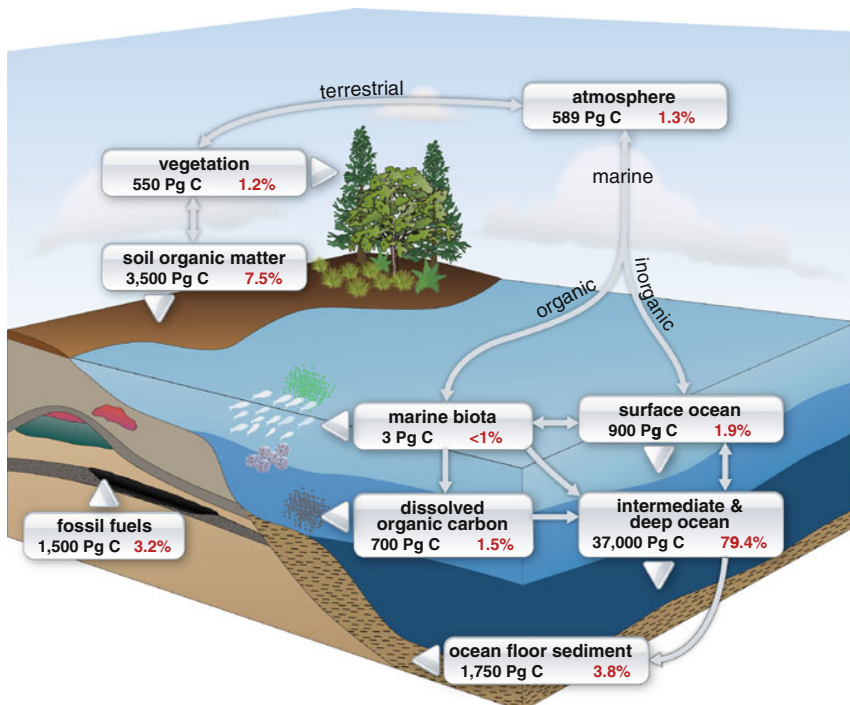
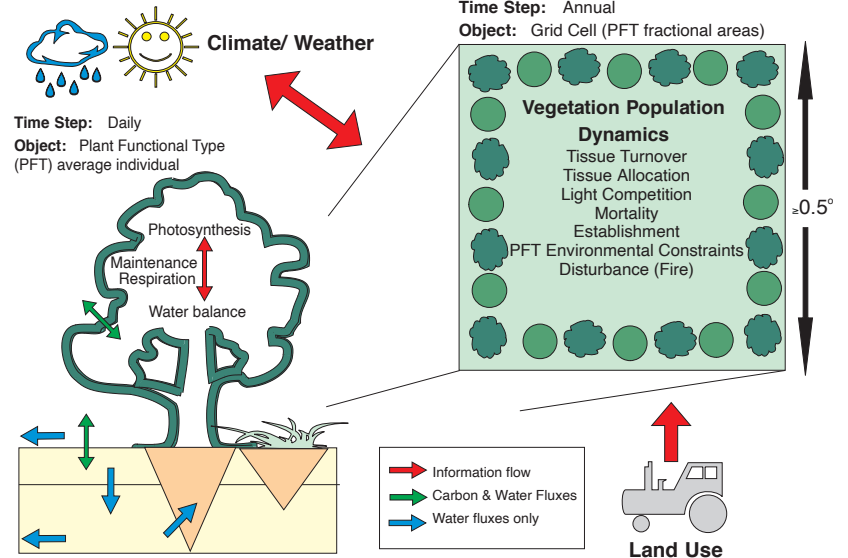


Earth system models including tracers and dynamical vegetation



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



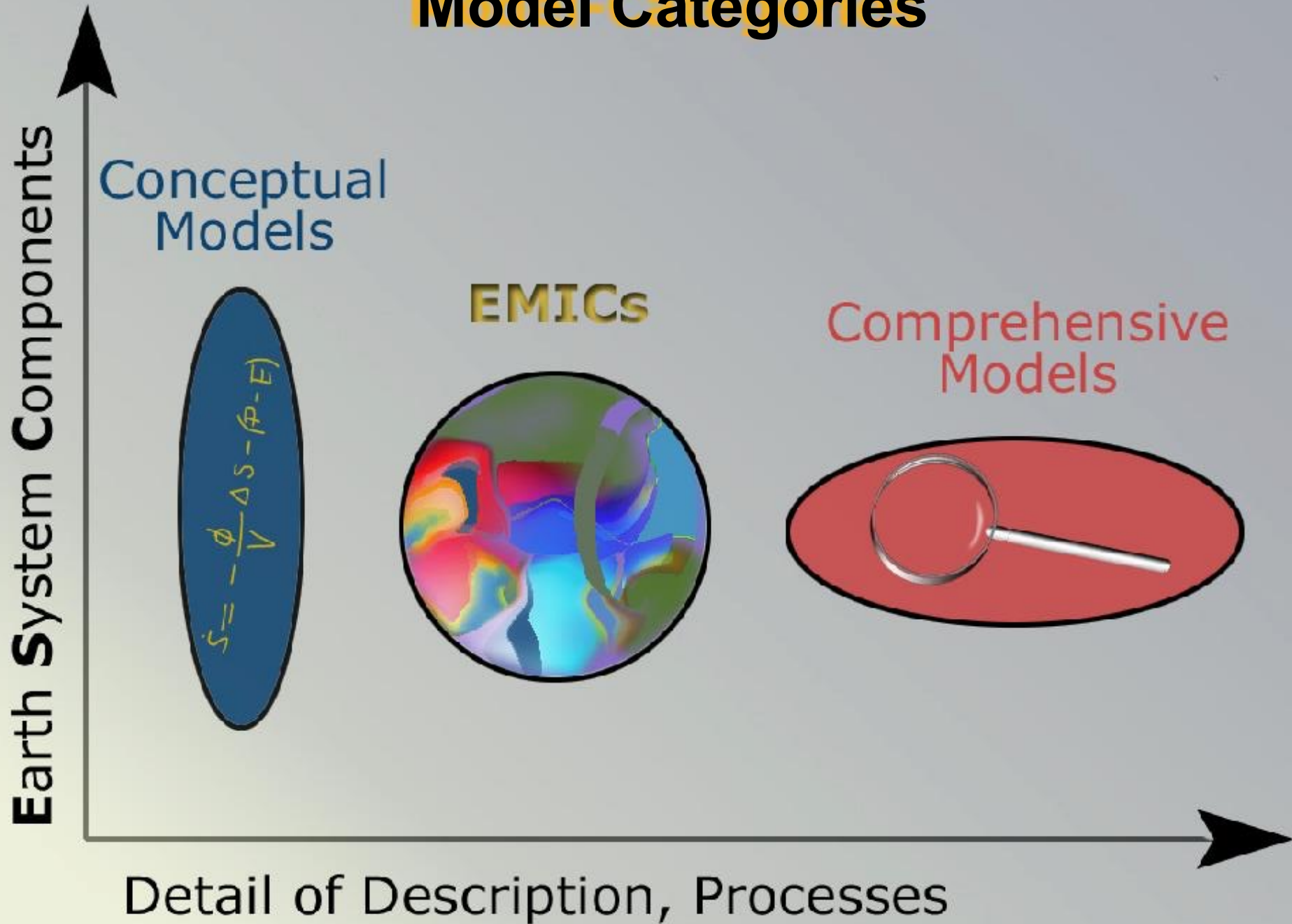


Today's lecture

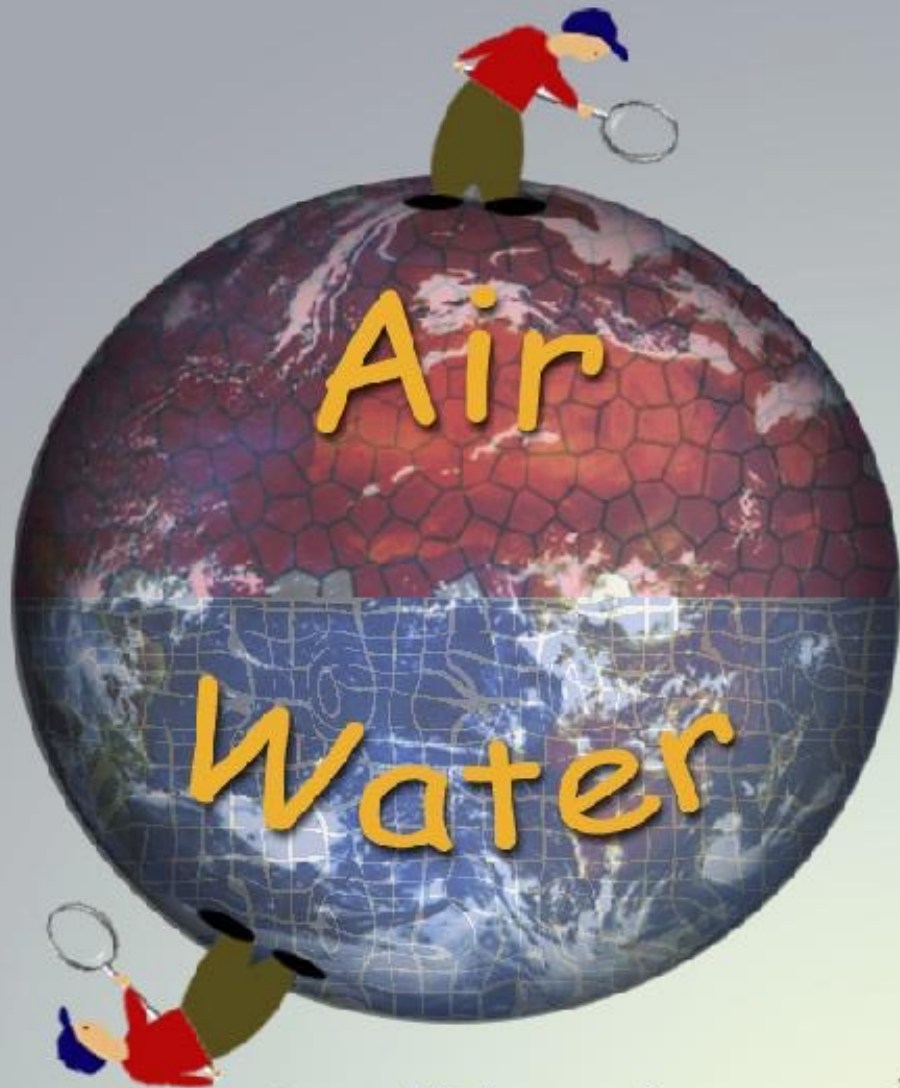
- Earth System Models
- Sea ice
- Carbon, Radiocarbon
- Tracers in the Sea
- Vegetation & Ecosystem models
- Daisy World

