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Invited review

Monsoon extremes and society over the past millennium on mainland Southeast Asia

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A B S T R A C T

The early 21st century has seen vigorous scientific interest in the Asian monsoon and significant development of paleo-proxies of monsoon strength. These include the Monsoon Asian Drought Atlas – a 700-year, gridded reconstruction of hydroclimate derived from 327 tree ring records – and several long speleothem records from China and India. Similar progress has been made on the study of monsoon climate dynamics through re-analysis data products and General Circulation Model diagnostics. The story has emerged of a variable monsoon over the latter Holocene, with extended droughts and anomalously wet episodes that occasionally and profoundly influenced the course of human history. We focus on Southeast Asia where an anomalous period of unstable climate coincided with the demise of the capital of the Khmer Empire at Angkor between the 14th and the 16th centuries, and we suggest that protracted periods of drought and deluge rain events, the latter of which damaged Angkor's extensive water management systems, may have been a significant factor in the subsequent transfer of the political capital away from Angkor. The late 16th and early 17th century experienced climate instability and the collapse of the Ming Dynasty in China under a period of drought, while Tonkin experienced floods and droughts throughout the 17th century. The 18th century was a period of great turmoil across Southeast Asia, when all of the region's polities saw great unrest and rapid realignment during one of the most extended periods of drought of the past millennium. New paleo-proxy records and the incorporation of historical documentation will improve future analyses of the interaction between climate extremes, social behavior and the collapse or disruption of regional societies, a subject of increasing concern given the uncertainties surrounding projections for future climate.

1. Introduction

The Asian monsoon comprises, arguably, the Earth's largest and most important climate phenomenon, one that directly influences the livelihood of more than 60% of our planet's human population (Wang, 2006; Clift and Plumb, 2008), and sustains regions with some of the highest and most vulnerable biodiversity on Earth (Sodhi et al., 2004). The life-sustaining rains that arrive annually with the changes in seasonal circulation over Asia give way to an annual drought of varying severity across the region. Human societies have adapted to the rhythm of the annual rains that come with the monsoon, and have flourished and suffered, often in concert with anomalous departures from its mostly predictable behavior. Over the period of recorded history, anomalously strong or weak monsoon rains have bestowed misery upon the inhabitants of widely distant regions of Asia, and this continues to the present day. Several dynamical factors in the oceans and the atmosphere either influence or are correlated with this mighty system, including the El Niño – Southern Oscillation (ENSO – Kumar et al., 1999; Krishnamurthy and Goswami, 2000), the Interdecadal Pacific Oscillation (IPO – Meehl and Hu, 2006), North Atlantic sea surface temperature (Goswami et al., 2006), the Indian Ocean

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Dipole (IOD – Ashok et al., 2001), and Eurasian snowpack anomalies (Hahn and Shukla, 1976; Bamzai and Shukla, 1999).

In this paper we present a brief overview of the rapidly growing body of paleoclimate proxies for the Asian monsoon, and we highlight the past millennium to identify the periods of greatest anomalies of climate and societal turmoil. We focus on mainland Southeast Asia (a.k.a. the Indochina Peninsula), in particular on what happened in the capital of the Khmer state at Angkor in the 14th and 15th centuries (centered in present-day Cambodia), and the events of the latter half of the 18th century when all of Southeast Asia's main polities were driven from power and drought dominated the climate (Buckley et al., 2007, 2010; Cook et al., 2010; Lieberman and Buckley, 2012). We also focus on the eastern flank of the Annamite Range, in present-day Vietnam, where the kingdoms of Tonkin and Conchinchina thrived. We present evidence from the historical chronicles from Hanoi and Hue, as well as several European sources, from the 14th through the 18th centuries of anomalous climate, disease and famine, and compare these with the results of an updated version of the tree-ring derived Monsoon Asia Drought Atlas (MADA – Cook et al., 2010: http://iridl.ldeo.columbia.edu/SOURCES/.LDEO/.TRL/.MADA/.pdsi/). We then analyze the dynamical features that lead to such anomalies over the modern period of instrumentation, and seek to identify how, and the ways in which societies dealt with their circumstances.

2. The Asian monsoon system

2.1. Background

The Asian monsoon is, at its most fundamental level, an annually occurring, hemispheric-scale wind reversal that is caused by the differential heating between the Eurasian continent and its adjacent oceans between summer and winter (Wang, 2006; Neelin, 2007; Clift and Plumb, 2008). The Inter-Tropical Convergence Zone (ITCZ) pools moisture-laden air from both hemispheres and creates strong, convective lifting that arises from heating of the surface, thereby transferring heat and moisture from the tropical oceans into the subtropics. Within the ITCZ the atmospheric moisture over the ocean ascends until it reaches the upper atmosphere where it cools, releases much of its moisture as rain, and then diverges before descending into the northern and southern subtropics, forming the classic Hadley Cell circulation. Over land, the position and expansion of the ITCZ are inter-related with the Monsoon's strength (Fleitmann et al., 2007; Yancheva et al., 2007; Sachs et al., 2009). Altering the mean location of the ITCZ therefore changes the regional hydroclimate, and has significant consequences for those who depend upon the reliability and predictability of the monsoon rains. This is particularly significant over South and Southeast Asia.

