Improvements in Landsat Pathfinder Methods for Monitoring Tropical Deforestation and Their Extension to Extra-tropical Areas

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Objectives

To assess whether the overall approach successfully used in Landsat Pathfinder for the humid tropics can also be used in other regions to satisfy the needs of the Global Observations of Forest Cover

To carry out large scale prototyping of several advanced processing procedures, including pre-processing to reduce atmospheric and MTF effects, multi-temporal unsupervised processing, application of decision-tree methodologies, mixture modeling and other advanced procedures developed under previous research.

Objectives

To assess the improvements introduced by advanced processing procedures using data from areas in the Pan-Amazon and Central Africa that were part of the previous Landsat Pathfinder work.

Investigate how the original Landsat Pathfinder methodology and the enhancements proposed operate in selected areas throughout the globe.

Paraguay, southern Africa, central Asia, Eastern United States, selected sites in the boreal forest.

Science Implications

The Landsat Pathfinder project has demonstrated the feasibility of monitoring forest cover change over very large areas using Landsat data. To extend this approach to satisfy the needs of the Global Observations of Forest Cover will require an assessment that the overall approach successfully used in Landsat Pathfinder for the humid tropics can also be used in other regions and that more automated procedures are used.

NASA Landsat Pathfinder Humid Tropical Deforestation Project

A collaborative effort between the University of Maryland at College Park's Geography Department, Michigan State University and NASA Goddard Space Flight Center's GIMMS Group. The goal of this work is to map global deforestation for the humid tropics.

Data sets from both the TM and MSS of Landsat have been used for three time periods, the 1970s, 1980s, and 1990s. The project has focused on - the Amazon Basin, Central Africa, and Southeast Asia, which are the three regions where most of the tropical deforestation in the world has occurred.
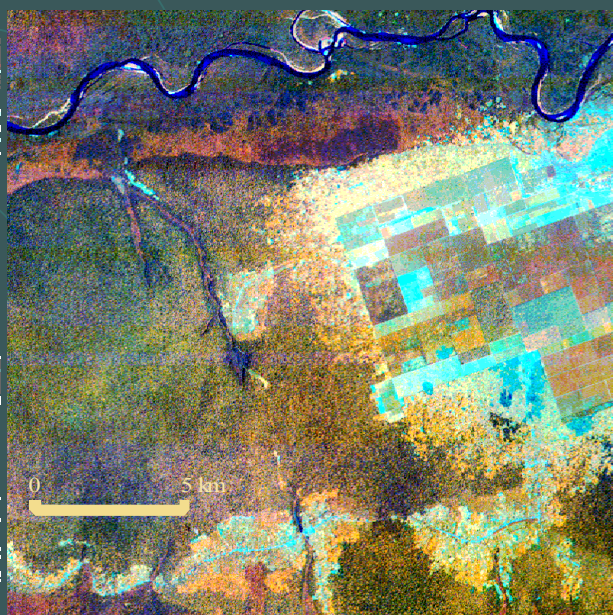
The Pathfinder project includes about 75% of the tropical rain forest areas. The University of Maryland has had responsibility for the non-Brazilian Amazon Basin (also known as the Pan-Amazon) along with central Africa (Details can be found at http://www.geog.umd.edu/tropical/main.html) and Michigan State University has responsibility for the Brazilian Amazon Basin and Southeast Asia.

Landsat Pathfinder Procedures for Classification

- Utilize existing automated methods

- Utilize the skills of the human interpreter to refine the classification

- Multispectral/ Multitemporal approach

Landsat Pathfinder Procedures for Classification

Landsat Pathfinder produces simple but accurate maps of the humid tropical forest - nonforest boundary based on Thematic Mapper (TM) data from the Landsat satellites. This information can be used to detect changes in forest cover, for modeling global climate change or for other research purposes.

Pathfinder uses isodata clustering image processing algorithms to produce thematic maps from Landsat imagery. Spectral data from two coregistered scenes are processed simultaneously so that areas of change can be readily identified. The example presented here uses a small portion of Landsat scenes of the northwest Democratic Republic of Congo from 1987 and 1994.
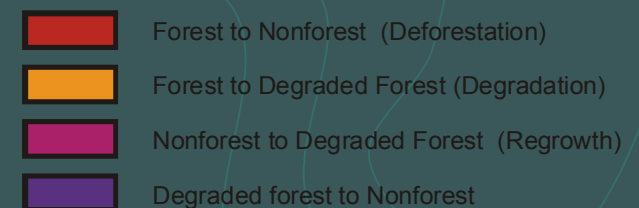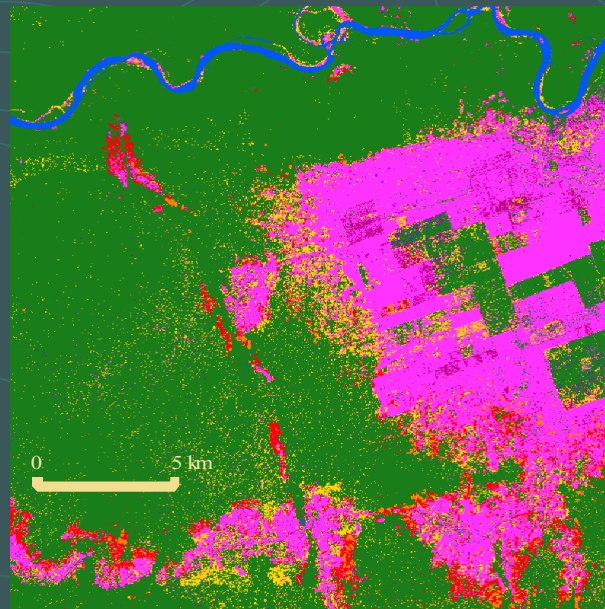

February 1987   Path 179 Row 058

An 800 x 800 pixel subset of Landsat 5 TM bands 4,5,3 (R,G,B)
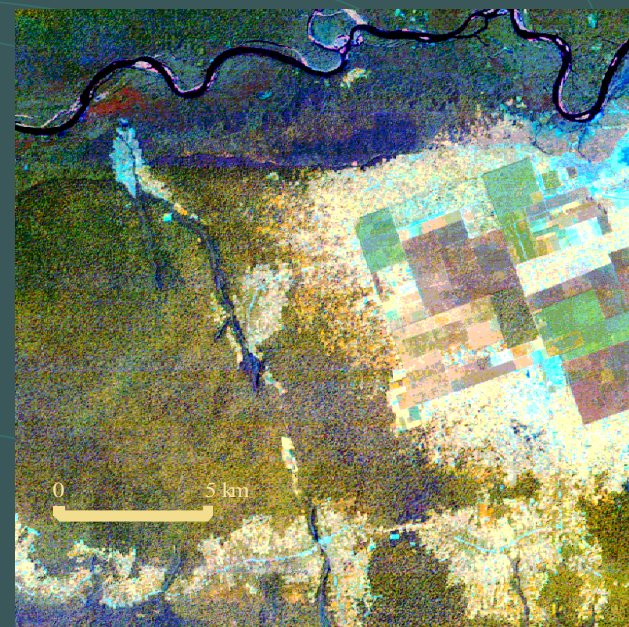
December 1994   Path 179 Row 058

An 800 x 800 pixel subset of Landsat 5 TM bands 4,5,3 (R,G,B)

Landsat Pathfinder Procedures for Classification

Masks of cloud, shadow, water and land cover are created from the data. Data under cloud, shadow or water masks are not processed further. An unsupervised classification process is applied to data under the land cover masks. Iterative isodata clustering produces large numbers of clusters or groups of pixels based on the spectral data from both images.

