REMOTE SENSING OF FOREST STRUCTURE ACROSS MULTIPLE SCALES FROM LEAVES TO CANOPIES AND STANDS

Award Number: NNX09AI30G

Progress Report

(Apr-22-2010 through Apr-21-2011)

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Project Abstract. The objective of the proposed research is to document the feasibility of deriving forest structural parameters – forest type composition, forest cover, tree density and crown shape – from multi-angle and hyperspectral data. The methodology is based on the novel idea of retrieving canopy spectral invariants – the recollision and escape probabilities – from optical remote sensing data. The recollision probability is a measure of the multi-level hierarchical structure in a vegetated pixel and can be obtained from hyperspectral data. The escape probability is sensitive to canopy geometrical properties such as forest cover, tree density and aspect ratio (crown diameter to crown height) and can be derived from multi-angle spectral data. The escape and recollision probabilities have the potential to separate forest types based on crown shape and the number of hierarchical levels within the landscape. We propose to develop this methodology and test it with experimental data using existing ground and aircraft-based remote sensing data from various sites in the USA, Finland and Estonia.

Our activities during Year 2 (Apr-22-2010 through Apr-21-2011) have focused on understanding relationships between leaf absorbing constituents, canopy structure and multi-angle hyperspectral data, with an emphasis on the decomposition of spectral BRF into structural and radiometric components and their dependencies on forest geometry and leaf biochemistry.

SUMMARY OF RESULTS

- Ability of the spectral invariant approach to decompose the spectral BRF into structural and radiometric components and relate them to canopy structure and leaf biochemistry has been demonstrated. See "Research Highlights"
- One PhD dissertation has successfully been defended
- Special session "Monitoring vegetation at multiple scales: canopy structure and spectrally invariant parameters" within the 2nd workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing WHISPERS 2010, 14-16 June 2010, Reykjavik, Iceland, has been organized
- NASA LCLUC/GOFC-GOLD/NEESPI International Regional Meeting on Boreal and Temperate Europe, August 25-28, 2010, Tartu, Estonia has been organized
- Collaborative work with Beijing Key Laboratory for Spatial Information Integration & Applications, School of Earth And Space Science, Peking University, Beijing, China, on developing methods to interpret hyperspectral data.
- Six papers in per-reviewed journals have been published
- Nine talks and nine posters describing the results were presented

PhD Thesis

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). This research was supported by this grant, the NASA Earth and Space Science Fellowship (NNX07AO41H), NASA EOS program (NNX08AE81G) and MISR team.

Outreach activities

- Organization of special session "Monitoring vegetation at multiple scales: canopy structure and spectrally invariant parameters" within the 2nd workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing WHISPERS 2010, 14-16 June 2010, Reykjavik, Iceland.
  One oral (5 talks) and one poster (10 posters) sessions covered all aspects of the multi-angle hyperspectral remote sensing of canopy structure: theory, modeling, field measurements, generation of satellite products and validation.
- Organization of NASA LCLUC/GOFC-GOLD/NEESPI International Regional Meeting on Boreal and Temperate Europe, August 25-28, 2010, Tartu, Estonia.
  More than 80 participants representing 14 nations in and around the Baltic region attended.
- Participation in the NASA Training Session on Quantitative Research Methods in Human Dimensions of Environmental Change Within Eastern Europe, Vidzeme University, Valmieara, Latvia, August 21 – August 23, 2010.
  Lecture and computer tutorial on Multi-angle Imaging Spectroradiometer (MISR) satellite image data products

RESEARCH HIGHLIGHTS

The results below are under preparation for publication. They were presented at {1,8,10-12} and summarized in the Schull's PhD thesis.

Ollinger[1] et al. (2008) found that both CO_2 uptake capacity and canopy nitrogen concentration (N) are strongly and positively correlated with near infra-red (NIR) surface albedo, indicating that nitrogen may play an additional, and unrecognized feedback in the Earth's climate system involving the N cycle as a factor influencing surface energy exchange, in addition to its known effects on C assimilation. They also suggested that canopy N can be monitored by using broadband satellite sensors only. Our analyses based on the spectral invariant approach not only indicate the importance of muti-angular and spectral information to relate remote sensing data and canopy nitrogen but also indentify misinterpretation of the observed positive correlation between canopy N and shortwave surface albedo. The following results illustrate this.

