The Green Sahara: Climate Change, Hydrologic History and Human Occupation

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Abstract— **Archaeology can provide insight into interactions of climate change and human activities in sensitive areas such as the Sahara, to the benefit of both disciplines. Such analyses can help set bounds on climate change projections, perhaps identify elements of tipping points, and provide constraints on models. The opportunity exists to more precisely constrain the relationship of natural solar and climate interactions, improving understanding of present and future anthropogenic forcing. We are beginning to explore the relationship of human occupation of the Sahara and long-term solar irradiance variations synergetic with changes in atmospheric-ocean circulation patterns. Archaeological and climate records for the last 12 K years are gaining adequate precision to make such comparisons possible. We employ a range of climate records taken over the globe (e.g. Antarctica, Greenland, Cariaco Basin, West African Ocean cores, records from caves) to identify the timing and spatial patterns affecting Saharan climate to compare with archaeological records. We see correlation in changing ocean temperature patterns ~ contemporaneous with drying of the Sahara ~6K years BP. The role of radar images and other remote sensing in this work includes providing a geographically comprehensive geomorphic overview of this key area. Such coverage is becoming available from the Japanese PALSAR radar system (Palliou, et. al., 2007), which can guide fieldwork to collect archaeological and climatic data to further constrain the climate change chronology and link to models. Our initial remote sensing efforts concentrate on the Gilf Kebir area of Egypt.**

I. Introduction

That the Sahara was favorable for human habitation at times of favorable climate has long been known (cf. Haynes, 1982). With the remarkable paleo-landscape revealed by the L-band (25 cm) Shuttle Imaging Radar-A in 1981, it became clear that ancient humans concentrated along integrated drainage systems dubbed "radar rivers" by McCauley et al. (1982, 1986). However SIR-A and subsequent long-wavelength radar coverage was limited and regional understanding of the drainage network has remained elusive. A complete map of sand buried channels of the region could also prove useful for development of water resources (Robinson et al., 2006; El-Baz et al., 2007). The relationship between human occupation of the Sahara and climate has been explored (cf. Claussen, et. al., 1999) but precise details remain elusive.

II. Remote Sensing Data Of the Sahara

The region of the Gilf Kebir has never been thoroughly mapped in terms of the landforms and subsurface signs of past climates conducive to human occupation. As part of ongoing work and through a new proposal to NASA, we are generating new maps of the paleohydrology, topography, geomorphology, and surficial deposits of the area and developing GIS-based models which use the data to pinpoint past resources and travel pathways. The maps we are generating will constitute a unique resource for exploration for archeological sites in the Gilf Kebir and other regions of N Africa.

We are mapping the area with three sensors optimized for mapping and characterizing arid regions: The Japanese PALSAR L-band imaging radar, NASA's SRTM, and ASTER (Fig. 1-at end of article). Together these sensors will allow characterization of surface and subsurface landforms formed and modified by former wetter climates. A mosaic of PALSAR images will use as a base the topographic map produced by the Shuttle Radar Topography Mission, flown in 2000 (Paillou et al., 2008). SRTM also produced C-band images, similar to those being produced by Europe's ERS and Envisat and Canada's Radarsat satellites which, despite their shorter wavelength (5.5 cm) and thus decreased penetration capability, have been used for mapping Sahara drainages (El-Baz et al., 2007). An advantage of the SRTM C-band images is that they are inherently registered to the topographic data and provide full, mosaicked coverage (Fig. 1b).

A third data set, visible-near infrared (VNIR) to thermal IR (TIR) images from ASTER, is being used mainly for mapping surficial landforms and vegetation. These wavelengths are sensitive to surface composition including rock types, weathering phenomena, and soil types (Fig. 1a). Vegetation also shows up well in near IR images. A unique capability of ASTER is the inclusion of several thermal IR bands. These allow increased sensitivity to composition, especially silica content, but also are capable of detecting thermal properties of the near-surface volume. Night-time thermal images have been shown to be sensitive to the bulk properties of the near-surface such as density and moisture content, as these determine the cooling rate (Fig. 1c). Combined with day-thermal images and a measure of the visible-wavelength albedo, thermal inertia, a quantitative measure of the thermal properties of a material can be derived.

