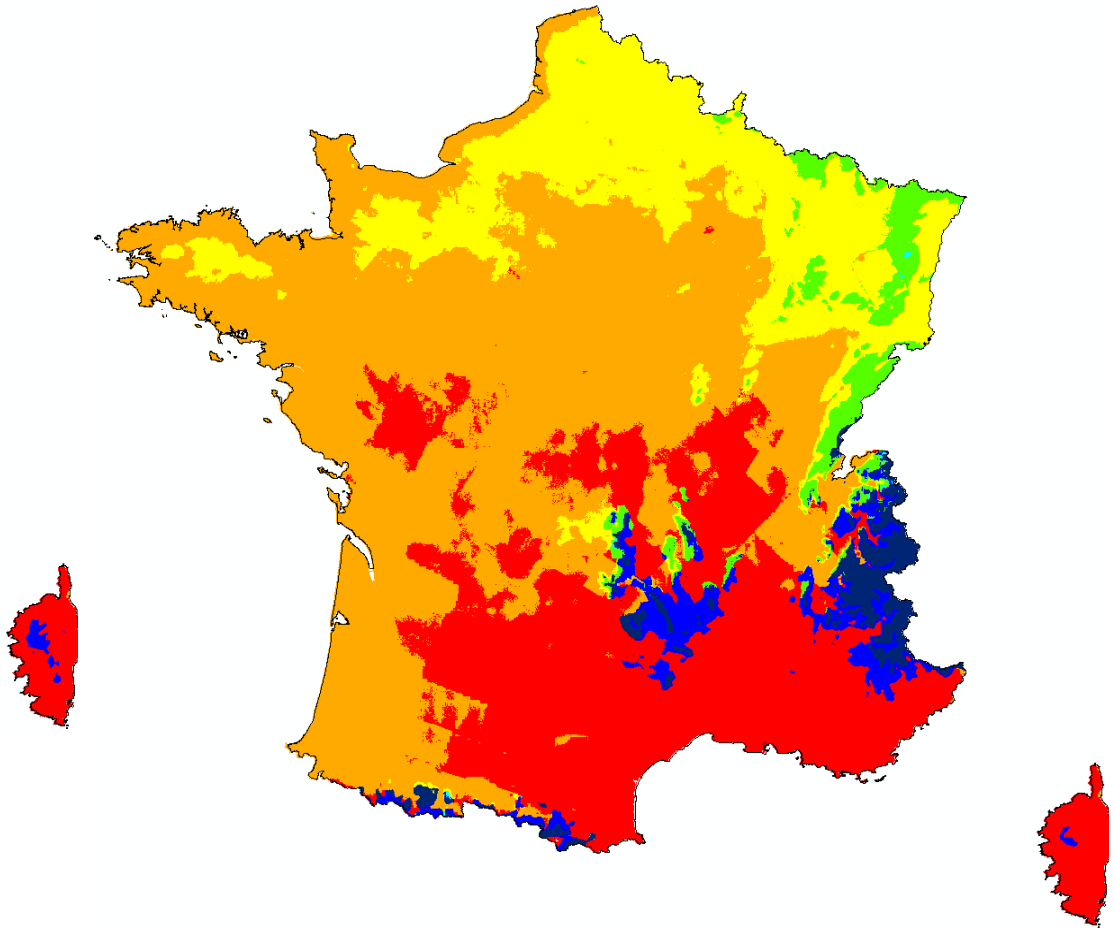
Changes in the areas suitable for Spruce bud burst



Climate 1980



Climate 2100



groupe Alpin

groupe Sub alpin

groupe Sapin

groupe Chênes

groupe Chataîgnier

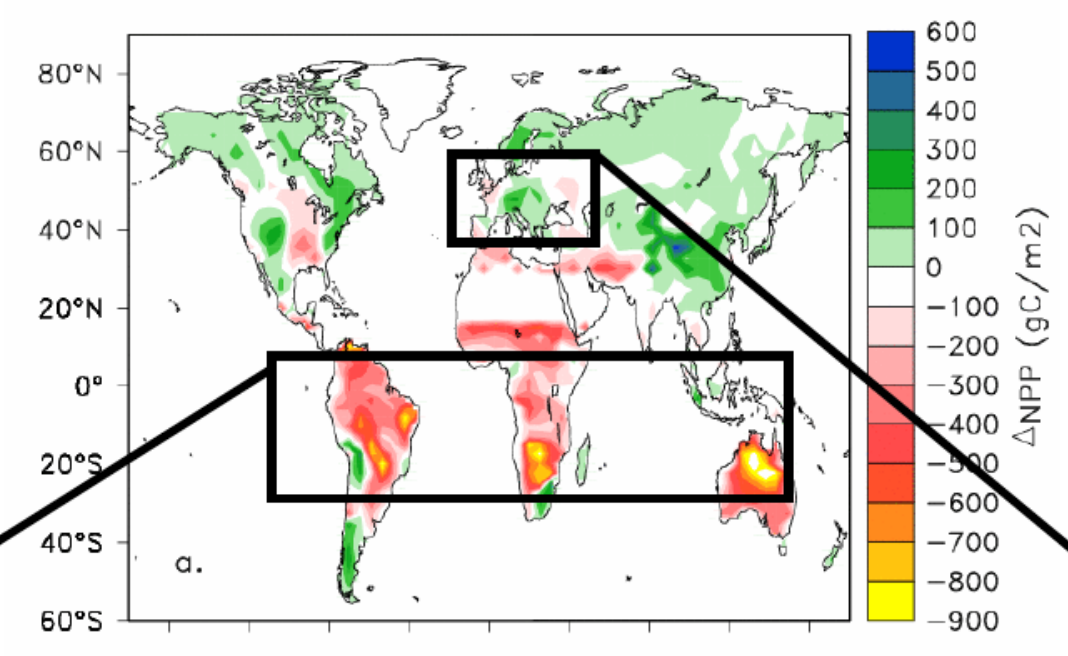
groupe Pin maritime

groupe Chêne vert

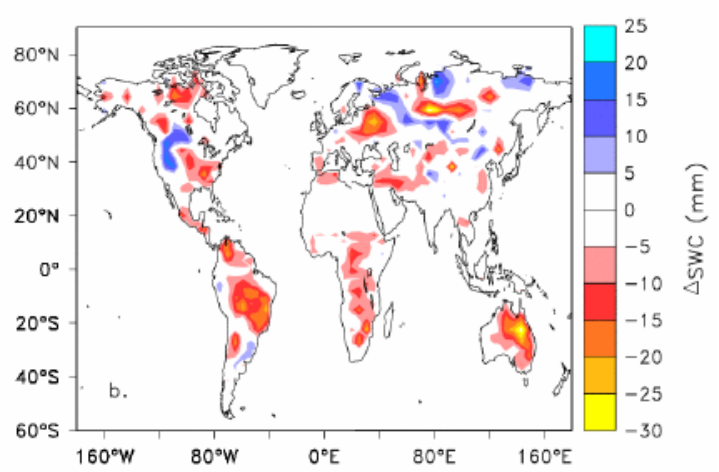
In 2100

- Strong Limitation of Oak expansion, and all alpine plants
- eastward and northward expansion of Atlantic vegetation types
- expansion of the mediterranean vegetation types

