How SST during Ice Age to the New Epoch, Last Interglacial to Holocene, and Miocene and Pliocene's affect the intensity of the Asian summer monsoon

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Abstract. Hypothesis from out group is: in warmer climates monsoons dry seasons were drier. Our group aim is to identify the locations that had greater temperatures in the past in order to predict the power of the monsoon in a warmer future. In order to comprehend how monsoons might impact a hot globe, we shall find the relationship between ocean surface temperature and monsoon strength. Essay mainly focus on three major factors of the past to explore the purpose: the historical period, the last interglacial and Holocene, and the Miocene Climatic optimum.

Keywords: summer monsoon, Miocene, Pliocene, Ice Age, the New Epoch

1. Introduction

A monsoon is a seasonal change of strong wind, which causes the dry and wet seasons across areas of land [1]. In the summer of the northern hemispheres from April to September, land receives and captures heat faster than the ocean, causing Low pressure over mainland regions, whereas the ocean surface accumulates high pressure because it maintains a more constant temperature and exhibits a lower range of seasonal temperatures. This phenomenon results in a cycle of airflow, mixing hot and cold air currents. It creates an immense wind blowing towards the mainland, and brings moisture and precipitation along with it, as shown in Figure 1 [2].

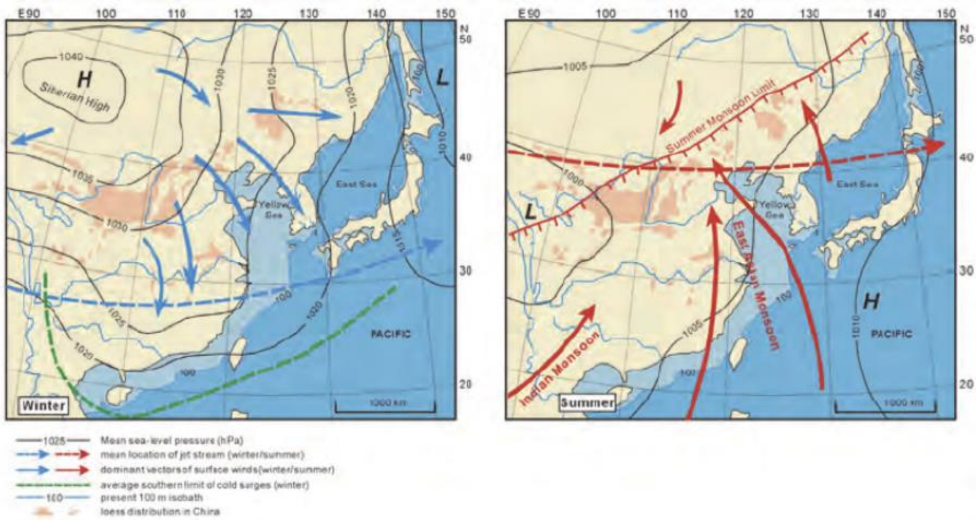

Figure 1. moisture and precipitation change in global [2].

Oppositely, during winter, from October to April, the mainland area has less heat than the oceans, resulting in high pressure over the ocean and low pressure over the mainland. Consequently, the wind blows from the mainland to the ocean. Asian monsoons are significant because they bring moisture from the Indian Ocean to South-Eastern Asia. Along with monsoons are precipitation and cool temperatures. Monsoons make the land beneficial to humans' habitat, by causing longer growing seasons for agriculture. It Is the main reason why the Asian monsoon is an essential part of such a vast population base.

Our research focuses on the relationship between monsoons and Sea surface temperature. Today with the increasing trend of global warming, to find out the behavior of monsoons in a warmer globe, we looked at paleoclimate studies covering 3 significant time periods in the past where higher sea surface temperature (SST) has shown relationships with the formation of monsoons. The 3 time periods to analyzed are [3] Last interglacial, Holocene, and Miocene SST, in relation to the monsoon. Sea temperature has an impact on how monsoons are formed. Predictions such as high SSTs cause weaker monsoons have been supported by climate models [4], However, by looking at Data of the high precipitation, follows high concentrations of atmospheric carbon dioxide levels. Historical records of the 3 time periods eventually lead us to dawn on a prediction that warmer climate causes stronger monsoon.

