# A Proposed New Metric For Quantifying The Climatic Effects Of Human-Caused Alterations To The Global Water Cycle

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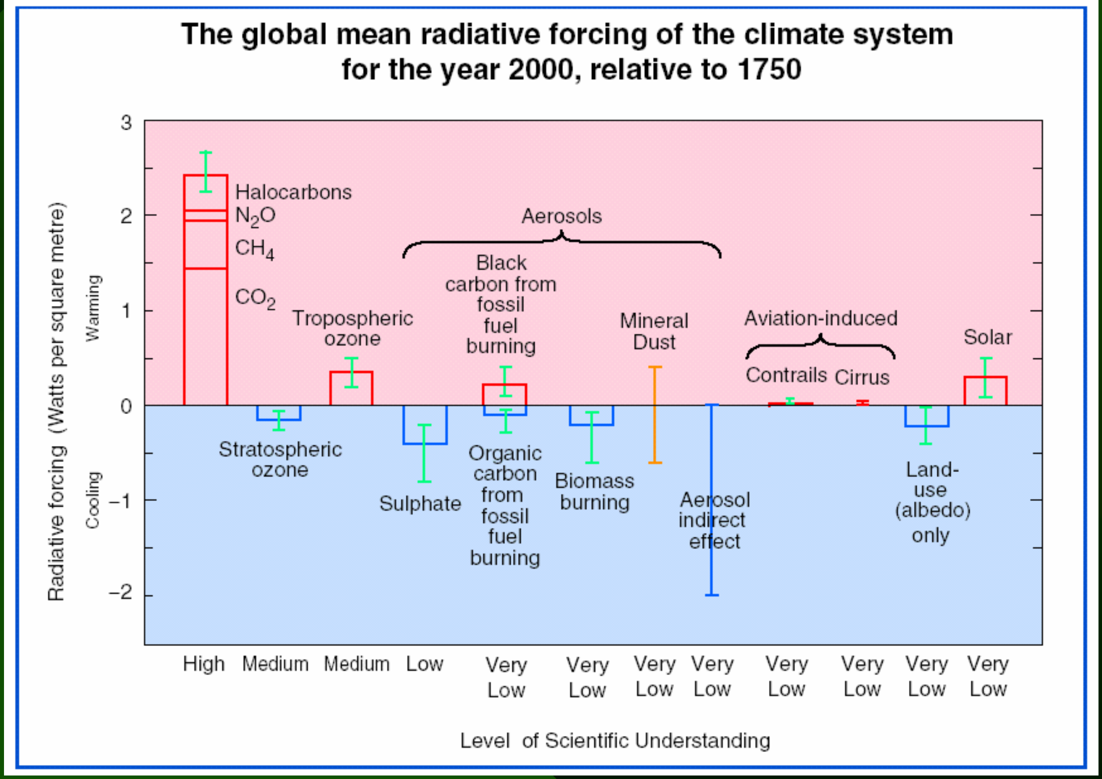
- The most appropriate metric to assess ‘global warming or cooling’ are the changes in heat unit (Joules) stores in accessible components of the earth’s environmental system.
- Humans can produce a net change in the storage and/or a redistribution of where the heat energy is stored.
- Heat units of Joules can be expressed in terms of a heating rate ($1.6 \times 10^{23}$ Joules per decade corresponds to an average earth system heating rate of 1.0 Watts $m^{-2}$).

# The Actual Global Heat Change in the Last 50 Years is Relatively Small



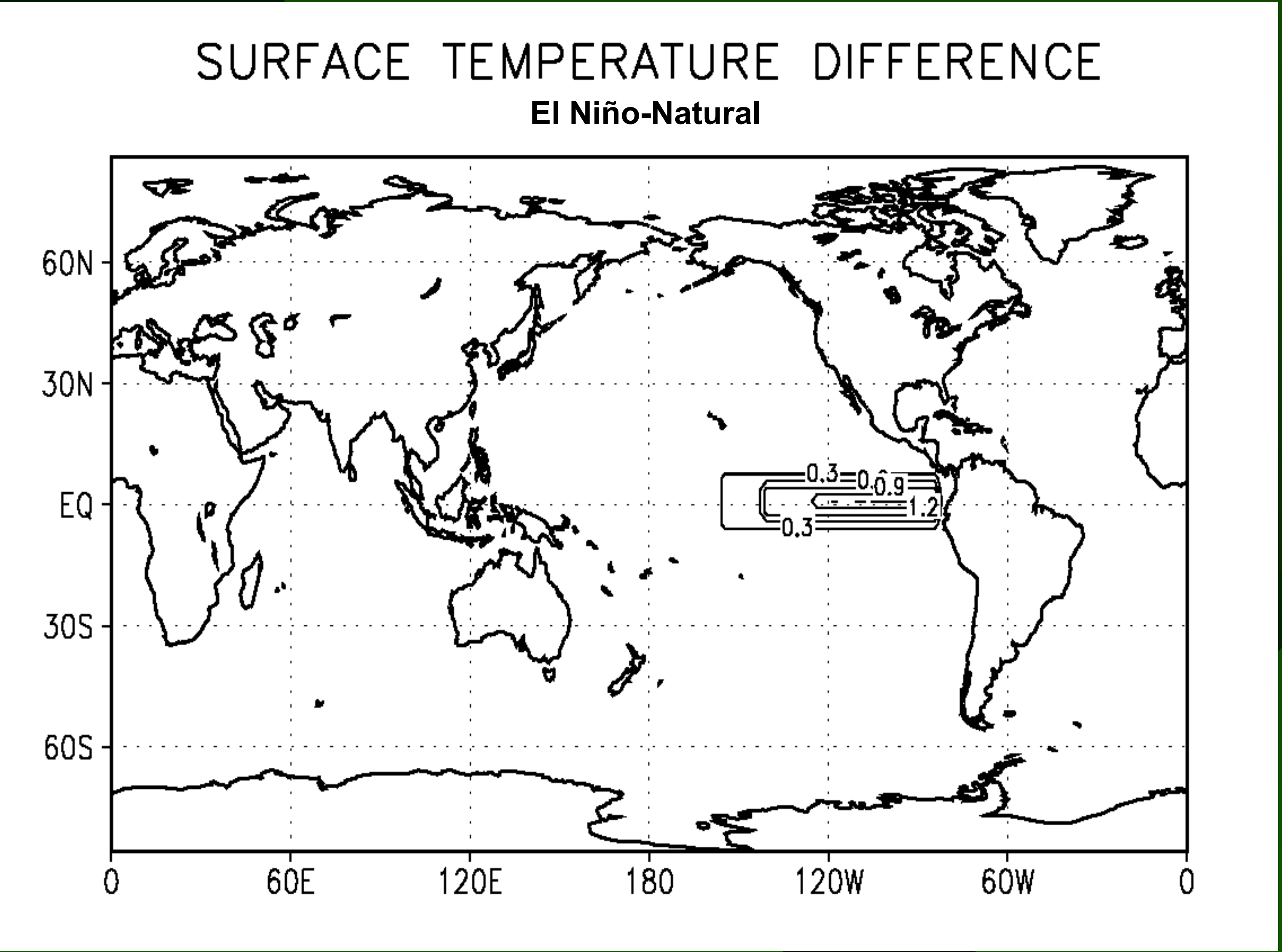

**Estimate of actual climate system heat change from the early 1950s-1995 is 0.3 Watts per meter squared (Pielke 2003) based on ocean heat storage changes (Levitus et al. 2000). Figure from Houghton et al. Eds., 2001: Summary for Policymakers: http://www.ipcc.ch**

