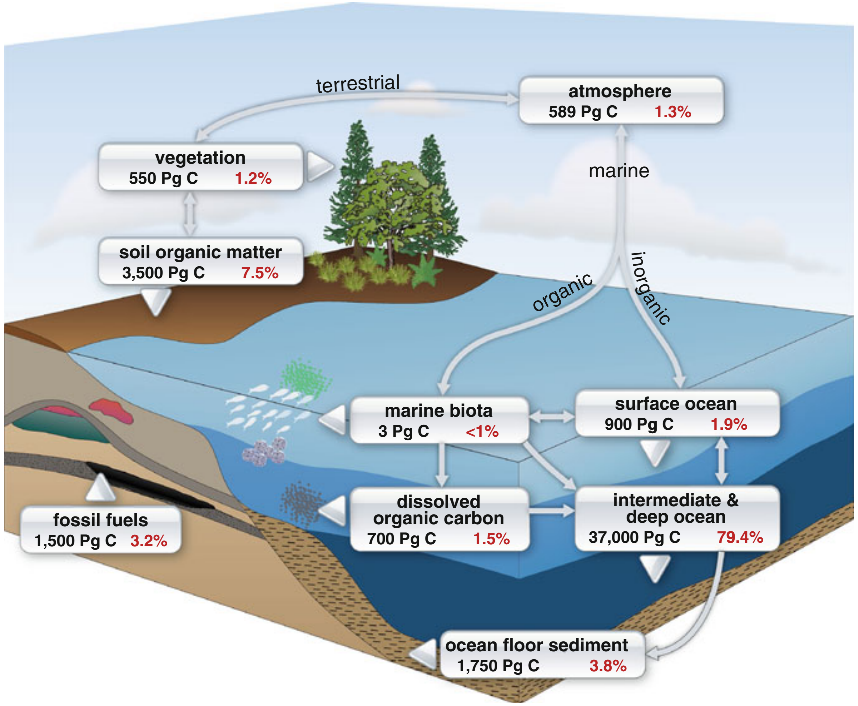
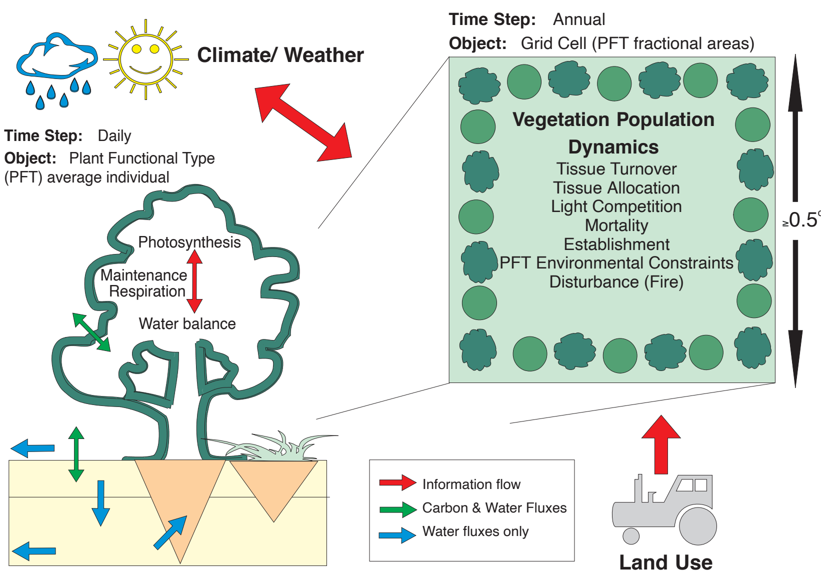
Gerrit Lohmann
MES, 21.06.2021

