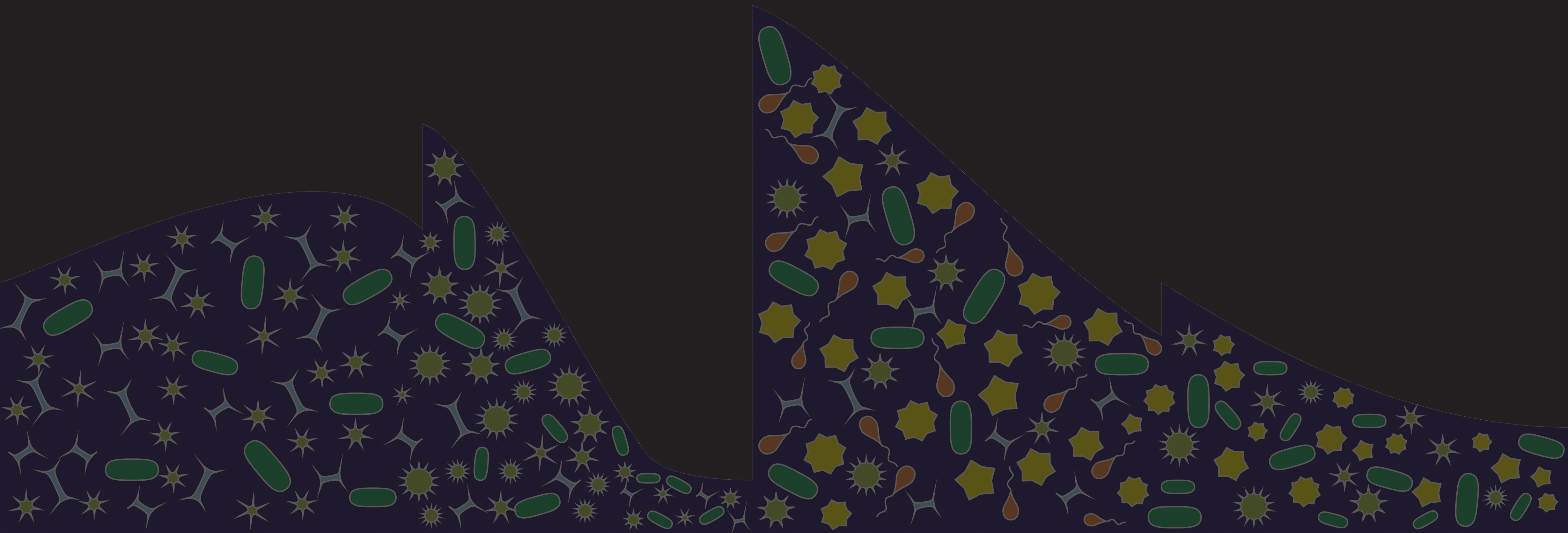
The ecology of numerical models and other baked goods

Andy Ridgwell

University of Bristol,
University of California – Riverside

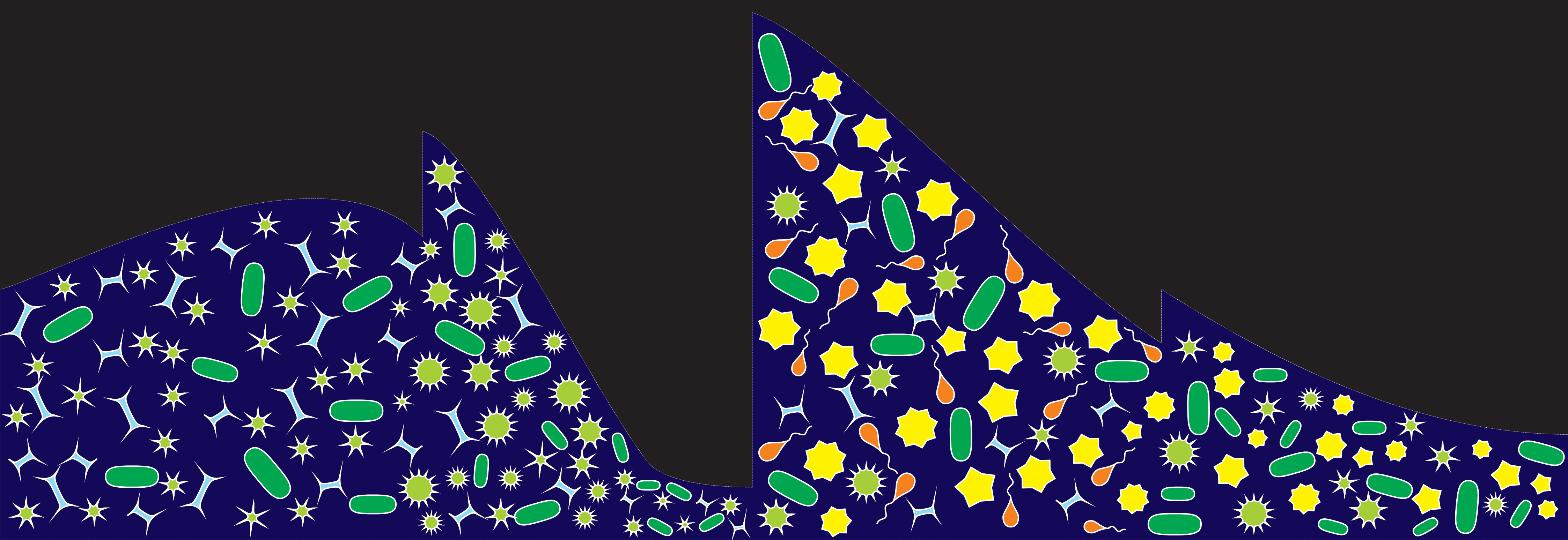


Outline

(1) Muffins.

(2) Cupcakes.

(3) Other baked goods.

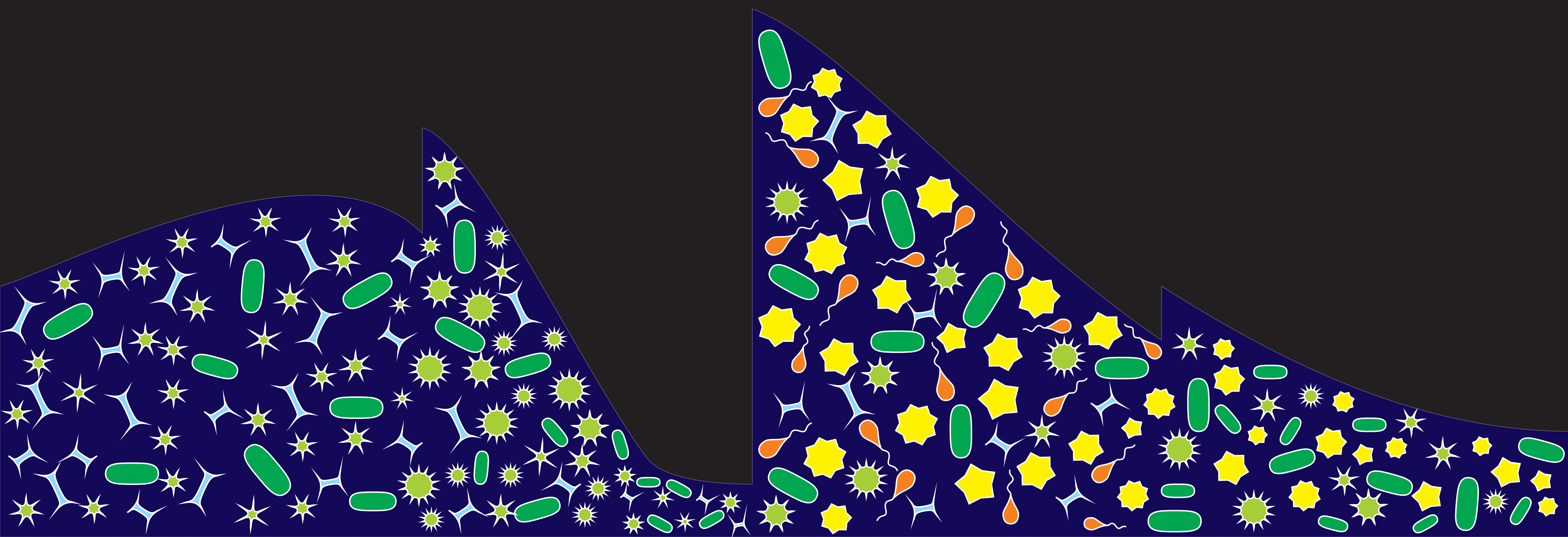


Outline

(1) Some GENIE results.

(2) Current/emerging GENIE developments and potential for a GUI-based 'teaching model'.

(3) Future directions in ecological modelling.



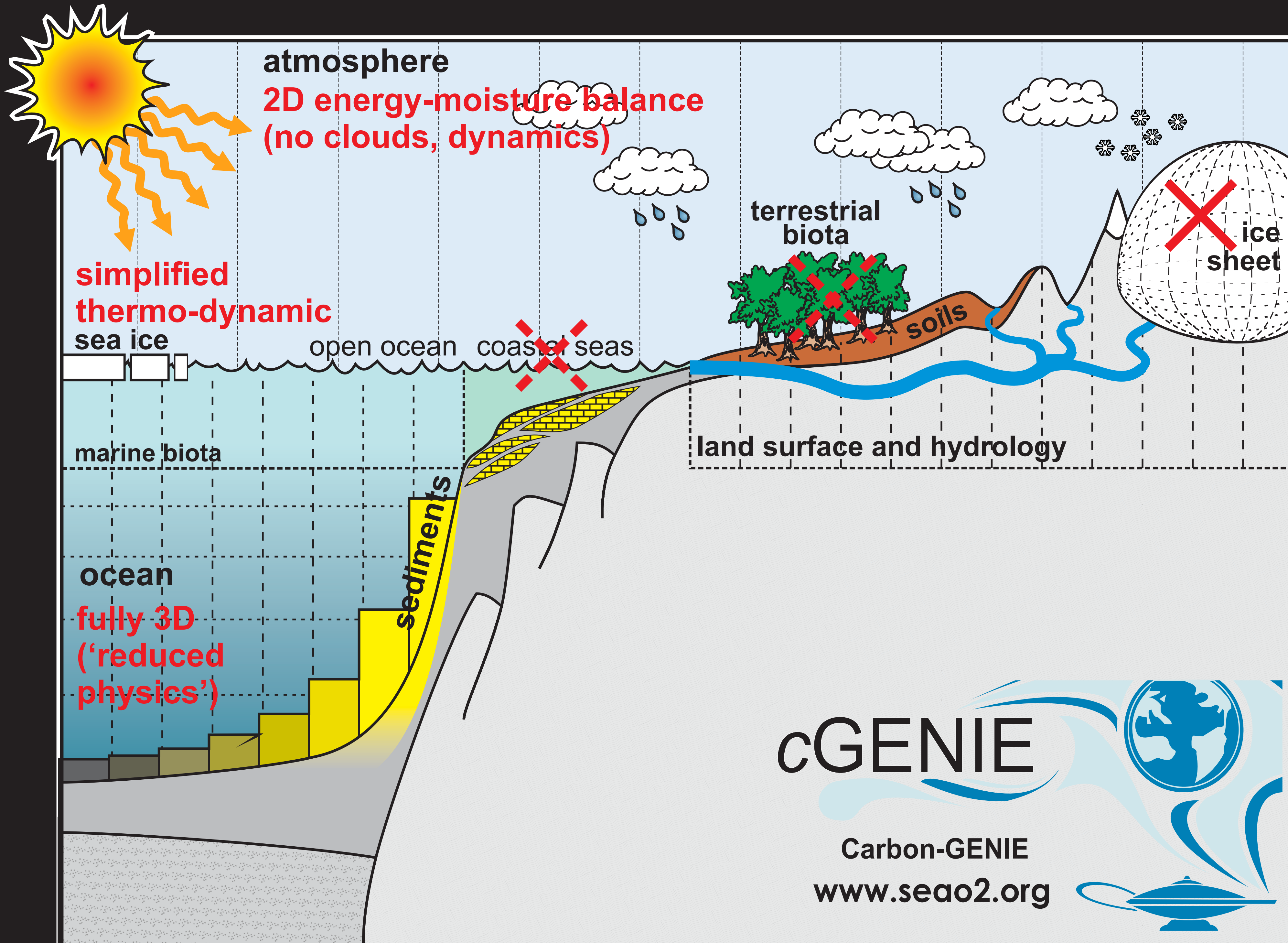
introduction

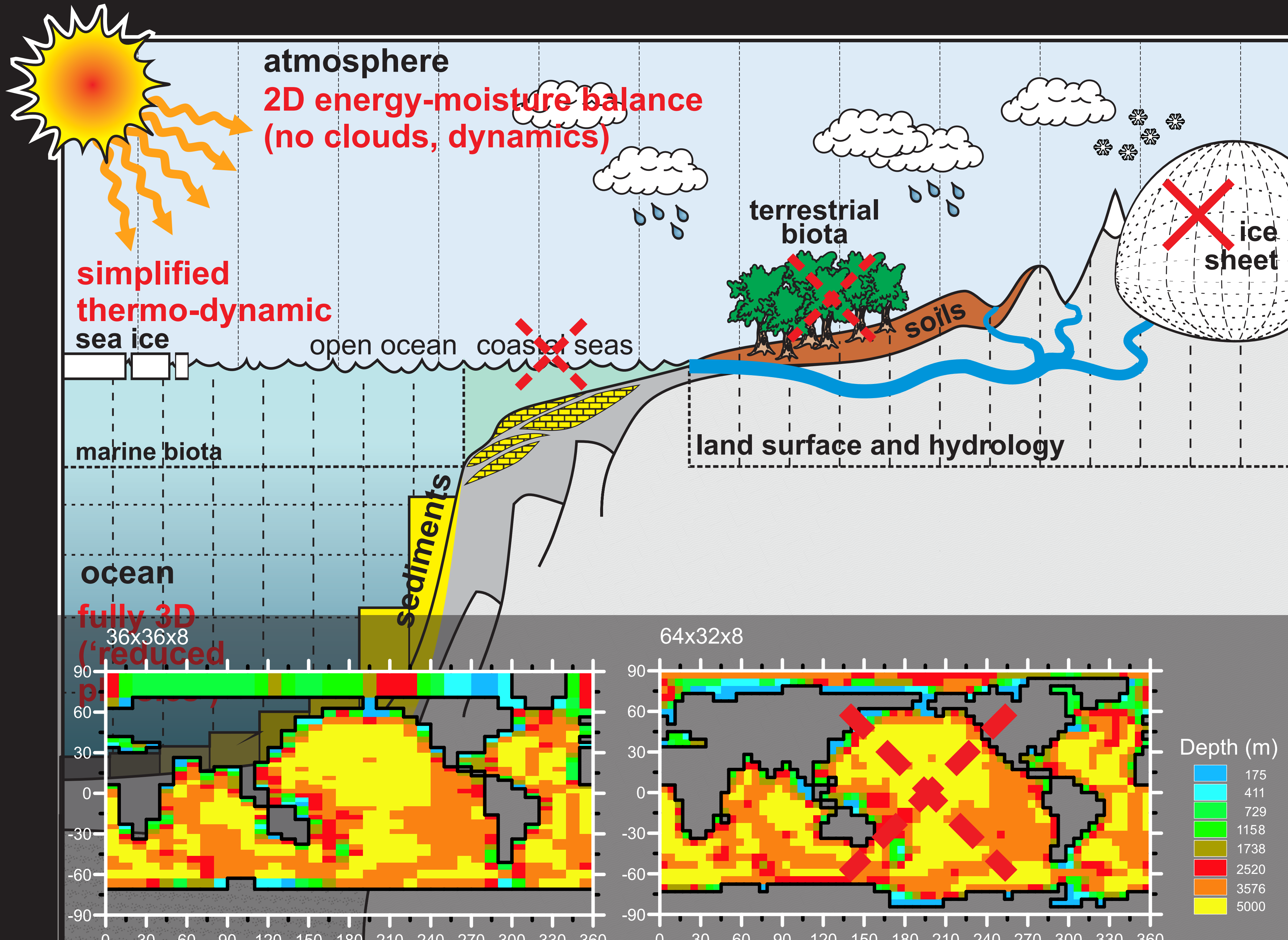
GENIE

Grid ENabled Integrated Earth system model

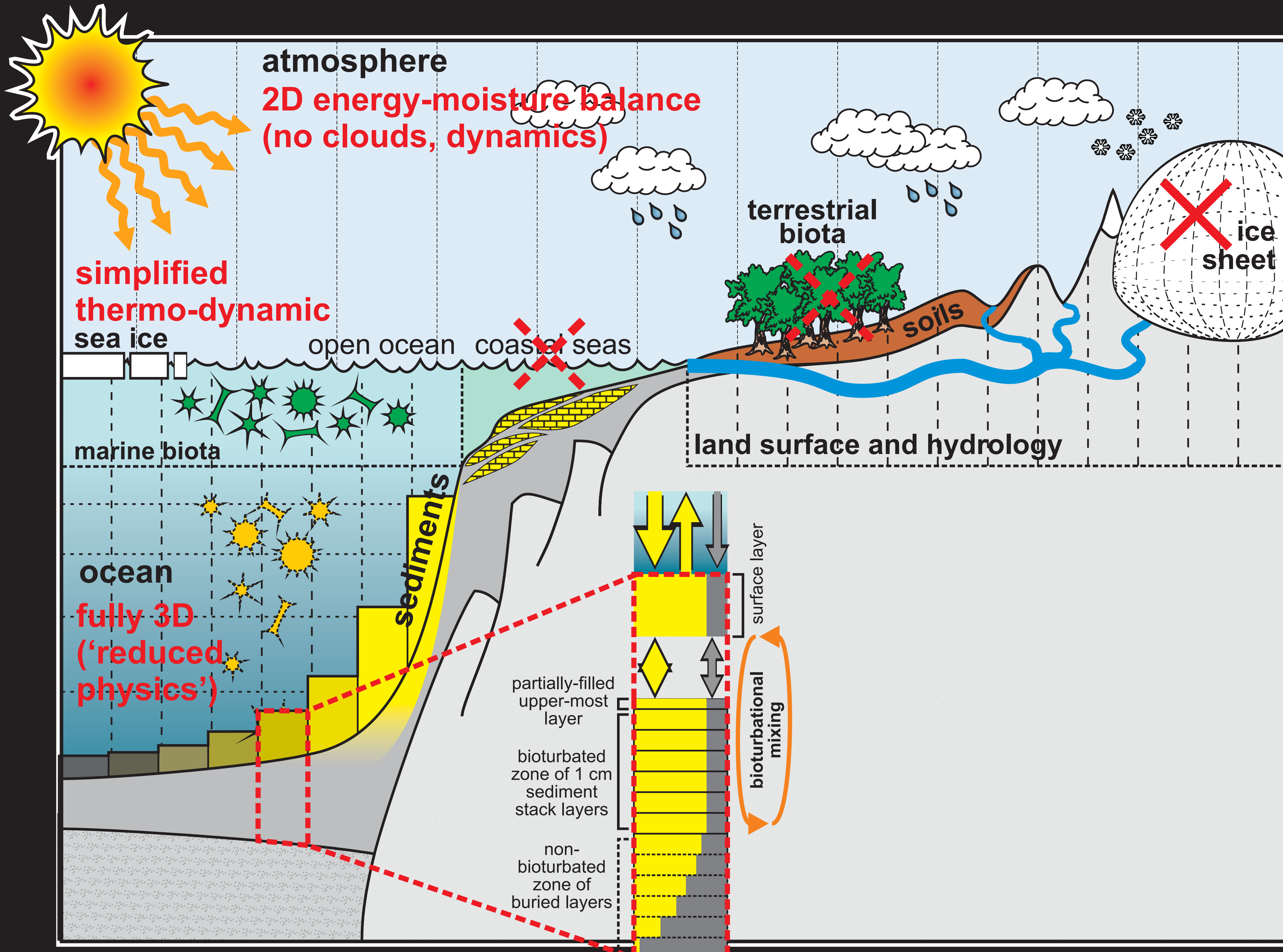
www.genie.ac.uk

introduction




atmosphere
2D energy-moisture balance
(no clouds, dynamics)
simplified
thermo-dynamic
sea ice
open ocean
coastal seas
terrestrial
biota
soils
ice
sheet
marine biota
land surface and hydrology
sediments
ocean
fully 3D
('reduced
36x36x8
64x32x8
Depth (m)
175
411
729
1158
1738
2520
3576
5000

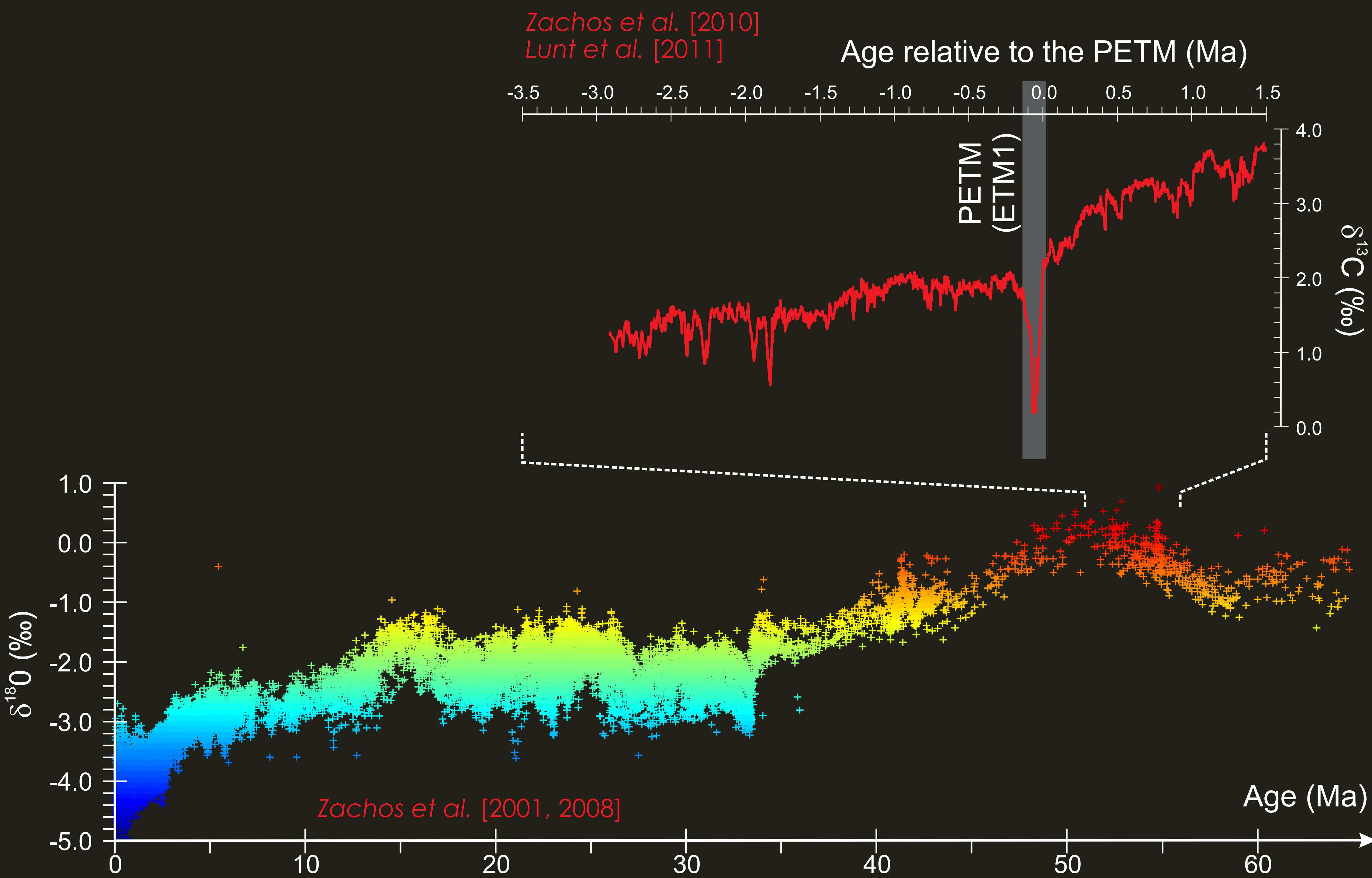
introduction



major changes vs. 'GENIE'

