Using past warm climates to inform us about our future world

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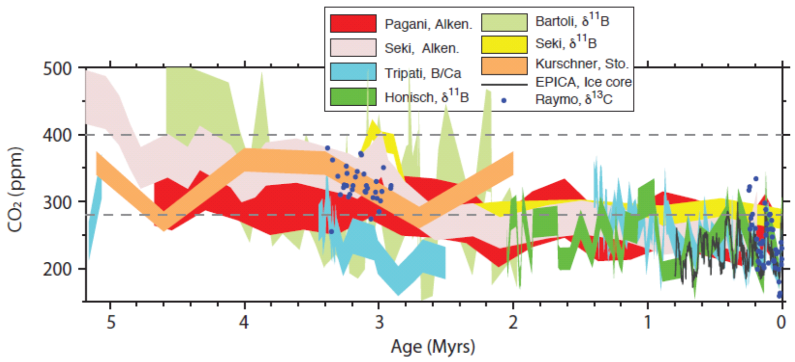
The speaker, who was previously at Yale and is now in the Department of Geography at University College London, has a great interest in oceans, climate and weather. His presentation covered past and present CO_2 levels, the Pliocene and its climate, compared this to future projections and looked at more realistic modelling and the questions it raises.

Past and present CO_2 levels

CO_2 is a well-mixed greenhouse gas so measurements give a good picture of the overall content of the atmosphere. Since pre-industrial times, CO_2 levels have increased by 40% up from 270ppm to 350ppm in 1979 and 400ppm now. It has come primarily from fossil fuel emissions and secondarily from net land-use change emissions. The IPCC 5th assessment report headline statement reports that atmospheric concentrations of CO_2, methane and nitrogen oxides have increased to levels unprecedented in at least 800,000 years. During this period, CO_2 has varied between 185 and 280ppm, using the record of CO_2 trapped in ice cores.

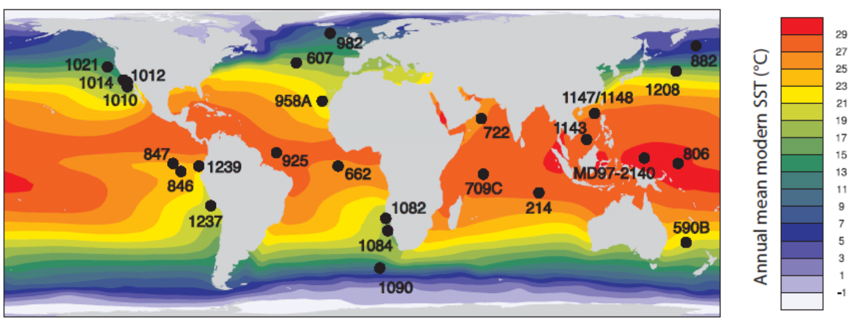
The question arises as to how far back we need to go to see levels of 400ppm. Looking back earlier than 800,000 years is problematic because indirect geochemical techniques are needed and there are temporal uncertainties. Based on analysis of the stomata of fossil leaves, ocean sediment isotope ratios of boron (which indicate the acidity of oceans) and other sources, the early Pliocene at about 4Ma had CO_2 levels approaching those of today. There have been at least 2 genera of hominims since 4Ma. At that time, *Ardipithicus ramidus* had a brain about 20% of the size of that of modern humans and the big toe was adapted for an arboreal life.



