National Aeronautics and Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
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SilvaCarbon
http://egsc.usgs.gov/silvacarbon/index.html
@SilvaCarbon

Remote sensing of forest cover and change assessment for carbon monitoring

Instructors: Amber McCullum, Grant Domke (USFS), Ty Wilson (USFS)

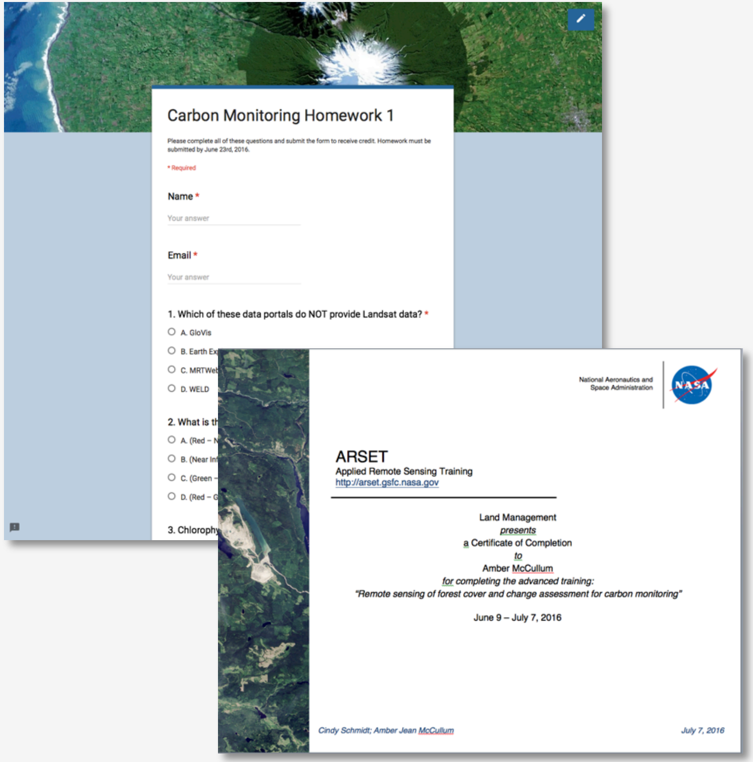
Week 3: June 23, 2016

Course Structure

- One lecture per week – every Thursday from June 9 to July 7 at 1:00-2:30 p.m. and 10:00-11:30 p.m. 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)

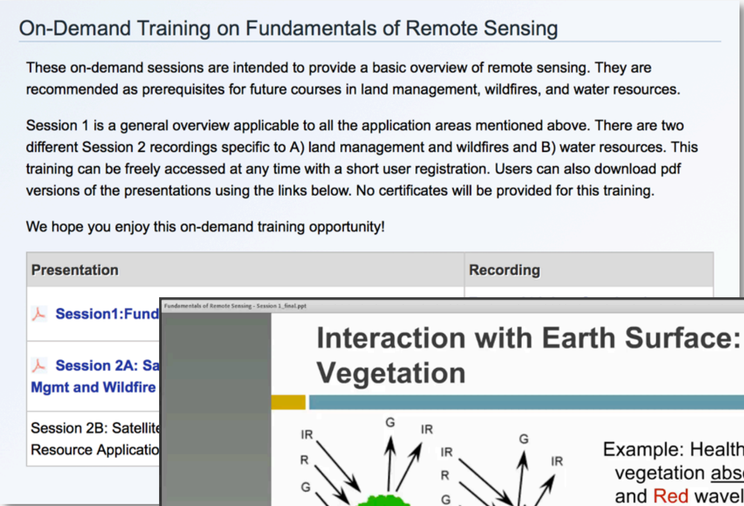
Homework and Certificates

- Homework
  - Answers must be submitted via Google Form
- Certificate of Completion:
  - Attend four out of five live webinars
  - Complete both homework assignments by the deadline (access from ARSET website above)
    - Week 2 HW Deadline: June 30th
  - You will receive certificates approximately 3 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

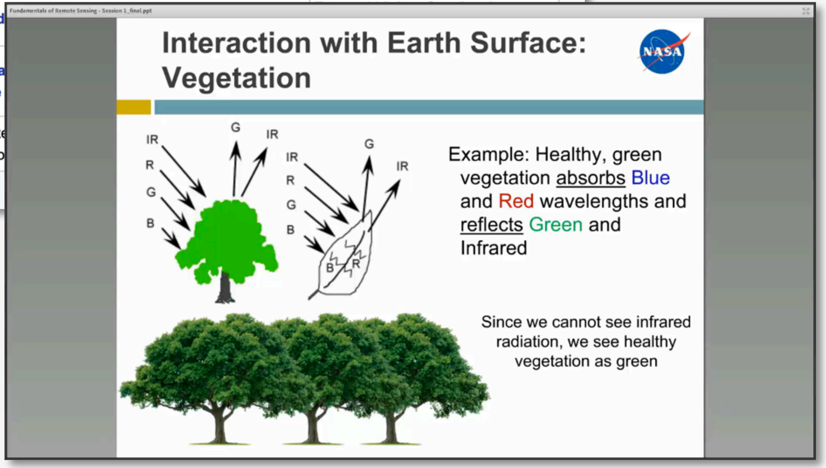

On-Demand Training on Fundamentals of Remote Sensing

These on-demand sessions are intended to provide a basic overview of remote sensing. They are recommended as prerequisites for future courses in land management, wildfires, and water resources.

Session 1 is a general overview applicable to all the application areas mentioned above. There are two different Session 2 recordings specific to A) land management and wildfires and B) water resources. This training can be freely accessed at any time with a short user registration. Users can also download pdf versions of the presentations using the links below. No certificates will be provided for this training.

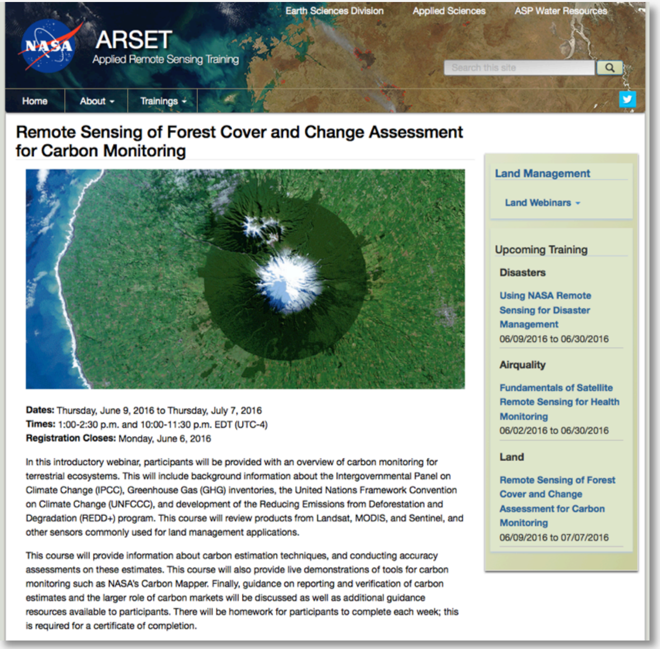
We hope you enjoy this on-demand training opportunity!

Presentation	Recording
Session1:Fund	
Session 2A: Sa Mgmt and Wildfire	
Session 2B: Satellite Resource Applicatio	



Accessing Course Materials

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



Earth Sciences Division Applied Sciences ASP Water Resources

ARSET
Applied Remote Sensing Training

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Remote Sensing of Forest Cover and Change Assessment for Carbon Monitoring

Dates: Thursday, June 9, 2016 to Thursday, July 7, 2016
Times: 1:00-2:30 p.m. and 10:00-11:30 p.m. EDT (UTC-4)
Registration Closes: Monday, June 6, 2016

In this introductory webinar, participants will be provided with an overview of carbon monitoring for terrestrial ecosystems. This will include background information about the Intergovernmental Panel on Climate Change (IPCC), Greenhouse Gas (GHG) inventories, the United Nations Framework Convention on Climate Change (UNFCCC), and development of the Reducing Emissions from Deforestation and Degradation (REDD+) program. This course will review products from Landsat, MODIS, and Sentinel, and other sensors commonly used for land management applications.

This course will provide information about carbon estimation techniques, and conducting accuracy assessments on these estimates. This course will also provide live demonstrations of tools for carbon monitoring such as NASA's Carbon Mapper. Finally, guidance on reporting and verification of carbon estimates and the larger role of carbon markets will be discussed as well as additional guidance resources available to participants. There will be homework for participants to complete each week; this is required for a certificate of completion.

Land Management

Land Webinars

Upcoming Training

Disasters

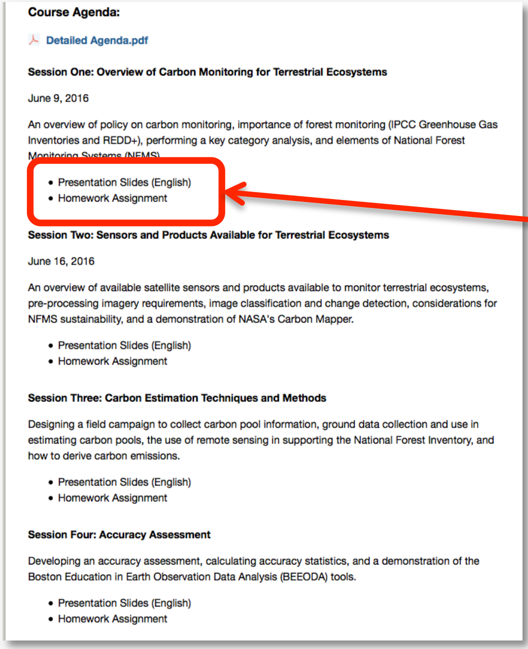
Using NASA Remote Sensing for Disaster Management
06/09/2016 to 06/30/2016

Airquality

Fundamentals of Satellite Remote Sensing for Health Monitoring
06/02/2016 to 06/30/2016

Land

Remote Sensing of Forest Cover and Change Assessment for Carbon Monitoring
06/09/2016 to 07/07/2016



Course Agenda:

Detailed Agenda.pdf

Session One: Overview of Carbon Monitoring for Terrestrial Ecosystems

June 9, 2016

An overview of policy on carbon monitoring, importance of forest monitoring (IPCC Greenhouse Gas Inventories and REDD+), performing a key category analysis, and elements of National Forest Monitoring Systems (NFMS).

- Presentation Slides (English)
- Homework Assignment

Session Two: Sensors and Products Available for Terrestrial Ecosystems

June 16, 2016

An overview of available satellite sensors and products available to monitor terrestrial ecosystems, pre-processing imagery requirements, image classification and change detection, considerations for NFMS sustainability, and a demonstration of NASA's Carbon Mapper.

- Presentation Slides (English)
- Homework Assignment

Session Three: Carbon Estimation Techniques and Methods

Designing a field campaign to collect carbon pool information, ground data collection and use in estimating carbon pools, the use of remote sensing in supporting the National Forest Inventory, and how to derive carbon emissions.

- Presentation Slides (English)
- Homework Assignment

Session Four: Accuracy Assessment

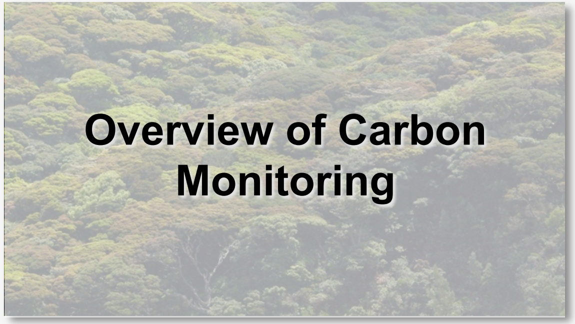
Developing an accuracy assessment, calculating accuracy statistics, and a demonstration of the Boston Education in Earth Observation Data Analysis (BEEODA) tools.

- Presentation Slides (English)
- Homework Assignment

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

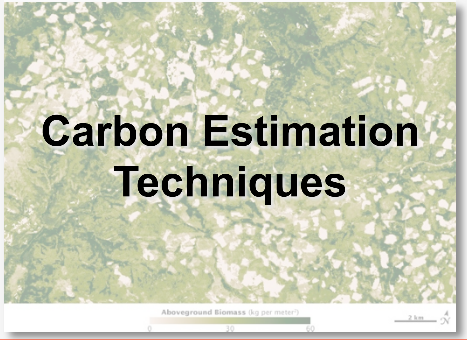
Course Outline

Week 1

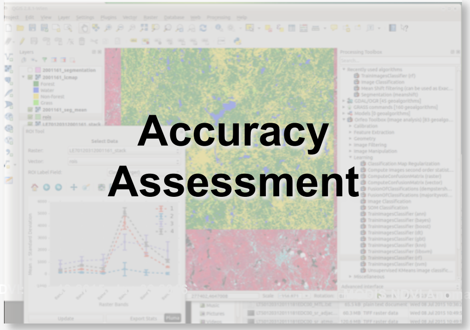


Week 2

Week 3



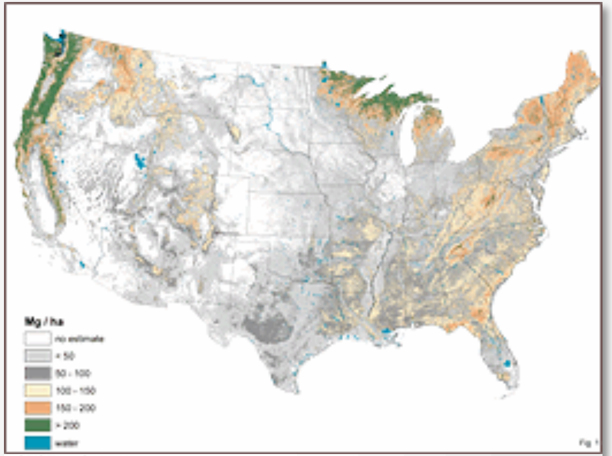
Week 4

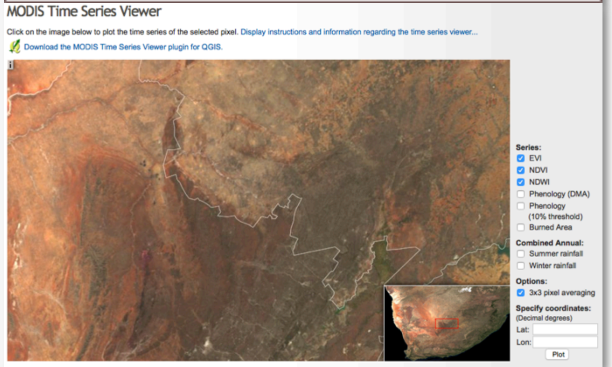


Week 5

Week 3 Agenda

- Role of forest carbon monitoring
- National Forest Inventory (NFI)
  - Status, trends, and sustainability of forests
- Forest carbon stock estimation and reporting
- Approaches for time series image processing and analysis
- Case study example
- Q&A





Top: Total forest carbon stocks (C Mg/ha, all pools) across the conterminous US. Image credit: USDA Forest Service. Bottom: MODIS time series viewer. Image Credit: WAMIS, http://wamis.meraka.org.za/time-series-viewer

Guest Speaker: Grant Domke

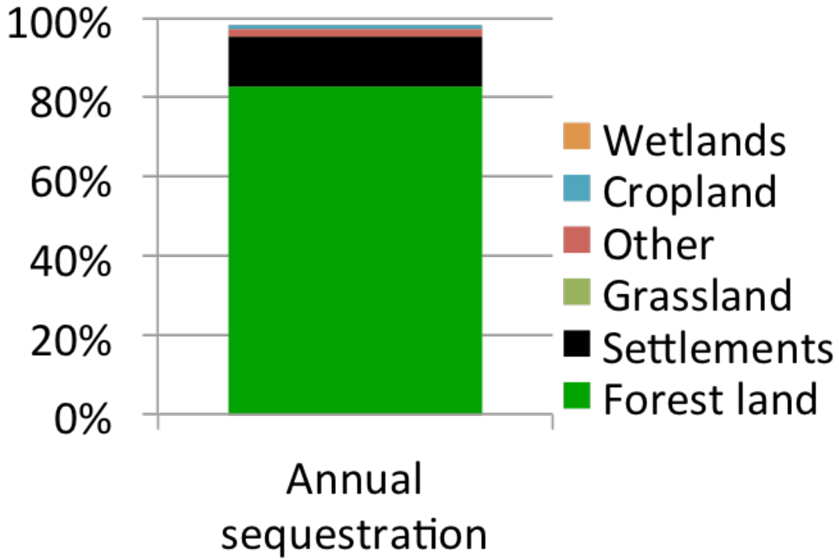
Forest carbon monitoring and reporting in the U.S.