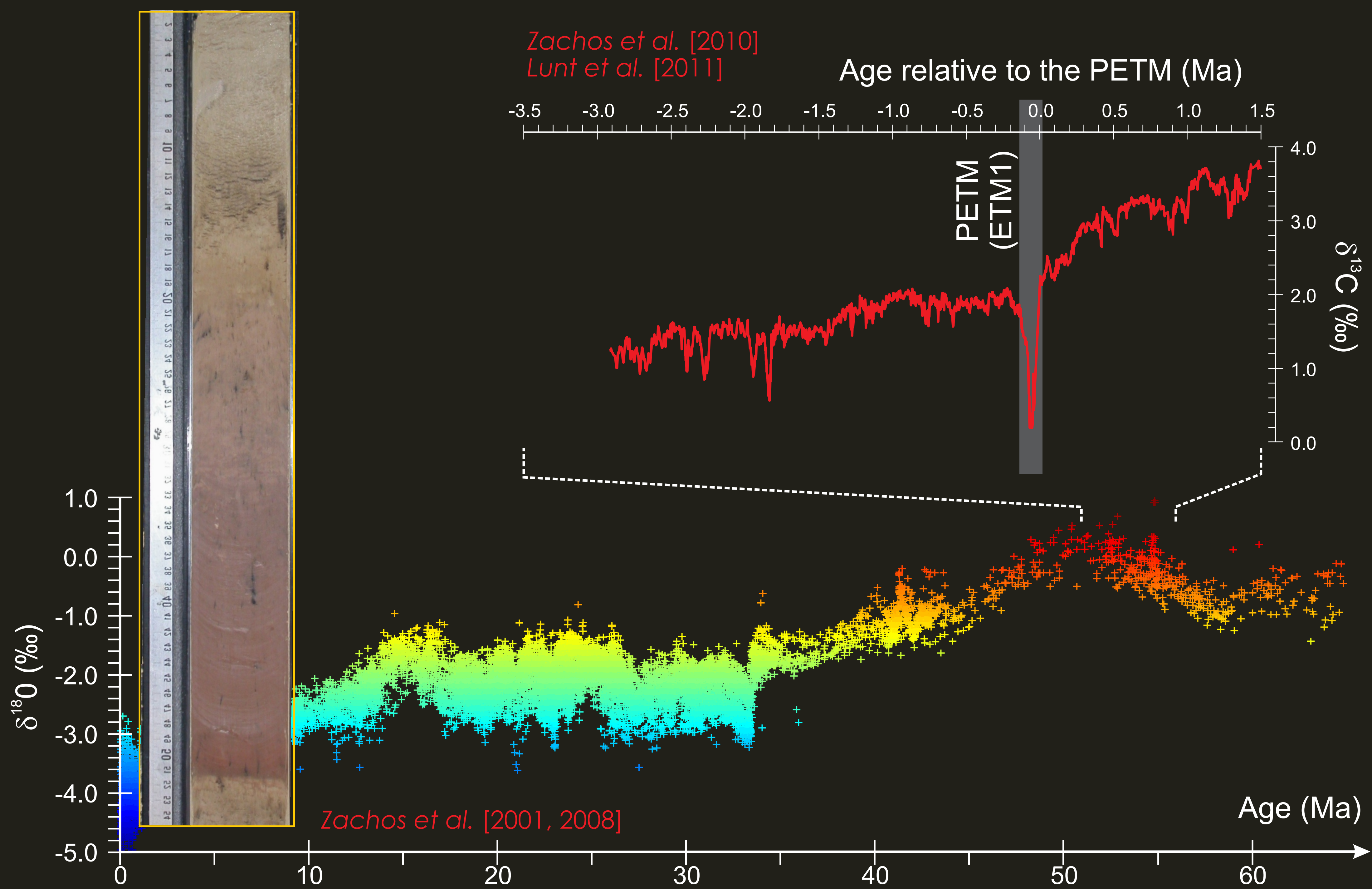
- deletion of 'legacy' science modules, e.g. IGCM, GLIMMER, MOSES/TRIFFID, etc. (improving compiler compatibility)
- attempt at parallelization (concurrent GOLDSTEIN/BIOGEM, domain de-compositoin of GOLDSTEIN)
- reorganization of main `GENIE.F` loop and introduction (completion) of 'GEMlite'
- simplification of `runmuffin.sh` script configuration, name-list checking
- complete reorganisation of redox (in progress)
- continued tracer addition and functionality such as proxy 'inversion' methodology
- added netCDF restarts for biogeochem modules
- added netCDF sedcor data saving
- MATLAB plotting and analysis function development

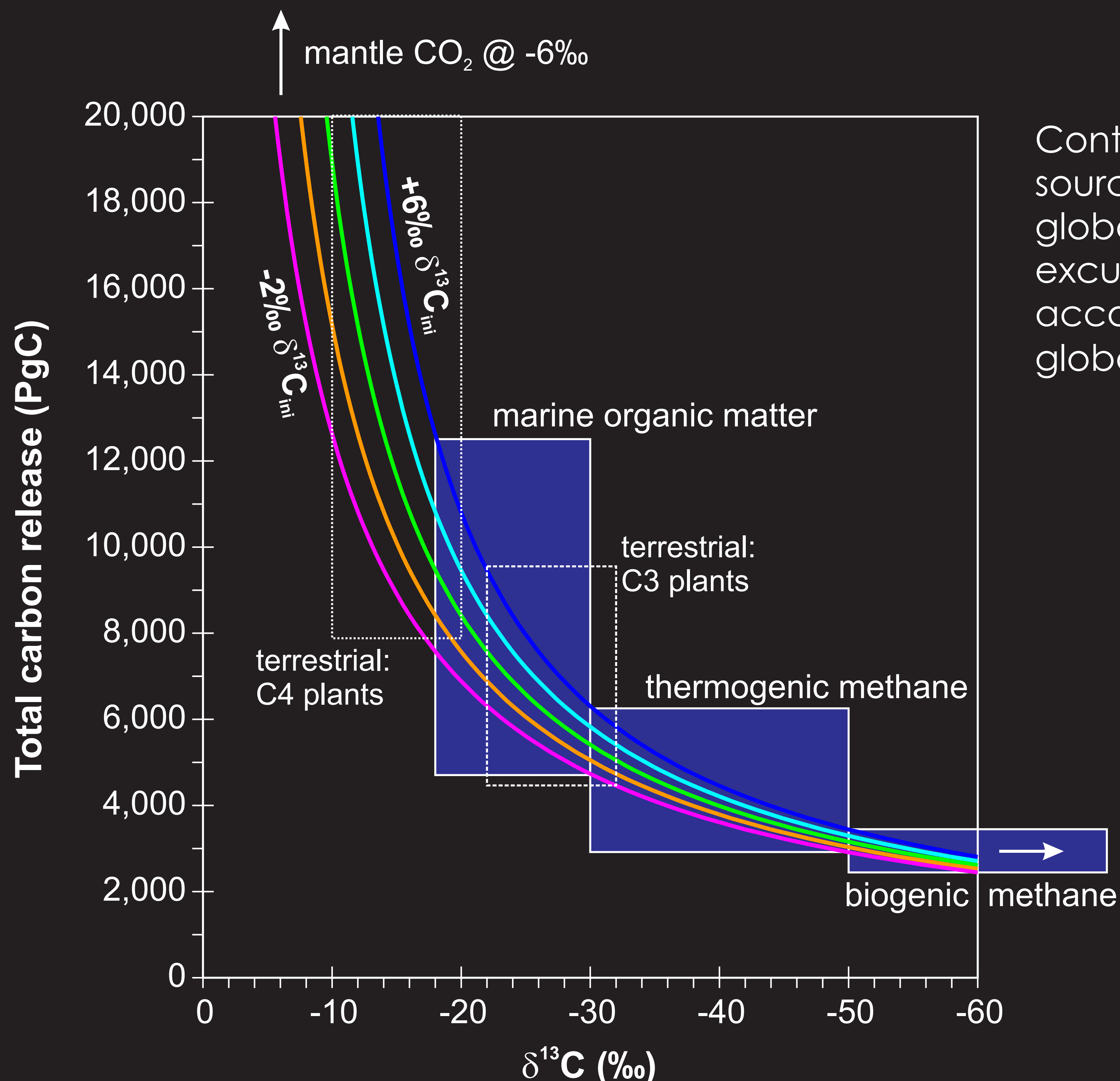
muffin application: Paleocene-Eocene Thermal Maximum



muffin application: Paleocene-Eocene Thermal Maximum

Computer models and other baked goods

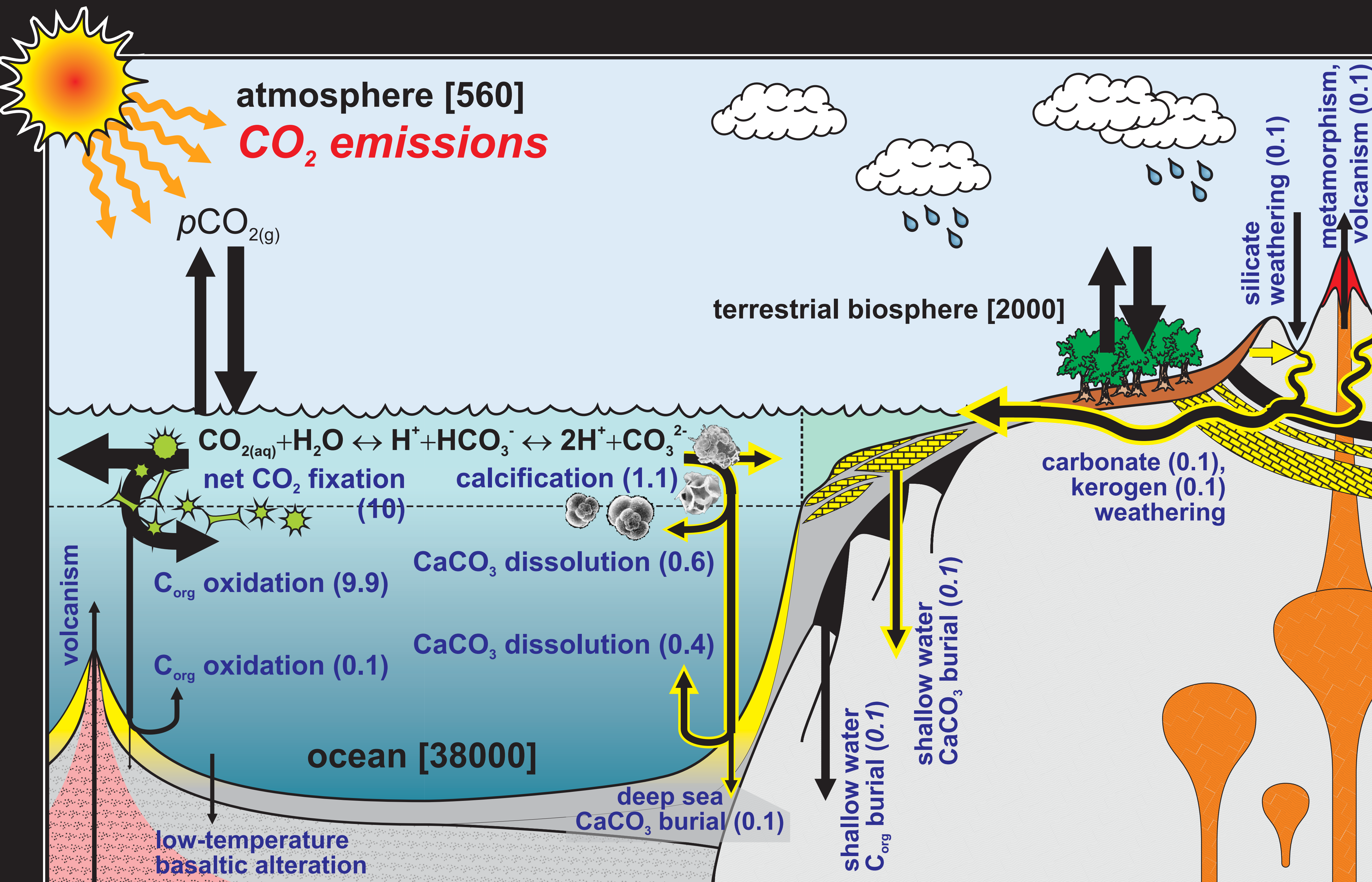




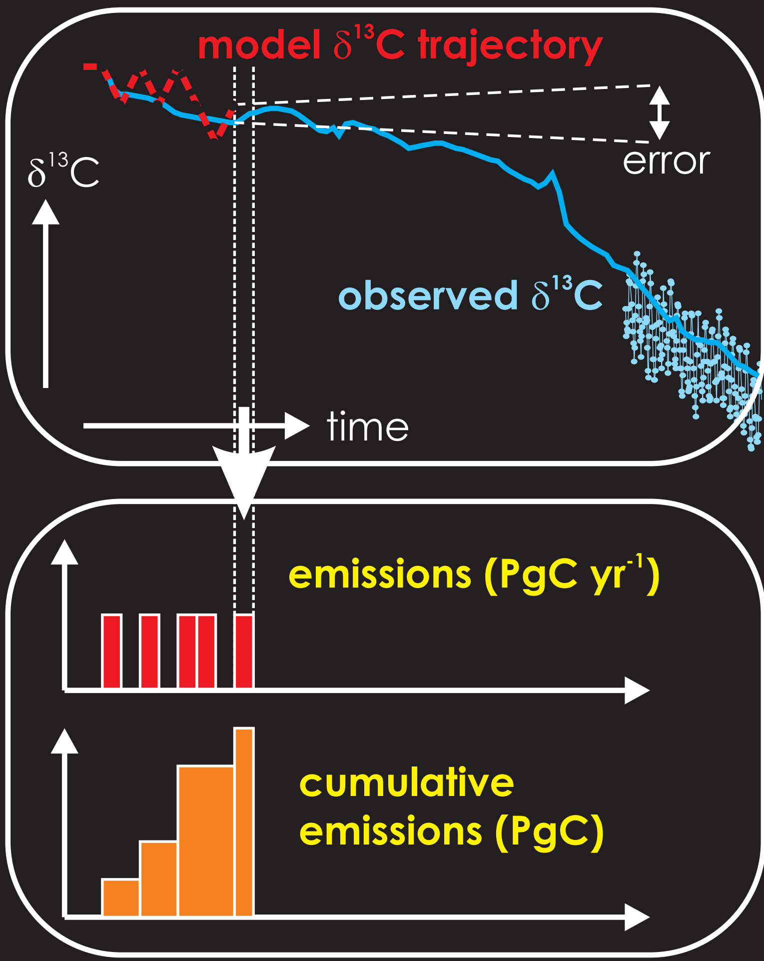
Contours of carbon release vs. source isotopic signature for a global -4‰ carbon isotopic excursion. Contours differ according to the initial mean global $\delta^{13}C$.

Ridgwell and Arndt [2014]

muffin application: Paleocene-Eocene Thermal Maximum



muffin application: Paleocene-Eocene Thermal Maximum



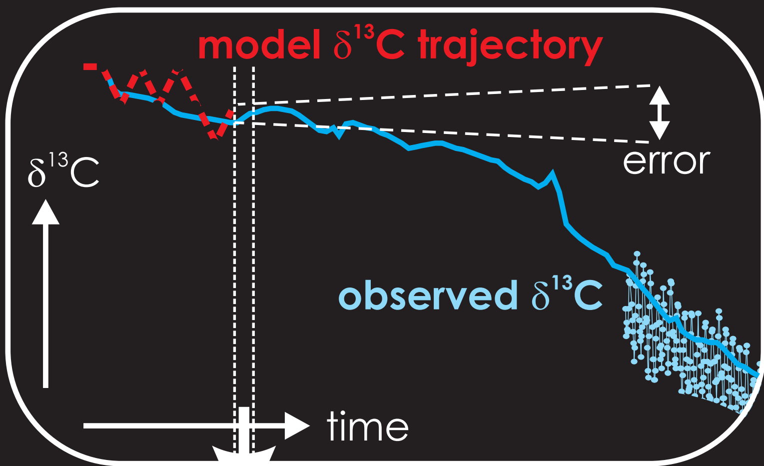
1. Calculate model-data error at a weekly time-step:

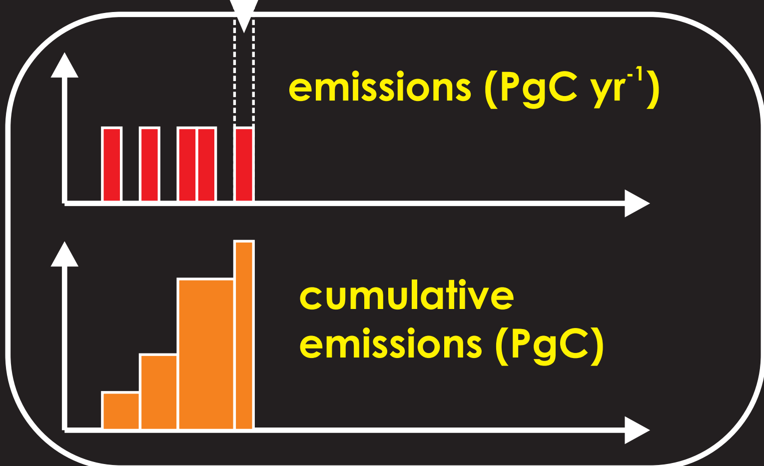
too high ⇒ emit carbon

'OK' ⇒ do nothing

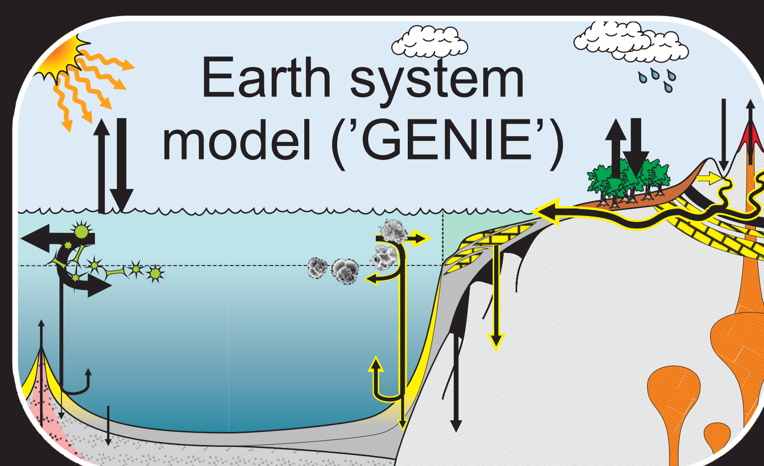
(too low ⇒ remove carbon)

muffin application: Paleocene-Eocene Thermal Maximum



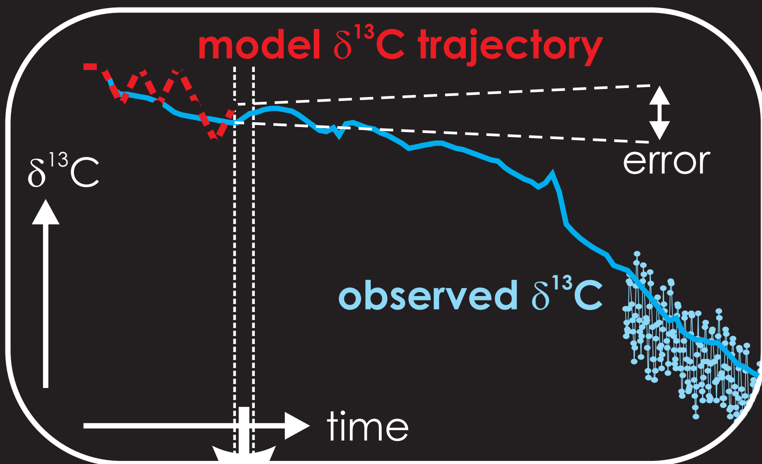


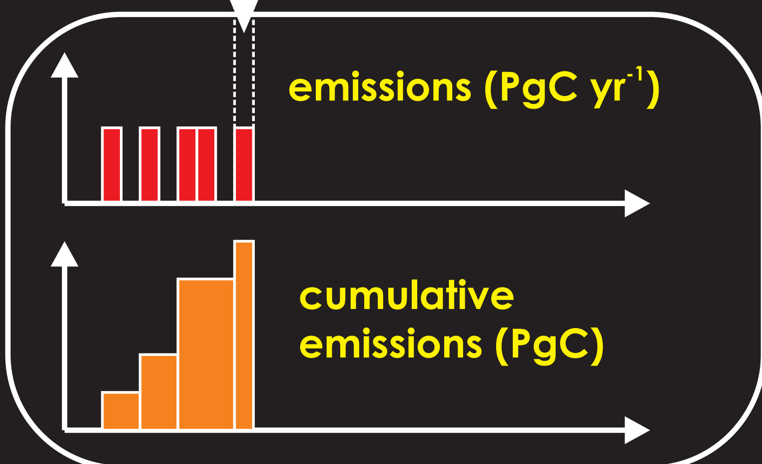
2. If CO_2 emissions required:
Add CO_2 to atmosphere
in an Earth system model



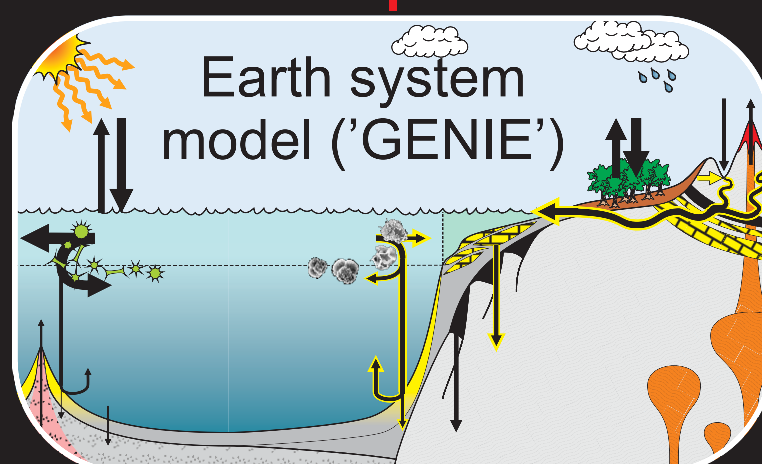
assume:
$\delta^{13}C$ signature
of fossil fuels
for emissions

muffin application: Paleocene-Eocene Thermal Maximum





3. Calculate new atmospheric CO_2 $\delta^{13}C$ value in model
<REPEAT>



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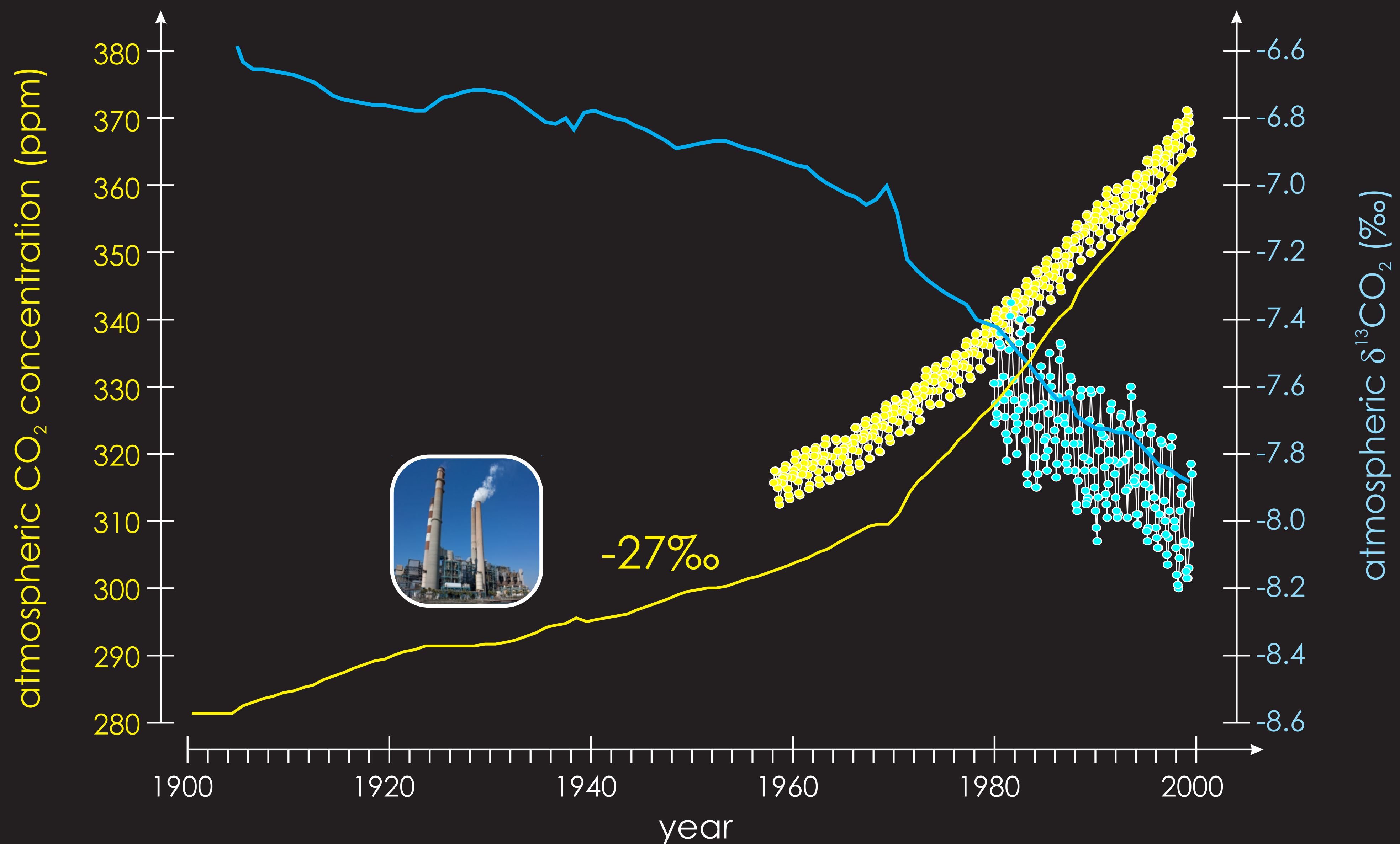
muffin application: Paleocene-Eocene Thermal Maximum

