Expansion of Loblolly Pines for Bioenergy feedstock in the Southeastern US: Climate model insights

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One Billion Ton biomass target

- Large land conversion to perennial crops if market for bioenergy emerges.
- Acres harvested under DOE/USDA land use change scenario:

<table>
<thead>
<tr>
<th>Perennials</th>
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<tr>
<td>Moderate crop yield increase: 35 million acres</td>
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<td>High crop yield increase: 55 million acres</td>
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- USDA/DOE assumes woody feedstock comes from additional forests planted on marginal agricultural land and pasture land.
Land Cover Change

- LCC impacts the energy, radiation and hydrological budgets at regional to global scales.

- LCC due to expansion of biofuels may have non-trivial effects on climate through biophysical feedbacks.

- Perennial grasses (Miscanthus) caused regional cooling (up to 1°C) compared to annual crops (maize) due to higher LAI, transpiration and rooting depth (Georgescu et al., 2009; Georgescu et al., 2011).

- Remote-sensing data showed growing sugar cane crops on agricultural land cooled temperatures by almost 1°C due to enhanced ET and higher albedo (Loarie et al., 2011).
Motivation

• Native Loblolly Pines are the prime candidate for plantation bioenergy in the Southeast US (Kline and Coleman, 2010).

• In this work we quantify the effects of woody crops for biofeedstock production on regional and hemispheric climate under a plausible 21st century deployment scenario in the SE US.
Methodology

- To represent Loblolly pine (LP) in CCSM4 we optimized PFT physiology parameters to minimize observed versus predicted differences in energy fluxes.

- We used observations from the AmeriFlux Duke Forest Loblolly site for the period 2003-2009.
Improved daytime energy fluxes

We altered two parameters that influence photosynthesis:
- Flnr – fraction of leaf N in Rubisco enzyme
- Mp – slope of conductance to photosynthesis relationship

- We ran a 36-member ensemble (gray) varying each parameter 6 times [(flnr = 0.05-0.1), (mp = 5-10)]
- Observations in red
- Default NET (blue): flnr = 0.05, mp = 6
- Loblolly pine (green): flnr = 0.05, mp = 10
### Experimental design

<table>
<thead>
<tr>
<th>Name</th>
<th>LAI</th>
<th>LCC</th>
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<tbody>
<tr>
<td>PD Loblolly</td>
<td>Duke Forest Loblolly LAI</td>
<td>Same as 1.</td>
</tr>
<tr>
<td>Future Loblolly</td>
<td>Same as 2.</td>
<td>Same as 1. In addition we converted C₄ grasslands to Loblolly Pines in the SE US.</td>
</tr>
<tr>
<td>CTL</td>
<td>Default LAI</td>
<td>PD land cover (NET in SE US).</td>
</tr>
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</table>

- We use a data ocean model and CN is off (“f_2000” compset)
- All simulations are integrated for 60 years with static land cover. Averages and statistical significance are calculated using the last 40 years of simulation.
Loblolly Pine (Pinus taeda)

http://fia.fs.fed.us/library/maps/
Results: JJA Heat fluxes

Sensible Heat flux

Heat Fluxes [W m$^{-2}$]

Latent Heat flux

PD (old LAI) - CTL

PD - CTL

Future - CTL
Results: DJF Heat fluxes

Sensible Heat flux  Latent Heat flux

PD (old LAI) - CTL

PD - CTL

Future - CTL
Results: 2m Air Temperature

- Cooling of a quarter degree between 40-70°N due to the addition of Loblolly pine.
Results: Circulation changes

- Aleutian low is slightly weakened during DJF.
- Eddy kinetic energy averaged longitudinally shows increase in Northern Hemisphere suggesting northward shift in storm tracks.
Results: Global precipitation anomaly (% change)
Results: Atmospheric divergence

Southern Hemisphere changes may result from the vorticity transport set up by perturbed large-scale divergence [Chase et al., 2000].

Transport of vorticity by the divergent field is an effective transport mechanism, especially for tropical-extratropical teleconnections [Sardeshmukh and Hoskins, 1987].
Conclusions

• Our new optimized Loblolly PFT resulted in decreased sensible heat flux and increased latent heat flux compared to the NET PFT.
• Cooling over the SE US was largest in summer.
• Northern Hemisphere cooling between 40-70°N is largest in winter.
• Changes in the Aleutian low may alter storm tracks in the Northern Hemisphere.
• Perturbations in atmospheric divergent field may lead to teleconnections in the Southern Hemisphere due to vorticity advection.
References and Pictures

- Slide 3: http://agronomyday.cropsci.illinois.edu/2005/Tour_D/Fuel/
- Slide 3: http://sites.google.com/site/sugarcanepm/pre-harvest-burning
THANKS!
Results: Canopy transpiration

- Higher transpiration over SE US during the summer is due to physiology changes and not LAI changes.
- Development of Low Pressure over Northern Canada results in greater low level cloud cover – which reduces the short wave radiation at the surface leading to less transpiration.

Years 20–60 canopy transpiration [watt/m^2]
PD temperate NET distribution

PD temperate NET distribution + C4 grasslands
Simulated vs Observed Graphs for Sensible Heat (SH) and Latent Heat (LH) Fluxes for Average 10am-4pm.

**SH Best**
- Simulated: \( y = 0.63x + 9.73 \)
- Observed

**LH Best**
- Simulated: \( y = 0.79x + 40.53 \)
- Observed

**SH Default**
- Simulated: \( y = 0.35x + 27.30 \)
- Observed

**LH Default**
- Simulated: \( y = 1.36x + 21.61 \)
- Observed

Figure:
Results: Atmospheric divergence

JJA Velocity Potential 300 h-Pa

years 20–60 velocity potential Anomaly [m^2/s]