Estimation of Carbon Emission from Deforestation

Satellite Analysis of the Effects of Land Use Change on the Carbon Cycle in Southern China

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This research is a element of:

“Modeling and Forecasting Effects of Land-Use Change in the People’s Republic of China Based on Socioeconomic Drivers”

R. Kaufmann, C. Woodcock, D. Dye, K. Seto,
Boston University
Li Xiaowen, *CAS Institute of Remote Sensing Applications, Beijing*
Wang Tongsan, *CASS Institute of Quantitative and Technical Economics, Beijing*
Liang Youcai, *Economic Forecasting Dept., State Information Center, Beijing*

Funding: NASA LUCC Program

Project Components

- Map & quantify recent changes in land-cover/land-use in Pearl River Delta of China
- Identify & model driving forces
- ☑ Evaluate the effects of observed land change on regional terrestrial carbon cycle
  - Dye, Hinchliffe & Woodcock, 2005, *Asian J. Geoinformatics*, 5(3)5-11.

Study Area:
Pearl River (Zhujiang) Delta Region
Guandong Province, China

Landsat
Path 122
Row 44

2.7 x 10^6 ha

Background
Economic Development as a Driver of Land Conversion in Pearl River Delta

- Pearl River Delta (PRD) has experienced rapid rates of economic growth since late 1970’s
  - Guandong GDP grew at avg. annual rate of 15.3% during 1985-1997
- Economic development has spurred widespread land conversion
- Most land conversion is from agriculture to urban
  - Urban areas increased by >300% between 1988 and 1996

Pearl River Delta Region

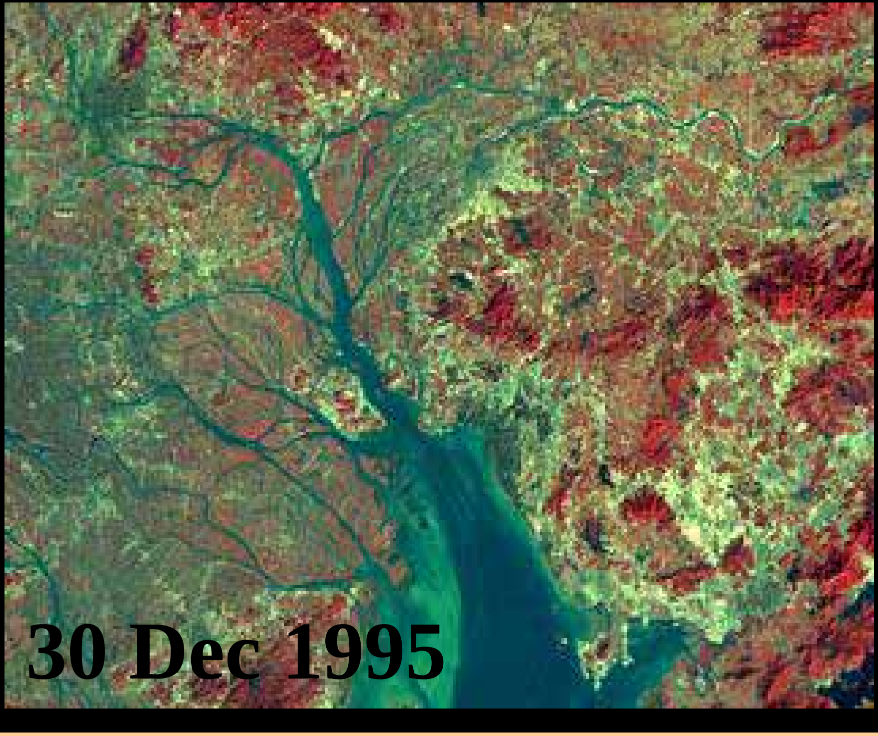
Landsat TM

false color infrared composites

1988, 1992, 1995

10 Dec 1988

20 Jan 1992

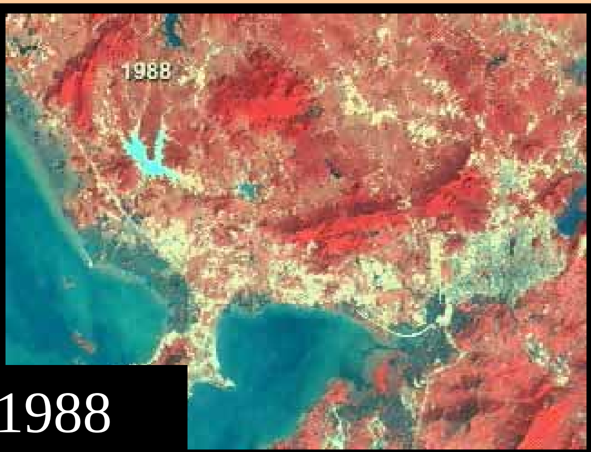


30 Dec 1995

Land Cover Change in Pearl River Delta Region observed by Landsat TM

False color IR composites

Shenzhen
1988-1996



1988

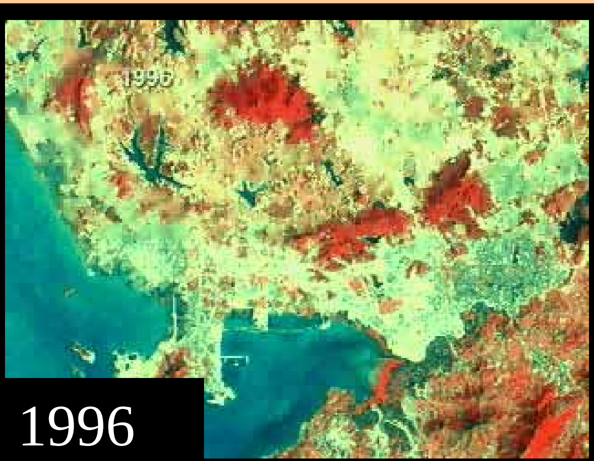
1989

1992

1993

1994

1995



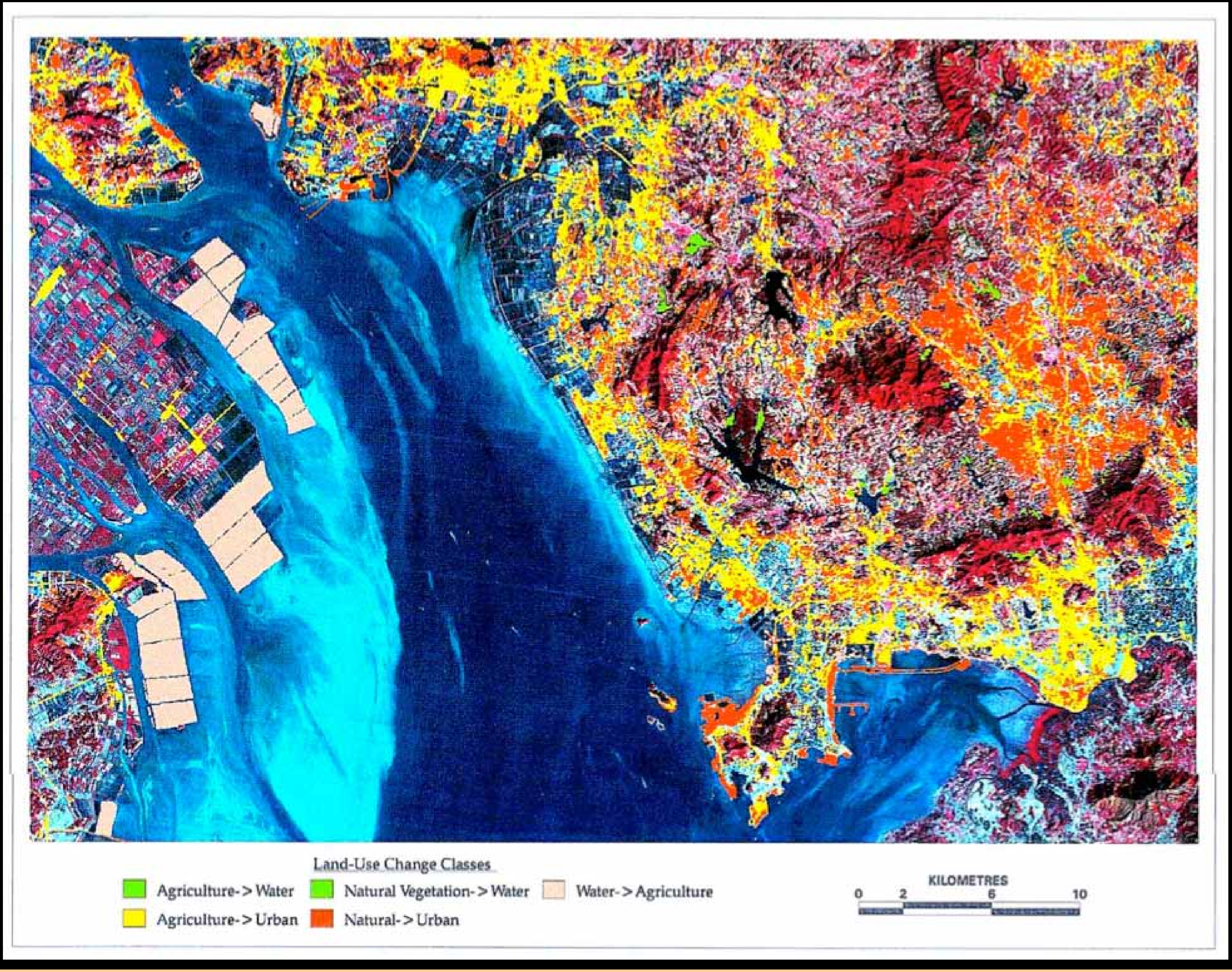
1996

Source: http://www.bu.edu/cees/NASA.html

Mapping & Quantifying Land Conversion in PRD Region

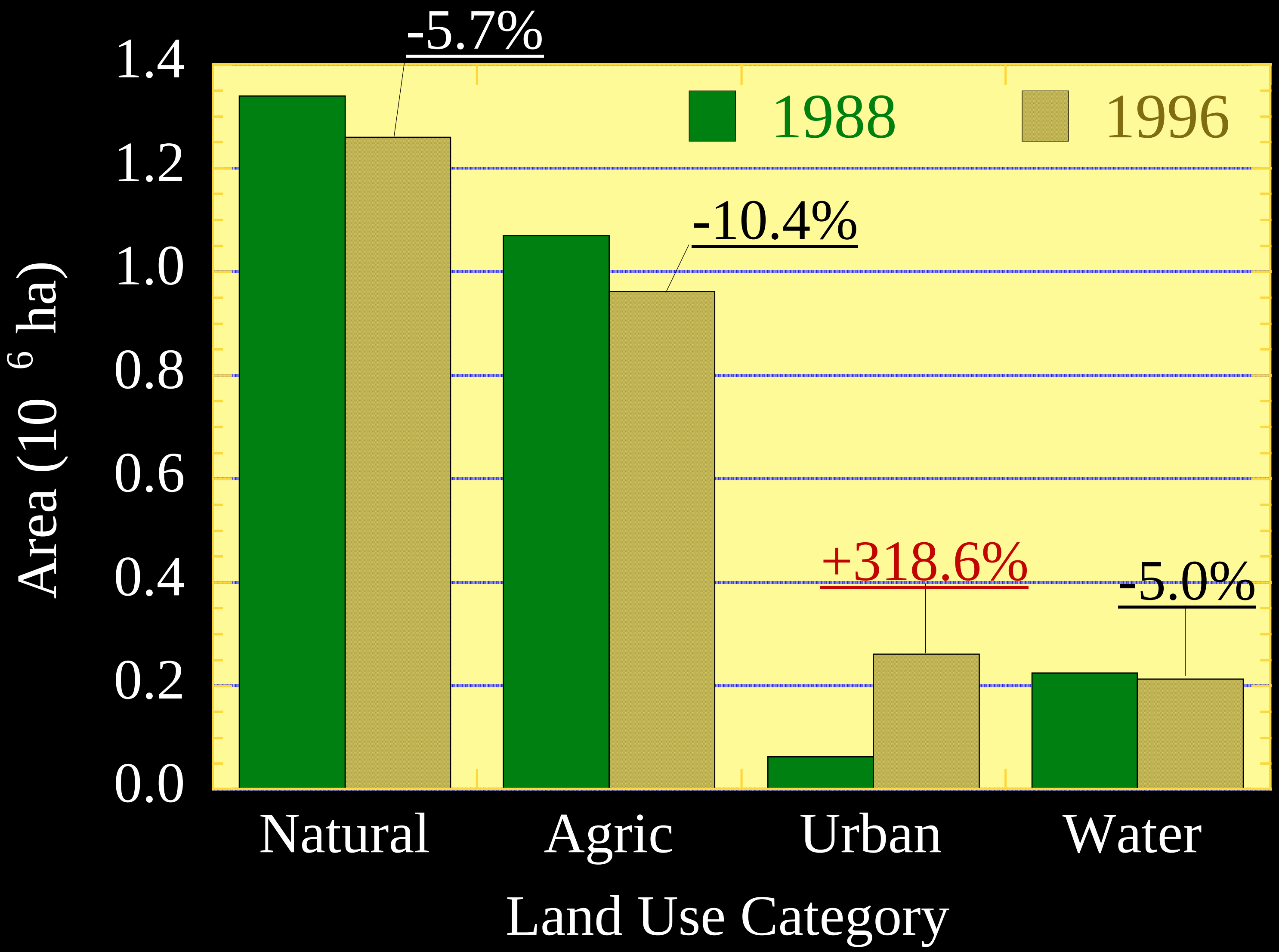
- Optical remote sensing is used (Landsat TM)
- **Four map classes** are identified by multidate Tasseled Cap multispectral transformation:
  - Water, urban, natural vegetation, agriculture
- Classes reflect focus on *land use* change
- Natural vegetation is primarily **forest and shrubland**
- Change Detection Methodology
  - Supervised classification of 23 land cover types

Land Use Change Map for Shenzen Region, 1988-1996



Seto,
et al.

