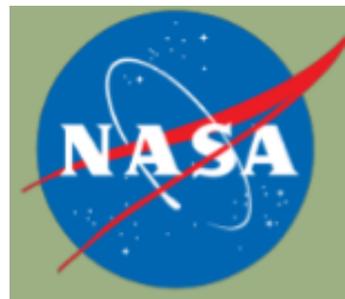# Land-Use Harmonization Progress 1:

# strategy, methods, preliminary results

## George Hurtt, Steve Frolking, & Louise Parsons Chini

## University of New Hampshire

<u>ESM Land-Use Attributes</u>:
- global & gridded, with sub-grid information
- land-use transitions
- continuous (<u>ideal</u>: hourly; <u>realistic:</u> annual - decadal)
- consistent with historical reconstruction
- consistent with IAM futures
- smooth history • future
- wood harvest (currently ~ 1 Pg C $y_{-1}$)
- shifting cultivation (~250M people; ~$10_5$ $km_2$ $y_{-1}$)

# Harmonization Proposal

**Strategy**:
- historical land use - Hyde 3 (Klein Goldewijk, 2007);
- historical wood harvest and shifting cultivation - Hurtt et al., 2006 methods;
- future land use & wood harvest - IAMs (gridded and/or regional data);
- future climate and $CO_2$ - IAMs;
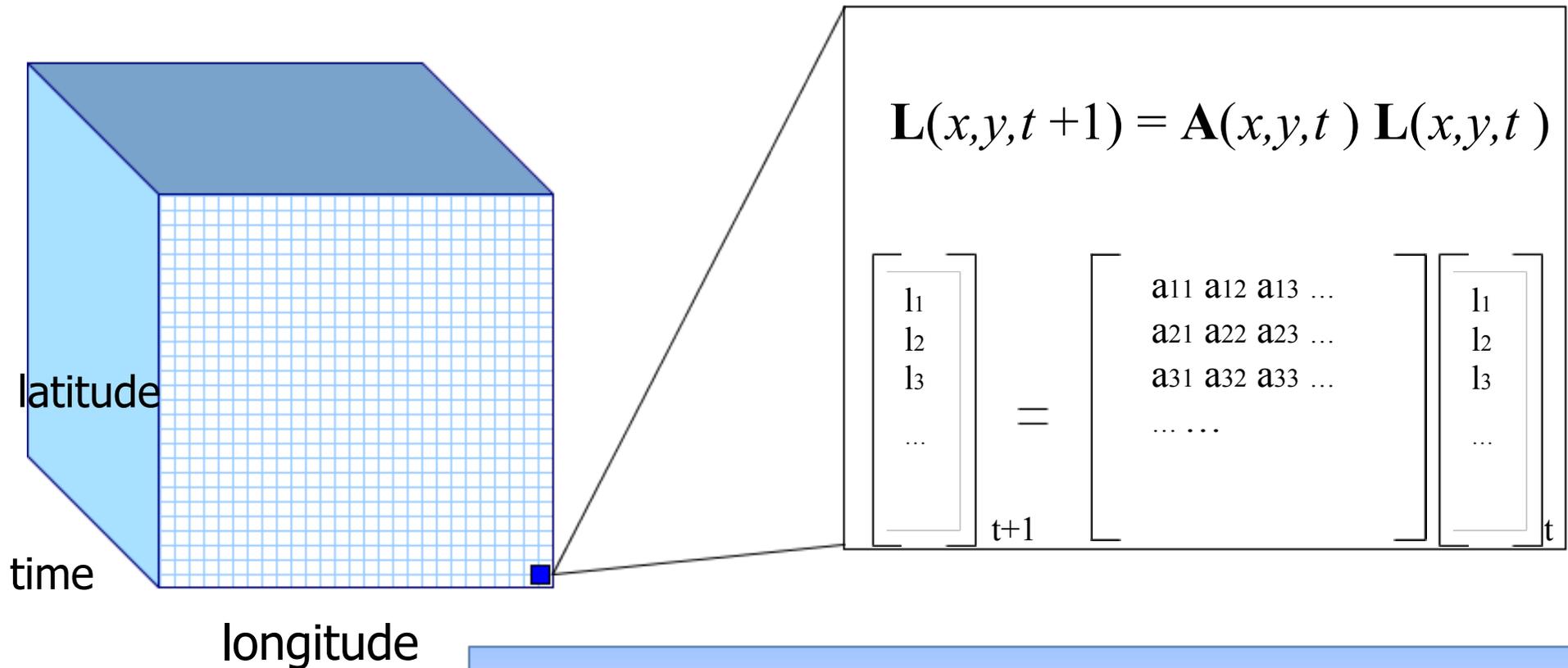- gridding & transitions methodology of Hurtt et al. 2006.

**Deliverables**: Gridded maps of annual land use & transitions

- **Beta** (1700-2100, 1° x 1° resolution)
- **Base** (1700-2100, 0.5° x 0.5° resolution)
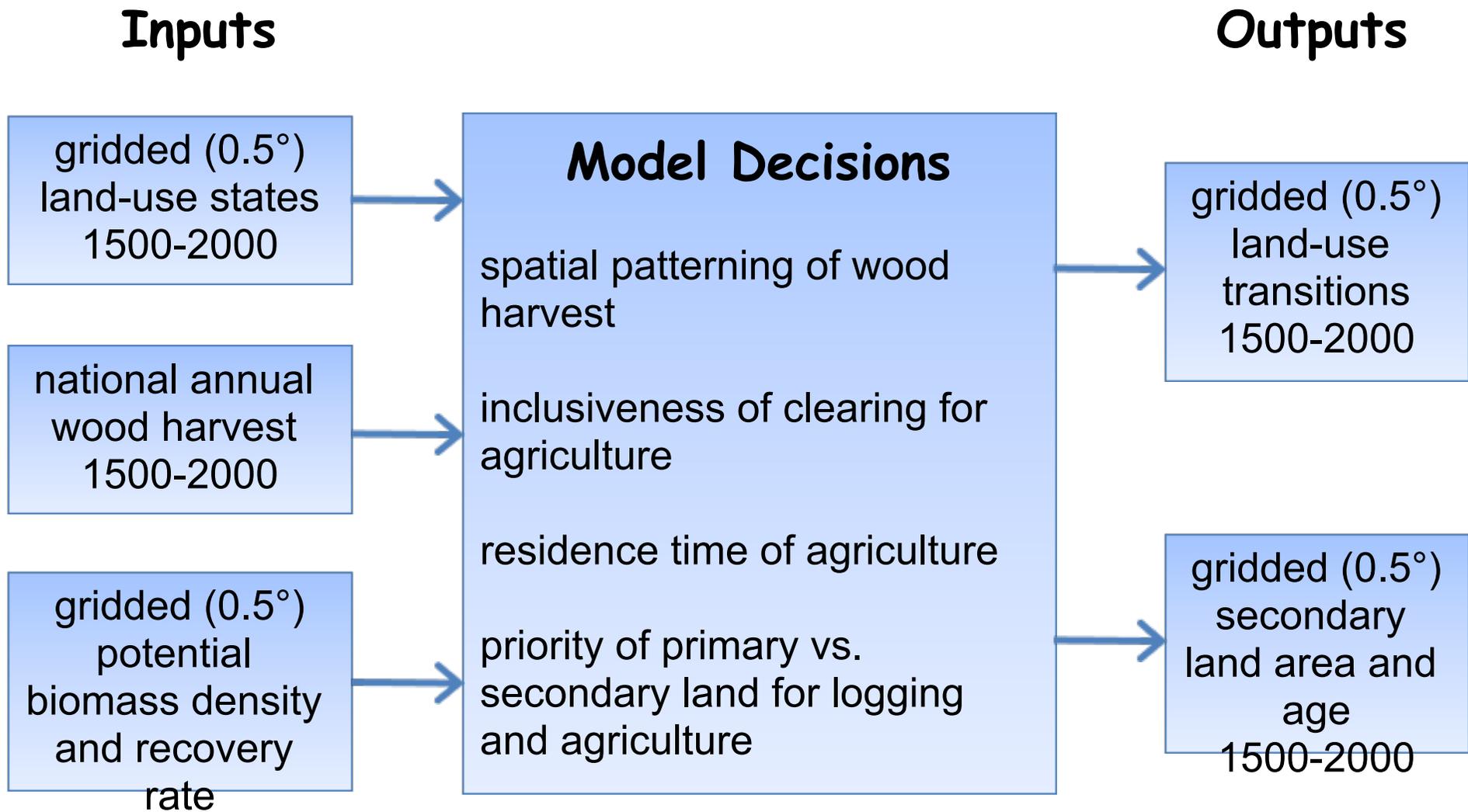- **Enhanced** (base, 1500-2300 , with plantation forests, and urban )

