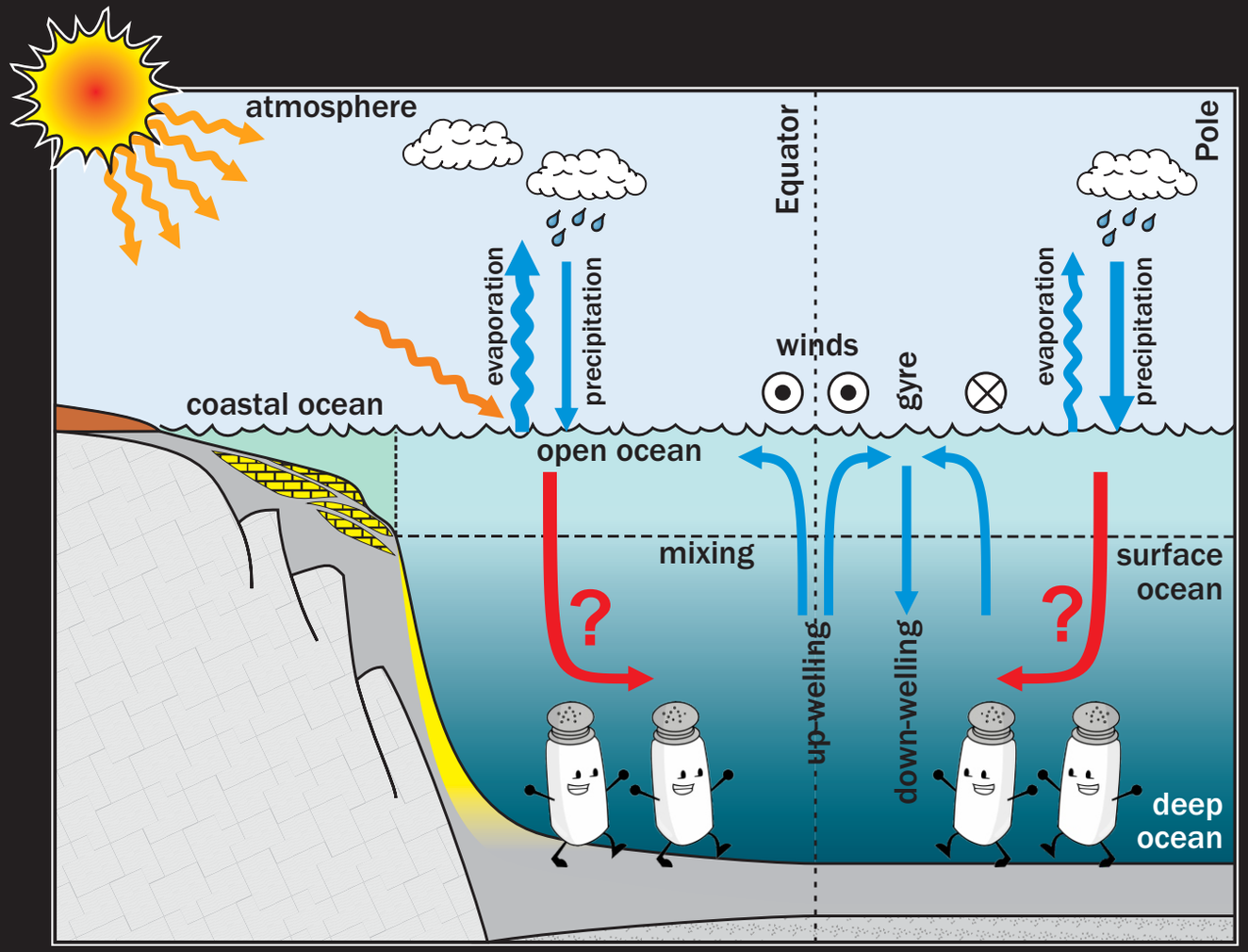
Tracing ocean Circulation – Past and Present

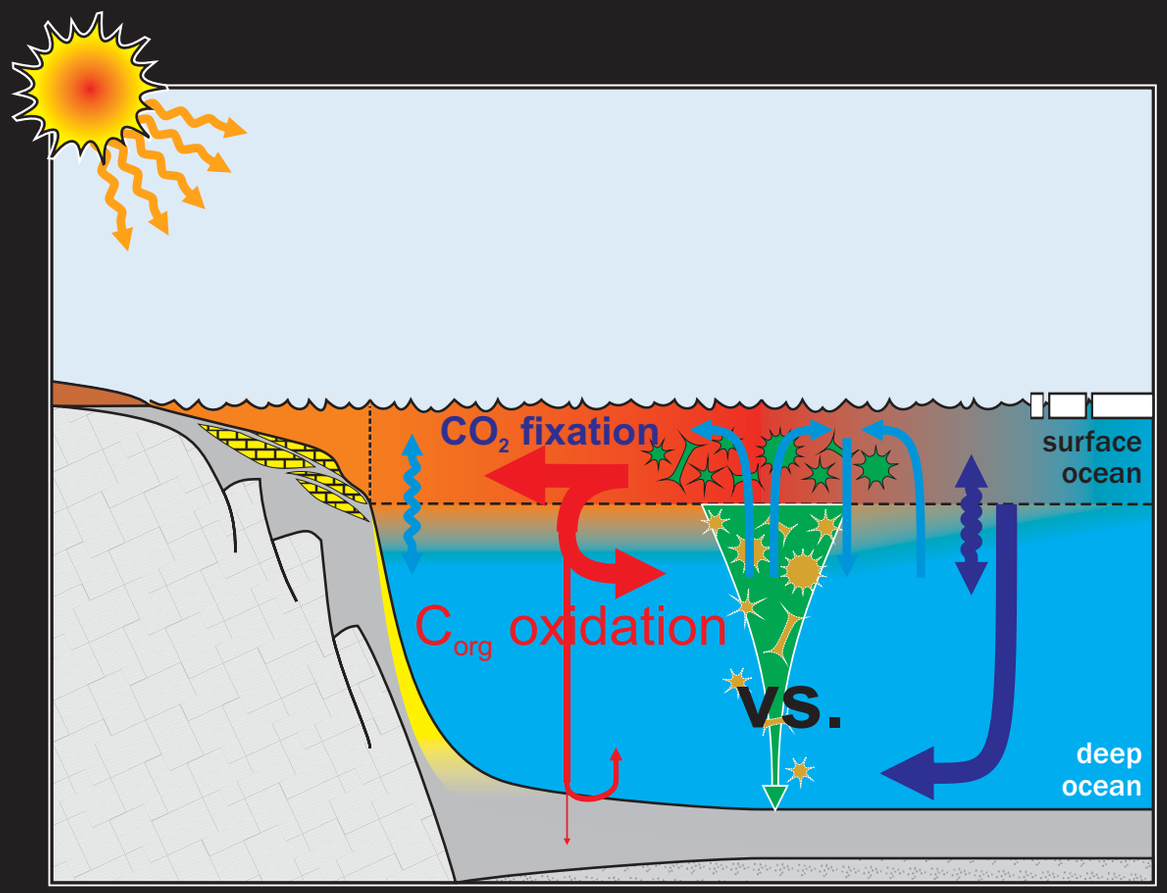
Hot, salty, bottom -waters in the past?

Andy Ridgwell

University of California – Riverside
University of Bristol



Introduction



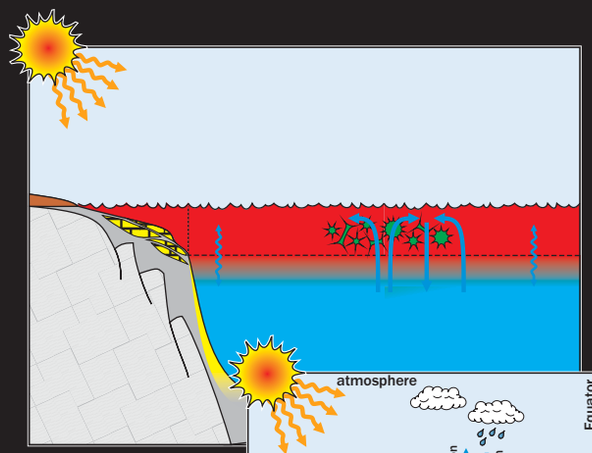
What controls the $[O_2]$ distribution in the ocean?

(1) The biological (soft tissue) pump and associated oxygen demand (with more minor contributions from dissolved organic matter and inputs of reduced species e.g. at hydrothermal vents).

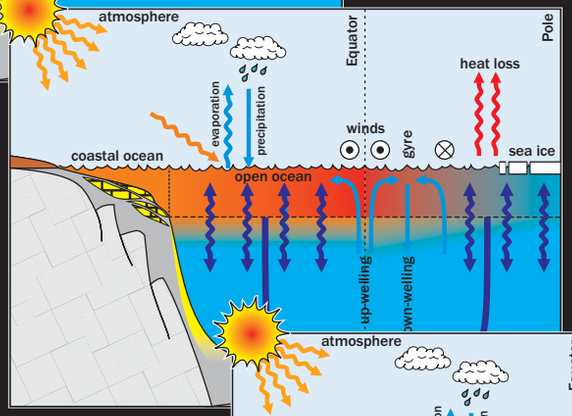
(2) Ocean circulation and the transport of $[O_2]$ in near equilibrium with the atmosphere, into the ocean interior.

(Although a circulation that strongly transport O_2 to depth most likely also returns nutrients to the surface.)

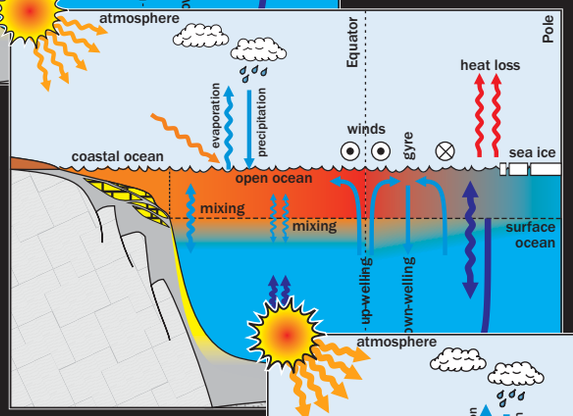
Introduction



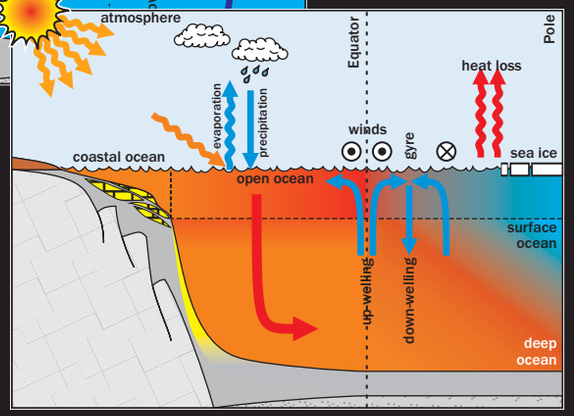
stagnant ocean
(no significant sources of deepwater)



‘completely mixed’ ocean
(large number of sources of deepwater spanning all latitudes)

