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**MULTITEMPORAL ANALYSIS OF SATELLITE IMAGERY:  
IMPLEMENTATION OF A LAND EVOLUTION MODEL IN ALCS  
(AATSR LAND CLASSIFICATION SYSTEM)**

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# Sommario

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In questa relazione è stato progettato un innovativo approccio di studio multi temporale di immagini satellitari e la sua applicazione nel monitoraggio delle zone umide irachene (Iraq Marshland), allo scopo di valutare il ripristino della situazione idrica e lo sviluppo della vegetazione su questi territori. Durante questo lavoro di tesi, svolto in collaborazione con MEEO Srl, è stato utilizzato il sensore satellitare (A)ATSR per raccogliere dati relativi a differenti periodi di studio compresi nella decade 2000-2009. La metodologia utilizza un approccio pixel-based, basato sull'acquisizione di immagini del satellite ESA ENVISAT seguita da una classificazione spettrale del suolo con SOIL MAPPER ® a 75 classi; tutto è stato sviluppato e applicato operando sui dati classificati accessibili via web dal catalogo del Service Support Environment Portal (SSE), supportato dall'Agenzia Spaziale Europea (ESA). L'inondazione delle paludi irachene, che si è protratta a partire dall'aprile 2003 in gran parte in relazione ad interventi susseguitisi sul territorio, è caratterizzata da un elevato grado di variabilità e da un alto livello di incertezza nella valutazione dei cambiamenti. Tenuto conto dei vincoli legati a fattori di sicurezza, della vastità delle paludi irachene interessate dal fenomeno ed infine delle risorse economiche disponibili, il telerilevamento satellitare è apparso l'unico strumento praticabile per osservare e documentare in modo oggettivo i cambiamenti che sono avvenuti in modo continuativo nel corso degli anni. Il sistema proposto (ALCS - AATSR LAND CLASSIFICATION SYSTEM) evita l'uso diretto delle immagini acquisite dal sensore AATSR ma prevede l'applicazione di modelli di evoluzione di Land Use and Land Cover Change (LULCC) a serie temporali di mappe classificate, non pesanti in termini di dimensioni e semanticamente comprensibili. Questo approccio è stato reso possibile dalla disponibilità di un importante database di 13 anni di immagini classificate, concepite e realizzate per il progetto CARD dell'ESA (<http://earth.esa.int/rtd/Projects/#CARD>). L'approccio qui presentato si evolve verso un metodo innovativo, efficace e veloce per sfruttare le potenzialità di analisi multi-temporale LULCC di immagini AATSR classificate. I due principali obiettivi di questo lavoro sono orientati allo sviluppo di criteri di valutazione: da un lato interessa verificare la funzionalità del prototipo ALCS in termini di validità concettuale e operatività dell'applicazione web, dall'altro, entrando nel merito del caso di studio indagato, interessa valutare con riscontri oggettivi l'entità, il carattere e l'estensione della riabilitazione delle zone umide.

# Abstract

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In this report it was designed an innovative satellite-based monitoring approach applied on the Iraqi Marshlands to survey the extent and distribution of marshland re-flooding and assess the development of wetland vegetation cover. The study, conducted in collaboration with MEEO Srl , makes use of images collected from the sensor (A)ATSR onboard ESA ENVISAT Satellite to collect data at multi-temporal scales and an analysis was adopted to observe the evolution of marshland re-flooding. The methodology uses a multi-temporal pixel-based approach based on classification maps produced by the classification tool SOIL MAPPER ®. The catalogue of the classification maps is available as web service through the Service Support Environment Portal (SSE, supported by ESA). The inundation of the Iraqi marshlands, which has been continuous since April 2003, is characterized by a high degree of variability, ad-hoc interventions and uncertainty. Given the security constraints and vastness of the Iraqi marshlands, as well as cost-effectiveness considerations, satellite remote sensing was the only viable tool to observe the changes taking place on a continuous basis.

The proposed system (ALCS – AATSR LAND CLASSIFICATION SYSTEM) avoids the direct use of the (A)ATSR images and foresees the application of LULCC evolution models directly to ‘stock’ of classified maps. This approach is made possible by the availability of a 13 year classified image database, conceived and implemented in the CARD project (<http://earth.esa.int/rtd/Projects/#CARD>).The approach here presented evolves toward an innovative, efficient and fast method to exploit the potentiality of multi-temporal LULCC analysis of (A)ATSR images.

The two main objectives of this work are both linked to a sort of assessment: the first is to assessing the ability of modeling with the web-application ALCS using image-based AATSR classified with SOIL MAPPER ® and the second is to evaluate the magnitude, the character and the extension of wetland rehabilitation.

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# 1 Multitemporal Analysis and Cover Change

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## 1.1 Introduction

To understand recent changes in the Earth system, the scientific community needs quantitative, spatially-explicit data on how land cover has been changed by human use. Such data can be generated through a dual approach: based on direct or indirect observations, for the regions and time slices for which such data exist, and based on projections by models.

To generate scenarios on future modifications of the Earth system, one has to project how changes in land use are likely to affect land cover in the future using integrated land-use change models. Measurements of past rates and spatial patterns of land-cover changes can be derived from: maps and indirect evidence on past land cover, for the historical period, paleo records for a more distant past, and remote sensing based data for the recent past (last 30 years). As none of these measurements can be produced at the global scale with the required level of detail and accuracy, some spatial sampling scheme needs to be put in place. Two approaches are to be pursued: definition of a typology of «land-use situations» and sampling of case studies which are representative of these situations, identification of critical regions or «hot spots» of change (whether these are defined in terms of rates of change or in terms of the vulnerability, ecological value or socio-economic sensitivity of the region affected by land-cover change).

The modelling of land-use change can be performed along two tracks:

- Empirical, diagnostic models based on an extrapolation of the patterns of change observed over the recent past, with a limited representation of the driving forces, and
- Dynamic integrated models based on an understanding of the processes of land-use change.

Diagnostic models integrate landscape variables and proximate causes of change in a data-rich spatial context. However, they can only provide short-range projections (5 to 10 years at most) due to non-stationarity in land-use change processes.

Longer range projections require an understanding of major human causes of land-cover changes in different geographical and historical contexts, as well as an understanding of how changes in climate and global biogeochemistry affect land use and land cover. Such understanding is gained through a collection of case studies of land-use dynamics, which highlight how land-use decisions are made. A generalized understanding of the drivers of land-use change, that can be linked to patterns of change at the regional scale, is gained through comparative analysis of these case studies.

Models of land use at regional to global scales include a representation of economy-environment linkages. They have to cope with such issues as heterogeneity and scales, technological innovations, policy and institutional changes, and rural-urban dynamics. Regional scenarios and assessments can be generated for projecting future land-use changes or for identifying land-use patterns with certain optimality characteristics. These models are used to evaluate the impact of policy or climate change on land use.

Creating a new generation of spatially-explicit land-use change models is another major challenge.

In addition, there are crucial human dimension questions related to land-use change that justify research aimed towards a better understanding of processes of land-use change in its own right. These questions are: How do human and biophysical dynamics affect the sustainability of land uses? And how do land uses and land covers affect the vulnerability of land users in the face of change? How do land-cover changes in turn impinge upon and enhance vulnerable and critical regions? Issues of human responses to land cover changes also need to be considered.



## **1.2 The overall objectives of LULCC**

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### **1.2.1 Research benefits**

The measures of success from Land Use and Land Cover Change science will be many and varied. One of the major benefits and measures of progress will be the establishment and operation of viable scientific networks around specific components of the Science Research Plan. In this way, scientists from both social and natural sciences will be able to gain access to improved local, regional and national data sets. Methodologies will be enhanced and scientific peer reviewed contributions will emerge. These networks are a vital way of gaining entry into global change science, particularly for those scientists from developing countries. A measure of success may thus be the degree to which such scientists have been able to contribute and enhance land-use/land-cover change science from those regions that may well be sensitive land-use/land-cover change areas in the future. Through the networks, other measures of success will include the production and development of integrated and comprehensive models for future assessment of transitions to sustainability, and the identification of criteria for evaluating success (failure) of various land-use/cover and land-use change scenarios. The identification of research gaps and areas where the science is lacking will also be a useful yardstick by which to measure land-use/land-cover change science. In these ways, land-use/land-cover change scientists will be able to offer a science which may be relevant to policy makers but also provide tangible, measurable benefits from the products of the research to a variety of scientists working both on landuse/ land-cover change and other related research issues.

## 1.2.2 The various approaches of LULCC

The level of integration and synthesis in research on land-use/land-cover change requires a combination of perspectives of understanding: namely the narrative, the agent based, and the systems approach. The narrative perspective seeks depth of understanding through historical detail and interpretation. It tells the LULCC story, providing an empirical and interpretative baseline by which to assess the validity and accuracy of the other visions. It is especially beneficial in identifying stochastic and random events that significantly affect land-use/land-cover changes but might be missed in approaches employing less expansive time horizons or temporal sampling procedures. Both the agent-based and the systems approaches depend on explicit model development and empirical testing.

The narrative, agent-based, and systems/structures-perspectives can be and are combined in various ways and need not be constrained to a particular explanatory genre.

It is within this cooperative spirit that the LULCC Science Plan and associated research foci have been framed, addressing research questions through interlocking strategies that differentially rely on the three perspectives and take advantage of the full range of LULCC practitioners.

“ Equally, the LULCC research agenda is building on, and needs to combine, three epistemological traditions: to observe and describe (i.e. inductive approach); to model (i.e. deductive approach); and to integrate (i.e. dialectic approach). The richness of land-use/ land-cover change research stems from its position at these multiple interfaces between different scientific traditions. Its main challenge is to integrate them to increase our understanding of a major aspect of human-environment interactions. “

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### **1.2.3 Key Tasks and Activities**

Three interlocking strategies are encapsulated in the research Focus of LULCC. These are:

Focus 1      Development of case studies to analyze and model the processes of land-use change and land management in a range of generalized global situations;

Focus 2      Development of empirical, diagnostic models of land-cover change through direct observations and measurements of the explanatory factors;

Focus 3      Utilization of analysis from Focus 1 and 2 for the development of integrated and prognostic regional and global models.

<b>FOCUS 1</b>	<b>FOCUS 2</b>	<b>FOCUS 3</b>
Land-Use Dynamics	Land Cover Changes	Regional and Global Models
Comparative Analysis	Direct observations and diagnostic models	Integrative assessments
<b>ACTIVITIES</b>	<b>ACTIVITIES</b>	<b>ACTIVITIES</b>
1.1 Understanding landuse decisions	2.1 Land-cover change, hot-spots and critical regions	3.1 Review and comparison of past and current regional modelling studies
1.2 From process to pattern: linking local land-use decisions to regional and global processes	2.2 Socializing the pixel	3.2 Major issues in methodologies of regional land-use/land-cover change models
1.3 Sustainability and vulnerability scenarios	2.3 From patterns to processes	3.3 Land-use/land-cover change and the dynamics of interrelated systems
		3.4 Scenario development and assessments of critical environmental themes

**Table 1-1 : Key Task and Activities Focus**

Each group of Focus Activities is trying to answer the same science questions formulated above but from a different scientific perspective and at different scales. Each Research Focus also incorporates activities that create the linkage with other perspectives and scales of analysis. The LULCC Implementation Strategy is an attempt to engage different scientific communities (e.g. human ecologists, land economists, remote sensing/geographic information system specialists, land-use/land-cover change modellers, scientists engaged in integrated assessment) to work together. The Focus Activities represent the natural entry point for these communities. Through the set of Activities and Tasks in each Focus, these communities are brought together.

Links between Foci are of particular importance: local to regional scale studies of land-use and land-cover dynamics (Foci 1 and 2) to inform the construction of integrated models (Focus 3); spatially-explicit analyses in Focus 2 to provide a spatial framework to the integrated models (Focus 3); regional-scale land-cover change projections (Focus 3) to provide contextual information to the understanding and projection of fine scale land-use dynamics (Focus 1); validation at the fine scale (Foci 1 and 2) of broad scale projections (Focus 3); and investigation of the scale-dependency of the relationship between driving forces and rates of land-cover changes (Foci 1, 2 and 3). Moreover, there are a number of methodological issues that are cross-cutting the three Foci - e.g. multi-scale approach, integration of spatial and socio-economic heterogeneity, and assembly of appropriate biophysical and socio-economic spatially explicit databases. As LULCC is exploring new grounds at the interface between social and natural sciences, it requires a number of methodological research and/or workshops.

### **1.3 The three Big Issues groups**

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The three “big issues” identified below represent the range of themes that draw diverse research communities to engage in an expanding LULCC

science. They are provided as examples that give meaning to the specific Activities and Tasks. The study in question refers in particular to the 2nd focus, about Critical regions and Vulnerable places.

### 1.3.1 Transition to a sustainable world

With origins in the Brundtland report and increasingly embedded in global change science agendas, the overarching concern is achieving this provisioning in a warmer, more crowded, and more resource demanding world characterized by unexpected and extreme events.

	<b>Transition to a Sustainable World</b>	
<b>FOCUS 1</b>	<b>FOCUS 2</b>	<b>FOCUS 3</b>
Activity: Understanding land-use decisions		Activity: Major issues in methodologies of regional land-use/landcover change models Activity: Land-use/land-cover change and the dynamics of interrelated systems  Activity: Scenario development and assessments of critical environmental themes
Task : Simulation Modelling of land-Use land-Cover change to identify sustainable future scenarios	Task : Definition of land-cover change indicators	

**Table 1-2 : Sustainable World**

Sustainability involves a balance between the environmental, economic and social dimensions of society. Unsustainable systems are those for which growing environmental degradation eventually surpasses society's ability to substitute productive systems or to intervene to control or mitigate the damage. Strategic environmental assessment, with its aim of focusing human impacts on specific places, thereby reducing stressors on others, cannot be effectively undertaken without serious land-use/land-cover change assessment.

### **1.3.2 Biogeochemical cycles and biodiversity**

LULCC studies also inform baseline assessments from which the degree of modification and transformation of landscapes are determined and hold the promise to establish measures of the human impact on natural landscape. LULCC examines the behaviour and structures of human populations in regard to how they value biodiversity and environmental change more generally as expressed through their landscape systems. Economic, political, and social considerations loom large in these analyses. LULCC is currently recognized as one of critical gaps in our knowledge of the terrestrial carbon cycle which in turn has implications for the rate of greenhouse gas accumulation in the atmosphere and potential climate change. LULCC contributes key knowledge to the processes that result in landscape transformation, including fragmentation and degradation. As such, land-use/land-cover change becomes a key driver of changes in biodiversity.

	<b>Biogeochemical cycles and biodiversity</b>	
<b>FOCUS 1</b>	<b>FOCUS 2</b>	<b>FOCUS 3</b>
Activity : From process to pattern: linking local-land use decisions to regional and global processes	Activity : Socializing the pixel	Activity: Major issues in methodologies of regional land-use/land cover change models  Activity : Land-use/land-cover change and the dynamics of interrelated systems
Task : Identify key biogeochemical and climate variables associated with changes in land cover over long time periods	Task : Monitoring biophysical and socio-economic variables	Task : Water issues in regional land-use/land-cover change

**Table 1-3 : Biogeochemical cycles and biodiversity**

### **1.3.3 Critical Regions And Vulnerable Places**

Environmental change does not affect all places similarly Central to the big issues above is the identification and understanding of dynamics giving rise to vulnerable people and places in the face of global change. Whether involving land fragmentation, degradation of agricultural productivity, declines in economic well being, or involuntary human migration, land-use/land-cover change plays an important role. Further work is needed on the identification of critical land-use/land-cover change regions and the dynamics giving rise to them. This emphasis examines the vulnerability



and resiliency of people, infrastructure, production systems or biodiversity rich “hot spots” in the face of trends such as sea-level rise, increased frequency of extreme storm events, and chronic land degradation.

These “big issues” and the themes embedded in them demand a new generation of spatially explicit, integrated land-use/land-cover change models of the kind which the LULCC project promotes. The necessary scientific studies must be developed within the reality of rapidly changing spatial and temporal data derived from technologies of earth observation.

Future LULCC work will be informed by global coverage on a seasonal basis at fine-tuned spatial resolutions, and the results of this work can be expected to challenge existing theories and models of land-use/land-cover change. As this research progresses, people and pixels need to be linked to analyze human agency and social structure in land change. The depth of understanding brought to bear from bottom-up, field-based approaches must be made spatially explicit, including efforts to integrate results with remote sensing information (pixelizing the social); remote sensing approaches that potentially increase spatial and temporal dimensions of land-use/land-cover change understanding must be pushed beyond its biophysical dimensions (socializing the pixel).

	<b>Critical regions and vulnerable places</b>	
<b>FOCUS 1</b>	<b>FOCUS 2</b>	<b>FOCUS 3</b>
	Activity : Land-cover change, hotspots and critical regions	Activity : Scenario development and assessment of critical environment themes
Task: Simulation models that identify key interactions associated with degradation and vulnerability	Task : Definition of risk zones and potential impacts	Task : Improving the environment-economy linkage  Task: Water issues in regional land-use/land-cover change  Task: Expanding the global food and fibre production

**Table 1-4 : Critical regions and vulnerable places**

## 1.4 Land-Cover Changes

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In the last twenty years land-cover change – whether it is deforestation in the tropics, urbanization, intensification of agriculture or land degradation – has been accelerating as a result of population pressure and economic development. It has been consistently singled out as a key element of many areas of global change research, and is central to many other international policy issues.

The objective of Focus 2 is to better measure the rates of land-cover changes and to integrate these empirical data into diagnostic models aimed at better understanding the processes leading to these changes.

Focus 2 research addresses the following questions:

- What are the rates and spatial patterns of land-cover change, and how will they likely progress?
- Where is land-cover change presently occurring, and where will it likely occur in the future?
- Which natural and cultural landscape attributes contribute the most to the explanation of land-cover change?

The first step in addressing these questions requires the identification of land cover dynamics at broad scales, to identify areas of high rates of land-cover change or high sensitivities to change. We label these critical zones or land-cover change hot spots. Once identified, it is necessary to assess the current state of land-cover in these critical areas and to determine the rate of change in their land cover attributes. These activities can be pursued, in part, using remotely sensed data, due to their ability to provide spatially explicit and repeated measurements at different spatial scales.

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Programme’ (IGBP)

Once robust representations of the proximate causality processes are achieved, these results can serve as a basis for identifying locations of high rates of future change. These land-cover change risk maps can then be overlaid on maps of environmental attributes such as biodiversity, sensitivity to erosion, and forest cover to identify regions that should be studied with more detailed case studies and/or structural models.

The assessment of land-cover change on a global scale is a daunting and monumental program, particularly in terms of the observations required to

document land-cover changes exhaustively. Therefore, the first activity of this Focus is to develop a strategy for identifying important regions and time periods. This can be accomplished using high *temporal and low spatial resolution data* (e.g., AVHRR, MODIS, VEGETATION, (A)ATSR, ERS and JERS SAR), and can be *coupled with broad scale, census and related data, since satellite observations alone cannot explain the socio-economic and institutional factors that influence land-cover change. Nor can they identify the factors that affect regional trends or local dynamics.*

## 1.5 ALCS Concept

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The here proposed method, that will be widely described in the next sections, represents a forward step with respect to current approaches to LULCC analysis.

Current LULCC systems are generally focused to bi-temporal analyses, with a strong limitation in the capability of extracting information and forecasting trends. The possibility to perform a real multi or hyper-temporal study of a phenomenon, with obvious consequences on its understanding, is still not exploited at all.

The approach here presented evolves toward an innovative and efficient method to exploit the potentiality of multi-temporal LULCC analysis of (A)ATSR images.

The current lack of a multi-temporal based system is mainly caused by technological limits: in fact, in case of large image databases, such as (A)ATSR database, storage systems should have high capacity and be efficient in term of query capability. Even in case more and more efficient storage systems and database querying systems are available, they could be a valid help but not sufficient for large database of images. Moreover, satellite image analysis, even for a simple bi-temporal analysis, generally requires great computational resources and the application of preliminary image processing steps, such as classification – supervised or unsupervised – or vegetation index computation. The classification

process is very labor intensive, above all in case of supervised classification or manual interpretation. This implies that most LULCC data products are released several years after the satellite images were taken, and thus, out of date to a certain extent when they are released. Nonetheless, LULCC provides a very valuable method for determining the extents of various land uses and cover types, such as urban, forested, shrubland, agriculture, etc.

For resuming the real advantages of the ALCS with respect to the other applications analyzed in the present section we can state that the system here proposed solves the limitations encountered by similar bi/multi temporal analysis methods which are:

- temporal limitations, most of applications are bi - temporal or restricted to few temporal frames;
- spatial limitations, none of abovementioned applications is worldwide applicable;
- rapid updating limitations, many applications release their results with significant delays with respect to the date of data acquisition and/or elaboration.

Moreover, the proposed system avoids the direct use of the (A)ATSR images and foresees the application of LULCC evolution models directly to 'stock' of classified maps. This approach is made possible by the availability of a 13 year classified image database, conceived and implemented in the CARD project. The use of classified maps instead of the images has two main advantages:

- they are 'computationally' easier to handle than the raw images;
- they already exploit the semantic meaning associated to each land cover class.

The system will allow the users to apply LULCC analysis models made available through the system interface or to easily implement their own models, developed for monitoring specific phenomena.

The database, in addition, could be easily updated with the processing of newly acquired images: the use of SOIL MAPPER® for classification (or to produce value added products), in fact, allows a very fast, unsupervised, processing of the images, avoiding all problems of interpretation connected to supervised classification.

## 2 The ALCS Architecture

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### 2.1 ALCS System General Overview

In the framework of the ESA Support by Pre-classification to Specific Project Applications (SPA), the (A)ATSR Land Classification System (ALCS) aims at implementing an automatic multi-temporal analysis tool that works on a 13-year database(DB) made of (A)ATSR image pre-classified by SOIL MAPPER® implemented in the framework of the Classification Application-service and Reference Datasets (CARD) project.

The (A)ATSR pre-classification maps database, which is the input of ALCS, is constituted by (A)ATSR scenes that have been first processed by means of the SOIL MAPPER® software then granulated in order to reduce the size for each single database element and remove unused information.

