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Cold surges and dust events: Establishing the link between the East Asian Winter Monsoon and the Chinese loess record

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ABSTRACT

The Chinese loess/palaeosol succession is one of the most comprehensive and intensively studied archives of Neogene and Quaternary global palaeoclimate events. Its stratigraphic details are widely recognised to indicate close links to the history and function of the East Asian Winter Monsoon (EAWM) – one of the most active components of the Earth's climate system. But the formal meteorological links between the EAWM and dust emission, both in the present day and in the past, have not been established and with it, the veracity of the loess record as an indicator of the EAWM questioned. Here we show that present day major dust events over northern China, while largely occurring during spring, are nevertheless 'conditioned' by the strength of the preceding EAWM. We also demonstrate, for the first time, a close link between the occurrence of dust events and the strength of the EAWM. From these findings, linked to global-scale climate model simulations, we conclude that the Chinese loess succession provides a convincing proxy record of the strength of the East Asian Winter Monsoon.

1. Introduction

The stratigraphy of the Chinese Loess Plateau, comprising interbedded loess and palaeosol sequences, provides an iconic Quaternary terrestrial record of East Asian glacial and interglacial events. The 'Red Clay' sequences extend the record into the early Neogene, and through this captures both East Asian 'inland aridification' and the on-set of the East Asian monsoon regime. (Ding et al., 1992; Liu and Ding, 1998; Guo et al., 2002; Stevens et al., 2007; An et al., 2014). The Quaternary component of the succession played a fundamental role in establishing the correlation between the terrestrial and marine glacial-interglacial records, stressing the loess record's global significance (Heller and Liu, 1982; Kukla, 1987; Ding et al., 2002; Williams, 2014) This correlation carried the implication that the East Asian glacial-interglacial scale climate shifts, were captured through dust entrainment, transport, deposition and post-depositional sediment 'modification', which in turn meant that the loess record provides a register of the function and intensity of the East Asian monsoon (EAM) regime (An et al., 1990, 2014; Liu and Ding, 1998).

Various loess related proxies have been used to reconstruct monsoon events. The record of East Asian Summer Monsoon (EASM) variability has been related to the weathering imprint of inter-bedded palaeosols with, traditionally, some emphasis on magnetic susceptibility (e.g., Heller and Liu, 1984; An et al., 2014). In the reconstruction of the East Asian Winter Monsoon (EAWM) variations, strong claims have been drawn from changes in the rates of deposition – mass accumulation rates (MAR) - and loess grain-size changes, not always without difficulties (Stevens et al., 2007). From these studies has emerged: (i) the general claim of a strengthening of the EAWM during glacial stages with a significant downturn of EAWM activity during interglacial stages (e.g. Stevens et al., 2007; Hao et al., 2012; An et al., 2014); and (ii) the recognition of more short term stadial-interstadial to millennial scale events (Porter and An, 1995; Sun et al., 2010, 2011; An et al., 2014).

Linked to an understanding of the East Asian component of the

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Asian monsoon winter regime at a range of time scales, are far-reaching implications, including the possibility of deciphering possible Atlantic–EAWM and EAWM–Indonesian–Australian Summer Monsoon teleconnections (Sun et al., 2011; Wyrwoll et al., 2007; Wang et al., 2012; Denniston et al., 2013). The recognition of millennial scale stronger EAWM events further emphasises the importance of the loess record in pointing to the global imprint of such events (Porter and An, 1995; Sun et al., 2011; Denniston et al., 2013).

These palaeoclimate interpretations of the significance of inferred winter loess depositional rates and grain size changes have been recently cast into doubt by claims that the record of dust events in the Chinese loess succession does not relate to a stronger EAWM (Roe, 2009; Lu et al., 2011). The claims have now entered the more general literature (Williams, 2014:153) and challenge a vast research effort with far-reaching implications for our understanding of global scale climate teleconnections and drivers.

Roe's (2009) claims are based on the fact that present-day dust events occur in spring and hence do not relate to or indicate winter synoptic states. Roe (op. cit.) recognises that such dust events are driven by strong winds associated with cyclogenesis and the passage of strong cold fronts, and points to the fact that such events occur as a result of the breakdown of the Siberian High – the ultimate driver of the EAWM.

