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GLOBAL CLIMATE DYNAMICS AND PLIO-PLEISTOCENE PALEOENVIRONMENTS OF NORTHWESTERN PERU AND SOUTHWESTERN ECUADOR

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INTRODUCTION

Almost half a century ago studies began on the fossil vertebrates of the upper Pleistocene (~13,900 B.P.) Talara Tar Seeps of northwestern Peru and similarly-aged deposits of the Santa Elena Peninsula of southwestern Ecuador. One of the surprising conclusions of these studies was that among the vertebrates living in these areas in the late Pleistocene were numerous species that would have required a considerably more equitable climate than occurs in this semi-arid region today. For example, among the bird species (Campbell, 1976, 1979), nine species of ducks (4 extinct) and 12 species of herons and ibises (3 extinct) indicate the presence of abundant bodies of standing water. And 25 species of plovers (1 extinct), sandpipers, and phalaropes, and the jaçana also denote abundant water. On the other hand, several species, such as the Peruvian Thick-knee, indicate the proximity of grassland savannas or open scrub habitat. These paleoenvironments were also indicated by many other species of vertebrates, plants, and insects (reviewed in Campbell, 1982).

At the time of these paleontological studies an explanation for the dramatic changes in climate from the last glacial episode to the present was unavailable. Although the climate phenomenon known as El Niño, which brings torrential, monsoon-type rains to southwestern Ecuador and northwestern Peru every 2–7 years, was considered to be a factor, why such episodes occurred was a mystery. And, in fact, the ultimate causal factor remains a mystery today. Still, we now know much more about the causes of El Niño and its past history, as well as other paleoclimatological aspects of the tropical Pacific. The paleontological data would seem to suggest that the possible future impact of El Niños in northwestern Peru as a result of global change could be quite significant, if the driving mechanism resembled that of the Pleistocene, or today. On the other hand, modern climatological data suggest the tropical Pacific might be moving toward a new normal, possibly like that of the early Pliocene, in which case the effects on northwestern Peru could be something completely unexpected. For that reason it is necessary to review the current understanding of the climate phenomenon known as El Niño.

POSSIBLE DRIVING FORCES OF EL NINO EVENTS

WARM WATER POOLS AND SOUTHERN OSCILLATION

The general model of an El Niño characterized as an El Niño-Southern Oscillation (ENSO) event that one encounters today (e.g., Fedorov and Philander, 2000) is fairly simple. In it, the easterly trade winds blowing across the Pacific cause the warm surface water of the equatorial region to be pushed westward, where it accumulates in the western equatorial Pacific (WEP). This leads to sea level being higher by ~60 cm in the WEP than in the eastern equatorial Pacific (EEP). This also creates a differential in the depth of the ocean thermocline, which is the sharp gradient between warm surface water and cool deep water. The ocean thermocline is shallow in the EEP and deepens toward the west. The shallow thermocline in the EEP leads to upwelling, which is important for bringing deep, cool, nutrient-rich water to the surface and stimulating biological productivity.

In the WEP, the warm surface water leads to atmospheric convection, with air next to the ocean surface warming and rising, thus creating a low pressure zone. Over cold water in the EEP, air is cooled and descends, forming a high pressure zone. In the equatorial Pacific, the cold surface air of the high pressure zone in the east flows westward to replace the rising warm air in the low pressure zone of the WEP. In turn, the cold air is replaced by the warm air that rose over the WEP, which descends in the EEP after cooling. This cycle is referred to as the Walker circulation, and the greater the atmospheric pressure difference between the low pressure WEP and the high pressure EEP, the greater the strength of the Walker circulation. A strong Walker circulation creates strong surface winds, which leads to more upwelling in the EEP. In El Niño years the Walker circulation is diminished, whereas in La Niña years it is greatly strengthened. The Southern Oscillation, or the changing atmospheric pressure differential between the WEP and the EEP, is clearly a critical factor in equatorial Pacific climate fluctuations, but is it a cause or a result?

