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

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Joint Land and BGC Working Groups

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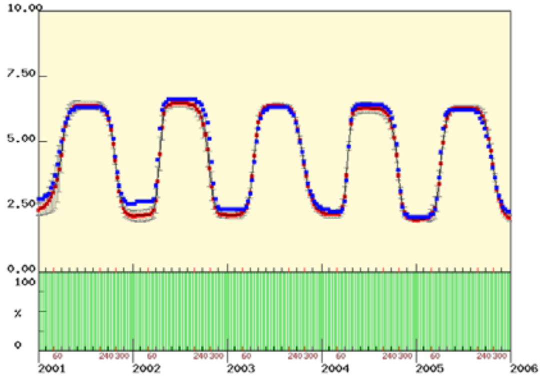
Short-Rotation Woody Crops

- Perennial woody crops are a potential biomass resource
  - Includes Southern Pines, Hardwoods, Coppice
- In 2008, woody biomass accounted for 10% of electricity produced from renewables (White et al., 2009)
- Short-rotation forests are more cost-effective and mitigate more climate change than long-rotation forests (Hedenus and Azar, 2009)
- Ecosystems can benefit from woody crops

Loblolly Pine (Pinus taeda)

- Most widely planted forestry species in world
- ~30 million acres of pine plantations
- Unlike other conifers, Loblolly has a dynamic seasonal LAI (Zhang and Allen, 1996)
- Prime candidate for plantation bioenergy in the Southeast (Kline and Coleman, 2010)

http://fia.fs.fed.us/library/maps/



MODIS LAI Product: ORNL

Connor, K.F., ed. 2006. Gen. Tech. Rep. SRS-92, USDA

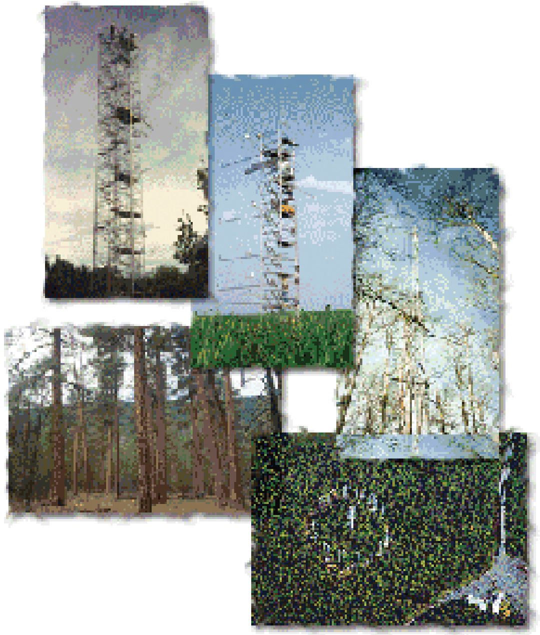
Objectives

- Represent Loblolly pine in CLM4 and use this for future applications to bioenergy
- What is the biophysical response of expanding woody crops for bioenergy?

Methodology

- Change PFT parameters to better simulate modeled energy fluxes
  – Bayesian fusion of model and NACP flux tower data

Observations



- NACP Synthesis/Ameriflux
  - Continuous observations of ecosystem level exchanges spanning diurnal, synoptic, seasonal, and interannual time scales
- Duke Forest/Loblolly Pine (US-Dk3)
  - 35^{o}N, 79^{o}W
  - Data 2001-2005