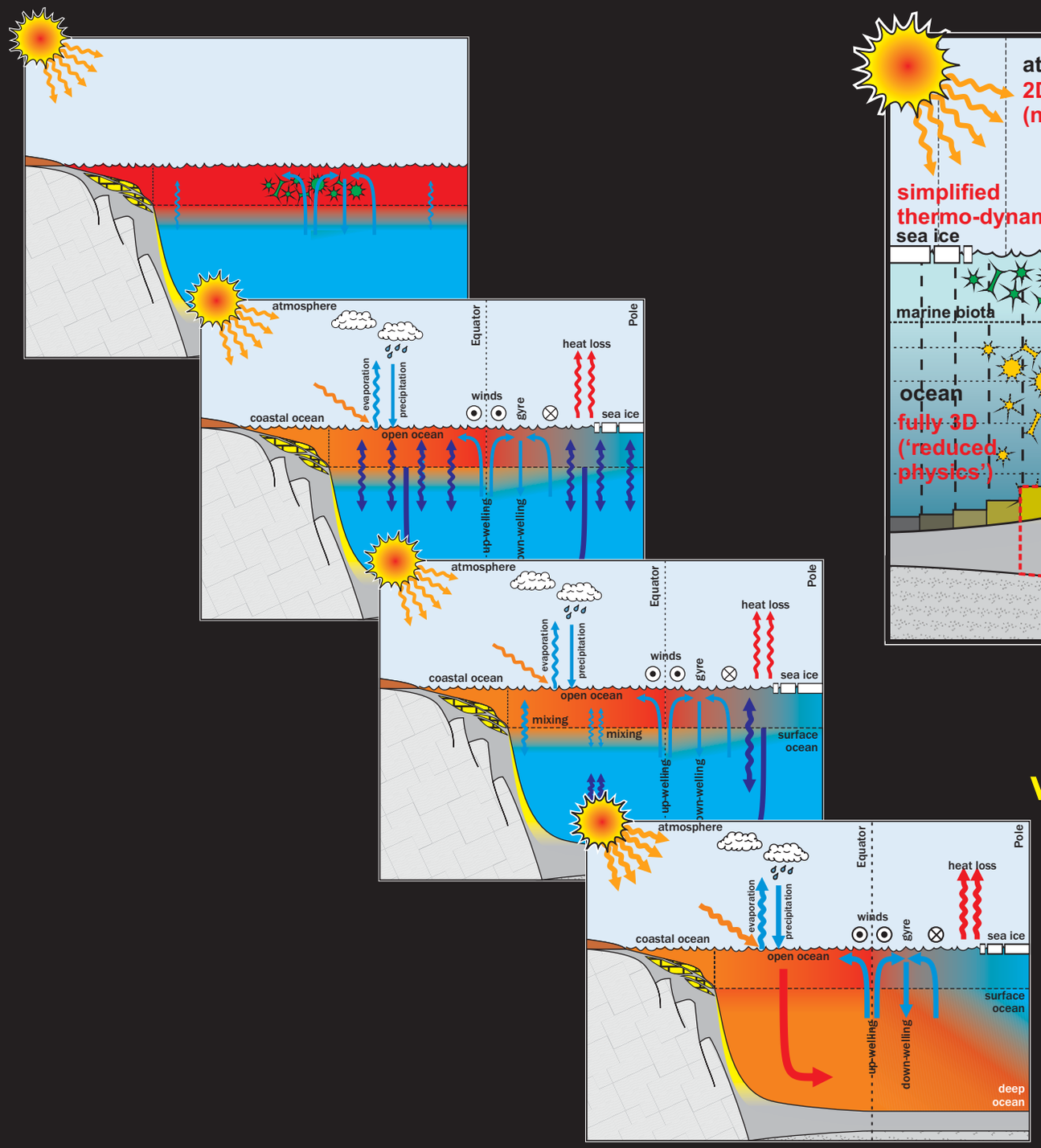


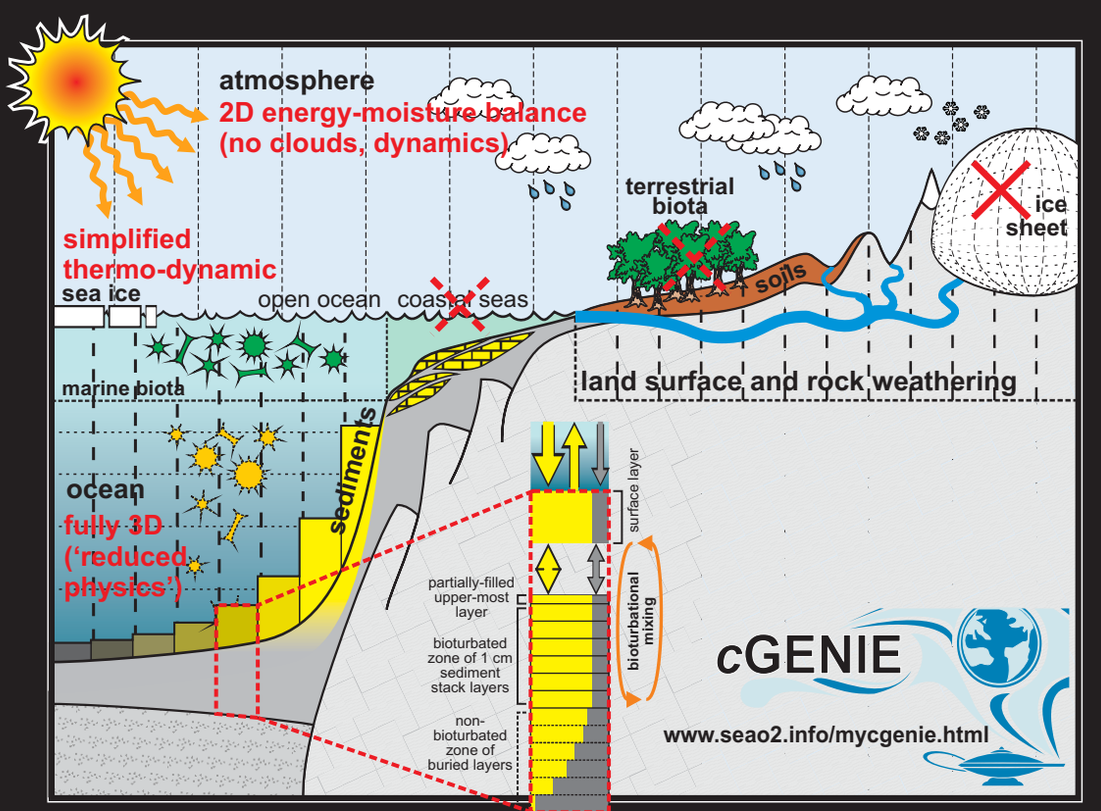
modern-like ocean
(deepwater formation dominated by high latitude sources)



‘Mediterranean on speed’
(deepwater formation at low latitudes)

Introduction



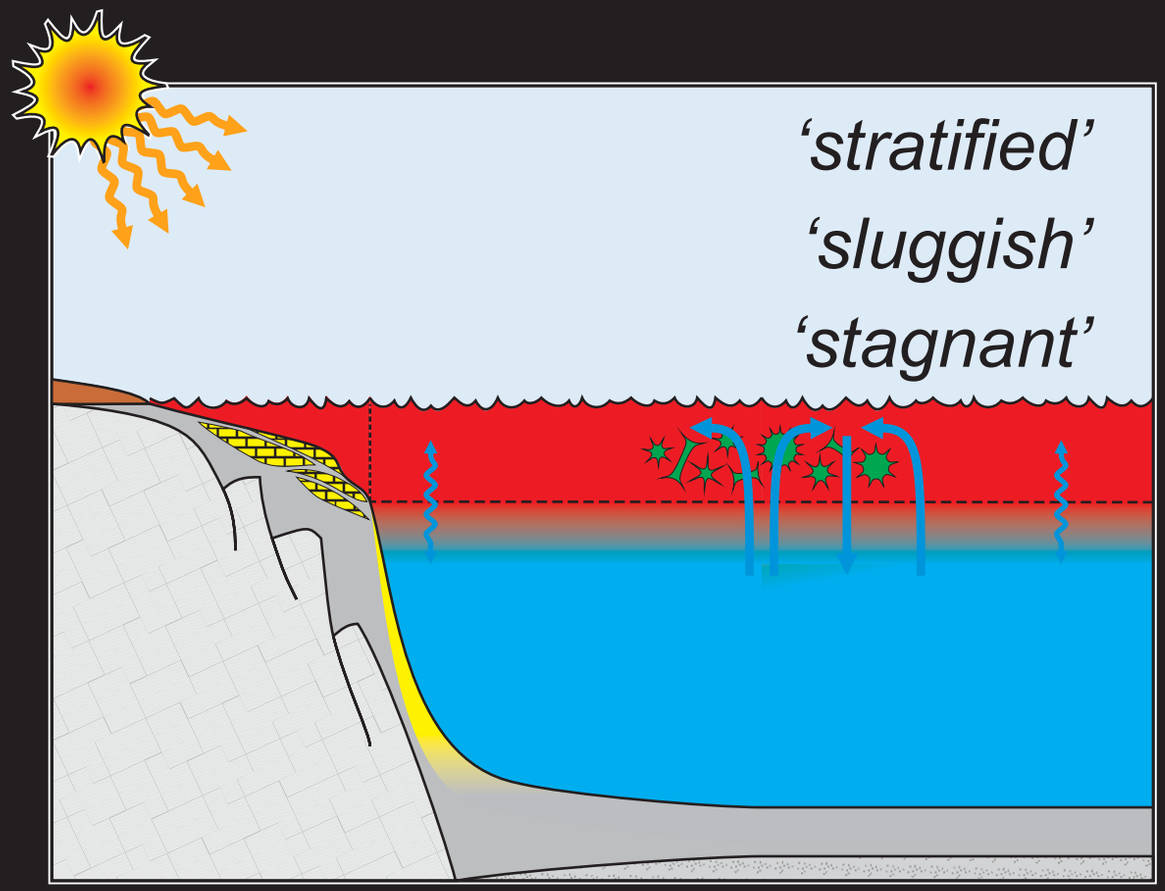


'cGENIE' Earth system model
('of Intermediate Complexity')

www.seao2.info/mycgenie.html

Circulation State I – no significant ventilation of the deep ocean

HOW?



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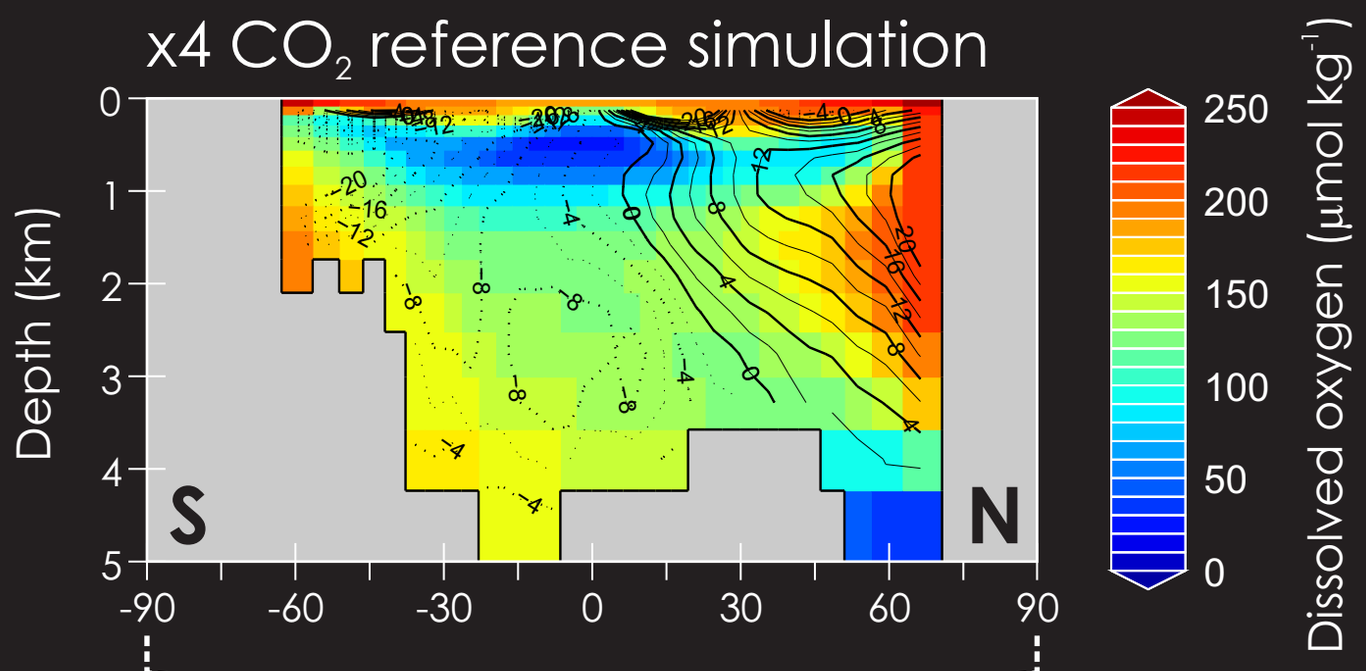

