National Aeronautics and Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

SilvaCarbon
http://egsc.usgs.gov/silvacarbon/index.html
@SilvaCarbon

Remote sensing of forest cover and change assessment for carbon monitoring

Instructors: Cindy Schmidt and Amber McCullum

Week 2: June 16, 2016

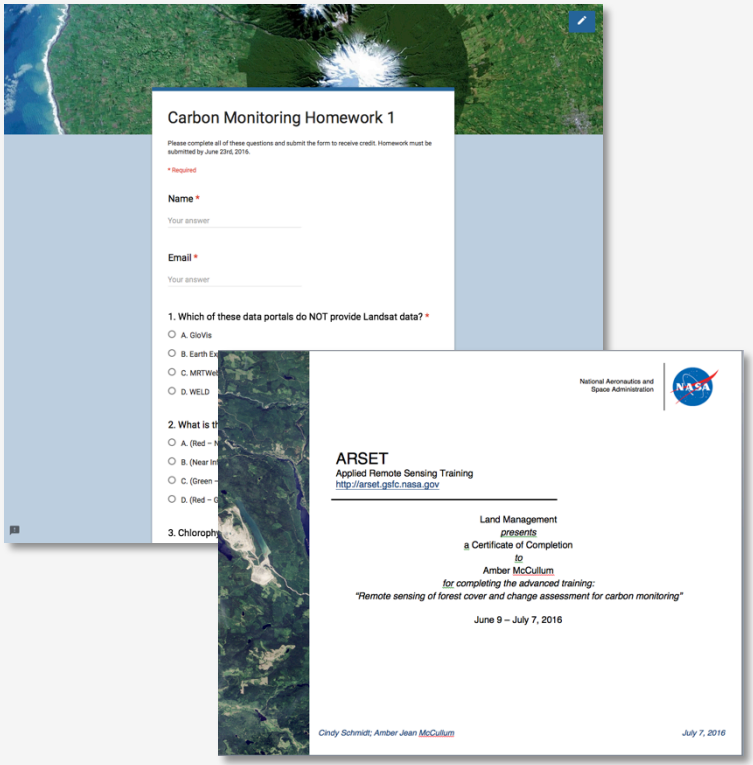
SilvaCarbon

Course Structure

- One lecture per week – every Thursday from June 9 to July 7 at 1:00-2:30pm and 10:00-11:30pm EDT(-04:00 UTC)
- Please only sign up for and attend the same session each week
  - Lectures
  - Q&A
  - Homework exercises
- Webinar recordings, PowerPoint presentations, in-class exercises, and homework assignments can be found after each session at:
  - http://arset.gsfc.nasa.gov/ecoforecasting/webinars/carbon-monitoring-2016
  - Q&A: Following each lecture and/or by email (cynthia.l.schmidt@nasa.gov) or (amberjean.mccullum@nasa.gov)

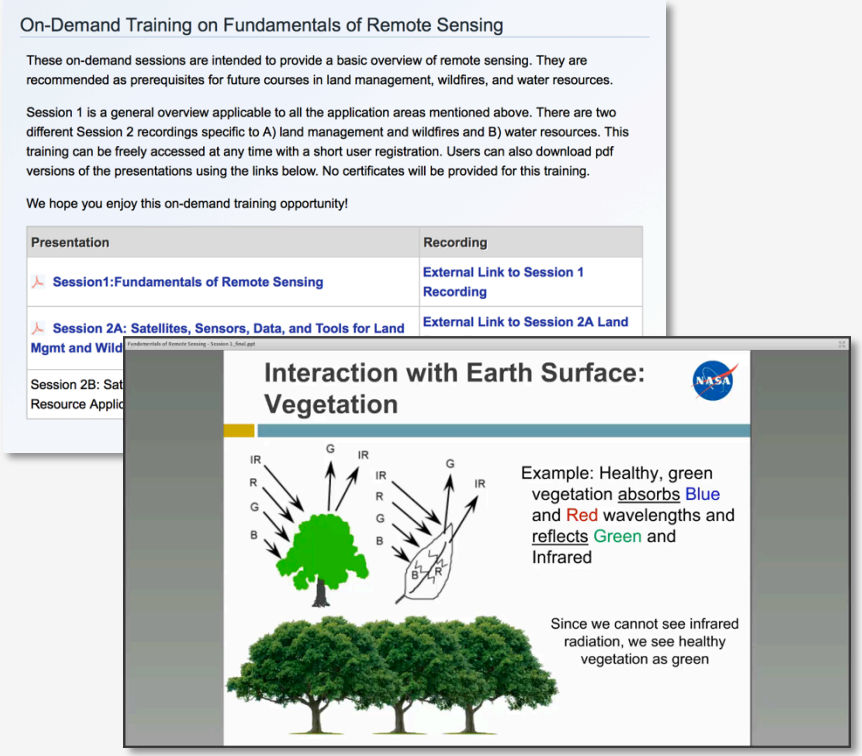
Homework and Certificates

- Homework
  - Answers must be submitted via Google Form
- Certificate of Completion:
  - Attend all 5 webinars
  - Complete all 5 homework assignments by the deadline (access from ARSET website above)
    - Week 2 HW Deadline: June 30th
  - You will receive certificates approximately 2 months after the completion of the course from: marines.martins@ssaihq.com



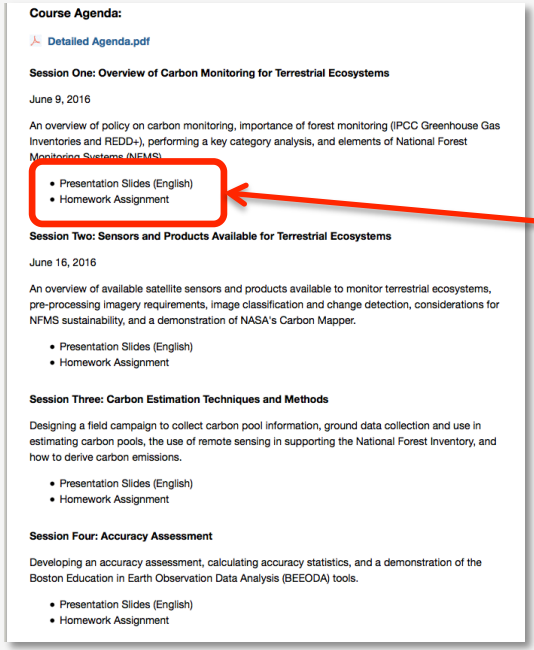
Prerequisite

- Fundamentals of Remote Sensing
  - Sessions 1 and 2A (Land)
  - On-demand webinar available anytime
  - http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing



Accessing Course Materials

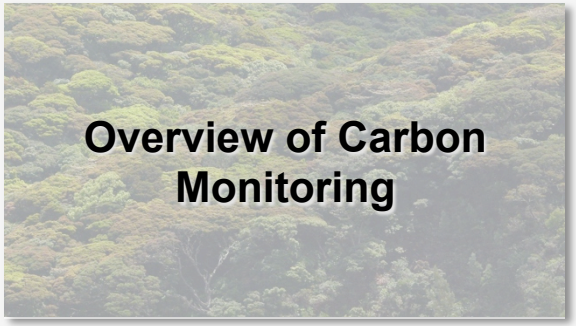
https://arset.gsfc.nasa.gov/land/webinars/carbon-monitoring-2016



Course materials are provided here using each specified link and will be active after each week

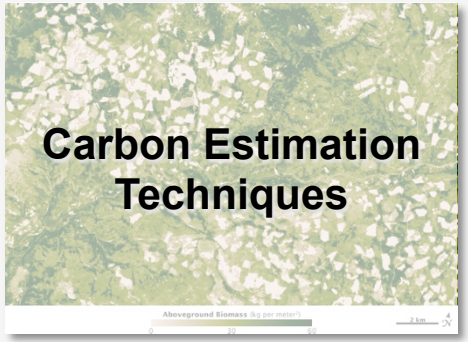
Course Outline

Week 1

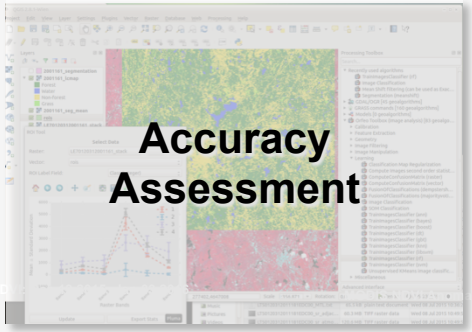


Week 2

Week 3



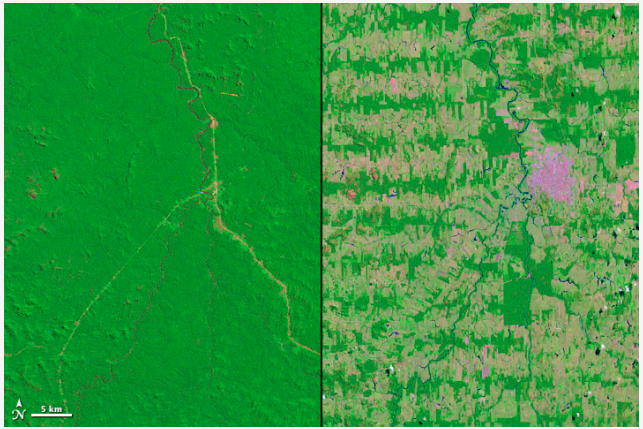
Week 4



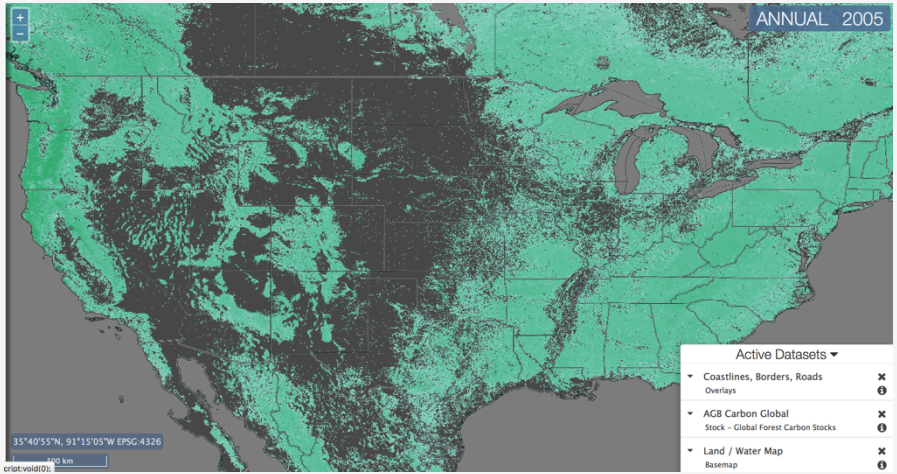
Week 5

Week 2 Agenda

- About ARSET
- What is Activity Data?
- Remote sensing data sources
- Pre-processing image requirements
- Image classification and change detection
- Considerations for National Forest Monitoring Systems (NFMS) sustainability
- NASA's Carbon Mapper
- Q&A



(Left) Deforestation in Brazil as shown by Landsat images from 1975 and 2012. Credit: Earth Observatory. (Below) NASA's Carbon Mapper

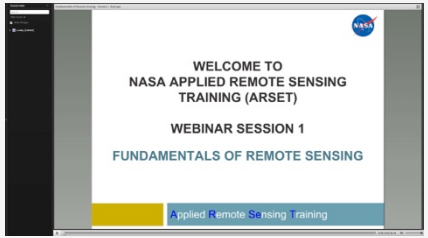


About ARSET

Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov

Training activities for environmental professionals to increase usage of NASA observational and modeling data for decision-making support.



Online Webinars

- 1 hr a week, 4-6 weeks
- Live & recorded
- Include demos on data access

In-person Workshops

- Held in a computer lab for 2 - 4 days
- Focus on data access
- Locally relevant case studies

Train the Trainers

- Courses & training manuals for those interested in doing their own remote sensing trainings

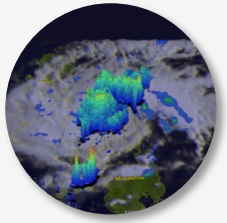
Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov

Provide online and on-site trainings tailored to:

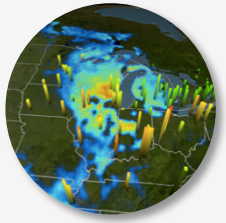
- policy makers
- regulatory agencies
- applied environmental professionals

to increase the use of NASA Earth Science models & data for environmental applications:

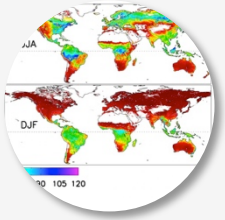


Disasters

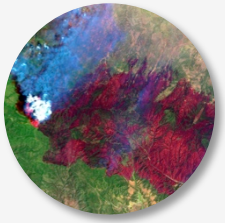
Ecoforecasting



Health & Air Quality



Water Resources



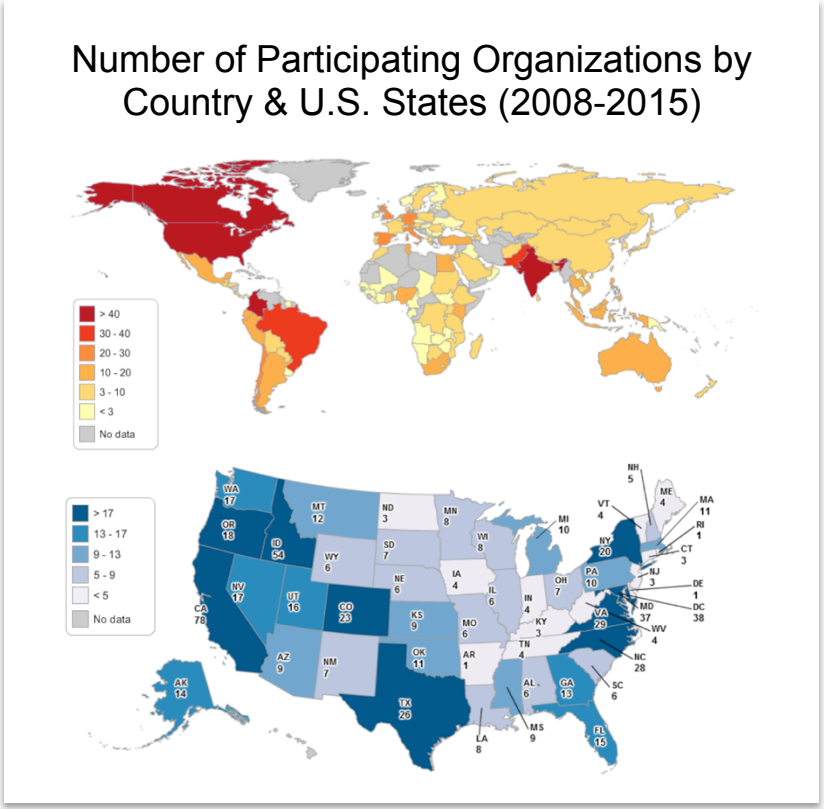
Wildfires

ARSET Trainings

Impact & Accomplishments

- 68 Trainings Completed
- 4,900+ participants worldwide from:
  - 1,600+ organizations
  - 130+ countries
- More participants trained in 2015 than all previous years combined

“The greatest benefit [of this training] is knowing where to find and access remote sensing data concerning vegetation cover and basic tools for analyzing habitat trends and characterizing rate of change.”
– U.S. Federal Government Employee, 2016 Advanced NDVI webinar



What is Activity Data?

What is Activity Data?

- IPCC guidelines refer to two basic inputs for calculating greenhouse gas inventories: **activity data** and **emission factors**
- Encourage spatially explicit land conversion information, derived from sampling or wall-to-wall mapping techniques
  - Examples of Activity Data include areas transferred from forest to other land uses
- Estimates are generally derived from maps produced using remote sensing
  - Especially good for tropical countries where accessibility to forested areas may be limited

Activity Data

Key role for Earth observations in monitoring forests

- Fundamental requirement of national monitoring systems are that they:
  - Measure changes throughout all forested area
  - Use consistent methodologies at repeated intervals to obtain accurate results
  - Verify results with ground-based or very high resolution observations

- Remote sensing data supported by ground-based observations is the only practical solution to implement for inaccessible forest areas

Activity Data

Requirements for REDD+ Activities

- Areas of different forest types
- Annual conversion from forest to non-forest land uses
- Annual transfer from one forest type to another
- Annual conversion from non-forest land uses to planted or other forest

A

B

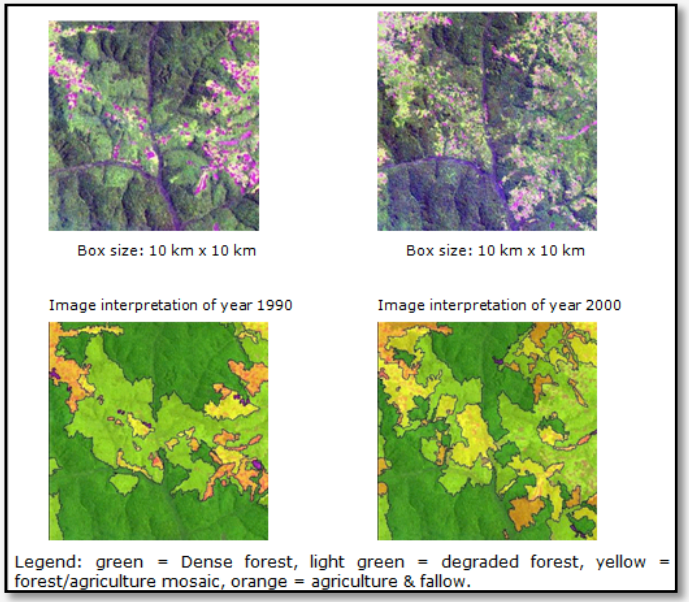
Example of (A) conversion from forest to non-forest: Small subsistence plots in Central Africa replace once-forested hillsides; (B) conversion of one forest type to another: Palm oil plantations in Indonesia replace primary forests

Source: earthobservatory.nasa.gov

Activity Data

Recommended remote sensing map products

- Forest/non-forest map (+ change maps)
- Forest Stratification
- Comprehensive land use maps (+ change)
- Change within forest land



Landcover maps derived from Landsat for an area in the Congo Basin. Source: GOFC-GOLD Sourcebook 2014

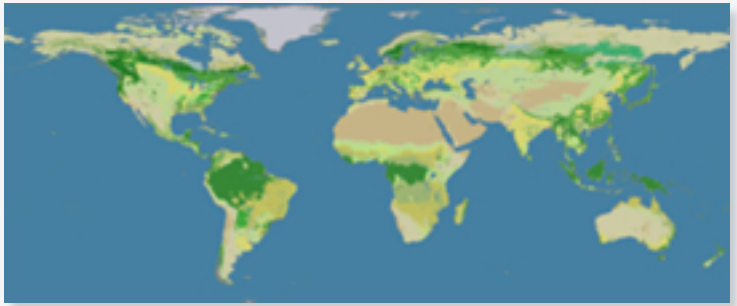
Remote Sensing Data Sources

Remote Sensing Data Sources

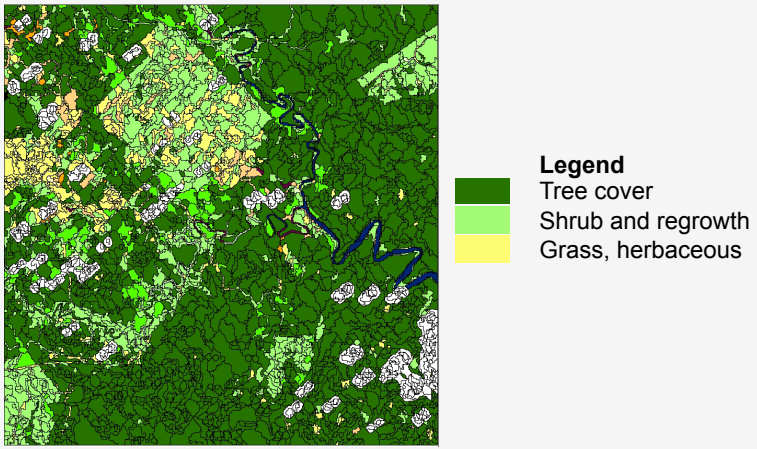
Overview

- Coarse spatial resolution (optical)
- Medium spatial resolution (optical)
- High spatial resolution (optical)
- Synthetic Aperture Radar
- LiDAR

MODIS Land Cover Map



Landsat Land Cover Map



Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.

Remote Sensing Data Sources

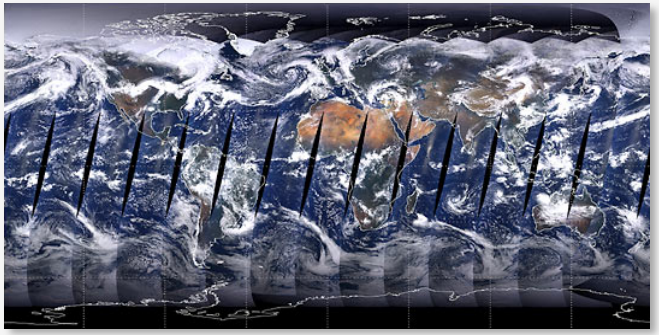
Considerations

- What geographical, phenological, and atmospheric (especially persistent cloud cover) conditions exist?
- What are the spectral regions, and bands within them, and how do these relate to the potential for distinguishing the land-cover types of interest, and changes among them?
- What is the spatial resolution of the data and how appropriate is it, relative to the scale of the land-cover changes to monitor?
- What is the temporal resolution in terms of potential frequency of acquisition of non-cloudy observations compared to the desired frequency of monitoring?
- What is the longevity of the image archive length – does this meet the historical mapping needs?
- What are the cost implications of these data in terms of purchase and analysis?
- What are the future satellite development and launch commitments?

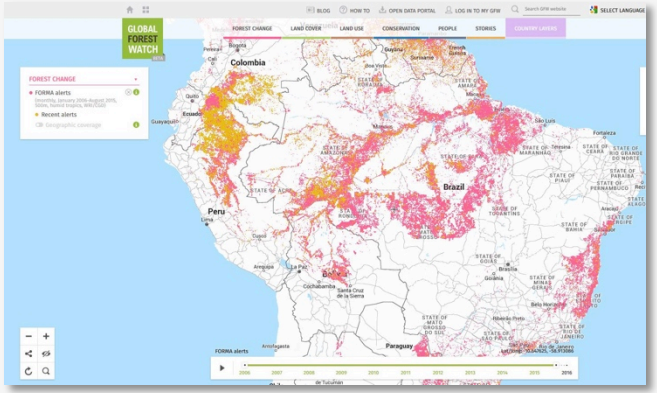
Remote Sensing Data Sources

Coarse Spatial Resolution (Optical)

- Greater than 250m
- Ex: MODIS, CBERS-2
- High temporal resolution useful for early warning and detection of forest clearing and degradation
- Example: FORMA
  - a monitoring system that issues monthly forest loss alerts for the humid tropics.
  - Generates alerts of likely forest clearing activity every 16 days at 500 m spatial resolution (Hammer et al. 2014)



NASA Worldview



FORMA Alerts from Global Forest Watch

Remote Sensing Data Sources

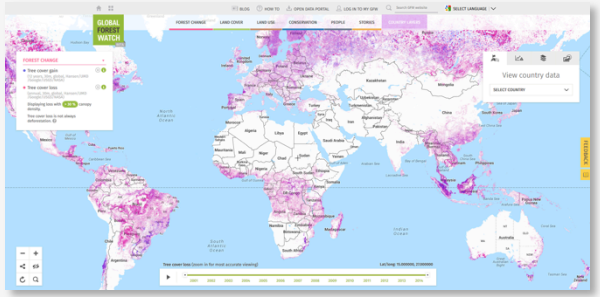
Medium Spatial Resolution (Optical)

- 10m – 80m spatial resolution
- Most common: Landsat (30m) and more recently, Sentinel 2
- Benefits:
  - Historical archive (early 1980s)
  - Easily accessible and freely available
  - Global coverage
- Limitations: Areas of persistent cloud cover
- Example: Global Forest Watch (Hansen et al. 2013)

Landsat satellite

Credit: NASA

Global Forest Watch



Remote Sensing Data Sources

High Spatial Resolution (Optical)

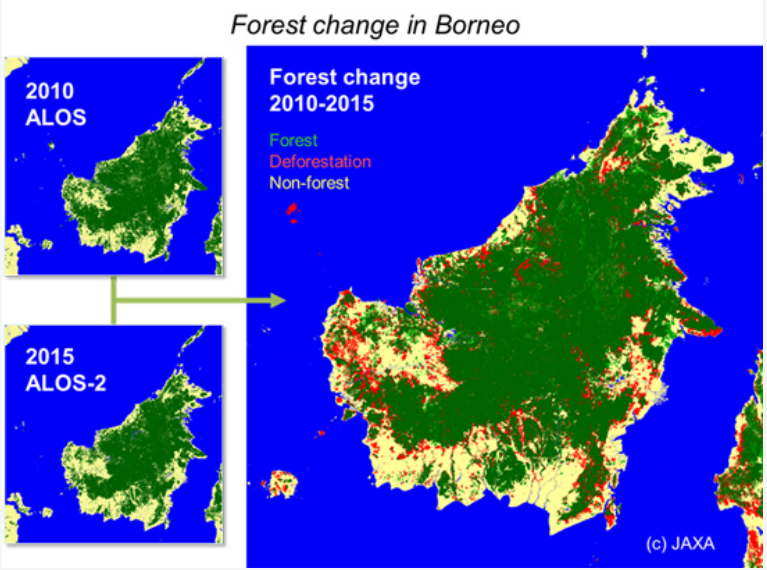
- Better than 10m spatial resolution
- Examples: Worldview 2 and 3
- Primarily used for accuracy assessment, sampling transects, or hot spot assessment
- Benefits
  - Forest activity data can be monitored more accurately and with greater differentiation
- Limitations
  - Higher acquisition and processing costs
  - Spatial and temporal coverage may not be adequate

Nilo Forest Reserve, Tanzania. Credit: Digital Globe and Norsk Regnesentral

Remote Sensing Data Sources

Synthetic Aperture Radar

- Two types: C-band and X-band SAR (shorter wavelengths) and L-band SAR (longer wavelengths)
- Can detect forest/non-forest and changes
- Benefits:
  - Useful in areas of persistent cloud cover
  - Can provide information on forest structure; complementary to optical data
- Limitations:
  - Difficult to process
  - Not currently used operationally

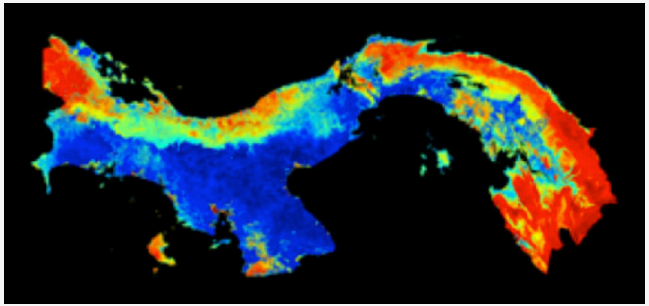


Forest change in Borneo (Masanobu et al. 2014)

Remote Sensing Data Sources

LiDAR

- Provides information on forest structure (e.g. tree height, canopy volume) and biomass
- Currently acquired using aircraft platform – no operational LiDAR satellites
- Benefits
  - Provides detailed information of forest structure
  - Verification of biomass estimates, reduces need for ground sampling
- Limitations
  - Expensive to acquire & process



National carbon map of Panama by integrating field data with satellite imagery and LiDAR (Carnegie Institution, 2013). Credit: Carnegie Institution.