Domke, G.M., Woodall, C.W., Walters, B.F., Smith, J.E., and many others

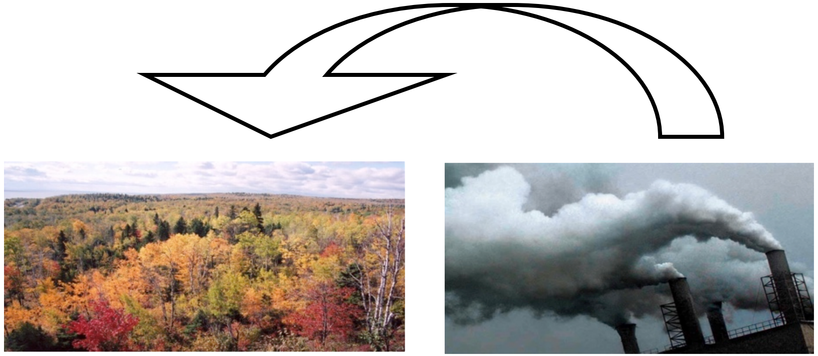
June 23, 2016

Importance of forest land in the U.S.

≈ 86%



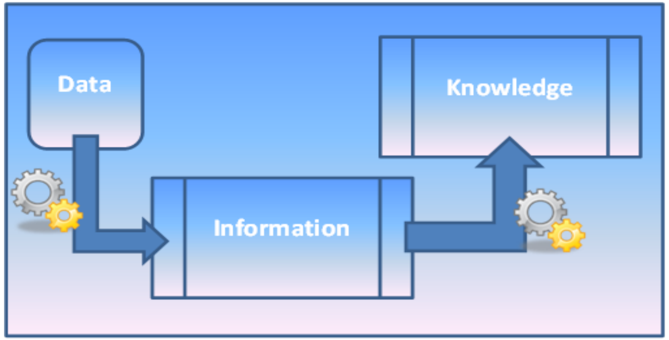
≈11%



2016: (172) MMT C yr^{-1}

EPA. 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Role of forest carbon accounting



California Environmental Protection Agency
Air Resources Board

Role of forest carbon accounting

EPA 430-R-15-004

Inventory of U.S. Greenhouse Gas Emissions and Sinks:

1990 – 2013

APRIL 15, 2015

U.S. Environmental Protection Agency
1200 Pennsylvania Ave., N.W.
Washington, DC 20460
U.S.A.

Improvements paradigm

"…inventories should contain neither over nor underestimates so far as can be judged, and the uncertainties in these estimates should be reduced as far as practicable." – IPCC

Intergovernmental Panel on Climate Change 2006. IPCC guidelines for national greenhouse gas inventories. http://www. ipcc-nggip. iges

Improvements paradigm

"…inventories should contain neither over nor underestimates so far as can be judged, and the uncertainties in these estimates should be reduced as far as practicable." – IPCC

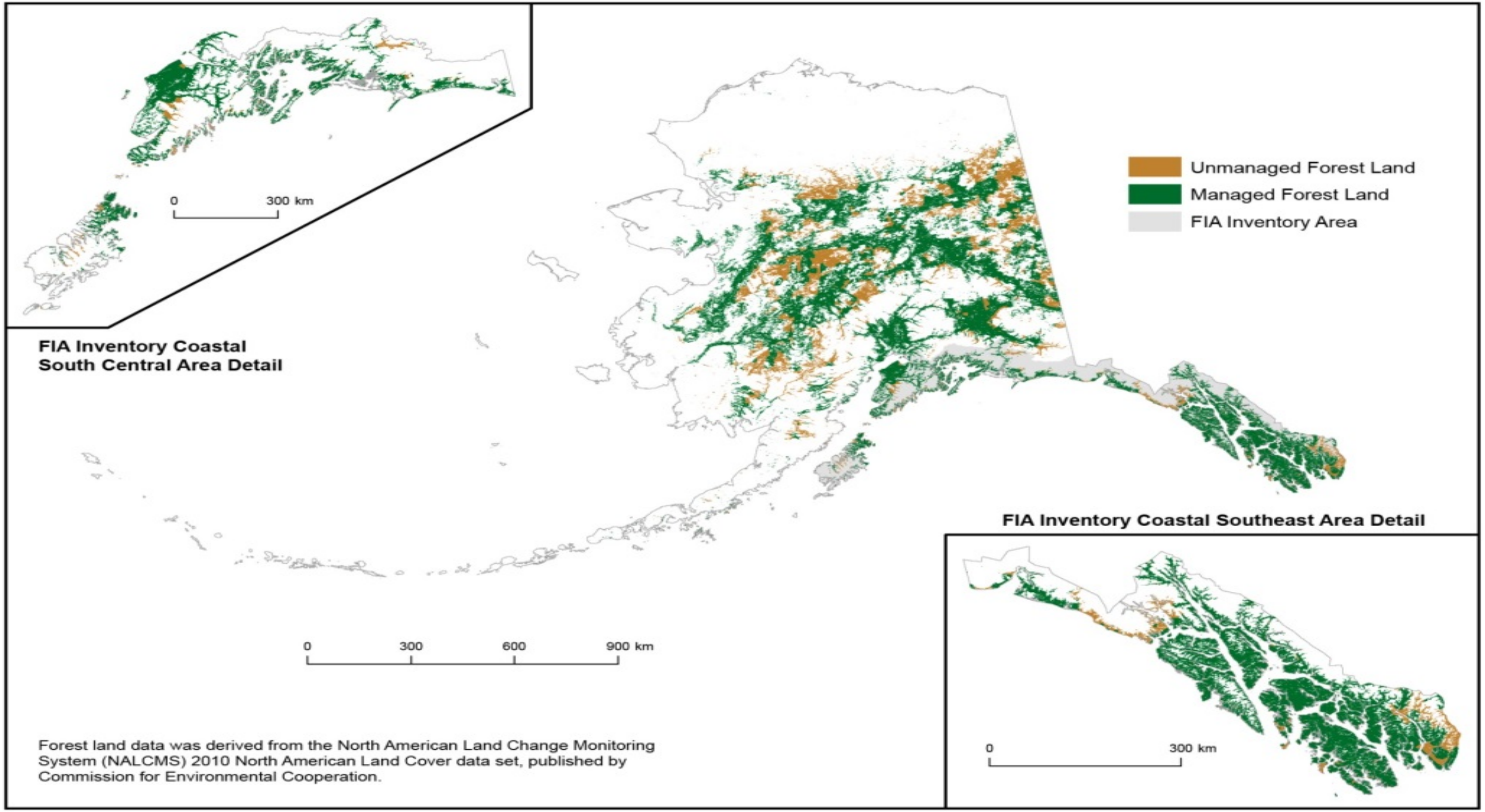
- Expand the use of in situ plots
- Integrate auxiliary information
- Align national and international reporting instruments
- Maintain transparency and open access
- Incorporate emerging science
- Build partnerships
- Remain nimble to address ever-changing requests, guidance, and stakeholder needs

Intergovernmental Panel on Climate Change 2006. IPCC guidelines for national greenhouse gas inventories. http://www. ipcc-nggip. iges

Managed lands

- Only managed lands included in UNFCCC reporting
- Direct human intervention has influenced its condition
- All forest land in the CONUS is classified as managed land

Managed lands

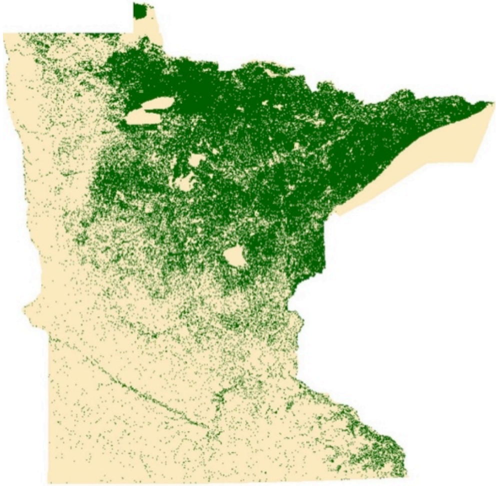


Forest land definition

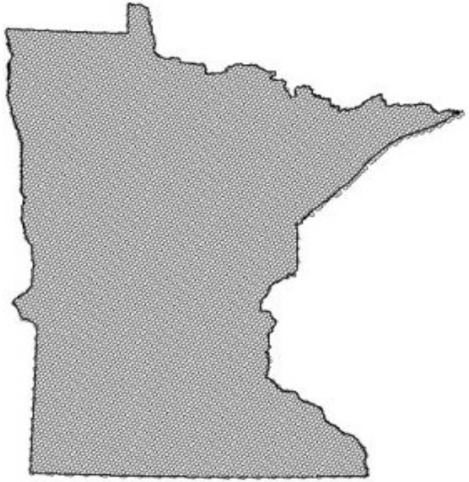
Land at least 37 meters wide and at least 0.4 hectare in size with at least 10% cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 7.6 cm in diameter at breast height, or 12.7 cm diameter at root collar, and a height of 5 meters at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and nonforest lands that have at least 10% cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 37 meters wide or 0.4 hectare in size. Forest land does not include land that is predominantly under agricultural or urban land use.

Oswalt, S.N., Smith, W.B., Miles, P.D. and Pugh, S.A., 2014. Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2015 update of the RPA Assessment. Gen. Tech. Rep. WO-91. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 218 p.

National forest inventory (NFI) sampling frame



Prefield analysis

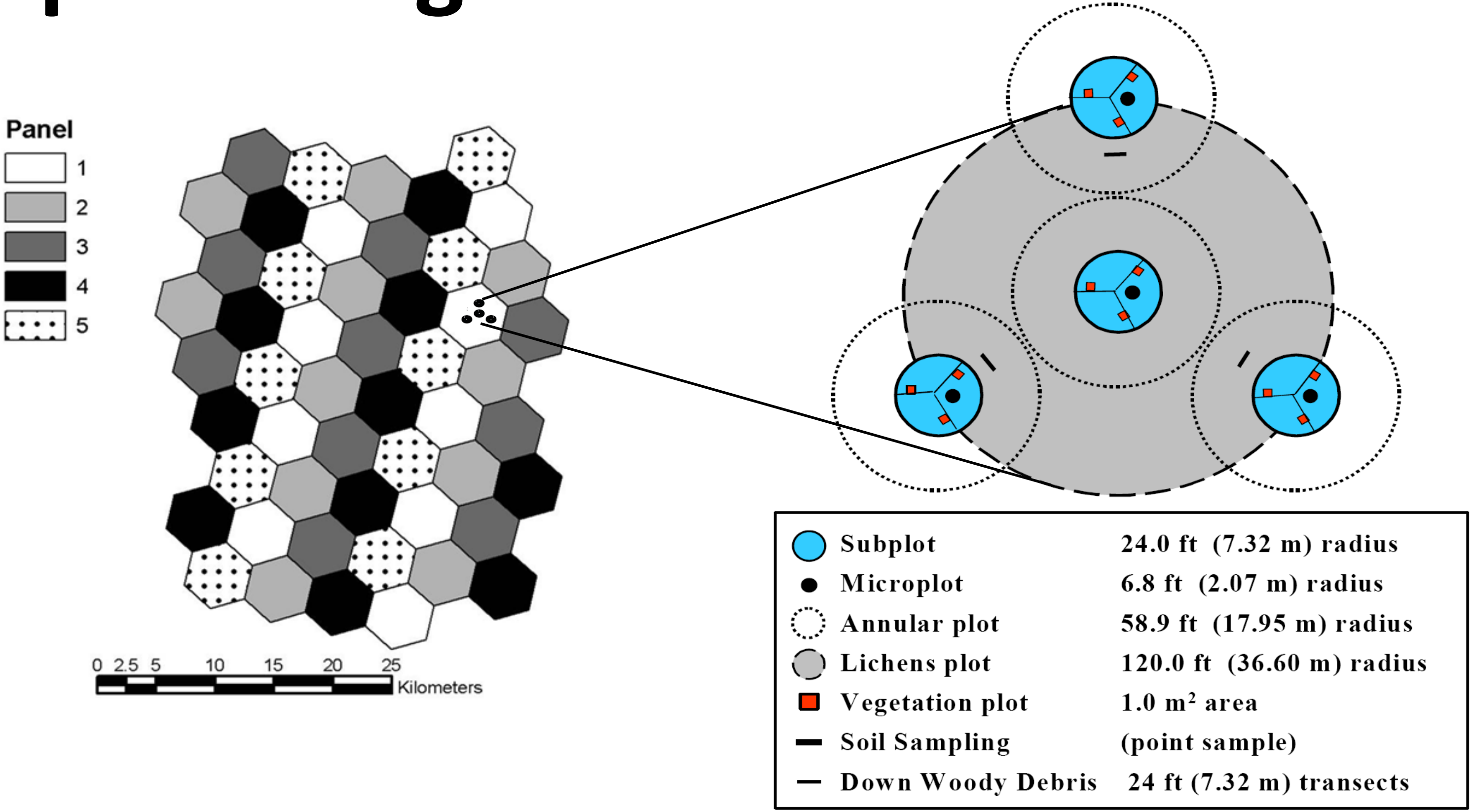


Core field
1 plot per 2,430 ha

Intensive field
1 plot per 38,880 ha

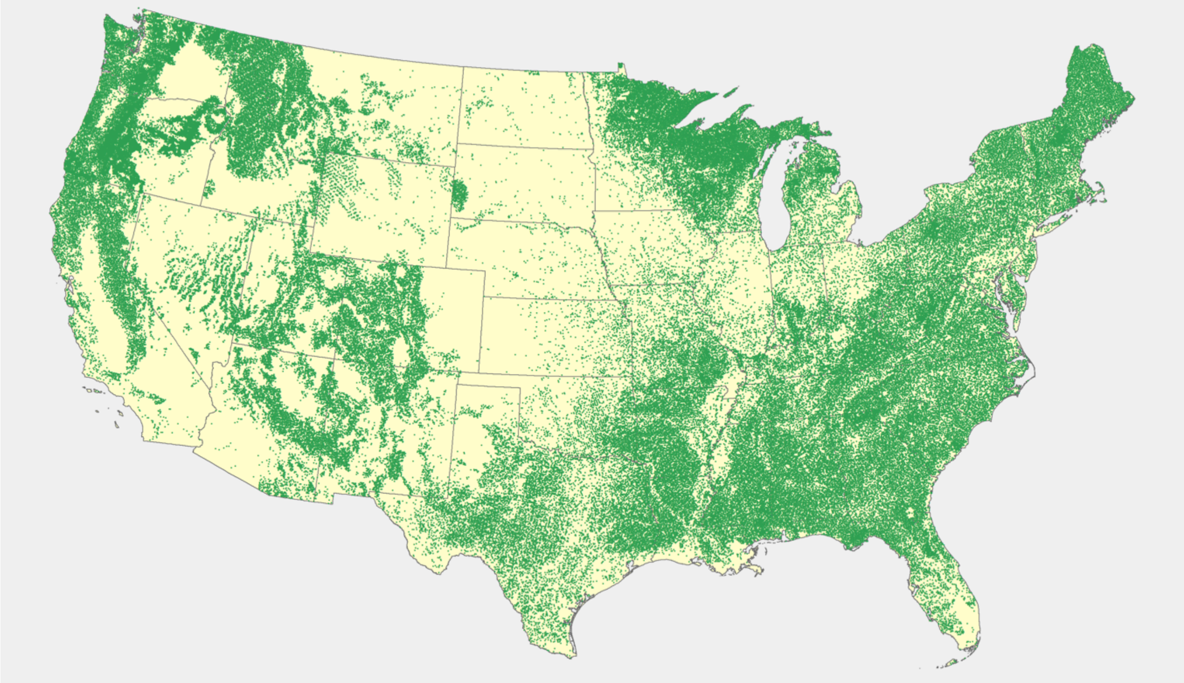
Bechtold W.A. and Patterson, P.J. 2005. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. 85 p.