2. Discussion

2.1. During 1700 to 1850, industrial revolution effect the changes in land cover and sea surface temperature change cause decrease rainfall from monsoon

Table 1[5]. the moisture convergence, evapotranspiration, precipitation in Western Indian subcontinent, Southeastern China, Mideastern China during 1700 to 1850.

Year	Western Indian subcontinent		Southeastern China		Mideastern China	
	1700	1850	1700	1850	1700	1850
Moisture Convergence	146.1	77.4	139.8	108.3	22.4	33.2
Evapotranspiration	135.8	126.6	133.2	130.7	128.3	123.1
Precipitation	281.9	204.0	273.0	239.0	150.7	156.3

Between 1700 and 1850, according to Takata et al. (2009) atmospheric general circulation model, shows rainfall from the Asian summer monsoon （ASM) decreased.[5] According to Takata et al. [5], the factories and agricultural practices that changed after the industrial revolution are a major impact on the fluctuation of the Asian summer monsoon during this time. However, changes in land cover and sea surface temperature change caused by the industrial revolution are the factors affecting the monsoon [5]. The same meteorological yearly cycle that governs the monthly distribution of sea ice and the current sea surface temperature drives both trials repeatedly. First, converting forests or lands to crops will change the water and energy balance on the planet's surface, which will have an impact on the monsoon. The change in land causes the surface to become smoother and the albedo to increase, resulting in less solar absorption at the surface. Reduced surface roughness also causes an increase in low-level wind speed, which affects the heat flux, which impacts profound cumulus convection and the planet boundary layer, which impacts the surface energy. If the surface roughness is large, atmospheric moisture is concentrated, so there is a lot of precipitation in these areas, and the wind usually slows down over land, but now the changes in the surface have caused a change from the original state, resulting in a decrease in the amount of precipitation brought by the monsoon. Besides surface roughness, sea surface temperature is another important factor. According to above, surface wind speeds have changed due to industrial revolutions, affecting continental air masses, that is, air masses that can carry moisture from one area to a new one. In general, an increase in ocean surface temperature leads to an increase in the amount of atmospheric water vapor over the ocean, which can lead to heavy rainfall. As can be seen from Table 1, the rainfall from 1700 to 1850 decreased significantly, which means that the decrease in surface roughness led to the decrease of continental air masses, which led to a significant decrease in ocean surface temperature. The transition in the west Indian subcontinent and southeast China is depicted in Table 1. The west Indian subcontinent and southeast China have less precipitation and moisture convergence as a result of faster surface winds. Reduced surface soil moisture leads to decreased local evaporation and humid convection, which in turn has a corresponding impact on decreased precipitation. Second, the water balance in many regions of Asia has altered as a result of variations in precipitation. Southeast China and the western Indian subcontinent experienced a high ratio of moisture concentration to the source of precipitation in 1700. Due to the combined effects of lessened surface roughness and lessened soil moisture, there was a dramatic fall in moisture convergence in these areas by the year 1850. The precipitation varies little in eastern China, since the dependency on moisture convergence is negligible, shown in Table 1. Takata et al. (2009) measured surface roughness and sea surface temperature using the Takata et al. (2009) atmospheric general circulation model to determine an essential element in the alteration in water balance and ultimately discovered that it affects the decrease in precipitation [5].

As you can see from the Table 1, the western Indian subcontinent and southeastern China were the most affected, with huge declines in all three factors [5]. However, in Mideastern China, it has little effect, and even the moisture convergence and precipitation have a slight rise. However, after industrialization, from 1700-1850, the monsoon was severely affected by industrialization, and the western Indian subcontinent and southeastern China had a marked decrease in rainfall.

2.2. Due to decreased rainfall, many areas of the Southeast Asian monsoon region experienced drought between 1950 and 2018.

