The Scientific Questions and Requirements

to Improve Our Understanding of

the Global Carbon Cycle

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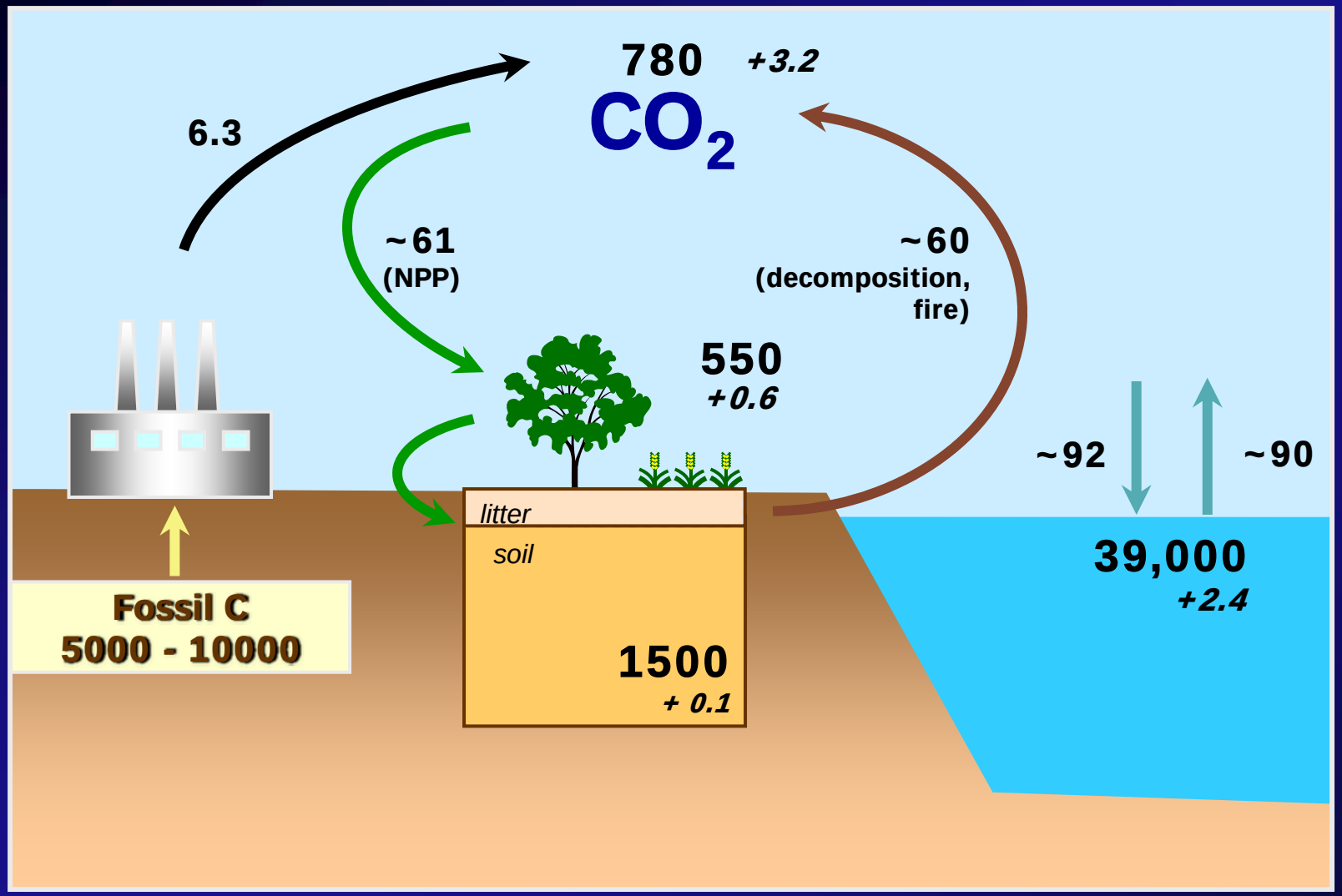
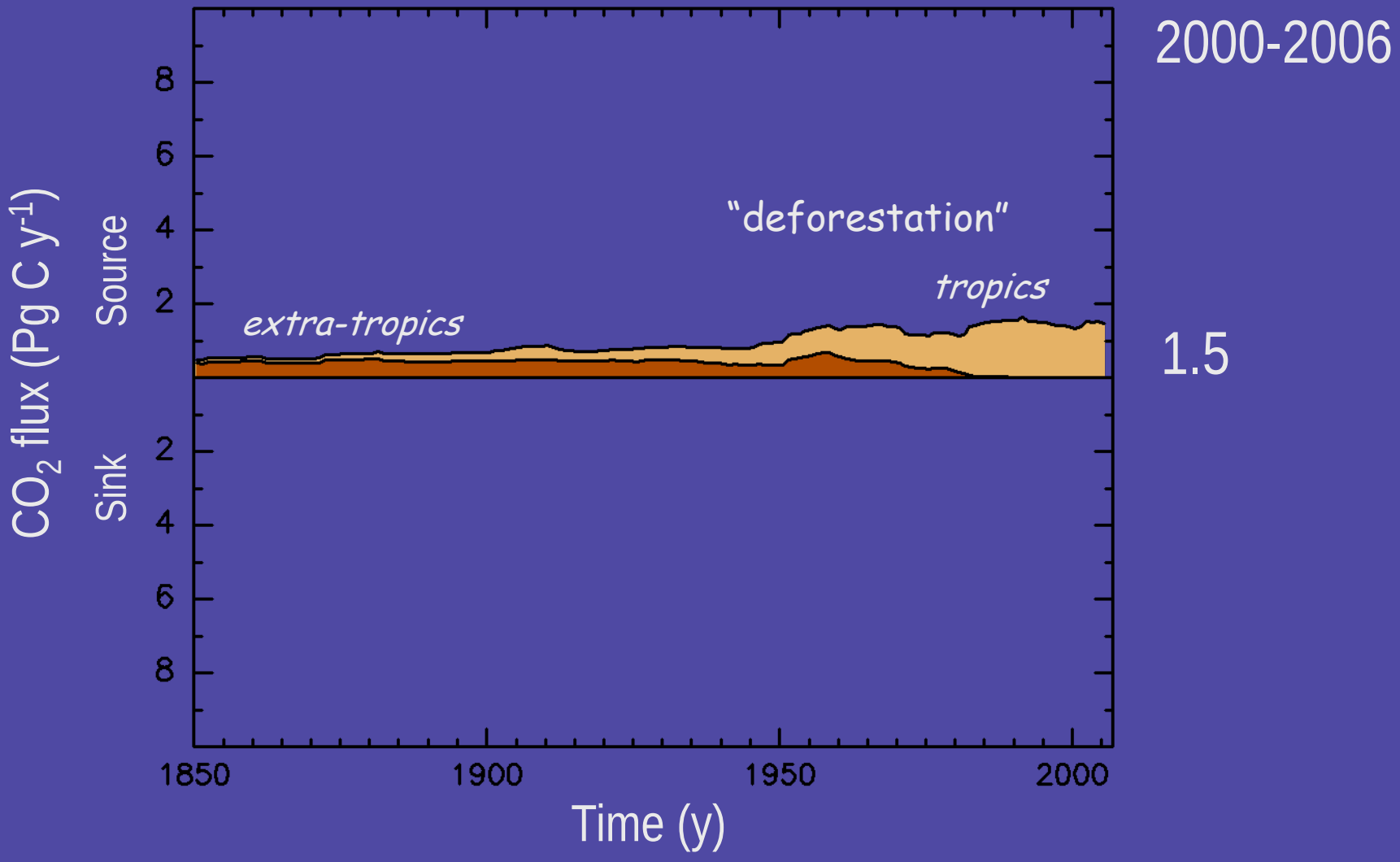
Two Questions:

1. What is the distribution of aboveground woody carbon stocks?
2. How much, where, and why are woody carbon stocks changing?



The Global Carbon Cycle

Perturbation of Global Carbon Budget (1850-2006)



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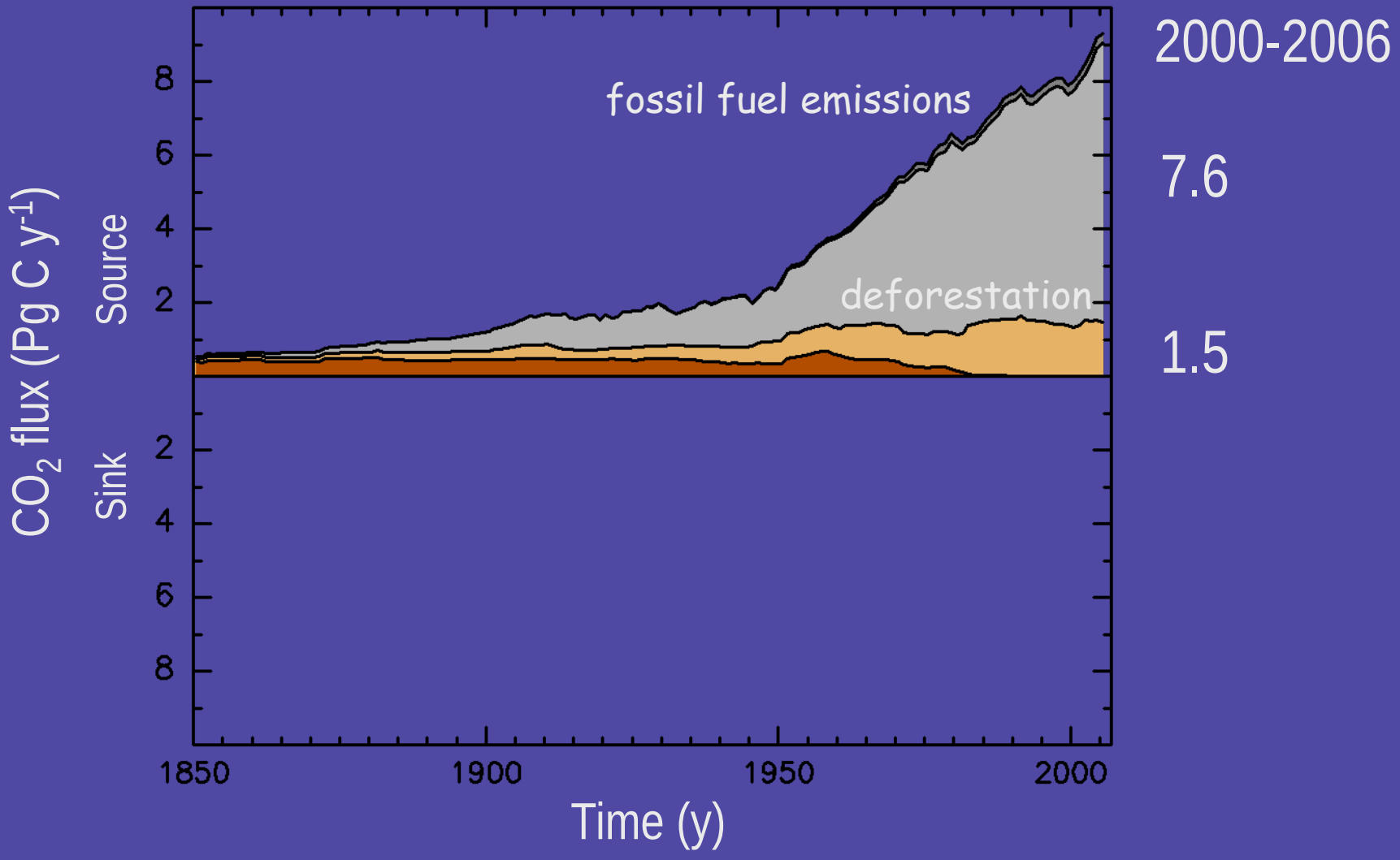