Pre-processing Requirements

Satellite Data Pre-Processing

Overview

- Necessary because it allows satellite observations over different time periods to be compared to each other
- Geometric Corrections (orthorectification)
  - Corrects for angle of view of the satellite sensor
  - Corrects for high relief terrain
- Radiometric corrections
  - Corrects for different atmospheric conditions between multi temporal images
- Satellite imagery is often available with both corrections

Satellite Data Pre-Processing

Geometric Correction

- Most important for detecting change over time using multi-temporal satellite imagery
- Image alignment
  - Images need to be aligned
  - Can be done using image processing software (i.e. ERDAS imagine, ENVI, etc.)
- Image distortion due to scanning system motion, platform instability, or high relief terrain
  - More apparent in aerial photographs than in satellite imagery
  - Use of a Digital Elevation Model (DEM) required for correction
  - Needs specialized software
- Most satellite imagery has been geometrically corrected and projected to a geographic reference system. **It is always good to check**.

Satellite Data Pre-Processing

Radiometric Correction

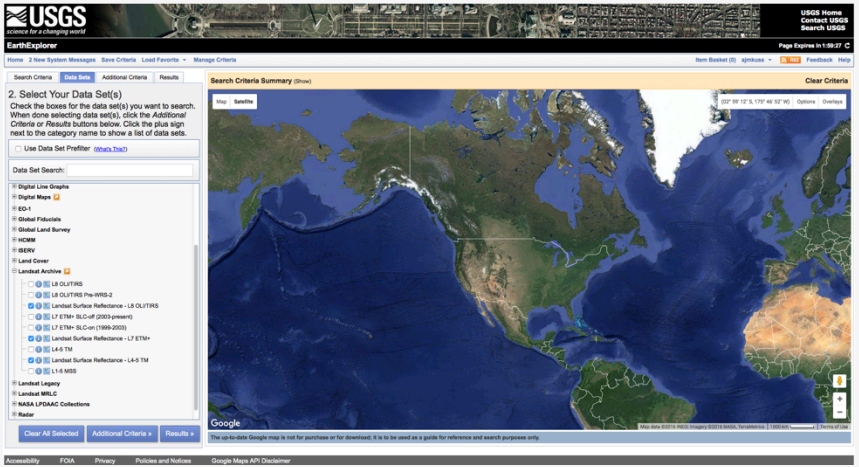
- The pixel values of a single date image are dependent on the viewing geometry of the satellite, the location of the sun and specific weather and atmospheric conditions.
- Radiometric correction enables comparison of one image to another (of multiple images for large regions and for multi-date images of the same region)
- “Raw” pixel values are converted to surface reflectance using various methods but satellite imagery (Landsat, MODIS) can now be acquired already corrected.

Subsets of a Landsat image displaying (A) natural color; (B) top-of-atmosphere correction; and (C) surface reflectance. Credit: USGS

Satellite Data Pre-Processing

Landsat Surface Reflectance Products

- Surface Reflectance products generated from the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)
  - Originally developed by NASA
- Available from EarthExplorer:
  - http://earthexplorer.usgs.gov

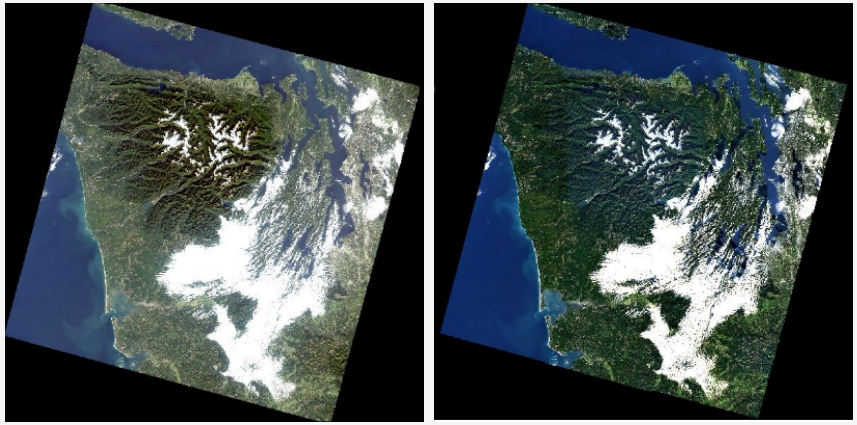


Landsat 4-7 and 8 Surface Reflectance Products Available from EarthExplorer

Satellite Data Pre-Processing

Landsat Surface Reflectance Products Caveats

- Products considered provisional
- Landsat 7 images not gap-filled
- Usefulness of surface reflectance products reduced in:
  - Hyper-arid or snow-covered regions
  - Low sun angle conditions
  - Coastal regions
  - Areas with extensive clouds
- Panchromatic band (ETM+ Band 8) not processed
- Specific date ranges: Landsat 4, 5, 7



Example of the unprocessed Landsat image (top) and the LEDAPS processed Landsat image (right). Credit: USGS

Image Classification and Change Detection

Image Classification

Overview

- Used for mapping forest/non-forest, land cover, or forest stratification
- There are many methods: visual interpretation, pixel-based (supervised, unsupervised), and object-based
- For improved results, often needs ground and/or other ancillary information (topographic or climatic data)
- Needs specialized software (commercial or open source) and training

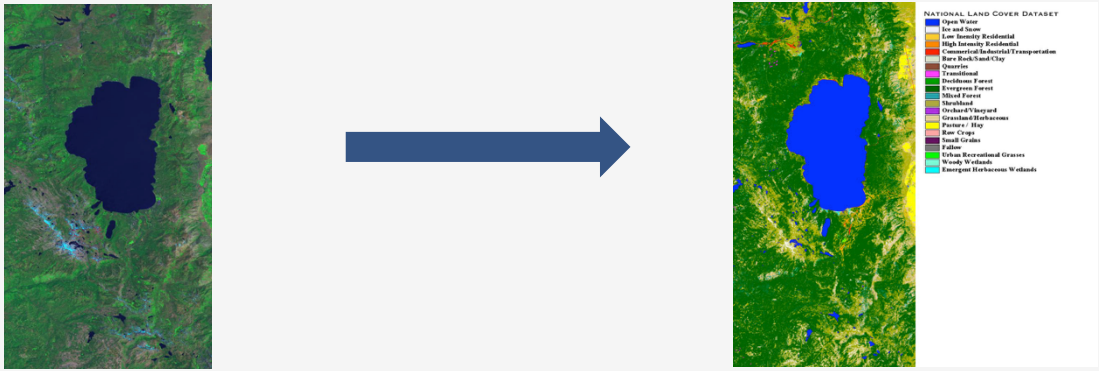
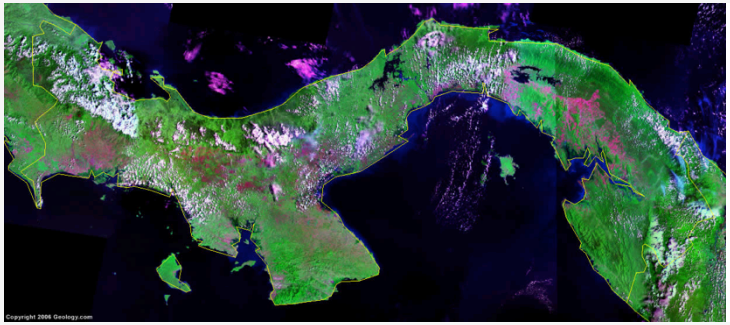
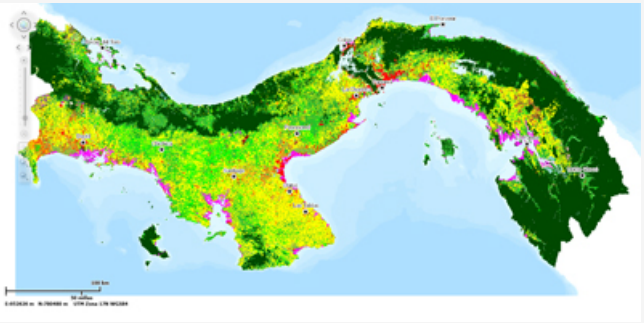


Image Classification

Land Cover Classes

- The image classification processes turns data (pixel values) into information
- That information must be categorized (e.g. forest/non-forest)
- The IPCC Good Practice Guide for Land Use, Land-Use Change and Forestry (GPG-LULUCF 2003) specifies top-level categories as:
  - Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land
- Defining classes will depend on the project/program needs and the region





Land cover map of Panama. Credit: ANAM.

Image Classification

Types of Maps

Map products/ classification system	Purpose	Description	Minimum Mapping Unit	Temporal Product Frequency
Forest/Non-Forest	Trend analysis, basis for other products	Extent of all forest types	< 0.5 ha	Annual
Forest Stratification	Provide consistency in biomass density with a stratum for more accurate estimates	Suggested primary stratification: primary forest, modified natural forest, planted forest	< 0.5 ha	Annual
All Land-Use Categories	National baseline mapping	Consider using the UN-FAO Land Cover Classification System	< 0.5 ha	Annual

Image Classification

Summary of types of remote sensing data and their perceived operational status in estimating REDD+ activities

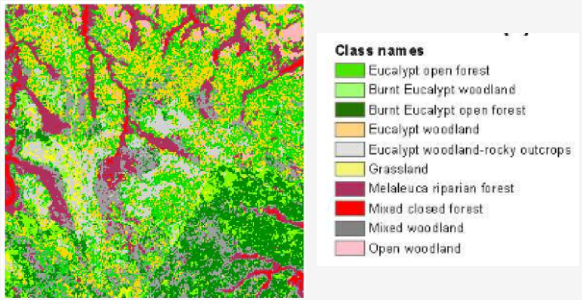
Map Product	Coarse resolution	Medium resolution	High resolution	L-band radar	C-band radar	X-band radar	LiDAR
Forest/Non-forest		Operational	Operational	Operational	R&D	Not used	Occasional use
Forest Stratification	Operational	Operational	Operational	Pre-Operational	R&D	Not used	Occasional use
All land use categories		Operational	Operational	Pre-Operational	R&D	Not used	Occasional use

Image Classification

Approaches

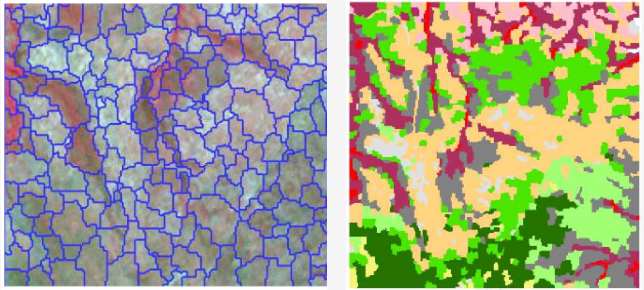
Pixel-based

- Each pixel is grouped into a class
- Useful where there are multiple changes in land use within a short period of time
- Best suited when there is complete data coverage and require methods to ensure time series consistency at the pixel level



Object-based

- Pixels with common spectral characteristics are first grouped together (segmentation)
- Useful for reducing speckle noise in radar images
- Useful for high spatial resolution imagery



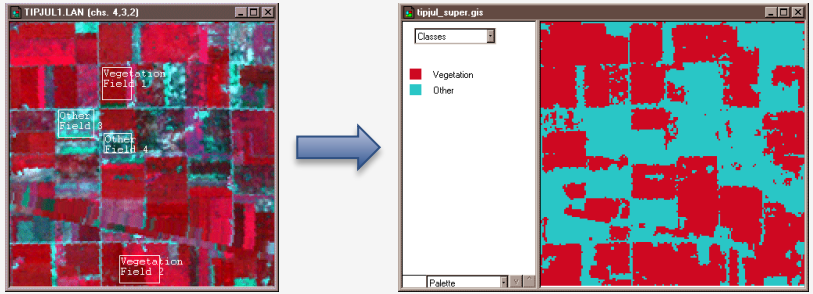
Whiteside et al., (2005), A Comparison of Object-Oriented and Pixel-Based Classification Methods for Mapping Land Cover in Northern Australia

Image Classification

Methods

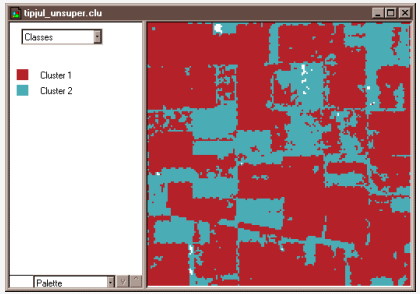
Supervised

- Uses expert-defined areas of known vegetation types (training areas) to tune parameters of classification algorithms
- Algorithm then automatically identifies and labels areas similar to the training data.



Unsupervised

- Uses classification algorithms to assign pixels into one of a number of user-specified class groupings
- Interpreters assign each of the groupings of pixels a value corresponding to a land cover class



Credit: David DiBiase, Penn State Department of Geography

Image Classification

Supervised Method

Supervised classification requires the analyst to select training areas where they know what is on the ground and then digitizes a polygon within that area

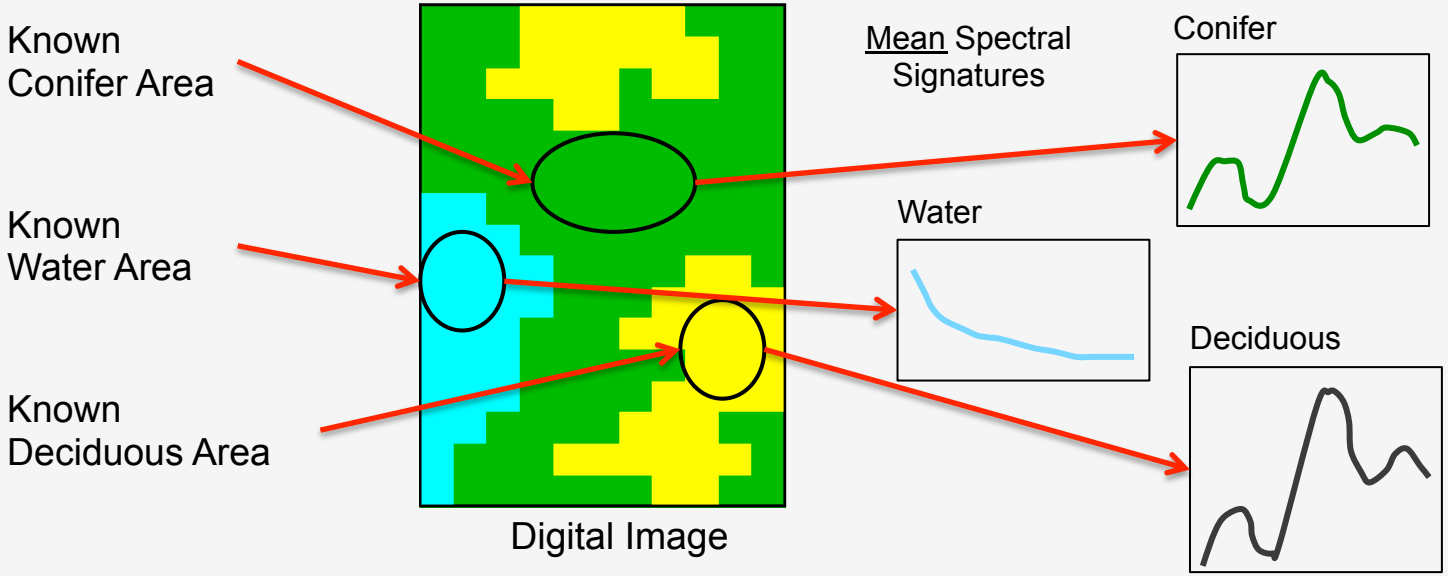
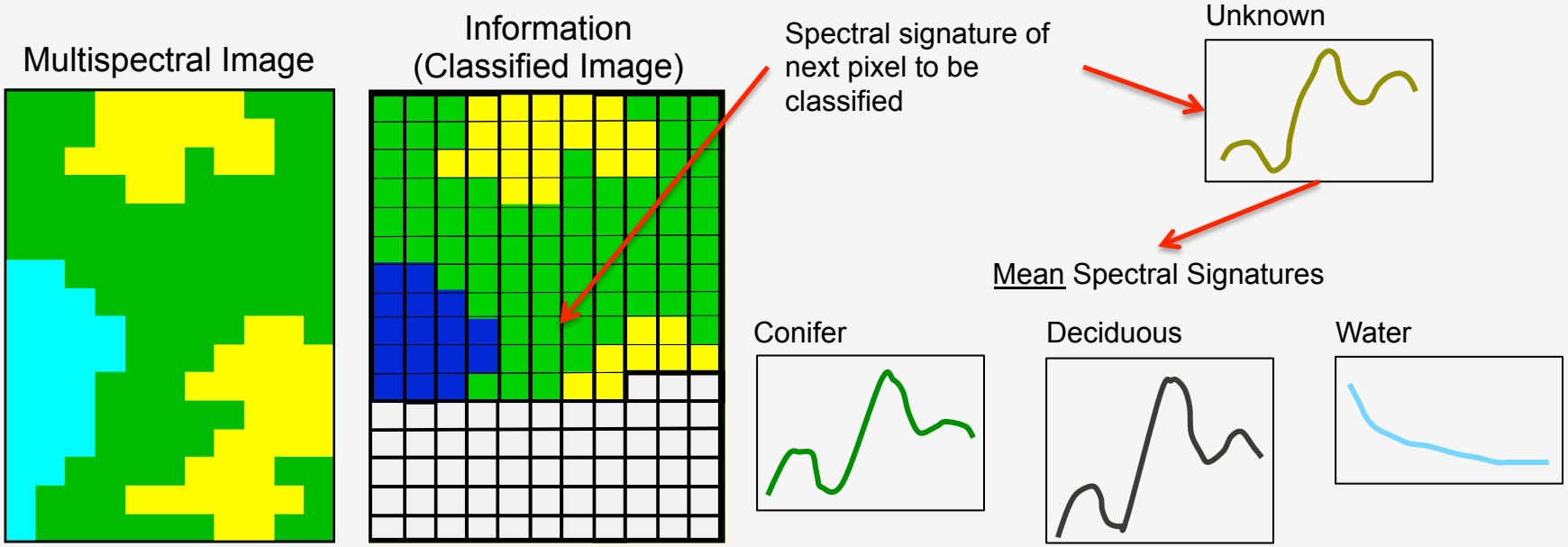


Image Classification

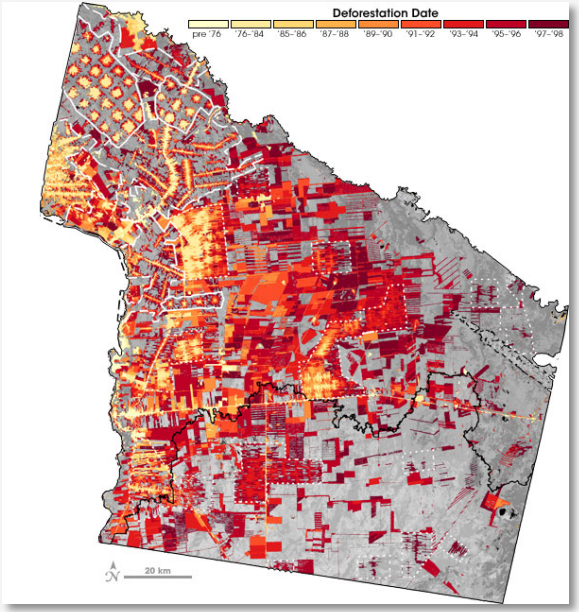
Supervised Method

The spectral signature of each pixel in the image gets matched with the training signatures and the image is classified accordingly



Change Detection

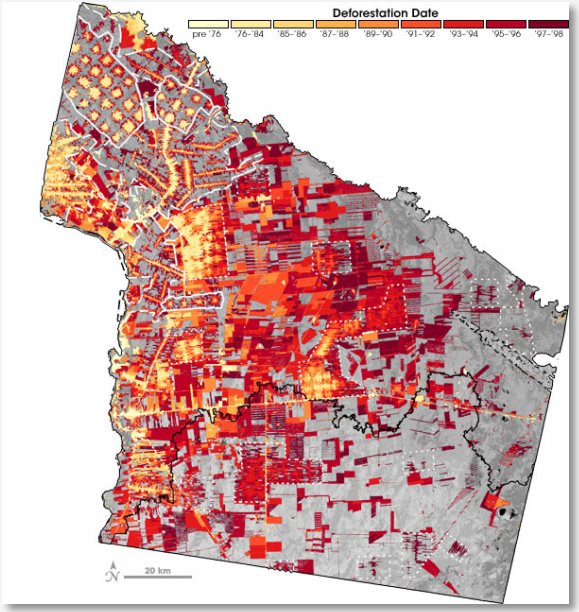
- Activities that cause degradation of carbon stocks within forests and are detectable by satellite imagery
  - tree harvesting (legal and illegal)
  - fire
- Recommend using Landsat-type data for monitoring forest cover changes every 5 to 10 years; although new automated techniques enable annual change detection.
- Many different methods:
  - Visual interpretation
  - Multi-date image segmentation
  - Digital classification techniques
  - Pixel trajectory techniques



Progress of deforestation in Tierra Bajas, Bolivia. Areas deforested before 1976 are yellow, while areas cleared from 1997-98 are dark red.

Change Detection

- Activities that cause degradation of carbon stocks within forests and are detectable by satellite imagery
  - tree harvesting (legal and illegal)
  - fire
- Recommend using Landsat-type data for monitoring forest cover changes every 5 to 10 years; although new automated techniques enable annual change detection.
- Many different methods:
  - Visual interpretation
  - Multi-date image segmentation
  - Digital classification techniques
  - Pixel trajectory techniques

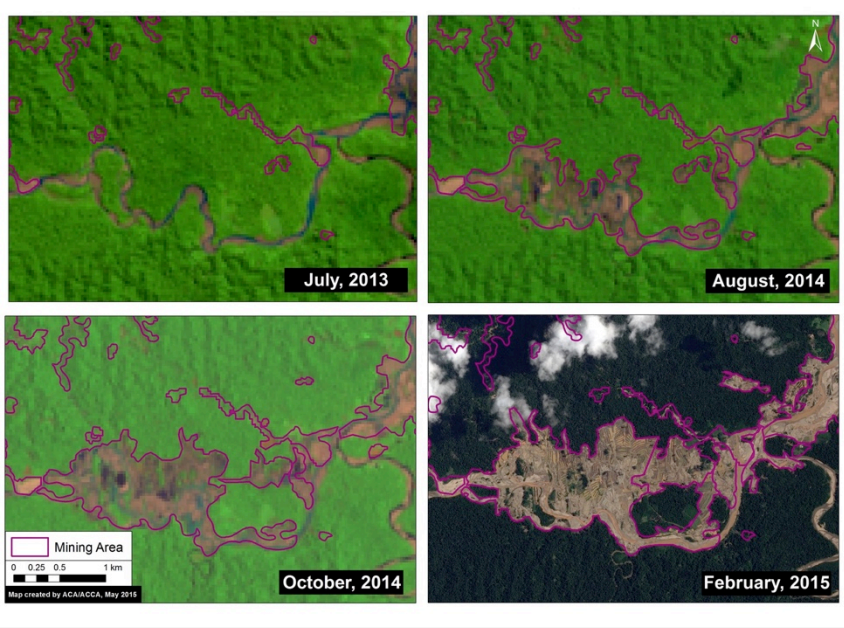


Progress of deforestation in Tierra Bajas, Bolivia. Areas deforested before 1976 are yellow, while areas cleared from 1997-98 are dark red.