Net Land-Use Change in Pearl River Delta Region, 1988-1996



(K. Seto, et al.)

Research Questions

- How has land-use change in the Pearl River Delta Region altered the regional carbon cycle?
  - Net primary production (g C yr^{-1})
  - Ecosystem carbon stocks (g C)

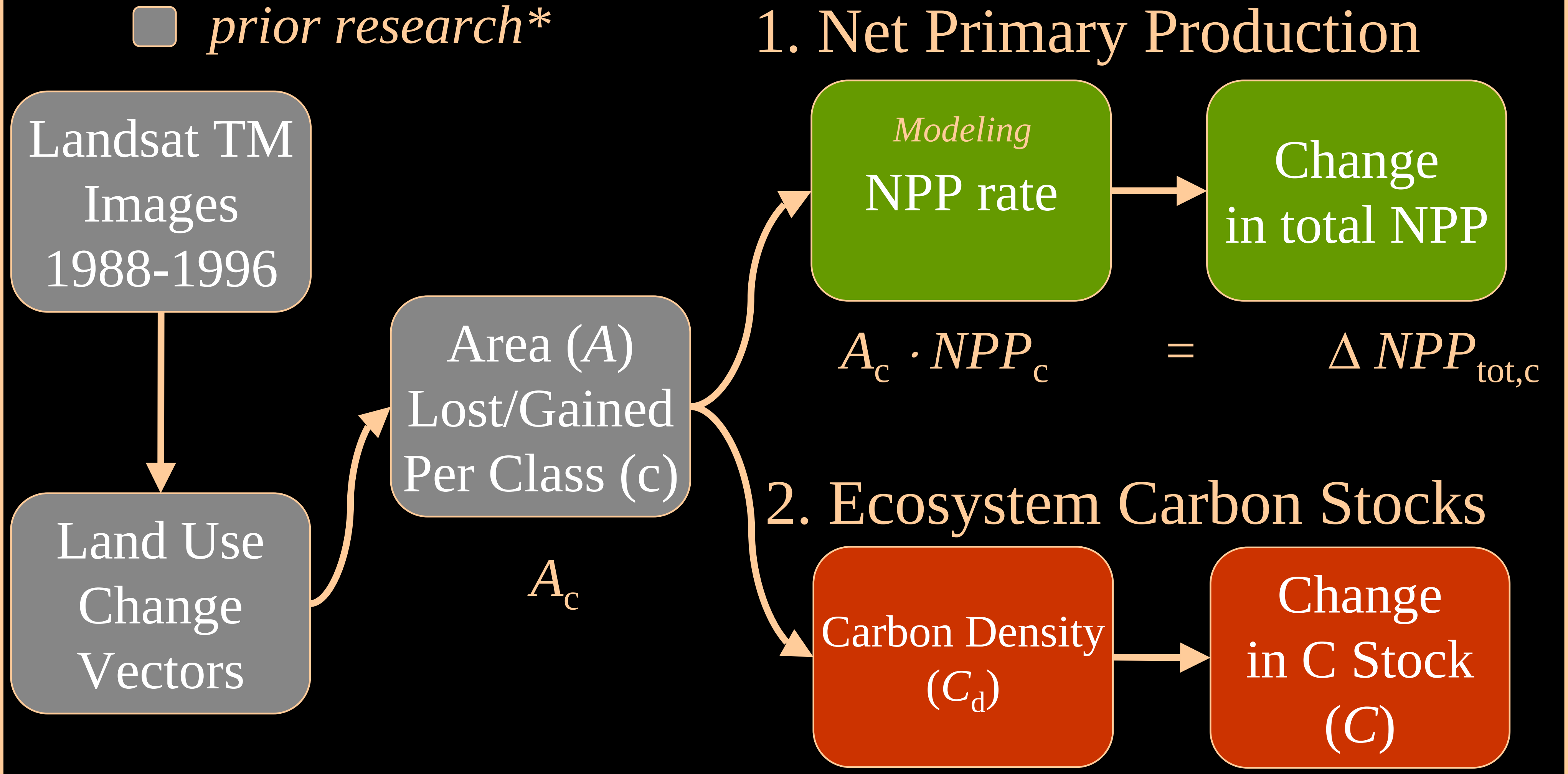
Approaches to Quantifying Change

- **Spatially Explicit Mapping**
  - Change in carbon storage
    - Retrieval by remote sensing for aboveground C (radar, lidar, optical)
    - Field studies for belowground C
  - Change in NPP
    - Modeling with satellite estimates of biophysical attributes & environmental conditions
      - LAI, fPAR, incident PAR, soil moisture status, phenological status, etc.
- **"Bookkeeping" Method** (Houghton, etc.)
  - Non-spatially explicit, category-based
  - Representative values are assigned to classes (storage, NPP)
  - Relies on reported data (forest inventories, field studies, etc.)

Methodology Summary for This Study

Bookkeeping Approach with NPP Modeling Based on Optical Remote Sensing

■ *prior research**



1. Net Primary Production

Landsat TM Images 1988-1996

Land Use Change Vectors

Area (A) Lost/Gained Per Class (c)

A_c

Modeling

NPP rate

Change in total NPP

$$A_c \cdot NPP_c = \Delta NPP_{tot,c}$$

2. Ecosystem Carbon Stocks

Carbon Density (C_d)

Change in C Stock (C)

$$A_c \cdot C_{d,c} = \Delta C_c$$

*Seto et al.

Methodology 1: NPP Modeling

Radiation Use Efficiency Model

$$NPP_m = f_m \cdot \varepsilon \cdot FPAR_m \cdot S_m$$

where

$m = \text{month}$

$S_m = \text{photosynthetically active radiation (PAR, MJ m}^{-2}\text{)}$

$FPAR = \text{PAR absorption efficiency (unitless)}$

$\varepsilon = \text{radiation use efficiency (g MJ}^{-1}\text{)}$

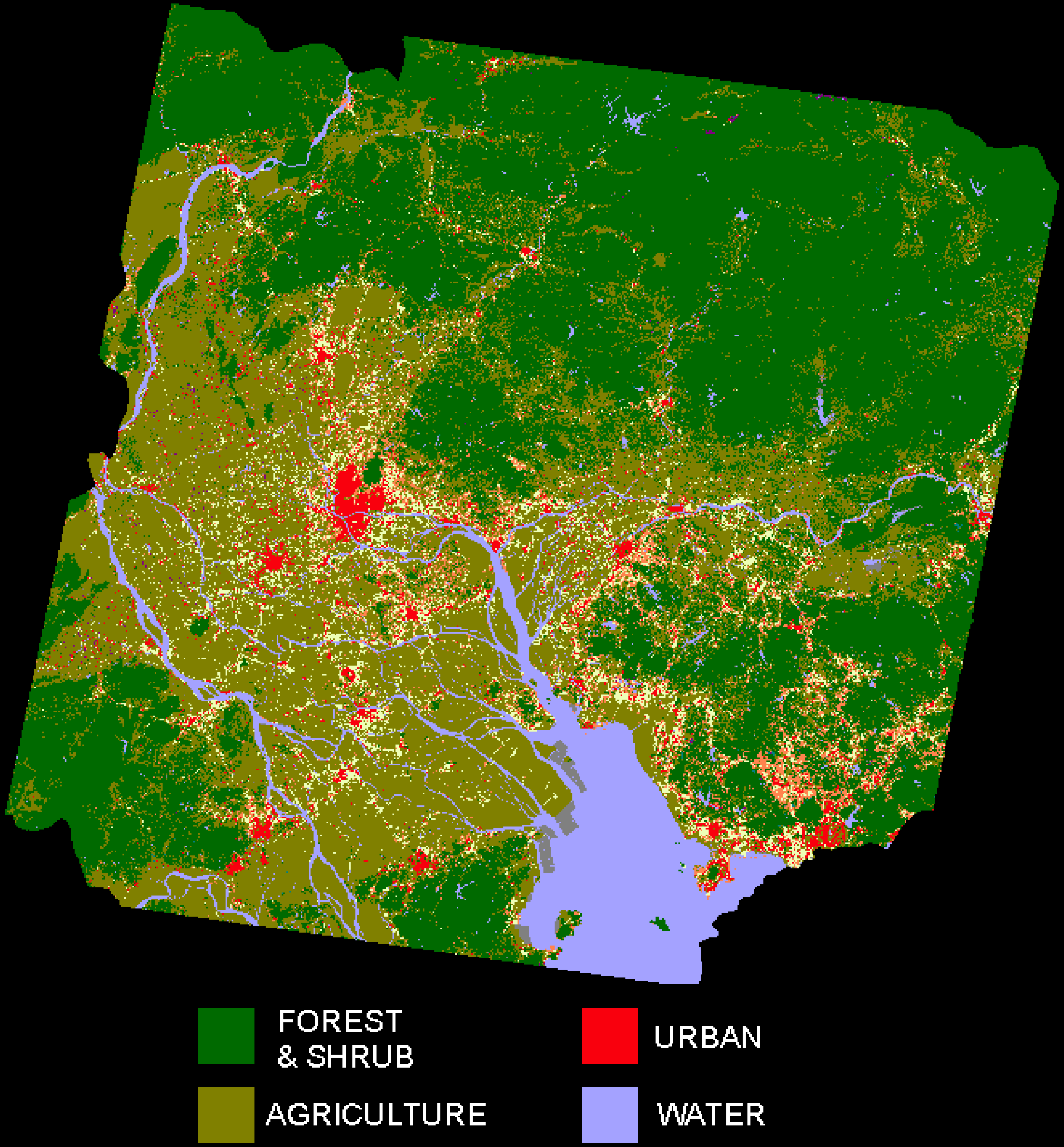
$f = \text{environmental constraints on } \varepsilon \text{ (unitless)}$

Methodology 1:
Data Sources for NPP Model

Variable	Source
FPAR	NDVI from AVHRR (Pathfinder) *Monthly composite, avg. 1988-1996,* *8 km resolution (Agbu & James, 1994; empirical relation from Ruimy et al., 1994)*
S	PAR from Nimbus-7 TOMS *Monthly Avg., 1979-1989, 100 km res.* *(Dye & Shibasaki, 1995)*
ε	Literature Sources *(Peng and Zhang, 1995; Ruimy, 1994)*

