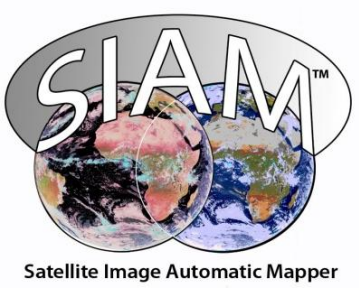




# Towards Operational Fully Automated Fine Resolution Automated Mapping

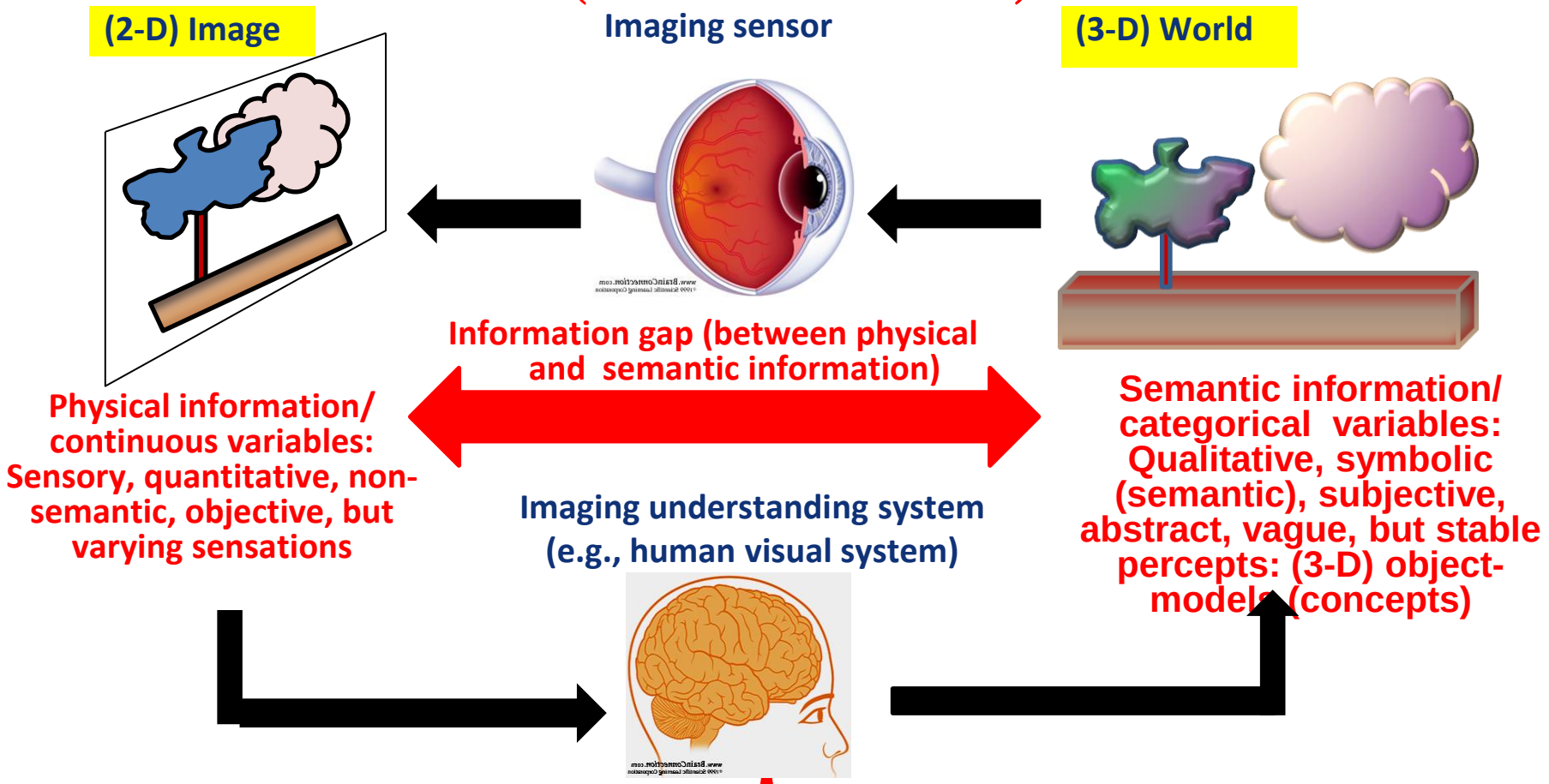
*Andrea Baraldi, Luigi Boschetti*

*David Roy, Chris Justice*

# Theoretical Background

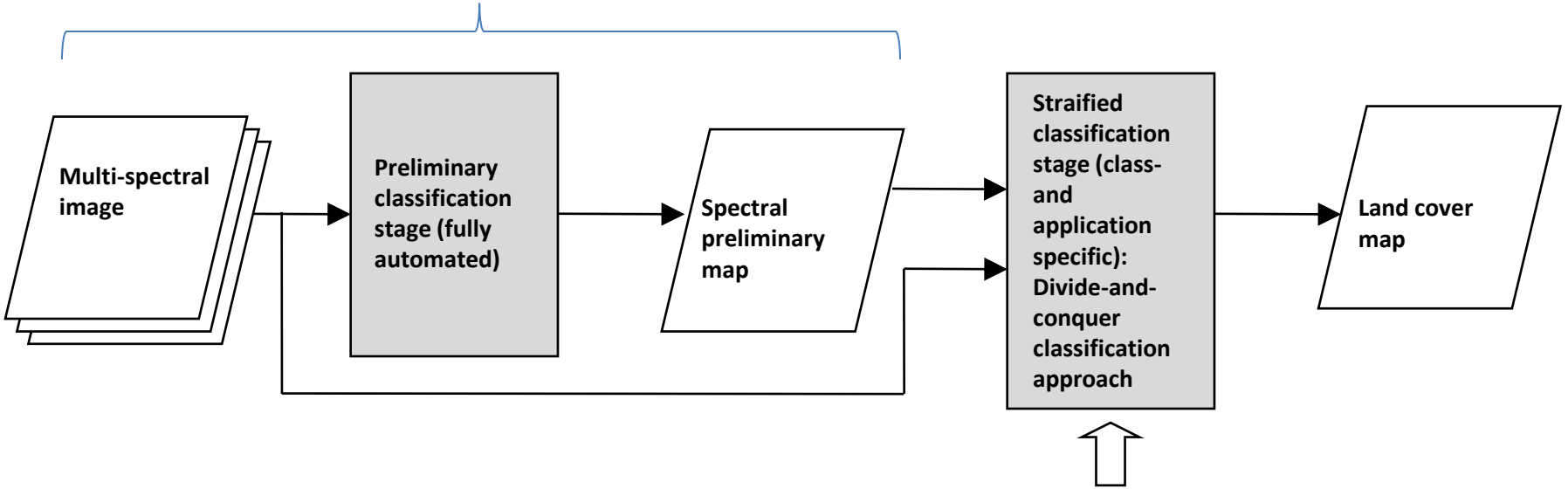
- The automatic classification system aims at reproducing the processes that allow the human brain to interpret satellite images.
- Rooted in concepts from computer vision and neurophysiology:
  - The recognition of objects happens in successive stages with increasing levels of abstraction
  - Preliminary semantic sketch (pre-attentive vision) followed by elaboration on shapes, textures and relationships (attentive vision)

# The image understanding problem (human vision)



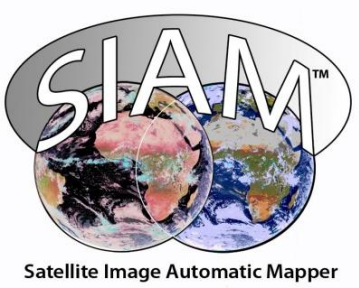
# 2-stage LCLU Classification System

**First stage**: Spectral Rule Classifier (fully implemented): SIAM™




**Second Stage**:
Traditional techniques (image clustering, segmentation, supervised classification algorithms ) are employed here

# First Stage:
# Satellite Image Automatic Mapper (SIAM™)



# SIAM adopts the following classification scheme.

a) A discrete and finite set of classes belonging to six target categories, namely:

I. Water/shadow. **BLUE**

II. Snow/ice. **LIGHT BLUE**

III. Clouds. **WHITE**

IV. Vegetation. **GREEN**

V. Bare soil/built-up. **BROWN**

VI. Outliers.

# SIAM adopts the following classification scheme.

a) A discrete and finite set of classes belonging to six target categories, namely:

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III. Clouds. **WHITE**

IV. Vegetation. **GREEN**

V. Bare soil/built-up. **BROWN**

VI. Outliers.

b) A set of rules, or definitions, or properties for assigning class labels.

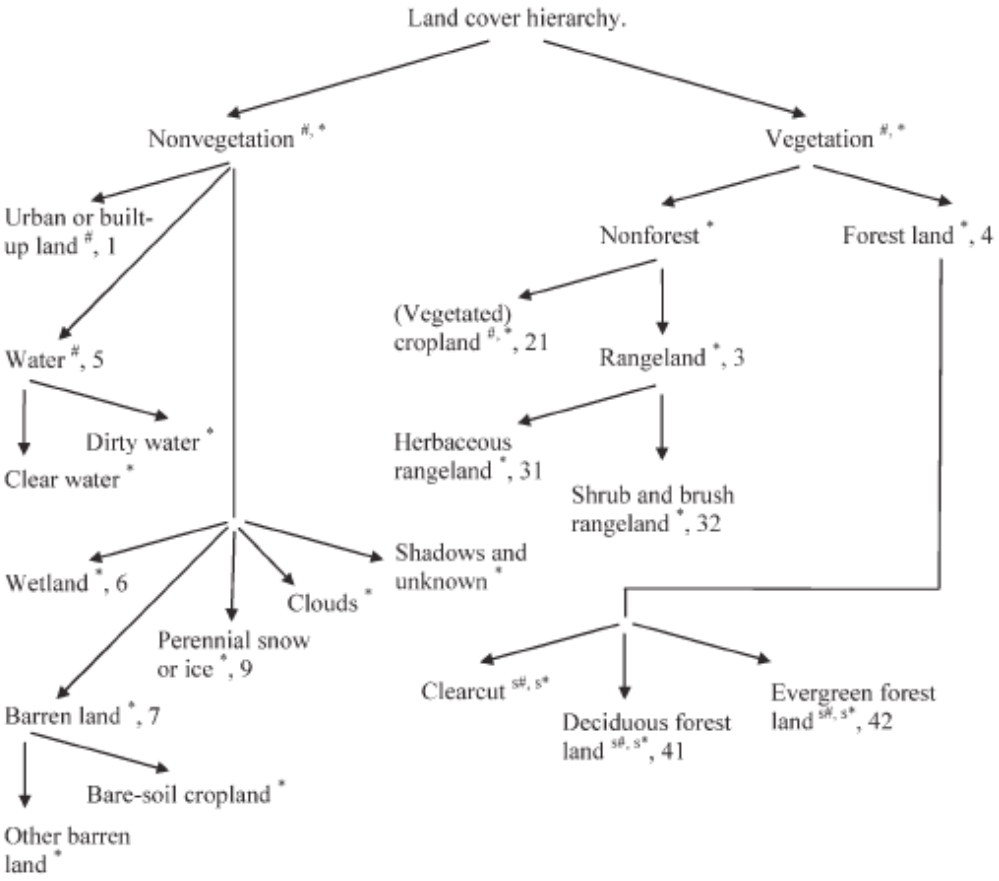
i. Pixel-based (context-insensitive), which is tantamount to saying purely spectral.

ii. Prior knowledge-based (non-adaptive).

This classification scheme is:

- Mutually exclusive, i.e., each mapped area falls into one and only one category.
- Totally exhaustive (which implies that outliers must be explicitly dealt with by class "others"). In other words, SRC provides a complete partition of an input RS image.

# Prior-Knowledge Based Decision Tree




Baraldi et al., 2006
Baraldi et al., 2010a, b

# Prior knowledge-based SIAM™ decision-tree classifier implementation

SIAM implementation.

a) Feature extraction (e.g., NDVI, NDBSI, NDSI, etc.)

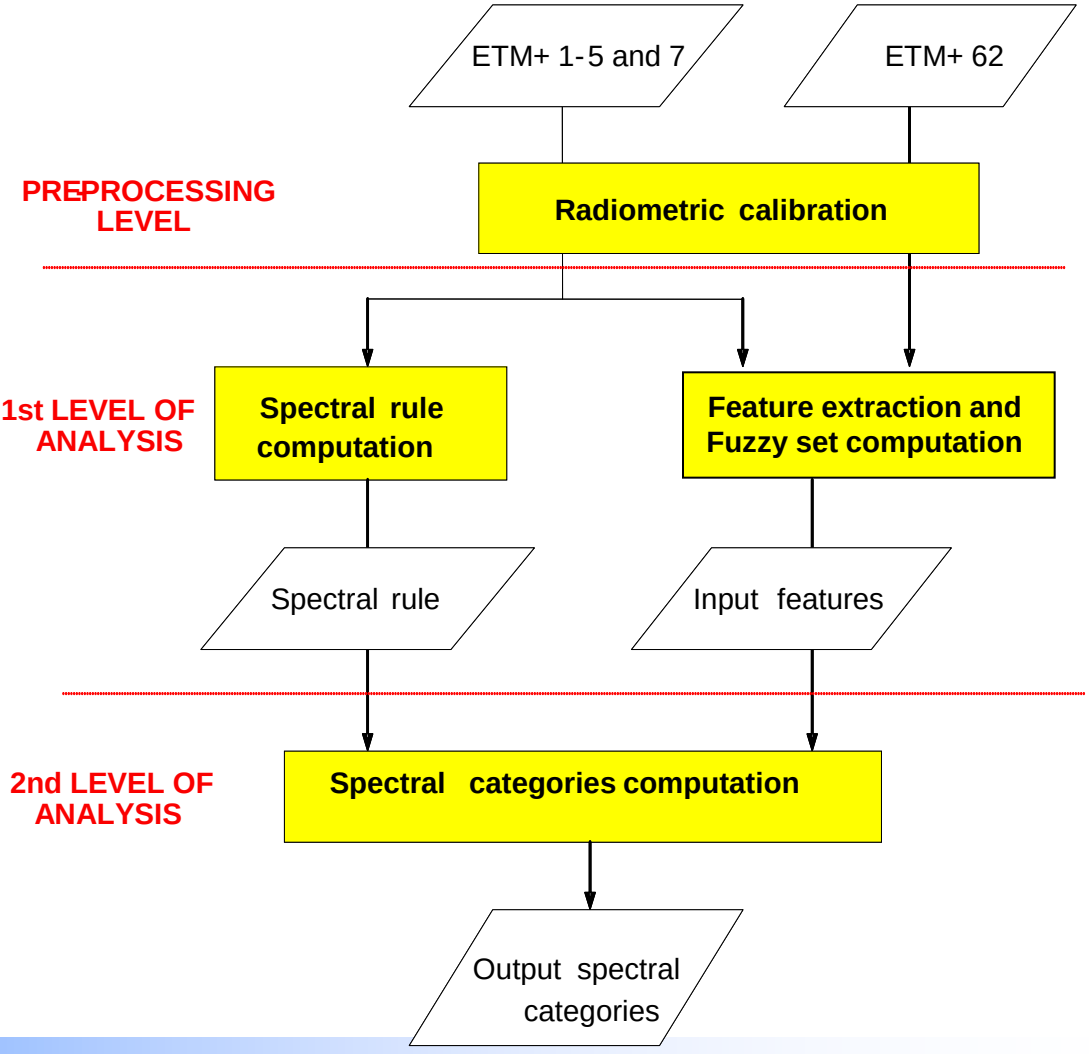
b) Relational properties (≤, ≥, etc.) among class-specific reflectance values in different portions of the electromagnetic spectrum.

c) Fuzzy set (*High*, *Medium*, and *Low*) computation.

d) Combination of fuzzy sets and relational properties.

