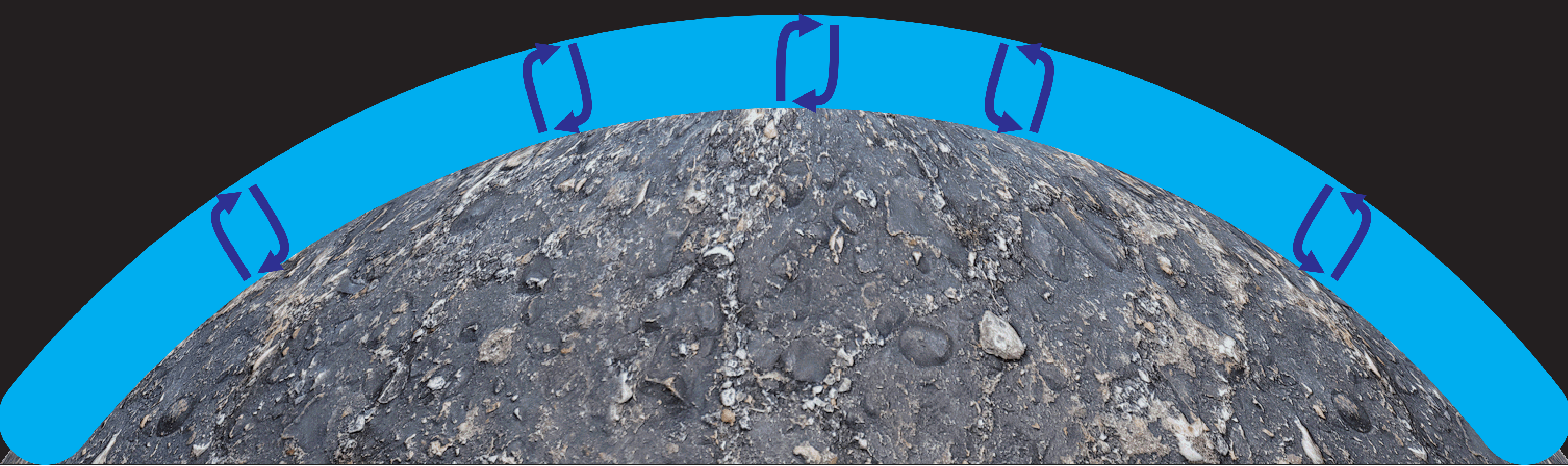
(How) Do oceans overturn on other worlds?

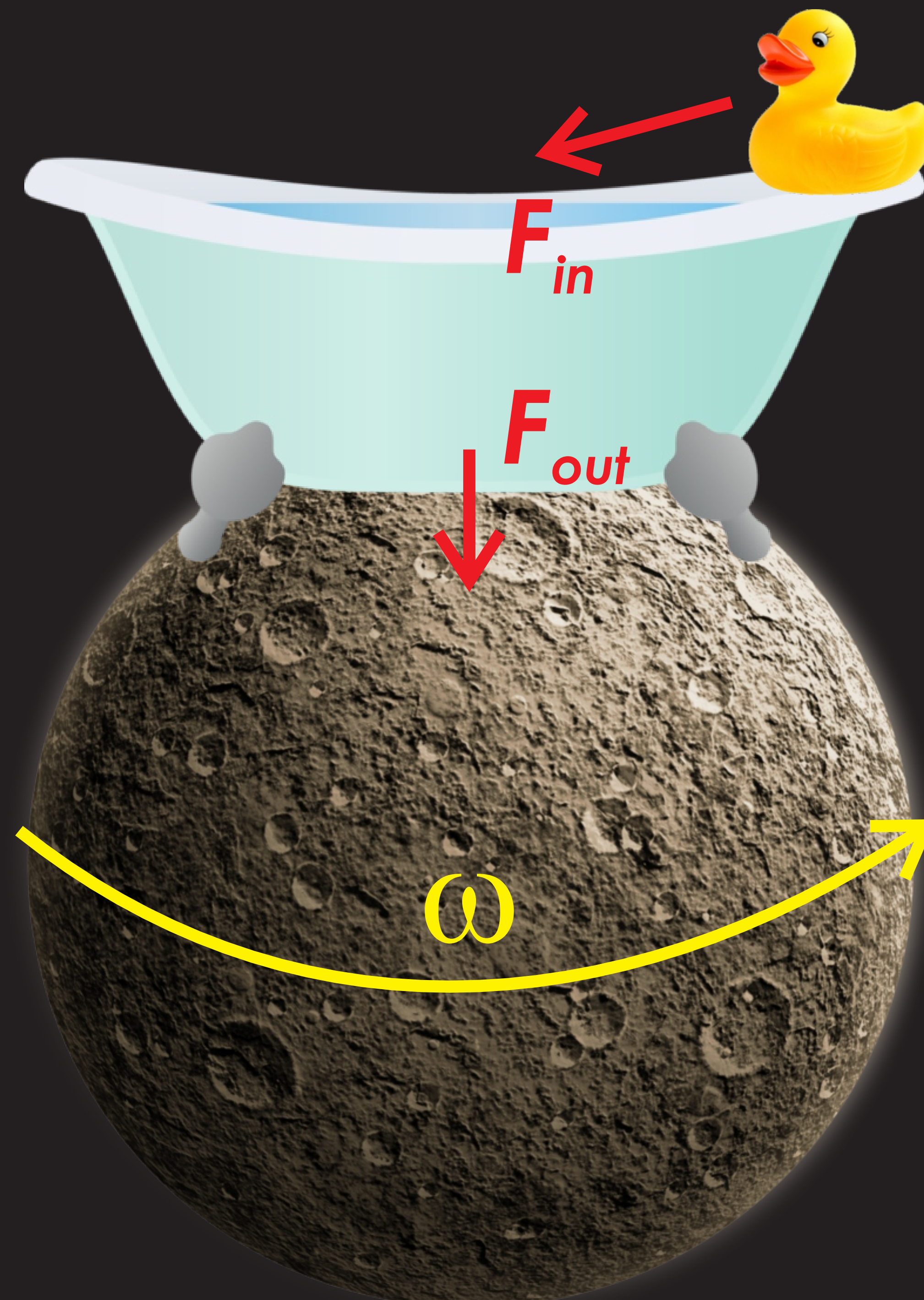
(implications for biogeochemical cycles and detectability)

