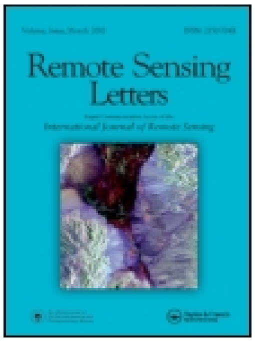

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Accessing free Landsat data via the Internet: Africa's challenge

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Since January 2008, the US Department of Interior/US Geological Survey has been providing terrain-corrected Landsat data over the Internet for free. This letter reports the size and proportion of the US Landsat archive that is over Africa by each Landsat sensor, discusses the implications of missing data and highlights the current bandwidth constraints on users accessing free Landsat data over the Internet from Africa.

1. Introduction

Africa is experiencing rapid and substantial social, economic and environmental change (UNEP 2006, Economic Commission for Africa 2008). Many African institutions, organizations, initiatives and networks use satellite sensor data, and there is an established recognition of the opportunities that satellite sensor data provide for African environmental and public sector applications (National Academy of Sciences 2002, Rowland *et al.* 2007, Global Marketing Insights, Inc. 2009). The Landsat satellite series, operated by the US Department of Interior/US Geological Survey (USGS) Landsat project, with satellite development and launches supported by National Aeronautics and Space Administration (NASA), represents the longest temporal record of space-based land observations, from 1972 to present, and provides a balance between the requirements for localized high-spatial resolution studies and global monitoring (Williams *et al.* 2006). In January 2008, the USGS implemented a free Landsat Data Distribution Policy that provides the entire US-held Landsat archive at no cost via the Internet (Woodcock *et al.* 2008). All Landsat acquisitions with a cloud cover $\leq$40% are being made available, and users may request any other acquisition from any Landsat sensor in the US Landsat archive to be processed and made available via the Internet at no cost (Roy *et al.* 2010).

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This letter evolved from discussions at an African Landsat data initiative meeting held at the USGS Center for Earth Resources Observation and Science (EROS) in May 2009. The meeting was attended by the letter authors and by other African remote-sensing experts and Landsat data users from Botswana, the Democratic Republic of Congo, Mozambique, Senegal, South Africa and Sudan, who represent different user networks, including the Southern Africa Fire Network, the Miombo Network, Observatoire Satellital des Forêts d'Afrique Centrale and the West Africa Regional Network (GOFC-GOLD website). At the meeting the constraints on the uptake of satellite sensor data in different African countries were discussed. These constraints may include limited tertiary education, especially in remote sensing, conflicting national interests and priorities, inadequate awareness of potential users, insufficient capacity and infrastructure for satellite sensor data access, analyses, distribution and high satellite sensor data costs (Aseno 1997, George 2000, Rowland *et al.* 2007, Trigg and Roy 2007, MacPhail 2009). Currently, the most pressing constraint on the African uptake of the free USGS Landsat data is the poor Internet connectivity between the United States and much of Africa.

2. US Landsat archive statistics for Africa

The Multispectral Scanner System (MSS) was onboard Landsat satellites 1–5 and acquired images of the Earth from 1972 to 1992, the Thematic Mapper (TM) on Landsats 4 and 5 has acquired images from 1982 to present and the Enhanced Thematic Mapper Plus (ETM+) is onboard Landsat 7 and has acquired images since 1999 (Williams *et al.* 2006). Each Landsat acquisition is defined in $\sim$180 $\times$ 170 km scenes in a worldwide reference system of path (groundtrack parallel) and row (latitude parallel) coordinates. At the time of writing, the US Landsat project archive has more than 2.3 million globally distributed acquisitions with more than 500,000 MSS, more than 800,000 TM and nearly 1 million ETM+ acquisitions (table 1). The volume of TM and ETM+ acquisitions is growing daily by $\sim$40 and 260 GB, respectively (Wulder *et al.* 2008).

Africa, including Madagascar and other surrounding islands, covers a total of 1324 path/rows, which corresponds to about 11.0% of the global land path/rows. In the US Landsat archive, 8.6% of the acquisitions are over Africa and by sensor 12.5, 6.0, 8.0 and 3.7% of the ETM+, TM, MSS 4–5 and MSS 1–3 acquisitions are over Africa (table 1).

Figure 1 shows the mean monthly number of ETM+ acquisitions over Africa (filled black circles) and the mean monthly number of acquisitions with cloud cover $\leq$40% (open black circles) from January 2000 to December 2008 in the US Landsat archive. There were 8736 (2000) to 14,103 (2005) African ETM+ acquisitions archived per year. Each month about 76% of the acquisitions have cloud cover $\leq$40%, providing an average of 9014 acquisitions per year over Africa. Similar proportions are expected

Table 1. Summary of Landsat data in the US Landsat archive and percentage of acquisitions that are over Africa (as of 14th September 2009).

