

Warm water upwelling in the Cenozoic Era

Yige Zhang

Department of Oceanography
Texas A&M University

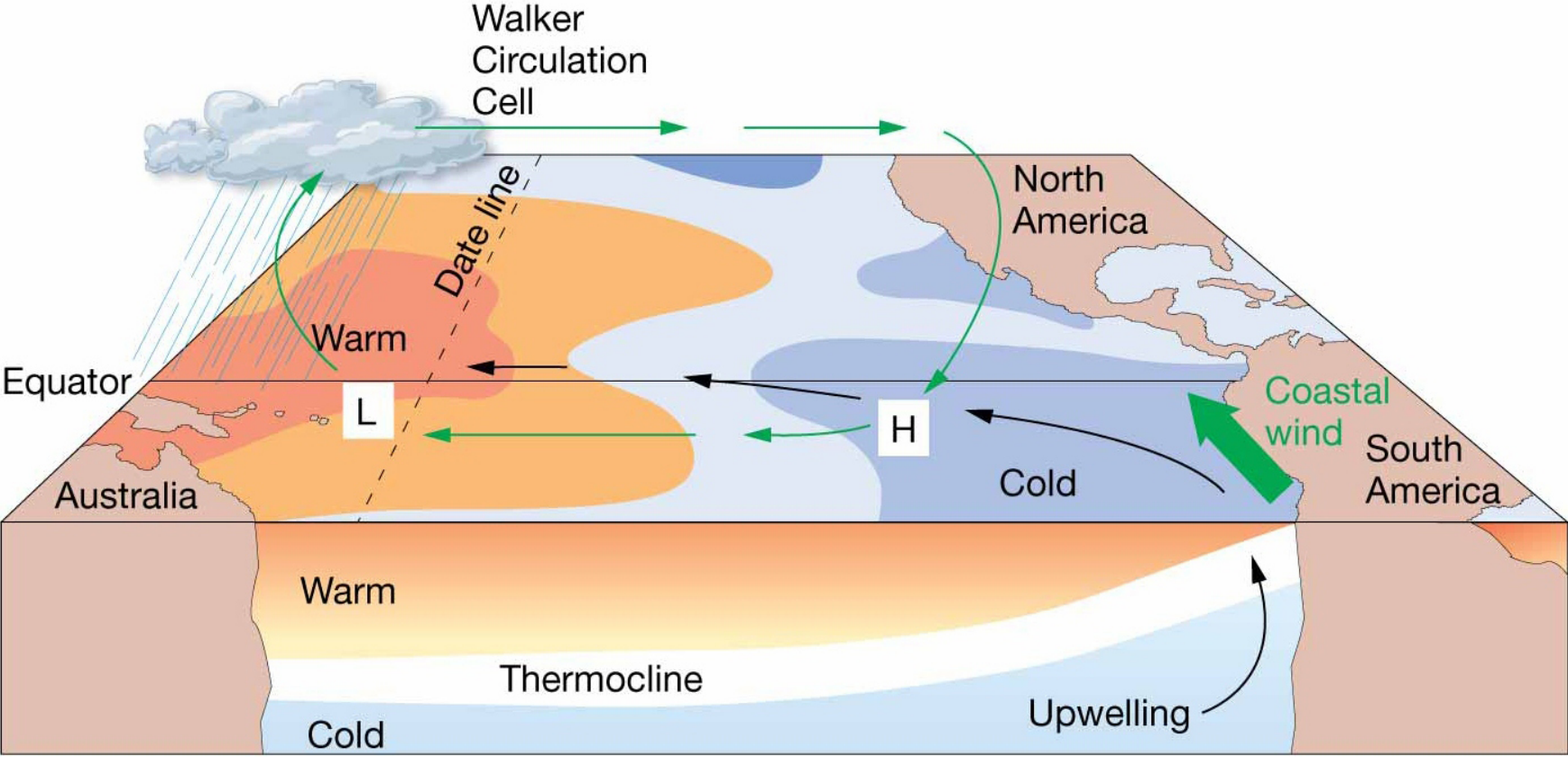
yige.zhang@tamu.edu



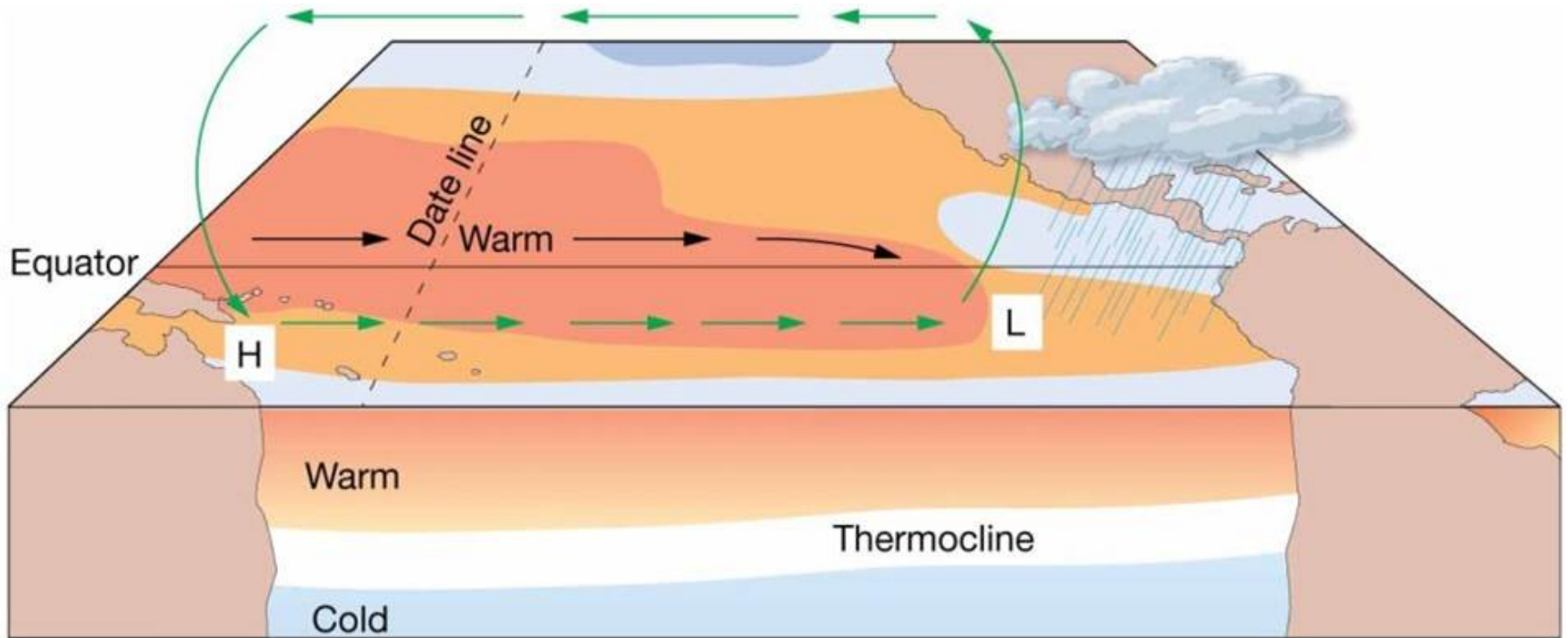
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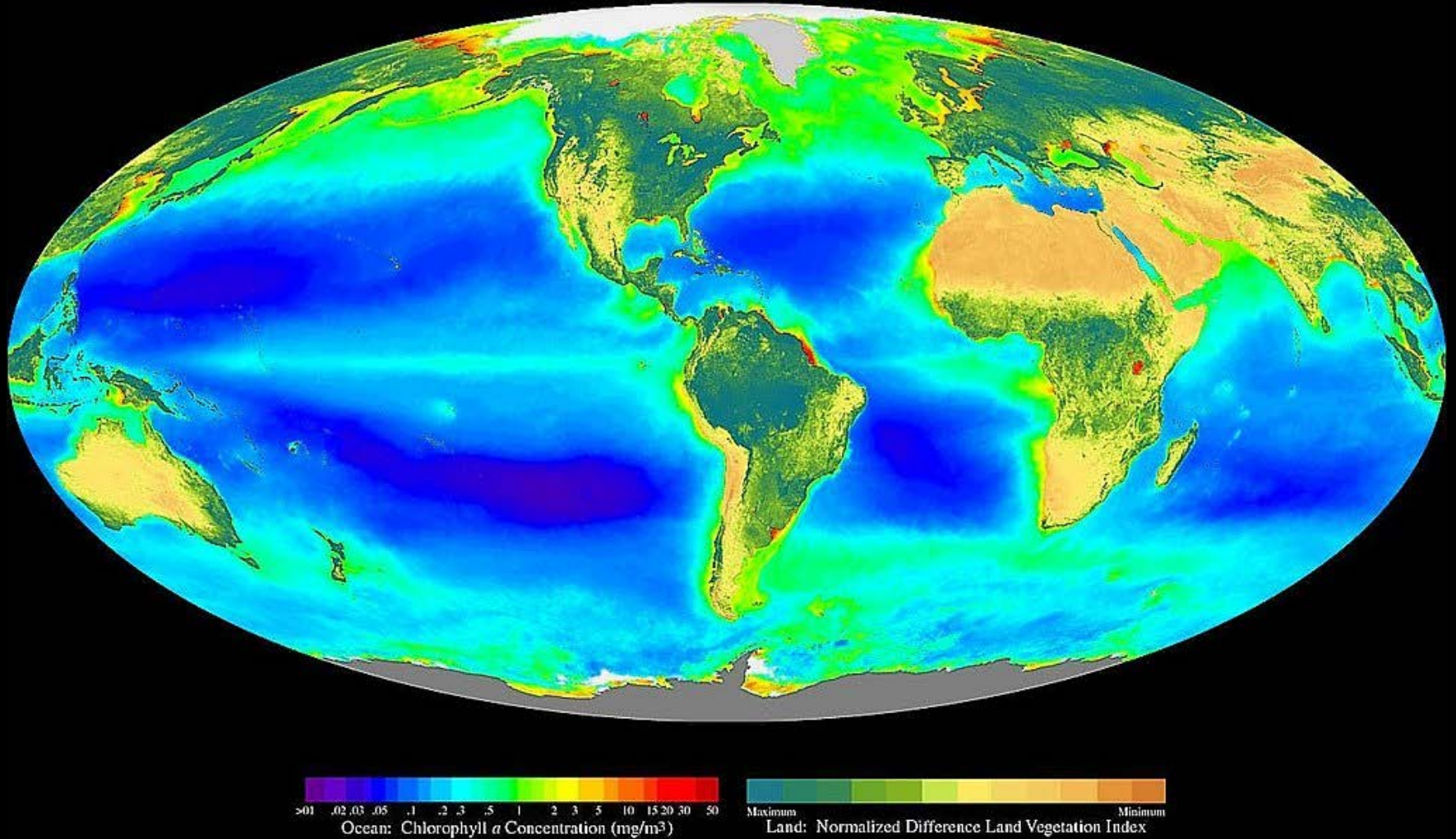
Upwelling and Global Climate