**Time Line**:
- ☑ March 2008 Refine and distribute proposal
- ☑ April 2008 Telecon involving all IAMs (and some ESMs)
- ☑ May 2008 IAMs deliver data (we have input from IMAGE)
- ☑ July 2008 ESMs have beta inputs (we have posted provisional values)
- ☑ August 2008 Snowmass Meeting
- ☐ Sept. 2008 ESMs have base inputs
- ☐ Fall 2008 ESMs have enhanced input

# The Mathematical Structure of a Historical Reconstruction of Land-Use Transitions



$$\mathbf{L}(x,y,t+1) = \mathbf{A}(x,y,t)\,\mathbf{L}(x,y,t)$$

$$\begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ \dots \end{bmatrix}_{t+1} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots \\ a_{21} & a_{22} & a_{23} & \dots \\ a_{31} & a_{32} & a_{33} & \dots \\ \dots & \dots & & \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ \dots \end{bmatrix}_{t}$$

latitude

time

longitude

Global, 0.5°, annual for 400 years, 3 categories: >100 million unknowns

# GLM land-use transitions methodology (Hurtt et al. 2006)

**Inputs**

**Outputs**

gridded (0.5°) land-use states 1500-2000

national annual wood harvest 1500-2000

gridded (0.5°) potential biomass density and recovery rate

**Model Decisions**

spatial patterning of wood harvest

inclusiveness of clearing for agriculture

residence time of agriculture

priority of primary vs. secondary land for logging and agriculture

gridded (0.5°) land-use transitions 1500-2000

gridded (0.5°) secondary land area and age 1500-2000

Early results incorporated into GFDL ESM (Shevliakova et al., in review)

HYDE 3: Cropland & rangeland in 2000 (Klein Goldewijk et al. 2007)

