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The impact of switching the NSW SLATS program from SPOT-5 to Sentinel-2 satellite imagery

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Abstract
The New South Wales Statewide Landcover and Tree Study (SLATS) used SPOT-5 imagery from 2009 until 2014. The SPOT-5 satellite was decommissioned on 31 March 2015. The Sentinel-2 satellite mission was launched on 23 June 2015, and the SLATS program has since transitioned to this newer satellite. This technical report analyses the potential impact of this change. Since there is no coincident SPOT-5 and Sentinel-2 imagery available for a direct impact assessment, a comparison of satellite characteristics along with a review of available studies is presented. Overall, the move to Sentinel-2 has been beneficial to the SLATS program. The transition has improved the overall quality and consistency of the observation imagery used by SLATS, and the theoretical advantages of Sentinel-2 over SPOT-5 should carry over to real-world operational use.

Table of Contents

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Introduction

The Science Division in the New South Wales (NSW) Department of Planning and Environment releases annual reports on woody vegetation loss. These reports are based on the NSW Statewide Landcover and Tree Study program (SLATS) [1], which tracks the location and extent of woody vegetation across the state. The SLATS program was originally developed by the Queensland Department of Environment and Science [2], and was adopted by the NSW government in 2006. The primary source of observational data used by the SLATS program is satellite imagery, which was initially from the Landsat 5 TM and Landsat 7 ETM+ satellites.

Unlike the QLD program, NSW SLATS analyses in the years 2009 to 2014 included measurements of woody vegetation change based on analysis of SPOT-5 satellite data. This provided the SLATS program with imagery that enabled interpretation of change at a 5x5 metre spatial resolution, significantly higher than the 30x30 metre resolution of Landsat imagery. The SPOT-5 satellite was decommissioned on 31 March, 2015. The Sentinel-2 satellite mission was launched on 23 June 2015, and the SLATS programs of both NSW and QLD have transitioned to this newer satellite. Sentinel-2 provides data at 10x10 metre spatial resolution, which is coarser than the SPOT-5 imagery.

For all satellite sources, probability change data from an automated process is visually interpreted and categorised by a team of expert interpreters. Before and during the NSW transition period from SPOT-5 and validation of the Sentinel-2 data, all interpretation of change was cross-checked by a second image interpreter. For the 2015 and 2016 reporting periods, the NSW SLATS change detection algorithm was run across a 2-year period using a combination of SPOT-5 images closest to 1 January 2015, and Sentinel-2 images closest to 1 January 2017. The year the change occurred was attributed by spatial analysts based on a change image created from these images, and visual interpretation of a SPOT-6 and SPOT-7 2016 image. From 2017 onwards, annual woody change analysis has been undertaken using Sentinel-2 imagery.

A key component of SLATS reporting is temporal continuity, so any changes to the program's classifications due to satellite source alone needs to be understood. This technical report analyses the potential impact of the NSW SLATS transition from SPOT-5 to Sentinel-2.

Methodology

There is no overlapping NSW SPOT-5 and Sentinel-2 imagery available for a direct data-driven comparison, and there are a wide range of clearing types and land use scenarios that need to be accounted for. To complicate matters further, this satellite transition coincided with a change in legislation regarding allowable clearing [16], invalidating a priori assumptions of timeseries continuity.

Altering satellite observation data primarily impacts two SLATS stages:

a. the automatic creation of a woody clearing index, and
b. the visual interpretation and map refinement performed by qualified map reviewers.

Three measurement-based approaches were initially considered to assess whether the satellite change introduced instrument bias:

1. simulate Sentinel-2 imagery from SPOT-5 imagery, repeat steps (a) and (b) on the simulated data, and compare the corresponding clearing indices and reviewer-refined maps,

2. use ground truth data sourced from the NSW Forestry Corporation to compare SLATS error rates across the SPOT-5 and Sentinel-2 SLATS eras, and
3. use Landsat imagery as an independent observation source across the satellite eras, repeat steps (a) and (b) using this data, and compare the timeseries trends in the peer-reviewed results with the timeseries trends in the official SLATS reporting.

The volume of manual interpretation and refinement required to achieve statistically significant spatio-temporal coverage made options (1) and (3) infeasible. Option (2) did not provide sufficient coverage of the SLATS clearing types.

So this report has taken a theoretical approach. We compared the technical specifications of the satellites with respect to SLATS usage, and searched the literature for studies that have directly compared SPOT-5 and Sentinel-2 to assess real-world performance.

Results

Satellite characteristics

The move to Sentinel-2 imagery has been beneficial to the SLATS program. The explicit mission objectives of Sentinel-2 include "enhanced continuity of multi-spectral imagery provided by the SPOT series of satellites", and observation data to support applications such as land cover maps, land-change detection maps, and geophysical variables ([3], p. 21-22; [4], p. 16; [5], p. 3; [6]). The local measurement time of Sentinel-2 has been set close to those of the SPOT-5 and Landsat missions, with the explicit goal of allowing seamless combination with the timeseries of these other satellites ([5], p. 10). Forest monitoring is a key capability of Sentinel-2, and Sentinel-2's design was guided by lessons learned from the SPOT-5 and Landsat missions. Its significantly improved revisit time (described below) was driven in part by the requirements of vegetation monitoring ([7], p. 418).

The information content, and hence the operational value, of a satellite system is a product of its interacting characteristics. Or to put it another way, there is much more to data quality than spatial resolution. For the SLATS program, the relevant satellite characteristics are the spectral, spatial, temporal, and radiometric resolutions, as well as sensor noise and viewing angle. Sentinel-2 provides an improvement over SPOT-5 for most of these features, which in turn enhances the accuracy and consistency of SLATS.

