# The Net Exchange Between Terrestrial Ecosystems and the Atmosphere as a Result of Changes in Land Use

Grant # NAGW-4748

## Summary of Research
**for the period July 1995 - June 1998**

**to**

**National Aeronautics and Space Administration**
**Washington, D.C.**

**from**

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The general purpose of this research was to improve and update (to 1990) estimates of the net flux of carbon between the world's terrestrial ecosystems and the atmosphere from changes in land use (e.g., deforestation and reforestation). The estimates are important for understanding the global carbon cycle, and for predicting future concentrations of atmospheric $CO_2$ that will result from emissions.

The emphasis of the first year's research was on the northern temperate zone and boreal forests, where the greatest discrepancy exists between estimates of flux. Forest inventories suggest net sinks of 0.6 PgC $yr^{-1}$ ; inversion analyses based on atmospheric data and models suggest much larger sinks 2-3.6 PgC $yr^{-1}$ (e.g., Tans et al. 1990, Ciais et al. 1995). The work carried out with this grant calculated the flux attributable to changes in land use. The estimated flux was somewhat smaller than the flux calculated from inventory data,suggesting that environmental changes have led to a small accumulation of carbon in forests that exceeds the accumulation expected from past rates of harvest. Two publications have described these results (Houghton 1996, 1998). The large difference between these estimates and those obtained with atmospheric data and models remains unexplained. The recent estimate of a 1.7 PgC yr-1 sink in North America, alone (Fan et al. 1998), is particularly difficult to explain. That part of the sink attributable to land-use change, however, is defined as a result of this grant.

The major effort in years 2 and 3 was to calculate the long-term net flux of carbon from changes in land use in tropical Asia and in the US. The revisions in the analysis of tropical Asia led to an increase in the estimated emissions. The total release of carbon to the atmosphere over the period 1850-1995 was 43.5 PgC. The clearing of forests for permanent croplands released about 75% of the total. The total release is about 30% higher for the period 1850-1990 than reported in an earlier study (Houghton and Hackler 1994). More than half of the increase resulted from a reduction in the amount of biomass assigned to long-lasting products at the time of agricultural clearing. The rest of the increase resulted from the way in which reductions in biomass were modelled (previously with a degradation multiplier and here by incorporating the direct effects of harvests and regrowth) and from new estimates of deforestation over the last 15 years. For the 15-yr period 1981-1995, annual emissions averaged 1.07PgC $yr^{-1}$, about 50% higher than reported for the 1980s in the earlier study. The emissions of carbon from land-use change in tropical Asia during the 1980s accounted for approximately 75% of the region's total carbon emissions. Since 1990 rates of deforestation and their associated emissions have declined, while emissions of carbon from combustion of fossil fuels have increased. The net effect has been a reduction in emissions of $CO_2$ from this region since 1990. The revised estimate of carbon flux for tropical Asia has been described in a manuscript in press in *Global Change Biology*. The new estimate of flux was also incorporated, along with an updating of temperate zone fluxes to 1990, into a new global estimate (Houghton, in press in *Tellus*). The revisions increased the long-term emissions of carbon from land-use change to 124PgC over the period 1850-1990. The global net flux for the 1980s was increased from 1.6PgC $yr^{-1}$ to 2 PgC $yr^{-1}$.

Previous work on land-use change in the US estimated the annual flux only through 1980 and included both the US and Canada in one region. The work being finished at present as a part of this grant extended the annual flux to 1990, used better data that have become available in

recent years, and considered a greater number of ecosystems and regions than the earlier study. The greatest difference between the analysis carried out here and earlier ones is that we considered fire in this analysis. Wildfire statistics were much more difficult to interpret and use than we had anticipated, but we think we will have used what can be used, made the data more accessible to the scientific community, and shown the questions that remain to be resolved. We are submitting two manuscripts that describe the results of this analysis, and a third manuscript is in preparation.

The major effect of considering fire was to reduce the long-term emissions of carbon (or increase the sink). There are two reasons. First, the natural fire cycle enhanced by Native Americans reduced the starting (1700) biomass of forests, but the emissions resulting from these early fires took place long before 1700 and were not counted in the net flux of carbon since 1700. Nevertheless, the biomass of forests was smaller in 1700 and resulted in a lower release of carbon when clearing or harvesting took place. Fire also reduced the estimated emissions of carbon because the dominant historical change in fire has been a suppression of wildfires, especially after 1850. The net effect was an accumulation of carbon in both forests and non-forests. After a reappraisal of Canada, these new estimates for North America will generate a new global estimate. The estimated annual emissions will be somewhat larger in the decades around 1900; they will be somewhat lower in recent decades. The changes will be on the order of tenths ofPgC $yr^{-1}$.