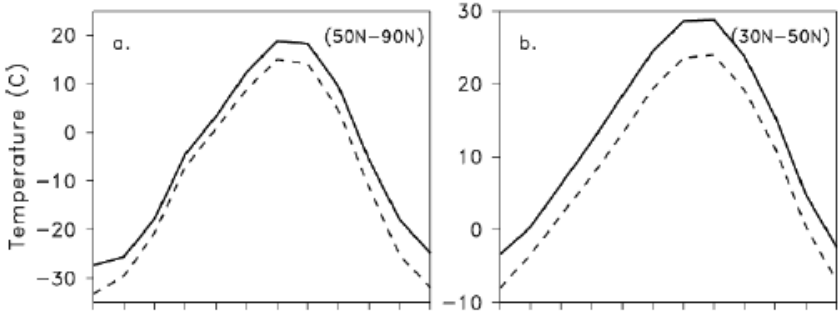
Coupled Climate-Carbon Models tend to predict an increase in carbon storage in Temperate Forests



Tropical soil drying



Longer growing seasons



Berthelot et al., GBC 2002

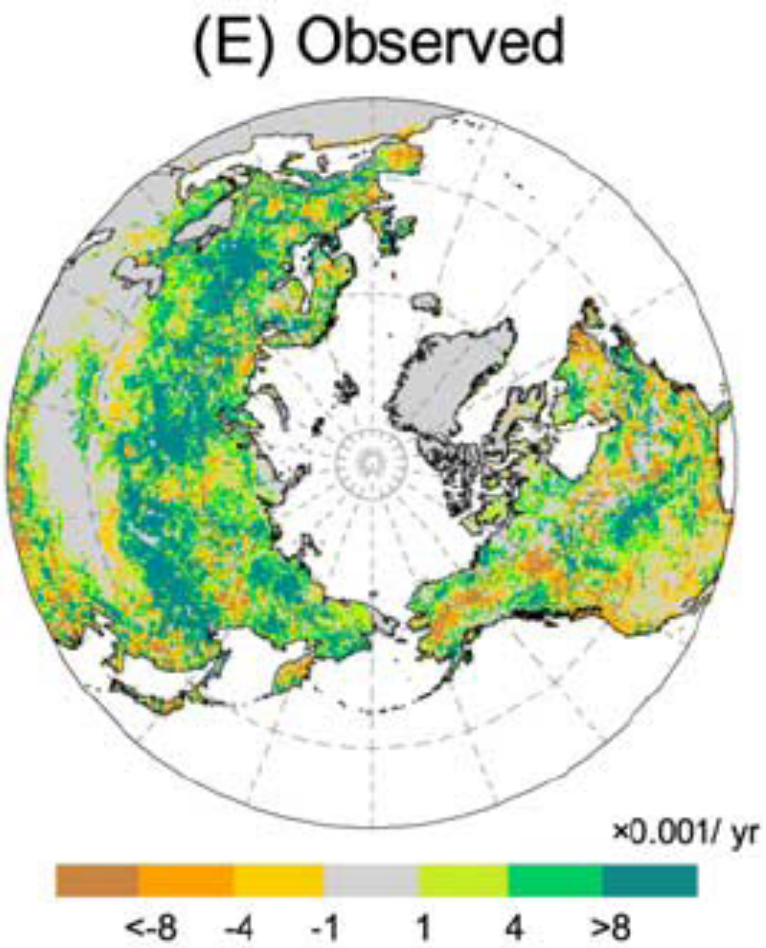
Cox et al., Nature 2000

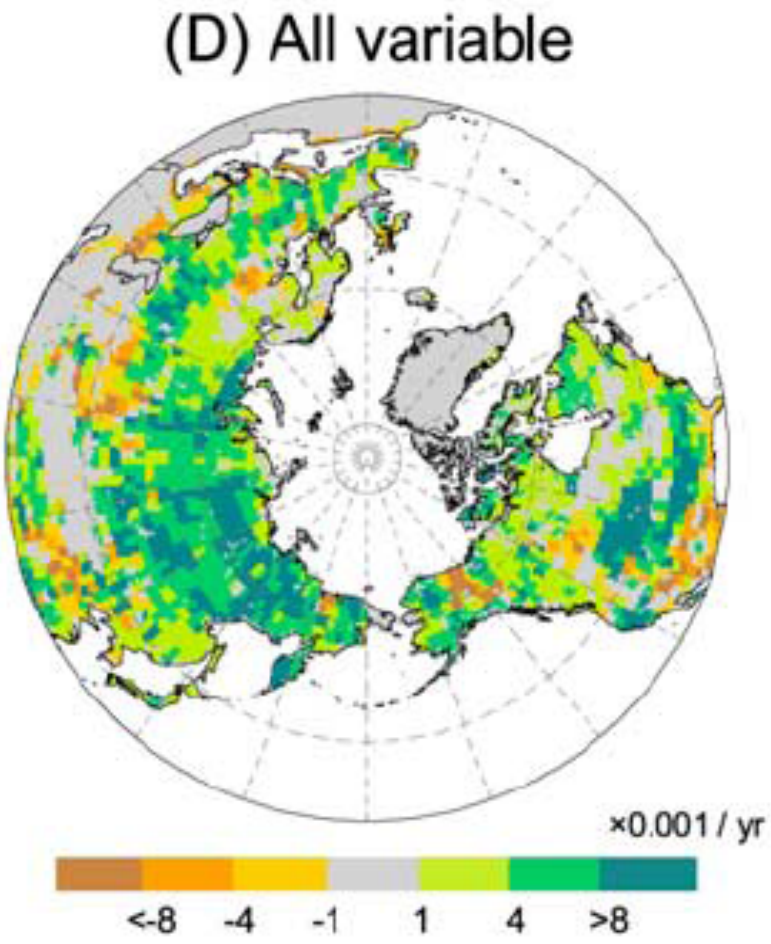
What are Biosphere Models used for ?

ATTRIBUTE

the historical changes in e.g. global runoff or crop productivity to climate changes or increased atmospheric CO2 or land-use changes.