NFI plot design



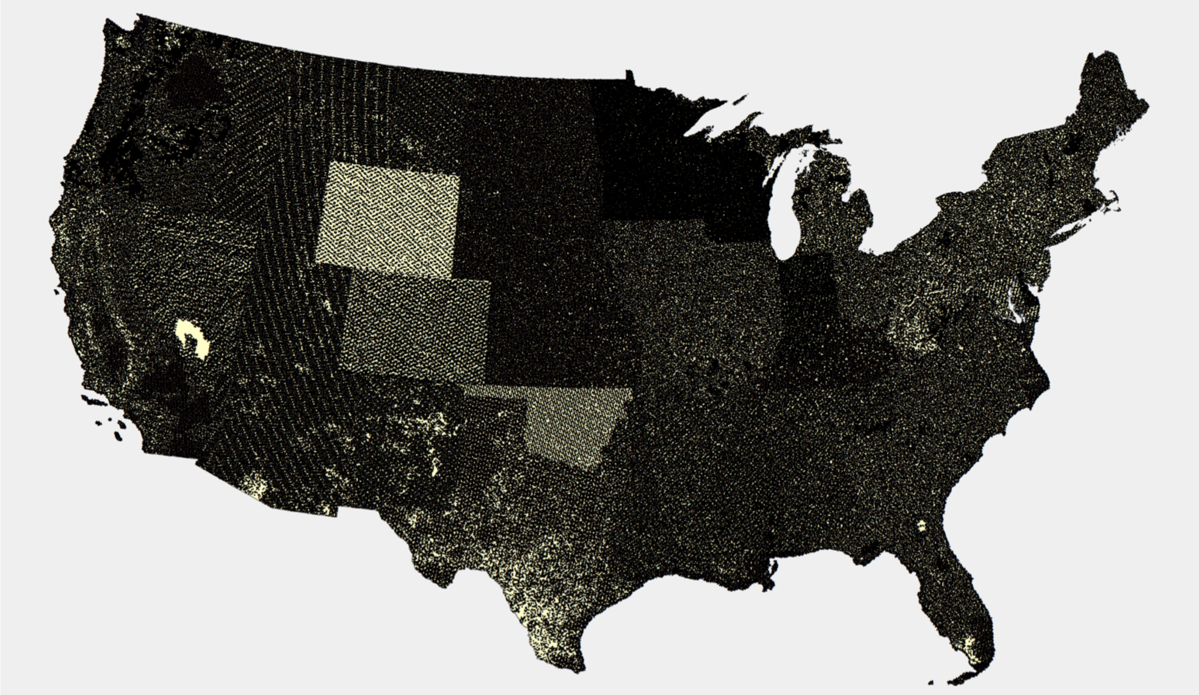
Bechtold W.A. and Patterson, P.J. 2005. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. 85 p.

NFI plots



NFI plots on forest land = 127,235

NFI plots



NFI plots on forest land = 127,235

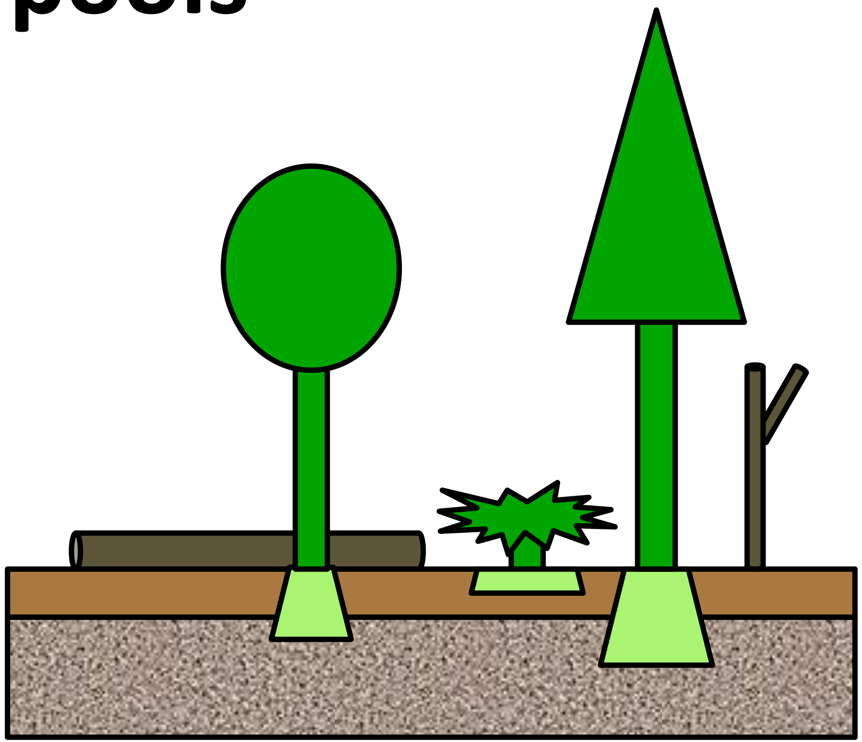
All plots = 316,359

Carbon estimation

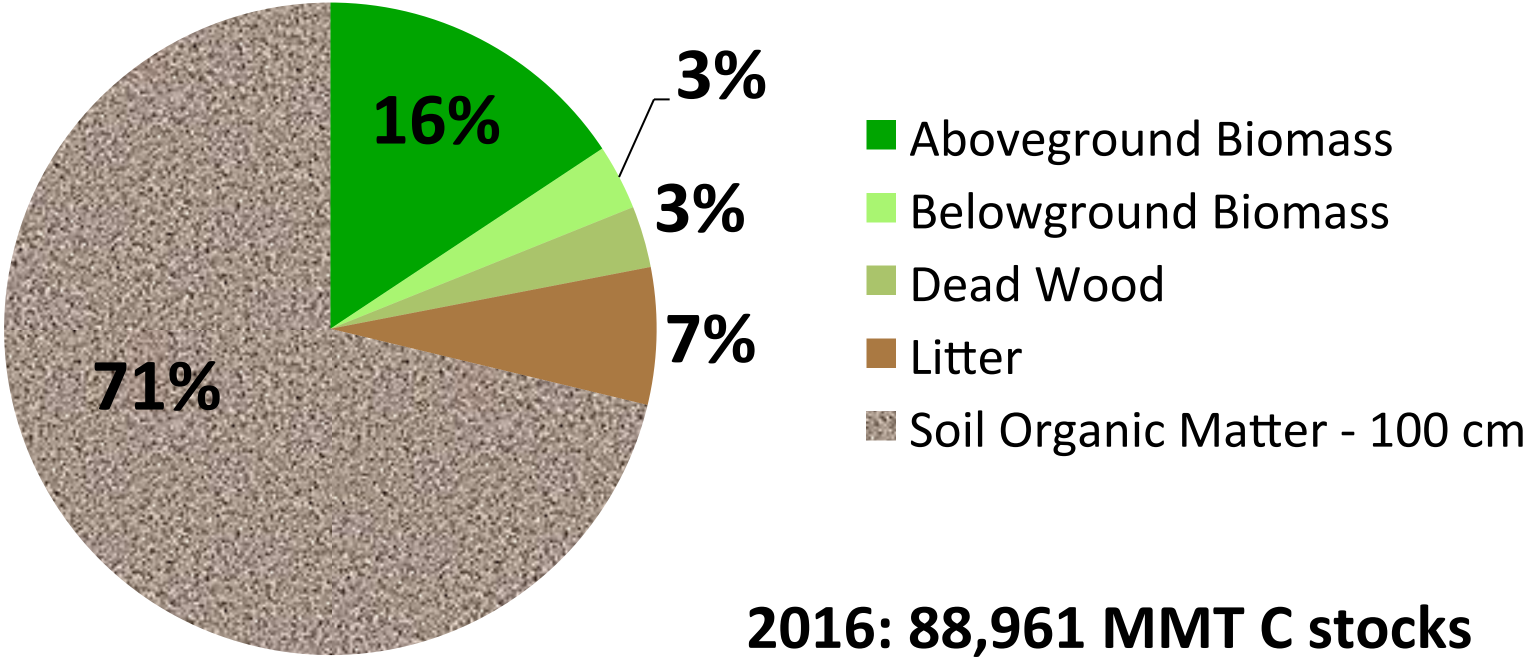
- Estimate C density at the plot level ($MT \cdot ha^{-1}$)
- C stocks summed to total by inventory cycle (MMT C)
- Stock-change is difference between successive stocks divided by time interval ($MMT \cdot yr^{-1}$)
- Estimates developed separately for each state or region

Forest ecosystem C pools

- Aboveground live biomass
- Belowground live biomass
- Dead wood
- Litter
- Soil organic matter



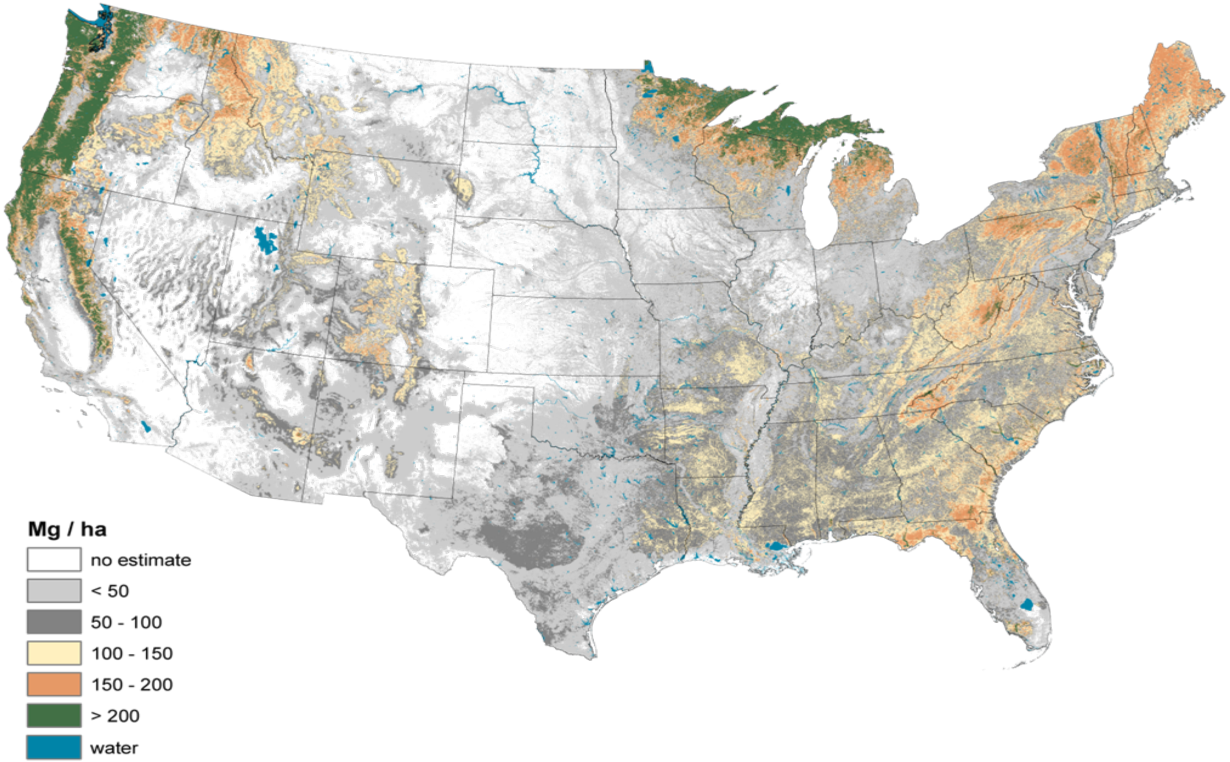
Forest C stocks by pool in the US



2016: 88,961 MMT C stocks

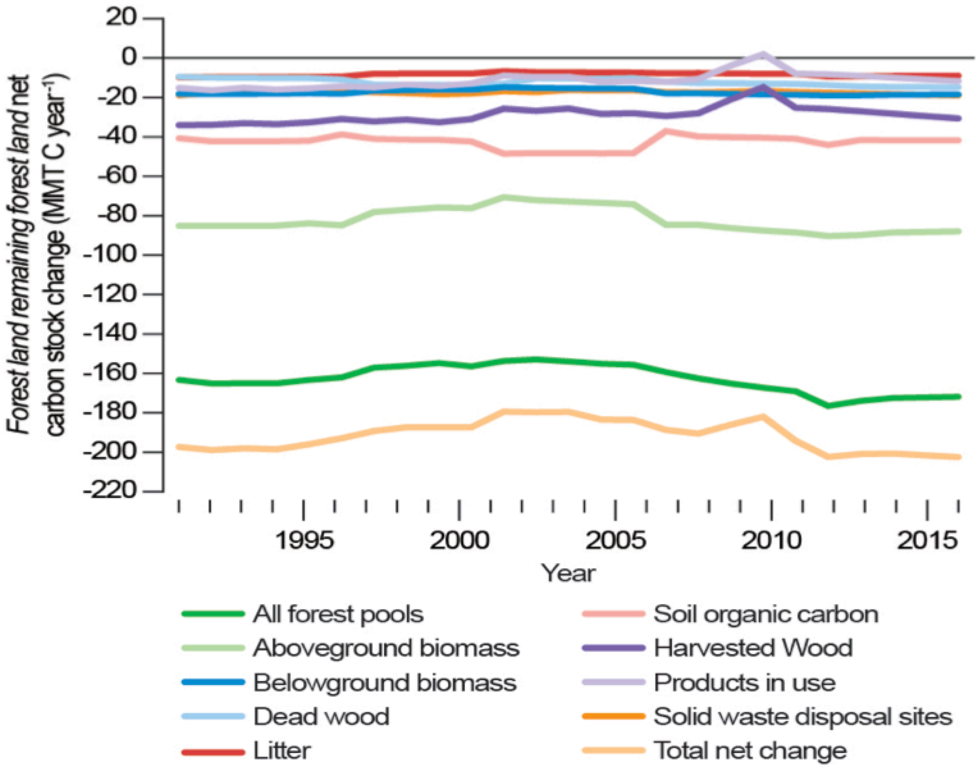
EPA. 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Forest C stocks in the US



