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Scene selection and the use of NASA's global orthorectified Landsat dataset for land cover and land use change monitoring

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Abstract

This study examines the utility of NASA's circa 1990 and circa 2000 global orthorectified Landsat dataset for land cover and land use change mapping and monitoring across Africa. This is achieved by comparing the temporal and spatial variation of NDVI, measured independently by the NOAA-AVHRR at the time of Landsat scene acquisition, against the seasonal mean for each Landsat scene extent. Decadal sequences of drift-corrected NOAA-AVHRR imagery were used to calculate NDVI means and standard deviations for the periods covered by the scenes composing the c.1990 and c.2000 Landsat datasets. The specific NOAA-AVHRR NDVI values at the acquisition date of each individual Landsat scene were also calculated and the differences, both from the mean and scaled by standard deviation, were mapped for the Landsat scene footprints in the c.1990 and c.2000 datasets. The resulting maps show the temporal position of each Landsat scene within the seasonal NDVI cycle, and provide a valuable guide to assist in quantifying uncertainty and interpreting land cover and land use changes inferred from these Landsat data.

1. Introduction

Substantial land cover and land use changes have occurred across Africa over the last two decades. High rates of urbanization for example, have led to rapid settlement expansion (Njoh 2003, Tatem and Hay 2004, Tatem *et al*. 2004), while natural resource exploitation has resulted in significant deforestation (Food and Agriculture Organization, 2005, Zhang *et al*. 2005) and desertification (Millennium Ecosystem Assessment 2005, Symeonakis and Drake 2004). These changes have direct ecological consequences but also significant indirect effects on public health (Hay *et al*. 2005a, Hay *et al*. 2005b, Snow *et al*. 2005). An absence of detailed contemporary and historical maps for much of the continent means satellite sensor imagery has an important role to play in the monitoring and understanding of such changes and attempting to define their public health impact.

Many land cover and land use changes take place at fine spatial scales, requiring spatial resolutions similar to those of Landsat imagery (or finer) to achieve accurate measurements (Tatem *et al*. 2005). NASA's global orthorectified Landsat dataset (Tucker *et al*. 2004), freely available through the University of Maryland's Global Land Cover Facility (URL:

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http://www.glcf.umiacs.umd.edu/), provides a significant public-domain resource for quantifying such changes. Globally consistent, co-registered satellite sensor data at a spatial resolution of tens of metres, with highly accurate within-scene and among-scene geodetic accuracies for three time periods, spanning almost three decades are available (Tucker *et al.* 2004). Absence of imagery, sensor problems, cloud cover and haze throughout the global catalogue of Landsat data have necessitated careful scene selection in the construction of this database. These choices inevitably involved balancing image quality and availability against the need to maintain consistency in scene year and season selection (Tucker *et al.* 2004). Such temporal and spatial consistency was often necessarily sacrificed to create datasets which maintained image quality, especially in areas such as tropical Africa where cloud cover duration is pervasive (Tucker *et al.* 2004).

Between-scene consistency, unbiased by seasonal variation, is important in land cover and land use change studies since decadal changes must be analysed in the absence of confounding vegetation phenology (Justice *et al.* 1985) and inter-annual variation (Linderman *et al.* 2005). These confounding factors can be measured using the Normalized Difference Vegetation Index (NDVI) (Tucker 1979). The NDVI is a spectral index of red and near-infrared reflectances and radiances, that is designed to be highly coupled to the radiation intercepted and absorbed by photosynthetically active plant canopies (Myneni *et al.* 1995).

Here we attempt to provide a guide for quantifying uncertainty and interpreting land cover and land use changes inferred from the c.1990 and c.2000 Landsat datasets for Africa. This is achieved by mapping the temporal position of each Landsat scene within the seasonal NDVI cycle using scene footprint extents and independent multitemporal Advanced Very High Resolution Radiometer (AVHRR) NDVI data.