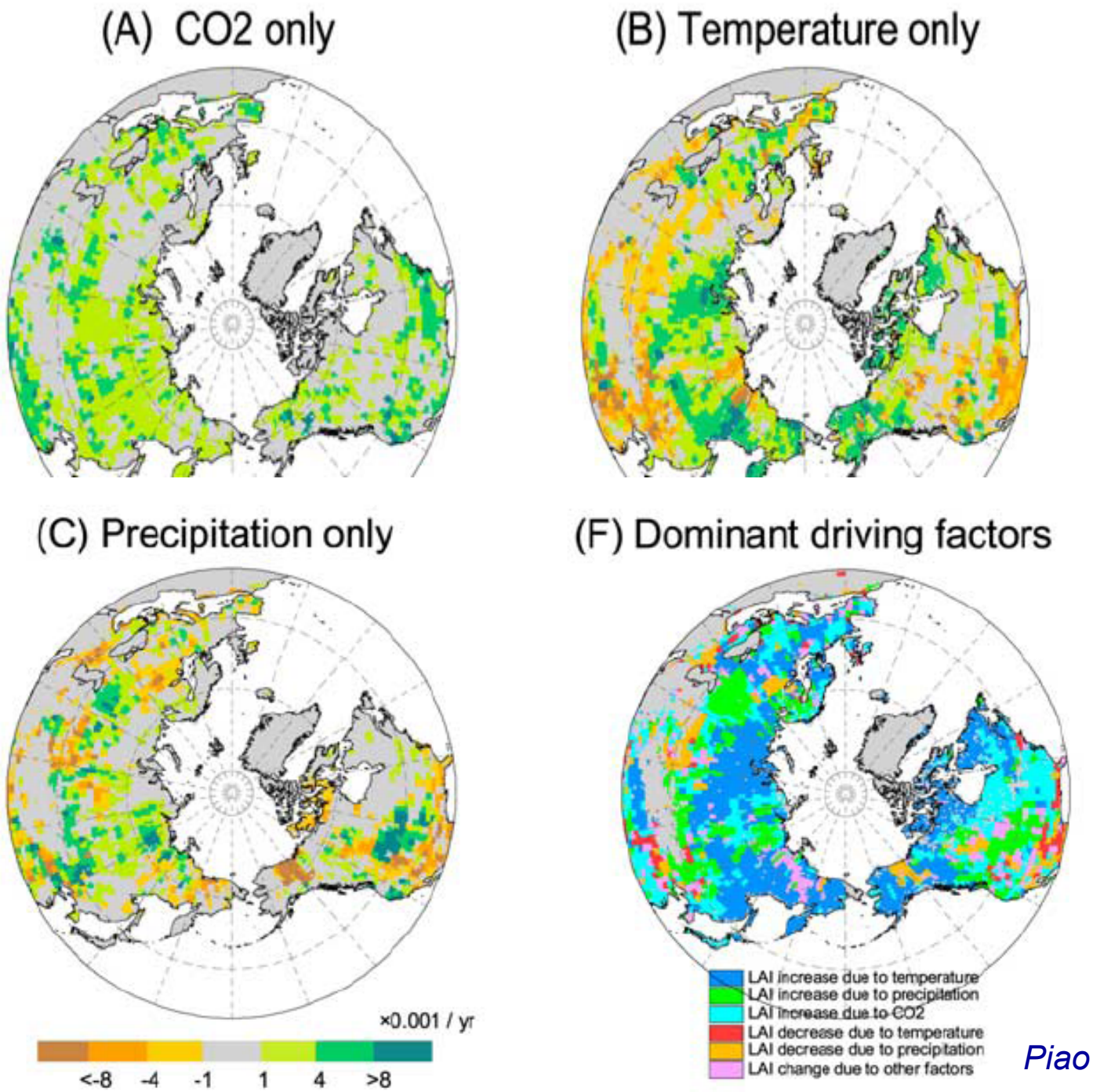
Trends in the growing season length (1980-2000)





