

TOWARDS GLOBAL MAPPING OF THE EARTH'S LAND SURFACE COMPOSITION

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Commission VIII, WG VIII/5

KEY WORDS: Global, satellite, land surface, composition, hyperspectral, ASTER, geoscience product standards.

ABSTRACT:

New “geoscience-tuned” remote sensing technologies are now available (e.g. satellite-borne multi-spectral ASTER and airborne HyMap imaging systems) or soon to be available (e.g. satellite hyperspectral Hyper-J and EnMap systems) for the resources (energy, minerals and soils) community. These imaging sensors have the potential to provide global information at high spatial resolution for baseline mapping and monitoring of land surface composition, including the abundance and physicochemistry of minerals. These mineral information products complement other types of public geoscience information currently available through government geosurveys, such as geology and soil maps, geophysics and geochemistry. However, the opportunity to capture the full potential of these mineral maps for public use by the global resources communities has not been realised, even though some of these remote sensing systems have been operating for over 10 years. The failure to act upon this opportunity is for a variety of reasons, including:

- Need for robust instrument correction, radiative transfer and cross-calibration corrections for generating seamless multi-scene imagery;
- Non-trivial processing of the “reflectance” data into valuable information products (requires image processing experts);
- Lack of geoscience products standards, including traceable validation and error assessment;
- Lack of easy standard information access (web delivery with associated interoperability and metadata structure); and
- Technology transfer (what do these maps mean for the resources sector?).

Many of these issues result from the current reliance on the private sector to deliver these geoscience information products to the resources community in a commercially competitive environment. This paper provides examples from Australia of how government geoscience and research agencies are working together to develop publicly available, web-accessible geoscience mineral mapping products from ASTER and hyperspectral imaging data of value to the resources, soils and agricultural communities.

1. INTRODUCTION

1.1 Global need-opportunity

“There is a wealth of information on soils but much is dated, inaccurate, unavailable at appropriate scales, or relatively inaccessible. New airborne and space-borne sensors offer unprecedented detail, accuracy, rapid regional or global coverage.” IUGS–UNESCO (2008)

“Earth observations that provide direct information on...soil moisture, soil type...are vital for effective global agricultural monitoring.” GEOSS (2007)

“a sustainable, exploration-based resource industry requires filling emerging gaps in collecting and accessing pre-competitive geoscience information” MEAA (2003)

“Australia continues to provide high-quality, pre-competitive geoscience data to encourage exploration investment. This requires that the continent be mapped with new technologies” SEIC (2001).

Although mapping and monitoring green vegetation at <100m pixel resolution has been achievable since the 70s and 80s using a range of Earth Observation (EO) imaging systems (e.g. Landsat and SPOT series), fewer resources have been devoted to the global measurement of the surface composition, especially its mineralogy, dry vegetation and absorbed/adsorbed water (in plant, soils and minerals). In particular, mineralogy is a fundamental component of all soils and is an indicator for many important soil parameters, such as type, loss, pH, redox potential, water/metal activities, and permeability. Mineralogy is also the critical component of rocks from which can be understood the nature of the parent geology and superimposed effects, such as regional metamorphism, metasomatism (including hydrothermal and hydrocarbon effects) and weathering. Accurately mapping the surface mineralogy of the Earth's land surface would thus provide new and valuable geoscience information for a range of applications.

1.2 Earth observation solutions

To remotely map the non-green vegetation component of the land surface requires sensing beyond the traditional visible to near infrared (VNIR, 0.4-1.0 μm) wavelengths and using the shortwave infrared (SWIR, 1.0-2.5 μm) and/or thermal infrared (TIR, 7.5-12.0 μm) wavelengths. Furthermore, this is better

achieved using more than just a few broad spectral channels because minerals, absorbed/adsorbed water and dry vegetation (cellulose, lignin) have relatively narrow, diagnostic absorption features (full width half height of 0.02-0.05 μm) compared with the broad ($\sim 0.3 \mu\text{m}$) green vegetation reflectance plateau in the NIR relative to the visible parts of the spectrum.

