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Monitoring and Modeling Managed Forest Ecosystems Using Interannual Multitemporal Landsat Data

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Presented to Landsat Science Team
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Collective Achievements

- Come together as a team
- No-cost access to high quality data from full extent of US archive; activity on “repatriation”
- Thermal back on Landsat 8
- OLI on time and within spec
- Working toward Landsat 9 and beyond
- Starting to think about products and associated preprocessing

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Key Points

- Attribution of land cover change requires interannual multitemporal approach
- Unmixing requires phenological information
- There are important issues remaining with respect to both preprocessing and analysis of multitemporal data
- Change in ecosystem structure and composition is insufficient; we need to be thinking about ecosystem function and associated services

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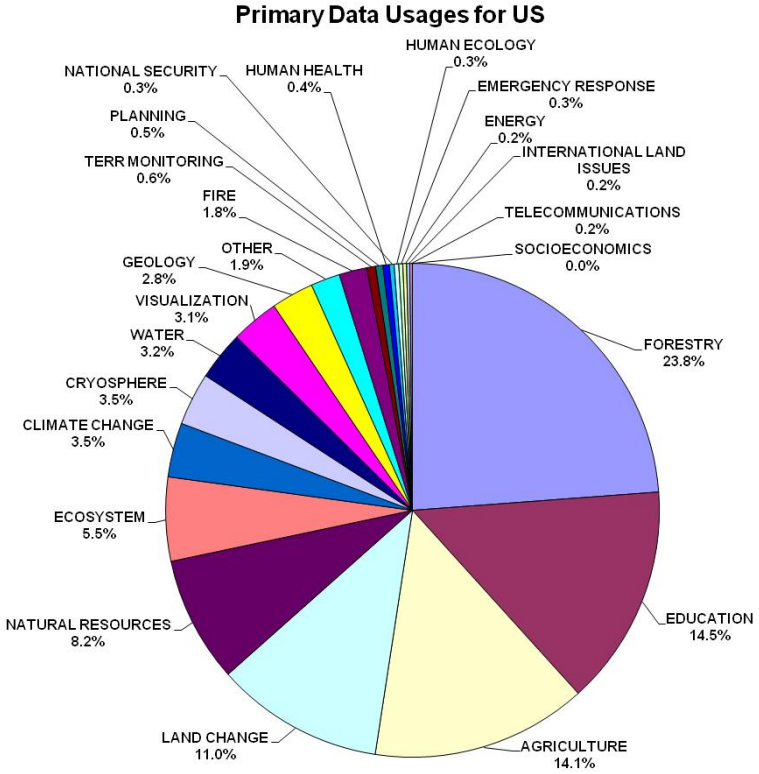
User Reported Primary Use of Landsat U.S. Users Only (Oct 1, 2008 – Mar 31, 2009)



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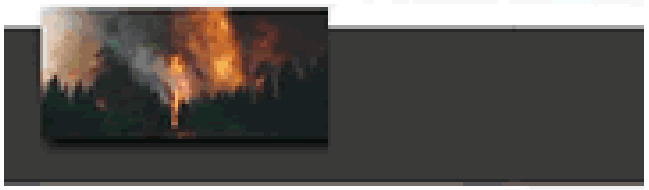
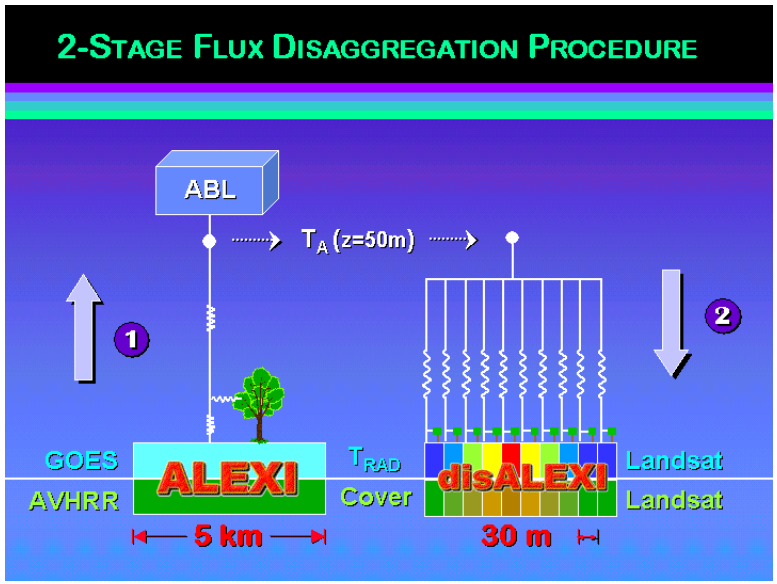
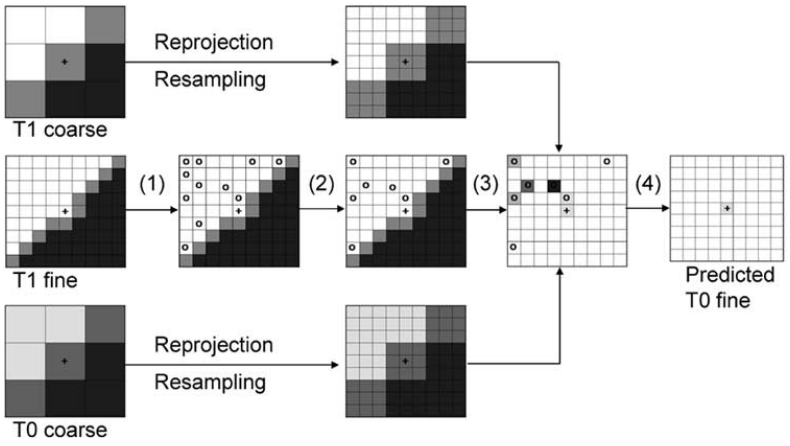
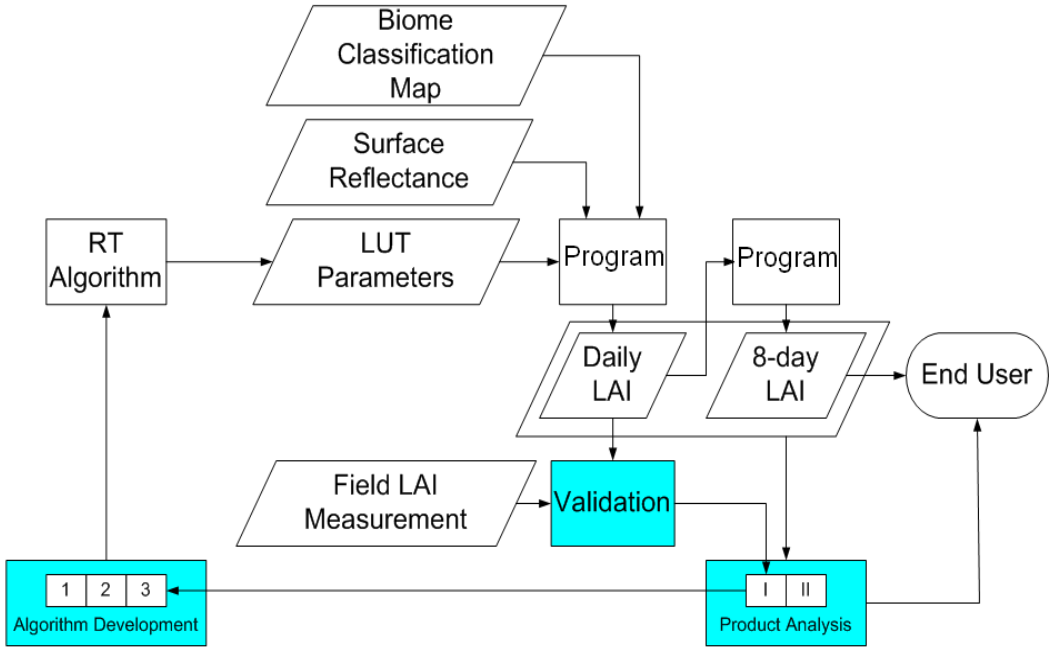
LEDAPS



Landsat Ecosystem Disturbance Adaptive Processing System







1. Development of the at-launch algorithm
2. Prototyping of the algorithm
3. Algorithm refinement

I. Input uncertainty constraint
II. Global algorithm performance

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Delineate reclaimed coal mined areas of south western Virginia that have been mined and reclaimed in specific time periods within the study time frame (1984-2008).

Specific objectives:

- **Develop methods to separate reclaimed mines from other disturbances**
- **Identify the year of mining for each mined pixel**
- **Analyze the vegetation developmental pattern of each reclaimed mined pixel**

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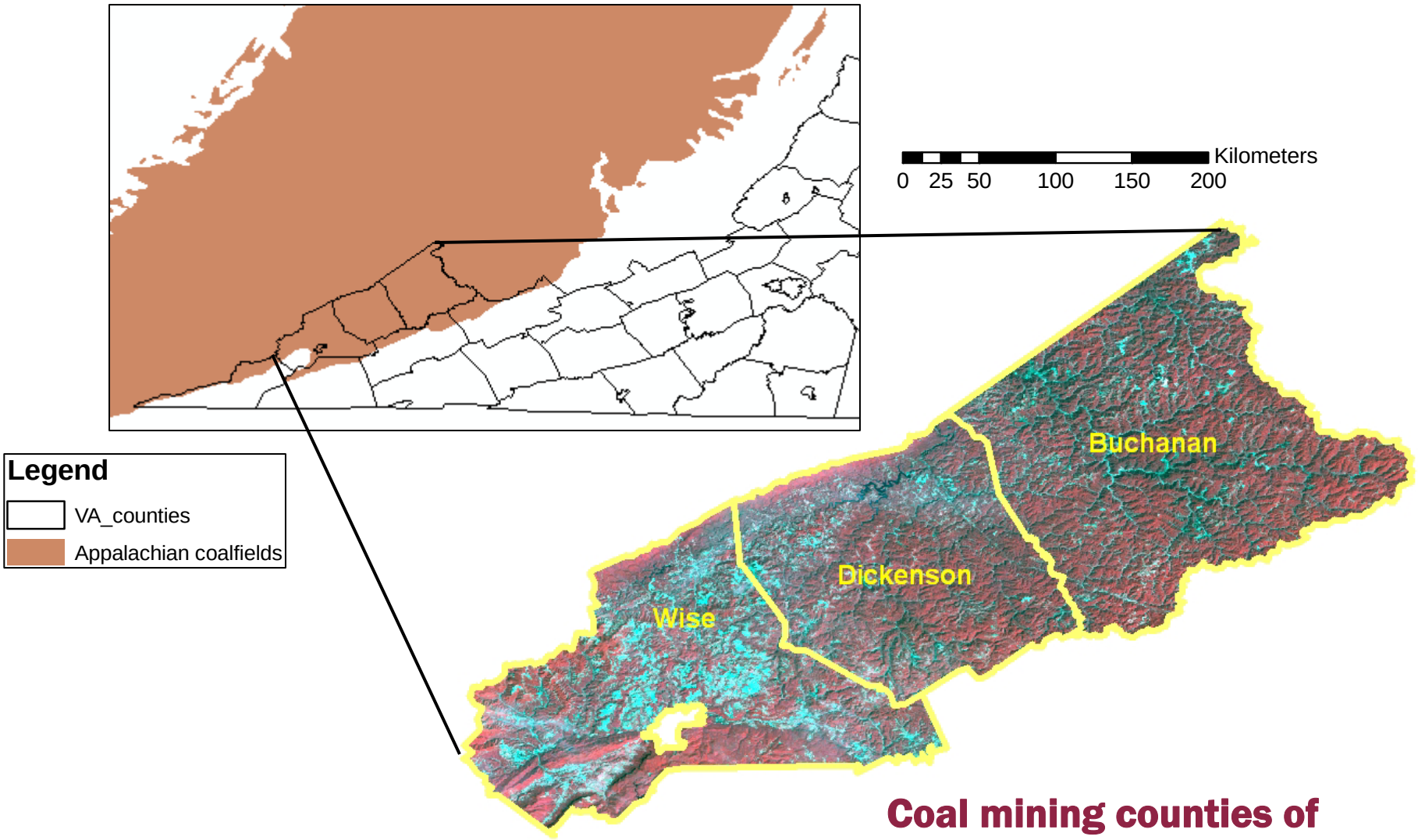
Study Area



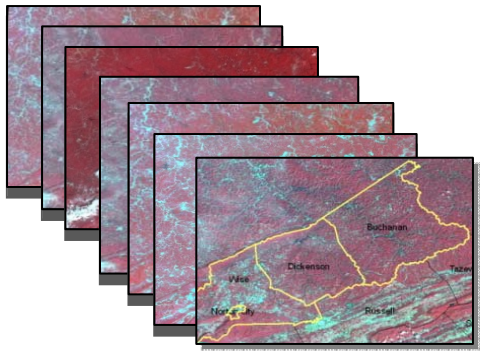
Coal mining counties of south west Virginia

Data: 11 leaf-on Landsat TM images

Landsat image dates
9/17/1984
6/6/1987
6/8/1988
9/21/1991
9/29/1994
9/5/1997
9/24/1998
6/9/2000
5/22/2002
6/2/2003
9/11/2005