Earth system models
including tracers and dynamical vegetation



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



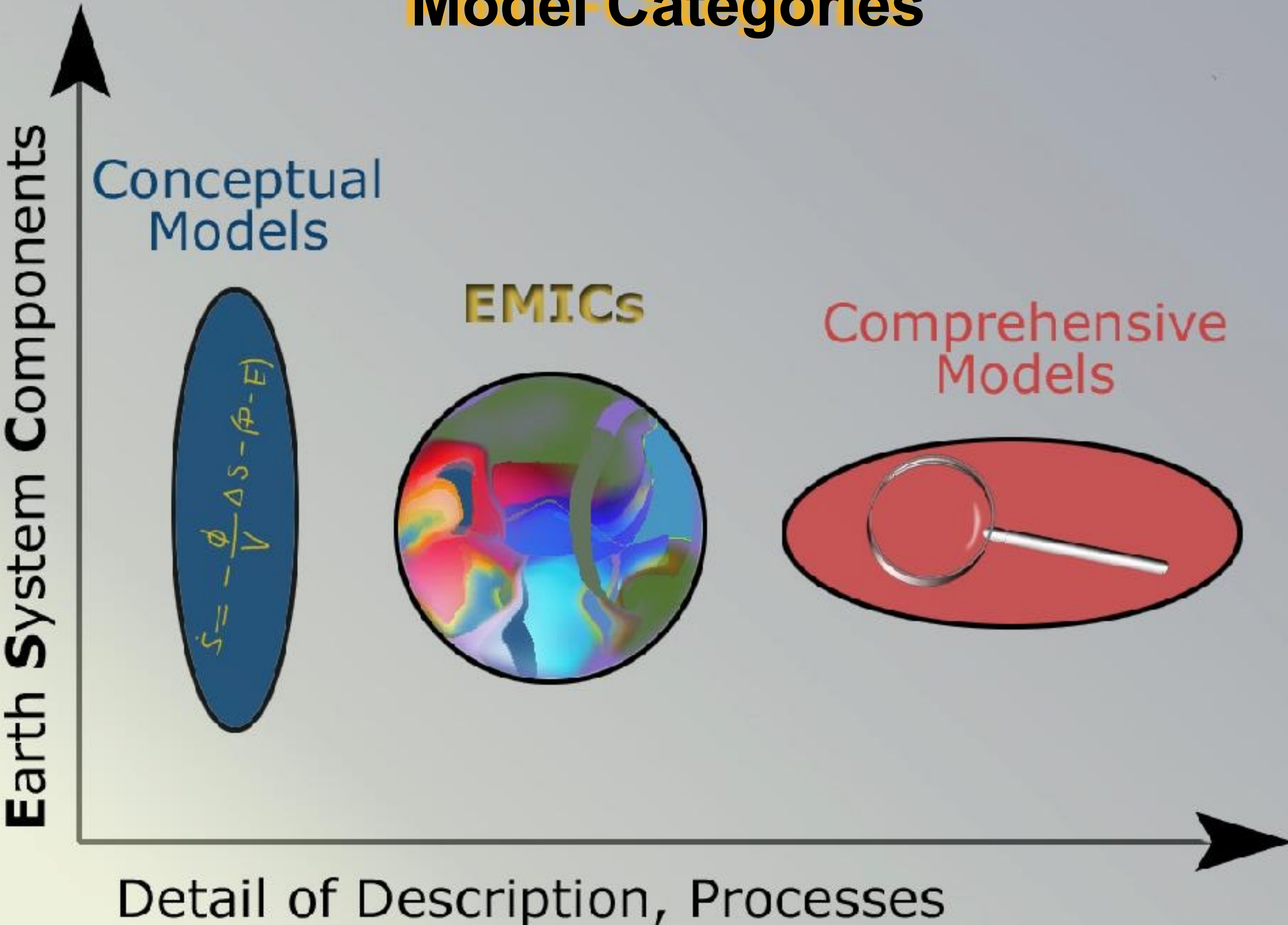
Gerrit Lohmann
MES, 21.06.2021

Todays 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

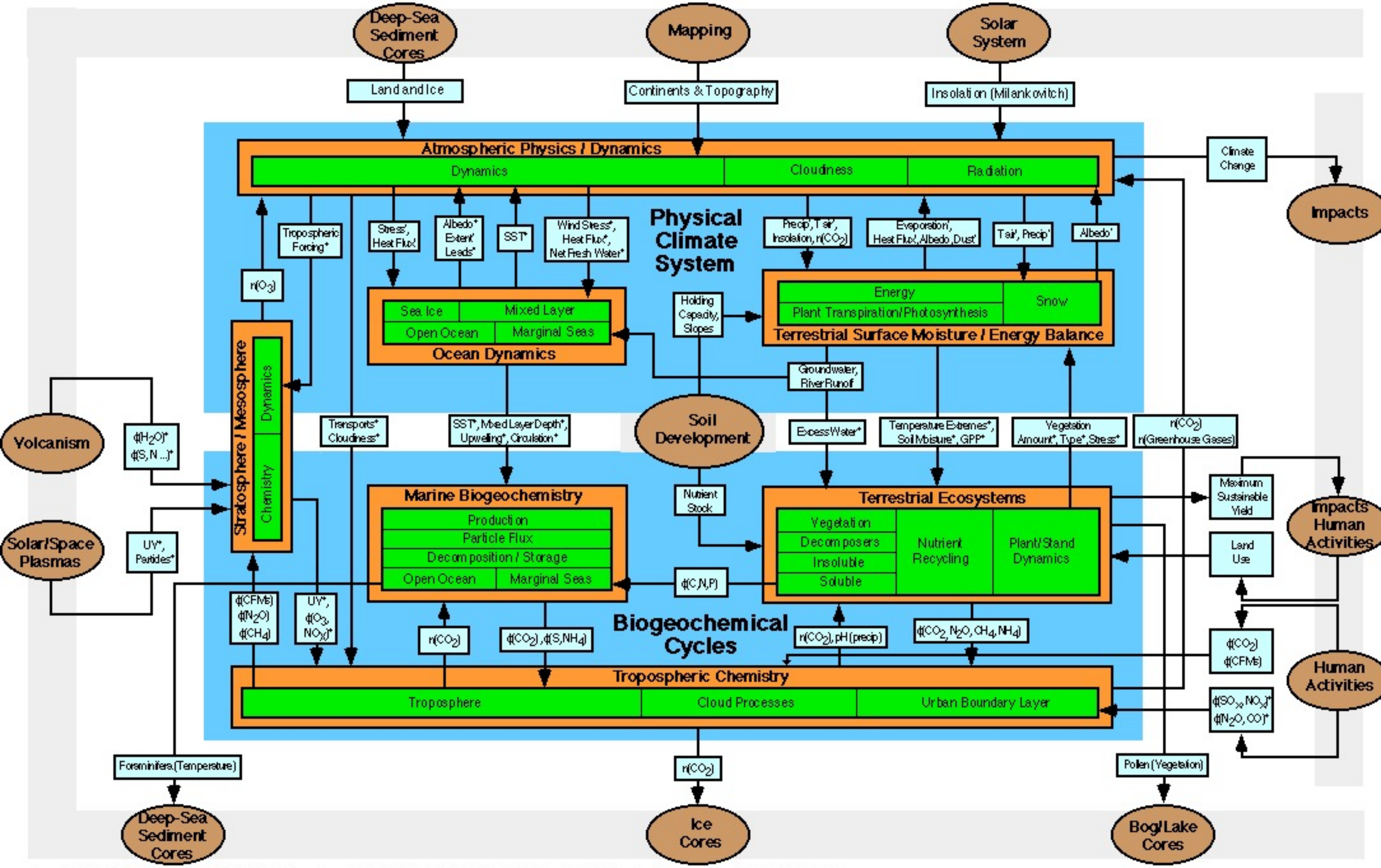


Different Point of View

traditional GCMs

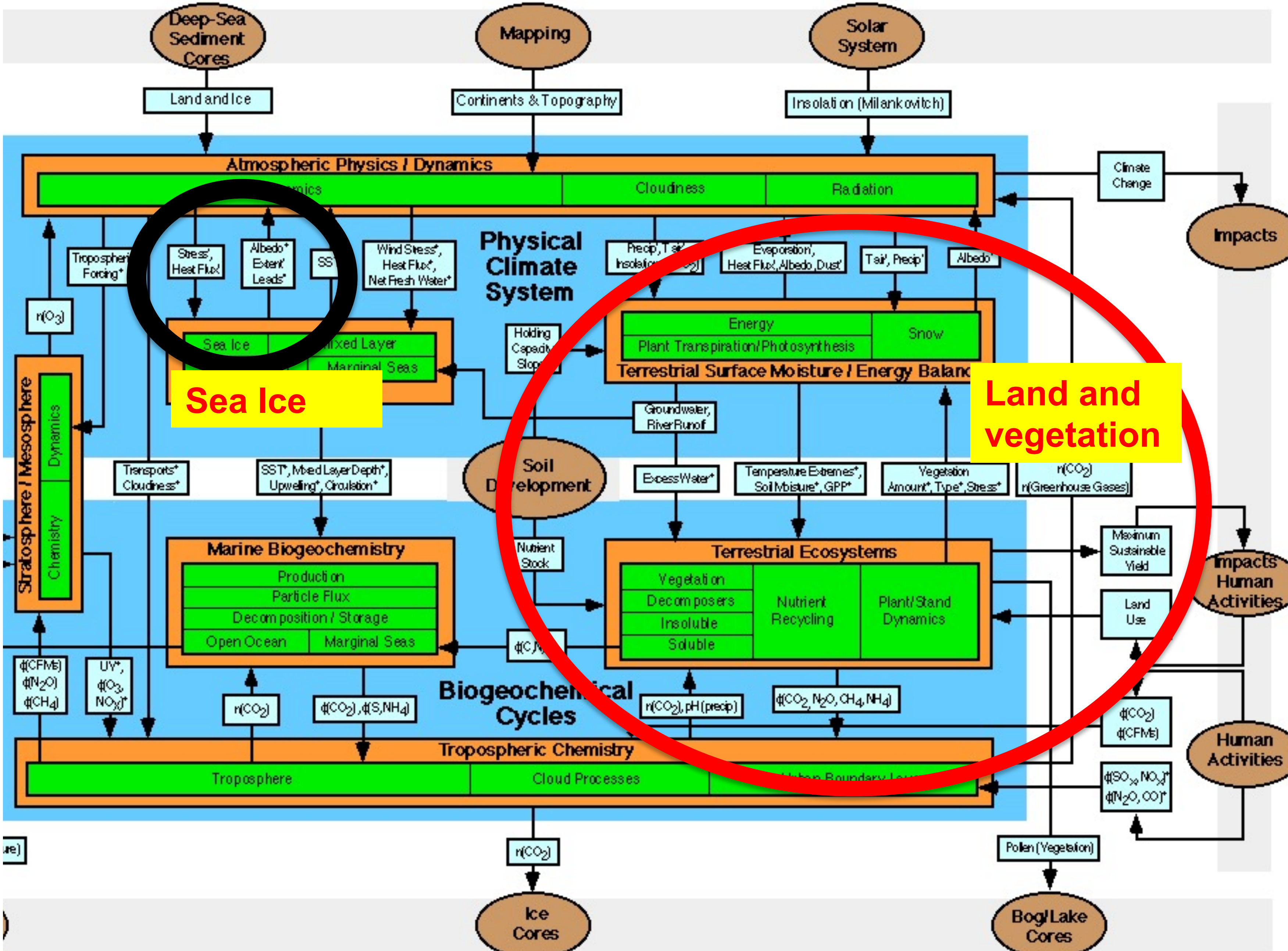
Earth System Models

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

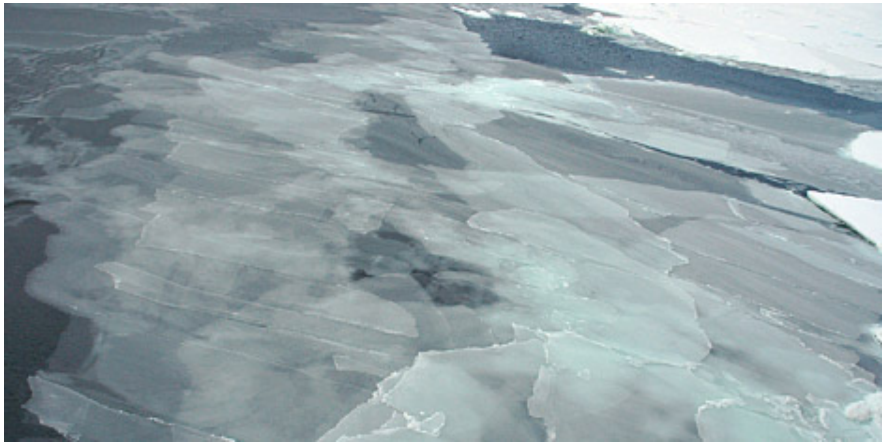


' = on timescale of hours to days * = on timescale of months to seasons ϕ = flux n = concentration

Bretherton



Deep-Sea Sediment Cores
Mapping
Solar System
Land and Ice
Continents & Topography
Insolation (Milankovitch)
Atmospheric Physics / Dynamics
Cloudiness
Radiation
Climate Change
Impacts
Physical Climate System
Troposphere Forcing*
Stress', Heat Flux'
Albedo* Extent* Leads*
Wind Stress*, Heat Flux*, Net Fresh Water*
Evaporation', Heat Flux', Albedo, Dust'
Tair', Precip'
Albedo'
n(O3)
Sea Ice
Mixed Layer
Marginal Seas
Holding Capacity
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)
Maximum Sustainable Yield
Marine Biogeochemistry
Production
Particle Flux
Decomposition / Storage
Open Ocean
Marginal Seas
Nutrient Stock
Terrestrial Ecosystems
Vegetation
Decomposers
Insoluble
Soluble
Nutrient Recycling
Plant/Stand Dynamics
Impacts Human Activities
Land Use
φ(CFMs) φ(N2O) φ(CH4)
UV*, φ(O3, NOx)*
n(CO2)
φ(CO2), φ(S,NH4)
Biogeochemical Cycles
n(CO2), pH (precip)
φ(CO2, N2O, CH4, NH4)
φ(CO2) φ(CFMs)
Human Activities
Tropospheric Chemistry
Troposphere
Cloud Processes
φ(SOx, NOx)* φ(N2O, CO)*
n(CO2)
Pollen (Vegetation)
Ice Cores
Bog/Lake Cores



thin sheets of smooth nilas in calm water

disks of pancake ice in choppy water

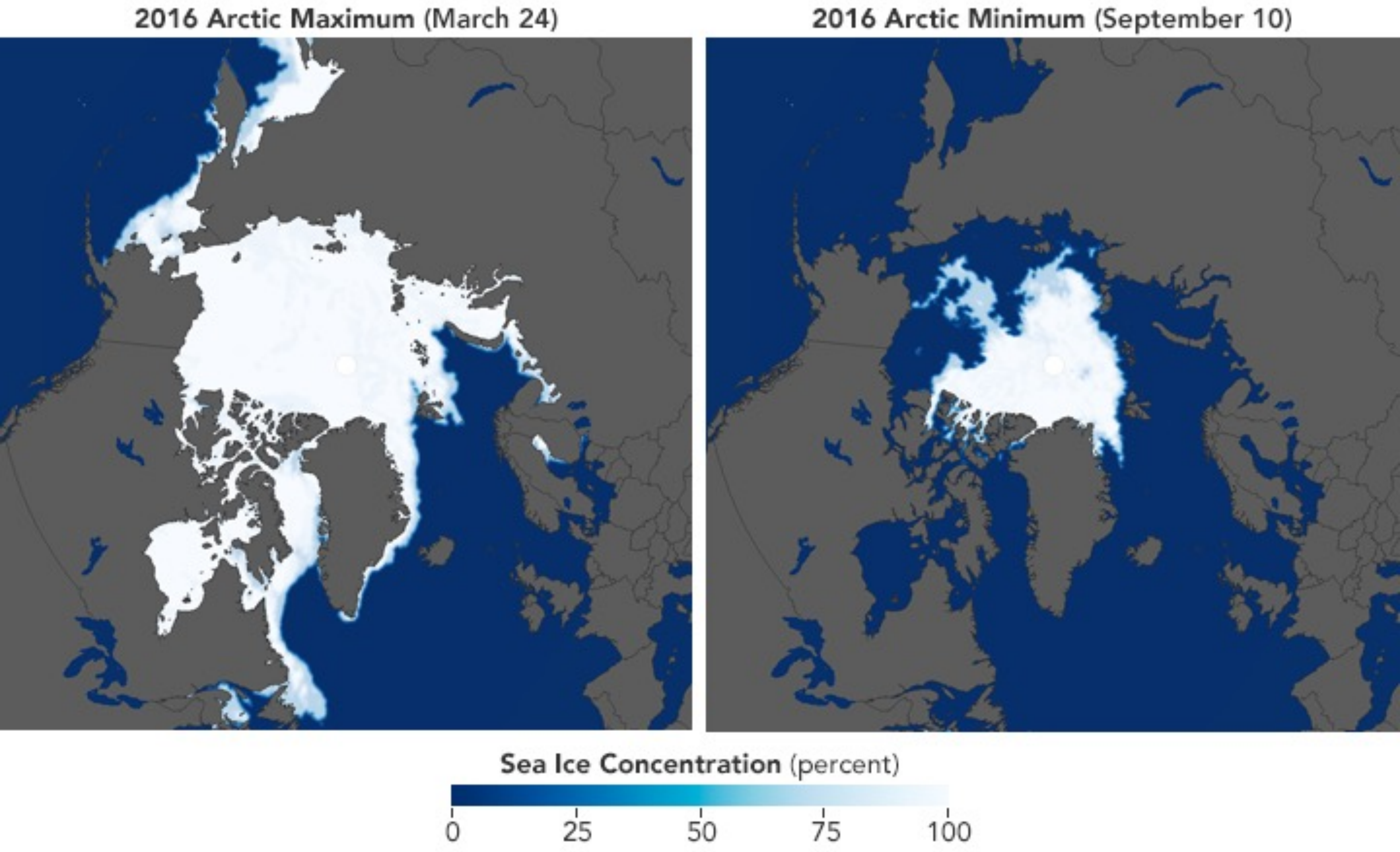
Last week

Sea ice

rafts and eventually solidify

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

Arctic sea ice



Energy balance with sea ice

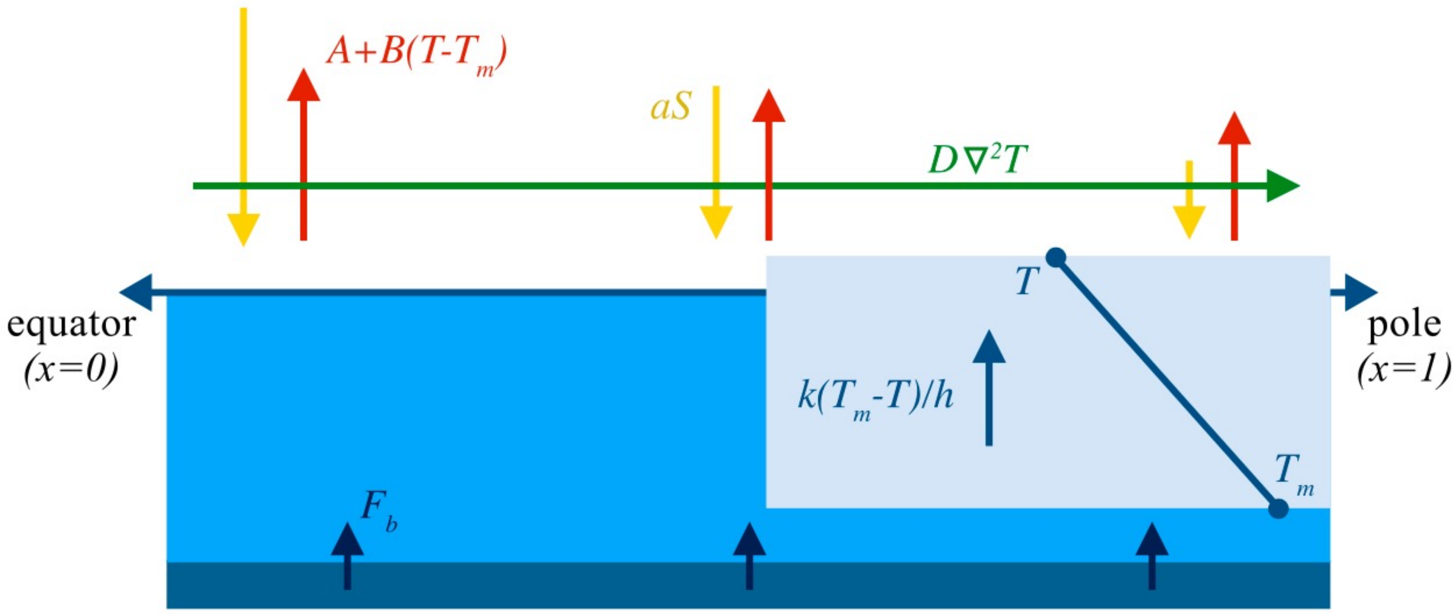
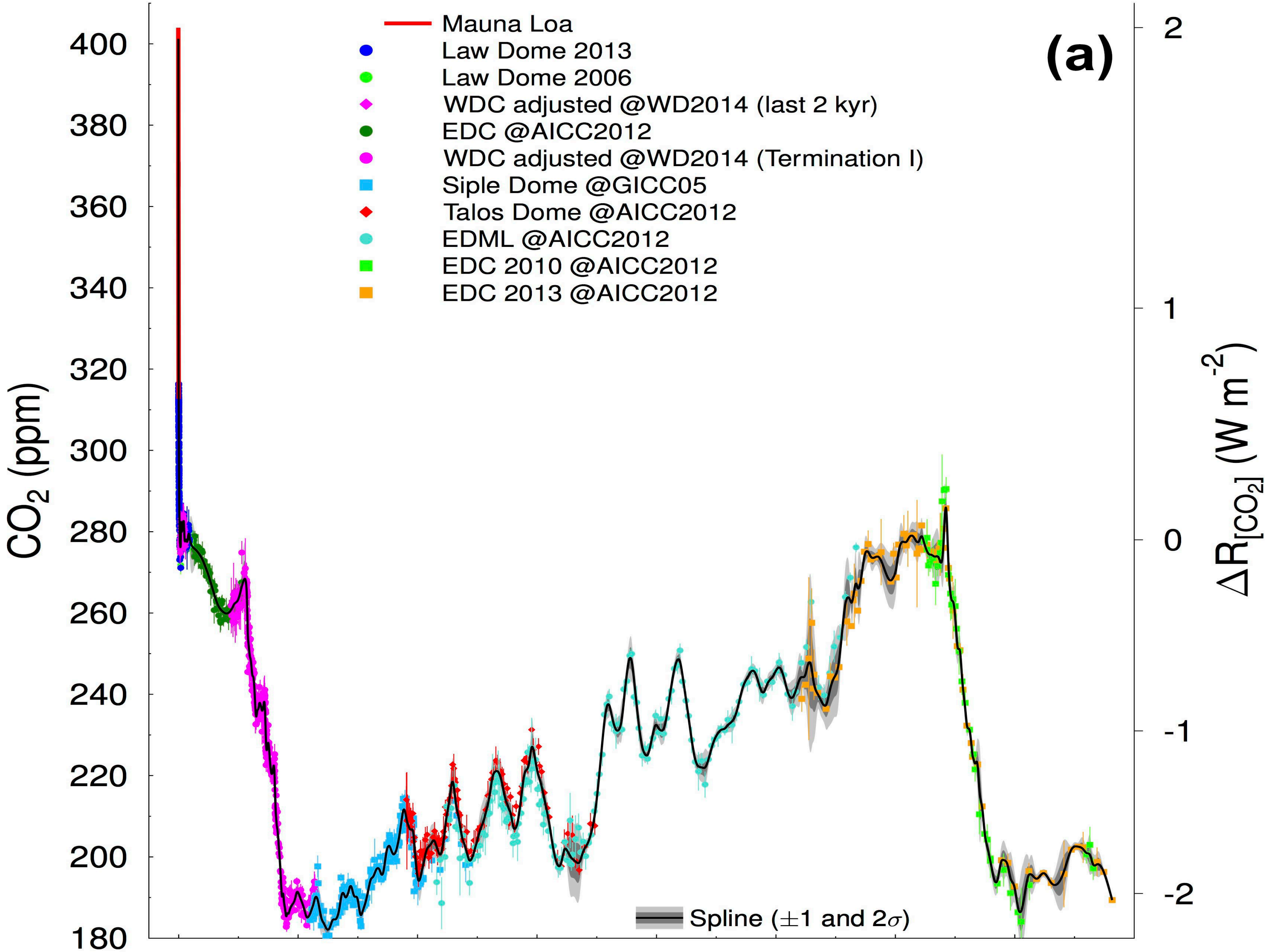