Andy Ridgwell
Chris Reinhard

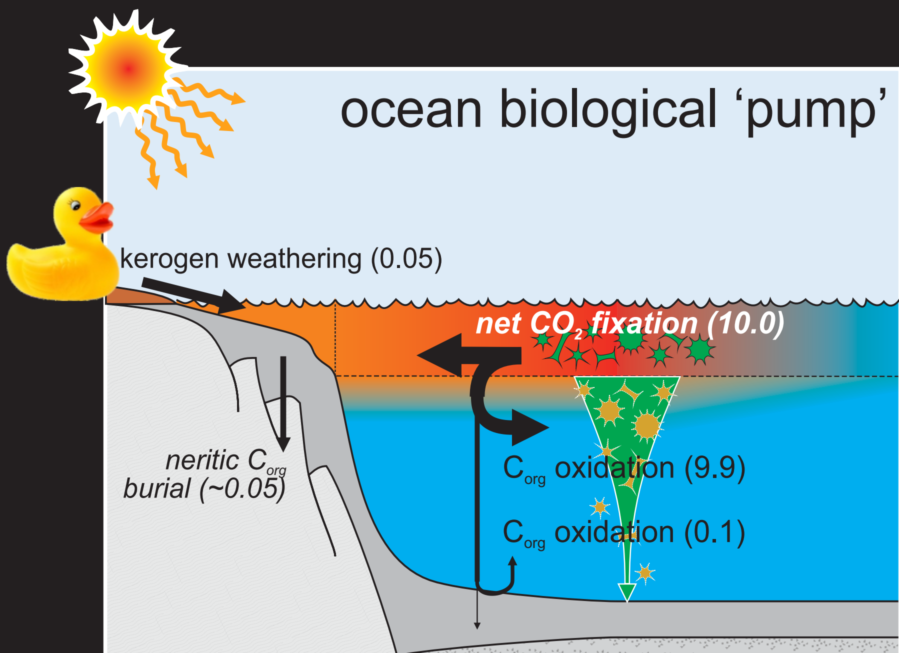


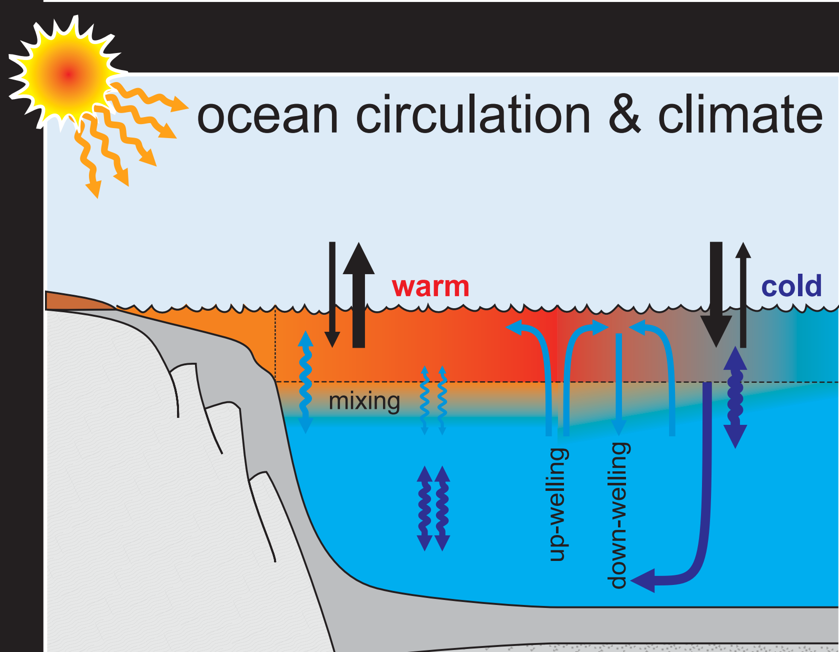
Earth 2.0.3

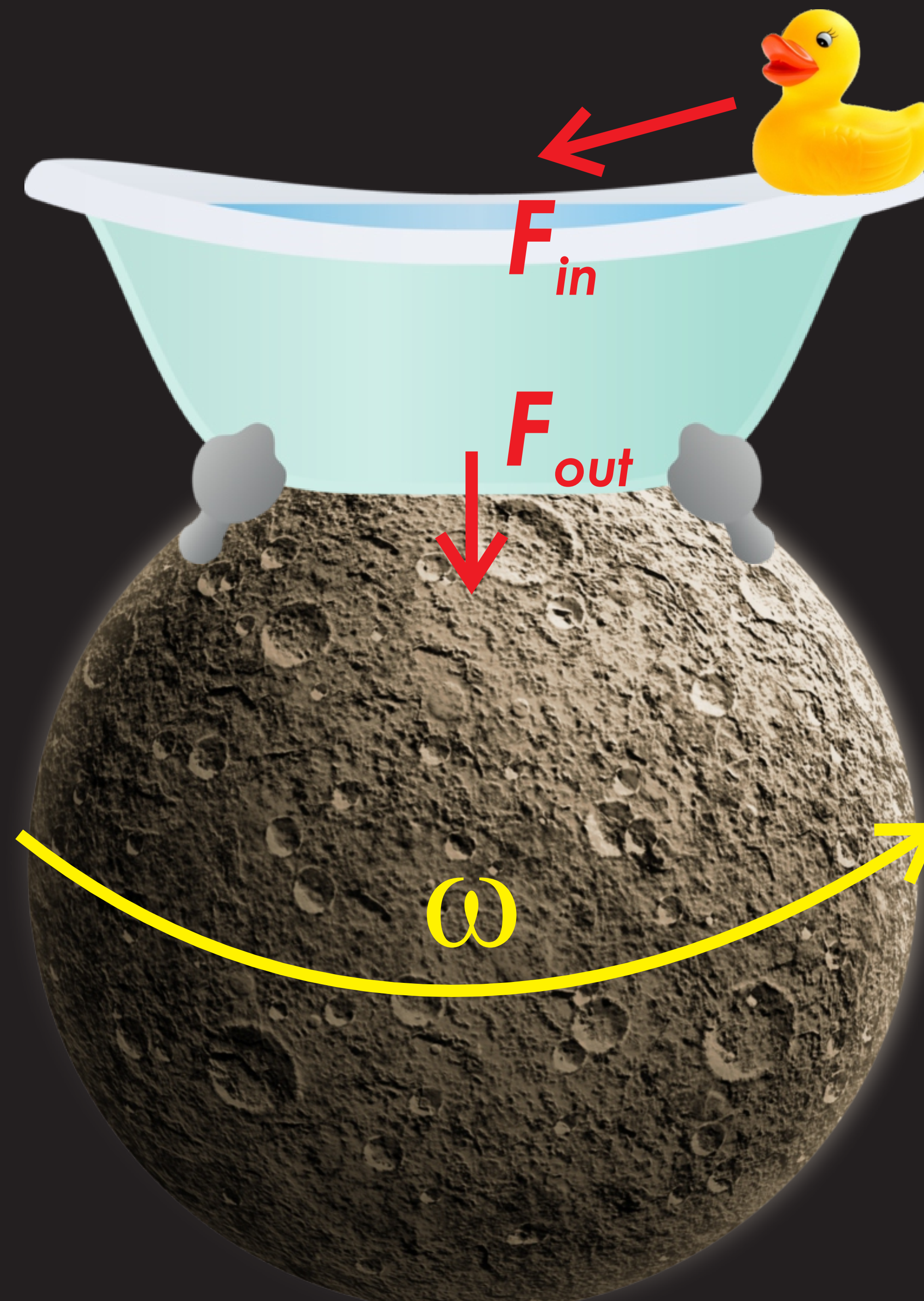
a numerical modeller's persepctive



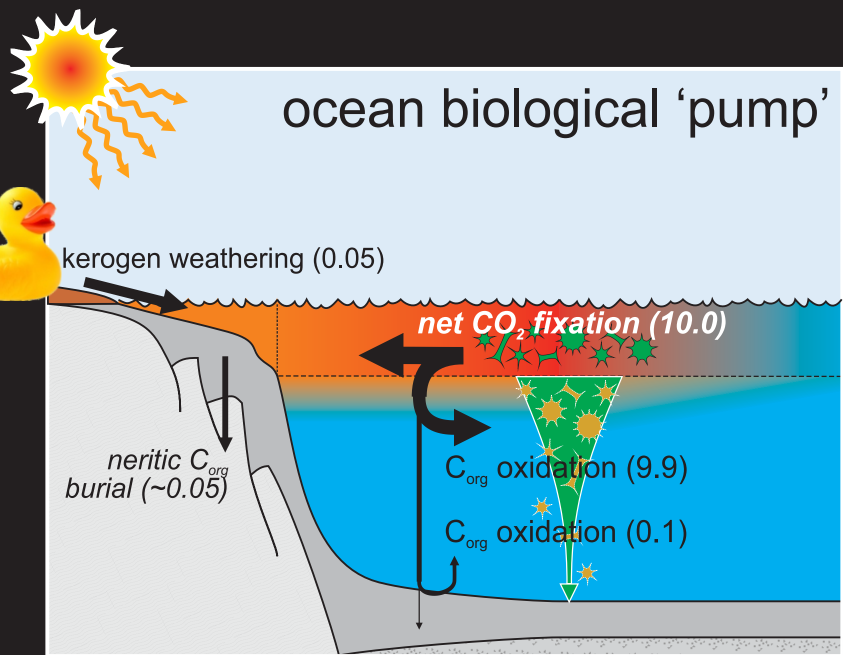
Introduction

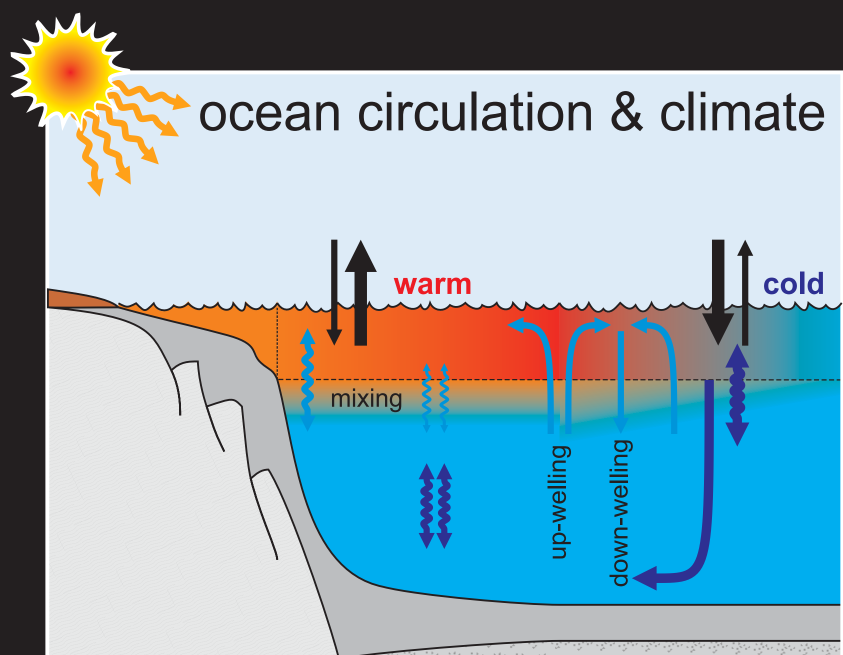






Introduction





On Earth ...

Significant exposed rocky surface (and active tectonics) leads to a *high* flux of dissolved elements to the ocean. This, in turn, supports *high* biologically driven burial fluxes.

=> drives atmospheric composition (e.g. O_2)

High rates of nutrient supply also favor *high* standing inventories of nutrients in the ocean. This, in turn, and in conjunction with vigorous ocean circulation, supports a productive ecology and biological pump ... in turn, creating *substantive* spatial heterogeneity (esp. in redox).

=> simultaneous flux to the atmosphere of disequilibrium species (e.g. CH_4 and O_2)

(Disclaimer: None of the statements in italics may be 'true'.)

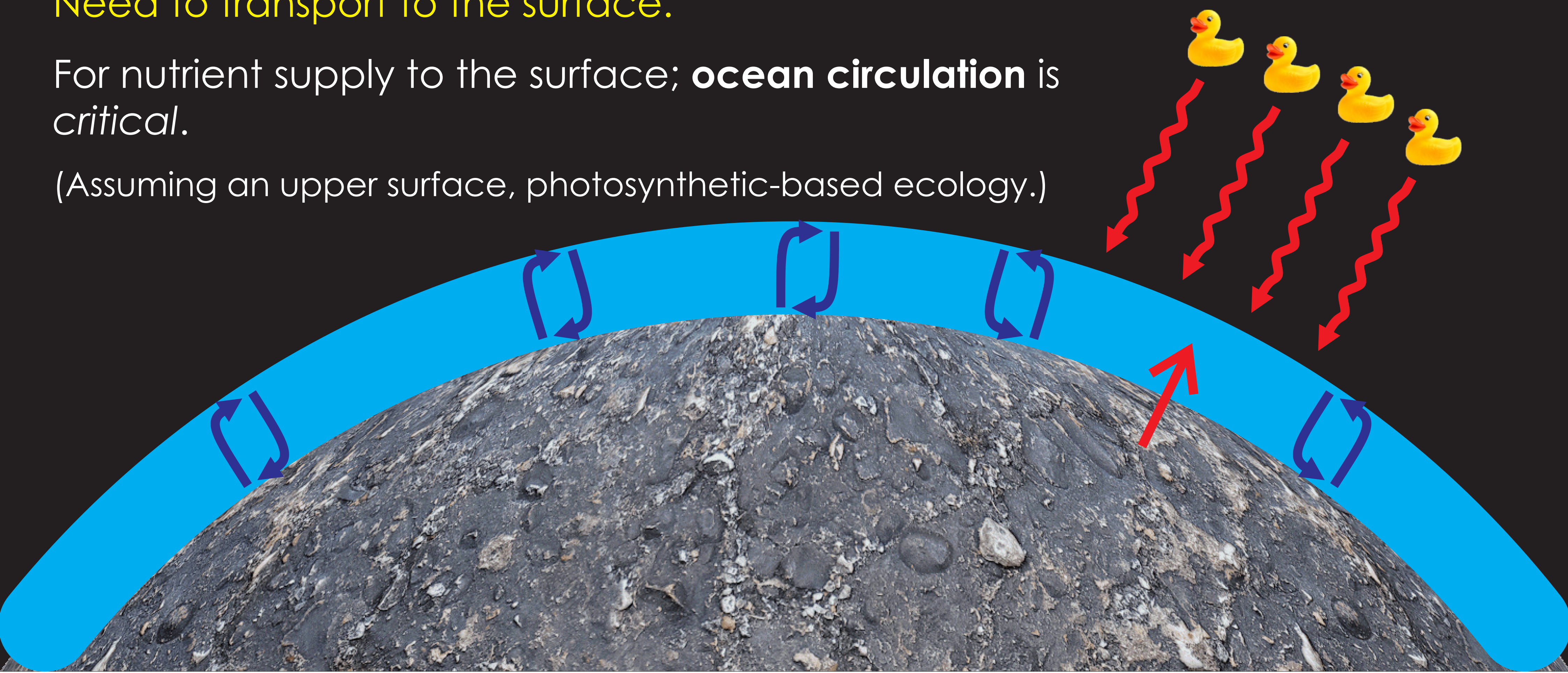
On a Water-World ...

Input via dust and micro-meteorites may be important, but *low*.
Need to recycle.

Hydrothermal input / crustal water-rock interactions at the sea-floor may also be important.
Need to transport to the surface.

For nutrient supply to the surface; **ocean circulation** is *critical*.

(Assuming an upper surface, photosynthetic-based ecology.)



Introduction

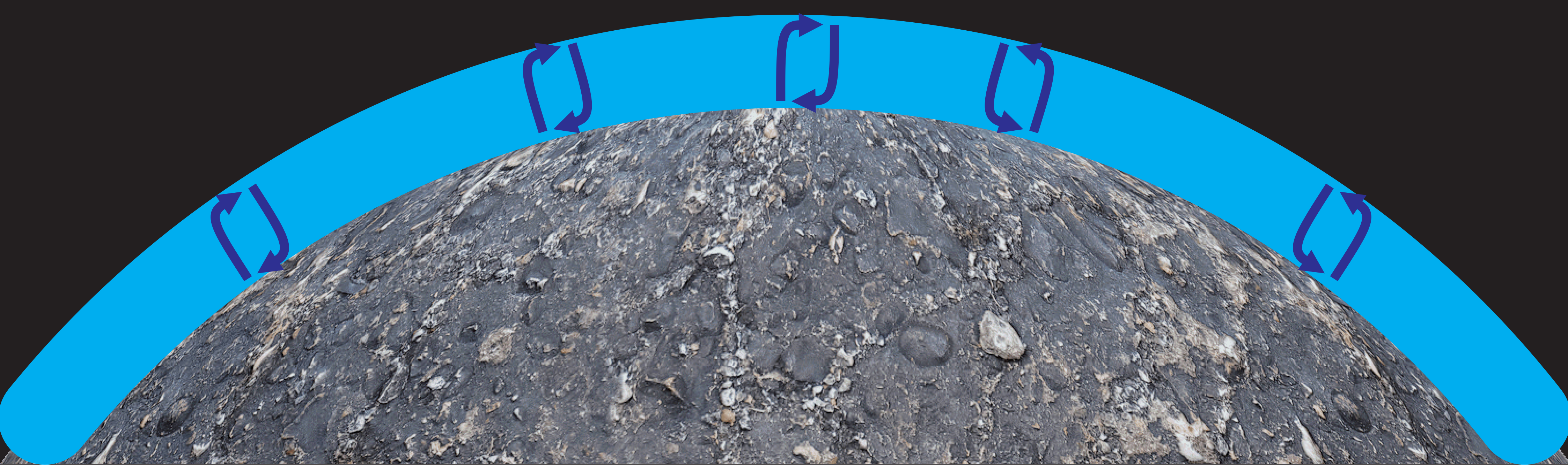
Motivation:

How deep is the ocean on a Water-World ... ?

Can the ocean on a Water-World be ‘too deep’ to effectively support life?

Is there a critical depth at which nutrients can no longer be efficiently returned to the surface?
Does geothermal energy input at the sea-floor rescue the situation?

(Disclaimer: Not necessarily answered here ...)

