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e-Sensing: Big Earth observation data analytics for land use and land cover change information

First yearly report: 01 January 2015 – 31 December 2015

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Project website: http://www.esensing.org

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1 Overview of the project objectives

This document provides the first year report of the "e-sensing" FAPESP project (grant 2014/08398-6), and describes the activities carried out during the period 01.01.2015 to 31.12.2015. We will use numbers (such as [10]) to refer to the list of papers published by us in 2015, available in the References section.

Currently, scientists ignore the time reference inherent to Earth observation data, producing land cover maps taking either a single or at most two time references. As a result, only a small part of the big data sets produced by remote sensing satellite are ever used. This leads to an important research question: *How can we use e-science methods and techniques to substantially improve the extraction of land use and land cover change information from big Earth Observation data sets in an open and reproducible way?*

In response to this challenge, *our project will conceive, build and deploy a new type of knowledge platform for organization, access, processing and analysis of big Earth observation data*. The key elements of this knowledge platform are:

(a) A scientific database based on the SciDB innovative array database management system, capable of managing large remote sensing data sets.
(b) An innovative set of spatiotemporal image analysis methods, mostly based in analysis of satellite image time series. These methods are all developed as open source software to promote reproducibility.

The innovative infrastructure developed in the project will be used for new types of information extraction of Earth observation data, focused on land cover and land use change of large data sets. Our knowledge platform will allow scientists to perform data analysis directly on big data servers. Scientists will be then able to develop completely new algorithms that can seamlessly span partitions in space, time, and spectral dimensions.

We aim to make two important contributions:

(a) New database methods and techniques that use array databases to build a geographical information system that handles big spatial data.
(b) New data analysis, data mining, and image processing methods to extract land change information from large Earth observation data sets.

2 Main results of year 1 (January – December 2015)

During 2015, our most relevant results were:

(a) Setting up the infrastructure, consisting of a large cluster with 5 servers and 96 TB, and organising the data required for the experiments.
(b) Design of the software infrastructure for handling and processing of large Earth observation data sets [8].
(c) Design and development of services for extraction of satellite image time series from of large Earth observation data sets [11].
(d) Design and development of the first version of the Big-EO time series R package, that contains methods suited for satellite image time series analysis [4][5][12][13]. We also tested other methods for time series analysis [3][10][11][18][19][21][23][24][25].
(e) An analysis of trajectories of forest degradation in Amazonia [26] and the proposal of a conceptual model for land use trajectories [6]. We also did extensive field work in Amazonia [14][27][28].
(f) Development of new methods for real-time deforestation detection in Amazonia [1].
(g) Validation and testing of baseline methods for automated classification of agricultural areas [2][15][16][17][20].

The results listed above in items (e), (f) and (g) are important and required to set the baselines and reference levels for the automated methods of information extraction form big data sets being developed in the project.

The most important result for year 1 was to have the necessary infrastructure and the first version of the data analysis package ready for usage for developing the applications in Forestry and Agriculture. We also needed that the key areas for the use cases to be defined. For each area, we also needed to have baselines to compare with the results that we expect to obtain in year 2. These results have been achieved.

A second important result, which was expected but was not achieved in year 1, was the integration of TerraLib and SciDB. This work is progressing in a slower pace than foreseen. We will discuss the problems we have faced and the corrective measures we will enforce in 2016.

3 Detailed description of the results in Year 1 (2015)

This section describes the results of the project in 2015. In the presentation, we follow the project organization in three work packages (WP), and associated milestones, as laid out in the proposal:

(a) *WP 1 – Databases*: research and development associated with using array databases to store large Earth observation data sets and developing workflows and methods for efficient storage, access and processing of large data, reproducibly.

(b) *WP 2 – Data analysis*: R&D on spatiotemporal techniques for extracting change information on large Earth observation data sets, relevant for forestry applications; include novel time series applications for remote sensing data, and combined time series and multi-temporal image processing.

(c) *WP 3 – Use case development*: case studies of forestry and agriculture applications that use large Earth observation data sets. These use cases will validate the methods and data developed by the other work packages.

