Satellite Image Automatic Mapper™ - SIAM™ -

Landsat 7 ET+ image of Pakistan, in false colors (RGB: 5-4-1). Path: 149, Row: 036, acquisition date: 2001-09-30, Pakistan

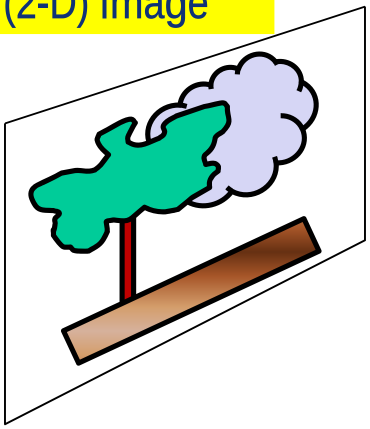
An operational, fully automated, multi-sensor, multi-resolution, efficient and accurate methodology for the (preliminary) classification of radiometrically calibrated remotely sensed images.

Preliminary classification map.

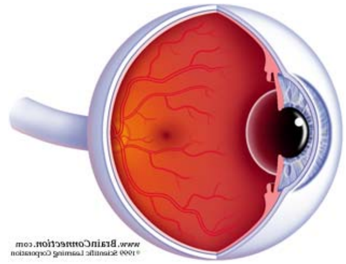
Andrea Baraldi
Research Associate Professor
Department of Geography, University of Maryland
4321 Hartwick Rd, Suite 209, College Park, Maryland, USA 20740,
Tel.: (+1)301-314-1467, Fax: (+1)301-405-6806, Cell.: (+1)240-478-4388, Email: andrea.baraldi@hermes.geog.umd.edu

Inherently ill-posed image understanding problem (vision)

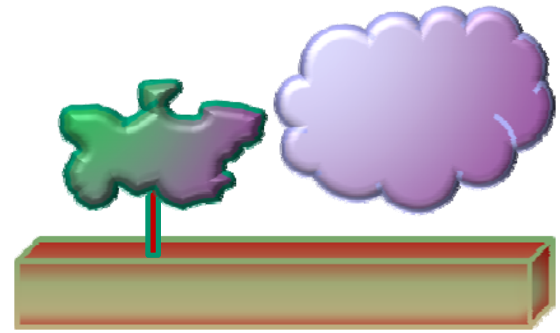
(2-D) Image



Imaging sensor



(3-D) World



Information gap (between physical and semantic information)

Physical information/ continuous variables: Sensory, quantitative, sub-symbolic (non-semantic), objective, but varying sensations

Semantic information/ categorical variables: Qualitative, symbolic (semantic), subjective, abstract, vague, but stable percepts: (3-D) object-models (concepts)

Imaging understanding system (inducer, e.g., human visual system)

1. Sub-symbolic (2-D) image features: points and regions / region boundaries

2. Color-based (2-D) semi-concept

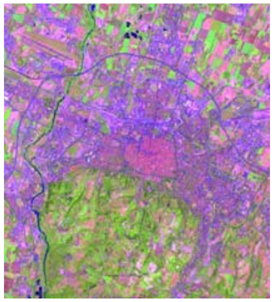
3. Plausible symbolic structural description(s) of the (3-D) scene

Context-insensitive (color)

Context-sensitive (e.g., texture, geometry, morphology)

Spaceborne EO data products taxomomy

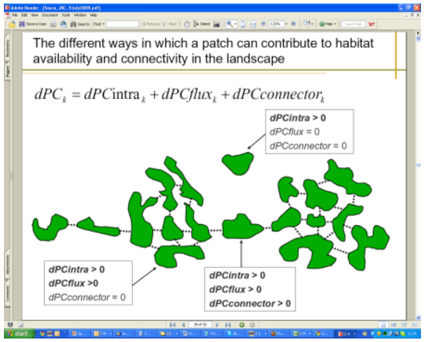
1. Land cover composition (<u>categorical variables</u>, e.g., clouds).



Satellite image

Land cover (LC) map

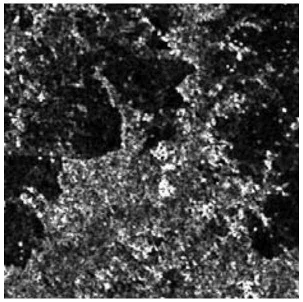
2. Landscape structure (landscape fragmentation/connectivity).



Patch compactness, Patch connectivity, Patch viscosity

3. <u>Continuous variables</u> estimation (e.g., leaf area index).

Satellite image



Greenness index

Four levels of understanding of an information processing system (Marr, 1982)

1. Computational theory (system architecture). According to Marr at this level is the lynch-pin of success of an information processing system!!!

2. Knowledge/information representation (e.g., crisp versus fuzzy reasoning).

3. Algorithm (module) design.

4. Implementation.

Preliminary spectral rule-based image classification: Summary of operational properties

Symbolic pixels in symbolic segments in symbolic strata

QuickBird-2 MS scene. False color image (R: band 3, G: band 4, B: band 1).

Step 1.

Preliminary classification map, in pseudo colors, generated from the calibrated image. It consists of labeled pixels/segments/strata.

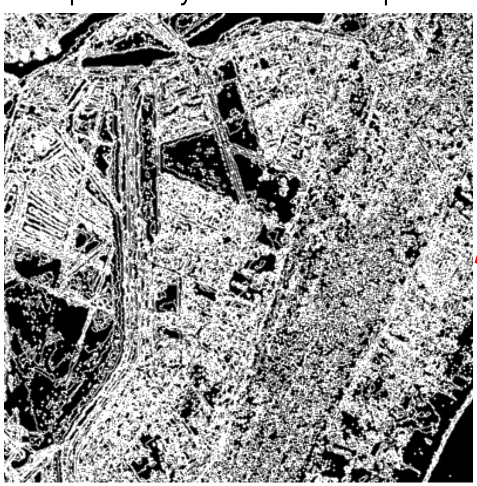
Traditional two-stage segment-based RS-IUS

Novel two-stage stratified RS-IUS

Step 1.

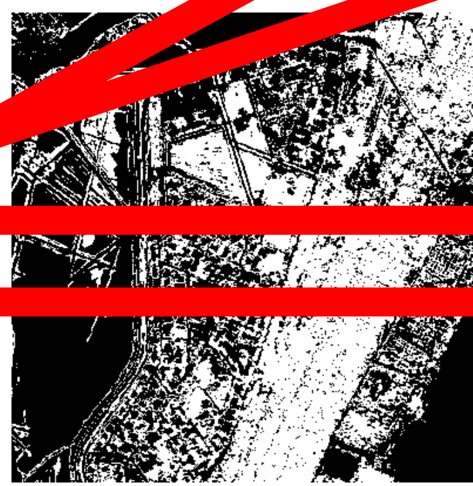
Step 2.

Contour image extracted from the preliminary classification map.



Step 2.

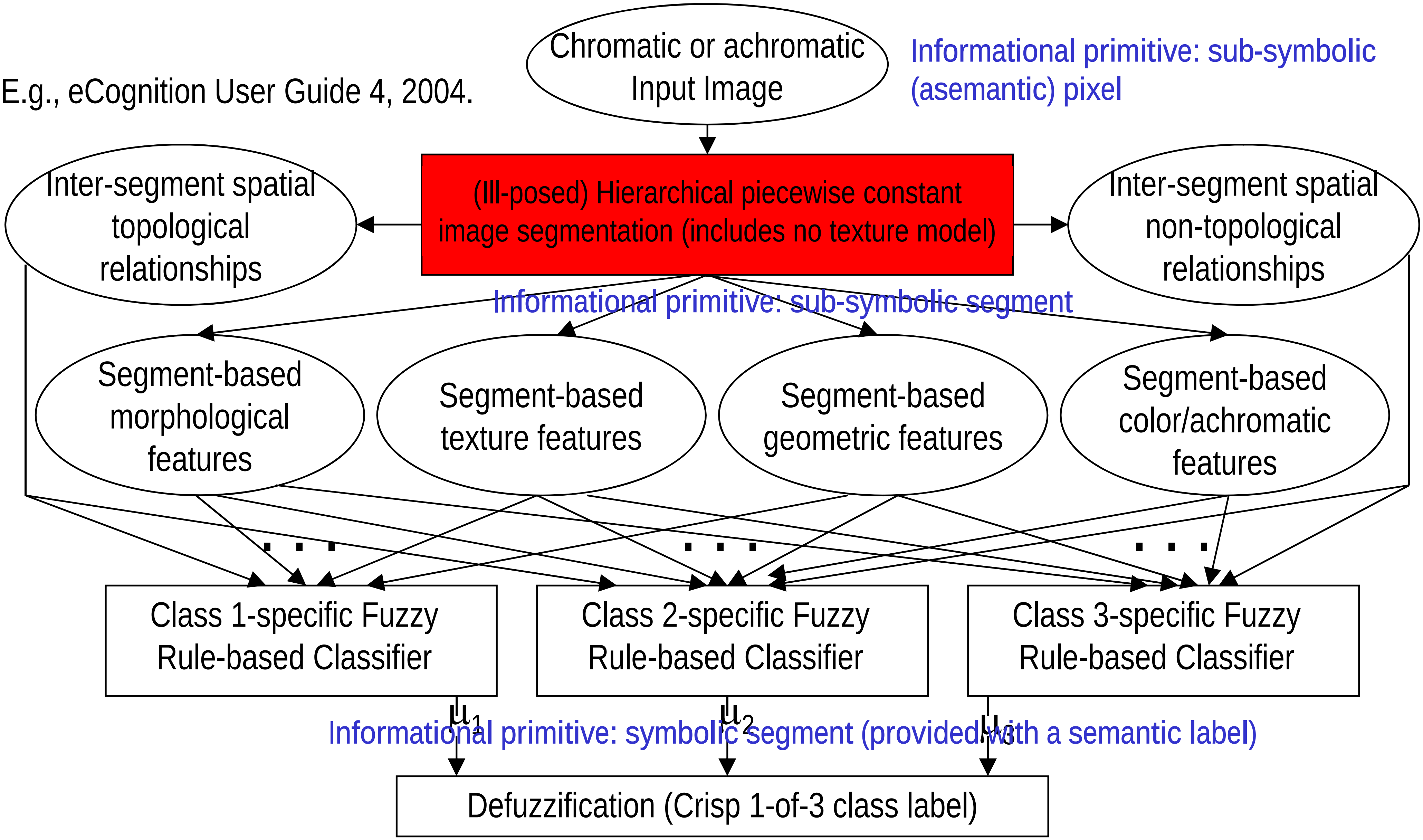
Example of a color-based (e.g., vegetation) stratum extracted from the preliminary classification map.



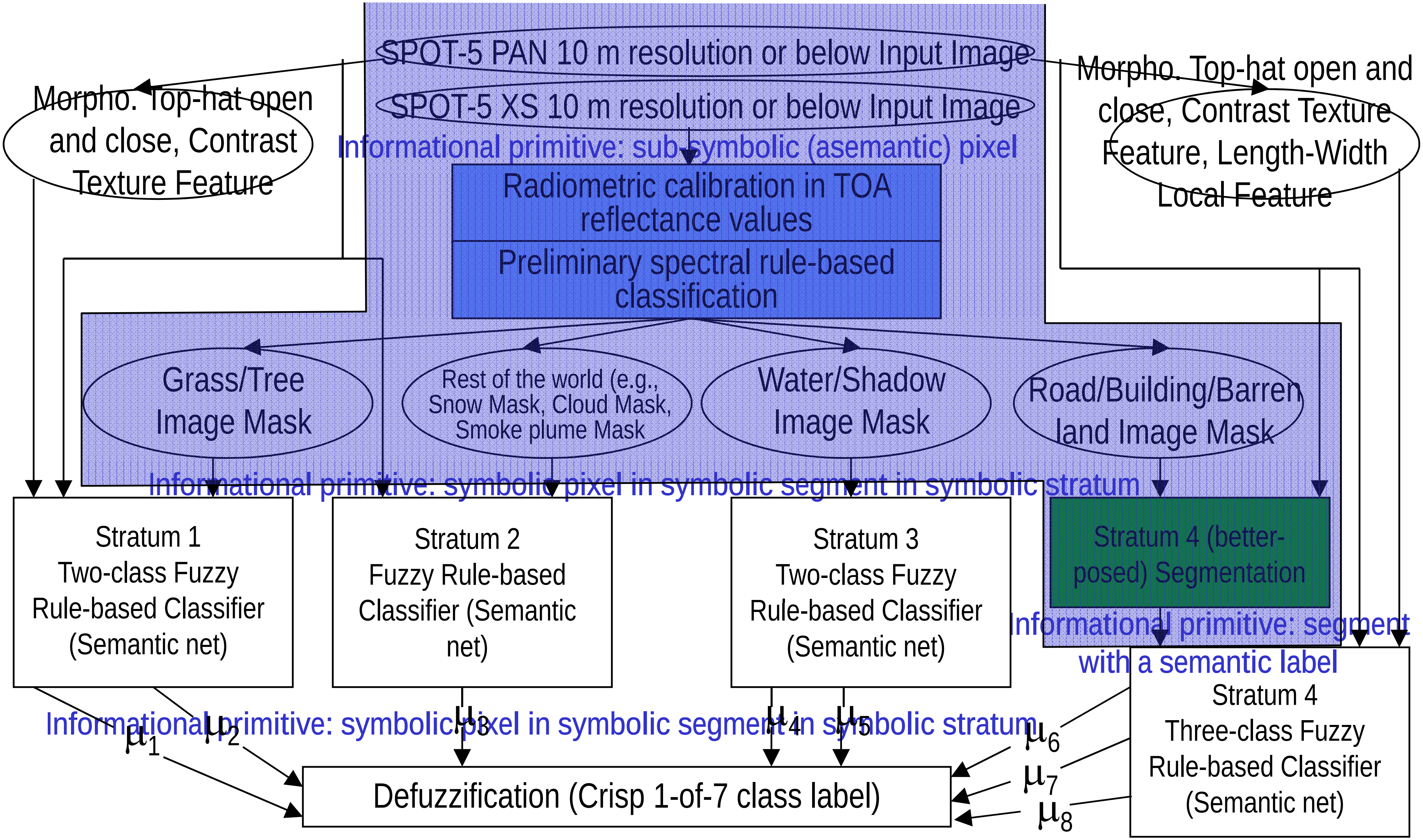
Segment-based piecewise constant image approximation (ENVI: region mean).

Two-stage segment-based RS image undesrtanding system architecture

E.g., eCognition User Guide 4, 2004.



Two-stage stratified hierarchical RS-IUS architecture (Baraldi, 2006-2010)



Four levels of understanding of an information processing system (Marr, 1982)

1. **Computational theory (system architecture).** According to Marr at this level is the lynch-pin of success of an information processing system!!!

2. **Knowledge/information representation** (e.g., crisp versus fuzzy reasoning).

3. **Algorithm (module) design.**

4. **Implementation.**

Preliminary image classification: rationale in computer vision

Simple inferences between surface colors found in nature in the visible portion of the electromagnetic spectrum and semantic classes of 3-D objects in the world.

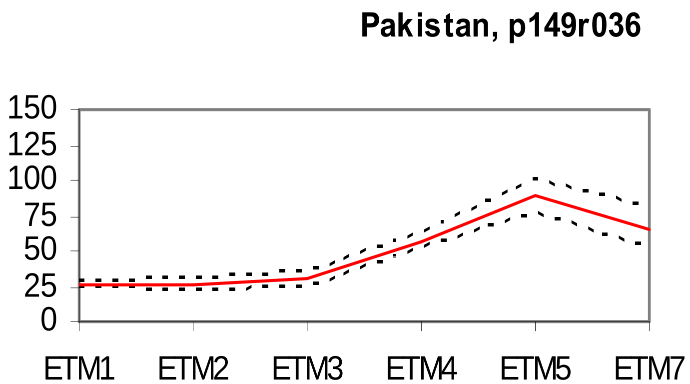
Color in nature	Semantic conjecture
Black	Soil with organic matter, oil.
Gray	Bare exposed rocks, Soil with clay and sand (with gray tones inversely related to soil moisture), Dirty snow.
White	Snow, Ice, Cloud.
Blue	Water.
Light blue	Sky.
Green	Vegetation, Water with green alga.
Brown	Soil with clay and silt, Water with suspended clay, Bricks, House tiles.
Pink	Special rocks (e.g., pink granite).
Red	Soil with iron oxide, Water with red alga, House tiles.

Extension of the GEO-CEOS Quality Assurance Framework for Earth Observation (QA4EO) guidelines to automatic EO data processing

RADIOMETRIC CALIBRATION not only ensures the harmonisation and interoperability of multi-source observational data according to the QA4EO guidelines, but it is A NECESSARY, ALTHOUGH NOT SUFFICIENT, CONDITION FOR AUTOMATING an EO data processing system.

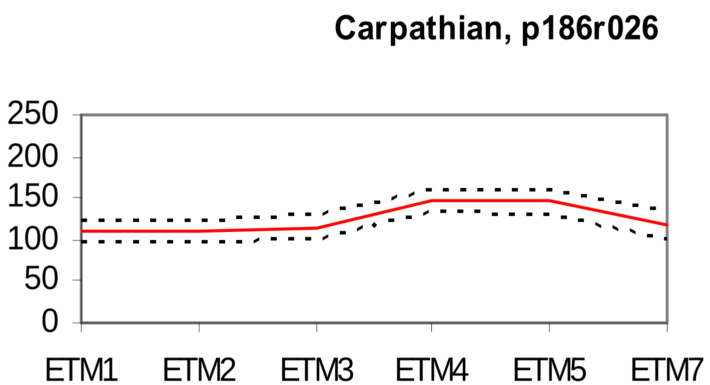
Commercial RS-IUSs	Radiometric calibration requirement
eCognition Server by Definiens AG	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific. Inconsistent with the QA4EO.
PCI Geomatics GeomaticaX	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific. Inconsistent with the QA4EO.
Pixel- and Segment-based versions of the Environment for Visualizing Images (ENVI) by ITT VIS	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific. Inconsistent with the QA4EO.
ERDAS IMAGING Objective	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific.
ERDAS ATCOR3	Surface reflectance, ρ $\Rightarrow$ inherently ill-posed atmospheric correction first stage. Consistent with QA4EO, but semi-automatic and site-specific.
Proposed two-stage stratified hierarchical RS-IUS architecture	Top-of-atmosphere (TOA) reflectance (TOARF) or surface reflectance ρ values, with TOARF $\supseteq \rho \Rightarrow$ atmospheric correction is optional. Consistent with QA4EO. Fully automated (no user-defined parameter, no training sample).

Reference dictionary of spectral signatures in top-of-atmosphere (TOA) reflectance (not surface reflectance!) values



Expose bare rock

Subset_Pakistan_p149r036_01	Min	Max	Mean	StDev
ETM1	23	29	25.68	1.61
ETM2	22	30	25.40	1.72
ETM3	25	35	30.18	2.27
ETM4	53	62	57.05	2.23
ETM5	76	99	88.07	3.07
ETM7	52	80	64.28	5.48
ETM62	131	133	132.30	0.77



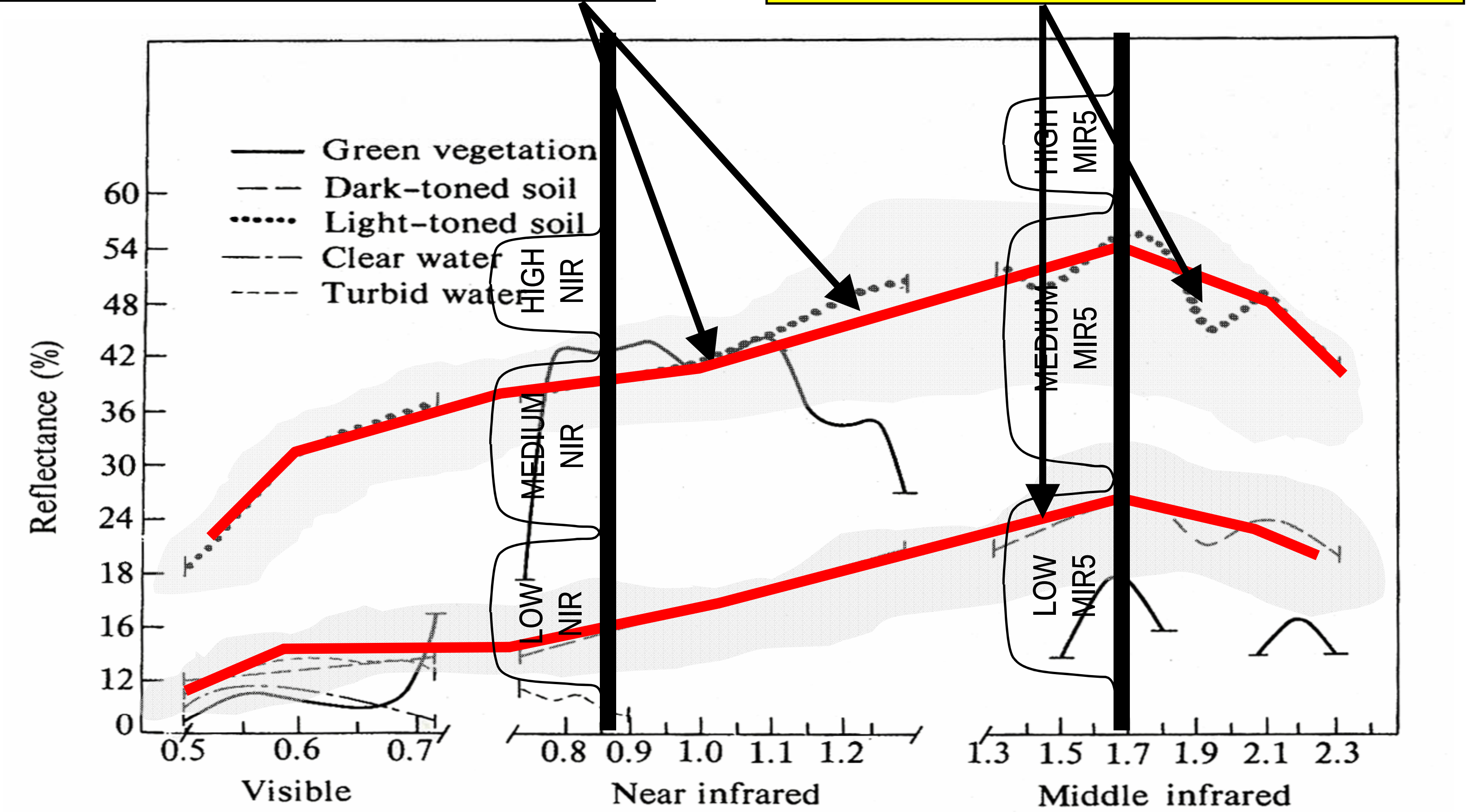
Thick cloud (cumulus)

Subset_Carpathian_p186r026	Min	Max	Mean	StDev
ETM1	95	122	110.70	5.40
ETM2	94	120	109.09	5.23
ETM3	99	128	114.74	6.01
ETM4	131	158	146.46	5.18
ETM5	129	159	145.38	6.32
ETM7	99	131	117.35	6.69
ETM62	104	105	104.21	0.41

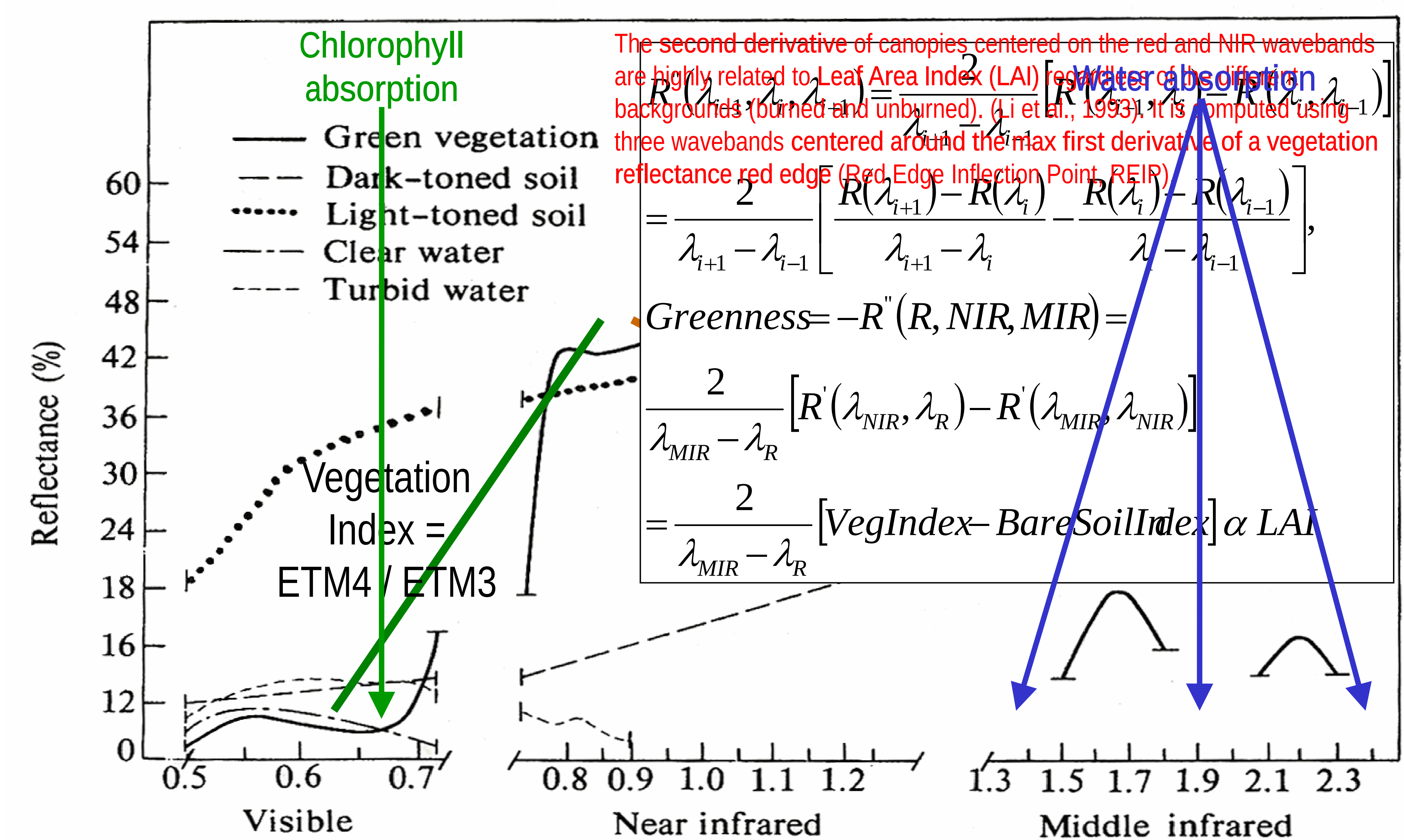
Rule-based system implementation

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., *<u>Bright</u> Barren Land* and *<u>Dark</u> Barren land* .



Operational system properties – Greenness ∝ Leaf Area Index (LAI)



The second derivative of canopies centered on the red and NIR wavebands are highly related to Leaf Area Index (LAI) regardless of the different backgrounds (burned and unburned). (Li et al., 1993). It is computed using three wavebands centered around the max first derivative of a vegetation reflectance red edge (Red Edge Inflection Point, REIP).

$$R''(\lambda_{i-1}, \lambda_i, \lambda_{i+1}) = \frac{2}{\lambda_{i+1} - \lambda_{i-1}} \left[R'(\lambda_{i+1}, \lambda_i) - R'(\lambda_i, \lambda_{i-1}) \right]$$

$$= \frac{2}{\lambda_{i+1} - \lambda_{i-1}} \left[\frac{R(\lambda_{i+1}) - R(\lambda_i)}{\lambda_{i+1} - \lambda_i} - \frac{R(\lambda_i) - R(\lambda_{i-1})}{\lambda_i - \lambda_{i-1}} \right],$$

$$Greenness = -R''(R, NIR, MIR) = \frac{2}{\lambda_{MIR} - \lambda_R} \left[R'(\lambda_{NIR}, \lambda_R) - R'(\lambda_{MIR}, \lambda_{NIR}) \right]$$

$$= \frac{2}{\lambda_{MIR} - \lambda_R} \left[VegIndex - BareSoilIndex \right] \alpha\ LAI$$

Classification system scalability to other sensors

Scalability of the 7-band Landsat-like rule-based classifier to 4-band NOAA AVHRR and MSG-like: From 95 to 82 output categories!!

