Changes of the Late Permian Ocean Circulation and Deep-Sea Anoxia in Response to Tectonic Changes - A Model Study with CCSM3*

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Abstract

The causes and dynamics of the mass extinction at the Permian-Triassic boundary (~251 Ma) are controversial. One hypothesis favors climatic responses to increased tectonic activity and associated large-scale volcanism, resulting in ocean stratification and widespread anoxia with fatal consequences for marine and land organisms. This hypothesis is supported by recent interpretation of geochemical data, suggesting that periodic upwelling of toxic hydrogen sulfide rich water masses contributed to the extinction of species. However, model results suggest that a sluggish ocean circulation did not lead to anoxic conditions in the deep sea.

In order to explore causes of deep-ocean anoxia, as well as patterns of presumably toxic deep-ocean waters, changes in deep-sea ridges are being explored with the fully coupled climate system model CCSM3 under end-Permian boundary conditions. The model simulations are compared with recent paleoclimatic proxies and previous modeling studies. Modeling results indicate that ridges promote diapycnal mixing along the ridge-axis, but enhance lateral gradients of oxygen.

Increased nutrient input into the ocean, justified by enhanced continental weathering and tectonic activities, could have drastically changed marine productivity patterns and hence oxygen consumption in the deep sea, as simulated in the model.

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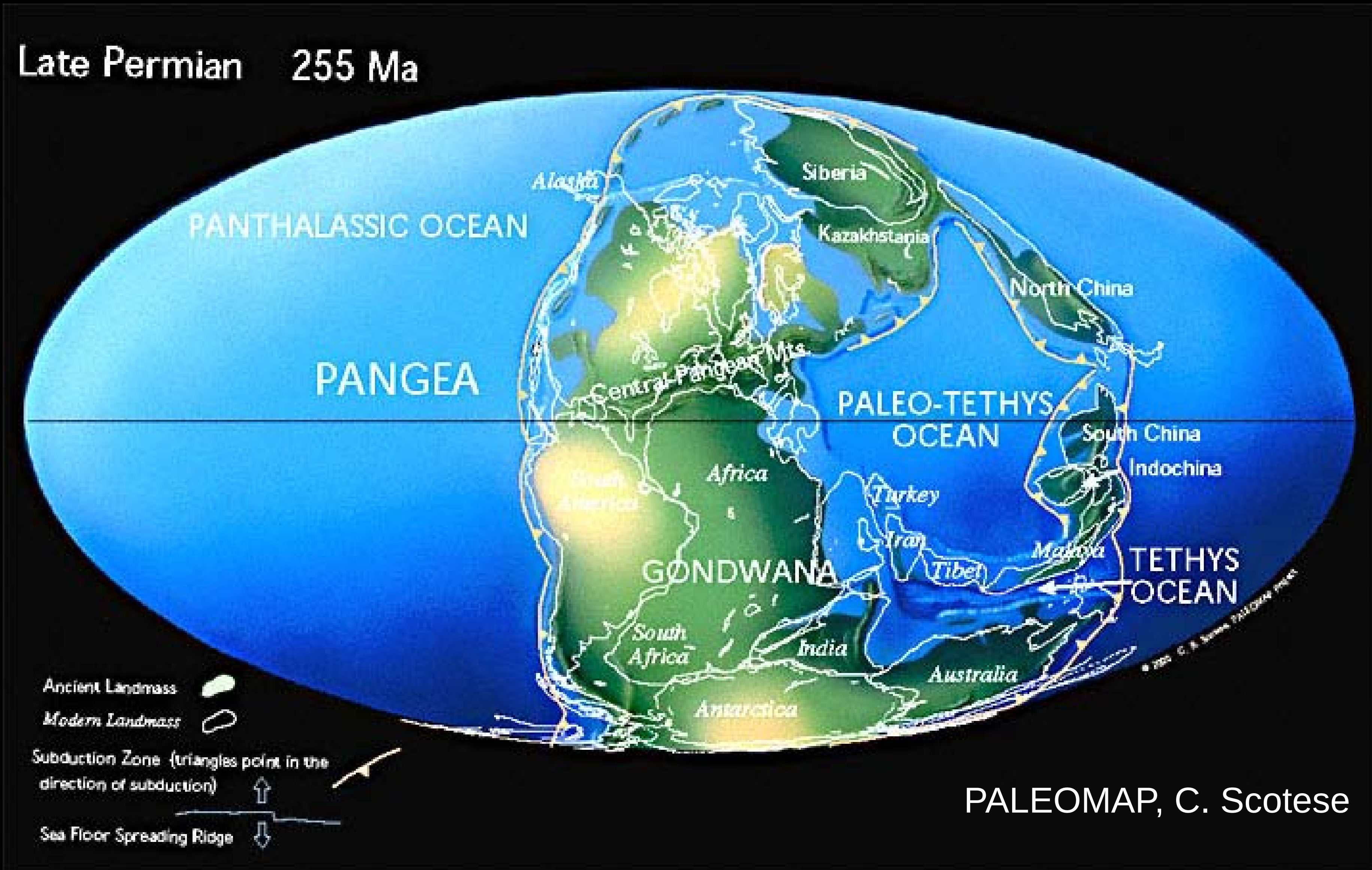
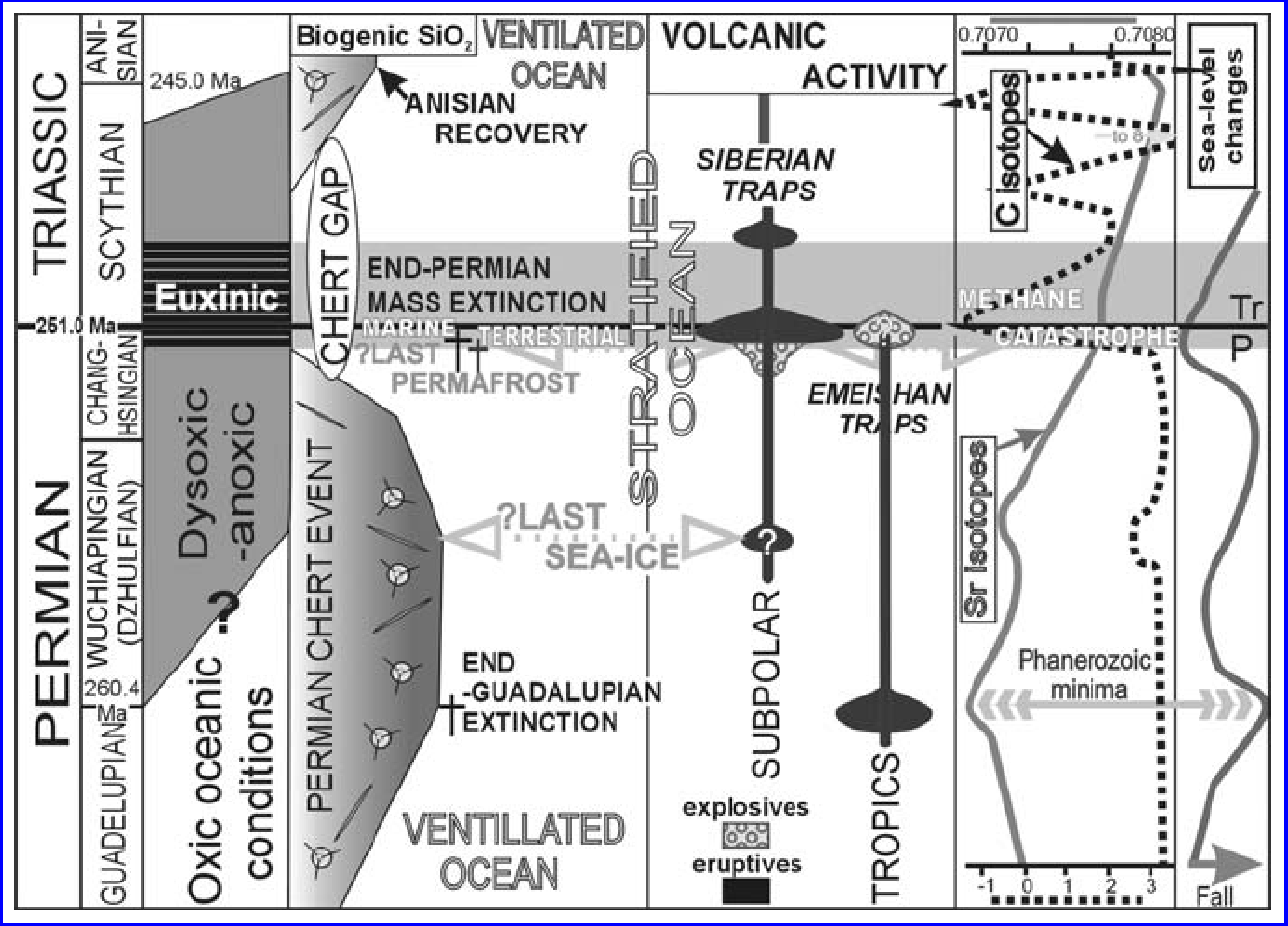
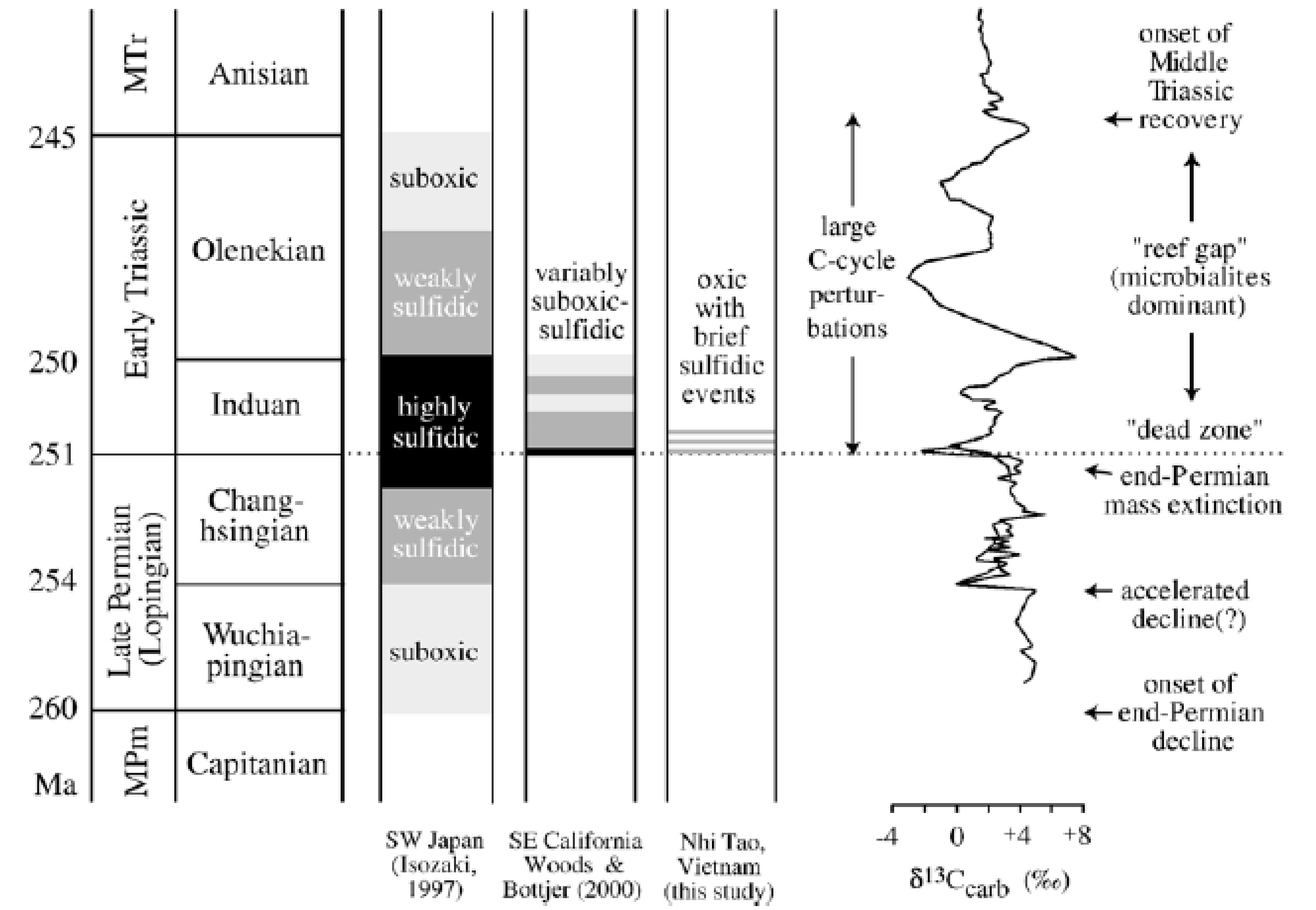


