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The amplifying effect of Indonesian Throughflow heat transport on Late Pliocene Southern Hemisphere climate cooling

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ABSTRACT

An unusually short glaciation interrupted the warm Pliocene around 3.3 Ma (Marine Isotope Stage (MIS) M2). Different hypotheses exist to explain why this glaciation event was so pronounced, and why the global climate system returned to warm Pliocene conditions relatively quickly afterwards. One of these proposed mechanisms is a reduced equator-to-pole heat transfer, in response to a tectonically reduced Indonesian Throughflow (ITF). The ITF is a critical part of the global thermohaline ocean circulation, transporting heat from the Indo-Pacific Warm Pool to the Indian Ocean. When ITF connectivity is reduced, the water and heat supply for the Leeuwin Current, flowing poleward along Australia's west coast, is also diminished. To assess the possible relationship between mid-Pliocene glaciations and latitudinal heat transport through the Indonesian Throughflow, we constructed a multi-proxy orbital-scale record for the 3.7–2.8 Ma interval from International Ocean Discovery Program (IODP) Site U1463, off northwest Australia. The comparison of the Site U1463 record with paleoclimate records from nearby Site 763 and West Pacific Warm Pool Site 806 allows for a detailed regional reconstruction of Pliocene paleoceanography and thus for testing the proposed hypothesis.

An astronomically-paced decrease in potassium content characterizes the late Pliocene interval of U1463. This record documents the increasing aridity of northwest Australia, periodically alleviated by reinforced summer monsoon precipitation under summer insolation maxima. The $\delta^{18}O$ record of the planktonic foraminifer *Globigerinoides sacculifer* correlates exceptionally well with the sea surface temperature (SST) record from Site 806 in the West Pacific Warm Pool, even during MIS M2. Hence, Site U1463 preserves an uninterrupted ITF signal even during Pliocene glaciations. However, the U1463 $\delta^{18}O_{G.sacculifer}$ record exhibits a 0.5‰ offset with the nearby Site 763A record around MIS M2. This implies that Site 763A, about 500 km west of U1463, more closely tracks Indian Ocean SST records across MIS M2. The U1463 data reveal that heat-transport through the Indonesian Throughflow did not shut down completely during MIS M2, but rather its intensity decreased prior to and during MIS M2, causing Site 763A to temporarily reflect an Indian Ocean, rather than an ITF signal. We conclude that ITF variability significantly influenced latitudinal heat transport by means of the Leeuwin Current and hence contributed to the relative intensity of MIS M2. We propose the ITF valve between the Pacific and Indian Ocean as a positive

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feedback mechanism, in which an initial sea level lowering reduces ITF heat transport, in turn amplifying global cooling by advancing the thermal isolation of Antarctica.

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1. Introduction

The mid-Pliocene Warm Period (3.29–2.97 Ma) is often used as an analogue for on-going climate change and its potential consequences, considering that the current atmospheric CO_2 concentration (Tans and Keeling, 2017) has recently reached Pliocene values, estimated around 400 ppm (Haywood and Valdes, 2004; Haywood et al., 2011 and references therein). The mid-Pliocene warm period also is the most recent period in the geological past with warmer than present climates, stable over tens of thousands of years (De Schepper et al., 2014; Haywood et al., 2013). In contrast, worldwide Pliocene climate records suggest significant climate variability, with evidence for brief cool intervals interrupting mid-Pliocene warmth (De Schepper et al., 2013; Dolan et al., 2015). Marine Isotope Stage (MIS) M2 (also known as the ∼3.3 Ma event) is such an interval that is globally recognized as a cooling event, interrupting the relatively warm background climate state. The large positive isotope excursion associated with this Pliocene glaciation event is an unusual and extraordinary feature of the benthic isotope stack (LR04, Lisiecki and Raymo, 2005) and mega-splice (DV17, De Vleeschouwer et al., 2017b). The magnitude of the excursion (0.64‰ in the LR04 stack, 0.74‰ in the DV17 mega-splice) suggests significant paleoclimate variability across MIS M2. Haug and Tiedemann (1998) interpreted this interval as a "failed attempt of the climate system to enter a full glacial state". Besides the significant positive oxygen isotope excursion in globally-distributed benthic records, global sea level reconstructions indicate an important sea level low-stand around ∼3.3 Ma, after a glacio-eustatic sea-level fall of several tens of meters (Dwyer and Chandler, 2009; Miller et al., 2012; Naish and Wilson, 2009; Rohling et al., 2014).