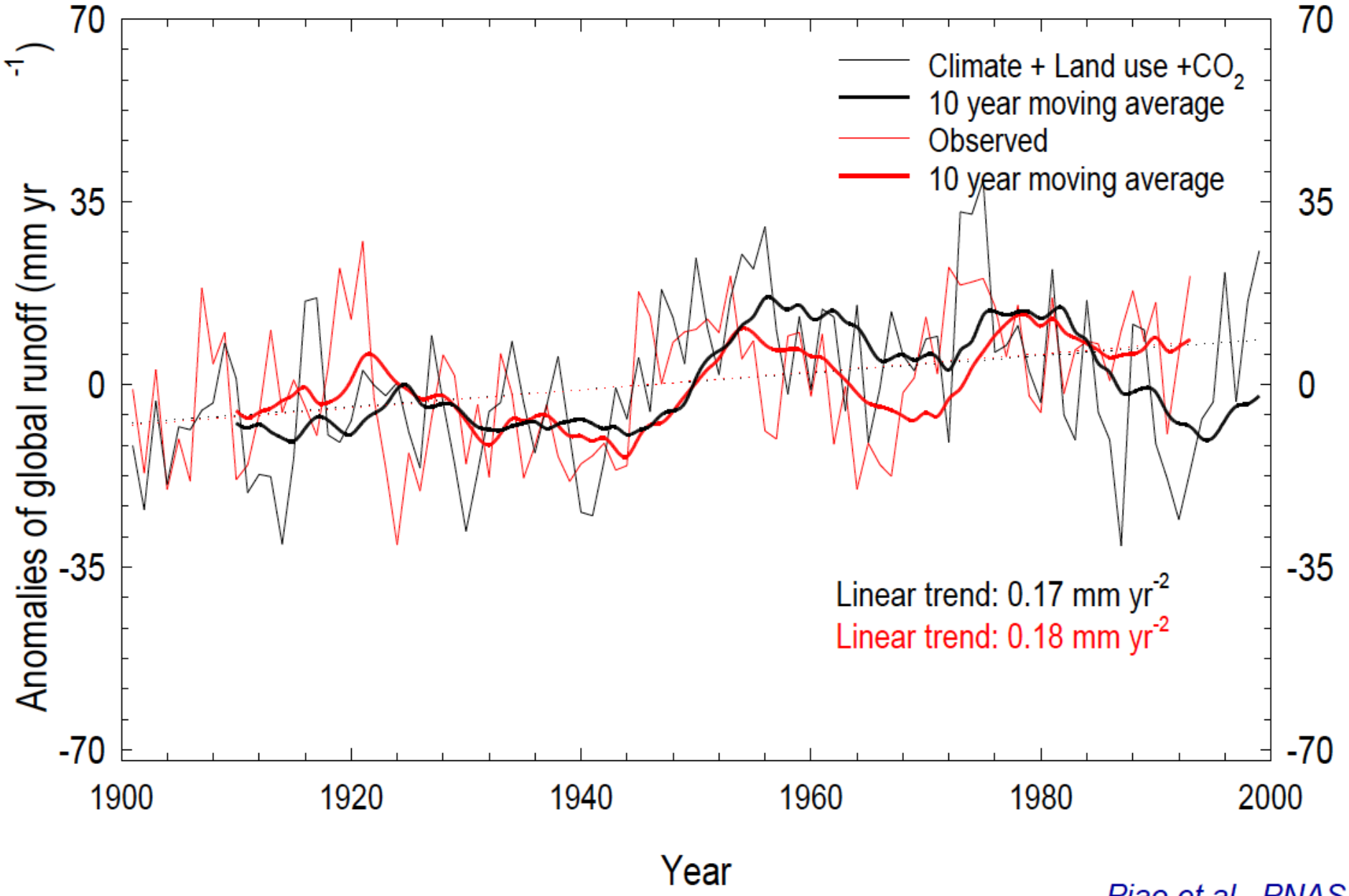
Piao et al., GRL 2006

attribution of trend in growing season length



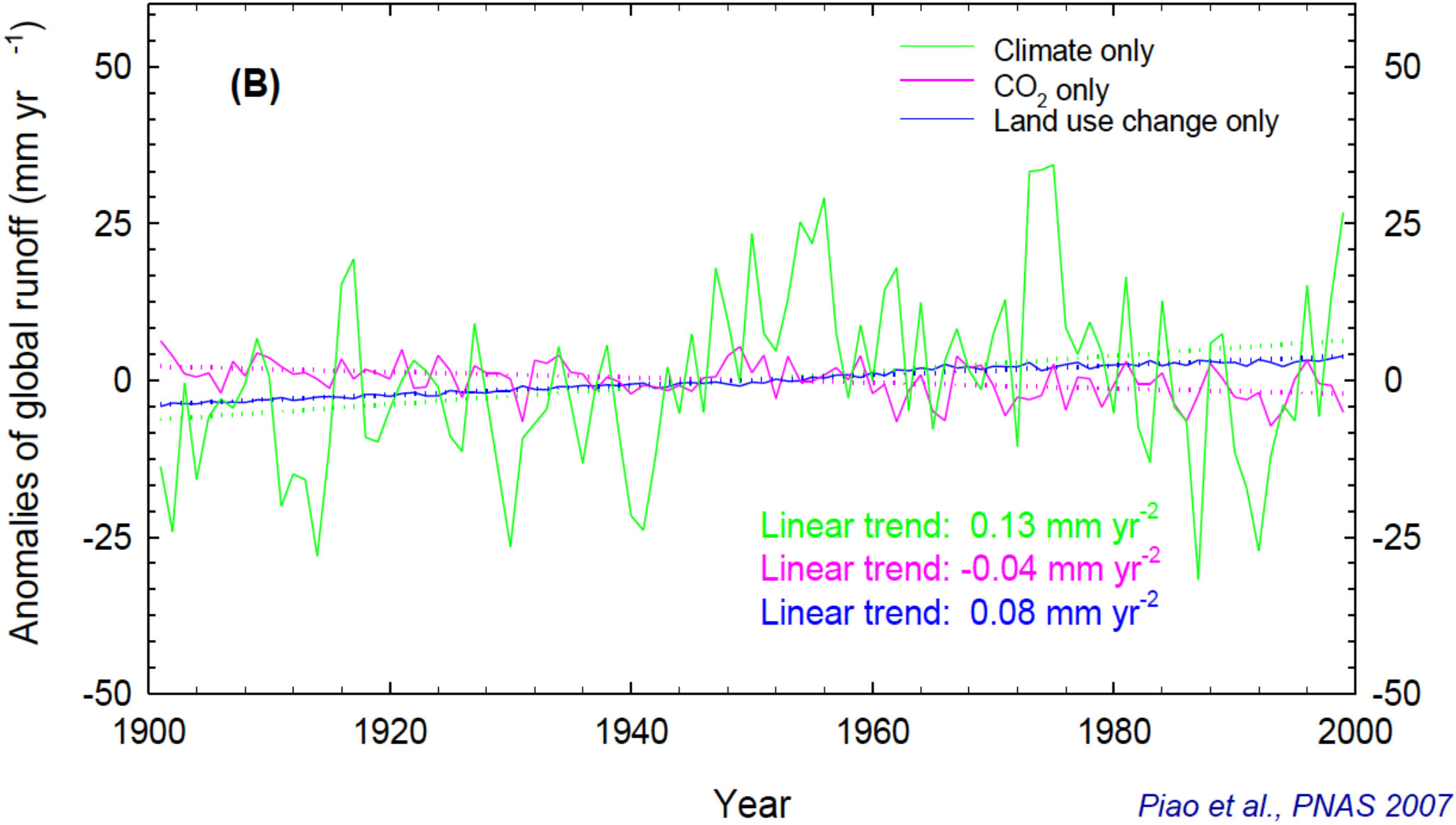
Piao et al., GRL 2006

Observed and simulated recent trend in global runoff: slow increase



Piao et al., PNAS 2007

Attribution of recent trend in global runoff to a) climate, b) Land-Use
CO2 change tends to reduce global runoff (opposite change)



Piao et al., PNAS 2007

What are the Biosphere Models used for ?

IMPROVE (?)

the global or regional climate simulations including more realistic feedbacks in the system

ACCOUNT for more FEEDBACKS

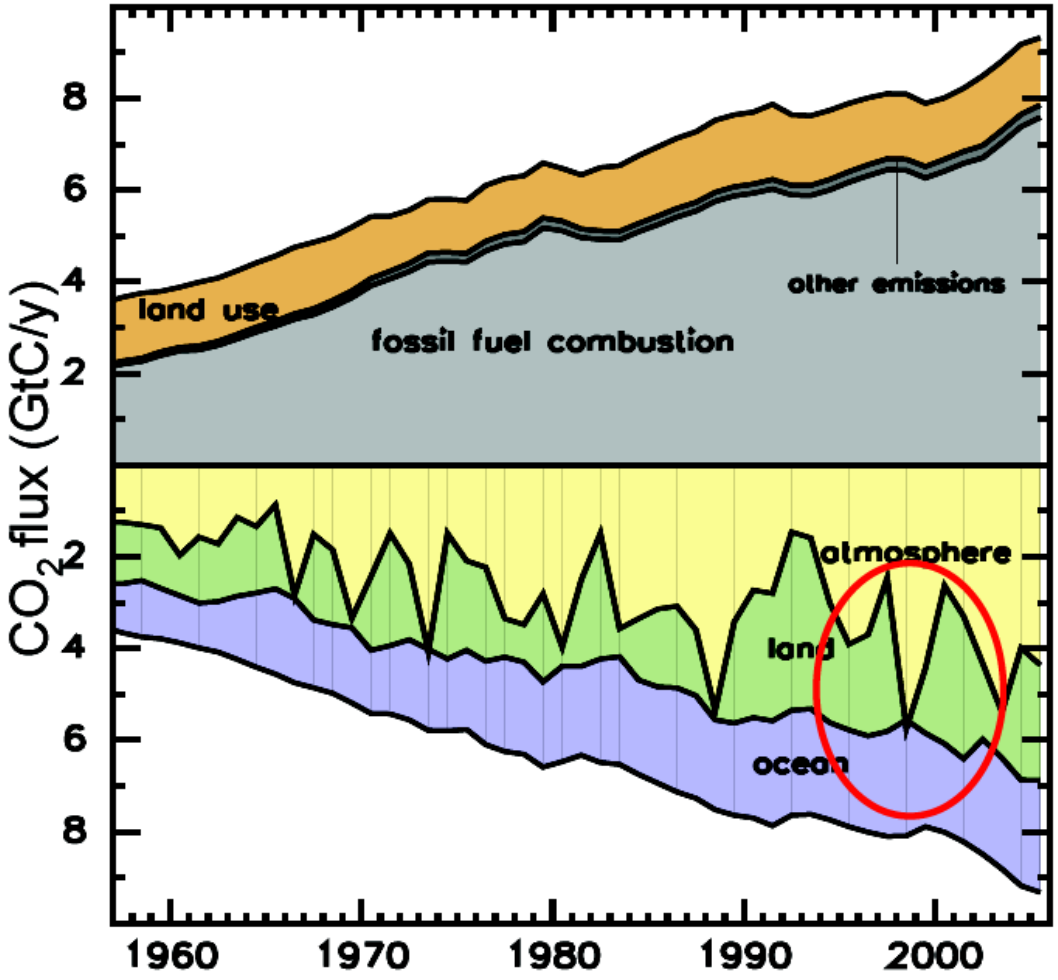
in climate scenarios of past and future climate changes

==> more realistic representation of climate changes

Future Climate Change: the role of the carbon cycle

Friedlingstein et al. (2006)

Carbon Budget



Emissions (fossil fuel, cement)	7.2 ±0.3 GtC/yr	100%
Atmospheric Increase	4.1 ± 0.1 GtC/yr	57%
Ocean-atmosphere flux	-2.2 ± 0.5 GtC/yr	30%
Land-atmosphere flux	-0.9 ± 0.6 GtC/yr	13%