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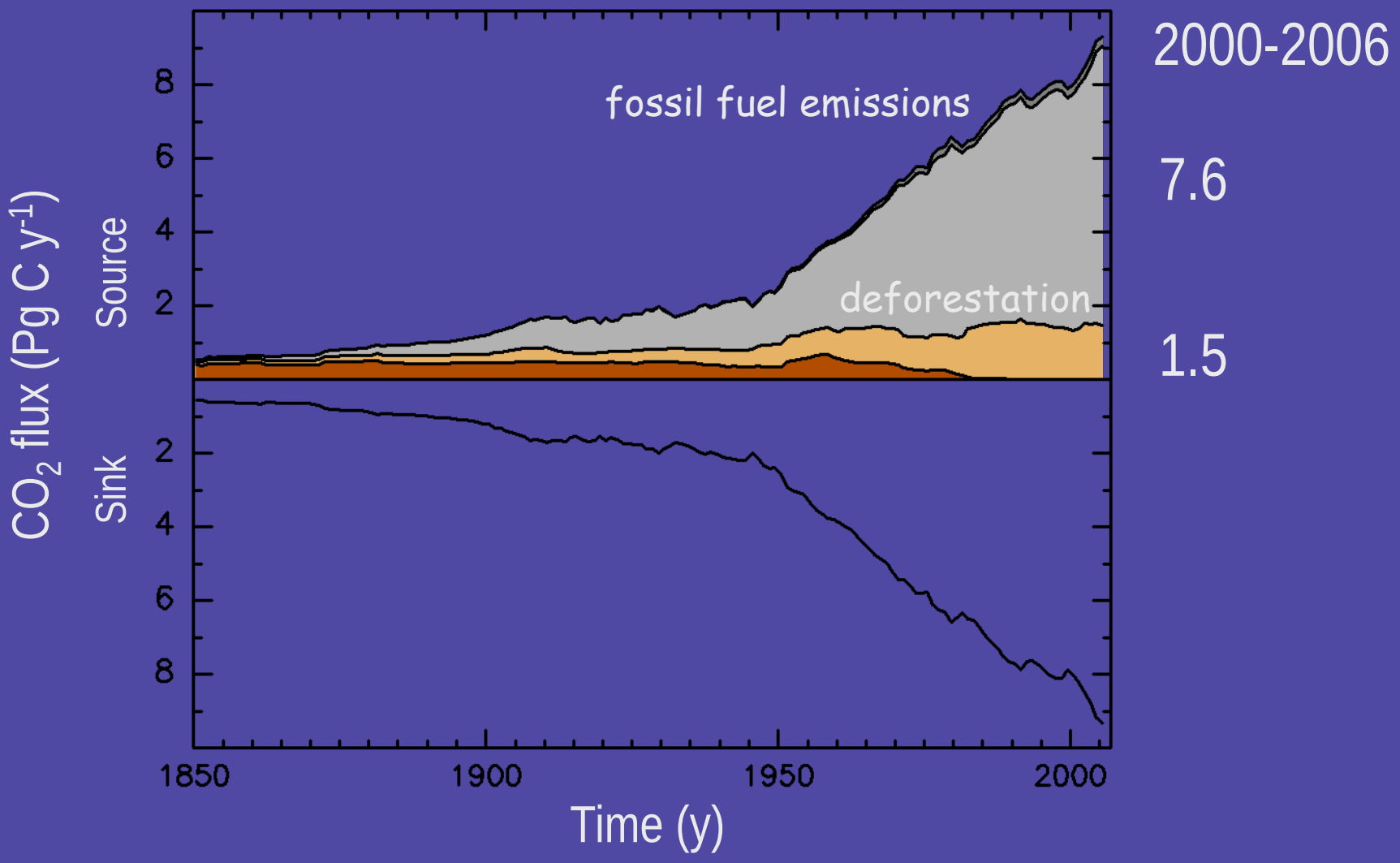

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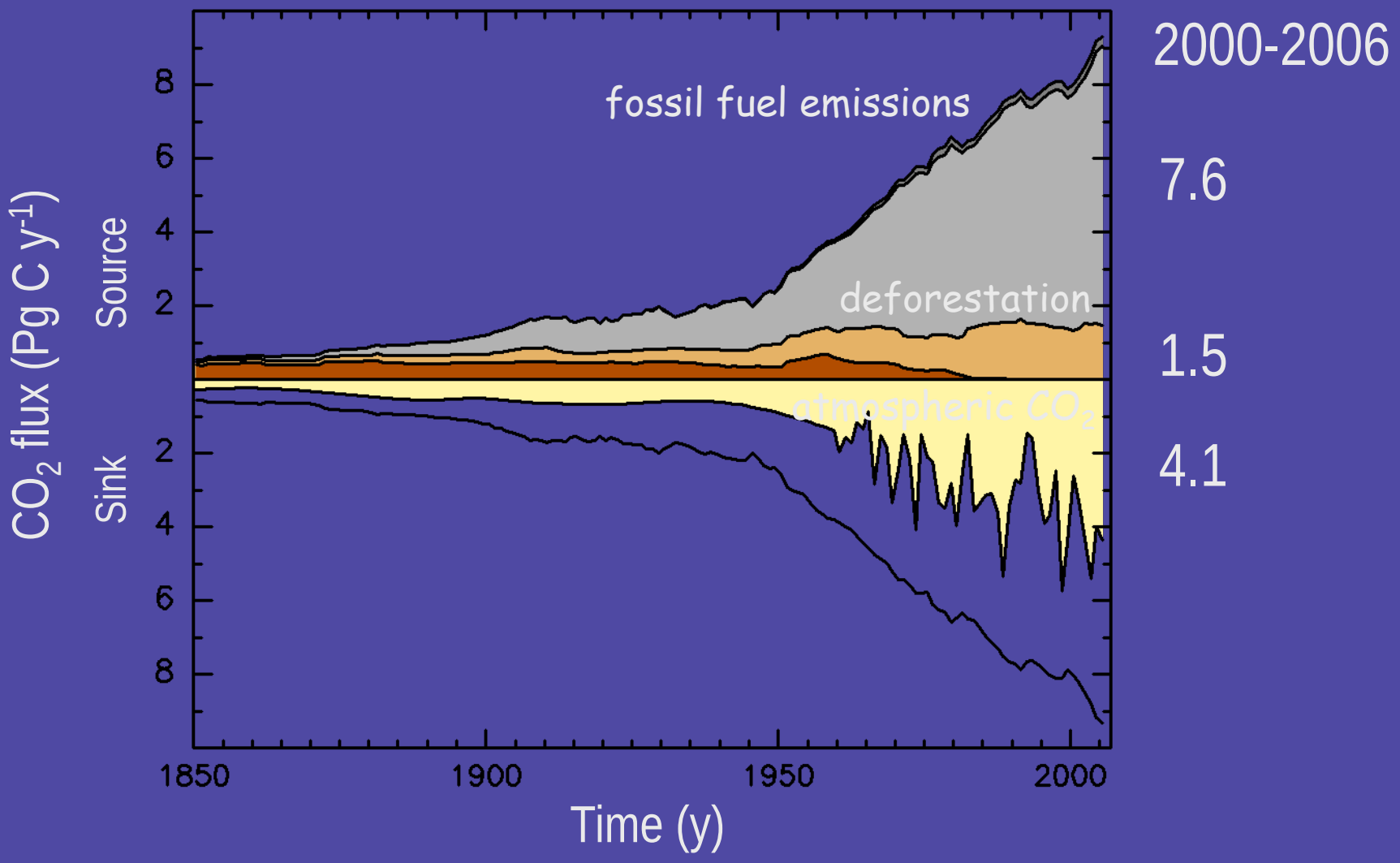