PALEOMAP, C. Scotese



Racki and Wignall, 2005

Algeo et al., 2007



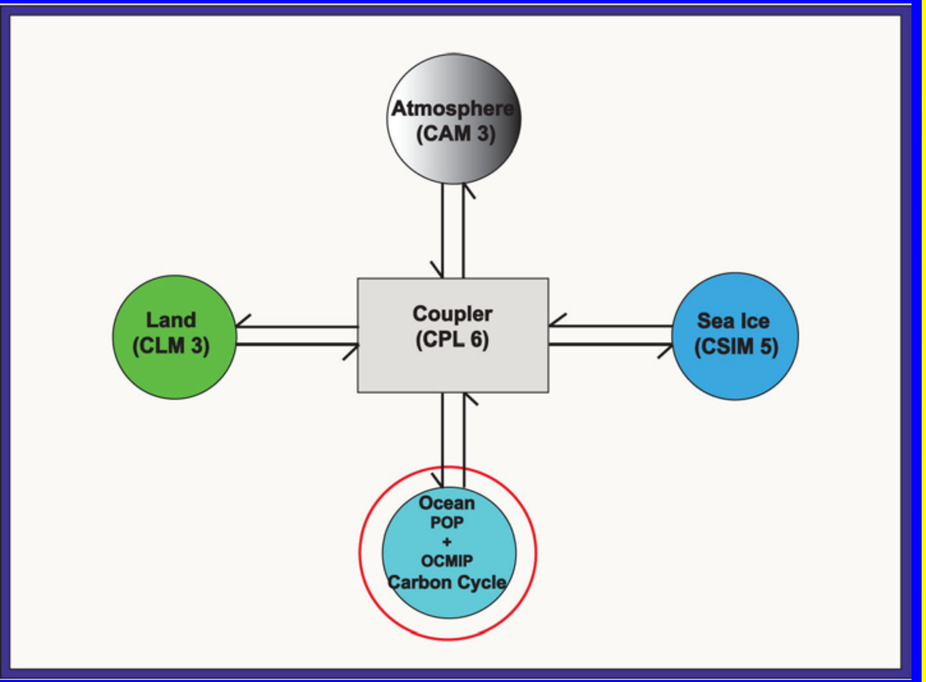
- Geochemical anomalies (CIE)
- Lithofacies changes

Anoxia/euxinia play a major role in many extinction hypotheses.

Causes of anoxia controversial:

- Ocean circulation (sluggish/stratified?)
- Change in ocean carbon inventories
- Reorganization of marine productivity

CCSM3.0
(Collins et al., 2006)



- Atmosphere and land:
  - T31 (~3.75° long. spacing)
  - 26 atmosphere levels
- Ocean and ice:
  - gx3v5 (0.8° -1.6° in latitude, ~3.6° in longitude)
  - 25 ocean levels

OCMIP* (Doney et al., 2006)

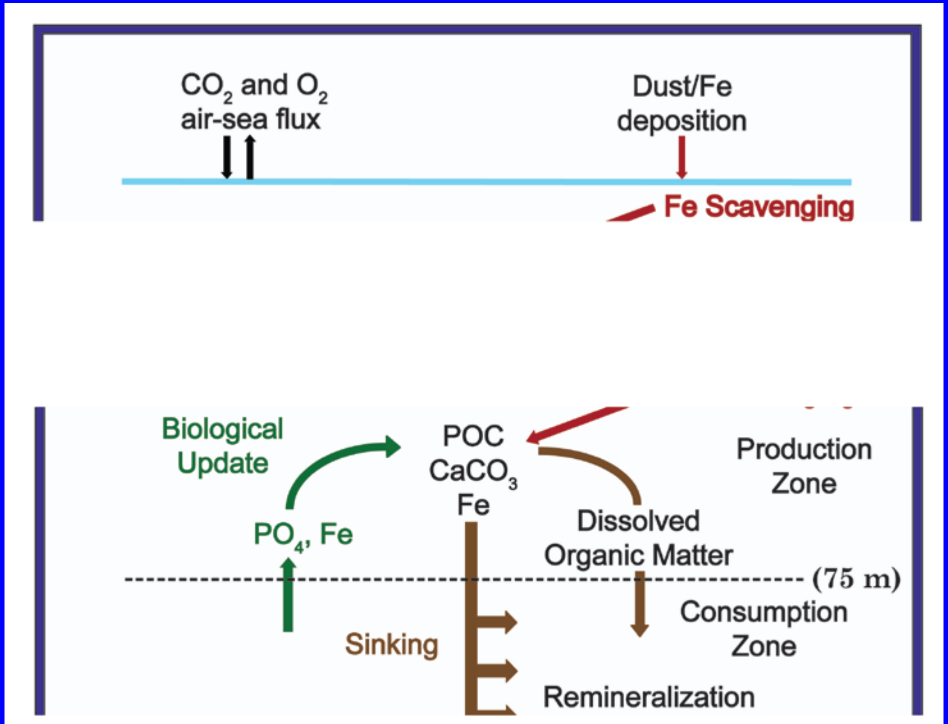
- Redfield Ocean Model
- $J_{prod} = F_T * F_N * F_I * B * \max(1, z_{ml}/z_c)$

  $F_T = (T+2)/(T+10)$

  $F_N = \min(PO_4/(PO_4+K_{PO4}), Fe/(Fe+K_{fe}))$

  $F_I = I/(I+\kappa_I)$

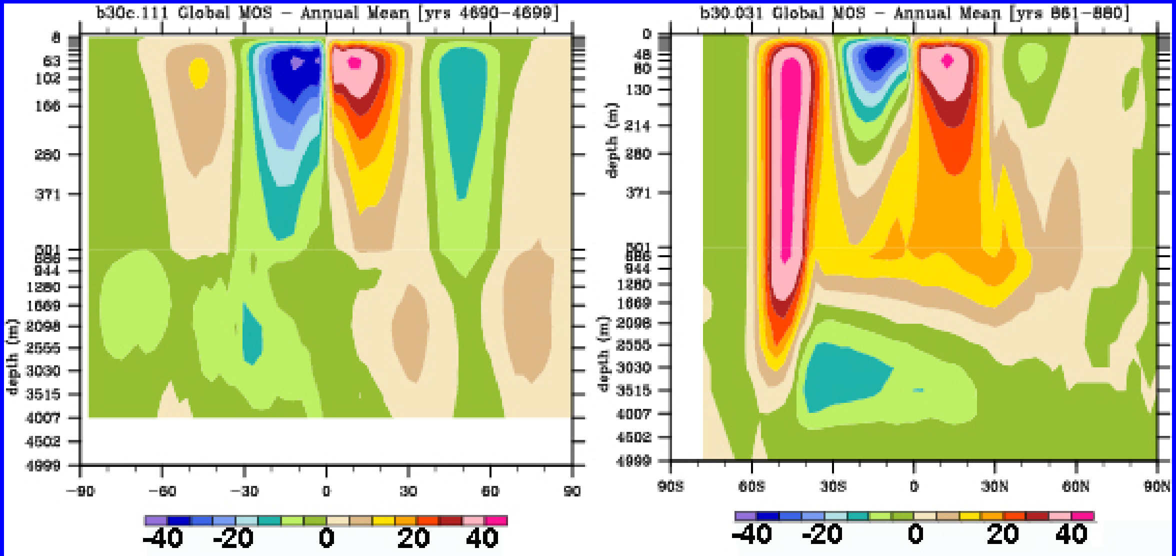
  $B_{min} = (PO_4, Fe/r_{Fe:PO4})$
- Martin et al. parameterization
- Deposition of Fe from atmosphere