To help the review of this report, we first present the table of milestones presented in the project proposal. We will then consider each the proposed milestones, stating whether it has been fulfilled or delayed.

For each milestone, we preview the result more directly associated with it. The rest of the results of the project can be found in the References section. All of the papers published by members of the research teams that are associated to the project are available at the project's website: http://www.esensing.org.

TABLE 1

PLANNED MILESTONES: RESULTS AFTER MONTH 12

Blue background	Target met
Red background	Target delayed
White background	For later years

TASK	Month 12	Month 24	Month 36	Month 48
T1.1 **Building big EO databases**	M1.1.1. V1 of the database for use cases in Brazil	M1.1.2 V2 of database for use cases in Brazil		
T1.2 **Extend SciDB for geographical data handling**	M1.2.1 Integration of TerraLib and SciDB	M1.2.2 Algorithms for SciDB server-side processing	M1.2.3 TerraScript for SciDB server-side processing	M1.2.4 Extension of SciDB as a spatial data manager
T2.1 **Integrate SciDB, TerraLib and R**		M2.1.1 aRT-SciDB package (V1)	M2.1.2 aRT-SciDB package (V2)	
T2.2 **Data analysis for big EO data**	M2.2.1 Big-EO time series R package (V1)	M2.2.2 Big-EO time series R package (V2)	M2.2.3 Big-EO space-time R package (V1)	M2.2.4 Big-EO space-time R package (V2)
T3.1 **Tropical forest change**	M3.1.1 Identification and selection of areas	M3.1.2 Preliminary detection of clear cut and degradation	M3.1.3 Detection of clear cut and degradation: final results	M3.1.4 Assessment of the forest change alert methods
T3.2 **Tropical agriculture mapping**	M3.2.1 Identification and selection of areas	M3.2.2 Mapping of soybeans, maize and sugarcane	M3.2.3 Mapping of soybeans, maize, rice sugarcane, and wheat	M3.2.4 Assessment of the agricultural mapping methods

3.1 Progress report on work package 1 - Big Earth observation databases

3.1.1 Task 1.1 - Building and deployment of big Earth observation databases to support data analysis and use cases

This task builds databases to be used by the project. In the proposal, we set the following milestone for month 12:

Milestone M1.1.1 - Version 1 of the database for use cases in Brazil (month 12)

The target of this milestone was to build a large remote sensing database containing the data needed for the use cases in Brazil in year 2. This result has been achieved.

To manage scientific data sets, we have chosen SciDB, an open source array database optimized for management of big data, that is suited for time series analysis of remote sensing imagery. When we arrange many images from the same areas as 3D arrays, each pixel is associated satellite image time series (Fig. 1a). Satellite image time series are important for land cover change analysis. Figure 1b shows an example of a time series of a vegetation index for a location in the Brazilian Amazonia from 2000 to 2008.

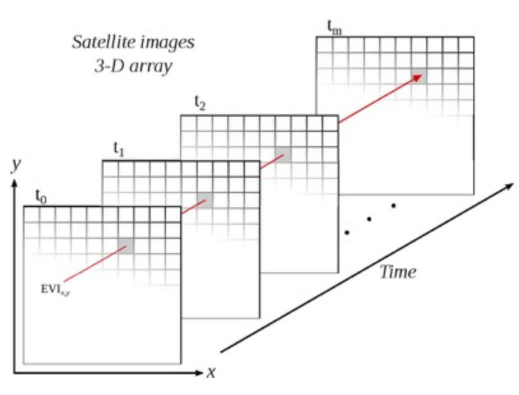

Figure 1 (a) – Organizing 2D images as 3D arrays

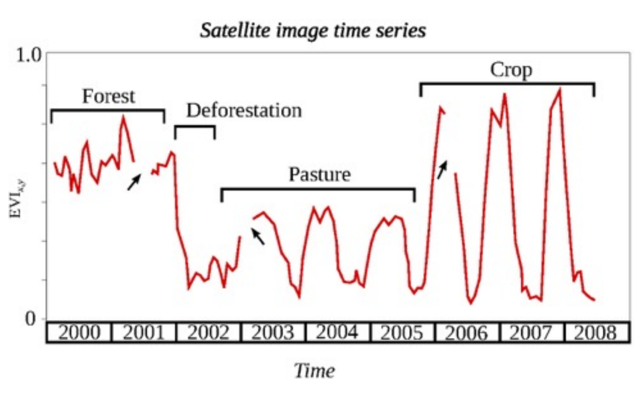

Figure 1 (b) – Example of a satellite image time series (MODIS EVI data)

