Issues of Land-Use Change in the Context of the Carbon Cycle

R.A. Houghton

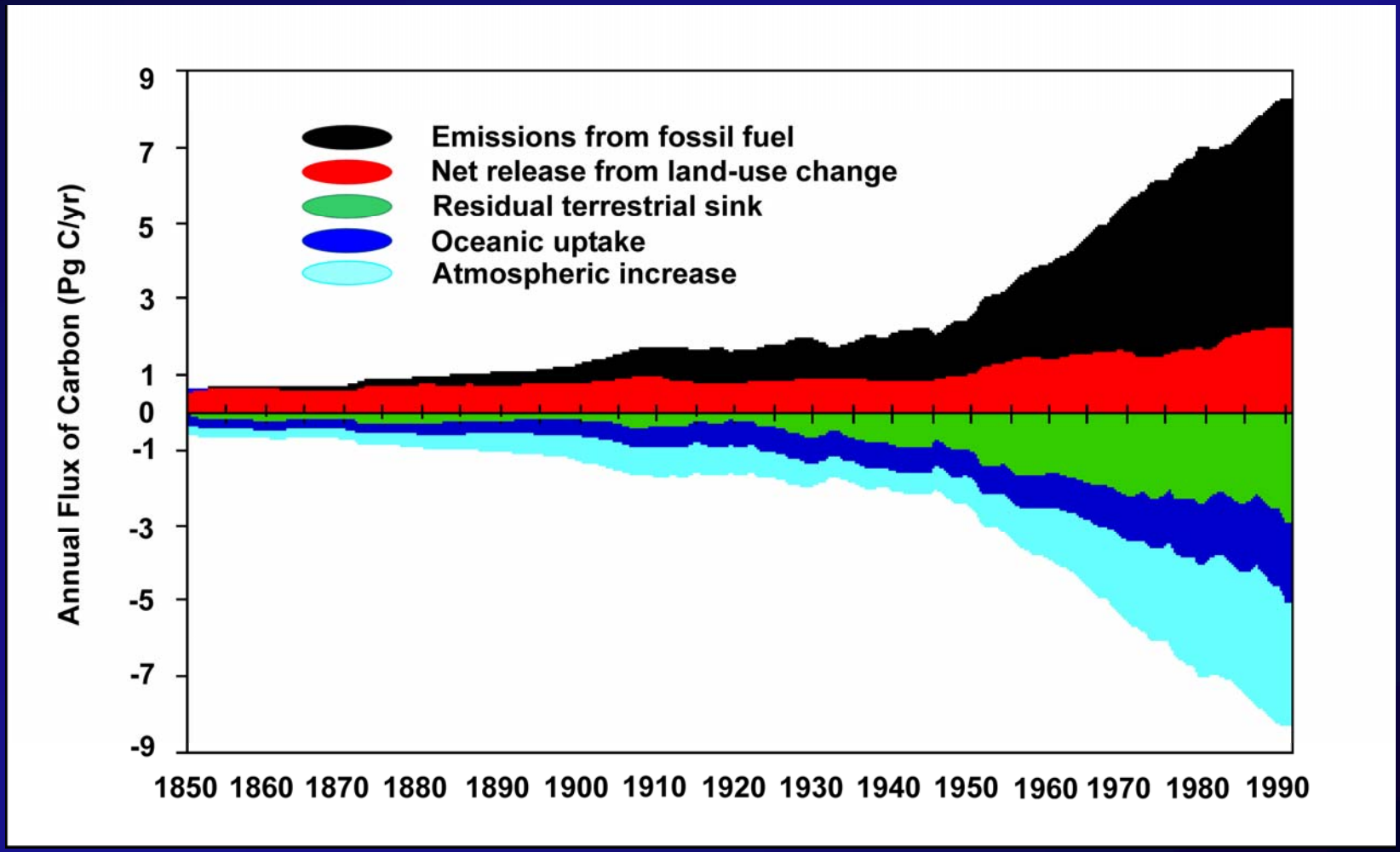
The Woods Hole Research Center

Snowmass July 28-30, 2008

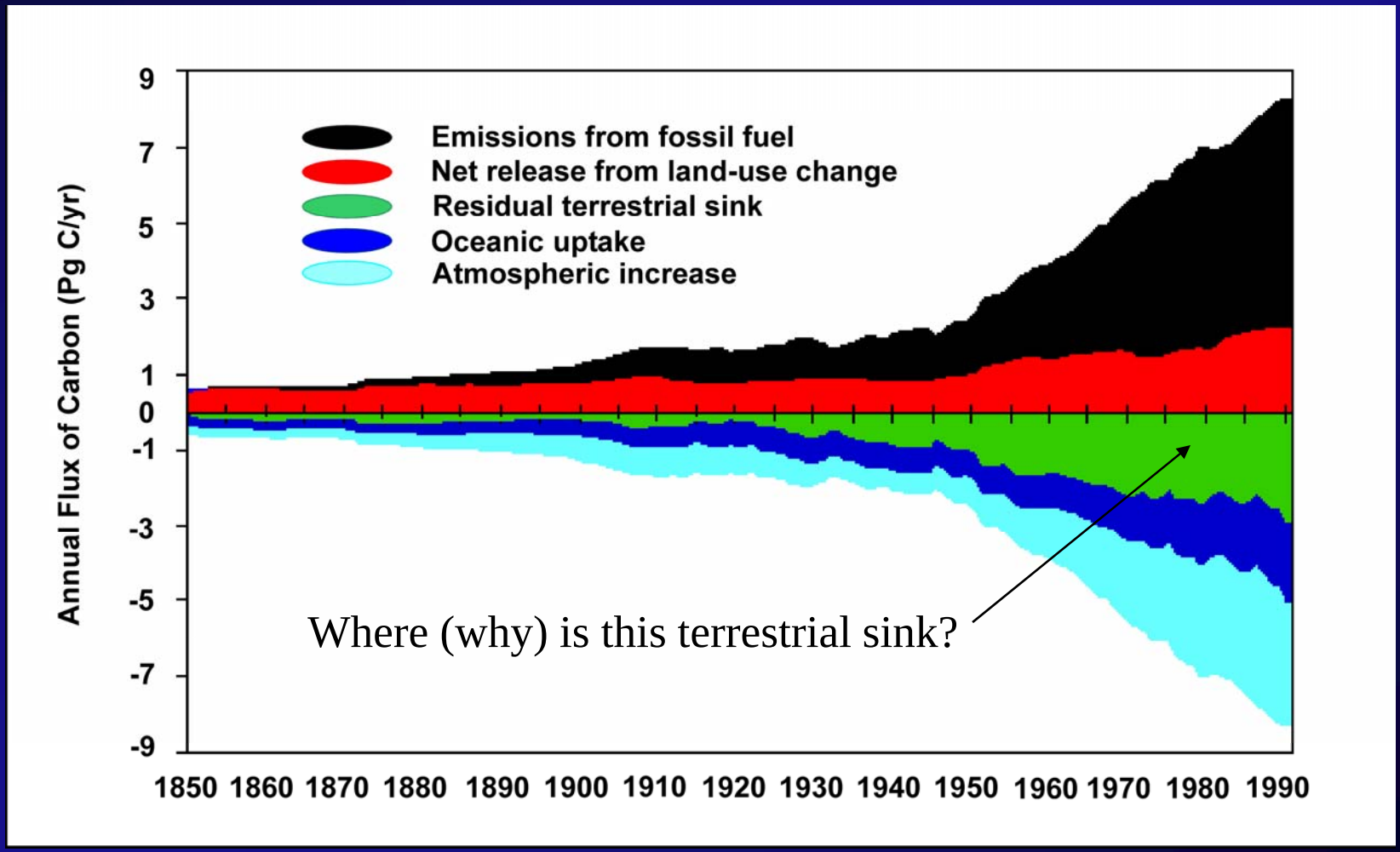
Outline

- The global carbon budget
  - The residual terrestrial sink
- Sources and sinks of carbon from land-use change: A METHOD
- What is land-use change?
- What if we had a ‘biomass satellite’ ?

