MULTI-SCALE ANALYSIS AND VALIDATION OF THE ENVISAT MERIS TERRESTRIAL CHLOROPHYLL INDEX (MTCI) IN WOODLAND

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ABSTRACT

Satellite remote sensing can be used to estimate and monitor the chlorophyll content of vegetation canopies which are a key and dynamic component of global terrestrial ecosystems. The red-edge algorithm can be used to estimate chlorophyll content from remotely sensed data but is unsuitable for use with most satellite sensor imagery. To overcome this problem, the new Envisat MERIS Terrestrial Chlorophyll index (MTCI) has been developed. It is the only operational satellite chlorophyll index and MTCI data are available as a Level 2 product from the European Space Agency. However, there is a need to 'validate' the MTCI over a wide range of environmental conditions. This paper reports on research that attempts to validate the MTCI using Compact Airborne Spectrographic Imager (CASI) imagery and ground data of chlorophyll content. The study site was predominantly woodland in the south of England (New Forest National Park) and had a wide range of chlorophyll contents. A transfer function derived from CASI data was used to produce a reference map of chlorophyll content, when aggregated it was compared to MERIS MTCI data and used to derive the MTCI – chlorophyll content relationship (R^2 = 0.56).

1. INTRODUCTION

Chlorophylls (chlorophyll a and chlorophyll b) play a key role in plant photosynthesis by absorbing solar radiation and converting it into chemical energy. Therefore, the amount of chlorophyll within a vegetation canopy is related positively to both the productivity and the health of that vegetation [1, 2, 3]. The amount of chlorophyll in a vegetation canopy can be estimated by sampling destructively or by using remotely sensed data. Destructive sampling is labour-intensive, time consuming and therefore, limited to local scale applications. Remotely sensed data in the 'red edge' part of the vegetation reflectance spectrum, obtained from ground to satellite sensors, are less labour intensive, non-destructive and offer the possibility of repetitive coverage. Resultant estimates of chlorophyll content are now used widely to help understand and manage the vegetated portion of our environment.

Over the past few decades the remote sensing of chlorophyll content has evolved from the development of empirical relationships between chlorophyll content and spectral reflectance in individual wavebands to the production of an operational product; the MERIS (Medium Resolution Imaging Spectrometer) Terrestrial Chlorophyll Index (MTCI) [4]. Unlike traditional 'red edge' based estimators of chlorophyll content which saturate at high chlorophyll contents the MTCI has a strong linear relationship with canopy chlorophyll content at such high values. The MTCI has been used in applications of varying scope (e.g.,[5,6,7,8,9,10]) and the ready availability of MTCI data through the European Space Agency (ESA) should lead to its greater adoption.
MTCI has been validated for different species using data from the laboratory [11] and field [12]. Validation at the MERIS spatial resolution of 300m has provided a quantitative relationship between MTCI and ground chlorophyll content for a range of agricultural crops which supports these findings [13]. However, to understand fully the performance of MTCI and its utility in the provision of scientifically-robust measures of canopy chlorophyll content there is a need to validate the index across a range of vegetative types and environmental conditions.

2. STUDY SITE

The study site is situated in the New Forest National Park in southern England (0º 56' N, 01º 5' W). It covers approximately 9 km^2 of both ancient semi-natural woodlands and managed coniferous plantations and adjacent heathland (figure 1). The deciduous woodlands were dominated by White Birch (*Betula pubescens*), Oak (*Quercus robur*) and Beech (*Fagus sylvatica*) and the coniferous woodlands were dominated by Scots Pine (*Pinus sylvestris*). The range of canopy structures and vegetation types provided a broad range and variability in chlorophyll content. The site was essentially flat; minimising terrain effects in remotely sensed data.

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Figure 1: MTCI validation study site in southern England.

3. REMOTELY SENSED DATA COLLECTION

Two set of remotely sensed data were used: Compact Airborne Spectrographic Imager (CASI) and MERIS. CASI data in the MERIS spectral bands were acquired on 20th July 2007 at a nominal spatial resolution of 2 meters. The overflight occurred around 13.00hrs and the study site was almost cloud free. Seven scan lines recorded in a north- south direction covered the study site. A cloud-free MERIS L2 image for 4th August 2006 at full spatial resolution (300m) was selected as it was the least-cloud contaminated image near to the time of field sampling.