Change Detection

Methods: Visual Interpretation

- Visual interpretation involves the delineation of change on a computer screen (rather than a paper map)
- This allows production of results that are automatically in digital form
- This method works best if image analysis tools and experiences are limited



Deforestation along the Upper Malinowski in Peru due to mining from Landsat and SPOT 7. Credit: Amazon Conservation Association

Change Detection

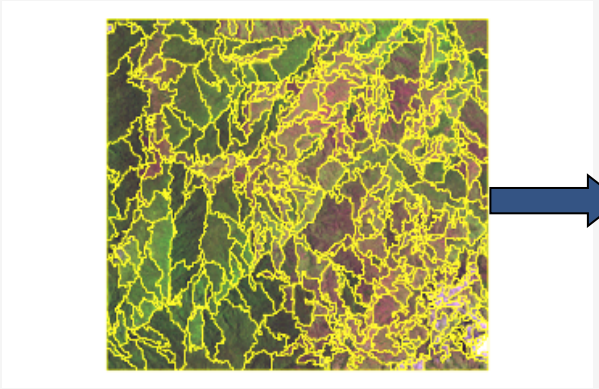
Methods: Multi-date image segmentation

- Automated segmentation reduces processing time and increases detail
- It is objective and repeatable
- It delineates changed areas as separate segments
- Ideally, analysis process would include:
  - Multidate image segmentation on image pairs
  - Training area/class signature selection
  - Supervised clustering of individual images
  - Visual verification and potential editing

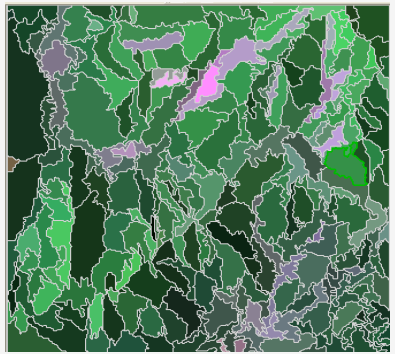
Change Detection

Example of multi-date segmentation

Paired segmentation



Automatic change label



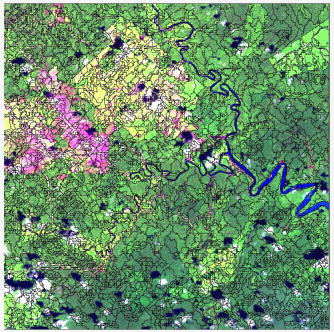
Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.

Change Detection

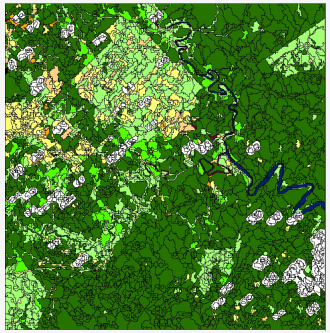
Digital Classification of Image Segments

- Two supervised object classifications run separately on the two multi-date images are recommended instead of a single supervised object classification on the image pair.
- A common predefined standard training data set of spectral signatures for each type of ecosystem should ideally be used to create initial automated forest maps.
- Supervised classification approaches are considered more efficient in the case of a large number of images than unsupervised clustering techniques.

(A)



(B)



(A) Multi-temporal segmentation from two images: 2000-2010

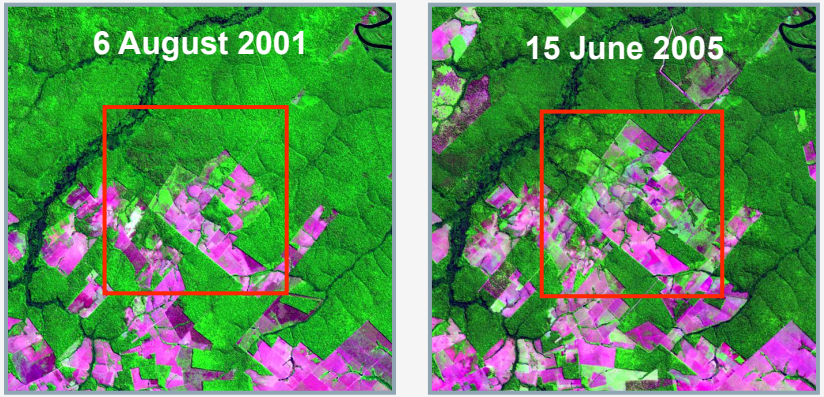
(B) Classification of the year 2000 image based on the supervised signatures.

Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011

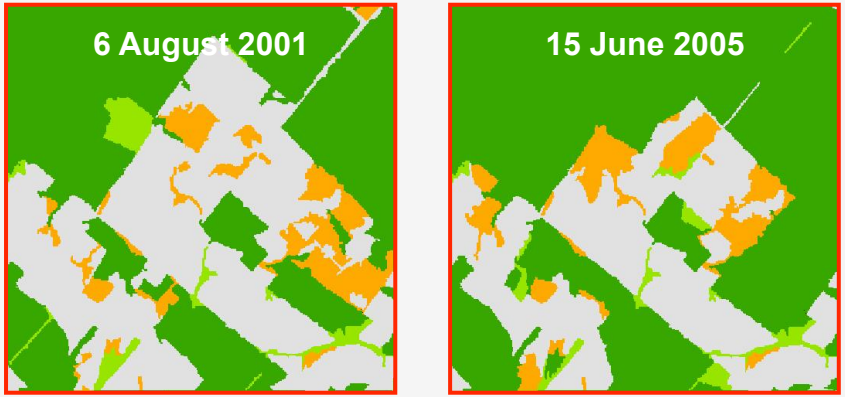
Change Detection

Example of multi-date segmentation approach: Brazil forest cover

Landsat-5 TM imagery



Land cover maps of 2001 to 2005



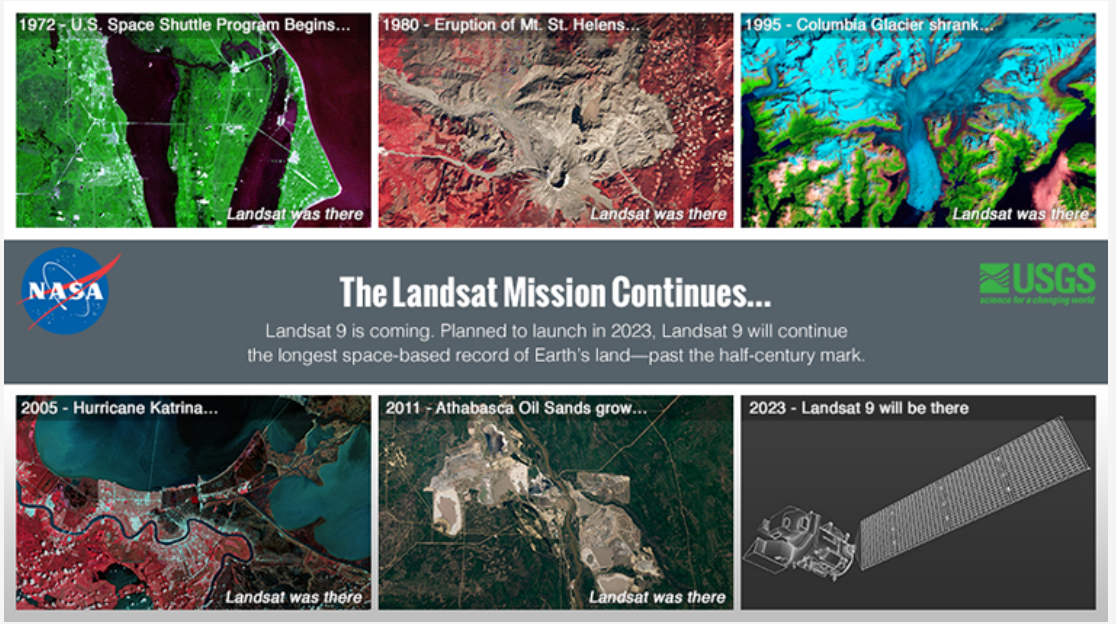
Sources: USGS 2015, GLS dataset; Eva et al. 2012.

National Forest Monitoring System – Remote Sensing Sustainability Considerations

National Forest Monitoring System

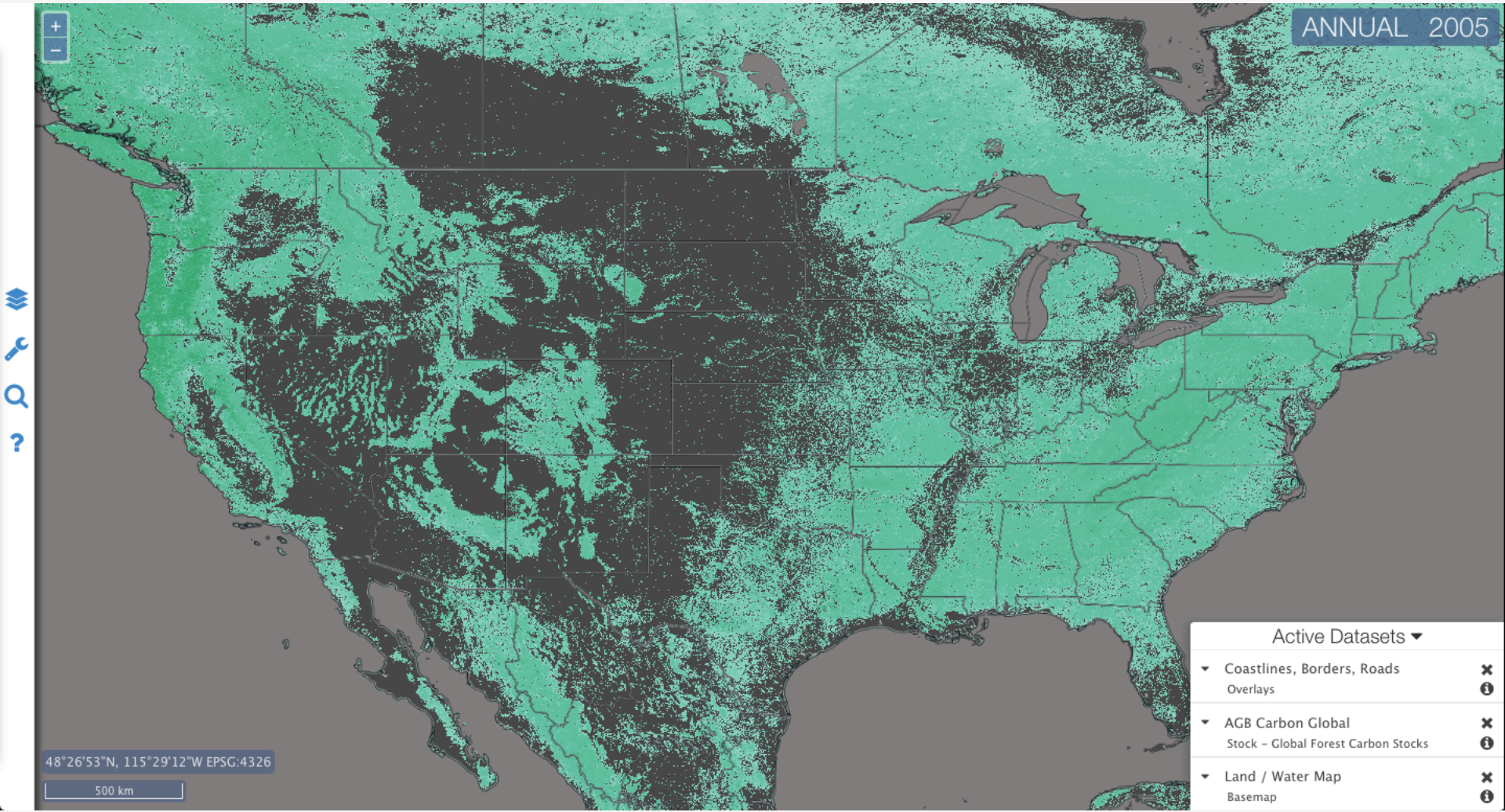
Sustainability Considerations

- Longevity of satellite mission providing data underlying Activity Data generation and future sensor launch and data acquisition strategy
  - Example: Landsat continuity
- Consistency of methods used to produce Activity Data
- Plans for archiving imagery and data prodcuts for transparency



NASA's Carbon Mapper

- Developed by NASA's Carbon Monitoring System (CMS)
- Beta version
- Common platform for visualizing carbon globally
- Features
  - Mapping and data visualizations
  - Regional carbon summaries
  - Time series plots of carbon flux and stocks
- Website: https://cmsun.jpl.nasa.gov


