The MODIS Land Cover Suite of Products

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Land Cover Groups

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Land Cover Products

- Global Land Cover products
  - At- launch categorical depiction
  - Post-launch categorical depiction
  - Post-launch “continuous fields” depiction
- Land Cover Change
  - 250m land cover change *(primarily forcing by anthropogenic factors)*
  - 1km land cover change *(primarily inter-annual climate change forcing)*
  - Fire product.

Requirements for Land Cover Products

- Biophysical parameterization for GCM, carbon and hydrologic modeling.
- Monitoring change for models especially biogeochemical, carbon and hydrological models.
- Improvements of remote sensing products (e.g. related to BRDF).
- Input related to international conventions (FCCC, desertification, biodiversity).
- Provision of ecological information.

At-Launch Land Cover Categorical Product

- Essential for the creation of some MODIS land products.
- Based on the AVHRR 1 km data set created at the EROS Data Center.
- Two alternative products made available
  - 1) Product created by Loveland - (EDC)
  - 2) Product created by UMCP.
- Uses classification proposed by the IGBP
  - Categorizes land cover according to life-form, %cover and height.

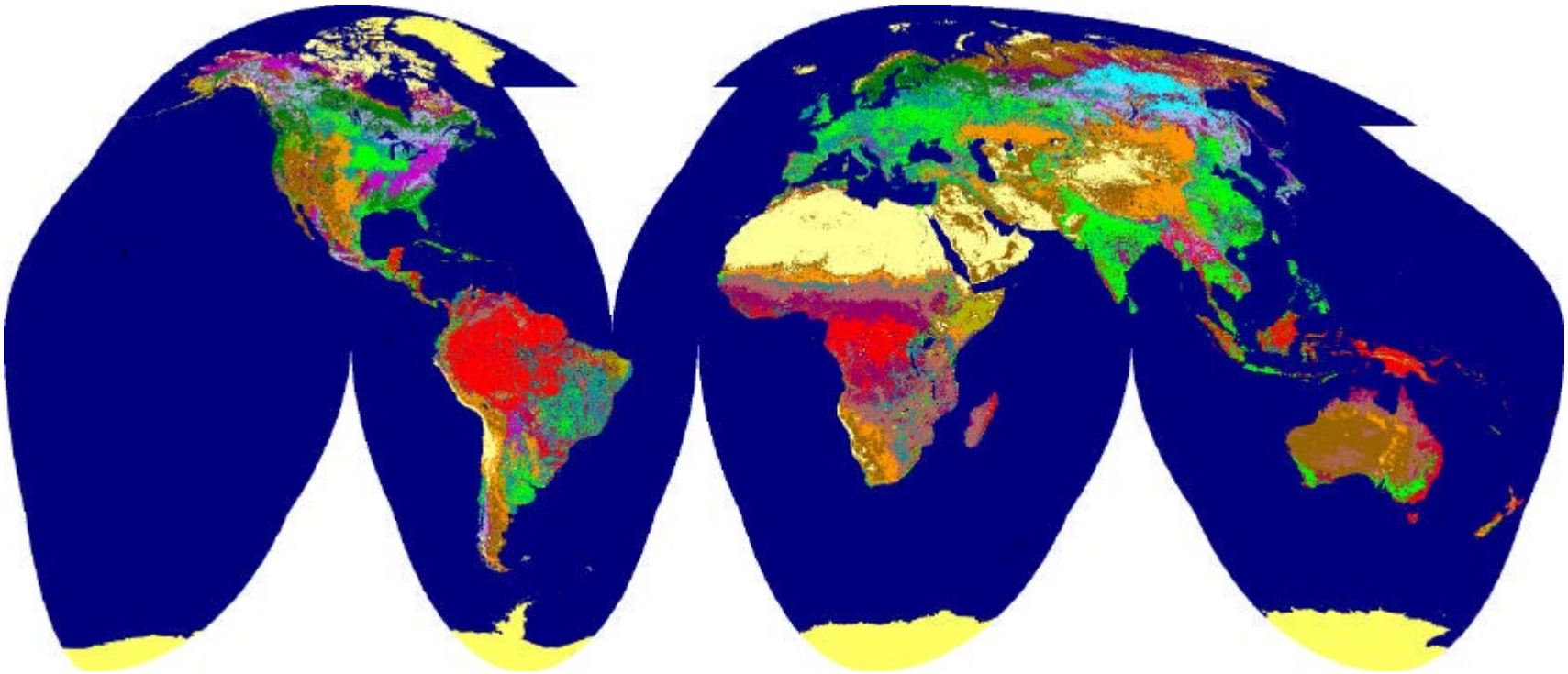
IGBP Land Cover Units (17)

- Natural Vegetation (11)
  - Evergreen Needleleaf Forests
  - Evergreen Broadleaf Forests
  - Deciduous Needleleaf Forests
  - Deciduous Broadleaf Forests
  - Mixed Forests
  - Closed Shrublands
  - Open Shrublands
  - Woody Savannas
  - Savannas
  - Grasslands
  - Permanent Wetlands
- Developed and Mosaic Lands (3)
  - Croplands
  - Urban and Built-Up Lands
  - Cropland/Natural Vegetation Mosaics
- Nonvegetated Lands (3)
  - Snow and Ice
  - Barren
  - Water Bodies

EDC Land Cover Categorical Product

- Uses Multi-temporal Vegetation Index properties alone.
- Unsupervised approach
- Incorporates much regional ancillary data
- Subjected to an objective statistical evaluation
  - (UCSB funded by NASA LCLUC)

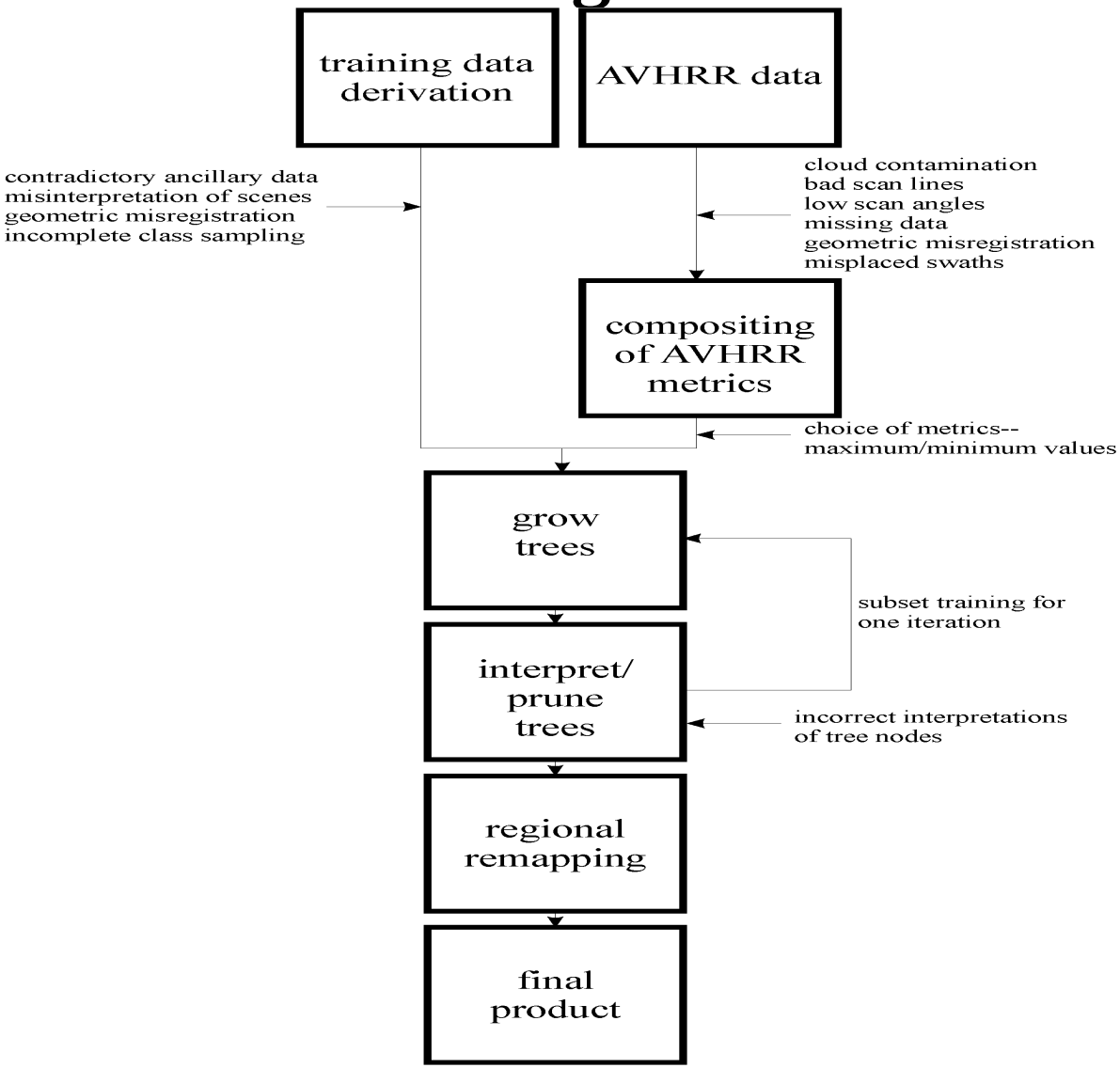
EDC 1km Land Cover Map



UMCP At Launch Product

- Decision-tree approach
- 41 metrics derived from twelve one-month composites of channels and the NDVI.
- Training via analysis and interpretation of high resolution sat. data with ancillary information.
- Entire globe processed simultaneously
- Simplified IGBP scheme of 13 classes.

Processing Stream



Accuracy of classification

- 1 km product
  - Mean class accuracy
    - Total training accuracy 69% (errors predominantly associated with woodland classes)
    - Excluding mixed forest 87%
- 8km product:
  - Overall accuracy
    - Reserved part (20%) of training data - 81.4%
    - Upper limit using training data - 90.3%
  - Mean accuracy
    - Reserved part (20%) of training data - 79.3%
    - Upper limit using training data - 86.9%

Post-launch land cover product

- Based at Boston University
- Relies on advanced classifier technologies
  - Neural nets
  - Decision-trees
- Uses data from spectral, spatial temporal and directional domains (from other MODIS products).
- Uses a network of global test sites for algorithm calibration and validation.

