Towards operational land cover change monitoring from space

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Abstract

This presentation gives a review of a number of ongoing projects in the European GMES initiative (Global Monitoring for Environment and Security). Institutional user needs are discussed with a view on the adequacy of current and near-future spaceborne observing systems. Methodological approaches using multi-sensor concepts (SAR, scatterometer, optical, thermal) at a range of resolutions are presented.

Introduction

This paper aims at presenting an overview of the current international initiative to move towards an operational monitoring system for land cover change using spaceborne Earth Observation data. It describes the progress made by several EU projects that deal with land cover and vegetation monitoring.

Coarse-resolution (1 km) instruments like AVHRR or SPOT-VEGETATION are limited in their capability of detecting land cover change at the sub-pixel scale. However, fine-scale land cover change can sometimes be detected in coarse-scale imagery (Borak et al. 2000). Medium-resolution (200-500 m) imaging instruments like MODIS and MERIS have their high temporal revisit frequency in common with coarse-resolution instruments. High-resolution (20-50 m) instruments like Landsat ETM+ provide much more spatial detail, at the expense of less frequent coverage. This implies problems in acquiring cloud-free imagery over some regions of the world. Multi-satellite systems like the Disaster Monitoring Constellation and RapidEye address this problem by launching several optical high-resolution satellites into a monitoring constellation that is able to provide daily coverage. Synthetic Aperture Radar (SAR) has a potential role for land cover mapping (Hoekman and Quinones 2000), but the required wavelengths and polarimetric capabilities are not currently operational. SAR penetrates clouds and provides data on temporal changes of the dielectric constant of the target, and its structural properties, which are related to moisture and land cover / vegetation type.

Coppin et al. (2004) provide a comprehensive overview of change detection methods using remote sensing data. These methods can be classified into bi-temporal and temporal trajectory methods. Coppin et al. (2004) describe the following techniques:

- post-classification comparison
- composite analysis
- univariate image differencing
- image ratioing
- bi-temporal linear data transformation using principal components
- multivariate change vector analysis

- image regression
- multi-temporal spectral mixture analysis
- multidimensional temporal feature space analysis
- hybrid schemes.

Global Monitoring for Environment and Security, land cover and vegetation

Global Monitoring for Environment and Security (GMES) is a joint initiative of the European Commission and the European Space Agency. It aims to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security by 2008. Three modules constitute the GMES system:

"1. the production and dissemination of information in support of EU policies for Environment and Security;

2. the mechanisms needed to ensure a permanent dialogue between all stakeholders and in particular between providers and users

3. the legal, financial, organisational and institutional frame to ensure the functioning of the system and its evolution." (source: www.gmes.info)

The European Commission has co-funded a the following GMES projects in the priority area of land cover and vegetation:

- Land cover change in Europe (BIOPRESS, Framework 5)
- Global vegetation monitoring (SIBERIA-2, Framework 5, not funded under specific GMES call, but supporting GMES)
- Global land cover and vegetation (GEOLAND, Framework 6)

In addition, the cross-cutting assessment study BICEPS has carried out a review of all GMES projects and drawn conclusions on the sufficiency and shortcomings of future observing systems.

User needs

The primary users of land cover change information in the context of GMES are a range of European institutions (including the European Environment Agency and Directorate General Environment), national agencies and international organisations (GMES Steering Committee 2004). European information needs are formulated in the 6th Environmental Action Programme. It identifies the priority areas of climate change, biodiversity, environment and health and sustainable use of resources. The global dimension of GMES is addressing the policy needs arising from the World Summit on Sustainable Development in Johannesburg in 2002. This summit identified the need for a coordinated Global Earth Observing "system of systems" (GEOSS) to fill gaps in regional observing systems. This was taken forward by the G8 Summit in Evian in June 2003 and the subsequent Earth Observation Summit in Washington in July 2003, which established the ad hoc Group on Earth Observations (GEO). GEO is developing a 10 year implementation plan for integrating the global observing systems. Besides the environmental mandate, GMES also has a security dimension, which includes civil protection, humanitarian aid and the EU Common Foreign and Security Policy.