ANNUAL 2005
Active Datasets
Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Land / Water Map
Basemap
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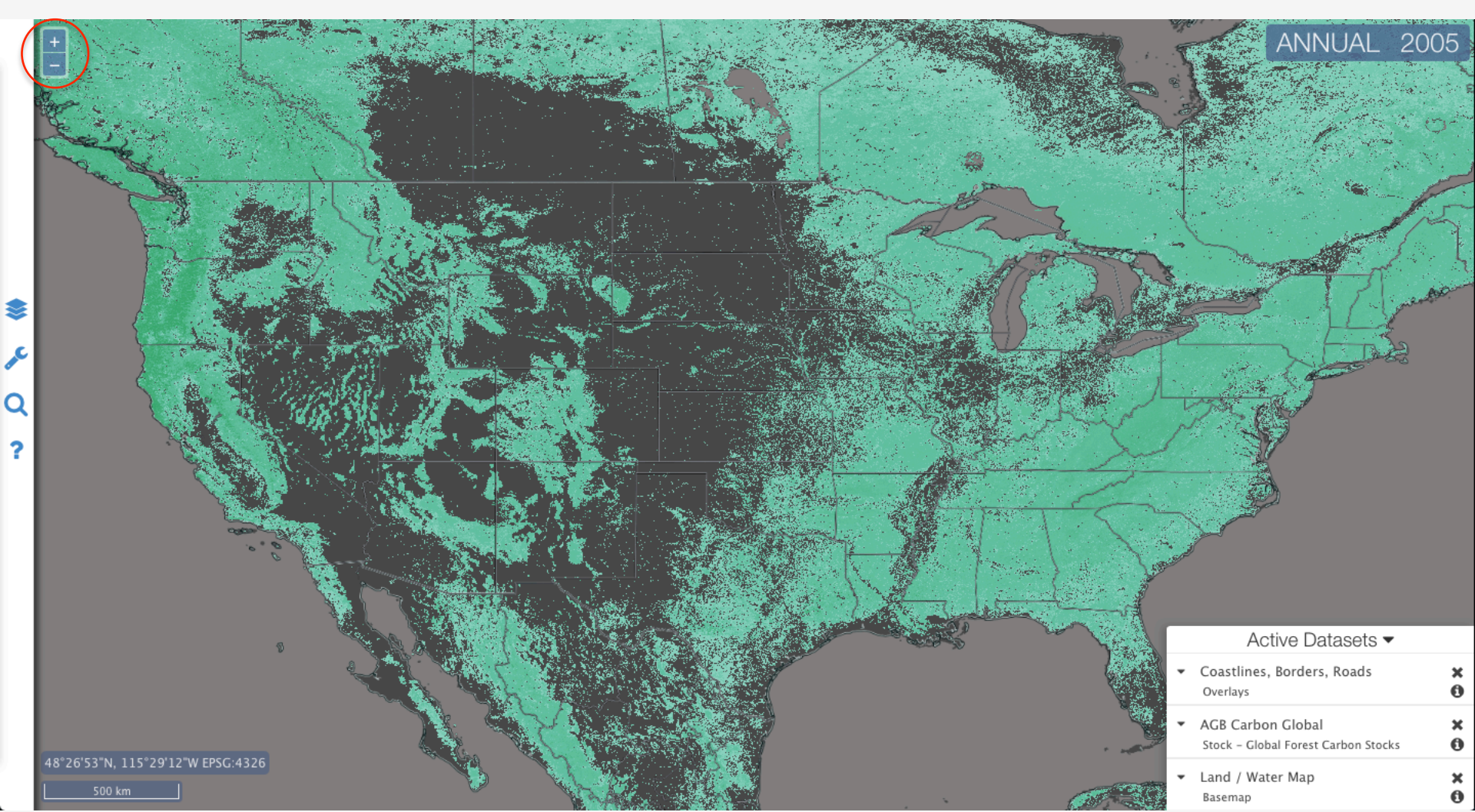
500 km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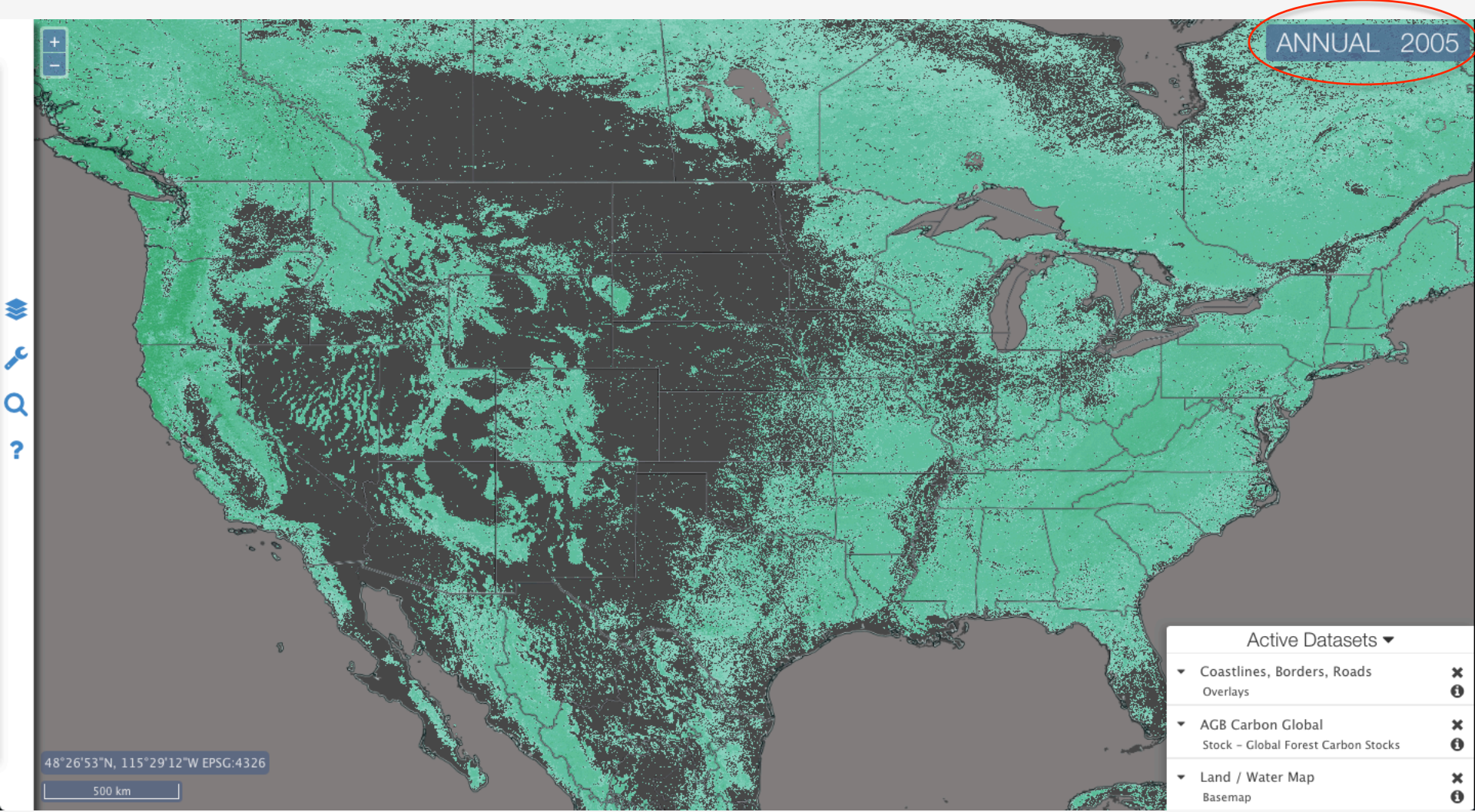
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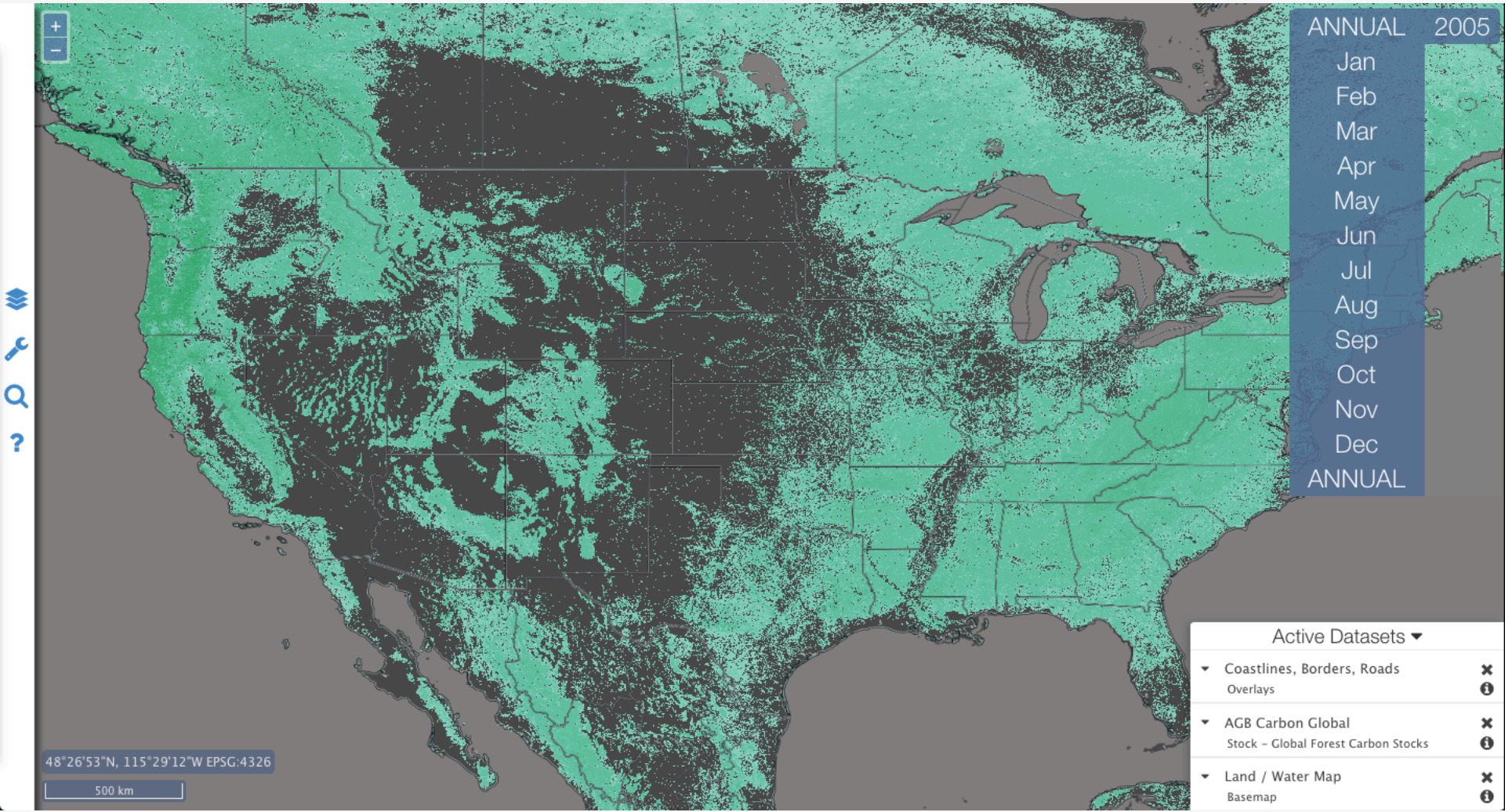
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Coastlines, Borders, Roads
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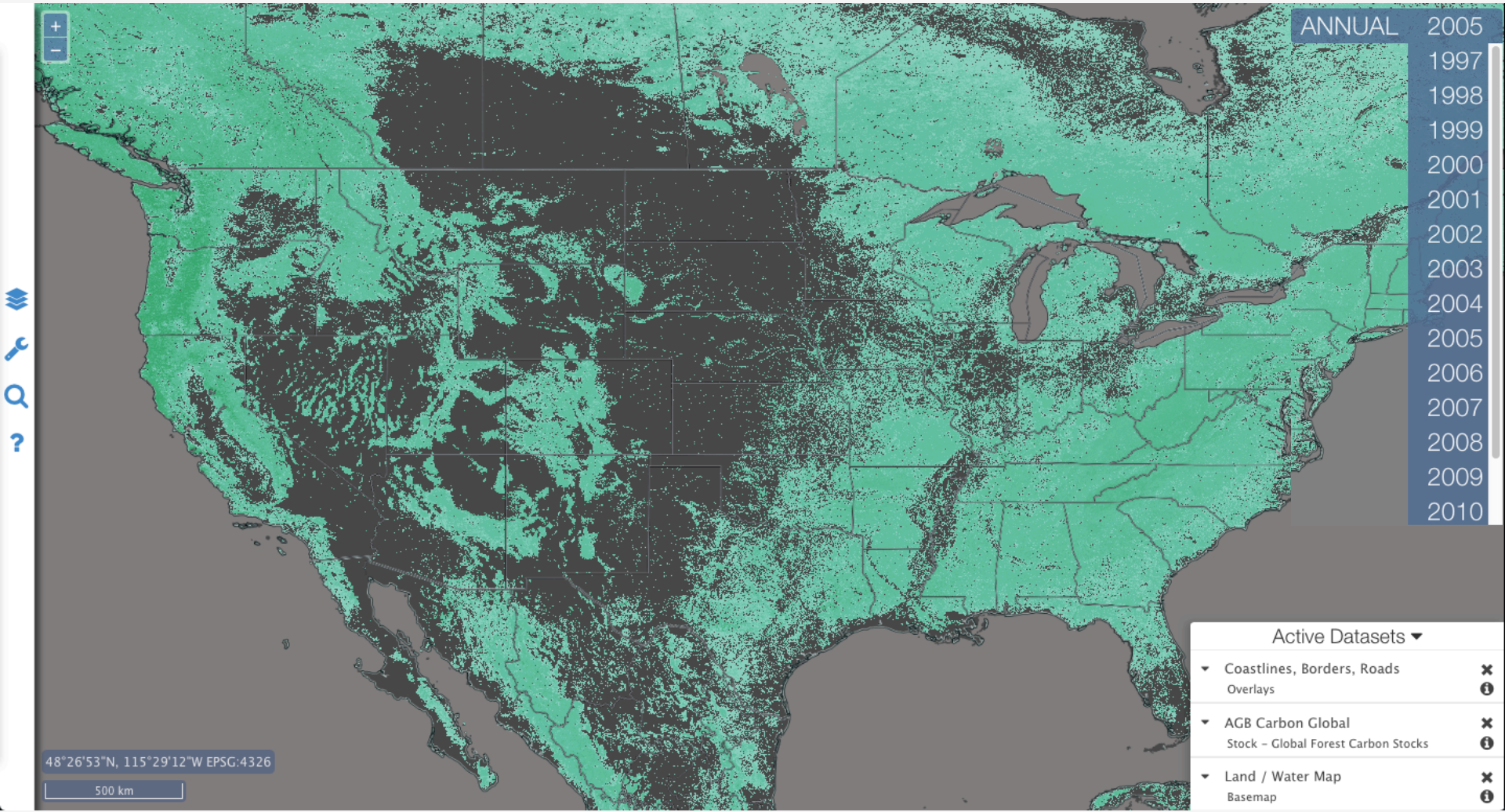
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Coastlines, Borders, Roads
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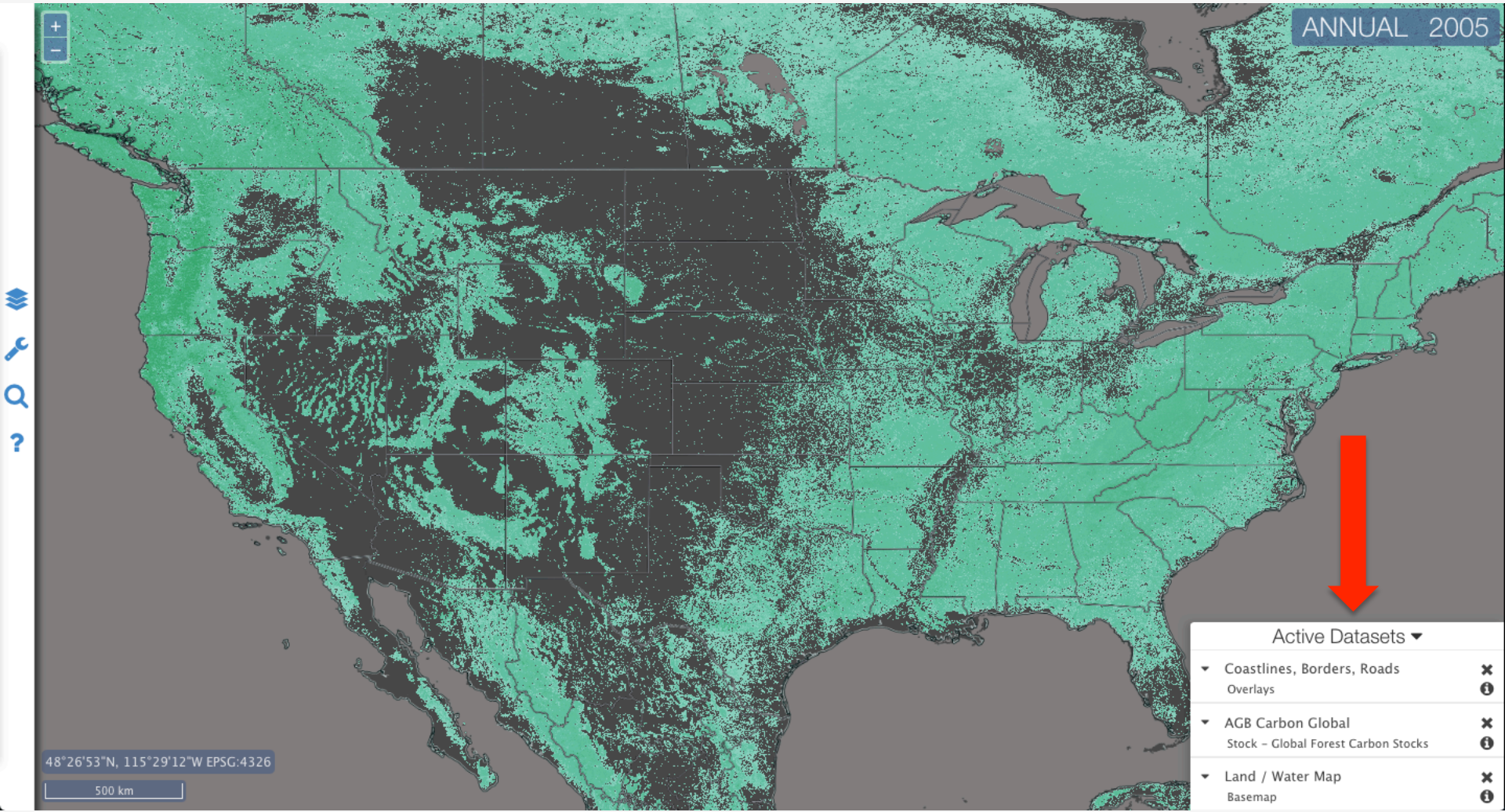
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Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Land / Water Map
Basemap
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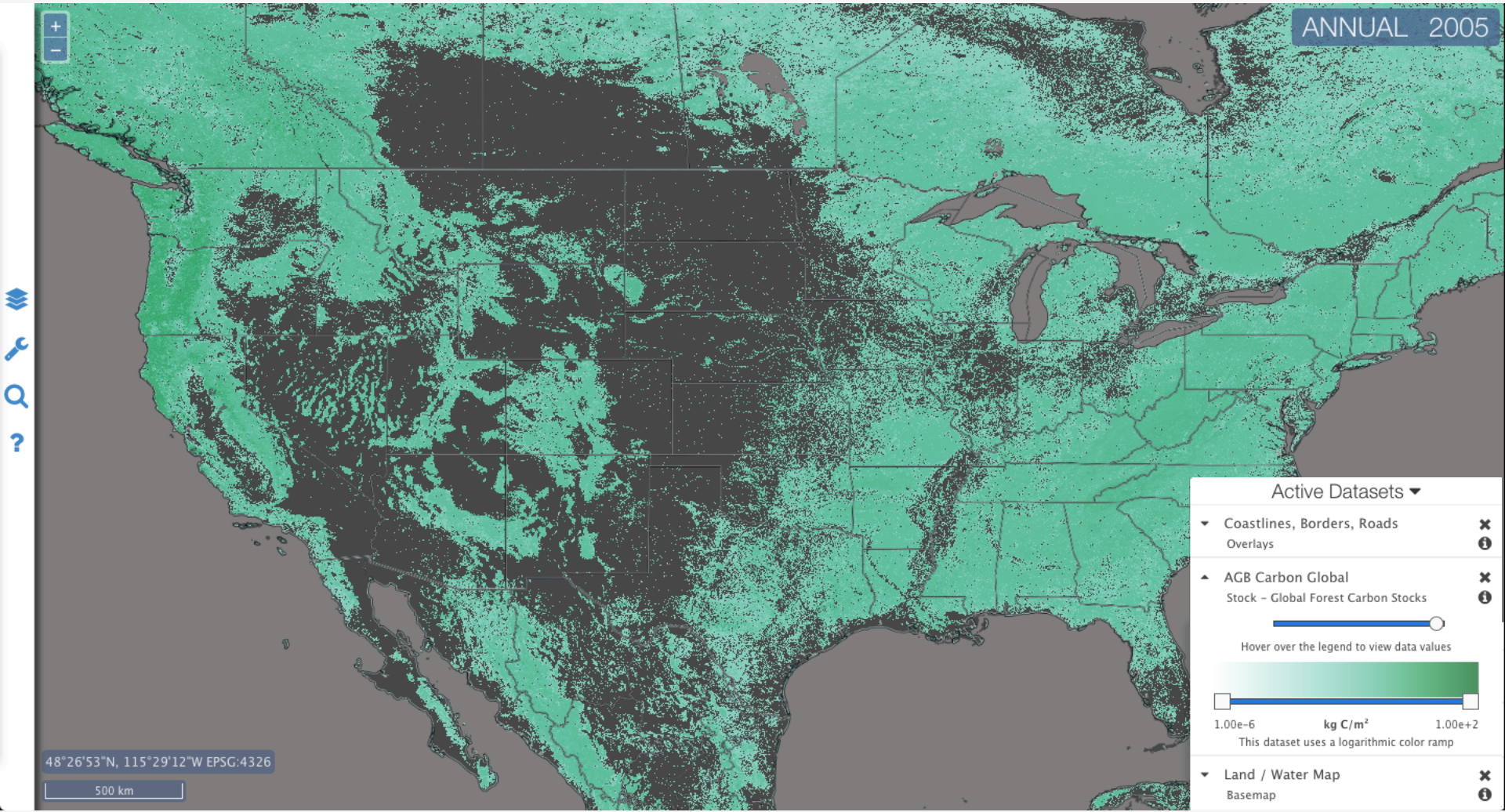
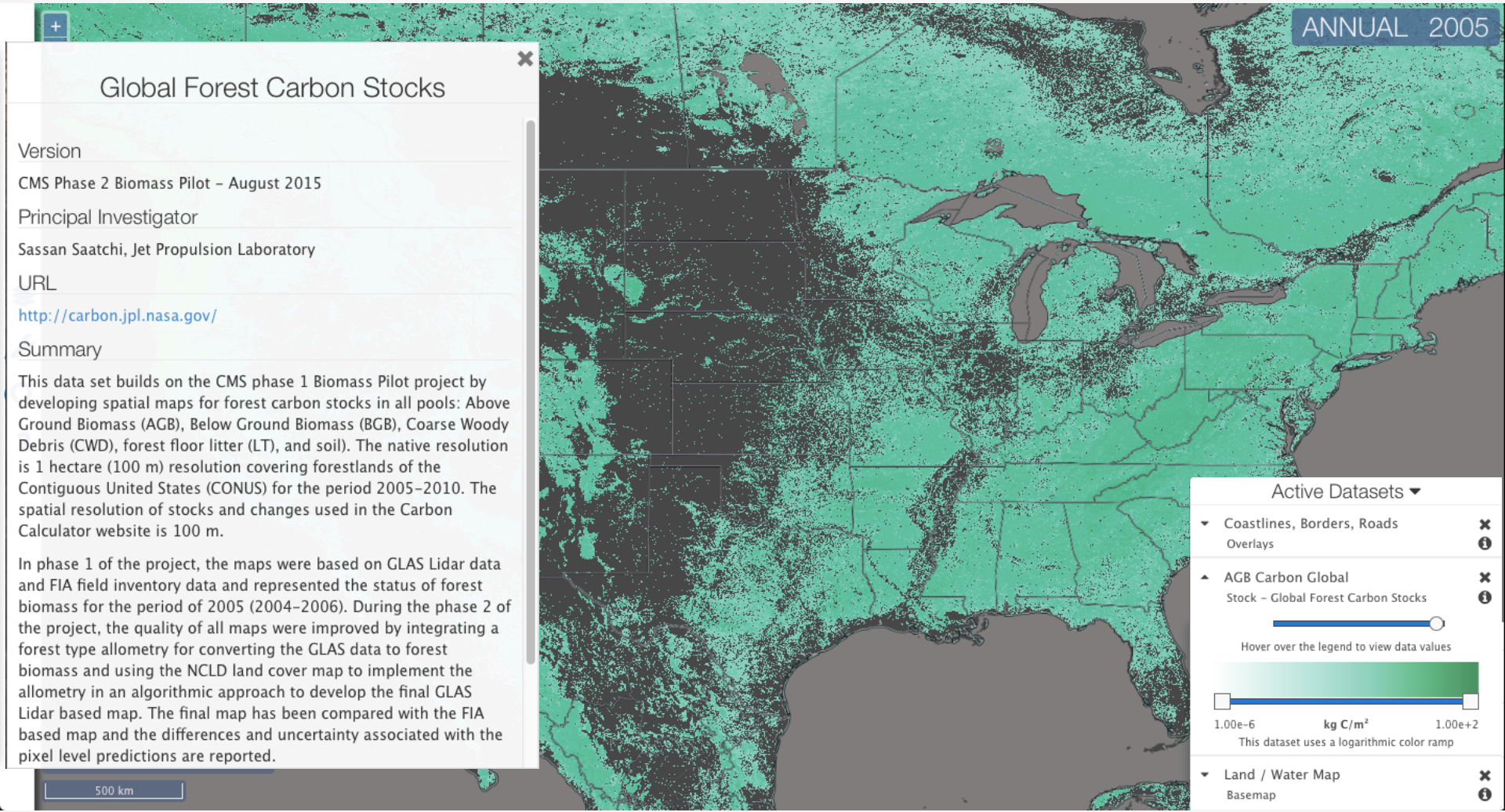
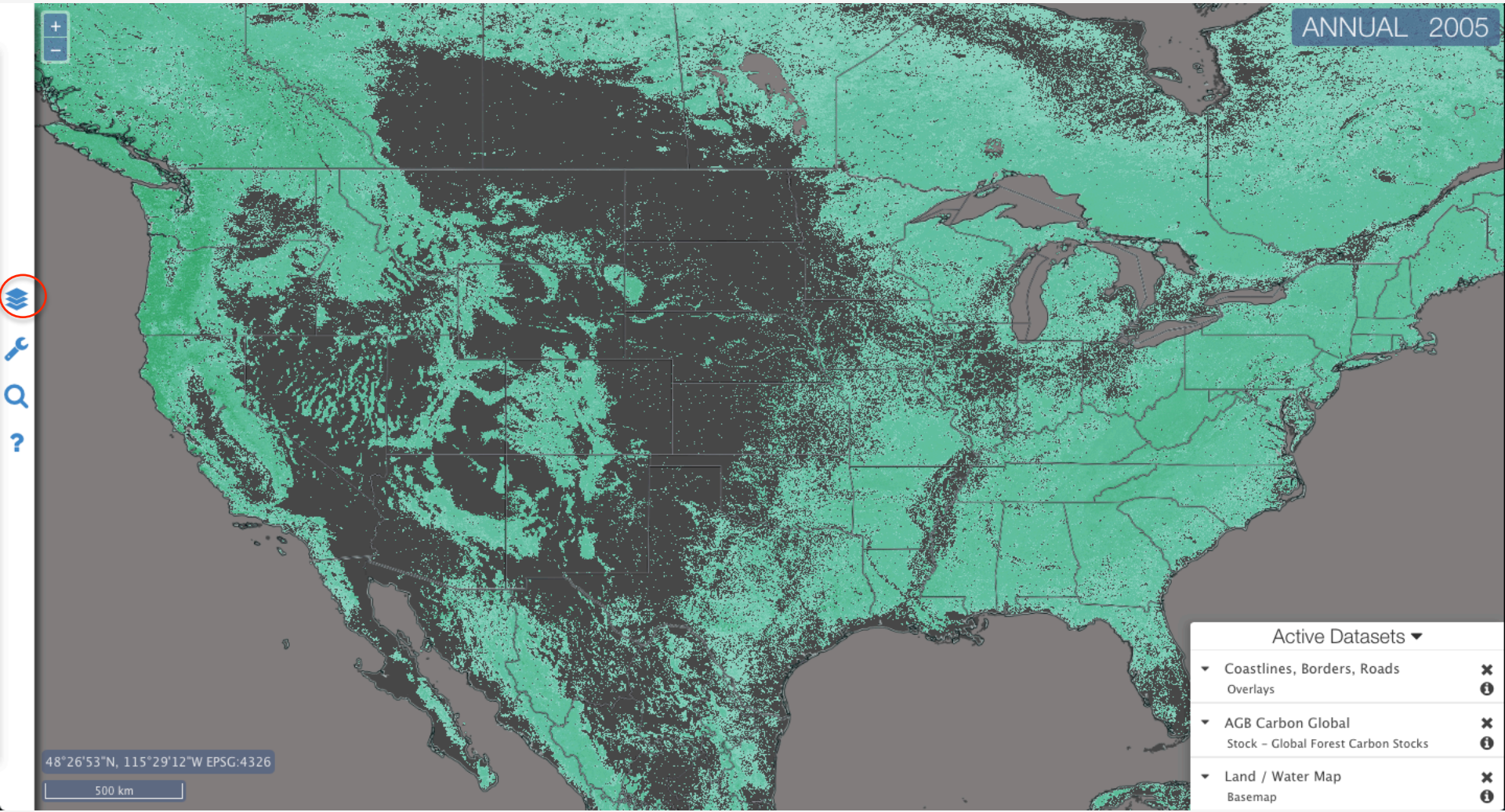

ANNUAL 2005
Active Datasets
Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Hover over the legend to view data values
1.00e-6
kg C/m²
1.00e+2
This dataset uses a logarithmic color ramp
Land / Water Map
Basemap
48°26'53"N, 115°29'12"W EPSG:4326
500 km


ANNUAL 2005
Global Forest Carbon Stocks
Version
CMS Phase 2 Biomass Pilot – August 2015
Principal Investigator
Sassan Saatchi, Jet Propulsion Laboratory
URL
http://carbon.jpl.nasa.gov/
Summary
This data set builds on the CMS phase 1 Biomass Pilot project by developing spatial maps for forest carbon stocks in all pools: Above Ground Biomass (AGB), Below Ground Biomass (BGB), Coarse Woody Debris (CWD), forest floor litter (LT), and soil). The native resolution is 1 hectare (100 m) resolution covering forestlands of the Contiguous United States (CONUS) for the period 2005–2010. The spatial resolution of stocks and changes used in the Carbon Calculator website is 100 m.
In phase 1 of the project, the maps were based on GLAS Lidar data and FIA field inventory data and represented the status of forest biomass for the period of 2005 (2004–2006). During the phase 2 of the project, the quality of all maps were improved by integrating a forest type allometry for converting the GLAS data to forest biomass and using the NCLD land cover map to implement the allometry in an algorithmic approach to develop the final GLAS Lidar based map. The final map has been compared with the FIA based map and the differences and uncertainty associated with the pixel level predictions are reported.
500 km
Active Datasets
Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Hover over the legend to view data values
1.00e-6
kg C/m²
1.00e+2
This dataset uses a logarithmic color ramp
Land / Water Map
Basemap


ANNUAL 2005
Active Datasets
Coastlines, Borders, Roads
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Basemap
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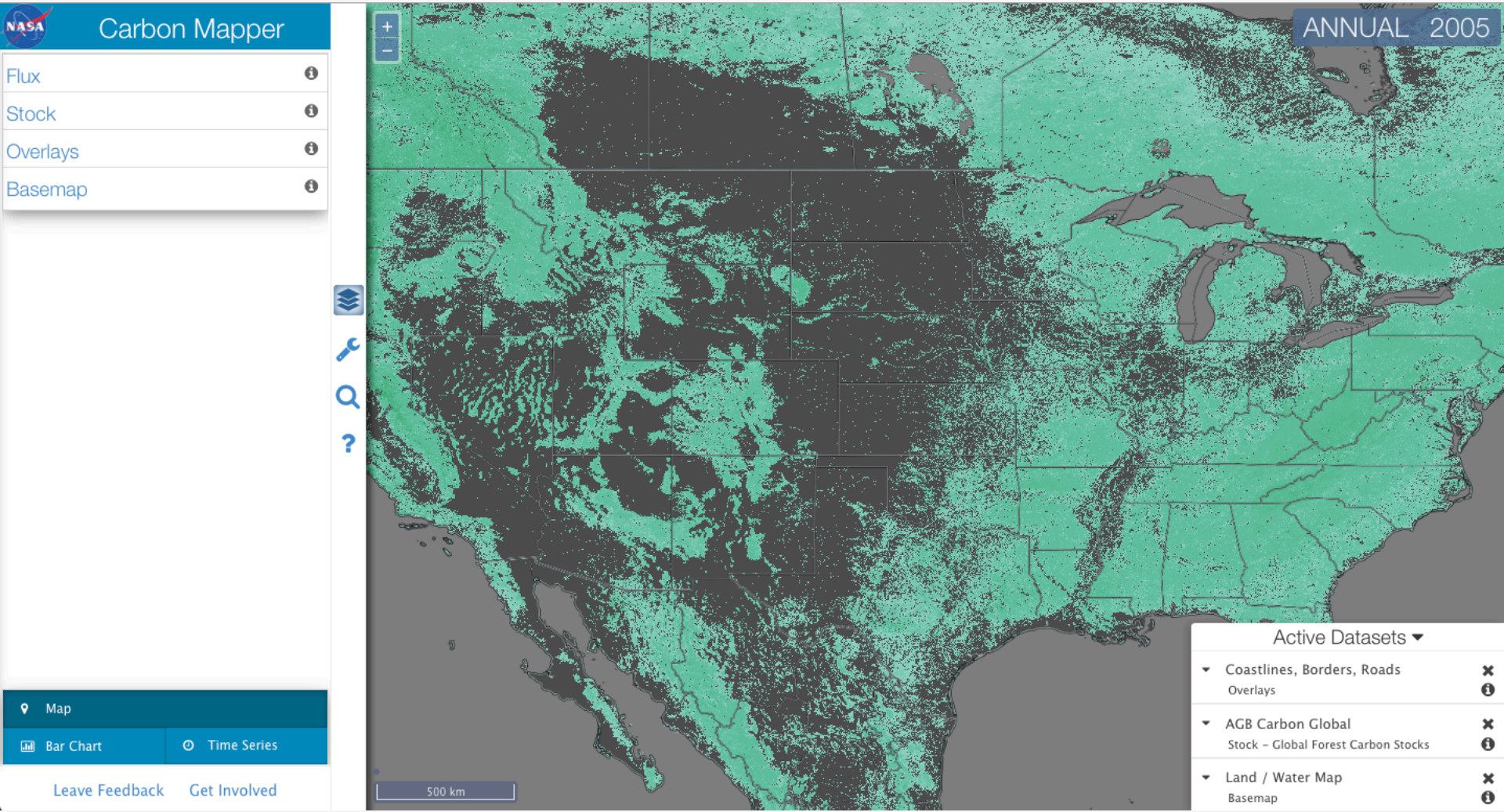
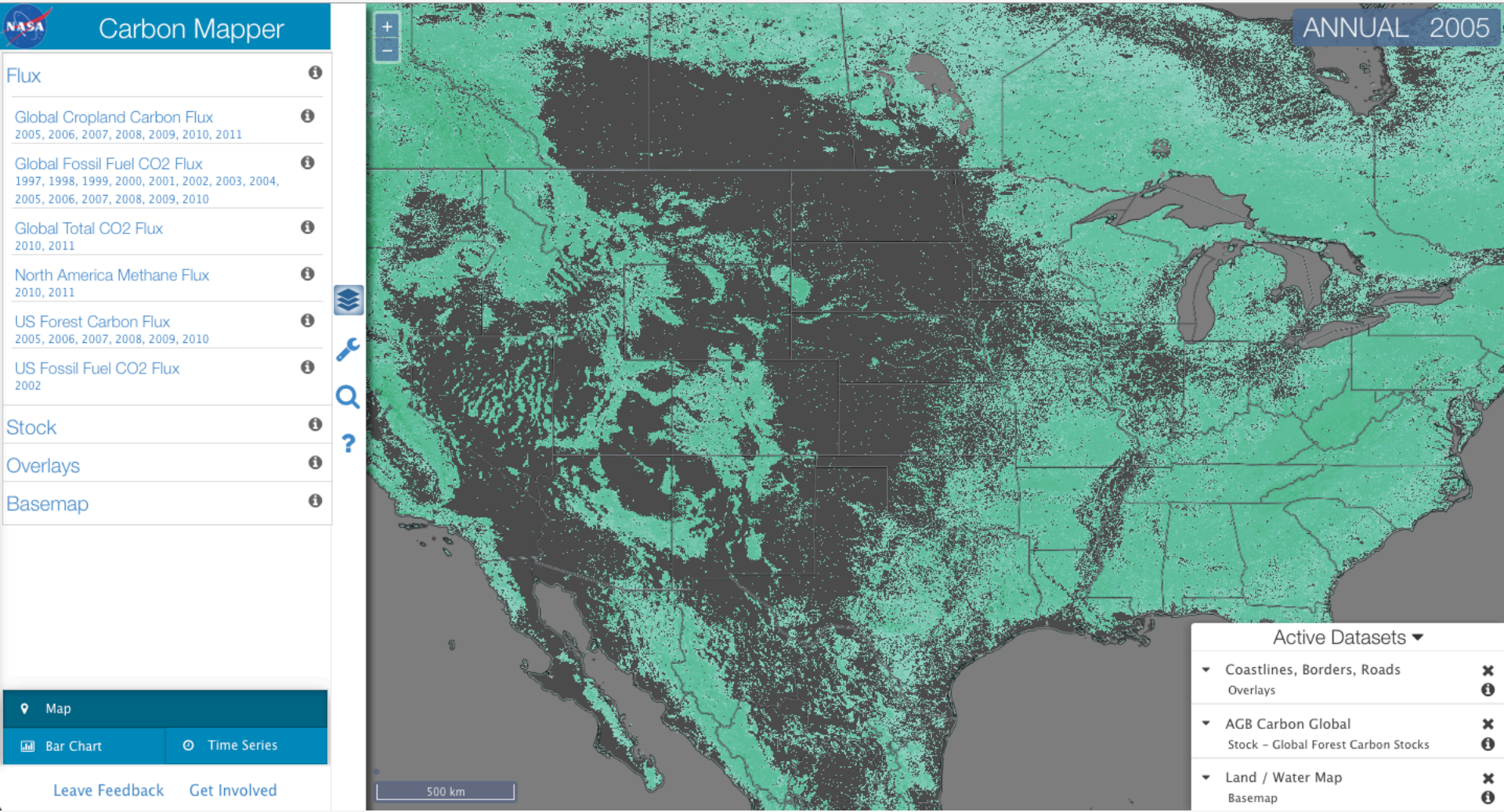