- Practicals: Daisy World, veg dynamics, stochastic dynamics

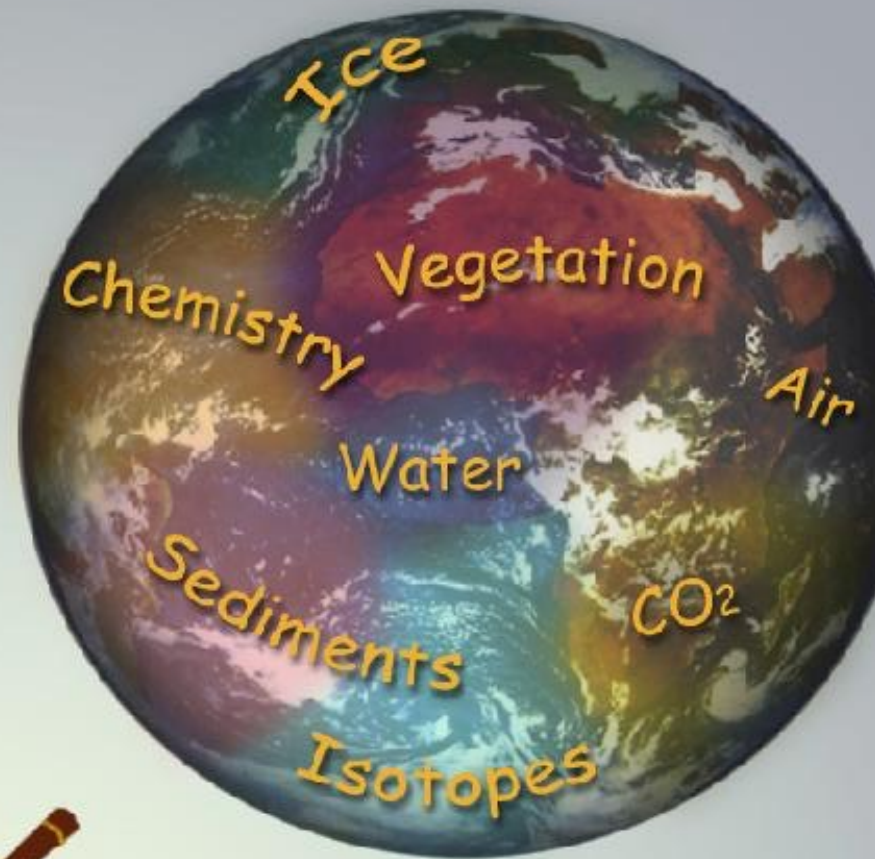
Model Categories



Different Point of View



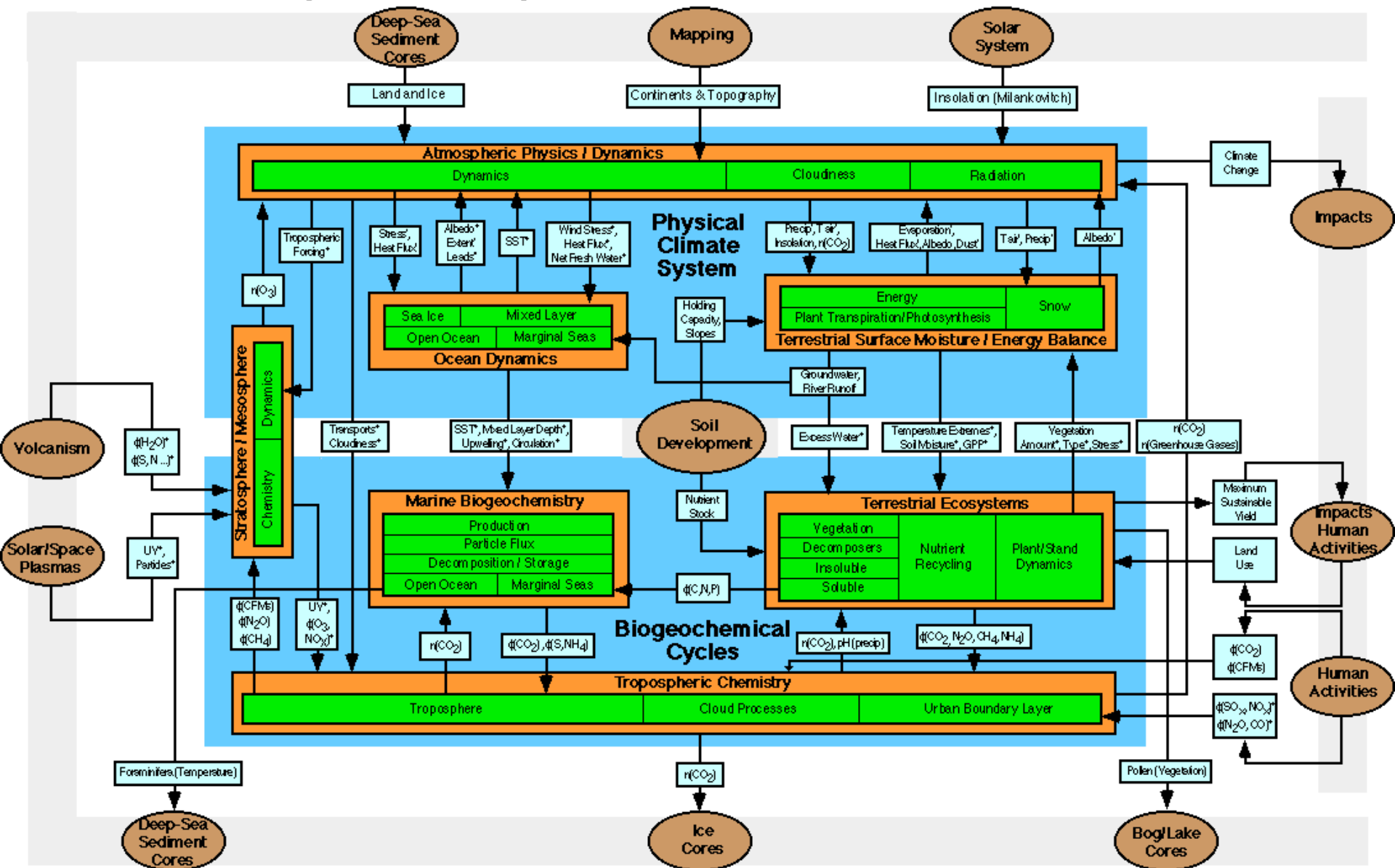
traditional
GCMs



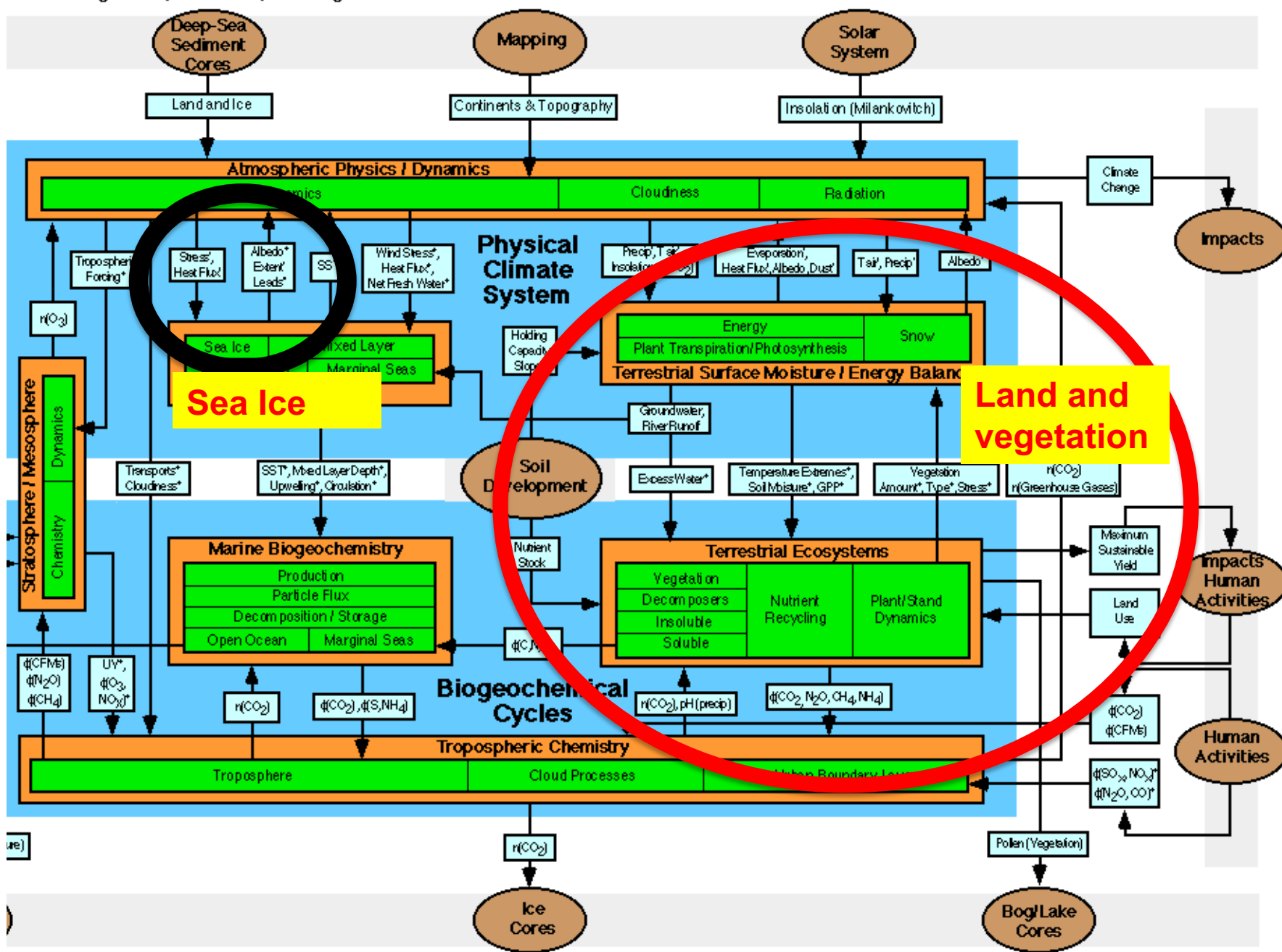
Earth System
Models

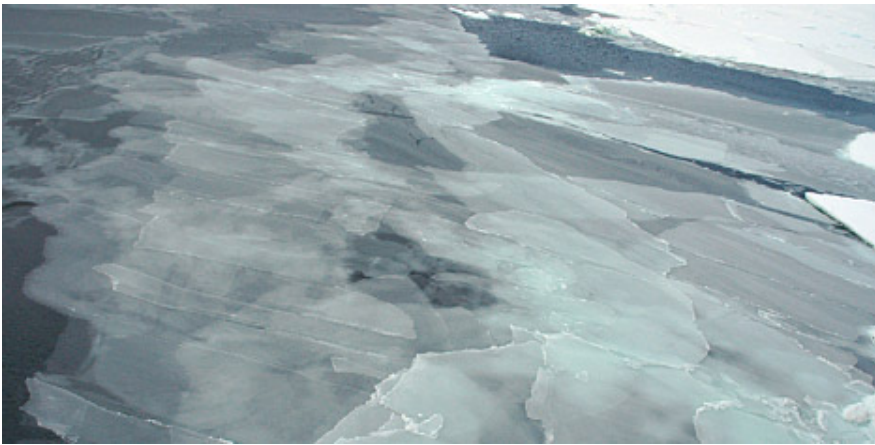


CONCEPTUAL MODEL of Earth System process operating on timescales of decades to centuries



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





thin sheets of smooth nilas in calm water



disks of pancake ice in choppy water

next week

Sea ice

rafts and eventually solidify

Over time, large sheets of ice collide, forming thick pressure ridges



Arctic sea ice



2016 Arctic Maximum (March 24)



2016 Arctic Minimum (September 10)



Sea Ice Concentration (percent)



Energy balance with sea ice

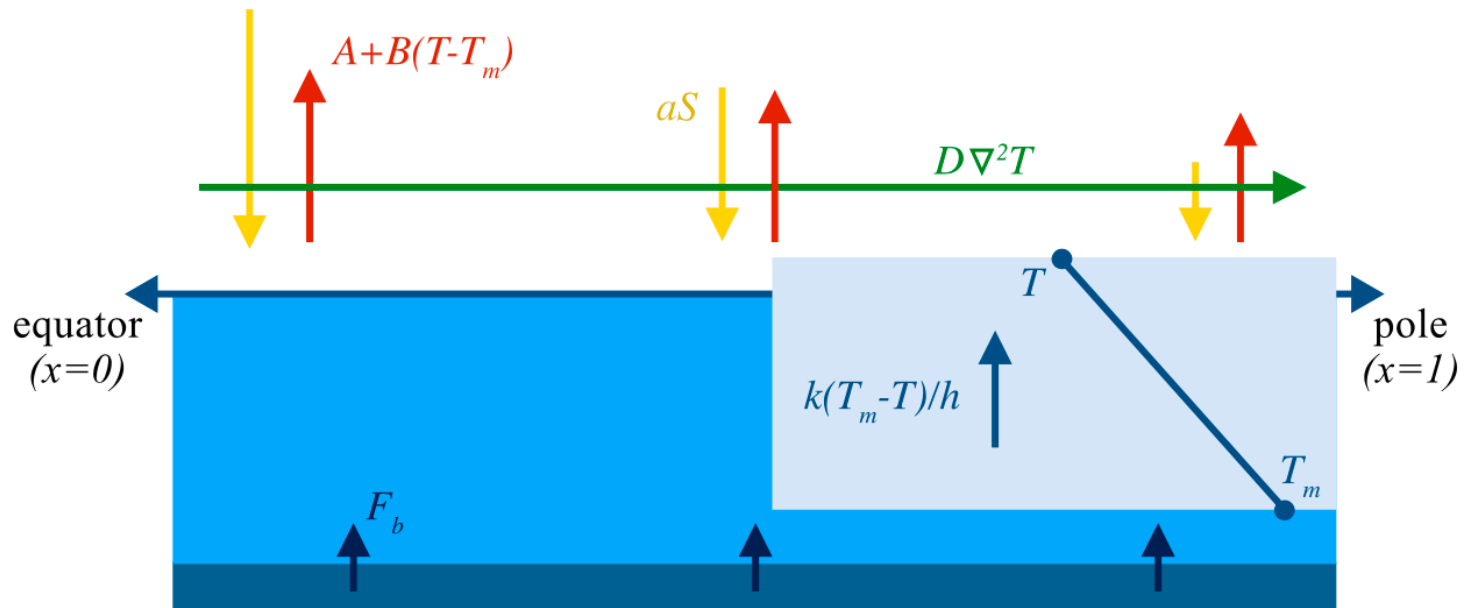
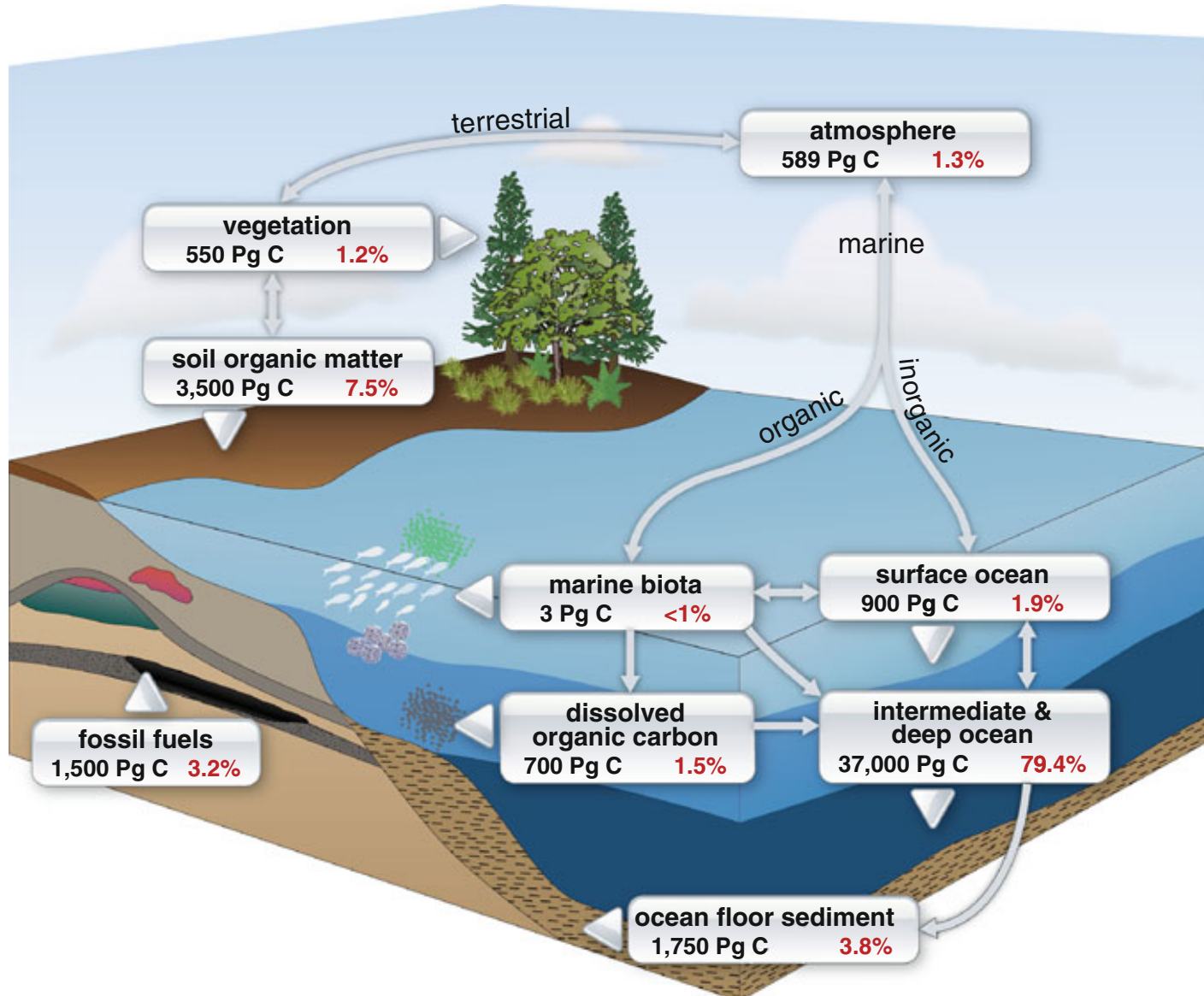
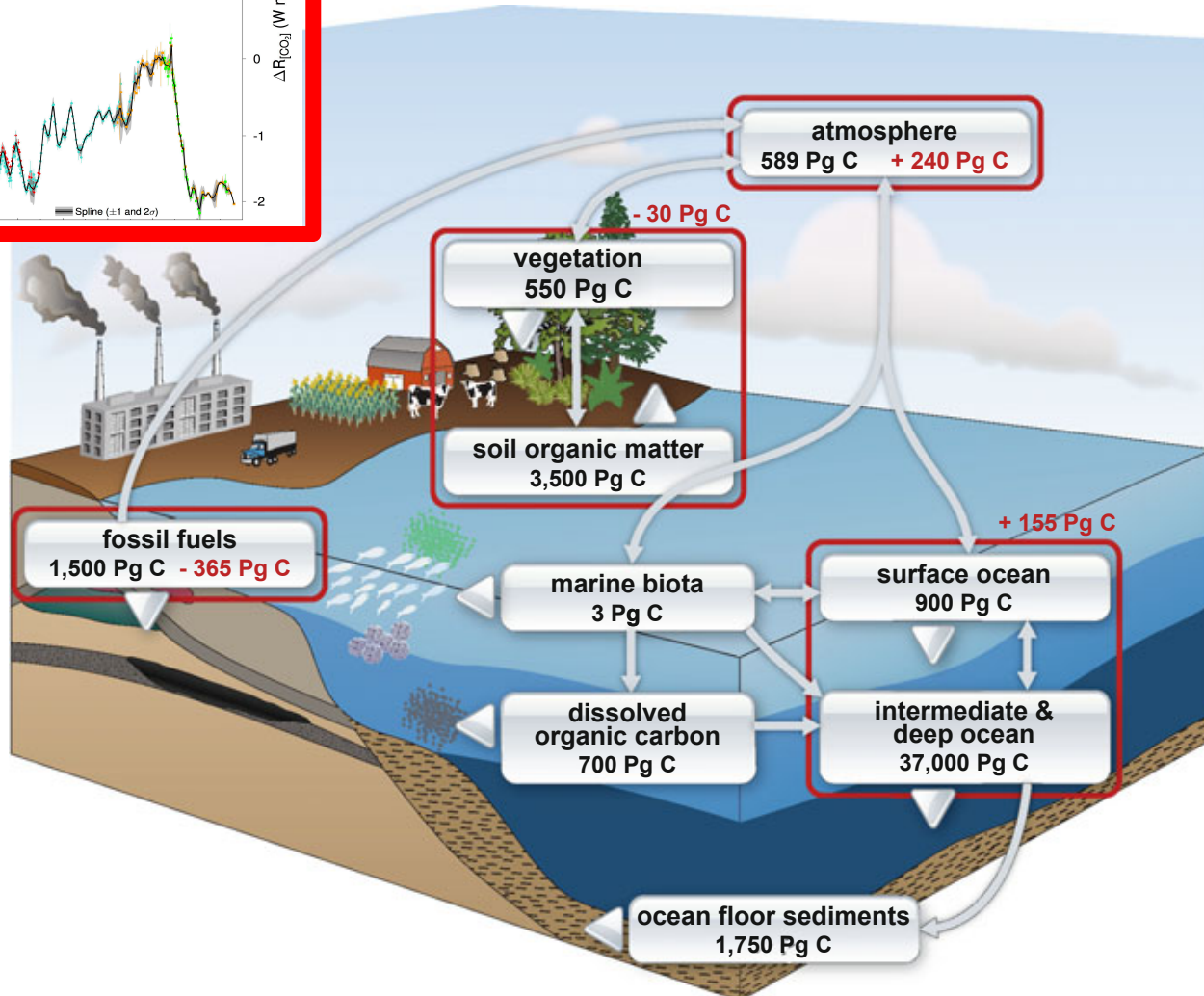
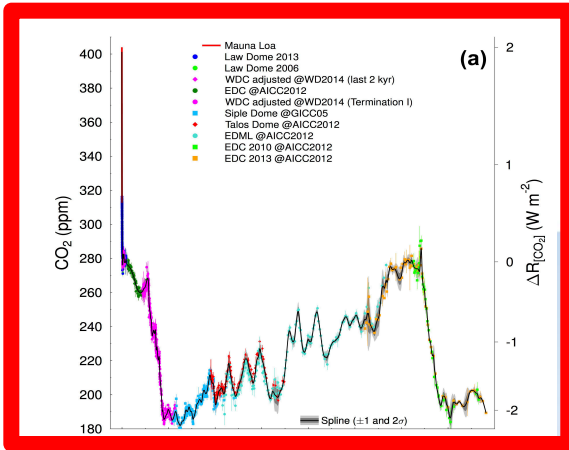


