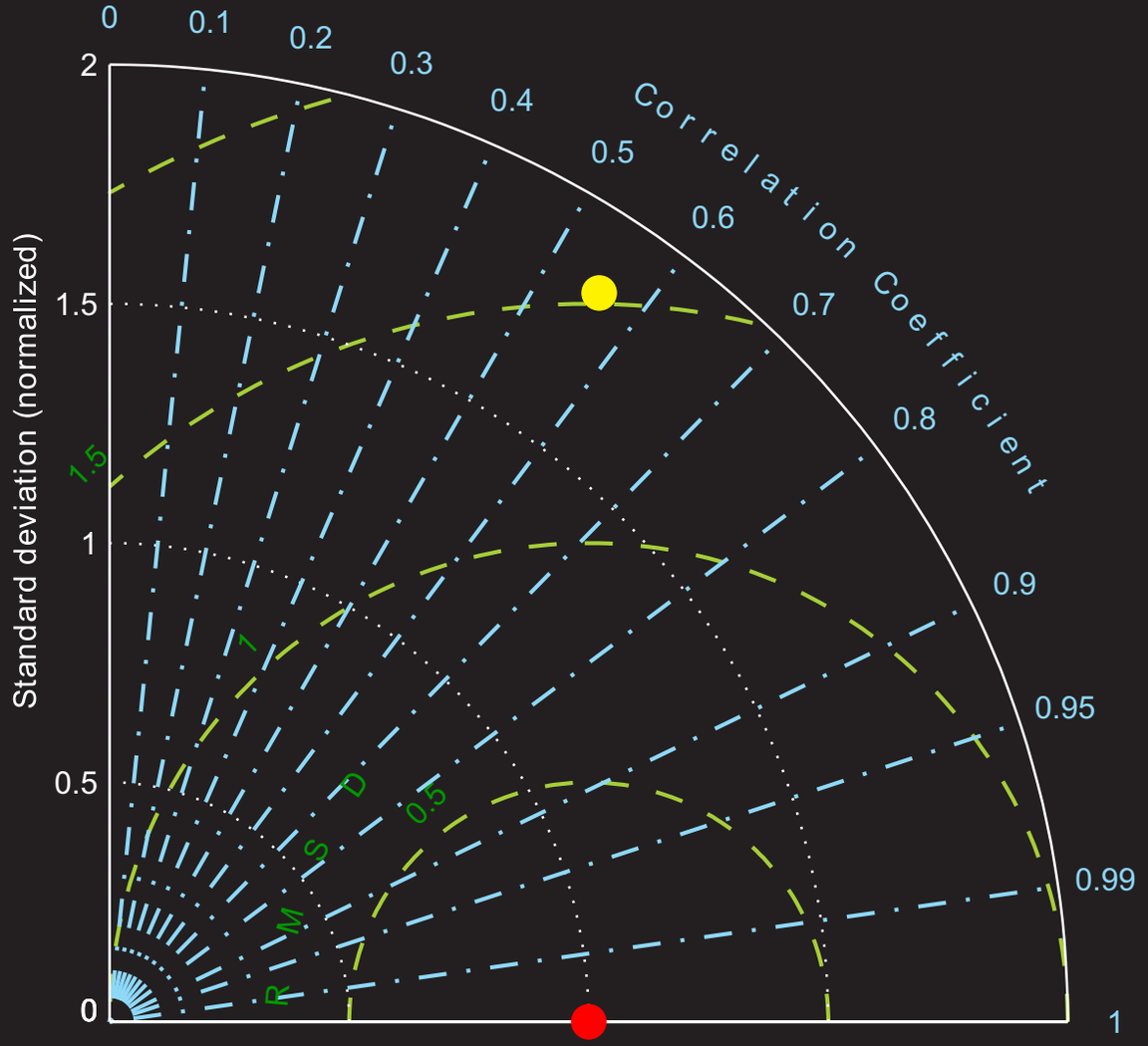
Models and past ocean de-oxygenation

Andy Ridgwell



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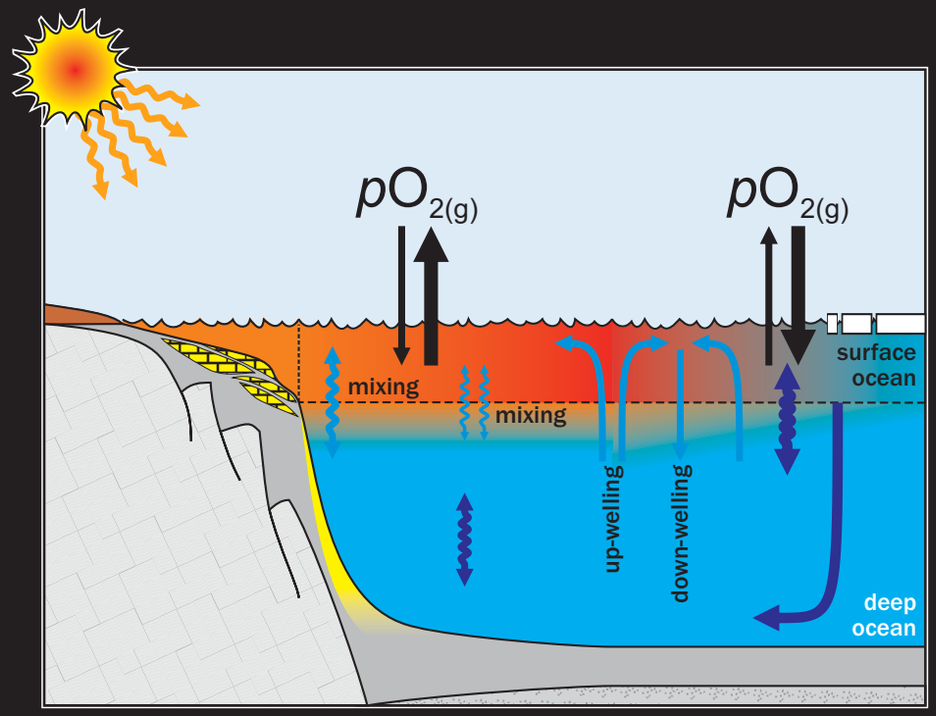
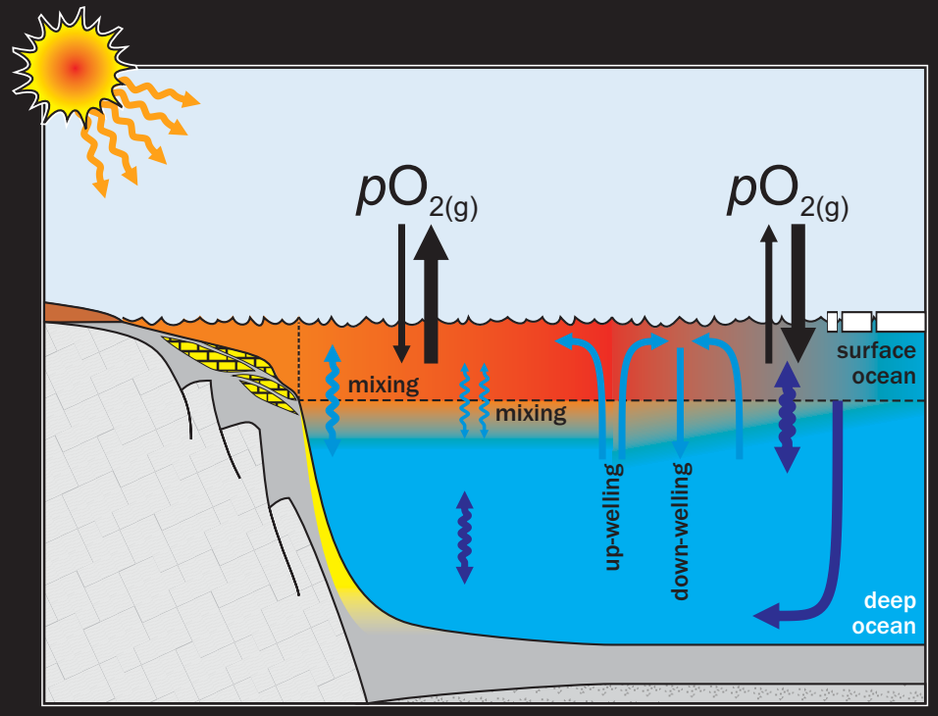
Controls on ocean oxygenation:

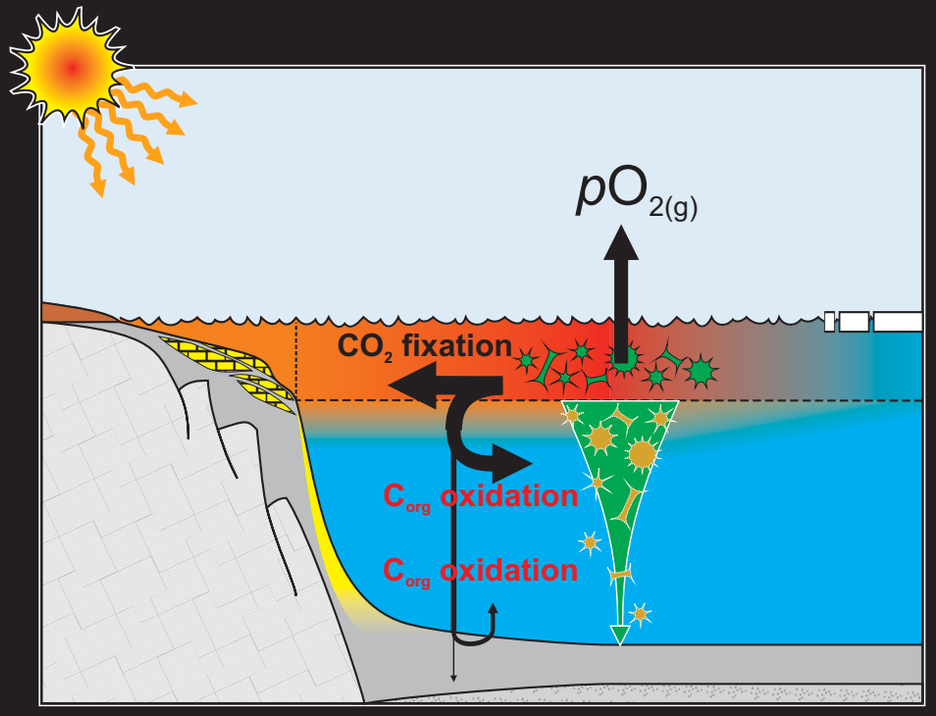
1. Ocean circulation and climate



Controls on ocean oxygenation:

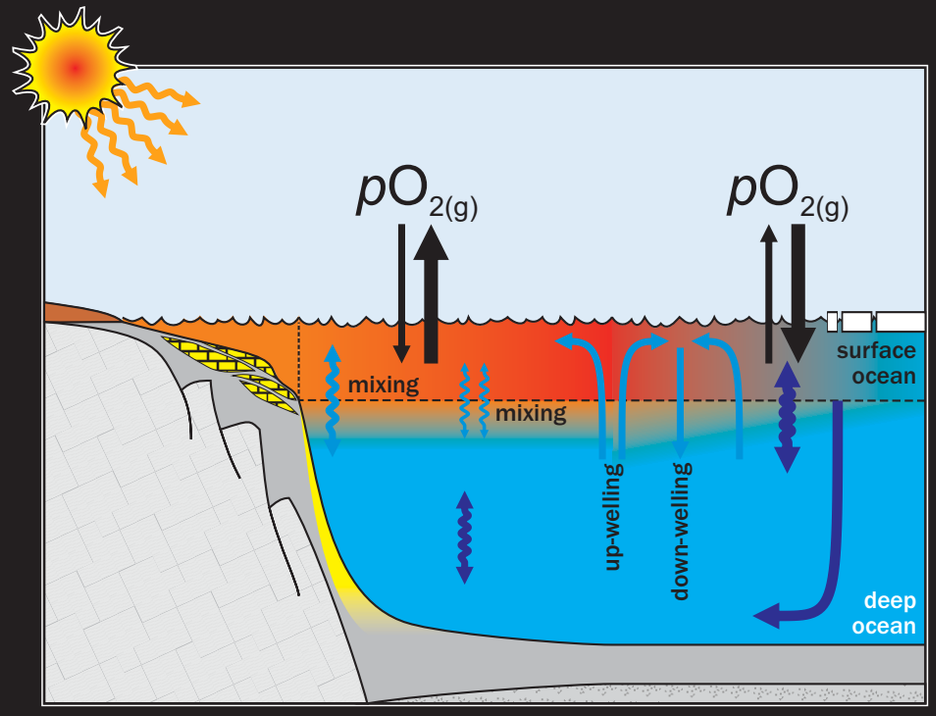
1. Ocean circulation and climate
2. Organic carbon degradation

