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Comparison of vertical resolved leaf area index measurements in an open canopy savannah-type forest

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Leaf area index (LAI) is a very important vegetation parameter in soil-vegetation-atmosphere exchange modeling. To represent the structure of ecosystems in vertically distributed modeling, vertical resolved LAI distributions as well as vertically and angular gap fraction (P_{gap}) distributions are needed, but rarely available. Additionally, former studies neglect woody plant components when using light interception or digital photography based methods for LAI or P_{gap} observations. This can lead to significantly biased results, particularly in semi-arid savannah-type ecosystems with low LAI values.

The objective of this study is to compare three non-destructive LAI measurement techniques in a sparse savannah-type cork oak canopy in central Portugal in order to derive vertically resolved LAI as well as vertically and angular resolved P_{gap}.

Since established canopy analyzers, such as the LAI-2000, rely on diffuse light conditions, which are rarely realized in semi-arid regions, we also employed fast, digital cover photography (DCP) working independently from diffuse light conditions. We used vertical and angular distributed DCP and applied object-based image analysis techniques to exclude woody plant components from P_{gap} estimation and LAI determination. We compared the results with vertically distributed LAI-2000 measurements, and additionally with vertical estimates based on easily measurable forest canopy parameters. We employed bootstrap resampling methods to determine the accuracy of all measurements depending on sample size.

Leaf inclination measurements indicate planophile leaf orientation. Thus LAI was calculated with P_{gap} and the leaf inclination information. This led to a spatial averaged LAI of 0.52 +- 0.06 for DCP while LAI-2000 measurements resulted in 0.67 +- 0.07. Uncertainty bounds of LAI converge much faster with increasing sample size for the DCP than for the LAI-2000. This allows a more efficient sampling design, which is of great importance in heterogeneous canopies. Both methods show comparable vertical LAI and P_{gap} distributions. Furthermore, the vertical distribution of LAI derived from the simple, canopy parameter based model matches very well with the directly measured distribution. However, P_{gap} of digital cover photographs shows a stronger dependence on zenith angle compared to LAI-2000. The latter follows more theoretical expectations because it uses a smaller viewing angle. Future analyses of DCP need, therefore, to determine optimal aperture for simultaneous estimate of LAI and angular-dependent P_{gap}.

In summary, we developed a fast method for measuring vertical LAI and vertical and angular dependent P_{gap} profiles within forest canopies using digital cover photography for the purpose of vertical resolved photosynthesis or radiative transfer modeling, in particular suitable for deployment in sparse, savannah-type ecosystems. A simple stand parameter based model is able to approximate the vertical profile of LAI if vertically distributed measurements are not feasible. However, the vertical profile of P_{gap} measured with digital cover photography needs further investigation.