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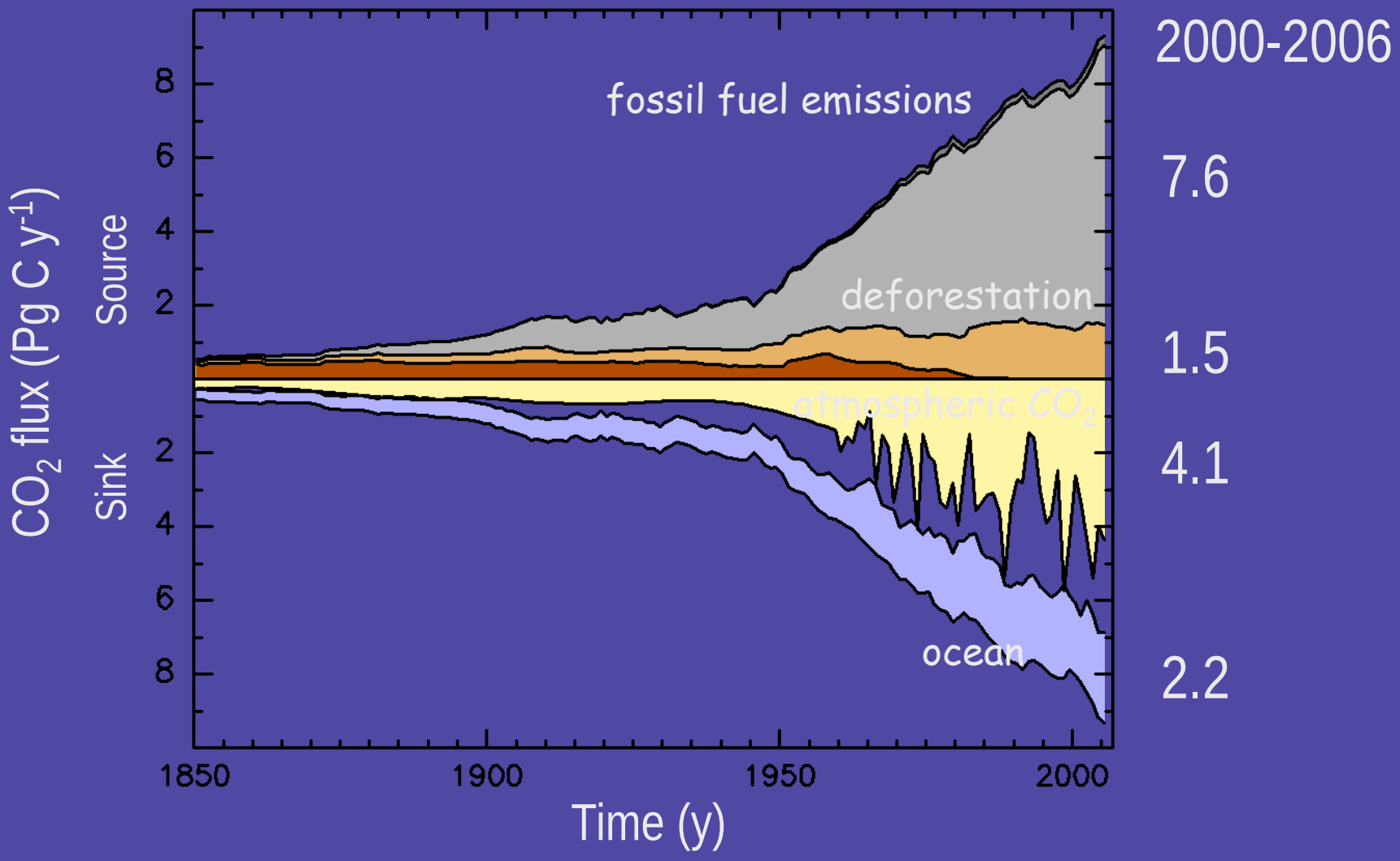

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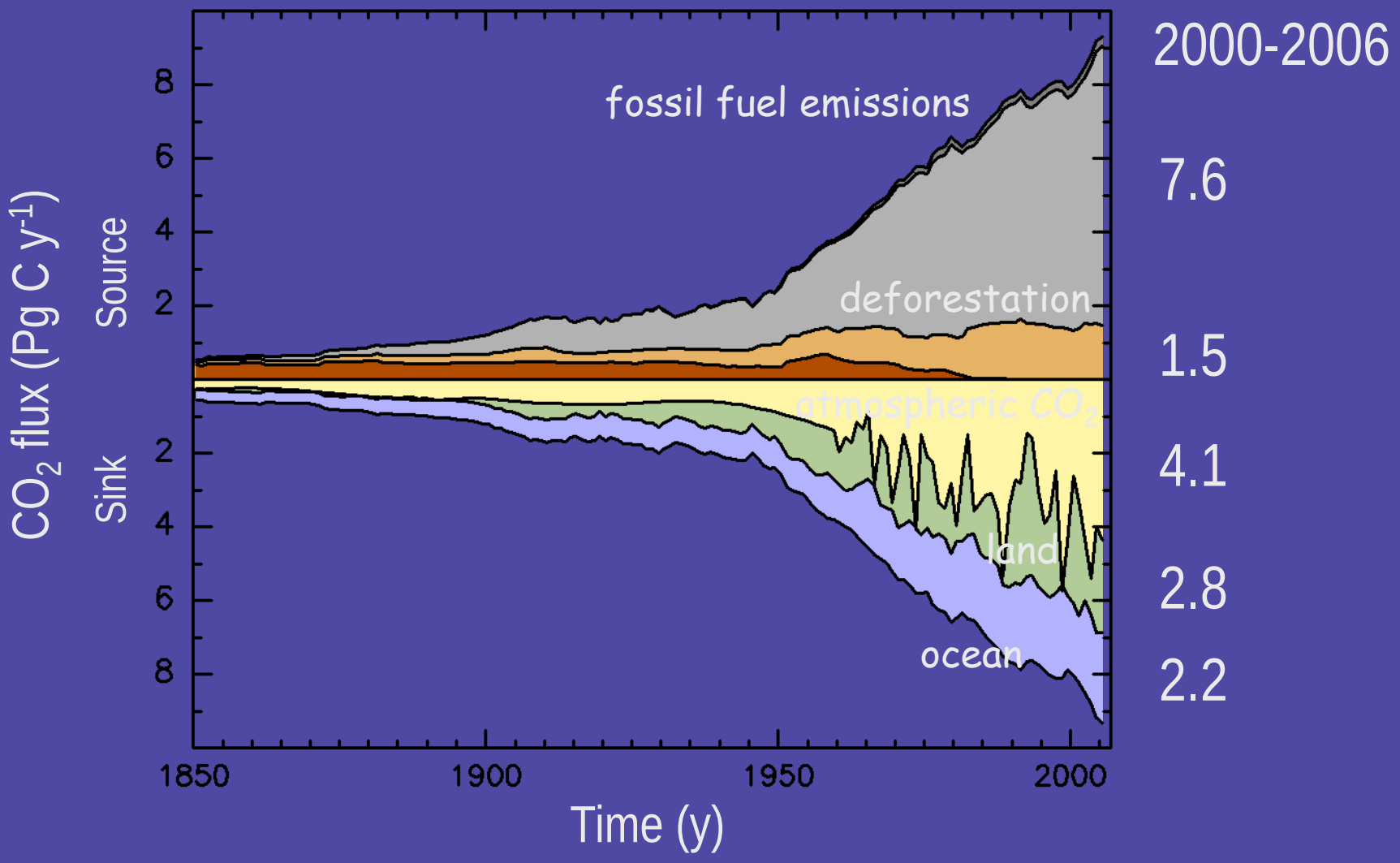

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Global Carbon Budget

	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

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[Net terrestrial flux	**-1.3 ± 0.5]**

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Global Carbon Budget

	2000-2006	
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Residual terrestrial flux	**-2.8 ± 0.7**	

Full range: 0.5-2.7 (1.6 ± 70%) (Denman et al. 2007; IPCC)
for 1990s

Question #1

Two Questions:

1. What is the distribution of aboveground woody carbon stocks?

   WHERE'S the CARBON?

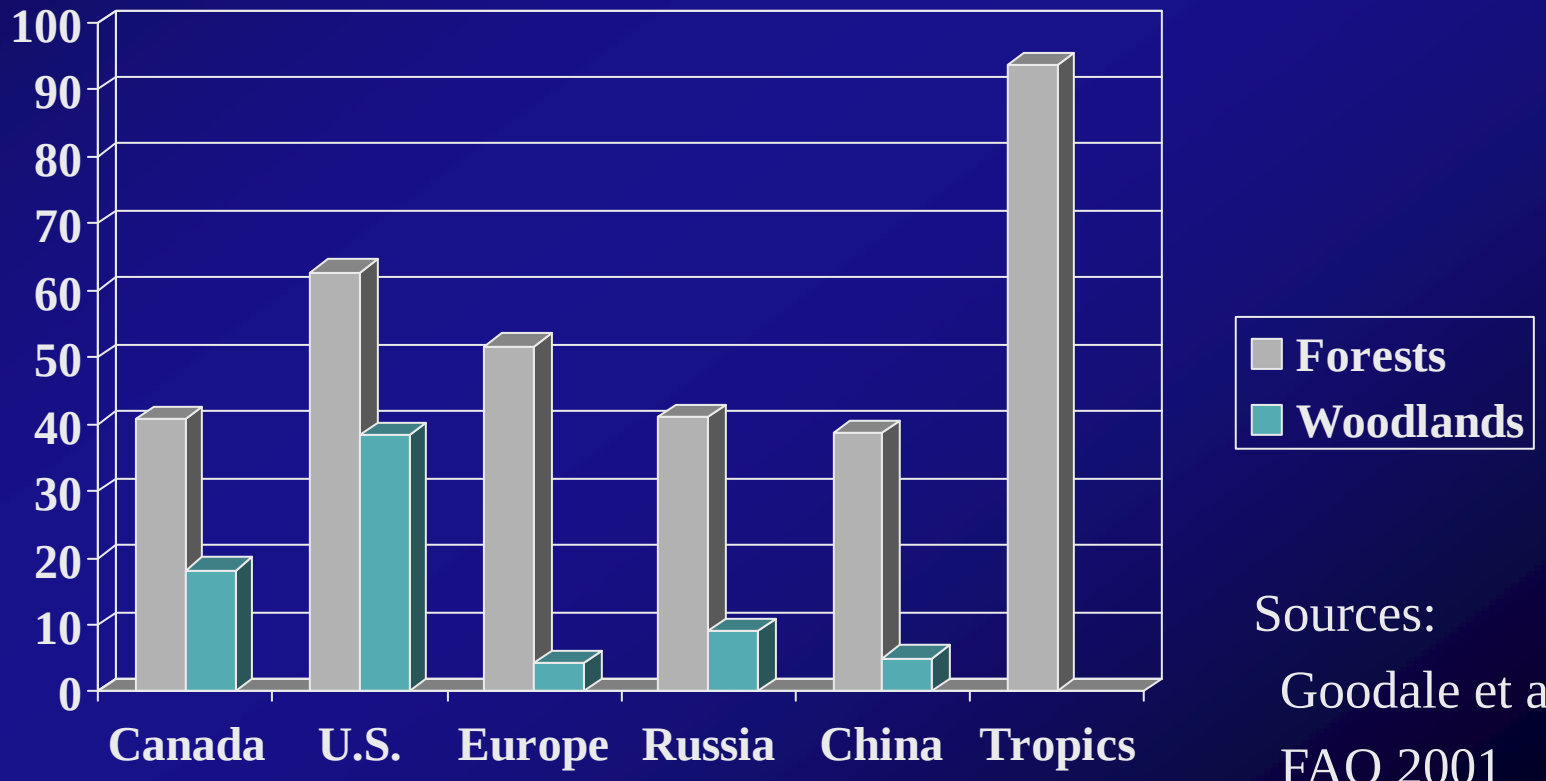
2. How much, where, and why are woody carbon stocks changing?