2. Materials and methods

The Global Inventory Modeling and Mapping Studies (GIMMS) satellite drift corrected and NOAA-16 incorporated AVHRR NDVI maximum value composited decadal imagery at 8×8 km spatial resolution (Tucker *et al.* 2005) for 1984–2002 (to match the periods covered by the c.1990 and c.2000 Landsat datasets) were obtained from the Africa Data Dissemination Service (ADDS) (URL: http://igskmncnwb015.cr.usgs.gov/adds/, accessed on 12 July 2005). Since these specific NOAA-AVHRR data were not available prior to 1981, the 1970s Landsat dataset was not examined. Vector files detailing the extent (scene footprint) and date of each Landsat scene used to create the c.1990 and c.2000 datasets for Africa were reprojected to an Albers equal-area projection to correspond with the NOAA-AVHRR NDVI imagery. These vector footprint files were then used to extract from the NOAA-AVHRR imagery, for each Landsat scene extent, the mean NDVI and standard deviation for the periods covered by the c.1990 (earliest scene date April 1984 – latest scene date August 1996) and c.2000 (earliest scene date July 1999 – latest scene date November 2002) Landsat datasets.

3. Results and discussion

Figures 1(*a*) and (*b*) show how different the NDVI values at the time of acquisition of each Landsat scene in the c.1990 and c.2000 datasets were from the seasonal mean for the range of dates covered by each dataset. Figures 1(*c*) and (*d*) show the NDVI standard deviation, and demonstrate how much NDVI values varied over the months and years covered by each Landsat dataset. By using the results in figures 1(*c*) and (*d*) to rescale the data in figures 1(*a*) and (*b*), we control for the differing levels of seasonal NDVI variation across Africa to produce coefficient of variation maps. Figures 1(*e*) and (*f*) thus provide a measure of how different the NDVI value of the Landsat scene in question is from the mean annual NDVI, as a proportion of the annual range of NDVI values for that area.

The results reveal that much of both of the Africa Landsat datasets demonstrate large areas of spatial correlation in NDVI variation. This is a clear indication of the implementation of rules imposed on Landsat scene selection in creating the datasets (Tucker *et al.* 2004). Figures 1(*a*) and (*b*) show some interesting spatial patterns in both c.1990 and c.2000 cases. Generally, the Landsat scenes chosen to represent the tropical belt above the Equator exhibit NDVI values below mean levels. In contrast, the majority of south-central Africa scenes exhibit above average NDVI values. These patterns are not completely consistent spatially or temporally, however. Landsat scenes acquired in above average NDVI periods also occur in the tropical belt and scenes acquired in below-average periods are seen in southern areas. The c.2000 image also has fewer scenes acquired in periods that were substantially different from the mean NDVI for each scene than the c.1990 dataset. Most likely, this results from the greater choice of scenes for dataset construction during this acquisition era (Tucker *et al.* 2004).

Figures 1(*a*) and (*b*) highlight the scenes acquired during the greatest NDVI deviations from mean values. These appear in those areas with substantial annual NDVI variation. Therefore, an estimate of the position of the Landsat scene NDVI level within the normal seasonal NDVI deviation (figures 1(*c*) and (*d*)) was required. Figures 1(*e*) and (*f*) thus provide a more complete picture of between-scene and between-dataset NDVI differences in the form of coefficient of variation maps. For example, while figure 1(*a*) shows that no scenes in the Landsat c.1990 dataset representing the Horn of Africa were acquired at a time when NDVI deviated more than 0.1 from mean levels, figure 1(*c*) indicates that very little NDVI deviation occurs in the region. Scaling by the NDVI deviation that does occur, however (figure 1(*e*)), reveals that the scenes chosen for the coastal section were acquired at a time of relatively high NDVI, although the absolute NDVI changes in such arid regions are small.

In construction of the NASA datasets, Landsat scenes were preferentially selected, where possible, from the growing season when NDVI is at a maximum (Tucker *et al.* 2004). The coefficient of variation maps (figures 1(*e*) and (*f*)) show that in general, this was achieved across both northern and southern Africa, with the majority of scenes acquired when NDVI was above mean values. However, for the tropical belt, as described in Tucker (2004), the reverse is true. Here, most scenes used in the datasets were acquired when NDVI values were significantly lower than normal levels, as peak NDVI is frequently accompanied by significant cloud cover.