The Lixia Zhang (2021) group discovered that the Southeast Asian monsoon region's rainfall had a steady decrease from 1950 to 2018, which resulted in drought in some parts, by using regional climate models (Amnuaylojaroen & Chanvichit, 2019) and CMIP5 multi-model simulations (Lu et al., 2019).[6] This was due to altered water balance as a result of changes in surface roughness and sea surface temperature. Annual precipitation in China, Myanmar, and Thailand in the monsoon period in Southeast Asia decreased from 1950 to 2000, with the greatest drought trends in China's Yunnan Province, northern Thailand, and Myanmar. Vietnam's west coast of the Pacific Ocean displayed a pronounced wet trend. The Southeast Asian monsoon region, focused in southwest China, northern Thailand, and Myanmar, had more frequent and substantial droughts between 1951 and 2018 according to Zhang et al(2021) .'s analysis of changes in drought in specific places during the period 1950–2018. Between 1951 and 2018, the area in the study region that experienced extreme drought nearly quadrupled. Water scarcity has created a significant barrier to the sustainable development of the Southeast Asian monsoon region due to tremendous urbanisation and population increase.

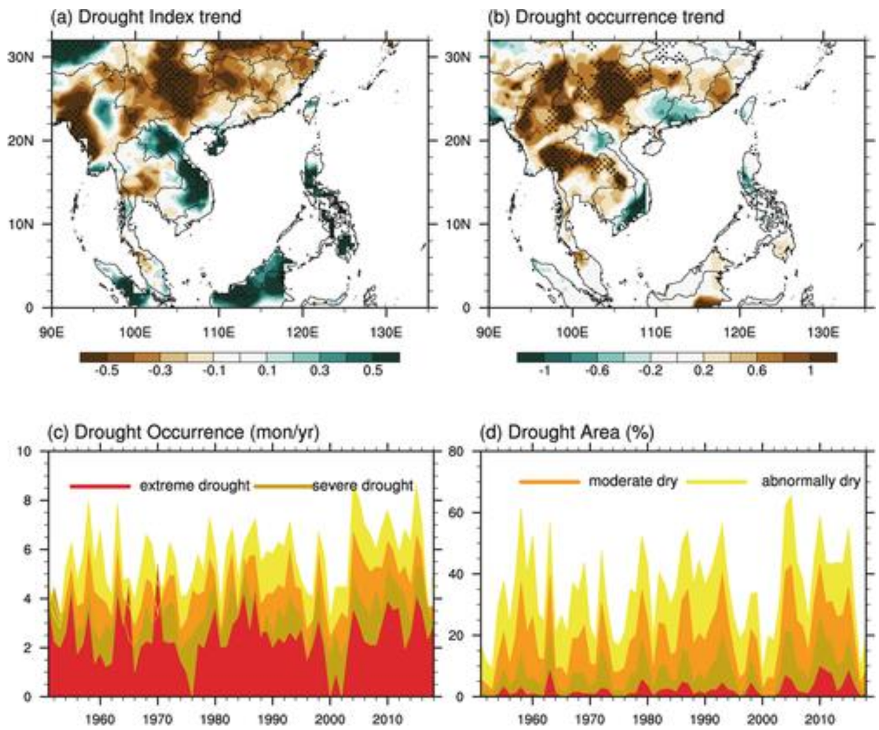

Figure 2. drought change in the Southeast Asian monsoon region between 1950 and 2018 [6].

Regional climate models (Amnuaylojaroen & Chanvichit, 2019) and CMIP5 multi-model simulations predict that the frequency and duration of drought episodes in continental Southeast Asia will increase during the coming years compared to the present. broad areas, shown in Figure.2 [6] From the temporal variation of the average in Southeast Asia, it can be seen that the occurrence of drought and the affected area have an obvious increasing trend (c and d) [Figure.2]. The frequency of severe and exceptional droughts has added 0.8 and 0.2 months. each year, or by around 23% and 8%, respectively, over the past 68 years [6]. The linearity of drought intensity, in contrast, is not very high. Even while droughts are occurring more frequently and more widely in Southeast Asia's monsoon zone, their severity may not be noticeably worsening when they do.

During the last interglacial period (130-115 ka) to the Holocene (11.6 ka to the present), the strength of the South Asian monsoon in the Indian Ocean was weakened, and its activity became unpredictable during the last interglacial period as global warming was applied to the Indian Ocean [7]. The strength of the monsoon is strongly influenced by solar insolation, and most of the proxies use monsoon rainfall to confirm the strength of the monsoon. In this study, a climate model was used to compare the changes in sedimentary leaf was δD and δ13C during the last interglacial and Holocene periods in the northern Bay of Bengal by the South Asian monsoon in response to the strength of the monsoon, and both isotopes were extracted from the sediments of the northern Bay of Bengal, which is influenced by precipitation and tides.

