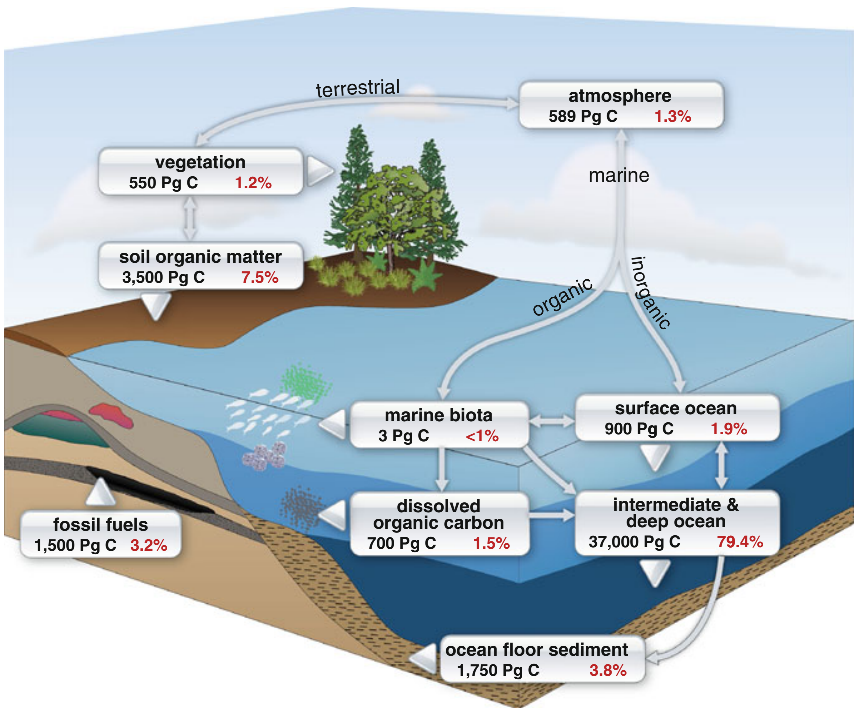
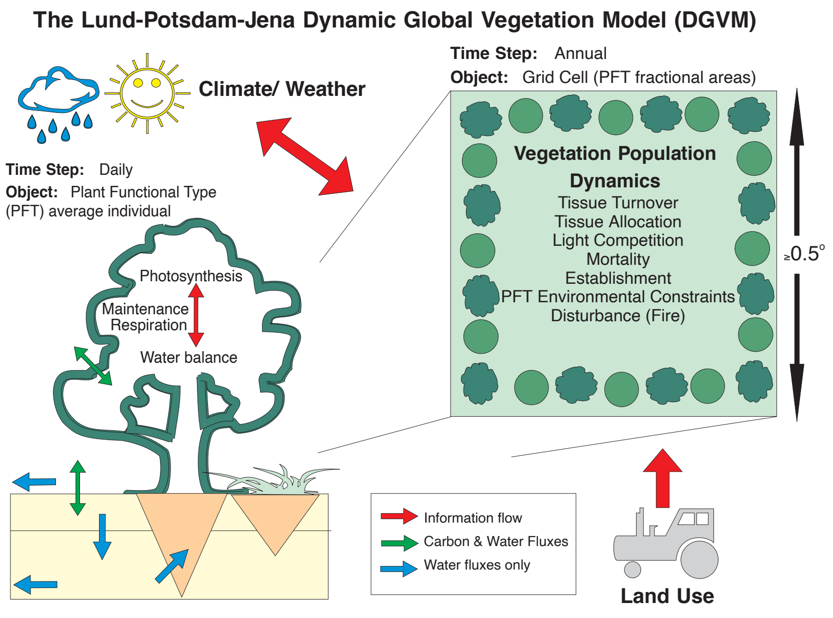
Gerrit Lohmann
MES, 22.06.2023

Earth system models including tracers and dynamical vegetation



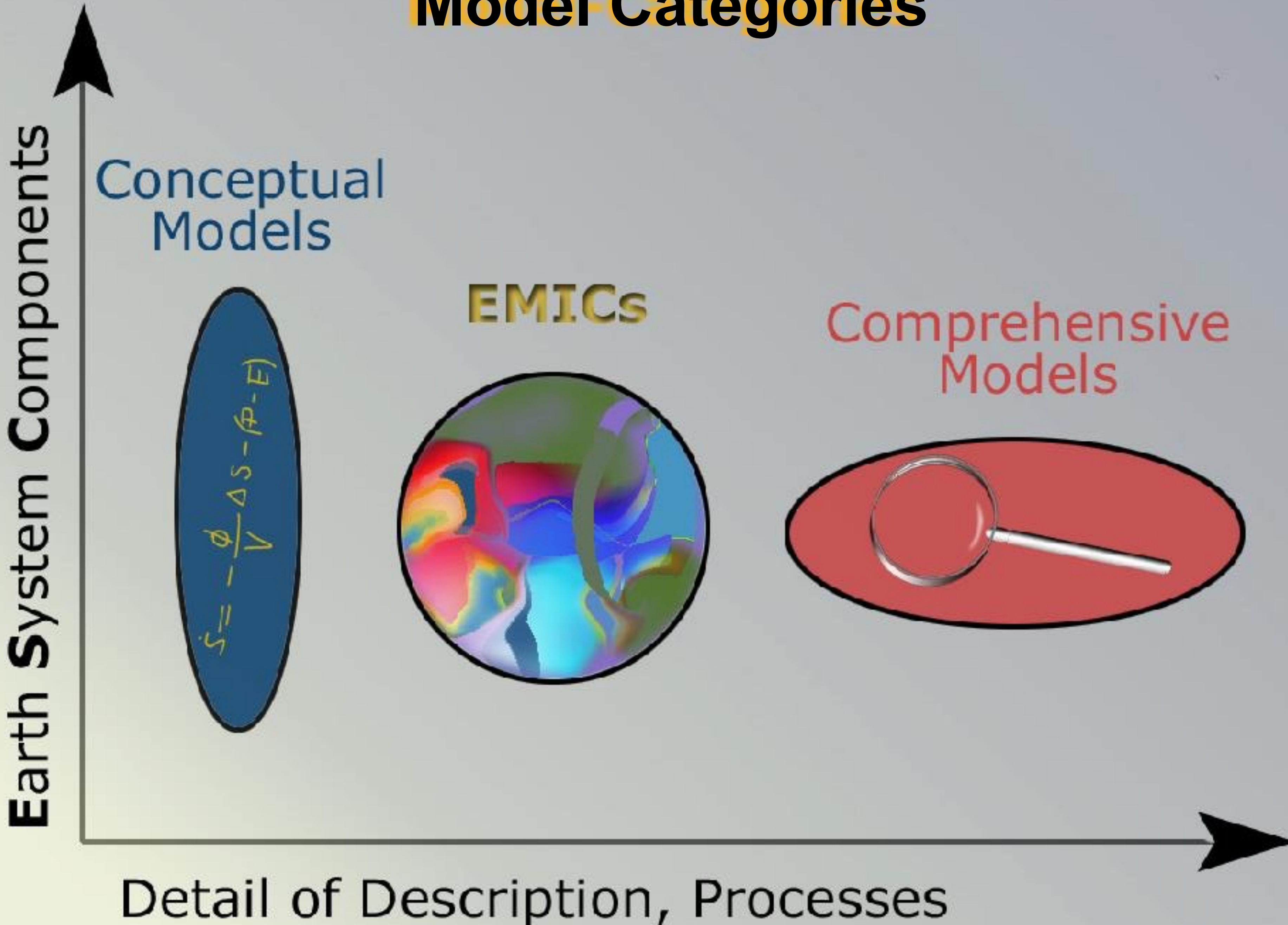


Gerrit Lohmann
MES, 22.6.2023

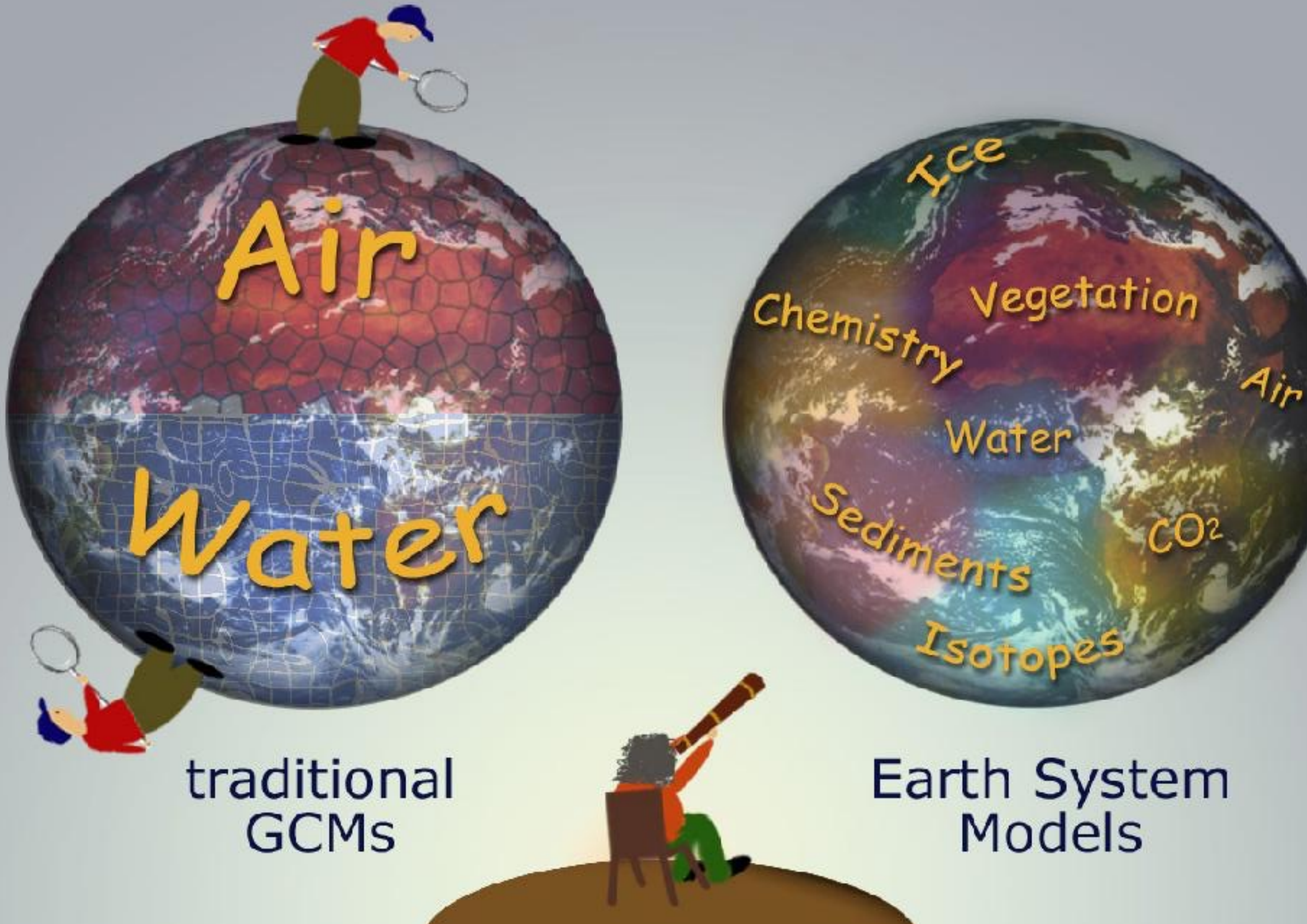
Todays lecture

- Earth System Models
- Vegetation & Ecosystem models
- Practicals: Daisy World, vegetation dynamics
- Tracers in the Sea (Carbon, Radiocarbon)