Computer models and other baked goods



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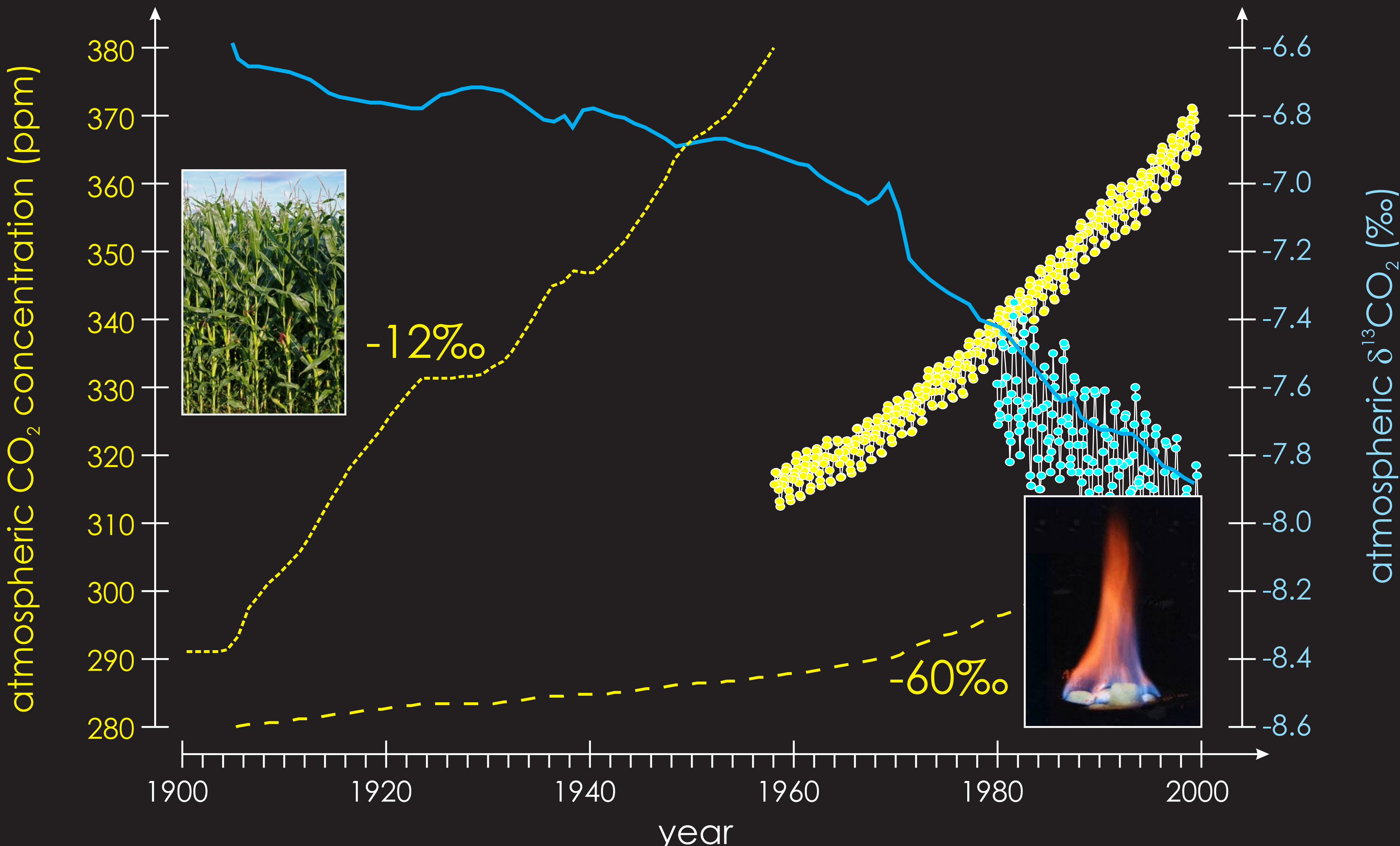

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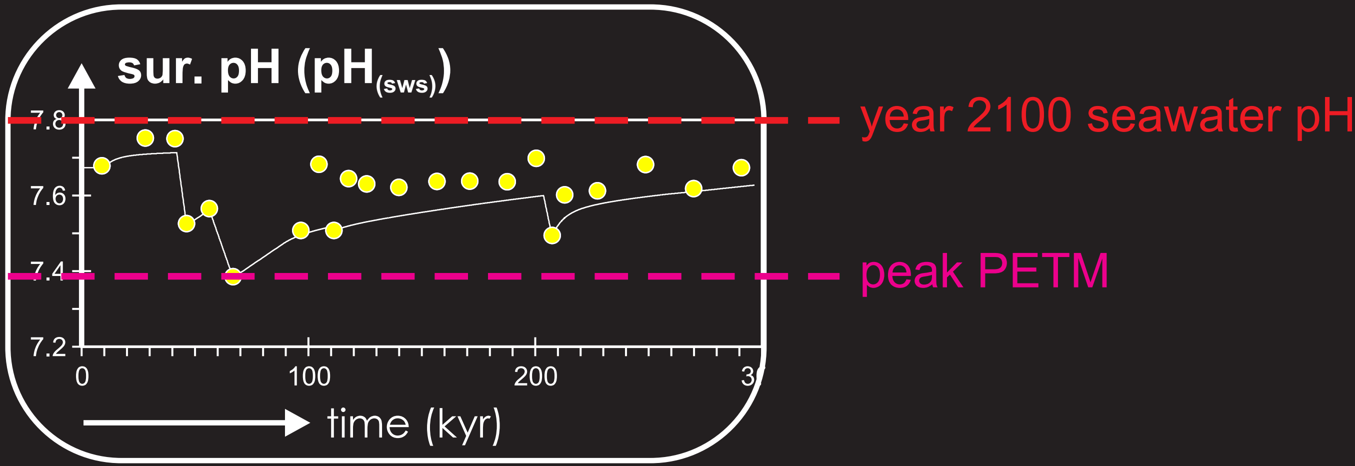

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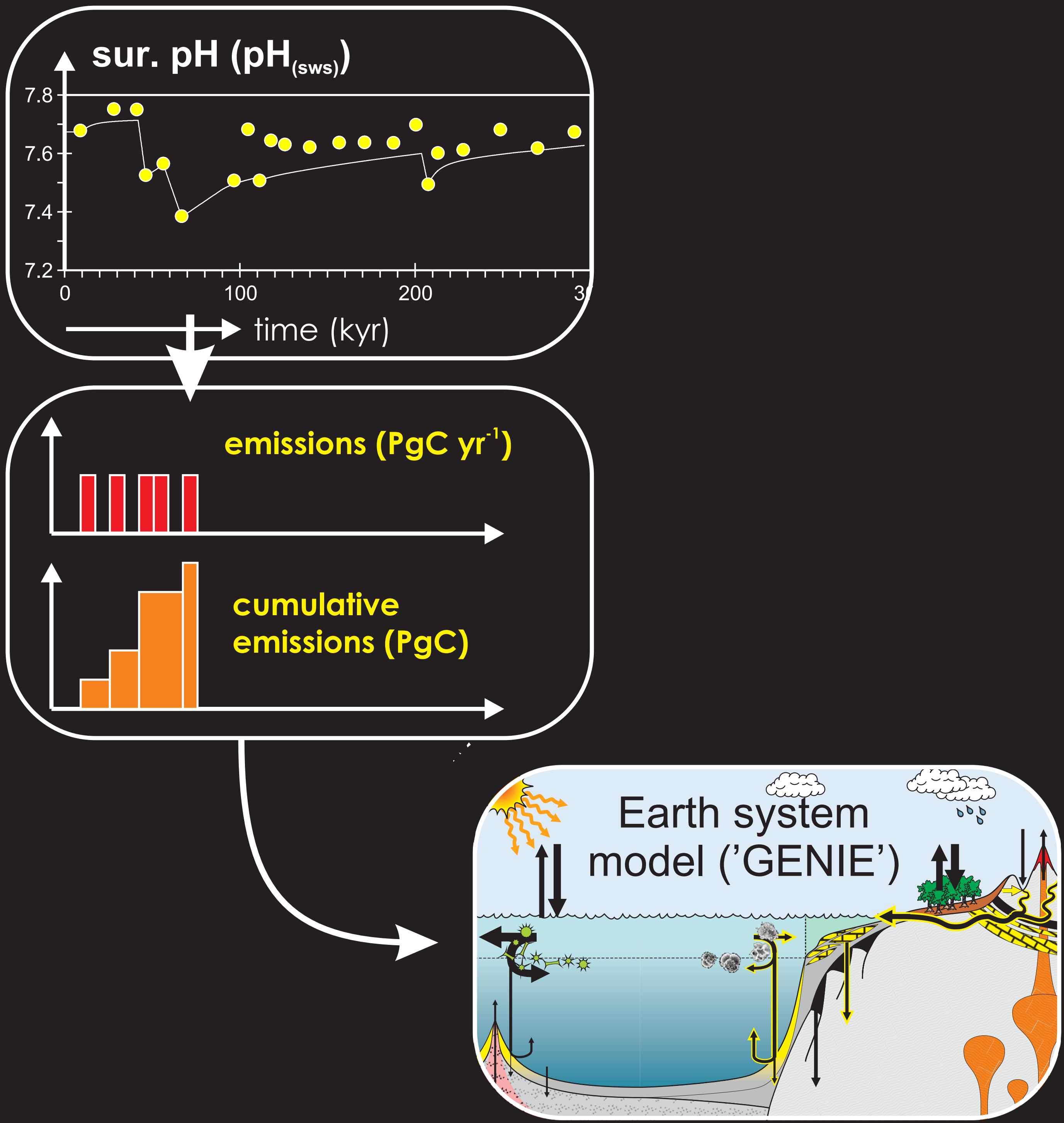

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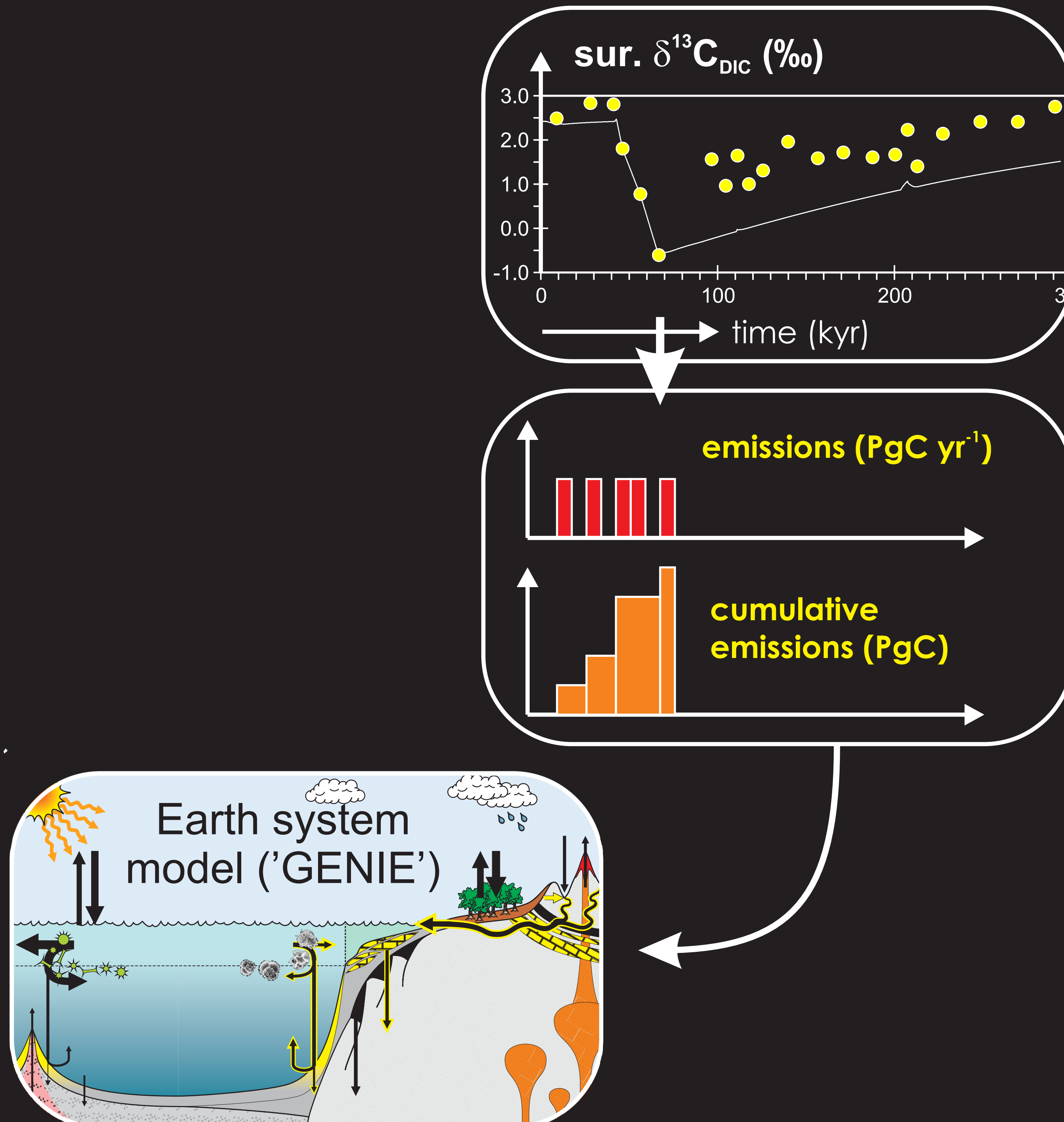

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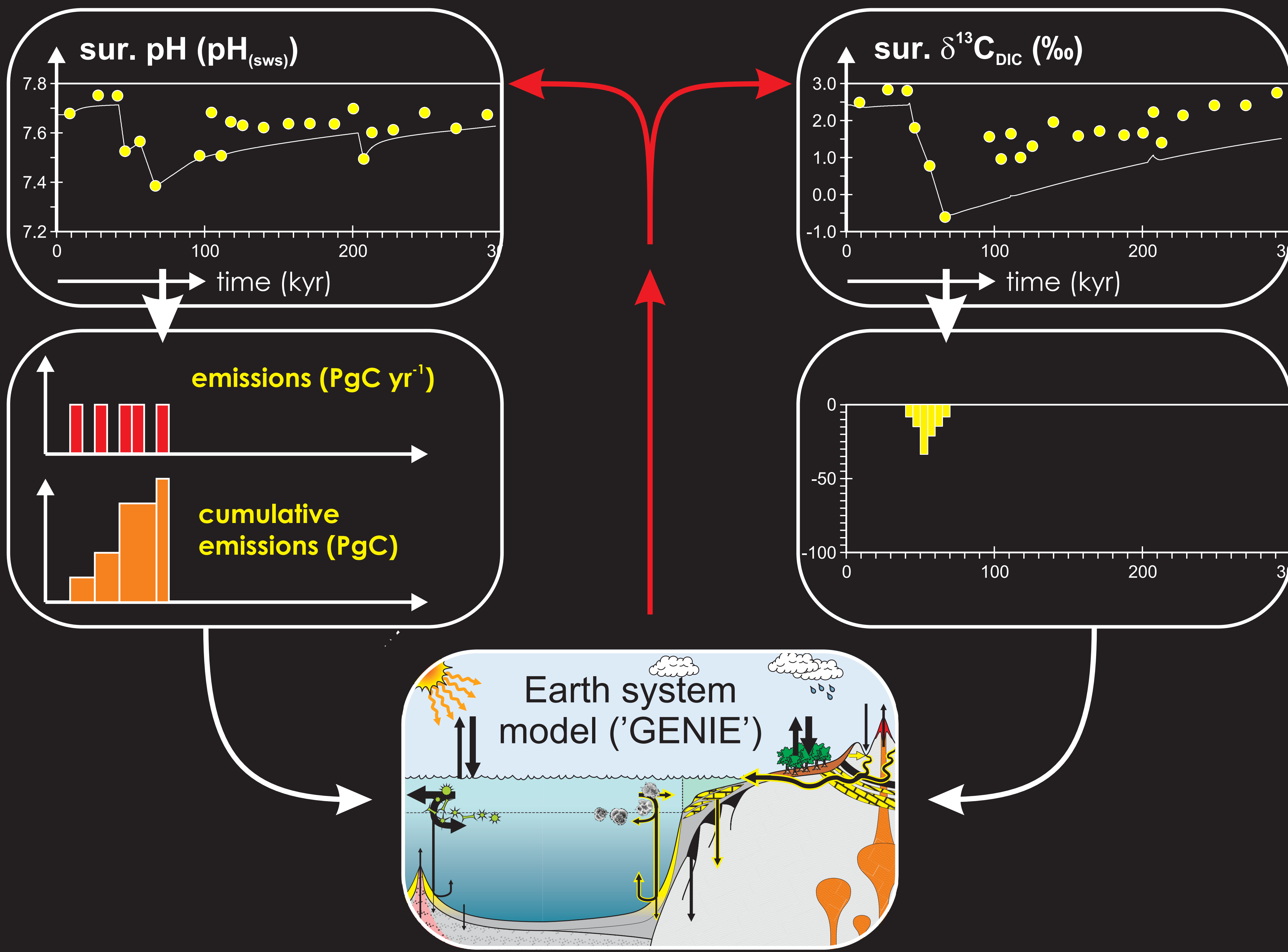

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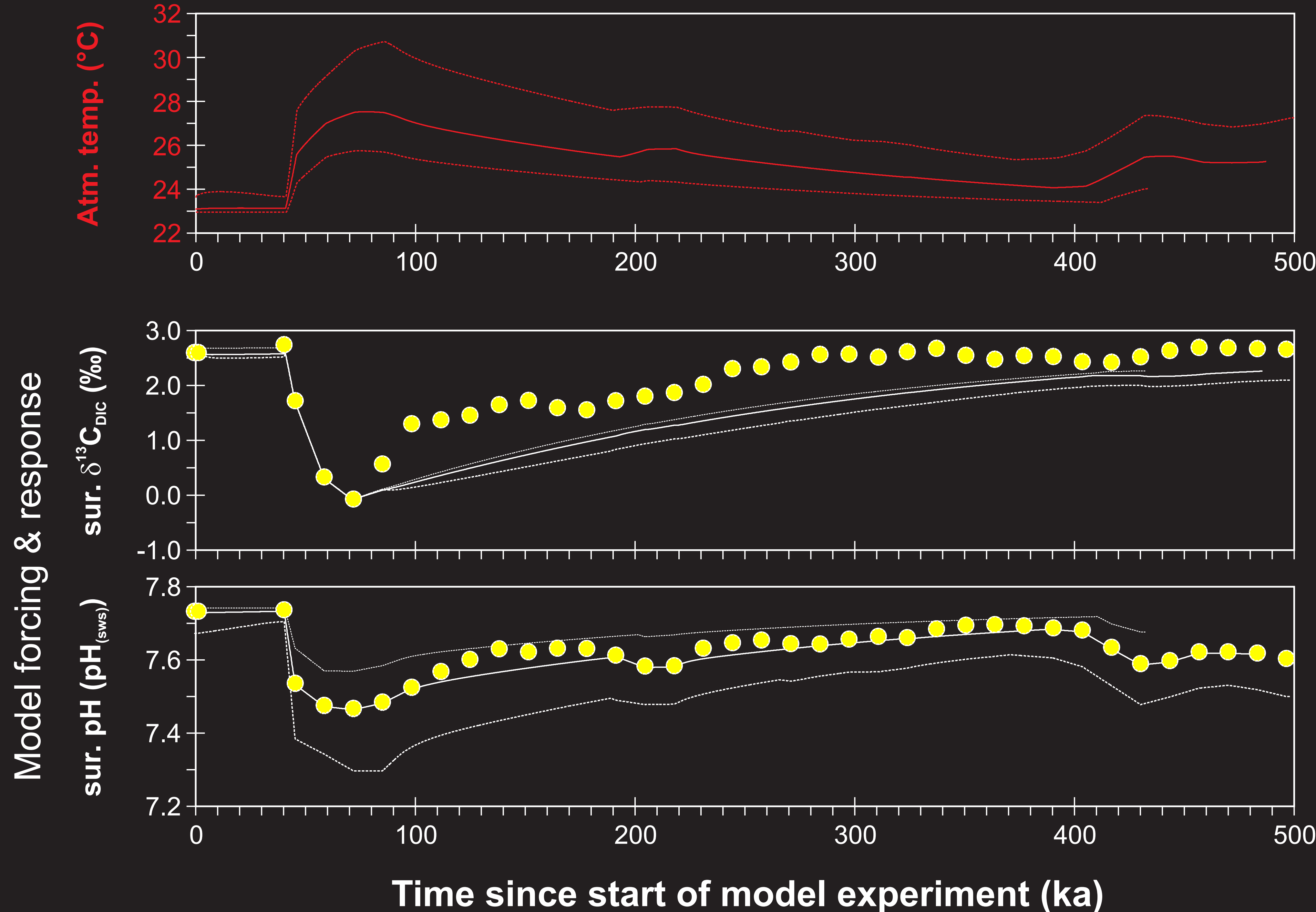

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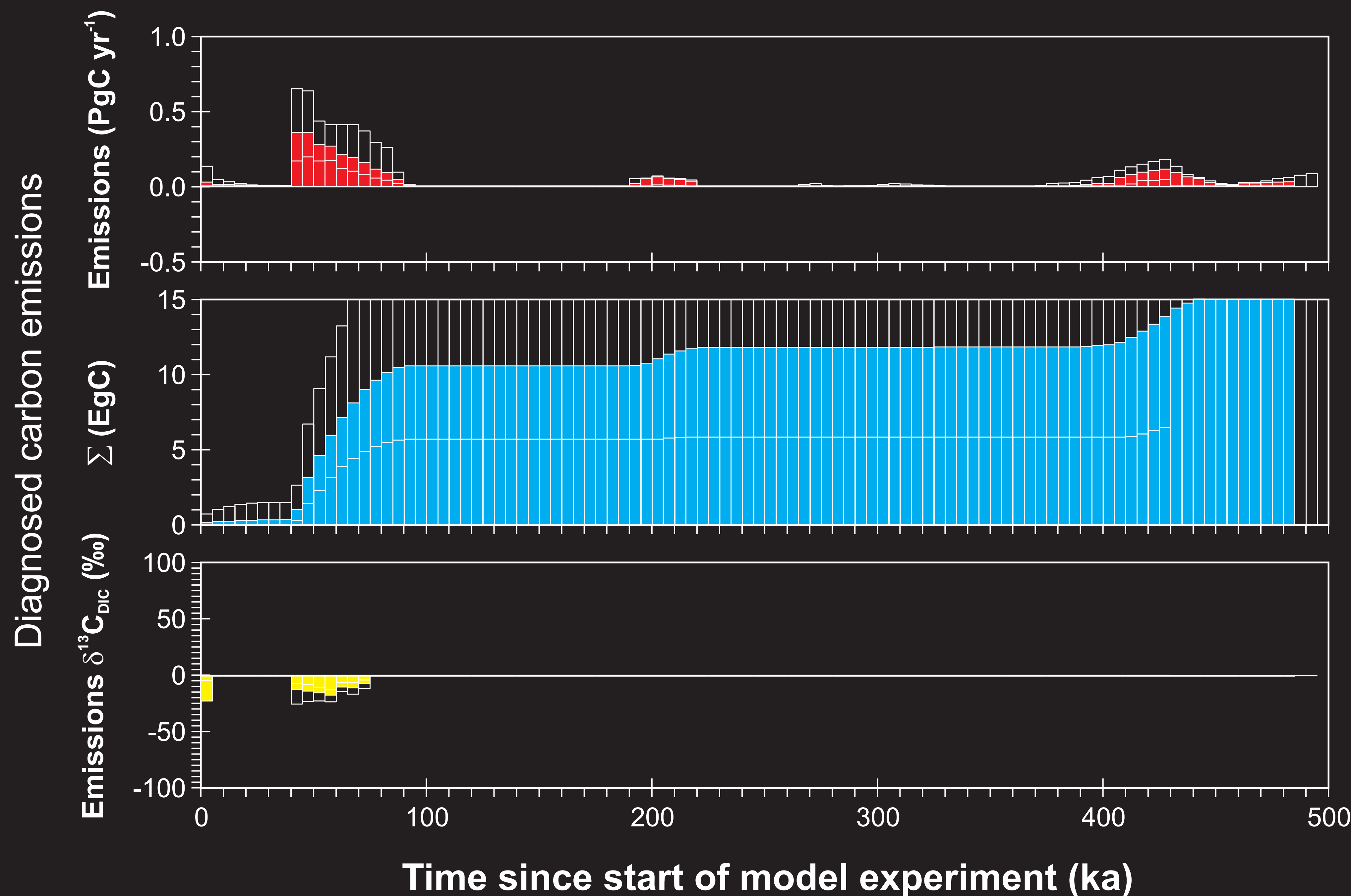


issues

- continued use of FORTRAN77 code, e.g. preventing compile-time array dimensioning
- netCDF installation issues (partly an issue of the use of C++ code in the netCDF comparison model 'test')
- linux-only (a problem?) (actually, can also now be natively on a Mac)
- non-intuative construction of experiments
- limited applicability in teaching due to linux and command-line basis of the model

cupcake

major changes

- code management under `git` (not `svn`), so has lost its explicit historical link with ‘GENIE’
- conversion to F90 throughout
- progress towards all run-time dimensioning of arrays (and no need for re-compilation)
- simpler directory structure and job creation/submission
- xml removed (and hence no need for python xml libraries (and hence a simpler install))
- cross platform support ... can be run under linux/MacOS/Windows