FIG. 1. Schematic of the global model of climate and sea ice described in section 2, showing the fluxes included in the model: insolation (yellow), OLR (red), horizontal heat transport (green), ocean heating (dark blue), and vertical heat flux through the ice (blue). The temperature of the ice is given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

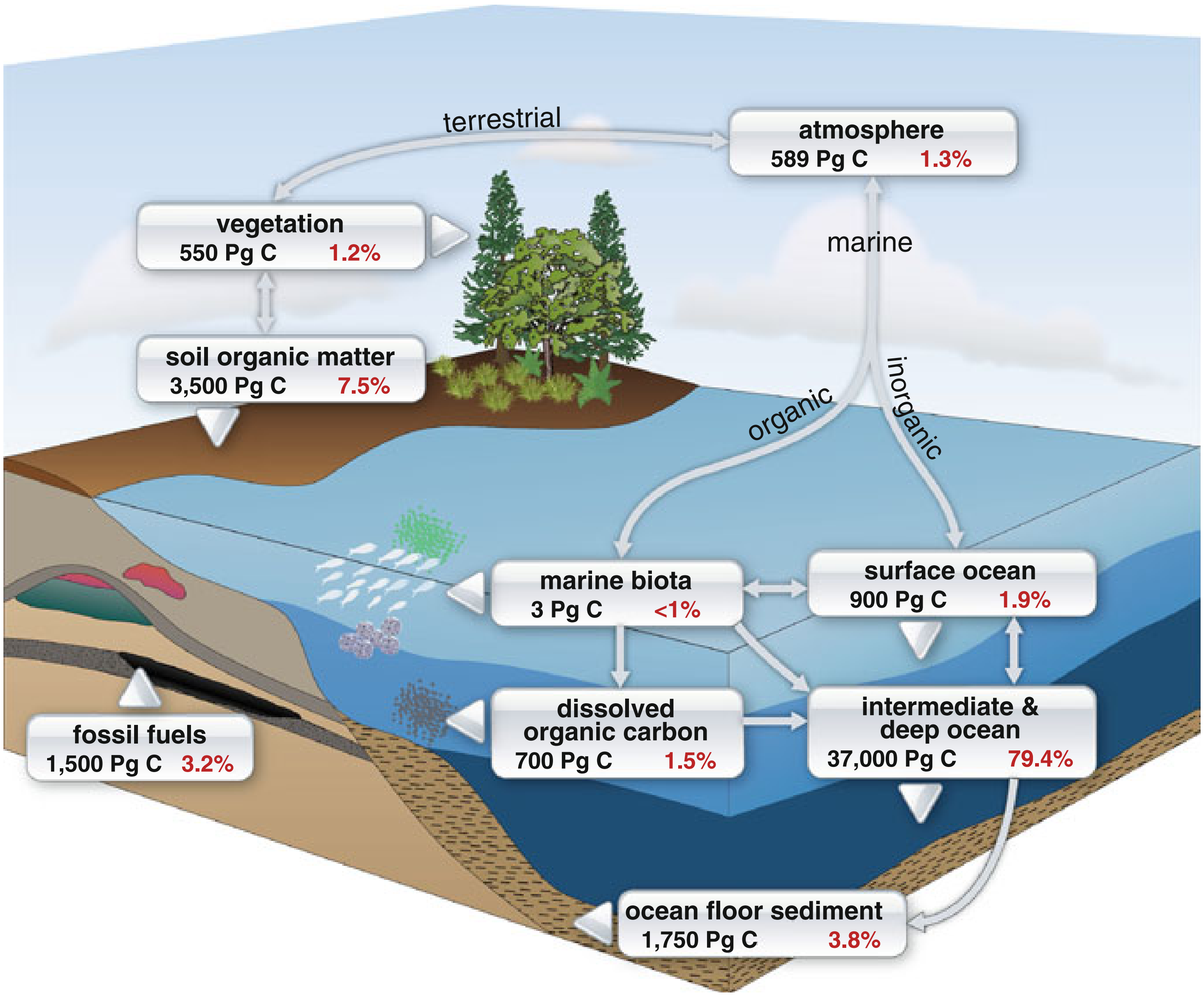
How Climate Model Complexity Influences Sea Ice Stability
TILL J. W. WAGNER AND IAN EISENMAN
JOURNAL OF CLIMATE
VOLUME 28

CO_2

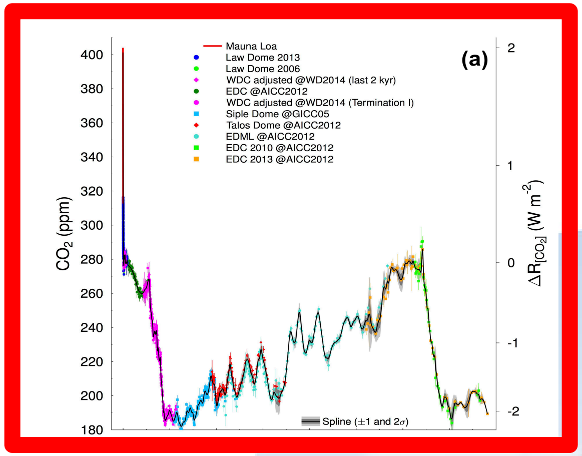


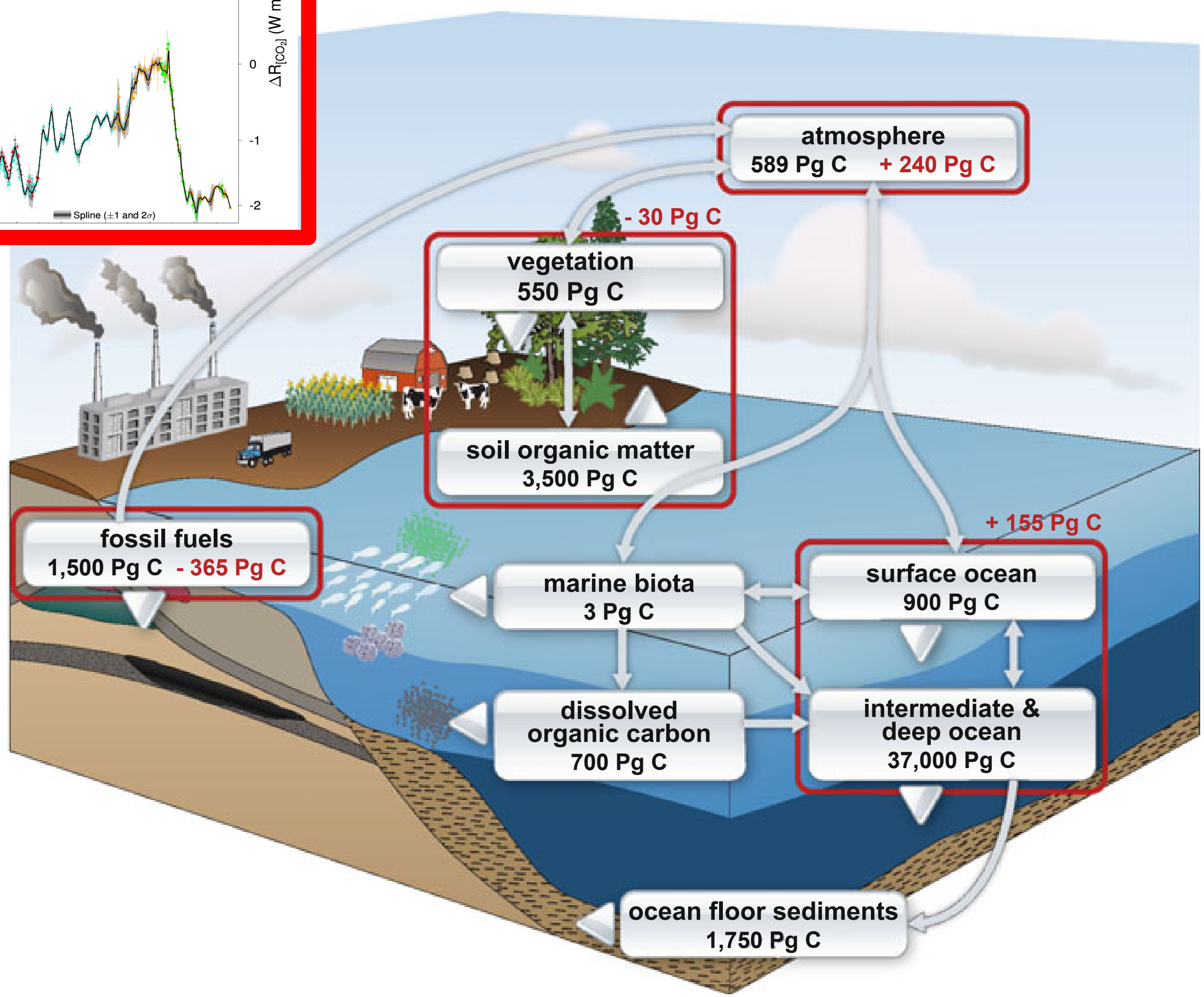
Time scale?