Carbon Mapper
Flux
Stock
Overlays
Basemap
Map
Bar Chart
Time Series
Leave Feedback
Get Involved
ANNUAL 2005
500 km
Active Datasets
Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Land / Water Map
Basemap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Global Fossil Fuel CO2 Flux
1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010
Global Total CO2 Flux
2010, 2011
North America Methane Flux
2010, 2011
US Forest Carbon Flux
2005, 2006, 2007, 2008, 2009, 2010
US Fossil Fuel CO2 Flux
2002
Stock
Overlays
Basemap
Map
Bar Chart
Time Series
Leave Feedback
Get Involved
ANNUAL 2005
500 km
Active Datasets
Coastlines, Borders, Roads
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AGB Carbon Global
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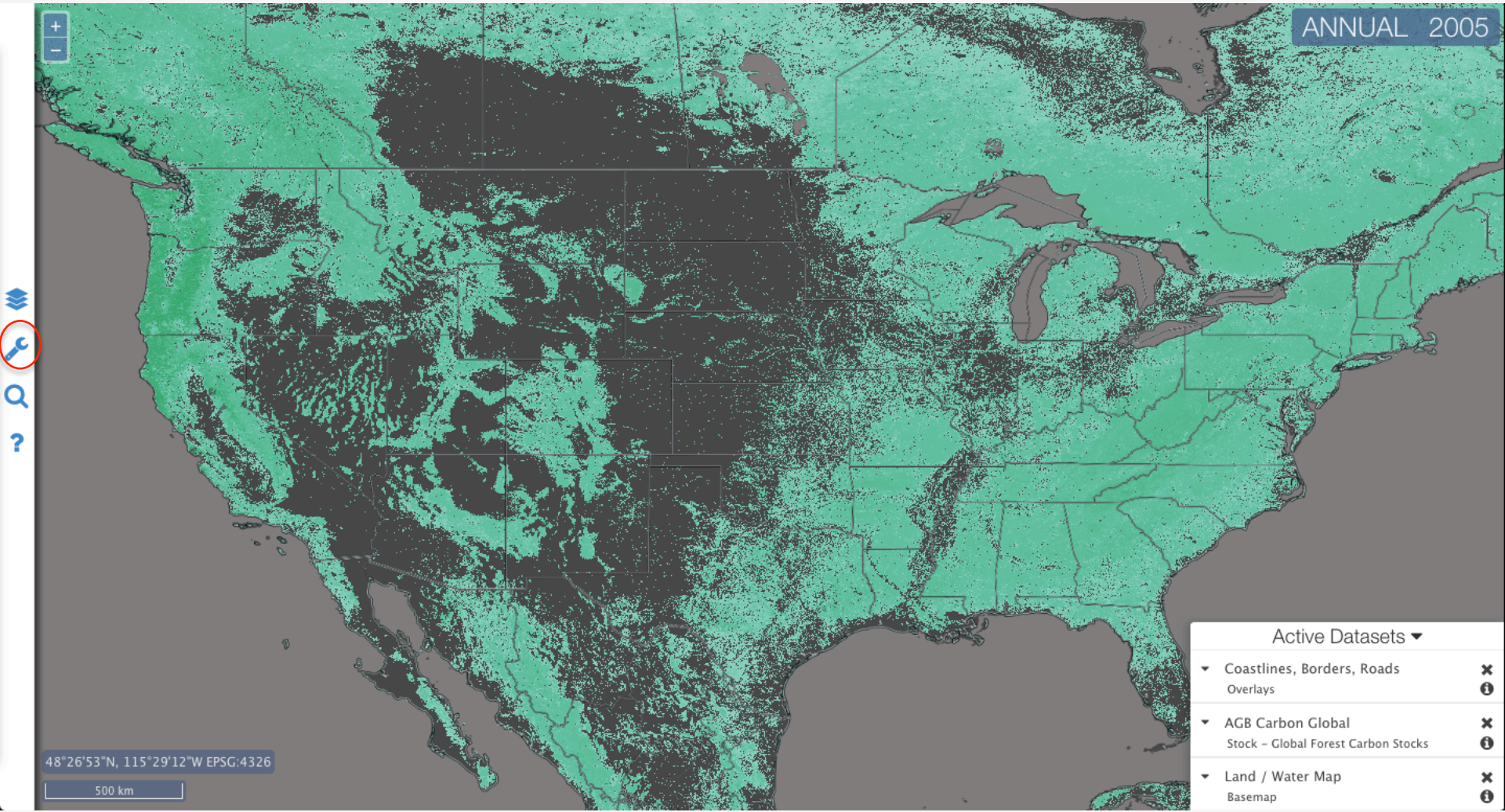
Land / Water Map
Basemap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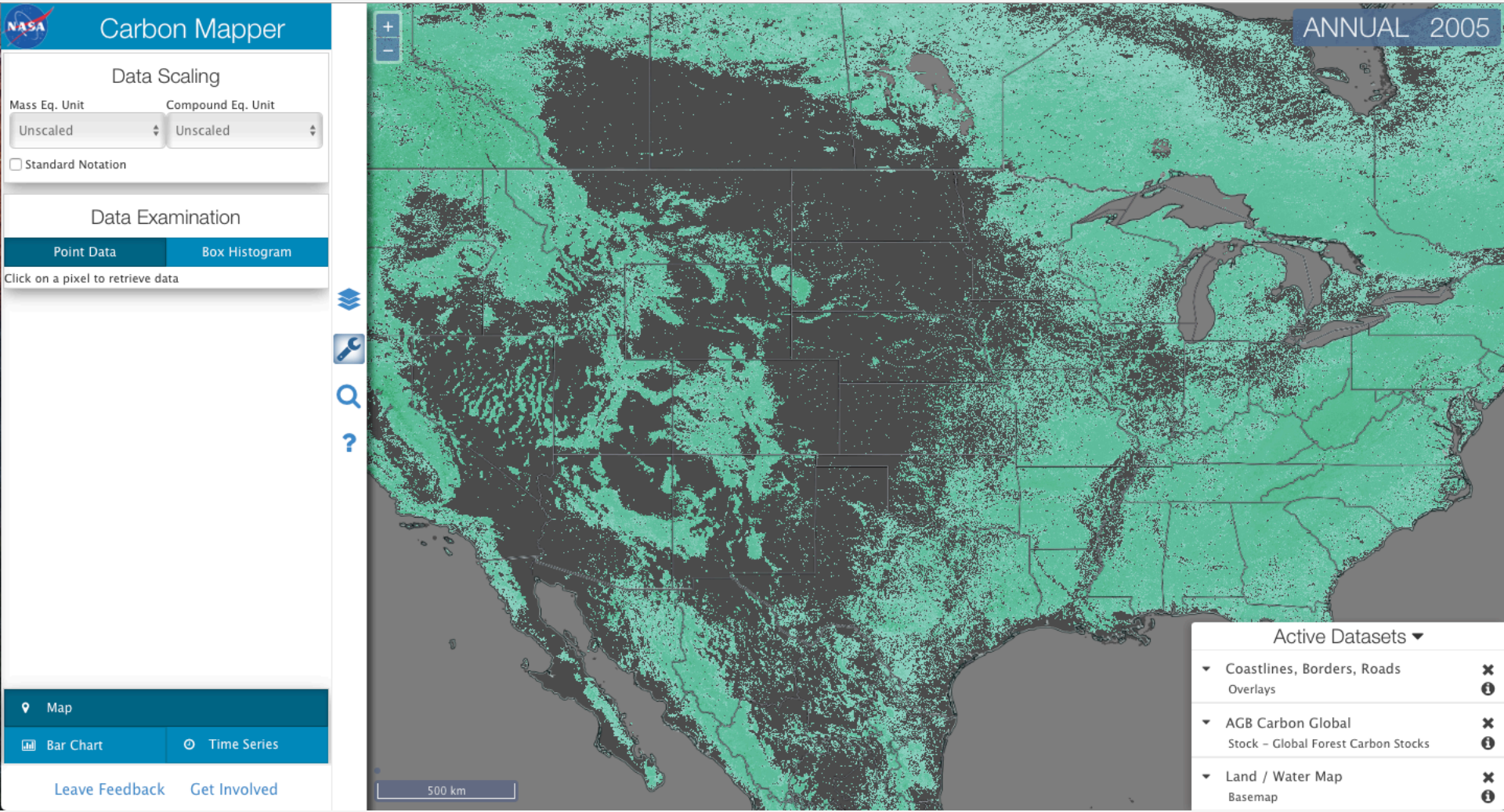
500 km


Carbon Mapper
Data Scaling
Mass Eq. Unit
Compound Eq. Unit
Unscaled
Unscaled
Standard Notation
Data Examination
Point Data
Box Histogram
Click on a pixel to retrieve data
Map
Bar Chart
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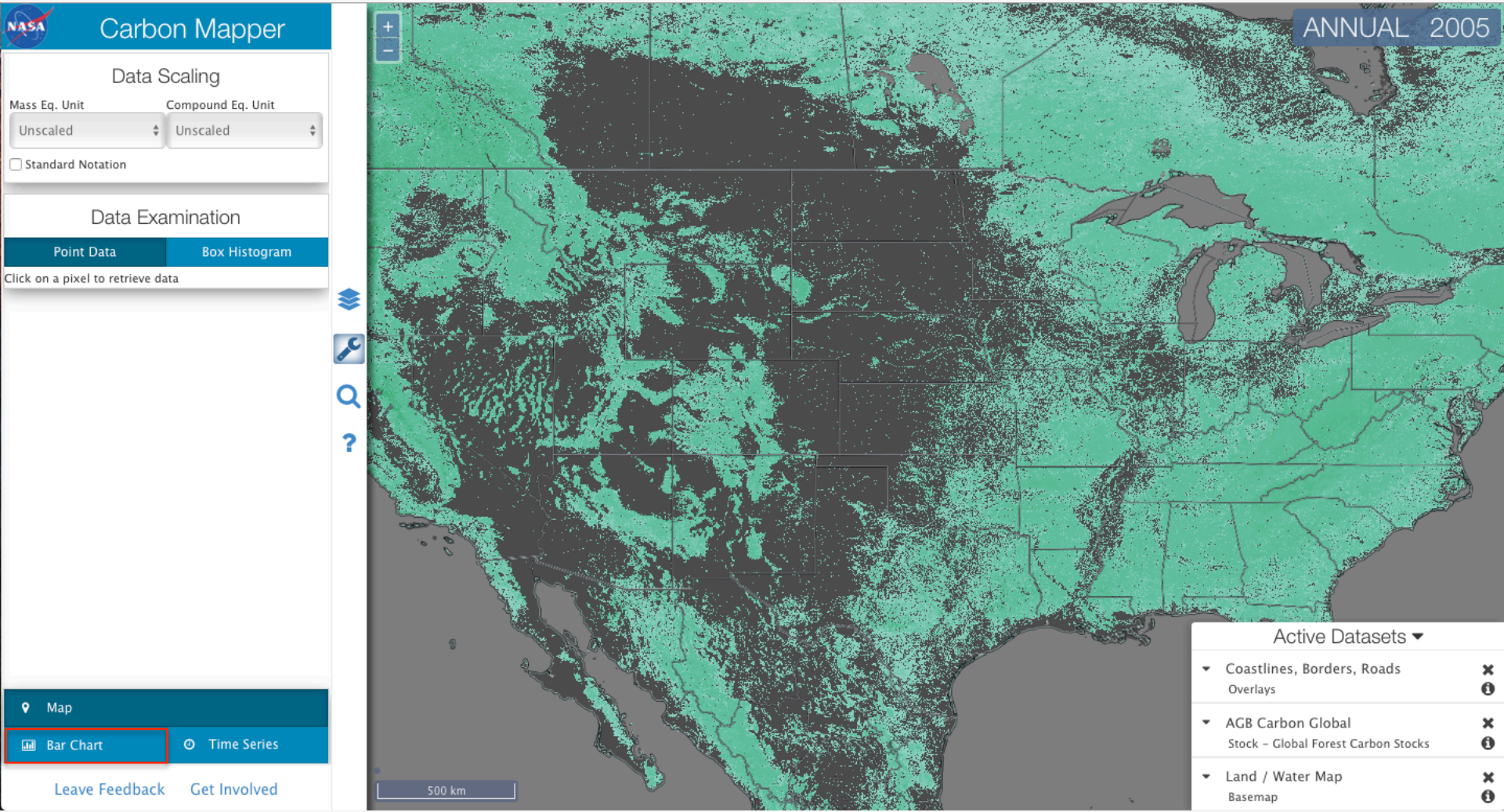
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Basemap

Carbon Mapper

Data Scaling

Mass Eq. Unit: Unscaled

Compound Eq. Unit: Unscaled

Standard Notation

Regional Selection

Region: World

Country:

Export Table

Compare Subregions

Map

Bar Chart | Time Series

Leave Feedback | Get Involved

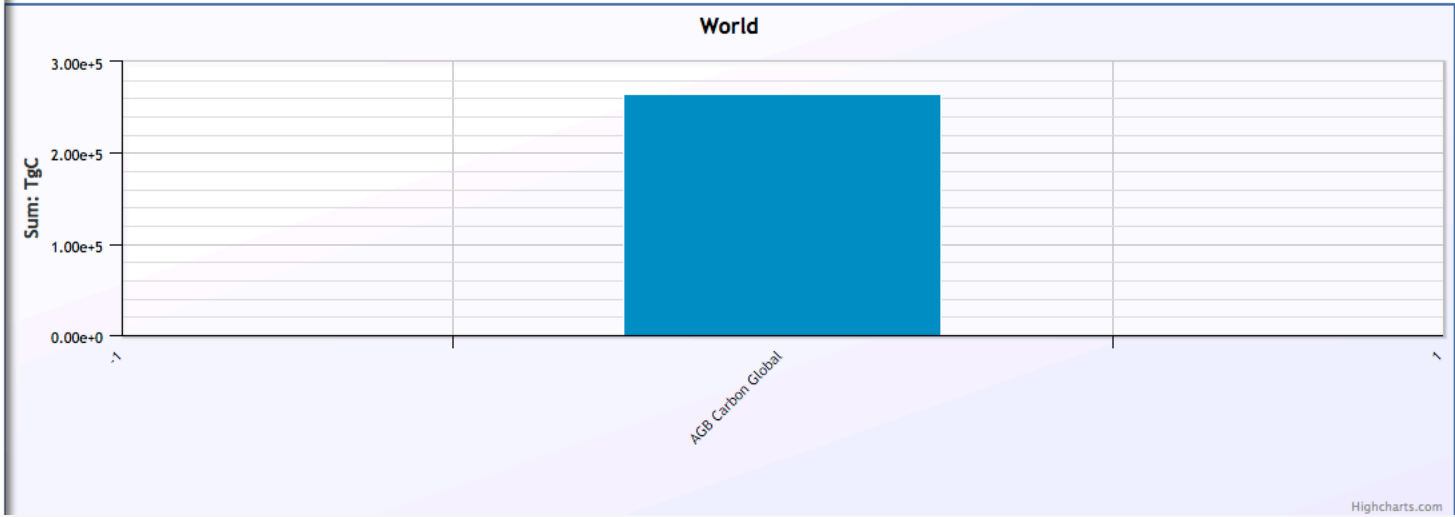
World

TgC

ANNUAL 2005

	Sum	Mean	Max	Min	Std
AGB Carbon Global	2.65e+5	Unknown	Unknown	Unknown	Unknown

* data entry was generated by Carbon Mapper Team



Carbon Mapper

Data Scaling

Mass Eq. Unit: Unscaled

Compound Eq. Unit: Unscaled

Standard Notation

Regional Selection

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Country:

Sort by Name | Sort by Total

Display by Value | Display by Percent

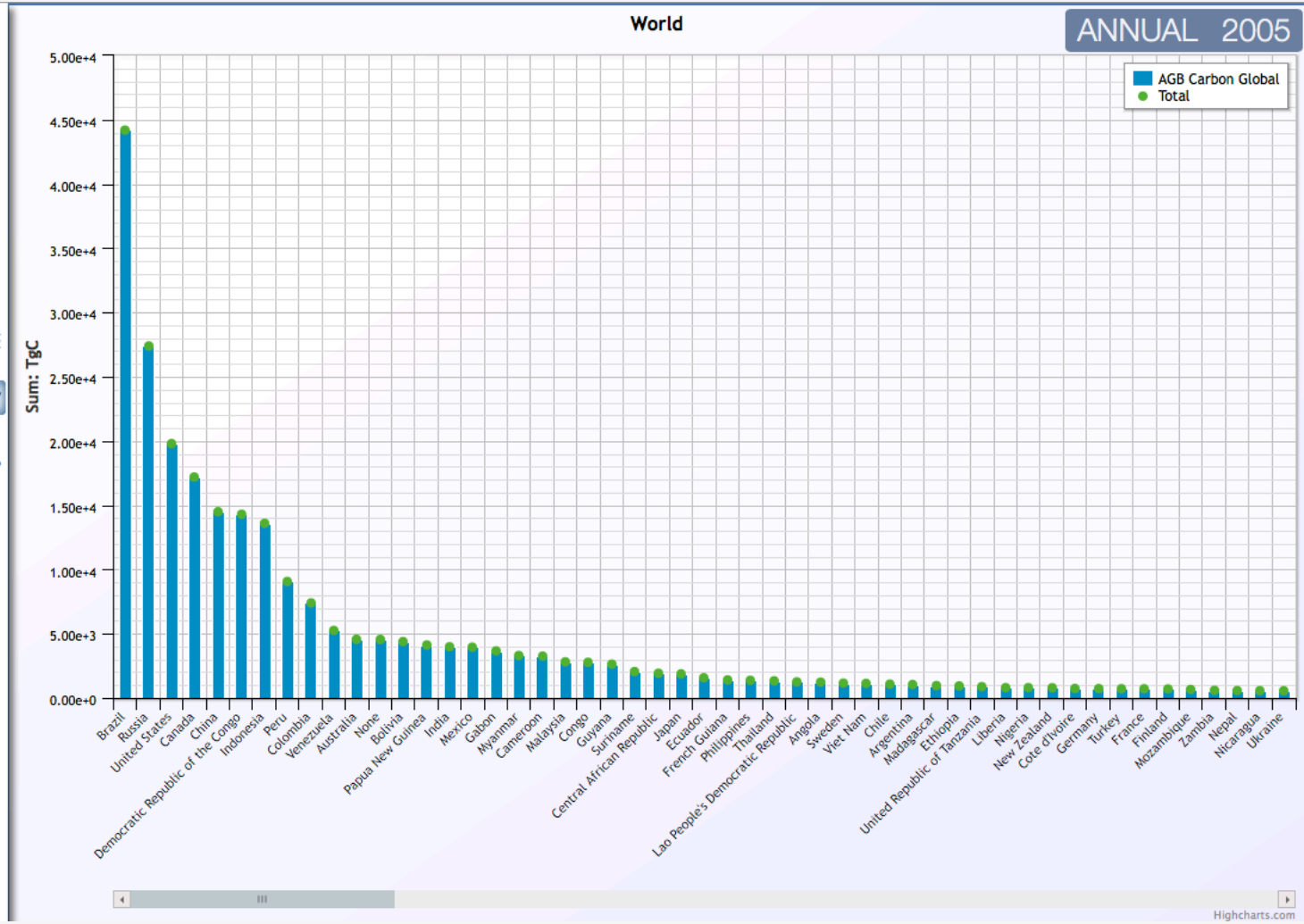
Show Table | Export Table

View Parent Region

Map

Bar Chart | Time Series

Leave Feedback | Get Involved



Carbon Mapper

Data Scaling

Mass Eq. Unit: Unscaled

Compound Eq. Unit: Unscaled

Standard Notation

Regional Selection

Region: World

Country:

Sort by Name | Sort by Total

Display by Value | Display by Percent

Show Table | Export Table

View Parent Region

Map

Bar Chart | Time Series

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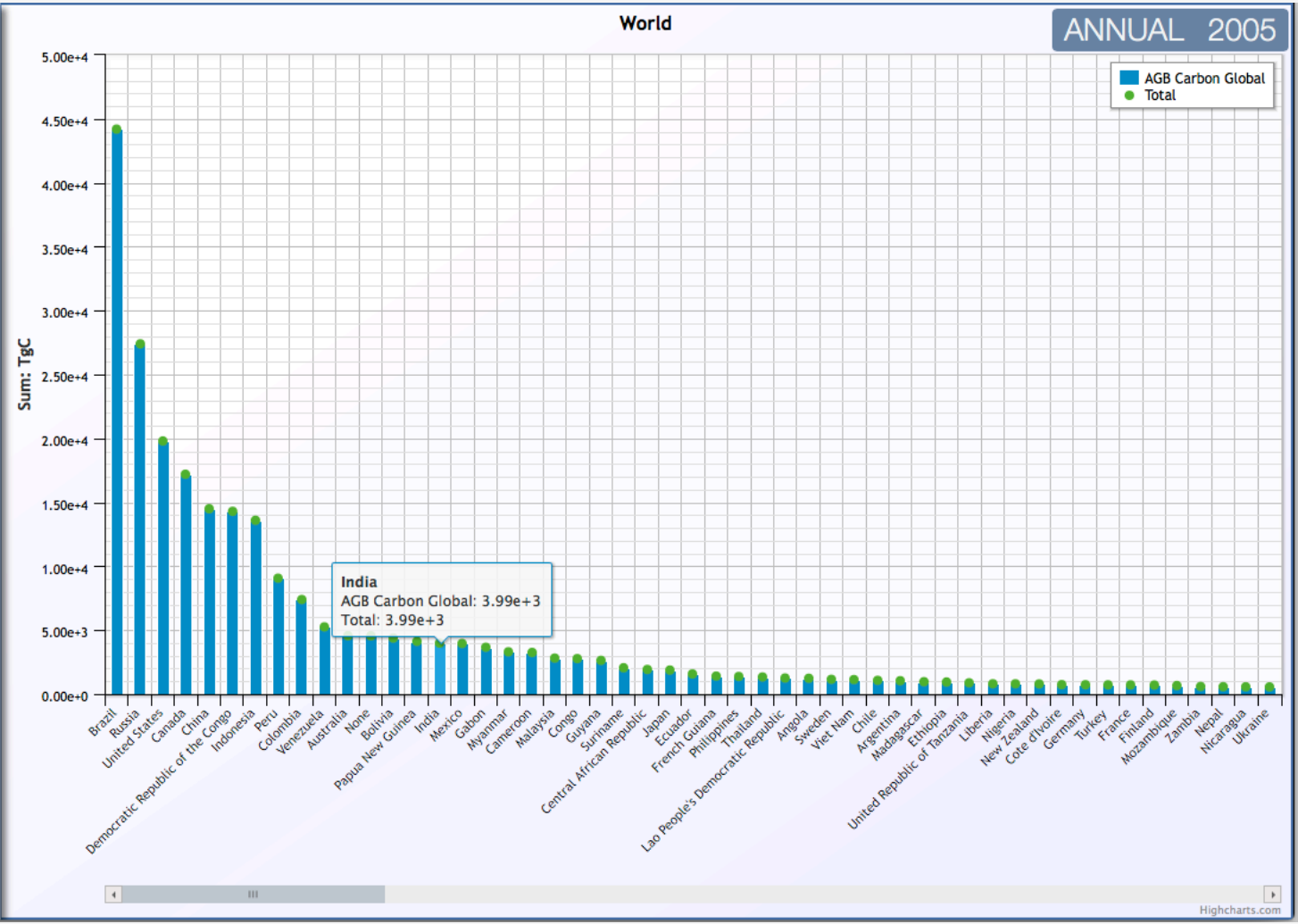

Carbon Mapper

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Region: World

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Sort by Name | Sort by Total

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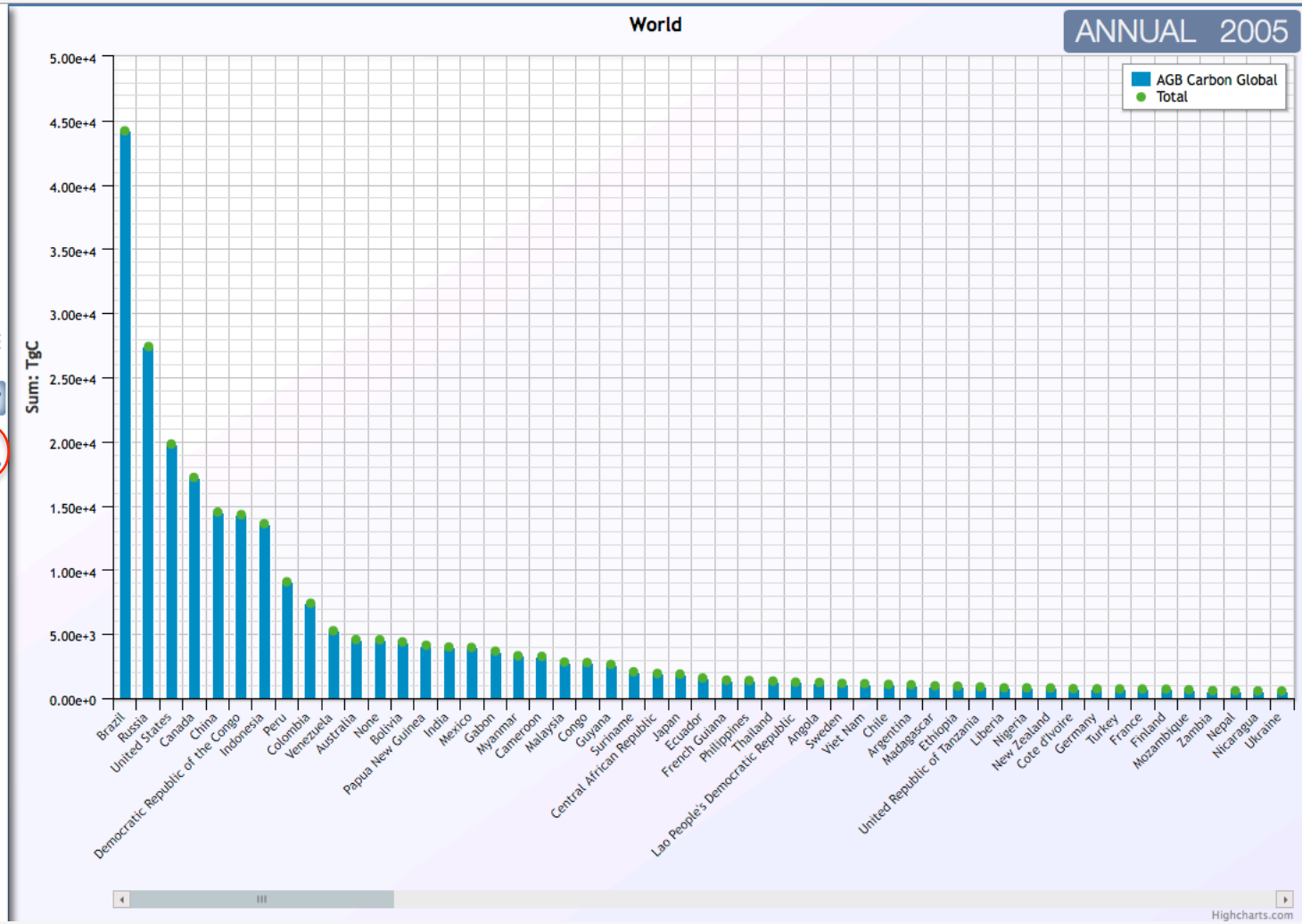


Carbon Mapper

Data Discovery

What is the distribution of Fossil Fuel CO2 fluxes by state within the United States?