While the above organisations are users and funders of Earth Observation, there is a range of organisations in the science community. The International Geosphere-Biosphere Programme (IGBP) is formulating a scientific framework requiring a set of parameters that can be retrieved from space. A number of meta-organisations advise on observation requirements: the Global Terrestrial Observing System (GTOS), the Global Climate Observing System (GCOS), and the Global Oceanic Observing System (GOOS). The Global Climate Observing System (GCOS) has produced the most advanced agreed assessment of observation requirements and gaps in observing capacity. GCOS was established in 1992 to ensure that information needed to address climate-related issues is available to all potential users. GCOS is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). In its “Second Report on the Adequacy of the Global Observing Systems for Climate” (World Meteorological Organisation 2003), GCOS identifies a list of required terrestrial variables that are highly relevant to climate: river discharge, water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally frozen ground, albedo, land cover (incl. vegetation type), fraction of absorbed photosynthetically active radiation (fAPAR), leaf area index (LAI), biomass, and fire disturbance.

Current observing systems

For land cover change monitoring, the following current satellites are operational:

- NOAA AVHRR
- Terra MODIS
- ENVISAT AATSR, MERIS and ASAR
- SPOT-VEGETATION and HRV
- Radarsat-1
- Landsat 7 ETM+
- Disaster Monitoring Constellation
- IRS

The differences in pricing policies often determine which sensors are being used. The breadth of the area of applications of these satellites to detect land cover change depends partially on the availability of repeated observations in comparable modes. Systems with many different imaging modes like the ENVISAT instruments or the planned ALOS mission provide more flexibility for specific local studies, but impact on its capabilities for operational land cover change monitoring. For some instruments, long-term data archives exist that can be exploited for long-term land cover change analysis, particularly for AVHRR (1978 onwards), but also for C-band SAR systems (1991 onwards through ERS-1, ERS-2 and ENVISAT ASAR), and the Landsat series (1972 onwards).

SIBERIA-2

The SIBERIA-2 project develops multi-sensor concepts for the greenhouse gas accounting of Northern Eurasia. It has the overall objective of demonstrating the viability of full carbon accounting on a regional basis using the environmental tools and systems available today and in the near future. A range of data products derived from Earth Observation data will be used to improve the parameterisation of a greenhouse gas accounting scheme:

- land cover and change
- fPAR and LAI
- snow depth
- burned forest area
- vegetation damage caused by industrial pollution
- Af- Re- and Deforestation
- freeze / thaw transitions
- open water bodies

Figure 1 shows an example of land cover change detection from SAR time-series data. The land cover change process of interest in this case study was the death of trees in the prevailing wind direction from the large Nickel smelters in the mining town of Norilsk, Northern Siberia. Different levels of damage were identified, using an earlier map by (Toutoubalina and Rees 1999) as a baseline data set. Deforestation through a forest fire picked up by the MODIS thermal anomaly product can be monitored at higher spatial resolution of 150 m pixel spacing using ENVISAT ASAR (Figure 2). After the fire the radar backscatter signal decreases (darker area). Using SAR together with thermal anomaly data could improve the area estimation of burned forest stands significantly, and lead to a better understanding of carbon dynamics in the boreal biome.

Land cover change in Siberia from post-classification differencing was investigated by Flety (pers. comm.) in the framework of the SIBERIA-2 project. He combined three land cover maps to detect change:

1. IGBP LAND COVER MAP 1992

   Land cover/land use classification data in the IGBP (International Geosphere Biosphere Programme) classes were obtained from http://edcdaac.usgs.gov/glcc/globdoc2_0.html through the European Commission Joint Research Centre (JRC) at a 1 km resolution. This data set was derived from the Advanced Very High Resolution Radiometer (AVHRR) satellite from April 1992 through March 1993. This data set distinguishes 17 classes identified on the basis of the science requirements of the IGBP's core projects (Belward et al. 1999; Loveland and Belward, 1997). The land cover is predominantly determined from satellite derived normalized difference vegetation index (NDVI) composites supplemented by ancillary data including digital elevation data, ecoregion interpretations, country or regional-level vegetation and land cover maps.
2. GLOBAL LAND COVER MAP (GLC) 2000