Carbon reservoirs

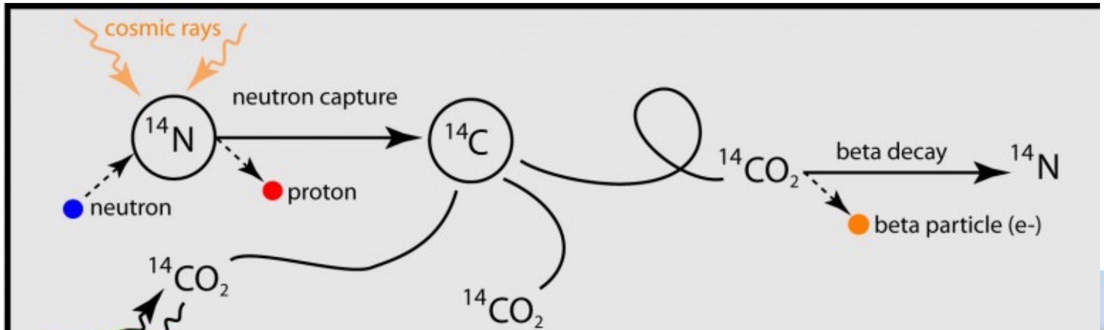


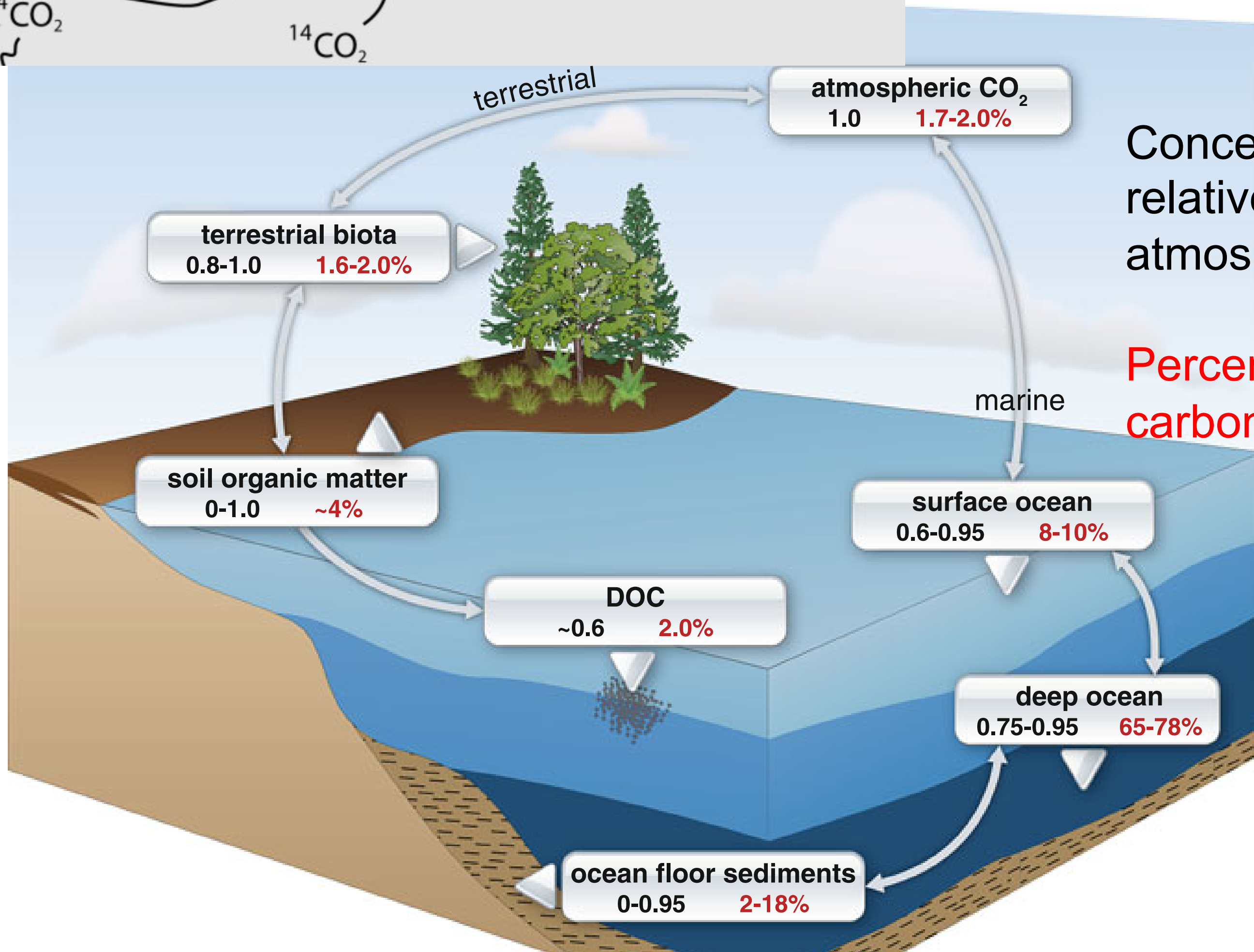
C reservoirs + perturbation





tracer: C-14

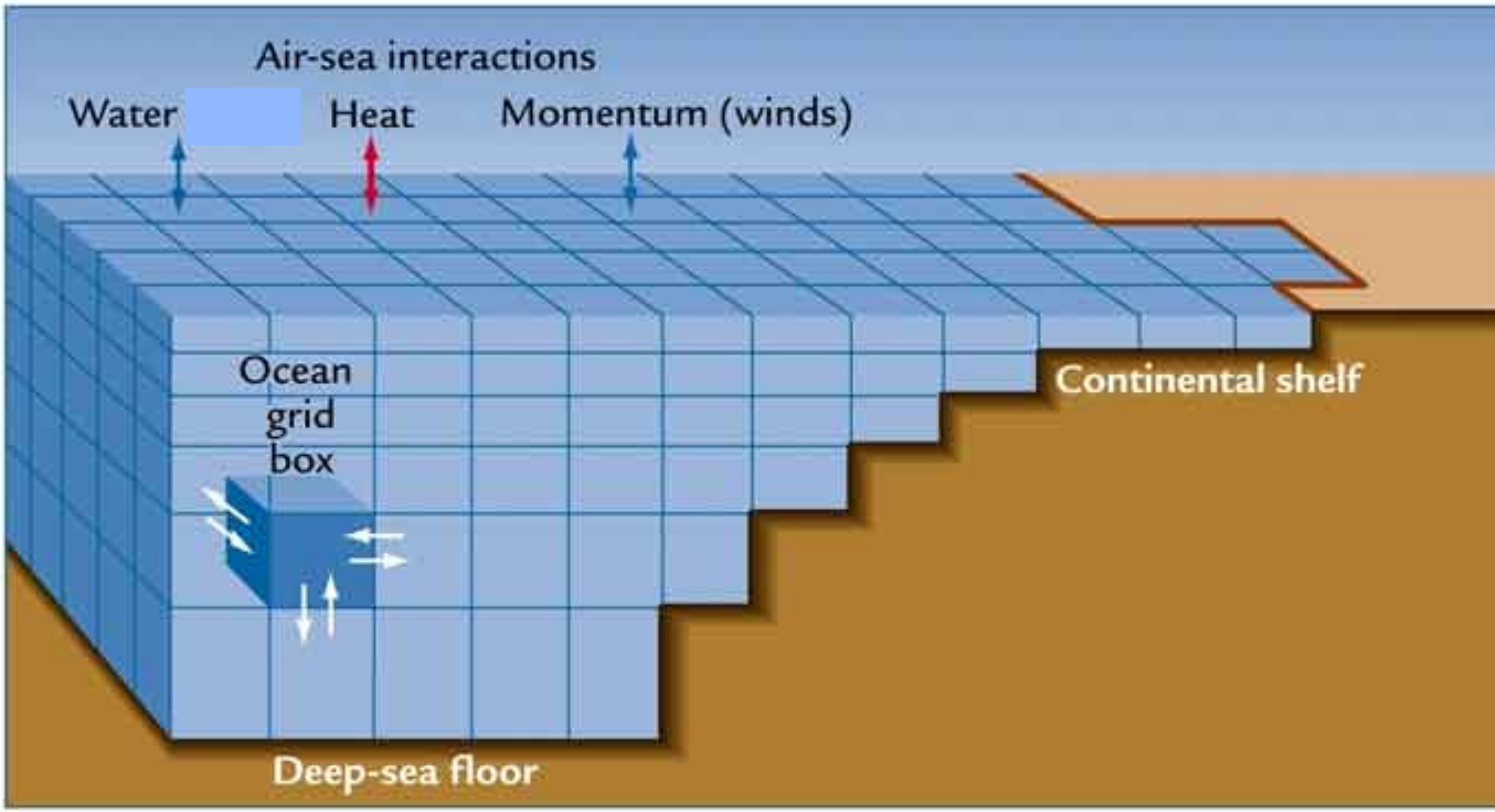




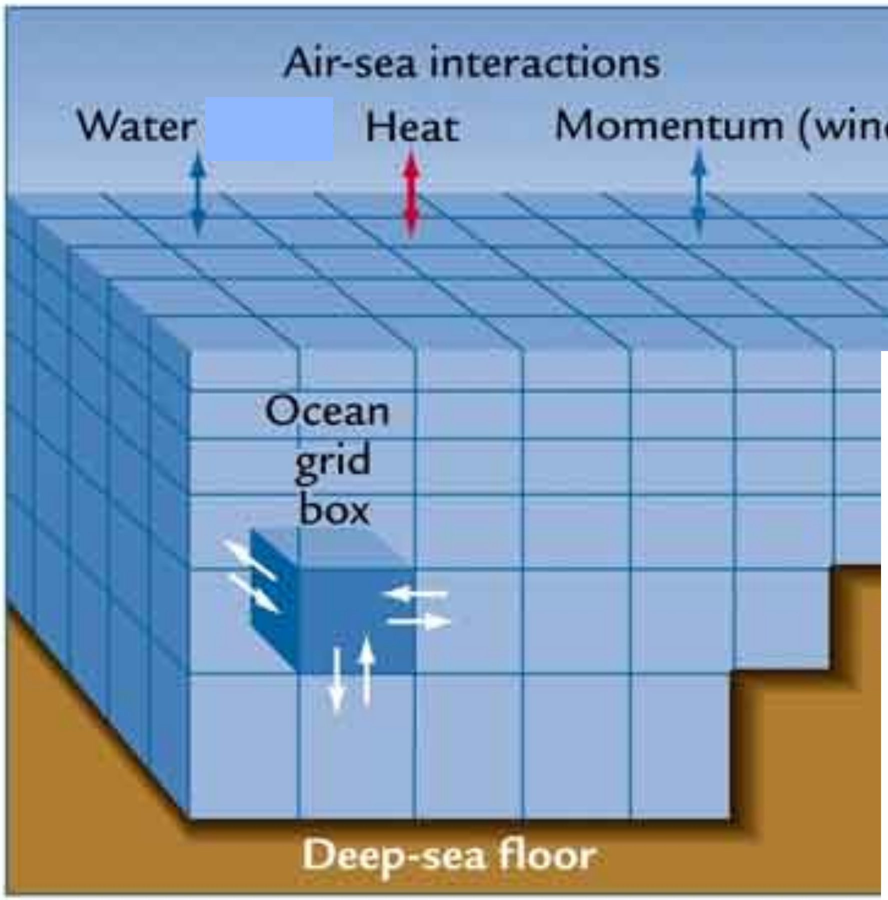
Concentration relative to atmosphere

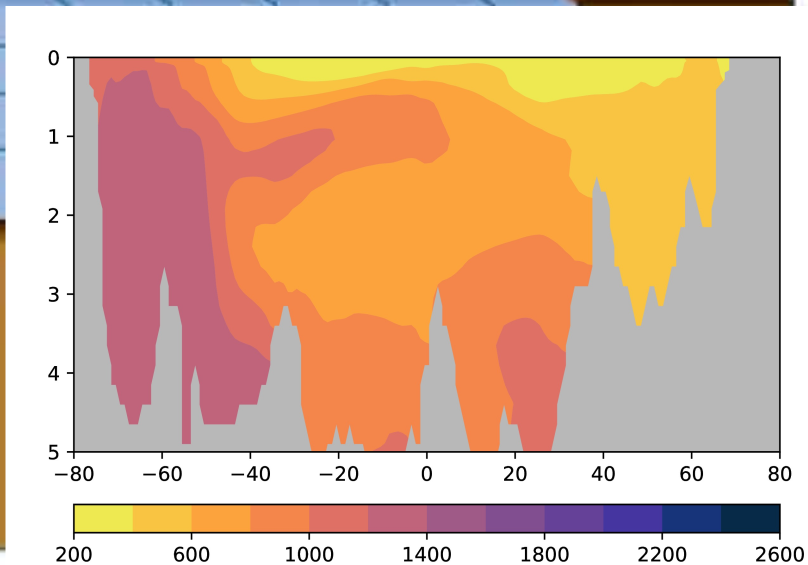
Percentage of total carbon content

Ocean circulation models tracers in the sea



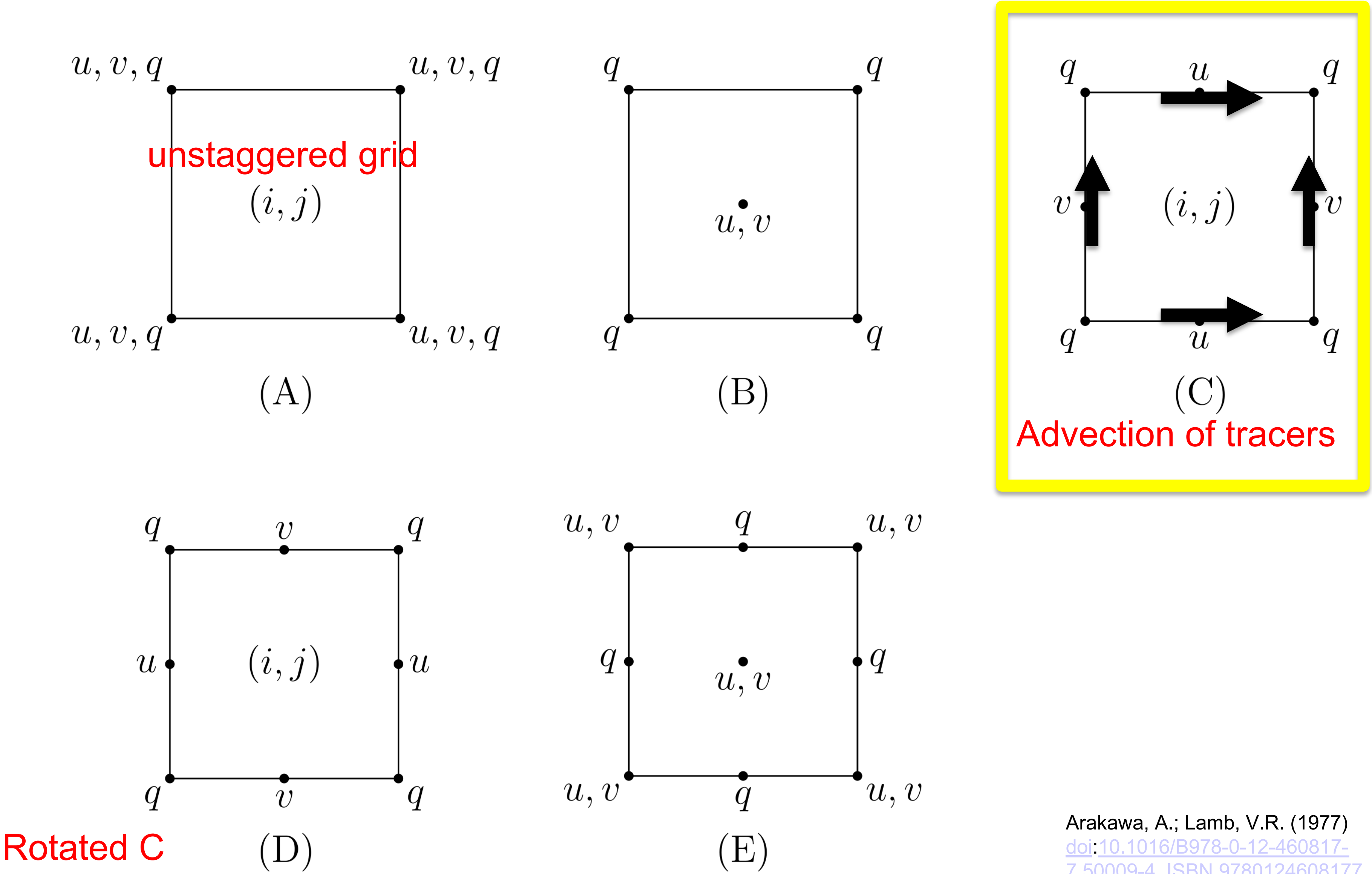
Ocean circulation models tracers in the sea





a perfect time tracer: C-14

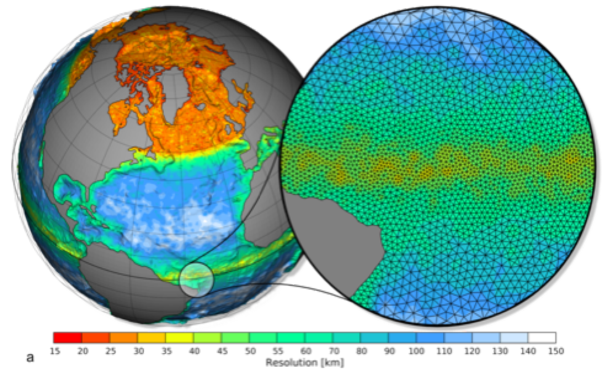
2D Staggered grids: Arakawa



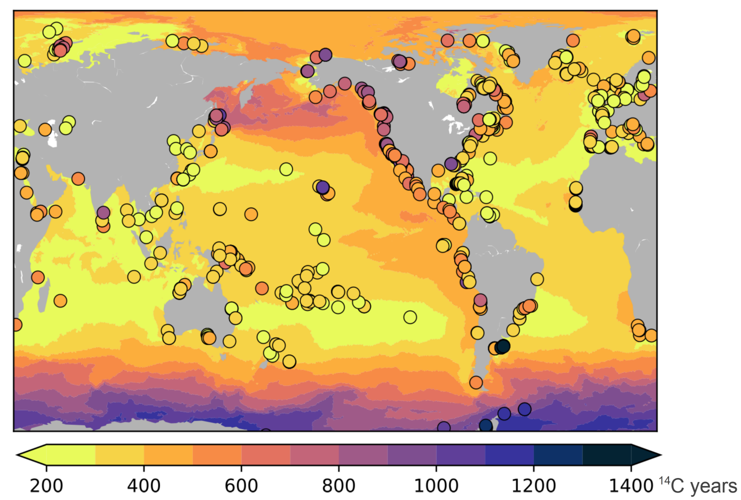
Arakawa, A.; Lamb, V.R. (1977) doi:10.1016/B978-0-12-460817-7.50009-4. ISBN 9780124608177.

