Tropical Forest Monitoring Integrating MODIS Percent Tree Cover Maps and Landsat Data

Matt Hansen
Geographic Information Science Center of Excellence
South Dakota State University

John Townshend – U. of Maryland
Chris Justice – U. of Maryland
Ruth DeFries – U. of Maryland
Tom Loveland – USGS EROS
Steve Stehman – SUNY-ESF
Kyle Pittman – South Dakota State U.
Alice Altstaat – U. of Maryland
Mark Carroll – U. of Maryland
Charlene Dimiceli – U. of Maryland
Erik Lindquist – South Dakota State U.

MODIS Vegetation Continuous Fields (VCF) – a flexible tool for characterizing tree cover

- Sub-pixel proportional estimate of tree crown cover
- Overcome artificial boundaries inherent in classification approaches, preserving landscape heterogeneity
- Appropriate for large pixels of global data sets, where most pixels are mixed assemblages of different cover types
- Independent of strict class type definitions, but can be used to create custom-made land cover classifications
- Possible to apply temporally to identify changes in % cover
- Derived from moderate resolution remote sensing imagery with calibration and validation from high resolution data

Percent Tree Cover
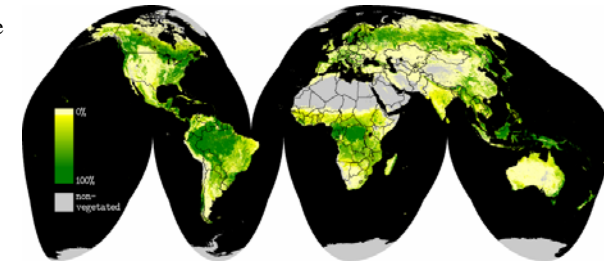
Comparison of net tree cover change of 8km and FAO Forest Resource Assessment data for 1980-2000.

	8km annual change estimate in 1000's of ha/yr		FRA annual change estimate in 1000's of ha/yr	
	80-90	90-00	80-90	90-00
Latin America	-4033 (-3746 to -4497)	-3909 (-3924 to -3883)	-7407	-4669
Tropical Africa	131 (-11 to 838)	53 (-4 to 450)	-4164	-5296
Tropical Asia	-1459 (-1450 to -1099)	-2307 (-2219 to -1913)	-1926	-2347
Developed Pacific	-64 (-28 to 1)	-13 (-2 to -74)	-126	-367
North America	-160 (-123 to -565)	-616 (-301 to -1054)	317	388
Europe	1106 (345 to 2259)	878 (225 to 1857)	191	427
North Africa & Middle East	25 (-7 to 116)	7 (-25 to 105)	-115	60
Former Soviet Union	-951 (-1176 to 571)	-1188 (-1185 to -252)	51	740
China and Mongolia	-257 (-101 to -966)	-342 (-159 to -774)	-400	1746
Total change	-5662 (-6296 to -3342)	-7437 (-7597 to -5539)	-13579	-9318
Percent difference in rate of change in forest cover	+31% (+21% to +66%)		-31%	

Multi-resolution approaches to delineating forest change area in the tropics

- MODIS VCF data provide synoptic/internally consistent overviews of global/regional/national tree cover

- Limited in delineating areal change and spatial arrangement of change

- When used in conjunction with high-resolution data sets, an improved approach to mapping change is enabled

- Allows global-scale information to be relevant at local scales

MODIS VCF forest cover monitoring capabilities

- Percent tree cover maps and annual phenological metrics used to detect forest change

    – Alarm/change indicator for sampling high-resolution data sets to delineate areal change

    – Reference data set for mapping high-resolution forest change wall-to-wall

Approach 1 - Use MODIS as a change indicator to sample change/no change strata within the tropics

- Implement a remote sensing-based, probability sampling framework that combines MODIS global forest cover maps and high resolution forest characterizations derived from Landsat images to:

    – estimate tropical forest cover change and the uncertainty of the estimate
    – determine the accuracy of the global MODIS tree cover change maps for the tropics
    – for the MODIS layer, apply regression estimators derived using the Landsat analyses to create a spatially explicit estimate of tropical forest change

- Improvement over past tropical forest change assessments
    – Change/no change strata objectively derived
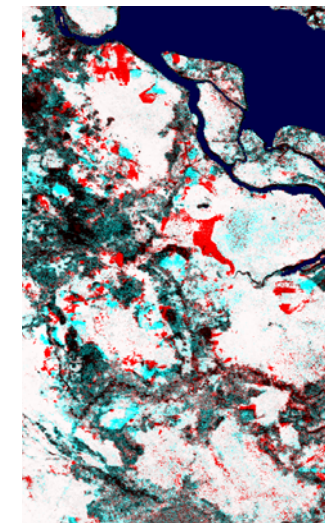   – Sampling problems with infrequently occurring change classes are overcome
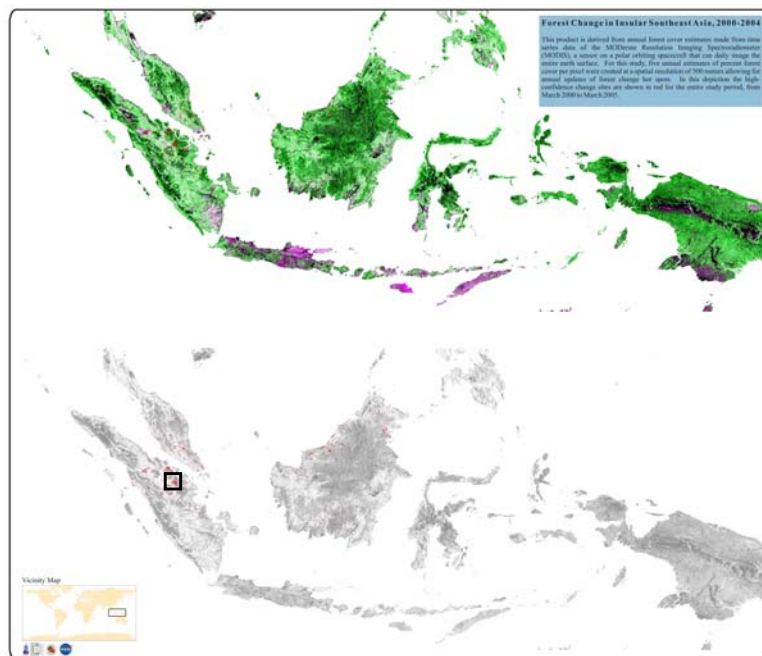
Forest Change in Insular Southeast Asia

Change in tree cover for central Sumatra
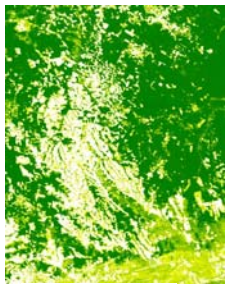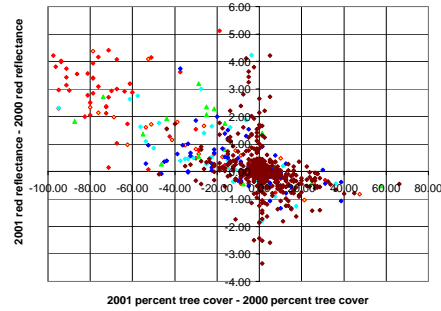