# Effect of the Spatial Redistribution of Surface Heating (El Niño)

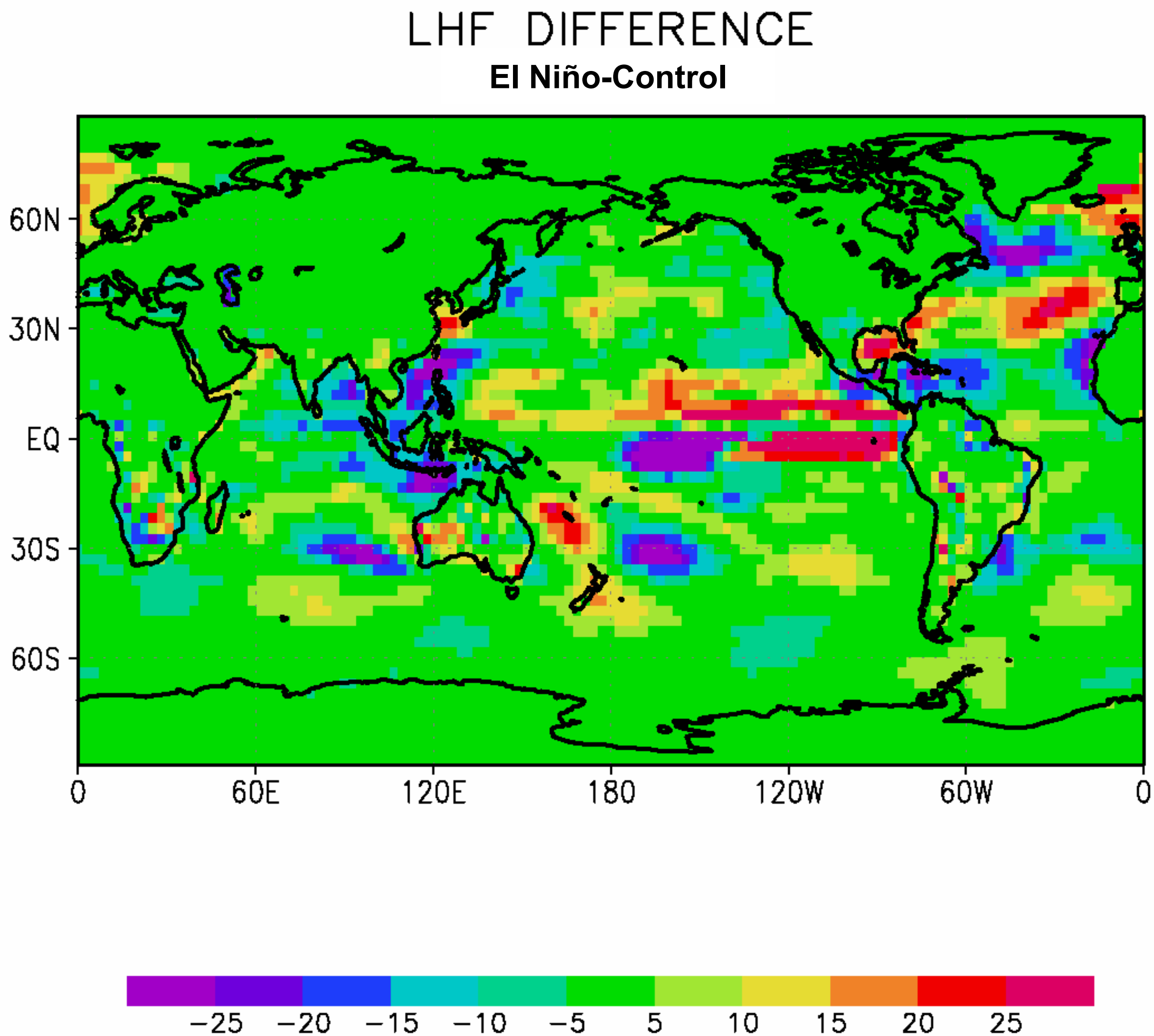
- El Niño has a major effect on weather thousands of kilometers from the tropical Pacific Ocean (Shabbar et al. 1997).
- The presence of warm SSTs permit thunderstorms to occur which otherwise would not have occurred.
- These thunderstorms export vast amounts of heat, moisture, and kinetic energy to the middle and higher latitudes, which alter the ridge and trough patterns associated with the polar jet stream (Hou 1998).
- El Niños have such a major effect on weather due to their large magnitude, long persistence, and spatial coherence (Wu and Newell 1998).
- Tropical thunderstorms are referred to as "hot towers" and are the conduit to higher latitudes as part of the Hadley circulations (Riehl and Malkus 1958; Riehl and Simpson 1979).
- Most thunderstorms occur over tropical and midlatitude land masses and in the warm season (Lyons 1999; Rosenfeld 2000).

***Therefore, the earth's climate system must also be sensitive to land-use change in those regions where thunderstorms occur.***

# El Niño Teleconnection Effect




Prepared by T.N. Chase, CU, Boulder, CO.

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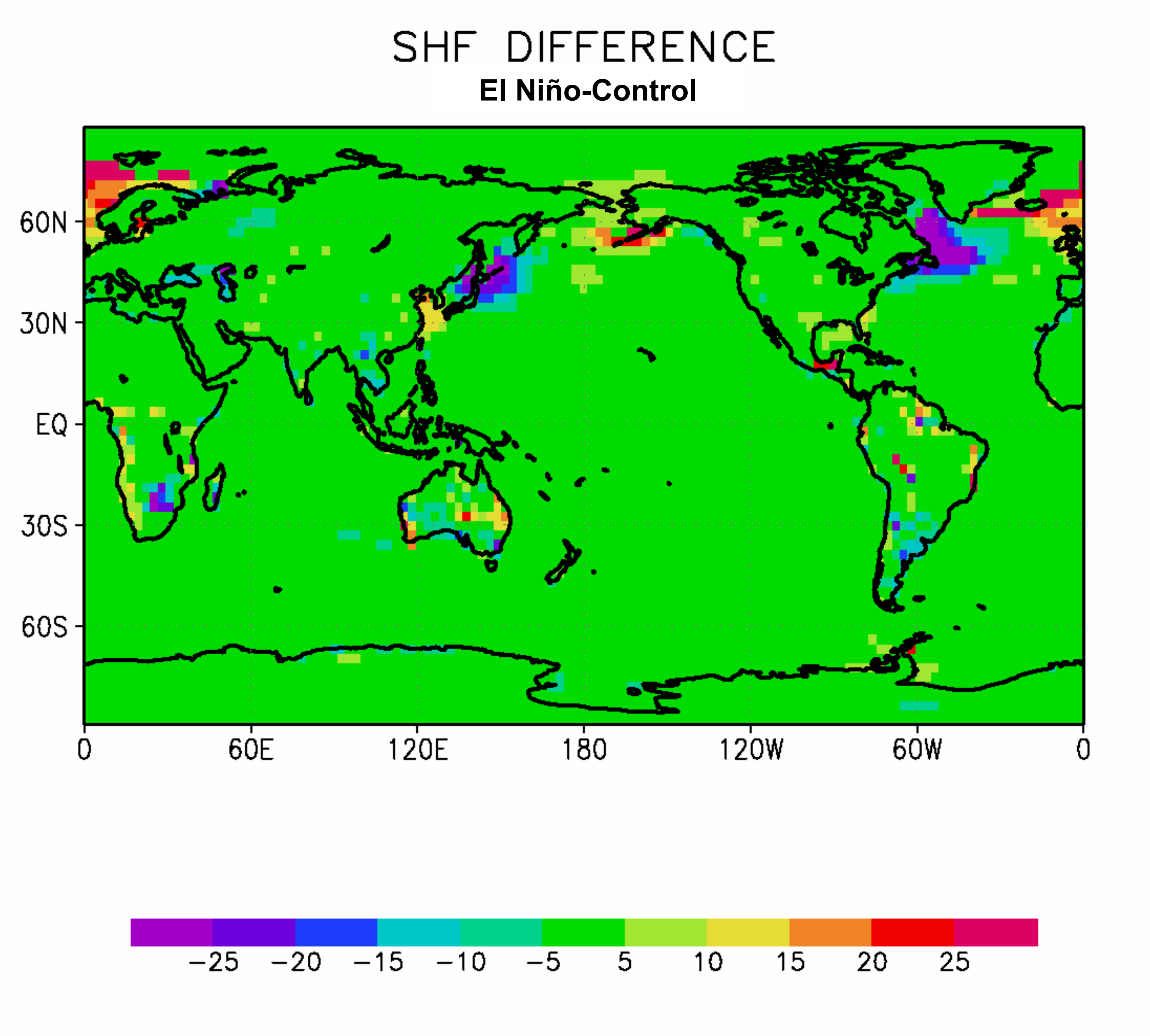
SHF DIFFERENCE
El Niño-Control
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−25
−20
−15
−10
−5
5
10
15
20
25