Radiocarbon tracer

ESM simulations of C-14



High-precision measurements



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:

Energy

$$6CO_2 + 6H_20 \rightarrow C_6H_{12}O_6 + 6O_2$$

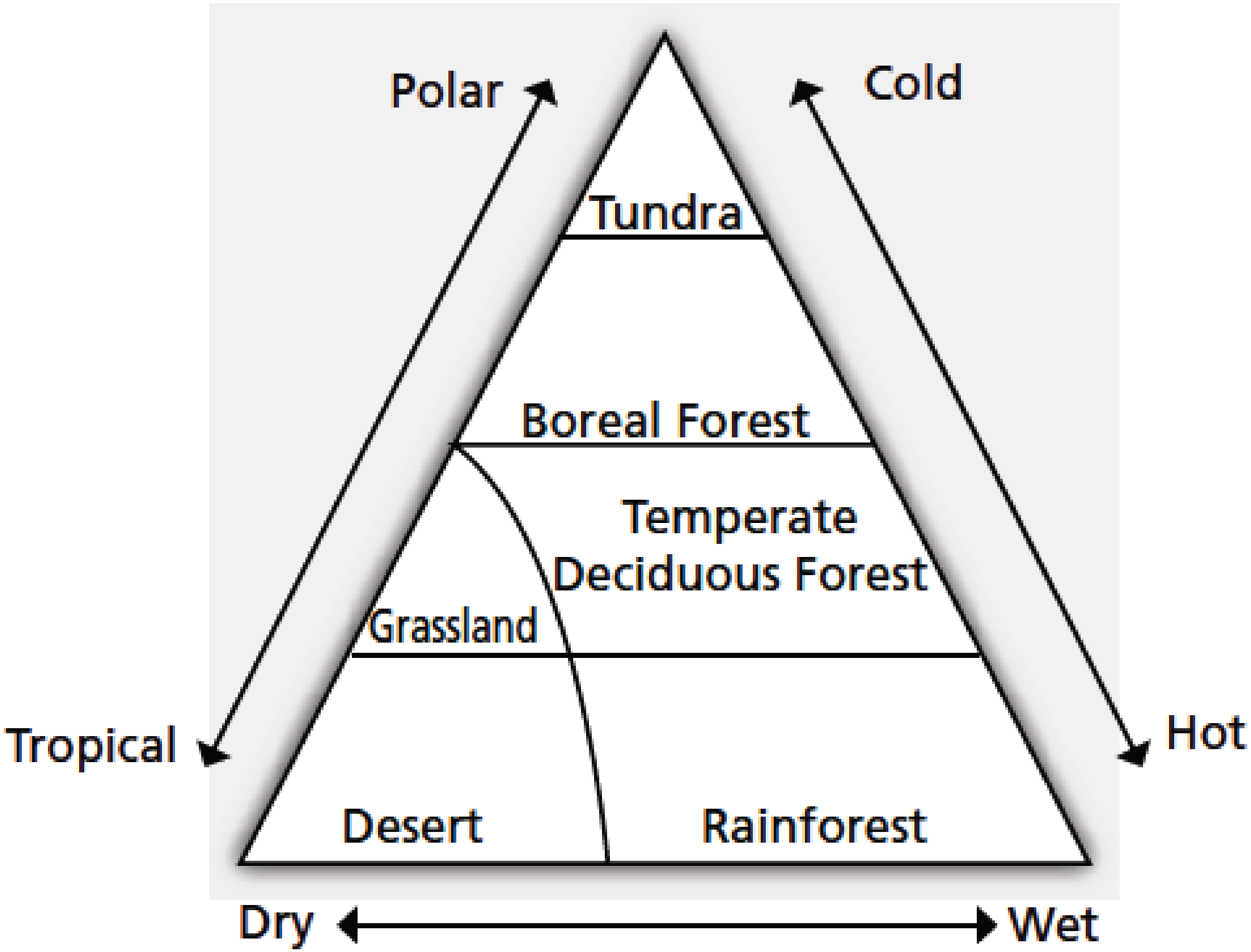
Carbon dioxide

Water

Carbohydrates

Oxygen

Vegetation & Ecosystem

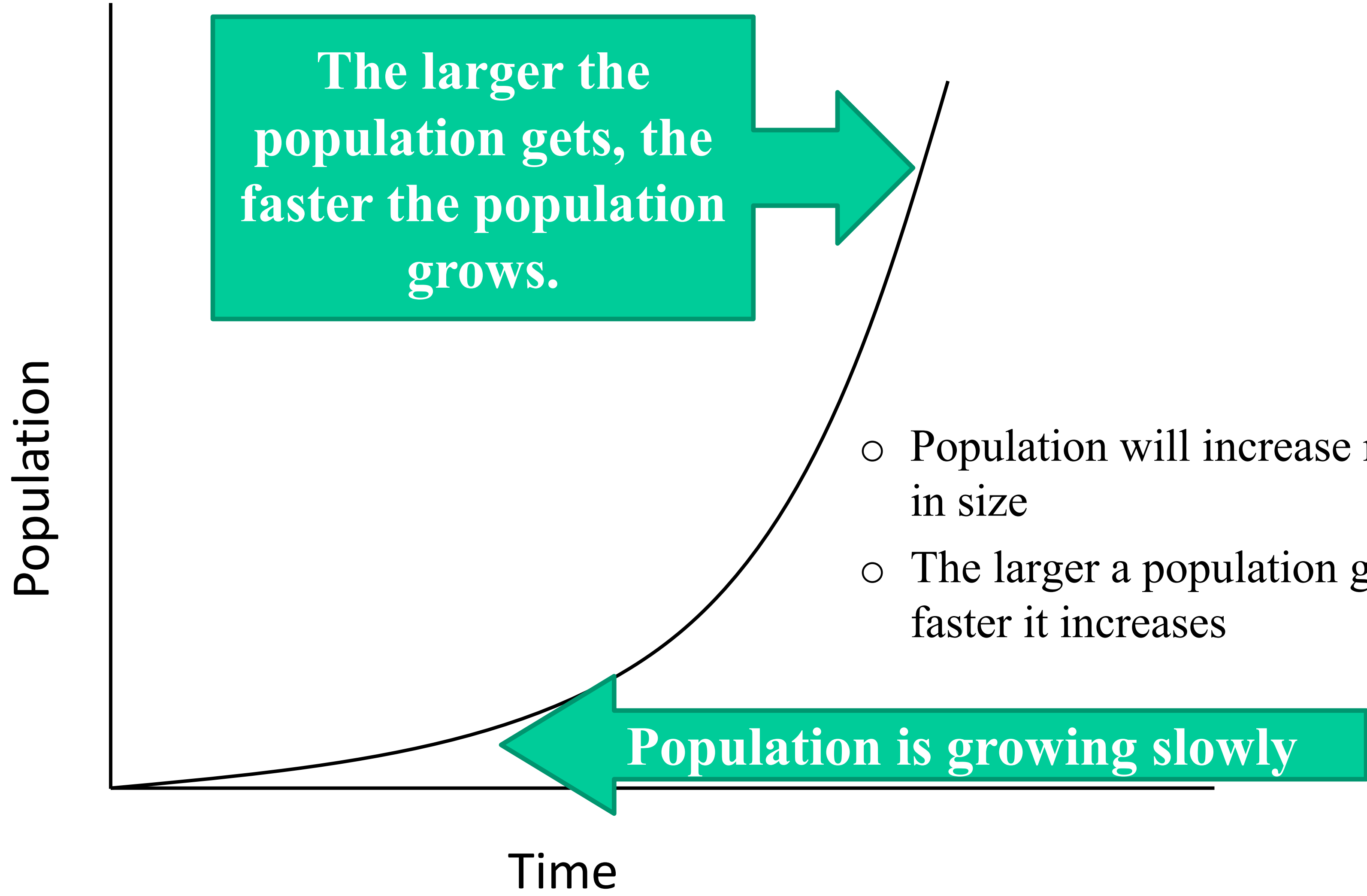


Human Impact

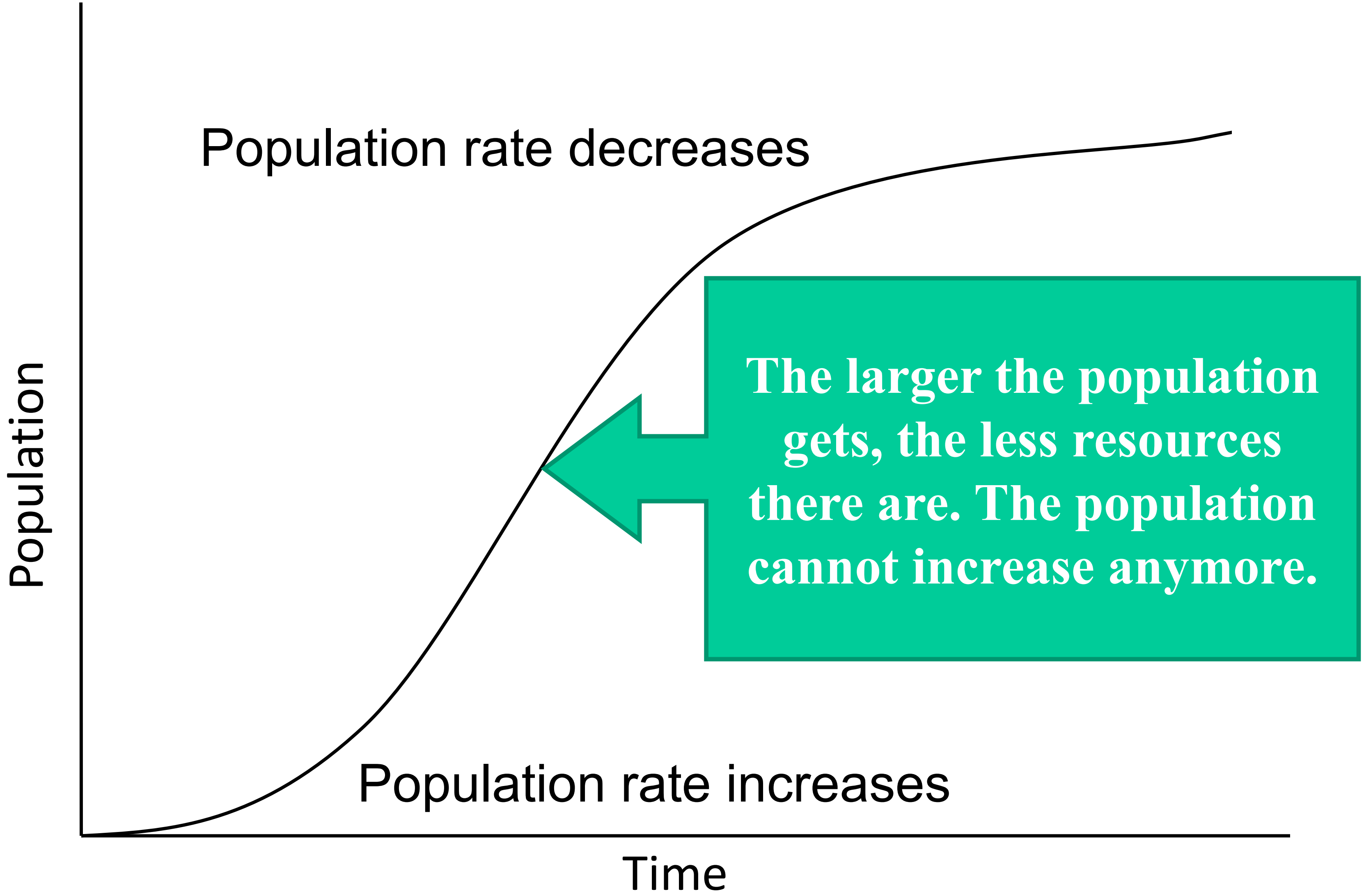
1. **Deforestation** – cutting down forests has reduced the amount of plants available for photosynthesis, which means that less CO_2 can be removed from the atmosphere.
2. **Burning (combustion) of fossil fuels** – gasoline, coal, and natural gas contain carbon and when burned, they release CO_2 into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


Of concern to all!
A tree is worth
$193,250
according to Professor T.M. Das of the University of Calcutta. A tree living for 50 years will generate $31,250 worth of oxygen, provide $62,000 worth of air pollution control, control soil erosion and increase soil fertility to the tune of $31,250, recycle $37,500 worth of water and provide a home for animals worth $31,250. This figure does not include the value of fruits, lumber or beauty derived from trees. Just another sensible reason to take care of our forests.
From Update Forestry
Michigan State University
THE VALUE OF A TREE
SAVE OUR MOTHER EARTH