cropland
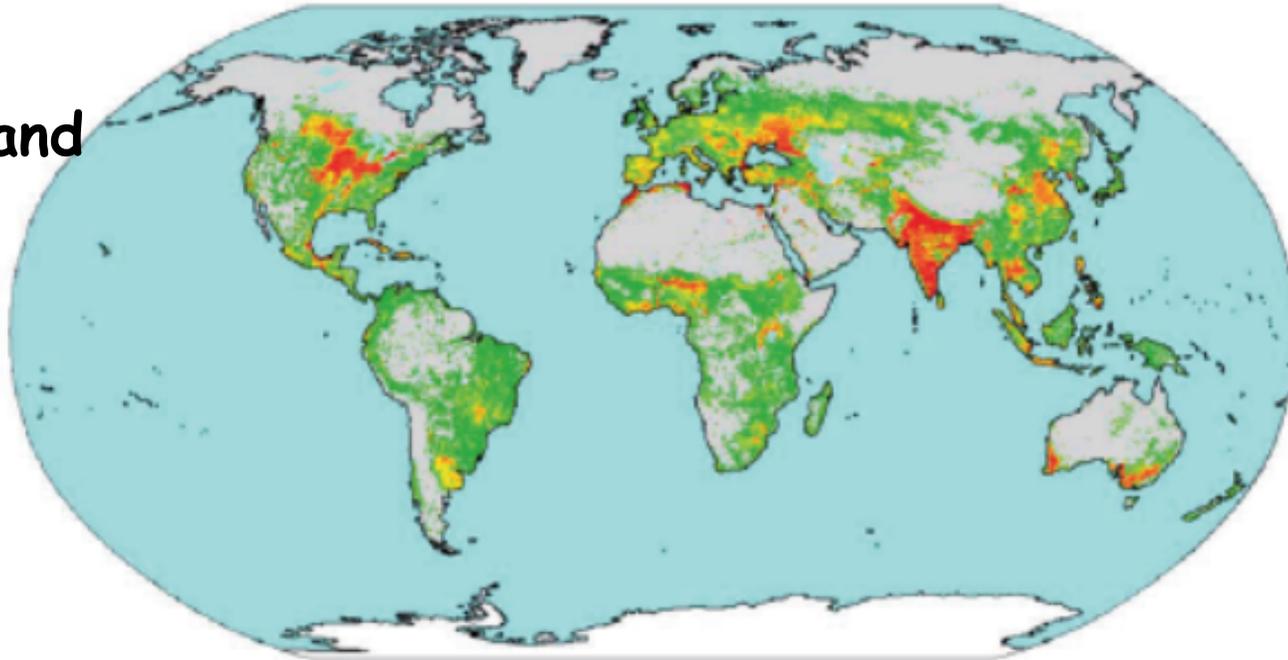
rangeland

Area (km$_2$)
per 5 min. grid

- 0
- < 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- > 60
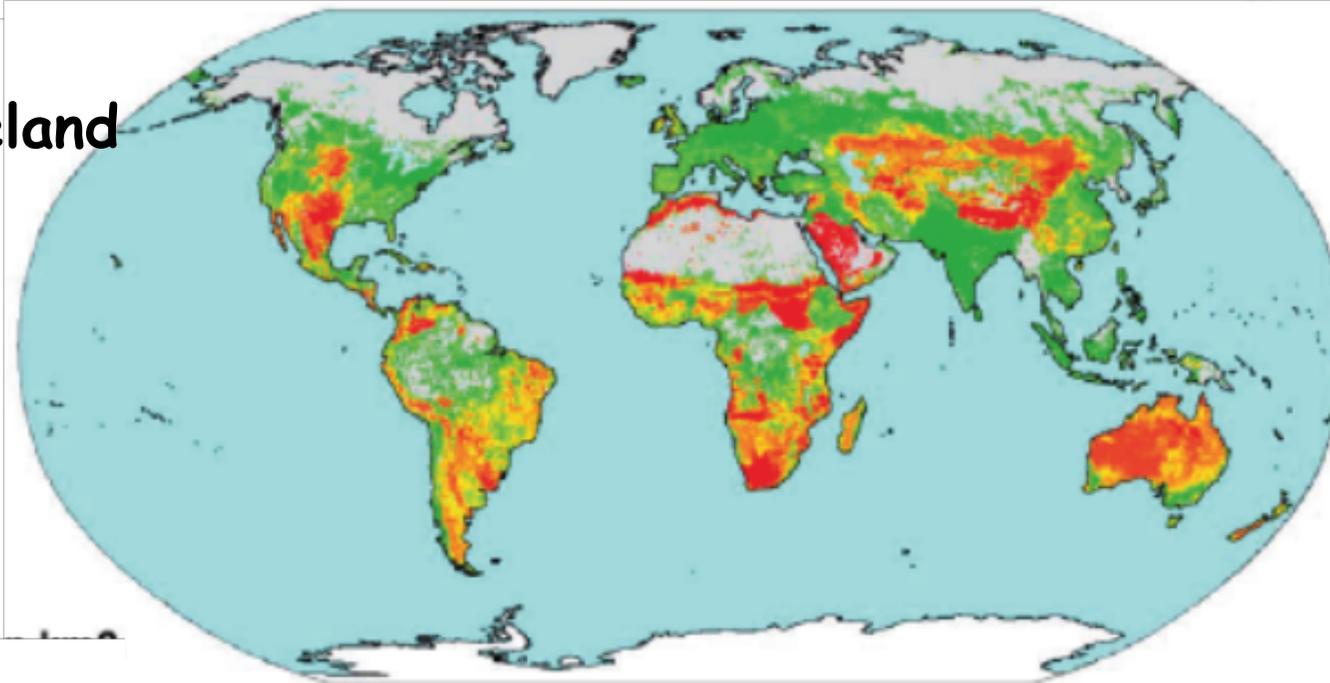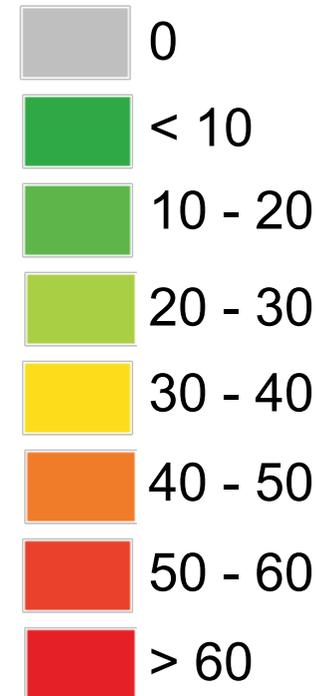
Other area = total area – cropland area – rangeland area – urban area

Global wood harvest by country, 1500-2000 (Pg C y-1)
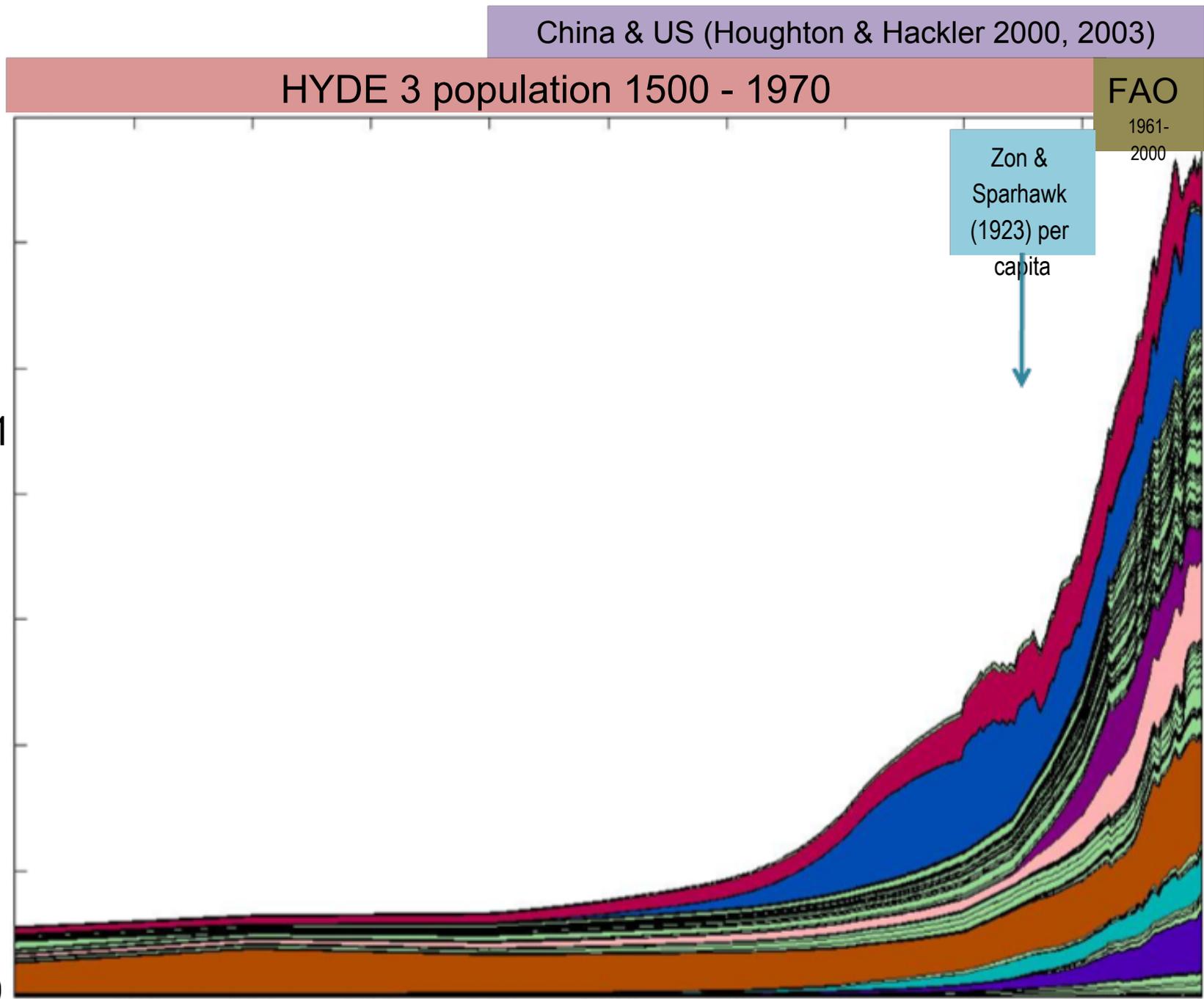
# Potential biomass density (kg C m$^{-2}$)
## potential forest if value > 2 kg C m$^{-2}$