2.3. Records of δD and δ13C which are proxies from sedimentary leaf wax lipids for ISM rainfall amount.

The location of 17286-1 in the data map is the location of the sediment extraction emphasis [8]. In the monsoon region, the variation of atmospheric water δD is usually considered to reflect the variation of rainfall, with more negative δD values indicating more rainfall and vice versa [9]. In the previous background, it is concluded from the generalization that a greater amount of precipitation in the last interglacial than in the Holocene would indicate a weakening of the monsoon.

The δD effect decreases abruptly at the beginning of the Holocene and Last Interglacial, indicating a rapid and considerable increase in ISM (Indian Summer Monsoon) intensity at the end of both ice ages. From the Last Glacial Maximum to the Holocene, the ISM intensity increases in two distinct successive steps, which is a typical pattern for the Asian-African monsoon domain. And then, at the beginning of the Last Interglacial, the δD value increases rapidly by 11‰ at 129 ka to reach the weakest ISM intensity, with δD values in our record. After that, the maximum rainfall intensity reached 124.5 ka, followed by an increase of δD by 20‰ for about 2,300 years (Figure 3,4). Gradually, this indicates that the weakening with temperature is accompanied by an increase in ISM, while the end is based on the pattern that the increasing intensity of temperature decreases before the Holocene.

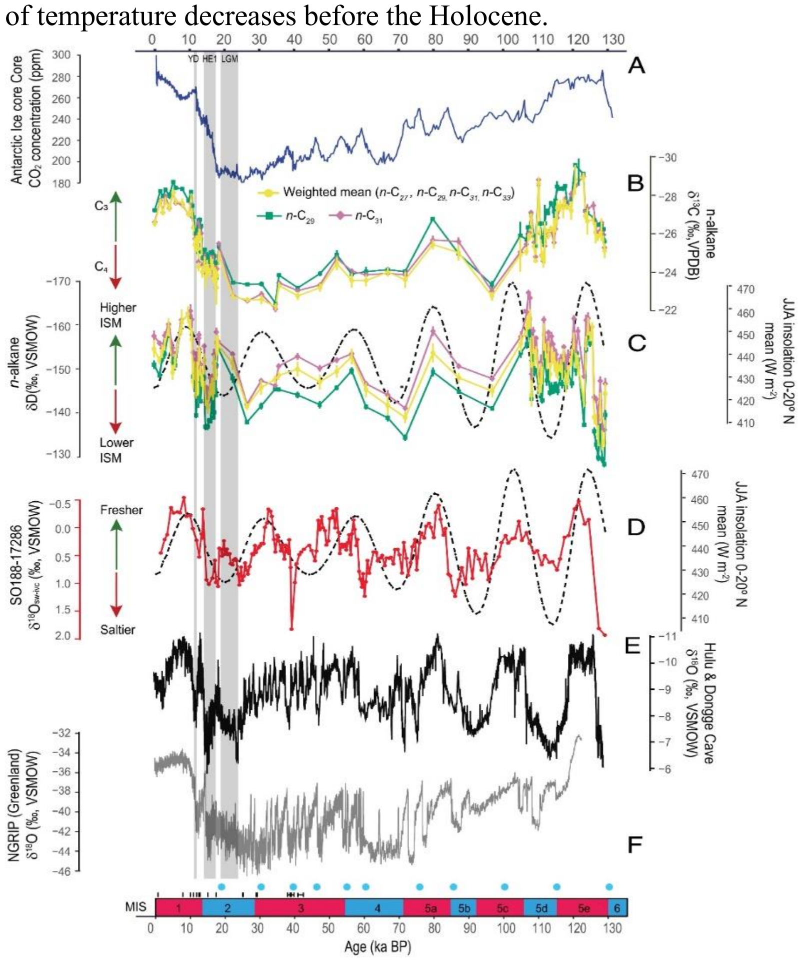

Figure 3. Comparison of climate records from sedimentary core 17286-1 with other high- and low-latitude climate proxies. (Using 3C: Ice volume-corrected δD for n-C 29 and n-C 31 and concentration-weighted average δD based on all four congeners from sedimentary core 17286-1 as a proxy for rainfall (this study). The black dotted line represents summer (JJA: June,July, August) with average sunshine between 0 and 20°N,). (Reprinted from ref. 7.)