Upwelling and Global Climate



Upwelling and Ocean Productivity



Warming of the Upwelling Region: Mio- Pliocene

Role of tropics in changing the response to Milankovich forcing some three million years ago

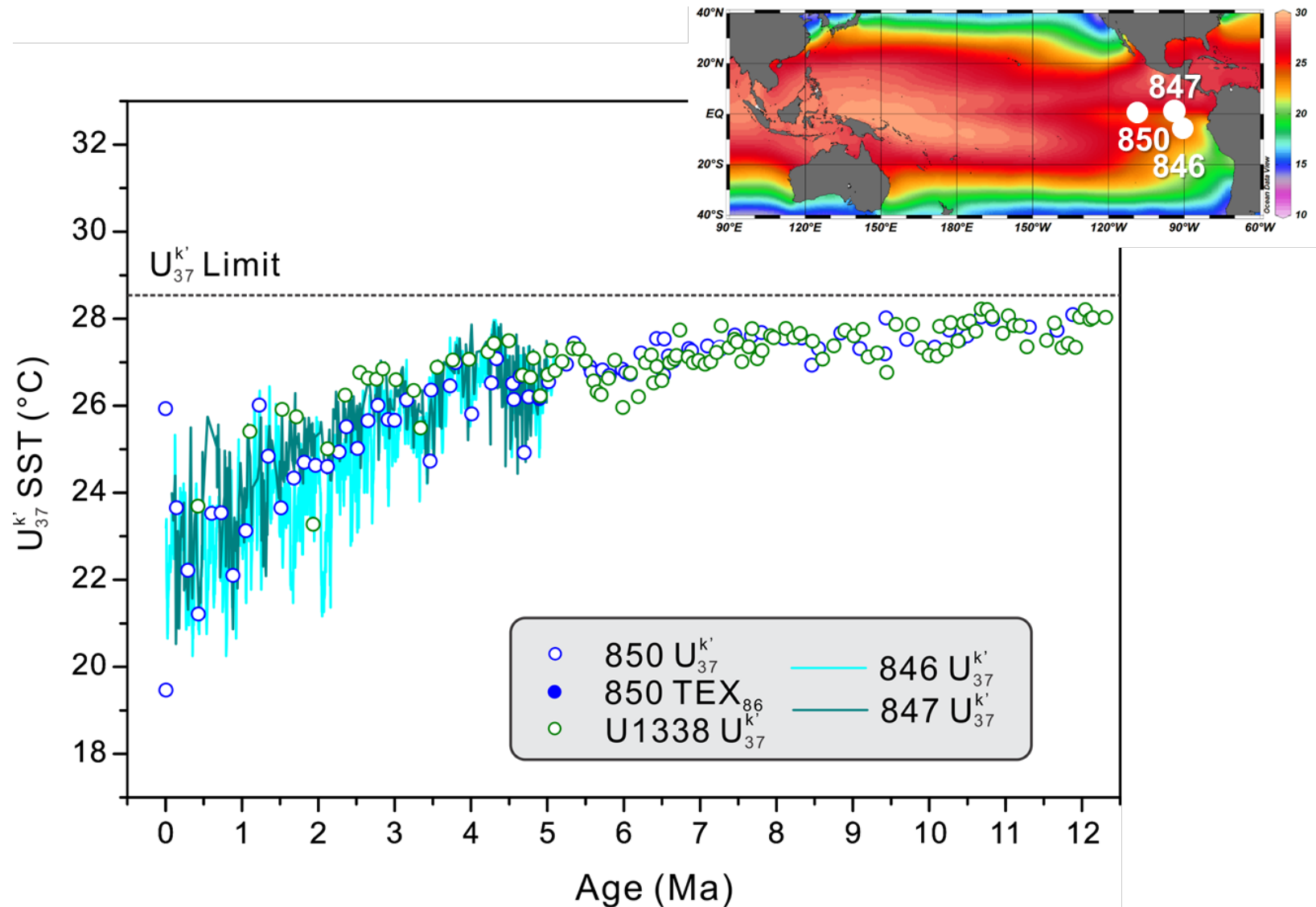
S. George Philander and Alexey V. Fedorov

Department of Geosciences, Princeton University, Princeton, New Jersey, USA

Received 9 August 2002; revised 27 December 2002; accepted 27 February 2003; published 5 June 2003.

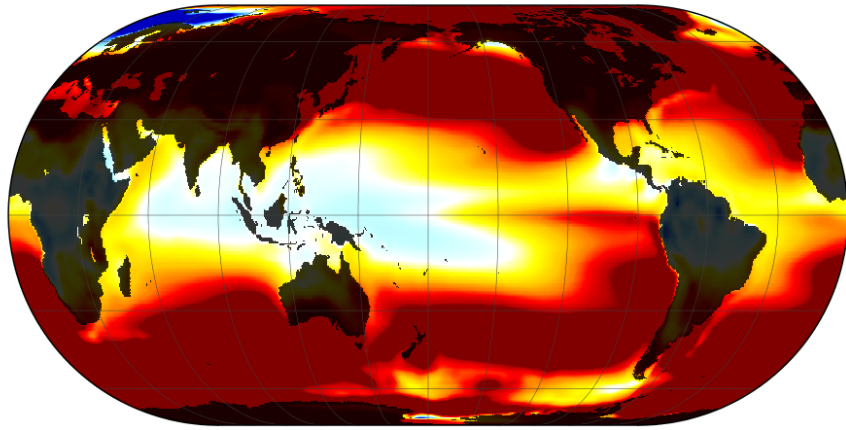
remained the same. The latter change in the Earth's response can be explained by hypothesizing that **the global cooling during the Cenozoic affected the thermal structure of the ocean; it caused a gradual shoaling of the thermocline. Around 3 Ma the thermocline was sufficiently shallow for the winds to bring cold water from below the thermocline to the surface in certain upwelling regions.** This brought into play feedbacks involving ocean-atmosphere interactions of the type associated with El Niño and also mechanisms by which high-latitude

Warming of the Upwelling Region: Mio- Pliocene



Lawrence et al., 2006, Dekens, et al., 2007
Rosselle et al., 2013, Zhang et al., 2014