Need to know biomass to calculate the flux from land-use change [Question #1]

Emissions = Area deforested x biomass

- Average biomass is well known in temperate and boreal forests;
- … poorly known in tropical forests.

Average biomass varies regionally (tC/ha)



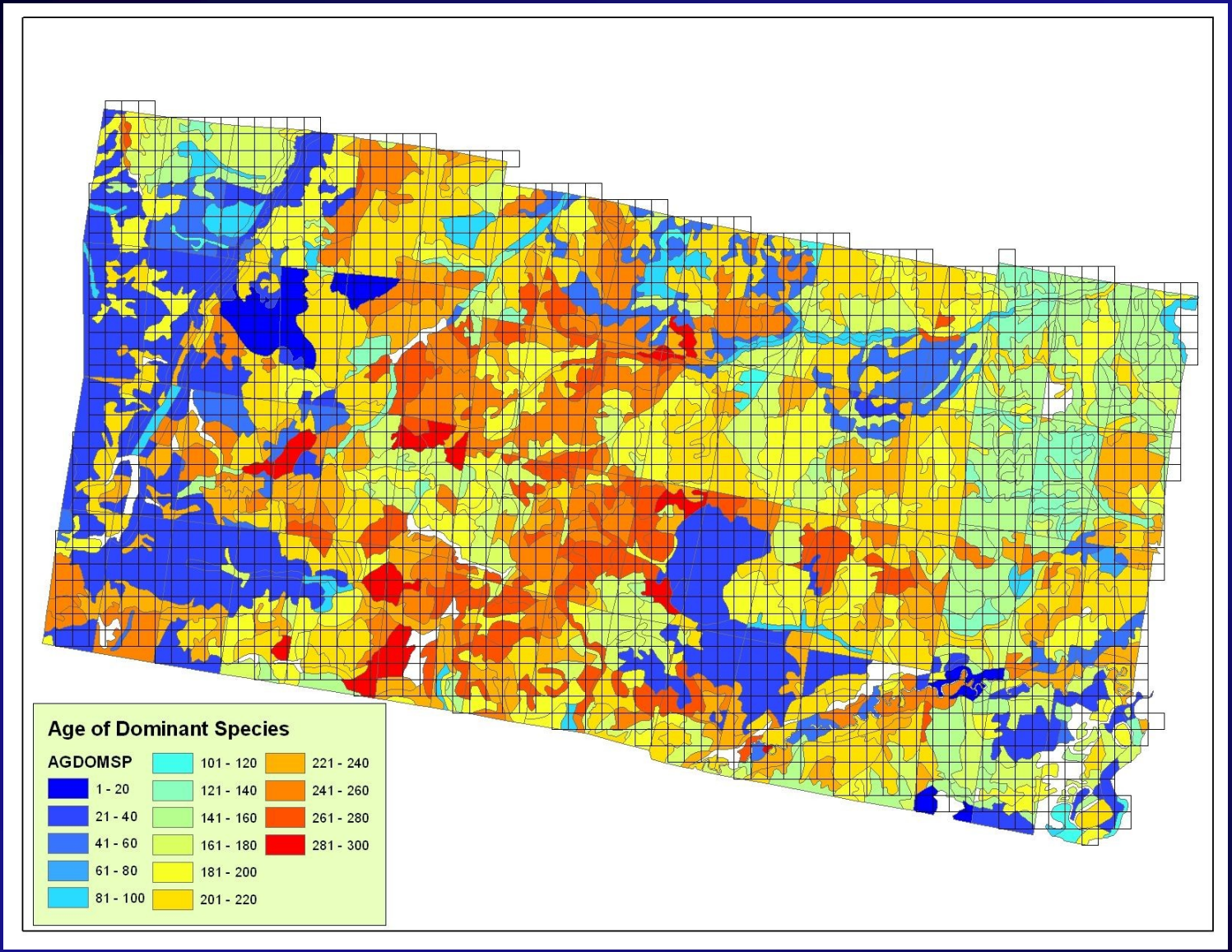
Sources:

Goodale et al. 2002

FAO 2001

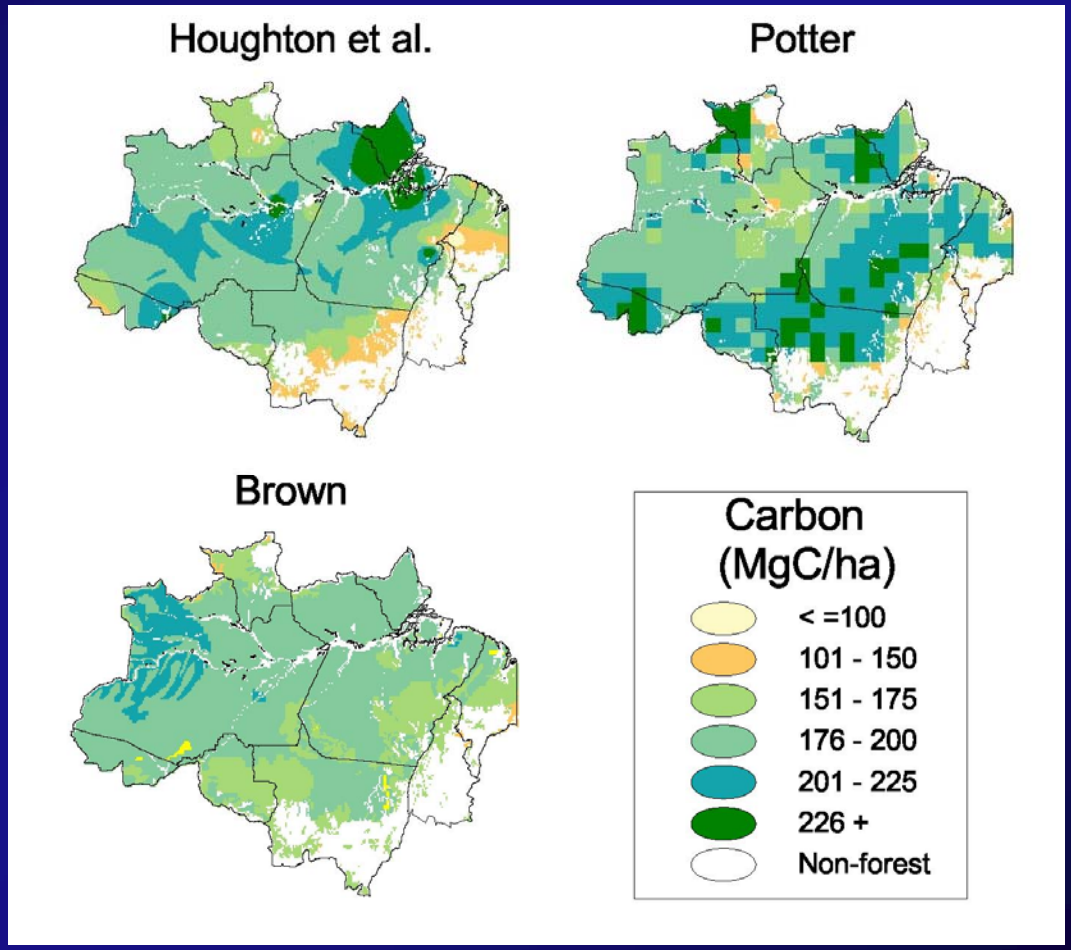
But averages are not good enough. Biomass varies over short distances…

…in part, from past disturbances.



Different ages of forest stands in Krasnoyarsk, central Russia

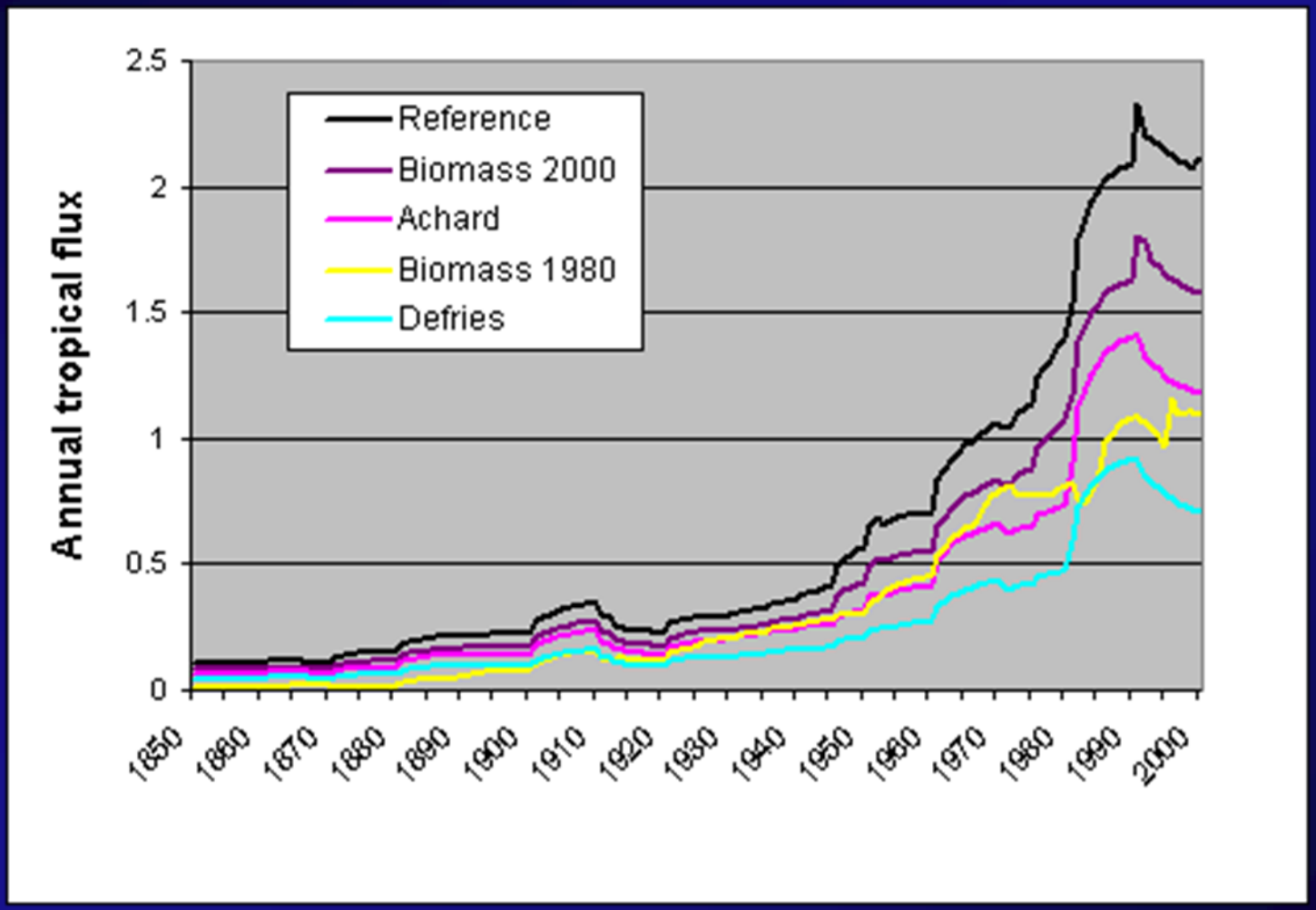
In the tropics, even the averages are uncertain.



