Advancing Techniques for Informing Terrestrial Ecosystem Models with Leaf and Imaging Spectroscopy to Improve the Representation and Prediction of Vegetation Dynamics and Carbon Cycling


#EuroSpec2013 Final Conference, Nov 6-8 2013, Trento, Italy
Terrestrial carbon cycle feedback is a leading order uncertainty for climate simulation.
This is true at the site level, too!

Willow Creek EC Tower Site, Wisconsin

www.pecanproject.org
Leaf and canopy high-spatial and spectral resolution spectroscopy to the rescue?

(a) Fresh

(b) Dry

Acer saccharum
Imaging spectroscopy has a wealth of underutilized observations for ecosystem models!
• Two possible pathways:
  – Data products assimilation
  – Direct optical properties assimilation
• Based on results from two field projects:
  – ChEAS Ameriflux Cluster
  – NASA HyspIRI prep mission
• With one assimilation system / model:
  – PEcAn with ED2
PEcAn: Predictive Ecosystem Analyzer is a workflow for model-data assimilation

Model-data assimilation

PEcAn Workflow
- Database
- Meta-analysis
- Parameters
- Model
- Analysis
- Reanalysis

Ecosystem C / H₂O / E

Initial parameter constraints

Var. Decomposition

Data Assimilation

Nitrogen

SLA

Optical Properties (leaf, IS reflectance)

LeBauer, D. et al., [2013]. Facilitating the feedbacks between field measurements and ecosystem models using meta-analysis, modeling, and variance decomposition. Ecol. Monographs

PEcAn Project: Mike Dietze (IU), Tomi Viskari (FI), Ankur Desai (UIW), David LeBauer (UIUC), Shawn Serbin (UIW), Rob Kooper (UIUC/NCSA), Konvien McHenry (UIUC/NCSA)
ED2 is a dynamic ecosystem model and already includes broadband radiative transfer.

Medvigy et al. 2009
PEcAn variance decomposition provides information on sensitivity of a model output variable (e.g., NPP) to uncertainty in input data (CV), model sensitivity (elasticity), and joint variance.
Two study regions in US

ChEAS: AVIRIS over 4 Ameriflux sites

165 Plots 120+ AVIRIS Scenes

NASA FFT Project

NASA HyspIRI Campaign

2013-2014
Spring
Summer
Fall

Of a total of 145 scenes, 26 in ChEAS:
All midsummer (July/August) images
7.0m - 16.8m resolution (low/high alt. ER-2)

DATA PRODUCT ASSIMILATION
MODIS LAI + Flux tower vertical PAR profile tames model phenology

Filled dot = MODIS LAI, open dot = LAI from flux tower profile FaPAR

Viskari et al., (in prep)
AVIRIS products generated with PLSR technique and leaf-level spectroscopy calibration

Serbin et al., 2012 J Exp Botany

Where we are today:

Standardized algorithms to predict foliar constituents (%C,%N,LMA,...) using spectroscopy across diverse forest types w/ uncertainty estimates.

• Our scaling methods propagate the uncertainties at the leaf-level through the canopy PLSR modeling to produce estimates of foliar traits (i.e. trait maps) with an estimate of the associated retrieval uncertainty (pixel by pixel).
• Thus, we can utilize these products in a model DA framework given that we have quantified uncertainty in retrievals.
Model-data Assimilation: AVIRIS

Willow Creek EC Tower Site, Wisconsin

Working toward the assimilation of AVIRIS-derived products. These include foliar chemistry (e.g. N, C, CN, lignin) and morphology (SLA).
Model-data Assimilation: AVIRIS

Willow Creek EC Tower Site, Wisconsin

- Of course this requires uncertainty for proper DA. Otherwise too much weight given to the RS estimates causing overconfidence. Therefore, our methods utilize the generation of AVIRIS retrieval uncertainty to properly assimilate datasets!
DIRECT OPTICAL ASSIMILATION
Strong atmospheric absorption features centered near 1700 nm, 2000 nm, and 2200 nm) to emerge in the spectral regions. Soil reflectance variability was highest to be difficult (Curran et al., 1992; Fourty et al., 1996). Spectral regions. Soil reflectance variability was highest to be difficult (Curran et al., 1992; Fourty et al., 1996). Spectral regions.

Leaf effects at canopy scales were greater in the SWIR1 than in the SWIR2 because the single scattering albedo (reflectance) in the NIR (14–18%; Fig. 4b). In the VIS and SWIR1, effects of leaf-level structural effects on canopy reflectance properties were taken from Figures 1 unless noted otherwise. The darkest soil spectrum at 35% (lowest in VIS, highest in SWIR2) and 23–51% (lowest in NIR, highest in SWIR2), respectively. These c.v.'s were 8–241% and 2 unless noted otherwise. The darkest soil spectrum was generally more variable compared to leaves (Fig. 3).

