MONITORING CANOPY STRUCTURE ACROSS MULTIPLE SCALES FROM LEAVES TO CANOPIES AND STANDS

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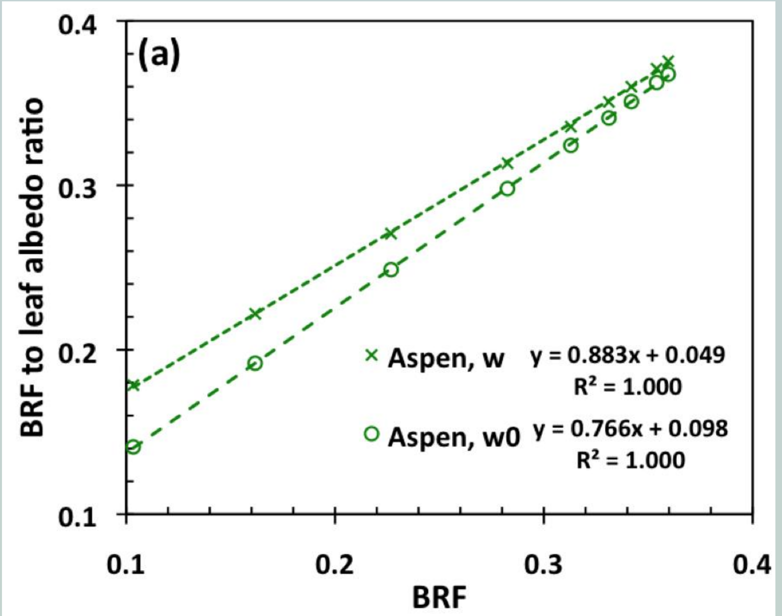
Abstract. Stand and landscape scale alternation of the mosaic composition of forests are ecological variables indicative of climate change. Changes in species composition of the northern forests have the potential to influence regional climate via biophysical mechanisms. The leaf level physiological processes are among the climate variables that most directly control the dynamics of terrestrial ecosystem processes. Leaf optical properties are the source of information about leaf level physiological processes. The objective of this research is to document the feasibility of deriving forest structural parameters – forest type composition, forest cover, tree density and crown shape – and leaf optical properties from multi-angle and hyperspectral data and demonstrate their ability to capture changes in species composition and leaf level physiological processes in the northern forests. The methodology is based on the idea of retrieving canopy spectral invariants – the recollision and escape probabilities – from optical remote sensing data. The spectral invariants are functions of the 3D canopy structure such as tree spatial distribution, crown shape and size, within-crown foliage arrangement and ground cover and thus have the potential to separate forest types based on stand geometry. These variables are critical to account for 3D canopy structure effects in the relationships between surface reflectance data and leaf biochemical constituents. This poster summarizes our results.

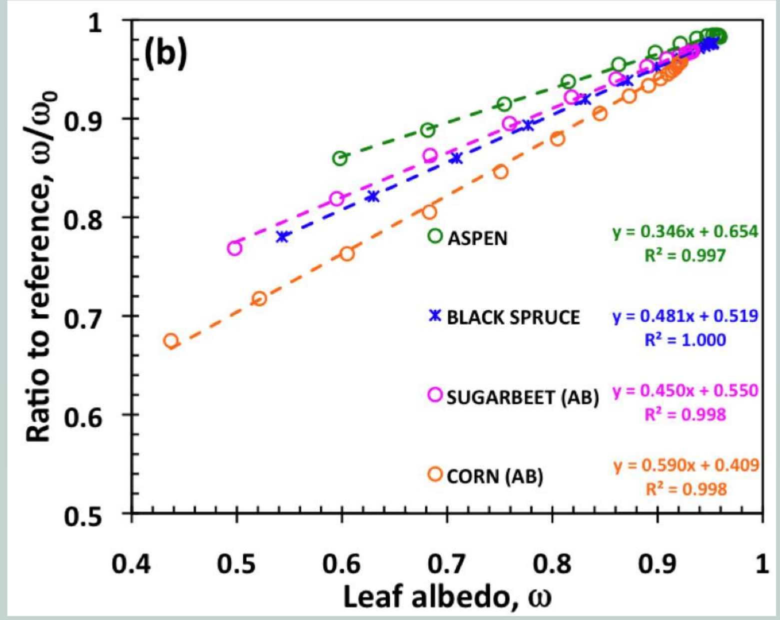
MATHEMATICAL FORMULATION

- ❑ Leaf level physiological processes are among the climate variables that most directly control the dynamics of terrestrial ecosystem processes
- ❑ The leaf reflectance spectrum conveys information about leaf-interior constituents
- ❑ Radiation scattered by leaves is transformed by canopy structure
- ❑ Stand and landscape alternations of forest structure are ecological variables indicative of climate change. Changes in species composition have the potential to influence regional climate via biophysical mechanisms

