The MODIS BRDF/Albedo Product: Global Bidirectional Reflectance, Land Surface Albedo, and Nadir BRDF-Adjusted Reflectance

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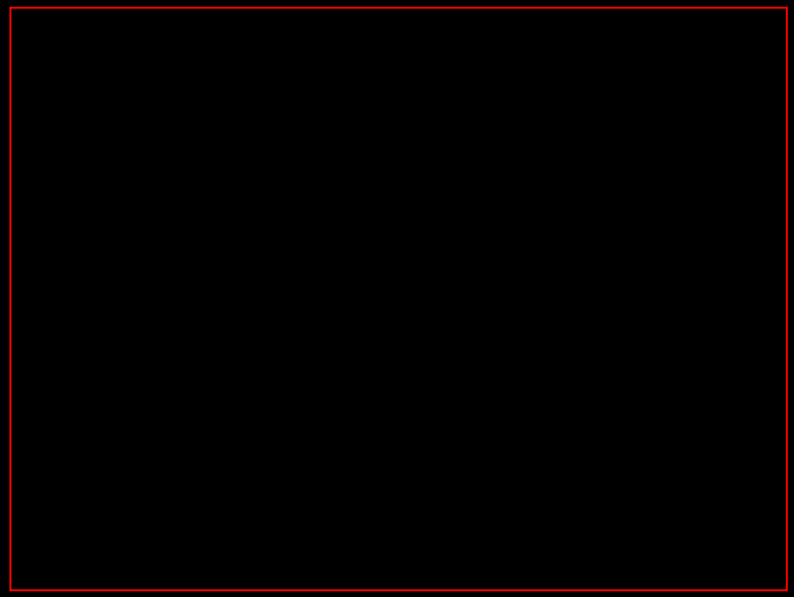
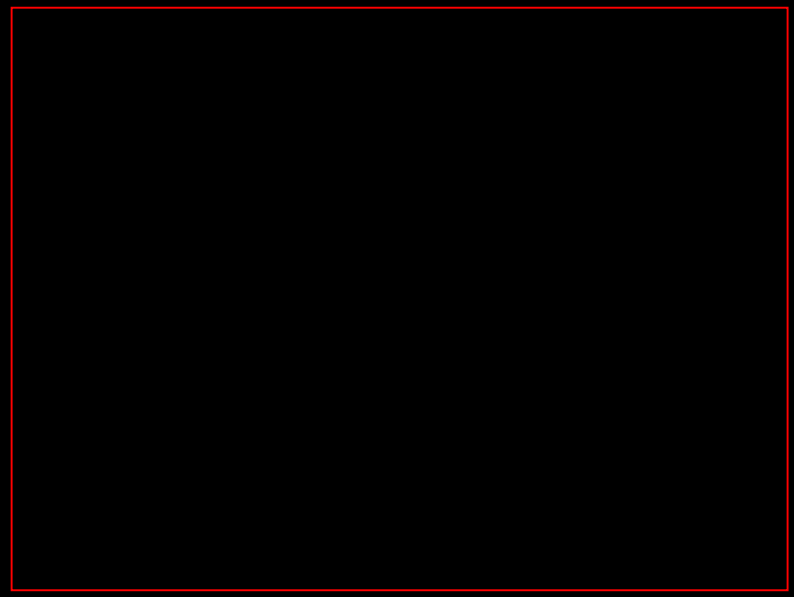


Terra Orbit and MODIS Swath

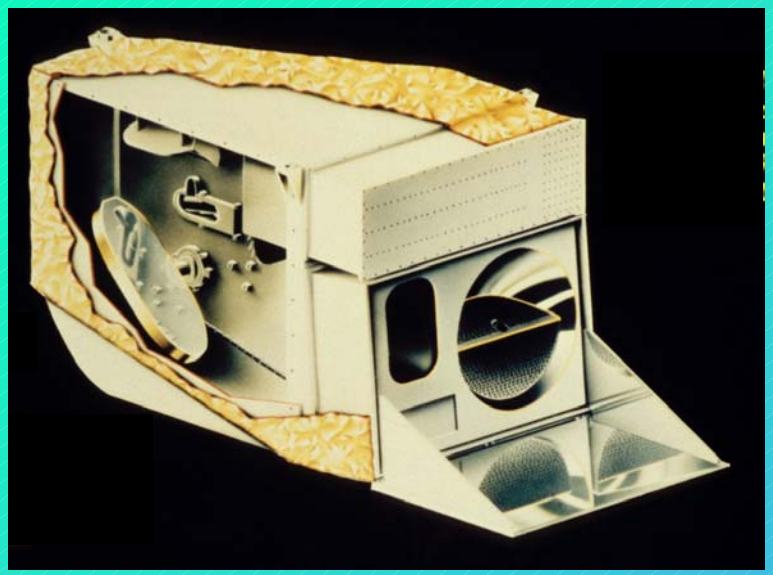


Terra Instrument Swaths

MODIS: System Characteristics

- Orbit—EOS-Terra Platform
  - Sun-synchronous, near-polar, 705.3 km, 98.21° inclination
  - 10:30 AM local solar equatorial crossing time (descending node)
  - Launched December 18, 1999
- Orbit—EOS-Aqua Platform
  - Sun-synchronous, near-polar, 705.3 km, 98.21° inclination
  - 1:30 PM local solar equatorial crossing time (ascending node)
  - Launched May 4, 2002

MODIS: System Characteristics, Cont.



Instrument Characteristics

- 36 spectral bands, VNIR, SWIR, TIR (0.4–14 μm)
- Spatial resolutions at 250-, 500-, and 1000-m (nadir) depending on waveband

- Whiskbroom design—double-sided rotating mirror, 10 lines per scan
- Four focal planes: Visible, NIR, SW-Midwave IR, Thermal IR
- Scan angle: ±55°, 2330–km swath
- Repeat: 2-day global repeat, 1-day or less poleward of 30° lat.

MODIS: System Characteristics,Cont.

- Onboard calibration
  - Spectroradiometric calibration assembly (SRCA)
  - Solar diffuser with stability monitor
  - Blackbody
  - Space view, lunar view
- Registration
  - Band-to-band registration ≤0.2 IFOV across focal planes, ≤0.1 IFOV within focal planes
- Geolocation
  - Present performance is ±50 m 1-σ (Terra)

BRDF/Albedo Product Overview

- Objective
  - ***Quantify angular variation in reflectance of land surface covers***
  - ***Map surface albedo measures for energy balance and climatic studies***
- Product Characteristics
  - ***Utilizes MODIS surface reflectance as input***
  - ***1-km spatial resolution***
  - ***16-day temporal resolution, utilizing all cloud-free looks for each pixel in a 16-day period***
  - ***BRDF: output is a parameter set for a semiempirical BRDF model fitted to each of 7 spectral land bands, 3 parameters per band***
  - ***Albedo: Two albedo measures ("black sky" albedo and "white-sky" albedo) provided in seven "land" bands and three broad bands: 0.4–3.0 μm , 0.4–0.7μm, 0.7-3μm***
  - ***NBARs: Nadir BRDF-Adjusted Reflectances in seven "land" bands***

Rationale

- Global mapping of surface albedo measures at fine resolution
  - ***Parameterizing of mesoscale atmospheric models***
  - ***Initializing numerical weather prediction models***
  - ***Quantifying the surface background for cloud studies***
  - ***Can be easily rescaled for GCMs at coarser resolutions***
- "Correction" of observations for directional effects
  - ***Nadir BRDF-Adjusted Reflectance (NBAR) standardizes reflectance to a specific view and illumination geometry—noon sun, nadir view***
- Enhanced atmospheric correction (to come)
  - ***Non-Lambertian surface BRDF influences multiple scattering***
  - ***Deriving surface reflectance requires BRDF correction for highest accuracy***
- Quantification of surface scattering behavior (to come)
  - ***Related to land cover and can be used in land-cover type inference***

Kernel-Driven Semiempirical BRDF Models

- BRDF model—linear combination of two BRDF shapes and a constant (J. L. Roujean)
- BRDF shapes described by kernels
  - ***trigonometric functions of incidence and view angles***
  - ***derived from physical models for surface scattering***
- Analytical form

$$R = f_{iso} + f_{vol}k_{vol} + f_{geo}k_{geo}$$

- ***where f_{iso} is a constant for isotropic scattering, k_{geo}, k_{vol} are trigonometric functions providing shapes for geometric-optical and volume-scattering BRDFs; and f_{geo}, f_{vol} are constants that weight the two BRDFs***
- ***We use the Ross-Thick kernel for volume scattering and the Li-Sparse kernel for geometric scattering***

Ross-Thick Kernel

- Kernel formula

$$k_{thick} = \frac{(\pi/2 - \phi)\cos\phi + \sin\phi}{\cos\theta_i + \cos\theta_v} - \frac{\pi}{4}$$

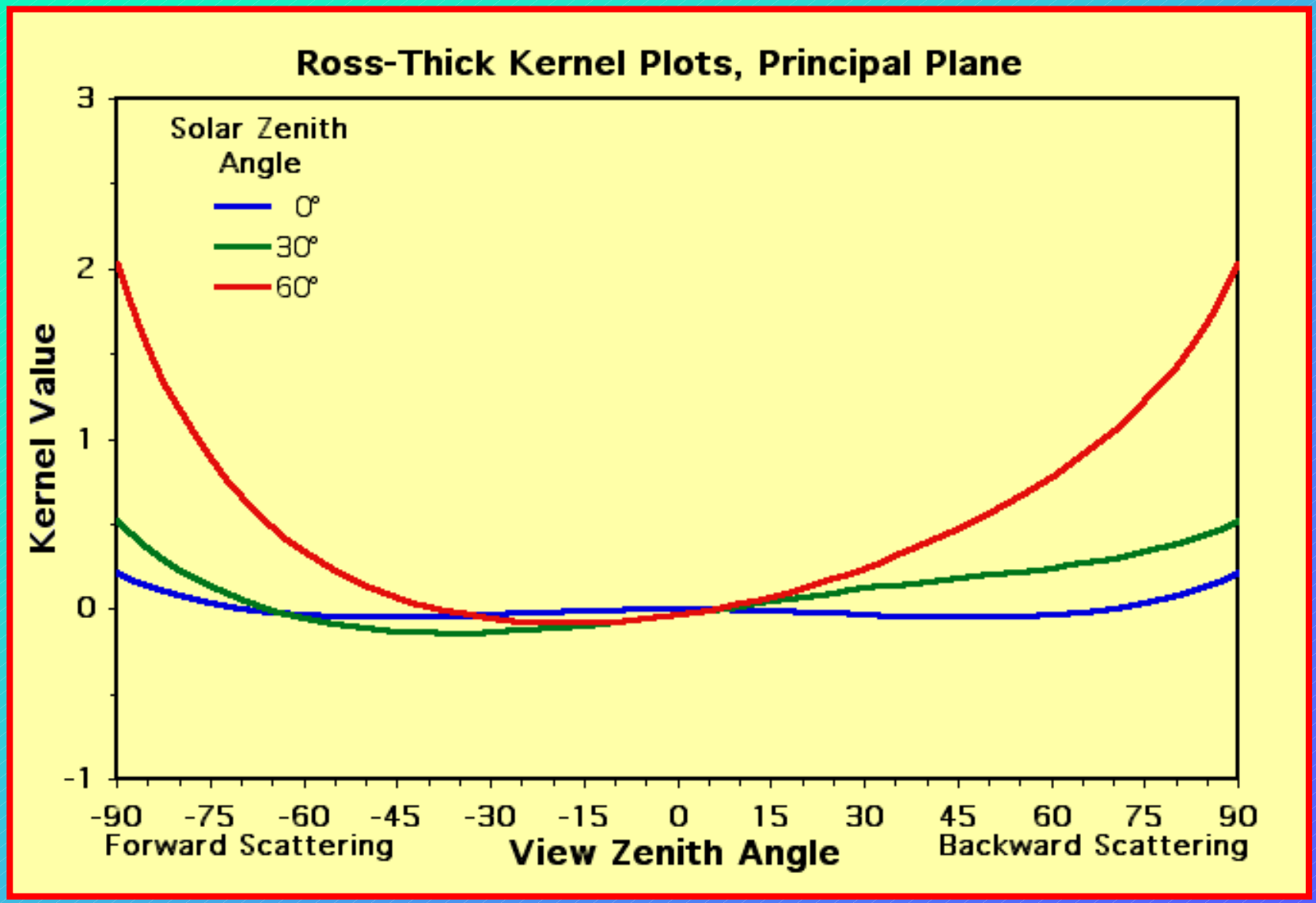
  - ***where ϕ is the phase angle between illumination and view positions in the hemisphere***

- Constants $R = c_1 k + c_2$

$$c_1 = \frac{4s}{3\pi}\left(1 - e^{-LAI\ B}\right) \qquad c_2 = \frac{s}{3} + e^{-LAI\ B}\left(\rho_s - \frac{s}{3}\right)$$

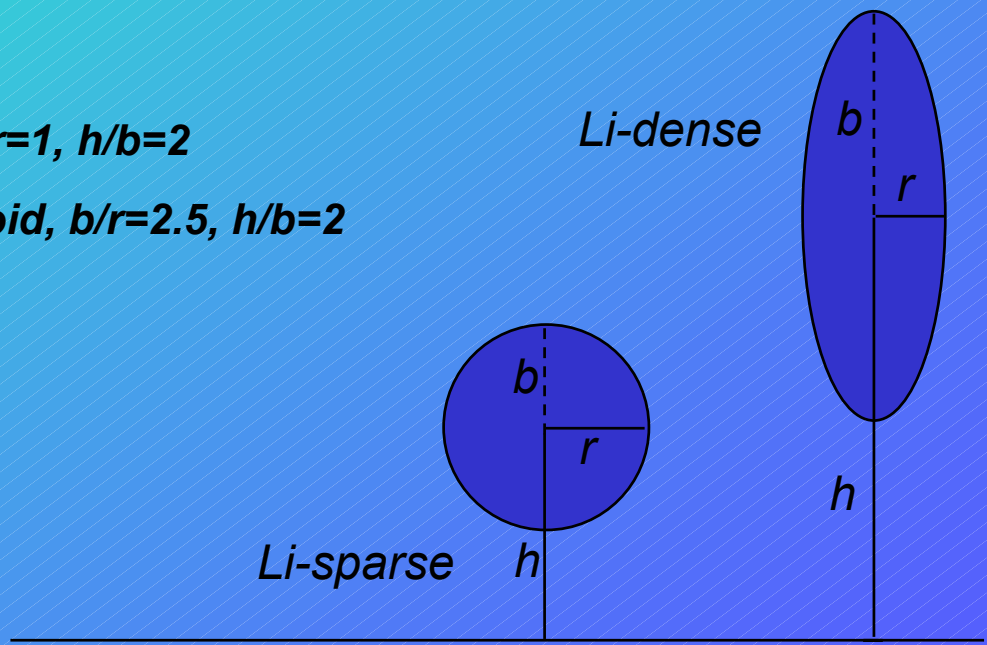
  - ***where s is leaf reflectance; ρ_s is the surface reflectance; LAI is the leaf area index; B is the average of secants of possible view and illumination angles (≈1.5)***

Ross-Thick Kernel Plots



Li Kernels

- Assumptions
  - ***Shadows are perfectly black***
  - ***Sunlit surfaces, whether object or background, are equally bright***
  - ***Some geometric approximations for the overlap of view and illumination shadows***
- Crown shape choices
  - ***Li-Sparse: low sphere, b/r=1, h/b=2***
  - ***Li-Dense: tall, thin spheroid, b/r=2.5, h/b=2***



Li-Sparse Kernel

- Kernel model

$$k_{sparse} = O(\theta_i, \theta_v, \phi) - \sec\theta'_i - \sec\theta'_v + \frac{1}{2}(1 + \cos\phi')\sec\theta'_v$$

  - ***where***

$$O = \frac{1}{\pi}(t - \sin t \cos t)(\sec\theta'_i + \sec\theta'_v) \qquad \theta' = \tan^{-1}\left(\frac{b}{r}\tan\theta\right)$$

$$\cos t = \mathrm{Max}\left[\frac{h}{b}\frac{\sqrt{D^2 + (\tan\theta'_i \tan\theta'_v \sin\phi)^2}}{\sec\theta'_i + \sec\theta'_v}, 1\right]$$

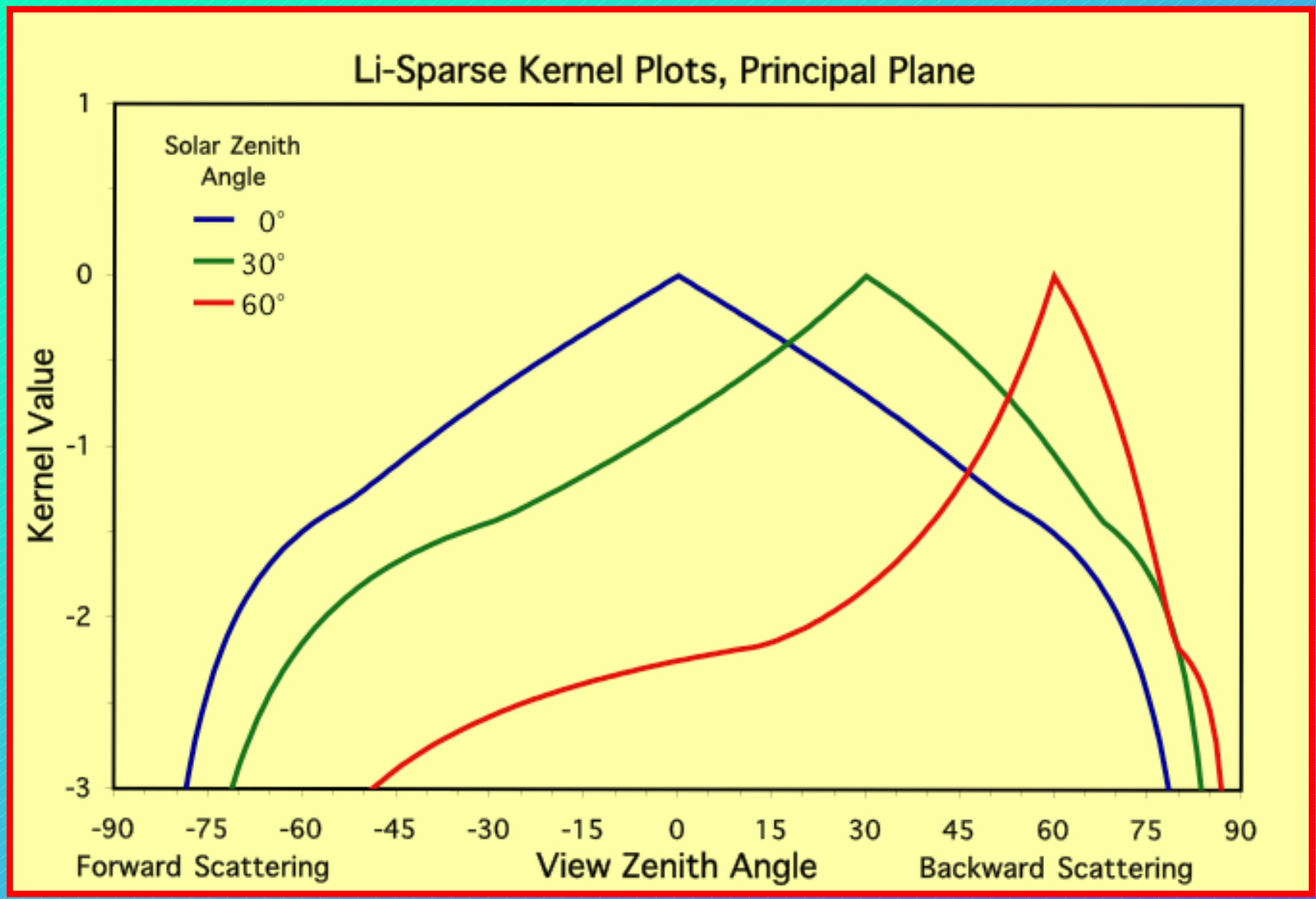
$$D = \sqrt{\tan^2\theta'_i + \tan^2\theta'_v - 2\tan\theta'_i \tan\theta'_v \cos\phi}$$

$$\cos\phi' = \cos\theta'_i \cos\theta'_v + \sin\theta'_i \sin\theta'_v \cos\phi$$

- Constants $R = c_1 k + c_2 \qquad c_1 = C\lambda\pi r^2 \qquad c_2 = C$

  - ***where C is the brightness of sunlit surface; and λ is the count density of spheroids***

Li-Sparse Kernel Plots



What BRDF/Albedo Product Provides

- BRDF parameters for Ross-Thick/Li-Sparse semi-empirical BRDF model
  - ***Three parameters per pixel and per band for 7 spectral bands***
- Albedo values
  - ***Black-sky (beam) and white-sky (diffuse) albedos***
    - ***Black-sky albedo: Integral of BRDF over all view angles = directional-hemispherical reflectance***
    - ***White-sky albedo: Double integral of BRDF over all view and illumination angles = bihemispherical reflectance***
  - ***Actual albedos can be estimated by interpolating the diffuse and direct beam albedos as a function of diffuse skylight***
  - ***Per-pixel values in 7 land bands plusVIS, IR, and solar broad bands using a narrow- to broadband conversion method developed by Shunlin Liang***
- Nadir BRDF-Adjusted Reflectance
  - ***Nadir-view, noon-sun geometry for each pixel in 7 spectral bands***

Primary and Backup Model Fitting

The primary BRDF retrieval algorithm is bolstered by a robust back-up algorithm.

1. The full model inversion is used when sufficient high quality MODIS observations are available to sample the BRDF (usually ≥ 7 looks).

2. The lower quality magnitude inversion couples *a priori* knowledge of the surface anisotropy with any MODIS observations that are available.

3. Extensive Quality Assurance Flags are supplied with the product indicating both the quality of the product and the processing method used.

CMG Broadband White-Sky Albedo (0.3-5.0µm)
1 Jan – 25 May, 2002

QuickTime™ and a
Video decompressor
are needed to see this picture.

No Data

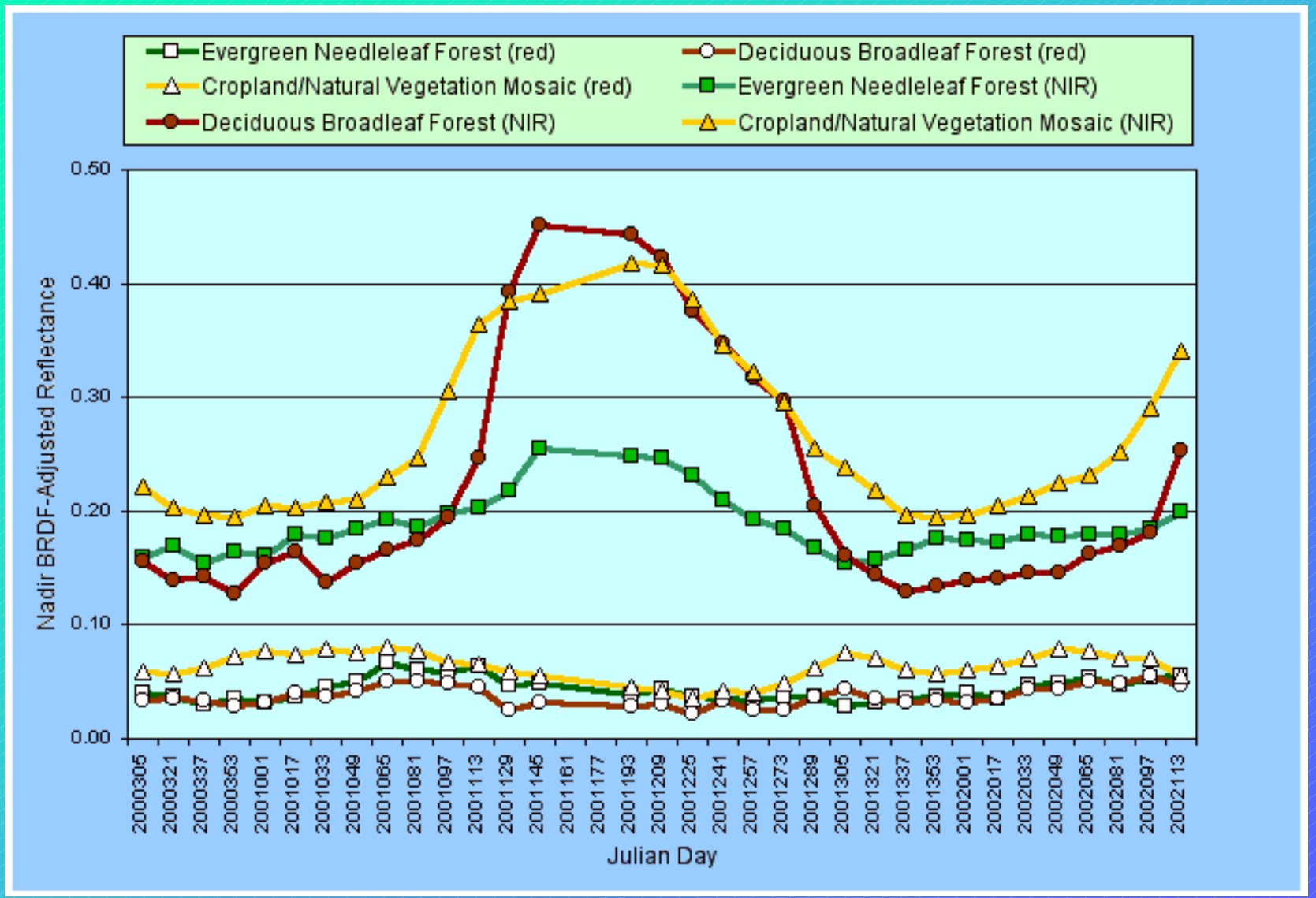
0.0 0.2 0.4+

White Sky Spectral Albedo
1 Jan – 25 May, 2002

No Data

NIR (0.1-0.4) Red (0.0-0.16) Blue (0.0-0.18)

NBAR from Land Cover Training Sites in the Southern US



Schaaf et al., First Operational BRDF, Albedo and Nadir Reflectance Product from MODIS, in press, Remote Sensing Environ., 2002

Current Status of MODIS BRDF/Albedo Products (MOD43)

- Operational production began in April 2000
  - V001–Beta Status files are now being removed from the archive
- Collection 3 reprocessed products (V003) are still available from November 2000 – December 2002 (in ISG in 10º tiles)
- Collection 4 reprocessed products (V004) are now available from April 2000 to present
- Collection 4 features:
  - Improved upstream processing
  - SIN projection for gridded products
  - New database for backup magnitude inversions (based on MODIS derived BRDFs)
  - BRDF products have been upgraded to a "Validated (Level 1) Status"
- Collection 5 reprocessing is expected to begin around 1 January 2004.