The first operational, “geoscience-tuned” satellite imaging system was the Japanese ASTER (Advanced Spaceborne Thermal emission and Reflectance Radiometer - www.gds.aster.ersdac.or.jp) launched in 1999 onboard the US EO1 satellite (<http://terra.nasa.gov>). ASTER has 14 spectral bands spread over the VNIR (15 m pixel), SWIR (30 m pixel) and TIR (90 m pixel) atmospheric windows in a 60 km swath. This was followed a year later by the first civilian hyperspectral VNIR-SWIR imaging satellite called Hyperion (Folkman *et al.*, 2010). This US sensor has 242 spectral bands across the VNIR-SWIR for a 7 km swath width.

By 2010, the ASTER Global Mapping campaign had acquired essentially three complete mosaics of the Earth’s land surface. The coverage of Hyperion has been much less because of its small swath width and different operational requirements.

From about 2014, a suite of hyperspectral VNIR-SWIR imaging satellites will be operating, including Japan’s Hyper-J, Germany’s EnMap and Italy’s PRISMA. Negotiations are underway to coordinate these and other possible hyperspectral imaging systems to operate as a constellation for global science purposes (www.isiswg.org).

To date, data from ASTER and Hyperion have been publicly accessible as calibrated radiance at sensor or ground reflectance or ground emissivity (Level 1 and 2 products, respectively). ASTER data can be downloaded from www.gds.aster.ersdac.or.jp/gds_www2002/index_e.html and Hyperion data from https://lpdaac.usgs.gov/lpdaac/get_data.

Typically, the reduction of the Level 0 instrument digital numbers through to Level 2 reflectance products involves the correction for instrument, illumination and atmospheric effects. This methodology is detailed as part of the “Algorithm Theoretical Basis Documents” for each sensor, e.g. ASTER - www.science.aster.ersdac.or.jp/en/documnts/atbd.html.

There are currently no higher level geoscience product standards available from ASTER or Hyperion, such as a standard SiO_2 content product from ASTER data (Ninomiya *et al.*, 2005). However, these products are required by users as demonstrated by the fact that over 10,000 GIS compatible maps of airborne hyperspectral mineralogy from the Queensland Geological Survey were downloaded over the web (<http://c3dmm.csiro.au>) after their release (Cudahy *et al.*, 2008).

1.3 Objectives

The objective of this paper is to show that global scale mapping and public delivery of higher level land surface products from geoscience-tuned imaging sensors is achievable. This is demonstrated using results from collaborative work being conducted in Australia between government researchers (CSIRO) and mapping agencies (Geoscience Australia and the State Geological Surveys) and international satellite teams (e.g. ERSDAC, Japan). In particular, methods and products have been developed to help generate web-accessible, ASTER

geoscience maps of the Australian continent. Similar methods are being developed for future hyperspectral EO imaging data.

2. DATA AND METHODS

2.1 ASTER data

A number of regional ASTER geoscience mosaics have been established over Australia including:

- Broken Hill, NSW: ~ 35 ASTER scenes (Hewson *et al.*, 2005);
- Mount Isa, Queensland: ~ 110 ASTER scenes (Cudahy *et al.*, 2008);
- Galwer-Curnamona; South Australia: ~ 110 ASTER scenes (C3DMM, 2010); and
- Western Australia: ~ 450 ASTER scenes (in progress).

A complete mosaic of the Australian continent requires approximately 3300 ASTER scenes. To date, the above large area mosaics have used ASTER L1B imagery collected pre-2003, which were provided free to the public by the USGS. These scenes were chosen on the basis of:

- Least cloud cover;
- Least green vegetation cover; and
- High sun angle.

Ideally, the most up-to-date ERSDAC Ground Data System (GDS) ASTER Level 1B processing and access to the most spatially complete ASTER coverage from data collected between 1999 and 2009 should instead be used for this continental-scale mapping.

