HyspIRI: Imaging Spectroscopy of Plant Metabolic and Ecological Function
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Photosynthesis:
A temperature-mediated photochemical reaction

Climate is key to photosynthetic potential.
Nutrient dynamics:
Plant allocation and use of resources

Cell structure (water use), shade tolerance (N use), recalcitrance (decomposition)
Key concepts for climate change research:

Photosynthesis is driven by light, temperature, water availability, nutrients, etc.

If we can measure specific processes of photosynthesis using imaging spectroscopy and thermal (temperature) measurements, then:

• We can measure changes in photosynthetic rates, and:
• Assess changes in carbon assimilation by vegetation and changes in vegetation function associated with $\Delta T$.
• *Global mission necessary to evaluate changes in photosynthesis that occur over large areas.*
Definition: \( V(c)_{\text{max}} \) – maximum rate of carboxylation

Carboxylation – initial addition of \( \text{CO}_2 \) to \( \text{RuBP} \) (catalyzed by RuBisCO). Addition of ATP and NADPH \( \rightarrow \) triose phosphate
Photosynthesis – The Chloroplast

- Outer Membrane
- Granum
- Lumen
- Inner Membrane
- Stroma (aqueous space)
- Thylakoids

http://photoprotection.clinuvel.com/custom/uploads/LUV_fig4_chloroplast_v(1).gif
Definition: Jmax – electron transport rate

Diagram from wikipedia commons
**Background:**

$V_{(c)\text{max}}$: Measurement of process by which Rubisco catalyzes RuBP with CO$_2$ to produce the carbon compounds that eventually become triose phosphates (G3P, PGAL)

Triose phosphates are the building block for sugars and starches.

$J_{\text{max}}$: Transport of electrons through the thylakoid membrane is critical to producing NADPH and ATP, which provide the metabolic energy necessary to produce triose phosphates.
Biochemical modeling of photosynthesis

\[ A_n = \min(A_c, A_j, A_p) - R_d \]

- Limited by
  - Rubisco
  - RuBP regeneration
  - Triose phosphate utilization

- Determine key metabolic variables
  - \( V_{cmax} \): Rubisco activity
  - \( J_{max} \): Electron transport

Intercellular CO₂ \((C_i; \: \text{µmol mol}^{-1})\)

Assimilation \((A; \: \text{µmol m}^{-2} \: \text{s}^{-1})\)

G3P utilization

Rubisco

\( V_{cmax} \)

\( J_{max} \)

RuBP
Across the range of a species**

Photosynthetic capacity varies according to climate

Changes in climate should be expressed in changes in rates (Vcmax, Jmax)

How will climate change affect composition and metabolism?

[Map showing climate data with AVIRIS 2009 and AVIRIS 2008 lines, PRISM Data: http://www.prism.oregonstate.edu]
How will climate change affect composition and metabolism?

- **Hyperspectral imagery**
- **Field collection**
  - Gas exchange
  - Spectra
  - Canopy temperature
- **Examine regional trends**
  - Lat/Long variation

PRISM Data: [http://www.prism.oregonstate.edu/](http://www.prism.oregonstate.edu/)
Where does HyspIRI fit in?

HyspIRI spectral and thermal measurements provide the opportunity to directly measure the photochemical processes associated with carbon assimilation (e.g., $A_{\text{max}}$) and respiration *by plants across the ranges of species.*

These HyspIRI products provide the potential to identify changes in photosynthetic processes associated with climate change (e.g., temperature) across species.
Detection of leaf metabolic rates using spectroscopy
Physiological data in glasshouse study

- Three temperature regimes
  - 13/20 °C, 18/25 °C, 23/30 °C
- Leaf gas exchange
  - $V_{\text{cmax}}$, $J_{\text{max}}$, $A_{\text{mass}}$, $A_{\text{area}}$
- Morphology and nutrition
  - SLA, Leaf N
- Leaf optical properties (350-2500 nm)
Empirical evidence: Cottonwood and Aspen
Physiological measurements across temperature regimes

N (mass)

LMA

V(c)max

Jmax

Night – Day Temperature
Predictions using leaf spectra and PLSR (%N example)

$R^2 = 0.89$

RMSE = 15.4
Biotron measurements show thermal effects on leaf metabolism

Pooled $R^2$ between spectra-predicted $V(c)_{\text{max}}/J_{\text{max}}$ and leaf N

$R^2 = 0.003$  

$R^2 = 0.33$

Pooled $R^2$ between spectra-predicted $V(c)_{\text{max}}/J_{\text{max}}$ and leaf N
Spectra are responsive to temp.-driven variations in metabolism

<table>
<thead>
<tr>
<th>Time</th>
<th>Tleaf (°C)</th>
<th>Vcmax (μmol m⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>23.8</td>
<td>54.8</td>
</tr>
<tr>
<td>Afternoon</td>
<td>31.4</td>
<td>114.3</td>
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</tbody>
</table>
Examples: AVIRIS imagery from the Upper Midwest

Baraboo Hills

Ottawa NF / Sylvania

Porcupine Mountains

Northern Minnesota

Old growth hemlock / Hwd
Northern hardwood
Oak / hickory
Boreal forest
Examples: LMA – based on hypothesized relationships

Baraboo Hills

Ottawa NF

Minnesota
Examples: $V(c)_{\text{max}}$ – based on hypothesized relationships

- **Baraboo Hills**
  - $V_{\text{cmax}}$ ($\mu$ mol m$^{-2}$ s$^{-1}$)
  - Water / Non veg

- **Ottawa NF**
  - $V_{\text{cmax}}$ ($\mu$ mol m$^{-2}$ s$^{-1}$)
  - Water / Non veg

- **Minnesota**
  - $V_{\text{cmax}}$ ($\mu$ mol m$^{-2}$ s$^{-1}$)
  - Water / Non veg
Examples: $J_{\text{max}}$ – based on hypothesized relationships

- **Baraboo Hills**: $J_{\text{max}}$ (µ mol m⁻² s⁻¹) varies from 20 to 120.
- **Ottawa NF**: $J_{\text{max}}$ (µ mol m⁻² s⁻¹) varies from 8 to 72.
- **Minnesota**: $J_{\text{max}}$ (µ mol m⁻² s⁻¹) varies from 8 to 56.
Now working on scaling leaf → canopy → sensor

Using HyspIRI-like data (AVIRIS + ASTER/MASTER), we are looking at forest acclimation to T and CO₂.
Remote sensing of genetic diversity in aspen:
Directly associated with vegetation response to climate change
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