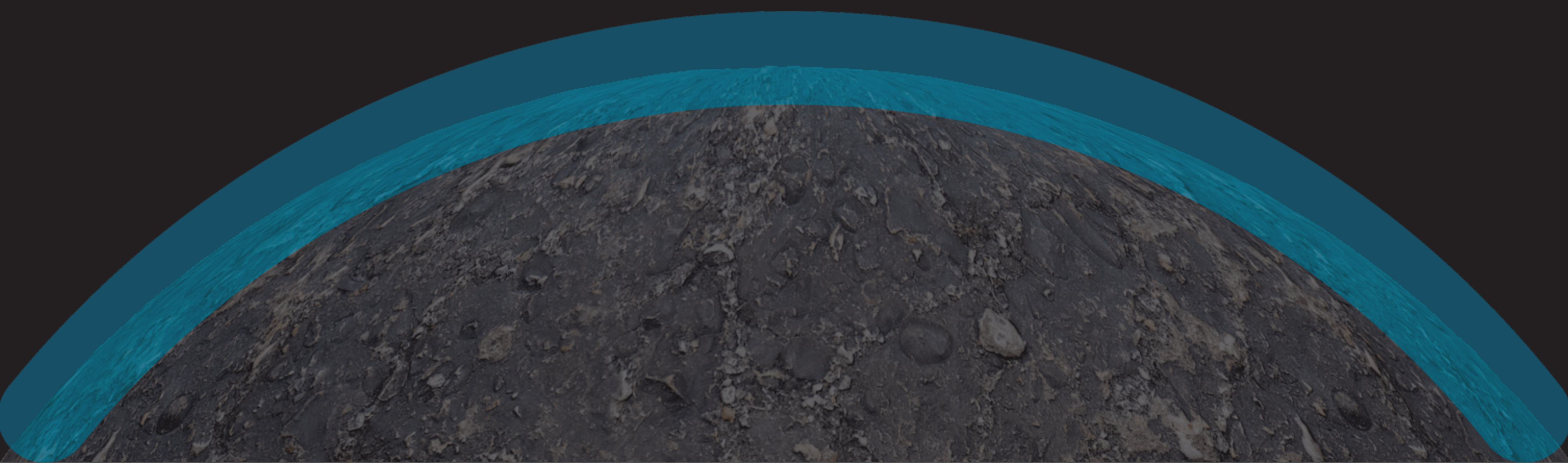


On a Water-World ...

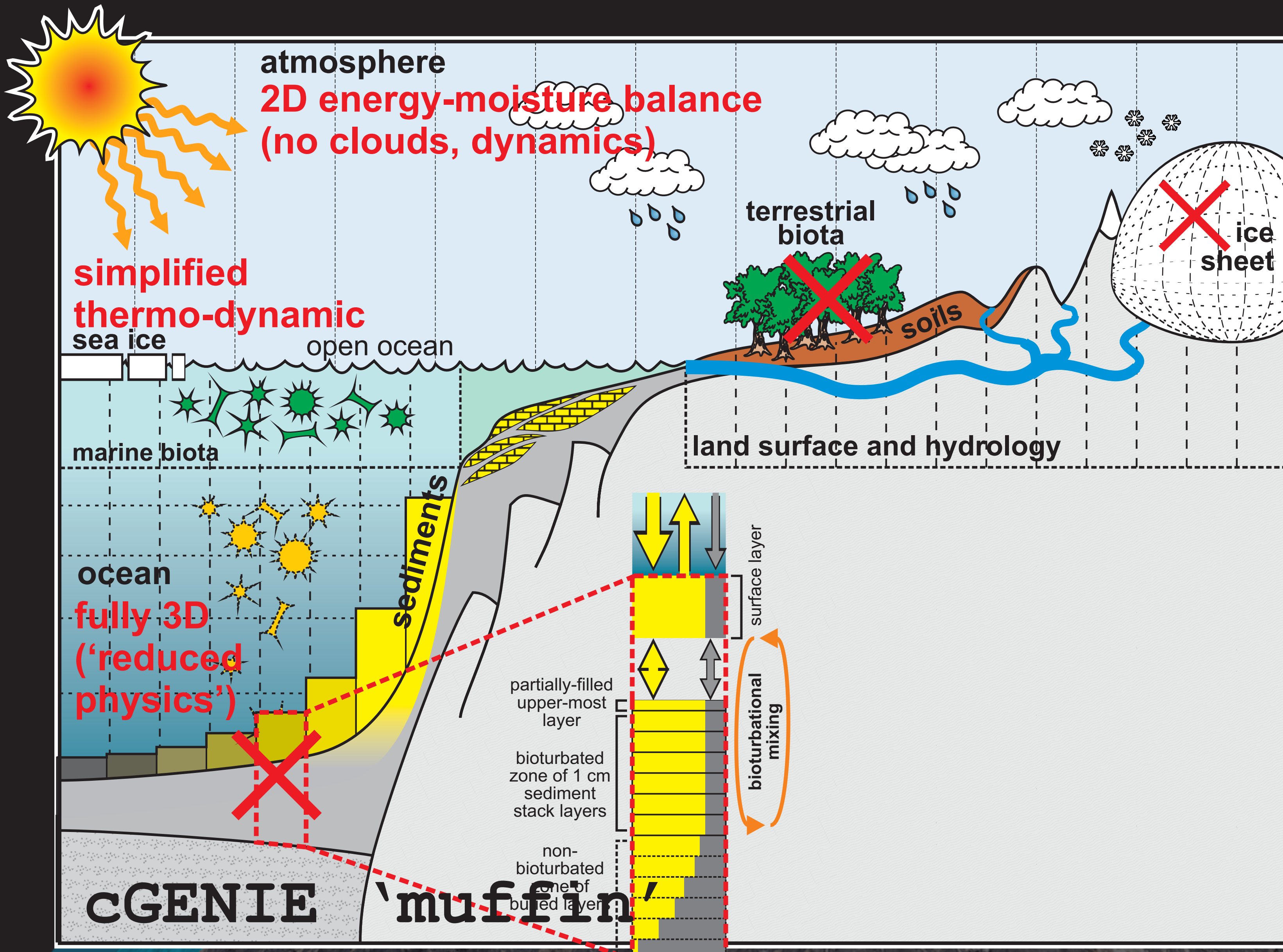
How deep is the ocean?

Role of climate state (surface energy forcing), geothermal input?

=> Implications for the biological pump in the ocean (and hence potential for biological driven burial, ocean geochemical heterogeneity).



Numerical methods

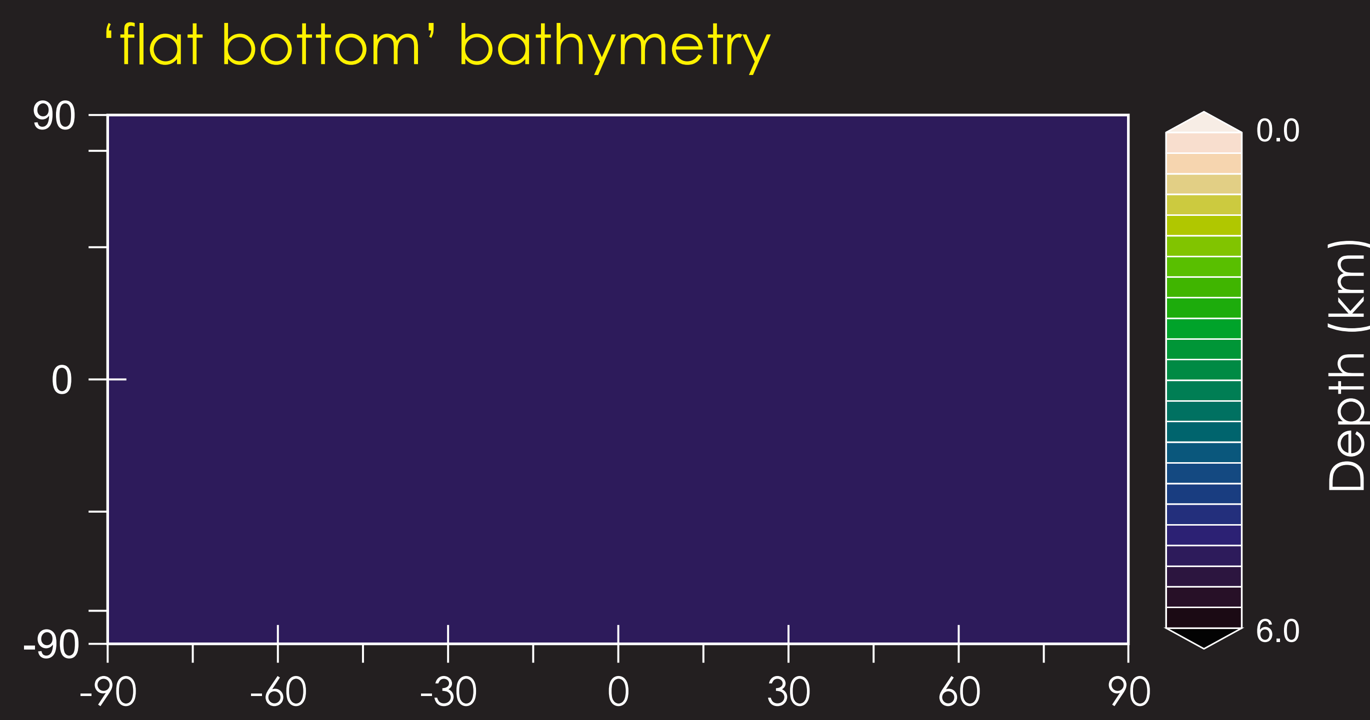


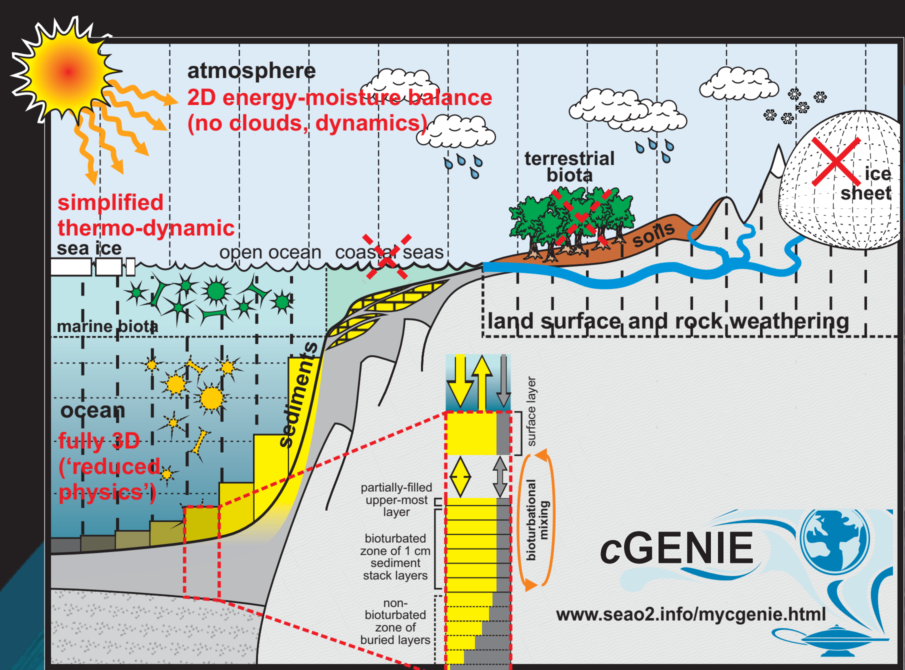
18x18 grid resolution (20 degrees longitude).

