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Global Modern Charcoal Dataset (GMCD): A tool for exploring proxy-fire linkages and spatial patterns of biomass burning

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A B S T R A C T

Progresses in reconstructing Earth's history of biomass burning has motivated the development of a modern charcoal dataset covering the last decades through a community-based initiative called the Global Modern Charcoal Dataset (GMCD). As the frequency, intensity and spatial scale of fires are predicted to increase regionally and globally in conjunction with changing climate, anthropogenic activities and land-use patterns, there is an increasing need to further understand, calibrate and interrogate recent and past fire regimes as related to changing fire emissions and changing carbon sources and sinks. Discussions at the PAGES Global Paleofire Working Group workshop 2015, including paleoecologists, numerical modelers, statisticians, paleoclimatologists, archeologists, and anthropologists, identified an urgent need for an open, standardized, quality-controlled and globally representative dataset of modern sedimentary charcoal and other sediment-based fire proxies. This dataset fits into a gap between metrics of biomass burning indicators, current fire regimes and land cover, and carbon emissions inventories. The dataset will enable the calibration of paleofire data with other modern datasets including: data of satellite derived fire occurrence, vegetation patterns and species diversity, land cover change, and a range of sources capturing biochemical cycling. Standardized protocols are presented for collecting and analyzing sediment-based fire proxies, including charcoal, levoglucosan, black carbon, and soot. The GMCD will provide a publically-accessible repository of modern fire sediment surface samples in all terrestrial

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ecosystems. Sample collection and contributions to the dataset will be solicited from lacustrine, peat, marine, glacial, or other sediments, from a wide variety of ecosystems and geographic locations.

1. Introduction

Fire is a terrestrial phenomenon that influences ecosystem composition, distribution, structures, processes from local to global scales, and operates at multiple timescales (Bowman et al., 2009a; Conedera et al., 2009). Therefore, fire constitutes the most important terrestrial disturbance on the earth (Bond et al., 2005) and is responsible for shaping and modifying terrestrial ecosystems over millions of years (Bird and Cali, 1998; Bond, 2014). The different components of the fire regime, such as burned area, intensity, frequency, severity and seasonality (Bowman et al., 2009a; Krebs et al., 2010), are tightly related to weather and climatic conditions, fuel type and availability, ignition probability and human modifications, such as landscape fragmentation (Archibald et al., 2013). As a consequence, ongoing global warming, changing patterns of precipitation and anthropogenic activities are expected to deeply modify fire regimes at various spatiotemporal scales (Allen et al., 2014; Bedia et al., 2015; Knorr et al., 2016; Moritz et al., 2012b; Westerling et al., 2006; Yue et al., 2013).

Nevertheless, large uncertainties and biases remain in our understanding of the complex interactions between fire and other Earth system components, and challenges exist for integrating these interactions into Earth system models (Hantson et al., 2016b; Lehsten et al., 2009; Pfeiffer et al., 2013). Paleo-fire reconstructions constitute a unique opportunity to examine long-term variations in fire-climate-vegetation-human relationships. For example, charcoal-based fire reconstructions of the Quaternary have documented how fire regimes have changed in the past, both locally (Blarquez and Carcaillet, 2010; Colombaroli et al., 2014; Hawthorne and Mitchell, 2016; Maezumi et al., 2015; Vanniere et al., 2008) and regionally (e.g. Blarquez et al., 2015; Carcaillet et al., 2002; Daniau et al., 2012, 2013; Gavin et al., 2006; Power et al., 2008; Vannière et al., 2011). Many studies have examined how fire activity in different parts of the world have responded to climate changes (Ali et al., 2012; Colombaroli and Gavin, 2010; Daniau et al., 2012; Marlon et al., 2006), anthropogenic activities (Leys and Carcaillet, 2016; Power et al., 2010; Vannière et al., 2016), vegetation changes (Blarquez and Carcaillet, 2010; Clark et al., 2001; Fletcher et al., 2014; Higuera et al., 2009), and how paleofire-regime changes have contributed to carbon emissions toward the atmosphere (Bremond et al., 2011) and sequestration into soils (Carcaillet and Talon, 2001; DeLuca and Aplet, 2008). Both conversions might represent the same flux of burned biomass (Tinker and Knight, 2000), thus stressing the need of further reconstructions to improve the function of paleo-fires on the global carbon budget.