Sensor	Total global number of acquisitions	Percentage over Africa
MSS 1–3	288,874	3.66
MSS 4–5	225,432	8.03
TM 4–5	822,880	6.03
ETM+	968,433	12.48
Total:	2,305,619	8.64

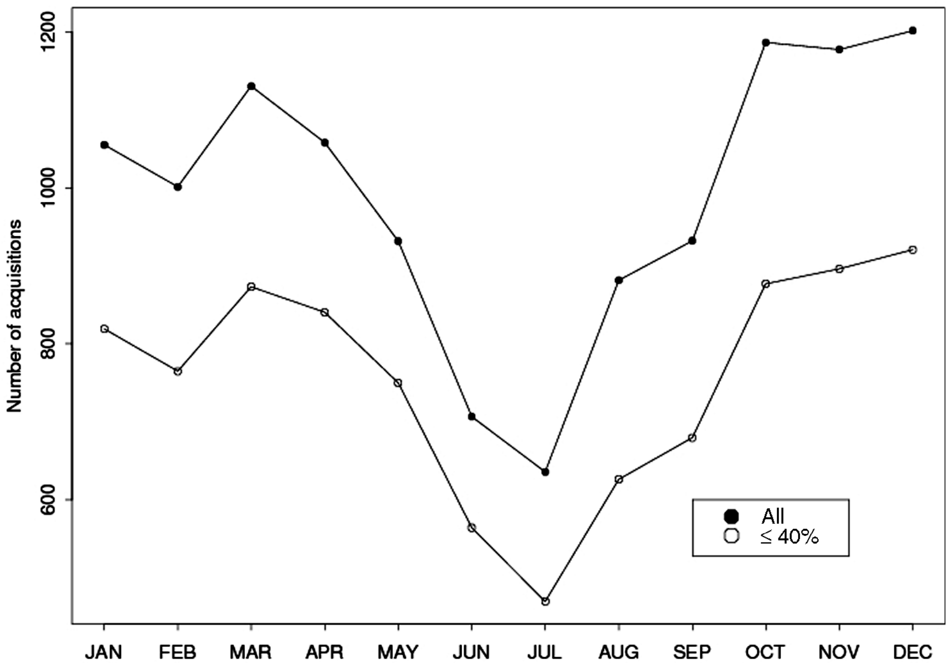

Figure 1. Mean monthly number of ETM+ acquisitions (filled black circles) stored in the US Landsat archive for Africa, 2000–2008. The open black circles show the mean monthly number of acquisitions with cloud cover ≤40%.

for the Landsat MSS and TM data although this cannot be quantified reliably as there is no systematic cloud cover assessment for these data.

Figure 2 shows the spatial distribution of the annual mean number of ETM+ acquisitions that have cloud cover ≤40%, with a mean of 6.9 acquisitions per path/row per year for all of Africa. The annual mean number of acquisitions illustrated in figure 2 varies spatially, reflecting predominantly cloudy regions where there are fewer acquisitions (Ju and Roy 2008) but also the programmatic acquisition of scenes in response to large volume user requests in support of African intensive field campaigns such as SAFARI2000 (Privette and Roy 2005).

The greater proportion of ETM+ African acquisitions summarized in table 1 reflects the more systematic approach to acquiring global annual coverage data and the improved data recording and US ground system capacity in the ETM+ era (1999 onwards). The US Landsat project uses a Long-Term Acquisition Plan (LTAP) to schedule ETM+ acquisitions in anticipation of user requests and to refresh annually a global archive of sunlit, substantially cloud-free acquisitions that capture the seasonal land surface dynamics (Arvidson *et al.* 2006). In the Landsat MSS and TM era, there was no LTAP and for the years 1974–1983 and 1989–1998 the *majority* of path/rows over Africa have no Landsat acquisitions in the US Landsat archive.

3. African Internet constraints on free access to the US Landsat archive

Researchers cannot take advantage of the free Landsat data if their Internet connectivity is not available, reliable or sufficiently fast to enable them to transfer