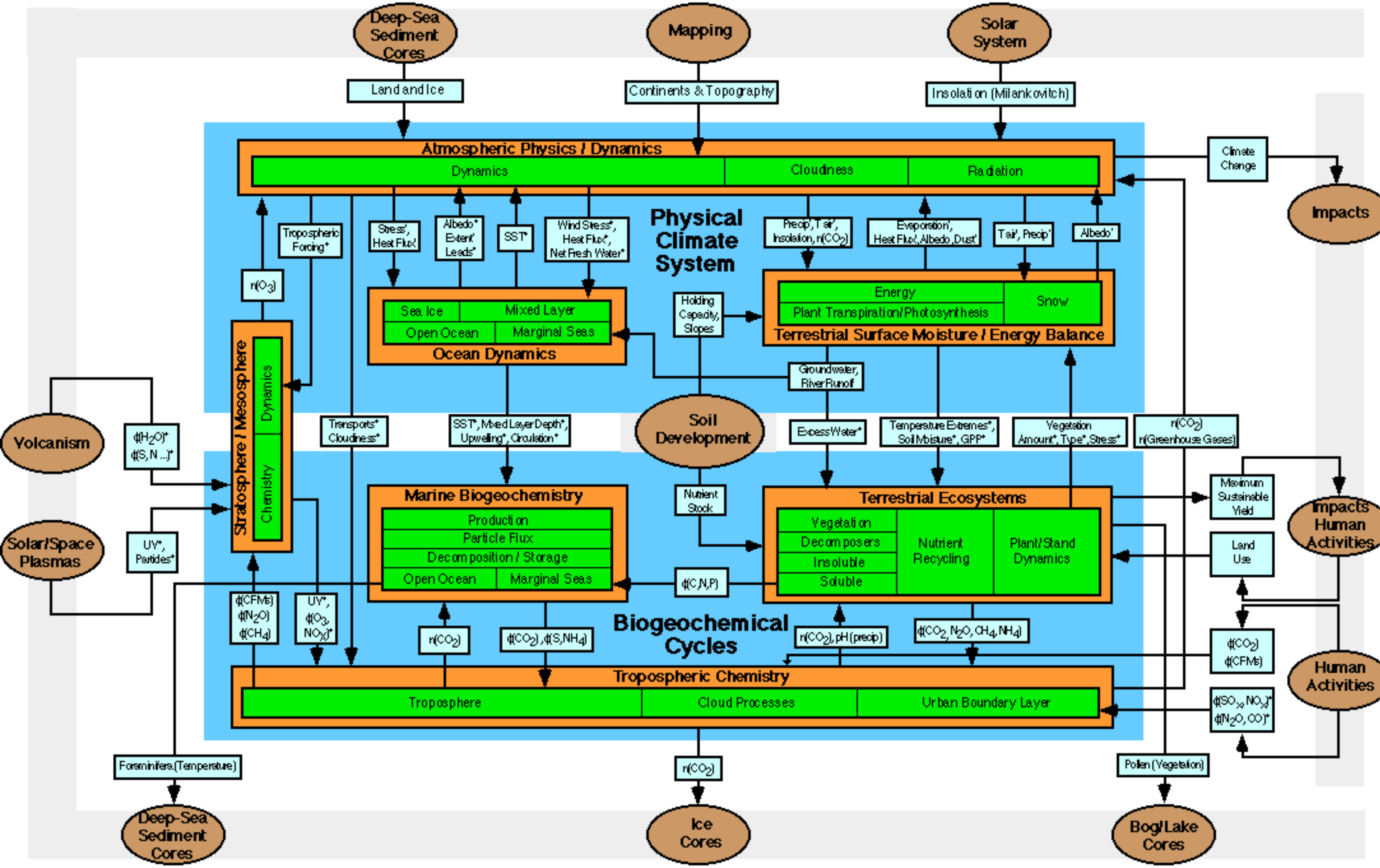
Model Categories



Different Point of View

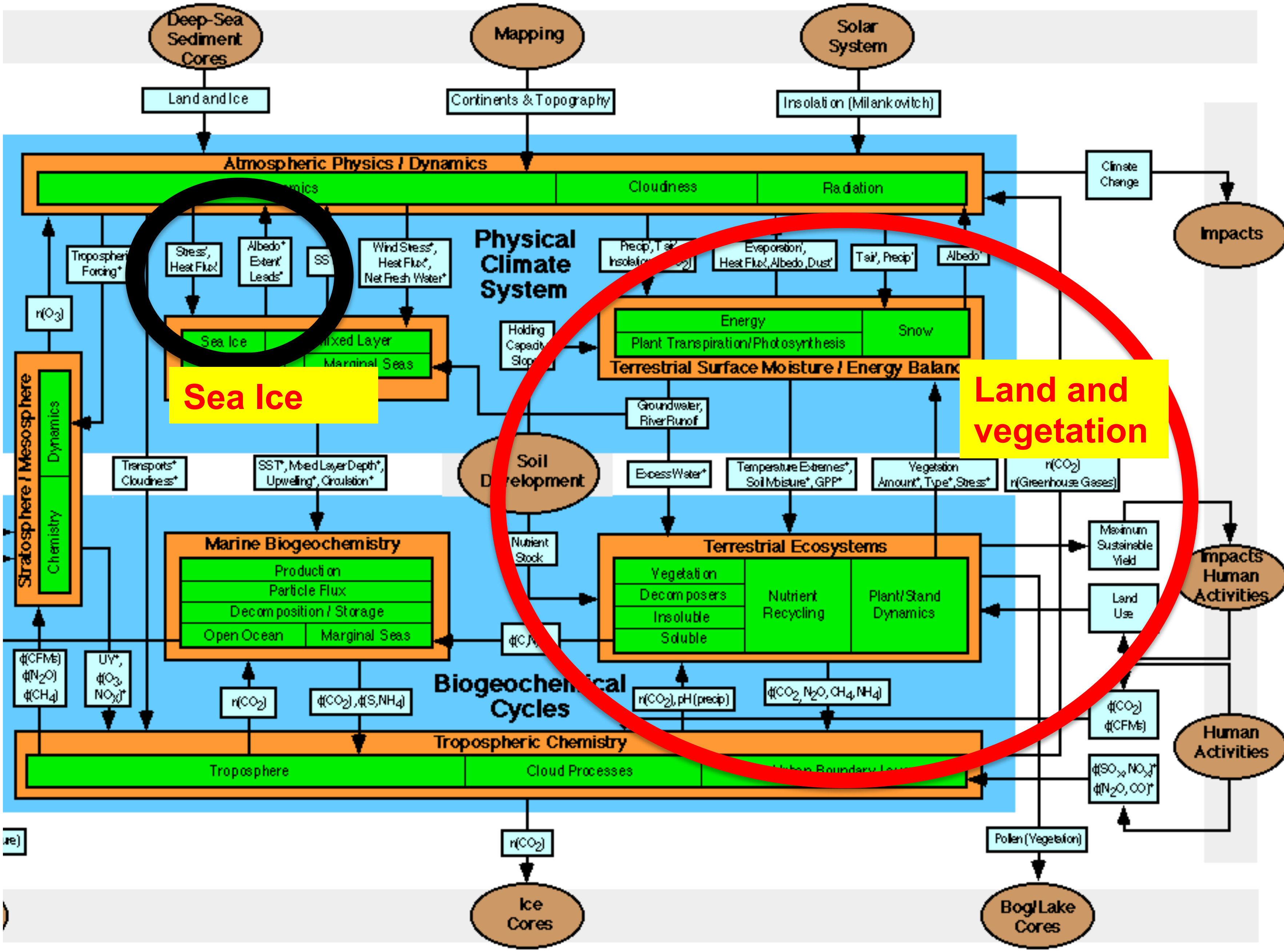


CONCEPTUAL MODEL of Earth System process operating on timescales of decades to centuries

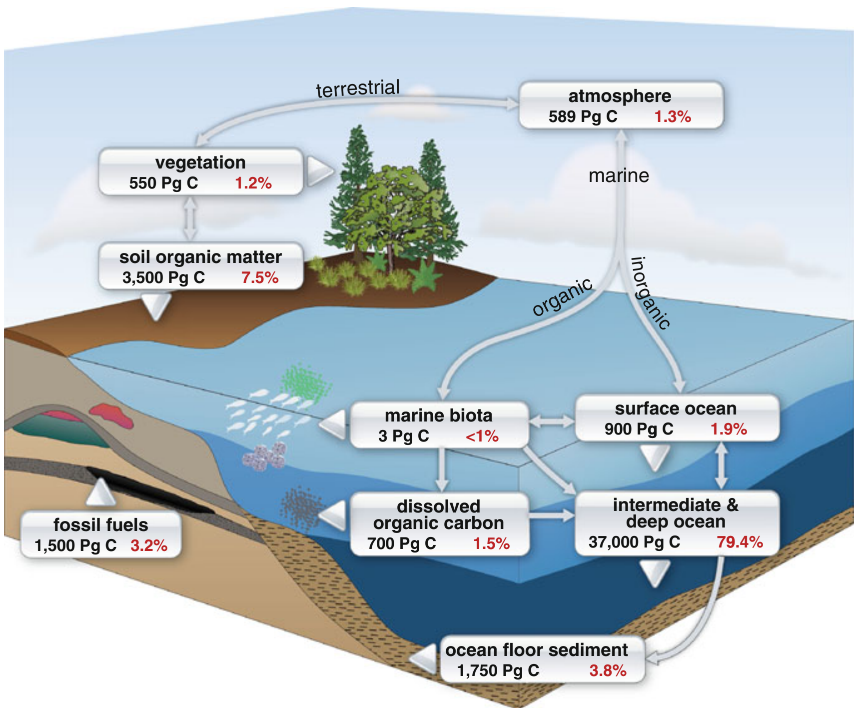


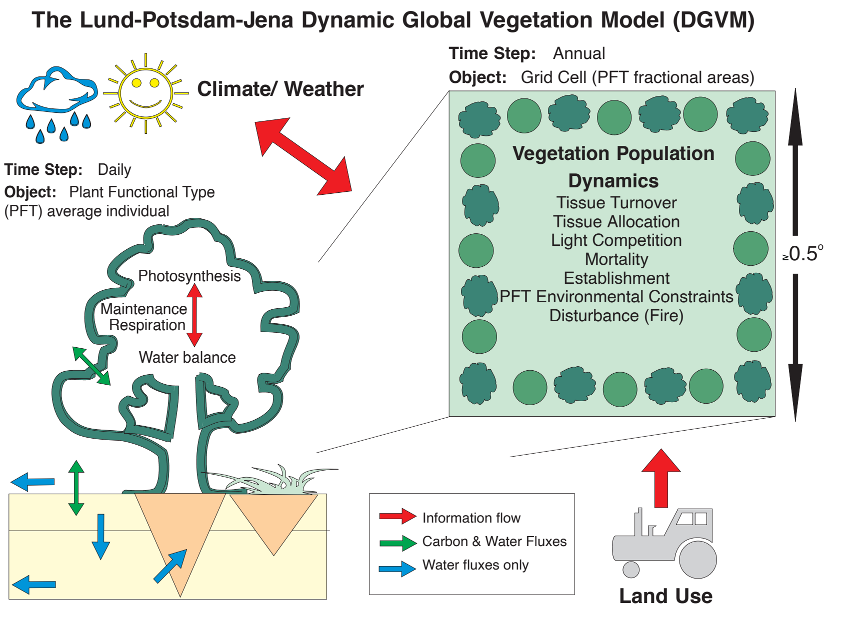
' = on timescale of hours to days   * = on timescale of months to seasons   φ = flux   n = concentration

Bretherton

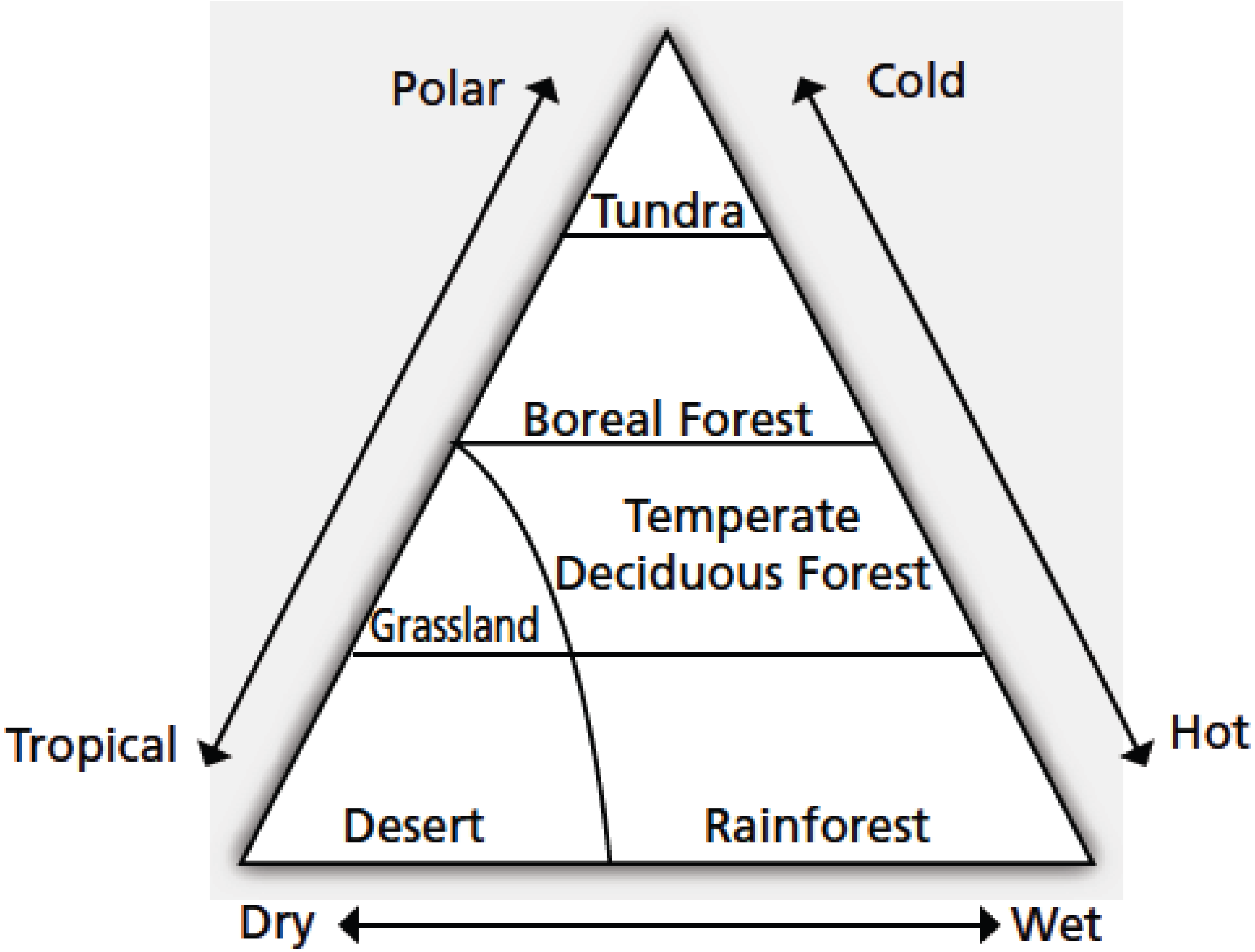

Deep-Sea Sediment Cores
Mapping
Solar System
Land and Ice
Continents & Topography
Insolation (Milankovitch)
Atmospheric Physics / Dynamics
Cloudiness
Radiation
Climate Change
Impacts
Tropospheric Forcing*
Stress', Heat Flux'
Albedo* Extent' Leads*
Wind Stress*, Heat Flux*, Net Fresh Water*
Physical Climate System
Evaporation', Heat Flux', Albedo, Dust'
Tair', Precip'
Albedo'
Sea Ice
Mixed Layer
Marginal Seas
Holding Capacity, Slope
Energy
Snow
Plant Transpiration/Photosynthesis
Terrestrial Surface Moisture / Energy Balance
Land and vegetation
Groundwater, River Runoff
Stratosphere / Mesosphere
Dynamics
Chemistry
Transports* Cloudiness*
SST*, Mixed Layer Depth*, Upwelling*, Circulation*
Soil Development
Excess Water*
Temperature Extremes*, Soil Moisture*, GPP*
Vegetation Amount*, Type*, Stress*
n(CO2) n(Greenhouse Gases)
Marine Biogeochemistry
Production
Particle Flux
Decomposition / Storage
Open Ocean
Marginal Seas
Nutrient Stock
Terrestrial Ecosystems
Vegetation
Decomposers
Insoluble
Soluble
Nutrient Recycling
Plant/Stand Dynamics
Maximum Sustainable Yield
Land Use
Impacts Human Activities
Biogeochemical Cycles
n(CO2)
n(CO2), pH (precip)
Tropospheric Chemistry
Troposphere
Cloud Processes
Human Activities
Pollen (Vegetation)
Ice Cores
Bog/Lake Cores