4. GROUND DATA COLLECTION

Ground data collection was completed within 10 days of the satellite and aircraft overpasses. The Sampling protocol for ground data collection was driven by the need to i) represent the spatial variability in canopy chlorophyll content across the spatial resolution of a MERIS pixel and ii) use ground data and CASI imagery, with a nominal spatial resolution of 2 meters, to produce a chlorophyll content map of the site. The study site was divided into 1 km by 1 km grids and within each grid 3 to 5 sampling plots (approximately 20 m X 20 m) were identified. Within in each sampling plot canopy Leaf Area Index (LAI) was measured using LAI-2000 Plant canopy analyser and chlorophyll concentration was measured using a Minolta-SPAD chlorophyll meter. For each sample site 20 LAI measurements and SPAD measurements (each SPAD measurement was an average of 10 readings to reduce variability) were taken. Where practicable, each LAI measurement was a combination of a single above canopy measurement with at least four below canopy measurements, although this varied with canopy structure. For coniferous trees destructive sampling was used to estimate chlorophyll concentration. Leaf samples were collected for each sampling plot and stored in DMF (N, N-dimethylformamide) in dark cool conditions for later analysis. For deciduous trees a second set of leaf samples were collected for SPAD calibration.

The leaf samples stored in DMF were transferred to the laboratory for chlorophyll extraction. Each sample was diluted (1:3 with DMF) to produce a chlorophyll concentration that fell within the sensitive and linear range of the spectrophotometer. The mean of three replicate dilutions of each sample was used to represent the amount of chlorophyll a and chlorophyll b (mg m^{-2}) using the specific absorption coefficients [14]. Estimated chlorophyll concentration for each vegetation type was plotted against SPAD measurements made in the field and a second-order polynomial was used to describe this relationship. This allowed the prediction of chlorophyll concentration to be made from SPAD measurement taken across the study site.

5. DATA PROCESSING

Data processing was undertaken in three steps: (i) CASI data processing, (ii) chlorophyll map production from CASI data and (iii) derivation of the relationship between MTCI and chlorophyll content at MERIS spatial resolution (figure 2).

5.1 CASI data processing

CASI data provided by the Natural Environment Research Council (NERC) Airborne Remote Sensing Facility had been partially radiometricly and geometrically corrected prior to receipt. These data were fully geo-corrected using AZGCOR software [15] and a high spatial resolution Digital Elevation Model (DEM). Further pre-processing was undertaken, using the FLASH tool in ENVI software to reduce the influence of illumination and the atmosphere on sensor recorded radiance. The resulting surface reflectances in bands 8, 9 and 10 were used to derive MTCI from CASI data at 2 m spatial resolution.

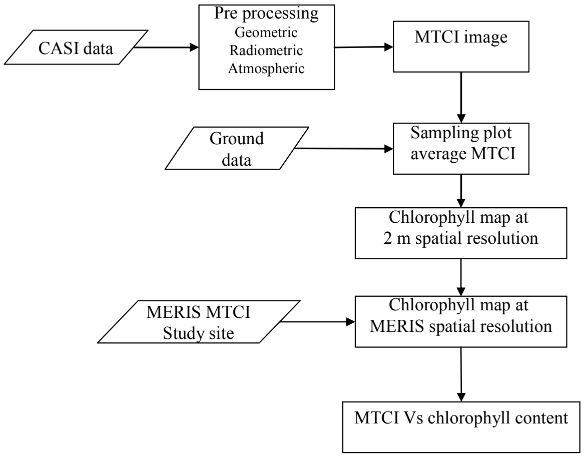

Figure 2. Methodology for MTCI validation.

5.2 Chlorophyll map production using CASI data

LAI and chlorophyll concentration data obtained for each sampling plot were averaged to obtain a single value for each plot. Chlorophyll content was estimated for each sampling plot by multiplying the average LAI by the average chlorophyll concentration for that sampling plot. The Global Positioning System (GPS) locations of these sampling plots were used to identify CASI 100 pixels that cover a sampling plot. Average MTCI for these CASI pixels were then related to chlorophyll content (figure 3). The coefficient of determination (R^2) of 0.72 was statistically significant at the 95% confidence level. A chlorophyll content map (figure 4) of the study site at 2 m spatial resolution was derived using the equation below

Chlorophyll content (mg) = 568.68*MTCI – 1382.1

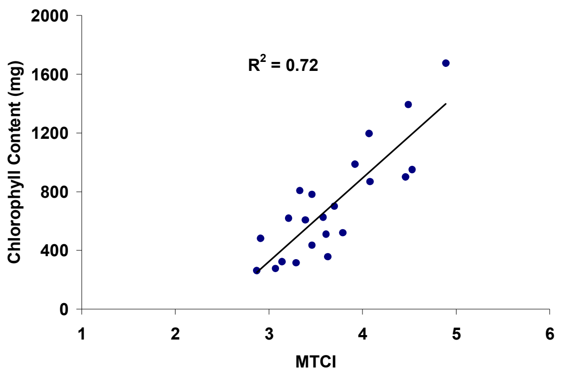

Figure 3: Relationship between MTCI derived from CASI data and chlorophyll content derived from ground data for all sampling plots in the study site.