   The Global Land Cover 2000 database classification data in the 29 classes were obtained from http://www.gvm.jrc.it/glc2000 through the European Commission Joint Research Centre (JRC) at a 1 km resolution. The data set is derived from 1 km resolution SPOT-VEGETATION data acquired between 1 Nov. 1999 and 31 Dec 2000.
3. SWANSEA LAND COVER MAP 2003

> This land cover map was produced by the University of Swansea, UK for the SIBERIA-2 project (provided by Laine Skinner). The map was generated using a network of Russian forest inventory test site data for training, and MODIS data from 2000 for the classification.

While the entire comparison was carried out for 3 million km^2 of Central Siberia, Figure 3 shows a zoom window over a test site in the Angara river basin. The land cover change map between 1992 and 2000 in Figure 3a shows a forest fire scar (arrow) that is picked up as deforestation when comparing the two maps. Between 2000 and 2003 the forest in this fire scar was recovering, and the succession of the vegetation is indicated in the change map in Figure 3b. A visual comparison with the GLC 2000 map shows that the fire scar was also identified by the GLC classification (Figure 3c). The annual burned area map produced by CEH (1992-2003) for the region (Figure 3e) also identifies the forest stand as a fire scar that burned between 1992 and 2000. Figure 3d shows the Swansea land cover map 2003, that classifies the fire scar partly as forest and partly as cropland, which indicates that the forest has started recovering. A validation with a Landsat quicklook confirms the detected fire scar (Figure 3f).

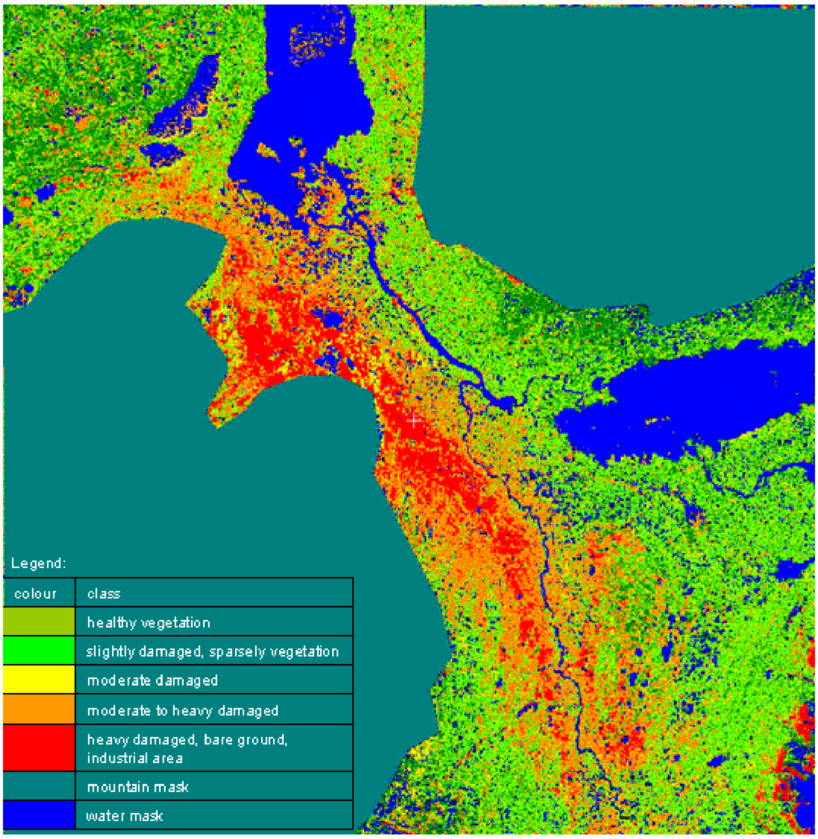
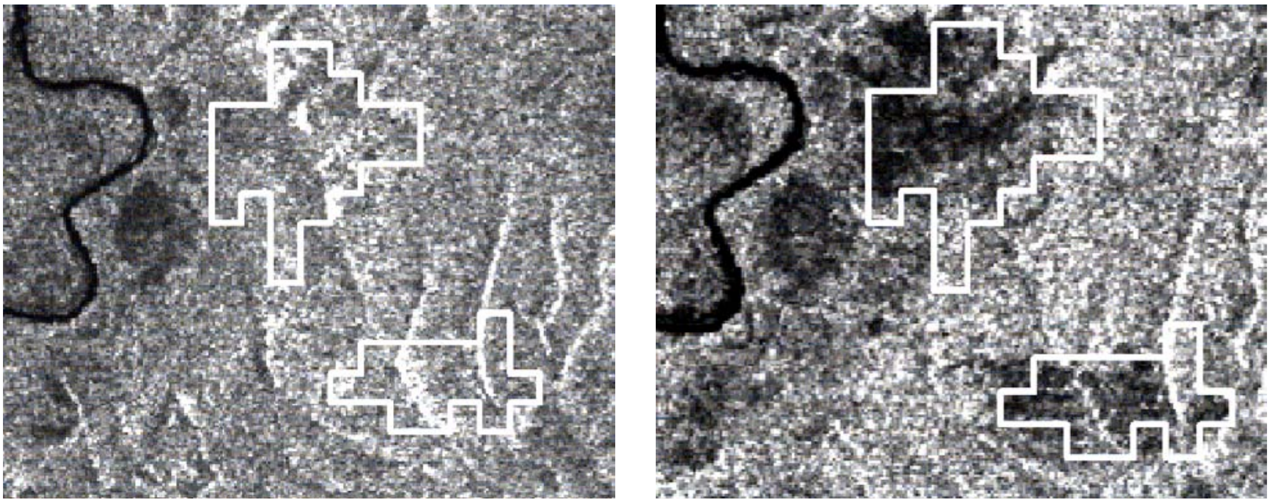