Earth system models
including tracers and dynamical vegetation





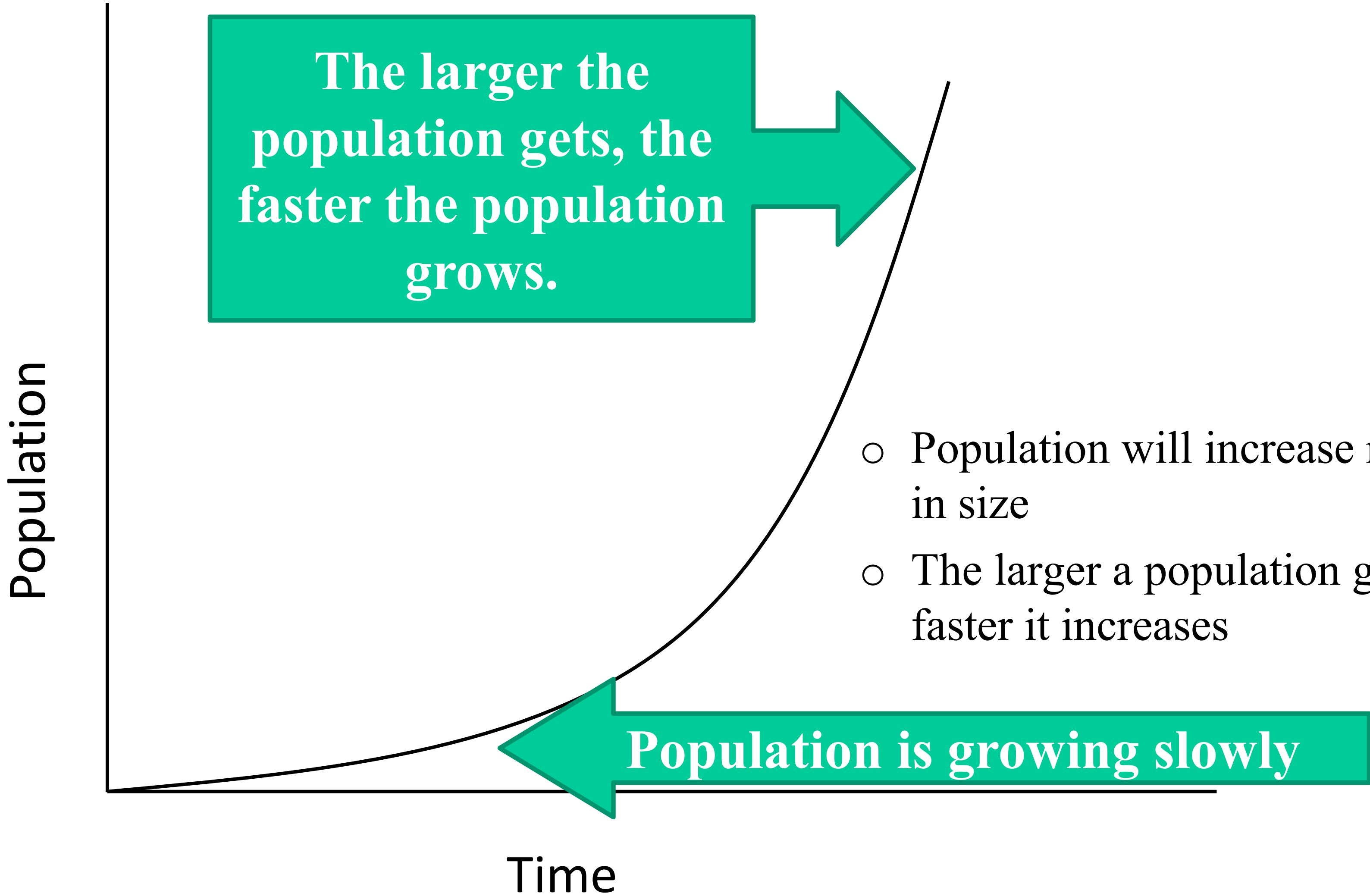
Vegetation & Ecosystem



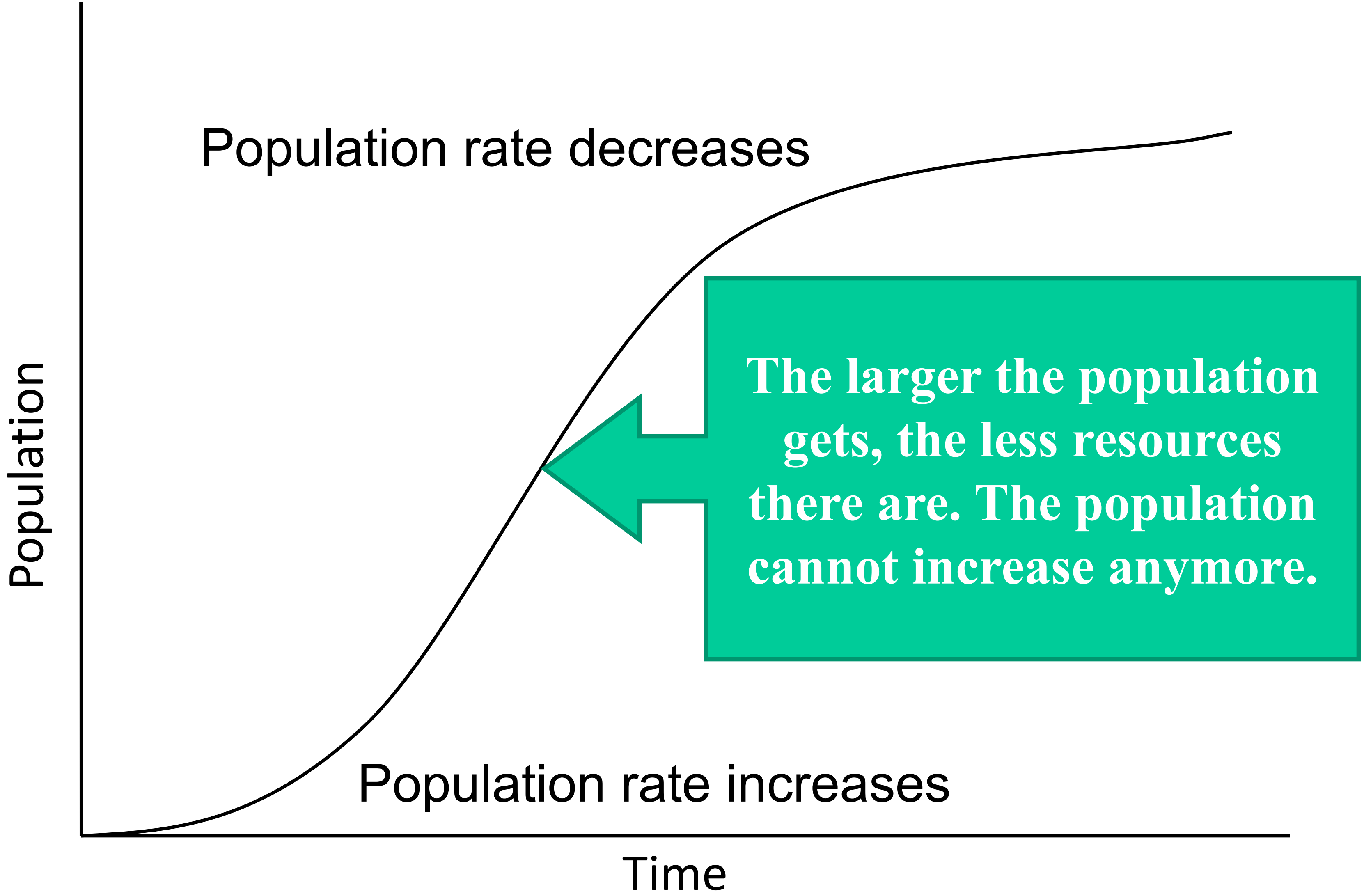
Human Impact

1. **Deforestation** – cutting down forests has reduced the amount of plants available for photosynthesis, which means that less CO_2 can be removed from the atmosphere.
2. **Burning (combustion) of fossil fuels** – gasoline, coal, and natural gas contain carbon and when burned, they release CO_2 into the Earth's lower atmosphere. There is concern that the increase in CO_2 will lead to global warming.

Population Growth (ideal conditions)



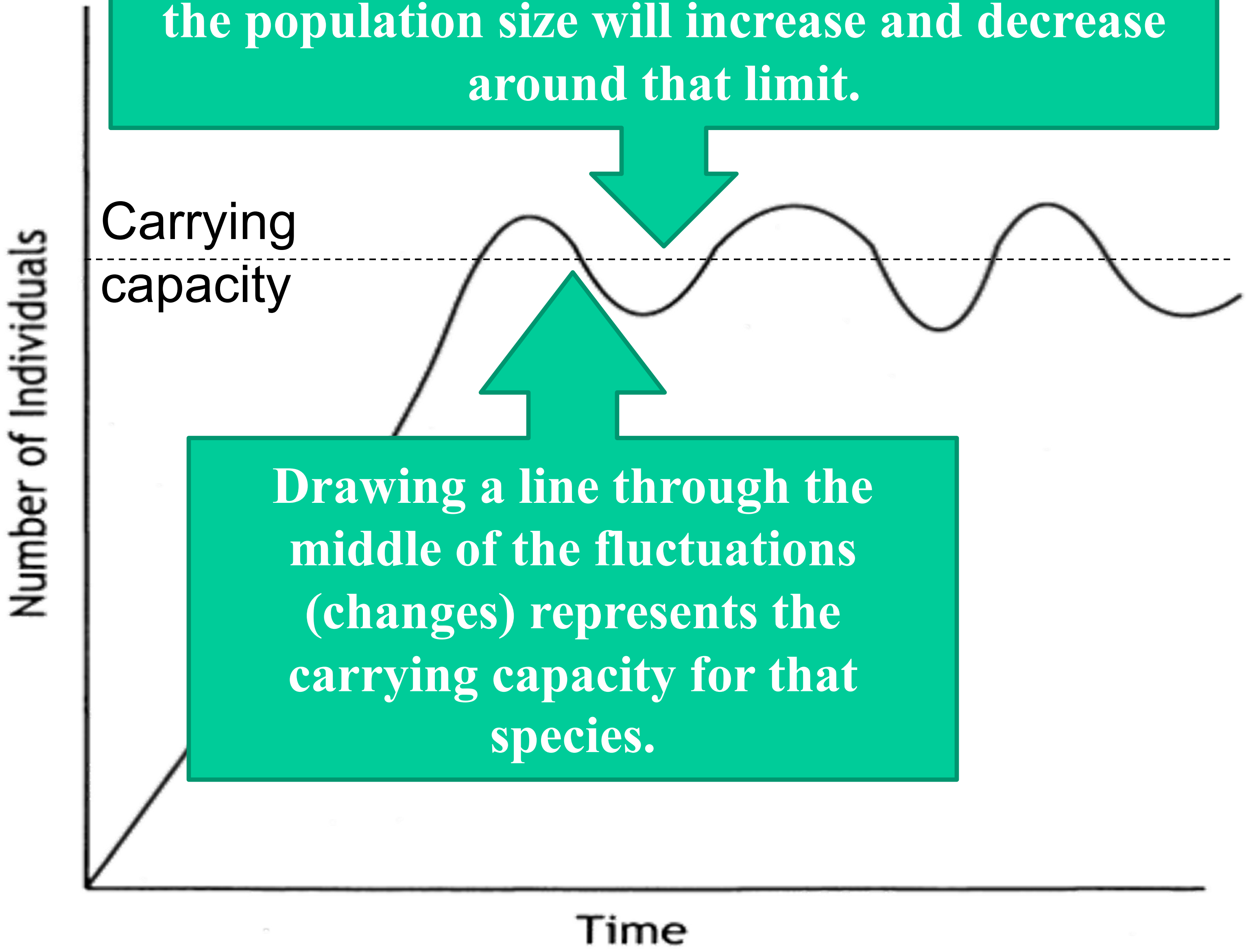
- Population will increase rapidly in size
- The larger a population gets, the faster it increases


Population rate decreases
The larger the population gets, the less resources there are. The population cannot increase anymore.
Population
Population rate increases
Time

Limiting Factors

- The environment provides factors that prevent populations from attaining their biotic potential. Any resource that is in short supply is a limiting factor such as food, water, territory, and the presence of pollutants.

Once the carrying capacity has been reached, the population size will increase and decrease around that limit.



Drawing a line through the middle of the fluctuations (changes) represents the carrying capacity for that species.

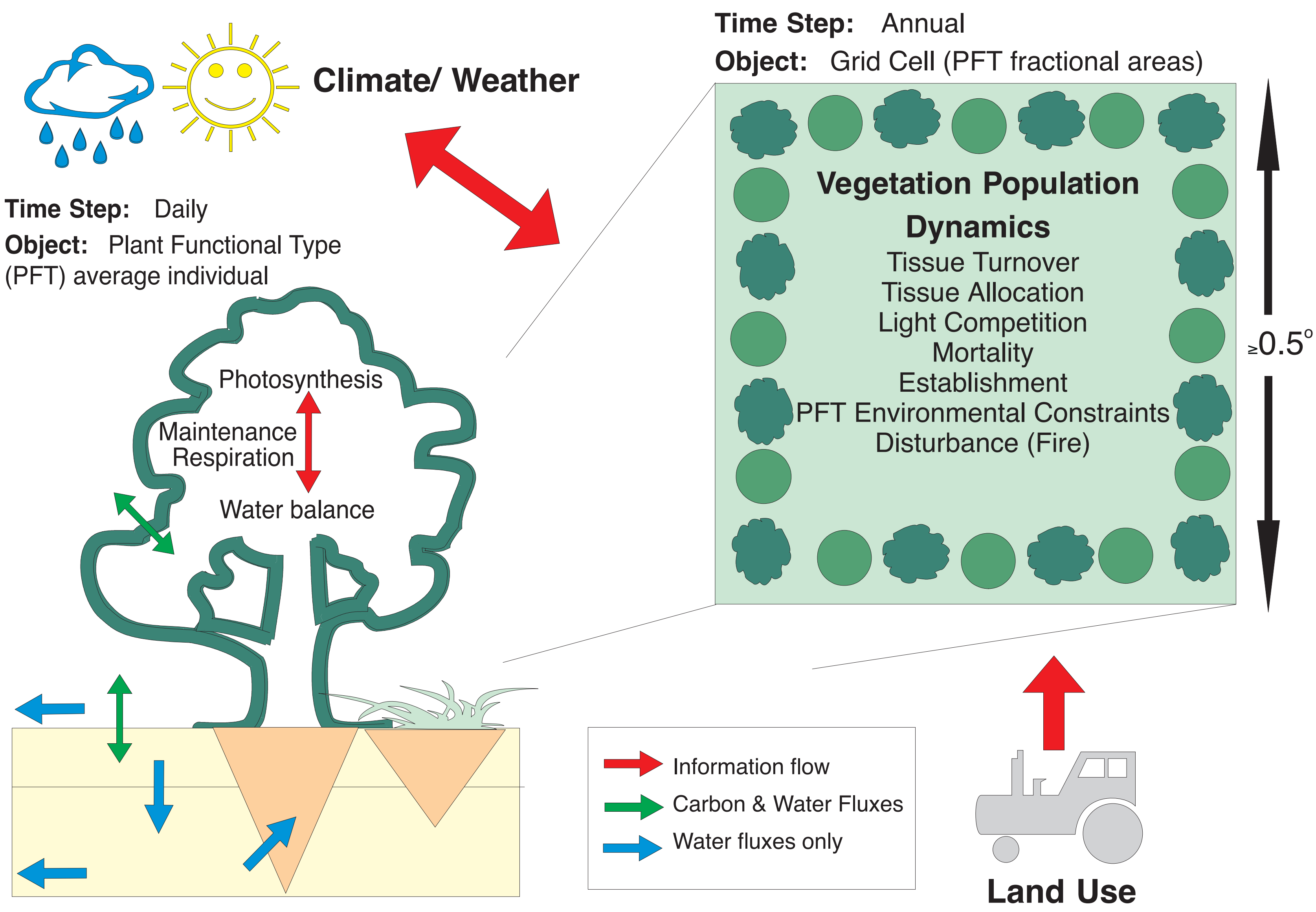
Dynamical vegetation models

- regional climate conditions and atmospheric CO_2
- vegetation composition and cover in terms of major species or **plant functional types (PFTs)**, biomass and soil organic matter carbon pools, leaf area index (LAI), net primary production (NPP), net ecosystem carbon balance, carbon emissions from wildfires,

Furthermore: managed land, methane emissions, and permafrost.