Software written in C programming language

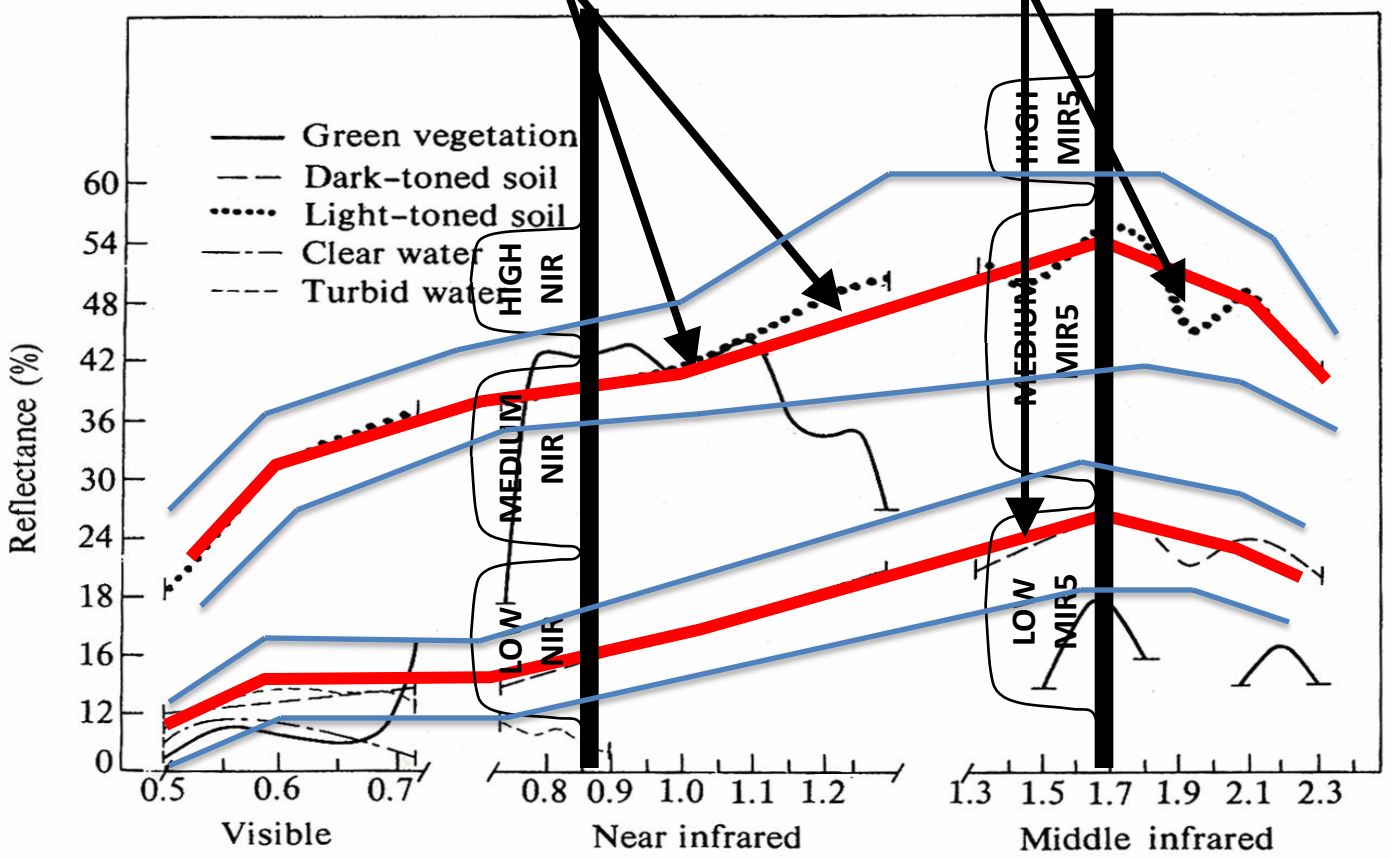
- Platform independent
- Fast processing (~5 minutes for full Landsat scene on a laptop)
- Easy to integrate in a processing chain



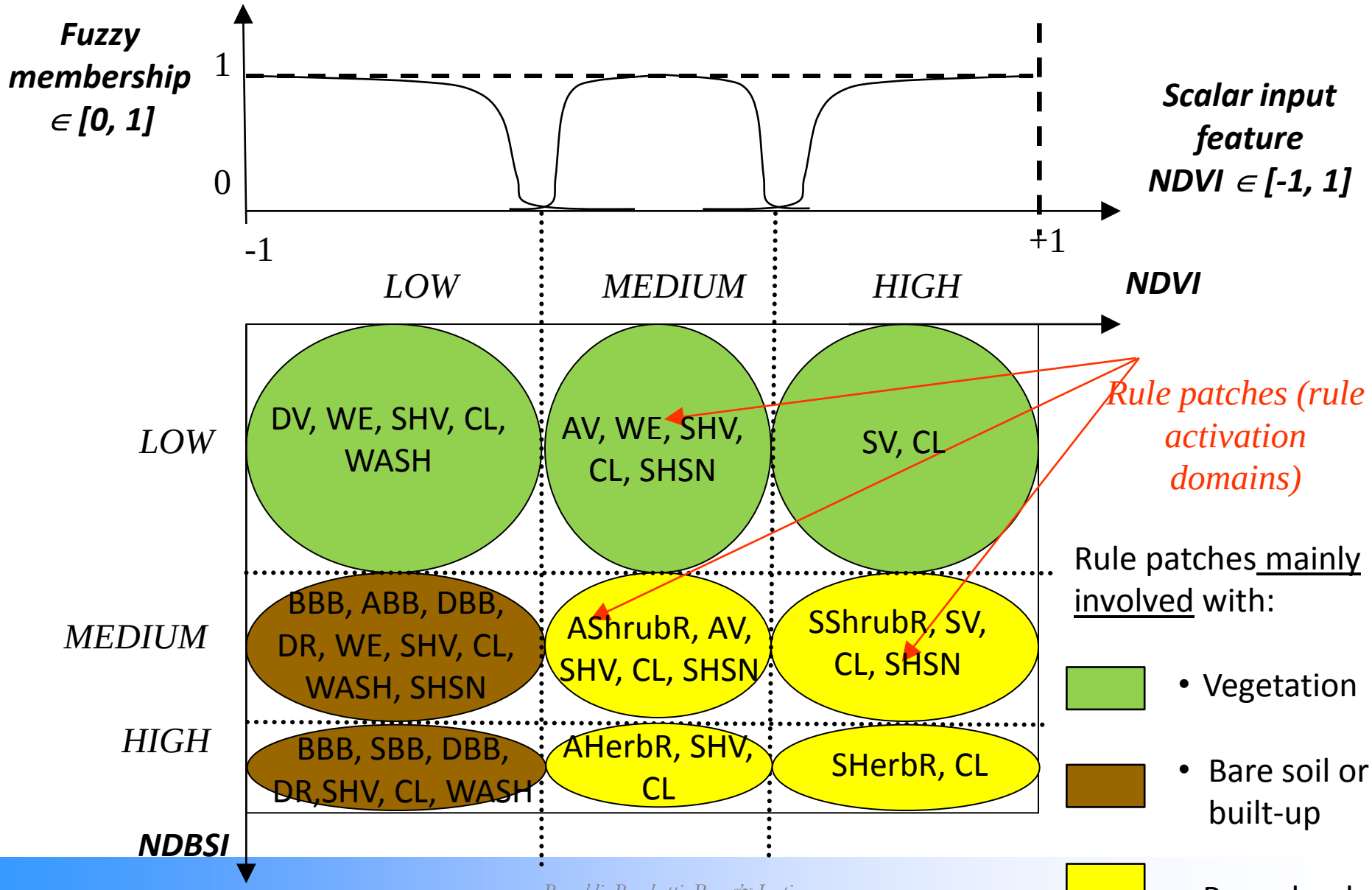
# Prior knowledge-based SIAM™ decision-tree classifier implementation

**1st LEVEL OF ANALYSIS:**
**For a given spectral signature (e.g., Barren land), model inter-band fuzzy relationships, e.g., *TM5* > *(TM4*± 10%).**

**2nd LEVEL OF ANALYSIS: Spectral signature quantization through fuzzy sets, e.g., *Bright Barren Land* and *Dark Barren land* .**



# Input space partitioning (irregular but complete) through fuzzy sets



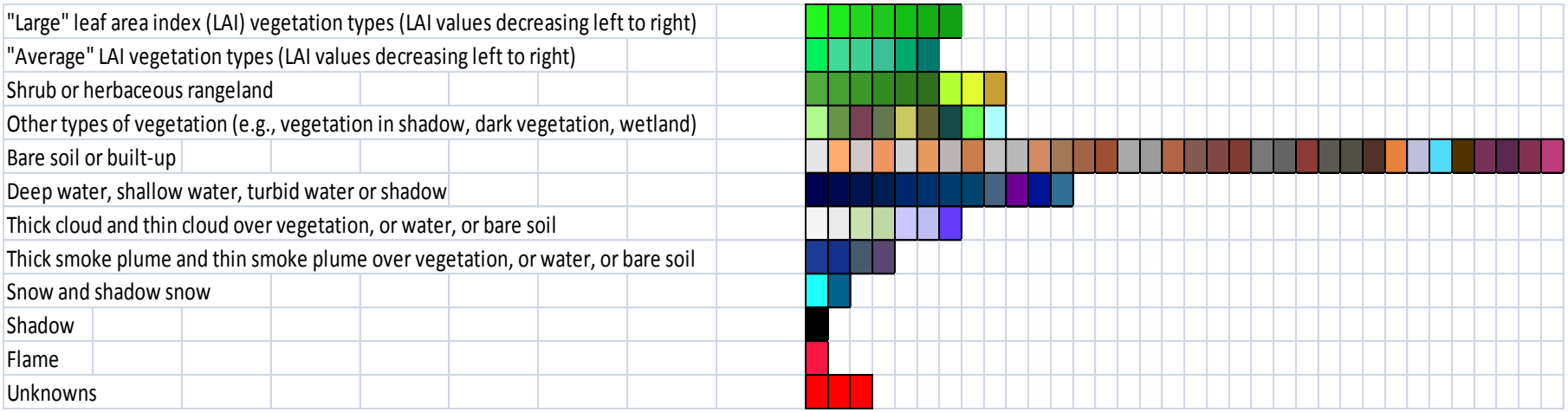
# Meaning of spectral categories: examples

| **Spectral category's acronym:** water/shadow, cloud, snow/ice, bare soil/built-up, vegetation, outliers. | **Spectral category's linguistic description** | **Candidate land covers (USGS, levels I and II)** |
|---|---|---|
| SV, AV, WV | *Strong/Average/Weak* Vegetation. | Forest land (4), (Vegetated) Cropland (21). |
| SSR, ASR | *Strong/Average* Shrub Rangeland. | Shrub and brush rangeland (32). |
| VBBB, BBB, SBB, ABB, WBB, DBB | *Very Bright / Bright / Strong / Average / Weak / Dark* Built-up and Barren land. | (Non-vegetated) Cropland (21), Urban or built-up land (1), Barren land (7). |
| TKCL, TNCL | *Thick/Thin* Clouds. | Clouds. |
| DPWASH, SLWASH | *Deep/Shallow* Water and Shadow areas. | Water (5). |

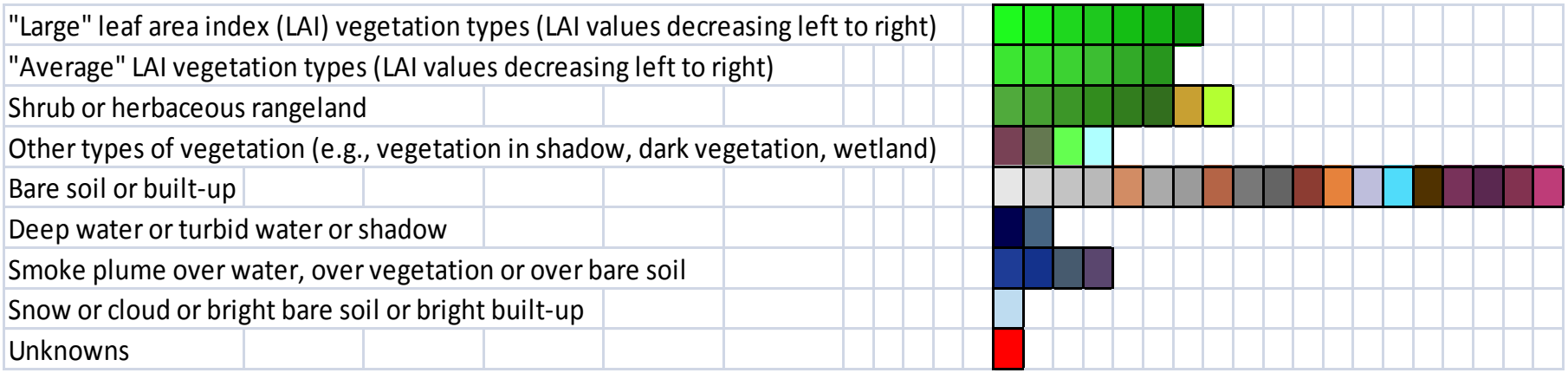
# Multi-Sensor Capabilities

- SIAM is capable to process data from all the multispectral sensors that have spectral bands overlapping with those of Landsat TM. The number of spectral categories detected depends on the bands of the sensor.
- Fully implemented (turn-of-the-key) for 6 classes of sensors:
  - Landsat TM (7 bands)
  - SPOT HRVIR (4 bands)
  - AVHRR (4 bands)
  - AATSR (5 bands)
  - IKONOS (4 bands)
  - DMC (3 bands)
- Applied to data from 0.5 m (Pan Sharpened World View) to 3 km (Meteosat SEVIRI) data, and from 3 to 7 bands.

# SIAM™ map legend

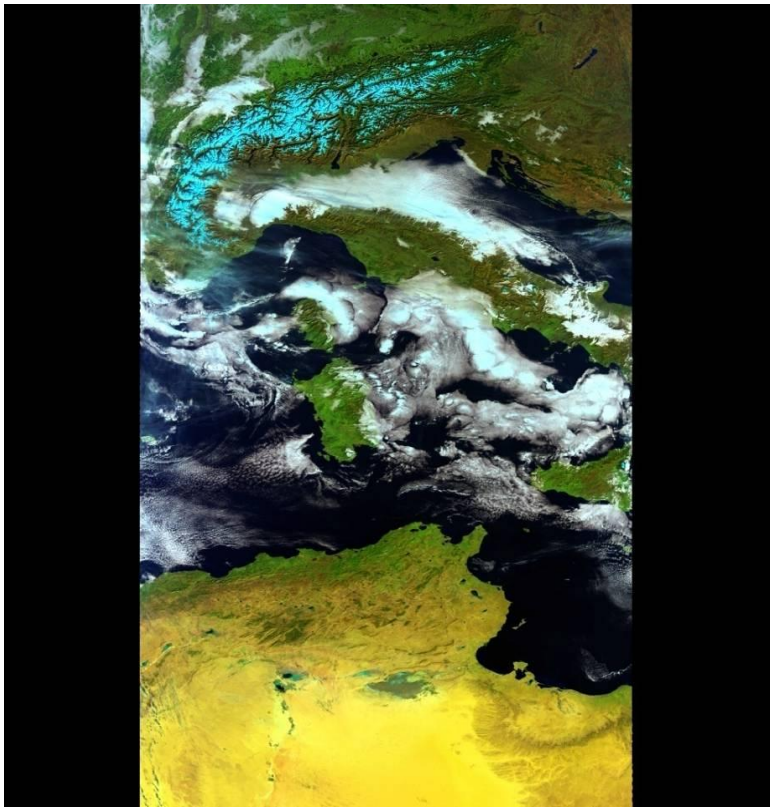



**Legend for Landsat TM: 95 classes**

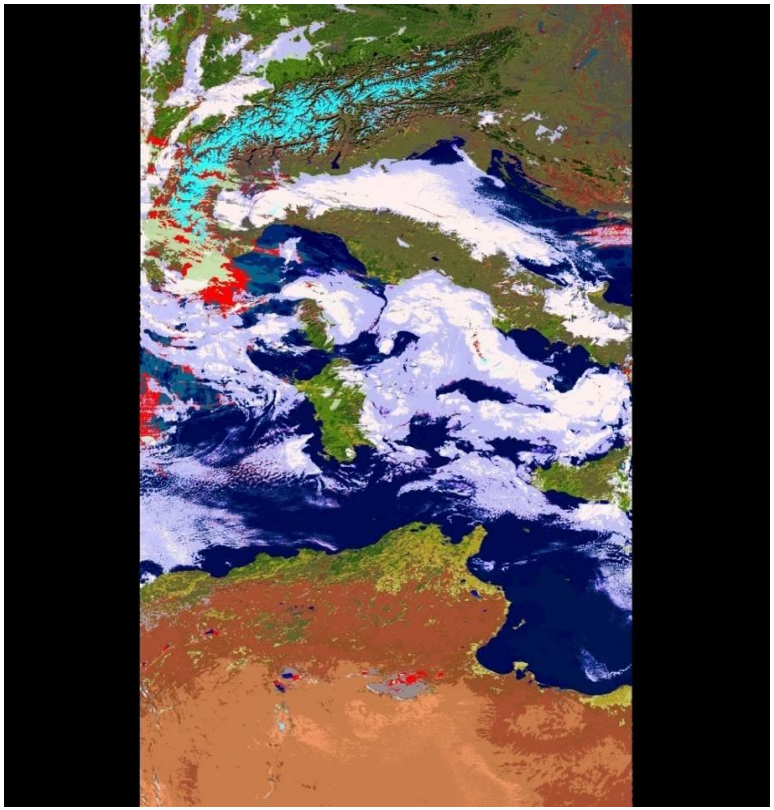



**Legend for IKONOS: 52 classes**

# MODIS

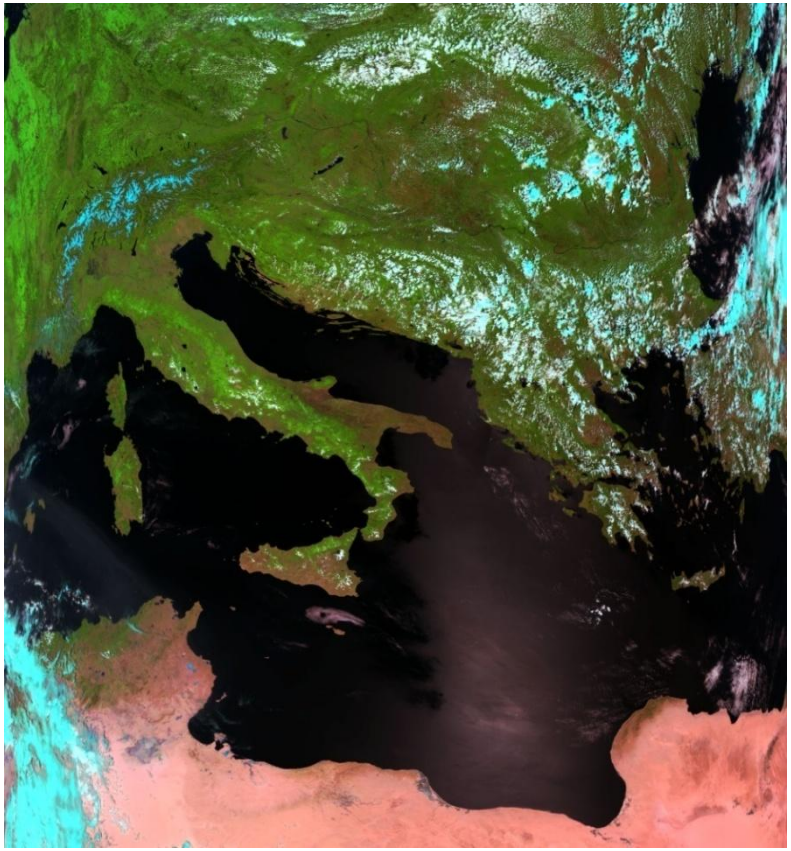


MODIS surface reflectance, covering northern Africa and Italy (R: band 1, G: band 4, B: band 3), spatial resolution: 1km.