| Global-Averaged Absolute Value Difference of Sensible and Latent Heat Fluxes Averaged for 12 Januaries: El Niño Teleconnection | | |
|---|---|---|
| Average Latent Heat Flux | January | 6.1 Watts $m^{-2}$ |
| Average Sensible Heat Flux | January | 2.4 Watts $m^{-2}$ |

# Effect of the Spatial Redistribution of Surface Heating (Land-Use Change)

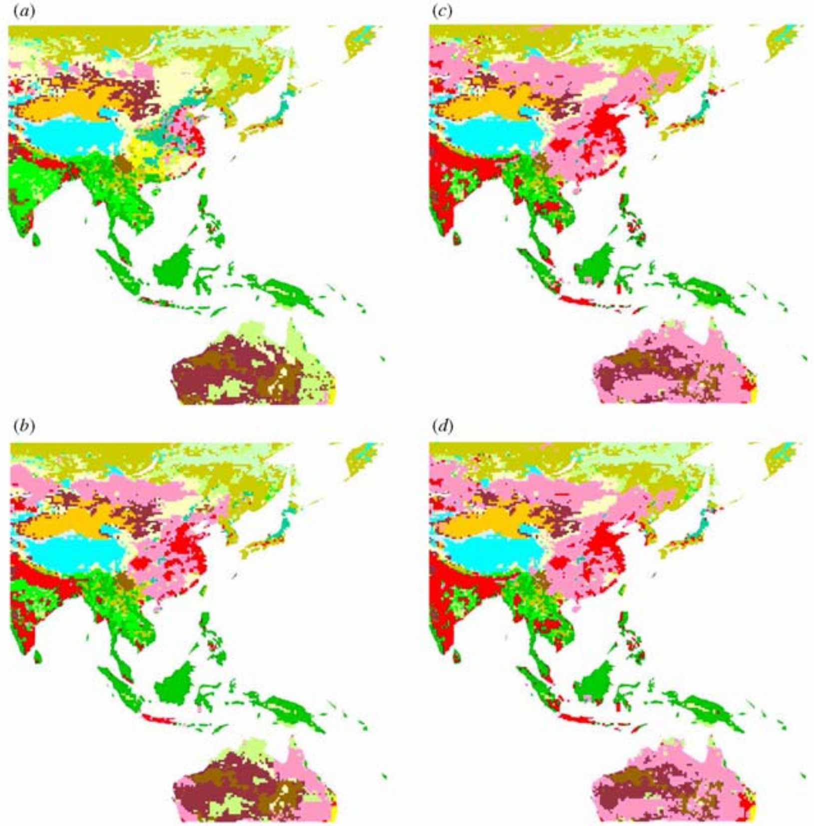


Figure 1. Examples of land-use change from (*a*) 1700, (*b*) 1900, (*c*) 1970 and (*d*) 1990. The human-disturbed landscape includes intensive cropland (red) and marginal cropland used for grazing (pink). Other landscape includes, for example, tropical evergreen and deciduous forest (dark green), savannah (light green), grassland and steppe (yellow), open shrubland (maroon), temperate deciduous forest (blue), temperate needleleaf evergreen forest (light yellow) and hot desert (orange). Of particular importance in this paper is the expansion of the cropland and grazed land between 1700 and 1900. (Reproduced with permission from Klein Goldewijk 2001).

**From: Pielke Sr., R.A., G. Marland, R.A. Betts, T.N. Chase, J.L. Eastman, J.O. Niles, D. Niyogi, and S. Running, 2002: 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. *Phil. Trans. A. Special Theme Issue*, 360, 1705-1719.**

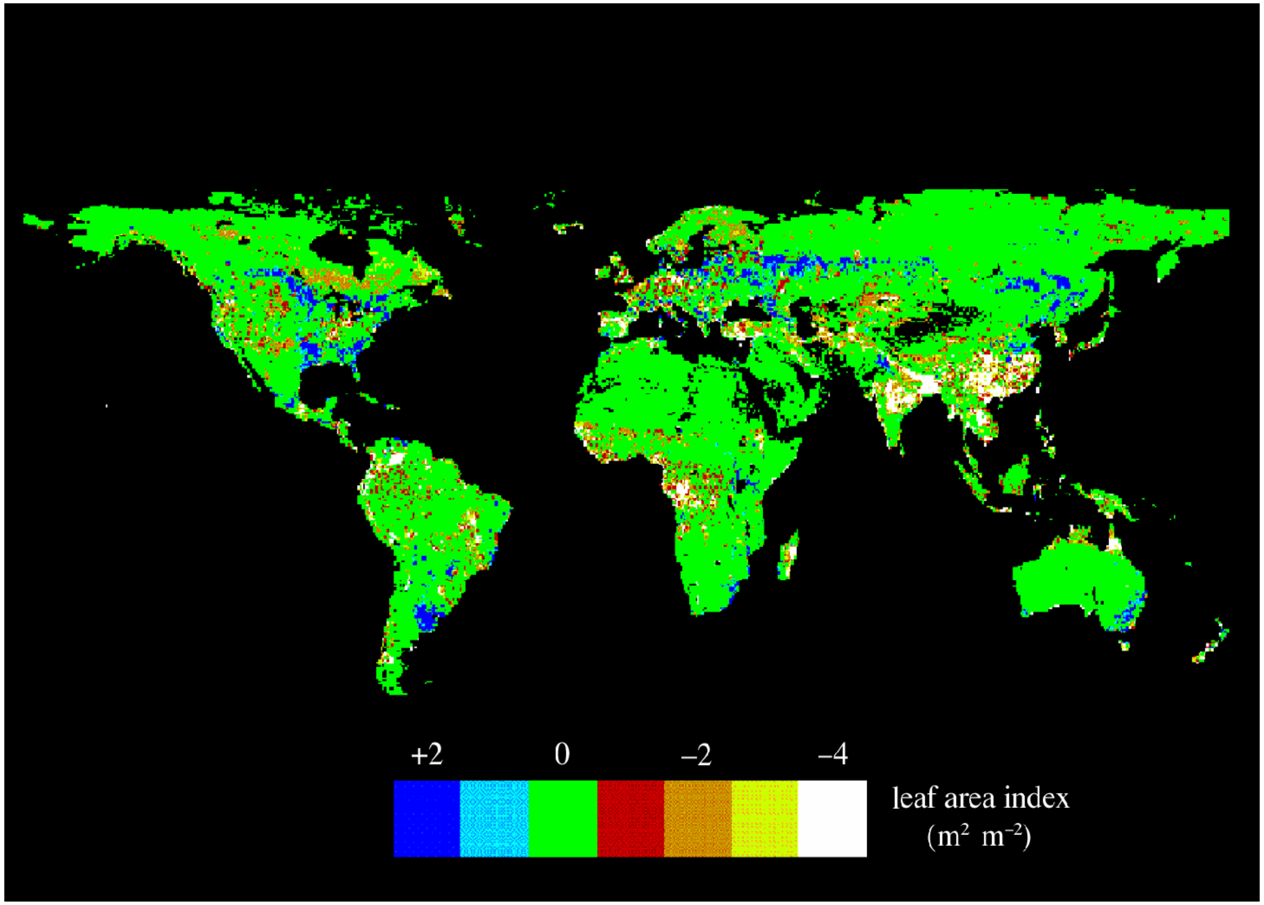


Figure 4. Effect of land-use changes on plant-canopy density (potential/actual). Scale 0.5 latitude × 0.5 longitude.