Modern/Earth ... solar constant, orbits, planetary diameter & density, rotation rate, atmospheric density and composition ... ocean salinity, nutrient (PO_4) inventory, biological activity ...

github.com/derpycode/cgenie.muffin

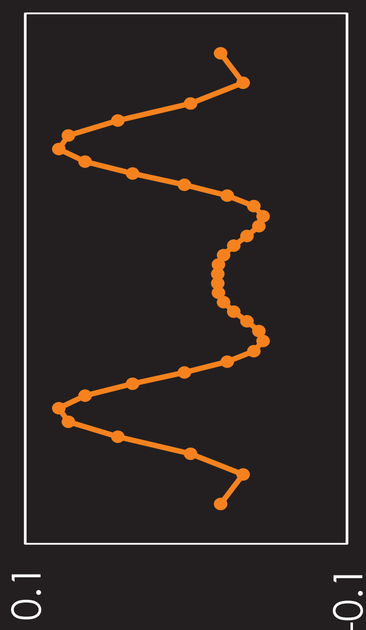
Numerical methods



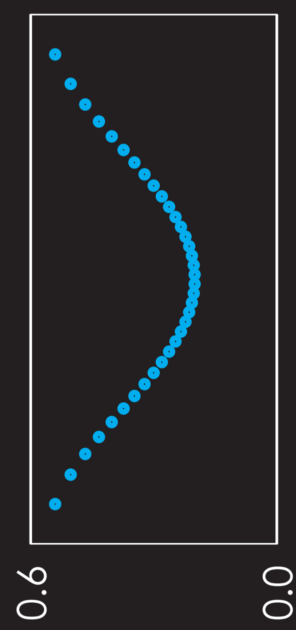


Numerical methods

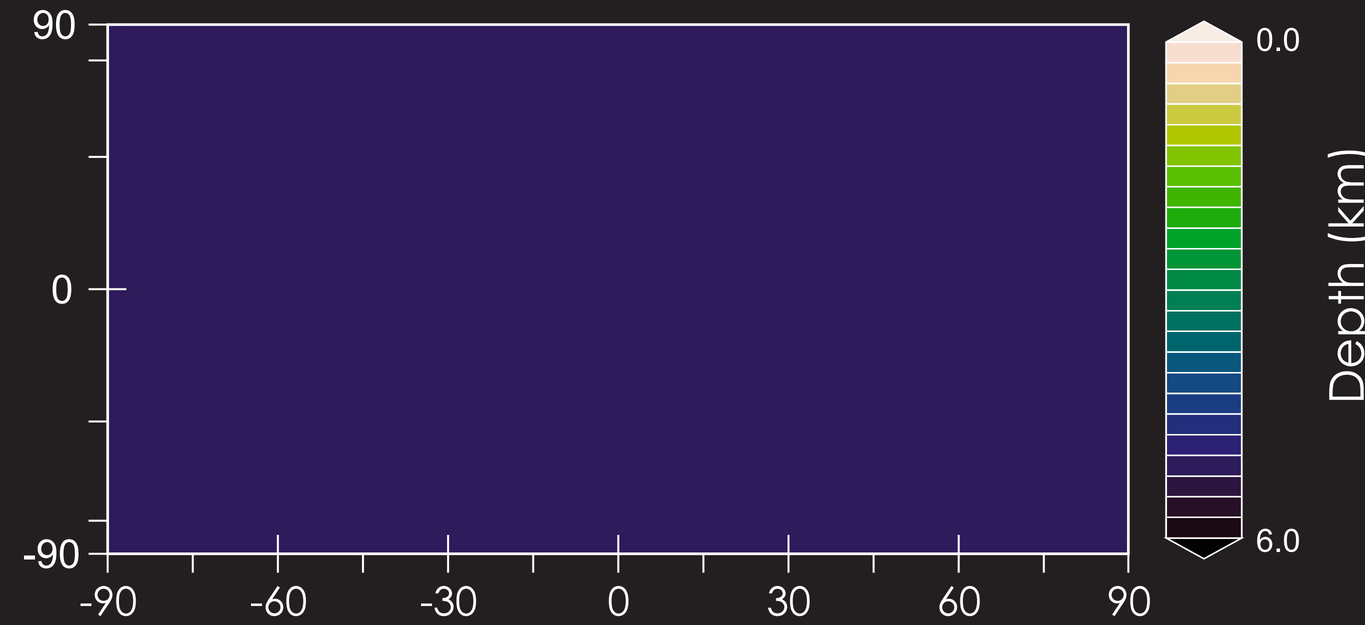
zonal wind stress

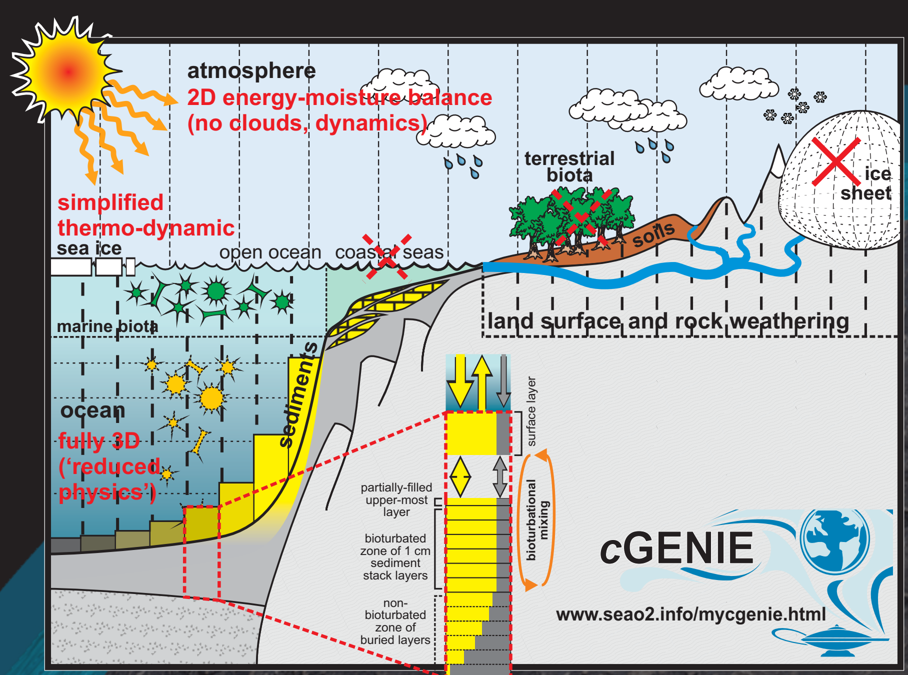


planetary albedo



+ seasonal insolation forcing & modern orbit





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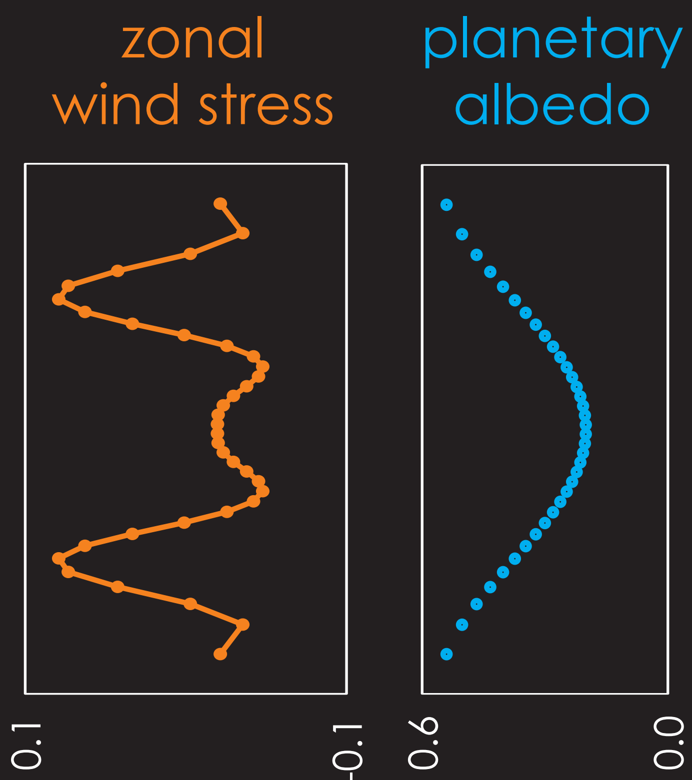
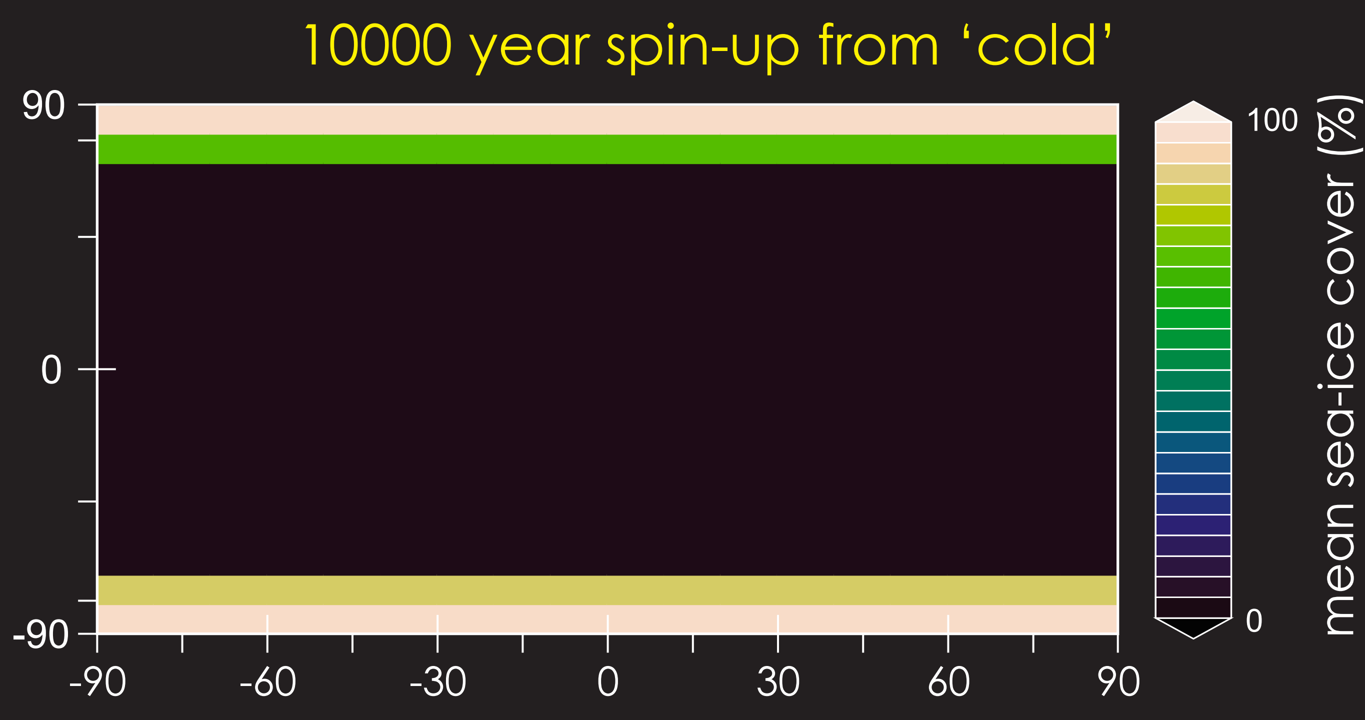
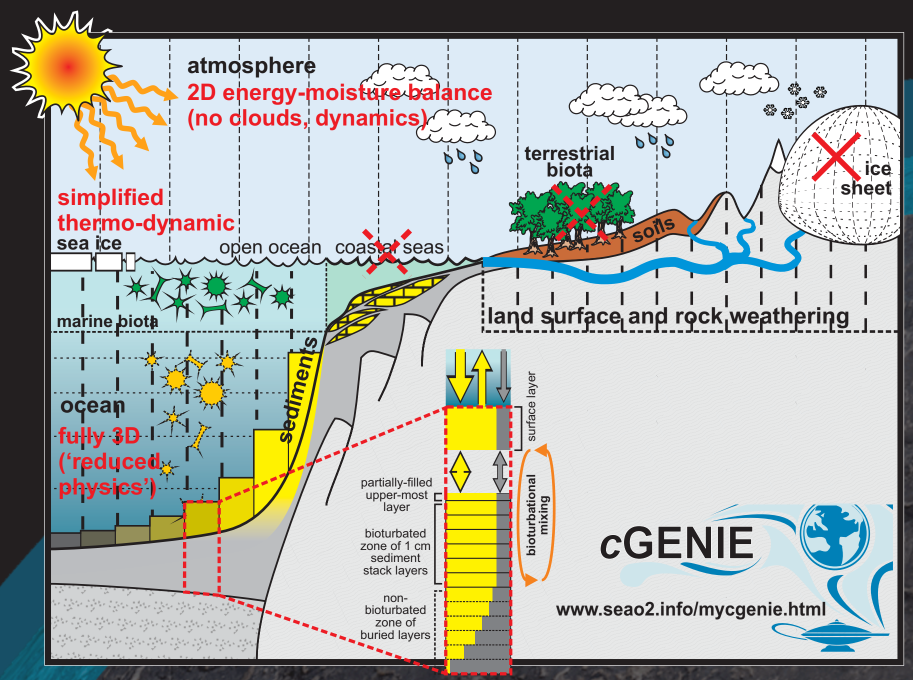