Duke Forest Loblolly Simulations

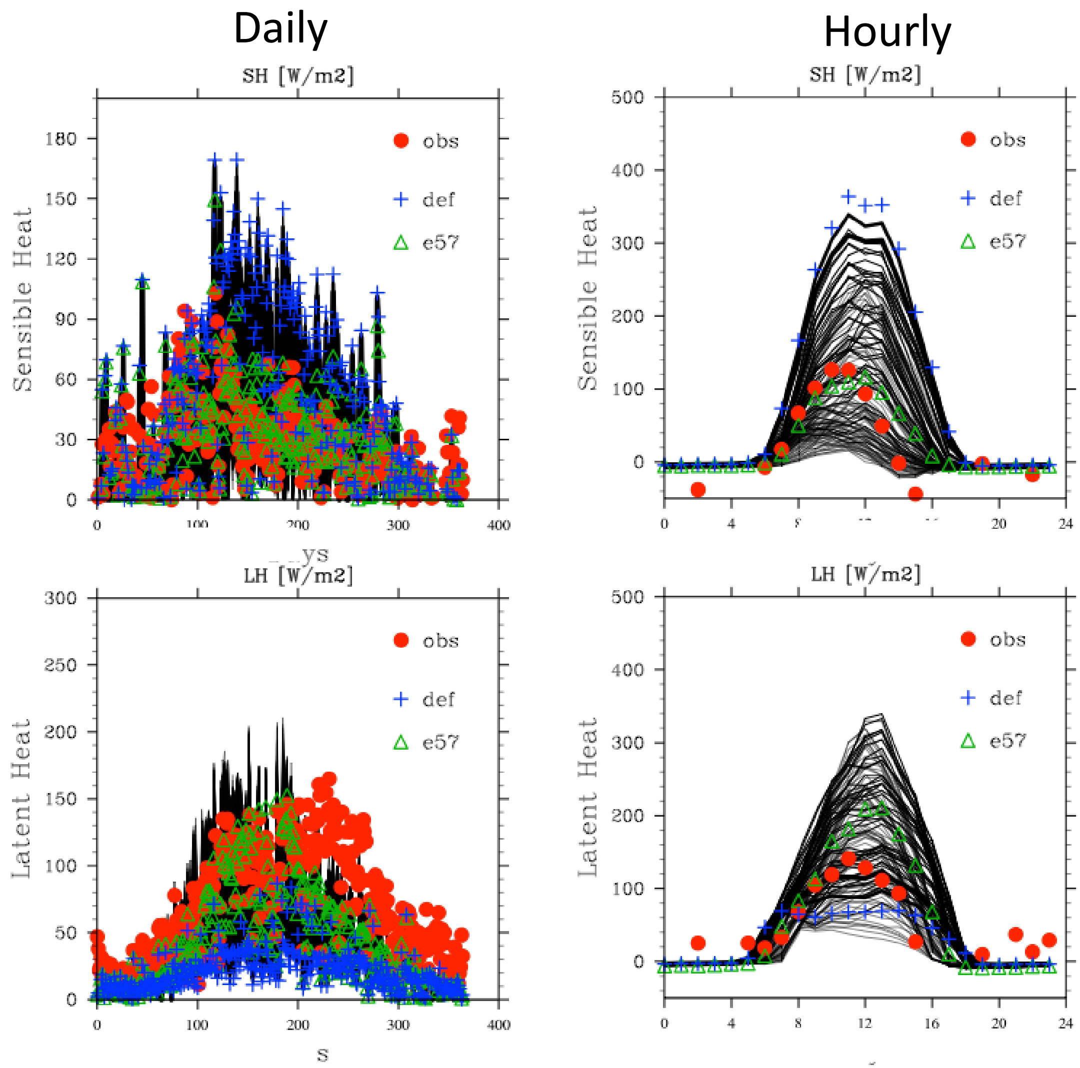
- CLM4 in site mode
  - CN off and LAI set to observed values
- Create a 125 member ensemble changing three parameters that influence photosynthesis

  mp = slope of conductance-to-photosyn. relationship (6)
    - **5,7,9,10,12**

  qe25 = quantum efficiency [μmol C/μmol photon] (0.06)
    - **0.01,0.05,0.10,0.25,0.50**

  flnr = fraction of leaf N in Rubisco enzyme (0.05)
    - **0.02,0.05,0.10,0.18,0.25**

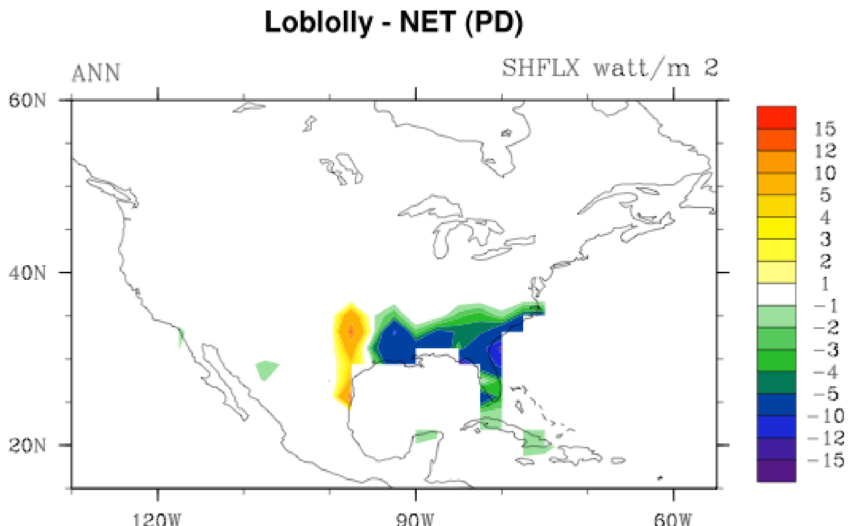
Growing Season Energy Fluxes

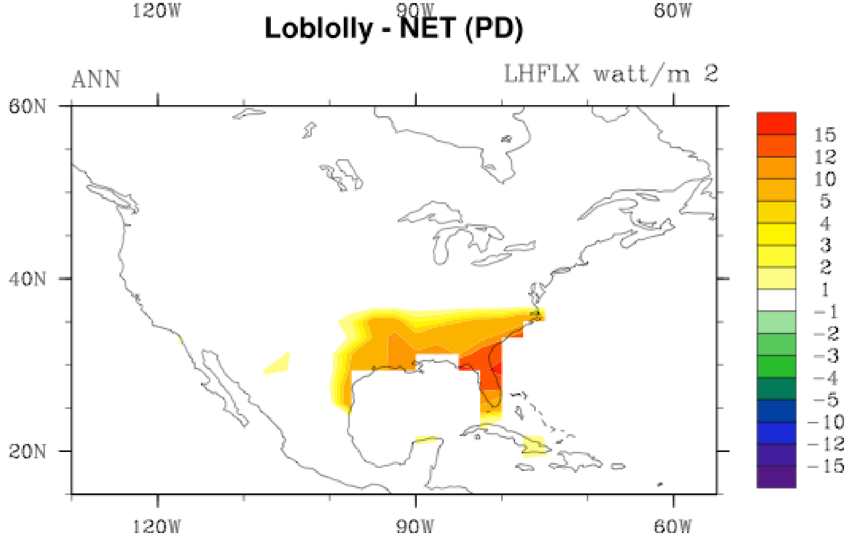


- Expected parameter values estimated from Bayesian inversion: 9, 0.05, 0.1 (default: 6, 0.06,0.05)

