Retrieval of Biophysical/Structural Canopy Properties: An evolving synthesis of imaging spectrometry data and models

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Imaging spectrometry data is increasingly being put to use in managed ecosystems as in agriculture and forestry as well as in natural ecosystems by exploiting and evaluating linked leaf-canopy models to retrieve quantitative estimates of leaf biochemical contents of total chlorophyll and water as well as canopy parameters such as crown or canopy leaf area index, fractional vegetative cover or soil moisture content and residue content. Retrieval accuracies for estimated biophysical/structural canopy variables as determined by comparison with intensive field data collection are typically 10% of nominal values under normal field conditions and therefore are making imaging spectrometry an effective tool being evaluated for a range of specific applications. This progress toward provision of a vegetative state mapping tool can be primarily attributed to (i) the wide availability of well-calibrated airborne imaging spectrometers with software to deliver good atmospheric correction and virtual turn-key generation of above-canopy reflectance imagery, (ii) wide availability of robust and understood leaf and canopy models for a range of canopy types that can be coupled and used to infer canopy biophysical/structural variables, and (iii) airborne, satellite and field data collection protocols and strategies that have allowed the assessment of the variable retrieval accuracy as well the appropriateness/limitations of models to be evaluated.

This paper provides a synthesis of research results recently reported using such approaches and strategies. Examples of applications of imaging spectrometry surveyed in this paper include: (i) mapping the spatial heterogeneity in cereal crops and tracking seasonal change of canopy green leaf area index, green biomass, absorbed photosynthetically active radiation, and vegetative cover, and leaf pigment content, (ii) tracking seasonal change and intersite differences in needle pigment content in coniferous trees crowns in the boreal forest region as a measure of stand condition and species, (iii) deriving leaf pigment content in structured canopies as in vineyards and olive groves and linking this to local growth conditions, (iv) deriving fractions of green and senescent vegetation, as well as beneath canopy soil moisture content for agriculture crop mapping, (v) mapping mid-day gross primary production distribution in cereal crops and tracking its seasonal variation, (vi) estimation of fire risk severity.

These results have provided quantitative estimates of canopy biochemical/structural properties but have employed a range of approaches: (i) the use of look-up tables from above-canopy bidirectional reflectance estimates from forward modelling using a range of input variables, (ii) the generation of algorithms using optimized spectral indices based on forward modelling results, (iii) pixel- by-pixel inversions of leaf/canopy models and matching observed spectral signatures, (iv) the use of forward modelling using leaf/canopy models to train neural networks that can then be used for property retrievals. The success achieved in canopy or leaf property retrievals has been found to be often critically dependent on spatial resolution of the hyperspectral imagery due to the spatial heterogeneity of most vegetated targets. Assessment studies of the applicability of specific leaf-canopy models has therefore required careful attention to: (i)study sites which encompass a sufficiently wide variation in the properties to be retrieved to allow for an unambiguous estimate of retrieval accuracies, (ii) detailed laboratory measurements at the leaf level to determine optical properties and biochemical constituents, (iii) image data at selected target areas with sufficient resolution to enable vegetation crown and background areas to be sampled and the canopy model assumptions to be assessed. Such strategies have permitted leaf/canopy property retrievals in cereal crops from emergence through maturity, in closed deciduous forest canopies, in open conifer stands, and in open canopies as in olive groves and vineyards.

These successes demonstrate that for a range of canopy conditions the model used for inference in conjunction with remote sensing data captures and detects the most important physical processes involved allowing the dominant biophysical/structural properties to be estimated. However, this progress also provides insights into the next challenges for continuing improvement of leaf/canopy models and a potential expansion of the range of applications.