Land Use and Climate Interactions [i.e. the role of land use within the climate system]

Roger A. Pielke Sr., CIRES/ATOC
University of Colorado, Boulder, CO
NASA Land-Cover and Land-Use Change Science Team Meeting
UMUC Inn and Conference Center
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What Are The New Conclusions Of The Role Of Land Use Within the Climate System

• The recognition that land use, land cover, land management and vegetation/soil dynamics are all part of the climate system
• Land use, through its role in the water, energy, carbon and other trace gas and aerosol effects, has a first order role in human and natural climate forcings and feedbacks
• The identification of global atmospheric teleconnections due to land use/land cover change which appear to alter weather and other aspects of the climate system as much or more than would occur due to the radiative effect of doubling CO2
• These conclusions are based on the outstanding research of many of our colleagues at this meeting!
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.
IPCC Perspective

## Radiative Forcing Components

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1.56 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>HNO</td>
<td>0.48 [0.43 to 0.55]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Ozone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratospheric</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Stratospheric water vapour from CH₄</td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Surface albedo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Black carbon on snow</td>
<td>0.1 [0.0 to 0.2]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Total Aerosol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td>Solar irradiance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
</tbody>
</table>

Note: LOSU stands for Local, Continental, Global, High, Low.
• The 2007 IPCC Focuses On The Role of Global Average Human-caused Radiative Forcing Relative To Other Measures of Human Climate Forcings
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
EXPANDING THE RADIATIVE FORCING CONCEPT (NRC 2005 Recommendations)

- Account for the Vertical Structure of Radiative Forcing
- Determine the Importance of Regional Variation in Radiative Forcing
- Determine the Importance of Nonradiative Forcings
- Provide Improved Guidance to the Policy Community
Account for the Vertical Structure of Radiative Forcing

National Research Council Report PRIORITY RECOMMENDATIONS

- Test and improve the ability of climate models to reproduce the observed vertical structure of forcing for a variety of locations and forcing conditions.
- Undertake research to characterize the dependence of climate response on the vertical structure of radiative forcing.
- Report global mean radiative forcing at both the surface and the top of the atmosphere in climate change assessments.
Determine the Importance of Regional Variation in Radiative Forcing

National Research Council Report PRIORITY RECOMMENDATIONS:

- Use climate records to investigate relationships between regional radiative forcing (e.g., land use or aerosol changes) and climate response in the same region, other regions, and globally.

- Quantify and compare climate responses from regional radiative forcings in different climate models and on different timescales (e.g., seasonal, interannual), and report results in climate change assessments.
Determine the Importance of Nonradiative Forcings

National Research Council Report PRIORITY RECOMMENDATIONS

- Improve understanding and parameterizations of aerosol-cloud thermodynamic interactions and land-atmosphere interactions in climate models in order to quantify the impacts of these nonradiative forcings on both regional and global scales.
- Develop improved land-use and land-cover classifications at high resolution for the past and present, as well as scenarios for the future.
Provide Improved Guidance to the Policy Community

Encourage policy analysts and integrated assessment modelers to move beyond simple climate models based entirely on global mean TOA radiative forcing and incorporate new global and regional radiative and nonradiative forcing metrics as they become available.
New or Under-Recognized Human Climate Forcings

- Biogeochemical Effect of CO₂
- Nitrogen Deposition
- Land-Use/Land-Cover Change
- Glaciation Effect of Aerosols
- Thermodynamic Effect of Aerosols
- Surface Energy Budget Effect
<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>
Potential Impacts of Aerosol-Land –Atmosphere Interactions

Figure 7: Possible aerosol-land-atmosphere interactions and surface, convection, and precipitation feedbacks in the monsoonal systems.

Niyogi et al., 2007. Accepted
Effect of Land-Use Change on Deep Cumulonimbus Convection

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.)


http://blue.atmos.colostate.edu/publications/pdf/R-258.pdf
DJF temperature differences due to land-cover change in each of the scenarios. Values were calculated by subtracting the greenhouse gas–only forcing scenarios from a simulation including land-cover and greenhouse gas forcings.