PROBLEM: separate the structural and radiometric components of the measured surface reflectance spectrum. The former is a function of the canopy geometrical properties such as tree spatial distribution, crown shape and size, within-crown foliage arrangement while the later is a function of leaf biochemistry.

710-790 NM SPECTRAL INTERVAL

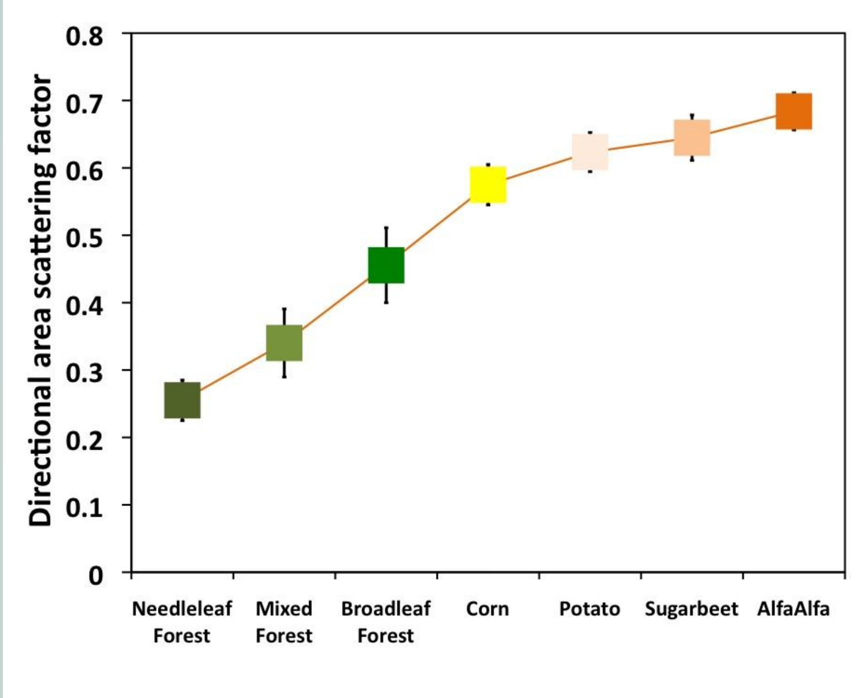




Panel a: BRF_λ to leaf albedo ratio, $BRF_\lambda/\omega_\lambda$, versus BRF_λ linear relationship in the spectral interval [710, 790 nm] for a 90m by 90 m dense patch of aspen at Bartlett Experimental Forest, NH. The BRF spectrum is derived from AVIRIS-Classic data. The first relationship (legend "Aspen, w") is obtained using albedo of an aspen leaf. A different leaf albedo, called a reference spectrum, calculated with the PROSPECT model is used in the second relationship (legend "Aspen, w0"). One can see that the use of the reference leaf albedo in place of the true aspen leaf spectrum does not violate the linear relationship, although it impacts the slope (p) and intercept (R). In both cases however the ratio $R/(1-p)$, which provides an estimate of the DASF is the same, i.e., DASF=0.049/(1–0.883)=0.098/(1–0.766)=0.4188. This is because the spectra, ω_λ, of green leaves are related to a fixed "reference" leaf albedo, $\omega_{0\lambda}$, via similar spectrally invariant relationship, $\omega_\lambda/\omega_{0\lambda}=p_L\omega_\lambda+(1-p_L)\omega_\lambda$ in [710, 790 nm]). **Panel b** illustrates this phenomenon. Note that the spectrally invariant relationships are for leaf albedo and are not applicable to leaf transmittance or leaf reflectance.