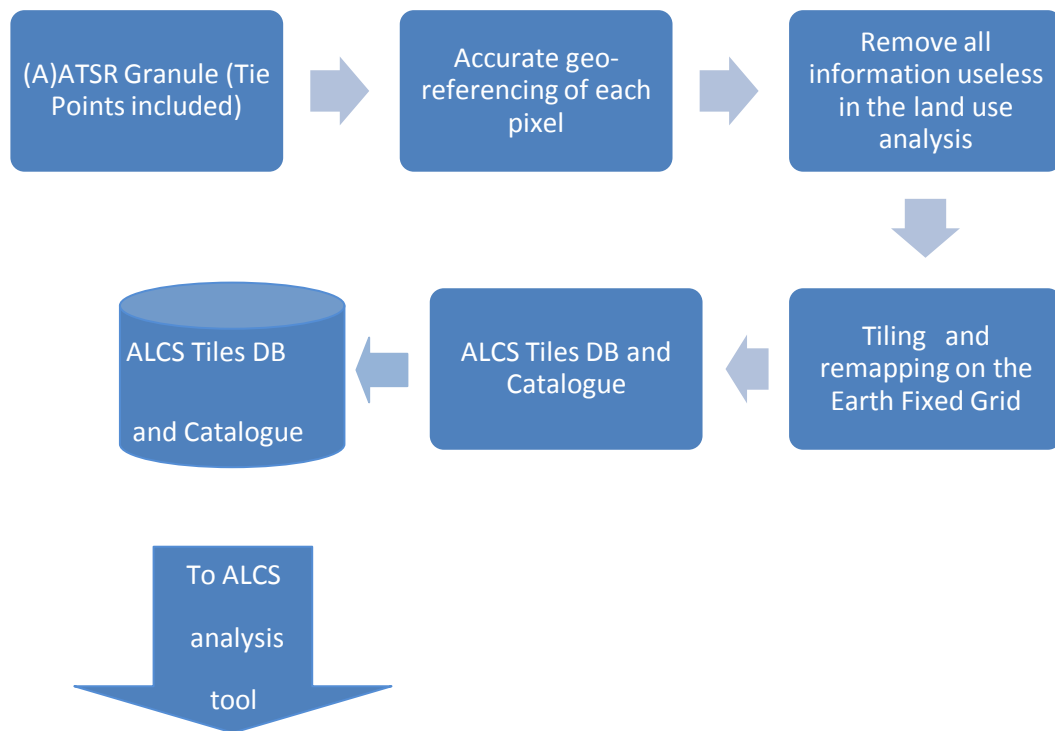
In addition, the (A)ATSR pre-classification maps database, contains an ancillary data file that will include all flag pixel information.

Each granule maintains the image format of the original scene; the satellite-projection raster file includes (not applied) georeferencing information.

Each granule is stored as a separate GeoTIFF file; the tie points extracted from the original ENVISAT data is stored into the GeoTIFF data structure as geographic tags.

ALCS works by means two main logic modules:

- Ingestion, remove unused information through the flag pixel information and remapping of pre-classified granules onto a Earth Fixed Grid (EFG);
- Population of tiles repository and implementation of the DB structure designed for near real time querying.



**Figure 2-1 :- ALCS data ingestion workflow**

The first key point to make the (A)ATSR preliminary classification maps DB usable for land use and land cover change analysis is the Earth Fixed Grid. The remapping of all (A)ATSR pre-classified maps onto a fixed reference system makes pixels acquired over the same area but at different time ready/available for multi-temporal analysis.

The use of an EFG requires:

- accurate geo-referencing of each pixel of the original image;
- accurate remapping system.

The second key point of ALCS is the tiles DB structure and, in particular, the Tiles Metadata DB Manager.

The tiles catalogue has to be designed and optimized to allow fast queries based on time, space and classification based rules parameters.



## 2.2 Earth Fixed Reference System

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The Earth Fixed Grid system is conceived for a general use and is not linked only to images - and relative pre-classified products - collected by a specific sensor. It has been originally conceived for (A)ATSR data but it could be easily extended to other sensors with a different spatial resolution. The mesh-grid has been set with a fixed size of  $\frac{1}{4}$  of degree in both Latitude and Longitude. Each Grid Element of  $\frac{1}{4}$  by  $\frac{1}{4}$  degree is named Tile. The pre-classified images will be remapped on this fixed grid.

An example of the proposed Tiles grid is shown in Figure



**Figure 2-2 : Tiles coverage of the Italian Peninsula**

Depending on the sensor, and, precisely, on its spatial resolution, each tile contains a different amount of pixels. Pixel size of the tile shall be under a threshold value, smaller than half of the original image pixel size in order to allow the pixel-based analysis and mitigate the displacement among the overlaid images due to systematic error into the original geo-referencing. The pixel size shall be also not too small to avoid computational problems (Database management and data display) due to the final size – in term of Bytes of the single tiles.

The pixel size of the remapped images is a compromise between the original resolution and the tile file size. The sizes (tiles and pixels in m) are computed at equator, taking into account that, for computational and archiving reasons, the dimension must be a power of 2.

The following steps have been performed:

- Computation of the tile size, in meters, at equator (on the basis of WGS84 ellipsoid parameters);
- Pixel size threshold estimation for each selected sensor;
- Computation of the maximum pixel size as ratio between tile size (in m) and power of 2.

The following tables (Table2-1 and Table 2-2) summarize the pixel size in m, and the tile dimension in pixel for a selected series of sensors.

For medium resolution sensors (e.g. (A)ATSR, MODIS) the threshold has been set at half of the original pixel size, while for higher resolution the most suitable value has been fixed as the ratio between the tile size and the power of 2, nearest to half of the original image resolution.

Constants														
<b>WGS84 Ellipsoid Equatorial Radius [m]</b>														6378137
<b>1/4 degree [rad]</b>														0,00436332 3
<b>Tile size [m] at Equator</b>														27829,8727
<b>Power of 2</b>														
<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>
<b>4</b>	8	1	3	6	12	25	51	102	204	409	819	1638	3276	65536
		6	2	4	8	6	2	4	8	6	2	4	8	

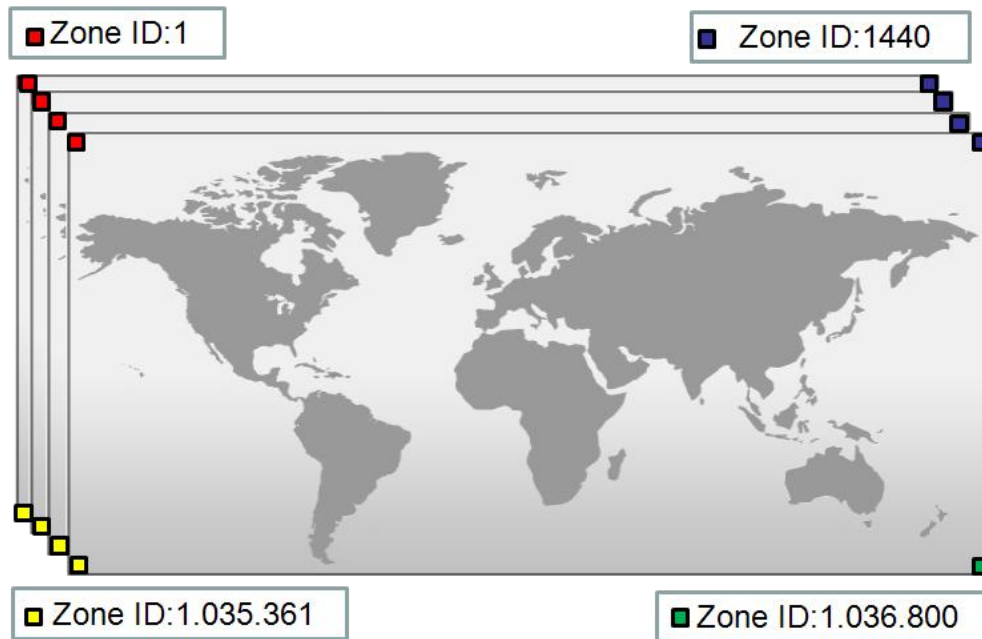
**Table 2-1: Constants for pixel computation**

	(A)ATSR	MODIS	LANDSAT	SPOT5	AVNIR-2
Original spatial resolution	1 km	1 km	30 m	10 m	10 m
Pixel size threshold [m]	500	500	15	7	7
Max computed pixel size [m]	434,84	434,84	13,59	6,79	6,79
Tile size in pixel (side)	64	64	2048	4096	4096
Ratio pixelsize/degree	1/256	1/256	1/8192	1/16384	1/16384
Tile size in Byte	4K	4K	4M	16M	16M

**Table 2-2 : Tile parameters for selected sensors**

Each Tile will be stored on the Tiles database; for (A)ATSR, for instance, due to the availability of a 13-year image archive, at the end of the ingestion process, the amount of elements contained in the Tiles database is estimated in the order of 300 millions.

Each Tile is indexed by an entry in the catalogue.



**Figure 2-3 : Tiles numbering.**

Due to the aim of the final system, only Tiles that cover land areas will be included on the database.

The grid is a simple table that contains three fields:

- ZoneID;
- Upper left corner Lat;
- Upper left corner Lon;

The Earth Fixed Grid is conceived to be automatically readable by the remapping module.

## 2.3 Remapping Module

---

The remapping module is the part of the system dedicated to ingest the pre-classified scenes and remap them onto the Earth Fixed Grid.

The ingested scene (granule for (A)ATSR, single image for other sensors) has its original geo-reference system, thus, before applying any remapping process, a geo-referencing pre-process is required in order to avoid co-registration problems among images.

It is then assumed that each input image to the ALCS system is accurately geo-referenced: this means that each pixel can be geolocated with a precision smaller than  $\frac{1}{2}$  of the pixel resolution.

The remapping module works through several processing steps as described below:

1. creation around the scene/granule of a region of interest re-projected onto geometric space of the grid;
2. identification on the Earth Fixed Grid Tiles covering the scene/granule by means of a bounding box;
3. starting from the first tile of the identified subset (upper left corner) the algorithm remaps the scene/granule on each tile;
4. the empty tiles (no data areas in the input scene/granule) are discarded;
5. the resulting files are labelled with the fields (e.g. TileID) in compliance with the standard of the Tiles metadata DB manager;
6. the tiles are stored into the tiles repository.

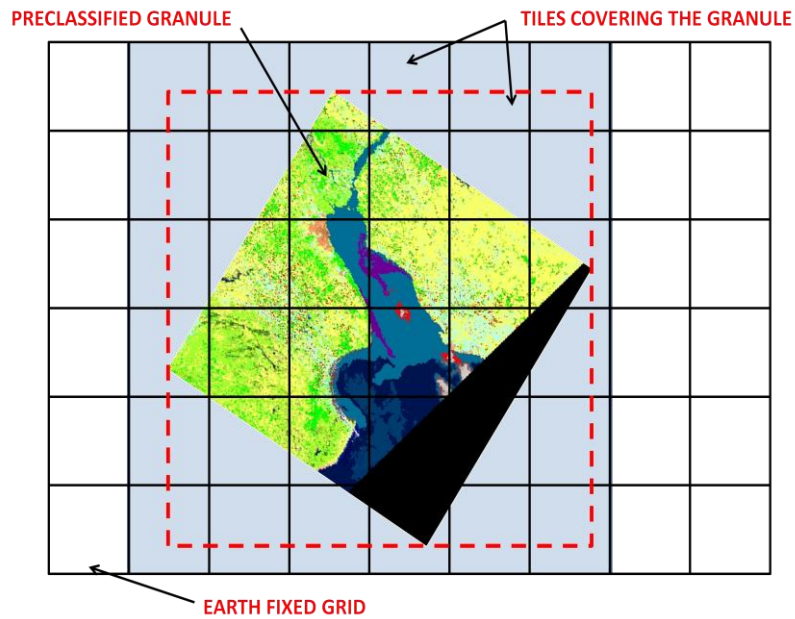


Figure 2-4 : Example of remapping algorithm for (A)ATSR – pre-processing phase.

## 2.4 Remapping Quality Assessment Tests

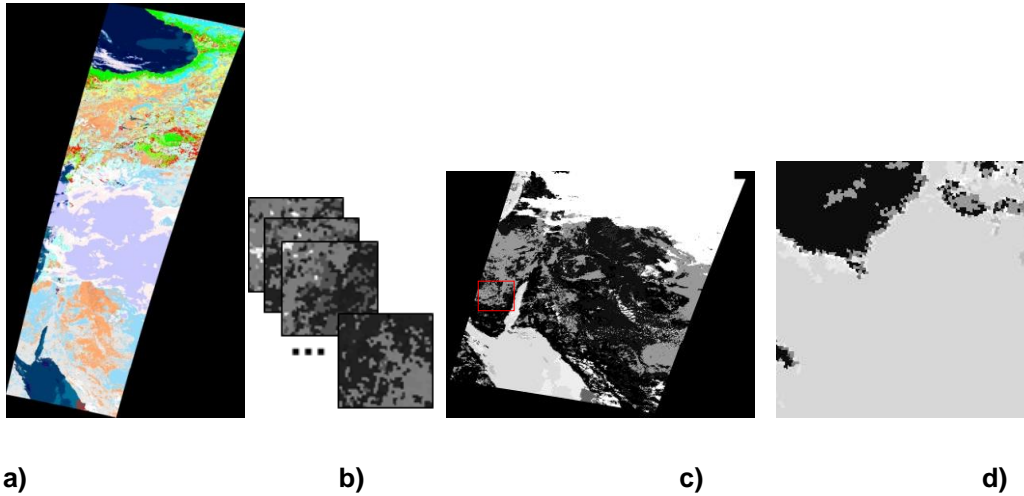
---

Before describing the additional graphical features of the system it is necessary to define some quality parameters of the system and in agreement with the remapping experts, MEEO S.r.l. has designed and implemented a set of tests in order to evaluate the performance and the accuracy of the remapping module.

These tests were subjected to processing and review by the DISTART Department of Engineering of Bologna University. In particular, the quality ratings were performed by Prof. Luca Vittuari. These results provide very useful data to evaluate the system and will be of vital importance in the validation of an evolutionary model of the territory that is correctly spatially positioned.

The following tests have been performed:

**TEST-1:** Image Mosaicking in order to evaluate the correct execution of the tiling operation.



**Figure 2-6:**

**a) original AATSR granule downloaded from the CARD database**

**b) example of the resulting Tiles**

**c) a mosaic of the generated tiles to verify the correct functioning of the processing chain;**

**d) The red area in the mosaic image.**

**TEST-2:** Quantitative analysis between (A)ATSR reflectance pixels and the remapped image.

**TEST-3:** Assessment of the remapping module with Synthetic data.

**TEST-4:** Evaluation between (A)ATSR and MODIS images with clear shapes.

In order to allow evaluations in terms of shape or surface of objects within images, it is necessary to adopt appropriate formulas for matching positions stored within the Earth Fixed Reference Grid and appropriate cartographic representations. The two main features of a remapping algorithm are the precision in projecting the remapped image onto the new geo-reference system and the computational efficiency.

The identified algorithm, based on the Nearest Neighbour (NN) approach, has been conceived to operate on MODIS images but can be easily applied to other sensor images include different geo-information as:

- MOD03 file;
- PTS file for MODIS or (A)ATSR;
- GCPs as field of GeoTIFF file;
- Transformation matrix as field of GeoTIFF file

The NN algorithm has been chosen because it doesn't change the pixel value, deriving from the pre-classification, after the resampling.

The proposed Earth Fixed Grid and the proposed remapping system have been considered adequate for the scopes of the project.

# 3 ALCS Interface Control

## 3.1 System Overview

The ALCS project aims at realizing an innovative environment for Land Use and Land Cover Change analysis (LULCC). In its reference context, ALCS is conceived to be accessible by its users as a web application allowing them to apply LULCC models to classification data based on SOIL MAPPER® (spectral classification system). Users can apply models registered into the system, made available through the Visual Analysis Client (VAC) or to easily implement their own models for monitoring specific phenomena, via the Expert user Visual Analysis Tool (EVAT).

ALCS leverages classification data provided by a data source, that is the (A)ATSR Classification Maps Data Catalogue, developed in the framework of CARD project.

User authentication is provided via ESA SSO architecture, hence the user is required to log in to ESA systems before he can use the user interfaces provided by ALCS; user authorization is managed by ALCS itself. The chart below describes the architecture in terms of its main logical blocks.

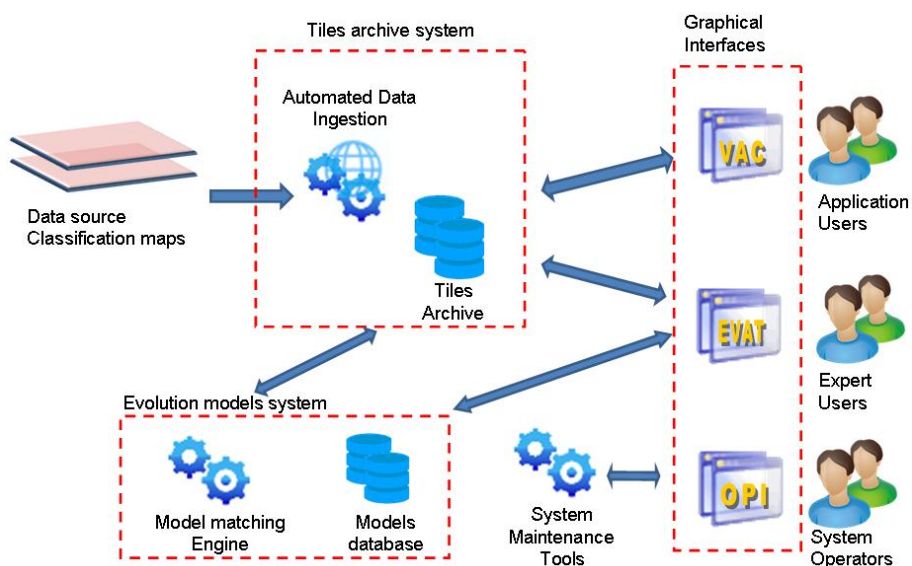


Figure 3-1 : logic chart



### **Expert user Visual Analysis Tool (EVAT):**

This component is a graphic user interface that allows expert users to create, edit and manage evolution models by simple graphic tools:

- from multitemporal pixel-based analysis;
- from existing models;
- from the ground.

It connects to the database storage of models translated in computer readable form.

### **Visual Analysis Client (VAC):**

This component is a graphic user interface that allows users to apply evolution models over an Area Of Interest (AOI) for one or more time frames.

It allows immediate visual analysis of the results and also exporting these results for offline analysis

### **Operator Panel Interface (OPI):**

This component is a graphic user interface that allows system operators / administrators defining input rules for classification data ingestion from the data source and to monitor the system status.

## **3.2 USER Interfaces design**

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The system provides three user interfaces, each accessible by a different kind of user to perform specific set of tasks as follows:

- EVAT – Expert Visual Analysis Tool is a GUI conceived to define evolution models. It is accessed by users with the “expert” user role, it provides:
  - a tool that allow the analysis of classified Tiles Time Series;

- a tool that allow a detailed analysis of a single pixel. This tool is conceived to identify significant pattern in the classification history of a pixel and to use this pattern as a baseline for the definition of a generic model;
- a model editor for the definition of the evolution models;
- a tool that allows the management of the defined model, the execution permission of the model for different levels of users and the definition of model's user groups.
- VAC – Visual Analysis Client is a GUI conceived to apply defined evolution models over a Region of Interest. This is a publicly accessible interface that is accessed by every kind of users (including unregistered ones). It provides a searchable evolution models catalogue to ease model selection. The application of an evolution model can be easily shown as an overlay on a map of the selected region and exported for further analysis.
- OPI – Operator Panel Interface is an interface accessible only to the users with the “administrator” user role. It is used to manage the ingestion and the processing of the AATSR granules and to check the health status of the entire system. Using this GUI the administrators can schedule the data processing and can retrieve information about the status of the various modules that compose the ALCS system. A backup tool is also accessible through that interface.

### **3.3 Expert User Visual Analysis Tool (EVAT)**

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Expert users are supposed to be scientists with expertises in land use and land cover changes. Their role in the ALCS system is of models creators able to define land cover changes in terms of temporal patterns. The GUI must support this function making available the classification maps DB and the model manager.

The specific functions of the GUI for expert users are:

- Multi – sensor capability. The system has to be designed for being as much as possible multi-sensor and more in general for being easily upgraded and as direct consequence of that, the GUI must support the multi – sensor accessibility;
- Model editing. The GUI must provide a tool to create evolution models. This tool should be easy as much as possible and the creation of an evolution model must be intuitive and fast. ALCS DB has been designed to guarantee a real time accessibility and the GUI shouldn't be the bottleneck of the system;
- Model management. The evolution model DB should be structured considering different levels of developing status of the model and different levels of accessibility to the models.

This interface is substantially composed of three main parts, each composed of one or more frames, grouped by function:

- Tile analysis area (upper area), in turn composed of three sub frames:
  - Map area (upper left) (Google Map API)
  - Read-only console (below map area)
  - Tiles Time Series tool (right)
- Detailed analysis area (central area), containing:
  - Pixel History visualization tool
- Model Definition area (lower area), composed of the following components, laid out one below the other:
  - Model Editor
  - Editor read-only console
  - Model management.

For each part of the interface, the next subsections provide a screenshot and a description of the actions that users can do through that part, along with instructions for correct use of the system.

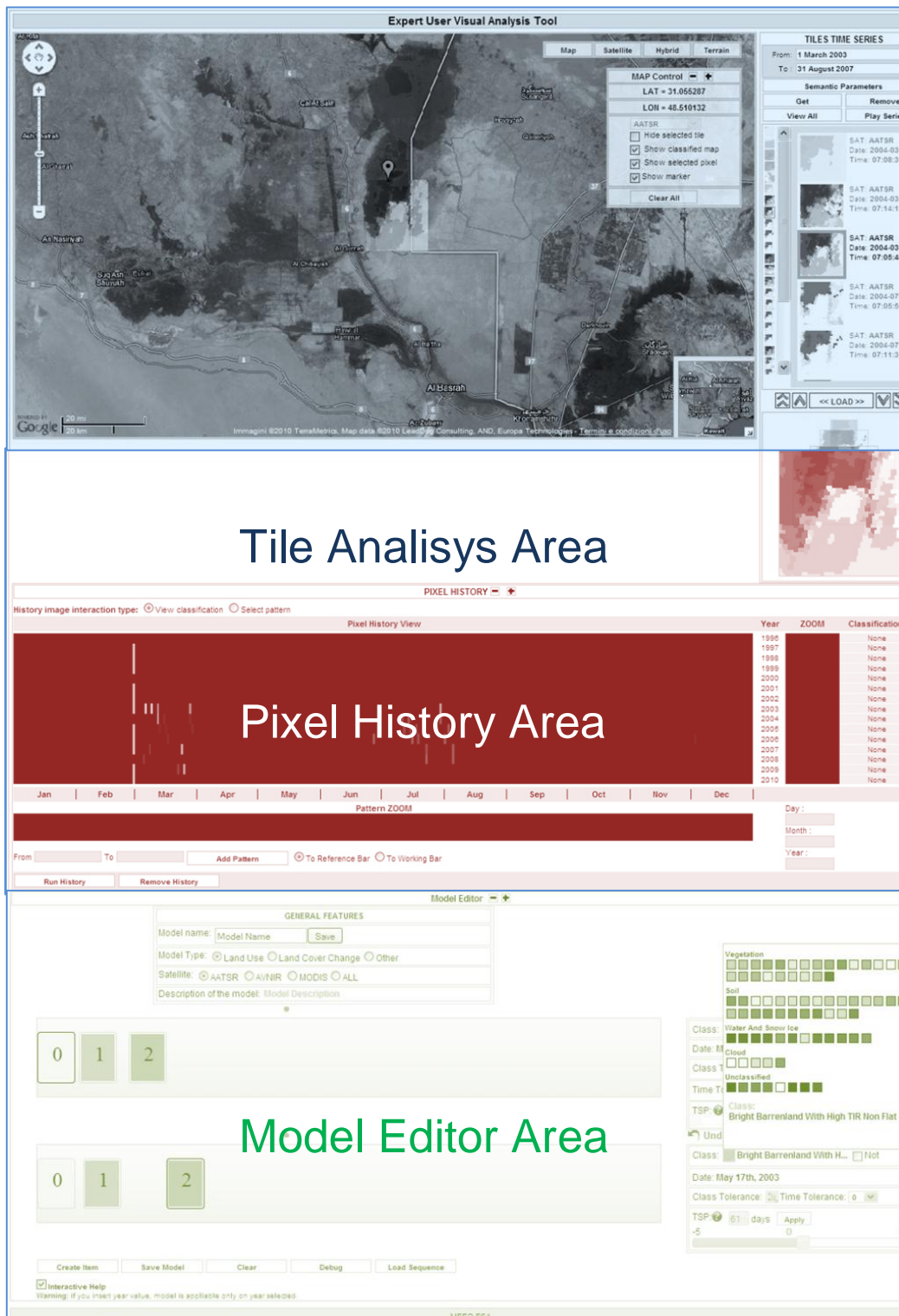


Figure 3-2 : Global overview of the EVAT interface.