Population Growth (ideal conditions)



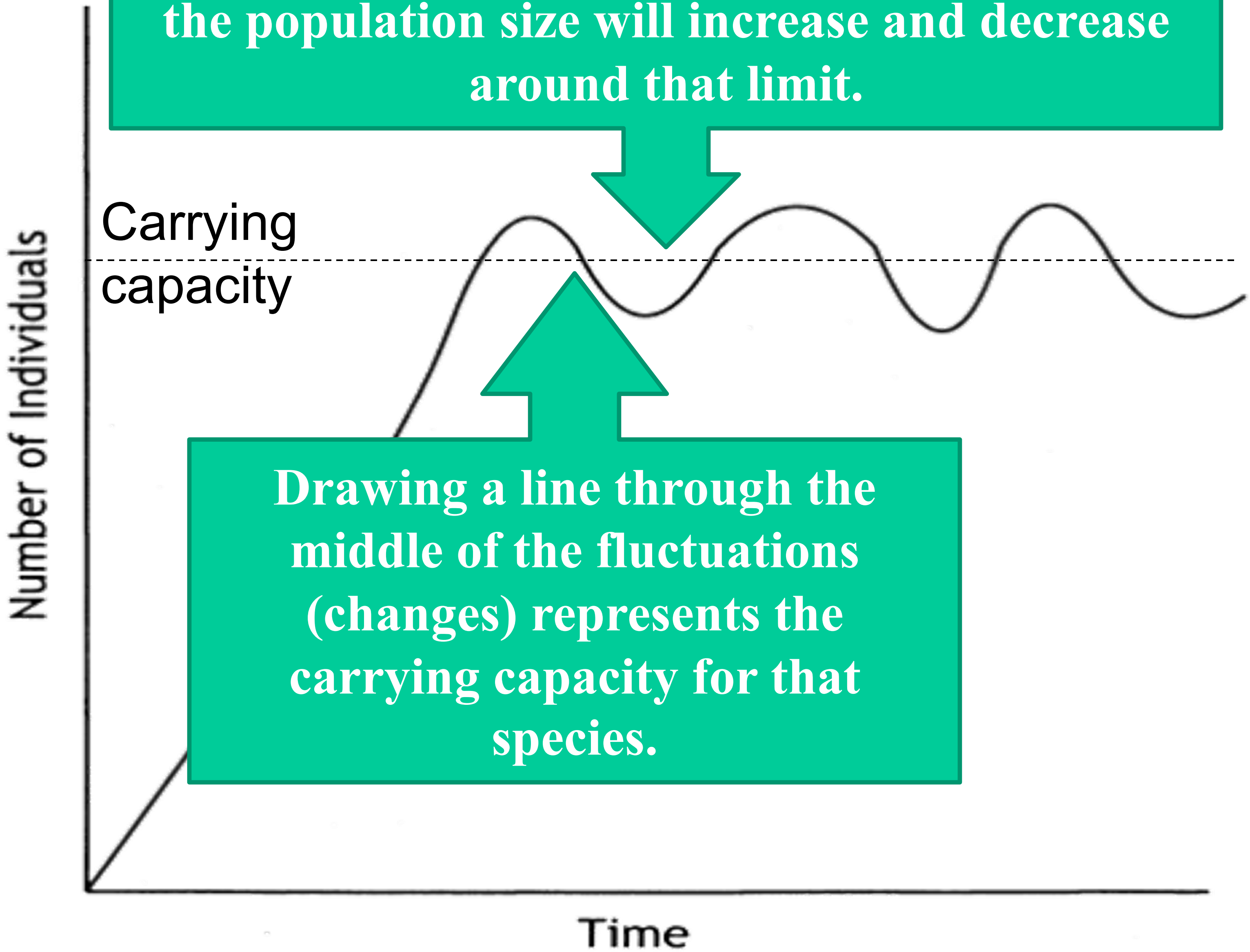
- Population will increase rapidly in size
- The larger a population gets, the faster it increases


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

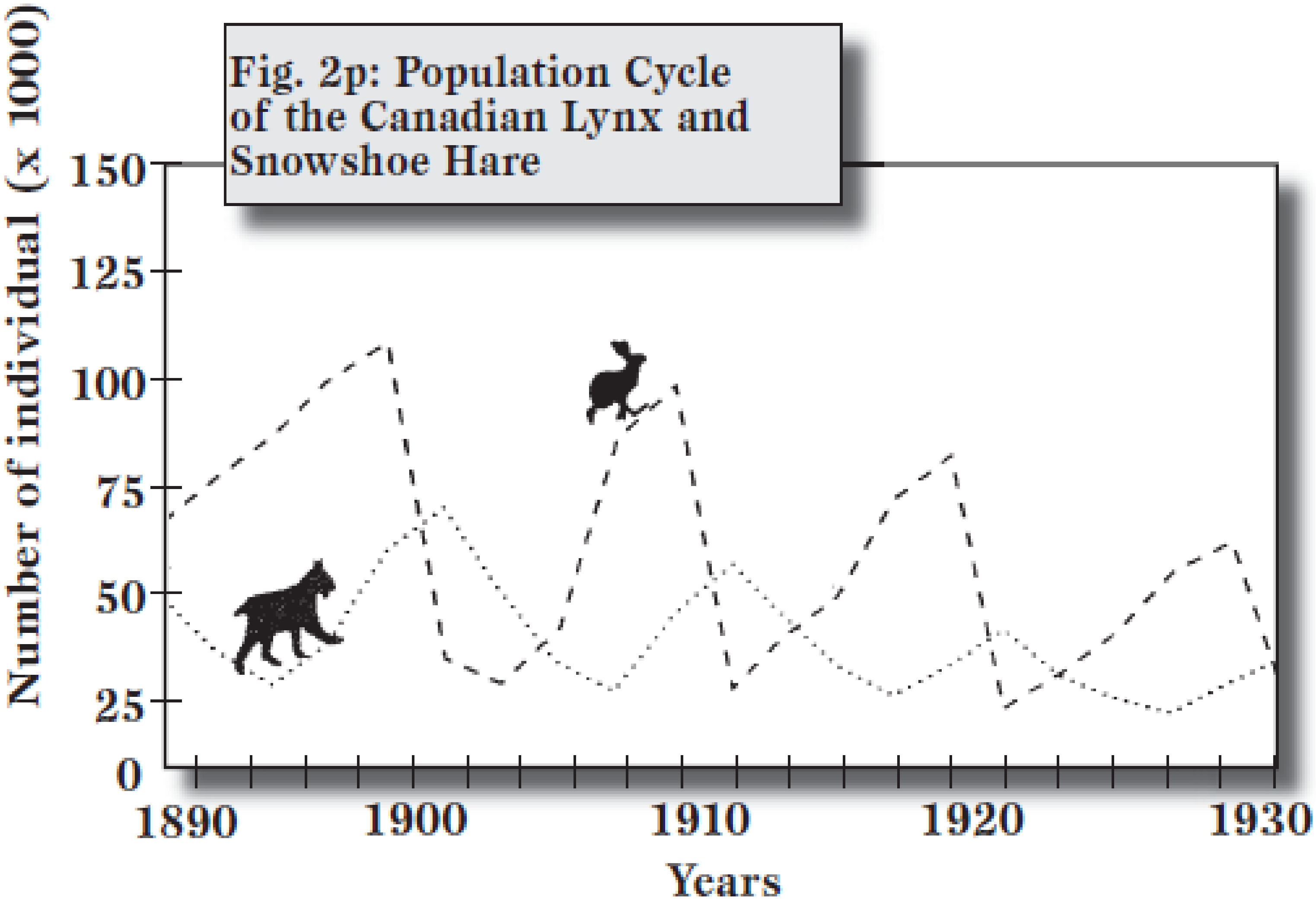


Fig. 2p: Population Cycle of the Canadian Lynx and Snowshoe Hare

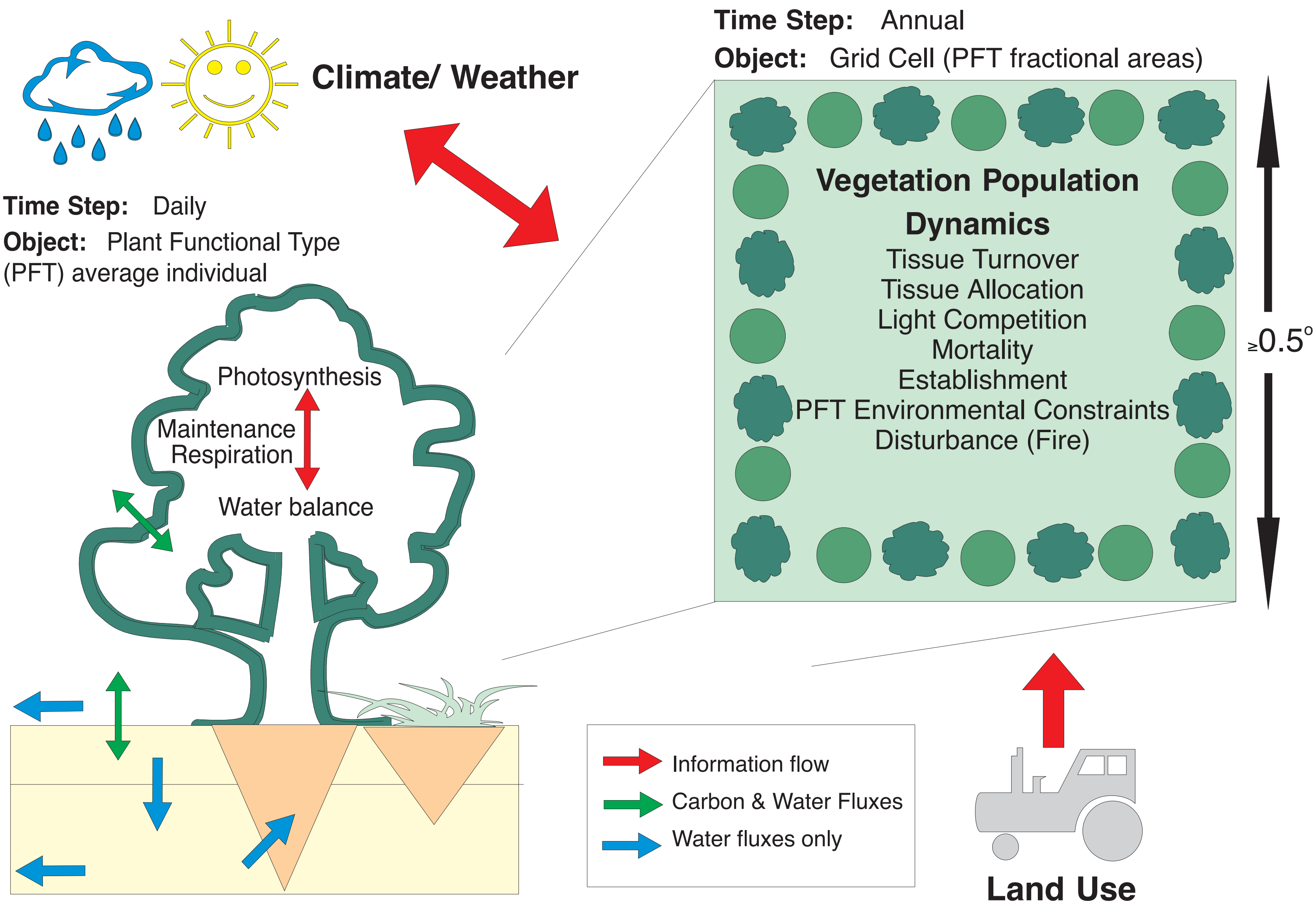
Dynamical vegetation models

- 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.

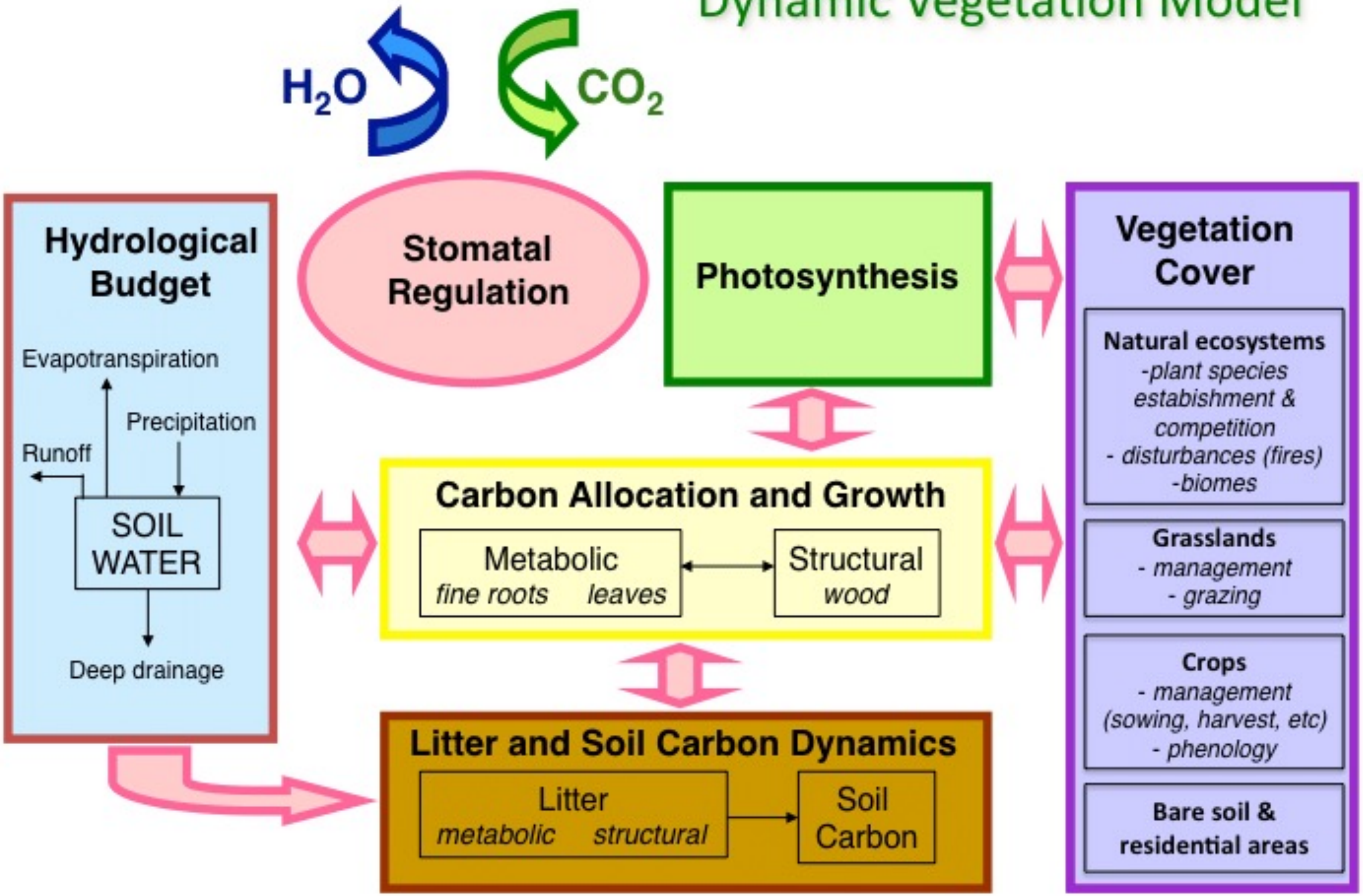
http://www.globalcarbonatlas.org/en/content/land-models