III. SOLAR IRRADIANCE, MODELING, AND CLIMATE CHANGE

Soon after the discovery of the Green Sahara it was suggested that this important and clear example of climate change was basically due to the changes in the position of the monsoon belt over the Sahara brought about by changes in the Earth's orbit relative to the Sun. The monsoon belt is associated with the Intertropical Convergence Zone (ITCZ). Over land, the ITCZ moves back and forth across the equator following the sun's zenith point. It is thus modulated by changes in the Earth's position relative to the Sun, i.e. by the Milankovich cycles. In addition there are other influences on the position, in particular the gradient of the sea surface temperature. Over the oceans, where the ITCZ is better defined, the seasonal cycle is more subtle, as the convection is constrained by the distribution of ocean temperatures. A quasi-linear relation has been found between the monsoon precipitation in Africa and the summer insolation integrated over the Northern Hemisphere (Prell and Kutzbach, 1987). Recently GCMs containing interactive atmosphere, ocean, land surface and sea ice have become remarkably successful in simulating Saharan climate for the Early Holocene (9.5 kyr) and the Mid- Holocene (6.0 kyr) (Liu et. al., 2007; Braconnot et. al., 2007b). The simulations demonstrate changes in the position of the monsoon belt that brought rain to the Sahara at those times. However, no modeling or simulations have been carried out to explain the timing of the maximum human occupation of the Green Sahara at about 7.7 kyrs BP.

PMIP (Paleoclimate Modeling Intercomparison Project) model experiments reported by Braconnot et. al., (2007a, b, 2008) show that the differences between Eastern North Africa during the early Holocene (EH) at 9.5 kyr BP and the Mid Holocene (MH) at 6.0 kyr BP are quite well simulated using the coupled interactive models with the parameters of the Earth's orbit (eccentricity, obliquity and precession) as initial conditions. The estimate of the climate of the Earth produced from these advanced PMIP experiments depends almost entirely on the parameters of the Earth's orbit chosen at the time to be investigated (Renssen et. al., 2006). The simulations using interacting models of the atmosphere, the ocean, land surface and sea ice show feedbacks from the ocean tend to amplify the strengthening of the African Monsoon induced by the insolation. The precession is important because it modulates the length of the season and the time during the summer when insolation is maximized. The estimate of the orbital parameters for the GSOM from those for the EH and MH shows that the most important change is that the obliquity of the orbit, which modulates the latitude of the summer solstice. The position of the monsoon is also effected by the latitudinal gradient of the sea surface temperatures (SST). We are looking at the Holocene SST data sets taken in North Atlantic.

Ocean sediment cores from the Cariaco basin have been used (Peterson and Haug, 2006) to estimate the position of the ITCZ and hence the monsoon belt position as a function of time throughout the Holocene. The changes in the position at the relevant times are quite complex, and seem to combine the extreme in obliquity with the effect of the changes in ocean circulation brought about by the 8.2 kyr BP event. The Cariaco data from Venezuela are well-correlated with data taken off the coast of Africa (deMenocal et. al., 2000).

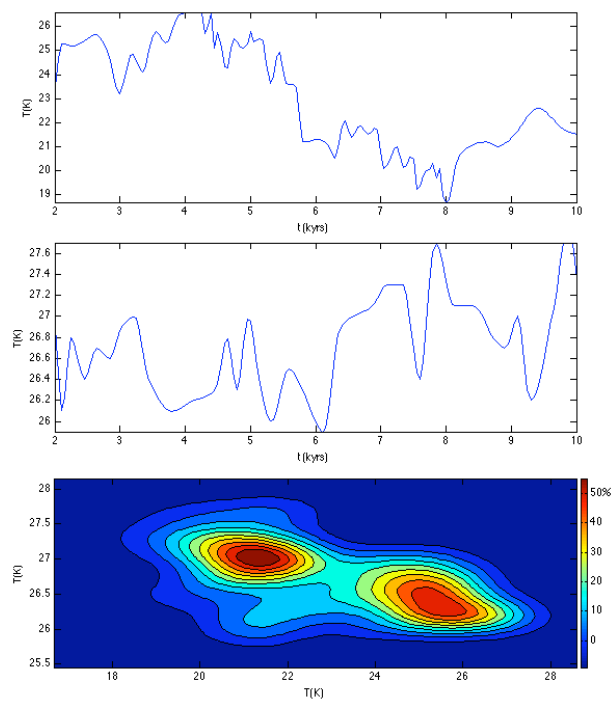

Figure 2 shows both sets of the data and their joint probability with respect to temperature. The data are anti-correlated (the correlation coefficient between these two data sets is about 0.57). The two maxima in their joint probability density function correspond to periods of the wet (right maximum) and dry Sahara (left maximum).

IV. SUMMARY

The paleogeography revealed in the radar images is being compared with the temporal changes in climate indicated by data and modeling. The georeferenced image data set will provide the regional context to analyze the timings and locations of human occupation reported by Kuper and Kreopelin, and compare with the climate modeling. Expected results include an improved understanding of the relationship between various climatic forcing functions and responses, and a better understanding of the relationship between humans and their changing environment during the Green Sahara phase.