Current Status of MODIS BRDF/Albedo Products (MOD43)

Note: At present Aqua-only products are being produced operationally
Aqua-plus-Terra products will start soon and run in parallel with Terra-only products.

Climate Modeling Grid products:

The V003 MOD43C1 CMG 1/4 degree Albedo and MOD43C2 BRDF Parameter Products are available from July 2001 onward (global files in a Lat/Lon Geographic grid) .

V004 CMG products are at a 0.05-degree resolution.
(includes Albedo, BRDF Parameters, and NBAR—
1-degree, 0.5 degree and 0.25 degree products will continue to be available from PI's website).

MOD43B MODIS BRDF/Albedo Product Evaluation

Team Evaluation has focused on:

MOD43B Quality Assurance Flags

Jin, Y., C. B. Schaaf, C. E. Woodcock, F. Gao, X. Li, A. H. Strahler, W. Lucht, S. Liang, Consistency of MODIS surface BRDF/Albedo retrievals: 1. Algorithm performance, J. Geophys. Res., 108(D5), 4158, doi:10.1029/2002JD002803, 2003.

Predictive capability of BRDF parameters

Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X., Tsang, T., Strugnell, N. C., Zhang, X., Jin, Y., Muller, J.-P., Lewis, P., Barnsley, M., Hobson, P., Disney, M., Roberts, G., Dunderdale, M., Doll, C. d'Entremont, R., Hu, B., Liang, S., and Privette, J. L., 2002, First operational BRDF, albedo and nadir reflectance products from MODIS, *Remote Sens. Environ.,* vol. 83, pp. 135–148.

Validation

Liang, S., Fang, H., Chen, M., Shuey, C. J., Walthall, C., Daughtry, C., Morisette, J., Schaaf, C., and Strahler, A. 2002, Validating MODIS Land Surface Reflectance and Albedo Products: Methods and Preliminary Results, *Remote Sens. Environ.,* vol. 83, pp. 149-162.

Jin, Y., C. B. Schaaf, C. E. Woodcock, F. Gao, X. Li, A. H. Strahler, W. Lucht, S. Liang, Consistency of MODIS surface BRDF/Albedo retrievals: 2. Validation, J. Geophys. Res., 108(D5), 4159, doi:10.1029/2002JD002804, 2003.

MOD43B Quality Assurance Flags

MOD43B 1km ISG products contain two 32 bit-packed words:

First Word (Band Independent): Mandatory QA, Period, Land/Water, Sensor, Snow/NoSnow, Solar Zenith Angle

Second Word (Band Dependent): Full Inversion Quality (0-7), Magnitude Inversion Quality (8-10)

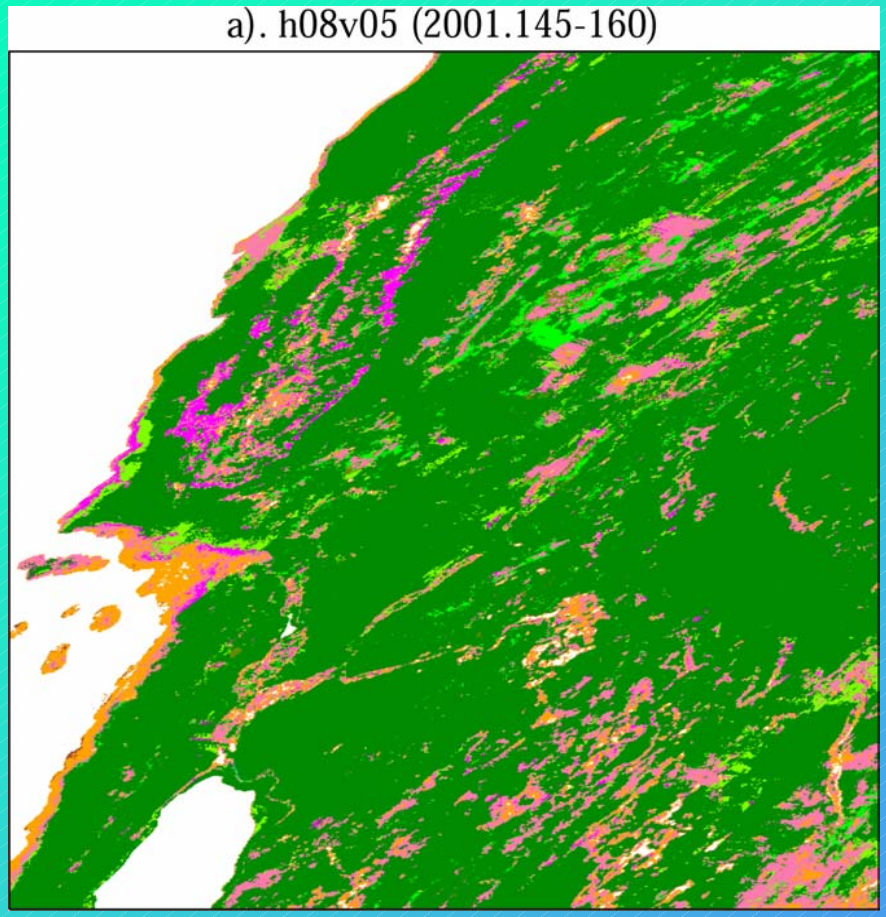
For Example: Between 60ºN - 60 ºS for September, 2001

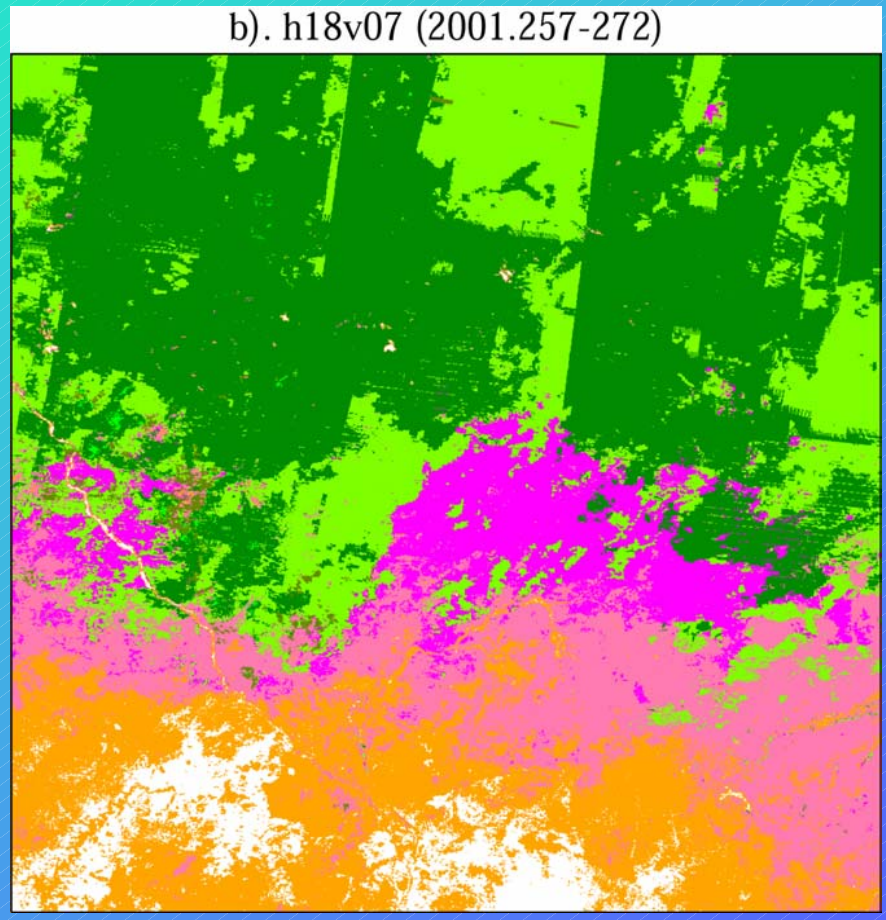
47% of all land pixels were retrieved with a full inversion

45% with a magnitude inversion

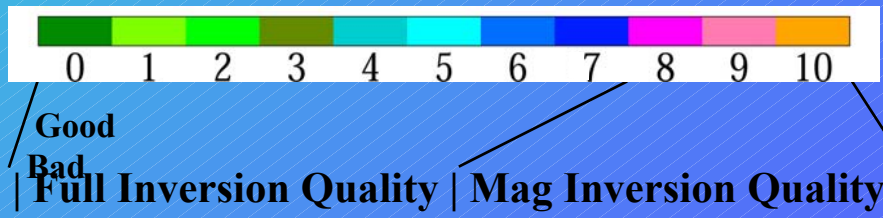
8% were not retrieved due to an absence of quality observations.

MOD43B Quality Assurance Flags





Southwestern North America



West Africa—Sahel

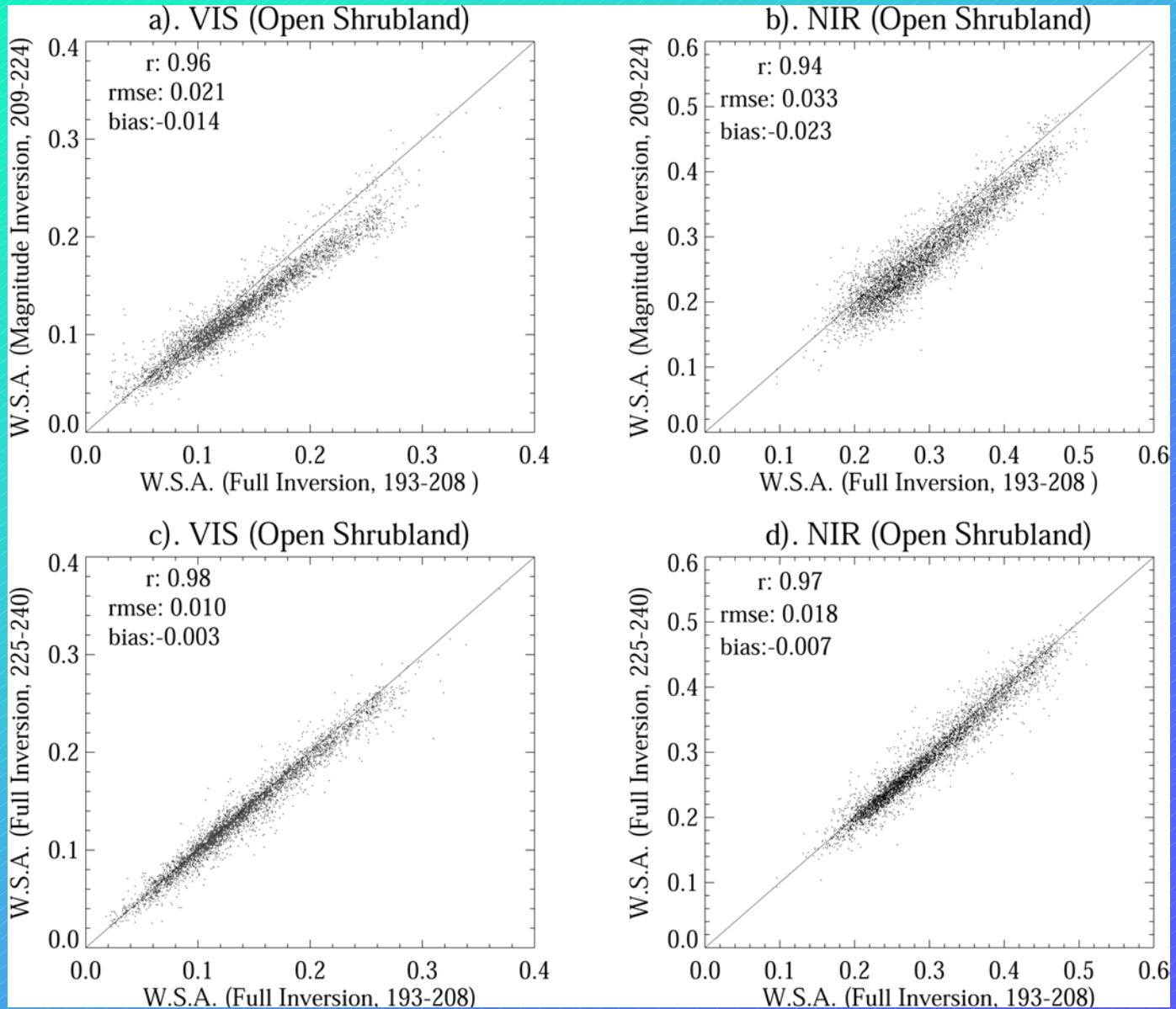
Full vs. Magnitude Inversions, Baja Tile

Dates:

193–208: Clear, full inversion pixels

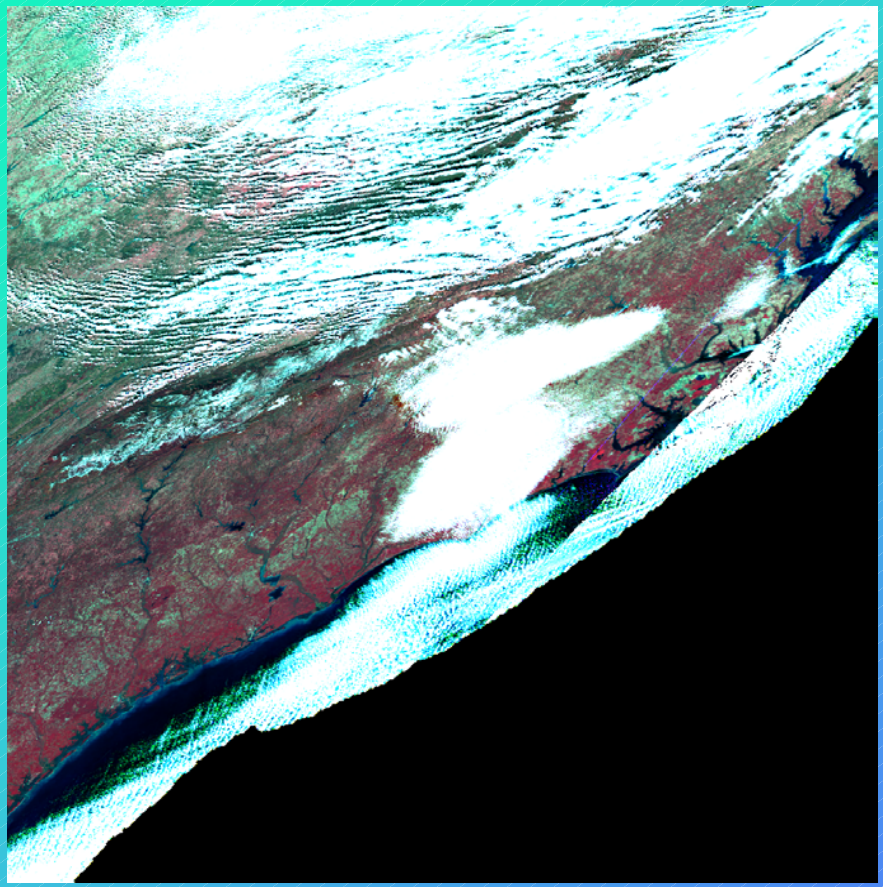
209–224: Many cloudy dates, magnitude inversion pixels

225–240: Clear, full inversion pixels

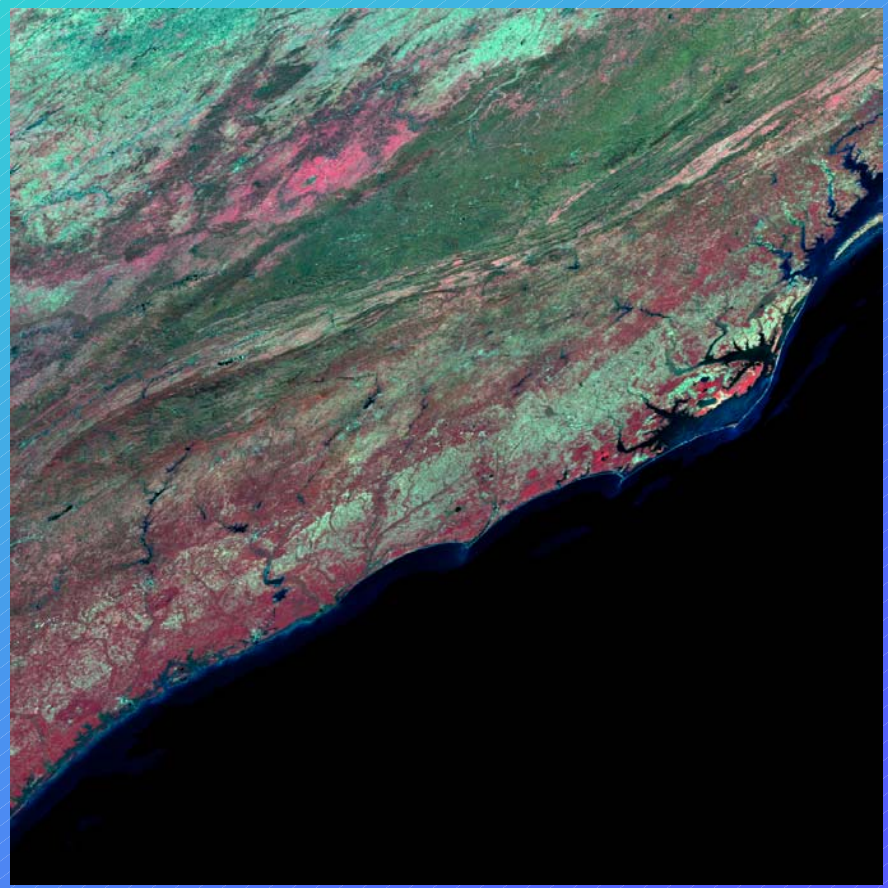


Using BRDF Parameters to Predict Future Surface Reflectances

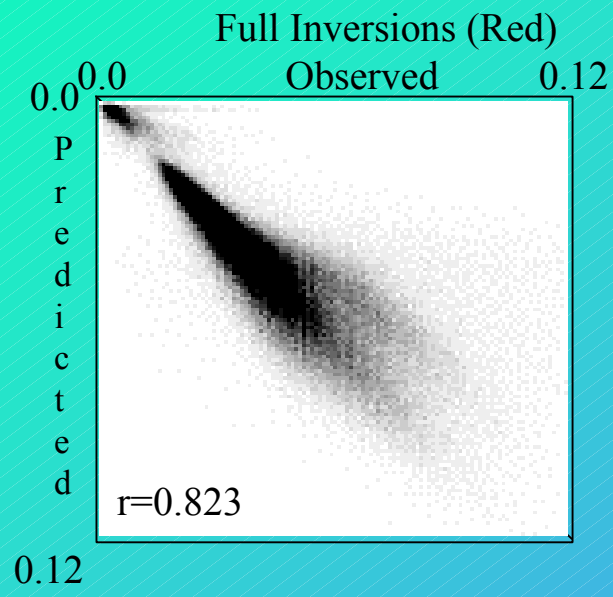
Observed 1km Surface Reflectances
20 November, 2000 (Day 325)

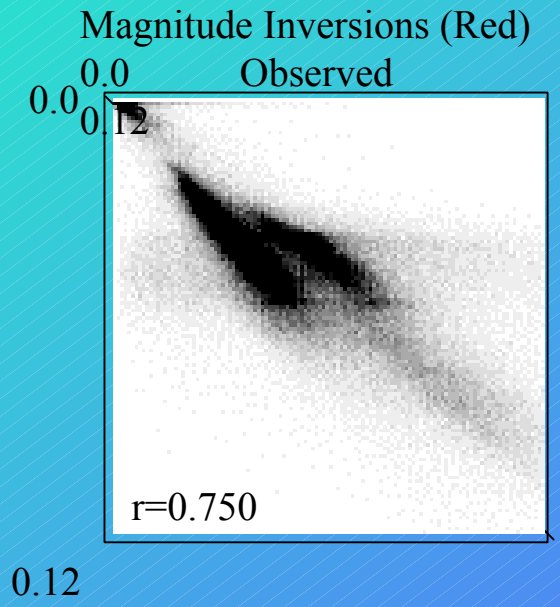


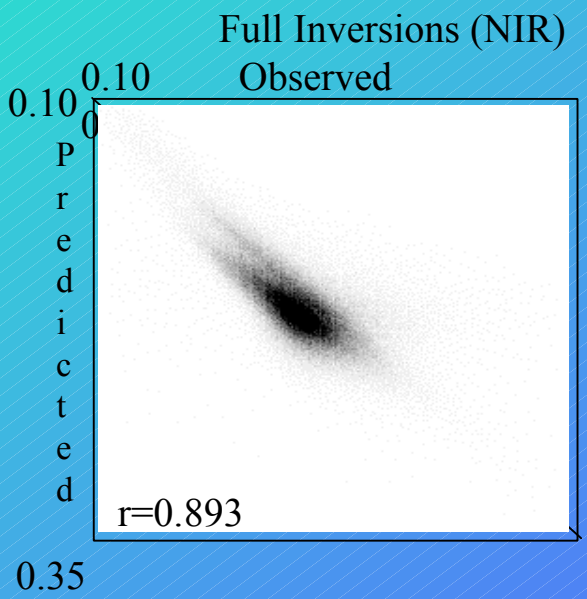
Predicted 1km Surface Reflectances
for 20 November, 2000, using BRDF
Parameters from 31 Oct - 15 Nov, 2000

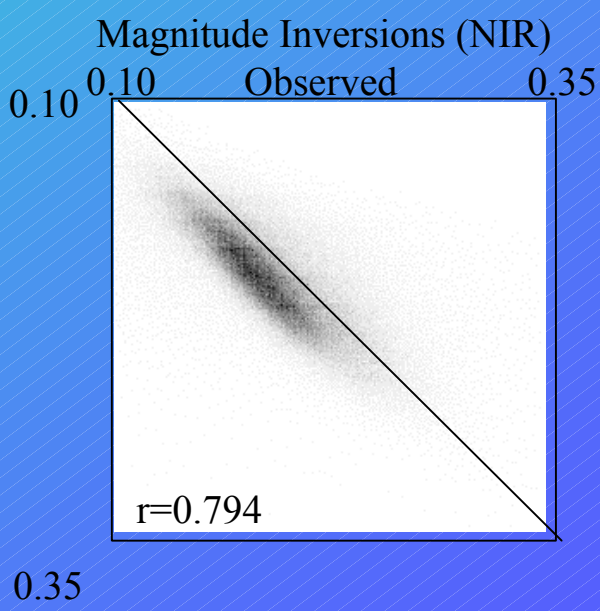


NIR (0.1-0.35) Red (0-0.12) Green (0-0.12)