With deforestation…

- Biomass determines the magnitude of the calculated tropical source
- Uncertainty in biomass accounts for much of the uncertainty in flux estimates for the tropics

Uncertainties



biomass

deforestation rate

Source: Houghton 2005

Are averages good enough?

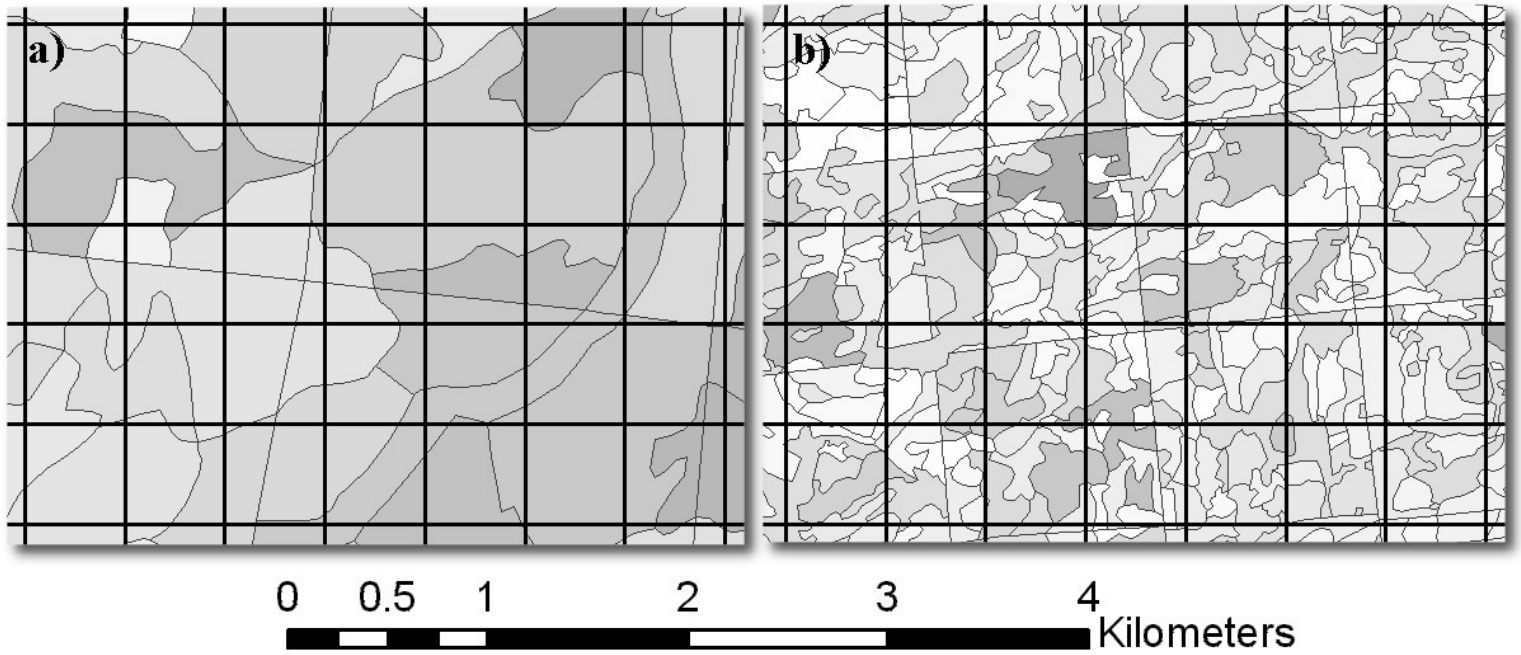
What is the biomass of the forests actually deforested?

With deforestation,
a 10% uncertainty in biomass
yields a 10% uncertainty in C flux

Requirements for carbon stocks
(Question #1)

- Spatial resolution
  - Size of disturbances (<100m)
- Temporal resolution
  - "Once"
- Wall-to-wall
- Accuracy
  - ±10% or 10 tC/ha

Spatial resolution <100m



Forest polygons within MODIS cells.

For deforestation,
10% uncertainty in biomass
yields a 10% uncertainty in C flux.

Question #2

Question #2:

How much, where, and why are carbon stocks changing?

Why do we need to know?

a. Quantification and mapping of terrestrial sources and sinks of carbon

b. The mechanisms responsible

If a sink of 2-3 PgC/yr is distributed globally in aboveground forest biomass…

- the average sink would be 0.5-0.8 tC/ha/yr or ~1% of aboveground biomass per year (at most)

If the sink of 2-3 PgC/yr is distributed in aboveground forest biomass in the northern mid-latitudes…

- the average annual sink would be 1.2 MgC ha^{-1} yr^{-1}) or ~3% of aboveground biomass per year
  - Good news: Sink is not evenly distributed spatially
  - Bad news: Some of the sink may not be in forests

Until recently, inverse approaches showed the terrestrial sink to be located predominantly in the northern mid-latitudes (tropics, a source).

Gurney et al. 2004

N mid-latitudes	-2.4 ± 1.1	PgC/yr 1992-1996
Tropics	1.8 ± 1.7	

Now, not so sure.

	Gurney et al. 2004	Stephens et al. 2007
N mid-latitudes	-2.4 ± 1.1	-1.5 ± 0.6
Tropics	1.8 ± 1.7	0.1 + 0.8

Units: PgC/yr 1992-1996

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 means…

- There will be areas where sources and sinks of carbon from disturbance and recovery are large enough to be observed from space over a 2-5-year interval.
- We don’t know what fraction of the landscape is in recently disturbed or rapidly regrowing stands?

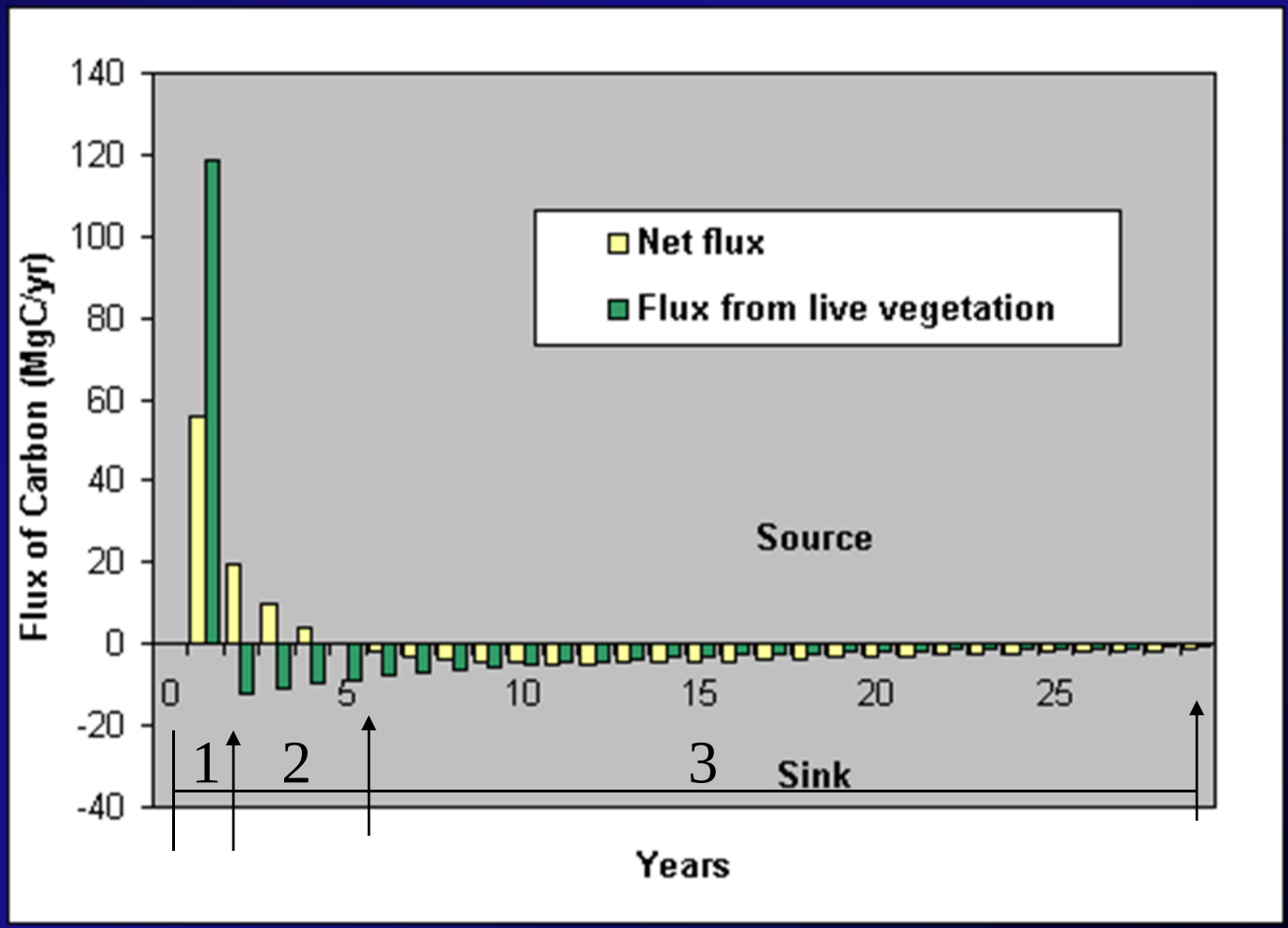
Three categories of forest:

- Large source (after disturbance)
- Large sink (early in recovery stage)
- Small flux or no change in carbon stocks (late in recovery stage, or old growth)

Areas with different net fluxes of carbon

Flux

(MgC/yr)



Consequence:

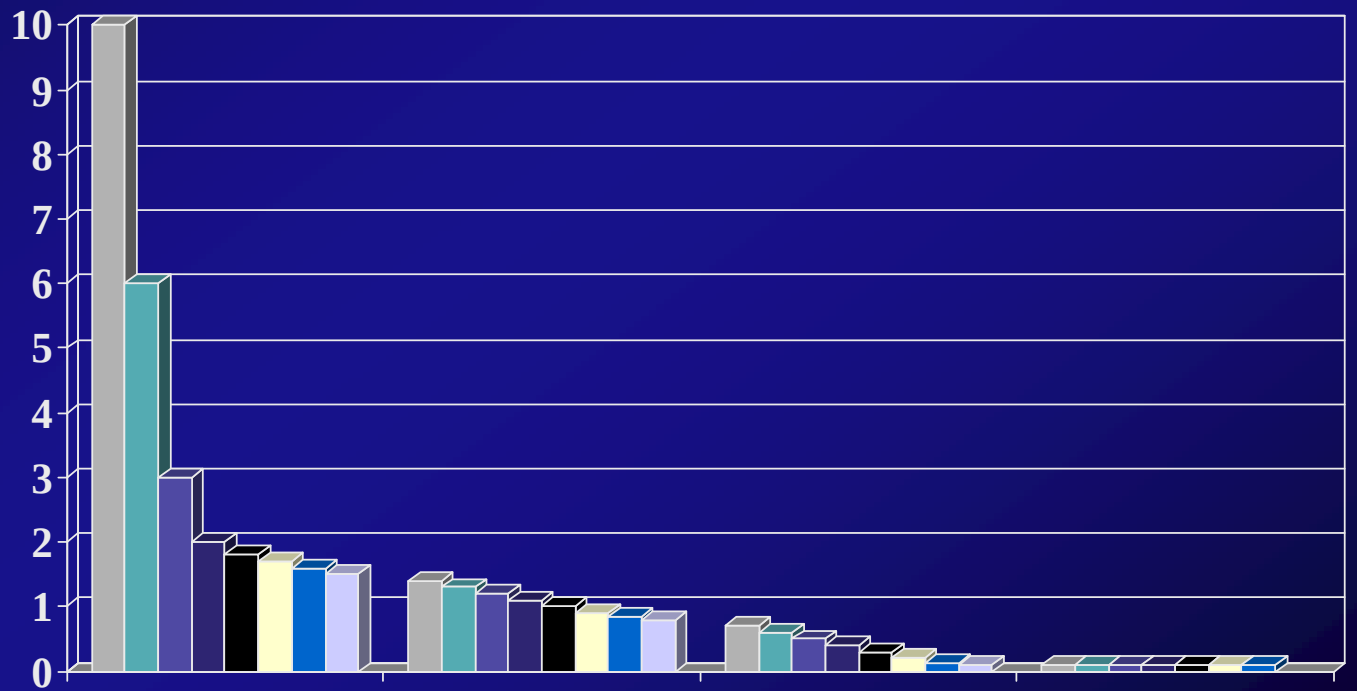
Even if we can't measure biomass, we can learn a lot by measuring the annual rate of forest disturbance over the surface of the Earth.

Question #2a

How much of the annual net flux from land is the result of disturbance and recovery?

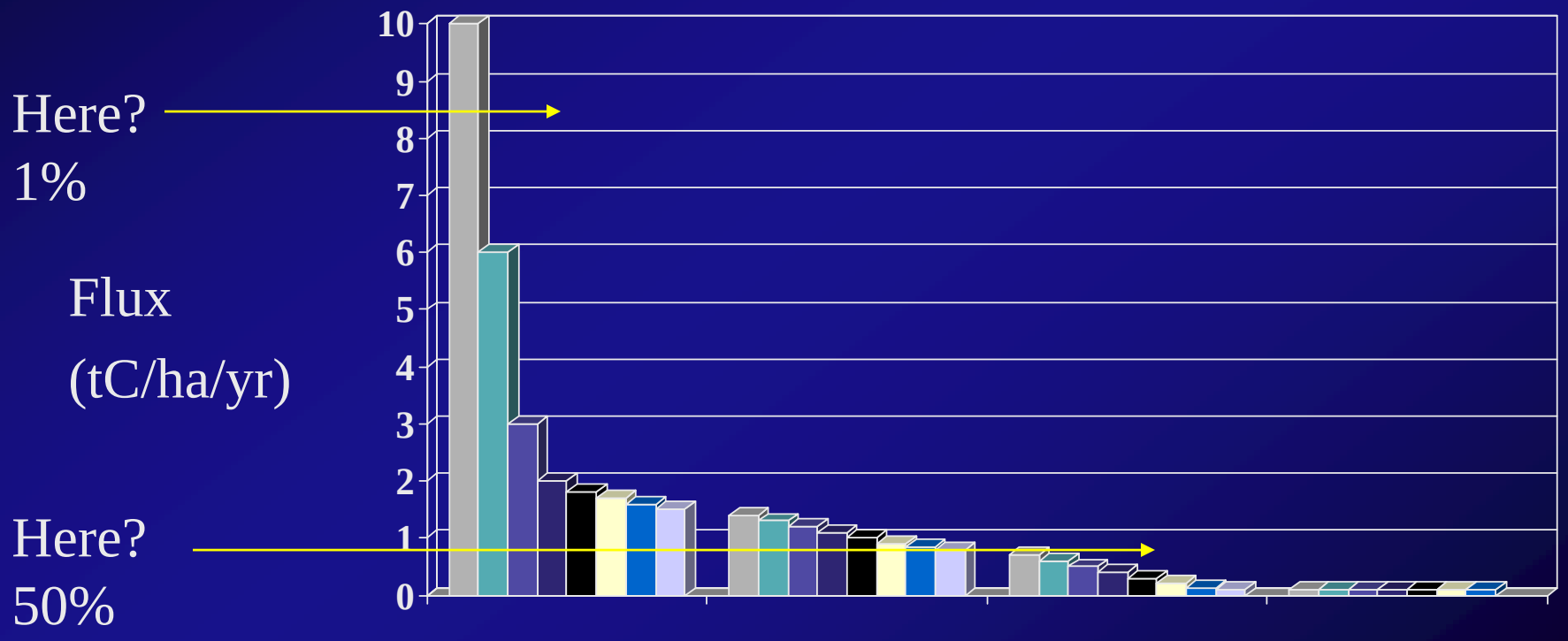
What area of land has a large net change in biomass?

Flux
(tC/ha/yr)



Each bar represents 10 million ha

What is the threshold of change that can be 'seen' over 1 year? 5 years?



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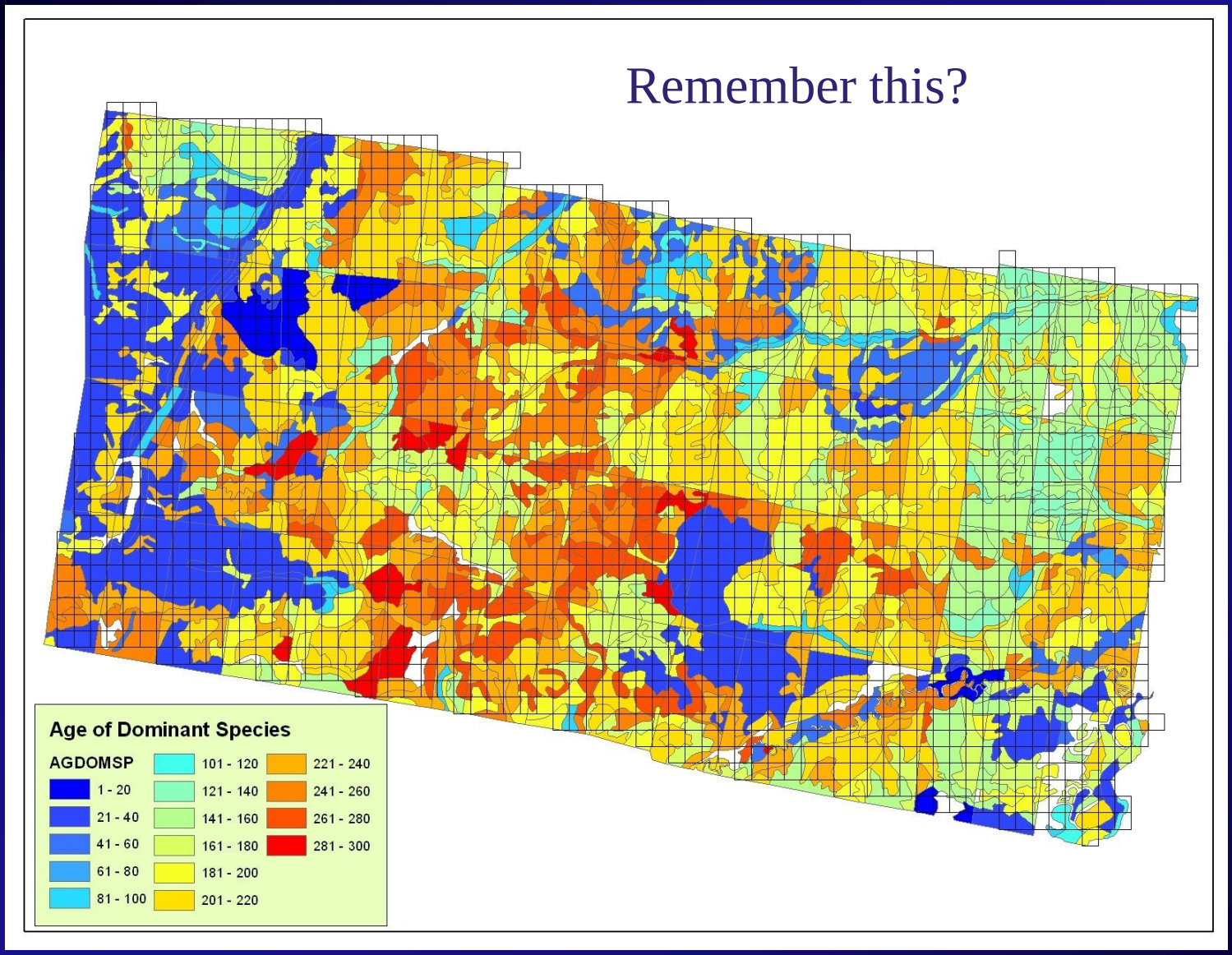