[1] Ollinger, S.V., Richardson, A.D., Martin, M.E., et al. (2008). Canopy nitrogen, carbon assimilation, and albedo in temperate and boreal forests: Functional relations and potential climate feedbacks. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 19336-19341.

SPECTRAL INVARIANTS ARE STONGLY CORRALATED WITH THE PROPOTION OF BROAD- AND NEEDLE LEAF SPECIES

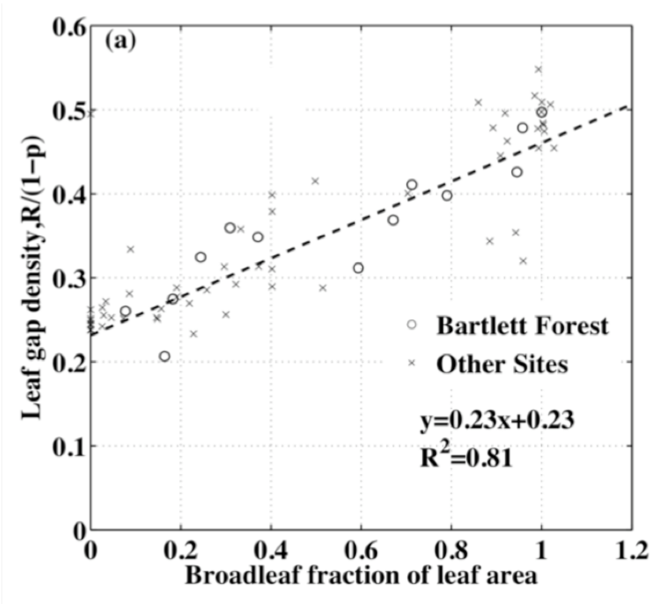
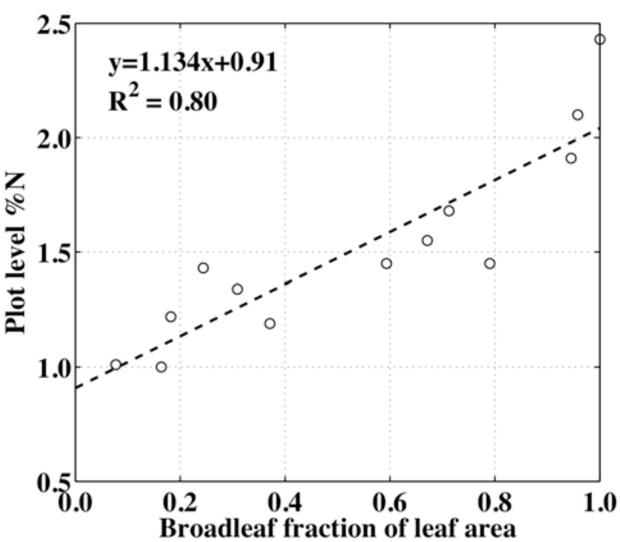


Figure 1. Correlation between satellite derived ratio, $R/(1-p)$, and *in situ* broadleaf fraction of leaf area (BfLAI) for 129 plots across 6 research sites located in the eastern US and Washington state. The directional escape (R) and recollision (p) probabilities were derived from AirMISR and AVIRIS data. Note that the BfLAI is labor intensive while the ratio not.

NITROGEN CONCENTRATION OF AN AVERAGE BROAD LEAF IS HIGHER THAN THAT OF AN AVERAGE NEEDLE AND THUS CANOPY NITROGEN IS POSITIVELY CORRELATED WITH THE PROPORTION OF BROAD- AND NEEDLE LEAF SPECIES



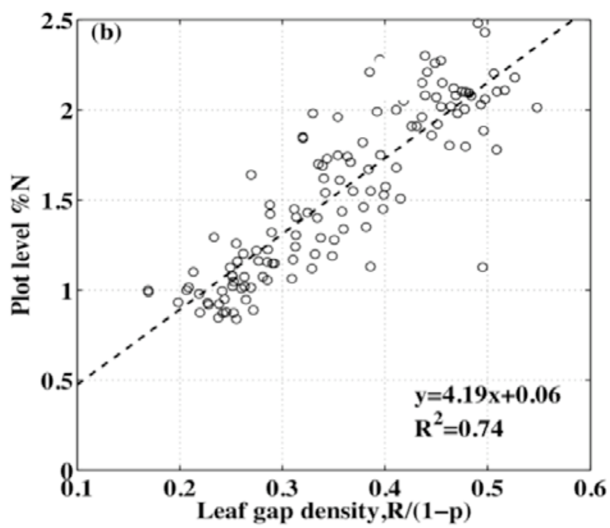


Figure 2. Correlation between canopy nitrogen and (a) *in-situ* BfLAI; (b) the ratio $R/(1-p)$. The positive tendency is due the positive difference in nitrogen content of an average leaf (2.17 g per 100 g of dry leaf mass) and needle (1.24 g per 100 g of dry leaf mass). The canopy nitrogen is a function of canopy structure in this data set.

