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Direct climate effects of perennial bioenergy crops in the United States

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1 Background

Bioenergy

• Bioenergy can usually be defined as energy produced from organic matter and biomass.

•In its most narrow sense it is a synonym to biofuel, which is fuel derived from biological sources. In its broader sense it includes biomass, the biological material used as a biofuel, as well as the social, economic, scientific and technical fields associated with using biological sources for energy.

Source: Sustainable Bioenergy: A Framework for Decision Makers (United Nations, Geneva); http://en.wikipedia.org/wiki/Bioenergy

- Biomass-derived energy provide energy independence and mitigate anthropogenic climate change.
- Whether we should increase the production of bioenergy requires a thorough accounting of costs and benefits.

Lifecycle Analyses (LCA)

- A lifecycle analysis is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal

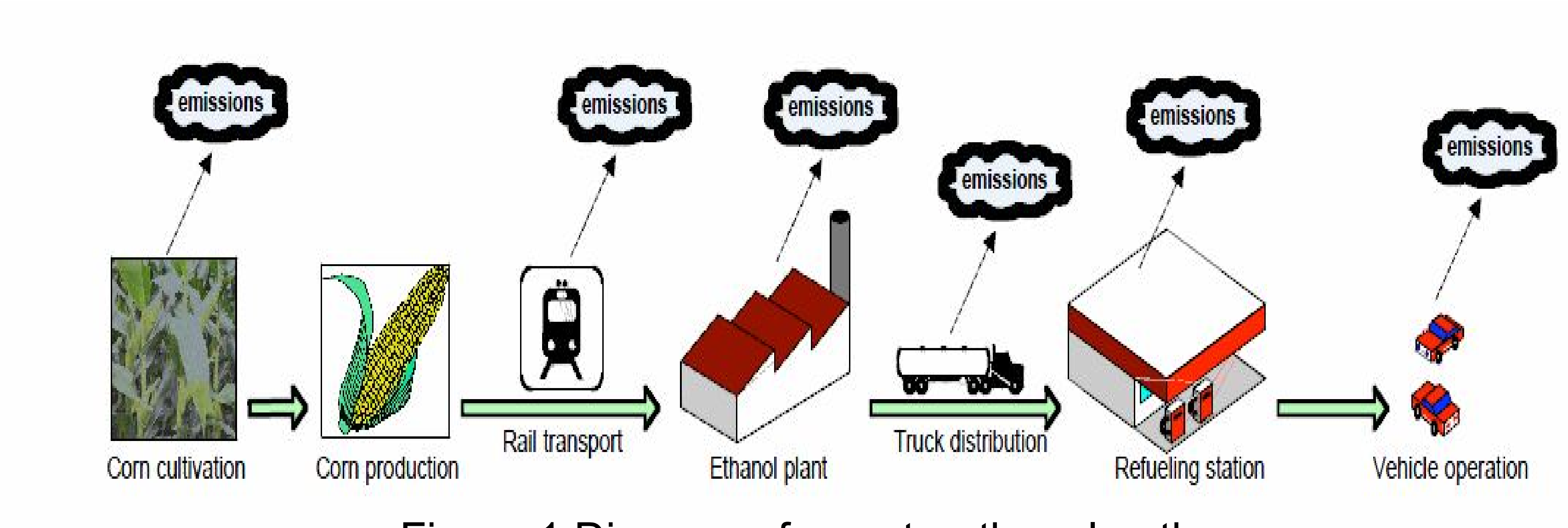


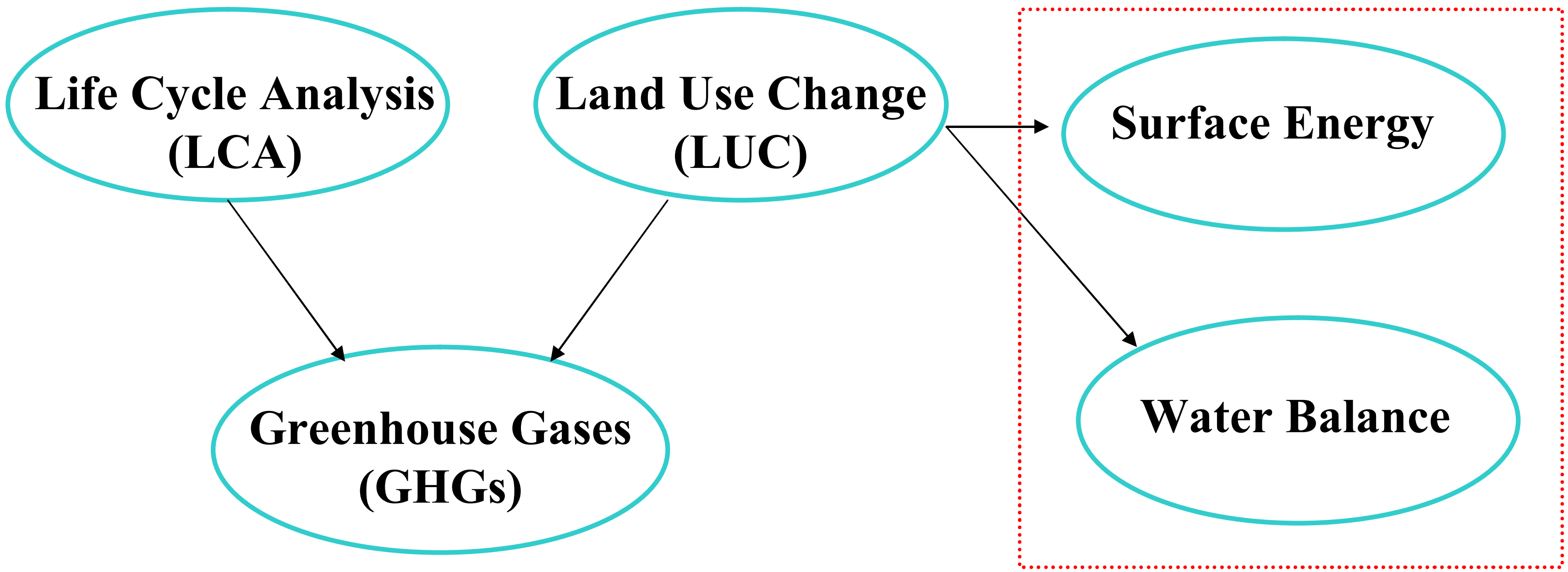
Figure.1 Diagram of corn-to-ethanol pathway

Source: http://en.wikipedia.org/wiki/Life-cycle_assessment; Lifecycle analyses of Biofuels (University of California, David, CA)

Efficacy of bioenergy

Biogeochemical Effects

Biogeophysical Effects



2 Objectives

- Use the Weather Research and Forecasting Model (WRF) to evaluate the climate effects of converting agricultural areas in the central United States to perennial crops.

3 Method

3.1 Site Information

Location	Latitude (° N)	Longitude (° W)	Area(km^2)	Vegetation	Year Included
Central United States	37-48.5	102.5-82.5	839,000	Cropland	1995