The Land Cover Input Database

- ***Surface Reflectance***
  - View-angle corrected (nadir) surface reflectance, 7 land bands
- ***Spatial Texture from 250-m Band 2***
  - Standard deviation-to-mean ratio in Band 2 (near-infrared), maximum value composite in 32-day period
- ***Vegetation Index***
  - MODIS Vegetation Index, maximum value composite
- ***Snow Cover***
  - MODIS Snow Cover Product, number of days with snow cover
- ***Land Surface Temperature***
  - MODIS Land Surface Temperature, maximum value composite
- ***Directional Information***
  - Bidirectional reflectance ratios for vegetation structure
- ***Ancillary Data***
  - DEM, Land/Water mask

Two-Stage Processing Strategy

- Monthly (32-day) Database Assembly Program
  - Reads and processes spectral, spatial, directional inputs for each 32-day month
    - 32-day period = two 16-day, four 8-day cycles of MODIS input products
- Annual (384-day) Classification Program
  - Reduces data volume by retaining only selected features
  - Classifies using advanced technology classifiers
  - Runs every three months (96 days) on 384 days of data to provide a quarterly updated product
  - Classifier training and processing proceeds by continents

Advanced Technology Classifiers

- Fuzzy ARTMAP Neural Network
  - Uses Adaptive Resonance Theory (ART) in building network
  - Nonlinear partitioning of measurement space
  - Significantly outperforms backpropagation algorithms
- Decision Tree
  - Rectangular partitioning of measurement space
  - Uses C5.0 algorithm
- Hybrid “Expert” Decision
  - Multiple classifiers “vote” to make the final decision
  - Uses neural net, decision tree, and possibly maximum likelihood classifiers as voters

Training/Test Sites

- Global Training/Test Site Network
  - By continents/regions: Central America, North America, South America, Africa, Eurasia, Australia
  - Present status (12/10/98):

	Sites	TM Images
Central America (completed)	428	18
North America (completed)	1050	78

- Global Confidence Site Database
  - Random stratified sample of IGBP Land Cover Product provides a global database of 400 30-by-30-km TM or SPOT images
  - Polygons (training/test sites) labeled and characterized by local experts
  - Allows early preparation of global land cover training/test database while continents/regional data are being acquired

STEP Database

- Test Site Database
  - Homogeneous polygons delimited on TM or SPOT imagery
  - Projected to MODIS sinusoidal grid
  - Parameterized using STEP: System for Terrestrial Ecosystem Parameterization
- Key STEP Parameters
  - Life form, height, and cover fraction of one or two layers
  - Leaf type, phenology, periodicity, physiognomy of dominants in layers
  - Elevation, moisture regime, perturbation
  - Classifications encoded
    - IGBP–17 classes for global modeling
    - VEGCLASS: 40-class physiognomic-structural classification for ecology and conservation use
    - EDC Seasonal Land Cover Regions (SLCRS)

North America Prototype

- Prototype Classification of North America
  - 1050 training sites from 78 TM scenes
  - 1995 AVHRR NDVI Maximum Value Composite (MVC) data
  - March and August split-window temperature
  - Decision tree classifier using C5A algorithm set for maximum generalization
  - All data are processed in integerized sinusoidal (MODIS) grid
  - Automated classification procedure using PERL scripts; no postprocessing, filtering or recoding
- limitations
  - multiple data dropouts, especially in polar regions
  - registration needs improvement in some areas

MODIS 250m Land Cover Change Product

- Detects land cover changes caused by human activities or extreme natural events, such as deforestation, agricultural expansion or contraction, urbanization, inundation, flood receding and burn scars;
- Serves as an alarm system of the typical land cover changes around the globe;
- Will be generated for changes in the past three months and the past year.

Change Detection Algorithms

- Uses the surface reflectance information of the MODIS two 250m resolution bands;
- Adopts mutiple algorithms for more confidence in the detected changes:
  - *Red-NIR space partitioning method;*
  - *Red-NIR space change vector method;*
  - *Modified Delta space thresholding method;*
  - *Texture change detection;*
  - *Linear feature change detection.*

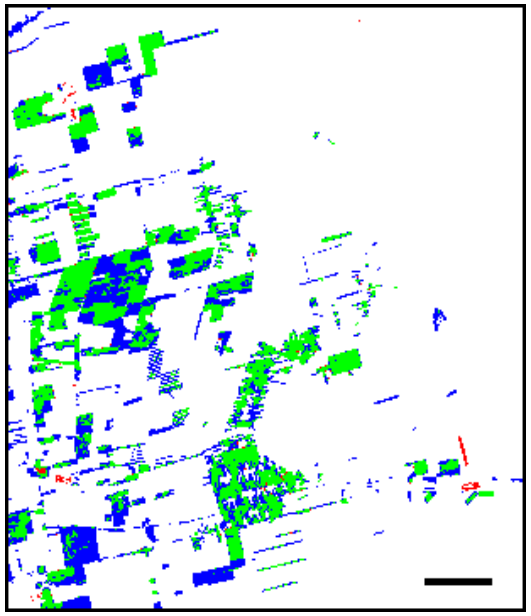
Change Detection Algorithms (Continued)

- Implemented with Look-Up Tables (LUTs) for different zones of the globe to consider the phenological differences:
  - *LUTs of thresholds for each of the five methods*;
  - *LUTs generated with available AVHRR data;*
  - *LUTs for integrating the results from the methods;*
  - *LUTs for the global zoning (curr., 4 zones).*
- Tested with a dozen pairs of MODIS resolution data simulated from Landsat TM images.

Algorithm Testing and Validation

- Algorithm testing data are MODIS resolution images simulated from pairs of Landsat TM images;
- Land cover changes in these image pairs include:
  - *Tropical deforestation (Bolivia, Brazil);*
  - *Agricultural expansion (Egypt);*
  - *Urbanization (DCMA, Charllote, Shanghai);*
  - *Burn scars (Yellowstone);*
  - *Flood receding (Manaus).*

Tropical Deforestation in Santa Cruz, Bolivia



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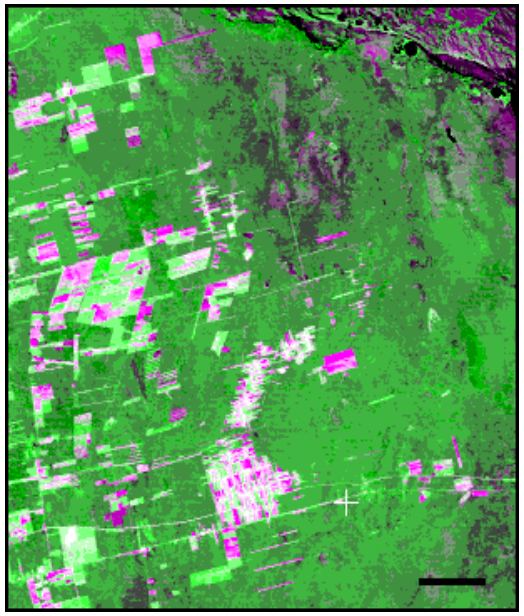

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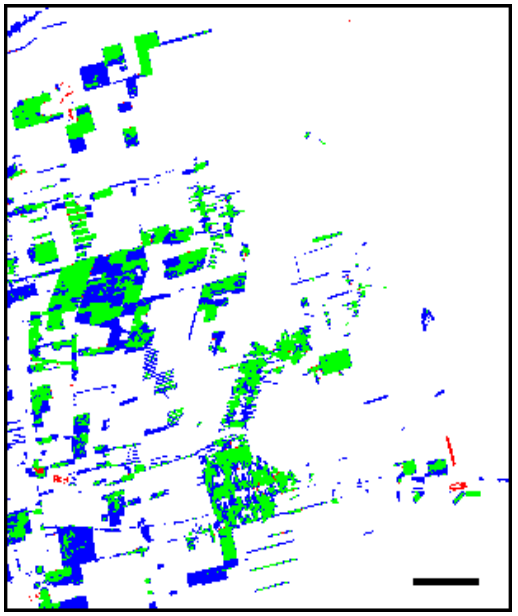


Map of Detected Changes

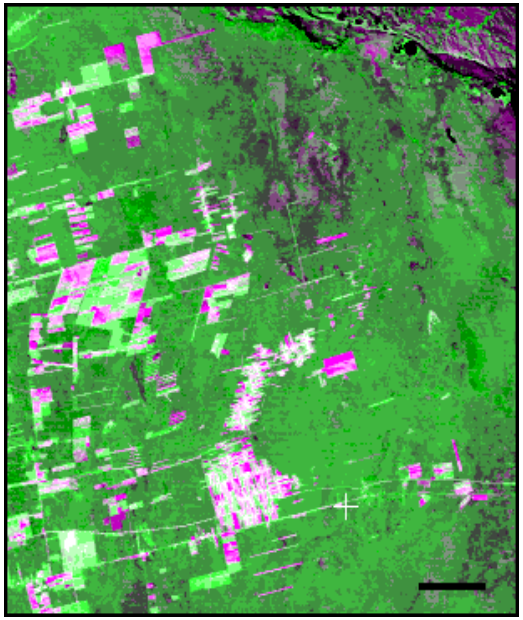
Green: Correct

Red: Commission error

Blue: Omission error

Black bar is 10 km

Agricultural Expansion in Northern Egypt



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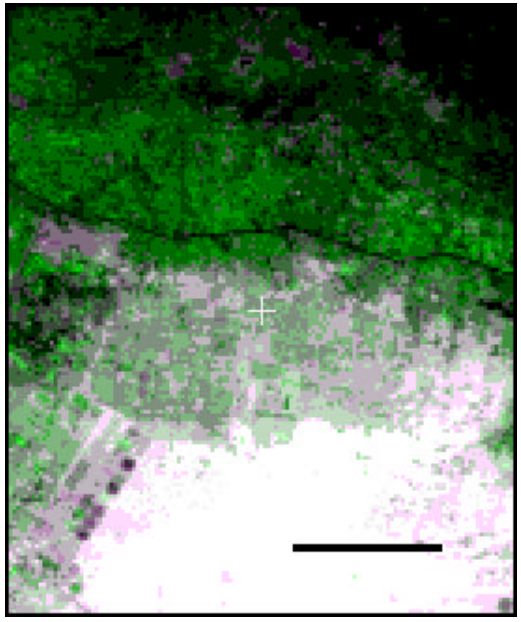

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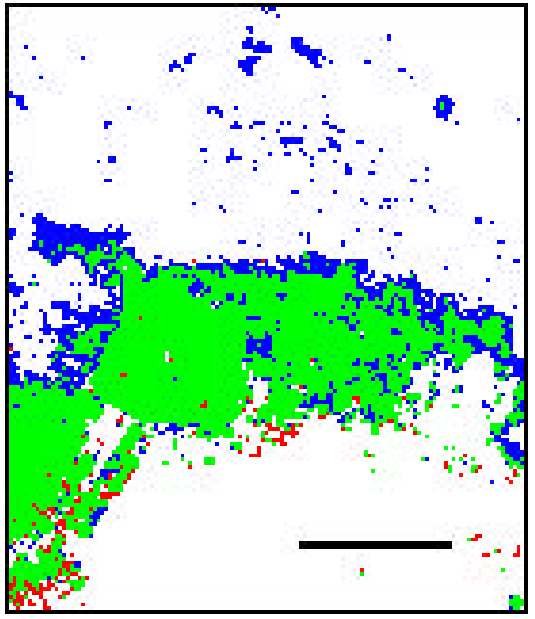


