A discussion on the possible significance of the "Warm Pool" on global oceanic circulation during the Late Quaternary

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Abstract. **The configuration and existence of the shallow seas surrounding the many islands and peninsulas of Southeast Asia play a significant role in the nature of the "Warm Pool". Being in the equatorial region, the Warm Pool continuously registers the warmest temperatures for a large body of surficial water anywhere on the globe and also receives a huge amount of rainfall. It is therefore the location on the globe that registers the largest transfer of heat and moisture between the surface and the atmosphere, and thus plays a crucial role in global climate.**

The Warm Pool is also the site of formation of very low density oceanic water that in itself makes an important contribution to the global Thermohaline Circulation system. A change of salinity and/or temperature [hence water density] of the Warm Pool can have a significant effect on the behaviour of the global circulation.

We document herewith a period of significant salinity increase in the southern portion of the Warm Pool that preceded the Holocene and which must have caused a significant change in oceanic circulation, at least in the Indian Ocean.

A reconstruction of the possible nature of oceanic surface currents in the region is also presented for the Last Glacial Maximum.

1. The Indonesian Archipelago [Maritime Continent] and surrounding seas

Crucial to the area of interest here are the surface waters in among the Indonesian Archipelago because they are in transit from the western Pacific Ocean before entering the eastern Indian Ocean. While in transit, these waters undergo much modification, especially with respect to temperature and salinity. Temperature changes are affected by changes in solar radiation, frequently interfered with by cloud cover, wind regimes and strength. The latter aeolian phenomena, of course, change direction and amplitude depending on seasons. The Eastern and Western Monsoons, as they are frequently called, relate to opposite periods of the year when seasonal changes similarly affect precipitation. Thus, local oceanic currents controlled by different wind regimes [see Figure 1] and sea-surface salinities are also substantially modified by rainfall changes [with seasonal differences reaching well over 3‰; see *Wyrtki*, 1961, and for a recent review *Godfrey*, 1996], even in this part of the globe where rainfall levels are extremely high. This is one of the reasons why this area is called the "Maritime Continent" sensu *Sturman and Tapper* [

1996]. Wind intensity will also affect the heat budget of the ocean, and consequently, a fine line exists between the various parameters which affect the waters in the Indonesian Archipelago. This surface water mass, best defined as the Australasian Mediterranean water [AAMW] has also been coined by others as Banda Sea Water and Indonesian Throughflow Water [see *Tomczak and Godfrey*, 1994: 231].

The present paper aims at attempting to define the characteristics of the AAMW using parameters that can be used by palaeoceanographers when reconstructing the history of the waters around the Maritime Continent. The overall aim has been to reconstruct the history of this body of water, and identify changes that have been of consequence globally.

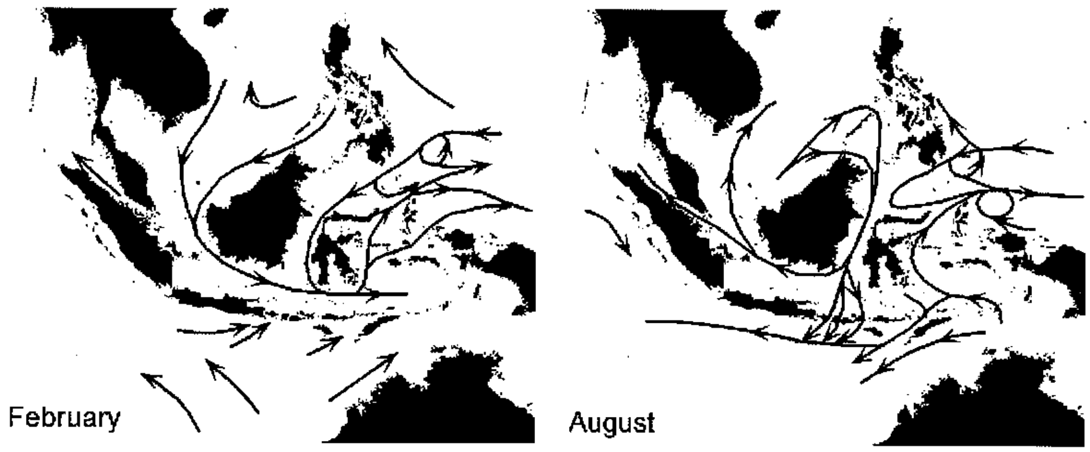

Figure 1. Generalised pathway of the oceanic currents at the surface in the Southeast Asian region for the 2 contrasting seasons [February and August]. Information on currents taken principally form *Wyrtki* [1961] and *Tomczak and Godfrey* [1994].