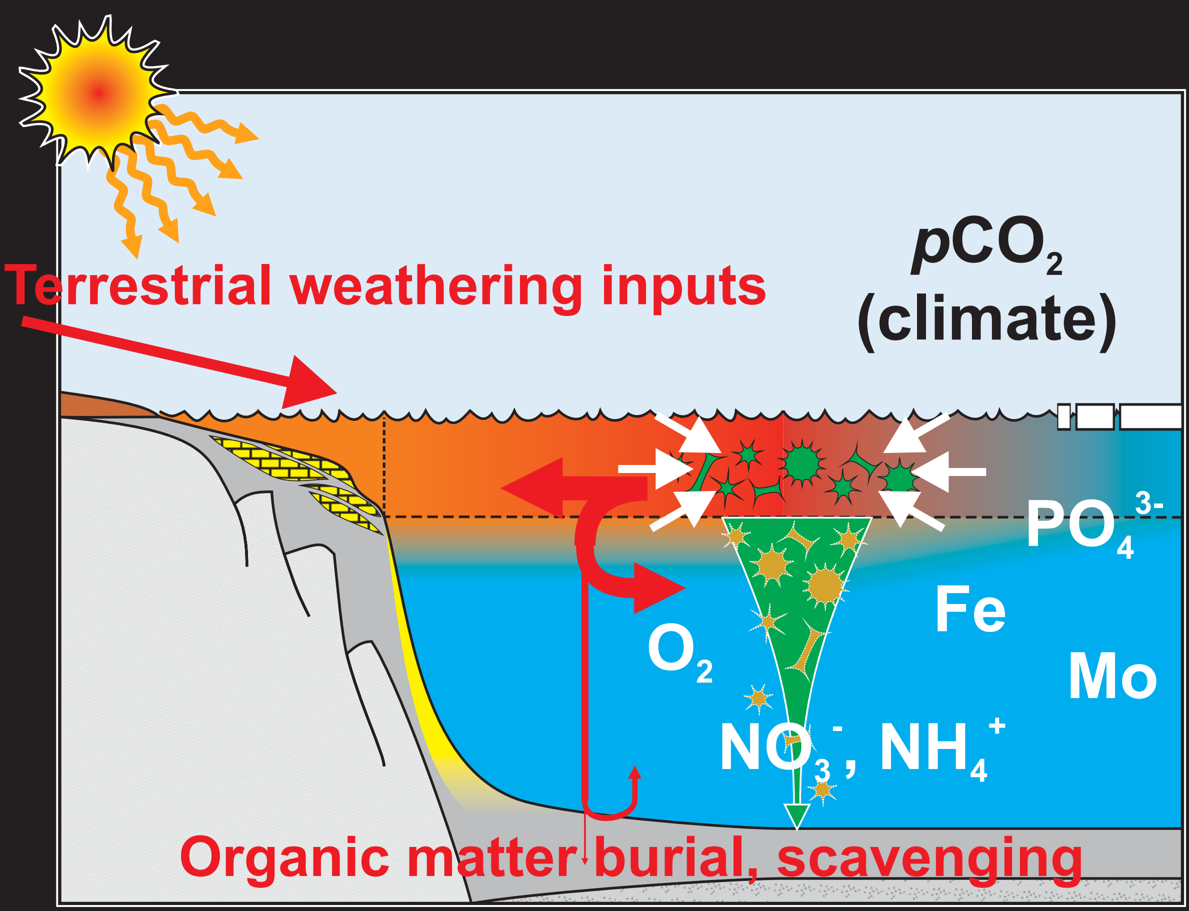
to-do

- thorough performance profiling and optimization
- on-line /off-line matrix transport option (eventually replacing GEMlite)
- addition of the Darwin ecosystem model
- addition of the PALEOGENiE project ‘PAM’ (paleo-assemblage model)
- addition of ECBILT AGCM??
- addition of JeDi terrestrial ecosystem model??

to-do

- GUI development ... ?

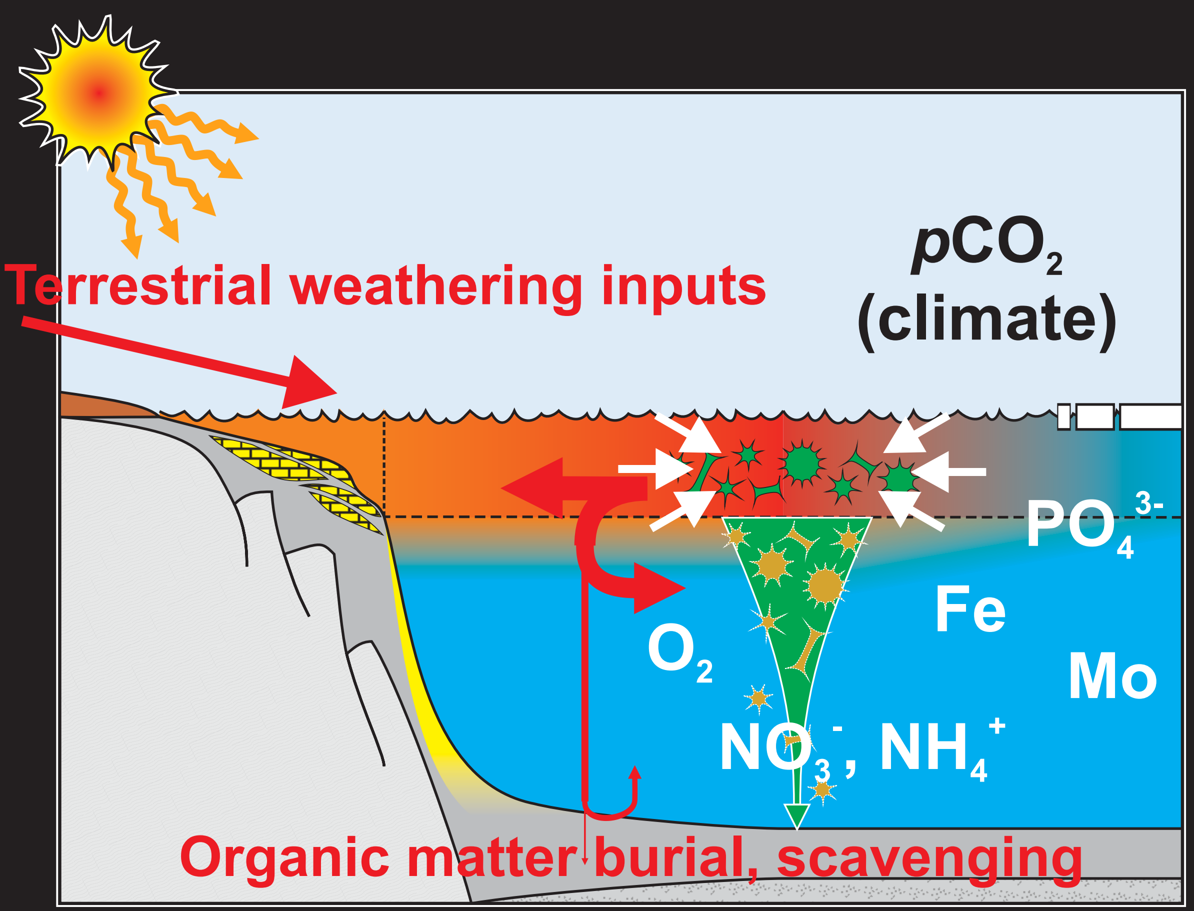
PALEOGENiE – motivation



The nature marine ecosystems and strength of biological productivity and remineralization affects:

- Oceanic macros nutrient inventories, esp. P and the form of fixed N.
- Ocean oxygenation and hence micro nutrient inventories, esp. Fe – scavanged in an oxic ocean, and Mo – scavenged in a sulphidic ocean.
- Atmospheric pCO_2 and climate.

PALEOGENiE – motivation



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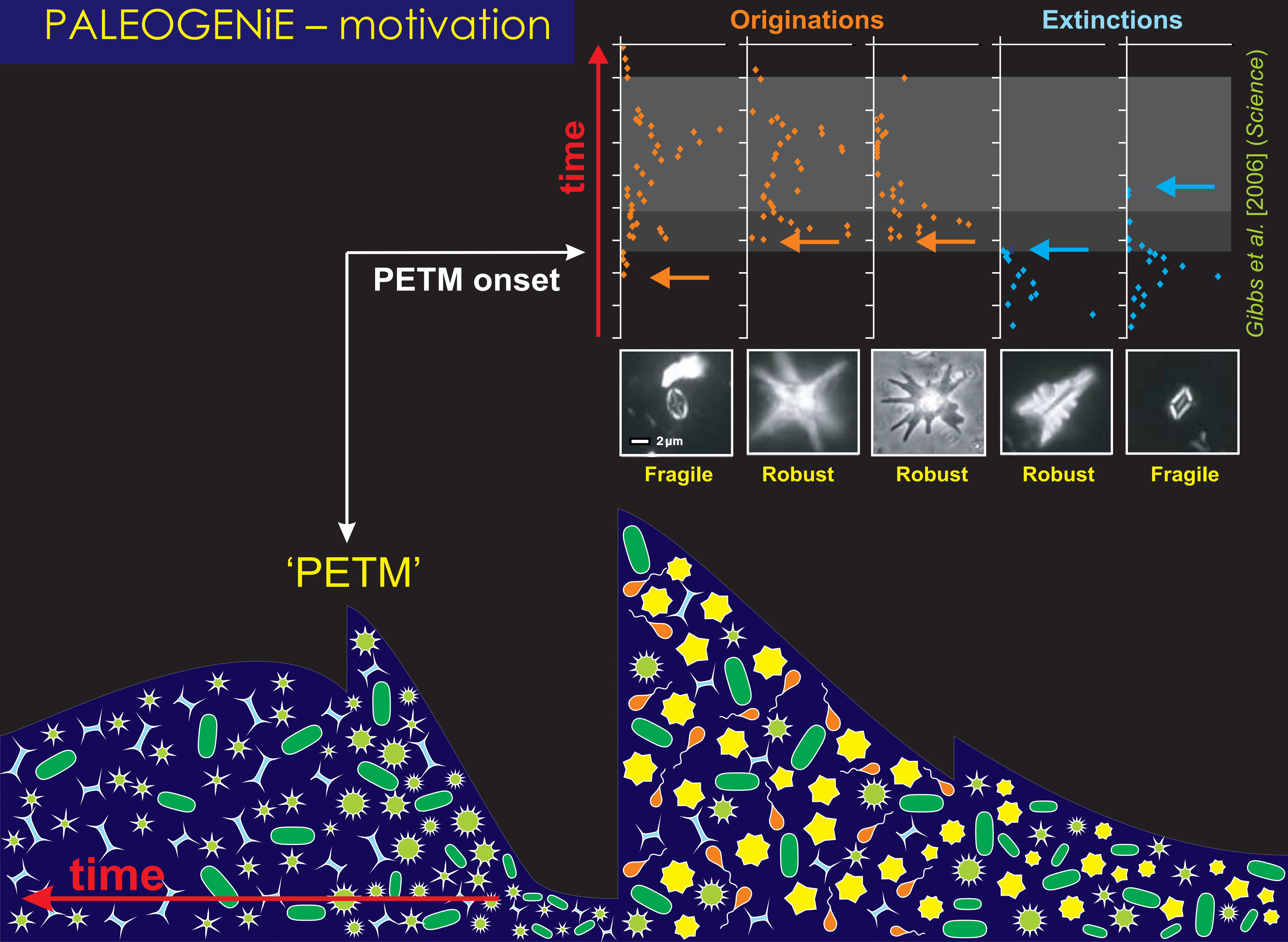
- Atmospheric pCO_2 and climate.

In turn, changes in the physical and biogeochemial (nutrient) environment will affect ecosystem composition and drive selection.

The approximate coincidence between plankton evolutionary time-scales and the residence time of many of the key ocean and atmospheric tracers raises the possibility of interesting dynamical behaviours of the full system.

`/end speculation`

PALEOGENiE – motivation



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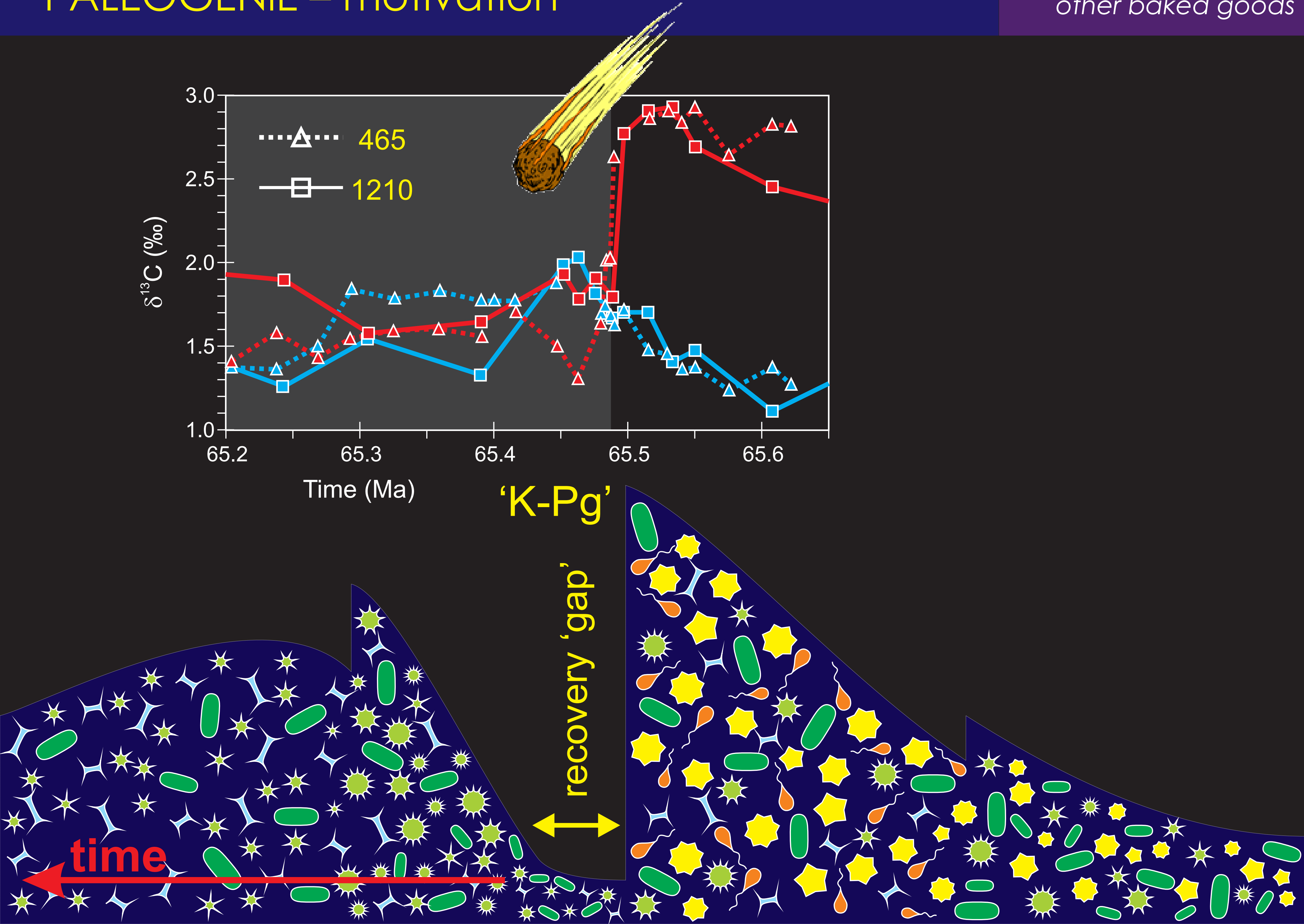
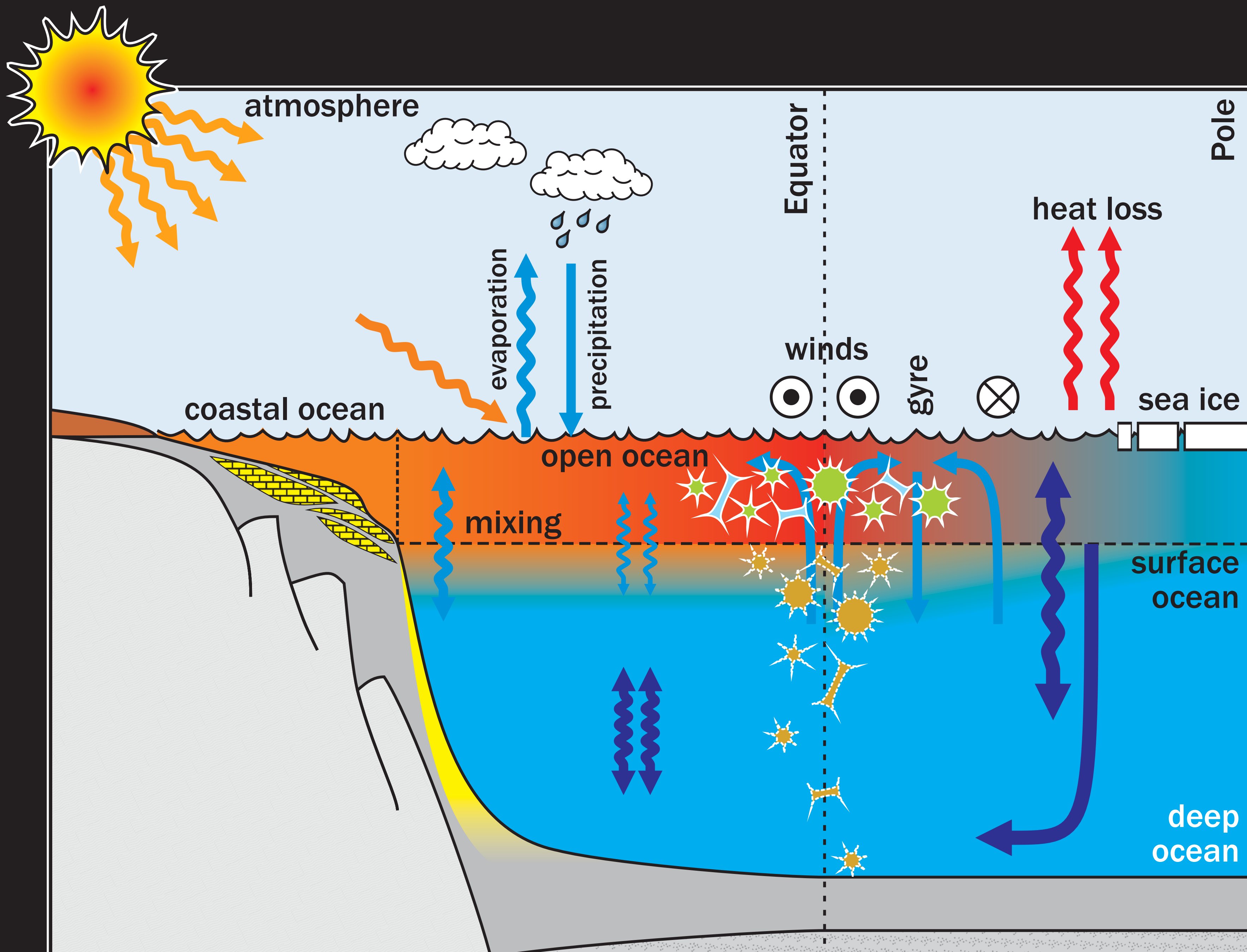
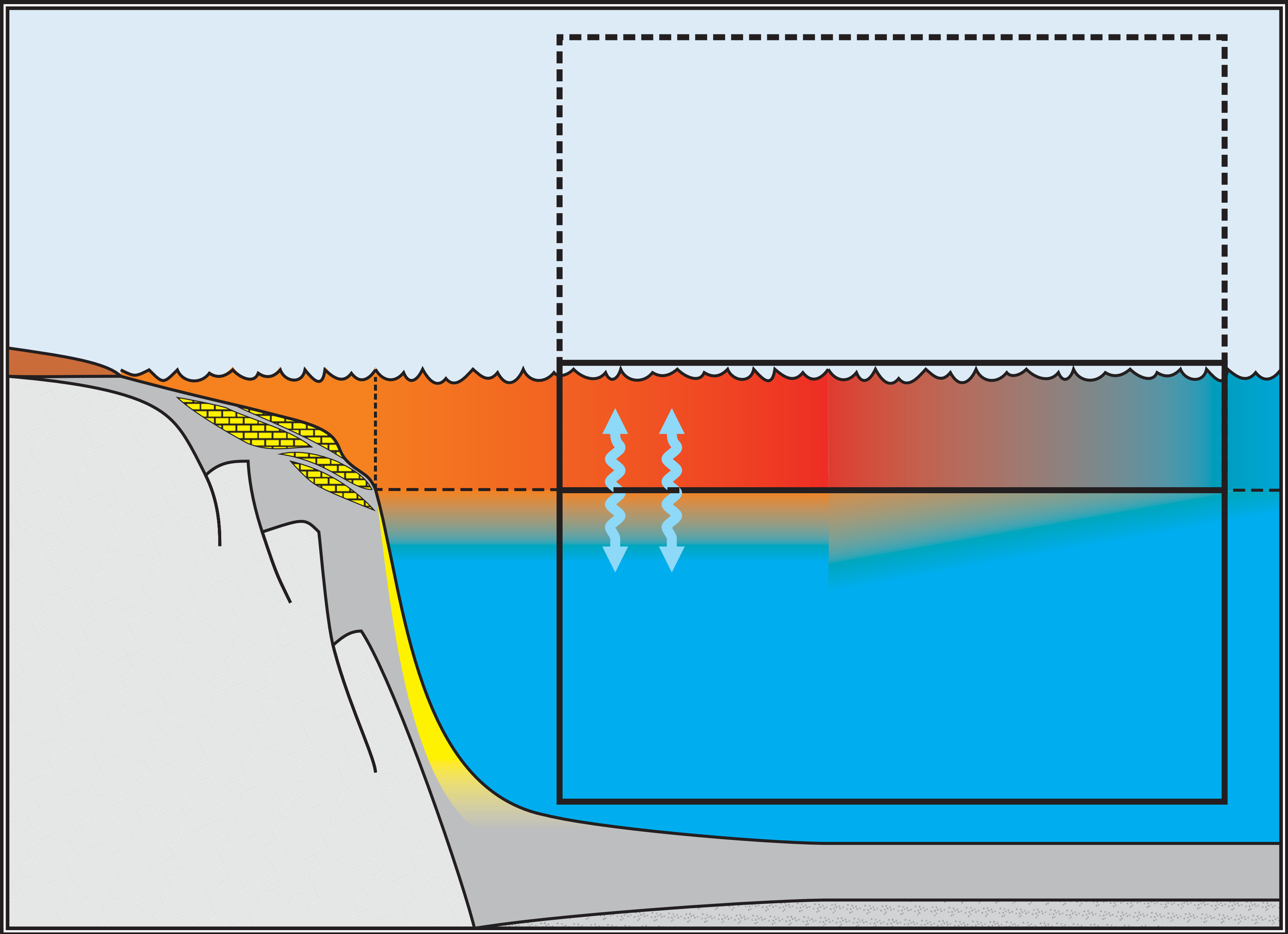



atmosphere
evaporation
precipitation
Equator
Pole
heat loss
winds
gyre
sea ice
coastal ocean
open ocean
mixing
surface ocean
deep ocean