Path 18, Row 34

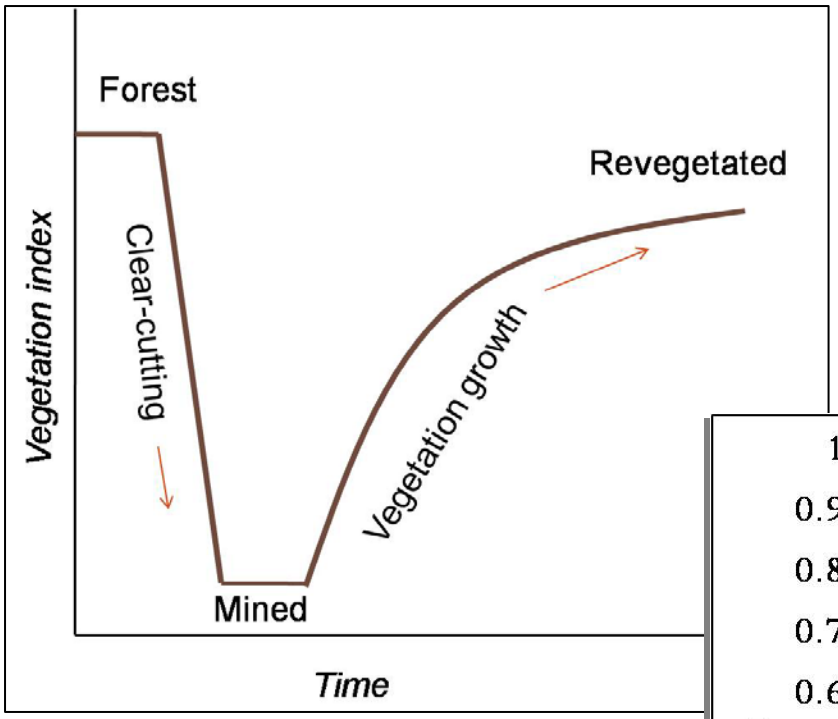
Multi-temporal change detection



- **Identifying change using a series of 11 Landsat images from 1984 to 2005**
- **Detecting progressive change in landcover**

Landsat image dates
9/17/1984
9/20/1985
6/19/1986
6/6/1987
6/8/1988
6/11/1989
6/30/1990
9/21/1991
7/5/1992
6/6/1993
5/27/1995
4/27/1996
9/5/1997
5/19/1998
9/24/1998
9/3/1999
6/9/2000
8/15/2001
5/22/2002
6/2/2003
9/24/2004
9/11/2005
7/20/2006
7/20/2006
4/10/2007
9/17/2007
7/17/2008

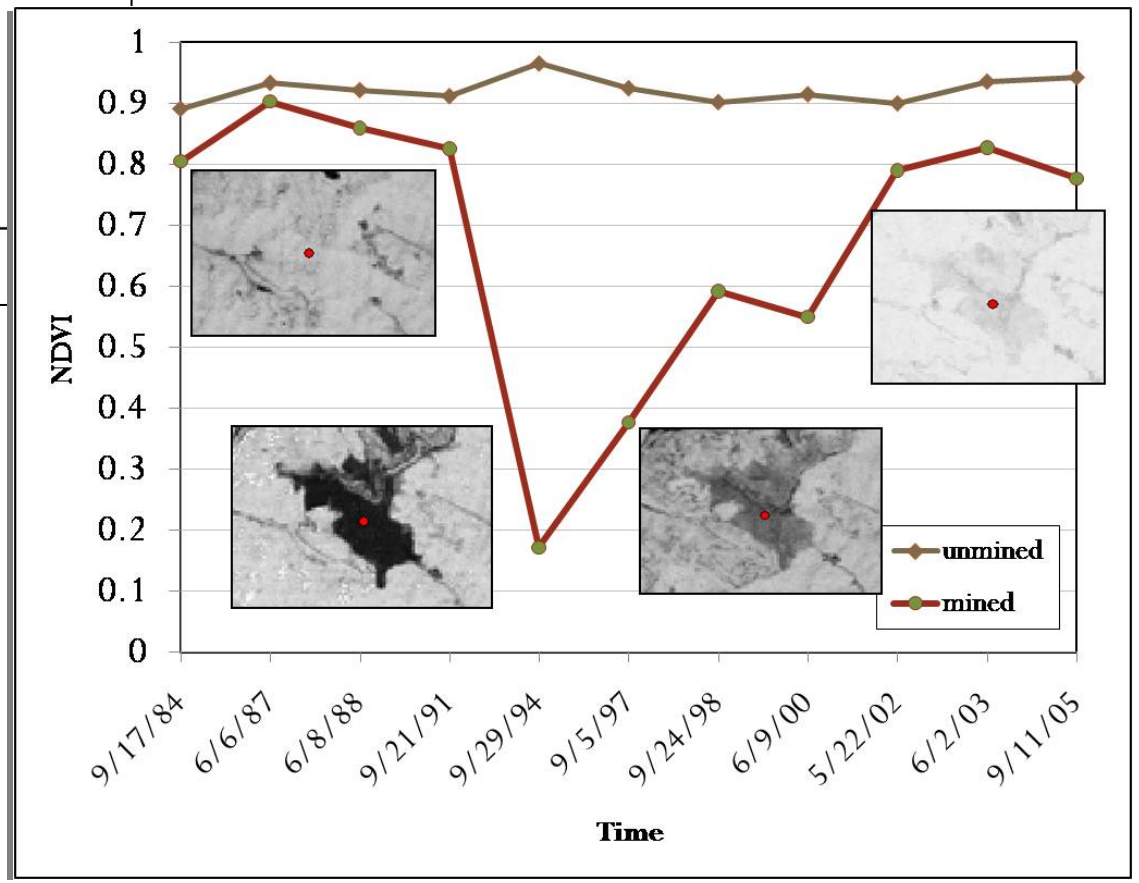
Spectral Trajectory Analysis



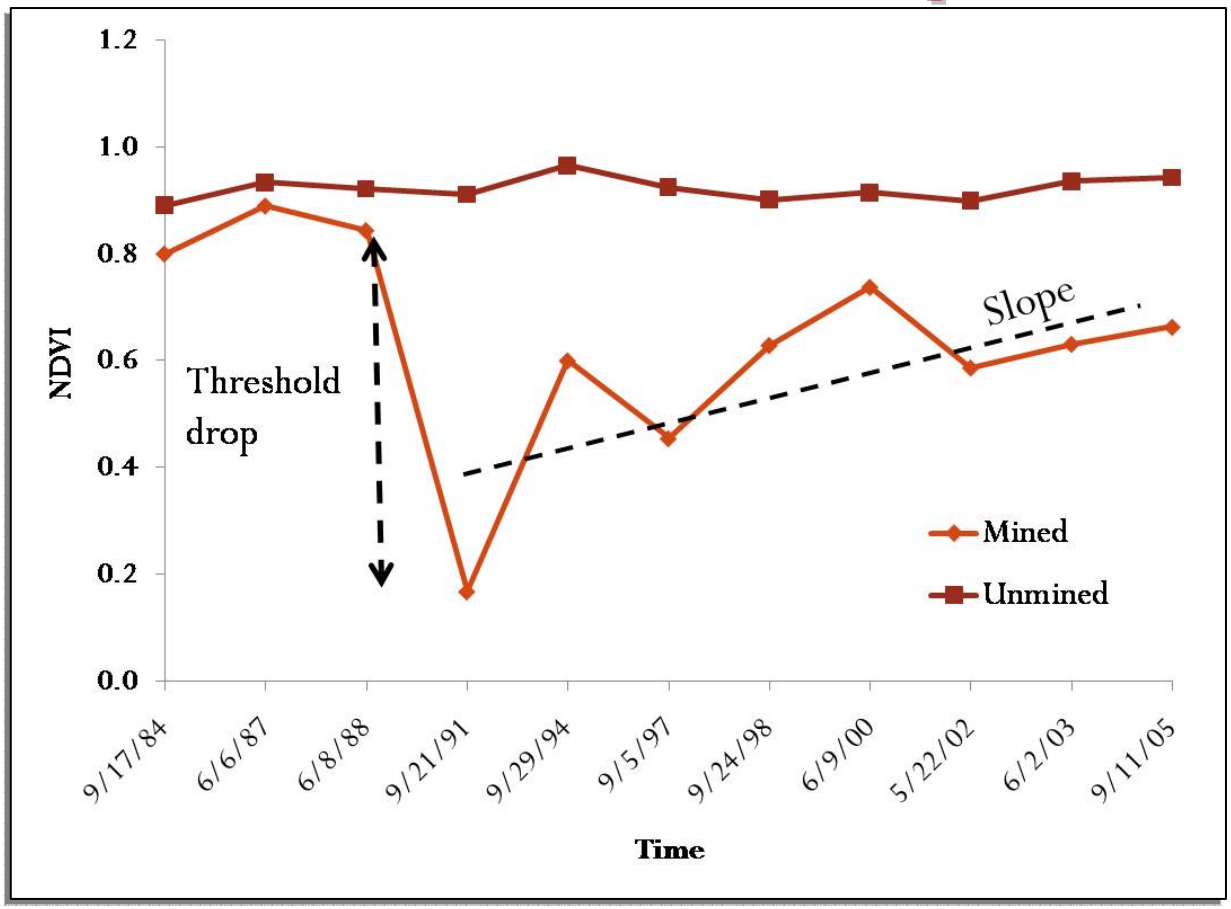
Other Vegetation Indices tested:

- **NDMI**
- **RSR**
- **TC 1, 2 and 3**
- **DI**

Ideal spectral trajectory of a reclaimed mine

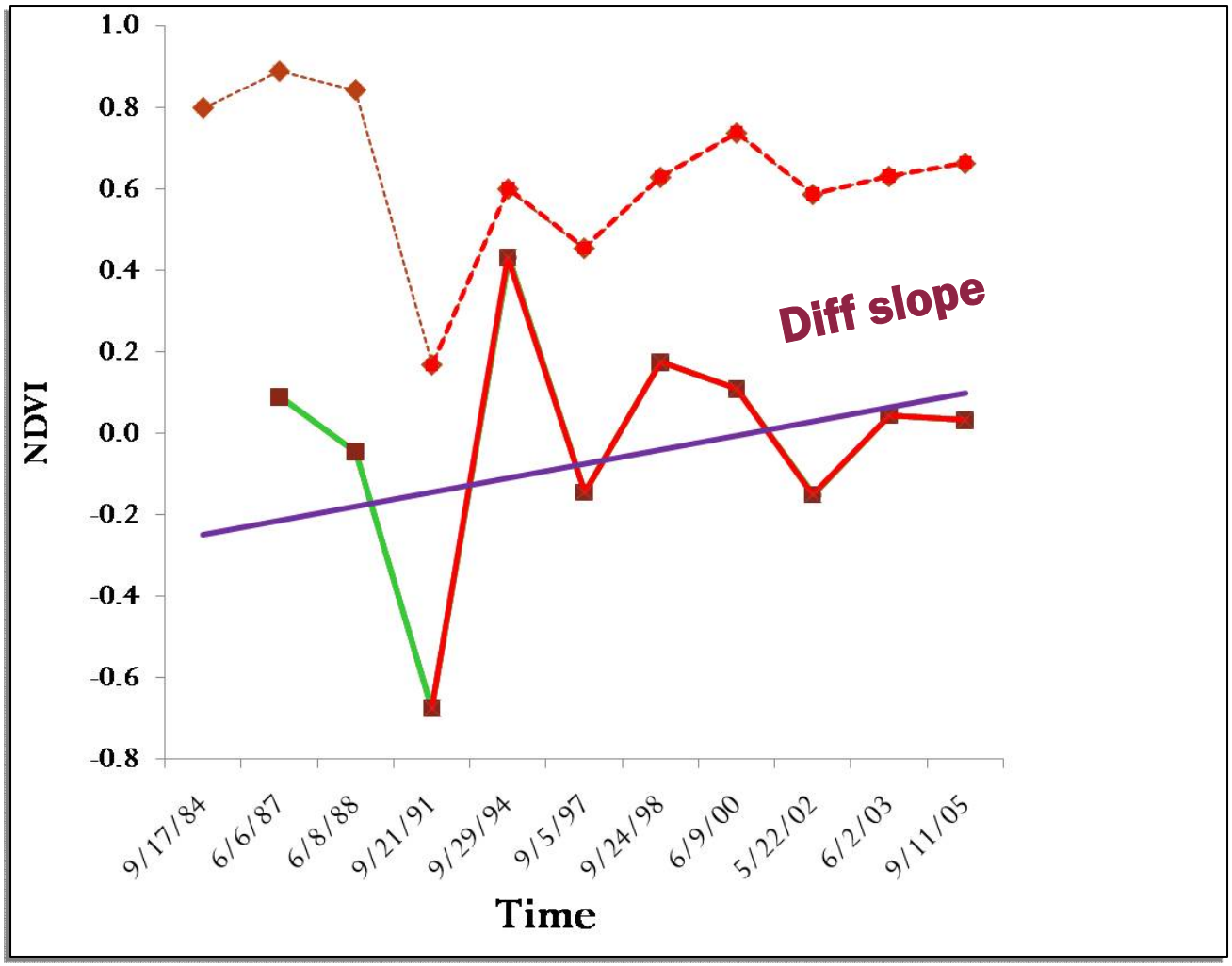


Algorithm: Absolute drop and true slope



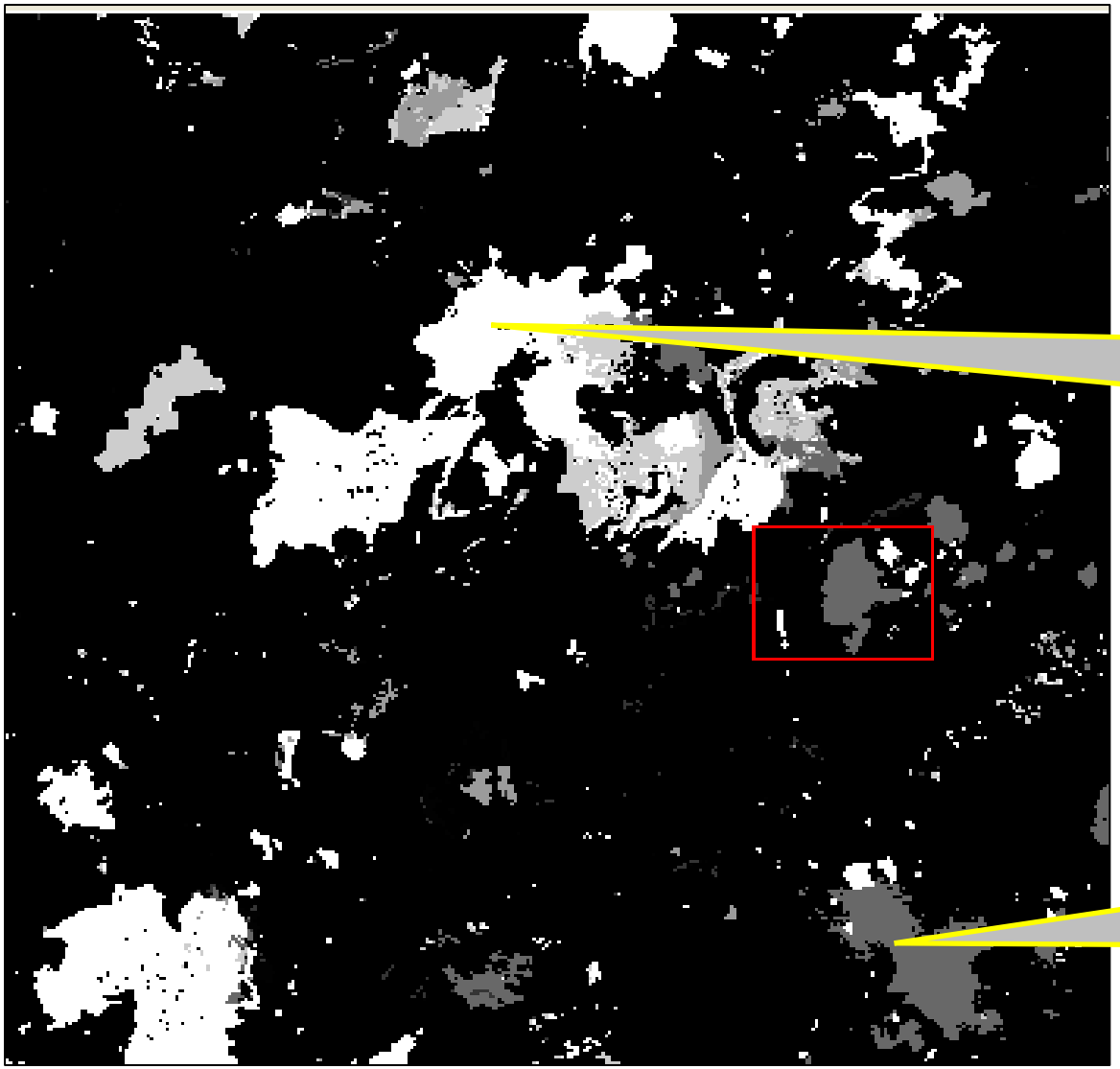
- Find pixels with threshold drop
- Identify the last year of visible mining
- Find slope of recovery trajectory
- Find lowest and highest NDVI

Algorithm: Difference drop and difference slope



- Identify pixels with difference drop (user defined)
- Identify year of biggest drop
- Determine slope of difference NDVI values in the recovery path (2nd derivative of NDVI).
- Find the max. decrease and the max. increase

Reclaimed Mined Area Map



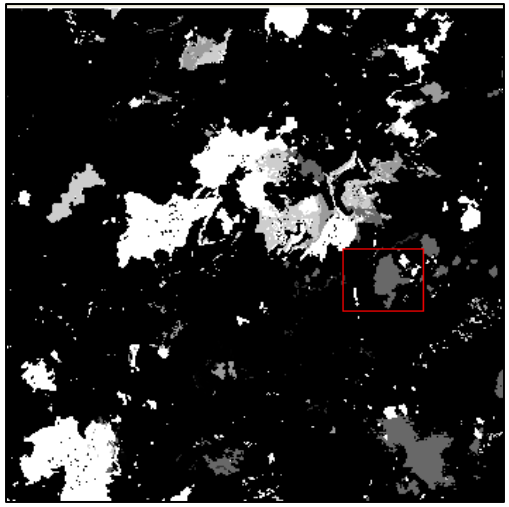
- Year of mining:
- Slope
- Highest/lowest NDVI

Year of mining
Slope
Highest/lowest NDVI

Absolute drop and true slope output

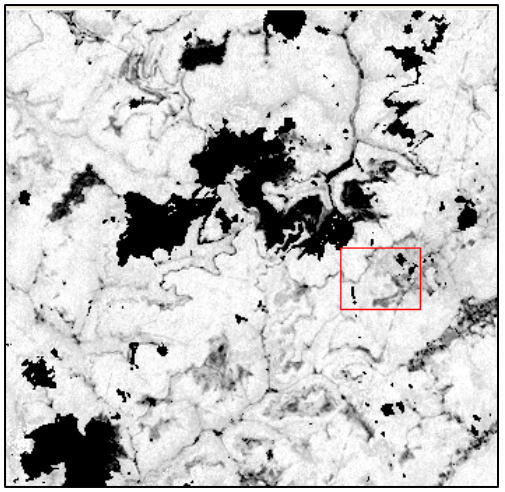
1984 2005

Year of mining



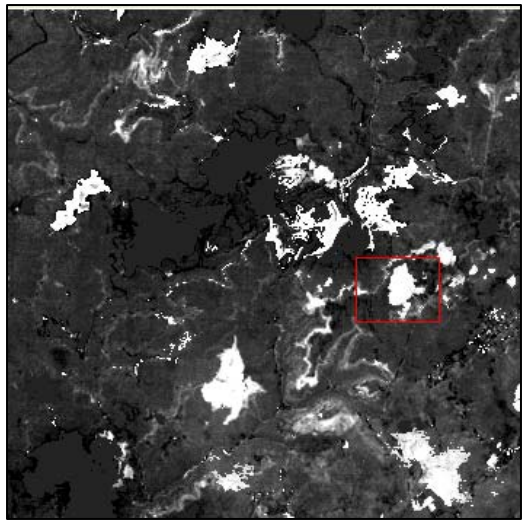
-0.538 1

Lowest NDVI



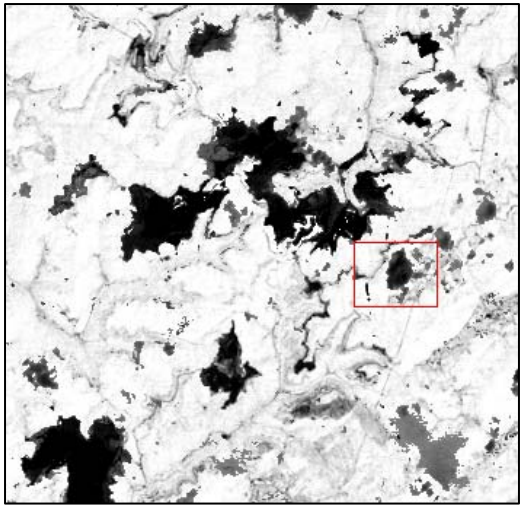
Input = stack of 11 NDVI images

OUTPUT



Slope of recovery curve

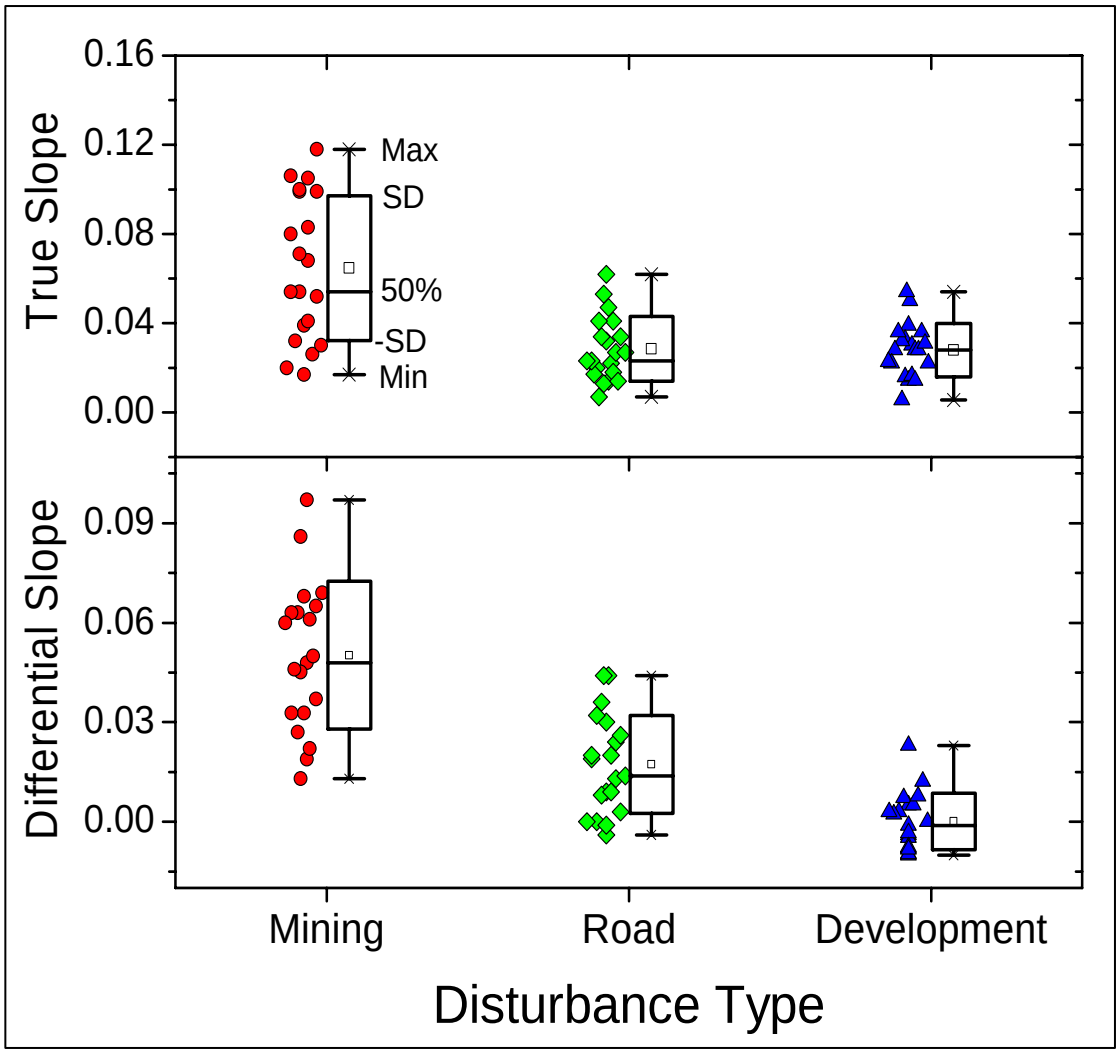
-0.205 0.189



Highest NDVI

0 1

Results

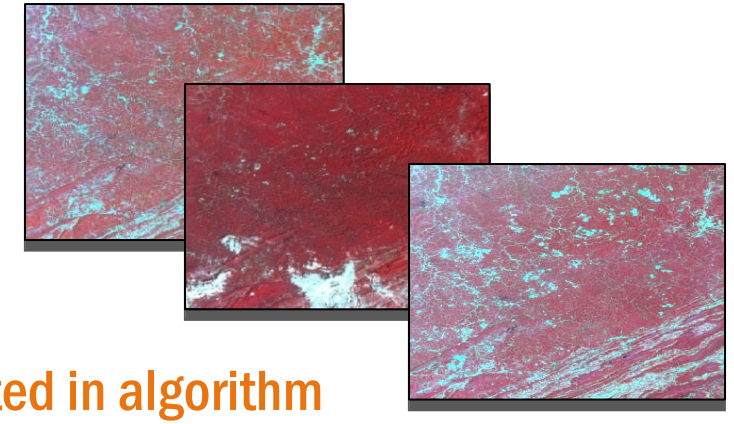


Level	No.	Mean	Std Dev
Development	20	0.03	0.01
Mining	20	0.06	0.03
Road	20	0.03	0.01