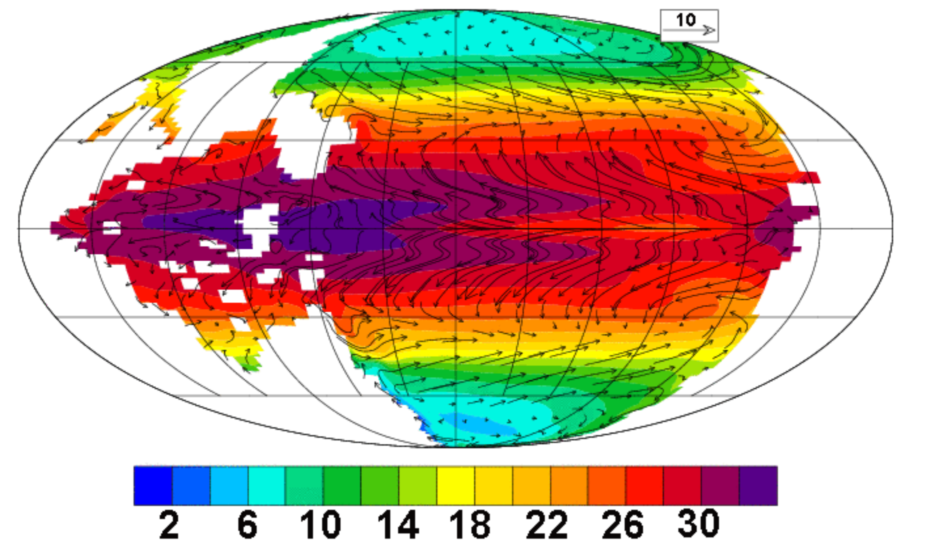
Simulations

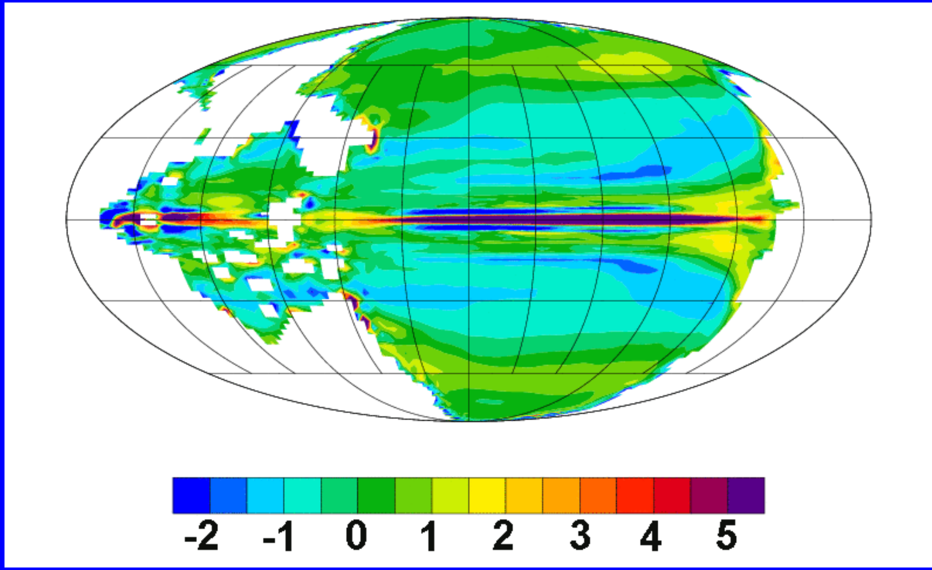
- Reference run:
  - Starting from fully coupled 2700 yrs 12xCO_2 PT run by J. Kiehl & C. Shields (2005);
    added carbon cycle model: 2000 yrs
- Sensitivity runs – 1000 yrs each
  (starting from reference run at yr 3710):
  - Increased nutrient supply (2 x, 4 x, 10 x PO_4)
  - Increased dust supply (10 x Fe)
  - Intensified biological pump
  - Intensified pump &
    increased nutrient supply
  - Sensitivity to mid-ocean ridges

Reference Run (PT, $12xCO_2$)



MOC (Sv)





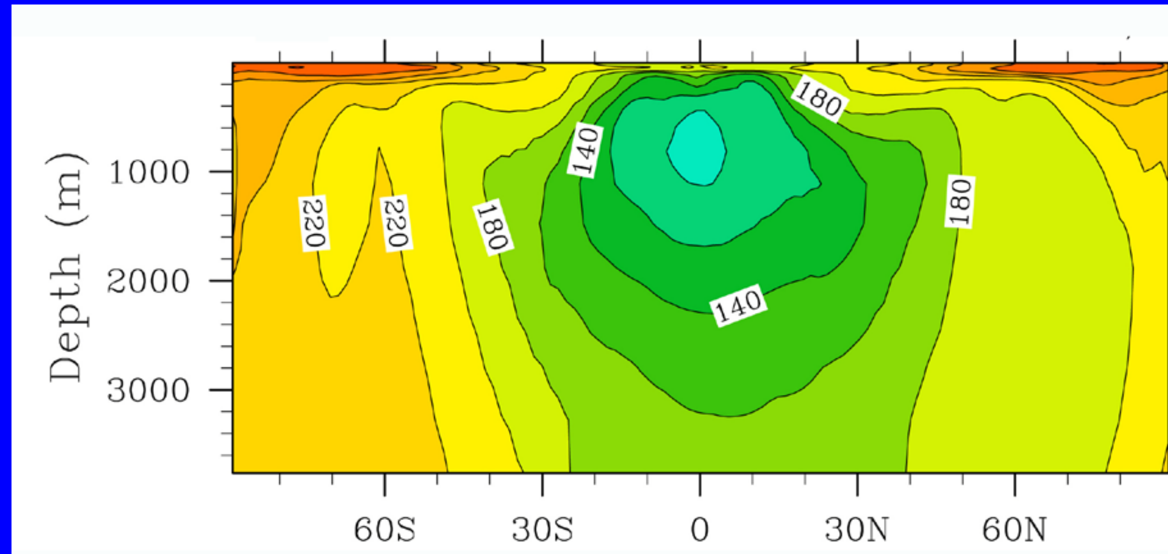
Surface Temperature (° C) and Circulation (Sv)

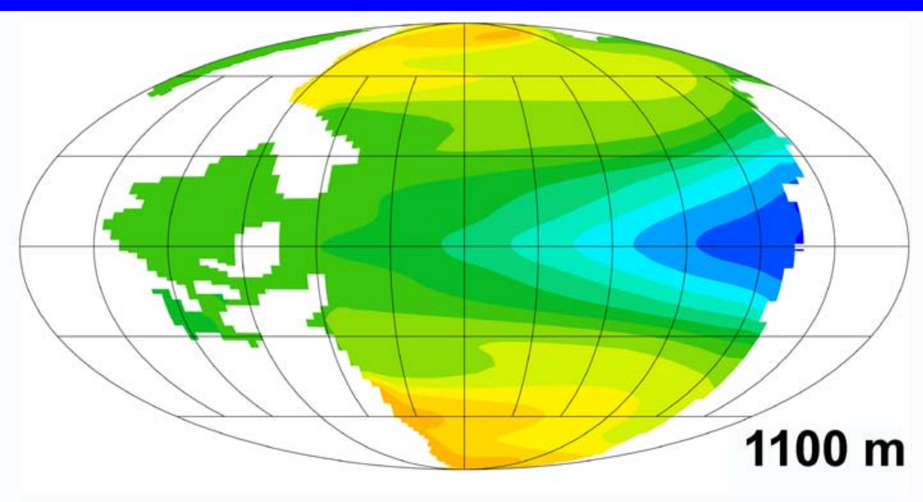
Vertical Velocity (10^{-6} m s^{-1})

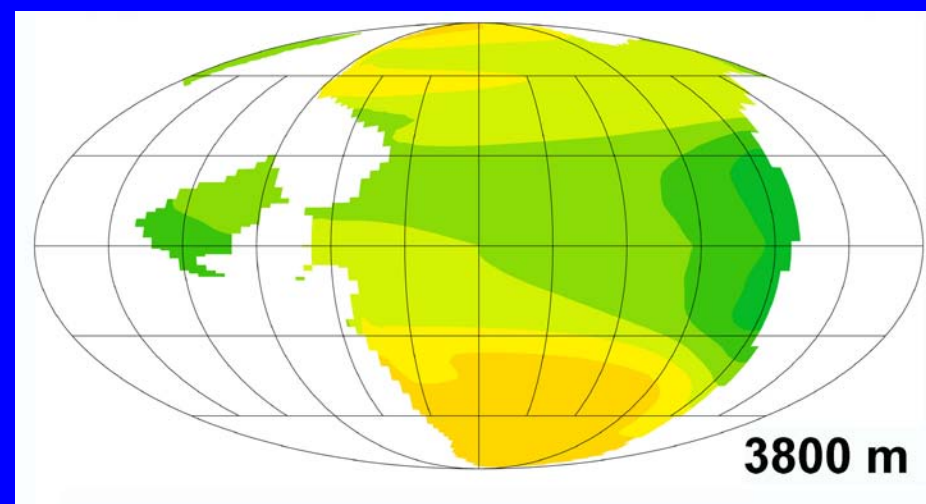
Also: old water masses in Tethys and mid-Panthalassic Ocean