The implications of these results for both land cover/use mapping by creating mosaics of scenes from a single Landsat dataset, or for land cover/use change studies examining scene differences between datasets, are significant. Across both figure 1(*e*) and (*f*) are Landsat scenes acquired when NDVI levels were substantially above mean levels, adjacent to scenes acquired when levels were substantially below mean. Without knowledge of such seasonal effects, construction of mosaics from such scenes to produce land cover/use maps introduces confounding effects from scene selection dates rather than land cover/use change processes. Similarly, problems may arise when using a single scene from each of the c.1990 and c.2000 datasets to infer land cover or use change between dates, without knowledge of the seasonal NDVI differences mapped. This may lead to land cover or use change being erroneously assigned to, for example, urbanisation, deforestation or desertification, when seasonal variation in vegetation levels is the cause.

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4. Conclusions

NASA's global orthorectified Landsat dataset represents a valuable resource for monitoring, understanding and modelling land cover and land use change across Africa. Landsat data availability and quality has constrained its temporal and spatial consistency, however, and users should be aware of how this may affect image interpretation and confidence in their results. Here we have mapped the levels of NDVI deviation at the acquisition time of each Landsat scene within the c.1990 and c.2000 datasets. Results show systematic differences in NDVI levels geographically, making the use of multiple scenes for land cover or use classification impractical in places. These maps should therefore provide an important accompaniment for estimating uncertainty in future work and help users understand the need to correct for inter-annual variation and NDVI seasonality in African land cover and land use studies that use the datasets.

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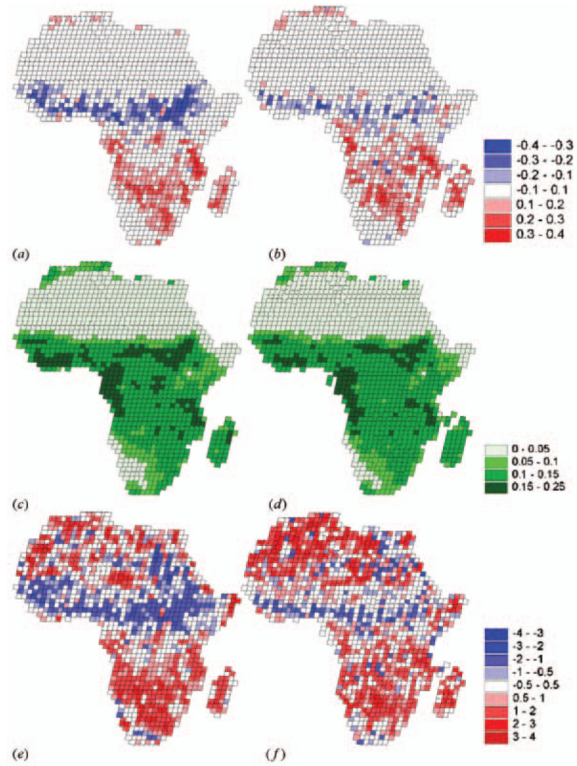

Figure 1.
(*a*) Mean difference from the 1984–96 NDVI mean for each scene from the c.1990 Landsat dataset; (*b*) Mean difference from the 1999–2002 NDVI mean for each scene from the c. 2000 Landsat dataset; (*c*) Mean NDVI standard deviation over the 1984–96 period for each scene from the c.1990 Landsat dataset; (*d*) Mean NDVI standard deviation over the 1999–2002 period for each scene from the c.2000 Landsat dataset; (*e*) NDVI difference from the mean divided by the standard deviation for the 1984–96 period for each scene from the c. 1990 Landsat dataset; (*f*) NDVI difference from the mean divided by the standard deviation for the 1999–2002 period for each scene from the c.2000 Landsat dataset.

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