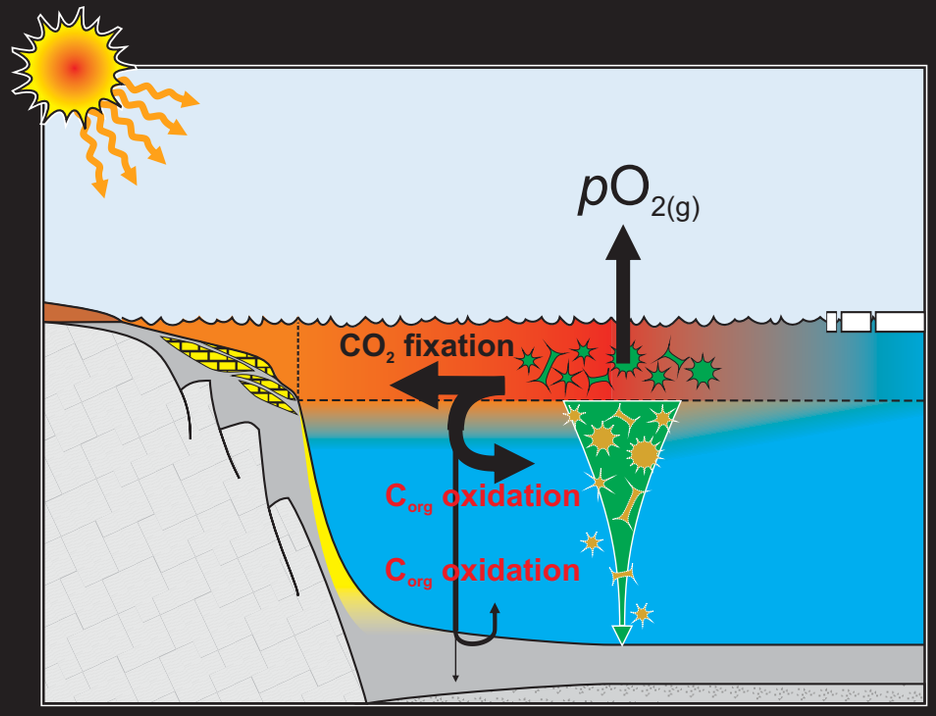




Controls on ocean oxygenation:

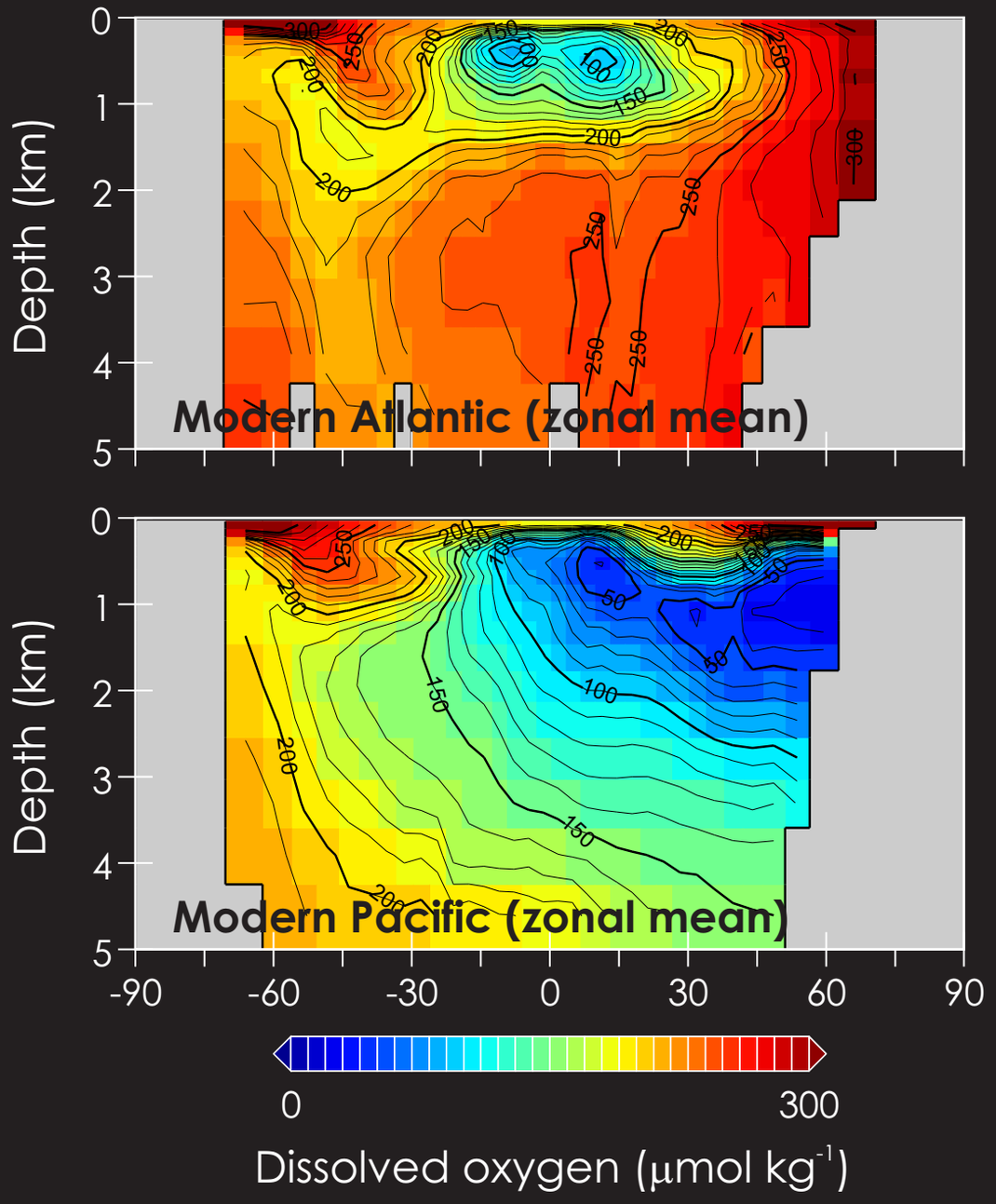
1. Ocean circulation and climate
2. Organic carbon degradation
3. Oxidation of reduced species





Controls on ocean oxygenation:

Modern (and general Phanerozoic?) ocean



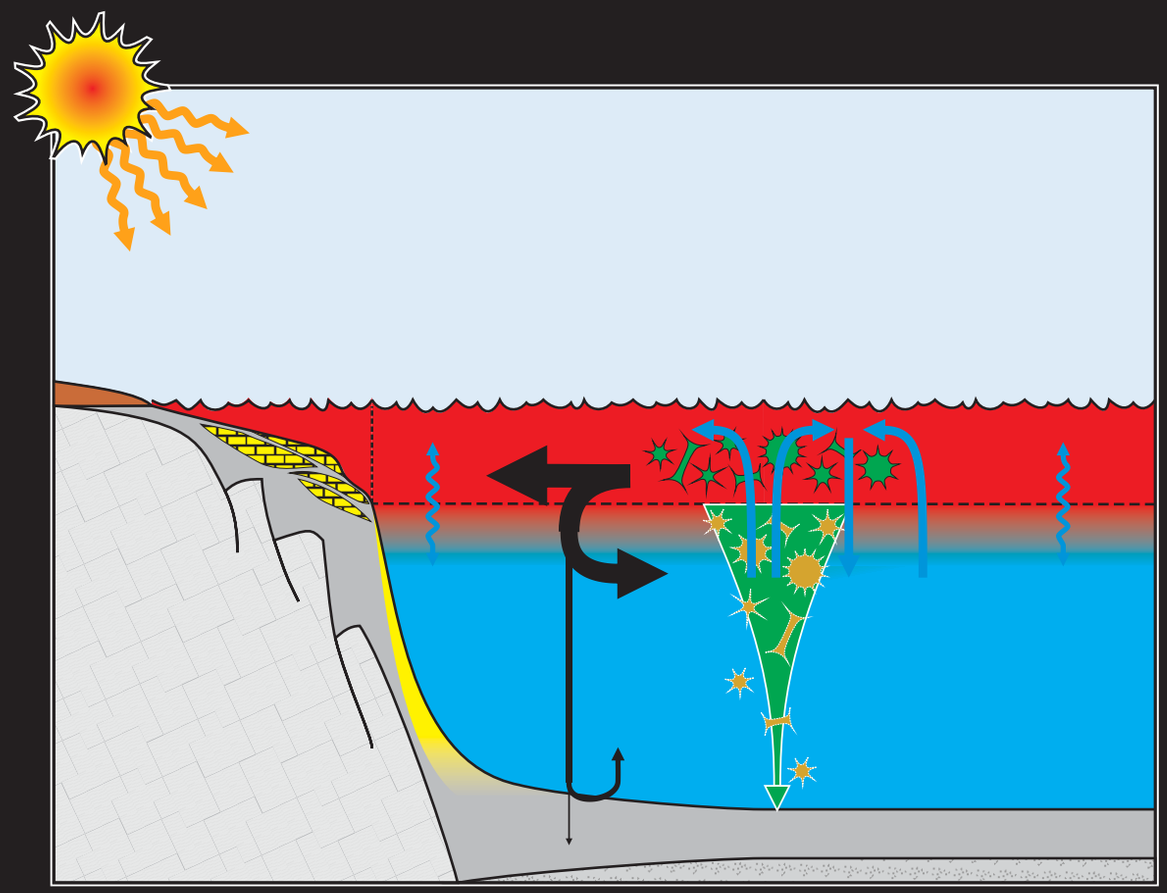
Modern observations, illustrating the combined controlling factors of ocean circulation in supplying O_2 (principally from the poles and to the abyssal ocean), and bacterial respiration of exported organic matter in consuming it (principally to intermediate depths).

Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate

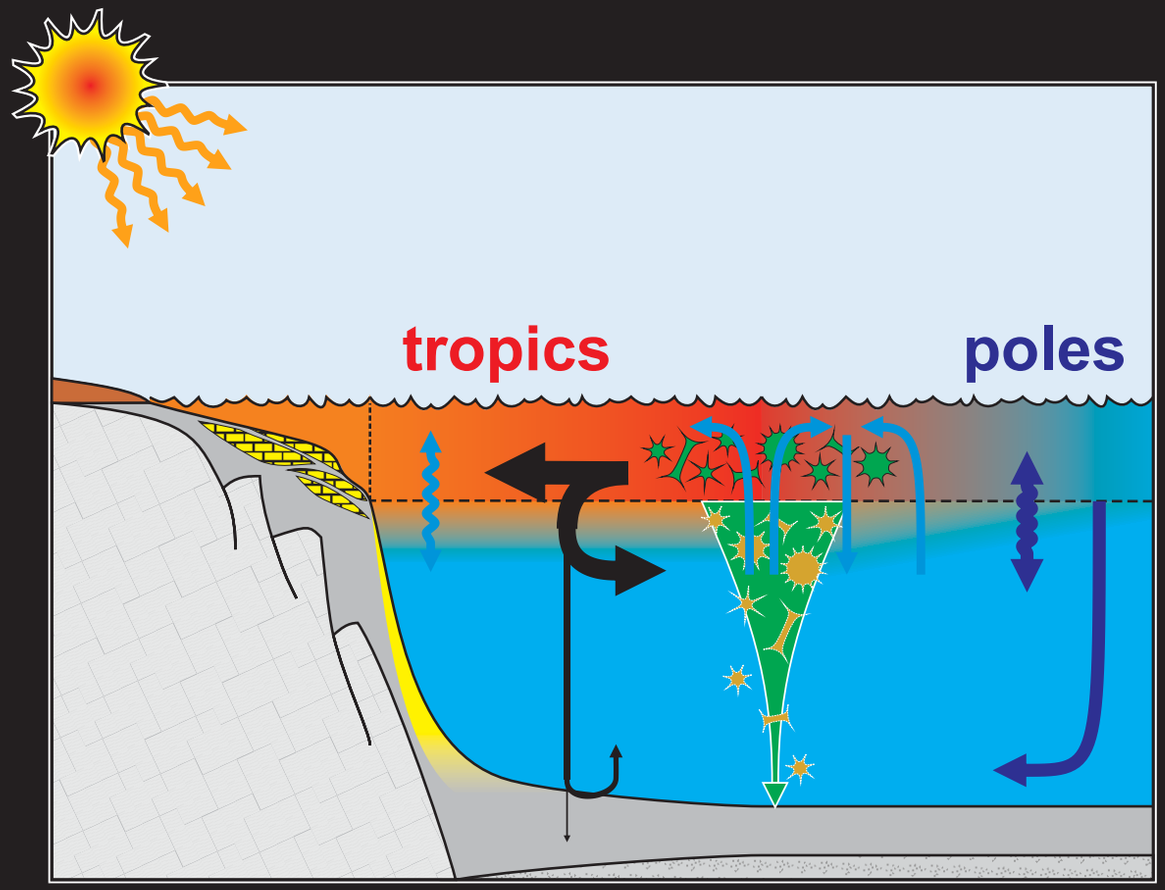
```
(warm == stratified) && (stratified == anoxic) == .true.
```

