Drivers of change:

Sources and sinks of Carbon from Changes in land use

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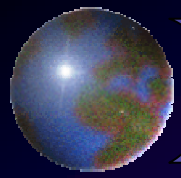
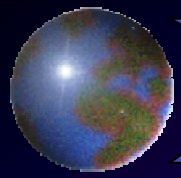


Outline

- The Approach
- Results
  - Net flux of carbon
  - Comparisons with other estimates of flux
- Uncertainties



An Approach…

Two kinds of data needed:

1. Rates of land-use change

2. Per hectare changes in carbon

And a bookkeeping model

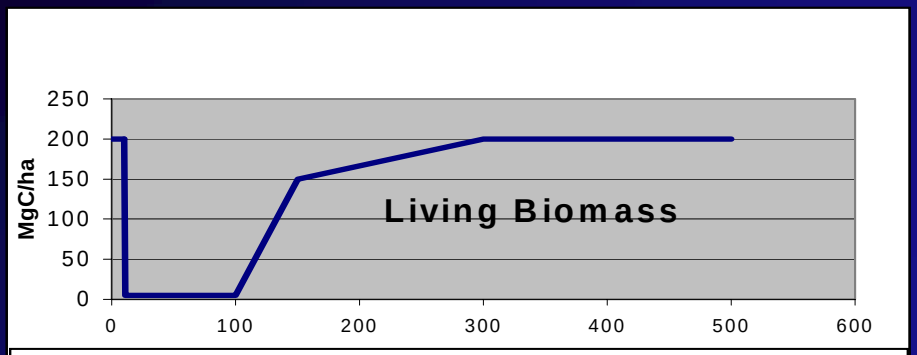
Changes in land use

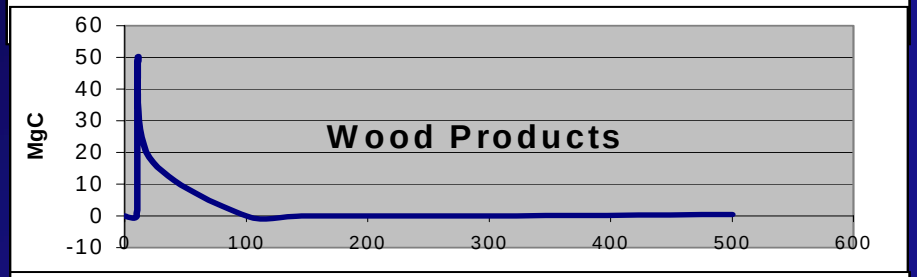
- Croplands (clearing and abandonment) (ha/yr)
- Pastures
- Shifting cultivation
- Wood harvest & recovery (m^3/yr)
- Degradation, restoration
- Management (fire, tillage, silviculture)