Global Carbon Budget



Global Carbon Budget



Global Carbon Budget

	2000-2006
Fossil fuel emissions	**7.6 ± 0.4**
Land-use change	**1.5 ± 0.5**
Atmospheric increase	**-4.1 ± 0.04**
Oceanic uptake	**-2.2 ± 0.4**
Residual terrestrial flux	**-2.8 ± 0.7**

Canadell et al. 2007

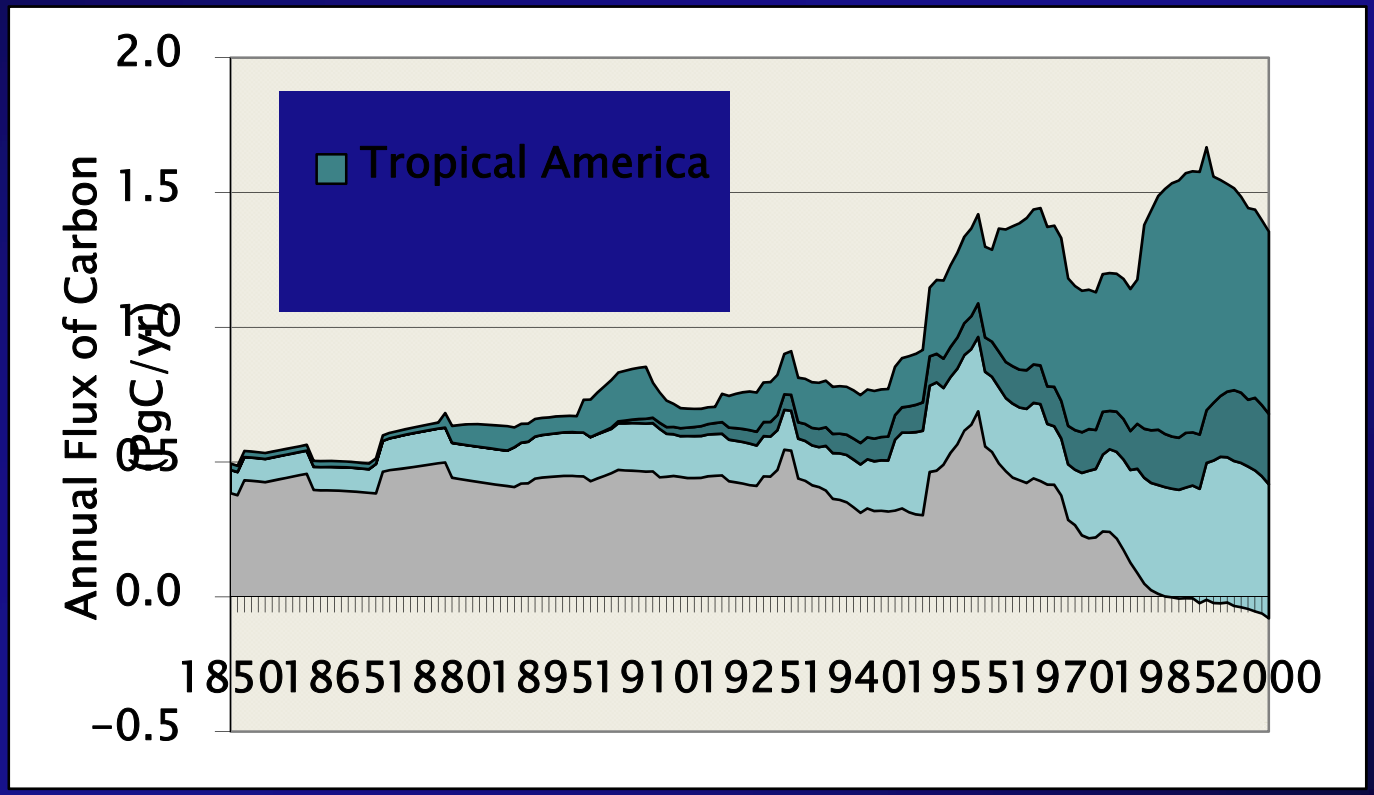
Global Carbon Budget

2000-2006

Fossil fuel emissions	**7.6 ± 0.4**
Land-use change	**1.5 ± 0.5**
Atmospheric increase	**-4.1 ± 0.04**
Oceanic uptake	**-2.2 ± 0.4**
Residual terrestrial flux	**-2.8 ± 0.7**
[Net terrestrial flux	**-1.3 ± 0.5]**

Canadell et al. 2007

Carbon sources and sinks from land-use change (PgC/yr)



	Tropics	Non-tropics
Long term	60%	40%
1990s	100%	0%

The same sort of 'residual' can be determined for the tropics and for the northern mid-latitudes.

However, the net terrestrial fluxes of carbon as estimated from top-down analyses are so variable as to give little definitive insight into terrestrial processes.

For example…

- Northern temperate zone
  - Changes in land use yield a smaller sink than top-down or inventory-based estimates
    - Are the analyses incomplete or is there enhanced growth?
- The Tropics
  - High emissions from deforestation suggest enhanced growth may be offsetting the emissions.
  - Low emissions from deforestation require no enhanced growth to offset emissions.

What are the mechanisms responsible for the residual terrestrial sink?

Historically the residual terrestrial sink has been attributed to environmentally-enhanced growth (e.g., CO_2 fertilization, N deposition, changes in climate).

Historically the residual terrestrial sink has been attributed to environmentally-enhanced growth (e.g., CO_2 fertilization, N deposition, changes in climate).

Enhanced growth

But the "residual" flux might also be due to demographic changes:

- Recovery from past (unknown) disturbances
- Omissions from analyses of land-use change
  - Management, other….
- Errors (rates of land-use change, carbon stocks)
- Bias ??

But the "residual" flux might also be due to demographic changes:

- Recovery from past (unknown) disturbances
- Omissions from analyses of land-use change
  - Management, other….
- Errors (rates of land-use change, carbon stocks)
- Bias ??

Re-growth

Two major sources of error

- Rates of deforestation (millions of hectares)
  - Rates of land-use change
- Carbon stocks per hectare
  - Changes in carbon stocks (tC/ha)

Average annual rates of tropical deforestation (10^6 ha yr^{-1})

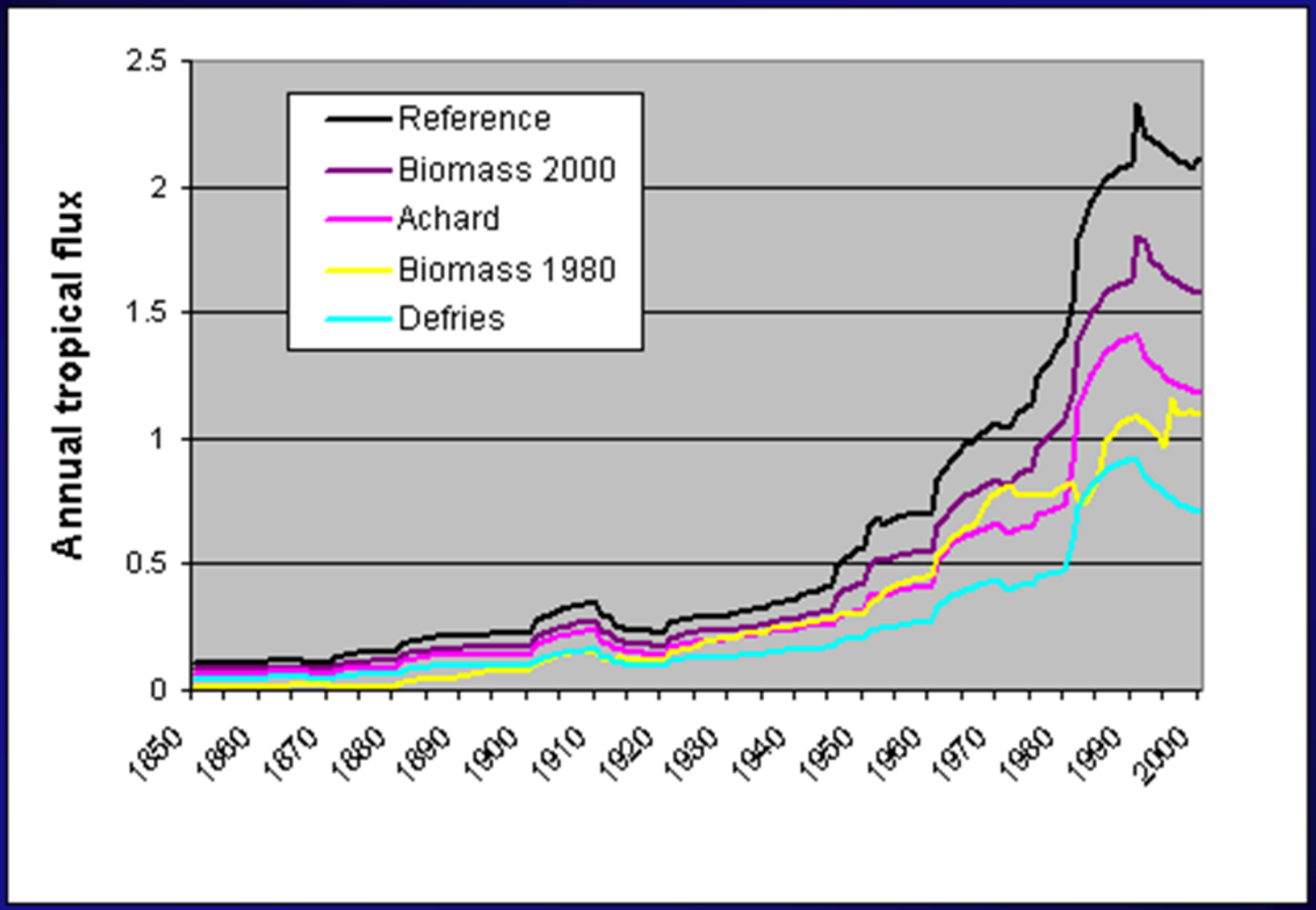
	1980s		1990s		
	FAO 1995	DeFries et al. 2002	FAO 2001	DeFries et al. 2002	Achard et al. 2004
America	7.4	4.426	5.2	3.982	4.41
Asia	3.9	2.158	5.9	2.742	2.84
Africa	4.0	1.508	5.6	1.325	2.35
Total	15.3	8.092	16.7	8.049	9.60

