Quaternary Science Reviews 93 (2014) 142–154

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Mid- to Late-Holocene Australian–Indonesian summer monsoon variability

Stephan Steinke [a,*], Mahyar Mohtadi [a], Matthias Prange [a], Vidya Varma [a,1], Daniela Pittauerova [b], Helmut W. Fischer [b]

[a] MARUM –Center for Marine Environmental Sciences and Department of Geosciences, University of Bremen, 28359 Bremen, Germany
[b] Bremen State Radioactivity Measurements Laboratory, Institute of Environmental Physics (IUP), University of Bremen, 28359 Bremen, Germany

ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form
31 March 2014
Accepted 4 April 2014
Available online 4 May 2014

Keywords:
Australian–Indonesian summer monsoon
Holocene
Orbital forcing
Solar forcing
Grand solar minimum

ABSTRACT

The Australian–Indonesian monsoon has a governing influence on the agricultural practices and livelihood in the highly populated islands of Indonesia. However, little is known about the factors that have influenced past monsoon activity in southern Indonesia. Here, we present a ~6000 years high-resolution record of Australian-Indonesian summer monsoon (AISM) rainfall variations based on bulk sediment element analysis in a sediment archive retrieved offshore northwest Sumba Island (Indonesia). The record suggests lower riverine detrital supply and hence weaker AISM rainfall between 6000 yr BP and ~3000 yr BP compared to the Late Holocene. We find a distinct shift in terrigenous sediment supply at around 2800 yr BP indicating a reorganization of the AISM from a drier Mid Holocene to a wetter Late Holocene in southern Indonesia. The abrupt increase in rainfall at around 2800 yr BP coincides with a grand solar minimum. An increase in southern Indonesian rainfall in response to a solar minimum is consistent with climate model simulations that provide a possible explanation of the underlying mechanism responsible for the monsoonal shift. We conclude that variations in solar activity play a significant role in monsoonal rainfall variability at multi-decadal and longer timescales. The combined effect of orbital and solar forcing explains important details in the temporal evolution of AISM rainfall during the last 6000 years. By contrast, we find neither evidence for volcanic forcing of AISM variability nor for a control by long-term variations in the El Niño-Southern Oscillation (ENSO).

1. Introduction

The Asian and Australasian monsoons affect roughly half the world's population, which largely depends on the monsoonal climate for their food and livelihood (Webster et al., 1998; Christensen et al., 2007). Despite the importance to so many, the monsoon is difficult to predict and model, making its future development in a changing global climate uncertain (Webster et al., 1998). Hence, it is vital to reconstruct monsoon variations beyond the instrumental record in order to improve our understanding of the mechanisms that may act on monsoonal rainfall variability. Most proxy evidence on multi-decadal to multi-millennial scale changes in monsoonal rainfall intensity during the Holocene has been deduced from continental and marine archives located in the Indian and East Asian monsoon domains. These studies on the Indian (Fleitmann et al., 2003; Gupta et al., 2005) and the East Asian (Wang et al., 2005; Zhang et al., 2008) summer monsoon rainfall indicate a strong response to orbital and solar forcing during the Holocene. In contrast to its Northern Hemisphere counterparts, very little is known about the development of the Australian-Indonesian summer monsoon (AISM) rainfall during the Holocene.

With respect to the AISM rainfall during the Holocene, Australian proxy records suggest wetter conditions during the Early and Mid Holocene compared to present (Nott and Price, 1994; Magee et al., 2004) which has been explained by a Northern Hemisphere insolation control (Magee et al., 2004; Miller et al., 2005), a response to regional sea-surface temperatures (Liu et al., 2003) or human-induced changes in vegetation cover during the Late Holocene (Miller et al., 2005). In contrast, two recent studies from southern Indonesia indicate reduced rainfall during the Mid Holocene compared to the Late Holocene (Griffiths et al., 2009; Mohtadi et al., 2011), highlighting the complex and contrasting patterns of AISM development in southern Indonesia and northern

* Corresponding author.
E-mail address: ssteinke@uni-bremen.de (S. Steinke).
[1] Now at the Department of Meteorology, Stockholm University, SE-10691 Stockholm, Sweden.

http://dx.doi.org/10.1016/j.quascirev.2014.04.006
0277-3791/

Australia. Another study relates the changes in AISM rainfall during the past two millennia to shifts in the mean position of the Inter-Tropical Convergence Zone (ITCZ) forced by variations in Northern Hemisphere climate mean state (Tierney et al., 2010). A recent study from the Australian tropics suggests that El Niño-Southern Oscillation (ENSO) may have played a dominant role in driving AISM variability since the middle Holocene (Denniston et al., 2013). Taken together, mechanisms that influence the AISM during the Holocene are far from being understood because of the limited number of AISM records and the strong disagreement on the nature and causes of rainfall changes in the existing AISM records.

Here, we present a ~6000 years high-resolution record of southern Indonesian rainfall based on bulk sediment element analysis in a sediment archive retrieved offshore northwest Sumba Island (Indonesia). This new record allows us to study the history of monsoonal rainfall in southern Indonesia at multi-decadal to multi-millennial time scales, and to explore the role of various potential forcing mechanisms in driving AISM rainfall through the Holocene.