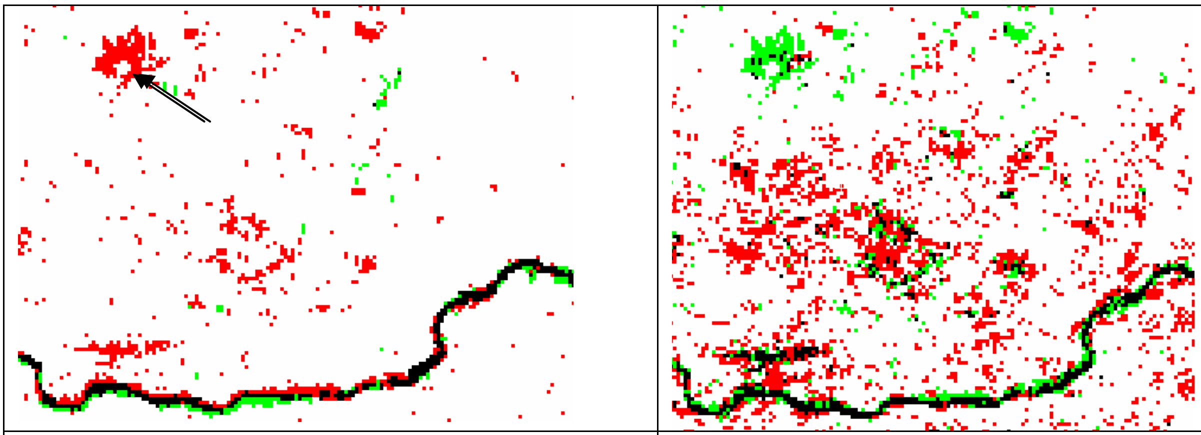
Figure 1. Maximum likelihood classification of ASAR wide swath images from 18/06/03 to 27/08/03 within the Rybnaya valley, in the vicinity of Norilsk, Northern Siberia. From Roscher et al. (2004), CEH, SIBERIA-2 project.