???

```
( 'stratified' || 'sluggish' || 'stagnant' )
```

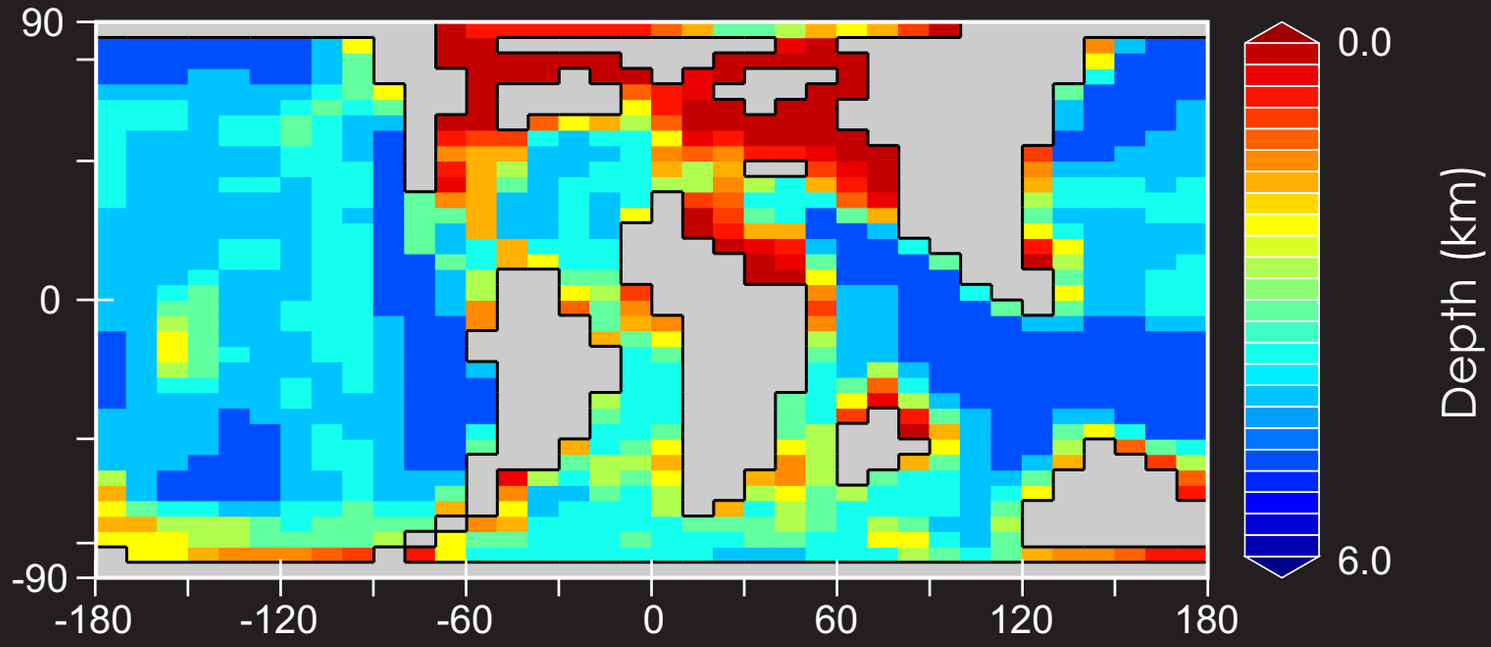


Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate



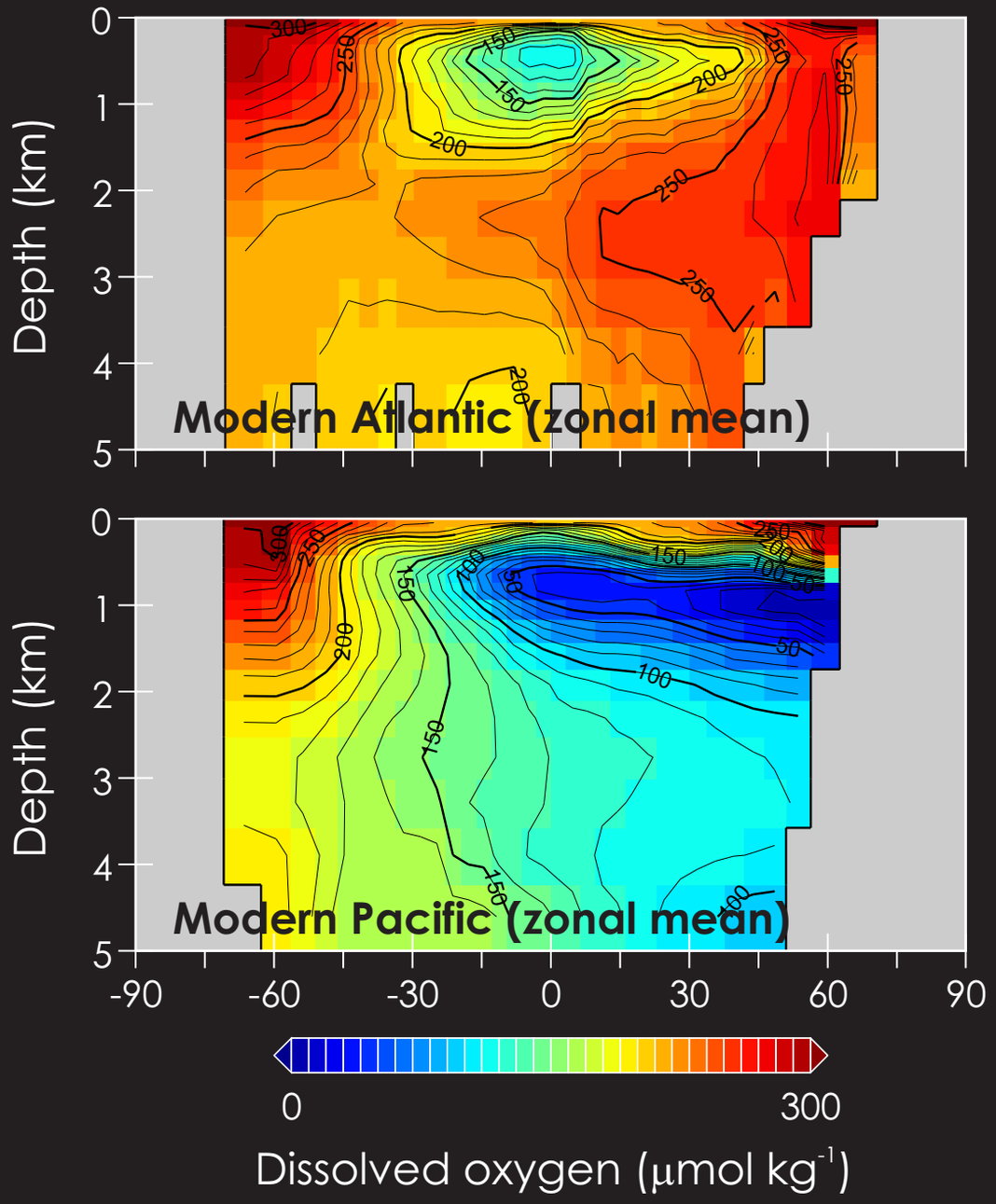
Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate

‘cGENIE’ Earth system model re-grided for the latest Maastrichtian following simulations from the HadCM3L fully-coupled GCM.



Controls on ocean oxygenation:

Modern (and general Phanerozoic?) ocean



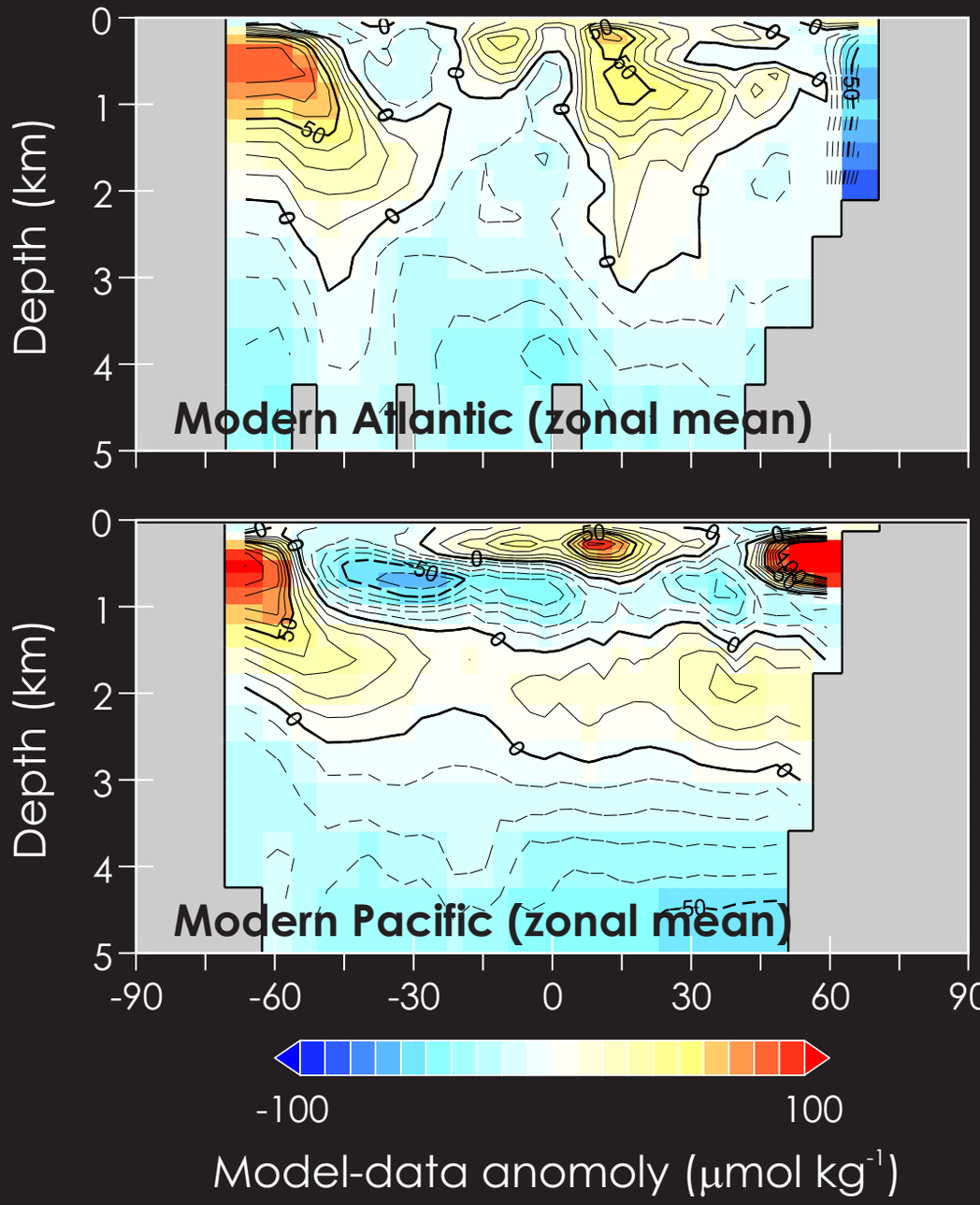
Same ocean zonal means … now in model world.

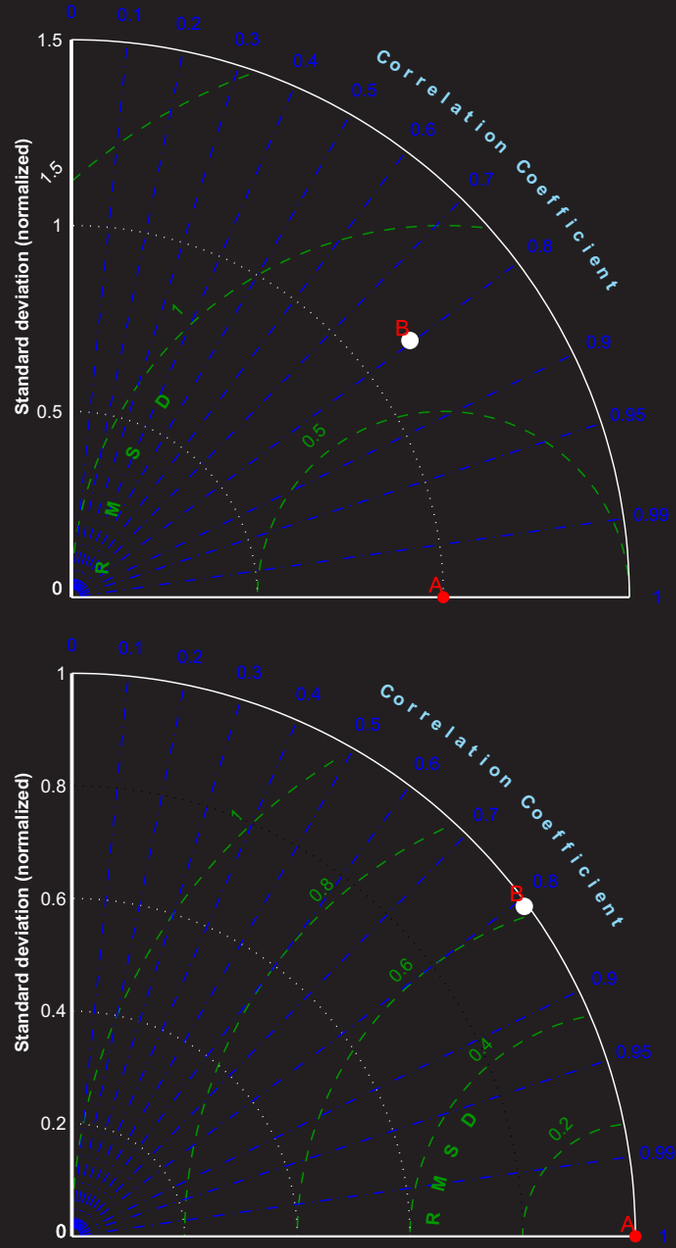
Are the main features ‘well reproduced’?