Average annual rates of tropical deforestation (10^6 ha yr^{-1})

	1980s		1990s		
	FAO 1995	DeFries et al. 2002	FAO 2001	DeFries et al. 2002	Achard et al. 2004
America	7.4	4.426	5.2	3.982	4.41
Asia	3.9	2.158	5.9	2.742	2.84
Africa	4.0	1.508	5.6	1.325	2.35
Total	15.3	8.092	16.7	8.049	9.60

11.6 FAO 2006

Biomass is uncertain, too



biomass

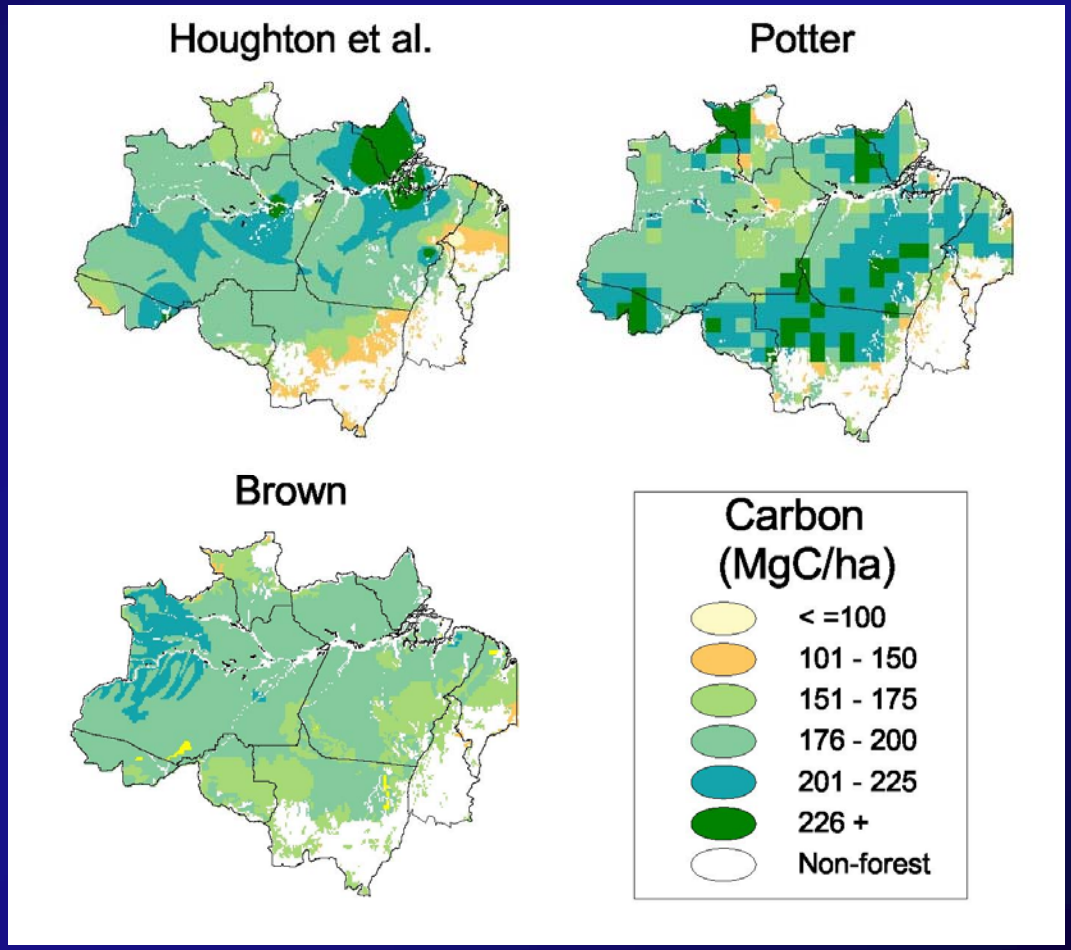
deforestation rate

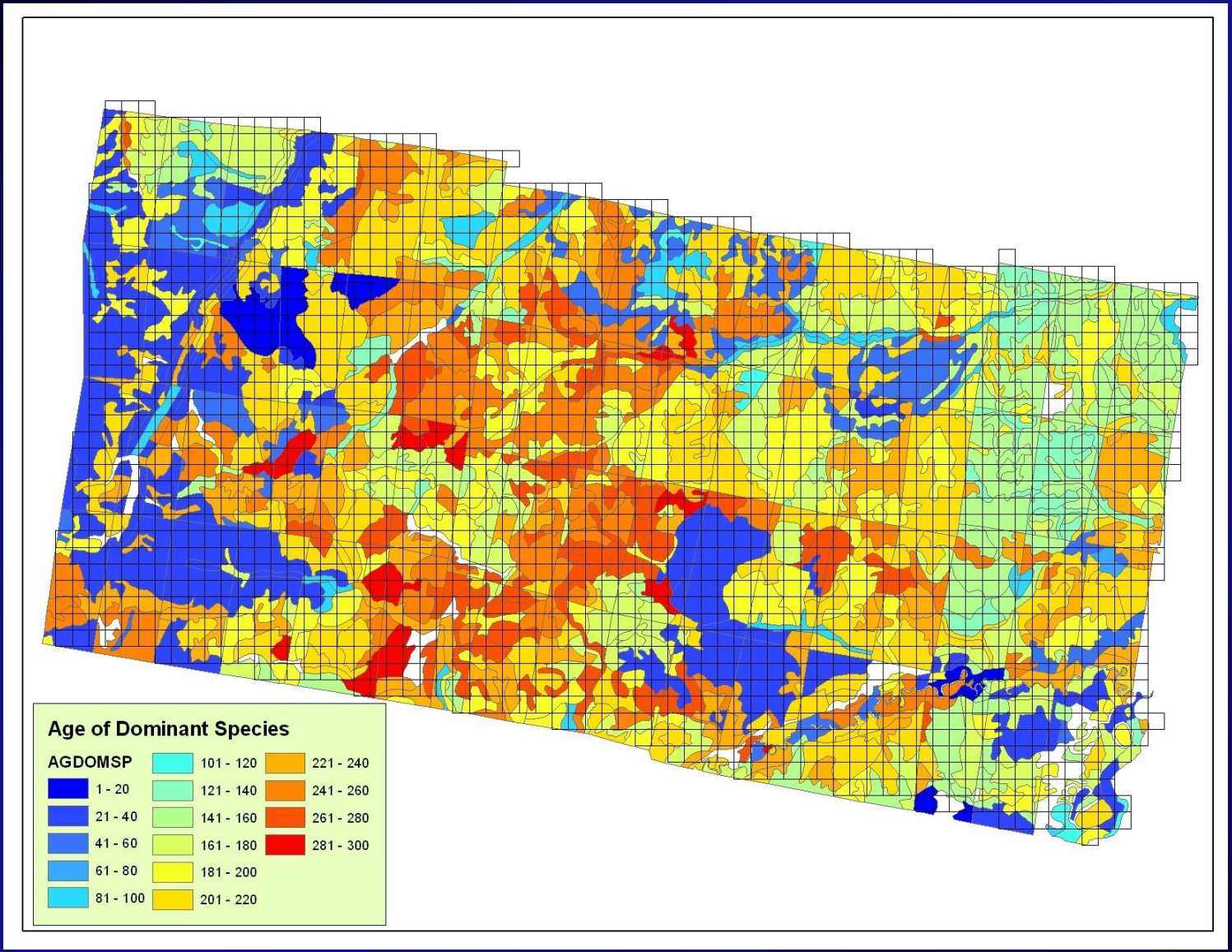
Source: Houghton 2005

Averages are not good enough.