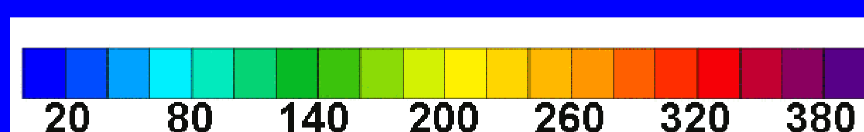
Reference Run (PT, $12xCO_2$)

Oxygen Distribution (μmol L^{-1})



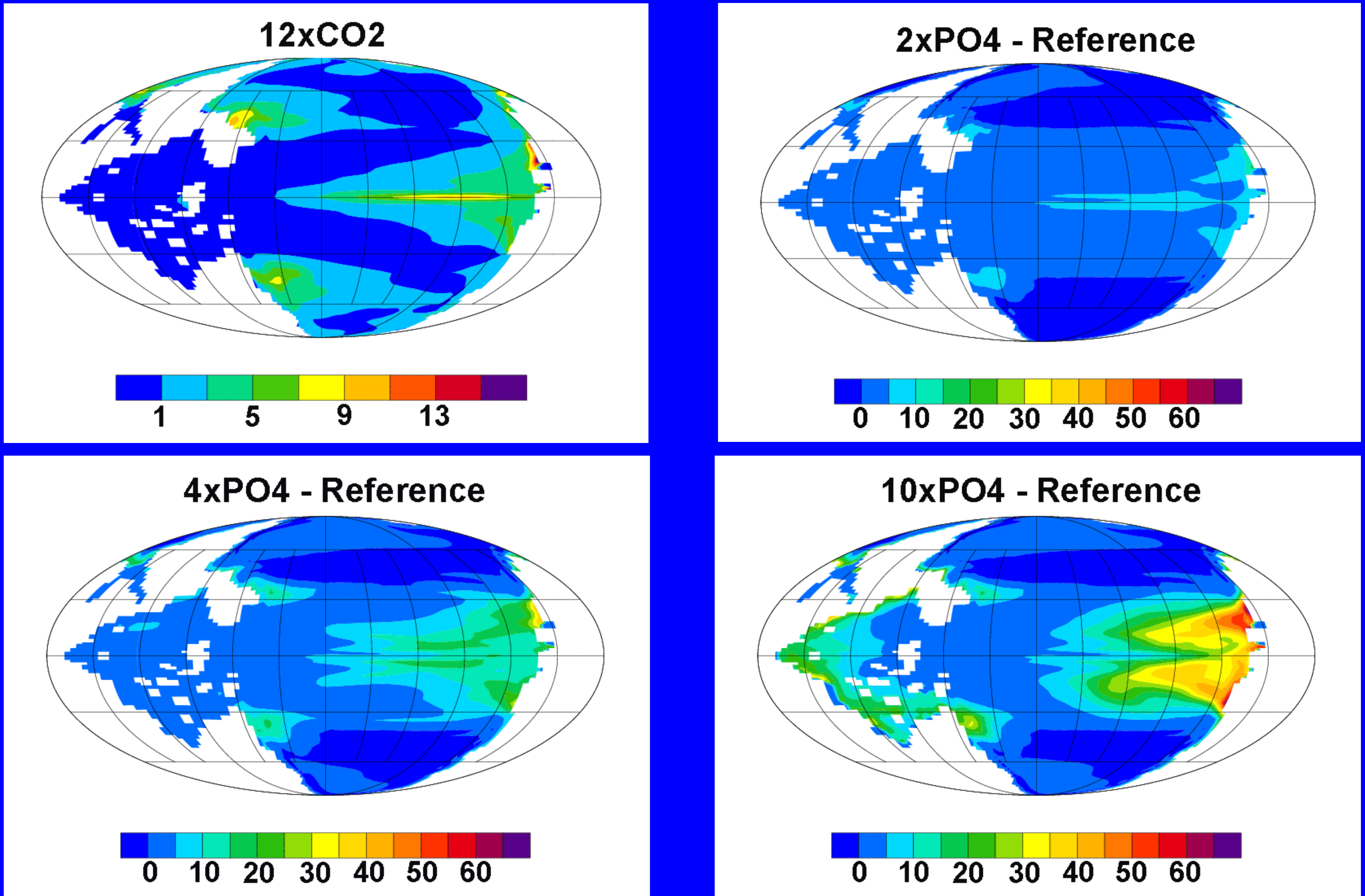






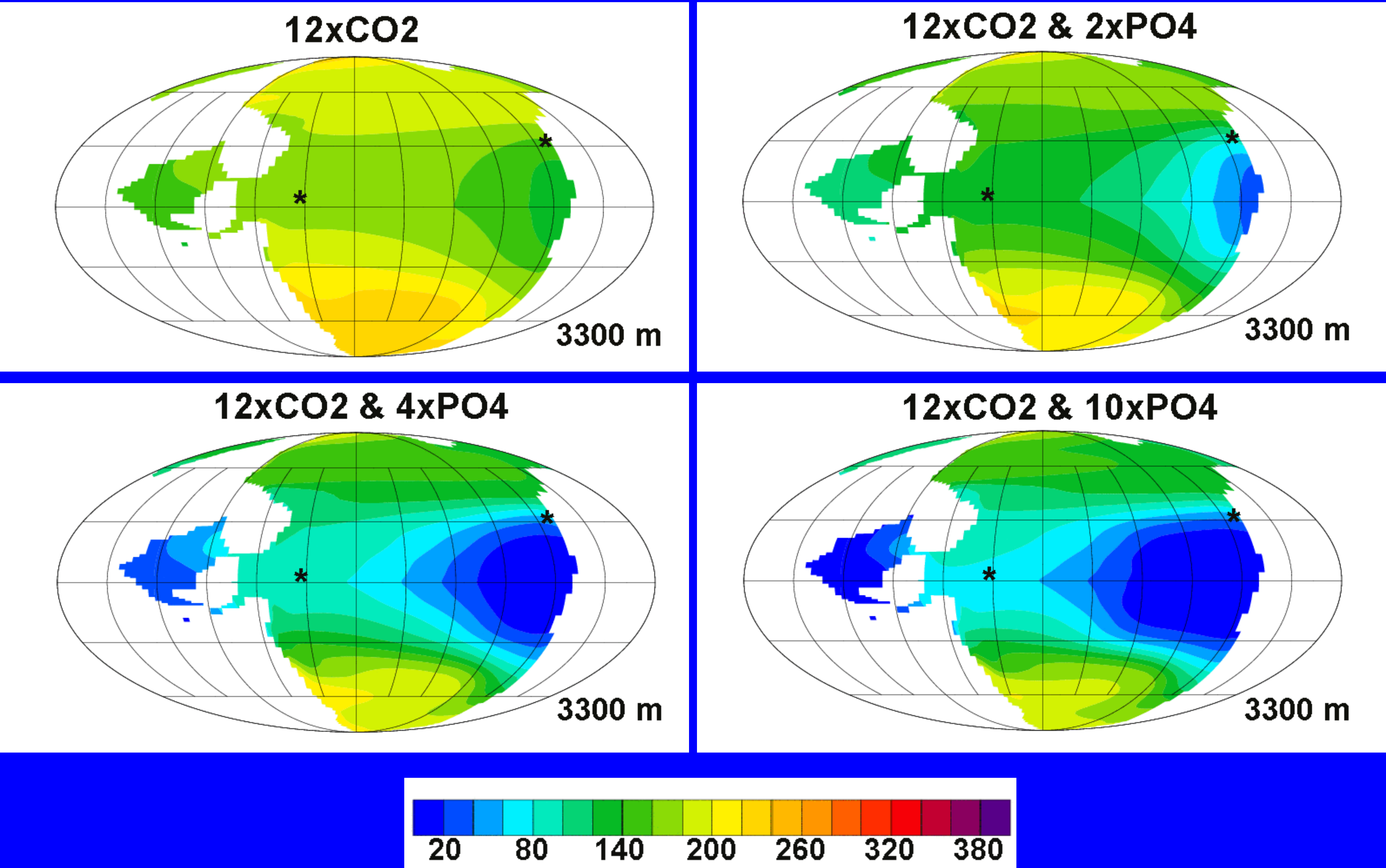
Increased Nutrient Supply

POC Export Production (mol C m^{-2} yr^{-1})