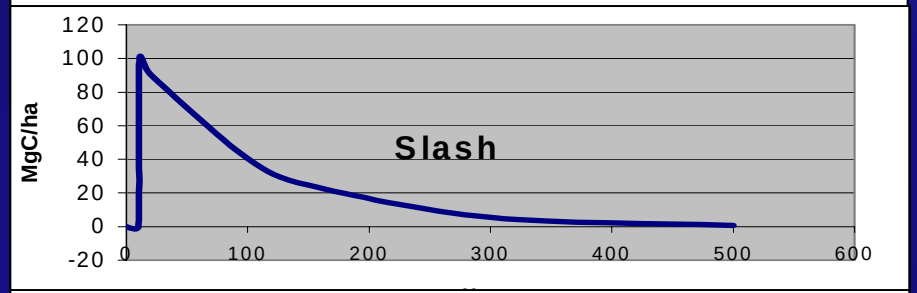
-- Emphasis on forests

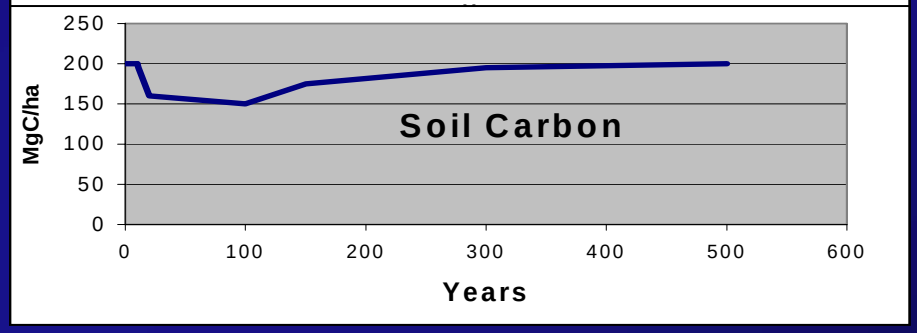

Data sources:
•Agricultural and forestry statistics
•Remote sensing data

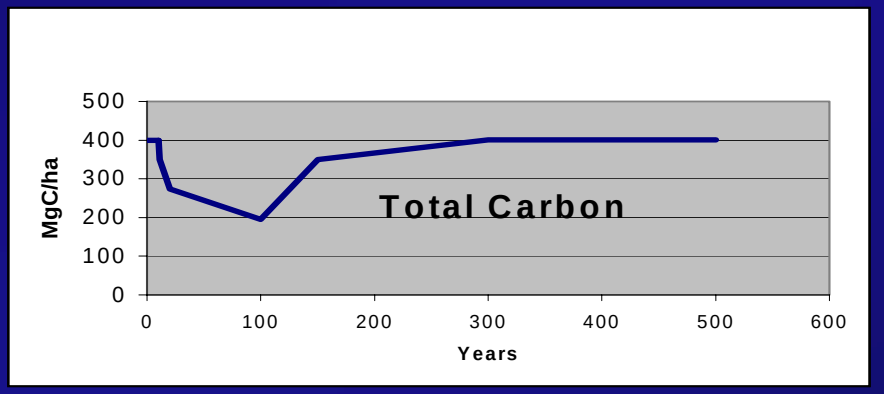
Response Curves

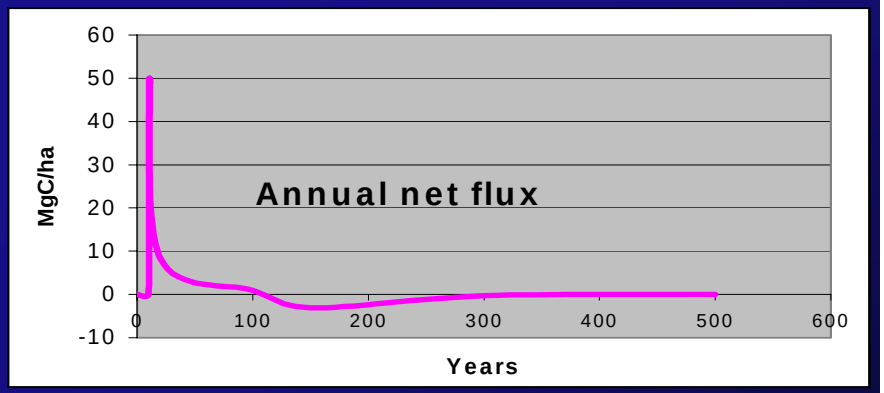












Per hectare changes in carbon stocks

1. Initial carbon stocks

- What type of ecosystem?
  - E.g., forest vs. non-forest (type of forest)
- What age or state?
  - Primary or secondary forest?

2. *Changes in carbon stocks*

- What happens to the initial biomass?
  - What fraction is killed? (Burned?)
  - Left alive?
  - Removed from site?
- Rates of decay and regrowth/accumulation?
  - Living biomass
  - Dead plant material
  - Soil carbon
  - Wood products
- Lateral transport