(What even are the ‘main features’?)

Controls on ocean oxygenation:

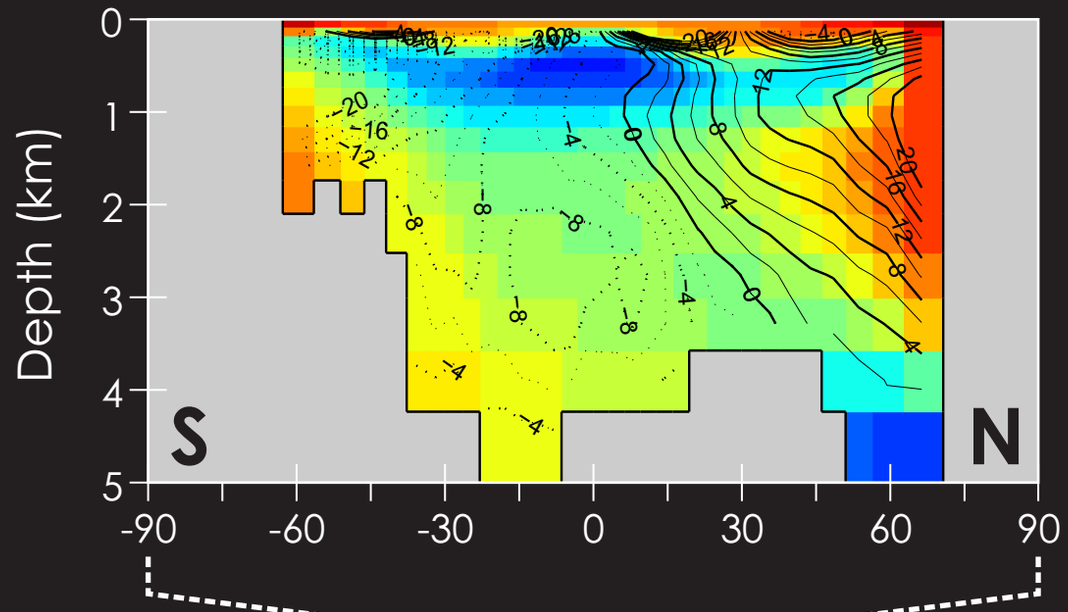
Modern (and general Phanerozoic?) ocean





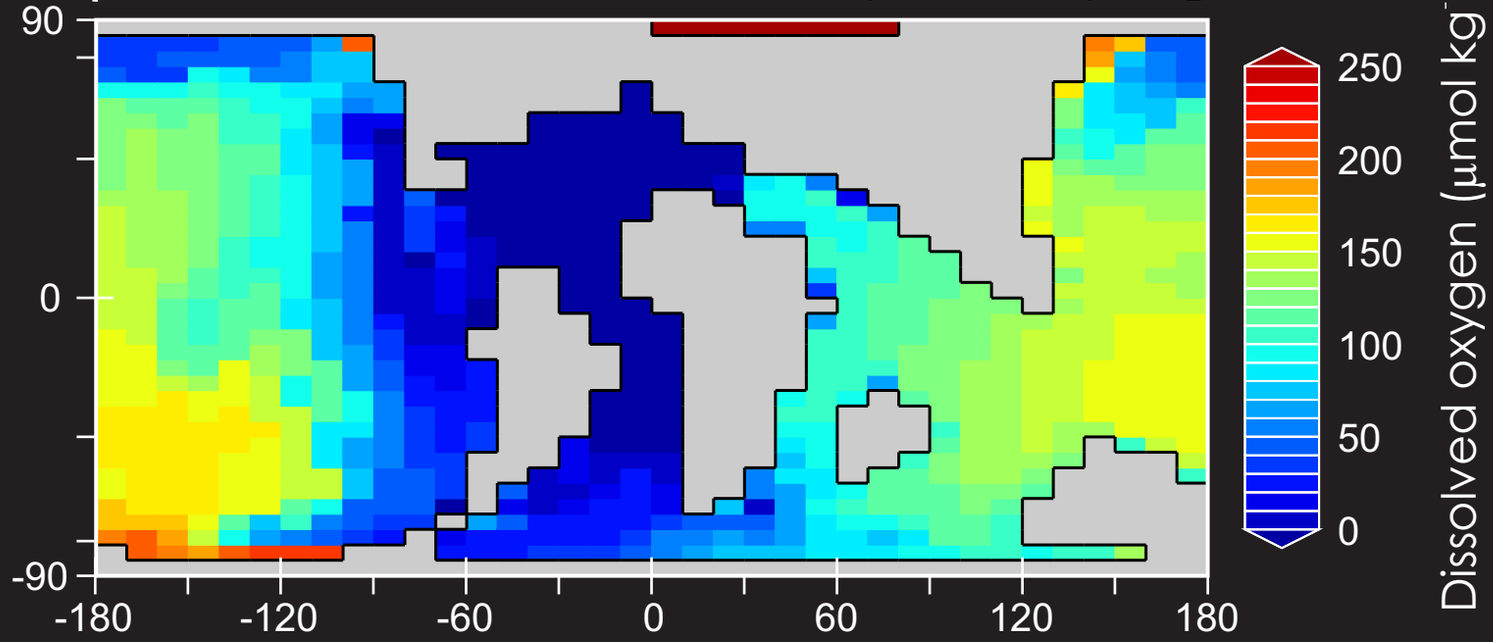
Model-data assessments can be made statistically by e.g., 'Taylor diagrams'

Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate

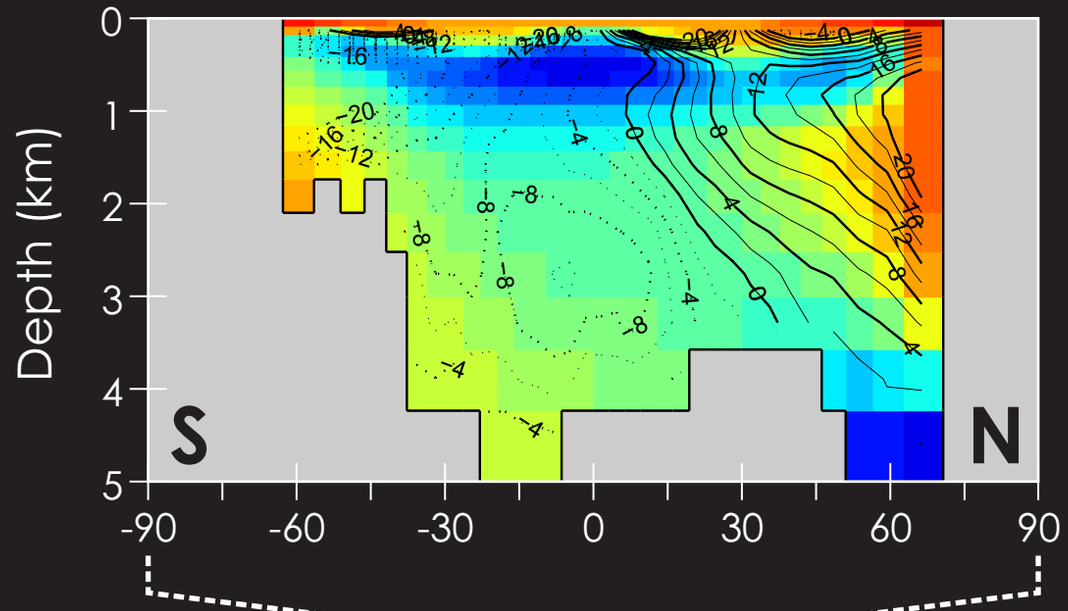


x4 CO_2 reference simulation

Benthic (>1000m) [O_2]

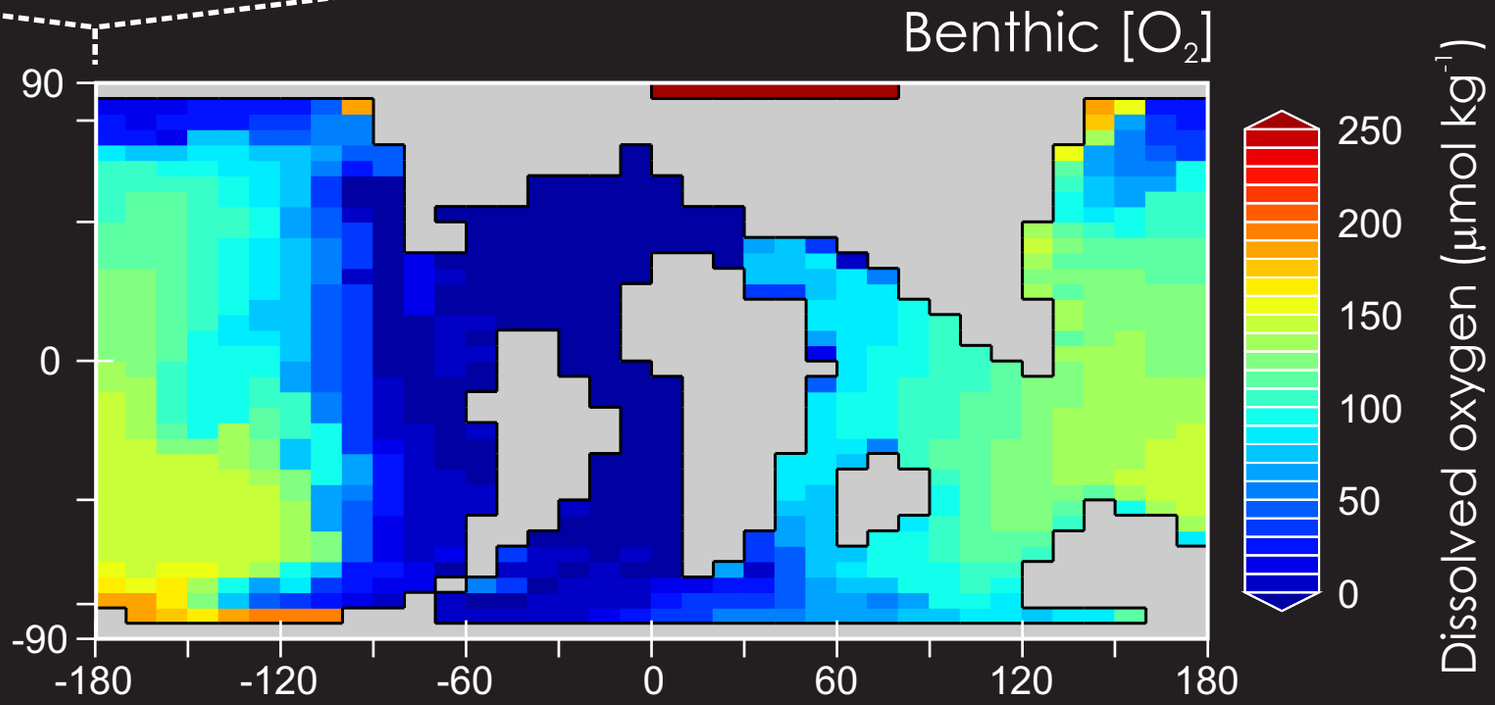


Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate

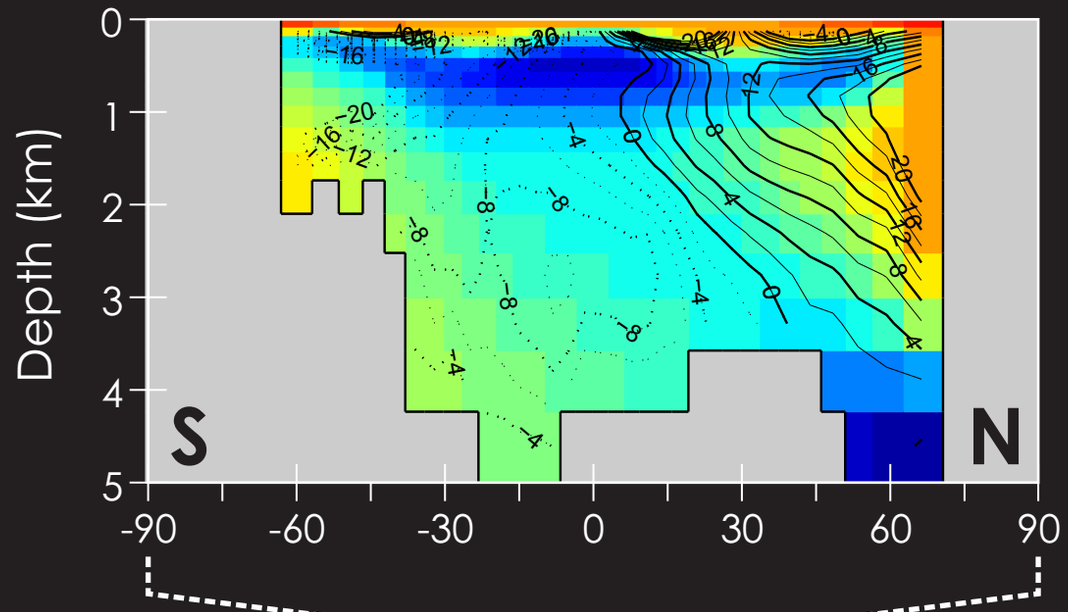


x8 CO_2 @ 10,000 yrs

(started from end of the x4 simulation)