Siberian forest stands of different ages (and growth rates)

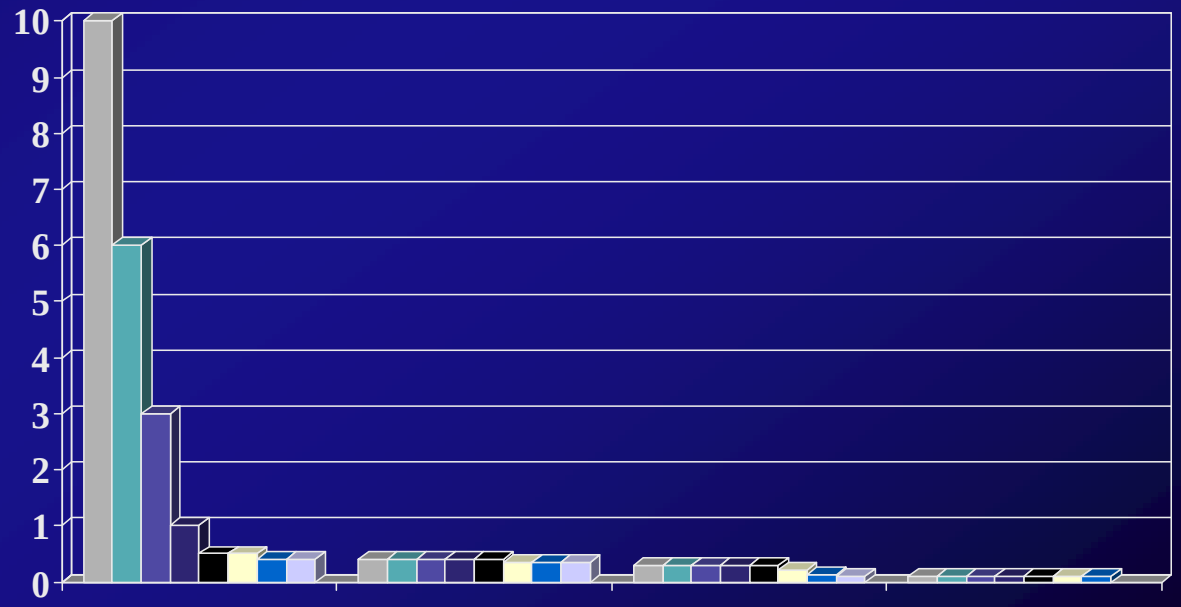
What fraction of the landscape is in recently disturbed or rapidly regrowing stands?

What fraction of the landscape is in recently disturbed or rapidly regrowing stands?

We don't know!

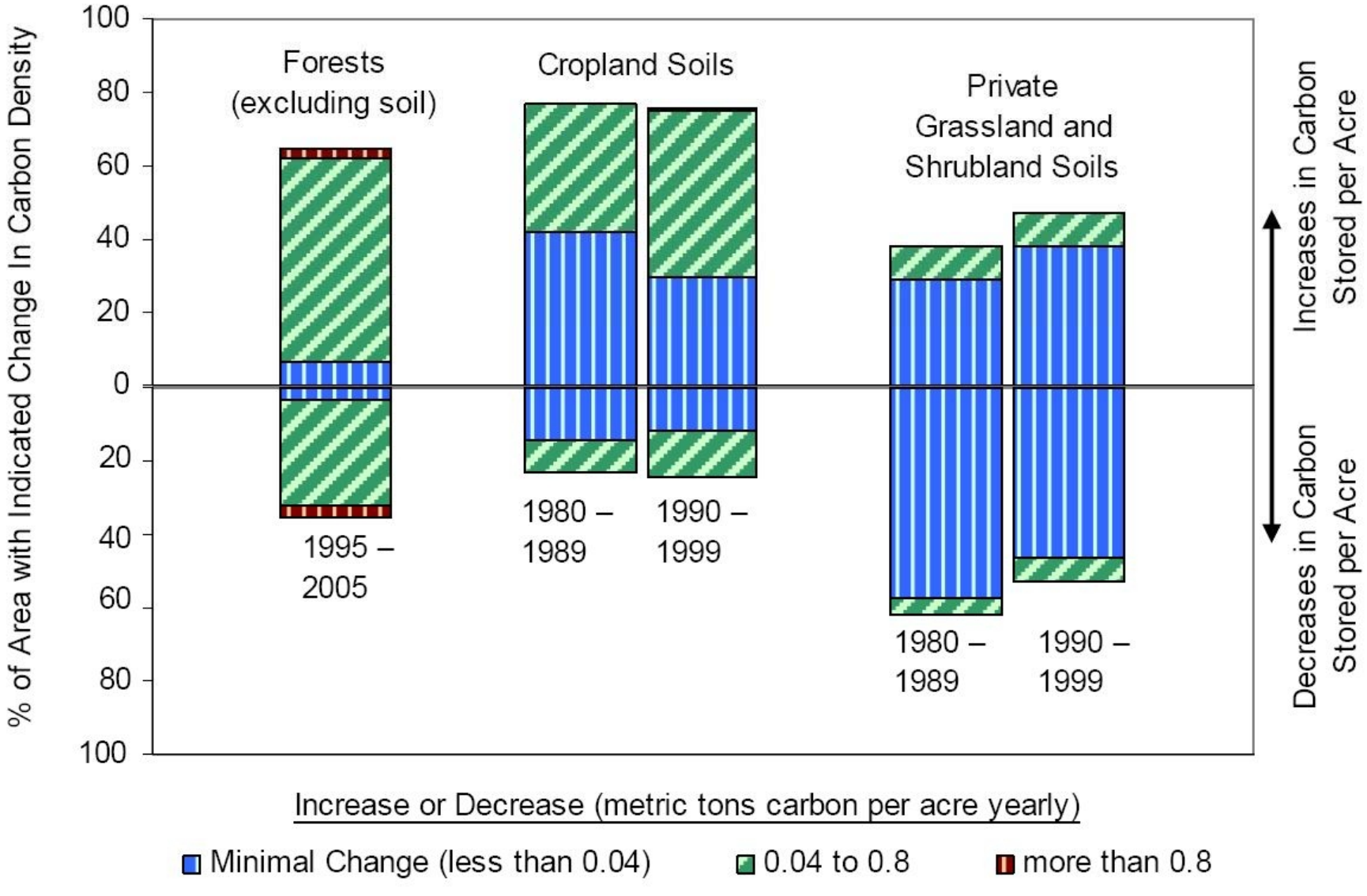
Better if we measured biomass too.

- What if 90% of the net terrestrial flux of carbon occurs on 5% of the earth's surface, and that 90% is 'observable'?

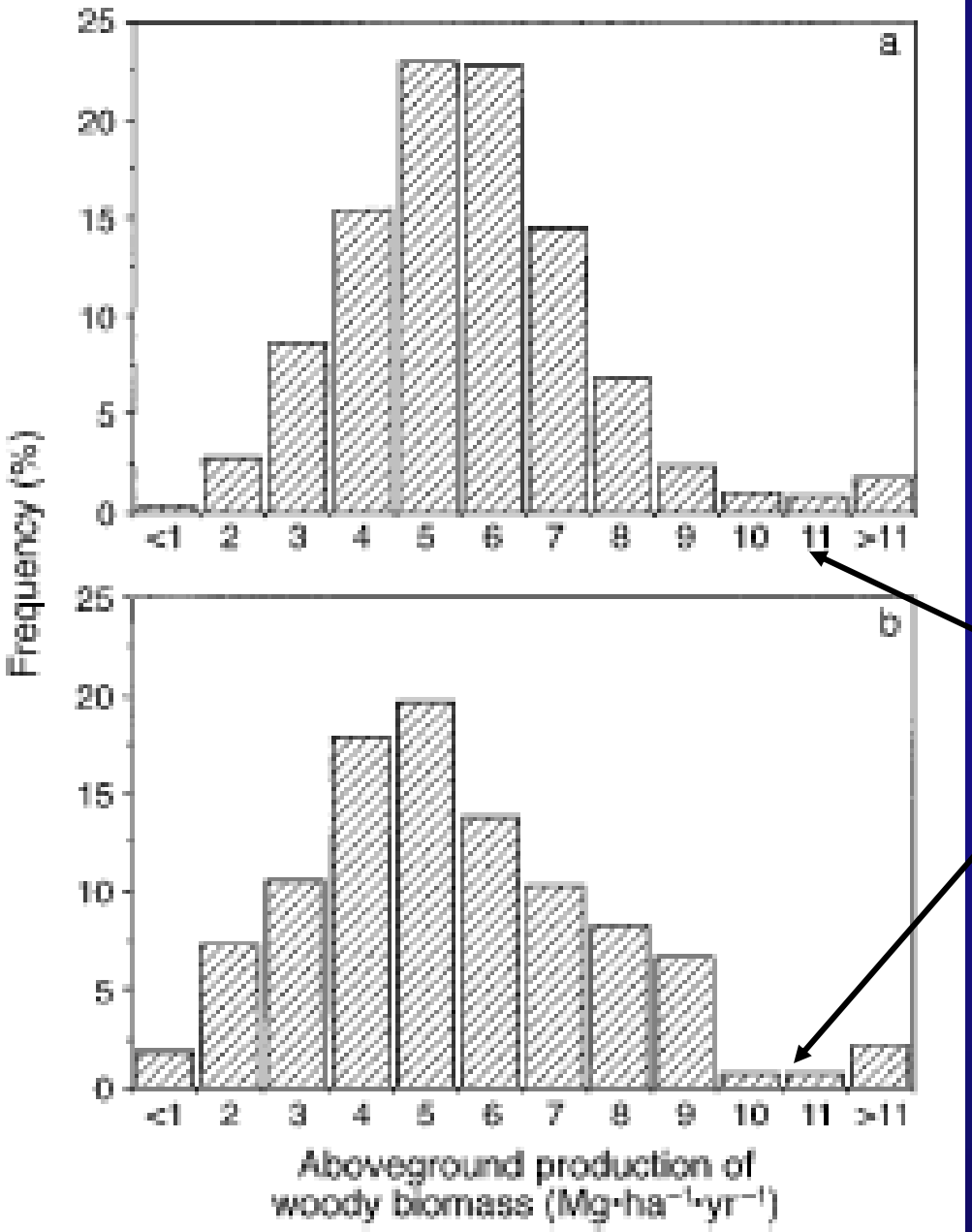


Any data?