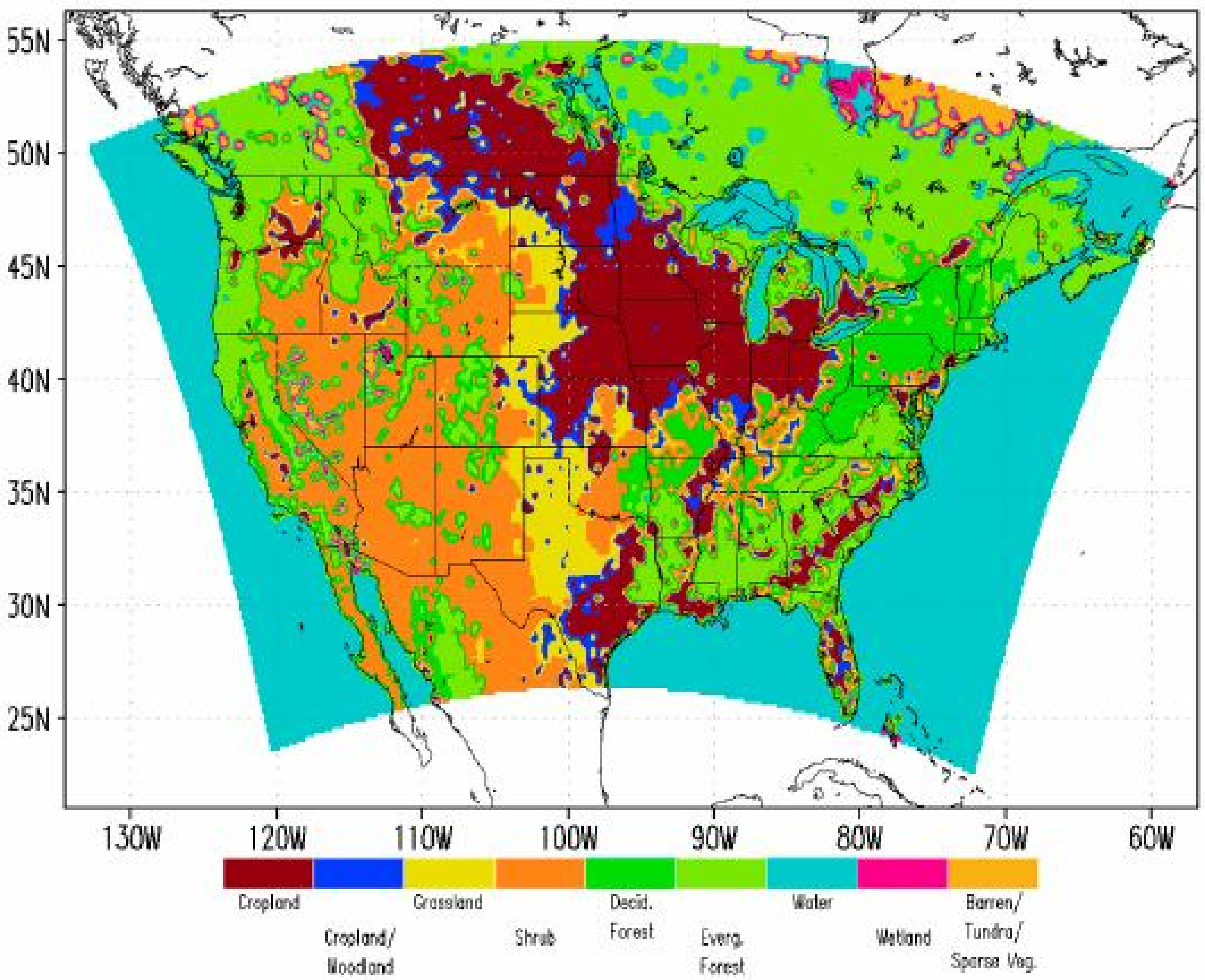


Figure.2 Geographical extent of domain and landscape representation used for all experiments

3.2 Methodology

- Shift WRF’s default vegetation characteristics: albedo, leaf area index and vegetation fraction.
- In the spring season, vegetation characteristics are advanced by 1 mo and delayed by 1 mo in the fall season. Vegetation properties were held constant for 2 mo at midway through the growing season (July 31^{st}).
- Sensitivity experiments: Perennials-NoAlb (as perennials but without the modification to albedo), Perennials-2m (as perennials but with a 2-m root depth).