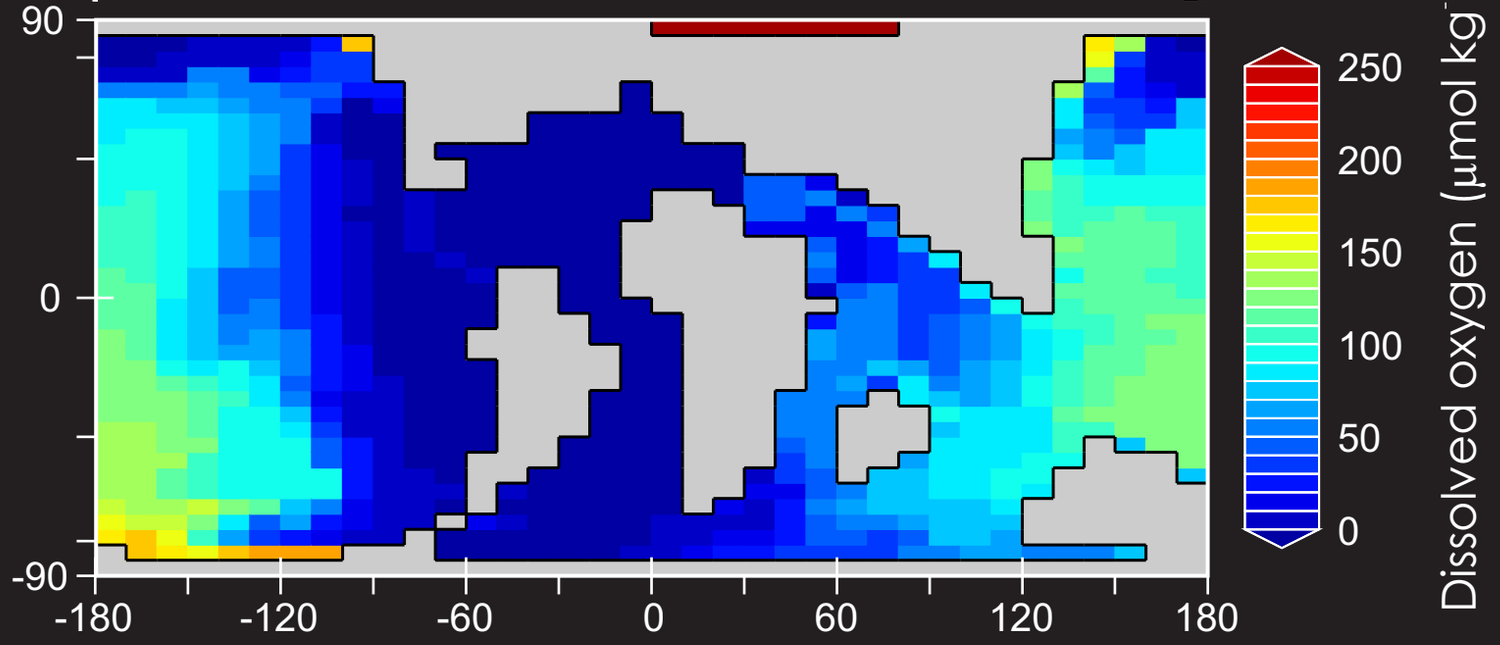


Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate

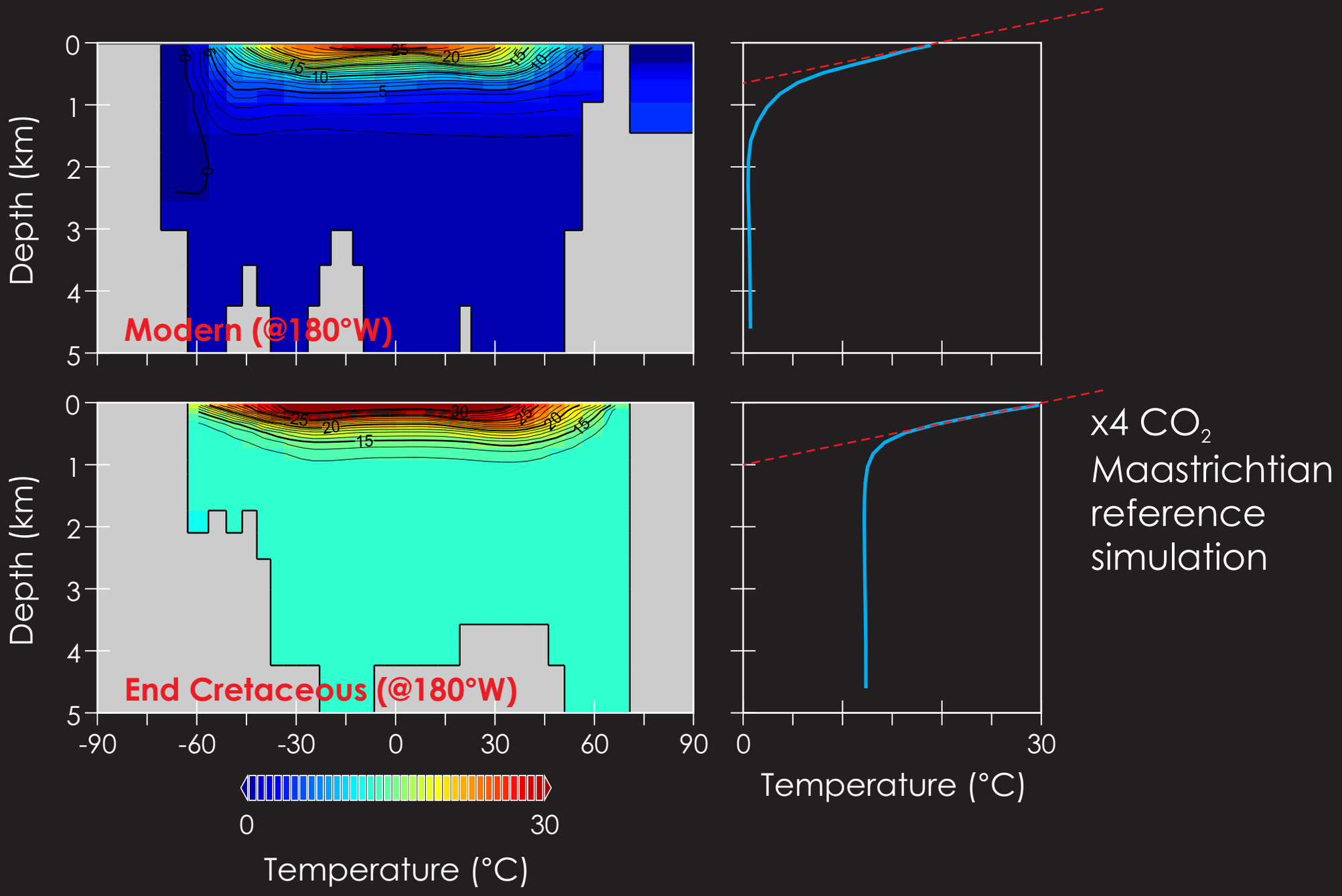


x16 CO_2 @ 10,000 yrs

(started from end of the x4 simulation)

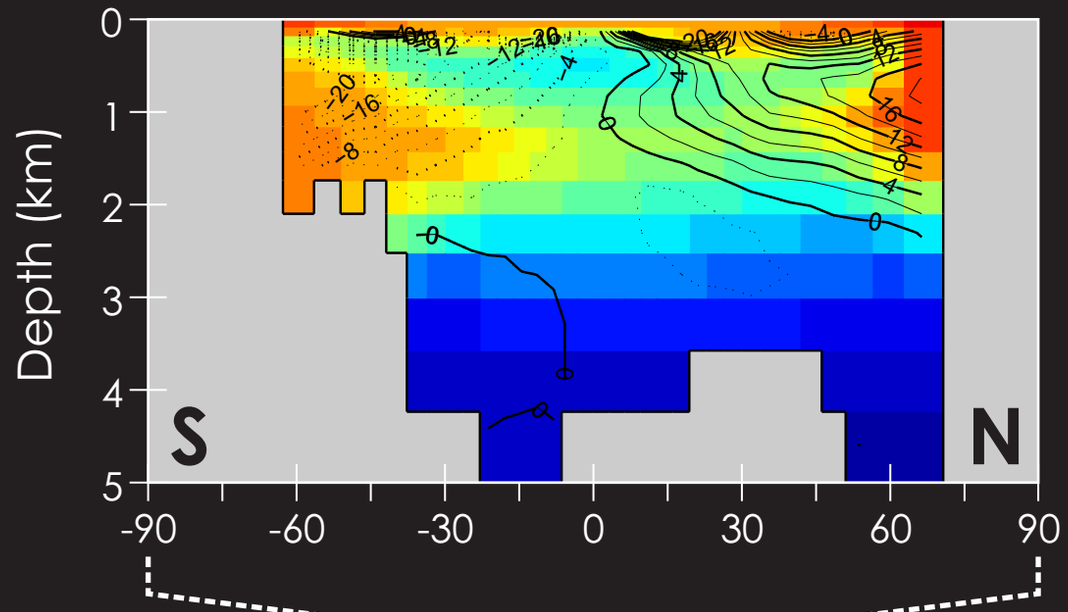


Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate



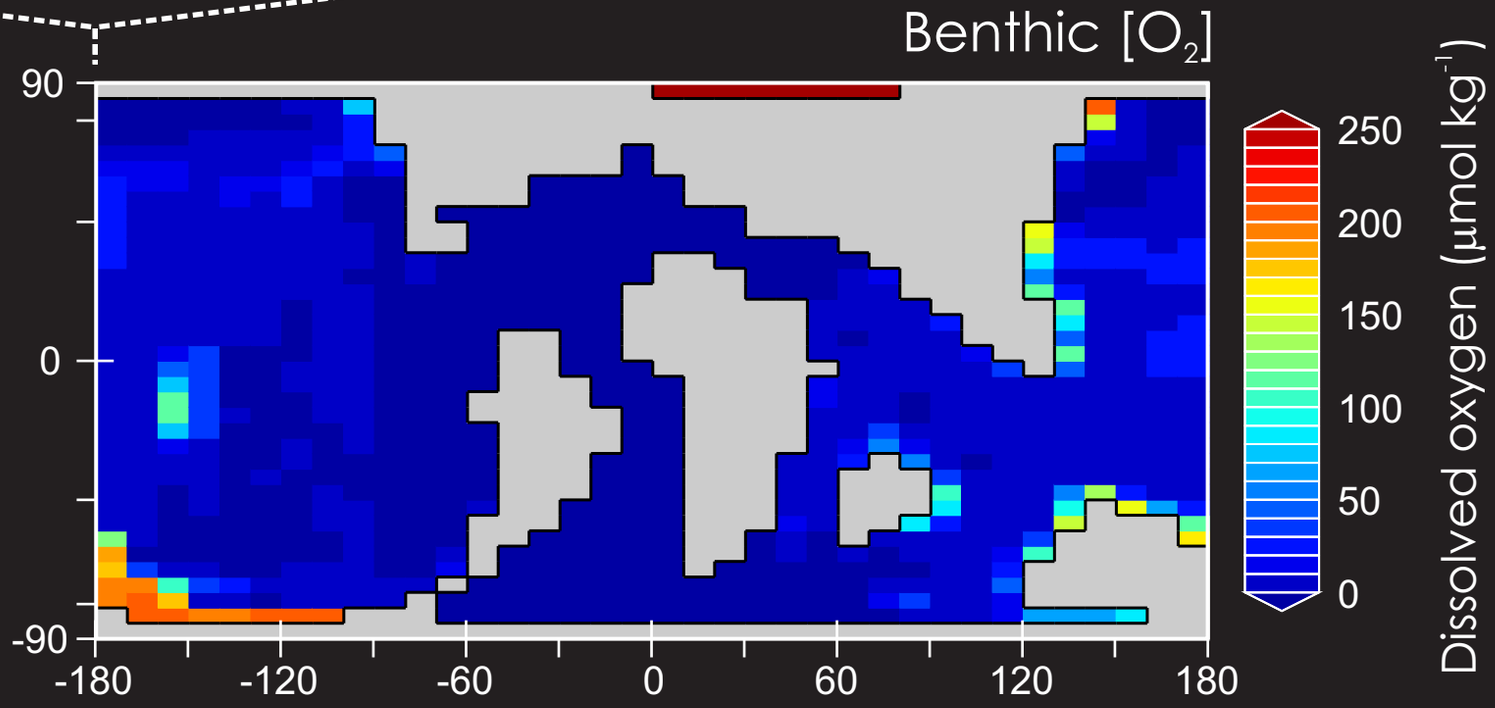
x4 CO_2
Maastrichtian
reference
simulation