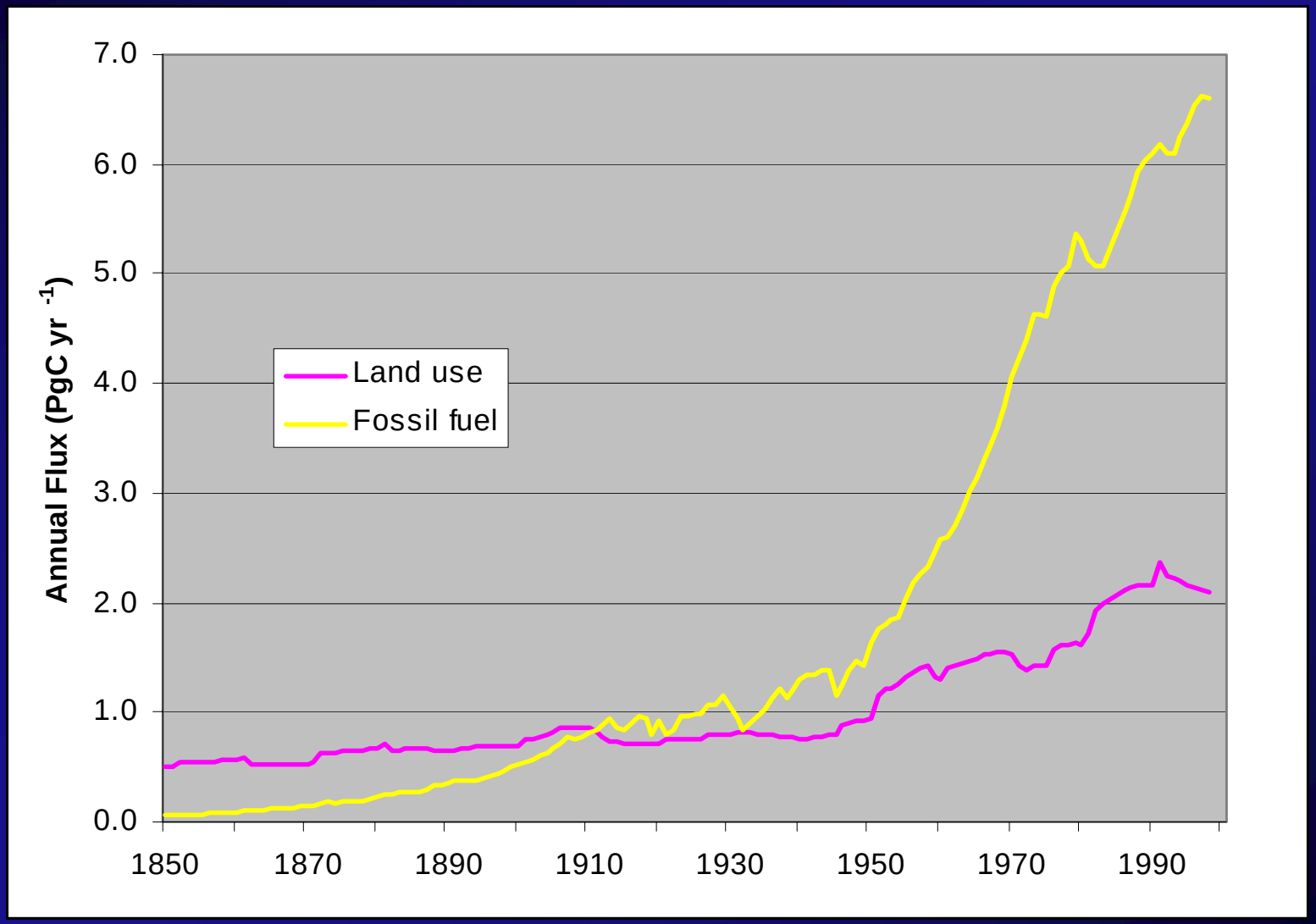
3. Time required for change

- Rates of decay and regrowth
- Half-lives of wood products

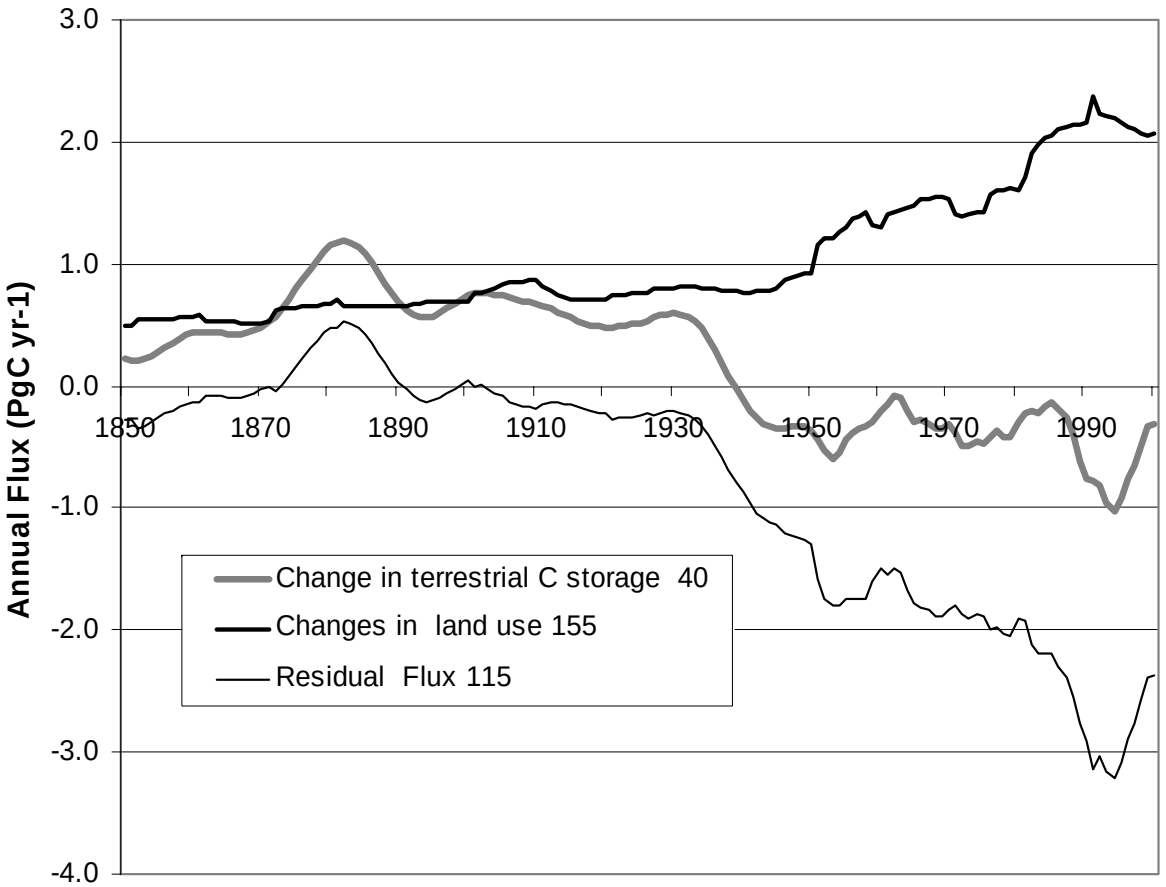
RESULTS - *Global*

- Long term (1850-2000)

Annual Emissions of Carbon



Source: Houghton 2003



Land-use change

Net terrestrial

Residual terrestrial flux

Deconvolution from Joos

RESULTS - *Global*

- Short term (1980s and 1990s)