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Table 1. *Tropical forest extent and loss (rainforest and moist deciduous forest ecosystems)* (Source: World Resources Institute (1994), adapted from O'Brien (2001).)

| country | rainforest extent in 1990 (kha) | decrease 1981 1990 (%) | moist deciduous forest extent in 1990 (kha) | decrease 1981 1990 (%) |
|---|---|---|---|---|
| Brazil | 291 597 | 6 | 197 082 | 16 |
| Indonesia | 93 827 | 20 | 3 366 | 20 |
| Dem. Rep. Congo (Zaire) | 60 437 | 12 | 45 209 | 12 |
| Columbia | 47 455 | 6 | 4 101 | 38 |
| Peru | 40 358 | 6 | 12 299 | 6 |
| Papua New Guinea | 29 323 | 6 | 705 | 6 |
| Venezuela | 19 602 | 14 | 15 465 | 36 |
| Malaysia | 16 339 | 36 | 0 | 0 |
| Myanmar | 12 094 | 24 | 10 427 | 28 |
| Guyana | 11 671 | 0 | 5 078 | 6 |
| Suriname | 9 042 | 0 | 5 726 | 4 |
| India | 8 246 | 12 | 7 042 | 10 |
| Cameroon | 8 021 | 8 | 9 892 | 12 |
| French Guiana | 7 993 | 0 | 3 | 0 |
| Congo | 7 667 | 4 | 12 198 | 4 |
| Ecuador | 7 150 | 34 | 1 669 | 34 |
| Lao People's Dem. Rep. | 3 960 | 18 | 4 542 | 18 |
| Philippines | 3 728 | 62 | 1 413 | 54 |
| Thailand | 3 082 | 66 | 5 232 | 54 |
| Vietnam | 2 894 | 28 | 3 382 | 28 |
| Guatemala | 2 542 | 32 | 731 | 0 |
| Mexico | 2 441 | 20 | 11 110 | 30 |
| Belize | 1 741 | 0 | 238 | 0 |
| Cambodia | 1 689 | 20 | 3 610 | 20 |
| Gabon | 1 155 | 12 | 17 080 | 12 |
| Central African Republic | 616 | 14 | 28 357 | 8 |
| Cuba | 114 | 18 | 1 247 | 18 |
| Bolivia | 0 | 0 | 35 582 | 22 |

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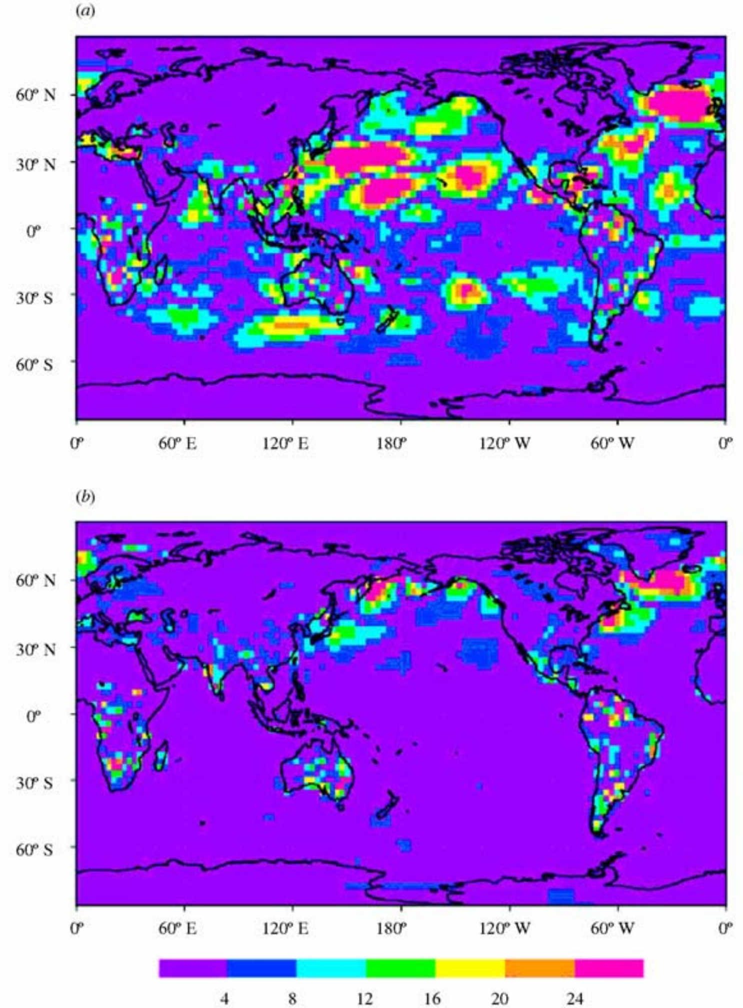


Figure 2. The 10-year average absolute-value change in surface latent turbulent heat flux in $W\ m^{-2}$ worldwide as a result of the land-use changes: (*a*) January, (*b*) July. (Adapted from Chase *et al.* (2000).)

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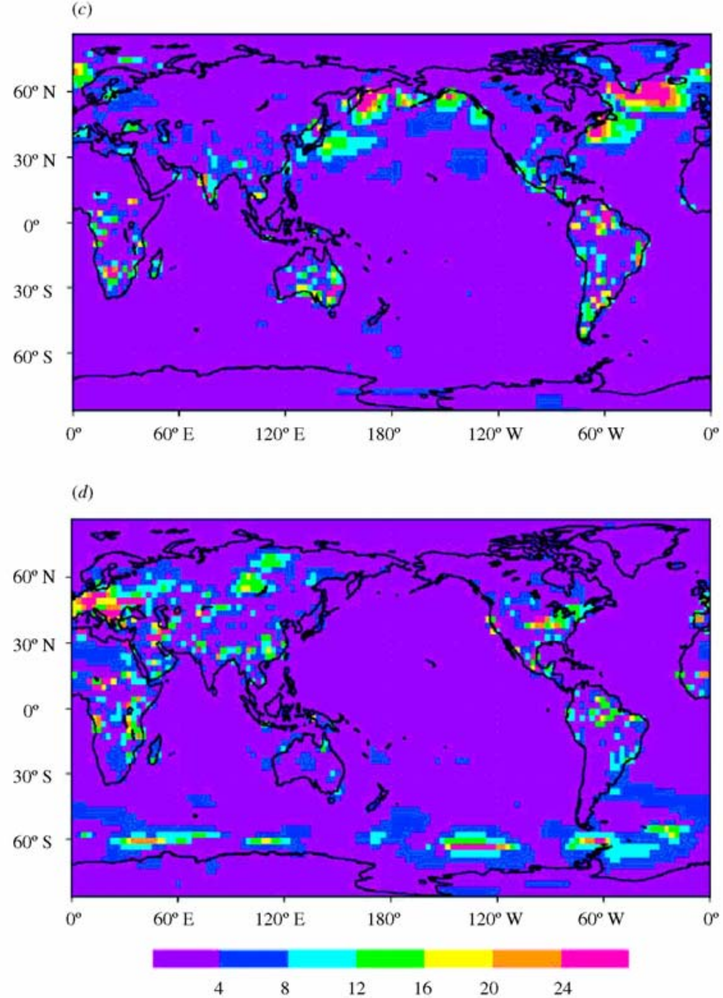


Figure 2. (*Cont.*) The 10-year average absolute-value change in sensible turbulent heat flux in W $m^{-2}$ worldwide as a result of land-use changes: (*c*) January, (*d*) July. (Adapted from Chase *et al.* (2000).)