To organize image data as 3D arrays using SciDB, we have bought a server configuration, with support from FAPESP, consisting of:

1. 5 PowerEdge R730 servers, each CPU with 2 processors with 6 cores each.
2. 96 GB of main memory per server.
3. 16.9 TB of disk storage per server, with a total of 96 TB of storage.

For the experiments on year 2, we have loaded in the servers the following data sets:

(a) MODIS MOD09Q1 images at 250 meter resolution from 2000 to 2015 for the whole of South America, with 13,800 images associated to 3.11 x 1011 (317 billion) different satellite image time series.
(b) MODIS MOD13Q1 images at 500 meter resolution from 2000 to 2015 for the whole of South America, with 13,800 images associated to 8.3 x 1010 (83 billion) different satellite image time series.

In the next years, we will continue to increase the database, with data from medium-resolution satellites, especially LANDSAT.

3.1.2 Task 1.2 – Extend SciDB for geographical data handling

To use the array DBMS SciDB for Earth observation applications, we need additional functions that handle information such as cartographical projections and image metadata. To this end, this task will develop software that extends SciDB to include information specific to Earth observation.

We have chosen the TerraLib software library, developed by INPE, as a source of data types and algorithms for geographical data. Our plan is to include an interface for SciDB in TerraLib. Applications written in TerraLib would then use the SciDB interface to store large data sets, and use TerraLib's other facilities to manage information not in array format such as satellite image metadata and cartographical projections information and ancillary vector data (e.g. municipalities boundaries).

In this task, the project proposal has the following milestone for month 12:

Milestone M1.1.2 – Integration of TerraLib and SciDB (month 12)

The aim of this milestone is to develop the interface between TerraLib and SciDB. In 2015, TerraLib has been upgraded to its version 5.0 with major modifications. Changes include architectural revision, better support for spatiotemporal datasets, improved decoding of geographical data formats, better support for plugins and external components, and inclusion of new algorithms for image processing and spatiotemporal data analysis. Given the magnitude of changes on TerraLib, we decided to start work on the implementation of the Terralib-SciDB interface only after we understood all changes in the new version. Thus, in Year 1 we focused on the study and design of the components of the TerraLib-SciDB interface. We are now in a better position than we were at the start of the project to make a realistic plan and to achieve a good result.

Although the milestone was not met, the project has achieved significant progress on two parts of the design of the interface between Terralib and SciDB:

(a) We developed a Web Time Series Service (WTSS) for serving time series extracted from remote sensing imagery on the internet [9].

(b) We designed a Spatial Data Infrastructure (SDI) architecture for big spatiotemporal data sets and described a pilot implementation of it [8].

The Web Time Series Service (WTSS) provides access to remote sensing time series. It is a new idea developed by our research team, and is not yet part of the current standards set by the Open Geospatial Consortium. WTSS assumes remote sensing data are organised as space-time coverages, using an array manager like SciDB. Figure 2 shows a client prototype that provides access and visualisation of remote sensing time series from our SciDB repository. We have also developed a prototype client for TerraView GIS, that is based on TerraLib. During year 2 of the project, we intend to further improve the WTSS service by validating and testing the service for large data sets stored in SciDB.