### 3.3.1 Tile Analysis area

The purpose of this frame is to aid an expert user in the analysis of the classified tiles, observing the temporal series of classified tiles through the use of some intuitive graphical tool and loading the classified tiles as overlays on the map.

This area is composed by different parts:

- Map area (upper left frame) used to select the tile of interest and to load the overlay;
- Pixel Classification Window (only available by clicking on a pixel in a tile) that provides some informative messages related to the geographical coordinates and the pixel Classification;
- Tiles Time Series tool (right frame) that provide the displaying of temporal series of classified tiles belonging to the selected zone, but acquired by the satellite in different periods.

### 3.3.2 Map Area and Pixel Classification Frame

The map area is located in the upper left part of the interface and takes up a large part of the application window because it has to let the user manage and observe overlays comfortably.

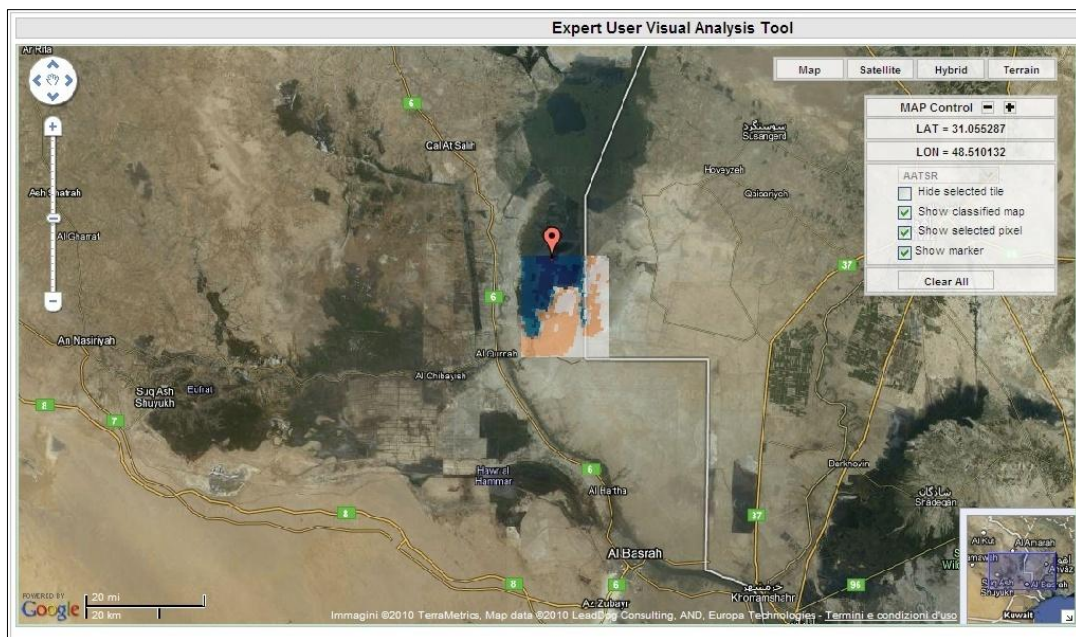
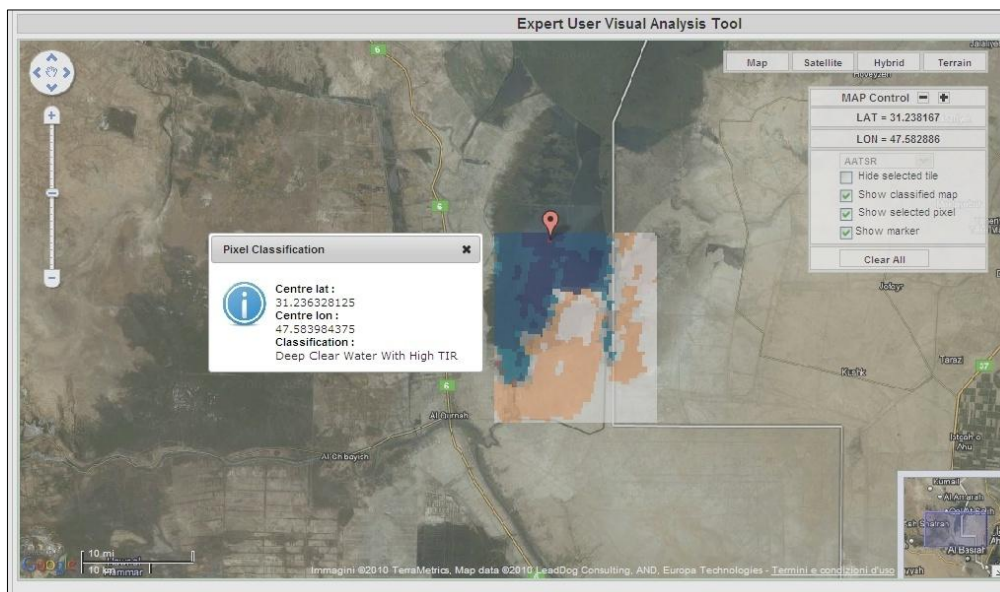


Figure 3-3 : Classified Tile over Google Maps API area

In the upper right portion of the map area it is placed the “**Map control**” frame where:

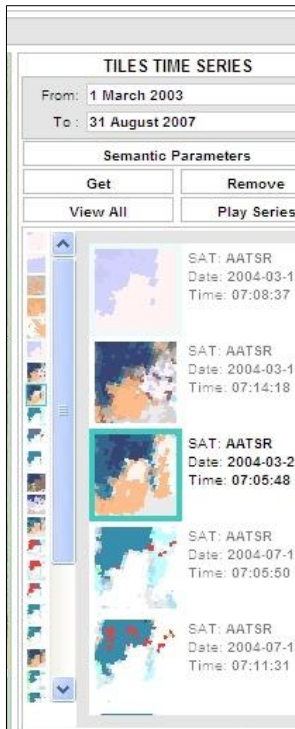
- Latitude and longitude coordinates of the cursor location on the map are displayed;
- The user can select the type of interaction with the map (exclusive radio buttons), that is needed to properly respond to mouse selections and overlay requests from the user.
- For each interaction type, the user can select the sensor (multi-sensor support prototyping feature) using a drop-down list. System is conceived for work with different sensors. Pixel dimension and tile resolution depend on selected sensor;
- For each interaction type, the user can choose to **Hide** or **Show** overlays coming from the tile time series frame or the Pixel History Tool, for the latter also pixel pinpointing marker can be hidden;
- By clicking the “Clear selection” button placed at the bottom of the frame, the user can clear the selection on the map with respect to the selected interaction type.

The window pixel classification is the cell area adjacent to the pixel clicked on the tile, and provides geographical indications of the pixel and its classification based on the SOIL MAPPER (R).



**Figure 3-4 : Pixel information over Google Maps API area**

### 3.3.3 Tiles Time Series



This frame allows visualizing tiles time series: The upper section of the frame allows inputting the time range to search for tiles; the central area displays a plain scrollable list of tile previews, allowing the user visual analysis of the complete contents of neighbouring (in the sense of the time dimension) every tile.

Figure 3-5 : Tiles Time Series

### 3.3.4 Pixel History Area

This is the only frame belonging to the detailed analysis area, it allows the visualization of a single pixel classification history across the entire database. The sole purpose of that frame is to provide the expert user with aiding information in the definition of an evolution model. To obtain the pixel history for a given pixel an user has to select that pixel on the map area by:

1. Select “**Pixel for history**” in the “**Map Controller**” and select one of the available satellites in the relative drop-down list. By default the satellite selected is the AATSR.
2. selecting the pixel on the map (single left-click on the map; right click to clear selection).
3. clicking the “**Run History**” button.

When pixel history has been run, the frame appears as shown in Figure 3.6:



**Figure 3-6 : Pixel History area**

The entire 13 years pixel history is displayed on the centre-left image, that is a graphical representation of the data matrix (image matrix), organised as follows:

Each row displays data for an entire year, with one day resolution. Each column references the same day of the year across all 13 years. For each day, the semantic information (land cover class) is displayed with the corresponding color, while black (empty) cells represent days with no land cover information (either no satellite acquisition, cloudy sky or unknown coverage).



## 3.4 Visual Analysis Client

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Standard users are supposed to be operators in fields like agricultural monitoring, soil management, public administration, in practice every field that can be influenced by some kind of land cover change. The GUI for these users must provide the accessibility to the DBs in real time and the possibility to apply the evolution models made by expert users.

The specific functions of the GUI for expert users are:

- Selection and application of evolution models. Potentially the number of evolution models can grow quickly and the GUI should guarantee the accessibility to a large number of different kind of models introducing concepts of ontology in the name of models and in their description and using a tree approach in the access to the evolution models DB;
- The result visualization. The GUI for standard users must apply graphic solutions to visualize when and where the pattern matches with the real land evolution.

The VAC can substantially divided into 4 Areas:

- Model Selection Area
  - Where the User can choose the Land Use / Land Cover Change Model to perform into the System.
- Dates Selection Area
  - In this frame, if the model allows, the user can specify the start / end date of execution model. It is also possible to specify more than one period of application of the model execution .
- Map Area
- Application Control Frame
  - The user can obtain information about application status and model match results details.
- Overlaps Management Frame, where the user can:
  - Manage multiple overlays of application results (also display them on the map area);
  - Save execution results to a file for subsequent analysis.

The image below depicts an overview of the Visual Analysis Client interface layout.

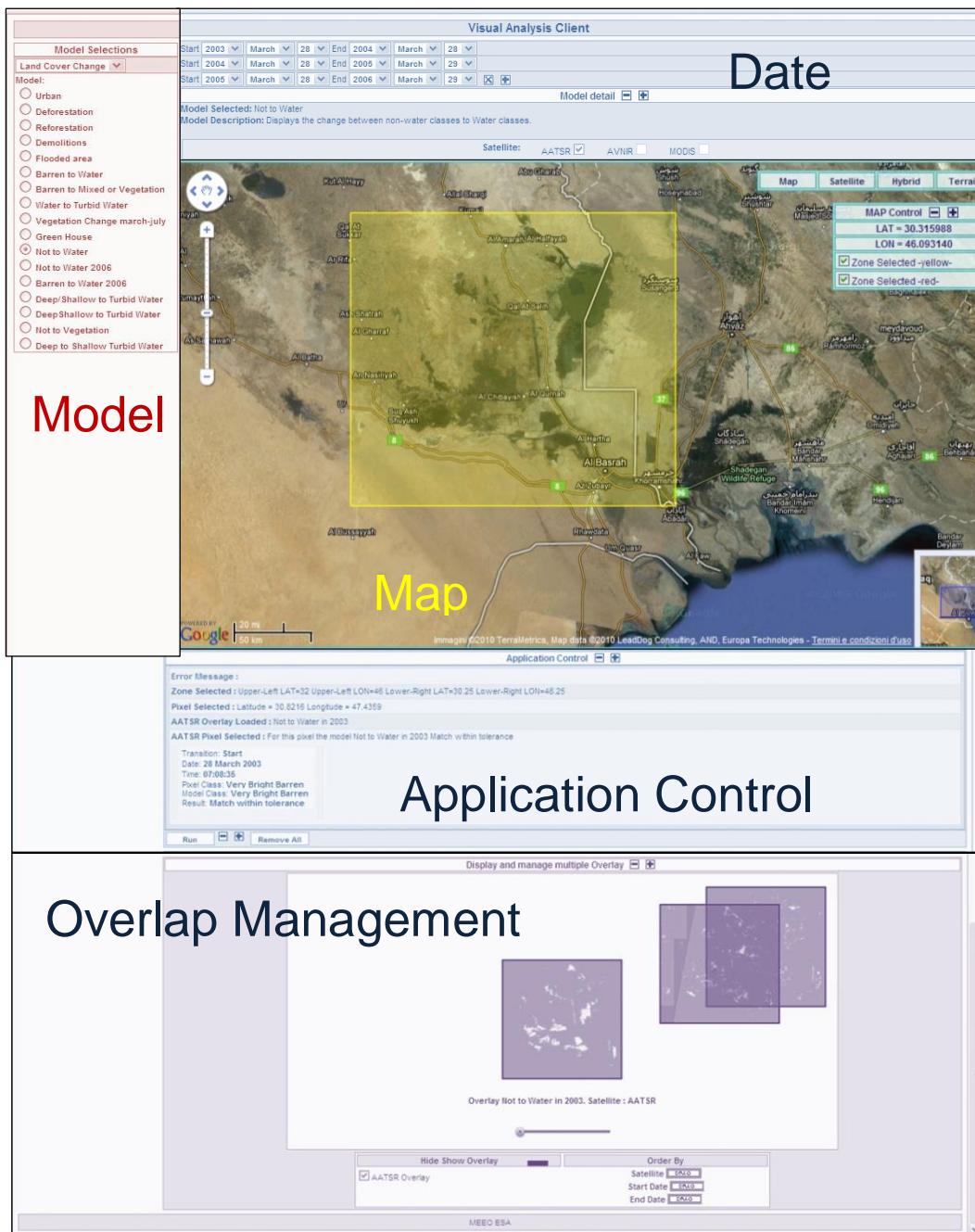


Figure 3-7 : Global overview of the VAC interface

### 3.4.1 Selection Area (Model-Dates-Map)

The area depicted in Figure shows the frames used for the parameters selection. The parameters to select are:

- The evolution model;
- The temporal range parameters;
- The Area Of Interest (AOI);

The selection of the evolution model is performed using the evolution models catalogue; the catalogue is accessed by clicking the “select Model...” button next to the selected model name (“Please select a model” label if no model is selected) in the model detail area.

After the model selection, user can choose the temporal parameters with a form composed by a set of drop-down list. This form is positioned at the top of the area. Below the form is located the map. Using this map user can select the AOI (in yellow colour in Figure) where apply the evolution model.

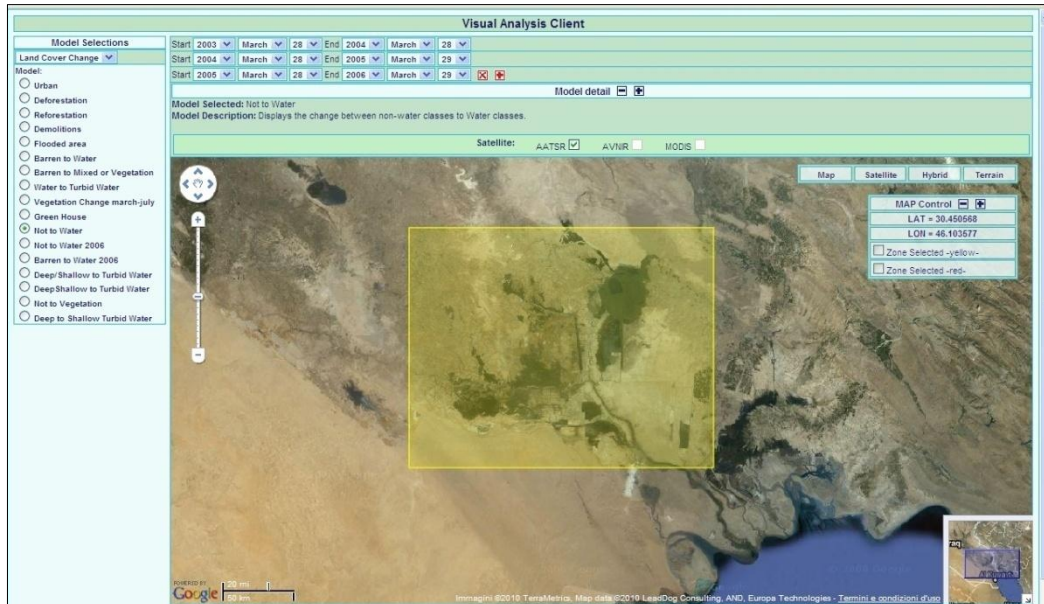


Figure 3-8 : Selection of the model application area

## 3.4.2 Results Area

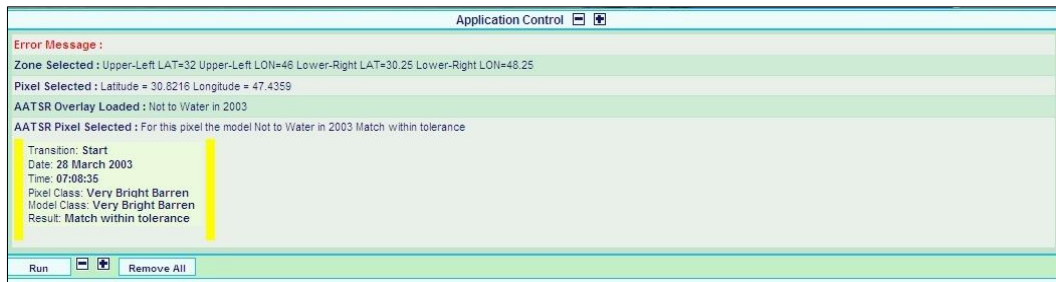
### (Application Control-Overlap Management)

The Application Control Frame shows the quality of the Match results, after selecting a pixel on the Map Frame.

When user selects a pixel, the system draws the borders of the selected pixel on the map, writes the coordinate on the console and prepares the “**pixel detail**” tool. This chain of events occurs contemporaneously for each image that is loaded on the map. The number of pixel detailed is proportional to the number of the loaded overlays.

For investigate pixel detail, user has to interact with the pixel detail tool. This tool looks like a set of vertical bars of different colours. Characteristics and use of this tool are listed below.

- The number of bars is proportional to the number of transitions defined in the evolution model applied;
- The set of colours that can take the bars is the same that is used for creating overlays and has the same meaning;
- Moving the mouse cursor over a bar user can see the transition name;
- Clicking over a bar, user selects a transition. When a transition is selected user can observe the transition detail. The entries are:
  - **Transition**, is the transition name;
  - **Date**, is the date of pixel acquisitions. “**No tile found**” if there are no tiles acquired in the transition time range;
  - **Time**, is the time of pixel acquisitions, blank if there are no tiles acquired in the transition time range;
  - **Pixel Classification**, is the classification of the acquired pixel. “**None**” if there are no tiles acquired in the transition time range;
  - **Model Classification**, is the class defined in the evolution model;
  - **Result**, is the result of the transition application over the pixel.



**Figure 3-9 : Application Control shows pixel matching results**

After model execution, system produces one overlay for any period selected and for any satellite selected. If user selects only one period and one satellite, the overlay is loaded automatically on the map, otherwise overlays are loaded on a frame called **“Display and manage multiple Overlay”**. This frame is observable in the Figure.



**Figure 3-10 : Overlay frame**

# 4 The Mesopotamian Marshes

## 4.1 Geographical Characteristics of Central Marshes



Figure 4-1 : 1994 Map of The Mesopotamian Marshes with draining features.

The **Mesopotamian Marshes** are a wetland area located in Southern Iraq bordering Iran. Historically the marshlands, composed of the Central, Hawizeh and Hammar Marshes, used to be the largest wetland ecosystem of Western Eurasia. It is a rare aquatic landscape in the desert, providing habitat for important populations of wildlife. As their name suggests the Mesopotamian Marshes are located in the larger region which used to be called Mesopotamia. Mesopotamia, literally meaning "in between rivers", is now occupied by modern Iraq, eastern Syria, south-eastern Turkey, and

Southwest Iran. In the late 4th millennium BC the first literate societies emerged in Mesopotamia, often referred to as the Cradle of Civilization, and the first cities and complex state bureaucracies were developed here. Due to the geographical location and the ecological factors of the Fertile Crescent, a crescent-shape fertile area running from the basins of the Nile in Egypt, northwards along the Mediterranean coast in Palestine and Israel, and southwards again along the Euphrates and the Tigris (Mesopotamia) towards the Persian Gulf, civilizations were able to develop agricultural and technological programmes. The crucial trigger was the availability of wild edible plant species. Farming arose early in the Fertile Crescent because the area had a great quantity of wild wheat and pulse species that were nutritious and easy to domesticate.

The **Central or Qurnah Marshes** were a large complex of wetlands in Iraq that were part of the Tigris-Euphrates river system, along with the Hawizeh and Hammar Marshes. Formerly covering an area of around 3000 square kilometers, they were almost completely desiccated following the 1991 uprisings in Iraq and have only in recent years started to show some signs of recovery.

The Central Marshes stretched between Nasiriyah, Al-'Uzair (Ezra's Tomb) and Al-Qurnah and were mainly fed by the Tigris and its distributaries. They were characterised by tall qasab reeds but included a number of freshwater lakes, of which the largest were the Haur az-Zikri and Umm al-Binni (literally "mother of binni", the latter being a species of barbel.) The marshes supported breeding populations of the Basra Reed-warbler and Marbled Teal, along with several other species of non-breeding birds. A bird subspecies unique to the marshes, the African Darter *Anhinga rufa chantrei*, may have already become extinct by the 1990s. There were also populations of several mammal species including the unique *Erythronesokia bunnii* (Bunn's Short-Tailed Bandicoot Rat) and the Smooth-coated Otter subspecies *Lutra perspicillata maxwelli*, which had only been described from specimens obtained in the Central Marshes.

The area was formerly populated by the Marsh Arabs or Ma'dan, who grazed buffalo on the natural vegetation and carried out cultivation of rice.

## 4.2 Historic Draining and Recovery Background

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The British were the first to drain Iraq's marshes which had no apparent economic value and bred mosquitoes. Prepared in 1951, The Haigh Report outlined a series of sluices, embankments and canals on the lower ends of the Tigris and Euphrates that would drain water for agriculture. In 1952, the Third River (a large canal) commenced. For the next thirty years construction continued and drain much of the marshes.

By the early 1980s, it was evident that irrigation projects were already affecting water levels in the marshes. In the early 1990s, the government of Iraq undertook a series of major drainage projects, at least partly in retribution for the events of the 1991 uprisings, and to prevent the area being used as a refuge by militias. The flow southwards from the distributor streams of the Tigris was blocked by large embankments and discharged into the Al-Amarah or Glory Canal, resulting in the loss of two-thirds of the Central Marshes by as early as 1993. A further canal, the Prosperity Canal, was constructed to prevent any overflow into the marsh from the main channel of the Tigris as it ran southwards from Qalat Saleh. By the late 1990s, the Central Marsh had become completely desiccated, suffering the most severe damage of the three main areas of wetland. By 2000, United Nations Environment Programme estimated that 90% of the marshlands had disappeared. Following the 2003 U.S. invasion of Iraq, embankments and drainage works were broken open, and the marshes began to reflood. The Central Marshes showed little recovery through 2003, but by early 2004 a patchwork of lakes had appeared in northern areas; there was flooding in southern areas which had previously been dry since the early 1990s. There has been some corresponding recolonisation by the natural marsh vegetation since that time, and return of some species of fish and birds, although recovery of the Central Marshes has been much slower compared to the Huwaizah and Hammar Marshes; the most severely damaged sections of the wetlands have yet to show any signs of regeneration. *Erythronesokia bunnii*, *Lutra perspicillata maxwelli* and *Anhinga rufa chantrei* are all thought to have become extinct.