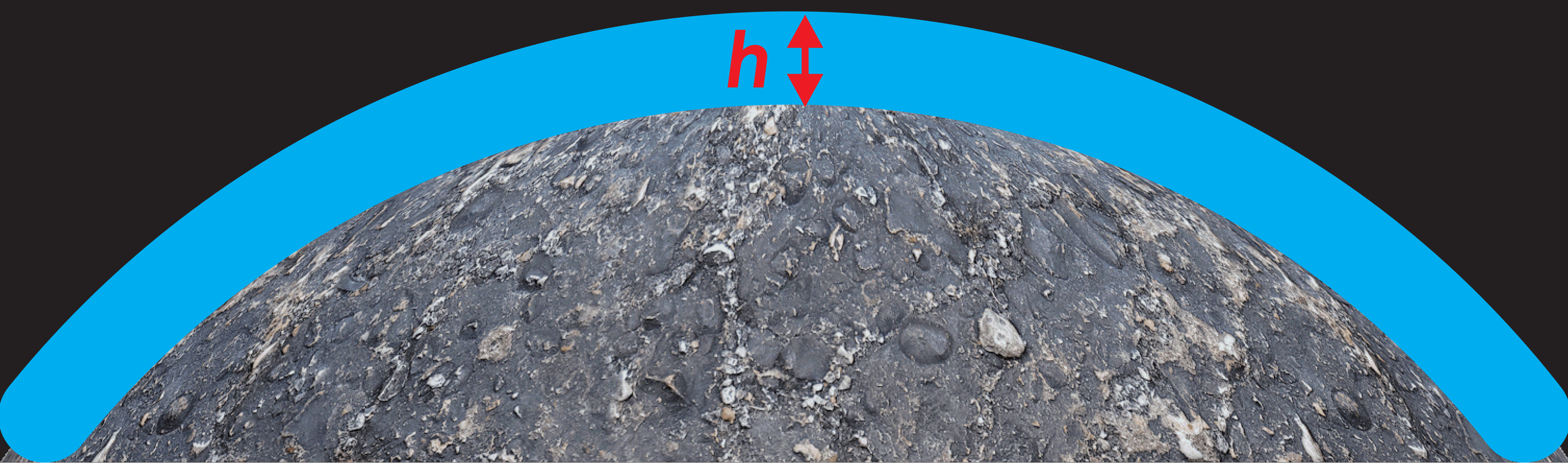
Numerical methods

Modern Earth:
~3.5 km mean depth
~2.5 km depth for a Water-World

Standard cGENIE.*muffin* model has 16 depth levels equating to 5 km maximum ocean depth. Retain upper ocean depth-level structure in the model across all configurations.

On a Water-World ...

... how deep is the ocean?



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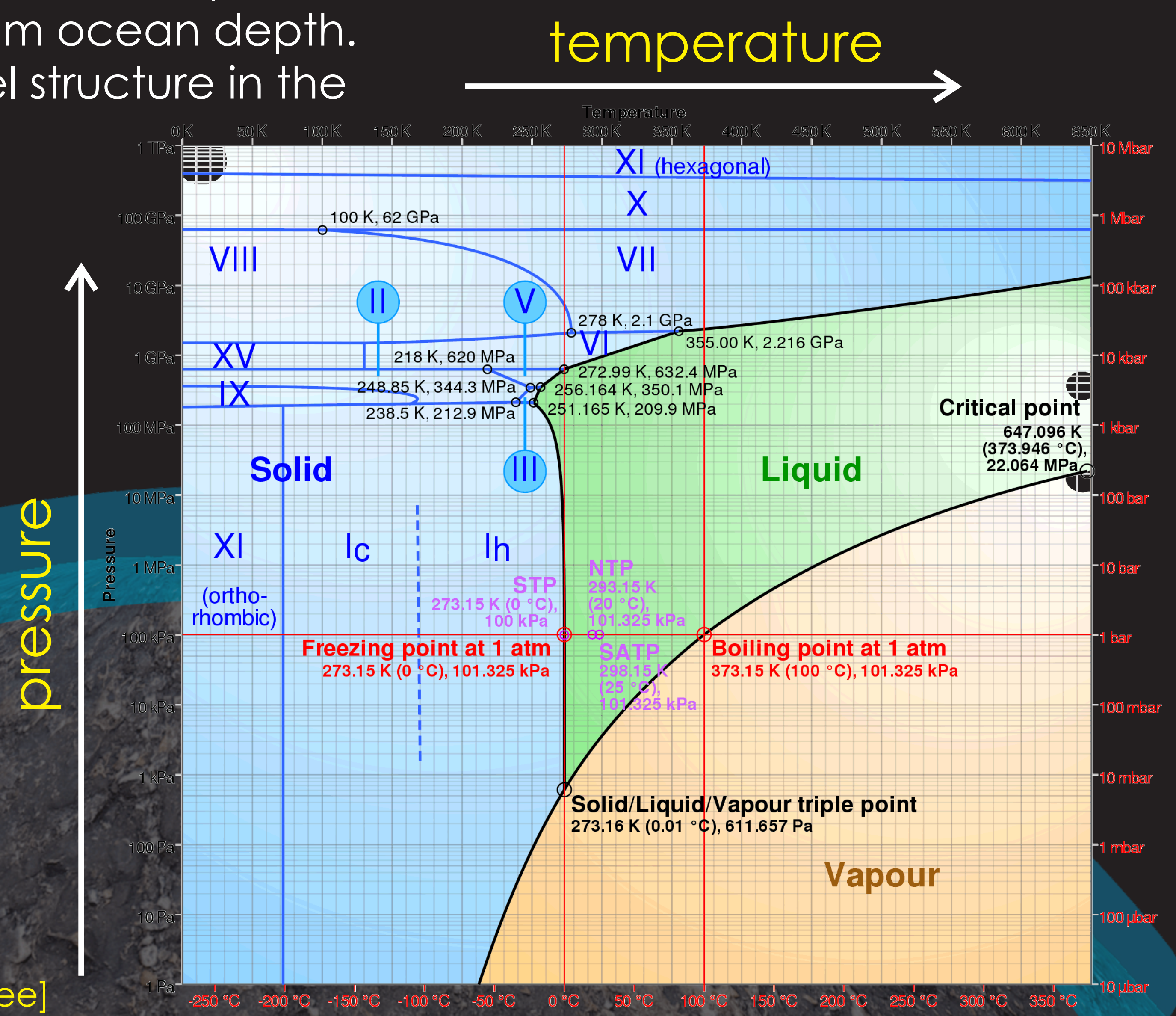
=> TEST:
09 levels == 2.5 km
12 levels == 3.5 km
16 levels == 5.0 km
32 levels == 10.4 km
48 levels == 15.8 km
64 levels == 21.2 km
96 levels == 32.0 km



Phase diagram of water [Wikipedia / Cmglee]

On a Water-World ...

Climate state (surface heating)
vs. geothermal input

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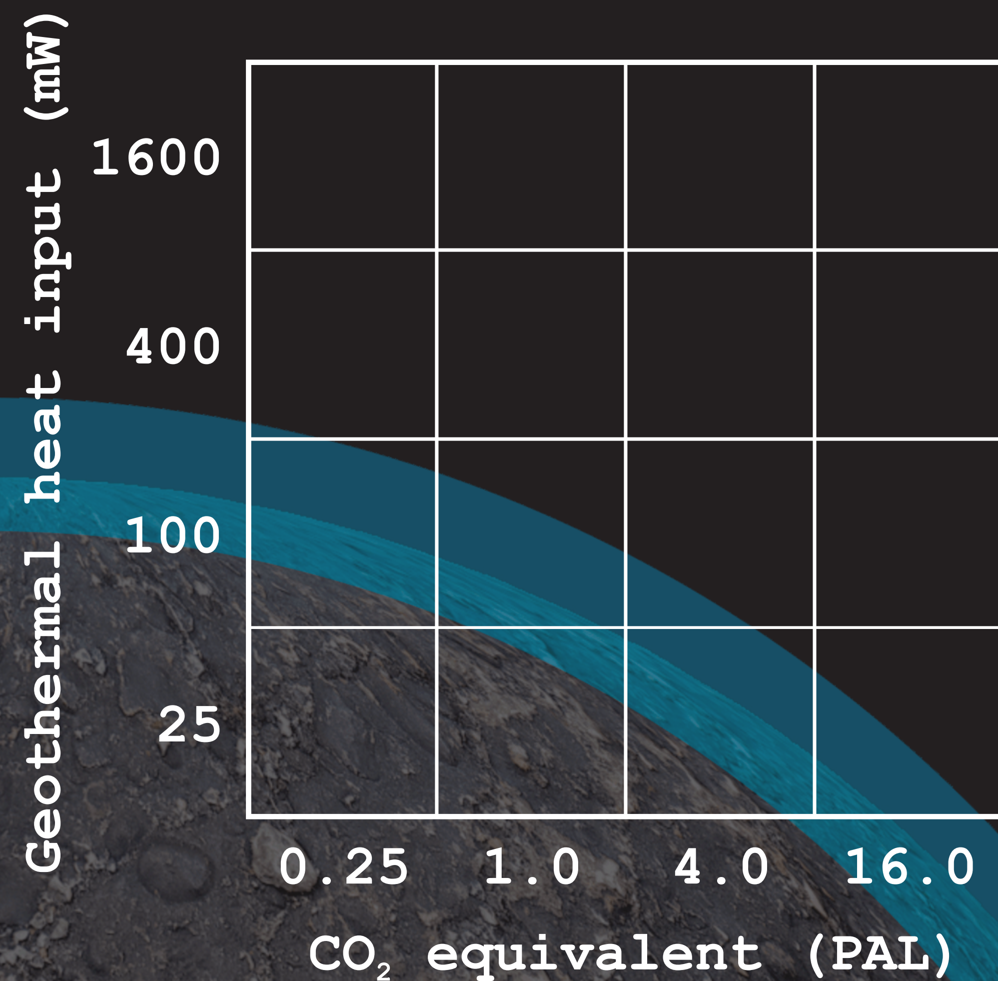

Numerical methods

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Geothermal heat input (mW) \ CO_2 equivalent (PAL)	0.25	1.0	4.0	16.0
1600	X		X	X
400		X	X	X
100			X	X
25			X	X

Results

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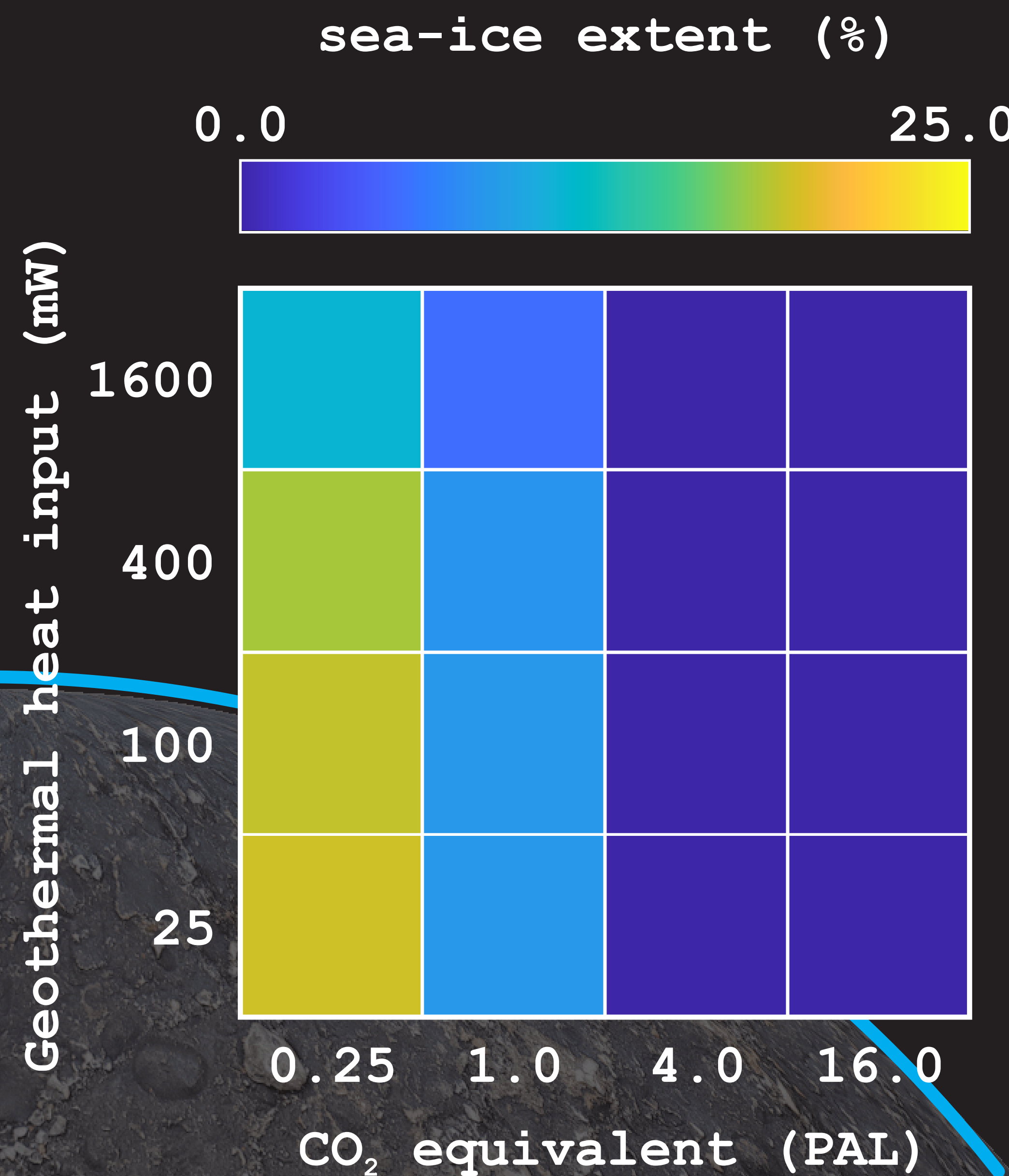