Map of Detected Changes

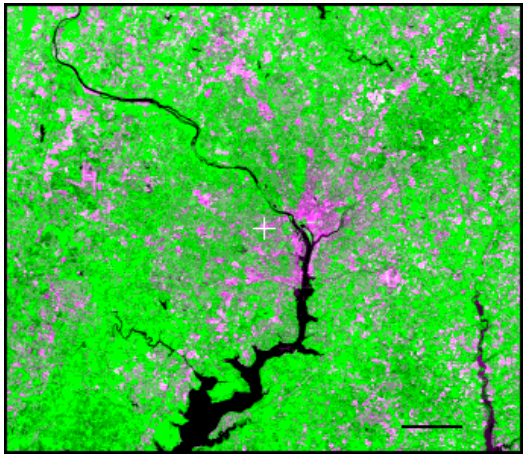
Green: Correct

Red: Commission error

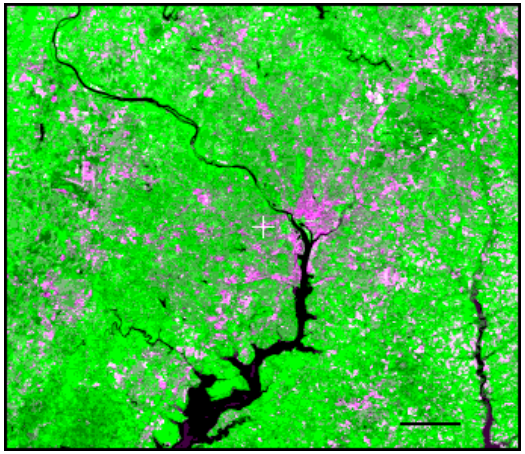
Blue: Omission error

Black bar is 10 km

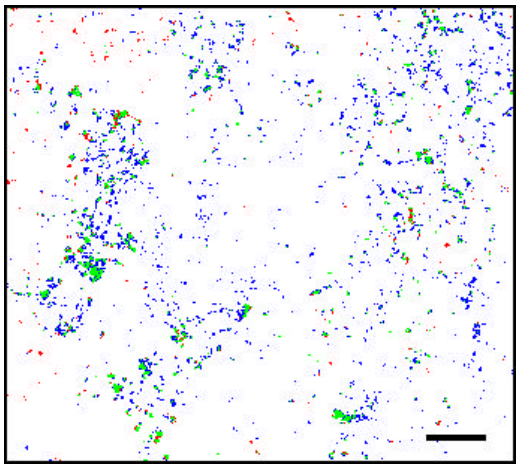
Urban Growth in DC Metropolitan Area



May 1985



May 1990



Map of Detected Changes

Green: Correct

Red: Commission error

Blue: Omission error

Black bar is 10 km

Accuracy of the Change Detection Method

Data Set	Commission Error [%]	Omission Error [%]
Bolivia	**3**	**49**
Egypt	**5**	**28**
Washington, DC	**27**	**69**

MODIS Vegetation Continuous Fields Product

- Depict gradients and mosaics in landscape;
- Capture spatial heterogeneity in vegetation;
- Data layers estimate proportional cover of vegetation characteristics;
- Based on linear mixture modeling;
- Will be generated annually at 500m resolution.

Continuous Fields Algorithm

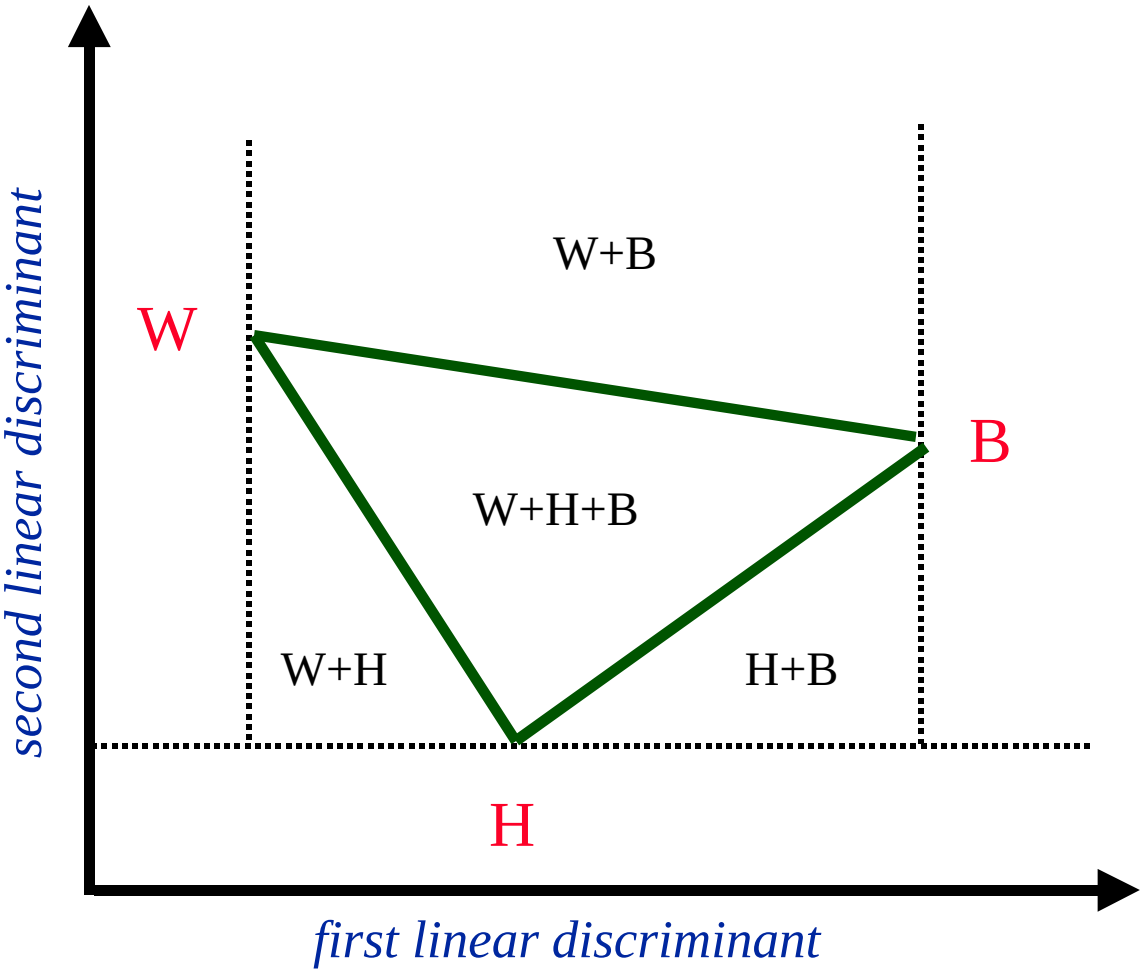
$$\begin{cases} \boldsymbol{r_{1w}}\, x_w + \boldsymbol{r_{1h}}\, x_h + \boldsymbol{r_{1b}}\, x_b = \boldsymbol{R_1} \\ \boldsymbol{r_{2w}}\, x_w + \boldsymbol{r_{2h}}\, x_h + \boldsymbol{r_{2b}}\, x_b = \boldsymbol{R_2} \\ x_w + x_h + x_b = \mathbf{1.0} \end{cases}$$

$\boldsymbol{R_1}$ & $\boldsymbol{R_2}$ -- Pixel values of linear discriminant 1 & 2;

$\boldsymbol{r_{1w}}$, $\boldsymbol{r_{1h}}$, $\boldsymbol{r_{1b}}$, $\boldsymbol{r_{2w}}$, $\boldsymbol{r_{2h}}$ & $\boldsymbol{r_{2b}}$ -- Linear discriminant 1 & 2 values for endmembers: woody, herbaceous vegetation and bare ground;

x_w , x_h & x_b -- Fractional coverage of woody, herbaceous vegetation and bare ground.

Continuous Fields Algorithm (Continued)



USING REMOTE SENSING TO ESTIMATE TREE COVER AND CARBON STOCKS IN FORESTS

The Issue

Article 3.3 of the Kyoto Protocol to the United Nations Framework Convention on Climate Change states that:

"The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8."

Operational implementation of this article will require accurate baseline values and accurate monitoring of carbon stocks in the Land Use Change and Forestry Sector, raising a number of fundamental questions:

- What is the spatial extent of forest cover in Annex I parties using a consistent definition of "forest?"
- What carbon stocks are contained in forests, and how do changes in the spatial extent of forests affect those stocks over time?
- How can the spatial extent of forests – and afforestation, reforestation, and deforestation – be routinely, accurately, and transparently monitored?

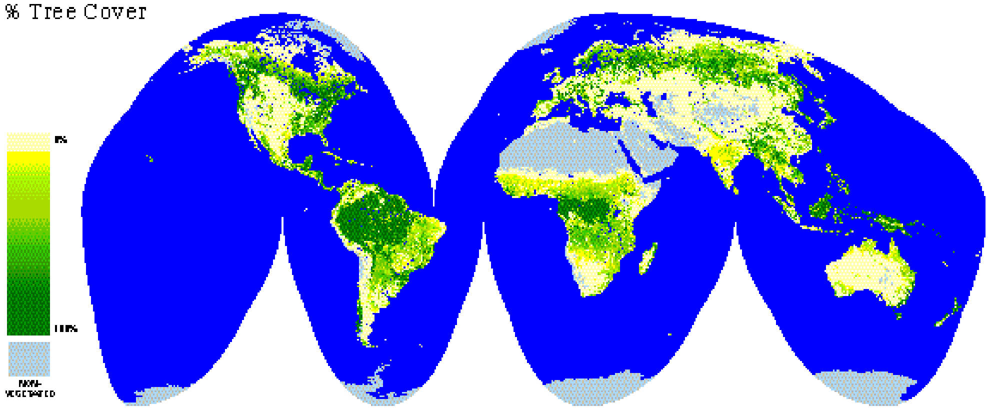
Contribution of Remote Sensing to Determining Tree Cover

Data acquired by the U.S. National Oceanic and Atmospheric Administration's polar-orbiting weather satellite enable an estimation of percent tree cover for each 1 square kilometer cell of a global grid*. Information on percent tree cover supplements country-level statistics on forest cover compiled by the United Nations Food and Agriculture Organization. Because "forest" can be defined according to different thresholds of percent tree cover, a global representation of percent tree cover enables estimates of carbon stocks to be based on a more consistent definition of forest. Furthermore, spatially explicit data on forest cover in conjunction with climatic and other biophysical data are required for models that estimate carbon stocks. In addition to percent tree cover, remote sensing data also enable estimates of leaf type (needleleaf or broadleaf) and leaf longevity (evergreen or deciduous) which are required to estimate carbon stocks.

The Future for Remote Sensing of Forests and Land Cover Change

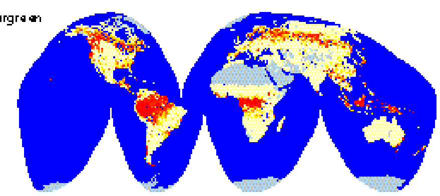
New satellites from NASA's Earth Science Enterprise program, with improved capabilities and higher spatial resolution, will enable scientists to identify land cover change and to more accurately determine forest extent in areas with fragmented forests. Several national and international activities are underway for using remote sensing to assess forest extent and land use change, including the Committee on Earth Observation Systems pilot project on Global Observations of Forest Cover and NASA's upcoming launches of Landsat 7 and the Earth Observing System.

