Land-Use/Land-Cover Change as a Major Climate Forcing: Evidence and Consequences for Climate Research

Professor Roger A. Pielke, Sr.
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado 80523
pielke@atmos.colostate.edu

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The following figures are from:
National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Committee on Radiative Forcing Effects on Climate, Climate Research Committee, 224 pp.
http://www.nap.edu/catalog/11175.html
Estimated radiative forcings since preindustrial times for the Earth and Troposphere system (TOA) radiative forcing with adjusted stratospheric temperatures. The height of the rectangular bar denotes a central or best estimate of the forcing, while each vertical line is an estimate of the uncertainty range associated with the forcing guided by the spread in the published record and physical understanding, and with no statistical connotation. Each forcing agent is associated with a level of scientific understanding, which is based on an assessment of the nature of assumptions involved, the uncertainties prevailing about the processes that govern the forcing, and the resulting confidence in the numerical values of the estimate. On the vertical axis, the direction of expected surface temperature change due to each radiative forcing is indicated by the labels “warming” and “cooling.” From: National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Committee on Radiative Forcing Effects on Climate, Climate Research Committee, 224 pp. http://www.nap.edu/catalog/11175.html
FIGURE 1-1 The climate system, consisting of the atmosphere, oceans, land, and cryosphere. Important state variables for each sphere of the climate system are listed in the boxes. For the purposes of this report, the Sun, volcanic emissions, and human-caused emissions of greenhouse gases and changes to the land surface are considered external to the climate system.
FIGURE 1-2 Conceptual framework of climate forcing, response, and feedbacks under present-day climate conditions. Examples of human activities, forcing agents, climate system components, and variables that can be involved in climate response are provided in the lists in each box.
BOX 1-1
Key Definitions

Climate system: The system consisting of the atmosphere, hydrosphere, lithosphere, and biosphere, determining the Earth’s climate as the result of mutual interactions and responses to external influences (forcing). Physical, chemical, and biological processes are involved in the interactions among the components of the climate system.

Climate forcing: An energy imbalance imposed on the climate system either externally or by human activities.

- Direct radiative forcing: A climate forcing that directly affects the radiative budget of the Earth’s climate system; for example, added carbon dioxide (CO₂) absorbs and emits infrared radiation. Direct radiative forcing may be due to a change in concentration of radiatively active gases, a change in solar radiation reaching the Earth, or changes in surface albedo. Radiative forcing is reported in the climate change scientific literature as a change in energy flux at the tropopause, calculated in units of watts per square meter (W m⁻²); model calculations typically report values in which the stratosphere was allowed to adjust thermally to the forcing under an assumption of fixed stratospheric dynamics.

- Indirect radiative forcing: A climate forcing that creates a radiative imbalance by first altering climate system components (e.g., precipitation efficiency of clouds), which then almost immediately lead to changes in radiative fluxes. Examples include the effect of solar variability on stratospheric ozone and the modification of cloud properties by aerosols.

- Nonradiative forcing: A climate forcing that creates an energy imbalance that does not immediately involve radiation. An example is the increasing evapotranspiration flux resulting from agricultural irrigation.

Climate response: Change in the climate system resulting from a climate forcing.

Climate feedback: An amplification or dampening of the climate response to a specific forcing due to changes in the atmosphere, oceans, land, or continental glaciers.