Controls on ocean oxygenation revisited:
Ocean circulation in a warm climate

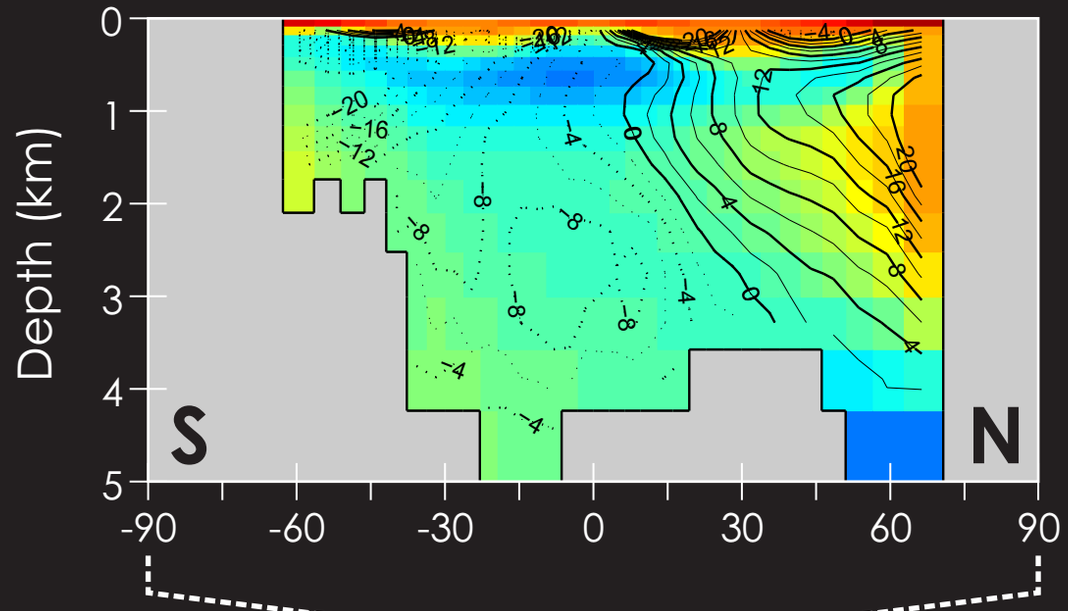


x16 CO_2 @ 2,000 yrs

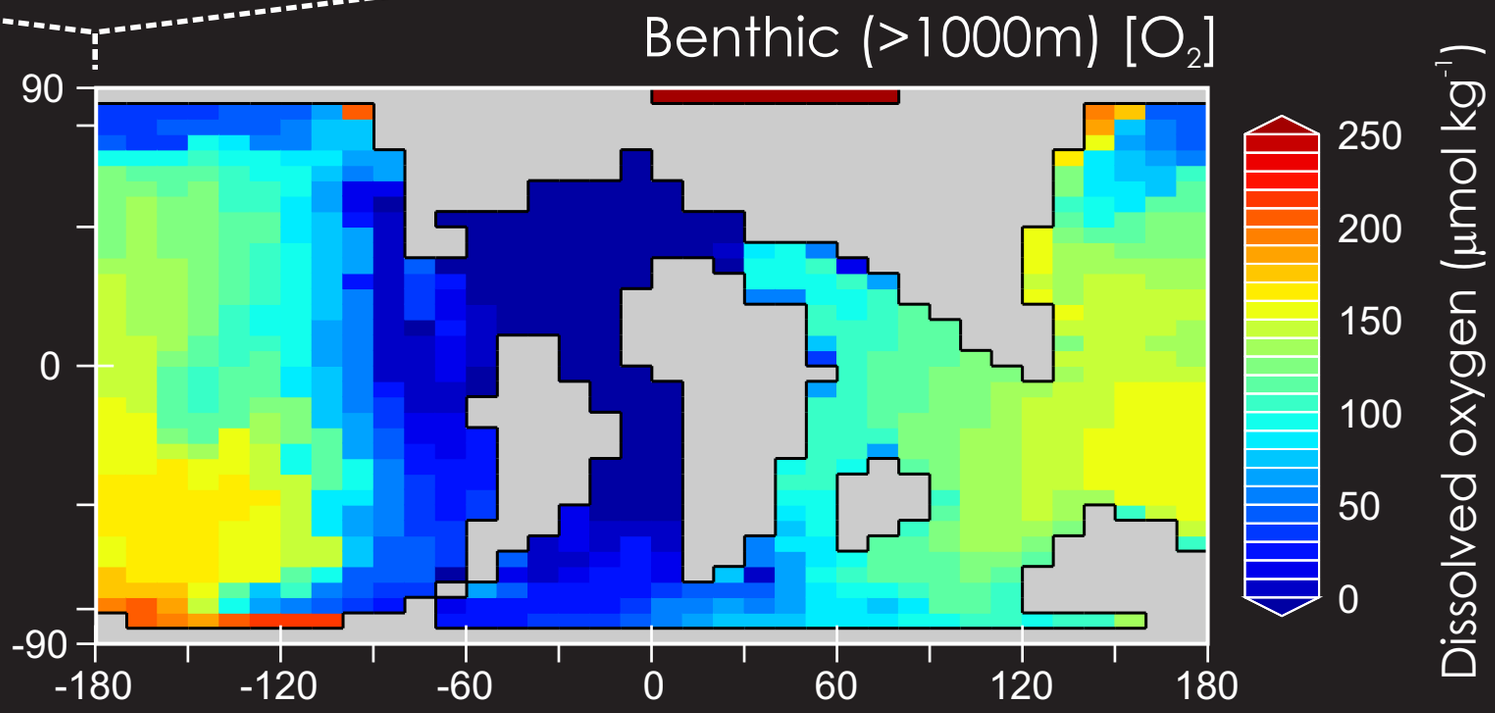
transient state
(incomplete adjustment to
increased radiative forcing)