The separation does not require canopy reflectance models and/or prior knowledge/ancillary information of the leaf optics

3D CANOPY STRUCTURE

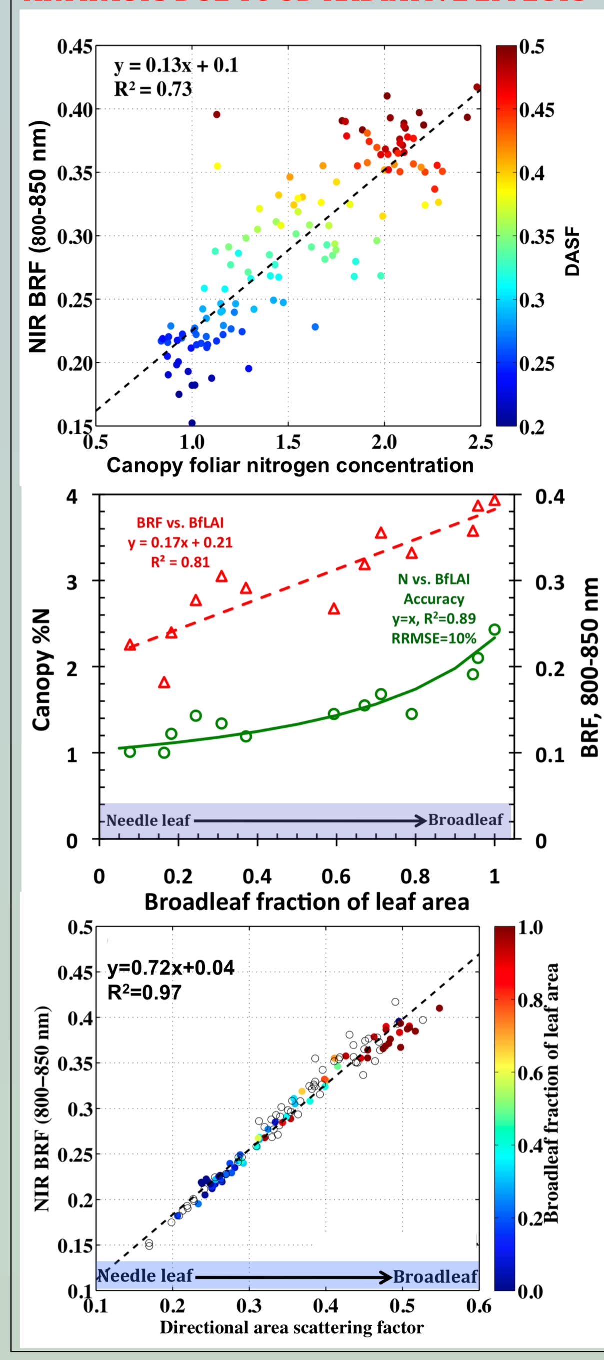


The directional area scattering factor, $R/(1-p)$, is an accurate approximation of the ratio of the area of leaves that form the canopy boundary as seen from a given direction to the total leaf area. This figure shows the DASF in the nadir direction for different types of vegetated surface. Vertical lines denote ±S.D. The lowest values of the DASF correspond to pure needle leaf forest. This is due to dense packing of needles in shoots, which lowers the fraction of foliage area visible from a given direction. In alfalfa leaves are not clumped allowing for the sensor "to see" up to 70 % of its leaf area.