Warming of the Upwelling Region: Mio- Pliocene

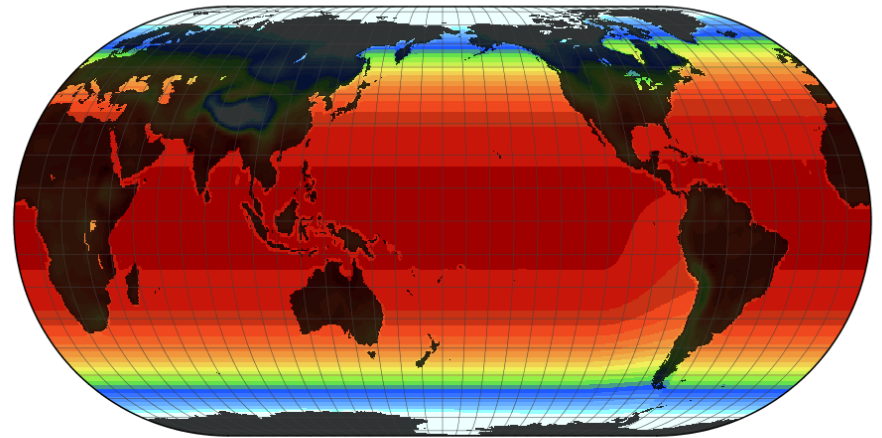


Vast warm pool change in surface temperature (oC)

◀ -5 -3 -1 1 3 5 ▶

Present Day

Pliocene



Vast warm pool temperature (K)

◀ 273 279 285 291 297 303 ▶

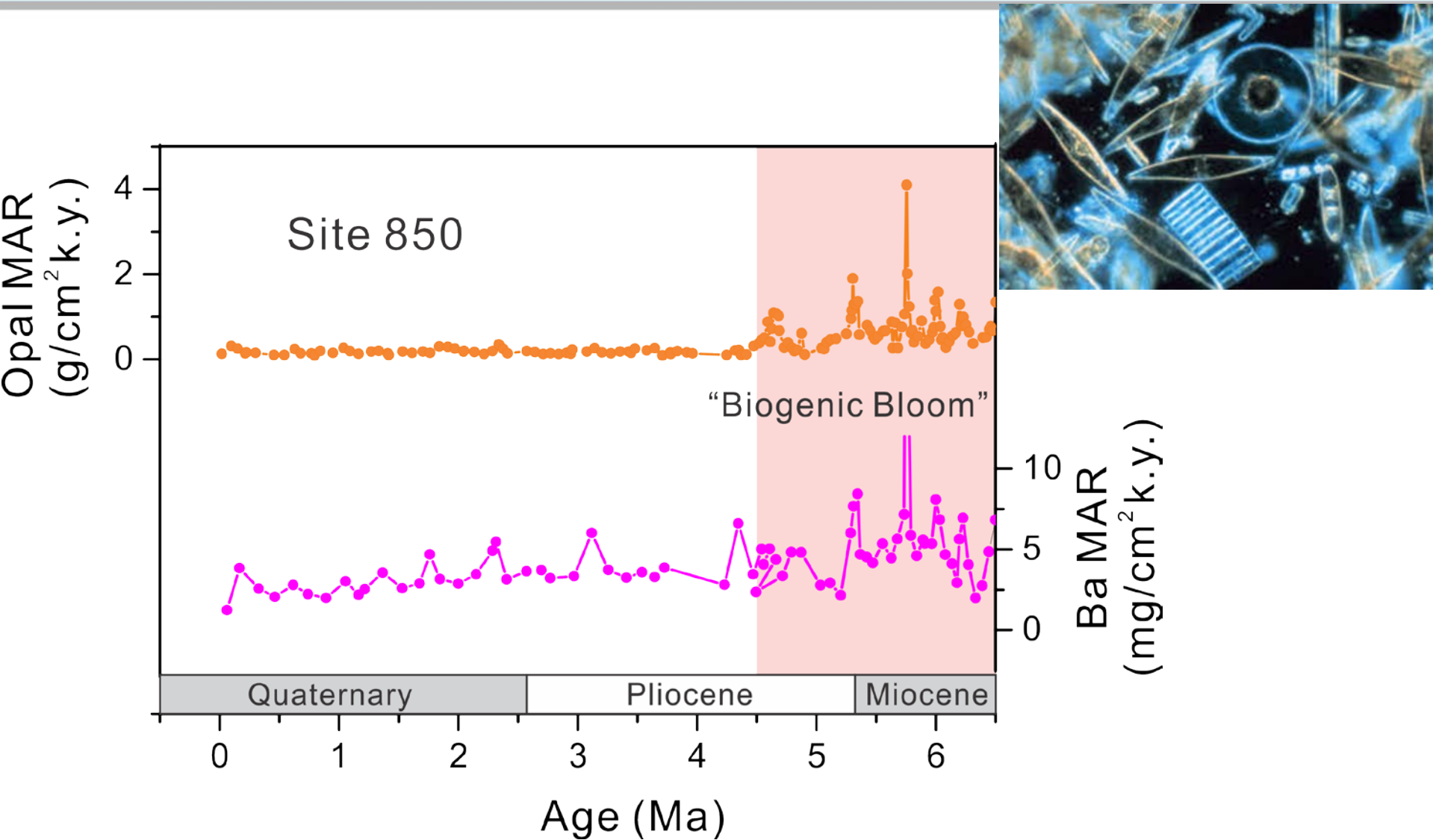
Warming of the Upwelling Region: Mio- Pliocene



5.4.1 Tropical Modes

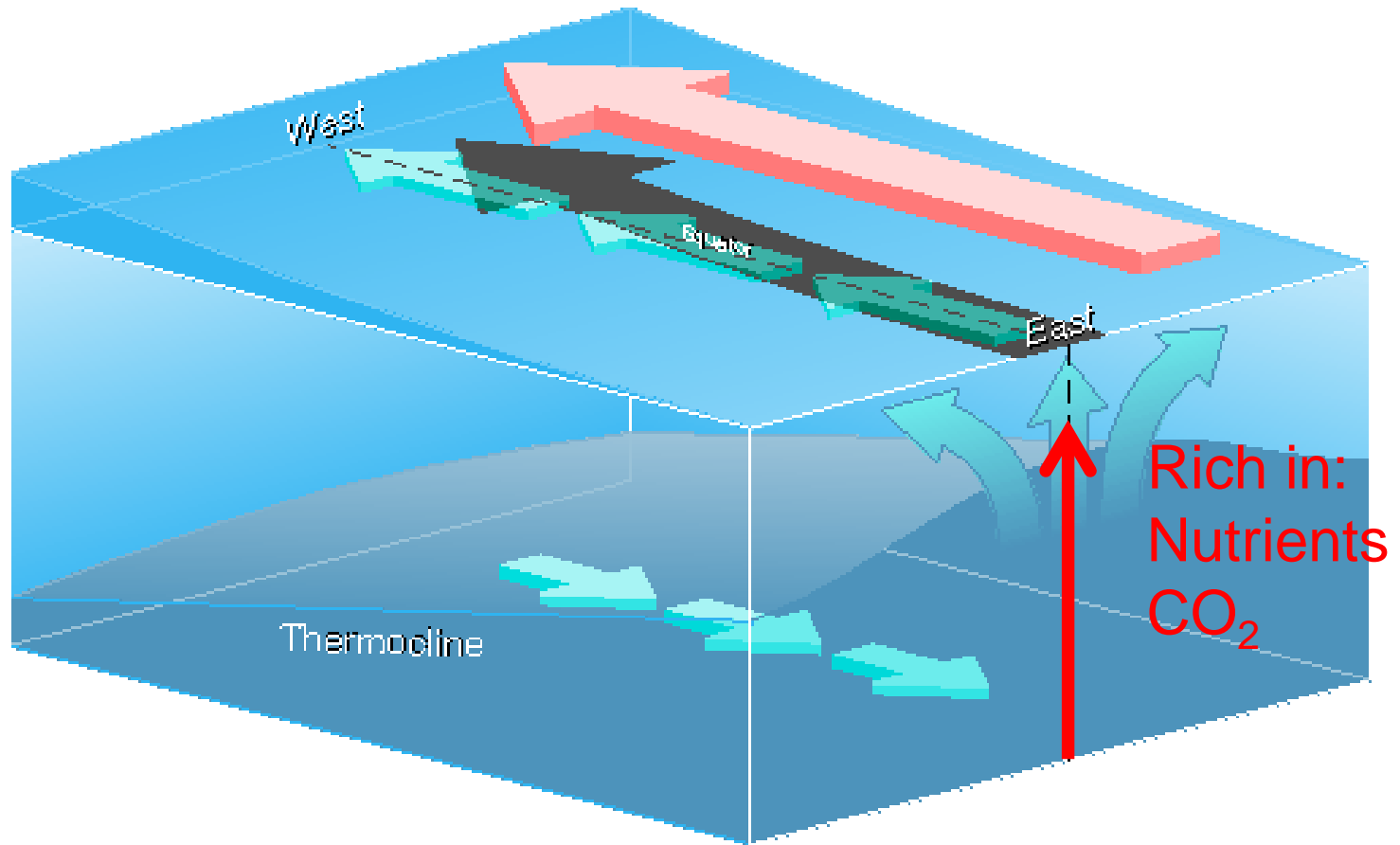
During the MPWP, climate conditions in the equatorial Pacific were characterized by weaker zonal (Wara et al., 2005) and cross-equatorial (Steph et al., 2010) SST gradients, consistent with the absence of an eastern equatorial cold tongue. This state still supported interannual