a) 14/07/2003 pre-fire ASAR image

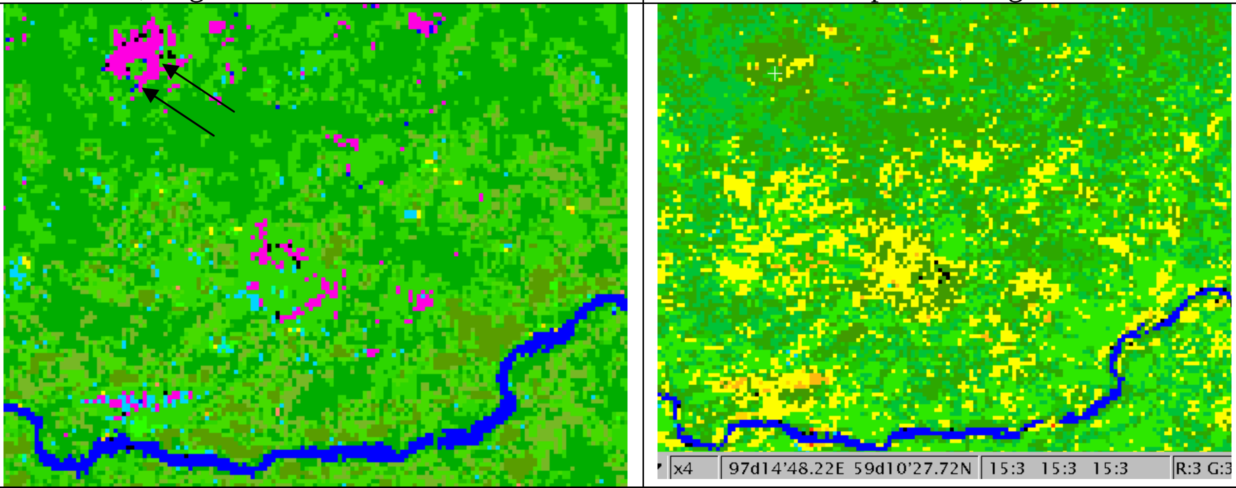
b) 18/08/2003 post-fire ASAR image

Figure 2. Decrease in ASAR backscatter caused by a forest fire occurring between a) 14/07/03 and b) 18/08/03. The white polygons show the burnt area identified using MODIS imagery. From Santoro et al. (2004).



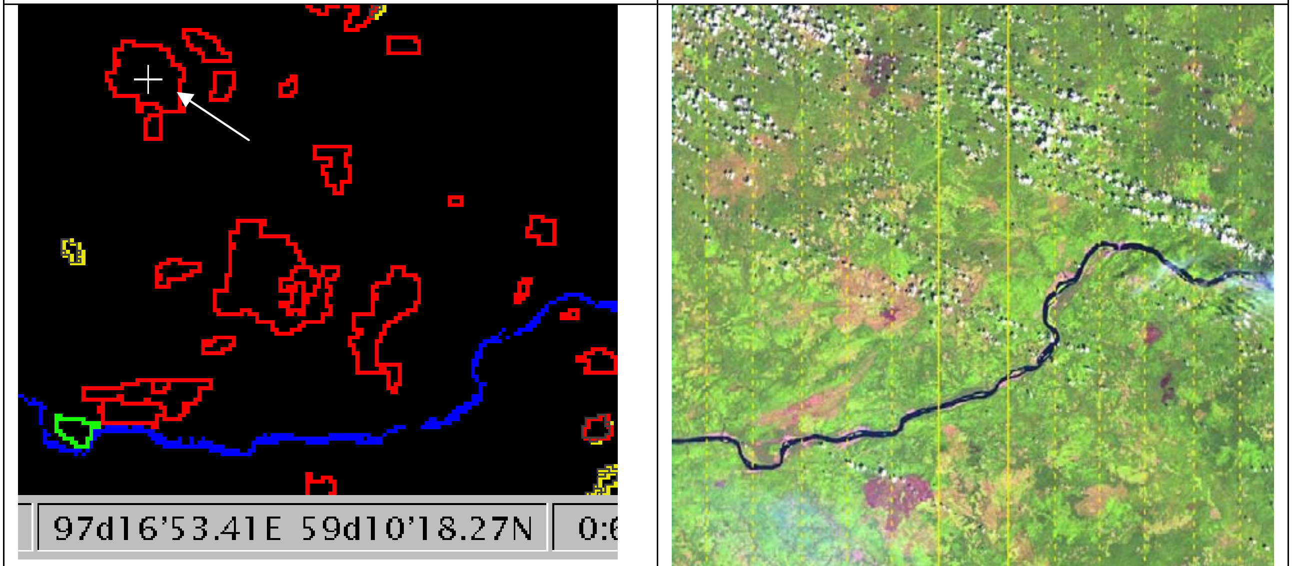
(a) Red is deforestation between IGBP 1992 and GLC 2000, in green reforestation.