Forest

Nonforest

Degraded forest

Water

Forest to Nonforest (Deforestation)

Forest to Degraded Forest (Degradation)

Nonforest to Degraded Forest (Regrowth)

Degraded forest to Nonforest
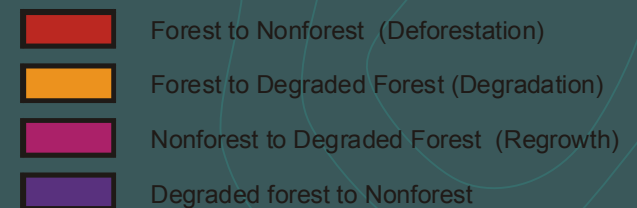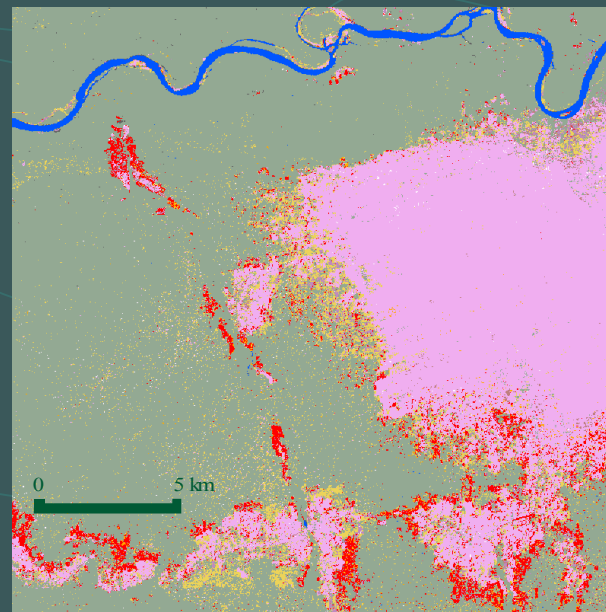
0   5 km

Composite Map

Each cluster is assigned a color which represents a particular land cover type or land cover change between the two images, e.g., forest to nonforest (deforestation), nonforest to forest (regrowth), etc. A modeling program classifies each pixel based on the color assigned to its cluster. The result is a composite map of land cover which includes change between the two scenes.
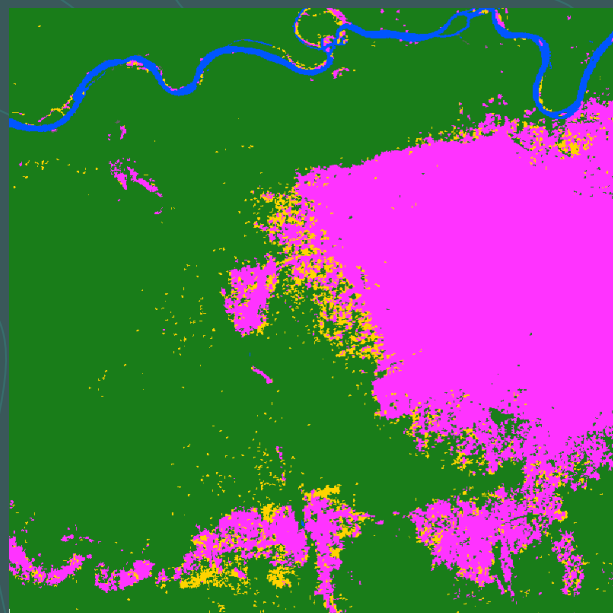
Landsat Pathfinder Procedures for Classification

The composite map may require editing to reclassify those pixels which are spectrally very similar but represent different cover types. In the example shown here, the plantation areas which appeared as forest are reclassified as nonforest according to the project definitions of cover type.


Forest

Nonforest

Degraded Forest

Water

Forest to Nonforest (Deforestation)

Forest to Degraded Forest (Degradation)

Nonforest to Degraded Forest (Regrowth)

Degraded forest to Nonforest

0   5 km

Edited Change Map

Landsat Pathfinder Procedures for Classification

The edited composite change map is split and filtered into thematic maps for each scene. The thematic maps are georegistered and mosaicked into a country wide product for a specific time period.
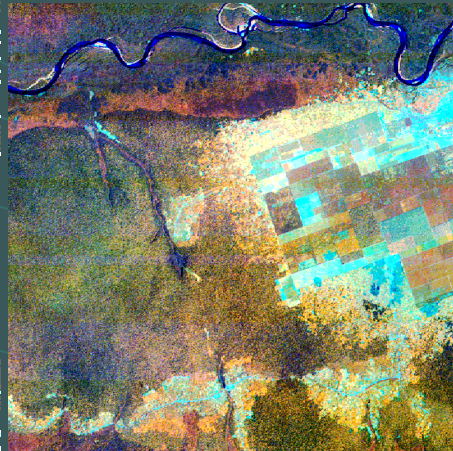

Forest

Nonforest

Degraded Forest

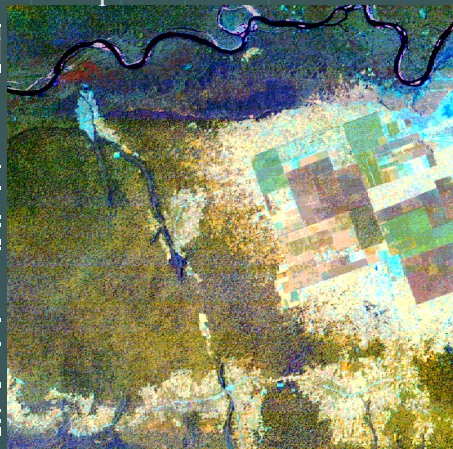Water

5 km
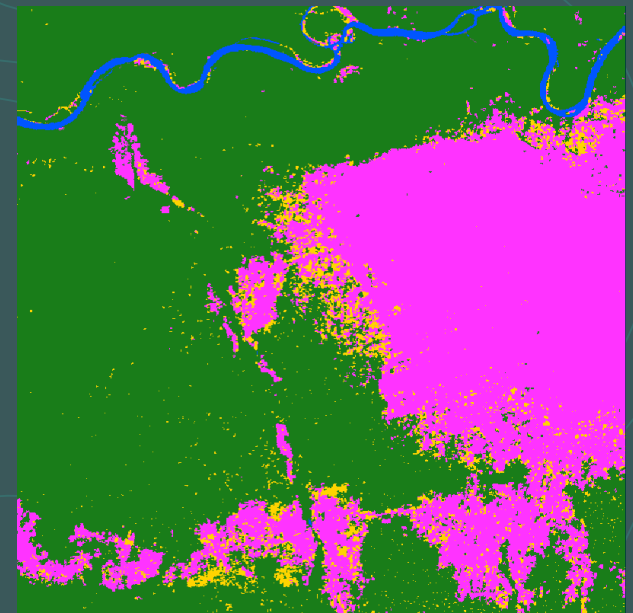
Thematic Map 1987

Thematic Map 1994

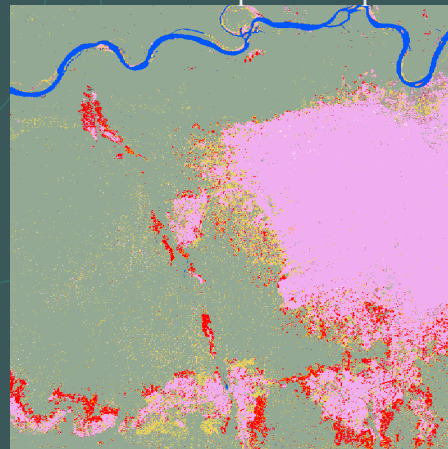# Landsat Pathfinder Procedures for Classification
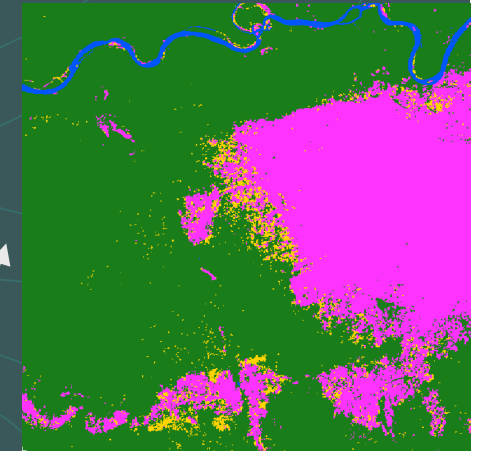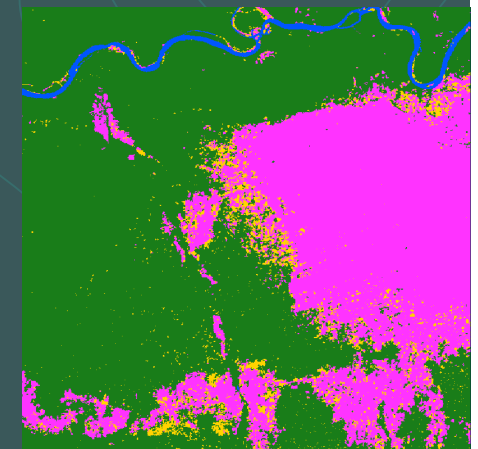
Spectral bands time 1

