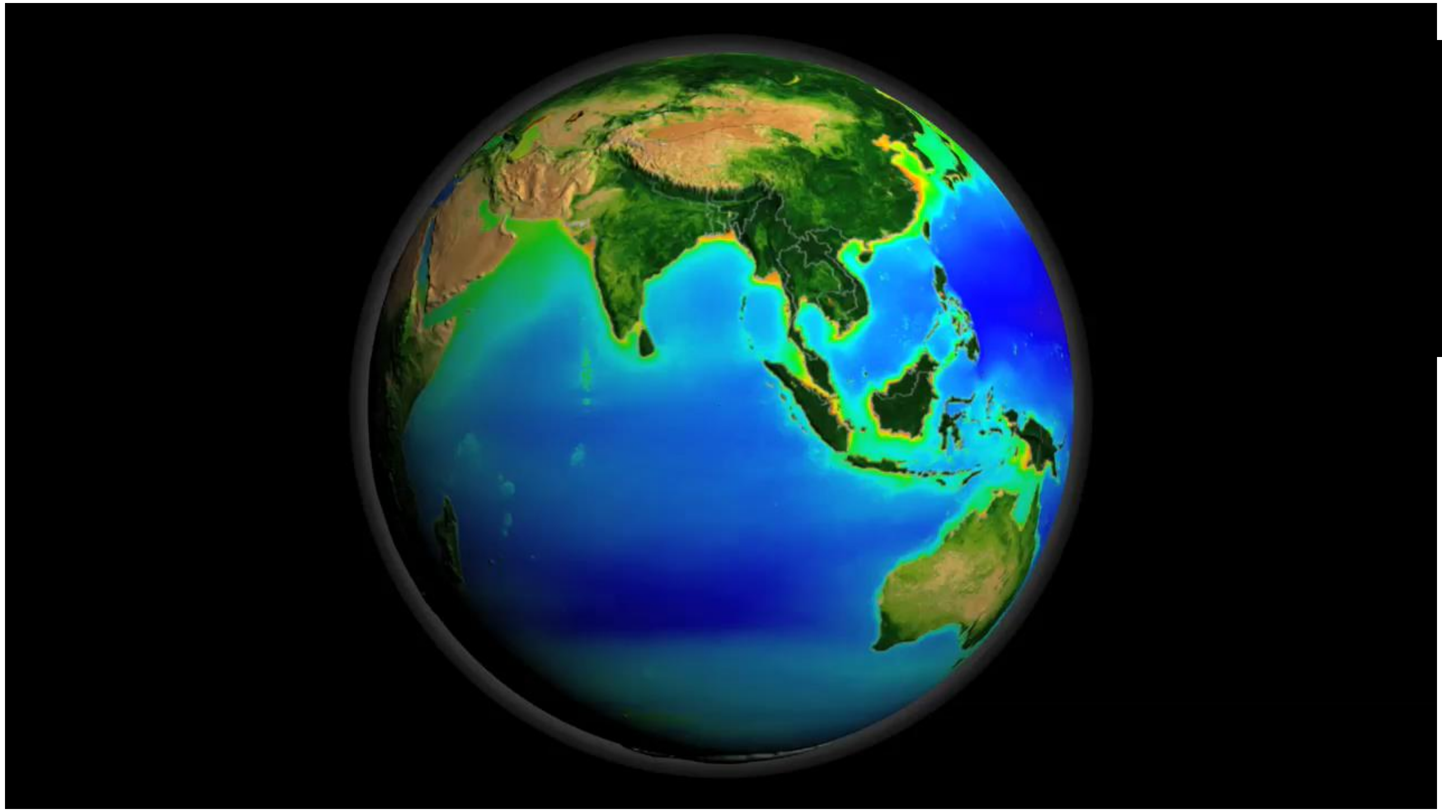
Imaging the Biosphere

Learning Objectives

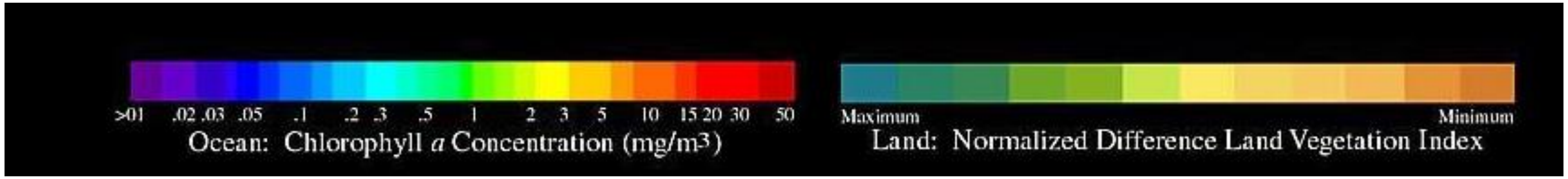
- What is the biosphere?
- Why monitor it?
- Metrics to monitor the biosphere
- Remote sensing technologies used to monitor the biosphere
- Applications/examples

What is the biosphere?

- The **biosphere** is all ecosystems on Earth
- Includes both terrestrial (land) and marine (ocean) ecosystems



SeaWiFS was launched in 1997 and died in 2010. It was designed to see chlorophyll in the water but also sense the NDVI on land. It has 1km spatial resolution and 8 bands.



Energy flows in the biosphere

Photosynthesis is the process by which plants convert solar energy, carbon dioxide and water into carbohydrates (sugar) and oxygen.

$$\text{Energy} + \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \rightarrow \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Light energy (photon)

This is carbon as a gas

This is (stored) carbon as a solid

Photosynthesis is the fundamental basis for energy flows in ecosystems and the biosphere.

Why monitor the biosphere?

- The biosphere (through photosynthesis) absorbs carbon dioxide from the atmosphere
  - Crucial to monitor the biosphere so we can understand carbon cycles

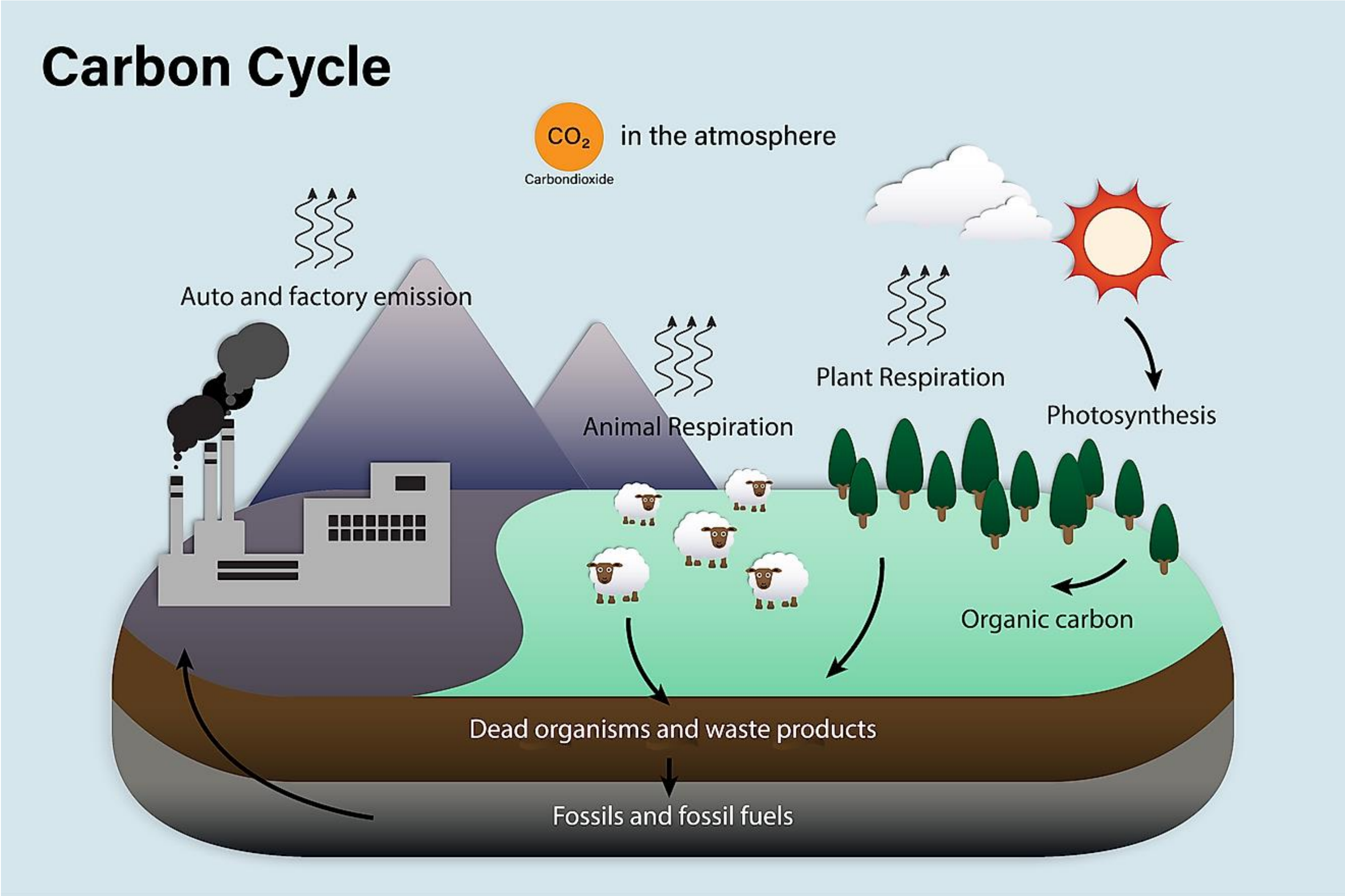
$$\text{Energy} + \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \rightarrow \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Light energy (photon)

