Integrating Measurements and Models of Carbon and Water Cycling at Tier II and III PINEMAP sites.

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How do we combined half-hourly measurements with monthly time step models?

Tier III Site Measurements

- Sap Flux Density (J^S)
- Height, DBH
- Light (PAR), above & below canopy
- Precipitation (P)
- Air Temperature, Humidity
- Soil Moisture (S)
- Carbon, Nitrogen Pools
- Crown Length, Width*
- Leaf Area Index (LAI)*
- Periodic Ceptometer Readings*
- Leaf Photosynthetic Responses*

*Proposed Measurements

3PG (Landsberg & Waring 1997)

- Monthly model of stand photosynthesis and growth
- Estimates max. gross primary productivity (GPP) from a light-use efficiency and absorbed PAR
- Modifies this maximum GPP by factors reflecting stressors such as low soil moisture and high evaporative demand
- Parameterized largely with allometry and inventory data, assumed ratio of net primary productivity to GPP.

WaSSI-C (Sun et al. 2011)

- Monthly model of regional water and carbon cycling
- Estimates GPP from a water-use efficiency and ecosystem evapotranspiration (ET)
- ET is modeled as function of grass-reference ET, P, LAI & S
- Parameterized originally with eddy-covariance data
- Validated ET and GPP against USGS stream gauge data, MODIS and EC-MOD at watershed level for continental US

Proposed approach: combining light and water-centric views in a detailed stand model.

We propose utilizing the sap flux data and a one-dimensional radiation transfer model to constrain estimates of GPP at Tier III sites in a 4CA approach.

- Produces absorbed PAR (aPAR), ET and GPP estimates for each Tier III site.
- Flexible approach allows us to identify what level of detail is necessary to model these site variables and areas of greatest uncertainty in these processes.
- Light-use (GPP/aPAR) and water-use (GPP/ET) efficiencies can then be used in validation of 3PG and WaSSI-C parameterizations against Tier II site data.

Why not use a big-leaf model to estimate stand GPP at Tier III sites?

A big-leaf abstraction becomes necessary in regional modeling, so canopy-level parameterizations must be made from these data. However, incorporating the response of *Pinus taeda* to future scenarios represented by Tier III site data, as well as that from other studies (e.g. Duke FACE) will require the consideration of ecophysiological processes that are often measured at the leaf scale. Identifying shifts in canopy-level parameters under such scenarios, and associated uncertainties, requires models that can translate processes across these scales.

Bayesian State-Space Approach to Conductance (Ward et al., in review)

Features

- **Consistent approach across sites to analyzing sap flux data**
- **Sets clear assumptions about missing data, scaling to stomatal conductance (G^S)**
- **Uncertainty associated with G^S and transpiration per unit LAI (E^L)**
- **Responses to environmental drivers (soil moisture, humidity, PAR)**

Inputs

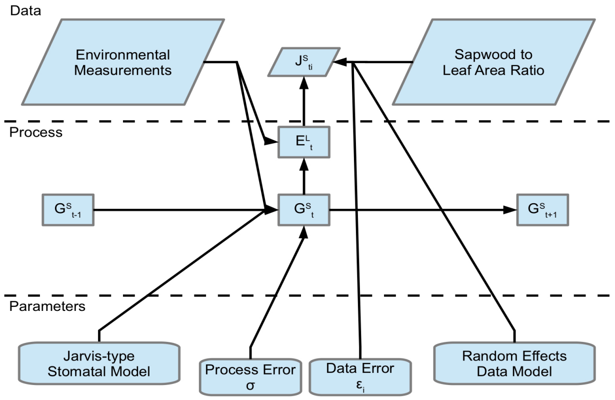
- **Clean (not gap-filled) sap flux estimates**
- **Vapor pressure deficit, incident PAR, soil moisture**
- **Plot sapwood and leaf area**
- **Priors for stomatal response of *P. taeda***

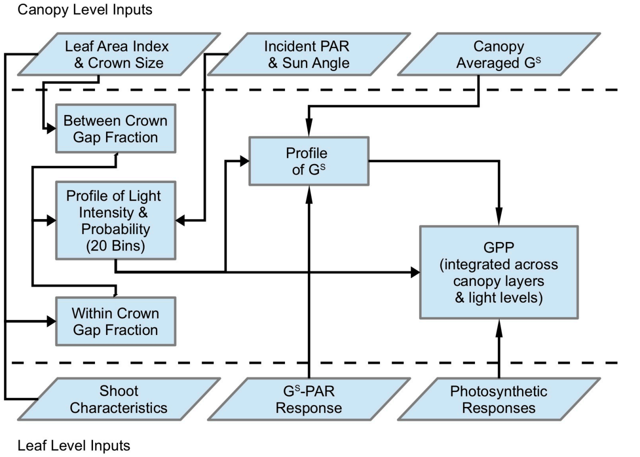
Outputs

- **Posterior distribution of transpiration and stomatal conductance**
- **Multivariate distribution of stomatal response parameters**