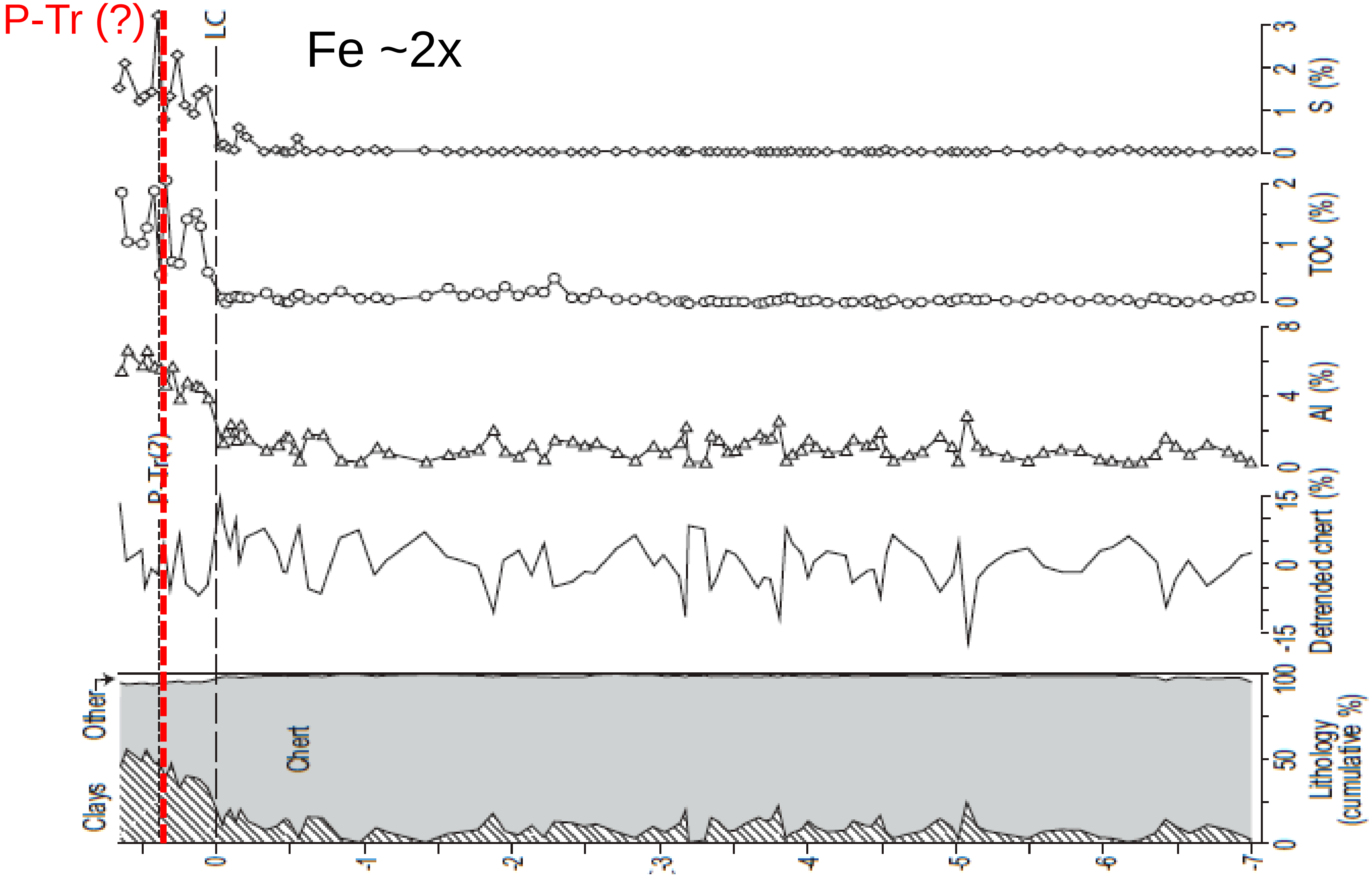
Increased Nutrient Supply

Oxygen at ~3300 m depth (μmol L^{-1})



Redox sensitive metal concentration (6x-8x) at the P-Tr boundary

Fe ~2x

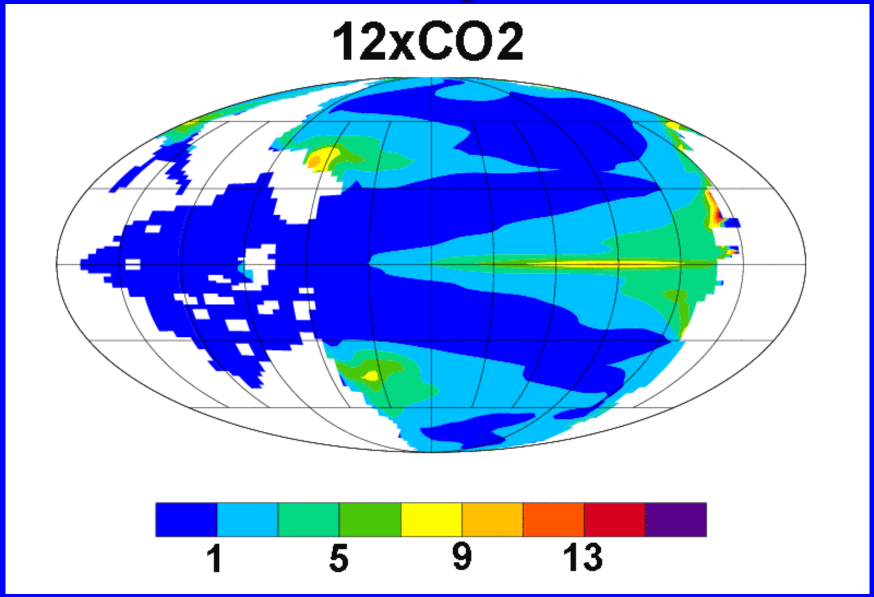


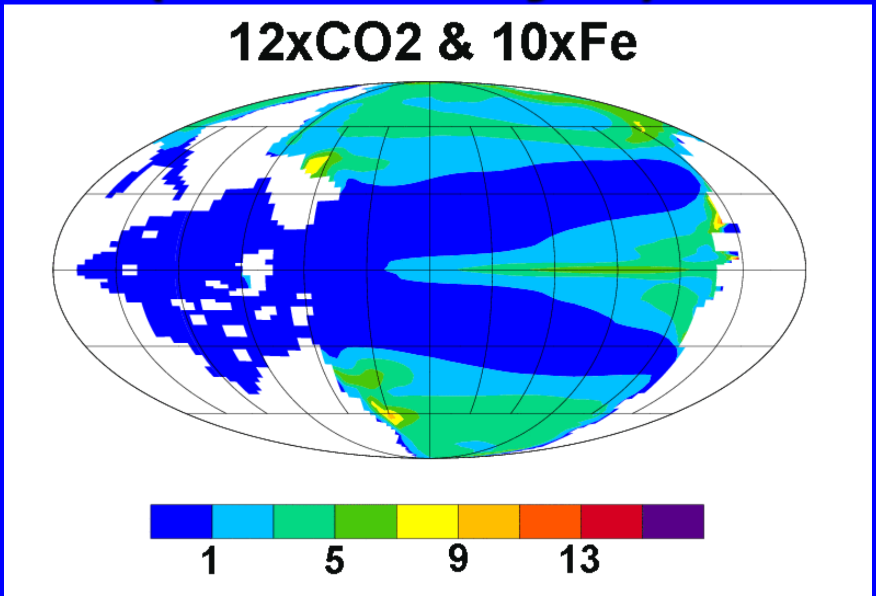
Elevation (m)

Algeo et al., 2010

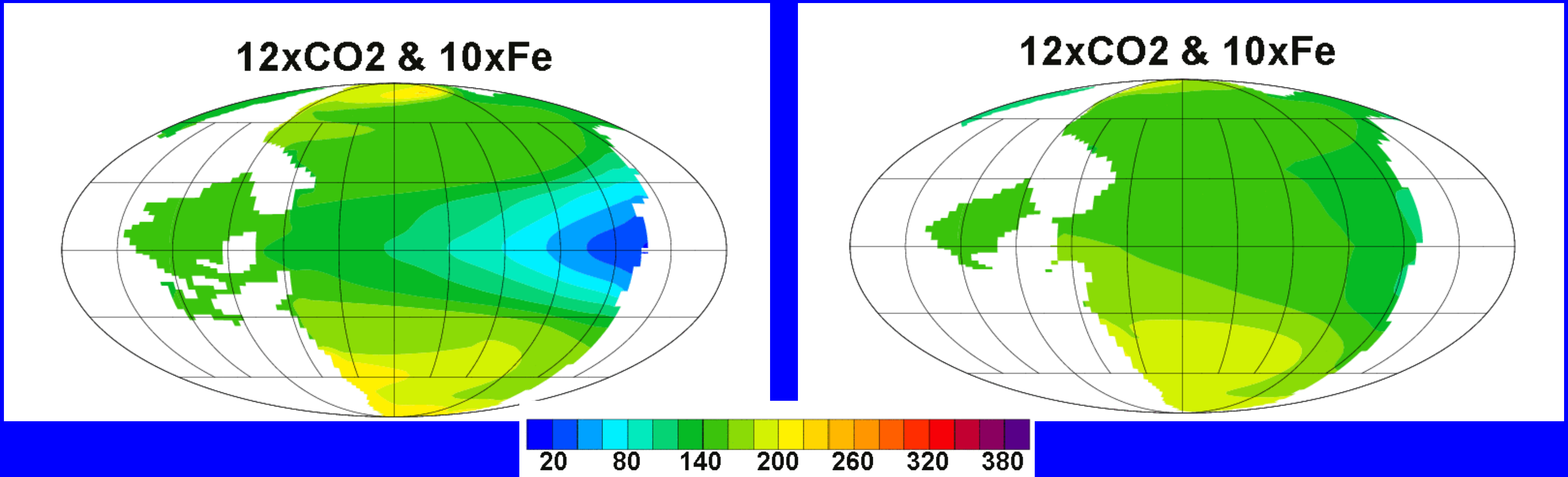
Increased Dust Supply

POC Export Production (mol C m^{-2} yr^{-1})