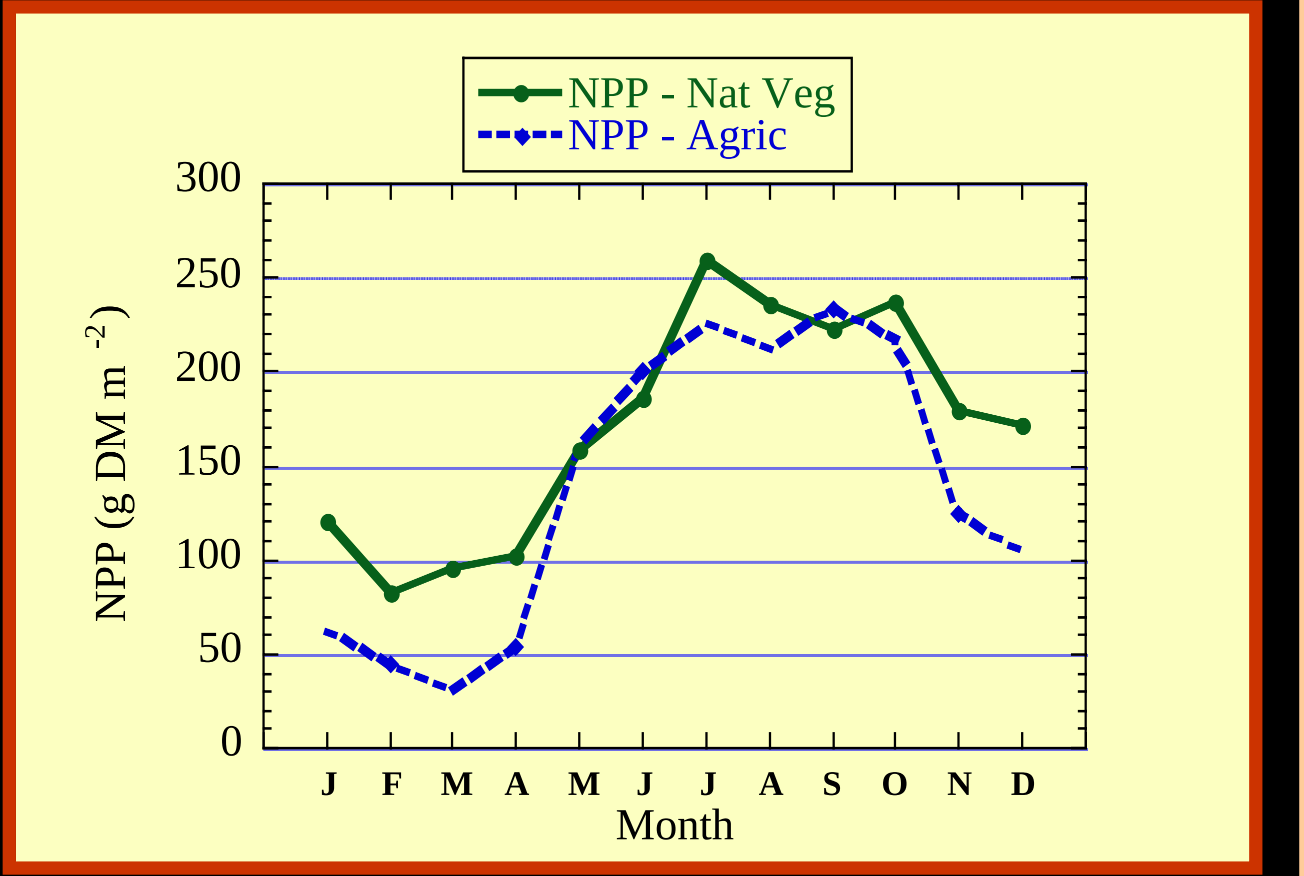
Methodology 1: Data for NPP Model

NDVI, PAR sampled for pixels corresponding to Stable Land Use Classes



Methodology 1: NPP Modeling

Monthly Times Series of Estimated NPP for Stable Land Use Classes



Avg. Annual NPP (t C ha^{-1} yr^{-1})

NAT: 9.3

AGR: 7.6

Methodology 2:
Carbon Stock Data Sources (Field Measurements)

Land Use Class	C Pool	Carbon Density (t C ha^{-1})			Source
		High	*Med*	*Low*	
NAT	Phyto-mass	178	107	36	Chen et al. (1992, 1993a,b, 1994); Peng and Zhang (1995)
	Soils	122	87	53	Cai (1996)
AGR	Phyto-mass	27	14	0.03	Atjay et al. (1977)
	Soils	65	52	39	Cai (1996)

Methodology 2: Estimating Soil Loss of Organic Carbon After Disturbance

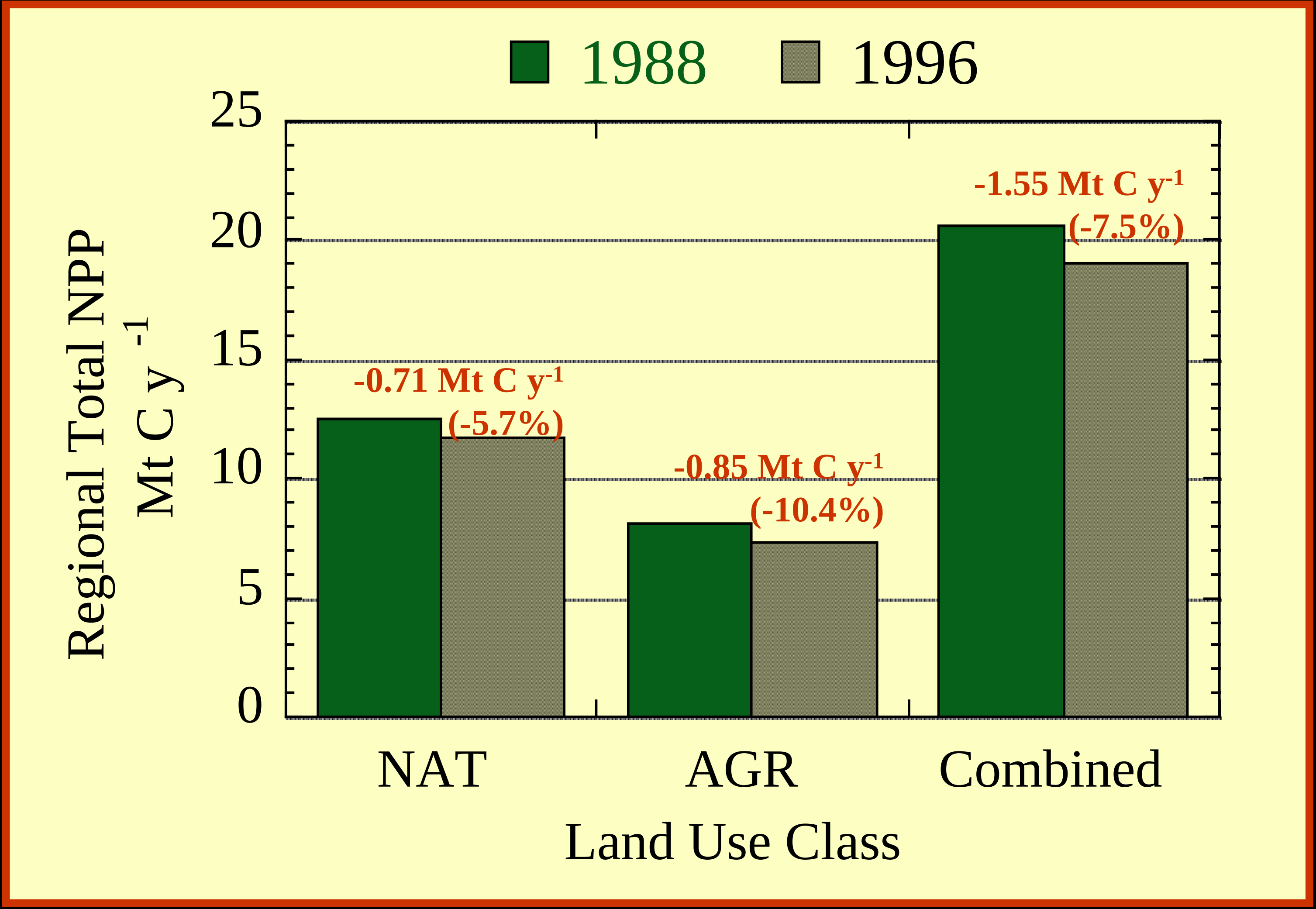
- Response of soil OC to land conversion is a gradual process (Schlesinger, 1997)
  - Greatest proportion lost in first 1-3 years
  - Full response can occur over 20+ years
  - Varies with initial conditions and ultimate land cover/land use
- Accurate accounting of soil OC emission after land conversion is major challenge
- Poor data availability, especially for conversions to urban land uses

Methodology 2:
Estimating Soil Loss of Organic Carbon After Disturbance: Two Key Assumptions

1. Direct NAT-to-URB conversion results in smaller average total loss of soil OC than for NAT-to-AGR conversion
   - 30% assumed for total loss of soil OC from NAT soils after conversion to URB (Cai, 1996; Bowman et al., 1990; Schlesinger et al., 2000)
   - Includes losses from initial disturbance and subsequent losses at slower rate
2. AGR-to-URB conversion induces a loss of soil OC that is *much smaller* than original NAT-to-AGR conversion
   - No quantitative data found in literature at time of this study
   - Assume small but nontrivial loss is initially incurred with urban construction
   - Subsequent loss is impeded by impervious surfaces
   - Additional loss of soil OC from AGR-to-URB conversion assumed at 5%

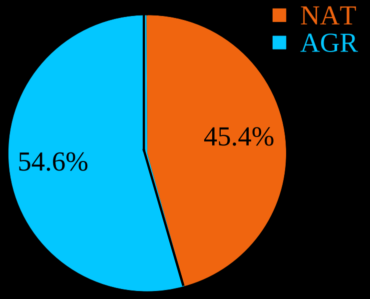
Results

Results 1: Effects of Land Use Change on Regional NPP



Regional NPP reduced by 1.55 Mt C y^{-1}

45.4% from AGR
54.6% from NAT



Change in Regional Total NPP

Conversion from dry matter to C assumes 0.45 g C per g DM

Results 2:
Change in C Stocks from Land Use Change

Median Estimate of
Gross C Emission

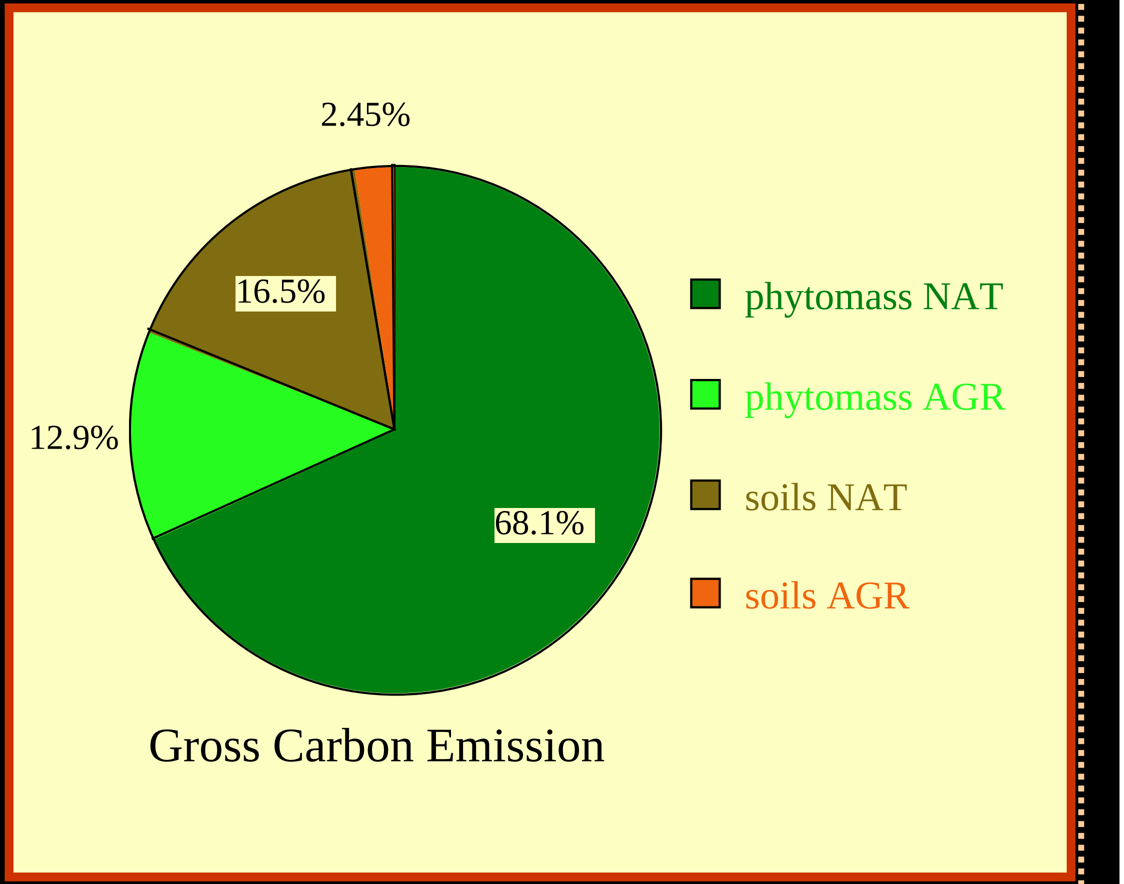
Total 11.9 Mt C
(6.1% of C stock)

Emission by Carbon Pool

Phytomass 9.6 Mt C (81%)
Soils 2.3 Mt C (19%)

Emission by Land Use Class

NAT 10.1 Mt C (85%)
AGR 1.8 Mt C (15%)