Biogenic Accumulation Rate in the EEP

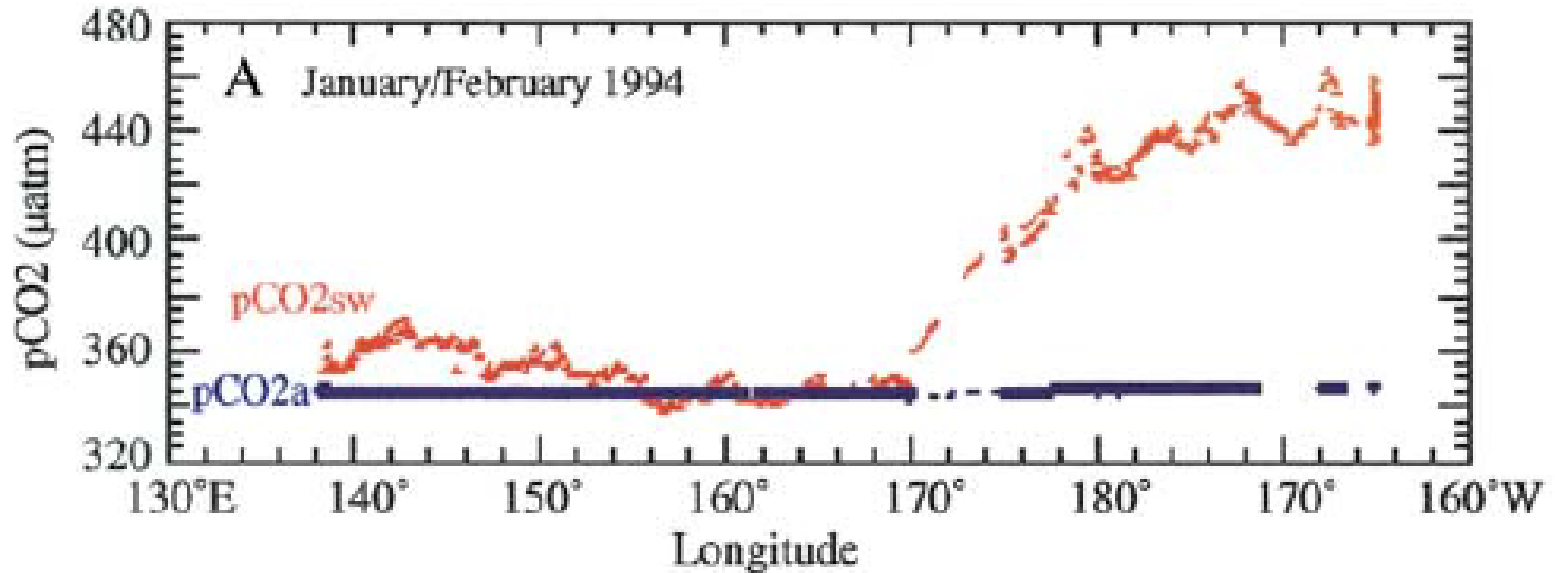


Farrell et al., 1995; Schroeder et al., 1997

Tracing Equatorial Upwelling by CO₂

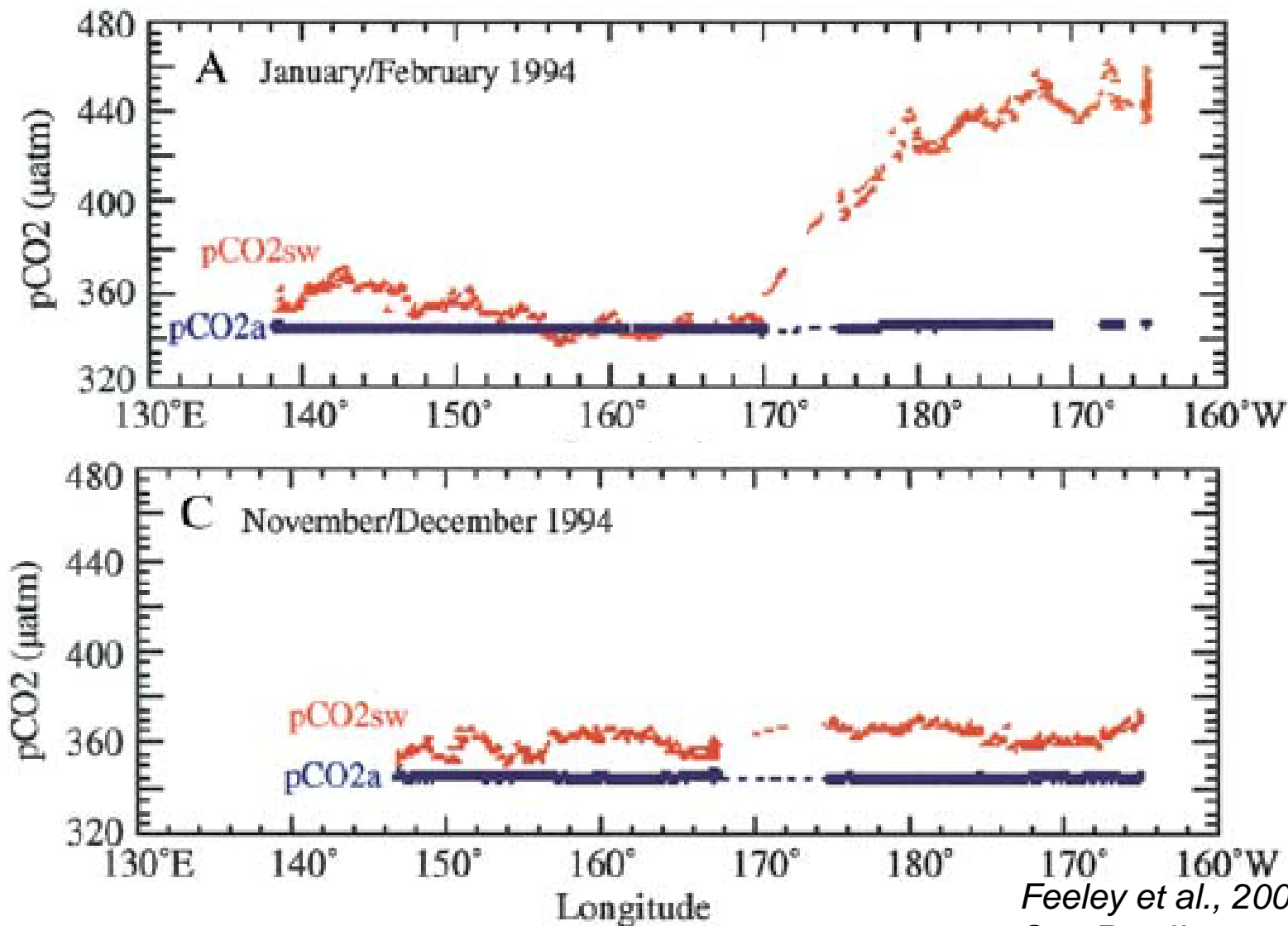


$p\text{CO}_{2(\text{sw})}$ Distribution Across the Equatorial Pacific



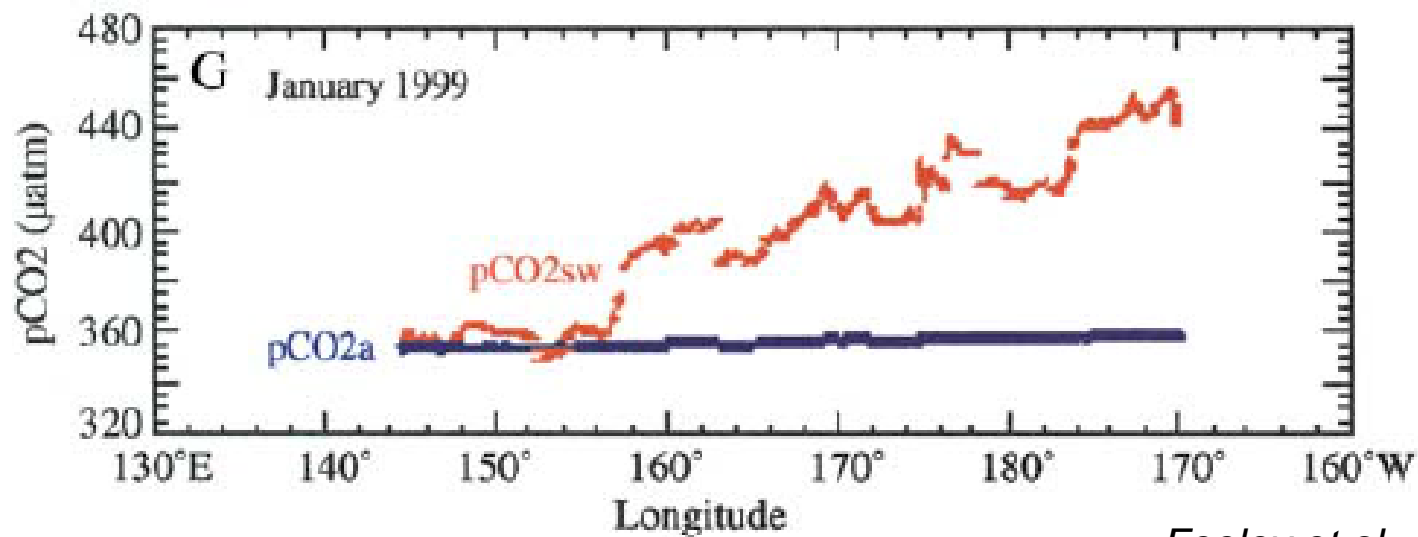
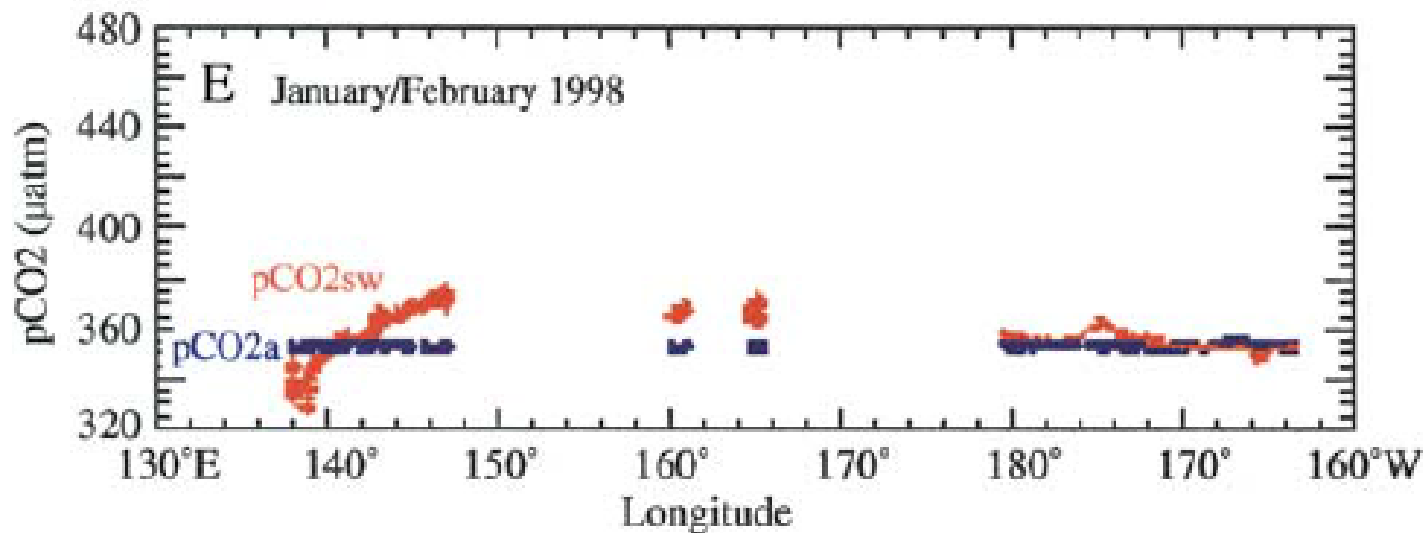
Feeley et al., 2002, Deep-Sea Res II