BROADBAND NIR SURFACE ALBEDO IS SENSITIVE TO CANOPY STRUCTURE.
CANOPY NITROGEN COVARIES WITH STRUCTURE

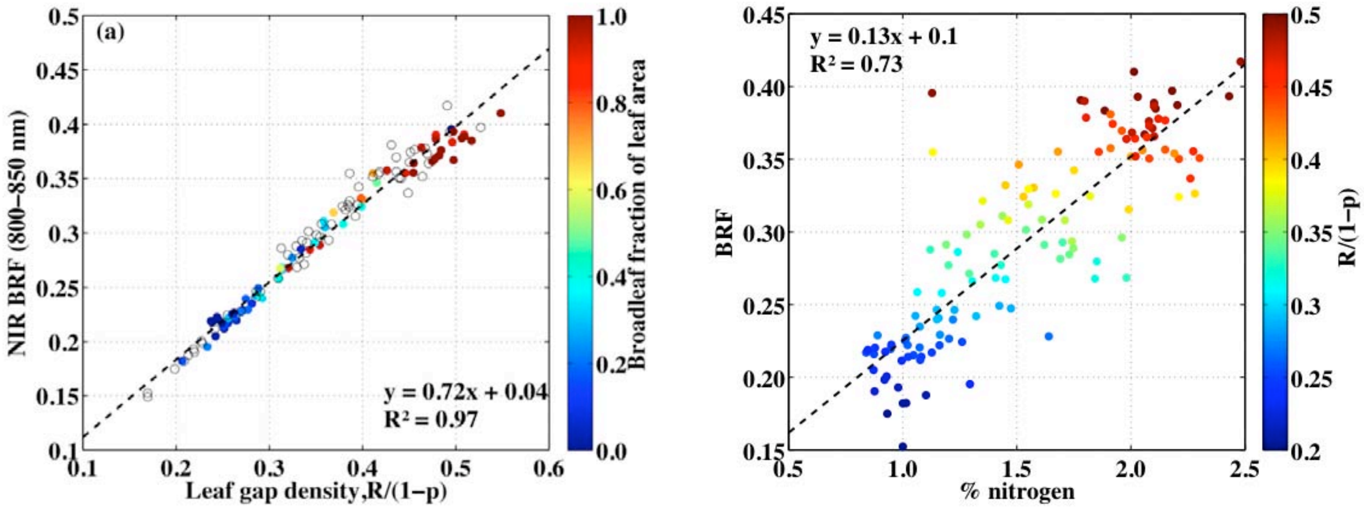


Figure 3. Correlation between NIR BRF and (a) the ratio $R/(1-p)$; (b) canopy nitrogen. Canopy structure can fully explain variation in surface albedo.