Landsat 5 TM and 7 ETM+		AVHRR		MSG	
Band	**Spectral region** (µm)	**Band**	**Spectral region** (µm)	**Band**	**Spectral region** (µm)
1 (B)	0.45-0.52	-	-	-	-
2 (G)	0.52-0.60	-	-	-	-
3 (R)	0.63-0.69	1	0.58-0.68	1	0.6
4 (NIR)	0.76-0.90	2	0.725-1.10	2	0.8
5 (MIR1)	1.55-1.75	3 [3(A)]	1.58-1.64	3	1.6
7 (MIR2)	2.08-2.35	-	-	-	-
6 (TIR)	10.4-12.5	(5+6) [4+5]	[(10.30-11.30) + (11.50-12.50)]	8 OR 9	10.8 OR 12.0

Classification system scalability to other sensors

- Scalability of the Landsat rule-based classifier to SPOT-4 and -5 (done! From 85 to 59 output categories), ASTER (done! 85 categories) and MODIS (done! 85 categories).

Landsat 5 TM and 7 ETM+ band	Landsat spectral region (μm)	SPOT-4 and -5 band	SPOT-4 and -5 spectral region (μm)	ASTER band	ASTER spectral region (μm)	MODIS band	MODIS spectral region (μm)
1 (B)	0.45-0.52	-	-	-	-	(3 + 10)	[(0.459 – 0.479) + (0.483 – 0.493)]
2 (G)	0.52-0.60	1	0.50-0.59	1	0.52-0.60	(11 + 4)	[(0.526 – 0.536) + (0.545 – 0.565)]
3 (R)	0.63-0.69	2	0.61-0.68	2	0.63-0.69	(1 + 14)	[(0.620 – 0.670) + (0.673 – 0.683)]
4 (NIR)	0.76-0.90	3	0.79-0.89	3	0.76-0.86	(15 + 2 + 17) OR (15 + 16 + 17)	[(0.743 – 0.753) + (0.841 – 0.876) + (0.890 – 0.920)] OR [(0.743 – 0.753) + (0.862 – 0.877) + (0.890 – 0.920)]
5 (MIR1)	1.55-1.75	4	1.58-1.75	4	1.600-1.700	6	1.628 – 1.652
7 (TIR)	2.08-2.35	-	-	(5 + 6 + 7 + 8)	[(2.145-2.185) + (2.185-2.225) + (2.235-2.285) + (2.295-2.365)]	7	2.105 – 2.155
6 (MIR2)	10.4-12.5	-	-	(13 + 14)	[(10.25-10.95) + (10.95-11.65)]	(31 + 32)	[(10.780 - 11.280) + (11.770 - 12.270)]

Four levels of understanding of an information processing system (Marr, 1982)

1. **Computational theory (system architecture).** According to Marr at this level is the lynch-pin of success of an information processing system!!!

2. **Knowledge/information representation** (e.g., crisp versus fuzzy reasoning).

3. **Algorithm (module) design.**

4. **Implementation.**

Operational SIAM™ system of systems' properties

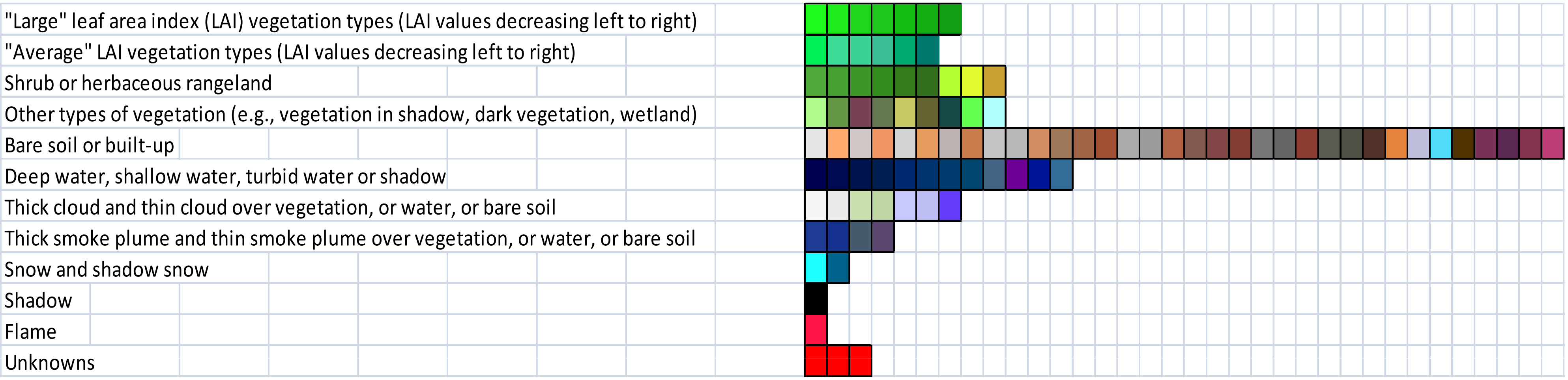
Integrated SIAM™ system of classifiers, v86r3					
SIAM™ module	Bands	Fine information granularity	Intermediate information granularity	Coarse information granularity	% Loss in spectral category discrimination capability
Landsat-like SIAM™	7 (B, G, R, NIR, MIR1, MIR2, TIR)	95	47	18	-
SPOT-like SIAM™	4 (G, R, NIR, MIR1)	68	40	15	30%
AVHRR-like SIAM™	4 (R, NIR, MIR1, TIR)	82	42	16	14%
IKONOS-like SIAM™	4 (B, G, R, NIR)	52	28	12	44%

17

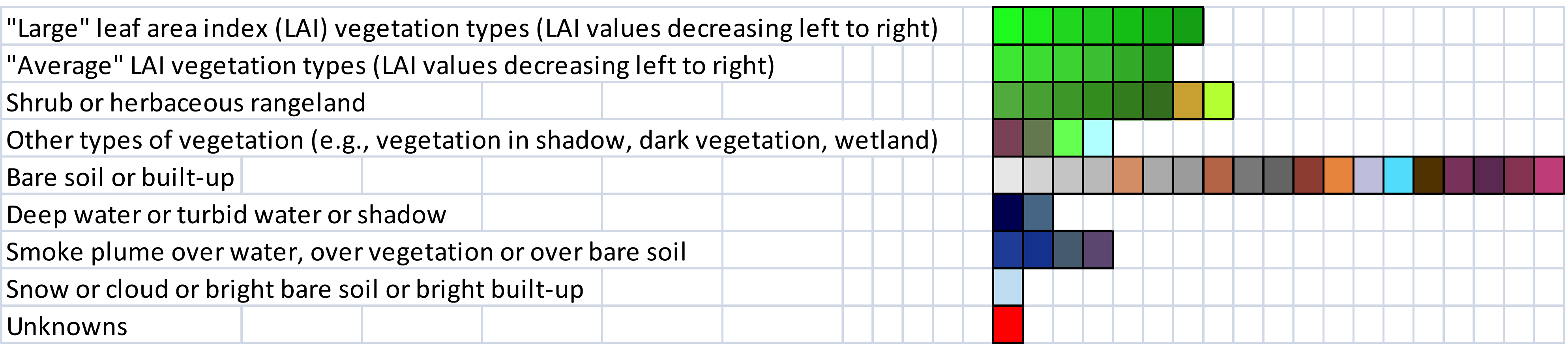
Symbolic (semantic) meaning of spectral categories: Some examples

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).

SIAM™ map legend



Preliminary classification map legend adopted by L-SIAM™. Pseudo-colors of the 95 spectral categories are gathered based on their spectral end member (e.g., bare soil or built-up) or parent spectral category (e.g., "strong" vegetation). The pseudo-color of a spectral category is chosen as to mimic natural colors of pixels belonging to that spectral category.



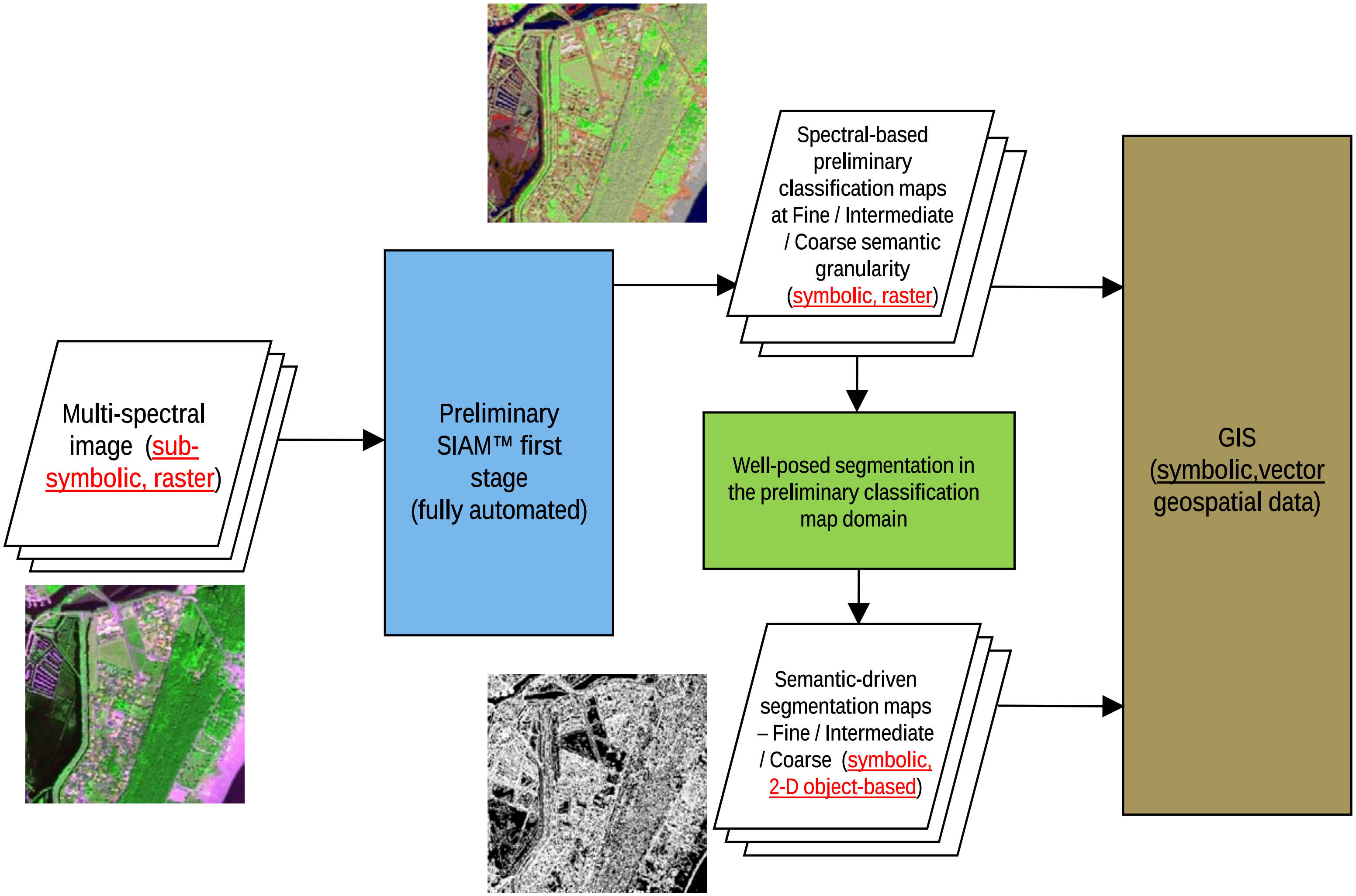
Preliminary classification map legend adopted by I-SIAM™. Pseudo-colors of the 52 spectral categories are gathered based on their spectral end member (e.g., bare soil or built-up) or parent spectral category (e.g., "strong" vegetation). The pseudo-color of a spectral category is chosen as to mimic natural colors of pixels belonging to that spectral category.

SIAM's QIs versus State-of-the-Art RS-IUSs

Legend of fuzzy sets. Very low (VL), Low (L), Medium (M), High (H), Very High (VH)

Quality Indicators (Qis)	State-of-the-art RS-IUSs	SIAM™
Degree of automation: (a) number, physical meaning and range of variation of user-defined parameters, (b)collection of the required training data set, if any.	VL, L	VH (fully automatic, it cannot be surpassed)
Effectiveness : (a) semantic accuracy and (b) spatial accuracy.	M, H, VH	VH
Semantic information level	Land cover class (e.g., *deciduous forest*)	Spectral semi-concept (e.g., *vegetation*)
Efficiency: (a) computation time and (b) memory occupation.	VL, L in training (hours per images)	VH (5 m to 30 s per Landsat image in a laptop)
Robustness to changes in input image	VL (specific training per image)	VH
Robustness to changes in input parameters	VL	VH (it cannot be surpassed)
Scalability to changes in the sensor's specifications or user's needs.	VL	VH (it works with any existing spaceborne sensor)
Timeliness (from data acquisition to high-level product generation, increases with manpower and computing power).	VH (e.g., the collection of reference samples is a difficult and expensive task)	VL
Economy (inverse of costs, increasing with manpower and computing power).	VL, L, high costs in manpower and also computing power	VH, almost zero costs

Seamless integration of RS imagery with GIS through SIAM™



Application domains 1 and 2.

Baseline map generation / ROI extraction from Landsat 7 ETM+ imagery. Example b: Pakistan.

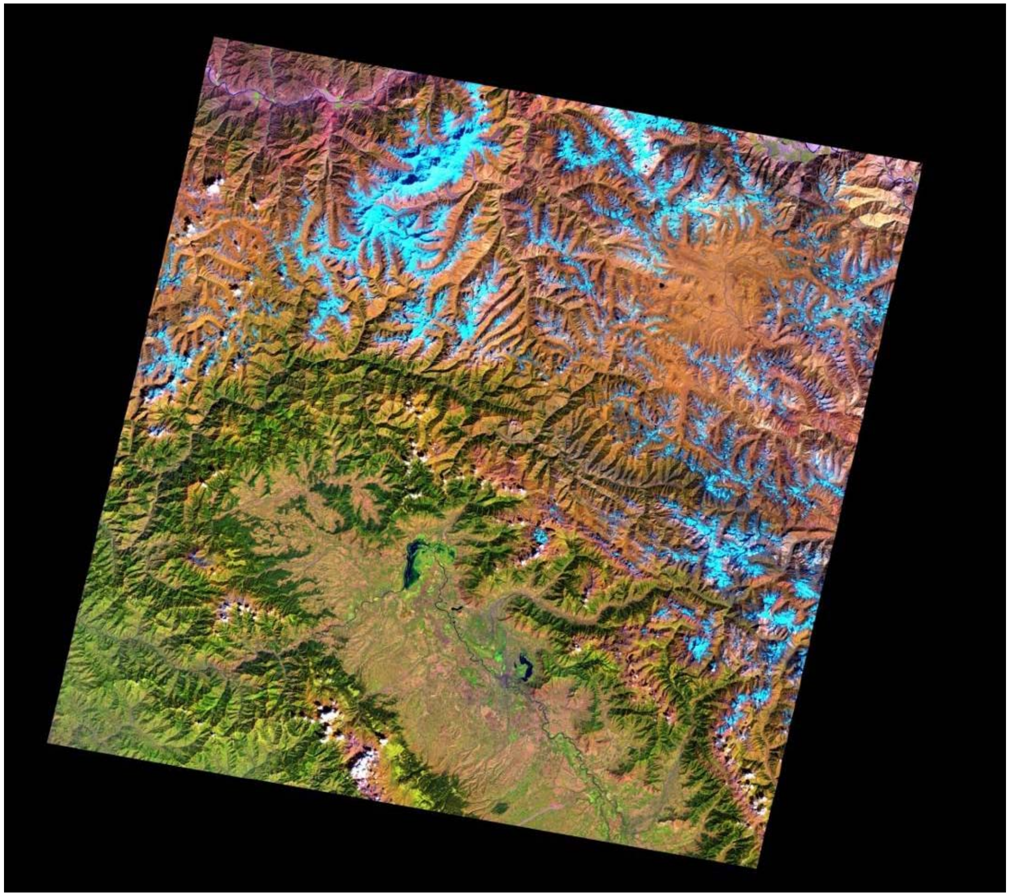


Fig. A. Landsat 7 ETM+ scene. False color image (R: band TM5, G: band TM4, B: band TM1). Path: 149, Row: 036, acquisition date: 2001-09-30, Pakistan.

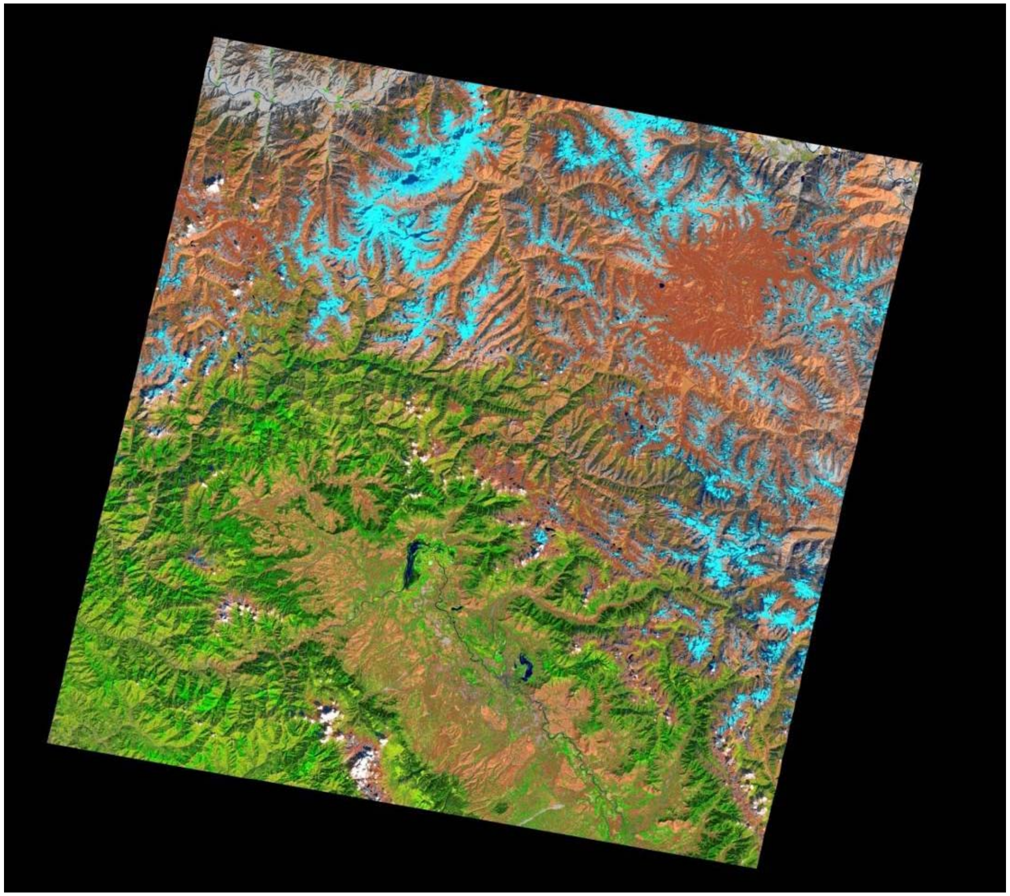


Fig. B. Output map generated from Fig. A, consisting of 45 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White tones: clouds, Light blue tones: snow and ice, etc.

Zoomed area. Example b: Landsat 7 ETM+, Pakistan.

Fig. C. Zoomed area extracted from Fig. A. False color image (R: band TM5, G: band TM4, B: band TM1). Path: 149, Row: 036, acquisition date: 2001-09-30, Pakistan.

Fig. D. Zoomed area extracted from the 45-class output map shown in Fig. B. 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 tones: clouds, Light blue tones: snow and ice, etc.

Example: Web-Enabled Landsat Data (WELD) Project.

Landsat Missions Página 1 de 3

USGS NASA
Landsat Missions

Search This Site

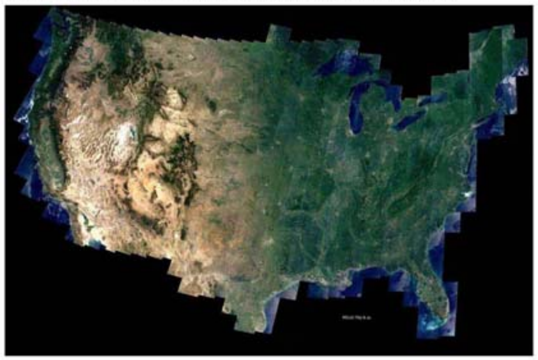
Home | About | Gallery | Products | Science | Tools | Links | Contact

Conterminous United States Landsat ETM+ Annual Mosaic

Web-Enabled Landsat Data (WELD) Project

The Web-Enabled Landsat Data (WELD) project will improve the consistency and quality of Landsat Enhanced Thematic Mapper Plus (ETM+) data through a fusion with MODIS land products to systematically generate "seamless" consistent mosaicked ETM+ data sets with per-pixel quality assessment information and derived land cover characterization at monthly, seasonal, and annual time periods. The resulting high spatial resolution Landsat mosaic products will be generated for the conterminous USA and Alaska for a 7-year period and made freely available to the user community. The WELD project is funded by NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program.

A preliminary WELD data set is available here, specifically, a 12-month annual composite of the conterminous U.S. generated from ETM+ orthorectified and terrain-corrected data acquired December 2007 to November 2008. In the future, other annual, seasonal, and monthly, mosaic data sets will be made available for evaluation by the user community. The large image below shows the ETM+ red, green, and blue wavelength bands of the annual mosaic, please click on it to see a higher-resolution version.



These data are defined with 30m pixels in the Albers Equal Area projection with standard parallels 29.5°N, 45.5°N, latitude of origin 23° N, and central Meridian 96°W. The data are stored in Hierarchical Data Format (HDF) with HDF internal compression. HDF is a data file format designed by the National Center for Supercomputing Applications to assist users in the storage and manipulation of scientific data across diverse operating systems and machines. For example, it is used to store the standard MODIS products. In this version, each pixel has 14 bands (termed HDF science data sets) storing the information described in the Table. Future product versions will have refined processing and content, most notably atmospheric correction, radiometric/BRDF normalization, improved cloud and ETM+ SLC-off gap-filling, and land-cover characterization.

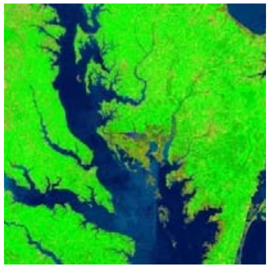
WELD Annual Mosaic Version 1.0 Product Format

Science Data Set Name	Data Type	Valid Range	Scale factor	Units	Fill Value	Notes
Band1_TOA_REF	int16	-32767 -- 32767	10000	unitless	-32768	Top of atmosphere (TO brightness temperatur standard formulae and associated with the se
Band2_TOA_REF	int16	-32767 -- 32767	10000	unitless	-32768	
Band3_TOA_REF	int16	-32767 -- 32767	10000	unitless	-32768	
Band4_TOA_REF	int16	-32767 -- 32767	10000	unitless	-32768	
Band5_TOA_REF	int16	-32767 -- 32767	10000	unitless	-32768	The conventional ETM+ b

http://landsat.usgs.gov/WELD.php 11/01/2010

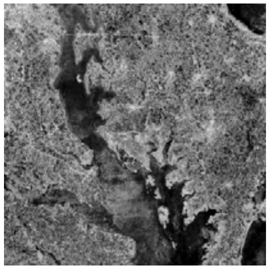
- http://landsat.usgs.gov/WELD.php
- Joint USGS and NASA project
- "Seamless" consistent mosaics of fused Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced TM Plus (ETM+) and MODIS data
- 663 fixed location tiles. Spatial resolution: 30 m.
- USA and Alaska area coverage
- 7-year period coverage
- Weekly, monthly, seasonal and annual coverage
- Top-of-atmosphere reflectance
- Made freely available to the user community.