$p\text{CO}_{2(\text{sw})}$ Distribution Across the Equatorial Pacific



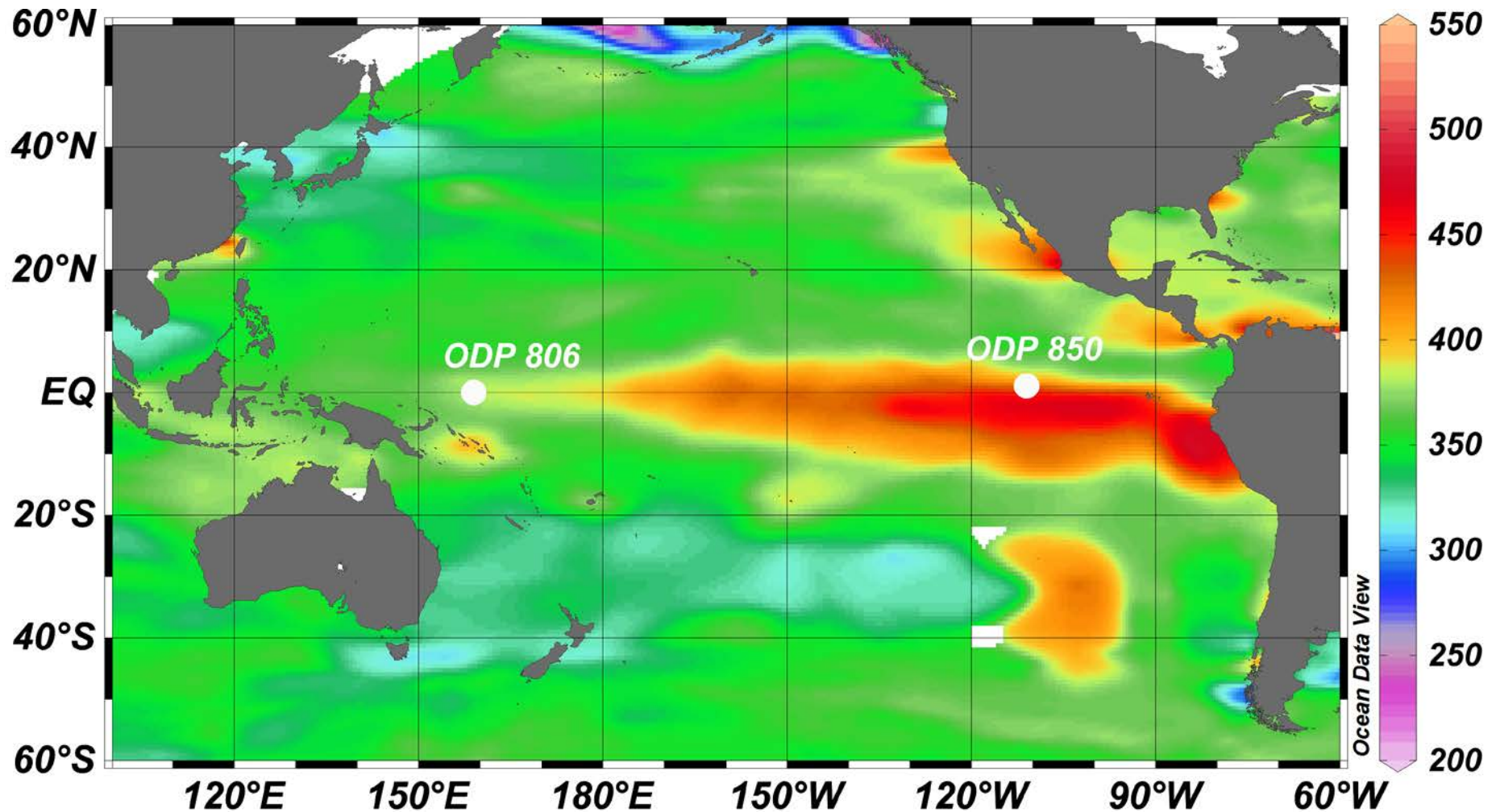
Feeley et al., 2002, Deep-Sea Res II

$p\text{CO}_{2(\text{sw})}$ Distribution Across the Equatorial Pacific



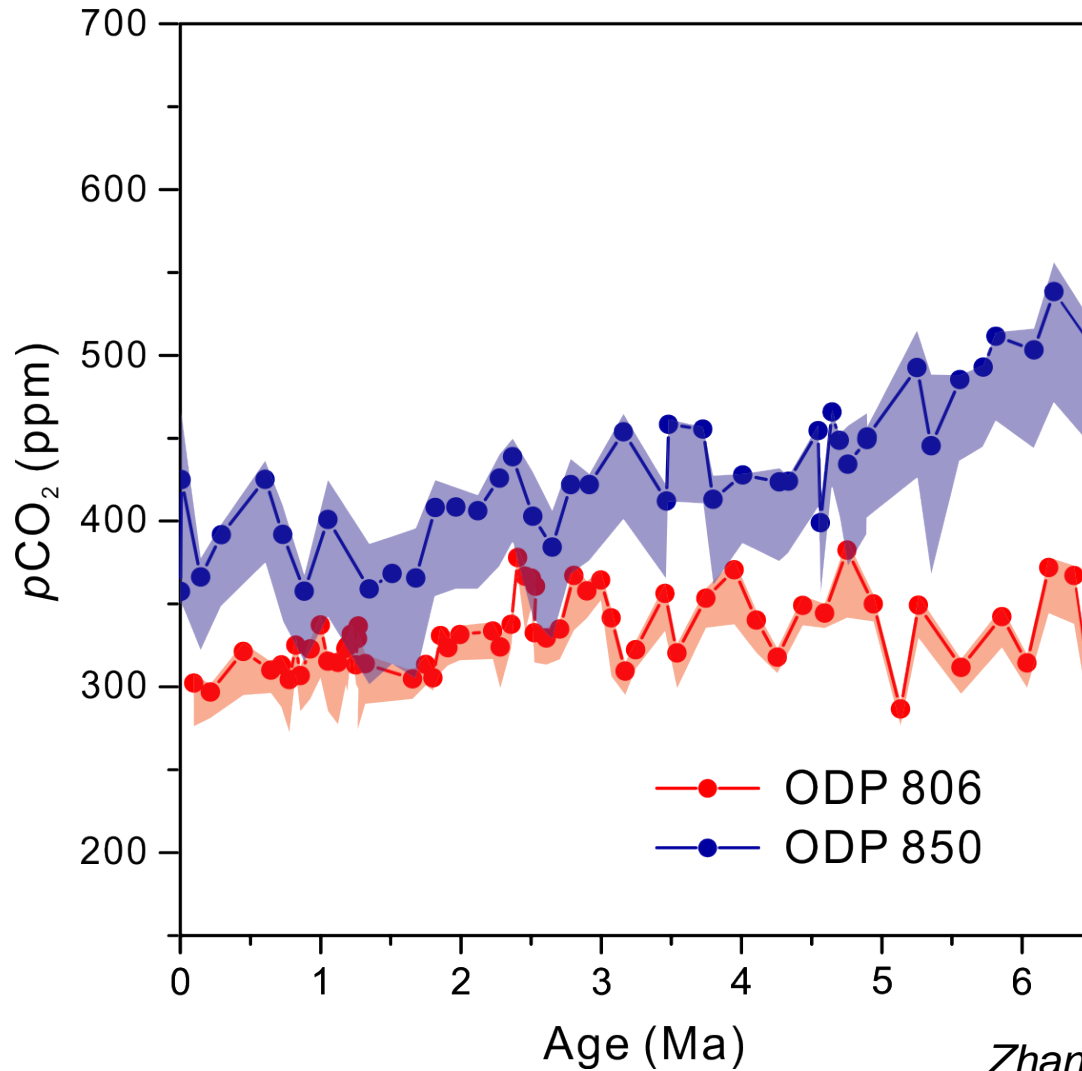
*Feeley et al., 2002,