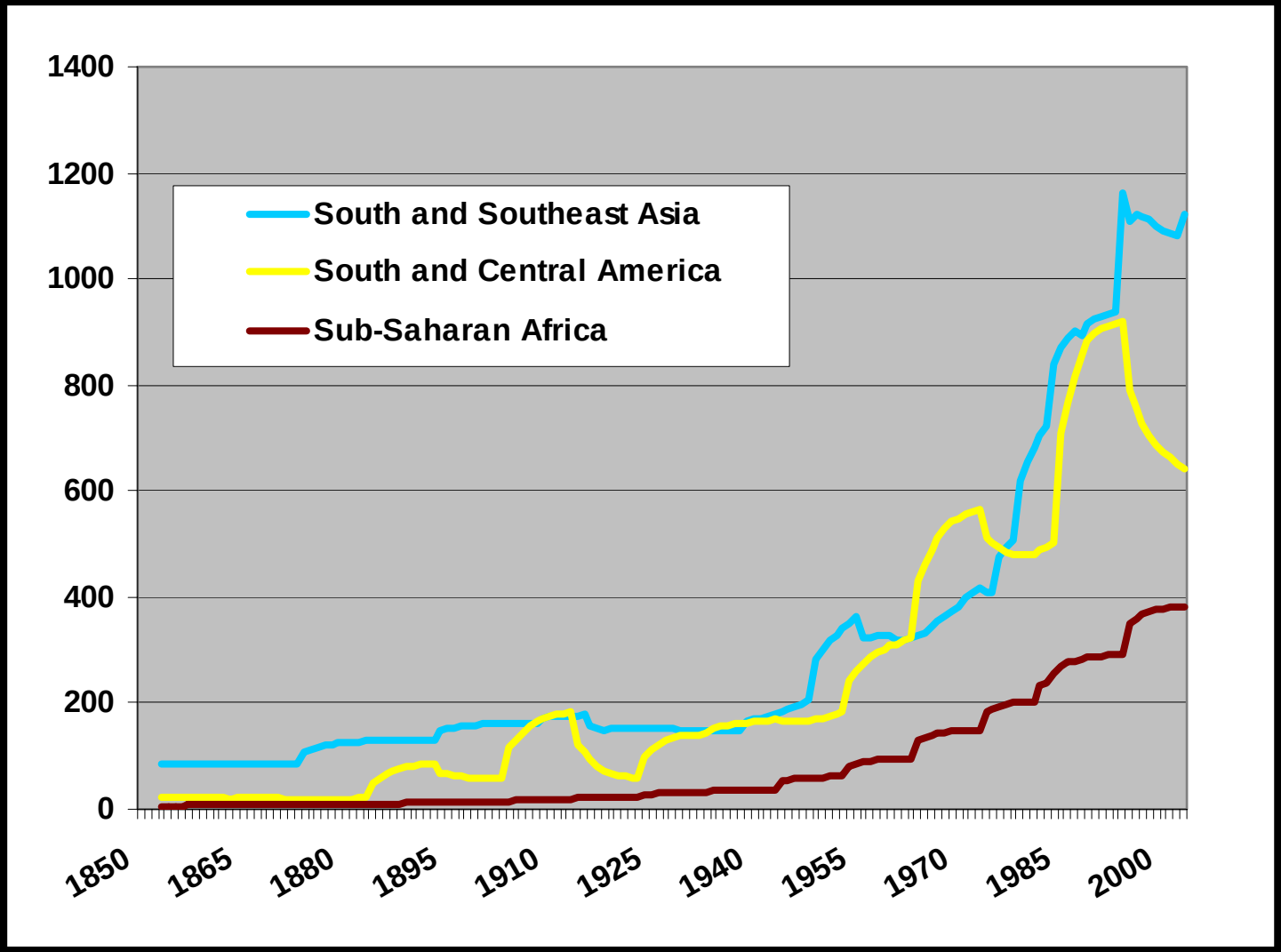
Global Carbon Budget

	1980s	1990s
Fossil fuel emissions	5.4 ± 0.3	6.3 ± 0.4
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.2
Oceanic uptake	-1.7 ± 0.6	-2.4 ± 0.7
Net terrestrial flux	-0.4 ± 0.7	-0.7 ± 0.8
Land-use change	2.0 ± 0.8	2.2 ± 0.8
Residual terrestrial flux	-2.4 ± 1.1	-2.9 ± 1.1

IPCC
Plattner
Houghton

RESULTS - The tropics

Tropical Regions



Annual terrestrial flux of carbon in the 1990s ($PgC\ yr^{-1}$)

	O_2 and CO_2	Inverse calculations CO_2, $^{13}CO_2$, O_2	Forest inventories	Land-use change
Globe	-0.7	-0.8	-	2.2
Northern mid-latitudes	-	-1.8	-0.65	-0.03
Tropics	-	0.6 to 1.2 Source	??	0.5 to 3.0 Source

The Tropics

Either...

- A moderate source from land-use change accounts for the total net source (no additional sink)

Or...

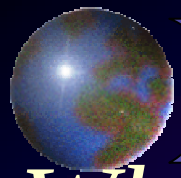
- A large source from land-use change is offset by a large sink in undisturbed forests

Or...

- A missing source?

Uncertainties

- Rates of land-use change (ha)
- Initial stocks of carbon and changes (C/ha)



Which contributes more to errors of carbon flux?

- Rates of deforestation?

or

- Biomass?

Recent estimates of tropical deforestation

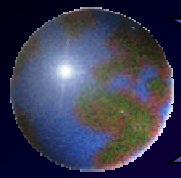
10^6 ha/yr during 1990s

8.9	Achard et al. 2004
5.6	DeFries et al 2002
15.5	FAO 2001 (Houghton 2003)

Emissions of carbon from tropical deforestation

Recent estimates (PgC/yr):

