New approaches to land cover mapping and change monitoring in the era of satellite observations

(Selected examples)

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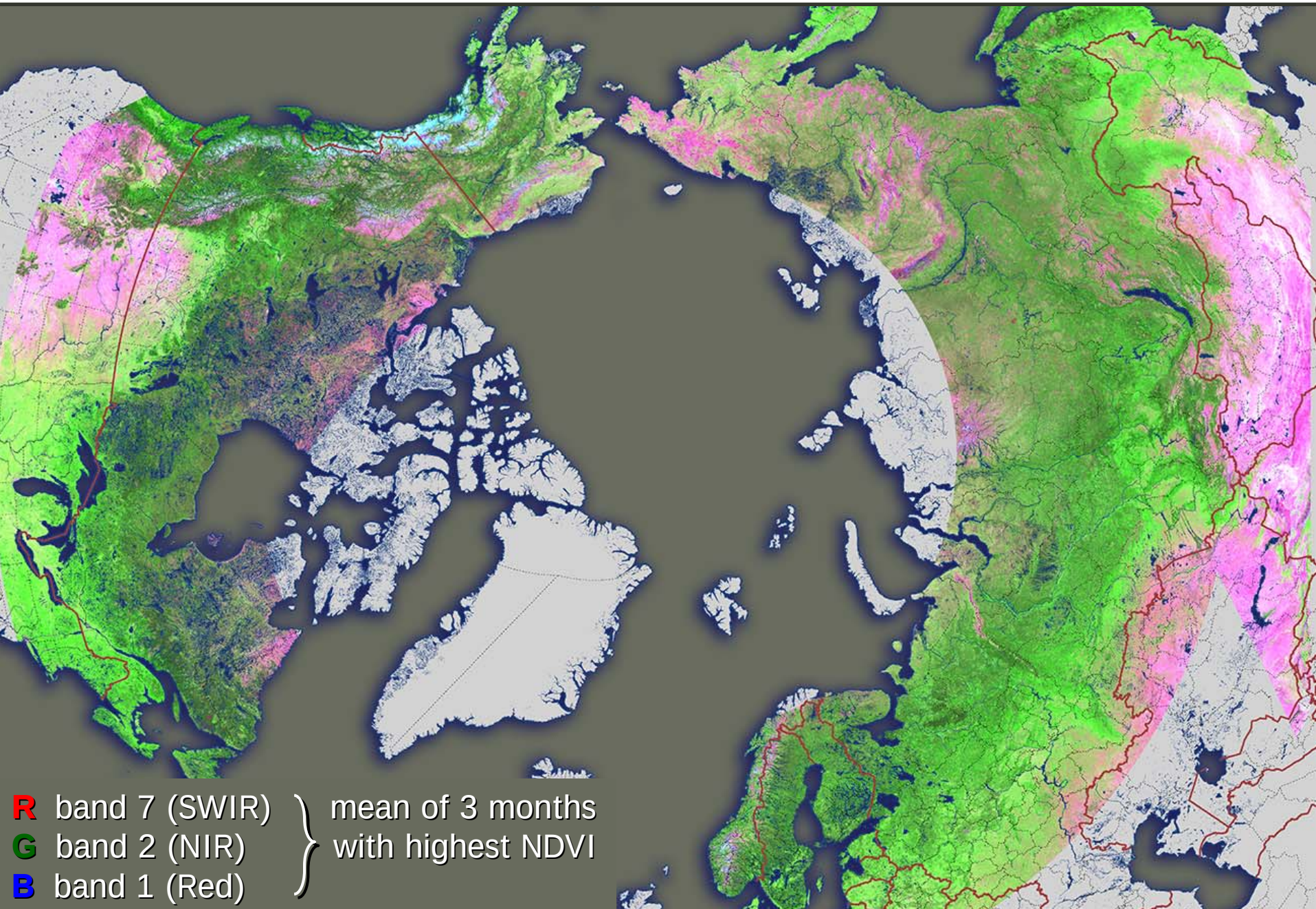
Outline

- Why new approaches are needed
- Land cover classification
  - Map legends: problems and solutions
  - LCCS overview and example
    - Exercise
- Map accuracy
- Land Cover Change
  - Land cover and land use
  - Disturbance
- Take home messages

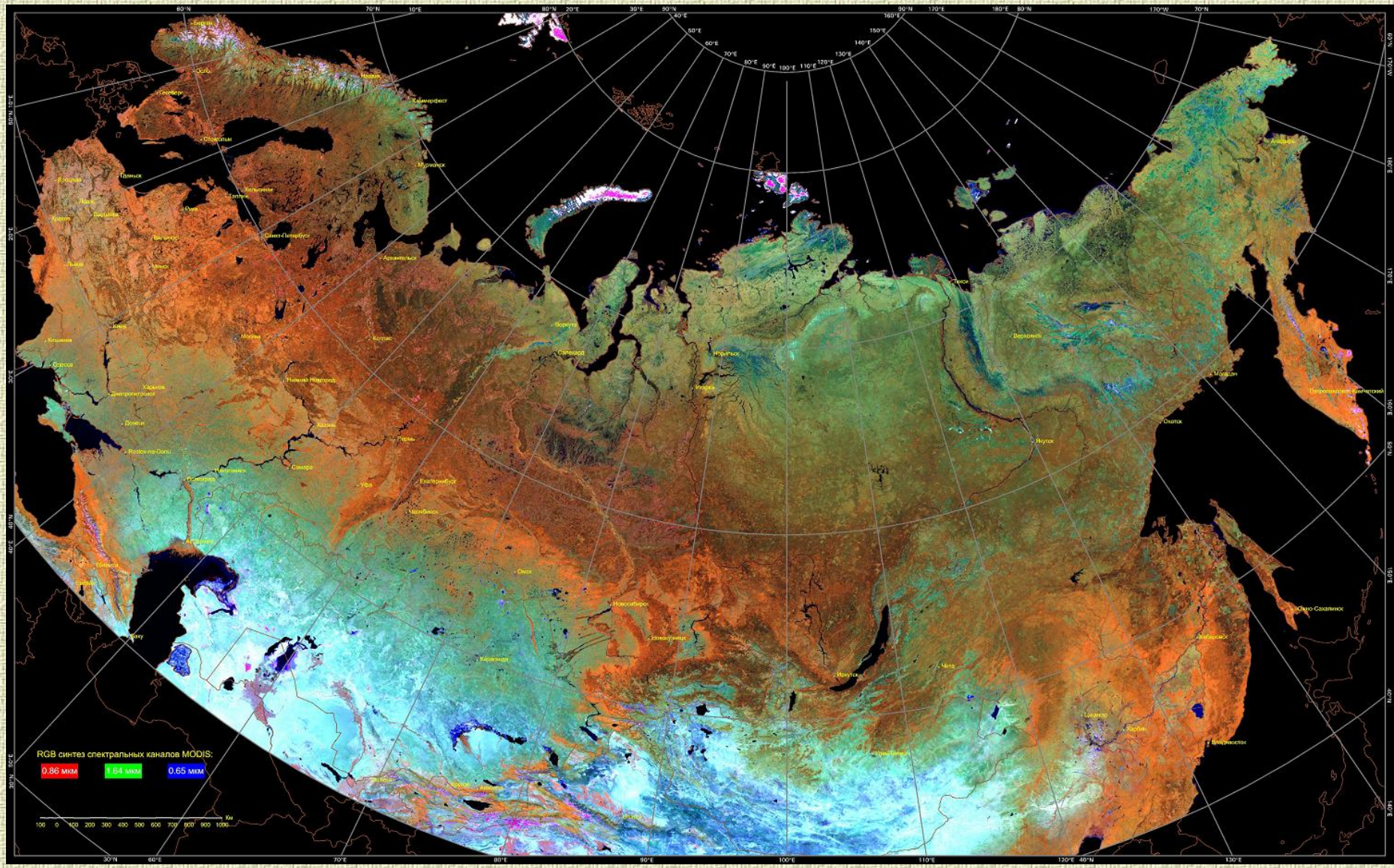
Take home messages

- Satellite Observations present new opportunities
  - Extracting information from data is a challenge
  - Grand challenge for the new generation of map-makers
- Remote sensing is the new frontier in geography
  - And the Wild West …

Example of annual MODIS metrics



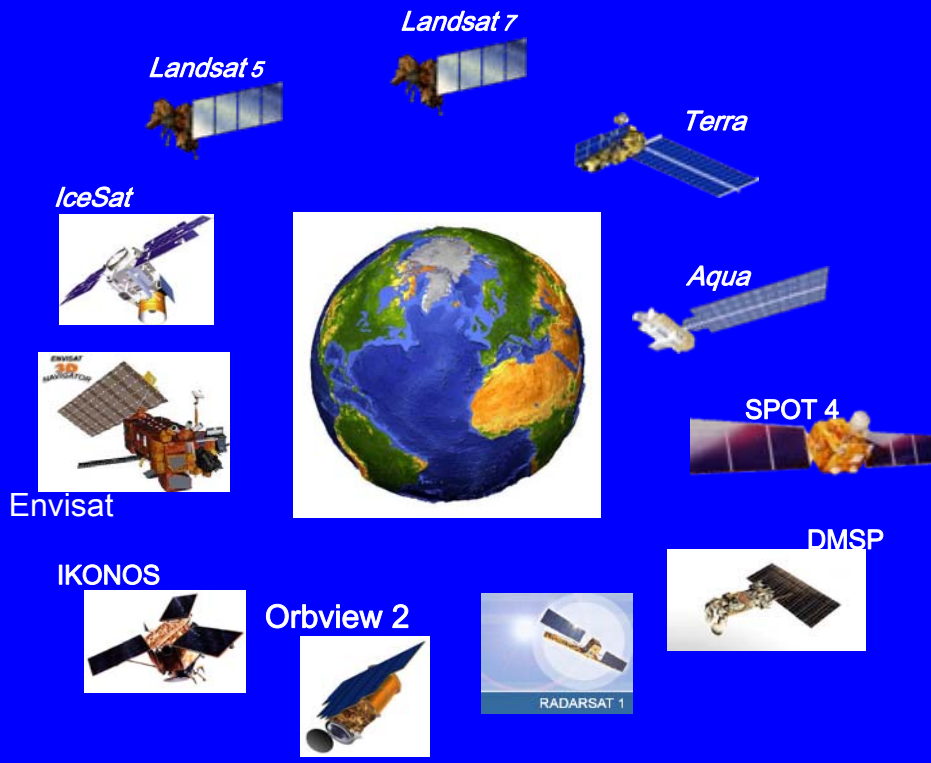
Cloud-free summer MODIS composite over Northern Eurasia



Spatial resolution – 250 м; June-August 2005

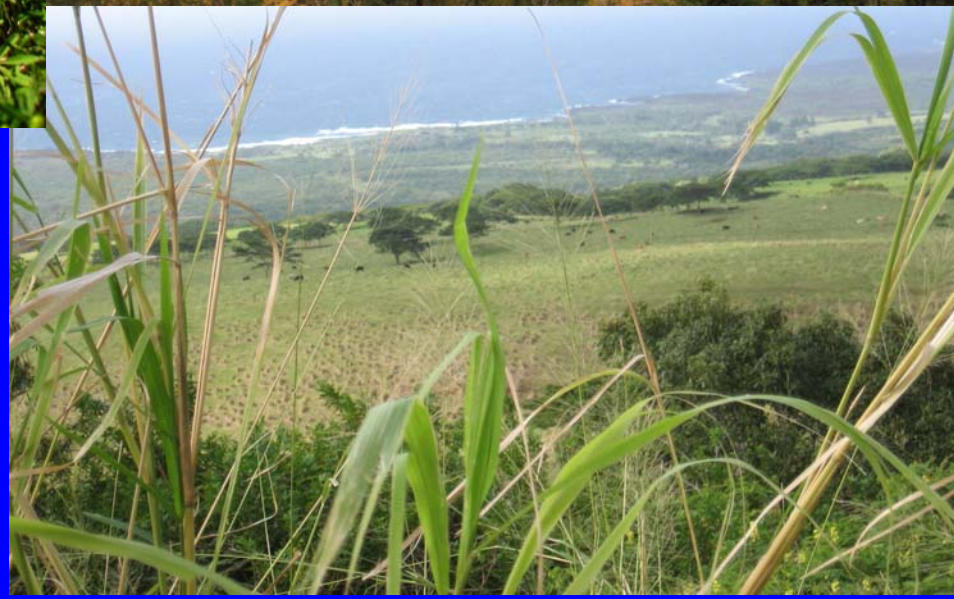
Earth Observation Systems

- Optical & IR
  - Coarse resolution 1-2 km:
    AVHRR, SeaWiFS, OLS, ATSR, Vegetation, Geostationary, etc.
  - Moderate resolution 0.2-1 km:
    MODIS, MISR, MERIS, etc.
  - High resolution 5-30m: Landsat, ASTER, ALI, SPOT, CBRS, IRS, etc
  - Fine resolution 1-4 m: IKONOS, Quickbird, etc
  - Active: Lidars
- Microwave
  - Passive: DMSP/SSMI, AMSU
  - Active: Radars

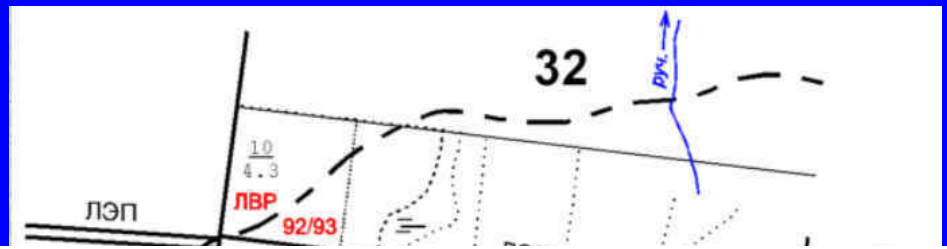


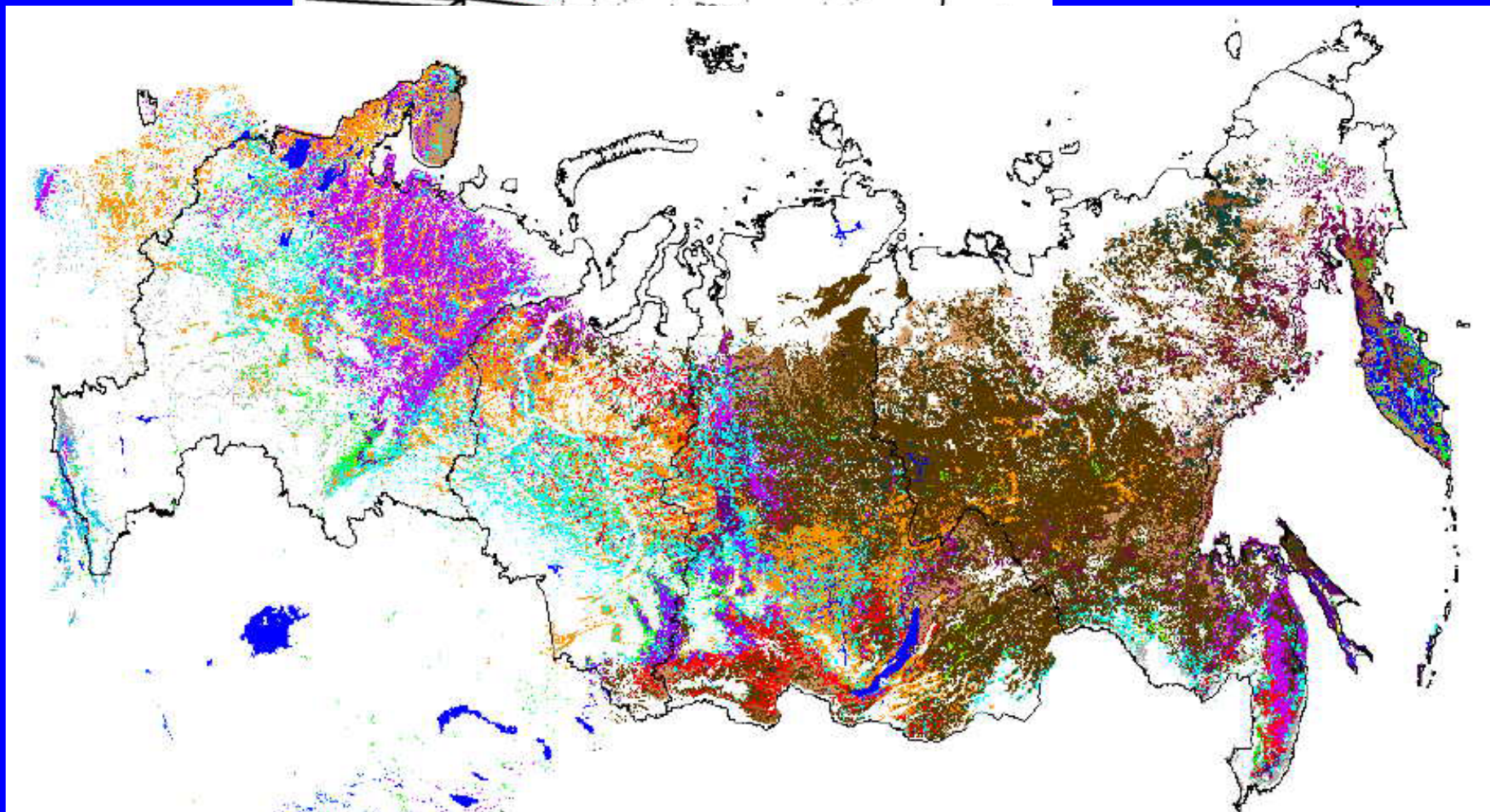
Land-Cover/Land-Use Change Program

- LCLUC is an interdisciplinary scientific theme within NASA's Earth Science program. The ultimate vision of this program is ***to develop the capability for periodic global inventories of land use and land cover from space, to develop the scientific understanding and models necessary to simulate the processes taking place, and to evaluate the consequences of observed and predicted changes***
- http://lcluc.hq.nasa.gov/

