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Temporal merging of remote sensing data to enhance spectral regolith, lithological and alteration patterns for regional mineral exploration

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ABSTRACT

Remote sensing has been widely used to map geological structure, regolith materials and hydrothermal alteration minerals in different regions of the world, based largely on the spectral characteristics of clay/carbonate and iron oxide minerals. Given that features related to minerals may form very subtle patterns in Landsat imagery, finding suitable methods for enhancing the spectral information due to alteration minerals has been the subject of much research since the satellites were launched. Although multispectral sensors such as Landsat do not have enough spectral resolution to distinguish between specific minerals, effective processing of the data does yield useful images for regional exploration and targeting when combined with a good understanding of the associated landforms. ASTER and various airborne systems can now provide useful, high-resolution mineral information. However, the cost and time taken to acquire and process good resolution spectral data should now be balanced against the enhanced spectral discrimination possible using temporal merging, or data stacking, from the existing Landsat data archive dating back to 1972. One critical characteristic of the spectra related to surface mineral composition is its persistence over time. This study proposes a further enhancement to the data using temporal merging to create images that are both easier to interpret, and more reliable indicators of lithology and alteration. The new approach is to select a large number of scenes, typically separated by two or more years, and to merge the data for each band to give a cumulative spectral signature. The technique of stacking Landsat data to create a new dataset with much greater spectral depth is termed Landsat TM3, or Landsat TM Temporal Merge for Terrain Mapping. This emphasises not only the process used to create the dataset, but also the dominant use to which these data are ideally suited, namely mapping geological and mineral-related terrains.

1. Introduction

The Landsat programme is the longest running enterprise for the acquisition of satellite imagery of the Earth. The first satellite in the series was launched on 23 July 1972, and the most recent, Landsat 8, was launched on 11 February 2013 (Table 1). Data from the Landsat series of remote sensing satellites is used for agriculture, cartography, forestry, regional planning, surveillance and geological mapping. The images are often used to map regional geological structure, regolith materials and hydrothermal alteration minerals, based largely on the spectral characteristics of clay/carbonate and iron oxide minerals.

For a single Landsat dataset, minerals at the surface may represent only a fraction of the information content of each pixel, as they are swamped by more prominent spectral features, such as seasonal vegetation growth and fire scars, in all but the most arid environments. Enhancing these very subtle mineral patterns in Landsat imagery has been the subject of much research since the satellites were launched.

Features susceptible to change over time have also been the subject of numerous research papers, almost entirely focused on detecting or monitoring change for environmental purposes, such as forest clearing. So, while some contributors to the spectral response will wax and wane, for example fire scars followed by re-vegetation, or cropping alternating with fallow periods, the mineral signature will be a constant factor. Given that this signature will be stronger at some times, and weaker or obscured at others, merging multiple years of data will progressively overcome these variations, thus highlighting the mineral response.

Numerous studies related to environmental change monitoring in silviculture and agriculture have used multi-temporal imagery, although stacking data to create a single, new dataset is not often considered. They typically use comparisons between processed imagery to determine changes in the environment. By contrast, geoscientists almost invariably use single scenes, combined with varying degrees of complexity in the algorithms applied to the data. The new work in this study, initially outlined by Langford (2007), uses stacked multi-temporal data to create a new dataset. Any algorithms applied to these new data capitalise on the greater depth and discrimination possible with a temporal merge.

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Table 1
Landsat satellite archives, modified from USGS Products Long Term Archive, Landsat Satellite Archives .

Name	Time range	Description
Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor)	2013–present	15- to 30-metre multispectral data from Landsat 8
Landsat Enhanced Thematic Mapper Plus (ETM+)	1999–2003 (SLC-on) 2003–present (SLC-off)[a]	15- to 30-metre multispectral data from Landsat 7
Landsat Thematic Mapper (TM)	1982 to 2012	30-metre multispectral data from Landsats 4 and 5
Landsat Multispectral Scanner (MSS)	1972–1992	68 × 83-metre (resampled to 60 m) multispectral data from Landsats 1–5

[a] The Scan Line Corrector (SLC) on the instrument failed in May 2003. This caused all Landsat 7 data acquired after this date to have line gaps.

Selecting a large number of scenes, typically separated by two or more years, and merging the data for each band to give a cumulative spectral signature, will give a significant improvement in the resulting imagery when compared with a single scene (Fig. 1). Good results have been obtained with as few as five years, although at least nine years is preferred, chosen for optimal seasonal conditions from 100% cloud-free scenes.

For the small effort required to select, download and merge multiple years of data, there is a significant improvement to the quality, and potential benefit to exploration, in the resulting images. The most noticeable imagery improvements can be seen when interband ratios are used, as the bit depth of the image data is up to one order of magnitude greater than for a single scene; this results in much less noise in the image, making target selection easier. Another area of improvement is in thermal radiance (Band 6), which is often difficult to use and interpret. Stacking the data allows areas of anomalous radiance to be identified with greater confidence than with a single dataset, although interpreting such variations is still difficult.