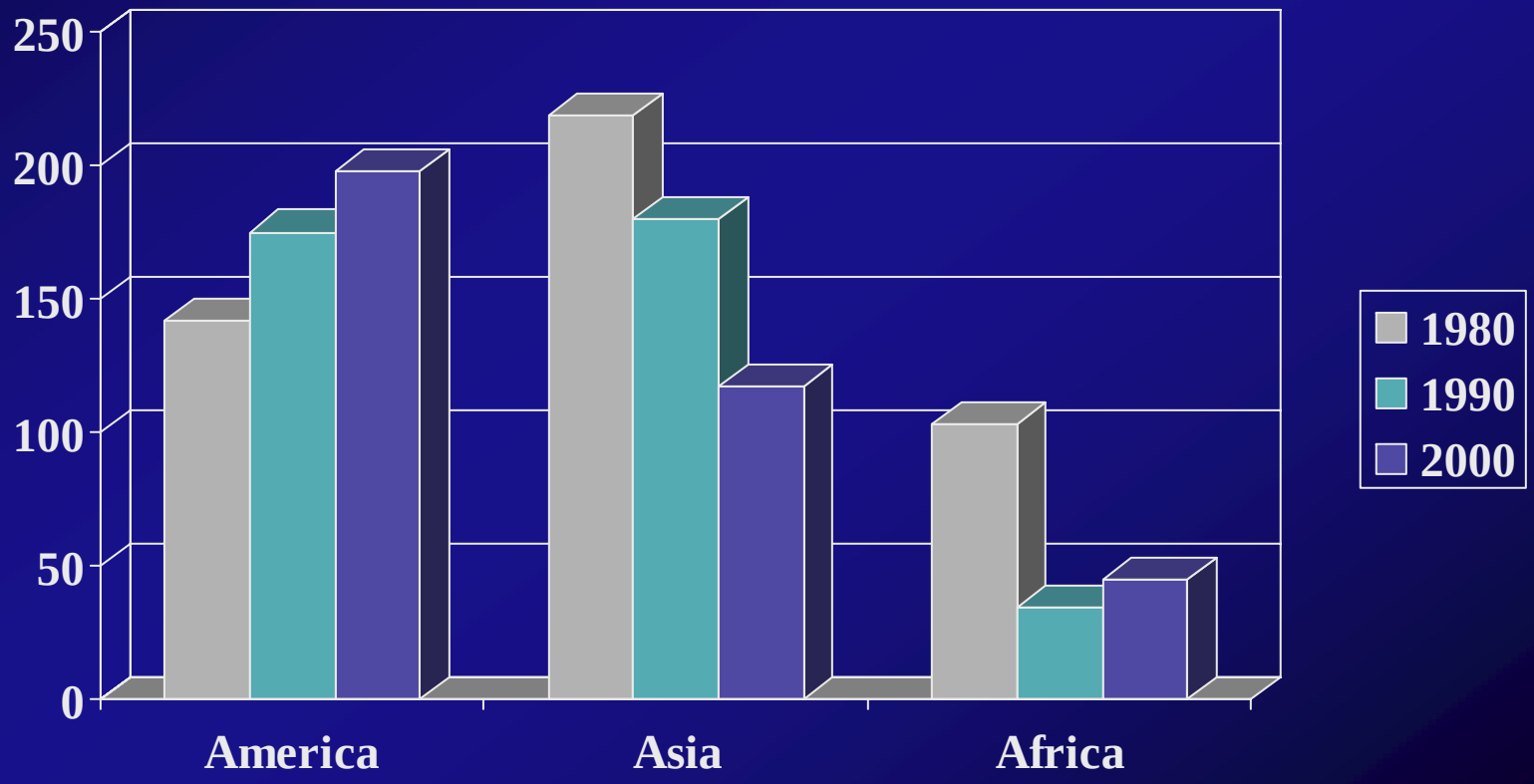
1.1 (±0.3)	Achard et al. 2004
0.9 (0.5-1.4)	DeFries et al 2002
2.2 (±0.8)	Houghton 2003



But all of these studies used essentially the same estimates for average biomass.

The uncertainty of tropical forest biomass has been underestimated.

Tropical forests: Average biomass (t dry weight/ha)



FAO Forest Resources Assessments

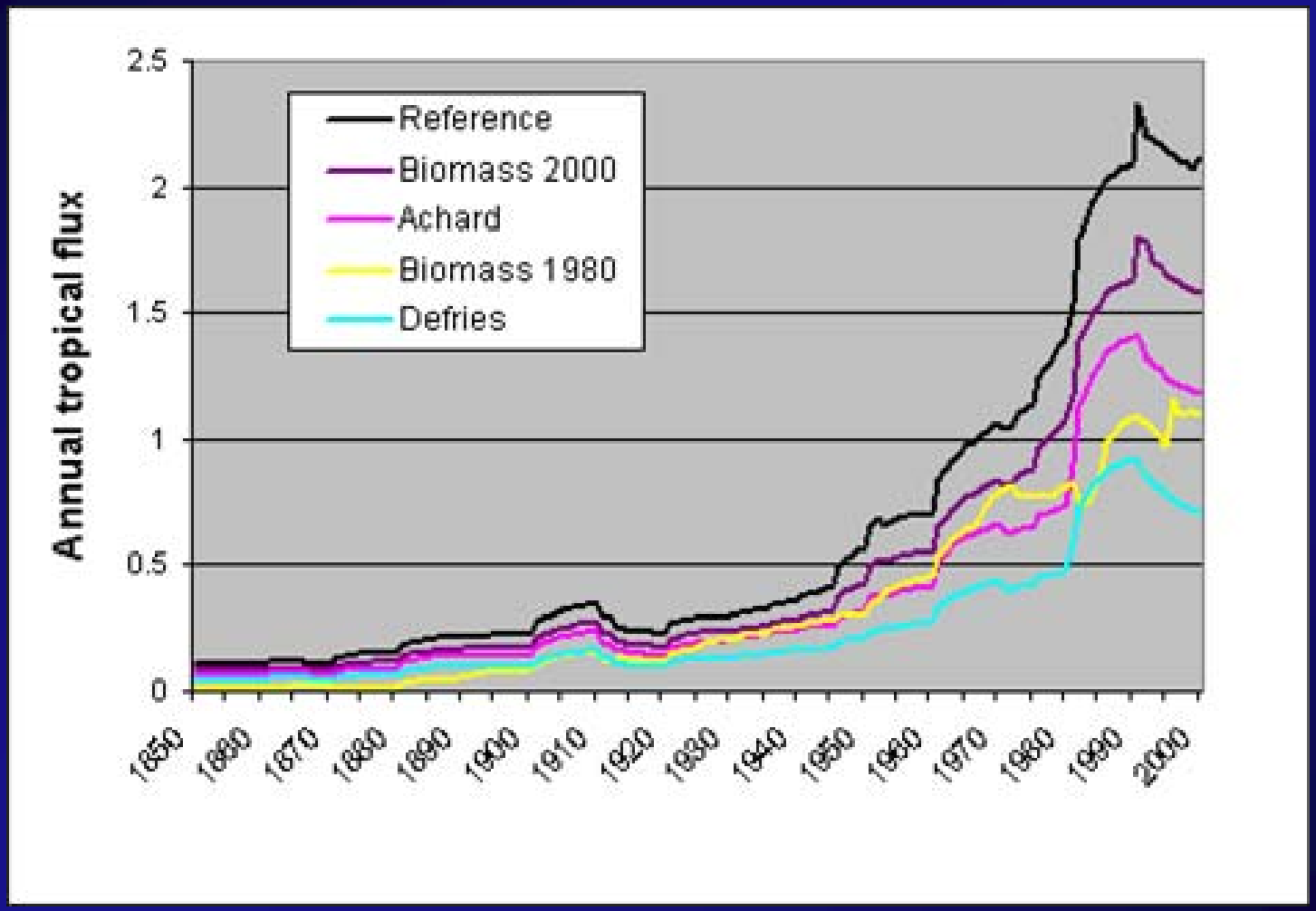
What do these changes mean?