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# Redistribution of Heat Due to the Human Disturbance of the Earth's Climate System

| Globally-Average Absolute Value of Sensible Heat Plus Latent Heat | | |
|---|---|---|
| Only Where Land Use Occurred | July<br>January | 1.08 Watts $m^{-2}$<br>0.7 Watts $m^{-2}$ |
| Teleconnections Included | July<br>January | 8.90 Watts $m^{-2}$<br>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

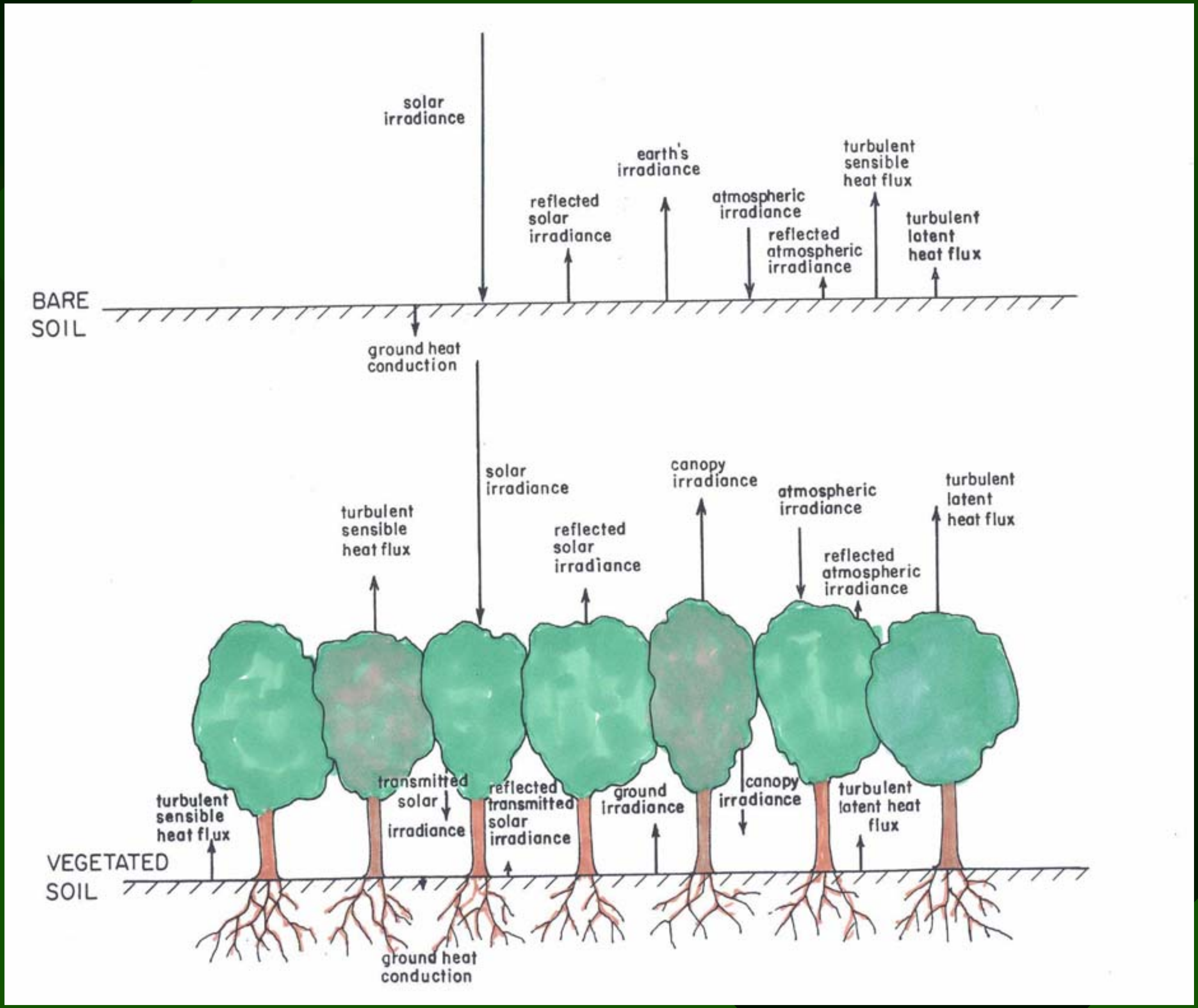
$$R_N = Q_G + H + L(E+T)$$

$$P = E + T + RO + I$$

***New Metric: Changes in δP; δT; δRO; δI***

**From Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys*., 39,151-177.**

# Alteration in Surface Water Fluxes Associated With Land-Use Change




Adapted from P. Kabat (personal communication, 1999). From Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39,151-177.

# Alteration of Thermodynamic Profile Associated with Land-Use Change

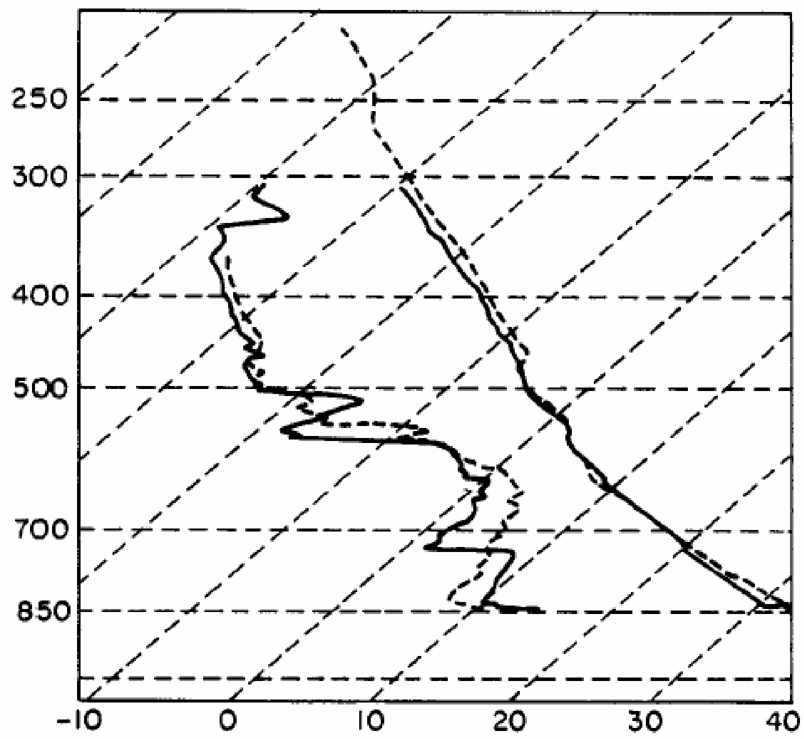
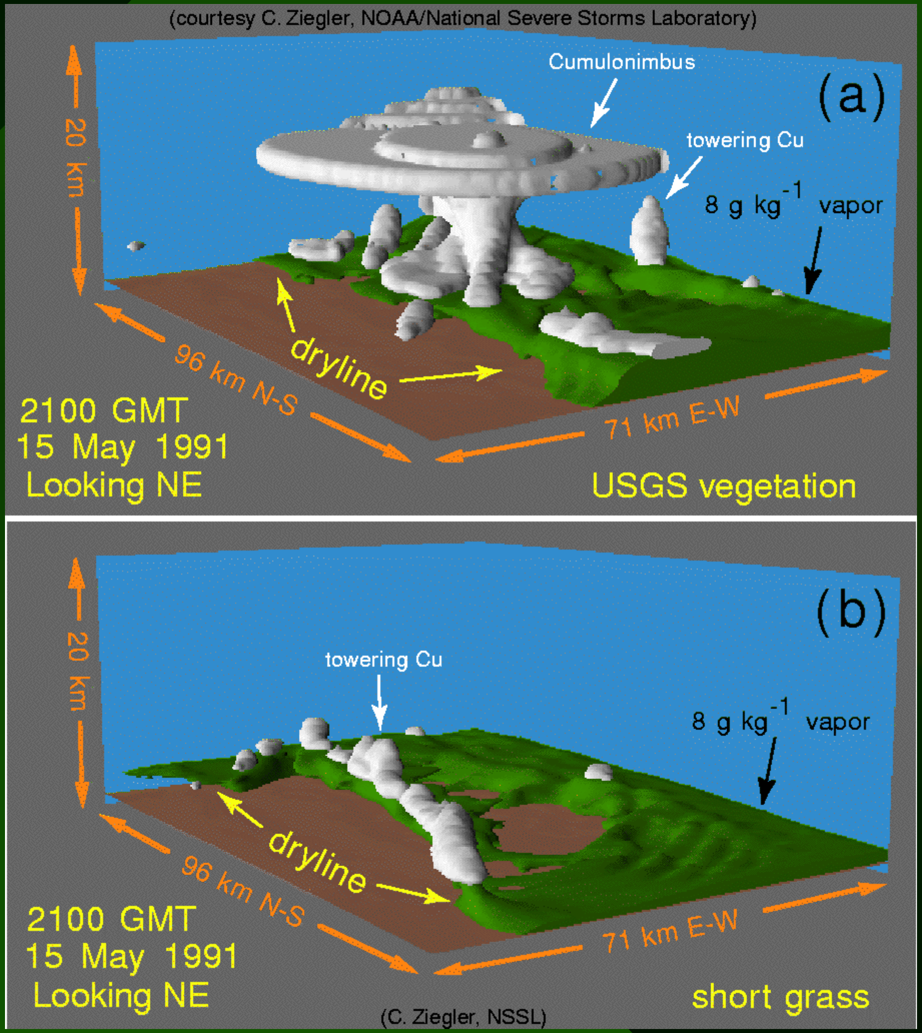



