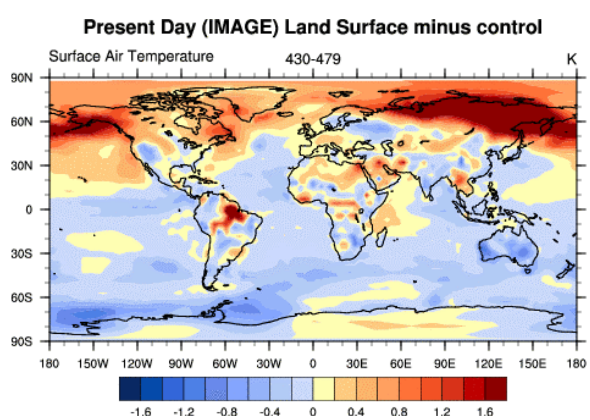
Progress report for the
Land Cover Forcing from the SRES Scenarios in Climate Models
component of the
Weather and Climate Impact Assessment Science Initiative

Purpose: To extend future climate change scenarios by including human impacts on land cover and soils. This work has been initiated with LSM/PCM and will be expanded to use CLM/CCSM. Simulated changes are land cover, human impacts on soil, and urbanization. These experiments will address how human land use and land cover change are altering climate, water and carbon cycles, and biogeochemistry. In particular it will address: (1) How changes in land use and land cover have altered present-day climate and are likely to alter future climates? (2) How important is the land use and land cover change forcing relative to other IPCC SRES forcings? Parts of this work will be accomplished in collaboration with the Biogeosciences initiative.

Results to date: We have completed a number of experiments using the Parallel Climate Model (PCM) to assess the model's sensitivity to land cover change. So far two experiments have been conducted, and the preliminary results will be presented here.

Our first sets of experiments were intended to assess the model's sensitivity to different land cover representations. This is important, because any future climate change simulations will have to include land cover information from external sources that are not based on the same land cover schemes used to create the land cover boundary conditions in the current model. Our experiment compared three different representations of land cover; 1) the standard NCAR Land Surface Model (LSM) landcover classification (LSMlc), 2) the IMAGE 2.2 present day land cover representation (also used extensively in the IPCC future climate simulations) translated to LSM land cover classes (IMAlc), and 3) a hybrid land cover classification that combined the IMAGE 2.2 agriculture and grassland types with the LSM background vegetation scheme (HYBlc). Simulations were run under identical 'pre-industrial' atmospheric conditions and all were branched from the 1000-year PCM pre-industrial control simulation – this run was also used as the LSMlc control.

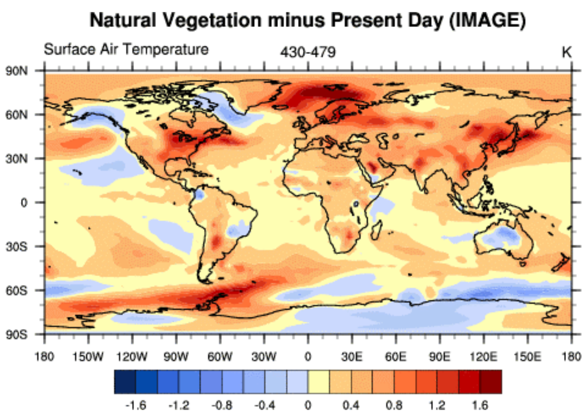
Figure 1:



Results showed significant differences between these simulations with the highest variations caused by differences in natural land cover classes. Two specific examples of uncertainty are represented by the different characterization of Siberian and Amazonian land covers in the different land cover schemes. In the IMAlc, Siberia is primarily represented as evergreen needleleaf trees, while in the LSM land cover this area was represented by deciduous needleleaf trees. In the simulations this led to very different albedo conditions, hence affecting net radiation and overall energy inputs to the system. Particularly in spring this resulted in much higher regional temperatures for the IMAlc simulations, with simulated temperature differences in excess of 5K (figure 1). In the second example, the Amazon, LSMlc has a tropical evergreen broadleaf tree representation over most of the region, while in the IMAlc simulation a large portion of the region is represented by tropical deciduous broadleaf trees. In this case albedo was slightly affected, but of greater significance was the difference in the disposition of energy into latent and sensible heat fluxes. Evaporation in the deciduous forest simulation was significantly reduced leading to much warmer surface temperatures (seasonally >3K – figure 1).