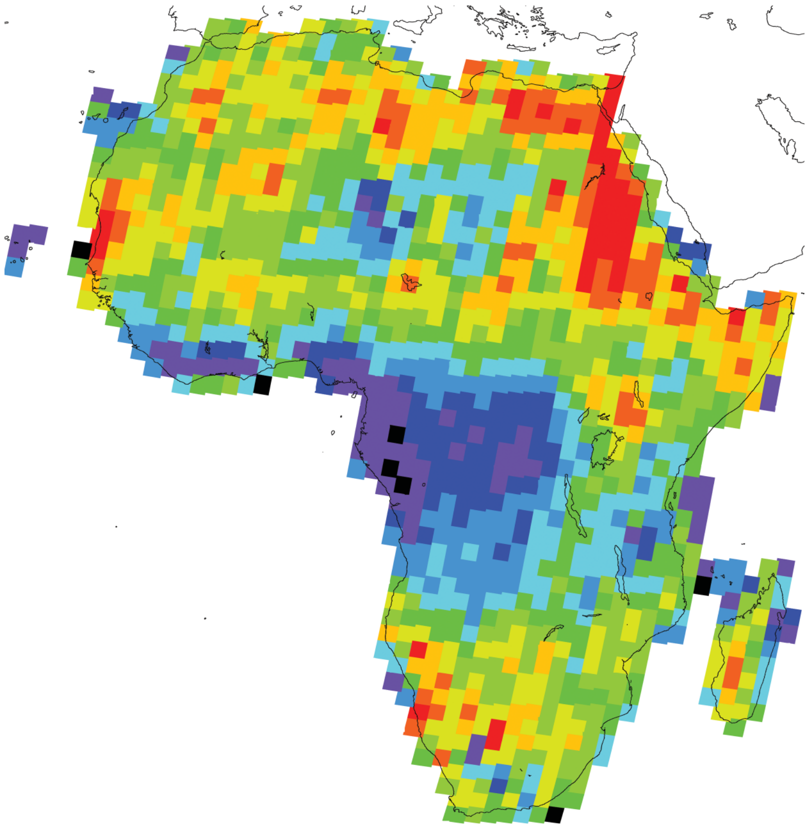

Figure 2. The annual mean number of African ETM+ acquisitions, 2000–2008, with cloud cover ≤40%, stored in the US Landsat archive. The data are shown in the Albers equal area projection (central meridian 20° E, 0° N; standard parallels 21° N and 20° S). The black vectors show major land–water boundaries. The colours show the mean number of acquisitions available at a given Landsat path/row (minimum 0.44, maximum 12.9): 0 < ■ < 1, 1 ≤ ■ < 3, 3 ≤ ■ < 4, 4 ≤ ■ < 5, 5 ≤ ■ < 6, 6 ≤ ■ < 7, 7 ≤ ■ < 8, 8 ≤ ■ < 9, 9 ≤ ■ < 10, 10 ≤ ■ < 11, 11 ≤ ■ < 13.

Landsat acquisitions from the US Landsat archive. This issue presents a fundamental and serious current constraint in Africa where the majority of countries have limited Internet capability. In March 2009, only about 5.6% of Africans had access to the Internet compared to a world average of 23.8% although Internet usage in Africa is thought to have increased by 1100% from 2000 to 2008 (IWS 2009). The relative difficulties in accessing large data volume files over the Internet in Africa are emphasized when the total 2006 African Internet bandwidth (28,177 Mbps) is compared with the equivalent total bandwidths of 1,360,002 and 3,060,002 Mbps, respectively, for Europe and the Americas; in 2006 Norway alone had 43,019 Mbps bandwidth, almost one and a half times more bandwidth than *all* of Africa (ITU 2007). Internet usage in Africa will continue to increase as new fibre-optic cables are now being laid. New fibre-optic cables will open up access to broadband connectivity but problems of establishing networks within countries and African government regulation may continue to restrict Internet access across the continent.

At the USGS EROS African Landsat data initiative meeting various approaches to Landsat data access and distribution in Africa were discussed. Potential approaches range from low-technology ones, such as African data brokers receiving the data from the United States and then redistributing the data on media within the region (Trigg and Roy 2007), to high-technology approaches including multicasting the data using commercial telecommunication geostationary satellites (EUMETSAT 2006). Given the significant economic and infrastructure challenges facing many African countries, the former type of inexpensive, low-technology solution was considered appropriate prior to broadband Internet connectivity across Africa and increased African user access to satellite reception systems.

4. Discussion

The 2008 free Landsat data policy opens a new era for utilizing Landsat data. Many applications that utilize Landsat data require a single cloud-free acquisition or multi-temporal acquisitions to capture surface change and to reduce missing data because of clouds and missing observations caused by sensor artefacts (Townshend and Justice 1988, Tucker *et al.* 2004, Lindquist *et al.* 2008). The spatiotemporal distribution of African ETM+ data illustrated in figures 1 and 2 and the fact that there is a mean of 6.9 acquisitions per path/row per year with cloud cover $\leq$40% imply that the free ETM+ data will largely meet African application needs. However, prior to 1999, in the Landsat MSS and TM era, there are far more data gaps over Africa. Indeed, the majority of African path/rows have no acquisition held in the US Landsat archive for the years 1974–1983 and 1989–1998. This high level of missing historical data precludes complete 'wall-to-wall' continental mapping on an annual basis, and many annual land surface monitoring and change detection applications, using the free Landsat data.

This letter highlights Internet access as one of the several constraints on the uptake of satellite sensor data in Africa. Even when there is a solution to African Internet constraints, it is unknown how much free Landsat data will be used in Africa, although a recent remote sensing user survey of 377 respondents from over 30 African countries found that the majority of respondents believed that they had an adequate amount of remote-sensing expertise and capability but that they needed a greater number of accessible geospatial data sets (Global Marketing Insights, Inc. 2009). However, until Internet constraints are ameliorated only African users and external agencies with sufficient Internet connectivity to the US Landsat archive will benefit from the free Landsat data policy.

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