(b) Red is deforestation between GLC 2000 and Swansea map 2003, in green reforestation.



(c) GLC2000 map, in purple are fire scars areas, in green forest, and in blue water.

(d) Swansea land cover map 2003, in yellow are croplands, in green forest, and in blue water.



(e) CEH annual burned area map, in red areas burned before 2000, other colours, after 2000. From SIBERIA-2.

(f) Quicklook of Landsat ETM+ SLC 7140019000320051 of the 19/07/2003.

Figure 3: Land cover change map in the Angara River Basin, Siberia. Latitude and longitude of the site are 59d10`18.27N / 97d16`53.41E. Images provided by Yann Flety, CEH.

Issues in performing a cross-tabulation of classes from different land cover maps are the different class definitions, classification methodology, class confusion (e.g. fire scar and cropland) and co-registration accuracy. Synergy between different maps has not yet been fully exploited, but class cross-tabulation at a very aggregated level (few classes) seems to give reasonably robust results. Combining land cover change maps with other remote sensing data products, e.g. burned area maps, thermal anomaly data, high-resolution data, can firm up evidence for change.

BIOPRESS

Driven by the user needs of the European Environment Agency in the BIOPRESS project, its land cover change product has to cover a long time period and high spatial resolution that could only be achieved by using airphotos. BIOPRESS is developing a standardised data product linking measurements of historical (1950-2000) land cover change around European nature protection sites (NATURA2000) to pressures on biodiversity. The change statistics are produced by means of two parallel activities, the backdating of CORINE land cover 1990 of circa seventy five 900 km^2 windows with aerial photography of the 1950'ies and, the interpretation of aerial photography from 1950, 1990 and 2000 for circa fifty 30 km^2 transects. The windows are interpreted to identify the CORINE level 3 land cover and use classes to a minimum mapping unit of 25 ha. The transects, at the other hand, are interpreted to a minimum mapping unit of 1ha and are also interpreted for linear and point features such as hedges, small streams and cluster of houses. Currently, adequate (> 75%) aerial photo coverage of the 1950'ies has been found for 49 windows and 48 transects and the substantial task of geo-coding, mosaicking and interpretation is in full flow. Currently the interpretation of circa 39 windows and 30 transects has been completed. Figure 4 shows, as an example, the location of the seven 900 km^2 windows in the Netherlands for which aerial photo coverage was found. These windows include in total of eight 30 km^2 transects. Photo interpretation of one of the transects revealed how the area surrounding one of the 75 Natura 2000 sites under investigation has been subjected to a substantial amount of urbanisation, and afforestation in the past 50 years (1953 – 1986 – 1998). This particular site contains a mixture of open grasslands, sandy heaths and alluvial forests. The change matrix suggests a natural or artificial encroachment of forests in the surrounding grass- and heath lands which, if not managed adequately, will lead to a continued change in the landscape and its associated biodiversity.

