Outline

• Vegetation modeling
• Model description and mechanics
• Input/output
• Performance/Validation
• Application
  • Biomass
  • Climate sensitivity analysis
  • GCM projections
• Future directions
Model comparison – types of vegetation models for large scale simulation

• Biogeographical approaches ask what vegetation matches what climate by associating a given vegetation type with a climate condition

• Canopy process models simulate flux of $CO_2$ and water between plant canopies and environment - scaled up to landscape or regional system response (big leaf model)

• Individual based gap models (IBM) simulate establishment, diameter growth and mortality of each tree to provide generalized forest community
Motivation - Why Individual Based Models?

- Response of forest to changing climate and disturbance patterns occurs at level of species

- Grouping species as functional types loses this fine scale response

- No longer limited by computing power or time
FAREAST: A Boreal Forest Simulator


- Individual based model of forest ecosystem
- Trees influenced by soil nutrients and water, climate, and canopy
- Species niche parameters drive competition (growth rates, regeneration needs, sizes, longevities)
- Forest community and species response to climate and disturbance regimes
Climate

Plant available nitrogen and carbon

PAR

Water

Monte Carlo simulation 200 independent plots

Output: Tree and Stand Level Details:
Species, Age, DBH, Biomass, Basal Area, C and N dynamics

Seed Bank
FAREAST: Tree Sub module

**Growth:**
- Available Light
- Soil Moisture
- Site Quality
- Growing-Degree Days
- Depth of Thaw
- Diameter
- Age
- Height

**Mortality:**
- Stress
- Fire
- Insects
- Age

**Regeneration:**
- Available Light
- Soil Moisture
- Site Quality
- Depth of Thaw
- Seed Bed
- Seed Availability
- Sprouting
- Layering
Input Data

• Average monthly climatic data
• Soil carbon and nitrogen in organic and mineral soils
• Soil water holding characteristics
• Species parameters
  – Age Max, DBH max, Height max, Growth curves, Seed dispersal and survival, Tolerance for climate, shade, drought, and nutrients
MODEL PERFORMANCE AND APPLICATION
Spatial Scale

Simulation of Stand data

Complexity
Validation with Inventory Data

Southern Siberia inventory *Larix spp.*

Southern Siberia model site *Larix spp.*

Inventory biomass

Model biomass

\[ y = 0.8804x \]

\[ R^2 = 0.994 \]

Shuman, J.K. *et al.* (in review) *Ecological Modelling*
Sensitivity to local conditions

Complexity

Spatial Scale
Inventory vs Model *Larix* Biomass (tCha\(^{-1}\)), Irkutsk

Shuman, J.K. *et al.* (in review) *Ecological Modelling*
Reproduces complex mountain community
Tests of the FAREAST Model on Mountain Gradients


Actual Versus Simulated Basal Area by Species at Four Elevations

\[ y = 0.8546x \]

\[ R^2 = 0.8539 \]
Validation across Russia:
Comparison to inventory

Tests of the PAREAST Model on Mountain Gradients

Validation with Inventory Data

Inventory vs Model Larix Biomass (tCha⁻¹)

For each point, given data on climate and soil, UVAFME simulates the growth, death and mortality of individual trees on a small plot to assemble and produce change in a forest.

Complexity
Validation across Russia

43 Forest Inventory Locations

- 93 Comparisons (Maximum Distance 125km)
- Original sites (Yan and Shugart 2005)
Validation across Russia
Linear regression of total model simulated to forest measured biomass (tC ha\(^{-1}\))

Successful correlations met all of the following criteria:
p\(<0.001, R^2 > 0.54, \text{ and slope} < 1.5 \text{ for a linear trend line with an intercept of zero}\)

Shuman, J.K. et al. (in review) Ecological Modelling
Validation across Landscape: Comparison to Biogeographical model
Comparisons to Biogeographical model

Forests of the USSR (Isaev 1990)

Pinus sylvestris  Kappa = 0.58 (good)
Validation across Landscape: Estimates of Primary Production
Model Estimates of Primary Production

Process based ecosystem simulation (Big Leaf and biogeographical)

MODIS NDVI and MERRA reanalysis surface meteorology
Model Application: Response to Climate Change Stand dynamics
For each point, given data on climate and soil, FAREAST simulates the growth, death and mortality of individual trees on a small plot to assemble and produce change in a forest.

High diversity
NRFE

Low diversity
Central Siberia

Low diversity
NW Siberia

\[ +4^\circ C \]

Shuman, J.K. et al. (2011) Global Change Biology
Model Application: Response to Climate Change
Landscape dynamics
Response of mixed-age forest

Current climate conditions at year 100

NCAR CCSM sres A1B at year 100 (2X CO$_2$, altered temp and precip)

*Larix* species biomass

Broad-leaved deciduous species biomass

Total mixed species biomass
Future work - UVAFME

• Object oriented code
  - Flexibility in adding new features (beetles)
  - Easier to introduce different parameters corresponding to different regions (i.e. solar radiation, sun angle, etc.)

• Existing capabilities allow us to run Monte Carlo style simulation of 31,000 sites with 200 replicates per site within 24 hours

• With additional computing power easily run global simulation
Conclusion

- IBM s represent new frontier for large scale simulation
  - Accurate at prediction
  - Provide detailed results at high resolution for large scale application
  - Useful for future predictions and hindcasting
THANK YOU!