This is carbon as a gas

This is (stored) carbon as a solid

Photosynthesis: Cycling Carbon



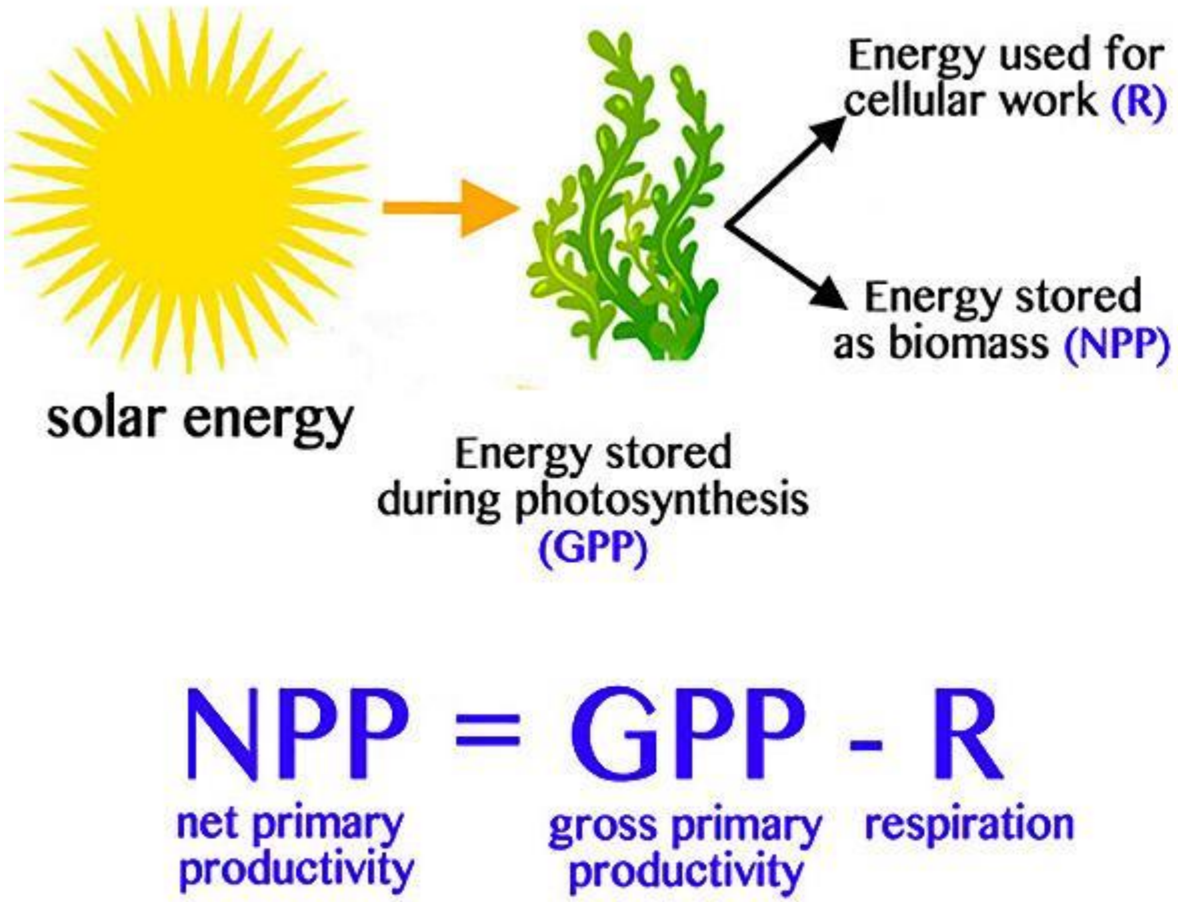
Metrics for Monitoring the Biosphere

- Productivity
  - GPP & NPP
  - What affects productivity?
- Carbon sinks and sources
- Biomass

Productivity in the biosphere

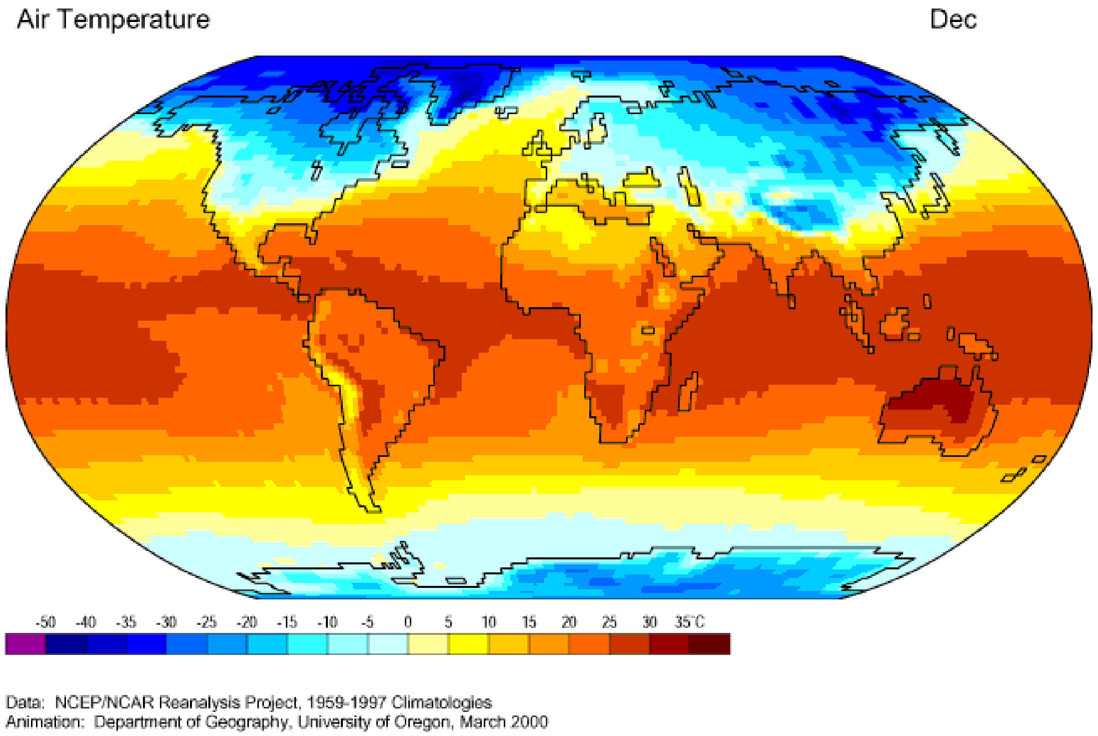
Primary production can be measured as:

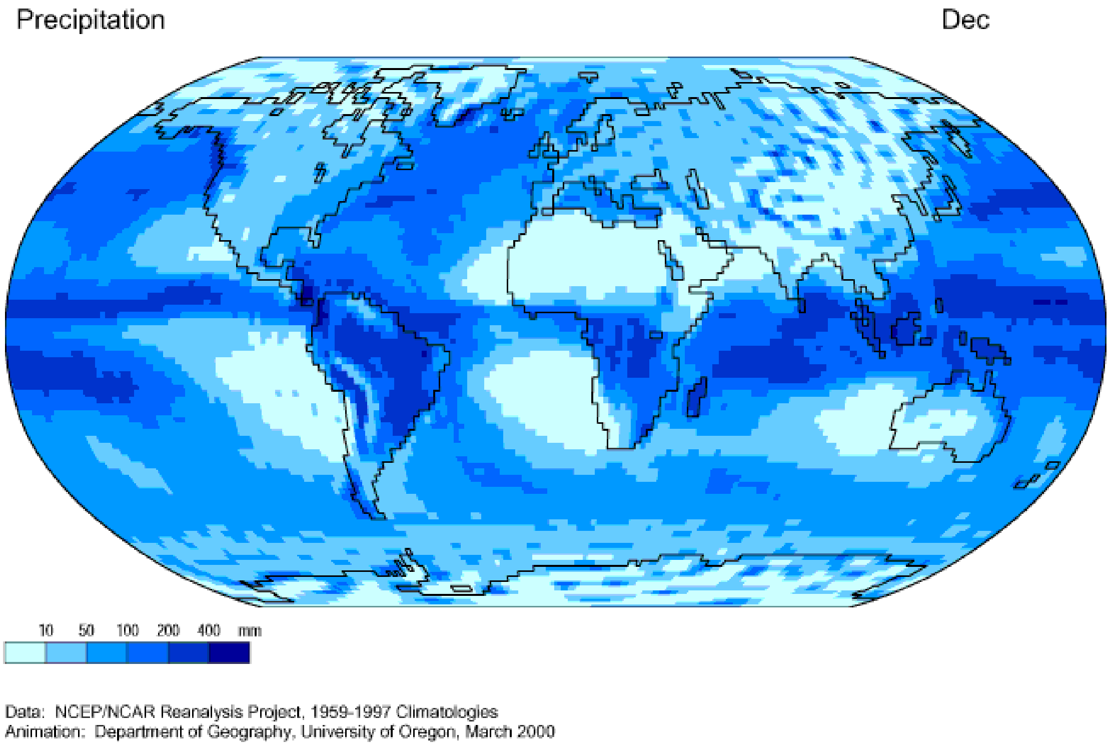
- **Gross primary production (GPP)** is the amount of energy created by plants
- **Net primary production (NPP)** is the amount of energy stored in the plant after accounting for plant respiration


solar energy
Energy stored
during photosynthesis
(GPP)
Energy used for
cellular work (R)
Energy stored
as biomass (NPP)
NPP = GPP - R
net primary
productivity
gross primary
productivity
respiration