Controls on ocean oxygenation revisited:
Constraining circulation

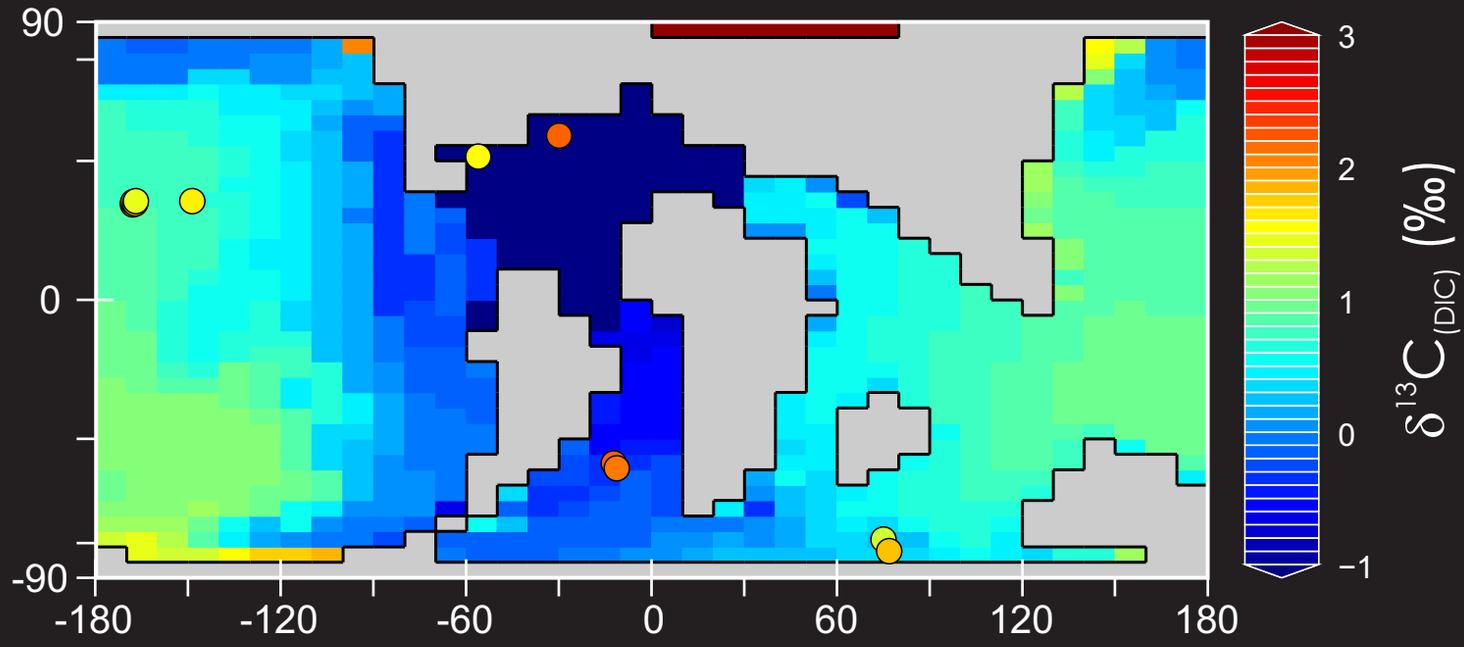


x4 CO_2 reference simulation;
latest Maastrichtian

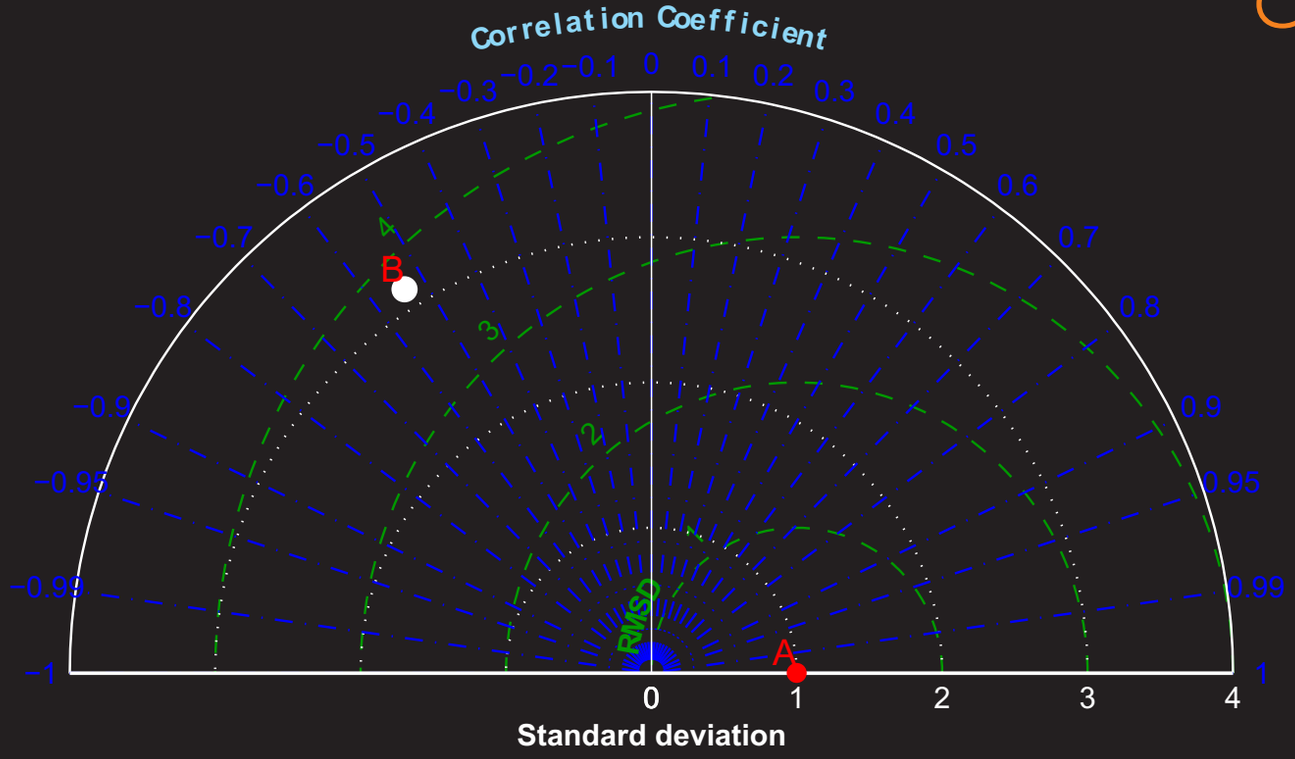


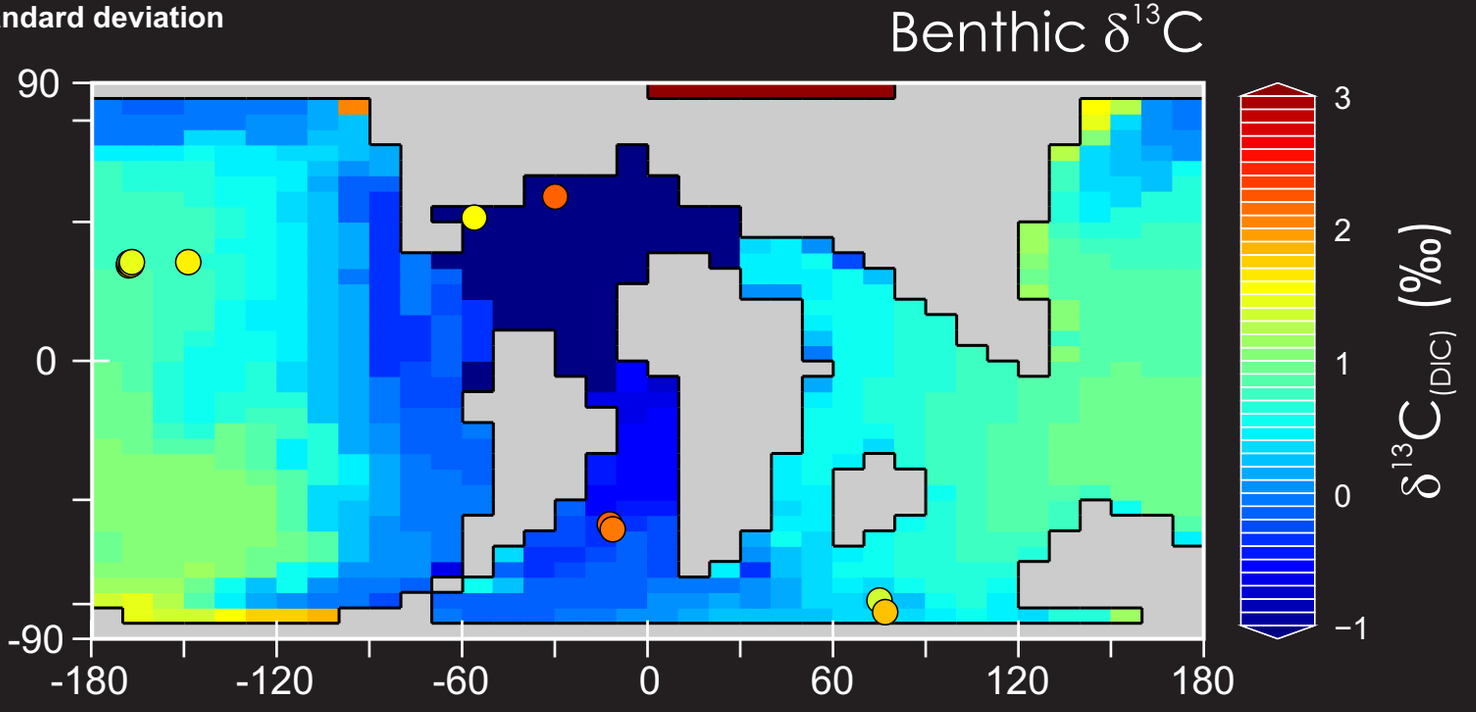
Controls on ocean oxygenation revisited:
Constraining circulation

Model bottom-water $\delta^{13}C$ with benthic foraminiferal $\delta^{13}C$ overlain (Cramer '09)