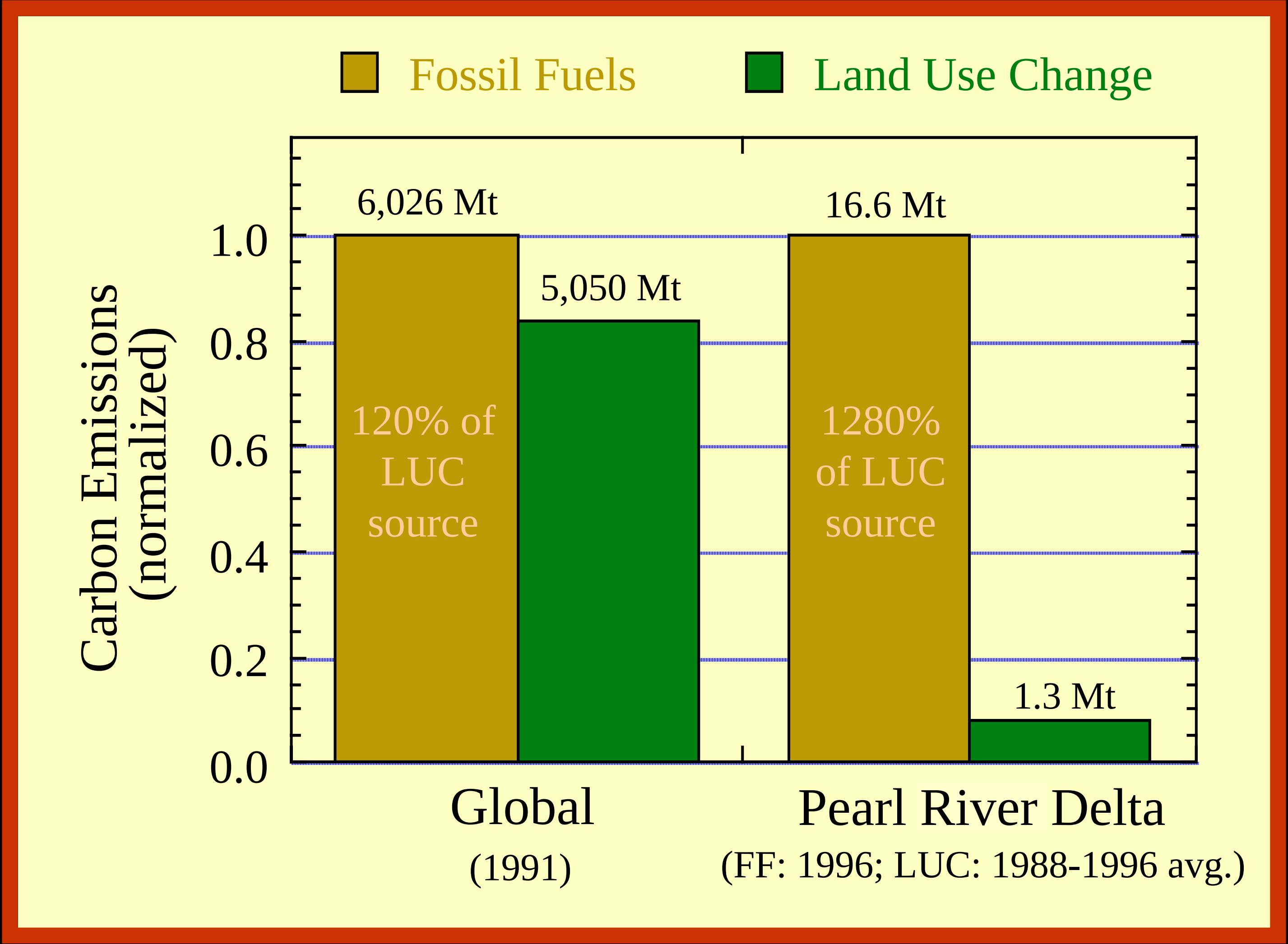


Gross Carbon Emission

Normalized Annual Gross C Emissions from Fossil Fuels & Land-Use Change:

Global vs. Pearl River Delta Region

Fossil Fuel C Emission is Dominant Source in PR Region



Sources:
Global:
Andres et al. (2000);
Houghton (2000)
Pearl River Delta:
this study

Conclusions (1 of 3)

- Land use change in PRD region during 1988-1996 had substantial effect on regional C cycle:
  - NPP: -1.6 Mt C yr^{-1} (-7.5%) (median)
  - Carbon stocks: -11.9 Mt C (-7.5%) (median)
- Dominance of urbanization implies:
  - low potential for ecosystem recovery by secondary growth
  - reduced capacity for C sequestration
- Offset of emission from land conversion depends on
  - C sinks *outside* PRD region
  - Reduced fossil fuel emission *within* the region

Conclusions (2 of 3)

- C emission may be estimated with higher confidence through:
  - Spatially explicit modeling/analysis approach
  - More sophisticated process modeling (e.g. SimCYCLE / VISIT)
- *However*, implementation often limited by poor data availability
    - E.g., soil OC storage and emission from urbanization process
    - Aboveground biomass

Conclusions (3 of 3)

Developing Improved Observing Systems for Monitoring and Quantifying Changes in Terrestrial Carbon Cycle

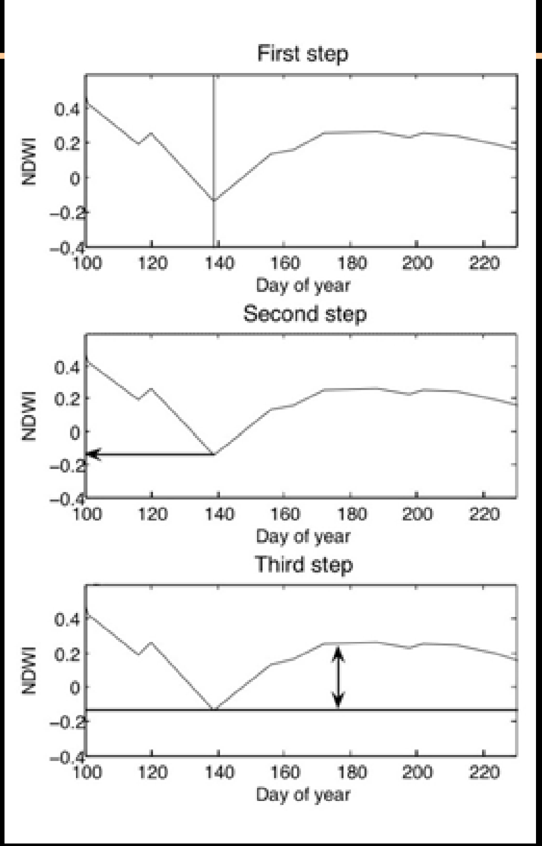
- Requires synergistic application of optical, SAR, and LIDAR observations
  - Improved direct retrieval of
    - vegetation biophysical properties (LAI, fPAR, height, density, biomass)
    - environmental variables (PAR, soil moisture, etc.)
  - Accounting for spatial gradients (within class variability) in land cover properties
- Current, GEOSS-related research at JAMSTEC-FRCGC is aimed at these objectives

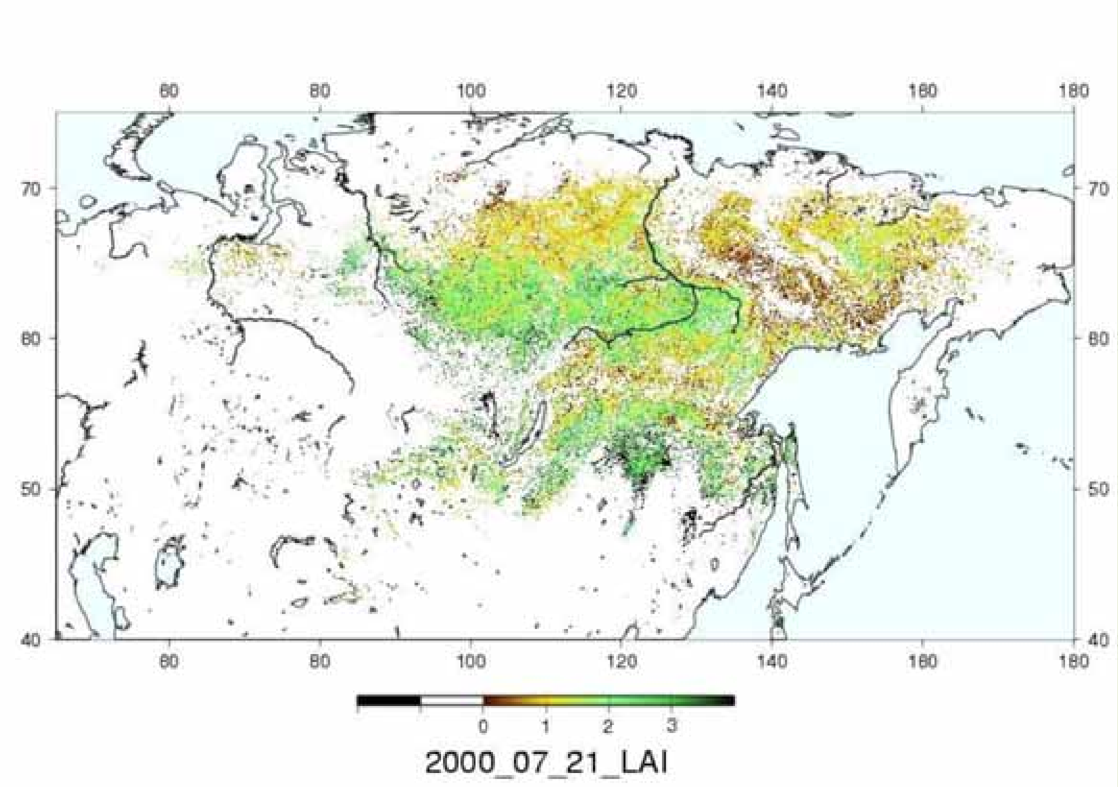
Improved Satellite Monitoring of Larch Forest LAI in Siberia

We have developed the most reliable canopy LAI datasets among the global LAI products through the following steps

- Comparison of satellite-observed reflectance with ground-based LAI ⇒Three-step estimation algorithm based on Normalized Difference Water Index (NDWI)
- Theoretical investigation by radiative transfer simulation
- Algorithm development
- Production of 10-years datasets (1998-2007)
- Validation of the satellite-derived larch canopy LAI

Three-step estimation algorithm





Larch canopy LAI map over Siberia

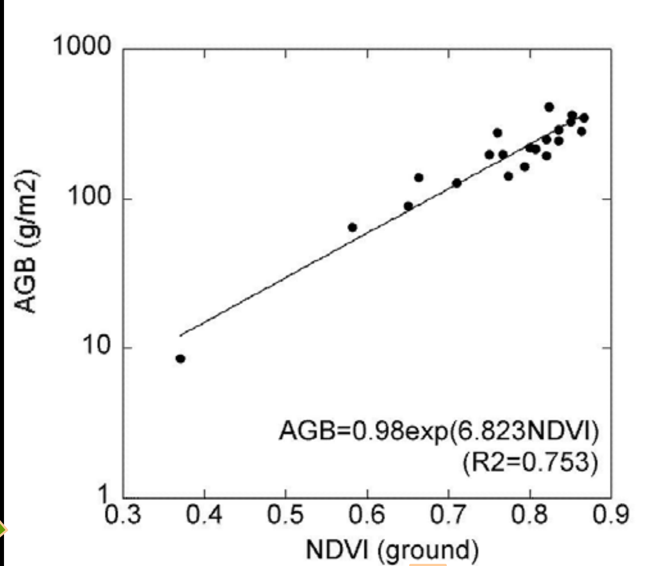
Validation with existing datasets

H. Kobayashi, N. Delbart & R. Suzuki

H. Kobayashi & T. Kato

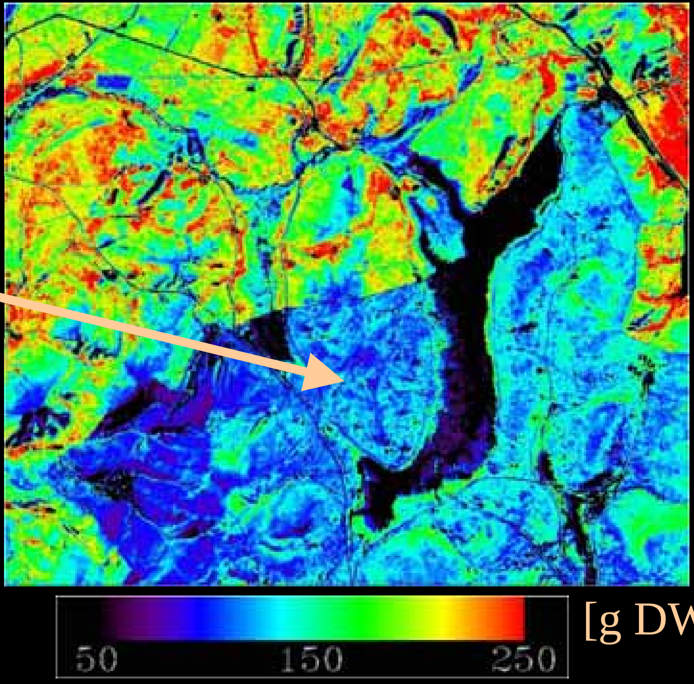
Improved Satellite Monitoring of Grassland LAI & Biomass

Improved LAI & Biomass Estimation
Using time-series satellite data and ground survey, reliable monitoring of grassland LAI/Biomass is started at two different spatial scales