Table.1 Summary of all experiments performed

Naming convention	Spinup	Analysis
Annuals	March	APR–OCT
Perennials	March	APR–OCT
Perennials-NoAlb	March	APR–OCT
Perennials-2m	March	APR–OCT

Table.2 Model details and specifications used for all experiments

WRF specifications	
Model version	WRF version 3.1
Horizontal grid	160×100; ΔX, ΔY, 32 km
Vertical levels	29 levels
Initialization time	March 1, 00Z 1995
Terminal time	October 31, 18Z 1995
ΔT:	MAR–MAY: 120 seconds; JUN–OCT: 90 seconds
Radiation scheme	Rapid Radiation Transfer Model (longwave); Dudhia (shortwave); RRTMG (shortwave)*
Surface model	Noah
Cumulus scheme	Kain–Fritsch
Microphysics scheme	WSM-3
PBL scheme	Yonsei University
Lateral boundary conditions	North American Regional Reanalysis

4 Results and interpretation

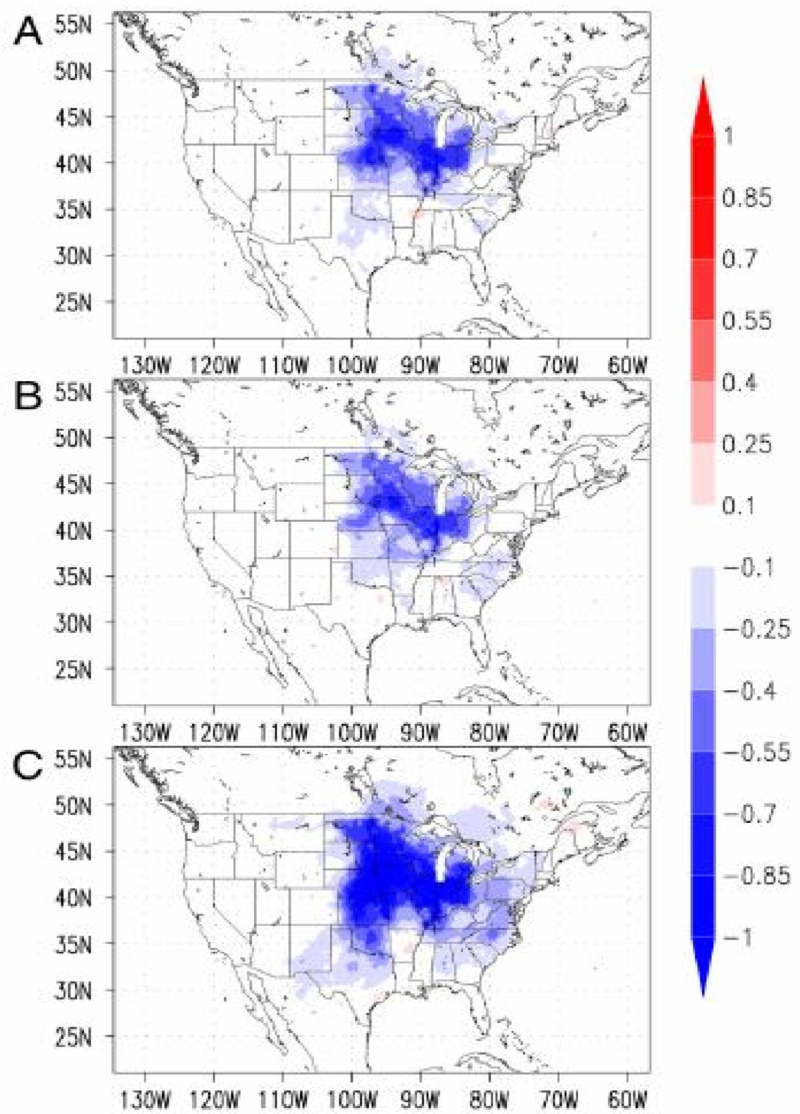


Figure.3 Simulated time mean (APR-OCT) difference in **(A)** 2-m temperature [℃] (Perennials minus Annuals); **(B)** as (A) but perennial crop representation does not include albedo modification; **(C)** as (A) but perennial crop representation includes rooting depth of 2m.