Full Inversions (Red)
0.0
Observed
0.12
0.0
Predicted
r=0.823
0.12


Magnitude Inversions (Red)
0.0
Observed
0.0
0.12
r=0.750
0.12

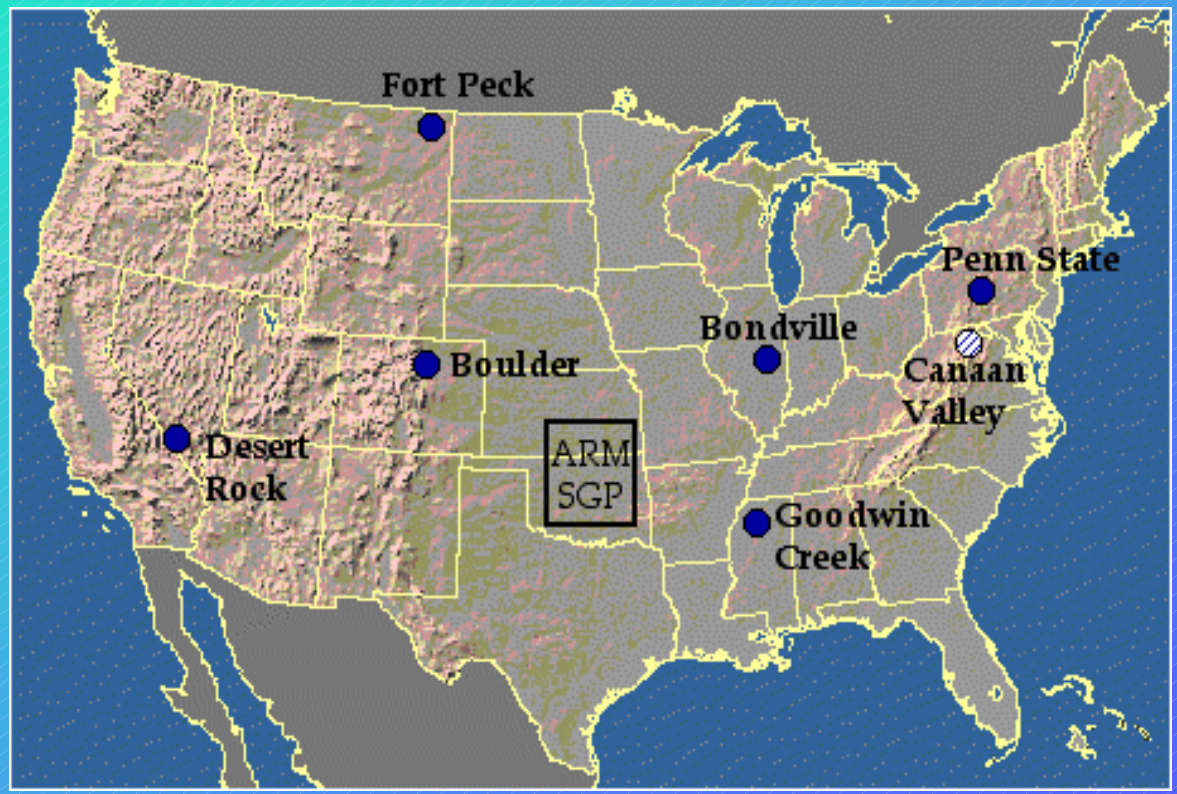

Full Inversions (NIR)
0.10
Observed
0.10
0
Predicted
r=0.893
0.35


Magnitude Inversions (NIR)
0.10
Observed
0.35
0.10
r=0.794
0.35

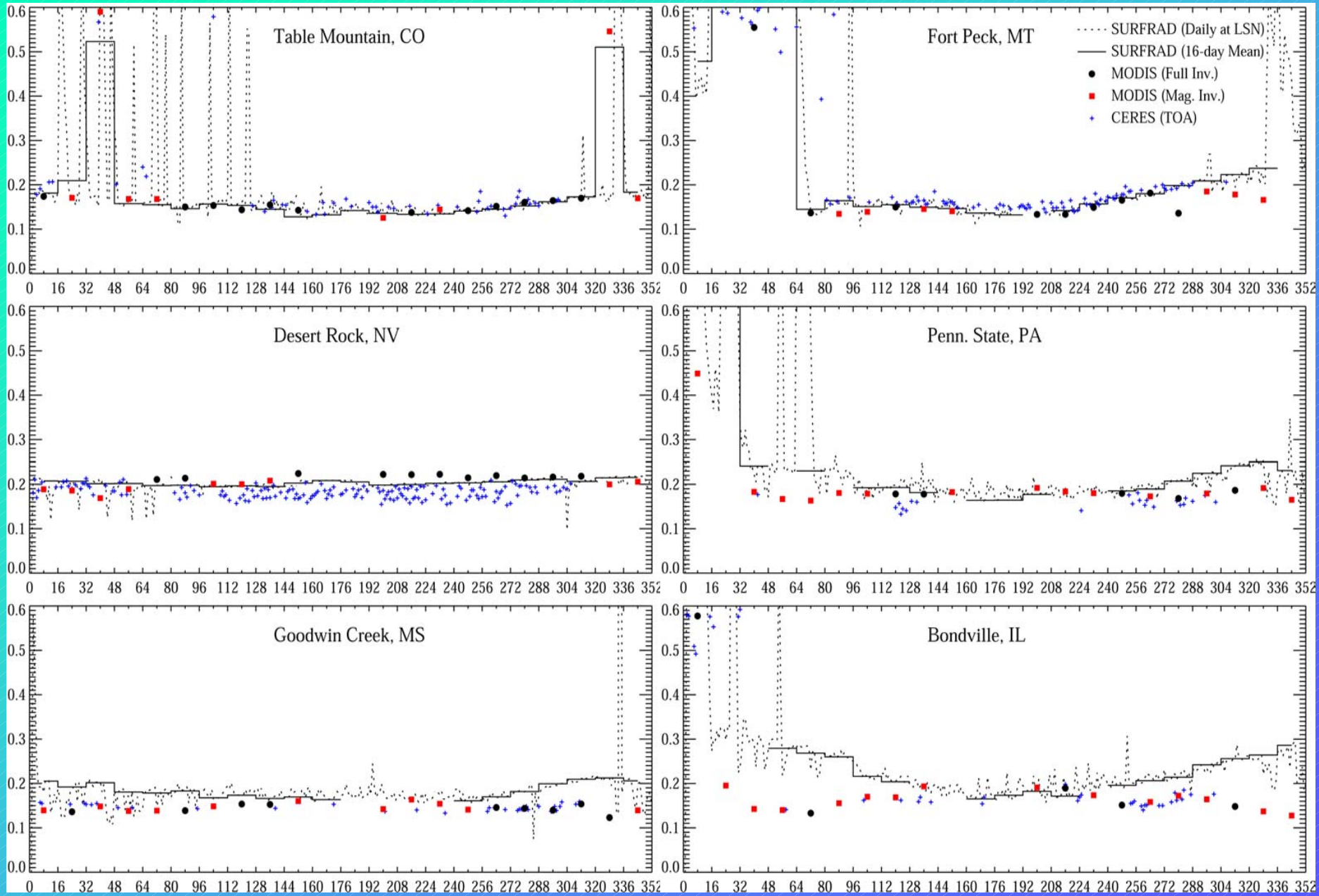
Surface Radiation Budget Network (SURFRAD)

Six instrumented sites continuously measuring solar radiation (including PAR, direct and diffuse).

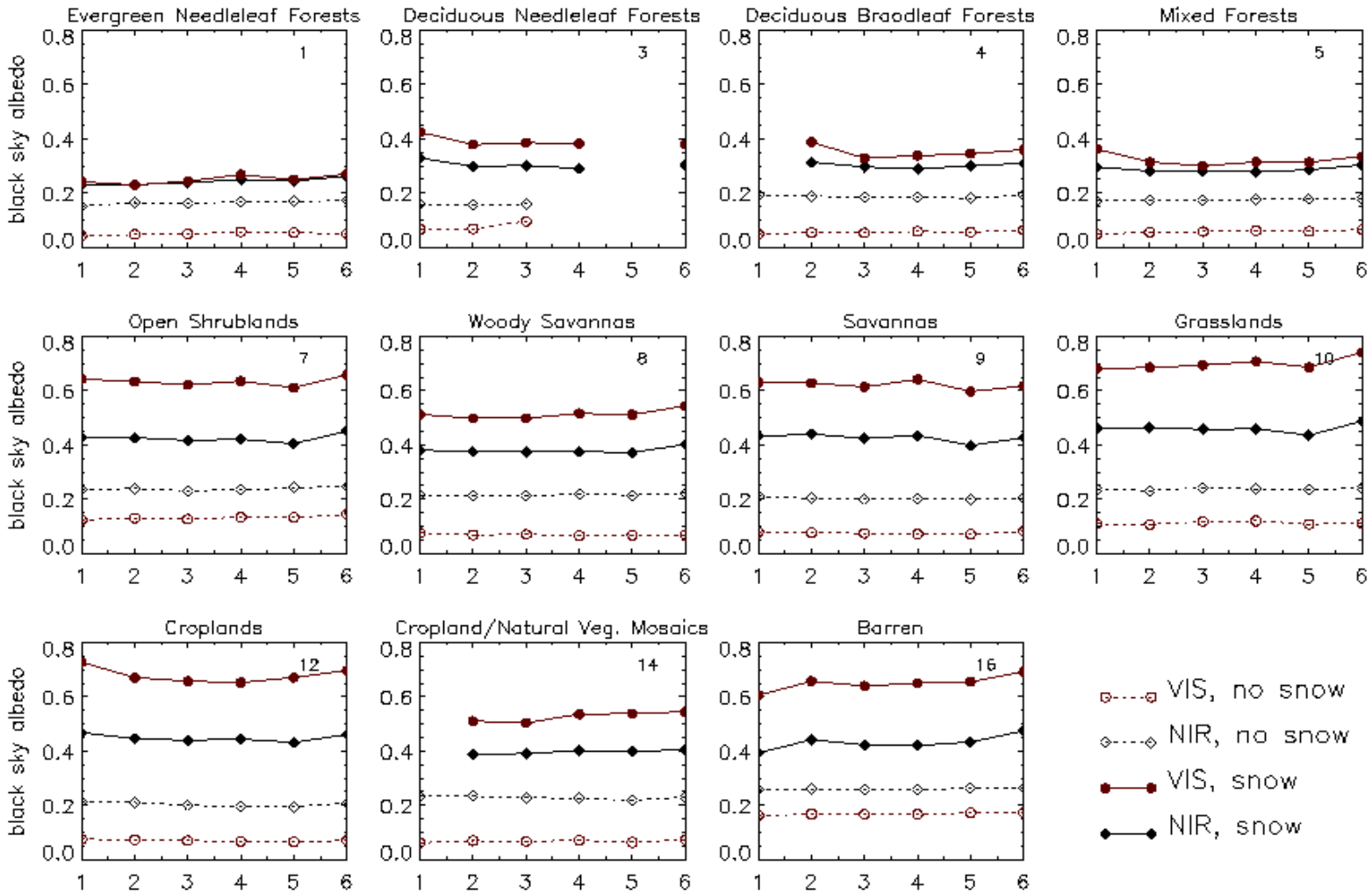
Data packaged and distributed as half hour values by the CERES/ARM Validation Experiment (CAVE) April - September, 2001.



MODIS, CERES, and SURFRAD Comparisons



Snow versus Non-snow Albedos 40–50°N Nov 00–Jan 01



Jin, Y., Schaaf, C., Gao, F., Li, X., Strahler, A., Zeng, X., Dickinson, R., 2002, How does snow impact the albedo of vegetated land surfaces as analyzed with MODIS data?, *Geophys. Res. Let.,* vol. 29, pp. 12-1–12-4.

Collection 003

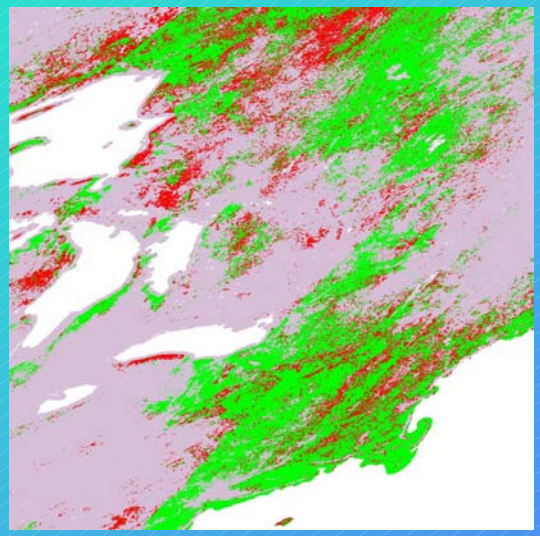
Collection 004

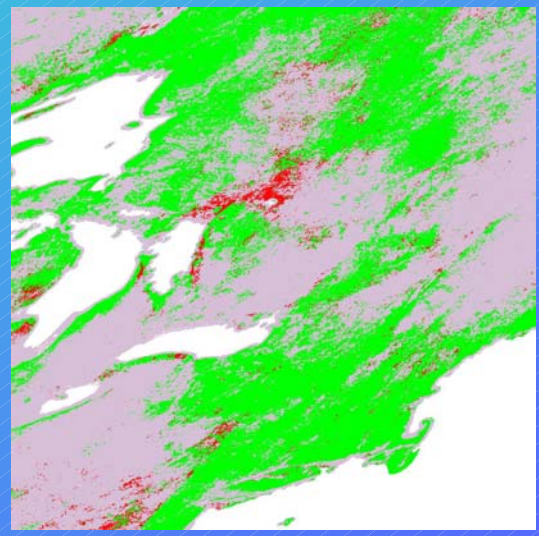
NBAR Products

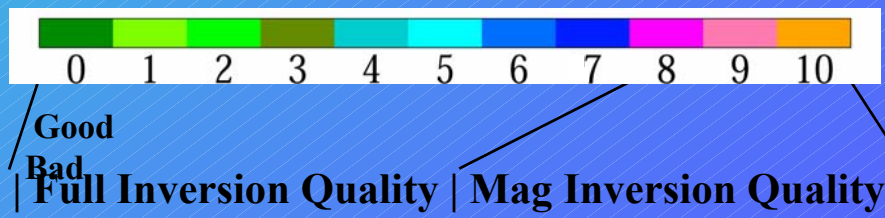
true color,
big stretch

Quality Flags

Green best
Red moderate
Gray backup





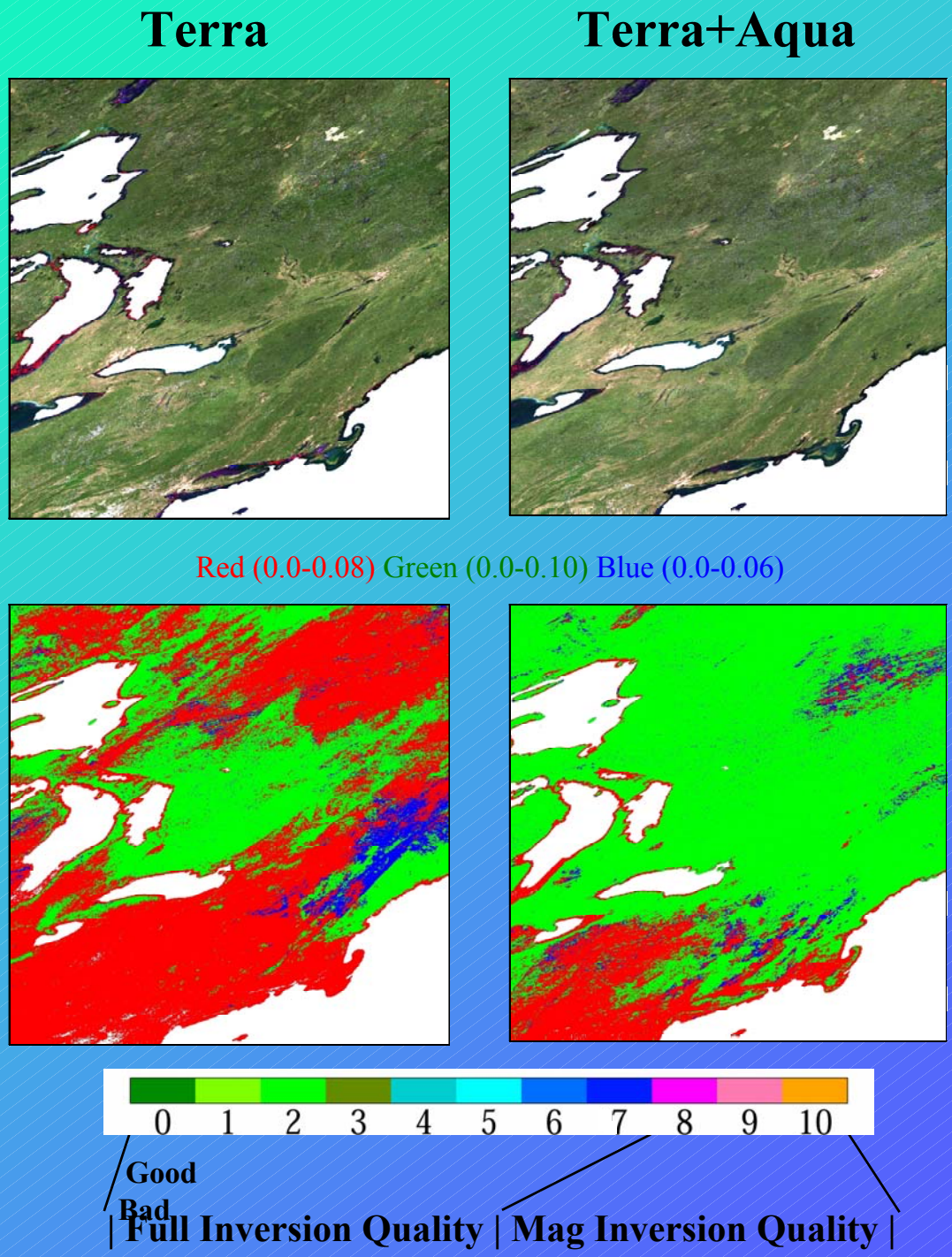


NBAR Products

true color

Quality Flags

Green best
Blue moderate
Red backup



MOD43B MODIS BRDF/Albedo Product Summary

- MOD43B algorithms have performed well since launch, and reprocessed data are temporally stable and consistent.
- Validations and comparisons with albedometers over the sites in the US are very encouraging with errors of well less than 10%. International comparisons are in progress.
- All indications are that our QA flags are performing very well—users MUST consult our flags to recognize whether they are looking at snow albedos values or not and whether retrievals are from the highest quality full inversions or the lower quality magnitude inversions.
- Based on these analyses, we assigned MOD43B the validation status "Validated (level 1)" on June 11, 2002.

MOD43B MODIS BRDF/Albedo Product Listing

Products at 1km:

MOD43B1: MODIS/Terra BRDF/Albedo Model-1 16-Day L3 Global 1km ISIN* Grid
MOD43B3: MODIS/Terra Albedo 16-Day L3 Global 1km ISIN Grid
MOD43B4: MODIS/Terra Nadir BRDF-Adjusted Reflectance 16-Day L3 Global 1km ISIN Grid (NBAR)

Products at 1/4 degree (moving to 1/20th degree in V004**):

MOD43C1: MODIS/Terra Albedo 16-Day L3 Global 0.25Deg CMG***
MOD43C2: MODIS/Terra BRDF/Albedo Parameters 16-Day L3 Global 0.25Deg CMG

Products at 1/20th, 1/4, 1/2, and 1 degree (in both HDF-EOS and binary) :

IDS website and CD effort (32 day quality composited)
ISLSCP-2 effort (2001 data)

Web Site: http://geography.bu.edu/brdf/

*ISIN = Integerized Sinusoidal Grid, is now (non-Integerized) Sinusoidal Grid in V004
**V004 = MODIS data reprocessing version number (V003 = “Consistent Year,” Oct 00–Oct 01)
***CMG = Climate Modelers’ Group products

The MODIS Land Cover Product

MOD12Q1: Global Land Cover
MOD12Q2: Land Cover Dynamics

A.H. Strahler (PI), Mark Friedl, Xiaoyang Zhang, and John Hodges

http://geography.bu.edu/landcover/

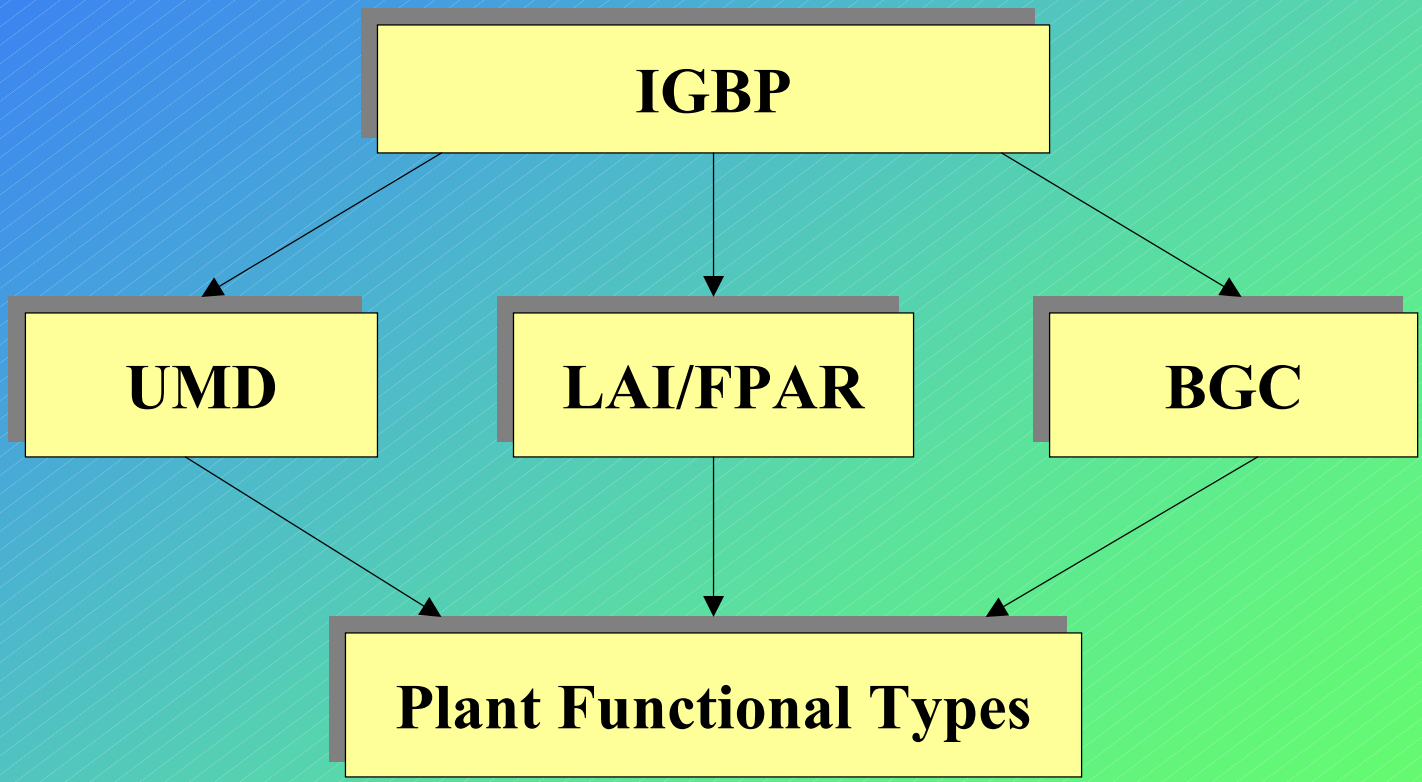
Center for Remote Sensing and Dept. of Geography
Boston University

MOD12Q1: What Is It?

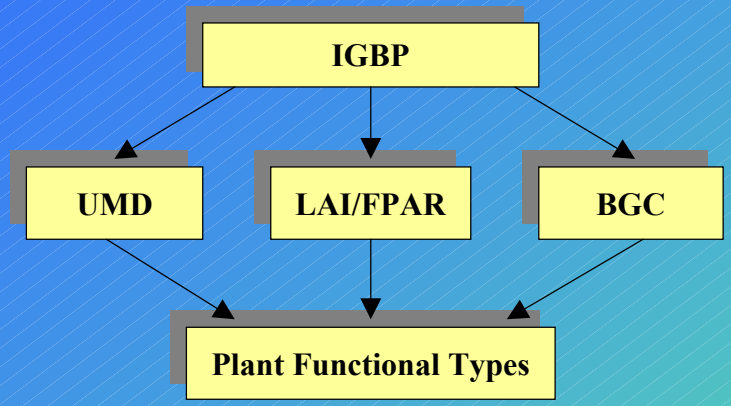
- ***A global database of land cover type classes***
  - **Prepared at 1-km spatial resolution from MODIS data**
  - **Remade at 3-month intervals using data from the preceding 12 months**
  - **Includes 5 different sets of land cover labels, label confidences, and quality assessment information**
  - **Available in coarser resolutions of 1/20°, 1/4°**

MOD12Q1: What Is It?

- *Five Consistent Layers of Land Cover Class Labels*



MOD12Q1: What Is It?



- *Plant Functional Types (Future)*
  - Plant functional types to be used with the community land model (NCAR, Bonan)
  - Exact classes TBD

- *IGBP:International Geosphere-Biosphere Project labels*
  - 17 classes of vegetation life-form
- *UMD: University of Maryland land cover class labels*
  - 14 classes without mosaic classes
- *LAI/FPAR: Classes for LAI/FPAR Production*
  - 6 labels including broadleaf and cereal crops
- *BGC: Biome BGC Model Classes*
  - 6 labels: leaf type, leaf longevity, plant persistence

MOD12Q1: What Is It?

- ***Land Cover Types***
  - **IGBP, UMD, LAI/FPAR, BGC, PFT (Future)**
- ***Confidences***
  - **Classification confidence (percent scale) for each pixel for each label**
- ***Secondary IGBP Label and Confidence***
  - **For IGBP, a secondary class label and confidence value for each pixel**
- ***Quality Assurance Flag Word for each Pixel***
  - **Includes quality for pixel, last update, and embedded land/water mask**

MOD12Q1: Where Does it Come From?