Productivity in the biosphere

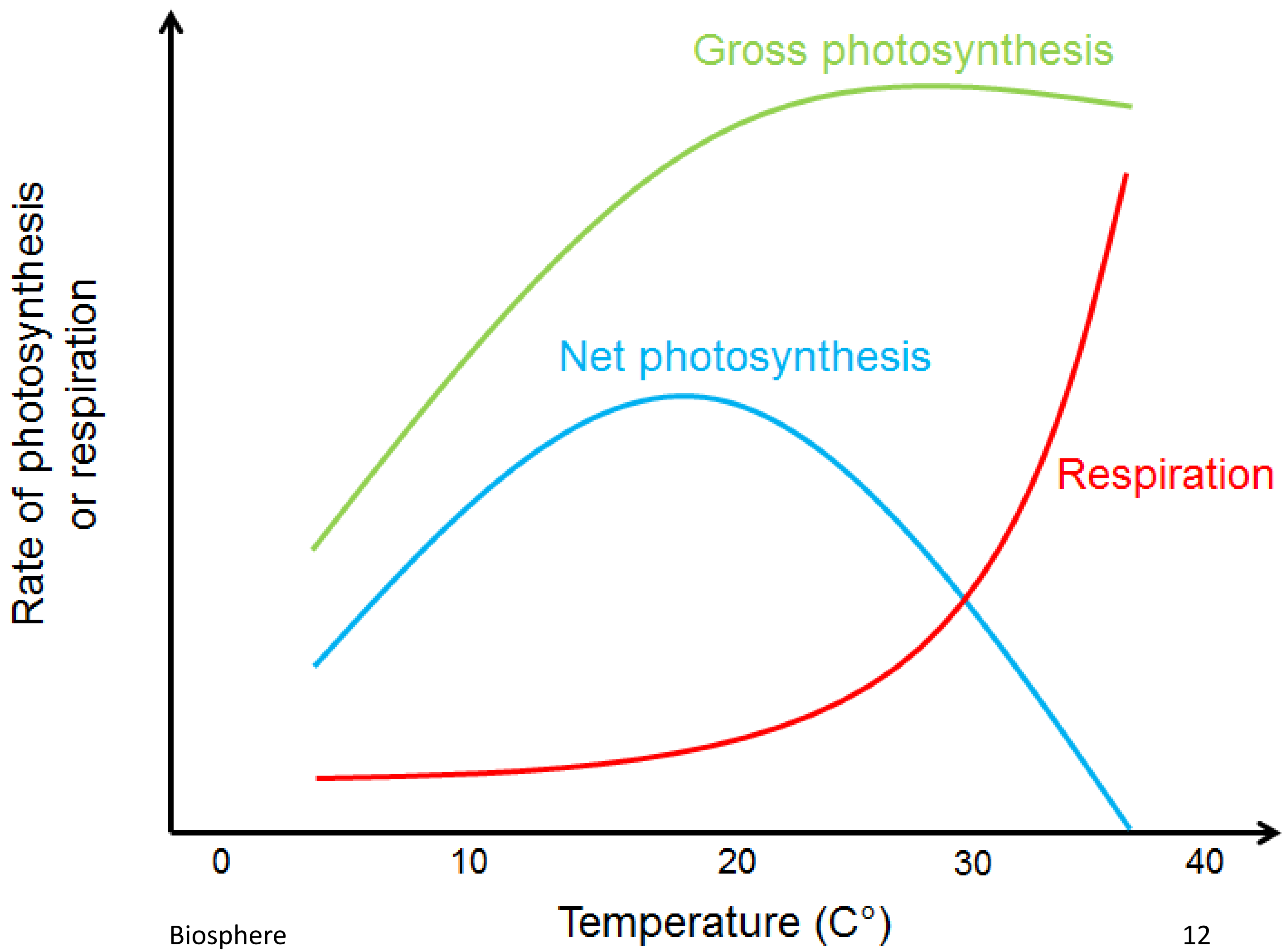
Productivity is affected by climatic factors: light, air temperature, precipitation, and carbon dioxide concentration





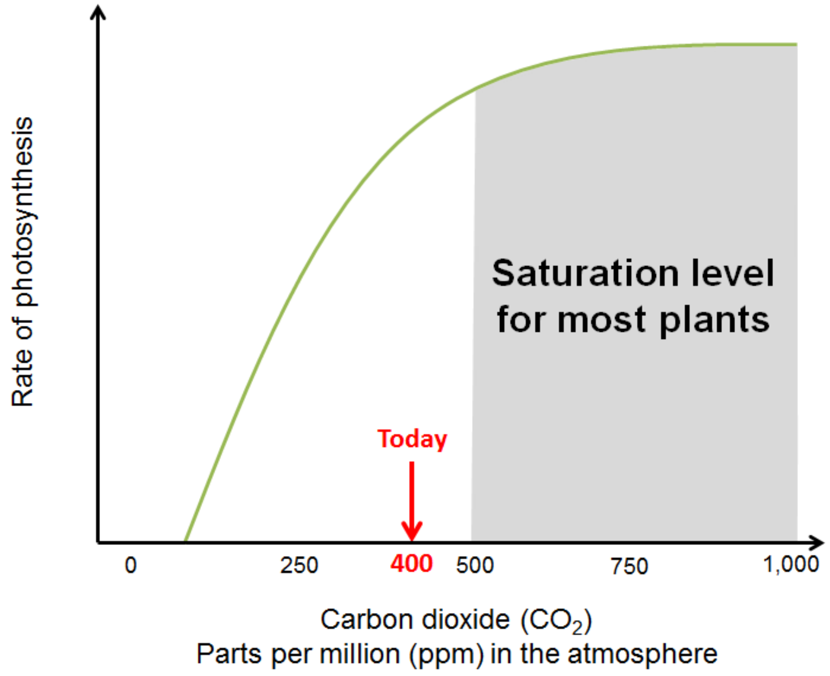
Productivity in the biosphere

- Productivity and respiration are affected by climate variables
- High temperature induces stress in plants
- Respiration increases and net photosynthesis decreases with higher temperature



Climatic Factors Affecting Productivity

- Light
  - Increases photosynthesis until saturation
- Carbon dioxide
  - Increases photosynthesis until saturation
- Water
  - Increases photosynthesis until saturation
- Temperature
  - Increases photosynthesis
  - But levels off at higher temperature
  - And net photosynthesis will start to decrease at higher temperatures
    - Plants will get stressed at higher temperature and require much higher respiration

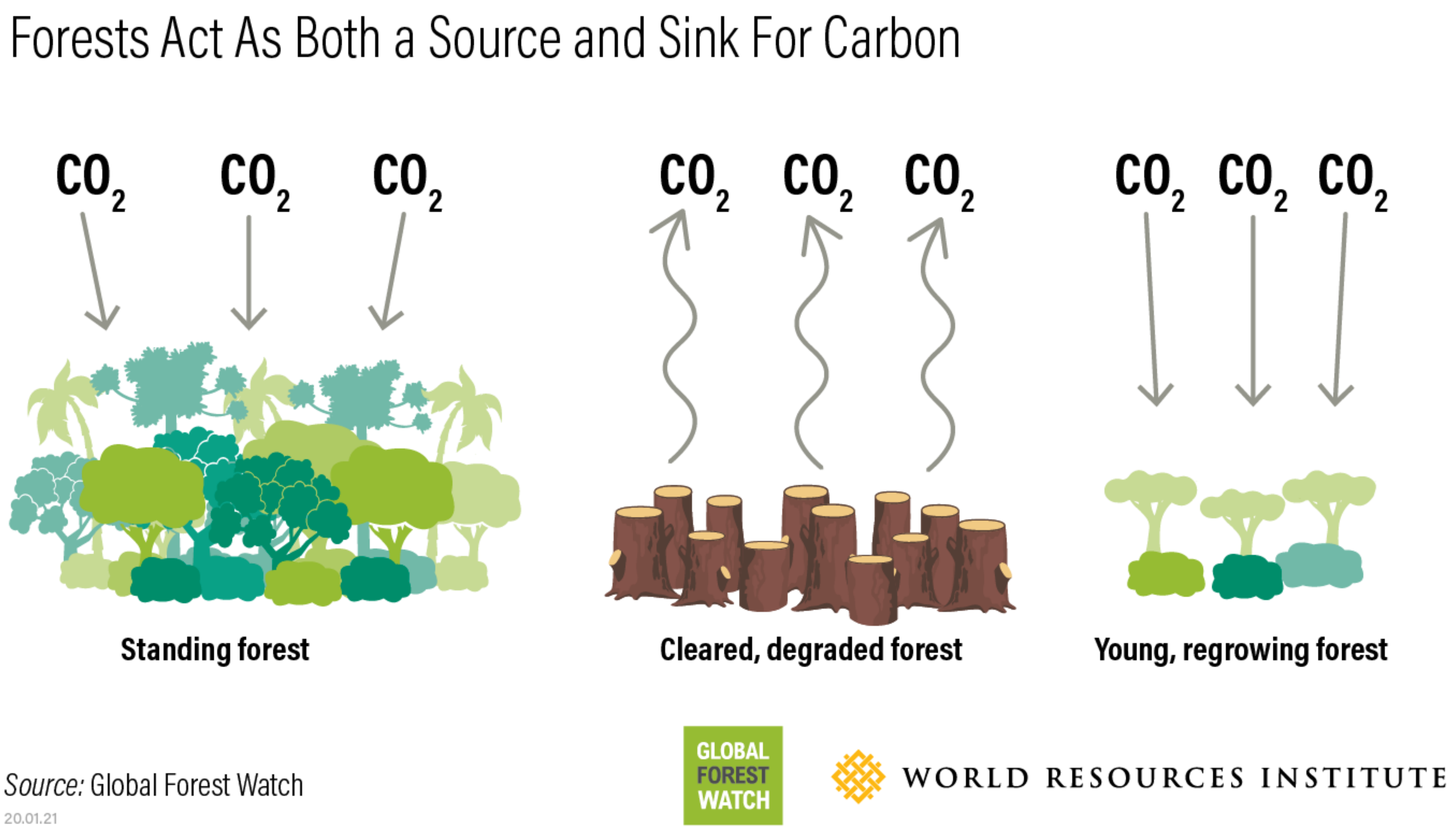


Carbon Sink vs. Source

- Sink: absorbs more carbon from the atmosphere than it releases
- Source: releases more carbon to the atmosphere than it absorbs
- By measuring carbon sinks and sources we can monitor carbon transfer and carbon storage in the biosphere
  - i.e. how much carbon is in the atmosphere vs. stored in the forests
    - And how much is that changing year to year

Sink or Source?