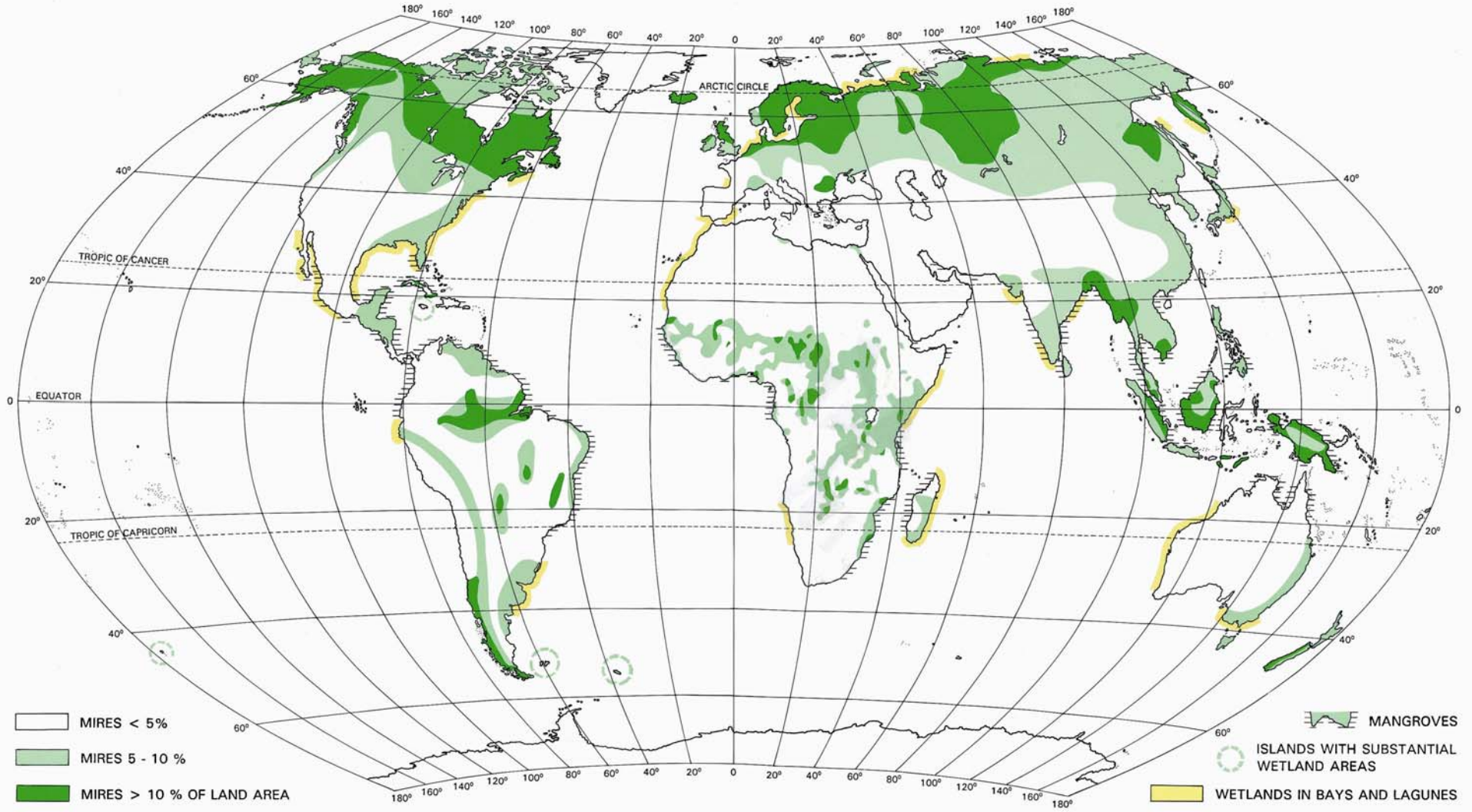


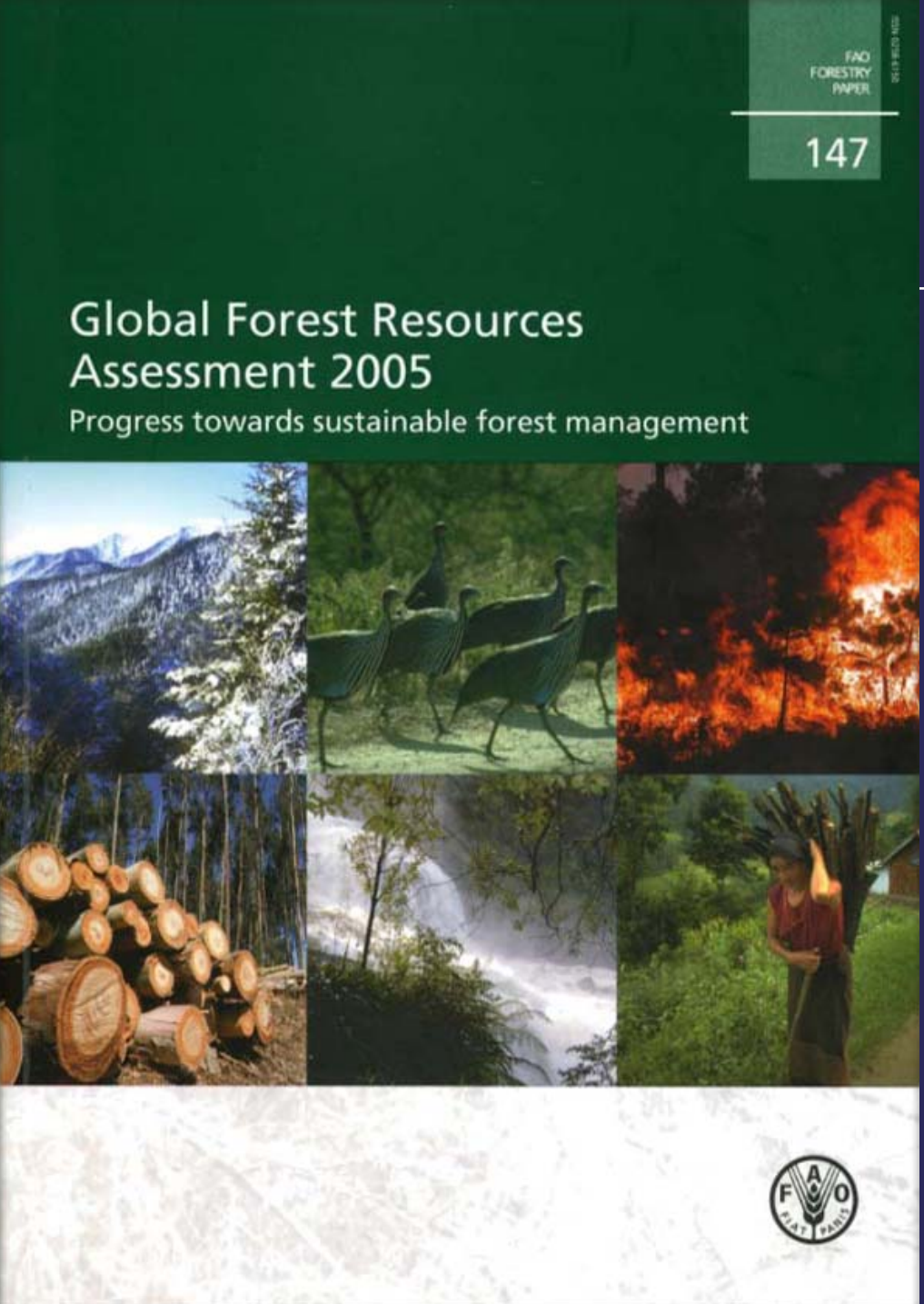
Stand-level forest inventory data





DISTRIBUTION OF MIRES





Information collected from 229 countries

Forests cover
30% of the total land area

Total forest area ~4 billion hectares or 0.62 ha per capita

Countries with largest forest area *(million ha)*

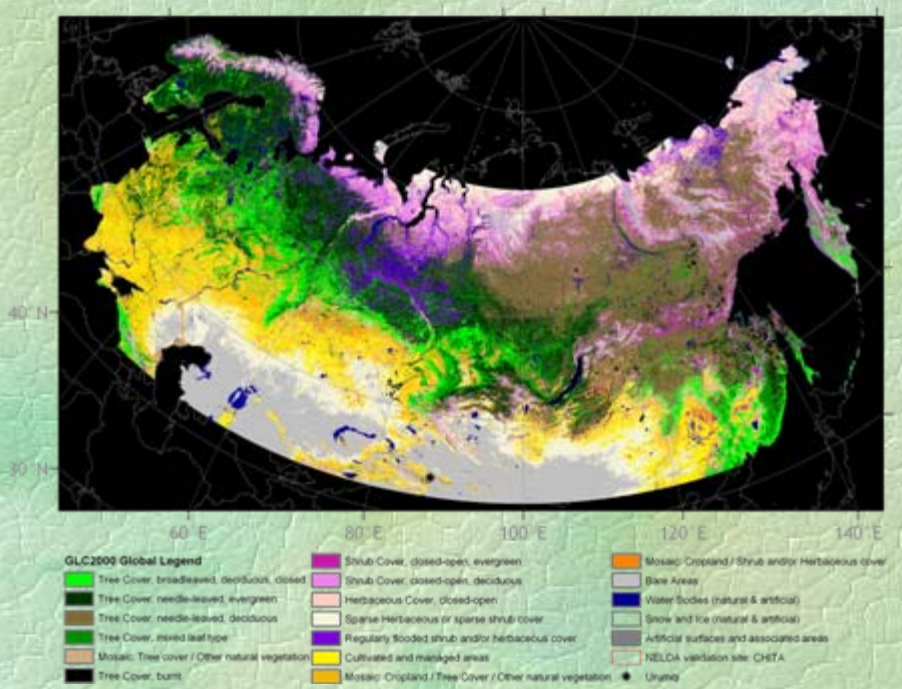
Russian Federation 809
Brazil 478
Canada 310
United States 303
China 197

Remote Sensing

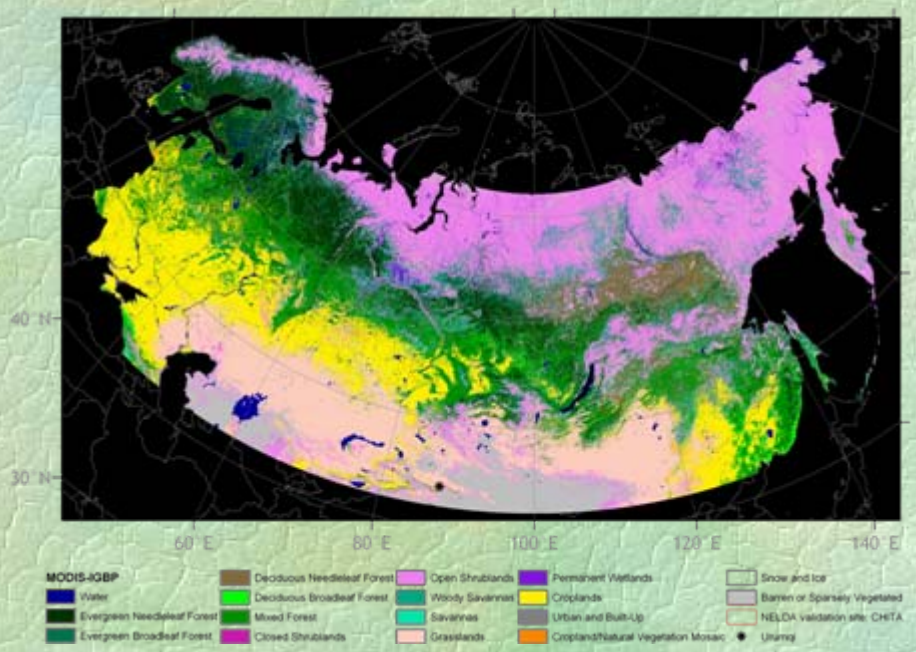
- Globally consistent source of data from which globally consistent characterization of land cover can be derived
- Data are
  - Quantitative
  - Multidimensional
    - E.g., a set of spectral bands measures at the point is space and time
  - Repeated
  - Spatially referenced
  - Known and consistent spatial resolution
  - Easily available
  - Variables measured are not those needed to classify land cover
- Methods are evolving rapidly
- Results have their specific shortcomings and limitations
  - The extraction of thematic results is neither quick nor easy

Land Cover of Northern Eurasia

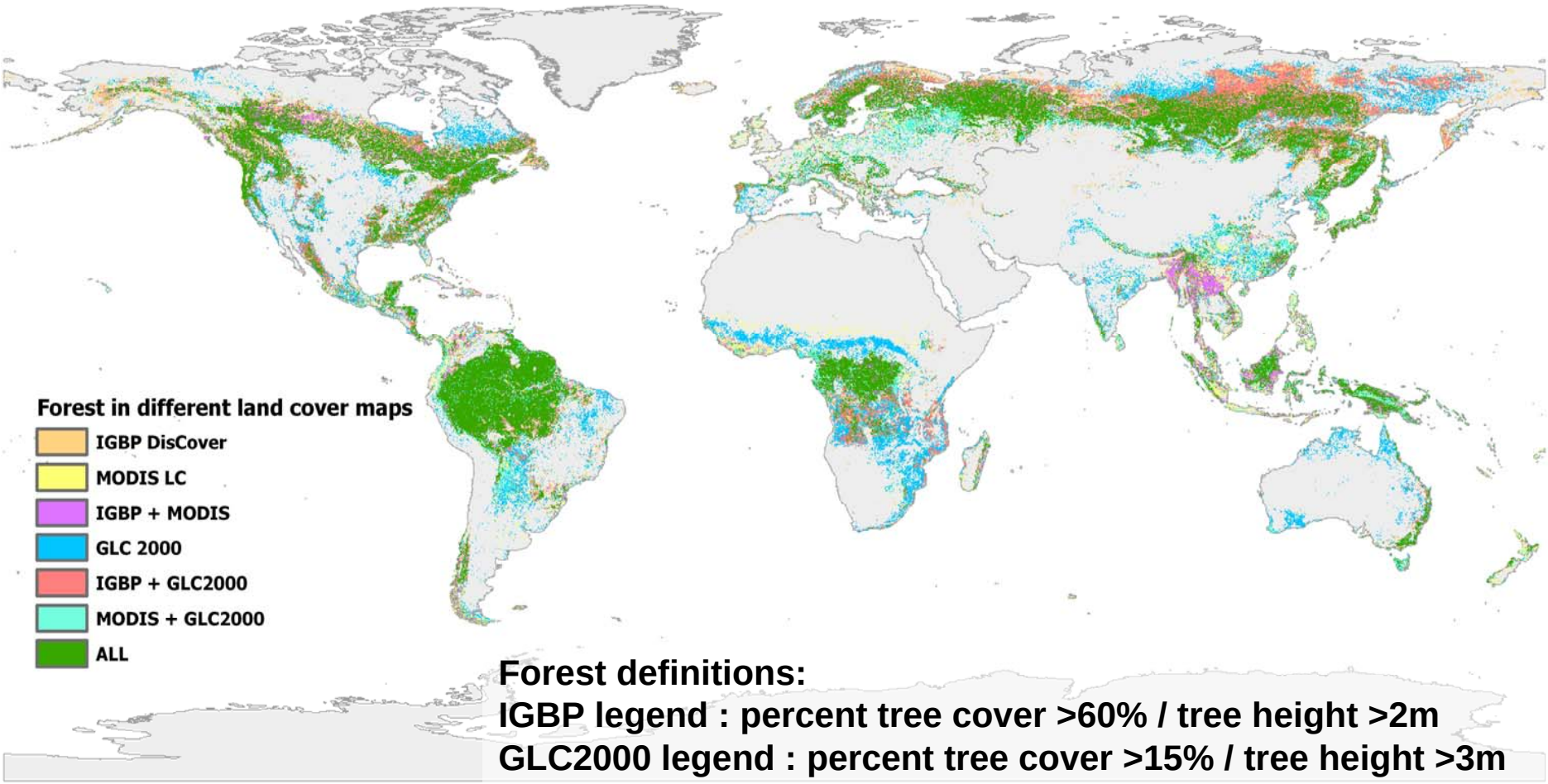
GLC2000



MODIS-IGBP 2001



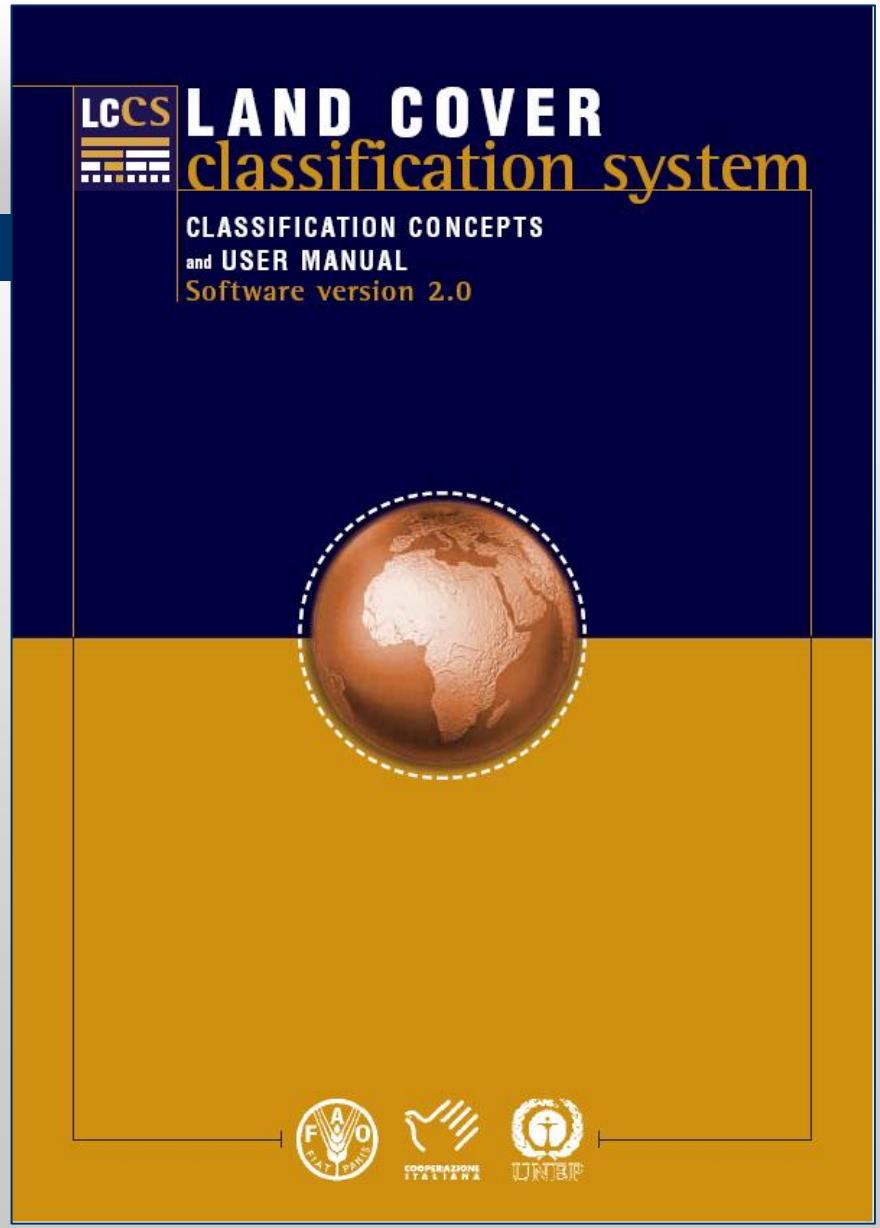
Forest areas in global land cover maps



Forest definitions:
IGBP legend : percent tree cover >60% / tree height >2m
GLC2000 legend : percent tree cover >15% / tree height >3m

LCCS to ISO TC211

- LCCS is now of an evolving standard of ISO TC 211 –
- already an FAO/UNEP standard
- Translated into Spanish, Arabic and Russian is available



Classification Concepts

Definition

Land cover is the observed (bio)physical cover on the earth's surface.

It includes vegetation and man-made features as well as bare rock, bare soil and inland water surfaces.

• LCCS is a new language to describe in a standardized way the different land cover features

• Launch of the first civilian Earth observation satellite ERTS-1 in 1972 has started a new era for Land Cover Classification as it provided a globally consistent source of data

•Many Land Cover classifications based on remotely sensed data were developed by peoples with no background in vegetation classification

• Legacy maps are limited to specific disciplines, projects or geographic area

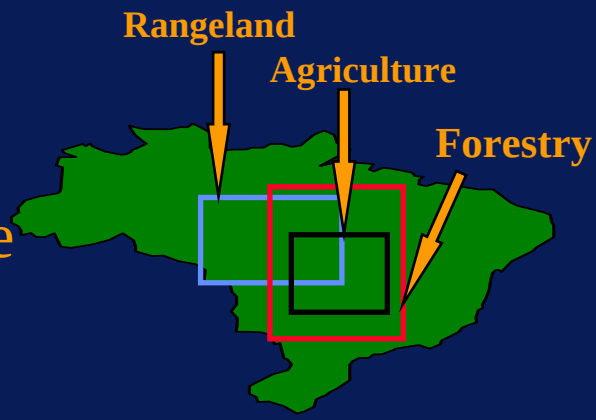
.

Negative Historical trend → **Each discipline producing is own land cover data base**

Derived consequences

- the same geographic area mapped several time

(at different scales, for different purposes, in different times, whit different type of data, whit different accuracy.)