- ***MODIS Data***
  - **16-day Nadir BRDF-Adjusted Reflectances (NBARs) assembled over one year of observations**
  - **7 spectral bands, 0.4–2.4 μm, similar to Landsat**
  - **16-day Enhanced Vegetation Index (EVI)**
- ***Training Data***
  - **>1,500 training sites delineated from high resolution satellite imagery (largely Landsat)**
- ***Classifier***
  - **Uses decision tree classifier with boosting**

Global Land Cover Products Released

- ***Beta Product, released April 15, 2001***
  - **Based on 2 16-day periods of Nadir BRDF-Adjusted Reflectance (NBARs)**
- ***Provisional Product 2001001, released June 15, 2001***
  - **Based on 9 16-day periods of NBARs within July 11– January 15, 2001**
  - **Used prior probabilities to help separate agriculture and natural vegetation**
  - **Included IGBP classification, secondary classes, confidence measures**
  - **Filled from at-launch product (EDC DISCover v.2) when only 0–2 views were available or when classification confidence was less than 40%**

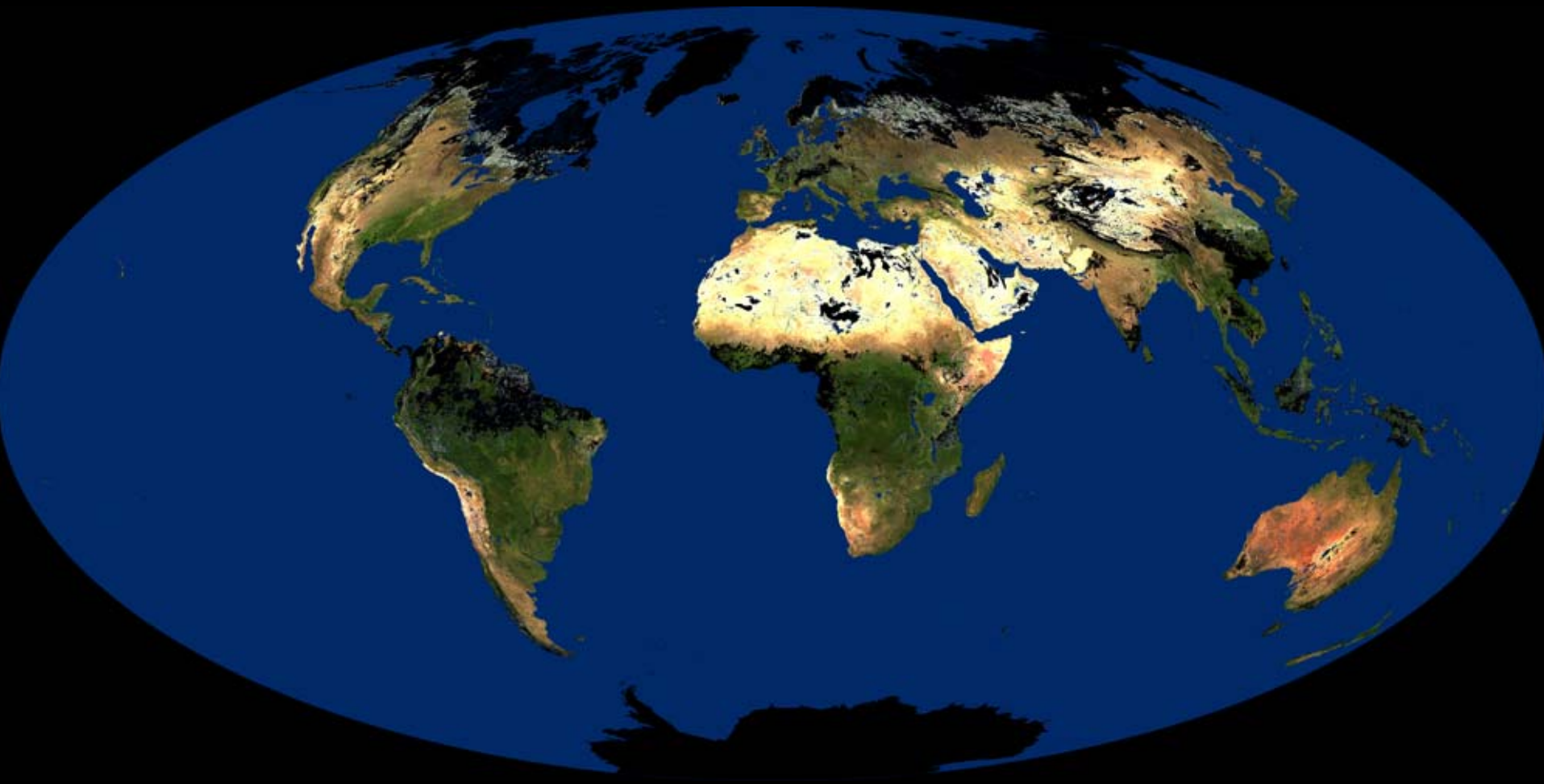
Recent Global Land Cover Products, Cont.

- ***First "Consistent Year" Land Cover Product***
  - **Completed June 1, 2002**
  - **Based on MODIS v003 data from Nov 2000–Oct 2001 (consistent year of reprocessed data)**
  - **Expect to assign "Validated Levels 1 and 2" status to product shortly**

The Land Cover Input Database

- ***242 Features From MODIS:***
  - *Temporal and spectral information; 16-day composites*
- ***Uses Surface Reflectance (NBAR)***
  - *View-angle corrected surface reflectance, 7 land bands*
- ***And Enhanced Vegetation Index (EVI)***
- ***Plus (in the future)….***
  - ***Spatial Texture from 250-m Band 2***
    - **Standard deviation-to-mean ratio in Band 2 (near-infrared)**
  - ***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 information from BRDF product**

Global Composite Map of Nadir BRDF-Adjusted Reflectance (NBAR)
April 7–22 2001



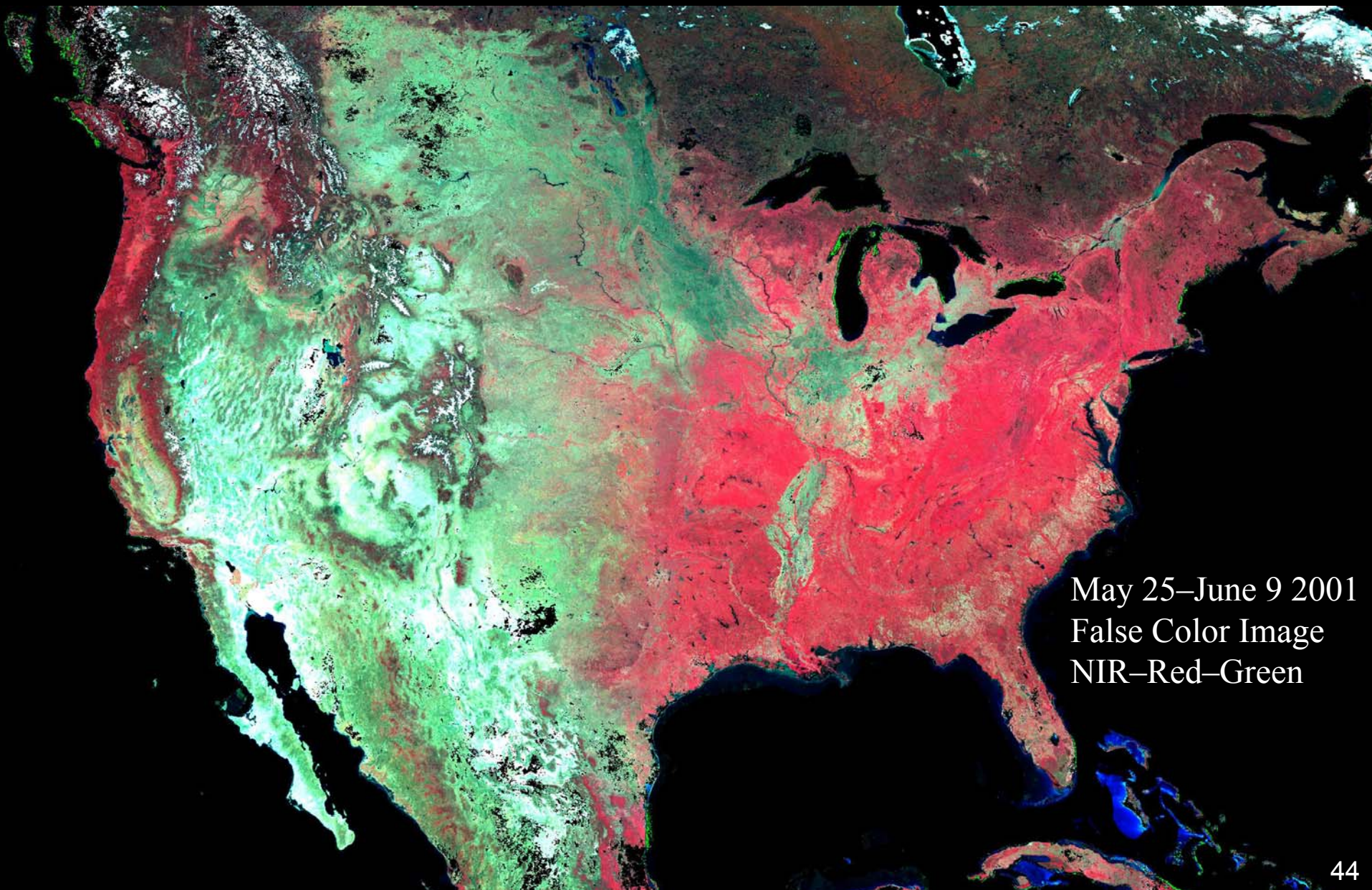
No data

True color, MODIS Bands 2, 4, 3

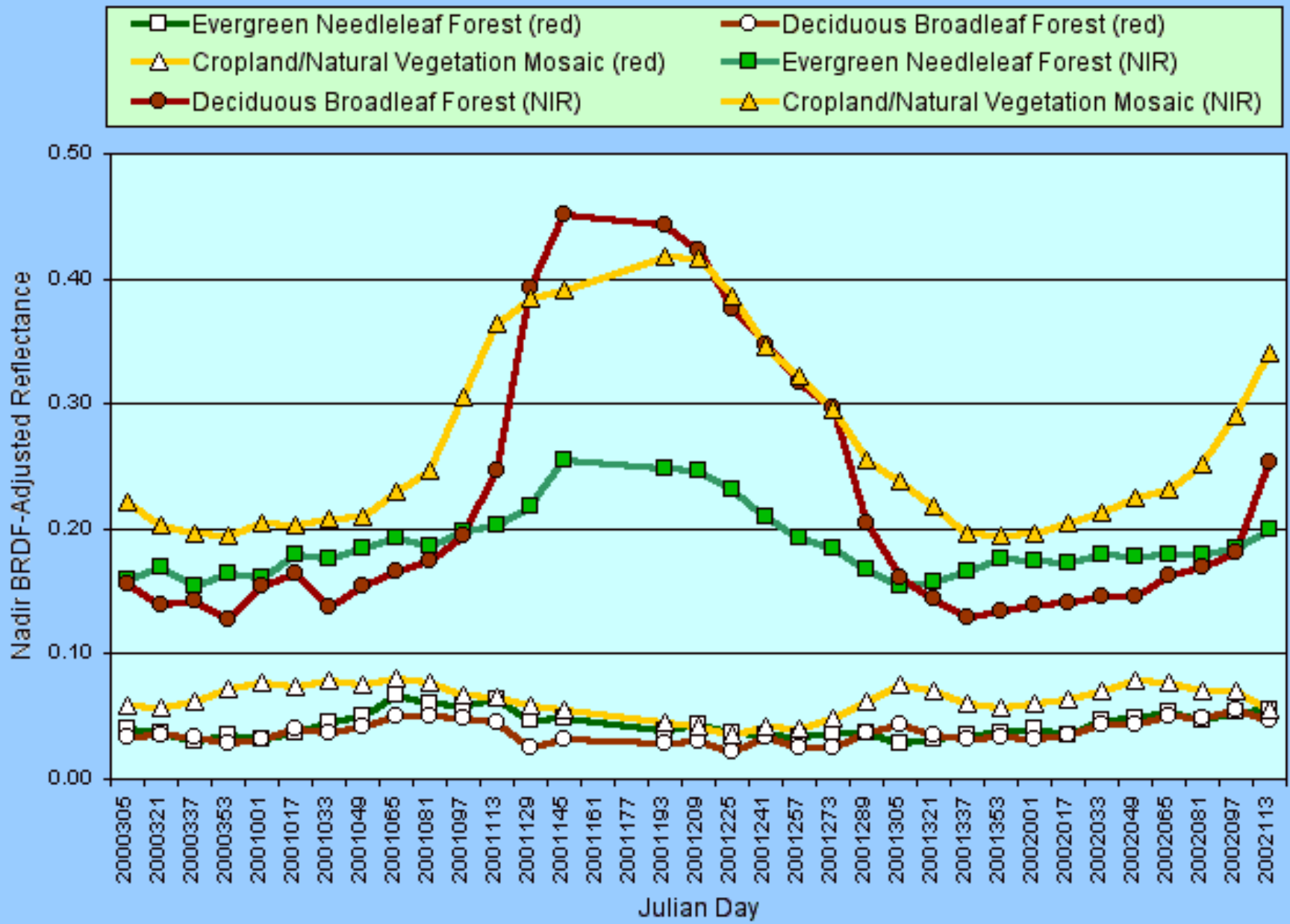
10 km resolution, Hammer-Aitoff projection,
produced by MODIS BRDF/Albedo Team

MODLAND/Strahler et al.

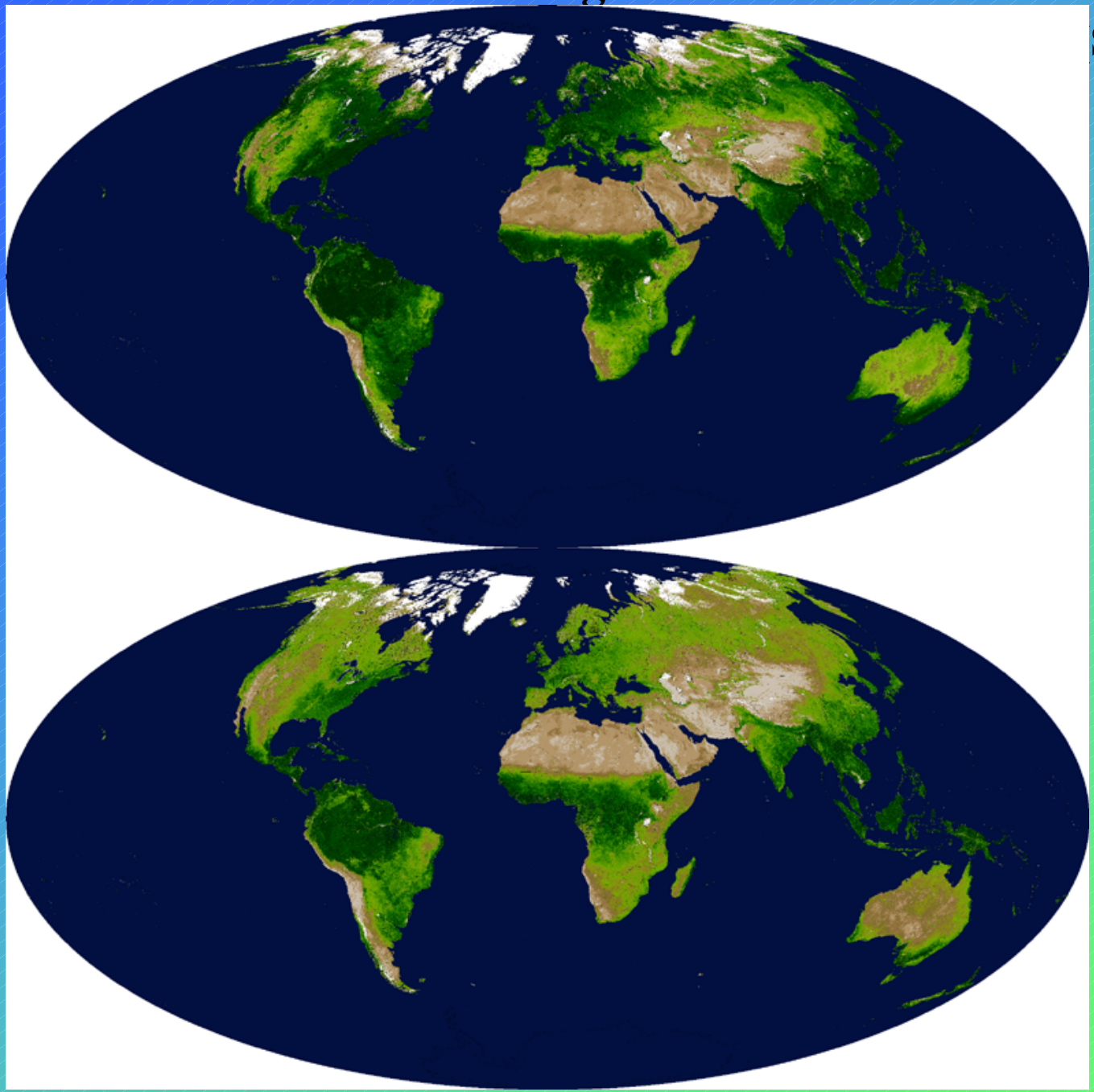
MODIS Nadir BRDF-Adjusted Reflectance



NBAR Time Trajectories

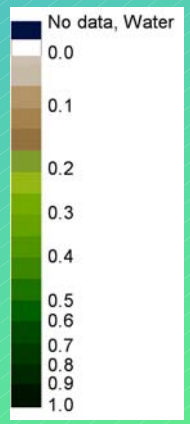


MODIS 500 m Vegetation Indices



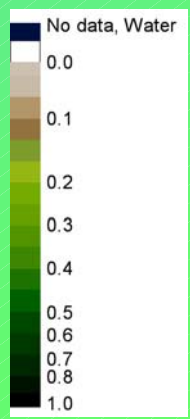
September 30 – October 15, 2000

NDVI



MOD13A1 16 day Composite

EVI



NDVI

EVI

EVI shows better dynamic range, less saturation

Two-Stage Processing Strategy

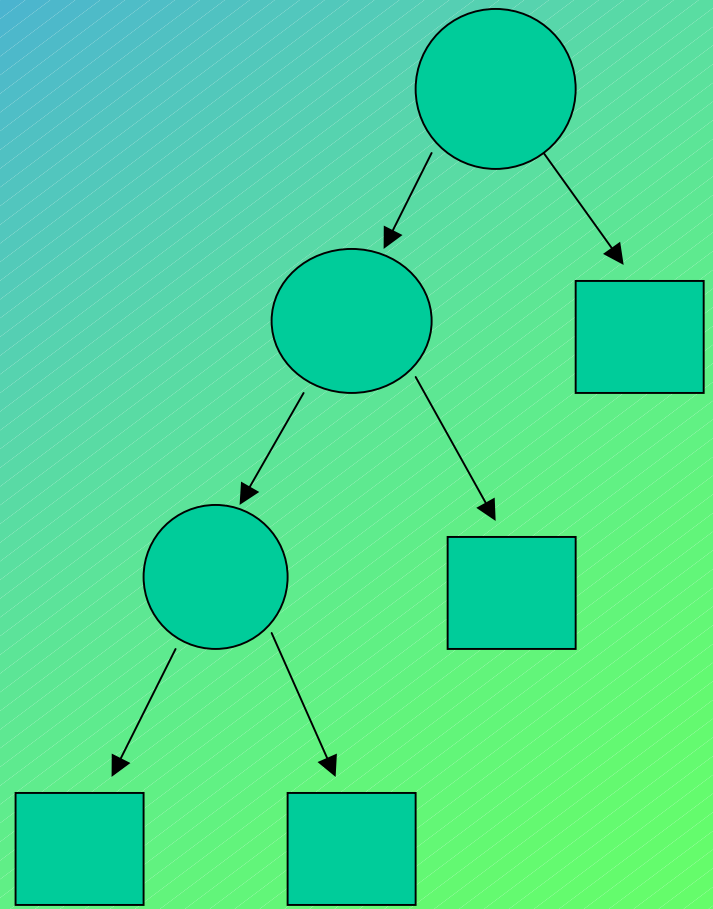
- ***Monthly (32-day) Database Assembly Program***
  - **Reads and processes spectral, spatial, directional inputs for each 32-day month**
    - **32-day period = two 16-day, four 8-day cycles of MODIS input products**
- ***Quarterly (128-day) Classification with Annual Input (384-day)***
  - **Reduces data volume by retaining only selected features**
  - **Classifies using advanced technology classifier (decision tree)**
  - **Runs every three months (96 days) to provide a quarterly updated product**
- ***Why Quarterly?***
  - **Input data changes**
  - **Algorithm and processing improves**

Advanced Technology Classifiers

- ***Supervised Mode***
  - **Use of supervised mode with training sites**
  - **Allows rapid reclassifications for tuning**
- ***Decision Trees*—**C4.5 Univariate Decision Tree
  - **Fast algorithm**
  - **Uses boosting to create multiple trees and improve accuracy, estimate confidence**
- ***Neural Networks*—**Fuzzy ARTMAP
  - **Uses Adaptive Resonance Theory in building network**
  - **Presently not in use. Too slow; does not handle missing data well.**

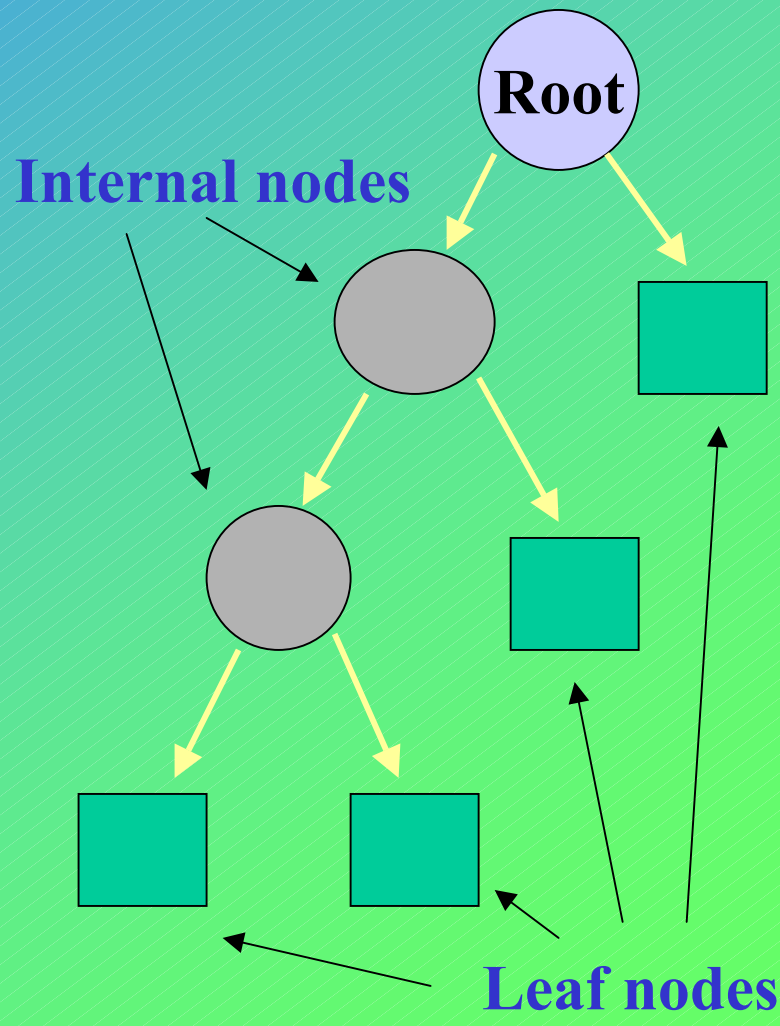
Decision Tree Classification

- *Goal:*
  - Optimal prediction of class labels from a set of feature values
- *Basic approach*
  - Supervised learning using training data
- *Key attributes:*
  - Nonparametric
  - Able to handle noisy or missing features
  - Adept at capturing non-linear, hierarchical patterns