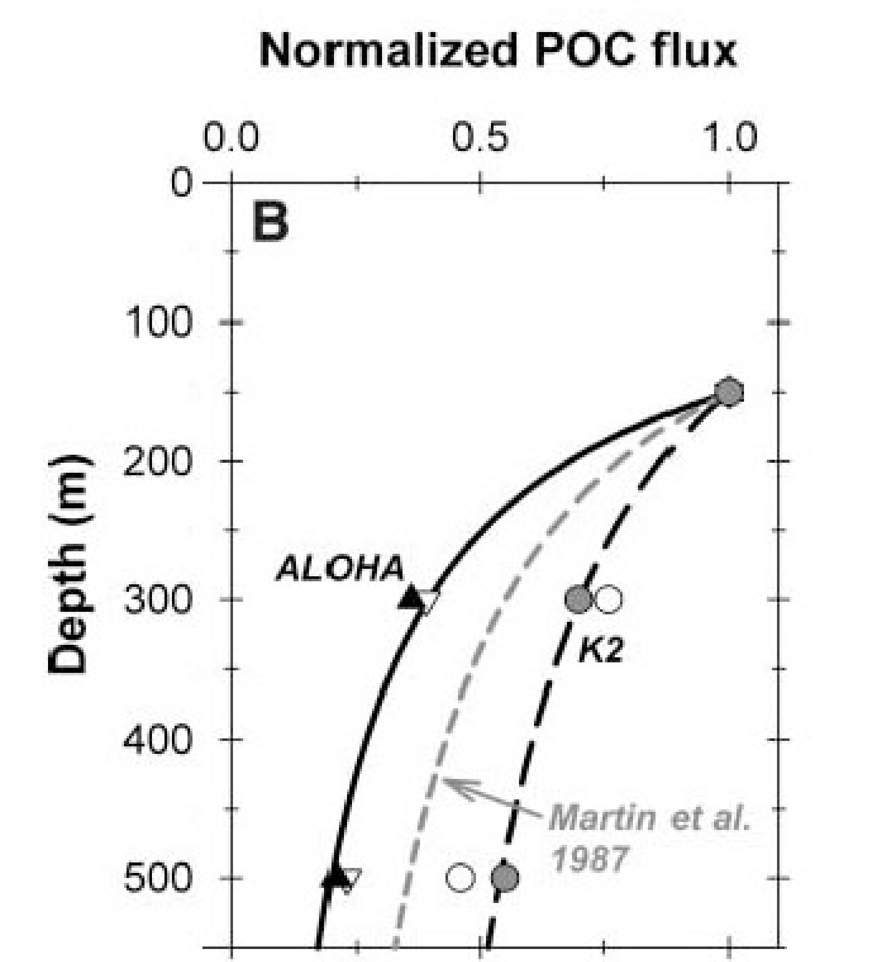


Oxygen at ~1100 and ~3800 m depth (μmol L^{-1})