## 4.3 Environmental Threats

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Iraq suffers from desertification and soil salination due in large part to thousands of years of agricultural activity. Water is scarce and plant-life sparse. Saddam Hussein's government water-control projects have drained most of the inhabited marsh areas east of An Nasiriyah by drying up or diverting streams and rivers. Population of Shi'a Muslims have been displaced. The destruction of the natural habitat poses serious threats to the area's wildlife populations. There are also inadequate supplies of potable water.

Marshlands were a fine and extensive natural wetlands ecosystem which developed over thousands of years in the Tigris-Euphrates basin and once covered 15–20,000 square kilometers. According to the United Nations Environmental Program and the AMAR Charitable Foundation, between 84% and 90% of the marshes have been destroyed since the 1970s. In 1994, 60 percent of the wetlands were destroyed by Saddam Hussein's regime – drained to permit military access and greater political control of the native Marsh Arabs. Canals, dykes and dams were built routing the water of the Tigris and Euphrates Rivers around the marshes, instead of allowing water to move slowly through the marshland. After part of the Euphrates was dried up due to re-routing its water to the sea, a dam was built so water could not back up from the Tigris and sustain the former marshland. Some marshlands were burned and pipes buried underground helped to carry away water for quicker drying.

The drying of the marshes led to the disappearance of the salt-tolerant vegetation; the plankton rich waters that fertilized surrounding soils; 52 native fish species; the wild boar, Red Fox, buffalo and water birds of the marsh habitat.

The issue of water rights became a point of contention for Iraq, Turkey and Syria beginning in the 1960s when Turkey implemented public-works project (GAP project) aimed at harvesting the water from the Tigris and Euphrates rivers through the construction of 22 dams, for irrigation and hydroelectric energy purposes.

Although the water dispute between Turkey and Syria was more problematic, the GAP project was also perceived as a threat by Iraq. The tension between Turkey and Iraq about the issue was increased by the effect of Syria and Turkey's participation in UN embargo against Iraq following the Gulf War. However, the issue had never become as significant as the water dispute between Turkey and Syria.

The 2008 drought in Iraq sparked new negotiations between Iraq and Turkey over trans-boundary river flows. Although the drought affected Turkey, Syria and Iran as well, Iraq complained regularly about reduced water flows. Iraq particularly complained about the Euphrates River because of the large amount of dams on the river. Turkey agreed to increase the flow several times, beyond its means in order to supply Iraq with extra water. Iraq has seen significant declines in water storage and crop yields because of the drought. To make matters worse, Iraq's water infrastructure has suffered from years of conflict and neglect.

In 2008, Turkey, Iraq and Syria agreed to restart the Joint Trilateral Committee on water for the three nations for better water resources management. Turkey, Iraq and Syria signed a memorandum of understanding on September 3rd, 2009, in order to strengthen communication within the Tigris-Euphrates Basin and to develop joint water-flow-monitoring stations. On September 19th, 2009, Turkey formally agreed to increase the flow of the Euphrates River to 450 to 500 cu. cms., but only until October 20th, 2009. In exchange, Iraq agreed to trade petroleum with Turkey and help curb terrorist activity in their border region. One of Turkey's last large GAP dams on the Tigris – the Ilisu Dam – is strongly opposed by Iraq and is the source of political strife.

# 5 Data Management

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To map the evolution of the marshlands, a multistage approach using low-scale resolution satellite imagery was followed to obtain a more comprehensive coverage and analysis. Preliminary to the development of Land Cover Evolution Models, much of the thesis work was done by searching specific satellite classified maps on the scheduled area. The SSE Portal - ATSR2-AATSR Classification Map Data Catalogue was the main instrument used in this research.

## 5.1 Service Support Environment Portal (SSE)

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The European Space Agency (ESA) provides an on-line platform, called Service Support Environment (SSE), to support the development, test and hosting of Services provided by Service Providers and based on protocols and standards for the access and chaining of Earth Observation (EO) metadata, data or products.

**The SSE service directory** offers access to a continuously expanding set of basic and more complex **Earth observation** and **GIS services**. Services can be free of charge, for demonstration or fully operational and requiring payment. It is possible to browse, request a quotation for each of the services or order them via an online form. To access the full set of available services, customers must Register as SSE portal users.

Main EO (Earth Observation) Contributors such as space agencies, data processing centres, data providers, educational establishments, private companies and research centres have chosen to actively participate in the SSE initiative enabling the SSE portal to give access to a large variety of services.

## 5.2 ATSR2-AATSR Classification Map Data Catalogue

The data needed to implement the model in the system ALCS are contained in the ATSR2-AATSR Classification Map Data Catalogue which is a service operated by MEEO Srl. The service is presently provided free of charge to authorised users, is daily updated and the delivery time after a classified map query (stated on the website) is maximum 0,25 days. The ATSR-2 and AATSR sensors have observed the earth-atmosphere system since 1995, collecting more than 20TB of compressed data. At the time of writing, ATSR-2 and AATSR data is stored into magnetic and optical media and accessible upon request (no real time access), while newly collected AATSR data are available through a ftp rolling archive over a moving window of one month. In the framework of the ESA project “Classification Application-services and Reference Datasets” (CARD) an online database with preliminary ATSR-2/AATSR classification maps was studied and implemented. The preliminary classification maps are created by applying the SOIL MAPPER® software, which is a fully automated, application-independent, multi-sensor, spectral rule-based preliminary (in the Marr sense) classifier of Earth Observation images calibrated into top-of-atmosphere reflectance. In the preliminary classification map each pixel is associated with one label out of a discrete set of spectral categories (each spectral category has a semantic meaning).

	Semantic Classes		Semantic Classes
1	V Vegetation	9	WASH Water or Shadow
2	SHV Shadow area with vegetation	10	CL Cloud
3	R Rangeland	11	TNCL Thin Cloud
4	WR Weak rangeland	12	SN Snow
5	PB Pit bog	13	SHSN Shadow Snow
6	GH Greenhouse	14	SH Shadow
7	BB Barren land and built-up	15	UN Unknown
8	SHB Shadow area with Barren		

Table 5-1 : Spectral Categories

This process allows to:

- Drastically reduce data size, since the output class information is stored into a 1-byte per pixel structure (compression about 60:1, when using only nadir view)
- Preliminarily associate a class / semantic meaning to each pixel, simplifying any following processing
- Efficiently pre-classify an entire ATSR-2/AATSR strip in less than 3 minutes.

The hardware includes a storage server that hosts the database of preliminary classification maps and two nodes to process the images downloaded from magnetic supports or the rolling archive. The system will allow accessing in real time the entire ATSR-2/AATSR database of preliminary classification maps, through geographic and semantic queries. Applications for bi-/multi-temporal interactive analysis of land areas are also under consideration.

The SOIL MAPPER® spectral classification system has been applied to the entire database and a database made of classification maps has been created. The availability of the classification maps database allows:

- Making the entire database accessible on line;
- Perform not only spatial and temporal but also semantic queries in order to refine the database search operation;
- Directly download the classification maps;
- Retrieve the ID of the original data to be retrieved/ ordered through the EOLI ATSR2 / AATSR catalogue service.

Multi-parametric semantic queries can be realised inserting the required percentage of a specific class in terms of “at least”, or “at most” or “between” the set values.

## 5.3 Search Framework

The search window, once entered in the service, appear as below:

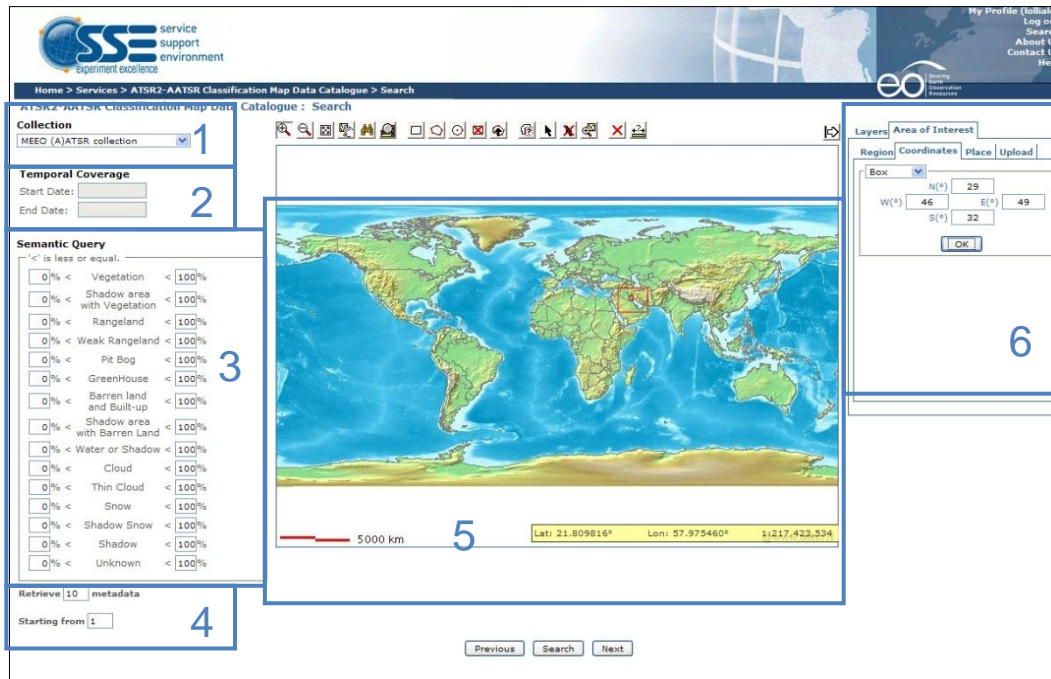


Figure 5-1 : SSE Portal Search Frame

Explanation of the different frames:

1. Type of Collection :
  - a. MEE0 (A)ATSR Collection
  - b. MEE0 AATSR ENVISAT Collection
  - c. MEE0 ATSR-2 ERS-2 Collection
2. Temporal Coverage
3. Semantic Query : you can specify the percentage of presence of spectral categories on the strip
4. Number of Metadata required to display
5. Map Window
6. Area of Interest, coordinates

Once all necessary fields were filled, especially those related to location and time frame, the search was started.

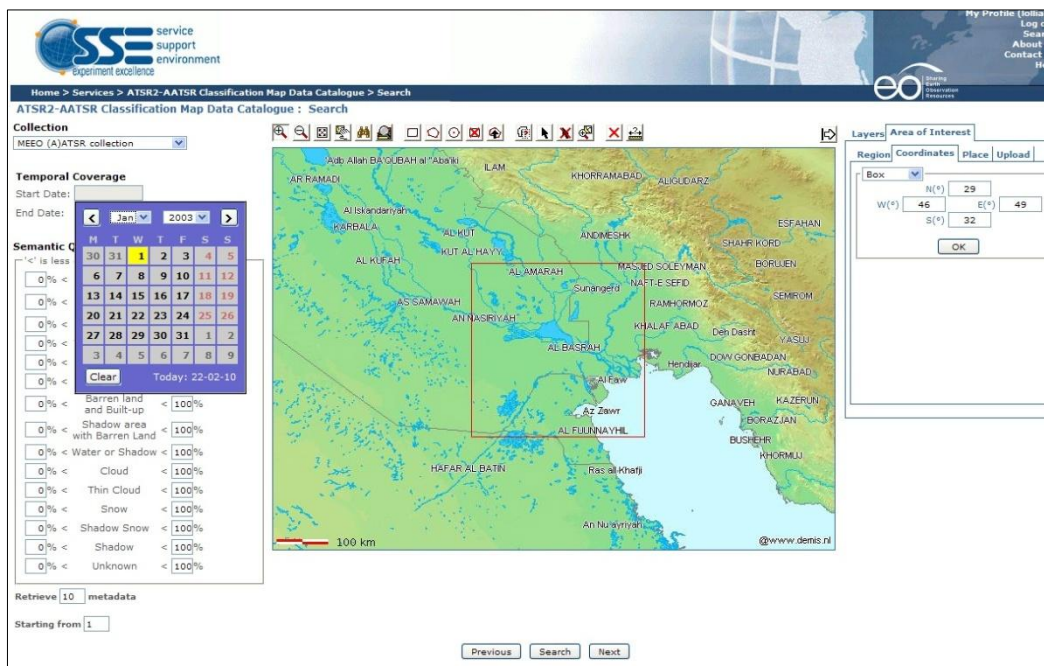


Figure 5-2 : SSE Portal Temporal Selection

In the selected area, centered in the marshlands, the maps related to the dates reported in chapter 5.5 were taken from the Catalogue.

## 5.4 Data example

Images provided by the catalogue are pre-classified with the SOIL MAPPER © system, developed by MEE0 Srl. Each pixel contains semantic information about the land cover type based on more than 50 different classes available

Each image downloaded has the following technical data:

**i. Product Identifier**

- ATS\_SpCI73\_1PRUPA20030302\_072214\_072705,  
AATSR sensor Type\_ Acquisition Date \_ start \_end  
Acquisition



**ii. Collection Type**

- AATSR or ATSR-2 / ERS-2 collection

**iii. Platform**

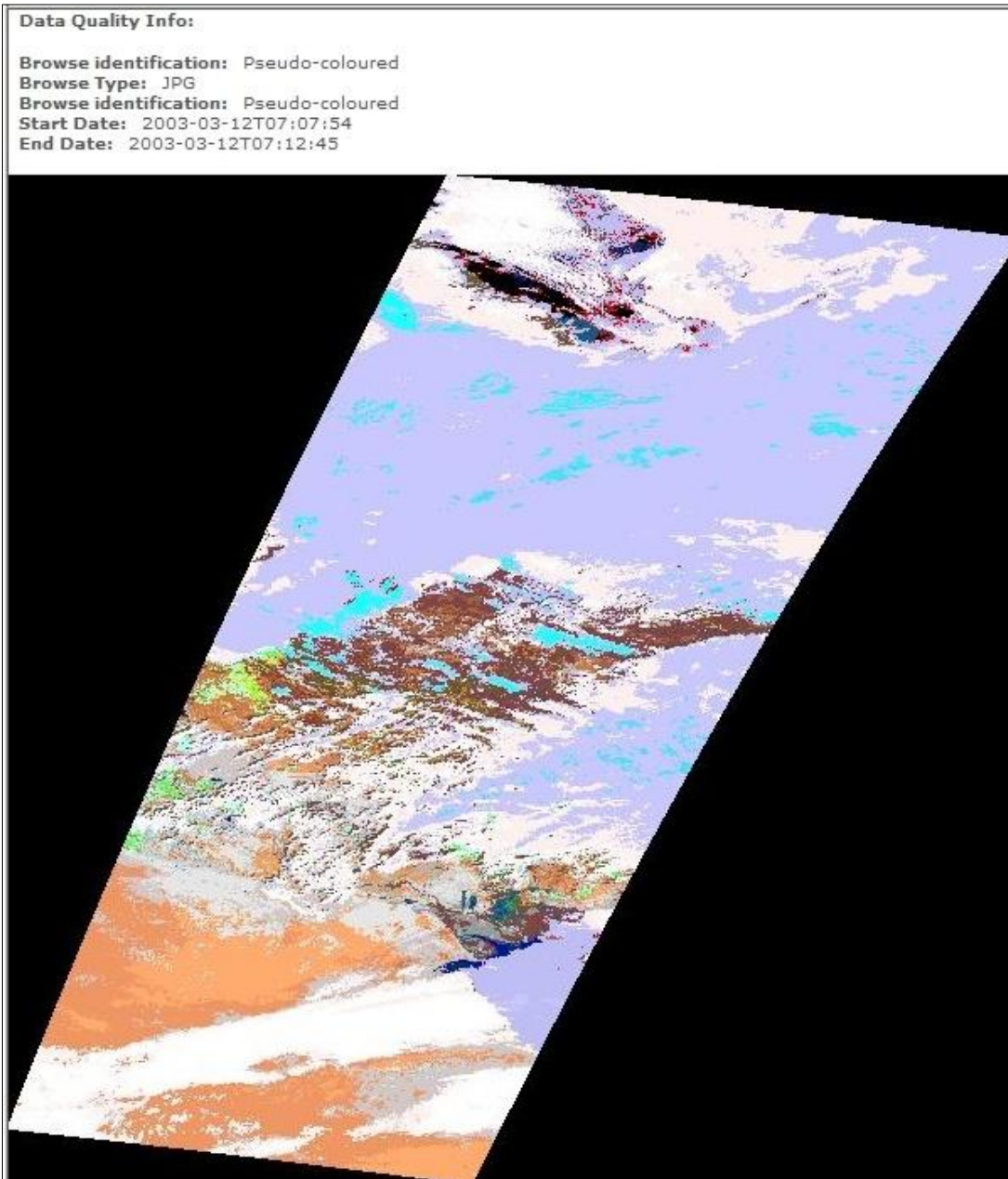
- ENVISAT Satellite

- iv. **Acquisition Date/Time**
  - Yy/mm/dd – TIME – hh:mm:ss
- v. **Satellite Domain**
  - Orbit Number
- vi. **Percentage of Overlap**
  - Overlap between AATSR strip and selected area
- vii. **Graphical Overview:**
  - Pseudo coloured JPEG RGB Map - Pre-classified ENVISAT AATSR Product

Select	Product Identifier ▲	Collection	Platform	Acquisition Date/Time	Satellite Domain	Percentage of Overlap	Graphical Overview
<input checked="" type="checkbox"/>	ATS_SpCI73_1PRUPA20030302_072214_072705	MEEO-ATSR	ENVISAT	2003-03-02T07:22:14	Orbit: 05241	1.24%	
<input checked="" type="checkbox"/>	ATS_SpCI73_1PRUPA20030328_070458_070949	MEEO-ATSR	ENVISAT	2003-03-28T07:04:58	Orbit: 05613	8.253%	

**Figure 5-3 : SSE metadata**





**Figure 5-4 : RGB pre classified strip**

<b>Administrative information</b>
<b>Organisation Name:</b> ESA
<b>Organisation Role:</b> custodian
<b>Product Identifier Element:</b> ATS_SpCI73_1PRUPA20030312_070754_071245
<b>Abstract Element:</b> Pre-classified ENVISAT AATSR Product
<b>Geographic location</b>
<b>Polygon Coordinates:</b> 44.009689,47.553917 42.762260,54.124786 25.619612,48.401871 26.739311,43.041199
<b>Temporal information</b>
<b>Start Date:</b> 2003-03-12T07:07:54
<b>End Date:</b> 2003-03-12T07:12:45
<b>Metadata Date:</b>

**Figure 5-5 : Metadata additional information**

Technical characteristics	
Mission: ENVISAT	
Code Identifier: ATS	
Sensor: AATSR	
Orbit Number: 05384	
Content information:	
typeName: imageType	
attribute name: imageQuality	
attribute type name: imageQualityType	
content type: 001	
Additional information:	
Local Attribute elements	
localName	localValue
Vegetation	0.1097%
Shadow area with Vegetation	0.0021%
Rangeland	0.1957%
Weak Rangeland	1.0355%
Pit Bog	0.1582%
Greenhouse	0.7255%
Barren land and Built-up	29.6601%
Shadow area with Barren	0.0009%
Water or Shadow	0.2929%
Cloud	65.3578%
Thin Cloud	1.4841%
Snow	0.0958%
Shadow Snow	0.5605%
Shadow	0.0000%
Unknown	0.3173%

**Figure 5-6 : Technical metadata info**

NB: The percentages correspond to the classified classes on the entire strip (A)ATSR, and don't give the correct information, in qualitative terms, if our area of interest is small (relative to the strip via satellite).

It is absolutely necessary to specify how an erroneous introduction of a Semantic Query (for example the cloud cover in the research phase of the metadata) may result the exclusion of zone maps with excellent qualitative features.

In this case study the maximum overlap between the strip and area monitoring

AATSR is just over 8%. Although the remaining 92% was covered by clouds, this would not affect the goodness of the image area.

## 5.5 Data Acquisition

The acquisitions were made at annually distance to highlight the changes related to the rehabilitation of the area of marshland as a result of geopolitical changes that occurred in the last ten years. Were also selected the months of March and July / August for the development of evolutionary models related to seasonal phenomena, especially for the study of the Vegetation spread, after previous re-flooding.

The key work is the compilation of a table dates. In order to develop reliable models is vital to have a good variety of pictures to submit to a

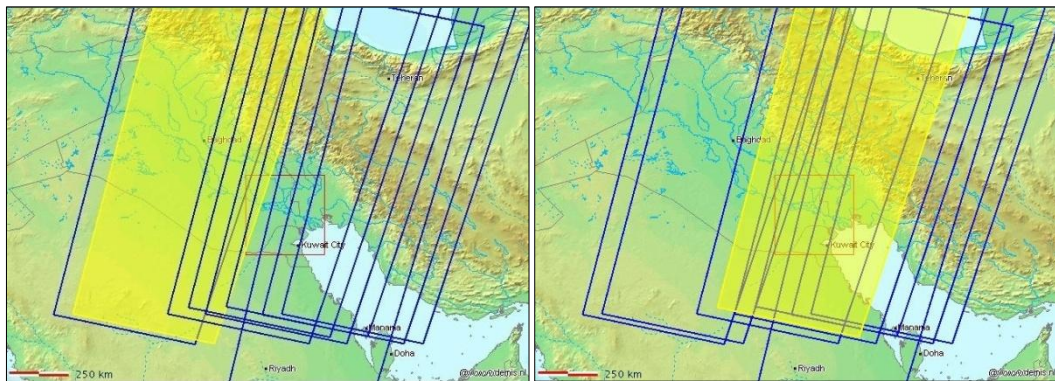
selection of quality. At best cases there are a dozen acquisitions per month.

These images must then be subjected to a critical view to define the quality parameters that can make images AATSR more or less valid for the creation of models.

Quality parameters used to choose best images to develop LULCC models:

- a) High overlap percentage of (A)ATSR strip on selected area ;
- b) Very limited or no cloud cover ;
  - b1. In an expeditious way it is possible to verify the cloud cover from the preview of the RGB pre-classified map (see 5.4 Data Example) . Visual interpretation is required to distinguish the actual presence of clouds over the area. It is an inaccurate method without geographical references but has the fastest speed of investigation.
  - b2. In a more accurate technically way, instead, it is possible to distinguish the actual cloud cover viewing the map already introduced into the system ALCS. In this way the pre-classified map is implemented in the Earth Fixed Grid, then correctly georeferenced. This method is very laborious in computational terms, and requires the download and implementation in ALCS of all the maps downloaded from the catalogue.

Example of application of a quality choice of a) type:



bad overlap: 2003-03-02T07:22:14

good overlap: 2003-03-28T07:04:58

Figure 5-7 : Strip Overlap over the study area

Select	Product Identifier ▲	Collection	Platform	Acquisition Date/Time	Satellite Domain	Percentage of Overlap	Graphical Overview
<input checked="" type="checkbox"/>	ATS_SpCI73_1PRUPA20030302_072214_072703	MEO.ATSR	ENVISAT	2003-03-02T07:22:14	Orbit: 05241	1.24%	
<input checked="" type="checkbox"/>	ATS_SpCI73_1PRUPA20030328_070458_070949	MEO.ATSR	ENVISAT	2003-03-28T07:04:58	Orbit: 05613	8.253%	

For the purpose of this study the best images are also those that meet the quality criteria b; one or maximum 2 images per month were used to define the LULCC models. Because of the great variability of climatic conditions is also necessary to make this selection so that they are temporally comparable. Were in fact selected the best images in the last weeks of March and July, with exceptions for early August and some images of mid-March as it best meets the b2 quality parameter.