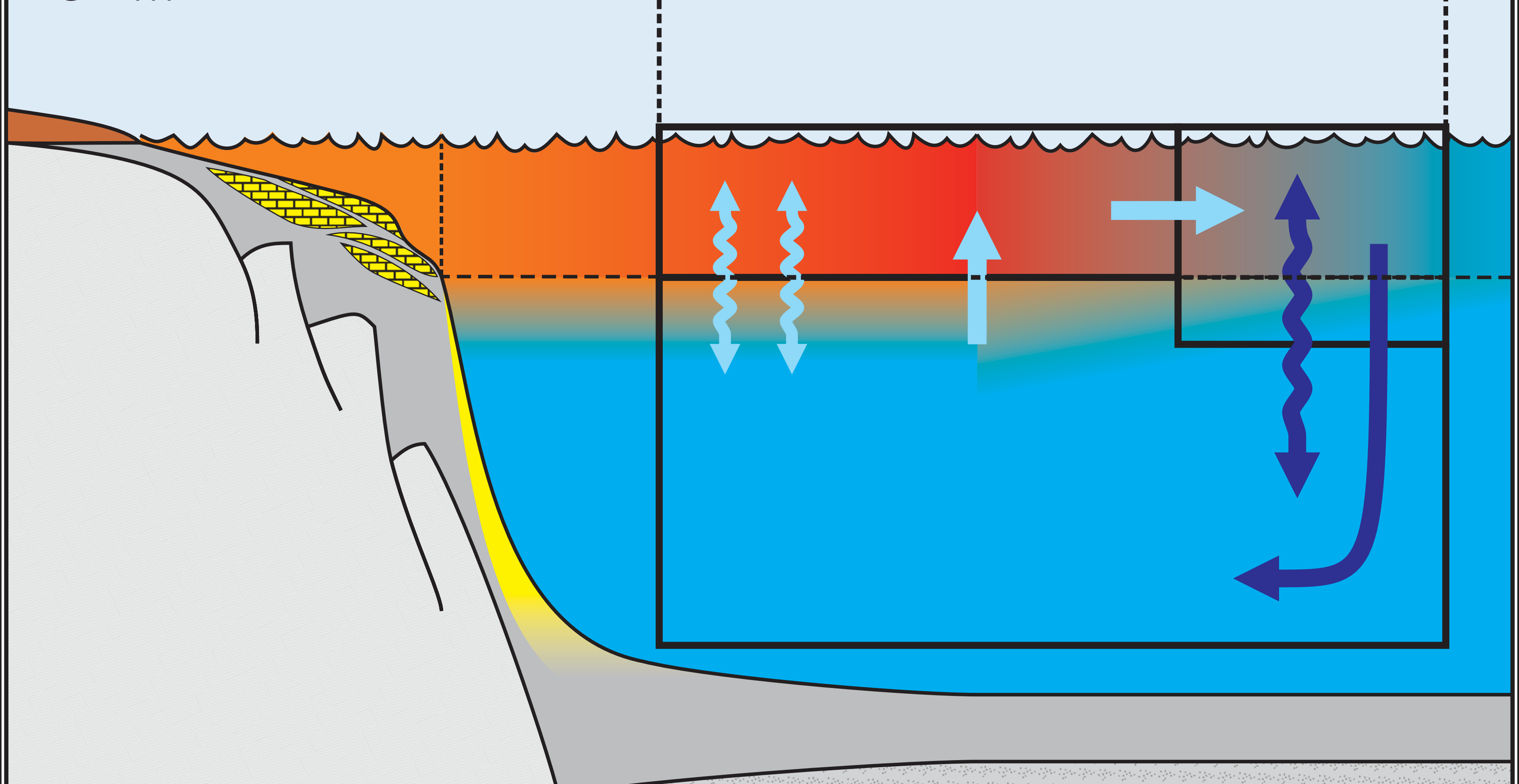
strategies for modelling complex (marine) systems

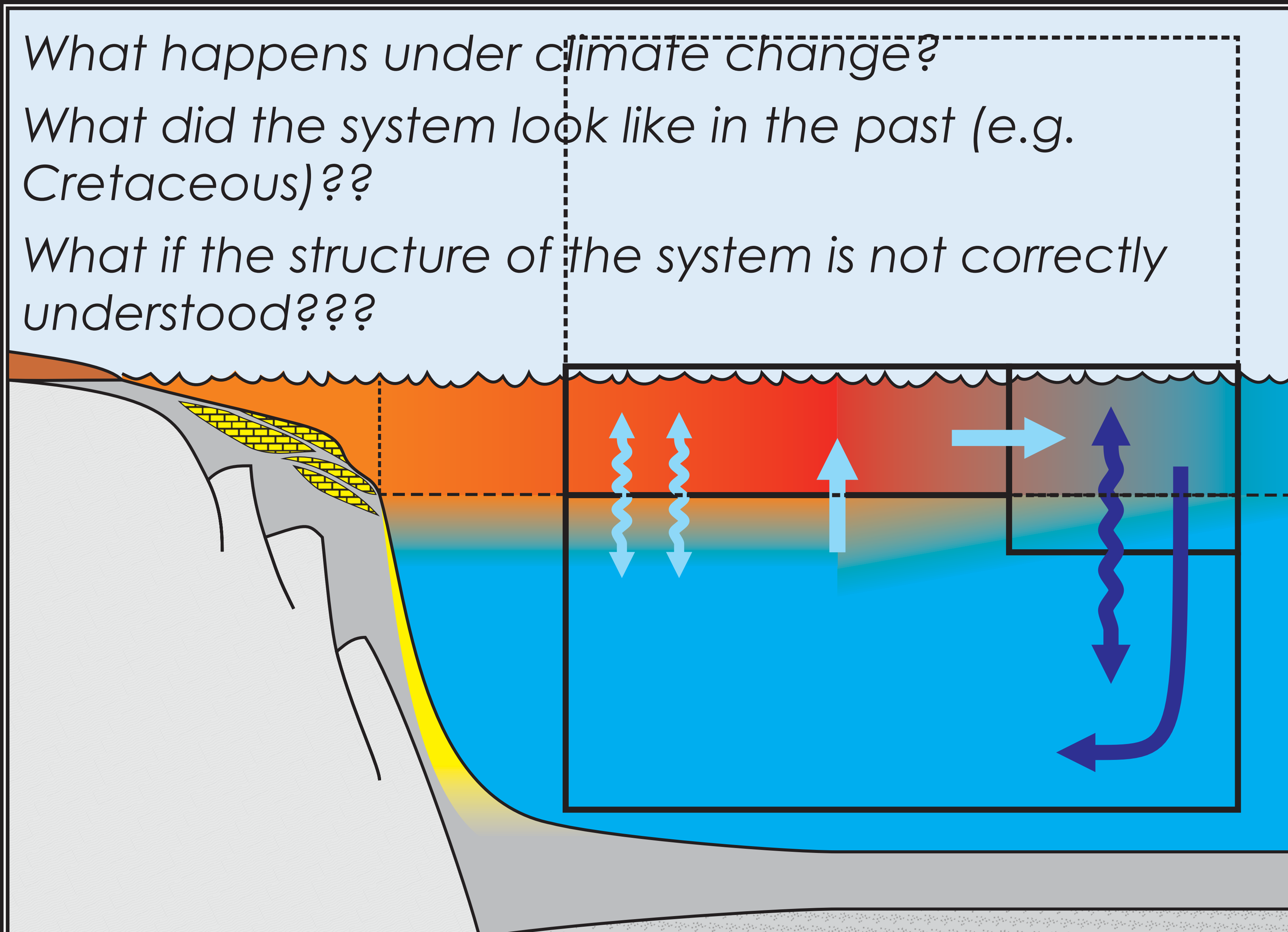


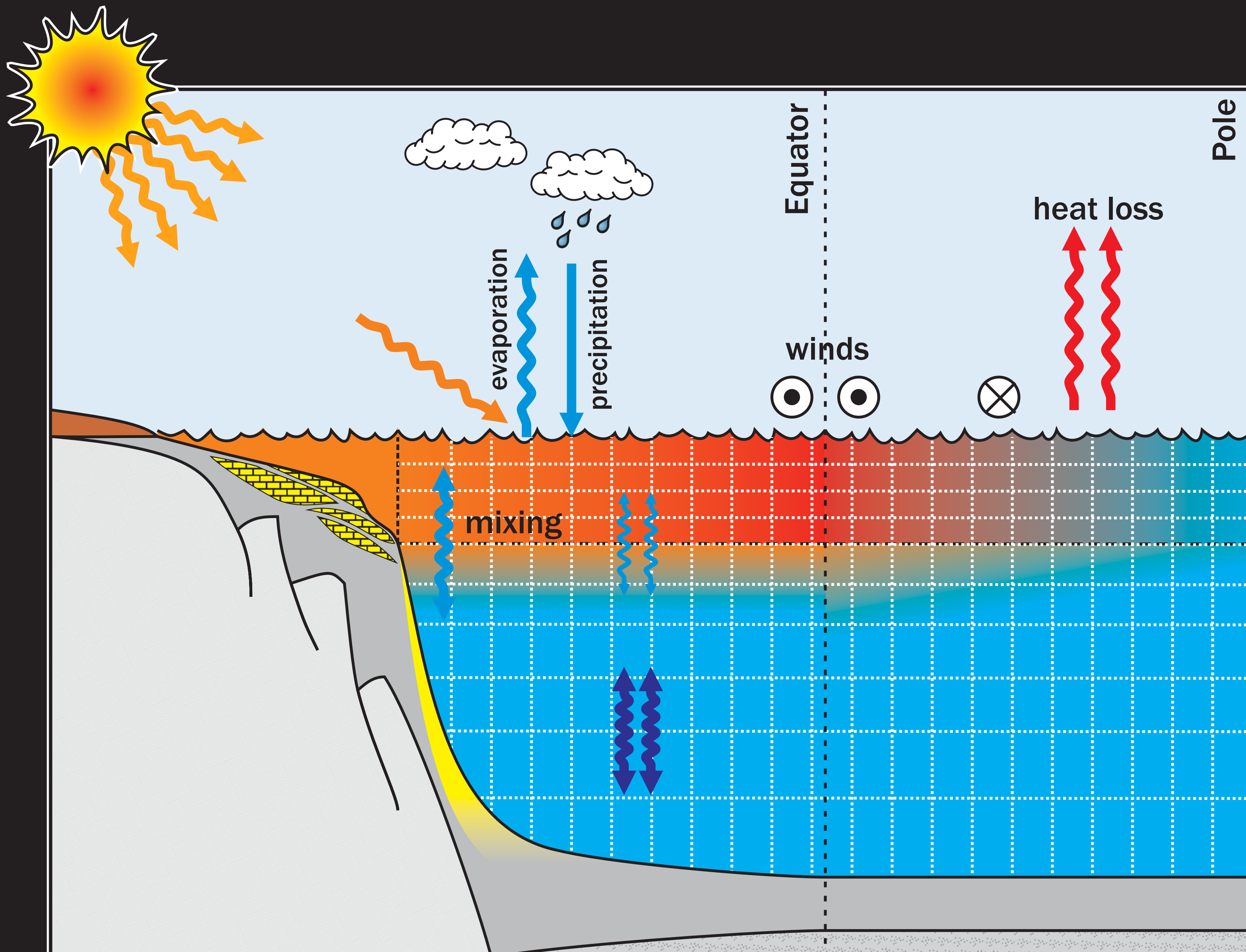
strategies for modelling complex (marine) systems

Creating models is effectively, the art of encapsulation of one's understanding (or preconceptions) of a system, numerically.

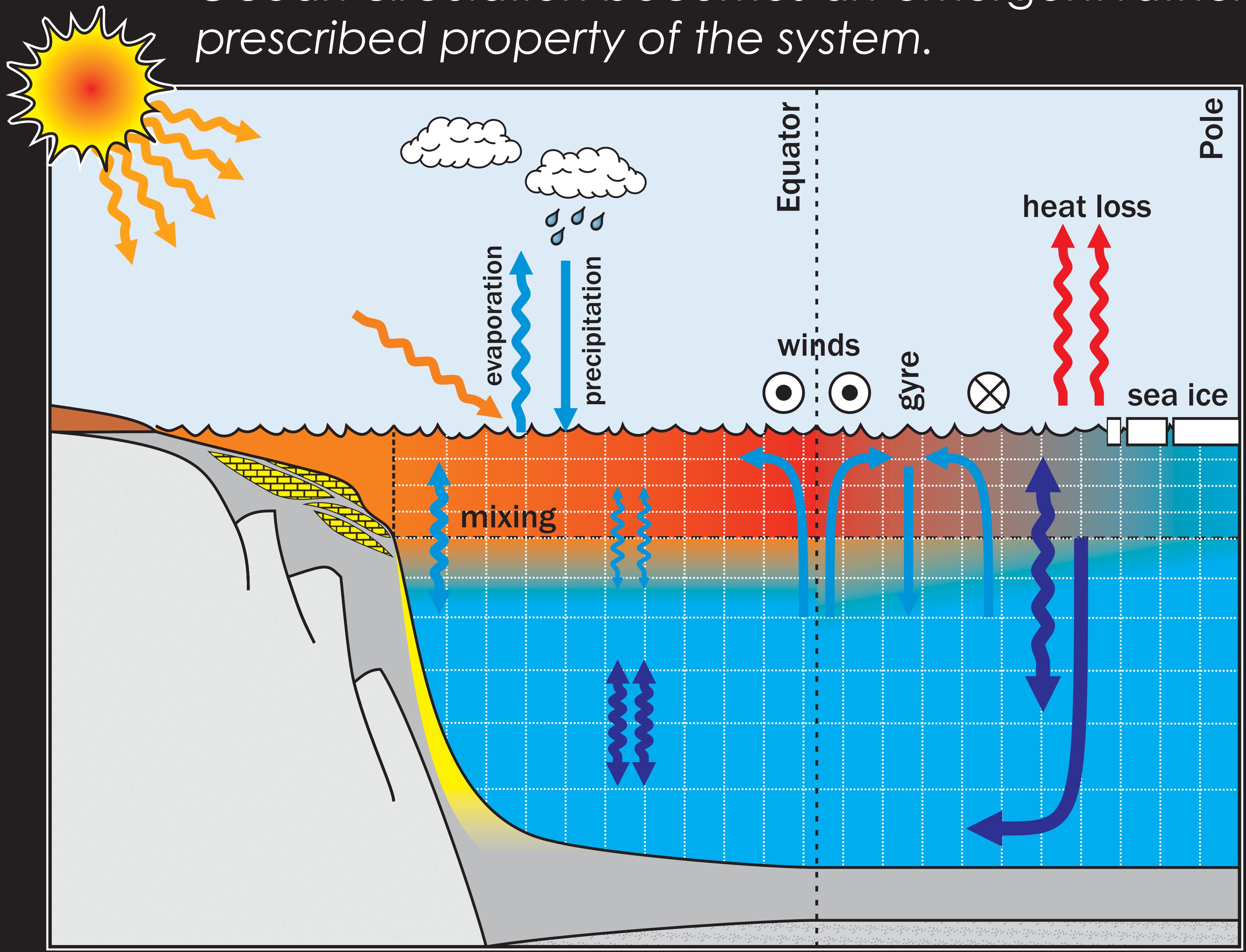
BUT ...



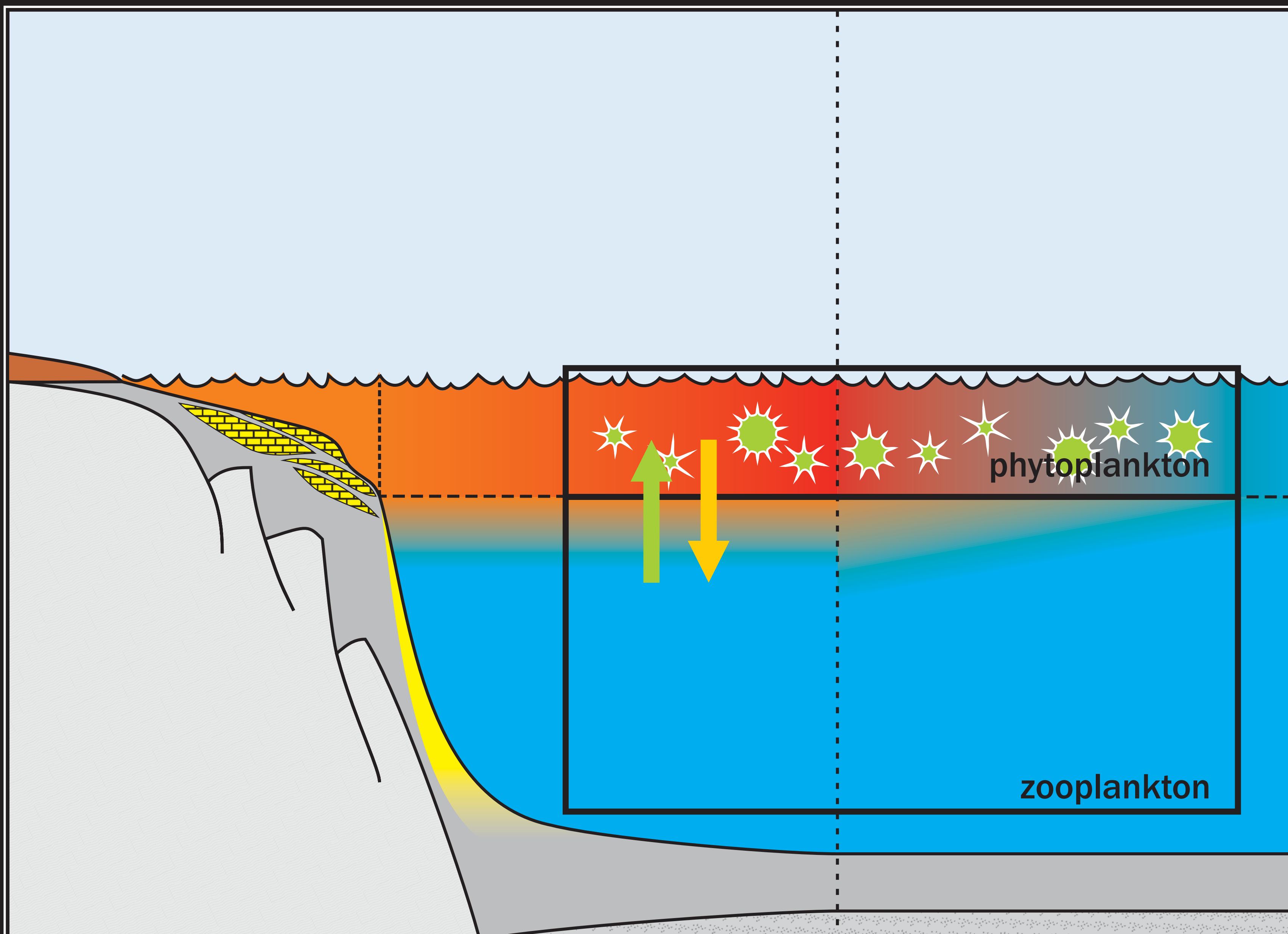

What happens under climate change?
What did the system look like in the past (e.g. Cretaceous)??
What if the structure of the system is not correctly understood???


Equator
Pole
heat loss
evaporation
precipitation
winds
mixing

Ocean circulation becomes an emergent rather than prescribed property of the system.



strategies for modelling complex (marine) systems



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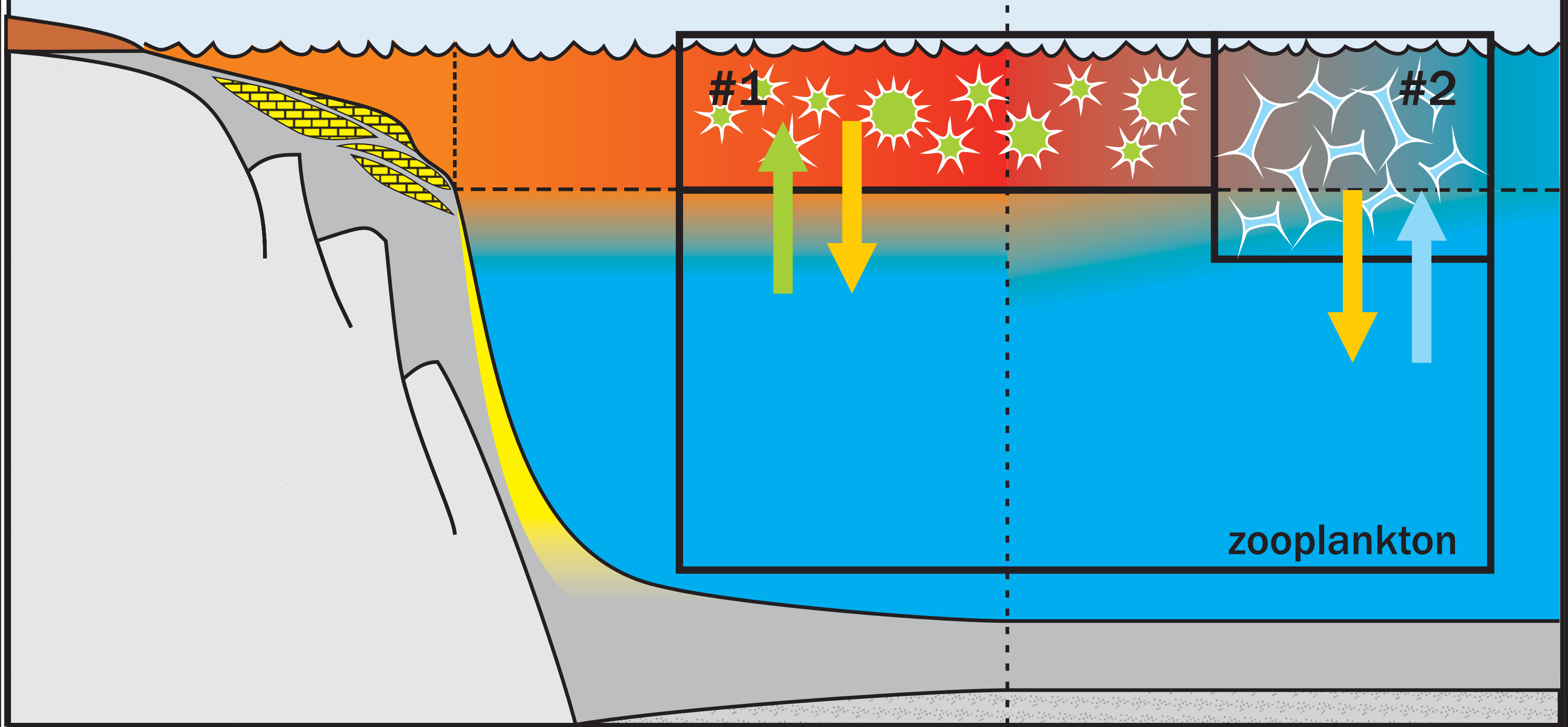
BUT ...