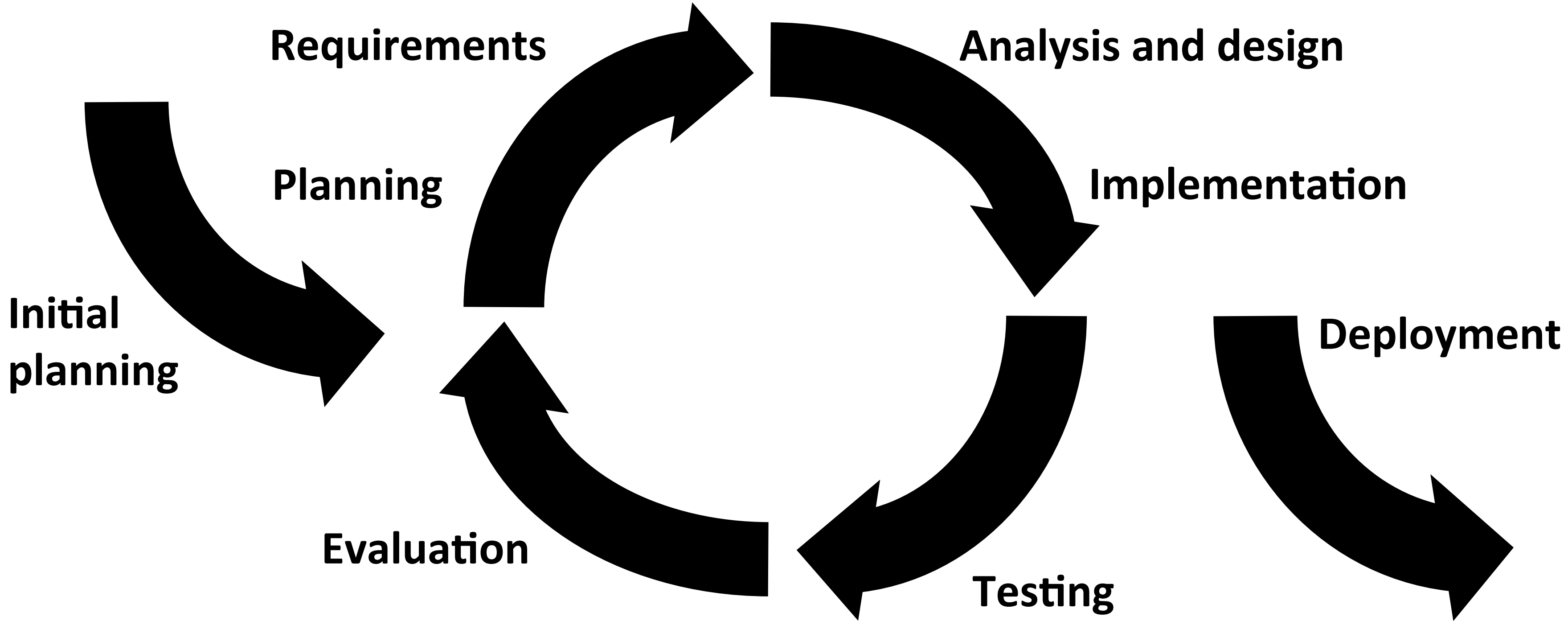
Wilson, B.T.; Woodall, C.W.; Griffith, D.M. 2013. Imputing forest carbon stock estimates from inventory plots to a nationally continuous coverage. Carbon Balance and Management. 8:1. doi:10.1186/1750-0680-8-1

Forest C stock change

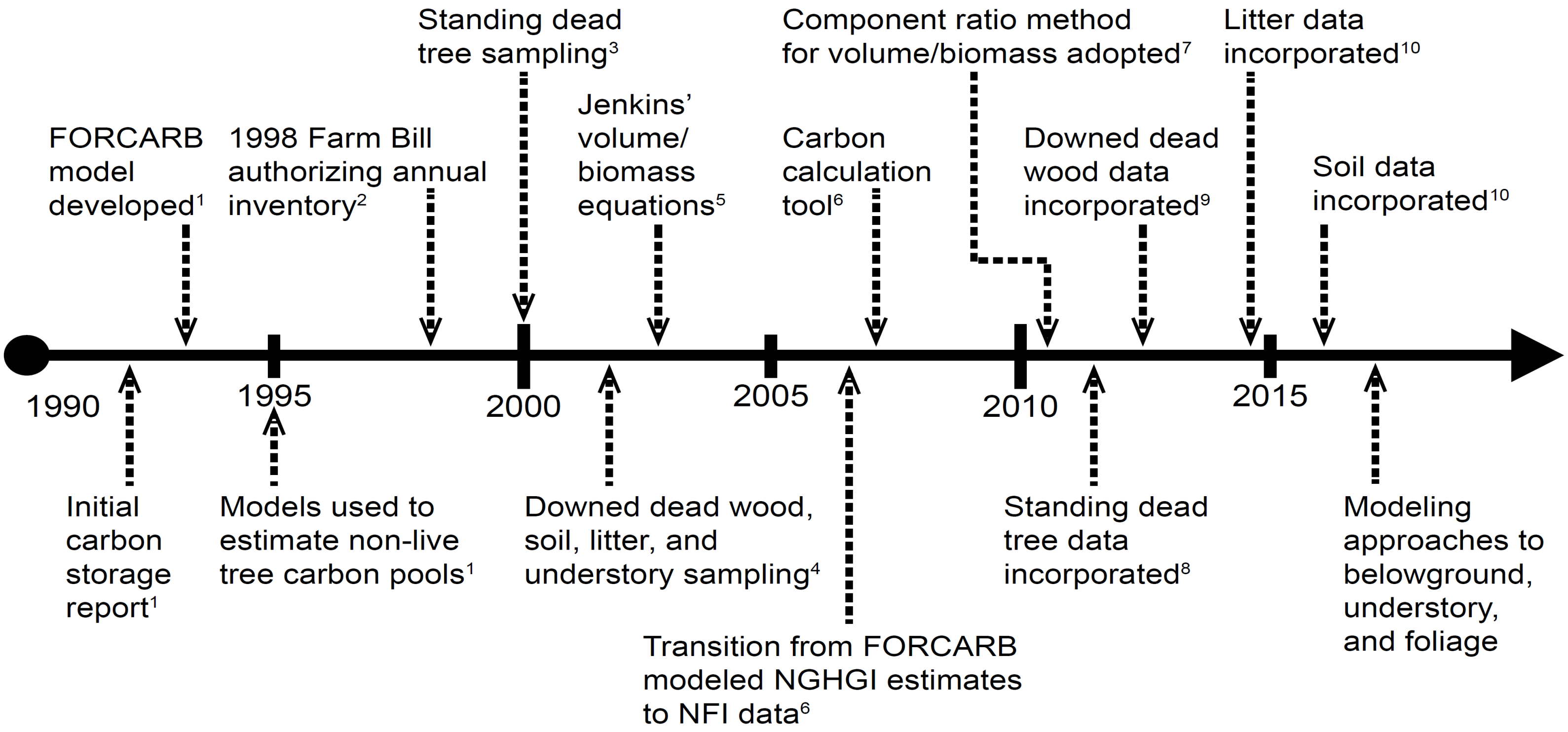


EPA. 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Iterative C accounting process…



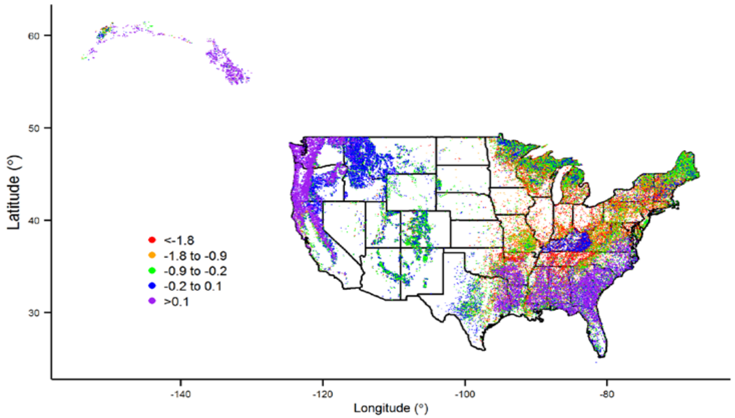
Development timeline for C reporting

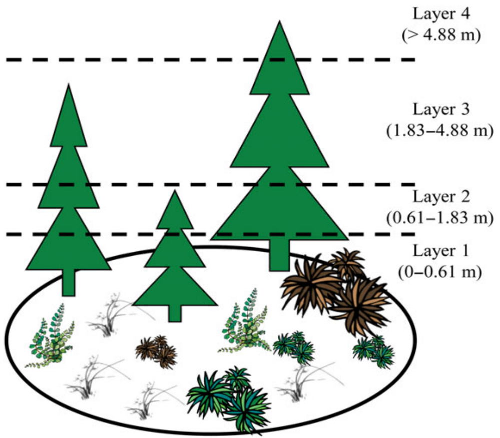


http://usfs-forestatlas.maps.arcgis.com/apps/MapJournal/index.html?appid=c157327957e8405790d94ebbbc8ab4bc

Continuous pool refinement

- Litter estimates from in situ observations
- Understory vegetation model from in situ observations
- Belowground model with climate coefficients
- Foliage model from legacy data



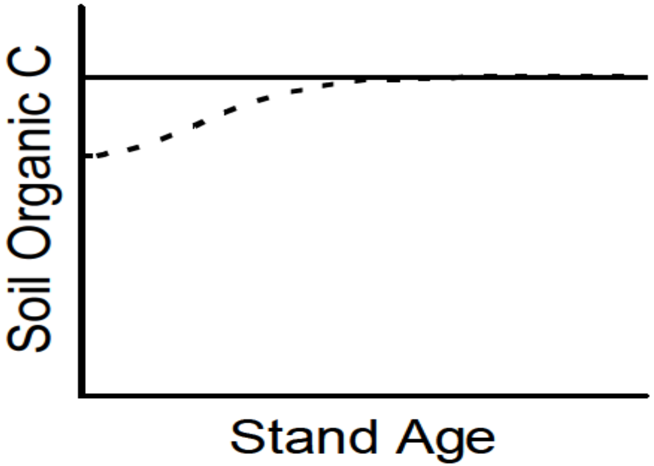


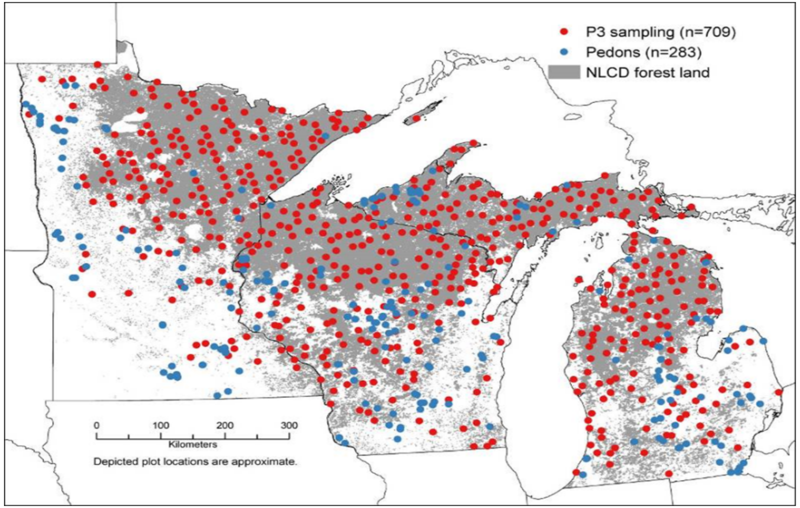
Russell, M.B., et al. 2015. Climate-derived estimates of tree coarse root carbon in forests of the United States. *Carbon Balance and Management*

Clough, B.J., et al. 2016. Comparing tree foliage biomass models fitted to a multi-species, felled-tree biomass dataset for the United States. *Ecological Modeling*

Domke, G.M., et al. 2016. Estimating litter carbon stocks in forest ecosystems of the United States. *Science of the Total Environment*

Example: soil organic carbon





$$\text{For } TypGr\ SOC = \left(\sum_{F=1}^{j}(MUID\_OC * Expacr)\right) \times \left(\sum_{F=1}^{j}(Expacr)\right)^{-1}$$

Amichev, B. Y., & Galbraith, J. M. 2004. A revised methodology for estimation of forest soil carbon from spatial soils and forest inventory data sets. *Environmental Management*, *33*(1), S74-S86.

Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p

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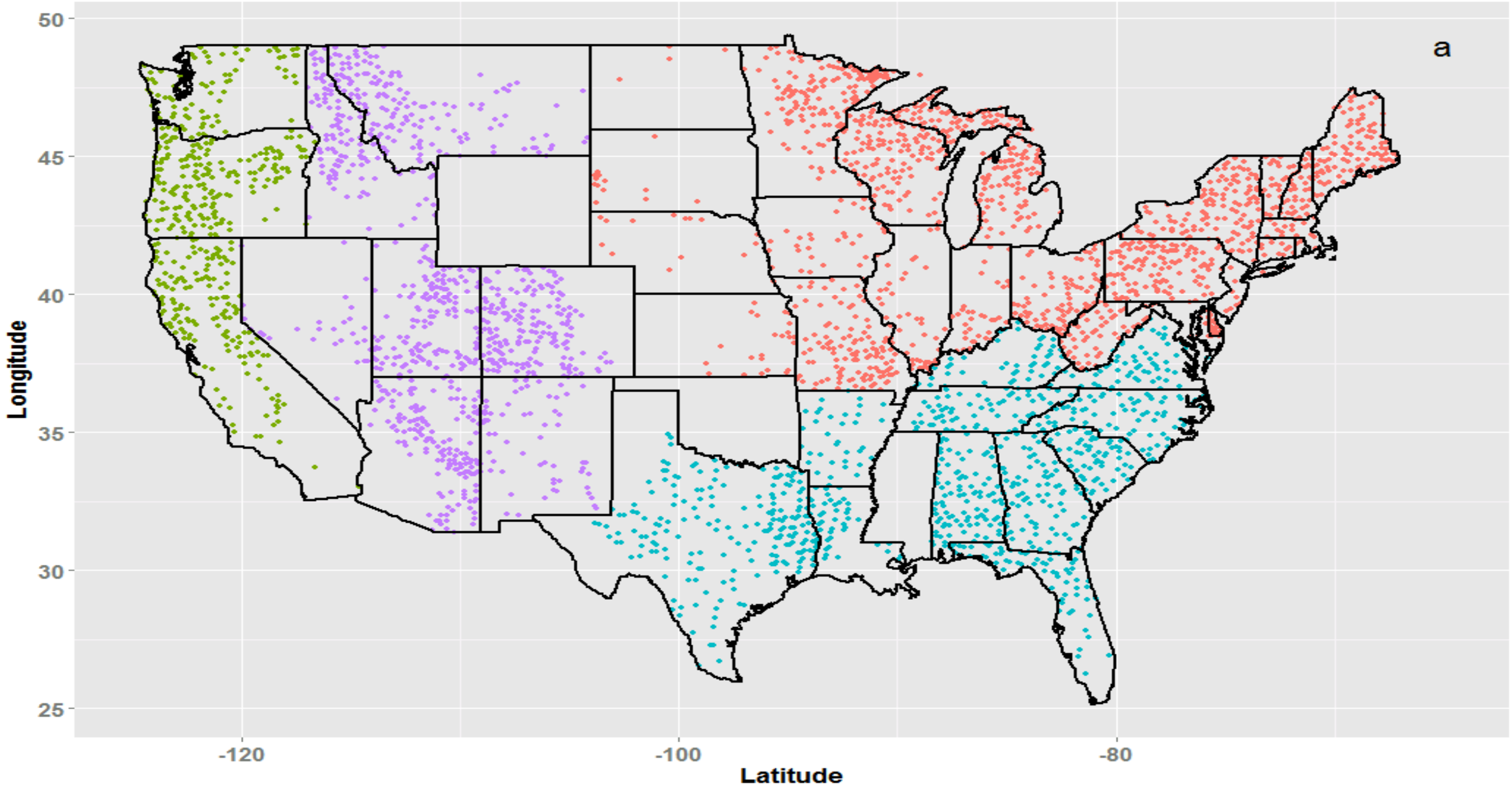

Amichev, B. Y., & Galbraith, J. M. 2004. A revised methodology for estimation of forest soil carbon from spatial soils and forest inventory data sets. *Environmental Management*, *33*(1), S74-S86.