Feddema et al. 2005: The importance of land-cover change in simulating future climates., Science 310
Changes in the annual average diurnal temperature range due to land-cover change in each of the scenarios. Values were calculated by subtracting the greenhouse gas–only forcing scenarios from a simulation including land-cover and greenhouse gas forcings. Shaded grid cells are significant at the 0.05 confidence level.

Feddema et al 2005
\[ Q_N + Q_H + Q_{LE} + Q_G = 0 \]

\[ Q_N = Q_{S} (1 - A) + Q_{LW}^{\downarrow} - Q_{LW}^{\uparrow} \]

*Phil. Trans. A. Special Theme Issue*, 360, 1705-1719.
http://blue.atmos.colostate.edu/publications/pdf/R-258.pdf
Redistribution of Heat Due to the Human Disturbance of the Earth’s Climate System

| Only Where Land Use Occurred | July       | 1.08 Watts m⁻² |
|                            | January    | 0.7 Watts m⁻² |
| Teleconnections Included    | July       | 8.90 Watts m⁻² |
|                            | January    | 9.47 Watts m⁻² |

Global redistribution of heat is on the same order as an El Niño.
Spatial Redistribution of Heat is also Associated with a Spatial Redistribution of Water

\[ R_N = Q_G + H + L(E+T) \]
\[ P = E + T + RO + I \]

New Metric: Changes in \( \delta P; \delta T; \delta RO; \delta I \)

Global Water Cycle Metric

Absolute Value of Globally-Averaged Change is 1.2 mm/day.

Prepared by T.N. Chase, CU, Boulder, CO.
Global Water Cycle Metric

Absolute Value of Globally-Averaged Change is 0.6 mm/day

Prepared by T.N. Chase, CU, Boulder, CO.
Importance of Spatially Heterogeneous Heating
\[ NGoRF = \frac{GoRF_{\text{anthro}}}{GoRF_{\text{total}}} \]

\[ GoRF_{\text{total}} = \frac{\partial R_{\text{total}}}{\partial \lambda} \]

\[ GoRF_{\text{anthro}} = \frac{\partial R_{\text{anthro}}}{\partial \lambda} \]

The Normalized Gradient of Radiative Forcing (NGoRF) is the fraction of the present Earth’s heterogeneous diabatic heating that can be attributed to human activity on different horizontal scales.
The Same Analysis Needs To Be Applied For Land Surface Forcings

What is the fraction of the present Earth’s heterogeneous diabatic heating from land use/land cover change and vegetation/soil dynamics that can be attributed to human activity on different horizontal scales?
Importance of Vegetation/Soil Feedbacks
Assessing Effects of Drought and Land Use Change on Diurnal Temperature Range over the Sahel

Dickinson research group

Georgia Institute of Technology
Observed DTR Trends: Global View

- DTR declines most over semi-arid regions such as the Sahel

(Data sources: Vose et al., 2005)
The drier the climate, the stronger the warming in \( T_{\text{max}} \) and \( T_{\text{min}} \), and the larger the DTR reduction - the warming and the reduction of DTR are strongest over the driest regions.

### Trends of \( T_{\text{max}} \), \( T_{\text{min}} \), and DTR averaged over 11 climate regions based on the climatology of rainfall (mm/day)

<table>
<thead>
<tr>
<th>Rainfall</th>
<th>( T_{\text{max}} ) trends</th>
<th>( T_{\text{min}} ) trends</th>
<th>DTR trends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>0.29</td>
<td>0.78</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td>0.59</td>
<td>0.85</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td>0.81</td>
<td>1.16</td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td>1.08</td>
<td>1.08</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>1.37</td>
<td>1.11</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>0.83</td>
<td>1.52</td>
</tr>
<tr>
<td></td>
<td>1.89</td>
<td>0.52</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>2.39</td>
<td>0.50</td>
<td>1.02</td>
</tr>
<tr>
<td>Wet</td>
<td>3.19</td>
<td>0.10</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>4.43</td>
<td>0.63</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>6.86</td>
<td>0.81</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Observed DTR Trends: The Sahel

- $T_{\text{min}}$ has a strong/significant warming trend while $T_{\text{max}}$ shows a small/insignificant trend, and thus the DTR declines.