Level	No.	Mean	Std Dev
Development	20	0.00	0.01
Mining	20	0.05	0.02
Road	20	0.02	0.01

Discussion

- **Sources of error in year mined output:**
  i. Roads (interstates/ highways)
  ii. Urban developments



- **Source of error in slope:**
  i. Year gap in time series
  ii. Different seasonality of images
  iii. Cloudy images
  iv. Asymptotic nature of curve unaccounted in algorithm

- **Error caused by over classification of potentially disturbed lands.**

- **Scale of fire and forest harvest insignificant with respect to mining.**

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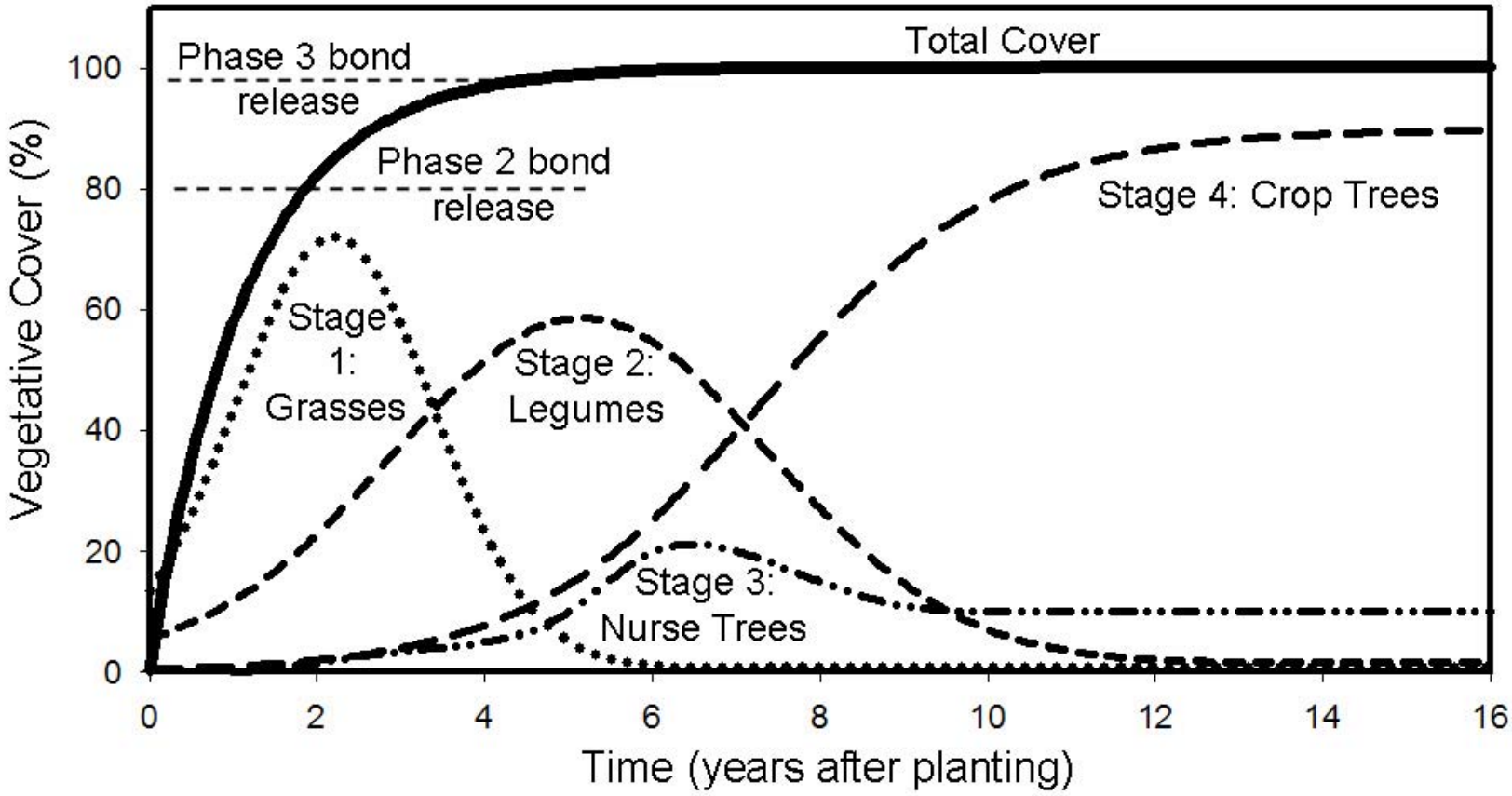

Forestry Reclamation Approach model of vegetative cover change over time. Four vegetation types are sown or planted during reclamation, but each type is dominant at a different stage. (Burger et al., 2008)

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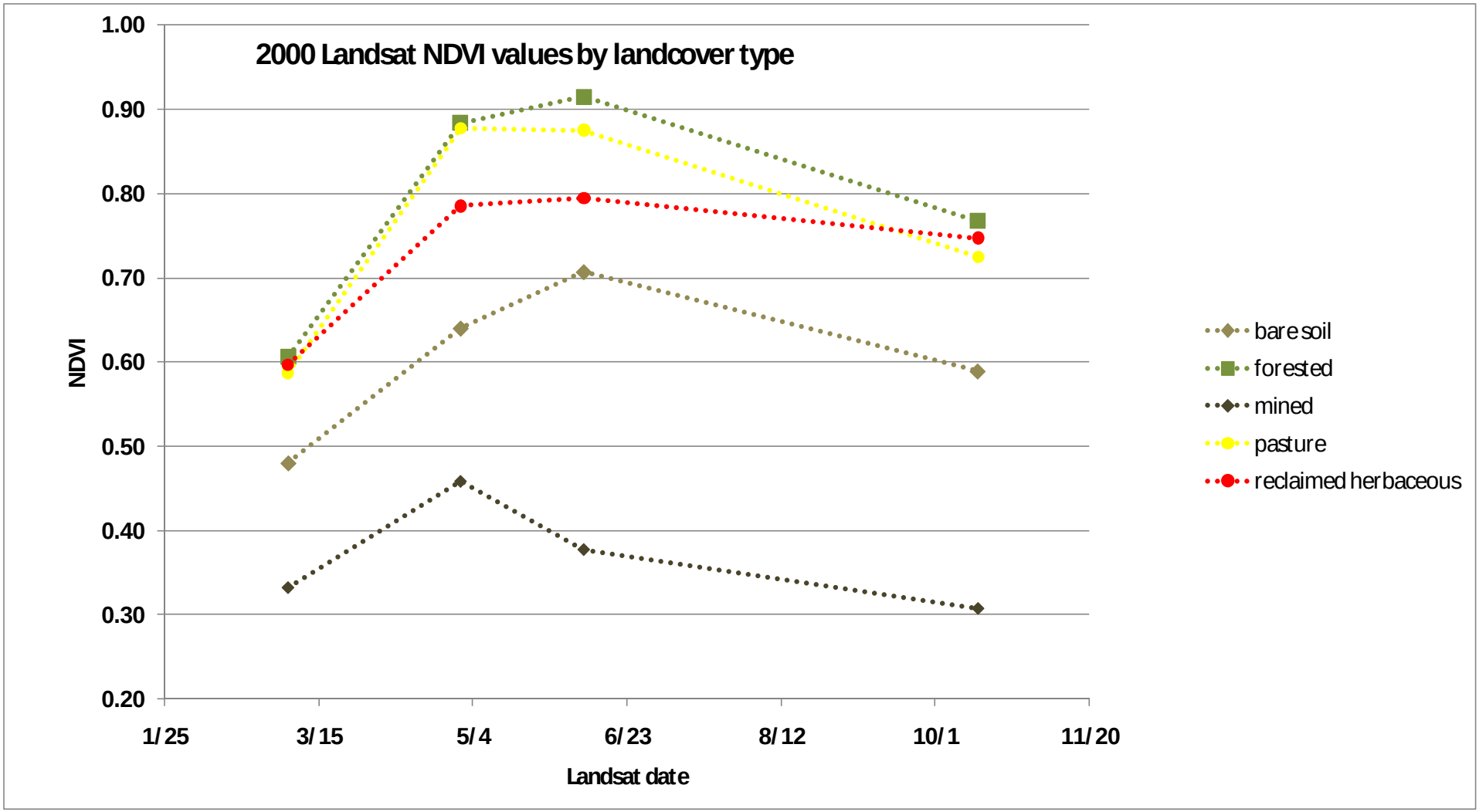
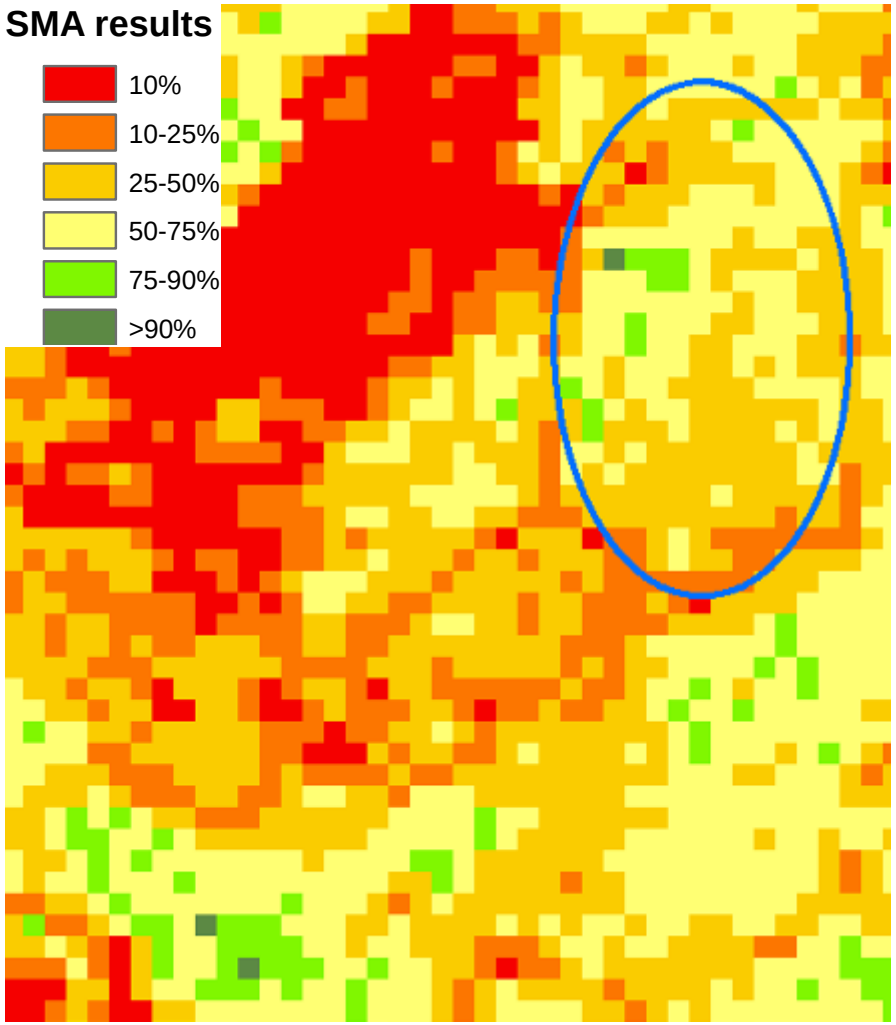


Graph showing NDVI values by landcover type throughout year. Reclaimed herbaceous fields have signature which is combination of pasture (dense, herbaceous vegetation) and bare soil signatures from early spring through summer.