2. The AAMW and the Global Thermohaline Belt

The Global Conveyor Belt which connects all oceans, both at the surface and in the deep, is now regarded as an important modulator of oceanic processes and climate because of two principal factors that affect its behaviour. These are temperature and salinity. A combination of these two parameters will engender a pattern of circulation which, at a global scale, is very significant. This is why it is also coined the Global Thermohaline Belt. The original, oversimplified pattern of oceanic circulation first identified by *Stommel* [1957] and later better defined by *Gordon* [1986] and finally best publicised by *Broecker* [1987] has now been examined in much more detail; the overall pattern being much more complex than originally anticipated. Nevertheless, despite some significant differences between interpretations of the movement and direction of the water flow at some locations on the globe [e.g. compare the return of the Conveyor Belt south of Africa at the surface as proposed by *Broecker* [1987] to the latest versions presented by *Schmiz* [1995] and *McDonald and Wunsch* [1996]], the transfer of water across the Indonesian Archipelago from the western Pacific Ocean into the eastern Indian Ocean remains the same. Already *Wyrtki* [1961] had summarised the oceanographic setting in the tropical region of Indonesia, and pointed to salinity values approaching 30‰, and with temperatures remaining around the 28°C mark, and even with shifts to higher values. Therefore, the region is the site of low density water formation before it eventually enters the Indian Ocean on its way to the Atlantic Ocean, although its path is currently disputed. The Leeuwin Current, which is an offshoot of the AAMW, will travel poleward along the west coast of Western Australia before mixing with other surface waters in the Great Australian Bight.

If, however, the AAMW was to maintain its low density and could reach the Atlantic Ocean as a low salinity surface water, it could have substantial repercussions on the behaviour of the Gulf Stream, and also directly affect climatic conditions on land masses in the vicinity of the Atlantic Ocean.

The relevance of studying the behaviour of the AAMW through time therefore aims at identifying whether it did change in the past, and perhaps to postulate its contribution to the global circulation system through time. For example, if the AAMW was to change salinity conditions by much, could we expect the Leeuwin Current to have been maintained, at least along the west coast of Australia, or instead, could it have taken a different path, and travelled across the central Indian Ocean before reaching the east coast of Africa and join the Agulhas Current? These are possible various scenarios that need to be envisaged if we are to better understand global oceanic circulation through time. The obvious implication is that modellers could then use our data when trying to predict future oceanic changes.

3. Changes in the oceanographic setting of the Southeast Asian region during the last glacial/interglacial cycle

Southeast Asia and the Indonesian Archipelago, in particular, are best characterised today by their numerous islands and peninsulas. Examination of the animated movie prepared by *Stanley et al.* [this issue] which shows the substantial change in land peripheries that must have immense implications for the oceanic currents in the region. First of all, for <u>most of the time</u> during a glacial/interglacial cycle, the Java and Flores Seas [making the Sunda Shelf] , the Strait of Malacca and a large portion of the Banda and Arafura Seas are continuously above water! The last 8,000 years of the record are an exception [check land periphery as a result of a sea-level drop of 20 m only in *Stanley et al.* [this issue] for example]. Thus, oceanic circulation in the region would have been quite different, and it would not be too difficult to postulate oceanic current reorganisation. Nevertheless, the AAMW would still be able to pass through some of the straits east of Bali due to the substantial depths there, whereas Sunda Strait itself was dry most of the time.

Martinez et al [1997] were able to identify that, during the climatic extreme that spanned the Last Glacial Maximum [= LGM], the isotopic composition [viz. $\delta^{18}O$] of surface waters in the equatorial region all around the Maritime Continent was significantly higher compared to the present after taking into account the expected increase in salinity as a result of sea-level drop [viz. ~125 m]. Such an increase in isotopic composition would have to imply an increase in salinity resulting from a change in precipitation in the region. Already *van der Kaars* [1990], *van der Kaars and Dam* [1995] and *van der Kaars et al.* [in press] who studied the palynological record from a core from the Banda Sea has identified a change in vegetation at the LGM, with predominance of grasses at that time, implying a possible drop of precipitation reaching values estimated to be around 40% [van der Kaars, pers. comm.].

Two Australian cruises onboard the *RV Franklin* in 1995 and 1996 recovered some 52 sediment cores from the eastern Indian Ocean along a broad north-south transect between Indonesia and Perth. Some 12 cores have been analysed in detail for the period of sedimentation spanning the last 30,000 years. Preliminary results presented in *Martinez et al.* [1999] discuss the overall significant changes in the Indian Ocean in the vicinity of Australia. In particular, two cores display some very important changes with respect to the "Warm Pool" because they are located today exactly at its southern boundary [where sea-surface temperatures are ≥ 28°C in summer]. *Martinez et al.* [in press] examined one of those cores [FR10/95 GC 11; located at 114° 59.93'E 17° 38.57'S, 2458 m water depth, see Fig. 1 for location], and by identifying the relationship of the ratio of abundance of 2 planktic foraminifers [*N. dutertrei* and *G. sacculifer*] in the core, they postulated that the southern boundary of the Warm Pool had shifted northward during the LGM.