Partial Indicator Data: Forests (above-ground plant matter only), croplands and grasslands (soil carbon only, private lands only).



Eastern U.S. forests



Hardwoods

2.5-3% of counties had wood production > 10 Mg/ha/yr

Softwoods

Brown & Schroeder 1999

Requirements for stock changes

Question #2

- Spatial resolution
  - Size of disturbances (<100m)
- Temporal resolution
  - Repeat measurements every 1-5 years
- Accuracy
  - ±10% or 10 tC/ha
- Sampling might be adequate

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Last but not least…

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

Then, the method for calculating flux is different.

We could use 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).

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.

A Biomass Approach might 'see'…

- *Degradation as well as Deforestation*
  - *REDD*
- *Reforestation or Growth*
  - *(Grainger 2008)*
- *And help identify mechanisms of sinks*
  - *(recently disturbed or not?)*

Forest Degradation

Estimates vary:

Emissions from forest degradation are very uncertain:
vary from 0 to > 100% of emissions from deforestation.

Forest Degradation & Growth

Estimates vary:

Emissions from forest degradation & growth could

- offset the emissions from deforestation

or

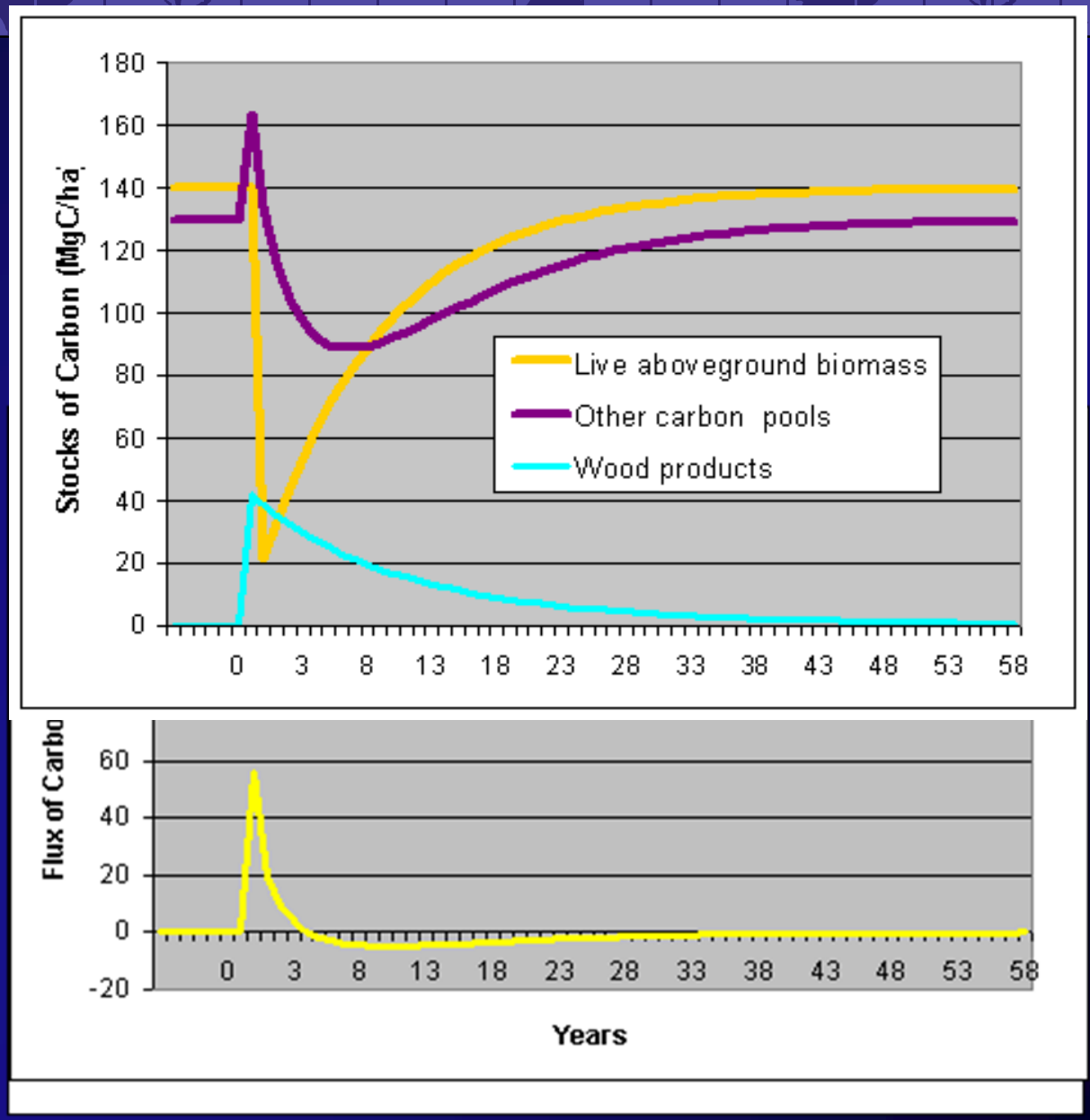
- > double them.

Two potential weaknesses with a method based on 'direct' measurement of biomass:

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

Carbon stocks (MgC/ha)

Carbon flux (MgC/ha/yr)



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

Need models for full carbon accounting.

Identification of mechanisms

- Changes in land use and management still need to be monitored/documented…
  - …to help with the Kyoto Protocol.
    - Are changes directly or indirectly the result of human activities?

Conclusions

Advantages of satellite over forest inventories

1. Wall-to-wall, spatial estimates (rather than averages)
2. Not all ecosystems are inventoried
   - Woody encroachment
   - Other wooded lands

Summary (continued)

- Biomass contributes ~ as much uncertainty as rates of deforestation to emissions
- Need spatially-specific biomass to assign to areas deforested
- Need repeat coverage to measure changes in biomass (forest degradation, growth)
- What fraction of forest area has large C fluxes…
  - …from disturbance and recovery?

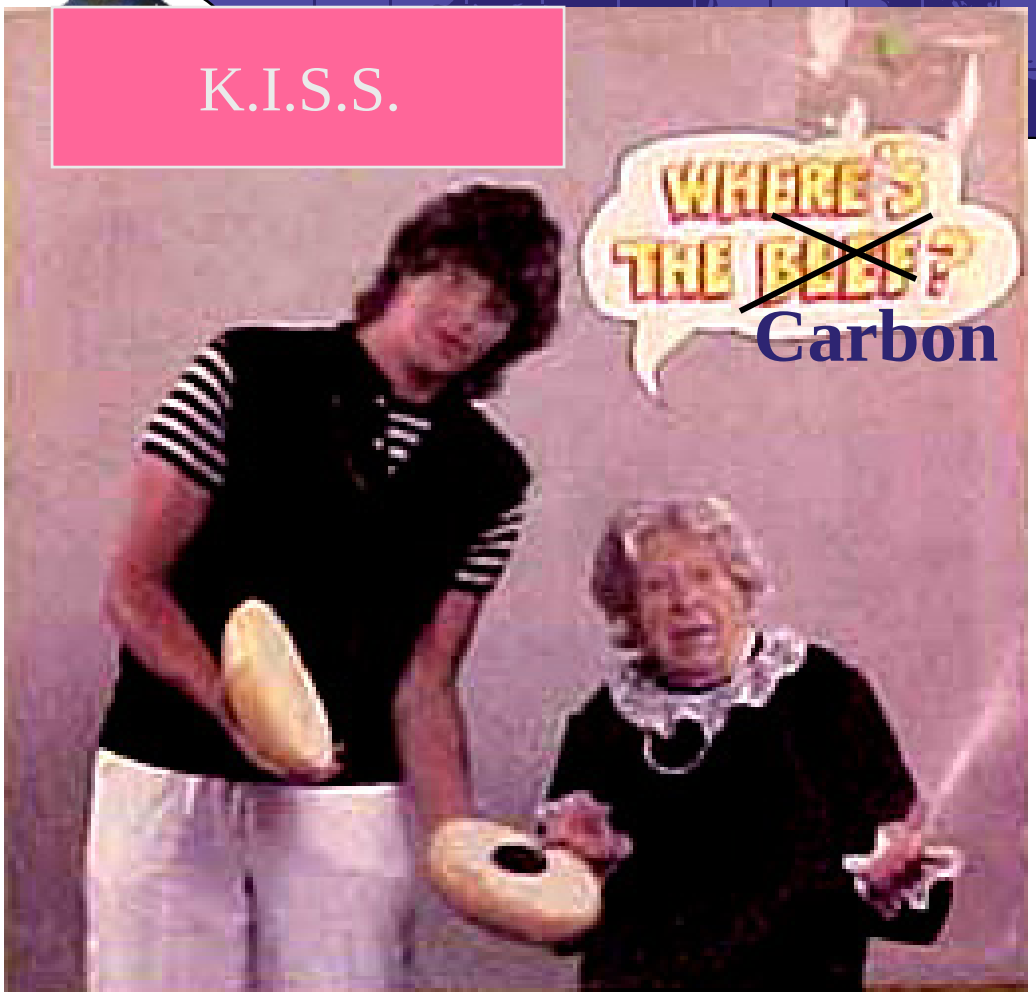
Summary (continued)

Two Questions:

1. What is the distribution of aboveground woody carbon stocks?
2. How much, where, and why are woody carbon stocks changing?

2a. How much of the annual net flux from land is the result of disturbance and recovery?

K.I.S.S.



The KISS version:

1. Where's the Carbon?

2. Where are the (largest) sources and sinks of carbon?

Thank you