Spectral bands time 2

Composite map

Edited composite map

Thematic map time 1

Thematic map time 2

Landsat Pathfinder Procedures for Classification

The current system is producing a very consistent and accurate product as is indicated by the fact that little, or no thematic corrections are ever necessary when adjacent classified scenes are joined together. Mechanisms are in place where, as further auxiliary information is made available, the classification can be improved.
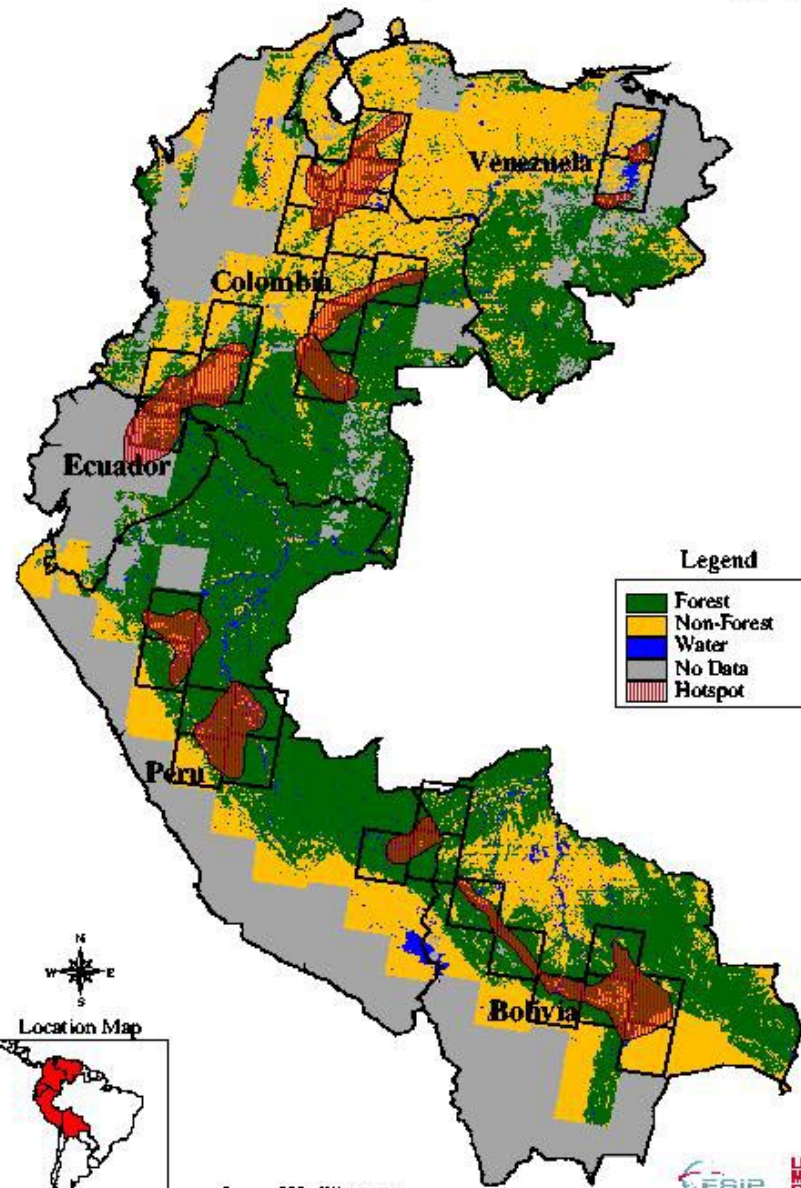
Results from Landsat Pathfinder

Results from Landsat Pathfinder project have produced delimitations of tropical deforestation in the Pan-Amazon with unprecedented accuracy for most areas.

Figure 1 shows in summary the distribution of the main hot spots in the Pan-Amazon, but this gives only a very superficial impression of the detailed data base that has been created.

Forest Cover and Hotspot Map for the Pan-Amazon Region
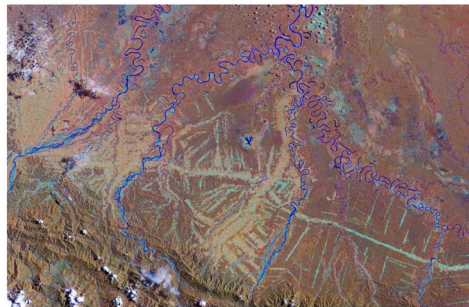Global Land Cover Facility - Deforestation Mapping Group

Results from Landsat Pathfinder

Large parts of the Pan-Amazon are being deforested.

We have documented a spatially-concentrated "deforestation zone" in Santa Cruz where >60% of the Bolivian deforestation is occurring at an accelerating rate in areas of tropical deciduous forest

Land Cover Change - Cochabamba, Bolivia
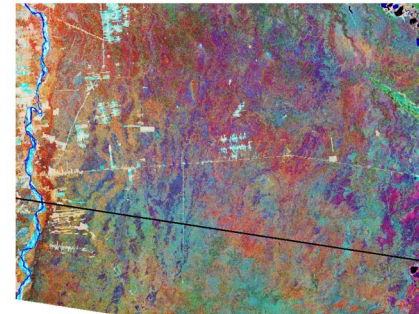
October 4,1986   Landsat 5 bands 4,5,3
111 Km. x 72 Km.
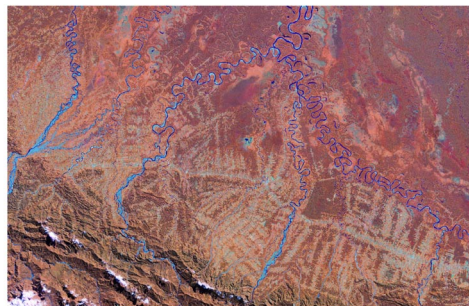
July 12, 1999   Landsat 7 bands 4,5,3
111 Km. x 72 Km.

Data Source: Global Land Cover Facility - Deforestation Mapping Group
http://glcf.umiacs.umd.edu

Land Cover Change - Tierras Bajas, Santa Cruz, Bolivia

July 2,1986   Landsat 5 bands 4,5,3
135 Km. x 102 Km.

August 31, 1999   Landsat 7 bands 4,5,3
135 Km. x 102 Km.

Data Source: Global Land Cover Facility - Deforestation Mapping Group
http://glcf.umiacs.umd.edu

Results from Landsat Pathfinder

Results of large area classifications are significantly changing views of the rates of tropical deforestation.

For example in Bolivia the total closed canopy forest cover extent, including tropical deciduous forest, totaled 472,000 km^2.

The **area** deforested totaled **15,000 km^2** in the middle 1980s and **28,800 km^2** by the early 1990s.

The **rate** of tropical deforestation in forest zone of Bolivia with >1,000 mm y^{-1} precipitation was **2,200 km^2 y^{-1}** from 1985-1986 to 1992-1994.

Our estimates of deforestation are significantly lower than those reported by the FAO, but are higher than in-country estimates since the mid-1980s (Steininger et al. 1999).

Table 1. *Summary of deforestation estimated for Bolivian forests, based on digital analysis of Landsat Thematic Mapper (TM) and Multispectral Scanning System (MSS) images. All areas are in km2 and rates are in km2 y-1. Data from the 1980s are from 1984 to 1987, the 1990s are from 1992 – 1994. All forest in the >1000 mm precipitation zone were mapped* (Steininger et al. 1999).

| Department	Potential Forest	Forest	Non-Forest	Deforested by the 1980s*	Deforested By the 1990s	Deforestation 1980s – 1990s	Water	Cloud	Nodata	Total Area
Ben	92,277	87,712	105,699	816	2,909	2,093	9,564	3,030	2,646	211,560
Cochabamba	26,390	20,322	27,834	1,520	2,774	1,255	492	3,346	2,964	57,732
La Paz	64,351	56,318	37,422	1,238	2,869	1,627	849	6,781	24,391	128,626
Pando	58,789	55,999	1,726	665	1,541	876	773	1,264	2,103	63,405
Santa Cruz	218,914	199,373	125,179	10,835	18,616	7,782	2,051	1,390	20,552	367,160
Chuquisaca	11,039	10,842	24,756	-	91	91	62	151	14,982	50,884
Sum	**471,760**	**430,566**	**322,615**	**15,073**	**28,801**	**13,724**	**13,791**	**15,961**	**67,638**	**879,367**

Areas deforested by the middle 1980s were only mapped below 1000 m elevation; 1,645 km2 of the total deforestation between the time periods were in areas over 1000 m above sea level.