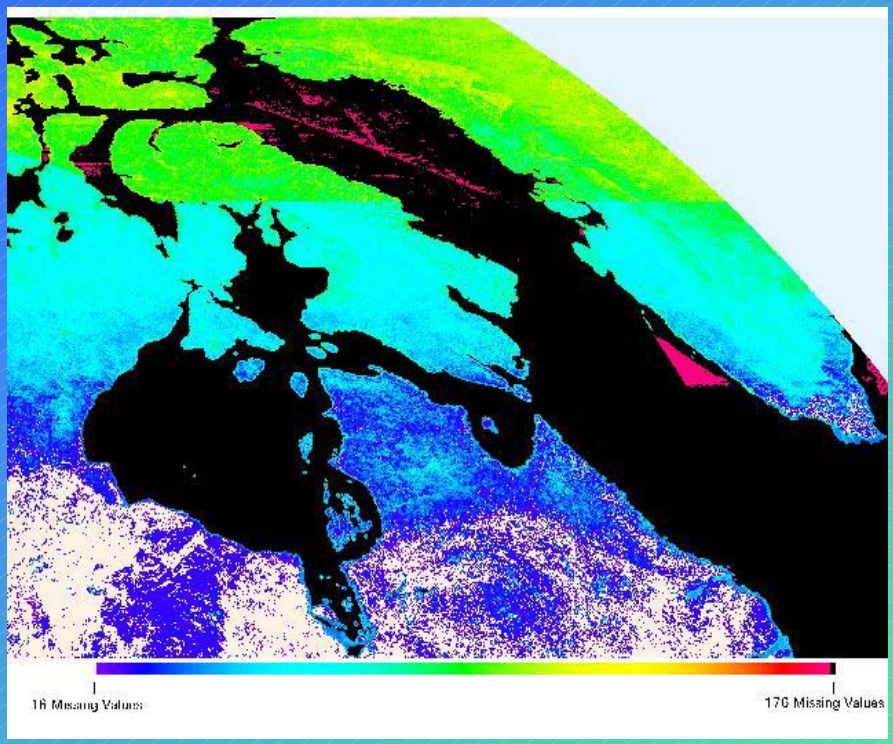


DTs: Basic Theory

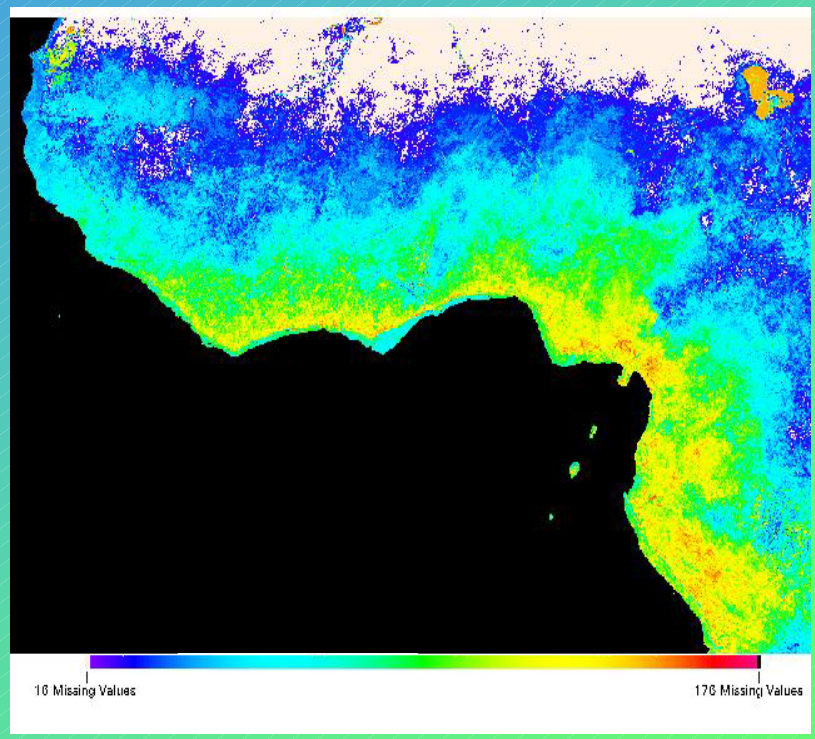
- *Terminology*
  - Root node (all data), internal nodes and terminal or leaf nodes (predictions)
- *DT Estimation:*
  - Recursive partitioning of training data into successively more homogeneous subsets
- *Multiple leaf nodes per class*
  - Leaf nodes identify class assignment
  - Sub-classes allocated individual leaves



Key Advantage of DTs: Ability to Handle Noisy and Missing Data



High Latitudes



Cloud Cover in Tropics

Color scale indicates number of missing values

16 176

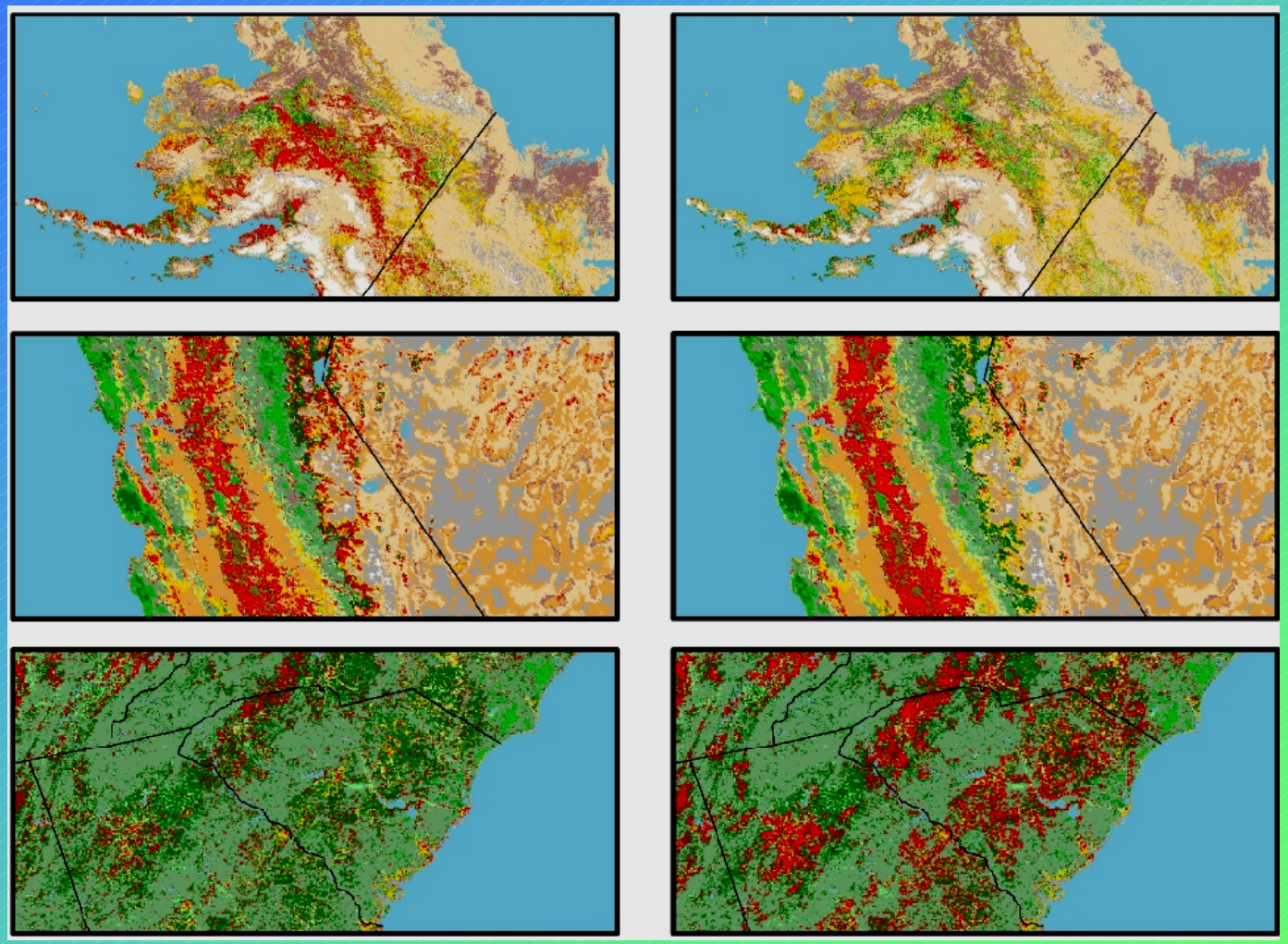
Postclassification Processing

- ***Application of Prior Probabilities***
  - **Use of priors to remove training site count biases (sample equalization)**
  - **Application of global and moving-window priors from earlier products**
    - **Increases accuracies, reduces speckle**
  - **Use of external maps of prior probabilities to resolve confusions**
    - **Agriculture/natural vegetation confusion in some regions**
    - **Use of city lights DMSP data to enhance urban class accuracy (to come)**
- ***Filling of Cloud-Covered Pixels from Earlier Maps***
  - **Use of at-launch (EDC DISCover v. 2) or provisional product when there are not sufficient values to classify a pixel with confidence**

Priors: Agriculture

- **Problem:**
  - Too much agriculture
- **Solution:**
  - Used available maps of agricultural intensity to parameterize likelihood of agriculture over natural vegetation
- **Result:**
  - 6% of land area changed to natural vegetation
  - 3% of land area changed to agriculture

Regional Views



Alaska

California

South Carolina

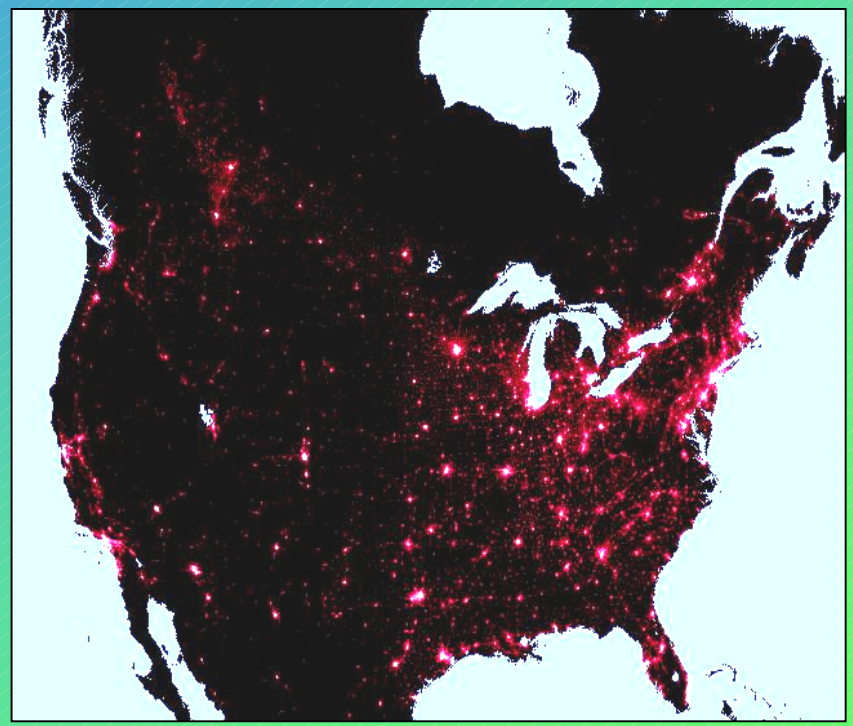
(Ag in red)

Before

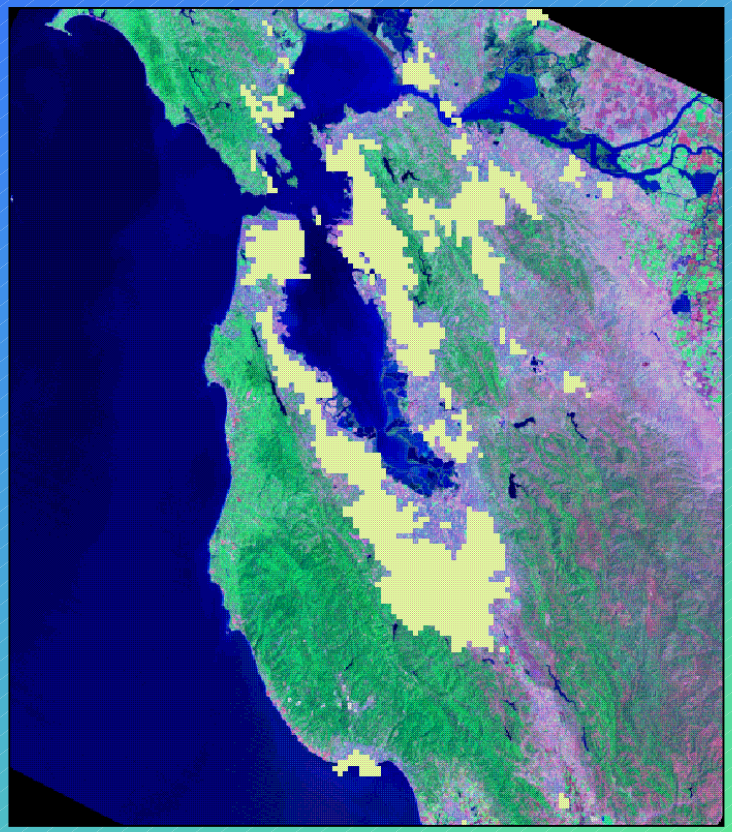
After

Urban Class Mapping

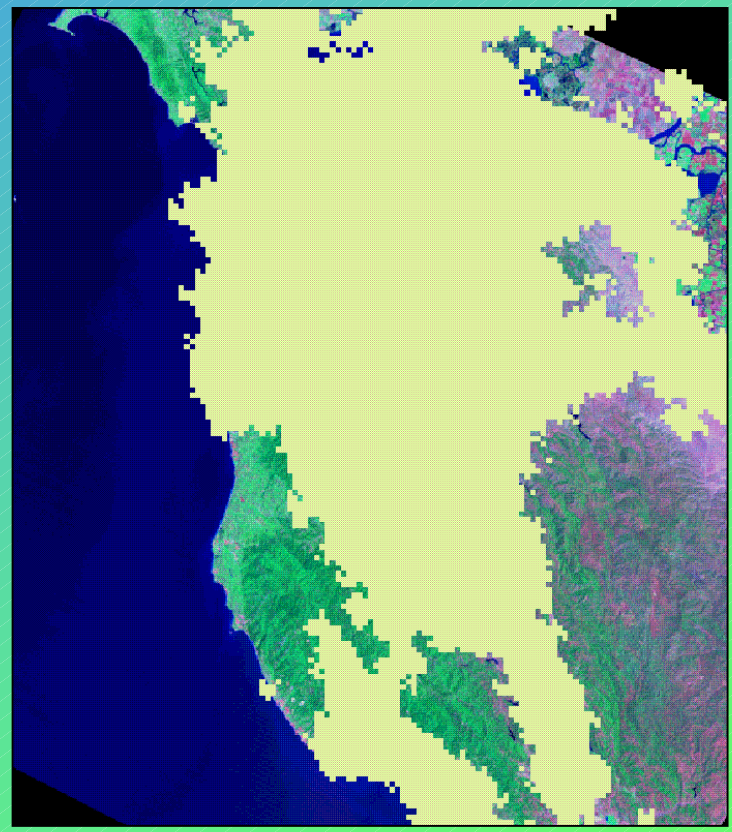
- ***Small but important class***
- ***Features do not distinguish urban areas***
  - **Confusion with barren**
- ***Solution:***
  - **Exploit DMSP OLS data**



DMSP-OLS Data Greatly Overestimates Urban Areas

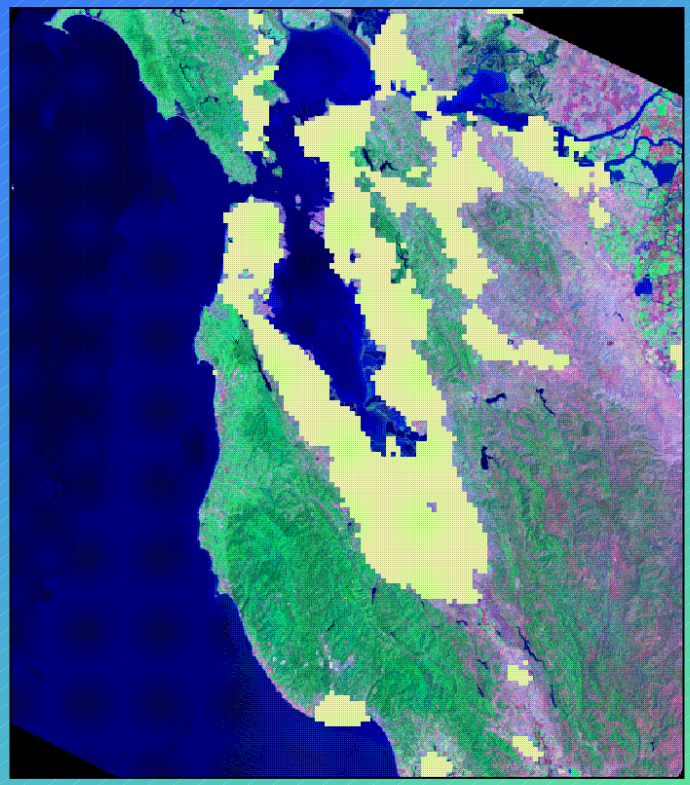


Digital chart of the world urban layer

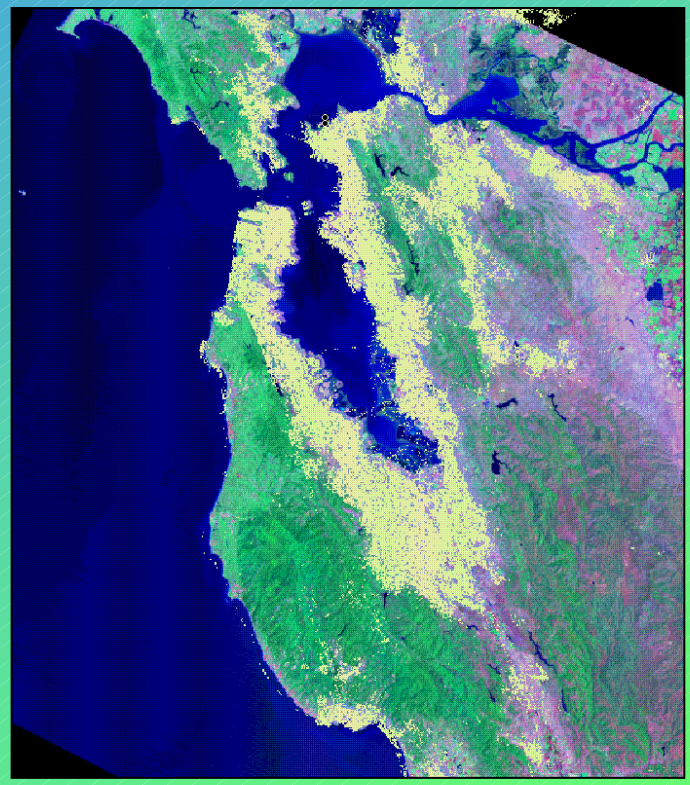


Thresholded DMSP data

Solution:Train Separate Logistic Regression Using DMSP Data & Use Results for Priors



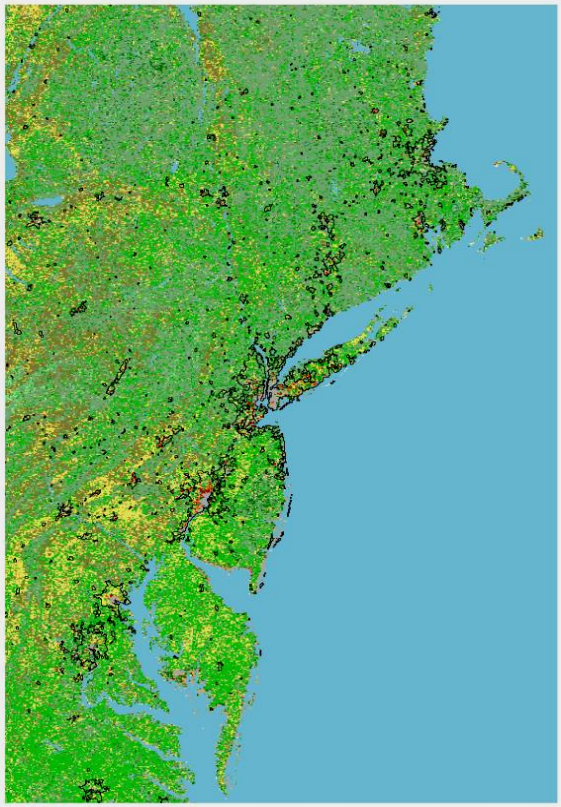
MODIS Classification
(draped on TM image)