- ✓…improvements in data?
- …degradation (e.g., logging)?
- …growth from past disturbance?
- …loss of forests with systematically low or high biomass?

Five scenarios:

1. Houghton (2003) (Reference)
2. Achard et al. (2004)
3. DeFries et al. (2002)
4. Adjust starting biomass to yield FAO 2000 biomass
5. Adjust starting biomass to yield FAO 1980 biomass, and try to obtain 1990 and 2000 biomass by shifting the forest types deforested

The tropics

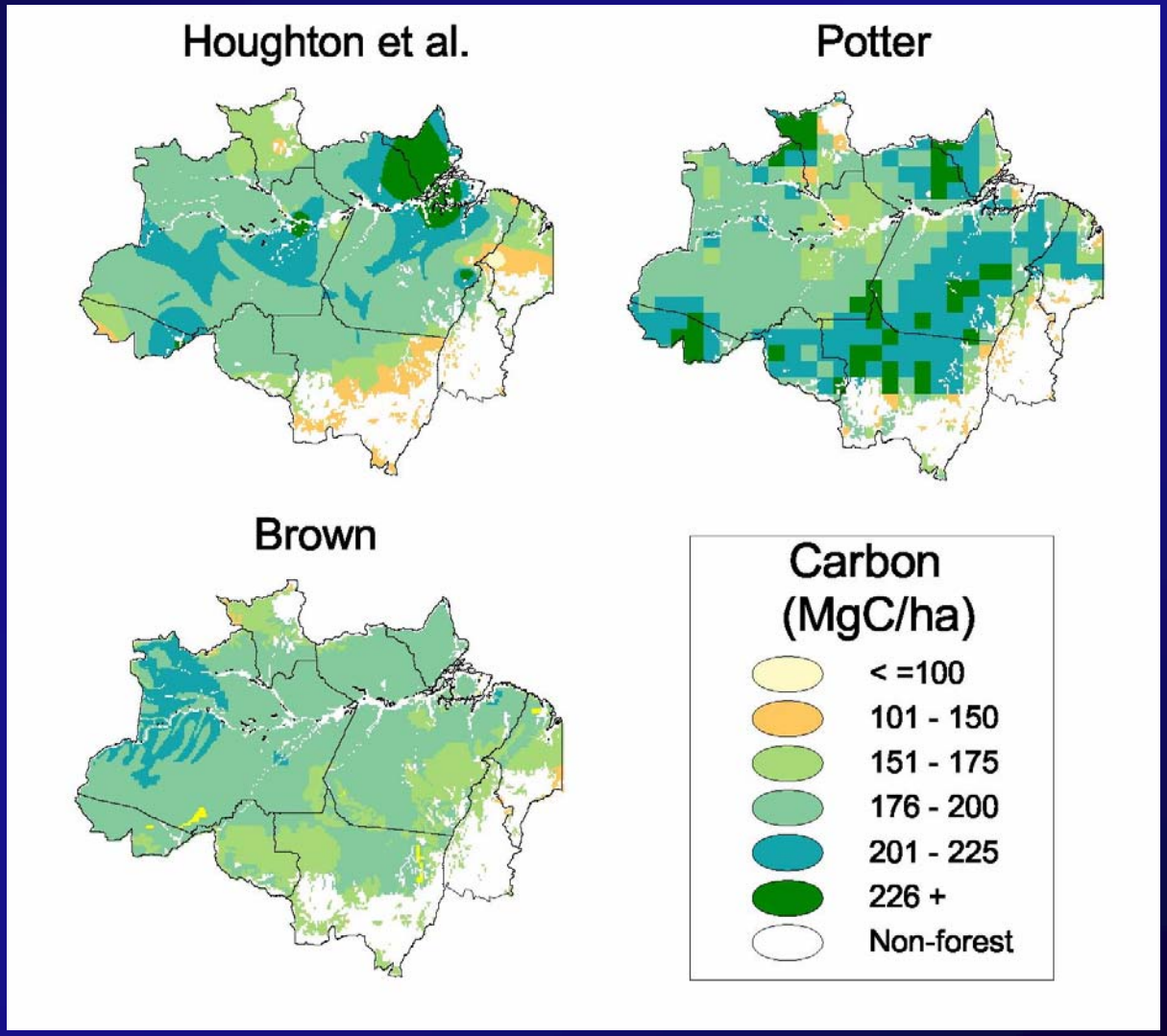


biomass

deforestation rate

The error attributed to biomass is probably larger than calculated here because these results are based on average estimates of biomass (and the biomass of the forests deforested may not be average).