Input image
In TOA reflectance



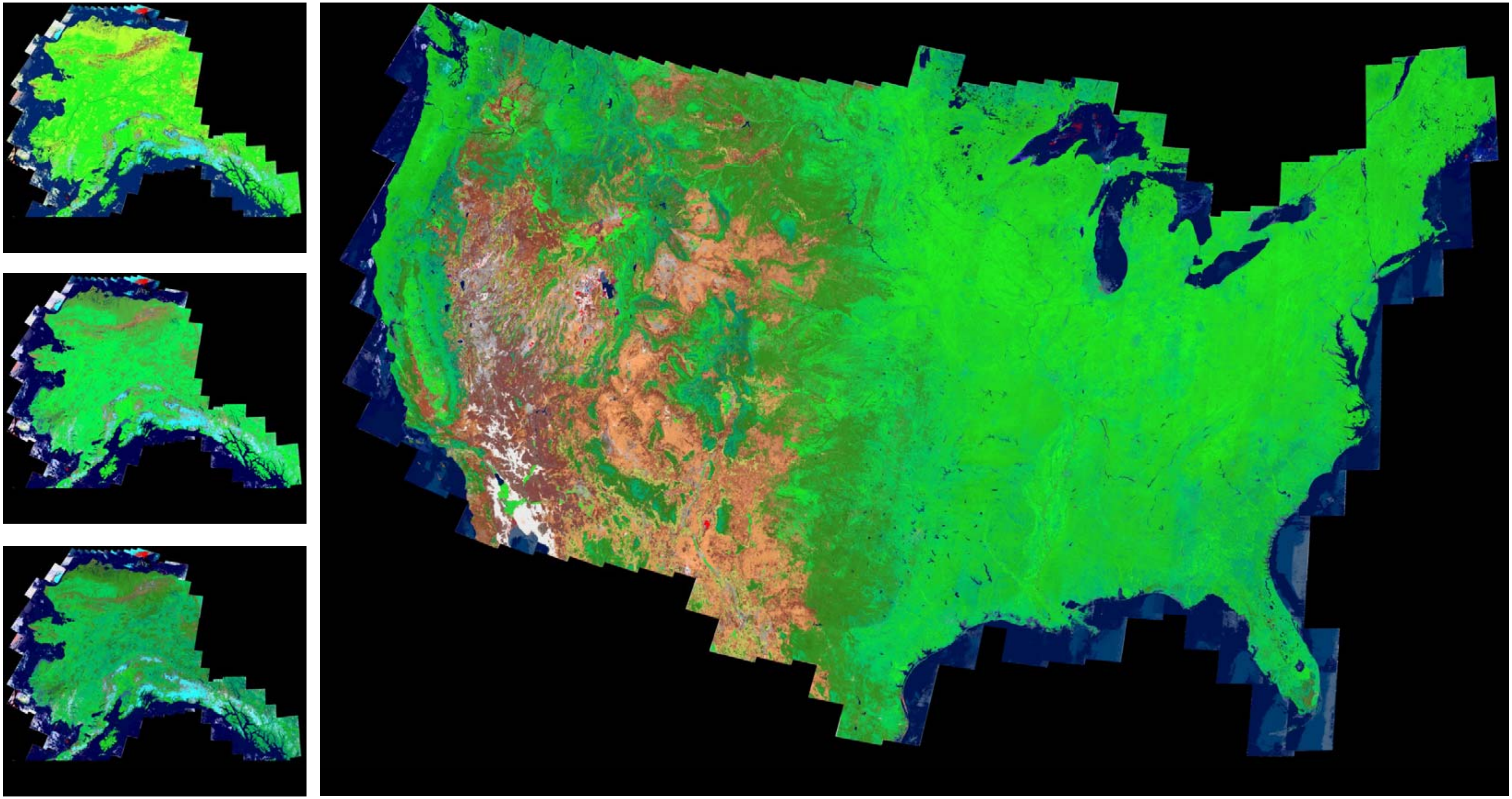
Automatic preliminary classification (refer to map legend)

Contour map



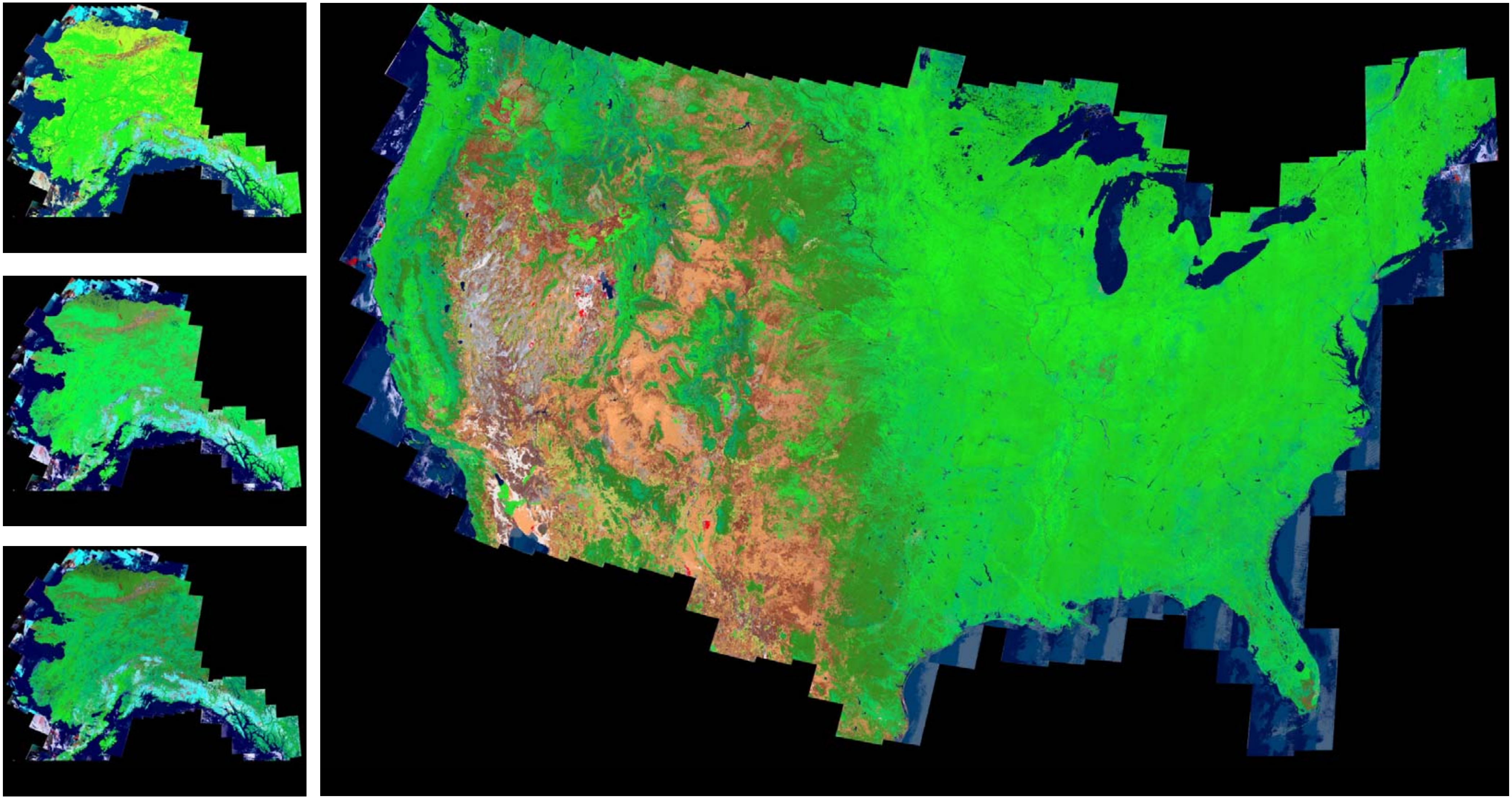
Segment-based piecewise constant image reconstruction

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



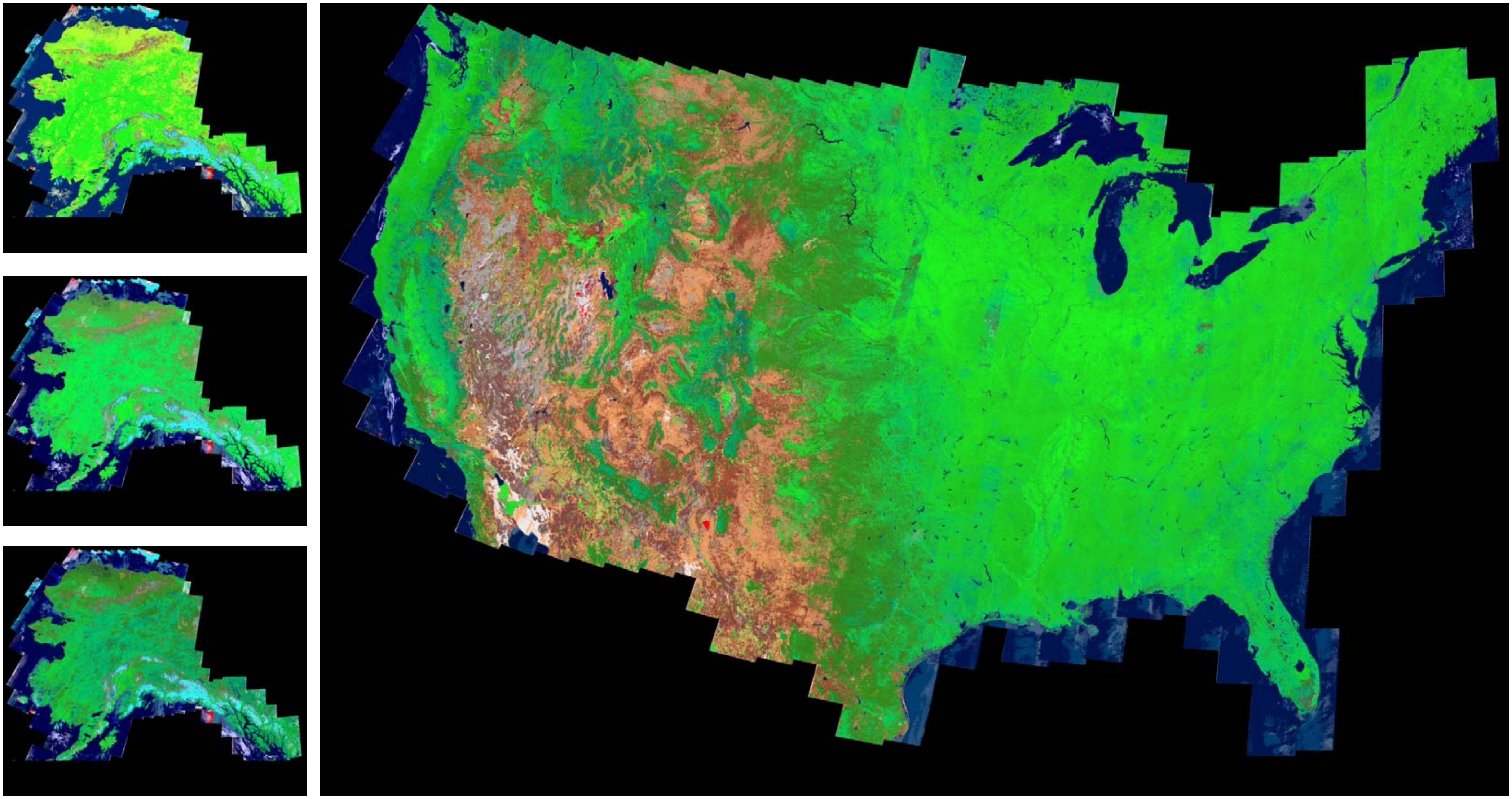
SIAM™ preliminary classification map, depicted in pseudo colors (refer to map legend), generated from the 2007 annual WELD mosaic shown in Fig. 3(a).
SIAM™ run by L. Boschetti (Univ. of Maryland), in 1 night of Dec. 2010. Fine: 95 SpCt, Intmedt.: 47 SpCt, Coarse: 18 SpCt.

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



SIAM™ preliminary classification map, depicted in pseudo colors (refer to map legend), generated from the 2008 annual WELD mosaic shown in Fig. 3(a). SIAM™ run by L. Boschetti (Univ. of Maryland), in 1 night of Dec. 2010. Fine: 95 SpCt, Intmedt.: 47 SpCt, Coarse: 18 SpCt.

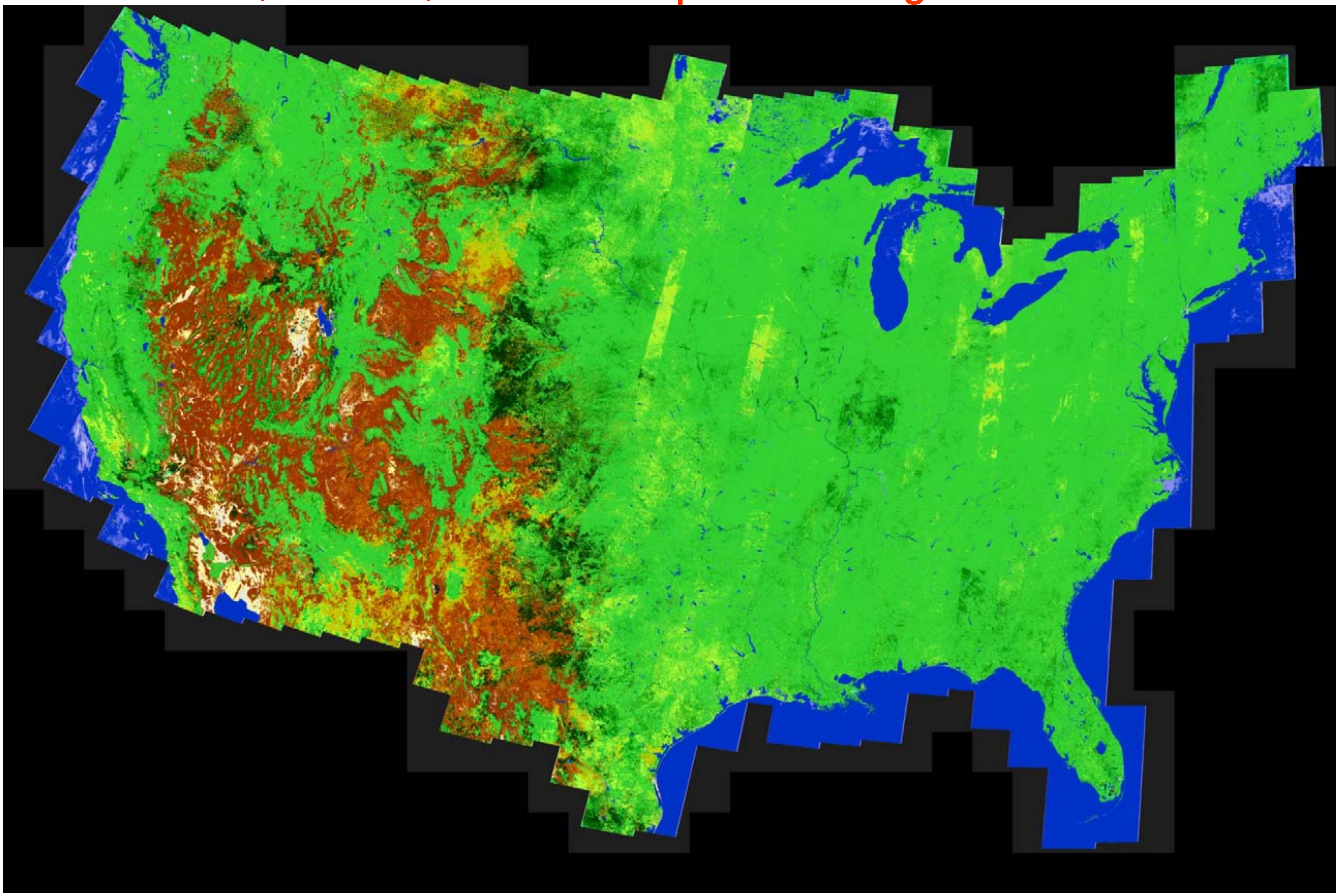
Example: Web-Enabled Landsat Data (WELD) Project. Year: 2009



SIAM™ preliminary classification map, depicted in pseudo colors (refer to map legend), generated from the 2009 annual WELD mosaic shown in Fig. 3(a). SIAM™ run by L. Boschetti (Univ. of Maryland), in 1 night of Dec. 2010. Fine: 95 SpCt, Intmedt.: 47 SpCt, Coarse: 18 SpCt.

Web-Enabled Landsat Data (WELD), Bi-temporal spectral category change detection. Year: 2008-2009, SIAM™, 33 Shared spectral categories.

1	Cnstnt Veg
2	Veg Dcrs
3	Veg Incrs
4	Veg Tot Gain from BB or Fire
5	Veg Tot Loss into BB
6	Veg Tot Gain from WASH
7	Veg Tot Loss into WASH
8	WASH Tot Loss into BB
9	BB Tot Loss into WASH
10	Cnstnt or previous (T1) WASH
11	Cnstnt BB
12	Within-BB change
13	Cnstnt CL
14	Cnstnt or previous (T1) SN
15	SN Tot Gain
16	SN Tot Loss
17	Cnstnt or previous (T1) SHSN
18	Cnstnt or previous (T1) SH
19	Cnstnt or previous (T1) FLAME
20	Cnstnt UN



Automatic bi-temporal SIAM™-based post-classification change detection, Web-Enabled Landsat Data (WELD). Year: 2008-2009, SIAM™, 33 shared sp. ct.

Application domains 1 and 2.

Baseline map generation / ROI extraction from SPOT-1 and -2 HRV imagery. Example i: Senegal

Fig. A. SPOT-2 HRV (High Resolution Visible) scene. False color image (R: band 3, G: band 2, B: band 1). Acquisition date: 2006-03-01, Senegal, spatial resolution: 20m.

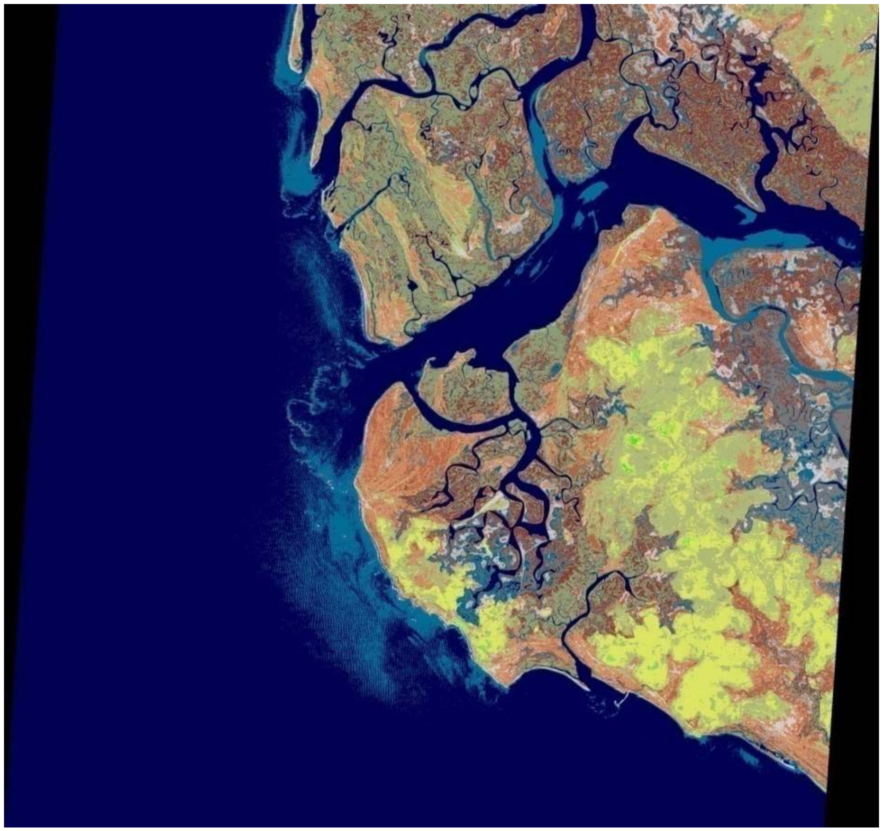


Fig. B. Output map generated from Fig. A, consisting of 46 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, etc.

Application domains 1 and 2.

Baseline map generation / ROI extraction from IRS-P6 AWiFS imagery. Example m: Greece.

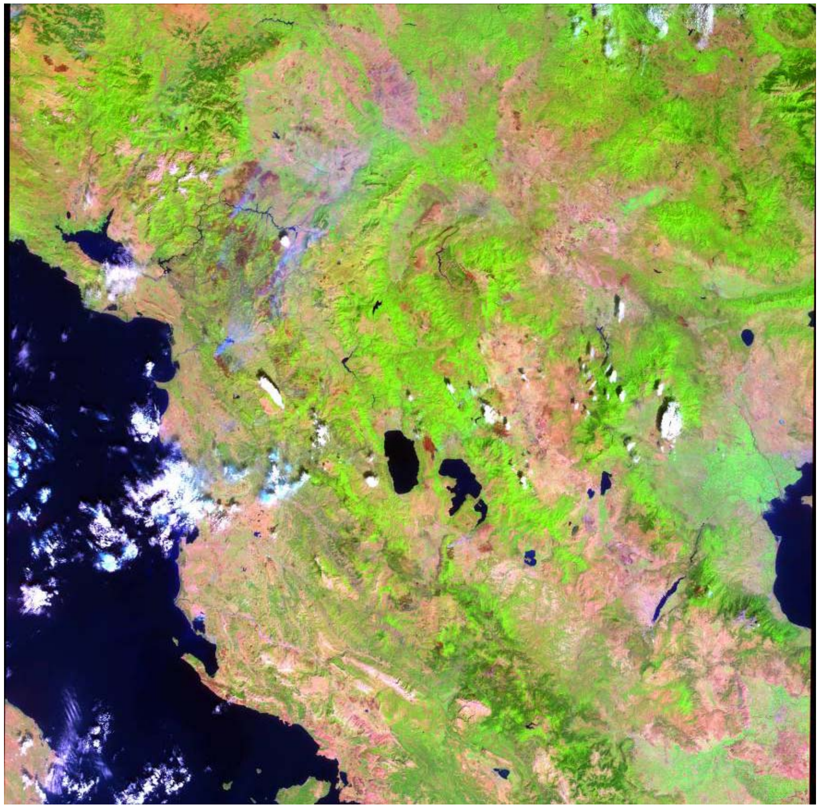


Fig. A. IRS-P6 AWiFS Image acquired on Sept., 2007, covering a surface area in Greece (R: band 4, G: band 3, B: band 1), spatial resolution: 56 m.

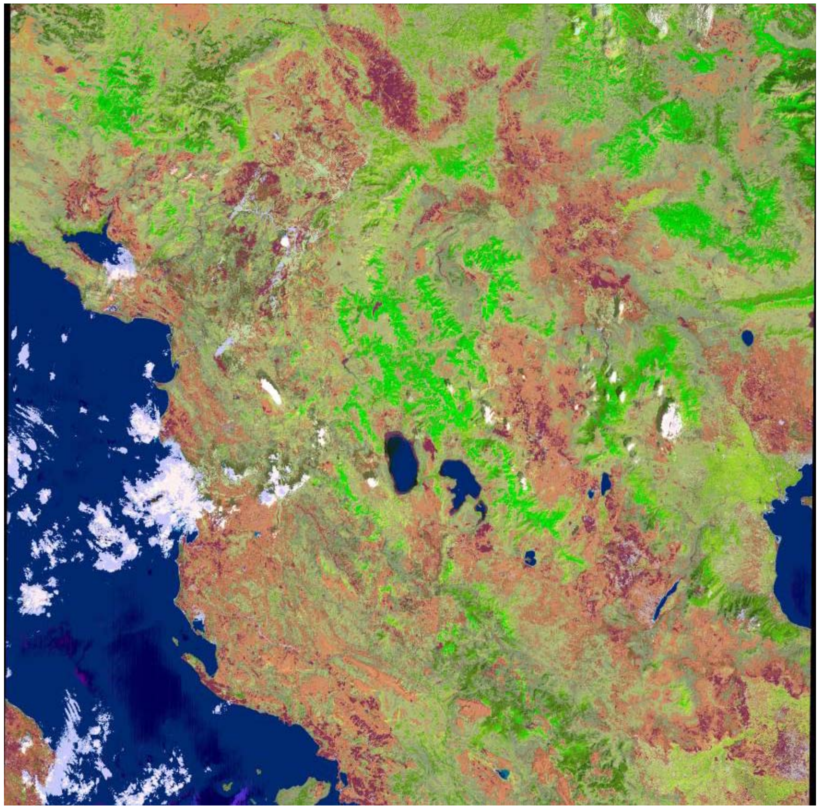


Fig. B. Output map generated from Fig. A, consisting of 62 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

Application domains 1 and 2. Image 2006 project.

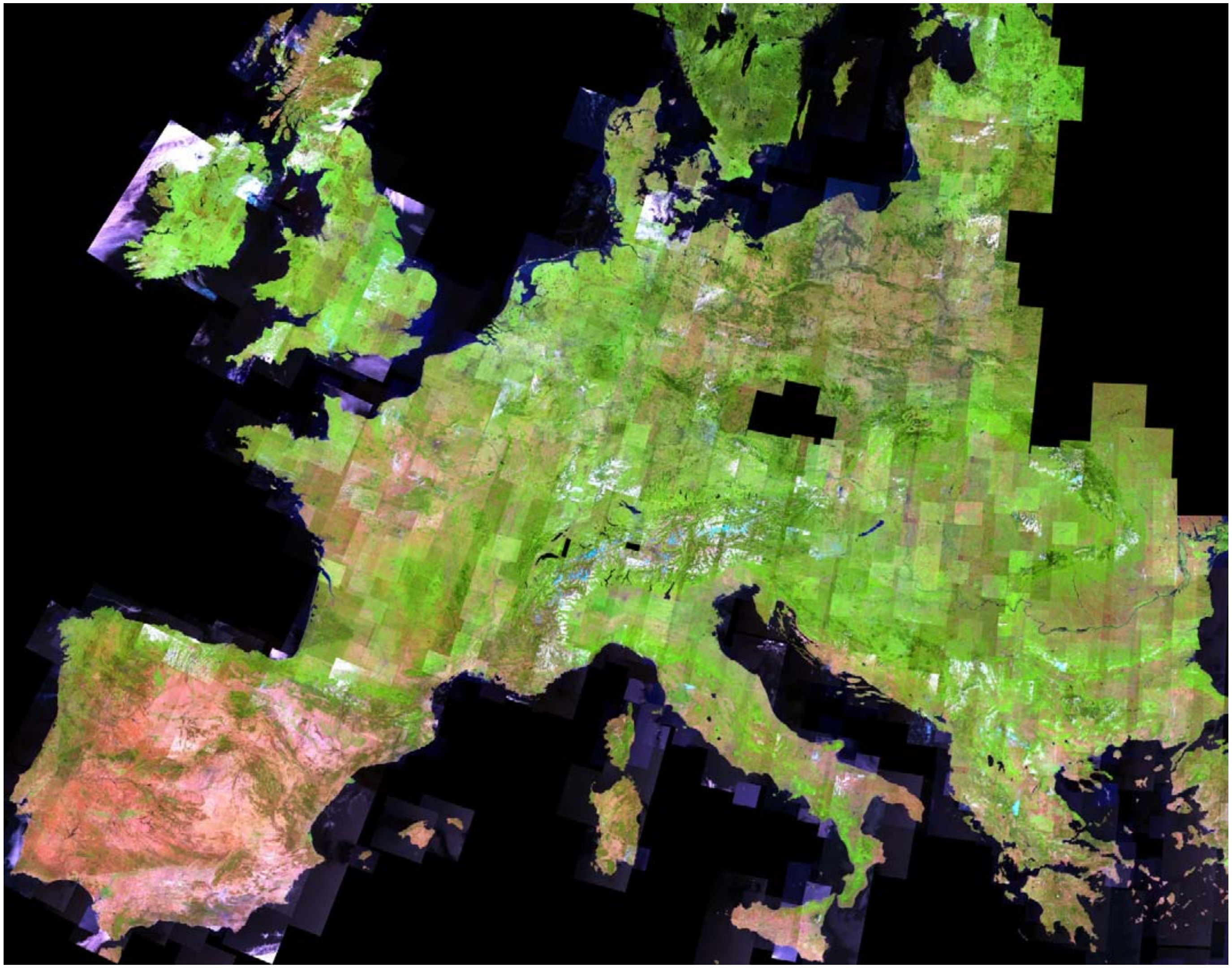


Image2006 Coverage 1 Mosaic and Value Added Products.

Image 2006 Coverage 1 mosaic, consisting of IRS-P6 LISSIII, SPOT-4, and SPOT-5 images, mostly acquired during 2006, radiometrically calibrated into top-of-atmosphere reflectance values and geometrically orthorectified. Images are depicted in false colors: Red – Band 4 (Short Wave InfraRed, SWIR), Green – Band 3 (Near IR, NIR), Blue – Band 1 (Visible Green).

Application domains 1 and 2. Image 2006 project.