2000-2004
red = loss
cyan = gain

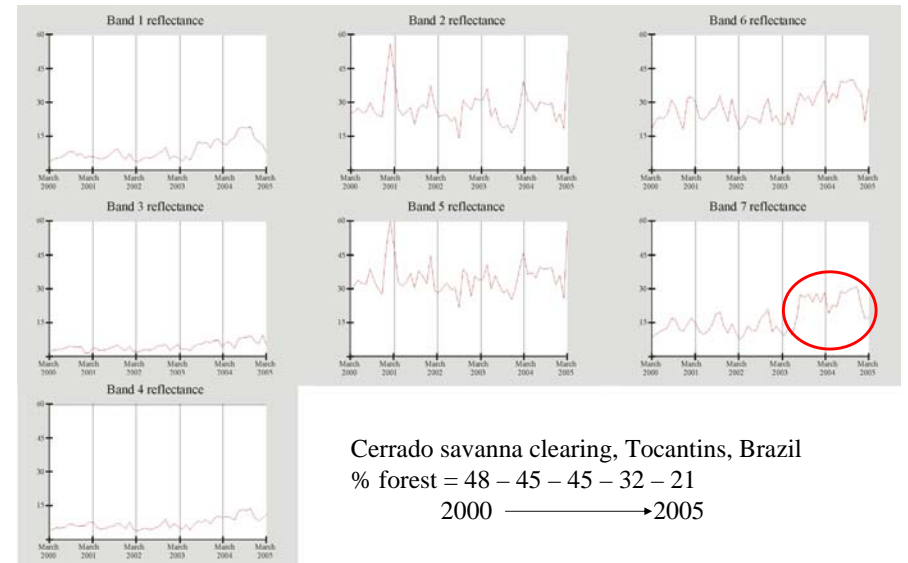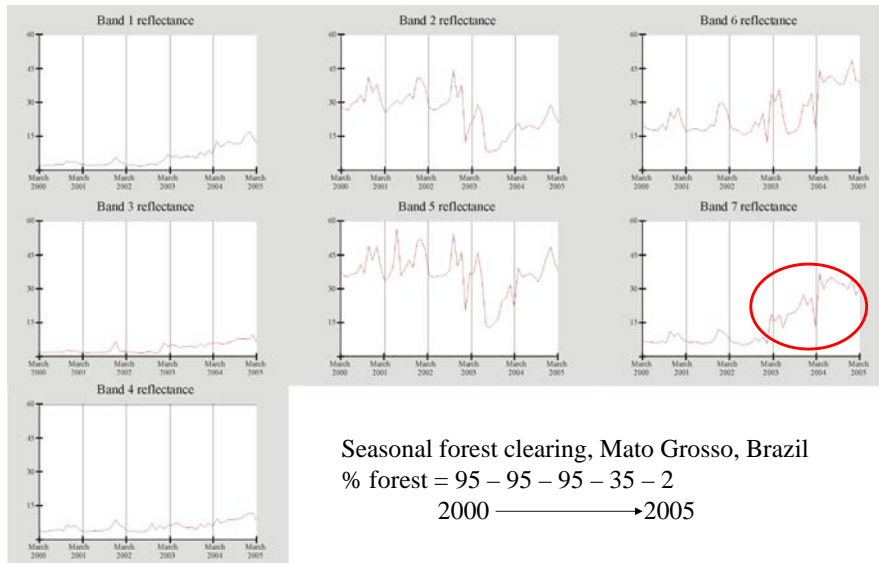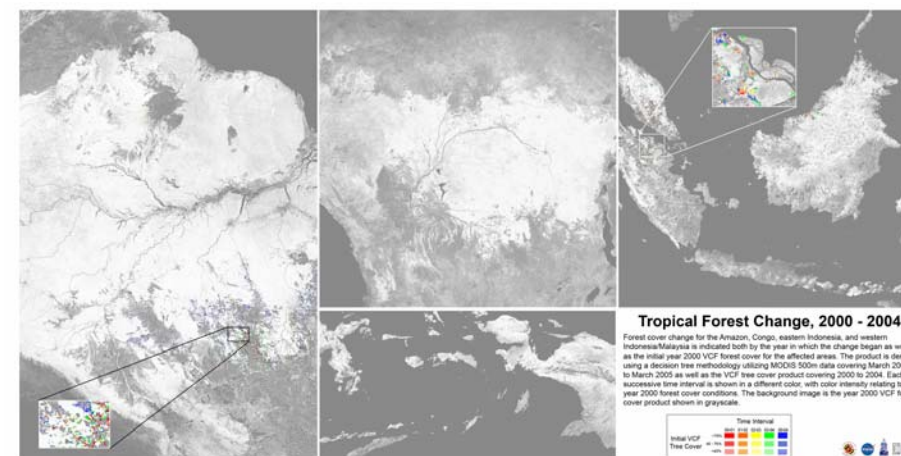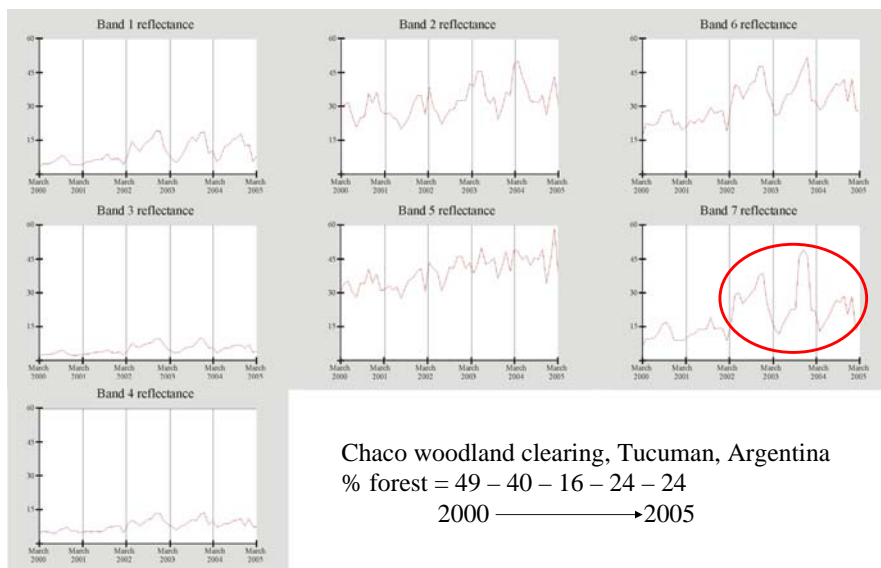Percent Tree Cover

100

0

50 km

%forest 2001

%red ref 2001

PRODES % 2001 deforested as a function of MODIS change in VCF % tree cover
and in % growing season red reflectance for southern Mato Grosso state
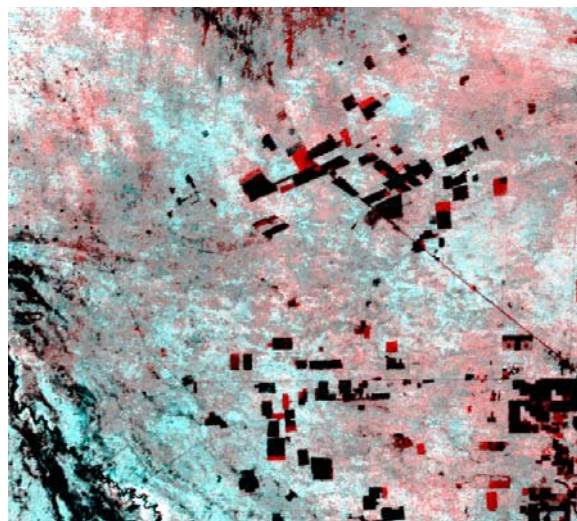
2001 red reflectance − 2000 red reflectance