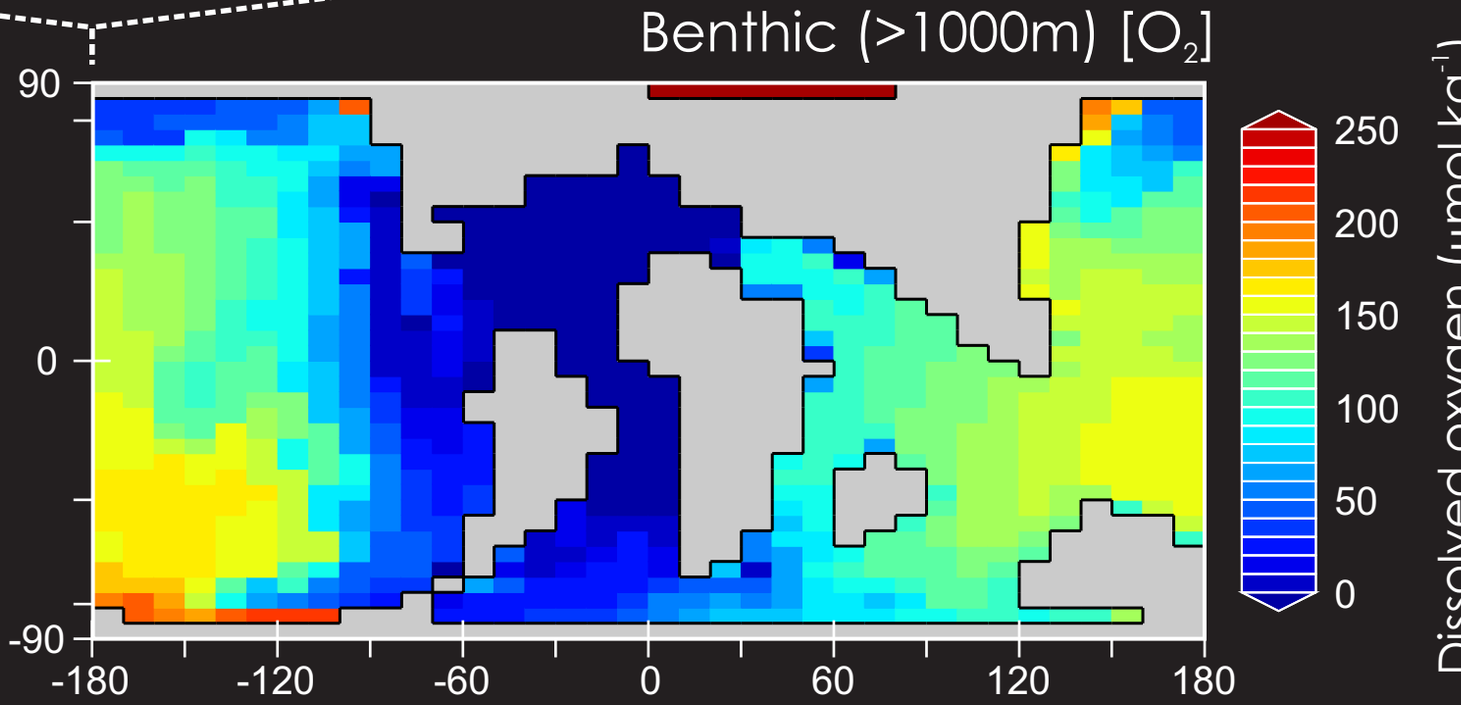

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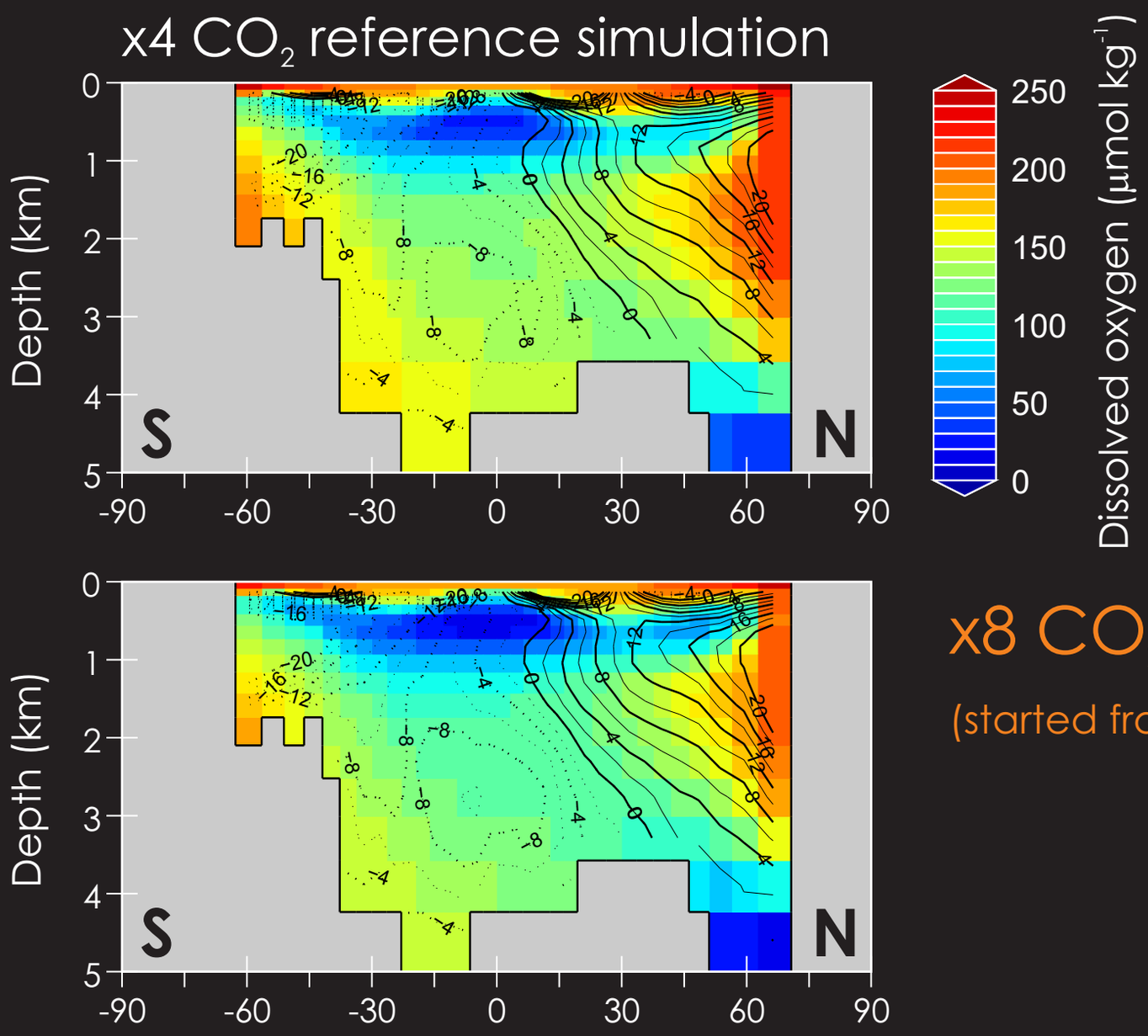
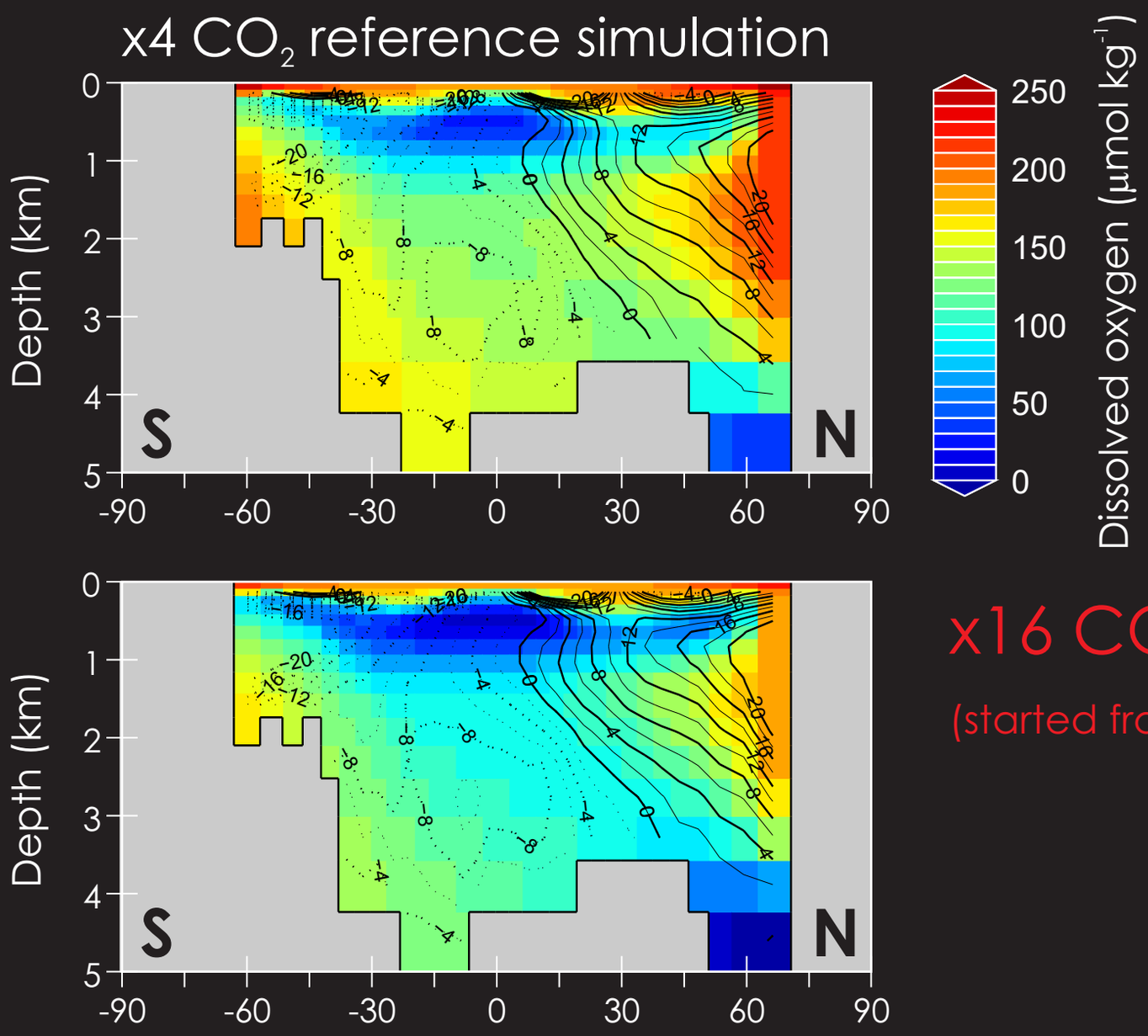


x8 CO_2 @ 10,000 yrs

(started from end of the x4 simulation)