GEOLAND

GEOLAND aims to provide and establish geo-information products and services to support the GMES programme. It utilises available Earth Observation resources, and integrates them with existing models into pre-operational end-user applications. The products and services focus on the monitoring of land cover and vegetation.
Regional services focussed on the implementation of newly established European Directives structured into

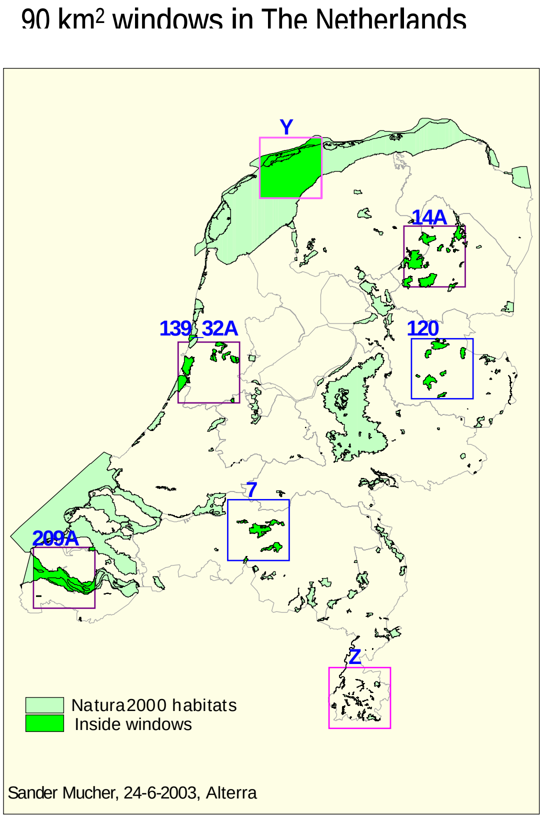
- Nature Protection Observatory addressing the Habitats and Bird Directive, the Ramsar Convention, the Convention on Biological Diversity;
- Water and Soil Observatory addressing the Thematic Strategy for Soil Protection, and the Water Framework Directive;

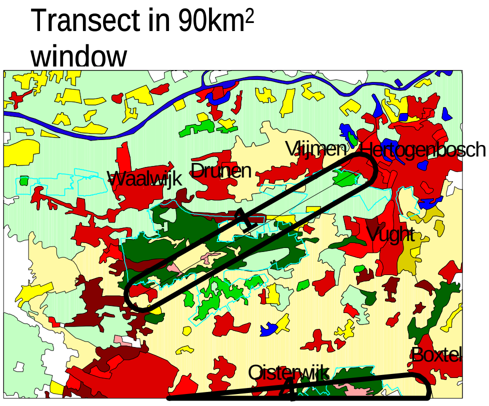
- Spatial Planning Observatory addressing the European Spatial Development Perspective, and the European Spatial Observatory Network;
- Core Service Land Cover supporting the Observatories with cross-cutting land cover and land cover change products.

Global services address international conventions and intergovernmental organisations:

- Natural Carbon Fluxes Observatory addressing the UN Framework Convention on Climate Change,
- Global Land Cover and Forest Change Observatory addressing the UN Forum on Forest, and the Forest and Development Communication of the Commission,
- Food Security and Crop Monitoring Observatory addressing the council regulations on Food Aid Policy, Environmental Measure in Developing Countries,
- Core Service Bio-geophysical Parametres supporting the observatories with cross-cutting parametre products.

The project kicked off in January 2004, with major milestones expected in summer 2005.