FIG. 1. Schematic of the global model of climate and sea ice described in [section 2](#), showing the fluxes included in the model: insolation (yellow), OLR (red), horizontal heat transport (green), ocean heating (dark blue), and vertical heat flux through the ice (blue). The temperature of the ice is given by T at the surface and T_m at the base.

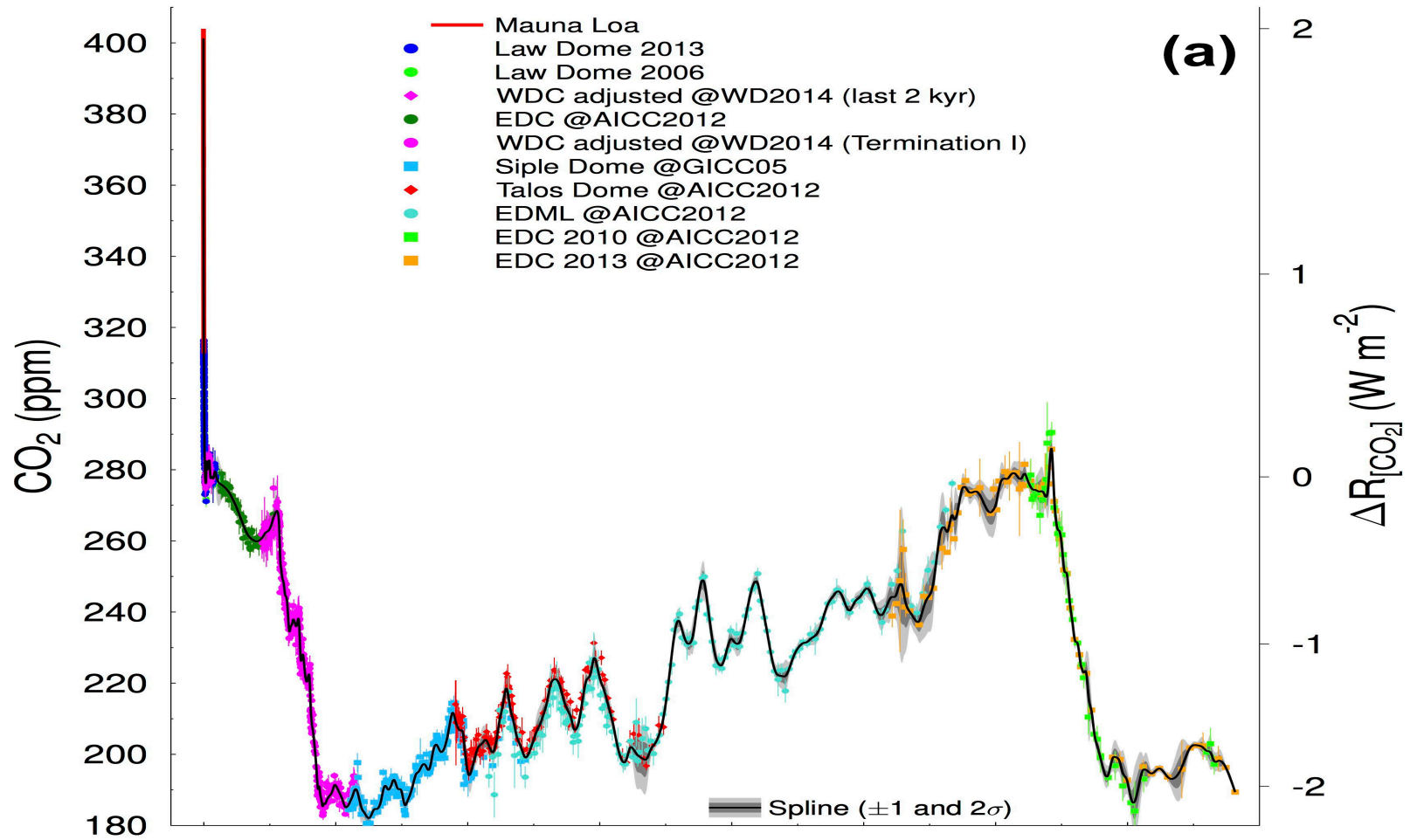
Carbon reservoirs



C reservoirs + perturbation

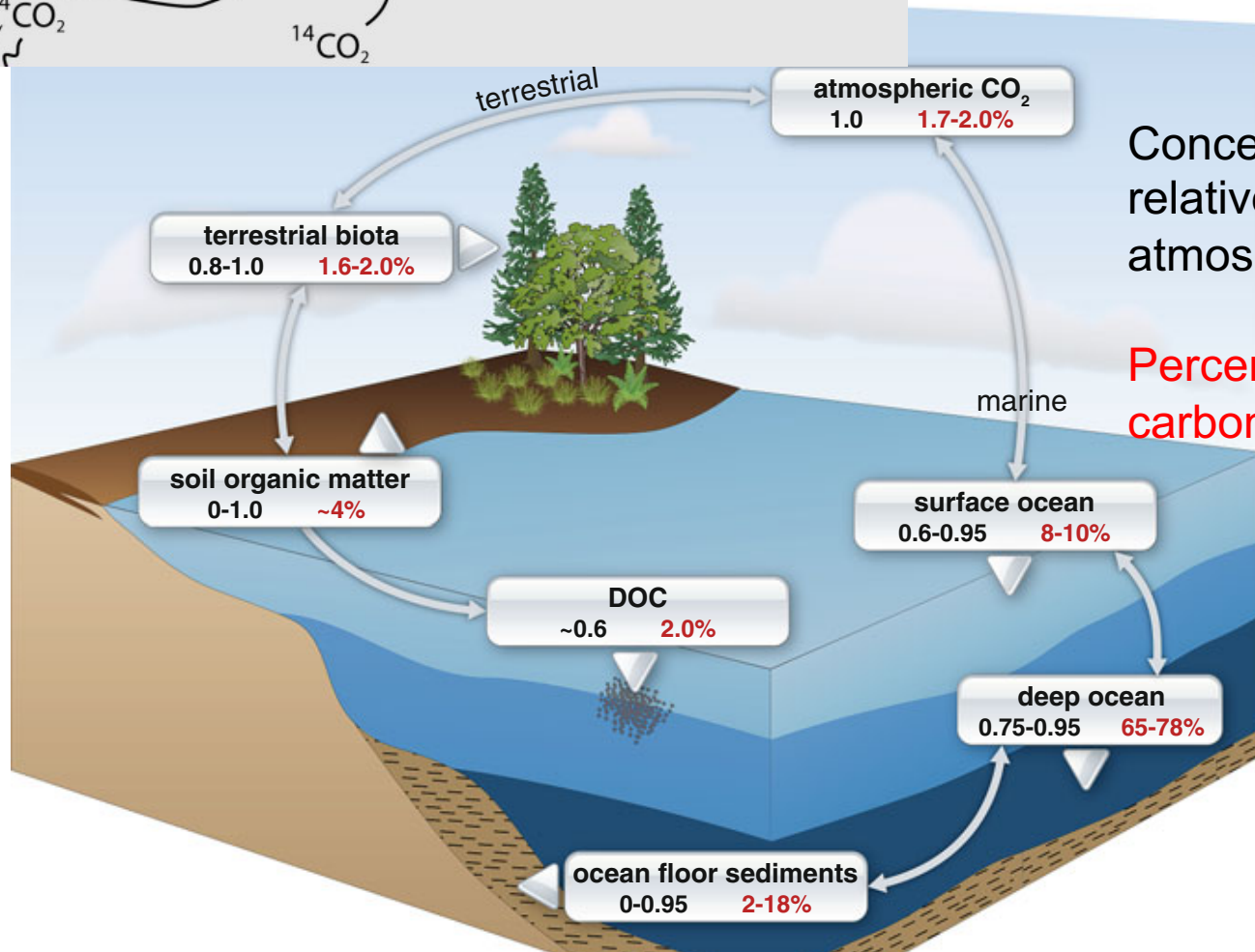
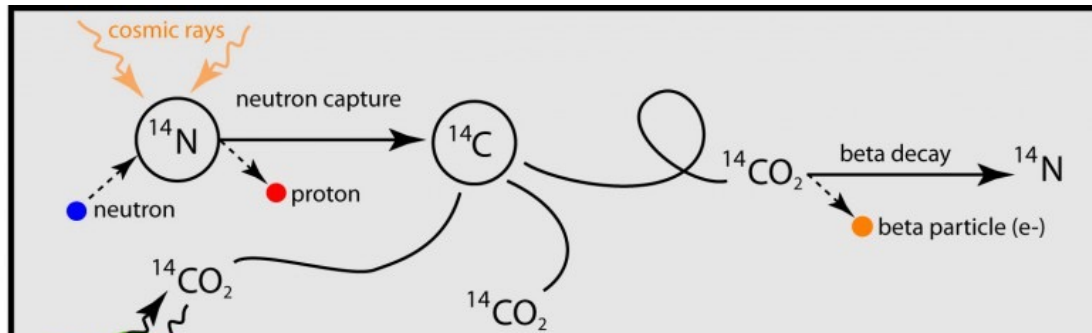


CO₂



Time scale?