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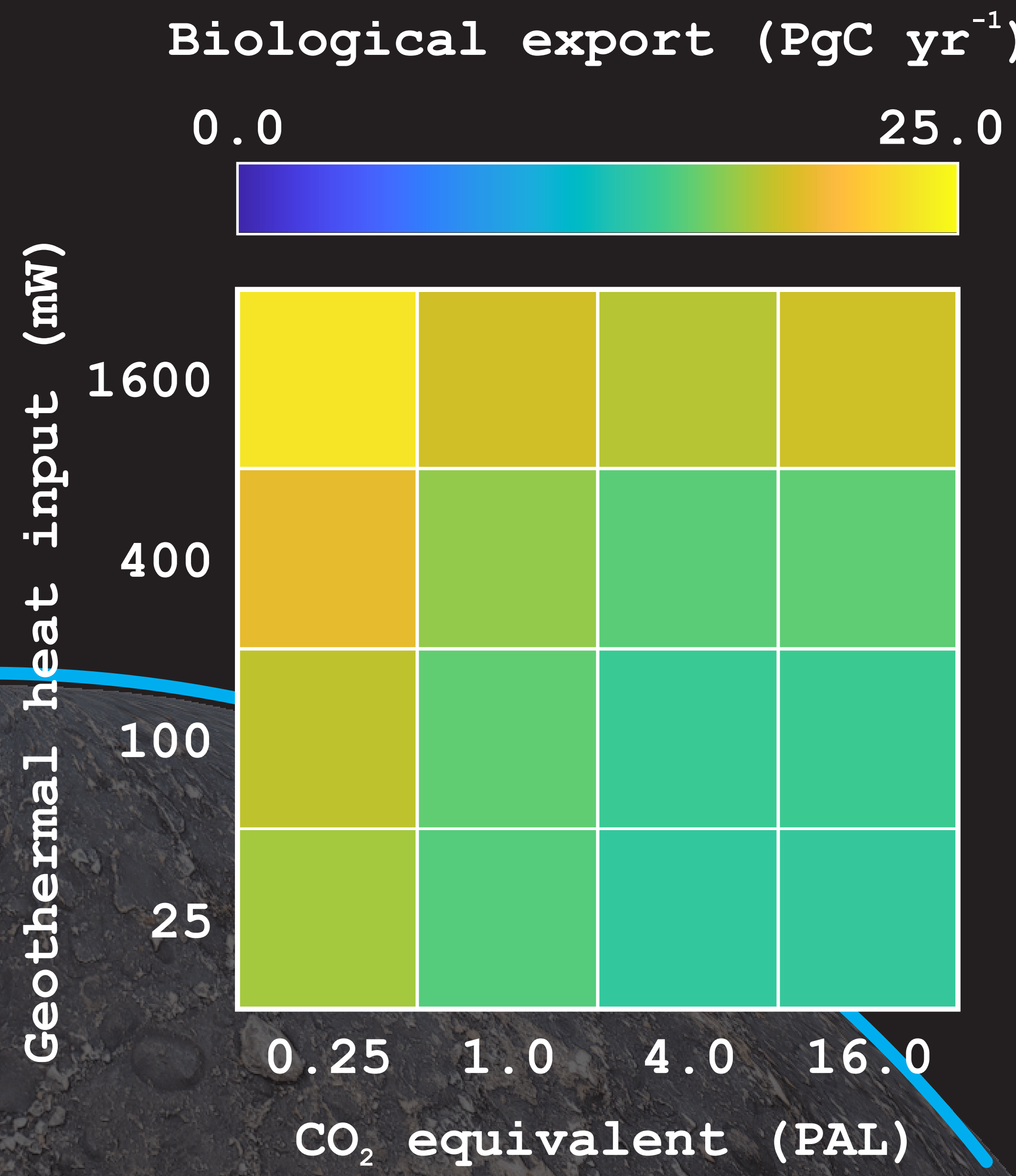
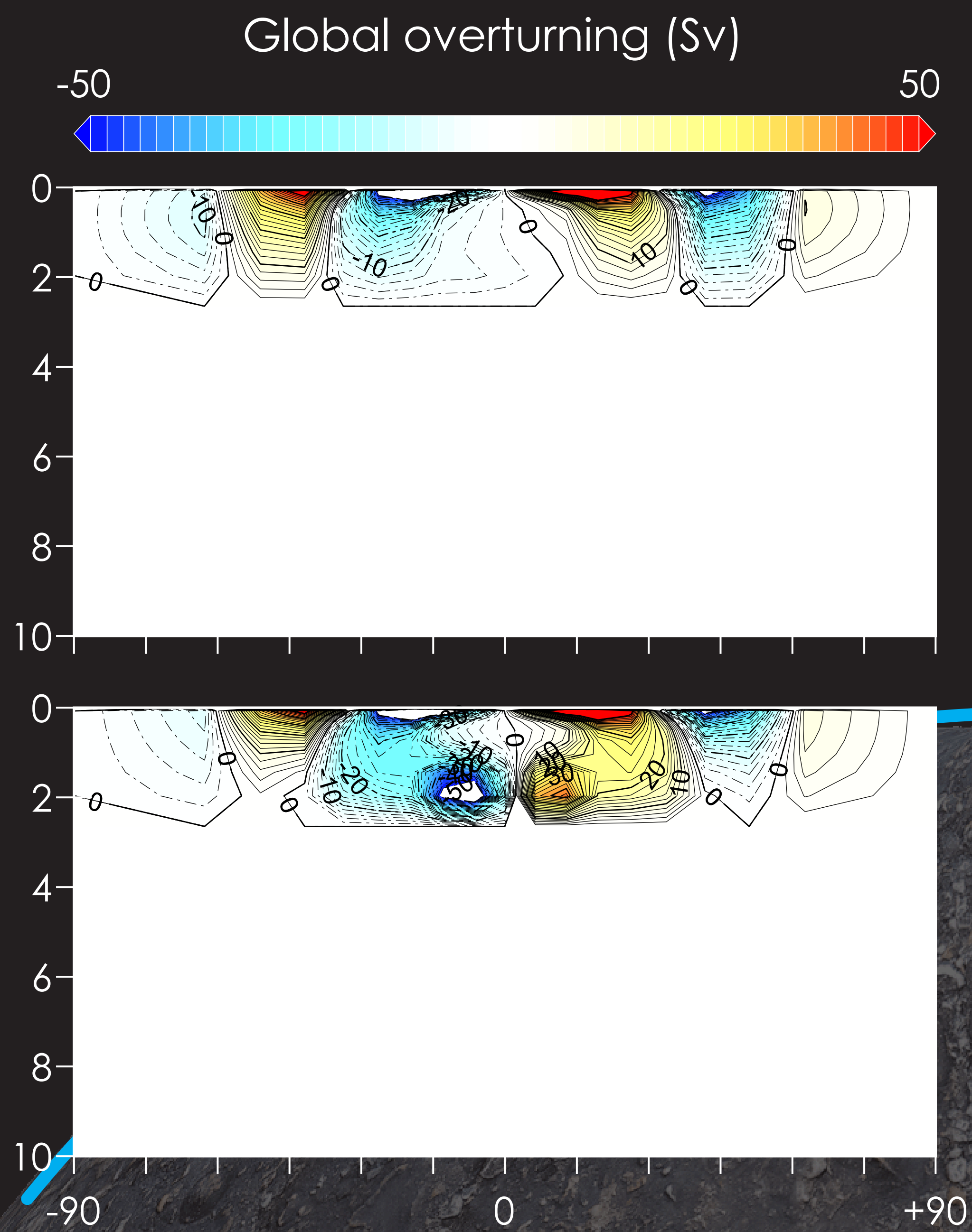
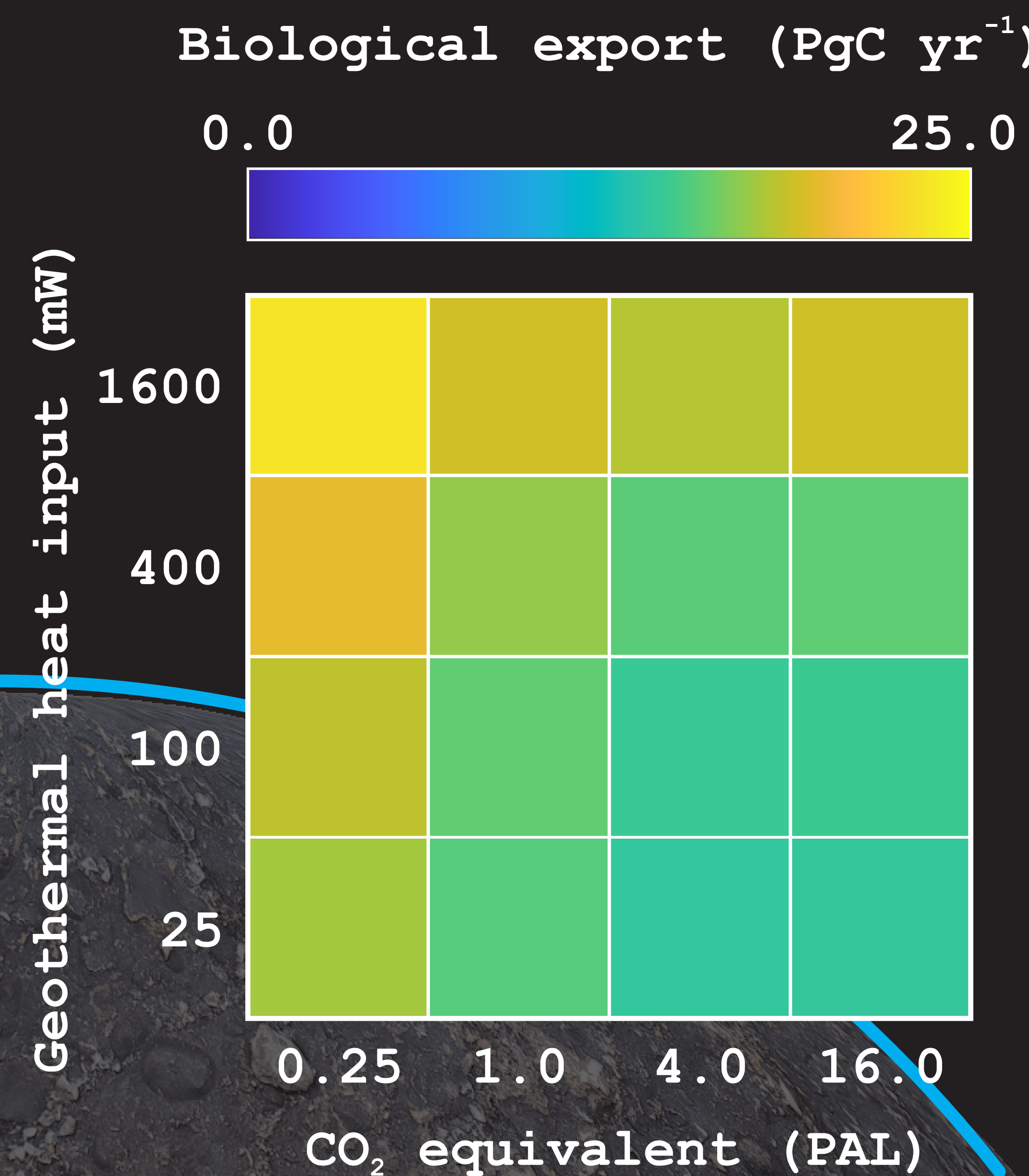