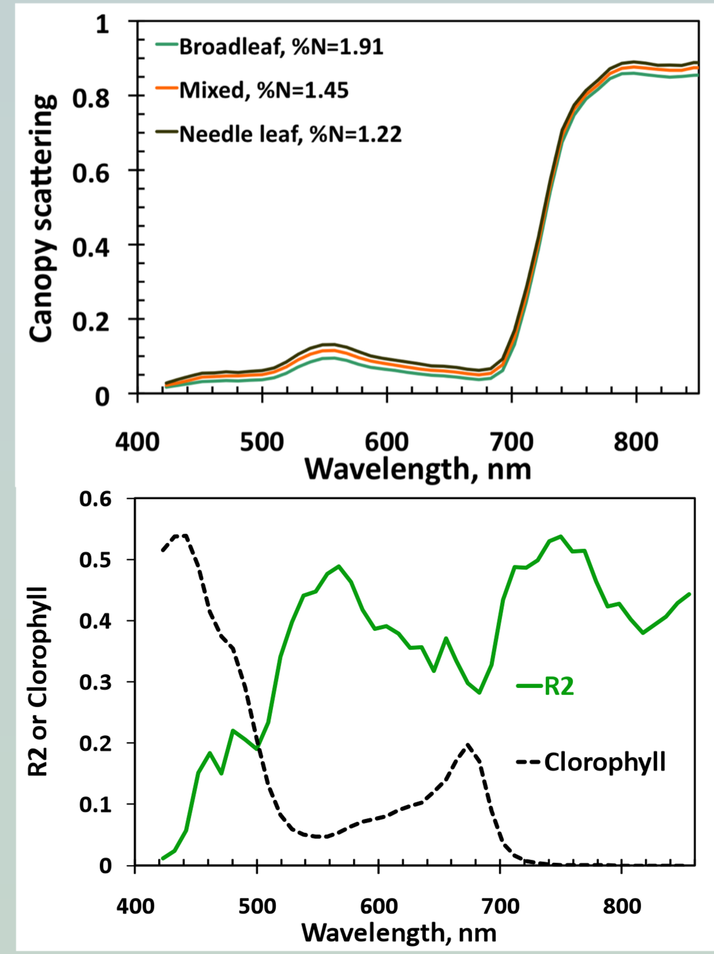
The DASF is a function of species composition and fully explains variation in BRF spectra due to variation in 3D canopy structure