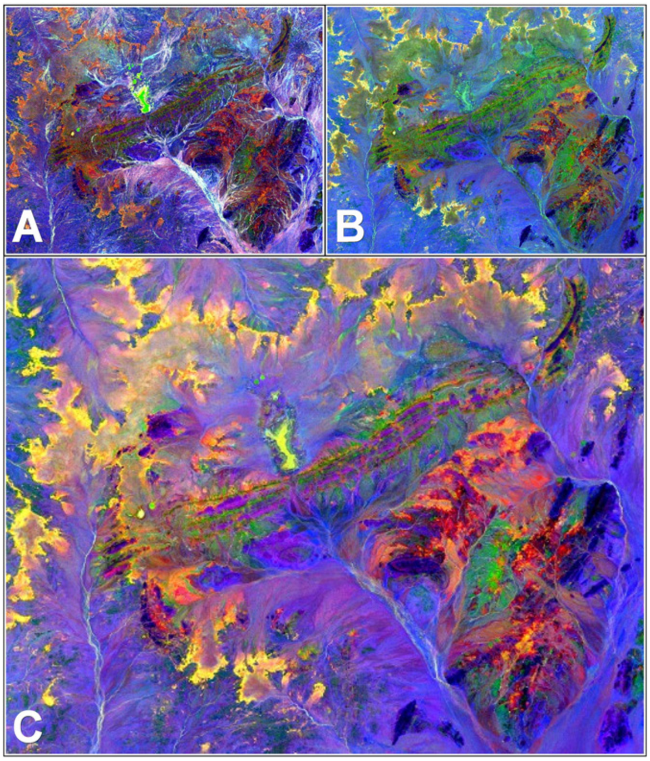

Fig. 1. Comparison between the most recent Landsat 5 and 8 data, and older TM3 data, Weld Range, Western Australia, using Gozzard Ratios (5/7:4/7:4/2); prospective for iron, chromium, nickel and PGM resources. (A) Landsat 5, April 2011. (B) Landsat 8, March 2014. (C) Landsat TM3 nine-year sum (1989–2005). Area 72 × 57 km, centre 27°00′S 117°37′E.

The consistent approach to data acquisition inherent in the Landsat TM data model is recognised in the proposed naming of the stacking technique. The technique of stacking, or merging, Landsat data to create a new dataset with much greater spectral depth is termed Landsat TM3 (Landsat TM Temporal Merge for Terrain Mapping). This emphasises that these data are ideally suited to mapping geological and mineral-related terrains where mineral patterns are often subtle and difficult to highlight.

2. Literature review

2.1. Temporal merging and change detection

One of the most prevalent uses of remotely sensed imagery is in change detection, and a number of the studies in this field touch on the research outlined in this study. Specifically, there are a number of studies reviewed in this section (Coppin and Bauer, 1996; Van Niel and McVicar, 2004; Healey et al., 2005; Kennedy et al., 2007, 2010; Jiang et al., 2011; Mitchell et al., 2013) that discuss or use methods that are similar to the TM3 method in this study, although most keep the temporal components as discrete entities. One study (Kennedy et al., 2010) uses a median value for pixels, but only the current study uses the much simpler arithmetic mean or sum for pixel values. Jiang et al. (2011) provides the most comprehensive review of image fusion, focusing on the more complex methods of merging and the associated algorithms. Given that change detection needs both the discrete and composite values to make sense of any change, there has been no move in these studies to use a simple composite that effectively masks or removes any element of change.

Coppin and Bauer (1996) reviewed many methods of change detection in forests, including an approximation to temporal merging as proposed in this study. By using combined registered datasets, or corresponding subsets of bands, collected under similar conditions on nearly the same day of the year but from different years, classes where forest canopy change is occurring would be expected to have statistics significantly different from those where no change has occurred, and could be identified as such. The method is sometimes called “layered spectral/temporal change classification”, “multi date clustering”, or “spectral change pattern analysis” (Coppin and Bauer, 1996). Landsat TM data from three different years (1984, 1986 and 1990) were selected for their study, enabling an evaluation of the potential for mid-cycle inventory updating over two-, four- and six-year periods.

Van Niel and McVicar (2004) completed a case study in south-eastern Australia that included a review of multi-date classifications performed by either combining various numbers of bands per date into a single image stack prior to classification (termed standard multi-date classification), or extracting maximum accuracy single-crop classes from different dates and combining them, post-classification (termed iterative multi-date classification). For their study of crop classification, the iterative approach resulted in higher accuracy than the standard multi-date image stack of the same dates. Van Niel and McVicar (2004) also noted that standard multi-date classification, which combines image data from various dates to form a single multi-date image prior to classification, is a common method in the literature (e.g., Key et al., 2001). They used two or three cloud-free Landsat-7 ETM+ images from 2001–02 to create the multi-date image stack. These standard multi-date variants resulted in 14-band (two dates by 7 bands), and 21-band (three dates by 7 bands) images. In this respect, they differ from the temporal merging proposed in this study, in which the band data are combined by summation to form a single band.

Healey et al. (2005) used spatially co-registered multi-date stacks to quantify the degree to which it is possible to identify stand-replacing