% Tree Cover

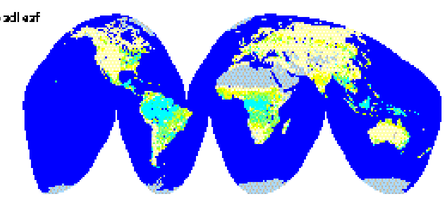


[illegible]

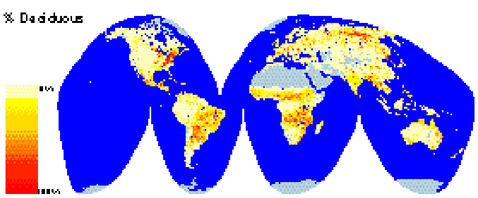
% Evergreen



% Broadleaf

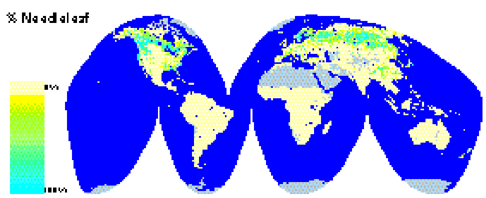


% Deciduous



[illegible]

% Needleleaf



[illegible]

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Acknowledgments

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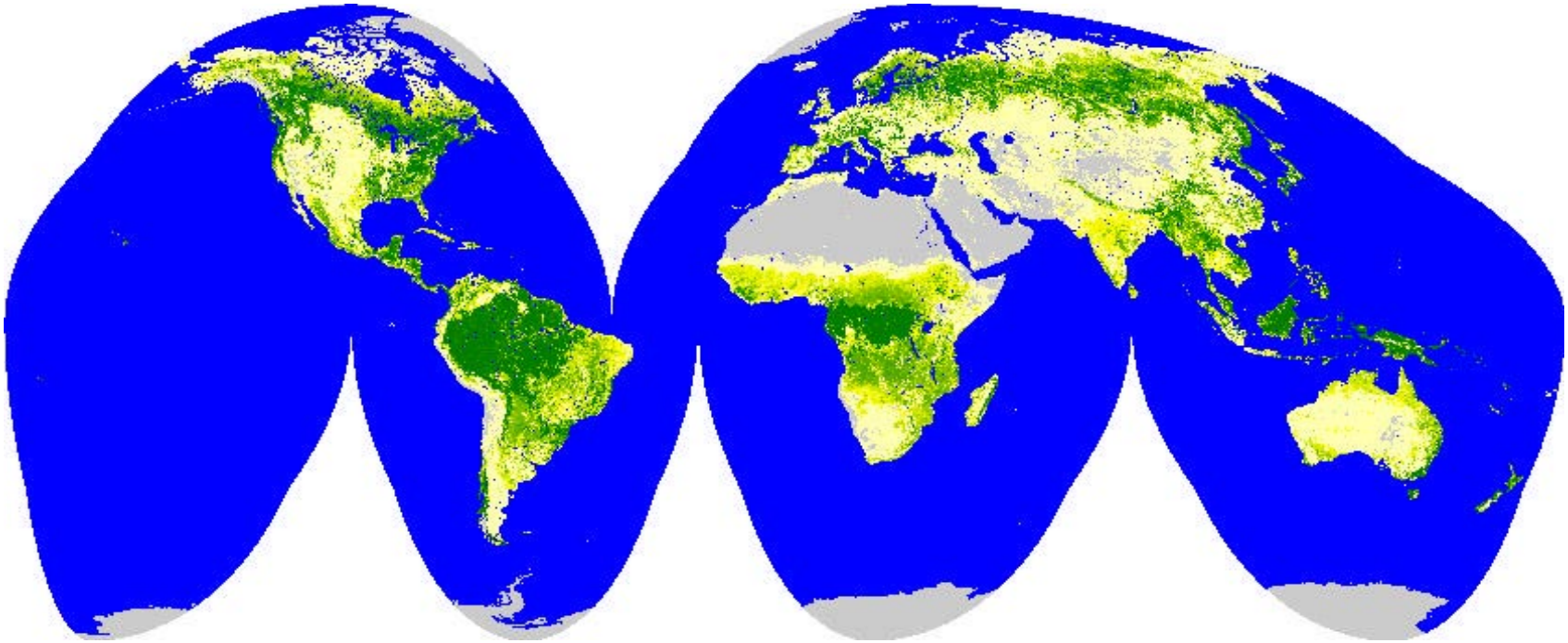
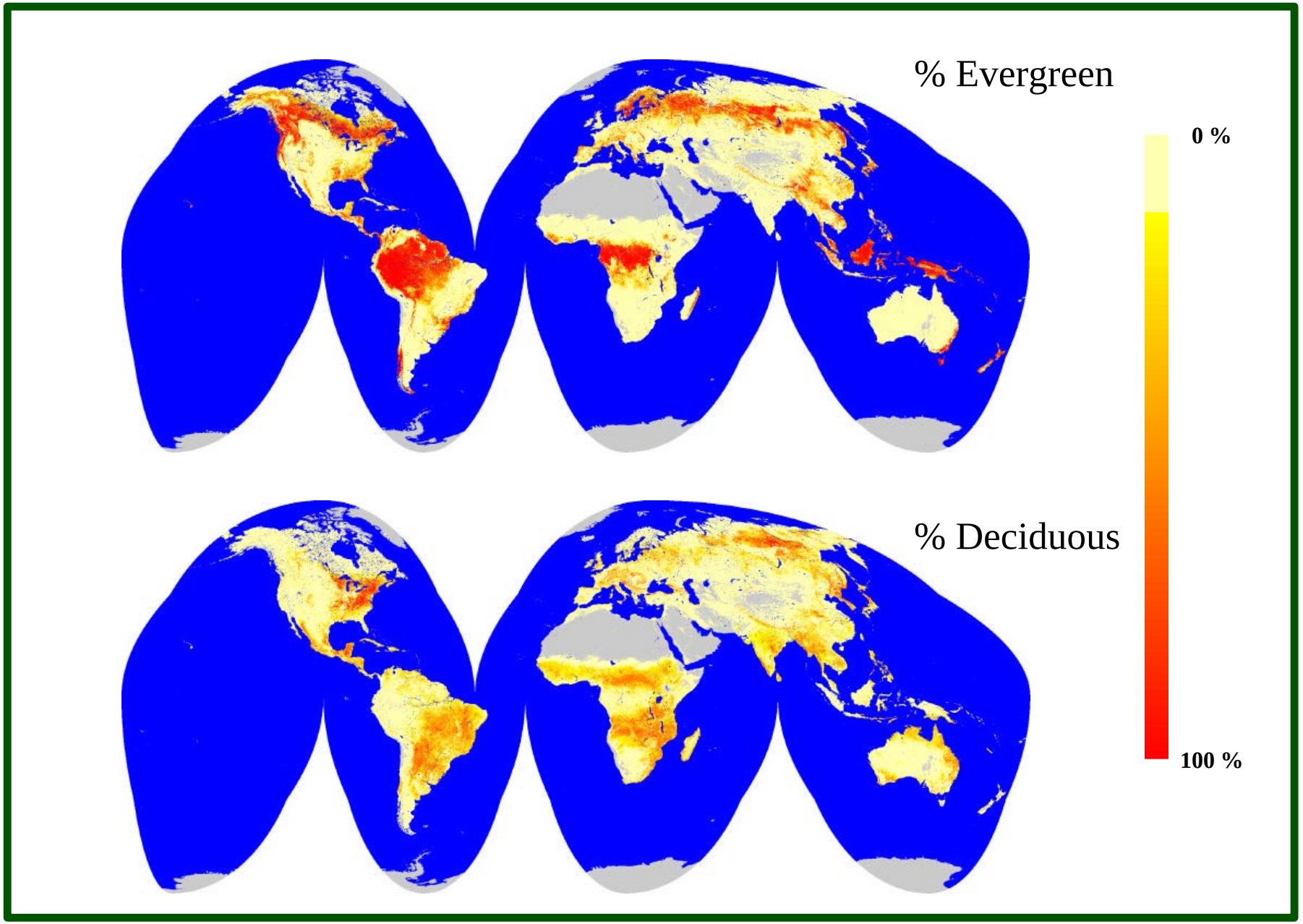
Copies available at:

http://glcf.umiacs.umd.edu

Global Tree Cover Maps



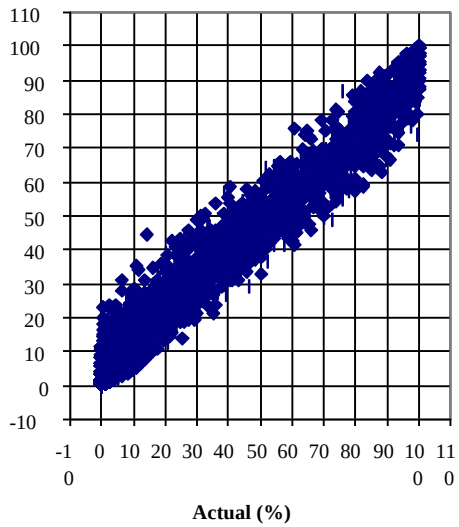
0% 100 %


% Evergreen
% Deciduous
0 %
100 %

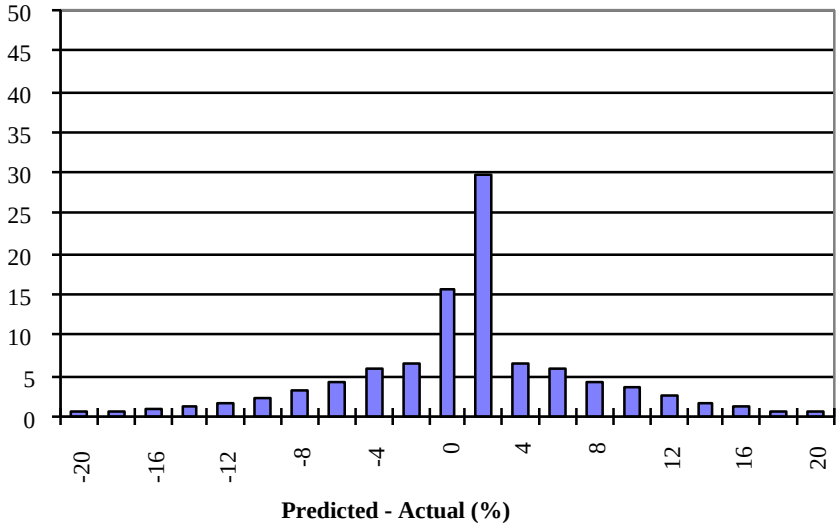
Simulation test of mixture modeling

- Ground-based estimates of mixtures very time-consuming
- Created landscape solely with pure TM pixels using actual land cover units.
- Degraded scene with MODIS MTF.
- Derived estimates of mixtures
- Images deconvolved using approximation to MTF.

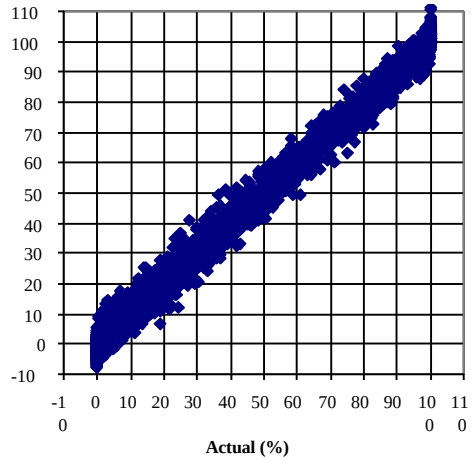
Impact of MODIS MTF on land cover percentage (250m)



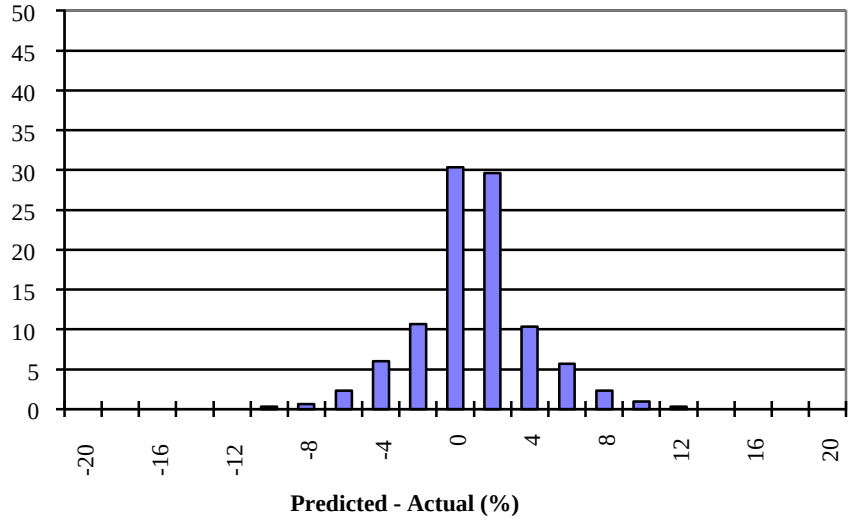
Distribution of the deviation of mixture model predicted from actual land cover percentages (MTF applied, 250m)



Impact of deconvolved MODIS MTF on land cover percentage (250m)



Distribution of the deviation of mixture model predicted from actual land cover percentages (MTF deconvolved, 250m)



90% confidence intervals of MODIS MTF simulated, deconvolved images and subsequently derived land cover percentages

Pixel size (m)	B1 (DN)	B2 (DN)	B3 (DN)	B4 (DN)	B5 (DN)	B7 (DN)	Land Cover Percentage (%)
250, averaged	0.00	0.00	0.01	0.01	0.01	0.00	0.01
250, MTF	3.19	2.99	5.08	2.97	4.58	2.13	11.00
500, aggregrated from above	1.19	1.14	1.93	1.03	1.68	0.80	4.16
250, MTF deconvolved	1.44	1.40	2.38	1.20	2.01	0.97	5.11
500, aggregated from above	0.62	0.63	1.06	0.44	0.85	0.42	2.24

Post launch research in continuous fields

- AVHRR is a very inadequate precursor in providing data to develop unmixing procedures
- Using SeaWifs products currently to improve methods.
- Will also examine changes in continuous fields as a method of land cover change detection.