- the legends too discipline specific

(good detail for the some specific theme poor for others)

Rangeland map

1a	1b	1c	1d	1e	1f	1g	1h	1i	1l	1m	2a	2b	3a	3b	3c	3d

Agriculture map

1a	1b	1c	1d	1e	1f	1g	1h	1i	1l	1m	2a	2b	3a	3b

Forestry map

1a	1b	1c	1d	1e	1f	1g	1h	2a	2b	3a

Natural vegetation classes

Agricultural classes

Forestry classes

THE OBJECTIVE

To produce a world-wide reference system for land cover classification

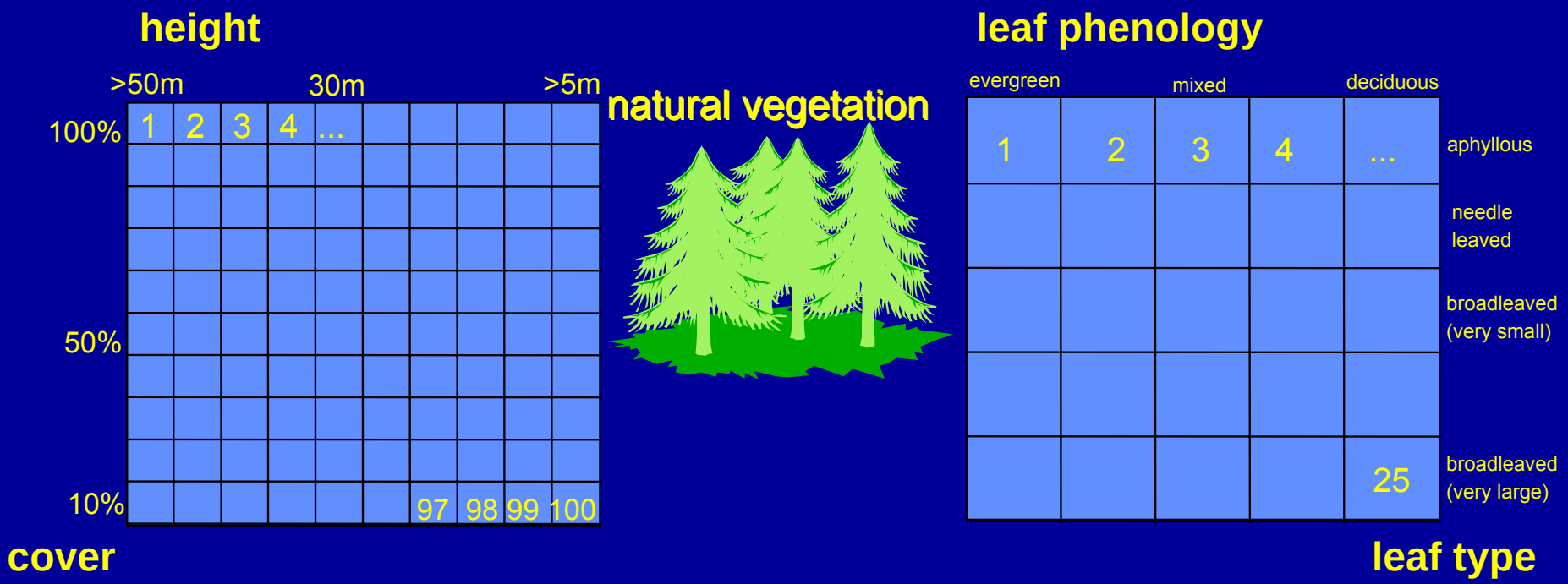
- *high level of flexibility* **(ability to describe land cover features all over the world at any scale or level of detail)**
- **an *absolute level of standardization* of the class definition**
- **hierarchy of classes for unambiguous aggregation**

THE BASIC CONCEPT

In LCCS a class is defined by a combination of *diagnostic attributes of land cover* called *classifiers*

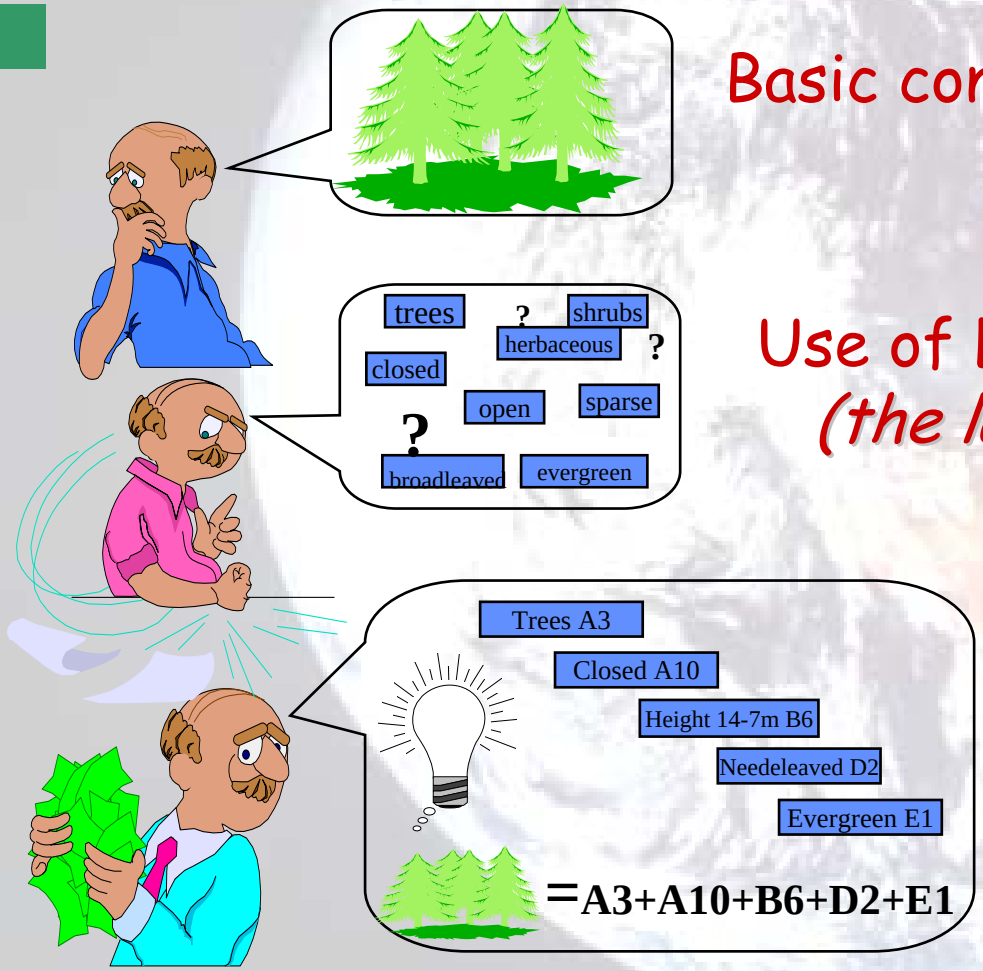
No pre-defined list of classes exists. The user creates classes -one by one- by converting the user's idea of the class, into a meaningful sequence of classifiers.

Diagnostic attributes of land cover or classifiers



Conceptual Basis

How to create Land Cover classes in LCCS :

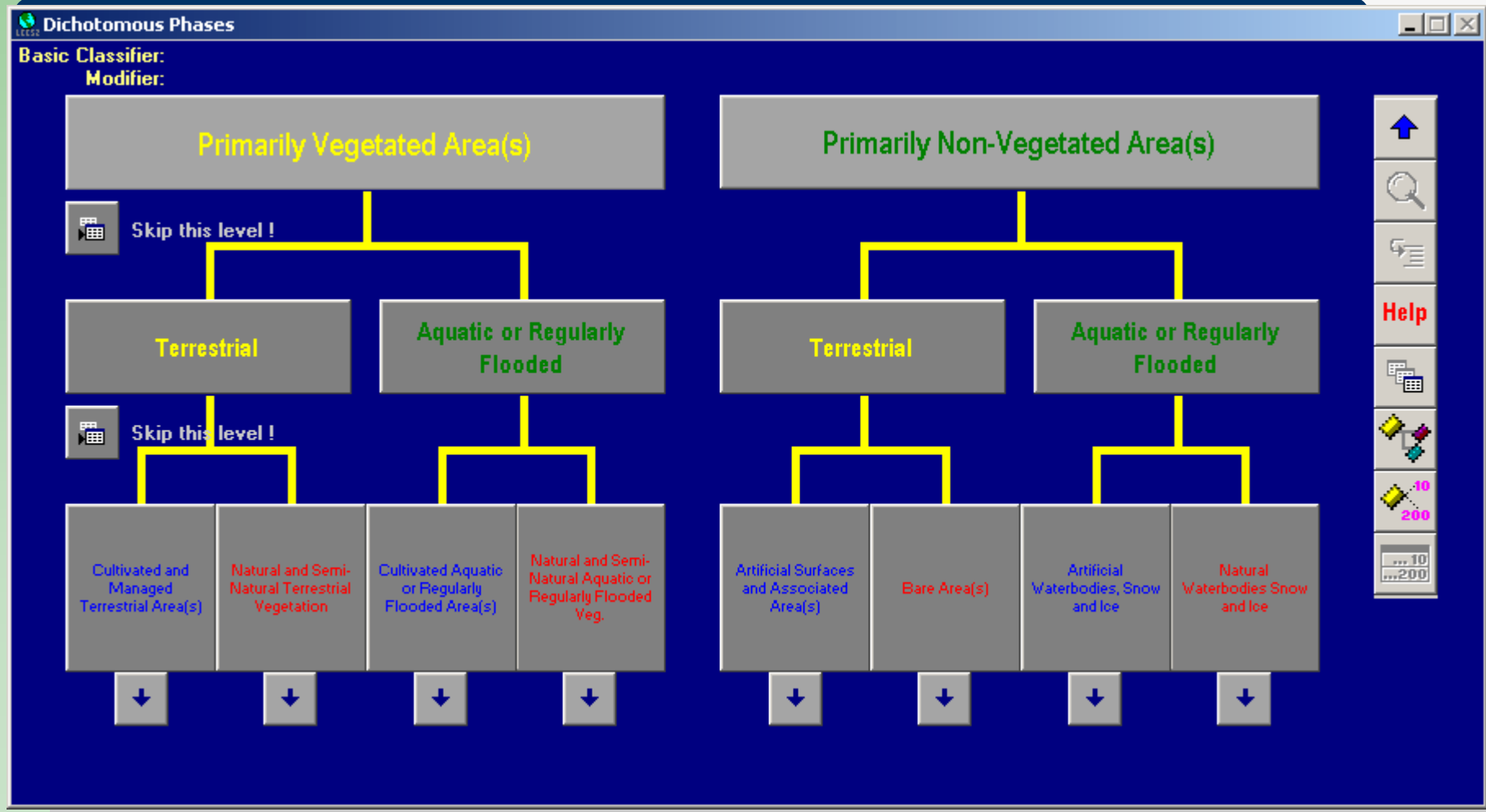


Basic concept of a land cover class
(the idea)

Use of LCCS method
(the language)

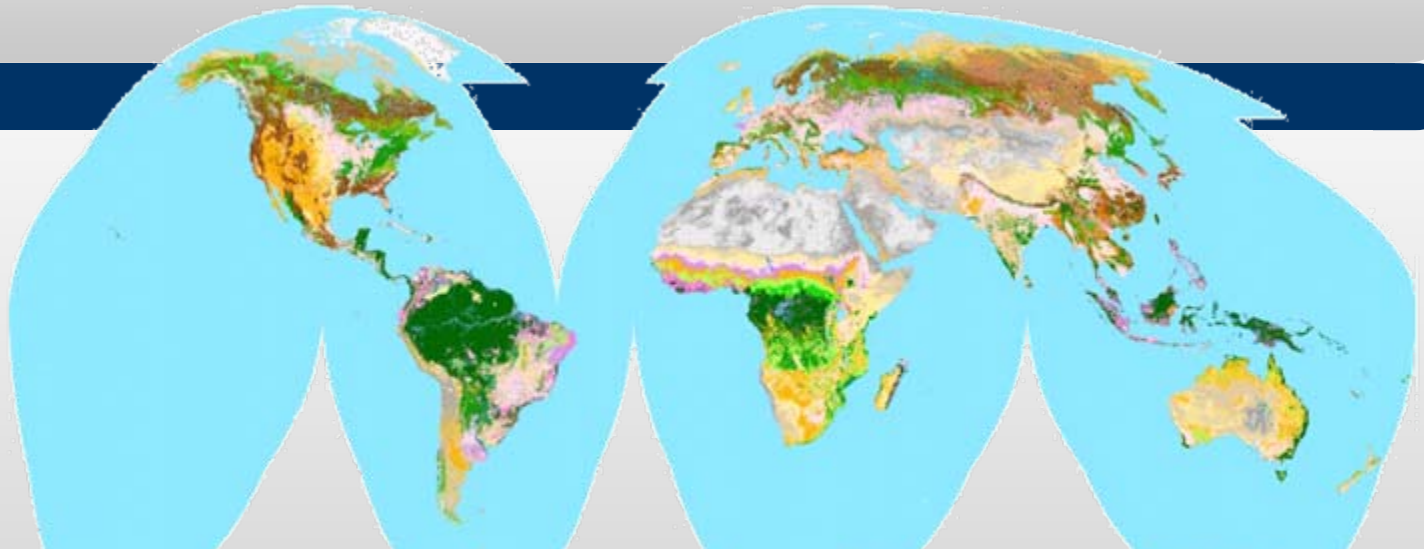
Elaboration of the concept
in the codified LCCS language
(the concept expression)

Development of LCCS v 2.0



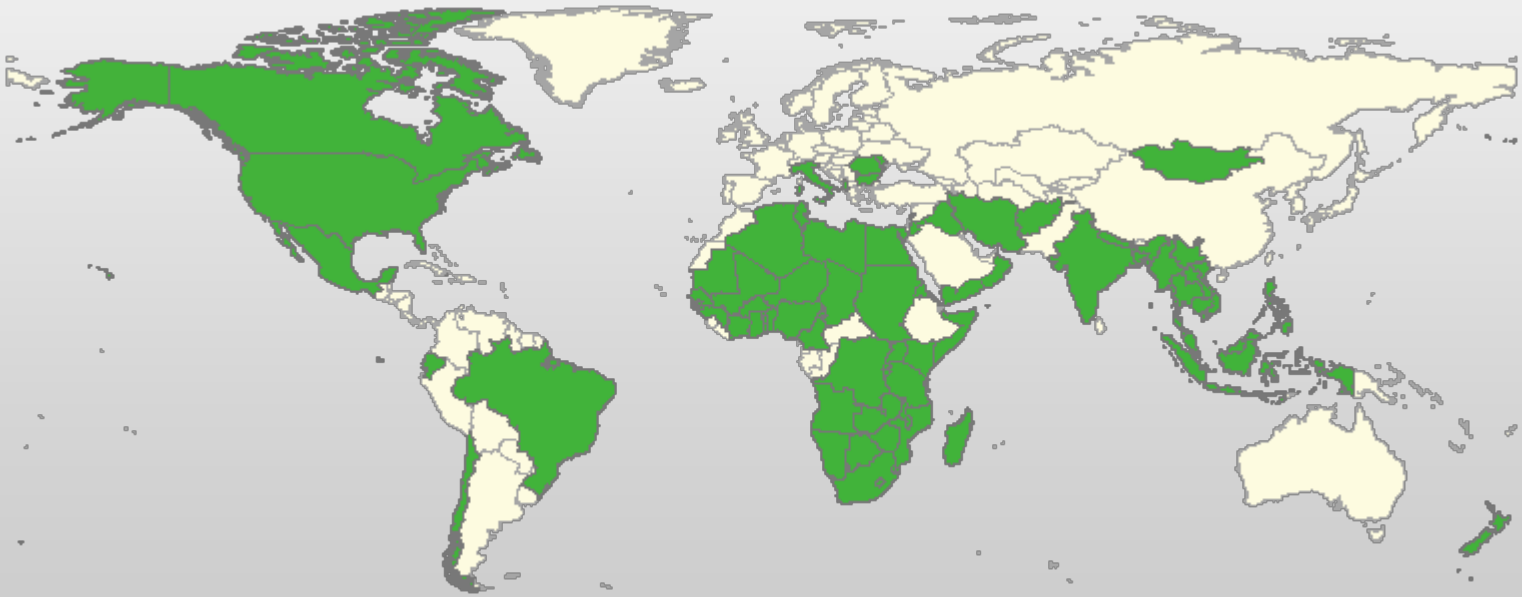
LCCS Operational Context – where is it being used?

Global Land Cover 2000 Database – JRC/EU; FAO/UNEP



Forest	Agriculture	Wetlands
Tree Cover, broadleaved evergreen	Cultivated and managed areas	Tree Cover, regularly flooded, fresh and brackish water
Tree Cover, broadleaved deciduous, closed	Mosaic: Cropland / Tree cover / Other natural vegetation	Tree cover, regularly flooded, saline water
Tree Cover, broadleaved deciduous, open	Mosaic: Cropland / Shrub or Grass Cover	Regularly flooded Shrub and/or Herbaceous cover
Tree Cover, needle-leaved evergreen	**Deserts**	**Grasslands and Shrublands**
Tree Cover, needle-leaved deciduous	Bare, sandy	Shrub Cover, closed-open, evergreen
Tree Cover, mixed leaf type	Bare, gravel	Shrub Cover, closed-open, deciduous
Mosaic: Tree cover / Other natural vegetation	Bare, rocky	Herbaceous Cover, closed-open
Tree Cover, burnt	**Other**	Sparse Herbaceous or sparse Shrub cover
Snow and Ice	Water bodies	**Urban**
Snow and Ice	No data	Artificial surfaces

LCCS Application - Countries



NELDA Land Cover Legend

***Baseline Legend*[1]**

Tree Dominated

Needleleaved

- Evergreen
  - Closed[2]
  - Open[3]
- Deciduous
  - Closed
  - Open

Broadleaved

- Evergreen
  - Closed
  - Open
- Deciduous
  - Closed
  - Open

Mixed

- Closed
- Open

Possible Additional Distinctions

Cover Detail
Mortality (yes/no, if yes what %)
Species
Wetland (yes/no)
Understory Characteristics (Shrubs or Herbaceous > 15%)
Managed Plantation (Tree Farm/Orchard)
Presence of Build up > 15%

[1] The assumption is to use high resolution imagery (20 – 50 meters) and minimum mapping unit 1 – 2 hectares
[2] Closed >(> 65) %
[3] Open (65-15)%

NELDA Land Cover Legend

Baseline Legend | ***Possible Additional Distinctions***

Herbaceous Dominated

Closed

Open

- Species (grasses, lichens, mosses, etc)
- Mortality (yes/no)
- Wetland (yes/no)
- Tundra (yes/no)
- Pasture (yes/no)
- Cultivated Lands
- Trees or shrubs < 15 % and >5% Present/not Present
- Presence of Build up > 15%

Bare Land and Sparse Vegetation

- Bare (Vegetation < 5%)
- Sparse Vegetated (Vegetation <> 15% and >< 15%)
- Presence of Build up > 15% (yes/no)

Permanent Snow and Ice

Water

Overview

St. Petersburg
Carpathians
Komi
Chita
Priangare
Kazakhstan
Amur
Vasyugan
Sikhote-Alin
Mongolia
Yoshkar Ola

Global Land Cover

To identify specific needs and possibilities for improved mapping of land cover across boreal and temperate Northern Eurasia, we compared the performance of recent land-cover products derived from different sensors: MODIS (MODIS IGBP Land Cover Collection 4 and 5), SPOT VEGETATION (GLC-2000) and MERIS (GLOBCOVER).

What are the differences and similarities between global datasets?

We examined the level of agreement among these data sets across the entire region. On a qualitative level, the assessment of general patterns indicates the highest degree of disagreement in transitional zones at the northern and southern fringes of boreal forest, in mountainous regions, and in areas of extensive wetlands, agricultural development, and urban land use. The quantitative analysis measured the level of disagreement between land-cover classes aggregated according to dominant life form type of vegetation (trees, shrubs, herbaceous, bare land, and permanent snow/ice).

What is the accuracy of global maps at NELDA test sites?

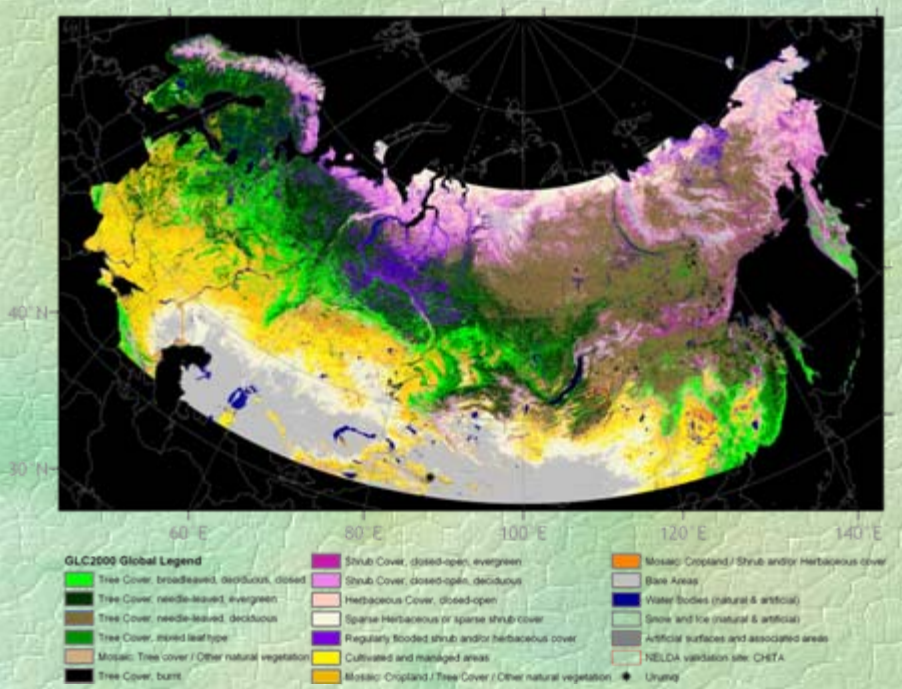
Validation of global datasets was performed with higher resolution, Landsat-based land cover maps from NELDA test sites. Fractional land cover was calculated for coarse resolution pixel and used to construct fractional error matrices. Most errors were associated with "mixed" coarse-resolution pixels (i.e. those having nearly equal percentage of multiple class types), while errors in "pure" (single class) pixels were low. In addition to actual differences in land-cover classifications, other sources of discrepancy among these land cover products include class definitions, map projections, and spatial resolution.