Results from Landsat Pathfinder

- In Africa rates of deforestation are much less than the Amazon

- Few very large areas of clearance observed

- Land cover changes that occur are often associated with previously cleared degraded forests, which have regrown

Results from Landsat Pathfinder
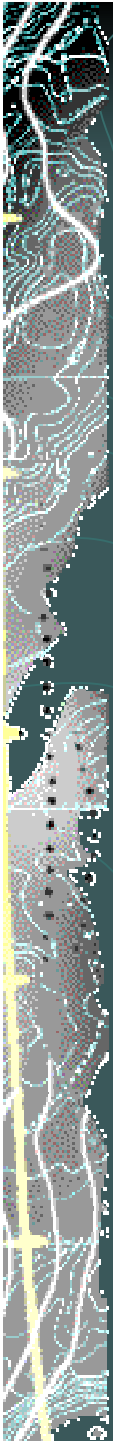
Methods

Preprocessing of Landsat data

Mixture Modeling

Improved Landsat Pathfinder Procedures

Supervised Approaches

Application of Coarse Resolution Data Products

Preprocessing of Landsat TM data

Automated co-registration

Previously tested algorithms (Fonseca and Manjunath 1996).

Atmospheric correction.

Dark target approach (Kaufman et al. 1988).

Algorithm has been successfully implemented on our SP-2 high performance computer

Preprocessing of Landsat TM data

MTF Effects

- Assess the optimal pixel size
- Explore the development of a non-linear filter
- Assess the implications of enhancing noise due to this procedure
- Assess the extent to which these problems impact Thematic Mapper data

Table 2　　　Standard Errors of the Estimate (SEE) * of MODIS Simulated Data for 250m Pixels (at the 90% Confidence Limit) for the Reflective Bands, Namely Bands 1 to 5 and 7 (B1 – B5 and B7) of the Thematic Mapper for Partially Forested Test Site in Central Maryland. The Final Column Shows the SEE for the Estimated Vs. The Actual Percentages of Land Cover. The Results Indicate the Major Impacts of the MTF of the Sensor and Reductions in Their Impacts by Pixel Enlargement and deconvolution (Townshend Et Al. 1999).

Pixel size (m) and procedure for generating images	B1 (DN)	B2 (DN)	B3 (DN)	B4 (DN)	B5 (DN)	B7 (DN)	Land Cover % Error
1. 250m, derived by simple averaging	0	0	0	0	0	0	0
2. 250m, MTF simulation	3.19	2.99	5.08	2.97	4.58	2.13	11.00
3. 500m, aggregated from **2**	1.19	1.14	1.93	1.03	1.68	0.80	4.16
4. 250m, MTF deconvolved	1.44	1.40	2.38	1.20	2.01	0.97	5.11
5. 500m, aggregated from **4**	0.62	0.63	1.06	0.44	0.85	0.42	2.24

Mixture Modeling

Intend to apply mixture modeling to assist in classifying areas of partial tree cover.

Two approaches will be tested.

- Characterize each scene as a mixture of basic components to assist in the labeling of the clusters in the unsupervised classification

- Derive proportions of scene components and then derive differences in proportions between adjacent time periods

Improved Landsat Pathfinder Procedures

The most time-consuming part of the work for the human analyst is the assigning the hundreds of spectral clusters labels of the land cover classes.

Instead we will implement a hybrid unsupervised and supervised classification.

Improved Landsat Pathfinder Procedures

This approach will rely on an unsupervised statistics based clustering algorithm to iteratively create several hundred cluster classes.

Clusters will then be automatically assigned to output classes based on training bitmaps created by the human analyst.

Improved Landsat Pathfinder Procedures

Where a cluster is included in more than one of the land cover classes, bit maps will automatically be created over all pixels belonging to those classes throughout the scene

Subsequent unsupervised classification will then be carried out until all clusters are only associated with a single land cover class.

Analyst input will still be needed but this procedure has been shown to reduce their level of effort by a factor between approximately 2 and 3 dependent on the scene being analyzed.

Improved Landsat Pathfinder Procedures

Analyst first identifies polygon bitmaps on image which are assigned to a vegetation or change class.

● Forest

● Deforestation
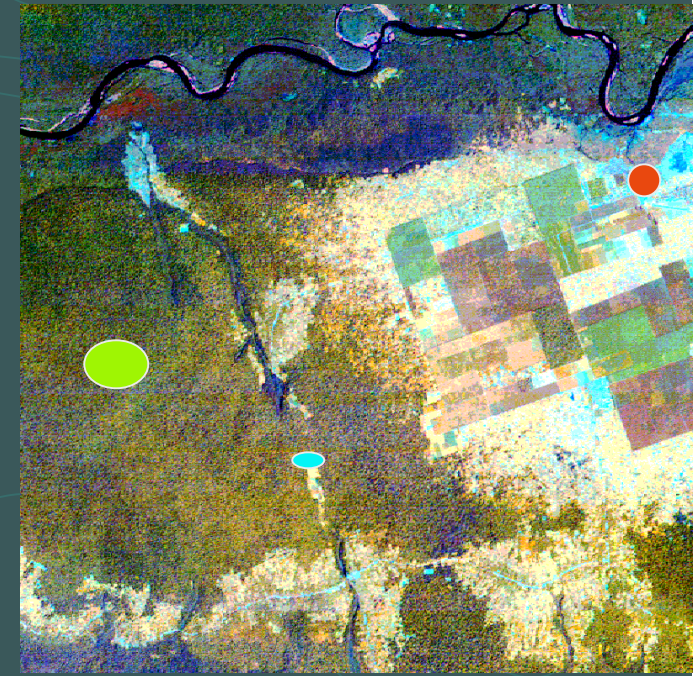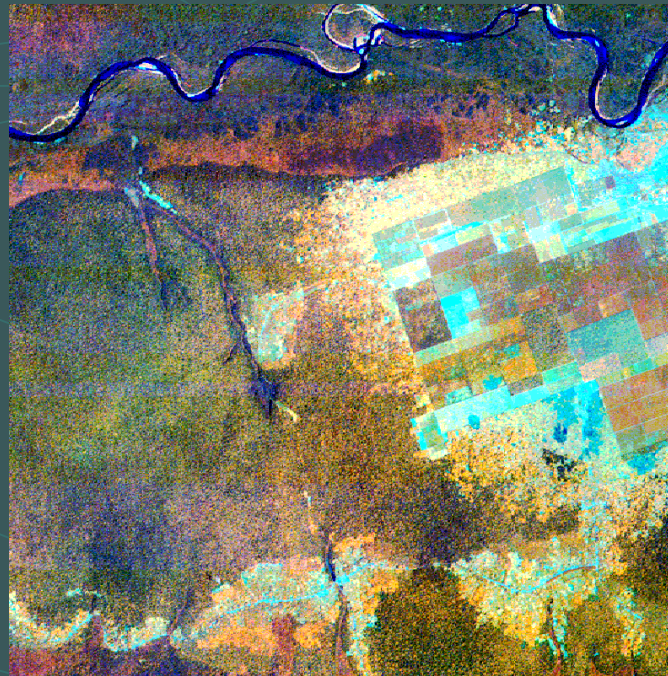
● Non-Forest