2.4. UK'37 and Globigerinoides ruber Mg/Ca models (GBM) discuss the effects of SST

The intensity of insolation was higher [10] during the last interglacial period compared to the Holocene, which means that usually, periods of higher insolation bring more precipitation; however, during the last interglacial period, the continuous warming of the equator and SST increased convective rainfall over the ocean but weakened the intensity of the ISM (Indian Summer Monsoon) on land.

A reasonable control to suppress ISM intensity during the Last Interglacial Thermal Maximum may be due to the warming of the Indian Ocean and changes in rainfall distribution between land and ocean. uk'37 and Globigerinoides ruber Mg/Ca are both paleoclimate models. Both models indicate that an increase in Indian Ocean SST reduces the intensity of the onshore monsoon in South Asia because higher summer SST favors local convection over summer. The warming of the Indian Ocean during the last interglacial could explain the weakening of the ISM (Indian Summer Monsoon) intensity in the GBM (Ganges–Brahmaputra–Meghna River) basin. The SST record based on the alkenone unsaturation index (UK ' 37) from position [11] shows that the mean SST during the peak of the last interglacial (~125 ka) was 1.5 to 2.5°C higher than during the early Holocene (Figure 4,5). Warmer SST was prevalent during the last interglacial in the equatorial and northern Indian Ocean. Due to the persistent high SST in the west [12], the ISM intensity has weakened in South Asia, including most of the GBM catchment area in the Indian Ocean. Slightly higher ISM intensities are observed in the early Holocene than during the marine isotope stage, which may also be due to the lower SST (up to 1 °C) in the western Indian Ocean during the Holocene (Figure 5).

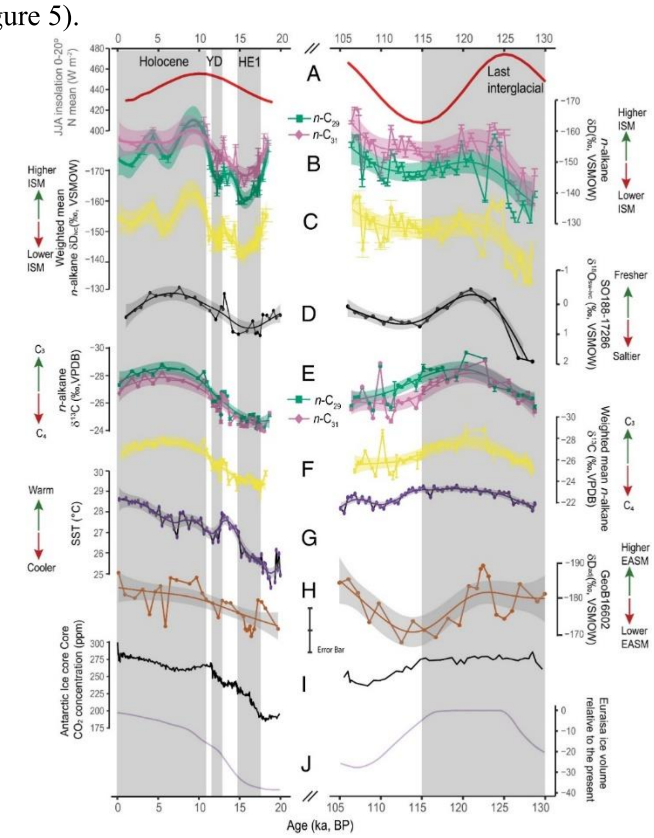

Figure 4. A detailed comparison of generalized additive model results is derived from paleoclimate proxy records in sedimentary core 17286-1 and from climate forcing during the Holocene and the last interglacial. Figure 4B: 95% confidence intervals for the δD and GAM (generalized additive model) results for n-C 29 and n-C 31. 4C: Concentration-weighted δD based on all four homologues (n-C 27, n-C 29, n-C 31, and n-C 33) and GAM (generalized additive model) results with 95% confidence intervals and 2.2G: Sedimentary core SST records based on U K' 37. (Reprinted from ref. 7.)