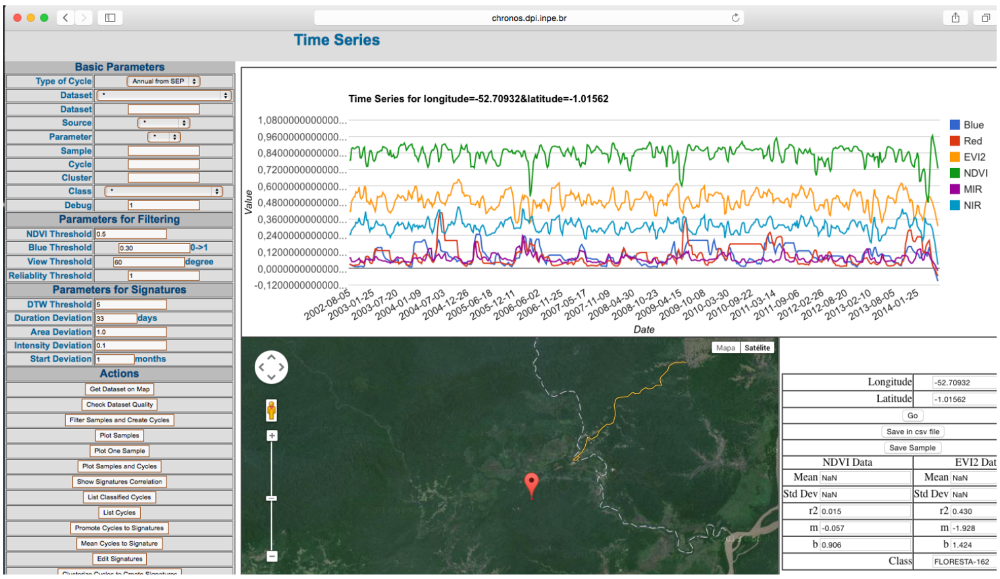

Figure 2 – Visualisation of satellite image time series retrieved using a WTSS service (source: [9]).

A second important development associated with Task 1.2 was the design of a SDI architecture for big spatiotemporal data sets [11]. The idea of the SDI is to bring together the set of technologies that are required to manage such big data. The SDI is divided in four components: Databases, Web services, and Geographical Information System (GIS) tools. The proposed architecture is shown in Figure 3 and briefly described below.