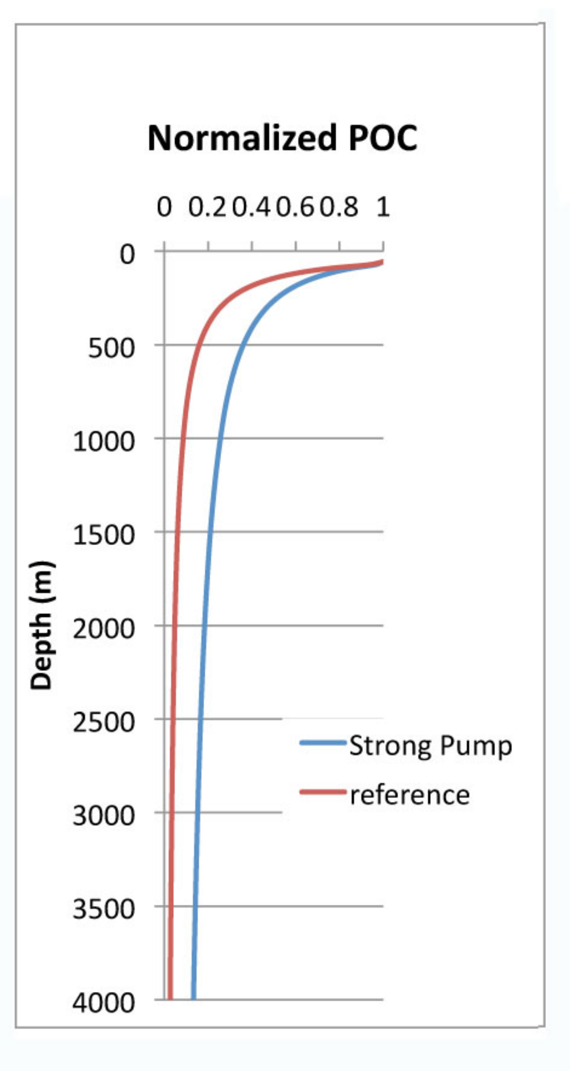


Simulations

- Sensitivity run: Intensified biological pump

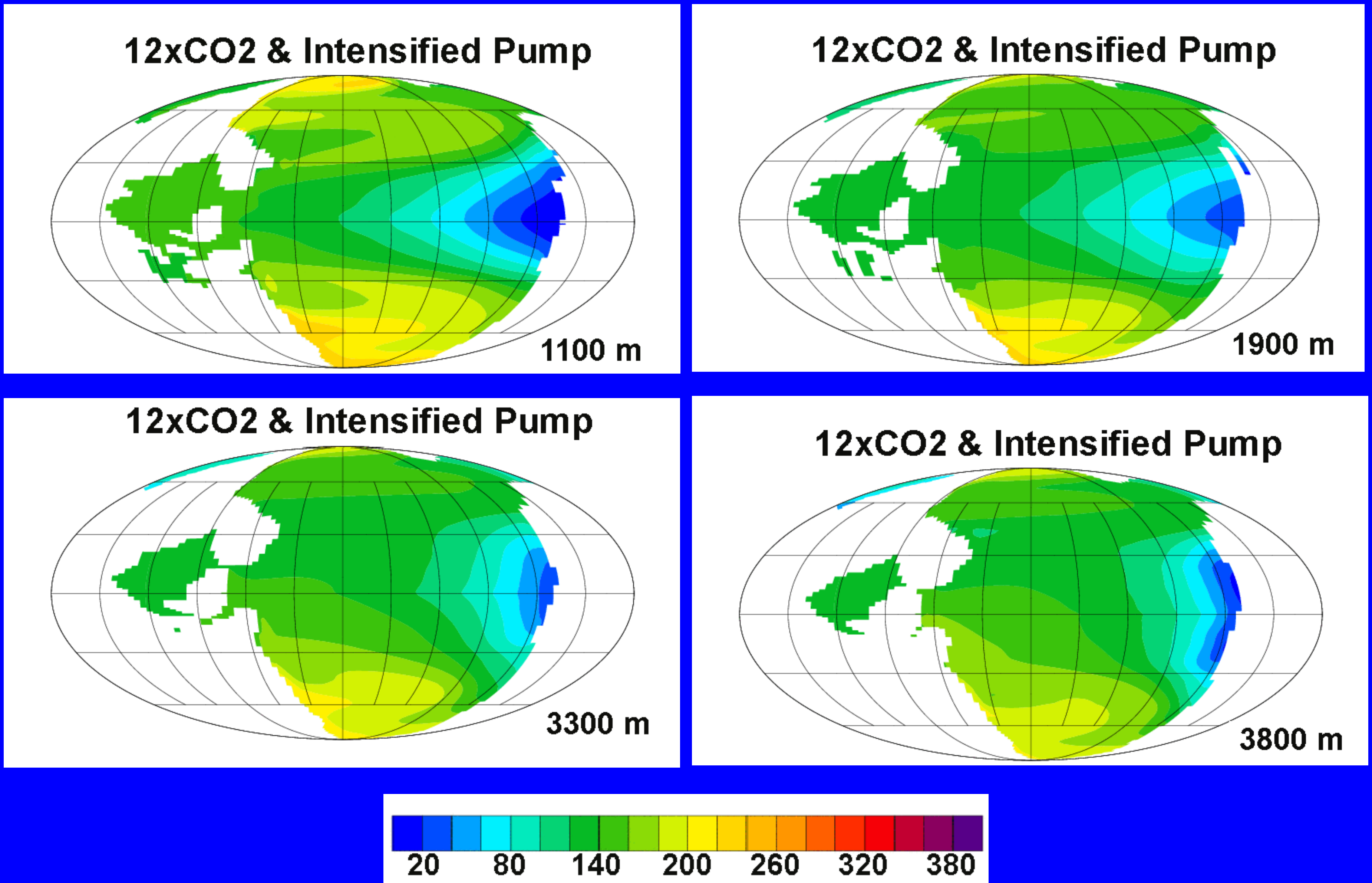


Buesseler et al., 2007



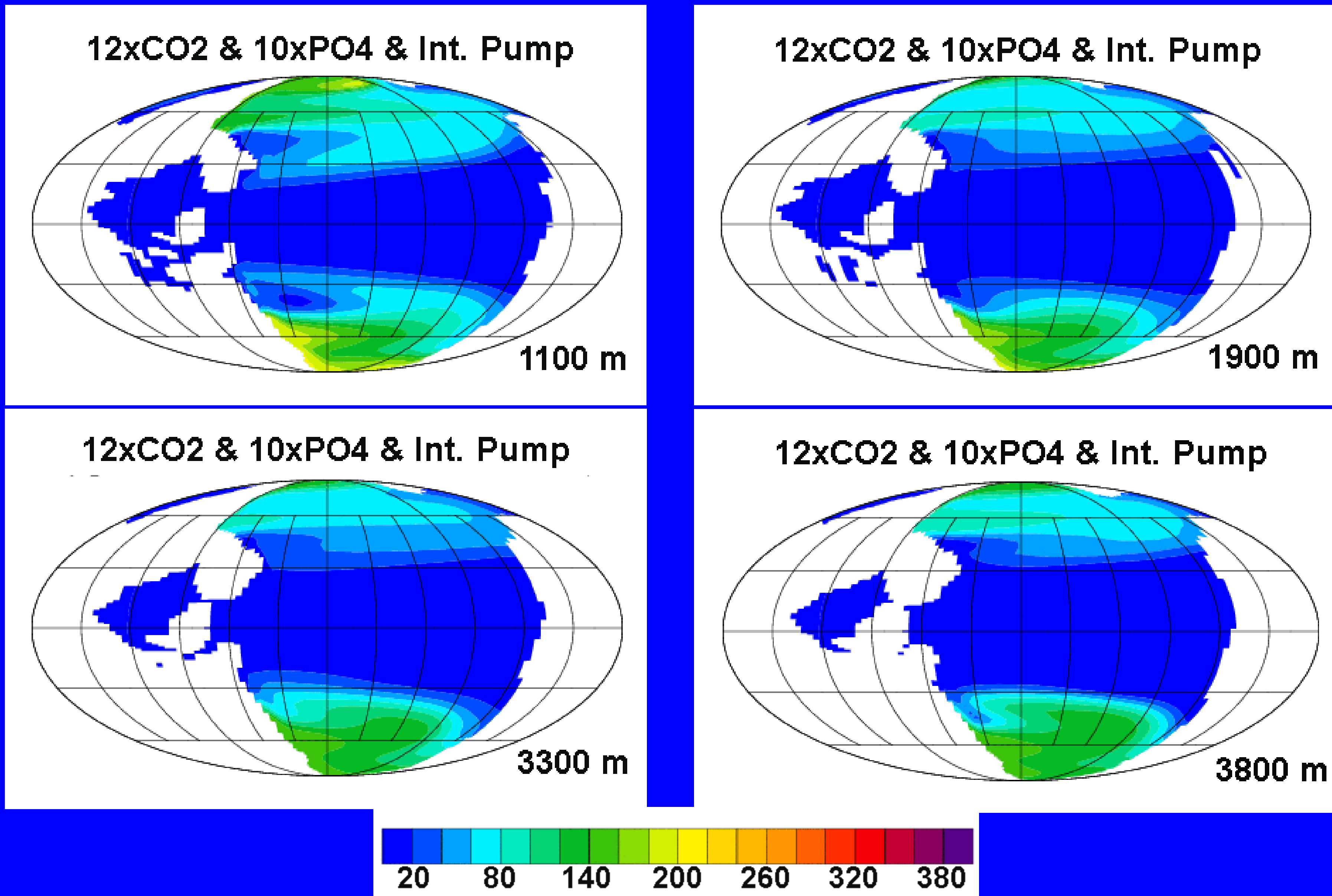
Intensified Pump

Oxygen (μmol L^{-1})



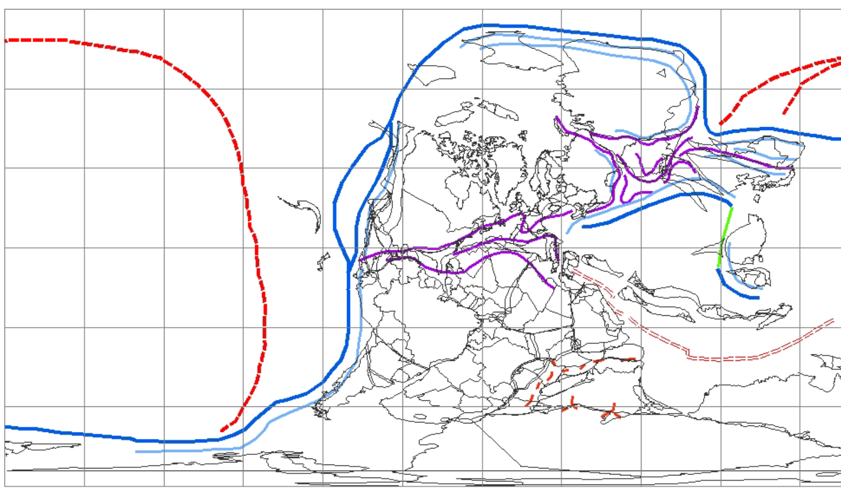
Increased Nutrient Supply and Intensified Pump

Oxygen (μmol L^{-1})

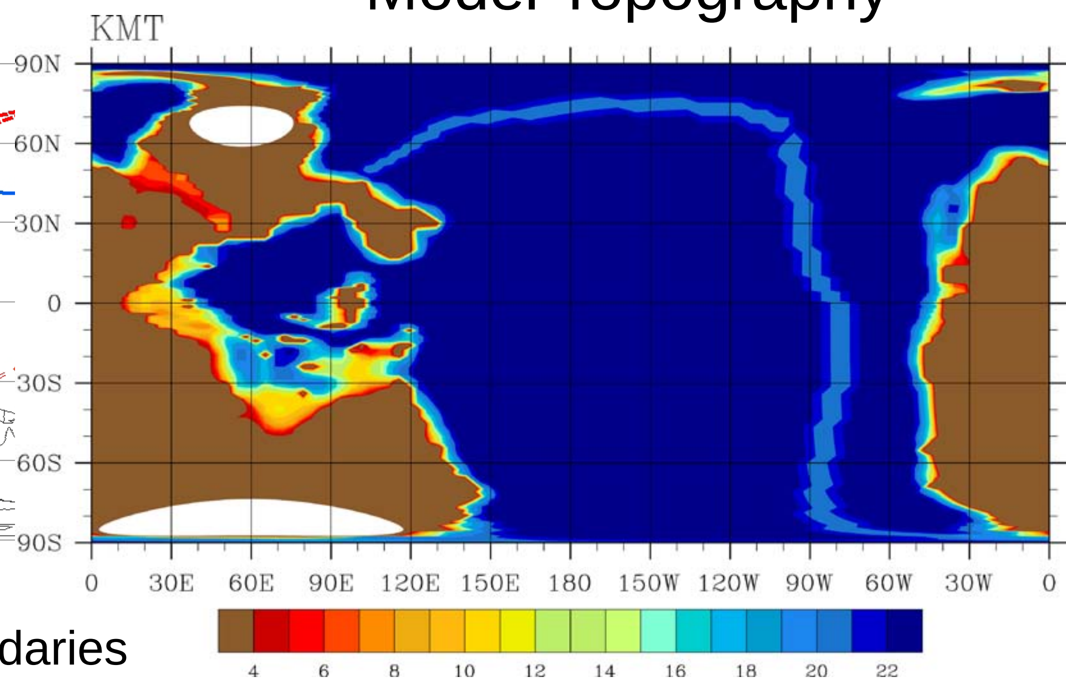


Late Permian Mid-Ocean Ridges

Reconstructed Topography



Model Topography



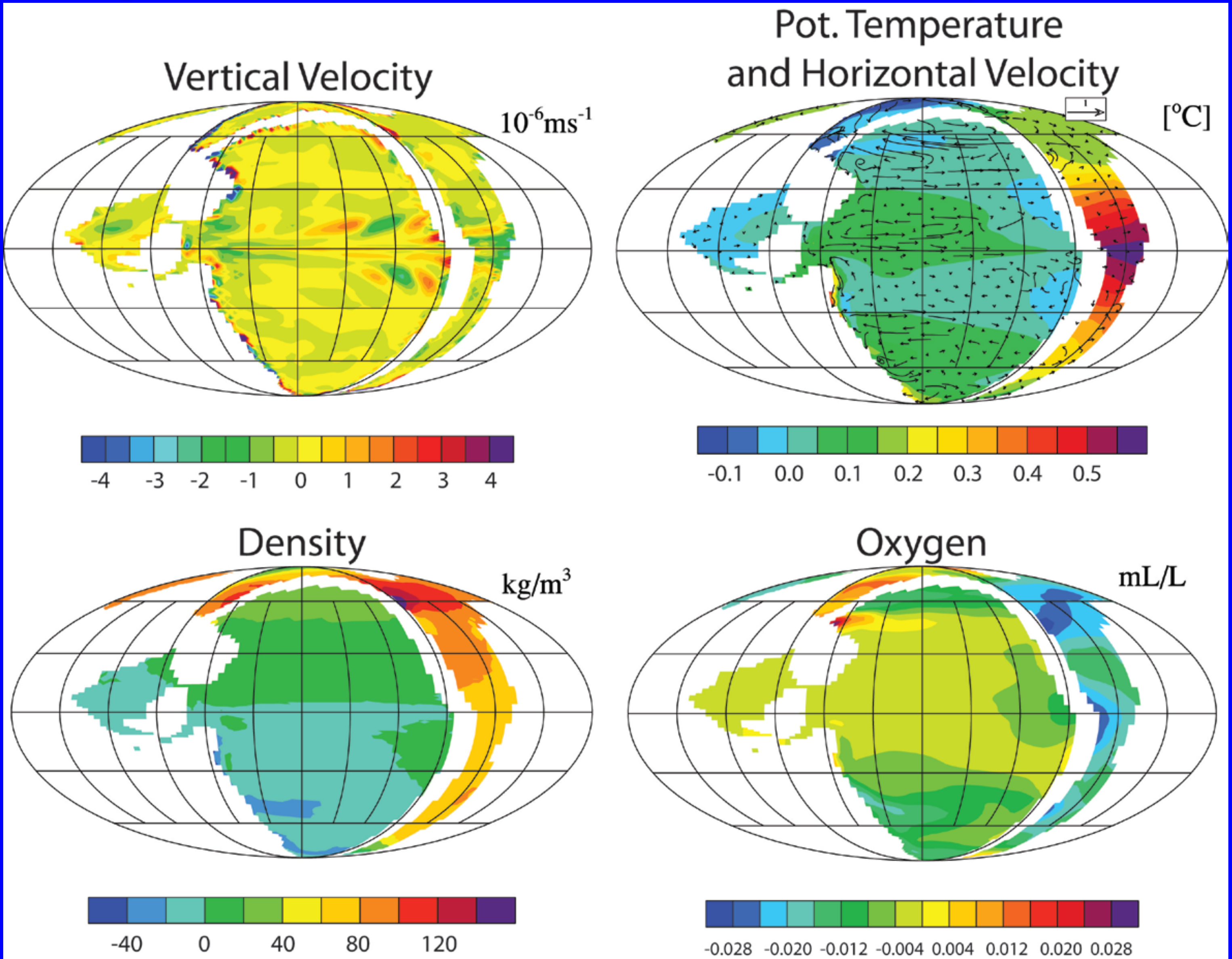
C. Scotese

- Divergent boundaries
- Convergent boundaries
- Transform fault
- Fault belts
- Collision zone