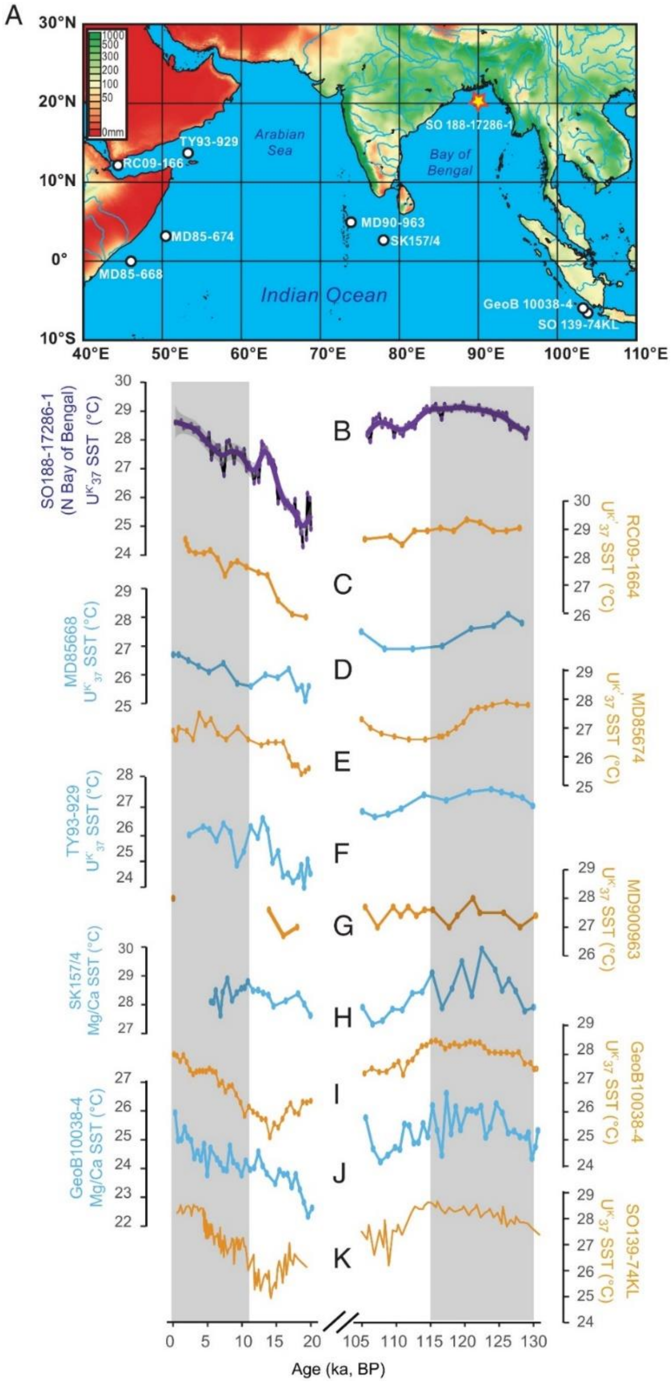

Figure 5. Comparison of equatorial and tropical Indian Ocean SST records during the Holocene and the last interglacial. Figure 5B: Sedimentary core SST based on U K'37. Marine sediment SST records are ordered west to east based on U K' 37 or G. ruber Mg/Ca from the tropical or equatorial Indian Ocean. The relatively high SST may explain the weakened ISM response during the last ice age in the Indian Ocean, which may have enhanced convective capacity over the ocean and, thus, reduced rainfall in the Indian subcontinent. This implies that under modern climate scenarios, warming of the Indian Ocean may continue to trigger severe dry monsoon extremes over much of the Indian subcontinent. (Reprinted from ref. 7.)

2.5. Miocene

The Miocene Climatic Optimum (MCO) was a greenhouse period of about 2myr in duration during the Miocene epoch (23.02-5.33Ma). It began at about 16.9 Ma, with a relatively abrupt warming. During the MCO, pCO2 was similar or slightly higher than that of the present, and the temperature was also higher than the modern world, which is about 7°C–8°C difference.