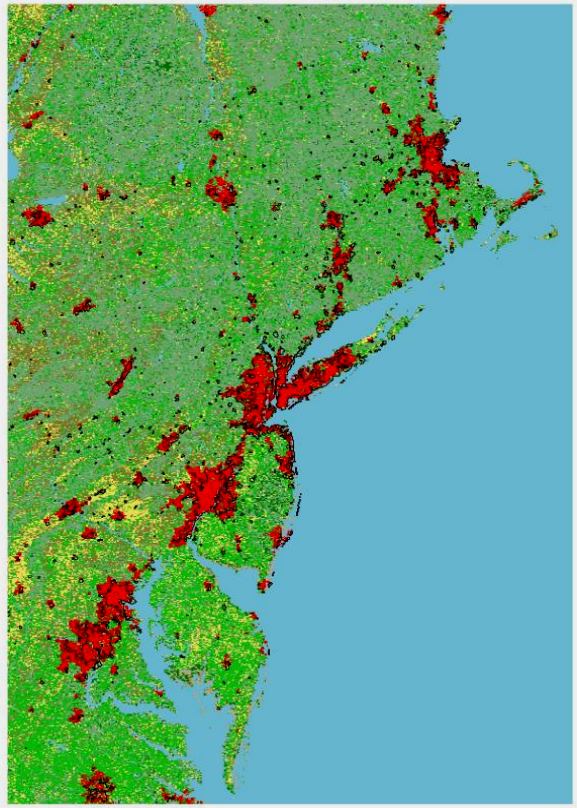
NLCD classification from
TM data

Mapping Urban Areas – Merging City Lights Data with MODIS

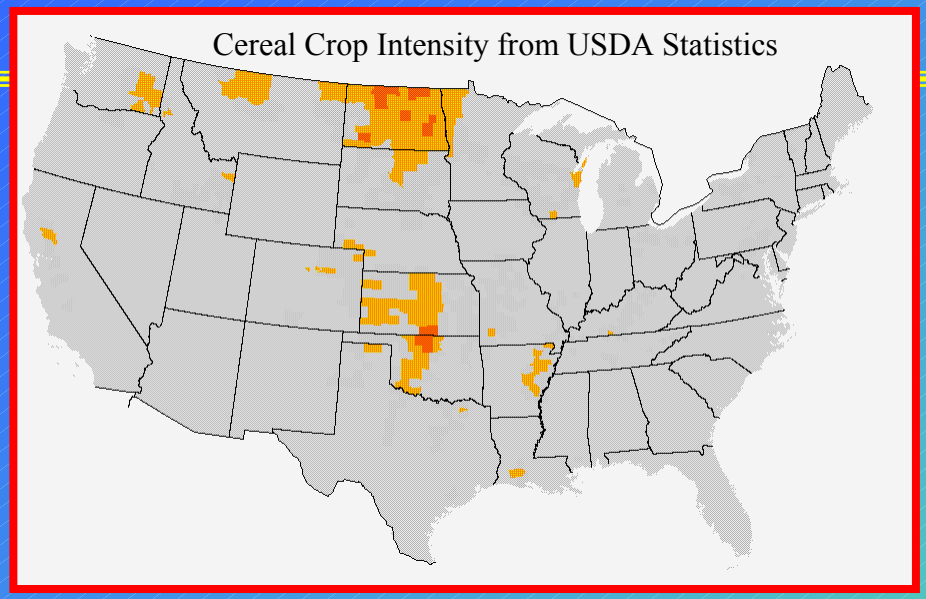
- ***MODIS Data Only***

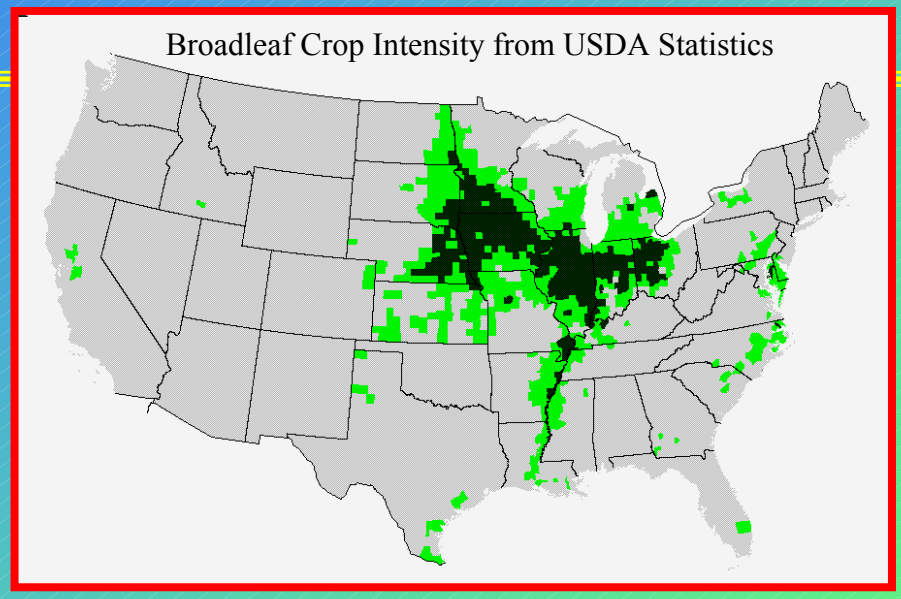


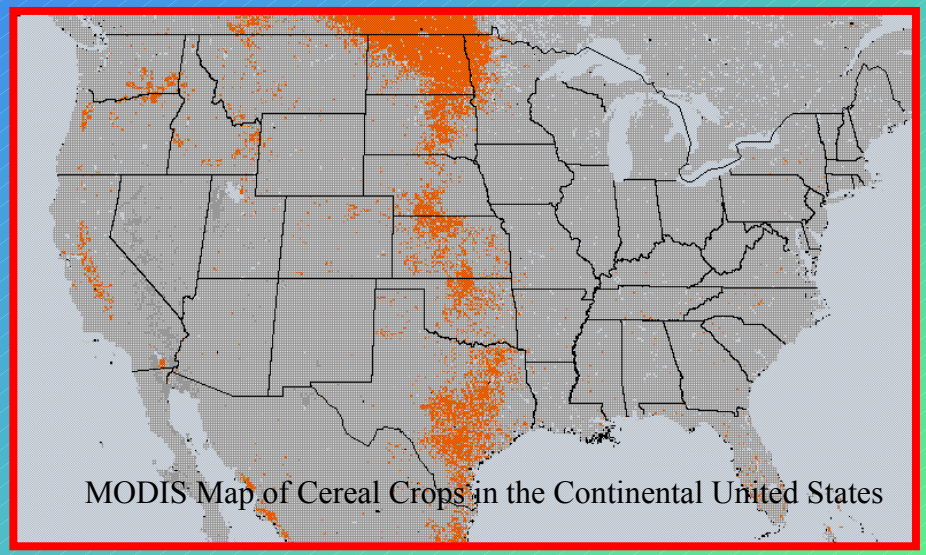
- ***MODIS + City Lights***

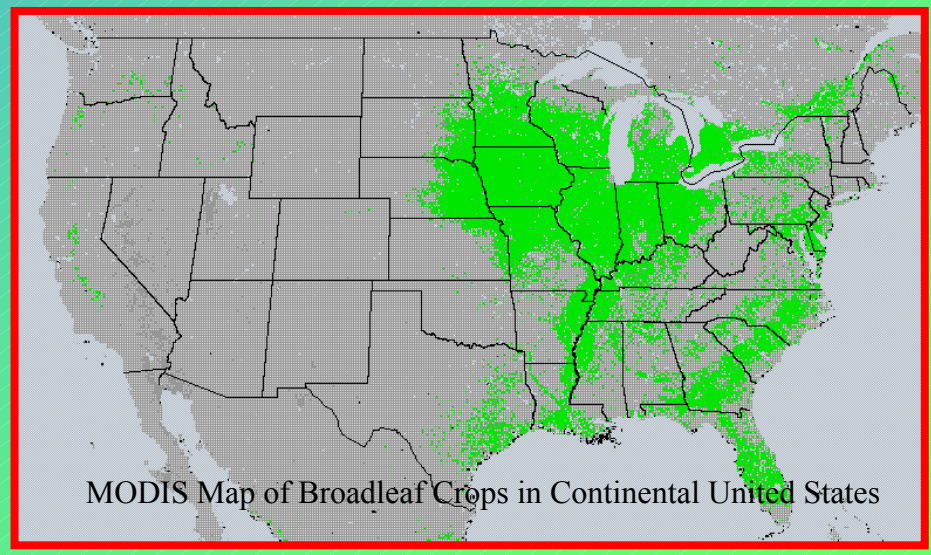


Using Priors to Classify Cereal and Broadleaf Crops







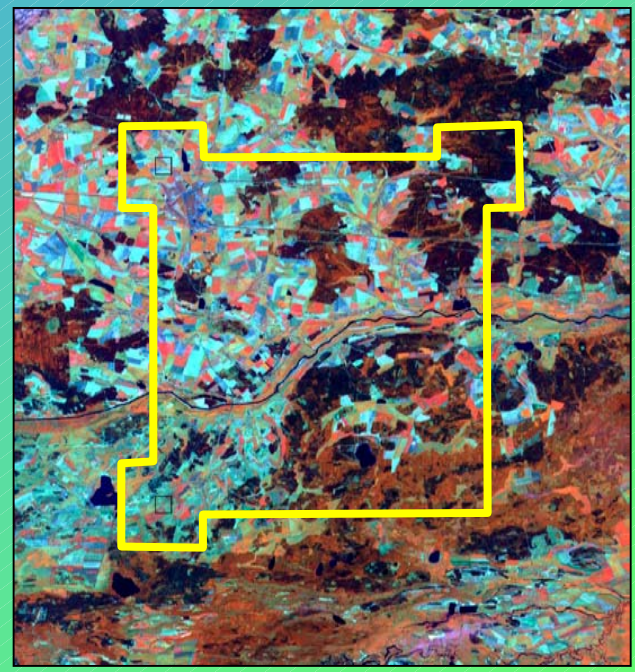


Training Sites—STEP Database

- ***STEP:***
  - **System for Terrestrial Ecosystem Parameterization**
- ***Key STEP Parameters***
  - **Life form, height, cover fraction, of layers**
  - **Leaf type, phenology, periodicity, physiognomy of dominants in layers**
  - **Elevation, moisture regime, perturbation**
  - **Classifications: IGBP, BU, EDC SLCRs, and others**
  - **Simple description of site and type (words)**
- ***STEP Flexibility***
  - **Allows application of many different land cover labeling schemes by inference of label from parameters in database**

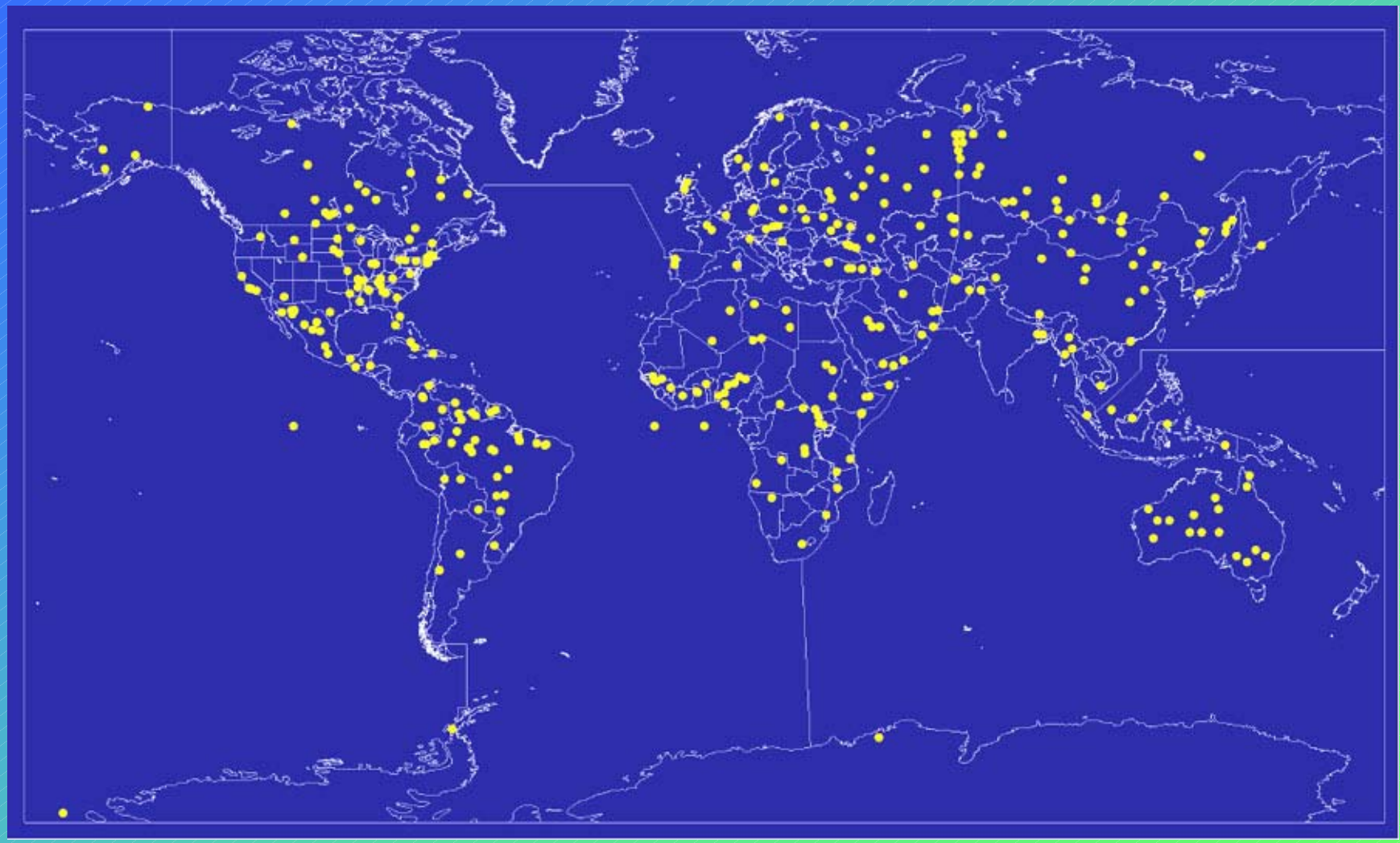
Test Sites

- *IGBP-DISCover Core/Confidence Sites*
  - Random stratified sampling of classes on 1992-93 IGBP Global Land Cover Product
  - 425 sites identified; 413 SPOT and TM scenes acquired; 91% migrated to WWW by BU
- *BU STEP Database*
  - >2500 training sites from >700 TM scenes
  - About 1500 training sites in current use for supervised classification

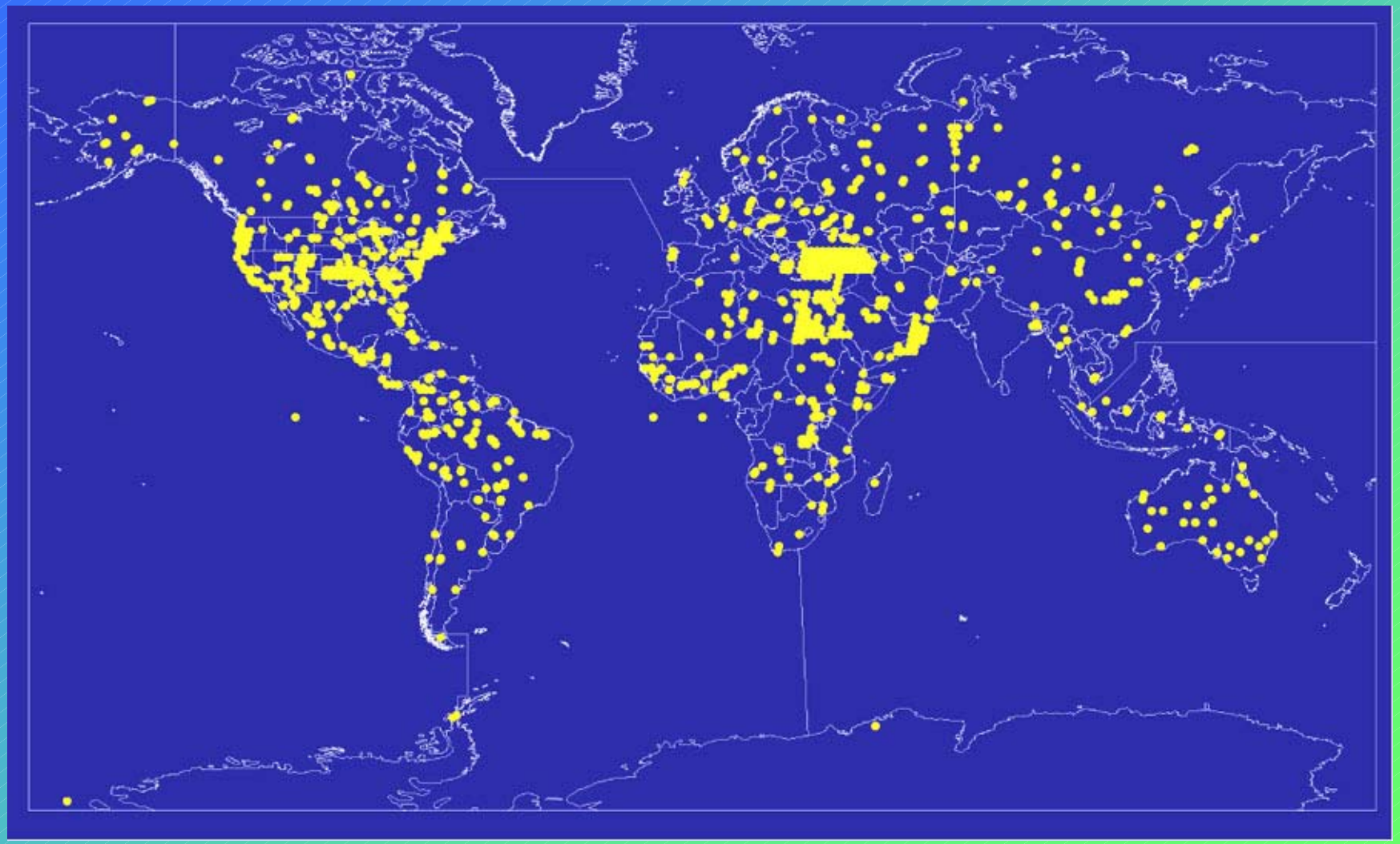


A confidence site
near Pinsk, Belarus
(20 x 20 km)

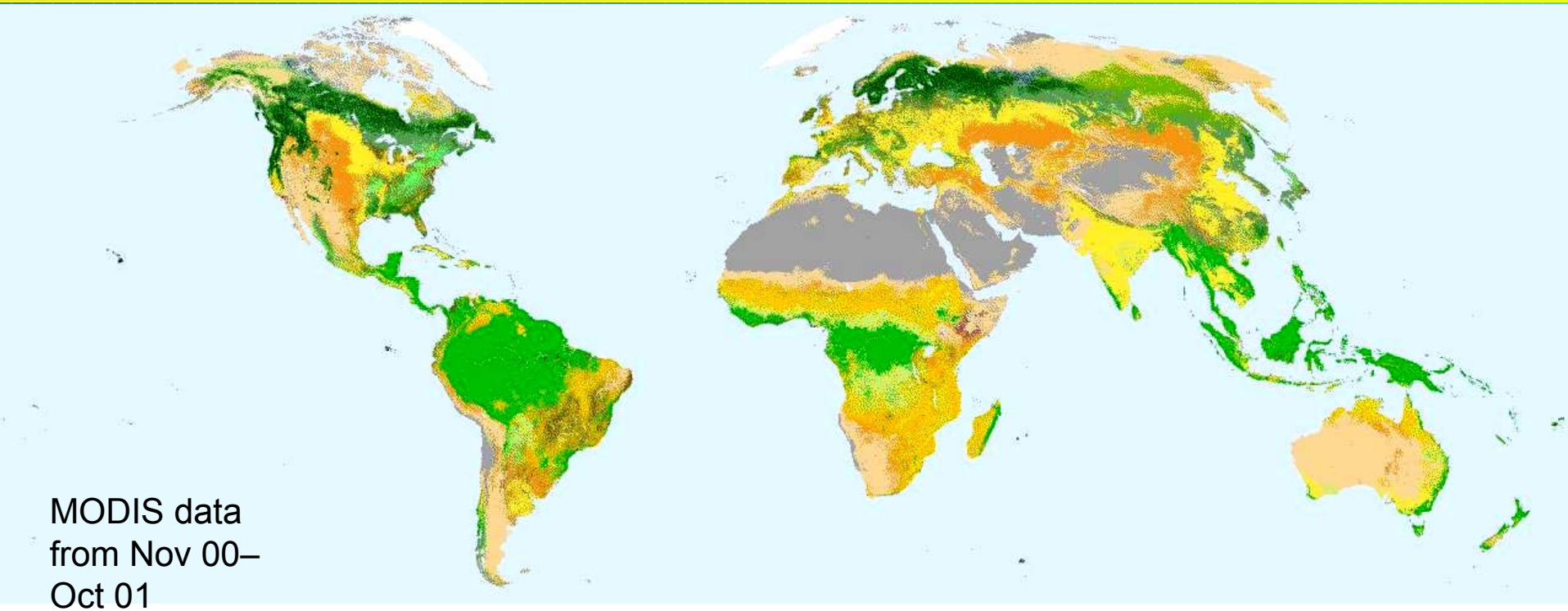
DISCover Core Validation Sites



Supplemental BU Training Sites



Consistent Year Land Cover Product
June 02—IGBP

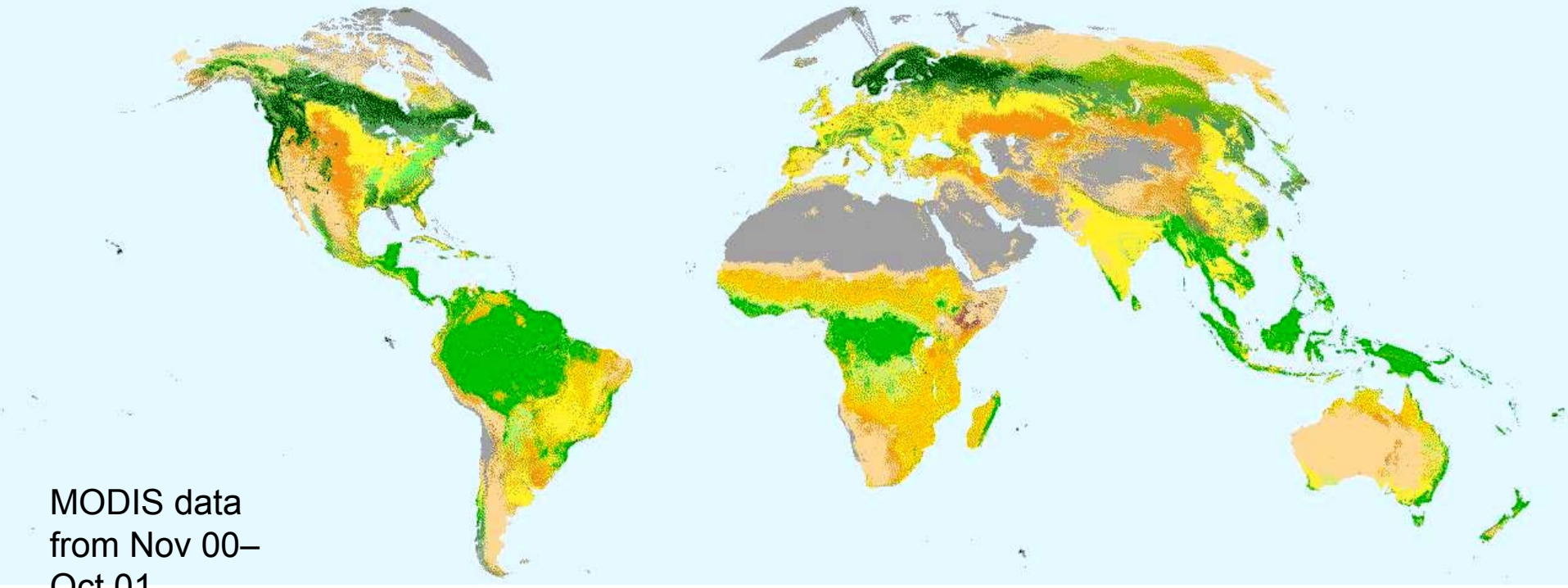


MODIS data from Nov 00–Oct 01

IGBP Land Cover Classes

- 0 Water
- 1 Evergreen Needleleaf Forest
- 2 Evergreen Broadleaf Forest
- 3 Deciduous Needleleaf Forest
- 4 Deciduous Broadleaf Forest
- 5 Mixed Forests
- 6 Closed Shrublands
- 7 Open Shrublands
- 8 Woody Savannas
- 9 Savannas
- 10 Grasslands
- 11 Permanent Wetlands
- 12 Croplands
- 13 Urban and Built-Up
- 14 Cropland/Natural Vegetation Mosaic
- 15 Snow and Ice
- 16 Barren or Sparsely Vegetated
- 254 Unclassified

Consistent Year Land Cover Product
June 02—UMd

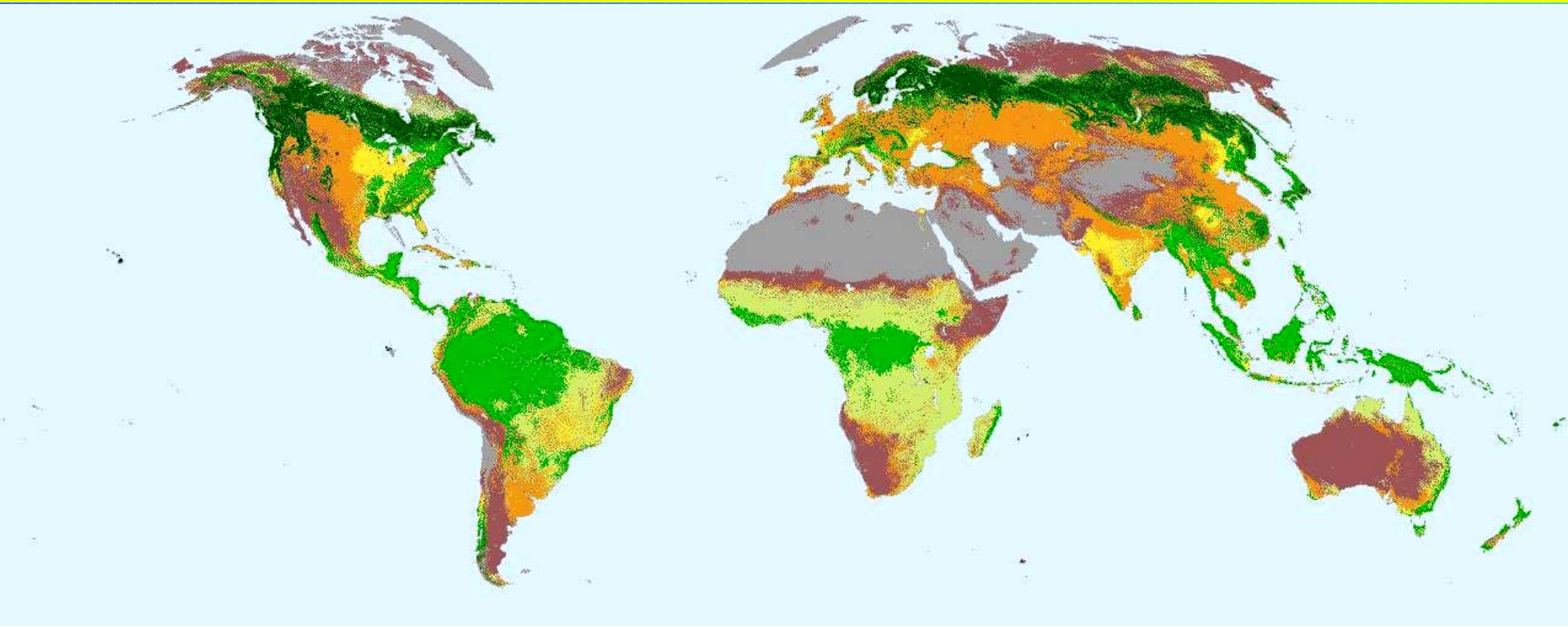


MODIS data from Nov 00–Oct 01

UMD Land Cover Classes

0 Water	5 Mixed Forests	10 Grasslands
1 Evergreen Needleleaf Forest	6 Closed Shrublands	12 Croplands
2 Evergreen Broadleaf Forest	7 Open Shrublands	13 Urban and Built-Up
3 Deciduous Needleleaf Forest	8 Woody Savannas	16 Barren or Sparsely Vegetated
4 Deciduous Broadleaf Forest	9 Savannas	254 Unclassified

Consistent Year Land Cover Product
June 02—LAI/FPAR Biomes

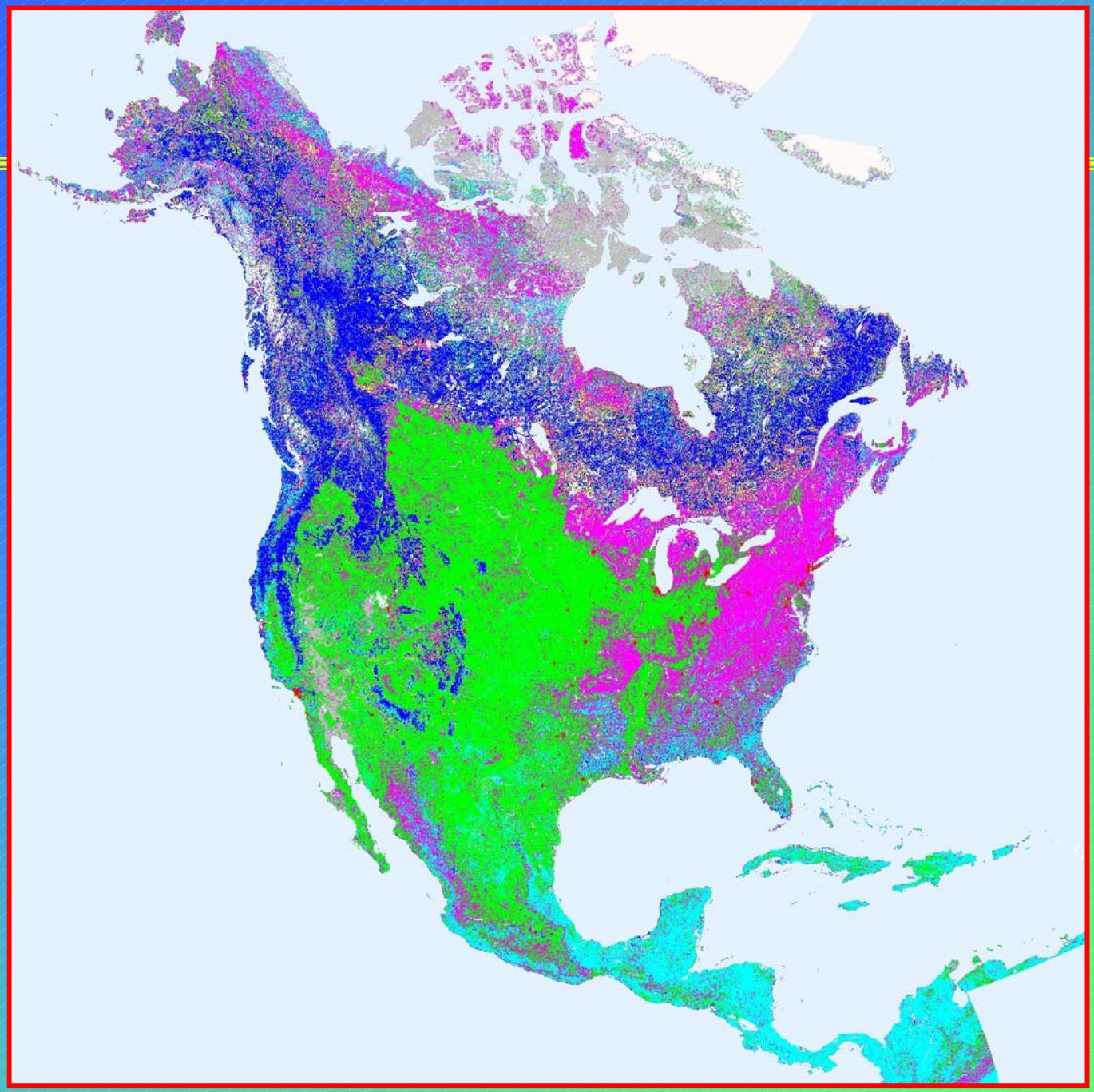


LAI/fPAR Biome Classes

Water	Shrubs	Savanna	Needleleaf forest	Urban
Grasses/Cereal	Broadleaf crops	Broadleaf forest	Unvegetated	Unclassified