kg C m$^{-2}$
- 0–2
- 2–4
- 4–6
- 6–8
- 8–10
- 10–12
- 12–14
- 14–16
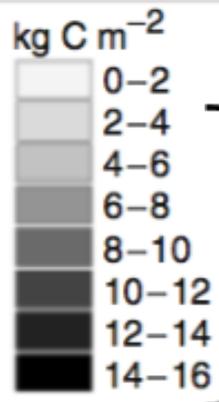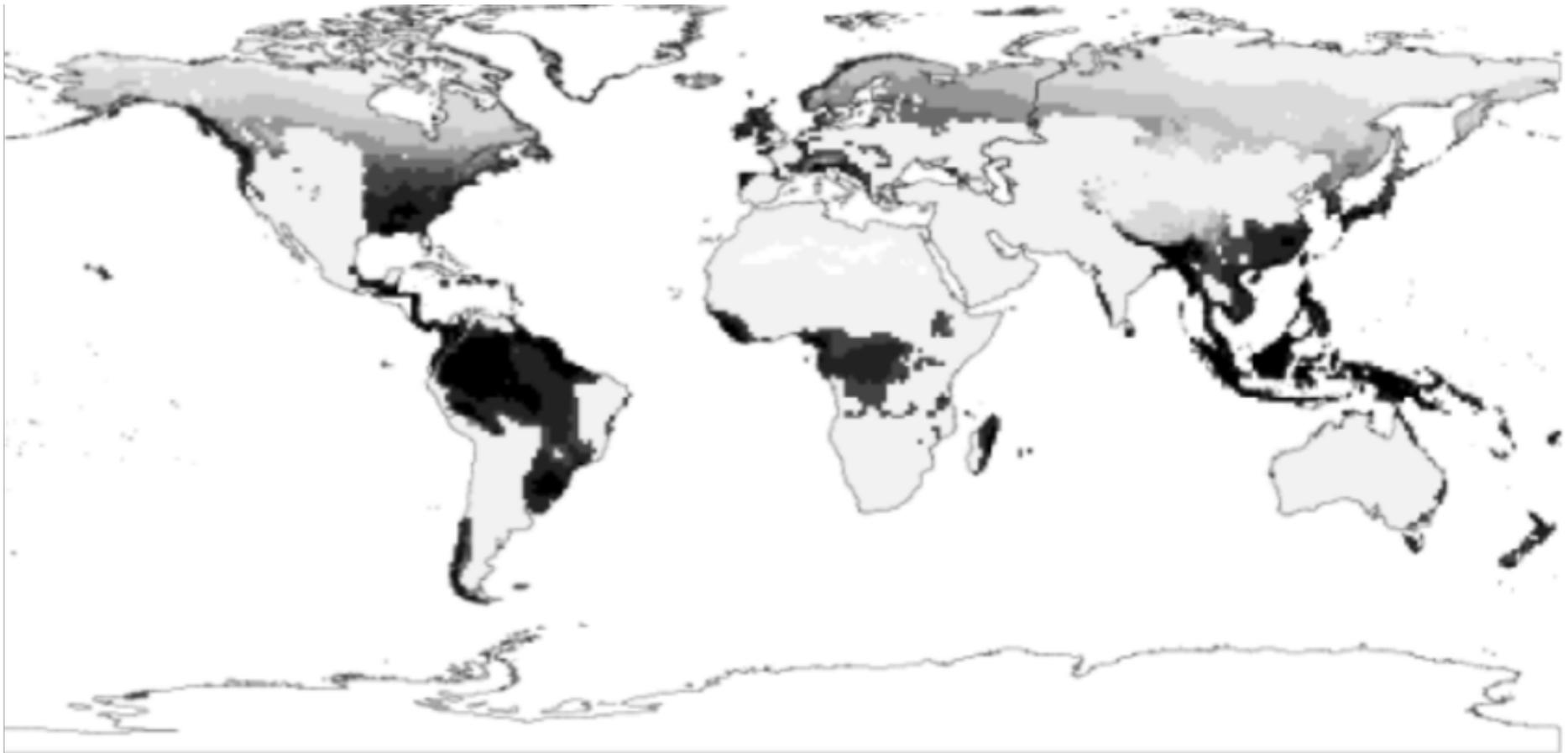
Forest (primary or secondary) area and biomass constrain location and extent of wood harvest.
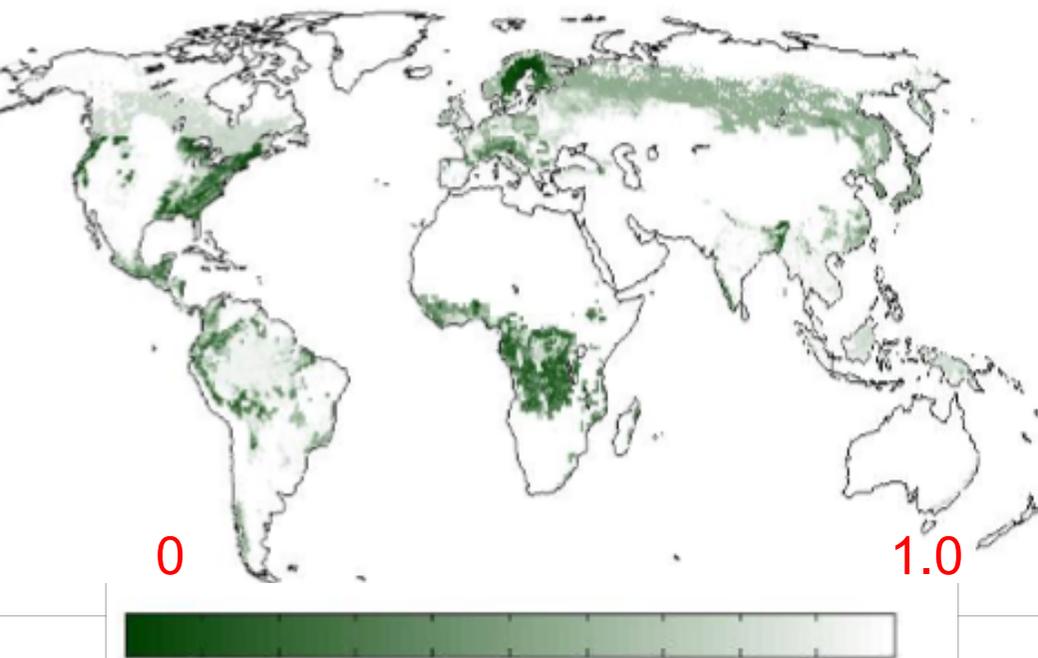
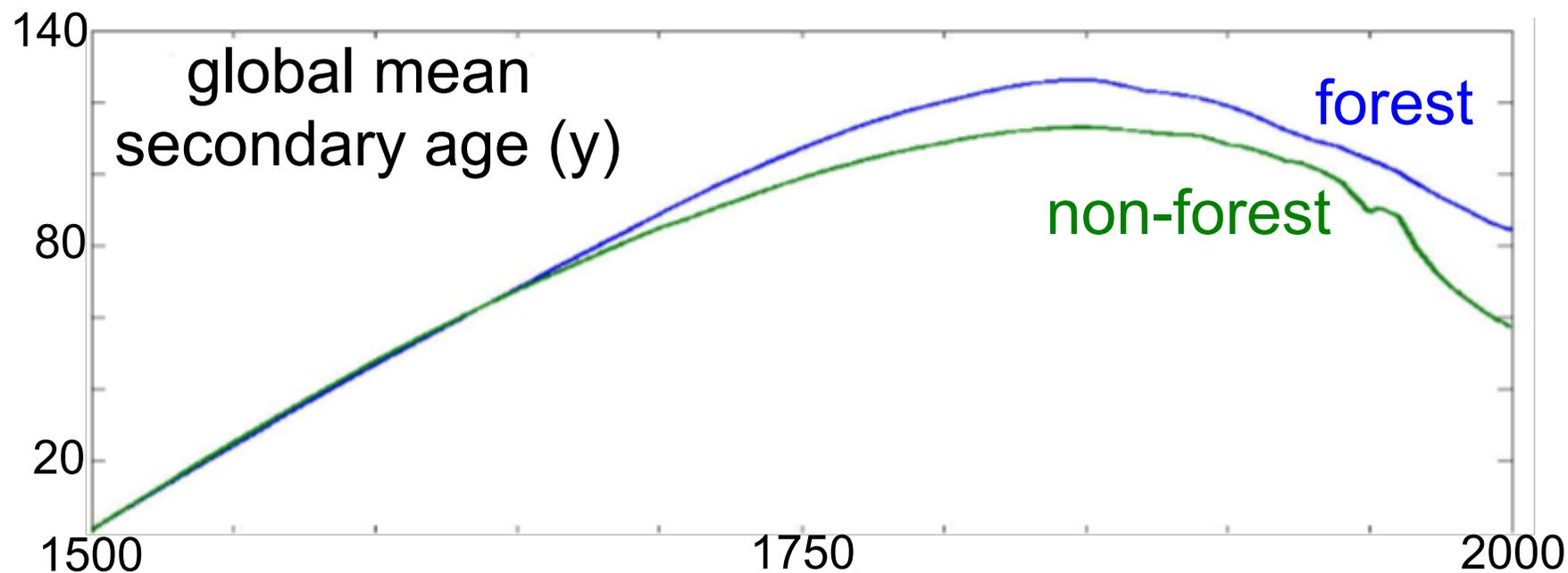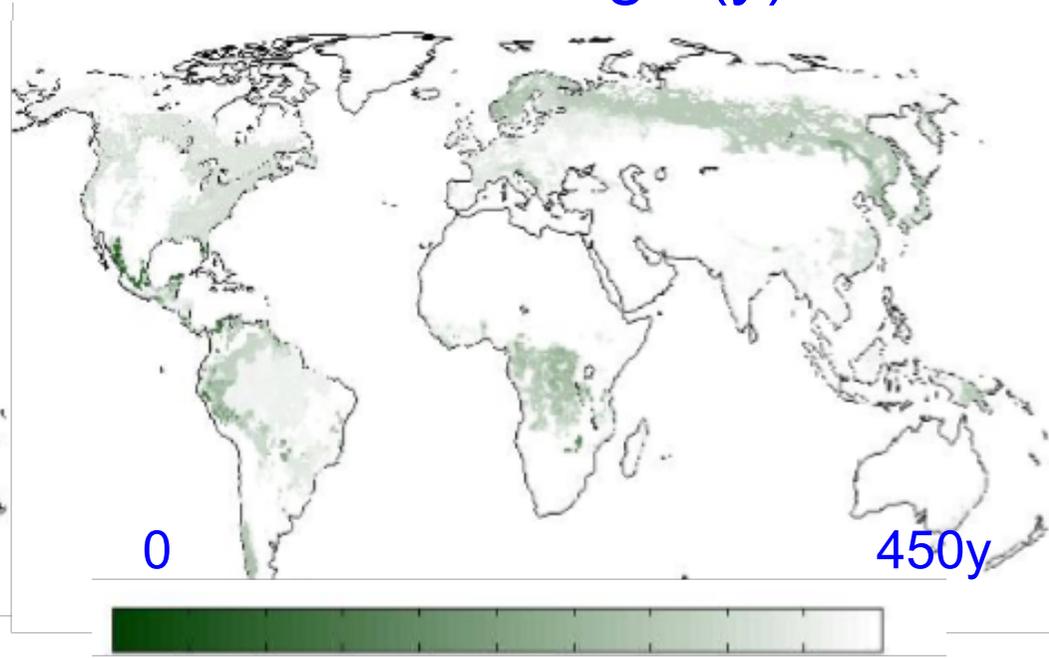Global area of crop, pasture, primary, and secondary land (10⁶ km²)
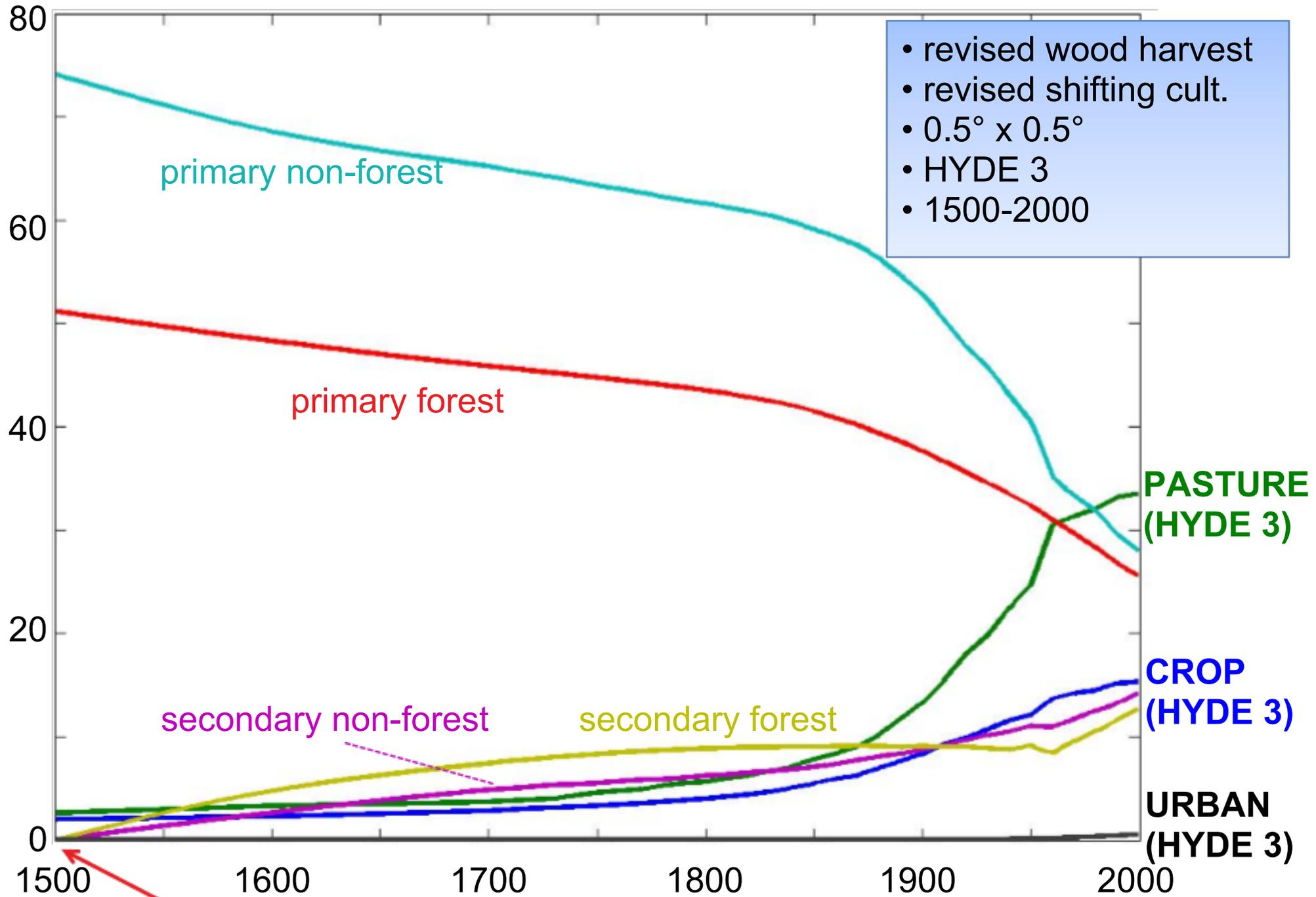
# Secondary forest distribution and age in 2000