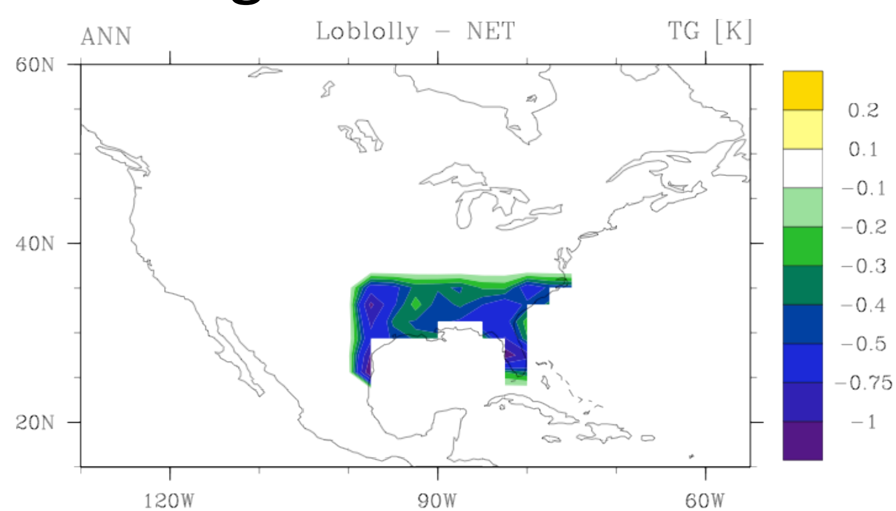
Left (right): July daily (diurnal) cycle for 125 member ensemble (black), observations (red dots), default simulation (blue cross), and the best simulation (green triangles)

Loblolly vs NET (PD distribution)





- Loblolly decreases sensible (most of the SE) and increases latent heat flux compared to NET
  - ↑ LAI intercepts more rain & results in greater transpiration
- Cooler ground



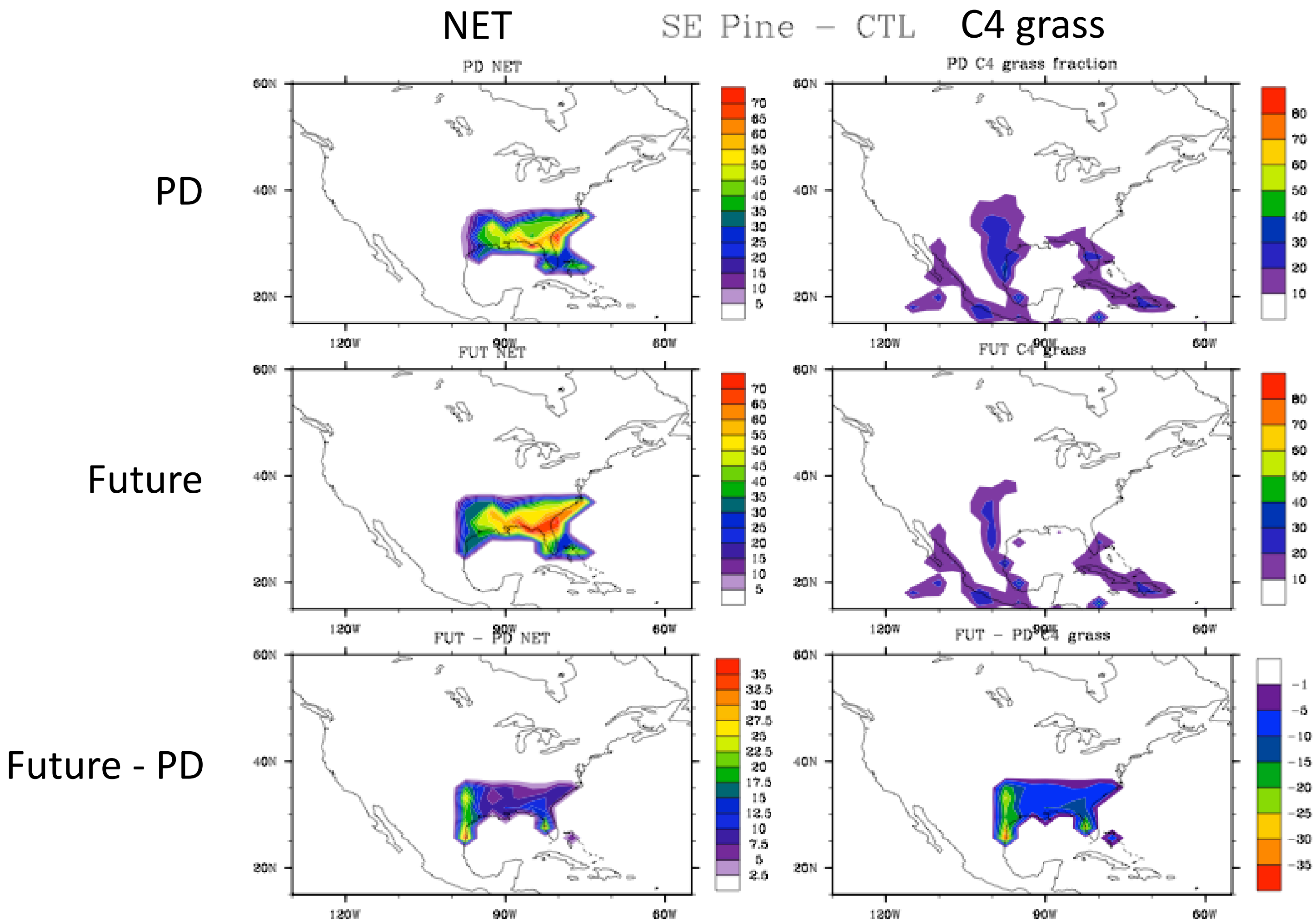
USDA/DOE Target: 1.3 Billion tons of Biomass