2001 percent tree cover − 2000 percent tree cover

- >80% cleared
- 60-79% cleared
- 40-59% cleared
- 20-39% cleared
- 1-19% cleared
- 0% cleared

Simple correlations of 500 meter percent change from PRODES vs. metric difference images

		red 1	nir 2	green 3	blue 4	swir 5	swir 6	swir 7	ndvi	lst
mean of 1-9	ranked	0.347074	0.089243	0.214038	0.282729	0.035993	0.337245	0.39784	0.352837	0.02158
	ndvi	0.344878	0.020367	0.228346	0.2931	0.082981	0.326278	0.383683		0.098607
	lst	0.303191	0.068404	0.167174	0.234349	0.045371	0.31219	0.376254	0.285282	
mean of 1-6	ranked	0.374487	0.097324	0.271737	0.32529	0.035516	0.32392	0.394355	0.349398	0.107333
	ndvi	0.365306	0.061511	0.26373	0.318564	0.122477	0.316133	0.368261		0.076288
	lst	0.293615	0.076297	0.161634	0.218485	0.045525	0.286811	0.360159	0.306289	
mean of 1-3	ranked	0.342126	0.112377	0.253321	0.312513	0.000251	0.253317	0.337984	0.285246	0.20354
	ndvi	0.301351	0.082684	0.222785	0.248167	0.092047	0.214286	0.266651		0.049177
	lst	0.248139	0.104962	0.132796	0.163772	0.006328	0.209316	0.312399	0.285153	
mean of 4-6	ranked	0.347549	0.063046	0.237891	0.280217	0.070566	0.337667	0.388615	0.349688	0.025509
	ndvi	0.317355	0.001856	0.212952	0.233289	0.075559	0.257511	0.319223		0.055707
	lst	0.19742	0.006009	0.099157	0.144359	0.056659	0.217705	0.269418	0.208229	
mean of 7-9	ranked	0.251415	0.05269	0.137346	0.175215	0.026591	0.281438	0.330074	0.298847	0.034771
	ndvi	0.225132	0.106886	0.13497	0.133964	0.020963	0.156295	0.260497		0.061522
	lst	0.122632	0.01145	0.063273	0.089725	0.013257	0.14620	0.189985	0.129666	
amp	ranked	0.168336	0.071702	0.117089	0.06159	0.071514	0.05977	0.185233	0.224067	0.079618
	ndvi	0.121123	0.06058	0.085765	0.033794	0.012169	0.025698	0.103126		0.046571
	lst	0.013791	0.06036	0.001311	0.014542	0.033809	0.014971	0.066748	0.022272	
greenest		0.182021	0.063454	0.019664	0.137917	0.060874	0.124206	0.144565		0.008659
warmest		0.197267	0.095336	0.034461	0.116834	0.015415	0.136793	0.250524	0.267021	
rank	1	0.090415	0.007479	0.02552	0.064414	0.001574	0.038559	0.032695	0.171368	0.202682
	2	0.160313	0.027856	0.099381	0.115398	0.016121	0.187267	0.26319	0.273051	0.16818
	3	0.203512	0.044095	0.115521	0.140233	0.008539	0.227051	0.293717	0.312829	0.156831
	4	0.227878	0.048661	0.112479	0.153678	0.02312	0.262392	0.329643	0.338576	0.034001
	5	0.264041	0.051479	0.142382	0.181515	0.043087	0.295142	0.34078	0.336467	0.018313
	6	0.299508	0.049989	0.170643	0.226488	0.05441	0.311862	0.363756	0.322295	0.005089
	7	0.330308	0.060393	0.234484	0.249436	0.075846	0.32161	0.371946	0.300974	0.001945
	8	0.352353	0.066628	0.277181	0.302606	0.065976	0.318575	0.374043	0.27759	0.011863
	9	0.34639	0.081789	0.292527	0.313221	0.040823	0.302326	0.356946	0.258871	0.039999
	10	0.328525	0.113069	0.250582	0.293857	0.000229	0.249889	0.322296	0.226412	0.072
	11	0.242746	0.100287	0.134867	0.227331	0.023934	0.139442	0.233126	0.161895	0.105958
composite	65-95	0.076705	0.011579	0.05916	0.065755	0.007073	0.022045	0.18112	0.087016	0.073373
	97-128	0.082785	0.007814	0.052132	0.066506	0.010766	0.108664	0.124513	0.093149	0.009968
	129-160	0.098436	0.059904	0.046236	0.083082	0.060018	0.203782	0.168177	0.105441	0.009184
	161-192	0.091765	0.052016	0.004666	0.031786	0.004255	0.072755	0.018905	0.153777	0.040237
	193-224	0.291432	0.037035	0.03858	0.234083	0.027331	0.309837	0.344256	0.308451	0.015519
	225-256	0.262453	0.106252	0.03042	0.188395	0.004755	0.212358	0.117263	0.315805	0.051372
	257-288	0.215047	0.08035	0.118693	0.14305	0.005401	0.176993	0.274563	0.2558	0.038545
	289-320	0.102322	0.109402	0.028111	0.034985	0.054086	0.06877	0.159962	0.165894	0.015483
	321-360	0.088944	0.0112	0.053299	0.074497	0.030328	0.101548	0.06362	0.092320	0.118268
	361-32	0.112377	0.015437	0.087934	0.096584	0.015097	0.048536	0.052136	0.12085	0.048805
	33-64	0.018162	0.010617	0.013476	0.014686	0.005266	0.041848	0.06772	0.022679	0.034366

Seasonal forest clearing, Mato Grosso, Brazil
% forest = 95 – 95 – 95 – 35 – 2
2000 ⟶ 2005

Cerrado savanna clearing, Tocantins, Brazil
% forest = 48 – 45 – 45 – 32 – 21
2000 ⟶ 2005

Chaco woodland clearing, Tucuman, Argentina
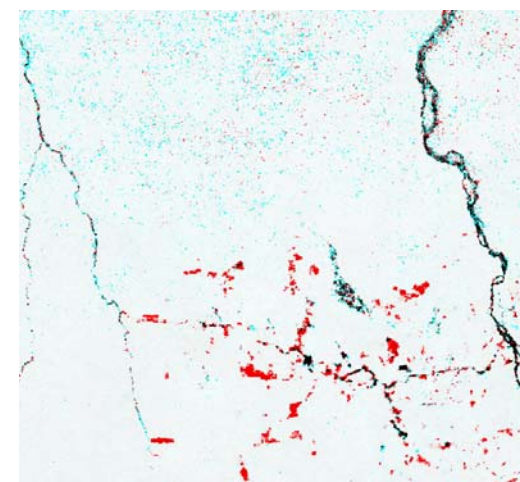% forest = 49 – 40 – 16 – 24 – 24
2000 ———————→2005

July 2000 to March 2004 (ETM+ 229/075)
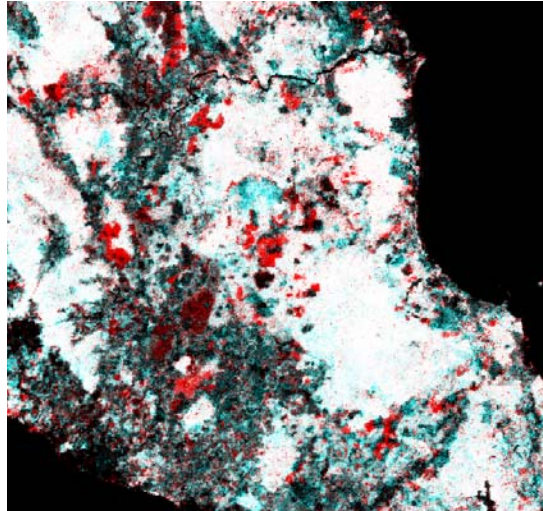with MODIS tree cover change 2000-2004