For example, in the Brazilian Amazon…



Summary for the Tropics…

What is the biomass deforested?

- Need to know biomass stocks spatially
- Biomass determines the magnitude of the calculated tropical source
- Uncertainty in biomass as important as uncertainty in deforestation rates

Results - Outside the tropics…

Annual terrestrial flux of carbon in the 1990s ($PgC\ yr^{-1}$)

	O_2 and CO_2	Inverse calculations CO_2, $^{13}CO_2$, O_2	Forest inventories	Land-use change
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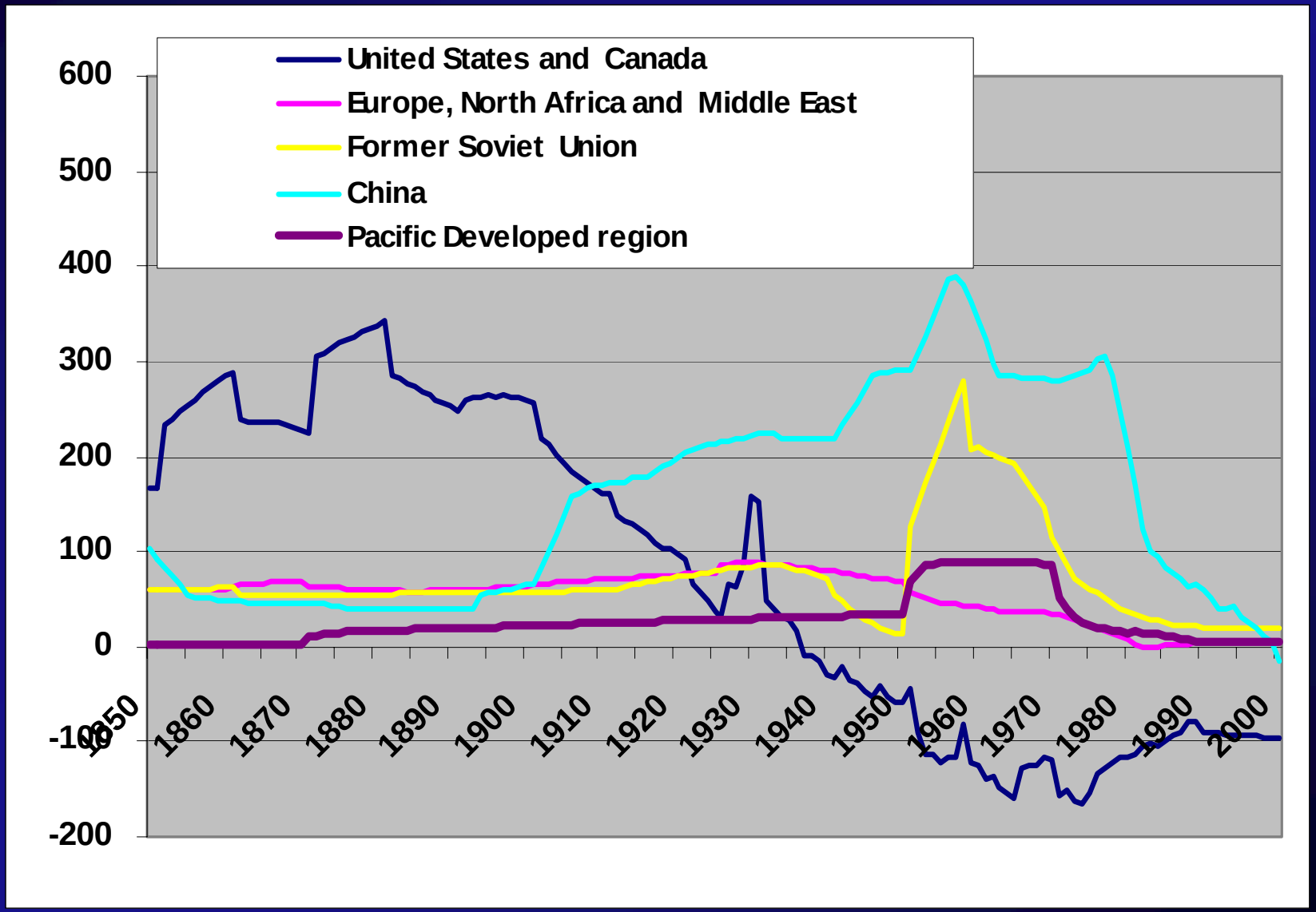
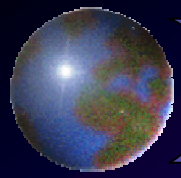
		Source		Source

Non-tropical Regions

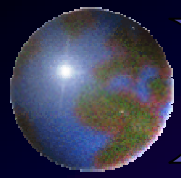


In Temperate Zone and Boreal Forests…

- There is little deforestation.
- Instead, forests are re-growing from past disturbances (fires, logging, and agricultural abandonment).
  - Many of these disturbances occurred before satellite data were available.

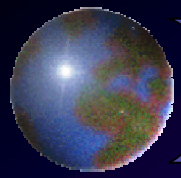


Thus, deforestation (in tropical forests) is easier to see with satellite data than regrowth (in temperate and boreal forests).



In Temperate Zone and Boreal Forests…

- Need to measure changes in biomass within forests



Summary for Temperate Zone and Boreal Forests…

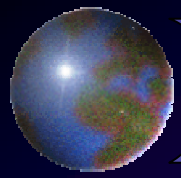
Where is biomass increasing? Decreasing? How fast?