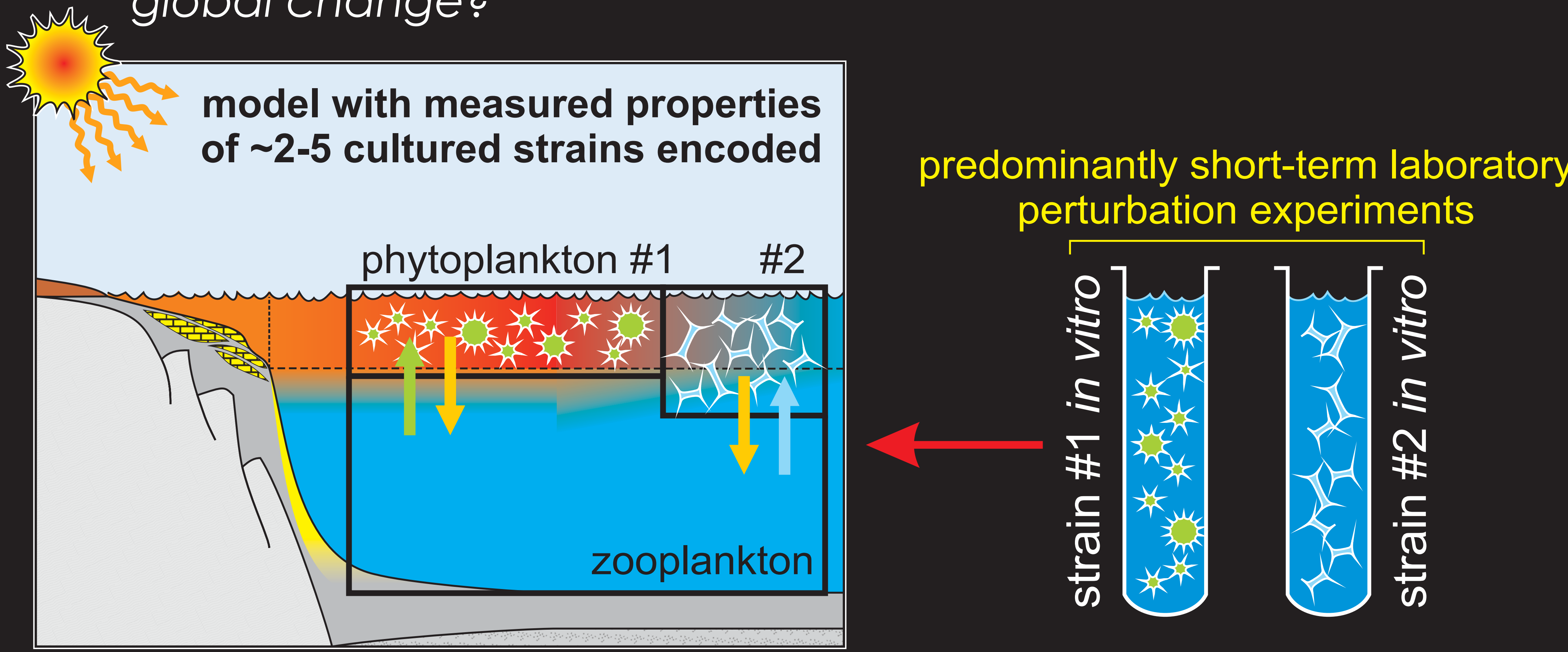


Again:

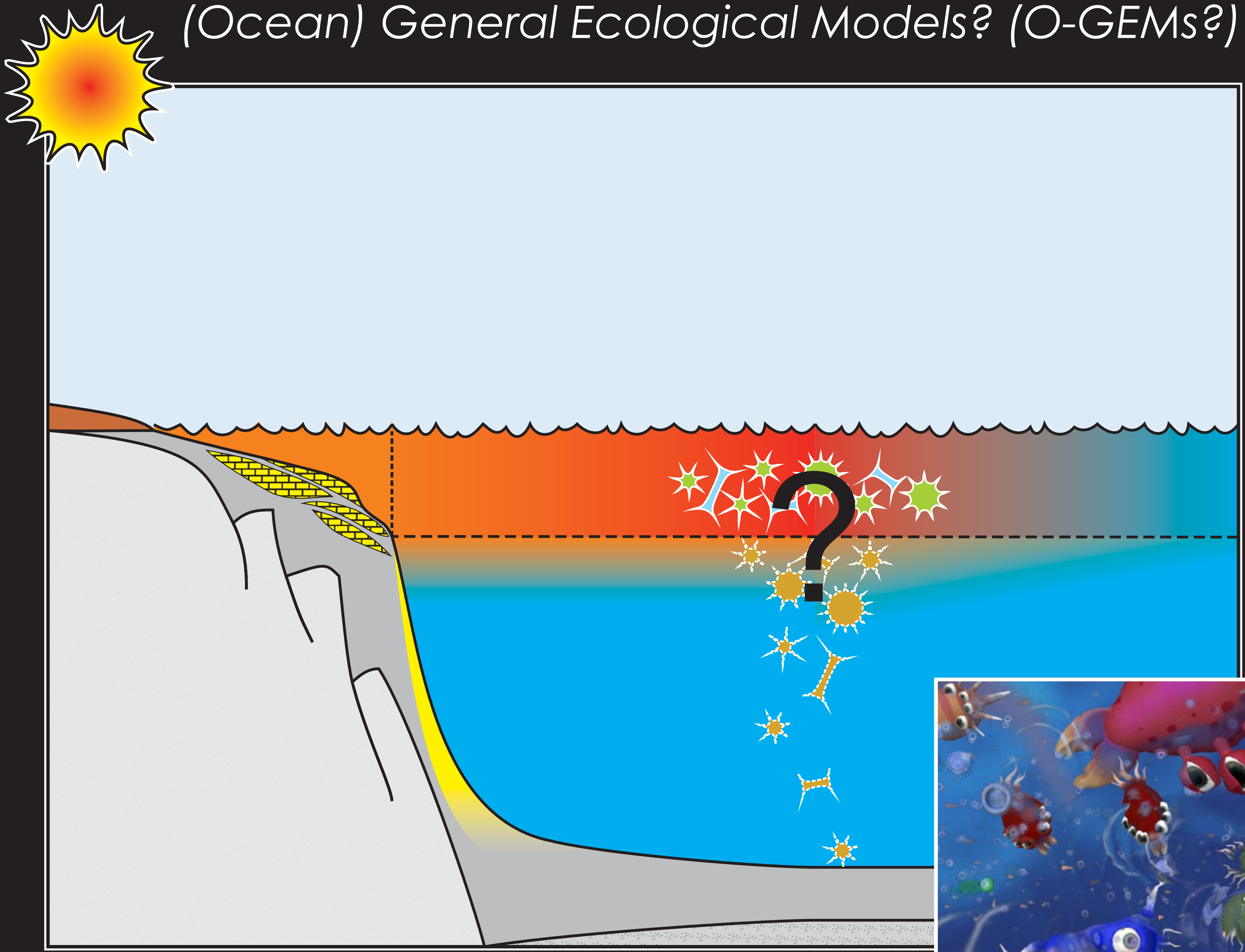
What happens under climate change?
What did the system look like in the past (e.g. Cretaceous)?
What if the structure of the system is not correctly understood?

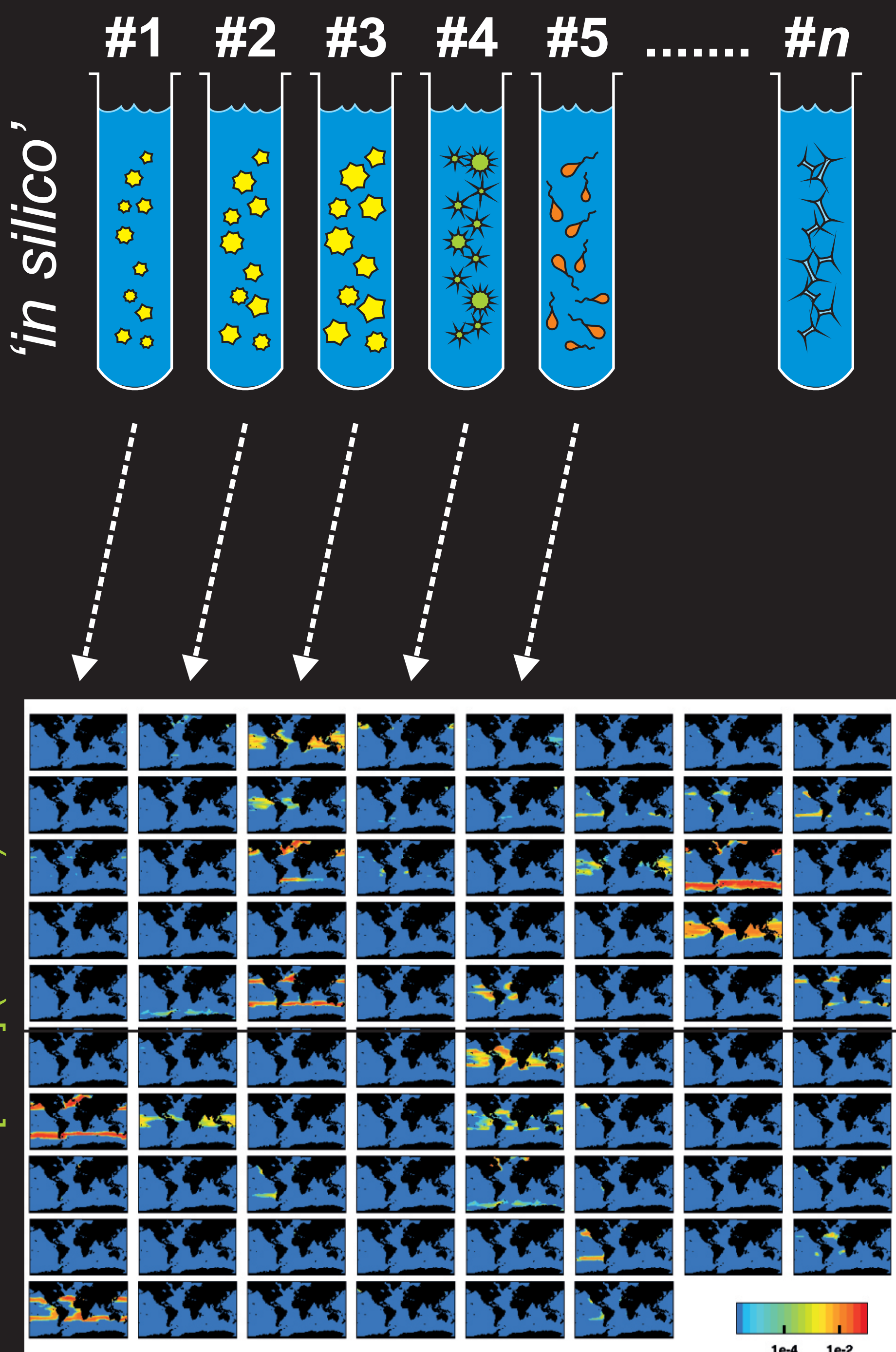
But also:

What about adaptation (or even evolutionary responses) to global change?



(Ocean) General Ecological Models? (O-GEMs?)



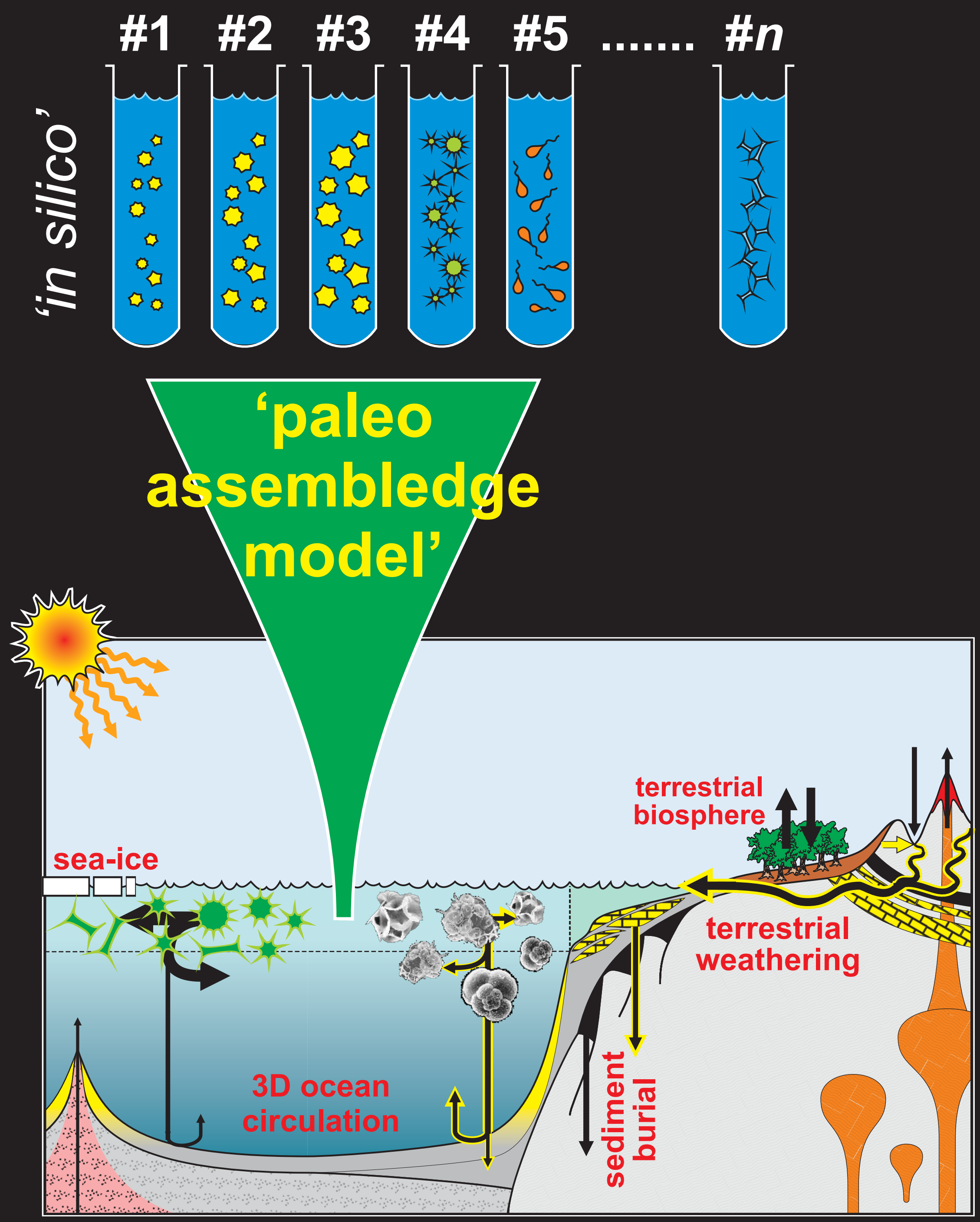


Follows et al. [2007] (*Science*)

Marine ecosystems *in silico*:

- The MIT ‘Darwin’ model typically considered ca. *n* = 76 randomly-generated trait vectors (’plankton’).
- Plankton trait vectors set according to physiological ‘rules’, e.g. larger cells have a higher nutrient limitation threshold, the ability to fixed N_2 comes at the expense of reduced growth rate, etc.
- Plankton compete and the ecosystem is an **emergent** rather than prescribed property.

But ...



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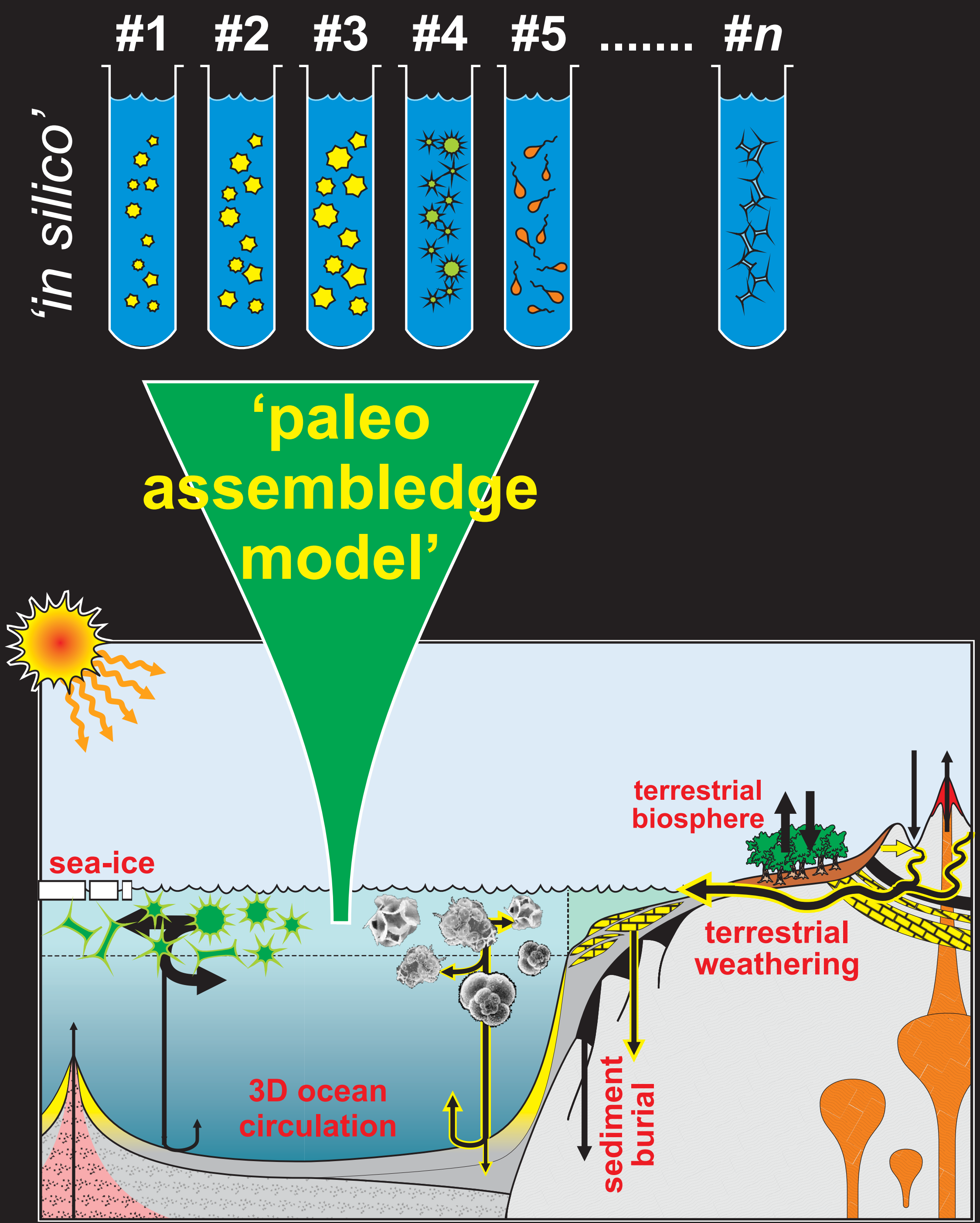
But ...

... the geochemical environment and climate co-evolves as global nutrient cycles are modified.

'PALEOGENiE'



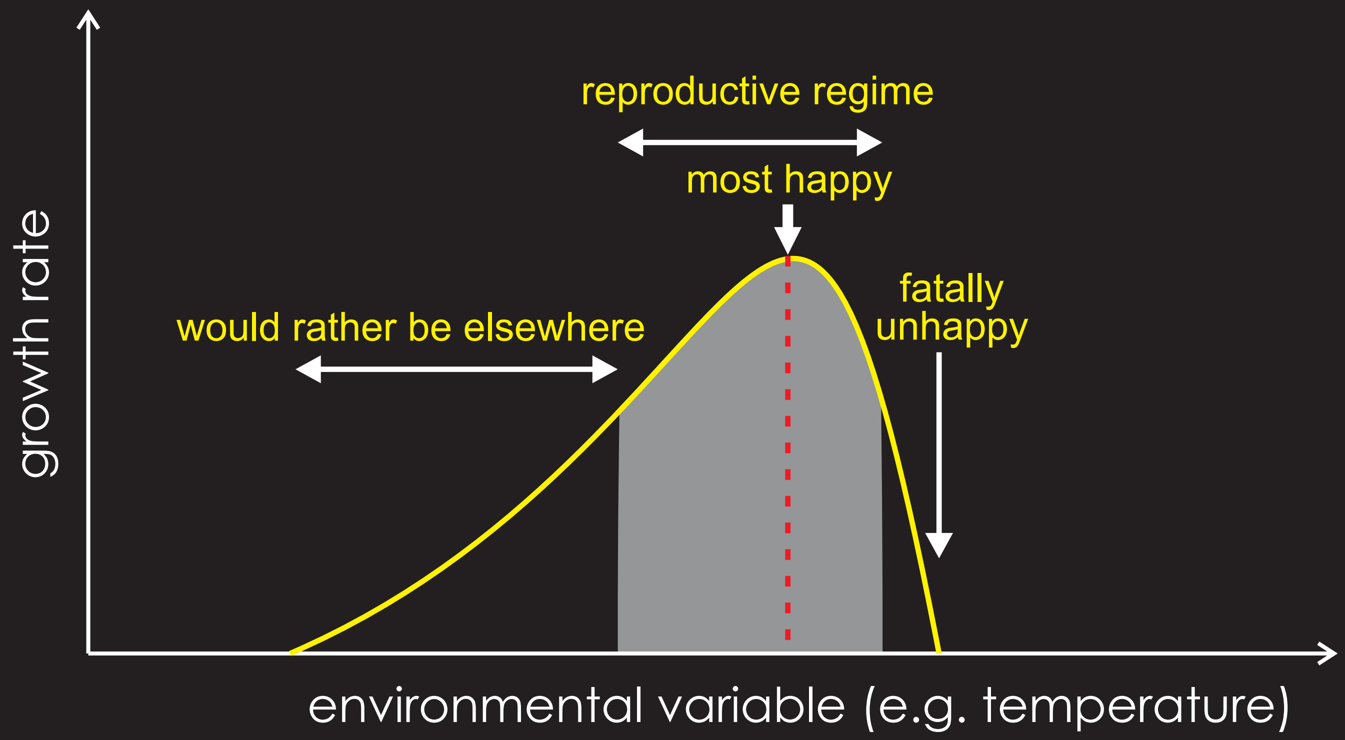
- n = 1,000-10,000 randomly-generated trait vectors ('plankton').
- Plankton trait vectors set according to physiological 'rules', e.g. larger cells have a higher nutrient limitation threshold, the ability to fixed N_2 comes at the expense of reduced growth rate, etc.
- Plankton compete and the ecosystem is an **emergent** rather than prescribed property.

  But ...

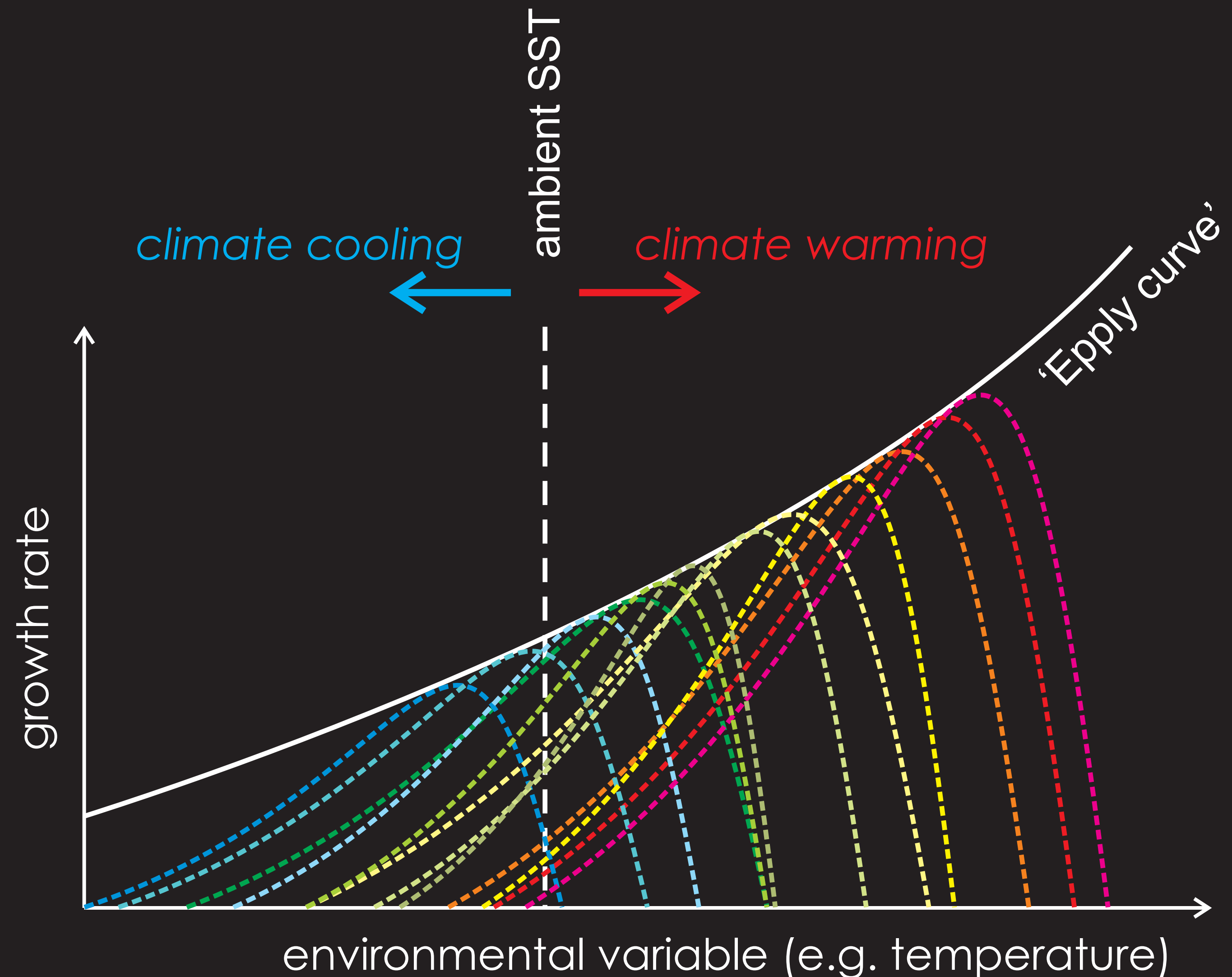
  ... *the geochemical environment and climate co-evolves as global nutrient cycles are modified*.
- At very high resolved diversity, we can explore questions of **adaptation** and rates of **evolutionary change** by spawning new plankton with perturbed characteristics.