**Figure 6.** Radiosonde measurements of (right) temperature and (left) dew point temperature for a dry land area (dashed curve) and an irrigated area (solid curve) in northeast Colorado at 1213 local standard time (LST) on July 28, 1987. Reprinted from *Pielke and Zeng* [1989] with permission from National Weather Association.

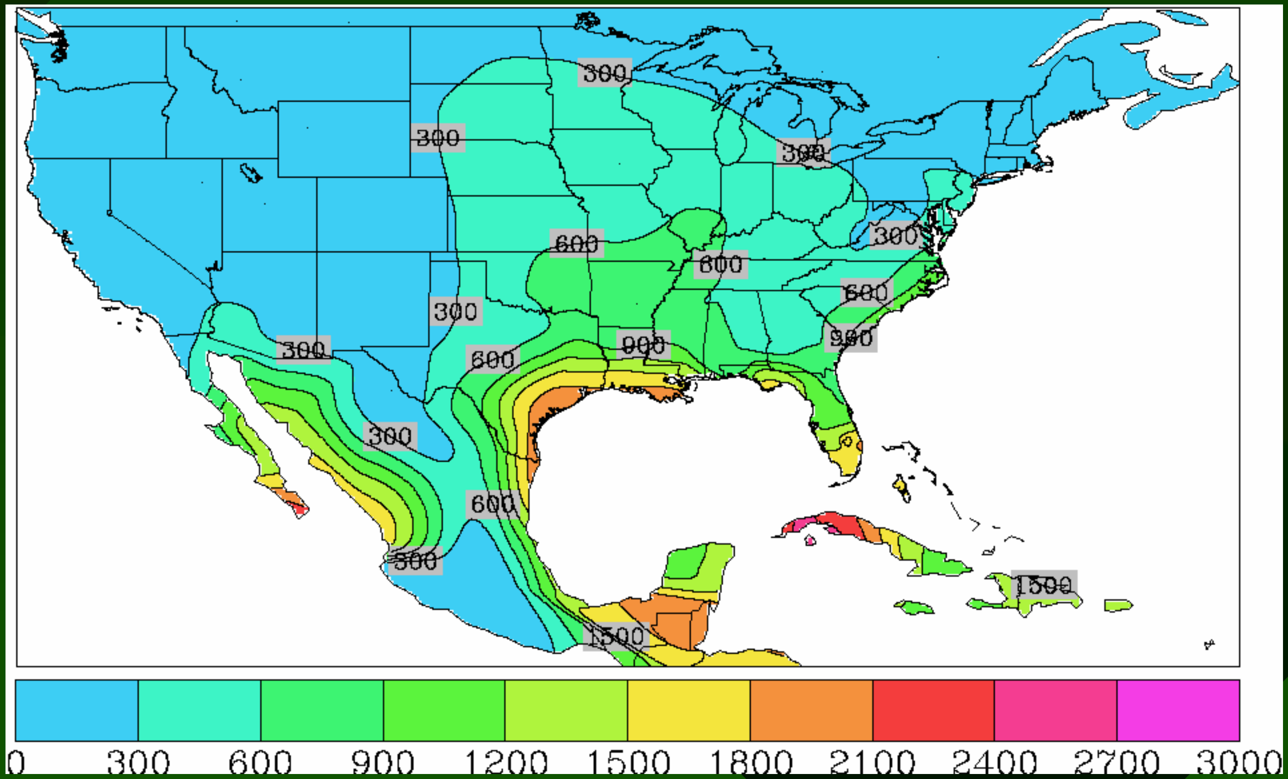
**From Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys*., 39,151-177.**

