Improving Forest Modeling with Spectrally Derived Traits

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Acknowledgements: Paul Montesano, Guoqing Sun and Jon Ranson
Individual-Based Gap Models

- Well established class of models
- Life history of each individual is simulated as a unique entity
- Main processes: establishment, diameter growth, and mortality
- Each tree on a modeled plot is subjected to simple interaction rules (shading, competition, resource limitation) in conjunction with the main processes
- Gap models have high levels of accuracy/prediction at the scale of small plots, but computer processor limitations previously prevented this resolution to extend across landscapes
- Higher resolution remote sensing and cloud computing has given rise to the capability to build models that are spatially explicit and can be linked to larger landscape level simulations
- Synergy with hyperspectral derived vegetation indices
Study Objectives

- Parameterize SIBBORK for Howland Forest, Maine (SIBBORK-ME)

- Use atmospherically corrected Hyperion data to derive vegetation indices across the Howland Forest, 2009-2010

- Compare indices (e.g. vegetation type, stress variables) with inventory data (calibrate at plot level, scale to Hyperion tiles)

- Test model parameterization with vegetation indices

- Validate Hyperion indices over time using LIDAR and modeled forest output raster datasets
SIBBORK-ME Study Framework
(On-going Effort)

EO-1

Forest Inventory Data
Soils Data
Weather Data
Ancillary Data

Initial SIBBORK-HF

Hyperspectral-Derived Indices
NDVI
fAPAR
Chlorophyll
Vegetation type
H2O stress

Model Initialization

Validation using LIDAR & time series

Improved SIBBORK-HF

SIBBORK-ME
The SIBBORK Model

- Model by Brahznick and Shugart (2015) individual-based 3D gap model
- Based on ZELIG (Urban, 1990)
- 3D light environment (topographic position)
- Compatible with hyperspectral derived vegetation indices in resolution and data format (raster)

**Inputs**

- Site Conditions
- Mortality
- Growth
- Regeneration
- Light Climate

**Model Framework**

**Outputs (annual, per plot)**

- Monthly temp, precip, total degree days, relative dry days
- # live trees in each size class, # dead trees from stress, # dead natural causes
- # live trees in each size class, # dead trees from stress, # dead natural causes
- # individuals per species, DBH size distribution, DBH, HT, crown height, diameter increment, stress flags due to: light, drought, soil fertility, temp, other env factors
- # and species of new sapplings, seed dispersal dependent on env factors

- For each species and each stand: stem density, BA, AGB, mean DBH, mean Ht, biovolume, LAI,
Study Area: Howland, Maine

- Old Growth Forest
- Shelterwood
- Stripcut
- 2010 Stem Map

- 1675m N
- 2010 NASA Forest Plots

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Howland, Me SIBBORK Parameterization

Environmental Data:
• Weather data from NOAA data product
• Soil data from ZELIG (Levine- NASA)

Tree Data:
• Forestry Weight Tables: biovolume, foliar volume
• Plot data: 2009, 2010, 4 stand types
• For 16 Tree Species:
  - life history: USDA (Agemax, Htmax, Dmax), ZELIG (Ranson et al 1995)
  - LAI: SLA, foliar variables – literature, weight tables
  - stem numbers: NASA 2010 stem map (~2800 trees measured in 3ha)
  - tree growth: ZELIG
  - basal area: standard equation, plot data

<table>
<thead>
<tr>
<th>SIBBORK Species Code</th>
<th>Common Name</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABBA</td>
<td>Balsam Fir</td>
<td>Abies balsamea</td>
</tr>
<tr>
<td>ACPE</td>
<td>Striped Maple</td>
<td>Acer pensylvanicum L.</td>
</tr>
<tr>
<td>ACRU</td>
<td>Red Maple</td>
<td>Acer rubrum</td>
</tr>
<tr>
<td>ACSA</td>
<td>Sugar Maple</td>
<td>Acer saccharum</td>
</tr>
<tr>
<td>BEAL</td>
<td>Yellow Birch</td>
<td>Betula alleghaniensis</td>
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<tr>
<td>BEPA</td>
<td>White Birch</td>
<td>Betula papyrifera</td>
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<tr>
<td>BEPO</td>
<td>Gray Birch</td>
<td>Betula populifolia</td>
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<tr>
<td>FAGR</td>
<td>American Beech</td>
<td>Fagus grandifolia</td>
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<tr>
<td>FRAM</td>
<td>White Ash</td>
<td>Fraxinus americana</td>
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<td>Black Ash</td>
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<td>Black Spruce</td>
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<td>Spruce</td>
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<td>PIST</td>
<td>White Pine</td>
<td>Pinus strobus</td>
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<tr>
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<td>Populus grandidentata</td>
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<td>Quaking Aspen</td>
<td>Populus Tremuloidus</td>
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<tr>
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<td>Northern White Cedar</td>
<td>Thuja occidentalis</td>
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<tr>
<td>TIAM</td>
<td>American Basswood</td>
<td>Tilia Americana</td>
</tr>
<tr>
<td>TSCA</td>
<td>Eastern Hemlock</td>
<td>Tsuga canadensis</td>
</tr>
</tbody>
</table>
SIBBORK-ME Model Equations