Dominant Live Form Types

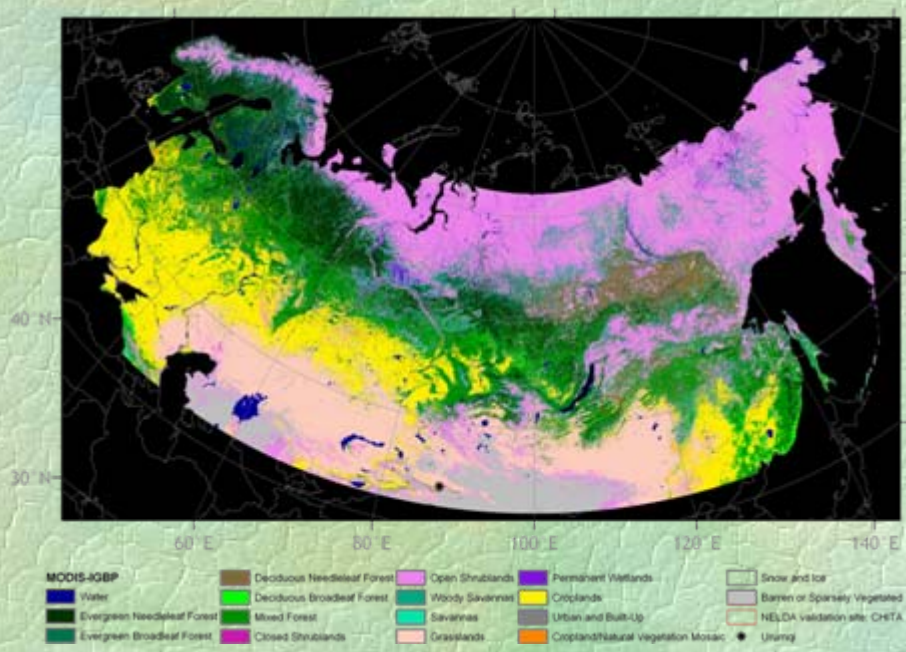
Differences in class definitions and legends between maps are a major difficulty for comparing global land cover data sets. We converted each legend to a standard classification on the basis of the dominant live form types (LFT): tree, shrub, herbaceous and barren/sparse vegetation and water. Classes representing mixtures of vegetation types were labeled as 'mosaic'. Select a site on the left menu to compare LFT maps derived from global land cover datasets with Landsat-based reference maps.

Land Cover of Northern Eurasia

GLC2000



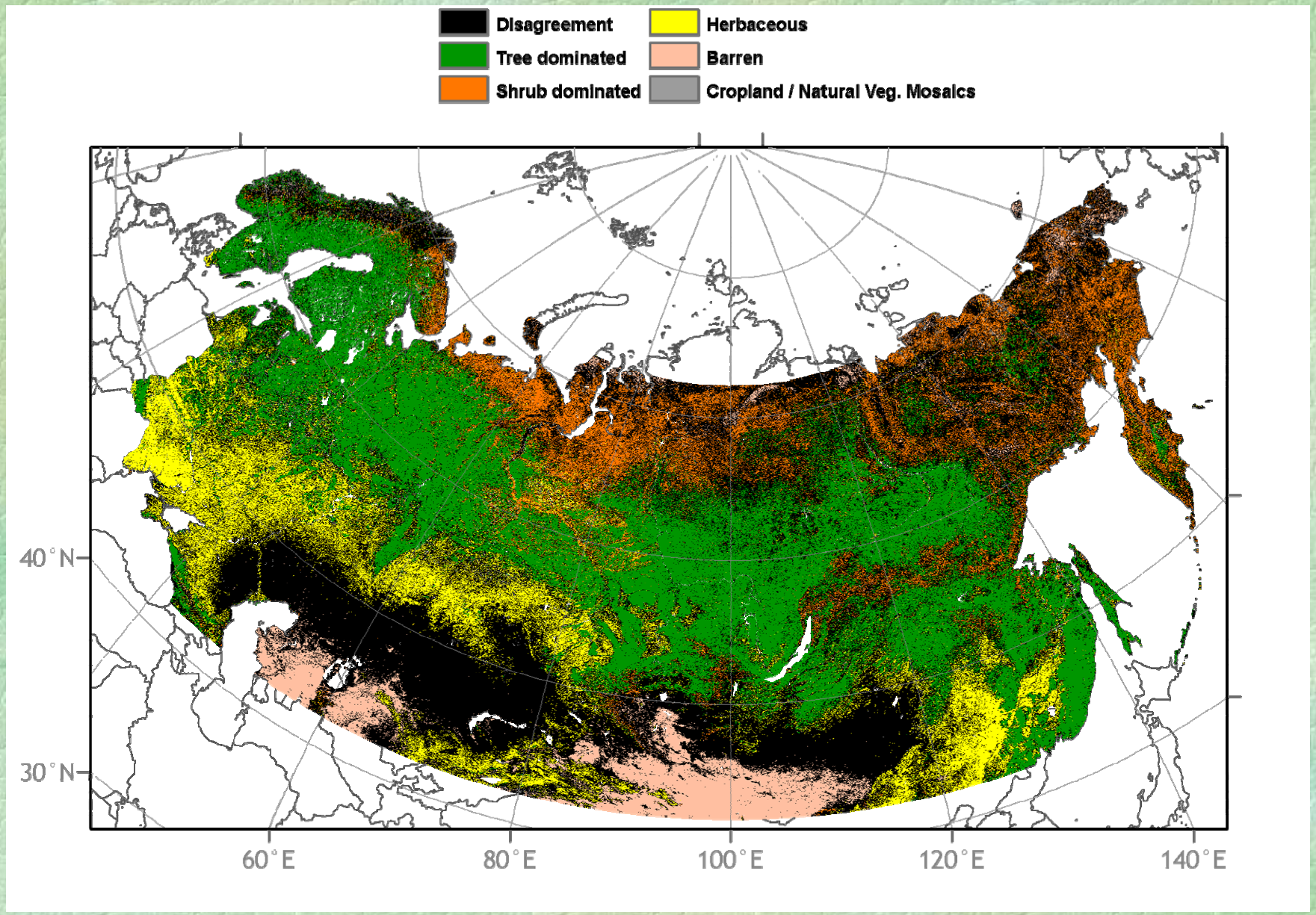
MODIS-IGBP 2001



Similarity matrix for the legends

GLC-2000.LCCS (rows) MODIS.PFT (columns)		1 Needleleaf evergreen tree	2 Broadleaf evergreen tree	3 Needleleaf deciduous tree	4 Broadleaf deciduoud tree	5 Shrub	6 Grass	7 Cereal crop	8 Broadleaf crop	9 Urban and built-up	10 Snow and ice	11 Barren or sparsely vegetated	0 Water
1	Tree Cover, broadleaved, evergreen	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
2	Tree Cover, broadleaved, deciduous, closed	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
3	Tree Cover, broadleaved, deciduous, open	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
4	Tree Cover, needle-leaved, evergreen	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
5	Tree Cover, needle-leaved, deciduous	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
6	Tree Cover, mixed leaf type	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
7	Tree Cover, regularly flooded, fresh water	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
8	Tree Cover, regularly flooded, saline water	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
9	Mosaic: Tree cover / Other natural vegetation	T	T	T	T	S	H	th	th	tb	tb	tb	lw
10	Tree Cover, burnt	T	T	T	T	ts	th	th	th	tb	tb	tb	lw
11	Shrub Cover, closed-open, evergreen	ts	ts	ts	ts	S	sh	sh	sh	sb	sb	sb	lw
12	Shrub Cover, closed-open, deciduous	ts	ts	ts	ts	S	sh	sh	sh	sb	sb	sb	lw
13	Herbaceous Cover, closed-open	th	th	th	th	sh	H	H	H	hb	hb	hb	lw
14	Sparse Herbaceous or sparse shrub cover	tb	tb	tb	tb	sb	hb	hb	hb	B	B	B	lw
15	Regularly flooded shrub and/or herbaceous cover	ts	ts	ts	ts	S	H	H	H	hb	hb	hb	lw
16	Cultivated and managed areas	th	th	th	th	sh	H	H	H	hb	hb	hb	lw
17	Mosaic: Cropland / Tree Cover / Other natural vegetation	T	T	T	T	S	H	H	H	hb	hb	hb	lw

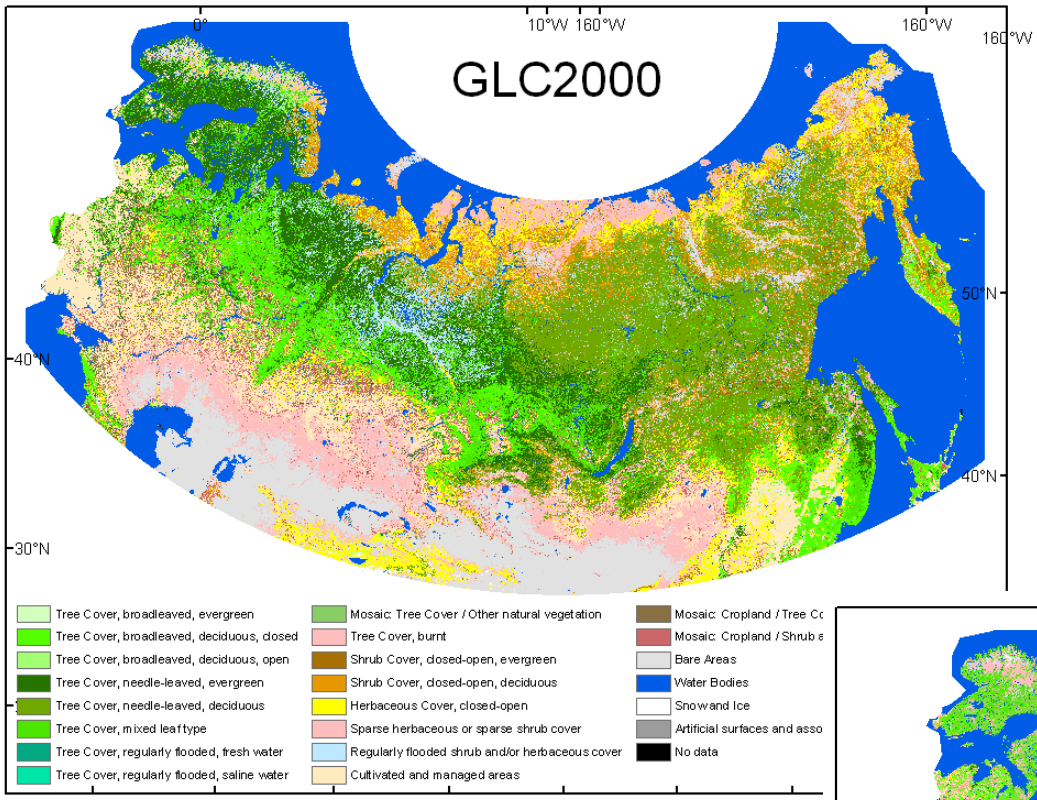
Agreement in dominant vegetation cover (54%)

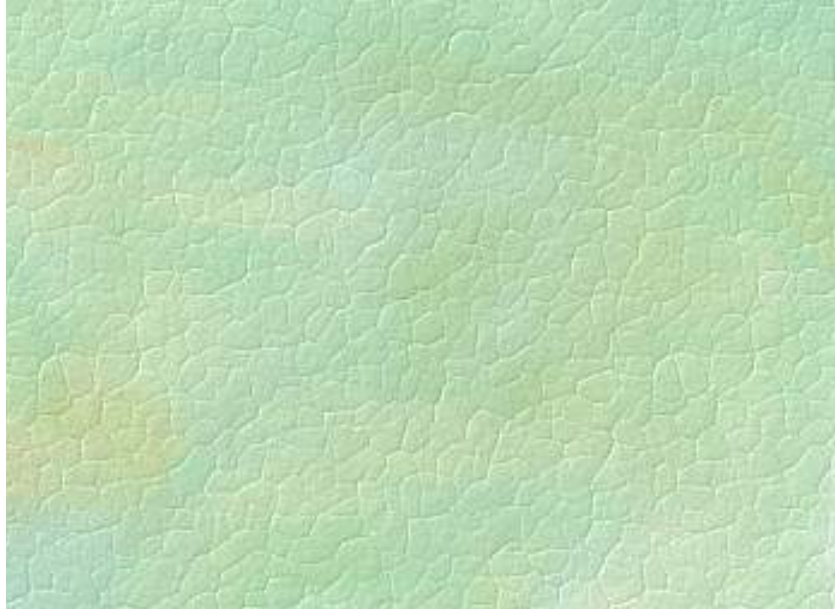


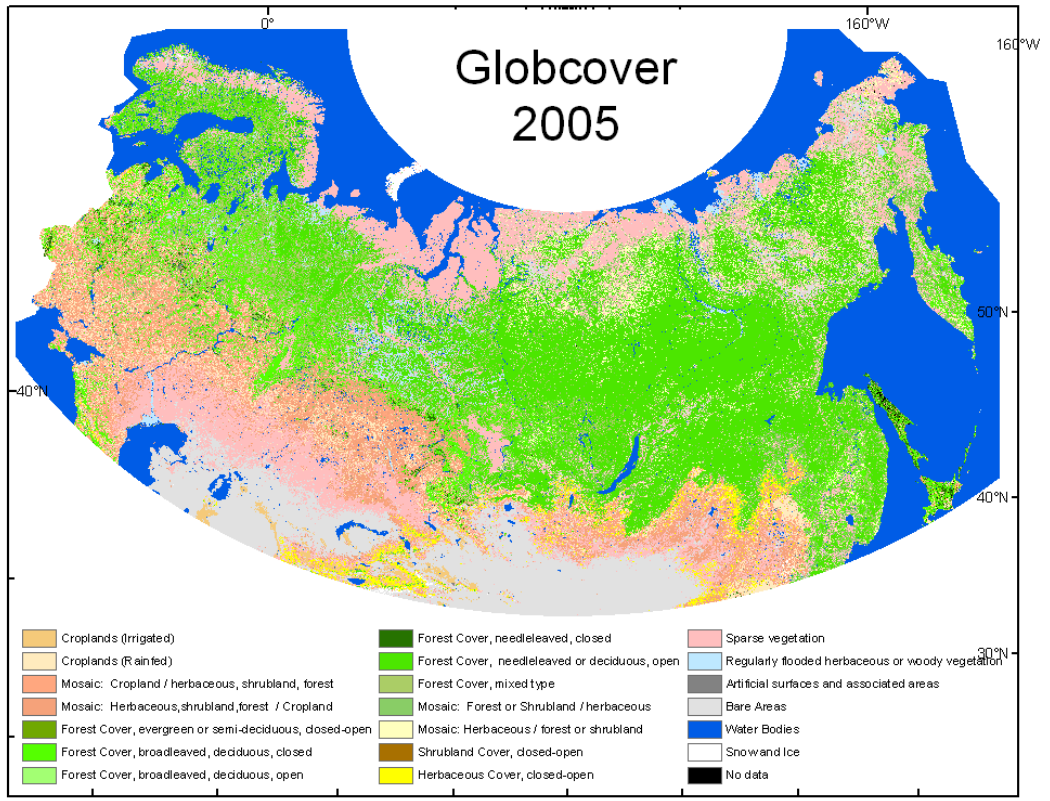
Agreement matrix for GLC-2000 and MODIS.PFT

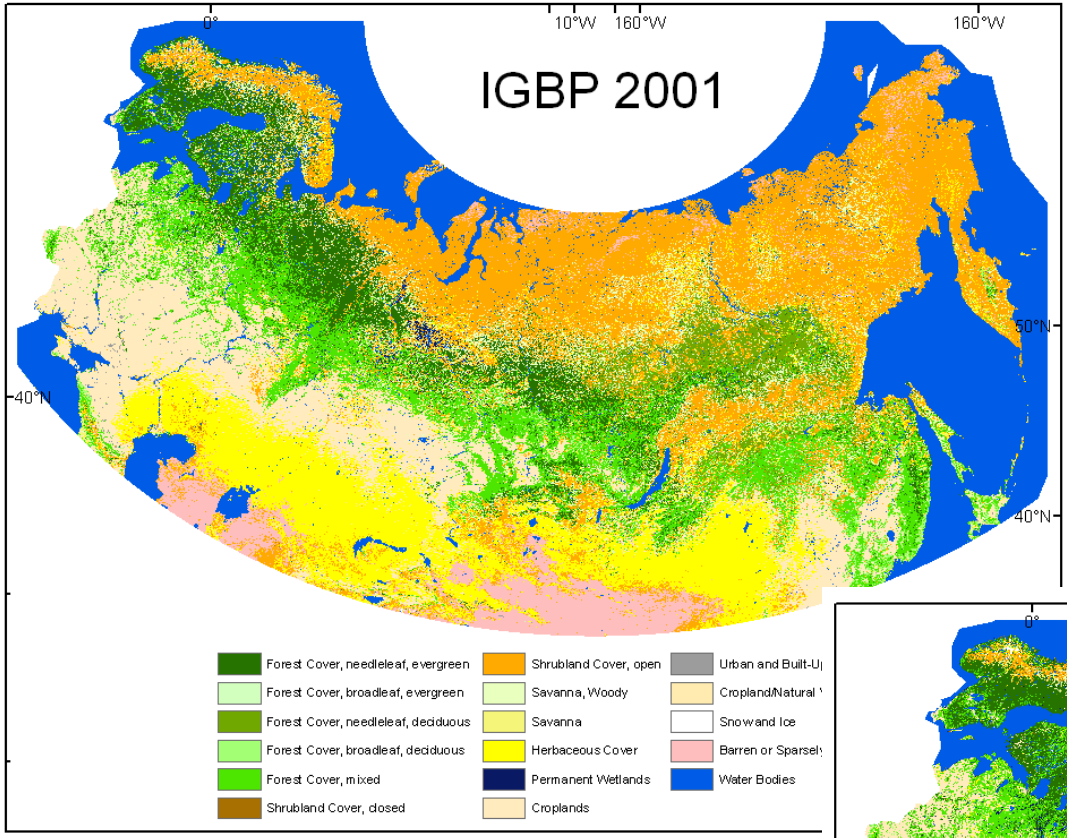
dominant vegetation types excluding water, 1000 km^2

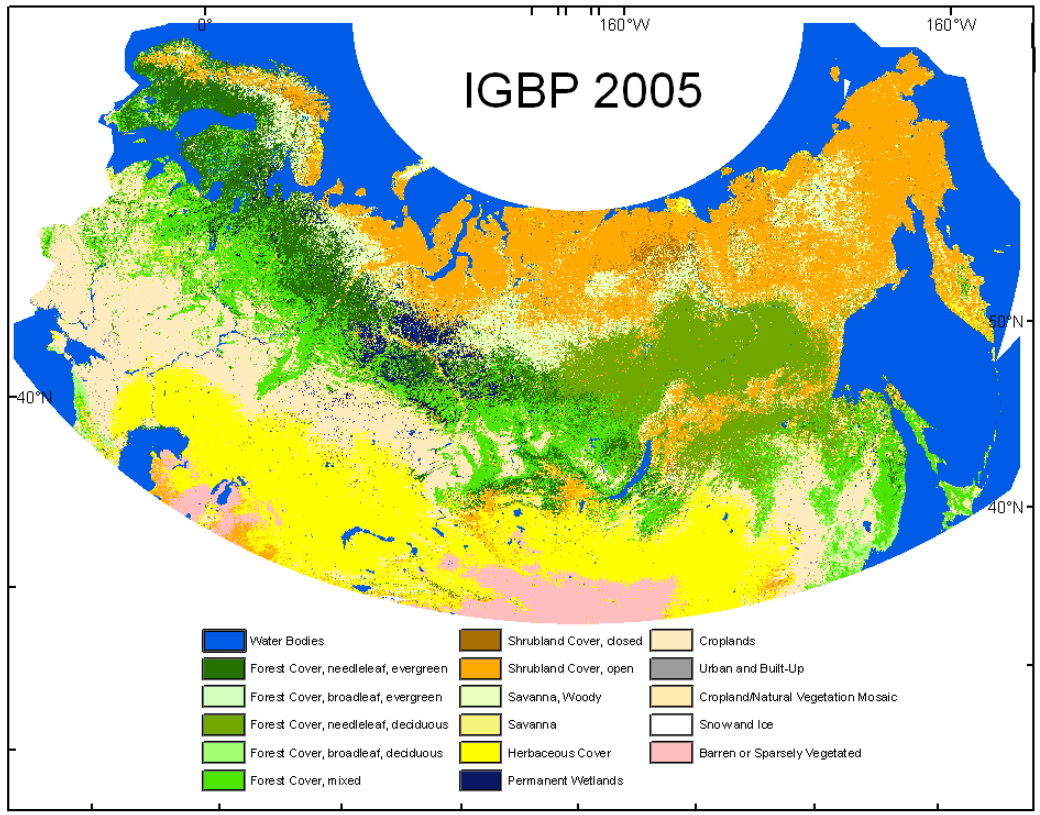
	MODIS.PFT					
GLC-2000	Tree	Shrub	Herbaceous	Barren		Agreement
Tree	**2,395**	1,697	351	7	4,450	54%
Shrub	200	**1,922**	105	31	2,258	85%
Herbaceous	24	698	**160**	34	916	17%
Barren	12	973	64	**183**	1,232	15%
	2,630	5,290	680	255	8,855	
Agreement	91%	36%	23%	72%		53%