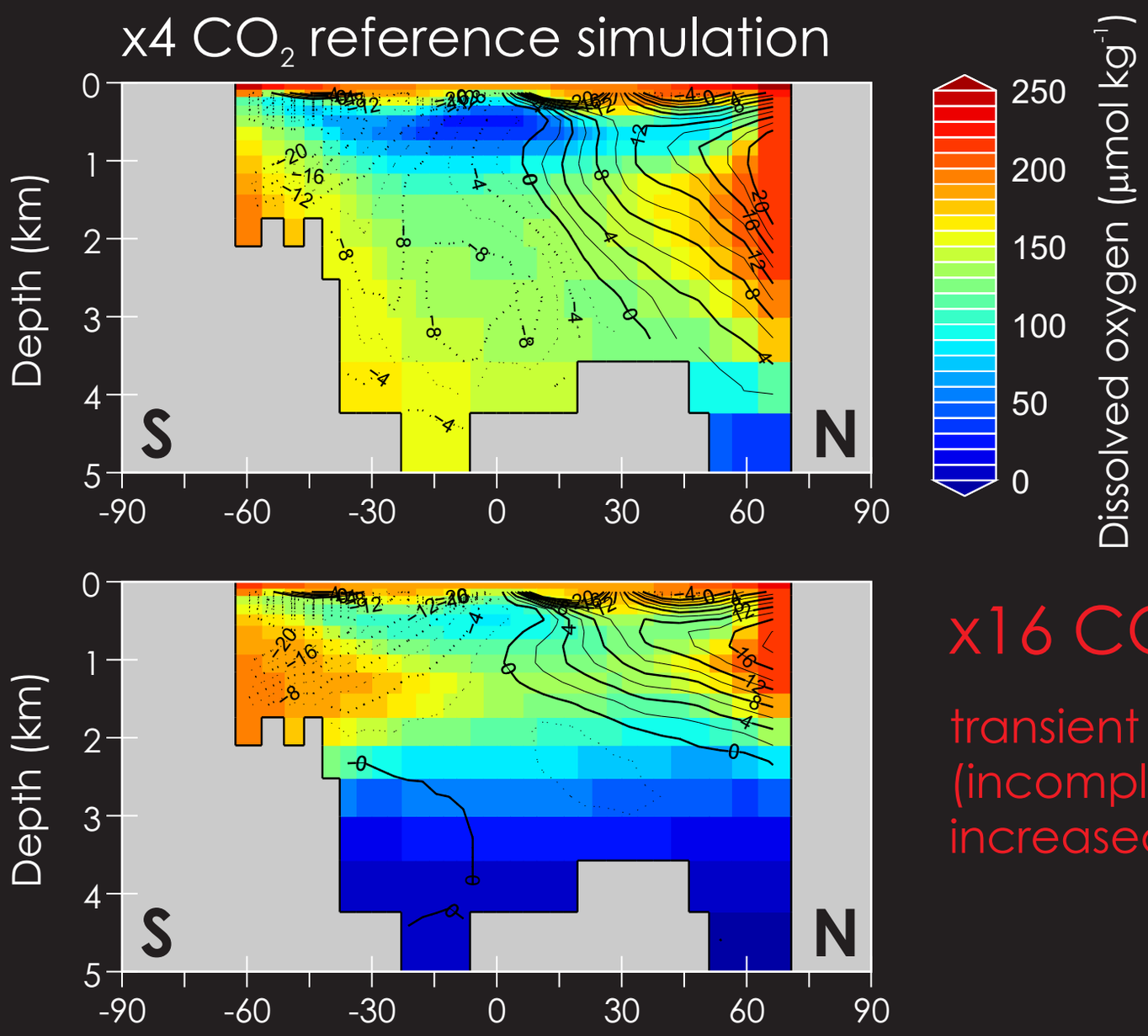
Circulation State I – no significant ventilation of the deep ocean



x16 CO_2 @ 10,000 yrs

(started from end of the x4 simulation)

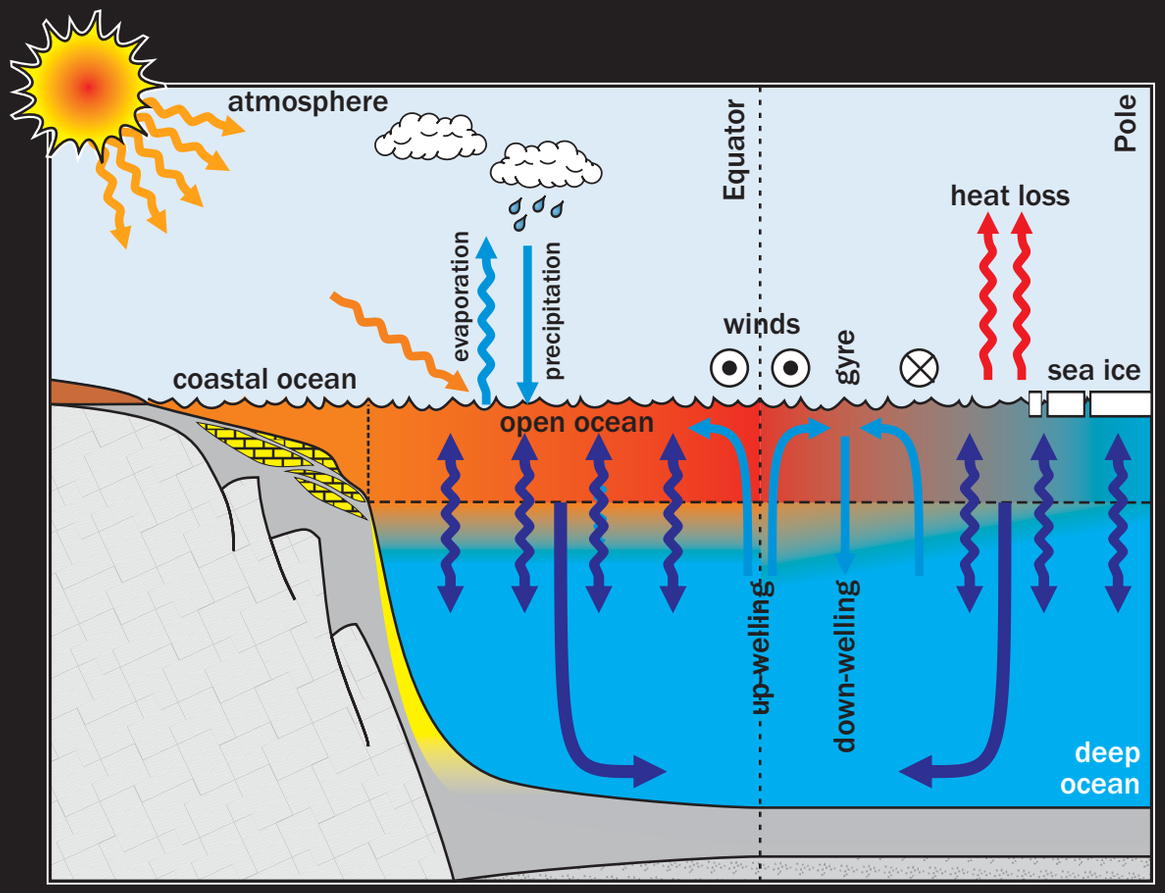
Circulation State I – no significant ventilation of the deep ocean



x16 CO_2 @ 2,000 yrs

transient state
(incomplete adjustment to
increased radiative forcing)

Circulation State II



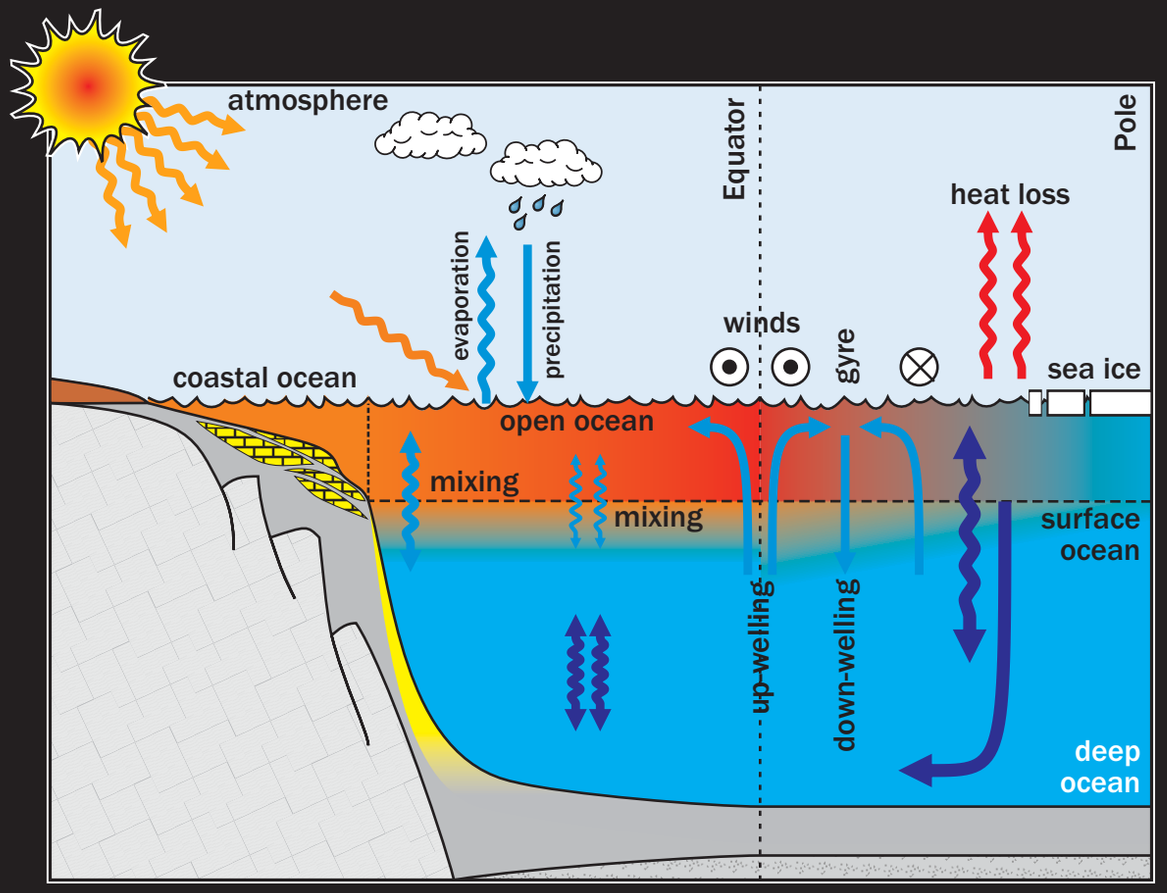
HOW?

Extreme winds and wind stress? (unlikely)

Extreme geothermal heating? (locally, associated with LIPs?)

Seasonal sea-ice covering much of the global ocean? (unlikely)

Circulation State III – sinking at high latitudes dominates

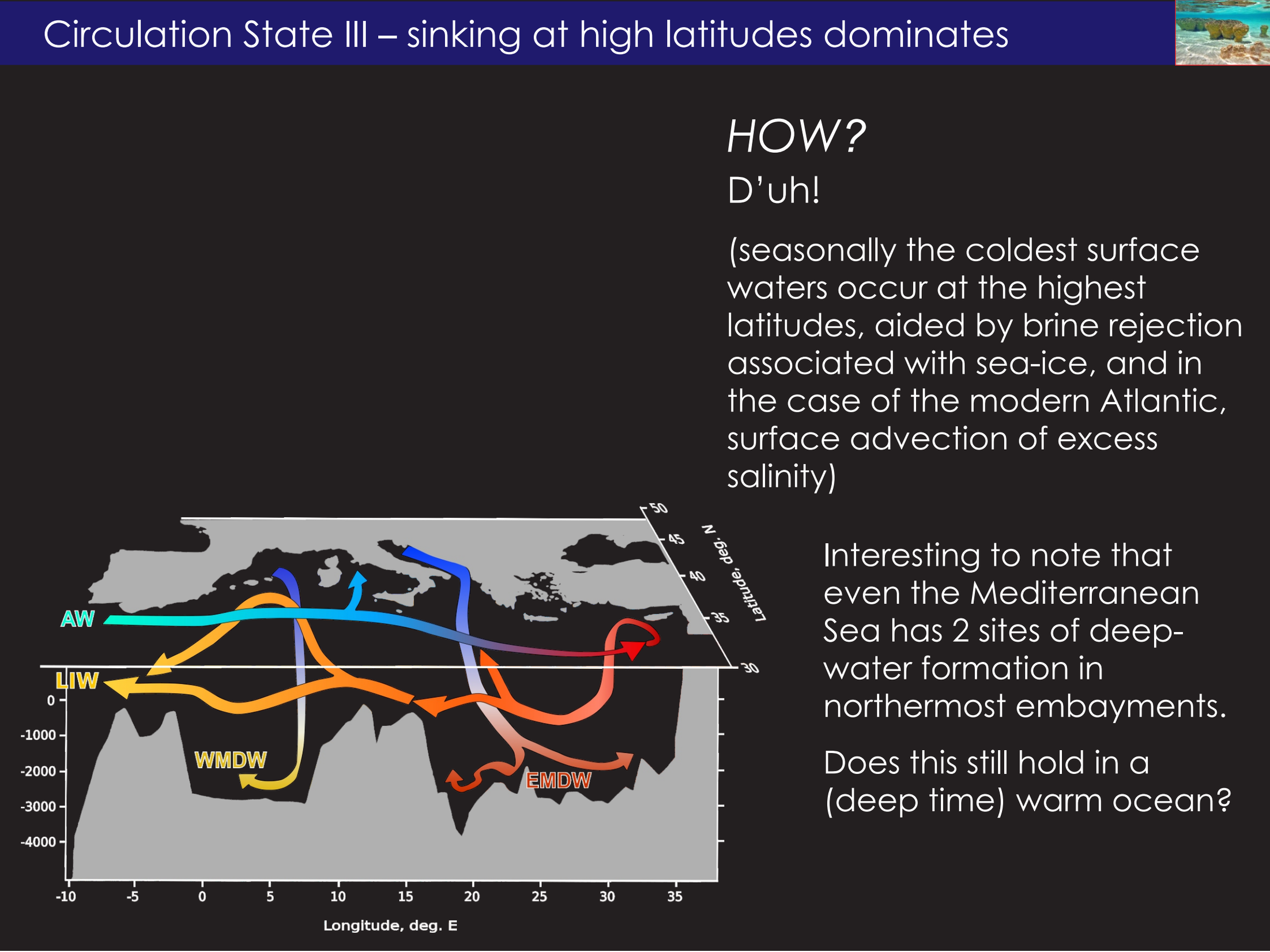


HOW?