2.2 ASTER data processing

The processing of the large area ASTER mosaics in Australia have used as input the Level 1B data corrected for SWIR Crosstalk effects (Iwasaki *et al.*, 2001) and geometrically corrected to latitude-longitude coordinate system. The cross-calibration of the ASTER Level 1B imagery was conducted using software developed by CSIRO Mathematics and Information Sciences for processing Landsat Thematic data (www.cmis.csiro.au/rsm/research/index.htm). The software can use a kernel-type approach that reduces the various physical effects (date, latitude/longitude, view and solar angles, bi-directional reflectance distribution function or BRDF, atmosphere) to a spatially-dependent, linear combination of spectral bands. This process also involves masking out areas of “thick” cloud, dark (wet) ground and green vegetation.

The next step in the reduction of the ASTER cross-calibrated mosaic to (apparent) surface reflectance involved a transformation based on a least squares regression between the ASTER and HyMap data (www.hyvista.com). This involves selecting invariant, spatially co-incident regions of interest (ROIs) of bright and dark targets from the available airborne imagery that was convolved using the ASTER band response functions. For each survey to date, over 60 ROIs have been collected with R^2 values typically >0.8 for ASTER Bands 1-9. The regression gains and offsets are then used to reduce the ASTER mosaic to apparent ground reflectance.

These cross-calibrated and reduced ASTER reflectance mosaics are the basis for the next step of generating the geoscience mosaics, though it is recognised that residual errors can remain, especially those caused by:

- Spatially-dependent, residual water vapour effects;

- Spatially-dependent residual SWIR Cross-talk effects;
- Scan-angle dependent atmospheric scattering, especially in moist tropical regions; and
- Thin clouds.

Extraction of the geoscience information extraction follows a physical model that assumes:

- Topographic illumination effects are pixel-dependent, multiplicative and wavelength-independent;
- Variations in surface bi-directional reflectance distribution function (BRDF) are pixel-dependent, multiplicative and wavelength-independent; and
- Mineral absorption features are pixel-dependent, multiplicative, narrow and wavelength-dependent.

Given the above, normalisation procedures prove useful in removing these complicating effects and extracting the desired surface composition information. From the nine ASTER reflected bands (bands 1-9), the Australian studies have been routinely generating ~15 geoscience products, such as:

- Al-clay content: $(B_5+B_7)/B_6$; and
- Al-clay composition: B_5/B_7 masked by Al-clay content for those pixels that have a value >2.0 , i.e. comprises an absorption at $2.2 \mu\text{m}$.

Details of all of the geoscience products and the related algorithms and masking procedures are provided by Cudahy *et al.* (2008).

The main contributions to error in these geoscience products include:

- Spectral/radiometric resolution of ASTER;
- Mixing with green vegetation;
- Mixing with dry vegetation;
- Mixing with other overlapping mineral groups;
- Residual atmospheric effects; and
- Residual instrument effects, especially SWIR Crosstalk.

Unmixing of the green vegetation is achievable (Rodger and Cudahy, 2009) though the spectral resolution/sampling of ASTER makes this difficult for unmixing the effects of dry vegetation and spectrally overlapping minerals.

The above methods have been integrated into a multi-scene processing package developed by CSIRO called *C-SatMAP* that is able to work with Terabytes of data and output GIS-compatible geoscience maps in geoTIF and JPGw format.

3. ASTER GEOSCIENCE MOSAIC

Figure 1a provides an example of a large area mosaic of pre-2003 ASTER Level 1B radiance at sensor data available for the State of Western Australia. This shows the limited spatial coverage of the pre-2003 free USGS imagery, with most of the western portion of the State not collected at that time. This ASTER coverage spans different geology units (Figure 1b), including: the Archaean Blocks of the Yilgarn, Pilbara and Kimberley. These Blocks were later overlain by large sedimentary basins, including: the Canning and Eucla Basins.

Figure 2a presents the cross-calibrated reflectance mosaic which shows relatively seamless character compared to the original Level 1B data (Figure 1a). From this false colour image can be seen areas of high green vegetation content evident by red tones, especially in the north and south of the State. The relatively green-vegetation poor central area (yellow colours)

corresponds with the semi-arid parts of the State. A band ratio of B_3/B_2 (Figure 2b) is useful for mapping this green vegetation.

