The Influence of Pre-settlement and Current High Plains Land Use and Land Cover on Atmospheric, Soils, and Vegetation Properties (Preliminary Results)

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Introduction

Changes in land use and land cover alter local and regional weather, hydrology, and ecosystem function (Dale 1997, Narisma and Pitman 2003, Pielke et al. 2003). In the High Plains Region of the central and western United States (the area immediately east of the Rocky Mountains from South Dakota to Texas), human landscape modification from native grasslands to intensively managed croplands is especially striking. Before this shift was initiated in the mid-19th century, relatively continuous short-, mixed-, and tallgrass prairies dominated the region (Fig. 1). In contrast, the current landscape is a mosaic of croplands (irrigated and non-irrigated), grasslands, reservoirs, and urban areas. Associated with the observed land-cover conversion over the last 150 years, land-atmosphere interactions, water cycling, and ecosystem functions have also changed.

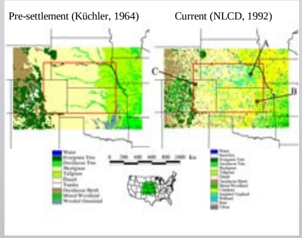

Fig. 1. The vegetation data used for the two simulations. The outer grid is marked by the vegetation map boundary and the inner grid is outlined in red. The map resolution is 10 km. Letters represent the location of comparisons (Fig. 8).

Our Objective Was To:

- Quantify the role of High Plains land-use and land-cover change in modifying near-surface air temperature, precipitation, soil moisture, and plant growth.

Methods

GEMRAMS is composed of three coupled models (Fig. 2): the General Energy and Mass Transport Model (GEMTM, Chen and Coughenour 1994), Land Ecosystem—Atmosphere Feedback model (LEAF-2, Walko et al. 2000), and the Regional Atmospheric Modeling System (RAMS, Cotton et al. 2003). GEMRAMS' capabilities include simulation of plant growth (carbon accumulation, C_3 and C_4 photosynthetic pathways), soil conditions, plant-land-atmosphere water and energy exchanges, and the attendant effects of these processes on the atmosphere (Eastman et al. 2001). We used GEMRAMS in a paired sensitivity analysis to assess the effects of pre-settlement and present land covers on plant, land surface, and atmospheric processes for June 1996.

With the exception of land cover, reanalysis data, biophysical parameters, and initial conditions used in the paired GEMRAMS simulations were identical (Fig. 2). Global NCEP-UCAR Reanalysis data (Kalnay et al. 1996) were downscaled in RAMS to provide the simulation's atmospheric forcing. The LEAF-2 biophysical parameters (Walko et al. 2000) were used for the vegetation classes (Fig. 1). Initial soil moisture and temperature conditions for 1 June 1996 were obtained from the North American Regional Reanalysis (NARR, Mesinger et al. 2005).

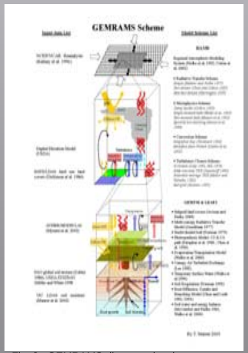

Fig. 2. GEMRAMS diagram showing interactions among the model components.

Vegetation

In this sensitivity experiment, land cover was the primary variable. Pre-settlement land cover was derived from Küchler's (1964) map of potential native vegetation (Fig. 1) and present land cover was adapted from National Land Cover Data (NLCD, Vogelmann et al. 2001) and agricultural statistics (Fig. 1). Further, both land cover datasets were enriched with C4 vegetation fractions from Tieszen et al. 1997 that were used to consider C_3 and C_4 vegetation patches for grasses and croplands.

Simulations

- Outer grid: 34 x 27 cells with a 40-km horizontal grid increment (Fig. 1)
- Inner grid: 82 x 70 cells with a 10-km horizontal grid increment (Fig. 1)
- Number of vegetation patches: 4
    1) Assigned in order of dominance

Results

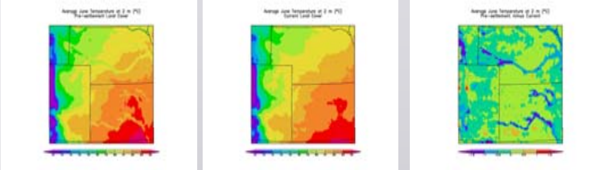

Fig. 3. Average near-surface air temperatures were influenced by land cover. River valleys were warmer under the current agricultural land use while most other areas were within ± 0.5 °C.