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

	Perennials
Moderate crop yield increase:	35 million acres
High crop yield increase:	55 million acres

- USDA/DOE assumes woody feedstock comes from additional forests planted on marginal agricultural land

Future Land Use Change



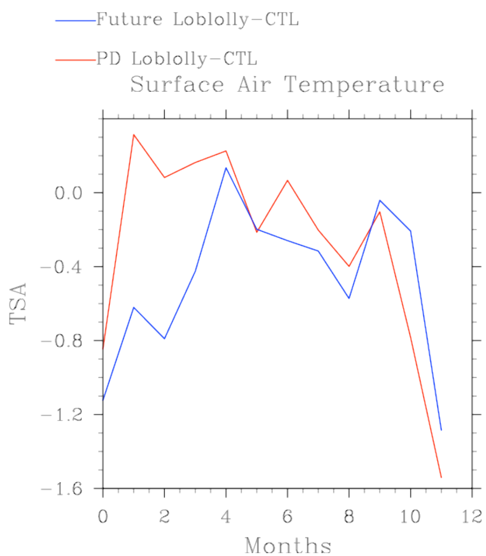
Additional 22 million acres of Loblolly by 2100 (less than half of the biomass goal)

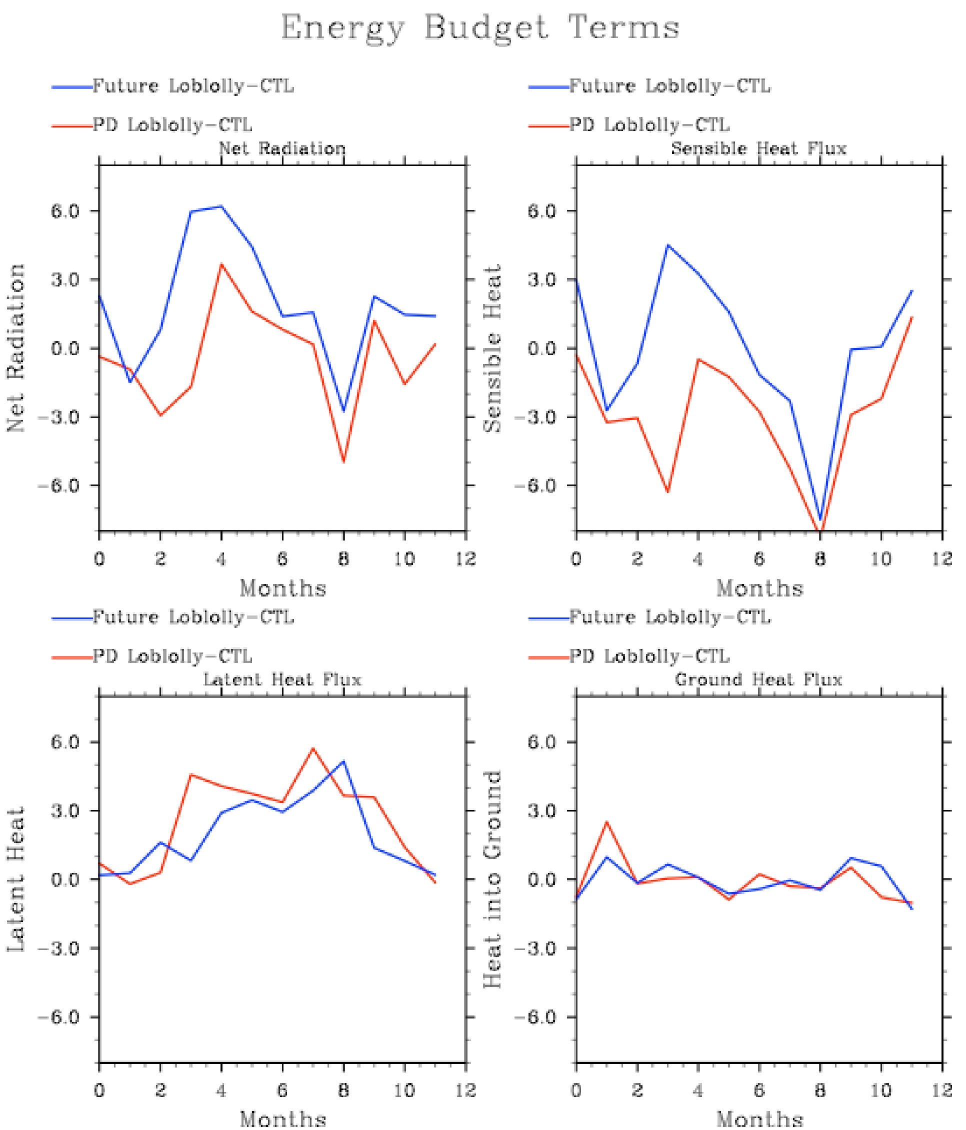
Future Energy Balance

- The surface energy budget is:

$$R_n = H + LE + G$$

- More net radiation with Loblolly afforestation





Surface Albedo

- Average albedo for Loblolly pine plantations ~0.25-0.31 are much higher than other forests types in the SE US (Sun et al., 2010)

Table 5
Albedo values for selected forests ecosystems.