Estimates of atmospheric CO2 levels, 5Ma to the present

The Pliocene and its climate

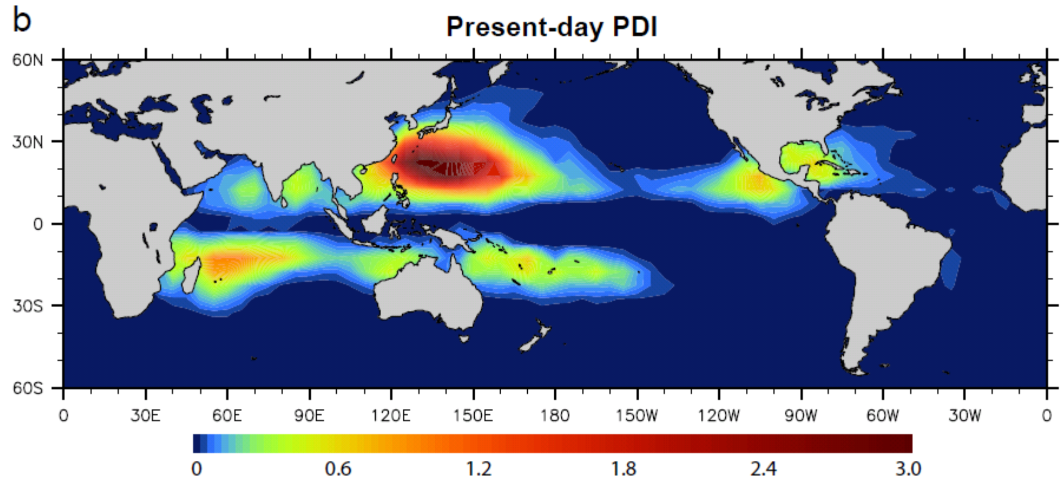
During the Pliocene, sea levels were up to 30m higher than today. The Greenland ice sheet was very small and the West Antarctic ice sheet came and went, but was 8m of sea-level equivalent smaller than today. The East Antarctic ice sheet, which had developed at about 35Ma was dynamic and about 10% was lost.



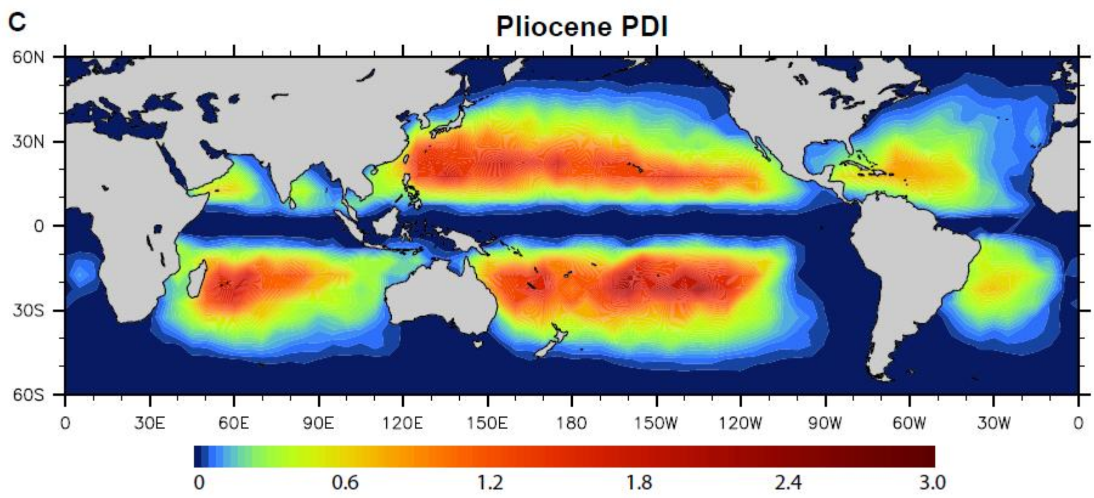
Annual mean modern sea surface temperatures

Plio-Pleistocene trends have been collated from long sea surface temperature records based solely on Mg/Ca in foraminifera or alkenones solution levels. The oceans can be grouped into 4 functional types:

- Warm pool region – eg the tropical Indian Ocean;
- Cold water upwelling – eg the Benguela Current;
- Sub-tropical areas; and
- High latitudes.



The tropical warm pool



The tropical warm pool

Over the last 5Ma, the warm pool area has moved up and down by about 2^{o}C around the mean, cold upwelling areas were warmer in the past by about 5^{o}C and sub-tropical areas were warmer by up to 5^{o}C. Thus the tropical oceans had much weaker temperature gradients and there was a vast pool of warm water throughout the tropics and a differential warming of over 5^{o}C in the East Pacific. There was a large warming in temperate and polar regions but not much going on in the warm pool.