LEAF BIOCHEMISTRY

ARTIFACTS DUE TO 3D RADIATIVE EFFECTS

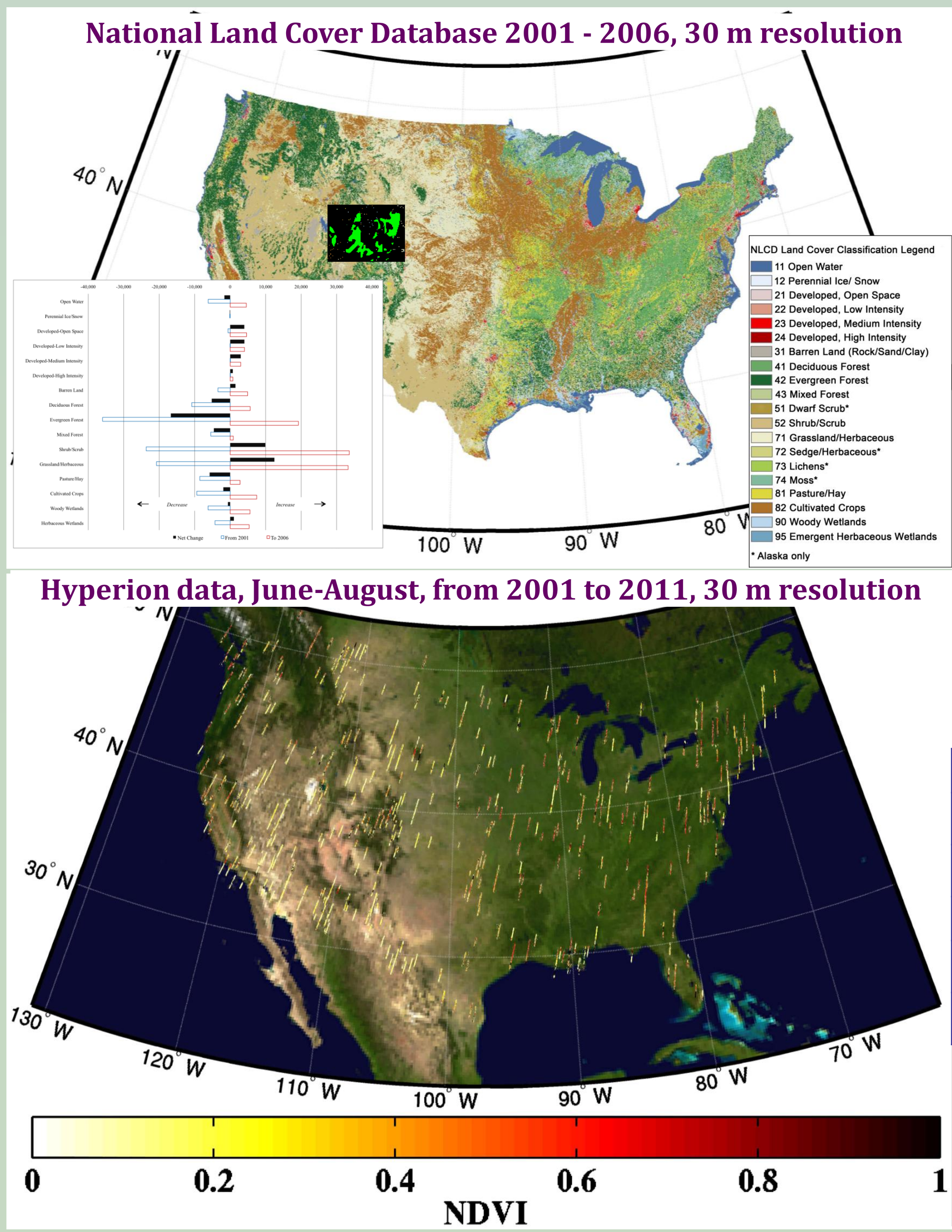


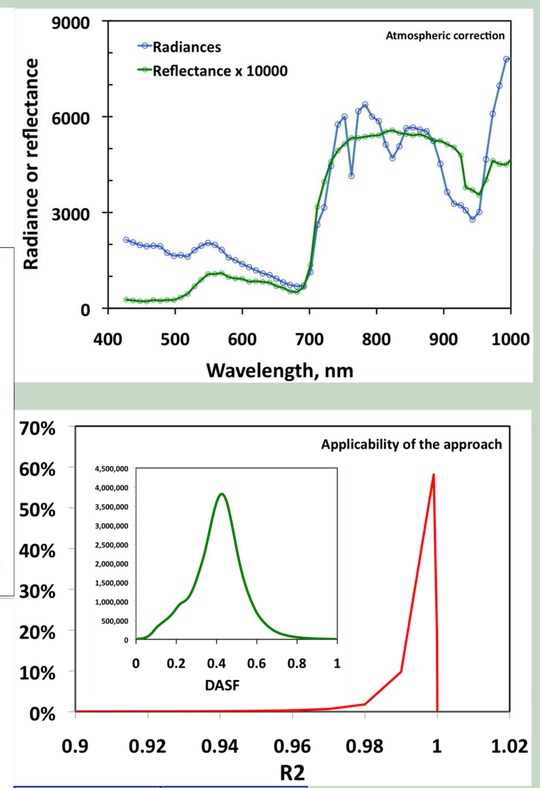
CORRECTION FOR 3D EFFECTS



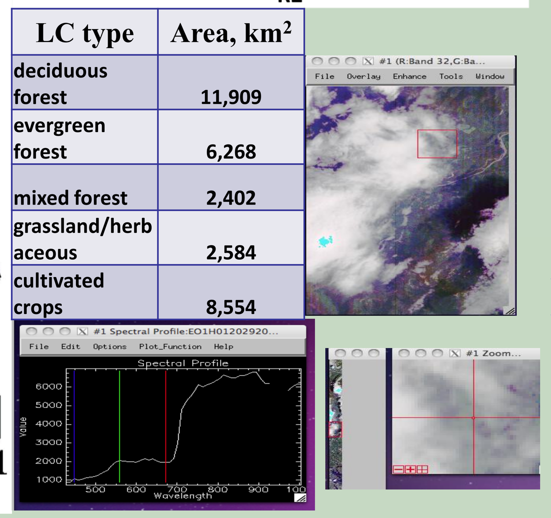
If BRF is plotted versus %N, then either no correlation (in PAR spectral region, R²~0.07) or positive (in NIR spectral region, upper left panel) correlation is observed. This is due to the 3D effects of the canopy structure, e.g., conical vs. ellipsoidal shaped crowns of coniferous and broad-leaf species. When the data are corrected for canopy structure influence, the residual reflectance variations are negatively related to %N.