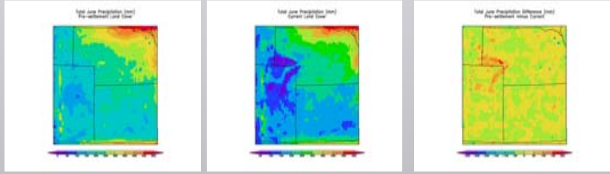

Fig. 4. Precipitation differences were heterogeneous, but some regional trends appeared. Areas in western Nebraska and northeast Colorado were wetter under pre-settlement land cover, but most of the area experienced ± 50 mm of precipitation change.

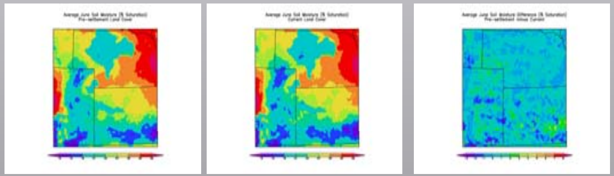

Fig. 5. Soil moisture (% Saturation) differed slightly between the simulations. In both simulations, soil texture is identical (see the Nebraska Sandhills). The influence of precipitation (Fig. 4) can be seen in the moisture difference.

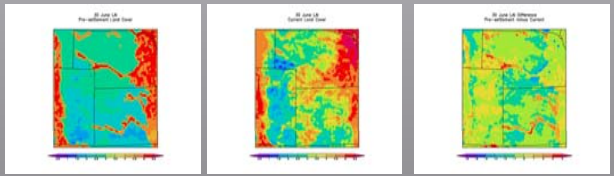

Fig. 6. Naturally, LAI was different with land cover. The difference is mostly due to initial conditions (Fig. 1) and partly due to growth. In general, agricultural areas had an increased LAI while relatively unchanged areas (e.g., Nebraska Sandhills) had a slightly higher LAI under the current land cover. In contrast, the current absence of large expanses of deciduous trees along river valleys resulted in a lower LAI.

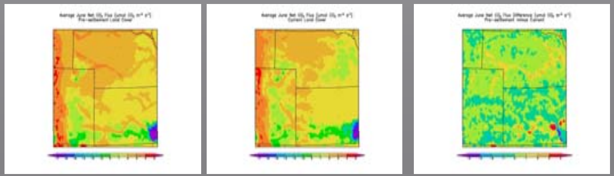

Fig. 7. Net CO_2 flux varied with land cover changes, as well. Most of the differences were ± 0.50 μmol m^{-2} sec^{-1}. The most obvious trend (decrease in flux) is from the loss of the deciduous tree class along the river valleys.

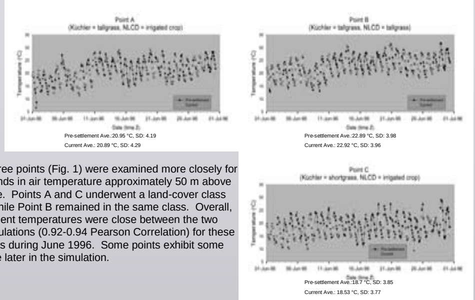

Fig. 8. Three points (Fig. 1) were examined more closely for diurnal trends in air temperature approximately 50 m above the surface. Points A and C underwent a land-cover class change, while Point B remained in the same class. Overall, the coincident temperatures were close between the two model simulations (0.92-0.94 Pearson Correlation) for these three points during June 1996. Some points exhibit some divergence later in the simulation.

Discussion

Holding all other variables constant, an alteration of land cover in GEMRAMS over the study domain produces changes in surface temperature, precipitation, soil moisture, and plant growth. The resultant changes are not homogenous or unidirectional; rather, they are spatially variable and dependent upon the type of landscape change.

