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Invited research article

Assessment of climate impacts on the karst-related carbon sink in SW China using MPD and GIS

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ABSTRACT

Riverine carbon fluxes of some catchments in the world have significantly changed due to contemporary climate change and human activities. As a large region with an extensive karstic area of nearly 7.5×10^5 km^2, Southwest (SW) China has experienced dramatic climate changes during recent decades. Although some studies have investigated the karst-related carbon sink in some parts of this region, the importance of climate impacts have not been assessed. This research examined the impacts of recent climate change on the karst-related carbon sink in the SW China for the period 1970–2013, using a modified maximal potential dissolution (MPD) method and GIS. We first analyzed the major determinants of carbonate dissolution at a spatial scale, calculated the total karst-related carbon sink (TCS) and carbon sink fluxes (CSFs) in the SW China karst region with different types of carbonate rocks, and then compared with other methods, and analyzed the causes of CSFs variations under the changed climate conditions. The results show that the TCS in SW China experienced a dramatic change with regional climate, and there was a trend with TCS decreasing by about 19% from 1970s to 2010s. This decrease occurred mostly in Guizhou and Yunnan provinces, which experienced larger decreases in runoff depth in the past 40 years (190 mm and 90 mm, respectively) due to increased air temperature (0.33 °C and 1.04 °C, respectively) and decreased precipitation (156 mm and 106 mm, respectively). The mean value of CSFs in SW China, calculated by the modified MPD method, was approximately 9.36 t C km^{-2} a^{-1}. In addition, there were large differences in CSFs among the provinces, attributed to differences in regional climate and to carbonate lithologies. These spatiotemporal changes depended mainly on hydrological variations (i.e., discharge or runoff depth). This work, thus, suggests that the karst-related carbon sink could respond to future climate change quickly, and needs to be considered in the modern global carbon cycle model.

1. 1. Introduction

Atmospheric CO_2 plays a significant role in controlling global climate. The established global carbon cycle models, however, cannot balance the atmospheric CO_2 budget, leaving a so-called “missing carbon sink” problem (Tans et al., 1990; Melnikov and O'Neill, 2006). Finding the missing carbon sink is becoming one of the most important questions in the research of global climate change. Although the weathering of silicate minerals can capture atmospheric CO_2 by forming HCO_3^- from continent to oceans (Berner et al., 1983; Berner, 1992), this carbon sink is limited due to the slow weathering kinetics of silicate minerals over short time scales (Liu et al., 2011). Carbonate rock is the world's biggest carbon reservoir, and the rapid kinetics of carbonate dissolution result in a large amount of atmospheric CO_2 consumption (Yuan, 1997; Liu and Zhao, 2000; Gombert, 2002; Liu et al., 2010; Liu et al., 2011). Furthermore, according to a new conceptual model of the carbon sink produced by H_2O-carbonate-CO_2-aquatic phototroph interaction, this carbon sink produced by carbonate weathering can be transferred by aquatic organisms and buried as organic matter (Liu and Dreybrodt, 2015). Therefore, carbonate weathering coupled with aquatic photosynthesis are a significant potential mechanism for the terrestrial missing carbon sink (Liu and Dreybrodt, 2015).

The increase in atmospheric CO_2 has resulted in remarkable contemporary global climate change (Friedlingstein et al., 2006, Gedney et al., 2006), but the carbon sink produced by chemical weathering of rocks has been considered to be unchanged since pre-industrial times in global carbon models (Sabine et al., 2004). However, recent investigations have found evidence that contemporary climate change is accelerating the chemical weathering rate and altering the relevant carbon fluxes (Raymond and Cole, 2003; Macpherson et al., 2008; Raymond et al., 2008; Gislason et al., 2009). Duo to the high sensitivity of carbonate weathering to environmental change (Liu et al., 2007; Yang et al., 2012), the response of this carbon sink may be rapid and considerable (Liu and Dreybrodt, 2015; Zeng et al., 2016). For instance, Raymond et al. (2008) and Raymond and Cole (2003) attributed a proximately 20%

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increase of alkalinity ($HCO_3^- + CO_3^{2-}$) (increasing from 20.3 mg/L to 25.4 mg/L) in the Mississippi River during the past half-century to a 9% increase in precipitation. Macpherson et al. (2008) found a 20% increase in groundwater pCO_2 and 13% increased alkalinity between 1990 and 2005 in the karst area of Konza Prairie, USA, due to the increasing atmospheric CO_2 and perhaps atmospheric temperature. An experimental air CO_2 enrichment study in Duke Forest also indicated that an elevated atmospheric CO_2 experiment of 200 ppm (+50%) in two years led to 33% increase in alkalinity of ground water duo to accelerating chemical weathering (Andrews and Schlesinger, 2001). Therefore, it is problematic that the conventional assumption that pre- and post- anthropogenic riverine carbon fluxes are the same (Sabine et al., 2004), and it is necessary to quantify the strength of the feedback of the karst-related carbon sink to changed climate conditions worldwide.

Many methods have been used to calculate the global karst-related carbon sink, including the DBL (Diffusion Boundary Layer) model (Liu and Zhao, 2000) and the MPD (Maximal Potential Dissolution) formula (Gombert, 2002). The MPD formula is a theoretical method based on climatic parameters. The calculations of MPD could be a powerful tool when used to estimate karst-related carbon sink perturbations due to changed climate conditions (Gombert, 2002). On the other hand, consideration of carbonate lithologies (limestone and dolomite) in estimating the karst-related carbon sink in a large karstic area is critical, due to their different solubilities (Dreybrodt, 1988).