Argentine chaco woodland clearing

August 1999 to July 2004 (ETM+ 226/064)
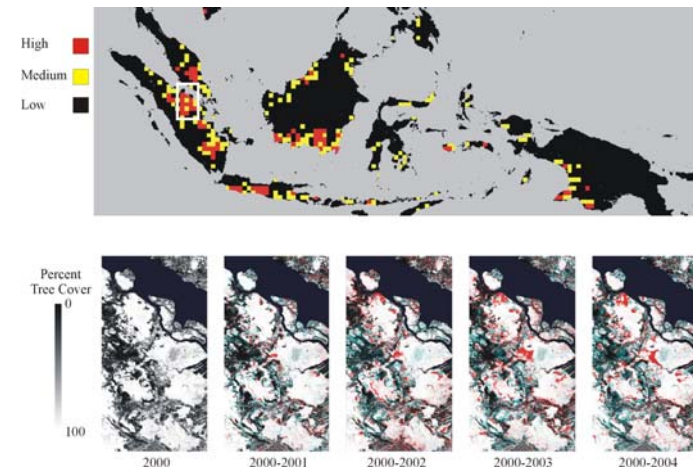with MODIS tree cover change 2000-2004
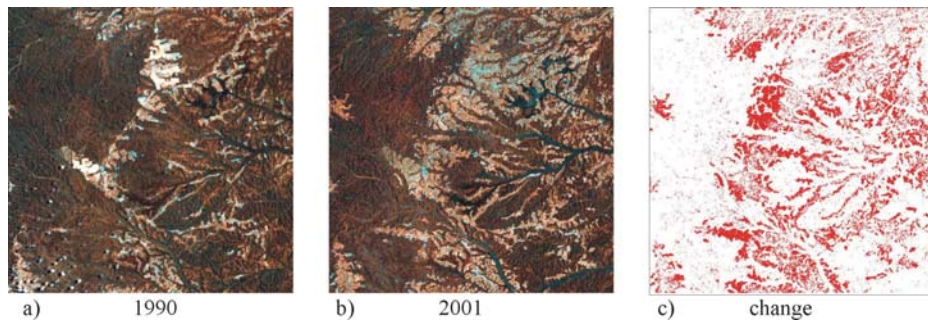
Brazilian humid forest clearing

September 1999 to June 2004 (ETM+ 126/058)
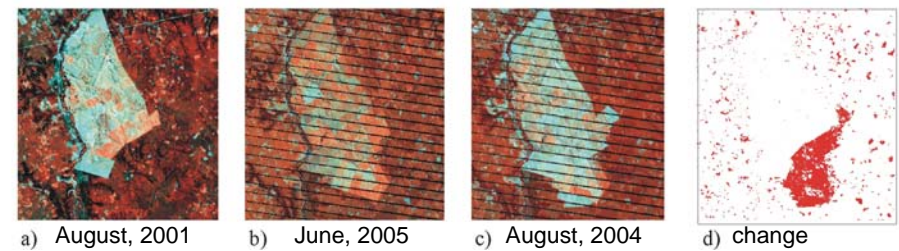with MODIS tree cover change 2000-2004



Malaysian montane forest clearing

Landsat change 1990-2000

a) 1990   b) 2001   c) change

Example from central Democratic Republic of the Congo

Change mapping using SLC-off ETM+ data inputs
example of cerrado clearing in Brazil, 220/064

a) August, 2001   b) June, 2005   c) August, 2004   d) change

Sample by biome to create global assessment of forest change

Like Land Cover Trends, except change is targeted via MODIS
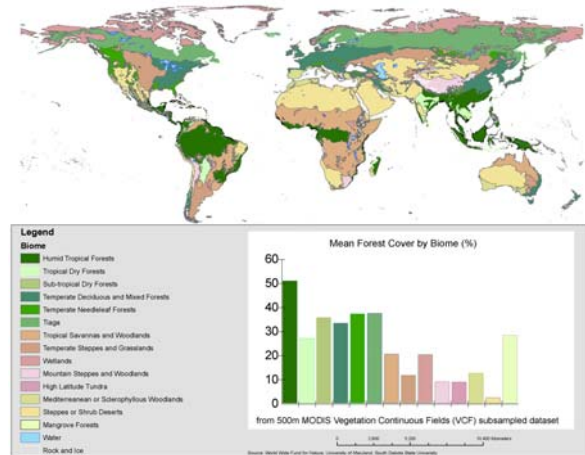
Tropical forest area change estimation using MODIS to target Landsat change and no change samples

- Tropical region includes Humid Tropical Forests, Tropical Dry Forests and Tropical Savannas and Woodlands biomes as defined by WWF

- Current plan is for 1990, 2000 and 2005 study intervals

- Will use SLC-off data for 2005 epoch

- Strata based on quantity of change from MODIS within the sample units (blocks of 10-20 sq. km.)

- Improve precision of sampling-based estimates via use in
  – Design (stratification by anticipated change)
  – Estimation (regression or ratio estimator)

- Research: potential gain and practical utility of model-based stratification

Approach 2 – Use MODIS forest cover maps to drive exhaustive change mapping at finer scales

- Use MODIS VCF percent tree cover maps to drive high-resolution mapping of forest change

- Automate method to allow for repeatable, comparable product generation through time

- Improve the internal consistency of region-wide high-resolution deforestation map products

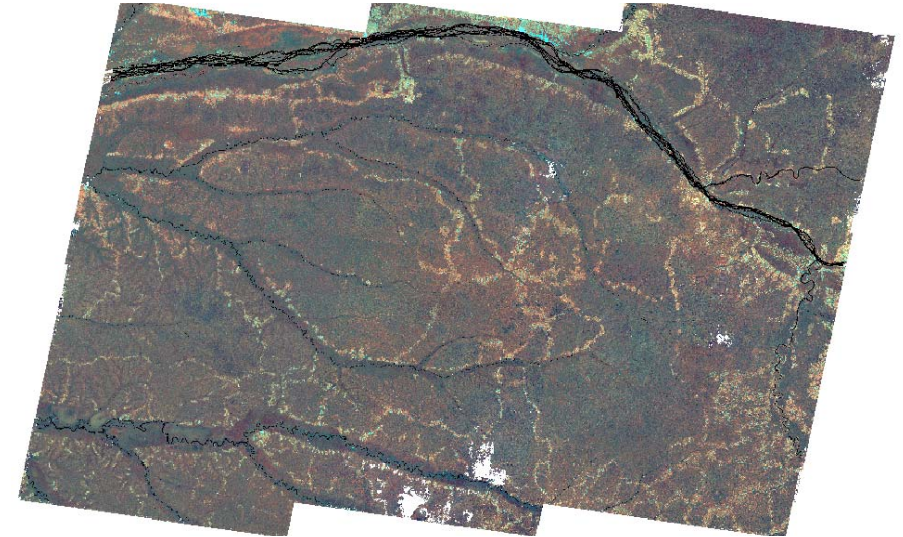- Retain global consistency while generating locally relevant products