Normalized time series anomalies of annual mean $T_{\text{max}}, T_{\text{min}}, DTR$, cloud cover and rainfall for the period of 1950-2004.
Climate Model Sensitivity Tests

- Three 20 yr simulations using NCAR CAM3/CLM3:
  - Control run (CTL): no changes in vegetation and $\varepsilon_g = 0.96$
  - Exp A: remove all vegetation and $\varepsilon_g = 0.89$
  - Exp B: remove all vegetation and $\varepsilon_g = 0.96$

Test region: Sahel

Typical soil emissivity:
$\varepsilon_g = 0.96$

Desert soil emissivity:
$\varepsilon_g = 0.89$

A-CTL: effects of vegetation + emissivity
B-CTL: effects of vegetation only
Observed vs Simulated Temp: Spatial Pattern

- Stronger warming for Tmin than Tmax over the Sahel

<table>
<thead>
<tr>
<th></th>
<th>Tmax</th>
<th>Tmin</th>
<th>DTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-CTL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-CTL</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observed and simulated annual mean $T_{max}$, $T_{min}$, and DTR
Control run (CTL): no changes in vegetation and $\varepsilon$ =0.96
Exp A: remove all vegetation and $\varepsilon$ =0.89  Exp B: remove all vegetation and $\varepsilon$ =0.96
Conclusions

• Our simulations show that the reduction in vegetation and soil emissivity warms $T_{\text{min}}$ much faster than $T_{\text{max}}$ and thus substantially declines the DTR.

• Drought and land use change induced vegetation removal and soil aridation over semiarid regions like the Sahel could initiate an important soil-vegetation positive feedback on warming land surface air temperature and decreasing the DTR.

Results from:
Prescription of Land Use
Land Surface Model Calibration

How can we improve the model?
Tuning-Oriented Satellite-Hydrology-Integrated (TOSHI) Cycles

Land Information System

- NLDAS
- FLUXNET

Meteorological Forcing

- Offline simulation
  - area
  - point

Initial set of tunable parameters

Parameter Estimation Model

Update tunable parameters by Gauss-Marquardt-Levenberg iterations

\[ u = (J^TQJ + \alpha I)^{-1}J^TQr \]

Errors

- Spectral albedo, land surface temperature
- CO2, LHF, SHF

Observations

- MODIS spectral albedo, land surface temperature
- FLUXNET CO2, LHF, SHF

Xserve G5

Max performance ~300GFlops

If \( \Psi \) (sum of squared deviation between model and observation) has no more improvement
Development and Sensitivity Analysis of High Resolution Land Surface Parameters for Mesoscale Atmospheric Modeling of Urban Areas

Christopher Small, Roni Avissar, Robert Walko, Kathy Voyko-Walko

1 Lamont Doherty Earth Observatory, Columbia University
2 Dept. of Civil and Environmental Engineering, Pratt School of Engineering, Duke University

- Influence of Sub/Urban Land Cover on Atmospheric Processes
- Biophysical Land Surface Parameters from Spectral Mixture Analysis
- Heterogeneity of Urban Land Cover Parameters
- Mesoscale Sensitivity Analysis & Scale Dependence
Preliminary Results

- Coalescence of suburbs & large cities into very large conurbations can dominate regional land cover and LC-related land surface processes.

- Spectral Mixture Analysis (SMA) yields robust spatial estimates of biophysical endmember (EM) fractions (e.g. water, vegetation, soil, snow) & shadow.

- Multiscale validation of urban vegetation fraction gives ~6% error.

- Comparative SMA of Landsat dat of 28 cities quantifies inter-urban and intra-urban LC heterogeneity not represented in thematic classes.

Current Work

- Estimate continuous LS parameter fields from EM fractions and incorporate parameter distributions into OLAM (Ocean Land Atmosphere Model).

- Quantify spatial scaling relationships between LS parameters and EM fractions to determine optimal scale for LS parameter estimation.