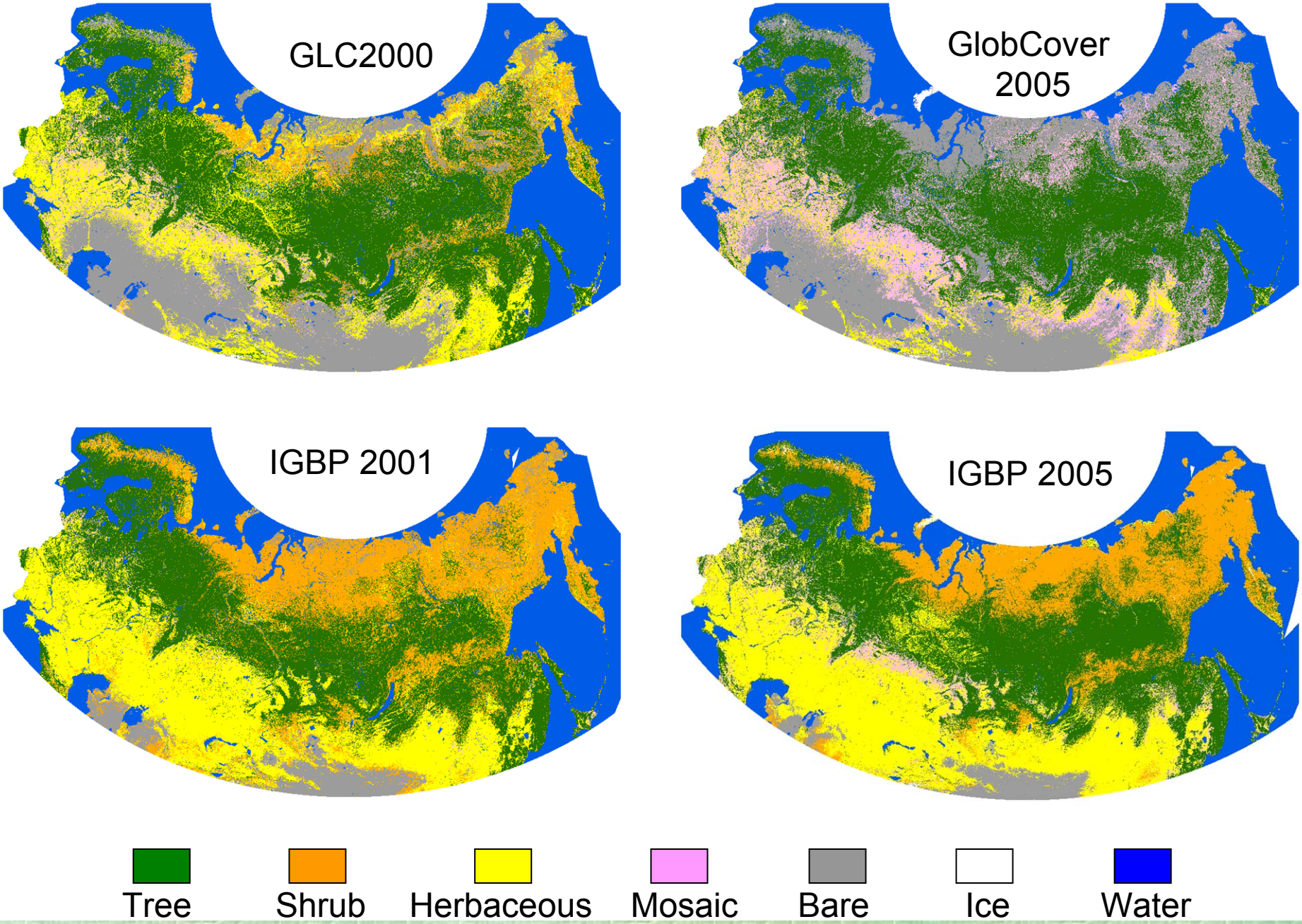

GLC2000
0°
10°W 160°W
160°W
160°W
50°N
40°N
40°N
30°N
Tree Cover, broadleaved, evergreen
Tree Cover, broadleaved, deciduous, closed
Tree Cover, broadleaved, deciduous, open
Tree Cover, needle-leaved, evergreen
Tree Cover, needle-leaved, deciduous
Tree Cover, mixed leaf type
Tree Cover, regularly flooded, fresh water
Tree Cover, regularly flooded, saline water
Mosaic: Tree Cover / Other natural vegetation
Tree Cover, burnt
Shrub Cover, closed-open, evergreen
Shrub Cover, closed-open, deciduous
Herbaceous Cover, closed-open
Sparse herbaceous or sparse shrub cover
Regularly flooded shrub and/or herbaceous cover
Cultivated and managed areas
Mosaic: Cropland / Tree Cc
Mosaic: Cropland / Shrub a
Bare Areas
Water Bodies
Snow and Ice
Artificial surfaces and asso
No data



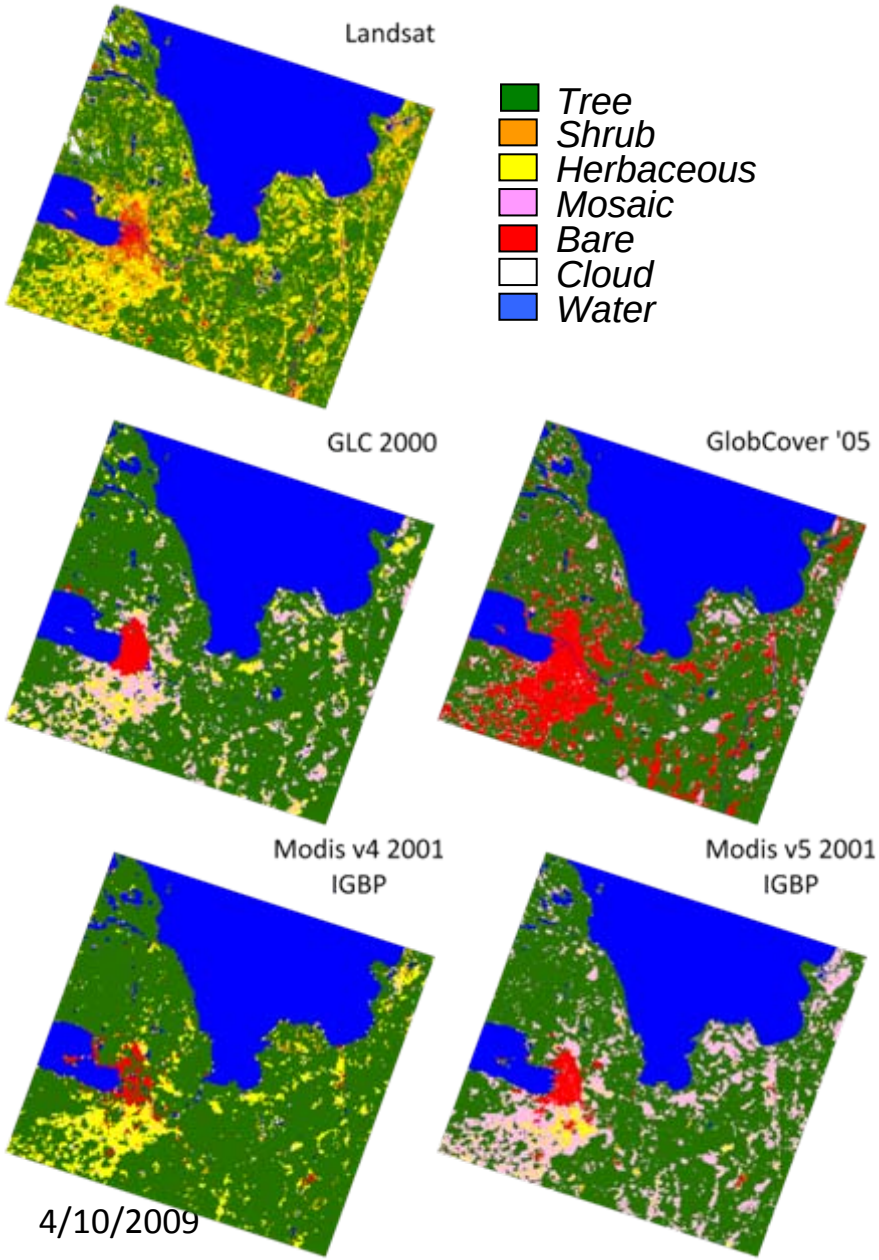

Globcover
2005
0°
160°W
160°W
50°N
40°N
40°N
30°N
Croplands (Irrigated)
Croplands (Rainfed)
Mosaic: Cropland / herbaceous, shrubland, forest
Mosaic: Herbaceous,shrubland,forest / Cropland
Forest Cover, evergreen or semi-deciduous, closed-open
Forest Cover, broadleaved, deciduous, closed
Forest Cover, broadleaved, deciduous, open
Forest Cover, needleleaved, closed
Forest Cover, needleleaved or deciduous, open
Forest Cover, mixed type
Mosaic: Forest or Shrubland / herbaceous
Mosaic: Herbaceous / forest or shrubland
Shrubland Cover, closed-open
Herbaceous Cover, closed-open
Sparse vegetation
Regularly flooded herbaceous or woody vegetation
Artificial surfaces and associated areas
Bare Areas
Water Bodies
Snow and Ice
No data


IGBP 2001
0°
10°W
160°W
160°W
50°N
40°N
40°N
Forest Cover, needleleaf, evergreen
Forest Cover, broadleaf, evergreen
Forest Cover, needleleaf, deciduous
Forest Cover, broadleaf, deciduous
Forest Cover, mixed
Shrubland Cover, closed
Shrubland Cover, open
Savanna, Woody
Savanna
Herbaceous Cover
Permanent Wetlands
Croplands
Urban and Built-Up
Cropland/Natural
Snow and Ice
Barren or Sparsely
Water Bodies

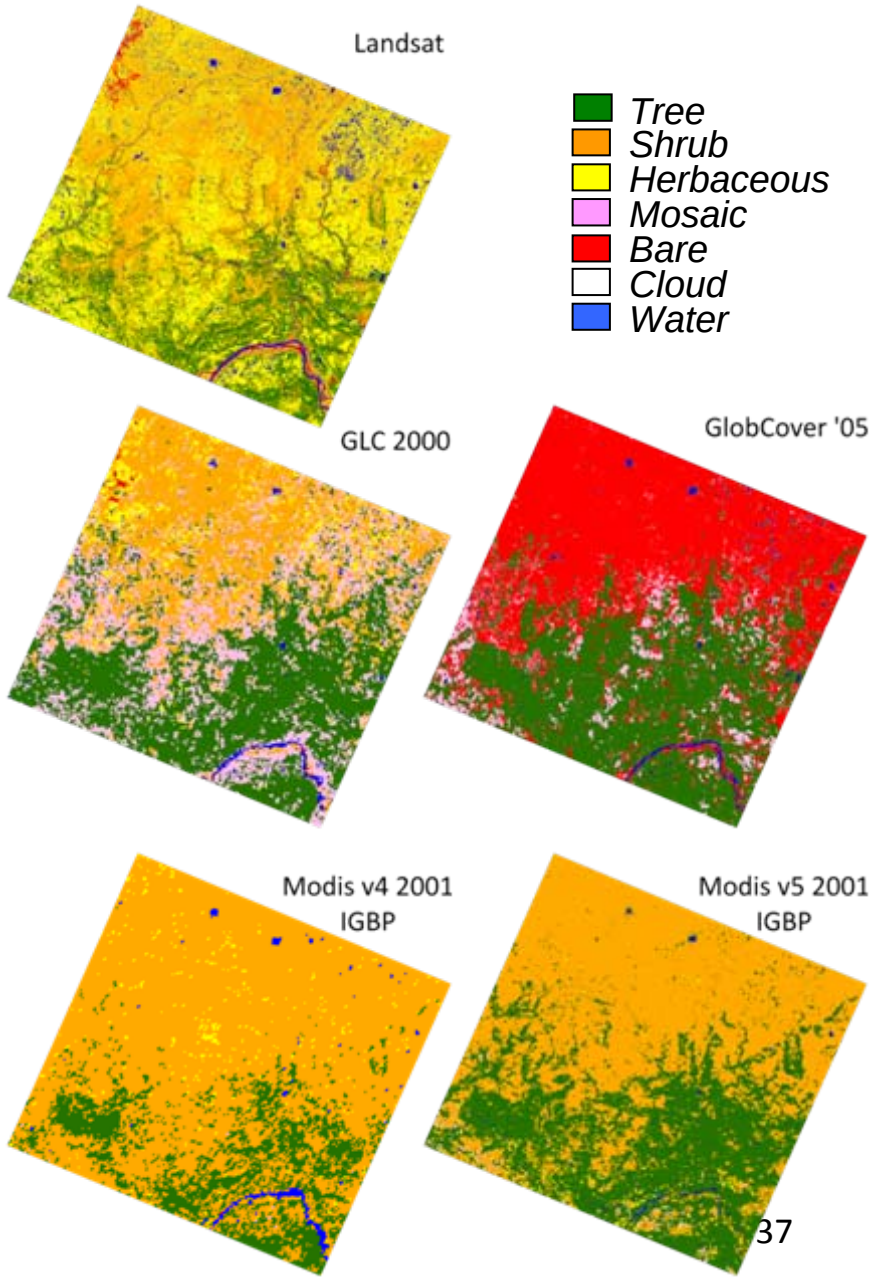

IGBP 2005
0°
160°W
160°W
50°N
40°N
40°N
Water Bodies
Forest Cover, needleleaf, evergreen
Forest Cover, broadleaf, evergreen
Forest Cover, needleleaf, deciduous
Forest Cover, broadleaf, deciduous
Forest Cover, mixed
Shrubland Cover, closed
Shrubland Cover, open
Savanna, Woody
Savanna
Herbaceous Cover
Permanent Wetlands
Croplands
Urban and Built-Up
Cropland/Natural Vegetation Mosaic
Snow and Ice
Barren or Sparsely Vegetated

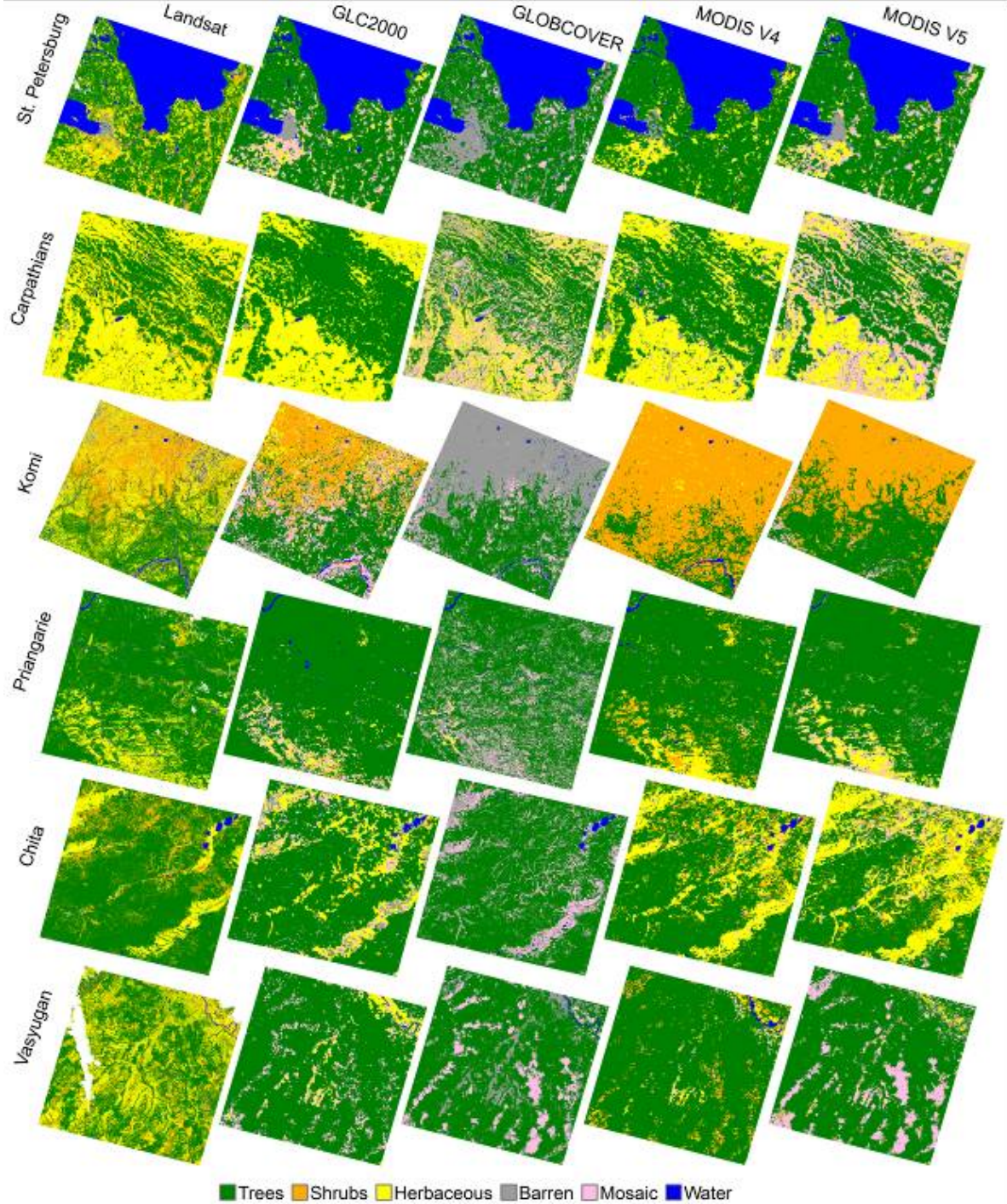

GLC2000
GlobCover 2005
IGBP 2001
IGBP 2005
Tree
Shrub
Herbaceous
Mosaic
Bare
Ice
Water