Powell River Site

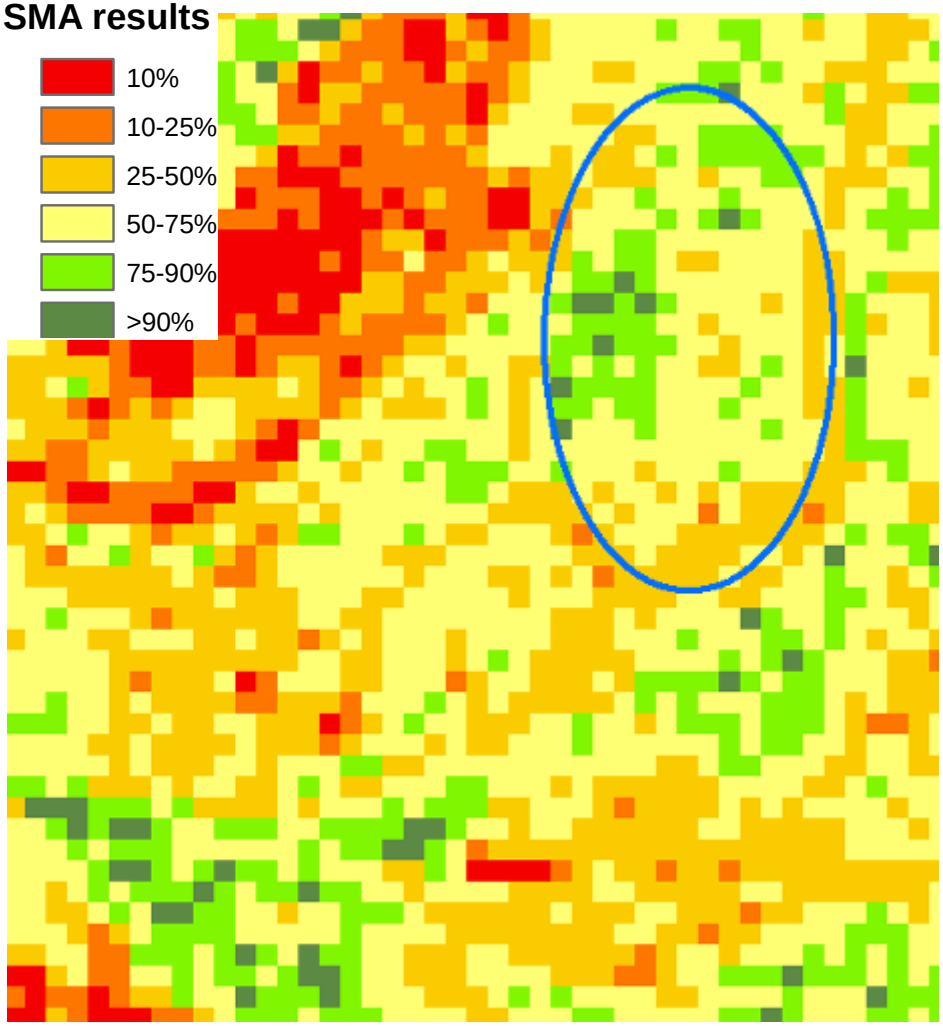


2003 NAIP

Forested SMA fraction

Powell River Site

2005 NAIP



Forested SMA fraction

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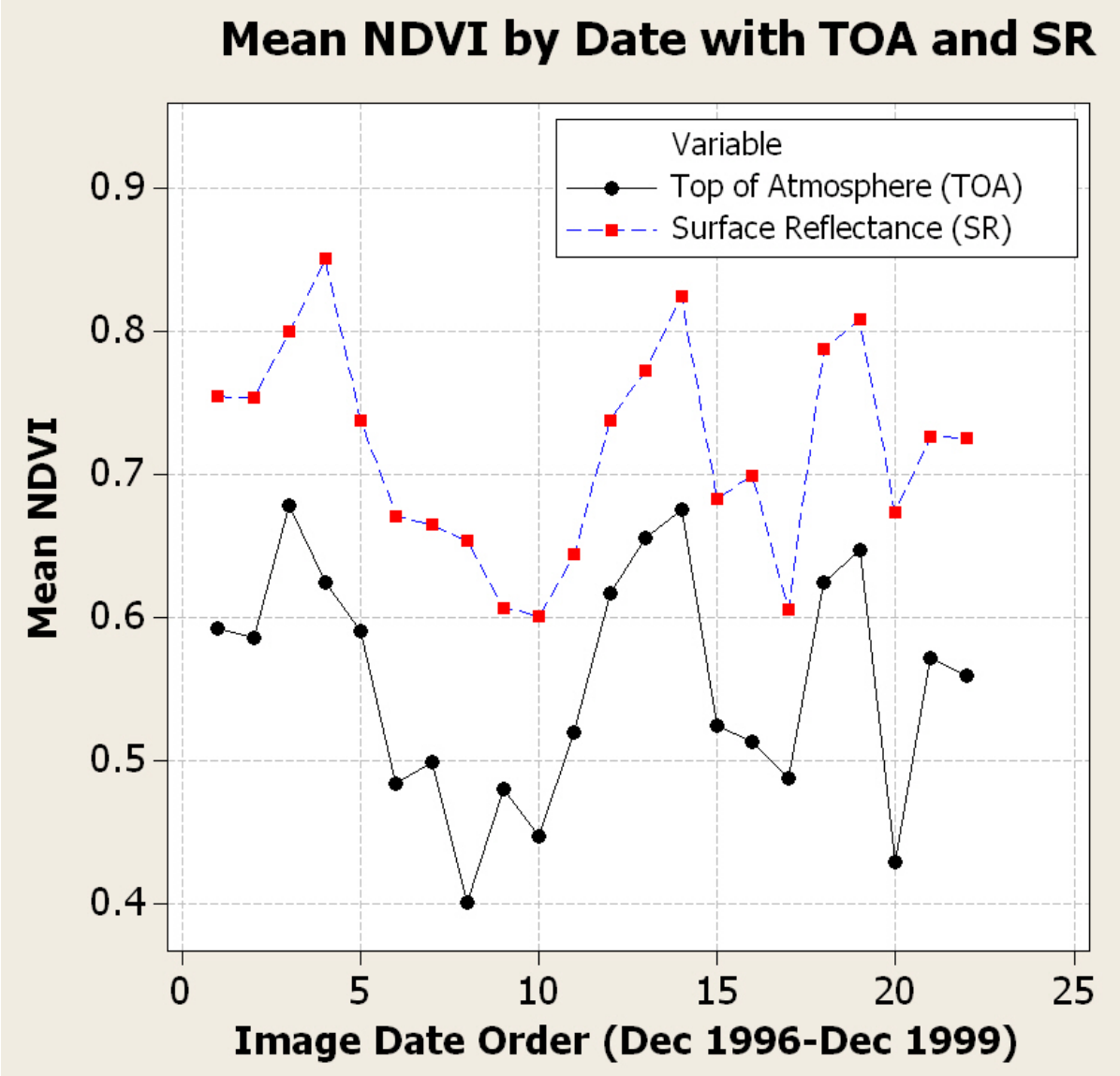

1) 22 image dates for Landsat 15/35 were processed through LEDAPS.
2) NDVI was calculated on each SR and TOA image.
3) The mean NDVI for a forest stand of interest was calculated on all 44 images and plotted to compare the trend through time.

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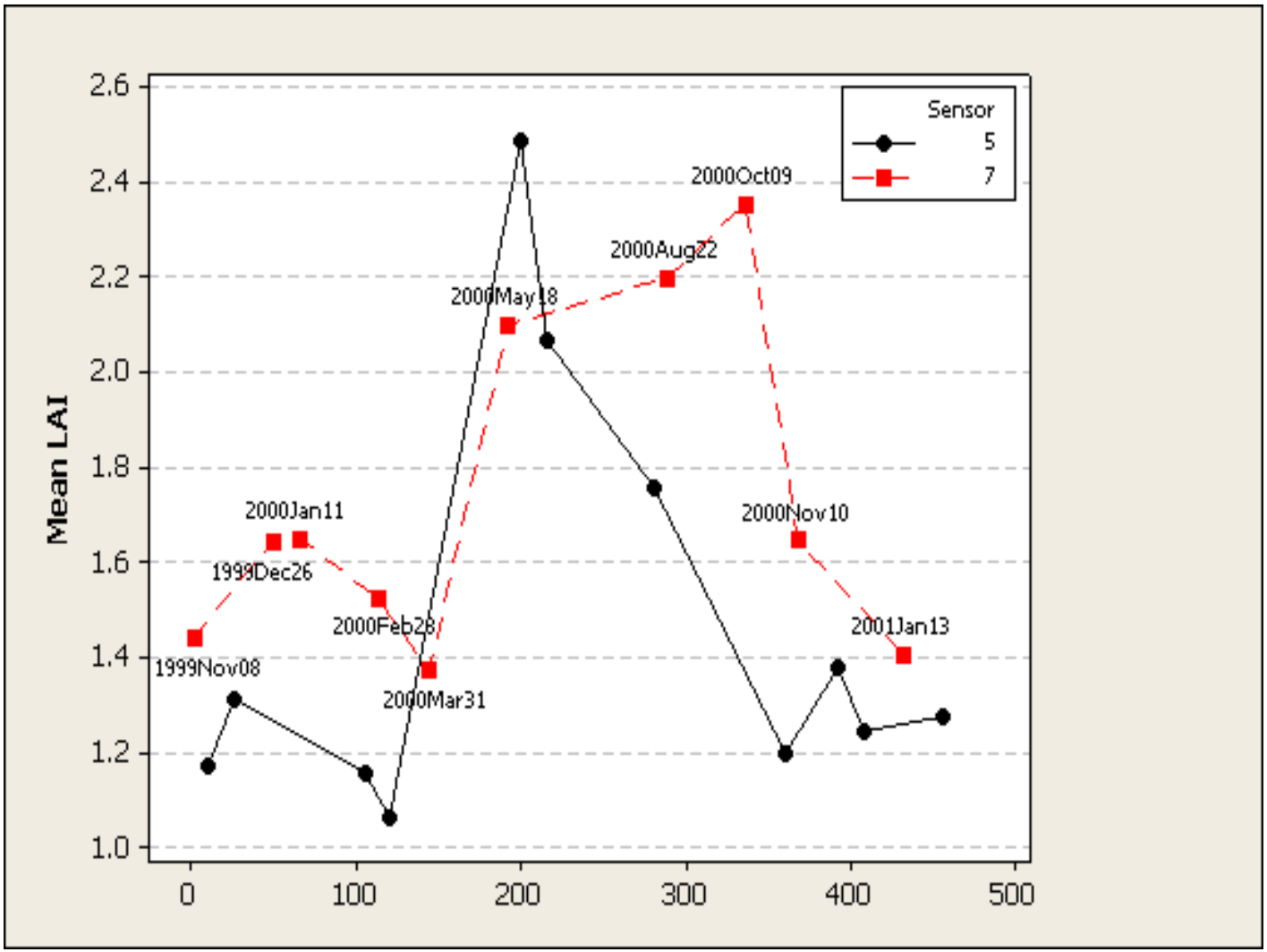
LAI with Landsat 5 vs. Landsat 7



Site 175101 in Chatham, NC

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Annual LAI Time Series for RW194001

Based on Landsat TM Imagery

Path 16 Row 36

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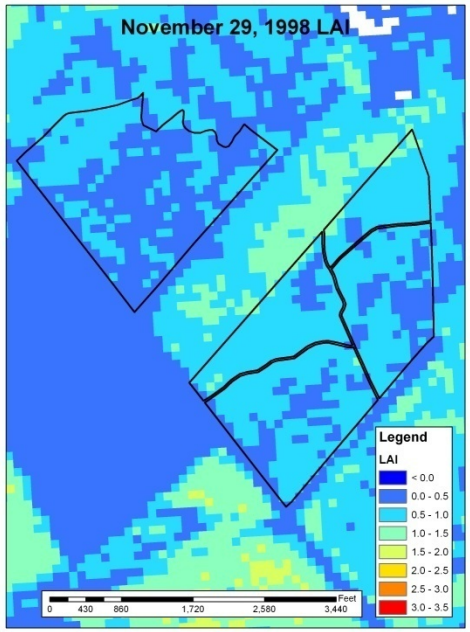
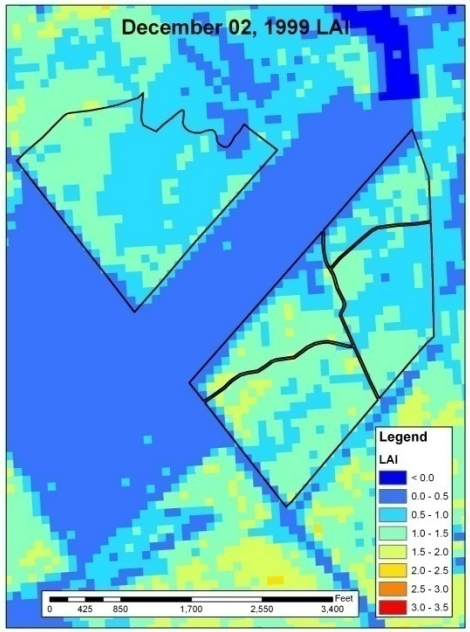
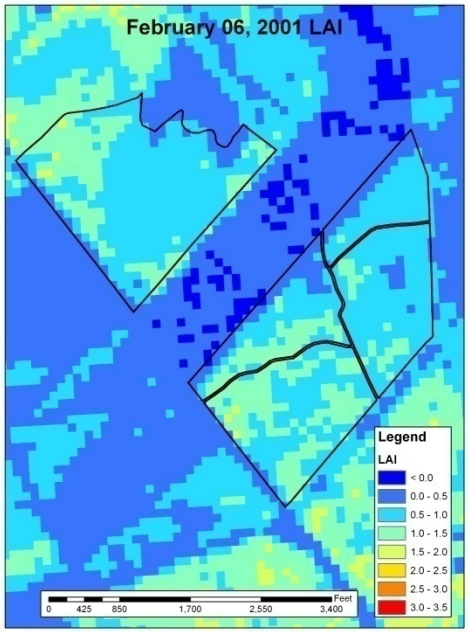
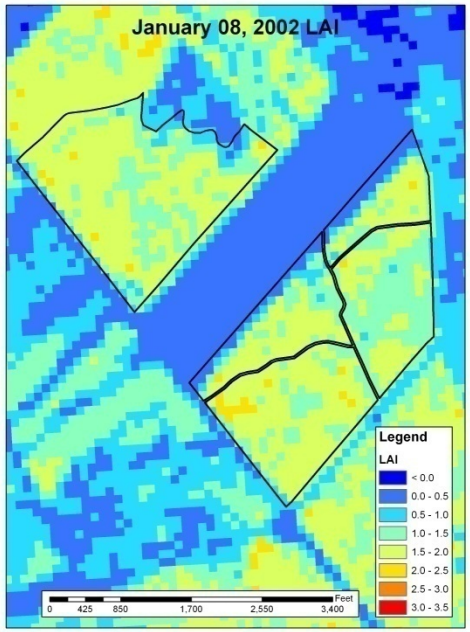
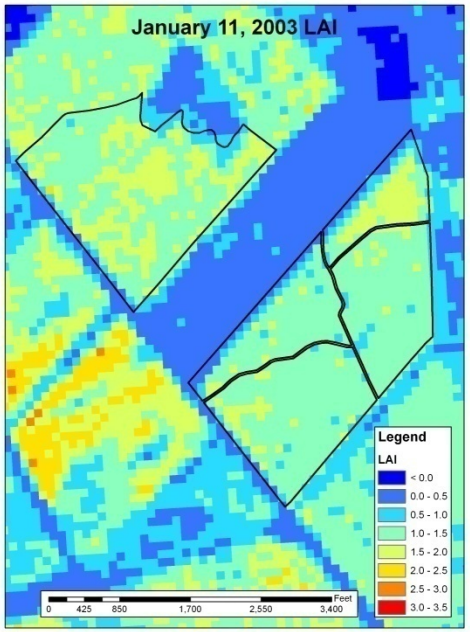
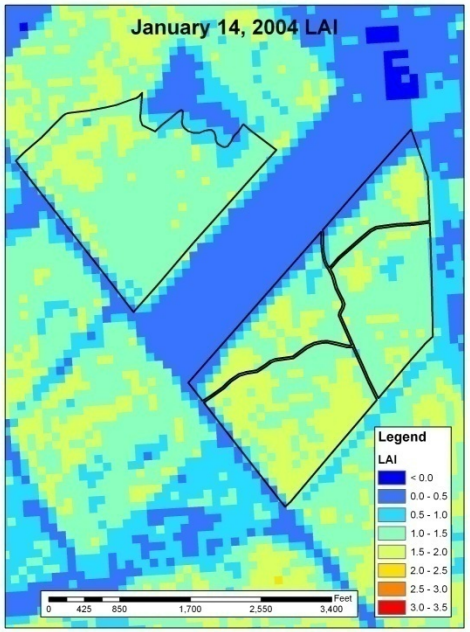