D'uh!

(seasonally the coldest surface waters occur at the highest latitudes, aided by brine rejection associated with sea-ice, and in the case of the modern Atlantic, surface advection of excess salinity)

Circulation State III – sinking at high latitudes dominates



HOW?

D'uh!

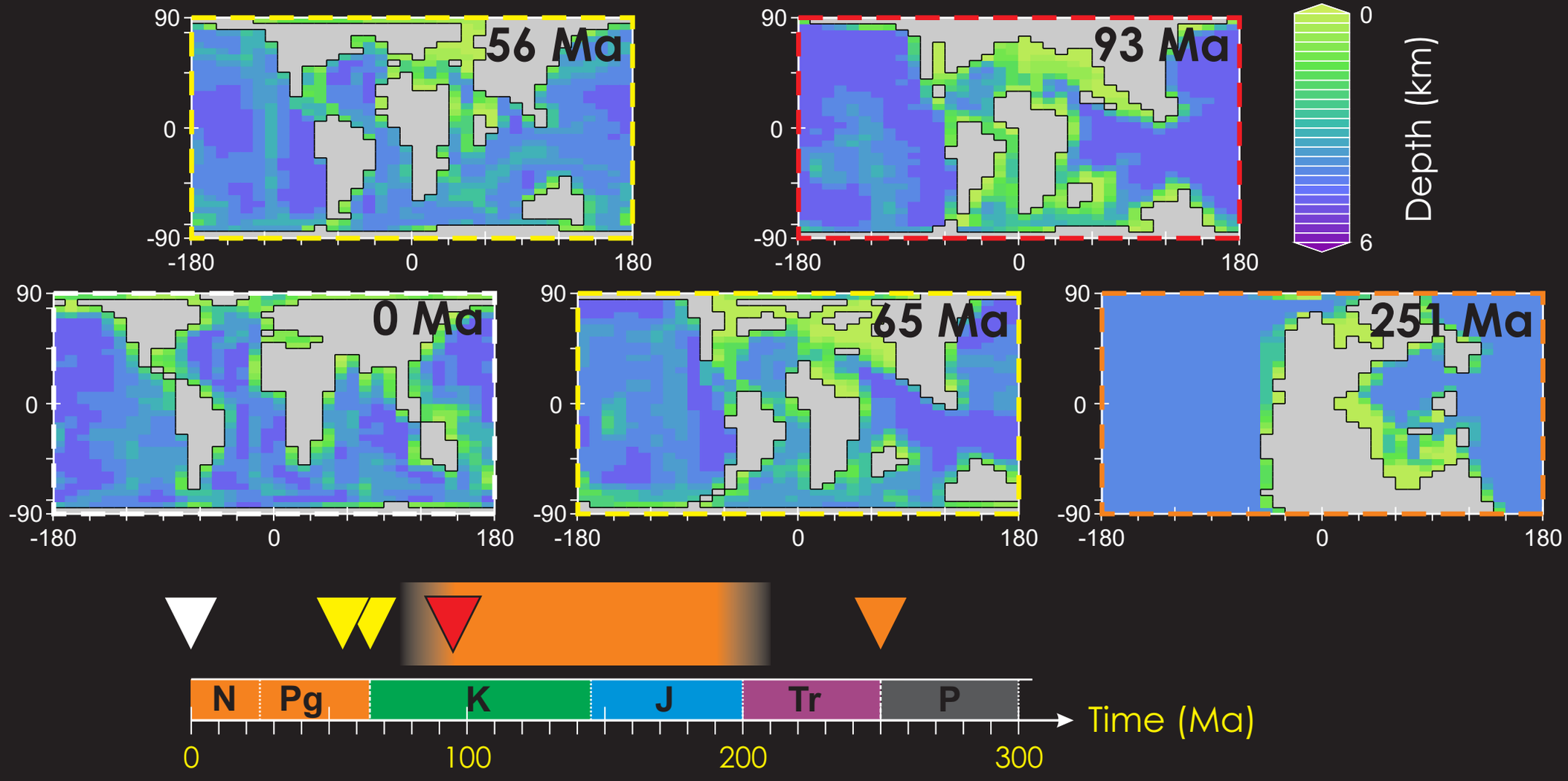
(seasonally the coldest surface waters occur at the highest latitudes, aided by brine rejection associated with sea-ice, and in the case of the modern Atlantic, surface advection of excess salinity)

Interesting to note that even the Mediterranean Sea has 2 sites of deep-water formation in northermost embayments.

Does this still hold in a (deep time) warm ocean?

Circulation State III – sinking at high latitudes dominates

ocean bathymetry &
continental configuration

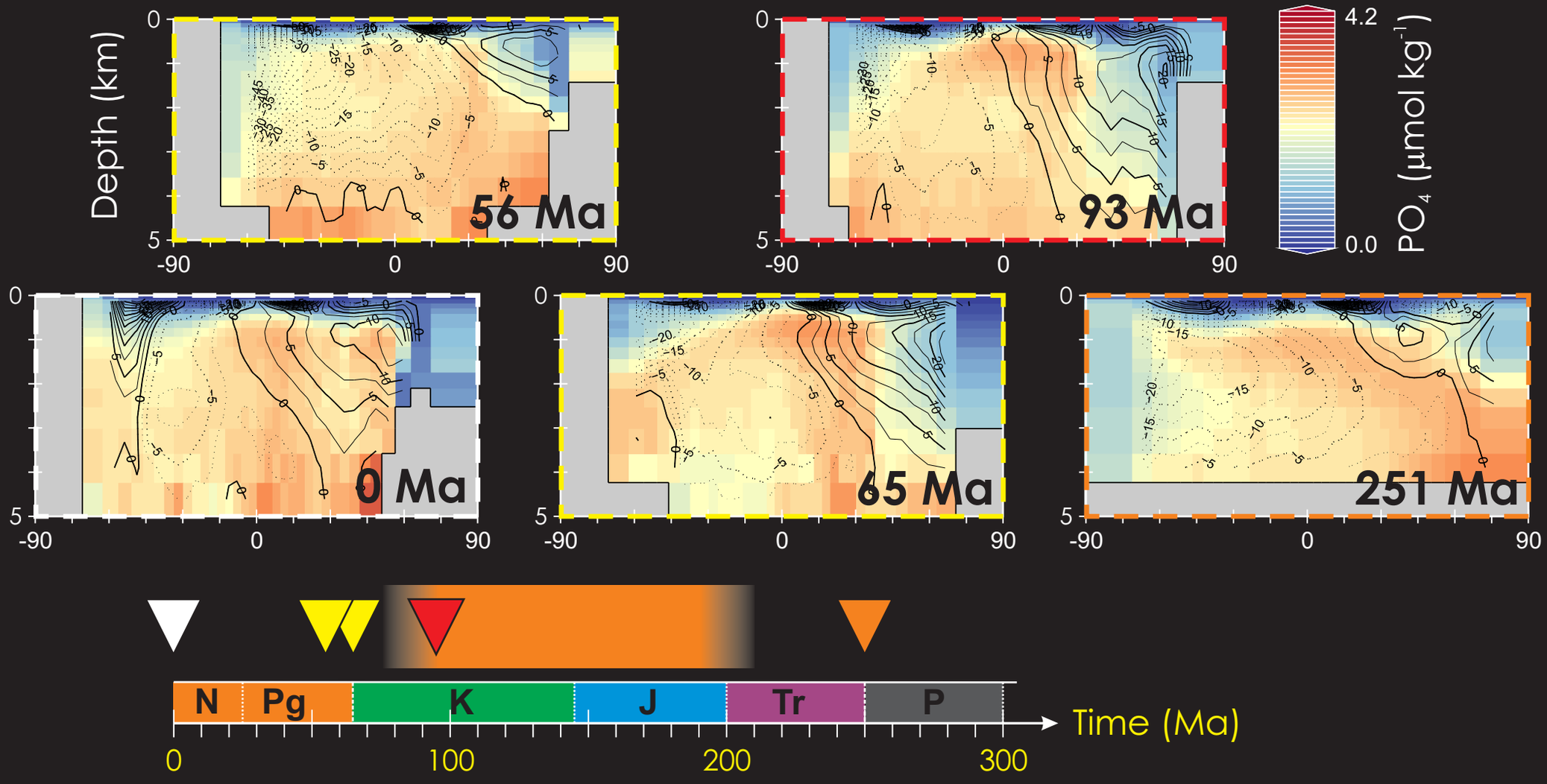


Circulation State III – sinking at high latitudes dominates

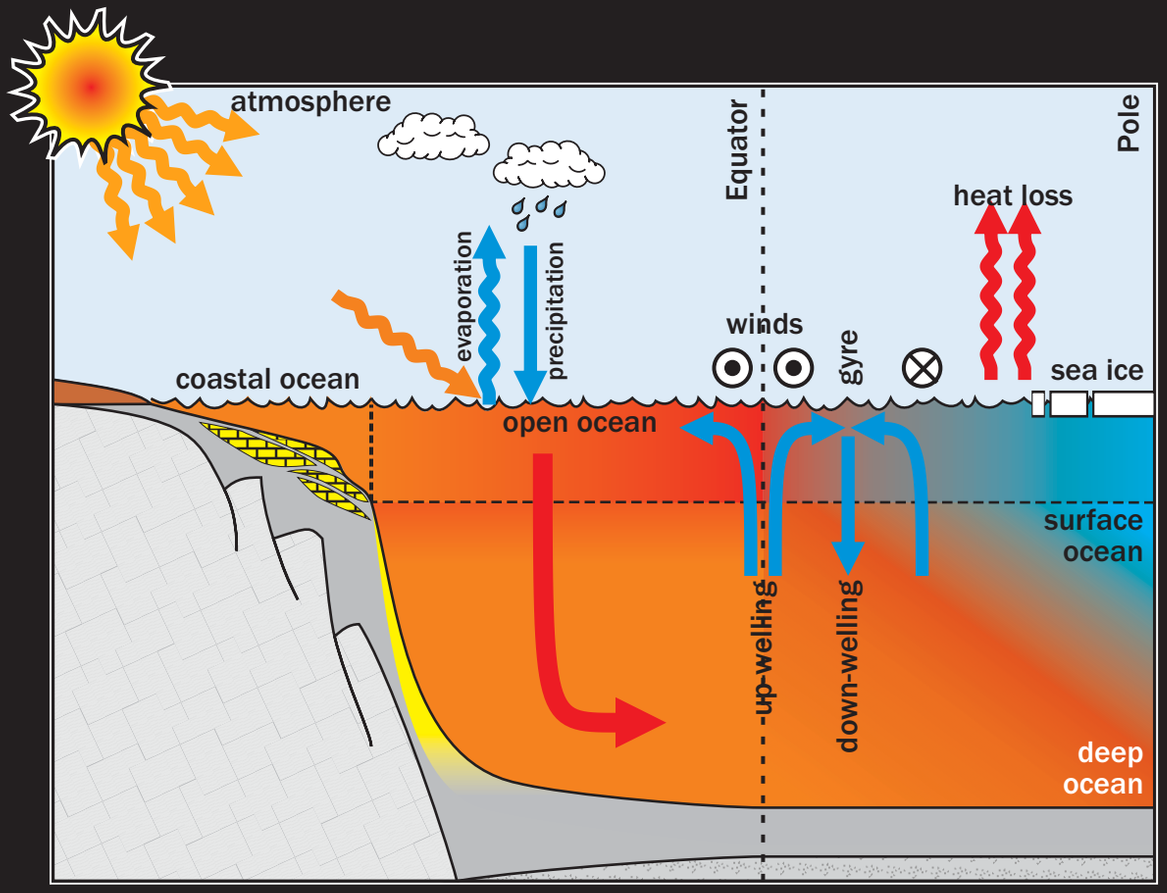
zonal mean latitude-depth [PO_4] distribution

A measure of the partitioning of PO_4 and hence oxygen consumption, in the water column.