Remaining mature forest of Central Africa from MODIS 250m data
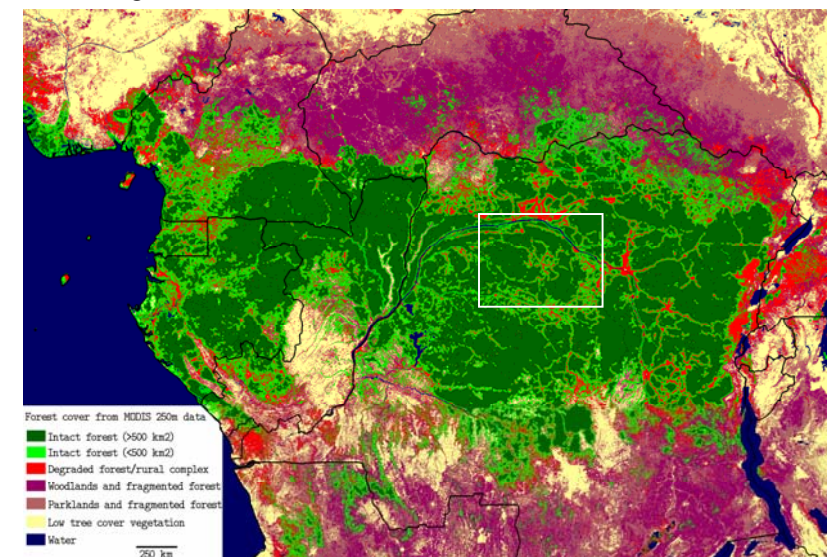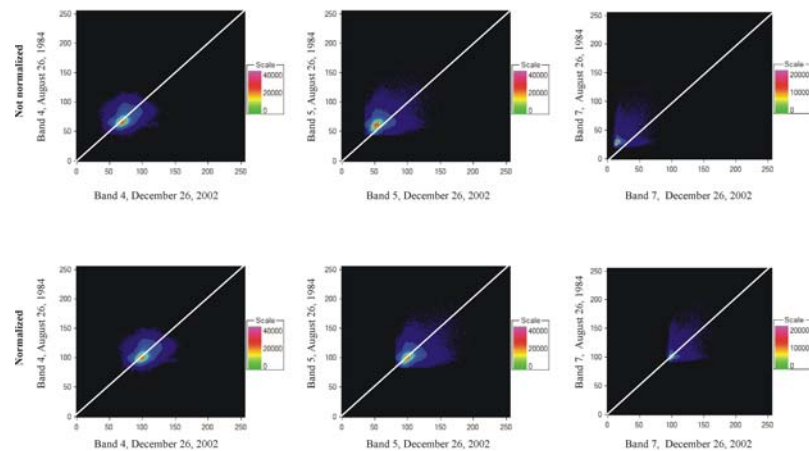
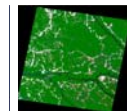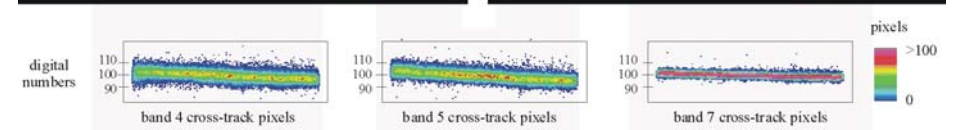MODIS forest/non-forest
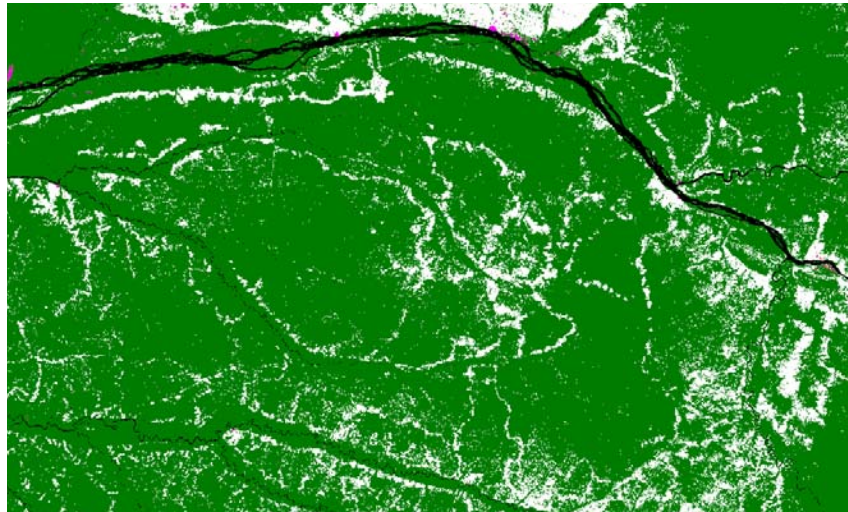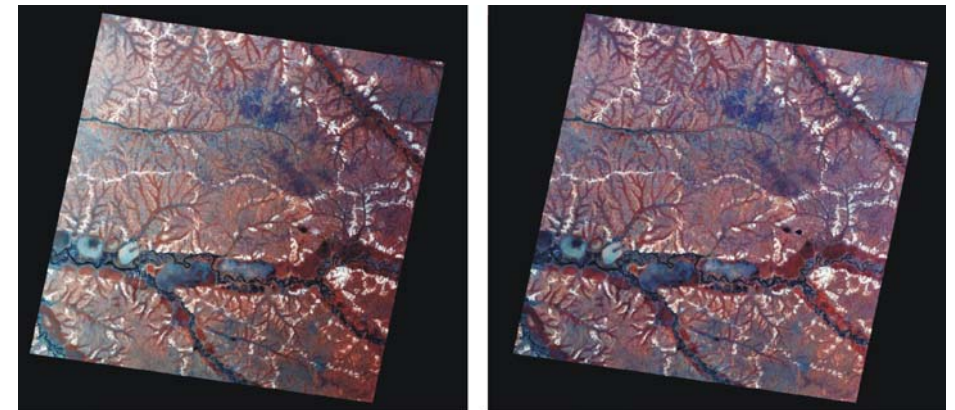

Landsat mosaic/composite

4-5-7

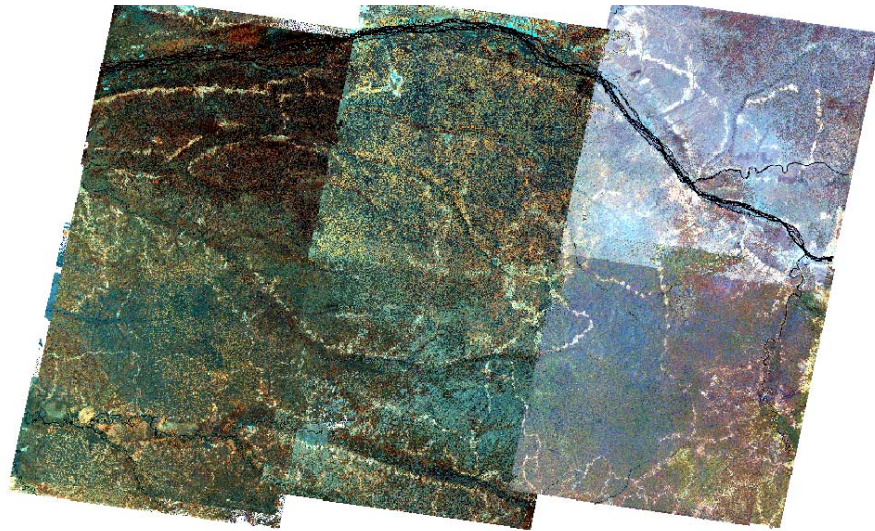## MODIS VCF used to normalize input Landsat imagery via simple bias adjustment