November 29, 1998 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 430 860 1,720 2,580 3,440
Feet

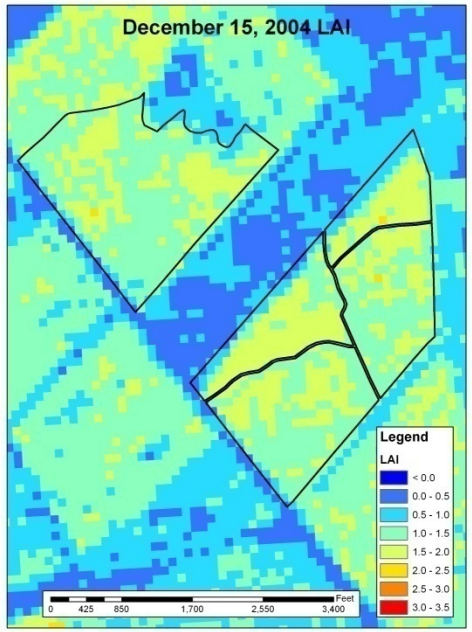

December 02, 1999 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet

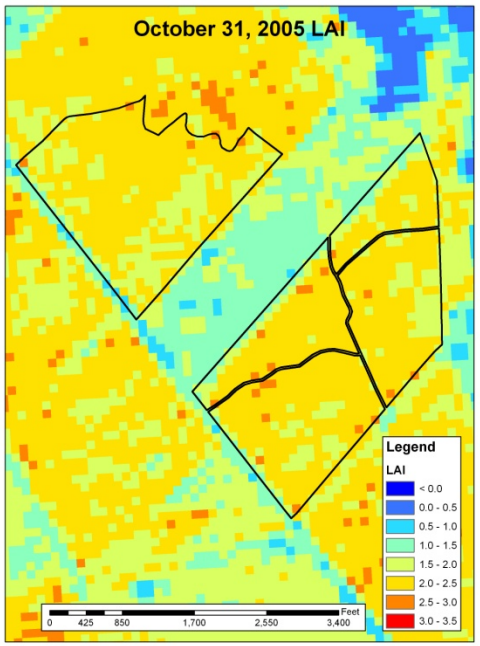

February 06, 2001 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet

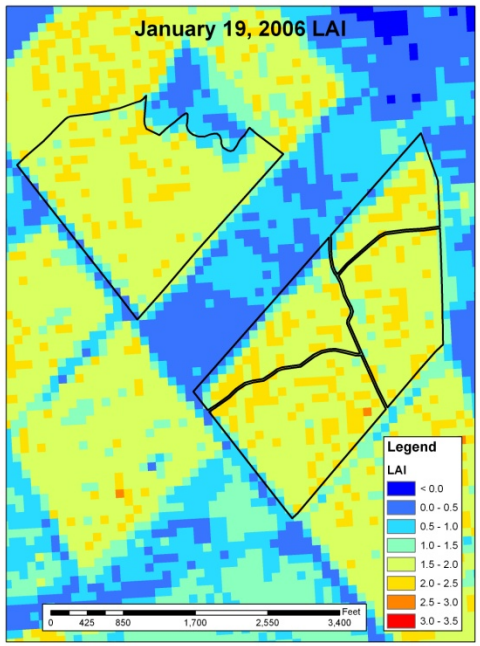

January 08, 2002 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet

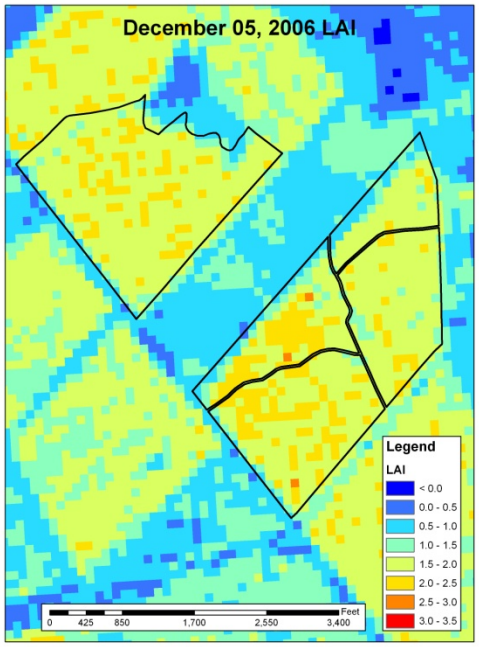

January 11, 2003 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet

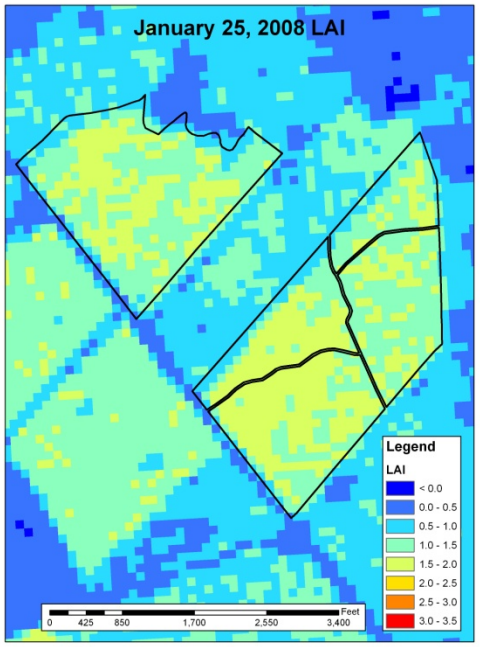

January 14, 2004 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet

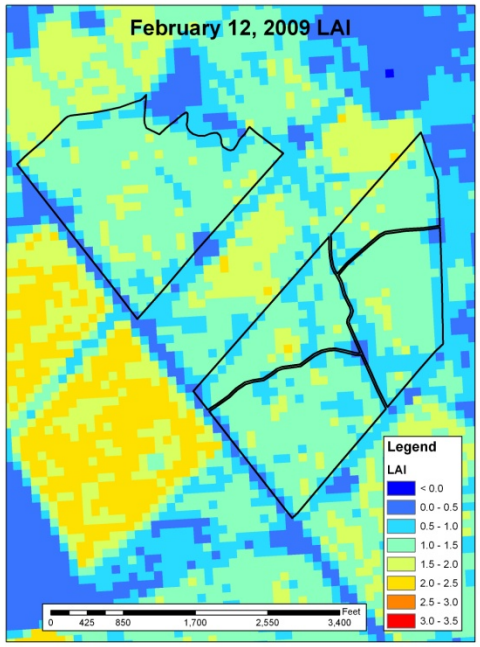

December 15, 2004 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet


October 31, 2005 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet


January 19, 2006 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet


December 05, 2006 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet


January 25, 2008 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet


February 12, 2009 LAI
Legend
LAI
< 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0 425 850 1,700 2,550 3,400
Feet

Decision Support for Forest Carbon Management: From Research to Operations

MODELS

ESE
- NASA-CASA

GYC
- PTAEDA 3.1
- FASTLOB

USDA Forest Service
- FORCARB

ESE MISSIONS
- Aqua
- Terra
- Landsat 7
- ASTER

Analysis Projects
- IGBP-GCTE
- IGBP-LUCC
- USDA-FS FIA
- USDA-FS FHM

Ancillary Data
- SPOT
- AVHRR NDVI
- Forest inventory data
- VEMAP climate data
- SRTM topographic data

Information Products, Predictions, and Data from NASA ESE Missions:

- MODAGAGG
- MOD 12Q1
- MOD 13
- MOD 15A2
- ETM+ Level 1 WRS
- AST L1B and 07

DECISION SUPPORT:

Current DSTs
- ***COLE (county-scale)***
- ***LobDST (stand-scale)***
  - ***Growth and yield***
  - ***Product output***
  - ***Financial evaluations***
- ***CQUEST (1 km pixels)***
  - ***Ecosystem carbon pools (g C/m^2)***
  - ***Partitioned NPP (g C/m^2/yr)***
  - ***NEP (g C/m2/yr)***

Linked DSTs and Common Prediction Framework (multiscale)
- ***Growth***
- ***Yield***
- ***Product output***
- ***Ecosystem carbon pools***
- ***Partitioned NPP***
- ***NEP***
- ***Total C sequestration***
- ***Forecasts and scenarios***

VALUE & BENEFITS

Improve the rate of C sequestration in managed forests

Decrease the cost of forest carbon monitoring and management

Potentially slow the rate of atmospheric CO_2 increase

Enhance forest soil quality

Inputs **Outputs** **Outcomes** **Impacts**

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Remote Sensing for Forest Carbon Management

- Regionwide CO_2 efflux and LAI acquired at network of monospecific sites with alternative forest management strategies
- Landsat downscaling prototyped using STARFM; pine age class evaluation of algorithmic performance
- Downscaled product being used for reducing variance in F_S models across southeast (CASA, potentially DisALEXI)
- CASA modeling with Landsat done (F_S, NEP)
- ArcGIS version of CASA complete
- FastLob C modifications made
- CASA/FastLob crosswalk in progress