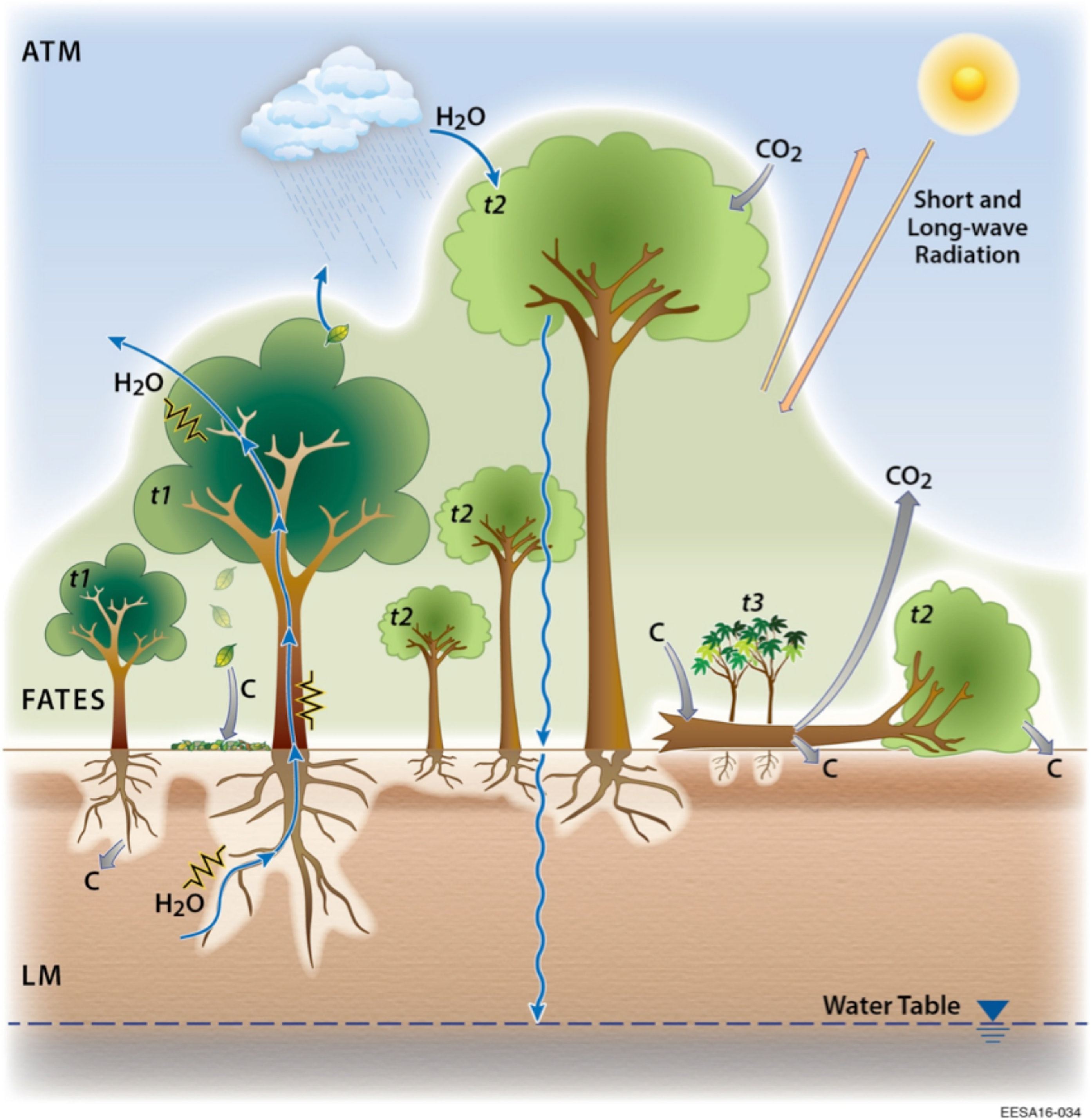
The Lund-Potsdam-Jena Dynamic Global Vegetation Model (DGVM)



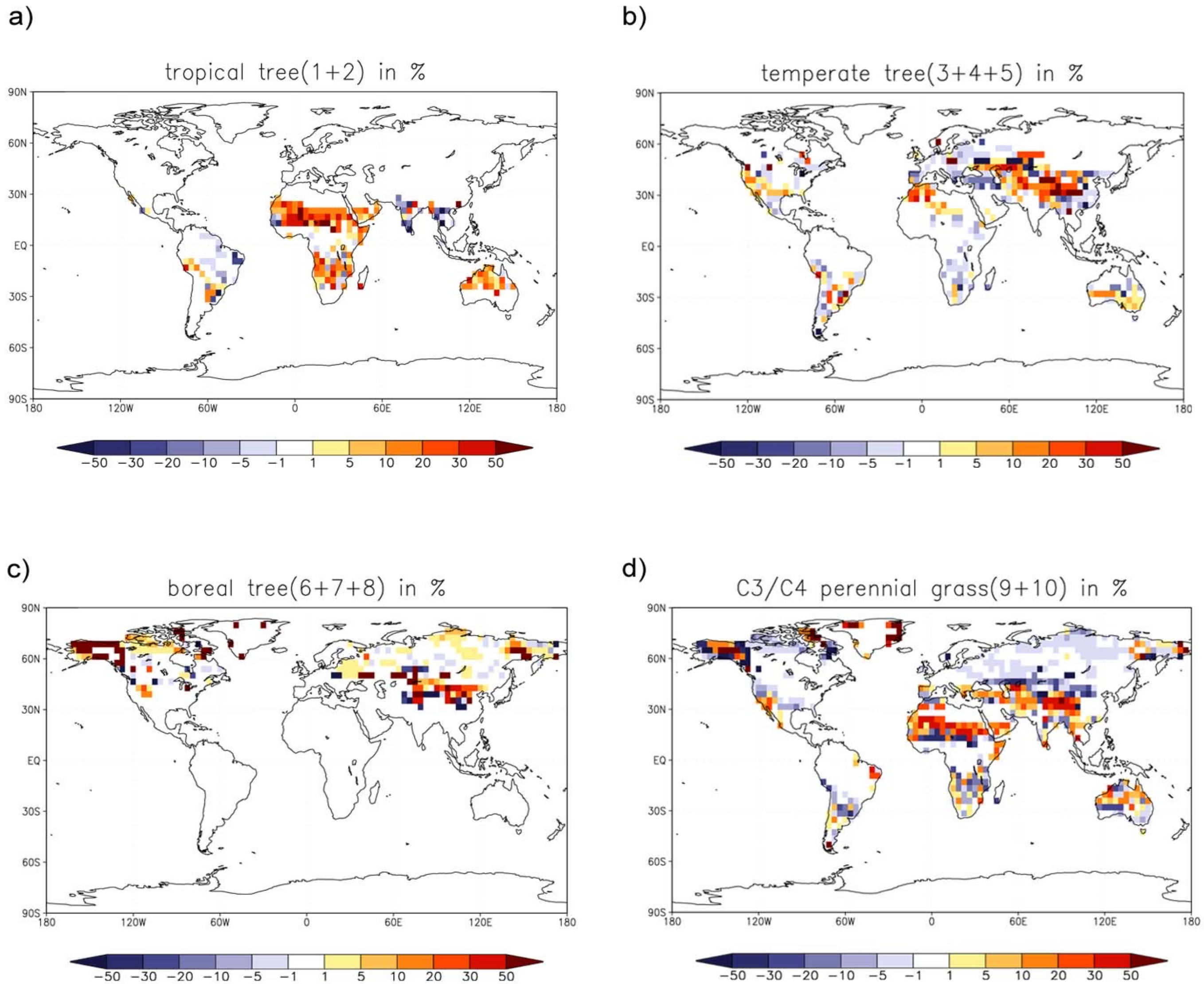
https://web.nateko.lu.se/lpj-guess/education/

CARAIB
Dynamic Vegetation Model

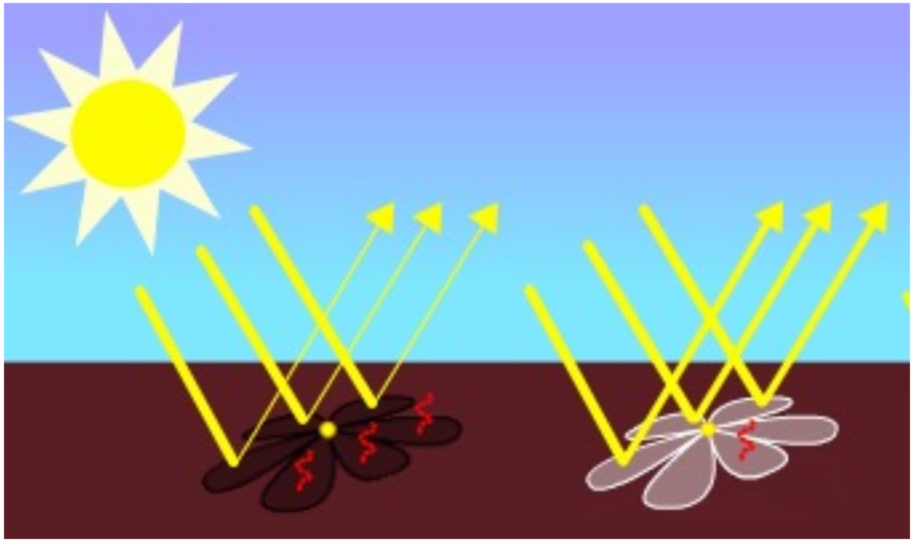



ATM
H_2O
CO_2
Short and Long-wave Radiation
t2
H_2O
t1
t1
t2
t2
CO_2
t3
C
t2
FATES
C
C
C
C
H_2O
LM
Water Table
EESA16-034

Typical output of a vegetation model



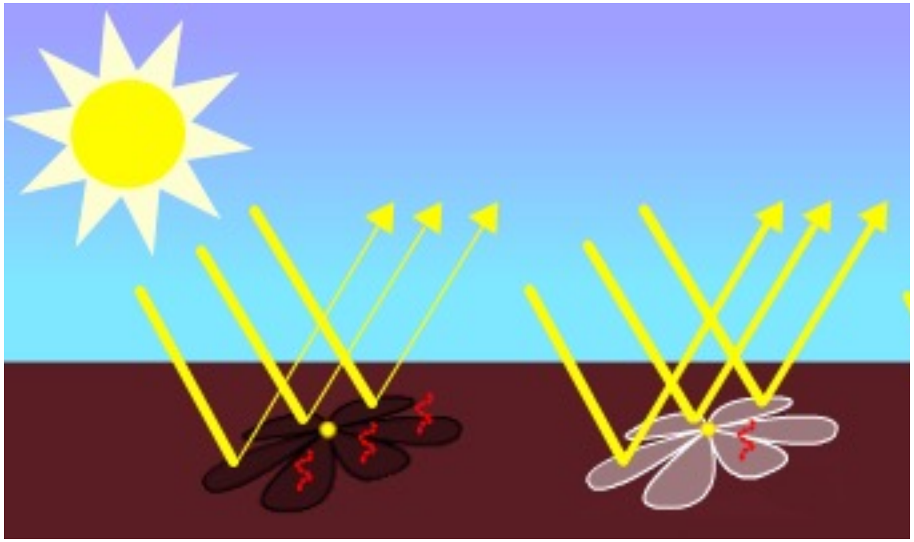
Daisy World & the Gaia Hypothesis



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_11.html

Daisy World & the Gaia Hypothesis



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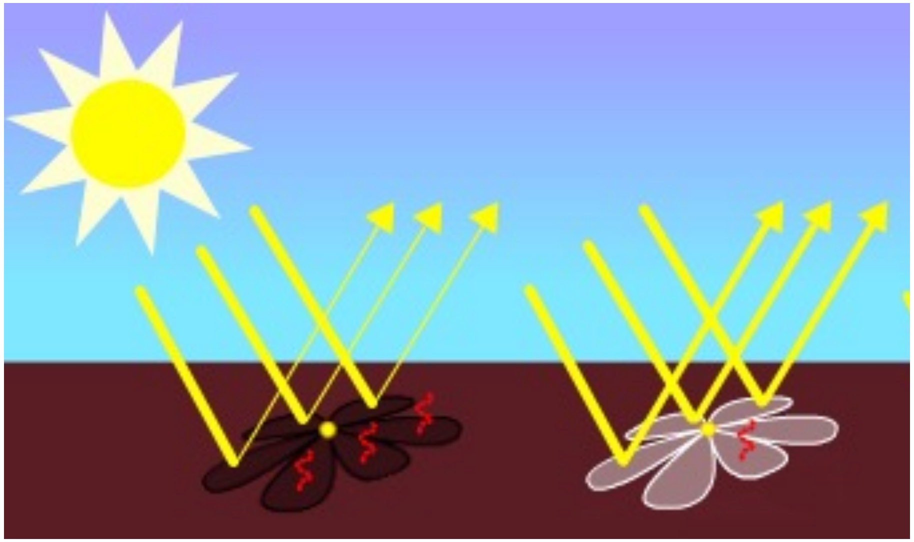
By the mix of white and black daisies and barren ground, Daisy World strives to keep its temperatures in the range that allows daisies to live.