fractional area

mean age (y)



0                  1.0                    0                   450y

global mean
secondary age (y)

forest

non-forest

# Harmonization Challenges:

1. Gridding

# Harmonization gridding strategies:

a) gridded HYDE 3/GLM history & <span style="color:red">regional</span>  IAM future:

• apply regional <u>fractional</u>  transitions to historical gridding:
 ↪ smooth transition in 2000; IAM regional variability
 ↪ diverge from IAM regional values & absolute changes


• apply regional transitions to historical gridding:
 ↪ preserve IAM regional absolute changes
 ↪ smooth transition in 2000


• apply regional states/transitions to historical gridding:
 ↪ preserve IAM regional values & absolute changes
 ↪ no smooth transition in 2000
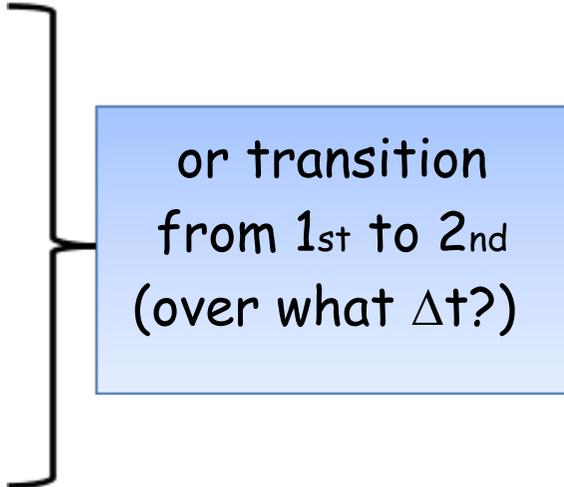
or transition from 1st to 2nd (over what $\Delta t$?)