As a climate modeller, the speaker uses sea surface temperatures to model the consequences for climate. These show a significant reduction in the Hadley circulation in the tropics and smearing out of rainfall patterns with a band of high rainfall along the equator and deserts beyond and extinction of monsoons. Hurricanes would be more pervasive, be stronger and last longer because of the warm water and right amount of shear in the upper levels plus the coriolis force. Atmospheric circulation would have been more sluggish in a warmer world leading to more wind shear.

Future climate projections

Future world long-term scenarios run out to 1,000 years. They assume constant CO_2 levels after 2300 and, therefore, no carbon cycle. 500ppm CO_2 gives a global mean temperature increase of 2.5^{o}C. The spatial pattern of warming is similar to the next 100 years.

Surface temperature would rise faster in the Arctic and on land and nowhere would be exempt from warming on a multi-model mean. Sea surface temperature minima would be in the Southern Ocean and North Atlantic. As far as precipitation is concerned, wet areas would get wetter and the Hadley cell expands. We can think of the changes as being linked to warming with more droughts and more extreme flooding events. In the UK, there would be more rain in winter and less in summer but the balance is uncertain. The thermohaline circulation is not expected to shut down, but if it did the UK would be 4^{o}C cooler.

More realistic modelling

This involves sea level 25m higher than now plus the effects on vegetation and ice sheets with 400ppm CO_2. The Pliocene model inter-comparison project simulated a pattern similar to the steady-state future projections. Modelled global mean temperature was up 2.5^{o}C. There is a concept of earth-system sensitivity, which is higher than conventional climate sensitivity. This is because if includes longer-term responses (such as ice-sheet feedback) than just the atmosphere and ocean ones. Pliocene warming was probably unrelated to solar forcing since it went on too long. It was stable for orbital variability but too short for stellar evolution. The explanation may lie in changes in land configuration, such as the closing of the gap through the isthmus of Panama or changes in Indonesia or the Bering Strait, or the models are not capturing CO_2 feedbacks correctly dues to changes in ocean mixing and/or changes in cloud properties, which can explain the vast warming pool in the Pliocene.

Using the NCAR's Community Earth System Model with atmosphere, ocean, sea ice and land surface models coupled, a low-resolution version for palaeoclimate has been run for 500 years. The climate is sensitive to connections between oceans, such as those in Panama, Indonesia and the Bering Strait. Indonesian through-flow between the Indian and Pacific Oceans has little impact on the Pacific. Flow through the Bering Strait between the Arctic and Pacific Oceans leads to changes in the Arctic and the North Atlantic. There were no changes in the Greenland Sea between the Arctic and Atlantic Oceans or in the Southern Ocean flow through Drake's Passage. The Flow between the Pacific and Atlantic through Panama was open at 15Ma and is closed today but when it closed is still open to interpretation. Possibly a shallow connection remained open and closed at 4.2Ma. Certainly, removing the Isthmus of Panama makes a big difference. Currently there is a net transfer of fresh water from the Caribbean to the Pacific through the atmosphere.

Climate feedbacks through small features are difficult to model at a global scale. Maybe greenhouse gases are the driver but we are modelling the response too conservatively in not taking sufficient account of hurricane mixing and clouds. Tropical cyclones churn up the water beneath them, mixing the upper 200m of the ocean, the depth being related to the cube of the maximum wind speed, which could lead to warming at the equator and only 2^{o}C warming not 5^{o}C in the sub-tropics. Combining hurricane mixing with exotic cloud physics to CO_2 changes then we may get close to the early Pliocene climate in models. Hurricanes and clouds are unmodelled feedbacks. They are potentially irreversible but they are not acting today with similar levels of CO_2.

Summary

The warm early Pliocene is a challenge for climate science. It had today's levels of CO_2 but no cold ocean upwelling. We need to invoke multiple strong positive atmospheric feedbacks and we have little idea of time scale. These are not included in models for future climate projections.