- Sensitivity & Scale Analysis of Parameter Fields vs. Thematic Maps.
Multiscale Influence of Urban Land Cover

Global Scale
~3% of land area
strongly clustered

Regional Scale ($meso-\beta$)
some conurbations 30-50% of land area at regional scales.

Local Scale ($< meso-\gamma$)
100% of land area
Alternative Representations of Land Cover

*Discrete Thematic vs. Continuous Physical*

**The Problem:** Land surface parameters derived from thematic classifications assume discrete transitions in physical properties and cannot represent spatial variability within classes or gradational transitions in land cover.

**The Question:** Can some physical properties (*Vegetation Fraction, LAI, Soil Exposure, Albedo, Surface Roughness*) be derived directly from spectral endmember fractions of moderate resolution optical & thermal imagery without thematic classification?

*If so, does it matter?*

Is model performance better for continuous physical fields than for discrete thematic?

*If so, what, where and when?*

What is the magnitude and scale dependence for which parameters?
Physical Properties & Spectral Mixture Analysis

Spectral Mixture Analysis (SMA) represents spectrally mixed pixels as linear mixtures of spectrally pure endmembers.

Global analysis of spectrally diverse landscapes consistently reveals similar, biophysically distinct, spectral endmembers.

Estimates of endmember area fraction can be validated at multiple spatial scales.

Linear scaling properties can facilitate upscaling and downscaling of landcover fraction parameters.

Global Landsat ETM+ spectral mixing space with physically distinct endmembers.
Reconstructed Historical Land Cover and Biophysical Parameters for Studies of Land-Atmosphere Interactions Within the Eastern United States

L.T. Steyaert and R.G. Knox
Manuscript in Review

NASA Land-Cover and Land-Use Change Science Team Meeting
April 4-6, 2007
Land Use Intensity: 1850 vs 1920

Reconstructed Historical Land Use Intensity Showing Fractional Areas:

Top: Remaining Old-Growth and Pre-settlement Vegetation
(a) 1850 and (b) 1920

Middle: Disturbed/Semi-natural Vegetation/Village
(c) 1850 and (d) 1920

Bottom: Mixed Agriculture
(e) 1850 and (f) 1920

Source: Steyaert and Knox (in review)
Albedo: 1650, 1850, 1920, 1992

Historical Patterns of Broadband Solar Albedo:

(a) 1650
(b) 1850
(c) 1920
(d) 1992

Source: Steyaert and Knox (in review)
Surface Roughness
Length:

Historical Patterns of Surface Roughness Length (cm):

(a) 1650
(b) 1850
(c) 1920
(d) 1992

Source: Steyaert and Knox (in review)
Results for the Eastern United States

- Land-use intensity maps characterize major historical changes in land cover between the 1650, 1850, 1920, and 1992 time-slices.

- Land use fractions were mapped to biophysical land cover classes and parameters for each time-slice.

- The effects of land cover change are evident in the maps of average biophysical parameters.

- These changes potentially affect land-atmosphere interactions, altering the water, energy, and carbon cycles.
Where Do We Go From Here

• The quantification of all of the first order climate forcings and feedbacks that affect the land surface part of the climate system
• The need to further assess the role of land surface processes in altering regional and global weather patterns including not just TOA radiative forcing but also the gradient of radiative forcing and precipitation processes
Where Do We Go From Here

- The improvement in the prescription of the landscape and the provision of scenarios of land use change in the future
- The identification of important land surface related vulnerabilities and the risks posed to critical resources
Vulnerability – An Overarching Theme

• What are the critical threats to important societal and environmental resources?
• Many of these resources involve land use/land cover and vegetation/soil dynamics
• Can we use “impacts” models to identify risks to these resources from climate and other environmental variability and change?
Humans are significantly altering the global climate, but in a variety of diverse ways beyond the radiative effect of carbon dioxide. The IPCC assessments have been too conservative in recognizing the importance of these human climate forcings as they alter regional and global climate. These assessments have also not communicated the inability of the models to accurately forecast the spread of possibilities of future climate. The forecasts, therefore, do not provide any skill in quantifying the impact of different mitigation strategies on the actual climate response that would occur.