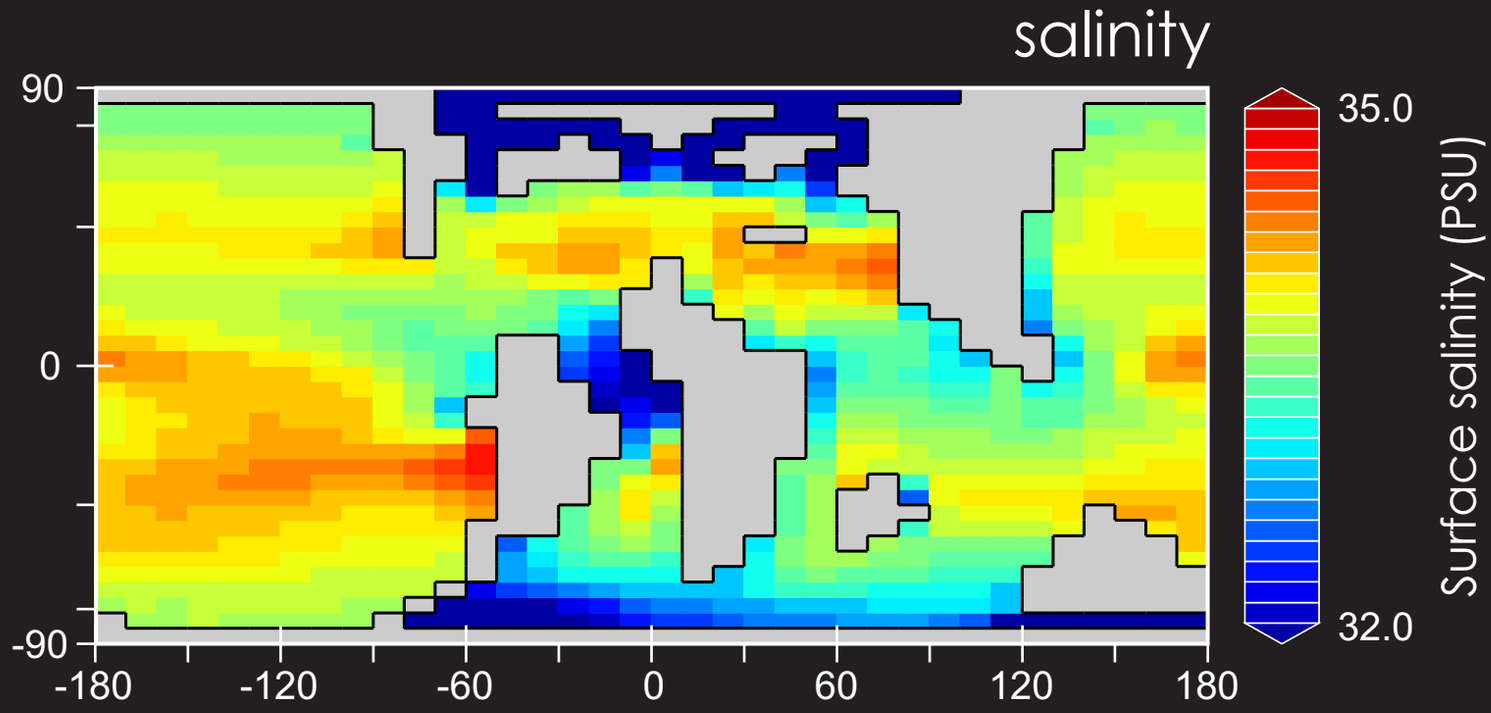


Controls on ocean oxygenation revisited:
Constraining circulation

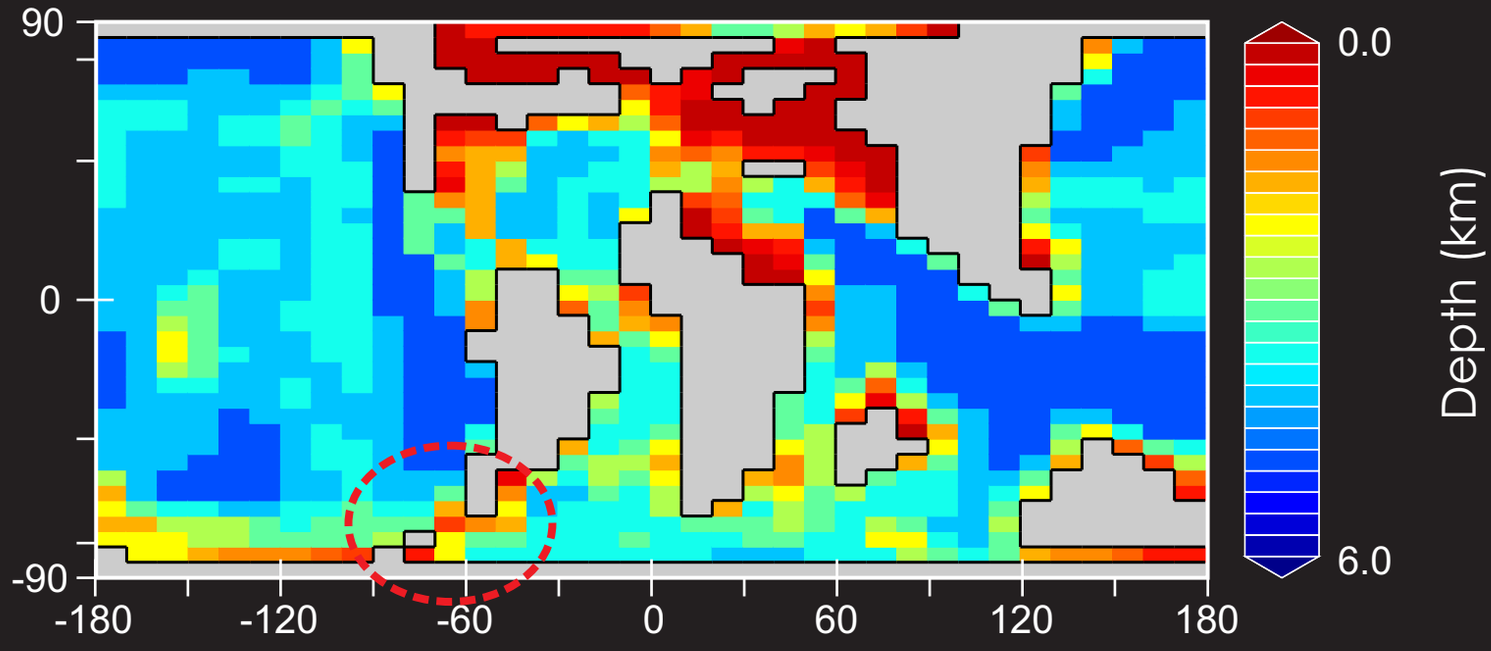




Controls on ocean oxygenation revisited:
Constraining circulation

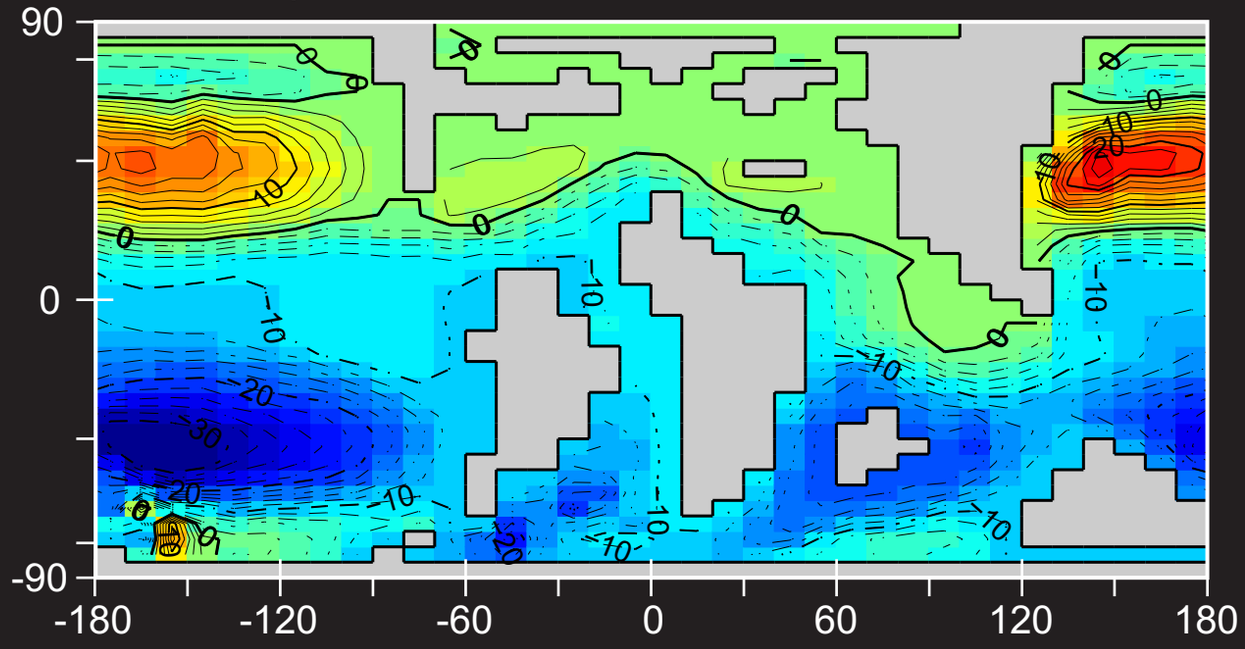


Controls on ocean oxygenation revisited:
Constraining circulation

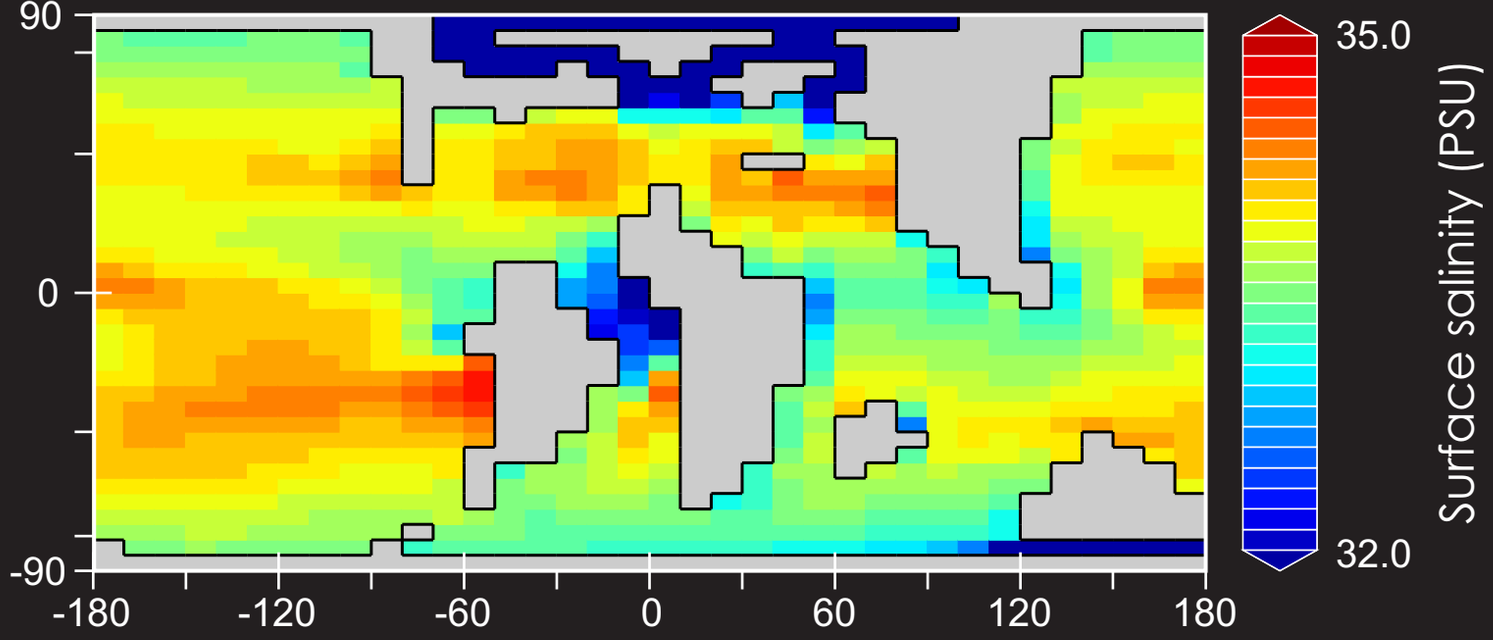


Controls on ocean oxygenation revisited:
Constraining circulation

Barotropic streamfunction



salinity



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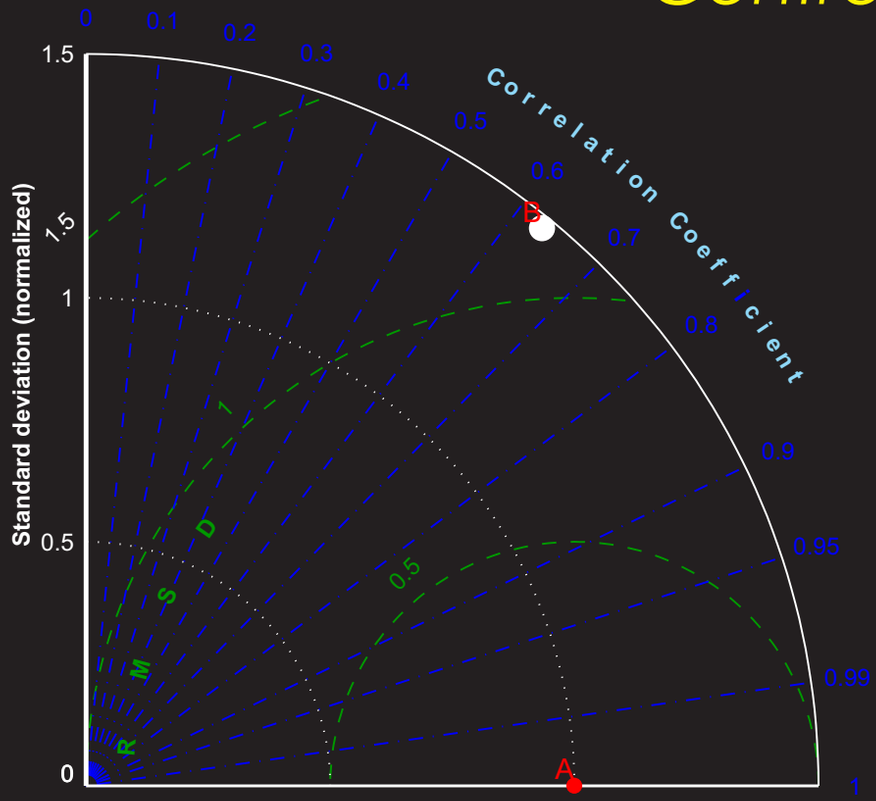
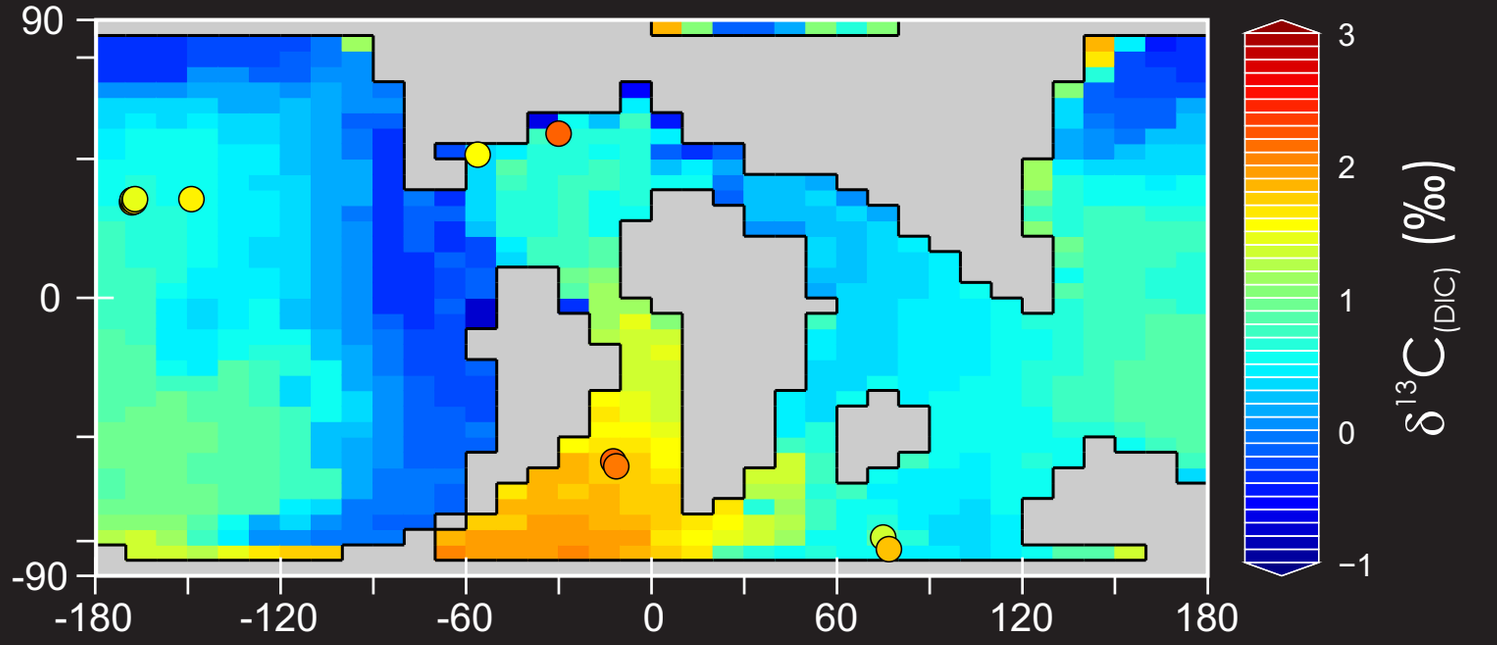
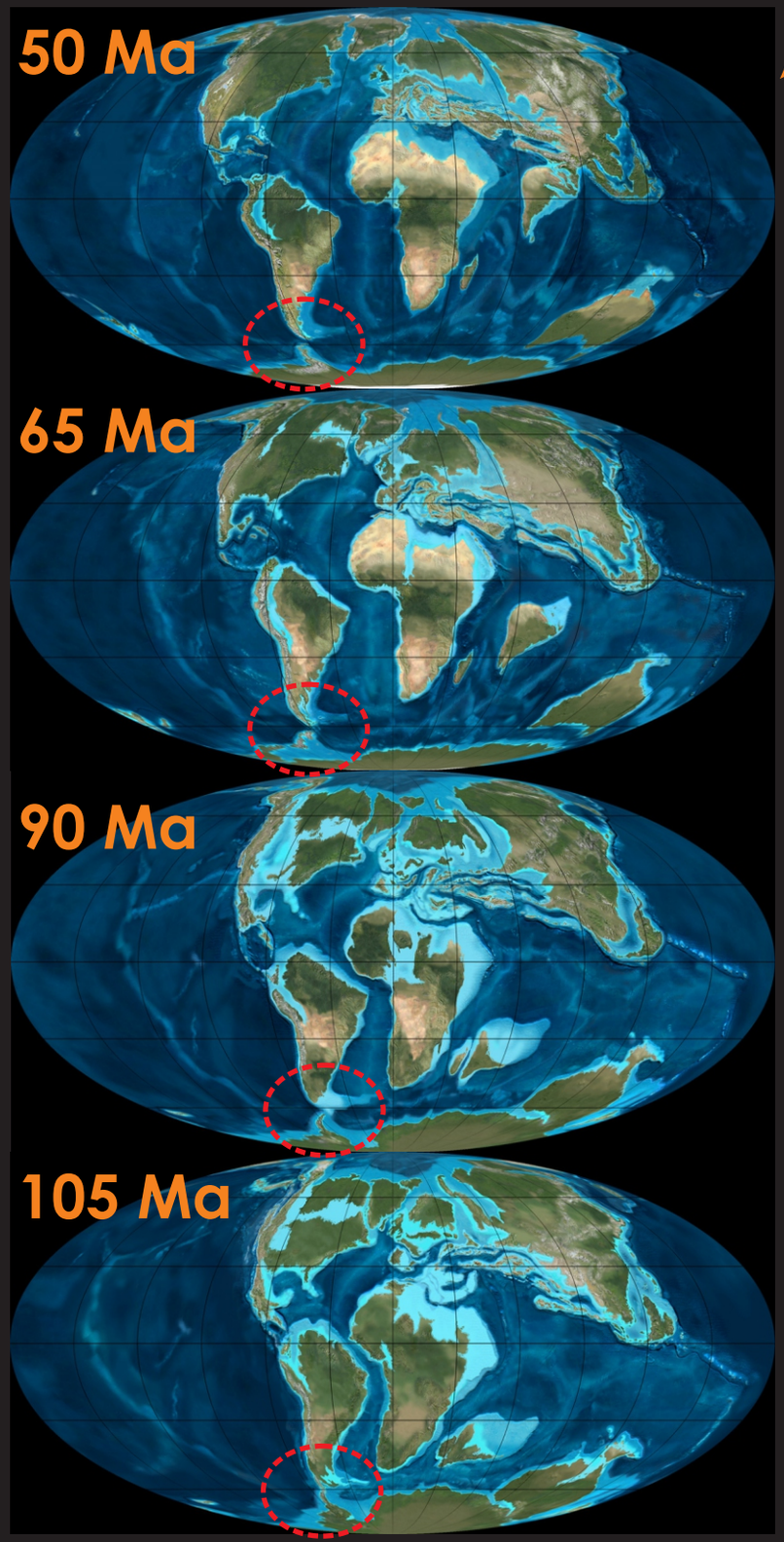
Constraining circulation







Controls on ocean oxygenation revisited: Tectonics and ocean gateways

Changing degrees of connectivity between the SE Pacific and SW Atlantic from the late Jurassic until the full 'opening' of the Drake Passage could have controlled (in combination with climate and local runoff) deep-water production in the S. Atlantic.

From ca. mid Cretaceous times, S. Atlantic sourced deepwater might have helped ventilate the N. Atlantic.

Think of the S. Atlantic and tectonic relationship in the same way as 'shallow time' N. Atlantic AMOC and the Panamanian gateway(?)

FROM: http://cpgeosystems.com/mollglobe.html

Conclusions/perspectives:

Deep-sea benthic $\delta^{13}C$ (post Jurassic age questions) gradients to constrain the pathway of oxygenation (taking with additional constraints on ocean circulation from e.g. Nd).

Statistical tests in assessing model vs. data (and importance of adequate model spin-up).

General importance of a wide-ranging multi-proxy approach (David Naafs talk).

Changing ocean gateways in the South Atlantic as a possible pre-conditioner for ocean oxygenation sensitivity to climatic perturbation.

Go play with the model (after beer) ...

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