Perspective

What is Tropical Sea Surface Cooling

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Abstract

Due to significant climatic and biological changes that contributed to the development of our present climate, the late Miocene is a fascinating historical period for paleo climatologists. Tracers that were used to reconstruct previous temperatures revealed a significant cooling of the world's surface waters; however, it is uncertain how much of this cooling occurred in the tropics and how much of it was caused by atmospheric Carbon Dioxide (CO2). Based on the temperature-dependent ratio of magnesium to calcium found in fossil zooplankton shells, we propose a new reconstruction of sea surface temperatures from the eastern equatorial Indian Ocean (Foraminifera). Our findings show a cooling (3.2°C) that is higher than earlier predictions of the tropical ocean cooling (1°C–2.5°C). We ran simulations to better understand how atmospheric CO2 is causing this cooling.

Keywords: Indian ocean • Midlatitudes • atmospheric • Miocene sea surface • Seasonality

Introduction

We used a sophisticated model to simulate the Miocene climate and discovered that a drop in atmospheric CO_2 from 560 ppm to 300 ppm could account for the majority of the reconstructed surface ocean cooling. This allowed us to better understand the role of atmospheric CO2 in driving this cooling. Our new reconstruction also reveals a more modest increase in ocean surface temperature gradients between the tropics and northern high latitudes compared to the late Miocene. that is well adapted to warm conditions, we reconstruct SSTs in an open-ocean, warm-pool location to estimate the degree of tropical late Miocene cooling. We offer new orbital-resolution SST estimates for the late Miocene and early Pliocene from sediments deposited at International Ocean Discovery Program (IODP) Site U1443, in the eastern equatorial Indian Ocean (9 Ma–5 Ma). Mg/Ca ratios obtained from tests on the foraminiferal species Trilobatus trilobus, which lives in mixed-layer environments, are used to determine SSTs. to investigate the notion that the worldwide sea surface cooling during the late Miocene was driven by a reduction in pCO_2, as suggested by recent investigations. Using the Earth System Model IPSL-CM5A2, we report new climate model simulations. We assess the impact of pCO_2 on latitudinal and tropical SST gradients.

We compare modelled SSTs to our new Site U1443 record as well as a revised global late Miocene SST data compilation to assess the impact of pCO_2 on tropical SSTs and latitudinal SST gradients using three different pCO_2 scenarios within the range suggested by late Miocene pCO2 proxy data (300 ppm, 420 ppm, and 560 ppm).

Seasonal South Asian monsoon circulation patterns are the primary factor influencing oceanographic conditions in the current northern Indian Ocean. Strong southwesterlies are present during the summer monsoon (June-August) and weaker northeasterlies are present during the winter monsoon (December-February) over the BOB due to seasonal variations in insolation and pressure gradients between the southern subtropical Indian Ocean and the Asian continent. Additionally, the Arabian Sea's saltier, denser water masses enter the BOB through the Southwest Monsoon Current in the summer while the BOB's less salty water masses enter the Arabian Sea through the Northeast Monsoon Current in the winter.

Wintertime Monsoon Current BOB also gets a lot of freshwater from inputs from rivers and direct rains. Strong salinity stratification is created as a result of this significant freshwater intake and its horizontal advection redistribution, which is controlled by the seasonal and spatial fluctuation of the barrier layer thickness. Since interactions between shallow and intermediate water masses are prevented by the development of a barrier layer between the bottom of the mixed layer and the top of the thermocline, BOB surface waters can remain warm (>28°C) all year long. As a result, the amount of wind-driven mixing during the (monsoonal) monsoon influences seasonal SST variability in the BOB most. by salinity stratification, as well (barrier layer formation). Strong southwesterlies provide the maximum annual surface ocean wind stress, deeper wind-driven mixing, and less stratification during the summer monsoon in the waters surrounding Site U1443.The Arabian Sea's significant salt infiltration during the summer also deepens the mixed layer, causing average SSTs of 28.7°C which are quite near to the mean annual SST (28.8°C). the gradual southward spreading of fresh water from riverine inputs in the northern BOB causes salinity stratification and the formation of a barrier layer in the autumn and early winter, which permits relatively warm SSTs to remain above Site U1443. The lowest sea surface salinities occur at this time.

Although the yearly sea surface salinity range is limited in comparison to further north in the BOB, this is the period with the lowest sea surface salinities SSTs peak at 29.9°C in April, the month with the lowest surface ocean wind stress, which causes substantial stratification and shoaling of the mixed layer. In conclusion, the waters surrounding Site U1443 are subject to local ocean-atmosphere processes that produce a relatively small annual SST variability; as a result, we believe this site is appropriate for reconstructing "open-ocean" tropical SSTs that are representative of the overall picture. such that previous SST records and our new Indian Ocean record can be compared, as well as Mg/Ca-SSTs model-data comparison. Then, we compared estimated latitudinal SST gradients to our updated global SST compilation, which was averaged across two 1-million-year time periods centred on 8 Ma and 6 Ma. In order to represent SSTs before and after the LMGC while excluding the impact of short-term/orbital-scale variability and to explore the potential contribution of pCO2 to this long-term cooling, we selected these time windows. Utilizing rotations and plate boundaries from the PALEOMAP PaleoAtlas for Gplates.