Continuous Fields Product Validation

- Will be validated with high resolution airborne data (photographs, MAS);
- Several transects proposed for airplane flights:
  - *The Appalachian transect;*
  - *The African SAFARI transects;*
- Existing NAPP orthophotos:
  - *eg. Gloucester, VA Digital Orthophoto Quad*

UMD work with CASA

- continuous fields of vegetation characteristics with AVHRR Pathfinder for 1982-94;
- use of continuous fields in CASA;
- estimates of carbon emissions and NPP with land use change from CASA.

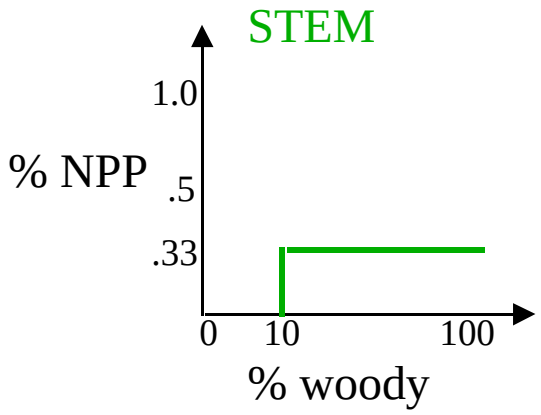
Possibilities For Using Continuous Fields In CASA

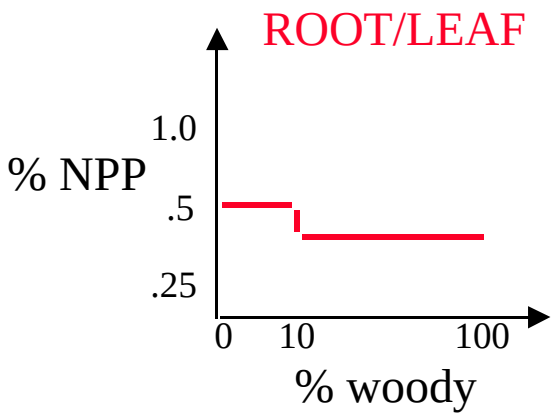
- revise scheme for allocating NPP to leaf, stem, root
- revise FPAR calculations

$$FPAR = \%woody(FPAR_{woody}) + \%herb\ (FPAR_{herb})$$

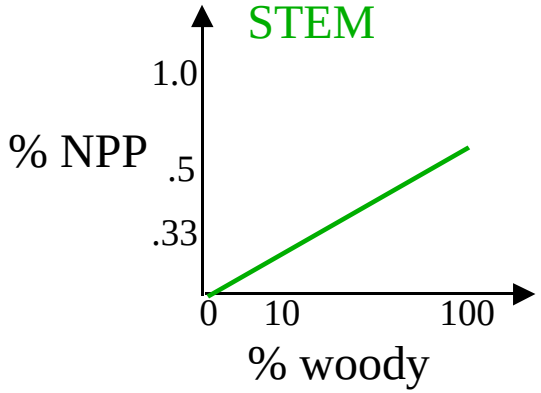
- make light use efficiency f(%woody)

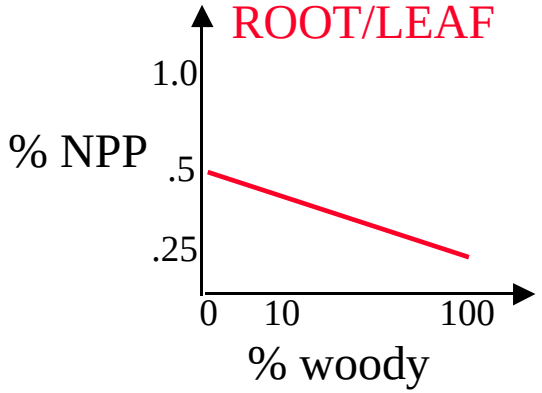
WITH LAND COVER CLASSES:

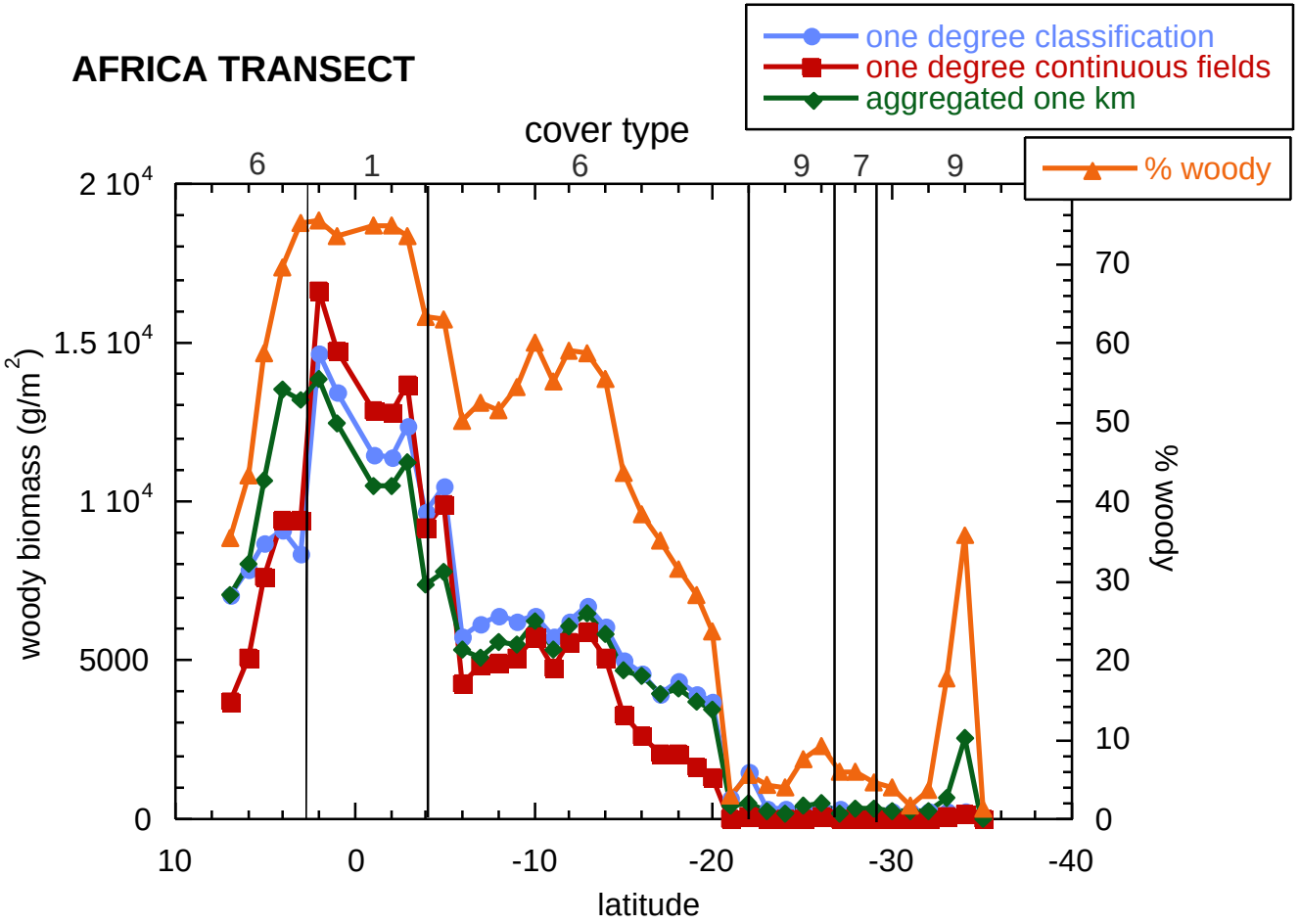




WITH CONTINUOUS FIELDS:

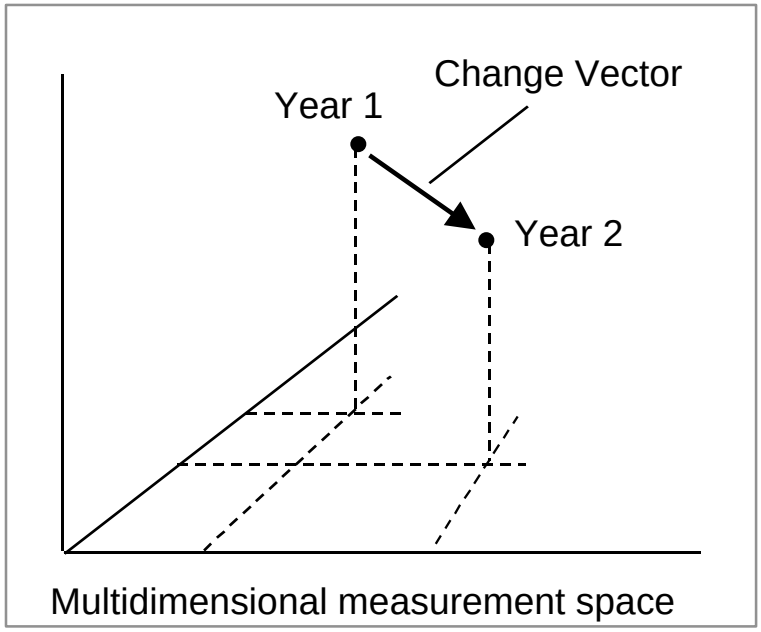





AFRICA TRANSECT
one degree classification
one degree continuous fields
aggregated one km
% woody
cover type
6
1
6
9
7
9
2 10^4
1.5 10^4
1 10^4
5000
0
woody biomass (g/m^2)
70
60
50
40
30
20
10
0
% woody
10
0
-10
-20
-30
-40
latitude

MODIS 1km Land Cover Change (Boston University)

- Change-Vector Analysis
  - Time-trajectory of each pixel through a year taken as a point in multidimensional measurement space
  - Change vector quantifies distance and direction of change



Compared to previous year or to a historical reference standard ("*e.g.,* best year")

Characterizes interannual variability

– Identifies abrupt change

– 1-km spatial scale

– Uses 32-day input database from land cover product

Land-Cover Change Indicators

- Prelaunch work focuses on NDVI, surface temperature (Ts) and the Ts/NDVI ratio

- When MODIS data available, NDVI to be replaced with U. of Arizona VI data; surface texture and BRDF information also to be added

Reference Standard

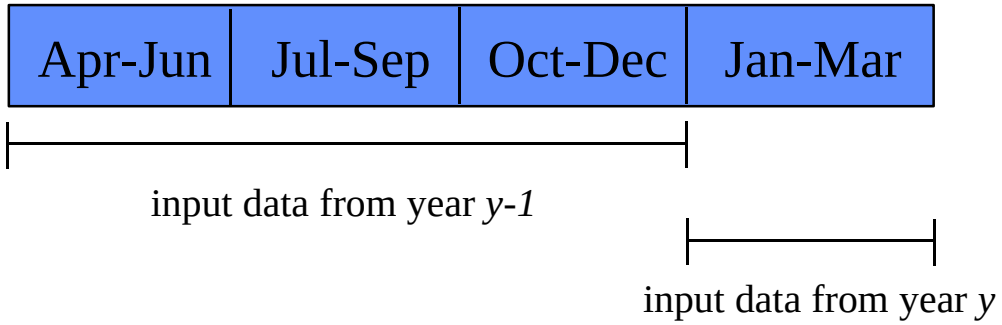
- Reference values used to identify deviations from baseline conditions

- Generated as a 12-element vector on a per-pixel basis consisting of the land-cover indicator values that correspond to the most favorable vegetation conditions for each of the 12 months *over the entire period of record*
  - For NDVI, these are maxima
  - For Ts and the Ts/NDVI ratio, these are minima

Quarterly Change Vectors

- Change vectors generated every 3 months from 12 most recent 32-day databases, resulting in a "rolling" database of change information, *e.g.*

Product generated in first quarter of year *y*



Quarterly Change Vectors (cont.)