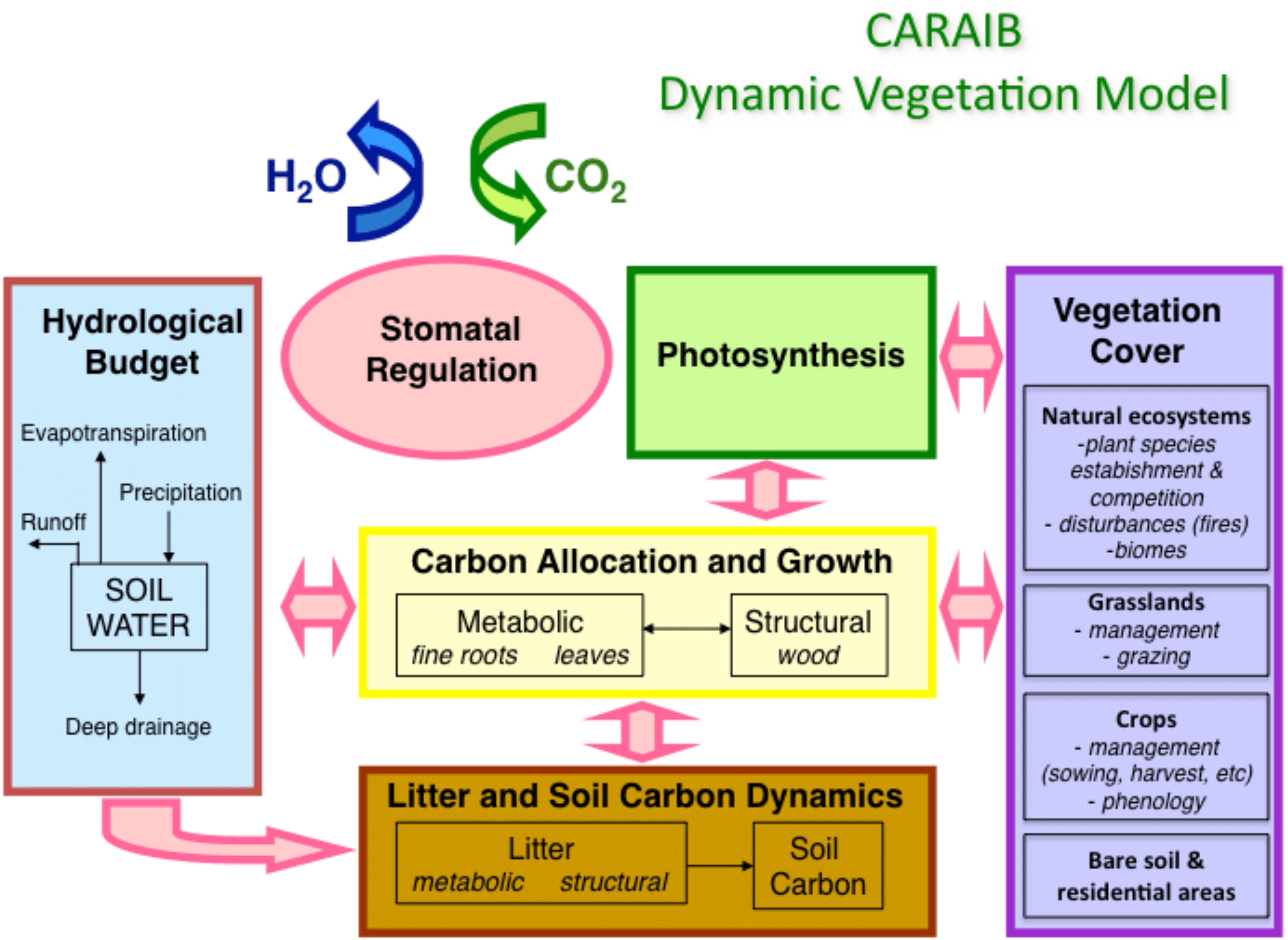
http://www.globalcarbonatlas.org/en/content/land-models

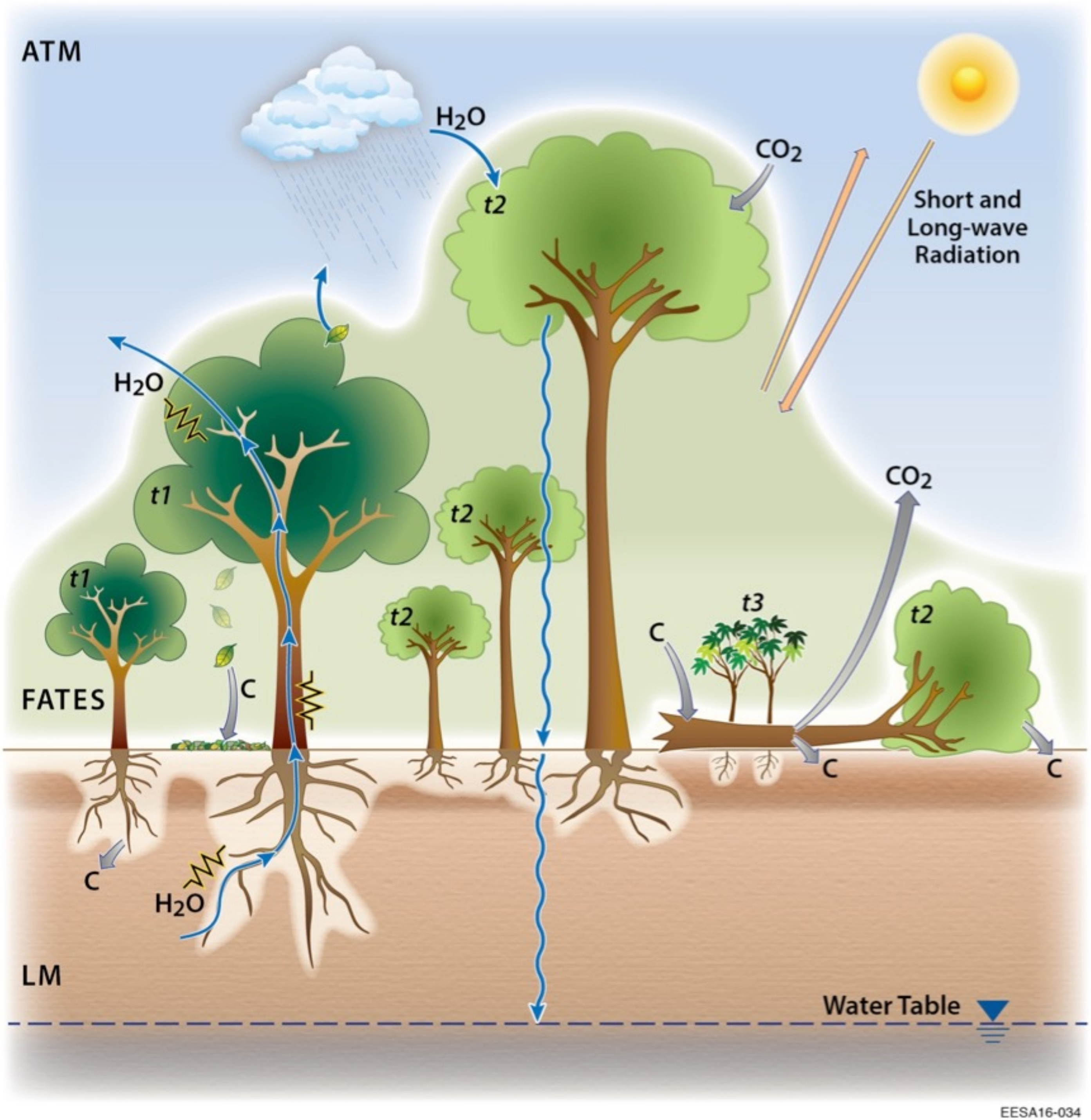
The Lund-Potsdam-Jena Dynamic Global Vegetation Model (DGVM)



https://web.nateko.lu.se/lpj-guess/education/

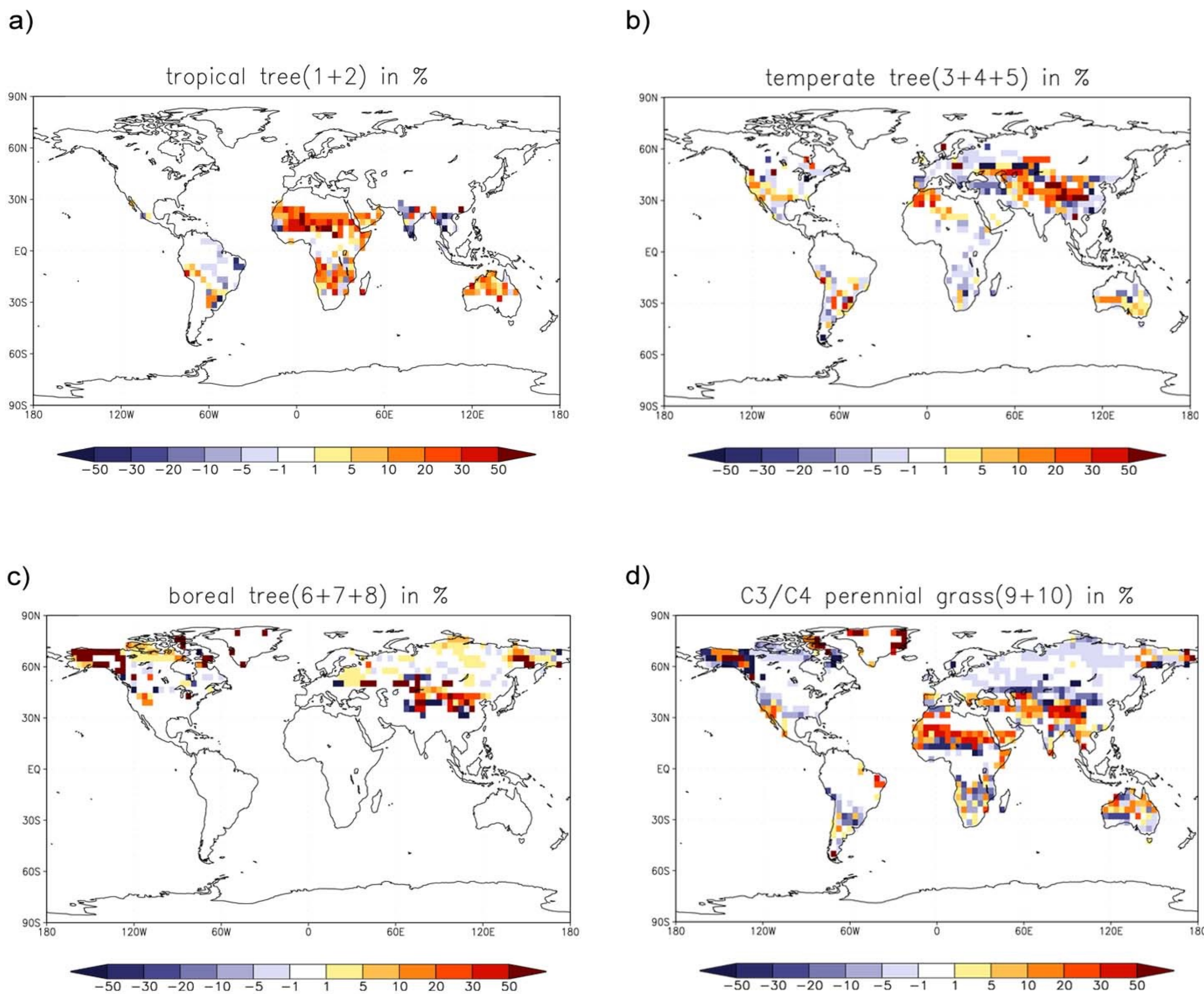
Similar concept :



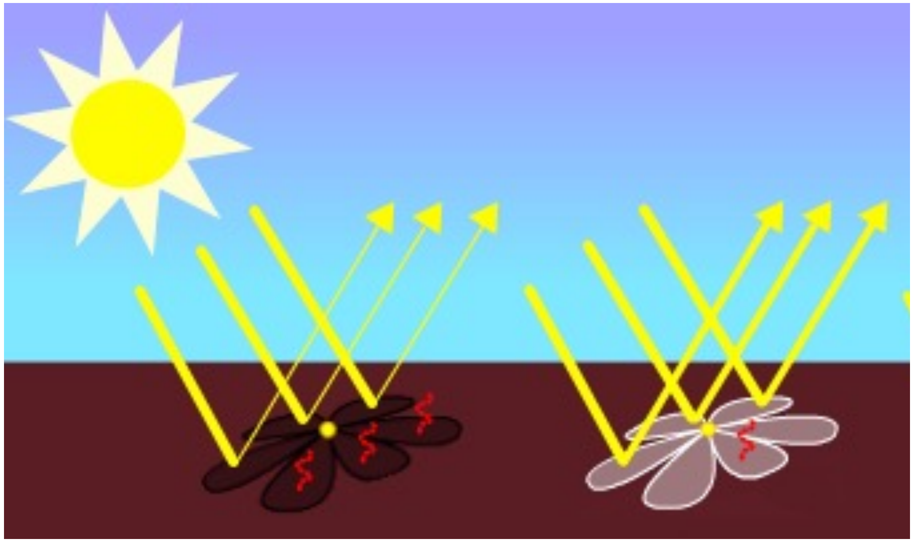


ATM
H_2O
CO_2
Short and Long-wave Radiation
t2
H_2O
t1
t2
CO_2
t1
t2
t3
t2
C
C
FATES
C
C
C
H_2O
LM
Water Table
EESA16-034

Typical output of a vegetation model



Daisy World & the Gaia Hypothesis



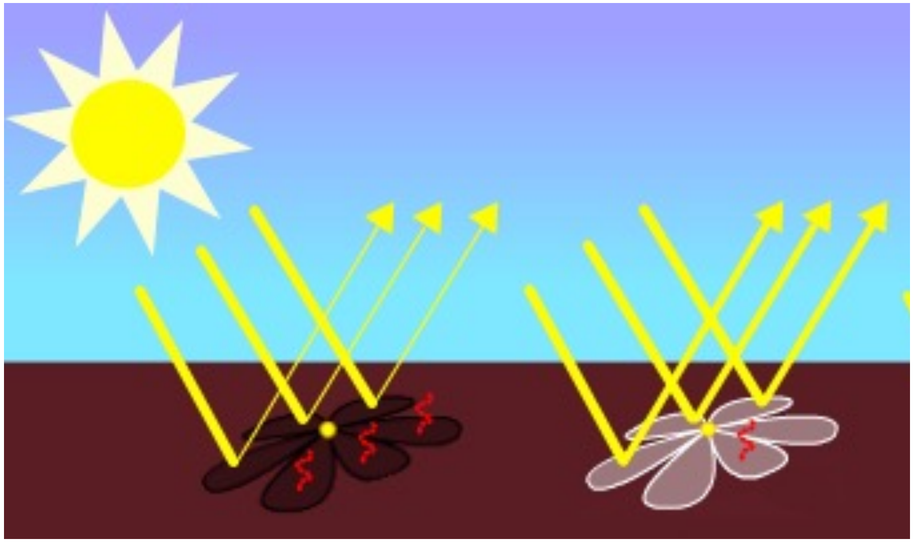
Sunlight reflects off different color daisies.

Black daisies absorb most light, turning it into heat.

White daisies reflect most light, and stay cooler.

https://paleodyn.uni-bremen.de/study/MES/MES_Vegetation_2023.html

Daisy World & the Gaia Hypothesis



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By the mix of white and black daisies and barren ground, Daisy World strives to keep its temperatures in the range that allows daisies to live.

