REMOTE SENSING OF THE HYDROLOGIC HISTORY OF SOUTHERN EGYPT

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The region of the Gilf Kebir in southeastern Egypt has never been thoroughly mapped in terms of the landforms and subsurface signs of past climates conducive to human occupation. As part of NASA's Space Archaeology program, 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.

That the Sahara was favorable for human habitation at times has long been known. 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. (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 the buried channels of the region could also prove useful for development of water resources in southern Egypt and northern Sudan (Robinson et al., 2006; El-Baz et al., 2007).

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). Together these sensors allow characterization of surface and subsurface landforms formed and modified by former wetter climates. A mosaic of PALSAR images uses as a base the topographic map produced by the Shuttle Radar Topography Mission, flown in 2000. 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 and Landsat TM, is being used for mapping surficial landforms and vegetation. These wavelengths are sensitive to surface composition including rock types, weathering phenomena, and soil types (Fig. 1a).

A global hydrologic net, Hydrosheds, has been generated from the SRTM DEM and released by the USGS (http://hydrosheds.cr.usgs.gov/). Many of the drainage lines in this data set are related to the ancient river valleys, indicating some surficial manifestation of their presence. This could be due to incomplete burial, sagging of the mantling sediment, or a small amount of penetration of the SRTM C-band radar signals. It is instructive to examine how Hydrosheds portrays radar-mapped channels. In some areas the Hydrosheds drainage lines match well where radar images at L (PALSAR) and C-band (SRTM, Radarsat, ERS) depict them. This is likely because sand cover is thin. Wider and deeper channels, filled with more sand, are darker in radar images and don't always coincide with Hydrosheds drainage lines (Fig. 2).

To test if penetration in SRTM caused lower elevation values for points in the sand-covered areas, the SRTM DEM was compared with the new Global DEM (GDEM) produced by the Japanese Space

Agency from ASTER visible-wavelength stereo images. This DEM should represent the surface only. Preliminary comparisons indicate that areas of expected penetration are indeed lower in the SRTM DEM, but noise and artifacts in the ASTER GDEM make the comparison difficult.

One of the main problems for mapping the buried channels is that the radar shows an overlay of all channels of all ages – a palimpsest – so it is difficult to assign ages to the imaged channels. However, it appears that the larger channels are probably older and the smaller ones are younger and inset into them (Fig. 2). Thus, the larger channels may represent older, wetter periods and the younger channels less favorable conditions for stream flow. Other workers have indicated that the major channels detected in the radar images are too large to have been formed in the Pleistocene (last 2 million years) and represent greater rainfall and lower base-levels found in the Miocene (over 5 my ago; Wendorf et al., 1987; Paillou et al., 2009). It may be that the major channels were formed in those periods, but it seems logical that the more recent wet periods could have caused water to flow in these pre-existing channels. Late Pleistocene human artifacts also attest to the presence of water in the channels at the later times.

Another way to map the signs of past wet periods is to map the distribution of calcareous deposits related to springs and lakes. These are associated with cultural artifacts of all ages (Wendorf et al., 1987). We are using ASTER to map the spectral signatures of calcium carbonate, travertine, playa clays, and other signs of springs and lakes found throughout the area.

Archaeologists have never had a synoptic view of the region around Gilf Kebir. In addition, the national governments of the region need a detailed map of landforms and resources for conservation efforts. The data and maps produced by this study will be unique and will be used for many years as a base for further studies of the archaeology of the region as well as other applications in hydrology, ecology, geomorphology, and tourism.

ACKNOWLEDGMENT

Part of this work was done under contract with NASA.

REFERENCES

El-Baz, F., C.A. Robinson, T.S.M. Al-Saud, 2007, Radar images and geoarchaeology of the eastern Sahara, ch. 2 in Wiseman and El-Baz, *Remote Sensing in Archaeology*, Springer.

McCauley, J.F., C.S. Breed, G.G. Schaber, W.P. McHugh, B. Issawi, C.V. Haynes, M.J. Grolier, A. El Kilani, 1986, Paleodrainages of the eastern Sahara- the radar rivers revisited (SIR-A/B implications for a mid-Tertiary trans-African drainage system), IEEE Trans. Geosci. Rem. Sens., v. GE-24, 624-648.

Paillou, P., M. Schuster, S. Tooth, T.G. Farr, A. Rosenqvist, S. Lopez, J-M Malezieux, 2009, Mapping of a major paleodrainage system in eastern Libya using orbital imaging radar: The Kufrah River, Earth and Planet. Sci. Lett., v. 277, p. 327-333, doi:10.1016/j.epsl.2008.10.029.

Robinson, C., F. El-Baz, T.S.M. Al-Saud, S.B. Jeon, 2006, Use of radar data to delineate paleodrainage leading to the Kufra Oasis in the eastern Sahara, J. African Earth Sci. v. 44, p. 229-240.

Wendorf, F., A.E. Close, R. Schild, 1987, A survey of the Egyptian radar channels: An example of applied archaeology, J. Field Arch., v. 14, p. 43-63.