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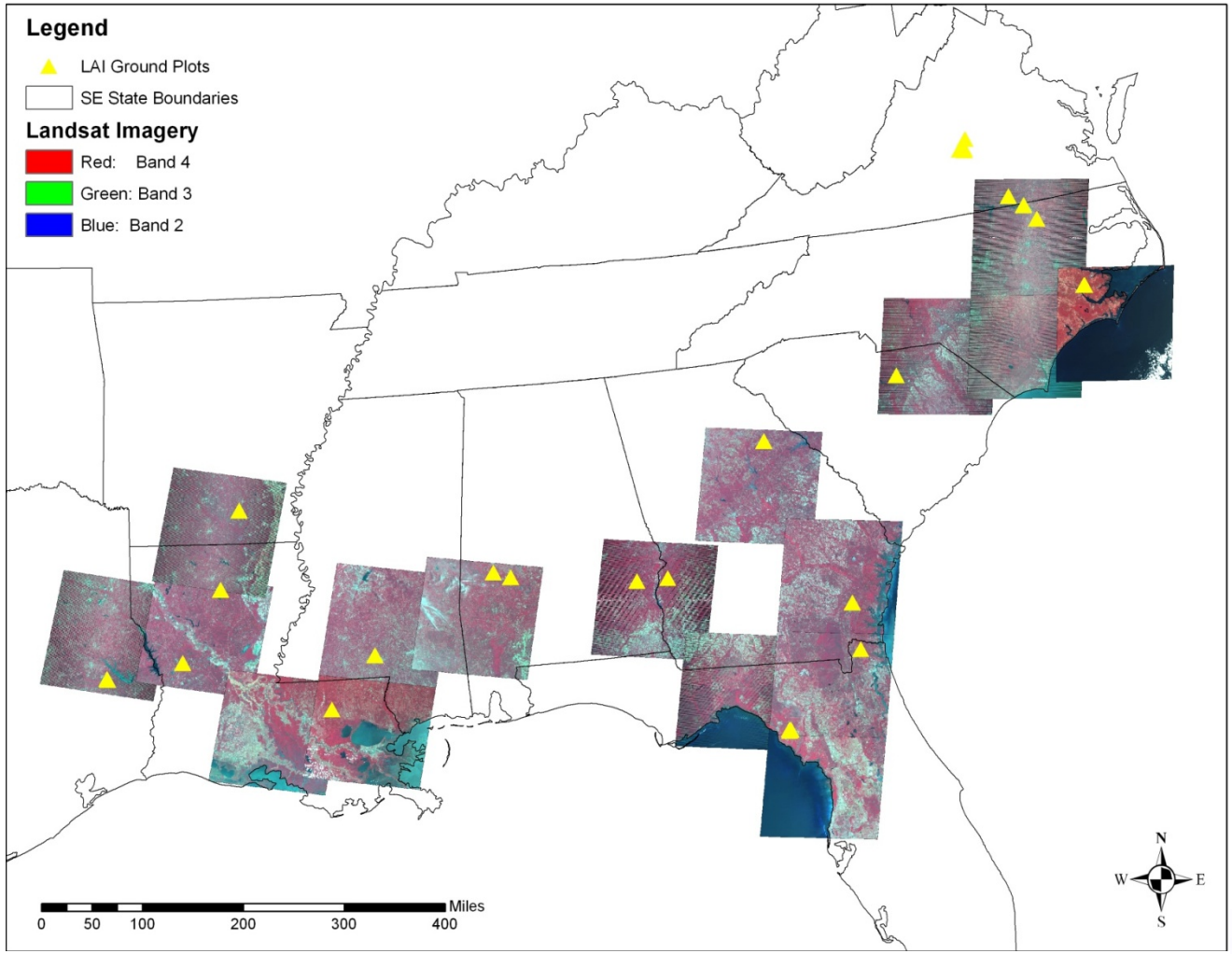

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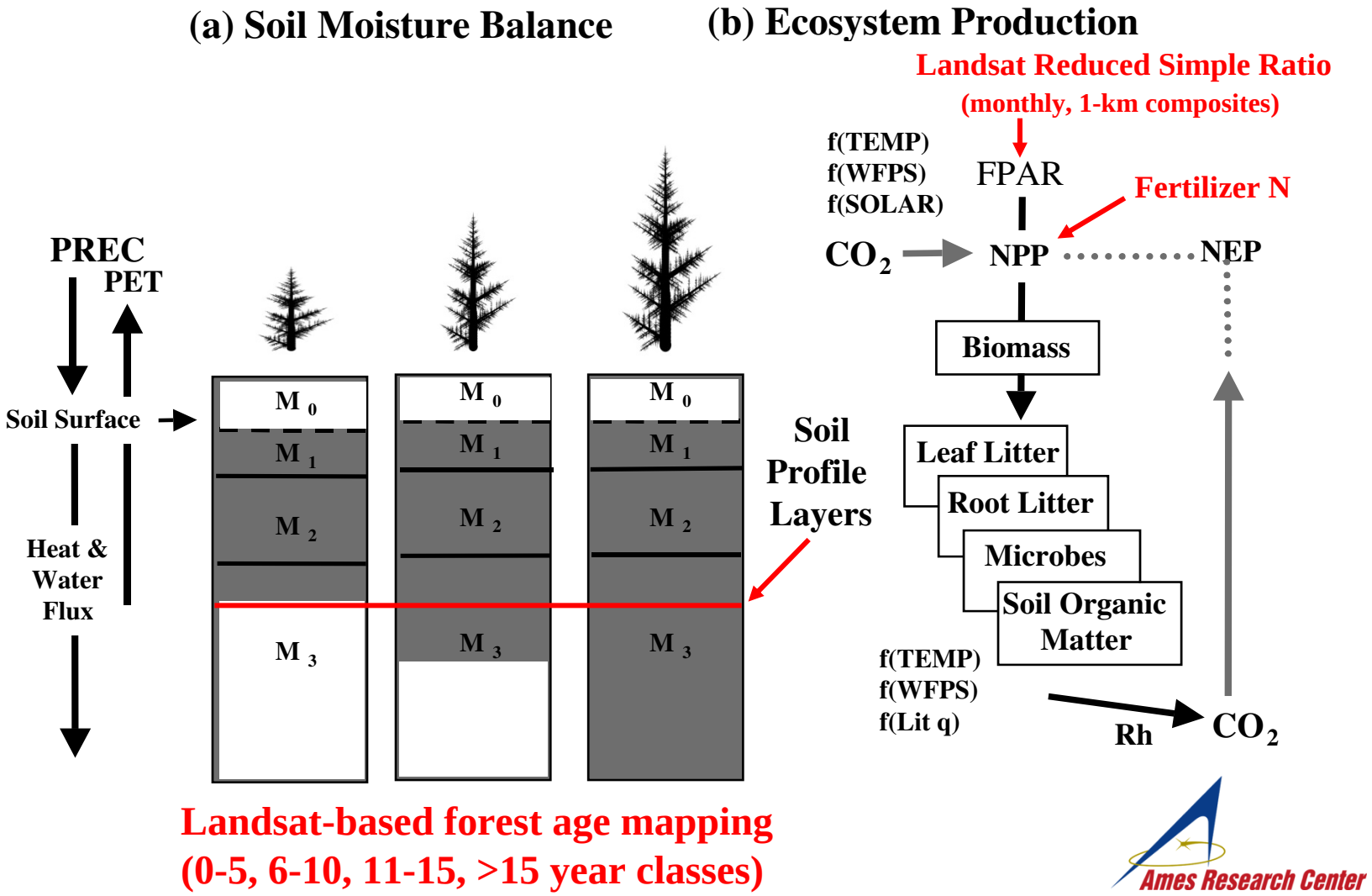
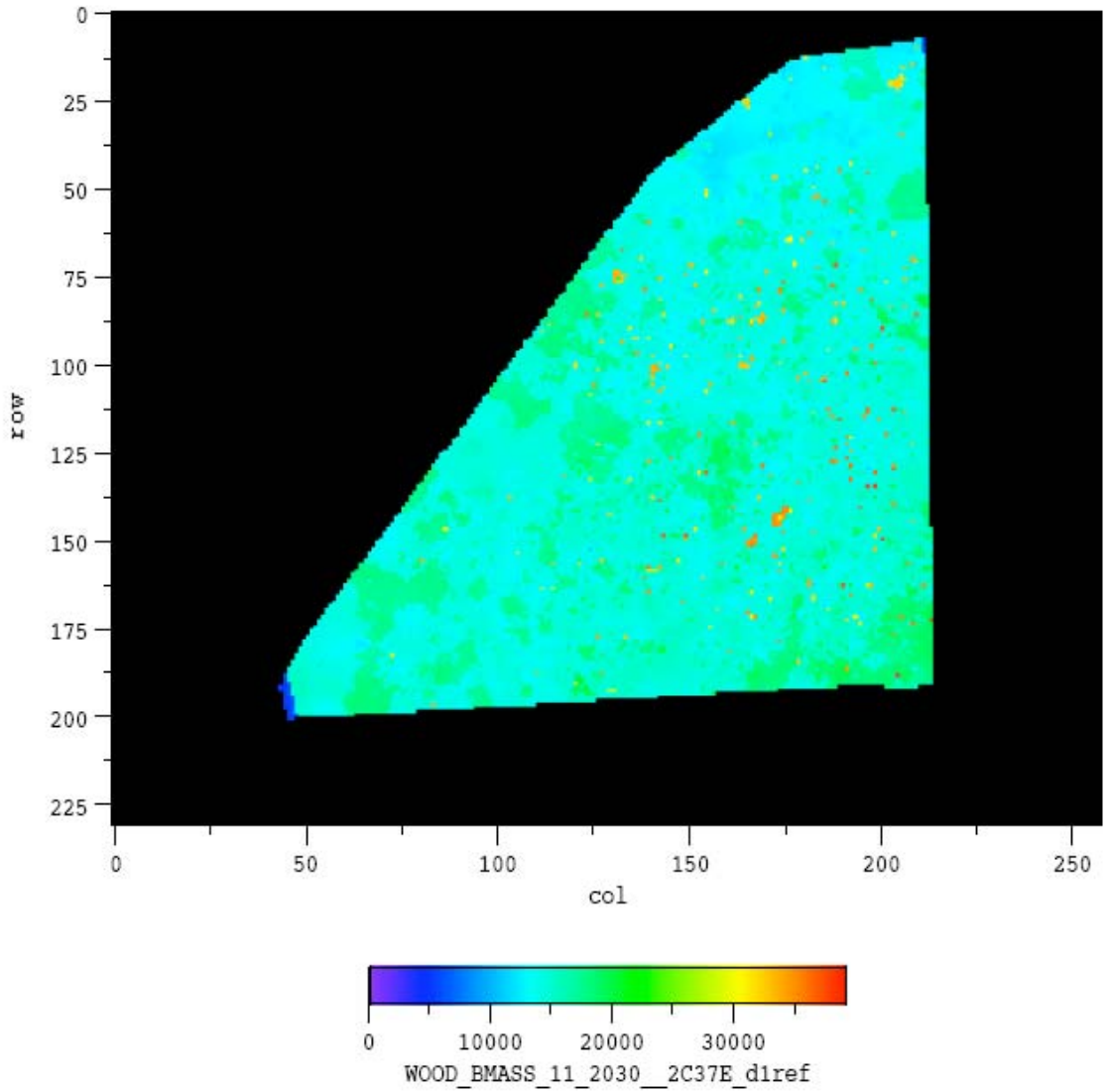
NASA-CASA Ecosystem Model (Potter et al. 2007)

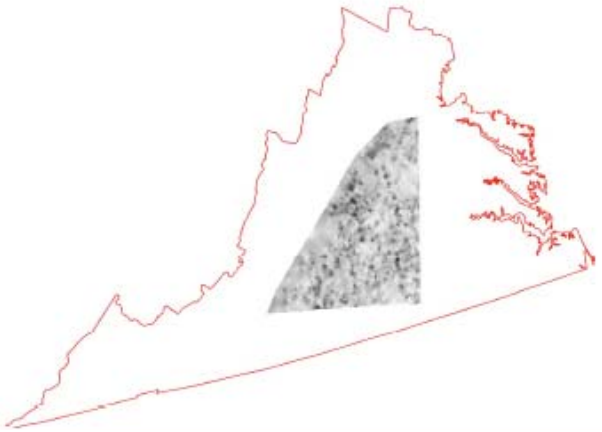
Modifications for Pine Growing Stands



Ames Research Center



NASA-CASA model standing wood carbon in loblolly pine stands after 30 years of regrowth across the Virginia region. Units are in g C m-2 yr-1



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What Next?

- Datasets obtained using industry cooperation have extensive long-term data on managed stands
- Eddy flux for managed pines (2 age classes) in NC coastal plain
- CASA-Fastlob crosswalk; web DSS
- Broader ecosystem services framework

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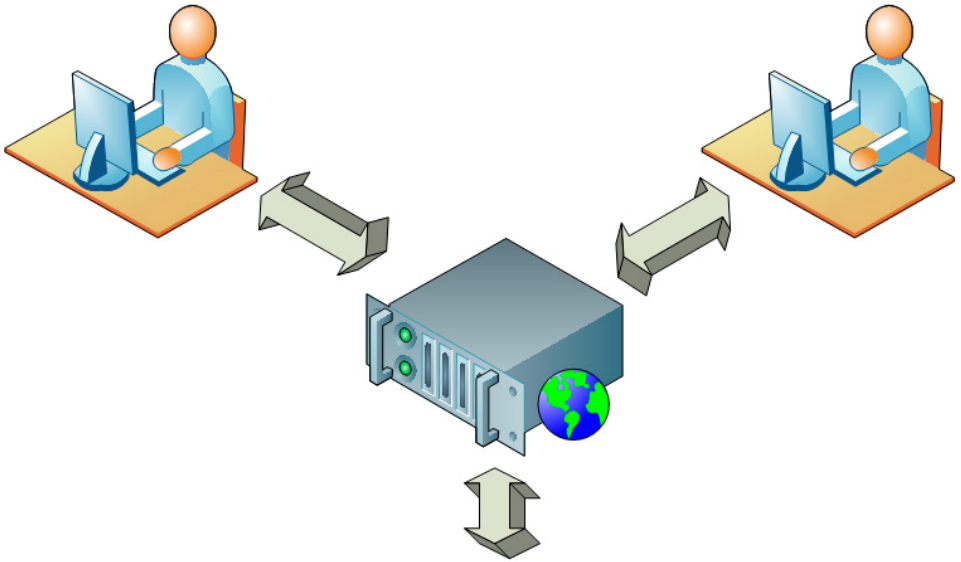
EcoServices Objective

- To provide spatially-explicit, web-based quantification of ecosystem services using extant best of breed models at the tract level.