We need to match disturbed areas to the 'before' and 'after' carbon stocks of the same areas.

Even the average biomass is poorly known in the tropics.



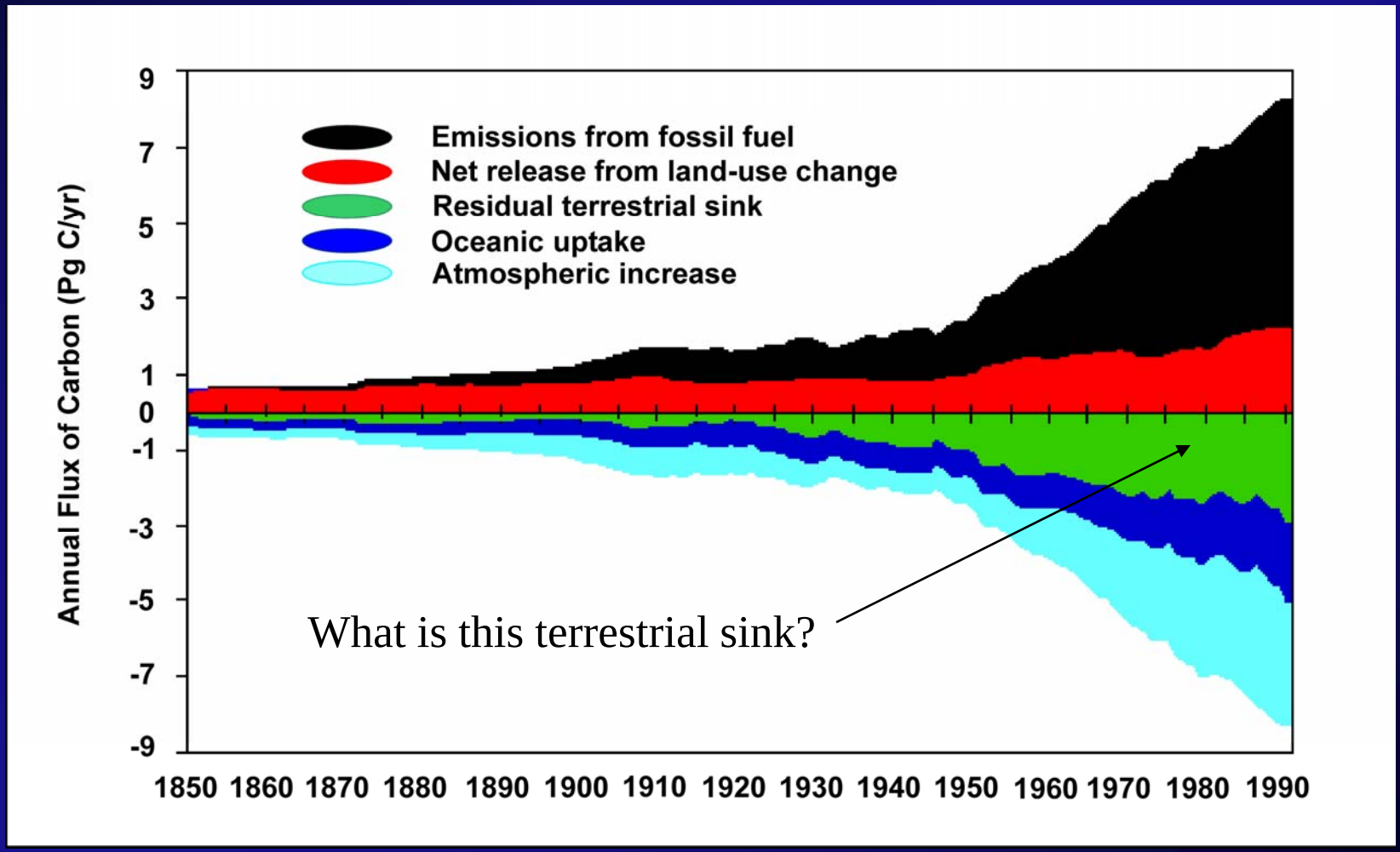


Different ages of forest stands in Krasnoyarsk, central Russia

Are estimates of emissions from land-use change biased?

- Gross vs. net rates of land-use change
  - Underestimates of secondary forest area?
- Disturbance is poorly documented.
- Forest and agricultural management
- How long do forests accumulate carbon?
- Dynamics of dead organic matter (CWD, soil C)
- Other…

Global Carbon Budget



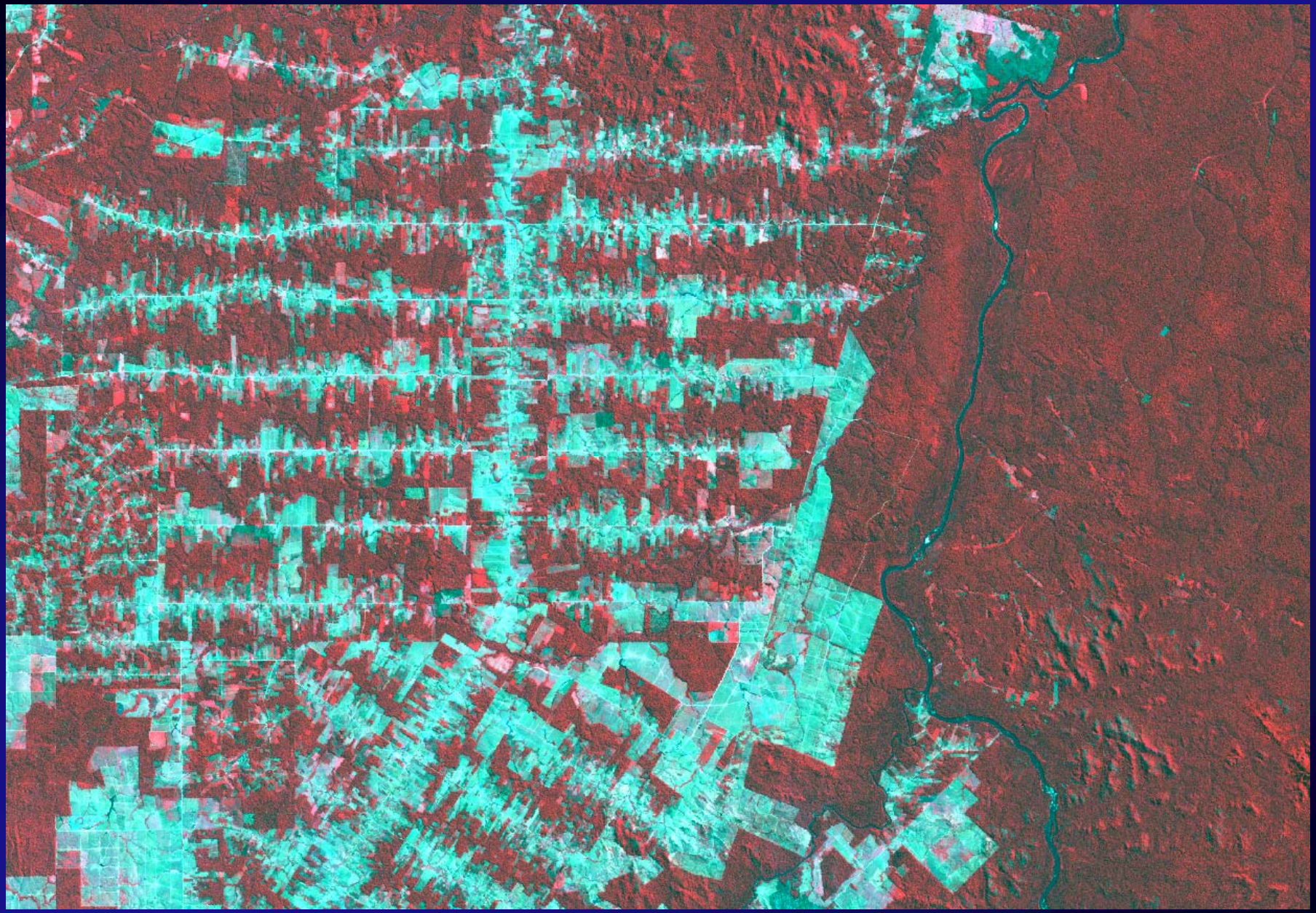
Outline

- The global carbon budget
  - The residual terrestrial sink
- Sources and sinks of carbon from land-use change: A METHOD
- What is land-use change?
- What if we had a ‘biomass satellite’ ?