The revisions that have resulted from this research confirm the importance of making similar revisions in at least three other regions: China, Africa, and the former Soviet Union. New data are available for these regions, which were last analyzed 10-15 years ago. The trend in analyses of land-use change has tended to increase geographic resolution, moving toward the use of satellite data rather than tabular statistics to document changes. The transition is just starting to be developed. We need to expand the existing model so that it can work with spatial data. The expansion should be done in a way that will make these analyses of land-use change compatible with global terrestrial models, which, to date, have emphasized natural ecosystems rather than those modified by humans. The interaction between 'metabolic' models and models of land-use change will also increase the accuracy of fluxes attributed to land use. Together the two types of analyses will constrain estimates of the terrestrial flux of carbon.

**Publications resulting in whole or in part from this grant**

Over the 3-year project period we have published 9 papers as a result of this research, 7 are in press, and 3 more are still in preparation. They are listed below.

Houghton, R.A. 1996. Climate and meteorology. Pages 112-114 in: G.T. Kurian and G.T.T. Molitor (editors). *Encyclopedia of the Future*. Simon & Schuster Macmillan, New York.

Houghton, R.A. 1996. Land-use change and terrestrial carbon: the temporal record. Pages 117-134 in M.J. Apps and D.T. Price (editors). *Forest Ecosystems, Forest Management and the Global Carbon Cycle*. Springer-Verlag, Berlin.

Houghton, R.A. 1996. Terrestrial sources and sinks of carbon inferred from terrestrial data. *Tellus 48B*:420-432.

Melillo, J.M., R.A. Houghton, D.W. Kicklighter, and A.D. McGuire. 1996. Tropical deforestation and the global carbon budget. *Annual Review of Energy and the Environment 21*:293-310.

Houghton, R.A. 1997. Terrestrial carbon storage: Global lessons for Amazonian research. *Ciencia e Cultura Sao Paulo 49*:58-72.

Houghton, R.A. 1998. Historic role of forests in the global carbon cycle. Pages 1-24 *in*: G.H. Kohlmaier, M. Weber, and R.A. Houghton (editors). *Carbon Dioxide Mitigation in Forestry and Wood Industry*. Springer-Verlag, Berlin.

Houghton, R.A., E.A. Davidson, and G.M. Woodwell. 1998. Missing sinks, feedbacks, and understanding the role of terrestrial ecosystems in the global carbon balance. *Global Biogeochemical Cycles 12*:25-34.

IGBP Terrestrial Carbon Working Group. 1998. The terrestrial carbon cycle: Implications for the Kyoto Protocol. *Science 280*:1393-1394.

Kohlmaier, G.H., M. Weber, and R.A. Houghton (editors). 1998. *Carbon Dioxide Mitigation in Forestry and Wood Industry*. Springer-Verlag, Berlin.

**In press**

Houghton, R.A. The annual net flux of carbon to the atmosphere from changes in land use 1850-1990. *Tellus*.

Houghton, R.A. Data requirements for estimating emissions of carbon from terrestrial ecosystems. Pecora 13 Symposium.

Houghton, R.A. Emissions of carbon from land-use change. In: *The Carbon Cycle* (T.M.L. Wigley and D.S. Schimel, editors), Cambridge University Press, Stanford, California.

Houghton, R.A. Global terrestrial productivity in the future: Inferences from the global carbon balance. In: H. Mooney, B. Saugier, and J. Roy (editors). *Terrestrial Global Productivity*.

Houghton, R.A. Interannual variability in the global carbon cycle. IBAV.

Houghton, R.A., and J.L. Hackler. Emissions of carbon from forestry and land-use change in tropical Asia. *Global Change Biology.*

Woodwell, G.M., F.T. Mackenzie, R.A. Houghton, M.J. Apps, E. Gorham, and E.A. Davidson. 1995. Biotic feedbacks in the warming of the earth. *Climatic Change.*

**In preparation**

Houghton, R.A., and J.L. Hackler. Changes in terrestrial carbon storage in the United States as a result of agriculture and wood harvest.

Houghton, R.A., J.L. Hackler, and K.T. Lawrence. Changes in terrestrial carbon storage in the United States as a result of agriculture and wood harvest: The role of fire.

Houghton, R.A. et al. Sources and sinks of carbon in the United States from land-use change and forestry.

**Conferences, Meetings and Workshops**

In addition, Houghton participated in several conferences, meetings and workshops. Travel costs were paid by the hosts in all but two meetings.

"Terrestrial Global Productivity: Past, Present, and Future"
Montpellier, France, March 19-22, 1997

"Interannual Biosphere-Atmosphere Variability"
Tucson, Arizona, March 24-26, 1997.

Fifth International Carbon Dioxide Conference, Cairns, Australia, 8-12 September, 1997.

GCTE/LUCC international meeting in Barcelona, March 15-18, 1998.

An IGBP workshop to address the implications of the terrestrial carbon cycle for the Kyoto Protocol (Stockholm, April 28-29, 1998).

A workshop in Westminster, Colorado, addressing the US program in carbon cycle research (August 18-19, 1998)

A scoping meeting (Rome, September 23-25, 1998) for preparation of an IPCC special report to address the role of land-use change in national accounting of sources and sinks of carbon and the implications for the Kyoto Protocol. R.A. Houghton was nominated to be a convening author of the chapter on the global carbon cycle.