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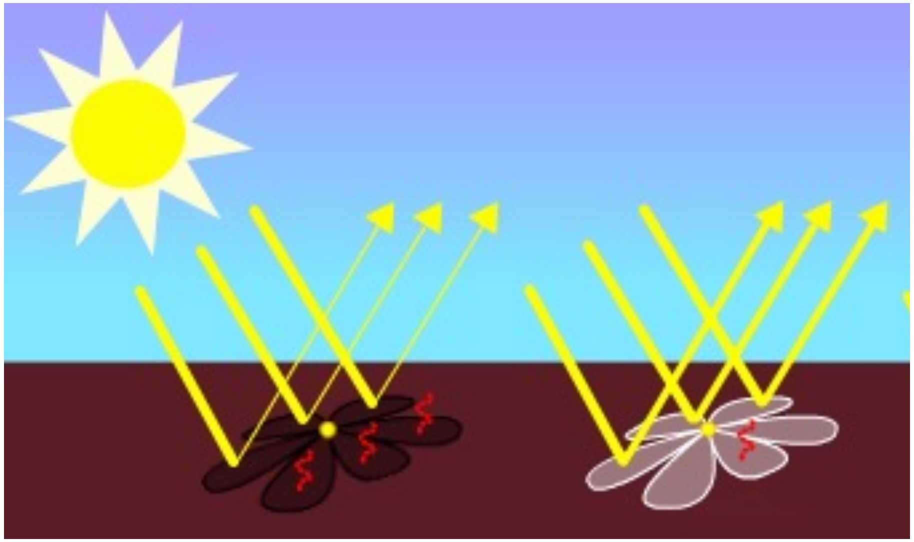

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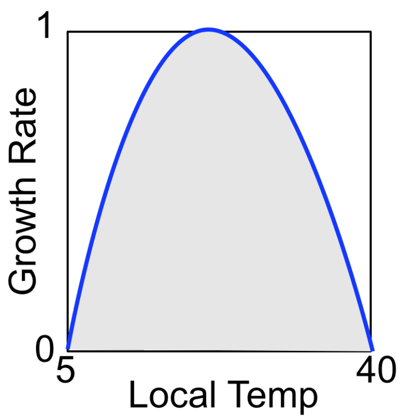
When the world is too cool for black daisies to warm it, or too hot for white daisies to cool it, the planet is barren.

How the model works



Formulas	
Planetary Albedo	$\alpha_p = \sum_{color} A_{color}\alpha_{color}$
Planetary Temperature	$T_p^4 = L\frac{S_o}{4\sigma}(1-\alpha_p)$
Local Temperature	$T_{color}^4 = RL\frac{S_o}{4\sigma}(\alpha_p - \alpha_{color}) + T_p^4$
Birthrate	$\beta_{color} = 1.0 - s(T_{color} - T_{color,\ ideal})^2$, $s = \frac{1}{(T_{ideal} - T_{min,\ max})^2}$
Area Change	$\frac{dA_{color}}{dt} = A_{color}(\beta_{color}A_{barren} - \chi)$

Evolution of area fractions of white (a_w) and black (a_b) daisies

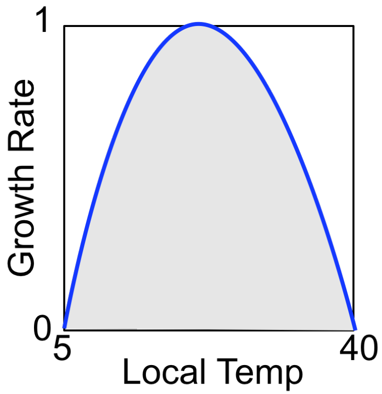
$$\frac{\partial a_w}{\partial t} = a_w \left[a_g \beta(T_w) - \gamma\right]$$

$$\frac{\partial a_b}{\partial t} = a_b \left[a_g \beta(T_b) - \gamma\right]$$

Vegetation Model

Growth rate is temperature dependent

$$\beta(T) = \begin{cases} 1 - k(T - T_{opt}) & \text{if } |T - T_{opt}| < k^{-\frac{1}{2}} \\ 0 & \text{otherwise} \end{cases}$$



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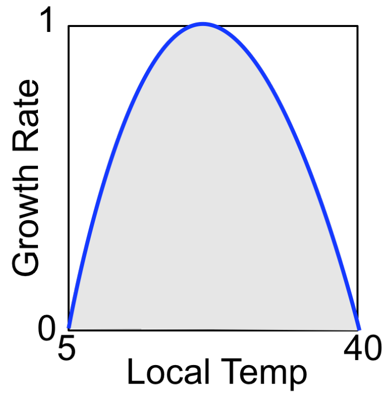

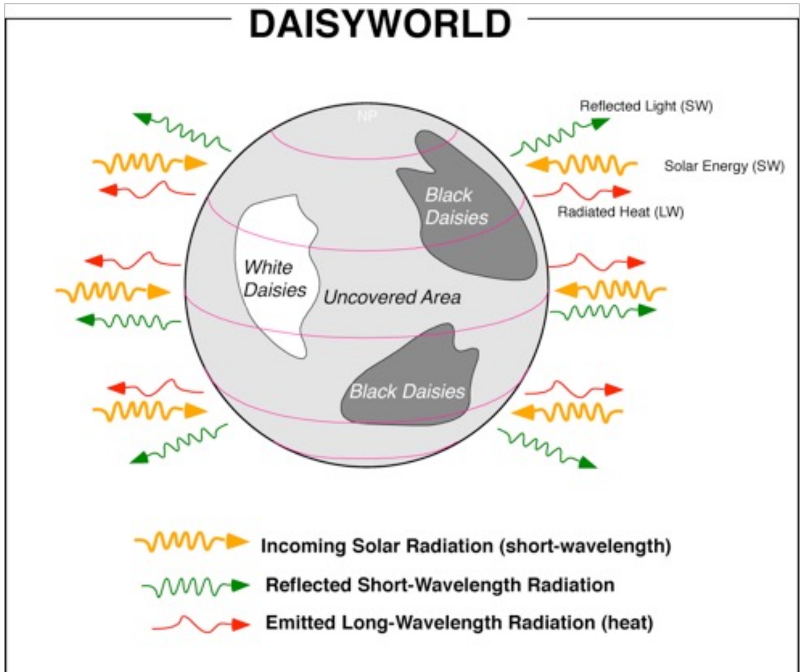

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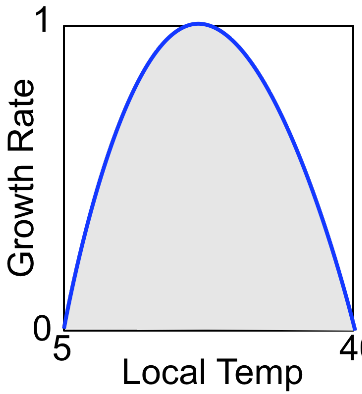


Planetary albedo $\alpha_p = a_w \alpha_w + a_b \alpha_b + a_g \alpha_g$

Gobal temperature $S_o L(1 - \alpha_p) = \sigma T^4$

L: luminosity

$$T_w^4 = q(\alpha_p - \alpha_w) + T^4$$

$$T_b^4 = q(\alpha_p - \alpha_b) + T^4$$

$$T_g^4 = q(\alpha_p - \alpha_g) + T^4$$

Climate Model

$q = 2.06 \times 10^9\ K^4$ is a heat transfert coefficient

Exercise I

1.Run Daisy World with the the Daisies - black and white. Notice for what range of luminosity the daisies manage to control the planet temperature.

2.Do you think control would be better if you set the low and high albedos (for black and white) to a wider spread?

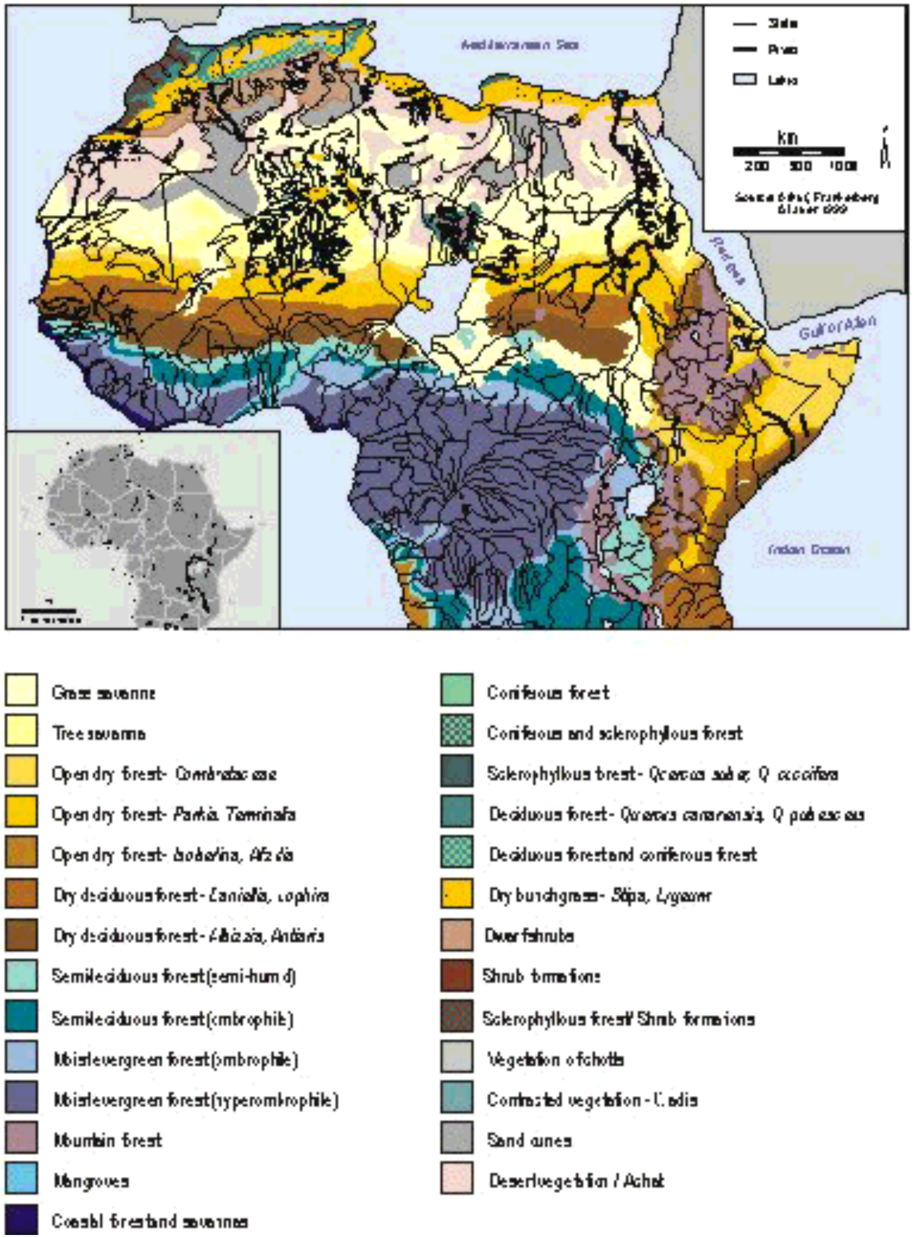
3.You will notice that the living area (“total daisies”) doesn’t exceed 70%. The deathrate is set to 0.3, which may explain the living percentage being no more than 0.7. Play with the deathrate parameter. What does the deathrate do to the daisies’ ability to control their environment’s temperature? To the species mix?

4.What is the influence of the optimal growth temperature? Please vary the numbers and describe the consequence !

5.Daisyworld Model quizz at http://www.climate.be/textbook/daisyworld.html

https://paleodyn.uni-bremen.de/study/MES/MES_Vegetation_2023.html

Vegetation of Africa (8.000 y BP)



Exercise II

1) Describe the vegetation dynamics for the Holocene (8000 years ago)! Which evidences?

2) Which feedbacks are acting in the system ?

3) Is it possible to generate a green Sahara and Sinai under present conditions?

4) Is this an option solving political conflicts ?

https://paleodyn.uni-bremen.de/study/MES/MES_Vegetation_2023.html

Vegetation Dynamics

A greener and cooler Sinai can bring more moisture to the Sinai region influencing the larger weather systems in the Mediterranean realm.

We envision a holistic, multidimensional, symbiotic approach for ecological regeneration in the Sinai. There is much to study and to do. We have identified five main steps for development:

STEP 1

Restore The Lagoon

STEP 2

Restore The Wetlands

STEP 3

Reuse Marine Sediments

STEP 4

Regreen The Desert

STEP 5

Restore The Watershed

https://www.greenthesinai.com/how

Paleo-evidence for an enhancement rainfall from Mediterranean sources,

a regional monsoon-type circulation induced by increased land-sea temperature contrast

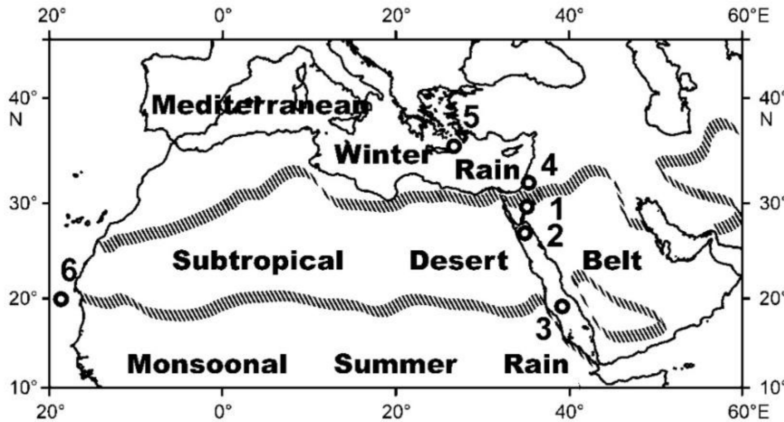


Fig. 1. Map with location of sites discussed in the text: 1, core GeoB 5804-4 (this study); 2, core GeoB 5844-2 (this study); 3, core KL 11 (*16*); 4, Soreq Cave (*18*); 5, core LC21 (*29*); 6, ODP Site 658C (*6*). The map also includes a schematic representation of modern rainfall regimes showing the 100 mm/year isohyets as limits of winter and summer rainfall regimes [after (*25*)].