Spectral resolution, defined as the central wavelength and corresponding bandwidth of each spectral band. The spectral bands used by the Sentinel-2 process are similar to the SPOT-5 bands. SPOT-5 measures 4 spectral bands, whereas Sentinel-2 captures 13. The bands used by the SLATS process (green, red, near-infrared, and shortwave-infrared) are almost identical across the two satellites.

Spatial resolution, the area of land covered in the ground instantaneous field of view, accounting for the point spread function, as encoded in each 2D 'pixel'. Each of the spectral bands used in the SLATS program are captured at an identical spatial resolution by both satellites: green (10m), red (10m), near-infrared (10m) and short wave infrared (20m). An advantage of SPOT-5 over Sentinel-2 is that SPOT-5 provides two high resolution (5m) sensors that combine to offer a single panchromatic band at approximately 3.5m resolution in practice.[1] This higher resolution panchromatic band has been used by the SLATS team to improve the multispectral data to a nominal 5m resolution, which assists visual interpretation. Pan-sharpening can result in spectral distortions and is not equivalent to capturing data using a 5m sensor.

Temporal resolution, or revisit time to the same position, is the length of time between consecutive scans of the same area. Cloud cover and cloud shadow are a key limitation in satellite-based remote sensing, as they reduce the amount of useable information in the imagery. Shorter revisit times mean more available imagery, which increases the probability of obtaining cloud-free data. The single-satellite SPOT-5 revisit time was nominally 26 days, which resulted in approximately 2% of pixels being unuseable due to cloud. The dual-satellite Sentinel-2 mission has a revisit time of 5 days. In the first year that Sentinel-2 was the only satellite source used (2018), 0.42% of pixels were unuseable due to cloud. The extra imagery also adds to the set of ancillary data available to the SLATS review team. Sentinel-2 is a routine-capture mission, whereas SPOT-5 was not. The SPOT-5 service provided NSW SLATS with bespoke single seasonal composites, which compensated for satellite revisit time by altering the sensor view angle (described below), at the cost of data quality.

Radiometric resolution, which is how many bits are used to digitally encode the physical light intensity measurements. More bits mean greater data fidelity. SPOT-5 encodes data using 8 bits per value [8], allowing for a range of 256 storable values, whereas Sentinel-2 encodes data using 12 bits per value (4096 storable values). Although SPOT-5 has the ability to use multiple gain states to optimize use of its 8 available bits, the 12-bit solution of Sentinel-2 is considered a superior solution in the general case. Note this resolution is distinct from how these values are shared; the Sentinel-2 measurements are subsequently converted to reflectances and stored and stored as 16 bit integers in the user-facing product.

Sensor noise, generally measured using the signal-to-noise ratio (SNR). Post-launch analysis has shown that Sentinel-2 SNR's for the SLATS green, red, near infrared and short wave infrared bands are 249, 230, 221 and 158 respectively ([9], p. 51). These are an improvement over SPOT-5's green, red and near-infrared SNR's of 152, 169 and 190 respectively. However, SPOT-5's short wave infrared band is better in this regard at 272 ([10], p. 8).

Sensor viewing angle. The SPOT-5 satellite included the ability to angle the sensor on-demand, which was used to mitigate cloud cover issues. The Sentinel-2 satellites use a fixed angle. Anecdotally, the SLATS team found SPOT-5 rasters with larger satellite view angles (off-vertical) difficult to interpret, and have found the consistency of the Sentinel-2 tiles easier to review.

Direct comparisons

The commercial nature of the SPOT-5 mission, and the lack of data overlap with Sentinel-2, means that few studies have directly compared these particular satellites. A review of the available studies indicates that the theoretical advantages of Sentinel-2 over SPOT-5 should carry over to real-world operational use.

An analysis of the ability to detect sub-pixel features in SPOT-5, Sentinel-2 and Landsat used coincident satellite data in Belgium and the USA [11]. This study considered soil, water, grassland/crops and woody patches as classes of interest, and compared imagery with high resolution orthophotos and field data. They found that Sentinel-2 generally outperformed SPOT-5 in mixed pixels, that spectral discrimination power was better with Sentinel-2 than either SPOT-5 or Landsat-8, and that the signal-to-noise ratio of Sentinel-2 was better than for SPOT-5. They found that "By combining high spatial and spectral resolutions, the overall performance of Sentinel-2 for small landscape feature detection placed it above SPOT-5 and Landsat-8". However, this study did

[1] Personal communication, SPOT Australia team.

not pan-sharpen the SPOT-5 imagery as the NSW SLATS team does, so these results are not directly applicable to the SLATS case.

A case study that mapped mangrove species compared SPOT-5 and Sentinel-2, and found that the two satellites had very similar accuracies (75% for SPOT-5, and 78% for Sentinel-2) [12]. The researchers found an overall improvement using Sentinel-2 over SPOT-5, and speculated that it might be due to Sentinel-2's higher radiometric resolution. Although these results show encouraging similarity between the satellites for vegetation mapping, they cannot be broadly applied to the range of vegetation types of interest to SLATS.

Other comparisons have dealt with the lack of coincident imagery by simulating SPOT-5 and Sentinel-2 data from hyperspectral field measurements. Simulated Sentinel-2 has been found to offer equivalent or better classification performance compared to simulated SPOT-5 for land-cover mapping [13], archeology [14], and irrigation scheduling [15]. However, such results need to be considered as indicative of theoretical performance, but incomplete, as real-world issues such as signal-to-noise ratio and cloud cover are not captured.

Conclusion

While there is no coincident SPOT-5 and Sentinel-2 imagery available for an impact assessment, both theoretical analysis and external studies indicate that the use of Sentinel-2 has improved the quality and consistency of the observation imagery used by SLATS.

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