# <u>Harmonization gridding strategies</u>:

b) gridded HYDE 3/GLM history & <span style="color:red">gridded</span> IAM future:
• regionalize IAM gridded values • back to previous slide…
  ↷ lose IAM spatial information
• preserve IAM gridded values
  ↷ preserve all IAM spatial information
  ↷ no smooth transition in 2000

• apply IAM gridded transitions to historical grids
  ↷ preserve IAM spatial change information
  ↷ smooth transition in 2000
  ↷ lose IAM absolute information

• aggregate IAM gridded values to sub-regional scale (e.g., 2°x2°) &
• back to above…
  ↷ preserve IAM sub-regional spatial information
  ↷ smooth transition between fractional & single class grid information
  ↷ smooth out small discrepancies in spatial distributions
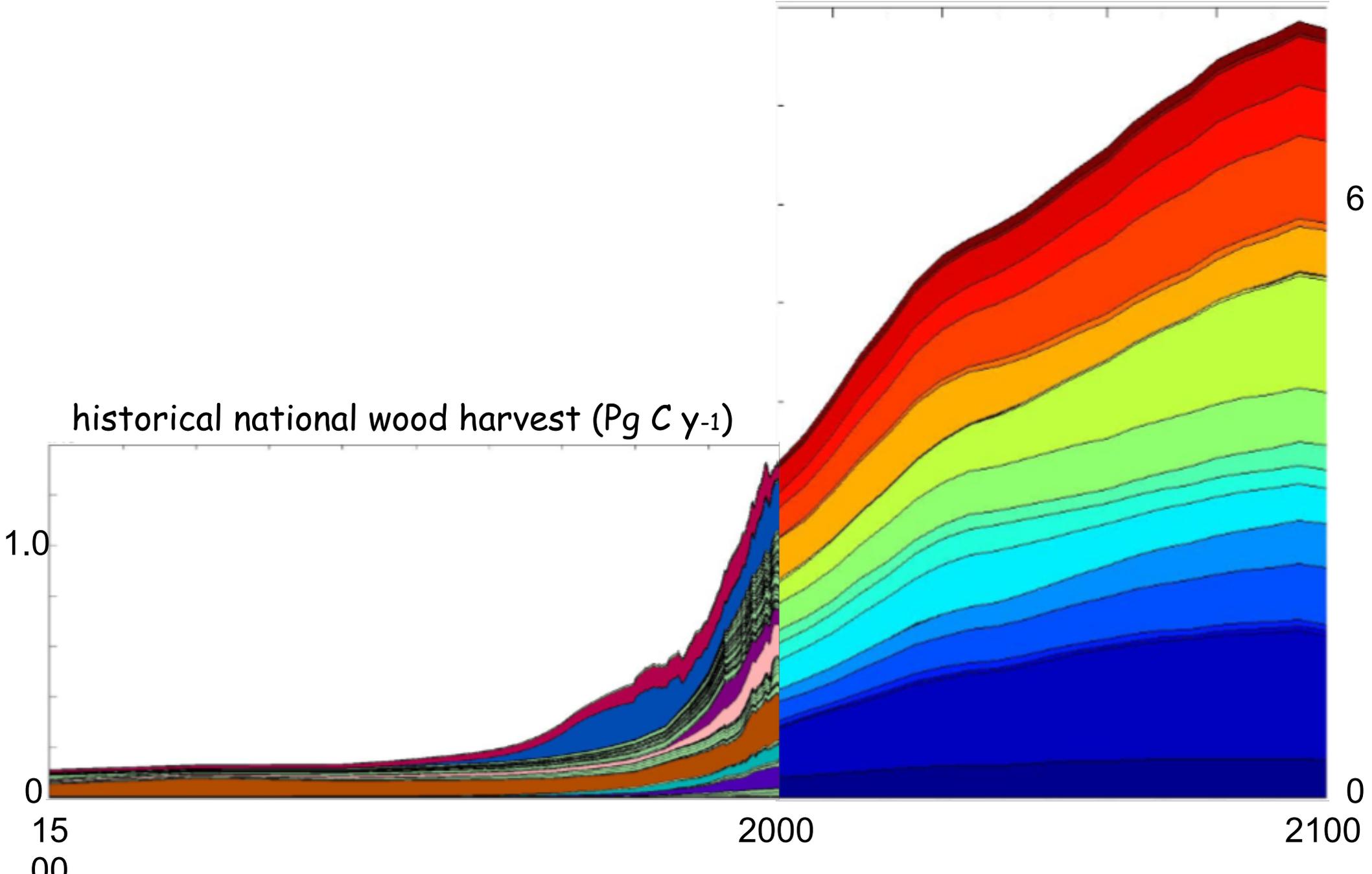
# Harmonization Challenges:
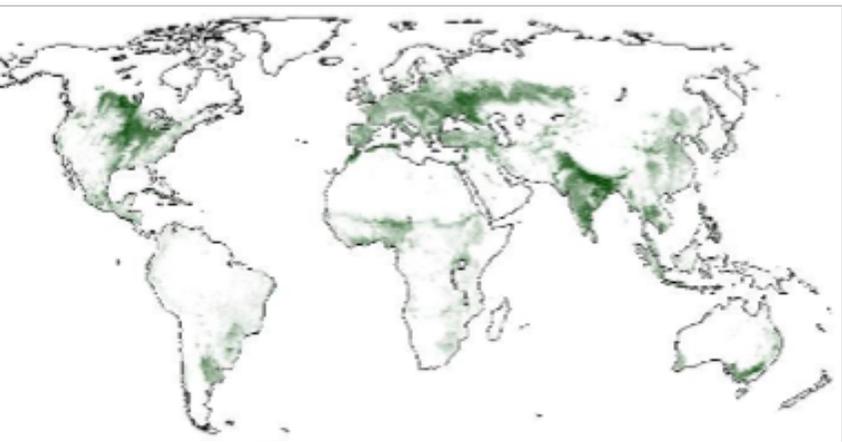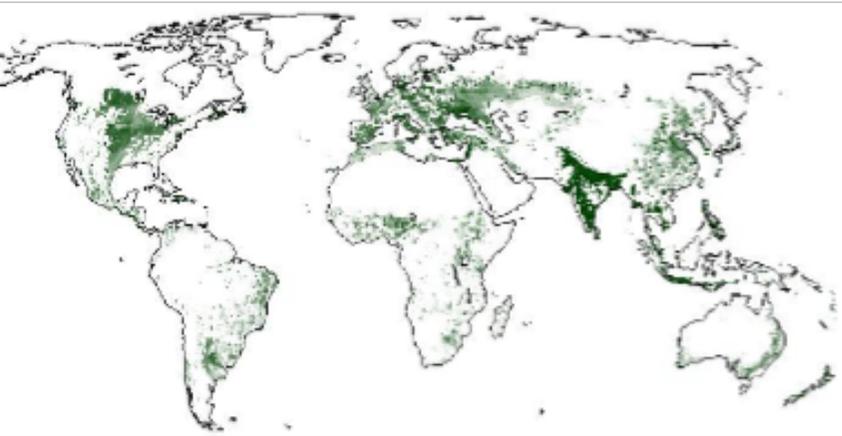
## 1. Gridding