Standing litter and woody stem optical properties collected at sites in the United States and Brazil; B) mean (Fig. 3). Asner et al. (1998) RSE.

Leaf Optical Variability at Canopy Scales

Figure 2. Standing litter and woody stem optical properties collected from sites in the United States and Brazil; B) mean (Fig. 3). Asner et al. (1998) RSE.

Canopy Reflect: f(Incident rad, leaf optics, stem/soil/litter optics, stem density, crown structure, LADF, LAI, dispersion of leaves, [e.g. random or clumped])
Canopy RTM Inversion
RMSE = 0.015
LAI = 4.89

PROSPECT Inversion (Modeled Optics)
Cab = 58.3
EWT = 0.020 cm
SLA = 18.4 m² / kgC

Single Scattering Albedo
Update Eco. Model leaf optics (refl. / trans)
$T_{\text{soil}}$

- leaf_trans_nir
- leaf_trans_vis
- leaf_reflect_nir
- leaf_reflect_vis
- *clumping
- root_respiration_rate
- *Vcmax
- *quantum_efficiency
- *leaf_respiration_rate_m2
- *SLA
- r_fract
- *fineroot2leaf
- *stomatal_slope
- growth_resp_factor
- root_turnover_rate
- mort2

*constrained by data

Variance (%)
GPP

- leaf_trans_nir
- leaf_trans_vis
- leaf_reflect_nir
- leaf_reflect_vis
  *clumping
- root_respiration_rate
  *Vcmax
- *quantum_efficiency
- *leaf_respiration_rate_m2
  *SLA
- r_f fract
- *fineroot2leaf
- *stomatal_slope
- growthResp_factor
- root_turnover_rate
- mort2

*constrained by data
Pros and Cons: Product assimilation

• **Product assimilation typically requires less modification of most ecosystem models**
  – Tradeoff is uncertainty of product directly propagates into uncertainty in model
  – Model and product make different assumption about canopy architecture – bias is likely if the two are fundamentally different (also scale dependent)
  – Computational cost for radiative transfer based parameter inversion is done at product stage instead of during model execution
  – Characterizing product uncertainty as important as actual value for data assimilation approaches
Pros and Cons: Direct optical assimilation

- Optical assimilation requires identification of proper canopy radiative transfer model
  - Increases parameters, but possibly allows for optics to directly guide model improvement without *a priori* assumptions of what spectral signatures mean
  - Similarly, no bias from difference in assumption of canopy architecture
  - Easily extendable to many remote sensing platforms
  - Initial model investment is high and model canopy may not be well suited for radiative transfer
A look forward

• HyspIRI (http://hyspiri.jpl.nasa.gov/) or similar future satellites (EnMAP; http://www.enmap.org/) along with continuous canopy spectral measurements (SpecNet) will dramatically increase the volume of spectral information in Visible, near IR, and thermal wavelengths.

• We can do more than just make pretty pictures and poorly validated “products” - need to move away from exclusively using vegetation indices.

• The need to reduce terrestrial carbon cycle model parameters is urgent and methods to assimilate spectral information directly into models is limited to date.

• Spectral databases (e.g. EcoSIS, SPECCHIO) can be mined for key PFT-level information useful for constraining model projections.
Estimates of $V_{\text{cmax}}$ and $J_{\text{max}}$ derived from imaging spectroscopy will be compared with those inverted from flux tower data at each site using a coupled 2-layer (sunlit-shaded canopy) FvCB ecosystem model. Uncertainty will be assessed using Bayesian parameter inversion.
HyspIRI overflies a range of Mediterranean and Western Pine ecosystem flux tower sites

- Subalpine Forest (high elevation)
- Mixed Conifer Forest (high elevation)
- Ponderosa Pine Forest (mid elevation)
- Oak-pine Woodland (low elevation)
- Coastal Sage (low elevation)
- Coastal Grassland (low elevation)
- Desert Chaparral (low elevation)

• Climatic & topographic variation in fluxes
• Water availability is key
Thank you

• Many collaborators in the field in Wisconsin and California, ED2 model developers, PEcAn data assimilation crew, NASA AVIRIS team
• More: http://pecanproject.org/
• Funding: NASA ROSES HyspIRI Preparatory NNX12AQ28G, NSF Advances in Biological Informatics DBI-1062204.