NOTE: Additional definitions are provided in Appendix C.
FIGURE 1-4 Conceptual framework for how radiative forcing fits into the climate policy framework. Blue-shaded boxes indicate quantities that have been considered as policy targets in international negotiations and other policy analyses. Radiative forcing (striped box) has not been treated as a policy target in the same explicit way that limiting emissions (e.g., Kyoto Protocol), limiting concentrations (e.g., greenhouse gas stabilization scenarios), and limiting temperature changes and impacts (e.g., environmental scenarios) have. That is, an explicit cap on anthropogenic radiative forcing levels has not been proposed analogous, for example, to the Kyoto Protocol cap on emissions. Note that land-use change has not received much attention as a forcing agent and is not included here, though this report recommends that it should be.
<table>
<thead>
<tr>
<th>Effect</th>
<th>Cloud Type</th>
<th>Description</th>
<th>Sign of TOA Radiative Forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>First indirect aerosol effect (cloud albedo or Twomey effect)</td>
<td>All clouds</td>
<td>For the same cloud water or ice content, more but smaller cloud particles reflect more solar radiation</td>
<td>Negative</td>
</tr>
<tr>
<td>Second indirect aerosol effect (cloud lifetime or Albrecht effect)</td>
<td>All clouds</td>
<td>Smaller cloud particles decrease the precipitation efficiency, thereby prolonging cloud lifetime</td>
<td>Negative</td>
</tr>
<tr>
<td>Semidirect effect</td>
<td>All clouds</td>
<td>Absorption of solar radiation by soot leads to evaporation of cloud particles</td>
<td>Positive</td>
</tr>
<tr>
<td>Glaciation indirect effect</td>
<td>Mixed-phase clouds</td>
<td>An increase in ice nuclei increases the precipitation efficiency</td>
<td>Positive</td>
</tr>
<tr>
<td>Thermodynamic effect</td>
<td>Mixed-phase clouds</td>
<td>Smaller cloud droplets inhibit freezing, causing supercooled droplets to extend to colder temperatures</td>
<td>Unknown</td>
</tr>
<tr>
<td>Surface energy budget effect</td>
<td>All clouds</td>
<td>The aerosol-induced increase in cloud optical thickness decreases the amount of solar radiation reaching the surface, changing the surface energy budget</td>
<td>Negative</td>
</tr>
</tbody>
</table>
Hypotheses chart of aerosol-cloud interaction.

http://blue.atmos.colostate.edu/publications/pdf/R-295.pdf
Hypotheses chart of CO₂ biological effect

http://blue.atmos.colostate.edu/publications/pdf/R-295.pdf
RAMS/GEMTM coupled model results. The seasonal domain-averaged (central Great Plains) for 210 days during the growing season, contributions to maximum daily temperature, minimum daily temperature, precipitation, and leaf area index (LAI due to $f_1 =$ natural vegetation, $f_2 = 2 \times$CO2 radiation, and $f_3 = 2 \times$CO2 biology.

http://blue.atmos.colostate.edu/publications/pdf/R-295.pdf
Overview of Landscape Effects on Climate
Hypotheses of the influence of LULCC on regional climate.

FIGURE 2-4 Schematic, based on observations in southwest France, of the influence on the surface energy budget of land-use change from forest to cropland. SOURCE: Kabat et al. (2004).
Microclimate Effects
Moist enthalpy provides a proper measure of surface air heat content, which is not provided by air temperature alone.

\[ T_E = \frac{H}{C_p} \]

\[ H = C_p \, T + L \, q \]

Fig. 1. $T$ and $T_p$ in °C (S and H, in 10, J kg$^{-1}$) for Fort Collins, Colorado, (left panels) and the CPER ungrazed site (right panels) are shown for 2002. The top two panels are for maximum daily temperature while the bottom two panels are for minimum daily temperature. The grey lines represent $T$ (and $S$) while the black lines represent $T_p$ (and $H$).
The following figures are from:

http://blue.atmos.colostate.edu/publications/pdf/R-274.pdf
Maximum-minimum temperature sensor (MMTS) installation near Lindon, Colorado.
MMTS installation near John Martin Reservoir, Colorado.
Map of study region, showing all surveyed COOP sites. The USHCN sites are indicated by stars. The following photos are for HCN sites.
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Eads, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the temperature sensor looking N, E, S, and W, respectively.
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Holly, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the temperature sensor looking N, E, S, and W, respectively.
Photographs of the temperature sensor exposure characteristics for the NWS COOP station near Rocky Ford, Colorado. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the temperature sensor looking N, E, S, and W, respectively. (CRS-Cotton Region Shelter)
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Trinidad, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the sensor looking N, E, S, and W, respectively.
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Cheyenne Wells, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the sensor looking N, E, S, and W, respectively.
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Lamar, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the sensor looking N, E, S, and W, respectively.
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Wray, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the sensor looking N, E, S, and W, respectively.
Photographs of the temperature sensor exposure characteristics of the NWS COOP station at Las Animas, CO. Panel a) shows the temperature sensor, while panels b)-e) illustrate the exposures viewed from the sensor looking N, E, S, and W, respectively.
Fort Morgan site showing images of the cardinal directions from the sensor (from Hanamean et al. 2003)
Mesoscale Climate Effects
FIG. 25. Regional average time series of accumulated convective rainfall (cm) from 1924 to 2000, with corresponding trend based on linear regression of all July-August amounts. The vertical bars overlain on the raw time series indicate the value of the standard error of the July-August regional mean.


http://blue.atmos.colostate.edu/publications/pdf/R-272.pdf
U.S. Geological Survey land-cover classes for pre-1900’s natural conditions (left) and 1993 land-use patterns (right).
http://blue.atmos.colostate.edu/publications/pdf/R-277.pdf
FIG. 4. Accumulated convective rainfall (mm) from the model simulations of July-August 1973 with pre-1900s land cover (top), 1993 land use (middle), and the difference field for the two (bottom panel; 1993 minus pre-1900s case).

FIG. 5. Same as in Figure 4, except for July-August 1989.

Fig. 9 – left: Two-month average of the surface sensible heat flux (W m-2) from the model simulations of Jul-Aug 1973 for the (top) pre-1900 land cover, (middle) 1993 land-use, and (bottom) the difference field for the two (1993 minus pre-1900 case).

Fig. 10 – right: Same as Fig. 9 but for two-month average of the surface latent heat flux.


http://blue.atmos.colostate.edu/publications/pdf/R-272.pdf
Fig. 15. Two-month average of the diurnal cycle of shelter-level temperature from the model simulations for Jul–Aug 1989 (a) averaged over all land grid points in the domain and (b) for a grid point in the Kissimmee River valley that is indicated by the “X” in Figs. 13 and 14.
Fig. 1. Number of citrus trees per county and principle areas of winter fresh vegetable production. Figure adapted from Florida Agriculture Facts Directory 2002.

http://blue.atmos.colostate.edu/publications/pdf/R-281.pdf
Minimum temperature (deg C) at 2 m above ground level simulated by RAMS for 19 January 1997 with the natural land cover (top), near current land use (middle), and the difference between the two (bottom; defined as the near current minus natural scenario). From: Marshall, C.H., R.A. Pielke Sr., and L.T. Steyaert, 2004: Has the conversion of natural wetlands to agricultural land increased the incidence and severity of damaging freezes in south Florida? Mon. Wea. Rev. 132, 2243-2258. http://blue.atmos.colostate.edu/publications/pdf/R-281.pdf
Time spent below 0 deg C in the RAMS simulations on the morning of 26 December 1983 with the natural land cover (top), near current land use (middle), and the difference between the two (bottom; defined as the near current minus natural scenario).

Global Climate Impacts
Examples of land-use change from (a) 1700, (b) 1900, (c) 1970, and (d) 1990. The human-disturbed landscape includes intensive cropland (red) and marginal cropland used for grazing (pink). Other landscape includes tropical evergreen forest and deciduous forest (dark green), savannah (light green), grassland and steppe (yellow), open shrubland (maroon), temperate deciduous forest (blue), temperate needleleaf evergreen forest (light yellow) and hot desert (orange). Note the expansion of cropland and grazed land between 1700 and 1900. (Reproduced with permission from Klein Goldewijk 2001.)
Vegetation classifications for (a) natural vegetation and (b) current vegetation in regions where current and natural vegetation differ (i.e., anthropogenically disturbed regions in the current case).