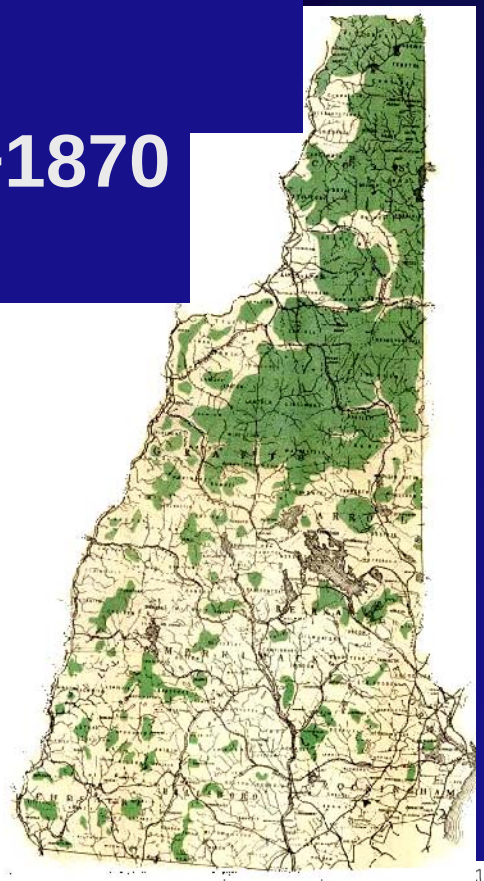
Changes in land use

Emphasis on forests

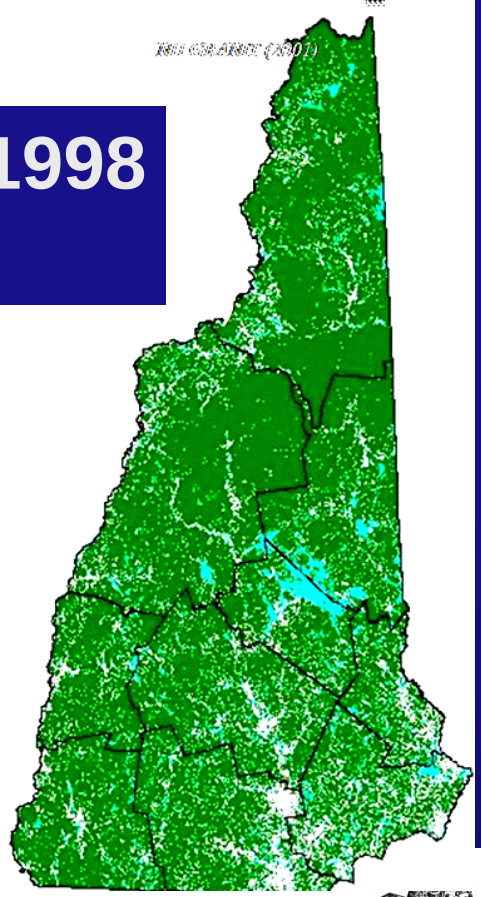
- Changes in area
  - Croplands (clearing and abandonment)
  - Pastures
  - Shifting cultivation