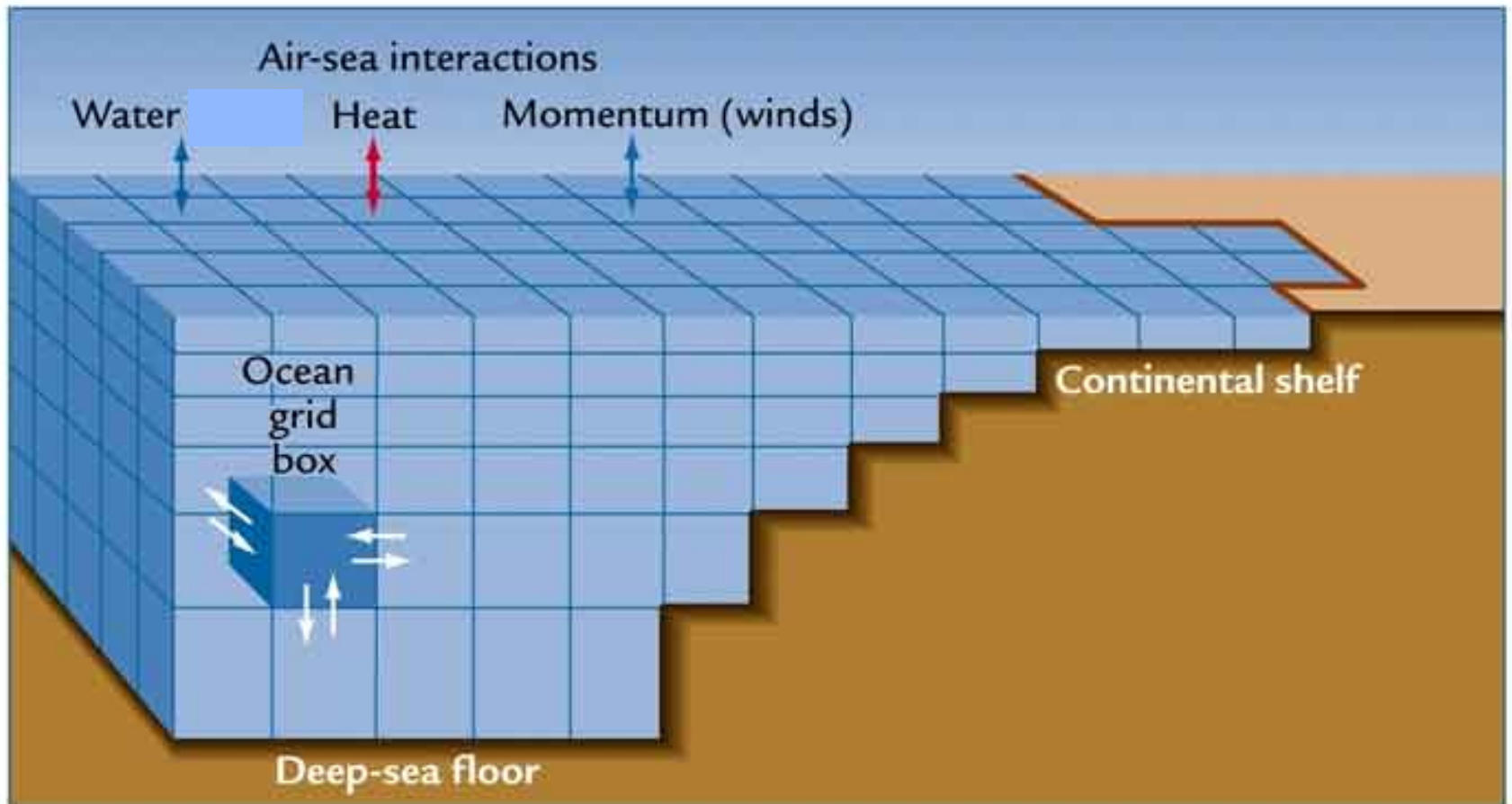
tracer: C-14



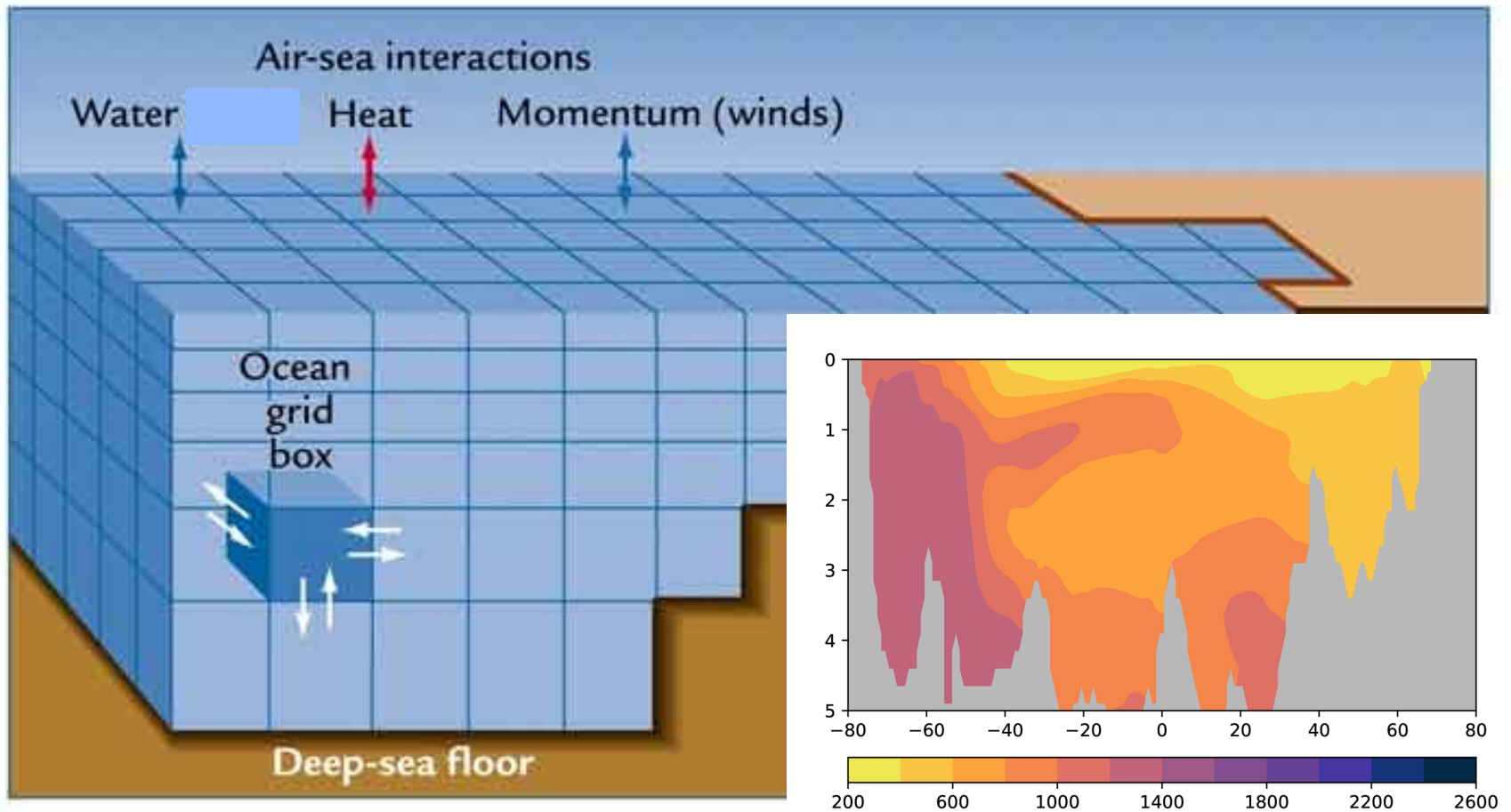
Concentration relative to atmosphere

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

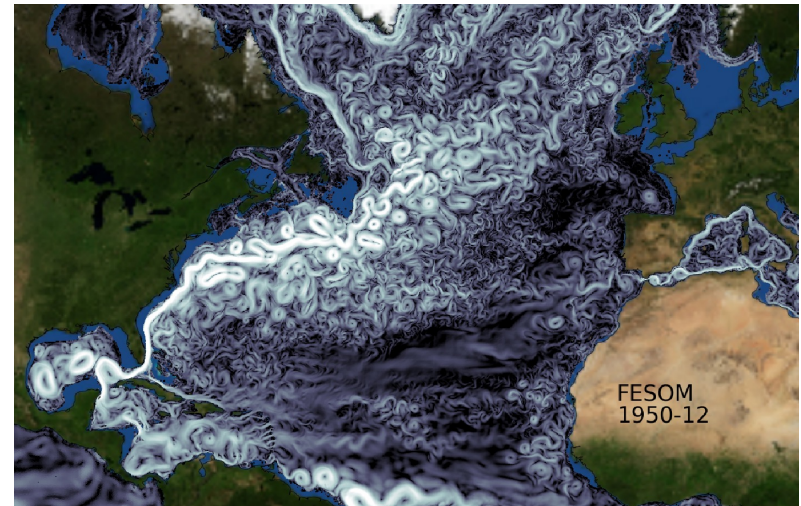
$$\underbrace{\rho \left(\underbrace{\frac{\partial \mathbf{u}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{u} \cdot \nabla \mathbf{u}}_{\text{Advective acceleration}} \right)}_{\text{Inertia (per volume)}} = \underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu \nabla^2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

$$D_t[\vec{v}] = \frac{1}{\rho} \nabla p + \text{Wind stress}$$

$$D_t[T] = \text{heat flux}$$

$$D_t[S] = \text{freshwater flux}$$

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



Climate-Radiocarbon Dynamics

Carbon

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

Radiocarbon

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

Ratio

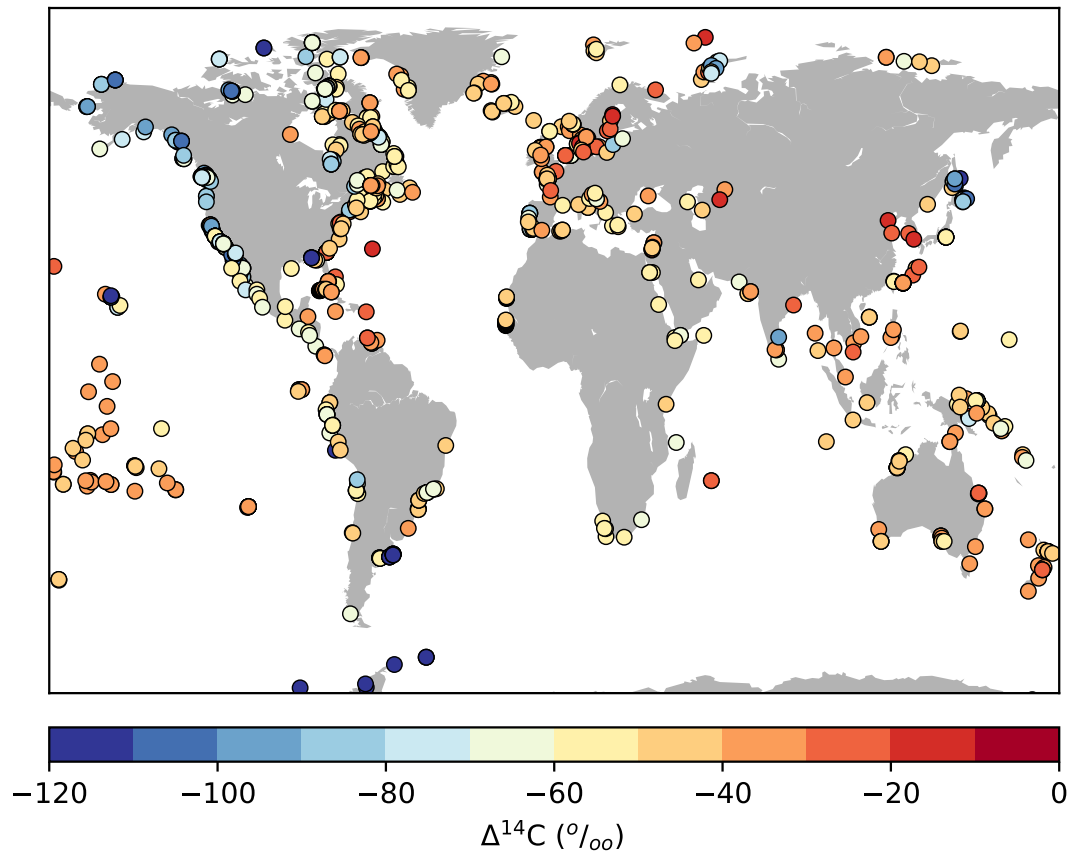
$$R = \frac{{}^{14}\text{C}}{\text{C}}$$

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

Ratio can be treated as a radio-conservative tracer

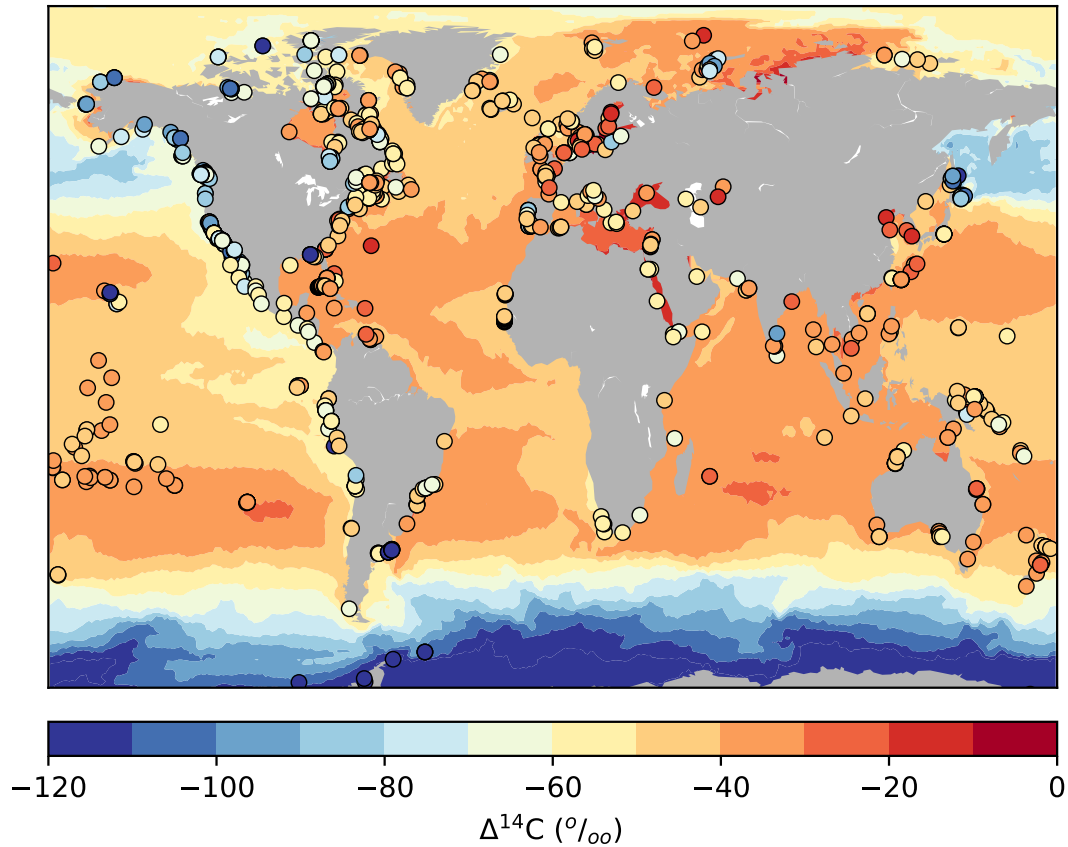
^{14}C in the surface ocean: Reconstructions

Pre-industrial



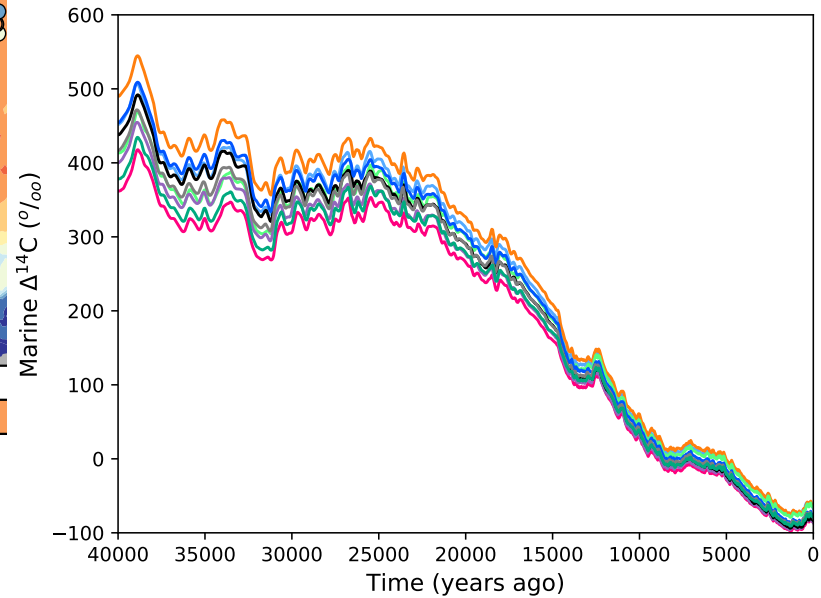
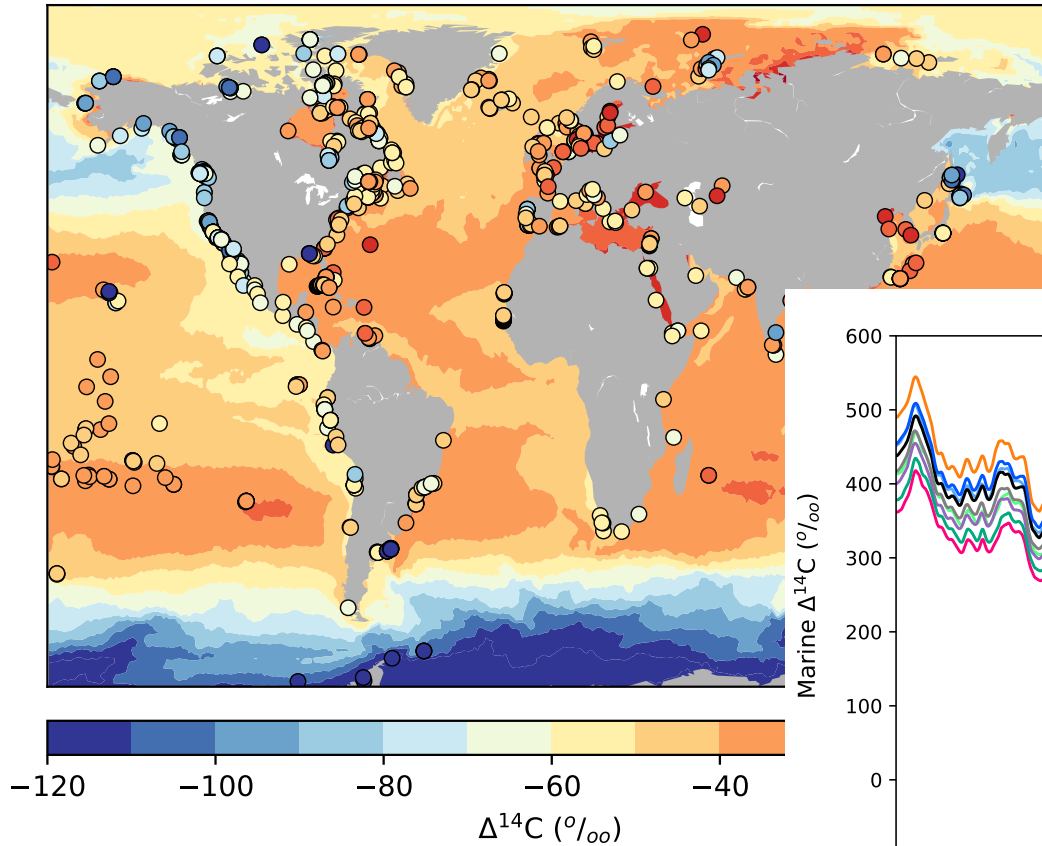
^{14}C in the surface ocean: Simulation