# Effect of Land-Use Change on Deep Cumulonimbus Convection



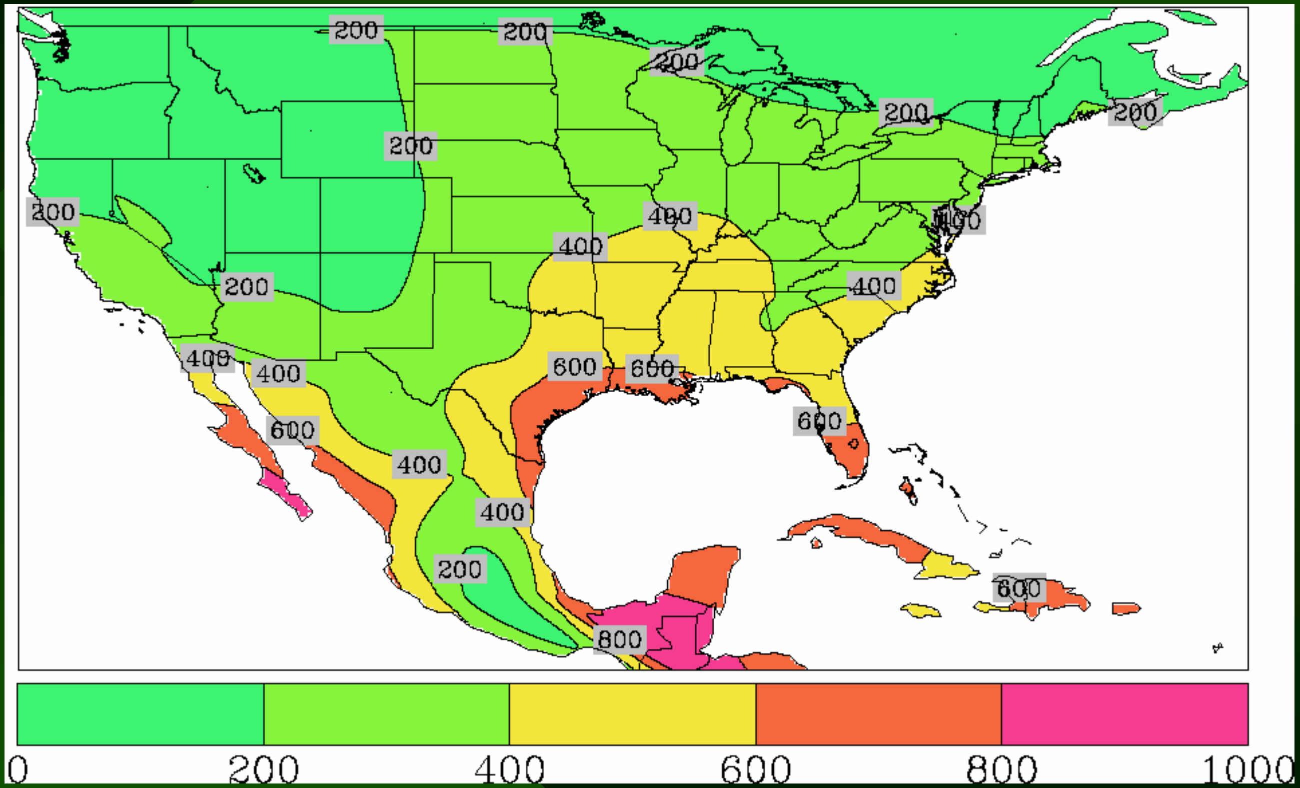

From Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39,151-177.

# Mean July Convective Available Potential Energy (CAPE) (J $kg^{-1}$) from 12 Z Radiosonde Observations




From U. Nair and R. Welch (personal communication, 2000). Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39,151-177.

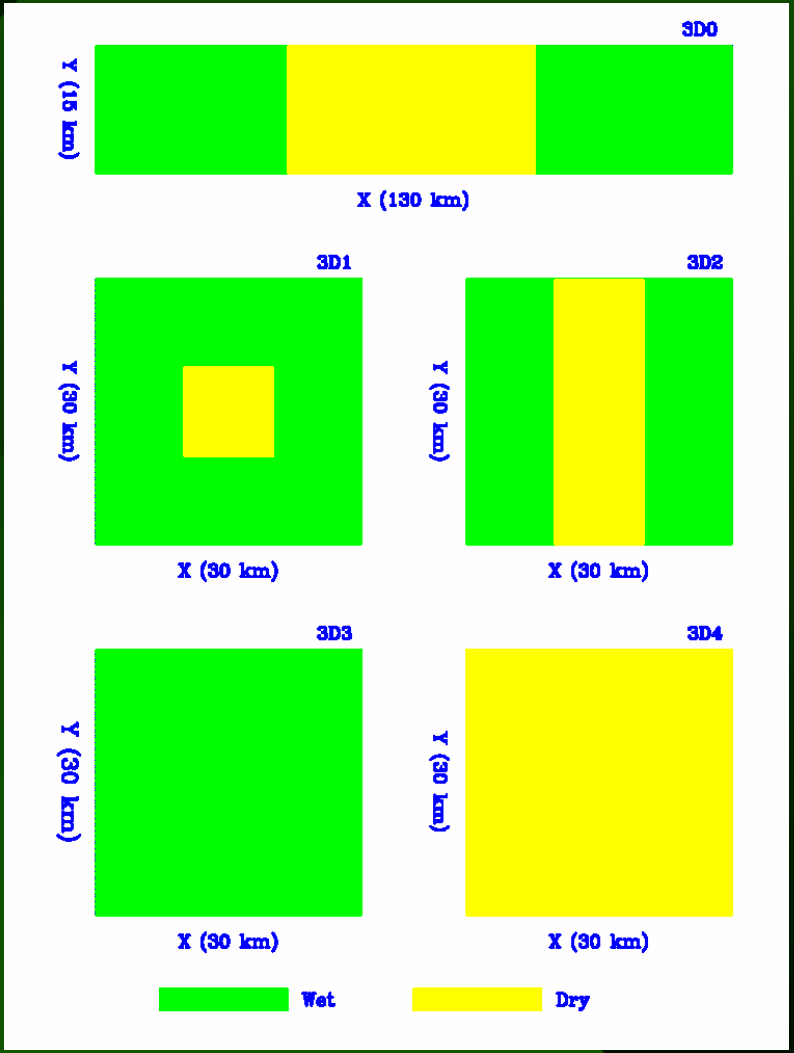
# Changes in Mean July CAPE Due to a 1°C Increase in Surface Layer Dewpoint Temperature




*Alterations in surface moisture fluxes alter CAPE*

**From U. Nair and R. Welch (personal communication, 2000). Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39,151-177.**

# Smaller-Scale Spatial Variations in Landscape Change Also Affect the Water Cycle




From Avissar and Liu (1996). Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys*., 39,151-177.