Improved Landsat Pathfinder Procedures

Unsupervised clustering algorithm is run independently of the training sites.
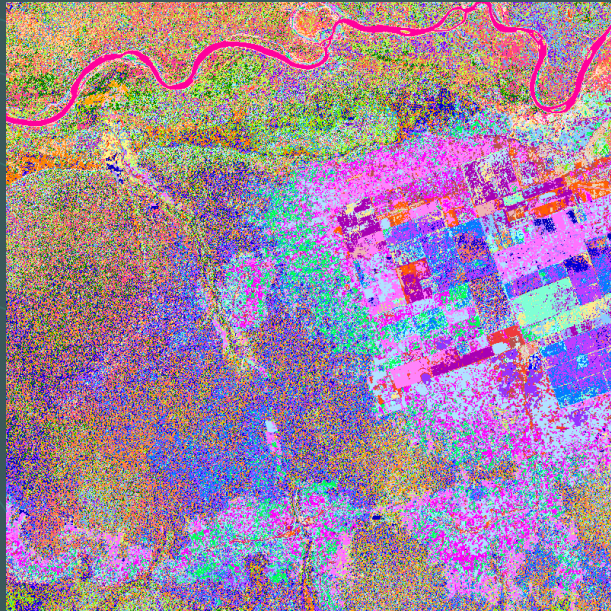
Clustering output
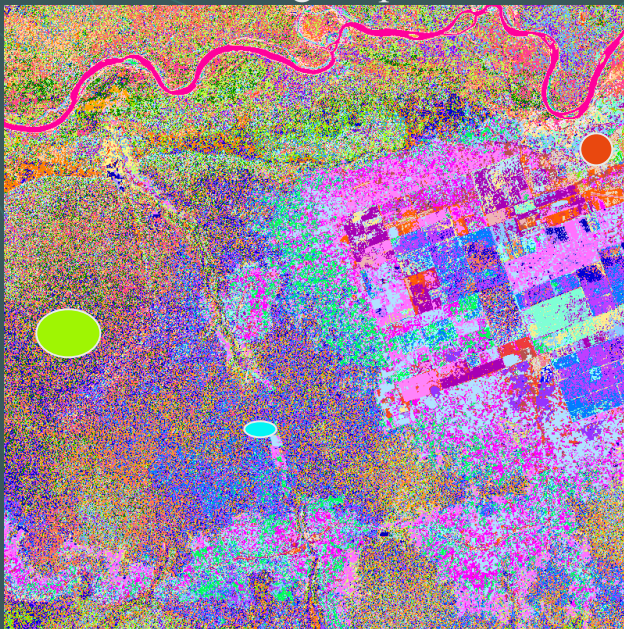
Forest	Non-Forest	Deforestation
2	7	33
3	12	50
6	15	120
7	25	200

We have developed a program to compare the training site bitmaps and the output clusters from the unsupervised classification.
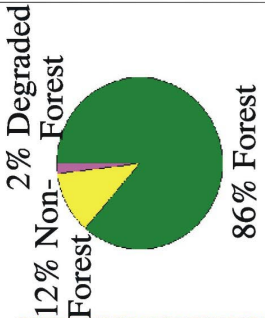
Improved Landsat Pathfinder Procedures
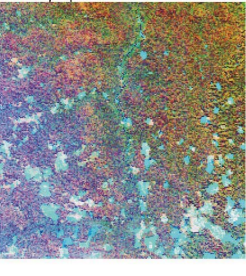
Clustering output
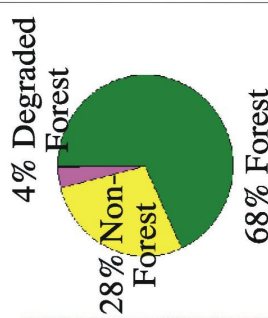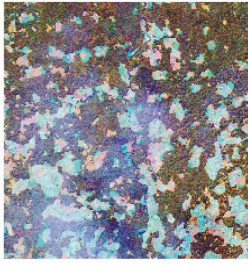
Thematic Map

Automatic
Modeling

Those clusters belonging solely to a single land cover class will be automatically labeled and will not need to be examined further by the analyst. Where a cluster is derived which includes more than one of the land cover classes, then bit maps will automatically be created over all pixels belonging to those classes throughout the scene and subsequent unsupervised classification will then be carried out until all clusters are only associated with a single land cover class.
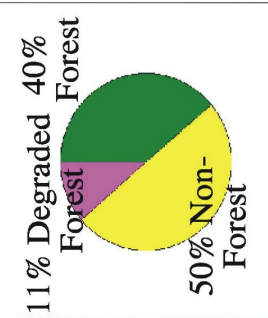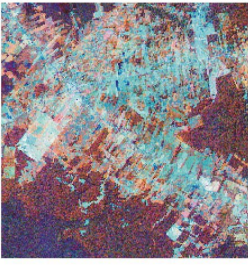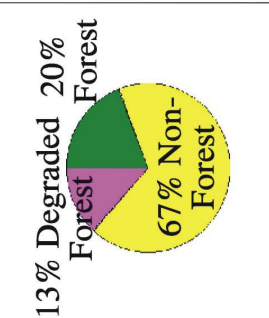
2% Degraded Forest
12% Non-Forest
86% Forest
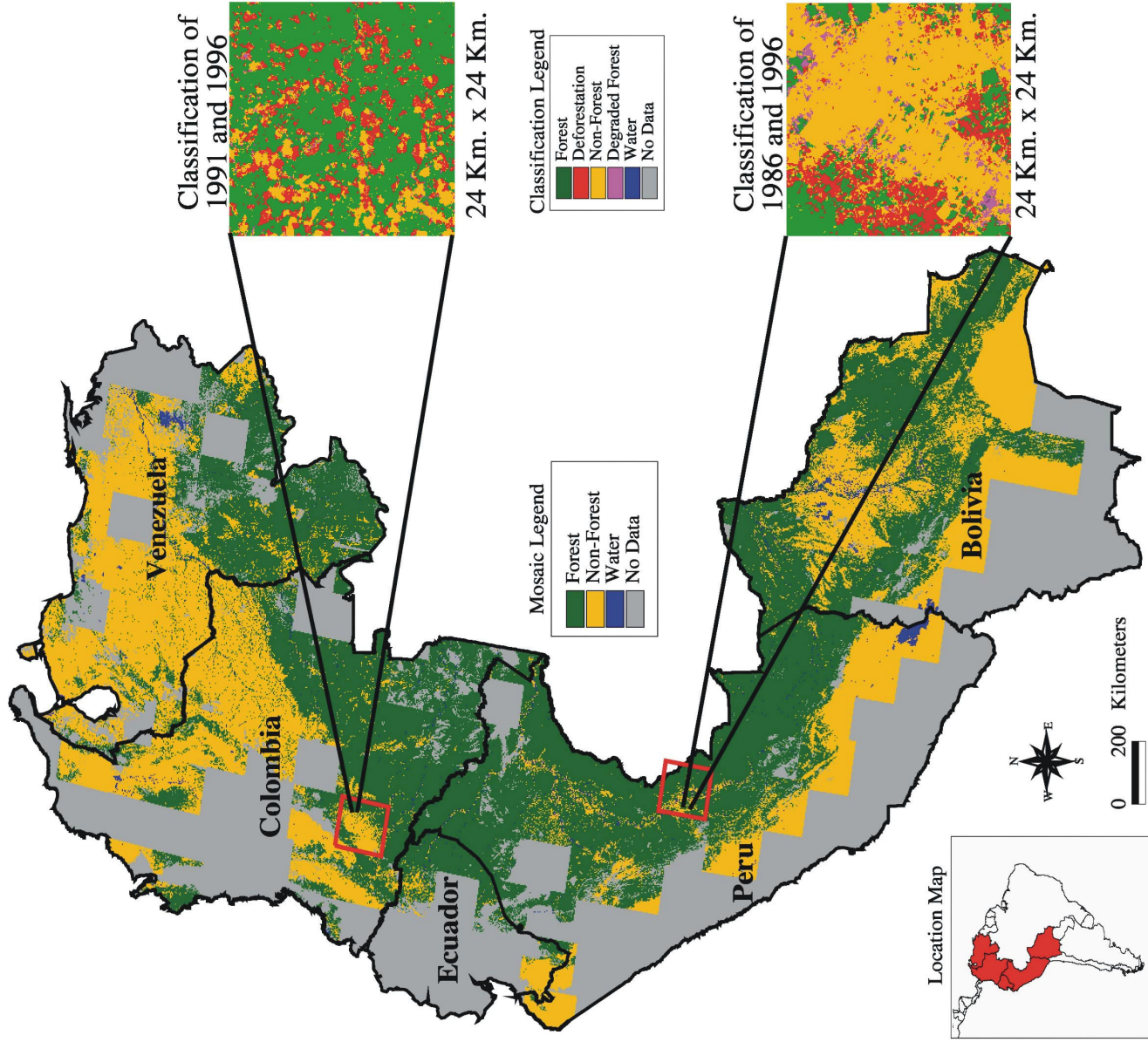
February 3, 1991
Path 008 Row 059

4% Degraded Forest
28% Non-Forest
68% Forest

August 11, 1996
Path 008 Row 059

40% Forest
11% Degraded Forest
50% Non-Forest

July 22, 1986
Path 006 Row 066

20% Forest
13% Degraded Forest
67% Non-Forest

October 16, 1996
Path 006 Row 066

Classification of 1991 and 1996
24 Km. x 24 Km.