## 2. Inconsistencies in link year (2000)

❖ wood harvest: <u>historical</u> national (Mg C $y_{-1}$) ≠ <u>future</u>: regional ($m_3$ $y_{-1}$)

# Matching wood harvest in 2000

IMAGE regional wood harvest ($10^6$ m$_3$ y$_{-1}$)

historical national wood harvest (Pg C y$_{-1}$)

6

1.0

0

0

15
00

2000

2100

# Harmonization Challenges:

## 1. Gridding

## 2. Inconsistencies in link year (2000)

❖ wood harvest: <u>historical</u> national ($Mg\ C\ y_{-1}$) ≠ <u>future</u>: regional ($m_3\ y_{-1}$)

❖ mismatch in distribution of cropland and/or pasture

# Matching cropland distribution in 2000

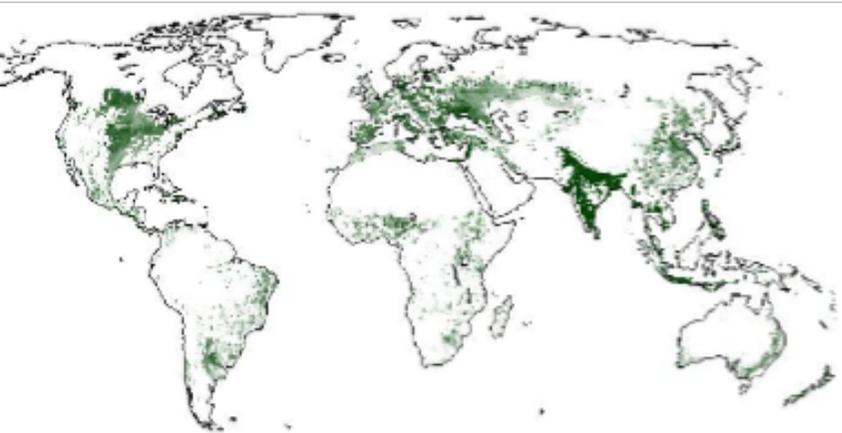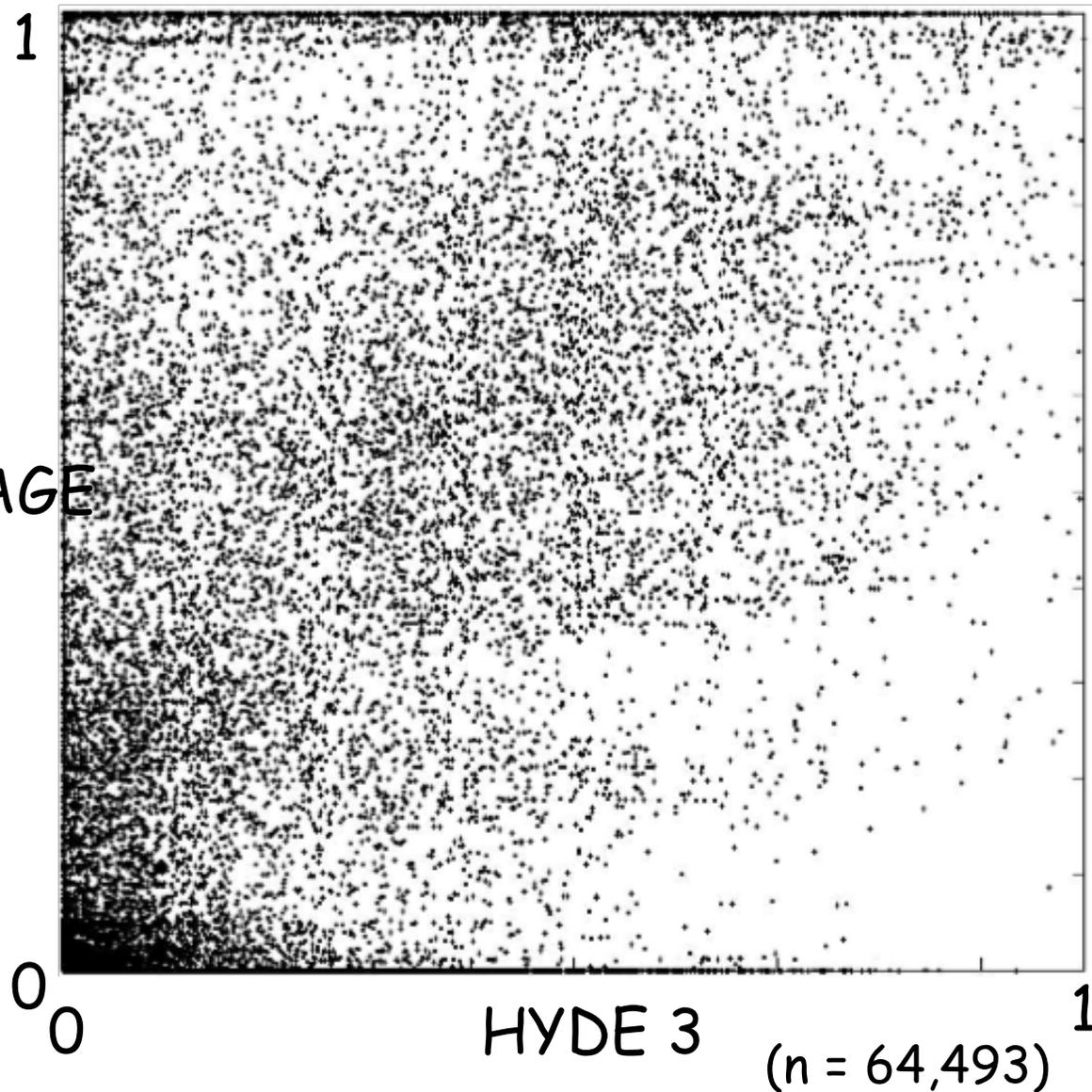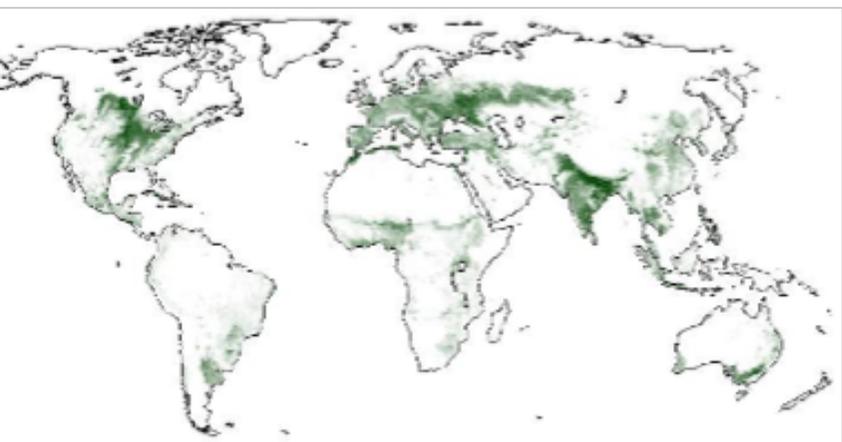IMAGE