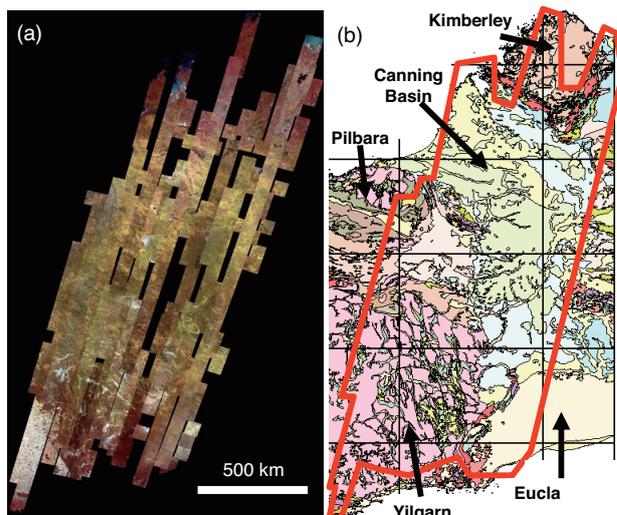


Figure 1. (a) Available pre-2003 ASTER Level 1B coverage (~450 scenes) of the entire State of Western Australia (excluding scenes without overlap) (R: band 3; B: band 2; B: band 1); and (b) geology of Western Australia overlain by the 1:1,000,000 mapsheet boundaries (black boxes) and ASTER coverage (red polygon).

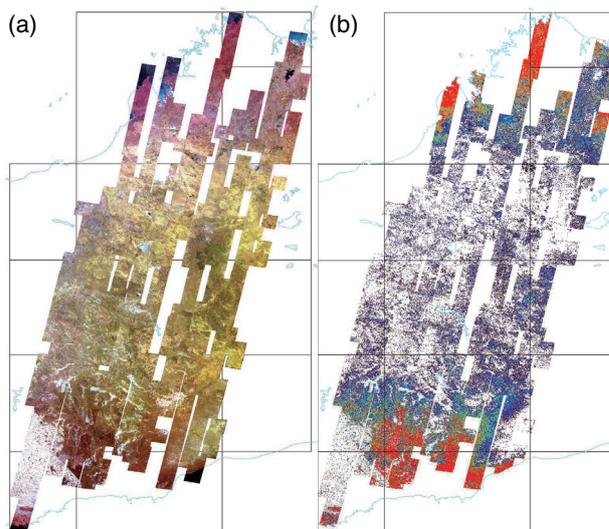


Figure 2. (a) cross-calibrated ASTER satellite imagery mosaic (R: band 3; B: band 2; B: band 1) (ASTER Level 1B imagery available pre-2003 from USGS); (b) green vegetation (B_3/B_2).

Figure 3a presents a geoscience product designed to map iron oxide information using a band ratio of B_4/B_3 (Figure 2b). The ASTER band configuration is not well suited for this task given that the available bands do not span the diagnostic iron oxide crystal field absorption centered at $0.9 \mu\text{m}$. However, Cudahy *et al.*, (2008) showed that it does provide better correlation with laboratory measurements of X-Ray Fluorescence Fe_2O_3 content compared with other ASTER band combinations, e.g. B_2/B_1 . The resultant iron oxide content mosaic shows seamless mapping across the State with high abundances associated with the green vegetation-poor parts of the Yilgarn Craton and Proterozoic basins immediately to the north, as well as the Eucla Basin.