Forest types	Reported albedo (α) values	Reference
Loblolly pine plantation (16 years old, North Carolina	0.25	This study
	0.22 (growing season)	
	0.29 (dormant season)	
Loblolly pine plantation (4 years old), coastal North Carolina	0.34	
	0.31 (growing season)	
	0.38 (dormant season)	
Loblolly pine plantation, 4 years old, North Carolina	0.25–0.31	Amatya et al. (2000)
Grass surface, North Carolina	0.35	Amatya et al. (2000)
Loblolly pine plantation, 25 year old, Piedmont North Carolina	0.10	Juang et al. (2007)
Mature hardwoods, piedmont North Carolina	0.15	Juang et al. (2007)
Grass-cover old field	0.20	Juang et al. (2007)
Slash pine plantation, clearcut, Florida	0.26	Gholz and Clark (2002)
Slash pine plantation, 10 years old, Florida	0.18	
Slash pine plantation, mid-rotation, Florida	0.18	
Eastern white pine (*Pinus strobus* L), 65 years old, Canada	0.12 (growing season)	Restrepo and Arain (2005)
Aspens	0.15 (growing season)	Betts and Ball (1997)
Jack pine and spruce	0.08 (growing season)	
Rain forests	0.12 ± 0.05	Pinker et al. (1980)

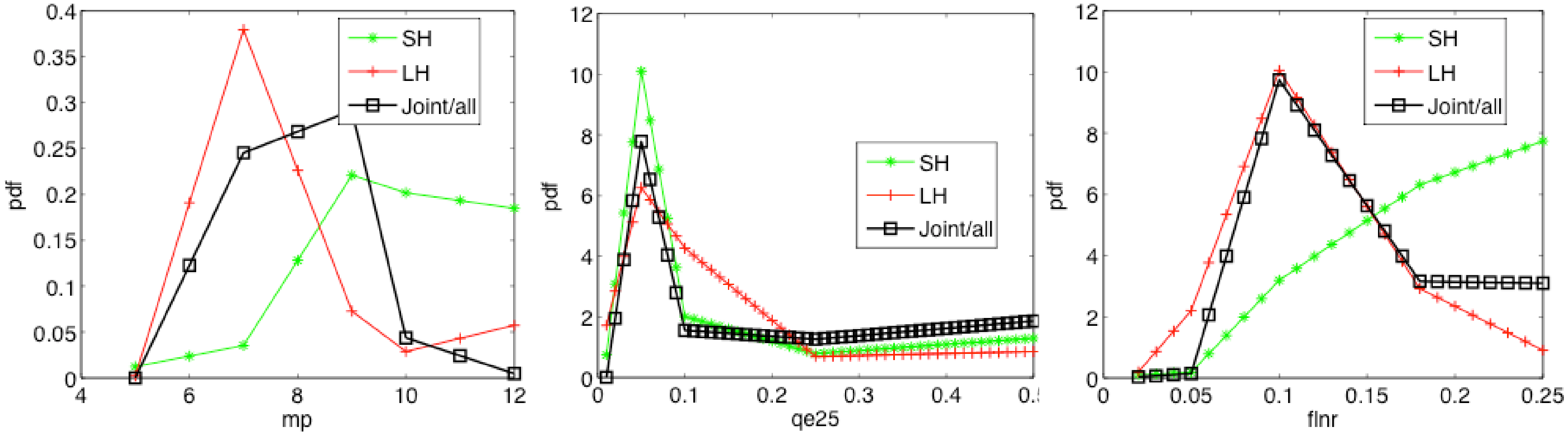
Conclusions

- We developed a new PFT for Loblolly pines in CLM4
- Loblolly pines decreased sensible and increased latent heat and may reduce the surface temperature compared to NET trees (possible regional bias)
- Future afforestation with Loblollys may cool region

CAVEATS: Albedo may be too dark; BVOCs form cooling haze in summer of SE (Goldstein et al., 2009)

Parameter Estimation

- We use a Bayesian data assimilation method to evaluate uncertainty in the parameter values [Goes et al., 2010]
- We assume a Gaussian likelihood function and estimate the posterior PDFs of our parameters through MCMC



Posterior pdf of the model parameters mp [left], qe25 [middle], and flnr [right] for each tracer: Sensible Heat (green), Latent Heat (red), and the joint posterior using all observations (black)

