Warm water upwelling in the Cenozoic Era

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Upwelling and Global Climate

- Walker Circulation Cell
- Equator
- Australia
- Warm
- L
- Date line
- H
- North America
- South America
- Coastal wind
- Thermocline
- Upwelling
- Cold
Upwelling and Global Climate
Upwelling and Ocean Productivity

[Image of a world map showing ocean productivity with a color scale for Ocean Chlorophyll Concentration (mg/m³) and Land Normalized Difference Vegetation Index.]

Legend:
- Ocean: Chlorophyll Concentration (mg/m³)
- Land: Normalized Difference Vegetation Index

Scale:
- Minimum
- Maximum
Role of tropics in changing the response to Milankovitch forcing some three million years ago

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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

Present Day

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

Site 850

"Biogenic Bloom"

Farrell et al., 1995; Schroeder et al., 1997
Tracing Equatorial Upwelling by CO$_2$

Rich in: Nutrients CO$_2$
$pCO_2^{(sw)}$ Distribution Across the Equatorial Pacific

Feeley et al., 2002, Deep-Sea Res II
$pCO_2^{(sw)}$ Distribution Across the Equatorial Pacific

Feeley et al., 2002, Deep-Sea Res II
$pCO_{2(sw)}$ Distribution Across the Equatorial Pacific

Feeley et al., 2002, Deep-Sea Res II
Sites for $p\text{CO}_2$ reconstructions

CO$_2$ Data from Takahashi et al., 2009, Deep Sea Res. II
Excess CO$_2$ and Biogenic MAR

Warm Water Upwelling: How?

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

![Graph showing U$_{37}^k$ SST (°C) vs. Age (Ma)]

- **U$_{37}^k$ Limit**
- **ODP 850**
- **IODP U1338**
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