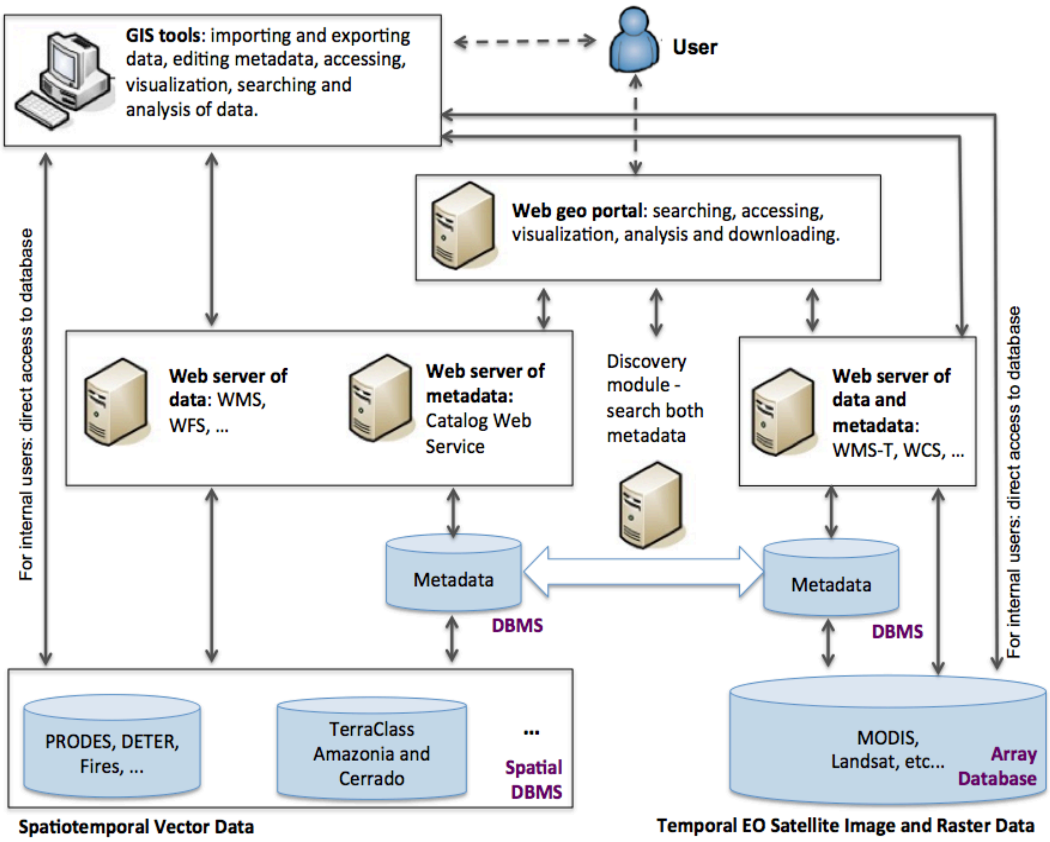

Figure 3 – Proposed spatial data infrastructure for handling big geospatial data (source: [8]).

We consider there are two main types of big spatiotemporal data sets, those in vector and raster formats. Vector data is best stored in spatial DBMS such as PostGIS that are compliant with the OGC-SFA (Open Geospatial Consortium - Simple Feature Access) specification. For raster data, such as remote sensing images, we propose the use of array databases such as SciDB. To disseminate the databases on the Internet, we propose the use of web services for raster and vector data sets as well as for their metadata. In additional to the well-established Open Geospatial Consortium standards for web services, such as WMS, WFS, WCS and CSW, we propose the WTSS – Web Time Series Service [9]. We also propose to extend the Web Coverage Service (WCS) to handle large spatiotemporal data sets stored in SciDB.

The GIS tools will have to be efficient to deal with big spatiotemporal data sets. As such, they need to provide the following features:

(a) *Tools to access and combine data sets from different types of data sources*: These tools split the processing into parts. This combines spatial DBMS (e.g., PostGIS) functionalities for vector data handling with array databases that handle multidimensional raster data.

(b) *Server-side processing mechanisms:* GIS tools should allow users to process data directly on the server, avoiding the transfer of big data sets from servers to local machines.

(c) *Script language to express complex processing:* These tools allow users to express complex processing through script languages, such as R, Python and LUA.

(d) *Spatiotemporal data handling:* GIS tools should include new algorithms to analyse spatiotemporal data.

In the next three years of the project, we will work to develop the vision that was laid out in our proposal [8].

3.2 Progress report on work package 2 - Data analysis for big Earth observation data

3.2.1 Task 2.1 - Integration between SciDB, TerraLib and R

This task will develop the integration between SciDB, TerraLib and the R software. R is an open-source platform and language for statistics and graphics. Many researchers in statistics around the world implement their methodologies in R, making them freely available in the internet as packages. More than 5,000 R packages are available, covering a wide range of modern statistics. Our research team has already developed aRT, a package for integrating spatial databases managed by TerraLib with R functions. In this task, we will extend aRT to be able to use the link between TerraLib 5.0 and SciDB (see Task T1.2). The integration between SciDB, TerraLib and R will be available as an R package to create, read, write, and query big geospatial databases without needing to load all data at once into R.

This task has no milestones for Year 1, and the first milestone is planned for the end of Year 2 (see Table 1 - *M2.1.1 Version 1 of aRT-SciDB package*).

3.2.2 Task 2.2 - Space-time analysis of big Earth observation data for land change monitoring

This task aims to develop new methods for space-time analysis of big Earth observation data. It is expected to produce new research results, since it will be the first time that EO scientists have full access to large data sets to validate their data analysis methods.

In this task, the project proposal set the following milestone for month 12:

Milestone M2.2.1: Version 1 of Big-EO time series R package

This milestone has been achieved. We have developed the **dtwSat** package, an R package that contains a new method for classification of satellite image time series: *time-constrained dynamic time warping*. A paper describing this method has been accepted by a leading journal of the area (*IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* – impact factor 3.00) [5]. The **dtwSat** package is also available at the R CRAN repository at the website cran.r-project.org/web/packages/dtwSat. The authors are also preparing a submission to the Journal of Statistical Software describing the R **dtwSat** package.

Research on time series data mining shows that methods based on dynamic time warping (DTW) have achieved significant results in many applications. DTW works by comparing a temporal signature of a known event (e.g. *a* person's speech) to an unknown time series (e.g. a speech record of unknown origin). The algorithm finds the optimal alignment between two series and provides a robust dissimilarity measure as a result (see Fig. 4). DTW is good at comparing time series, even if they are irregularly sampled or are out of phase in the time axis.