Table.3 Mean difference (APR-OCT) response of climate variables between perennials and annuals

	2 m temp. [°C]: all land	2 m temp. [°C]: perturbed pixels	2 m dew-point temp: [°C]: all land	2 m dew-point temp [°C]: perturbed pixels	ET [mm day^{-1}]	Net surface SW [W m^{-2}]	Net surface LW [W m^{-2}]
Perennials—Annuals	−0.08	−0.51	0.02	0.16	0.1	−2.36	−0.65
Perennials-NoAlb—Annuals	−0.07	−0.45	0.02	0.18	0.1	−1.42	−0.23
Perennials-2m—Annuals	−0.16	−0.84	0.09	0.54	0.22	−3.63	−1.06

Where not specified, calculations are for perturbed pixels only. ET, evapotranspiration; SW, shortwave; LW, longwave

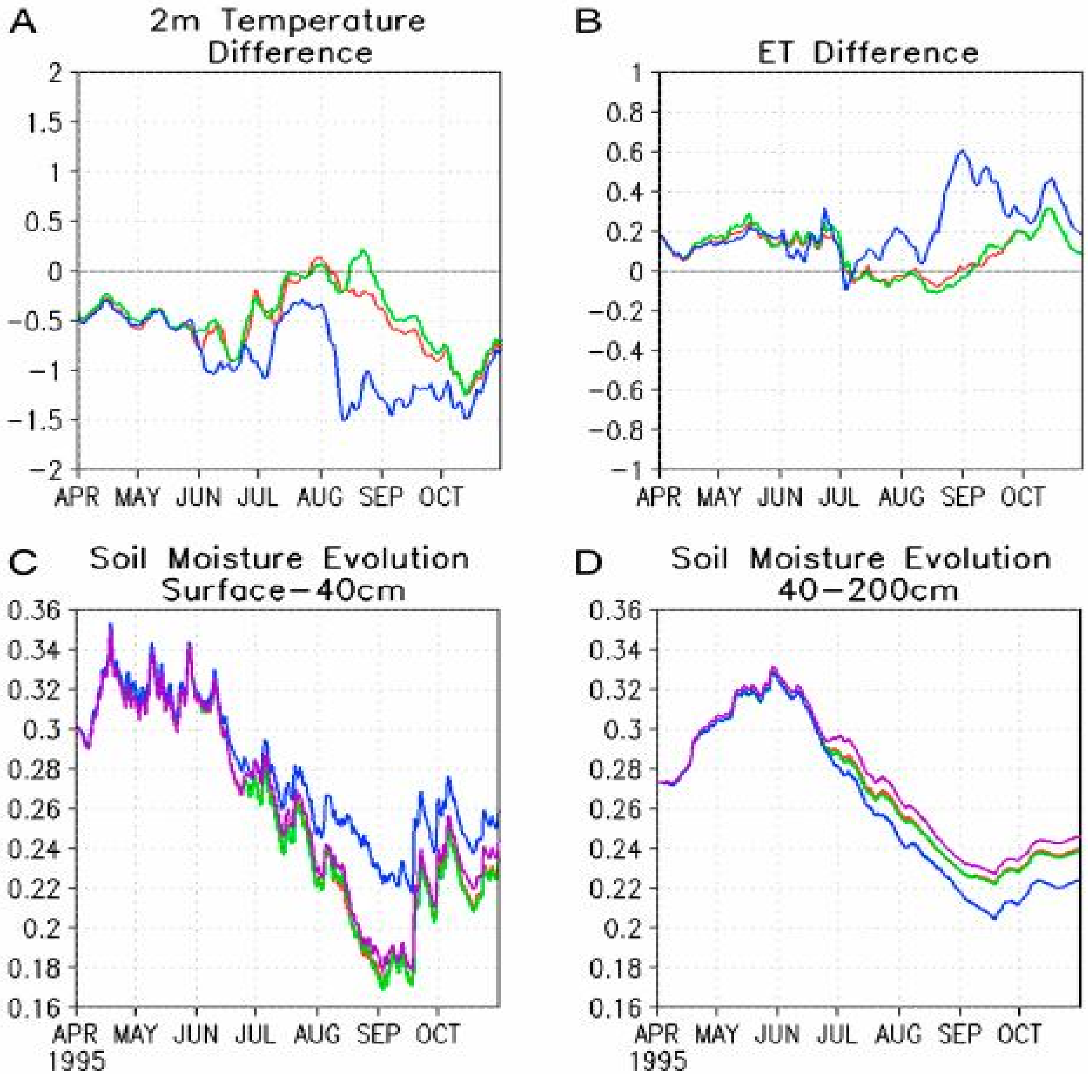
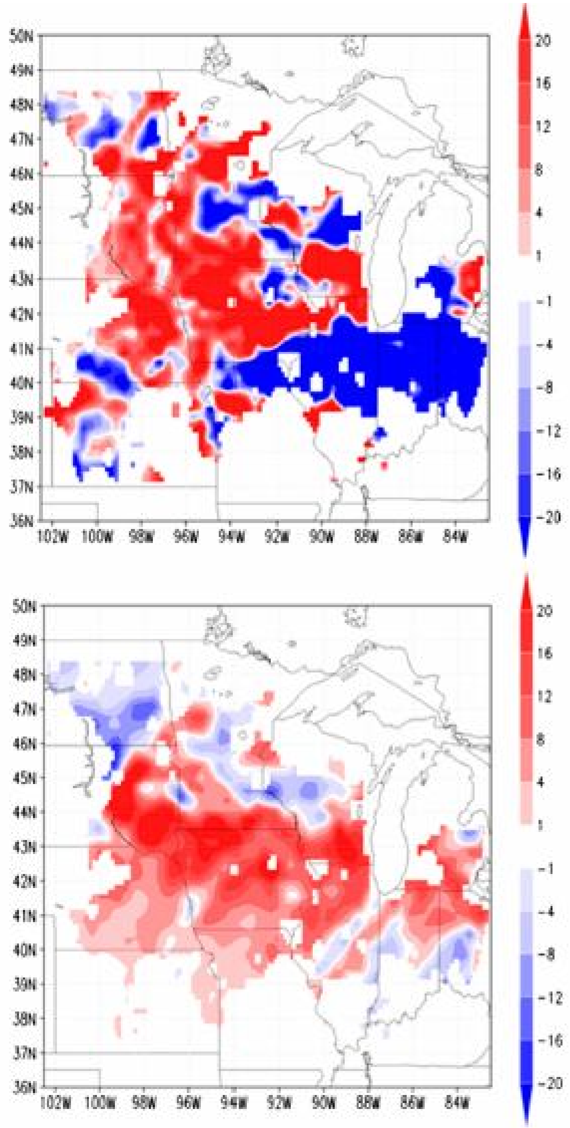