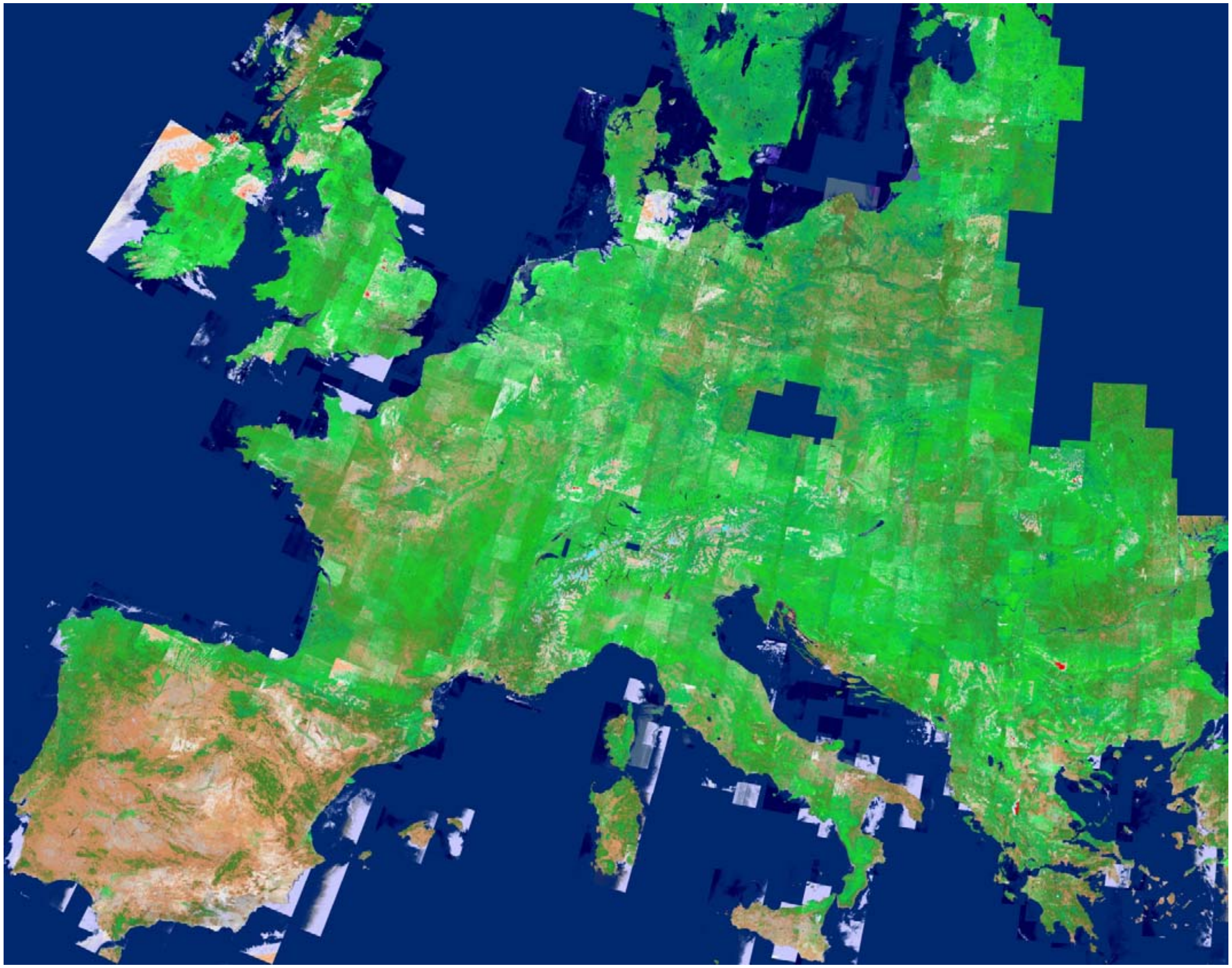


Image2006 Coverage 1 Mosaic and Value Added Products.

Fully automated preliminary spectral classification of the Image2006 Coverage 1 mosaic, consisting of 59 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland. Brown and grey tones: barren land and built-up areas. Blue tones: water types. Light blue and white: thin (stratus) and thick (cumulus) clouds.

Application domains 1 and 2.

Baseline map generation / ROI extraction from MODIS imagery. Example n: Italy

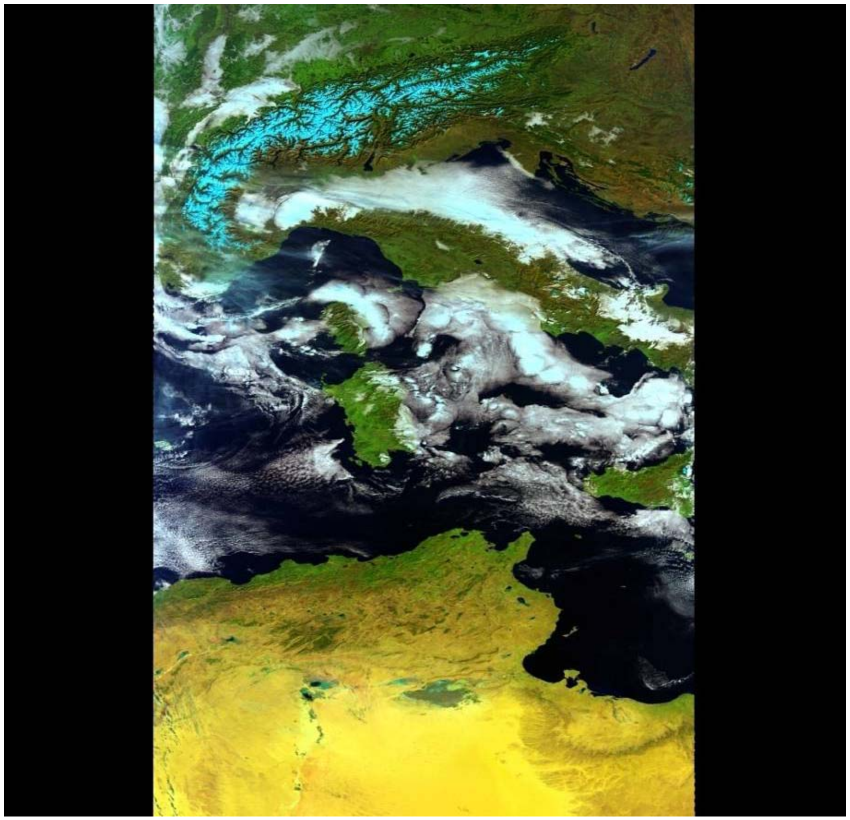


Fig. A. MODIS Image acquired on Jan. 5, 2007, covering northern Africa and Italy (R: band 1, G: band 4, B: band 3), spatial resolution: 1km.

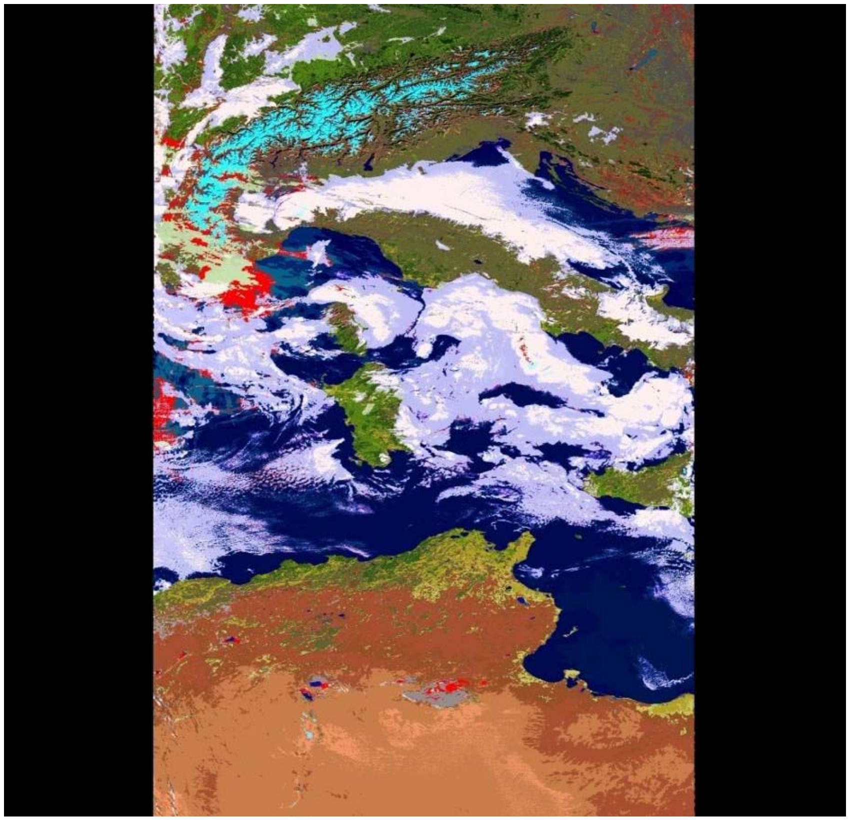


Fig. B. Output map generated from Fig. A, consisting of 72 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

Application domains 1 and 2.

Baseline map generation / ROI extraction from NOAA-AVHRR imagery. Example o: Italy.

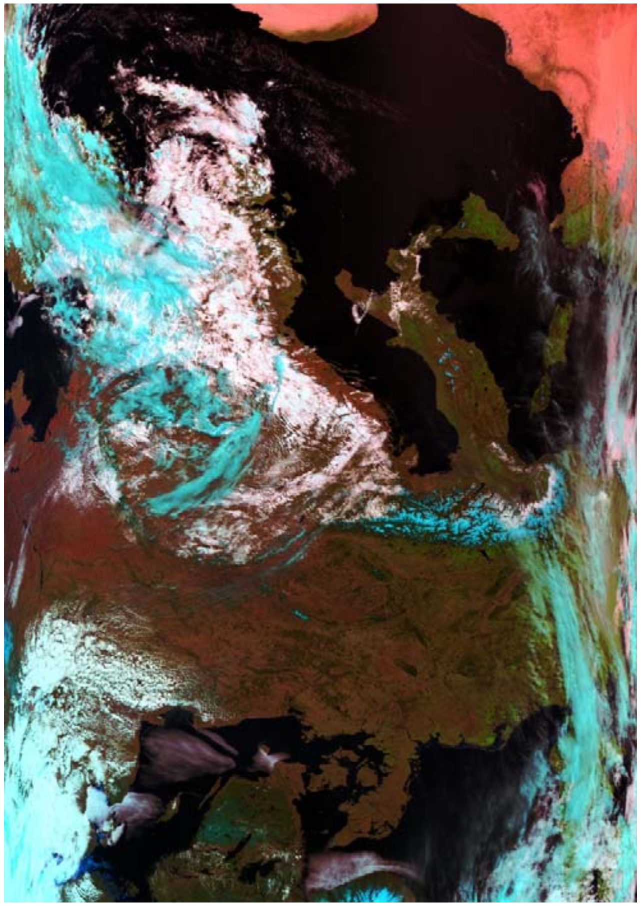


Fig. A. NOAA-AVHRR (Sat. 17) image acquired on 2003-04-14 covering Mediterranean and Northern Europe (R: band 3a, G: band 2, B: band 1), spatial resolution: 1.1 km.

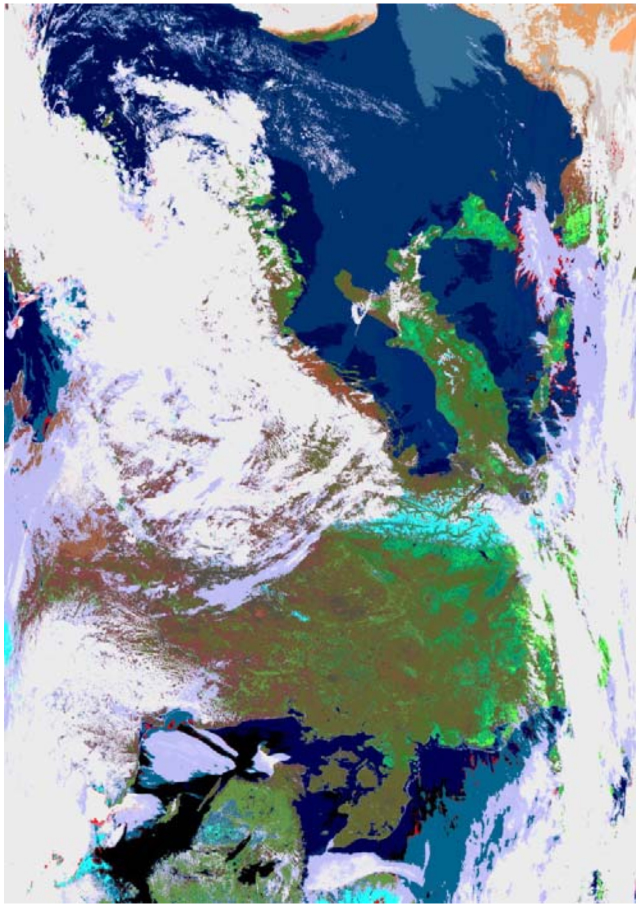


Fig. B. Output map generated from Fig. A, consisting of 82 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

Application domains 1 and 2.

Baseline map generation / ROI extraction from NOAA-AVHRR imagery. Example o: Italy.

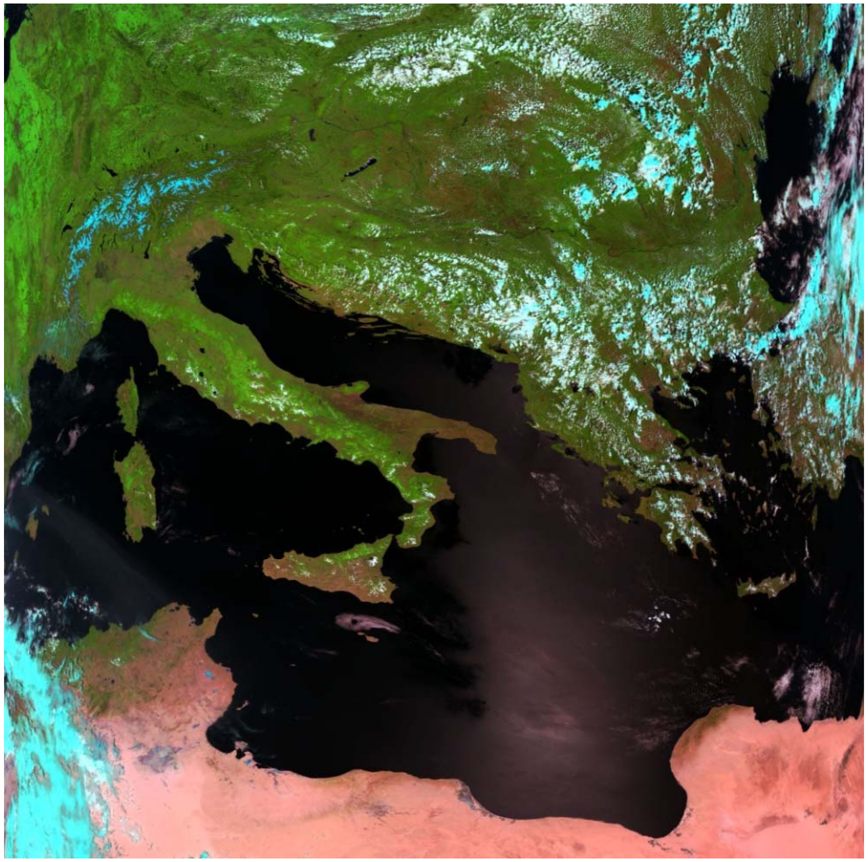


Fig. A. NOAA-AVHRR (Sat. 17) image acquired on 2004-06-08 covering Mediterranean and Balcanic areas (R: band 3a, G: band 2, B: band 1), spatial resolution: 1.1 km.

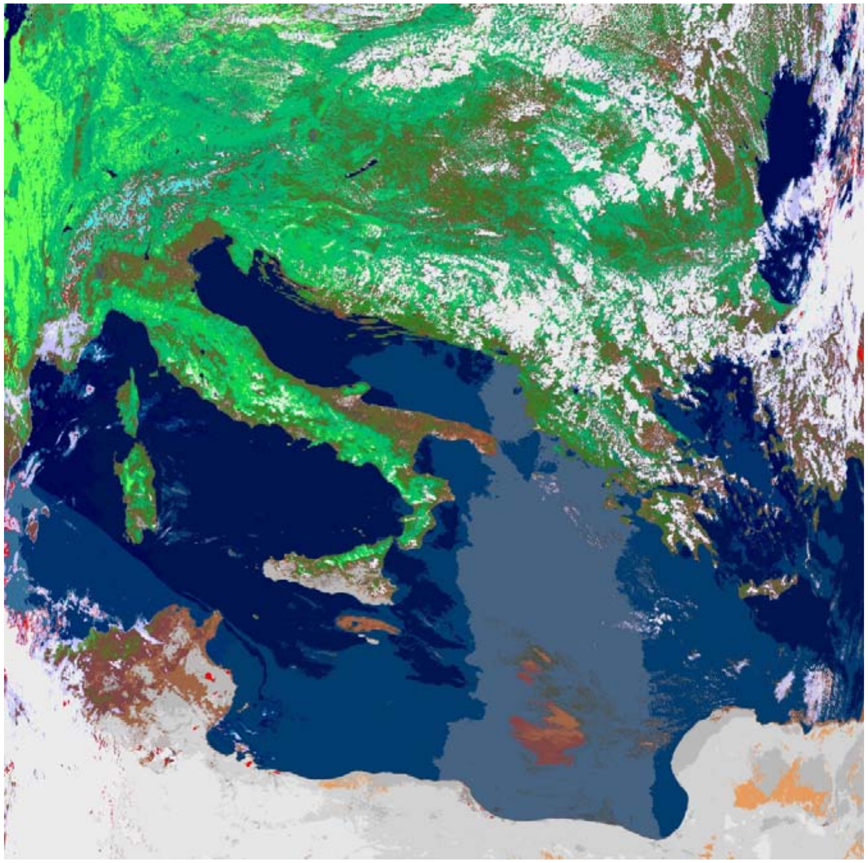


Fig. B. Output map generated from Fig. A, consisting of 82 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

Application domains 1 and 2.

Baseline map generation / ROI extraction from NOAA-AVHRR imagery. Example o: Turkey.

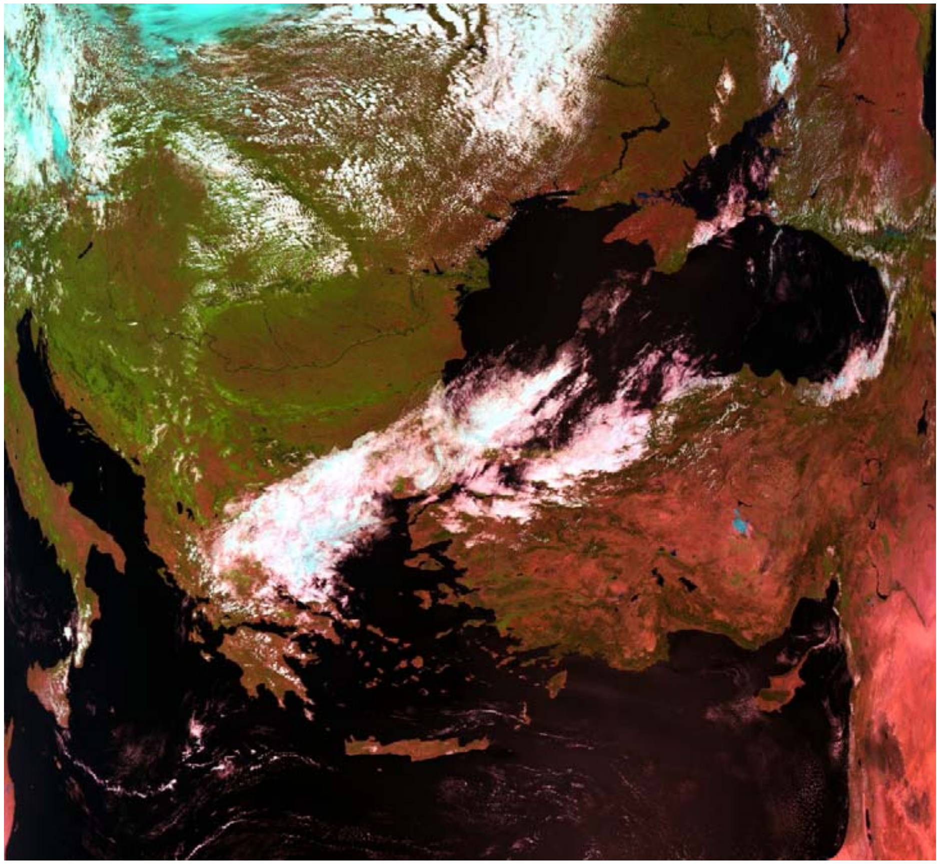


Fig. A. NOAA-AVHRR (Sat. 17) image acquired on 2005-08-09 covering Turkey and the Balcans (R: band 3a, G: band 2, B: band 1), spatial resolution: 1.1 km.

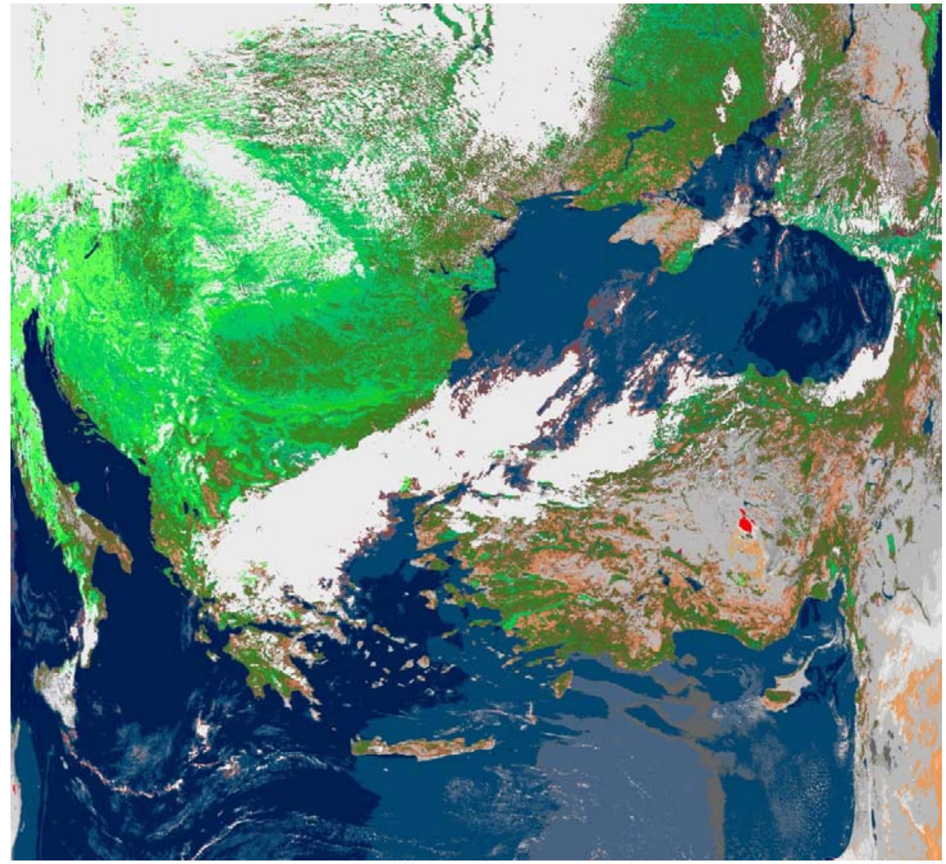


Fig. B. Output map generated from Fig. A, consisting of 82 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

Application domains 1 and 2.

Baseline map generation / ROI extraction from ENVISAT AATSR imagery. Example p: Black sea.

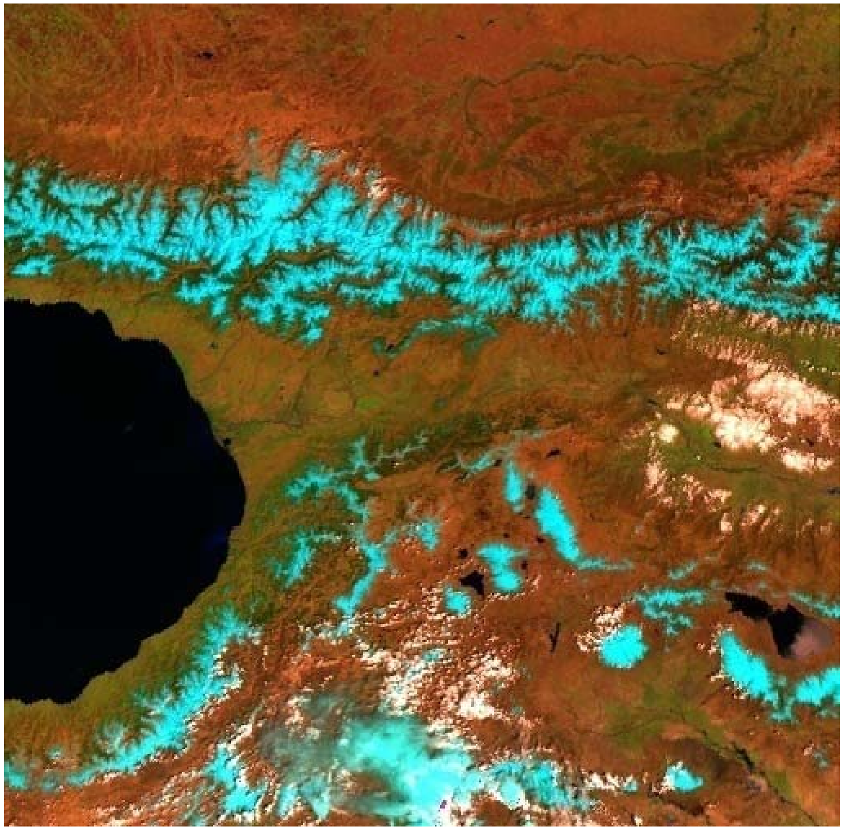


Fig. A. ENVISAT AATSR image acquired on 2003-01-05, covering a surface area over the Black sea (R: band 7, G: band 6, B: band 4), spatial resolution: 1 km.

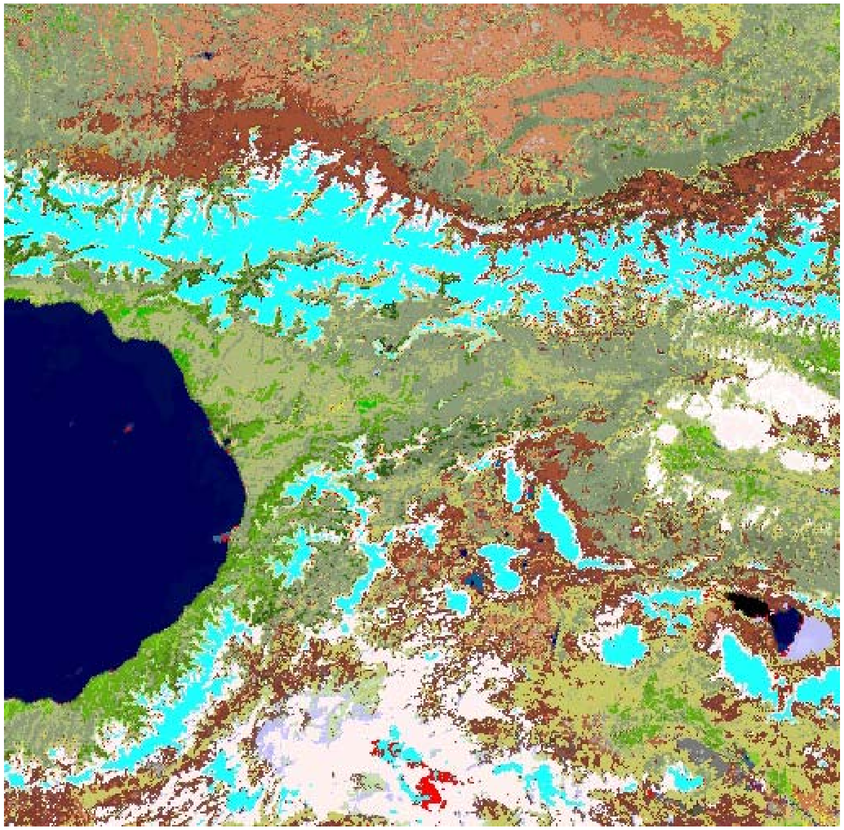


Fig. B. Output map generated from Fig. A, consisting of 72 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

Application domains 1 and 2.

Baseline map generation / ROI extraction from MSG imagery. Example p: Africa.