Le Quéré and GCP

1997/98 El Niño

for 2000-2005 (IPCC, AR4)

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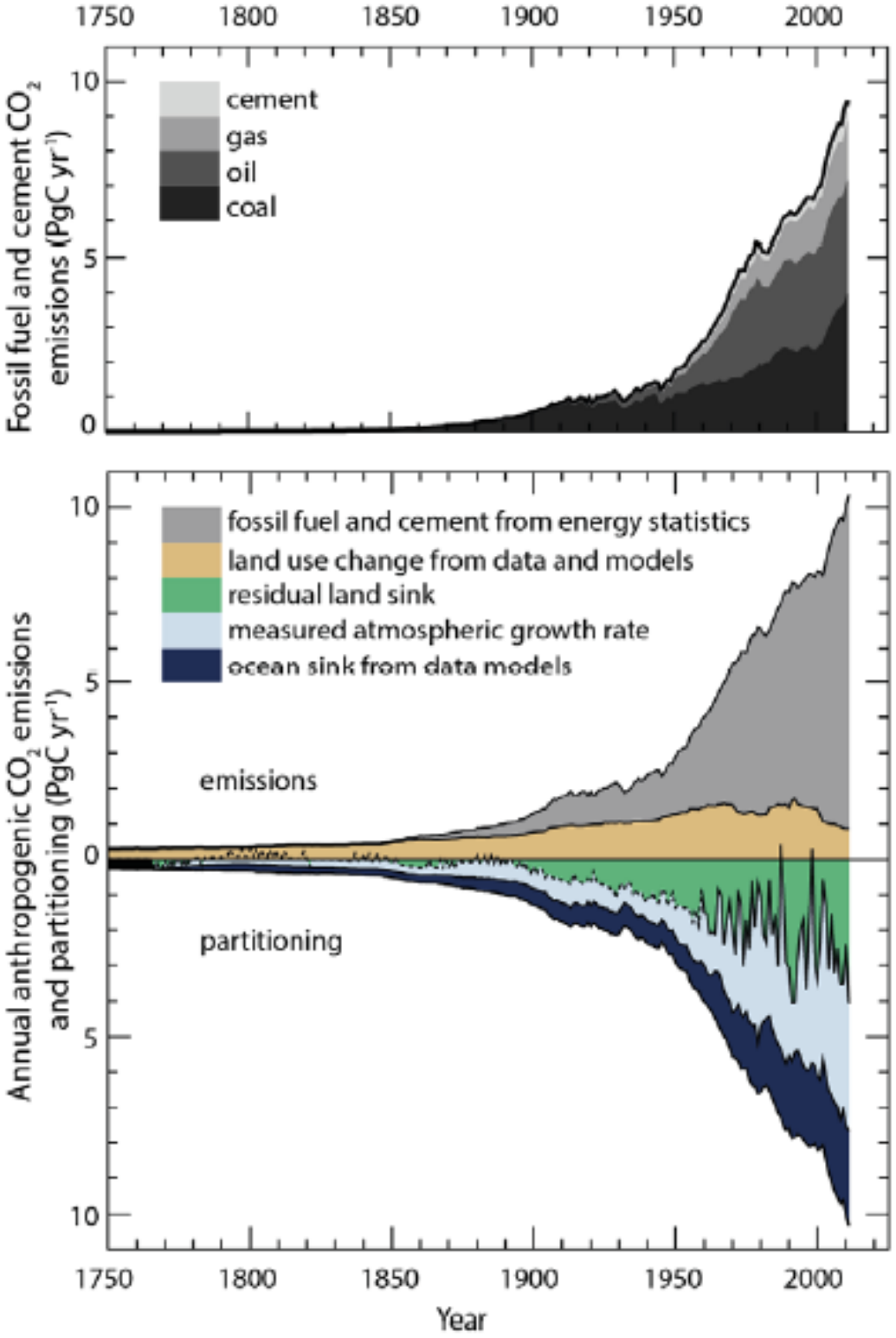
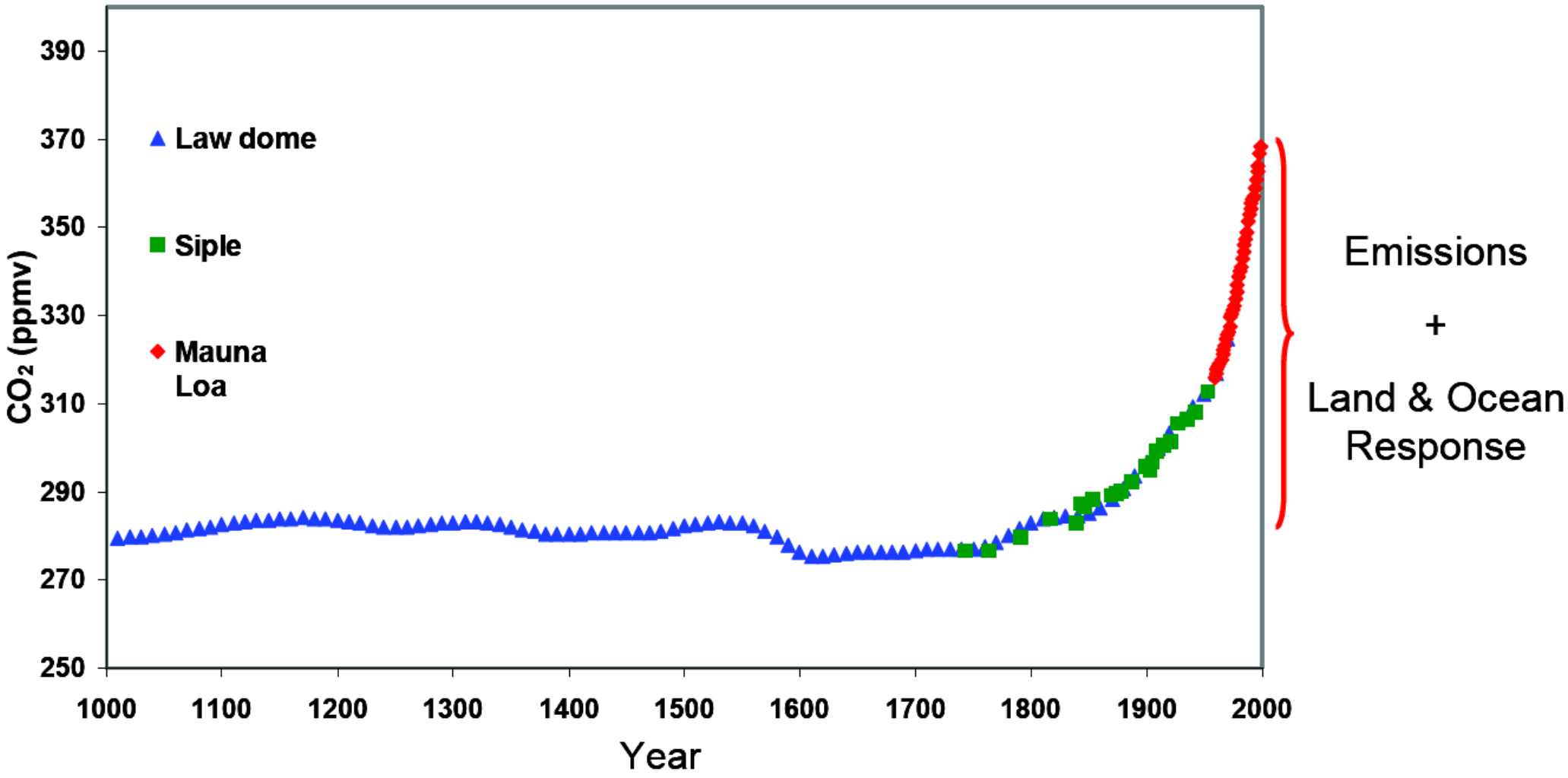