However, examination of the $\delta^{18}O$ record of *G. sacculifer* from cores Fr10/95-GC5 [121° 01.58'E 14° 00.55'S; 2472 m water depth] and Fr10/95-GC17 [113° 30.11'E 22° 07.74'S; 1093 m water depth] [in conjunction with the reconstructed SST carried out by Mr T. T. Barrows using his AUSMAT-2 database], shows that SST changed little during the last ~30,000 years. On the other hand, the $\delta^{18}O$ composition of the foraminifers displays at times surprising isotopic shifts. Examination of Figure 2 would identify frequent shifts of well over 1‰ and reaching up to 3‰ at times. As these shifts could not have been caused by temperature changes [otherwise these would be in parallel with faunal reconstructions; see Figure 2 for more details], the only plausible cause being a shift in sea-surface salinity. The additional, important point to note is that those large isotopic shifts only.

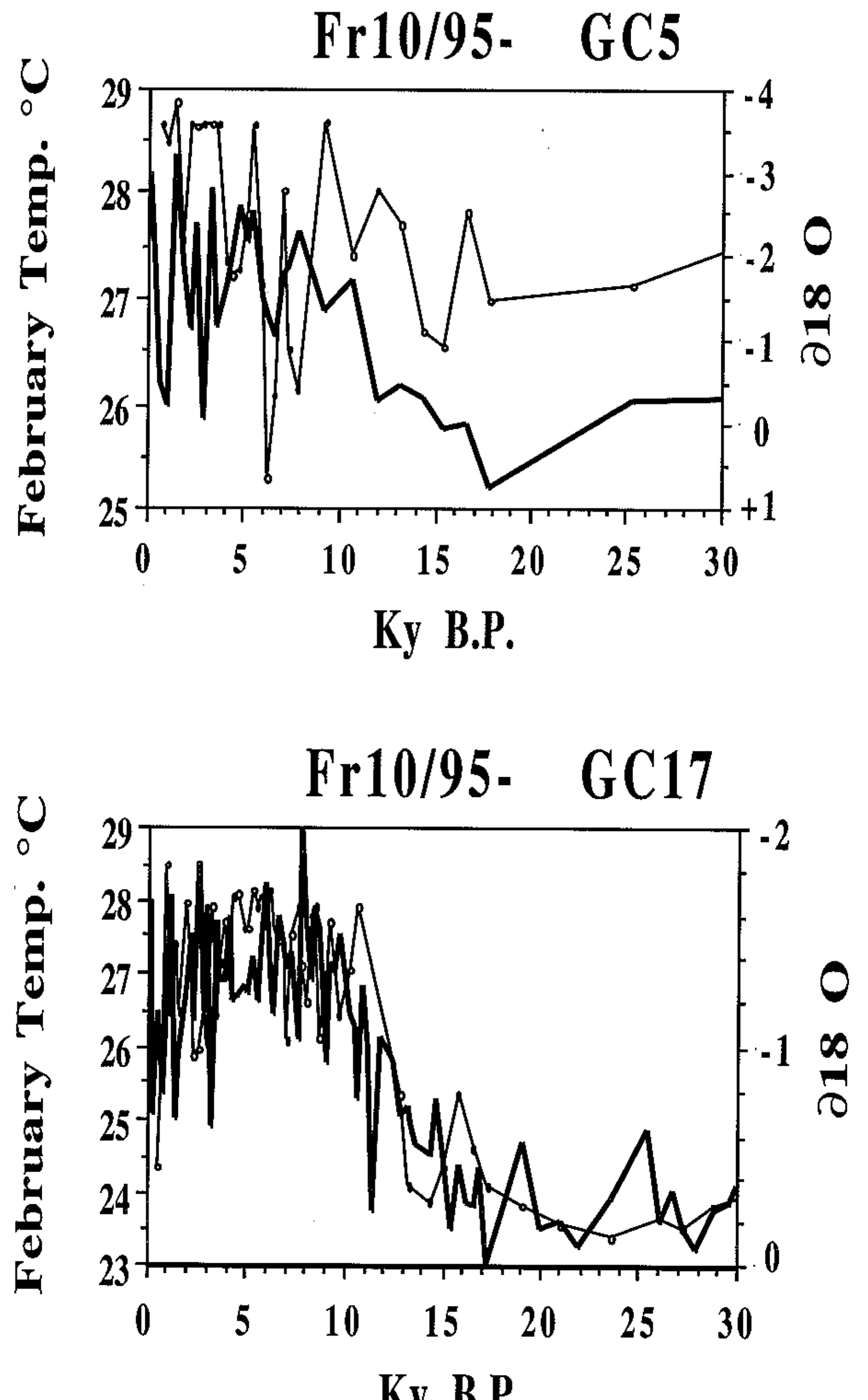

Figure 2. Reconstruction of the $\delta^{18}O$ composition of *G. sacculifer* for the last 30,000 years from cores Fr10/95 -GC5 and Fr10/95-GC17 [for location of cores, see Figure 3] and the reconstructed sea-surface temperatures obtained through the AUSMAT-2 database of T. T. Barrows and based on foraminifer faunal assemblages. Note the substantial fluctuations in $\delta^{18}O$ for the Holocene [0-10Ky B.P.] period compared to the preceding marine isotope stage 2 spanning the LGM. The bold line represents the $\delta^{18}O$ values, and the thinner one with small circles, the SST record for February.

occurred during the Holocene, whereas during the phase preceding this, $\delta^{18}O$ fluctuations were minimal. This would imply small salinity fluctuations, probably resulting from 'constant' rainfall averages around the Maritime Continent, at least north of the coring sites from where the surface waters would have originated.

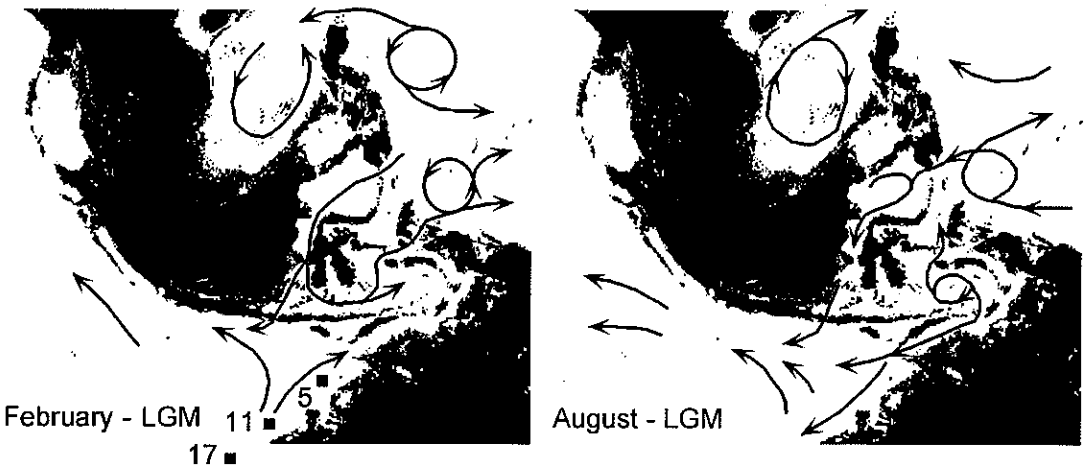