MONITORING CHANGE IN VEGETATED LAND AND LEAF BIOCHEMISTRY (IN PROGRESS)





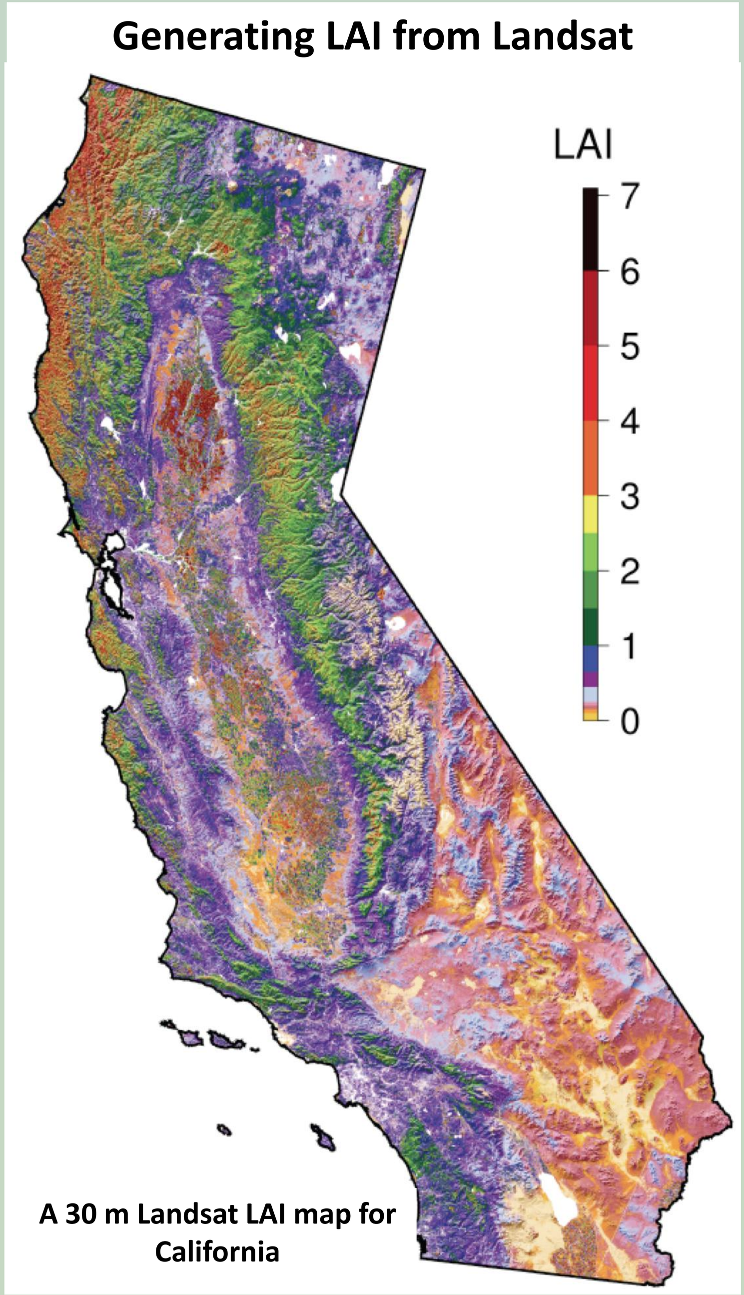
LC type	Area, km²
deciduous forest	11,909
evergreen forest	6,268
mixed forest	2,402
grassland/herbaceous	2,584
cultivated crops	8,554