1750
1800
1850
1900
1950
2000
Fossil fuel and cement CO_2 emissions (PgC yr^{-1})
10
5
0
cement
gas
oil
coal
Annual anthropogenic CO_2 emissions and partitioning (PgC yr^{-1})
fossil fuel and cement from energy statistics
land use change from data and models
residual land sink
measured atmospheric growth rate
ocean sink from data models
emissions
partitioning
10
5
0
5
10
Year

Atmospheric CO_2 record



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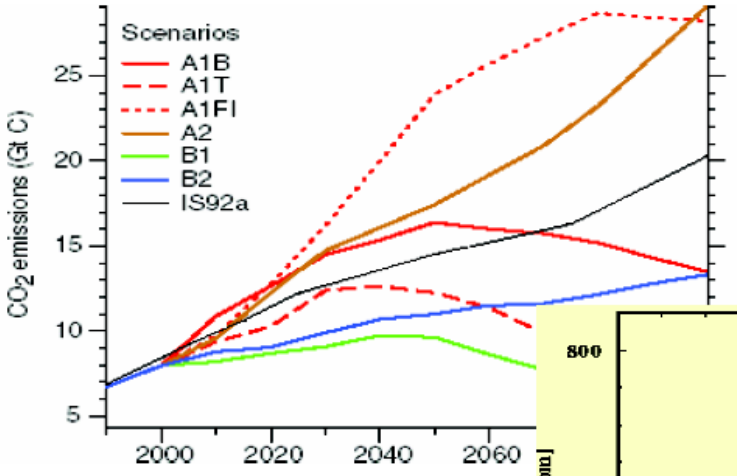
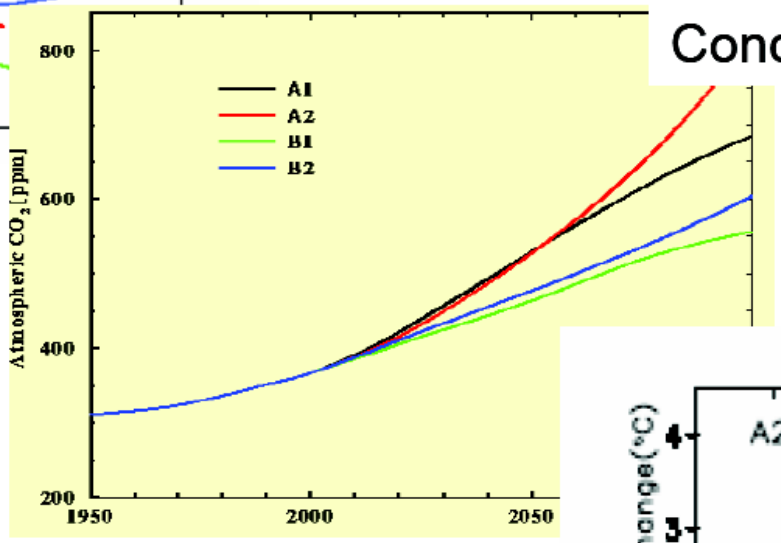
« Classical » climate simulations



Emissions

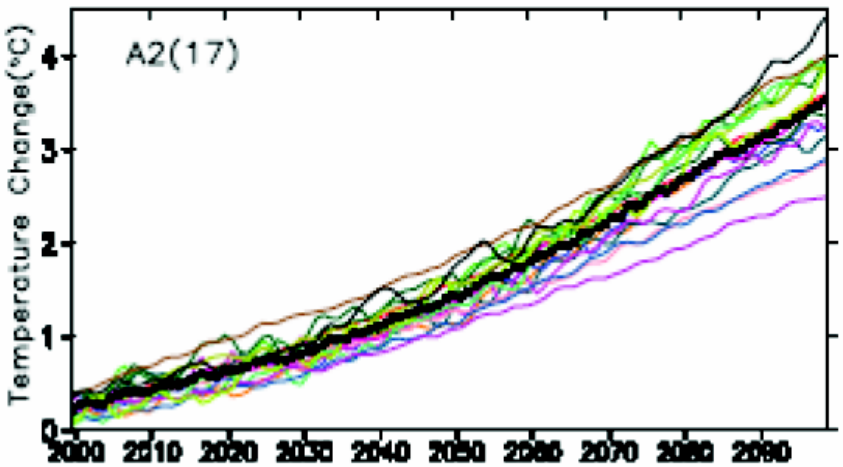
(Simple models)

Concentrations



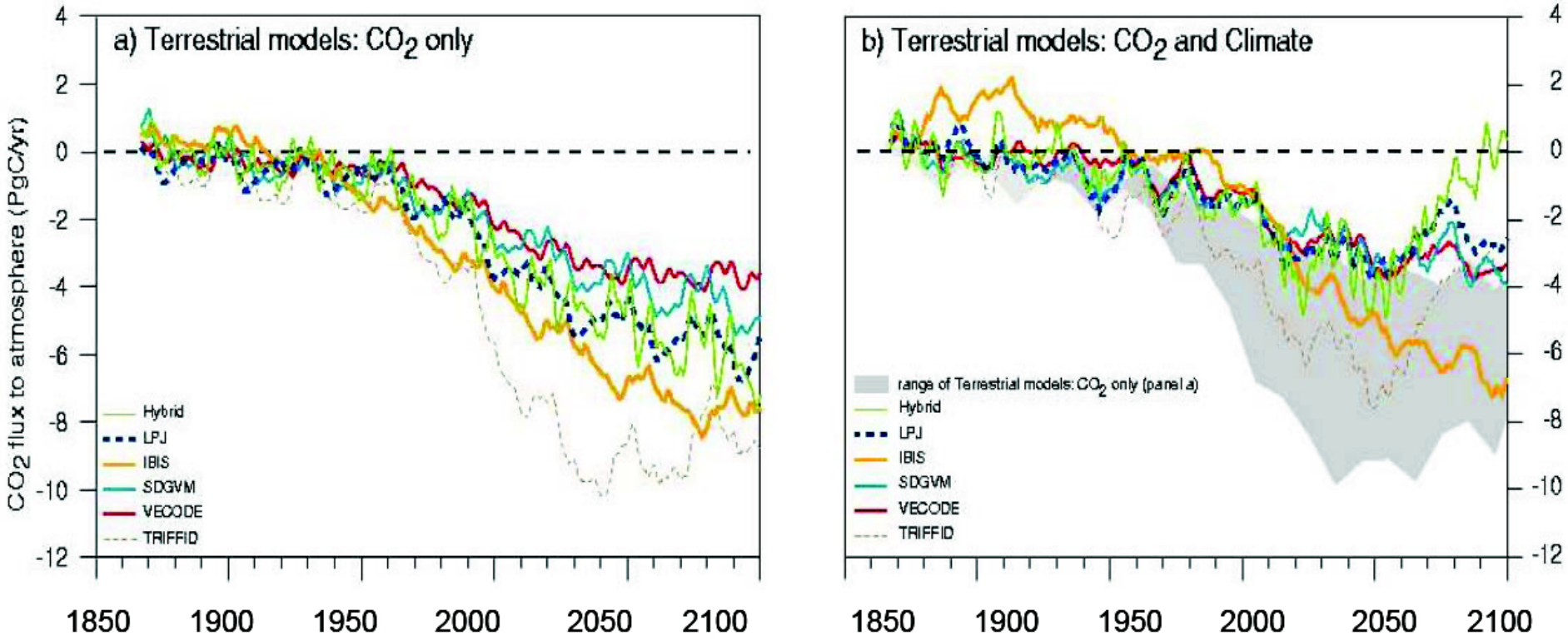
(GCMs)

