ESTIMATING TERRESTRIAL GROSS PRIMARY PRODUCTIVITY WITH THE ENVISAT MEDIUM RESOLUTION IMAGING SPECTROMETER (MERIS) TERRESTRIAL CHLOROPHYLL INDEX (MTCI)

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1. INTRODUCTION

Gross primary productivity (GPP) is a measure of photosynthetic activity and an important variable in the global carbon cycle, as it defines the rate at which an ecosystem will accumulate biomass. Estimates of GPP at the regional to global scale, indicate ecosystem response to elevated atmospheric carbon dioxide (CO_2) levels and temperatures. Also, GPP is a useful measure of ecosystem health and is relevant to understanding the impact of human activity on ecosystems (Wu *et al*., 2009). Eddy covariance measurements from flux towers, have been used across a wide range of terrestrial ecosystems to provide estimates of GPP and flux tower networks have now been established across the globe (e.g., FLUXNET). However, this method of deriving GPP is (i) based on CO_2 flux estimates over a sample area that vary in size and shape (according to the physical height of the tower, canopy physical characteristics and wind velocity), (ii) has an inherent problem in partitioning autotrophic respiration and heterotrophic respiration and (iii) requires flux towers that are expensive to establish and maintain (Wylie *et al*., 2003). Remote sensing allows systematic and consistent observations of vegetated ecosystems, overcomes the problems of ‘point measured’ GPP and permits the monitoring of ecosystem productivity across large areas of the Earth's land surface.

Estimating terrestrial vegetation GPP using remote sensing is a major challenge in global change research. Satellite sensors measuring in visible and near infrared wavelengths have been used to provide quantitative estimates of GPP. However, many of the existing approaches assume cloud free skies, the availability of land cover data and knowledge of the radiation use efficiency of vegetation under investigation. Therefore, it is important to explore new remote sensing methods for the estimation of GPP that do not have such limiting assumptions (Wu *et al*., 2009).

According to the logic of Monteith (1965), GPP in unstressed vegetation is related linearly to the amount of absorbed photosynthetic active radiation (APAR) and the ability of the vegetation to utilise light in photosynthesis (i.e., Light Use Efficiency (LUE)). In this paper it is hypothesized that foliar chlorophyll content is a surrogate for LUE, as plant physiological status and vegetation productivity are related closely to chlorophyll content (Sellers *et al*., 1992). For example, laboratory studies have shown that variation in the canopy chlorophyll content of miniature Douglas fir canopies were significantly correlated with photosynthetic rate (Yoder and Waring, 1994) and in the field Waring *et al*. (1995) found a strong correlation between canopy leaf chlorophyll concentration (which is related to cholorophyll content) and maximum LUE in deciduous forest canopies. Given that vegetation responds to changes in the availability of nutrients and other environmental conditions through its photosynthetic capacity, vegetation productivity will be related positively to foliar chlorophyll content. Similarly, the degree of vegetation stress will be related negatively to foliar chlorophyll content and subsequently photosynthetic rates and productivity.

Using field spectroradiometers, Gitelson *et al*. (2006) demonstrated that remote sensing techniques used to estimate canopy chlorophyll content can also be used to drive models for estimating GPP in soya bean and maize by employing the rational that LUE is proportional to GPP/PAR. A similar approach was adopted by Wu *et al*. (2009), when they used various vegetation indices to estimate chlorophyll content, and therefore GPP, in wheat. To date, the above approaches have not been applied using satellite sensor data or to other vegetation types. The European Space Agency's environment monitoring Envisat platform carries the Medium Resolution Imaging Spectrometer (MERIS). The MERIS Terrestrial Chlorophyll Index (MTCI) was developed by Dash and Curran (2004) in order to improve the accuracy of estimating chlorophyll content from space, overcoming the limitations of using other measures (such as the red edge position (REP)) and as such should provide an accurate proxy for LUE and be useful for estimating GPP across ecosystems from space.