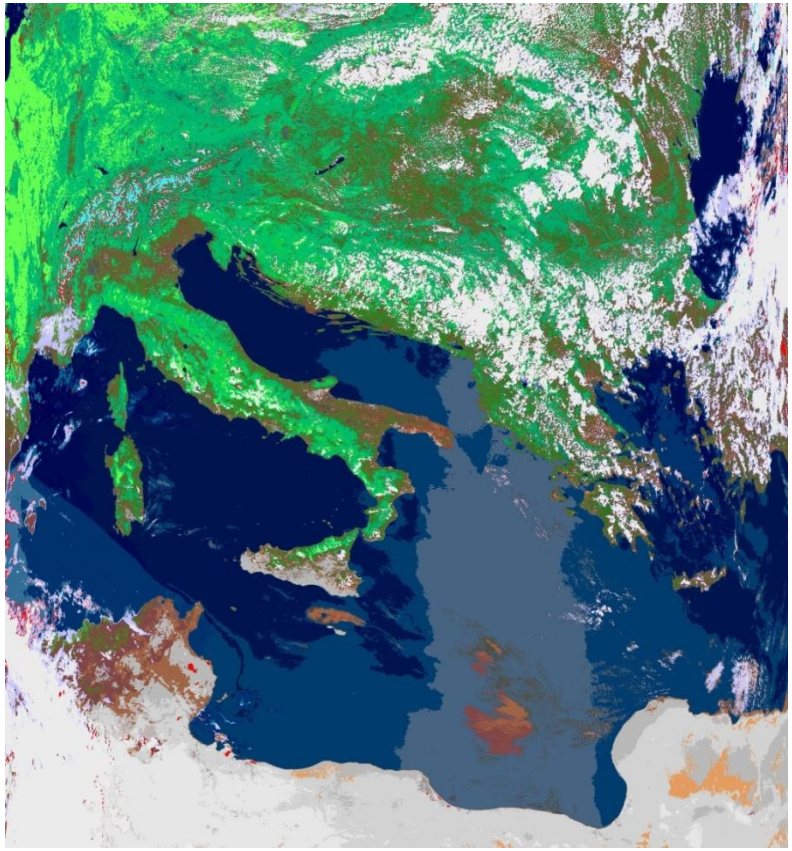


SIAM preliminary classification. (72 classes)

# NOAA-AVHRR

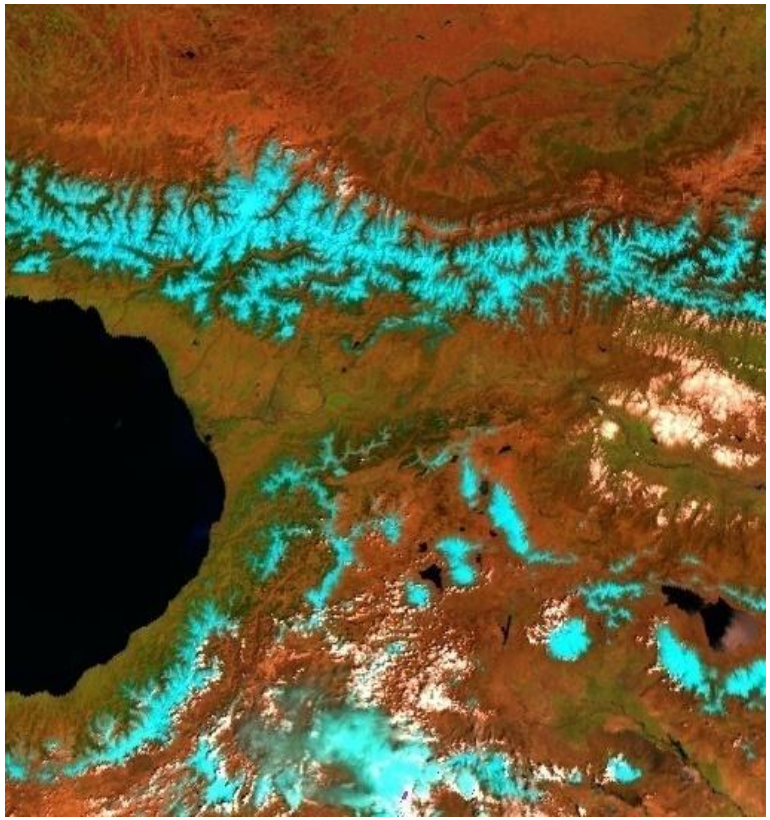


NOAA-AVHRR (NOAA 17) image acquired on 2004-06-08 covering Mediterranean and Balcanic areas (R: band 3a, G: band 2, B: band 1), spatial resolution: 1.1 km.

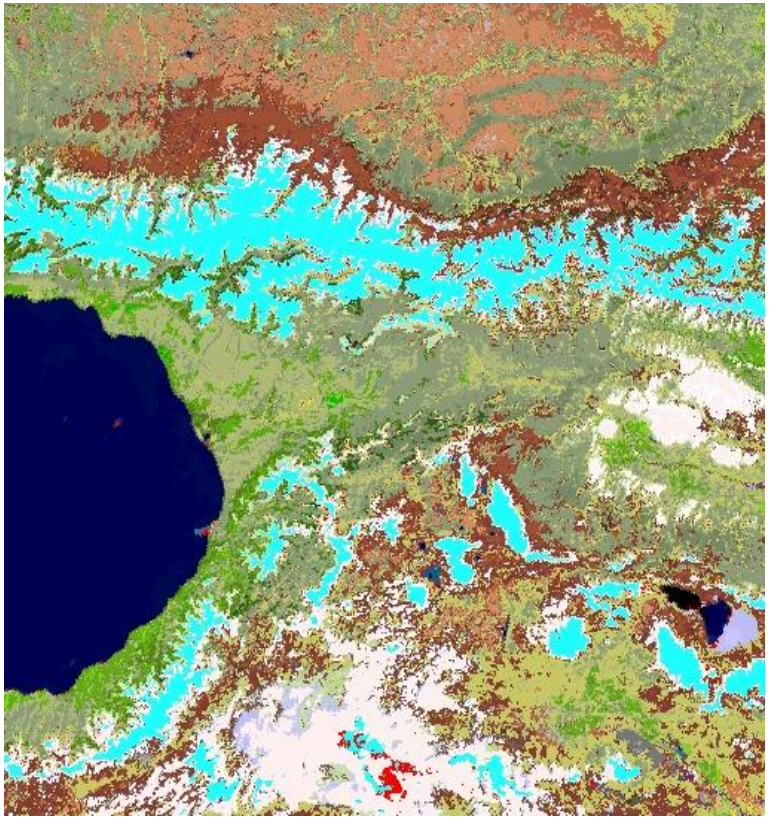


SIAM preliminary classification

# ENVISAT AATSR



ENVISAT AATSR image acquired on 2003-01-05, covering a surface area over the Black sea (R: band 7, G: band 6, B: band 4), spatial resolution: 1 km.



SIAM preliminary classification

# MSG

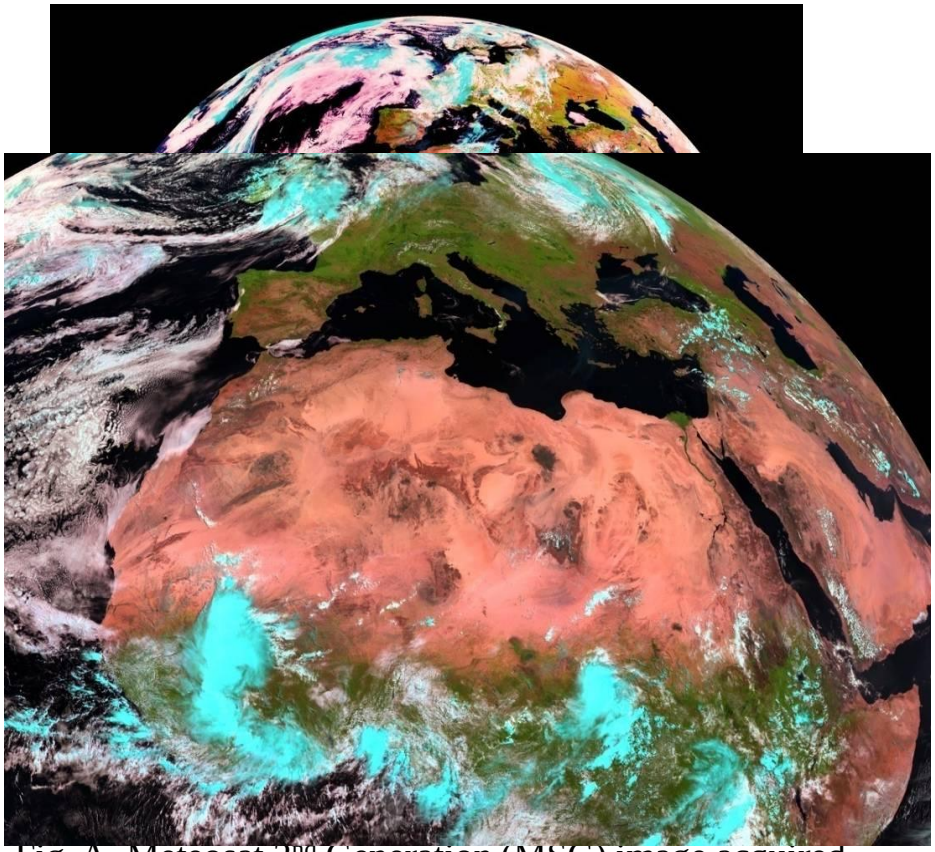


Fig. A. Meteosat 2nd Generation (MSG) image acquired on May 16, 2007, at 12.30 (CEST), covering Africa (R: band 3, G: band 2, B: band 1), spatial resolution: 3 km.

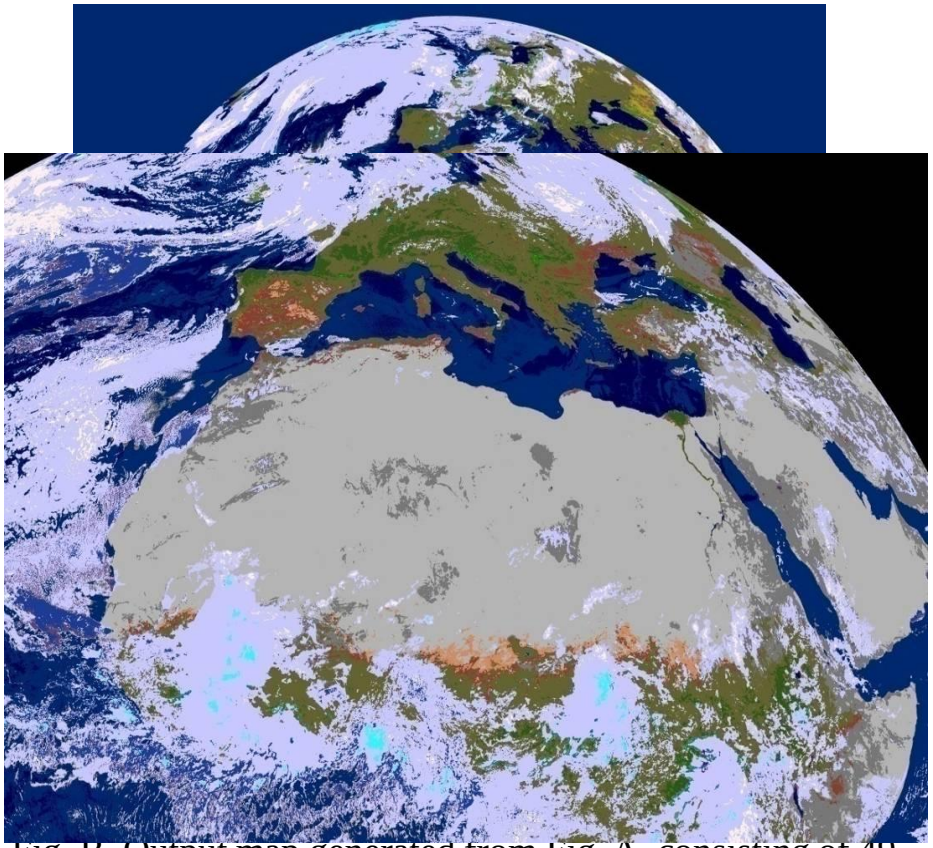


Fig. B. Output map generated from Fig. A, consisting of 49 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

# World-View 2

Fig. A. 8-band WorldView-2 VHR image of the city of Rome, Italy, acquired on 2009-12-10, at 10:30 a..m., depicted in false colors (R: band R, G: band NIR1; B: band B) (provided by DigitalGlobe, http://www.digitalglobe.com/index.php/70/Product+Samples), calibrated into TOA reflectance. Spatial resolution: 2.0 m.

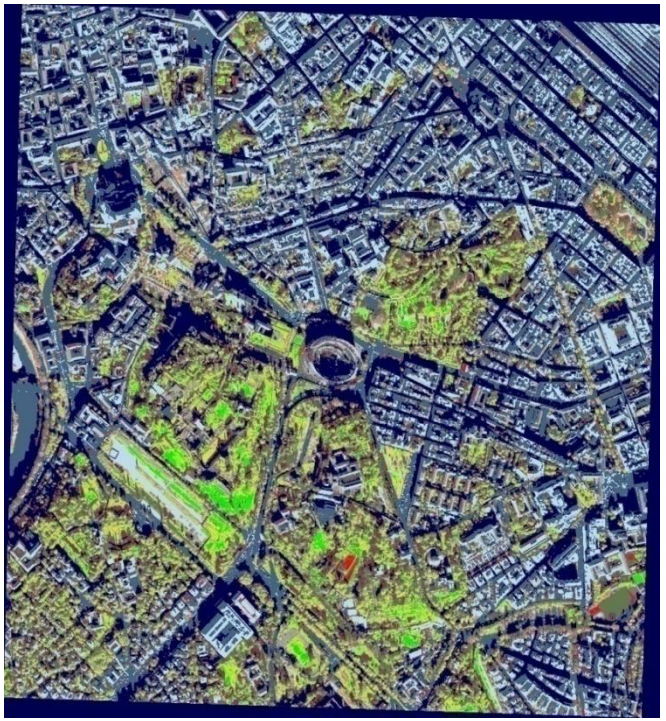


Fig. B. Output map generated from Fig. A, consisting of 52spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

# World-View 2

Fig. C. Segment-based piecewise constant approximation of the 8-band WorldView-2 VHR image of the city of Rome, Italy, acquired on 2009-12-10, at 10:30 a..m., depicted in Fig. A. Spatial resolution: 2.0 m. Note: the bridge has disappeared (Omission error!!!)

Fig. D. Contour map generated from the preliminary classification map shown in Fig. B.

# World-View 2

Fig. E. Zoomed image extracted from the 8-band WorldView-2 VHR image of the city of Rome, Italy, acquired on 2009-12-10, at 10:30 a..m., shown in Fig. A. Spatial resolution: 2.0 m.

Fig. F. Zoomed image extracted from the preliminary classification map shown in Fig. B.