Results

Young == productive planet?
(cold star, warm planetary interior)





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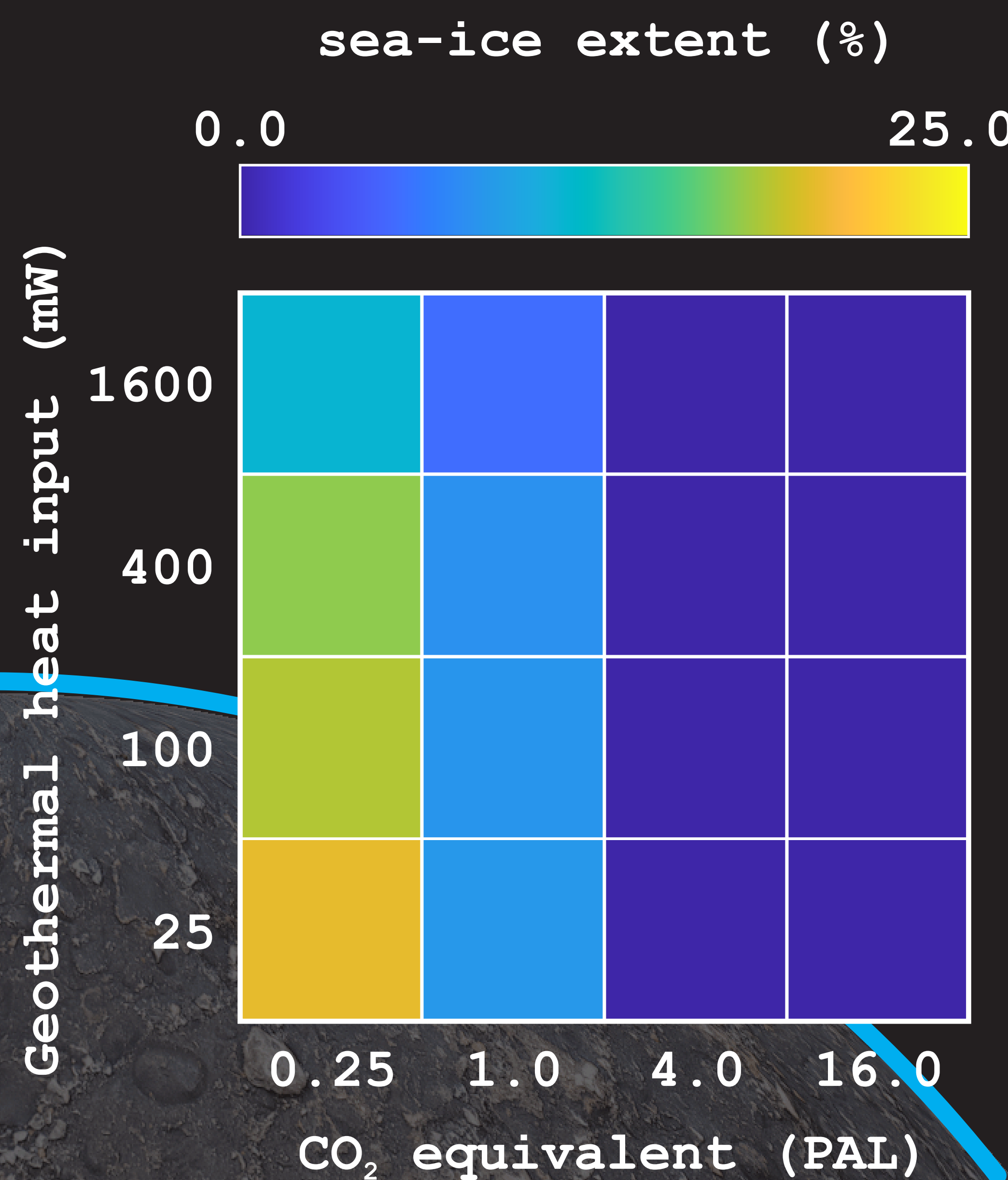

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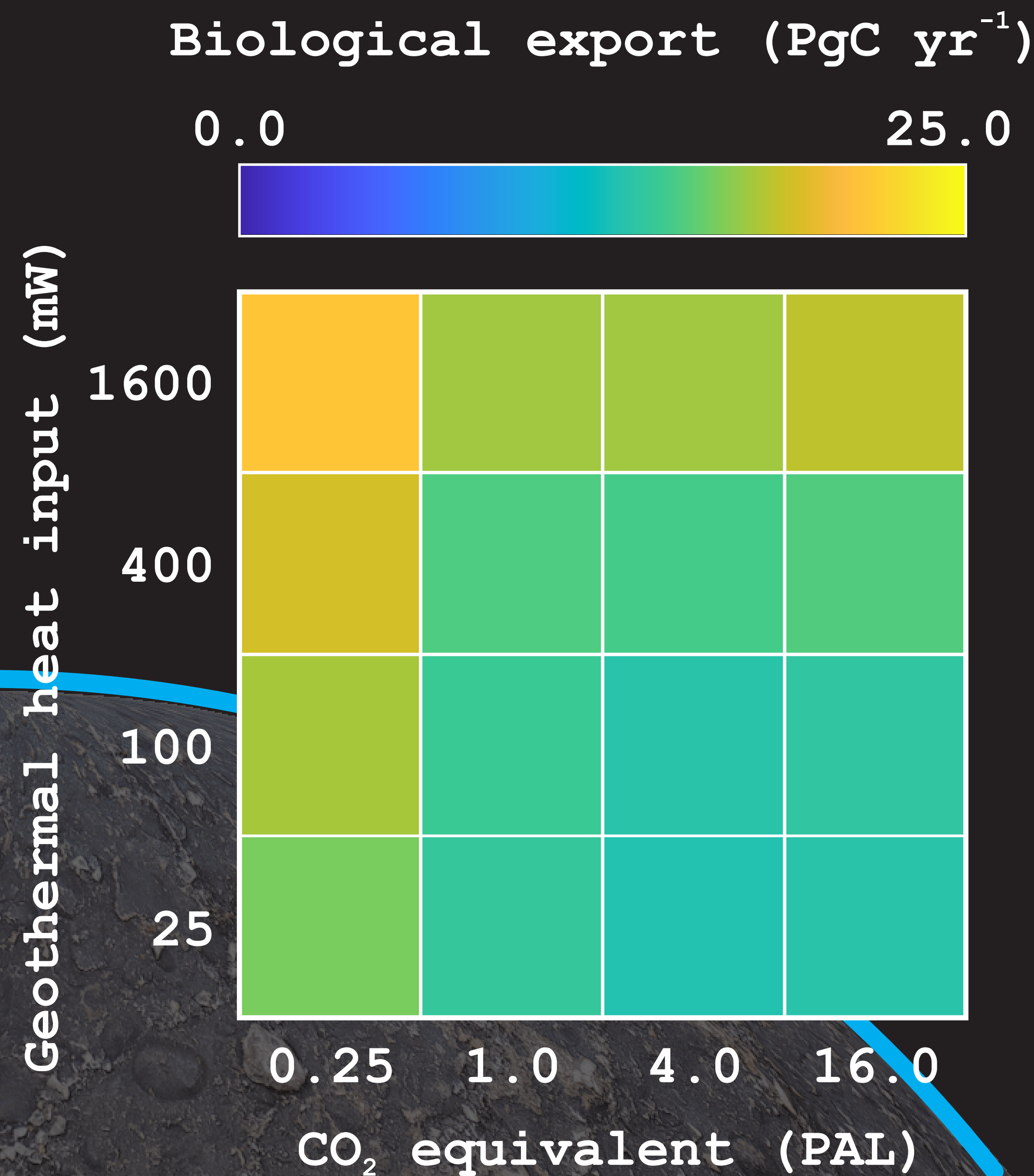

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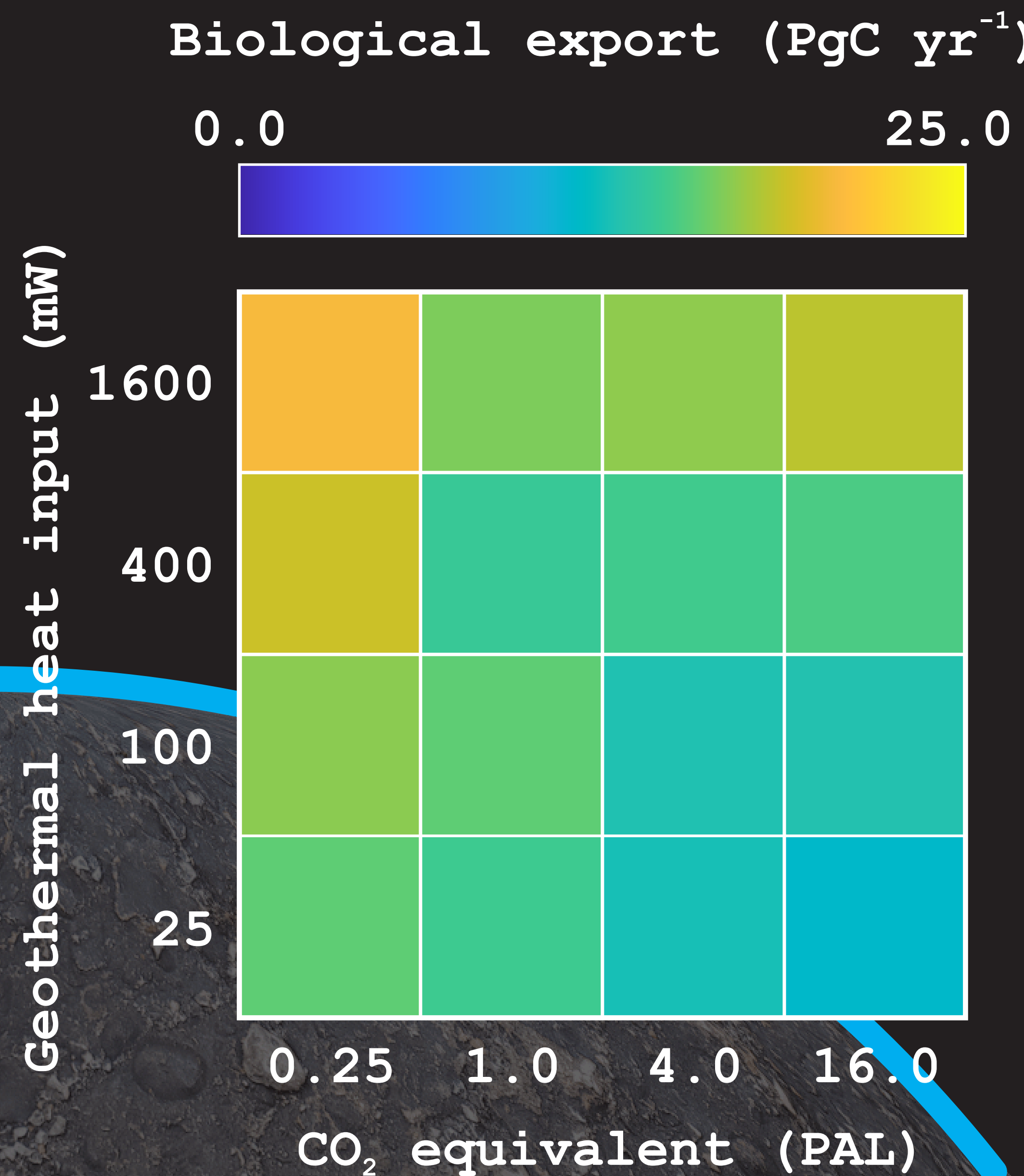