Forest mask from MODIS

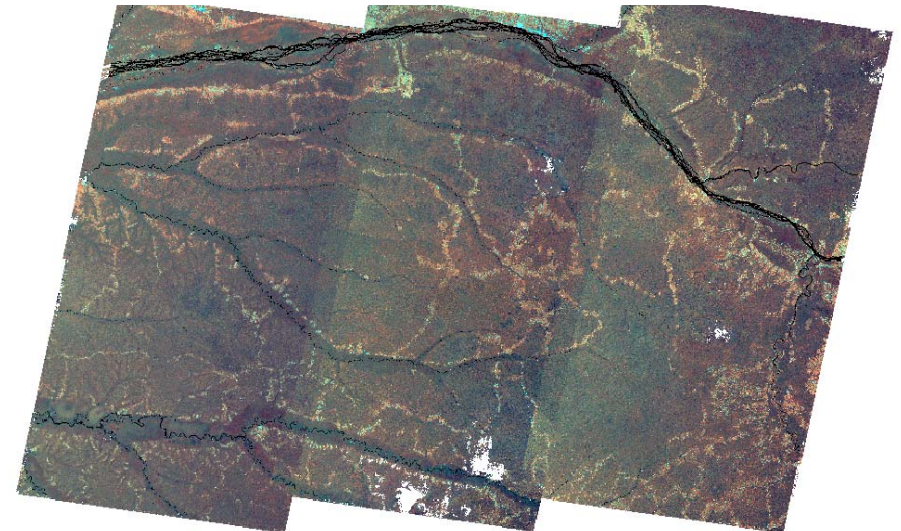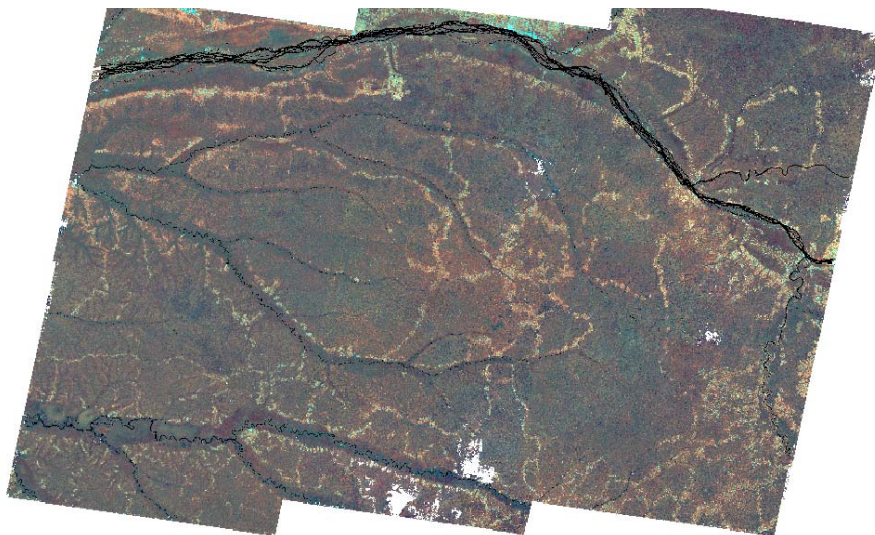## First-order BRDF correction

Raw DN's

4-5-7

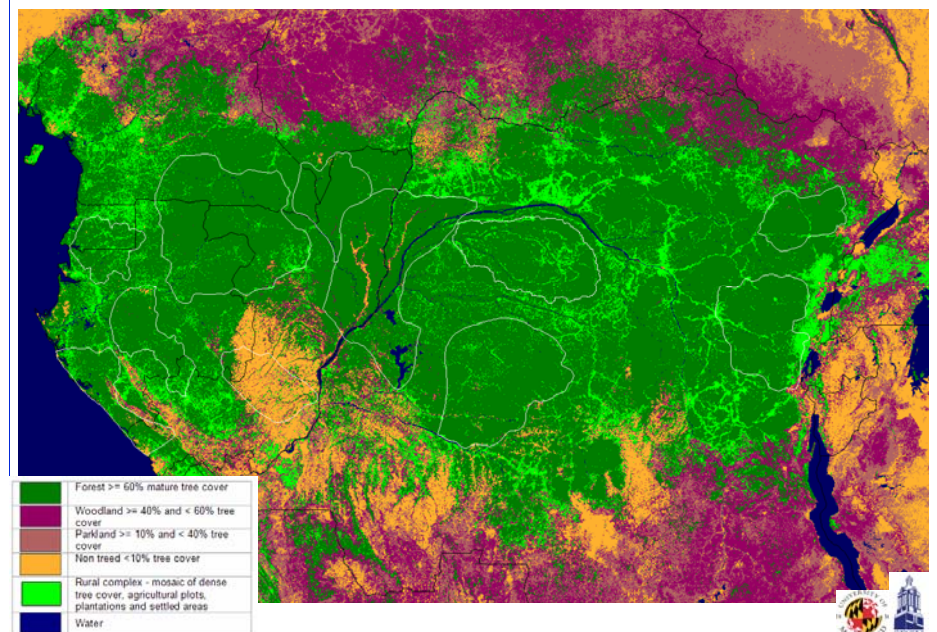Bias adjusted/normalized DN's

4-5-7

BRDF-corrected DN's

4-5-7

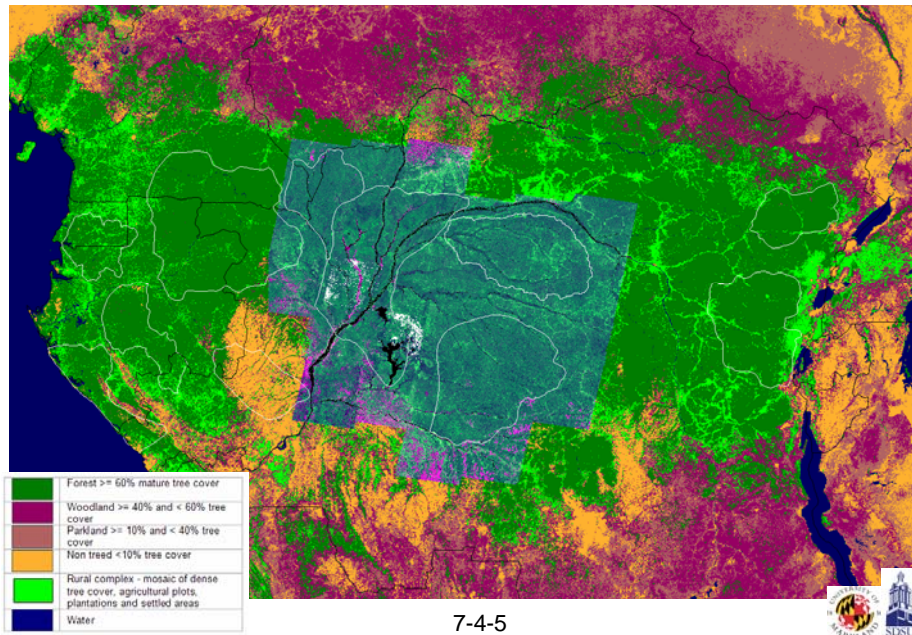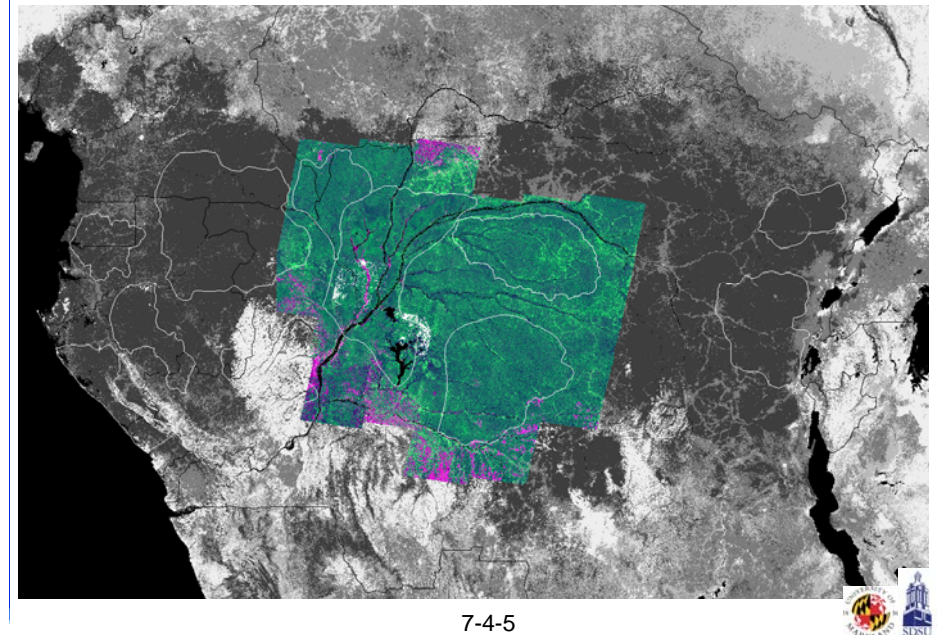MODIS 250 meter forest map as a reference for mapping change with Landsat data