- Biomass needs to be measured repeatedly to estimate change.

What if we could measure changes in aboveground biomass from space?

Advantages of a 'biomass' satellite over forest inventories

1. Wall-to-wall, spatial estimates (rather than averages)
2. Ecosystems not inventoried
   - Woody encroachment
   - Other wooded lands
3. Potential to 'see' the largest changes in carbon (what fraction of the net flux?)

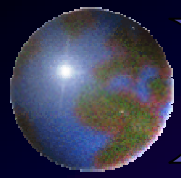


How Well Would We Have to Measure Biomass of the World's Forests…

- …to determine the magnitudes of terrestrial sources and sinks of carbon?

If a sink of ~2 PgC/yr were distributed in aboveground forest biomass in the northern mid-latitudes…

- the average annual sink would be 1.0 MgC ha^{-1} yr^{-1}) or ~3% of aboveground biomass per year



But…

- Some of the sink is not in forests
- The sink is not evenly distributed spatially

Much of the northern sink may be outside of forests

	Pacala et al. (2001) low	Pacala et al. (2001) high	Houghton et al. (1999)	Houghton (2003)	Goodale et al. (2002)
Forest trees	0.11	0.15	0.072	0.046	0.11
Forest organic matter	0.03	0.15	-0.010	-0.010	0.11
Cropland soils	0.00	0.04	0.138	0.00	…
Woody encroachment	0.12	0.13	0.122	0.061	…
Wood products	0.03	0.07	0.027	0.027	0.06
Sediments	0.01	0.04	…	…	…
Total sink	0.30	0.58	0.35	0.12	0.28
Outside forests	43%	36%	74%	51%	

Sink not evenly distributed within northern forests

- Canadian and Russian forests lost 0.08 PgC from biomass in 1990 (source)
- U.S., European, Chinese forests gained 0.28 PgC in biomass in 1990 (sink)

Goodale et al. 2002

The uneven distribution of sources and sinks may be good news.

- There will be areas where sources and sinks of carbon from disturbance and regrowth are large enough to be observed from space over a 2-3-year interval
- What fraction of the landscape is in recently disturbed or rapidly regrowing stands?

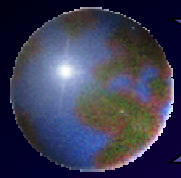
What if…

- What if 90% of the net terrestrial flux of carbon occurs on 5% of the earth's surface?

We'd be able to measure it 'directly' from space.

If changes in biomass could be determined 'directly' from successive 'looks' with satellite…

- …a different accounting could be used.
  - No longer rates of land-use change
  - Rather, biomass at t_1, t_2, t_3, t_4…. equals the net terrestrial flux of carbon.
- The new method would include more changes in carbon stocks (not just land use).



Two potential weaknesses:

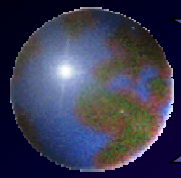
- What about roots, soil carbon, litter, wood products, etc?
- What about understanding the mechanisms responsible for a sink?

What is missed by considering only aboveground biomass?

Components of long-term terrestrial flux (1850-1990)

89% Biomass
28% Soil carbon
-14% Wood products
-3% Slash

Houghton 1999



To identify mechanisms…

(…for predictions or Kyoto)

Are fluxes directly or indirectly the result of human activities?

- Changes in land use and management still need to be monitored/documented.

Summary

- In the tropics, deforestation is most important (for the old approach).
- In temperate and boreal zones, regrowth is most important (Visible from space?) (If ‘Yes”, a new approach possible).
- In both regions growth and degradation need to be measured (with a new approach).

Summary

- In the tropics
  - Biomass is ~ as uncertain as rates of deforestation
  - Need spatial biomass to assign to areas deforested
  - Can we also measure degradation? Growth?
- Outside the tropics
  - Need repeat coverage (over long enough intervals) to measure changes in biomass
  - Need to monitor lands outside forest inventories
  - What areas have a large C flux from land-use change...
    - or from disturbance and recovery?

In the tropics…

… different estimates of a source overlap.

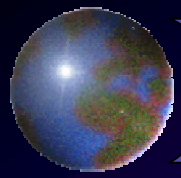
Outside the tropics…

… changes in land use underestimate the sink, but analyses of land-use change have been incomplete. They haven't included:

Natural disturbances and recovery

Management

Enhanced growth (e.g. CO_2 fertilization)



Summary

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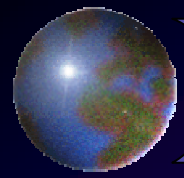
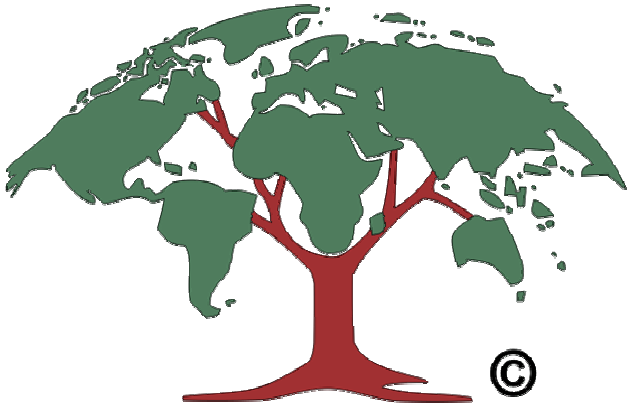
- Results
  - Net flux of carbon
  - Comparisons with other estimates of flux
- Uncertainties
  - In estimates of source/sink
  - In mechanisms responsible for a sink

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