- Quarterly time step allows earlier detection of interannual variability than annual time step

- Prototype produced from Pathfinder AVHRR Land (PAL) data collected over Africa
  - Illustrates effects of the ENSO warming of 1982-1983
  - Entire period of record covers 1981-1991

Quarterly Change Vectors (cont.)

- The four images depict change vector magnitudes generated from the fourth quarter of 1983 through the third quarter of 1984
- Bright tones indicate high degrees of change
  - Southern Africa and Morocco were subjected to severe droughts during this time period, especially during the first half of 1983
  - The Sahel and coastal West Africa experienced drought throughout 1983
- Dark tones indicate optimal and/or stable conditions
  - Dem.Rep. of the Congo and Western Namibia experienced optimal conditions
  - The Sahara was stable over the entire time series

Science Rationale for the MODIS Fire Products

Significance of Fire:

- An important source of trace gas and particulate emissions;
- A proximate cause / indicator of land cover change;
- An important biogeochemical process with a major role in the carbon and nitrogen cycles;
- An important ecological disturbance regime;
- Fire frequency can be expected to change with climate change and variability;
- Use of fire is a major land management practice in tropical systems;
- Fire frequency will change with population dynamics;
- Fire can be a natural hazard with large societal costs and impacts.

The MODIS Fire Products

- Active Fires (Justice, Giglio, Kaufman, Fisher)

– Intermediate Products (3 month archive)

- L2 orbit granules @ 1km
- L2G daily per tile @ 1km

– L3 Products (sent to EDC for distribution)

- Daily Product (day and night) @ 1km
- 8 day composite @ 1km
- Fire Characteristics (Kaufman, Wald)

– L3 CMG (sent to EDC for distribution)

- monthly composite @ 10km
- monthly composite @ .5 degrees
- Burned Area (Justice, Roy, Giglio)

– L3 Postlaunch

- 16 day composite @ 1km
- Fire / Volcano Alert (Flynn)

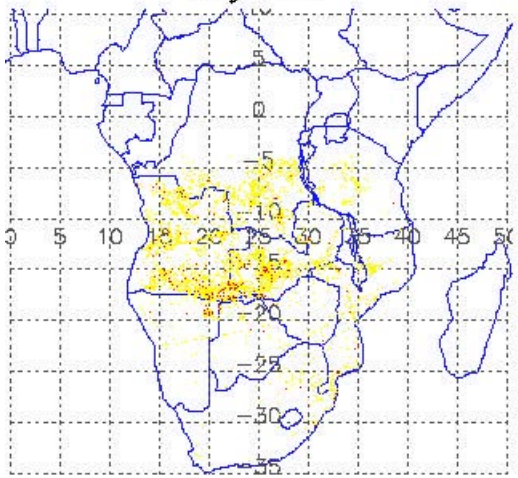
MODIS Fire Prototyping

- Active Fire Detection
  - AVHRR (daily fire occurrence, climatology)
  - GOES (diurnal cycle studies)
  - MAS (spectral characteristics)
- Fire Characteristics
  - MAS (energy estimation for prescribed fires)
  - Lab measurements (energy and gas measurements)
- Burned Area
  - AVHRR 1km (GIMMS/ MODIS)
  - ATSR (JRC / ESA product development)
  - Landsat TM

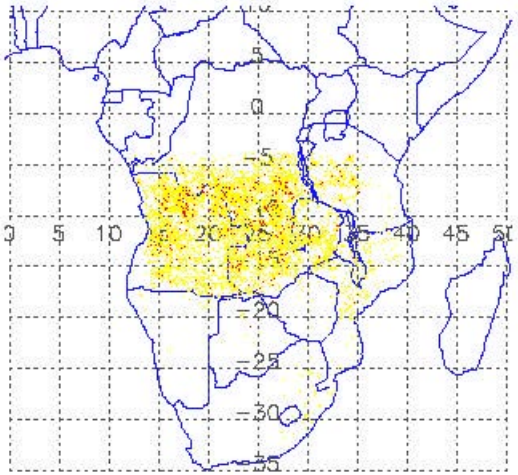
AVHRR Prototype Fire Product

Southern Africa

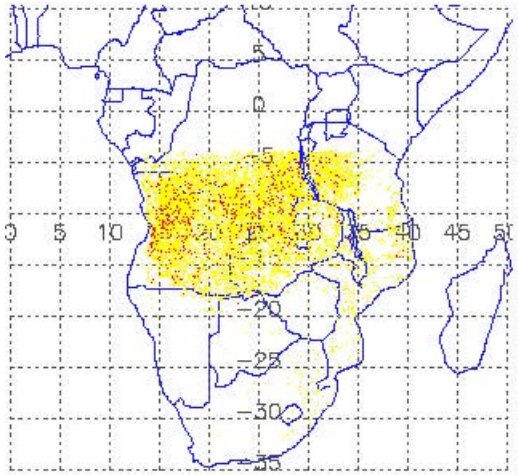
May 1992



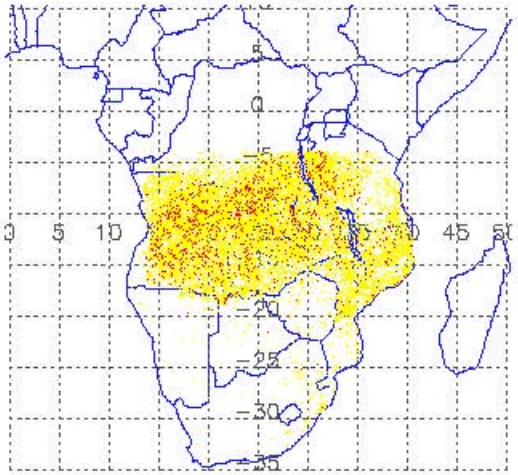
June 1992



July 1992

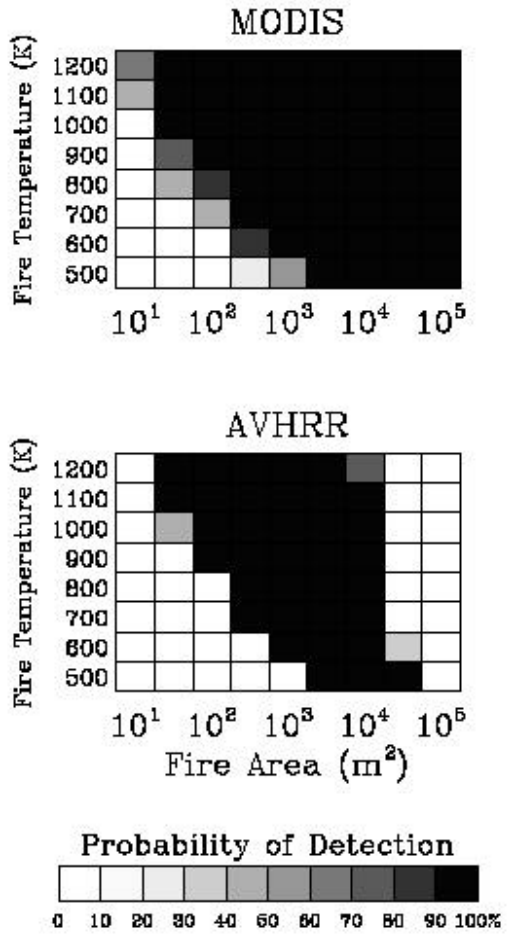


August 1992



MODIS Fire Preliminary Simulation Results

Tropical Rainforest Biome



Multitemporal active-fire based burn-scar algorithm

Burned areas are characterized by

- the removal of vegetation and alteration of its structure
- deposits of charcoal and ash
- exposure of the soil layer

these vary temporally and spatially because of variations including

- the type of vegetation that burns
- the completeness of the burn
- the rate of charcoal and ash dissipation by the elements
- the post fire evolution and revegetation of the burned area

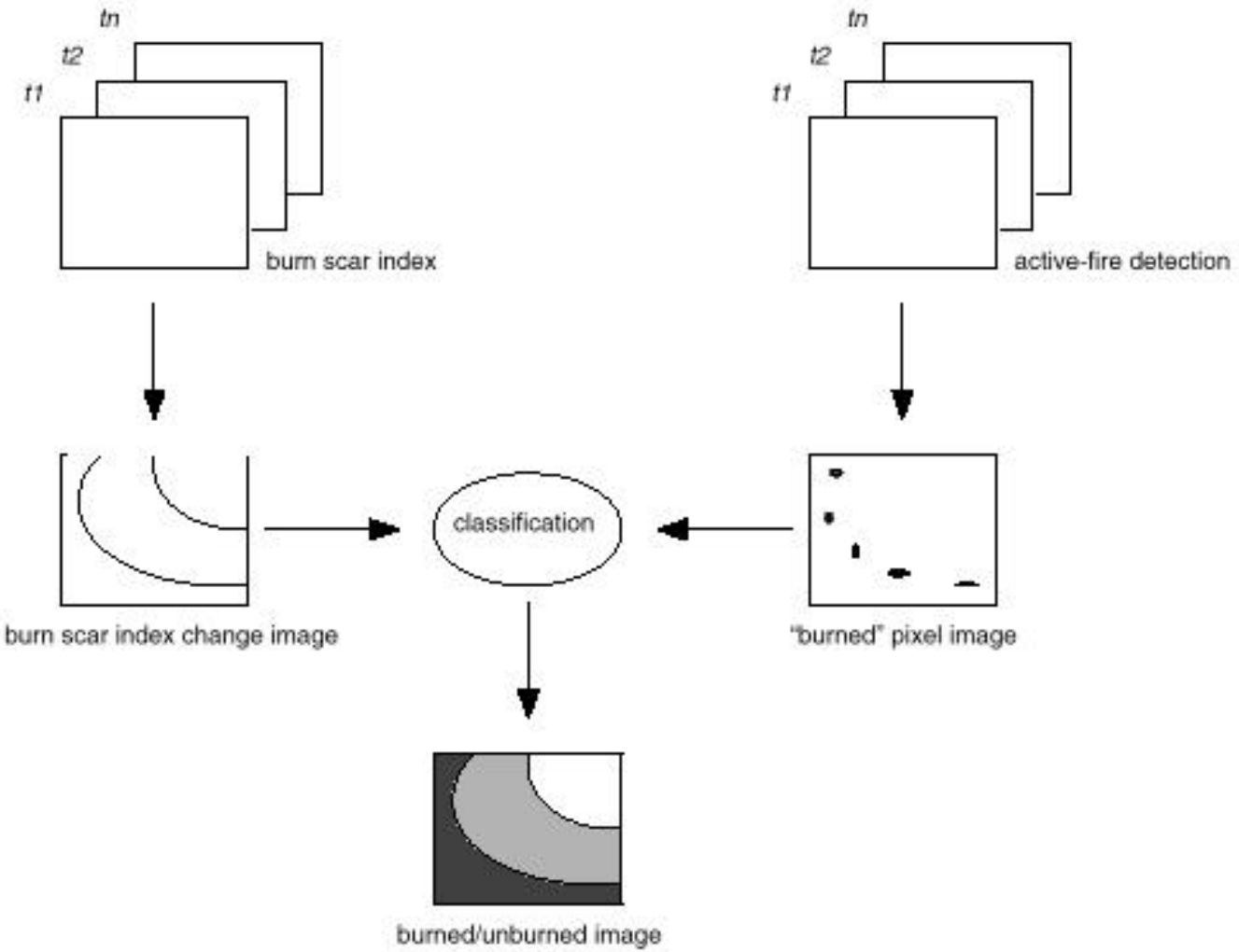
Multitemporal:

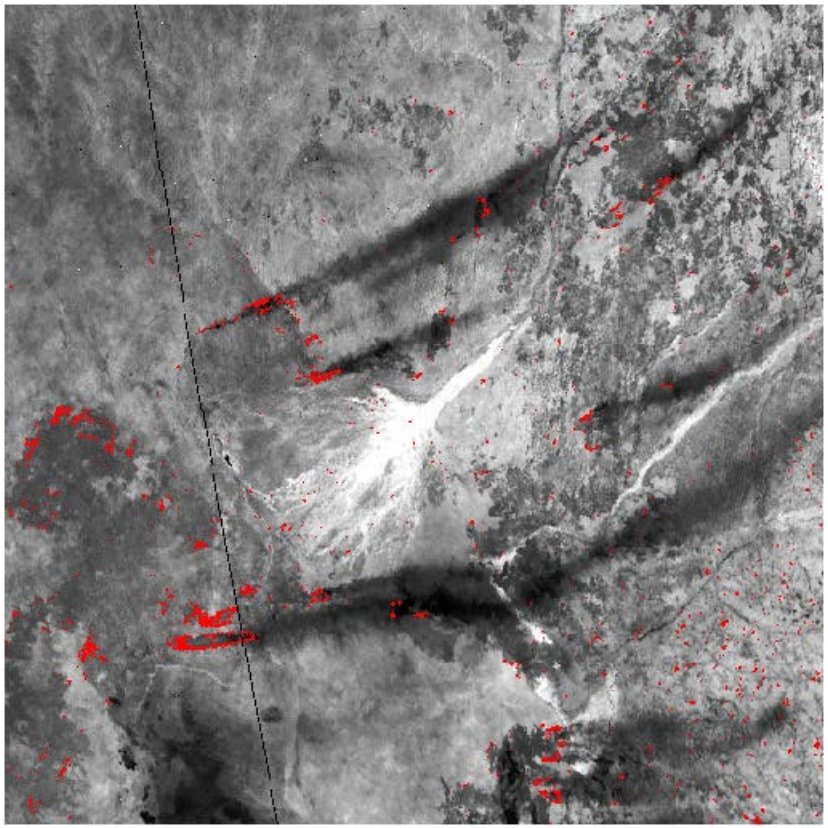
- burning is a temporal phenomena
- improved discrimination between burned areas and spectrally similar features that are temporally invariant (e.g. water bodies)
- reduced sensitivity to viewing and solar geometry

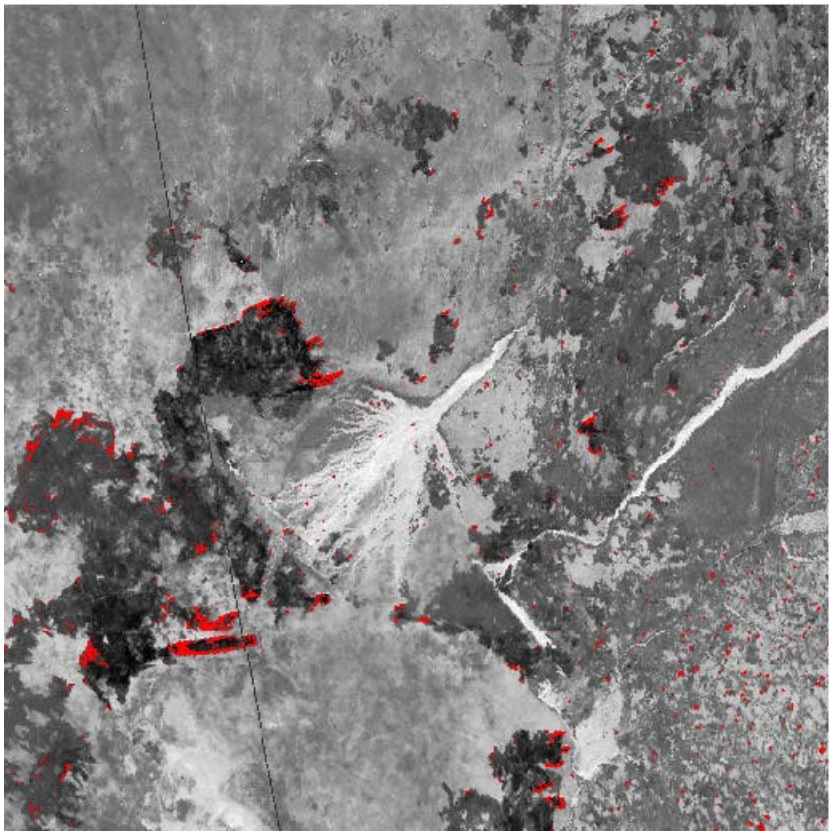
Active-fire based:

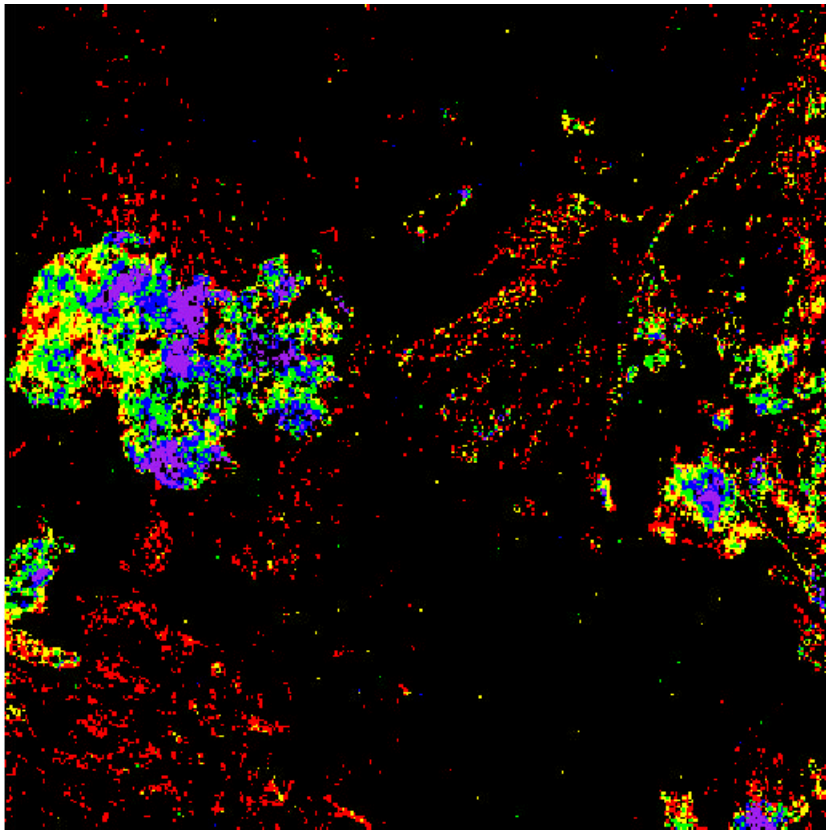
- MODIS active fire algorithm used to *infer* the locations of burned pixels
- these used to train a classifier to classify pixels not burning at the time of satellite overpass.

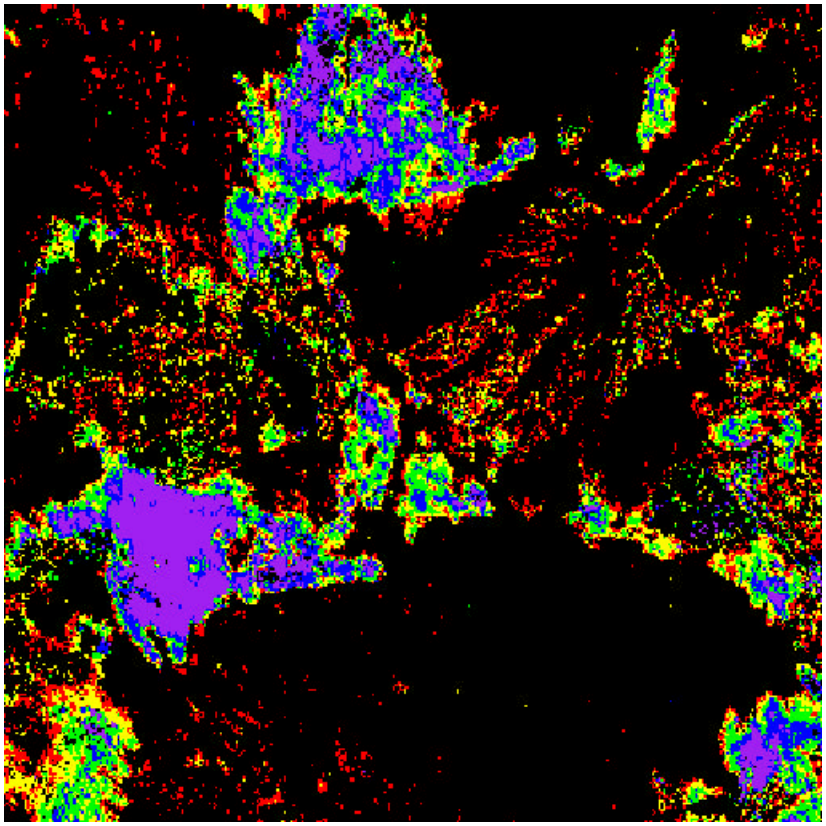
Multitemporal active-fire based algorithm











Ongoing Research Issues

- Burn scar index
  - sensitive to the presence of liquid water (burning reduces vegetation and soil water)
  - insensitive to scattering by smoke aerosols
  - discriminates between burned and unburned surfaces