Forest >= 60% mature tree cover
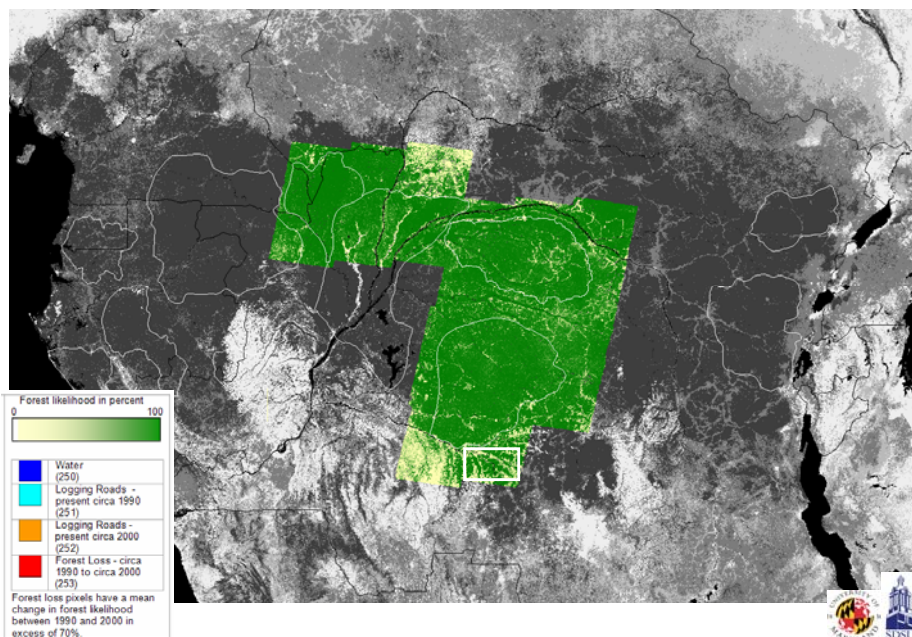
Woodland >= 40% and < 60% tree cover

Parkland >= 10% and < 40% tree cover

Non treed <10% tree cover

Rural complex - mosaic of dense tree cover, agricultural plots, plantations and settled areas

Water

Use MODIS map to pre-process and characterize forest change with Landsat data

Legend:
- Forest >= 60% mature tree cover
- Woodland >= 40% and < 60% tree cover
- Parkland >= 10% and < 40% tree cover
- Non treed <10% tree cover
- Rural complex - mosaic of dense tree cover, agricultural plots, plantations and settled areas
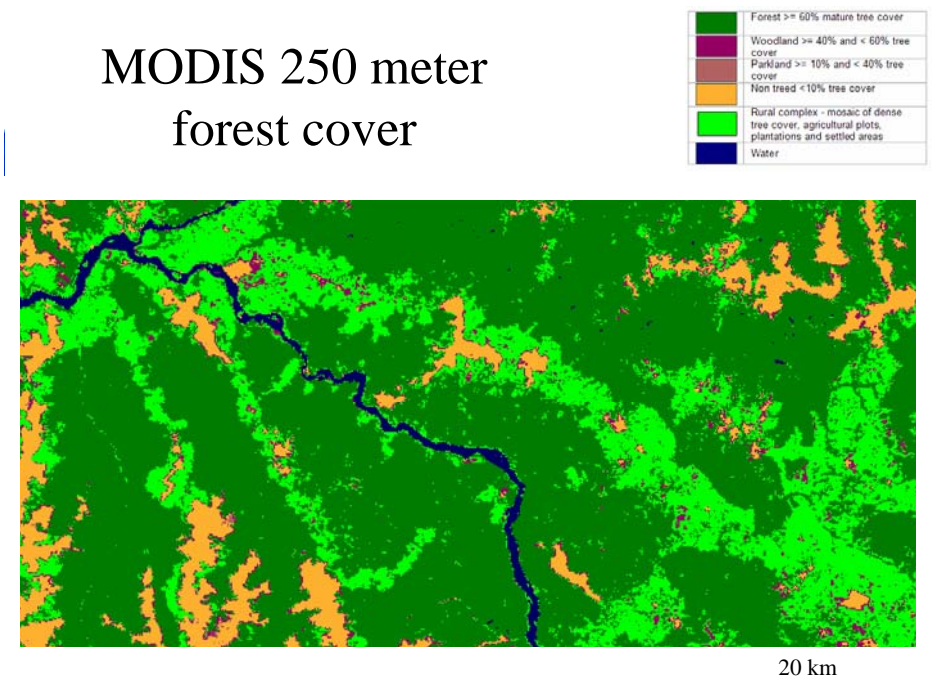- Water

7-4-5

Processed Landsat tiles to date for MODIS-calibrated Landsat mapping

7-4-5

Completed Landsat-scale forest change mapping to date

Legend:
Forest likelihood in percent
0 — 100
- Water (250)
- Logging Roads - present circa 1990 (251)
- Logging Roads - present circa 2000 (252)
- Forest Loss - circa 1990 to circa 2000 (253)
Forest loss pixels have a mean change in forest likelihood between 1990 and 2000 in excess of 70%.