HYDE 3

# Matching cropland distribution in 2000

IMAGE



HYDE 3

Cropland fraction by 0.5° gridcell in 2000



IMAGE

1

0

0                    HYDE 3                    1
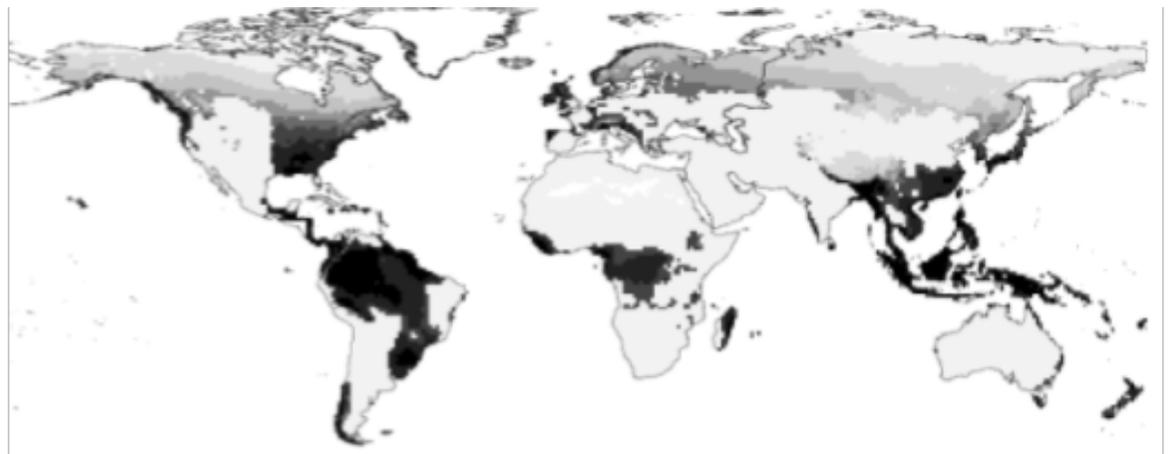
(n = 64,493)

# Harmonization Challenges:

## 1. Gridding

## 2. Inconsistencies in link year (2000)
❖ wood harvest: <u>historical</u> national (Mg C $y_{-1}$) ≠ <u>future</u>: regional ($m_3$ $y_{-1}$)
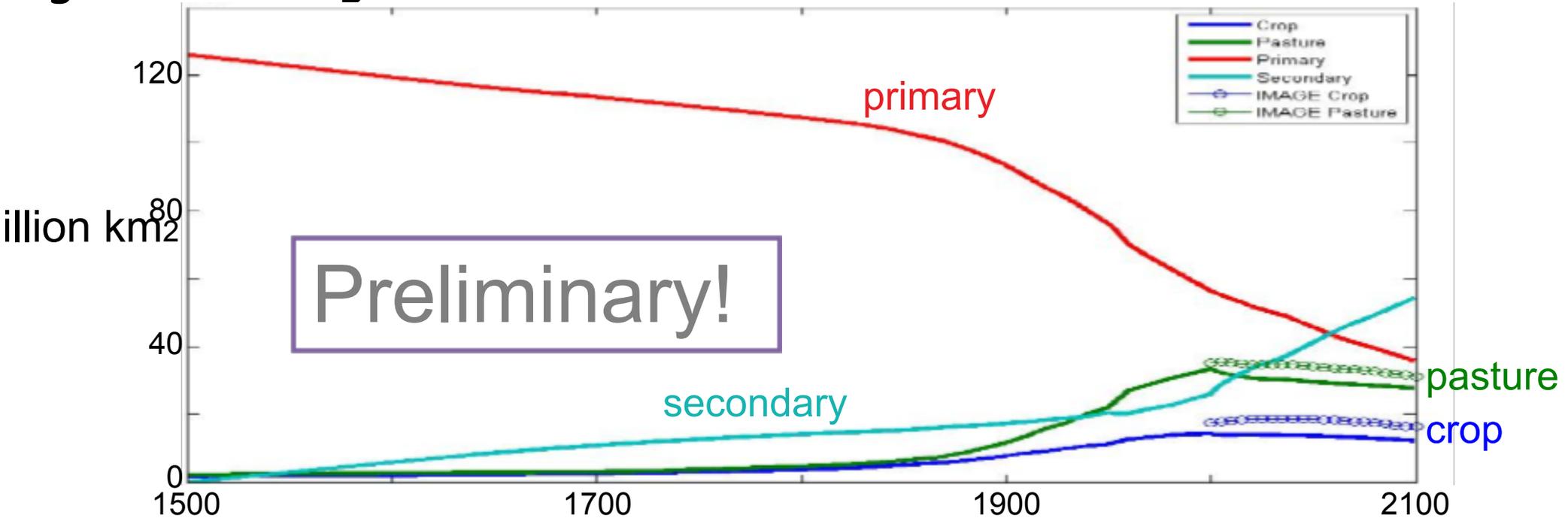❖ mismatch in distribution of cropland and/or pasture

## 3. Model differences
❖ vegetation productivity (NPP) response to elevated $CO_2$ and climate
❖ wood harvest rates and available & harvestable woody biomass
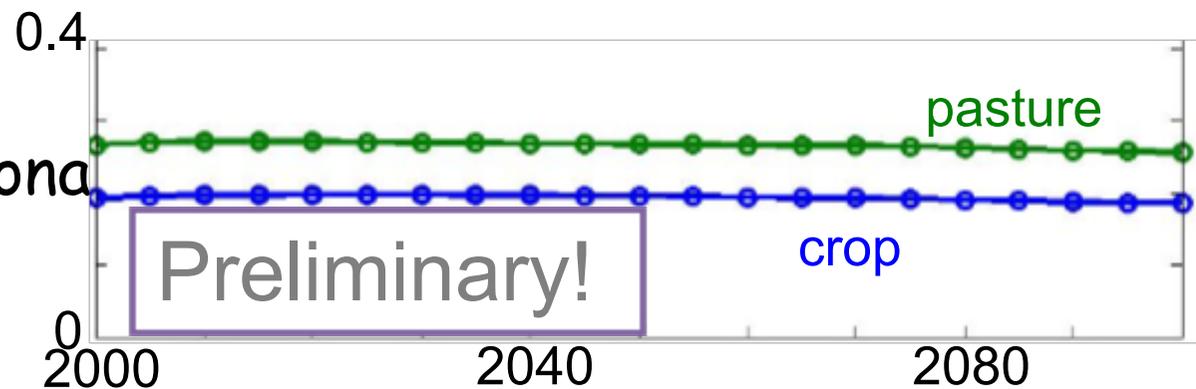
# Harmonization output can be different from IAM results

Requires metrics for comparison:

- **global** and regional total land use areas:



- **gridded** $(0.5°, 2°, ...)$ or regional

$$D_{RMS} = \sqrt{\frac{\sum_n \overline{(A_H, ..., A_{IAM})^2}}{n}}$$

# Harmonization - Inputs from IAMs
## Preferred Data Format (annual, 0.5°ESRI grid, ASCII)

- Crop, Pasture/Rangeland, and Urban areas ($km^2$)
- Total wood harvest demand ($m^3 y^{-1}$ or $Mg\ C\ y^{-1}$)
- Total population, and rural and urban fractions
- Ice and water areas ($km^2$)
- Mean temperature (°C) and total precipitation (mm)
- Global mean atmospheric $CO_2$ levels (ppmv)
- GDP (1990 International Geary-Khamis Dollars)

-------------------------------------------------

- Assumptions about disturbance rates (e.g. fires, storms)
  - [$CO_2$] and climate effects on model NPP