Main Takeaway: Consider Dynamic Sink/Sources



Source: Global Forest Watch

20.01.21

Measuring biomass

- **Biomass** is the dry weight of living organic matter in an area
  - Can include above, or belowground or both

- Good reflection of the productivity of an ecosystem

Monitoring the Biosphere Historically

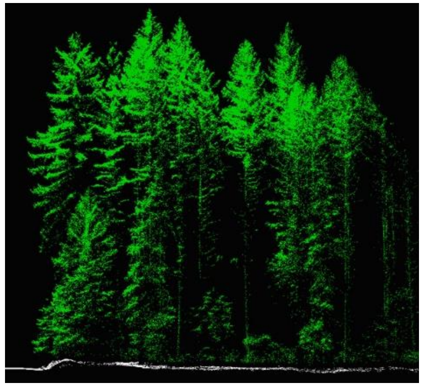
- Field based estimates
  - Estimating vegetation cover, vegetation width & height
  - Gives us an estimate of biomass

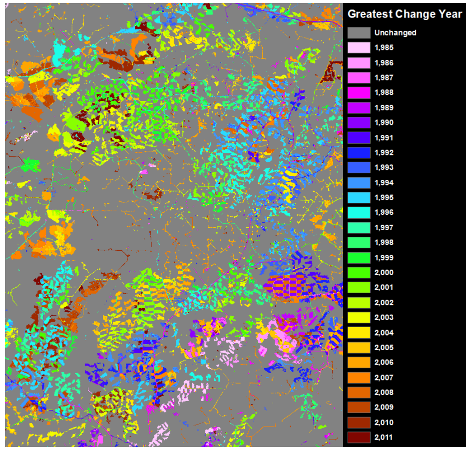
Monitoring the Biosphere Historically

- Eddy Flux towers
  - Measure carbon flux at a single point
  - Monitor gas concentrations at high frequency well above the height of vegetation
  - Post-processing enables:
    - Estimates on exchange of CO_2

Remote Sensing Technologies

- MODIS
  - Measuring productivity
    - Building models using inputs known to affect productivity
- Lidar
  - Building high resolution 3 dimensional datasets
  - Accurately estimate aboveground biomass
- Landsat
  - Helps us monitor carbon sink and carbon sources
    - Detecting disturbances and monitoring recovery





Measuring Productivity: MODIS

J. Xiao, et al. *Remote Sensing of Environment 233 (2019) 111383*

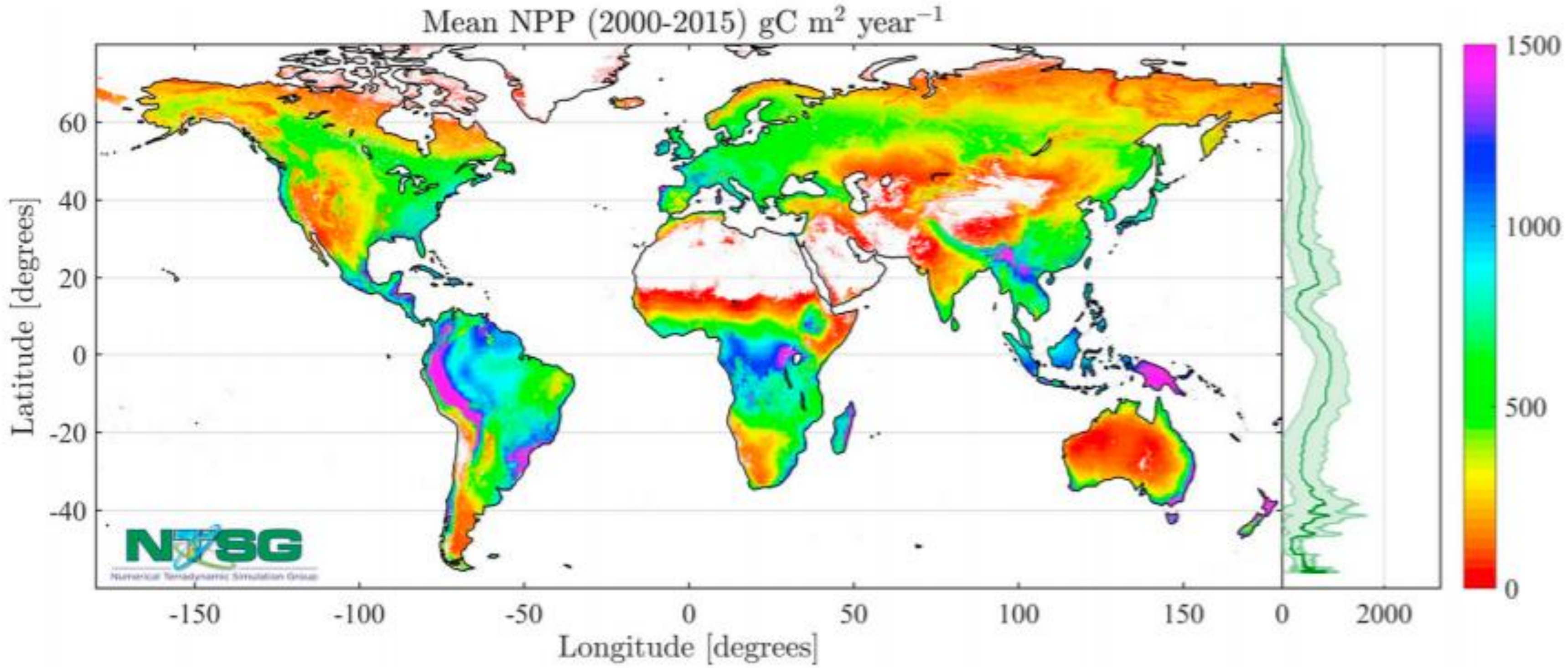


Fig. 4. Global mean annual NPP (gC m^{-2} year^{-1}) over the period 2000–2015 based on the MODIS GPP/NPP product. (Courtesy of Steven W. Running)

Measuring Productivity: MODIS

J. Xiao, et al. Remote Sensing of Environment 233 (2019) 111383

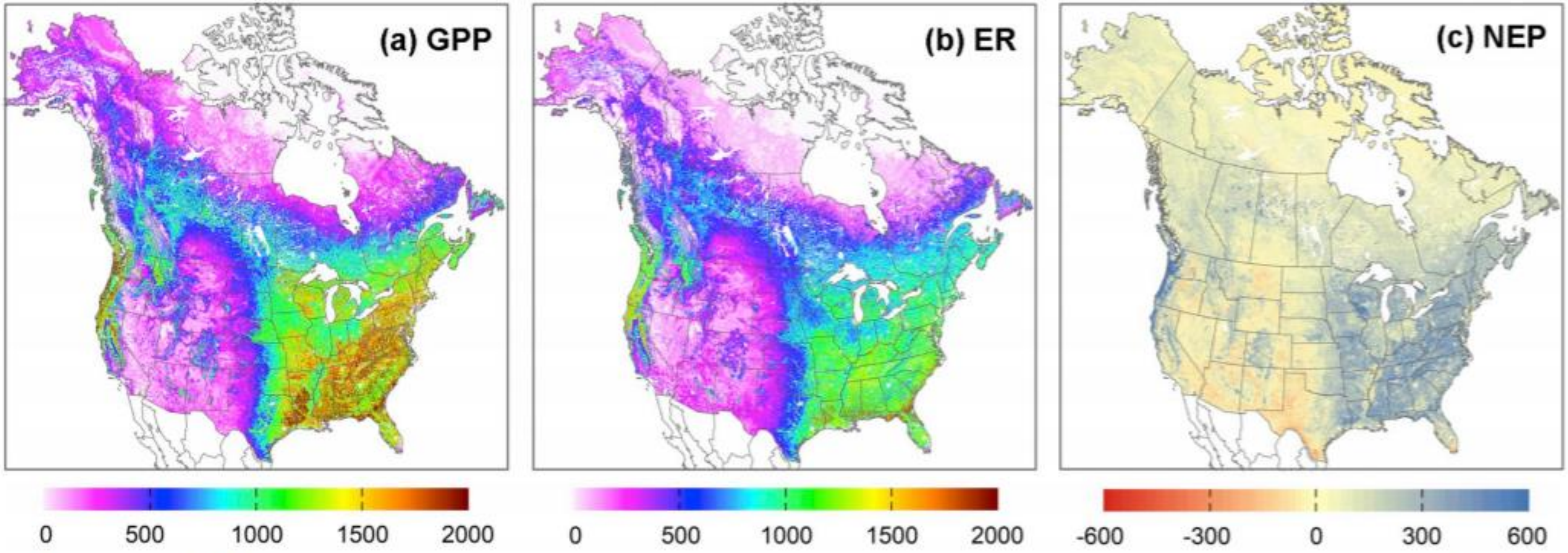
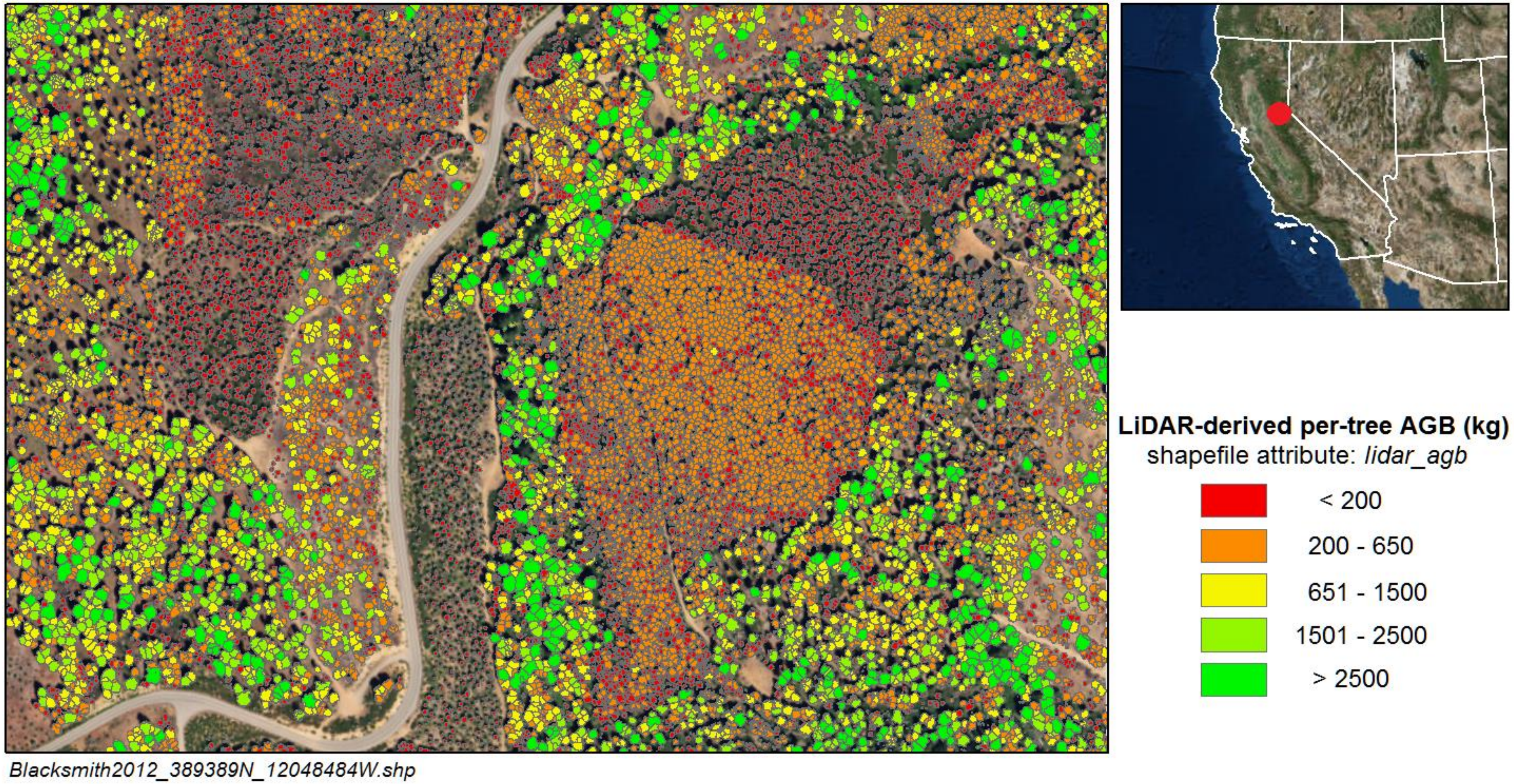