Preliminary Model Ridge

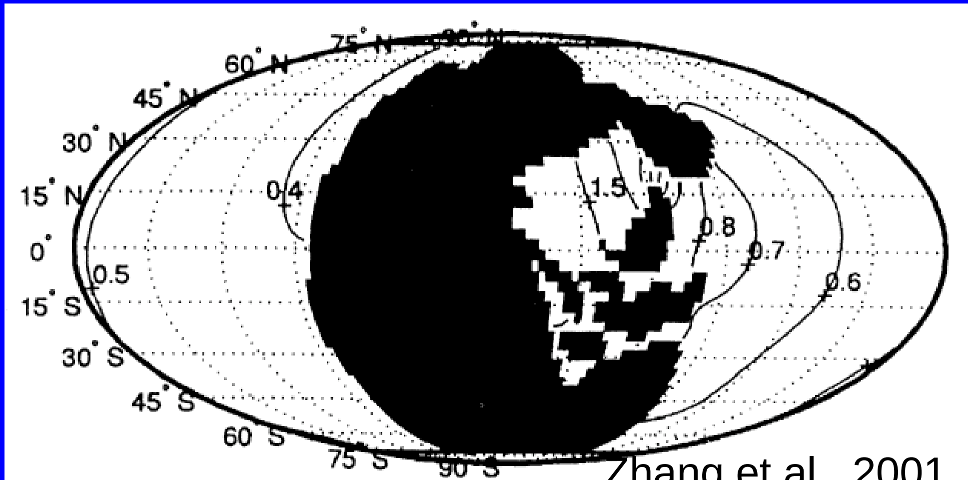
Effect of Mid-Ocean Ridge

Ridge-Baseline Experiment (3000 m)



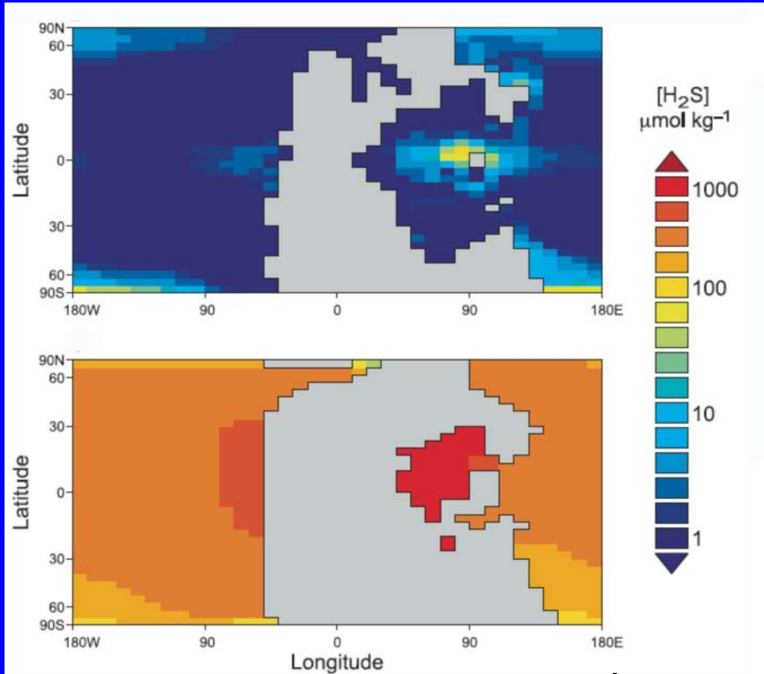
Discussion

- Range of modeled oxygen values consistent with several ocean modeling studies (e.g. Zhang et al., 2001; Hotinski et al., 2001; Winguth & Maier-Reimer, 2005)



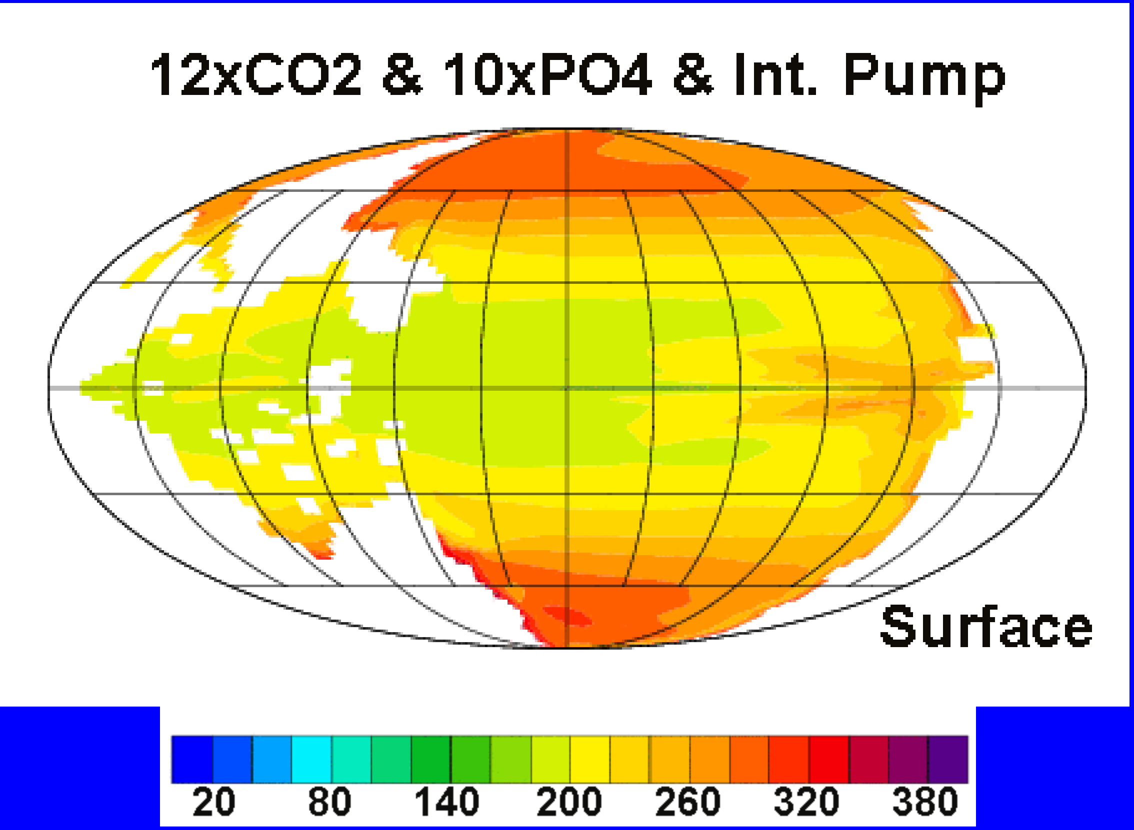
Zhang et al., 2001

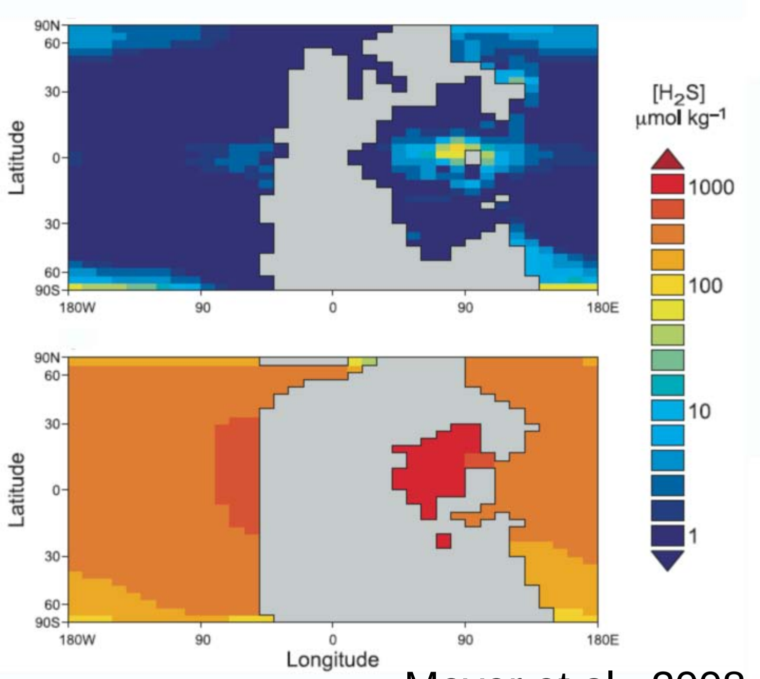
- No ocean-wide anoxia modeled by increase of nutrients alone, even with $10xPO_4$, contrary to study by Meyer et al. (2008)



Meyer et al., 2008

Oxygen ($\mu mol\ L^{-1}$)





Meyer et al., 2008

- Even for the “most extreme” case, the ocean surface layers remain well-oxygenated, contrary to study by Meyer et al. (2008)

Conclusions

- Response of ocean circulation to CO_2-induced warming alone cannot explain the widespread presence of anoxia
- Combination of effects required in order to generate basin-wide anoxia
- Anoxia less widespread than commonly assumed?

Outlook

- Implementation of sulfur cycle and sediment model