MODIS 250 meter forest cover

Legend:
- Forest >= 60% mature tree cover
- Woodland >= 40% and < 60% tree cover
- Parkland >= 10% and < 40% tree cover
- Non treed <10% tree cover
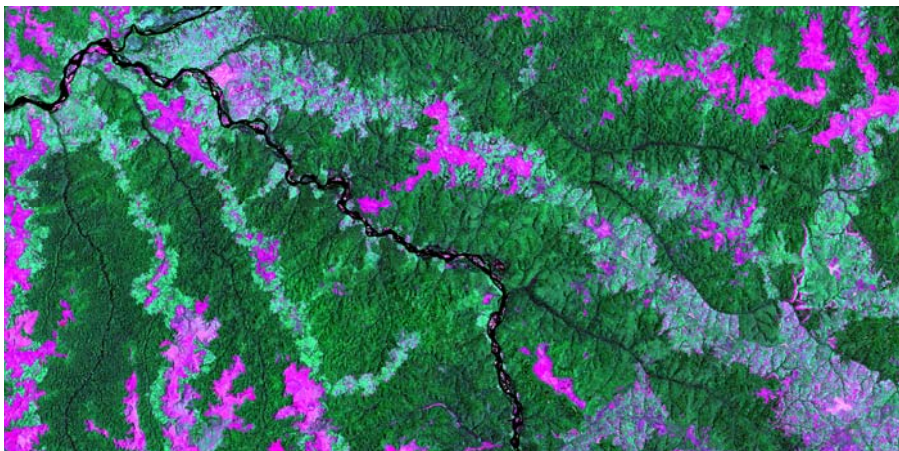- Rural complex - mosaic of dense tree cover, agricultural plots, plantations and settled areas
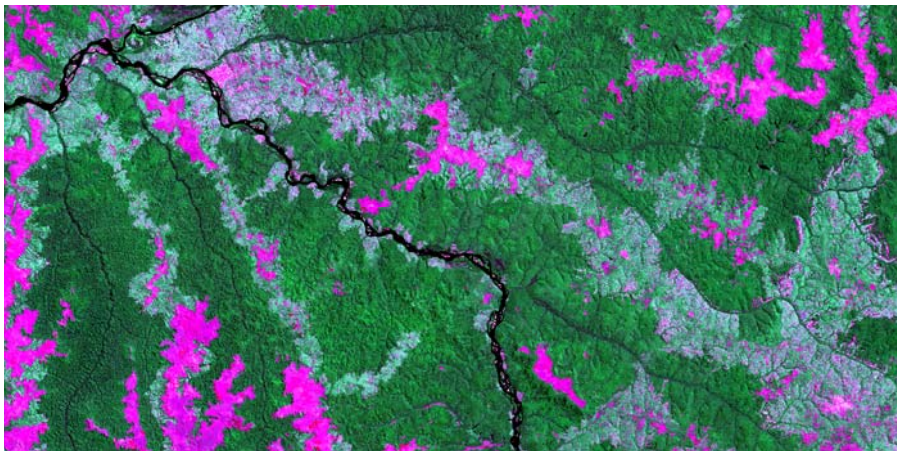- Water

20 km

MODIS 250 meter filtered forest cover
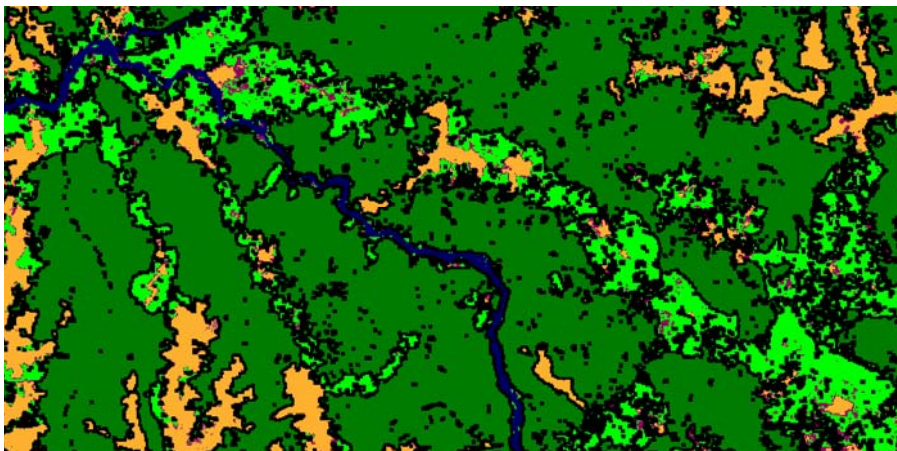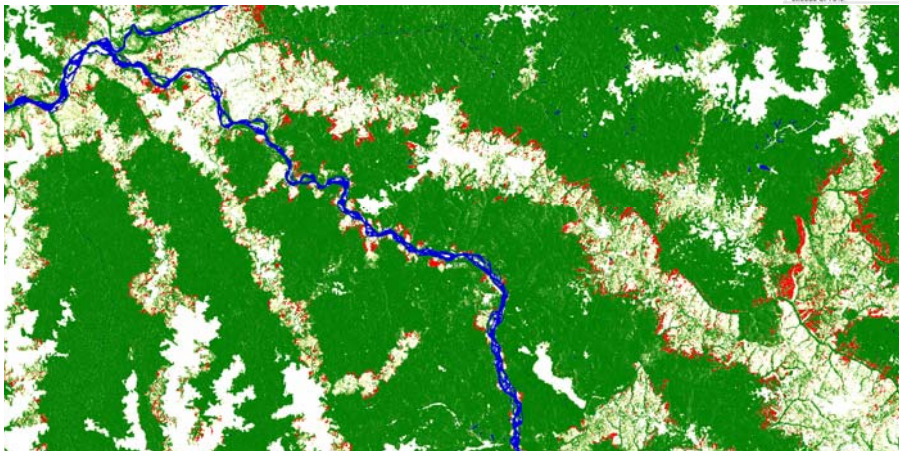
1990 Thematic Mapper 7-4-5 normalized composite

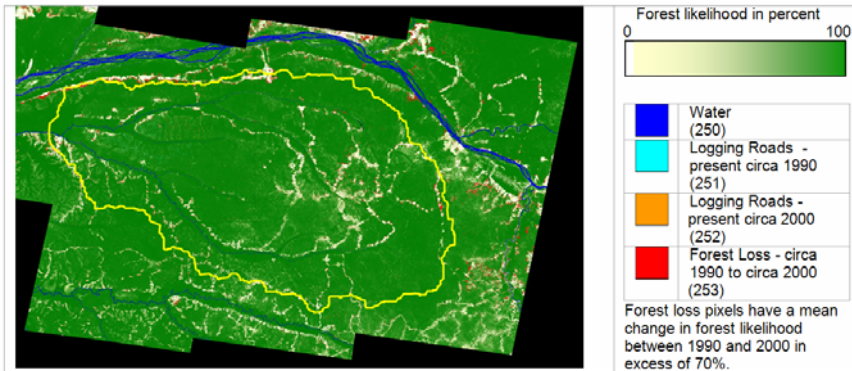2000 Thematic Mapper 7-4-5 normalized composite

Forest change, 1990-2000

20 km

7-4-5

Maringa-Lopori-Wamba change map

0.098%/year

Forest likelihood in percent
0   100

Color	Legend
Water (250)
Logging Roads - present circa 1990 (251)
Logging Roads - present circa 2000 (252)
Forest Loss - circa 1990 to circa 2000 (253)

Forest loss pixels have a mean change in forest likelihood between 1990 and 2000 in excess of 70%.

	Km²		Km
Landscape Area	74,973		
Forest Time 1	70,610	Forest/Non Forest edge Time 1	75,508
Non Forest Time 1	4,363		
Forest Time 2	69,918	Forest/Non Forest edge Time 2	81,938
Non Forest Time 2	5,055		

Summary of MODIS/Landsat forest change mapping

- MODIS data are useful in monitoring tropical forest change, especially when used in concert with higher spatial resolution imagery

  – 1) MODIS change indicator maps for sampling high-resolution change/no change sites

  – 2) MODIS forest cover maps for automatically mapping forest using high-resolution image inputs

- Detecting selective logging/fine-scale forest disturbance not possible with MODIS (impacts method 1)

- Wall-to-wall mapping at high spatial resolutions still too costly (primary limitation to method 2)

- Data availability key to successful monitoring