Different hypotheses have been put forward to explain why this glaciation event was so pronounced, and why the global climate system returned to warm Pliocene conditions relatively quickly. One of the proposed mechanisms is a reduced equator-to-pole heat transfer, in response to a tectonically reduced Indonesian Throughflow (De Schepper et al., 2014; Karas et al., 2011a, 2011b; Sarnthein et al., 2017). Indeed, the geometry of the Indonesian Throughflow (ITF) exerts an important control on the heat transport from the Pacific to the Indian Ocean (Fig. 1). Although the tectonic history of the ITF is complex, the general trend on a Myr-timescale indicates that the Indonesian seaway became more restricted with time in response to the northward movement of the Australian plate (Cane and Molnar, 2001; Gallagher et al., 2009; Molnar and Cronin, 2015). In the early Pliocene, the Throughflow was still relatively unbound by the Maritime Continent, whereas a more restricted connection between the Pacific and Indian Ocean is suggested from the Late Pliocene onwards (Christensen et al., 2017; De Schepper et al., 2014; Gallagher et al., 2009, 2014; Karas et al., 2011b, 2017). Changes in ITF connectivity also influence Leeuwin Current intensity, transporting warm, low-salinity, nutrient-deficient water poleward along the west Australian coast. The Leeuwin Current is unique in that it is the only southward flowing eastern boundary current in the Southern Hemisphere, linking the Timor Passage in the ITF region with southeast Australia (Church et al., 1989). The Leeuwin Current is a surface current that is only up to ∼300 m deep (Fig. 4 in Furue et al., 2017; Fig. 3 in Wijeratne et al., 2018; Fig. 9 in Woo and Pattiaratchi, 2008) and exhibits significant seasonal variability (Ridgway and Godfrey, 2015). On the northwest Australian shelf,

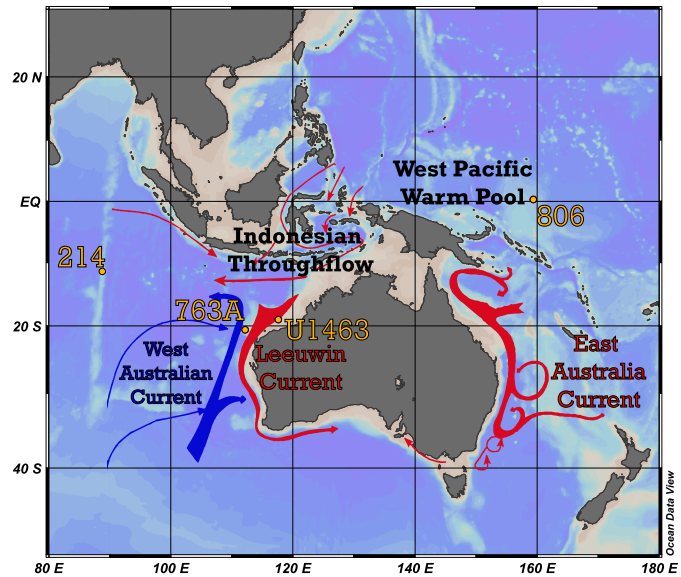

Fig. 1. Surface oceanography in the Indo-Pacific Region (adapted from Gallagher et al., 2009). Orange dots indicate the position of studied sites U1463 (northwest Australian Shelf), 763A (eastern Indian Ocean), 214 (equatorial Indian Ocean) and 806 (West Pacific Warm Pool). (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

surface boundary current is strongest from April till June, when transport exceeds 2 Sv at a section across the shelf at 116.7°E (Wijeratne et al., 2018), just 100 km west of Site U1463 studied in this paper. South of the North West Cape, the Leeuwin Current strength builds up, with a seasonal maximum around 8 Sv in June (Wijeratne et al., 2018). Seasonal variability in Leeuwin Current System strength is governed by the passage of a sea level pulse, which itself originates in the seasonal movements of wind stresses (Furue et al., 2017). The Leeuwin Current surface water constitutes a warm-water low-density cap, sufficient to restrain upwelling to water depths between 1000 and 500 m (Feng et al., 2007; Holloway, 1995; Pearce, 1991; Thompson et al., 2011; Waite et al., 2007).

Here, we present new orbital-scale paleoclimate records from IODP Site U1463 (18°57.9′S, 117°37.4′E, Gallagher et al., 2017a), on the northwest Australian Shelf, downstream of the outflow of the ITF and upstream of the Leeuwin Current. We juxtapose the new U1463 paleoclimate archive with contemporaneous records in the eastern Indian Ocean (Site 763A, Karas et al., 2011b) and the West Pacific Warm Pool (Site 806, O'Brien et al., 2014; Wara et al., 2005) to reveal that the ITF outflow was reduced during the M2 event, leading to a more dimensionally constrained and lower intensity Leeuwin Current.

2. Materials and methods

IODP Expedition 356 drilled sediments on the northwest Australian shelf and in the Perth Basin (Gallagher et al., 2017b), yielding long and continuous climate archives that already proved useful in detailing the million-year scale climate evolution of western Australia throughout the Neogene (Christensen et al., 2017; Groeneveld et al., 2017). Site U1463 was drilled at a present-day water depth of 145 m, which implies that the modern-day Leeuwin

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