How much carbon flux is there due to Forest Sequestration in California?

Compare carbon fluxes associated with crop production and consumption in the United States.

How are Forest Carbon stocks distributed within the United States?

Compare the changes in CO2 emissions by sector in India over time.

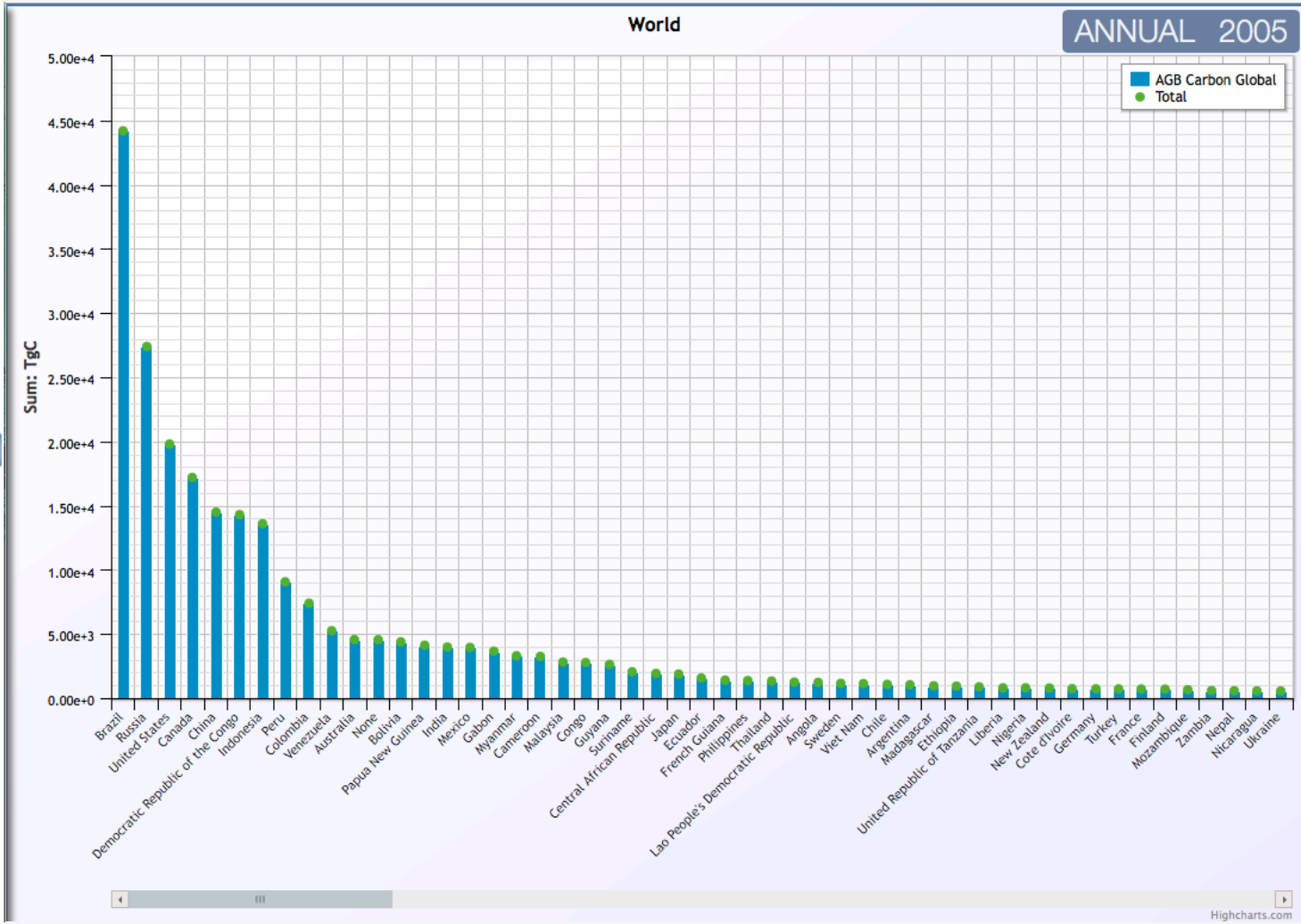
How do CH4 and CO2 emissions from fires compare using the AR5 20yr GWP scales in the North American Boreal region?

Compare a dataset's regional sum to its uncertainty.

Map

Bar Chart | Time Series

Leave Feedback | Get Involved



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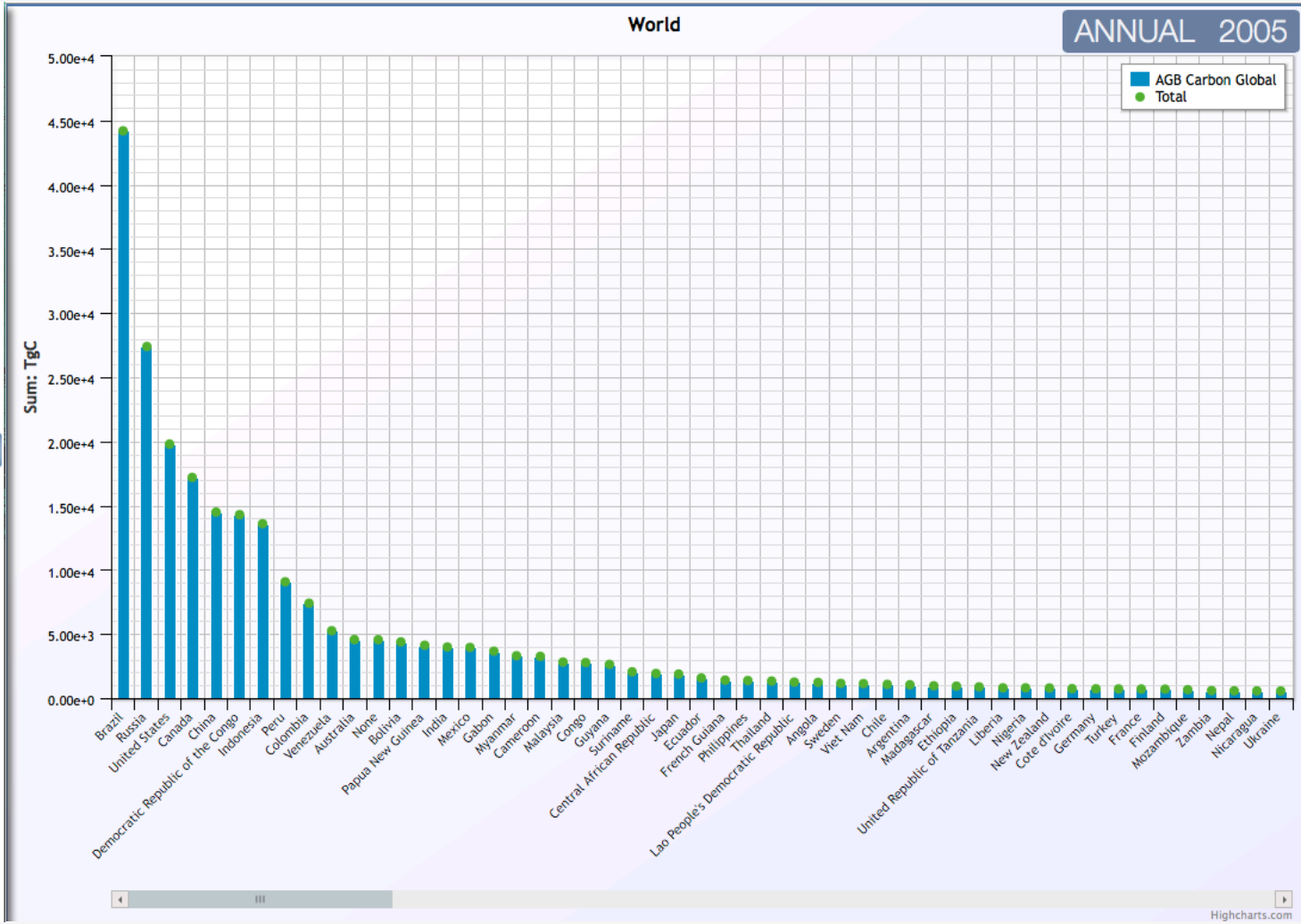

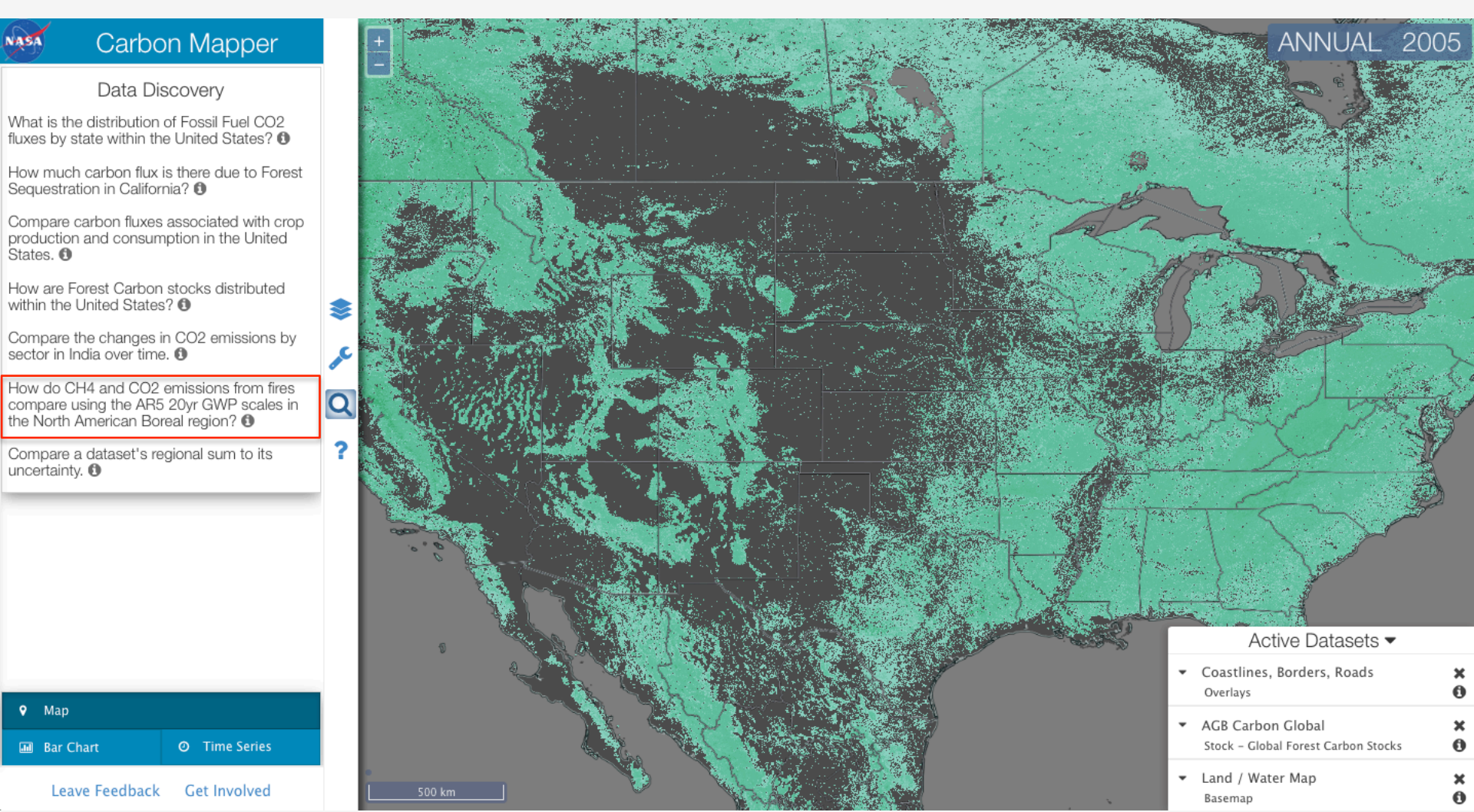
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Map
Bar Chart
Time Series
Leave Feedback
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ANNUAL 2005
500 km
Active Datasets
Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Land / Water Map
Basemap

Carbon Mapper

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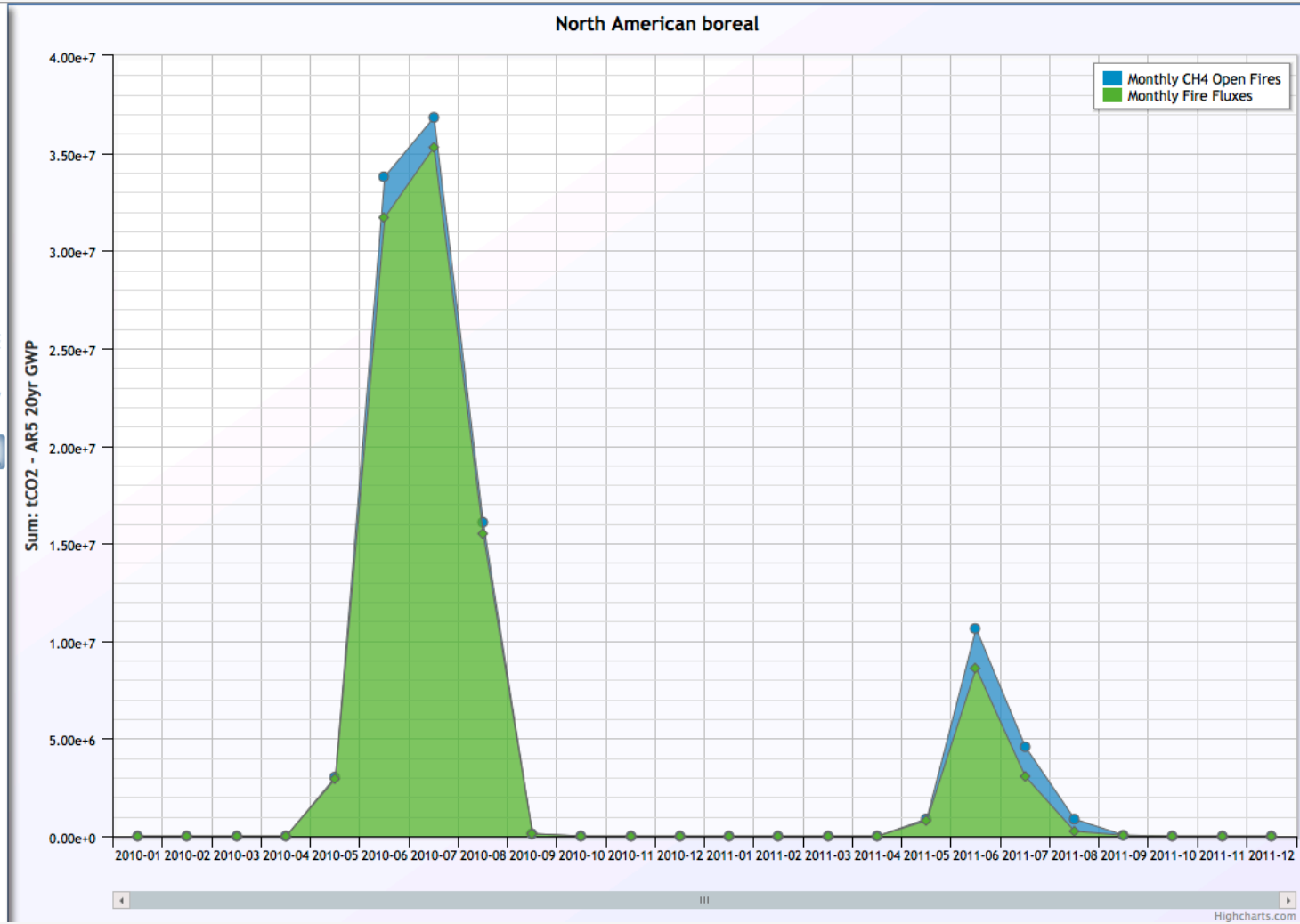
Map

Bar Chart | Time Series

Leave Feedback | Get Involved



Carbon Mapper

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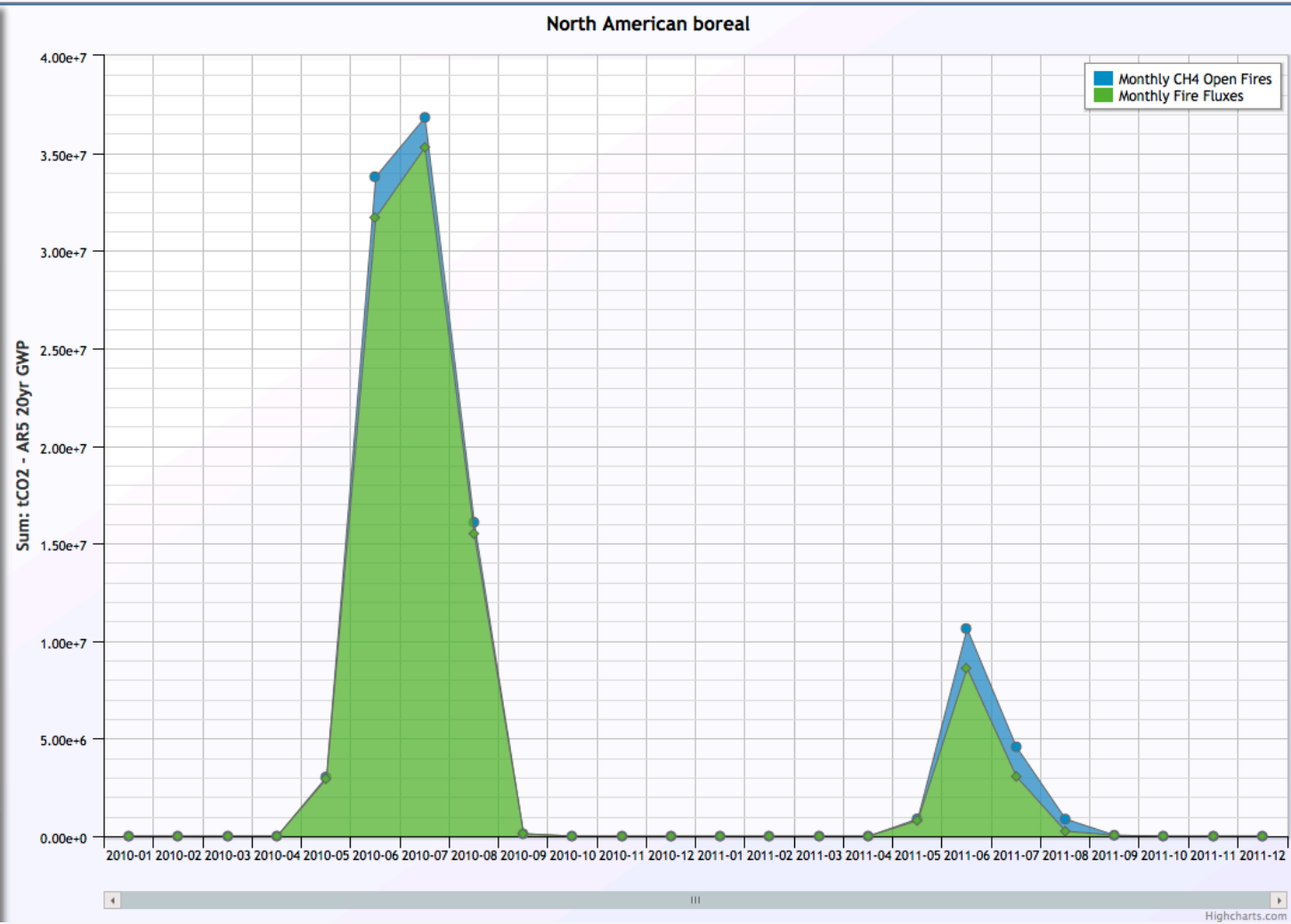
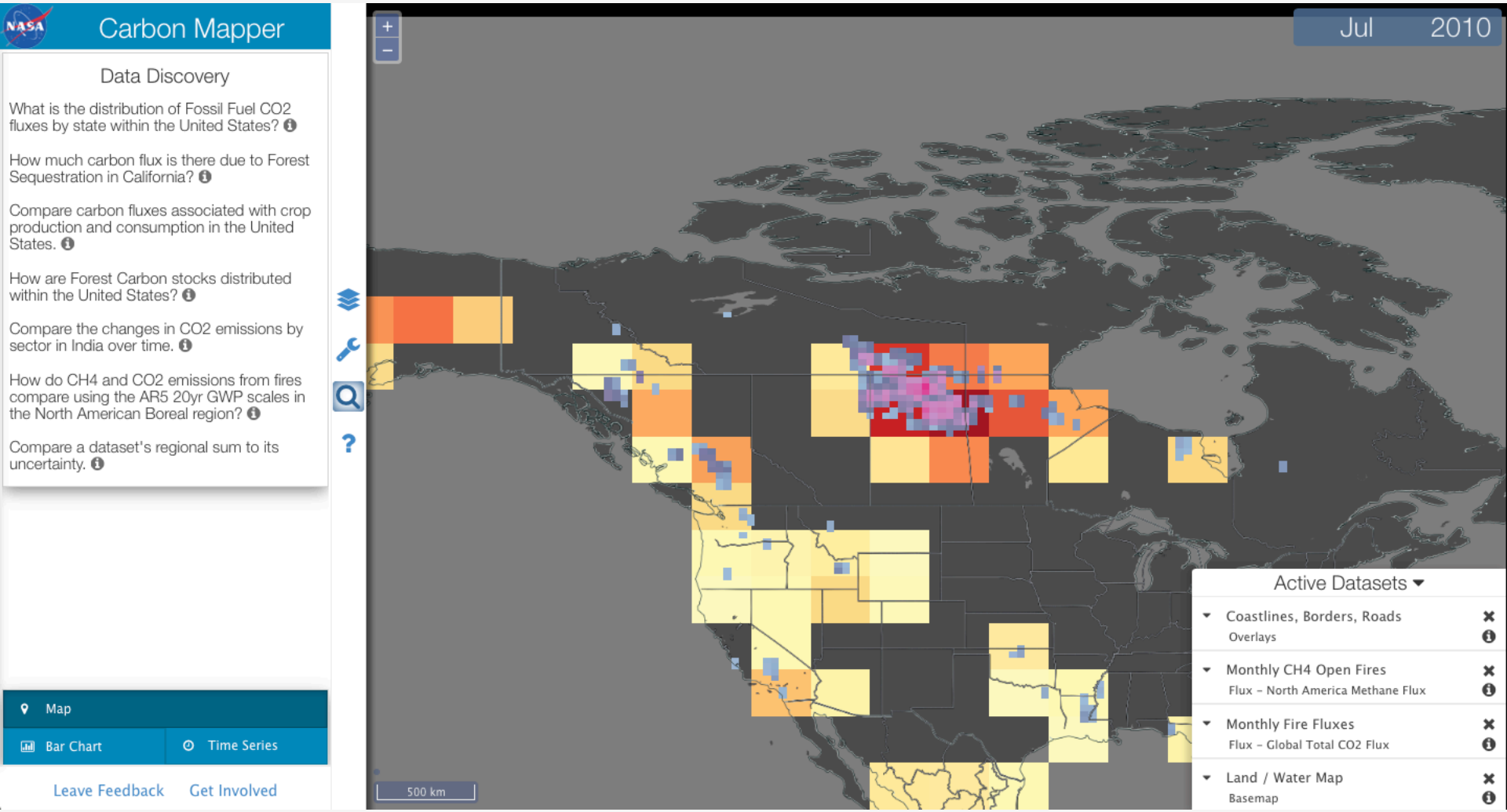
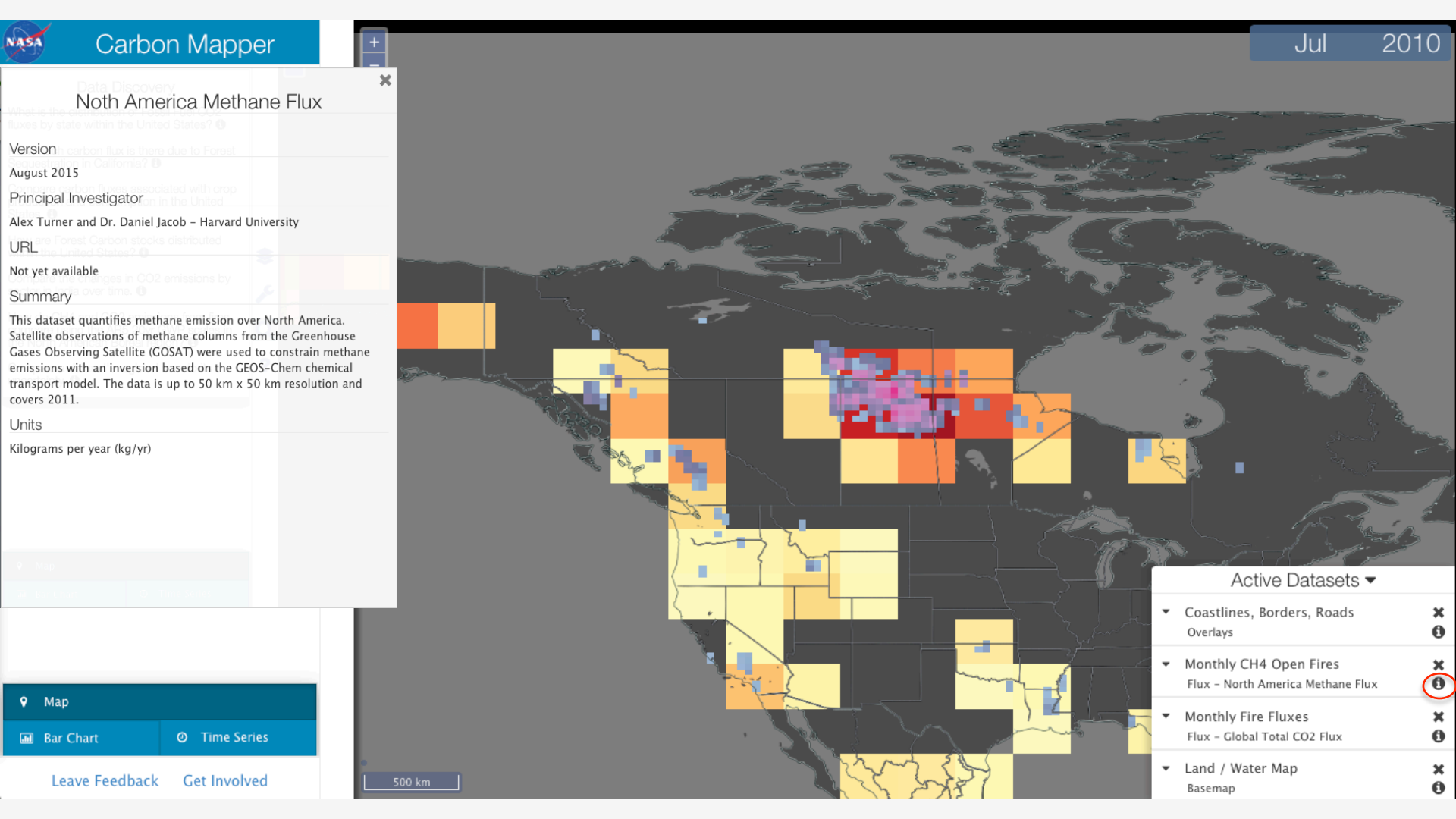
Leave Feedback