Regional scale
(Qinghai-Tibetan Plateau)

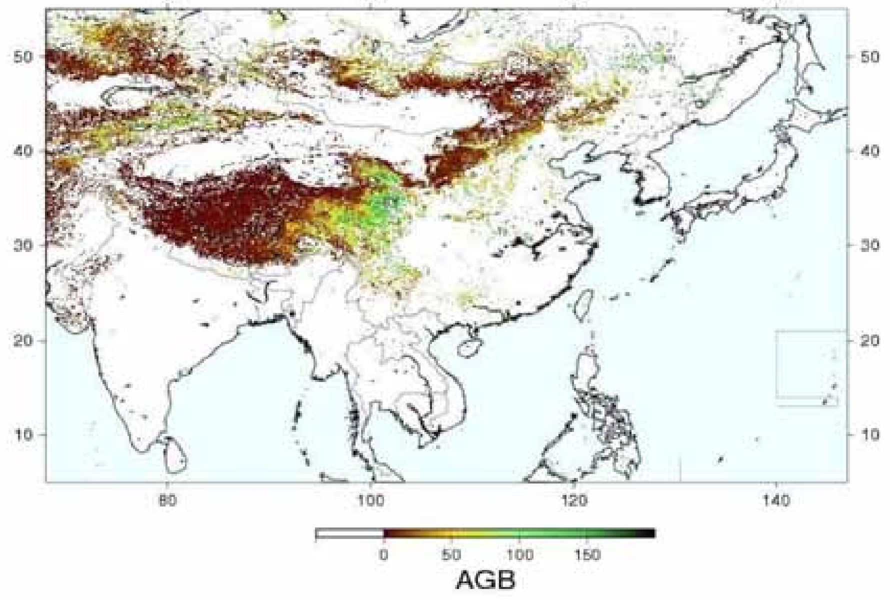
Grazing Effect



[g DW/m2]

August 13, 2007 SPOT

Continental scale (Asia)

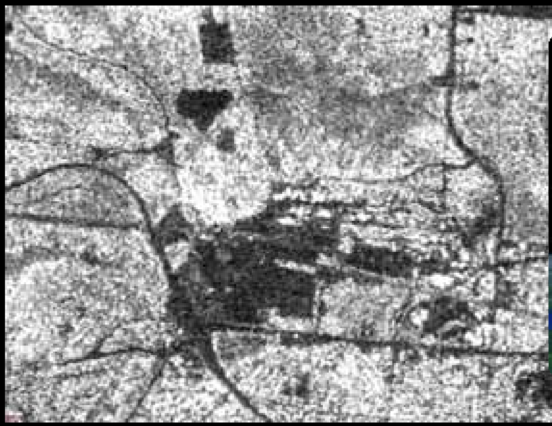


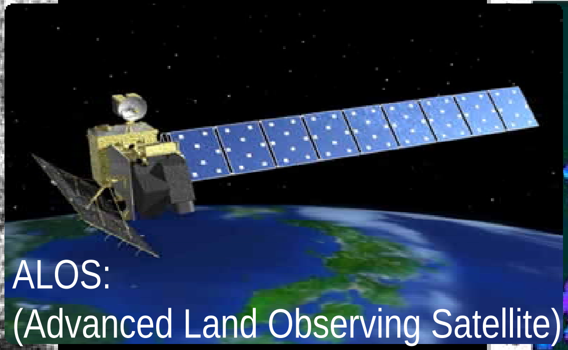
2007/7/20-31

Data Set Development
FOREST BIOMASS ESTIMATION & MAPPING with RADAR

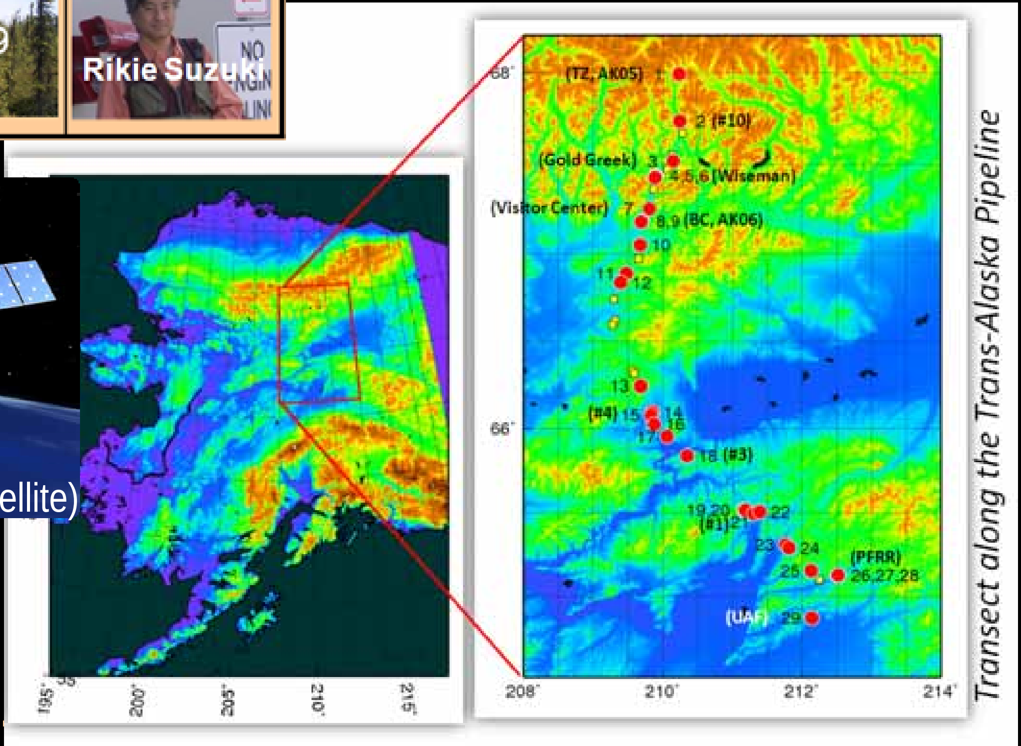
Completed forest survey for the biomass estimation algorithm based on ALOS/PALSAR measurement in Alaska

← Biomass (dried matter ton/ha) at 29 forests in Alaska.





ALOS:
(Advanced Land Observing Satellite)



Transect along the Trans-Alaska Pipeline

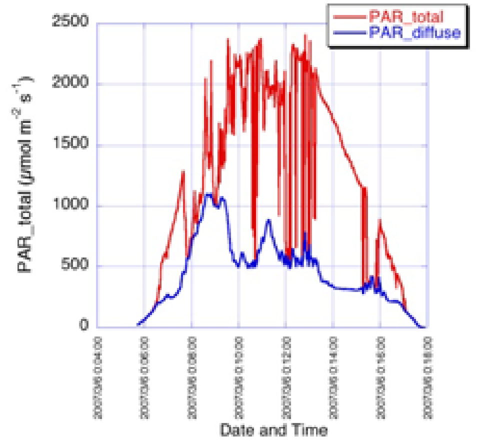
Sample image of ALOS/PALSAR

R. Suzuki & R. Ishii

Data Set Development & Modeling ……

Development of an Asian PAR Sensor Network for Ecosystem Process Studies

- validation of satellite PAR estimates
- improved understanding of atmosphere-radiation photosynthesis relations
- improved carbon cycle modeling

