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Peatland initiation and carbon accumulation in China over the last 50,000 years

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ABSTRACT

Peatlands are one of the largest biosphere carbon (C) reservoirs. Understanding the responses of these C-rich ecosystems to past climate change will provide useful insights into projecting the fate of peatland C in the future. Here we present a data synthesis of peatland basal ages and C accumulation rates in China over the last 50 ka (1 ka = 1000 cal yr BP) and provide a conceptual framework for understanding the dominant controls of wetland dynamics. China's peatlands are distributed throughout the climate domain from −5 °C to 18 °C in mean annual temperature and from 200 to 1600 mm in mean annual precipitation. Peatland basal dates show that subtropical peatlands initiated more frequently during the Marine Isotope Stage 3 (MIS 3) than in the Holocene, while northern peatlands mostly initiated in the early and mid Holocene. Peat-core data from peatlands in northern China show high apparent rates of C accumulation (30–40 g C m^{-2} yr^{-1}) during the early and mid Holocene. The peatland initiation and C accumulation histories are closely linked with summer insolation and monsoon intensities, suggesting the possible causal connection between peatland dynamics and Asian summer monsoon. Furthermore, peatland formation and expansion in the subtropical region of China, especially during the MIS 3 and the Bølling–Allerød periods, might have contributed to high atmospheric methane concentrations.

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1. Introduction

Peatland ecosystems and their carbon (C)-rich peat deposits have been studied for more than a century, mostly for reconstructing past vegetation and climate (Charman, 2002). Over recent decades, attention

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has also turned to carbon cycling in peatlands and their long-term ecosystem dynamics and climate sensitivity (Clymo, 1984; Gorham, 1991; Rydin and Jeglum, 2006; Yu et al., 2009; Charman et al., 2013). Ongoing and future climate warming has generated significant interest in understanding terrestrial carbon and ecosystem feedbacks to climate change (Christensen et al., 2007). Several large-scale synthesis efforts over the last years, mostly for Holocene peatlands, have allowed one to document peatland development histories, such as in West Siberia (Smith et al., 2004), Alaska (Jones and Yu, 2010), Canada (Tarnocai, 2006), Southeast Asia (Page et al., 2006), Finland (Turunen et al., 2002) and northern or global peatlands as a whole (MacDonald et al., 2006; Tarnocai and Stolbovoy, 2006; Yu et al., 2009, 2010). These syntheses of northern and tropical peatland data shed light on the response of northern peatland ecosystems and C dynamics to global climate change. In this regard, data from many other extratropical and subtropical regions, including ones influenced by monsoons, would contribute to a more comprehensive understanding of peatland histories and climate controls.

China's wetlands represent ca. 10% of the world wetland area (Gong et al., 2010) and are important an methane source and carbon reservoir. Peatland is a type of wetlands that have relatively stable water tables and accumulate deep peat. Peatlands cover about 41,590 km^2 in China (Bord na Mona, 1984). Although the peatland area is small in China compared to many peatland-rich regions, their accumulation histories would provide insight into climate controls of peatland development under monsoon climates. In China previous studies have focused on Holocene climate reconstruction using peat deposits as paleoclimate archives, mainly in northeastern China (e.g., Hong et al., 2003; Seki et al., 2009; Zheng et al., 2011) and the Zoige Basin on the eastern Tibetan Plateau (e.g., Yan et al., 1999; Zhou et al., 2010; Zhao et al., 2011). In the 1980s, some studies were carried out to investigate peatland distribution and initiation, mostly for the purposes of peat mining and peat resources (e.g., Cai, 1981). So far no systematic studies about peat initiation have been carried out in China, and therefore the relationship between peatland initiation and climate controls is still poorly documented and understood. In addition, the knowledge of carbon accumulation rate is scarce as there were very few studies with bulk density analysis and adequate dating controls (but see recent studies by Large et al., 2009; Zhao et al., 2011).

In this paper, we synthesize available peat-core data across China and provide a conceptual framework for understanding the dominant controls of China peatland initiation and long-term peat C accumulation dynamics. We use modern instrumental climate data to explore the climate envelope of today's peatland distribution in China. We investigate temporal and spatial patterns of peat initiation over the last 50 ka (1 ka = 1000 cal yr BP), synthesize limited data on C accumulation rates during the Holocene in different regions and discuss climatic controls. Understanding the causal connection between peatland initiation and C dynamics and past climates would provide insight into the possible future response of these C-rich ecosystems to climate change in different regions.