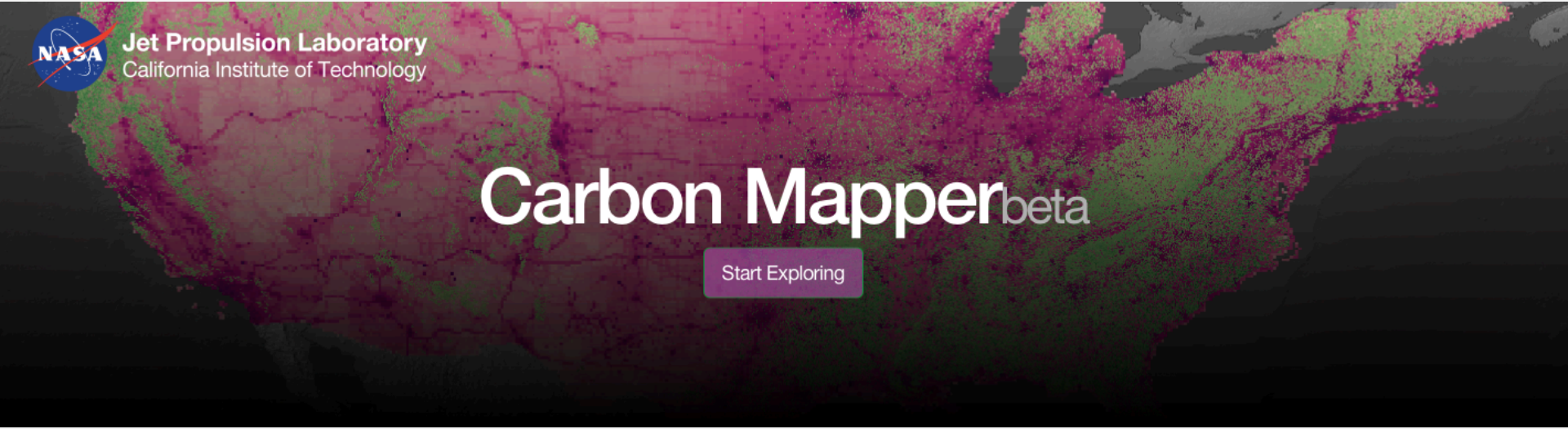
Get Involved

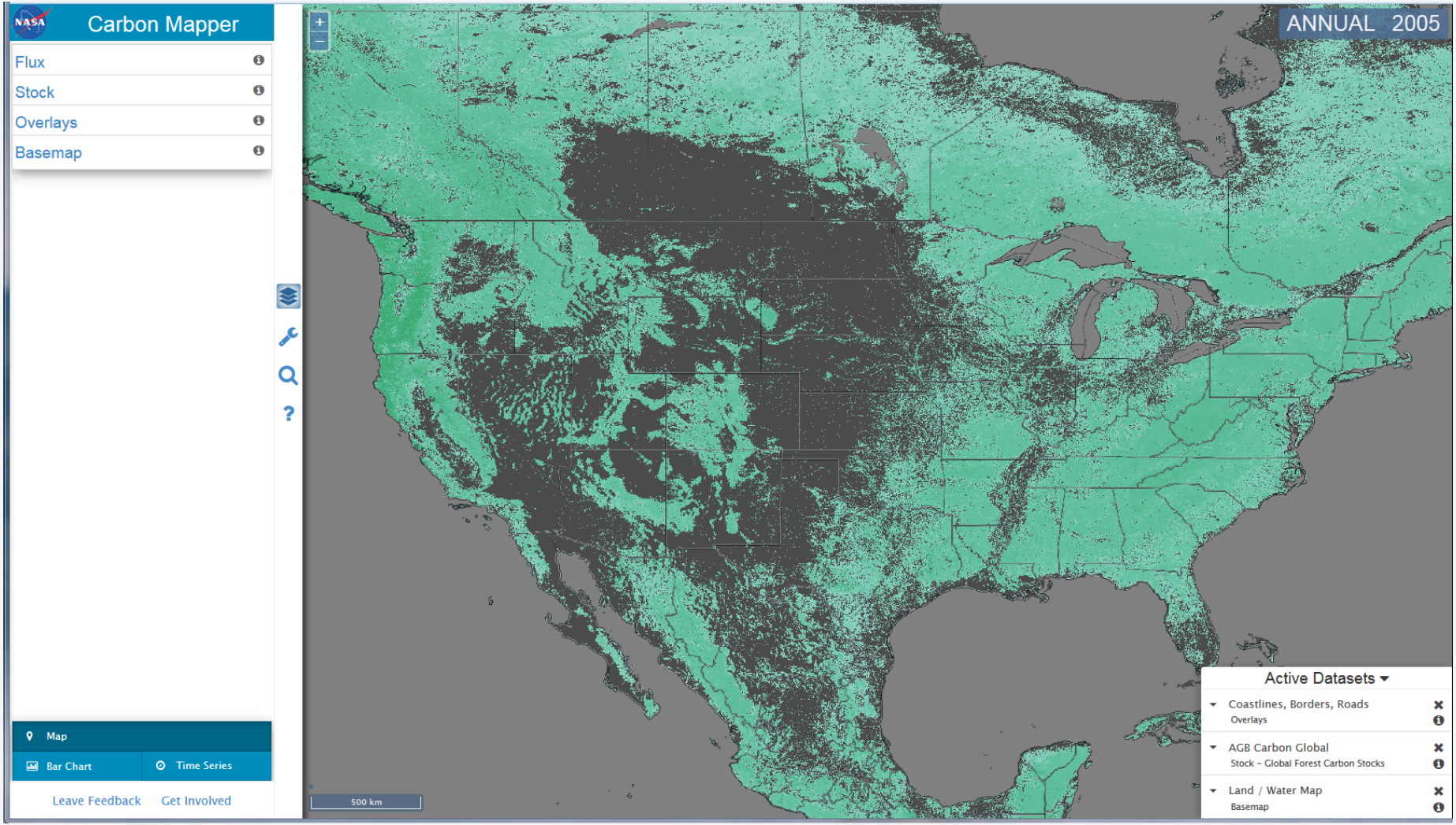


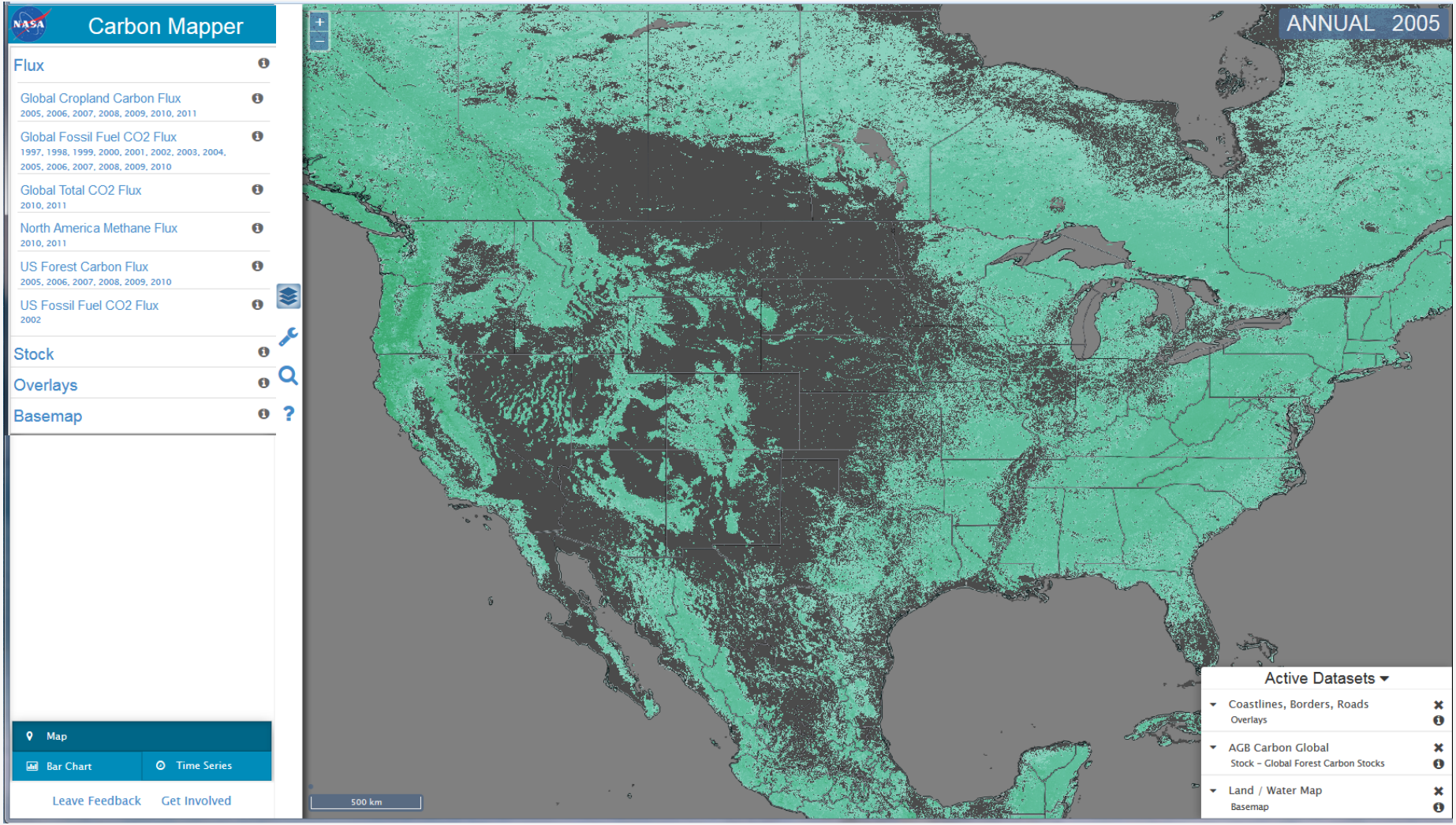

Carbon Mapper
Data Discovery
What is the distribution of Fossil Fuel CO2 fluxes by state within the United States?
How much carbon flux is there due to Forest Sequestration in California?
Compare carbon fluxes associated with crop production and consumption in the United States.
How are Forest Carbon stocks distributed within the United States?
Compare the changes in CO2 emissions by sector in India over time.
How do CH4 and CO2 emissions from fires compare using the AR5 20yr GWP scales in the North American Boreal region?
Compare a dataset's regional sum to its uncertainty.
Map
Bar Chart
Time Series
Leave Feedback
Get Involved
Jul 2010
500 km
Active Datasets
Coastlines, Borders, Roads
Overlays
Monthly CH4 Open Fires
Flux – North America Methane Flux
Monthly Fire Fluxes
Flux – Global Total CO2 Flux
Land / Water Map
Basemap


Carbon Mapper
Noth America Methane Flux
Version
August 2015
Principal Investigator
Alex Turner and Dr. Daniel Jacob – Harvard University
URL
Not yet available
Summary
This dataset quantifies methane emission over North America. Satellite observations of methane columns from the Greenhouse Gases Observing Satellite (GOSAT) were used to constrain methane emissions with an inversion based on the GEOS-Chem chemical transport model. The data is up to 50 km x 50 km resolution and covers 2011.
Units
Kilograms per year (kg/yr)
Jul 2010
Active Datasets
Coastlines, Borders, Roads
Overlays
Monthly CH4 Open Fires
Flux – North America Methane Flux
Monthly Fire Fluxes
Flux – Global Total CO2 Flux
Land / Water Map
Basemap
500 km
Map
Bar Chart
Time Series
Leave Feedback
Get Involved

One more example…..




Carbon Mapper
Flux
Stock
Overlays
Basemap
ANNUAL 2005
Active Datasets
Coastlines, Borders, Roads
Overlays
AGB Carbon Global
Stock – Global Forest Carbon Stocks
Land / Water Map
Basemap
Map
Bar Chart
Time Series
Leave Feedback
Get Involved
500 km