We rely on geochemical proxies to reconstruct sea surface temperatures (SSTs). In the South China Sea, the sea surface temperatures was between 26°C and 30°C from 15.7 to 12.7 Ma. In 2002, the SSTs in the South China Sea was from 29-30.2 °C [13], which was similar with the Middle Miocene. During the Late Miocene, the sea surface temperatures decreased in all oceans all over the world [14].

The sea breeze-dominated monsoon begun in the Early Miocene and the intensification of it continued into the Middle Miocene [15]. Figure 6 shows the erosional and depositional histories, reflecting the monsoon strength. The green line (Figure 6a) represents the chemical weathering index CRAT in the core of the ODP Site 1148 in the South China Sea. Higher value indicates a wetter climate, which means a stronger monsoon. We could see that the dry climate became wetter between the early and middle Miocene. And then, the monsoon intensity gradually increased from 15 to 10 Ma, and decreased from 10 to 3 Ma. Figure 6b illustrates the chemical weathering at the Indus marine A-1 well in Arabian Sea. The south Asia monsoon intensity increased from 16-10 Ma, and decreased from 10-3 Ma [16].

However, monsoon strength is affected by a combination of factors, including paleogeography, pCO2, and land-sea thermal contrasts. Changing palaeogeography has had an impact on the climate system by disrupting past atmospheric and ocean circulation [15]. So the slight difference between the East and South Asian monsoons in Figure 6 may be due to the Tibetan Plateau uplift. The rain shadow effect generated by Himalayas could affect the intensity of the South Asia monsoon.

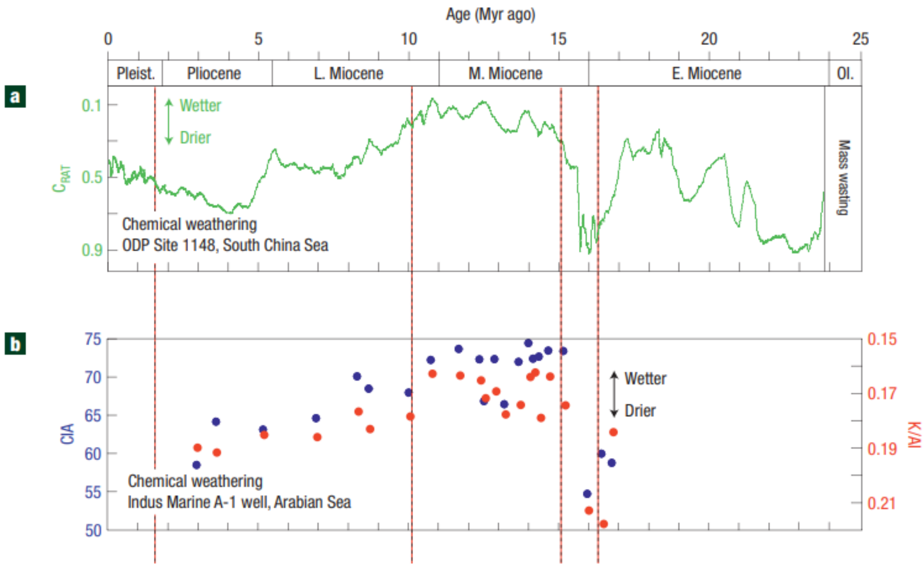

Figure 6. The monsoon intensity in Miocene.

2.6. *Pliocene*

Mid Pliocene Warm Period (PWP) (3.3–3 Ma) had a pCO2 (~400 ppm) close to today and a 2°C–3°C difference of average global warming.

During the Early Pliocene (~4.2-4.5 Ma), Asian paleoclimate became wetter from a relatively dry state, and the monsoon dominated the climate [17]. The East Asia summer monsoon strengthened significantly. Also, the monsoon rainfall increased compared to the dry period of the Late Miocene. From 3.1 to 2.2 Ma, we also noticed that the East Asian winter monsoon increased sharply, by the δ13C of the planktonic foraminifera in the northern South China Sea [18].

The general trend of the Neogene is that the SSTs of the South China Sea increased in the Early and

Middle Miocene, then gradually decreased, and then increased again during the Early Pliocene. Correspondingly, the Asian monsoon also showed a trend of first strengthening, then weakening, and then strengthening. Although there are local differences due to the coupling effect of palaeogeography, pCO2 and other factors, it can be seen that the SSTs has a positive correlation with monsoon intensity roughly. The Miocene and Pliocene climates are similar to the present, which provides a great help for us to study the future climate [19].