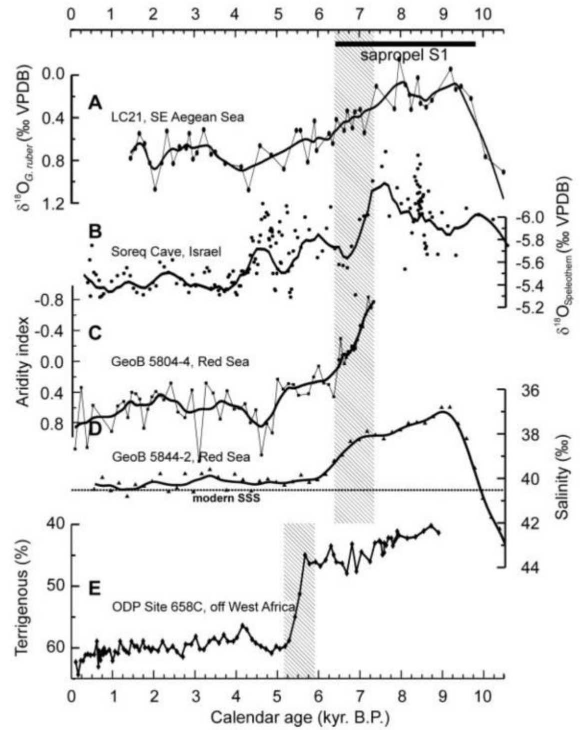


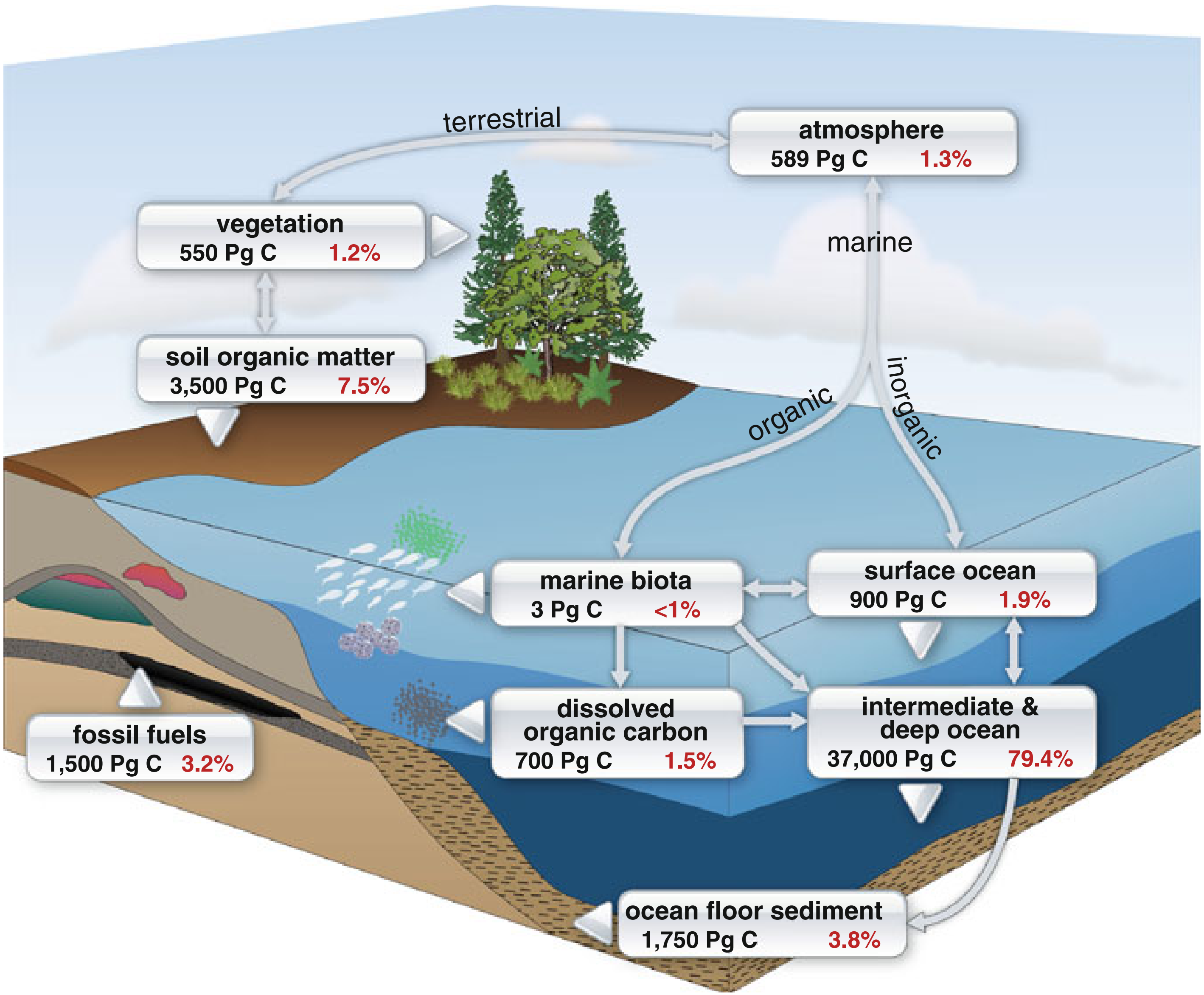
Fig. 3. Timing of the early- to mid-Holocene humid interval in the northern Red Sea compared with proxy records from the eastern Mediterranean, southern Oman, and West Africa. **(A)** $\delta^{18}O$ record of *G. ruber* (white) of the southeast Aegean Sea core LC21 (*29*), marking the enhanced freshwater flux to the eastern Mediterranean Sea. Black bar indicates the extent of anoxic sedimentation in LC21, representing sapropel S1. **(B)** $\delta^{18}O$ speleothem record, Soreq Cave, as a proxy for regional rainfall in Israel (*18*). **(C)** Aridity index from the northern Gulf of Aqaba core GeoB 5804-4 (this study). **(D)** Paleosalinity record from the northern Red Sea core GeoB 5844-2 (this study). **(E)** Eolian sedimentation, ODP Site 658C, off West Africa as a proxy for aridity in subtropical North Africa (*6*). Original data in (A) to (D) have been smoothed by simple moving averaging (bold lines). Vertical bars emphasize the major humid to arid transition in the various records.

Arz, Lamy et al., 2003

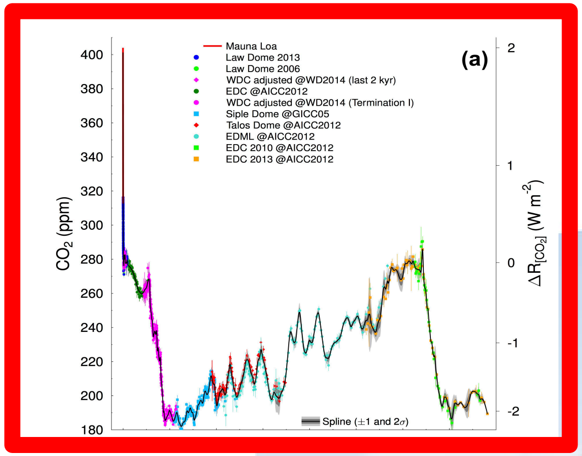
The Loess plateau in northern China

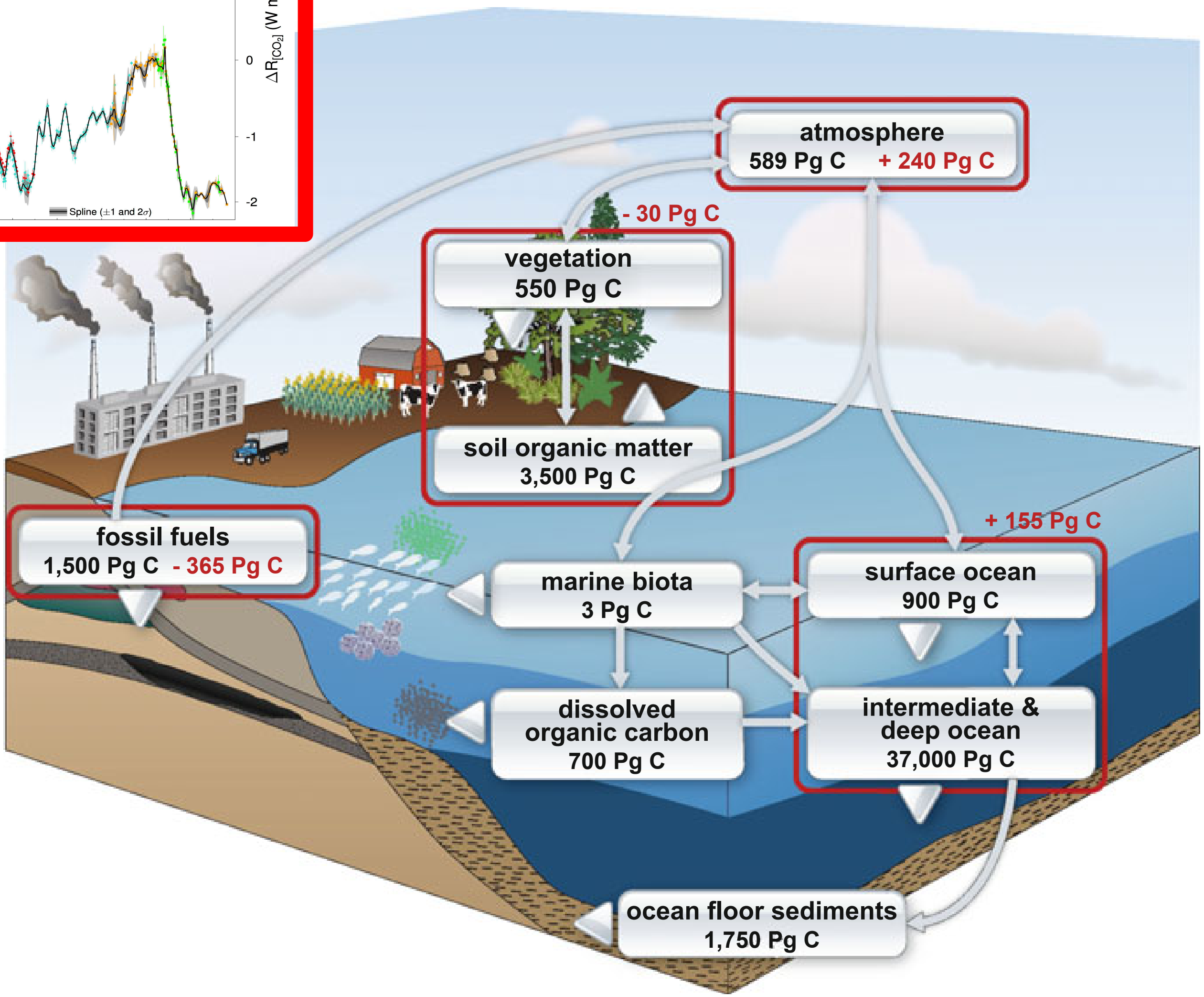
Within 20 years, the deserts of the Loess plateau became green valleys and productive farmland