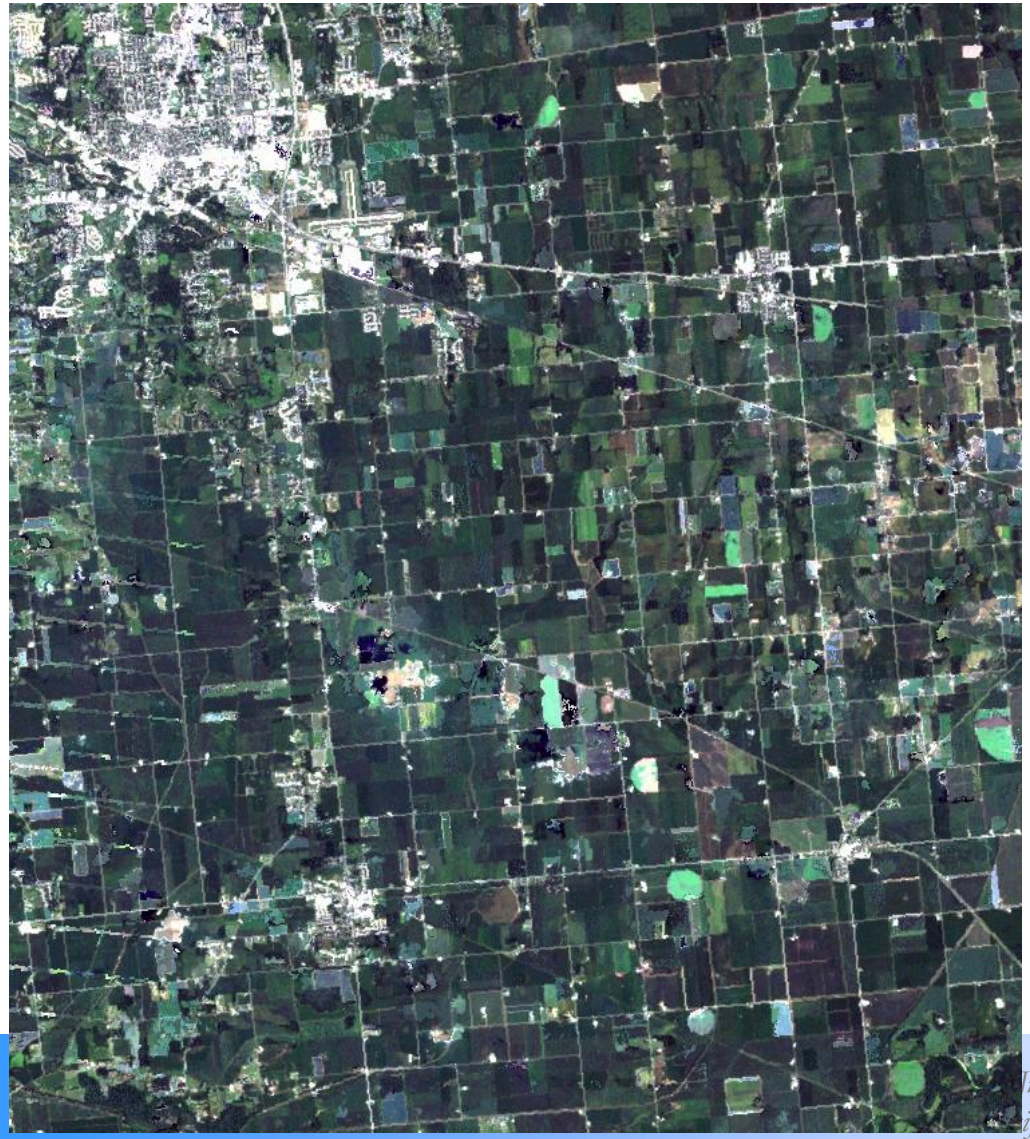
Fig. F. Zoomed image extracted from the contour mapshown in Fig. D.

# World-View 2

Fig. A. 8-band WorldView-2 VHR image of the city of Brazilia, Brazil, acquired on 2010-08-04, at 13:32 p.m., depicted in false colors (R: band R, G: band NIR1; B: band B) (provided by DigitalGlobe, 8-Band Challenge), calibrated into TOA reflectance. Spatial resolution: 2.0 m.

Fig. B. Output map generated from Fig. A, consisting of 52spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

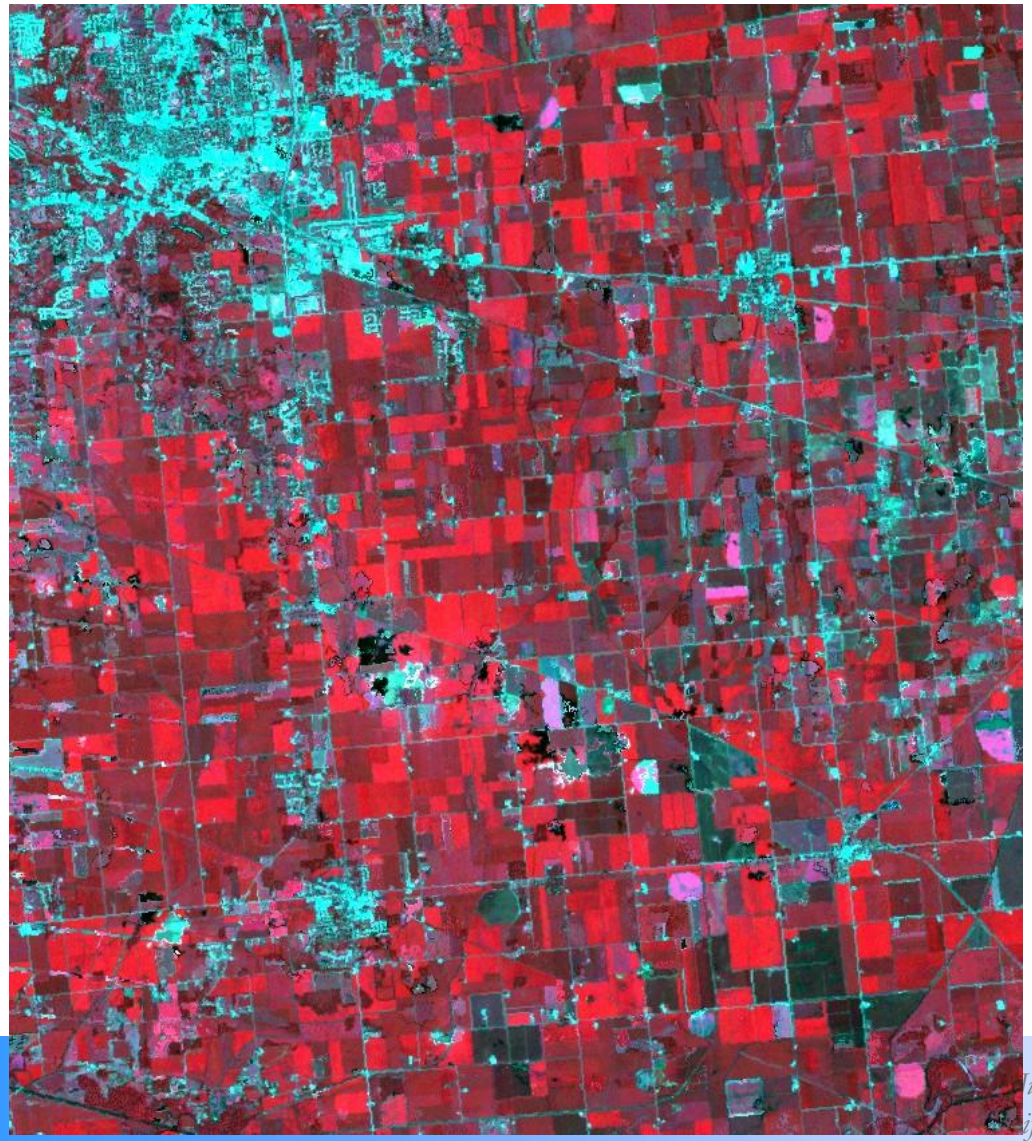
# The first stage is not landcover…



WELD tile
h22v08, annual composite

true color
(20x30km subset)

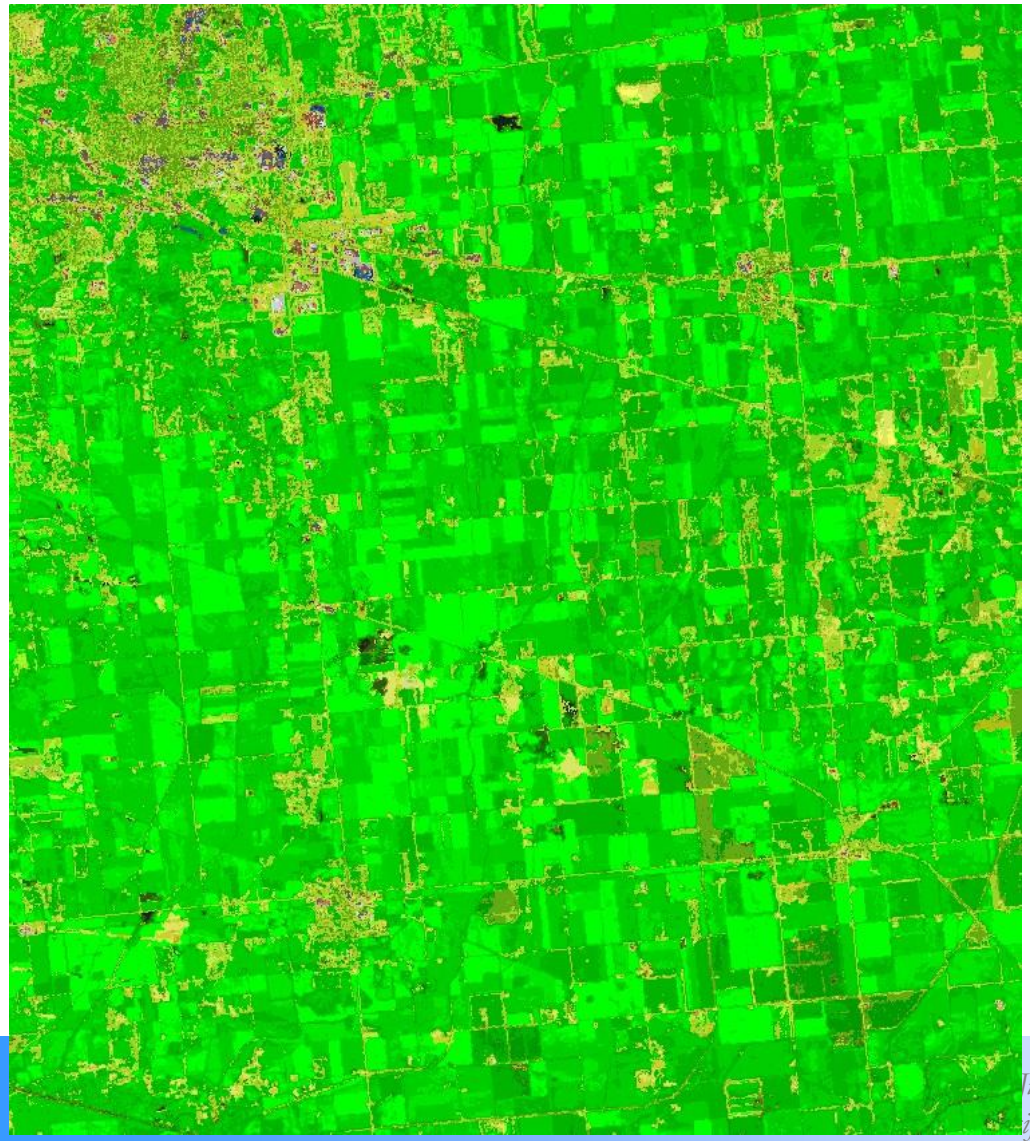
# The first stage is not landcover…



WELD tile h22v08, annual composite

false color

# The first stage is not landcover…



WELD tile h22v08,

Preliminary classification

Strong vegetation

Average shrub

Average barren lands

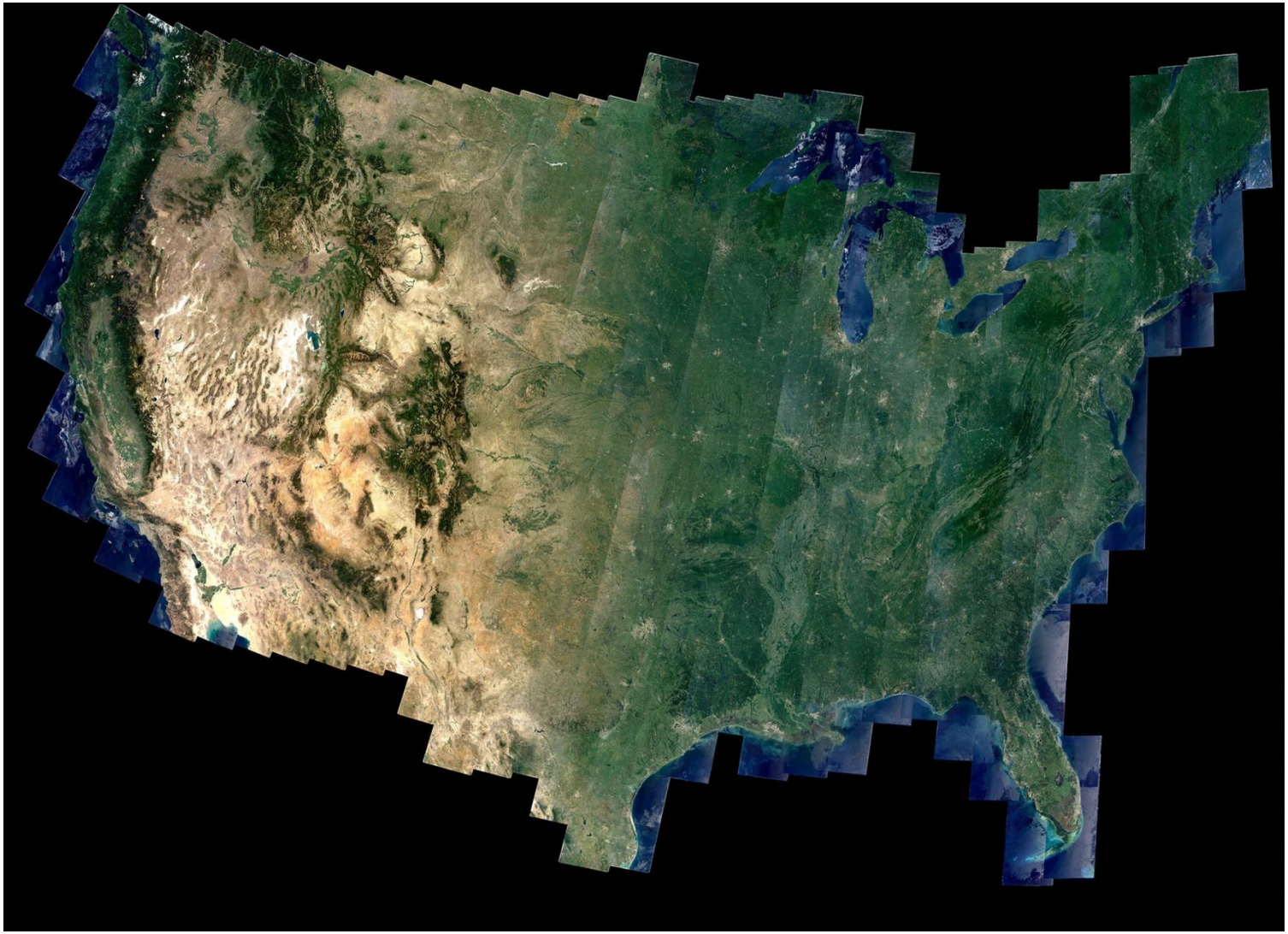
Dark barren lands

# Relationship between spectral categories and vegetation land cover classes

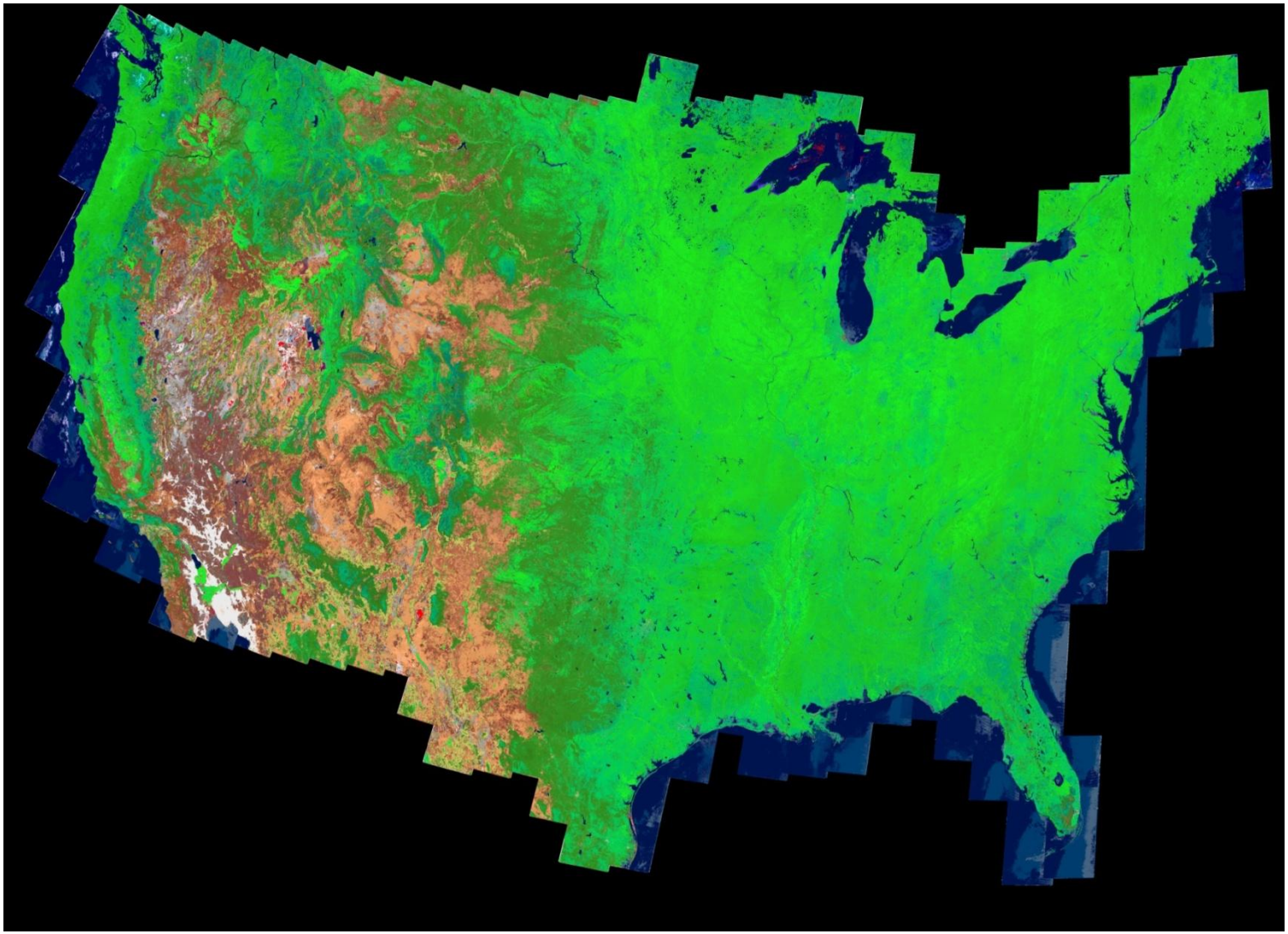
| | |
|---|---|
| Strong Vegetation (SV) – VHNIR<br>Average Vegetation (AV) – VHNIR<br>Average Shrub Rangeland (ASR) – VHNIR or HNIR | - Crop field (Vegetated agricultural fields)<br>- Pastures |
| Strong Vegetation (SV) – HNIR<br>Average Vegetation (AV) - HNIR | - Deciduous Broadleaved forests<br>- Deciduous Permanent crop (deciduous fruit-trees)<br>- Crop field (Vegetated agricultural fields) |
| Strong Vegetation (SV) – MNIR<br>Average Vegetation (AV) - MNIR | - Evergreen Broadleaved forests<br>- Evergreen Permanent crop (evergreen fruit-trees, e.g., orange tree field)<br>- Crop field (Vegetated agricultural fields) |
| Strong Vegetation (SV) – LNIR<br>Average Vegetation (AV) - LNIR | - Evergreen Coniferous forests<br>- Forests in shadow areas |
| Average Shrub Rangeland (ASR) – MNIR or LNIR | - Open forest<br>- Sparse trees (e.g., olive grows)<br>- Regrowth<br>- Transitional woodlands<br>- Clear cuttings |
| Average Herbaceous Rangeland (AHR)<br>Strong Herbaceous Rangeland (SHR)<br>Weak Rangeland (WR) | - Natural grassland |