Example of application of a quality choice of b2) type:

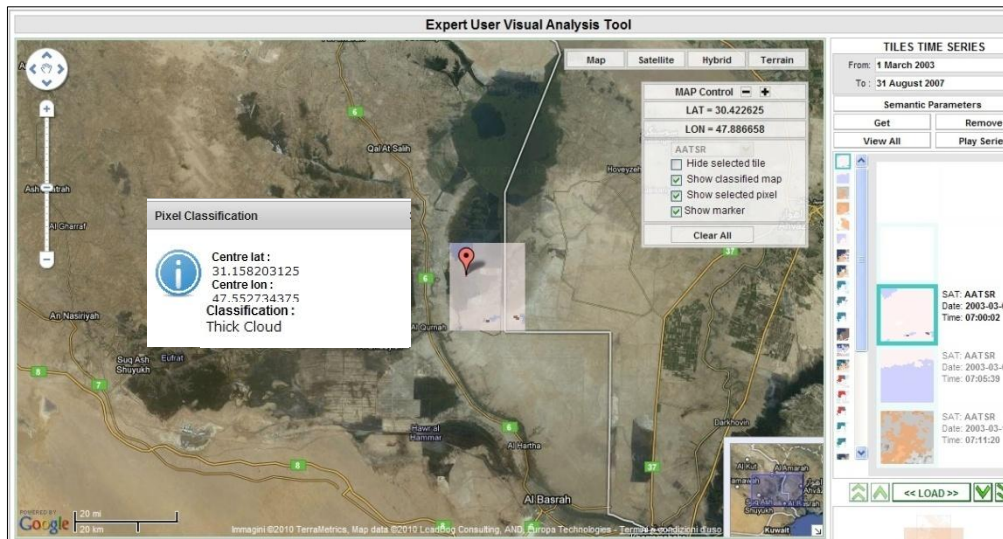


Figure 5-8 : Pixel Info – Thick Cloud class

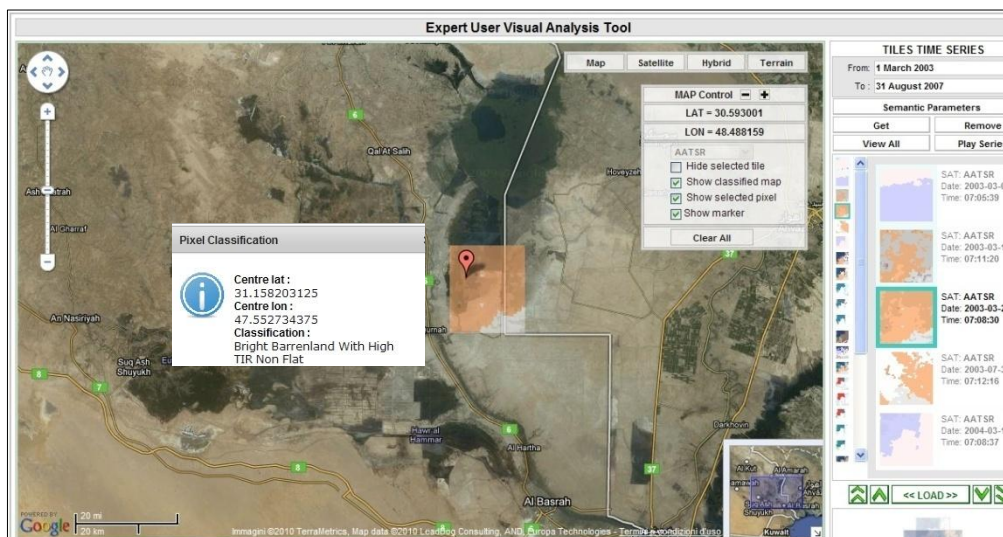


Figure 5-9 : Pixel Info – Bright Barrenland class

Type of Sensor	Spatial Resolution (m)	Swath Width (km)	Bands	Repeat Cycle Orbit (days)	Number of Images Used
AATSR	1000	512	Band 1 (MWIR)	35	94
	1000	512	Band 2 (TIR)		(2003-
	1000	512	Band 3 (TIR)		2007)
	1000	512	Band 4 (VIS)		
	1000	512	Band 5 (VIS)		
	1000	512	Band 6 (NIR)		
	1000	512	Band 7 (SWIR)		

**Table 5-2 : AATSR Characteristics**

	March	July	August
YEARS			
2003	02,03,06,09,12,21,22,25, <b>28</b>	01,02,04,05,14,20,21,27, <b>30</b>	/
2004	02,06,09,12,15,18,21,22,25, <b>28</b>	01,04,05,08,11,14,17,20,24,27, <b>30</b>	/
2005	03,06,07,10,13,16,19,22,26, <b>29</b>	02,05,09,12,15,18,21,24,25, <b>28</b>	<b>03</b>
2006	01,04,07,11,14,17,20, 23, 30	03,06,09,13,16,19,22,25,29	<b>01</b>
2007	<b>08</b> , 11,24,27	01,04,07,10,14,20, <b>23</b> ,26, 29,30	<b>05</b>

**Table 5-3 : Date of downloaded images**

Pre-classified images collected: 94

Pre-classified images used to develop LULCC models: 14, Correspondent to about 15% of the Total Images implemented in ALCS.

## 6 LULCC Models

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### 6.1 Models general overview

An environmental conditions model can be defined as a phenomenon or statistic associated with a particular environmental condition. A Land model quality change may include direct and indirect indicators. A direct indicator will generally be a specific set of descriptors of the physical environment itself (e.g. decrease in soil organic matter content as an indicator of land degradation). Indirect indicators may reflect secondary interactions or consequences that arise in adjoining systems.

There are two general classes of Models, which are relevant for LULCC research. Models of land cover (e.g. fractional vegetation cover, leaf area index) can be used for detection of change and for providing information on shifting trends or trajectories in land-use/land-cover change. Models of land quality can be used to determine whether land-use potentially is changing. The potential degradation of land is an important dimension of LULCC research.

Several organizations are in the process of developing scientifically credible and technically feasible Land Quality Models. LULCC models can play an important role in assisting the scientific community in the study of land evolutionary phenomena. Such research must identify, test and recommend models that are the most useful and cost effective, and based on best available data and information. Models should be designed so as to inform important policy questions, to be comparable across regions, and to be sufficiently robust to stand up to scientific scrutiny and to be useful over time.

A land-cover change hot spot can be conceived of from different perspectives (Lambin and Ehrlich, 1997). First, it could be defined according to high rates of land-cover changes being observed at present, or in the recent past.

Second, hot spots could be defined as areas where land-cover changes are likely to occur in the near future. This anticipative approach is more

difficult to implement since it requires a predictive model applicable at a broad scale. Yet, it is useful to support policy interventions aimed at mitigating the adverse effects of dramatic land cover changes.

Third, to define a location as an hot spot, one could not only look at the observed or anticipated rate of change but also at the likely severity of the impact of the change. The concept of hot spot would therefore be tied to specific issues of interest - e.g. biodiversity loss, carbon release, hydrological cycle alterations, cultural heritage destruction o socio-economic impacts. For example, for some areas, even a moderate rate of land-cover change could have dramatic impacts on biodiversity.

High spatial resolution satellite remote sensing provides a uniform approach to measuring and mapping land-cover change over large areas at fine spatial resolution (100 m or lower), tracking land-cover conversions (and some modifications) at a sub-national level with a high degree of accuracy. Classic change detection techniques are based on the comparison of sequential maps or land-cover classifications derived from remote sensing data for the same area. When applied at coarse resolutions (1km<sup>2</sup>), this approach has significant limitations:

- (i) the comparison of successive maps does not allow the detection of minor changes within broad land-cover classes (and most coarse spatial resolution maps only represent broad classes),
- (ii) the change map product exhibits an accuracy not greater than the product of the accuracy of the coarsest map, and
- (iii) the individual classifications may be affected by exceptional, short-term events (e.g. vegetation stress, flooding or burning) which may lead to the detection of spurious changes. To overcome these limitations, preferred land-cover change detection approaches rely on a comparison of remotely-sensed land-cover indicators of surface conditions.

To advance the analysis of landscape dynamics, spatial statistical models of land cover change should be developed. Such models support the following aims:



- (i) to test over an entire region hypotheses on change processes and on the influence of some driving forces,
- (ii) to suggest specific issues that should be investigated further,
- (iii) to identify areas that are likely to be subject to dramatic land-cover modification in the near future, and
- (iv) to predict likely impacts of these transformations. The last two points are particularly important for land-use planners since, in order to focus policy interventions, one needs not only to measure the rates and identify the factors of land-cover changes, but also to anticipate where conversions are more likely to occur next. Such predictive information is essential to support a timely policy response - e.g. where land cover changes are associated with a degradation of land quality and the depletion of essential resources.

The main goal of these spatial models is the projection and display in a cartographic form of future landscape patterns, which would result from the continuation of current trends. The approach consists in analyzing the location of different categories of land-cover changes in relation to maps of natural and cultural landscape variables. Maps of changes in land cover are derived from multi-temporal sequences of remotely sensed data. Changes in land cover are categorized and their spatial occurrences are correlated with landscape and location attributes.

Developing the basis for a new generation of models is a major task in terms of both database compilation and methodological innovation.

## **6.2 ALCS Model Editor – General Features**

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Model Editor is a part of the expert user interface which allows expert users to create, modify or remove evolution models.

A pattern is a sequence of relations pixel value - sampled instant. A pattern can be, for an expert user, the starting basis to create a model. For the description of evolution models, it must be introduced the concepts of

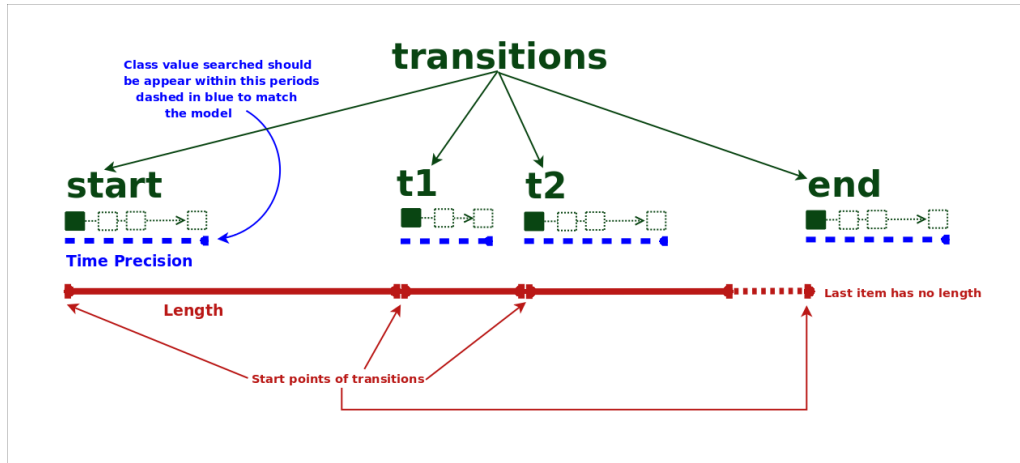
tolerance, in particular tolerance for class values assumed (one or many) and tolerance for time period in which a pattern is valid. Only with these concepts an evolution models can be more general and adaptable to different phenomena, including coarse level classification (i.e. any kind of vegetation, addressed by class tolerance) and missing or cloudy satellite data (addressed by time tolerance). An evolution model is composed by a sequence of items with certain features. A single item assumes a certain class value, Class, for a certain time period. The concept of class tolerance provides a parameter, "Tolerance", which is a range of classes that may be present instead of a single value of the Class. Besides that, the parameter "Not" constitutes the set of all classes except the one selected by Class. It may be useful for models where it is important that the class doesn't take some values (for example, in re-flooding, the sequence switches from a value of non water to a value of water).

The time variability is determined by the first value of the sequence and by the time parameters left empty: if in the model there is complete Date (year, month, day), the model is applicable only for that period of time, if year field is missing, the model is periodic; at last, if Date-field is missing, the model is a non-seasonal model, applicable to different times of the year, but within a time length of the model. The time length of the model is a common feature to all kind of model: to calculate that we need to introduce two time parameters. Length is the transition time between two elements of the sequence and it is a mandatory field for all items of the sequence except for the last.

Rarely the exact moment of transition foreseen in the model is the same moment of transition in the pattern; it is then planned to seek the expected value in a subsequent time range. This concept of tolerance is expected by the Time-precision parameter that determines how long (in days) you may deviate from the nominal value of the transition to consider it still conforms to the model.

Without the temporal tolerance concept it would not be possible to obtain reliable results in patterns of seasonal/annual variation defined in the next paragraph. The usefulness of this parameter is not in doubt, since it is

unlikely to be able to obtain maps qualitatively comparable to the exact same date from different periods. Problems of cloud cover, incomplete overlap between acquisition and study area due to satellite different orbit or misclassification of the pixels are very frequent, so it is necessary to seek a comparison between two different states of the pixels within a certain time tolerance.



**Figure 6-1 : Time Precision and Length**

For these concepts, the constraint is  $\text{Time-precision} < \text{Length}$ , otherwise the concept of transition became meaningless. When you create a template you must remember that Time-precision is included within Length and the next transition will be after an interval equal to Length, regardless of the value of Time-precision that will be used in matching; otherwise the real Length applied became  $\text{Length} + \text{Time-precision}$  and this would make the model not much accurate.

Because of the parameters above, the Time-length foreseen by the model is the sum of the single item Lengths and Time-precision of last item.

This structure has been reviewed in advantage of user usability. Length has been renamed TSP and Time Precision has been renamed Time Tolerance and these parameters have some differences from the previous:

- TSP (Time Since Previous) depicts the nominal value of the starting point of transition through the distance (in seconds) from previous

element of sequence. Therefore “start” transition has not TSP value.

It is similar to time of sampling with a variable step: it depicts when transition starts.

- Time Tolerance depicts the temporal range in which searching expected value. It is the maximum possible value in days from which one can departures (after or before the nominal starting of transition).

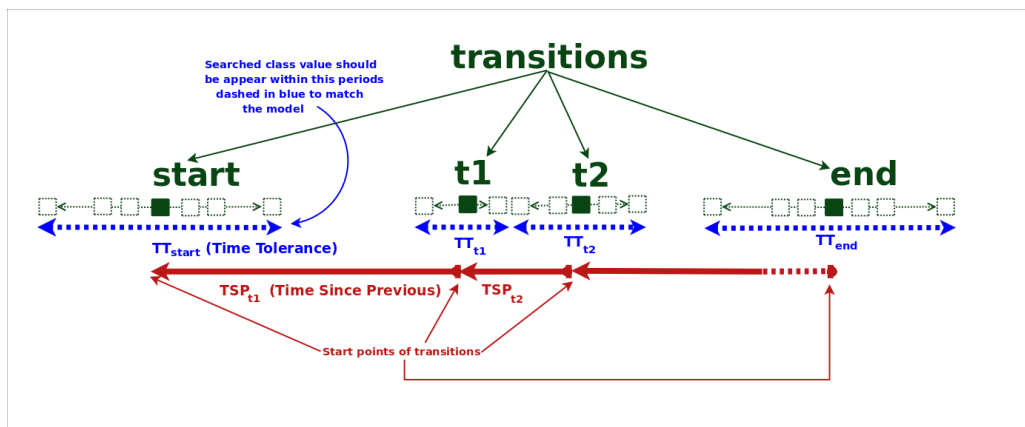


Figure 6-2 : TSP and Time Tolerance

Figure 6-2 shows the meaning and the relationships between TSP and Time Tolerance. Time Tolerance has a range which starts from its minimum value (one day) and it arrives to its maximum possible value, which is the minimum between:

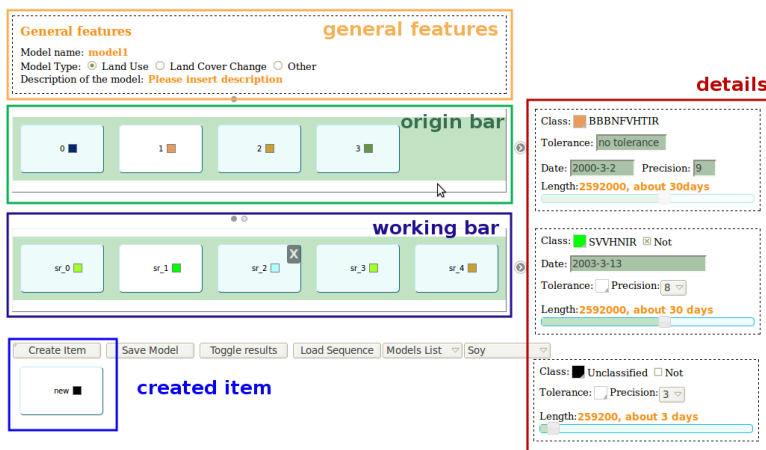
- $TSP$  (in days) - (Time Tolerance of previous item) - 1 and
- $(TSP$  of next item in days) - (Time Tolerance of next item) - 1.

Time Tolerance of “start” transition has not a previous item, therefore it only must be minor than  $(TSP$  of next item in days) - (Time Tolerance of next item) - 1.

Time Tolerance of “end” transition has not a next item, therefore it only must be minor than  $(TSP$  of previous item in days) - (Time Tolerance of previous item) - 1.

These constraints are needed to avoid possible overlapping or temporal inconsistencies: within the Time Tolerance, a value of a transition must be located after previous transition effective value and before the next one. “-1” indicates that overlapping is not possible: in the worst case, two consequent values of the model must be separated from one day.

Model editor has to allow expert users to create a new sequence by the beginning, to edit an existing sequence or to use that from Pixel History; at last to save the created sequence. Evolution model is represented by a section of general features (model name, owner user, description of the model) and by a multi-temporal description of the model transitions. The approach behind this interface is to provide users with not programming skills with a most intuitive as possible model editor, which auto-generate final xml. So the choice turned on an auto-explanatory model editor with tools as possible closer to stand-alone technology.



**Figure 6-3 : Model Editor Architecture**

## 6.3 Iraq Marshlands Developed Models

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The figure below represents the complete land cover change occurred in the area of interest, with extension of 10,000 square kilometres acquired by NASA using the Moderate Resolution Imaging Spectroradiometer sensor (MODIS, with 250m spatial resolution on visible bands) on NASA's Terra satellite. Several large marsh areas located at the north and the south of the Euphrates had been re-flooded, and the dry land south of Al Hawizeh Marsh was being systematically filled. These areas appear almost purely dark blue or nearly black, which indicates that standing water was present, but that vegetation was absent or extremely sparse.



Figure 6-4 : NASA MODIS Image - February 6, 2003



Figure 6-5 : NASA MODIS Image - February 9, 2004

In the next Chapter are listed the five models developed to describe different types of change occurred in the study area.

### 6.3.1 Not-to-Water Model

The first model, called "Not-to-water", analyzes the differences between classes previously classified as non-water classes and the re-flooded areas. The degree of environmental restoration is calibrated on an annual basis, thus excluding the possible behaviours of a seasonal nature. The monitoring is in fact based on an annually TSP between the months of March for several years.

#### MODEL DEFINITION:

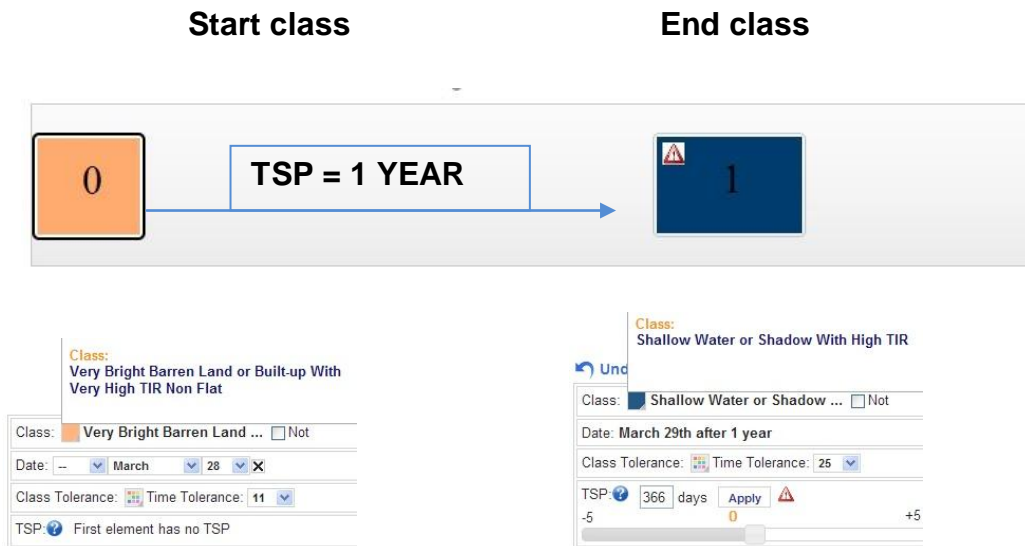


Figure 6-6 : Not-to-Water Definition pattern

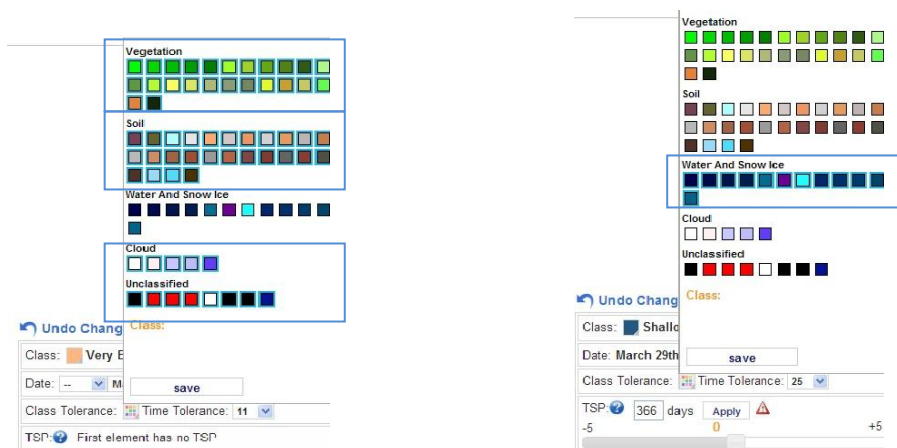


Figure 6-7 : Not-to-water Class Tolerance parameters

<b>Not-to-Water Annual Model</b>	<b>Start</b>	<b>End</b>
<b>Date</b>	<b>28 March</b>	<b>29 March</b>
<b>Time Tolerance</b>	<b>11 Days</b>	<b>25 Days</b>
<b>Class Tolerance</b>	(0) - Class Tolerance: <input type="checkbox"/> Vegetation <input type="checkbox"/> Soil <input type="checkbox"/> Cloud <input type="checkbox"/> Unclassified classes.	(1) - Class Tolerance: <input type="checkbox"/> Water and Snow Ice Classes.
<b>TSP</b>	<b>366 Days</b>	

**Table 6-1 : Not-to-Water Features Table**

Below is the legend, universally used for the ALCS application in Visual Analysis Client. The output matching between the models and maps classified implemented in the system uses the following colours to describe the results:

**LEGEND:**





-  **Model Not Matching : Both Classes are different from Class model**
-  **Model Matching with Class Tolerance**
-  **Model Perfect Matching**
-  **Model missing pixel info** : when in the area the classified map lack





Figure 6-8 : Iraq Marshland VAC map area

2003 - 2004

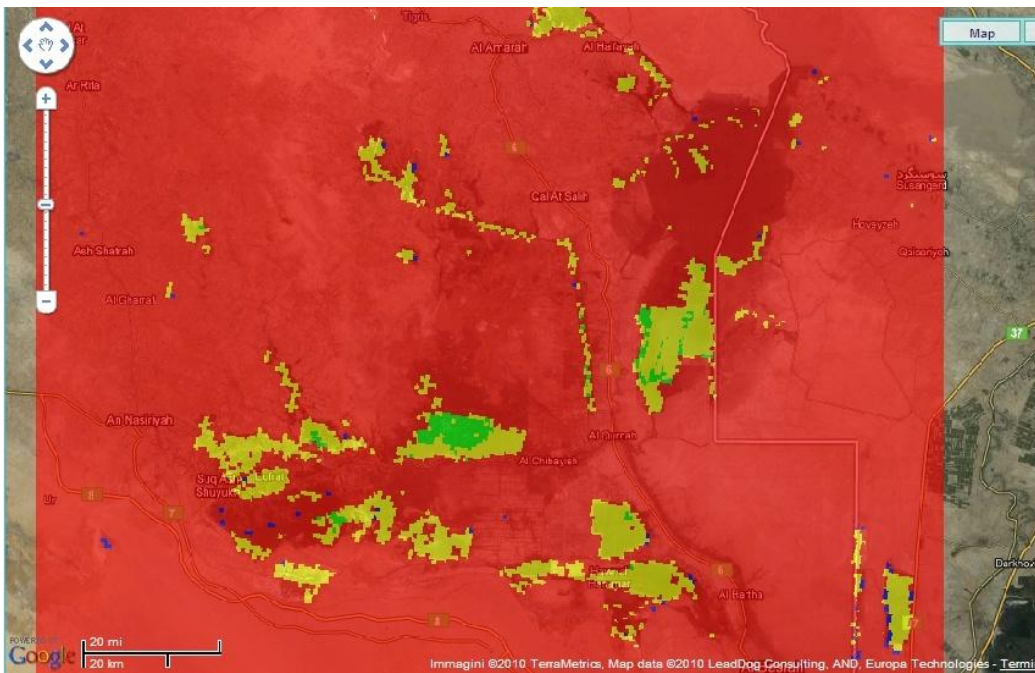
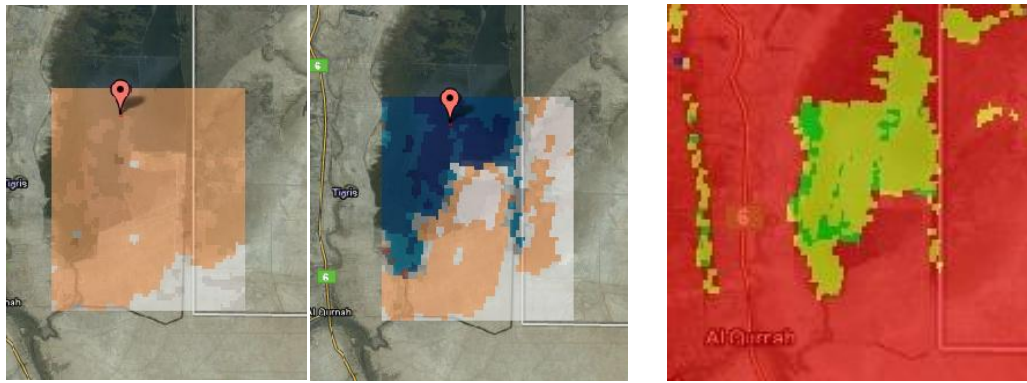


Figure 6-9 : Iraq Marshland model 2003-2004 Overlay

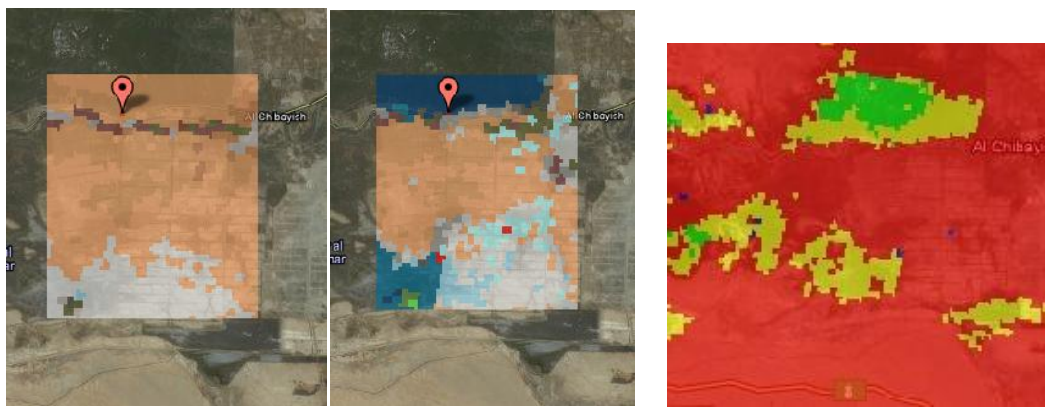


2003-03-28

2004-03-28

2003-2004 LCC

Figure 6-10 : Al Qurnah East Area Tiles on 2003-2004 and model comparison



28-03-2003

28-03-2004

2003-2004 LCC

Figure 6-11 : Hawr Al Hammar Central Area Tiles on 2003-2004 and model comparison



28-03-2003

28-03-2004

2003-2004 LCC

Figure 6-12 : Hawr Al Hammar Sud Area Tiles on 2003-2004 and model comparison

## 2004 - 2005

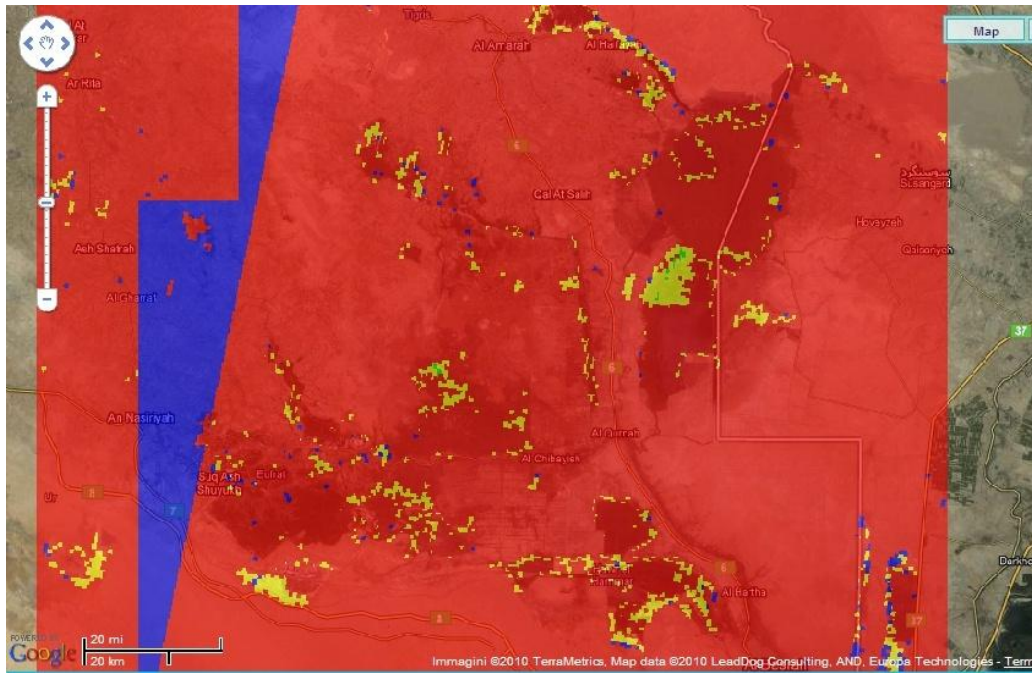


Figure 6-13 : Iraq Marshland model 2004-2005 Overlay

## 2005 – 2006

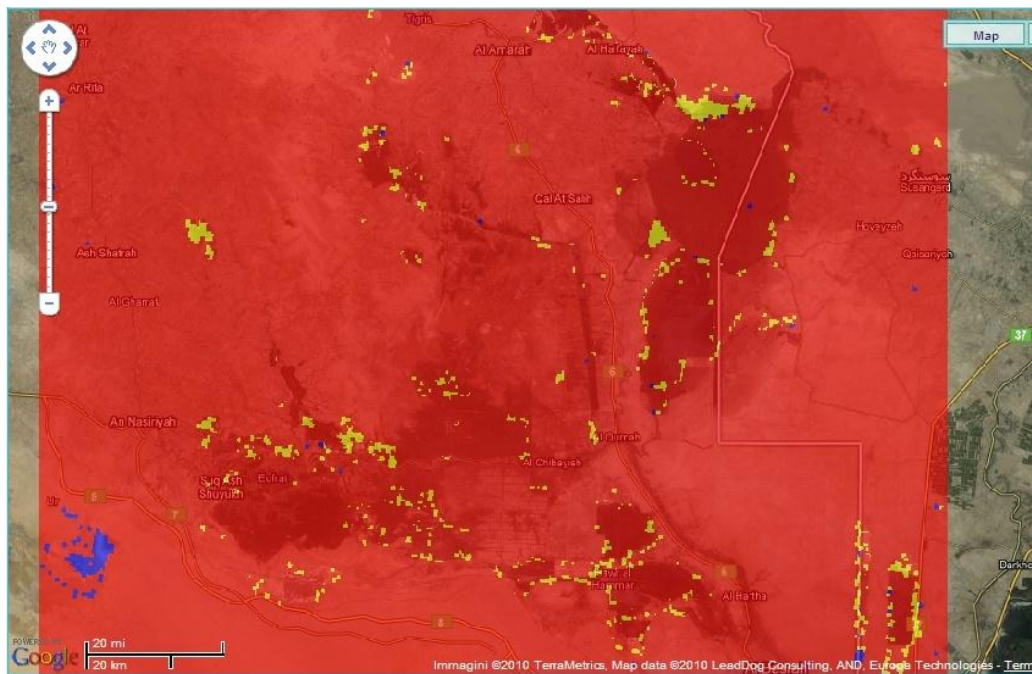


Figure 6-14: Iraq Marshland model 2005-2006 Overlay

For questions of lack of data at the same time period 2006-2007 the model has been calibrated with different date parameters:

<b>Not-to-Water</b> <b>2006-2007</b> <b>Annual Model</b>	<b>Start</b>	<b>End</b>
<b>Date</b>	<b>28 March</b>	<b>29 March</b>
<b>Time Tolerance</b>	<b>11 Days</b>	<b>3 Days</b>
<b>TSP</b>	<b>345 Days</b>	

Table 6-2: Not-to-Water 2006-2007 Features Table

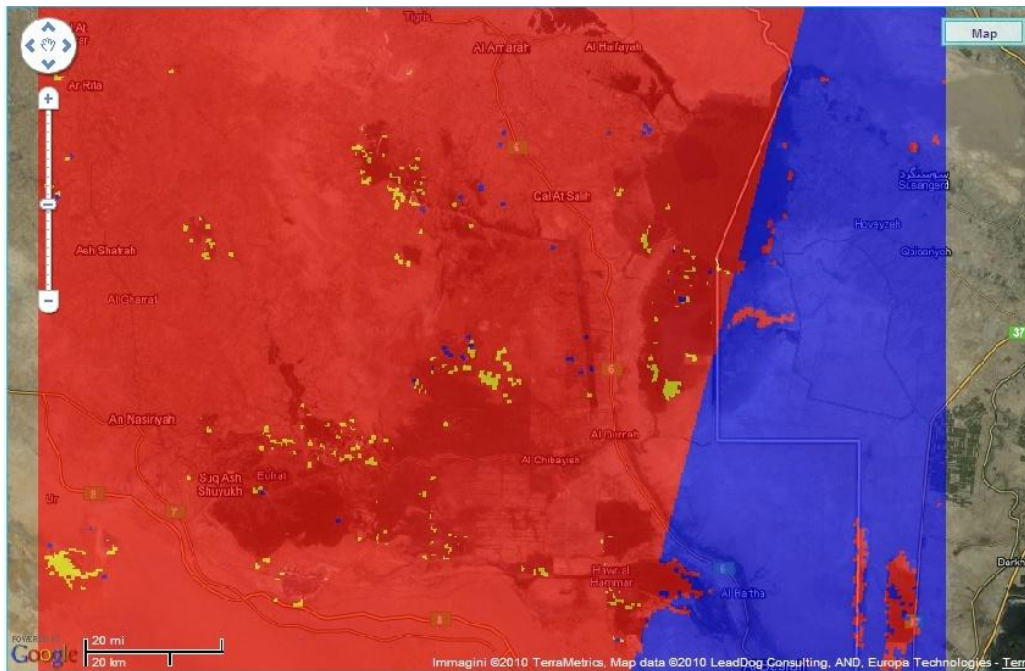


Figure 6-15: Iraq Marshland model 2006-2007 Overlay

### 6.3.2 Barren-to-Water

The second model developed follows the same principle as the first: the same area of application, and the same time frame of investigation. But are considered more specific initial class, only related to the types of soil (no vegetation, no clouds, no waters, no unclassified).

#### MODEL DEFINITION:

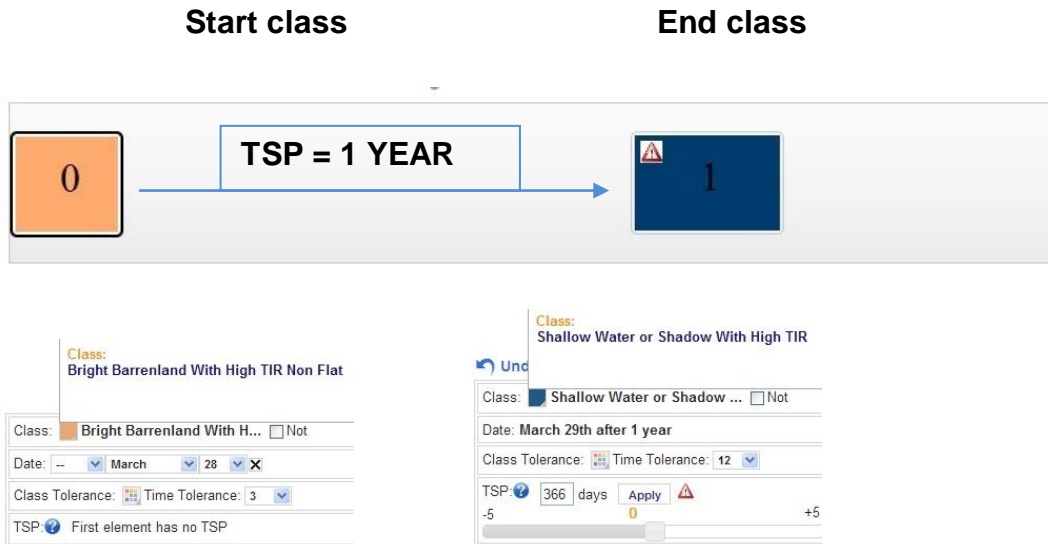


Figure 6-16 : Barren-to-Water Definition pattern

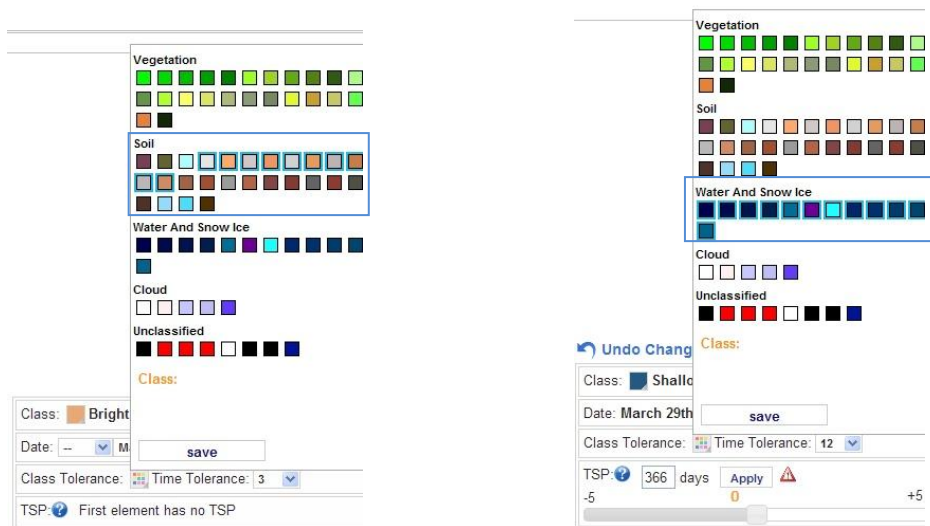


Figure 6-17 : Barren-to-water Class Tolerance parameters

<b>Barren-to-Water Annual Model</b>	<b>Start</b>	<b>End</b>
<b>Date</b>	<b>28 March</b>	<b>29 March</b>
<b>Time Tolerance</b>	<b>3 Days</b>	<b>12 Days</b>
<b>Class Tolerance</b>	(0) - Class Tolerance: <input type="checkbox"/> Very Bright Barrend Land <input type="checkbox"/> Bright Barren Land <input type="checkbox"/> Strong Barren Land-High TIR FLAT <input type="checkbox"/> Strong Barren Land-High TIR non Flat	(1) - Class Tolerance: <input type="checkbox"/> Water and Snow Ice Classes.
<b>TSP</b>	<b>366 Days</b>	

Table 6-3 : Barren-to-Water Features Table

**LEGEND:**





-  **Model Not Matching : Both Classes are different from Class model**
-  **Model Matching with Class Tolerance**
-  **Model Perfect Matching**
-  **Model missing pixel info : when in the area the classified map lack**



Figure 6-18 : Iraq Marshland VAC map area

2003 - 2004

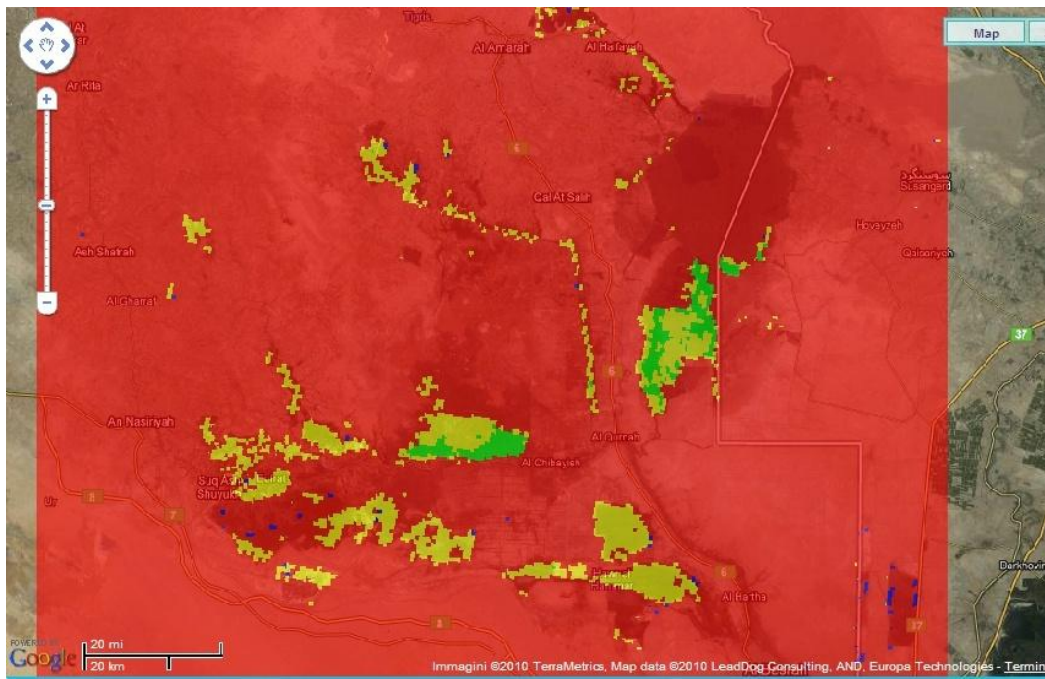


Figure 6-19 : Iraq Marshland model 2003-2004 Overlay

2004 - 2005

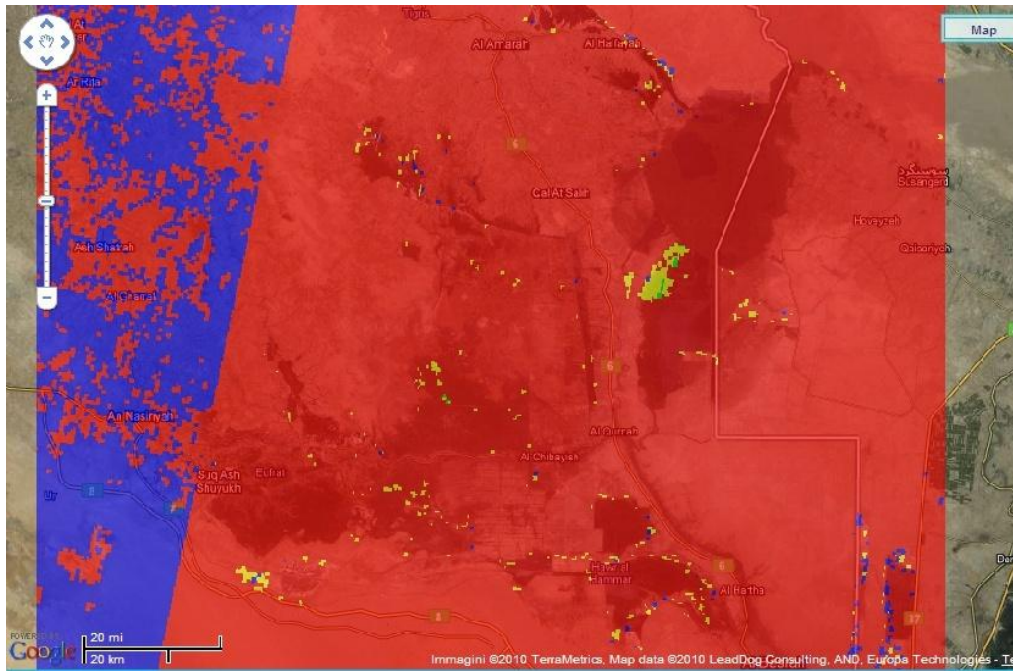


Figure 6-20 : Iraq Marshland model 2004-2005 Overlay

2005 - 2006

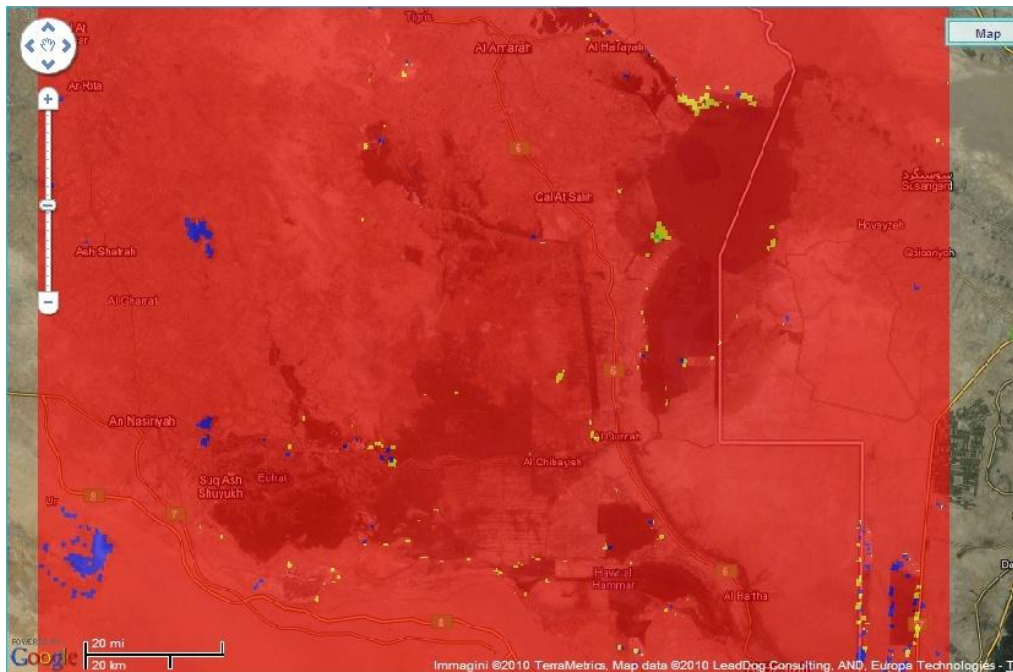


Figure 6-21 : Iraq Marshland model 2005-2006 Overlay





### 6.3.3 Not-to-Vegetation

The third model has a qualitative aspect and instead provides some food for thought more. Is analyzed the changes occurred on a seasonal basis, between bare soil and land vegetation. You will notice how this expansion is related to the vegetative growth above water.