Figure 3. Map showing the change in periphery of the land masses for Southeast Asia during the LGM by dropping sea level by 125m [compare these maps with those in Figure 1 and for further details, see *Stanley et al.* , this volume]. In addition, an attempt is made here to postulate the surface currents for the 2 seasons. Location of the 3 cores mentioned in the text are provided.

4. Changes of conditions for the Warm Pool, and implication for global oceanic circulation

It is becoming evident that the southern part of the Warm Pool at least was quite different during the LGM in contrast with today's conditions. Salinities at the surface were higher [see *Martinez et al.* , 1997] and did not register broad fluctuations compared to today [see Figure 2]. Precipitation was also much reduced [see *van der Kaars* , 1990, *van der Kaars* and *Dam*, 1995 and *van der Kaars et al.*, in press]. Sea-surface temperatures had dropped by ~2°C or less [see *Martinez et al.*, 1999] in the southern end of the Warm Pool. The consequences of all these changes - in contrast with today - provide the following scenario for the LGM:

1. the Warm Pool, with its characteristic high temperatures still existed in the Southeast Asian region;
2. the southern extent of the Warm Pool in vicinity of Australia had shifted slightly northward;
3. at least, the southern extent of the Warm Pool and its throughflow was more saline than today as a result of reduced precipitation in the region;
4. at the LGM, winds were definitely stronger, and therefore these would have enhanced the throughflow of water through the various pathways as indicated in Figure 3;
5. it is very likely that, as a consequence of enhanced salinity at the surface of the AAMW, the Leeuwin Current would have disappeared. On the other hand, the Southeast Tropical Current

would have been stronger and therefore have delivered saltier water to the Central Indian Ocean Gyre compared to today. Implications for the Thermohaline Belt would have, therefore, been that eventually less of a 'freshwater' component would have reached the North Atlantic, thus perhaps reducing the strength of the Conveyor Belt, if it at all existed during that time.

5. Acknowledgements

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