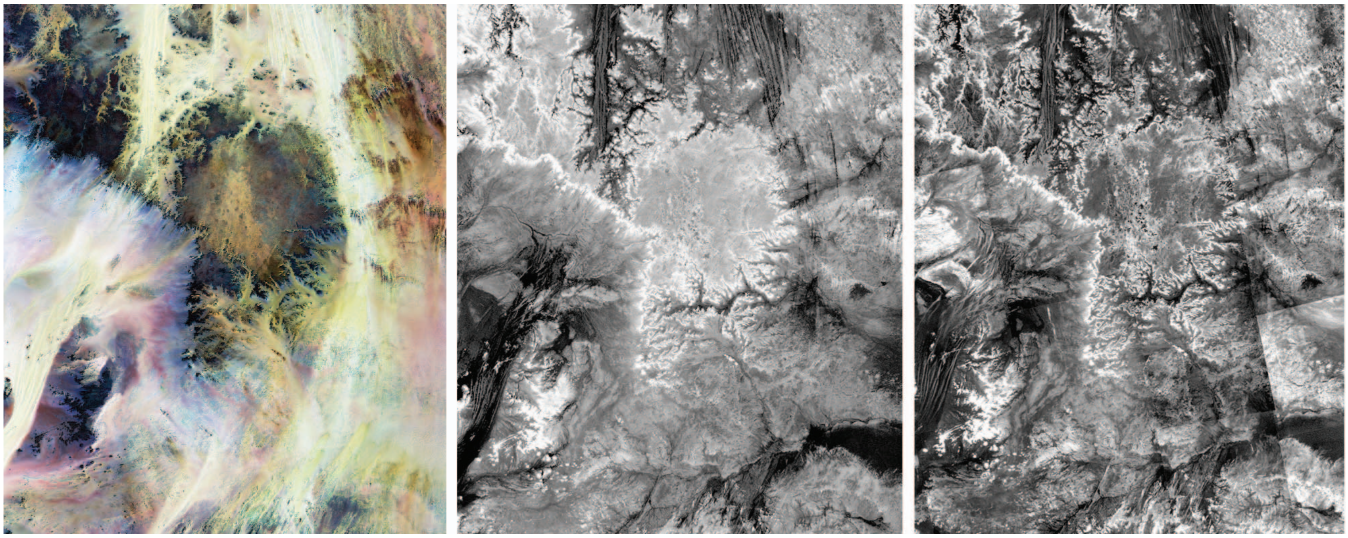

Figure 1. Images of the Gilf Kebir, Egypt.
a) Landsat Thematic Mapper mosaic from GeoCover 1990 (https://zulu.ssc.nasa.gov/mrsid/). Sand covered areas are easily discriminated from rocky areas. Other color variations reflect differences in composition of rocks and weathering products. Area covered is from about 22-24° 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.
c) PALSAR mosaic. Note additional structures visible on the plateau and adjacent sandy areas. In particular, some dark buried river channels are visible at the lower right in both this image and the SRTM image.

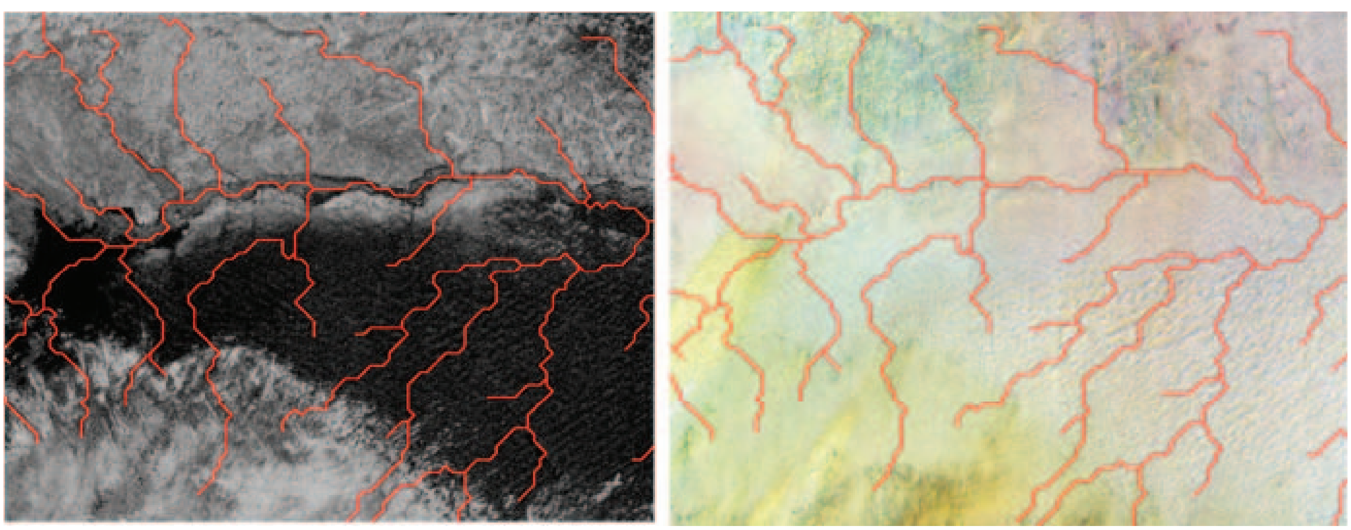

Figure 2. Hydrosheds drainage lines (red) on SRTM and TM.
a) SRTM C-band image of area at lower right of Figure 1. Note large dark, presumably older drainage with inset, probably younger, drainage on its north flank. Hydrosheds, using the SRTM DEM, ‘found’ only the smaller drainage.
b) TM image showing lack of surface manifestation of the drainages seen in the SRTM image.