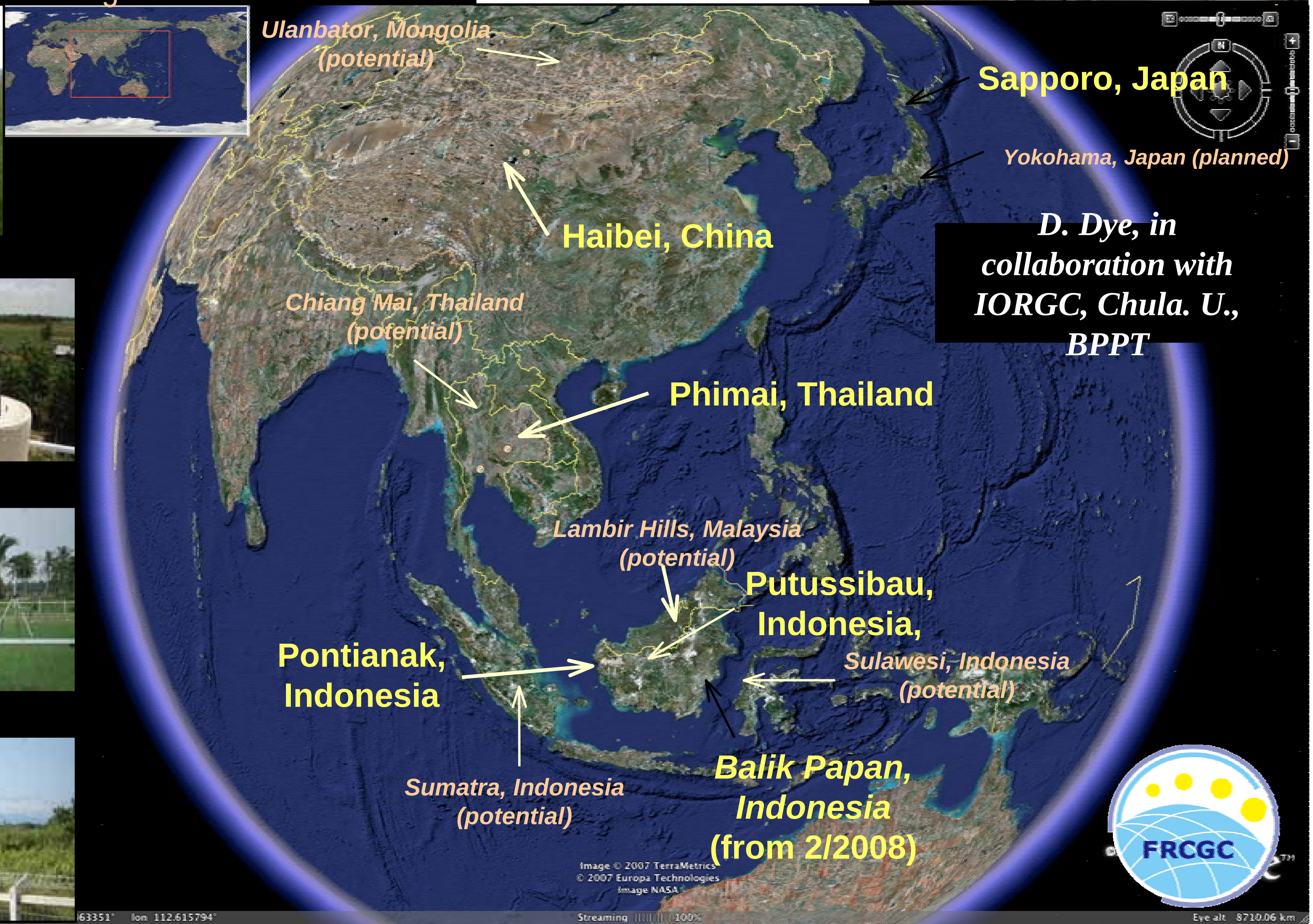


Haibei, Qinghai, China 37.61 N,101.38 E

Phimai, Nakhon Ratchasima, Thailand 15.18 N, 102.57 E

Pontianak, West Kalimantan, Indonesia 0.08 N, 109.191 E

Putussibau, West Kalimantan, Indonesia 0.84 N, 112.94 E

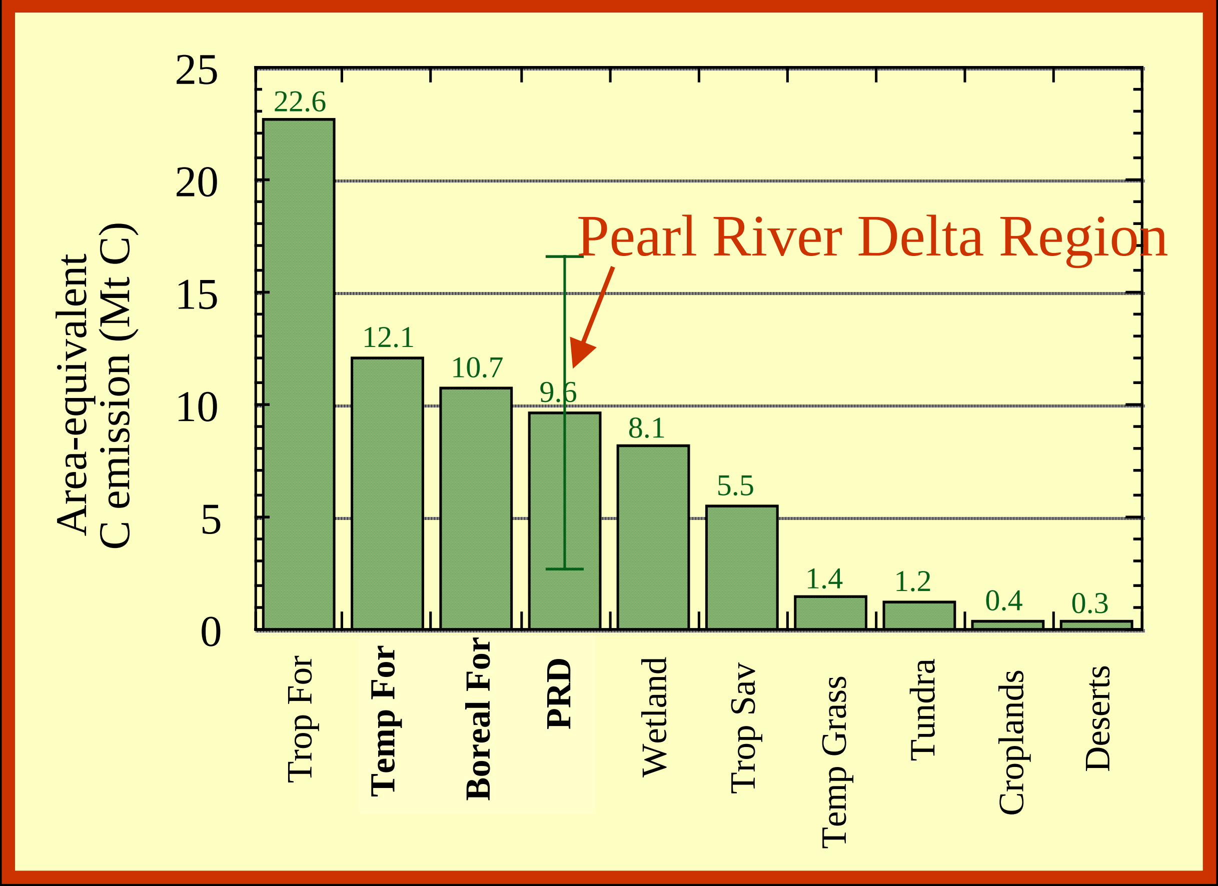


D. Dye, in collaboration with IORGC, Chula. U., BPPT

FRCGC

Thank you

Potential Gross C Emission from Land Use Change in Equivalent Areas of Major Biomes



assumes natural-to-urban conversion

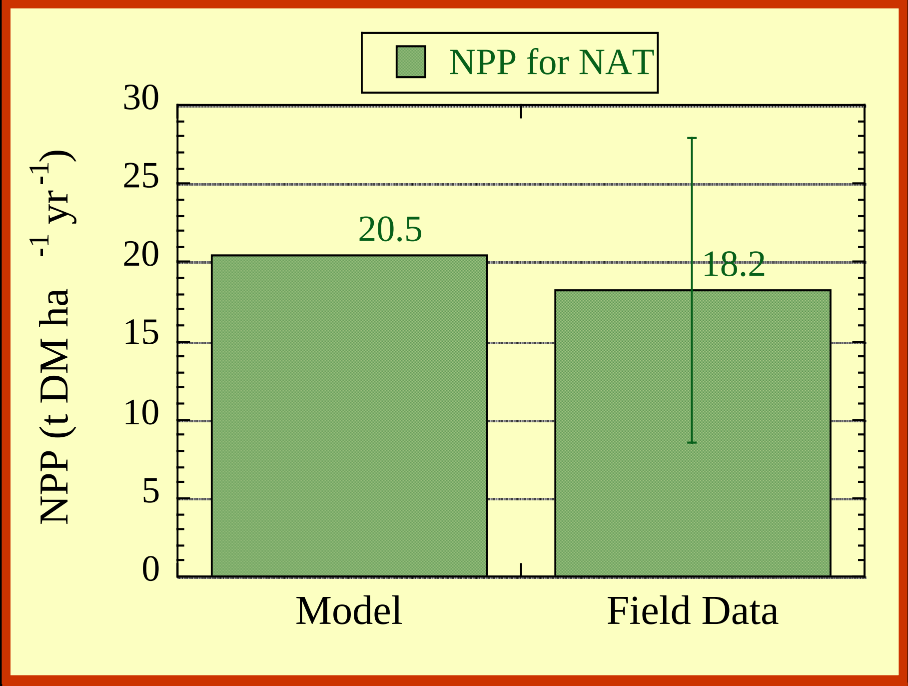
Includes gross emissions from phytomass only

Biome figures based on Watson et al. (2000)

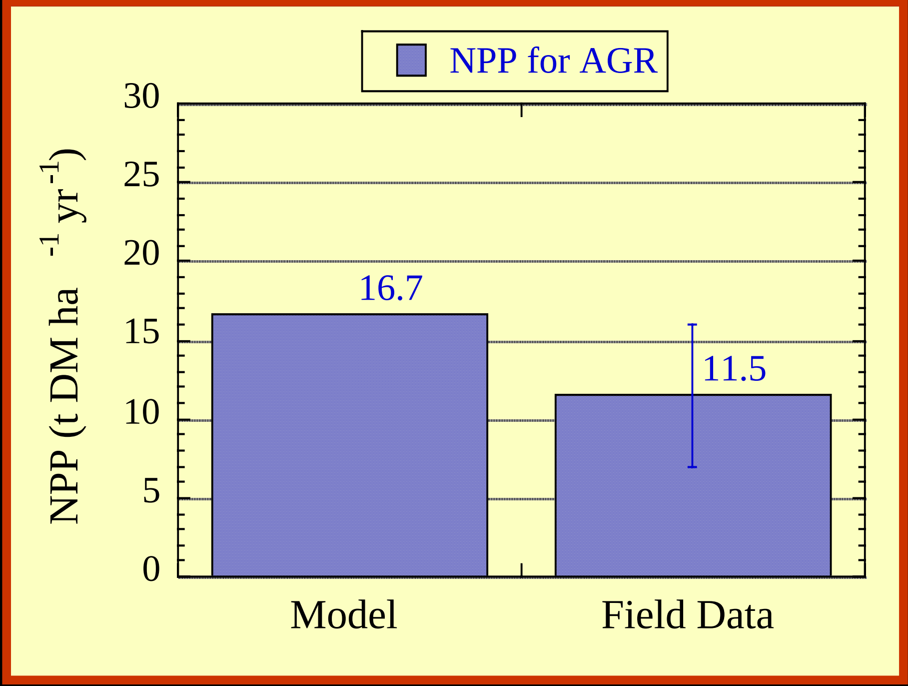
NPP Model Validation

Model Estimates vs. Reported Values

Natural Vegetation (NAT)

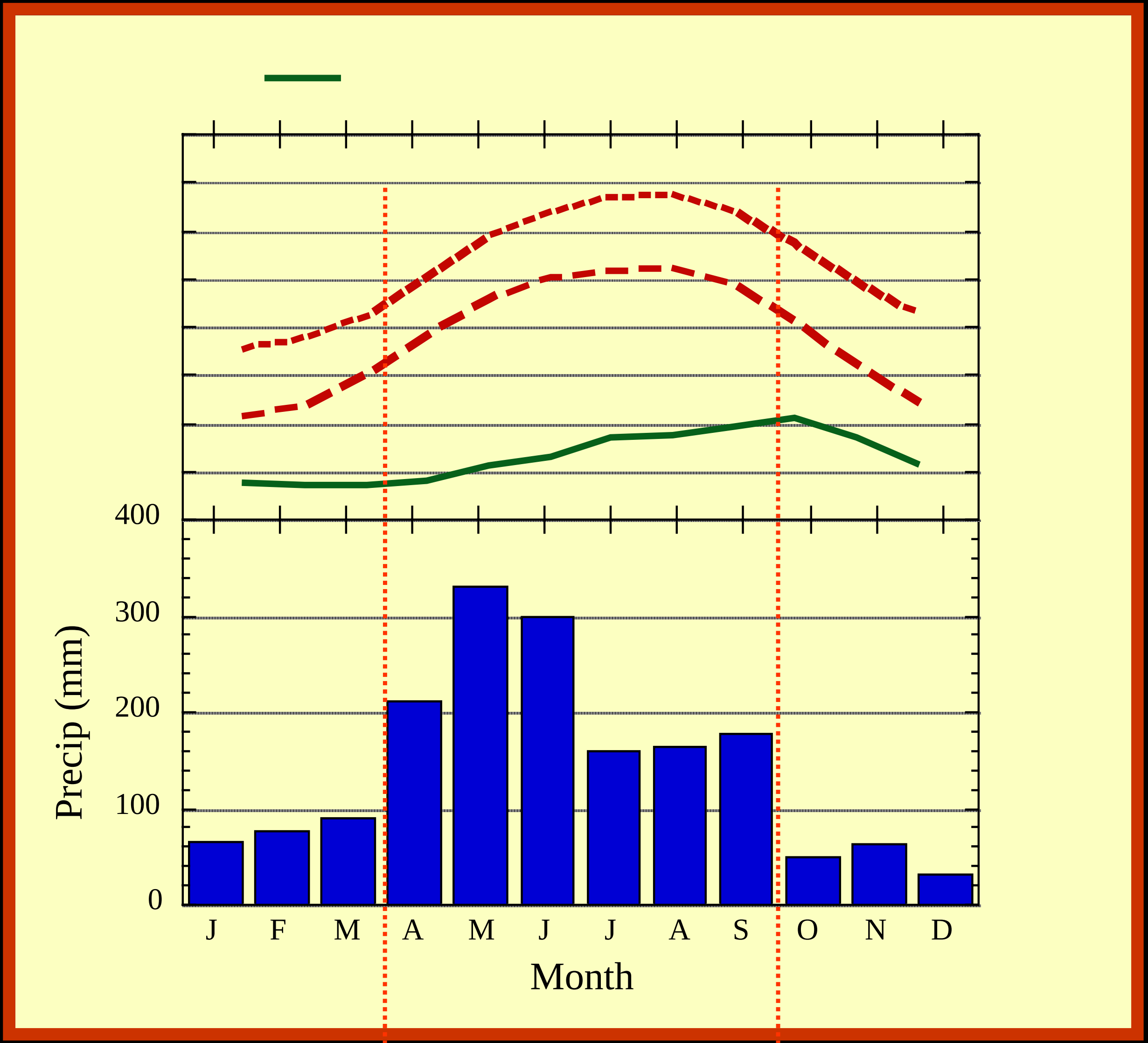


Agriculture (AGR)