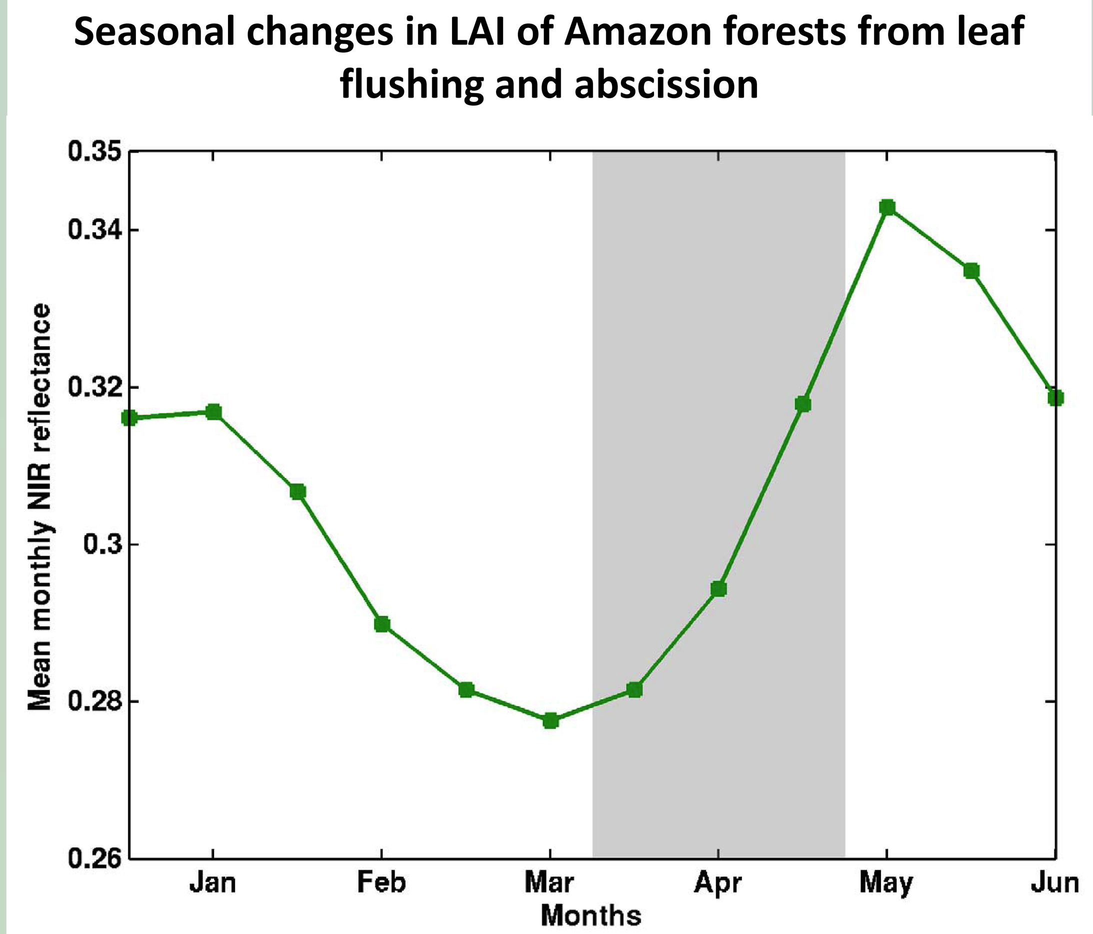


To evaluate reliability of the spectral invariant approach to capture changes in vegetation type and leaf biochemistry

- ➢ algorithm is very simple
- ➢ based on physics of 3D radiative transfer
- ➢ does not require initial training based on characteristics of known leaf and/or canopy spectra, and land cover types
- ➢ under cloud-free conditions impact of atmosphere is minimal

CONTRIBUTIONS TO OTHER PROJECTS





Left Panel: The Landsat LAI algorithm is based on the canopy spectral invariants theory and provides a computationally efficient way of parameterizing the BRF as a function of spatial resolution and spectral band composition. **Right Panel**: Changes in both leaf area and leaf optical properties are responsible for the observed increase in NIR reflectance during the dry season and decrease during the wet season. Analyses of spectral invariants and leaf optics underlies this result, which is consistent with known phonological behavior of tropical forests, ground-based reports of seasonal changes in leaf area, litterfall, leaf optics and fluxes of evapotranspiration.

PUBLICATIONS (2009-2012)