2. Data and methods

We compared the distribution of peatlands with gridded instrumental climate data (10′ × 10′grids) (New et al., 2002) to generate the climate domain of peatlands in China in temperature vs. precipitation space. We used the inland marshes polygons within the inland wetlands type of the wetland map derived from satellite images by Gong et al. (2010) to represent peatlands in China. This wetland class may not reflect the exact distribution of peatlands, but it is the most accurate source available at the country scale. We argue that the general distribution pattern should be adequate for our climate space analysis presented here. The gridded climate data were from CRU for the period of 1961–1990 (New et al., 2002).

We used 672 basal peat ^{14}C dates from previously published sources (some in gray literature like institute reports) and our own unpublished newly collected data (see Supplementary Table S1) across China (see site locations in Fig. 1) to assess the temporal and spatial pattern of peatland initiation. We compiled and examined a total of 1045 dates from peatlands across China, but for our synthesis we only chose 672 ^{14}C dates based on the following selection criteria: (1) the peat profiles are thicker than 40 cm; (2) the profiles are mostly continuous peat; and (3) only the oldest date was used from a single peatland basin as initiation age. As a result, these dates were likely from peat profiles rather than isolated thin peat layers.

These basal peat ^{14}C dates were calibrated to their 2σ age ranges using the program CALIB Rev. 6.0.1 with the IntCal09 calibration dataset (Reimer et al., 2009). The calibrated 2σ age ranges were grouped into 200-year bins for calculating the frequency of peatland initiation (MacDonald et al., 2006). The 2σ age ranges in our dataset are about 230 years on average. We recognize that there are age uncertainties due to the quality of some of the basal dates, especially old dates during the Marine Isotope Stage 3 (MIS 3) period collected and analyzed several decades ago. We also generated 50-year bins and 500-year bins to evaluate the sensitivity of results/conclusions on specific bins selected. Furthermore, we generated the initiation frequency for two regions: northern peatlands (including northeastern China, northern China, the Tibetan Plateau, and northwestern China), and subtropical peatlands (including Central China, South China, and southwestern China). We generated the summed probability distributions for the peat basal dates, using the "Sum Probabilities" option in CALIB 6.0.1 (http://calib.qub.ac.uk/calib/) with the IntCal09 calibration dataset (Reimer et al., 2009).

To examine temporal pattern of peatland C accumulation, we calculated apparent C accumulation rates based on multiple age determinations and bulk density measurements at four peatland sites from NE China, Tibetan Plateau, and NW China (Xinjiang). These sites are Hongyuan site 2 (Large et al., 2009), Zoige core ZB08-c1 (Zhao et al., 2011) and two sites from Altai Mountains (Y. Zhao, unpublished). Each of these four cores has at least 7 radiocarbon dates spanning most of the Holocene. We have described the detailed methods for laboratory analysis and calculations elsewhere (Zhao et al., 2011), but here we just provide a brief summary of the methods. We use fresh sample volume and dry weight to calculate bulk density. Ash-free (organic matter) bulk density was calculated from the measurements of bulk density and organic matter content estimated using loss-on-ignition analysis. Apparent carbon accumulation rates were calculated using calibrated ^{14}C ages, ash-free bulk density measurements and carbon content of peat organic matter in peatlands (using 52% C in peat organic matter as in Vitt et al., 2000). For other two sites, Hongyuan site 1 from the Tibetan Plateau (Zhou et al., 2010) and Hani peatlands from northeastern China (Hong et al., 2003), bulk density measurements and organic matter content data are not available directly from the cores, so we used the average value from other sites in the same region (Zhao et al., 2002, 2011) and mean C content (52%) for calculating carbon amounts. The mean of carbon accumulation rates from four or six sites was calculated for each 1000-year bin using time-weighted averaged C accumulation rates for each core, and the errors are standard errors of the mean.

3. Results

The climate space of mean annual temperature and annual precipitation (T vs. P space) shows that the peatlands typically occur where mean annual temperatures are between −5 °C and 18 °C and mean annual precipitation is between 200 and 1600 mm (Fig. 2). However, most peatlands occur in regions with temperatures between −5 °C and 5 °C and precipitation at 300–700 mm. Unsurprisingly there are clear differences in climate conditions between northern and subtropical peatlands. Northern peatlands in China occur where mean annual

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