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Modelling spatio-temporal variations in leaf chlorophyll content for broadleaf and needle forest canopies

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Foliar chlorophyll content in forested ecosystems plays a fundamental role in plant photosynthesis, determines plant productivity and can indicate vegetation stress and disturbance. Obtaining accurate measurements of leaf chlorophyll content across a range of spatial and temporal scales is crucial for monitoring vegetation productivity and providing inputs to photosynthesis and carbon cycle models. However, leaf chlorophyll retrieval is complicated as canopy reflectance in the visible and near-infrared wavelengths is affected not only by leaf pigment concentration but also by leaf area index (LAI), canopy architecture, illumination and viewing geometry and understory vegetation. Consequently, empirical indices, often developed at leaf-level, are species, site and time specific. In order to investigate the potential of monitoring chlorophyll dynamics over a growing season at the canopy scale, a process modeling approach is needed to account for the variation of other variables affecting canopy reflectance. Canopy radiative transfer models use physical laws to describe the interaction of solar radiation inside the canopy between scattering elements, which could provide a more accurate estimate of chlorophyll content over multiple vegetation species, time-frames and across broader spatial extents.

This study used a coupled canopy (4Scale) and leaf (PROSPECT) model approach to investigate the ability of radiative transfer models to estimate foliar chemistry for multiple vegetation types and species (broadleaf and needle) from optical remote sensing data. Canopy reflectance data was acquired from the Medium Resolution Imaging Spectrometer (MERIS), from 390–1040 nm in 15 wavebands at a spatial resolution of 1200 m, and inverted using a look up table (LUT) approach. Twenty sites were selected in Ontario, Canada representing different dominant vegetation species (Picea mariana, Pinus banksiana and Acer saccharum), and a variety of canopy closures and structures. These sites were sampled over multiple time-frames, where a number of ground measurements were conducted. Ground data include LAI, measured using Tracing Radiation and Architecture of Canopies (TRAC), leaf reflectance spectra from ASD Spectroradiometer (400-2500 nm) and leaf samples were taken for laboratory chlorophyll determination. Leaf chlorophyll content ranged from 19-62 μg/cm^2 and LAI from 1.15 to 8.4, providing a large dynamic range to test the approach. The model results show that MERIS derived chlorophyll content demonstrated a good relationship with measured leaf chlorophyll content, particularly from denser canopies at higher LAI values.

This research provides an empirical and theoretical basis for the future retrieval of spatially distributed assessments of leaf chlorophyll content over different spatial and temporal scales. The ability of this technique to characterise variations in chlorophyll content across different vegetation species and canopy structures is important for making the method operational across coarser spatial extents, and for its inclusion in photosynthesis and carbon cycle models.