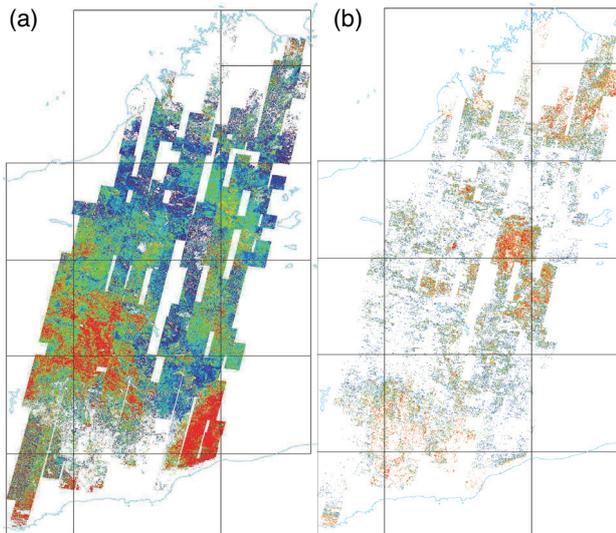


Figure 3. ASTER geoscience information mosaics of Western Australia, including: (a) iron oxide content (B_4/B_3); and (b) kaolin content (B_6/B_5).

Figure 3b presents the *advanced argillic* product based on a band ratio of B_6/B_5 . In this environment, kaolin, which has formed in the regolith, is the chief mineral detected. Although complicated by relatively dense vegetation in the south, the Yilgarn shows high kaolin abundances as expected, though it is possible that some of this character can be caused by the effect of strong leaf water absorption between 1.9 and 2.1 μm . However, this potential complication is not a key driver in other parts of the mosaic, such as the high abundances kaolin abundances in the green vegetation-poor central parts of the Canning Basin and the margins of the Kimberley Block.

These examples of seamless, large area mosaics of ASTER-derived surface composition demonstrate the opportunity of providing to users GIS-compatible higher level information products suitable for local to global scale applications using a new generation of geoscience-tuned imaging satellite systems, including a constellation of hyperspectral satellites coming on stream from around 2014.

4. FUTURE WORK

The current CSIRO methods and products can be improved through removal of thin cloud and green vegetation effects. However, the limited spectral bands of ASTER make removal of the complicating dry vegetation and other overlapping mineral absorptions difficult. Hyperspectral imagery is better suited to this task as well as more accurately measuring the content and composition of specific minerals. CSIRO's *C-HyperMAP* multi-image processing software has been developed to capture this opportunity as demonstrated by the successful large area airborne hyperspectral surveys conducted in Australia which have delivered over the web ~25 standard geoscience products to the public (<http://c3dmm.csiro.au>). Finally, if quantitative geoscience products are to be adopted as standards, then ideally these should have associated accuracy (error) and traceability documentation conforms to metadata protocols and is web-accessible. Finally, global mapping is best achieved through international coordination, e.g. GEOSS (www.earthobservations.org/geoss.shtml) and deliver into international science coordination programs, such as "OneGeology" (www.onegeology.org) and the "Global Soil

Map" (www.globalsoilmap.net) projects, for which these global geoscience products could provide valuable global mapping and monitoring information.

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4.1 Acknowledgements

This paper represents long-term collaborative work between CSIRO, Geoscience Australia (GA), Geological Survey of

Western Australia (GSWA), Geological Survey of Queensland (GSQ), New South Wales Geological Survey (NSWGS), Primary Industry and Resources of South Australia (PIRSA), Geological Survey of Japan (GSJ), Earth Remote Sensing Data Applications Centre (ERSDAC - Japan) and the ASTER science Team. Within CSIRO, this work has been supported by the Minerals Down Under Flagship, Discovery Theme and the Division's of Earth Science and Resource Engineering (CESRE) and Mathematics and Information Sciences (CMIS). Key people involved in this collaboration include: Matilda Thomas (GA); Mal Jones (GSQ); Ian Tyler (GSWA); Bill Reid (NSWGS) Alan Mauger (PIRSA); Peter Caccetta (CMIS); Yoshiki Ninomiya (GSJ) and Osamu Kashimura and Masatane Kato (ERSDAC). Funding is also acknowledged from the WA Department of Commerce through their support for the WA Centre of Excellence for 3D Mineral Mapping. To all of these people and organisations we give our sincere thanks.