Pre-industrial



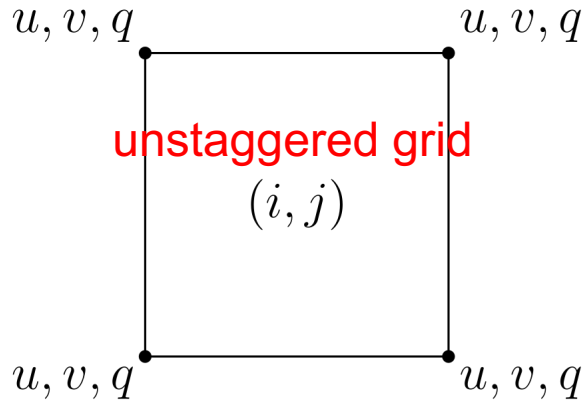
Paleo-reanalysis: Filling the gaps in space

^{14}C in the surface ocean: Simulations

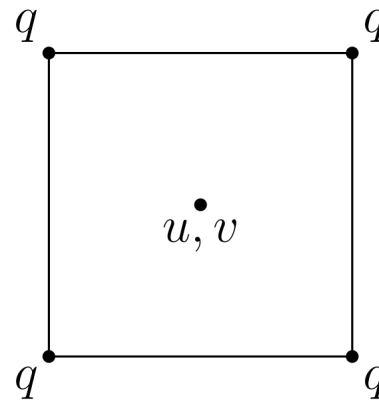


Paleo-reanalysis: Filling the gaps in space and time

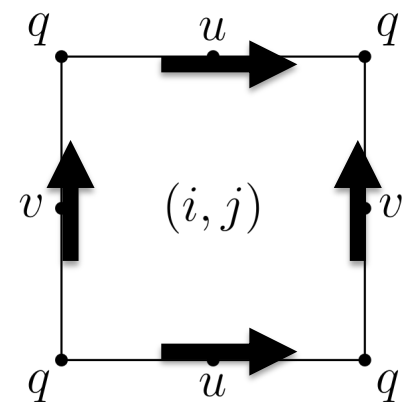
2D Staggered grids: Arakawa



(A)

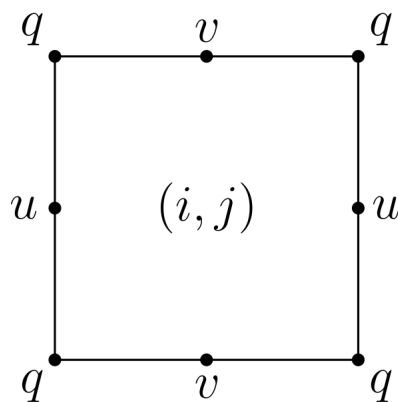


(B)

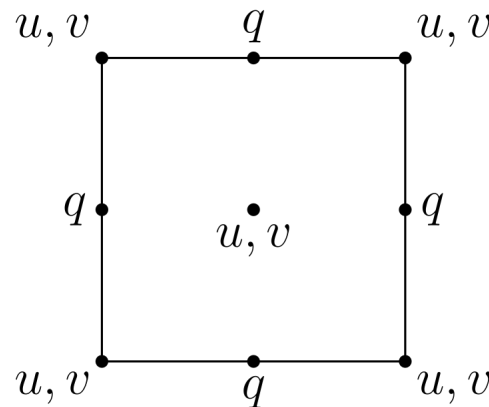


(C)

Advection of tracers



(D) „Rotated C“



(E)

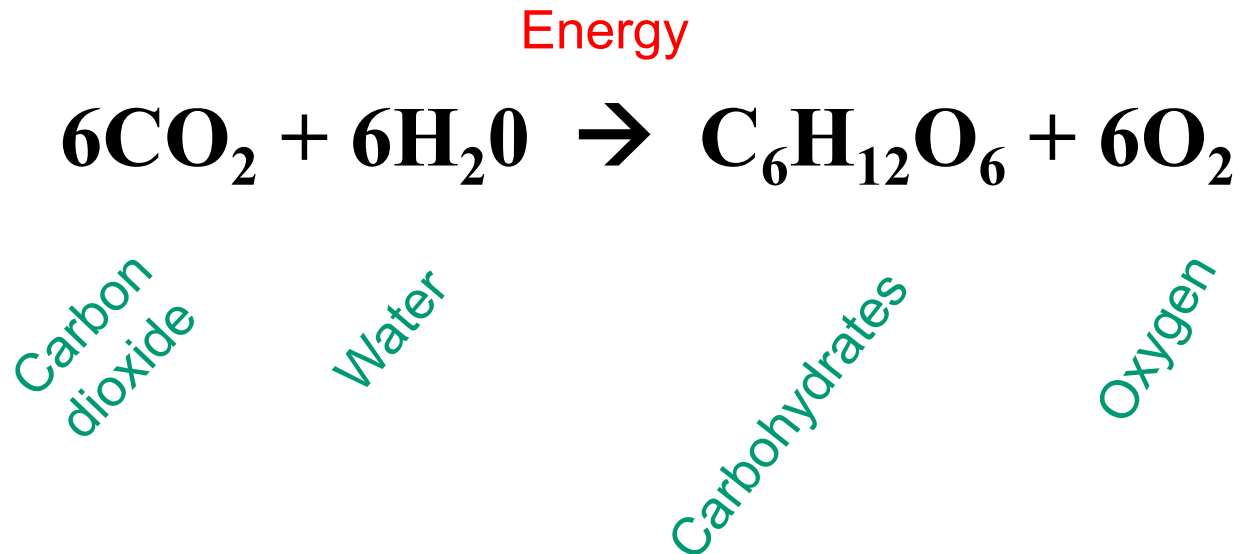


The Carbon Cycle

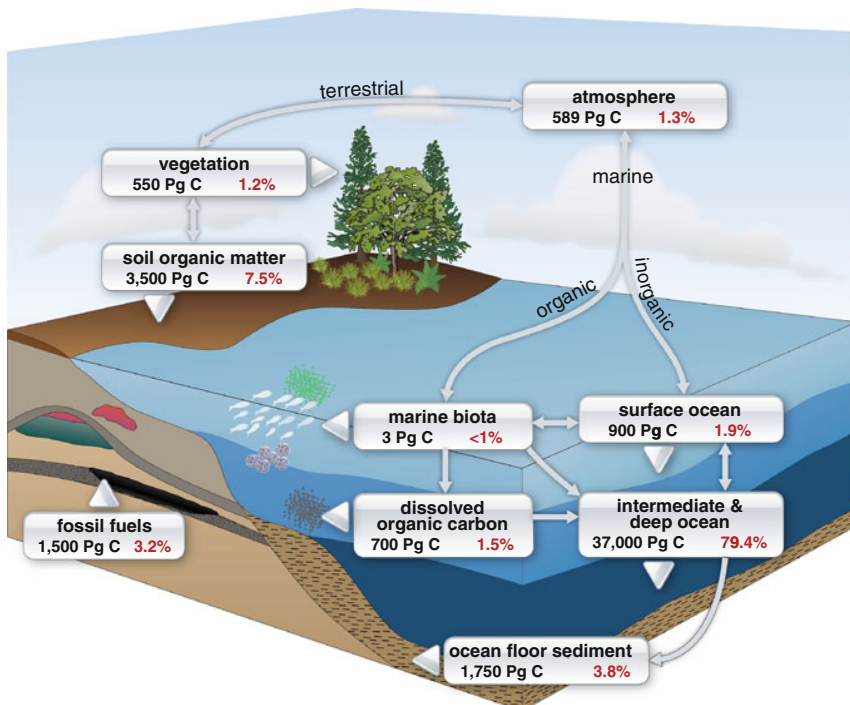
- Carbon is the key element for **living** things.
- Carbon in the atmosphere and dissolved in the oceans as part of the inorganic CO_2
- CO_2 is recycled into more complex organic substances through **photosynthesis**.



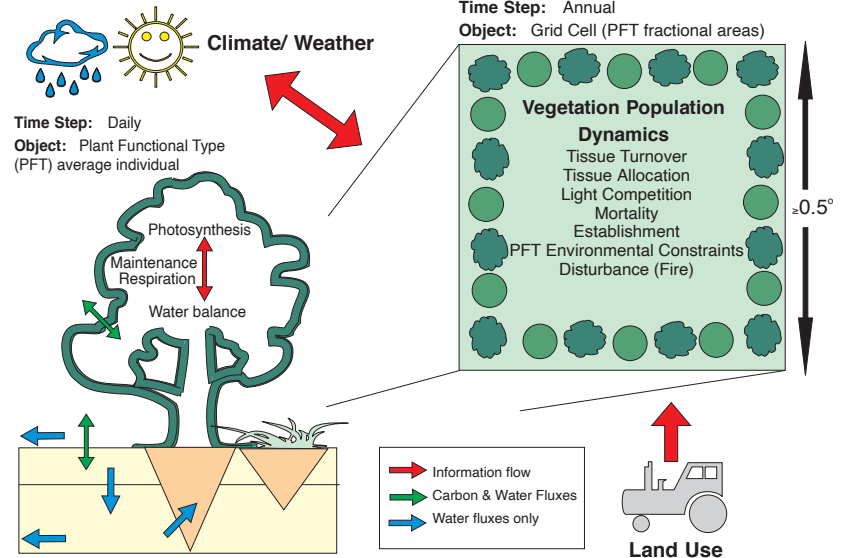
- **Photosynthesis** – process by which green plants make their own food from **water**, carbon dioxide, and light energy, producing sugar (stored energy) and oxygen (a by-product).
- The general equation for photosynthesis is:



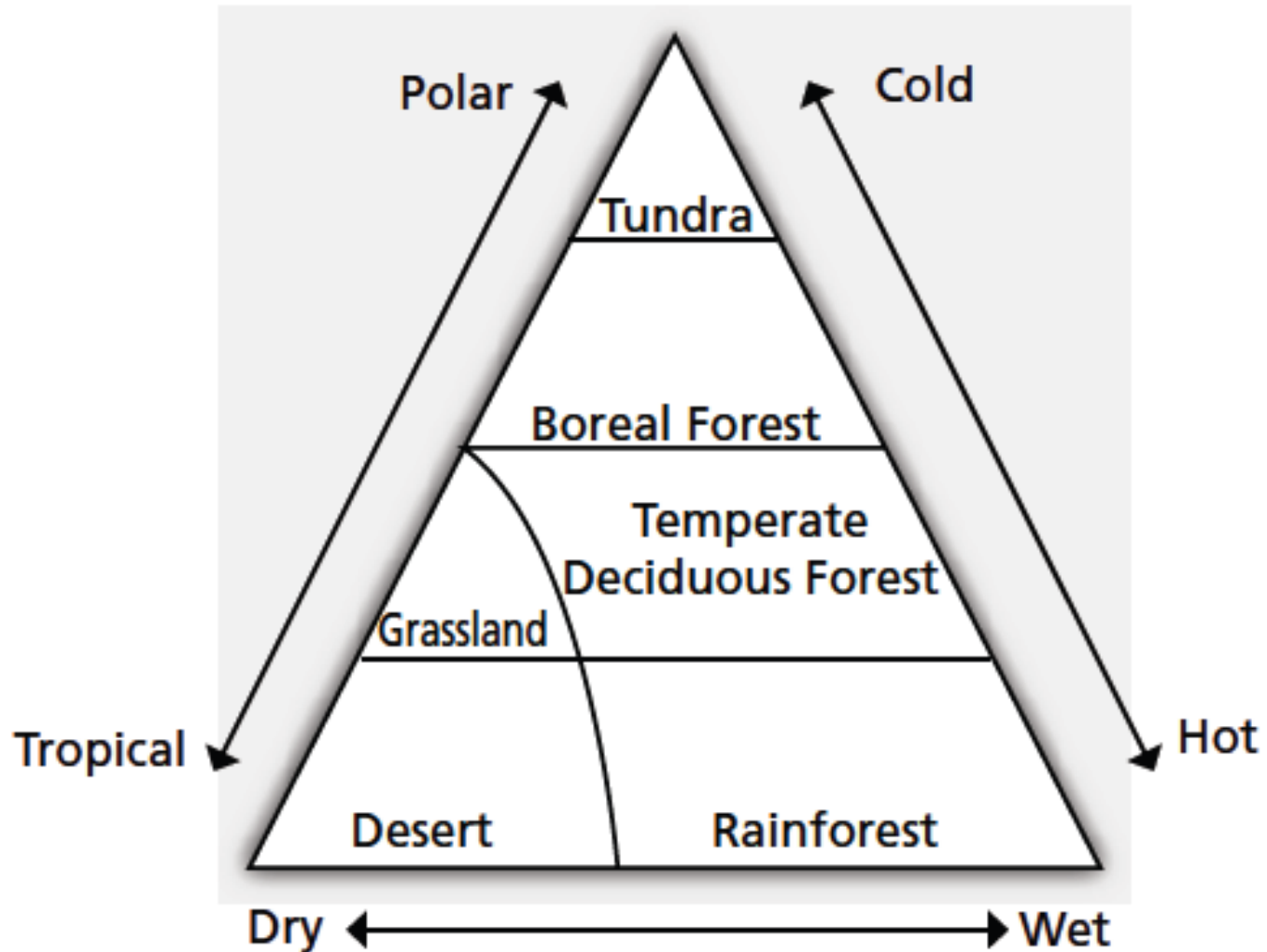
Earth system models including tracers and dynamical vegetation