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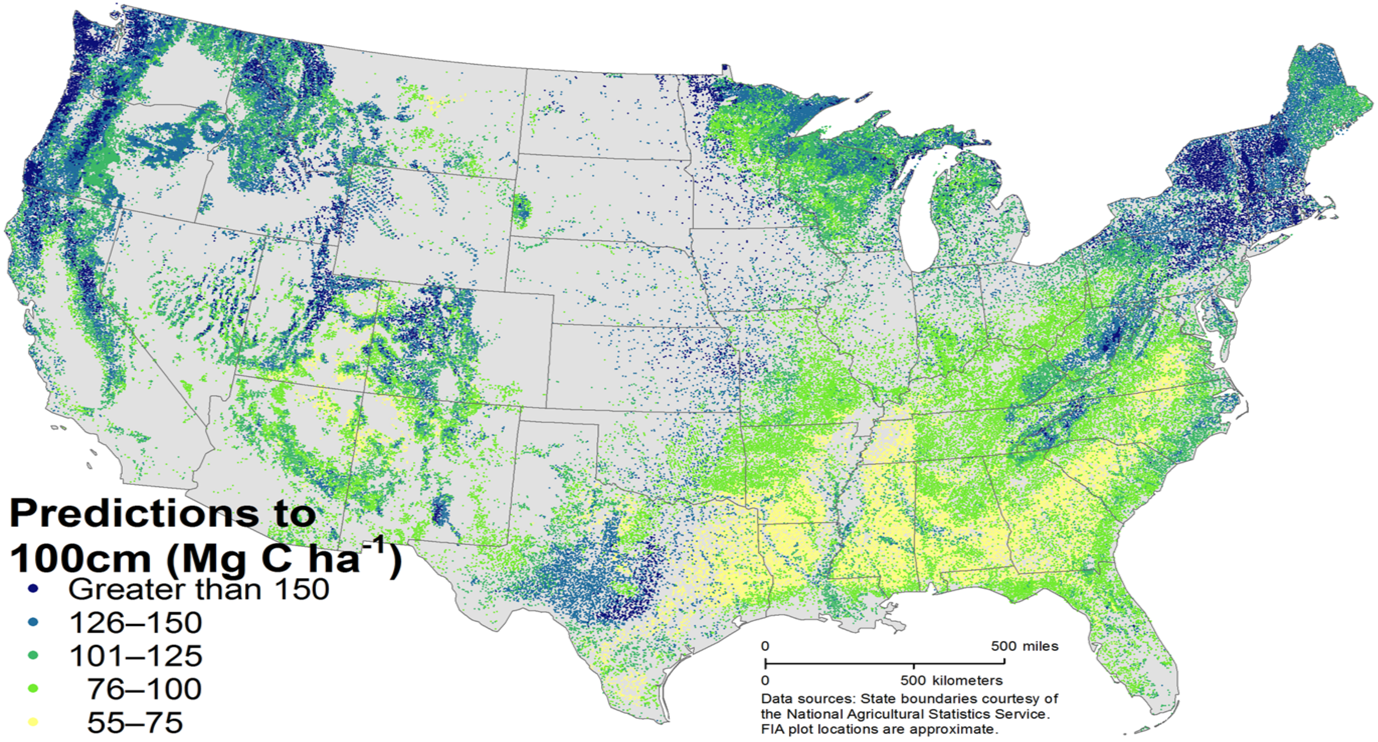
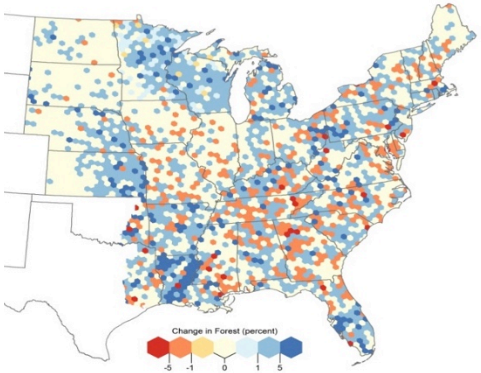


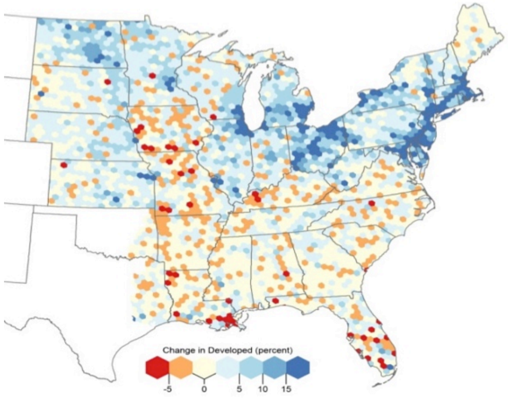
Domke, G.M., Perry, C.H., Walters, B.F., Woodall, C.W., Nave, L., Swanston, C. In preparation. Estimating soil organic matter carbon stocks on forest land in the United States. Intended outlet: Ecological Applications.

Land use and land use change

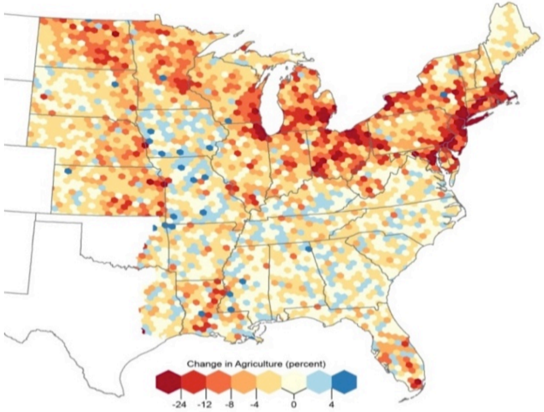
Forest land



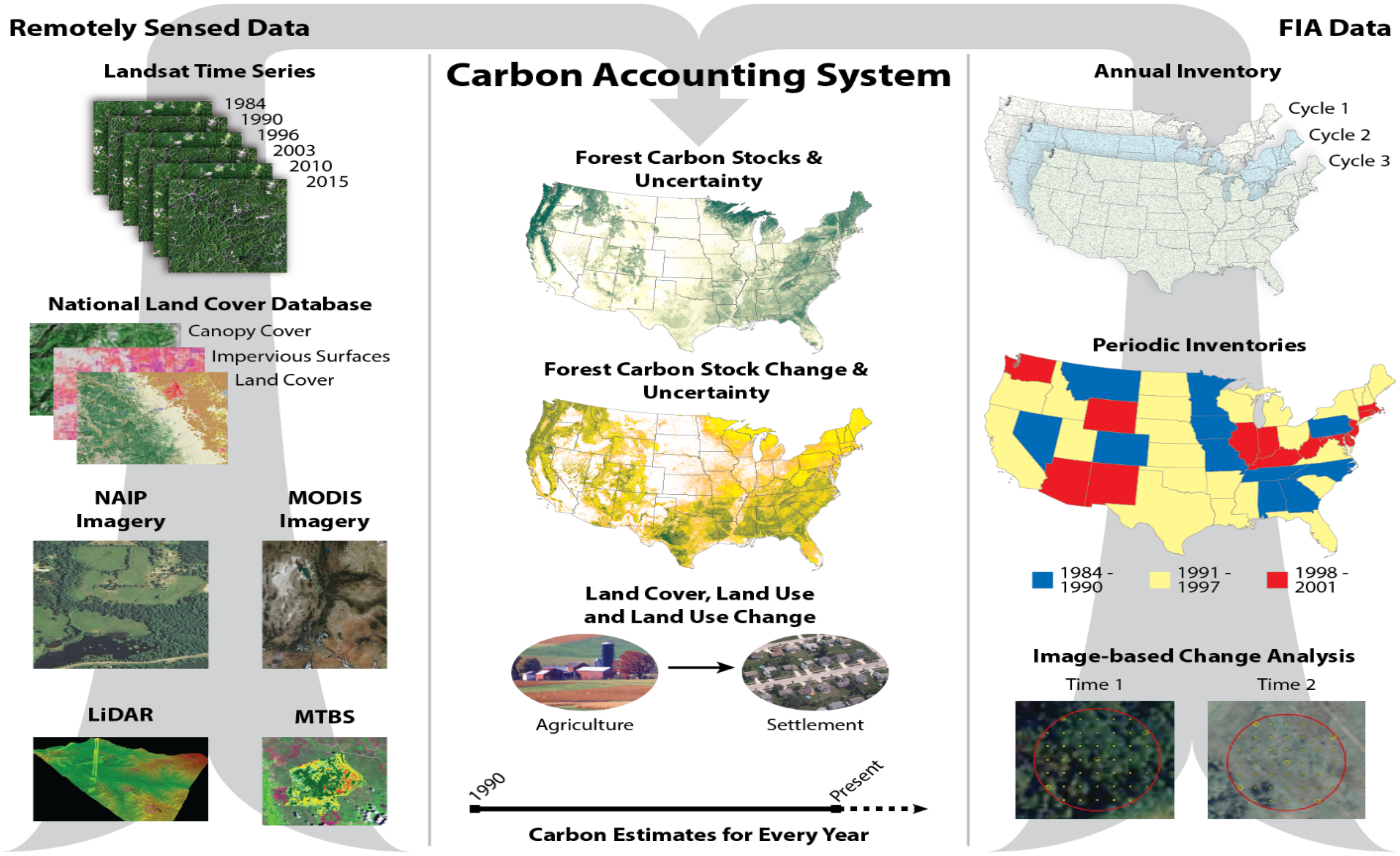
Settlements



Croplands



Woodall et al. 2015. Recent Land Use Change is a Substantial Component of the Forest Carbon Sink in the eastern United States. *Scientific Reports, 5*.



Remotely Sensed Data
Landsat Time Series
1984
1990
1996
2003
2010
2015
National Land Cover Database
Canopy Cover
Impervious Surfaces
Land Cover
NAIP Imagery
MODIS Imagery
LiDAR
MTBS
Carbon Accounting System
Forest Carbon Stocks & Uncertainty
Forest Carbon Stock Change & Uncertainty
Land Cover, Land Use and Land Use Change
Agriculture
Settlement
1990
Present
Carbon Estimates for Every Year
FIA Data
Annual Inventory
Cycle 1
Cycle 2
Cycle 3
Periodic Inventories
1984 - 1990
1991 - 1997
1998 - 2001
Image-based Change Analysis
Time 1
Time 2

Final thoughts

- The national forest inventory remains the foundation of forest carbon estimates for the US
- Working on forest land conversions is relatively new for the US
- Think about GHG monitoring and reporting as a continuous system across all lands
- Must work with other land use categories to ensure internal consistency
  - Methods development for C transfer from land conversions (e.g., SOC)
  - Avoid double counting and ensure complete accounting

Guest Speaker: Ty Wilson

Using NFI data and satellite imagery for estimating emissions and removals

Barry Tyler "Ty" Wilson
Research Forester
USFS Northern Research Station

Outline

- IPCC guidance on carbon reporting
- U.S. National Forest Inventory
- Dense time series satellite imagery
- Example from research study
- Results using different approaches

IPCC guidance concerning NFI

- Not required, but can be used
- Design-based sampling
- Multiple measurements yields change
- Emissions or removals factors (EF/RF) for REDD+ strata
- Tier 3 for AGC pool
- Focus on forest land and remaining forest land
- Stock change approach, rather than gain-loss

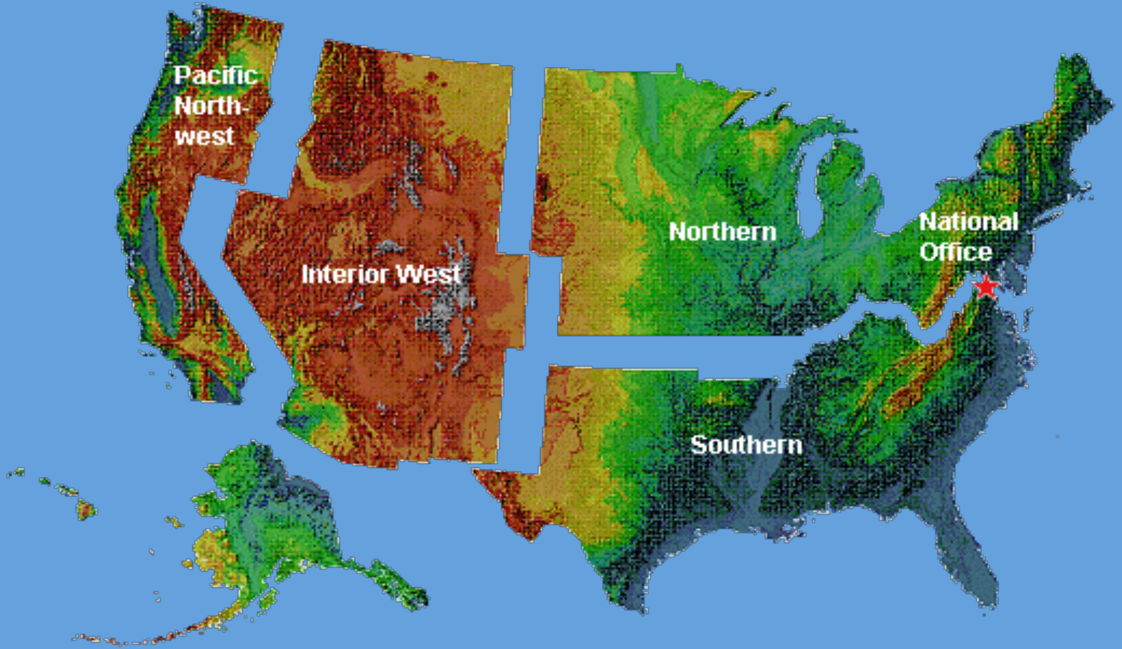
Forest Inventory and Analysis (FIA)

- U.S. Forest Service program
- Forest status and trends
- Strategic survey

Credit: USDA Forest Service

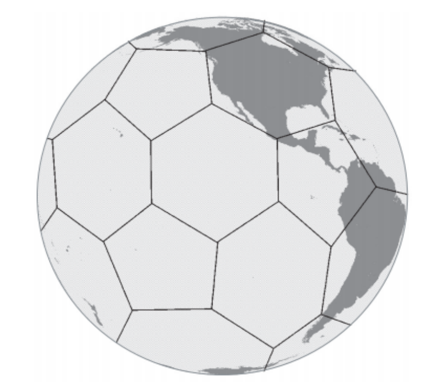
The FIA program

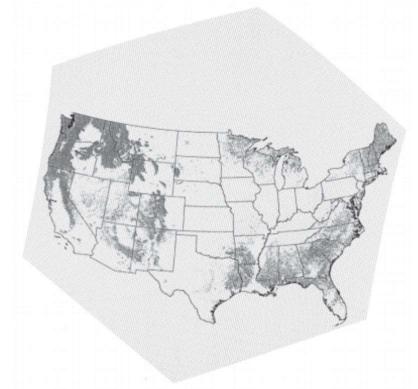
- Implemented regionally
- Use common standards