Carbon reservoirs

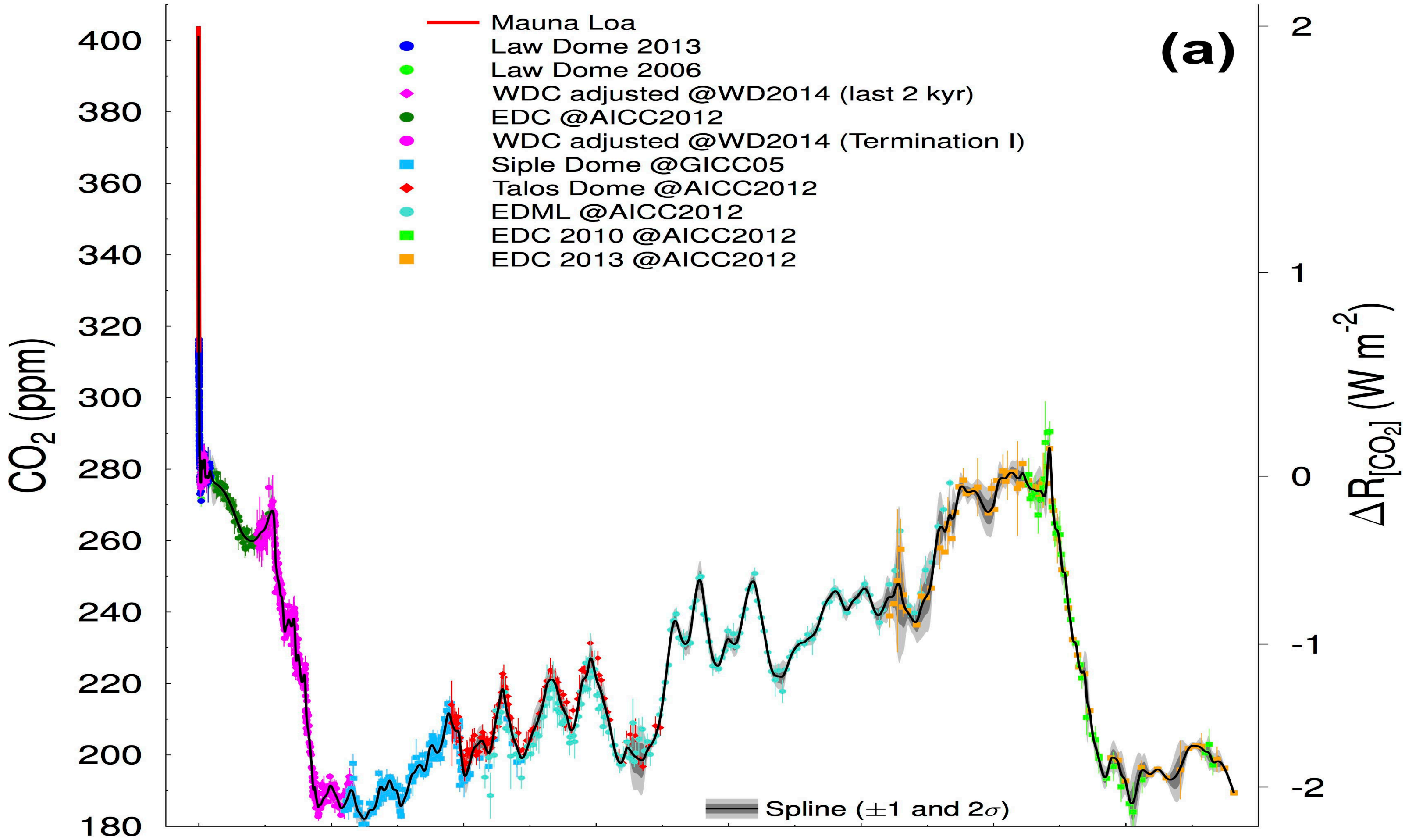


C reservoirs + perturbation



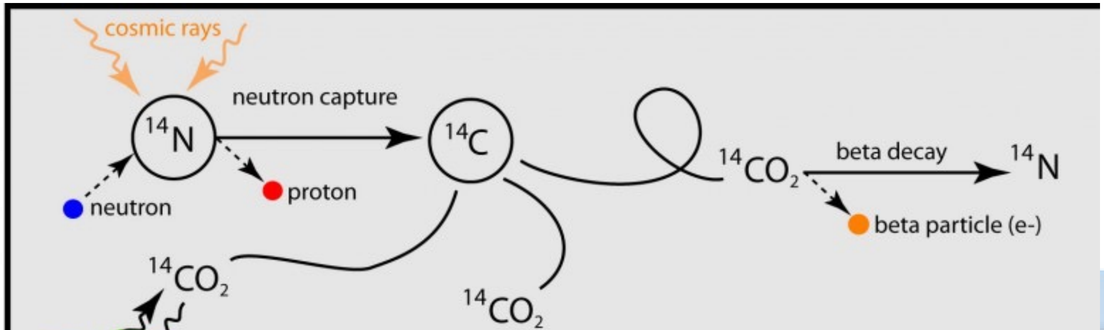


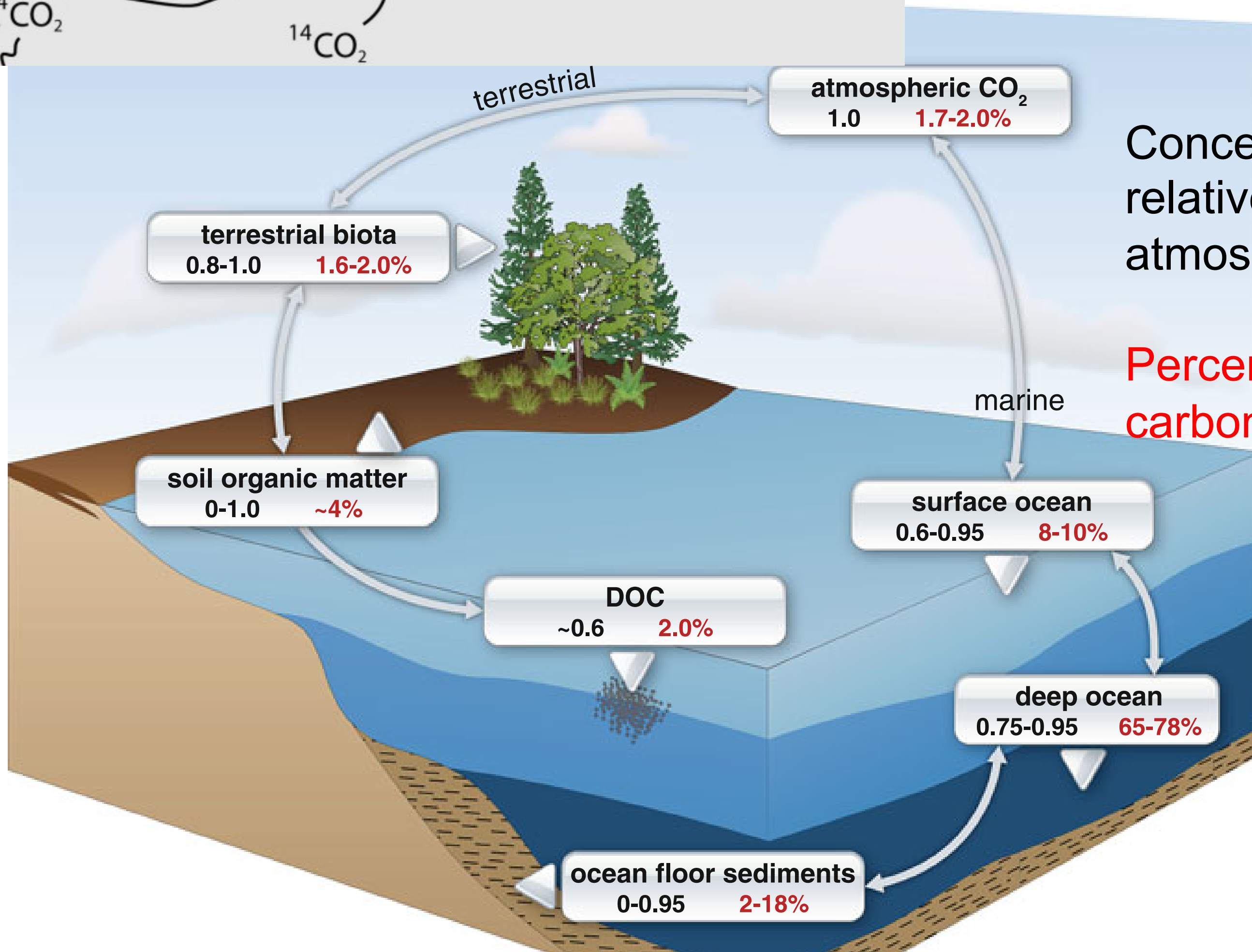
CO_2



Time scale?

tracer: C-14

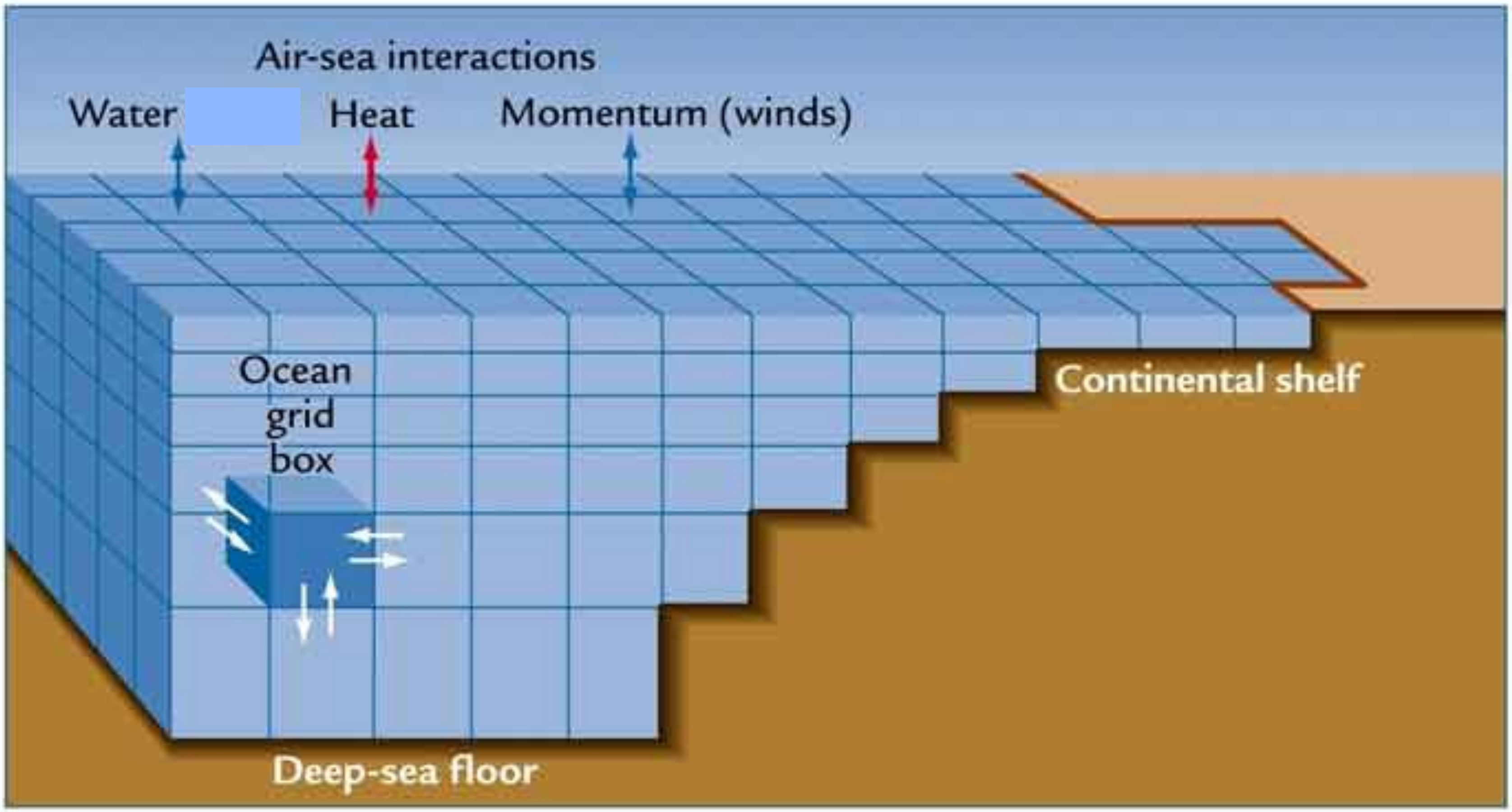




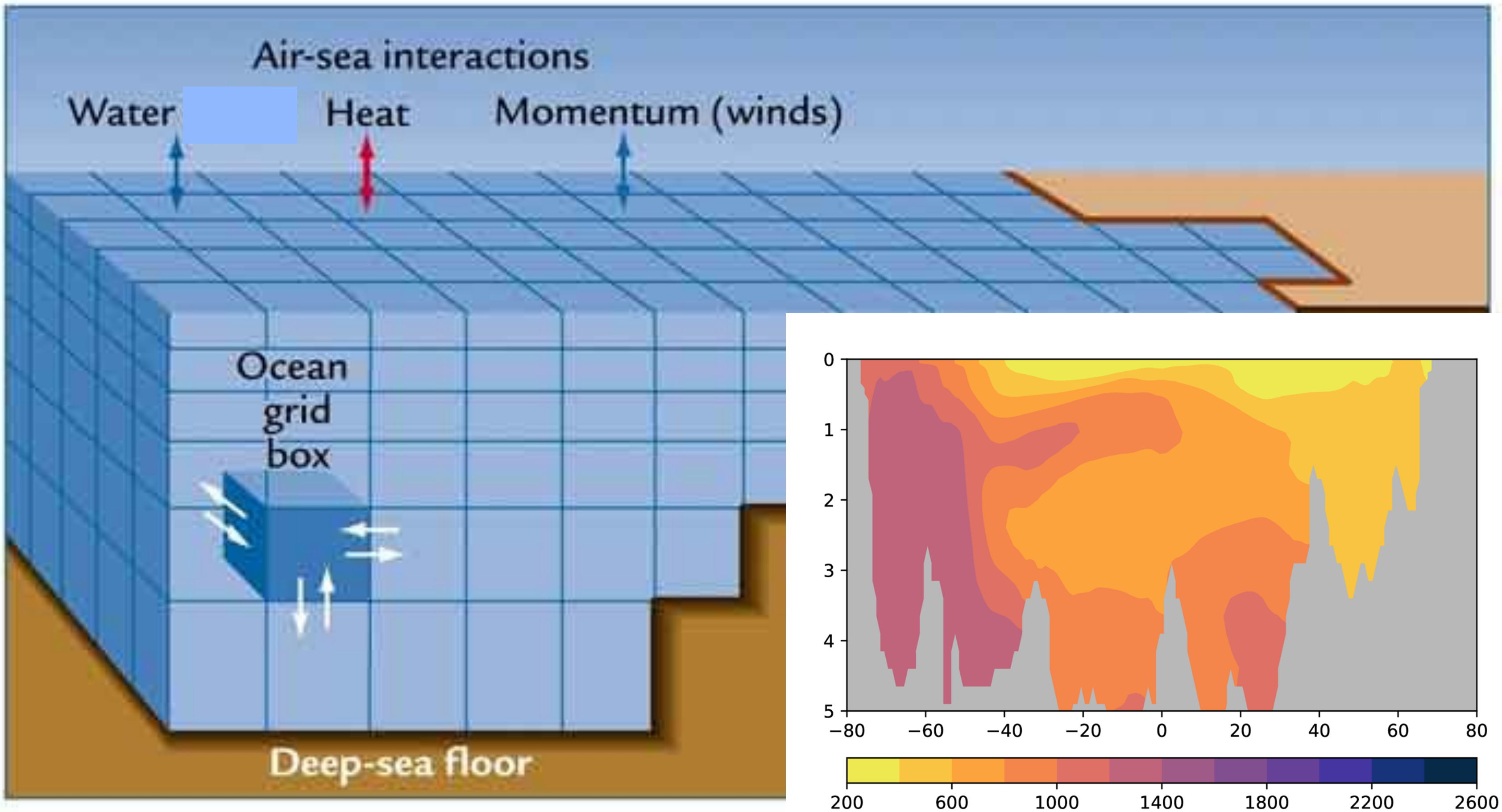
Concentration relative to atmosphere

Percentage of total carbon content

Ocean circulation models tracers in the sea



Ocean circulation models tracers in the sea



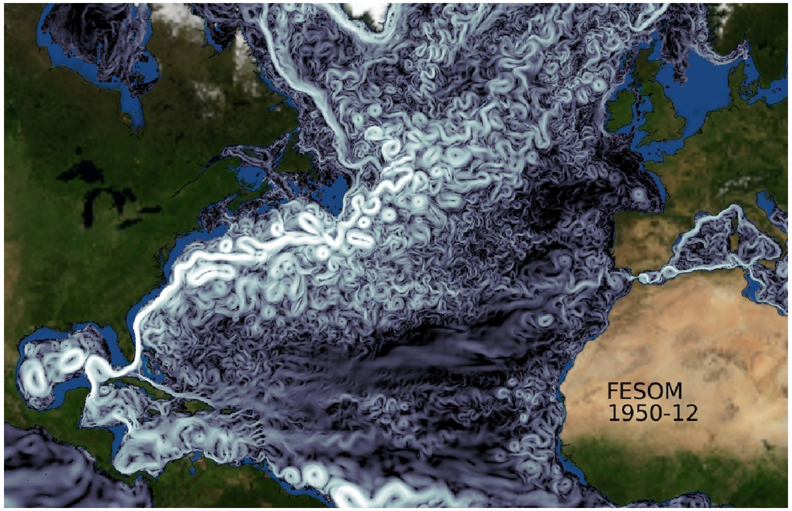
a perfect time tracer: C-14

Climate-Radiocarbon Dynamics

$$\overbrace{\rho\Big(\underbrace{\frac{\partial \mathbf{u}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{u}\cdot\nabla\mathbf{u}}_{\text{Advective acceleration}}\Big)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu\nabla^2\mathbf{u}}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{F}}_{\text{Other body forces}}$$

$$\begin{aligned} D_t[\vec{v}] &= \frac{1}{\rho}\nabla p + \text{Wind stress} \\ D_t[T] &= \text{heat flux} \\ D_t[S] &= \text{freshwater flux} \end{aligned}$$

$$D_t[\bullet] = \frac{\partial \bullet}{\partial t} + \mathbf{v}\cdot\nabla\bullet - \nabla\cdot(k\nabla\bullet)$$