# Evaluation of the SIAM preliminary classification

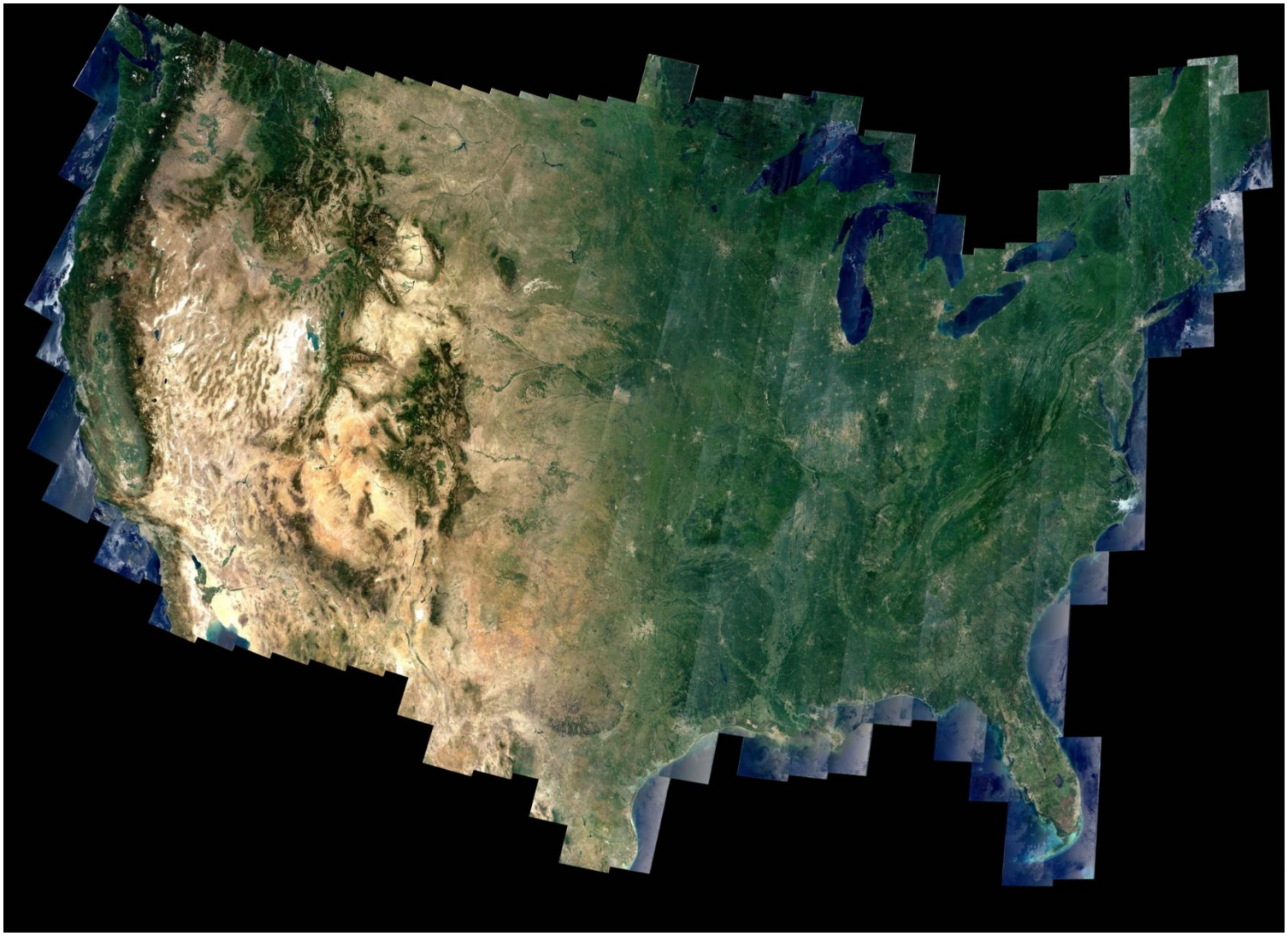
# Example: Web-Enabled Landsat Data (WELD). Year: 2007



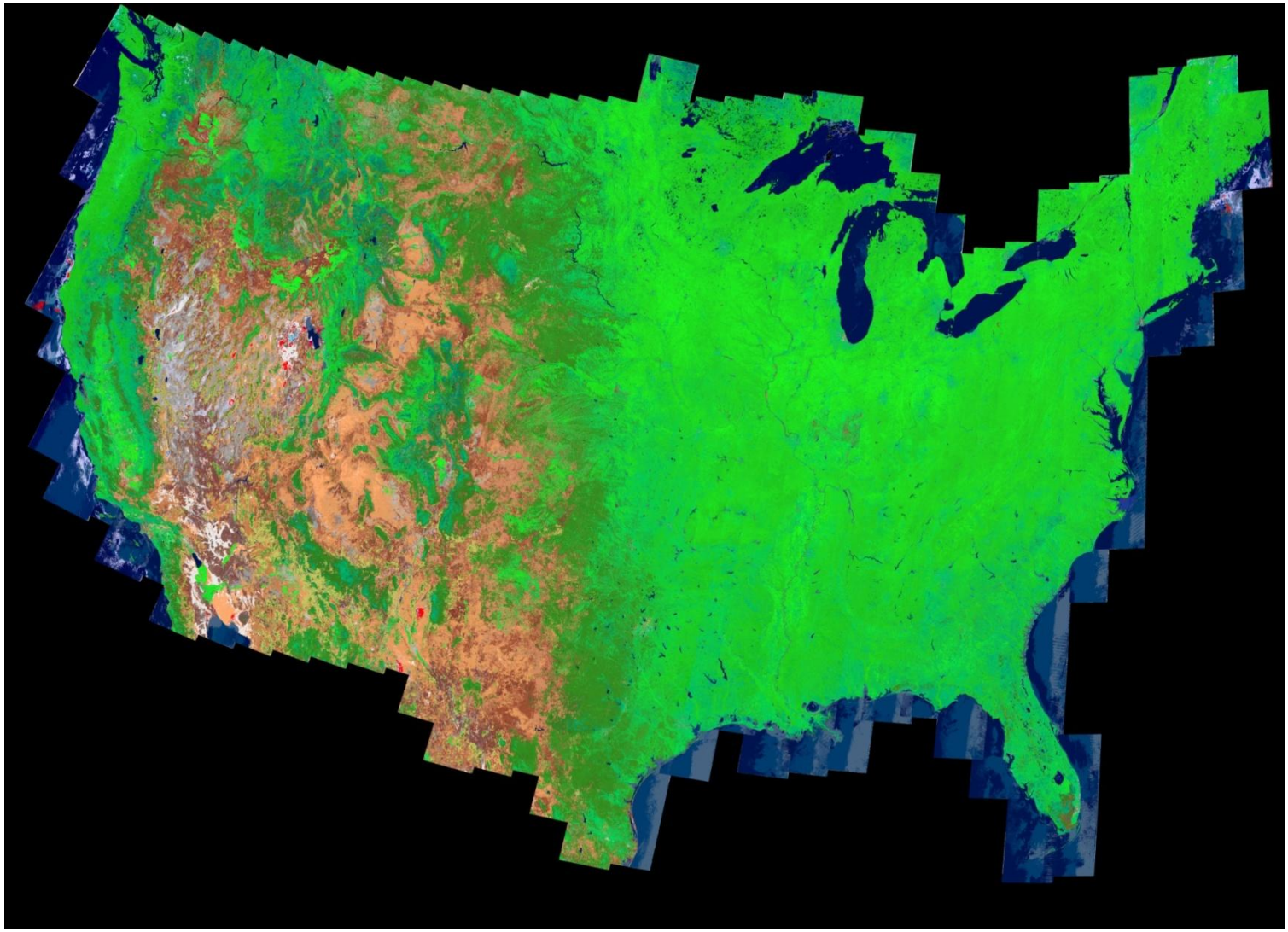
# Example: Web-Enabled Landsat Data (WELD). Year: 2007



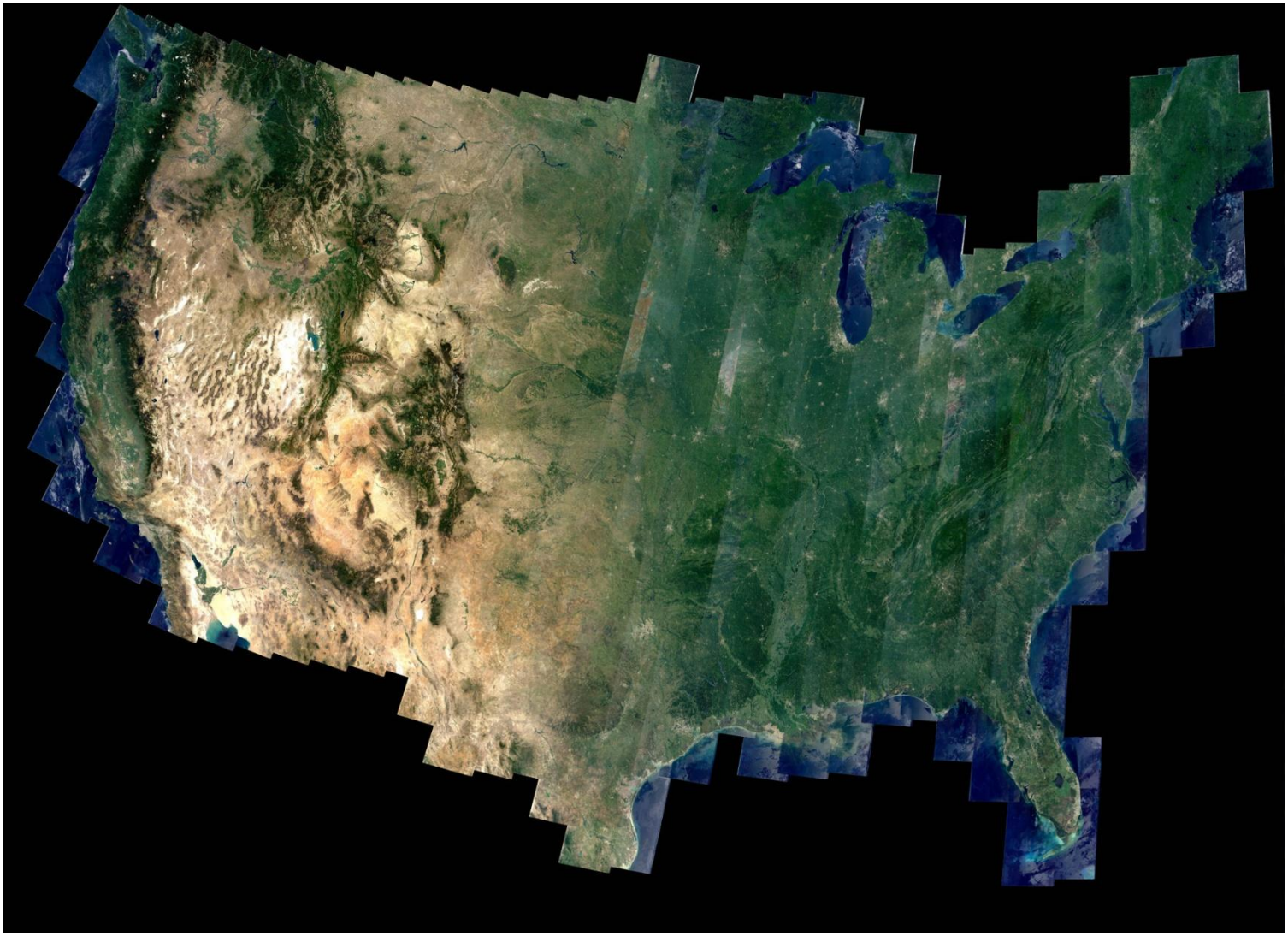
# Example: Web-Enabled Landsat Data (WELD). Year: 2008



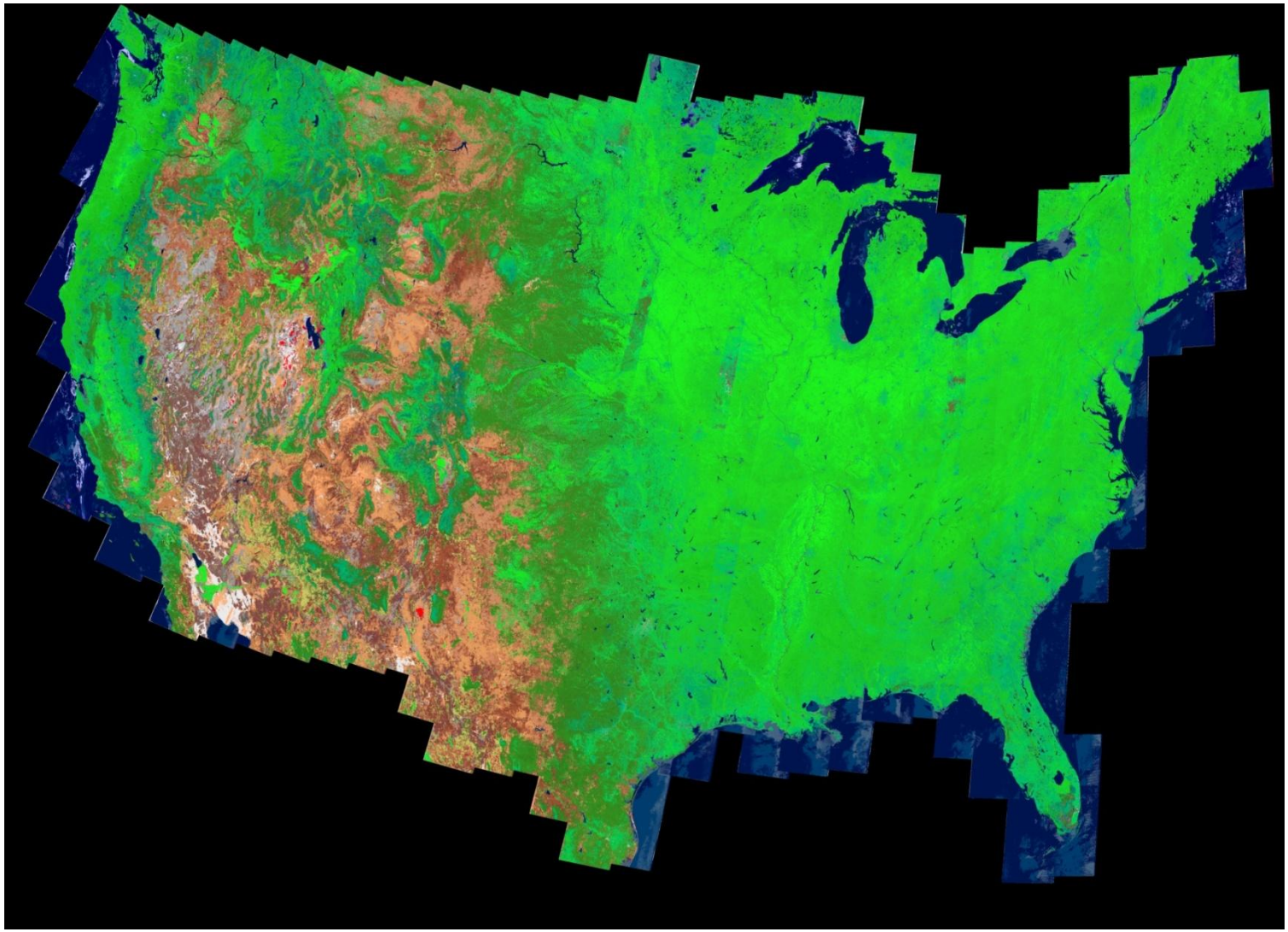
# Example: Web-Enabled Landsat Data (WELD). Year: 2008