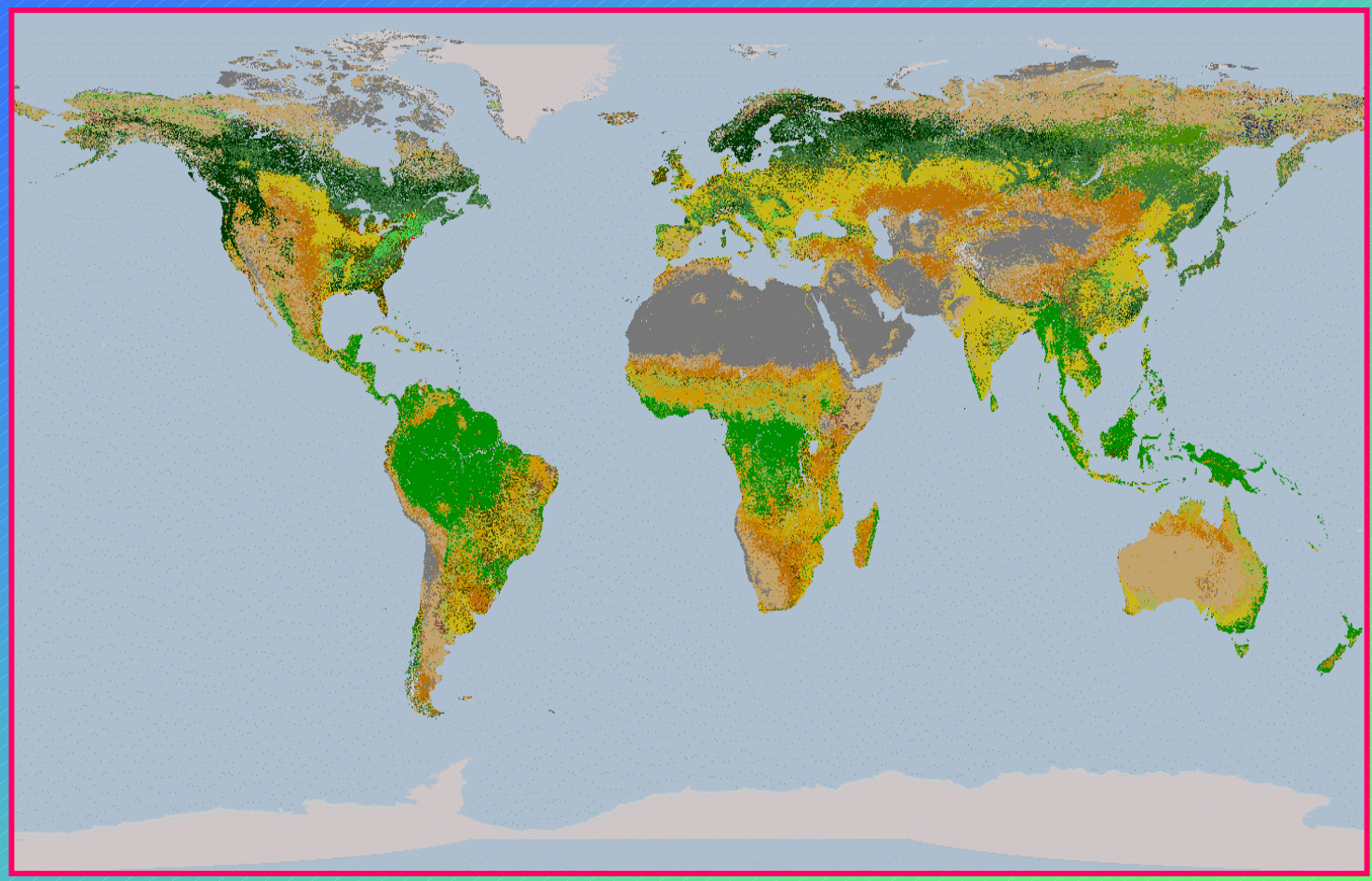
Biome-BGC Labels

(Provisional Product)

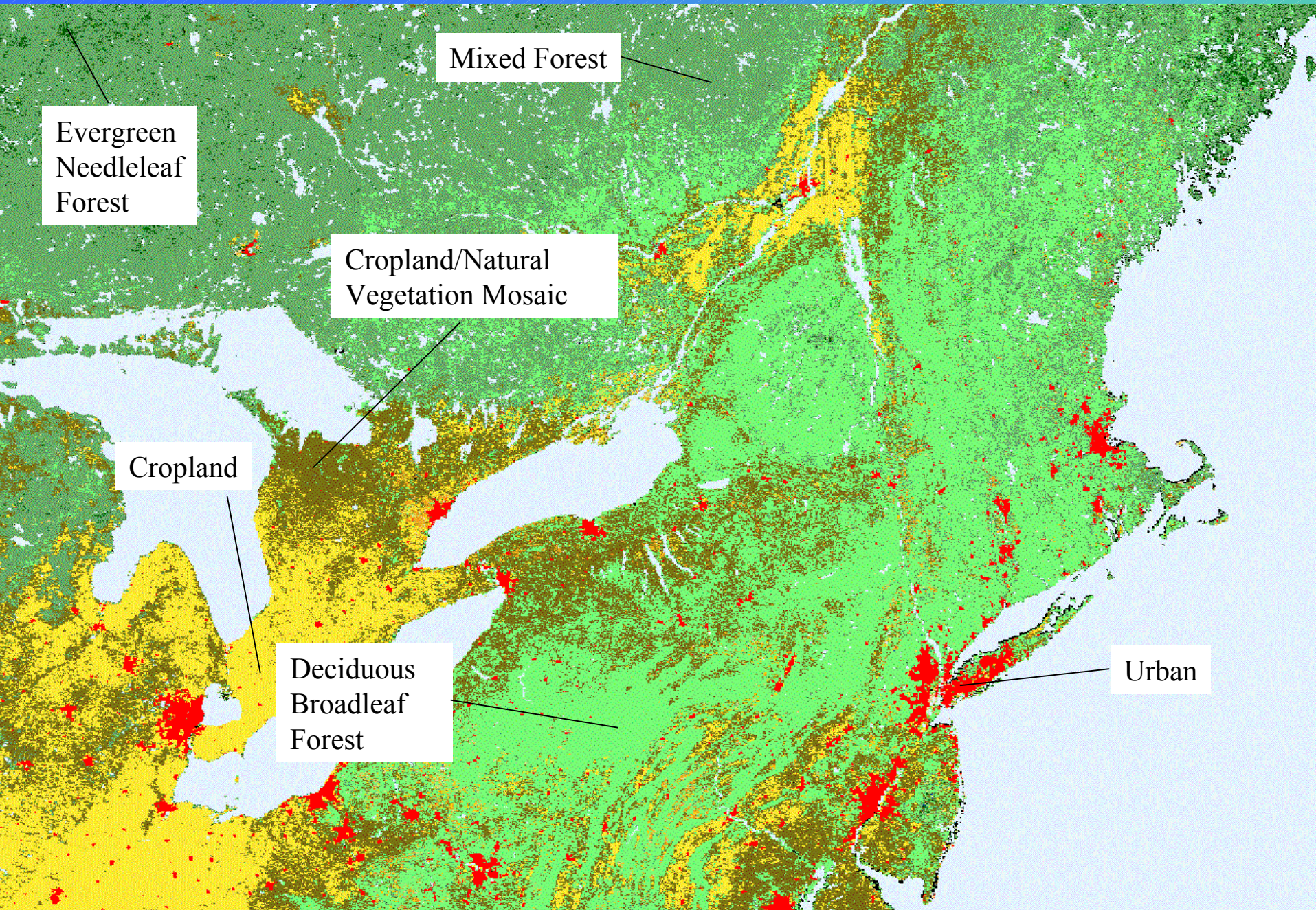


- Deciduous Broadleaf Annual
- Evergreen Broadleaf Perennial
- Evergreen Needleleaf Perennial
- Deciduous Broadleaf Perennial
- Deciduous Needleleaf Perennial
- Barren or Sparsely Vegetated
- Permanent Snow or Ice
- Urban or Built Up
- Water

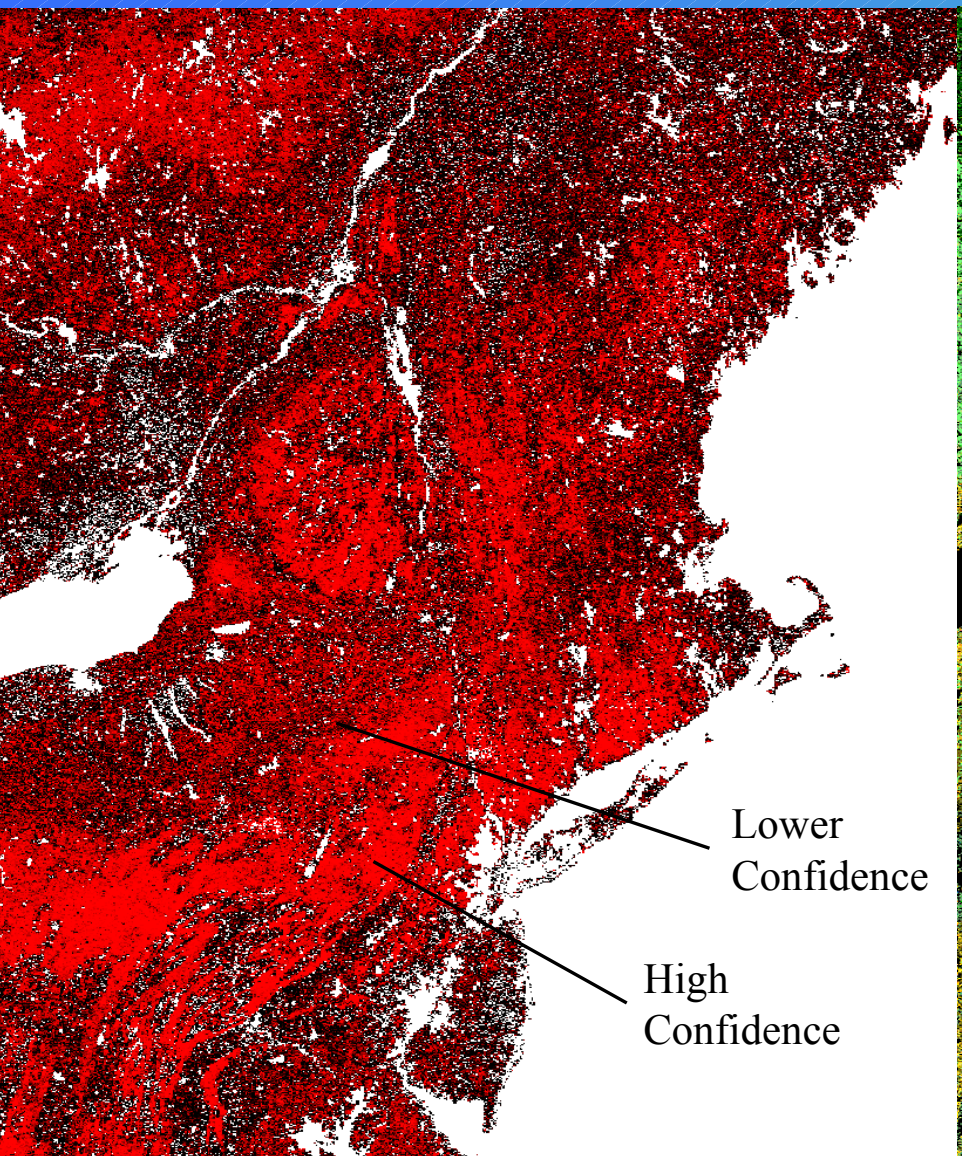
Climate Modeling Grid (CMG)



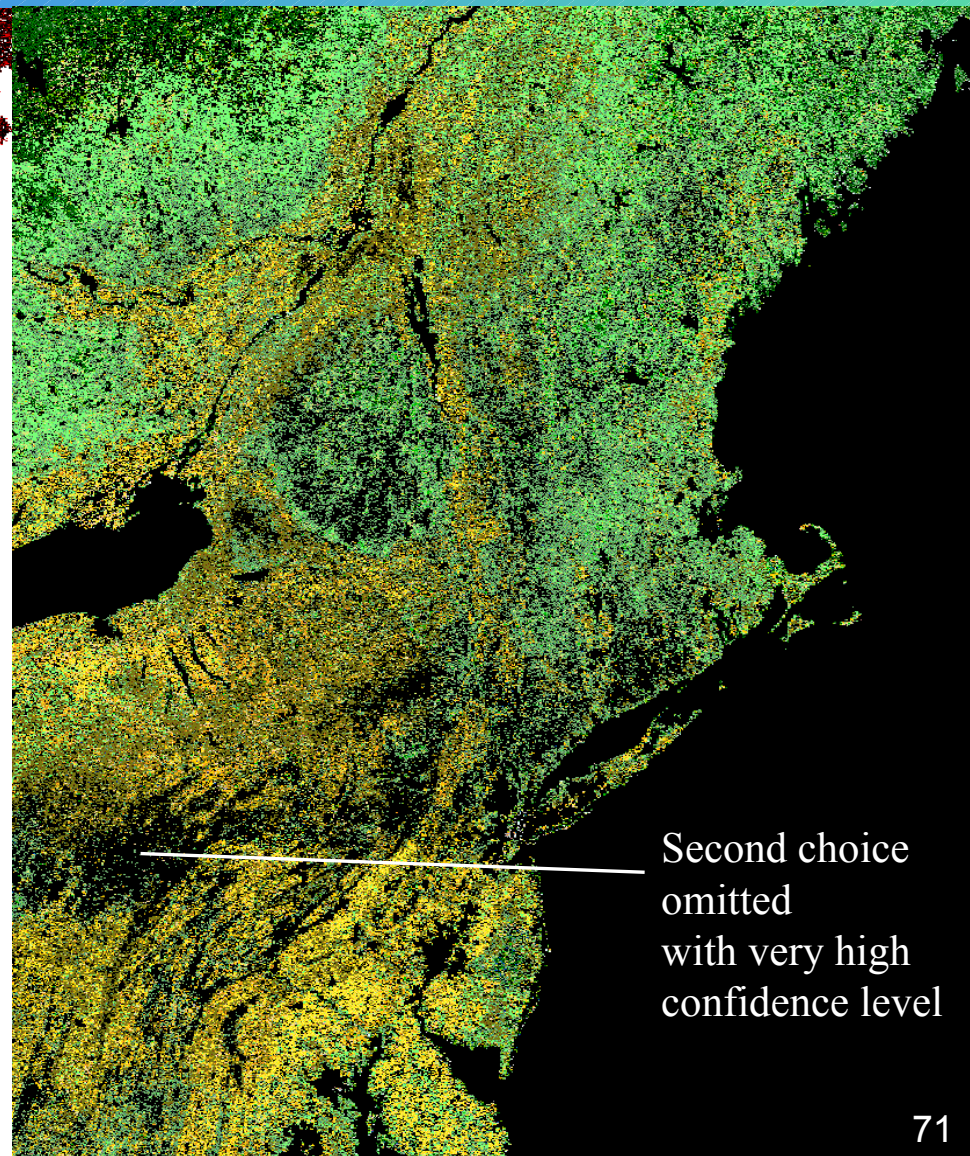
Consistent Year Land Cover Product, Nov 00–Oct 01



Classification Confidence Map



Second Most-Likely Class



Land Cover Validation

- ***Validation Plan Utilizes Multiple Approaches***
- ***Level 1: Comparisons with existing data sources***
  - **Examples**
    - **Global AVHRR land cover datasets: DISCover, UMd**
    - **Humid Tropics: Landsat Pathfinder**
    - **Forest Cover: FAO Forest Resources Assessment**
    - **Western Europe: CORINE**
    - **United States: USGS/EPA MLRC**
    - **United States: California Timber Maps (McIver and Woodcock)**
    - **MODIS and Bigfoot test site comparisons**

Validation Levels, Cont.

- ***Level 2: Quantitative studies of output and training data***
  - **Per-pixel confidence statistics**
    - **Aggregated by land cover type and region**
    - **Describe the accuracy of the classification process**
  - **Test site cross-comparisons**
    - **Confusion matrices globally and by region**
    - **Provides estimates of errors of omission and commission**
- ***Level 3: Sample-based statistical studies***
  - **Random stratified sampling according to proper statistical principles**
  - **Costly, but needed for making proper accuracy statements**
- ***CEOS Cal-Val Land Product Validation Land Cover Activity***

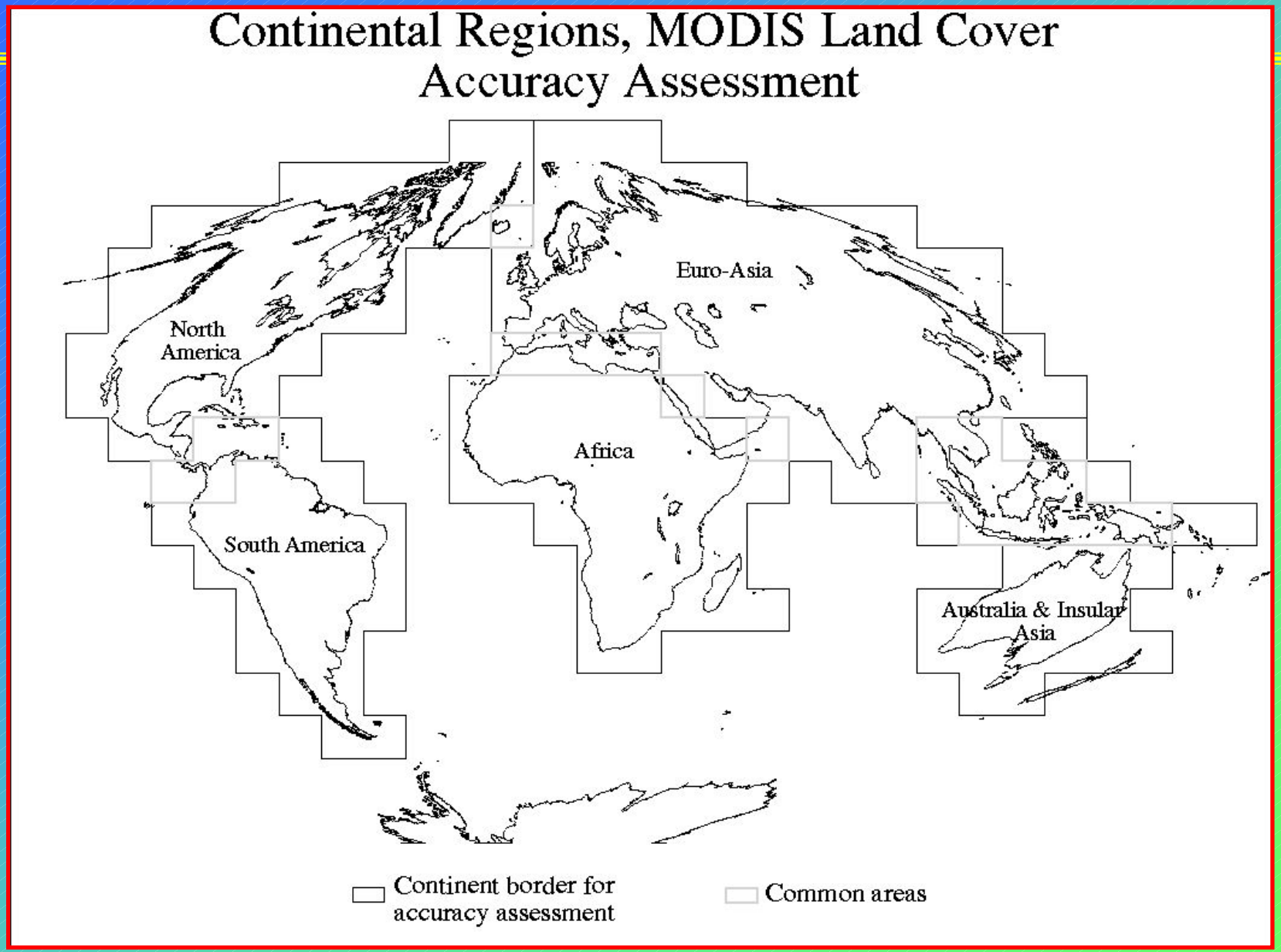
Cross Validation with Training Sites

- ***Cross-Validation Procedure***
  - **Hide 10 percent of training sites, classify with remaining 90 percent; repeat ten times for ten unique sets of all sites**
  - **Provides "confusion matrix" based on unseen pixels where whole training site is unseen**
  - **NOT a stratified random sample, but a useful indication of global and within-class accuracies**

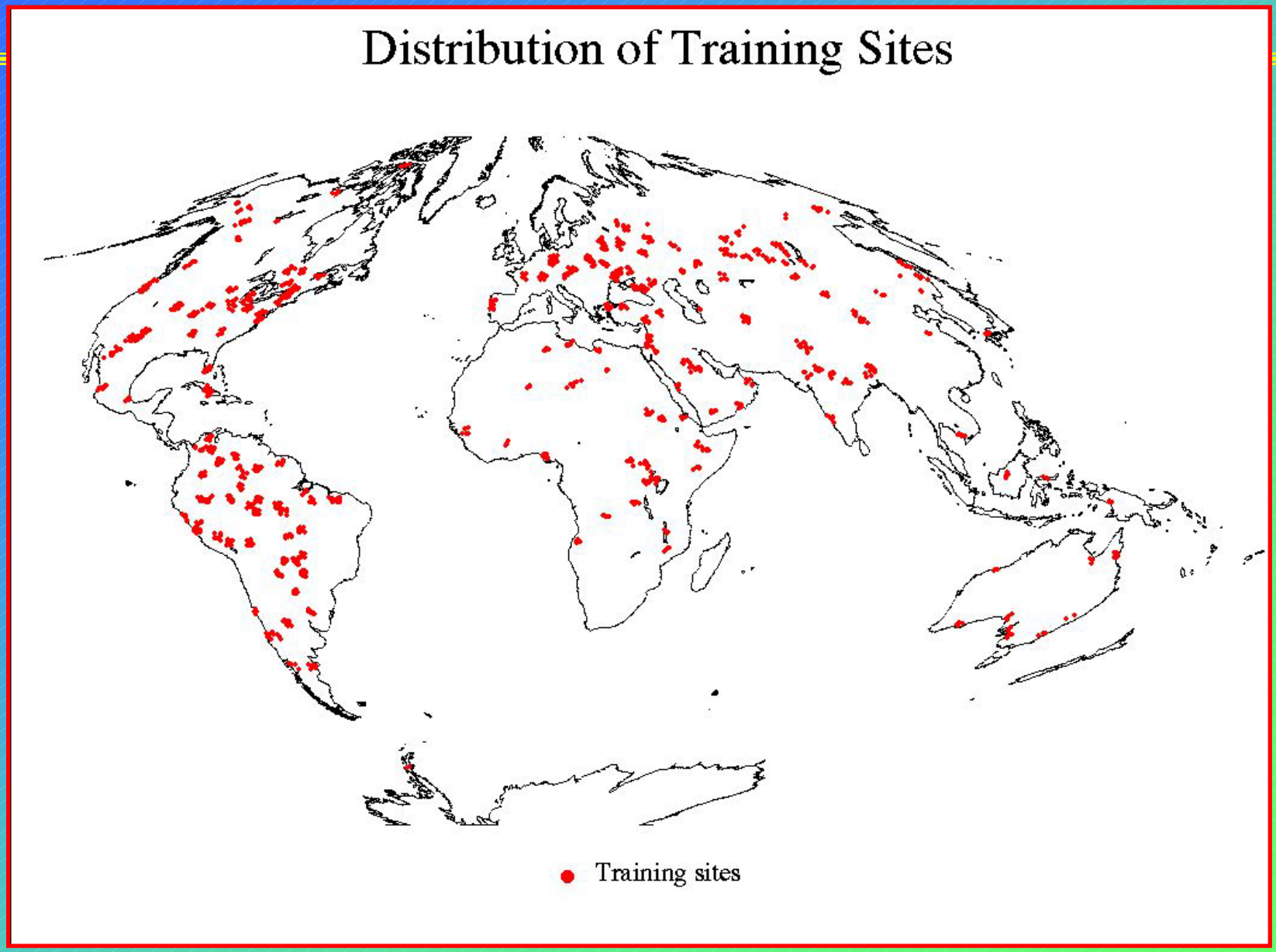
Global Site and Pixel Count

Table 1. Global counts of sites and pixels by land cover class.				
IGBP Land Cover Class	Training Site Count	Training Pixel Count	Global Pixels Classified	Global Areal Percentage
1. Evergreen Needleleaf	131	2,056	7,100,847	3.9
2. Evergreen Broadleaf	204	5,409	17,583,346	9.7
3. Deciduous Needleleaf	15	261	2,374,908	1.3
4. Deciduous Broadleaf	57	758	2,016,765	1.1
5. Mixed Forest	96	2,077	8,209,766	4.5
6. Closed Shrubland	20	466	1,068,970	0.6
7. Open Shrubland	87	1,679	31,929,221	17.8
8. Woody Savanna	55	1,167	10,702,581	5.9
9. Savanna	44	1,098	11,218,832	6.2
10. Grasslands	87	1,474	12,363,432	6.8
11. Permanent Wetlands	13	289	559,675	0.3
12. Cropland	263	6,240	17,087,489	9.4
14. Cropland/Nat Veg Mosaic	72	1,447	5,660,478	3.1
15. Snow and Ice	10	1,346	16,501,715	9.1
16. Barren/Sparse	108	4,492	21,977,613	12.2
17. Water	63	9,213	14,575,749	8.1
Total	1,370	39,472	180,928,968	100.0