Funding:

NEESPI: Northern Eurasian Earth Science Partnership Initiative
FAREAST Model subroutines, functions and interactions
Management and biomass
Regional age cohort distribution

Regional forest age cohort distribution

Total area (%) vs Age (years)

- NW
- East
- South

Age categories:
- 0-30
- 30-60
- 60-90
- 90-120
- 120-150
- 150-180
- 180-210
- 210+
Total biomass corrected for age distribution

Babushkin

Years from bare ground

Biomass (tCha$^{-1}$)

0 20 40 60 80 100

0 50 100 150 200 250

Years from bare ground

Biomass (tCha$^{-1}$) for Babushkin

Larix

Pinus

Picea

Populus

Abies

GDLO inventory station

Percent of Forest Area

Age of Cohort (Years)

Current total biomass: 69.5 tC ha$^{-1}$

Even total biomass: 63.01 tC ha$^{-1}$

Mature total biomass: 85.84 tC ha$^{-1}$

Cohort contribution to biomass for GDLO inventory station

Babushkin

Years from bare ground

Biomass (tCha$^{-1}$)

0 20 40 60 80 100

0 50 100 150 200 250

Years from bare ground

Biomass (tCha$^{-1}$) for Babushkin

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Current total biomass: 69.5 tC ha$^{-1}$

Even total biomass: 63.01 tC ha$^{-1}$

Mature total biomass: 85.84 tC ha$^{-1}$
Management and biomass

Difference in letters indicates significantly different biomass (p<0.05)

Shuman, J.K. et al. (in review) Environmental Research Letters
Continental Scale results for non-parametric factorial ANOVA of biomass ($tC \text{ ha}^{-1}$), $p < 0.001$ 

$+4^\circ C$, Precipitation $\pm 10\%$, $\pm$ Larix decidua

Temperature early in succession prior year 150 for all classes

Precipitation variable response later in succession - connection to evergreen conifer replacement

Larix decidua significantly alters biomass from start
Species distribution for the historical and temperature increase climates

Shuman, J.K. et al. (2011) Global Change Biology
Impacts of climate change on biomass and species composition

<table>
<thead>
<tr>
<th>Forest Stand Initialization (years)</th>
<th>Model simulation year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>25</td>
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<td>begin climate change</td>
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<tr>
<td>50</td>
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</tr>
<tr>
<td>75</td>
<td>historic climate</td>
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<tr>
<td></td>
<td>begin climate change</td>
</tr>
<tr>
<td>100</td>
<td>historic climate</td>
</tr>
<tr>
<td></td>
<td>begin climate change</td>
</tr>
</tbody>
</table>

Table 1: Forest model initialization and timing of incorporation of climate change scenario data

FAREAST was run at 31,010 sites across Russia for historic climate and with climate change data from NCAR CCSM sresA1B (720ppm CO₂), and GEOS sresA1B (720ppm CO₂)
Results for mixed-age forest landscape

Historic climate at year 100

GEOS A1B at year 100

*Larix* species biomass

Broad-leaved deciduous species biomass

Total mixed species biomass

Carbon biomass (tC ha⁻¹)
Impacts of climate change (sresA1B from NCAR CCSM and GEOS)

• NCAR CCSM data more impact on forest biomass

• Evergreen conifer biomass similar in historic and altered climate

• Broad leaved deciduous biomass increases where Larix biomass decreases

• Total mixed species biomass in altered climate not as high as historic levels

• Results again identify Siberian forests as area of a high degree of change in species composition and biomass dynamics
Species
Age
Biomass
Basal Area
Diameter at Breast Height

Model output: average of individually simulated plots with dynamic climate and vegetation
Test sites in China and Russia

Successful prediction of observed forest type by model
FAREAST model results for mature forest (200 simulated plots for 500 years from bare ground): biomass values from 0 to 206.28 tCha$^{-1}$

Species Range Maps

Increase from 44 to 52 total species

28 species specific parameters for 12 new species

- 52 species ranges incorporated as presence or absence using GIS
Climate sensitivity analysis in Siberia

12 treatments: +4°C, Precipitation ± 10%, ± Larix decidua

<table>
<thead>
<tr>
<th>Change in temperature</th>
<th>Base + 4 degrees C</th>
<th>Average 9 tree species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in precipitation</td>
<td>Base ± 10%</td>
<td></td>
</tr>
<tr>
<td>Introduction of Larix decidua (mitigate shift in species)</td>
<td>Base ± Larix decidua</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Treatments used in climate sensitivity analysis

572 sites for continental scale analysis
6 regions: NW Siberia, central Siberia, two sets in S Siberia, N RFE, and SW RFE

200 years of linear change in precipitation, temperature, or both followed by 300 years with climate stabilized around conditions in year 200
Siberian Pine regeneration under a Larch canopy
In the cold Siberian winter

Snow reflects radiation from the Sun back into space
In the cold Siberian winter, deciduous Larch trees allow snow to reflect radiation from the Sun. With the warming climate, these are replaced by evergreen conifers...
In the cold Siberian winter

Evergreen trees absorb sunlight, reduce reflection and produce a warmer surface.
Larch trees reflect more light back into space year-round but the effect is very large in the winter.
Conversion from larch to evergreen forest creates positive feedback: forest absorbs 2 to 7% more solar radiation reinforcing local warming trends.