~1870



1998

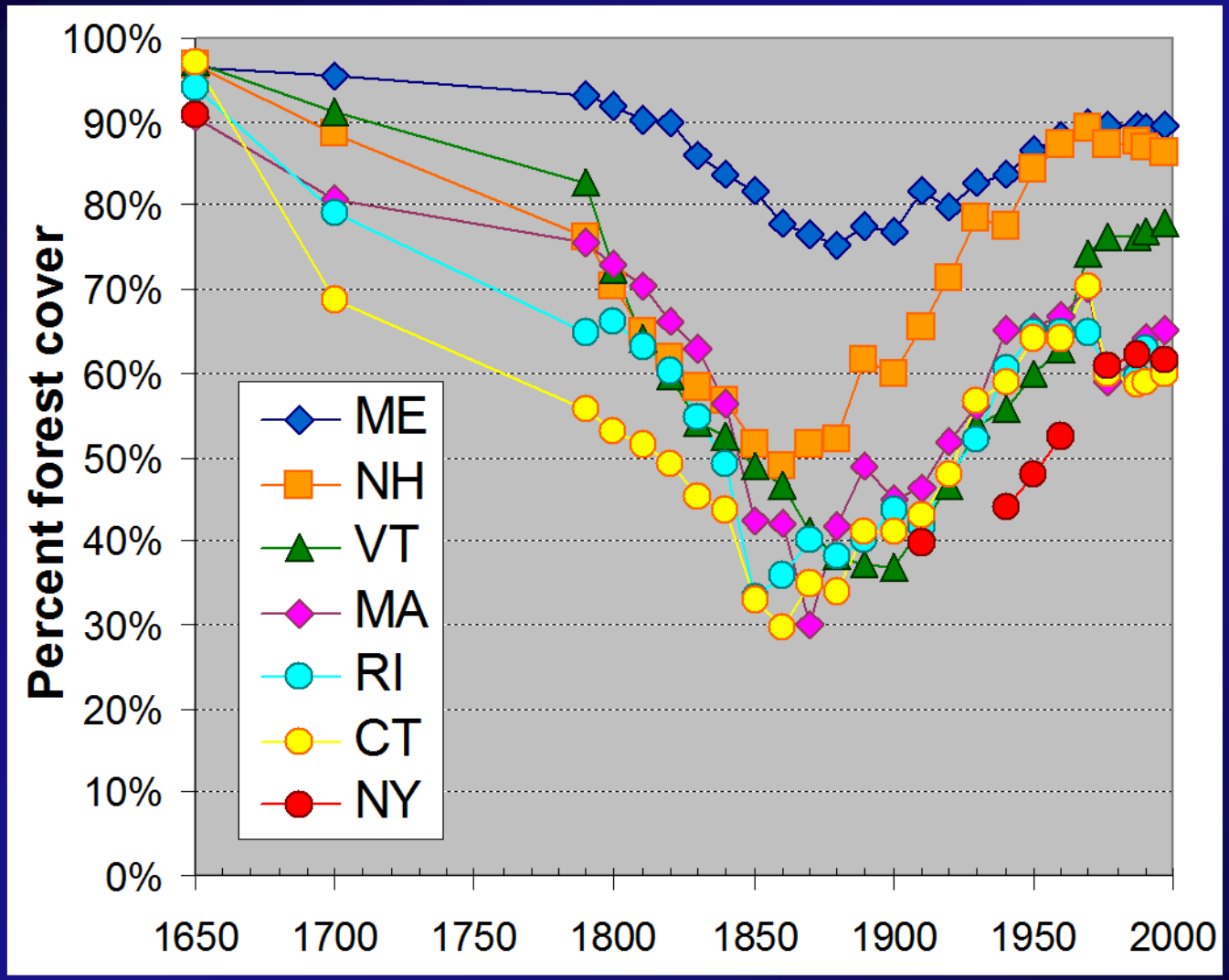


~1830

1999

Hall et al. 2002, *J. Biogeog.*

Northeastern U.S. Forest Cover

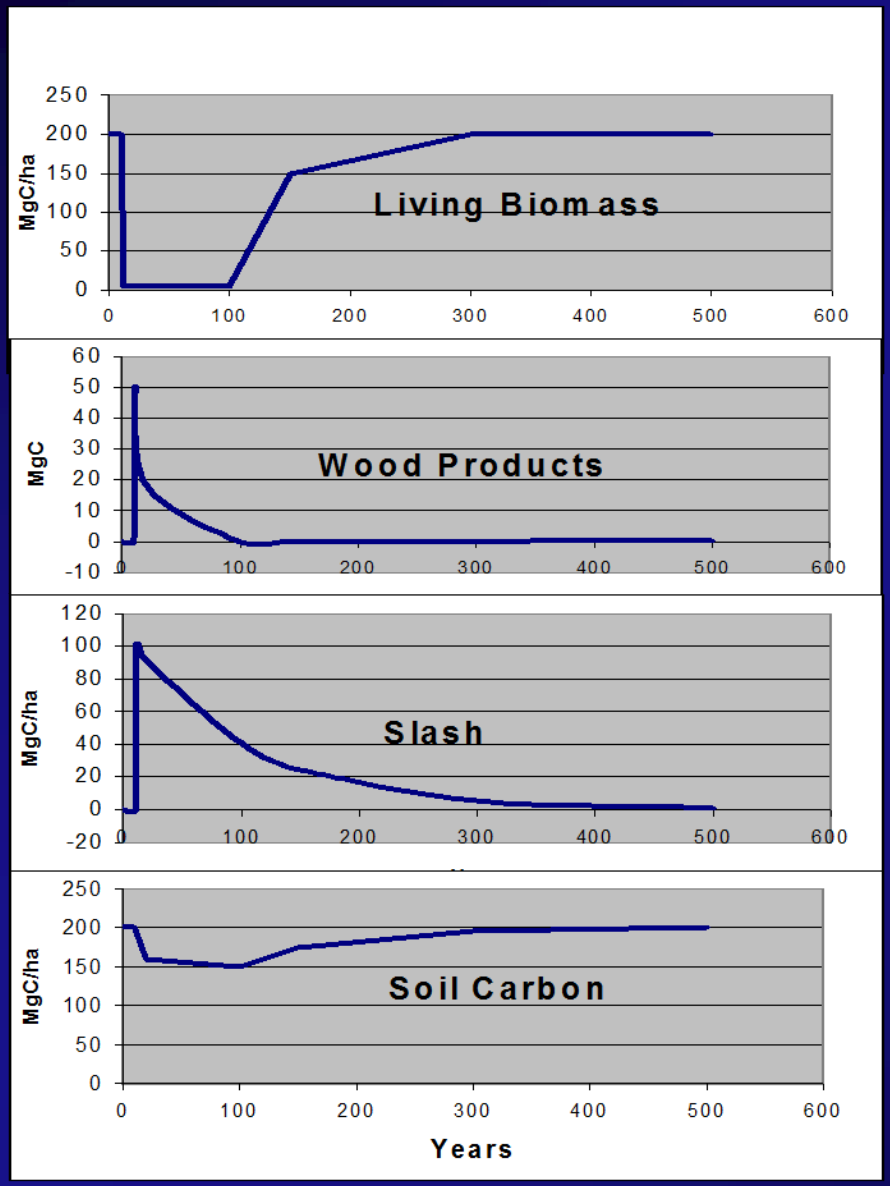


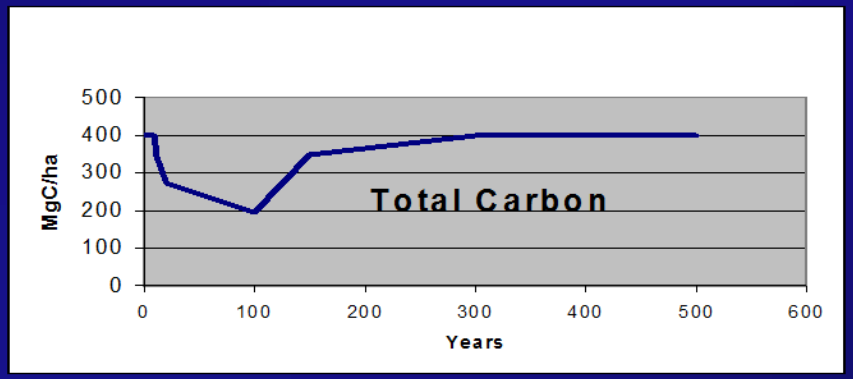
Source: D. Foster, Harvard Forest; and US RPA 1997 (Smith et al. 2001).

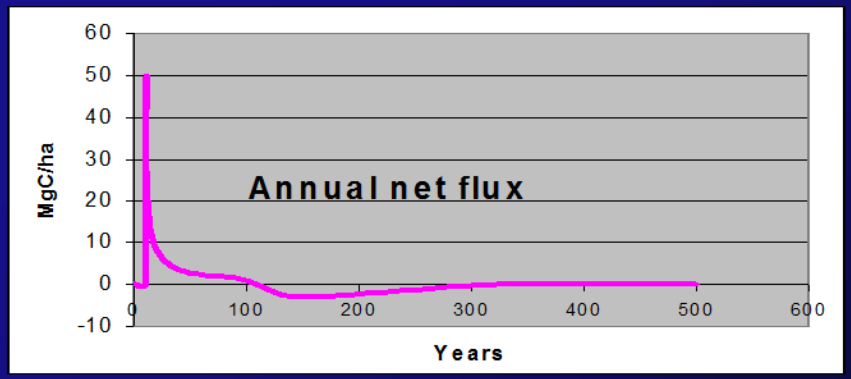
Land use affects carbon stocks

Carbon tracking model

MgC/ha







or process-based model

Outline

- The global carbon budget
  - The residual terrestrial sink
- Sources and sinks of carbon from land-use change: A METHOD
- What is land-use change?
- What if we had a ‘biomass satellite’ ?

Is Land Management a part of Land-Use Change?

Changes in land use

Emphasis on forests

- Changes in area
  - Croplands
  - Pastures
  - Shifting cultivation

  } Land-use conversions

- Changes in carbon stocks (C/ha)
  - Wood harvest & recovery
  - Fire management
  - Forest degradation

Changes in land use

Emphasis on forests

- Changes in area
  - Croplands (clearing and abandonment)
  - Pastures
  - Shifting cultivation
- Changes in carbon stocks (C/ha)
  - Wood harvest & recovery
  - Fire management
  - Forest degradation

} management

Forest Degradation

How important?

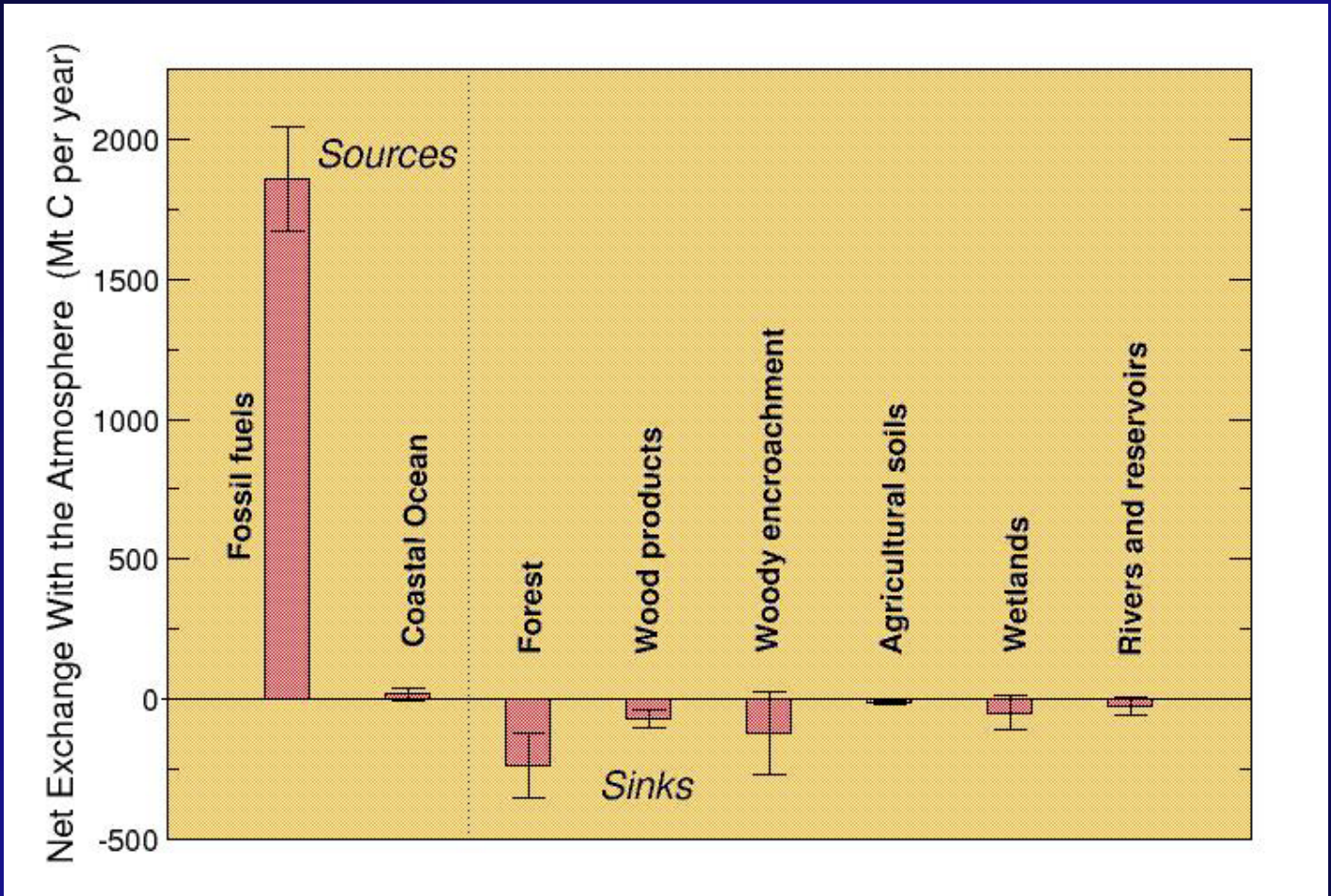
Estimates vary from 0 to > 100% of emissions from deforestation.