Climate Conditions at Guangzhou

Long-term monthly average temp., precip, & VPD

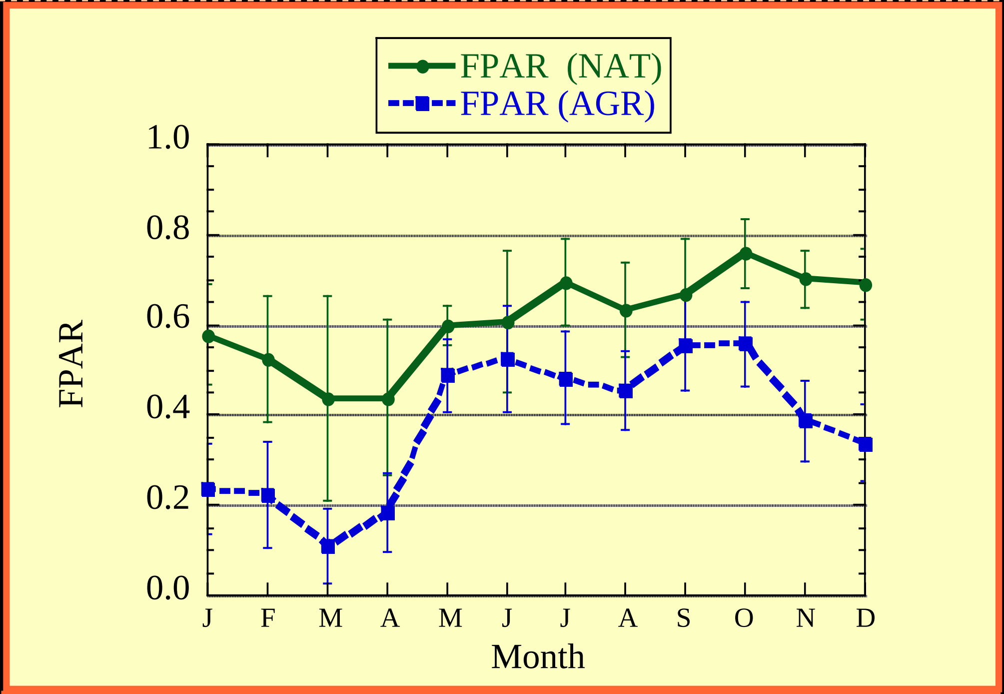


← rainy season →

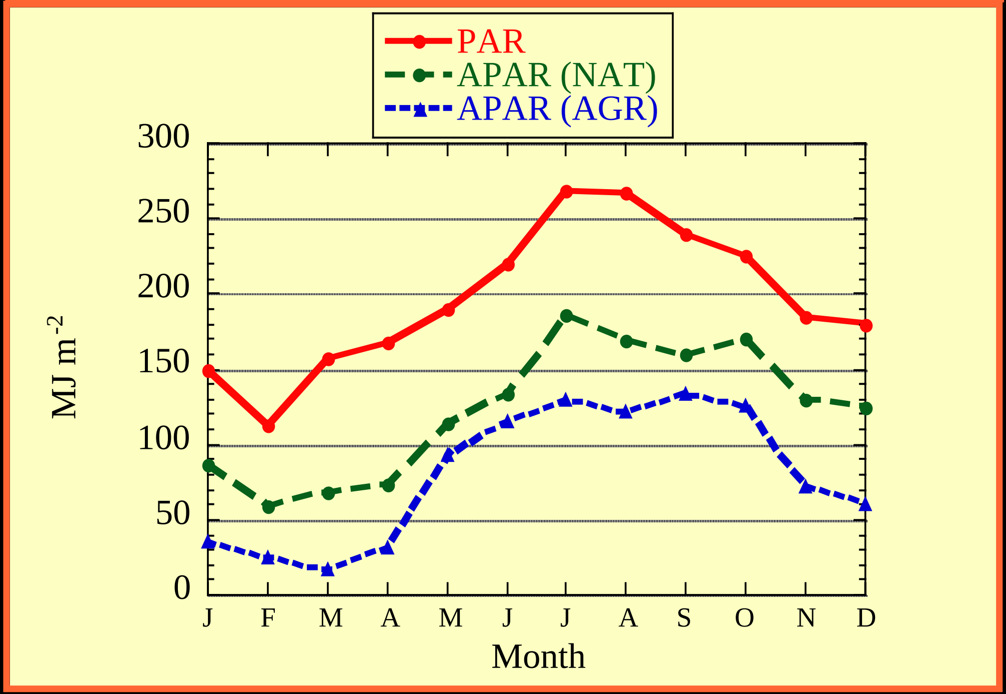
Methodology 1: NPP Modeling

Monthly Times Series of Model Variables

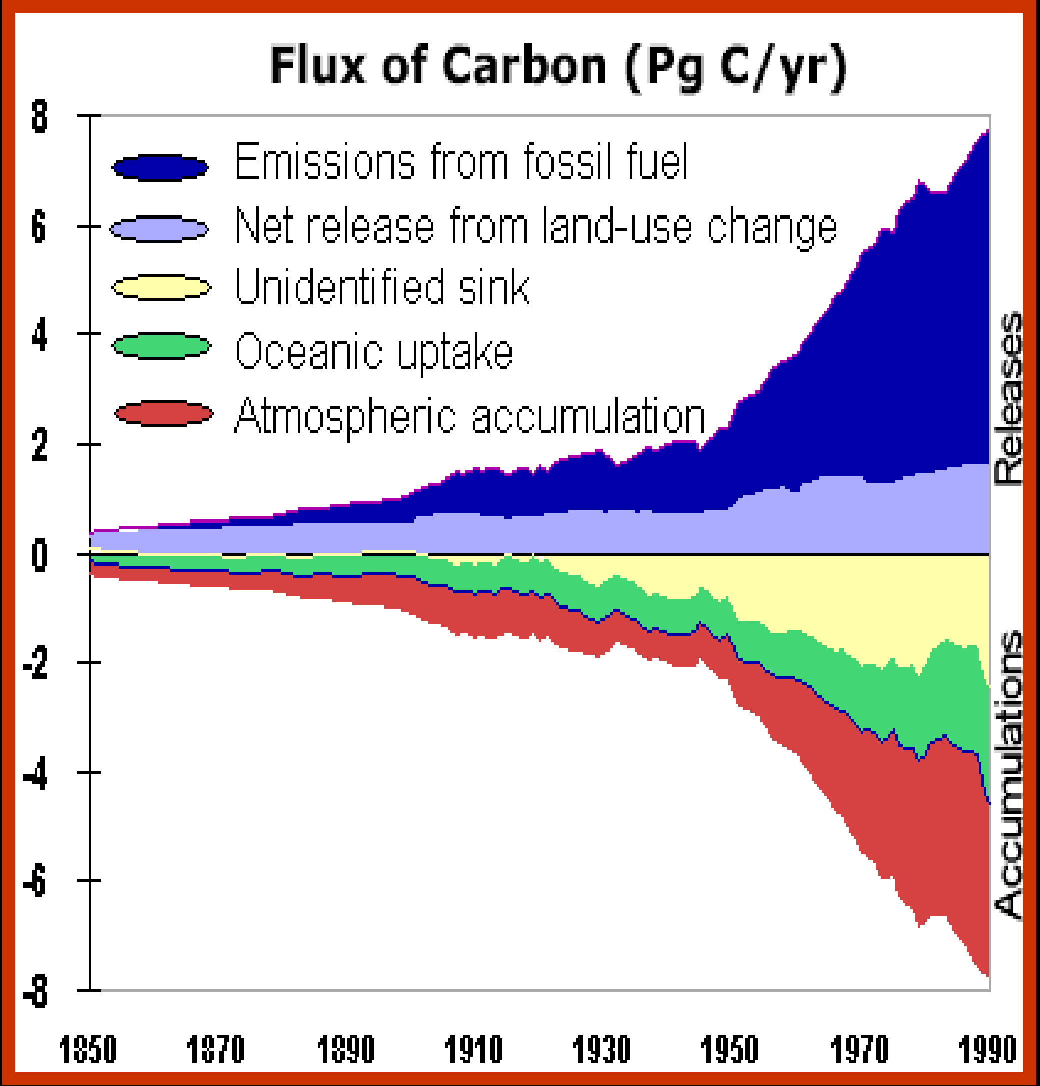
FPAR



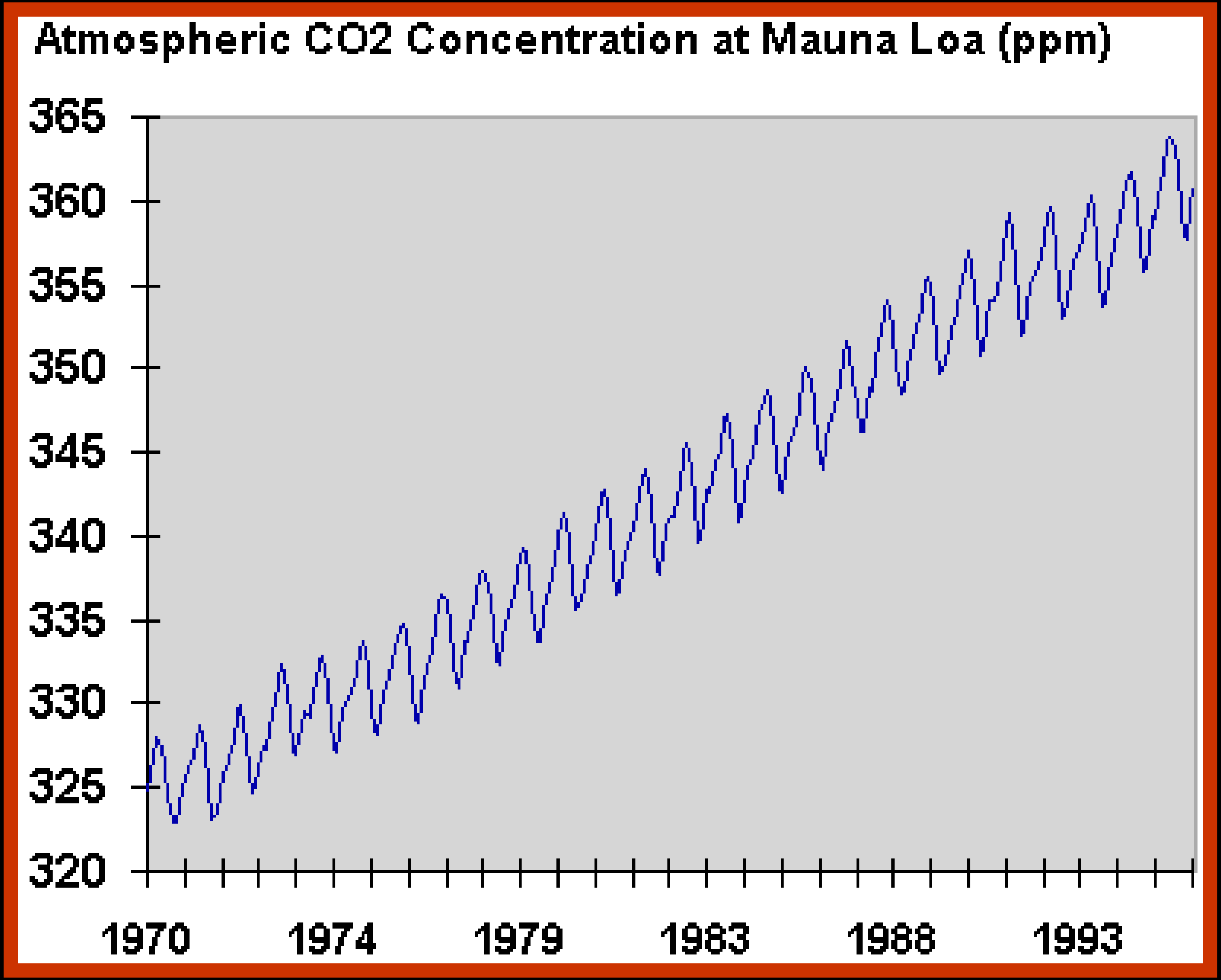
PAR, APAR



Global Atmospheric Carbon Budget 1850-1990

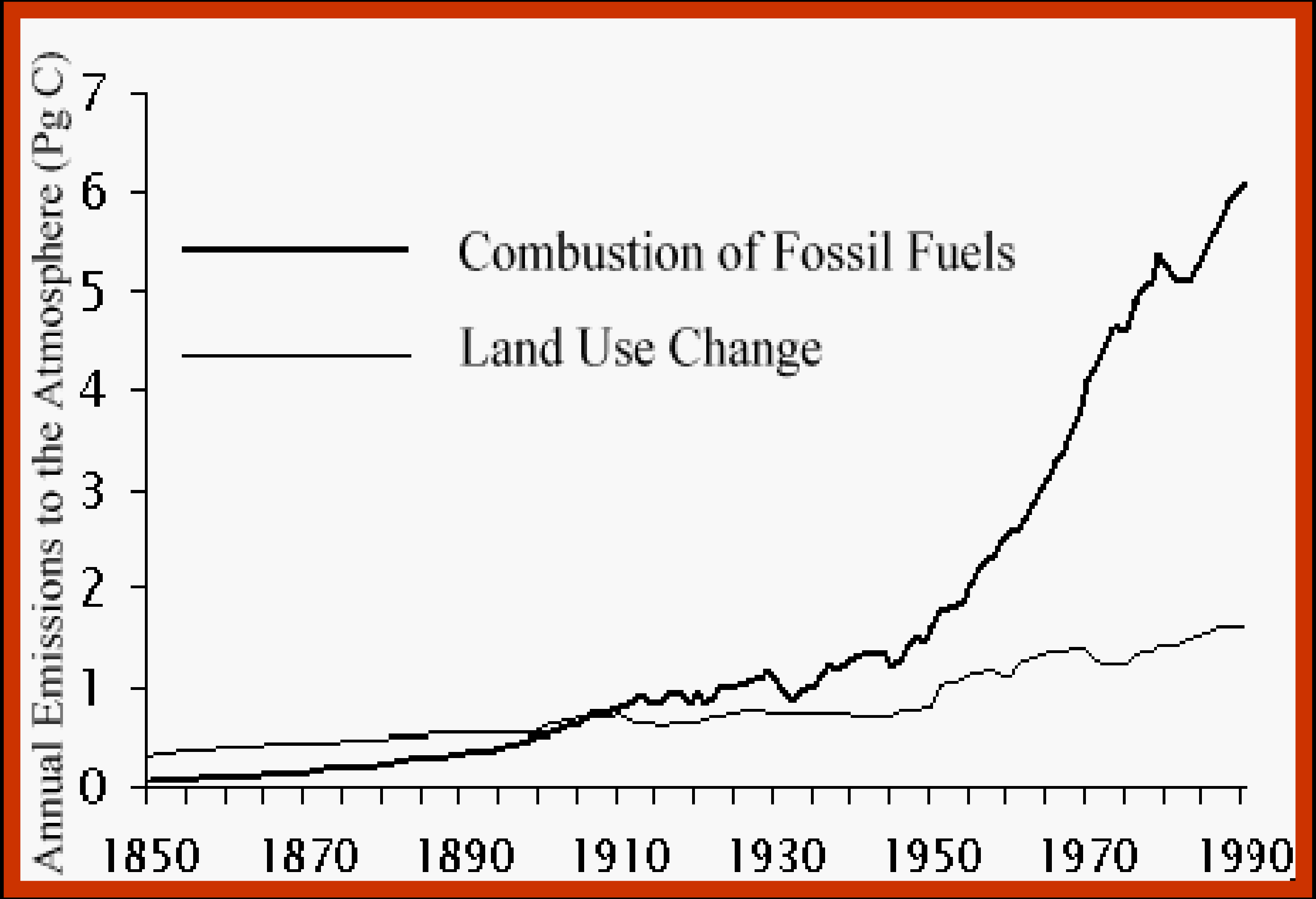


Source:
R. Houghton et al.,
Woods Hole Research Center



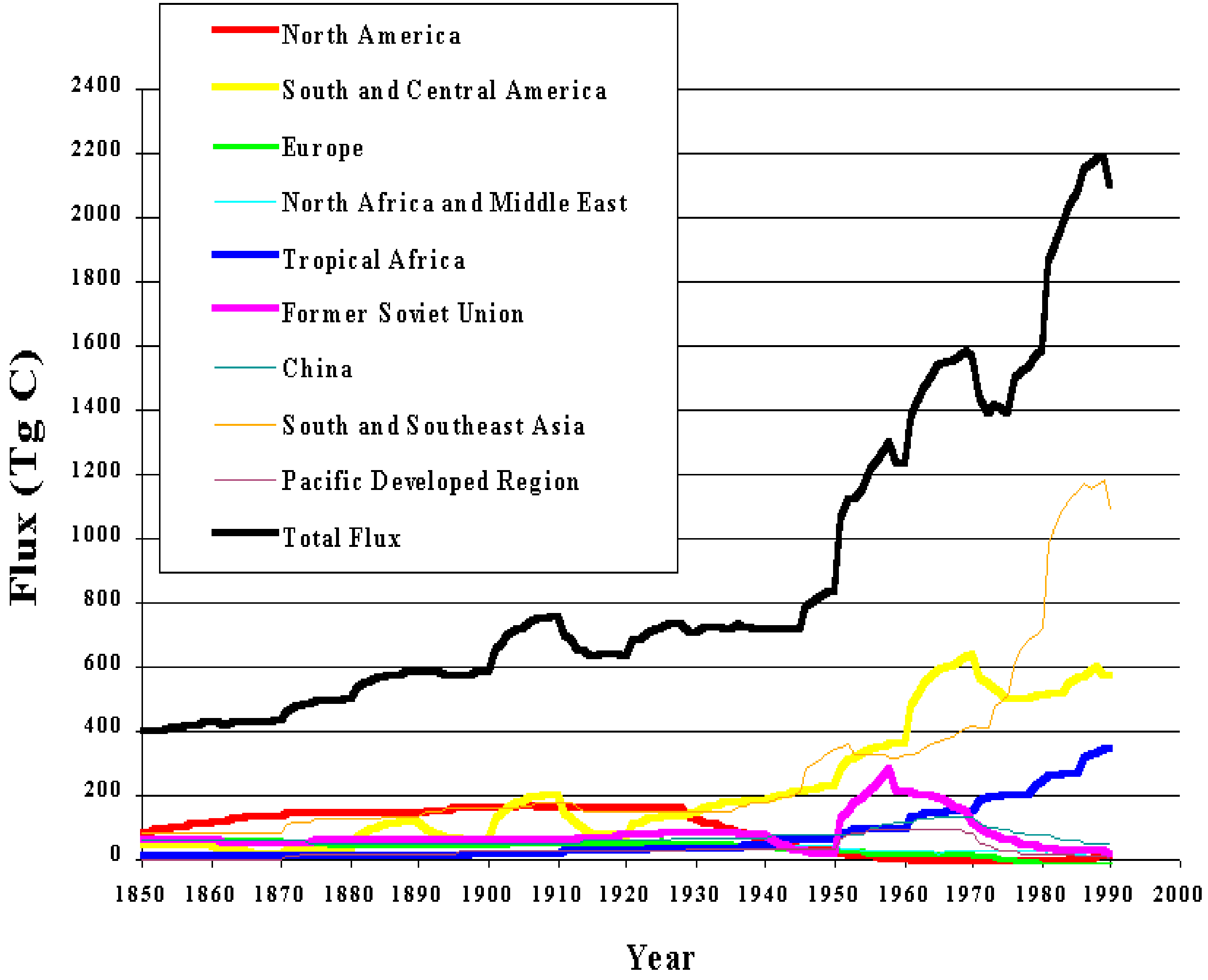
Atmospheric CO2 Concentration at Mauna Loa (ppm)

Annual Carbon Emissions from Human Activities, 1850-1990



Houghton (2000)

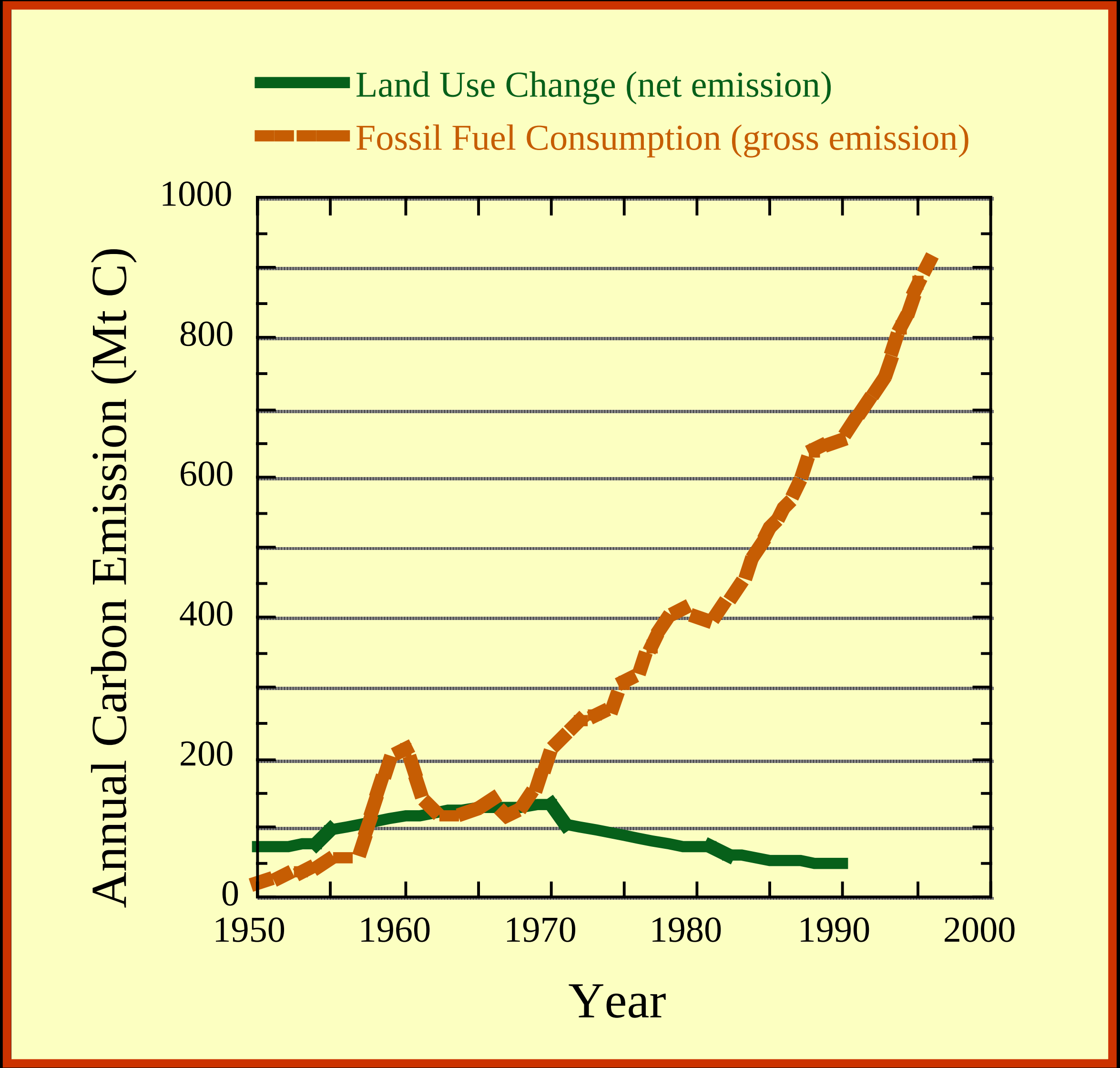
Annual Net Flux of Carbon to the Atmosphere from Land-Use Change: 1850-1990