A second component of this experiment evaluated the differences between a pre-human land cover simulation, based on potential vegetation, and an equivalent present day land cover simulation. Differences is in these simulations are almost entirely based on the extent of agricultural and grazed lands in the present day land cover. Results from this simulation showed large regional climate differences, primarily resulting in cooling in regions dominated by agriculture (e.g. eastern US, eastern China, Europe and parts of South America and southern Africa). In addition, we found some evidence of significant feedbacks in the simulations, cloud cover in particular was strongly affected over agricultural regions, generally increasing, leading to cooling (figure 2). However, over north central Australia cloud cover decreased leading to drying and heating. In terms of average annual temperature changes, regional changes were on the order of 1K. There is also some evidence that tropical deforestation could lead to warming also.

Figure 2:

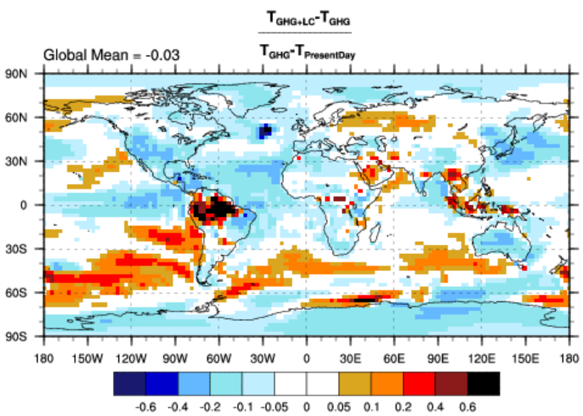


Based on these results we found that proper land cover representation is crucial to implementing IPCC based land cover simulations, and that land cover change could lead to significant regional climate change. One complication arising from these results is that it is difficult to assess the relative importance of land cover induced climate change in the generally accepted radiative forcing concept. This results because land cover tends to lead to regionally offsetting climate changes, and because these changes can be based on differences in the way energy is partitioned at the surface without a directly affecting net radiation. When we compared globally averaged temperature changes we found that the present day land cover simulations ranged by about 0.21K, while the cooling from pre-human land cover was about 0.386K. But from a climate assessment point of view these averages are not near as significant as the projected regional impacts. Results from this study have been submitted to Climate Dynamics.

Our second set of results focused on simulating future climate change projections based on land cover change, and determining its relative importance compared to the projected climate changes from GHG forcings. We used the PCM and ran the model in a transient mode from 1870 to 2100 using the IPCC A2 climate change scenario GHG forcings. Using the hybrid methodology developed in the first paper as background, we ran the model with a present day simulation for the entire period, and then a series of separate experiments to simulate the effect of 2050 land cover from 2033 to 2066 and 2100 land cover scenarios from 2066 to 2100.

Comparing these sets of simulations we could assess the impact of land cover relative to the impacts of changing GHG concentrations. Land cover was again found to have large regional impacts on the outcome of the experiments. In general, expanded agricultural regions showed cooling in mid-latitudes, while tropical conversion to agriculture resulted in significant warming. In the first case this change was primarily albedo driven, while in the second case the altered hydrologic cycle led to the warming results.

Figure 3



We also realized that without the ability to effectively use the concept of radiative forcing there was a need to consider different statistics to assess the relative importance of land cover change compared to GHG induced forcings. In an attempt to compare these different forcing, with respect to their effects on temperature, we devised a statistic that shows the relative magnitude of land cover change induced temperature change to that of GHG forcing. This magnitude was expressed as a ratio between the two forcings (figure 3). In this scheme a values less than 1 mean that land cover forcing is the indicated fraction of the forcing from GHGs. Values greater than 1 mean that land cover forcing has a greater impact compared to GHG forcing. Areas in red indicate that land cover change resulted in warming, and areas in blue indicate areas cooled due to land cover forcing. Results from this study will be submitted for publication by the end of this summer.

Future work: The completed experiments show the need for an integrated treatment of human induced land surface change in climate change science. While these treatments so far only include the treatment of vegetation change, other human impacts also need to be included. We are in the process of developing an urban canyon type model for inclusion in CLM. In addition we propose to simulate the human impacts on soils and the consequences of these actions on climate. These improvements will all be implemented in CLM for use in CCSM. In addition to model improvements we also foresee a need for much improved representation of human induced land cover change datasets. At present there are no transient datasets that adequately represent human included land cover change over the recent historical period. As part of this project we have received additional NSF funds to develop such datasets for use with CCSM. We have prioritized the following data development activities:

1. Develop an updated and completely revised present day land cover representation (1km spatial resolution), and develop a pre-human potential vegetation dataset at the same resolution
2. Simulate land cover change using these datasets as a starting point. We will develop new models that incorporate multiple sources of human information to improve the geographic representation of urban areas, agricultural lands and grazing lands, for past, present and future.

3. Simulate future land cover change datasets starting from the present day using IPCC scenario data.
4. Soil degradation scenarios based on land cover and human population change scenarios.

Include statement to link this to including the human component in the Earth System modeling framework