#### MODEL DEFINITION:

Start class

End class



Figure 6-23 : Not-to-Vegetation Definition pattern

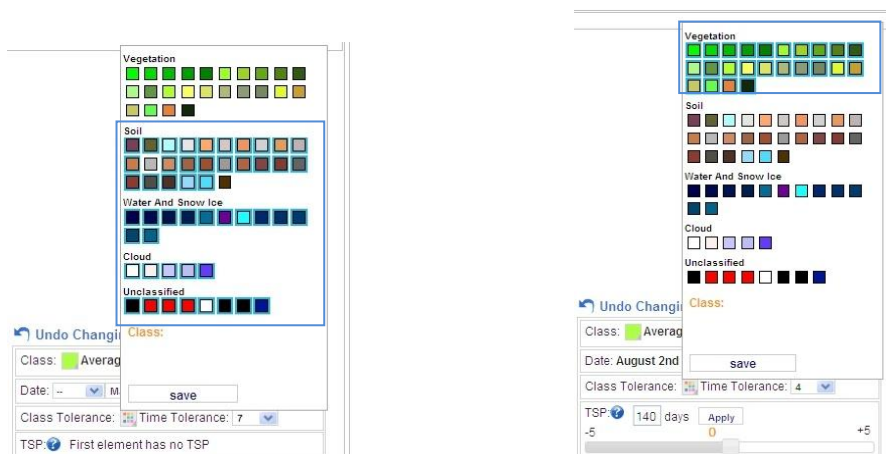


Figure 6-24 : Not-to-Vegetation Class Tolerance parameters

<b>Not-to-Vegetation Seasonal Model</b>	<b>Start</b>	<b>End</b>
<b>Date</b>	<b>15 March</b>	<b>02 August</b>
<b>Time Tolerance</b>	<b>07 Days</b>	<b>04 Days</b>
<b>Class Tolerance</b>	(0) - Class Tolerance: <input type="checkbox"/> NOT Average Vegetation with Very High NIR <input type="checkbox"/> All NON Vegetation Classes	(1) - Class Tolerance: <input type="checkbox"/> Vegetation Classes
<b>TSP</b>	<b>140</b>	

Table 6-5 : Not-to-Vegetation Features Table

**LEGEND:**





-  **Model Not Matching : Both Classes are different from Class model**
-  **Model Matching with Class Tolerance**
-  **Model Perfect Matching**
-  **Model missing pixel info : when in the area the classified map lack**



Figure 6-25 : Iraq Marshland VAC map area

March – August 2003

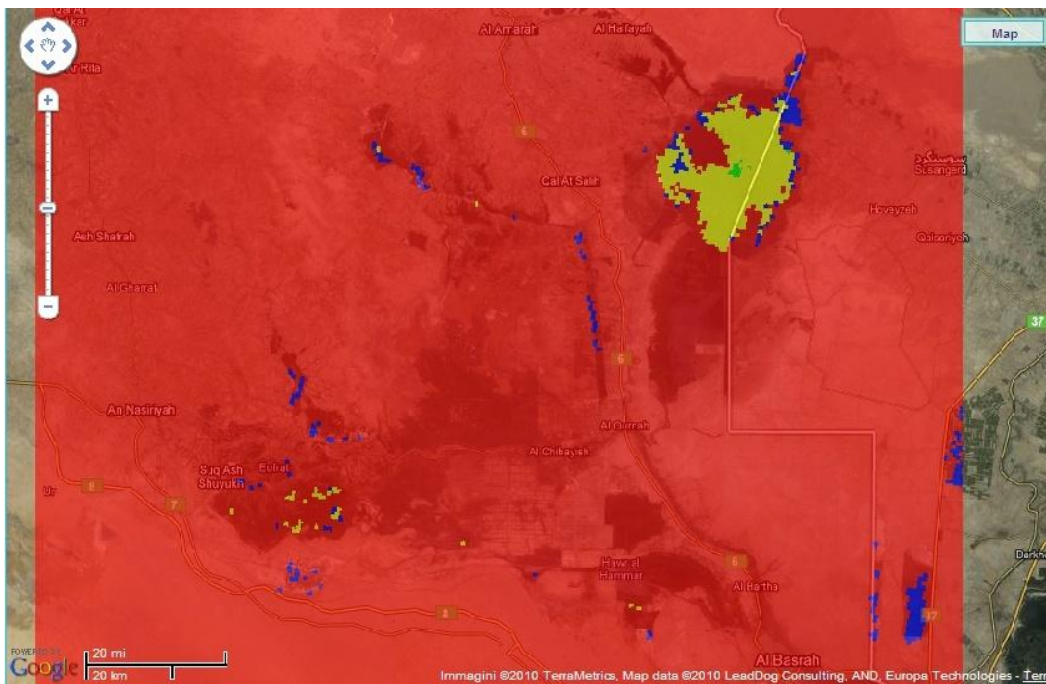


Figure 6-26 : Iraq Marshland model March-August 2003 Overlay

### March – August 2004

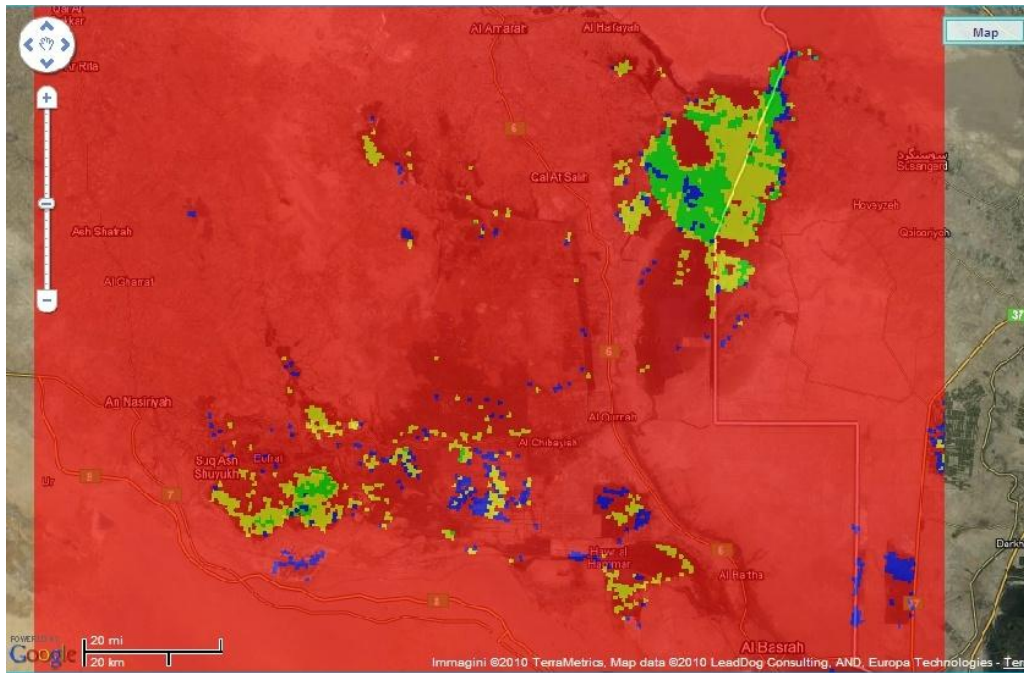


Figure 6-27 : Iraq Marshland model March – August 2004 Overlay

### March – August 2005

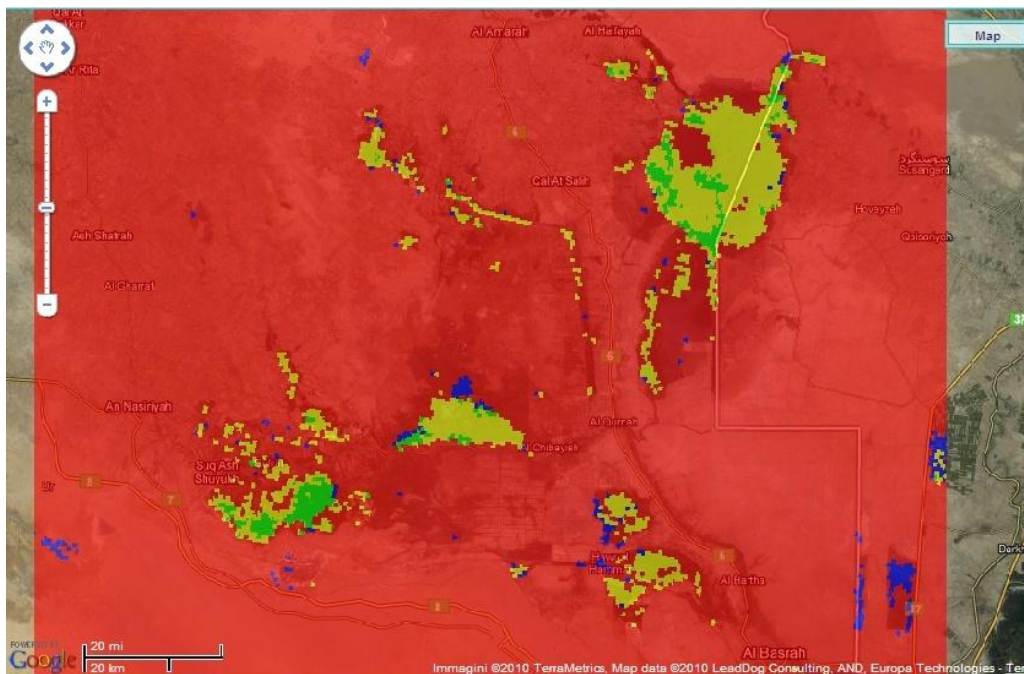


Figure 6-28 : Iraq Marshland model March-August 2005 Overlay

### March – August 2006

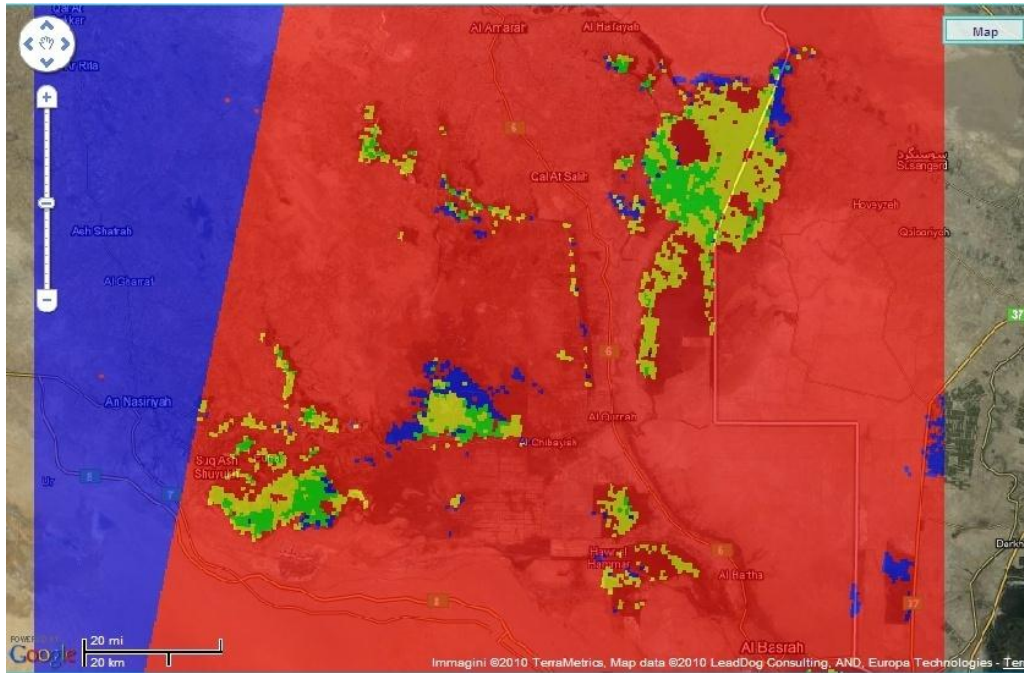


Figure 6-29 : Iraq Marshland model March-August 2006 Overlay

### March – August 2007

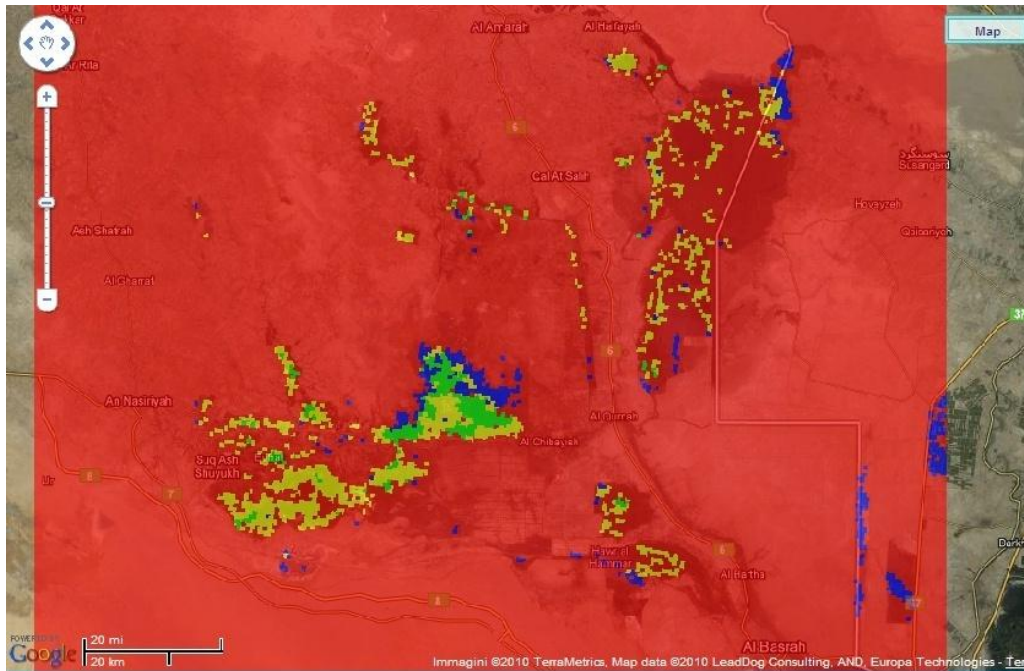


Figure 6-30 : Iraq Marshland model March-August 2007 Overlay

### 6.3.4 Deep/Shallow-to-Shallow/Turbid Water

The fourth model has a qualitative aspect related to water. It analyzes the changes on a seasonal basis, including clear and deep type water scheduled in March and shallow and turbid water scheduled during summer months. The model can be a reflection on the morphology of the terrain (related to the change deep-shallow waters) and a reflection of the quality of the waters ( related to the Turbid change). In the absence of a positive result in some pixel ( where in previous years the model show a matching change) is also possible to deduce that maybe there are areas subject to drought (no presence of water table).

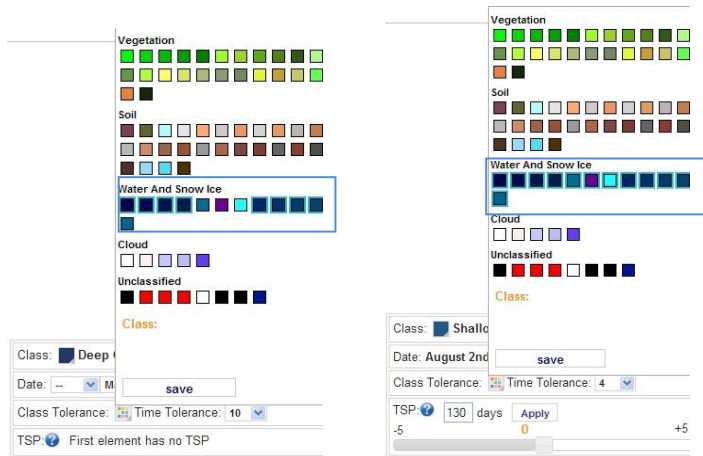
#### MODEL DEFINITION:

**Start class**

**End class**



**Figure 6-31 : Deep-shallow-Turbid Water Definition pattern**







**Figure 6-32 : Deep-shallow-Turbid Water Class Tolerance parameters**

<b>Deep/shallow to Shallow/Turbid Water Seasonal Model</b>	<b>Start</b>	<b>End</b>
<b>Date</b>	<b>25 March</b>	<b>02 August</b>
<b>Time Tolerance</b>	<b>10 Days</b>	<b>04 Days</b>
<b>Class Tolerance</b>	(0) - Class Tolerance: <input type="checkbox"/> Deep and Shallow waters	(1) - Class Tolerance: <input type="checkbox"/> Shallow and Turbid Waters
<b>TSP</b>	<b>130</b>	

Table 6-6 : Deep-Shallow-Turbid Features Table

**LEGEND:**

-  **Model Not Matching : Both Classes are different from Class model**
-  **Model Matching with Class Tolerance**
-  **Model Perfect Matching**
-  **Model missing pixel info : when in the area the classified map lack**