Fig. 5. Mean annual carbon fluxes over North America for the period 2001–2012: (a) GPP; (b) ER; and (c) NEP derived from a data-driven approach. The units for carbon fluxes are g C $m^{-2} yr^{-1}$.
(Adapted from Xiao et al., 2014a)

Lidar

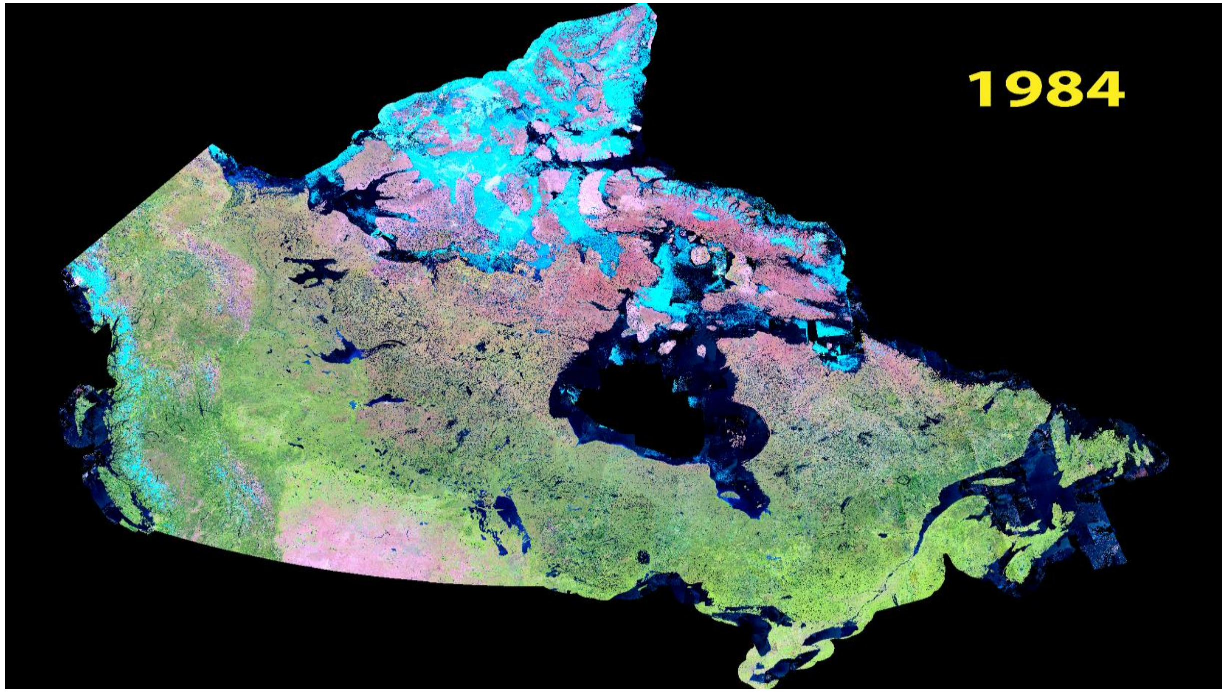
- Efficient 3D data collection
- High accuracy aboveground biomass estimates

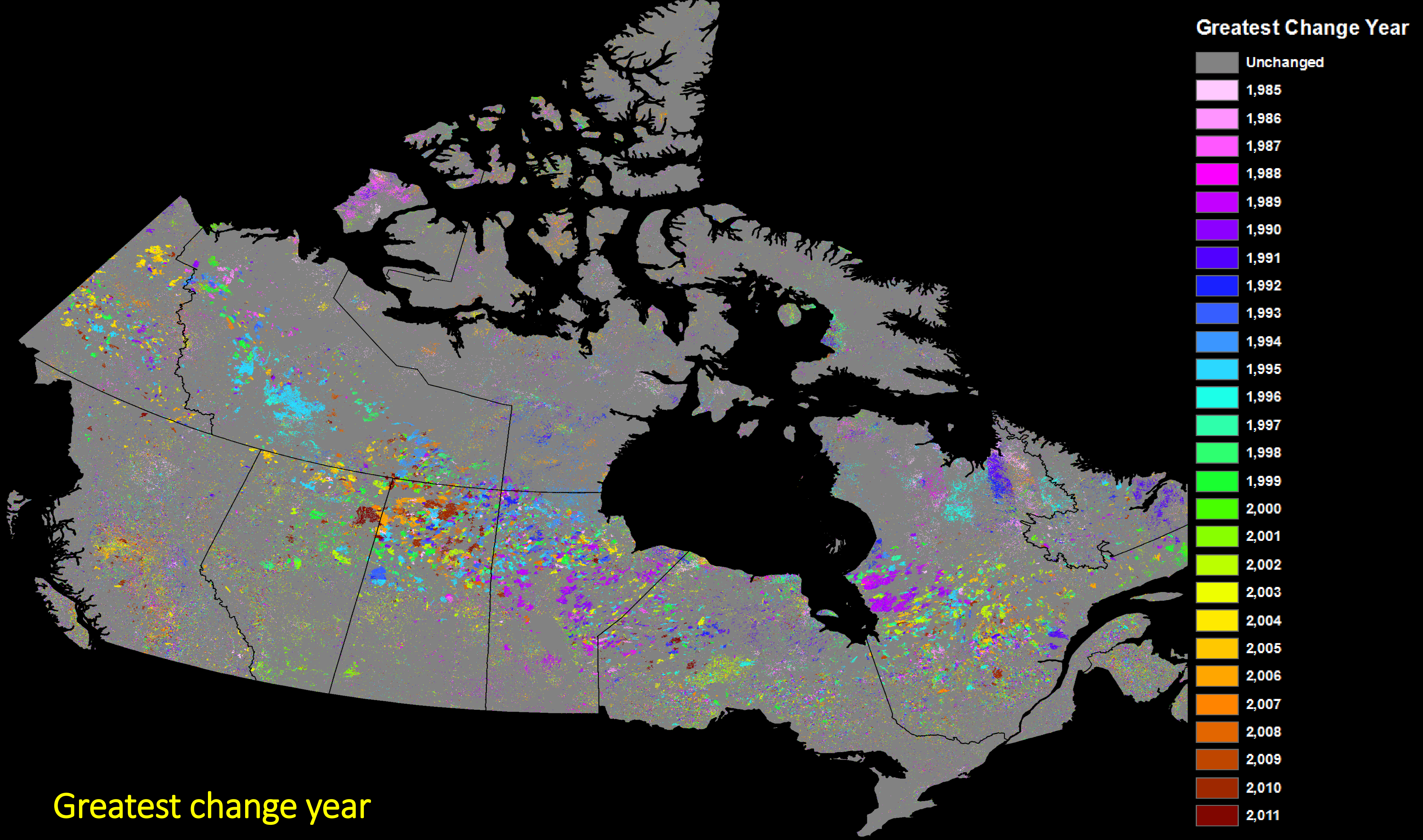


Xu, Q., A. Man, M.M. Fredrickson, Z. Hou, J. Pitkanen, B. Wing, C. Ramirez, B. Li, and J. Greenberg. 2018. LiDAR-Derived Aboveground Biomass and Uncertainty for California Forests, 2005-2014. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1537

Landsat

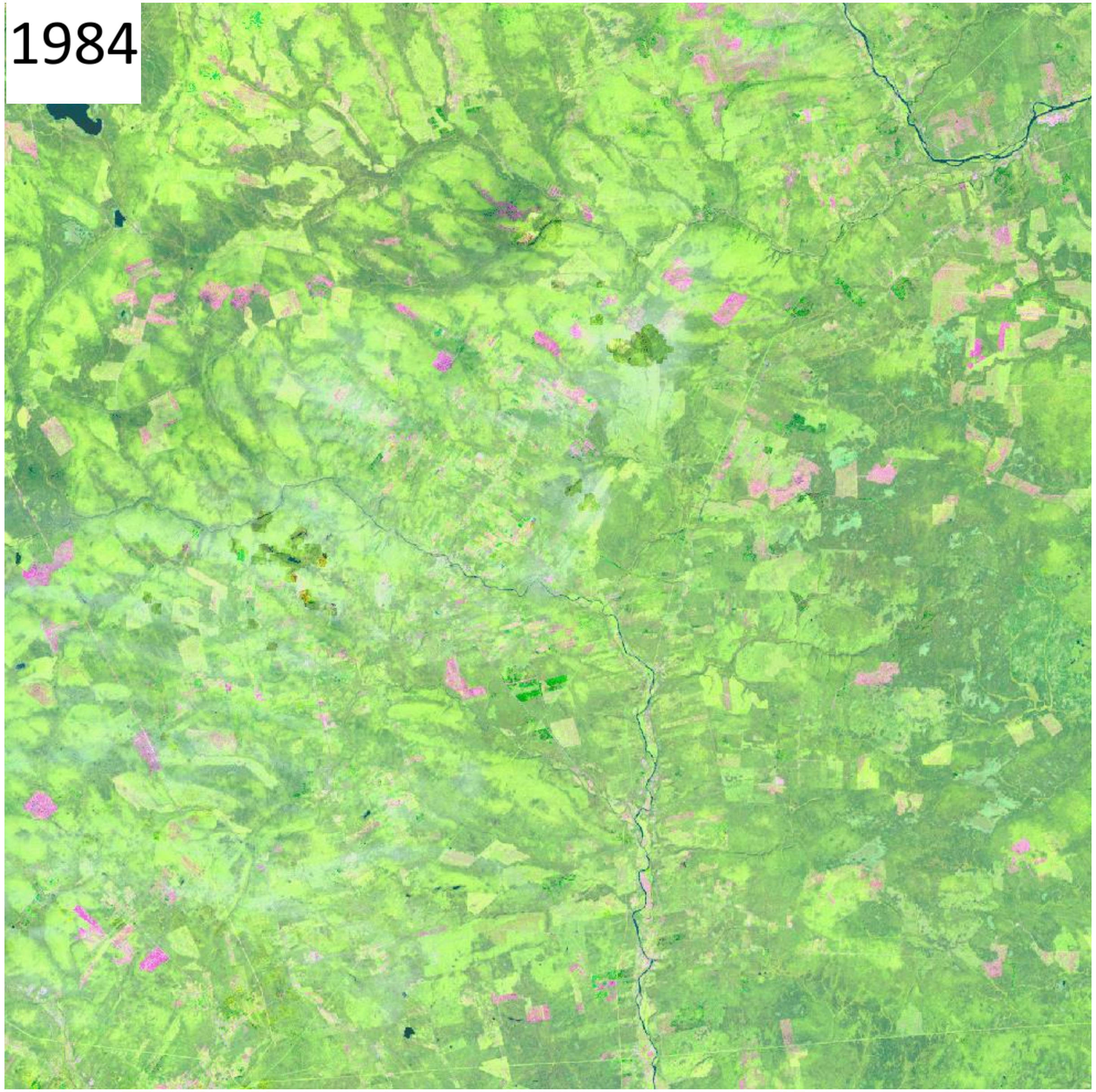
- Large time dimension
- Moderate spatial resolution
- Moderate temporal resolution
- High accuracy disturbance/change estimates
  - Quantification of carbon losses/gains