Deep-Sea Res II*

Sites for $p\text{CO}_2$ reconstructions



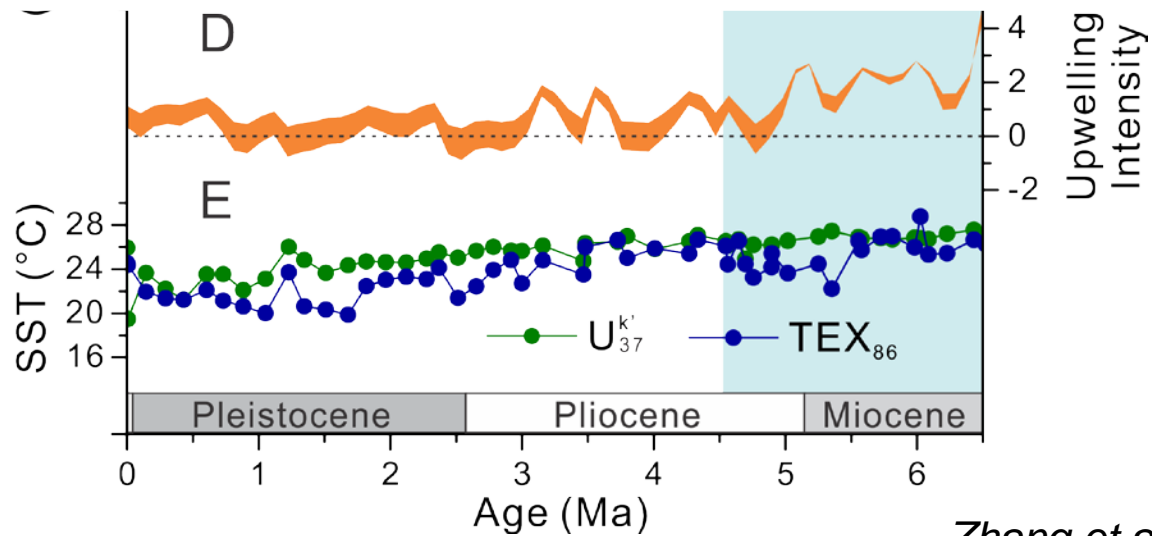
CO₂ Data from Takahashi et al., 2009, Deep Sea Res. II

CO₂ Across Equatorial Pacific



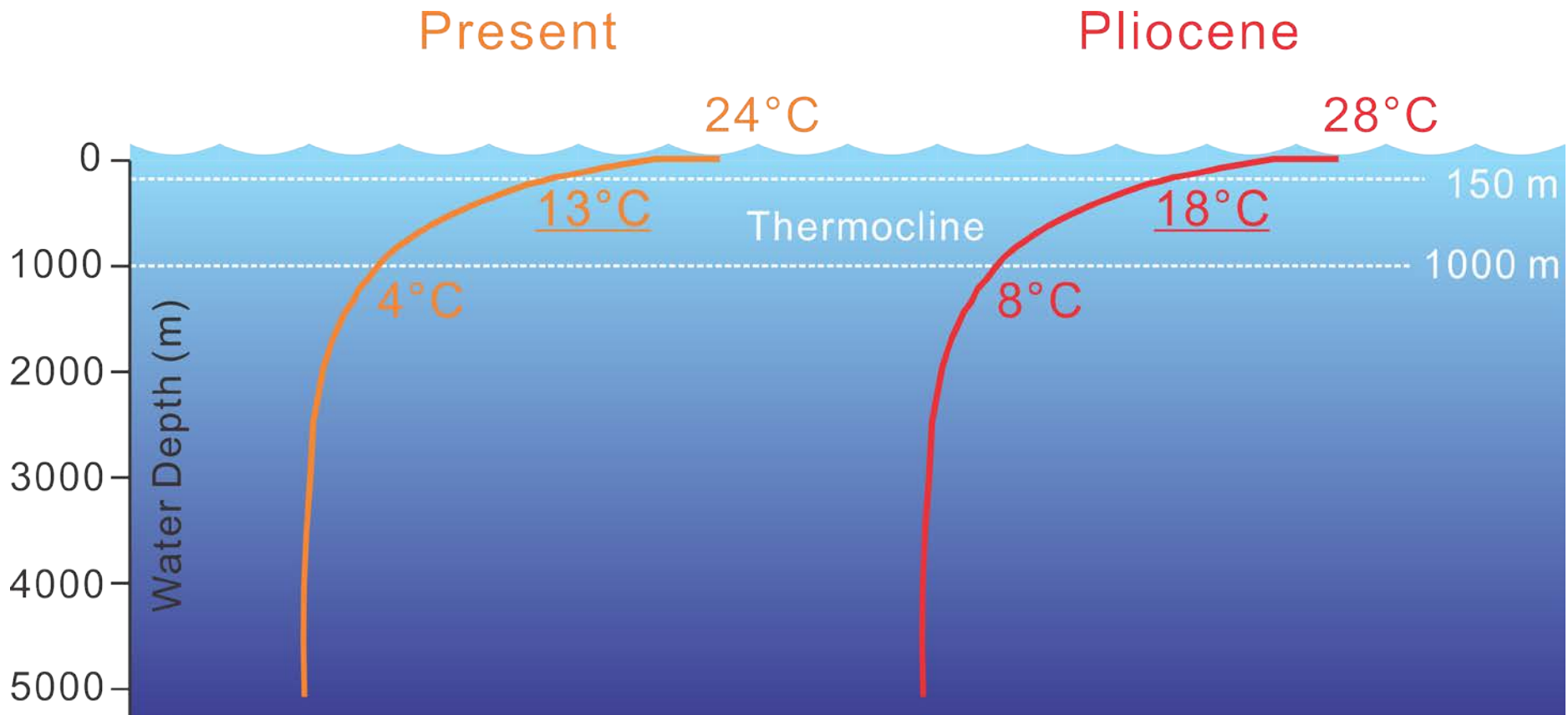
Zhang et al., 2017,
Earth Planet. Sci. Lett.