Height (m)
(Range 0 - 40.0)
SIBBORK-ME Captures Succession...
Study Area: Multiple Forest Stand Types

- Old Growth Forest
- Shelterwood 2000
- 2010 Stem Map
- Stripcut 1995
- Stripcut 1990
- Stripcut 1985 Clearcut
- Stripcut 2000

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2010 NASA Forest Plots
Initial Model Testing Results

Year
2010
Stem Plot = yr180

AGB (MgC/ha)
Initial Model Results Through Simulation

<table>
<thead>
<tr>
<th>Species</th>
<th>% of Stems</th>
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<tbody>
<tr>
<td>ABBA</td>
<td>17.2%</td>
</tr>
<tr>
<td>ACPE</td>
<td>0.6%</td>
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<tr>
<td>ACRU</td>
<td>2.2%</td>
</tr>
<tr>
<td>ACSA</td>
<td>5.3%</td>
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<tr>
<td>BEAL</td>
<td>0.5%</td>
</tr>
<tr>
<td>BEPA</td>
<td>4.9%</td>
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<tr>
<td>BEPO</td>
<td>7.1%</td>
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<tr>
<td>FAGR</td>
<td>0.9%</td>
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<tr>
<td>FRAM</td>
<td>2.3%</td>
</tr>
<tr>
<td>LALA</td>
<td>11.6%</td>
</tr>
<tr>
<td>PIRU</td>
<td>13.0%</td>
</tr>
<tr>
<td>PIST</td>
<td>0.4%</td>
</tr>
<tr>
<td>POGR</td>
<td>1.1%</td>
</tr>
<tr>
<td>POTR</td>
<td>1.1%</td>
</tr>
<tr>
<td>THOC</td>
<td>5.4%</td>
</tr>
<tr>
<td>TSCA</td>
<td>26.2%</td>
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SIBBORK output

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<tr>
<th>Species</th>
<th>% of Stems</th>
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<tbody>
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<td>ABBA</td>
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<tr>
<td>ACPE</td>
<td>10.4%</td>
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<tr>
<td>ACRU</td>
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<tr>
<td>ACSA</td>
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<tr>
<td>BEAL</td>
<td>14.9%</td>
</tr>
<tr>
<td>BEPA</td>
<td>17.6%</td>
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</table>

2010 Stem Map

<table>
<thead>
<tr>
<th>Species</th>
<th>% of Stems</th>
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<tr>
<td>ABBA</td>
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SIBBORK-ME Study Framework (On-going Effort)

EO-1

Hyperspectral-Derived Indices

H2O stress
Vegetation type

NDVI
fAPAR
Chlorophyll

Validation using LIDAR & time series

Model Initialization

Improved SIBBORK-HF

Initial SIBBORK-HF

Ancillary Data

Forest Inventory Data
Soils Data
Weather Data
Hyperion Vegetation Indices

\[ \text{NDVI} = \frac{B_{57} - B_{27}}{B_{57} + B_{27}} \]

\[ \text{GitelsonChl} = \frac{1/B_{20} - (1/B_{44}) \times B_{44}}{} \]

\[ \text{MTCI} = \frac{B_{40} - B_{36}}{B_{36} - B_{33}} \]

\[ \text{PRI} = \frac{B_{531} - B_{570}}{B_{531} + B_{570}} \]

Image Year: 2009
Relating Vegetation Indices to Field Data

NDVI: Clearcut 1985 (red above)

NDVI: Old Growth (cyan above)
NDVI shows expected differences across stand age...

- **Clearcut (1985)**
- **Stripcut plots (1990, 1995)**
- **Shelterwood (2000)**
- **Old Growth**

**Axes:**
- **NDVI**
- **Biomass MgC/ha**

**Legend:**
- 2009
- 2010
Gitelson Chlorophyll also relates to stand age...

Stripcut plots (1990, 1995)

Shelterwood (2000)

Clearcut (1985)

Old Growth

Biomass (MgC/ha)

GitCl

50.00  70.00  90.00  110.00  130.00  150.00  170.00

2009

2010
Model Refinement with Vegetation Indices

- Improve model accuracy
- Derive forest composition from Hyperion spectral indices, compare to field data and model output to expand simulation area
- Relate PRIs to LUE for model ingestion
- Investigate fAPAR (Zhang et al.) and Water stress characteristics for diameter growth increment limitation, GEP effects
- Spatially explicit simulation
Initial Model Equations

**Height (m) (Range 0 - 40.0)**

**Optimal diameter growth increment (cm) (Range 0-2.4)**

**Aboveground Biomass (MgC) (Range 0 - 40.0)**

**Leaf Area (m²/ha) (Range 0 - 1000)**

X-axis = DBH (cm)
Initial Model Testing Results

<table>
<thead>
<tr>
<th>Year</th>
<th>Leaf Area (m²/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
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</tr>
<tr>
<td>4000</td>
<td></td>
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