Classification of 1986 and 1996
24 Km. x 24 Km.

Classification Legend
Forest
Deforestation
Non-Forest
Degraded Forest
Water
No Data

Mosaic Legend
Forest
Non-Forest
Water
No Data

Venezuela
Colombia
Ecuador
Peru
Bolivia

Location Map

N
W E
S

0   200   Kilometers
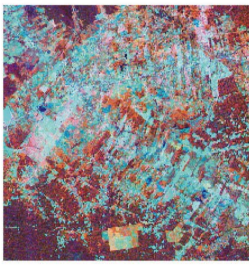
Supervised Approaches

Increasingly improvements in our understanding of spectral classes and ground conditions means that a more directed supervised approach becomes feasible in many areas.

We will evaluate the following approaches.

- Neural nets

  Multi-layer perceptron (MLP) - Three layer network structure (input, hidden and output)

- Decision Tree Classifiers

Application of Coarse Resolution Data Products

We will examine the extent to which we can use multi-temporal sequences of MODIS data, especially the NDVI and its improved vegetation indices to assist the characterization of forest types especially in relation to leaf type and duration.

Extension to Other Regions

- Sub-tropical forests in South America including the Chacoan Forests

- Woodlands and wooded grasslands of Eastern Africa including woodland types such as miombo and mopane woodlands

- Deciduous and mixed temperate forests in Maryland.

- Boreal forests from central Asia in Mongolia, Russia and Alaska.

Assessment of Procedures

Two main approaches will be adopted in assessing the performance of the various procedures

- Carefully characterized ground sites based on field work

- Previously well characterized complete scenes based on field work and previous Landsat Pathfinder classification

Ground sites based on field work by collaborators

These sites will be used primarily to assess the accuracy of the procedures that are developed

- Southern Santa Cruz, Bolivia - Dr. Tim Killeen

- Noel Kempf National Park, Bolivia - Dr. Tim Killeen

- Venezuela - Dr. Otto Huber of the University Simon Bolivar, Caracas

- Manaus, Brazil - Dr. Marc Steininger

- Southern Africa Woodlands – MODIS validation team

- Boreal Forests - Dr. Eric Kasischke of ERIM, Dr Clyde Goulden of the Institute of Mongolian Biodiversity & Ecological Studies

- 3 sites in Maryland – MODIS

Previous Landsat Pathfinder Classifications

Sites in the tropics will be used primarily to assess the extent to which Landsat Pathfinder results involving intensive human intervention can be reproduced with much less intervention.
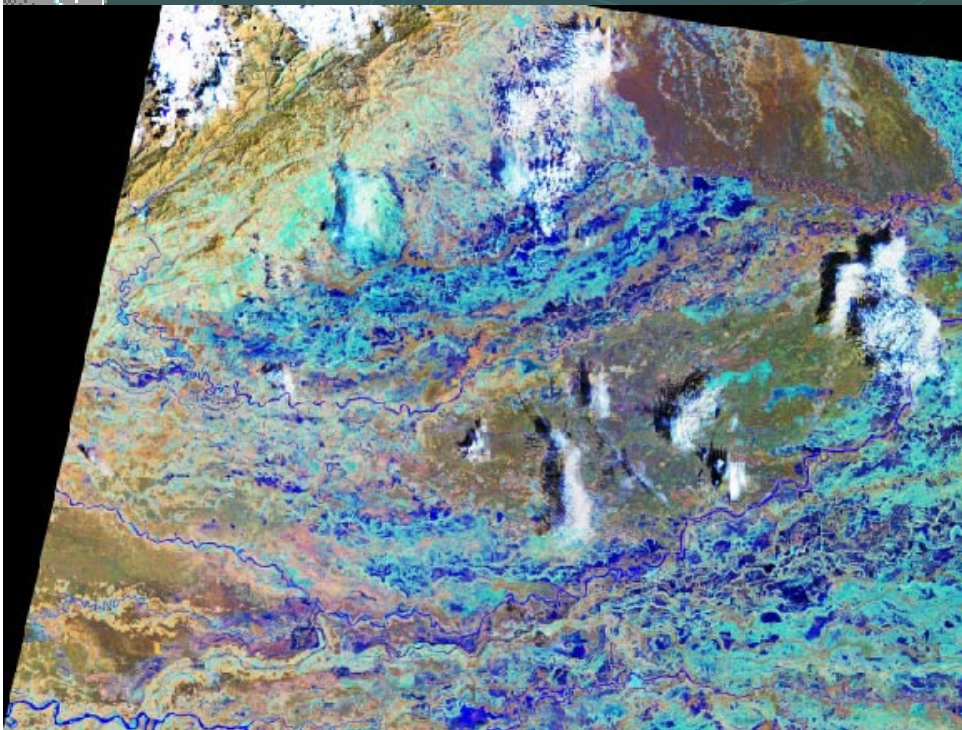
Sites include:

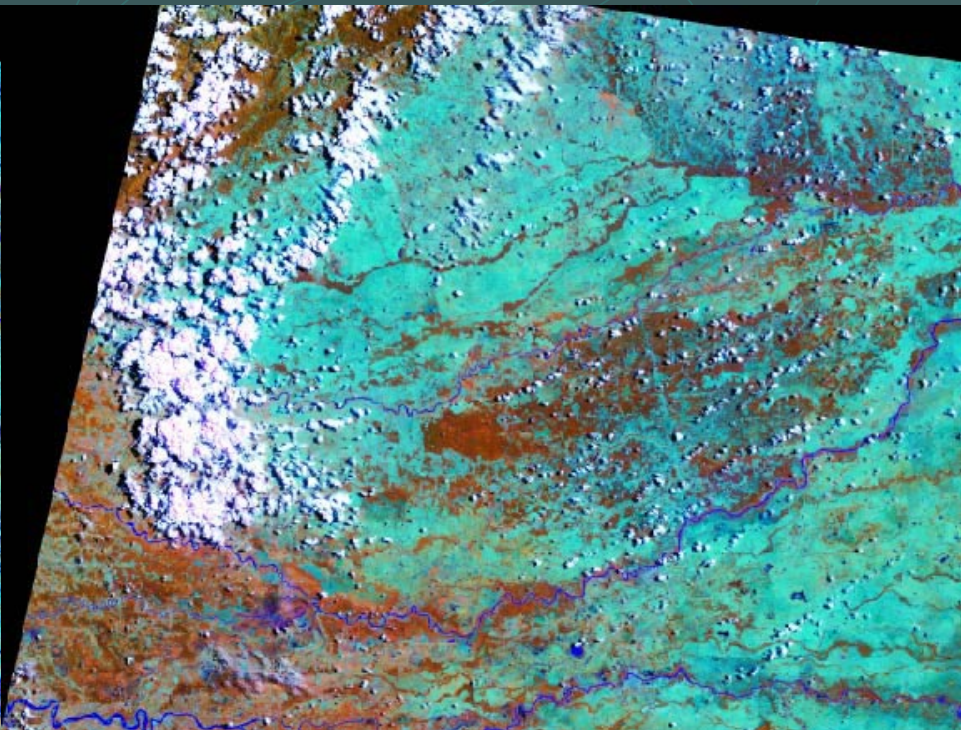230-072 near Santa Cruz

006-055 in Venezuela

231-062 in Brazil

Central African image TBD

# Path 006 Row 055

Nov. 1 1987

Apr. 26 1999

Extra-Tropical Test Sites

We intend to develop similar thoroughly checked scenes in temperate forests in Paraguay and in boreal forests in Mongolia, Russia, and Alaska.
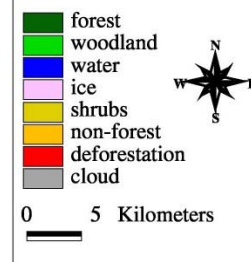
The scenes and reference sites from outside of the tropics will be used to assess the extent to which Landsat Pathfinder methodology and the proposed enhancements to this approach can be extrapolated to other regions