Is Land Management a part of Land-Use Change?

In theory, but….

An example from North America

North American sources and sinks of carbon

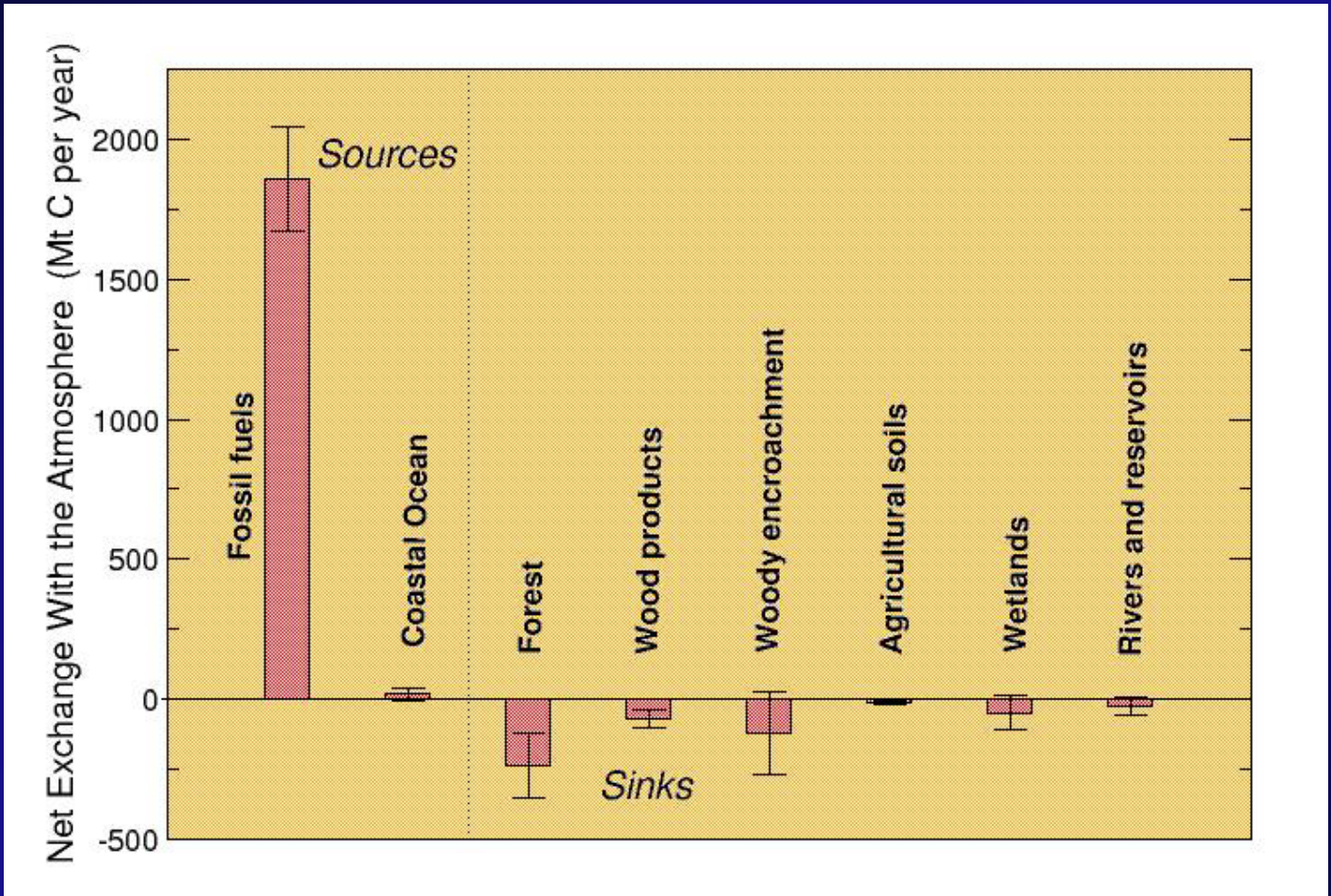


A net terrestrial sink of 500 ± 250 Mt C yr^{-1} is equivalent to about 30% of North American fossil fuel emissions in 2003.

Source: SOCCR CCSP SAP 2.2 2007

Are these sources and sinks a result of changes in land use or management?

North American sources and sinks of carbon



A net terrestrial sink of 500 ± 250 Mt C yr^{-1} is equivalent to about 30% of North American fossil fuel emissions in 2003.

Source: SOCCR CCSP SAP 2.2 2007

Three drivers of change in terrestrial carbon stocks or flux:

- Direct anthropogenic effects; i.e., management
- Indirect effects
  - CO_2 fertilization
  - N deposition
  - Climate change, including changed disturbance regimes
- Natural effects, including disturbances

Three drivers of change in terrestrial carbon stocks or flux:

- Direct anthropogenic effects; i.e., management
- Indirect effects
  - CO_2 fertilization
  - N deposition
  - Climate change, including changed disturbance regimes
- Natural effects, including disturbances

All three may be effective at once.