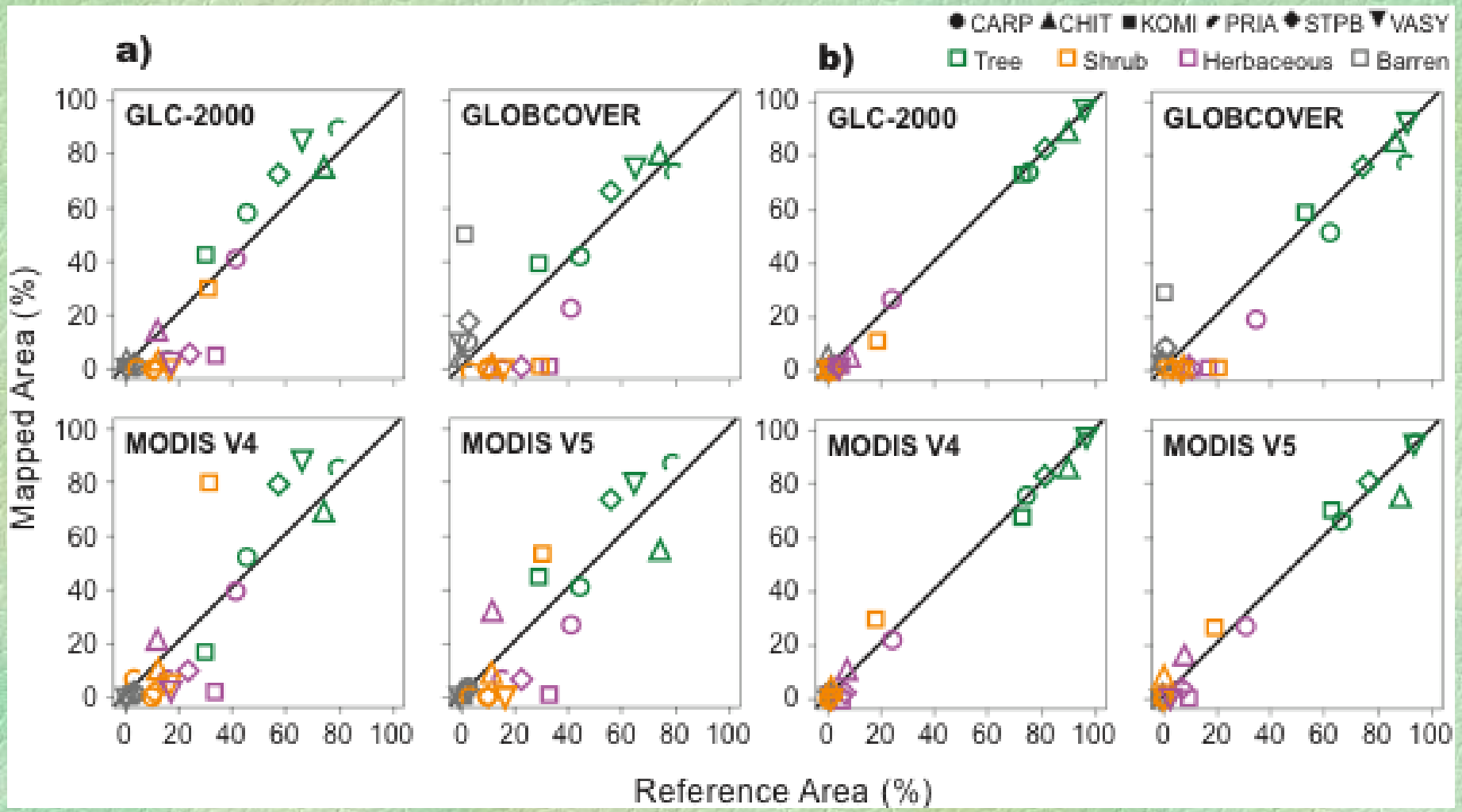
St. Petersburg

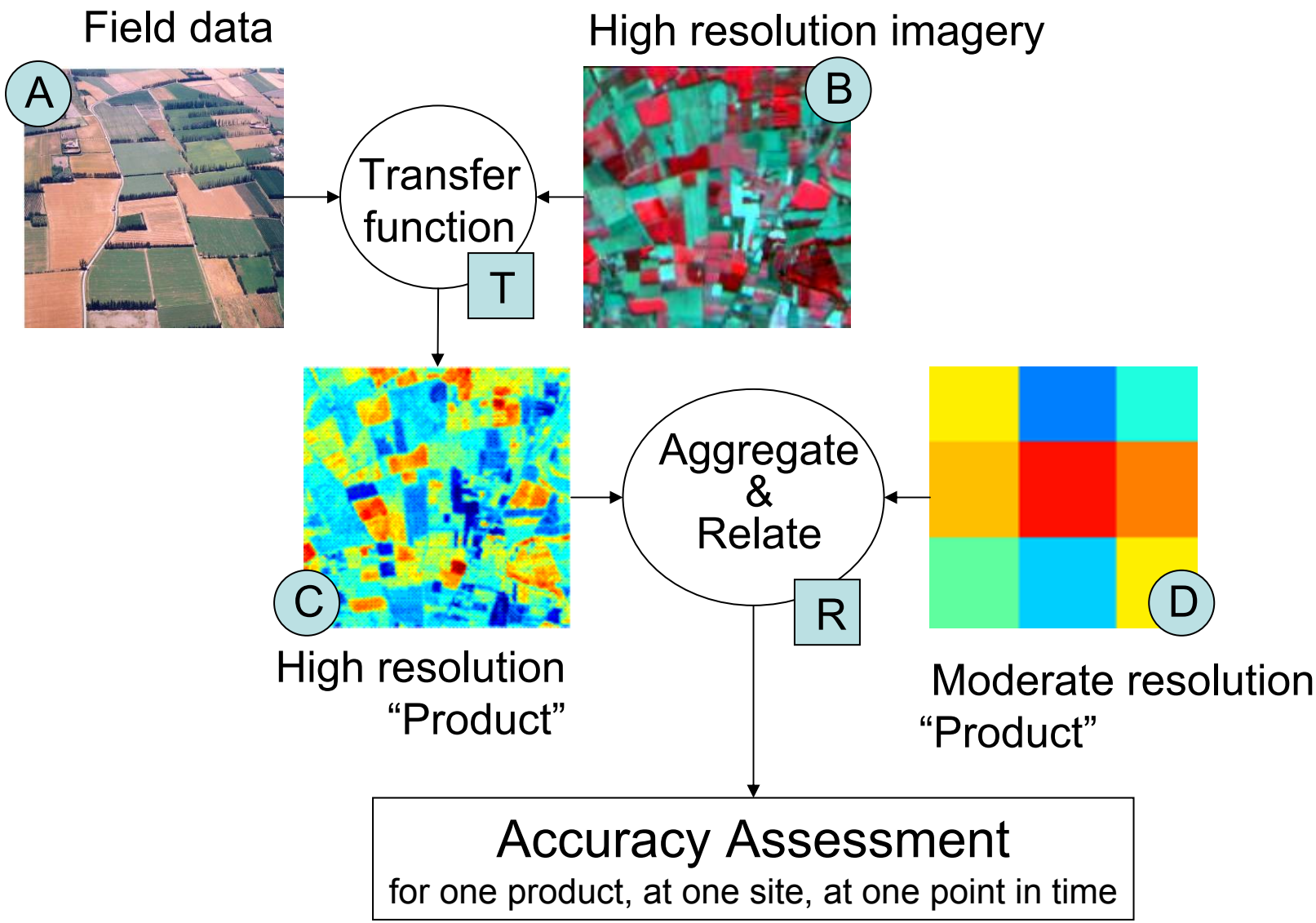


Komi

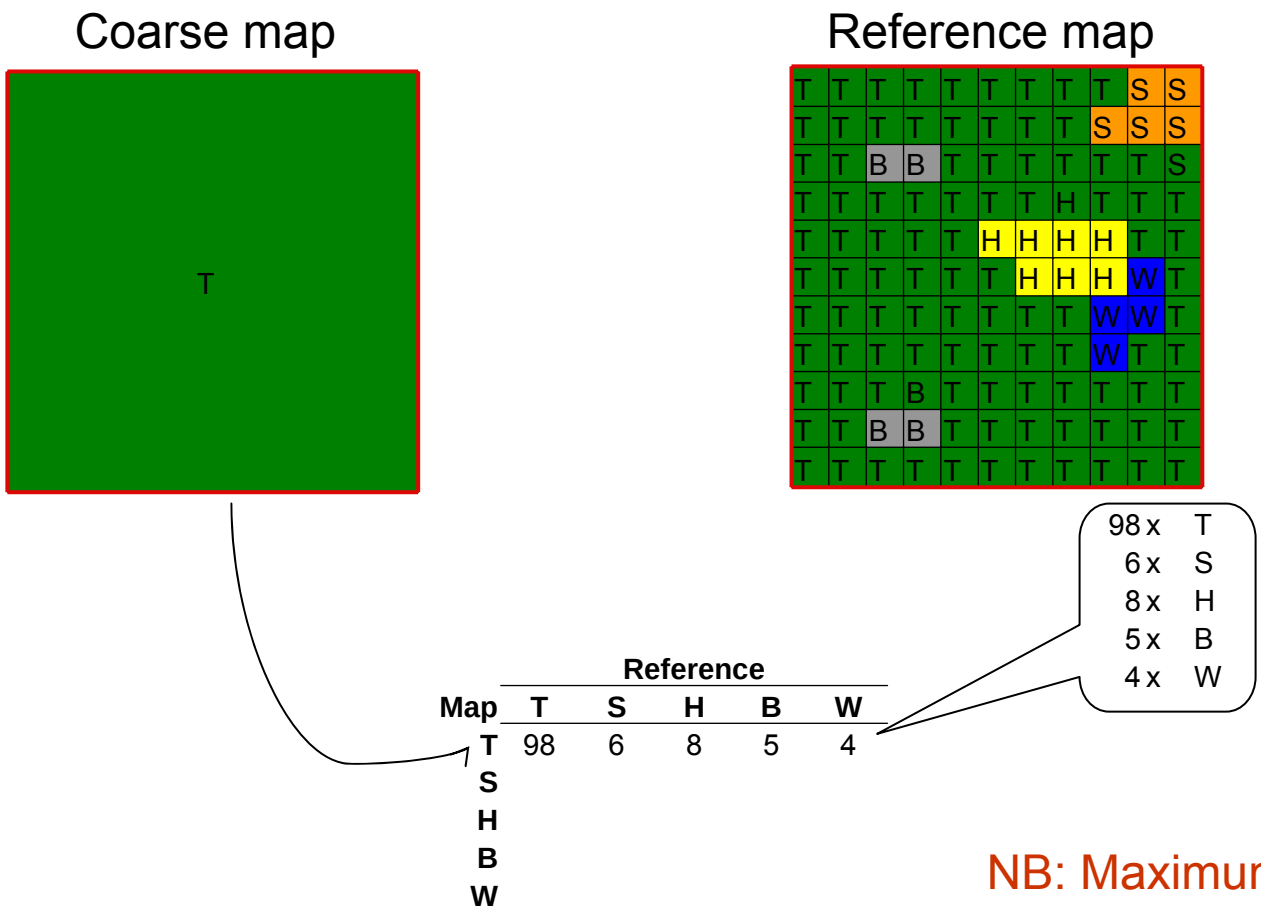



Landsat
GLC2000
GLOBCOVER
MODIS V4
MODIS V5
St. Petersburg
Carpathians
Komi
Priangarie
Chita
Vasyugan
Trees
Shrubs
Herbaceous
Barren
Mosaic
Water


CARP CHIT KOMI PRIA STPB VASY
Tree Shrub Herbaceous Barren
a)
b)
GLC-2000
GLOBCOVER
MODIS V4
MODIS V5
Mapped Area (%)
Reference Area (%)
0 20 40 60 80 100


Field data
High resolution imagery
A
B
Transfer function
T
C
Aggregate & Relate
R
D
High resolution "Product"
Moderate resolution "Product"
Accuracy Assessment
for one product, at one site, at one point in time

Confusion matrix: **pixel-based**



NB: Maximum achievable agreement < 100%

Agreement matrix for St. Petersburg site, km^2

GLC-2000	**NELDA land cover (km^2)**					
	Trees	Shrubs	Herbaceous	Barren	Water	Commission
Trees	**11,264**	1,103	2,635	177	298	4,213
Shrubs	1	**2**	2	1	0	5
Herbaceous	324	444	**926**	97	32	1,499
Barren	39	44	96	**239**	25	404
Mosaics	**535**	**671**	**1,349**	**133**	33	2,186
Water	167	33	87	47	**940**	1,107
Omission	1,066	1,194	2,460	517	1,030	

Agreement = 73.2%, Kappa = 50.5%

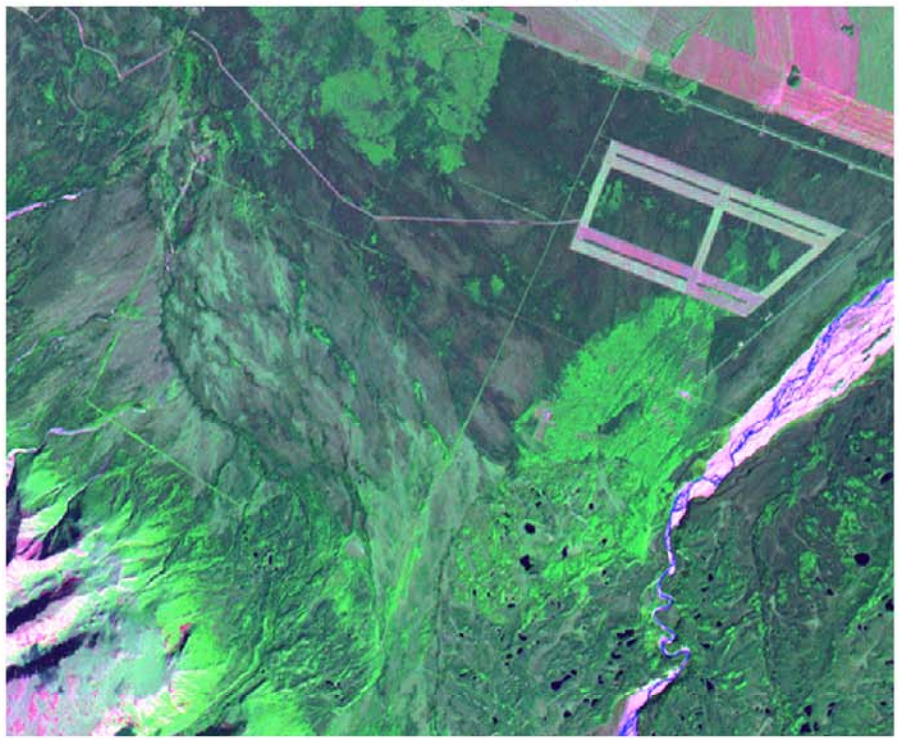
Accuracy Assessment Protocol for a Land cover map (Example from NELDA Project)

- Randomly generated points
  - 2x2 clusters of Landsat pixels of a single class at least 250 m apart
- Minimum required number of points is 300 per site
  - Distributed in proportion to area of classes
  - Min 30 points per class