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

Daisy World & the Gaia Hypothesis



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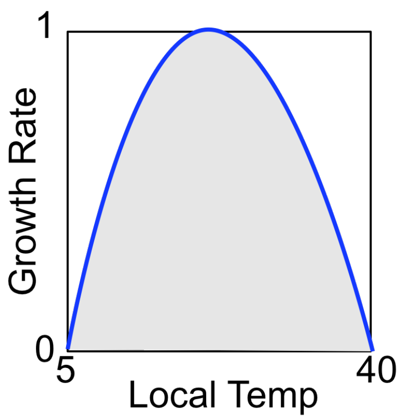
By the mix of white and black daisies and barren ground, Daisy World strives to keep its temperatures in the range that allows daisies to live.

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.

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

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

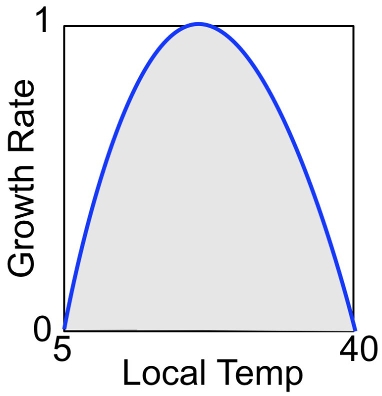
$$\frac{\partial a_w}{\partial t} = a_w\,[a_g\,\beta(T_w) - \gamma]$$

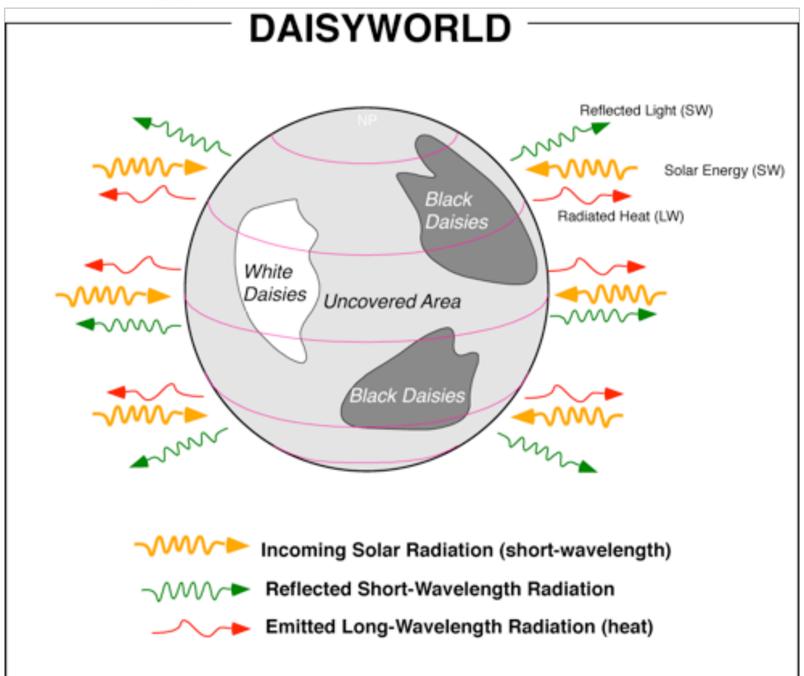
$$\frac{\partial a_b}{\partial t} = a_b\,[a_g\,\beta(T_b) - \gamma]$$

Vegetation Model

Growth rate is temperature dependent

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





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

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

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

Vegetation Model

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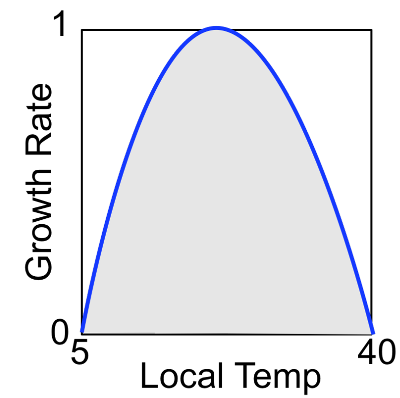


Planetary albedo $\alpha_p = a_w \alpha_w + a_b \alpha_b + a_g \alpha_g$

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

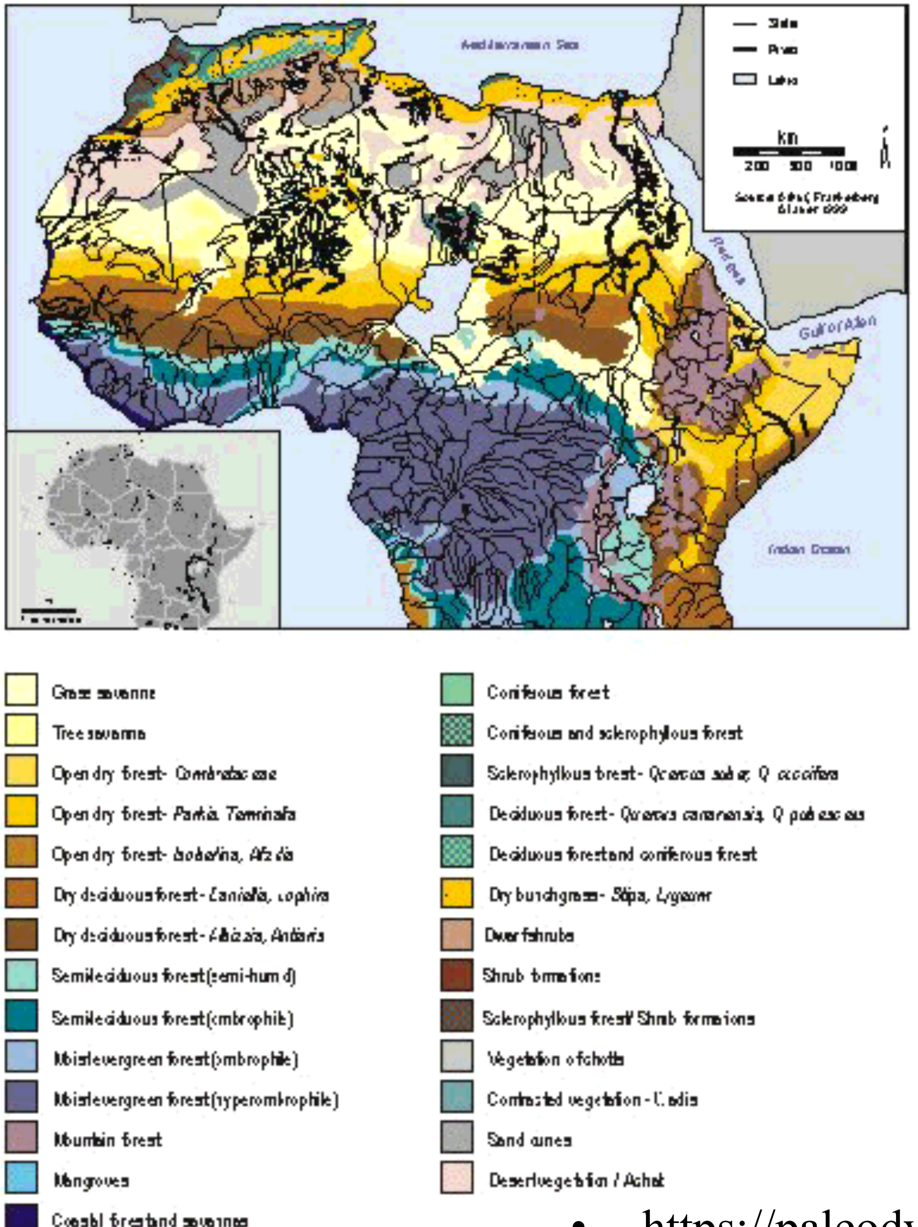
Exercise I

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_11.html

Exercise II

Vegetation of Africa (8.000 y BP)



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_11.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

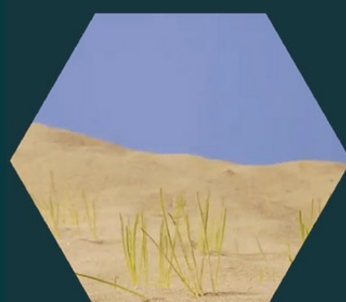
STEP 2

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

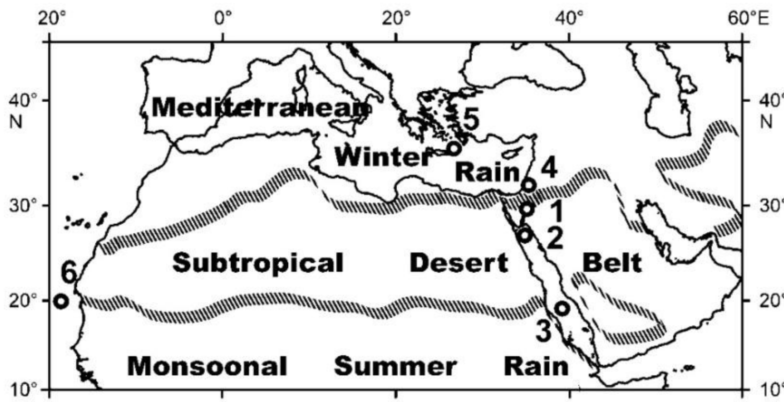


Fig. 1. Map with location of sites discussed in the text: 1, core GeoB 5804-4 (this study); 2, core GeoB 5844-2 (this study); 3, core KL 11 (*16*); 4, Soreq Cave (*18*); 5, core LC21 (*29*); 6, ODP Site 658C (*6*). The map also includes a schematic representation of modern rainfall regimes showing the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

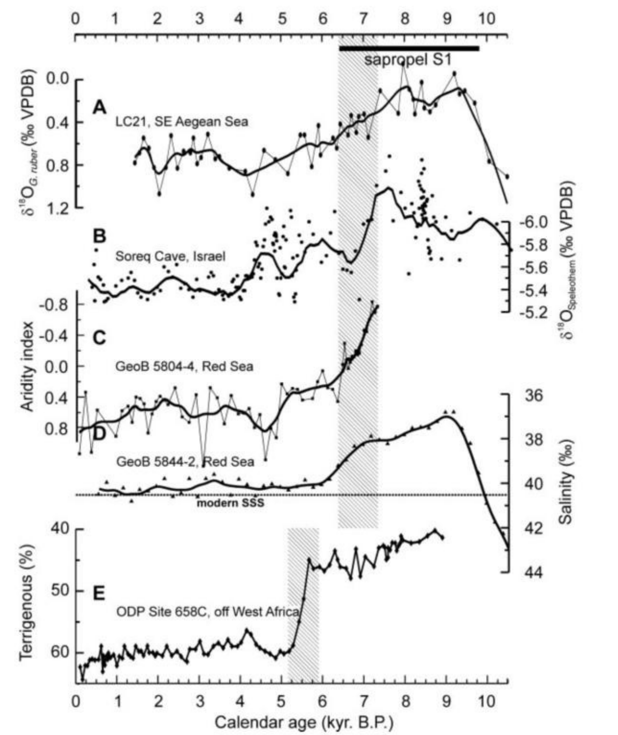


Fig. 3. Timing of the early- to mid-Holocene humid interval in the northern Red Sea compared with proxy records from the eastern Mediterranean, southern Oman, and West Africa. **(A)** $\delta^{18}O$ record of *G. ruber* (white) of the southeast Aegean Sea core LC21 (*29*), marking the enhanced freshwater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

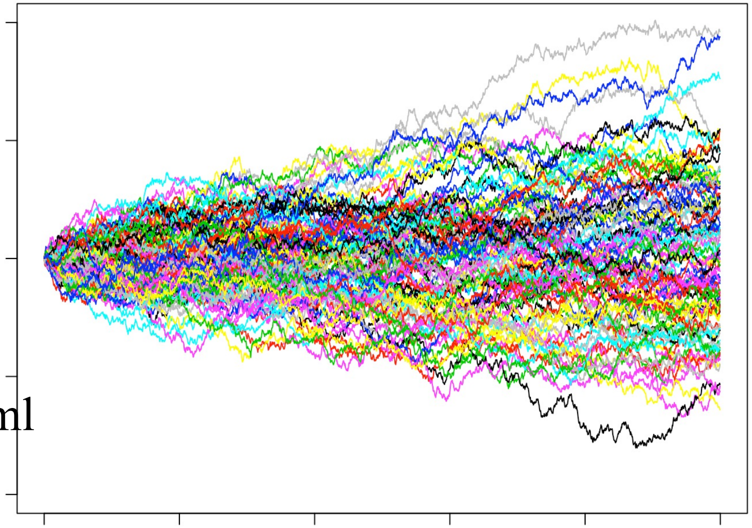
The Loess plateau in northern China

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

Exercise III

Random Systems

1. Simulate the velocity evolution of one particle which is determined by the following stochastic dx/dt = -b*x* + *k*W(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