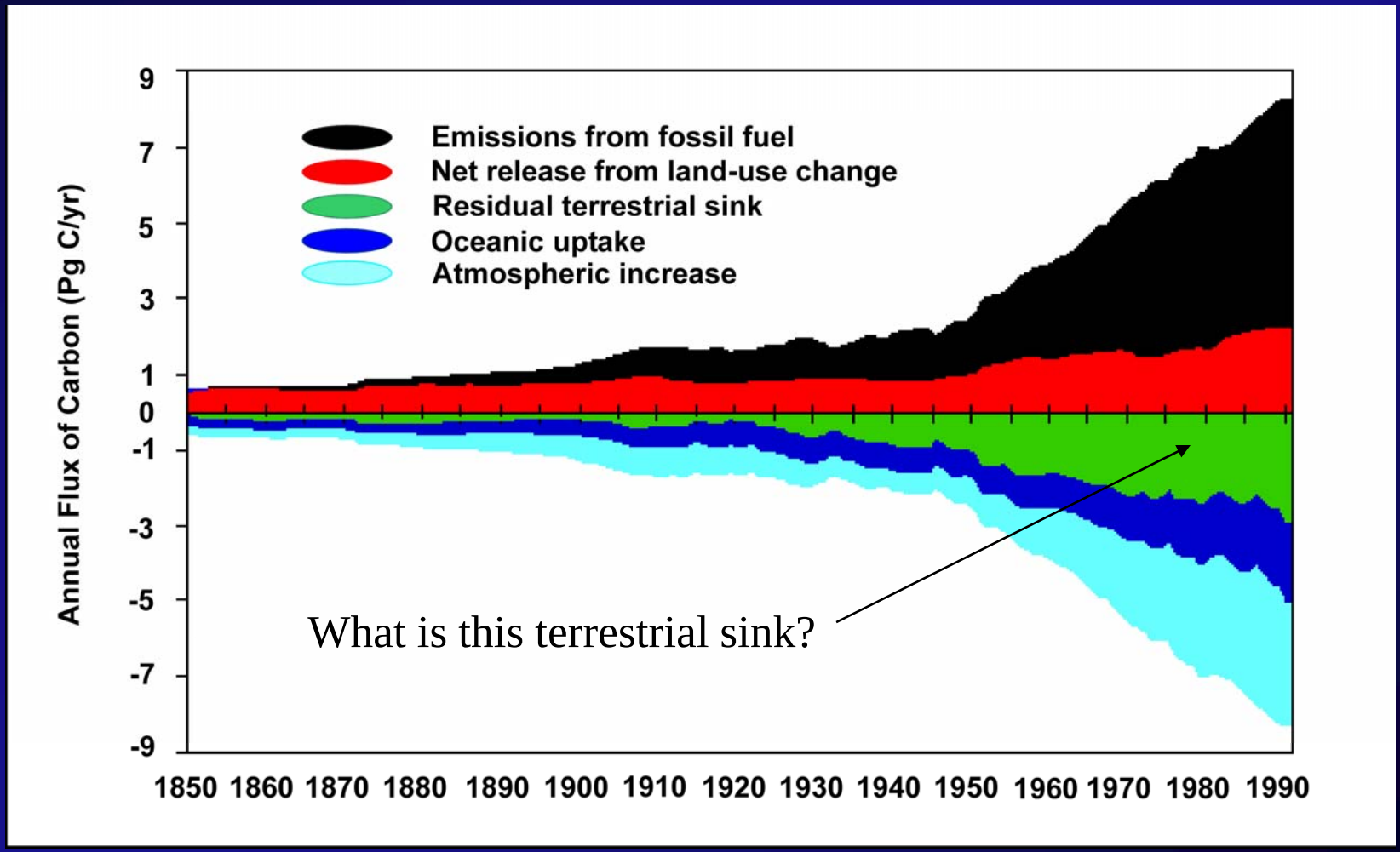
Can we separate the effects of land use and management from natural sources and sinks of carbon?

Can we separate the effects of land use and management from natural sources and sinks of carbon?

Do we need to?

Which models (IAMs, ESMs) include which aspects of changes in carbon stocks?

Global Carbon Budget



Outline

- The global carbon budget
  - The residual terrestrial sink
- Sources and sinks of carbon from land-use change: A METHOD
- What is land-use change?
- What if we had a ‘biomass satellite’ ?

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

e.g. with DESDynI

(radar and lidar)

Canopy structure from lidar

If we could measure biomass from space, we could determine changes in carbon stocks more directly.

A different accounting method:

- No longer rates of land-use change **x** biomass.
- Rather, Δ biomass from $t_2 - t_1$ equals the net terrestrial flux of carbon.
- The new method would include more changes in carbon stocks (not just deforestation/reforestation).

A Biomass Approach might 'see'…

- *Degradation as well as Deforestation*
  - *REDD*
- *Reforestation or Growth*
  - *(Grainger 2008)*
- *…and might help identify mechanisms of sinks (recent disturbance?)*

Forest Degradation & Growth

Emissions from forest degradation & growth can

- offset the emissions from deforestation

or

- > double them.

AND…

‘Direct’ observation of changes in aboveground biomass obviates the need for definitions of *forest* and *deforestation* --- major points of ambiguity and contention in negotiations for REDD.

Conclusions

Conclusions

- Changes in land use and management play a dominant role in determining sources and sinks of carbon.
- Regrowth accounts for a major portion of today's carbon sink, perhaps all of it.
  - Have secondary forests been underestimated?
  - Are all forests growing?

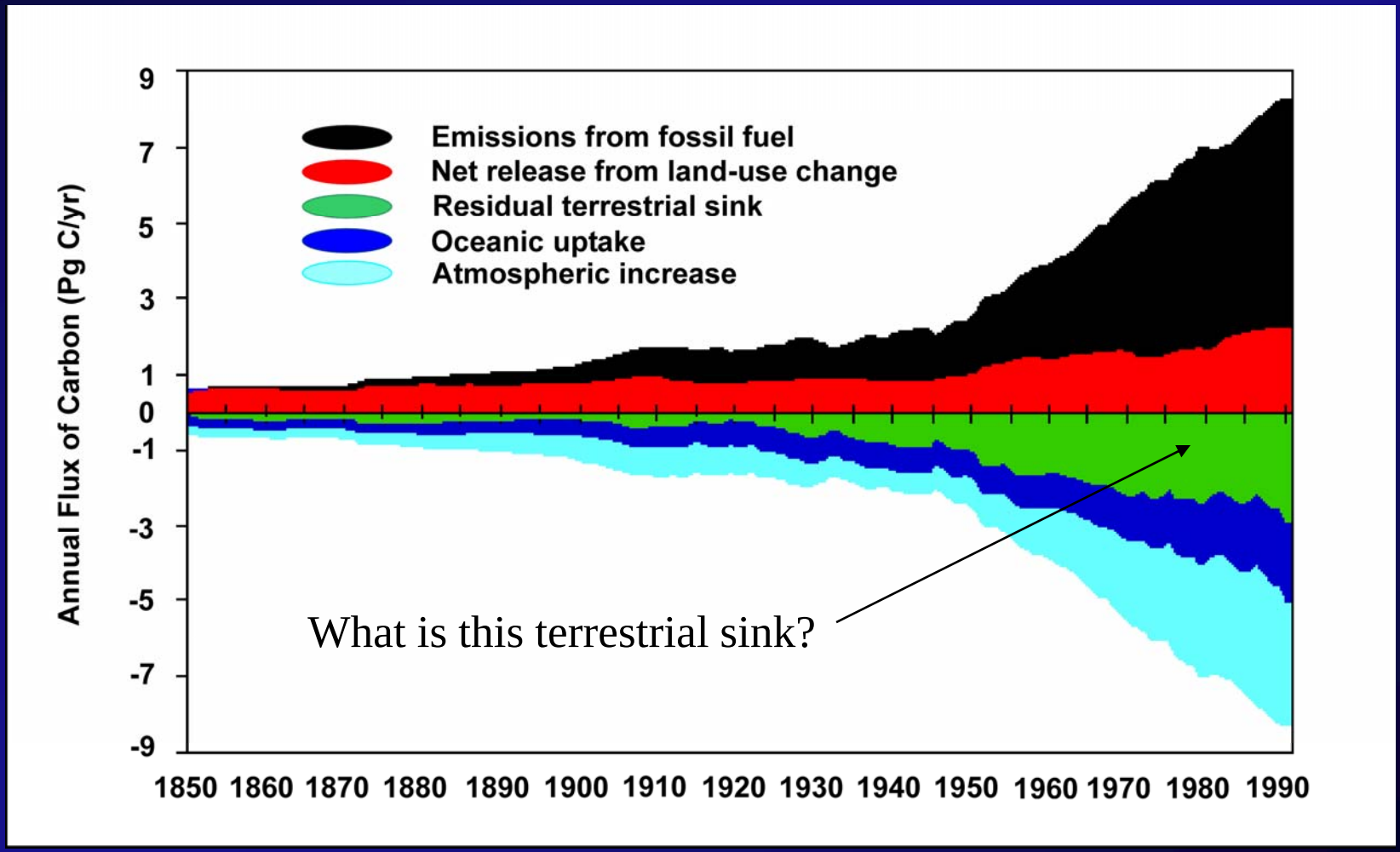
Conclusions

- Three types of change in terrestrial carbon stocks:
  - Direct anthropogenic effects; i.e., management
  - Indirect effects
    - CO_2 fertilization
    - N deposition
    - Climate change, including changed disturbance regimes
  - Natural effects, including disturbances

Conclusions

- Is management a part of land-use change?
- Can we separate the carbon effects of land-use change and management from natural sources and sinks of carbon? Do we need to?
- Are estimates of emissions from land-use change biased?
  - e.g. have we underestimated the area of 2º forests?

Global Carbon Budget



Thank you