The primary objective of this paper is to assess the karst-related carbon sink response to the changed climate over the past 40 years in SW China, where there is a high percentage (~43%) of karstic area with different carbonate lithologies and there is a monsoonal climate, using the MPD and GIS.

2. 2. Study area

The study area is situated in SW China (20°54′–34°19′ N, 97°21′–116°08′ E) (Fig. 1), covering approximately 17.6×10^5 km^2 and including seven provinces: Sichuan, Chongqing, Hubei, Yunnan, Guizhou, Hunan and Guangxi. The northwestern and eastern sides of the study area are bordered by the Tibet Plateau and the Central China Plain, respectively, and thus the altitude is higher in the west (Fig. 1). The karst region of SW China is well known for its extensive carbonate rock outcrop and intensive karst landform development. Plateaus, mountains and plains are the main landform types in the region, and the area is characterized by typical monsoonal climate. Annual precipitation in the area is about 1148 mm, most of which falls in the monsoon season from April to September. The mean annual air temperature in SW China is about 15.4 °C, with hot summers (June–August) and cold winter (December–February) (http://cdc.cma.gov.cn).

3. Methods

3.1. Data collection

The distribution of karst in SW China was extracted from maps of soluble rock types in China, as edited by Institute of Karst Geology, Chinese Academy of Geological Sciences (1985). By calculation and classification, the karst region in SW China covers an area of approximate 7.5×10^5 km^2 and the main lithologies include limestone, dolomite, mixed limestone/dolomite and impure carbonate rocks mixed with clays or other silicate minerals (Fig. 2). The areas underlain by karst in each province are shown in Table 1.

Daily meteorological data, including precipitation (P, mm), mean temperature (T_{mean},°C), insolation duration (n, h), mean humidity (RH_{mean}, %), and mean wind speed (WS, m/s), in 240 stations in and around the SW China from 1970 to 2013 (data from 1981, 1982 and 1984 are missing) (station locations are shown on Fig. 1), were obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn).

3.2. Maximal potential dissolution (MPD) method

Many methods can be used to calculate the carbonate dissolution rate. However, most of these methods need long-term field measurements or complicated parameters which are difficult to obtain, which

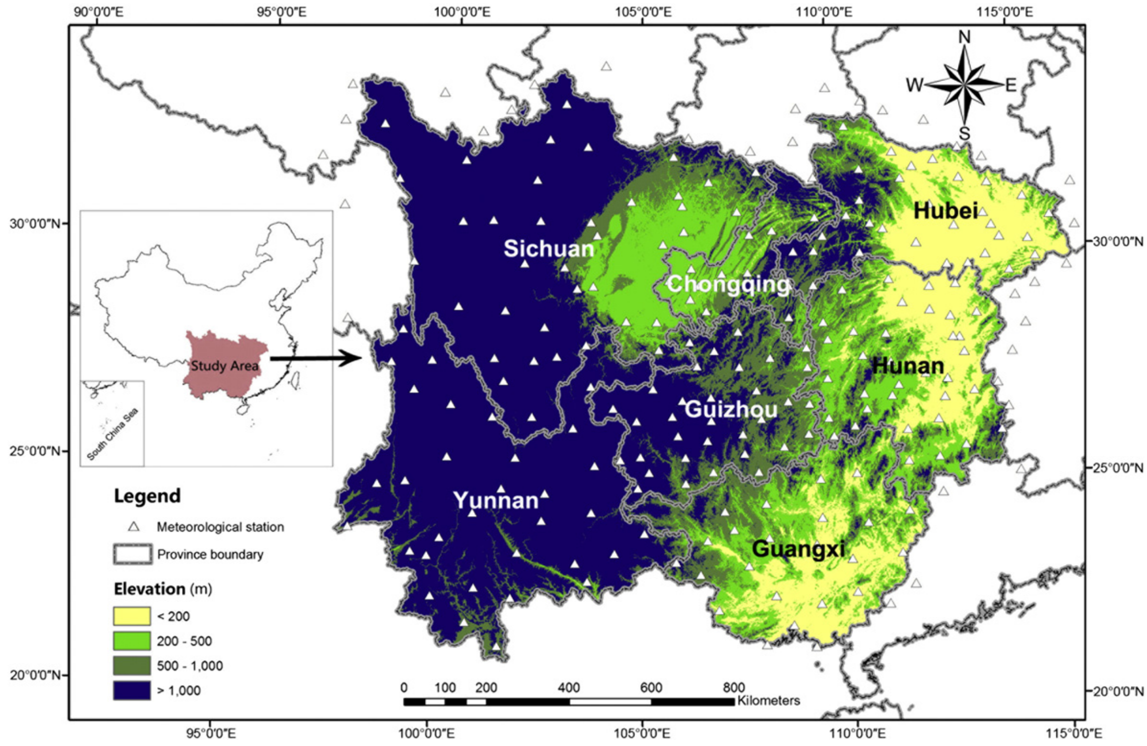

Fig. 1. Location of SW China and the distribution of meteorological stations in the area (modified after http://cdc.cma.gov.cn).