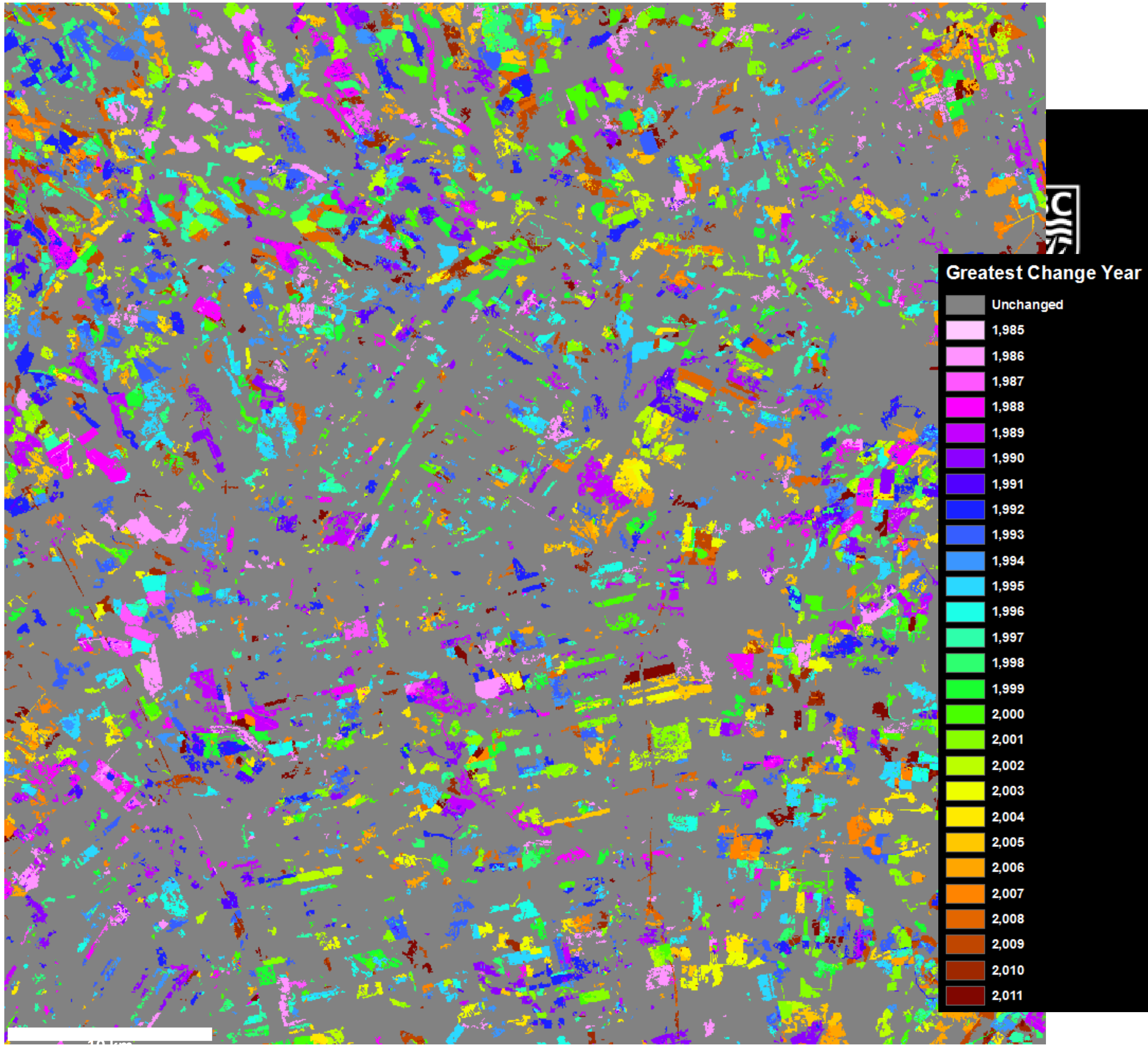




Greatest change year

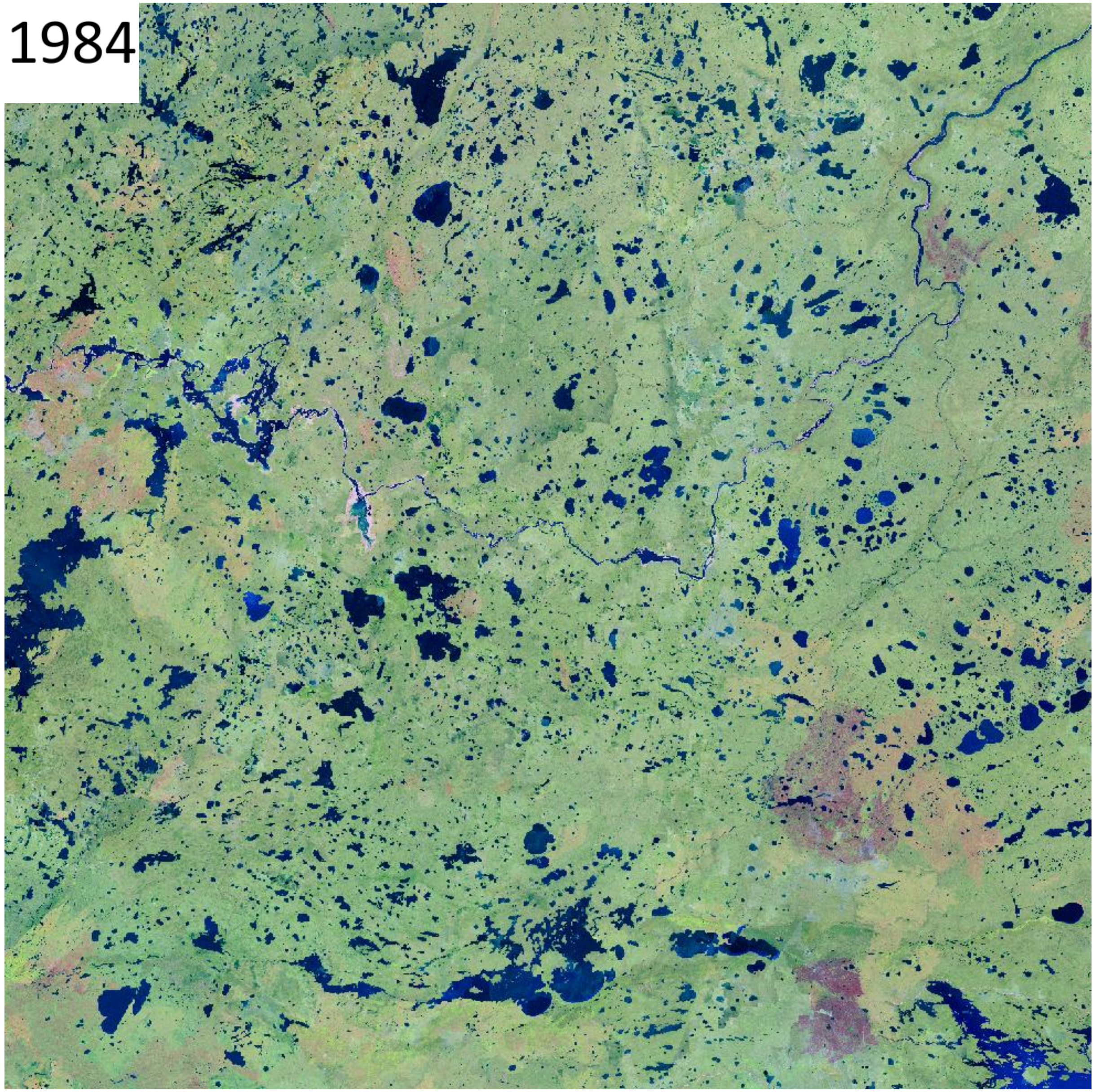
New Brunswick

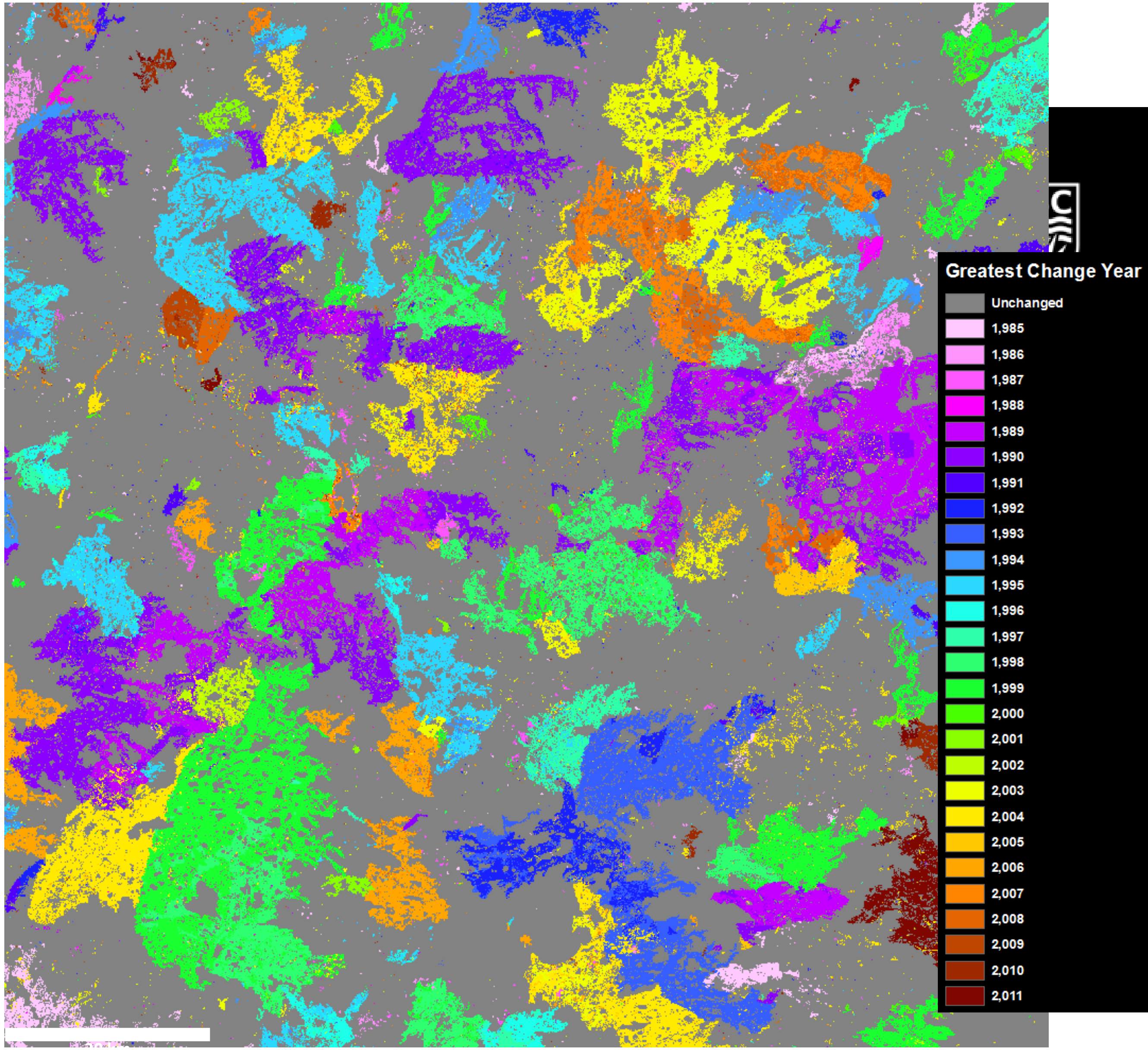




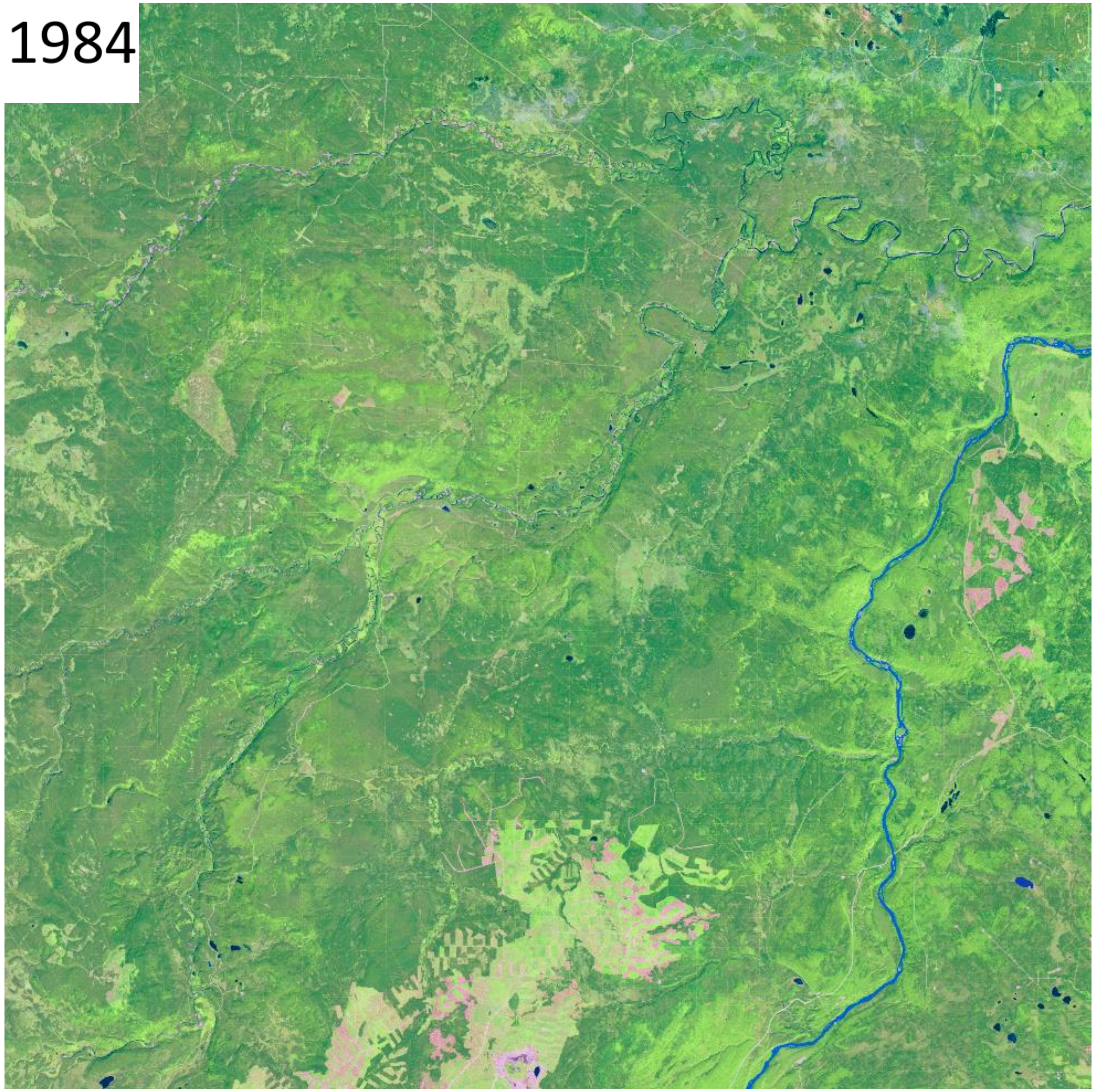
Manitoba

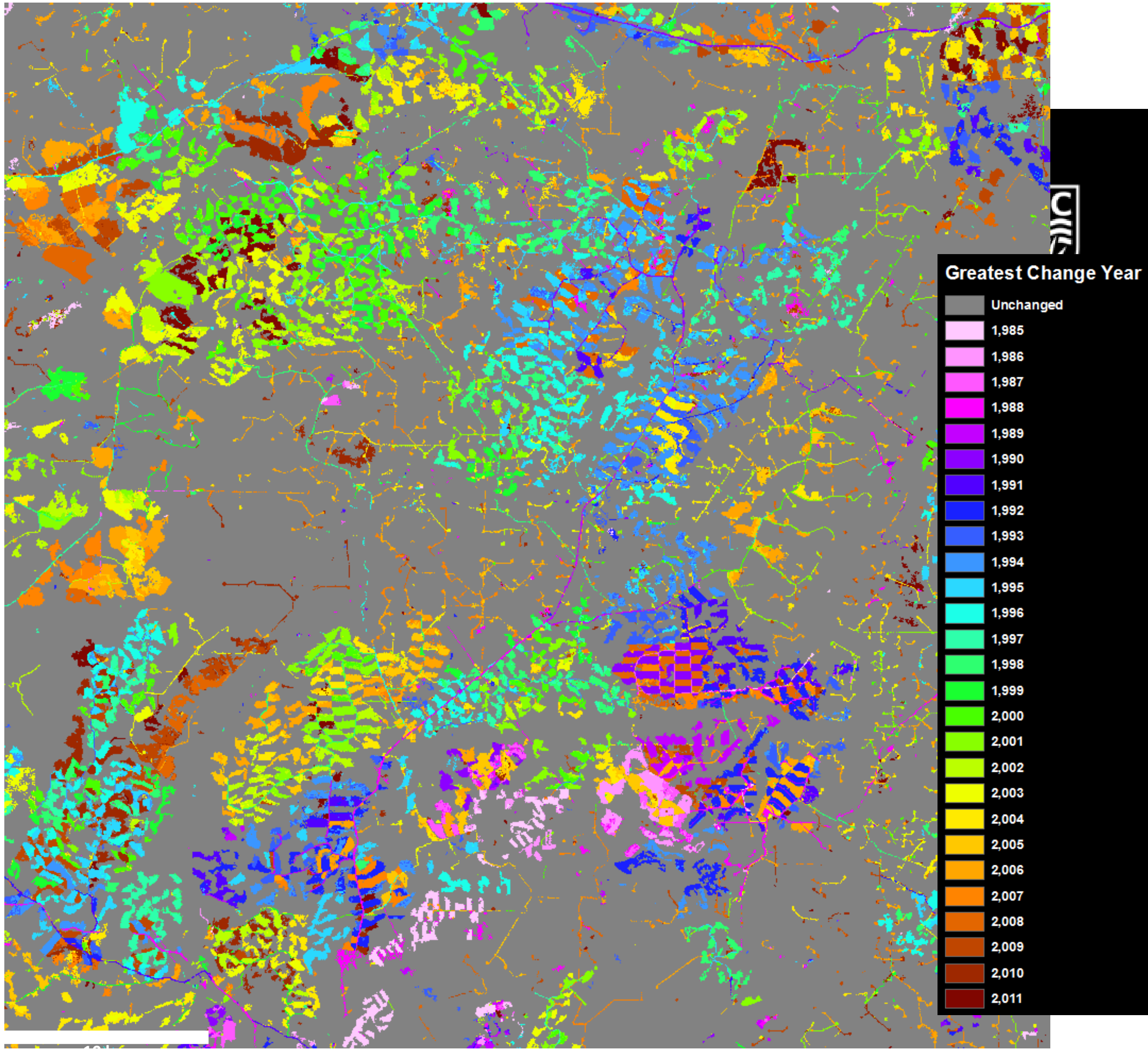
1984



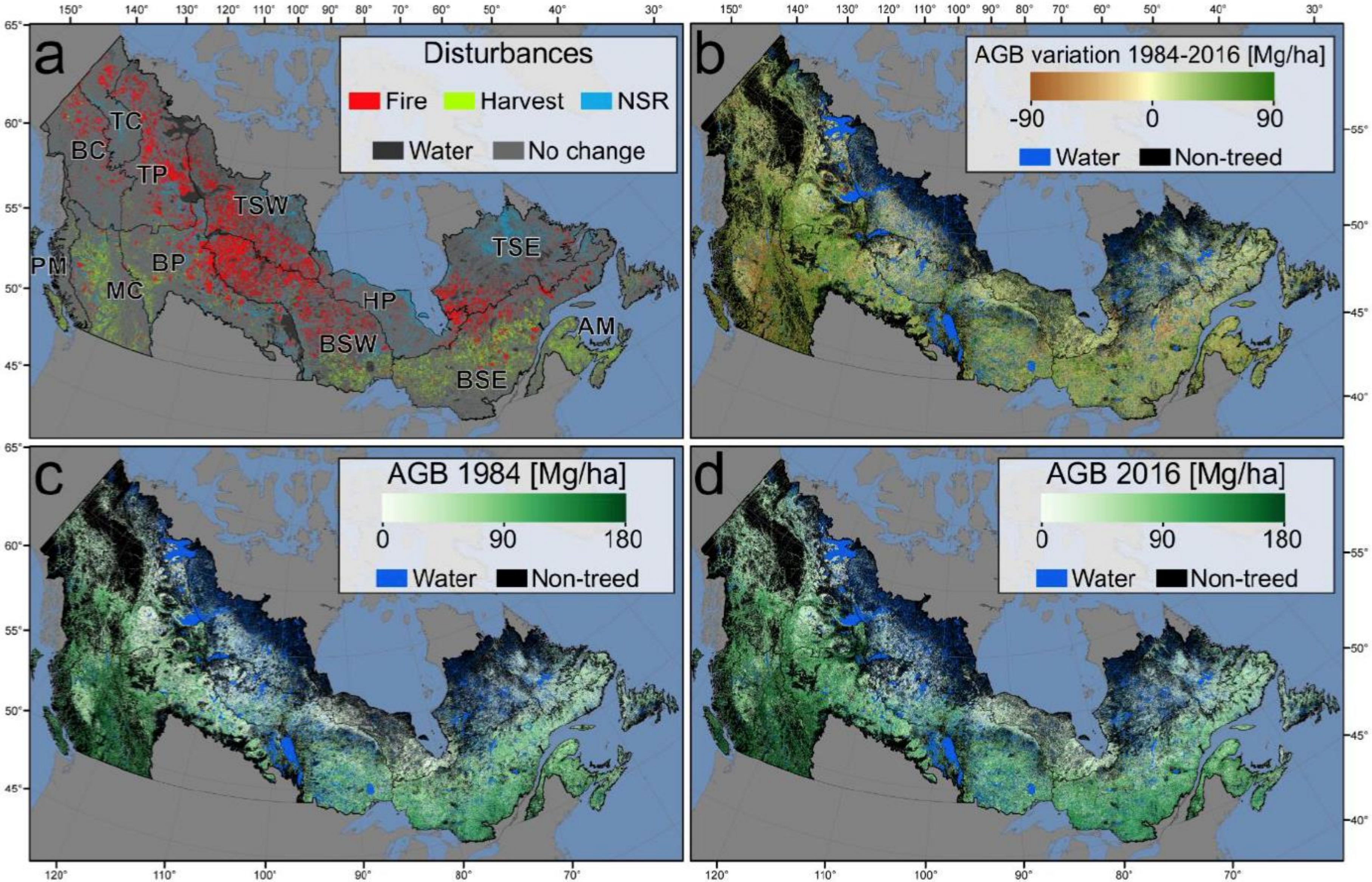


Alberta


1984


Greatest Change Year
Unchanged
1,985
1,986
1,987
1,988
1,989
1,990
1,991
1,992
1,993
1,994
1,995
1,996
1,997
1,998
1,999
2,000
2,001
2,002
2,003
2,004
2,005
2,006
2,007
2,008
2,009
2,010
2,011

Combining Datasets: Lidar & Landsat



Biosphere Monitoring

Field & Carbon Flux Towers

- Point based data collection
  - Limited spatial coverage
- Operational costs
  - To install towers
  - To conduct field work
- Limited collection of standardized data

Remote Sensing Earth Observation