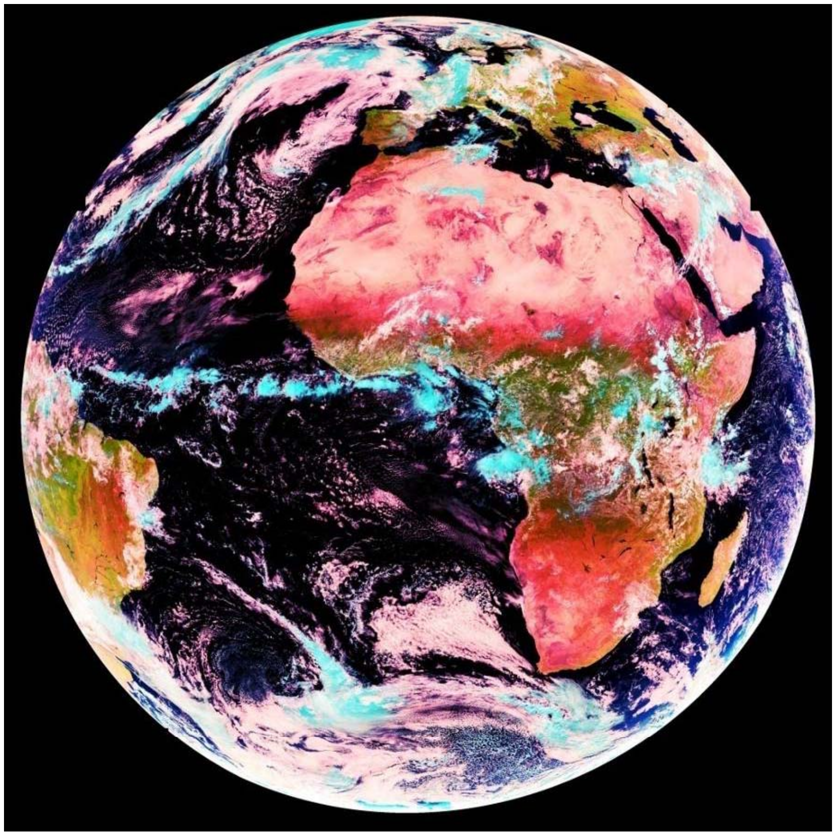


Fig. A. Meteosat 2nd Generation (MSG) image acquired on May 16, 2007, at 12.30 (CEST), covering Africa (R: band 3, G: band 2, B: band 1), spatial resolution: 3 km.

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.

Application domains 1 and 2.

Baseline map generation / ROI extraction from IKONOS-like imagery. Example q: Bologna, Italy (synthetic IKONOS from Landsat 7 ETM+).

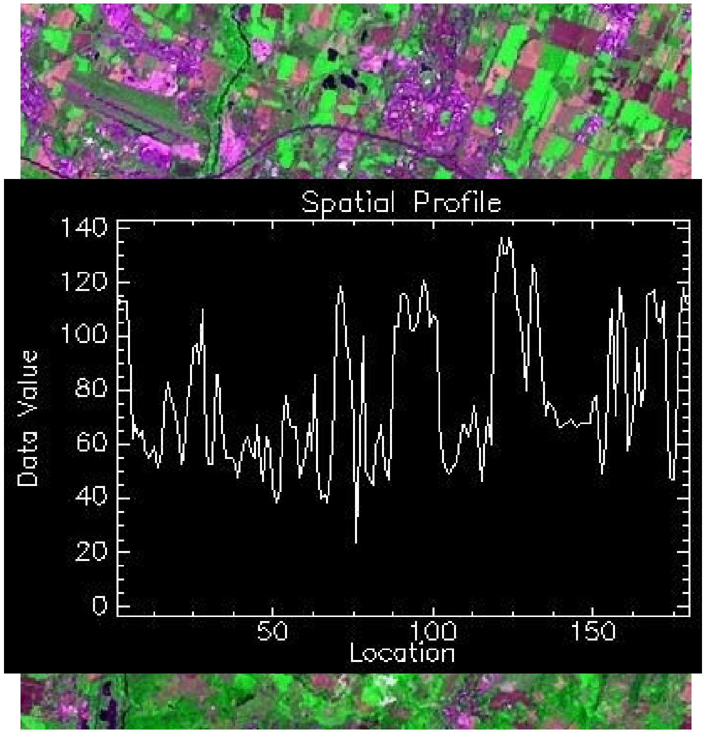


Fig. A. Simulated IKONOS- and QuickBird-like 4-band image generated from a Landsat 7 ETM+ image of the Italian city of Bologna, Italy, acquired on June 20, 2000 (R: band 3, G: band 4, B: band 1), spatial resolution: 30 m.

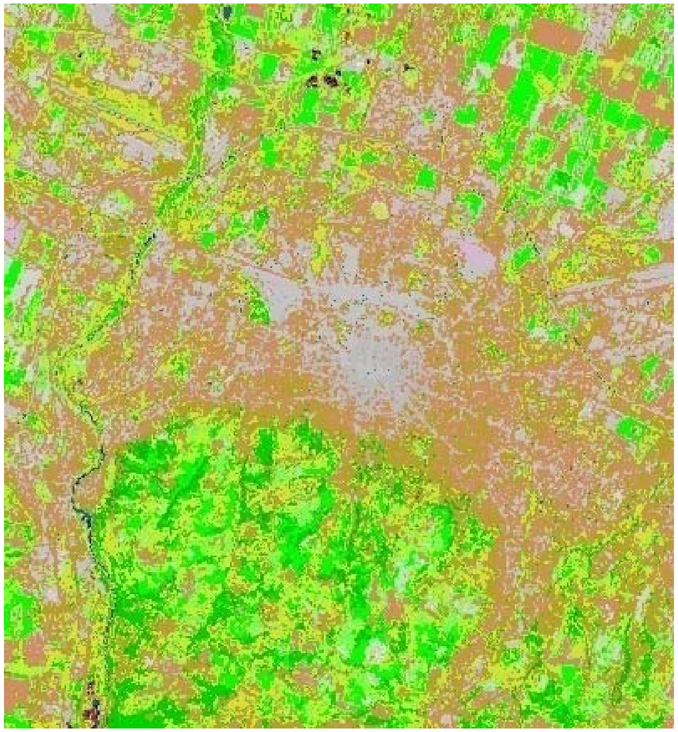


Fig. B. Output map generated from Fig. A, consisting of 31spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

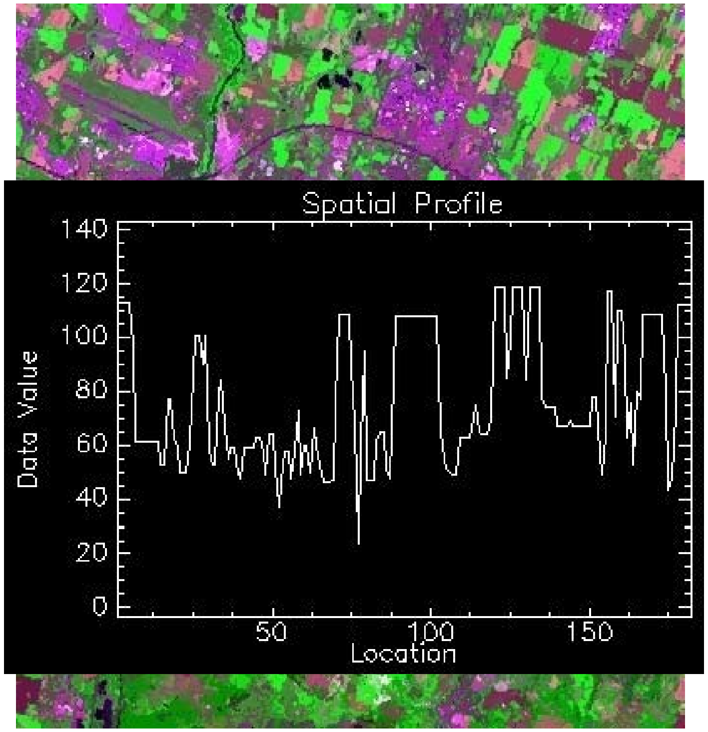


Fig. C. Piecewise constant approximation of Fig. A based on segments extracted from Fig. B, such that each segment is replaced with its mean reflectance value.

Application domains 1 and 2.

Baseline map generation / ROI extraction from WorldView-2 imagery. Example r: Brazilia, Brazil.

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.

Application domains 1 and 2.

Baseline map generation / ROI extraction from QuickBird-2 imagery. Example r: Brazilia, Brazil.

Fig. A. 8-band WorldView-2 VHR image of the city of Brazilia, Brazil, acquired on 2010-03-16, at 13:25 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: 2.4 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.

Application domains 1 and 2.

Baseline map generation / ROI extraction from ALOS AVNIR-2. Example q: Sicily, Italy.

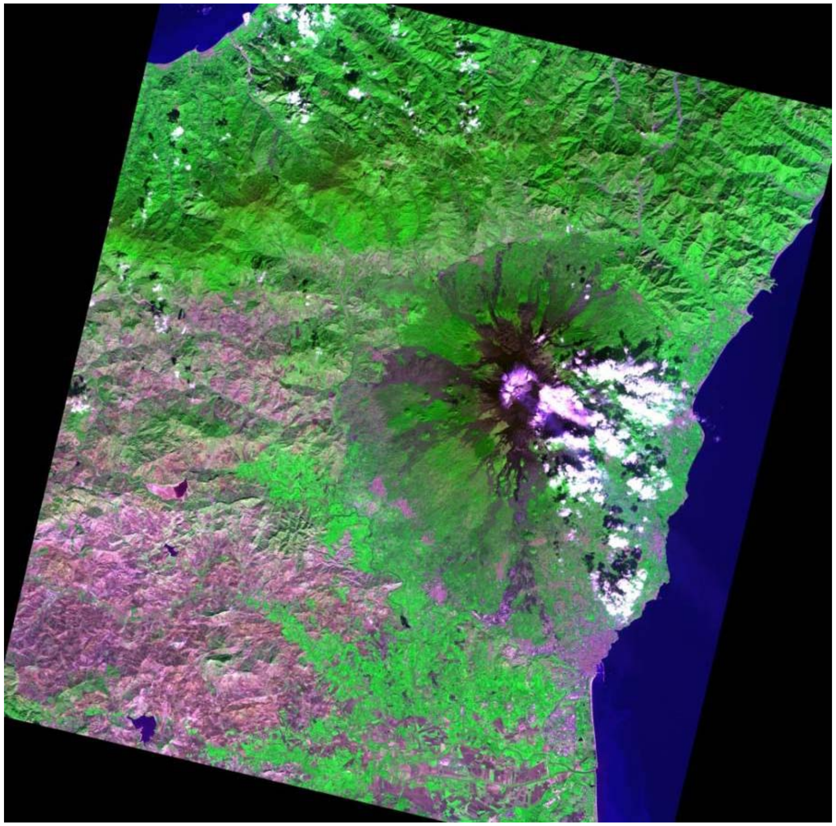


Fig. A. ALOS AVNIR-2 image of Sicily, Italy (acquisition date: 2004-13-06, 09:58 GMT), depicted in false colors (R: band CH3, G: band CH4, B: band CH1), 10m resolution, calibrated into TOA reflectance.

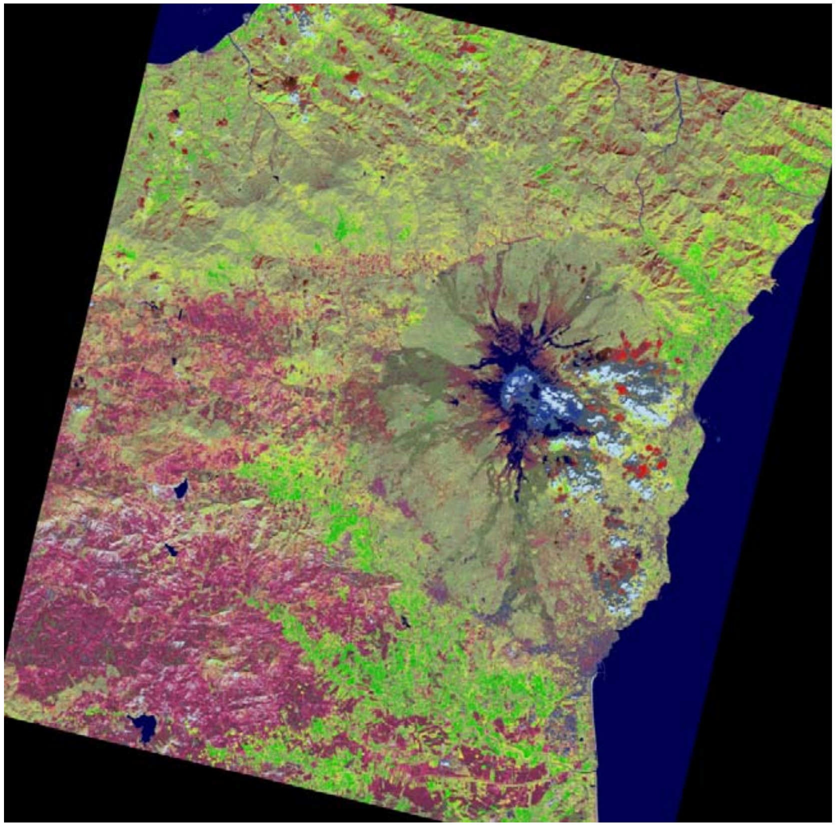


Fig. B. Output map generated from Fig. A, consisting of 46 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

Application domains 1 and 2.

Baseline map generation / ROI extraction from RapidEye. Example q: Dallas, Texas.

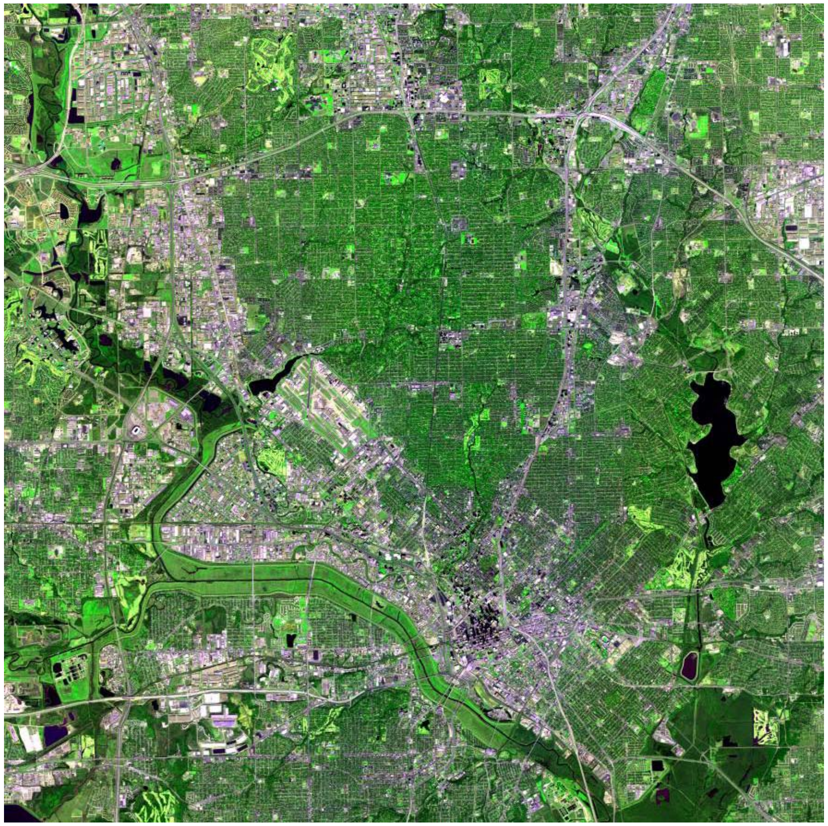


Fig. A. RapidEye image of Dallas, Texas (acquisition date: 2009-02-04, 17:54 GMT), depicted in false colors (R: band CH3, G: band CH5, B: band CH1), 5 m resolution, calibrated into TOA reflectance.

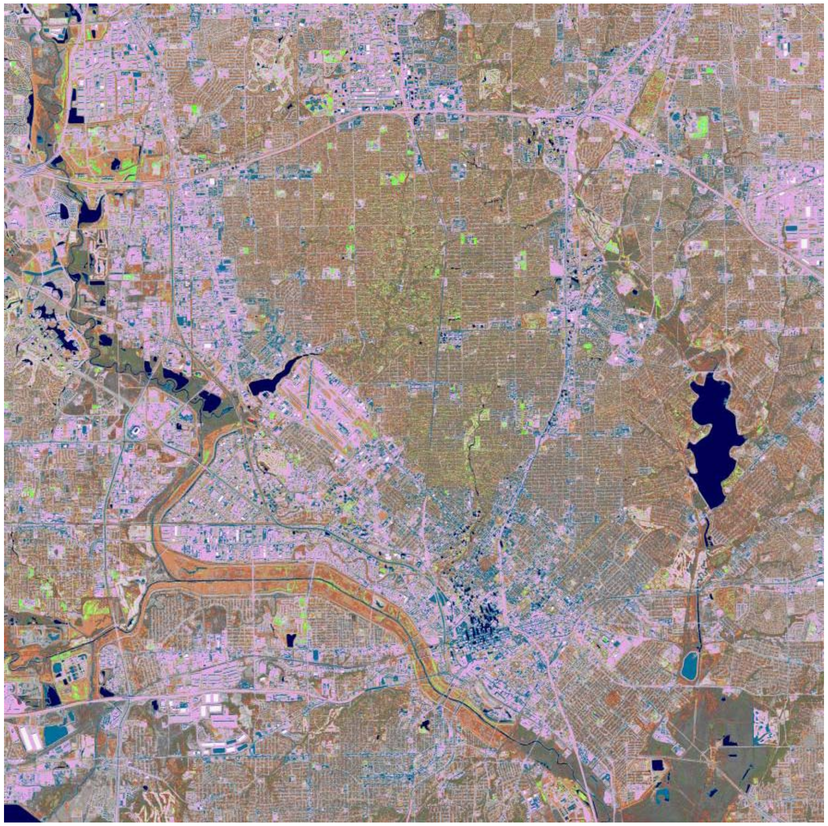
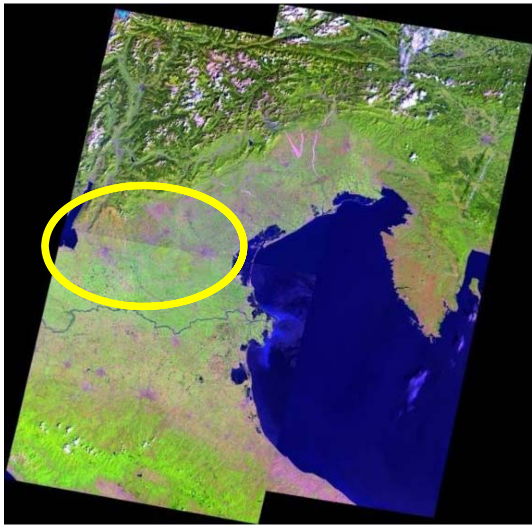


Fig. B. Output map generated from Fig. A, consisting of 50 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

Application domain 3.b.

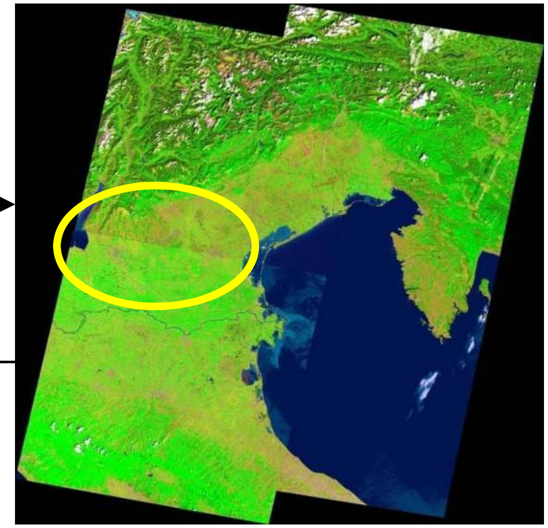
Stratified histogram matching (e.g., in image mosaicking).

Mosaic of 4 rad. calibrated Landsat 7 ETM+ images: Emilia, Roma-gna, Veneto, Friuli.



Preliminary classification (SIAM™)

Stratified histogram matching



Mosaic of 4spectral classification maps, 85 classes.

Master image: Veneto image

Slave image: Romagna image.

Target spectral strata: vegetation types, bare soil types, water types.

Mosaic of 4spectral classification maps, 85 classes.

Preliminary classification (SIAM™)

Mosaic of 4 histo.-matched and rad. calibrated Landsat 7 ETM+ images: Emilia, Roma-gna, Veneto, Friuli.

Application domain 3.b.
Stratified cloud detection.

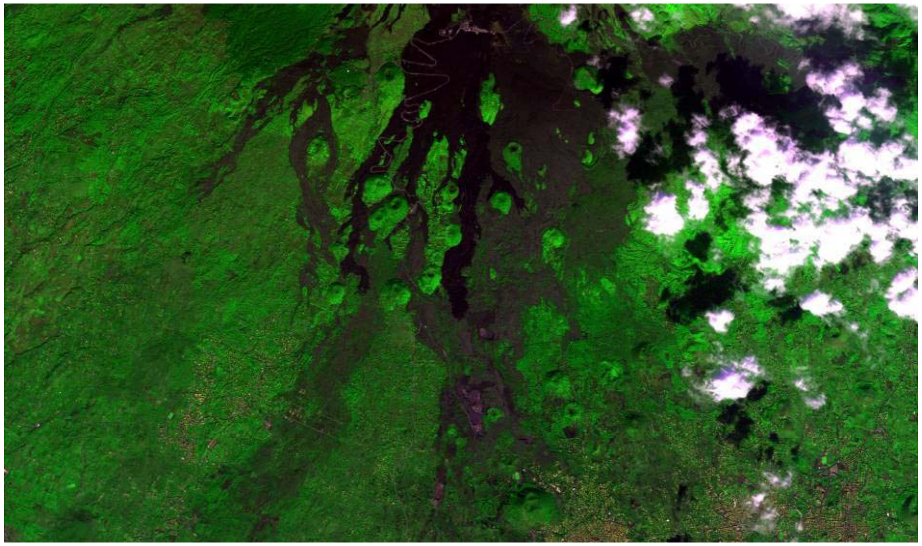


Fig. A. AVNIR-2 ALAV2A041622840 image of Sicily in false colors (R: band 2, G: band 4, B: band 1). Path: …, Row: …, acquisition date: YYYY-MM-DD.

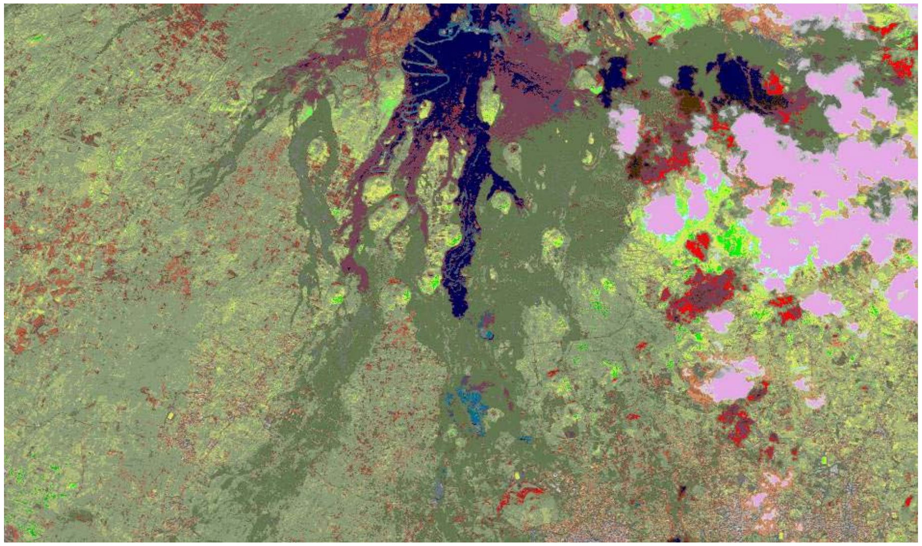


Fig. B. Preliminary classification map generated from Fig. A., consisting of 46 spectral categories.

Fig. C. Binary cloud mask generated from Fig. B, based on segment-based color and geometric properties plus spatial topological relationships (e.g., adjacency, inclusion).

Application domain 3.b.
Stratified topographic correction.

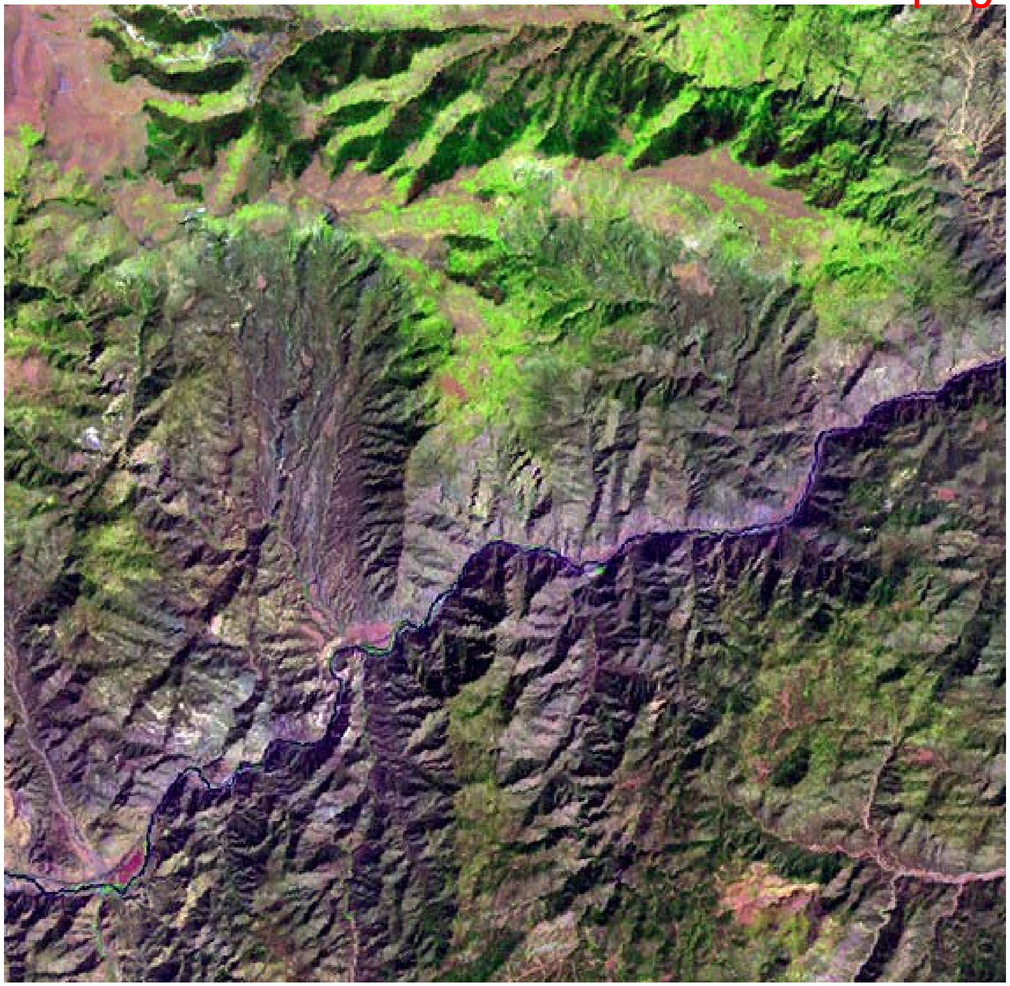


Fig. A. Zoomed area of a Landsat 7 ETM+ image of Colorado, USA (path: 128, row: 021, acquisition date: 2000-08-09), depicted in false colors (R: band ETM5, G: band ETM4, B: band ETM1), 30m resolution, calibrated into TOA reflectance.