Continental Regions



Continental Regions



Site and Pixel Counts by Region

Table 2. Site and pixel counts by region.				
IGBP Land Cover Class	Training Site Count	Training Pixel Count	Global Pixels Classified	Global Areal Percentage
Global	1,370	39,472	180,928,968	100.0
North America	368	13,731	30,918,663	17.1
South America	321	8,030	22,181,052	12.3
Eurasia	560	13,290	71,275,640	39.4
Africa	194	5,744	38,711,576	21.4
Australia-Insular Asia	46	1,766	18,046,575	10.0

Confusion Matrix

Site Class	Class Name	Classification Outcome															
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	Total
1	Evergreen Needleleaf	1323	13	65	23	407	7	35	96	11	6	20	35	7	0	2	6	2056
2	Evergreen Broadleaf	12	5139	0	3	3	2	7	141	48	14	1	18	14	0	3	4	5409
3	Deciduous Needleleaf	20	0	102	3	85	0	5	38	1	3	1	3	0	0	0	0	261
4	Deciduous Broadleaf	7	11	15	381	243	1	10	34	10	9	0	16	11	0	2	8	758
5	Mixed Forest	167	3	50	178	1370	1	9	59	7	29	70	71	52	0	0	11	2077
6	Closed Shrubland	24	18	0	0	6	129	154	37	55	14	0	29	0	0	0	0	466
7	Open Shrubland	4	4	2	17	9	53	1204	27	9	170	3	5	0	1	168	3	1679
8	Woody Savanna	76	56	0	6	61	3	97	617	154	47	0	36	12	0	0	2	1167
9	Savanna	1	53	3	0	4	25	84	303	504	49	7	13	49	0	3	0	1098
10	Grasslands	5	36	0	1	4	1	161	15	69	1028	0	78	20	0	54	2	1474
11	Pmnt Wtlnd	60	15	0	1	7	0	9	9	2	8	174	3	1	0	0	0	289
12	Cropland	23	46	3	33	21	15	243	142	252	365	0	4775	299	0	13	10	6240
14	Cropland/Natural Vegn	2	134	0	195	62	3	9	113	150	29	0	197	546	0	3	4	1447
15	Snow+ice	1	0	0	0	0	0	31	0	0	3	0	2	0	1261	47	1	1346
16	Barren	2	6	0	2	12	38	491	10	10	56	0	9	2	0	3853	1	4492
17	Water	7	5	0	9	11	1	2	0	2	6	0	12	3	0	0	9155	9213
	Total	1734	5539	240	852	2305	279	2551	1641	1284	1836	276	5302	1016	1262	4148	9207	39472

Global and Regional Accuracy

Table 4. Global accuracy and accuracy of continental regions (percent).				
Region	Accuracy Estimate	Standard Error	95% Confidence Interval	
			Low	High
Global	71.6	0.25	71.1	72.1
Africa	61.7	0.66	60.3	63.0
Australia & Insular Asia	71.9	2.93	66.1	77.8
Eurasia	67.8	0.40	67.0	68.6
North America	61.3	0.62	60.0	62.5
South America	75.4	0.46	74.4	76.3

(Analysis follows Card (1982) to correct for bias induced because contingency table marginal proportions don't match global proportions)

Per-Class Accuracies

Table 5. Global per-class accuracies, consistent-year land cover product (percent)												
IGBP Land Cover Class	Producer's Accuracy				User's Accuracy				Areal Proportions			
	Est.	Std. Err.	CI -	CI +	Est.	Std. Err.	CI -	CI +	Est.	Std. Err.	CI -	CI +
1. Evergreen Needleleaf	60.0	1.0	58.0	62.0	75.8	1.0	73.8	77.9	4.9	0.1	4.7	5.1
2. Evergreen Broadleaf	90.3	0.5	89.2	91.4	92.7	0.3	92.0	93.4	9.8	0.1	9.7	10.0
3. Deciduous Needleleaf	57.7	2.8	52.2	63.3	42.3	3.2	36.0	48.7	0.9	0.1	0.8	1.1
4. Deciduous Broadleaf	34.0	1.5	31.0	37.1	43.3	1.7	40.0	46.7	1.4	0.1	1.3	1.5
5. Mixed Forest	61.5	1.1	59.4	63.6	58.7	1.0	56.7	60.7	4.3	0.1	4.1	4.4
6. Closed Shrubland	14.2	1.1	12.1	16.3	46.2	3.0	40.3	52.2	1.9	0.1	1.7	2.1
7. Open Shrubland	85.0	0.6	83.7	86.3	46.8	1.0	44.8	48.7	9.6	0.2	9.2	9.9
8. Woody Savanna	51.6	1.4	48.8	54.4	37.5	1.2	35.1	39.8	4.2	0.1	4.0	4.5
9. Savanna	52.4	1.4	49.6	55.1	39.1	1.4	36.4	41.8	4.6	0.1	4.3	4.8
10. Grasslands	66.2	1.2	63.7	68.7	55.3	1.2	53.0	57.6	5.6	0.1	5.4	5.9
11. Permanent Wetlands	37.9	2.7	32.6	43.2	62.6	2.9	56.8	68.4	0.5	0.0	0.4	0.6
12. Cropland	58.1	0.6	56.8	59.4	87.4	0.4	86.5	88.3	14.0	0.2	13.7	14.3
14. Cropland/Nat Veg Mosaic	42.5	1.1	40.2	44.8	53.5	1.6	50.4	56.6	3.9	0.1	3.7	4.1
15. Snow and Ice	96.6	0.4	95.9	97.4	99.9	0.1	99.8	100	10.8	0.0	10.7	10.9
16. Barren/Sparse	74.8	0.7	73.4	76.2	92.8	0.4	92.0	93.6	14.9	0.1	14.6	15.2
17. Water	98.3	0.2	97.9	98.8	99.4	0.1	99.2	99.6	8.0	0.0	8.0	8.1

Confidence Values by Land Cover Type

Table 6. Global confidence values by land cover class (percent)	
IGBP Land Cover Class	Average Confidence Value
1. Evergreen Needleleaf	68.3
2. Evergreen Broadleaf	89.3
3. Deciduous Needleleaf	66.7
4. Deciduous Broadleaf	65.9
5. Mixed Forest	65.4
6. Closed Shrubland	60.0
7. Open Shrubland	75.3
8. Woody Savanna	64.0
9. Savanna	67.8
10. Grasslands	70.6
11. Permanent Wetlands	52.3
12. Cropland	76.4
14. Cropland/Natural Veg	60.7
15. Snow and Ice	87.2
16. Barren	90.0
17. Water	(Not Available)
Average Value, All Classes	70.7
Area-Weighted Average (Table 5)	78.3

Confidence Values by Region

Table 7. Global confidence values by continental regions (percent).	
Region	**Average Confidence Value**
Global	76.3
Africa	79.4
Austr & Insular Asia	83.2
Eurasia	76.8
North America	71.9
South America	78.5

Overall Accuracies

- *Proper accuracy statements require proper statistical sampling*
- *AVHRR state of the art has been 60–70 percent, depending on class and region*
- *MODIS accuracies are falling in 70–80 percent range*
- *Most "mistakes" are between similar classes*
- *Land cover change should **NOT** be inferred from comparing successive land cover maps*

Conclusions

- Training sites are NOT a random sample
  - Many (perhaps most) training sites are placed in equivocal areas where the classifier needs new and better examples
  - Thus, the training sites do not represent well the broad regions of core areas for land cover classes
  - This leads to the conclusion that actual accuracies are probably better than observed from the training sites
  - So we estimate that:

GLOBAL ACCURACY IS 75–80 PERCENT

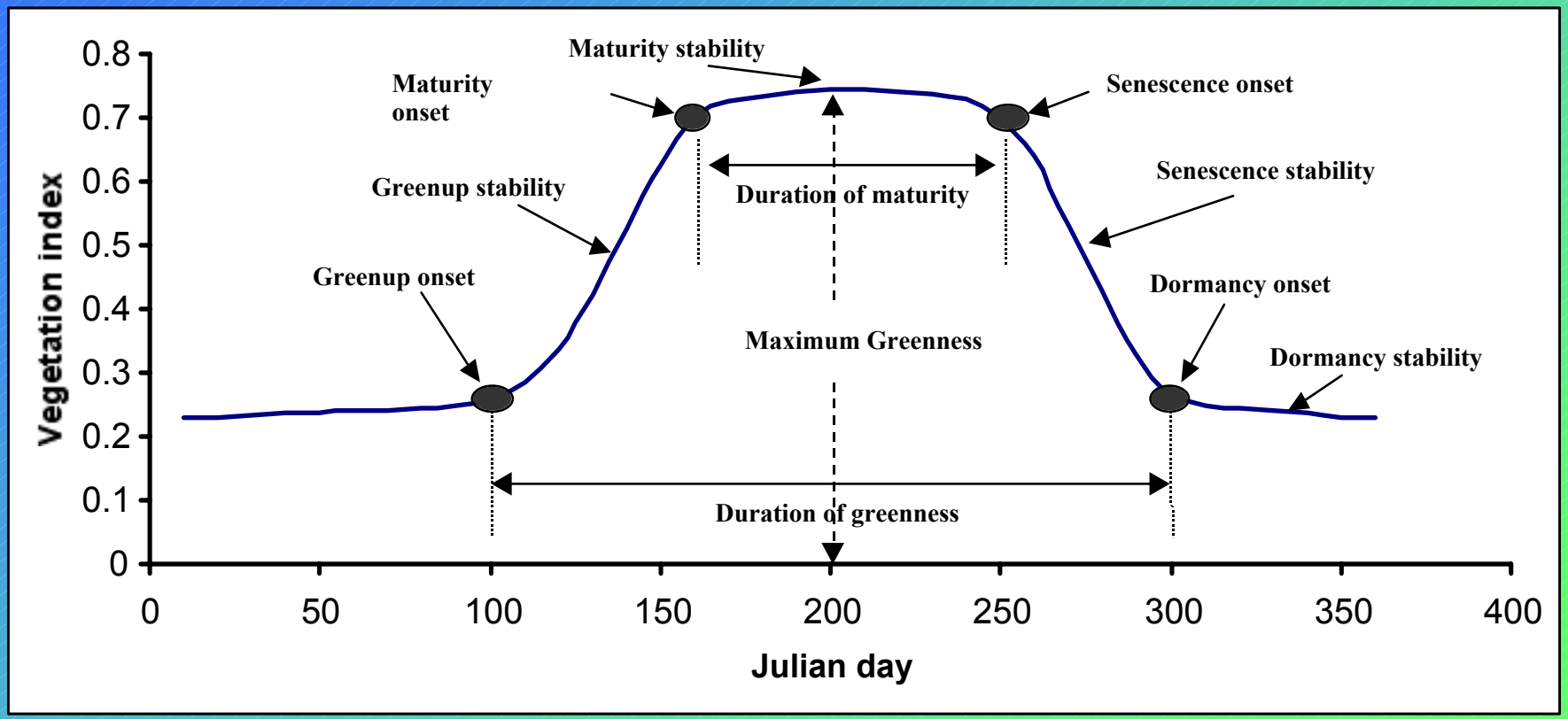
PER-CLASS ACCURACIES RANGE 60–90 PERCENT

CONTINENTAL REGION ACCURACIES RANGE 70–85 PERCENT

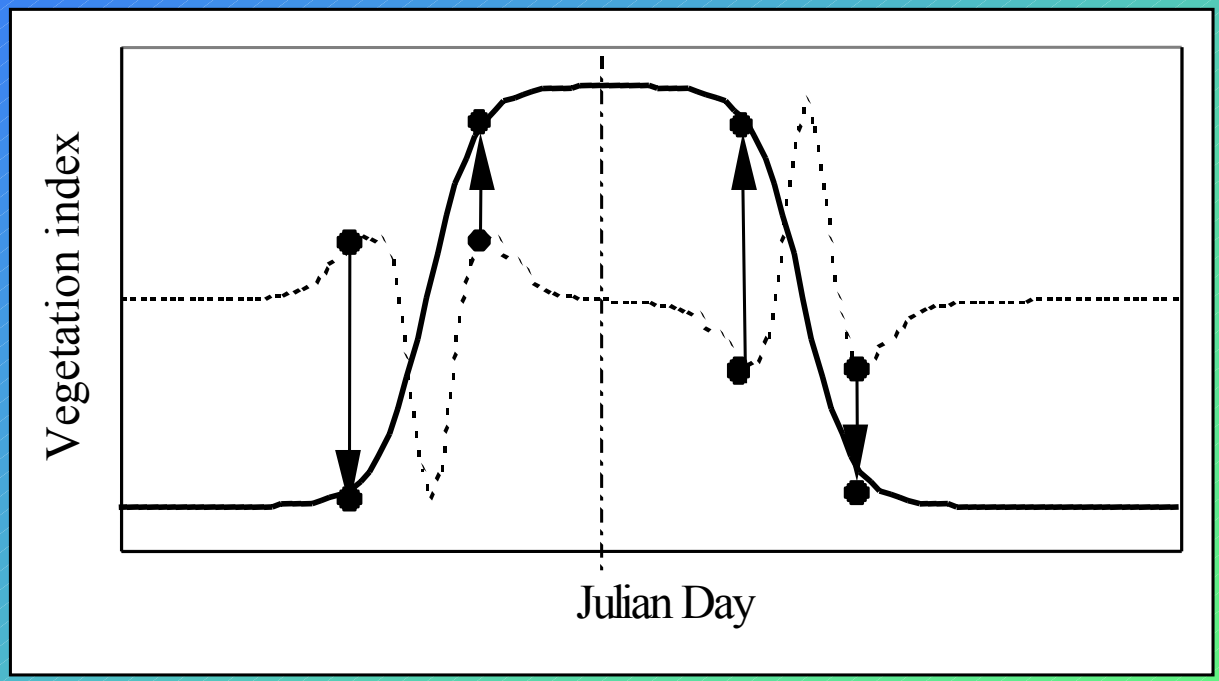
Land Cover Dynamics

- ***Primary Objectives:***
  - **Quantify interannual change**
    - **Uses change vectors comparing successive years**
    - **Identifies regions of short-term climate variation**
    - **Under development with Eric Lambin, Frederic Lupo at UCL, Belgium**
  - **Quantify phenology**
    - **Greenup, maturity, senescence, dormancy**
    - **Values of VI, EVI at greenup and peak, plus annual integrated values**
    - **Uses logistic functions fit to time trajectories of EVI**

Land Cover Dynamics: Defining Phenological Attributes

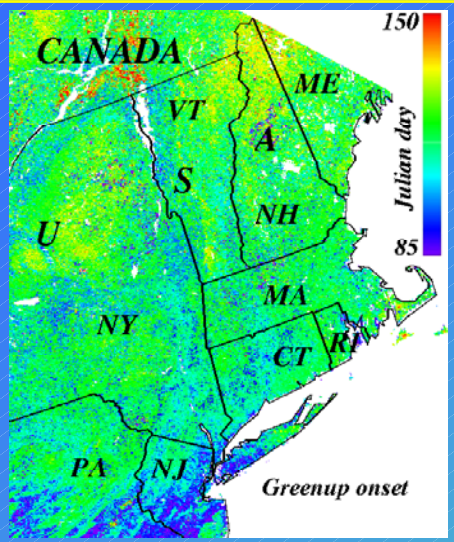


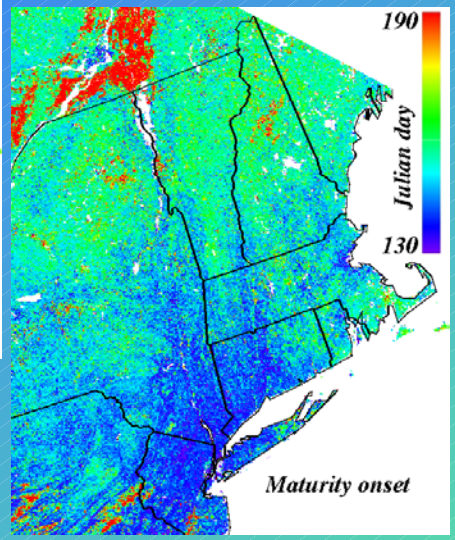
Quantifying Phenology

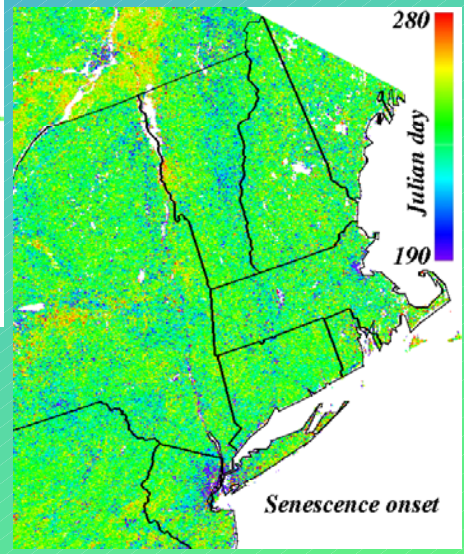


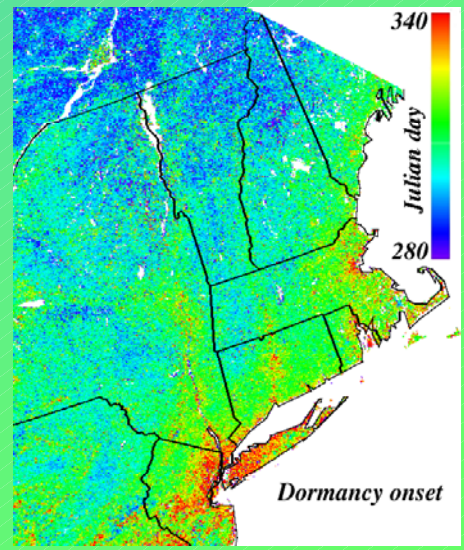
Use extreme points of the change rate of curvature to calculate phenology transition dates from NBAR-EVI

Northeast Phenology

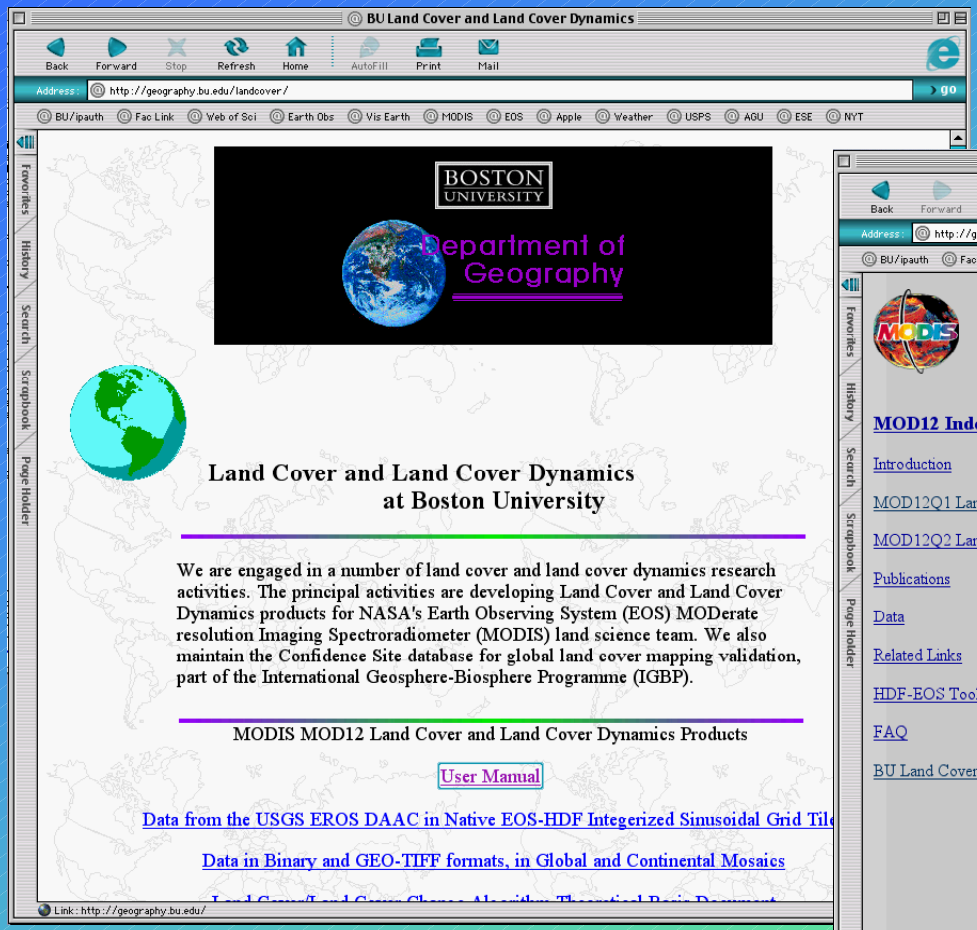


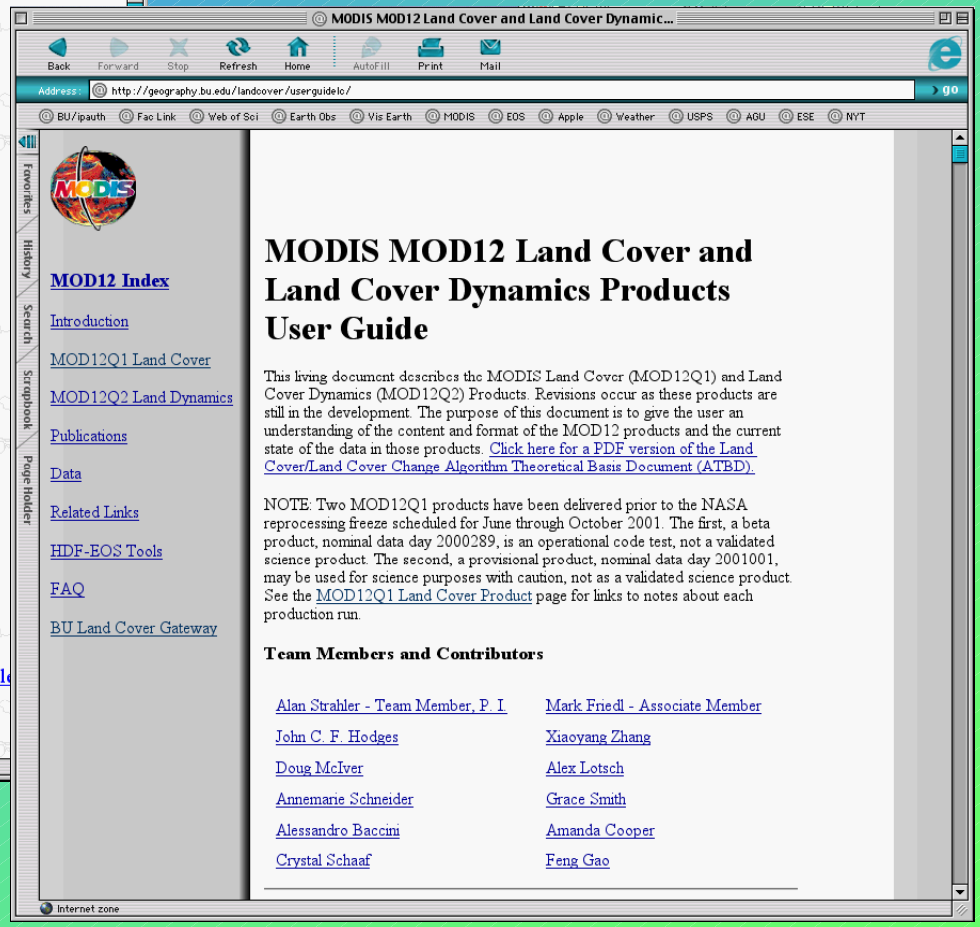






Web Site: http://geography.bu.edu/landcover





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