Biogenic VOCs

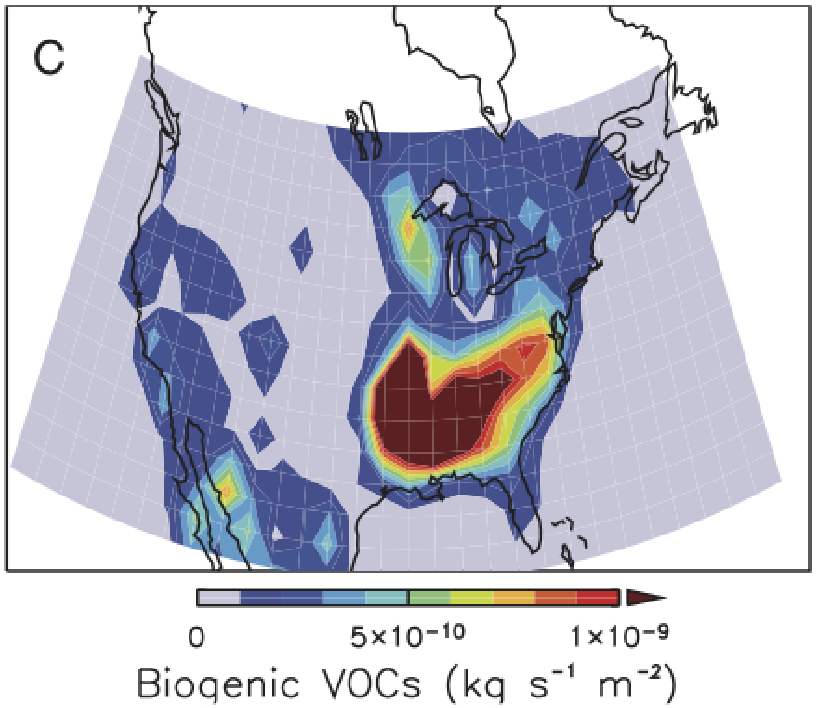
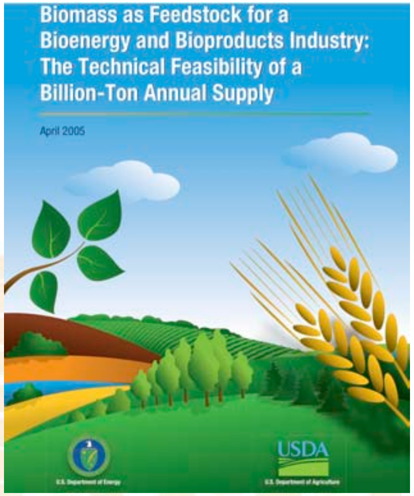


Fig. 2 from Goldstein et al. (2009)

- We replaced PFT 16 which is designated as "wheat"
  - No BVOCs
- BVOCs form cooling haze in summer of SE (Goldstein et al., 2009)

Billion Ton Biomass Goal



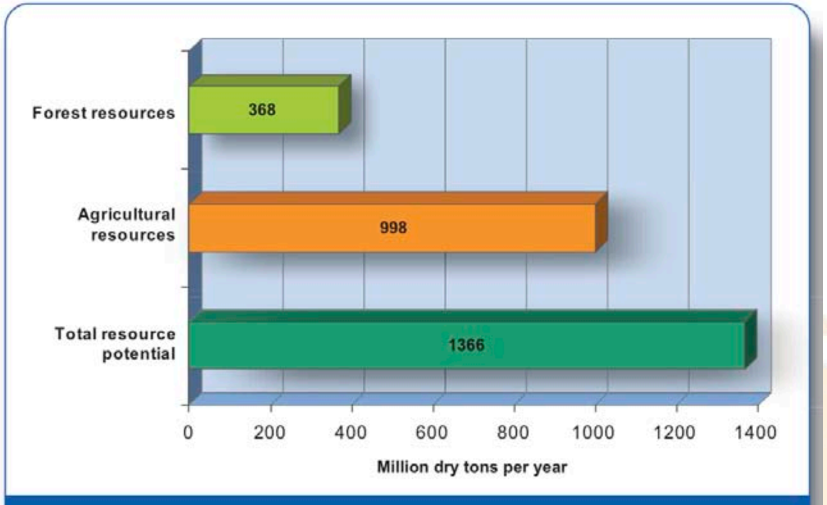
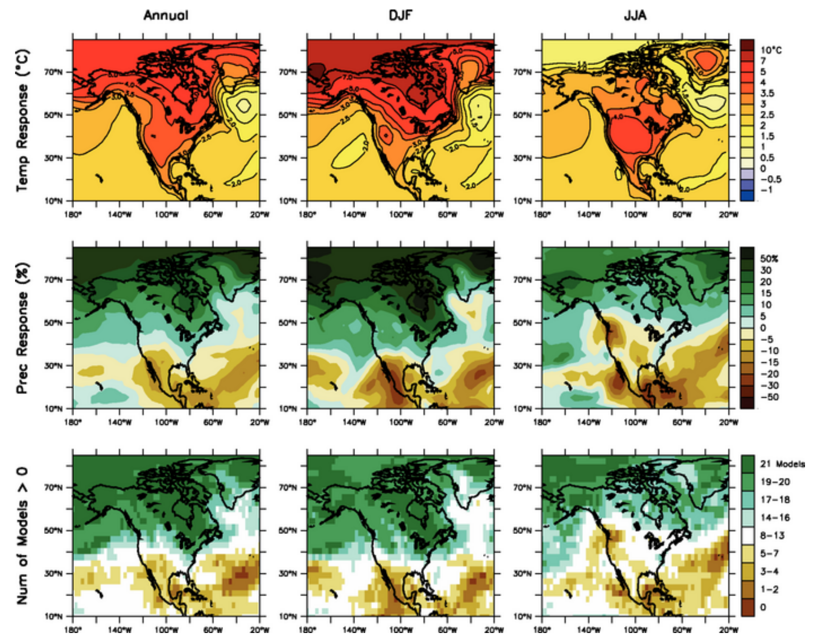