Climate



IPCC, 2007

Ecosystem Response to Environmental Change



Cramer et al., 2001; Prentice et al., TAR 2001

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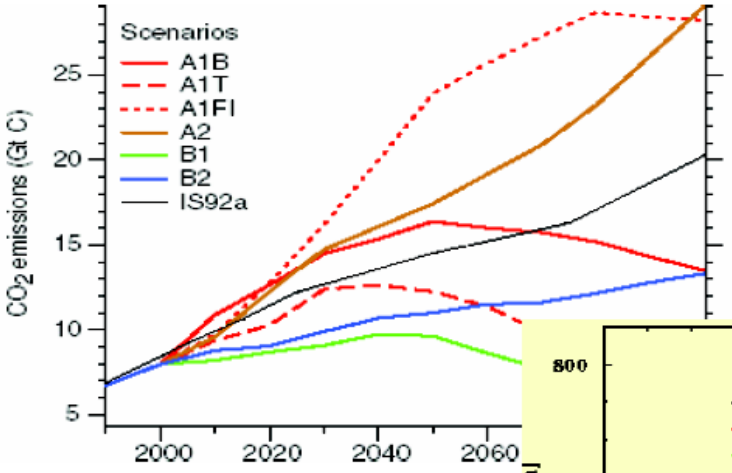
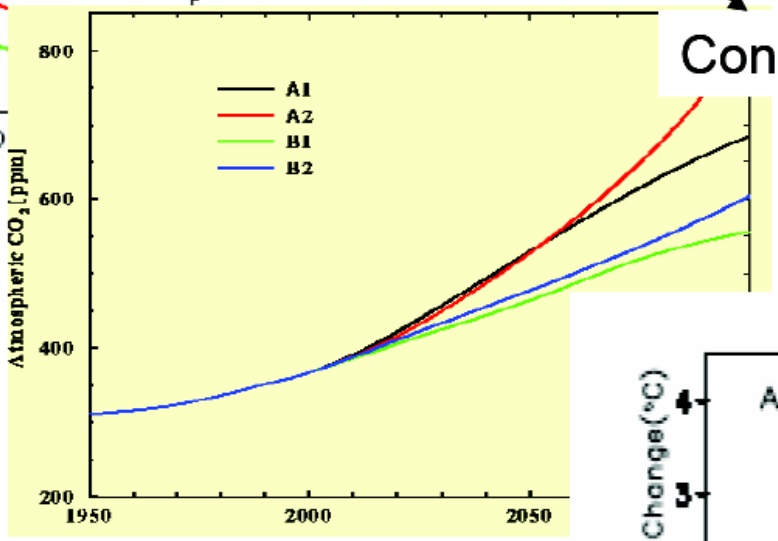
Climate-Carbon Coupling (2000-2100)



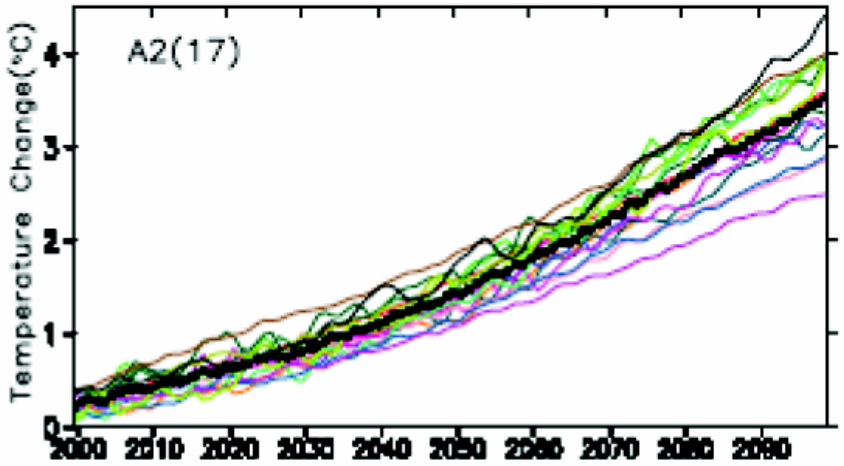
Emissions

Carbon Sinks



Concentrations

Climate



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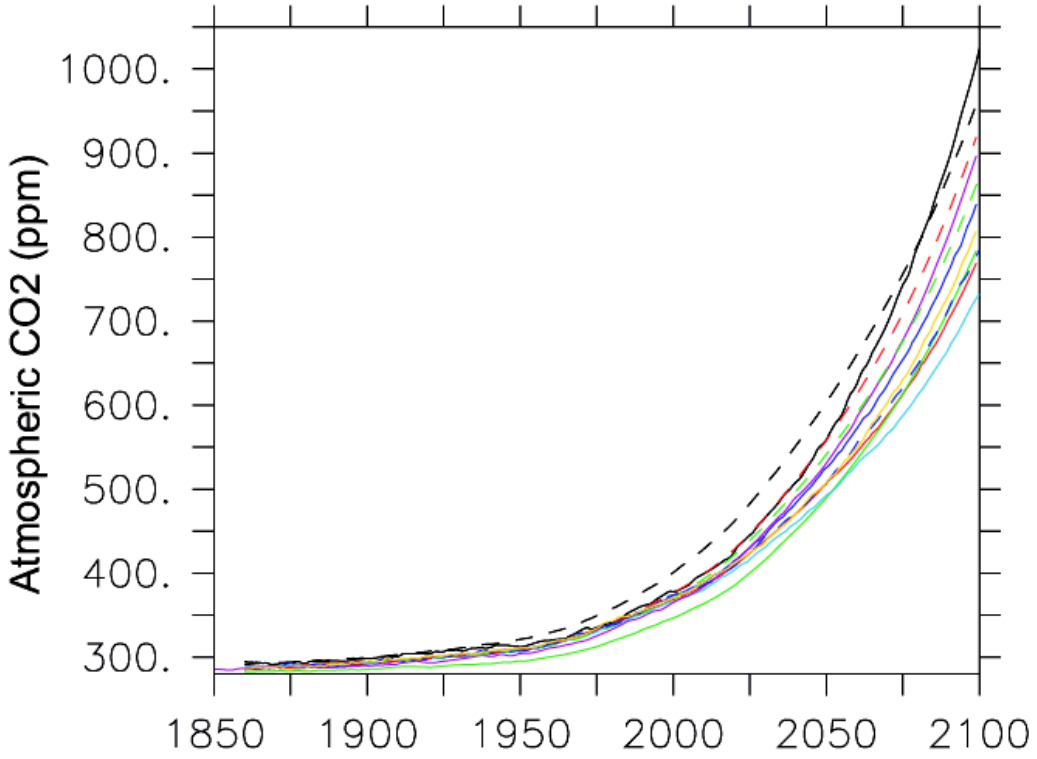
IPCC, 2007