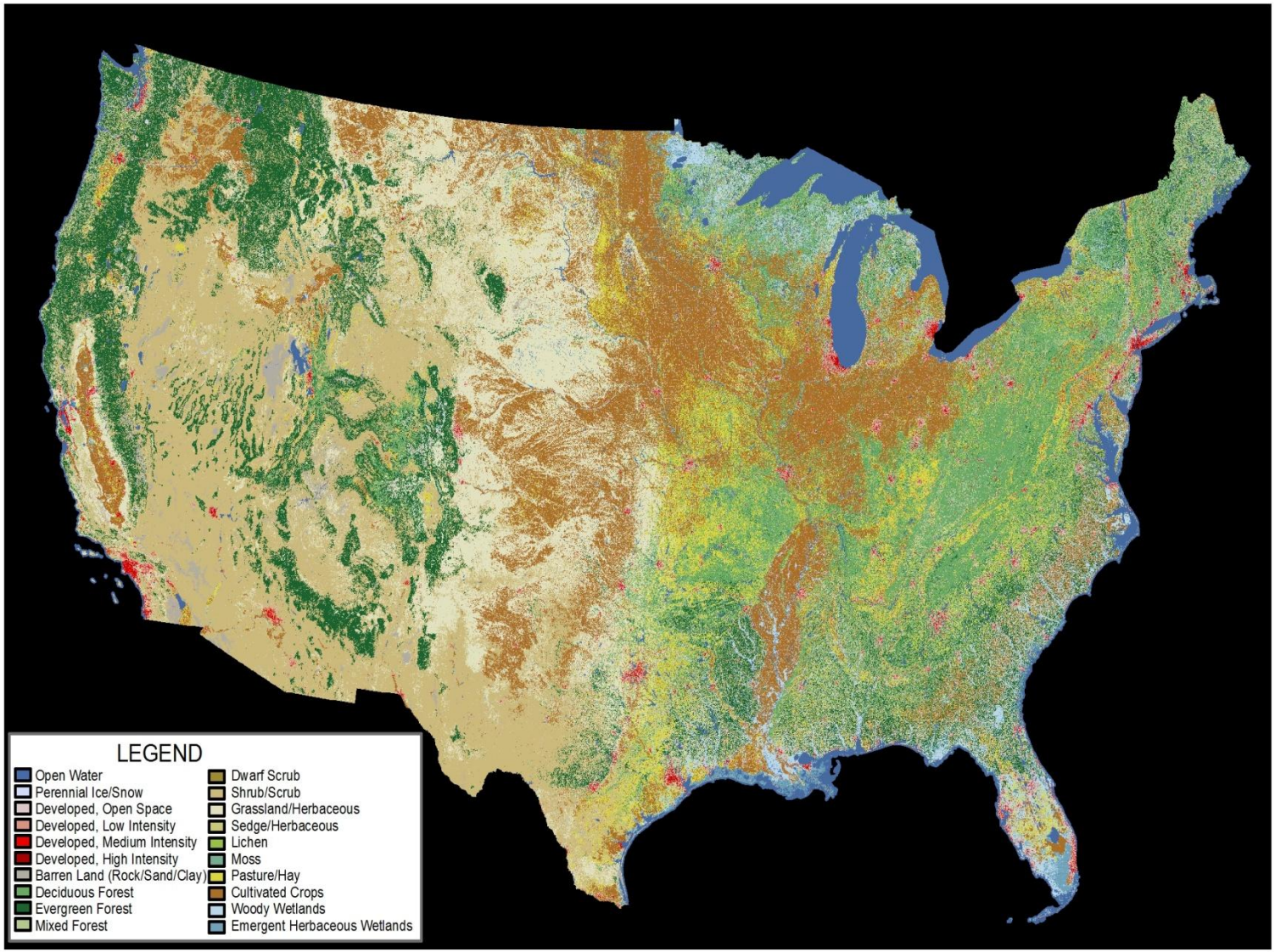


# Example: Web-Enabled Landsat Data (WELD). Year: 2009



# Example: Web-Enabled Landsat Data (WELD). Year: 2009






Reference: NLCD2006 Land Cover Map

# SIAM-NLCD intercomparison

Cross-tabulation of SIAM and NLCD (whole US)

Example: Vegetation and agriculture.

| | Vegetation | Rangeland | Soils | Other |
|---|---|---|---|---|
| **Deciduous forest** | **0.97** | **0.03** | **0.00** | **0.00** |
| **Evergreen forest** | **0.74** | **0.25** | **0.01** | **0.00** |
| **Mixed forest** | **0.96** | **0.04** | **0.00** | **0.00** |
| **Crops** | **0.79** | **0.15** | **0.04** | **0.00** |

# SIAM-NLCD intercomparison

Cross-tabulation of SIAM and NLCD (whole US)

Urban areas: 4 NLCD classes

| | Vegetation | Rangeland | Artificial | Other | Smoke |
|---|---|---|---|---|---|
| **Developed Open Space** | **0.71** | **0.22** | **0.01** | **0.01** | **0.00** |
| **Developed Low Intensity** | **0.65** | **0.25** | **0.06** | **0.06** | **0.00** |
| **Developed Medium Intensity** | **0.37** | **0.38** | **0.14** | **0.14** | **0.04** |
| **Developed High Intensity** | **0.10** | **0.27** | **0.35** | **0.35** | **0.20** |

# SIAM-NLCD intercomparison

What is the correspondence between landcover and SIAM (16 classes vs 95 spectral categories)?

**Deciduous forest: SVVHNIR (0.34)  SHVHNIR (0.29) SVVH1NIR (0.13)**

**Evergreen forest: AVLNIR(0.12) AVMNIR (0.12) SVMNIR(0.12)**

**Mixed forest: SVHNIR(0.42) SVVHNIR(0.21) AVMNIR(0.12)**

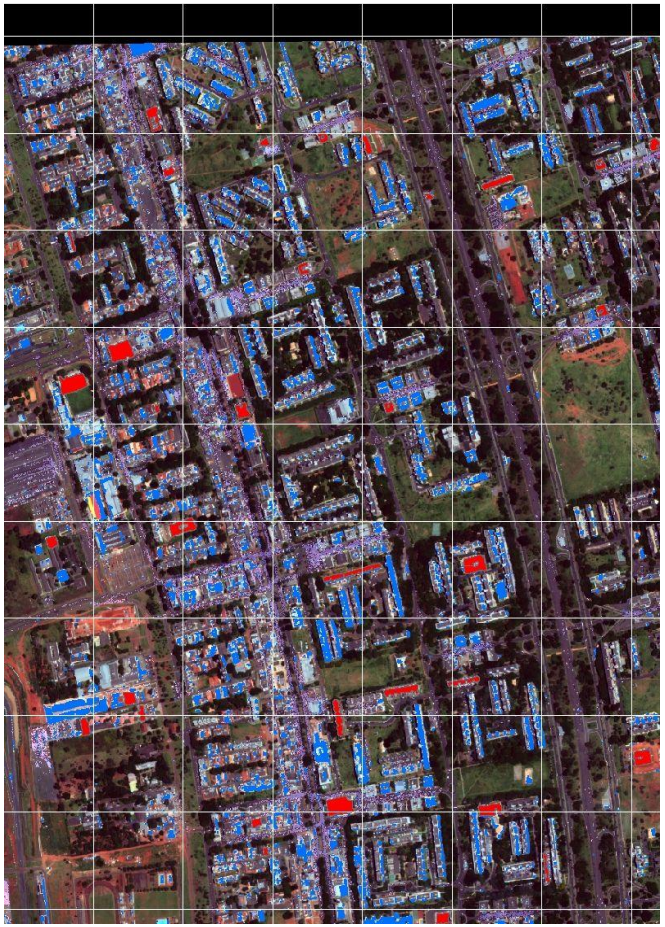
**Crops: SVVHNIR(0.20) SVVH1NIR(0.16) AVHNIR(0.15)**

# Evaluation on Very High Resolution

**Areal estimates**

- Visual interpretation of points extracted using a stratified random sampling within a regular grid
- 6 macroclasses:
  - Water
  - Tree crowns
  - Grass
  - Soil
  - Light artificial surfaces
  - Dark artificial surfaces

# Evaluation on Very High Resolution



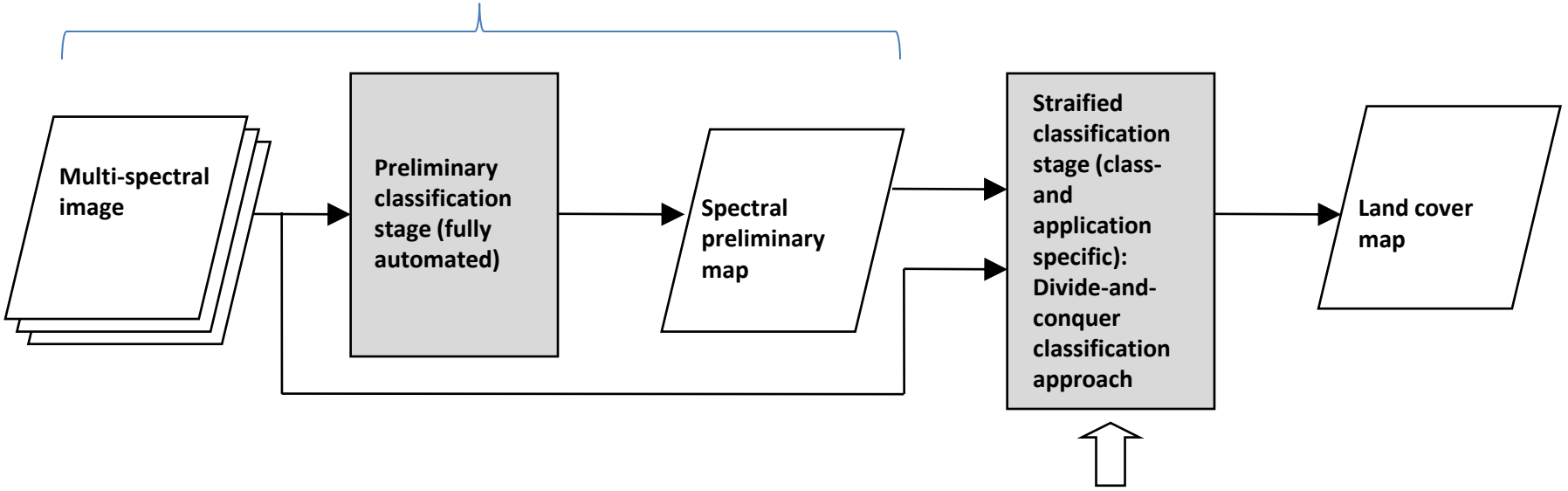
- Visual interpretation of points extracted using a stratified random sampling within a regular grid
- Visual interpretation and digitization of the object including the point (building, road, tree crown…)
- Evaluation of the accuracy in extracting the contour of the object

(M. Humber)

# Development of 2nd-stage LCLU Classification System

# 2-stage LCLU Classification System

**First stage**: Spectral Rule Classifier (fully implemented)




**Second Stage**:
Traditional techniques (image clustering, segmentation, supervised classification algorithms ) are employed here

# Second-stage stratified LCLU classification

**The second stage classifier produces a land cover classification**

Hierarchical land cover classification system using:

i) the **original data** (i.e. the multispectral TOA reflectance)

ii) the **preliminary classification**

iii) image **features from additional information domains**, e.g.,

– **Texture**.

– **Geometric attributes** (area, perimeter, compactness, straightness of boundaries, elongatedness, rectangularity, number of vertices, etc…)

– **Morphological attributes** of objects, bright objects of known shape and size which are located in a darker background or vice versa.

– **Color/Brightness** attributes of objects.

– **Spatial relationships** between objects (e.g., distance, angle/orientation, adjacency, inclusion, etc.).

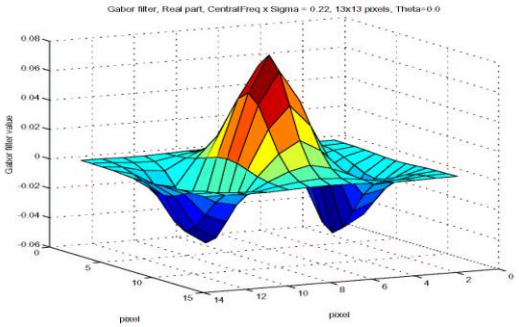
# Forest-Non Forest prototype classification

- Input:
  - SIAM classification
  - Multispectral data
- Stratification based on SIAM (i.e. selection of all the vegetation classes)
- Extraction of additional features:
  - Brightness
  - Texture

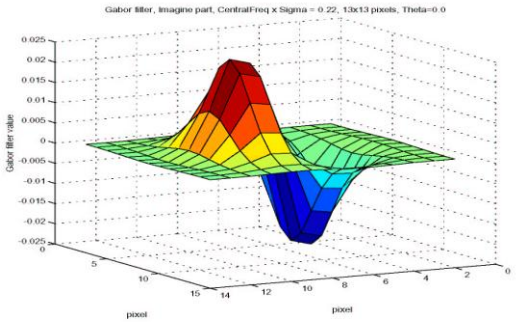
# Texture measures

- **Gabor wavelets = Gaussian function (spread, σ) modulated by a complex sinusoid (freq., f).**