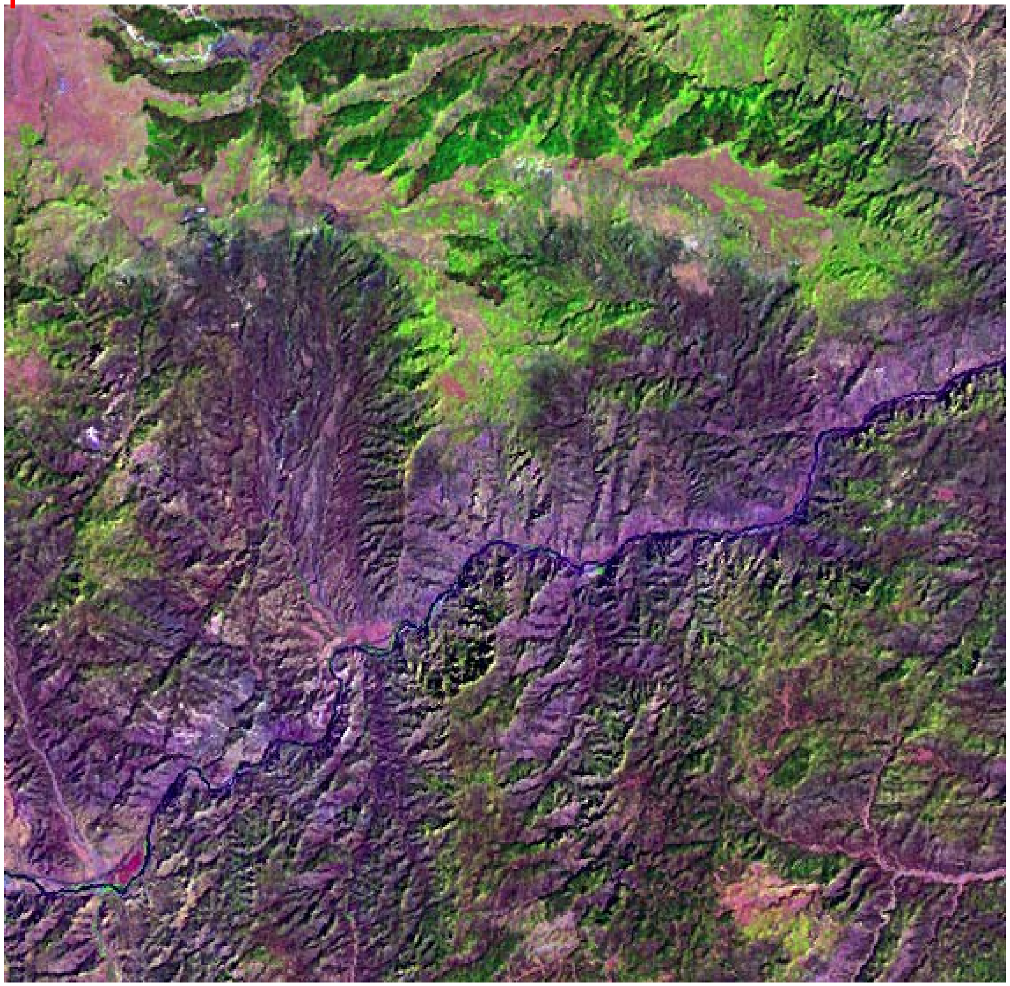
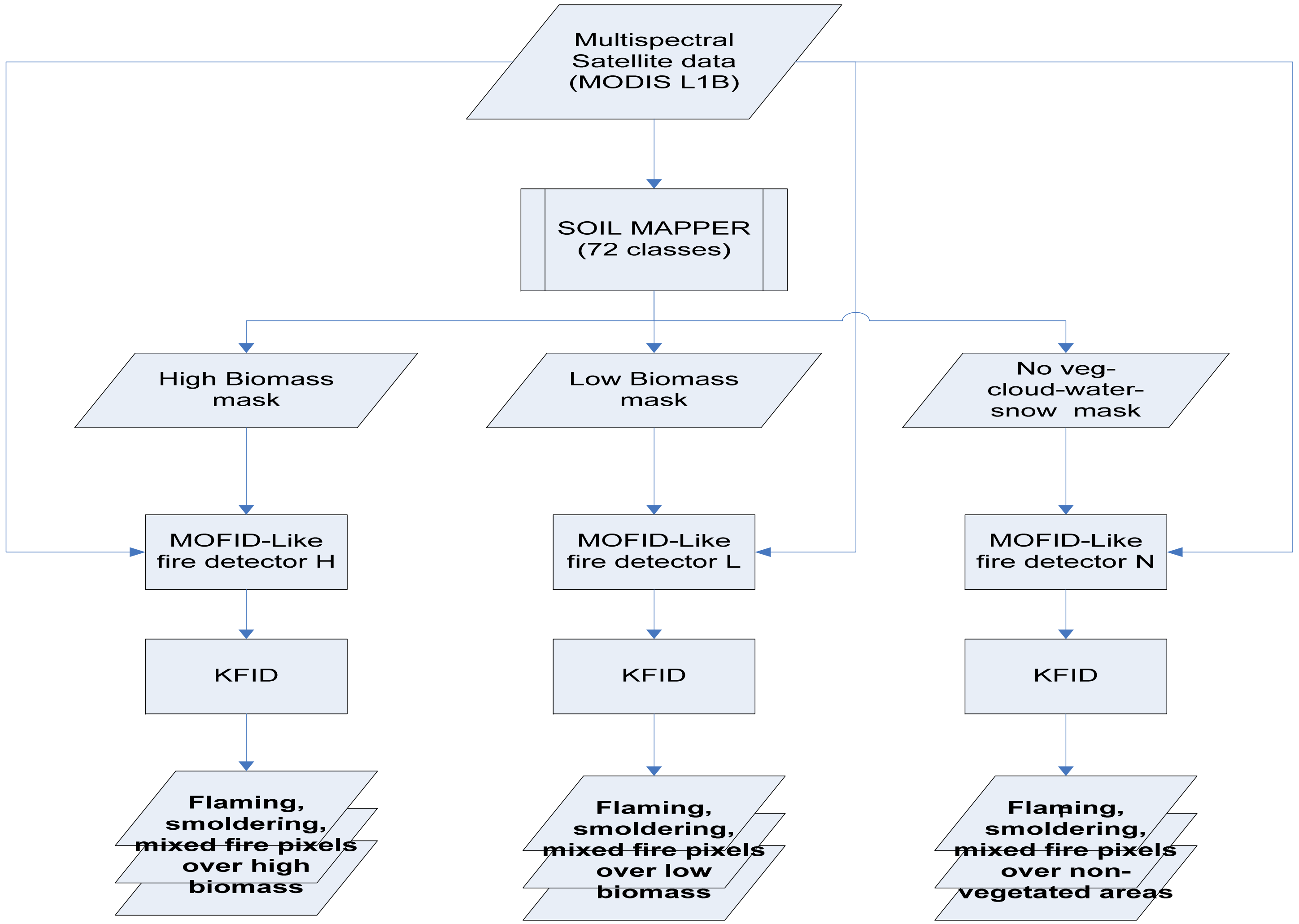


Fig. B. Stratified topographic correction of Fig. A, based on a 16-class preliminary spectral map and the SRTM DEM.

Application domain 3.d.

Stratified image classification. Example: SOIL MAPPER-driven Fire Detection (SOMAFID) algorithm for MODIS, MSG, and AATSR.



Kaufman's rule-based detection of: a) flaming fire, b) smoldering fire (Kaufman et al., Potential global fire monitoring from EOS-MODIS, Journal of Geophysical Research,103, 32215 – 32238, 1998.

Application domain 3.d.

Stratified image classification. Example: **fire detection** in MODIS imagery combined with smoke **plume detection.**

Fig. A. MODIS image acquired on August 23, 2007, at 9.35 (CEST), covering Greece (R: band 6, G: band 2, B: band 3), spatial resolution: 1 km.

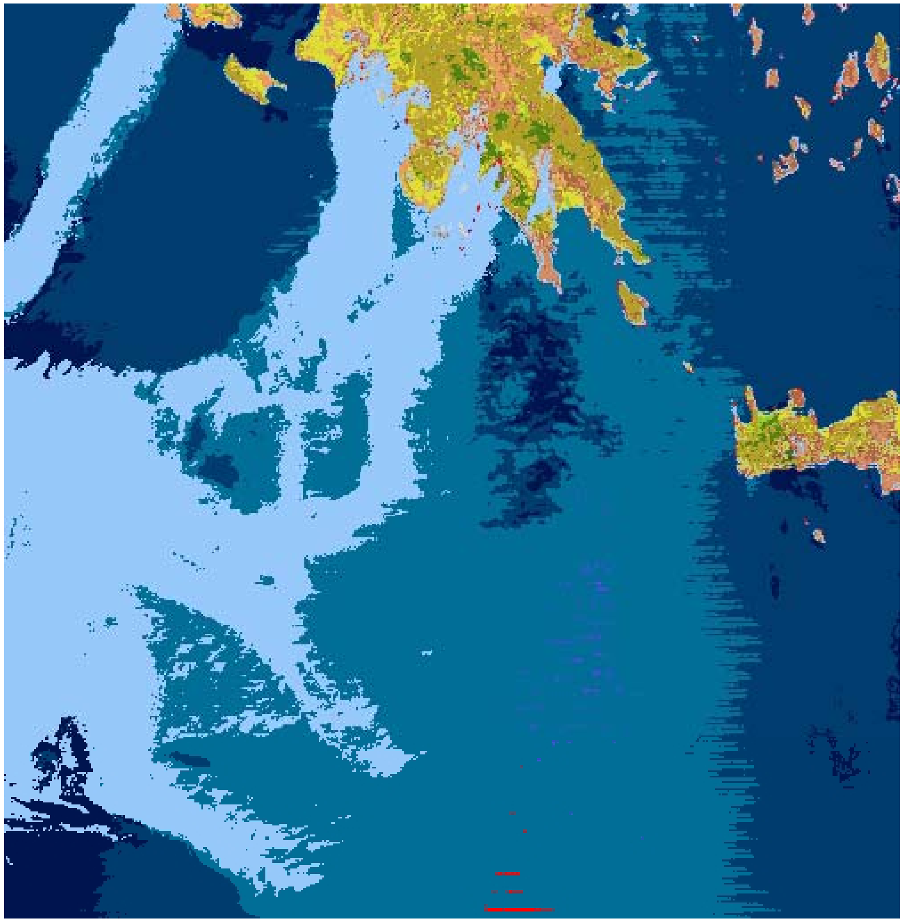


Fig. B. Output map generated from Fig. A, consisting of 82 spectral categories, depicted in pseudo-colors.

Application domain 3.d.

Stratified image classification. Example: **fire detection** in MODIS imagery combined with smoke **plume detection.**

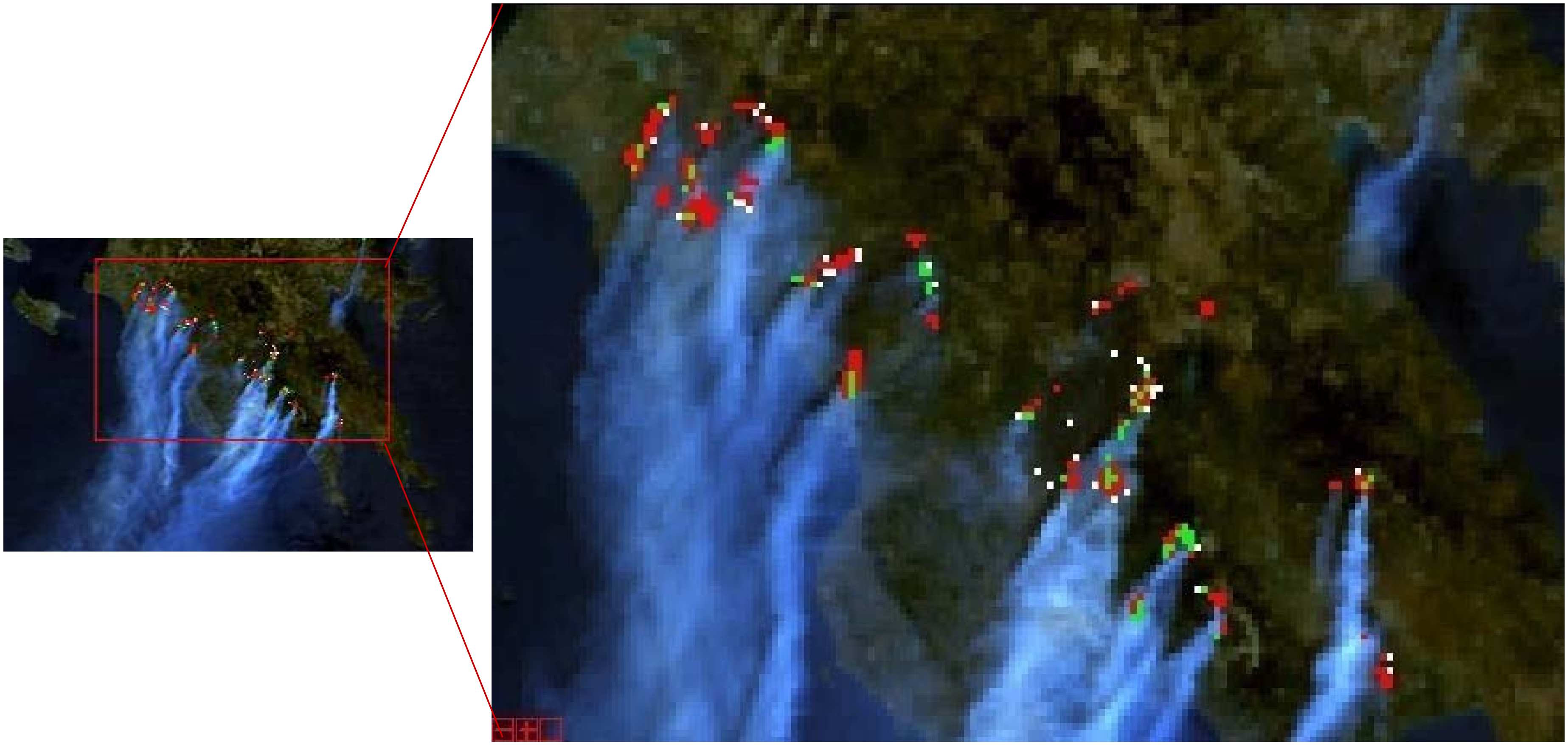


Fig. A. MODIS image acquired on August 23, 2007, at 9.35 (CEST), covering Greece (R: band 6, G: band 2, B: band 3), spatial resolution: 1 km. Legenda – Red: fire pixel detected in both MODIS Fire Detection (MOFID) and SOIL MAPPER® -based Fire Detection (SOMAFID). White: fire pixel detected by SOMAFID, exclusively. Green: fire pixel detected by MOFID, exclusively.

Application domain 4.

Bi-temporal semantic-based land cover change detection. Landsat-5 TM imagery. Example a: Brazil.

Fig. A. Zoom of a preliminary classification map depicted in pseudo colors, generated from a Landsat-5 TM imagery acquired on 1986-08-10, covering an area of Brazil (path: 231, row: 068), spatial resolution: 30 m.

Fig. D. Zoom of a continuous greenness (Gr) index change image, where, (i) Gr < 0 if (Gr2 < Gr1); (ii) Gr >= 0 if (Gr2 >= Gr1); and (iii) DblNeg (= - 150) if ((Gr1 == 0) AND (Gr2 == 0)).

Fig. B. Zoom of a preliminary classification map depicted in pseudo colors, generated from a Landsat-5 TM imagery acquired on 2006-07-16, covering an area of Brazil (path: 231, row: 068), spatial resolution: 30 m.

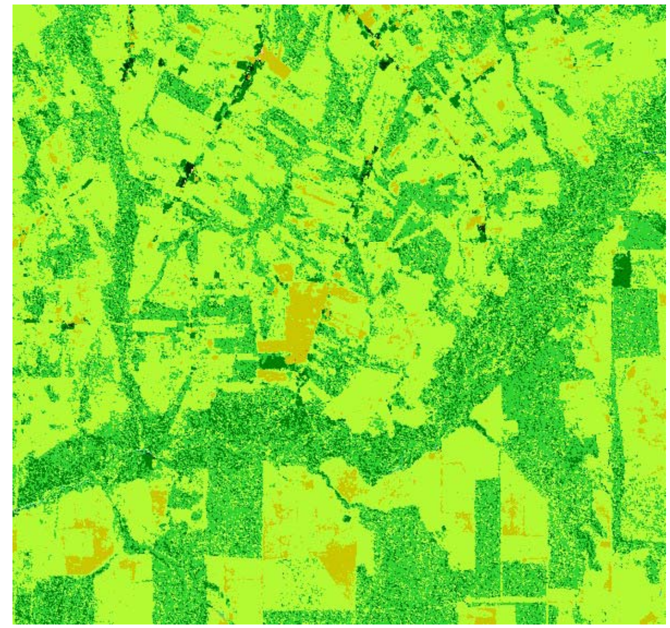


Fig. C. Zoom of a Bi-Temporal change detection map generated from the preliminary classification map pair shown in Fig. A and Fig. B.

Application domains 1, 2 and 4.

Baseline map generation / Burned area detection (in single date imagery!!!).

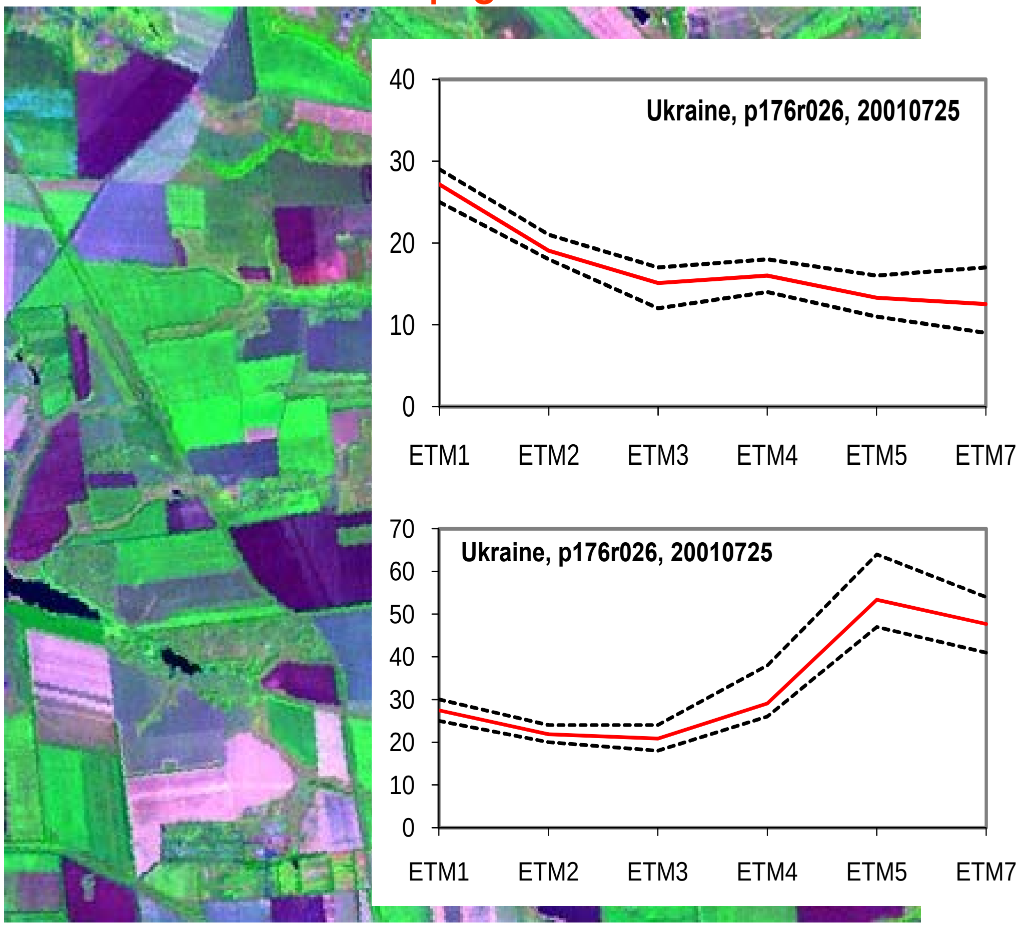


Fig. A. Zoomed area extracted from a Landsat 7 ETM+ image depicted in false colors (R: band TM5, G: band TM4, B: band TM1). Path: 176, Row: 026, acquisition date: 2001-07-25, Ukrain.

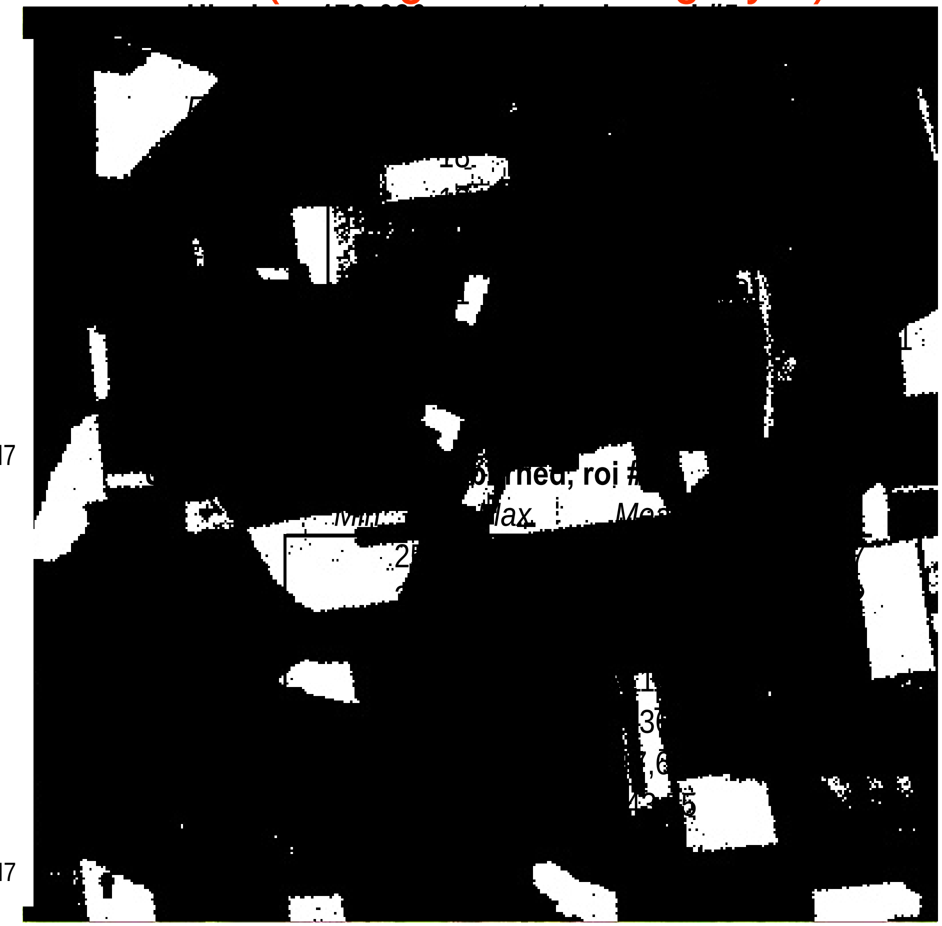
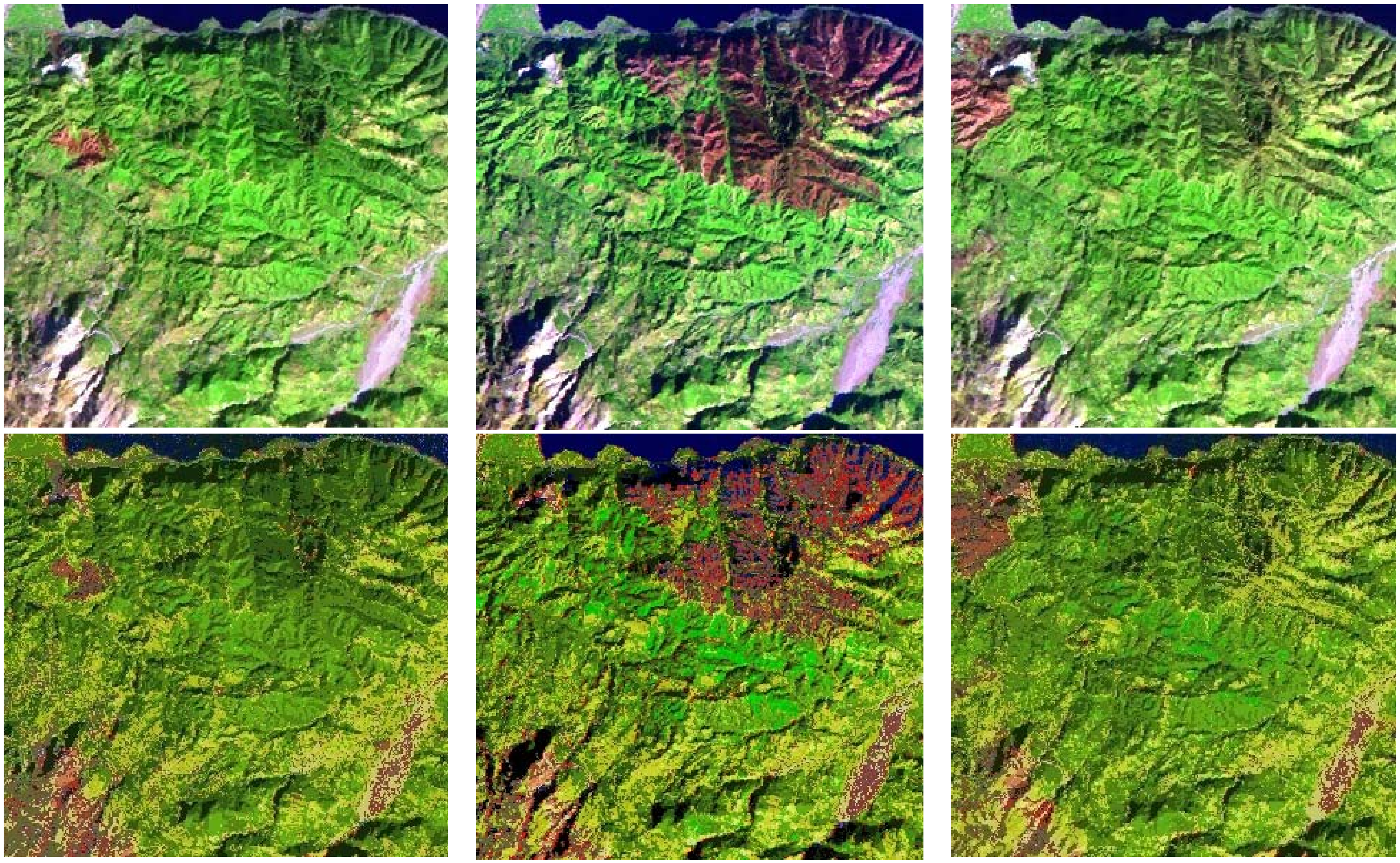


Fig. B. Output map generated from Fig. A, consisting of 88spectral categories depicted in pseudo colors. Violet: old and recently burned areas. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White tones: clouds.

Application domain 4.

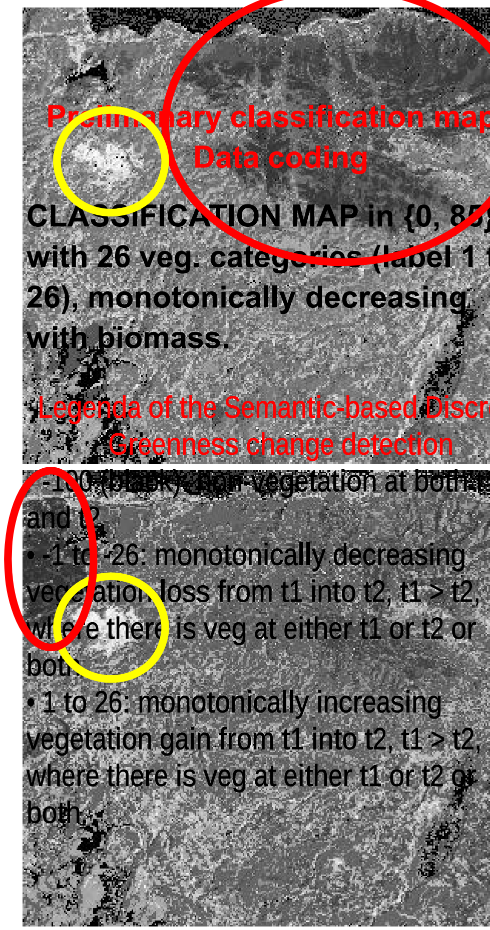
Semantic-based Discrete Greenness change detection. Landsat-5 TM imagery. Example c: Greece.

