Clim. Past, 14, 1331–1343, 2018
https://doi.org/10.5194/cp-14-1331-2018

Climate of the Past
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Variations of the Somali upwelling since 18.5 ka BP and its relationship with southwest monsoon rainfall

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Received: 6 June 2017 – Discussion started: 7 July 2017
Revised: 2 August 2018 – Accepted: 23 August 2018 – Published: 20 September 2018

Abstract. Somali upwelling history has been reconstructed for the last 18.5 ka BP based on biogenic silica fluxes estimated from a sediment core retrieved from the western Arabian Sea. Surface winds along the east African coast during the southwest monsoon (SWM) cause the Somali upwelling; thus, the intensity of this upwelling has been related to the variability of the SWM. Biogenic silica flux variation suggests periodic weakening and strengthening of the Somali upwelling. Weakened upwelling during the 18.5–15 ka BP period and strengthened upwelling during the Bølling–Allerød (15–12.9 ka BP) suggest the onset of the SWM. The Younger Dryas (12.9–11.7 ka BP) is marked by reduced upwelling strength, with an intensification of the Somali upwelling observed at the beginning of the Holocene and a further decline at 8 ka BP. The increase in the upwelling strength recorded since 8 ka BP suggests SWM strengthening during the latter part of the Holocene. A comparison of upwelling variations with the SWM precipitation record demonstrates a reversal in the relationship between the strength of the Somali upwelling and SWM rainfall at the beginning of the Holocene. This observed shift has been attributed to the variation in the SWM strength due to the latitudinal shift of the intertropical convergence zone (ITCZ) associated with changes in moisture sources.

1 Introduction

A large fraction of the world's population resides in the tropics, where the climate is mainly driven by monsoon rainfall. Therefore, understanding the causes of past climatic changes plays a crucial role in deciphering past, present and future monsoon variability. India, as a tropical country comprising a significant fraction of the world's population, has an economy that is largely dependent on rainfall from the southwest monsoon (SWM); hence, slight changes in SWM rainfall can have immense societal impacts in this region. Several attempts have been made to identify the factors responsible for SWM rainfall variations, and several global phenomena, such as ENSO (El Niño–Southern Oscillation) (Goswami et al., 1999; Annamalai and Liu, 2005), the Atlantic sea surface temperature (sea surface temperature hereafter referred to as SST; Goswami et al., 2006; Yadav, 2017), Eurasian snow cover (Hahn and Shukla, 1976; Pant and Rupa Kumar, 1997; Bamzai and Shukla, 1999), the pre-monsoon 500 hPa ridge (Mooley et al., 1986), the Indo-Pacific warm pool (Parthasarathy et al., 1988, 1991), the Pacific decadal oscillation (Krishnan and Sugi, 2003), and the Atlantic multi-decadal oscillation (Krishnamurthy and Krishnamurthy, 2016) have been correlated with variations in SWM rainfall. In addition to these factors that influence the SWM, the Indian Ocean warm pool (IOWP) has been identified as the prominent source of moisture for SWM rainfall (Ninomiya and Kobayashi, 1999; Gimeno et al., 2010). During its maxima in the pre-monsoon period (April) the IOWP extends throughout the northern Indian Ocean, before reducing by almost half during the SWM (Izumo et al., 2008). The extent of the IOWP is primarily controlled by the Somali upwelling and to a lesser extent by the latent heat flux increase in the Arabian Sea during the SWM season (Izumo et al., 2008). Both the Somali upwelling and SWM rainfall are triggered by the SWM winds during boreal summer.

The upwelling of deep water during the SWM brings nutrients to the photic zone, thereby enhancing surface productiv-