2.2. Components of the Asian monsoon

The Asian monsoon can be conceptualized as encompassing several related components that are not explicitly correlated. It is the boreal summer's Indian Summer Monsoon (ISM), for example, that is commonly referred to when describing the Asian Summer Monsoon, but the East Asian Summer Monsoon (EASM) and the Western North Pacific Summer Monsoon (WNPSM) have been shown as separate monsoon subsystems. The boundaries of ISM, EASM and WNPSM are outlined in Fig. 1. Importantly the Indochina Peninsula, a main focus of this paper, is sandwiched between these three regional monsoon systems, highlighting its complex climate dynamics in the context of rainfall distribution and intensity (Chen and Yoon, 2000).

In summer, moisture from the ISM is carried across the Indian subcontinent and the two adjacent seas – i.e., the Arabian Sea to the west and the Bay of Bengal to the east. The monsoonal westerly flows then split. One branch curves northward into Myanmar and Bhutan and forms a heavy precipitation belt on the windward slopes and a 'rain shadow' with contrasting semi-arid climate on the leeward slopes. A second branch crosses the Indochina Peninsula into the South China Sea where the monsoon flows turn northeastward, towards East Asia. There, the monsoon flows meet the mid-latitude westerly wind and storm track, which is still active during early summer, creating a thermodynamically unstable zone or rain band, known locally as the *Meiyu* in Chinese, *Baiu* in Japanese, and *Jangma* in Korean for "plum rain". The meteorological community generally refers to this rain band as the EASM (e.g., Ding, 2004; Chen et al., 2004a; Hoskins and Wang, 2006), and significant fluctuations in its intensity and/or position can bring epic droughts and floods to this highly populated region.

During the warm season, the WNPSM is integrated into the western portion of the North Pacific anticyclonic gyre – a gigantic subtropical high-pressure system that is formed by the descending branch of the Hadley circulation. Its interaction with the ISM forms a broad region of convergence due to the two opposite-direction flows – i.e., the westerly monsoon flow and the easterly Trade Winds that meet around the Philippine Sea. This convergence zone pumps moisture into the atmosphere, generating large volumes of rainfall and releasing latent heat. Its position and intensity also change year-to-year depending on the strength of the subtropical high-pressure system and/or the ISM. Long-term changes of these monsoon systems can, and have, had great societal and ecosystems impacts.

3. Significant monsoon variability of the past millennium

The Asian monsoon as we describe it above is thought to have developed about 10 million years ago, long before the first humans appear in the geo-archaeological record (Molnar, 2005). By the early Holocene the summer monsoon was more intense than today, and has steadily diminished in strength throughout the past several millennia in accordance with changes in solar insolation (Kutzbach, 1981; Wang et al., 2005; Maher, 2008). Rapid development in the field of paleoclimatology over the past few decades has uncovered several reliable proxies of Asian monsoon strength from a variety of archival sources – deep-sea cores, Himalayan-Tibetan ice cores, loess deposits, cave speleothems, peat bogs and, more recently, tree ring records. Fig. 2 plots a selection of high-resolution monsoon proxies that span the past millennia and these are used throughout the remainder of this paper.

Some of the strongest evidence for Asian monsoon variability over the most recent millennia comes from speleothem records from China and India (Fig. 2), two regions with the highest population density and, hence, the greatest vulnerability to variations in the strength of the monsoon (site locations plotted in Fig. 3). Sinha et al. (2010) show that the speleothem record from Dandak Cave, located in the core monsoon region of India, agrees well with the Wanxiang Cave record from China of Zhang et al. (2008), and with the Vietnam tree ring record of Buckley et al. (2010). The agreement among these paleoclimate records is particularly remarkable during the 14th and 15th centuries, one of the most tumultuous times in pre-modern Southeast Asia as well as China and northern Eurasia (e.g., Kahan, 1985; Lieberman, 2003). It was at this time that the Khmer Empire fell into disarray and its capital was abandoned, as we discuss later in this paper. It was an equally tumultuous time in China, as Zhang et al. (2008) note, when drought contributed to the demise of the ethnic-Mongolian Yuan Dynasty in 1368, and in present-day Vietnam where the kingdom of Tonkin dealt with epic drought and famine.