Landsat 5 TM, 20-10-92 — Landsat 5 TM, 29-10-95 — Landsat 5 TM, 21-10-98



Preliminary spectral maps, 85 spectral classes, depicted in pseudo colors.

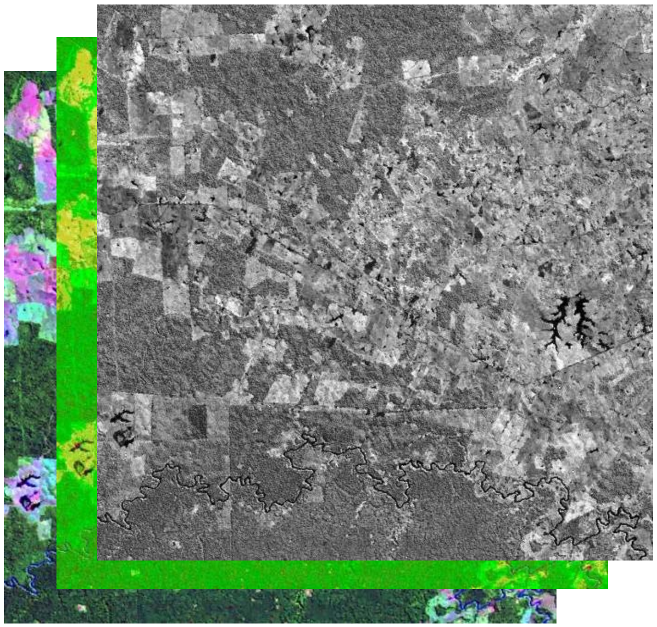
Spectral map difference, 95-92.



Spectral map difference, 98-92.

Application domain 4.

Semantic-based Continuous Greenness change detection. Landsat-7 ETM+ imagery. Example d: Brazil.

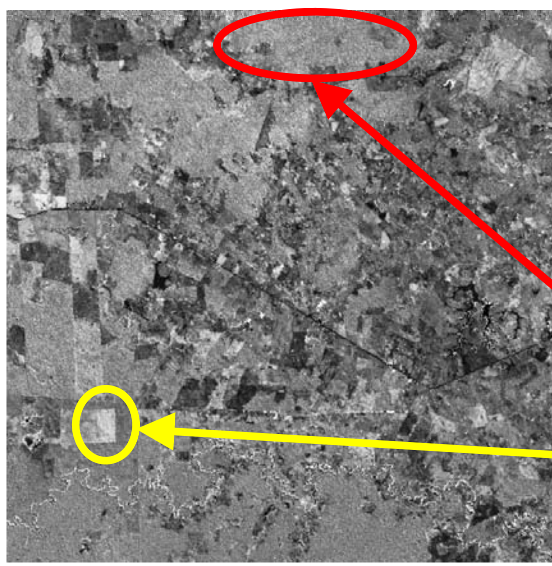


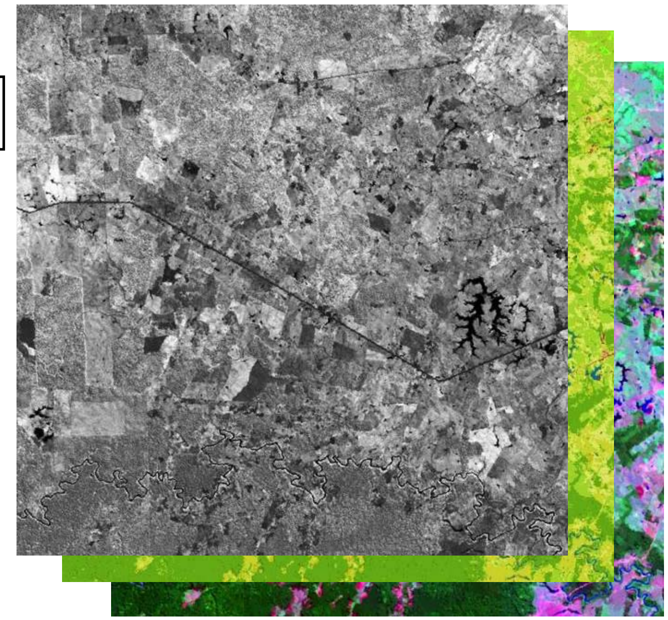
Input image 1: Landsat 5 TM image of Brazil (path: 002, row: 067, acquisition date: 1993).

1. Spectral classification map in {0, 85}, with 26 veg. categories (label 1 to 26).

2. Greenness estimate ≥ 0.

Bi-temporal Grenness Estimate Image Difference masked by $VegMask_{t1}$ and $VegMask_{t2}$, t2 > t1, range (-∞, +∞).





Input image 2: Landsat 7 ETM+ image of Brazil (path: 002, row: 067, acquisition date: 1999).

Note:

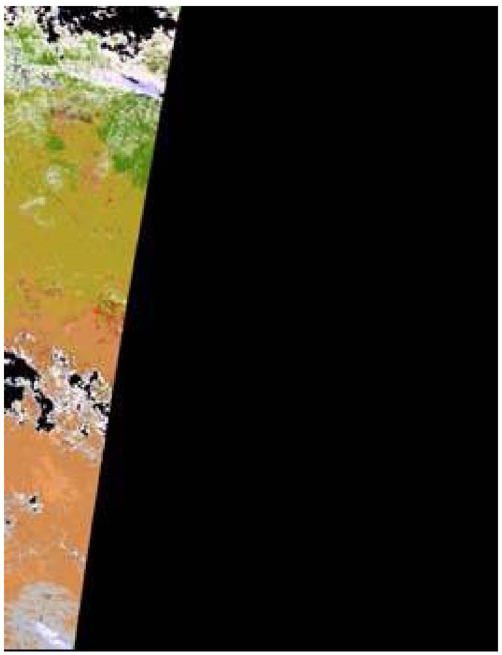
In case, a preliminary classification map pair difference ($CLMap_{t1}$ – $CLMap_{t2}$), t1 < t2, is possible because the classification map indexes decrease monotonically with greenness estimates.

Grenness Estimate Image Difference - Legenda:

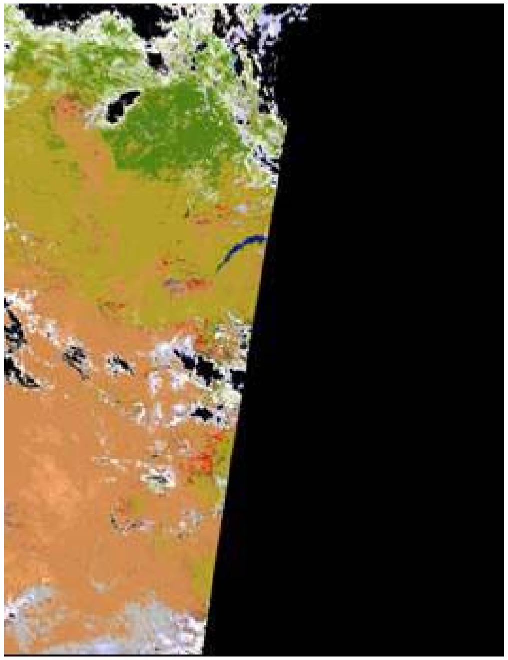
- **< 0: Grenness loss from time t1 to t2 > t1.**
- **> 0: Grenness gain from time t1 to t2 > t1.**

Application domain 4.

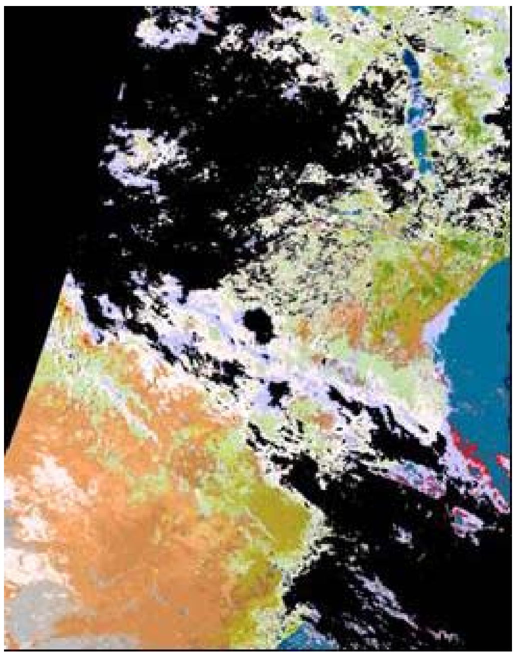
Semantic-based composition of a temporal sequence of classification maps. SPOT-5 VMI imagery. Example e: Zimbabwe.



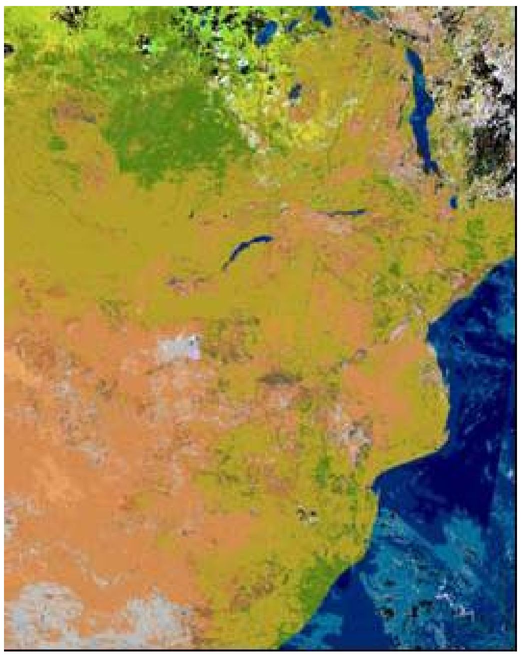
49 spectral category-map, depicted in pseudo colors, generated from a SPOT-5 VMI image of Zimbabwe acquired on 01-12-2006, spatial resolution: 1.1 km.



49 spectral category-map, depicted in pseudo colors, generated from a SPOT-5 VMI image of Zimbabwe acquired on 02-12-2006, spatial resolution: 1.1 km.



49 spectral category-map, depicted in pseudo colors, generated from a SPOT-5 VMI image of Zimbabwe acquired on 31-12-2006, spatial resolution: 1.1 km.

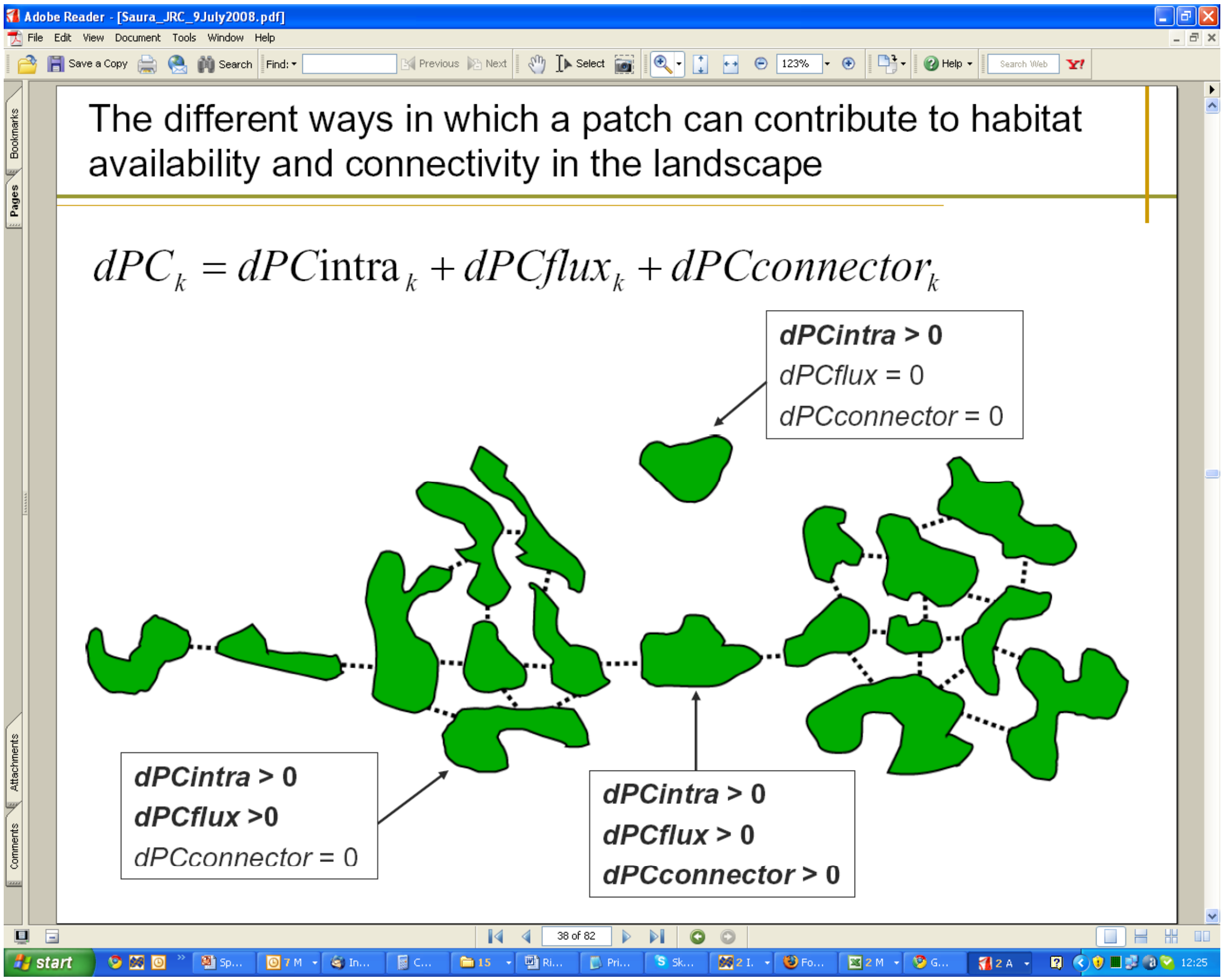


Semantic-based composition of 49 spectral category-maps, depicted in pseudo colors, generated from a sequence of SPOT-5 VMI images of Zimbabwe acquired on Dec. 2006, spatial resolution: 1.1 km.

Application domain 4. Automatic landscape connectivity.

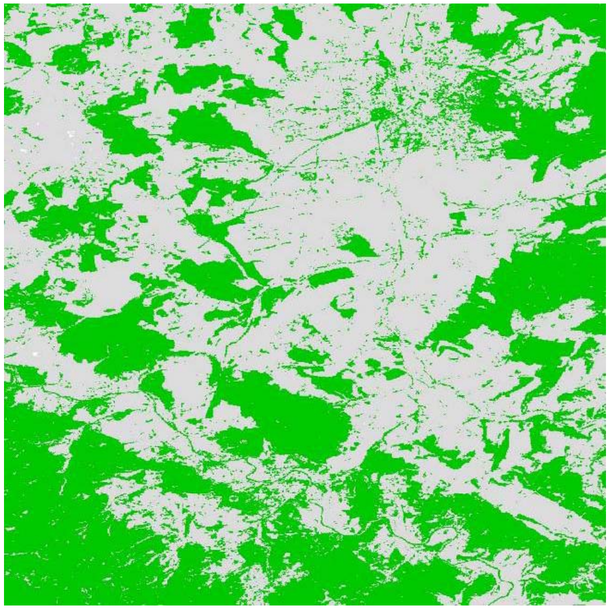
CONEFOR SENSINODE 2.5 software. Available for download from: www.conefor.udl.es

ssaura@eagrof.udl.es, www.udl.es/usuaris/saura

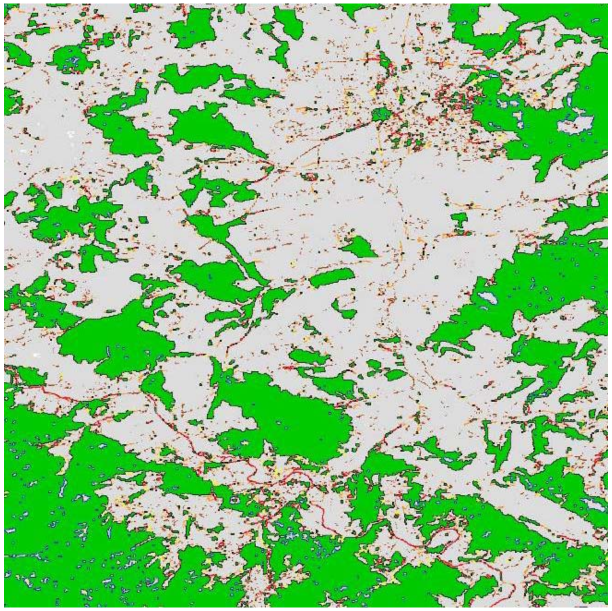


Application domain 4. Automatic landscape connectivity.

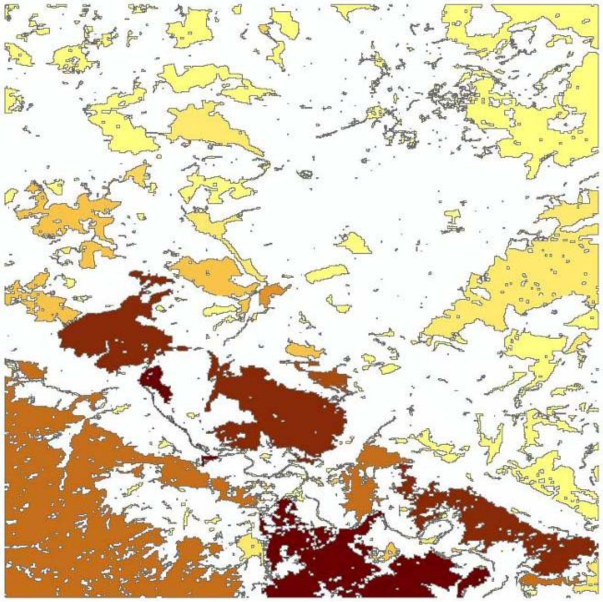
CONEFOR SENSINODE 2.5 software. Available for download from: www.conefor.udl.es
ssaura@eagrof.udl.es, www.udl.es/usuaris/saura



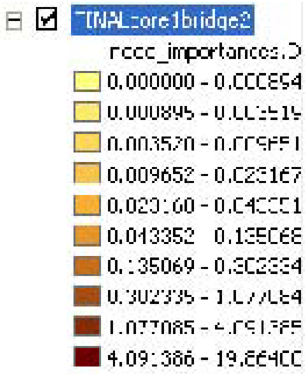
Input information product: binary forest map.



Get cores (patches) and bridges (links) and go into the Conefor Sensinode software.

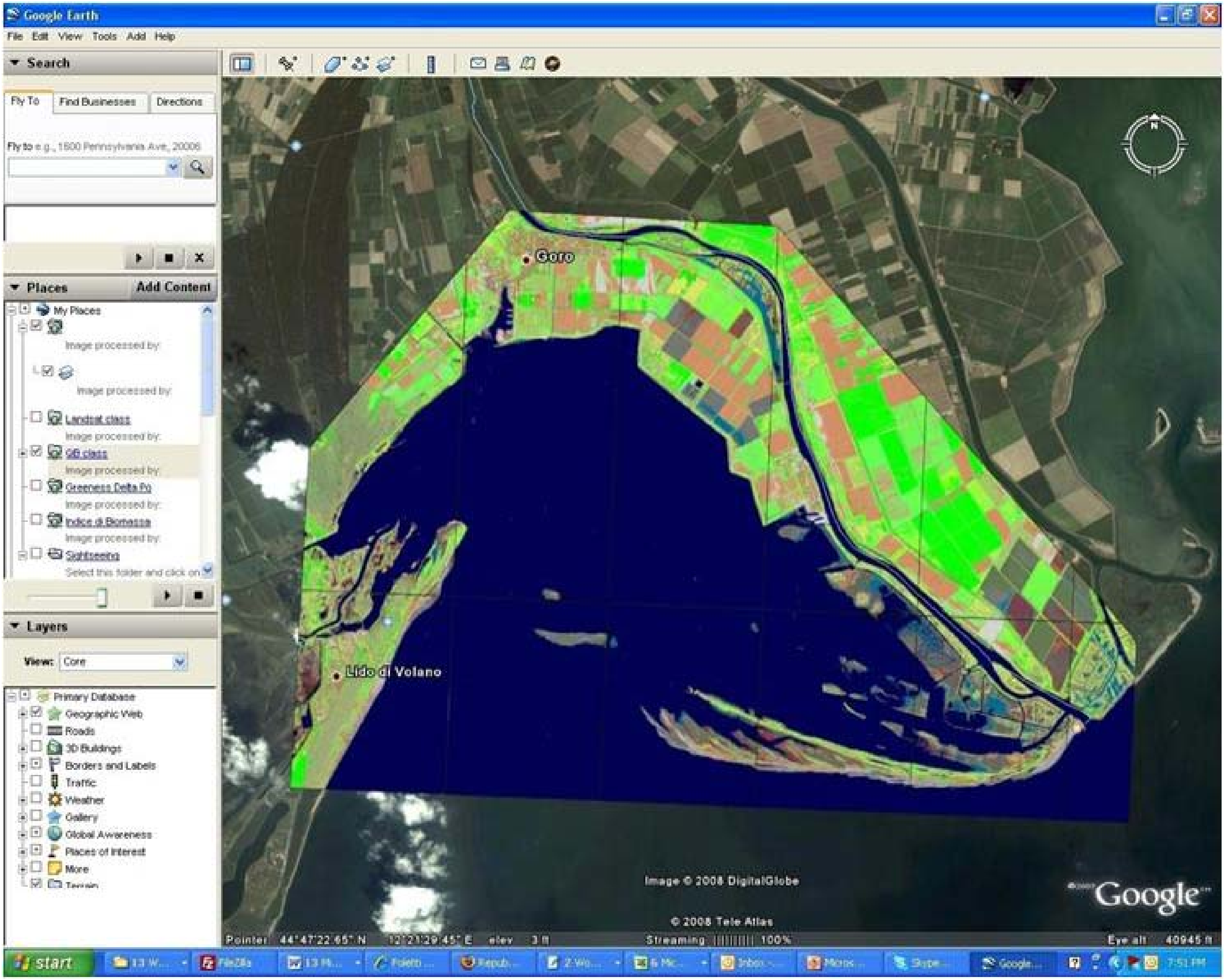


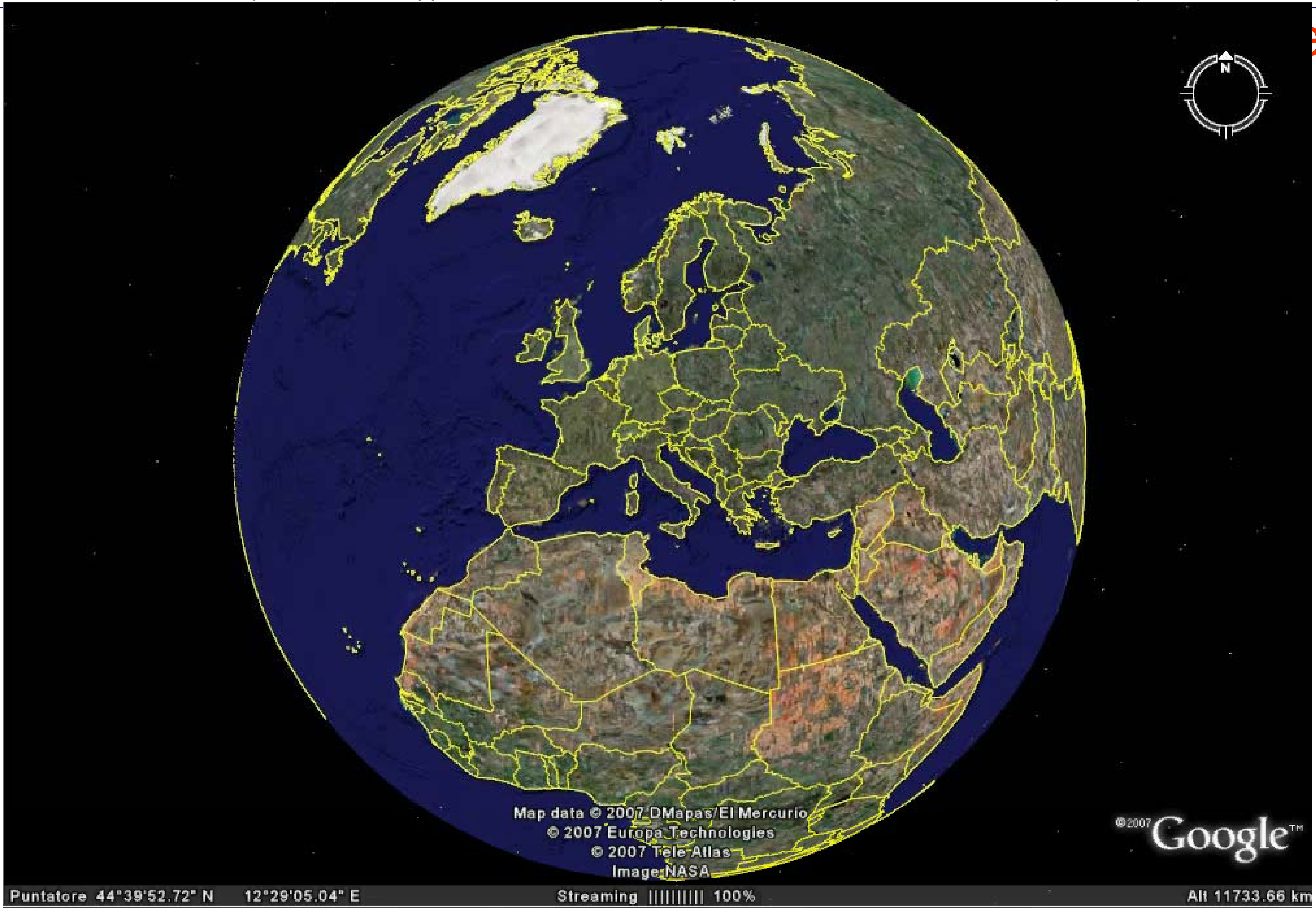
dPCconnector for both cores and bridges.



Application domain 5. Virtual globe-based map visualization/generation on demand.