With the simulated alteration of land-cover in this domain from pre-settlement to current vegetation:

- River valley environments and western upland environments were warmer.
- Eastern agricultural areas and the eastern edge of the Front Range have cooled slightly.
- Precipitation changes were less identifiable overall, but areas in northeast Colorado and western Nebraska received less rain.
- Soil moisture varied by a few percent throughout the domain, but spatial patterns were elusive.
- With changed LAI and vegetation, CO2 flux differences were evident and, depending on the location, considerable.

Eastman et al. (2001) examined a similar domain using larger horizontal grid-increments (50 km) and over a longer time period. Further, they examined differences between natural and present vegetation. For the June 1989 comparison, they reported much higher increased temperatures (2-5 °C) in the eastern portion of their domain and slightly higher temperatures in the western areas. Interestingly, our simulations for the same month in 1996 show slight cooling in the east with a similar vegetation change. However, our comparisons agree with slightly higher temperatures found in the western 1/2 of the domain, along with isolated cool areas (e.g., Front Range). It should be noted that vertical and horizontal scaling issues are important when making these comparisons.

Future Work

- This project will be expanded to cover more of the Great Plains.
- Full summer simulations are being performed (June-August).
- Wet (1993) and dry (2002) years will be compared with 1996 (intermediate).
- 1920s and 2020 land covers will be added.
- Model verification with coincident station data will be performed.
- Satellite-derived parameterizations will be incorporated into the simulations.

References

Chen, D. X., and M. B. Coughenour. 1994. GEMTM: a general model for energy and mass transfer of land surfaces and its application at the FIFE sites. Agricultural and Forest Meteorology 68:145-171.

Cotton, W. R., R. A. Pielke, R. L. Walko, G. E. Liston, C. J. Tremback, H. Jiang, R. L. McAnelly, J. Y. Harrington, M. E. Nicholls, G. G. Carrio, and J. P. McFadden. 2003. RAMS 2001: Current status and future directions. Meteorology and Atmospheric Physics 82:5-29.

Dale, V. H. 1997. The relationship between land-use change and climate change. Ecological Applications 7:753-769.

Eastman, J. L., M. B. Coughenour, and R. A. Pielke. 2001. The regional effects of CO2 and landscape change using a coupled plant and meteorological model. Global Change Biology 7:797-815.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph. 1996. The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society 77:437-471.

Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society, Special Publication No. 36.

Mesinger, F., G. DiMego, E. Kalnay, K. Mitchell, P. C. Shafran, W. Ebisuzaki, D. Jovic, J. Woollen, E. Rogers, E. H. Berbery, M. B. Ek, Y. Fan, R. Grumbine, W. Higgins, H. Li, Y. Lin, G. Manikin, D. Parrish, and W. Shi. 2005. North American Regional Reanalysis. Submitted to Bulletin of the American Meteorological Society.

Narisma, G. T., and A. J. Pitman. 2003. The impact of 200 years of land cover change on the Australian near-surface climate. Journal of Hydrometeorology 4:424-436.

Pielke, R. A., G. Marland, R. A. Betts, T. N. Chase, J. L. Eastman, J. O. Niles, D. Niyogi, and S. W. Running. 2003. The influence of land-use change and landscape dynamics on the climate system: Relevance to climate-change policy beyond the radiative effect of greenhouse gases. Pages 157-172 *in* I. R. Swingland, editor. Capturing Carbon and Conserving Biodiversity: The Market Approach. Earthscan Publications Ltd., London, U.K.

Tieszen, L. L., B. C. Reed, N. B. Bliss, B. K. Wylie, and D. D. DeJong. 1997. NDVI, C3 and C4 production, and distributions in great plains grassland land cover classes. Ecological Applications 7:59-78.

Vogelmann, J. E., S. M. Howard, L. M. Yang, C. R. Larson, B. K. Wylie, and N. Van Driel. 2001. Completion of the 1990s National Land Cover Data set for the conterminous United States from Landsat Thematic Mapper data and Ancillary data sources. Photogrammetric Engineering and Remote Sensing 67:650-652.

Walko, R. L., L. E. Band, J. Baron, T. G. F. Kittel, R. Lammers, T. J. Lee, D. Ojima, R. A. Pielke, C. Taylor, C. Tague, C. J. Tremback, and P. L. Vidale. 2000. Coupled atmosphere-biophysics-hydrology models for environmental modeling. Journal of Applied Meteorology 39:931-944.

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