In this model, an ENSO event begins when, for some reason, the easterly trade winds lose strength, allowing the warm pool of water in the WEP to slosh eastward, lowering the thermocline in the EEP, cutting off upwelling, and bringing monsoon rains to northwestern Peru. One serious problem with this model is that water pushed by wind does not go in the direction of the wind. Ekman transport dictates that surface waters pushed by the wind travel at an angle to the wind. Thus, warm surface water is not, and cannot be, pushed westward directly to the WEP by easterly trade winds. A second problem is the distance the warm water would have to travel eastward down a slope of ~0.005 cm/km before it could affect the west coast of South America, combined with the time available for this "sloshing" eastward to occur. Is this even physically possible?

THE INTERTROPICAL CONVERGENCE ZONE

The Intertropical Convergence Zone (ITCZ) is defined as the region dividing the northern hemisphere climate systems from those of the southern hemisphere. The ITCZ can be pictured as a belt circling the globe that moves north and south with the seasons, following, or seeking, warm climates. Its position is driven by Hadley cell convection, which transfers heat from the equatorial regions poleward. In the southern hemisphere summer, the ITCZ loops far south, extending well into South America. However, in normal years the ITCZ stays north of the equator at the western edge of the continent, even while looping far to the south over the center of the continent. As a consequence, the southern hemisphere easterly trade winds cross the equator, and, because of the Coriolis effect, are turned into southwesterly winds, whereupon they carry moisture from warm equatorial water northeastward and bring torrential monsoon rains to the Chocó region of Colombia, one of the wettest areas in the world.

During an ENSO event, however, the ITCZ moves south of the equator west of the west coast of South America and the northern hemisphere easterly trade winds, upon crossing the equator, become northwesterly winds because of the Coriolis effect. Upwelling near the equator ceases because the southern hemisphere trade wind belt is pushed southward by the ITCZ and the atmospheric pressure differential between the EEP and the WEP decreases, resulting in a diminished Walker circulation. The northwesterly winds also move warm equatorial water south-southeast, furthering the lowering of the thermocline and disrupting upwelling. Moreover, under the equatorial sun, the surface waters of the ocean warm quickly once upwelling ceases. Warm surface water leads to atmospheric convection, which carries moist air aloft where northwest winds then move it eastward. Monsoon rains then follow over coastal Peru, their southern reach dependent upon how far south the ITCZ moves. This was the explanation Schott (1932) presented to explain the severe 1891 El Niño.

Similarly, Leduc et al. (2009) present evidence that the ITCZ shifted southward during abrupt cooling episodes of glacial periods in the North Atlantic region. The driving force behind the shift of the ITCZ was the increased equator-to-pole temperature gradient during the glacial episodes, which required a shift southward in the ITCZ in order to accommodate the strengthened poleward heat transport by atmospheric circulation. The shift to the south of the ITCZ would bring about the consequences noted above. This model is comparable in its basics, but not in its details, to that suggested by Campbell (1982) (i.e., El Niño events result from increased energy transfer from the equator to the pole). A similar model is presented by Koutavas et al. (2002). In these instances, the movement of the ITCZ initiates the El Niño, not the Southern Oscillation as in other models.

Still, the ITCZ model is another simplistic explanation of why an El Niño occurs and how it affects the climate of northwestern Peru and southwestern Ecuador. What is lacking in both the ENSO and ITCZ models is the ultimate causal factor. That is, what would cause a reduction in the strength of the easterly trade winds, or Walker circulation, on the one hand, or, on the other, the movement across the equator of the ITCZ during the non-glacial period of today?