The ten-year average absolute-value change in surface latent turbulent heat flux in W m\(^{-2}\) at the locations where land-use change occurred for (a) January, and (b) July. (Adapted from Chase et al. 2000.)
The ten-year average absolute-value change in surface sensible heat flux in W m\(^{-2}\) at the locations where land-use change occurred for (c) January, and (d) July. (Adapted from Chase et al. 2000.)
The ten-year average absolute-value change in surface latent turbulent heat flux in W m\(^{-2}\) worldwide as a result of the land-use changes for (a) January, and (b) July. (Adapted from Chase et al. 2000.)
The ten-year average absolute-value change in sensible turbulent heat flux in W m$^{-2}$ worldwide as a result of the land-use changes for (c) January, and (d) July. (Adapted from Chase et al. 2000.)
## Redistribution of Heat Due to the Human Disturbance of the Earth’s Climate System

<table>
<thead>
<tr>
<th>Only Where Land Use Occurs</th>
<th>Globally-Average Absolute Value of Sensible Heat Plus Latent Heat</th>
<th>January</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teleconnections Included</strong></td>
<td></td>
<td>0.7 Watts m⁻²</td>
<td>1.9 Watts m⁻²</td>
</tr>
<tr>
<td><strong>Globally-Average Absolute Value of Sensible Heat Plus Latent Heat</strong></td>
<td></td>
<td></td>
<td></td>
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<td><strong>Globally-Average Absolute Value of Sensible Heat Plus Latent Heat</strong></td>
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<td></td>
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</tr>
</tbody>
</table>
Fig. 11 Difference in near-surface air temperature (current-natural) using a 9-point spatial filter for easier visibility. Contours at 0.5, 1.0, 1.5, and 3.0°C. Shaded regions as in Fig. 3.


Why Should Landscape Effects, Which Cover Only a Fraction of the Earth’s Surface, Have Global Circulation Effects?
“AS SHOWN IN THE PIONEERING STUDY BY RIEHL AND MALKUS (1958) AND BY RIEHL AND SIMPSON (1979), 1500-5000 THUNDERSTORMS (WHICH THEY REFER TO AS ‘HOT TOWERS’) ARE THE CONDUIT TO TRANSPORT THIS HEAT, MOISTURE, AND WIND ENERGY TO HIGHER LATITUDES. SINCE THUNDERSTORMS OCCUR ONLY IN A RELATIVELY SMALL PERCENTAGE OF THE AREA OF THE TROPICS, A CHANGE IN THEIR SPATIAL PATTERNS WOULD BE EXPECTED TO HAVE GLOBAL CONSEQUENCES.”


http://blue.atmos.colostate.edu/publications/pdf/R-231.pdf
Most thunderstorms (about 10 to 1) occur over land.
From: http://thunder.nsstc.nasa.gov/images/HRFC_AnnualFlashRate_cap.jpg
The Regional Alteration in Tropospheric Diabatic Heating has a Greater Influence on the Climate System than a Change in the Globally-Averaged Surface and Tropospheric Temperatures
(a) and (b) show recent trends in annual, 300 mb winds from the NCEP/NCAR and ECMWF40 Reanalyses respectively. Significant trends at the 90 and 95% levels are thickly contoured.
Global Climate Effects occur with ENSOs for the Following Reasons:

1. Large Magnitude
2. Long Persistence
3. Spatial Coherence

We Should, Therefore, Expect Global Climate Effects With Landscape Changes!
Landscape Change Continues at a Rapid Pace
Abstract. The Earth’s climate system is highly nonlinear: inputs and outputs are not proportional, change is often episodic and abrupt, rather than slow and gradual, and multiple equilibria are the norm. While this is widely accepted, there is a relatively poor understanding of the different types of nonlinearities, how they manifest under various conditions, and whether they reflect a climate system driven by astronomical forcings, by internal feedbacks, or by a combination of both. In this paper, after a brief tutorial on the basics of climate nonlinearity, we provide a number of illustrative examples and highlight key mechanisms that give rise to nonlinear behavior, address scale and methodological issues, suggest a robust alternative to prediction that is based on using integrated assessments within the framework of vulnerability studies and, lastly, recommend a number of research priorities and the establishment of education programs in Earth Systems Science. It is imperative that the Earth’s climate system research community embraces this nonlinear paradigm if we are to move forward in the assessment of the human influence on climate.
An Alternate Paradigm is Needed

A focus on vulnerability is more inclusive and scientifically defensible
Maps of relative change in water reuse under (A) GCM-simulated climate change, (B) population and economic development, and (C) GCM-simulated climate change and population and economic development. (From Vörösmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers, 2000: Global water resources: Vulnerability from climate change acid population growth. Science 289, 284-288.)

See also: Pielke, R.A. Sr., 2004: Discussion Forum: A broader perspective on climate change is needed. IGBP Newsletter, 59, 16-19.

http://blue.atmos.colostate.edu/publications/pdf/NR-139.pdf
Resource Specific Impact Level with Respect to Water Resources - June 2004

Resource Specific Impact Level
Examples from Larimer County

- **Negligible**
- **Minor**
- **Moderate**
- **Major**
- **Exceptional**

**Impacted Groups**

- Anheuser-Busch
- Fort Collins Municipal Water
- Grant Family Farms
- Dryland Ranching
Hot or cold, wet or dry, sunny or stormy, everyone loves to talk about the weather, says Scott Stephens, a meteorologist for the National Climatic Data Center in Asheville, N.C. (p. 80,200). The center has the world’s largest archive of weather data and tracks extremes based on the best data available.

"The weather affects everyone," Stephens says. "Everyone can relate." Residents of Xenia, Ohio (p. 21,879), still talk about the day their town earned the record books—dominated by one tornado among the "superoutbreak" of April 1-4, 1974. Xenia’s tornado, which killed more than 30 people, was one of 158 twisters—the most ever recorded—47 in the United States and one just across the border in Canada. In the U.S., 310 people died, while 8 were killed in Canada.

People don’t live in fear of hordamones," says Bob Stewart. Xenia’s retired city manager. "I think people go about their normal lives. How do you prepare for something like a hurricane or tornado?” he asks.

Florida’s got their share of extreme weather, too. With a tropical climate conducive to storms, the Sunshine State leads the nation in lightning-related fatalities and also faces the ever-present danger of hordamones—getting more than any other state—as evidenced by last year’s record-setting season.

"Years ago, there was more loss of life because there was no warning," Stephens says. "Today, with more warning, there’s less loss of life and more loss of property because there’s more built close to the beach.”

Chris Tucker, his wife Diane and their three children moved to Pan St. Louis, Fla. (p. 80,360), last summer now in time for Hurricane Charley. Frances, Ivan and Jerome. "It’s no different from living with the threat of tornadoes in Nashville or earthquakes in Los Angeles," Tucker says. "You learn what to do to prepare, what to do in case you broke off.”

Buckley’s hordamone was large in size than the one measuring 57 inches in diameter and 175 inches in circumference that fell in Coffeyville, Kan. (p. 11,021), on June 3, 1979, though the Kansas stone still holds the weight record of 1.67 pounds.

Vicki Brown features writer in Nashville, Tenn.

For more U.S. weather records, log on to the National Climatic Data Center website at www.ncdc.noaa.gov.

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Selected papers:


PowerPoint Presentation Prepared by
Dallas Staley
Research Coordinator
Colorado State University
Department of Atmospheric Science
Fort Collins, CO  80526