Role of Land in Understanding and Responding to Climate

Roger A. Pielke Sr., CIRES, University of Colorado, Boulder, Colorado, USA
### 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>
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<tbody>
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<td>Long-lived greenhouse gases</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.48 [0.43 to 0.53]</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>
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<tr>
<td>Ozone</td>
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<tr>
<td>Stratospheric</td>
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<td>Tropospheric</td>
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<tr>
<td>Surface albedo</td>
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<tr>
<td>Black carbon on snow</td>
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<tr>
<td>Direct effect</td>
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<tr>
<td>Aerosol</td>
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<td></td>
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<tr>
<td>Liquid aerosol effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
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<tr>
<td>Total linear contrails</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>1.8 [0.6 to 2.4]</td>
<td></td>
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Figure SPM.2. Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness. (2.9, Figure 2.20)
FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. Range for linear contrails does not include other possible effects of aviation on cloudiness.
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.
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
Determine the Importance of Regional Variation in Radiative Forcing

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.
Determine the Importance of Nonradiative Forcings

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.
Determine the Importance of Nonradiative Forcings

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

National Research Council Report

PRIORITY RECOMMENDATIONS

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.
• Human Caused Global Warming is a Subset of Human Caused Climate Change [The Term Global Warming ≠ The Term Climate Change]

• Significant Climate Change Can Occur Without a Change in the Global Average Surface Temperature

• Carbon is an Incomplete Metric to Characterize the Human Role within the Climate System – the IPCC Approach is Actually on Energy Policy Not on an Inclusive Assessment for Effective Climate Policy

• The Use of an Annual Global Average Temperature Change (e.g. +2C) Provides No Value In Characterizing Regional Climate Change
The Assessment of The Global Radiative Imbalance [Global Warming] in Watts per Meter Squared From Changes In Ocean Heat Content in Joules
Global Radiative Imbalance

Figure 1. Globally averaged annual OIICA [$10^{22}$ J] in the upper 750 m estimated using in situ data alone from 1993 through 2005 (black line) and using in situ data excluding profiling floats (gray line). Error bars (from Figure 3) reflect the standard error estimates discussed in Section 3. Linear trends are computed from a weighted least square fit [Wunsch, 1996] and reflect the OIICA estimate made using all available profile data. Errors for inset linear trend estimates are quoted at the 95% confidence interval.

## Radiative Forcing Components

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<td>Ozone</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Stratospheric water vapour from CH₄</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental to global</td>
<td>Med</td>
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<tr>
<td>Surface albedo</td>
<td></td>
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<td>Land use</td>
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<tr>
<td>Black carbon on snow</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med - Low</td>
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<tr>
<td>-0.1 [0.0 to 0.2]</td>
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<tr>
<td>Total Aerosol Direct effect</td>
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<tr>
<td>Cloud albedo effect</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med - Low</td>
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<td>Continental to global</td>
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2007 IPCC Total Radiative Forcing = 1.72 (0.66 to 2.7) Watts per meter squared

Best Estimate of Total Radiative Imbalance (1993-2005) = 0.33 (0.10 to 0.56) Watts per meter squared

If the IPCC Forcing is accepted as the current forcing, than the net global radiative feedbacks are negative!
The Evidence Indicates That Other Climate Forcings and Feedbacks, That Have Been Inadequately Recognized, Are Important
These Climate Forcings and Feedbacks Include The Land Surface Processes:

- Land Use/Land Cover Change
- Nitrogen Deposition
- Black Carbon Deposition
- Dust Deposition
- Biogeochemical Effect of Added CO2
- Ozone Effects On Vegetation
Important IGBP Book On The Role Of Land Surface Processes Within The Climate System
Several Examples Follow
Regional Land-Use Change Effects On Climate In The Eastern United States in June
Albedo: 1650, 1850, 1920, 1992

Historical Patterns of Broadband Solar Albedo:

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

Surface Roughness Length: 1650, 1850, 1920, 1992

Historical Patterns of Surface Roughness Length (cm):

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

REGIONAL LAND-USE CHANGE EFFECTS ON CLIMATE IN FLORIDA IN THE SUMMER
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.