Excess CO₂ and Biogenic MAR



Zhang et al., 2017,
Earth Planet. Sci. Lett.

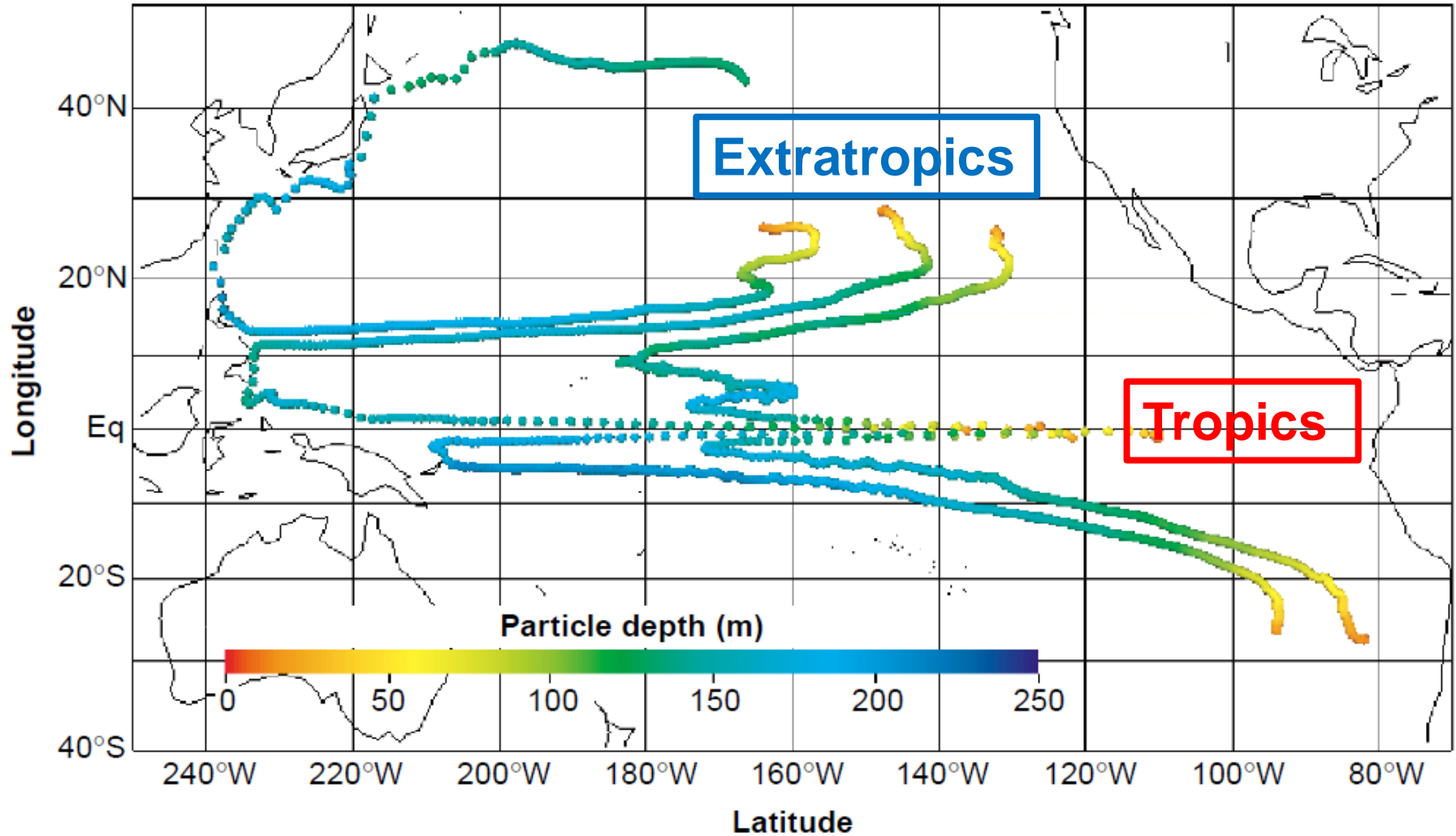
Warm Water Upwelling: How?



Zhang et al., 2017, *Earth Planet. Sci. Lett.*

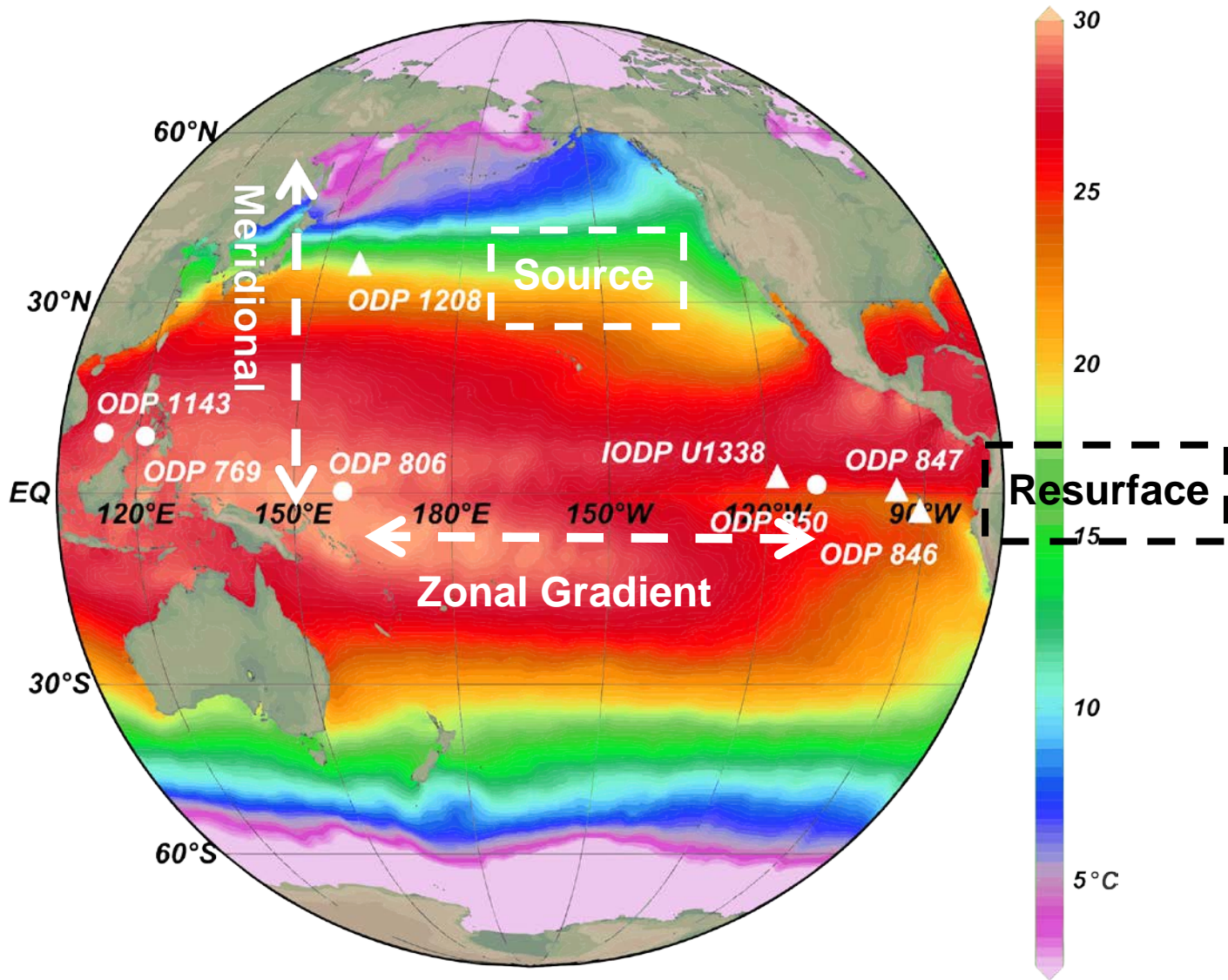
Subsurface and bottom water from Ford et al., 2012 and Lear et al. 2015

Warm Water Upwelling: Why?