2. Modern climate

At present, south and central Indonesia from south Sumatra to Timor Island, parts of Kalimantan, Sulawesi, and Irian Jaya as well as the northern portions of Australia experience a monsoonal climate, with the majority of the annual rainfall occurring in austral summer (December–March) when the northwest monsoon carries humid air and heavy rainfall as the ITCZ-related rainbelt migrates southward (Fig. 1a). During austral winter (June–September), the southeast monsoon winds are relatively cool and dry while the ITCZ is located over mainland Asia. The annual rainfall in the study area is highest during the summer wet season (~6.5 mm/day; December–March) and negligible during the winter dry season (~0.3 mm/day; June–September; Fig. 1b). On interannual timescales, rainfall in southern Indonesia is highly sensitive to ENSO (e.g. Webster et al., 1998; Aldrian and Susanto, 2003) with El Niño events typically resulting in reduced rainfall and subsequent drought while increased rainfall and severe floods are associated with La Niña events over much of central and southern Indonesia.

3. Strategy and proxy variables used for rainfall reconstruction

We use the logarithmic ratio between titanium (Ti) and calcium (Ca) as a proxy for riverine terrestrial input as in Mohtadi et al. (2011). The linkage between riverine detrital input and AISM rainfall has been demonstrated previously for the study area by Rixen et al. (2006). The supply of terrigenous material as monitored by the ratio between the lithogenic particles and calcium carbonate

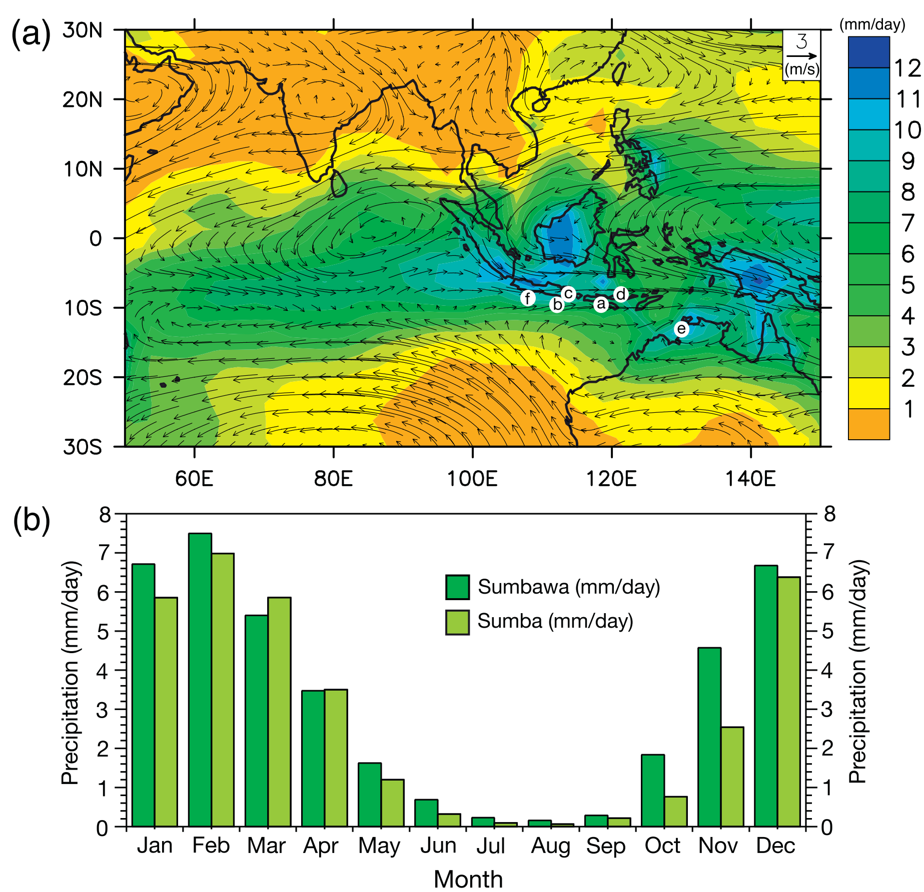

Fig. 1. (a) Precipitation and 850-hPa wind climatologies (1981–2010) for the austral summer season (December–February) in the Asian–Australian monsoon region. Data sets are Global Prediction Climatology Project (GPCP) version 2.2 for precipitation (Adler et al., 2003) and NCEP/NCAR reanalysis for wind (Kalnay et al., 1996). Other records of Australian–Indonesian summer monsoon (AISM) variability discussed in the text are also indicated: (a) Ti/Ca ratios in core GeoB10065-7 (this study), (b) Ti/Ca ratios in core GeoB10053-7 (Mohtadi et al., 2011); (c) Lake Lading leaf wax δD record (Konecky et al., 2013); (d) Liang Luar stalagmite $\delta^{18}O$ record (Griffiths et al., 2010); (e) Kimberley stalagmite $\delta^{18}O$ record (Denniston et al., 2013). (f) Indicates the position of sediment trap JAM off south Java (Rixen et al. (2006)); (b) Monthly average rainfall between 1998 and 2010 for Sumbawa (114.5–119.2°E; 9.15–8.15°S) and Sumba (118.5–120.5°E; 10.15–9.15°S) derived from the Tropical Rainfall Measuring Mission (TRMM; http://trmm.gsfc.nasa.gov) and the Global Precipitation Climatology Centre (GPCC; Deutscher Wetterdienst; http://dwd.de) precipitation 0.25° dataset interpolatd via http://climexp.knmi.nl.