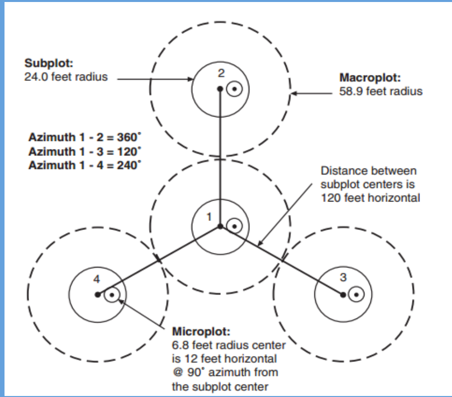


Sampling frame and plot design

- 1 plot per ~2,400 ha
- 5-10 year cycle
- Quasi-systematic sample







Field measurements

Plot
- *Location*
- *Elevation*

Condition
- *Land cover*
- *Ownership*
- *Stand age*
- *Slope*
- *Disturbance*

Tree
- *Status*
- *Species*
- *Diameter*
- *Height*
- *Damage*

Modeled attributes

- Forest type
- Volume
- Biomass
- Carbon pools

Credit: USDA Forest Service

Population estimates

- Design-based inference
- Source of uncertainty is sample
- Determined by sample design
- Post-stratified estimators
- Design weights equal within each stratum
- Estimates of current state or change
- Use auxiliary data to improve precision

From IPCC guidance

- Gain-loss approach from NFI alone
  - No map
- Gain-loss approach with stratified estimator
  - Thematic map
- Stock change approach with model-assisted regression estimator
  - Continuous map

Use auxiliary information

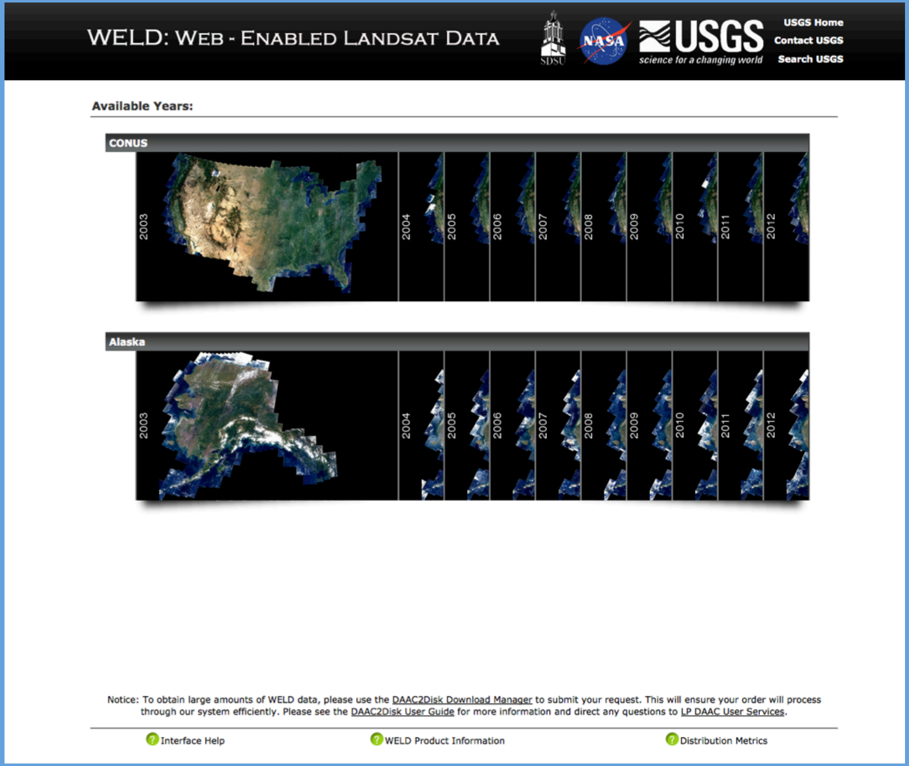
Landsat 7 ETM+

- 8 bands
- 15m – 60m pixel resolution
- 16 day period

Band No.	Wavelength (µm)	GSD (m)
8 PAN	0.52 - 0.90	13 x 15
1 VIS	0.45 - 0.52	30 x 30
2 VIS	0.53 - 0.61	30
3 VNIR	0.63 - 0.69	30
4 VNIR	0.78 - 0.90	30
5 SWIR	1.55 - 1.75	30
7 SWIR	2.09 - 2.35	30
6 TIR	10.4 - 12.5	60

Web-Enabled Landsat Data (WELD)

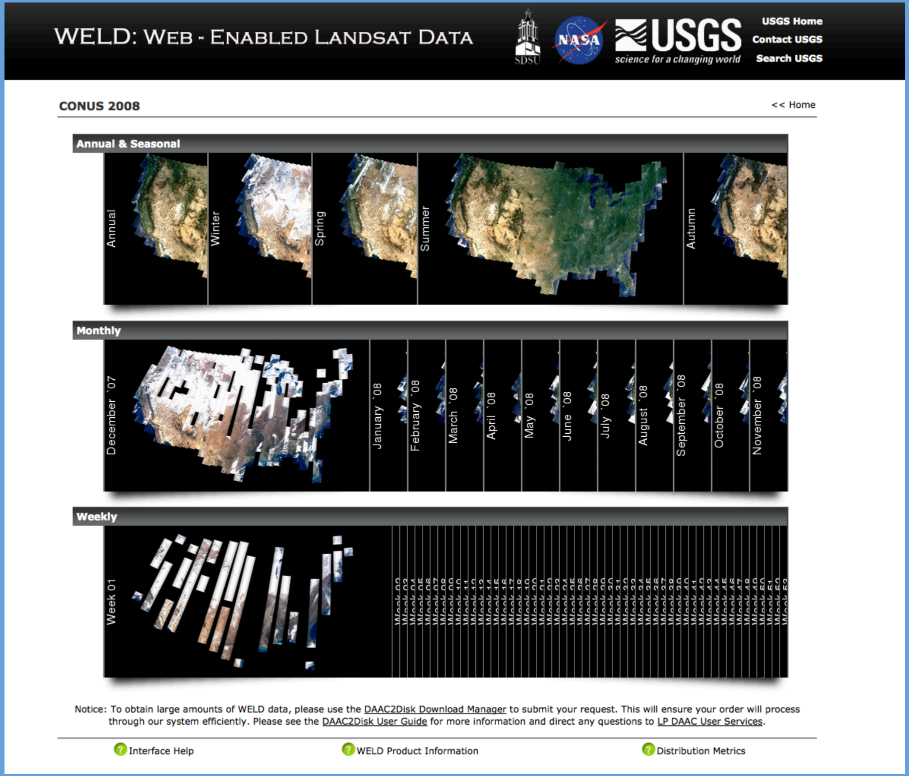
- Pre-processed
- Ortho-rectified
- TOA reflectance
- Monthly composites



Credit: Web-Enabled Landsat Data (http://weld.cr.usgs.gov)

WELD record

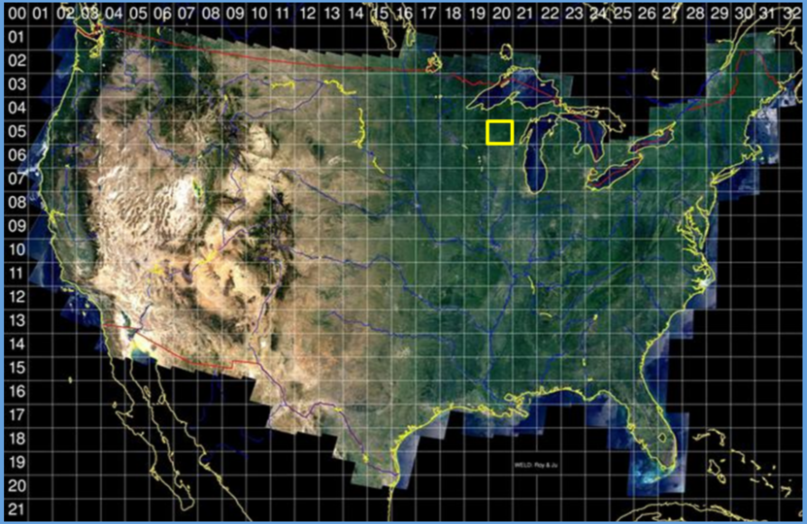
- Decade of images
- 2003-2012
- Two 5-year FIA cycles



Credit: WELD

WELD tiles

- Tile = 5,000 by 5,000 pixels
- Study area = single tile
- Complex landscape in terms of LULUCF



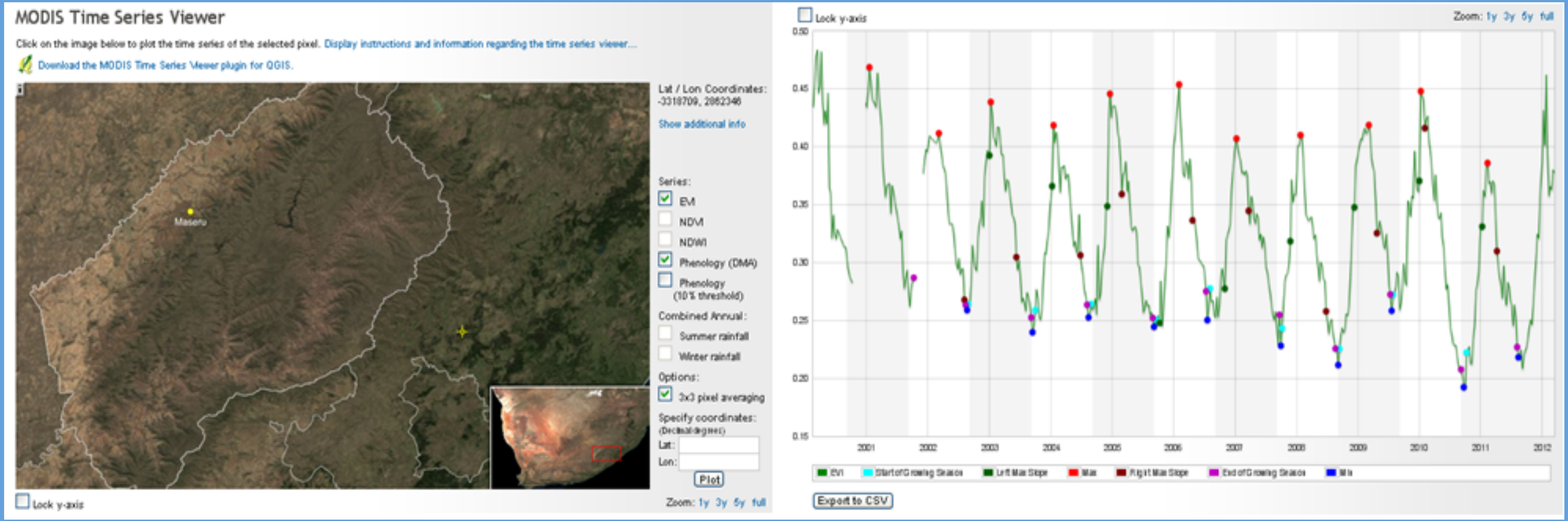
Credit: WELD

Issue #1: data gaps

- Clouds and missing data

Credit: USGS/NASA

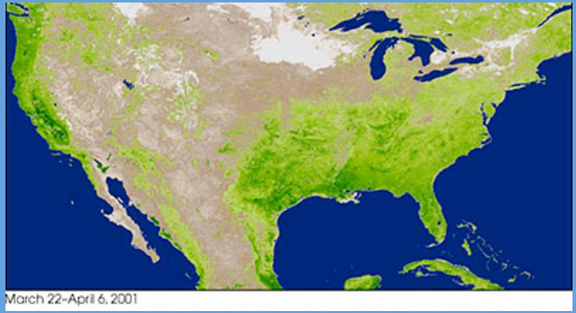
Issue #2: seasonality

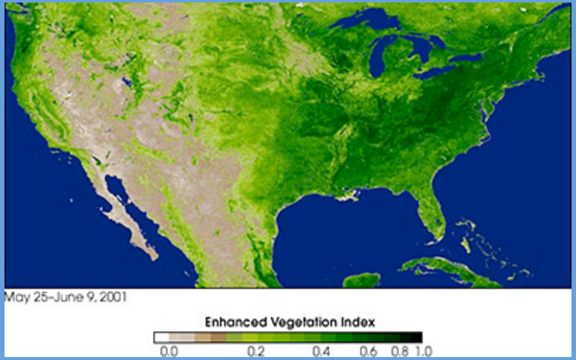


Credit: Wide Area Monitoring Information System (WAMIS)

Image processing

- How to handle gaps?
- How to characterize seasonal patterns?
- Harmonic regression of monthly composites





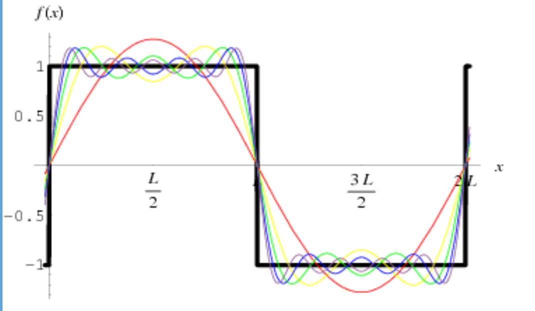
MODIS images of seasonal cycle in the contiguous United States during 2001. (Credit: NASA/GSFC/University of Arizona)

Fourier series

- Fourier series equation

$$f(x) = \sum_{n=0}^{\infty} a_n \cos(nx) + b_n \sin(nx)$$

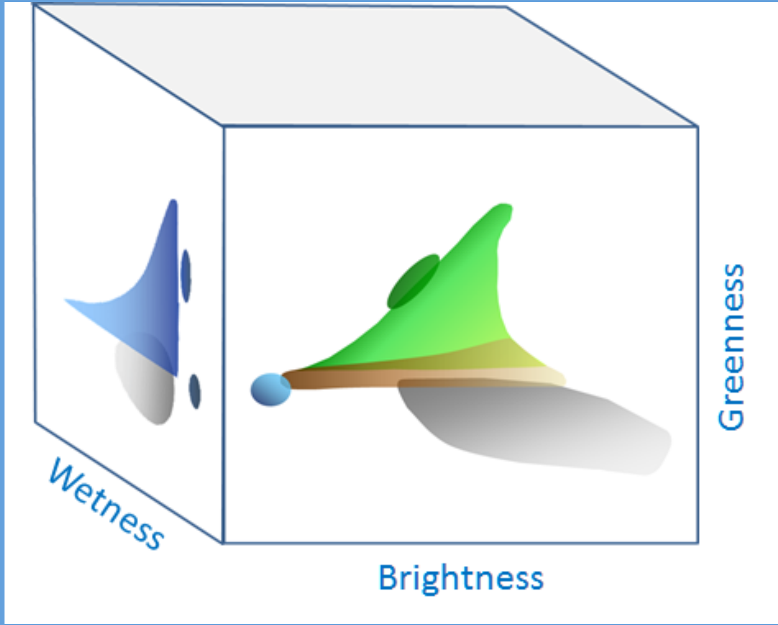
- Adding harmonics



Credit: Wolfram Research, Inc.