Verification

- **Closure of site hydrologic budget to estimate ET**
- **Comparison to ET from local eddy-covariance studies**
- **Transpiration efficiency estimates from stable isotope analyses**





One-Dimensional Radiation Transfer Model (Stenberg et al. 1995, Kim et al. 2011)

Features

- **Penumbral effects of conifer needles partially obscuring sun**
- **Clumping at shoot and tree crown levels for multiple size classes**

Inputs

- **Site elevation, latitude, longitude, incident PAR**
- **Tree height, crown length and width of up to 5 size classes**
- **Profiles of canopy leaf, stem and branch areas**
- **Shoot clumping and transmission coefficients**

Outputs

- **Profile of absorbed PAR**
- **Intensity and probability of 20 penumbral light levels**
- **Comparisons of complex and simplified crown structure**

Verification

- **PAR sensors below canopy at each site**
- **Ceptometer readings taken on clear and cloudy days**

4CA: Canopy Conductance Constrained Carbon Assimilation (Schafer et al. 2003, Kim et al. 2008)

Features

- **Flexible approach to estimating GPP from leaf level models**
- **Conductance partitioned to canopy levels based on light model**
- **Assimilation model applied at 1 m intervals in canopy**
- **Light output from another model (e.g. MAESTRA) can be used**
- **Can use to integrate any leaf level assimilation model**
- **Options for Farquhar et. al (1980), Collatz et al. (1991) and Katul et al. (2000), as well as simple light response curves are currently implemented**

Inputs

- **Air temperature, ambient carbon dioxide**
- **Canopy averaged stomatal conductance**
- **Light profile**
- **Photosynthetic parameters for model of choice (i.e. Vcmax, Jmax)***
- **Stomatal light response curves***

***Multiple heights (usually sun/shade)**
***Literature or site-specific porometry values**

Outputs

- **Profile of carbon assimilation**
- **Explicit predictions of light-use and water-use efficiencies**

Verification

- **Sum of NPP and estimated respiration components at annual time scales**
- **Comparison to NEE from local eddy covariance studies and respiration estimates**

References

- Collatz G.J., Ball J.T., Grivet C. & Berry J.A. (1991) Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: a model that includes a laminar boundary layer. *Agricultural and Forest Meteorology*, **54**, 107-136.
- Farquhar G.D., Caemmerer S. & Berry J.A. (1980) A biochemical model of photosynthetic CO_2 assimilation in leaves of C3 species. *Planta*, **149**, 78–90.
- Katul G.G., Ellsworth D.S. & Lai C.T. (2000) Modelling assimilation and intercellular CO2 from measured conductance: a synthesis of approaches. *Plant, Cell & Environment*, **23**, 1313-1328.
- Kim H.-S., Palmroth S., Therezien M., Stenberg P. & Oren R. (2011) Analysis of the sensitivity of absorbed light and incident light profile to various canopy architecture and stand conditions. *Tree Physiology*, **31**, 30-47.
- Kim H.S., Oren R. & Hinckley T.M. (2008) Actual and potential transpiration and carbon assimilation in an irrigated poplar plantation. *Tree physiology*, **28**, 559.
- Landsberg J.J. & Waring R.H. (1997) A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest Ecology and Management*, **95**, 209–228.
- Schäfer K.V.R., Oren R., Ellsworth D.S., Lai C.T., Herrick J.D., Finzi A.C., Richter D.D. & Katul G.G. (2003) Exposure to an enriched CO2 atmosphere alters carbon assimilation and allocation in a pine forest ecosystem. *Global Change Biology*, **9**, 1378–1400.
- Stenberg P. (1998) Implications of shoot structure on the rate of photosynthesis at different levels in a coniferous canopy using a model incorporating grouping and penumbra. *Functional Ecology*, **12**, 82-91.
- Sun G., Caldwell P., Noormets A., McNulty S.G., Cohen E., Moore Myers J., Domec J.C., Treasure E., Mu Q., Xiao J., John R. & Chen J. (2011) Upscaling key ecosystem functions across the conterminous US by a water-centric ecosystem model. *J. Geophys. Res.*, **116**, G00J05.
- Ward E., Oren R., Bell D.M., Clark J.S., McCarthy H., Kim H.S. & Domec J.C. (in review) The effects of long-term elevated CO2 and nitrogen fertilization on stomatal conductance estimated from scaled sap flux measurements at Duke FACE. *Tree Physiology*.