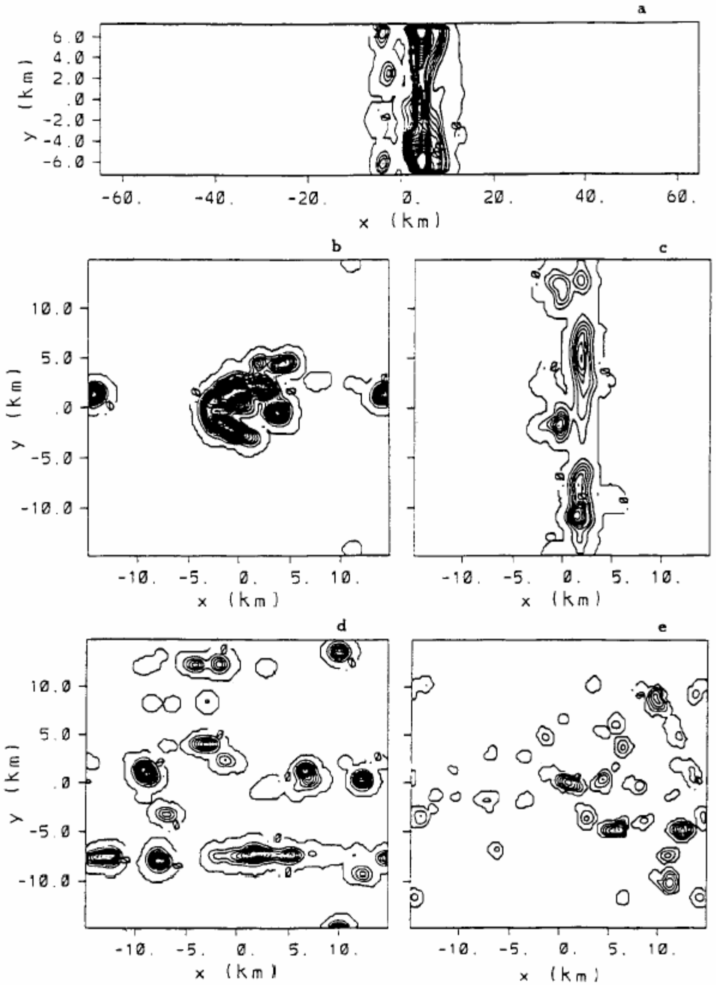
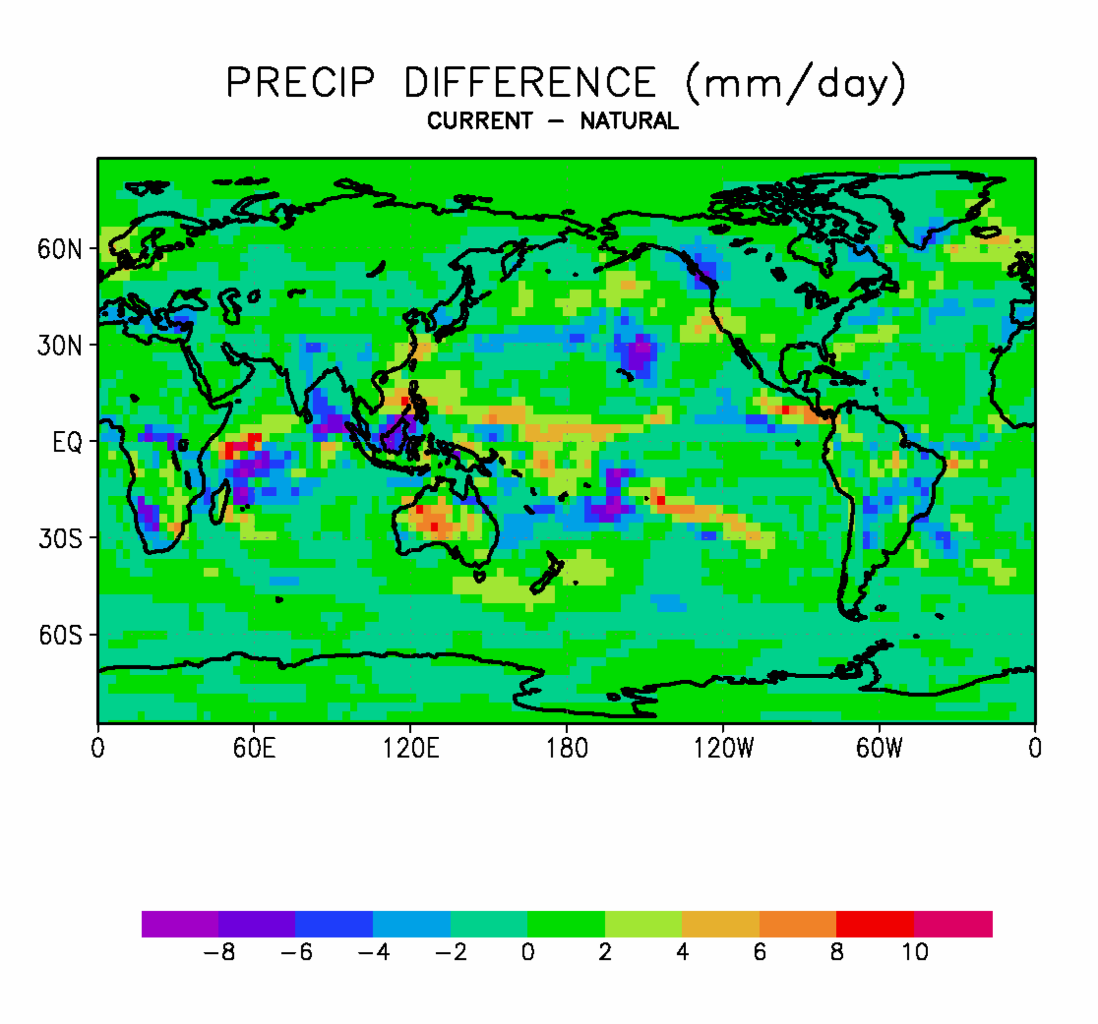



**Figure 11.** Accumulated precipitation (millimeters) at 1800 LST in domain (a) 3D0, (b) 3D1, (c) 3D2, (d) 3D3, and (e) 3D4. Contour intervals are 2 mm in 3D0, 1 mm in 3D1, 3D2, and 3D3, and 0.05 mm in 3D4. From *Avissar and Liu* [1996].

**From Avissar and Liu (1996). Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39,151-177.**

# Global Water Cycle Metric

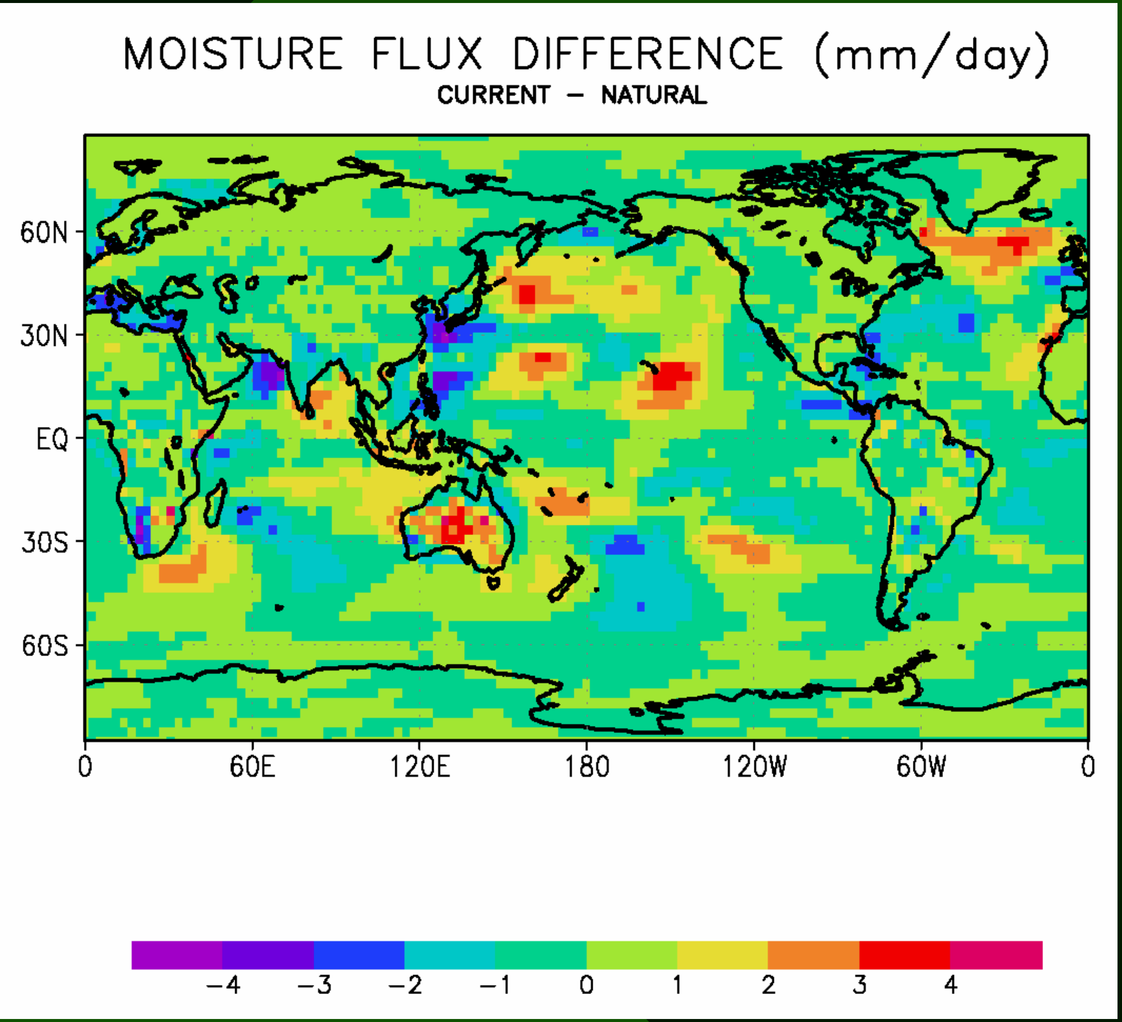



*Absolute Value of Globally-Averaged Change is 1.2 mm/day.*




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.**

# SUMMARY

- Landscape change and vegetation dynamics both result in a significant global redistribution of heat and water within the global climate system.
- This redistribution of heat and water has already had an effect on the global climate system this is at least as large as the IPCC and National Assessment have attributed to the radiative effect of a doubling of carbon dioxide.