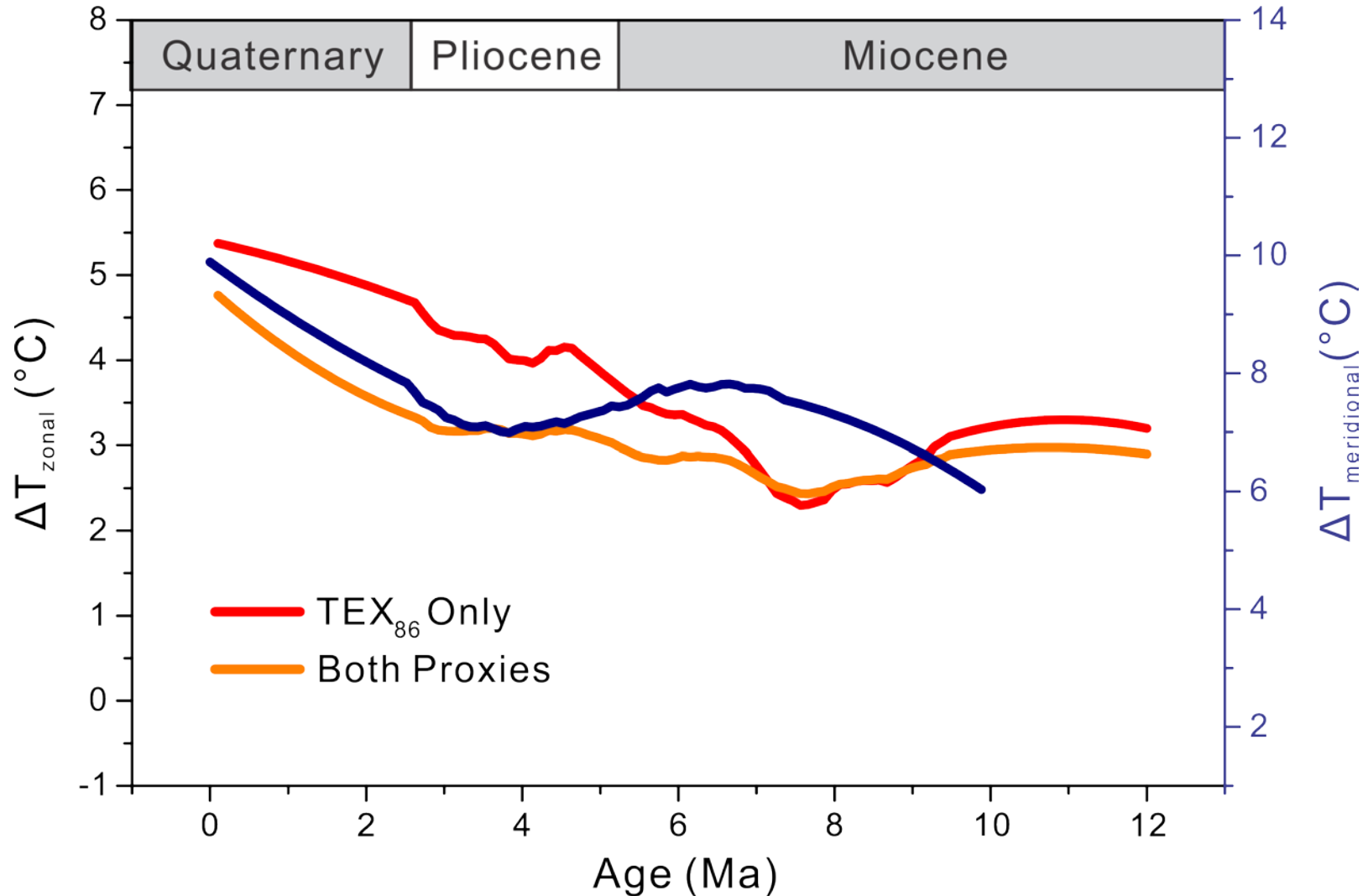
Gu and Philander, 1997, Science

Outcropping of high-latitude waters at EEP



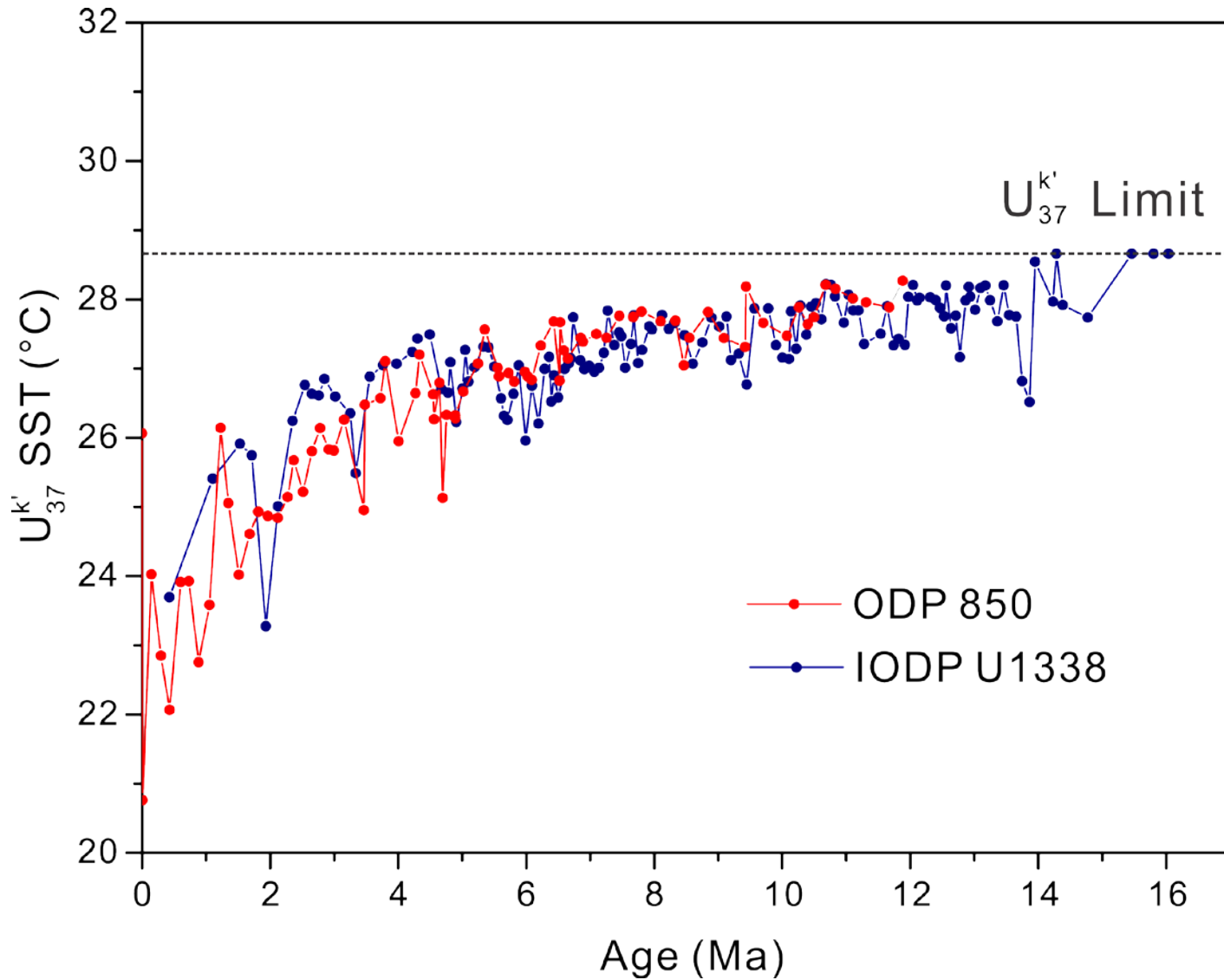
Site 1208 data from: LaRiviere et al., 2012, Nature

Pacific Meridional and Zonal Gradient



Zhang et al., 2014, Science

Warm Water Upwelling in the Cenozoic



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