  -> reflective component of the middle- infrared being considered

- Multitemporal data misregistration
  - causes burned area overestimation

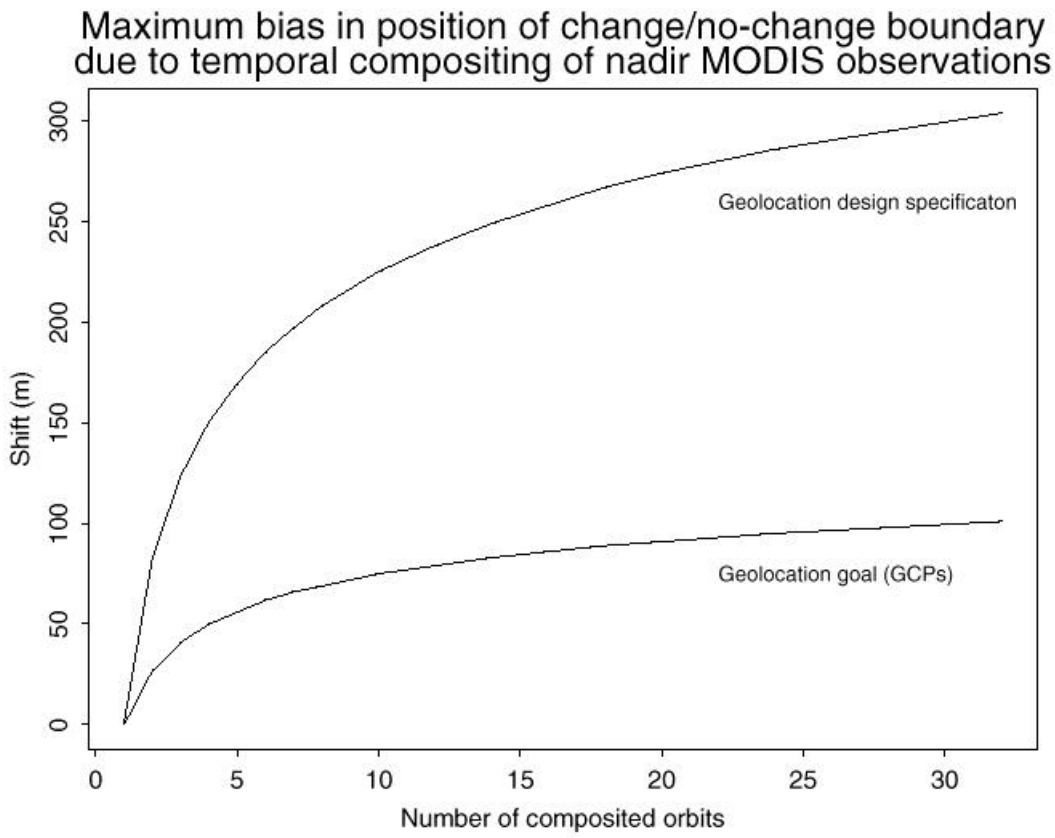
  -> statistical modeling being undertaken to quantify these effects

- Burned area detection biases due to spatial aggregation effects
  - spatial resolution of the sensed pixels
  - spatial arrangement of the burned areas (proportion and fragmentation)

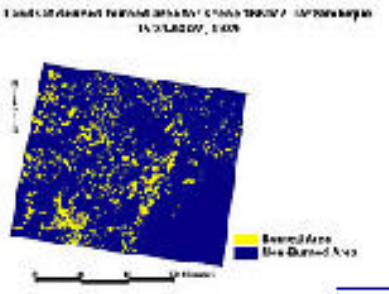
  -> use MODIS multi-resolution (250m, 500m, 1km bands) to calibrate for these

- Spatial extent over which active fire based information may be meaningfully applied
  - land cover and properties
  - proportion of pixels burned

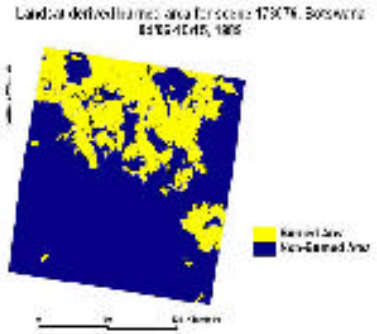
  -> MODIS land cover product and derived fire regime maps being considered


Maximum bias in position of change/no-change boundary
due to temporal compositing of nadir MODIS observations
Shift (m)
0
50
100
150
200
250
300
0
5
10
15
20
25
30
Number of composited orbits
Geolocation design specificaton
Geolocation goal (GCPs)

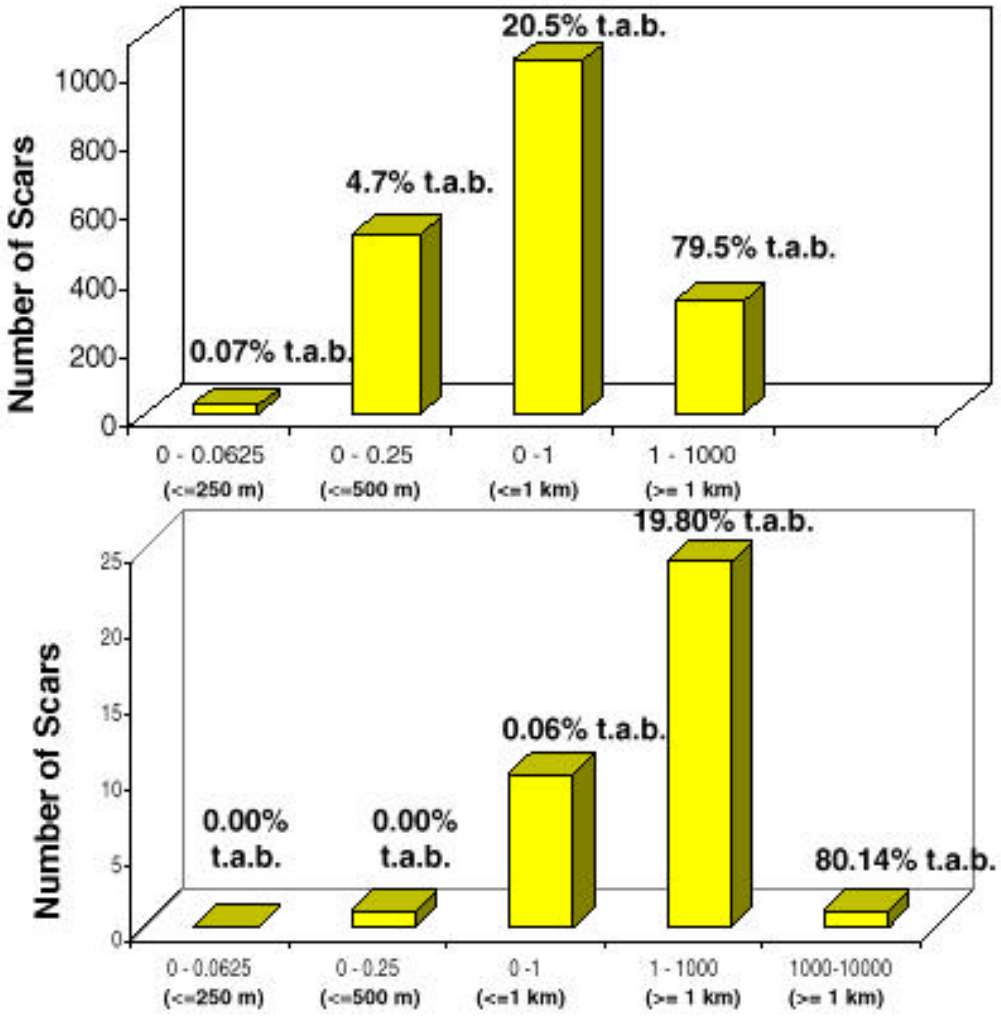
Landsat Burn Scar Size Distributions



min = 0.02 km²
max= 193.29 km²



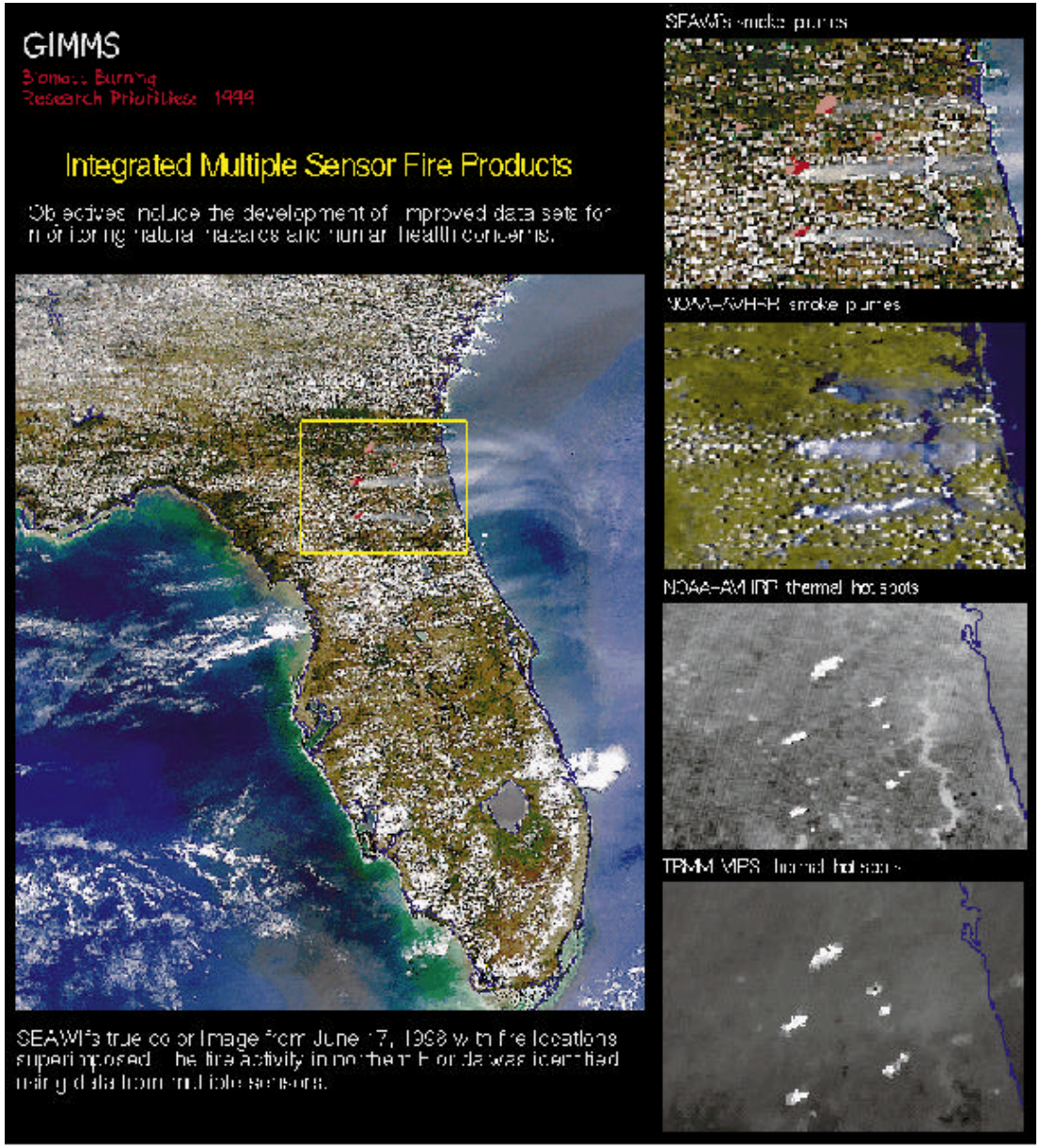
min = 0.21 km²
max = 6786.6 km²



t.a.b. = total area burned

Burn Scar Size Distribution (km²)

Korontzi--GECP


GIMMS
Biomass Burning
Research Priorities: 1999
Integrated Multiple Sensor Fire Products
Objectives: reduce the development of improved data sets for
monitoring natural hazards and human health concerns.
SEAWiFS smoke plumes
NOAA-AVHRR smoke plumes
NOAA-AVHRR thermal hot spots
TRMM VIRS thermal hot spots
SEAWiFS true color image from June 17, 1998 with fire locations
superimposed. The fire activity in northern Florida was identified
using data from multiple sensors.