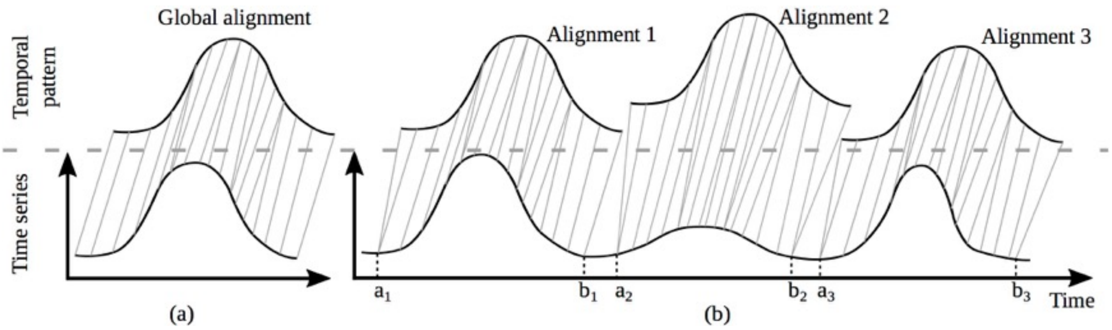

Figure 4 – Examples of alignments between a temporal pattern and a time series (source:[5]).

The original DTW algorithm works well for shape matching, but is not suited *per se* for satellite image time series classification. It disregards the temporal range when finding the best alignment between two series. Since each land cover class has a distinct phenological cycle that is relevant for space-time classification (see Fig. 6(a)), a good time-series classifier for remote sensing data needs to balance between shape matching and temporal alignment. For example, the soybean cycle ranges from 90 to 120 days. A time series with similar shape but with much larger cycle is unlikely to come from a soybean crop. To improve the standard DTW, we introduce in [5] a time constraint that helps to distinguish between different types of land use and land cover classes. The resulting algorithm is called *time-weighted dynamic time warping* (TWDTW). It is a significant improvement on standard DTW for land use and land cover classification of satellite image time series.

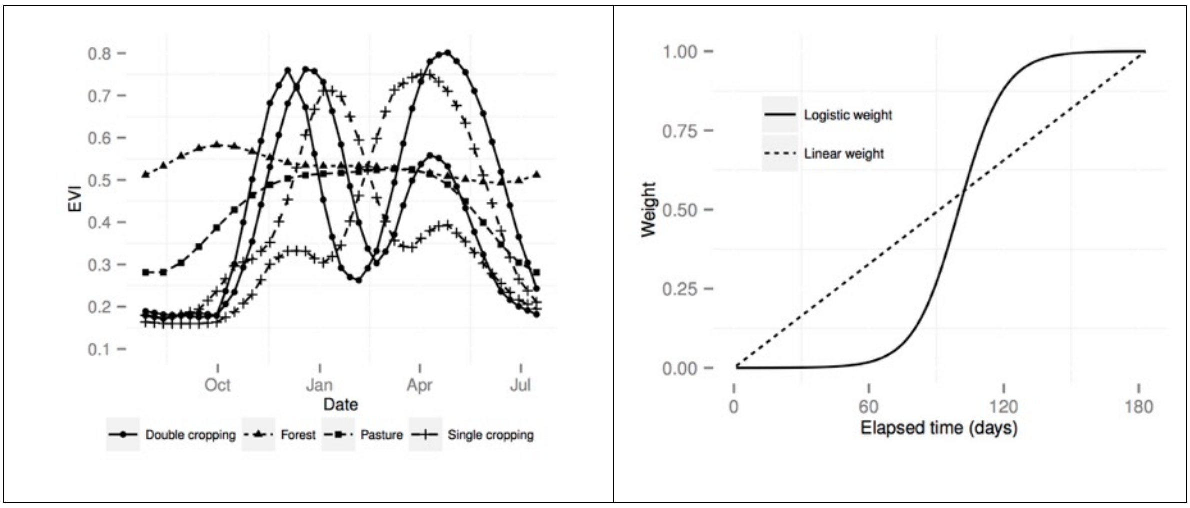

Figure 5 – (a) Left: Phenological cycles of different land cover classes; (b) Right: linear and logistic time constraints (source: [5])