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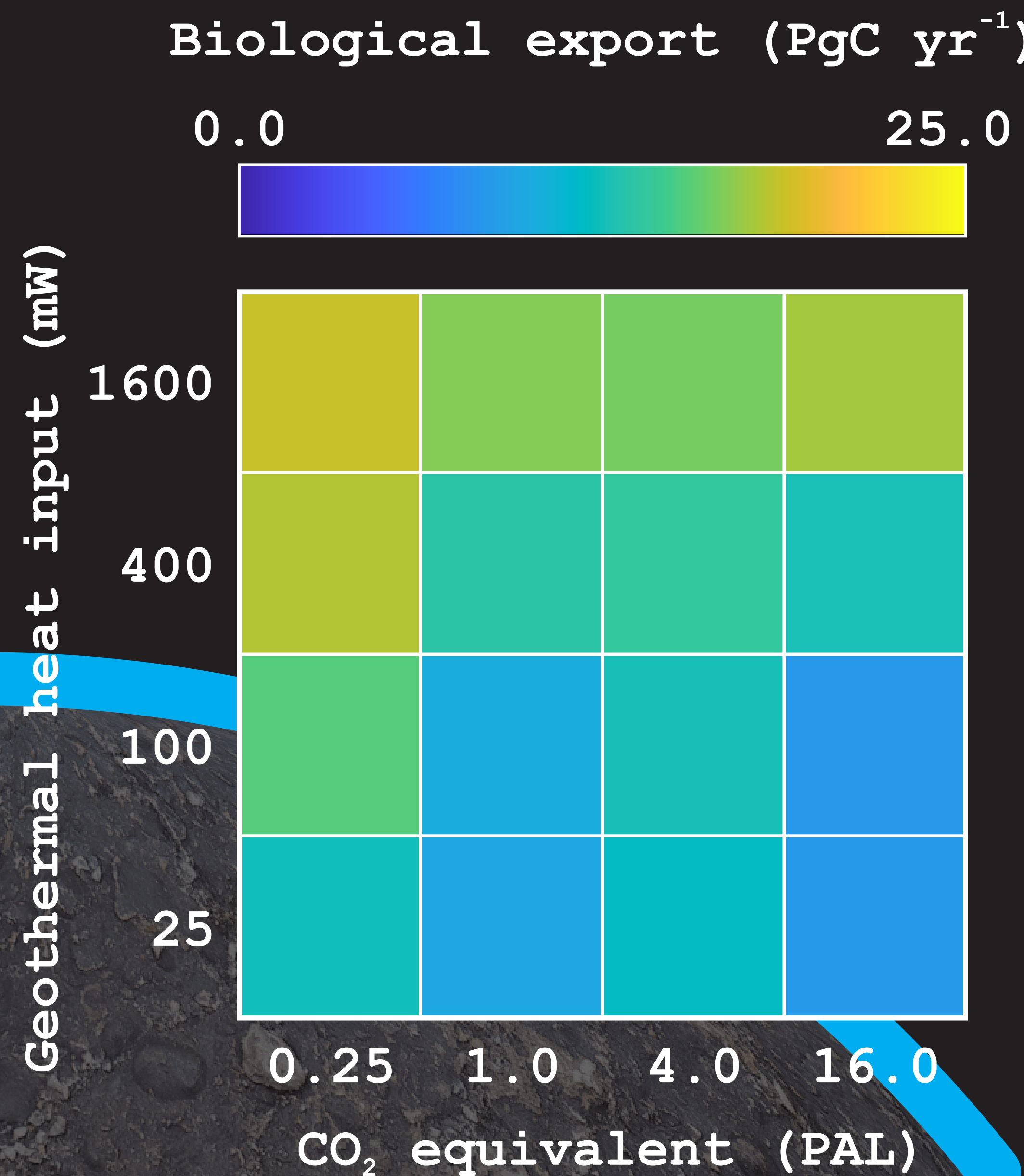

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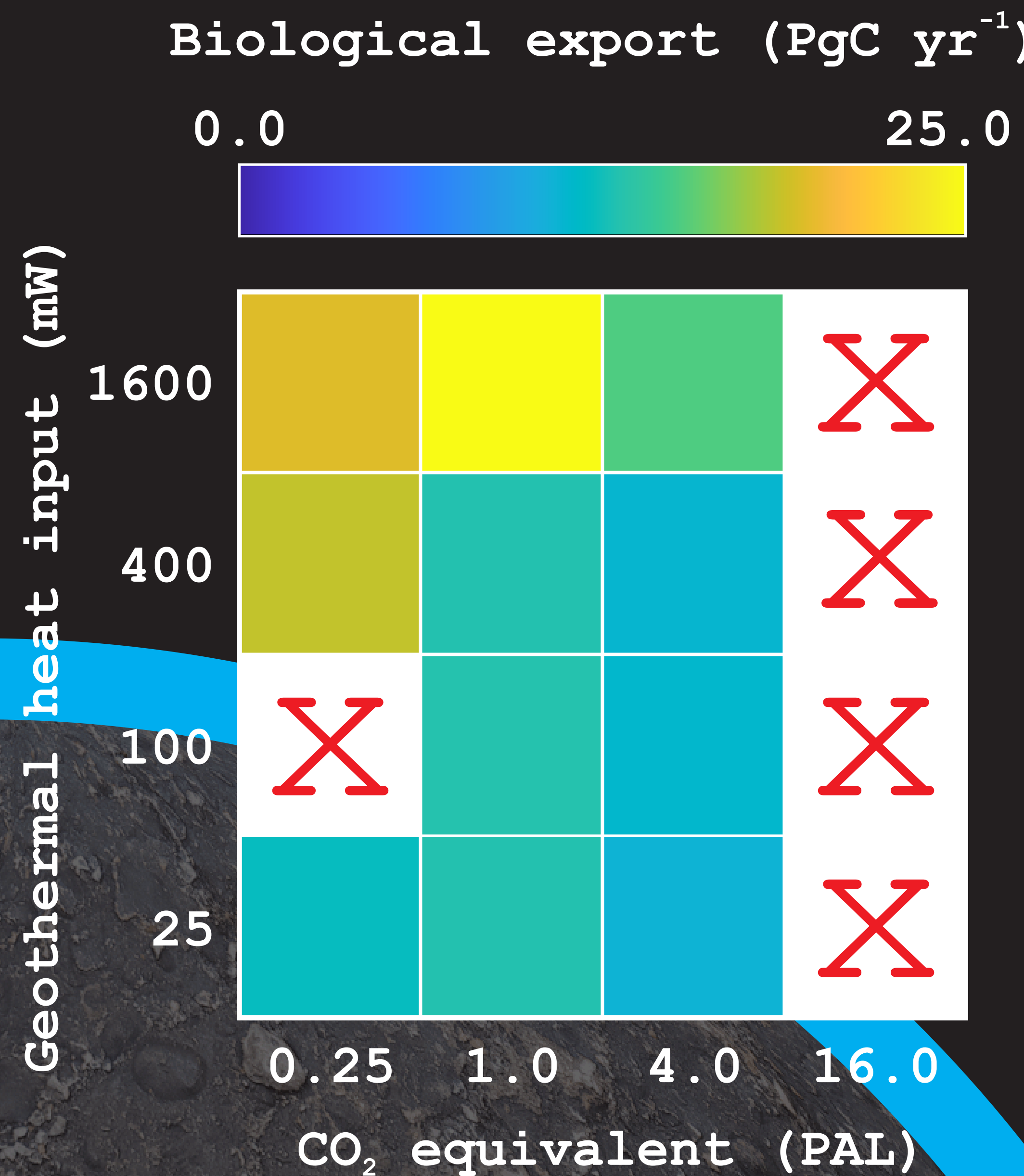

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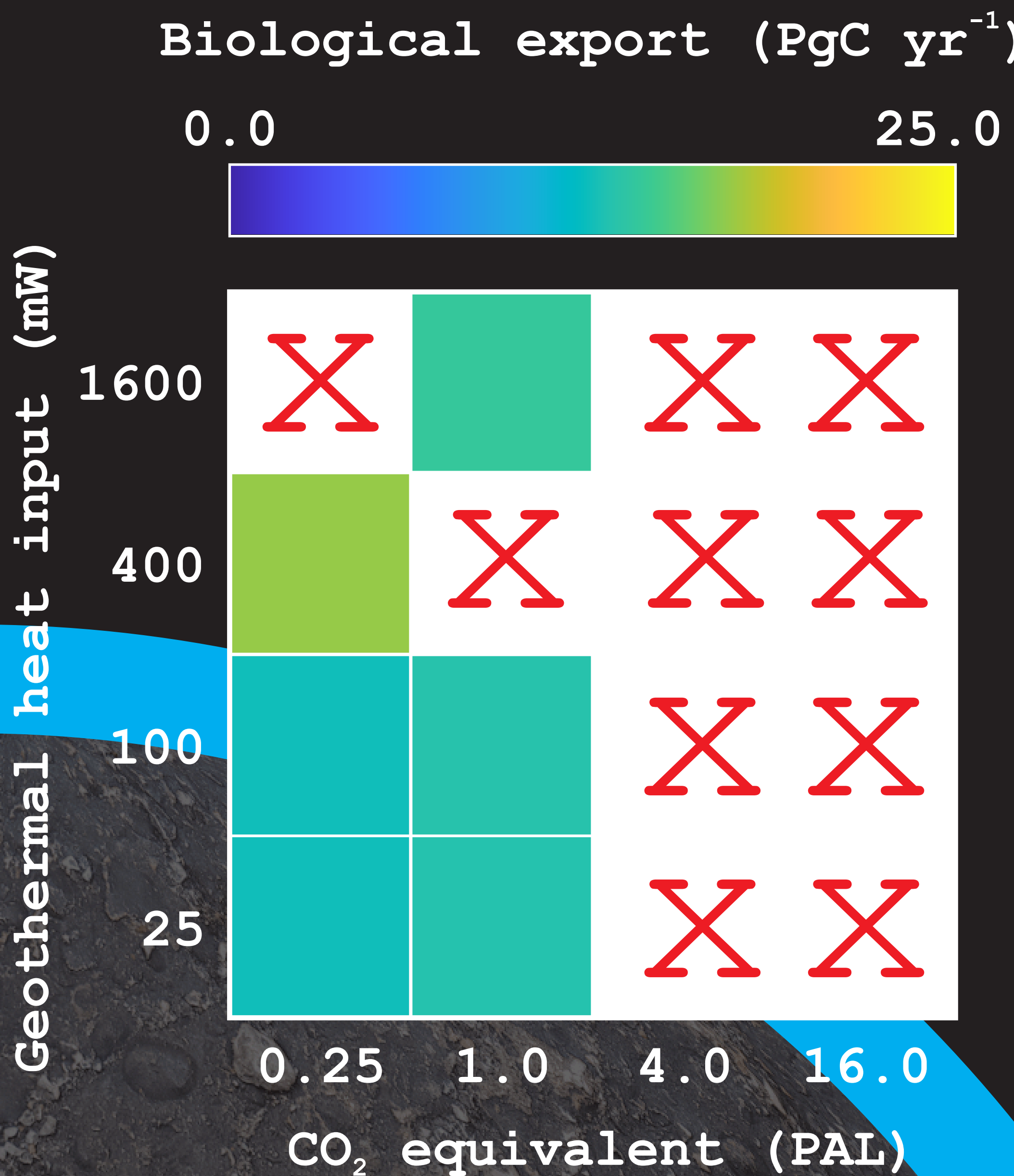

Conclusions

‘lessons’ / discussion

- The most productive Water-World might be a geologically young planet, with a cooler/younger host star, and a warmer planetary interior – the up-side-down vertical energy balance lends itself to instability and vigorous ocean mixing. (S_0 increases with time, while the rate of heat generation by radioactive decay declines.)

- Unanswered questions:
  – How do you get a Water-World in the first place? Does it *a priori* have to be characterized by a deep ocean (so no sub-arial exposure). A shallow ocean implies little tectonic activity (no mountaining building or volcanic islands), or sufficiently strong tidal mixing to erode any ocean floor topography? Geochemical cycling (input fluxes and ocean transport) will significantly differ between them.
  – In the case of a highly efficient (recycling) ecosystem evolved under low nutrient availabilty, there would be little burial loss and little ocean geochemical hetrogeniety => weak biosignature?