Carbon Mapper
Flux
Global Cropland Carbon Flux
2005, 2006, 2007, 2008, 2009, 2010, 2011
Global Fossil Fuel CO2 Flux
1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010
Global Total CO2 Flux
2010, 2011
North America Methane Flux
2010, 2011
US Forest Carbon Flux
2005, 2006, 2007, 2008, 2009, 2010
US Fossil Fuel CO2 Flux
2002
Stock
Overlays
Basemap
Map
Bar Chart
Time Series
Leave Feedback
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ANNUAL 2005
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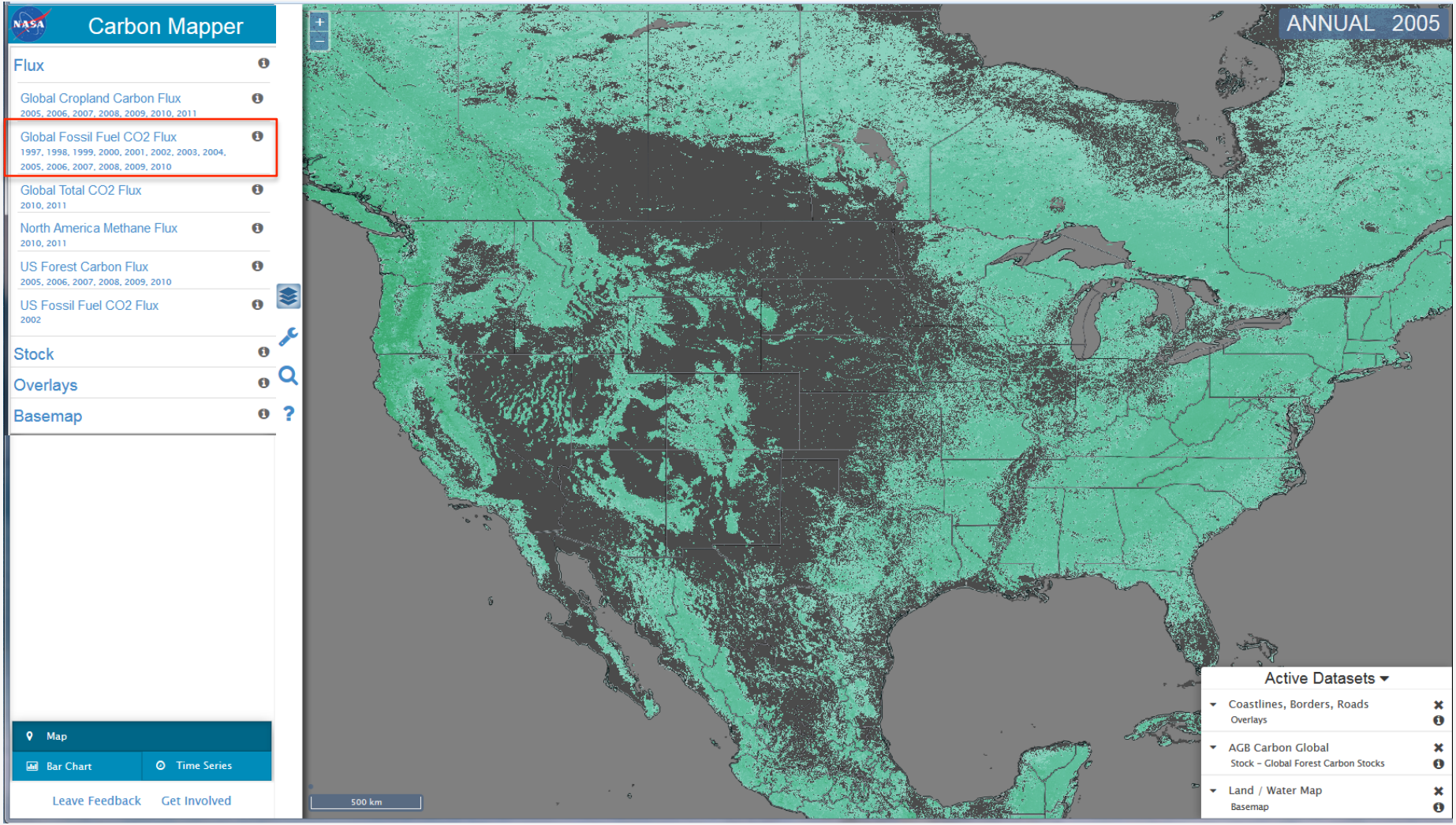
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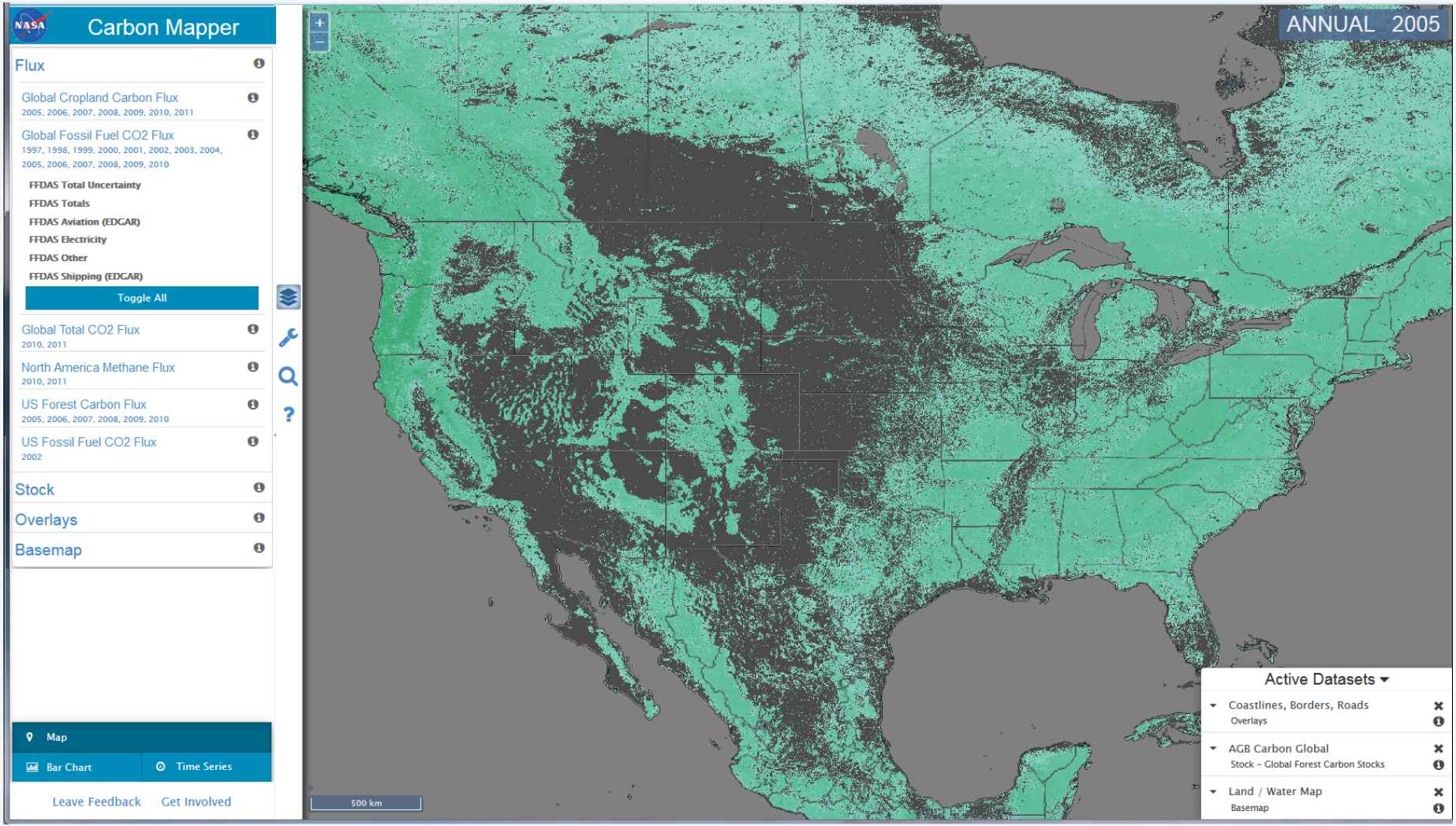
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FFDAS Total Uncertainty
FFDAS Totals
FFDAS Aviation (EDGAR)
FFDAS Electricity
FFDAS Other
FFDAS Shipping (EDGAR)
Toggle All
Global Total CO2 Flux
2010, 2011
North America Methane Flux
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2005, 2006, 2007, 2008, 2009, 2010
US Fossil Fuel CO2 Flux
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Stock
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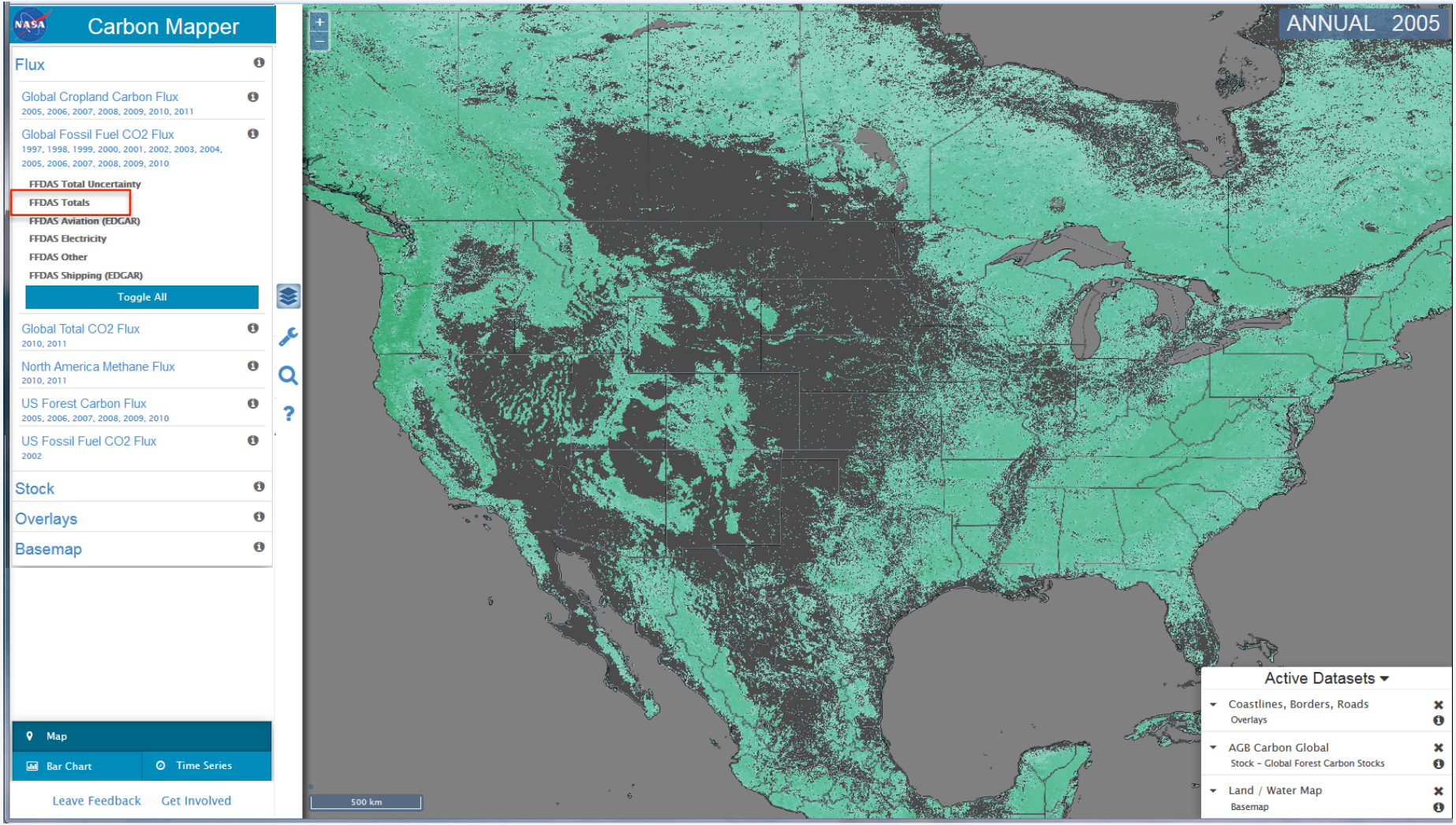
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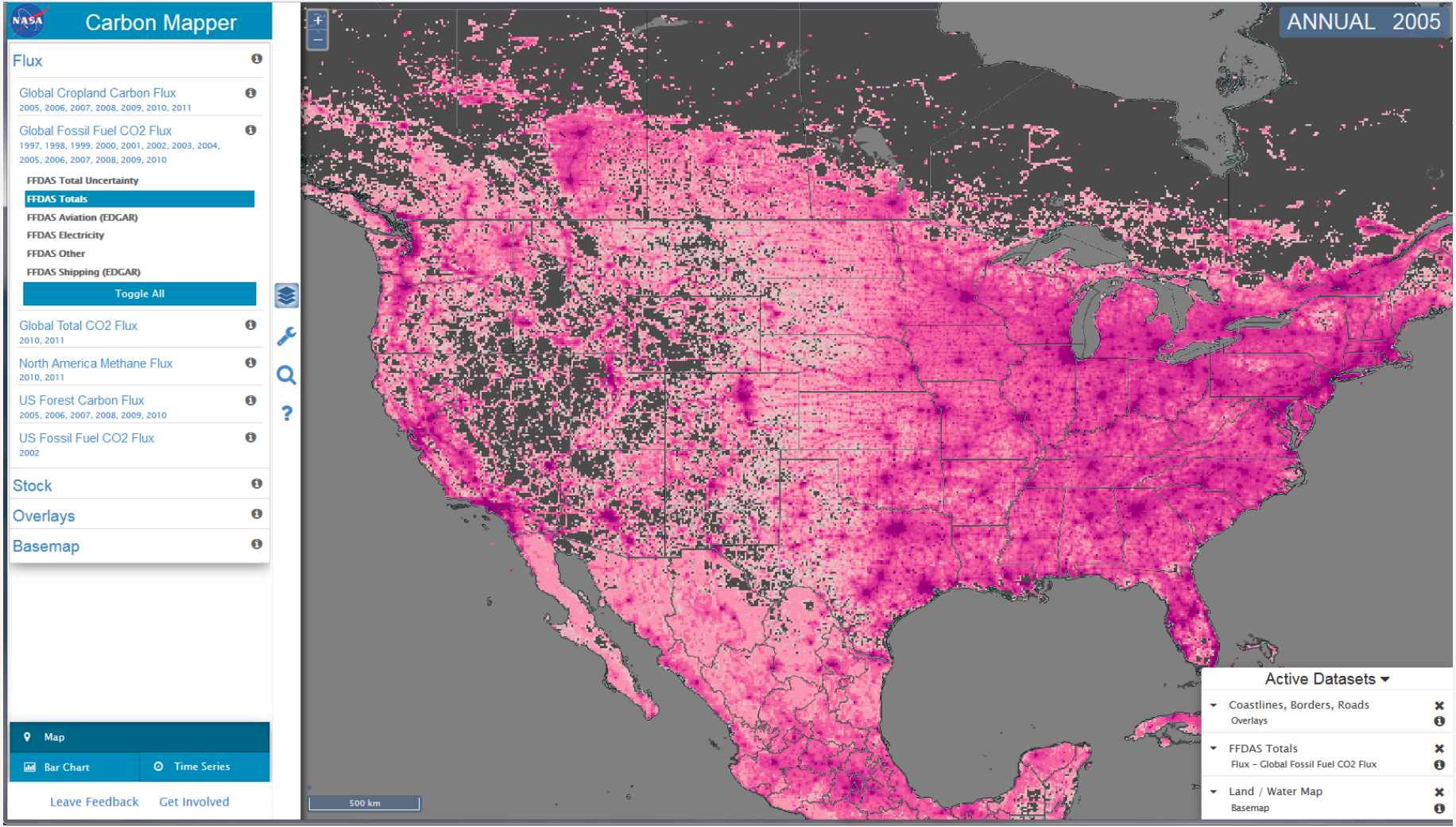
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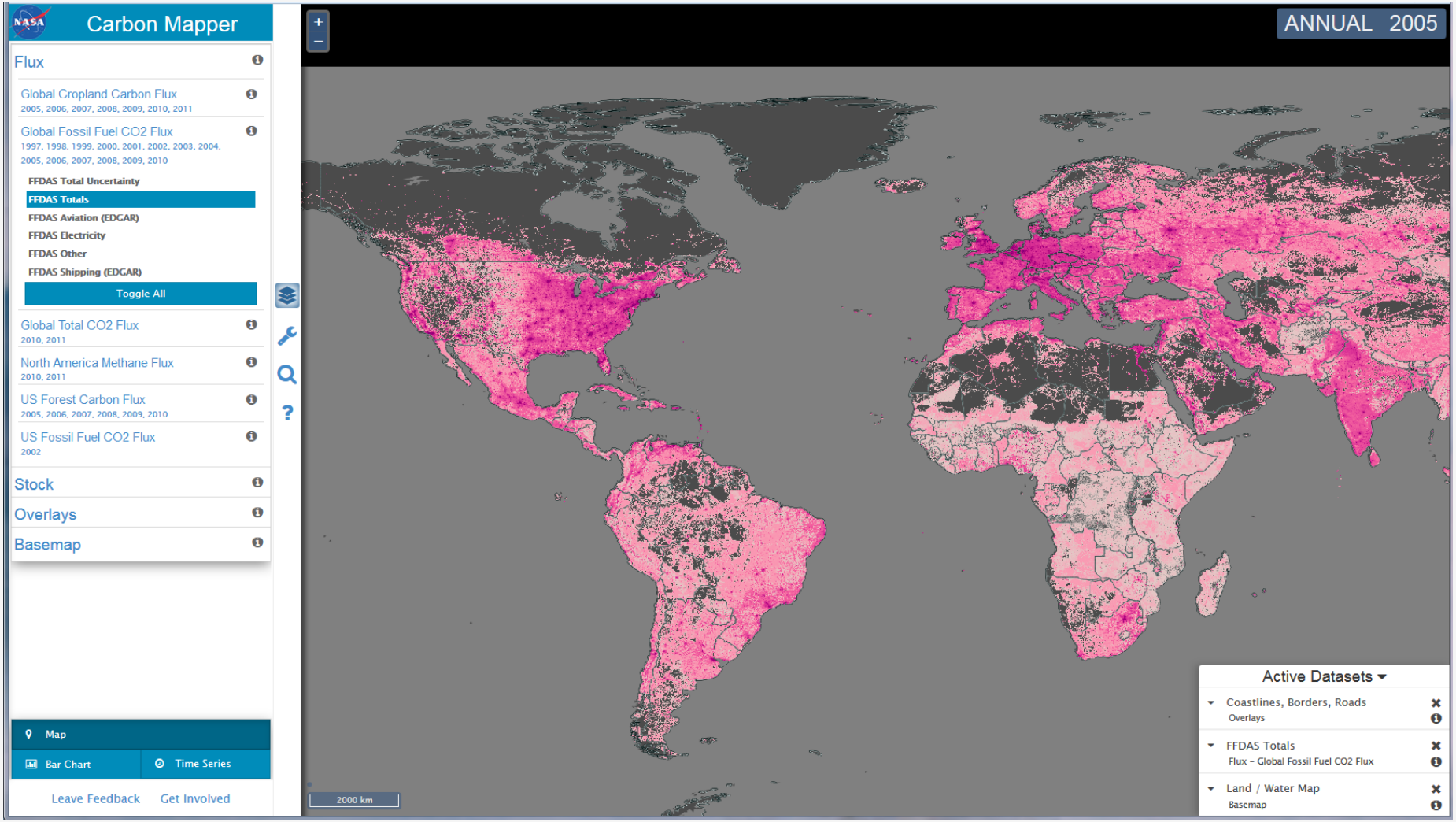
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Overlays
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Map
Bar Chart
Time Series
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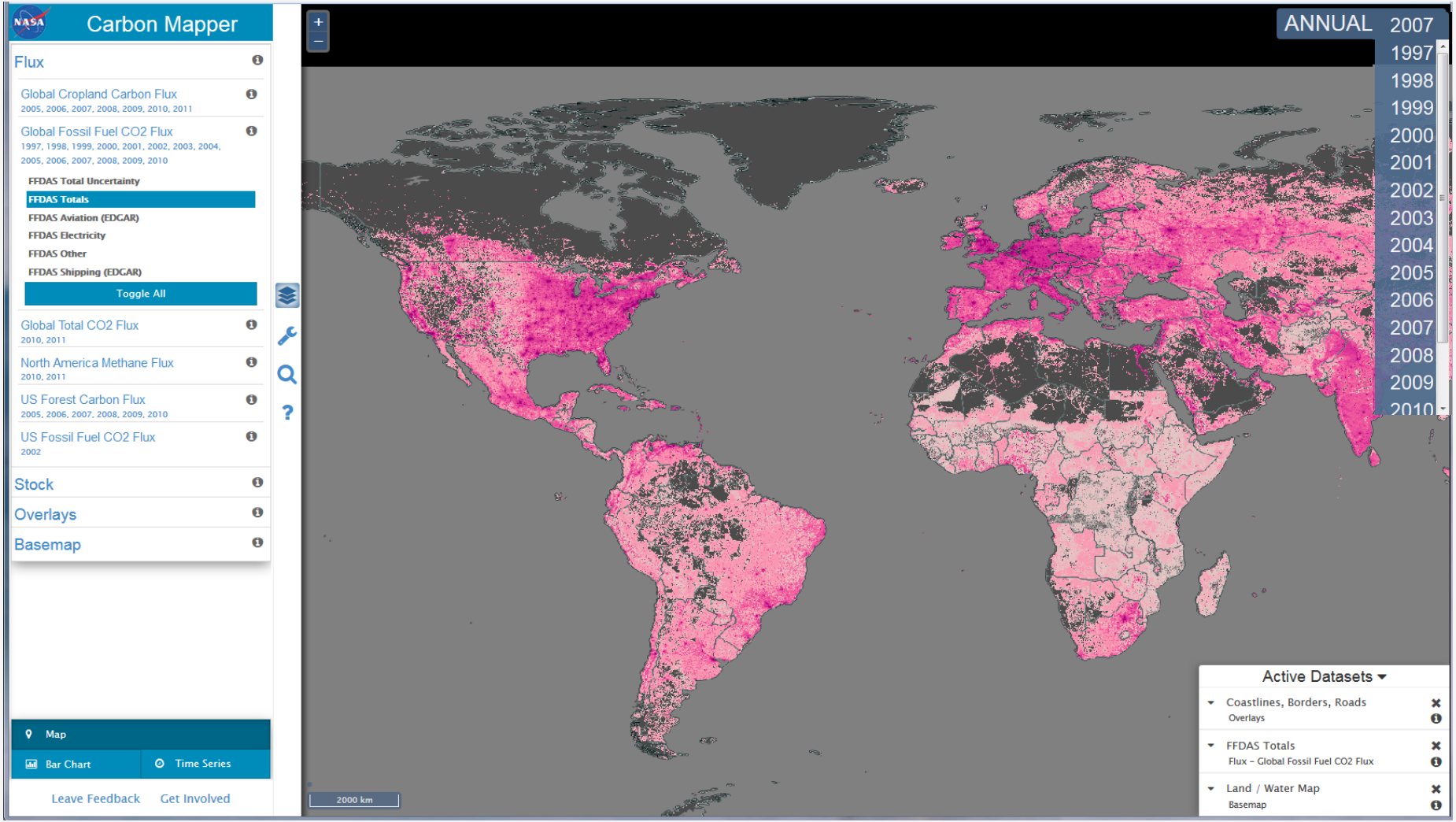
Get Involved
ANNUAL 2005
2000 km
Active Datasets
Coastlines, Borders, Roads
Overlays
FFDAS Totals
Flux – Global Fossil Fuel CO2 Flux
Land / Water Map
Basemap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Stock
Overlays
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Map
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Time Series
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Get Involved
ANNUAL
2007
1997
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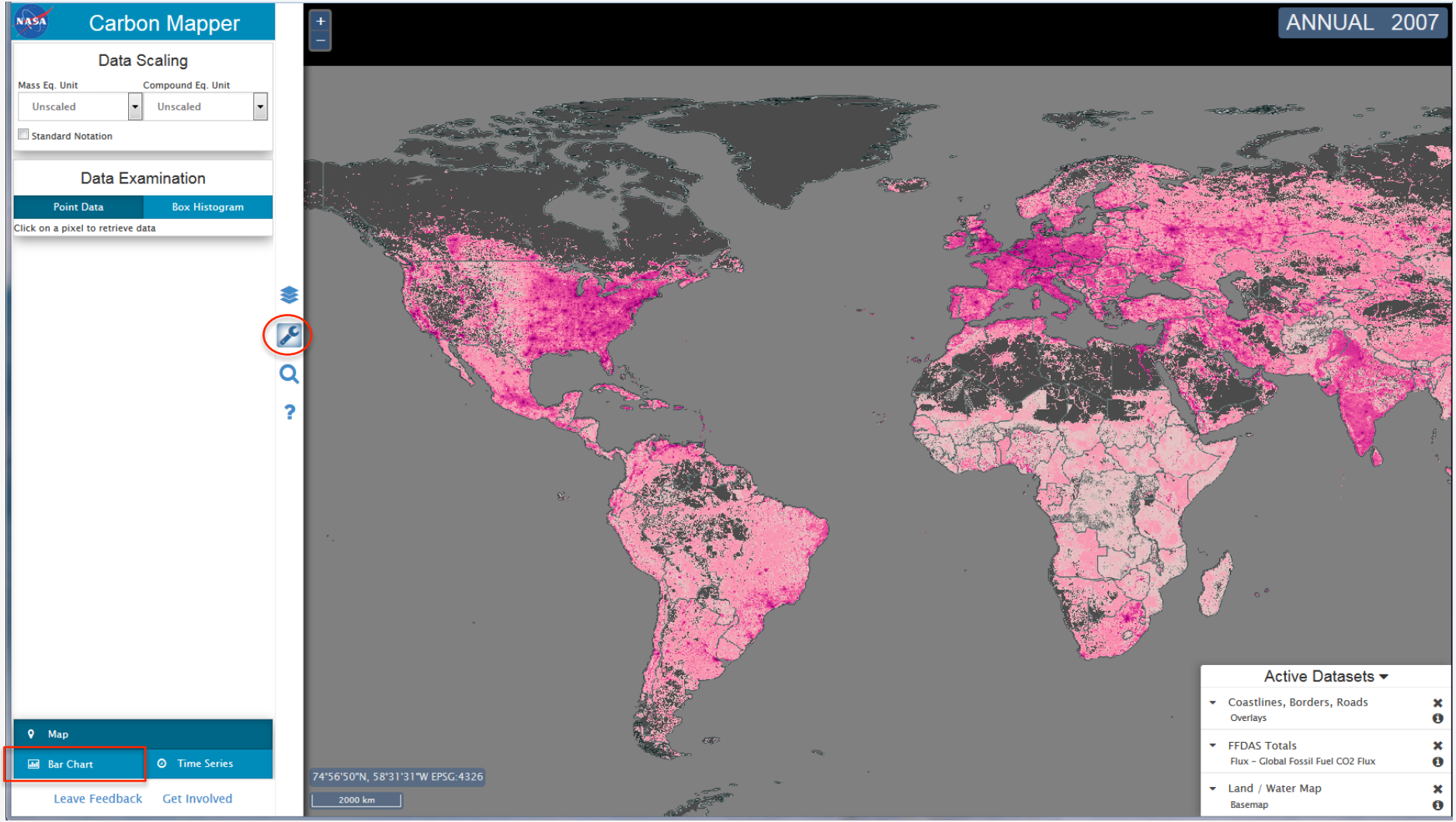
2010
2000 km
Active Datasets
Coastlines, Borders, Roads
Overlays
FFDAS Totals
Flux – Global Fossil Fuel CO2 Flux
Land / Water Map
Basemap


Carbon Mapper
Data Scaling
Mass Eq. Unit
Compound Eq. Unit
Unscaled
Unscaled
Standard Notation
Data Examination
Point Data
Box Histogram
Click on a pixel to retrieve data
Map
Bar Chart
Time Series
Leave Feedback
Get Involved
ANNUAL 2007
74°56'50"N, 58°31'31"W EPSG:4326
2000 km
Active Datasets
Coastlines, Borders, Roads
Overlays
FFDAS Totals
Flux - Global Fossil Fuel CO2 Flux
Land / Water Map
Basemap

Carbon Mapper

Data Scaling

Mass Eq. Unit: Unscaled

Compound Eq. Unit: Unscaled

Standard Notation

Regional Selection

Region: World

Country:

Export Table

Compare Subregions

Map

Bar Chart | Time Series

Leave Feedback | Get Involved

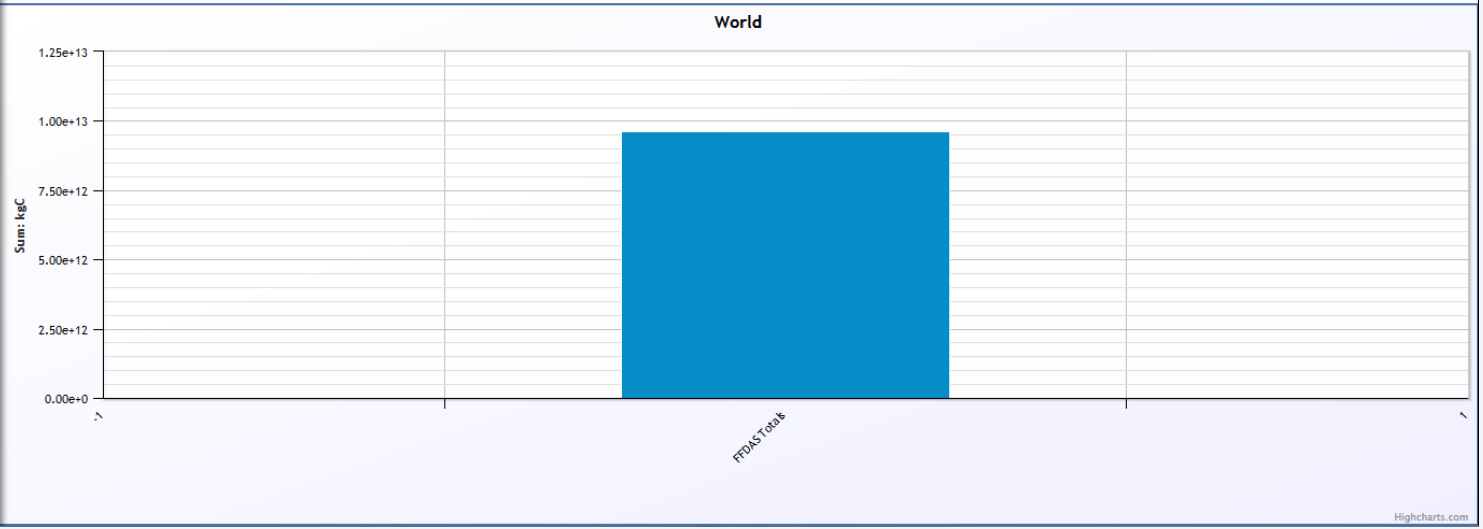
World

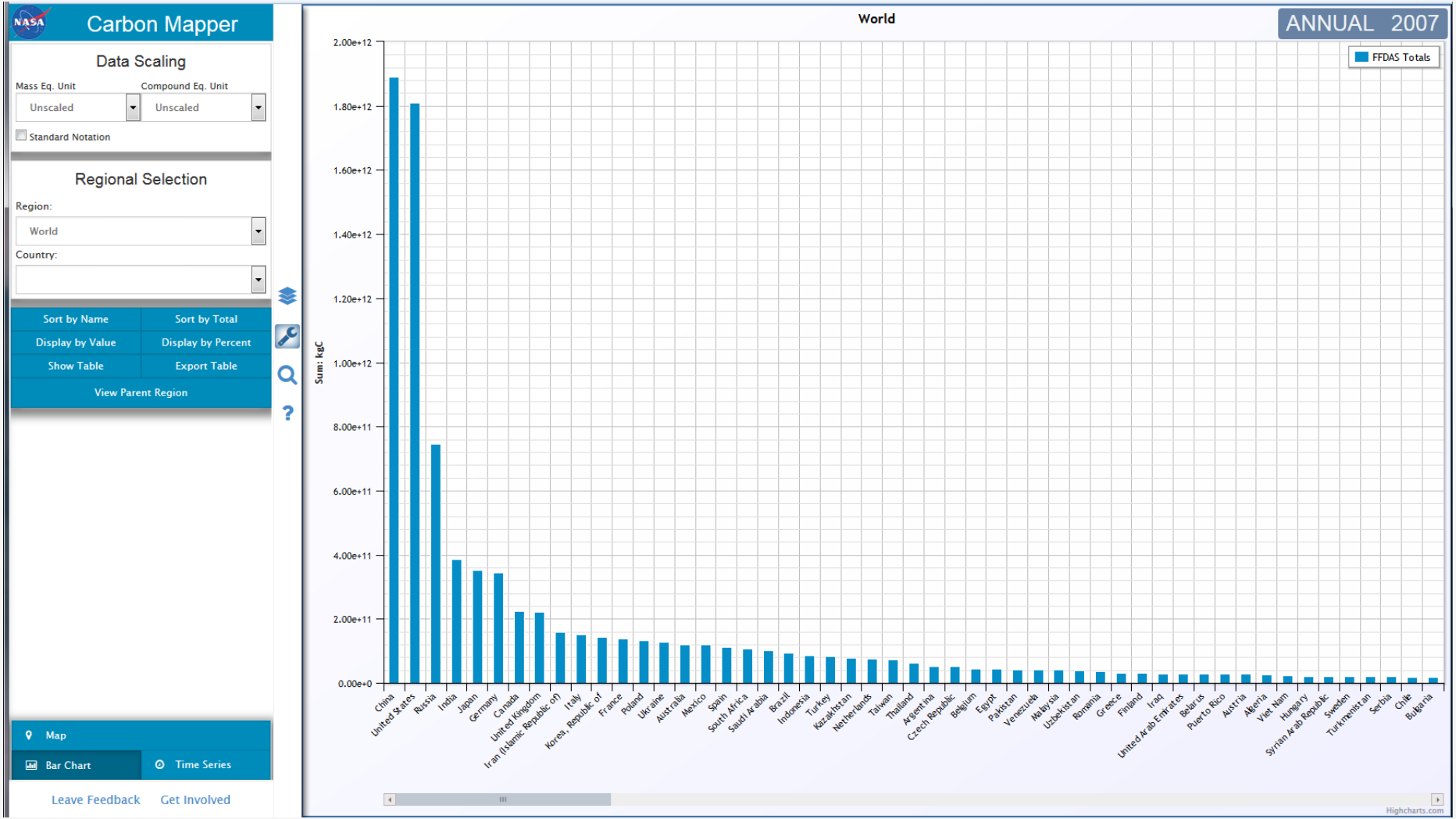
kgC

ANNUAL 2007

	Sum	Mean	Max	Min	Std
FFDAS Totals	9.62e+12*	1.20e-2*	1.11e+2*	-2.63e+0*	3.92e-1*

* data entry was generated by Carbon Mapper Team




Carbon Mapper
Data Scaling
Mass Eq. Unit
Unscaled
Compound Eq. Unit
Unscaled
Standard Notation
Regional Selection
Region:
World
Country:
Sort by Name
Sort by Total
Display by Value
Display by Percent
Show Table
Export Table
View Parent Region
Map
Bar Chart
Time Series
Leave Feedback
Get Involved
World
ANNUAL 2007
FFDAS Totals
Sum: kgC
2.00e+12
1.80e+12
1.60e+12
1.40e+12
1.20e+12
1.00e+12
8.00e+11
6.00e+11
4.00e+11
2.00e+11
0.00e+0
China
United States
Russia
India
Japan
Germany
Canada
United Kingdom
Iran (Islamic Republic of)
Italy
Korea, Republic of
France
Poland
Ukraine
Australia
Mexico
Spain
South Africa
Saudi Arabia
Brazil
Indonesia
Turkey
Kazakhstan
Netherlands
Taiwan
Thailand
Argentina
Czech Republic
Belgium
Egypt
Pakistan
Venezuela
Malaysia
Uzbekistan
Romania
Greece
Finland
Iraq
United Arab Emirates
Belarus
Puerto Rico
Austria
Algeria
Viet Nam
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Bulgaria
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  - Ana Prados: aprados@umbc.edu
- ARSET Website:
  - http://arset.gsfc.nasa.gov

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Thank You

Next Week:

Carbon Estimation Techniques and Methods