Climate-Radiocarbon Dynamics

Carbon

$$D_t[C] = \text{Sources - Sinks} = Q$$

Radiocarbon

$$D_t[RC] = -\lambda RC + R_q Q$$

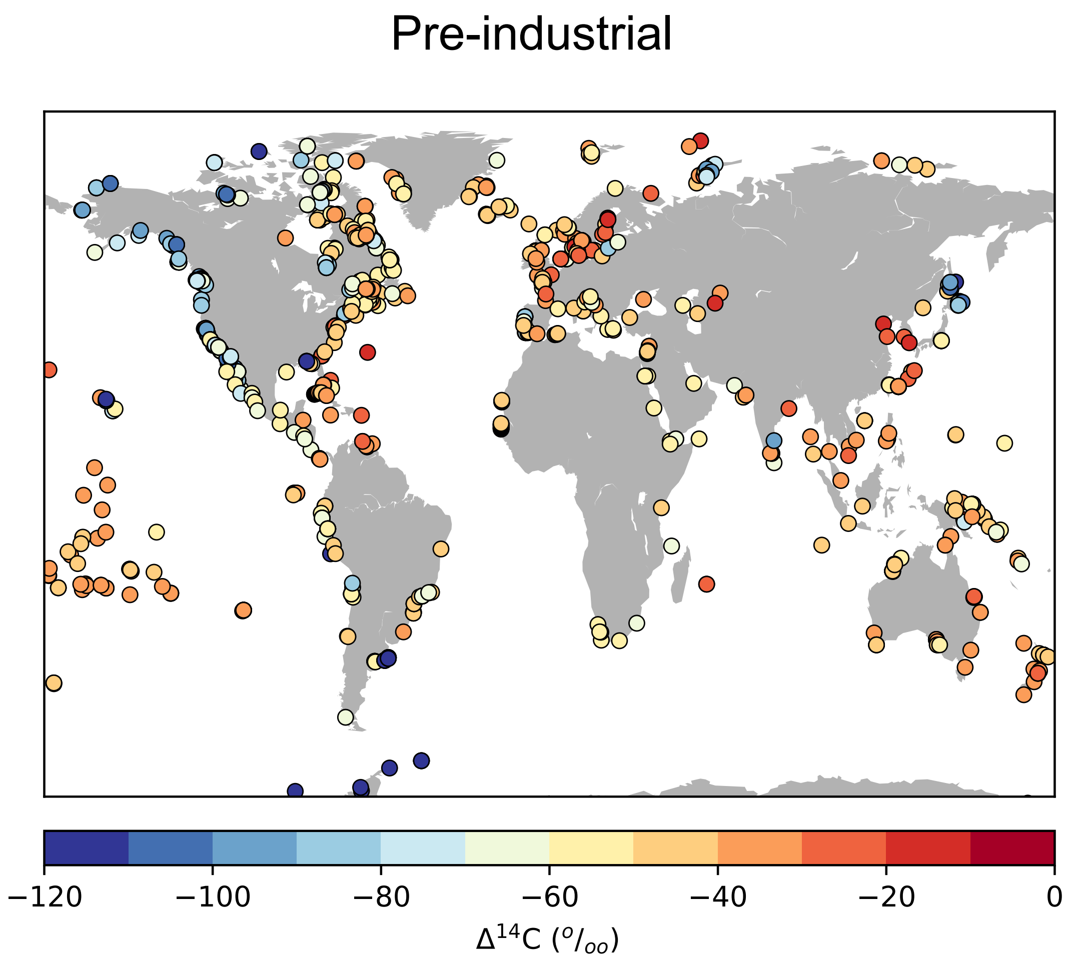
Ratio

$$R = \frac{^{14}\mathrm{C}}{\mathrm{C}}$$

$$D_t[R] = -\lambda R$$

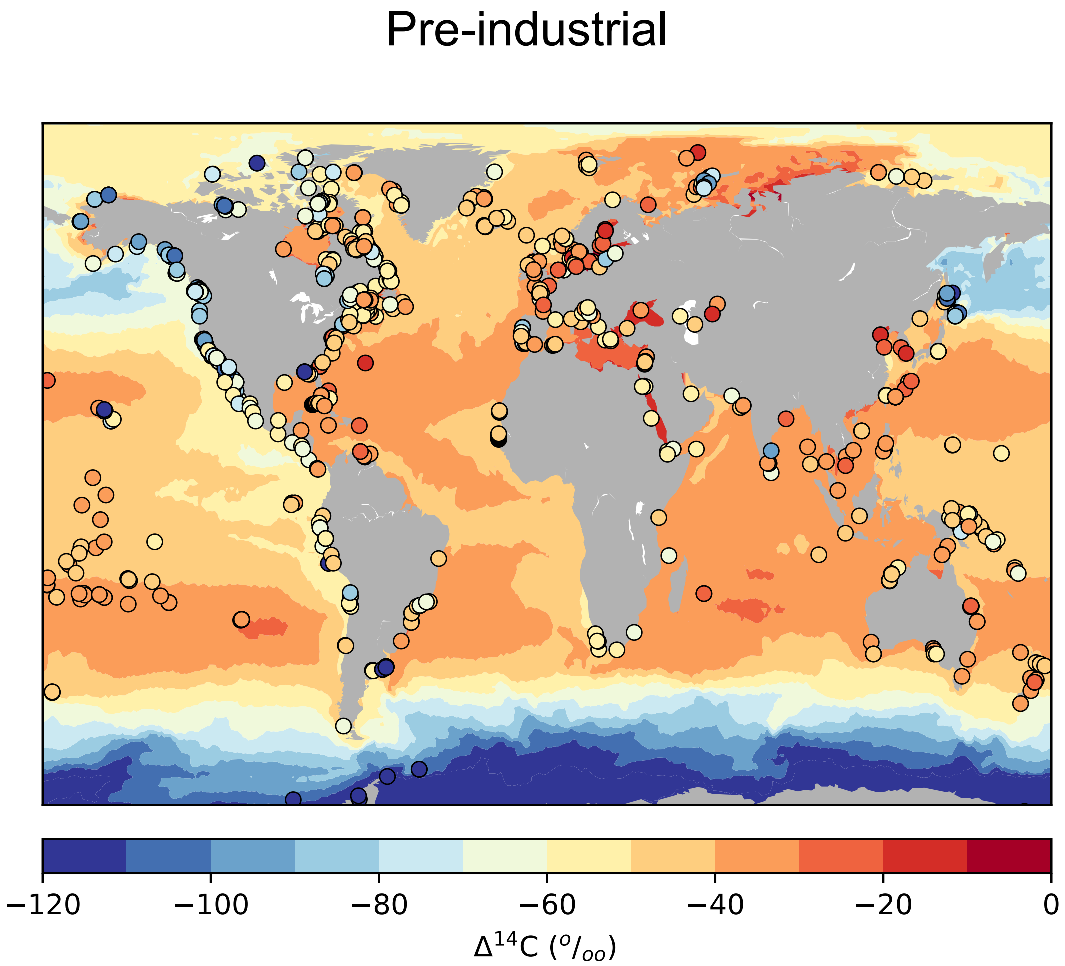
Ratio can be treated as a radio-conservative tracer

^{14}C in the surface ocean: Reconstructions



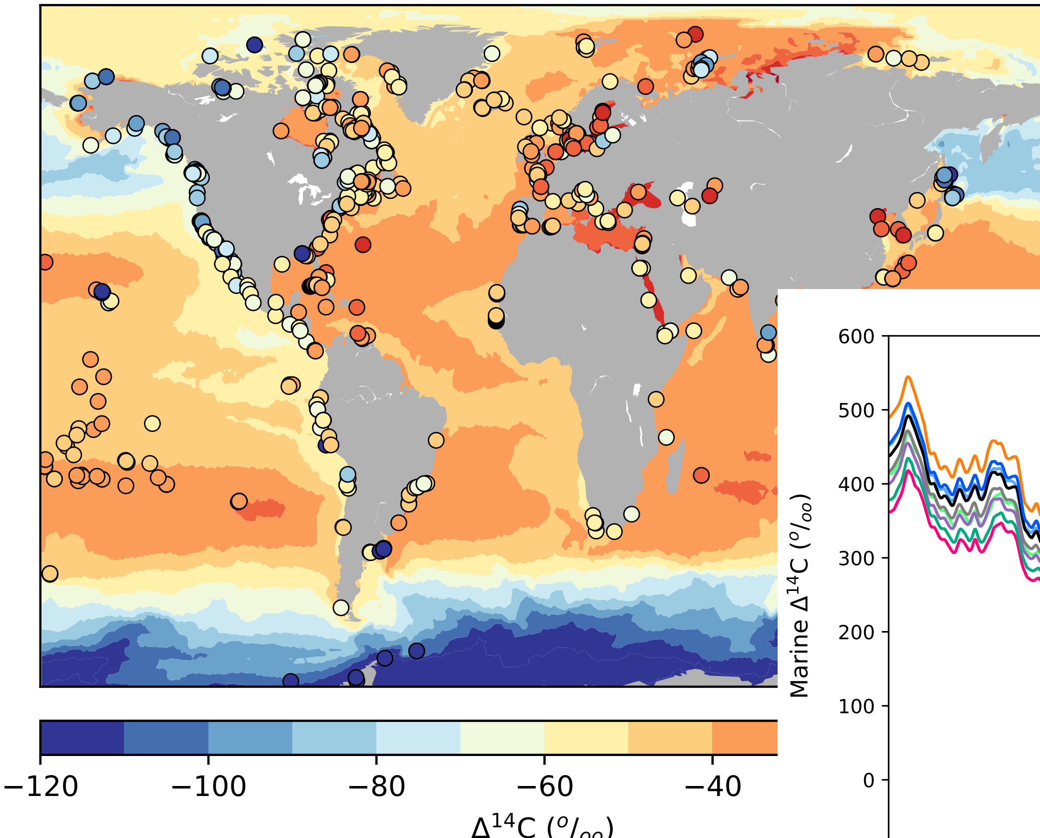
Chrono-data base, xxxx

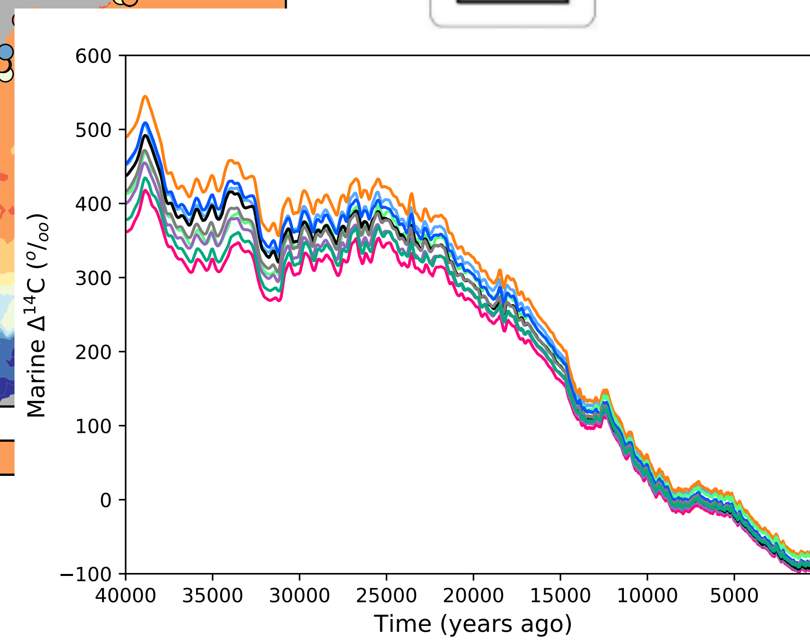
^{14}C in the surface ocean: Simulation



Paleo-reanalysis: Filling the gaps in space

^{14}C in the surface ocean: Simulations

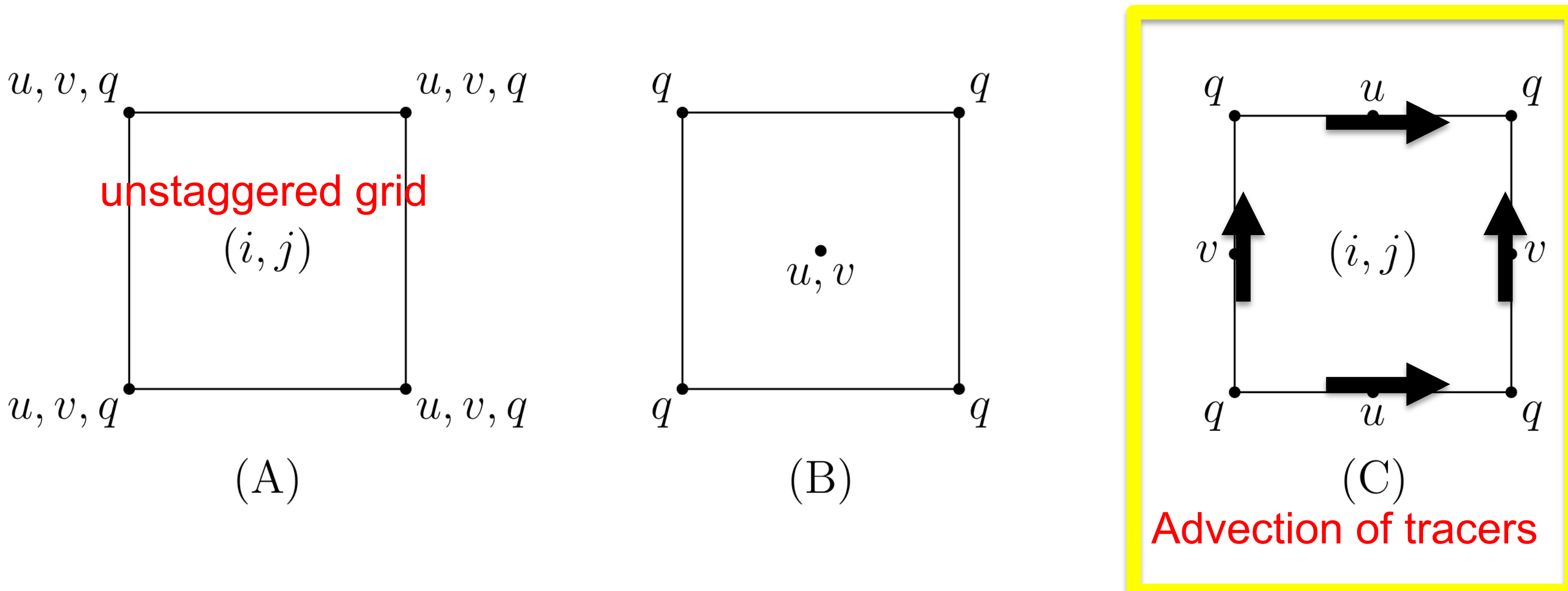


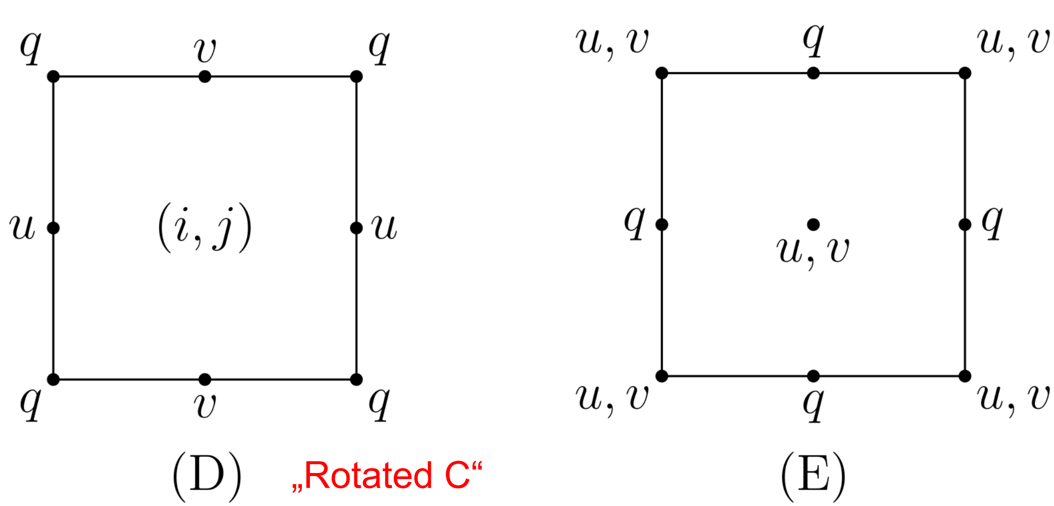


Paleo-reanalysis: Filling the gaps in space and time

Butzin et al., 2019

2D Staggered grids: Arakawa





Arakawa, A.; Lamb, V.R. (1977)
doi:10.1016/B978-0-12-460817-7.50009-4. ISBN 9780124608177.

The Carbon Cycle

- Carbon is the key element for **living** things.
- Carbon in the atmosphere and dissolved in the oceans as part of the inorganic CO_2
- CO_2 is recycled into more complex organic substances through **photosynthesis**.

- **<u>Photosynthesis</u>** – process by which green plants make their own food from **water**, carbon dioxide, and light energy, producing sugar (stored energy) and oxygen (a by-product).

- The general equation for photosynthesis is:

$$6CO_2 + 6H_20 \xrightarrow{\text{Energy}} C_6H_{12}O_6 + 6O_2$$

Carbon dioxide

Water

Carbohydrates

Oxygen