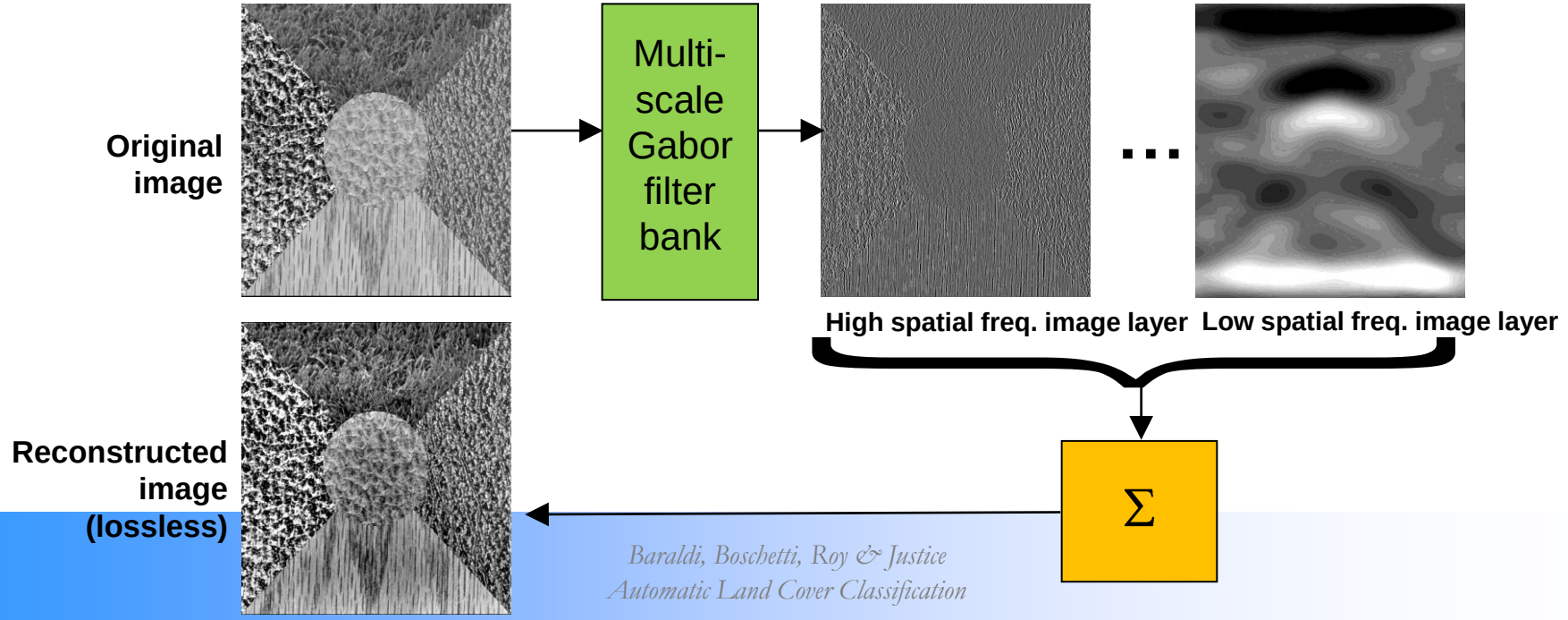
**Even-symm.**

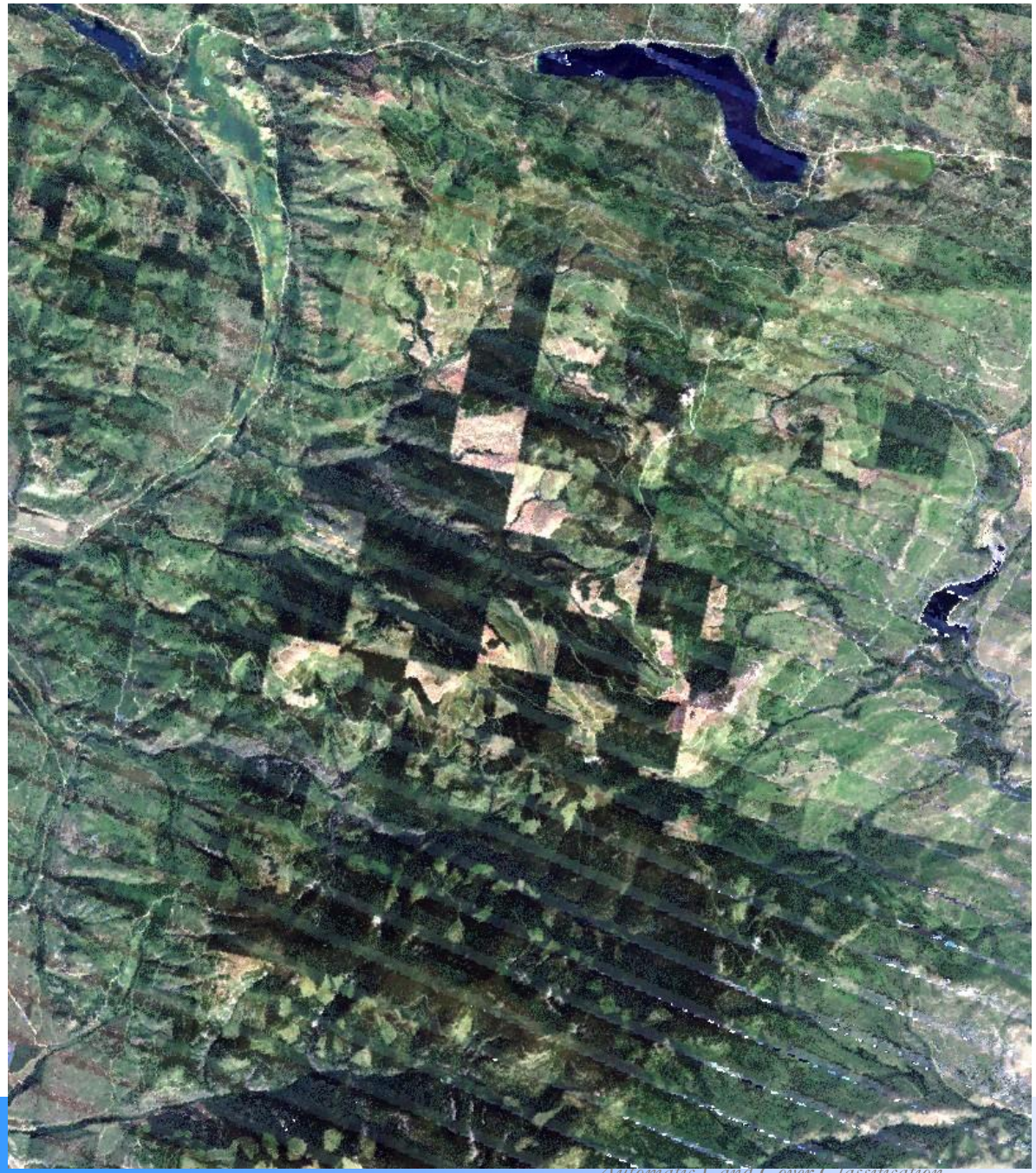



**Odd symm.**

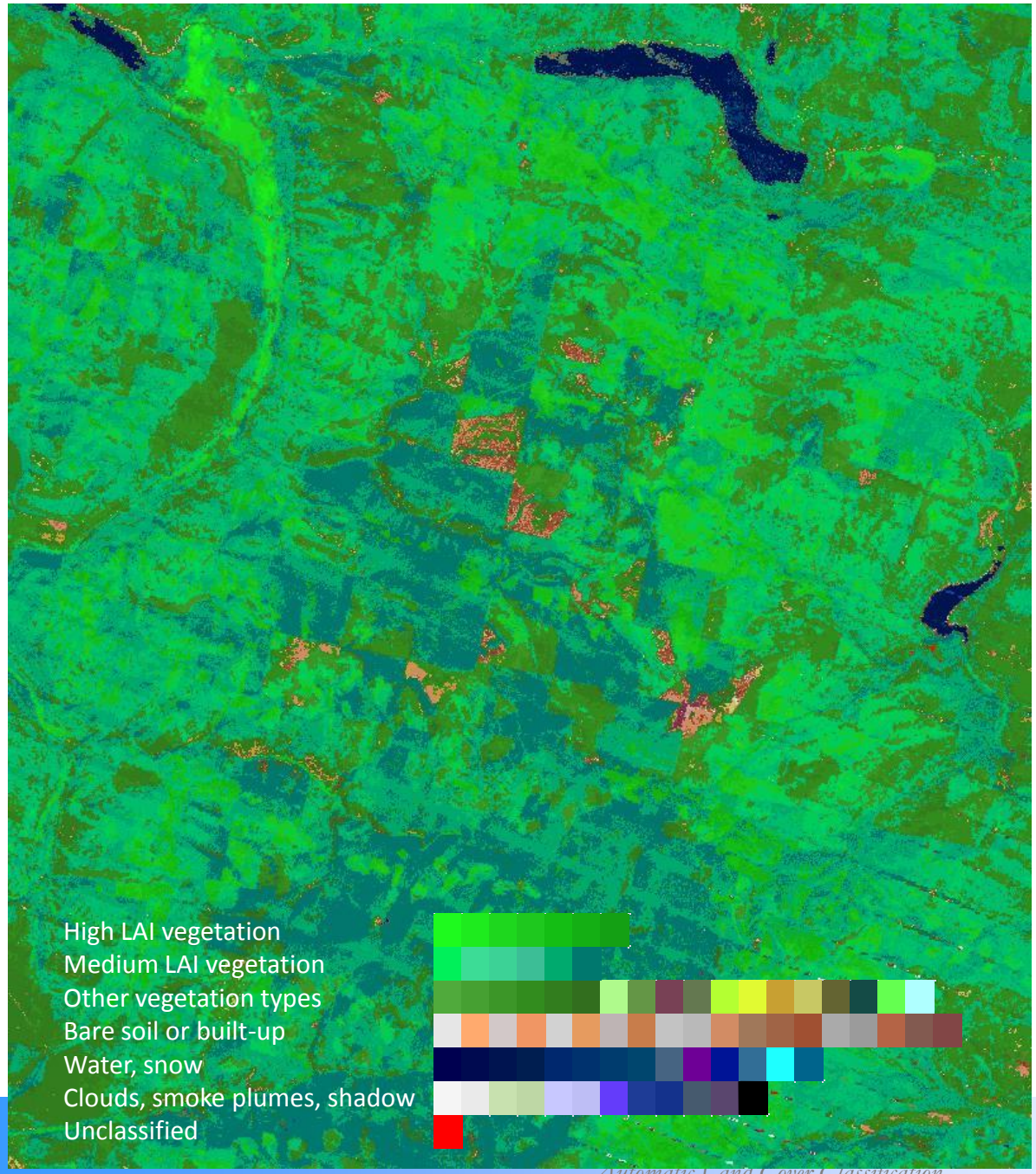



- **Near-orthogonal multi-scale (e.g., 7-scale) Gabor wavelet-based image decomposition.**

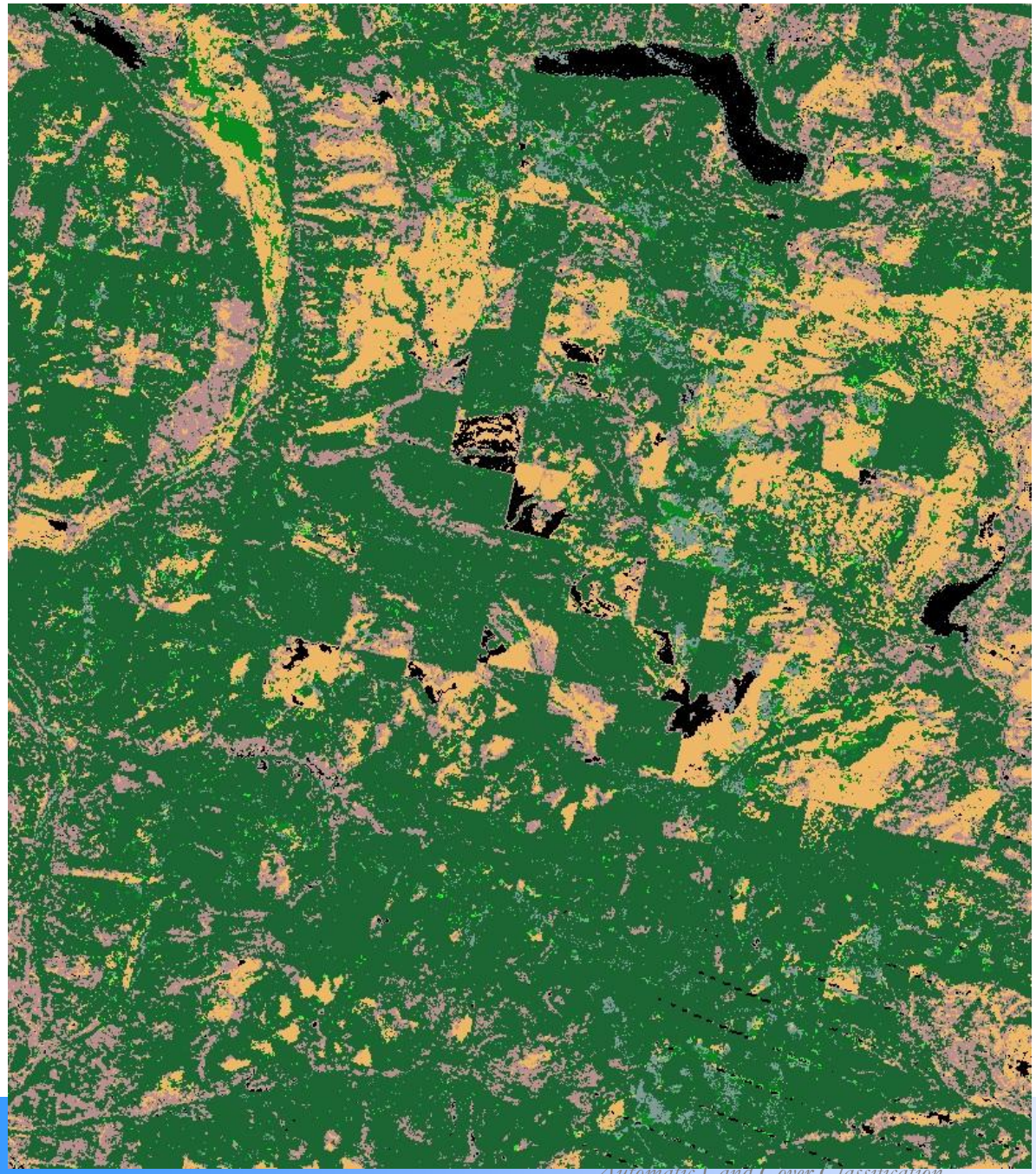




WELD
Tile h07v02,
2007 yearly composite
True Color RGB




SIAM™ preliminary classification: spectral categories

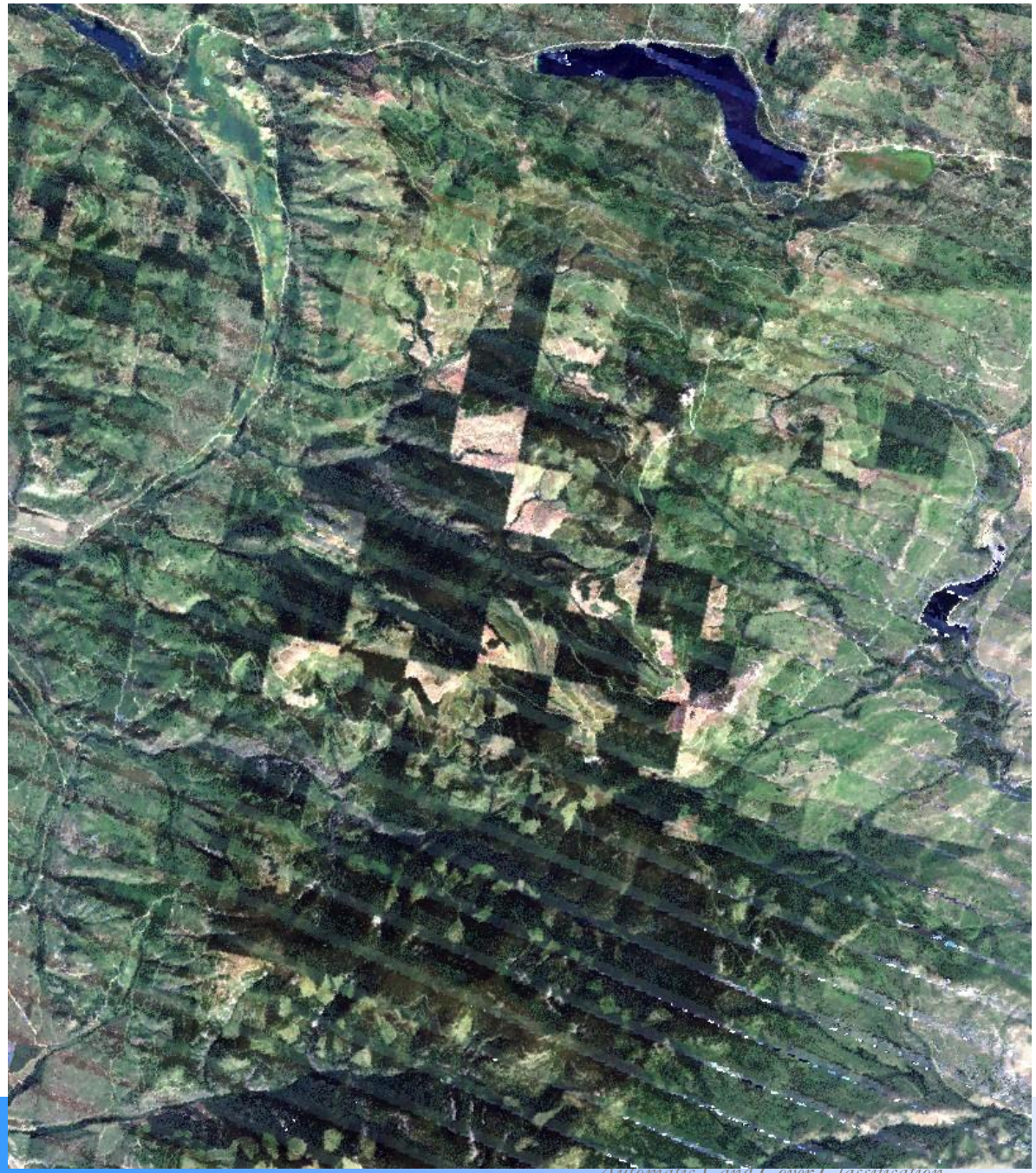


Automatic two-stage land cover classification system.
It employs:
(i) SIAM™ as its preliminary classification first stage and
(ii) a second-stage battery of stratified context-sensitive class- and application-specific rule-based classifiers.

**Forest**
**Croplands, Pasture, Grasslands**
**Shrubland**
**Unclassified vegetation**
**Non-vegetation classes**

Reference dataset:
NLCD 2006

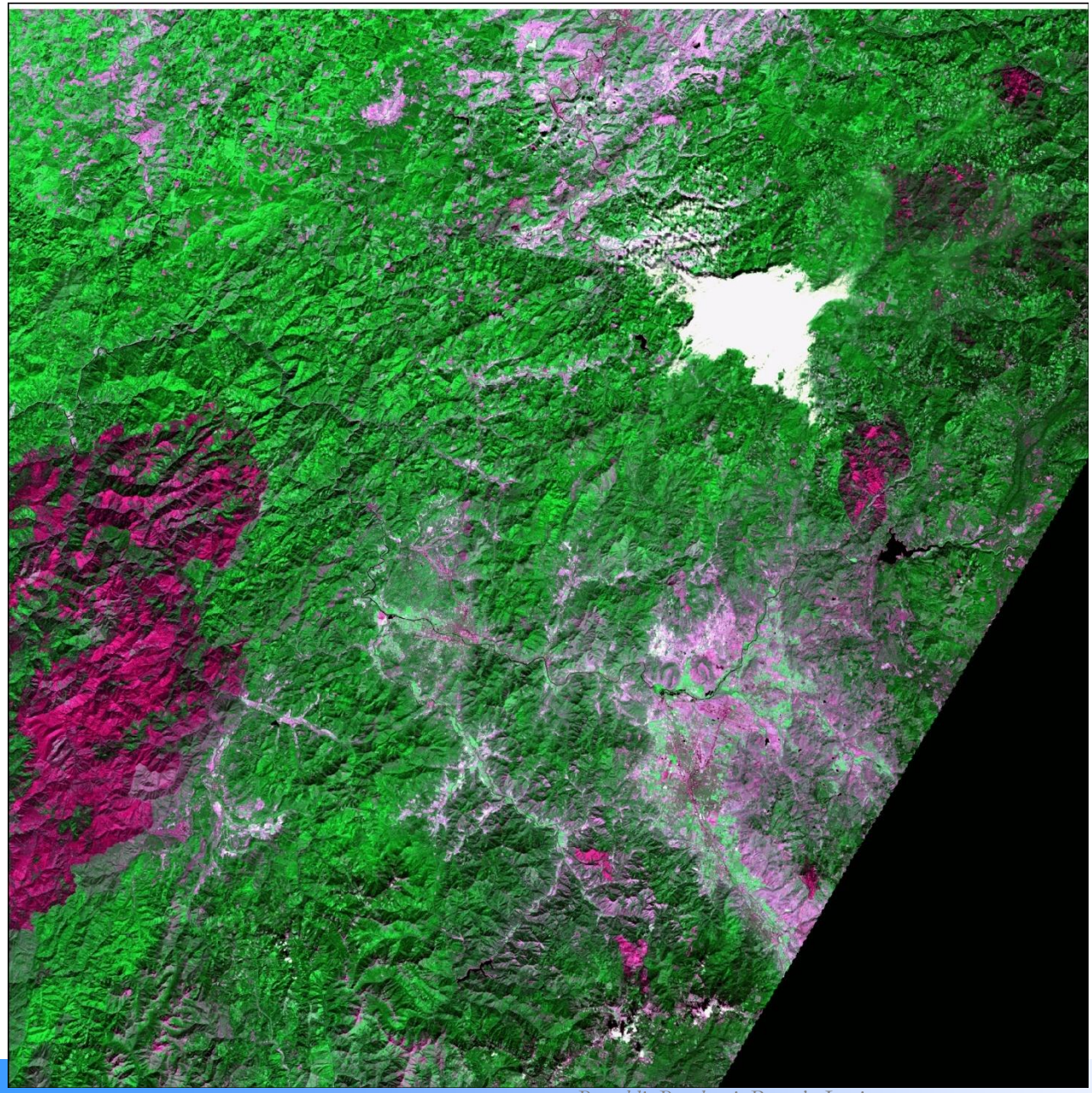
**Evergreen Forest**
**Shrub**
**Grassland**