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



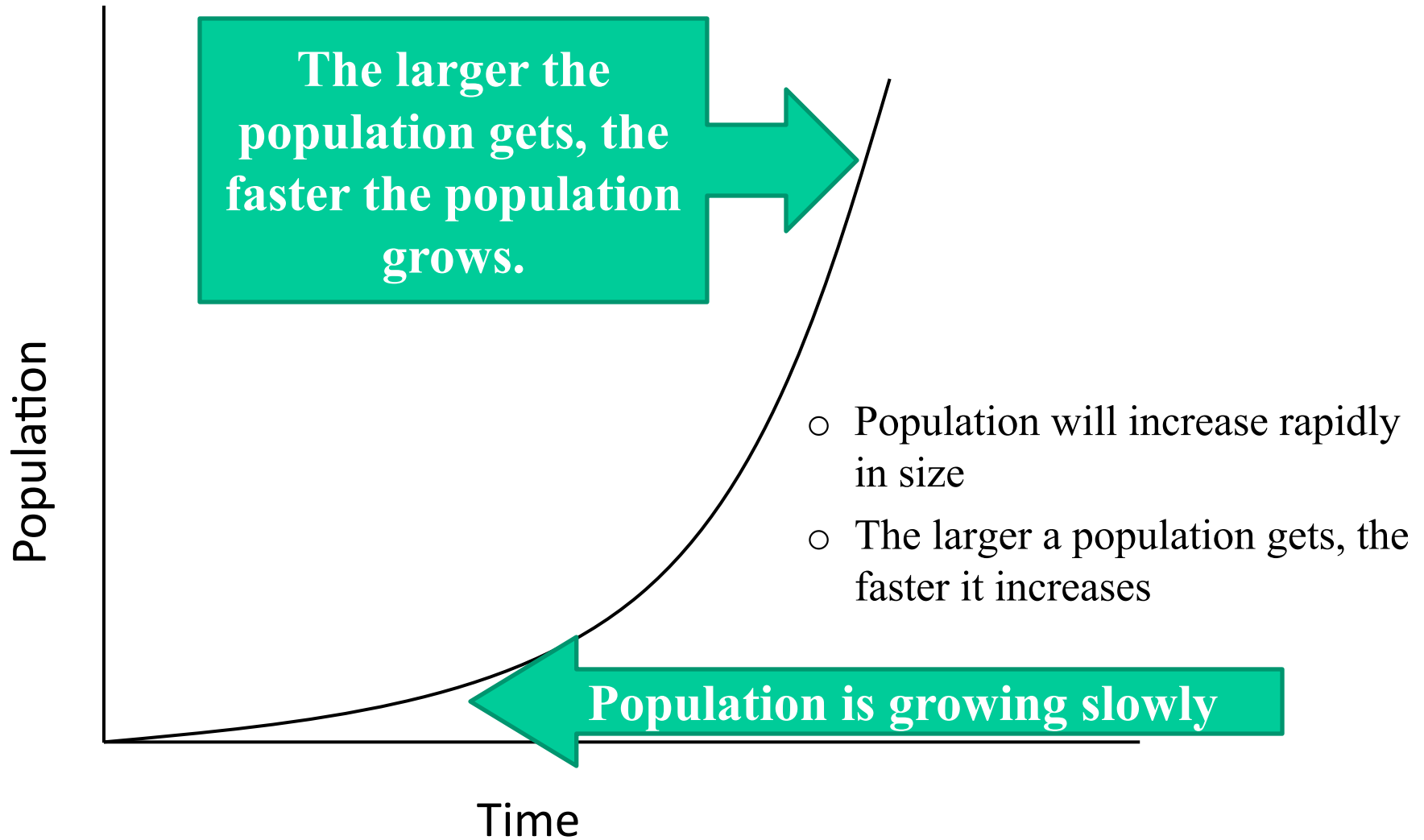
Vegetation & Ecosystem

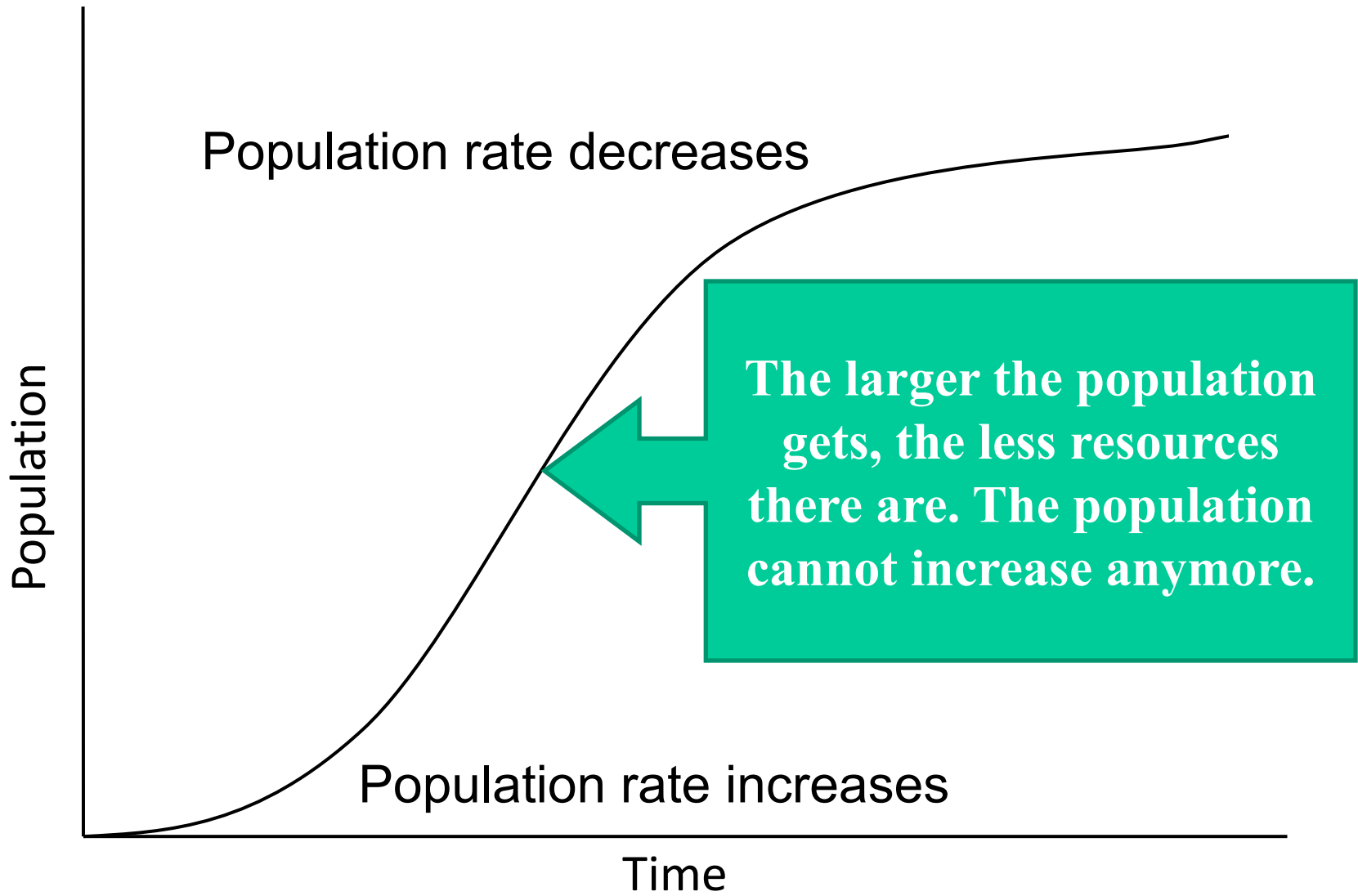


Human Impact

1. **Deforestation** – cutting down forests has reduced the amount of plants available for photosynthesis, which means that less CO₂ can be removed from the atmosphere.
2. **Burning (combustion) of fossil fuels** – gasoline, coal, and natural gas contain carbon and when burned, they release CO₂ into the Earth's lower atmosphere. There is concern that the increase in CO₂ will lead to global warming.

Population Growth (ideal conditions)



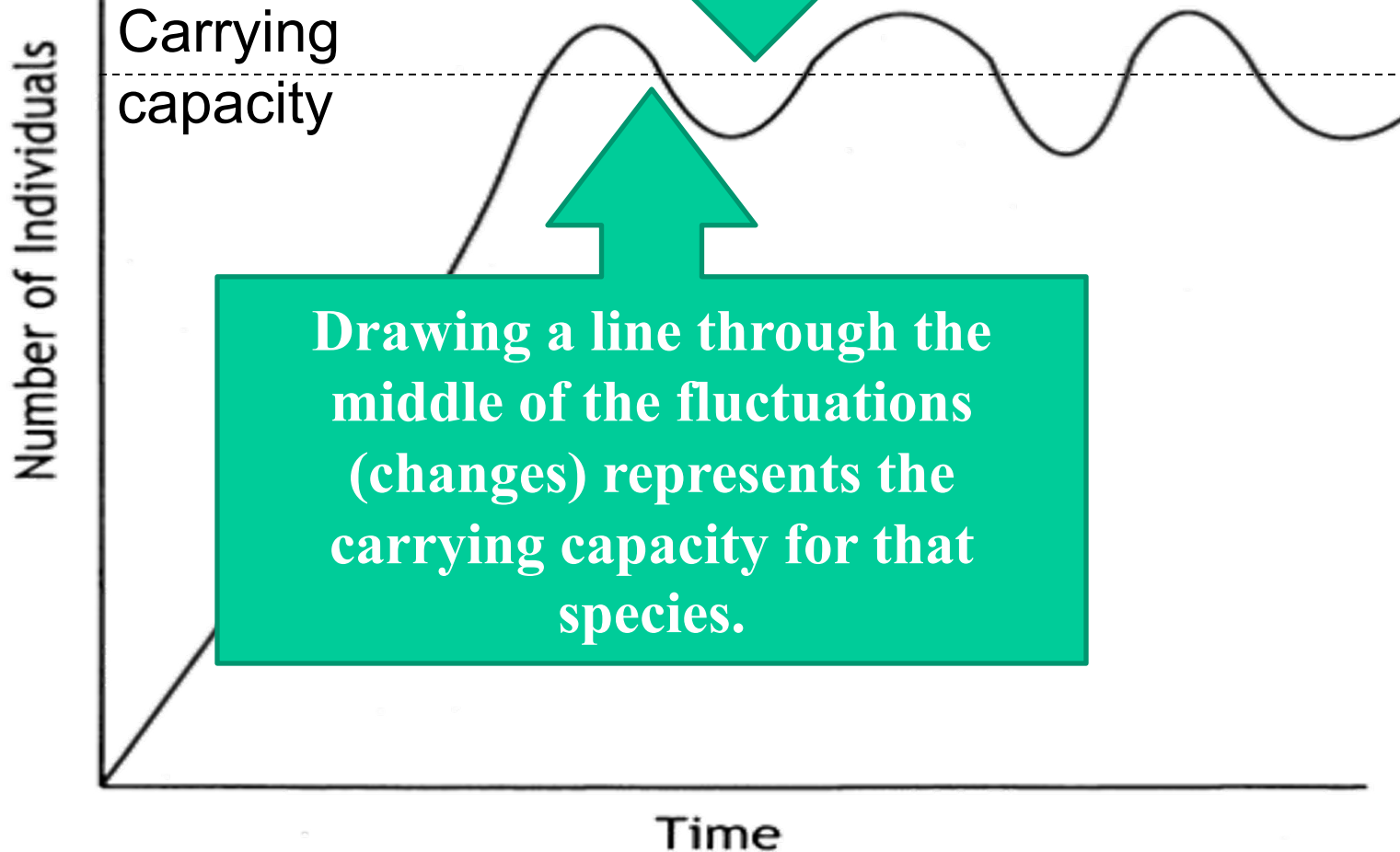


Limiting Factors

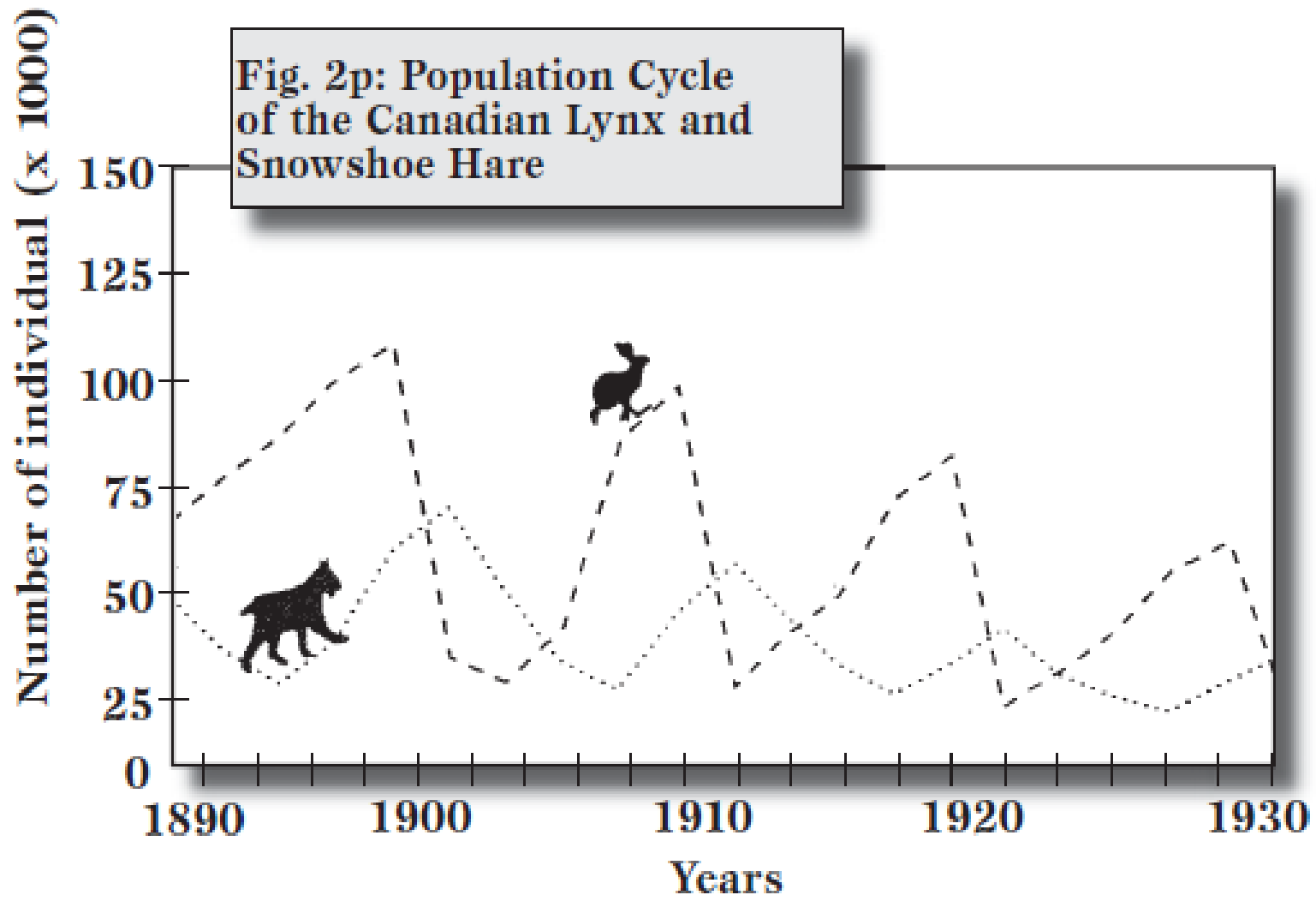
- The environment provides factors that prevent populations from attaining their biotic potential. Any resource that is in short supply is a limiting factor such as food, water, territory, and the presence of pollutants.



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.