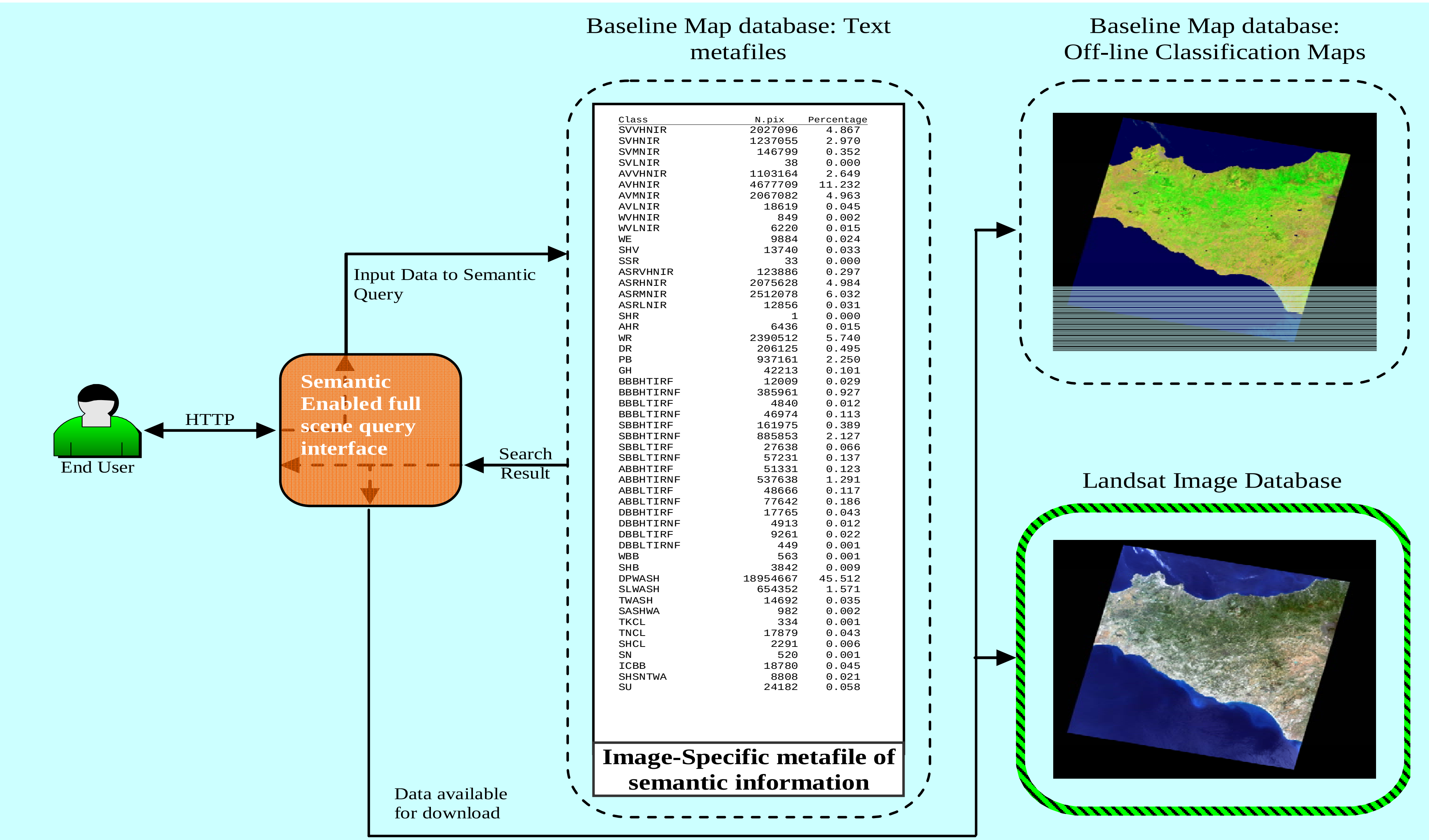
Preliminary spectral map, depicted in pseudo colors, generated from a QuickBird-2 image of the Goro area in the Po river delta, Italy (acquisition date: 2003-05-28, 12:45; spatial resolution: 2.44m), calibrated into TOA reflectance. The map is transformed into the kml data format and, finally, it is loaded as a thematic layer in a commercial 3-D earth viewer (Google Earth).




N
Map data © 2007 DMapas/El Mercurio
© 2007 Europa Technologies
© 2007 Tele Atlas
Image NASA
©2007 Google™
Puntatore 44°39'52.72" N 12°29'05.04" E
Streaming |||||||||| 100%
Alt 11733.66 km

Application domain 5.

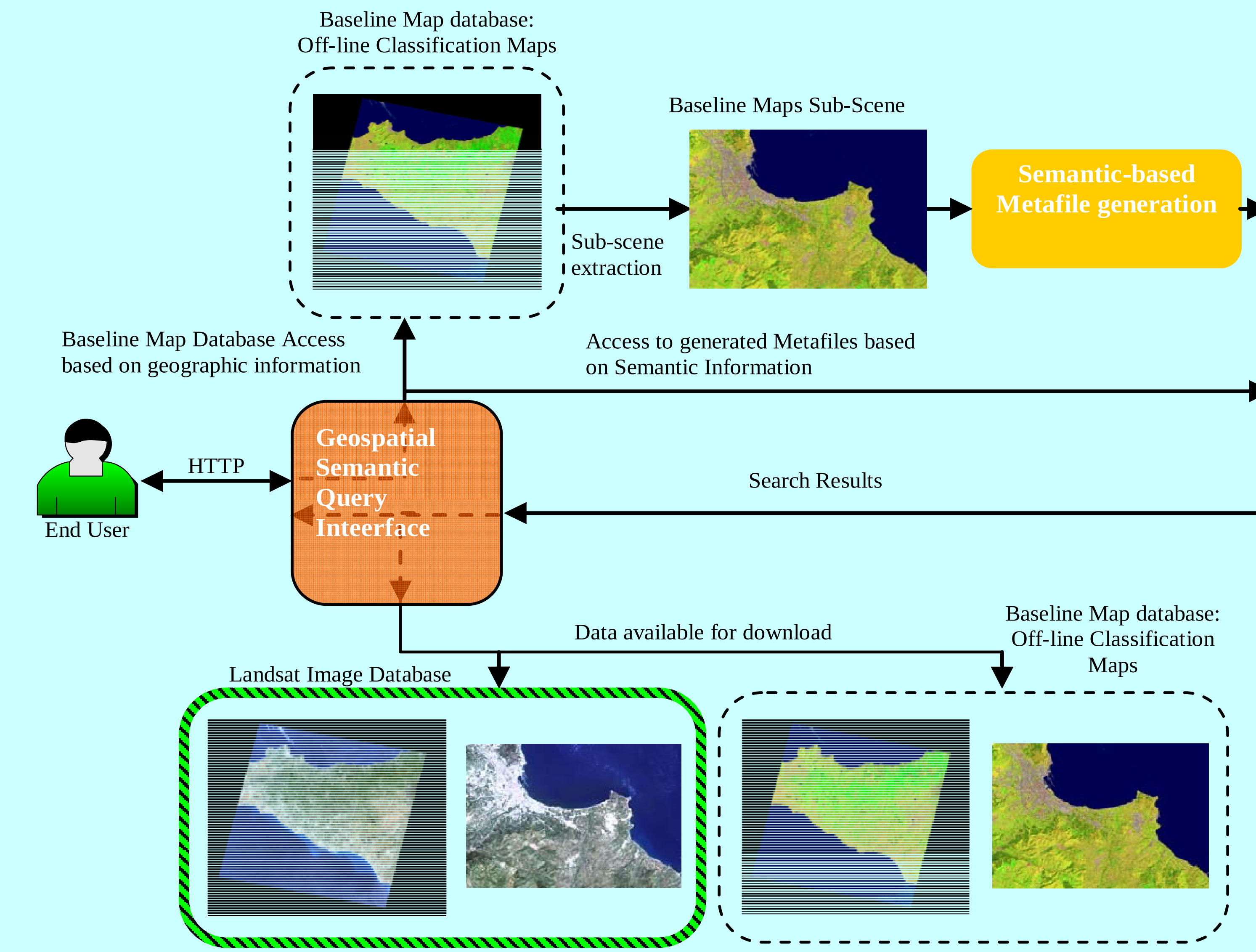
Example b: statistical semantic queries into an image database.



Class	N.pix	Percentage
SVVHNIR	2027096	4.867
SVHNIR	1237055	2.970
SVMNIR	146799	0.352
SVLNIR	38	0.000
AVVHNIR	1103164	2.649
AVHNIR	4677709	11.232
AVMNIR	2067082	4.963
AVLNIR	18619	0.045
WVHNIR	849	0.002
WVLNIR	6220	0.015
WE	9884	0.024
SHV	13740	0.033
SSR	33	0.000
ASRVHNIR	123886	0.297
ASRHNIR	2075628	4.984
ASRMNIR	2512078	6.032
ASRLNIR	12856	0.031
SHR	1	0.000
AHR	6436	0.015
WR	2390512	5.740
DR	206125	0.495
PB	937161	2.250
GH	42213	0.101
BBBHTIRF	12009	0.029
BBBHTIRNF	385961	0.927
BBBLTIRF	4840	0.012
BBBLTIRNF	46974	0.113
SBBHTIRF	161975	0.389
SBBHTIRNF	885853	2.127
SBBLTIRF	27638	0.066
SBBLTIRNF	57231	0.137
ABBHTIRF	51331	0.123
ABBHTIRNF	537638	1.291
ABBLTIRF	48666	0.117
ABBLTIRNF	77642	0.186
DBBHTIRF	17765	0.043
DBBHTIRNF	4913	0.012
DBBLTIRF	9261	0.022
DBBLTIRNF	449	0.001
WBB	563	0.001
SHB	3842	0.009
DPWASH	18954667	45.512
SLWASH	654352	1.571
TWASH	14692	0.035
SASHWA	982	0.002
TKCL	334	0.001
TNCL	17879	0.043
SHCL	2291	0.006
SN	520	0.001
ICBB	18780	0.045
SHSNTWA	8808	0.021
SU	24182	0.058

Application domain 5.

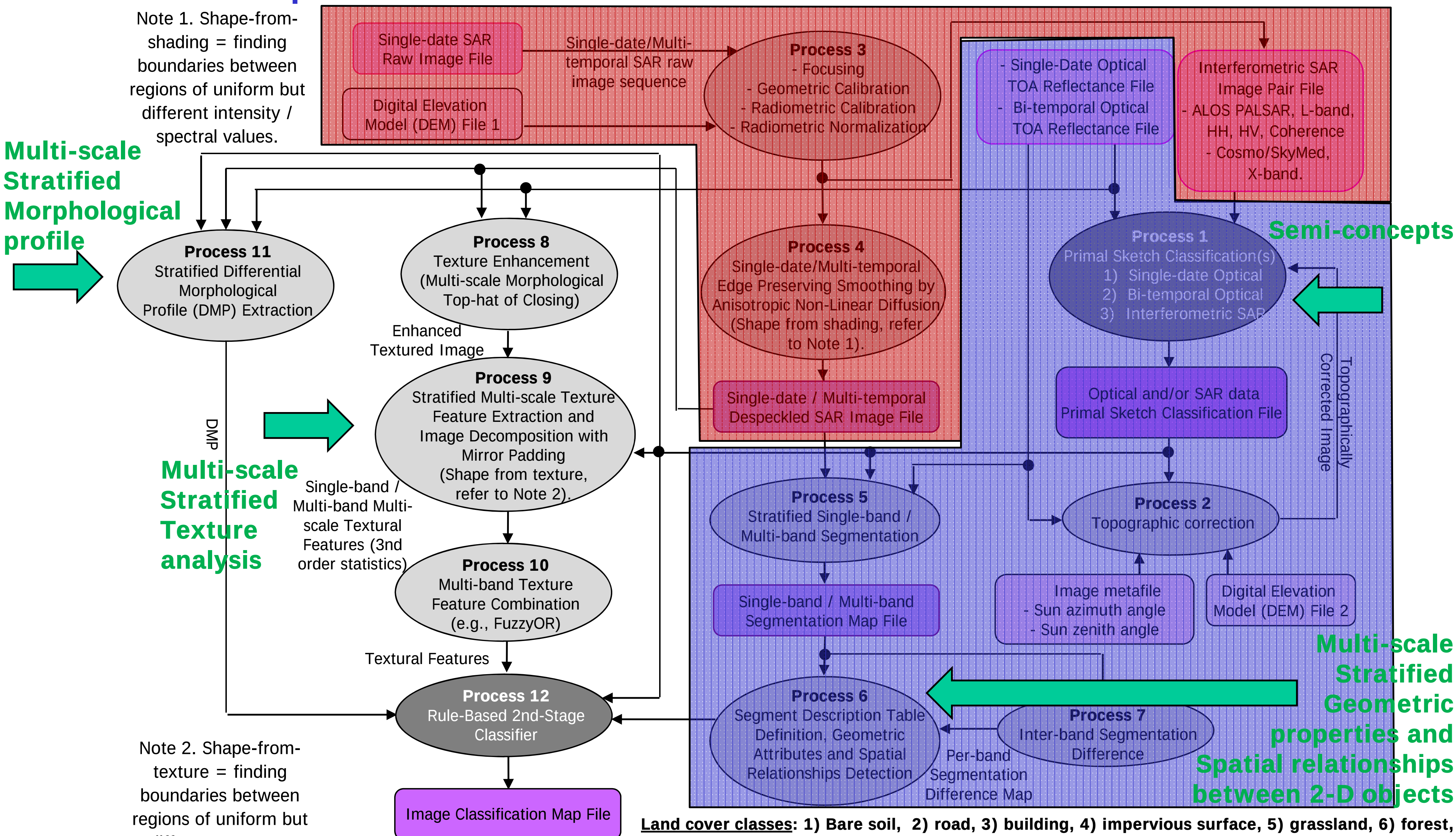
Example b: statistical semantic queries into an image database.



Class	N.pix	Percentage
SVVHNIR	3148	0.439
SVHNIR	3885	0.542
SVMNIR	249	0.035
SVLNIR	0	0.000
AVVHNIR	7103	0.991
AVHNIR	92417	12.893
AVMNIR	74388	10.378
AVLNIR	806	0.112
WVHNIR	1	0.000
WVLNIR	334	0.047
WE	502	0.070
SHV	372	0.052
SSR	1	0.000
ASRVHNIR	557	0.078
ASRHNIR	60080	8.382
ASRMNIR	89367	12.467
ASRLNIR	36	0.005
SHR	0	0.000
AHR	22	0.003
WR	47907	6.683
DR	3859	0.538
PB	10810	1.508
GH	484	0.068
BBBHTIRF	259	0.036
BBBHTIRNF	1250	0.174
BBBLTIRF	1348	0.188
BBBLTIRNF	5282	0.737
SBBHTIRF	2185	0.305
SBBHTIRNF	2320	0.324
SBBLTIRF	6605	0.921
SBBLTIRNF	2737	0.382
ABBHTIRF	4123	0.575
ABBHTIRNF	3678	0.513
ABBLTIRF	17277	2.410
ABBLTIRNF	10593	1.478
DBBHTIRF	410	0.057
DBBHTIRNF	0	0.000
DBBLTIRF	1552	0.217
DBBLTIRNF	1	0.000
WBB	5	0.001
SHB	196	0.027
DPWASH	256620	35.801
SLWASH	757	0.106
TWASH	703	0.098
SASHWA	0	0.000
TKCL	18	0.003
TNCL	974	0.136
SHCL	13	0.002
SN	3	0.000
ICBB	993	0.139
SHSNTWA	141	0.020
SU	429	0.060

Optical-SAR data fusion at the semantic level

Note 1. Shape-from-shading = finding boundaries between regions of uniform but different intensity / spectral values.



Note 2. Shape-from-texture = finding boundaries between regions of uniform but different textures.

<u>Land cover classes</u>: 1) Bare soil, 2) road, 3) building, 4) impervious surface, 5) grassland, 6) forest, 7) agricultural field: i) orchard, ii) vineyard, iii) tilled field, 8) shrubland, 9) water, 10) cloud, 11) snow, 12) shadow.

Automatic optical image SIAM™ classification: Landsat-5 TM,1986.

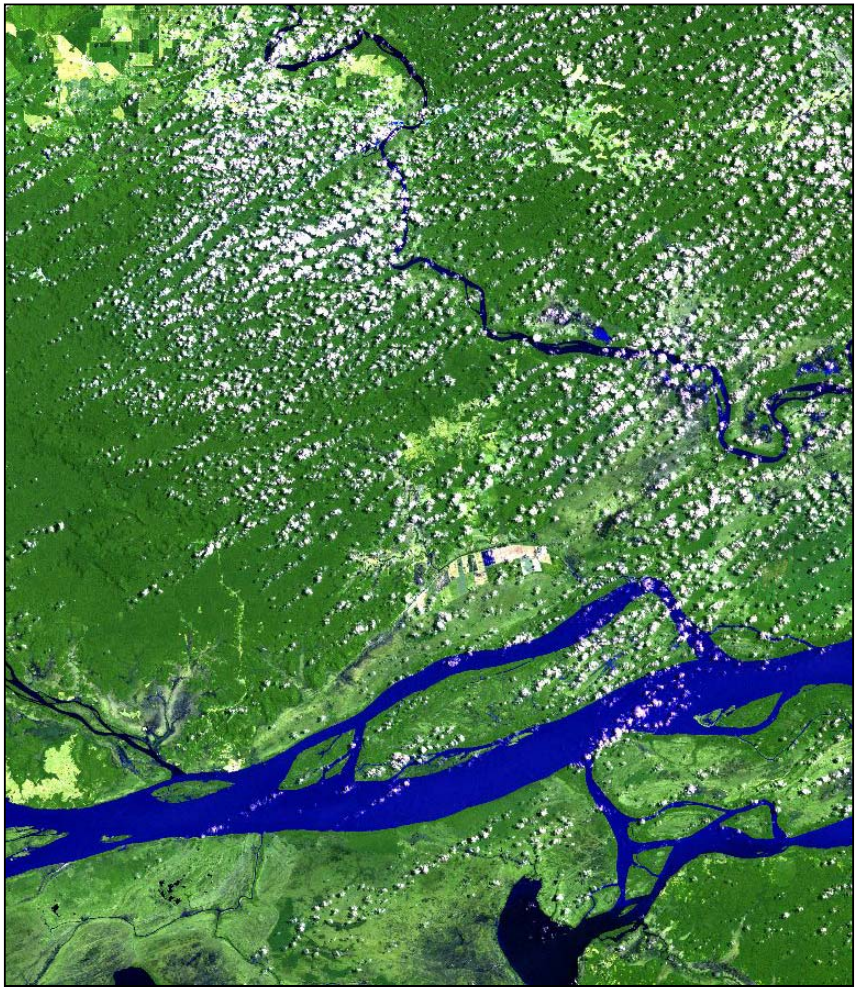


Fig. A. Landsat-5 TM image of Brazilian Amazon (acquisition date: october 1986), depicted in false color (R: band TM5, G: band TM4, B: band TM1) .

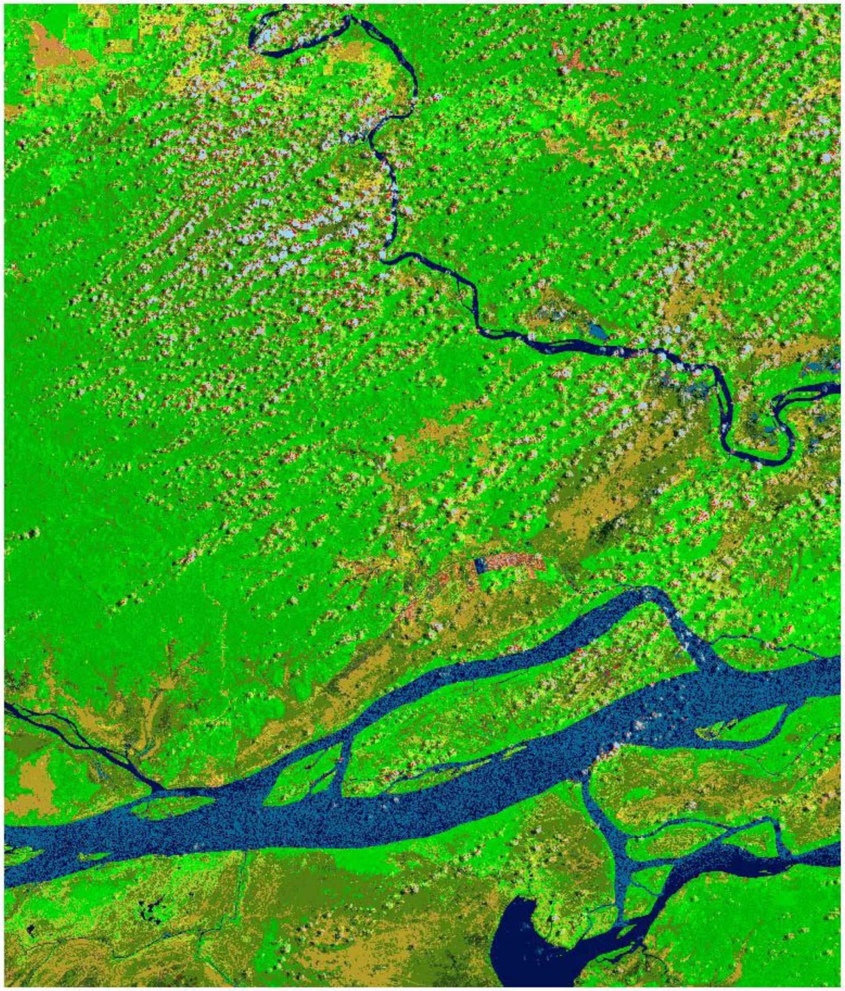


Fig. B. Spectral map generated from Fig. A featuring 49 spectral types (strata, categories), depicted in pseudo colors.

Automatic SAR image rule-based classification:ALOS PALSAR HH/HV, 2007.

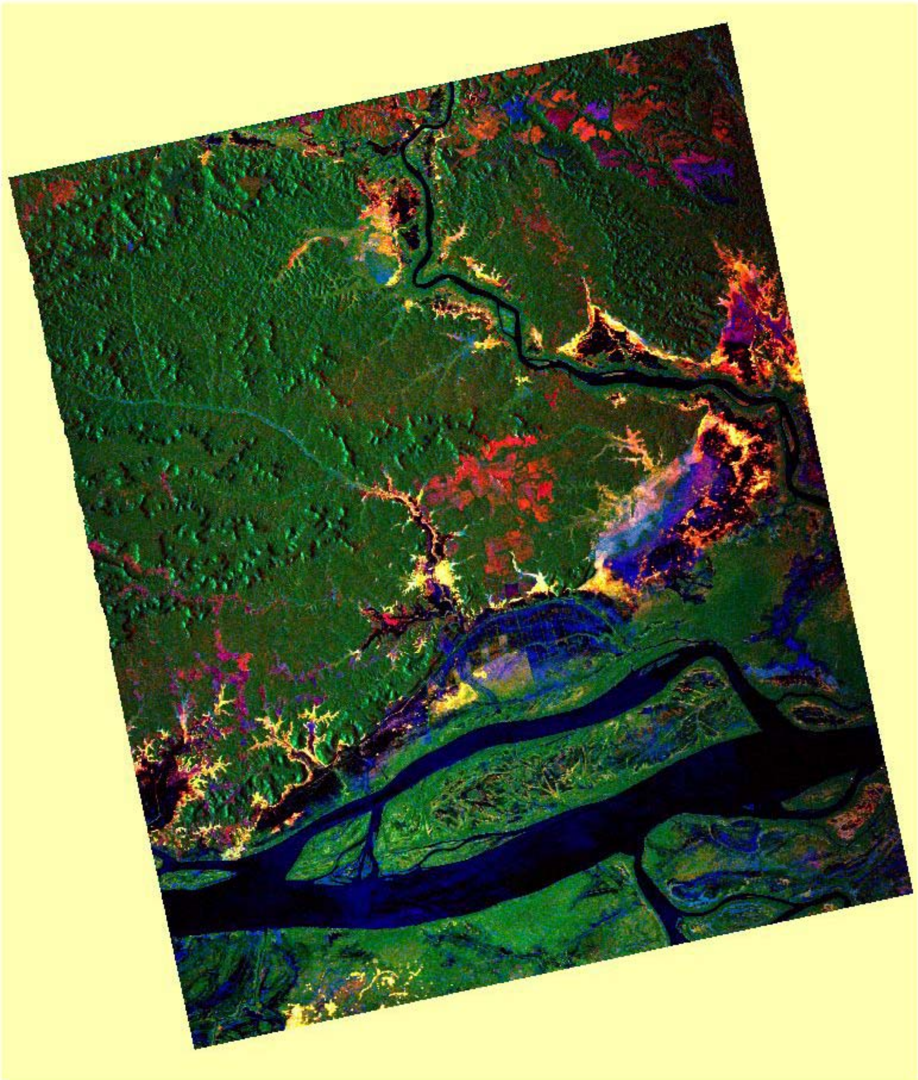


Fig. A. Interferometric ALOS PALSAR HH/HV Dual Polarization (acquisition date: June-Aug 2007) image of Brazilian Amazon (R: coherence, G: average intensity, B: intensity difference).

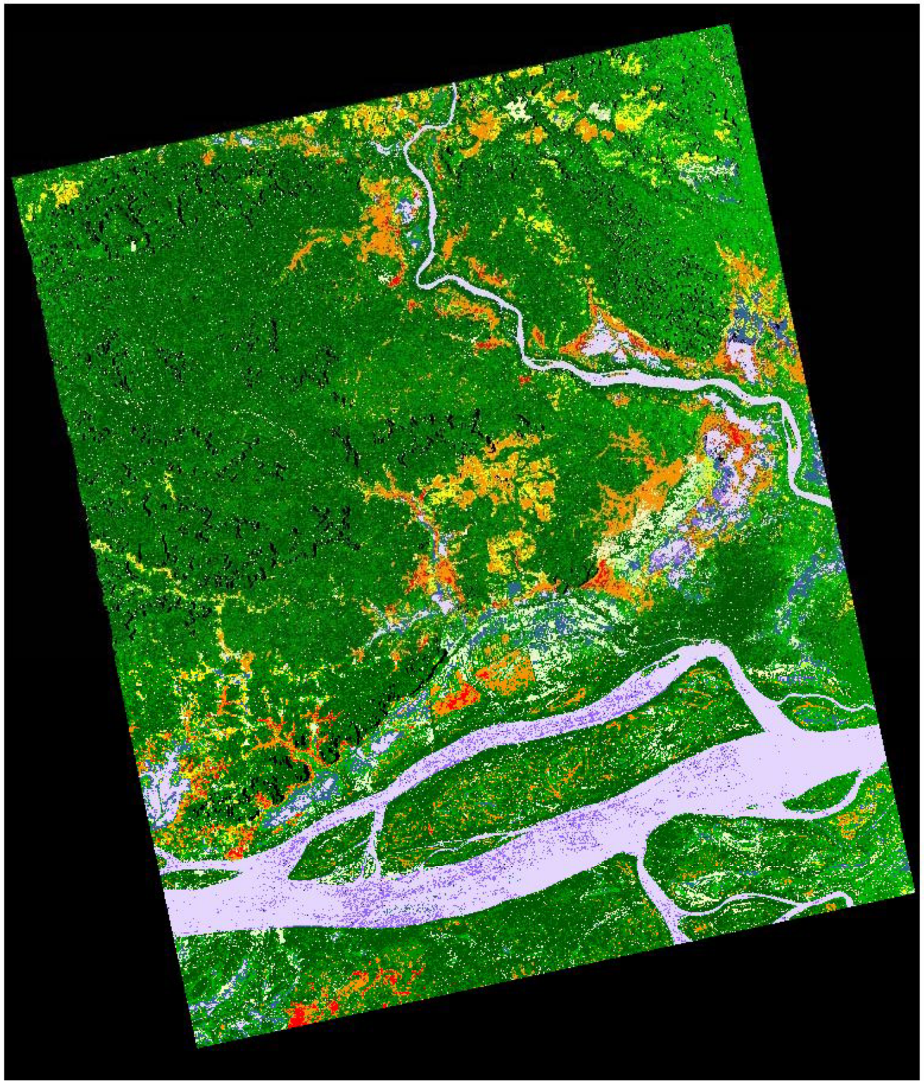


Fig. B. SAR data preliminary classification map of the image shown in Fig. A-

Bi-temporal SAR-optical data change detection: 1986-2007.

Fig. A. Semantic change detection in a SAR-optical data preliminary map pair.

Legend

No Land Cover Change
- Unclassified
- Not applicable
- Water
- Snow / Snowfall
- Swamp / Wetlands
- Forest
- Grassland
- Bare soil
- Urban/Rock

Land Cover Change
- Inundated / Irrigated areas
- Deforestation / Vegetation loss
- Afforestation / Vegetation increase
- Agricultural area
- Potential agricultural area
- New settlements / Soil degradation
- Water body / Wet area loss