3. Conclusion

To summarize, in this research, we focused on looking at different time periods and how they are associated with stronger monsoons. For instance, a study published in Sciences Advances about monsoon rainfall in the Indian subcontinent over the past million years shows that changes in the intensity of monsoon rainfall over the past 900,000 years are "associated with fluctuations in atmospheric carbon dioxide, continental ice volume and moisture import from the southern hemisphere Indian Ocean." [20]

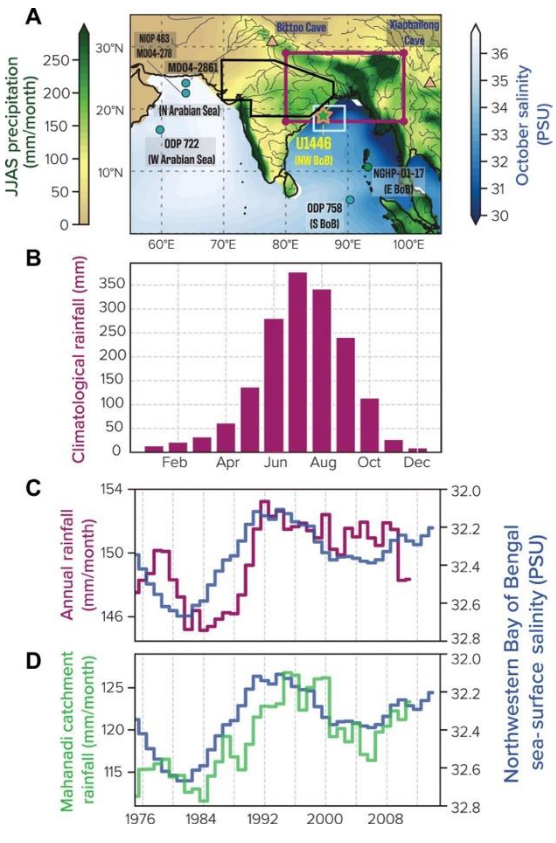

Figure 7. Precipitation in the Indian subcontinent.

In addition, more intense monsoon winds and rainfall tend to follow peaks in atmospheric carbon dioxide and low points in global ice volume [22]. We also looked at model predictions for future monsoons, which we found are consistent with evidence from the geological record. Furthermore, research predicts that there will be stronger monsoon seasons due to rising carbon dioxide levels and higher global temperatures, and increasing temperature will cause frequent changes and shifts to the monsoon precipitation [24]. Models show that there will be more water vapor in the atmosphere in a warming Earth.

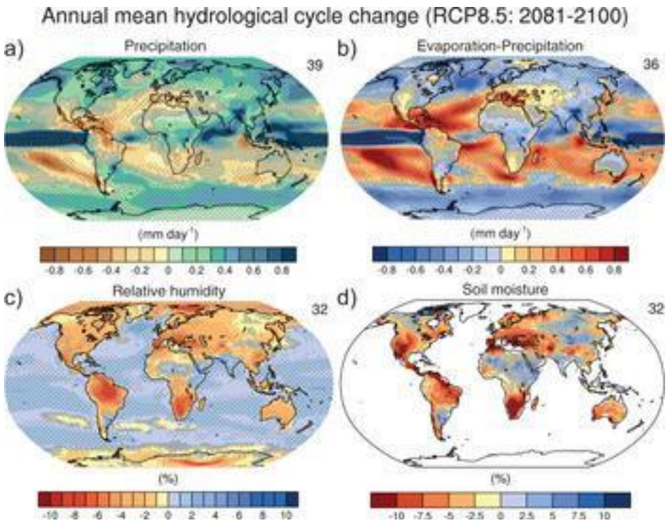

Figure 8. Annual changes of the hydrological cycle.

Thus, regions that rain a lot now will experience even more rain in the future [22], which is consistent with the studies and predictions of the South Asian monsoons. The geological record shows that atmospheric carbon dioxide concentrations have been increasing at a high rate, which corresponds with prediction models.

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Ruochen Lei, Sixue Liu, Ruiyi Wang, Taiyang, Zhang and Yiran Zhang contributed equally to this work and should be considered co-first authors.

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