Global Land Cover Facility - Deforestation Mapping Group

Legend

- forest
- woodland
- water
- ice
- shrubs
- non-forest
- deforestation
- cloud

0   5   Kilometers
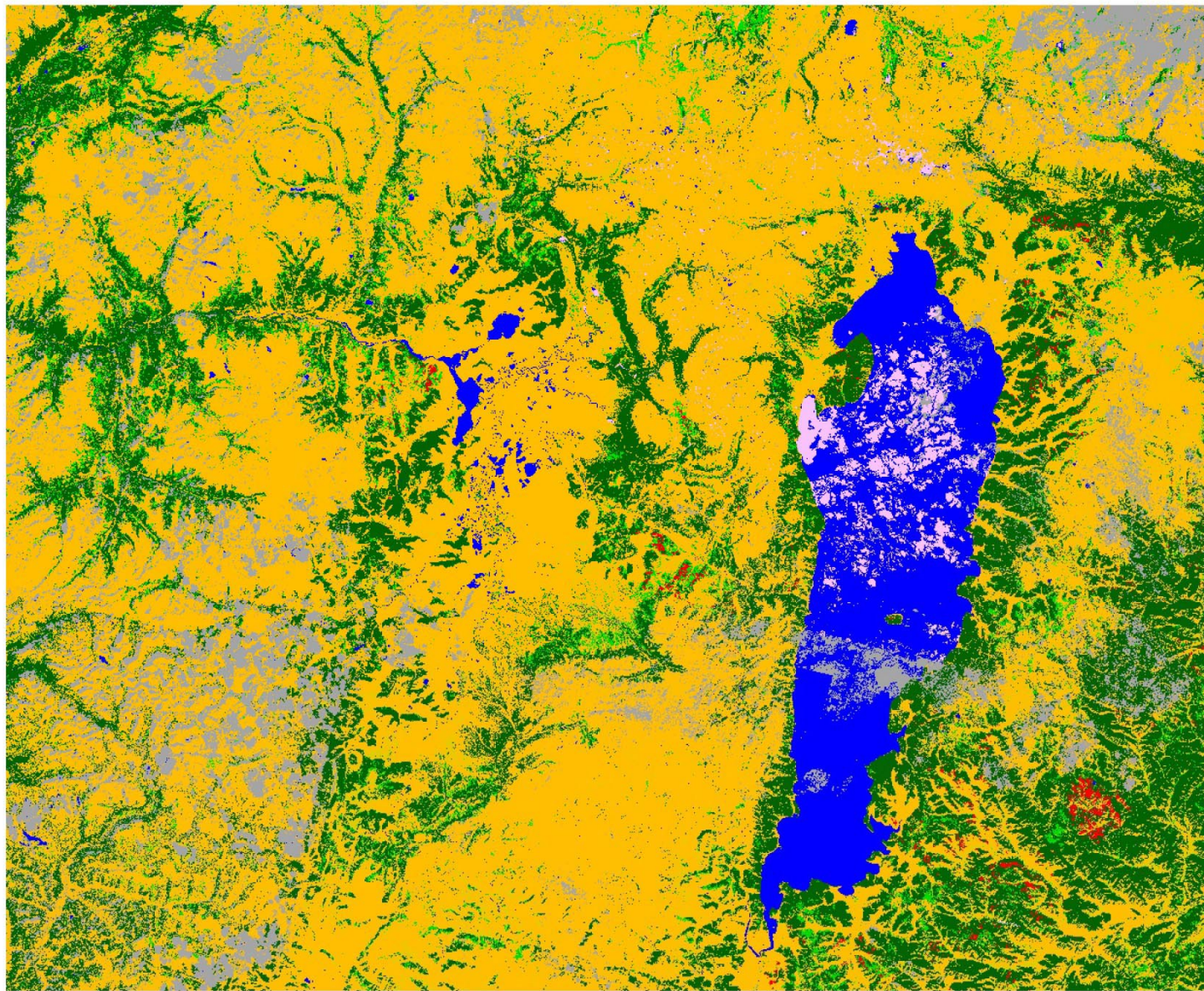
Location Map

Lake Hovsgol, Mongolia

Data Plan

New Methods Testing

> Landsat 4 & 5 TM images acquired through Landsat Pathfinder Project

Extension to New Regions

> Landsat 7, EarthSat Geo-registered dataset, Landsat 4 & 5

Selected Ikonos scenes and other ultra-high resolution images

Data Plan

Landsat Images and classification products will be stored and distributed through the Global Land Cover Facility.

Work Schedule -Year 1

- Landsat Pathfinder methods will be first tested in those extra-tropical areas most similar to the areas in tropical areas characterized by large scale clearance such as the clearance types in Paraguay discussed above.

- Test automated co-registration techniques and implement the most accurate and robust techniques based on our evaluation.

Work Schedule -Year 1 (cont'd)

- Implement the pre-processing procedures associated with atmospheric correction and test the MTF effects for TM data to decide the pixel size to be used and whether deconvolution should be implemented.

- The improvements in unsupervised procedures will be tested and implemented.

Work Schedule -Year 2

- Test the mixture modeling and supervised components of the approach to assess whether they bring substantial additional benefits.

- Assess Landsat Pathfinder methods including enhancements in test sites in the boreal zone.

Work Schedule -Year 3

- The most spatially and temporally complex areas will be examined to assess whether processes provide sufficiently reliable performance.

- Investigate the contribution of coarser resolution data sets for improved characterization of forest types in terms of leaf type and duration.