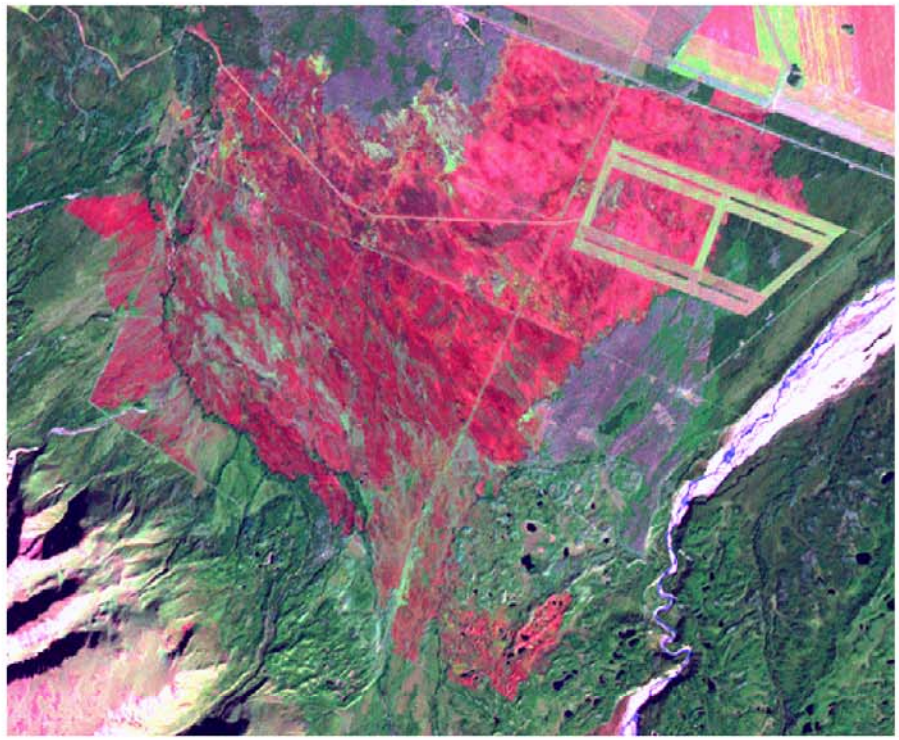
Accuracy assessment is essential

A map without accuracy assessment is an untested hypothesis

Pre-Burn Image, 30 August 1992



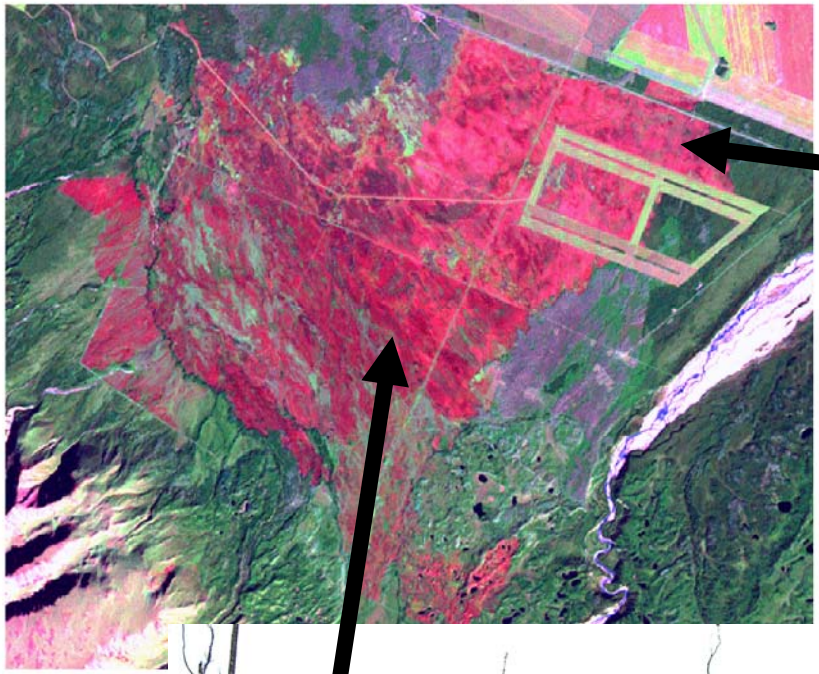
Post-Burn Image, 16 September 1995



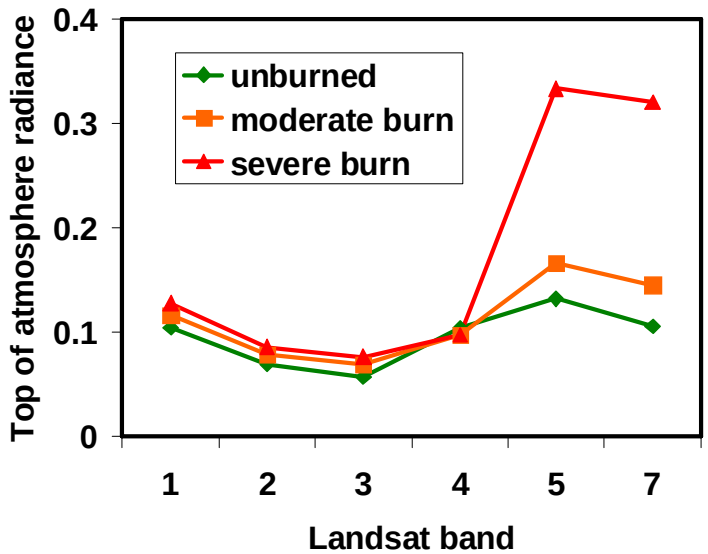
Scale 1:175,000

5 0 Kilometers

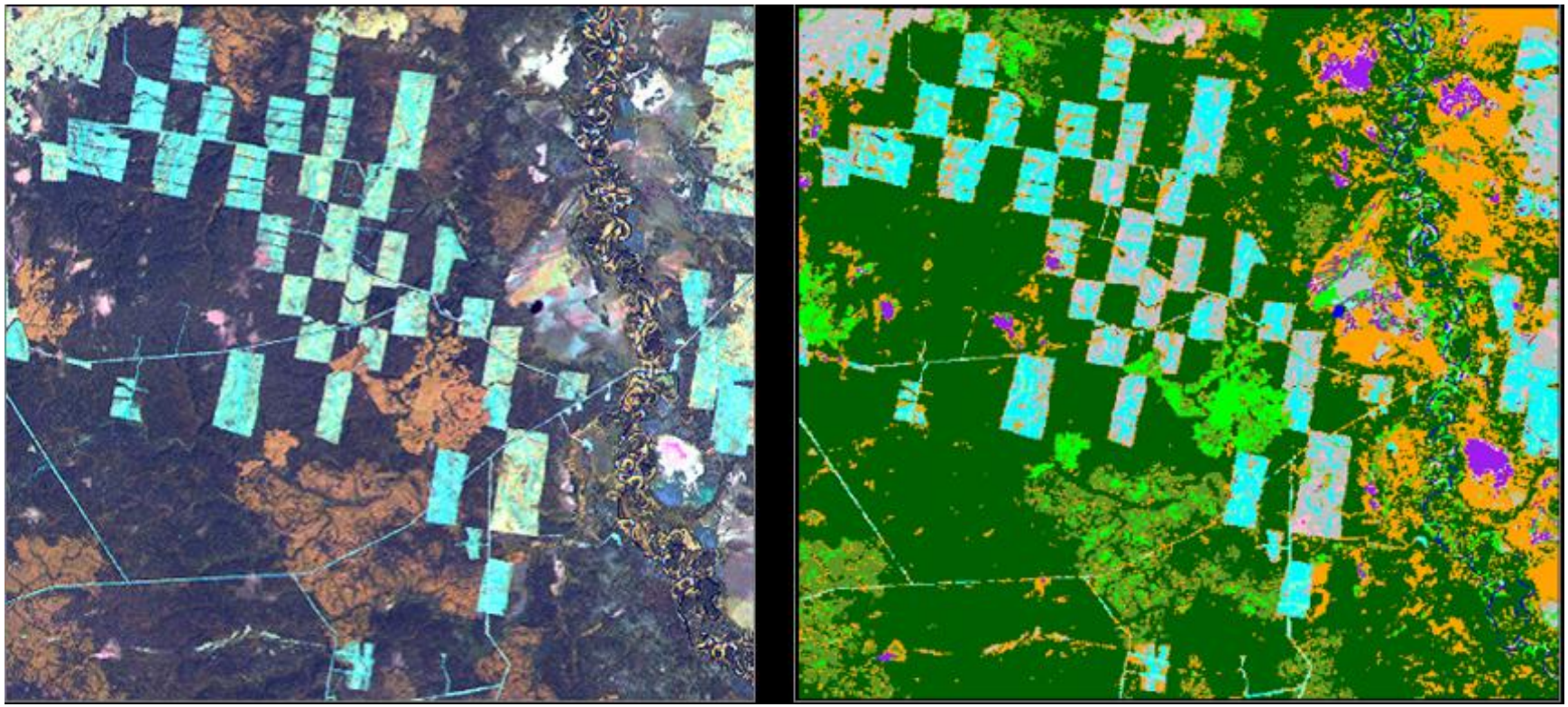
Post-Burn Image, 16 September 1995

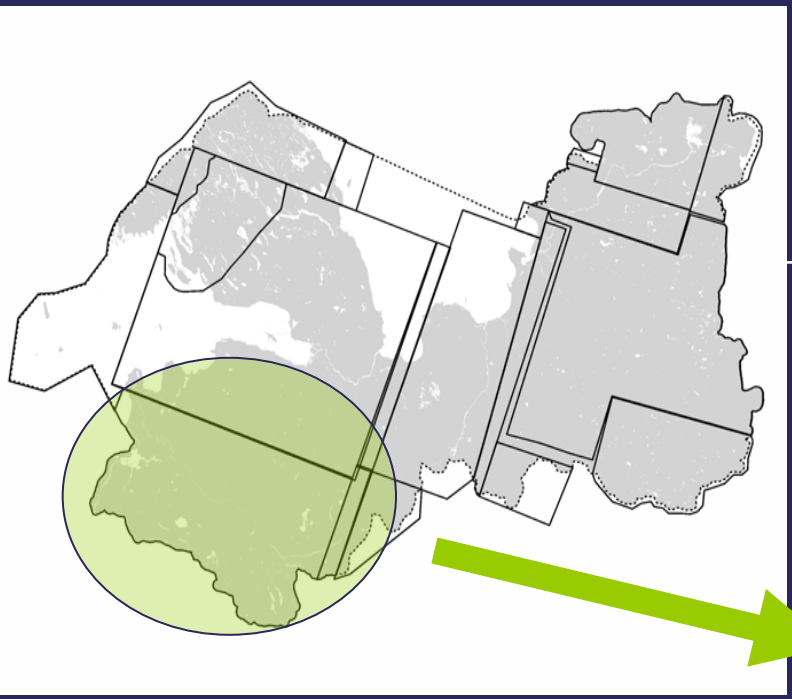


Landsat radiance values for burned black spruce stand

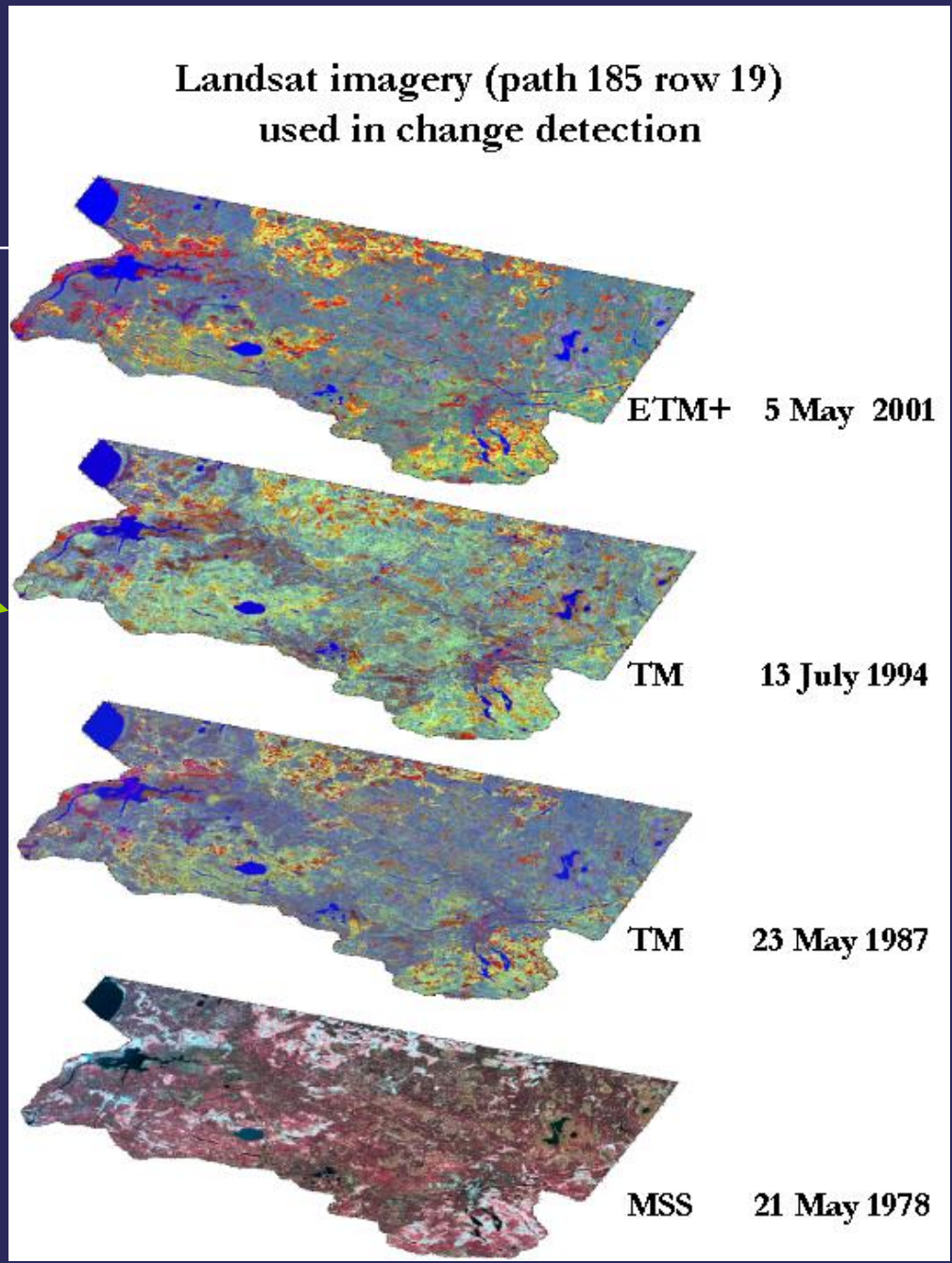


Timber harvest

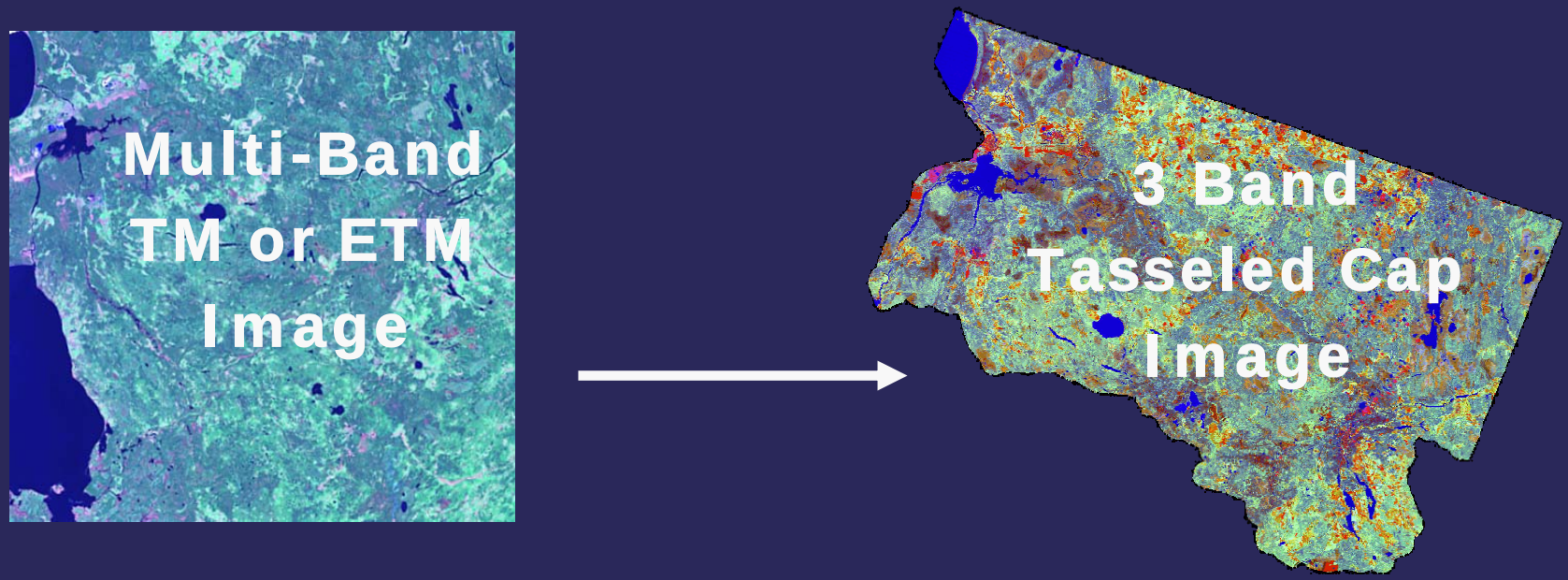




Стопка из 3-4 разновременных снимков

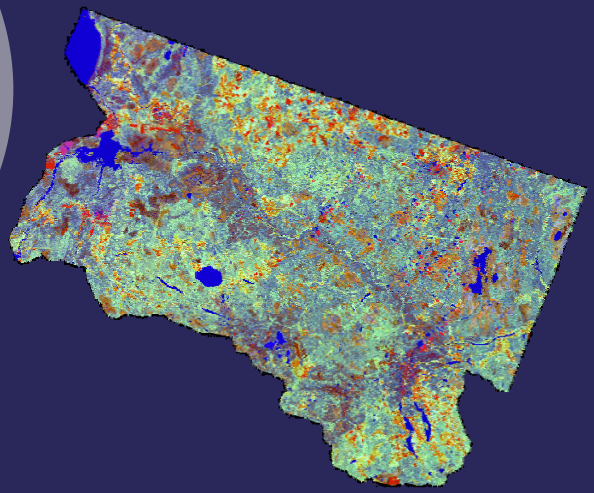


Преобразование многоканального снимка в 3-х канальный



Tasseled cap (TC) indices of brightness, greenness and wetness (яркость, зеленость, влажность)

Индекс нарушенности лесного покрова

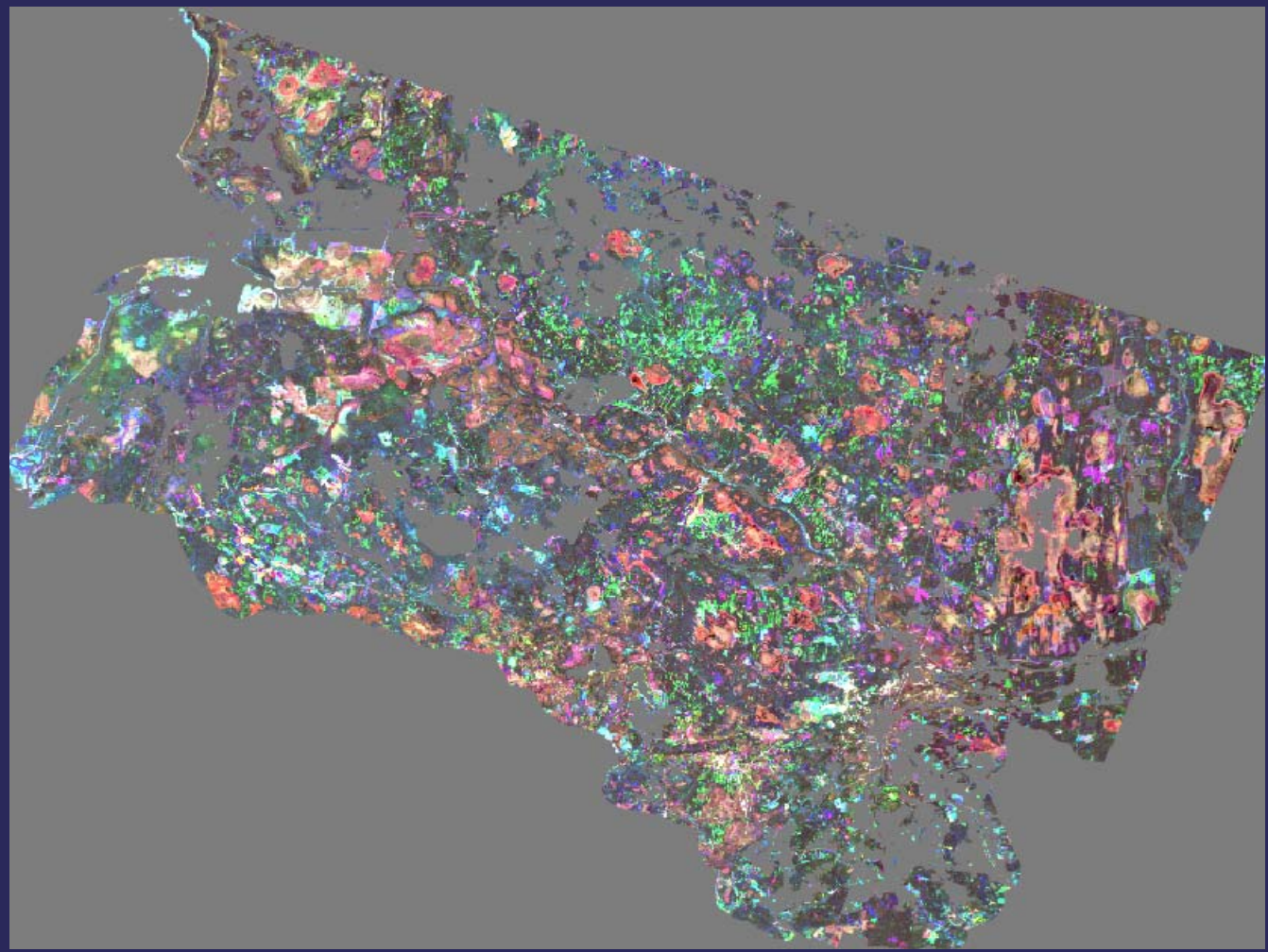


3 Band Tasseled Cap Image

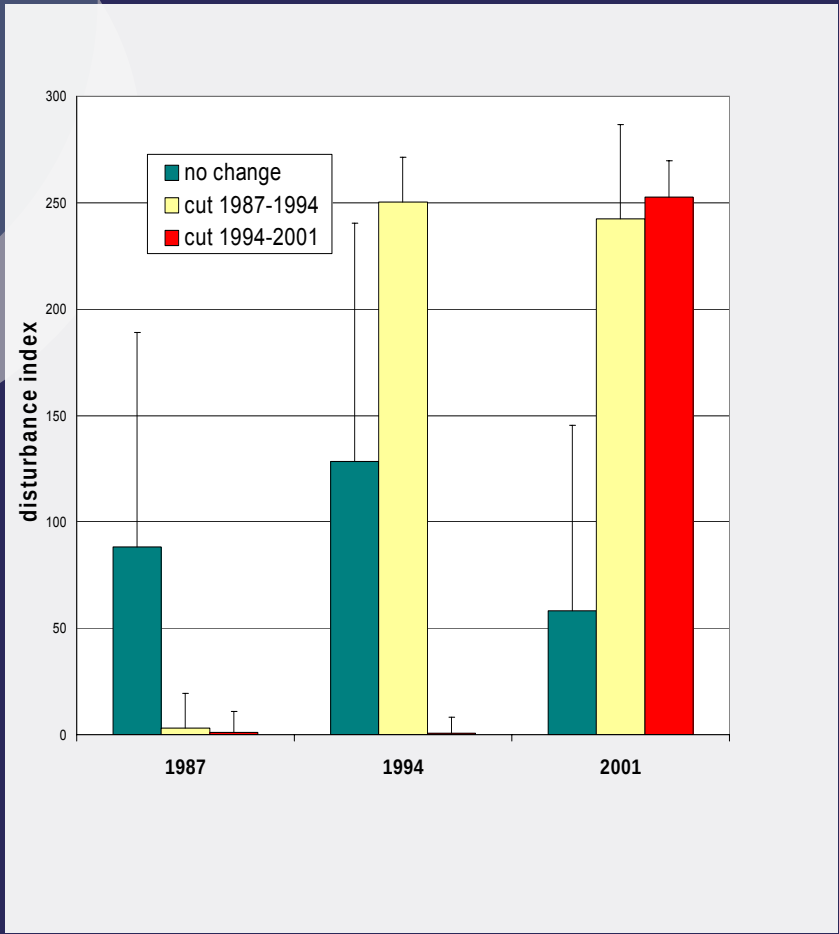
Disturbance Index =
Brightness –
(Greenness + Wetness)

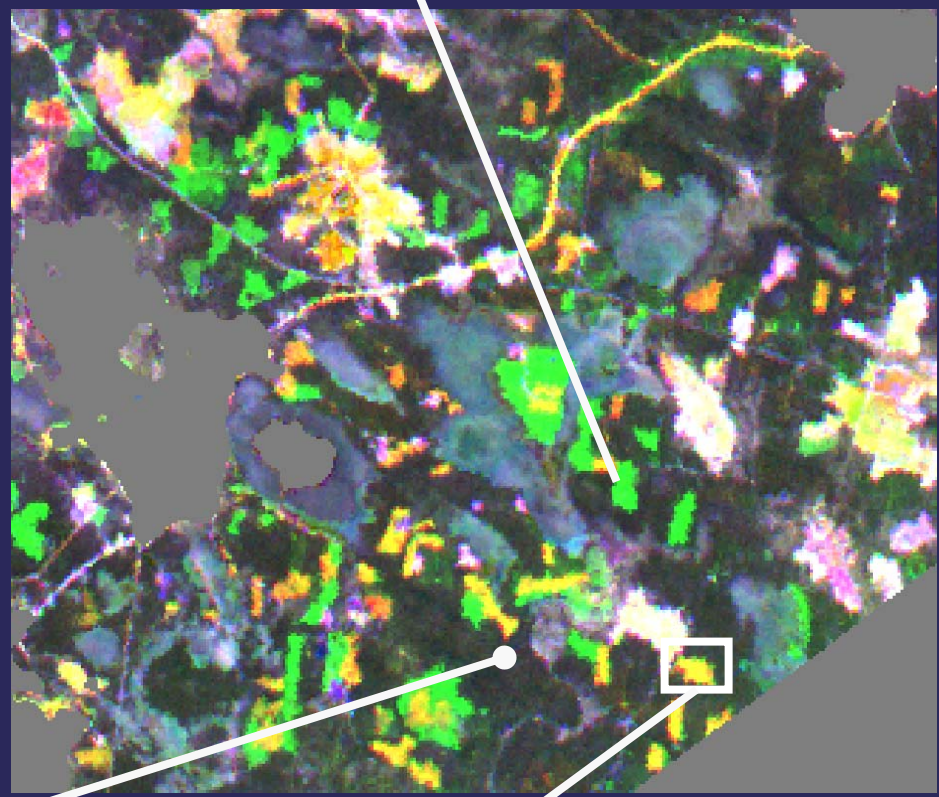
На участках с недавно нарушенным лесным покровом высокое значение индекса яркости, а значения индексов зелени и влажности - низкие.

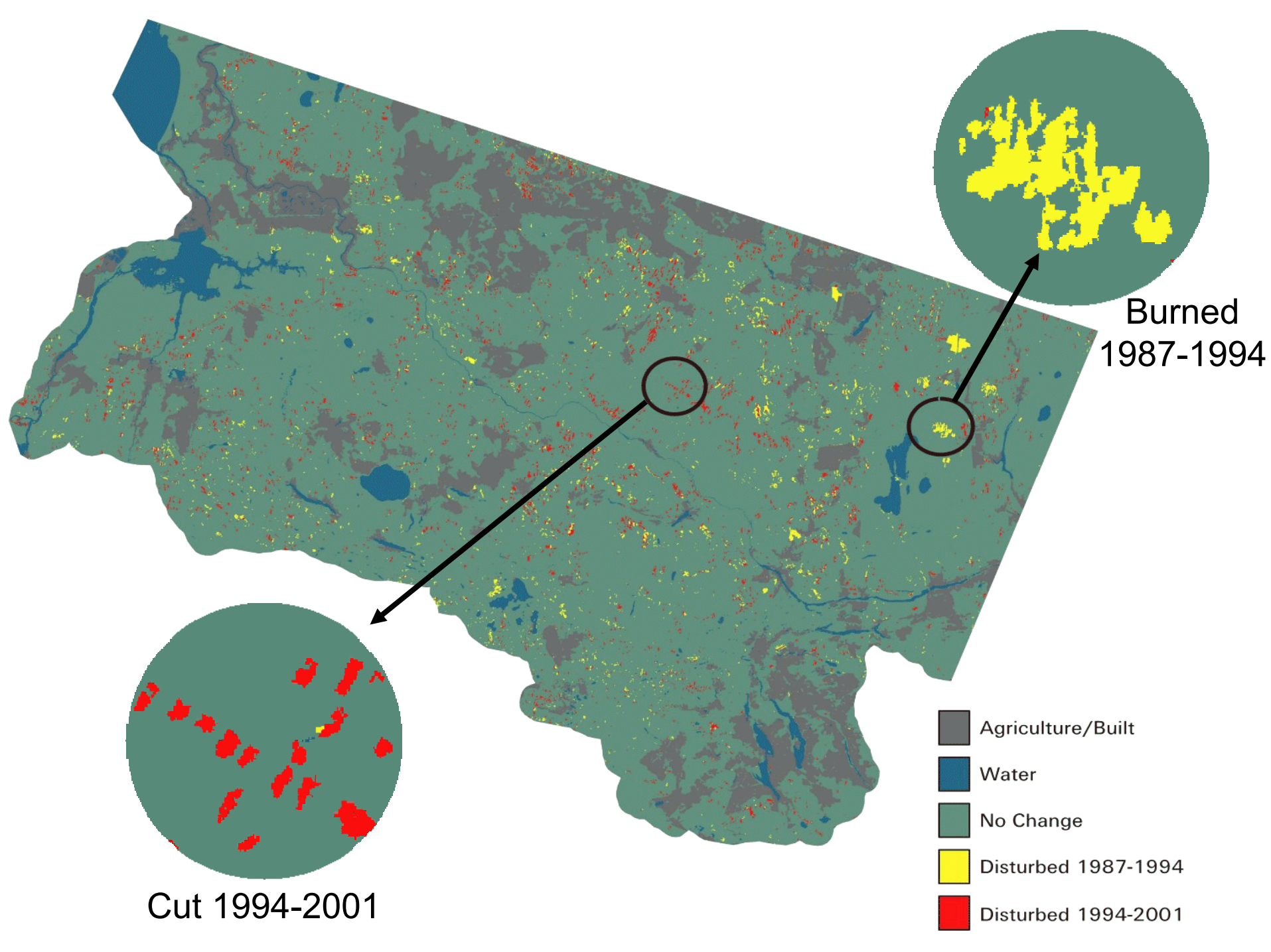
Единый слой нарушенности лесного покрова за период 1975-2001