Contour overlay is the global mean overturning stream-function.



Circulation state IV – ventillation from the tropics?



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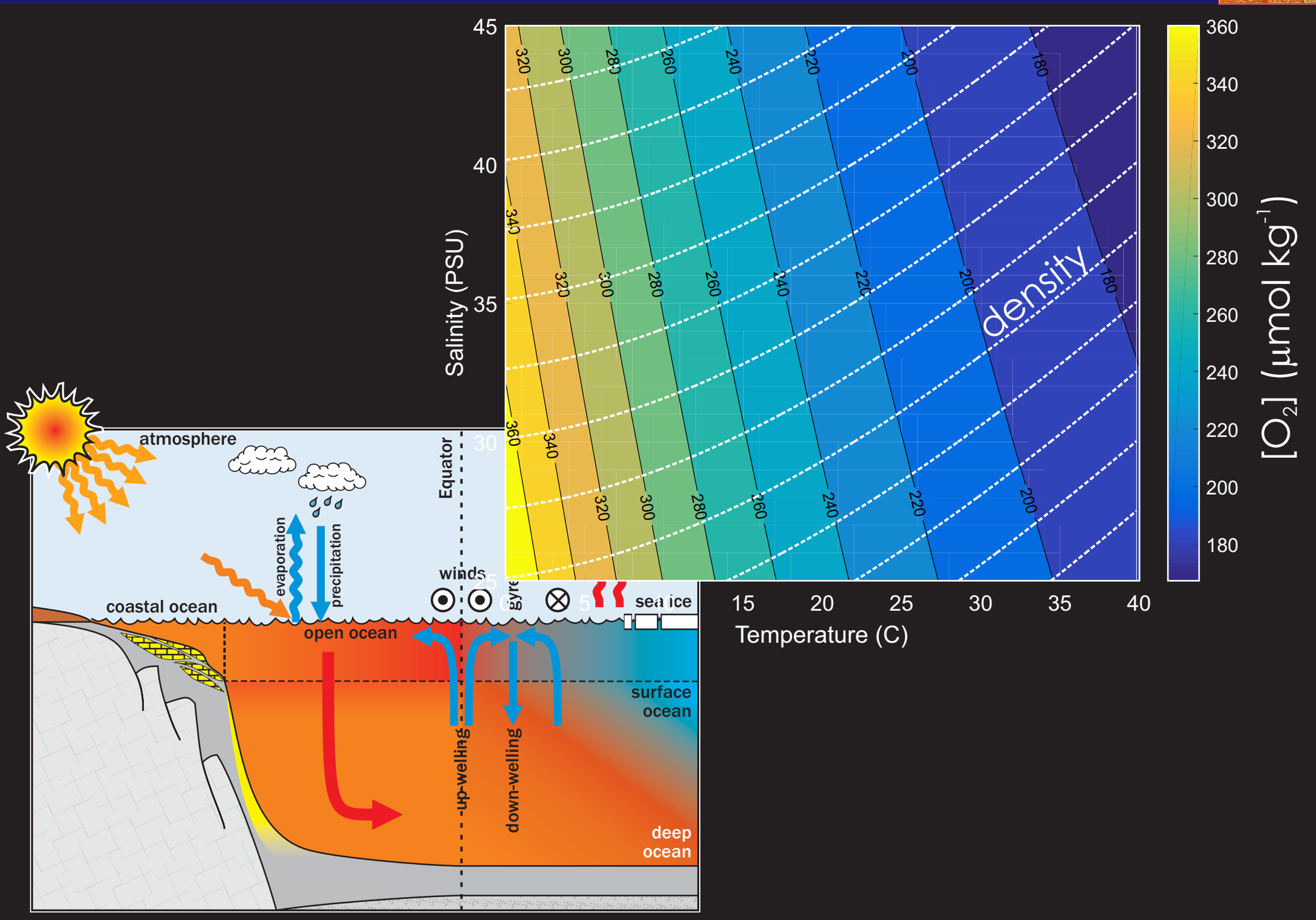

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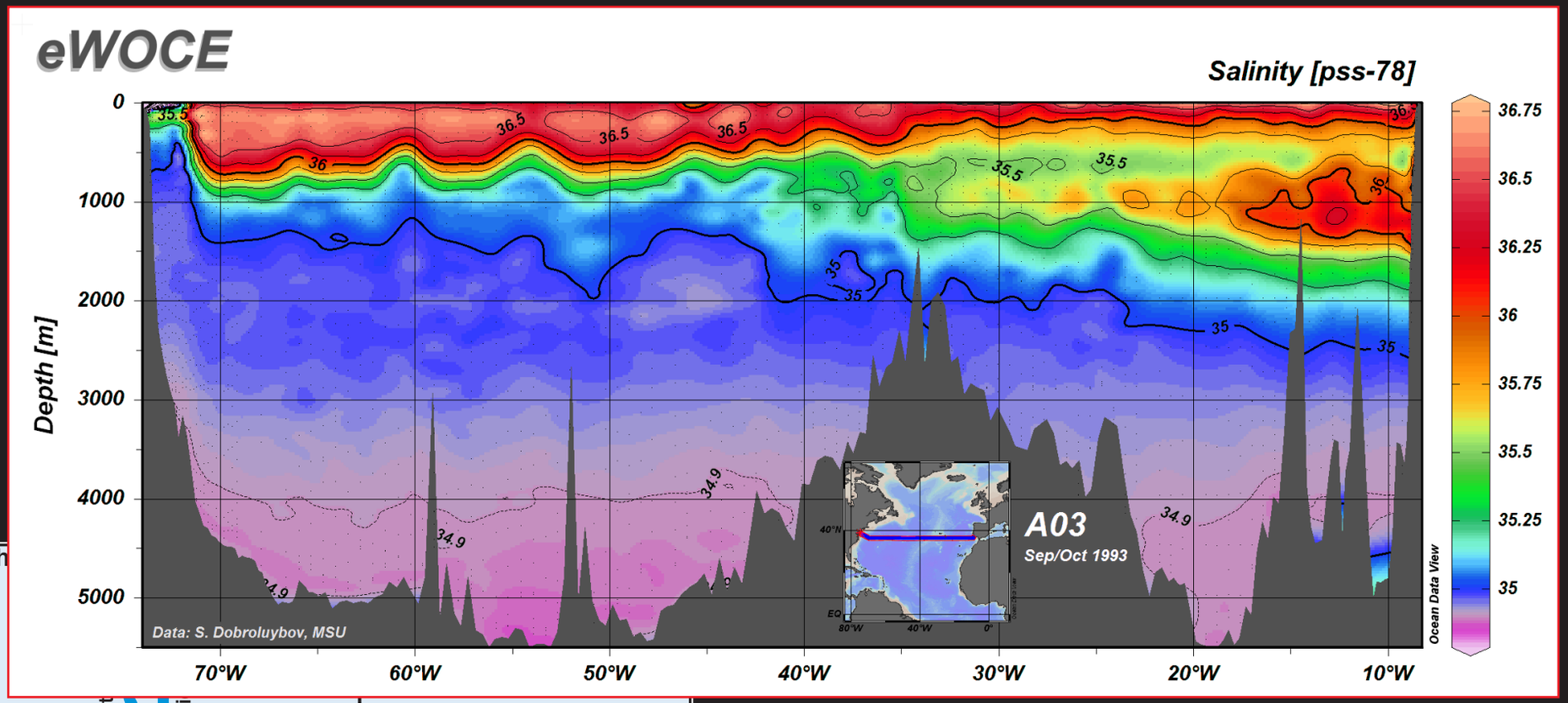
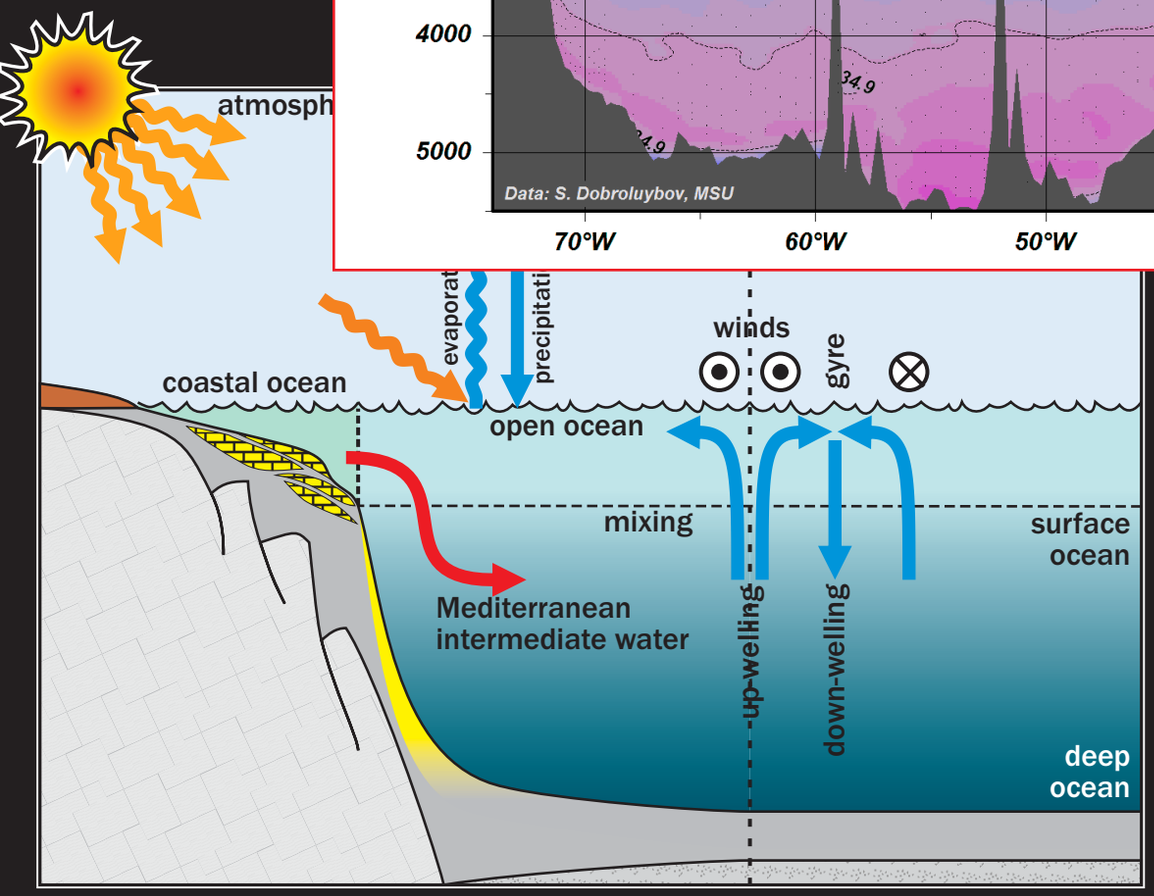
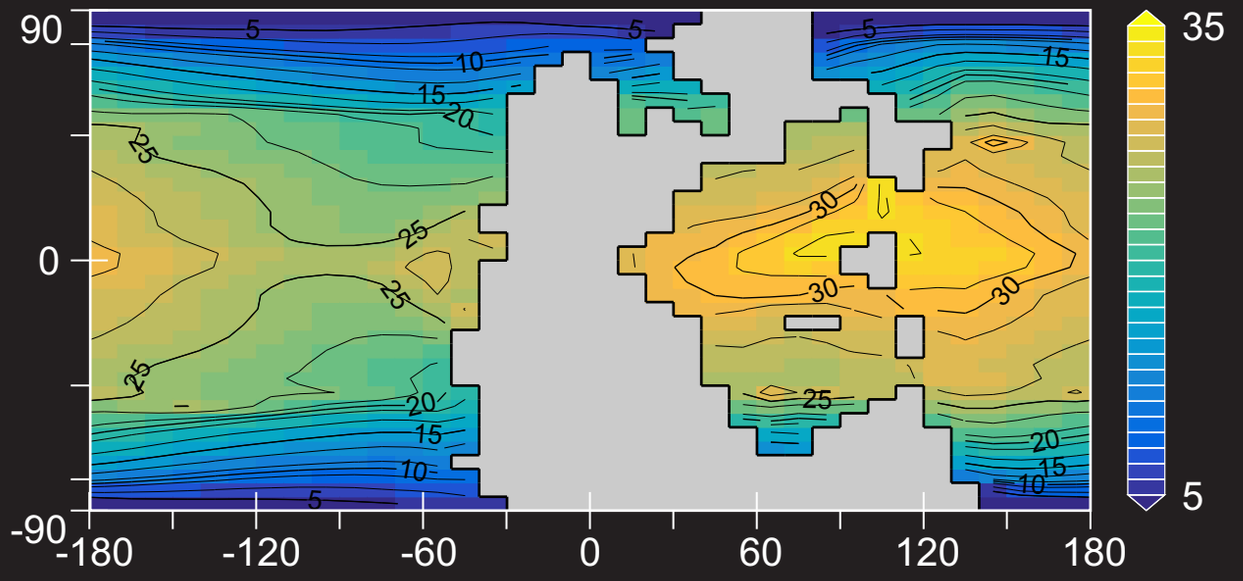


