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Reconstruction of Megalake Chad using Shuttle Radar Topographic Mission data

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Abstract

In the 2,500,000 km^2 Lake Chad Basin in central Africa, the 2000 Shuttle Radar Topographic Mission (SRTM) data have been used to supplement the existing topographic data. SRTM data produce much sharper images of the region's topography and provide new insights into debates about the nature and extent of late Quaternary Lake Chad. This paper shows that the accuracy of SRTM30, the recently released 30 arc seconds topographic data from SRTM, largely surpasses that of previous global Digital Elevation Models (DEMs) available in the region. Using a GIS we identified from SRTM30 elevation data key features in the landscape topography providing further evidence for the existence of a Megalake Chad. The SRTM30 data corroborate the presence of two ancient shorelines associated with stillstands of the paleolake at the elevation of the Mayo Kebbi and Bahr el Ghazal spillovers. We found a general flattening of the topography in the region covered by Megalake Chad which is most likely the result of wave-cut action. The SRTM30 data show that the remains of the highest paleoshoreline have a constant elevation of 325±5 m amsl. At its maximum extent, Megalake Chad had an area of about 340 000 km^2 (only 8% less than the present-day world's largest lake, the Caspian Sea). The SRTM30 data also revealed ancient drainage networks in the Sahara that lead to Megalake Chad. We compiled available ^{14}C dates to constrain Holocene Megalake Chad events. The results presented in this paper have significant consequences for improving our knowledge of regional paleohydrology and continental climate change. This study is also the first step for a GIS-based reconstruction of late Quaternary paleohydrology in tropical Africa.

Keywords: Climate change; Paleohydrology; Lake Chad; SRTM; GIS; DEM; Africa; Paleolimnology; Hydrology; Terrain analysis

1. Introduction

The Lake Chad Basin occupies 2,500,000 km^2 in central Africa. It is the world's largest endorheic basin and most surface water drains into Lake Chad — a vast

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and shallow fresh water lake located in the central part of the basin. Presently, most of the northern portion of the basin lies in the Sahara desert and is dry. Most of the inflows to Lake Chad are provided by the Chari and the Logone rivers, which are flowing from the south. Lake Chad is located in a region of little relief and has currently no surface outlet. Its areal extent is very sensitive to climate fluctuations. For example, from 1960 to 1990 the level of the lake fluctuated approximately between 284 and 277 m amsl and its extent from 25,000 km^2 to less than 6000 km^2 (Olivry et al., 1996). The presence of a much larger lake during the late Quaternary, referred to as Megalake Chad, is debated. Some archeological, geomorphological, sedimentological and stratigraphical investigations have supported the existence of this large and deep Megalake Chad (Pias and Guichard, 1957; Schneider, 1967; Maley, 1981; Servant and Servant, 1983; Schneider, 1994; Schuster et al., 2003). However, it was strongly argued that the landforms which are considered to be the remains of the paleoshoreline for Megalake Chad were too discontinuous and too irregular in elevation to be of lacustrine origin, and were in fact neotectonic features following the directions of major structural faults (Durand, 1982; Durand et al., 1984; Durand, 1995).

Digital Elevation Models (DEMs) have proved to be of great assistance in the reconstruction of large paleolakes. For example, DeVogel et al. (2004) used a DEM to calculate areas and volumes for terminal lakes of the Lake Eyre Basin and identify flow directions across spillovers. In the Lake Chad Basin other DEMs, TOPO6 and GLOBE (which is similar to GTOPO30 in the region) have been used to calculate area and volume of Megalake Chad according to level fluctuations (Ghienne et al., 2002). These datasets have suggested the existence of a very large lacustrine shoreline terrace (Ghienne et al., 2002).

However doubt about the existence of Megalake Chad has in part resulted from a paucity of topographic and geomorphological observations due in part to the vast expanse of the Lake Chad Basin and difficulties in accessing some sites from the ground. The best topographic maps covering Lake Chad Basin are in two series (1/200,000 and 1/1,000,000) and are based on sparse topographic field measurements, if any in some regions to the north. The previous best global DEM available for the region, GTOPO30, was largely derived from these topographic maps. A new DEM derived by NASA from the February 2000 Shuttle Radar Topographic Mission data (SRTM30) has the potential to significantly improve our knowledge of the region's topography. In this paper we present a first accuracy assessment in the region for SRTM30. The result is encouraging enough for us to use the SRTM30 data to reconstruct the regional paleohydrology in a GIS.

We also compiled available ^{14}C dates in the region to better constrain Holocene Megalake Chad events.

2. Methods

2.1. Shuttle Radar Topographic Mission data

In February 2000, the space shuttle carried onboard, for the first time, a space-borne, single-pass interferometer. The mission was referred to as the Shuttle Radar Topographic Mission (SRTM). Two antennae operating in C- and X-bands simultaneously illuminated and recorded radar signals over the entire land mass between 60°N and 57°S. Global DEMs were processed by NASA-JPL from C-band radar using single-pass interferometry (Farr and Kobrick, 2000; Rosen et al., 2000). This method requires no ground control, and hence is very useful for inaccessible regions. The overall absolute horizontal and vertical accuracy of these 1 arc second data is estimated to be significantly better than the original mission requirements of 20 m and 16 m respectively (Rosen et al., 2001; Sun et al., 2003). For example, in southeastern Michigan, Sarabandi et al. (2002) found the 'Principal Investigator Processor' C-band data (not even the refined final data product) offered an average absolute height offset of 9 m with a standard deviation of 2 m.

SRTM3 and SRTM30 are the two DEMs at 3 and 30 arc seconds horizontal resolution respectively that have recently been released by NASA. They are both given with 1 m vertical precision and were generated by averaging SRTM elevation data first obtained at a 1 arc seconds resolution. In this paper, we propose a first analysis of SRTM elevation data in the whole of the Lake Chad Basin (2,500,000 km^2) using the most suited DEM at this scale considering computer limitations, SRTM30.

2.2. SRTM30 quality assessment

We realised a preliminary assessment of the quality of SRTM30 and a comparison with GTOPO30 in the Lake Chad Basin using elevation data from surveys reported on topographic maps. SRTM30, GTOPO30 and survey points were referenced to the same horizontal datum: the World Geodetic System of 1984 (WGS84). However, the vertical reference for SRTM data is the EGM96 geoid (a modeled surface of the