‘PALEOGENiE’

Computer models and other baked goods



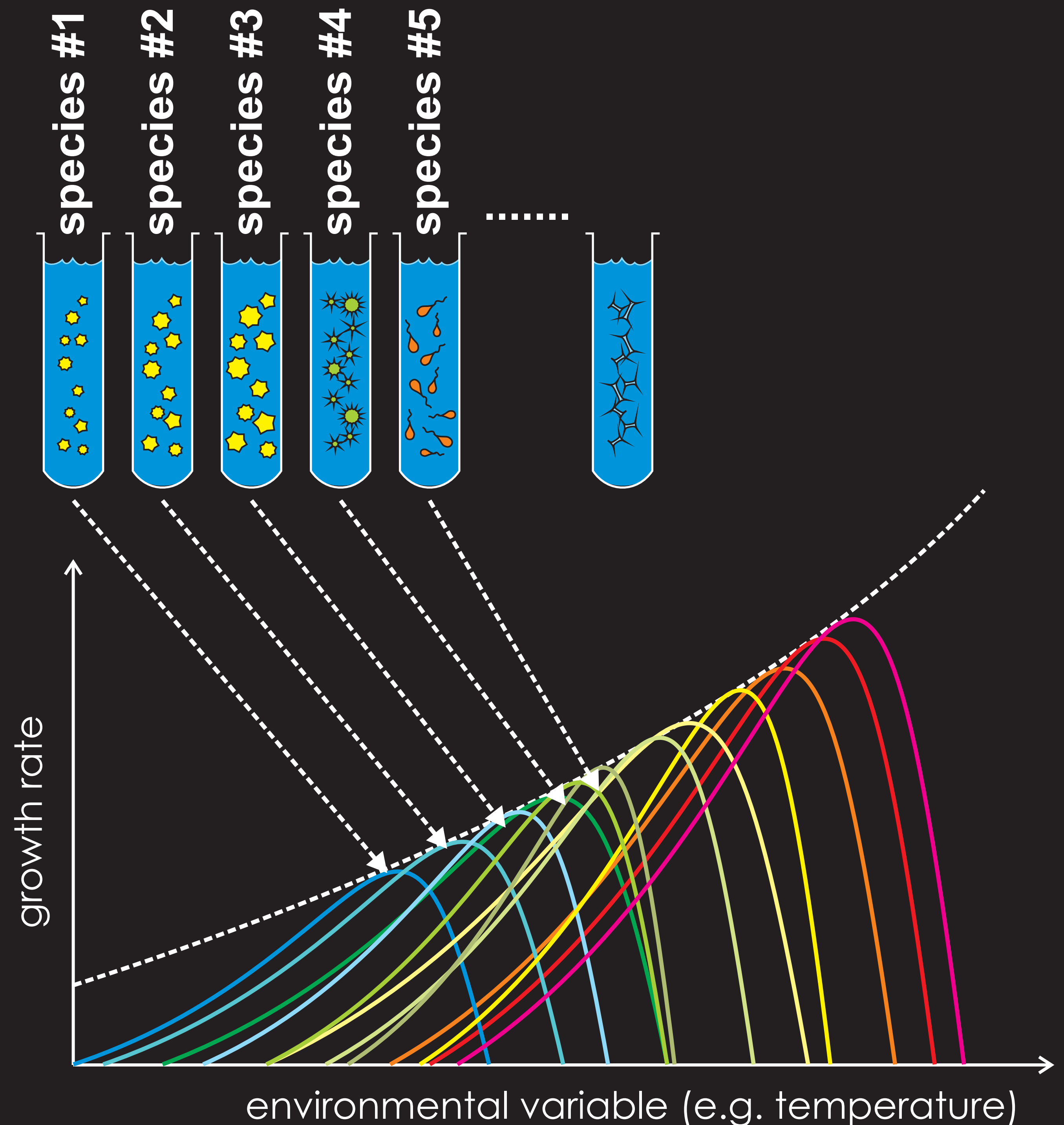
‘re-drawn’, with sincere apologies, from Schmidt et al. [2006]



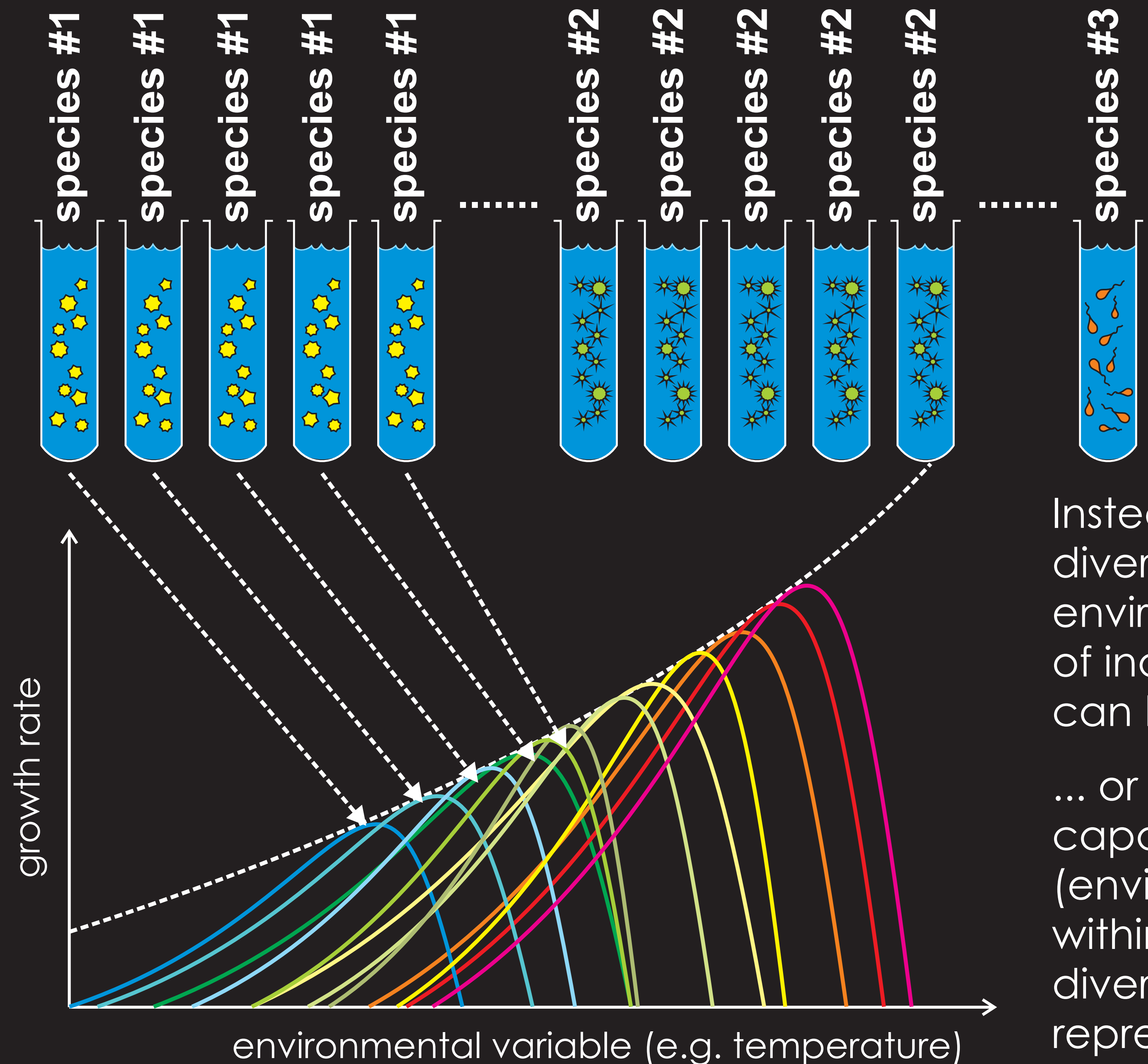
In traditional ‘functional type’ ecosystem models, diversity is not resolved, but instead its effects highly parameterized (e.g. the ‘Epply curve’).

The response to a change in climate is then instantaneous and fully reversible.

'PALEOGENiE'

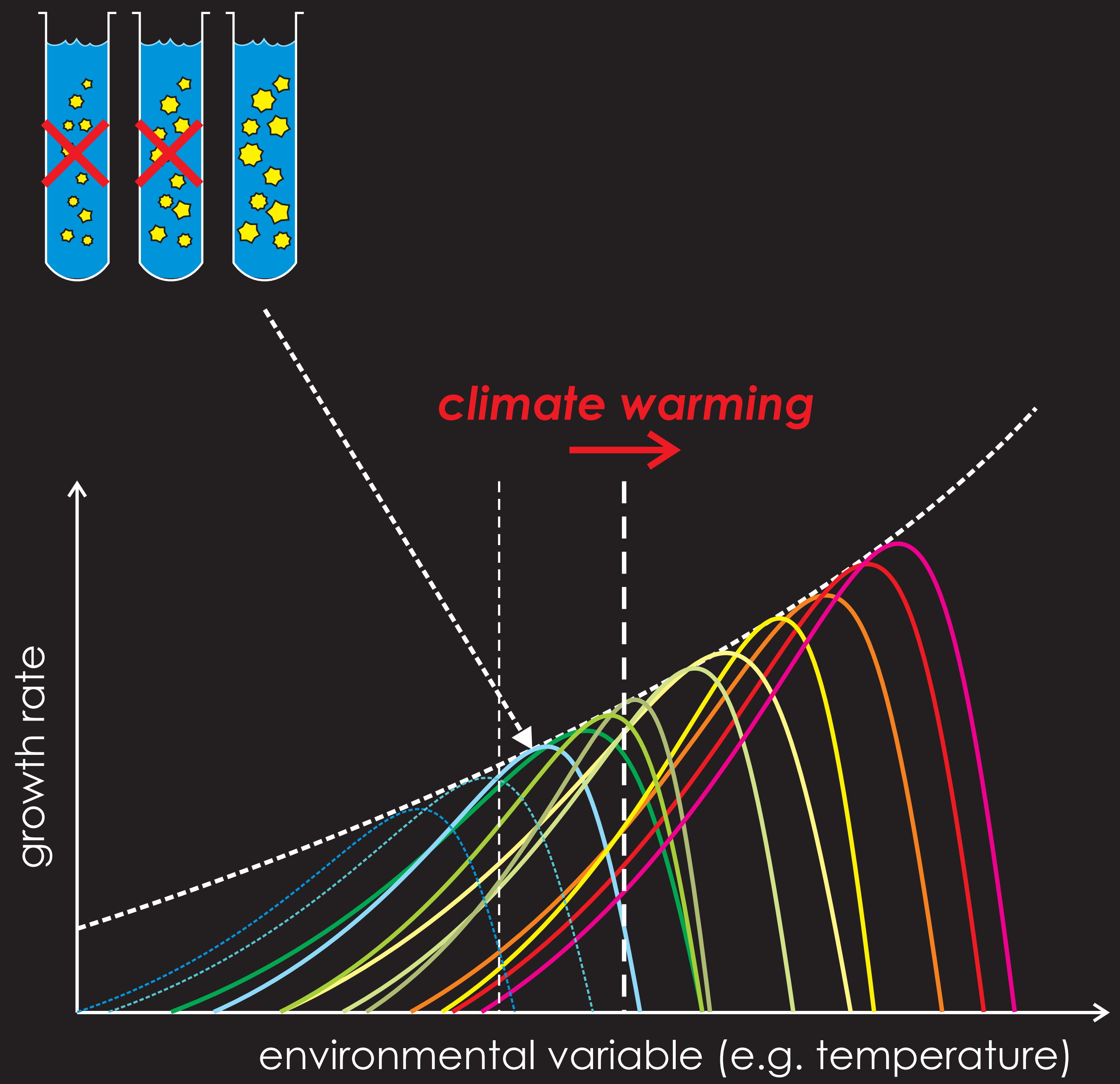


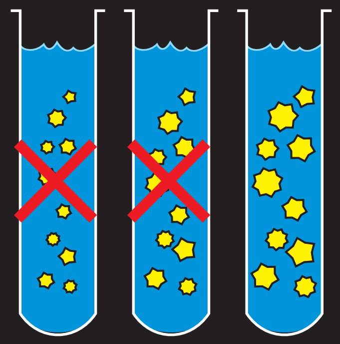
Instead, in a highly diverse model, the environmental response of individual 'species' can be resolved ...

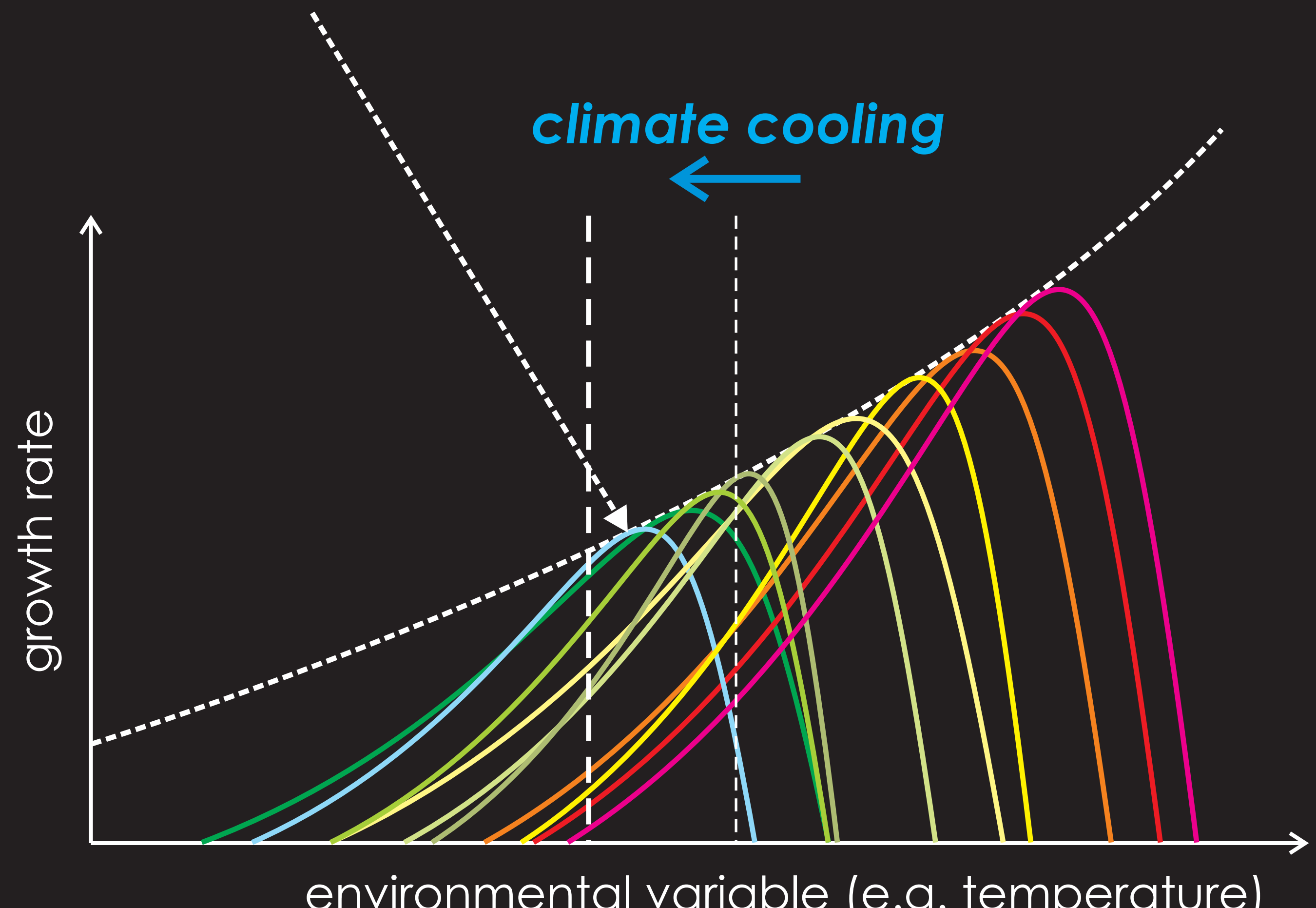


Instead, in a highly diverse model, the environmental response of individual ‘species’ can be resolved ...

... or instead, the capability for adaptation (environmental selection within existing genetic diversity) can be represented(?)


climate warming
growth rate
environmental variable (e.g. temperature)

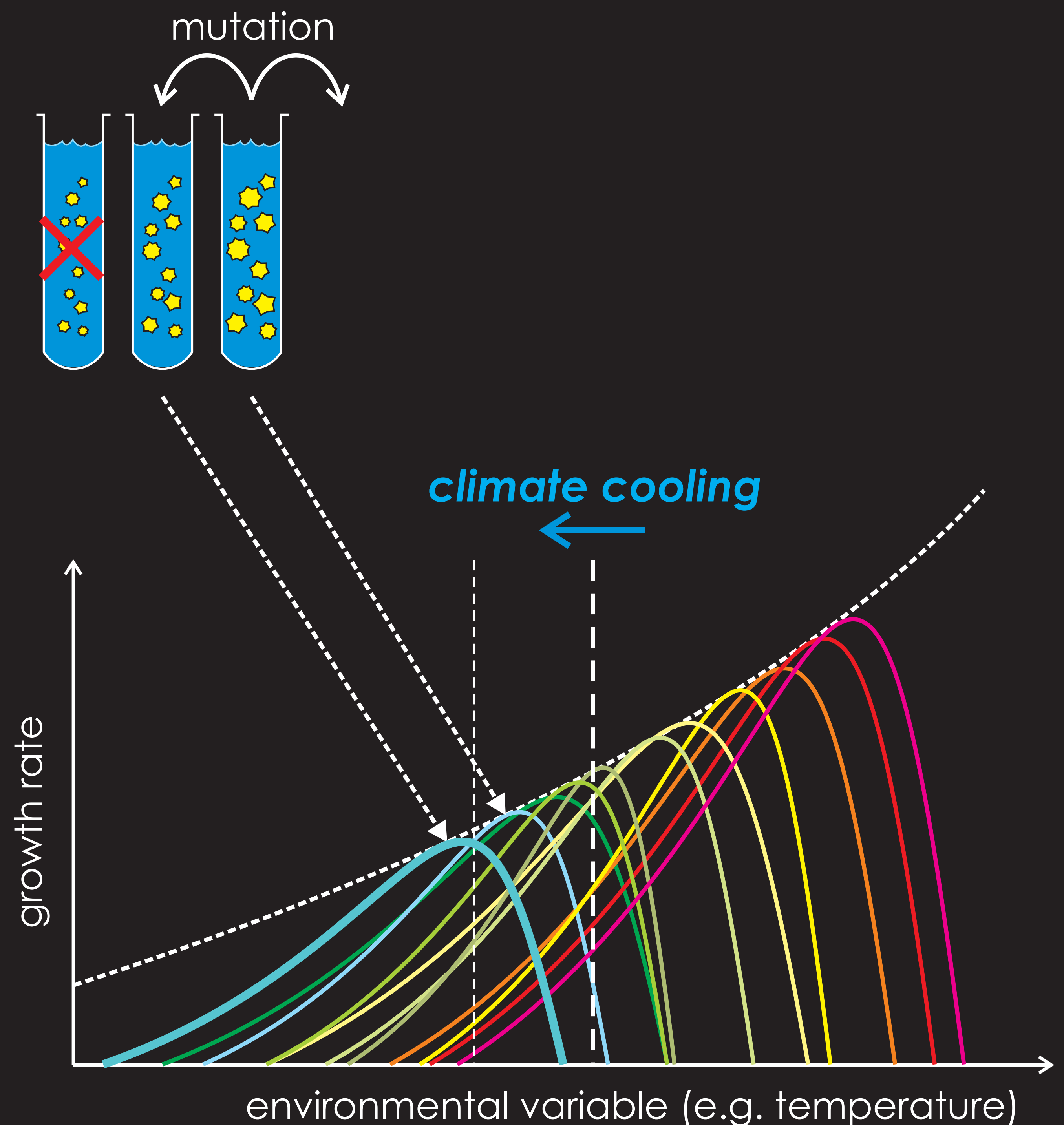




If climate cools, the low SST optimized species/varients no longer exist. Ecosystem dynamics are presumably different.

Niches are unfilled, so ...

‘PALEOGENiE’

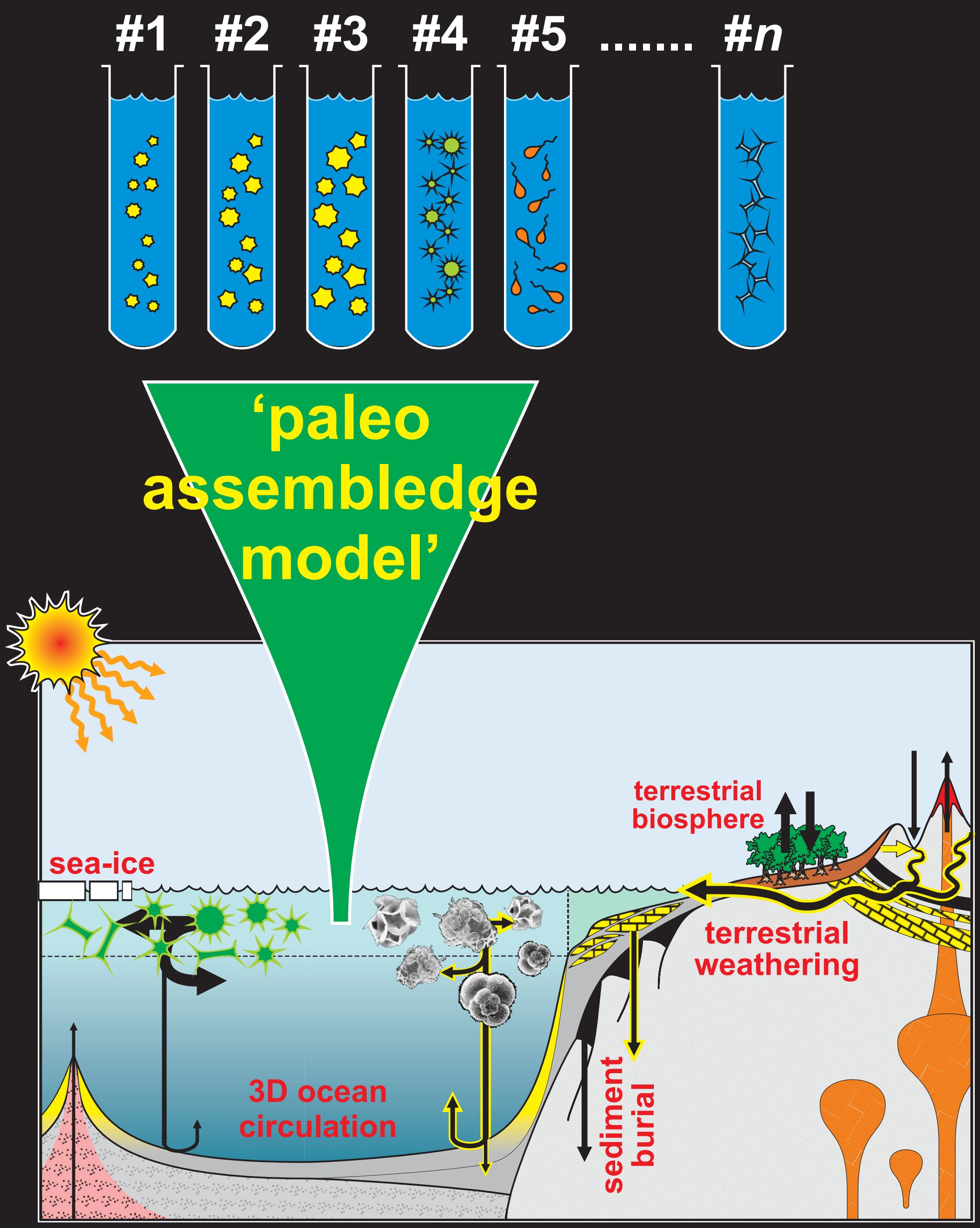


Allow non-viable plankton to be replaced with ‘mutations’ of surviving species, using the trait based trade-offs.