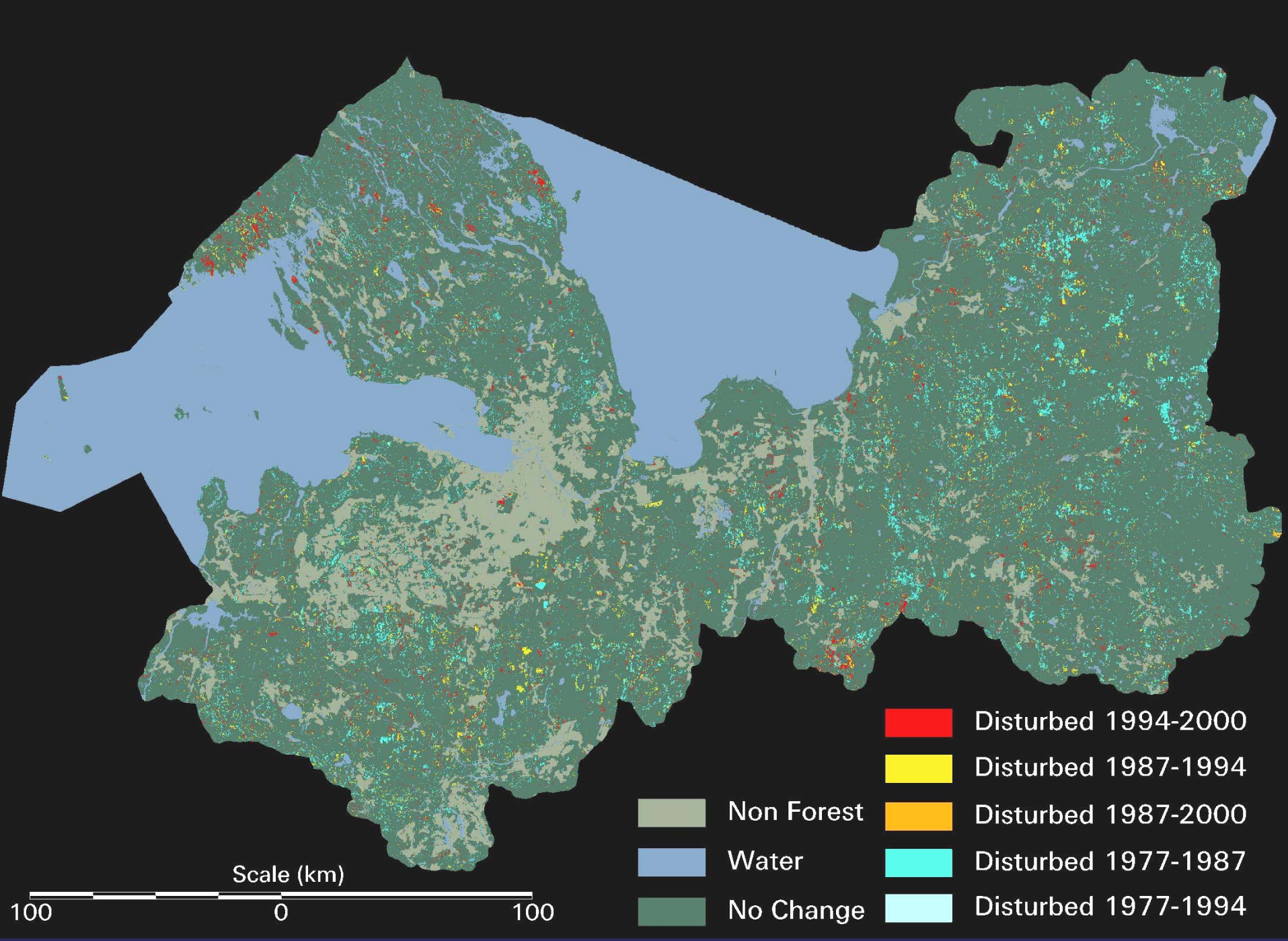


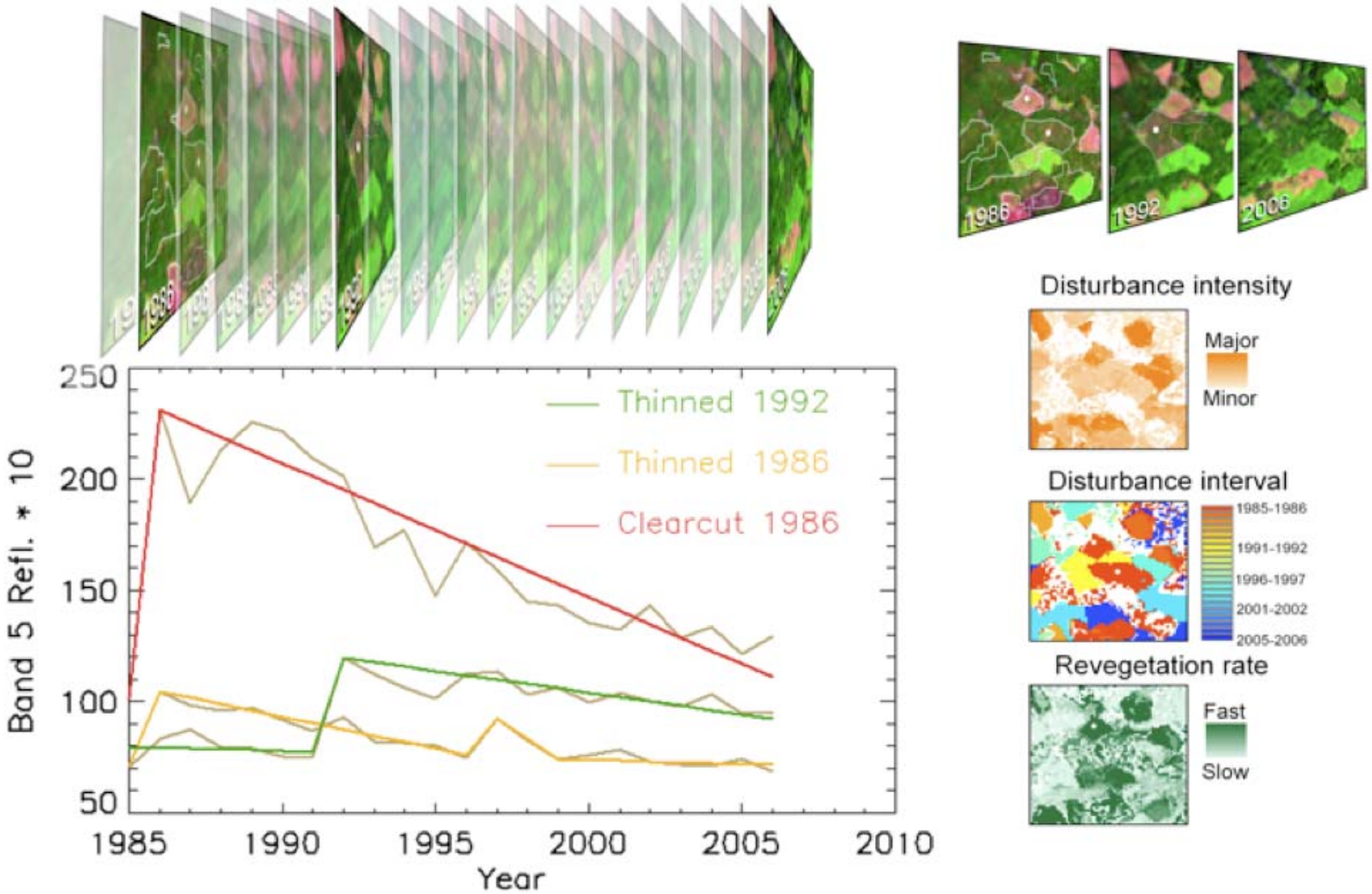
Выделение ненарушенных участков и классификация нарушенных по временным интервалам



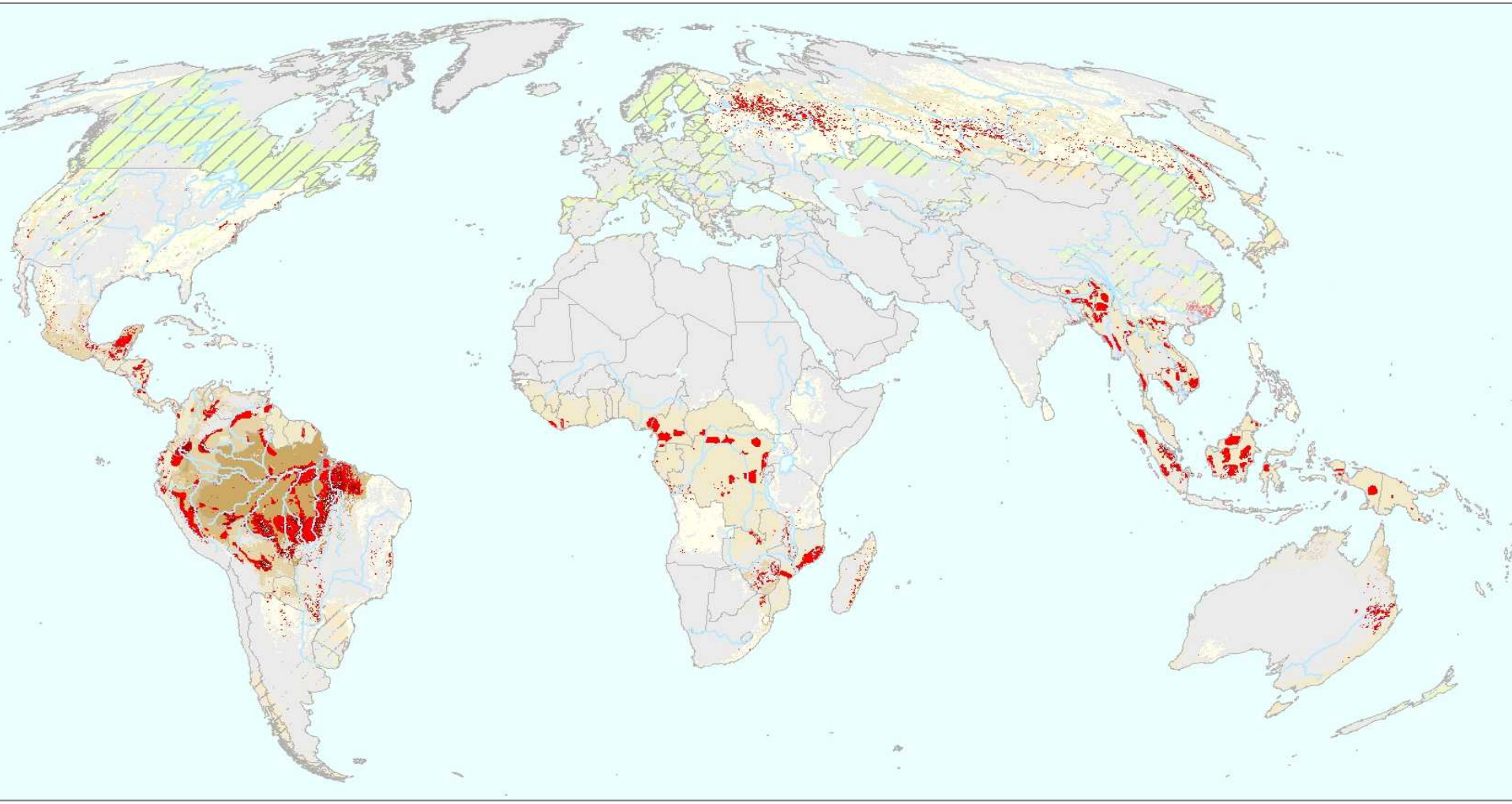



Burned
1987-1994
Cut 1994-2001
Agriculture/Built
Water
No Change
Disturbed 1987-1994
Disturbed 1994-2001


Disturbed 1994-2000
Disturbed 1987-1994
Disturbed 1987-2000
Disturbed 1977-1987
Disturbed 1977-1994
Non Forest
Water
No Change
Scale (km)
100
0
100

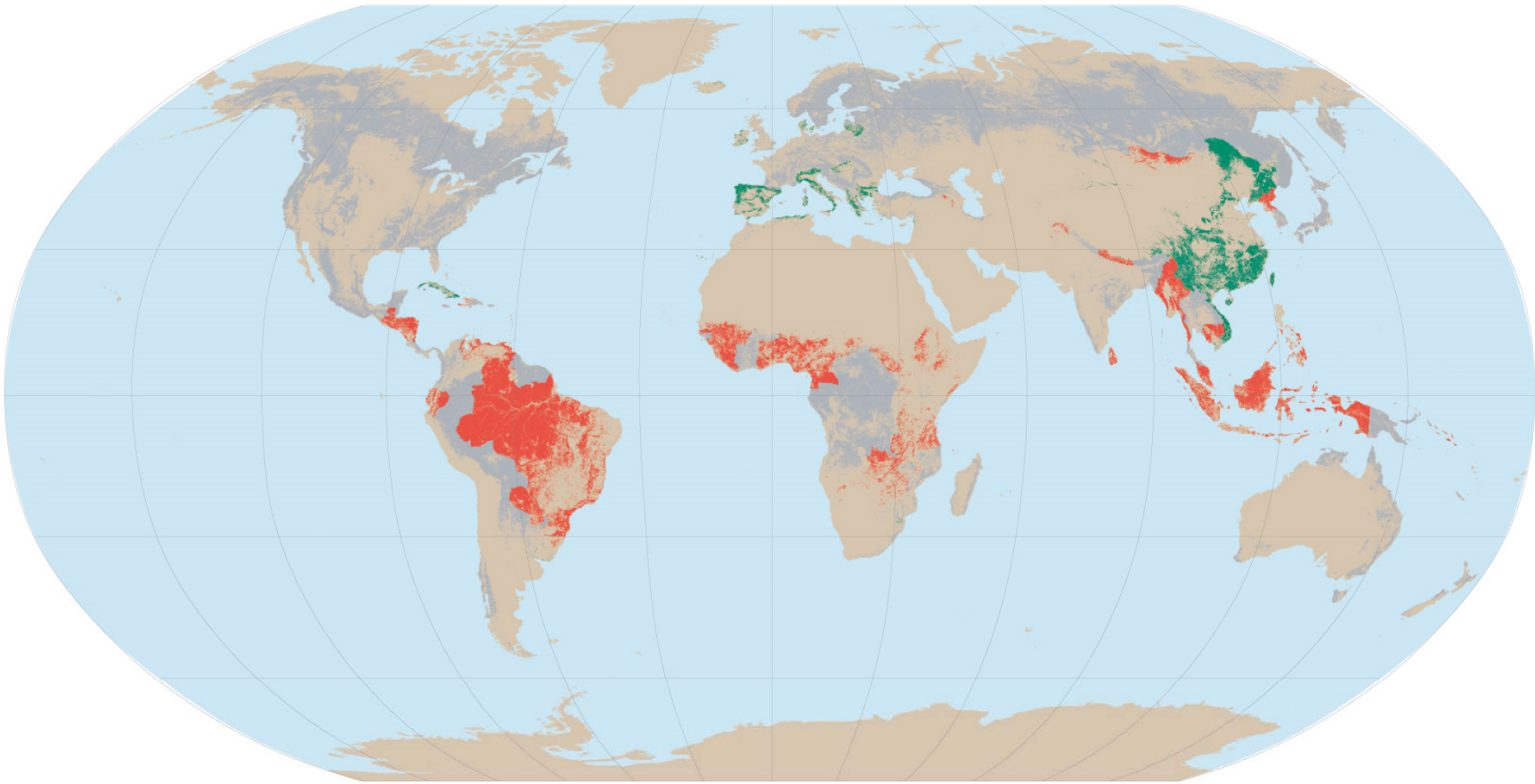


LandTrendr algorithms segment time-series of yearly Landsat TM data to characterize both long-term trends and abrupt events (disturbances). Source: Robert Kennedy et al. 2007



E. Lepers, E. F. Lambin, A. C. Janetos, R. DeFries, F. Achard, N. Ramankutty and R. J. Scholes, 2005. A Synthesis of Rapid Land-Cover Change Information for the 1981-2000 period. BioScience 2(55): 115-124.

Countries with large net changes in forest area 2000–2005

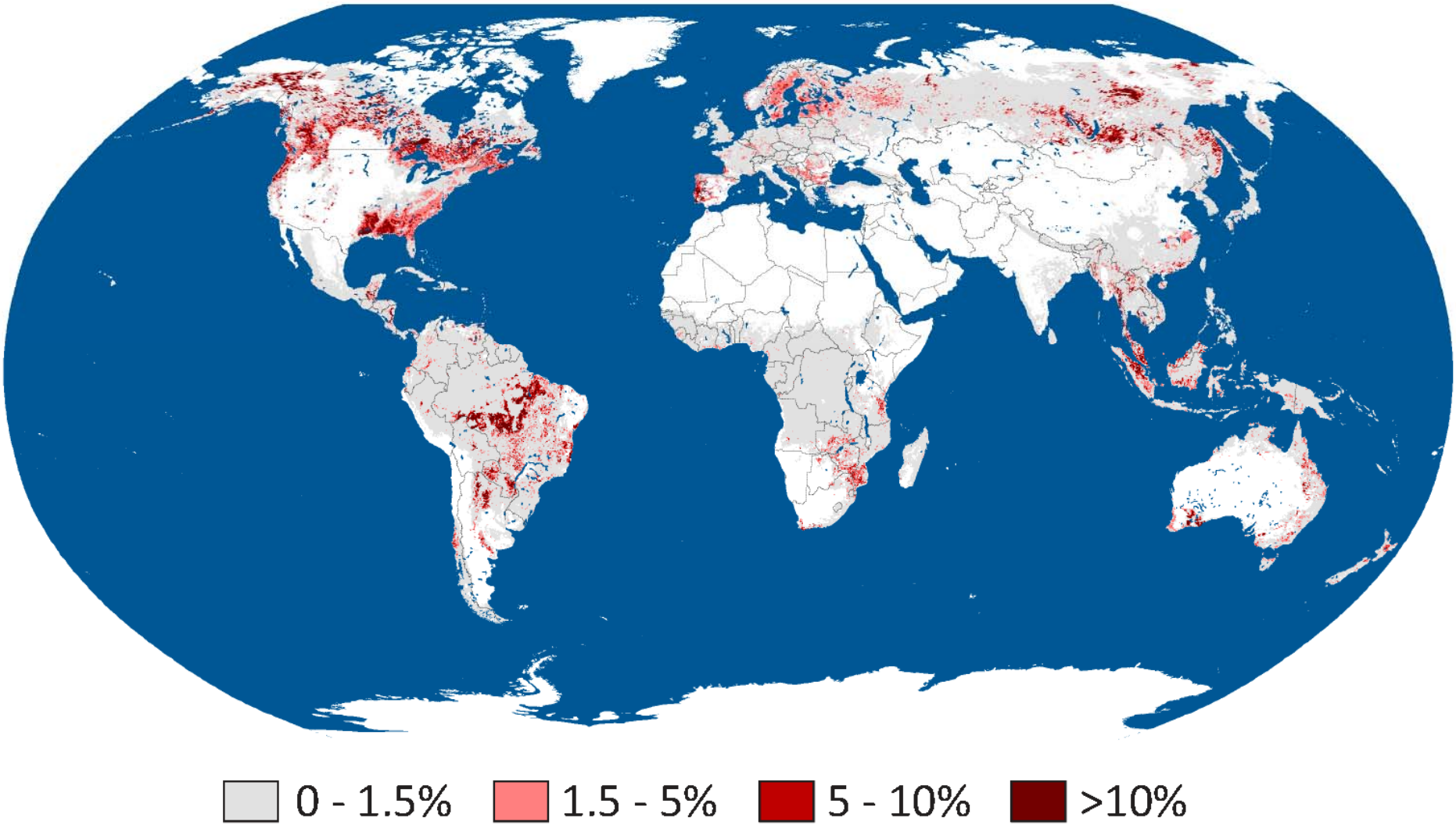


>0.50% decrease per year

>0.50% increase per year

Change rate between -0.50 and 0.50% per year

Percent forest cover loss, 2000 to 2005



Take home messages

- Satellite Observations present new opportunities
  - Extracting information from data is a challenge
  - Grand challenge for the new generation of map-makers
- Remote sensing is the new frontier in geography
  - And the Wild West …
- We know less about LC than we tend to think
  - Improved knowledge is critical

Thank you! Спасибо!

- Tom Maiersperger, Maureen Duane, Robert Kennedy, Peder Nelson, Dirk Pflugmacher, Mark Harmon, and Doug Oetter, OSU
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- Garik Gutman, NASA