5.3 Relationship between MTCI and chlorophyll content

CASI data were re-projected to match the projection of the MERIS data and pixels in the derived chlorophyll map were aggregated to map chlorophyll content at the spatial resolution of MERIS data. The area of interest derived from CASI data was overlain on MERIS L2 data and MTCI for pixels within the area of interest was extracted. In the aggregated chlorophyll map, pixels with cloud cover and non-vegetated areas were identified and removed from further analysis. The relationship between per-pixel MTCI and chlorophyll content was then derived.

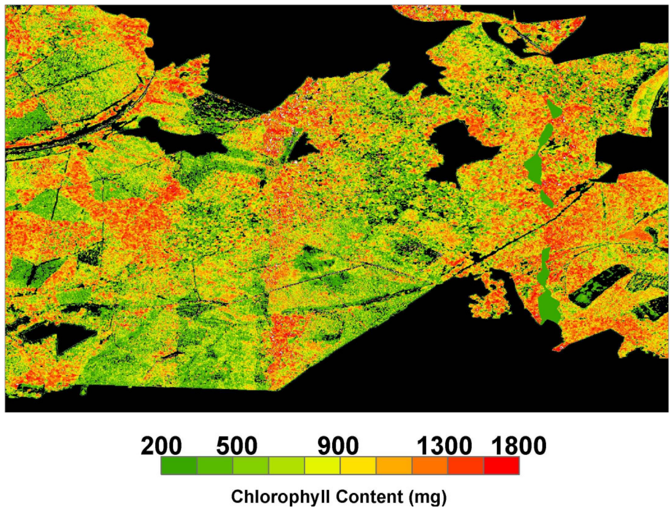

Figure 4. Chlorophyll content map of the study area derived from CASI data and ground data of chlorophyll content. Areas in black represent missing data or non-vegetated areas.

6. RESULTS AND DISCUSSION

A major concern with MERIS full resolution data is geolocation accuracy as studies have suggested an accuracy of ± 150m [16]. However, aggregated CASI data had a more accurate geolocation than this and a resampled CASI pixel coved more than 75% of a MERIS pixel. The relationship between MTCI and chlorophyll content was strong with a coefficient of determination (R^2) of 0.56 the 95% confidence level (Figure 5).

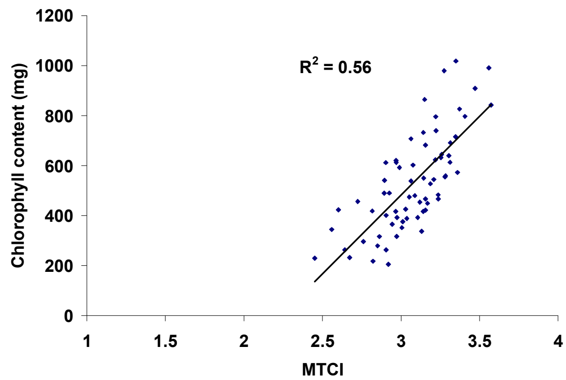

Figure 5. Relationship between MTCI and chlorophyll content for the study site at MERIS spatial resolution.

However, this relationship was not as strong as reported in previous studies [11,12,13]; four possible reasons for this are:

- The chlorophyll map was derived using one MTCI - chlorophyll content relationship for the entire study area without considering the effect of land cover type. If the relationship between MTCI and chlorophyll content varies with land cover type then this will have decreased the accuracy of the chlorophyll map derived form CASI data.
- Some coniferous trees had a high proportion of non-green biomass and this would have resulted in over-estimation of LAI when using the Sunscan. Therefore, in some areas the chlorophyll content would also have been over-estimated.
- The geo-location accuracy of MERIS pixels ment that it was not possible to obtain a 100% match between the aggregated (and CASI-derived) chlorophyll content map and the MERIS pixels. Therefore, the MTCI estimated from MERIS data did not represent exactly the ground over which chlorophyll content was estimated.
- Finally, the point-spread-function for MERIS was not considered in the aggregation of CASI data. This might have introduced some further uncertainty in the MTCI - chlorophyll content relationship.

7. CONCLUSION

MTCI was validated with ground chlorophyll content for a woodland area in Southern England. Ground chlorophyll concentration and LAI data were obtained for 31 sampling plots (20 m x 20 m) and these, in conjunction with CASI data were used to derive a high spatial resolution chlorophyll content map. This was aggregated to the spatial resolution of MERIS and then related to MTCI. There was a positive relationship between chlorophyll content and MTCI with coefficient of determination (R2) 0.56. Although results were promising and align with earlier studies the effect of land cover type was not considered, LAI was over-estimated in some areas and these alone introduced a large degree of variability into the MTCI – chlorophyll content relationship. Future studies will account for the effect of land cover and use LiDAR data for a more accurate estimation of LAI.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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