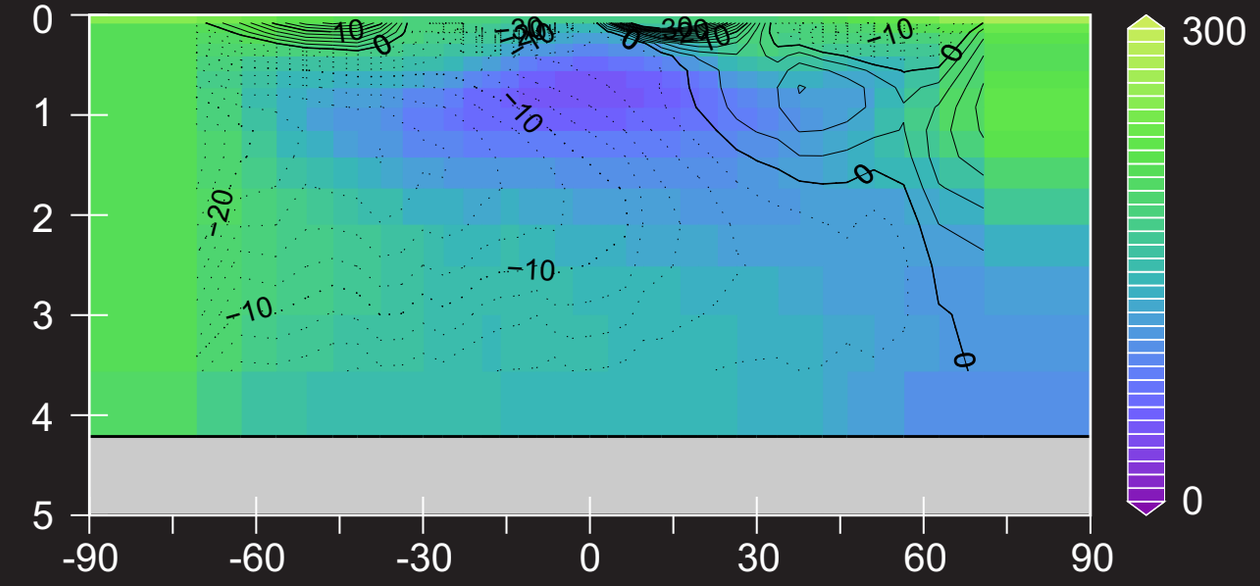


Circulation state IV – ventillation from the tropics?

Mean annual ocean surface temperature

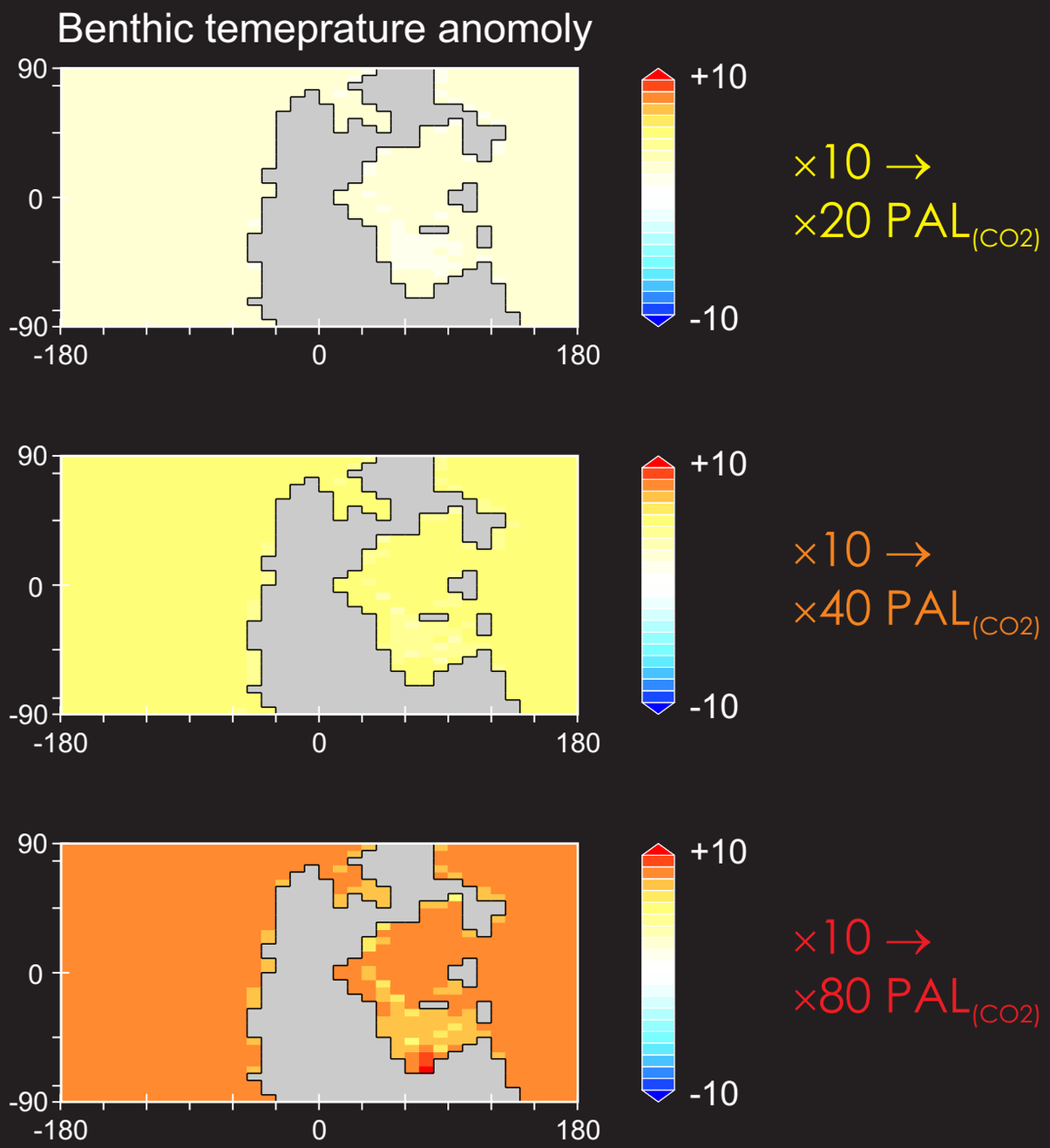


Global stream-function and $[O_2]$ field



Late Permian example

Circulation state IV – ventillation from the tropics?

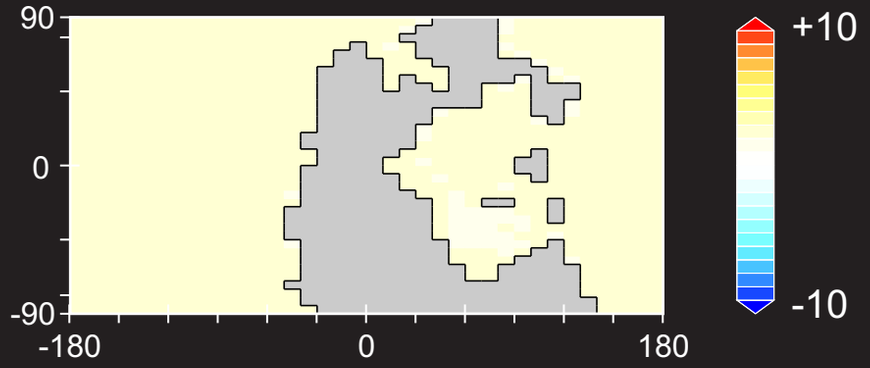


Late Permian example

Response to progressive applied surface warming

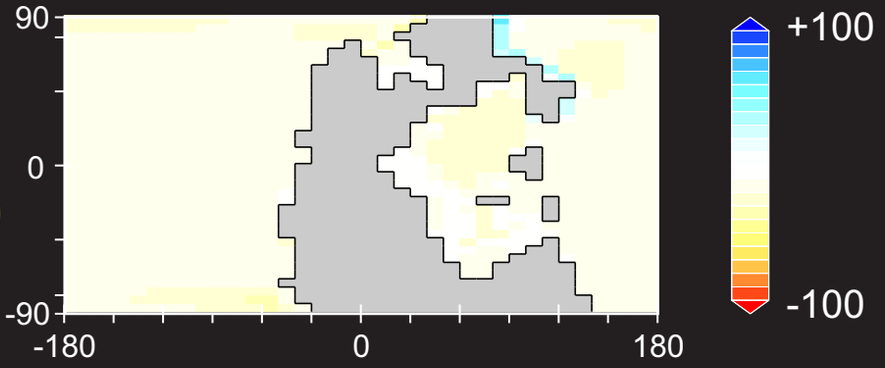
Circulation state IV – ventillation from the tropics?