(Houghton and Hackler)



Landsat Observations of Land Cover Change in the Zhu Jiang Delta Region, PRC

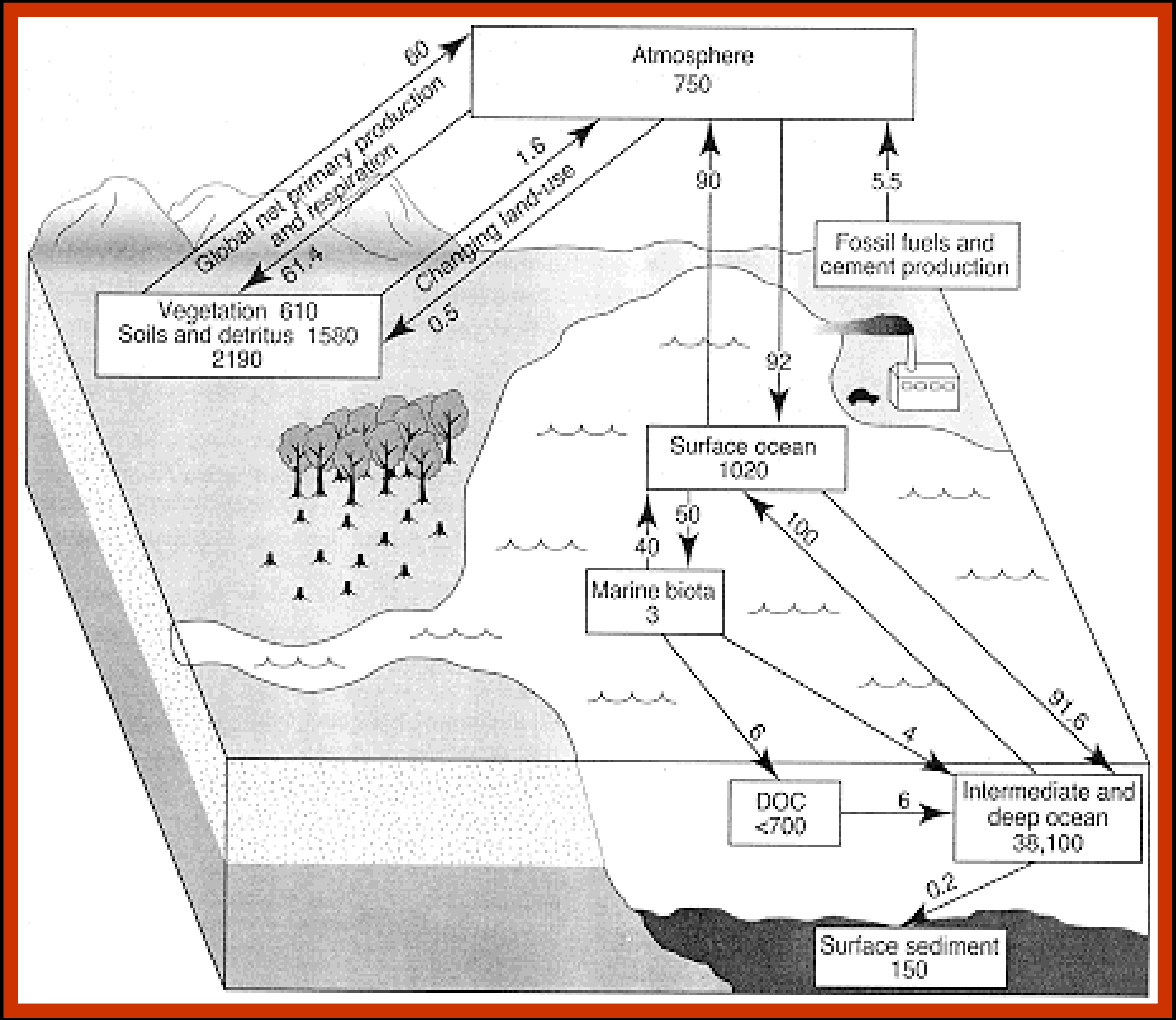
Shenzhen,
Guangdong
1988-1996

Carbon Emission Trends in China from Land Use Change & Fossil Fuel Consumption 1950-1990+



Sources:
Marland et al. (1999);
Houghton (1999)

Global Carbon Cycle



Schimel et al.
(2000)

Estimating the Net C Flux from Land Use Change in PRD

- Net flux from ***global*** land use change was 40% of gross flux in 1990 (Houghton, 2000)
- C emission estimates from this study are ***gross*** fluxes (regrowth not included).
- Urbanization is dominant in PRD, therefore:
  - C accumulation is low
  - net flux will approach gross flux

Acknowledgements

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