Tasseled Cap (TC)

- Transformation of ETM+ bands
- Brightness
- Greenness
- Wetness



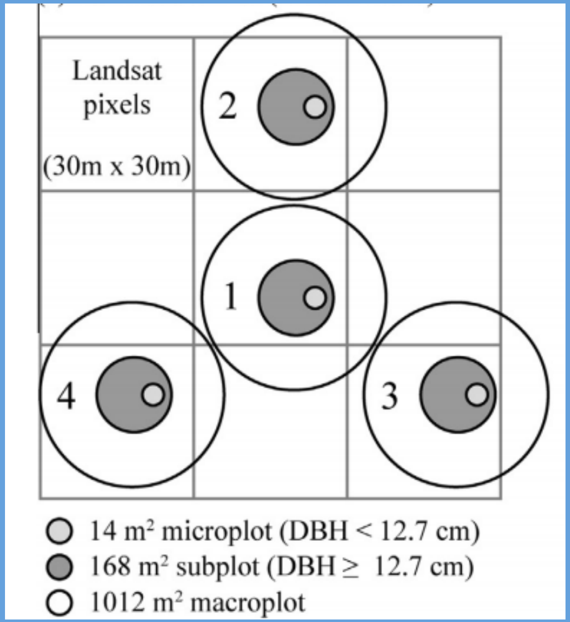
Credit: iSciences, LLC

Fourier series coefficients

- Two harmonics per series
- Fit to each 60-month time period
- 3 TC x 5 FS x 2 time periods = 30 features

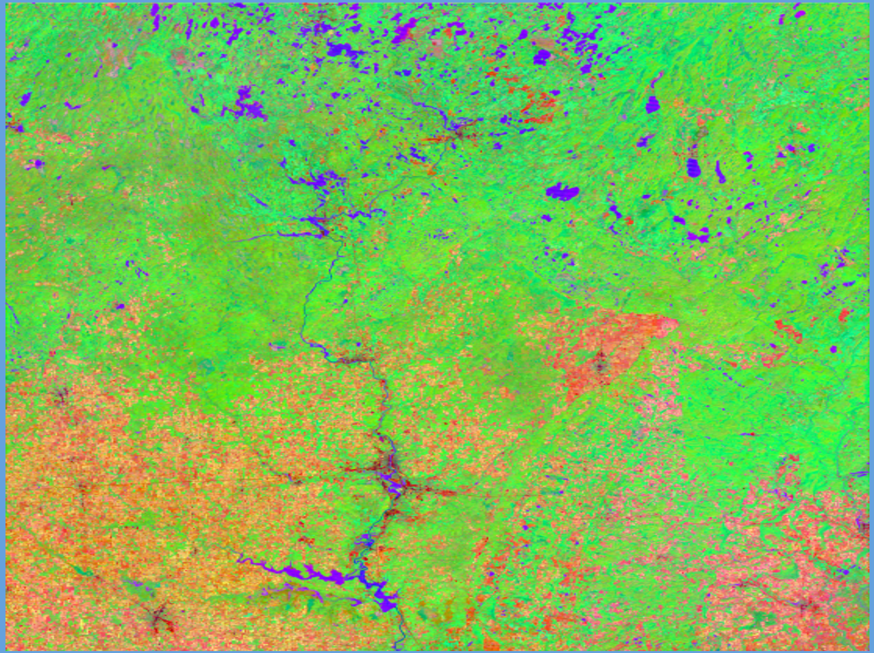
Issue #3: spatial mismatch

- Plots larger than pixels
- Mean of 3x3 window



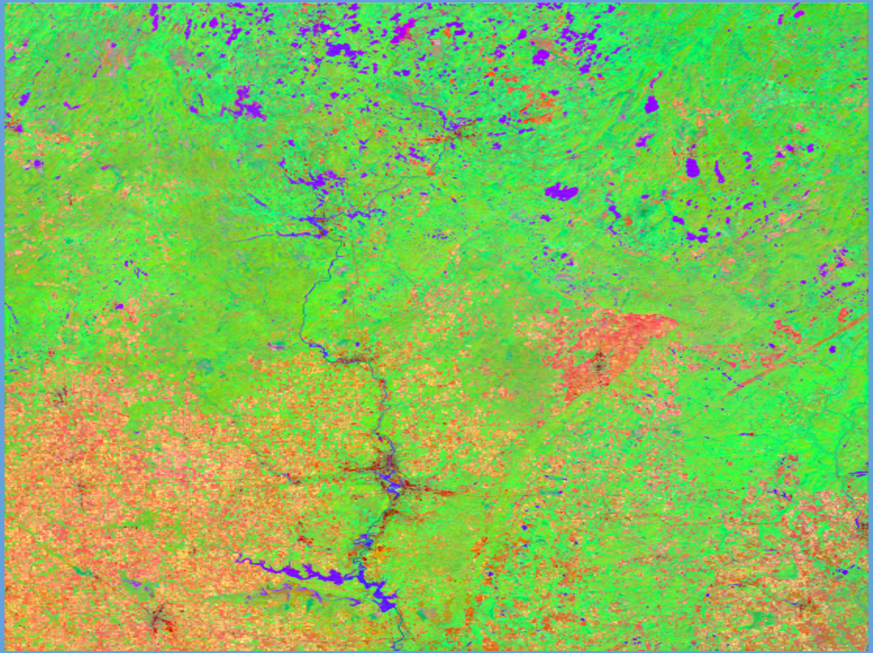
Credit: Bell et al., 2015 (http://dx.doi.org/10.1016/j.foreco.2015.07.017)

Time period 1



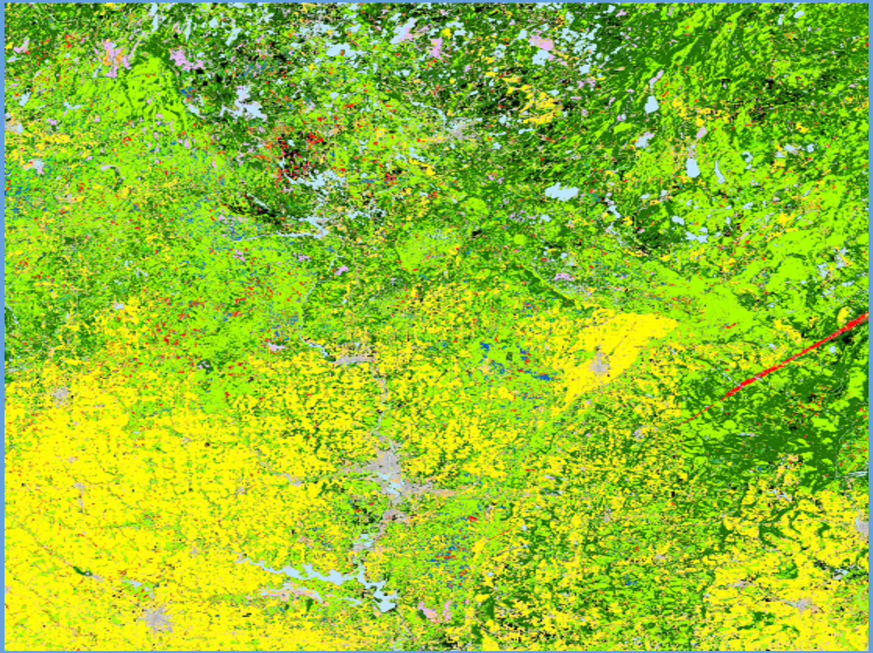
- RGB = mean(brightness, greenness, wetness)

Time period 2



- RGB = mean(brightness, greenness, wetness)

Thematic map of change



- ISODATA classification on all 30 features

Revisiting IPCC guidance

- Gain-loss approach from NFI alone
  - No map
- Gain-loss approach with stratified estimator
  - Thematic map

- Stock change approach with model-assisted regression estimator
  - Continuous map

Model-based inference

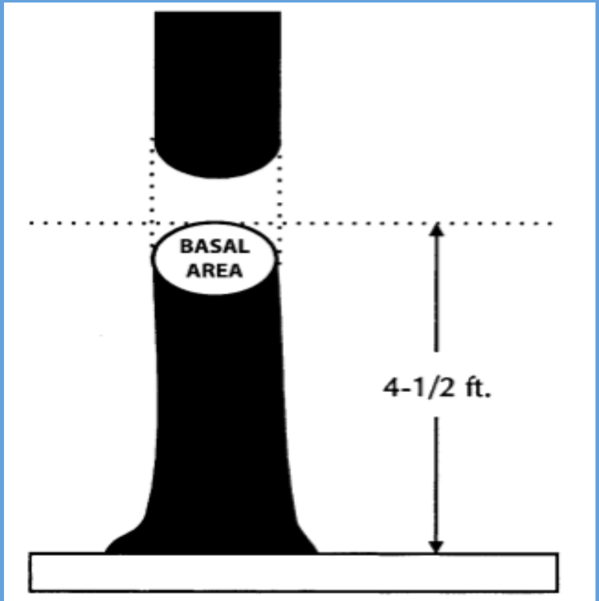
- Borrow strength
- Useful with auxiliary variables
- Reductions in variance, but...
  - Depends on strength of relationship
  - Potential for bias
- All maps are models

"All models are wrong; some models are useful."

George Box

Response variable

- Land cover rather than use
- Tree canopy cover ~ basal area
- Basal area
- Proxy for AGC
- 1,446 re-measured plots (2003-2012)

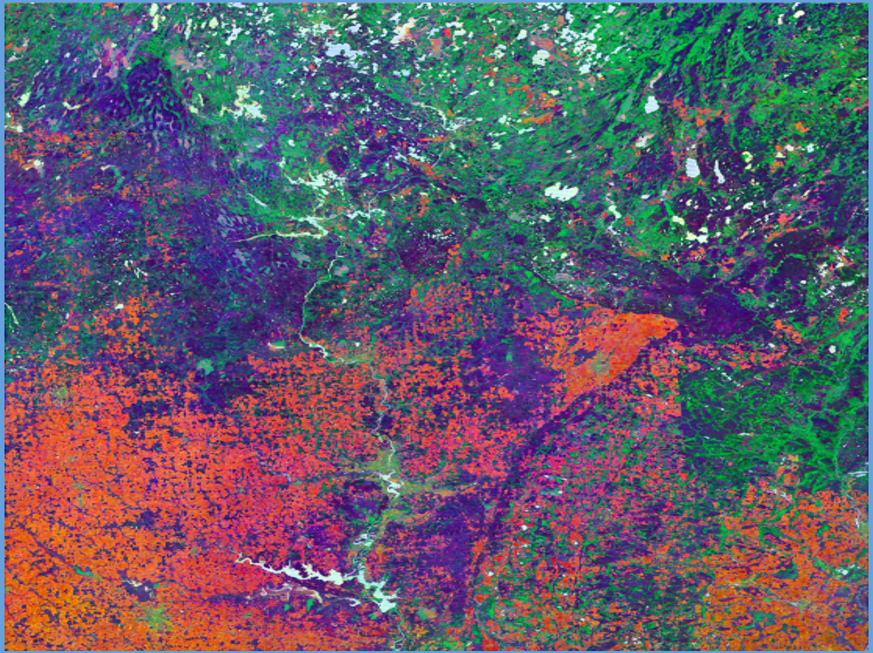


Credit: Woodland Stewardship

Predictor variables

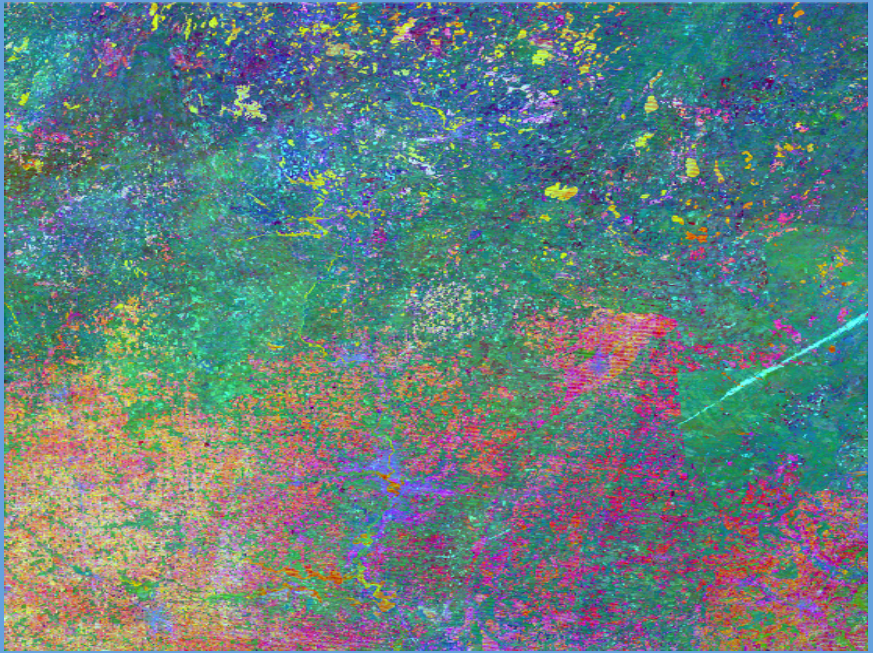
- Principal Components Analysis (PCA)
- Multivariate data transformation
- Standardized and orthogonal components
- First 8 components ~ 93% of variance

RGB=PCA(1,2,3)



- Principal axes of variability

RGB=PCA(1,5,7)

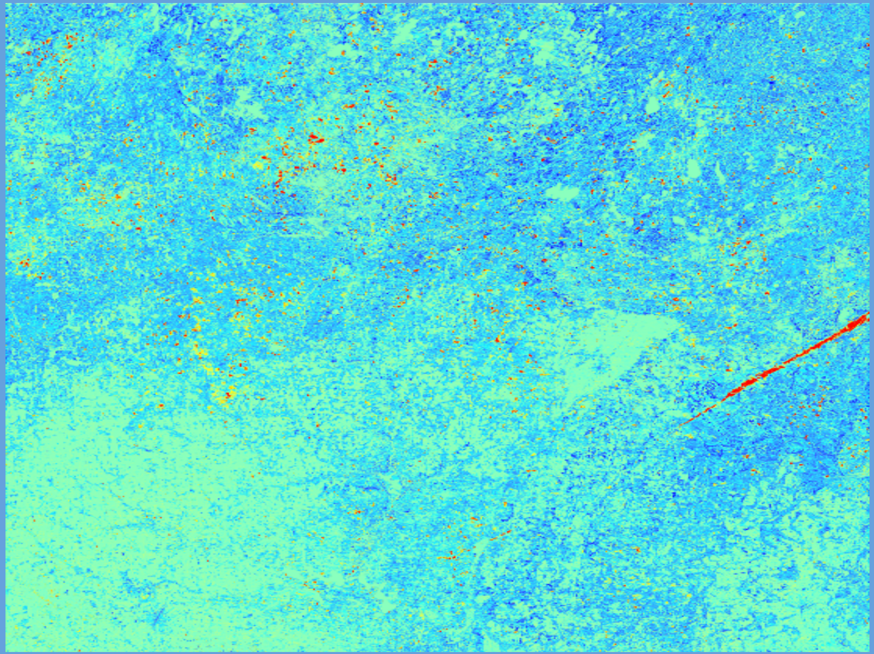


- Principal axes of change

The kNN estimator

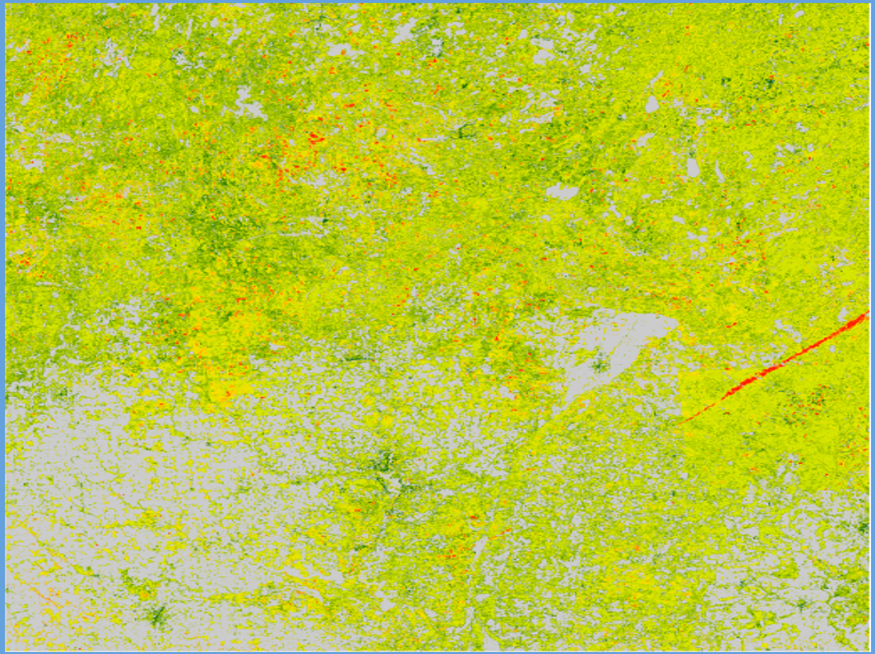
- Non-parametric
  - No assumptions about relationship
- Weighted average of k-nearest neighbors
  - Not nearest in geographic space
  - Nearest in feature space