Figure 1: Annual biomass resource potential from forest and agricultural resources

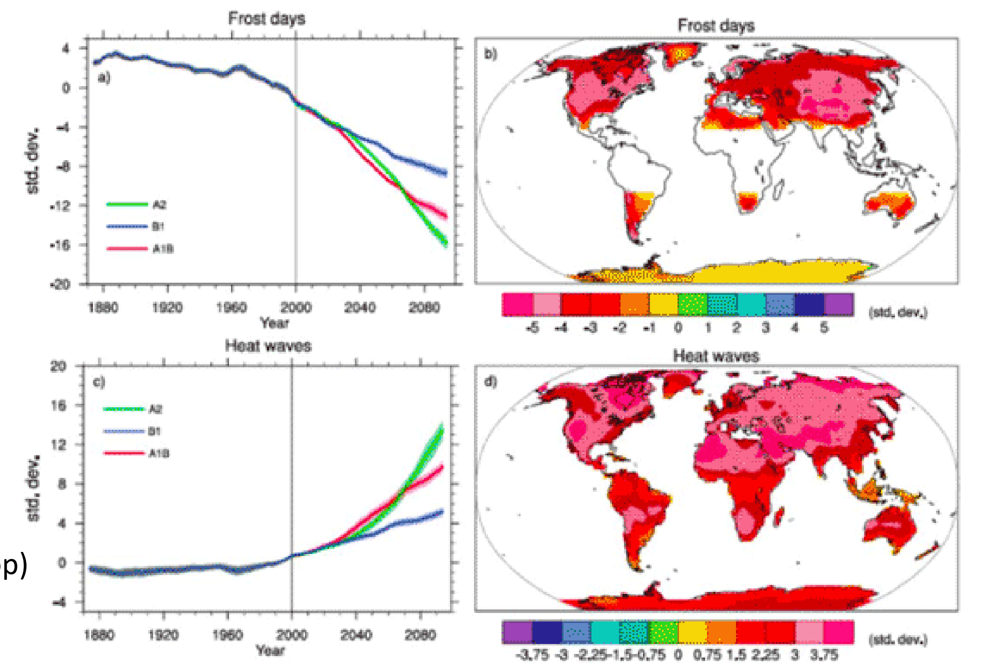
- Perennial crops are fast growing grasses and trees grown on idle crop and pasture land
  - Switchgrass, miscanthus, short-rotation woody crops

Climate Change

- Loblolly less sensitive to heat stress than Cottonwood (Luxmoore et al., 2008)
- IPCC – warming of North America, more growing-degree days (GDD) (Robeson, 2002; Feng and Hu, 2004).



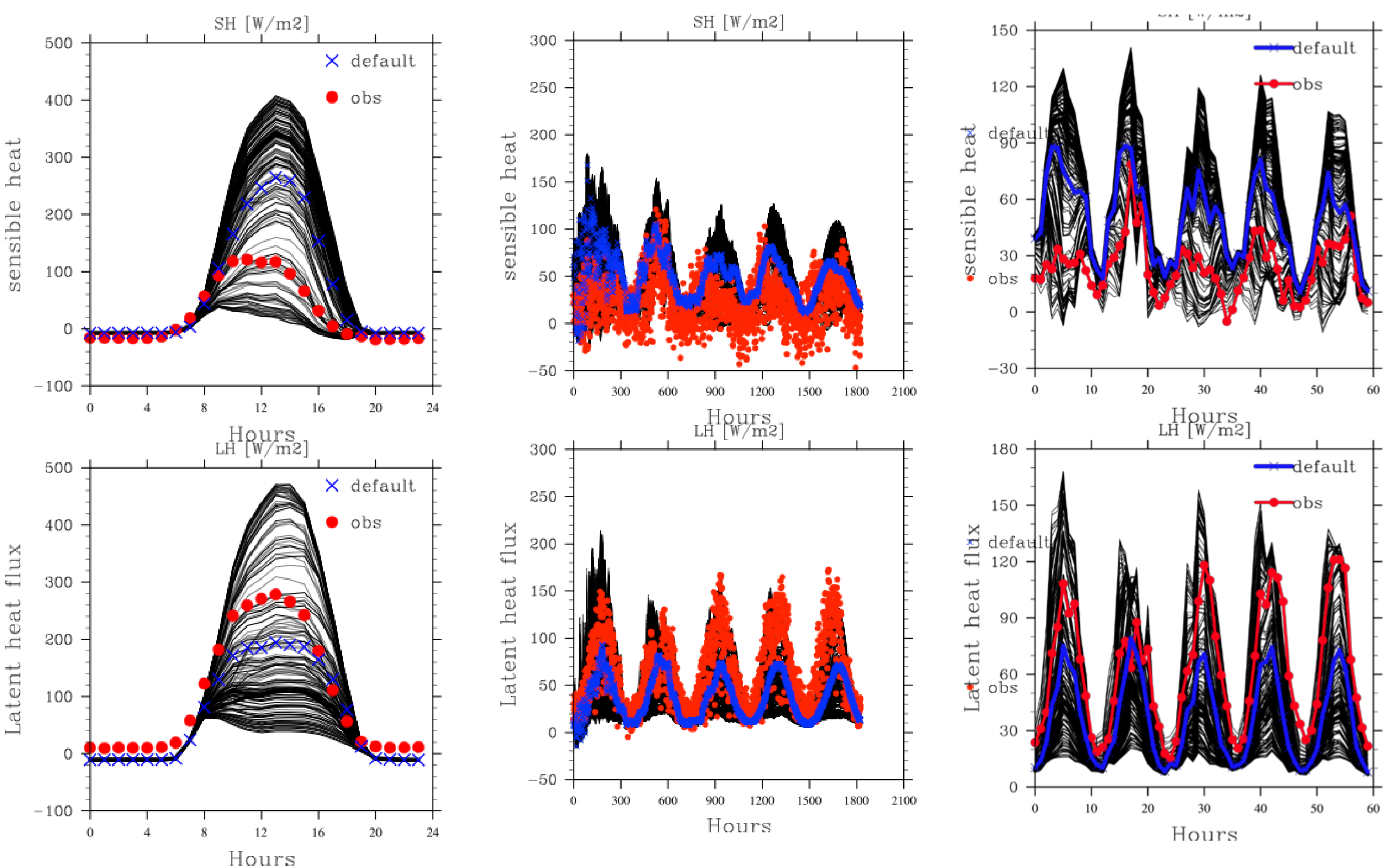
TOP: Multi model mean temperature and precipitation changes (2090:2080 – 1980:1999) for A1B simulation (IPCC, 2007).