- Participate with GOFC activities providing advice on how to improve the characterization and monitoring of forest cover.
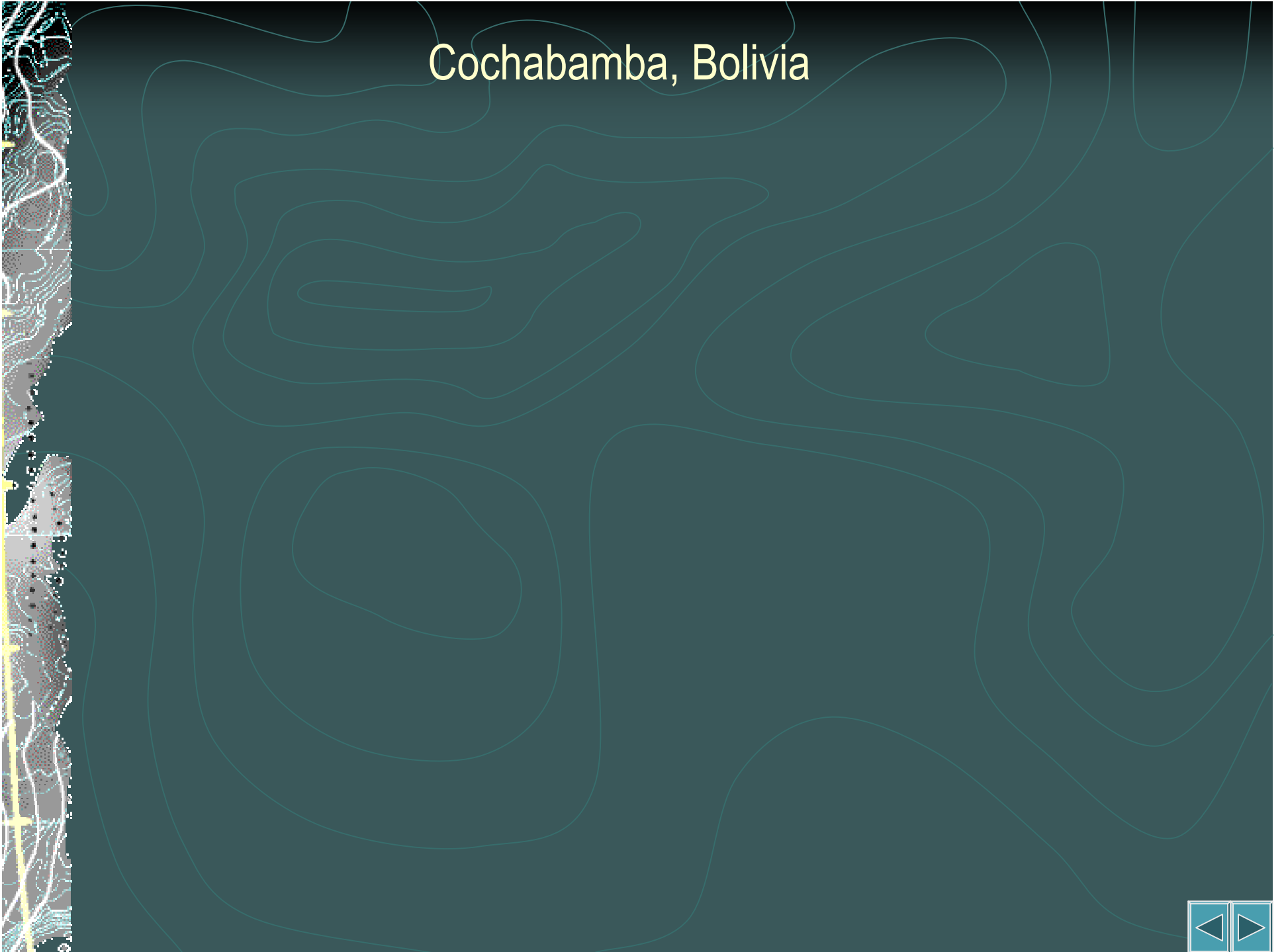
Paraguay example
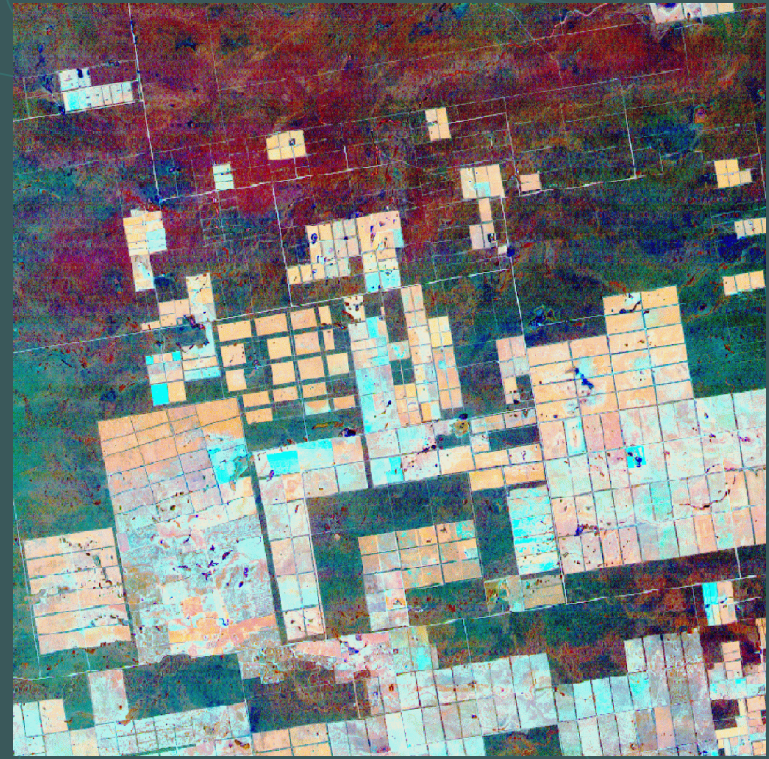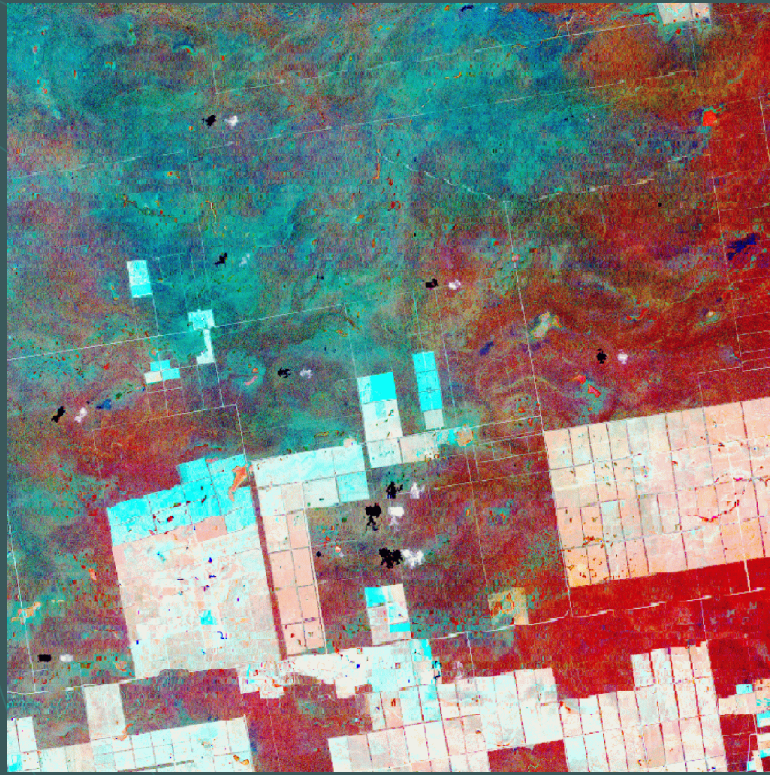
Tierras Bajas, Bolivia
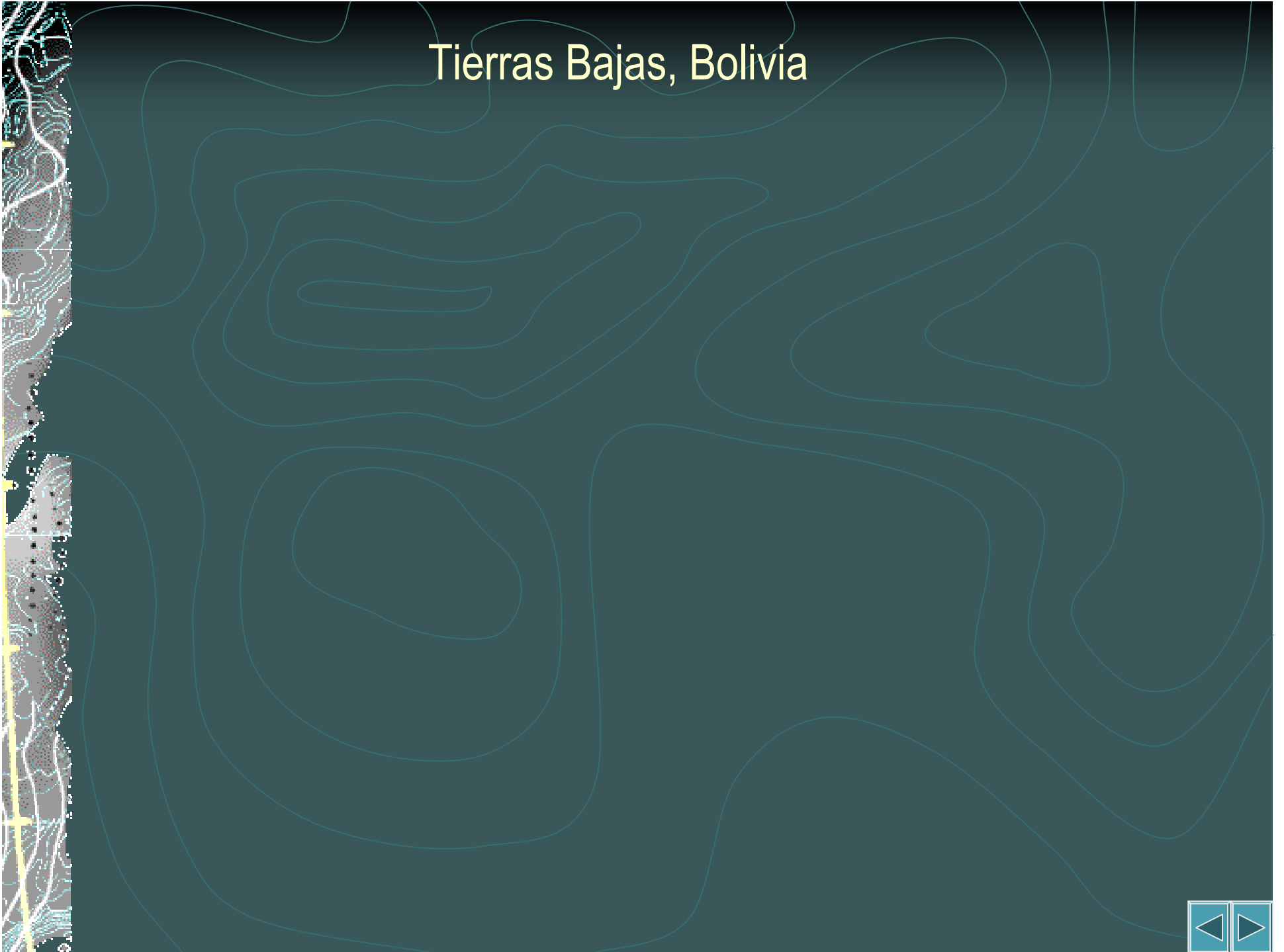
Cochabamba, Bolivia

References