- Efficient data collection
- Large spatial coverage
  - And high spatial resolution
- Free
  - in the case of Landsat & MODIS
- Standardized data
- Collections back to the 80s & 70s
  - In the case of Landsat

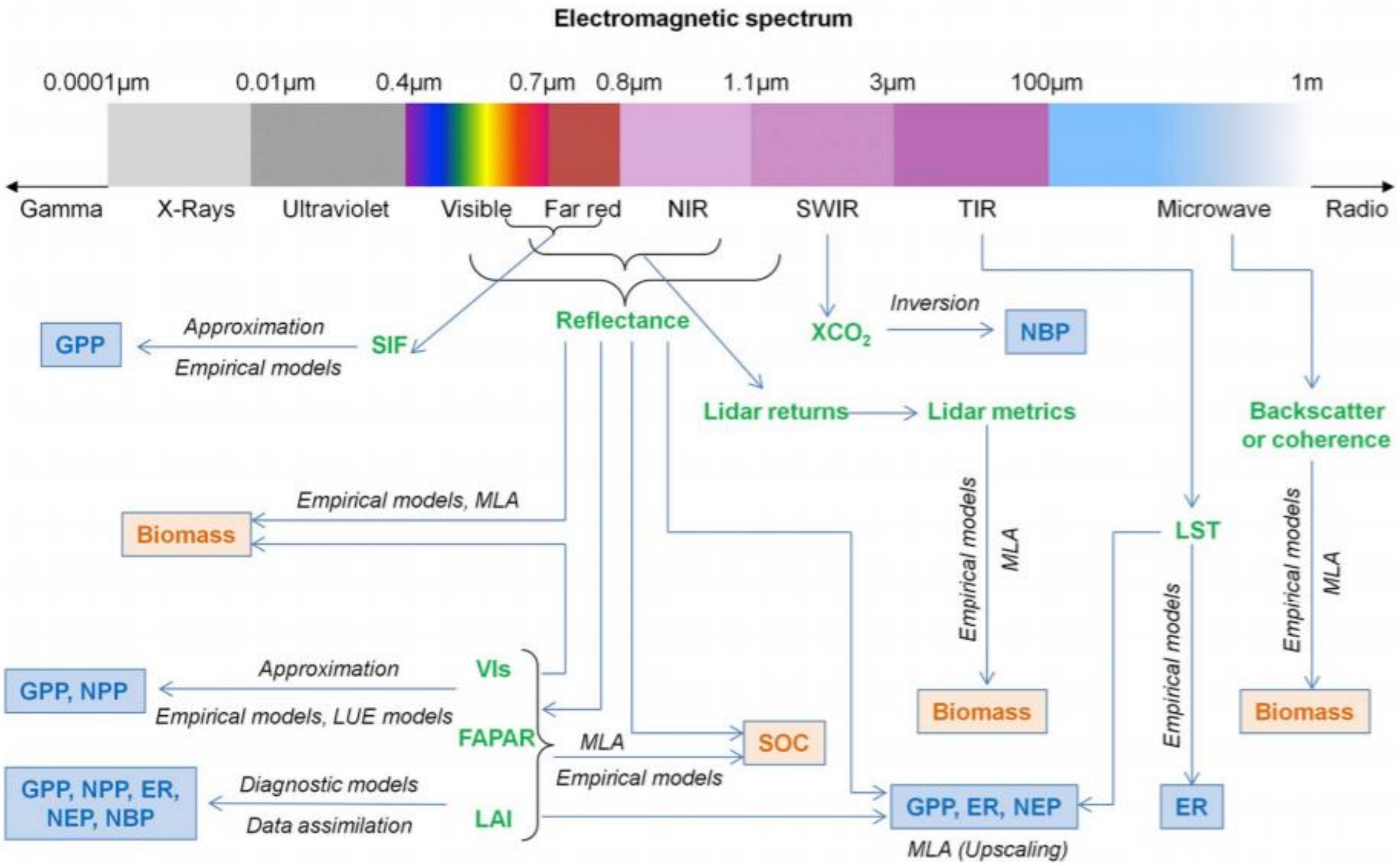


Fig. 2. The electromagnetic spectrum and the remote sensing of the terrestrial carbon (C) cycle. The C flux components typically consist of gross primary production (GPP), net primary production (NPP), ecosystem respiration (ER), net ecosystem production (NEP), and net biome production (NBP). The C stocks consist of biomass and soil organic C (SOC). NIR, SWIR, and TIR stand for near-infrared, shortwave infrared, and thermal infrared wavelength, respectively, while MLA stands for machine learning approaches.

Important Topics

- What is the biosphere?
- Describe the pattern of gross and net photosynthesis as temperature increases
- Which of these are carbon sinks? Which are carbon sources?
  - Growing forest
  - Wildfire
  - Insect outbreak (in a forest)
- How has the biosphere been monitored historically?
- Describe the use of Landsat to monitor the biosphere.
  - What can it track and how is that related to carbon?
  - Why is it advantageous?

Additional Resources

- Sunlight on Earth: http://earthobservatory.nasa.gov/Features/EnergyBalance/
- Photosynthesis and respiration: https://www.ck12.org/life-science/Connecting-Cellular-Respiration-and-Photosynthesis-in-Life-Science/lesson/Connecting-Cellular-Respiration-and-Photosynthesis/?referrer=featured_content
- Human appropriation of net primary productivity: http://www.eoearth.org/view/article/153031/