2. RESEARCH AIM

The research aims were to evaluate the use of MTCI within a number of chlorophyll based models for the estimation of GPP across a range of vegetation types, including temperate deciduous forest, coniferous boreal forest, mixed temperate forest, grass rangelands and agricultural lands. In total, 56 study sites across the globe were selected; sites consisted of one dominant vegetation type and were required to be at least 3x3 km to allow for potential geolocation errors in imagery and reduce any errors associated with mixed pixels. Careful consideration was given to minimise the effects of topography, therefore only small-scale topographic variations were permitted in selecting the sites.

3. DATA

MERIS 1km reduced resolution 8-day composite MTCI data were downloaded from the UK's NERC Earth Observation Data Centre (NEODC). Level 4, gap filled data on estimated GPP and incoming PAR (μmol photons m-2 s-1) were obtained from FLUXNET (http://www.fluxnet.ornl.gov/fluxnet/index.cfm). Datasets from MODIS; MOD17 GPP and MOD15 *f*PAR, were downloaded from the NASA's Warehouse Inventory Search Tool (WIST). The study was from January 2004 to December 2005 and all data were aggregated in to 8-day periods that corresponded to the MTCI dataset.

LUE was derived to determine the relationship between remotely sensed and flux tower estimates of GPP and to indicate the role which factors other than PAR and foliar chlorophyll (such as metrological variables) have in defining ecosystem GPP. LUE was estimated from flux tower PAR, aggregated to mean daily PAR to match the 8–day compositing of compositing of MOD17, MTCI and MOD15 *f*PAR .

4. ANALYSES AND RESULTS

GPP was estimated for each of the 56 study sites using three MTCI-driven models. The first model was that of Gitelson *et al.* (2006), in which GPP is estimated through canopy chlorophyll content and incident radiation in the 400 – 700nm region. A strong relationship between GPP and MTCI was evident at all sites and MTCI proved a robust estimator for GPP in most cover types. For example, the relationship between MTCI and GPP was particularly strong for the deciduous forest site, where MTCI accounted for 89-84% of the variation in GPP (2004 and 2005 respectively). The second model used combined MTCI and PAR to estimate GPP and was of limited success, with weaker correlation coefficients obtained at all sites. The third model used MTCI combined with APAR (PAR**f*PAR) to derive a regression model that accounted for 82% of the variation in GPP. The scatter of points from the regression line were less than for the MTCI*PAR model, suggesting that MTCI*APAR could account for small variations in GPP that may, in turn, be attributed to environmental stress. The results from the three models suggested that chlorophyll content, as estimated using MTCI, can be used to derive GPP in contrasting cover types.

The MODIS sensor has provided near real-time estimates of gross primary production (GPP) since March 2000 (Heinsch *et al.,* 2006). Comparison of the performance of the MTCI against the MOD17 GPP product indicated that overall, the correlation between flux tower and MOD17 GPP estimates were not as strong as when the first two MTCI-driven models (above) were used to derive GPP. Also, the MOD17 requires additional meteorological data and a land cover LUT to define site specific LUE.

The photosynthetic efficiency (LUE) of the contrasting cover types shows temporal profiles that correspond with canopy phenological development (as inferred through the MTCI temporal profile) and reach a maximum during early summer and decreasing in the winter. The temporal trends observed in LUE were matched by APAR and MTCI, showing that chlorophyll content (inferred though MTCI) increased in line with APAR (PAR**f*PAR). Similar trends were observed for all sites for both years of data.

5. CONCLUSIONS

The findings of this paper demonstrated the potential of estimating GPP with MTCI data across a range of vegetation types; MTCI is sensitive to a range of chlorophyll contents. The simple model, GPP = MTCI*APAR was based on the hypothesis that chlorophyll content is a good proxy for LUE. The paper will highlight areas of further work and further the attributes of the model as well as ascertain the physical basis for the approach.

6. REFERENCES

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