Figure.4 (A) Simulated evolution of daily mean temperature[℃] difference (Perennials minus Annuals) over grid cells where land surface was perturbed. (B) As (A) but for ET [mm day-1]. (C) Simulated evolution of near-surface (surface-40cm) volumetric soil moisture [m^3m^{-3}] averaged over grid cells where land surface was perturbed. (D) as (C) but for deep soil (40-200cm).



A Positive Feedback

Enhancement of ET (not transient)

↓

Cooling effects

↓

The increase of vertically integrated cloud and water vapor mixing ration and rainfall

↓

Reduce of net surface shortwave radiation

Figure.5 WRF simulated total monthly precipitation difference [mm] (Perennials-2m minus Annuals) over those grid cells where vegetation properties were perturbed for (A) July and (B) October.

- Based on net fossil fuel savings of 140g CO_2 e-C m-2 yr-1, the effect of biogeochemical for the complete conversion from annual to perennial bioenergy crops over the central United States can save an additional 13t C ha-1 yr-1 while that of biogeophysical influence is 78t C ha-1 yr-1.

- Considering the joint effects of biogeochemical and biogeophysical mechanism on global radiative forcing (RF) , it would take 7 yr for the biogeochemical impacts to surpass biogeophysical impacts for the region.

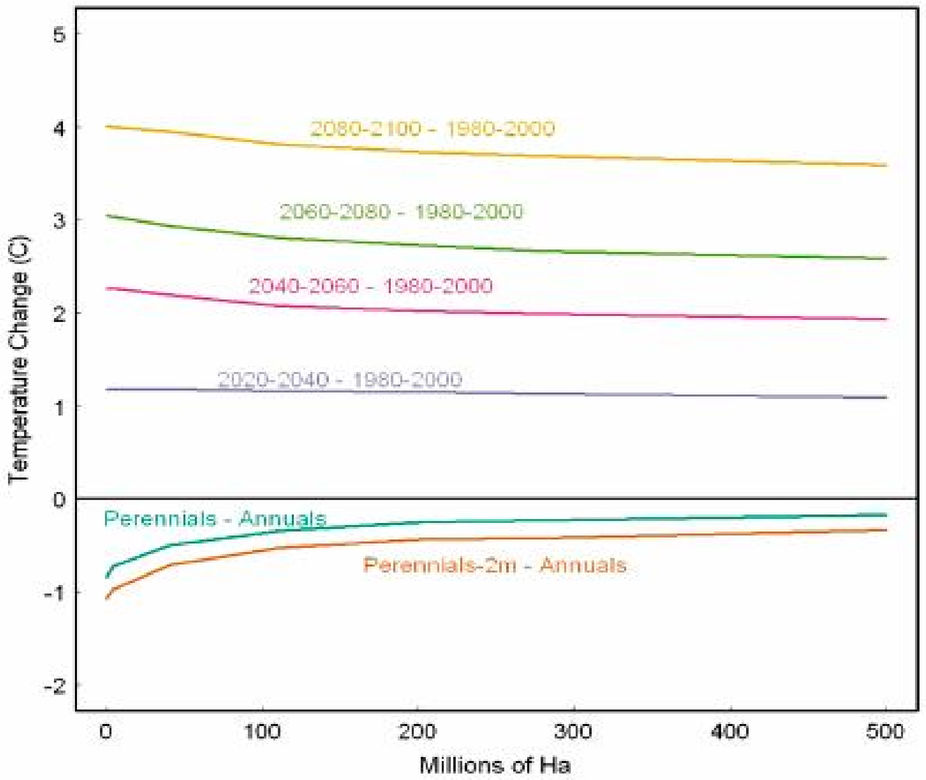


Figure.6 Comparison of near-surface temperature change (April-October) associated with simulated conversion from annual to perennial bioenergy crops against projected WCRP CMIP3 warming, with increasing spatial scale (centered on lat: 40° N, longitude: 87.75° W)

- Whereas the impact of perennials may offset a significant fraction of future greenhouse warming at local scales, it remains small when compared to projected warming from global GHG emission from large scales.

5 Conclusions

- Phenological contrasts associated with conversion of annual to perennial bioenergy crops in the United States may impart significant local and regional cooling effects and through nearly the midcentury are of similar order of magnitude as projected impacts due to rising GHGs.
- Additional biophysical differences between cropping systems during green-up and senescence may lead to further impacts, and it is necessary to improve location- and vegetation-specific representation of bioenergy cropping systems.
- Further work assessing the long-term evolving nature of soil water depletion and associated equilibrium ET resulting from soil moisture/temperature and atmospheric changes are necessary.

6 Implication

- This paper assessed the climate effects of perennial crops in central US from the biogeophysical aspect.
- Whether can we expand the local climate effects on larger scale?

- Given the lack of biogeophysical observational data associated with bioenergy crops, their approach omits additional features associated with biogeophysical characteristics of crops.
- Different species of bioenergy crops have different biogeophysical characteristics and we have to consider the representation of these parameters.
- This paper considered the interaction between atmosphere and surface energy by using WRF and it can help me for my future work since I can simulate the climate effects of land use conversion such as from grassland to forest.

Thank you