The Global Charcoal Database (GCD, www.paleofire.org) has supported cross-disciplinary research (Marlon et al., 2016b) as both a tool for multi-scalar analyses and as a repository for paleofire records. The database now contains records from upwards of 1076 sites with nearly 40% from Europe and 30% of records from the Americas, derived from six different depositional environments (i.e. lake, mire, bog, peat, soil, and marine) and over 120 individual approaches for classifying and reporting charred plant residues. The records can be analyzed individually or as spatiotemporal composites via a process of rescaling transformation and standardization (Marlon et al., 2008; Power et al., 2008, 2010) for multiscalar analyses (Blarquez et al., 2014; Marlon et al., 2013).

However, most currently available regional-to-global scale paleofire reconstructions reveal only changes in biomass burning relative to a study-specific base period, for example the past 200 or 500 years for a Holocene analysis. The wide range of incomparable units (Iglesias et al., 2014) employed in proxy measurement from diverse sediment archives have prevented the reconstruction of absolute quantities of biomass and an estimation of area burned. In addition, the myriad factors that determine quantities of charcoal accumulated in a given lake's sediment, for example, require systematic analyses across a broad range of environments, and have only been examined in a very few regional studies (Clark and Royall, 1996; Marlon et al., 2006). Thus, a standardized methodology, nomenclature and defined units are required to enable comparisons across records and locations, as well as methods for bridging modern fire metrics with fire historical reconstructions from sediment archives to make these independent data sources directly comparable.

Comparisons of recent sedimentary charcoal with fire scars from trees or historical fire events have helped improve quantitative reconstructions of past fire regimes (Brossier et al., 2014; Clark, 1990; Duffin et al., 2008; Gardner and Whitlock, 2001; Higuera et al., 2005, 2010; Marlon et al., 2012; Millspaugh et al., 2000; Oris et al., 2014; Pitkänen et al., 1999; Whitlock, 2001; Whitlock and Millspaugh, 1996a). Such calibration studies, however, are predominantly located in middle to high latitudes, leaving gaps in knowledge in many areas, especially tropical and sub-tropical savannas and forests, tundra, temperate grasslands, and Mediterranean ecosystems (Aleman et al., 2013; Duffin et al., 2008; Leys et al., 2015).

Moreover, taphonomic processes that influence charcoal records represent a challenge to quantitatively reconstruct past fire regimes. Some studies have explored charcoal production, dispersal and deposition (Higuera et al., 2007; Lynch et al., 2004; Ohlson and Tryterud, 2000; Tinner and Lotter, 2006), and have developed models of charcoal source area (Clark, 1988a; Clark et al., 1998; Higuera et al., 2007; Lynch et al., 2004; Peters and Higuera, 2007), but additional data-model comparisons covering all flammable ecosystems are needed. It has also been demonstrated that the size of the deposition site or body of water, of the watershed (Marlon et al., 2006) or even the vegetation burned can impact the accumulation of charcoal (Aleman et al., 2013; Leys et al., 2015; Marlon et al., 2006). Indeed, ignitability and flammability of vegetation depends on plant traits and community composition, plant biomass as well as stand (vertical) and landscape (horizontal) structures and fuel conditions. Understanding the link between vegetation, fire, and the production, transportation and deposition of charcoal particles has been a topic of interest for decades (Blackford, 2000; Clark, 1988a; Clark et al., 1998; Hudak et al., 2013; Lynch et al., 2004; Scott et al., 2000), but once again studies are limited to some ecosystems.

Despite the growing body of knowledge within the fire sciences, limited emphasis on issues of calibration at regional and global scales have thus emerged in the paleofire literature. Improving the ability to quantify paleofire proxies in terms of the specific fire variables which ecologists and land managers consider in conservation strategies, i.e. location, frequency, type (i.e. crown vs ground