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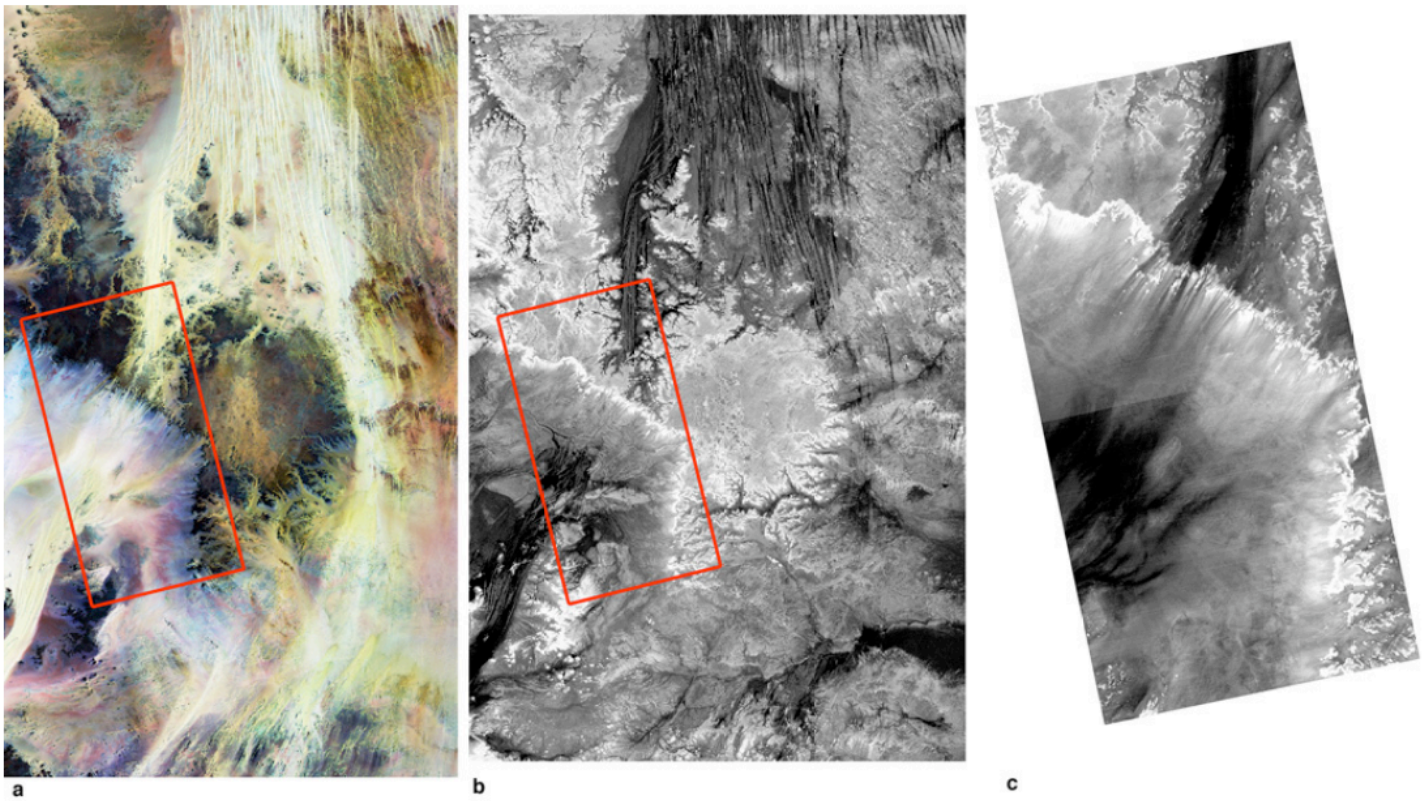

Figure 1. Images of the Gilf Kebir, Egypt. a) Landsat Thematic Mapper mosaic from GeoCover 1990 (https://zulu.ssc.nasa.gov/mrsid/). Sand covered areas are easily discriminated from rocky areas. Other color variations reflect differences in composition of rocks and weathering products. Area covered is from 22-25° N, 25-27° E. b) SRTM radar image mosaic of same area as a. Sand areas are generally dark except for thin covers of sand, which are penetrated by C-band (5.5 cm) radar. Some drainage paths shown here are buried by dry sand. c) ASTER thermal IR image acquired at night. Note sandy areas are dark as their low thermal inertia allows them to cool faster than the rocky areas at the cliff edge. Area of image is shown in boxes in a) and b). Image acquired 20 October 2004.