Change in basal area



- Pixel values are estimates of EF/RF

Relative change in basal area

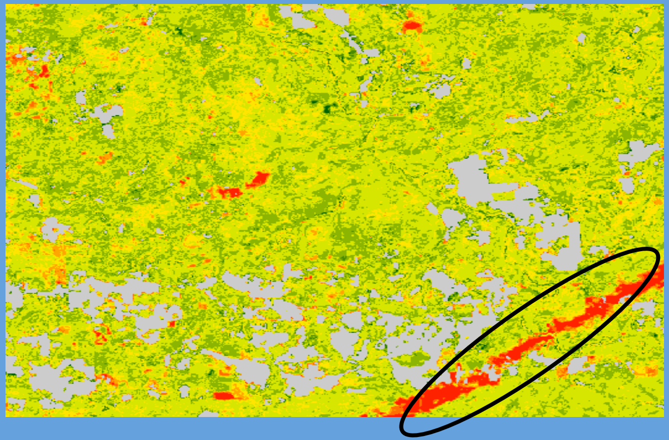


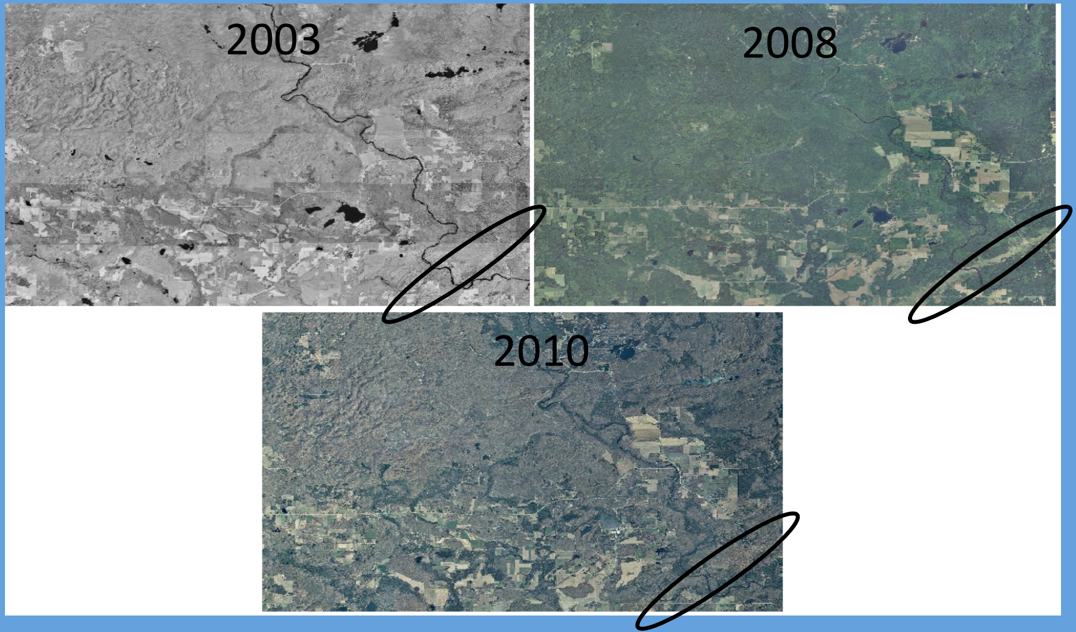
- Estimated EF or RF / basal area in time period 1

Comparison to photos

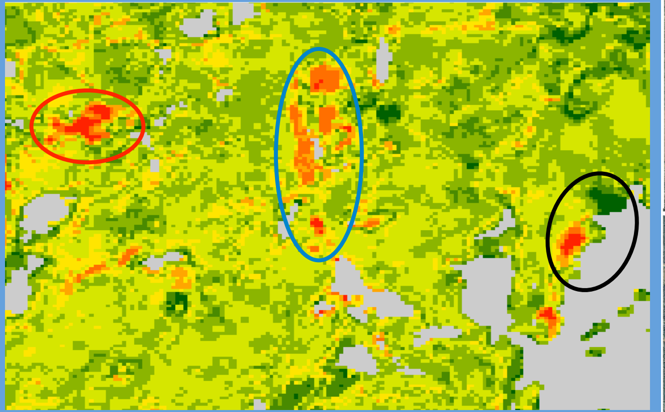
- Multi-date aerial photos
- Langlade County
  - 2003, 2008, & 2010
- Price County
  - 2005, 2006, 2008, 2010, & 2011

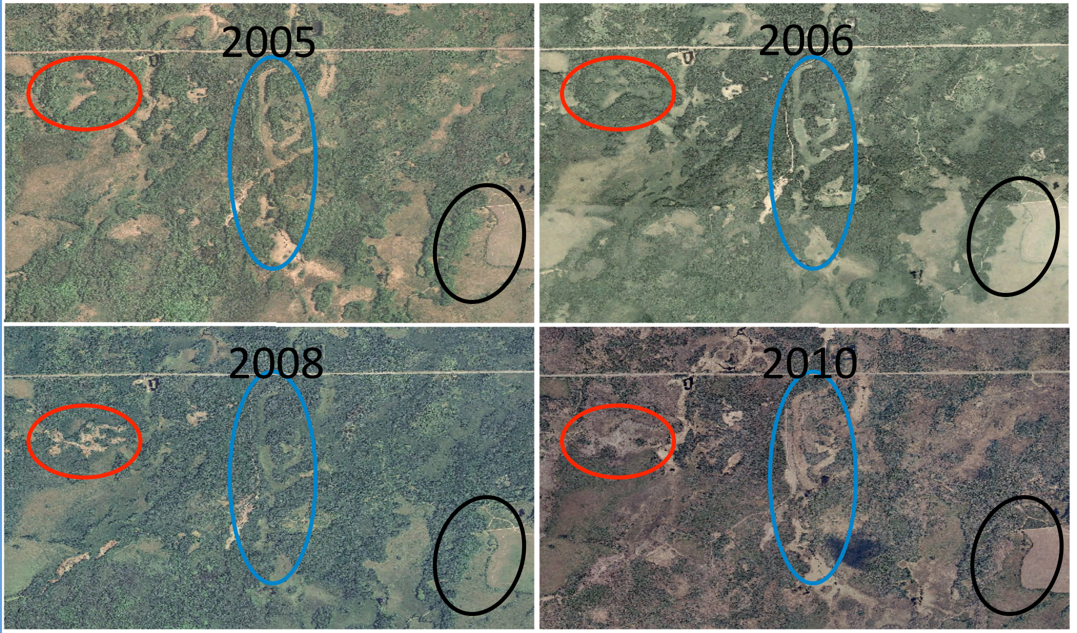
Langlade County





Price County





Revisiting IPCC guidance

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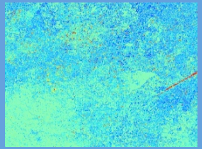

Combining uncertainties

- Ultimately interested in removals/emissions
- For gain-loss, the product of two sets of random variables

Relative efficiency (RE)

- Measure of precision of estimator
- Sample size multiplier
- Ratio of variances

RE = benchmark/alternative estimator variance

NFI results: plots

Plots by land use		Period 2						
		Water	Forest land	Cropland	Grassland	Settlements	Wetlands	Grand Total
Period 1	Water	50.50	1.00	0.00	0.00	1.00	5.75	**58.25**
	Forest land	0.00	806.00	2.00	0.00	3.00	3.25	**814.25**
	Cropland	0.00	6.25	327.50	18.50	8.25	0.00	**360.50**
	Grassland	0.00	8.75	5.00	25.25	1.00	1.75	**41.75**
	Settlements	1.00	2.50	0.25	0.50	83.75	0.00	**88.00**
	Wetlands	10.25	11.50	0.25	3.00	2.00	47.25	**74.25**
	Grand Total	**61.75**	**836.00**	**335.00**	**47.25**	**99.00**	**58.00**	**1437.00**

NFI results: area

Area (ha) by land use		Period 2 Water	Forest land	Cropland	Grassland	Settlements	Wetlands	Grand Total
Period 1	Water	79071	1566	0	0	1566	9003	**91206**
	Forest land	0	1262004	3132	0	4697	5089	**1274922**
	Cropland	0	9786	512787	28967	12918	0	**564457**
	Grassland	0	13700	7829	39535	1566	2740	**65371**
	Settlements	1566	3914	391	783	131133	0	**137787**
	Wetlands	16049	18006	391	4697	3132	73982	**116258**
	Grand Total	**96686**	**1308977**	**524530**	**73982**	**155010**	**90814**	**2250000**

NFI results: annual EF/RF

Annual removals factor (m^2/ha) by land use		Period 2						
		Water	Forest land	Cropland	Grassland	Settlements	Wetlands	Grand Total
Period 1	Water	0.00	6.99	0.00	0.00	0.00	0.00	**0.12**
	Forest land	0.00	0.19	-3.40	0.00	-3.02	-1.18	**0.16**
	Cropland	0.00	1.84	0.00	0.00	0.00	0.00	**0.03**
	Grassland	0.00	2.09	0.00	0.00	0.00	0.00	**0.44**
	Settlements	0.00	3.33	0.00	0.00	0.00	0.00	**0.09**
	Wetlands	0.00	1.60	0.00	0.00	0.00	0.00	**0.25**
	Grand Total	**0.00**	**0.26**	**-0.02**	**0.00**	**-0.09**	**-0.07**	**0.14**

NFI results: annual emissions/removals

Annual removals (m^2) by land use		Period 2 Water	Forest land	Cropland	Grassland	Settlements	Wetlands	Grand Total
Period 1	**Water**	0	10938	0	0	0	0	**10938**
	Forest land	0	238254	-10641	0	-14192	-5986	**207435**
	Cropland	0	17968	0	0	0	0	**17968**
	Grassland	0	28666	0	0	0	0	**28666**
	Settlements	0	13037	0	0	0	0	**13037**
	Wetlands	0	28786	0	0	0	0	**28786**
	Grand Total	**0**	**337648**	**-10641**	**0**	**-14192**	**-5986**	**306829**

SE=33,028 m^2

RSE=10.8%

Stratified results: plots

Plots by land use		Reference						
		Water	Forest	Cropland	Grassland	Settlements	Wetlands	Grand Total
Map	Water	45.75	4.5	1	0.25	2	7.25	**60.75**
	Forest	7.25	750.75	9.5	4.75	23.25	21.75	**817.25**
	Cropland	0	16	288.25	31	23	6.75	**365**
	Grassland	1.5	14.5	15.75	5.5	11.25	3.5	**52**
	Settlements	2.25	32	13.25	3.5	35	7	**93**
	Wetlands	5	18.25	7.25	2.25	4.5	11.75	**49**
	Grand Total	**61.75**	**836**	**335**	**47.25**	**99**	**58**	**1437**

Stratified results: proportions

Weighted proportions		Reference							User's accuracy
		Water	Forest	Cropland	Grassland	Settlements	Wetlands	weight	
Map	Water	0.025605	0.002519	0.00056	0.00014	0.001119	0.004058	0.034	75.31%
	Forest	0.0057	0.590231	0.007469	0.003734	0.018279	0.0171	0.642513	91.86%
	Cropland	0	0.008711	0.156936	0.016878	0.012522	0.003675	0.198722	78.97%
	Grassland	0.001019	0.009846	0.010695	0.003735	0.007639	0.002377	0.03531	10.58%
	Settlements	0.001409	0.020036	0.008296	0.002191	0.021915	0.004383	0.058231	37.63%
	Wetlands	0.003186	0.011629	0.00462	0.001434	0.002868	0.007487	0.031224	23.98%
	Total	0.036918	0.642973	0.188576	0.028112	0.064342	0.039079	1	
Producer's accuracy		69.36%	91.80%	83.22%	13.29%	34.06%	19.16%	Overall	80.59%
								Kappa	64.20%
RE		2.518	2.7587	3.440	1.393	1.265	1.089		

- Large gains in RE for AD in W, FL, and CL
- Smaller gains in RE for AD in GL, S, and WL

Stratified results: annual removals

Annual removals (m^2) by land use	Reference						
	Water	Forest land	Cropland	Grassland	Settlements	Wetlands	Grand Total
Grand Total	0	337648	-10641	0	-14192	-5986	306829

SE=32,839 m^2

RSE=10.7%

RE=1.012

Model-assisted regression estimator

- Model doesn't have to be parametric
- Works with results from any continuous model

Estimate mean EF/RF =
Mean (all pixels) – mean of residuals (sampled pixels)

Variance of estimated mean =
Variance of mean of residuals

MAR results: annual removals

Annual removals (m^2) by land use	Period 2		
	Estimated total	Estimated bias	Bias-corrected estimated total
Grand Total	415563	74315	341248

SE=30,475 m^2

RSE=8.9%

RE=1.175

Conclusions for study area

- Deforestation is a small percentage of change
- Too few plots for reliable estimates
- Removals mostly within FL remaining FL
- Relative uncertainty in EF/RF greater than in AD
- Stratification did not result in substantial RE gains for annual removals, but MAR did
- Satellite imagery increased precision of estimates

Forest Service Contacts and Website

- Grant Domke: gmdomke@fs.fed.us
- Ty Wilson: barrywilson@fs.fed.us
- Forest Inventory Analysis Program: http://www.fia.fs.fed.us

Contacts

- ARSET Land Management and Wildfire Contacts
  - Cynthia Schmidt: Cynthia.L.Schmidt@nasa.gov
  - Amber McCullum: AmberJean.McCullum@nasa.gov
  - Jenny Hewson: Jhewson@conservation.org
- General ARSET Inquiries:
  - Ana Prados: aprados@umbc.edu
- ARSET Website:
  - http://arset.gsfc.nasa.gov

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ARSET
Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

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

@SilvaCarbon

Thank You

Next Week:

Accuracy Assessments