SURFACE REFLECTANCE DATA SHOULD BE CORRECTED FOR CANOPY STRUCTURE EFFECT IN ORDER TO ESTIMATE CANOPY NITROGEN

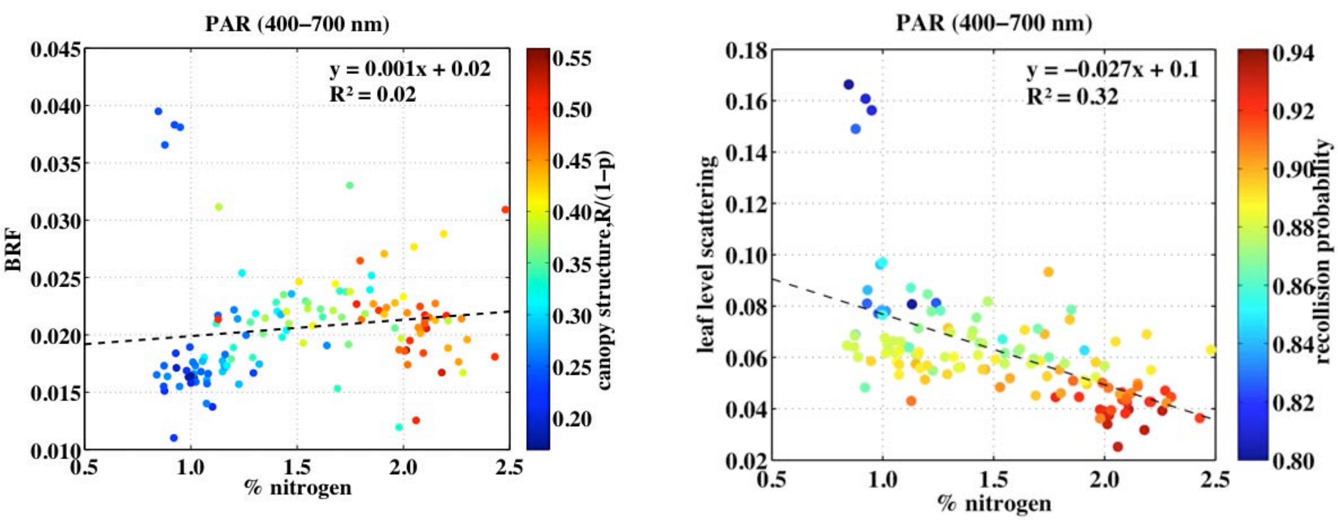


Figure 4. *Left Panel*: there is no correlation between PAR surface albedo and canopy N. *Right Panel*: if the effect of canopy structure is removed, canopy scattering is negatively related with N: the more N, the more leaf absorbs and the darker it is. The synergy of multiangle and hyperspecral data is required to decompose the spectral BRF into structural and radiometric components. The former is related to canopy structure (Figs. 1-3) while the latter is a function of leaf biochemistry (this figure)

Publications

[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] 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.

[4] 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

[5] 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.

[6] Rautiainen, M., Heiskanen, J., Eklundh, L., Mottus, M., Lukes, P., & Stenberg, P. (2010). Ecological applications of physically based remote sensing methods. *Scandinavian Journal of Forest Research*, 25, 325-339.

Conferences, Meetings and Workshops where the results were presented

A. Invited lectures

{1} Knyazikhin, Y. Monitoring vegetation from space: from theory to satellite products. *Beijing Key Laboratory for Spatial Information Integration & Applications, School of Earth And Space Science, Peking University*, Beijing , China, 5 July – 10 July , 2010.

B. Oral Presentations

{2} Ganguly, S., Nemani, R.R., Knyazikhin, Y., Weile, W., Hashimoto, H., Votava, P., Michaelis, A., Milesi, C., Dungan, J.L., Melton, F.S., & Myneni, R.B. (2010). A physically based approach in retrieving vegetation Leaf Area Index from Landsat surface reflectance data. *In, Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS),* 2010 2nd Workshop on (pp. 1-4). Reykjavik, Iceland: IEEE, doi: 10.1109/WHISPERS.2010.5594875.

{3} Latorre Carmona, P., Schull, M., Knyazikhin, Y., & Pla, F. (2010). The application of spectral invariants for discrimination of crops using CHRIS-PROBA data. In, *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2010 2nd Workshop on* (pp. 1-4). Reykjavik, Iceland: IEEE, doi: 10.1109/WHISPERS.2010.5594879

{4} Mõttus, M. (2010). The physics of spectral invariants. In, *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2010 2nd Workshop on* (pp. 1-4): IEEE, doi: 10.1109/WHISPERS.2010.5594910.

{5} Mõttus, M. (2010). Decomposition of multiangular reflectance. In, Recent Advances in Quantitative Remote Sensing III, September 27 –October 01, 2010, Valencia, Spain.

{6} Rautiainen, M., Stenberg, P., Lukes, P., Mõttus, M., & Heiskanen, J. (2010). Estimating canopy spectral invariants from ground reference and remote sensing data. In, *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2010 2nd Workshop on* (pp. 1-4). Reykjavik, Iceland: IEEE, doi: 10.1109/WHISPERS.2010.5594861.

{7} Diner, D.J., Ackerman, T.P., Braverman, A.J., Bruegge, C.J., Chopping, M.J., Clothiaux, E.E., Davies, R., Di Girolamo, L., Kahn, R.A., Knyazikhin, Y., Liu, Y., Marchand, R., Martonchik, J.V., Muller, J., Nolin, A.W.,

Pinty, B., Verstraete, M.M., Wu, D.L., Garay, M.J., Kalashnikova, O.V., Davis, A.B., Davis, E.S., & Chipman, R.A. (2010). Ten years of MISR observations from Terra: Looking back, ahead, and in between. In, *Geoscience and Remote Sensing Symposium (IGARSS)*, 2010 IEEE International (pp. 1297-1299), doi: 10.1109/IGARSS.2010.5649389.