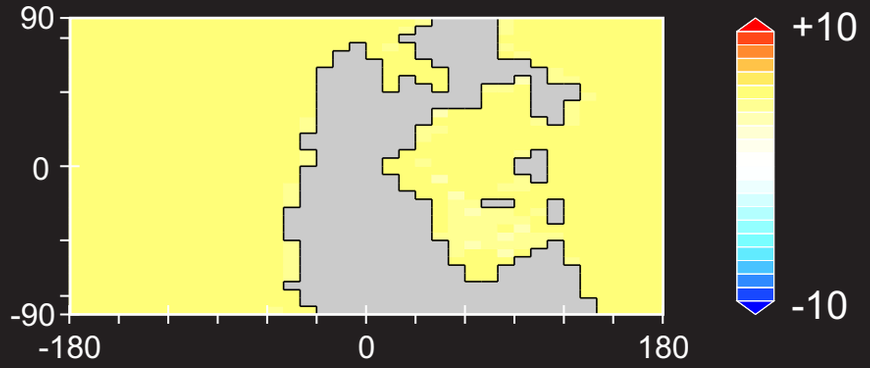
Benthic temeprature anomoly



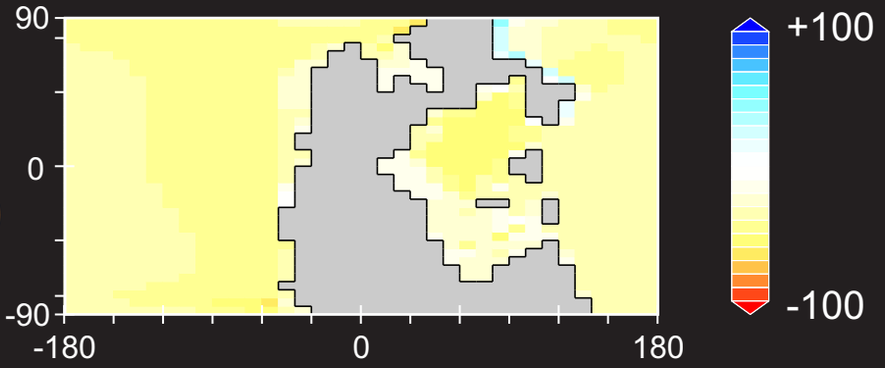
×10 →
×20 $PAL_{(CO2)}$

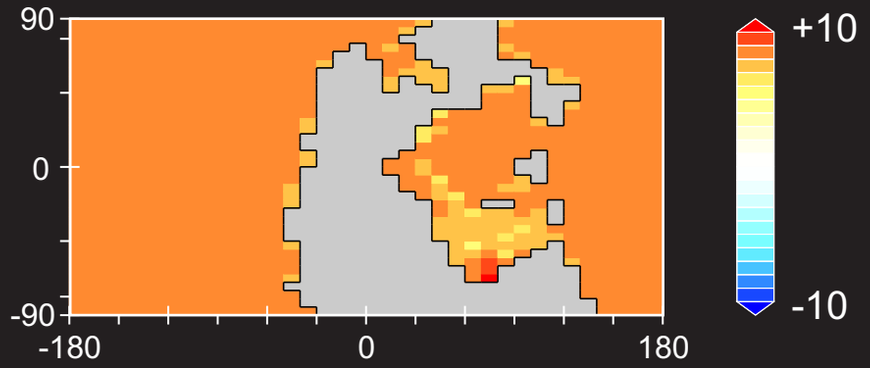
Benthic dissolved oxygen anomoly



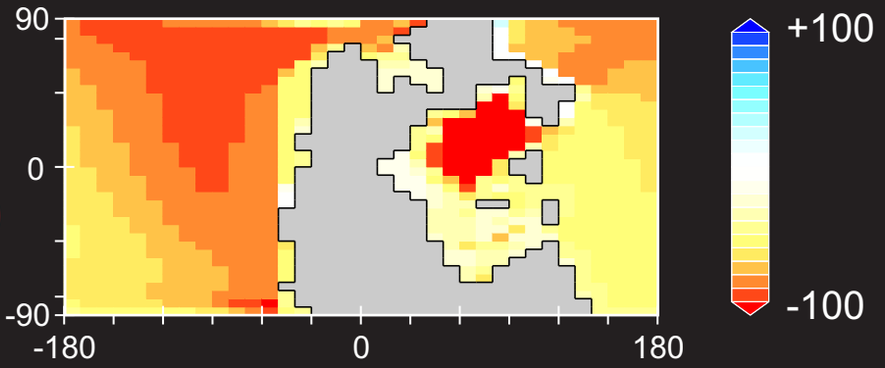


×10 →
×40 $PAL_{(CO2)}$

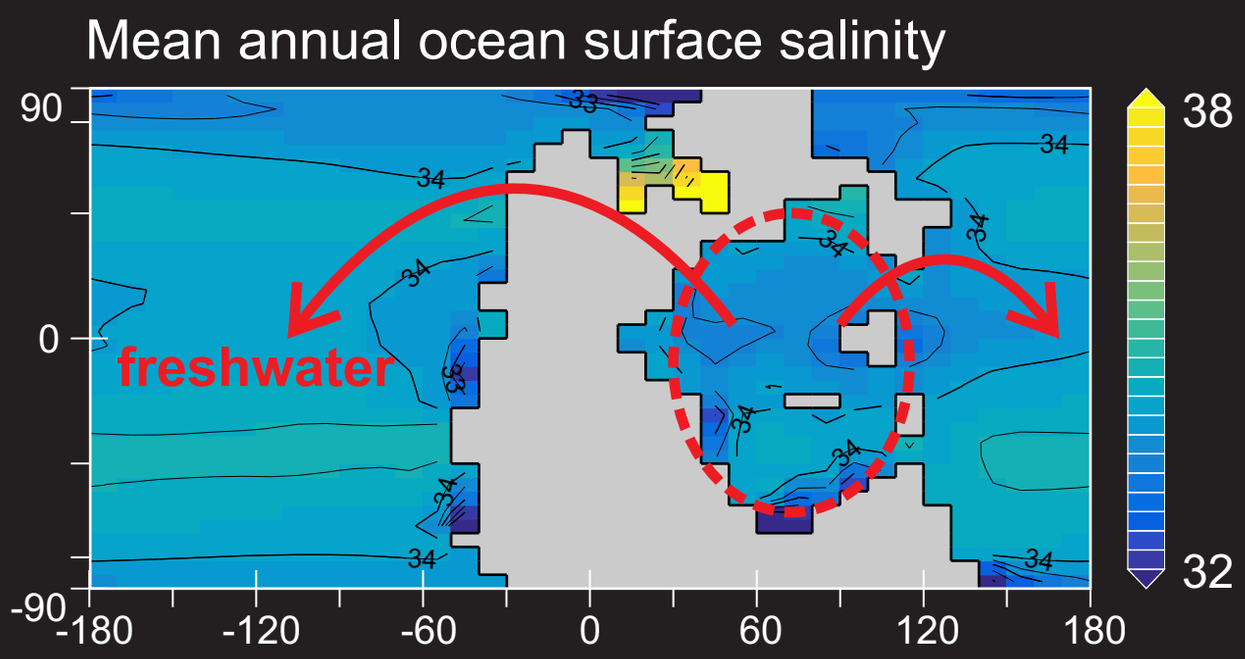




×10 →
×80 $PAL_{(CO2)}$

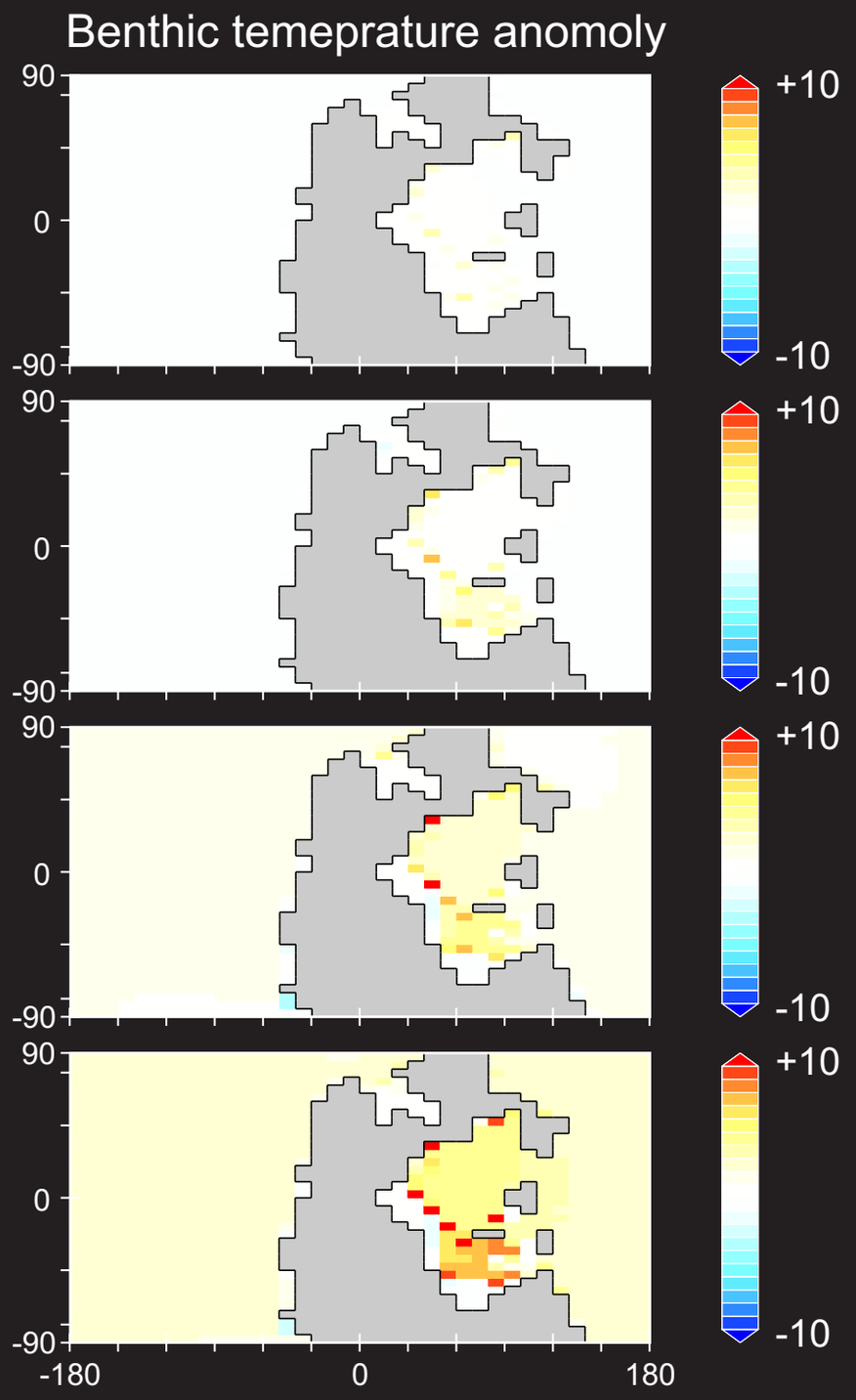


Circulation state IV – ventillation from the tropics?



Late Permian ‘hosing’ experiment

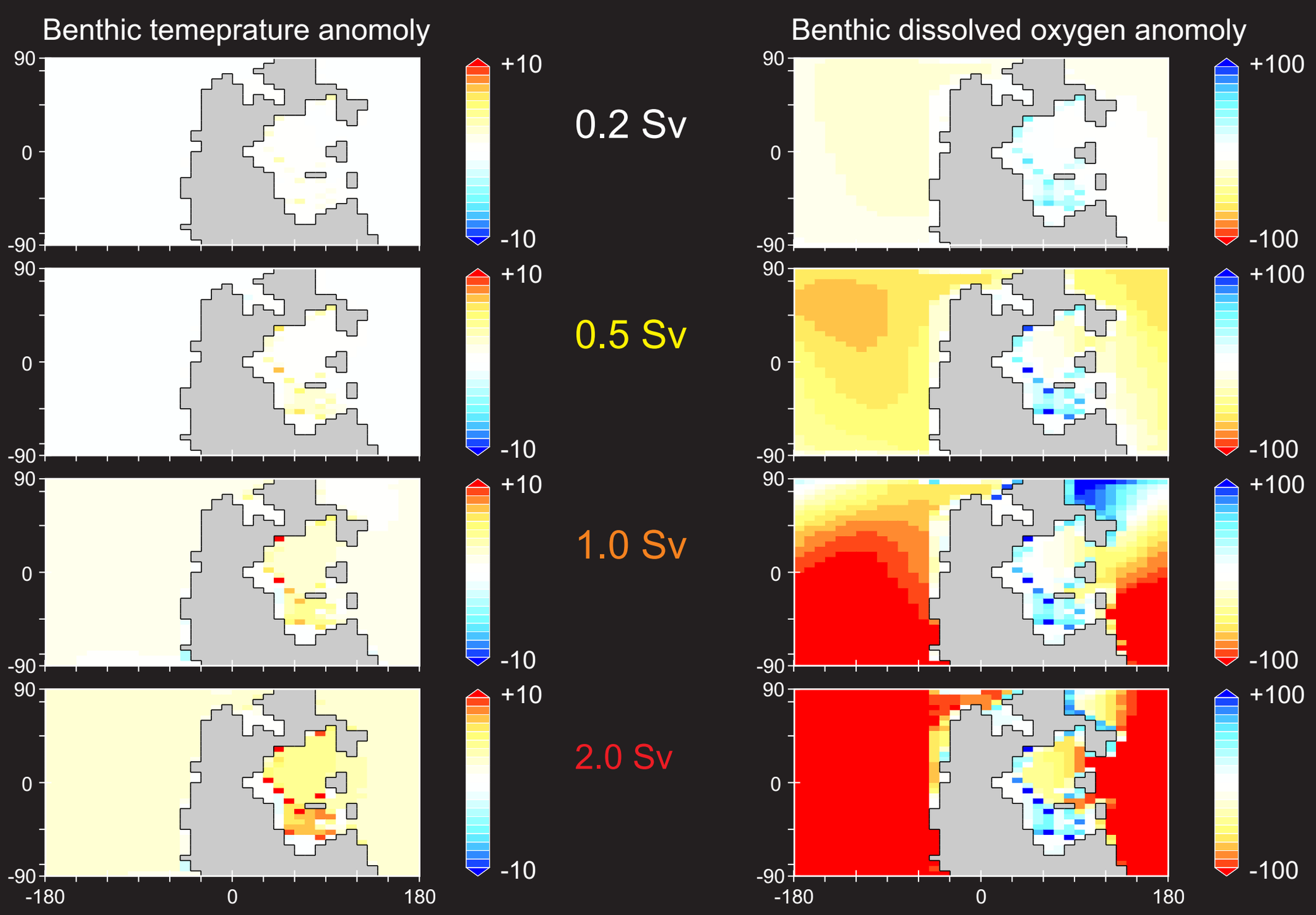
Circulation state IV – ventillation from the tropics?



Late Permian example

Response to freshwater reorganization

Circulation state IV – ventillation from the tropics?



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