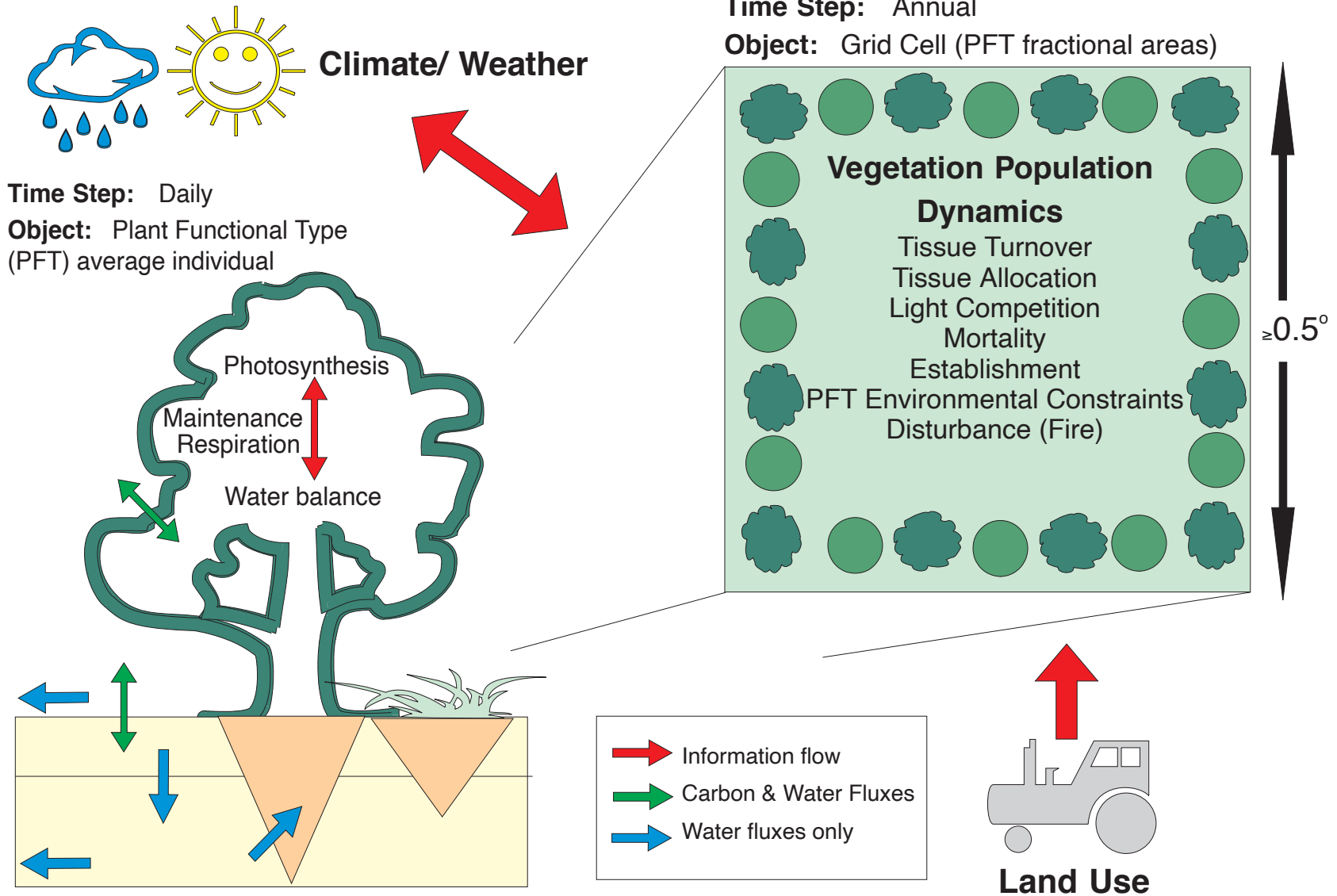


Dynamical vegetation models

- regional climate conditions and atmospheric CO₂
- 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.

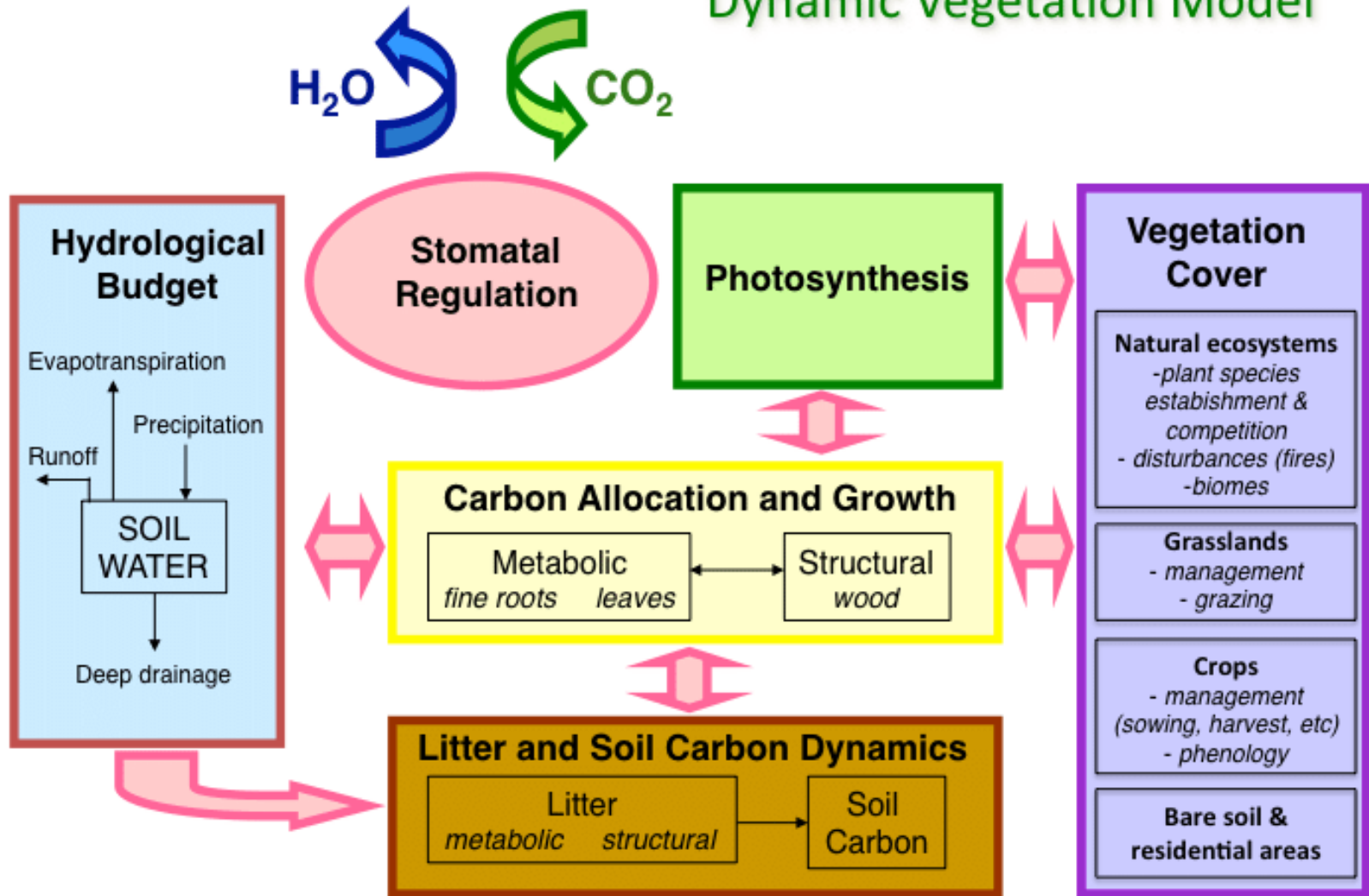
The Lund-Potsdam-Jena Dynamic Global Vegetation Model (DGVM)



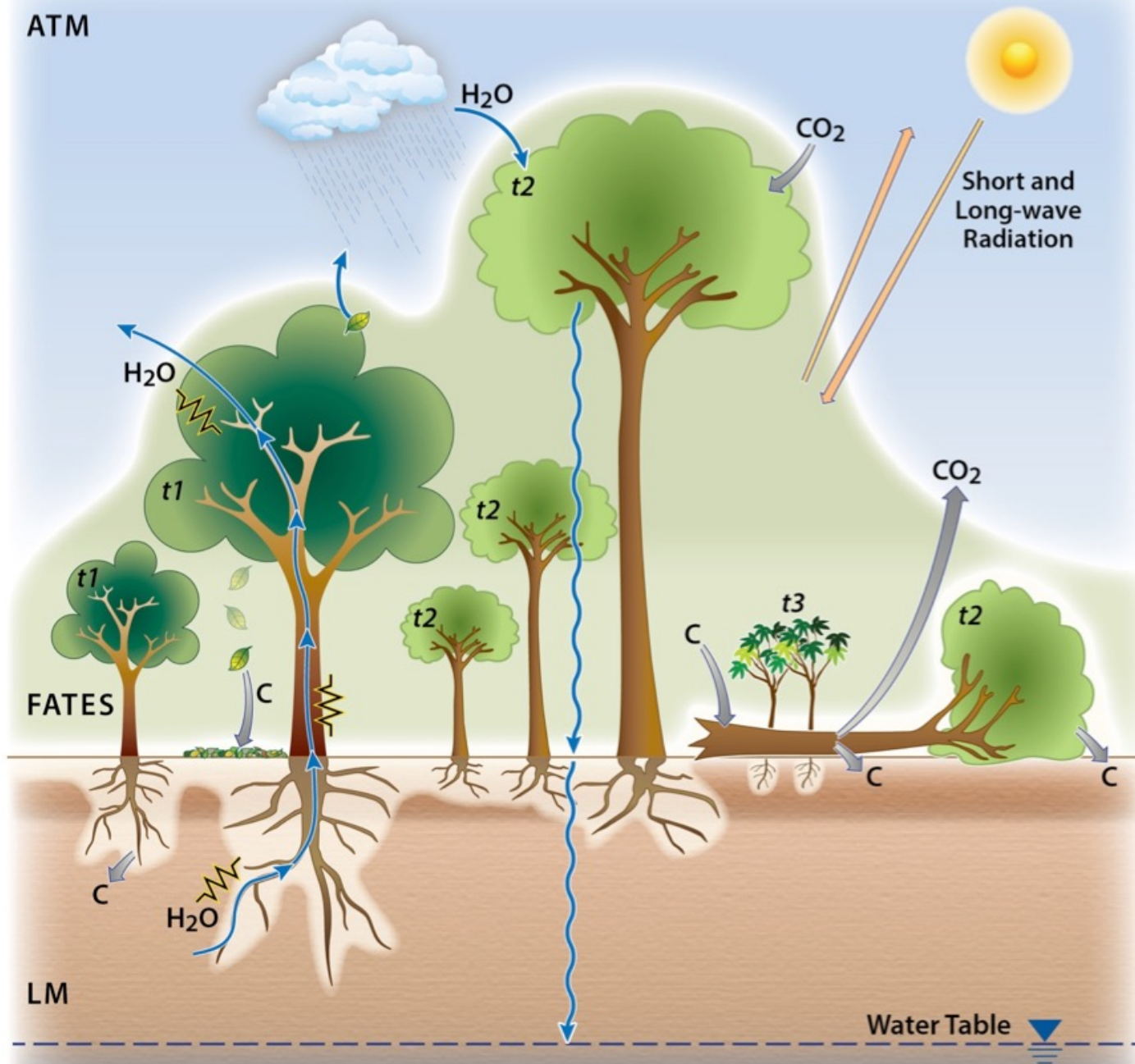


CARAIB

Dynamic Vegetation Model

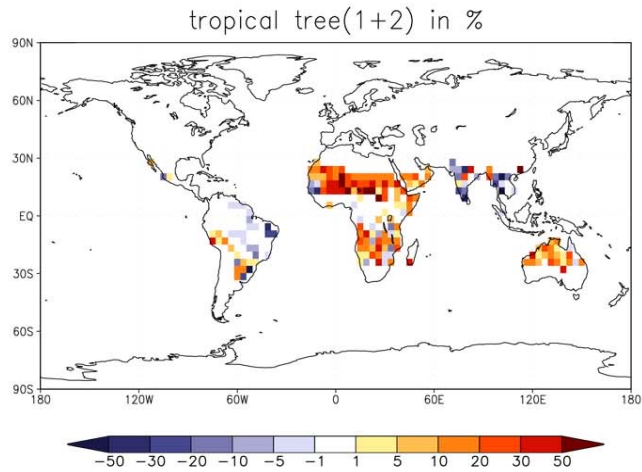


ATM

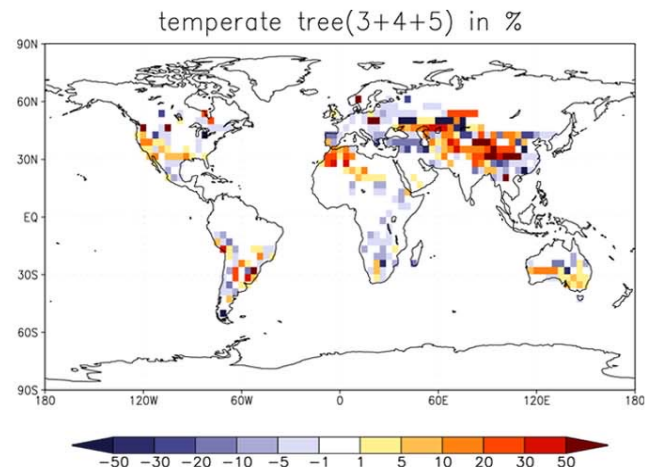


Typical output of a vegetation model

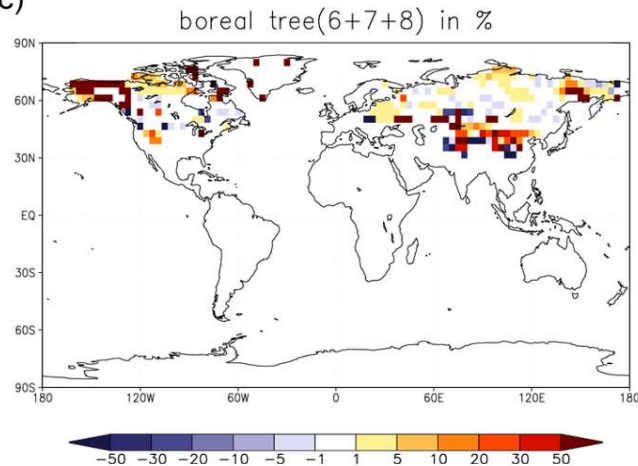
a)



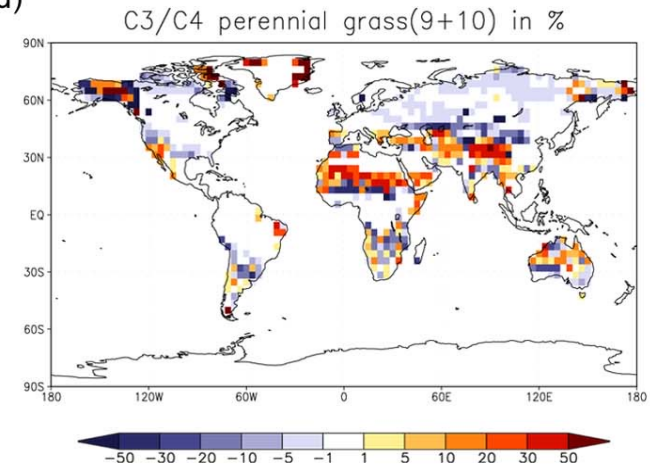
b)