THE OCCURRENCE OF PALEOENSOS

Geological and paleontological data provide vital information for interpreting past events, including the occurrence of paleoENSOs. Data from deep sea cores and terrestrial localities suggest that during the global warmth of the early Pliocene, when global temperatures were ~3-4 ºC warmer than now, ENSOs were a permanent condition in the western Pacific. There have been a number of recent articles discussing the possible occurrence of ENSOs during the warm Pliocene, and various explanations for permanent ENSO conditions have been offered (e.g., Molnar and Cane, 2002; Lawrence et al., 2006; Fedorov et al., 2006, 2010; Ravelo et al., 2006; Bonham et al., 2009). Still, some authors question whether permanent ENSO conditions actually existed during the warm Pliocene. Unfortunately, there are no terrestrial data of which I am aware that provides any information on what the possible effects such a climate state would have had on northwestern Peru. Readers are referred to the above papers for extensive discussions of the subject of early Pliocene ENSOs.

Interestingly, however, the paleontological data from upper Pleistocene deposits of northwestern Peru and southwestern Ecuador indicate that ENSOs must have been a common, if not a permanent, annual event of the glacial ages. How does one explain the occurrence of ENSO events during the opposing extremes of hot and cold global climates?

A NEW KIND OF EL NINO

In the past few decades evidence has been accumulating that indicates a new kind of El Niño is occurring (Larkin and Harrison, 2005; Ashok et al., 2007; Kao and Yu, 2009; Kug et al., 2009; Yeh et al., 2009). This form of El Niño occurs as a warming in the central Pacific, flanked by cooler surface waters both east and west along the equator. The Central Pacific El Niño (CPLN) has been linked to global warming (Yeh et al., 2009), and it is projected to increase in frequency as global warming continues. It is of great interest because climatic teleconnections from the tropical central Pacific bring about global changes in local and regional weather conditions, promoting excess rains or heat in some areas and droughts or cold in others. Not enough is known yet about the formation of a CPLN, although it is known that it brings about a moderation of thermocline depth across the equatorial Pacific, thus diminishing Walker circulation. Whether it represents a return to the conditions experienced during the warm early Pliocene remains to be seen. What its affect will be on coastal South America remains unclear.

CONCLUSION

As a climatic phenomenon, El Niño appears to occur during periods of global warmth as well as during glacial episodes. This seeming conflict can be resolved by viewing the warm Pliocene as having an entirely different climate state than that of the Quaternary. By itself, the absence of northern hemisphere glaciations would mean that atmospheric circulation patterns would be weaker globally, resulting in less upwelling in the EEP. At the same time, however, a warm Earth means warmer continental land masses, which might result in greater north-south movements of the ITCZ (see Wang et al., 2004). El Niños in a warm Earth might have been an annual event, but whether they were like El Niños of the Pleistocene, or today, is unknown. It can be reasoned, however, that in the absence of strong atmospheric circulations, it is unlikely that La Niñas would occur.

During the Pleistocene, however, the equator-to-pole temperature differential would have driven a much stronger atmospheric circulation, leading to a different driving force for the movement of the ITCZ. The mechanism for a hot-house Earth El Niño event might have been the same as that for an icebox Earth, but, if so, on the one hand heat is the driving force, whereas, on the other, cold is the driving force.

The ultimate causal factor that brings about an El Niño remains unknown, thus we do not know if a hot-house Earth El Niño is comparable in all, or any, aspects to an icebox Earth El Niño. That question brings us back to basic geology and paleontology. It is clear that glacial age El Niños dramatically changed the climate of coastal southwestern Ecuador and northwestern Peru by bringing monsoon rains on what was probably a regular, or annual, basis. On the other hand, geological deposits and paleontological data from southwestern Ecuador and northwestern Peru dating from the warm early Pliocene remain sparse, and most known are of marine origin. What are badly needed are terrestrial Pliocene deposits and fossils that can tell us what the effects in this region were, if any, of warm Earth El Niños. To prepare for global warming, which is happening as we speak, it is necessary to know what happened during the last period the Earth was as warm. This is something that only the rocks and fossils can tell us.

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