The details of proposed EAWM changes, whether in strength and/or frequency, have generally not been firmly grounded in a framework of the controlling climate drivers. With associated discussions bringing with them an element of circularity – high mass accumulation rates (MARs) and 'coarse' grain-size indicate a stronger EAWM, and from a stronger EAWM, high MARs and 'coarse' grain-sizes can be expected. Our objective here is to break this nexus and specifically determine the relationship between dust events–loess deposition and the strength of the EAWM. We attempt this by focusing on the controlling climatology of dust events and employ Ocean Atmosphere Global Climate Model simulation results for selected periods over the last 21,000 years to strengthen our claims.

2. Cold surges in the climatology of the East Asian Winter Monsoon

The EAWM dominates the climate of East Asia during the winter months (e.g., Chang et al., 2006) and is closely associated with the development of a cold core high pressure system over the Siberian-Mongolian region (Fig. 1). The strength of the EAWM is defined through the associated surface pressure and/or a consideration of the details of its dynamic controls (Jhun and Lee, 2004; Li and Yang, 2010). During the EAWM, the Siberian High with its central pressure reaching in excess of 1035 hPa, dominates much of the Eurasian continent; individual cases of central pressure as high as 1085 hPa have been reported. More strong northwesterly flows occur at its eastern margins, where the flow separates into one branch directed eastward into the subtropical western Pacific, and then tending southward in the direction of the South China Sea. At 500 hPa, a trough (the East Asian Trough) is evident, aligned with the longitudes of Japan. At 200 hPa, the Polar East Asian Jet is prominent, with its maximum located just southeast of Japan. The Polar Jet is associated with strong baroclinic instability, large vertical wind shear and cold air advection.

The cold air 'excursions', also described as 'cold surges', are channeled by the trough southwards and are a characteristic feature of the EAWM (Lau and Chang, 1987) that impact strongly on the winter climate of eastern China. Their path is in part related to relief controls of the Tibetan Plateau, with their effect extending to the tropics, where they can lead to the flare-up of convective activity over the Maritime Continent (Chan and Li, 2004). The recognition of cold-surges as a meteorological feature extends back to the early part of the last century (Li, 1954; Lu, 1954). They were then termed 'cold waves' and were recognised as being associated with 'sandstorms' (Lu, 1954). Lu (op.cit.) described an event in March 1936, which could be traced over much of east China extending into the south and associated with a regionally extensive

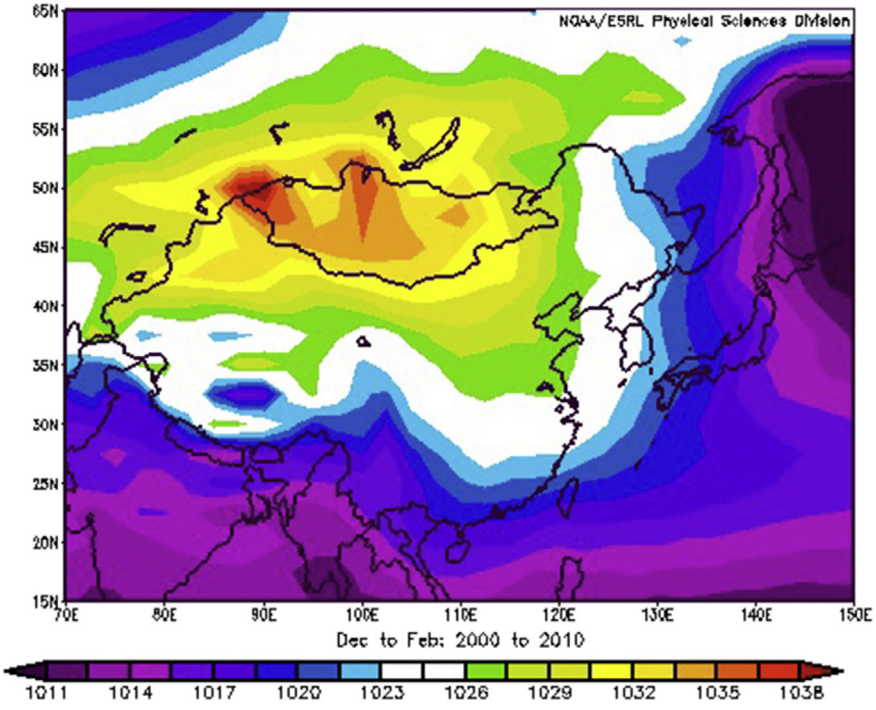

Fig. 1. December/January/February sealevel pressure (mb) – 2000–2010 (NCEP/NCAR Reanalysis).