FVS FSWEPP AVGWLF

NASA-CASA Project
National Aeronautics and Space Administration - Carnegie Ames Stanford Approach

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Vision

- Select tract via database or spatial query, enter other data as appropriate, and see *bundled* ecosystem services delivered
- Real-time model runs rather than static scenarios
- Alternative land use (1st) and management (2nd) options available for "what-if" scenarios
- Innards model-independent, affording capacity to choose best-of-breed and facilitating updates to latest versions

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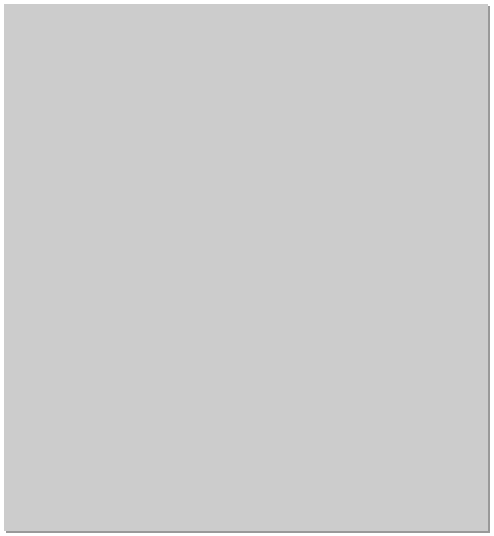
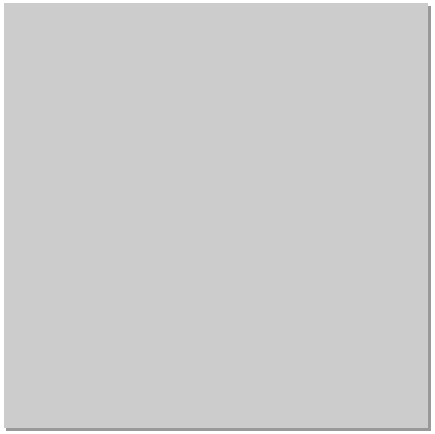
Initial Emphases





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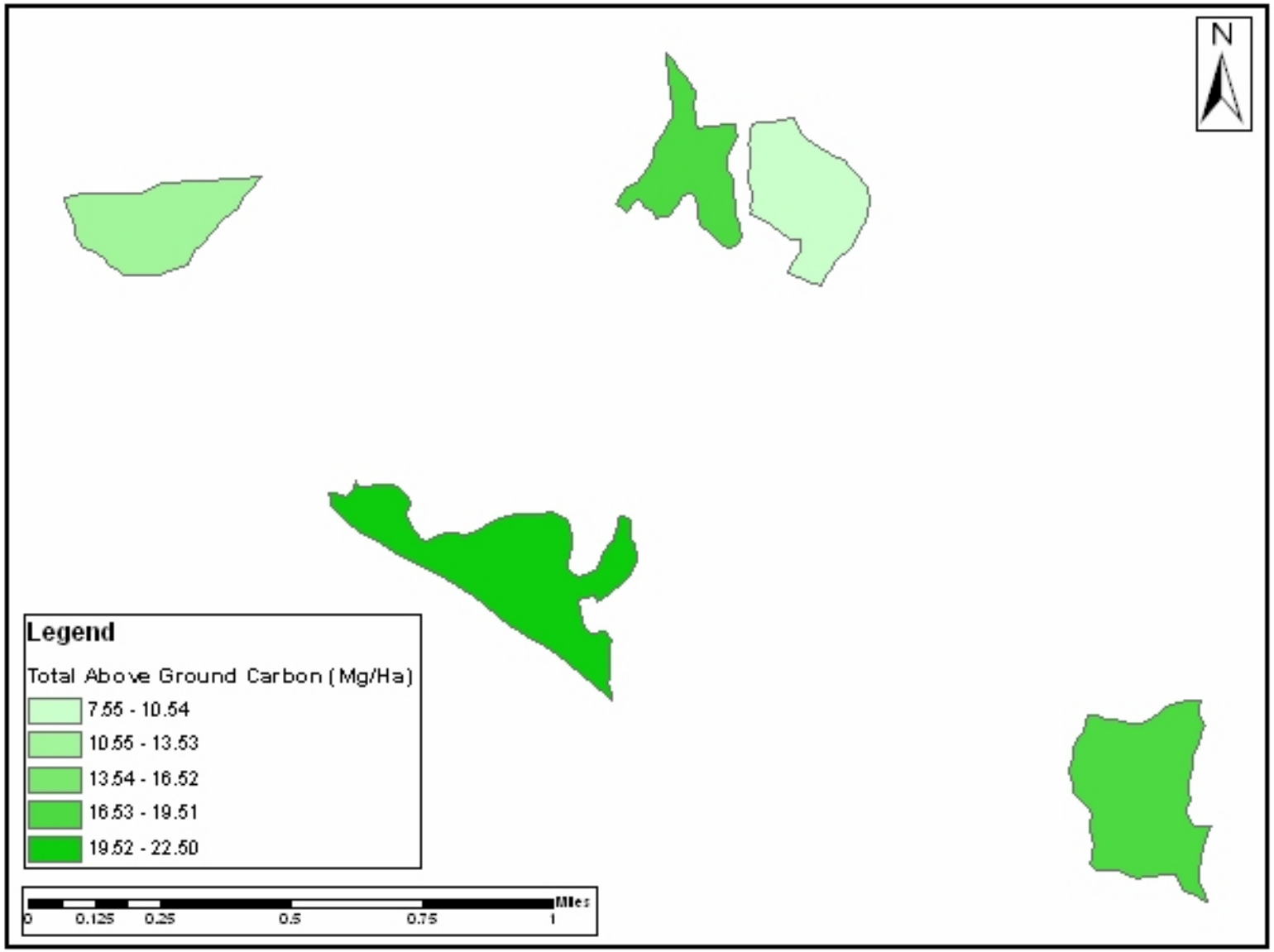
Stand Output



Biomass and Carbon Estimates

stemBM	branchBM	cRootsBM	fRootsBM	foliage2BM	foliage1BM	woodyDebBM
19.2	2.8	6.3	3	1.9	2	0.2
37.2	4.1	9.4	3.9	1.7	2	9.2
28.4	3.7	8.7	4	2.3	2.4	0.5
10.5	1.7	3.8	1.8	1.4	1.5	0.1
29.8	3.6	8.7	3.9	2.1	2.2	0.8

Biomass estimates for the stem, branches, coarse roots, fine roots, first and second cohorts of foliage, and woody debris are added to the stand's attribute table.

MgPerHa	TonsPerAc	Std_Acres	C_Mg	C_Tons
12.95	5.7768	27.284688	142.99001	157.618
22.5	10.0369	52.43351	477.42999	526.271
18.4	8.20796	22.960449	170.968	188.45799
7.55	3.36794	29.342438	89.652199	98.823601
18.85	8.4087	43.652428	332.995	367.06

Total above ground carbon estimates in Mg/Ha and Tons/Ac, stand acreage, and stand total above ground carbon in Mg and Tons are also added to the stand's attribute table.

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Water Quality

- Dr. Gene Yagow, VT BSE, program element lead
- Current Chesapeake Bay program nutrient trading guidelines already implemented
- Chesapeake Bay Watershed Model (CBWM) from EPA Chesapeake Bay Program selected
  - CBWM based on Hydrologic Simulation Program-Fortran (HSPF)
  - All watersheds in Chesapeake Bay watershed states to be included in 2010 assessment

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Water Quality

- Commonwealth of Virginia 305b reporting through 2008 has used the Generalized Watershed Loading Functions (GWLF) model with 6th order hydrologic units from the Nat'l Watershed Boundary Dataset
- GWLF model calibrated to CBWM; all VA modeled
- GWLF has some advantages for real-time simulation, including
  - daily vs. hourly (or shorter) time-steps
  - runoff and sediment loading factors

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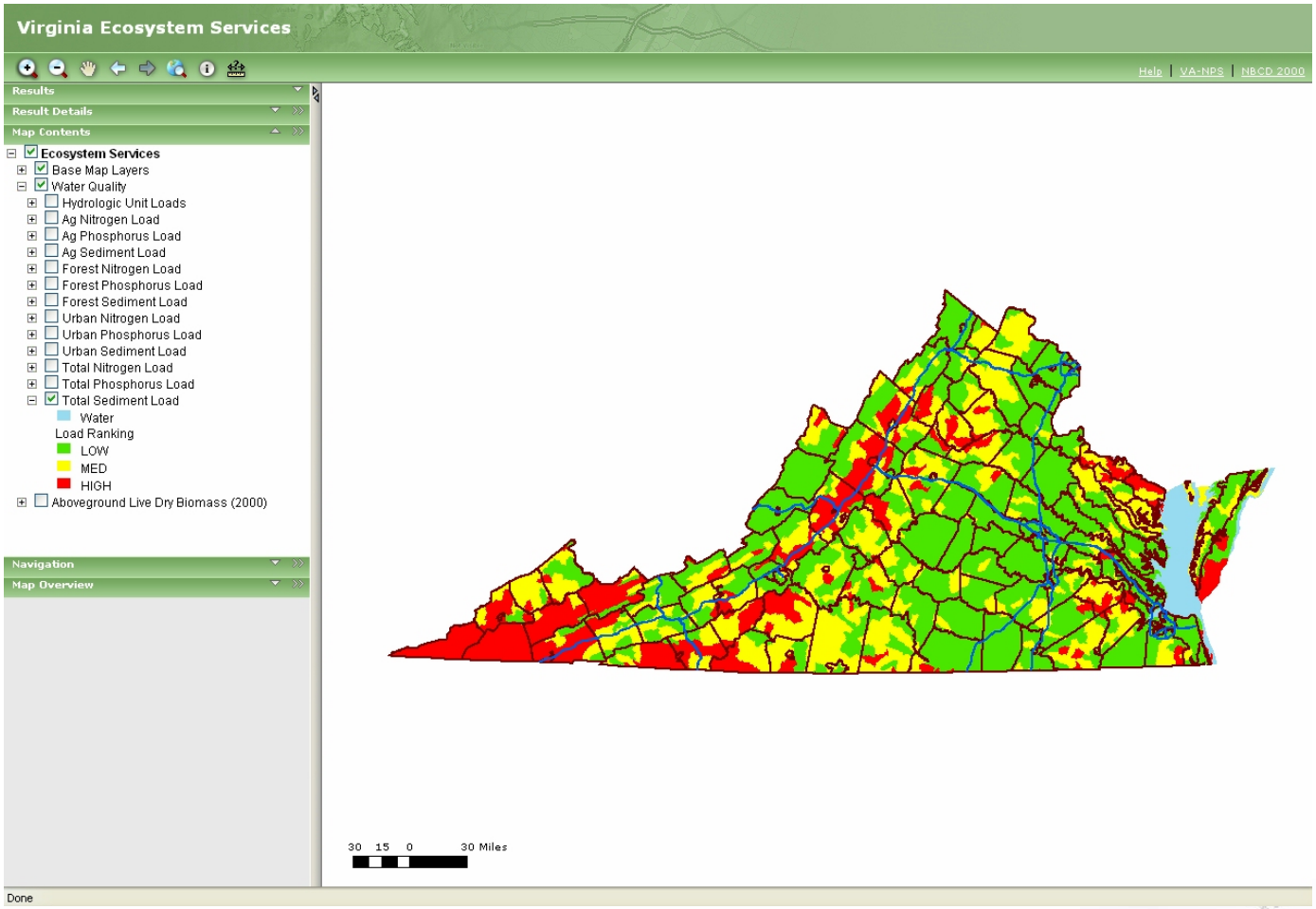
Web Application



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EcoServices Summary

- Web-based credit calculators designed for use by land owners, land managers, and planners
- Both land use (1st) and land management (2nd) scenarios supported
- Focus on tract-level information
- Bundled ecosystem services concept
- Best-of-breed modular model approach
- Field and remotely-sensed inputs

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Lessons for Team

- Time series analysis opens up wonderful opportunities for land use and land cover change, but important research issues remain
- Ecosystem function and resulting services as important as land use/cover, and requires a larger suite of products (LAI/fPAR, VIs, etc.)

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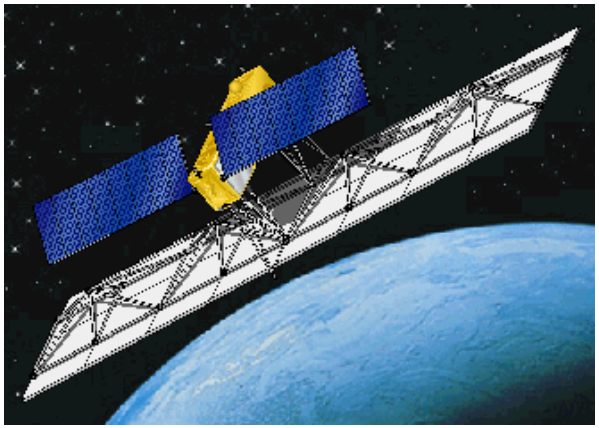
Thanks!



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Randolph H. Wynne