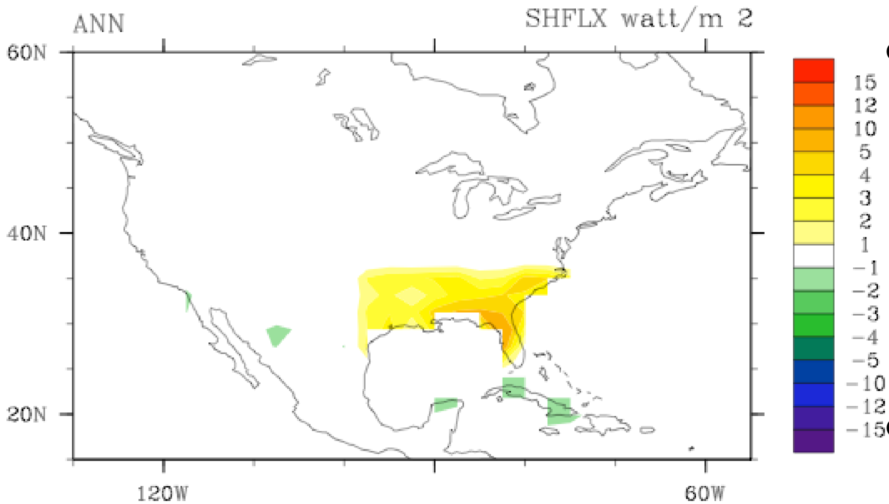
BOT: Model Projections of Changes in Frequency of Frost Days (top) and Heat Waves (bottom) by end of 21st Century in Various Emissions Scenario (based on average over all IPCC models) (PSU, IPCC, 2007).

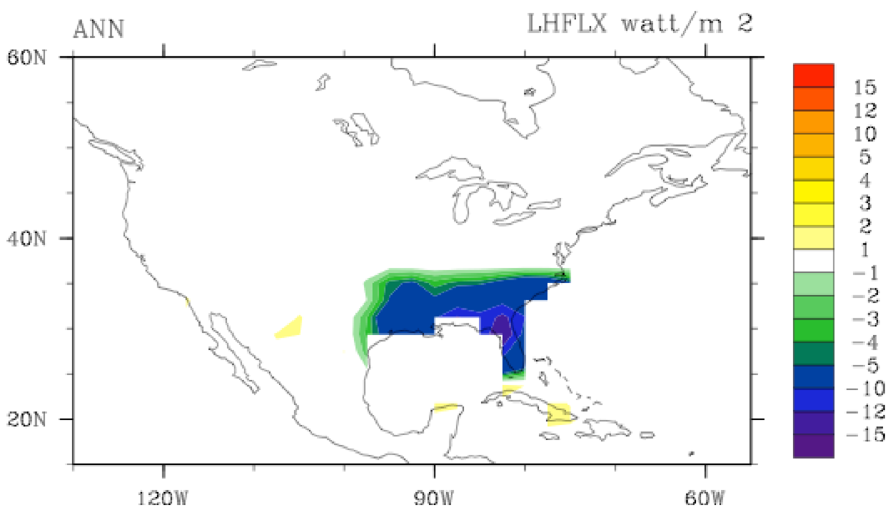
Hourly, Daily, Monthly Energy Fluxes

JJA Diurnal Cycle | Daily Cycle | Monthly Cycle



Future Energy Partitioning





- Afforestation increases sensible heat by ~2 Wm^{-2} and decreases latent by ~5 Wm^{-2}
- Consistent with Teuling et al.'s (2010) study on European forests vs grasslands

Loblolly vs NET (PD distribution)

- Dynamic LAI of Loblolly compared to NET in CLM
- Results in greater photosynthesis, canopy transpiration and less ground evaporation