Strong seasonality in planktic foraminiferal production and shell flow might cause Mg/Ca-SST records to deviate from mean annual values in some geographical areas. There are two productivity maxima in the area around Site U1443, and the yearly SST variability there is low (1.7°C). The second peak in primary productivity is seen in winter, with the highest surge occurring in late summer (July to September; mean SST 28.5°C). At a southern BOB sediment trap site, the seasonality of planktonic foraminiferal mass fluxes appears to roughly correspond to annual primary productivity, peaking in July. The temperatures recorded by *T. trilobus* at Site U1443 are therefore still representative of the mean annual mixed-layer temperatures (28.8°C), with a potential small bias toward high productivity seasons even if foraminiferal shell fluxes were biased.

According to some studies, some species of planktic foraminiferal Mg/Ca can be extremely sensitive to variations in salinity and pH. Modern sea surface salinity above Site U1443 is relatively near to the open ocean value of 34 PSU, and seasonal changes are negligibly tiny (1 PSU). Between 33 and 38 PSU, SST sensitivity to salinity is rather modest. We therefore believe that a salinity-related monsoon influence on Mg/Ca at this site is improbable. The fact that only minor long-term changes in benthic 18O are observed at Site U1443 and that they occur independently of the SST trend suggests that salinity changes caused by rising sea levels have little impact on Mg/Ca. The sources of potential salinity variation are thoroughly discussed in Text S6 in Supporting Information S1.

We go into great depth on the possible salinity variation sources above Site U1443 and assess the salinity's combined impact on Mg/Ca-SST. Because there is no evidence of a pH effect on Mg/Ca in cultures of *T. sacculifer,* calibration equations do not contain a term to account for the pH effect. Furthermore, Site U1443 paleoproductivity and biogenic sedimentation records indicate that this site was shielded from significant long-term changes in productivity throughout the late Mioceneindicating that temporal changes in pH related to upwelling are unlikely to have taken place. In conclusion, Mg/Ca ratios found in *T. trilobus* are believed to be a good indicator of historical mean annual ocean temperatures in the upper mixed layer. The Earth's climate system became more sensitive to obliquity during the LMGC, and after 7.5 Ma, feedbacks associated with glacial-interglacial variability also began to affect tropical SSTs. This increased sensitivity to obliquity has been observed in both benthic foraminiferal isotopes and tropical SSTs. Coherence in cyclicity between tropical SSTs and direct measurements of glacial-interglacial fluctuations in atmospheric CO2 and other greenhouse gases recorded in ice cores during the last 0.8 million years. In order to directly compare SSTs and pCO2 at the glacial-interglacial period, there are currently no late Miocene pCO2 reconstructions with enough resolution. Tropical SSTs are reported to have shown strong variability on glacial-interglacial timescales in the late Pliocene to early Pleistocene, coinciding with global climate cycles noted in benthic 18O and pCO2. This was after the start of large-scale Northern Hemisphere glaciation at about 2.7 Ma. Prior to the mid-Pleistocene transition, which took place between 1.2 Ma and 0.6 Ma, 41-kyr cycles dominated low-latitude SST records. During the late Pleistocene, 100-kyr cycles emerged.

Conclusion

Our Mg/Ca-based SST record exhibits variability at the 400 kyr period in addition to variation in the obliquity and precession bands which may be due to the direct influence of lengthy eccentricity cycles or the modulation of precession by eccentricity. Other research have noted a 400 Kyr cyclicity in Plio-Pleistocene tropical SSTs, but the underlying mechanisms are still unknown. According to one study from the South China Sea, 400-kyr cycles in SST may be linked to how the El Nino–Southern Oscillation affects the East Asian winter monsoon. The earliest portion of the Site U1443 SST record between 9 Ma and 8.6 Ma shows the presence of two clearly apparent cycles that span around 225 kyr, which might either indicate represent a genuine eccentricity cycle or a harmonic effect of extensive eccentricity cycles. Our updated open-ocean tropical Indian Ocean SST record reveals a 3.2°C late Miocene cooling that began at 7.4 Ma and reached its minimum between 6.2 and 5.8 Ma. After that, there is a warming of 1°C between 5.8 Ma and 5.4 Ma. We observe that the magnitude of cooling from 7.4 Ma to 5.8 Ma is greater than 2.5°C in all scenarios, despite the fact that the absolute reconstructed SSTs and the magnitudes of change are sensitive to Mg/Casw and H value corrections..