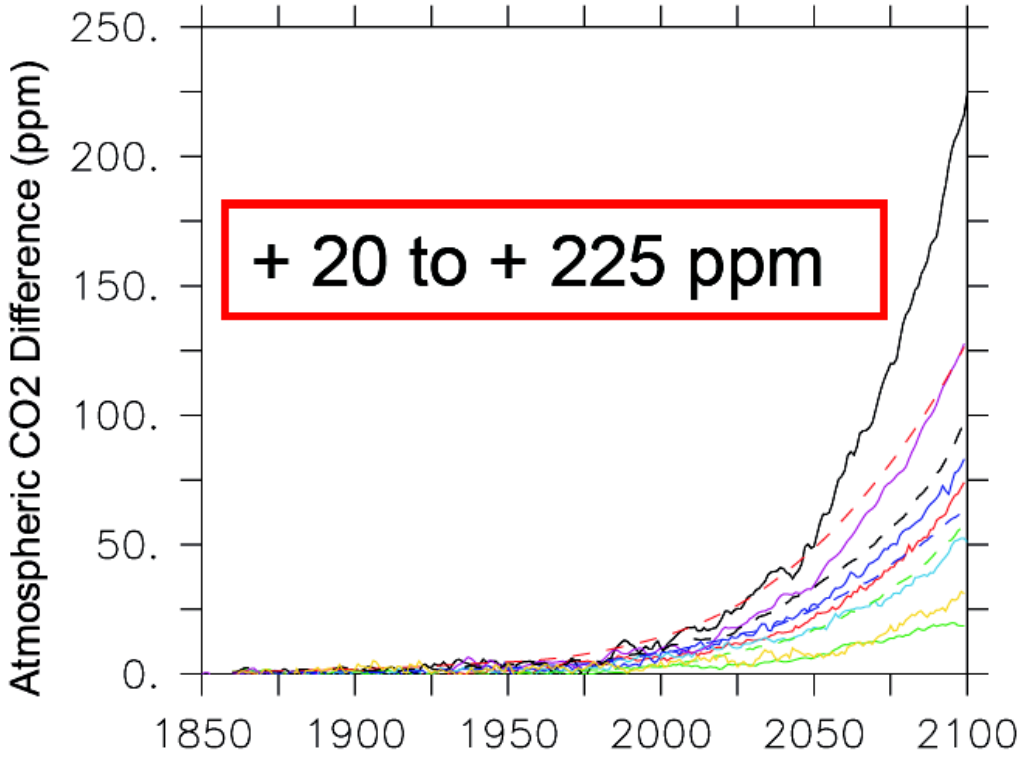
Met Office

Climate-Carbon Coupling

- C4MIP : Coupled Carbon Cycle – Climate Models InterComparison

  - 11 coupled climate-carbon models (7 GCMs + 4 EMICs)
  - One emission scenario (SRES A2) from 1860 to 2100
  - 2 simulations: coupled and un-coupled

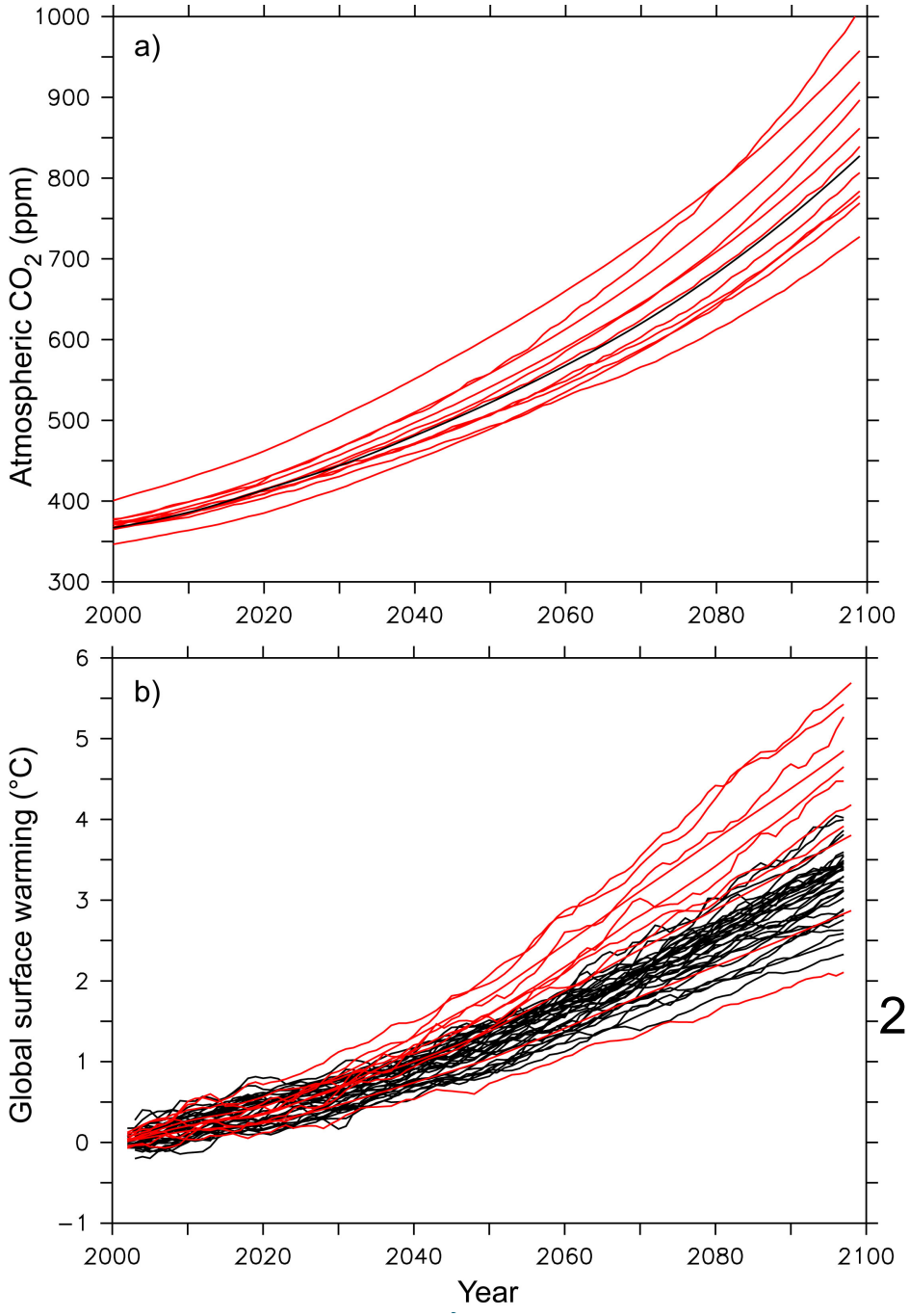




Friedlingstein *et al.*, 2006

- Uncertainty due to the carbon cycle uncertainty

- Higher [CO2], larger climate change



830 ppm

730 – 1000 ppm

2.6 – 4.1 °C

2.4 – 5.6 °C

IPCC, 2007