Q. How ‘frequently’ to mutate, and as a function of what?

Q. What ‘step size’ to take for mutation?

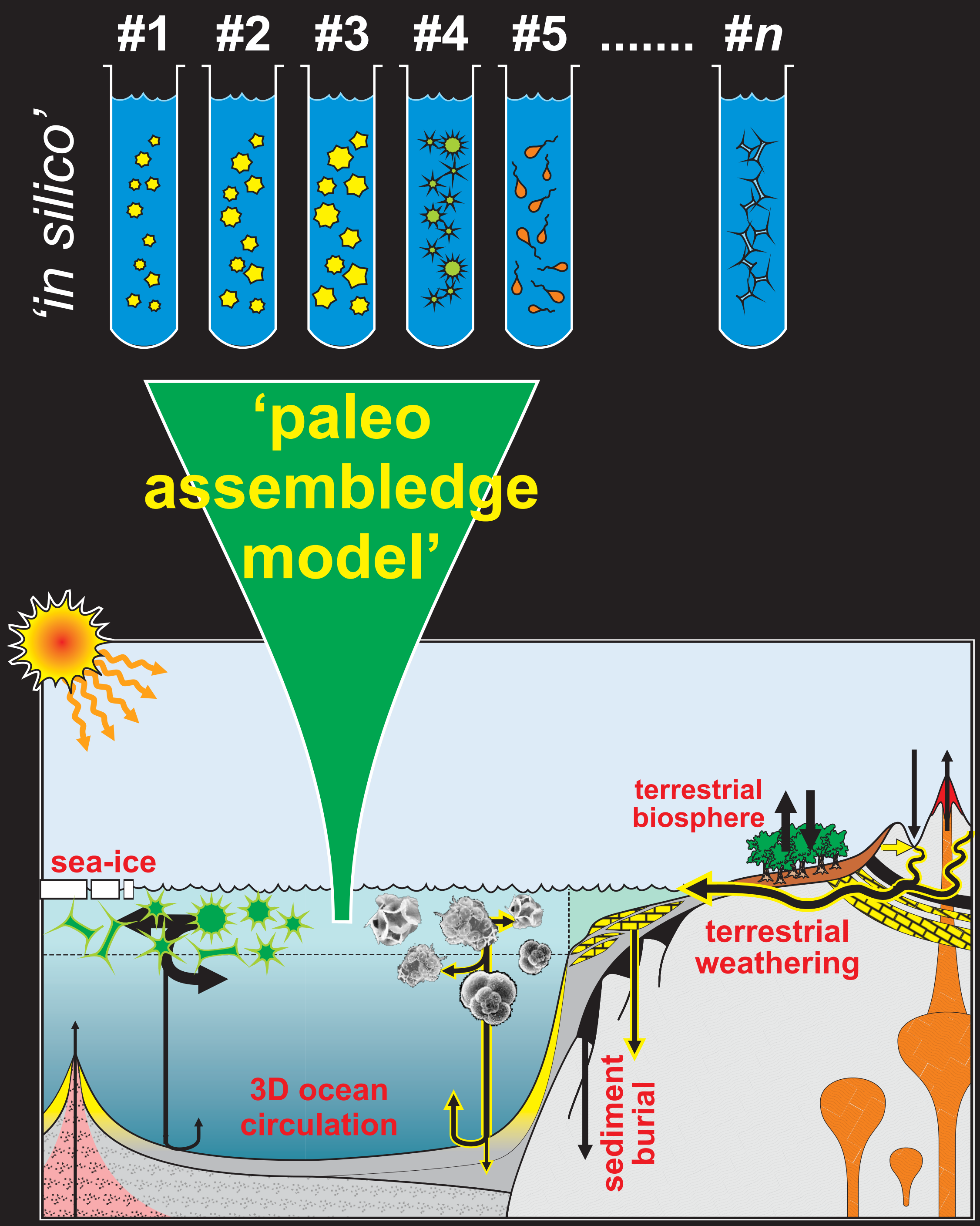
'PALEOGENiE'



'PALEOGENiE':

- A radical paleo model-data concept for theoretically exploring questions of marine plankton adaptation and evolution.
- Specific questions:
  Cause(s) of the delayed recovery (100s of kyr) from end Cretaceous extinction
  Determining which factor(s) best explain ecological responses to PETM carbon release.
- A tool for gaining understanding about future ecosystem stability (+ proof concepts for future models).

‘PALEOGEN*i*E’ – computational strategies



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- *n* = 1,000-10,000 randomly-generated trait vectors (’plankton’).

...

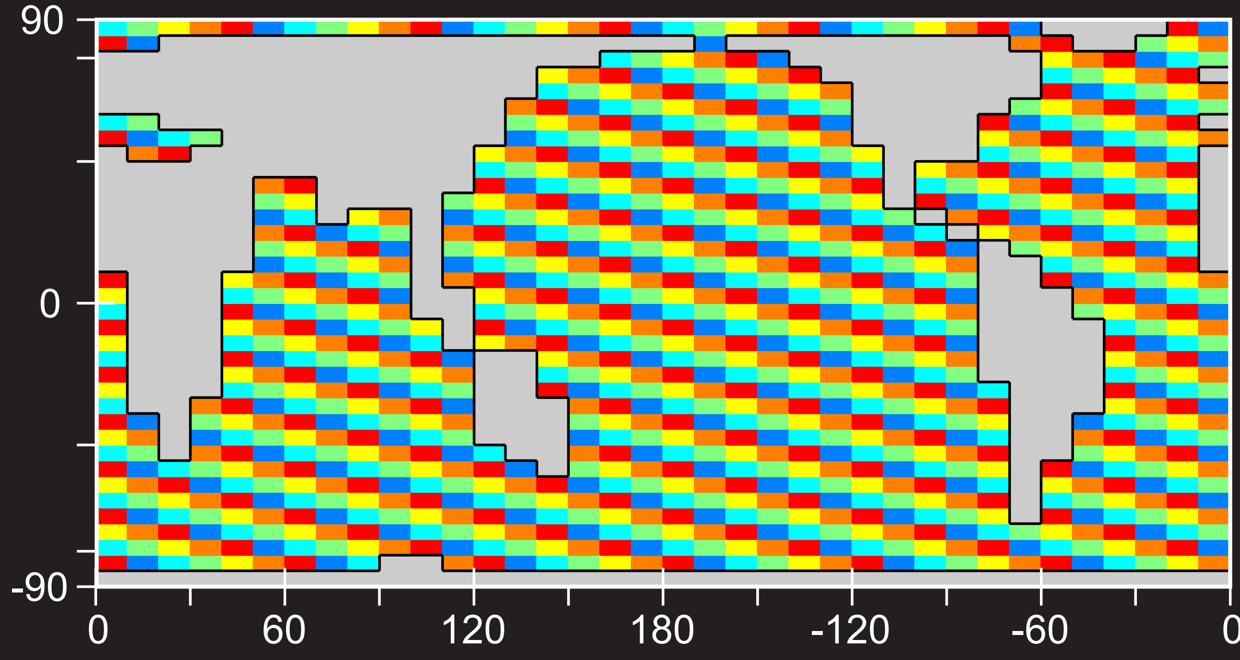
...

- At very high resolved diversity, we can explore questions of **adaptation** and rates of **evolutionary change** by spawning new plankton with

There is clearly a very significant computational expense involved, even if using low resolution/efficient Earth system models such as ‘GENIE’.

‘PALEOGENiE’ – computational strategies

‘Color’ tracer pattern to unambiguously diagnose surface ocean transport



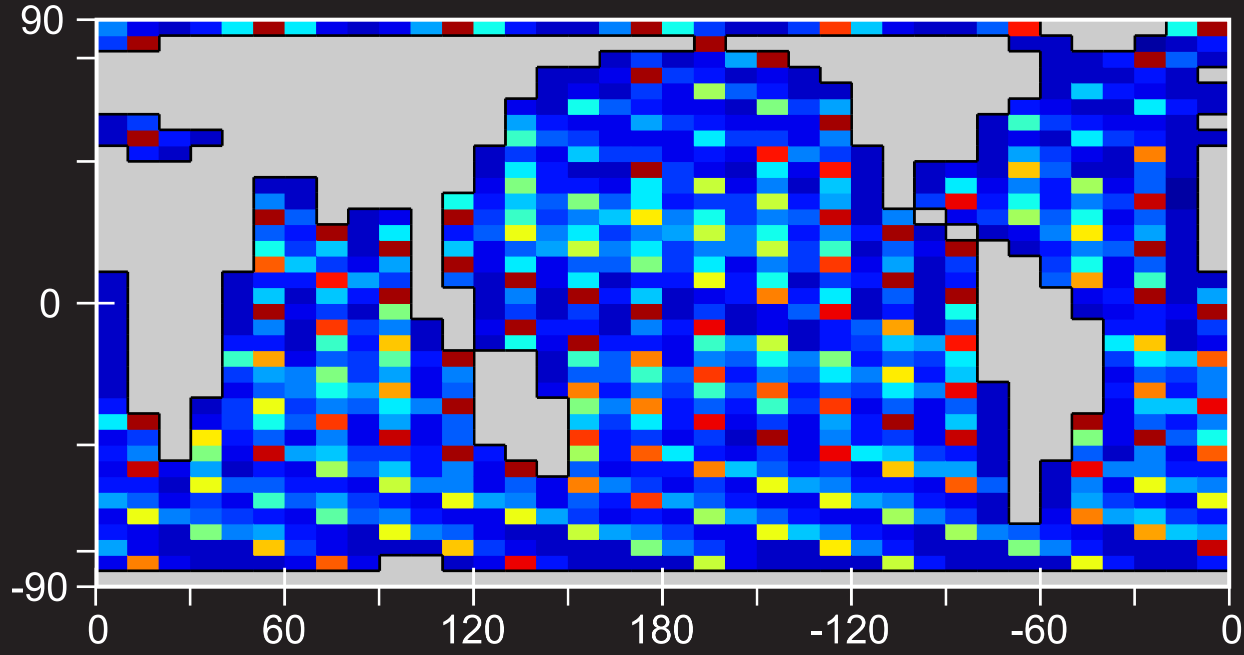
=> Diagnose full 3D circulation, and employ (sparse) parallelized matrix multiplication.

=> Calculate plankton transport separately from nutrients (and other dissolved tracers)?

'PALEOGENiE' – computational strategies

Computer models and other baked goods

Dispersal of a single 'color' after 1 year



=> Diagnose full 3D circulation, and employ (sparse) parallelized matrix multiplication.

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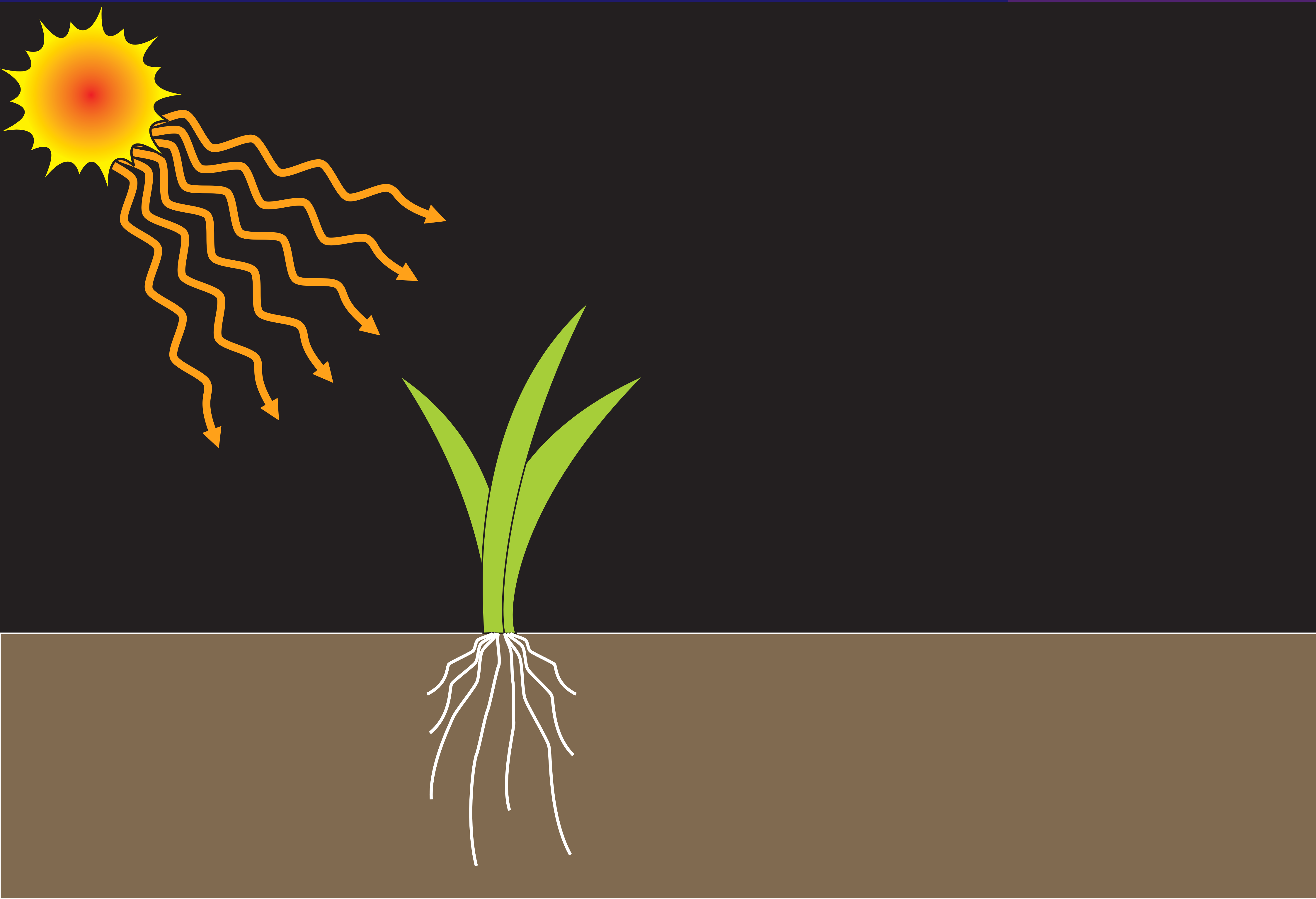
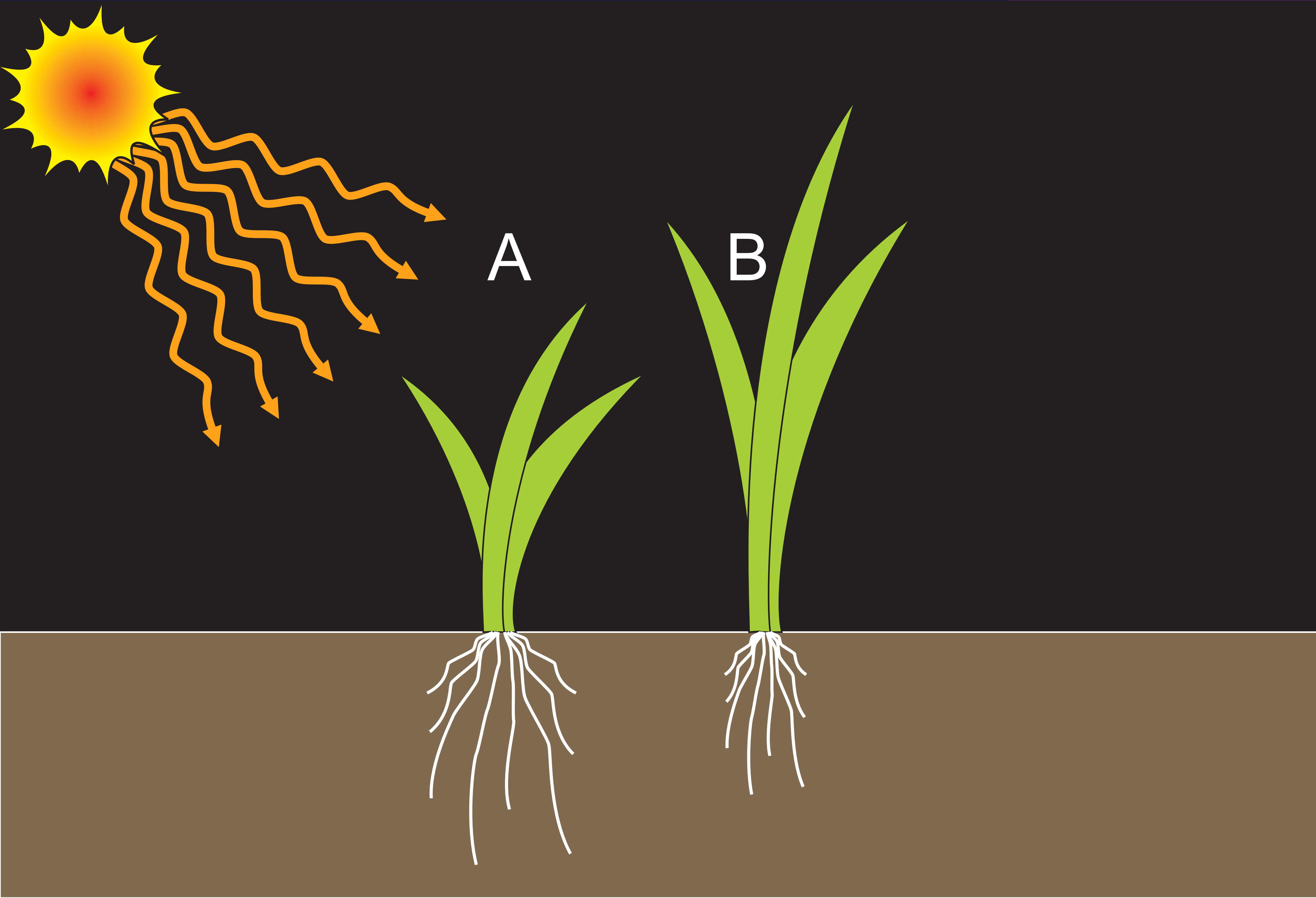
Terrestrial ecosystem modelling

Computer models and other baked goods



Terrestrial ecosystem modelling

Computer models and other baked goods

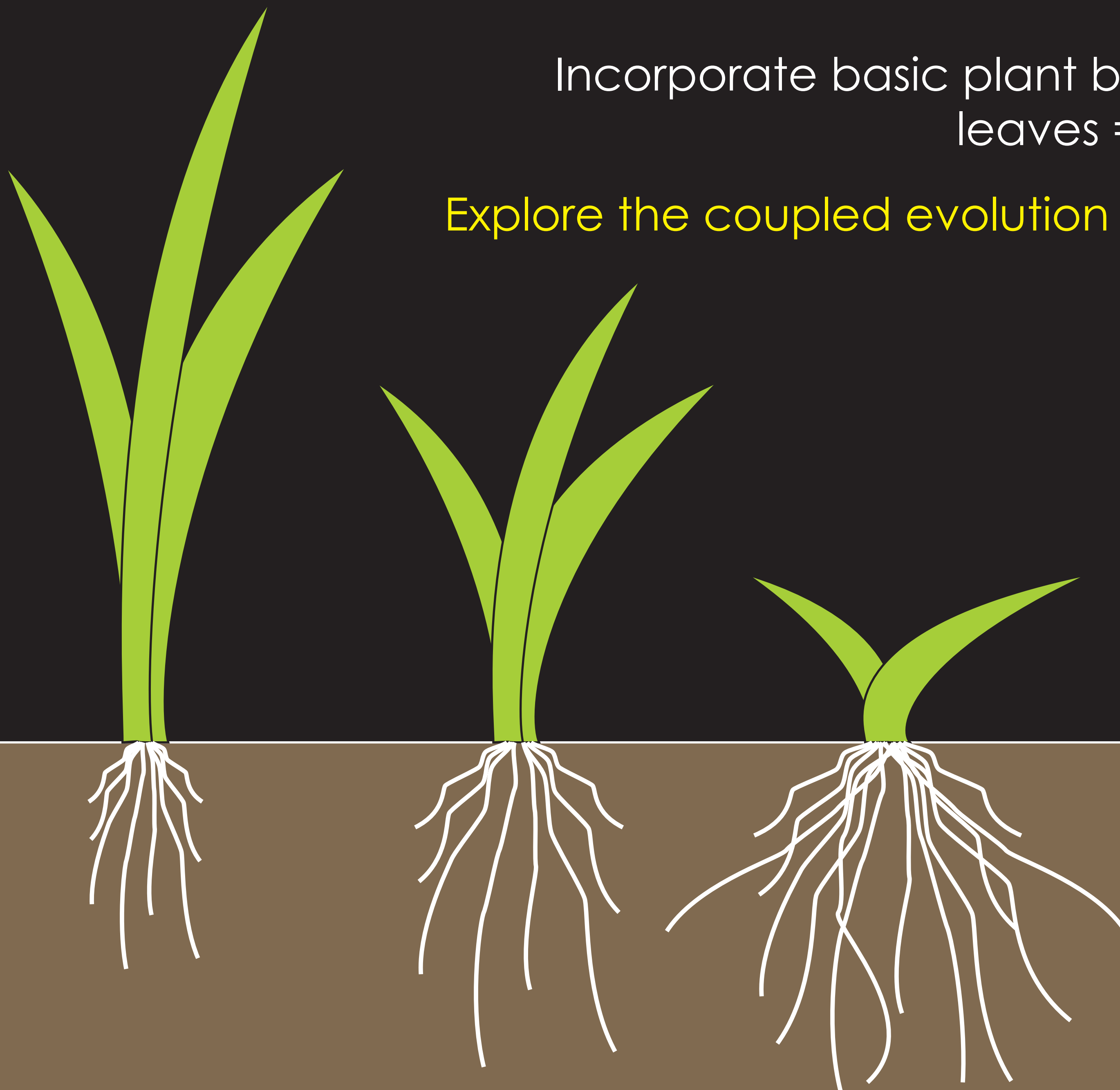


Terrestrial ecosystem modelling

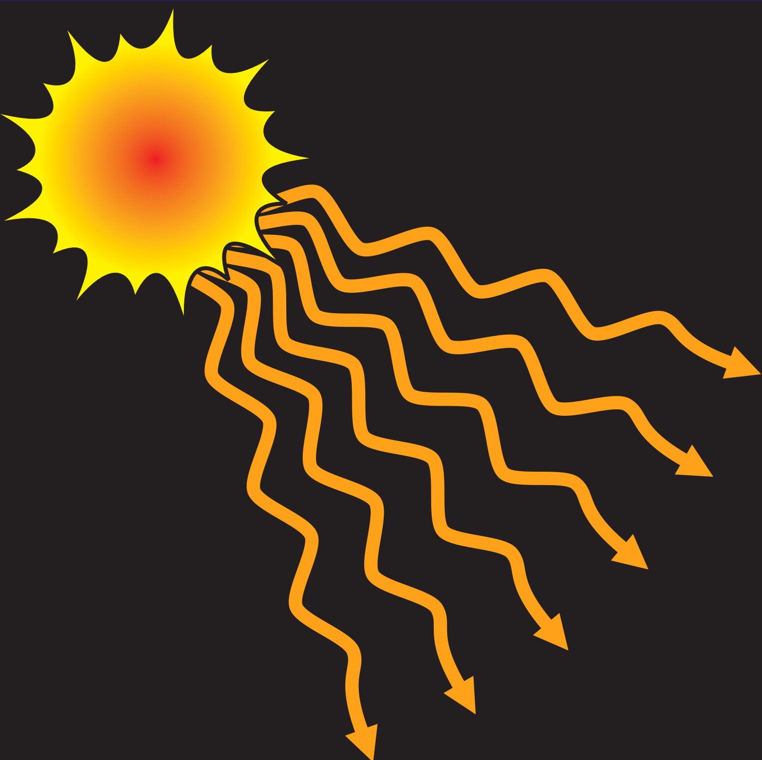
Use a crop (plant) model based on carbon resource allocation.

Incorporate basic plant biomechanics (60ft long leaves == not a good idea ...).

Explore the coupled evolution of terrestrial plants and environment?



Terrestrial ecosystem modelling ... and crops



Mutate the plants across millions of generations and across millions of 'fields' on a massively parallel computing basis.

Select for yield (but at the field scale, hence dealing with 'competition').

Can also select for e.g. water use efficiency, tolerance to gusty wind conditions, etc. etc.

Q. Would an 'optimal' crop plant have 6 triangular leaves that enables a hexagonal space-filling tessellation across the soil surface??

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