1. Knyazikhin, Y., Schull, M.A., Xu, L., Myneni, R.B., & Samanta, A. (2011). Canopy spectral invariants. Part 1: A new concept in remote sensing of vegetation. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 112, 727-735.
2. Schull, M.A., Knyazikhin, Y., Xu, L., Samanta, A., Carmona, P.L., Lepine, L., Jenkins, J.P., Ganguly, S., & Myneni, R.B. (2011). Canopy spectral invariants, Part 2: Application to classification of forest types from hyperspectral data. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 112, 736-750.
3. Wang, Z., Schaaf, C.B., Lewis, P., Knyazikhin, Y., Schull, M.A., Strahler, A.H., Yao, T., Myneni, R.B., Chopping, M.J., & Blair, B.J. (2011). Retrieval of canopy height using moderate-resolution imaging spectroradiometer (MODIS) data. *Remote Sensing of Environment*, 115, 1595-1601.
4. Yu, Y.F., Saatchi, S., Heath, L.S., LaPoint, E., Myneni, R., & Knyazikhin, Y. (2010). Regional distribution of forest height and biomass from multisensor data fusion. *Journal of Geophysical Research-Biogeosciences*, 115, G00e12, doi:10.1029/2009jg000995.
5. Ganguly, S., Nemani, R.R., Zhang, G., Hashimoto, H., Milesi, C., Michaelis, A., Wang, W., Votava, P., Samanta, A., Melton, F., Dungan, J.L., Vermote, E., Gao, F., Knyazikhin, Y., & Myneni, R.B. (2012). Generating global Leaf Area Index from Landsat: Algorithm formulation and demonstration. *Remote Sensing of Environment*, doi: 10.1016/j.rse.2011.1010.1032.
6. Samanta, A., Knyazikhin, Y., Xu, L., Dickinson, R.E., Fu, R., Costa, M.H., Saatchi, S.S., Nemani, R.R., & Myneni, R.B. (2012). Seasonal changes in leaf area of Amazon forests from leaf flushing and abscission. *J. Geophys. Res., 117*, G01015.
7. Samanta, A., Anderson, B.T., Ganguly, S., Knyazikhin, Y., Nemani, R.R., & Myneni, R.B. (2010). Physical Climate Response to a Reduction of Anthropogenic Climate Forcing. *Earth Interactions*, 14, 1-11.
8. Samanta, A., Ganguly, S., Hashimoto, H., Devadiga, S., Vermote, E., Knyazikhin, Y., Nemani, R.R., & Myneni, R.B. (2010). Amazon forests did not green-up during the 2005 drought. *Geophysical Research Letters*, 37, L05401, doi: 10.1029/2009gl042154

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9. Rautiainen, M., Heiskanen, J., Eklundh, L., Mõttus, M., Lukeš, P., & Stenberg, P. (2010). Ecological applications of physically-based remote sensing methods. *Scandinavian Journal of Forest Research*, 25, 325–339, doi:10.1080/ 02827581.2010.497159.
10. Heiskanen, J., Rautiainen, M., Korhonen, L., Mõttus, M. & Stenberg, P. 2011. Retrieval of boreal forest LAI using a forest reflectance model and empirical regressions. *International Journal of Applied Earth Observation and Geoinformation*, 13: 595-606.
11. Lukes, P., Rautiainen, M., Stenberg, P. & Malenovsky, Z. 2011. Empirical test of the spectral invariants theory using imaging spectroscopy data from a coniferous forest. *International Journal of Applied Earth Observation and Geoinformation*, 13: 668-675.
12. Rautiainen, M., Mõttus, M., Heiskanen, J., Akujärvi, A., Majasalmi, T., & Stenberg, P. (2011). Seasonal reflectance dynamics of common understory types in a northern European boreal forest. *Remote Sensing of Environment*, 115, 3020–3028, doi:10.1016/j.rse.2011.06.005.
13. Rautiainen, M., Stenberg, P., Mõttus, M. & Manninen, T. (2011). Radiative transfer simulations link boreal forest structure and shortwave albedo. *Boreal Environment Research*, 16, 91–100.
14. Mõttus, M., Rautiainen, M. & Schaepman, M. E. (2012). Shoot scattering phase function for Scots pine and its effect on canopy reflectance. *Agricultural and Forest Meteorology*, 154–155, 67–74, doi:10.1016/j.agrformet.2011.10.012.
15. Rautiainen, M., Mõttus, M., Yáñez-Rausell, L.; Homolová, L.,Malenovský, Z. & Schaepman, M. E. (2012). A note on upscaling coniferous needle spectra to shoot spectral albedo. *Remote Sensing of Environment*, 117, 469–474, doi: 10.1016/j.rse.2011.10.019.

PhD Thesis

16. Schull, M.A. (2010). Application of spectral invariants for monitoring forest across multiple scales. *PhD Thesis. Department of Geography and Environment, Boston University*, November 2nd, 2010, 137 pp., http://library.bu.edu/search/X. Advisors: Drs. Y. Knyazikhin (first reader), P. Stenberg (University of Helsinki), R. B. Myneni, A. Strahler and N. Phillips (Boston University).

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