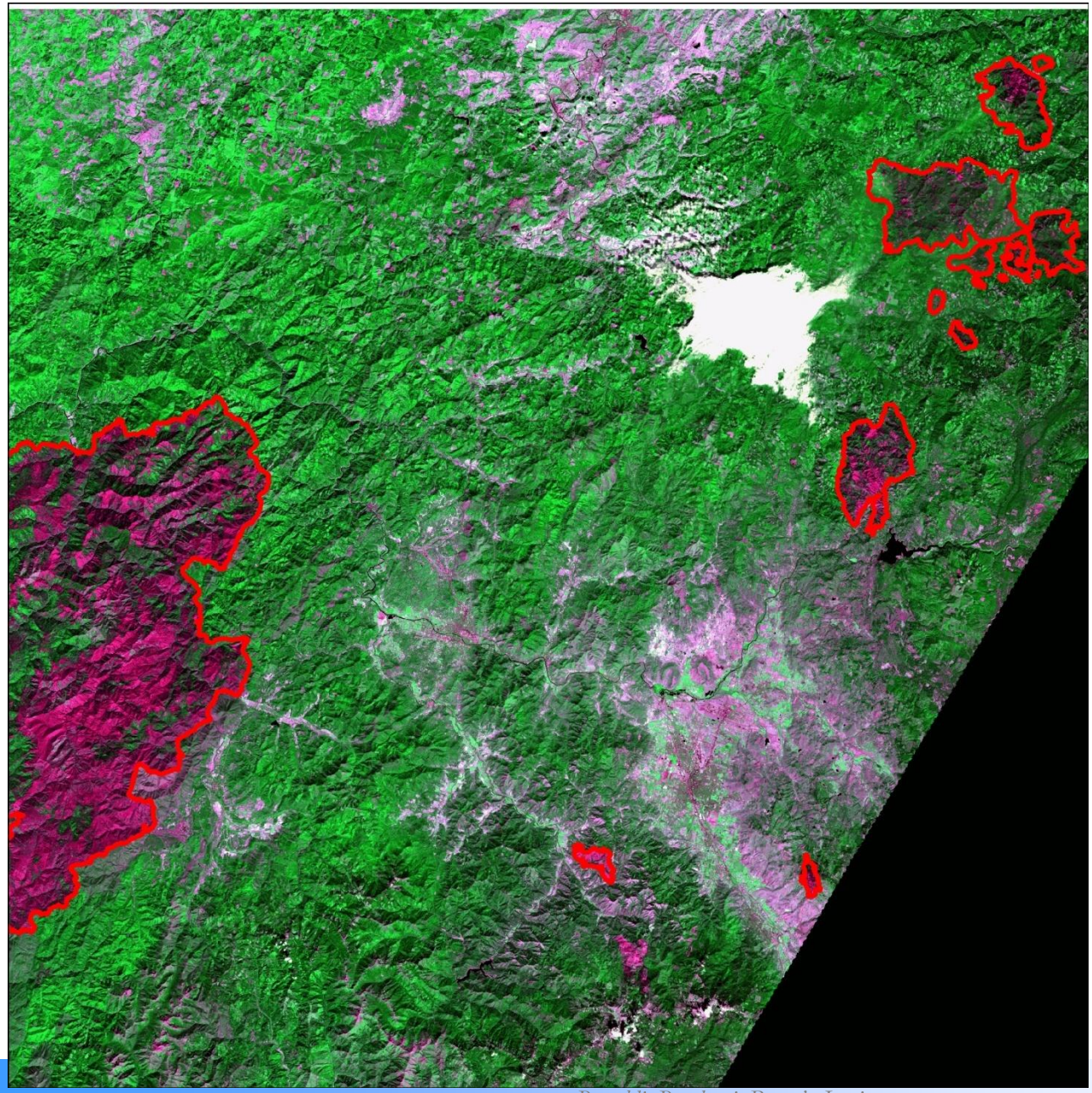
WELD
Tile h07v02,
2007 yearly composite
True Color RGB

# Multitemporal burned area detection through data fusion with MODIS

- Input:
  - Time series (1 year) of SIAM classification
  - Multispectral data
- Identification of candidate burned areas through rules based on the temporal effects of fire on vegetation (transition between SIAM classes)
- Contextual rules in the space and time domain
- Convergence of evidence: data fusion with MODIS fire products

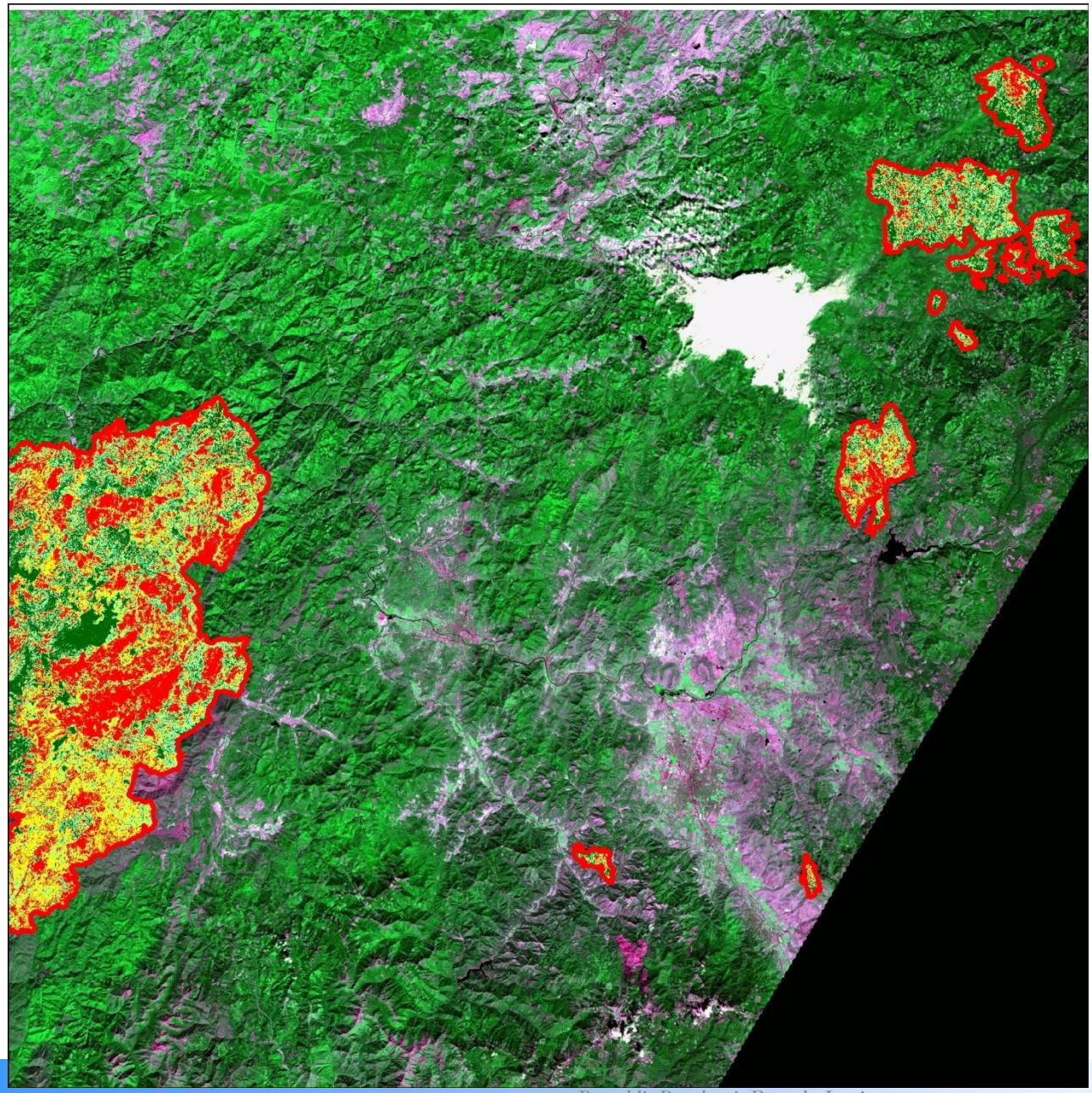


Post_fire image:
Tile h02v05,
2002 week 35,
745 composite



Post_fire image:
Tile h02v05,
2002 week 35,
745 composite

RED: MTBS
polygons
(plenty of
unburned
islands)



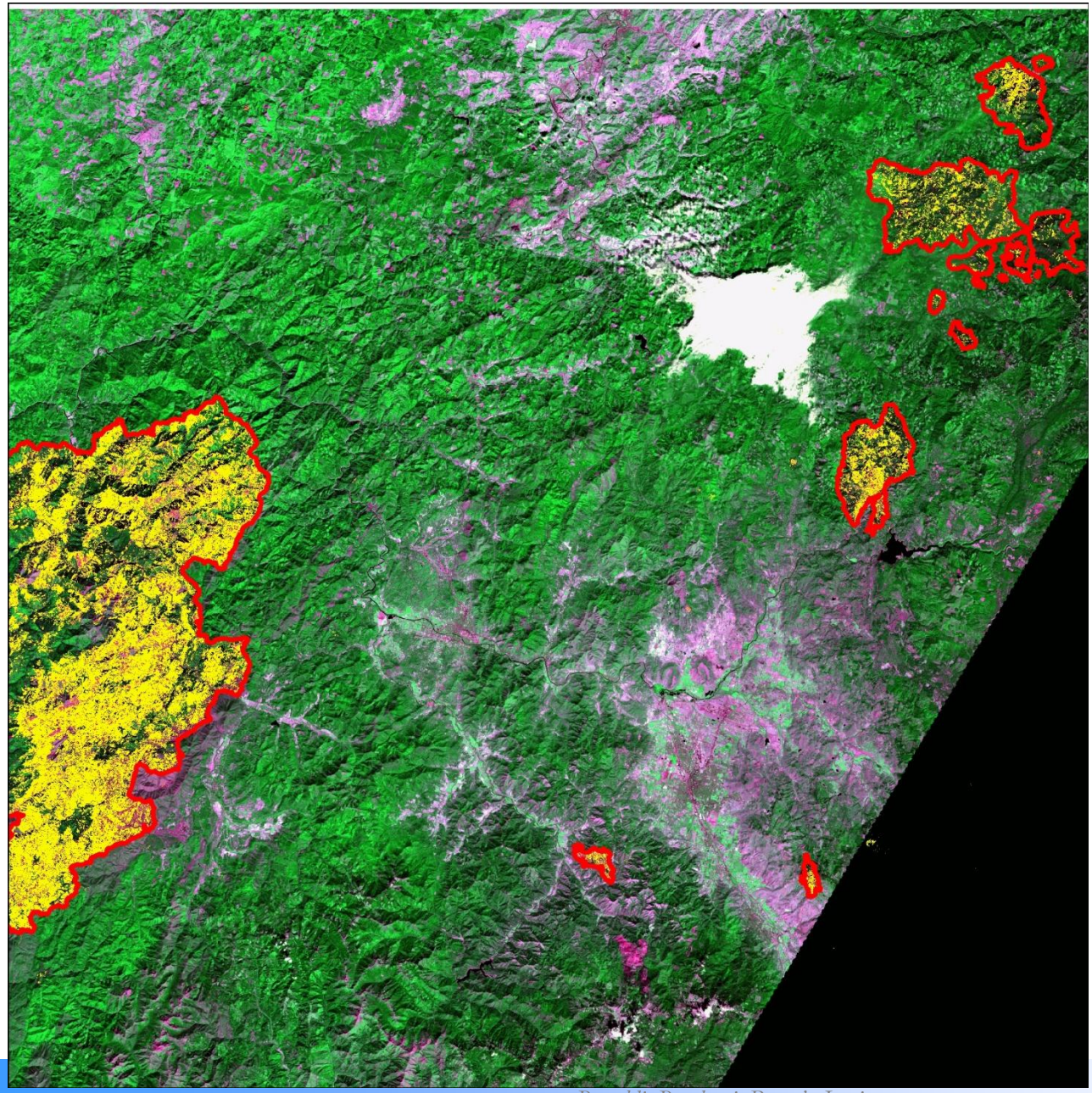
Post_fire image:
Tile h02v05,
2002 week 35,
745 composite

RED: MTBS polygons (plenty of unburned islands)

MTBS severity:

- unburnt to low
- low
- medium
- high

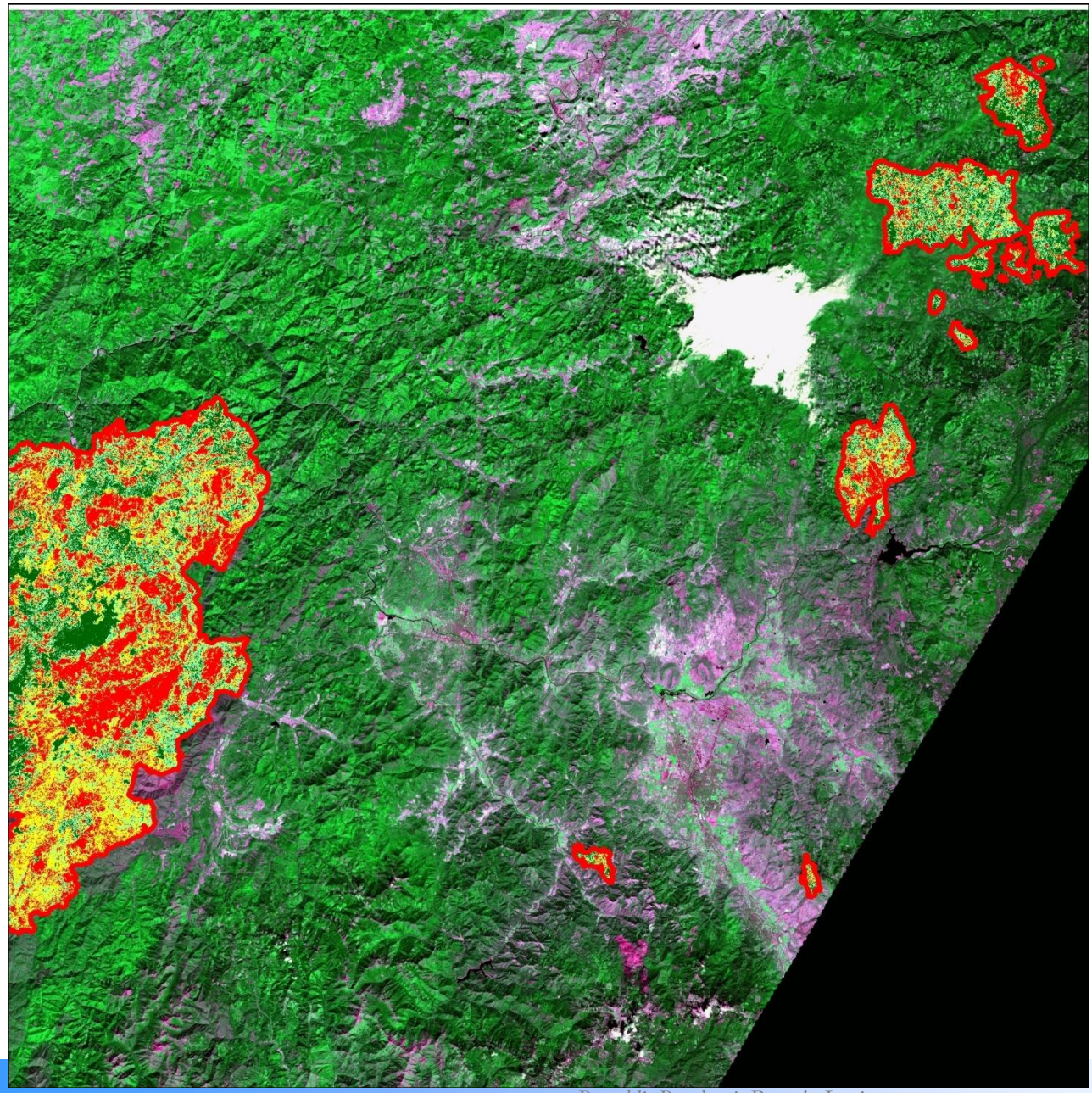
The WELD fire prototype maps all the medium and high, and part of the low serverity MTBS areas



Post_fire image:
Tile h02v05,
2002 week 35,
745 composite

RED: MTBS
polygons
(plenty of
unburned
islands)

Yellow: WELD-
Fire Prototype



Post_fire image:
Tile h02v05,
2002 week 35,
745 composite

RED: MTBS polygons (plenty of unburned islands)

MTBS severity:

- unburnt to low
- low
- medium
- high

The WELD fire prototype maps all the medium and high, and part of the low serverity MTBS areas

# Conclusions

## First stage: SIAM™

- Fully operational
- Sensor-independent
- Completely automated – no training
- Fast processing: can be used for real-time applications
- Systematic evaluation ongoing

## Second Stage

- Semantic information incorporated into LCLU classification from an early stage
- Successful tests for single date (Forest/Non Forest) and multitemporal (Burned area mapping, detection of field boundaries) applications
- Ongoing development for a single date Landcover Classifier for Landsat data; Key classes: Forest, Grassland, Agriculture, Urban, Barren Land, Perennial Snow
- Ongoing development for object recognition from Very High Resolution data