FIG. 26. Same as in Figure 25, except for daily (a) maximum and (b) minimum shelter-level temperature (°C)
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.)
WHAT IS THE IMPORTANCE OF MORE HETEROGENEOUS CLIMATE FORCINGS RELATIVE TO MORE HOMOGENEOUS CLIMATE FORCING SUCH AS THE RADIATIVE FORCING OF CO$_2$?
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, 1674-1678.
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://climatesci.colorado.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

http://blue.atmos.colostate.edu/publications/pdf/R-312.pdf
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!
Human-Caused Climate Change However, is Just a Subset of Human-Caused Environmental Change
1) Land Clearing / Degradation

- massive changes to Earth’s land
  - ~40% of land converted to agriculture
    - ~18 million km² in crops
    - ~30 million km² in pastures, rangeland
  - today, ~40% of global photosynthesis now in human hands

Lesson #3

- key point: land use practices are changing quickly; much more than changing land cover

- massive shifts in the coming years...
  - increasing biofuels (maize, sugarcane, oil palm, ...)
  - increasing demands for animal feed
  - increasing participation in global markets

- throw all of our old assumptions about land use / land cover change out the window...
Points on Greenhouse Gases

**wow!** global land use & agriculture, taken together, contribute more greenhouse gases than any single societal activity

- more than global transportation..
- more than global electricity...
- more than global heating...
- more than global manufacturing...

altogether, agriculture and deforestation appear to contribute *at least 1/3 of all GHG forcing*
Points on Greenhouse Gases

- **CO₂** from land use is important...
  - *but only about half the story*

- **the other half...**
  - CH₄ from rice paddies, livestock
  - N₂O from agricultural lands

- **and that doesn’t consider...**
  - fires: O₃, black carbon, aerosols
  - biogenic VOCs: O₃
  - linked chemistry of O₃, CH₄
Lesson #2

- changes in land use / land cover have many other, direct impacts on human societies

- direct effects...
  - *agricultural production (food, feed and fuels)*
  - *water quantity and water quality*
  - *vector-borne disease*
  - *etc...*
Bottom Line

Global Change is Much More Than CO₂ and Global Warming

Current Focus on $\text{CO}_2$ / Climate Connection is Very Short Sighted
Need More Comprehensive Framework to Exploring Changes in Earth System
WE NEED A NEW PERSPECTIVE ON THE ROLE OF ENVIRONMENTAL VARIABILITY AND CHANGE ON SOCIETY AND THE ENVIRONMENT

A FOCUS ON VULNERABILITY
Fig. E.5.
A schematic illustration in which risk changes due to variations in the physical system and the socio-economic system. In all the cases risk increases over time (with modifications after Smith 1996).
<table>
<thead>
<tr>
<th>Approach</th>
<th>Scenario</th>
<th>Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed dominant stress</td>
<td>Recent greenhouse gas emissions, CO\textsubscript{2} in the atmosphere, changes in ocean temperatures, aerosols, etc.</td>
<td>Multiple stresses: climate (historical climate variability), land use and water use, altered disturbance regimes, invasive species, contaminants/pollutants, habitat loss, etc.</td>
</tr>
<tr>
<td>Usual timeframe of concern</td>
<td>Long-term, doubled CO\textsubscript{2}, 30 to 100 years in the future.</td>
<td>Short-term (0 to 30 years) and long-term research.</td>
</tr>
<tr>
<td>Usual scale of concern</td>
<td>Global, sometimes regional. Local scale needs downscaling techniques.</td>
<td>Local, regional, national and global scales.</td>
</tr>
<tr>
<td>Major parameters of concern</td>
<td>Spatially averaged changes in mean temperatures and precipitation in fairly large grid cells with some regional scenarios for drought.</td>
<td>Potential extreme values in multiple parameters (temperature, precipitation, frost-free days) and additional focus on extreme events (floods, fires, droughts, etc.); measures of uncertainty.</td>
</tr>
<tr>
<td>Major limitations for developing coping strategies</td>
<td>Focus on single stress limits preparedness for other stresses.</td>
<td>Approach requires detailed data on multiple stresses and their interactions at local, regional, national and global scales – and many areas lack adequate information.</td>
</tr>
<tr>
<td></td>
<td>Results often show gradual ramping of climate change-limiting preparedness for extreme events.</td>
<td>Emphasis on short-term issues may limit preparedness for abrupt &quot;threshold&quot; changes in climate some time in the short- or long-term.</td>
</tr>
<tr>
<td></td>
<td>Results represent only a limited subset of all likely future outcomes – usually unidirectional trends.</td>
<td>Requires preparedness for a far greater variation of possible futures, including abrupt changes in any direction – this is probably more realistic, yet difficult.</td>
</tr>
<tr>
<td></td>
<td>Results are accepted by many scientists, the media, and the public as actual &quot;predictions&quot;.</td>
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<tr>
<td></td>
<td>Lost in the translation of results is that all models of the distant future have unstated (presently unknowable) levels of certainty or probability.</td>
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</tbody>
</table>
Background Photograph Courtesy of Mike Hollingshead

http://www.extremeinstability.com/index.htm