11	Urban fabric
12	Industrial, transport
13	Mine, dump, constr.
14	Artificial vegetated
22	Permanent crop
31	Forests
32	Shrub, Herbaceous
33	Open spaces
41	Inland wetlands
51	Inland waters
62	Ambiguous

LC1998

LC1953

	11	12	13	14	22	31	32	33	41	51	62	Total
11	51			8								58
12		3										3
13			0									0
14				5								5
22	1				1							2
31	2	2	1	9		739	23		3		17	795
32	1	3			0	115	59	2			3	182
33						16	39	210				266
41		3				80	8		4			95
51		4								23		27
62	255	46	4	53	23	52	1		0		1435	1868
Total	309	60	4	75	24	1002	131	212	7	23	1455	3302

urbanisation	383	deforestation	28	other changes	8
intensification	43	afforestation	312		

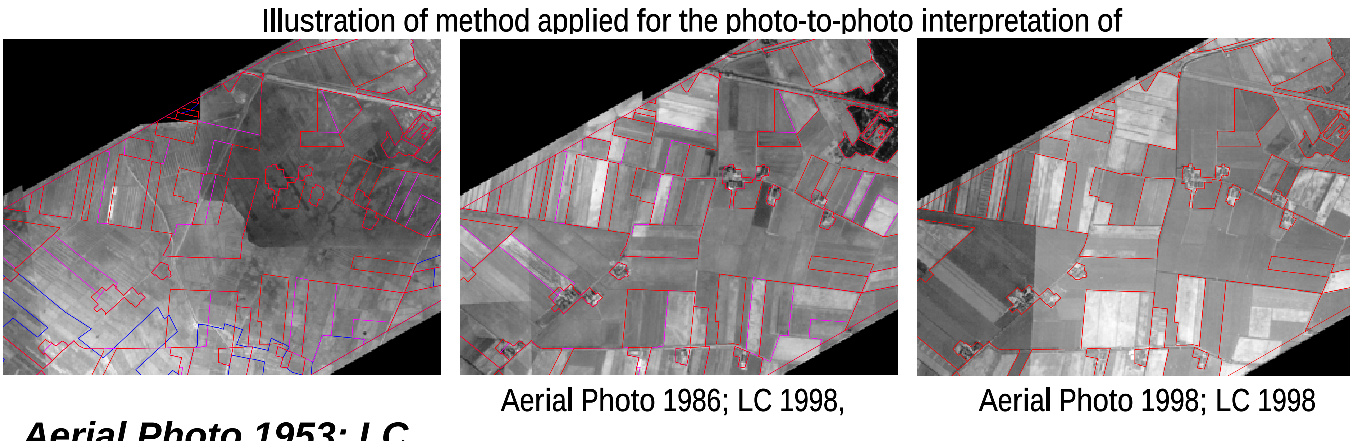


Figure 4: Concept of detecting land cover change around NATURA 2000 sites between 1950 and 2000 using historic aerial photographs. Provided by Sander Mucher and Gerard Hazue from Alterra, The Netherlands.

Conclusions

Land cover change monitoring still requires substantial research and development to operationalise an observing system. While methods for land cover mapping are well developed, detection and attribution of change is a more complex topic. In post-classification comparisons the propagation of classification errors limits the accuracy of land cover change products. However, by aggregating land cover classes into a few major land cover types (e.g. forest, cropland, water) conclusions can be drawn from post-classification analysis. The varying classification legends should be harmonised by using international standards, such as the Land Cover Classification Scheme

(LCCS 2), to describe with a unique identifier how the classification definition relates to other products. Approaches that use regularly acquired time-series image data are currently being developed, and look promising.

The GMES initiative has led to a commitment by the European member states to maintain and develop a capacity of future observing systems to operationally monitor land cover change. Its final report from the Initial Phase states:

- "All-weather imaging capability at high and medium resolutions for land, coastal zones and ice observations in cloudy regions and during night coupled with radar interferometry capability for detection of small (millimetre or sub-millimetre level) ground movements, with the appropriate frequencies and operating modes required to support the GMES services. This is needed in support of disaster management, urban management and security, humanitarian aid and conflict crisis management, coastal zone pollution monitoring and ice surveillance;
- High (10 meters) to medium (200 meters) spatial resolution, wide field-of-view, multispectral and multi-directional optical imagery for global / regional observations over land and ocean surface. This is needed in support of global vegetation (including forestry) and biosphere monitoring, coastal zone water quality management, coastal surveillance, disaster management and humanitarian aid..." (GMES Steering Committee 2004).

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