### 2003 - 2003

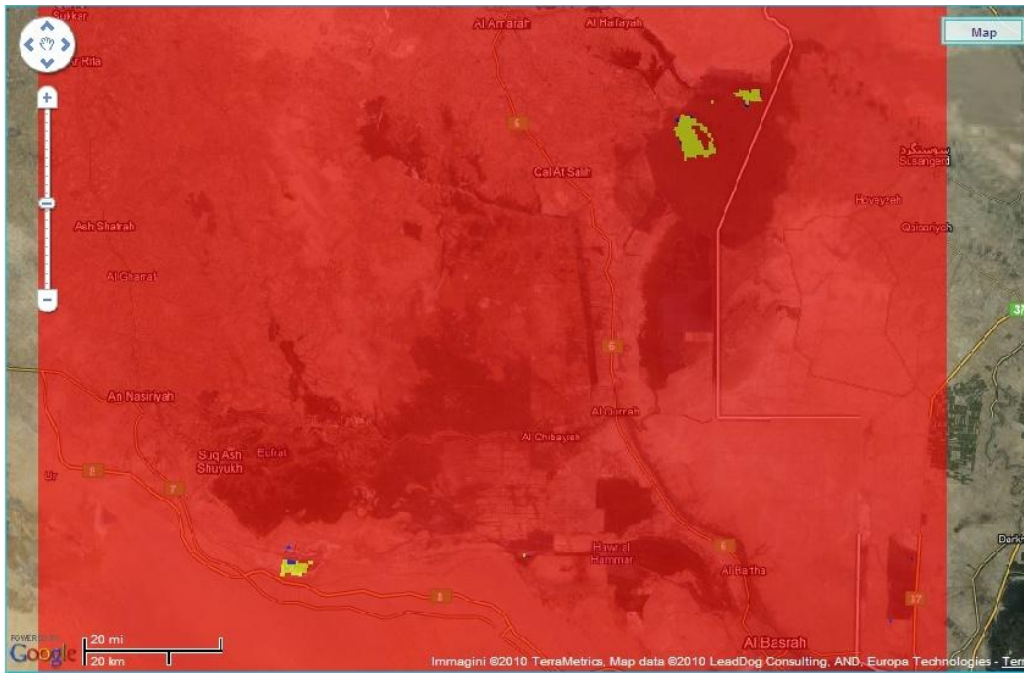


Figure 6-33 : Iraq Marshland model March-August 2003 Overlay

### 2004 - 2004

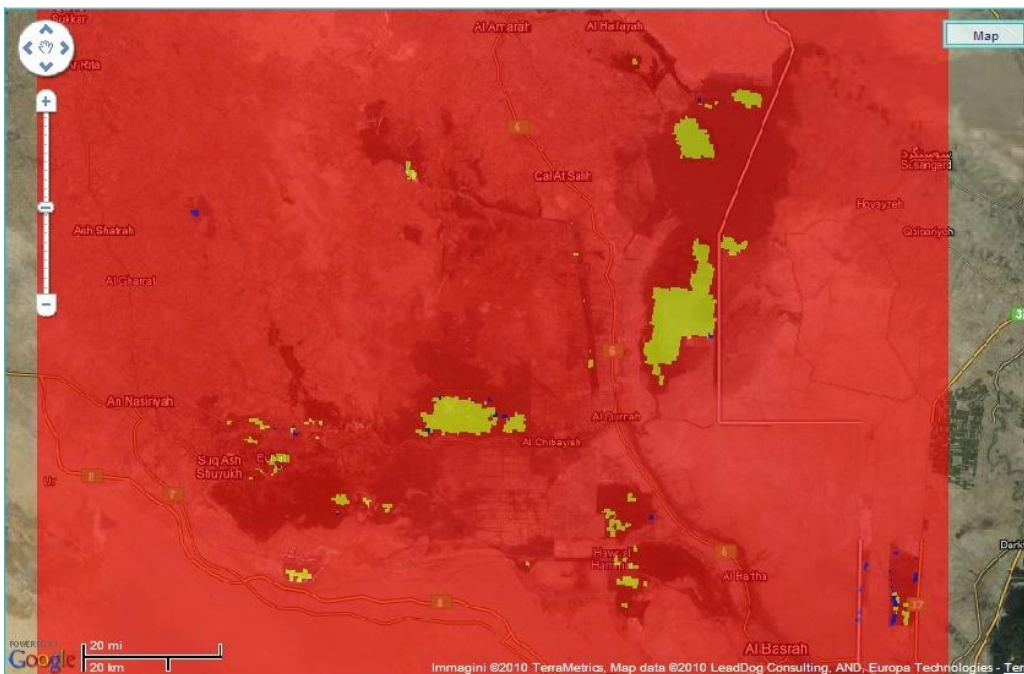


Figure 6-34 : Iraq Marshland model March-August 2004 Overlay

2005 - 2005

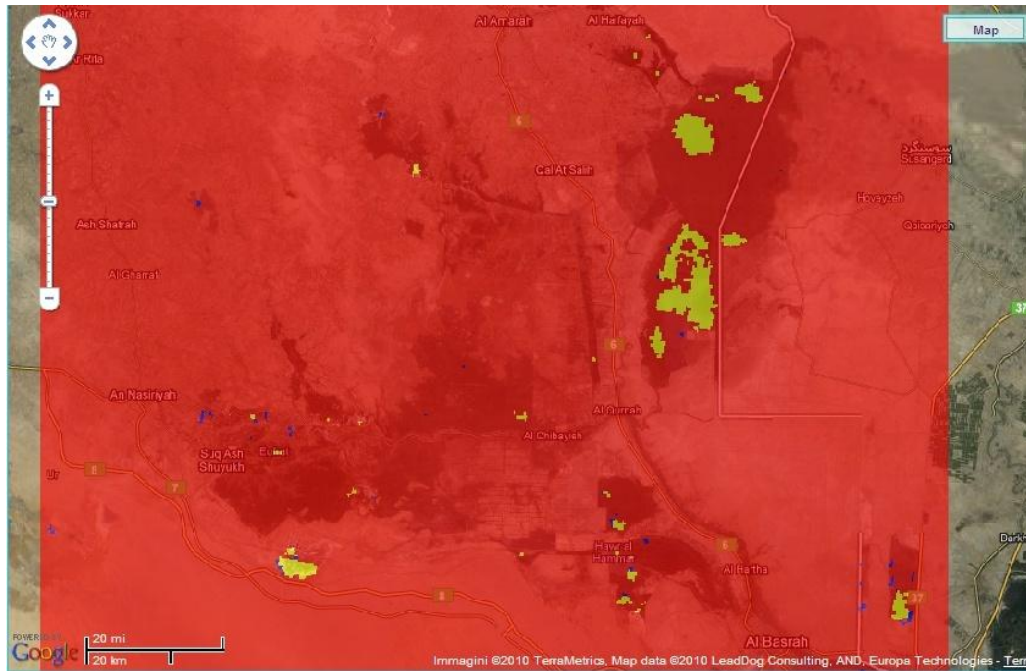


Figure 6-35 : Iraq Marshland model March-August 2005 Overlay

2006 - 2006

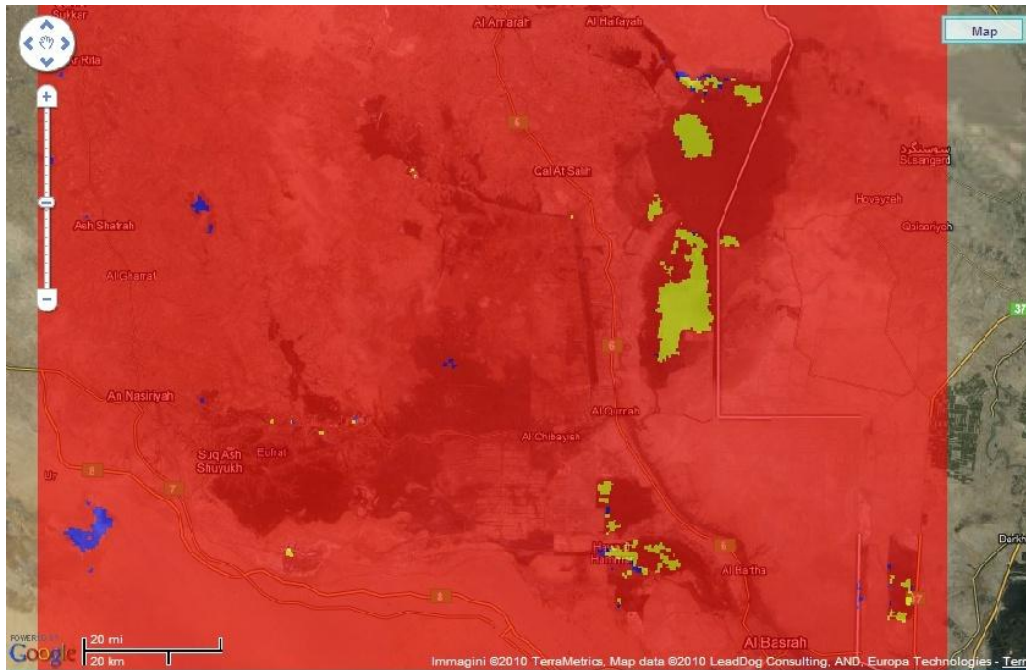


Figure 6-36 : Iraq Marshland model March-August 2006 Overlay

### 6.3.5 Green House spread

The fifth model developed on a seasonal basis analyzes the spread of class Green House. The particularity of this model is that don't seems to be cyclical, but cumulative. A comparison with other studies of land cover the same area operated by other bodies, including UNEP, shows as the behavior of this model is very similar to an expansion of the classes defined terrestrial vegetation. Studies are underway on classifier SOIL MAPPER (R) to better identify the behavior of this type of class.

#### MODEL DEFINITION:

**Start class    End class**







**Figure 6-37 : Green House Spread Definition pattern**

<b>Green House Spread Seasonal Model</b>	<b>Start</b>	<b>End</b>
<b>Date</b>	<b>15 March</b>	<b>02 August</b>
<b>Time Tolerance</b>	<b>07 Days</b>	<b>04 Days</b>
<b>Class Tolerance</b>	(0) - Class Tolerance: <input type="checkbox"/> Not Green House	(1) - Class Tolerance: <input type="checkbox"/> Green House
<b>TSP</b>	<b>140</b>	

**Table 6-7 : Green House Spread Features Table**

**LEGEND:**

-  **Model Not Matching : Both Classes are different from Class model**
-  **Model Matching with Class Tolerance**
-  **Model Perfect Matching**
-  **Model missing pixel info : when in the area the classified map lack**

### March – August 2003

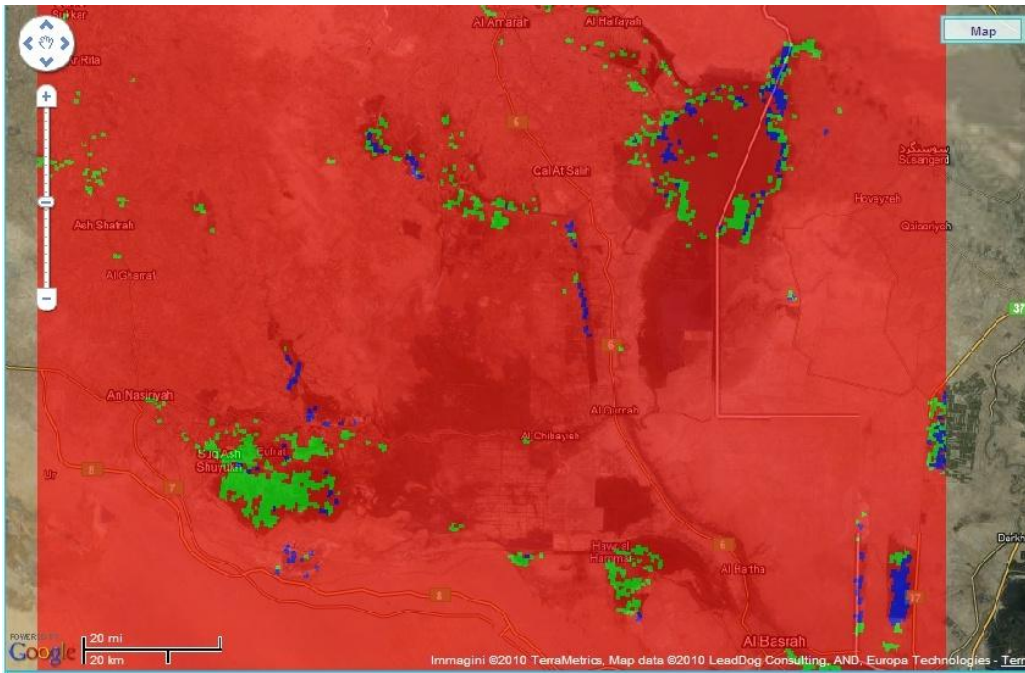


Figure 6-38 : Iraq Marshland model March-August 2003 Overlay

### March – August 2004

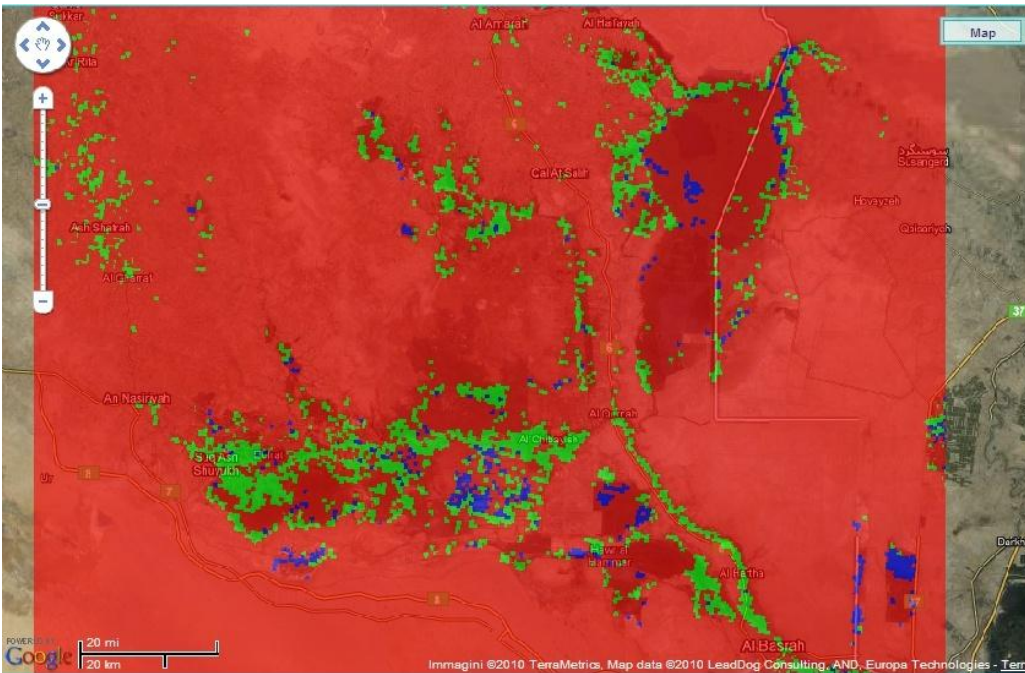


Figure 6-39 : Iraq Marshland model March-August 2004 Overlay

### March - August 2005

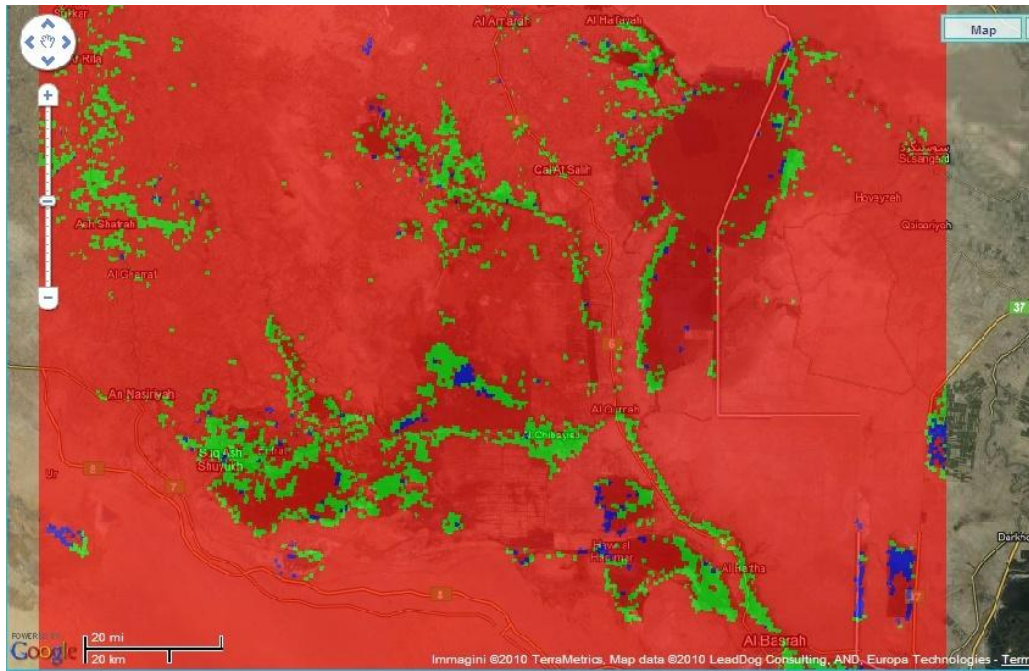


Figure 6-40 : Iraq Marshland model March-August 2005 Overlay

### March - August 2006

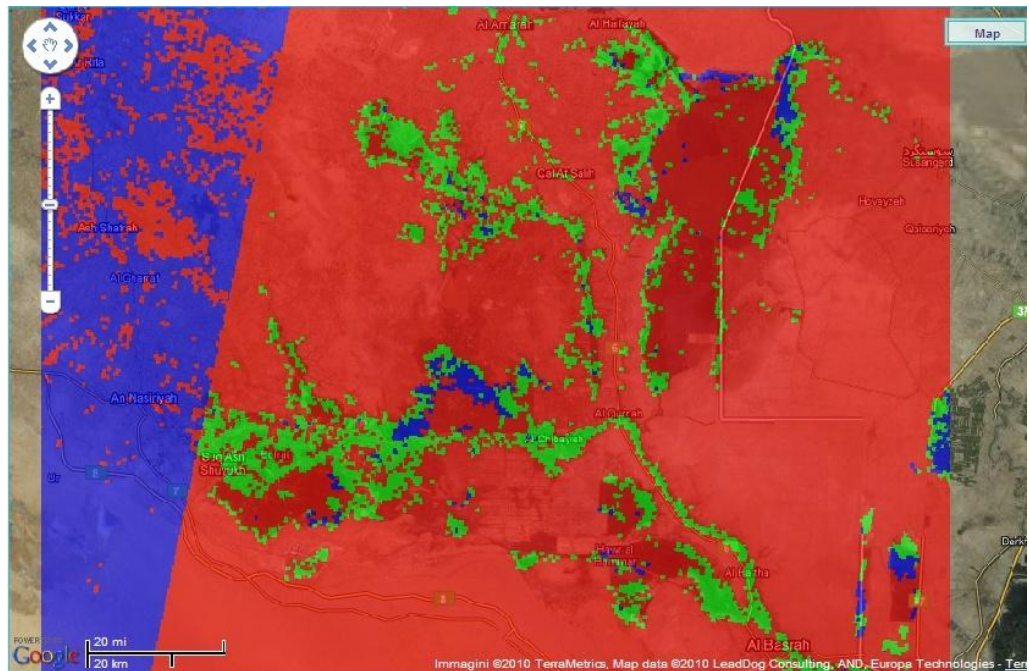


Figure 6-41 : Iraq Marshland model March-August 2006 Overlay

## March - August 2007

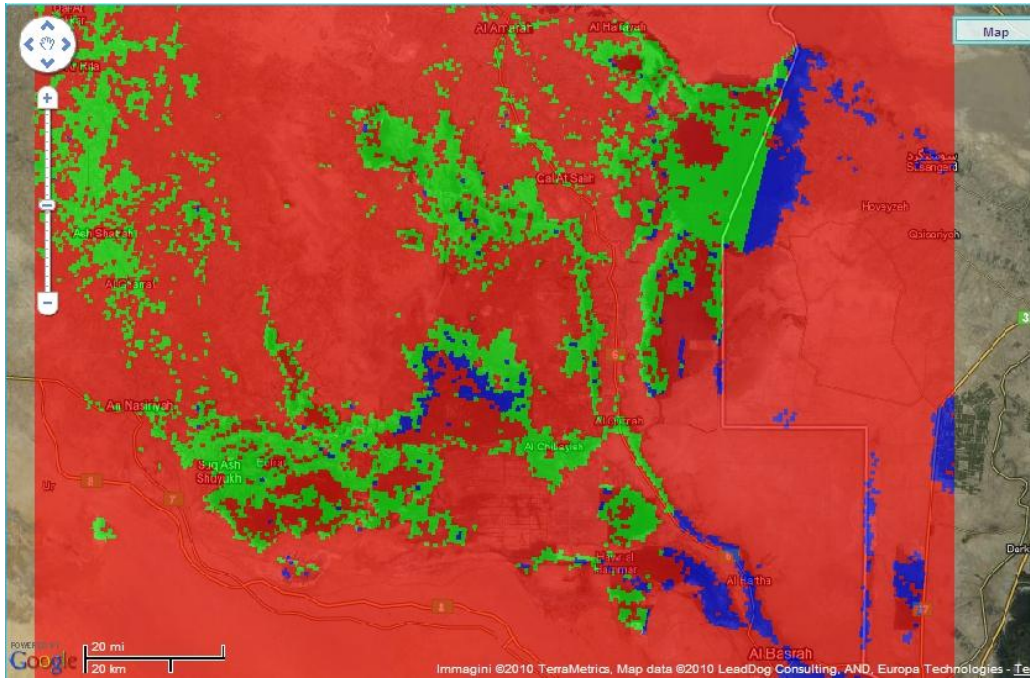


Figure 6-42 : Iraq Marshland model March-August 2007 Overlay

## 7 Conclusion

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The first part of this work is a bibliographic research on the state of the art in the theme of multi-temporal land evolution studies. This has led to a thorough knowledge of the remote sensing subject, the available instruments (including different types of satellite platforms) and the analysis that can be conducted on various types of investigations.

Following extensive research on the topic the area of the Iraqi Marshlands was selected. The reasons for this choice are mainly based on having an available area whose history shows the last ten years significant changes in several environmental restoration areas. These marked changes are visible on a large scale and well monitored continuously by satellite. The further transformation extended over a span wide, making it possible to produce models more reliable because they rely on a greater variety of images in terms of quality.

Furthermore, given the limited accessibility and vastness of the Iraqi marshlands, satellite data has proven to be a key source of valuable information on prevailing environmental conditions in the region. In the same way that satellite imagery was used to document the demise of the marshlands, it can play a critical role in tracking and surveying ongoing efforts to re-flood and revive the ecosystem.

When control structures were opened and embankments breached by local communities in April and May 2003, satellite images provided a unique perspective of the swollen rivers and canals, as water swept through a landscape that had been desiccated for over a decade. The potential for an accurate assessment of rapidly changing conditions by conventional ground surveys is hindered by the marshlands sheer physical scale and the hazards of navigating across a difficult environment. Due to the current security constraints, moreover, remotely sensed satellite imagery provides an exceptional tool and, in certain cases, the only means to observe the changes taking place on a continuous basis. In addition, benefits of satellite-based surveillance include cost-effectiveness, a global



perspective and timeliness, as well as replicable and systematic survey methods.

The web-application ALCS system allows the users to apply LULCC analysis models made available through the system interface or to easily implement their own models, developed for monitoring specific phenomena. The database of ALCS pre-classified images, in addition, could be easily updated with the processing of newly acquired images stored in the SSE portal. These pre-classified maps are obtained from the use of SOIL MAPPER® which allows a very fast, unsupervised, processing of the images, avoiding all problems of interpretation connected to supervised classification.

The ALCS system has proved to be a very valuable service for developing and applying land evolution models, moving from a pixel level to a wide area level of analysis and interpretation. The experience confirmed the suitability of the system toward a wide availability of data, both temporally and spatially, its speed of use and a user-friendly graphical interface. The possibility to log via web and store the models developed, moreover, guarantees that the results would be fully replicable.

The methodology adopted to develop Land Use and Land Cover Change models has demonstrated to be satisfactory, and a continuous effort is underway to address the remaining uncertainties through the study of anomalies and review of the classification procedures accordingly.

## 8 References

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Web Pages Consulted:

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[http://rst.gsfc.nasa.gov/Sect13/Sect13\\_4c.html](http://rst.gsfc.nasa.gov/Sect13/Sect13_4c.html)

<http://www.gisdevelopment.net/aars/acrs/1997/ps1/index.asp>

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<http://wdc.dlr.de/>

<http://www.ihdp.uni-bonn.de/html/projects/i-lucc.html>

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<http://ies.jrc.ec.europa.eu/global-land-cover-2000>

<http://www.eea.europa.eu/themes/landuse/clc-download>

<https://lpdaac.usgs.gov/>

<http://www.maps-for-free.com/>

### **NASA WEB SIT:**

<http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=12707&oldid=11938>

<http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=12611>

<http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=14757>

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Partow, H. (2001). [The Mesopotamian Marshlands: Demise of an Ecosystem \(13.3 MB pdf\)](#). Division of Early Warning and Assessment, United Nations Environment Programme. Nairobi, Kenya.  
<http://earthobservatory.nasa.gov/images/imagerecords/1000/1716/mesopotamia.pdf>

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<http://earth.esa.int/EOLi/EOLi.html>

<http://wdc.dlr.de/sensors/aatsr>

## **BBC Articles:**

<http://news.bbc.co.uk/2/hi/science/nature/5295044.stm>

BBC. (2006, August 30). [Iraq marshes' recovery 'in doubt.'](http://news.bbc.co.uk/2/hi/science/nature/5295044.stm) BBC Website. Accessed May 4, 2009.

<http://news.bbc.co.uk/2/hi/science/nature/5295044.stm>

## **IRAQ GEOGRAPHY:**

[http://en.wikipedia.org/wiki/Geography\\_of\\_Iraq](http://en.wikipedia.org/wiki/Geography_of_Iraq)

[http://en.wikipedia.org/wiki/Mesopotamian\\_Marshes](http://en.wikipedia.org/wiki/Mesopotamian_Marshes)

[http://en.wikipedia.org/wiki/Tigris-Euphrates\\_river\\_system](http://en.wikipedia.org/wiki/Tigris-Euphrates_river_system)

## **UNEP:**

United Nations Environment Programme. [Iraqi Marshland Observation System Website.](http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=449&ArticleID=4902&l=en)

<http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=449&ArticleID=4902&l=en>

<http://marshlands.unep.or.jp/>

<http://imos.grid.unep.ch/>

## **SSE Portal:**

<http://services.eoportal.org/index.jsp>

<http://services.eoportal.org/portal/service/ShowServiceInfo.do?serviceId=86818B>

[81](#)

## **MEEO - ESA - Technical Note:**

**SPA - Task 4 (A)ATSR Land Classification System Analysis - Feasibility study and solutions – SPA-TN-MEEO-GS-0140.doc**

**SPA - ALCS Earth Fixed Grid Extension System generalization**  
SPA-TN-MEEO-GS-0140-1.doc

**SPA-ALCS GUI Implementation Technical Note - Software Technical Implementation : SPA-TN-MEEO-GS-0140-2.doc**

**SPA - Task 4 (A)ATSR Land Classification System Analysis ALCS Test application definition : SPA-TN-MEEO-GS-0141.doc**

**PreQu Technical Note - Remapping system performance evaluation and validation: PRQ\_TN\_MEEO\_GS\_0434.doc**

## **MEEO - ESA – Interface Control Document:**

**SPA ALCS Interface Control Document Technical Specifications**

SPA-ICD-MEEO-GS-0143.doc

## 9 Ringraziamenti

---

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*Dott. Ing. Per L'Ambiente e il Territorio*

*Laurea Specialistica 2008-2009.*

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