{8} Knyazikhin, Y., Schull, M., Xu, L., and Myneni, R. (2010). Monitoring canopy nitrogen using multiangle and hyperspectral data. *MISR Data Users Science Symposium*, Pasadena, CA, Dec 9-10, 2010.

{9} Knyazikhin, Y. and L., Xu (2010). DSCOVR NDVI and LAI. DSCOVR EPIC Workshop, *NASA Goddard Space Flight Center*, November-09-2010.

C. Posters

{10} Knyazikhin, Y., M. Schull, P. Stenberg, M. Rautiainen and M. Mõttus (2010). Monitoring canopy structure across multiple scales from leaves to canopies and stands. NASA LCLUC/GOFC-GOLD/NEESPI International Regional Meeting on Boreal and Temperate Europe, August 25-28, 2010, Tartu, Estonia.

{11} Schull, M.A., Xu, L., X., Knyazikhin, Y., & Myneni, R.B. (2010). A physical interpretation of the correlation between canopy albedo and nitrogen using hyperspectral data. In, *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2010 2nd Workshop on* (pp. 1-4). Reykjavik, Iceland: IEEE, doi: 10.1109/WHISPERS.2010.5594889.

{12} Schull, M.A., Xu, L., Samanta, A., Lepine, L., Ollinger, S., Knyazikhin, Y., and Myneni R.B. (2010). A Physical Explanation of the Correlation Between Albedo and Canopy Nitrogen. *2010 NASA Terrestrial Ecology Science Team Meeting*, La Jolla,CA, March 15-17, 2010. (http://cce.nasa.gov/meeting_te_2010/index.html)

{13} Schull, M.A., Xu, L. Carmona, P., Samanta, A., Knyazikhin, Y., and Myneni, R.B. (2010). Classification of Forest and Crop Types From Hyperspectral and Multi-Angular Data. *2010 NASA Terrestrial Ecology Science Team Meeting*, La Jolla,CA, March 15-17, 2010. (http://cce.nasa.gov/meeting_te_2010/index.html)

{14} Xu, L., Schull, M.A., Myneni, R.B., & Knyazikhin, Y. (2010). Modeling recollision and escape probabilities using the stochastic radiative transfer equation. In, *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2010 2nd Workshop on* (pp. 1-4). Reykjavik, Iceland: IEEE, doi: 10.1109/WHISPERS.2010.5594885.

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{16} Zhuosen, W., Schaaf, C.B., Philip, L., Knyazikhin, Y., Schull, M.A., Strahler, A.H., Myneni, R.B., & Chopping, M. (2010). Canopy vertical structure using MODIS Bidirectional Reflectance data. In, *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2010 2nd Workshop on* (pp. 1-4): IEEE, doi: 10.1109/WHISPERS.2010.5594952.

{17} Rautiainen, M., Heiskanen, J., & Mõttus, M. (2010). Seasonal Dynamics of Boreal Forest Structure and Reflectance. In, *AGU Fall Meeting* (pp. B31B-0306). San Francisco: AGU.

{18} Mõttus, M and Rautiainen, M. (2010). Radiative transfer theory for imaging spectroscopy of vegetation canopies. Hyperspectral Worshop 2010, March 17–19, 2010, ESA Esrin, Frascati, Italy.

Work plan for year 3 (Apr-22-2011 through Apr-21-2012)

Our goals for Y3 are (a) to generate of maps of the recollision and escape probabilities over selected sites in USA, Finland and Estonia; (b) to relate the maps to dominant forest/plant/crop type and optical properties of an overage leaf in the pixel, the latter is a function of leaf biochemistry, and (c) to evaluate uncertainties and reliability of the spectral invariant approach to capture changes in forest type composition and leaf physiology. This activity includes calibration and validation of the algorithm, analyses of the generated data set. A special emphasis will be given to deriving leaf level spectra, their analyses and understanding of the relationship between leaf physiology, canopy structure and multi-angle hyperspectral data. Results are expected to be documented in per-reviewed journal articles.

Year 3 Budget: $107,338 (as proposed and approved)