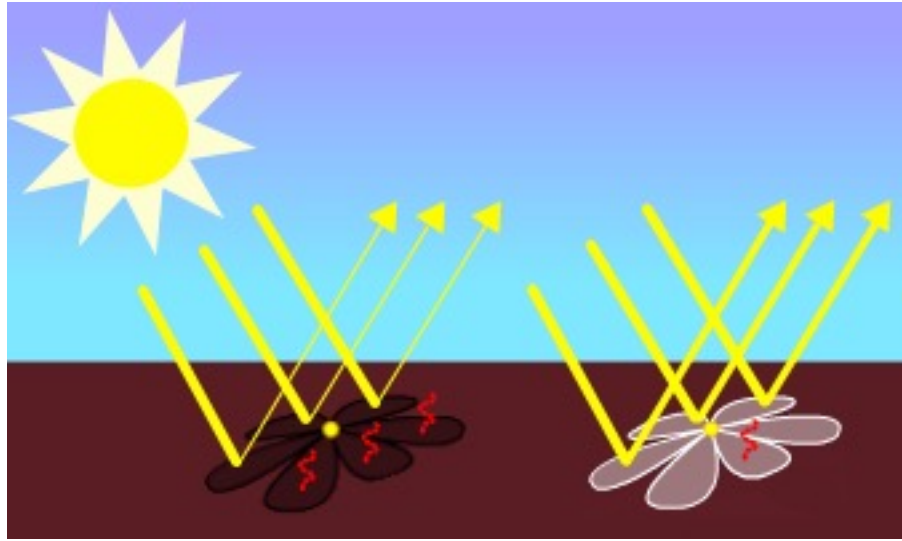
c)



d)

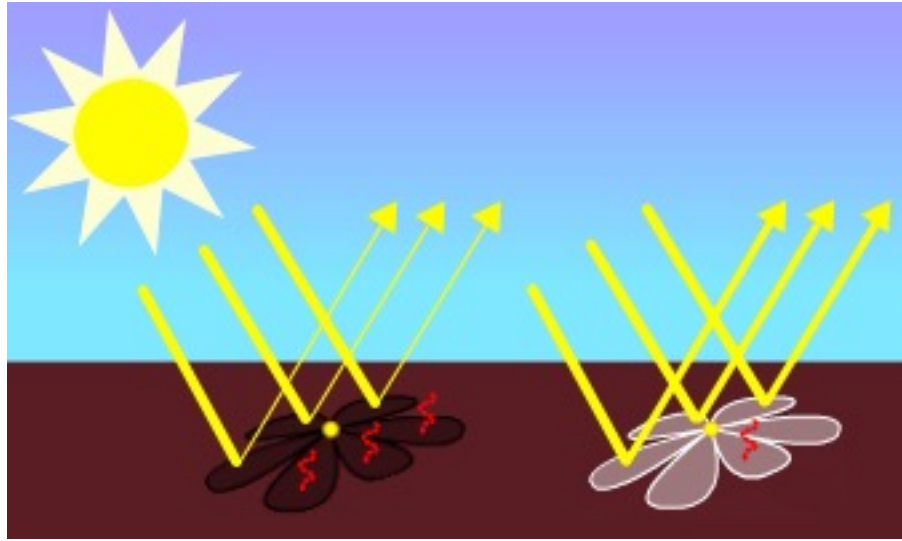


Daisy World & the Gaia Hypothesis



Sunlight reflects off different color daisies.
Black daisies absorb most light, turning it into heat.
White daisies reflect most light, and stay cooler.

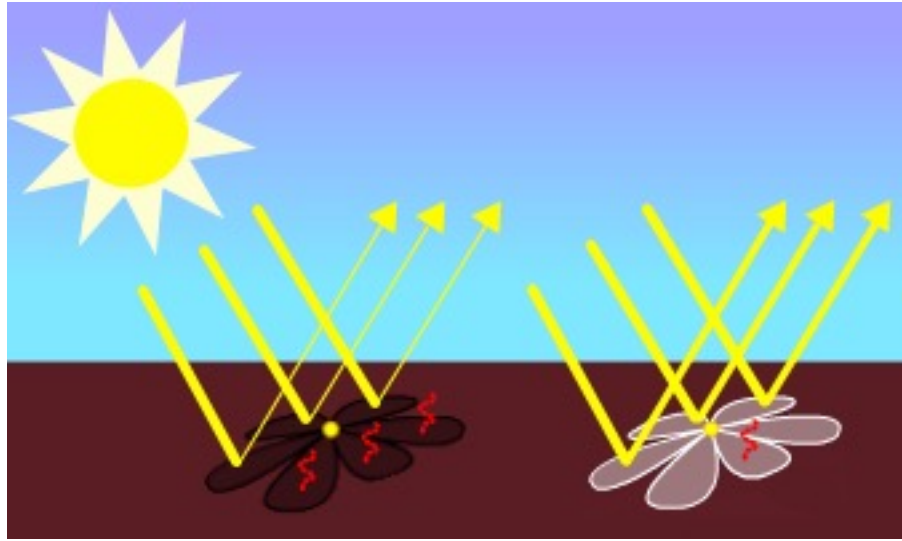
Daisy World & the Gaia Hypothesis



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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.

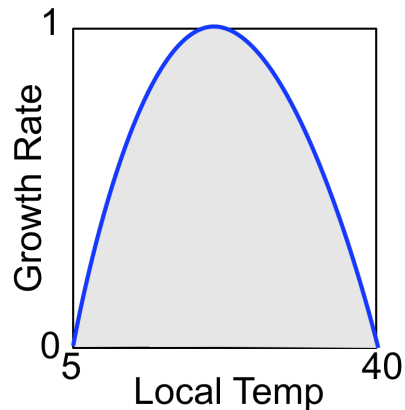
Daisy World & the Gaia Hypothesis



Sunlight reflects off different color daisies.
Black daisies absorb most light, turning it into heat.
White daisies reflect most light, and stay cooler.

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. 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

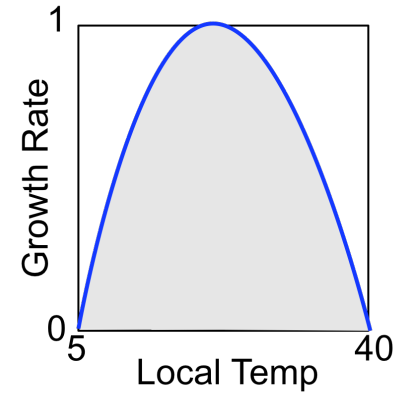
$$\frac{\partial a_w}{\partial t} = a_w [a_g \beta(T_w) - \gamma]$$

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

Vegetation Model

Growth rate is temperature dependent

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





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

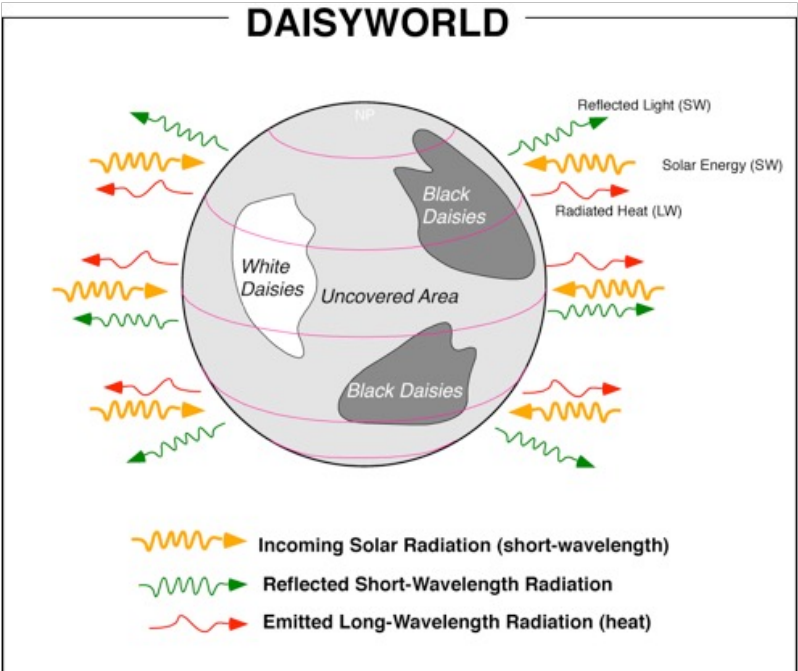
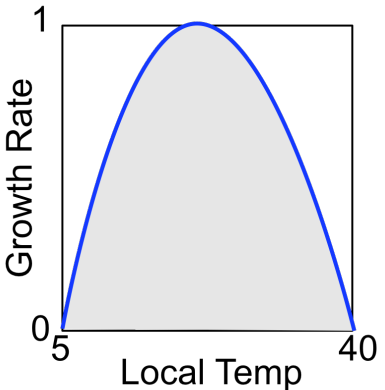
$$\frac{\partial a_w}{\partial t} = a_w [a_g \beta(T_w) - \gamma]$$

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Vegetation Model

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

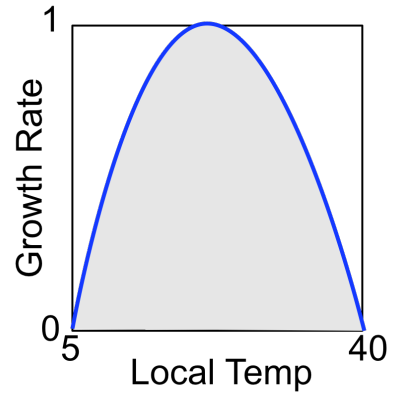
$$\frac{\partial a_w}{\partial t} = a_w [a_g \beta(T_w) - \gamma]$$

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

Vegetation Model

Growth rate is temperature dependent

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



Planetary albedo

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

Global 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

$q=2.06 \times 10^9 \text{ K}^4$ is a heat transfer coefficient



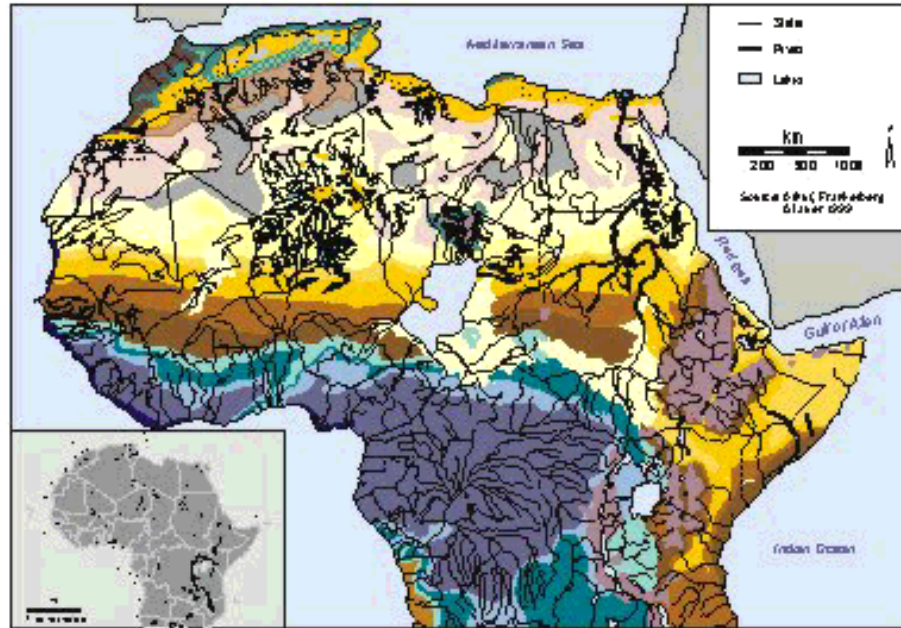
Exercise I

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](http://www.climate.be/textbook/daisyworld.html) at <http://www.climate.be/textbook/daisyworld.html>

https://paleodyn.uni-bremen.de/study/MES/MES_Vegetation_2022.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 ?

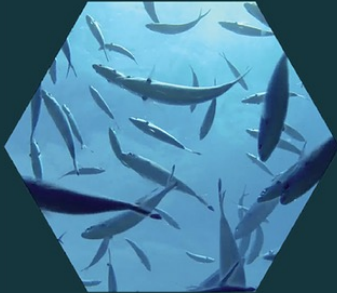
Vegetation Dynamics



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.greenthessinai.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)].

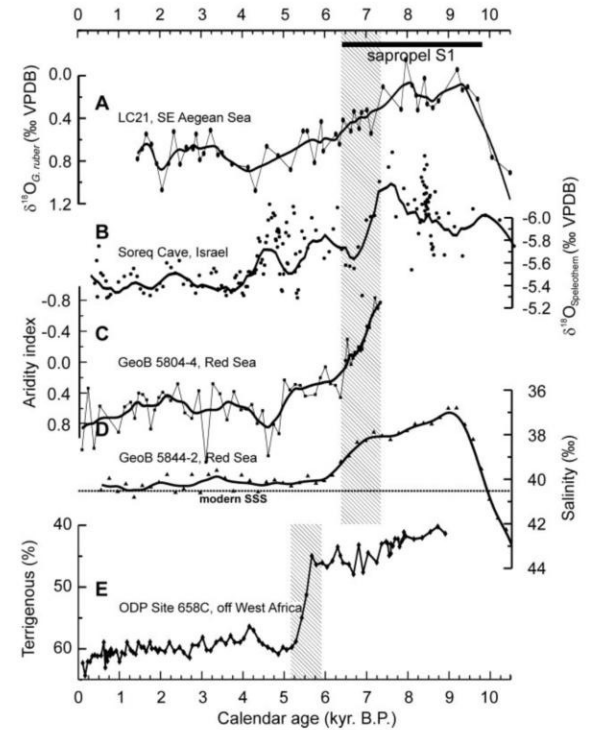
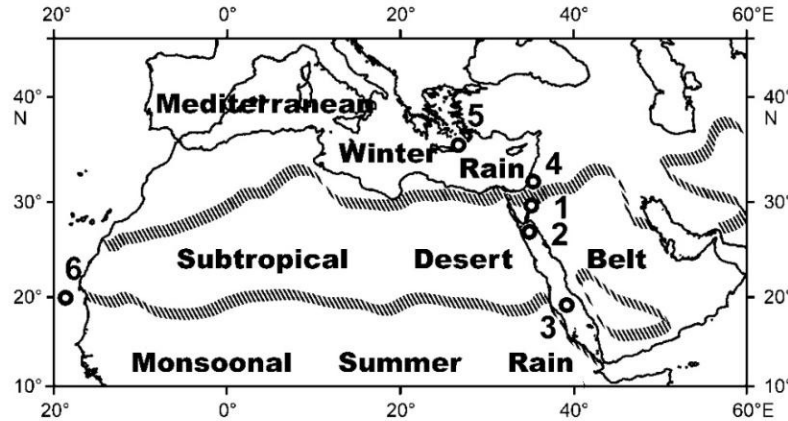


Fig. 3. Timing of the early- to mid-Holocene humid interval in the northern Red Sea compared with proxy records from the eastern Mediterranean, southern Oman, and West Africa. (A) $\delta^{18}\text{O}$ record of *G. ruber* (white) of the southeast Aegean Sea core LC21 (29), marking the enhanced freshwater flux to the eastern Mediterranean Sea. Black bar indicates the extent of anoxic sedimentation in LC21, representing sapropel S1. (B) $\delta^{18}\text{O}$ speleothen 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.

The Loess plateau in northern China



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



Exercise III

Random Systems

1. Simulate the velocity evolution of one particle which is determined by the following stochastic $dx/dt = -bx + kW(t)$
2. What happens if you change the timestep ?
3. Simulate the ensemble of multiple particles and plot the time evolution of the v-distribution and compare with the diffusion equation !
4. Test the ergodic theorem: time average is equal ensemble average !
5. Have a look at the more complex 2D diffusion equation program. When are the two colors are mixed?

https://paleodyn.uni-bremen.de/study/MES/MES_11.html