We found out that a logistic function (Fig. 5b) provides a good constraint for matching time series whose classes are known (Fig. 5a) to parts of a longer time series that will be classified. Phonological cycles deviating up to 60 days from a known pattern are not "punished". For temporal differences greater than 100 days, even if there is a good shape matching, the algorithm will disregard the matching due to the "punishing" weight. This means that we expect that farmers behave according to an established agricultural calendar. In the Brazilian Cerrado, for example, farmers plant soybeans in end of the year (October to December) and harvest in February. Corn or cotton are planted in March and harvested in July. These time constraints are necessary for good classification of satellite image time series (see Fig. 6).

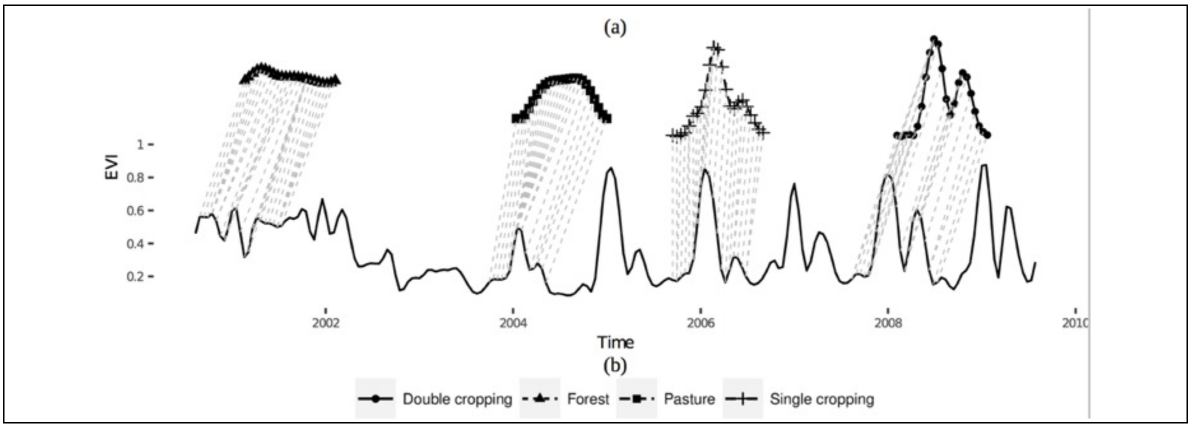

Figure 6 – TWDTW matching between known samples and a satellite image time series (source: [5]).

We ran a case study in an area in the Porto dos Gaúchos municipality, that covers 7,000 km^2 in the state of Mato Grosso, Brazil. In 2013 its deforested area was 3023 km^2, that is 43% of the original forest. The cropland area grew from 60 km^2 in 2000 to 581 km^2 in 2013. We classified matches in the time series as either *forest, secondary vegetation, pasture, single cropping, or double cropping*. These classes are the most relevant ones for our study on trajectories of change in Amazonia. Our proposed logistic time-weighted version achieved an overall accuracy of 87% (see Fig.7). We also compared our classification with the MODIS land cover product, currently the only global land cover product available yearly (Table 2). Results show a better performance of TWDTW. We thus consider that TWDTW is an innovative and promising approach, that needs to be further investigated in larger areas.

TABLE 2

Assessment of MODIS Land Cover and TWDTW for Porto dos Gaúchos (source:[5])

	Reliability		Accuracy	
Class	MODIS	TWDTW	MODIS	TWDTW
Forest	87%	94%	77%	88%
Pastureland	67%	88%	85%	85%
Cropland	89%	92%	75%	96%

In the above table, the column *reliability* ("user's accuracy") shows the probability that a pixel labelled as a certain land-cover class in the map is really this class. The figures in column *accuracy* (also known as "producer's accuracy") refer to the probability that a certain land-cover of an area on the ground is classified as such.

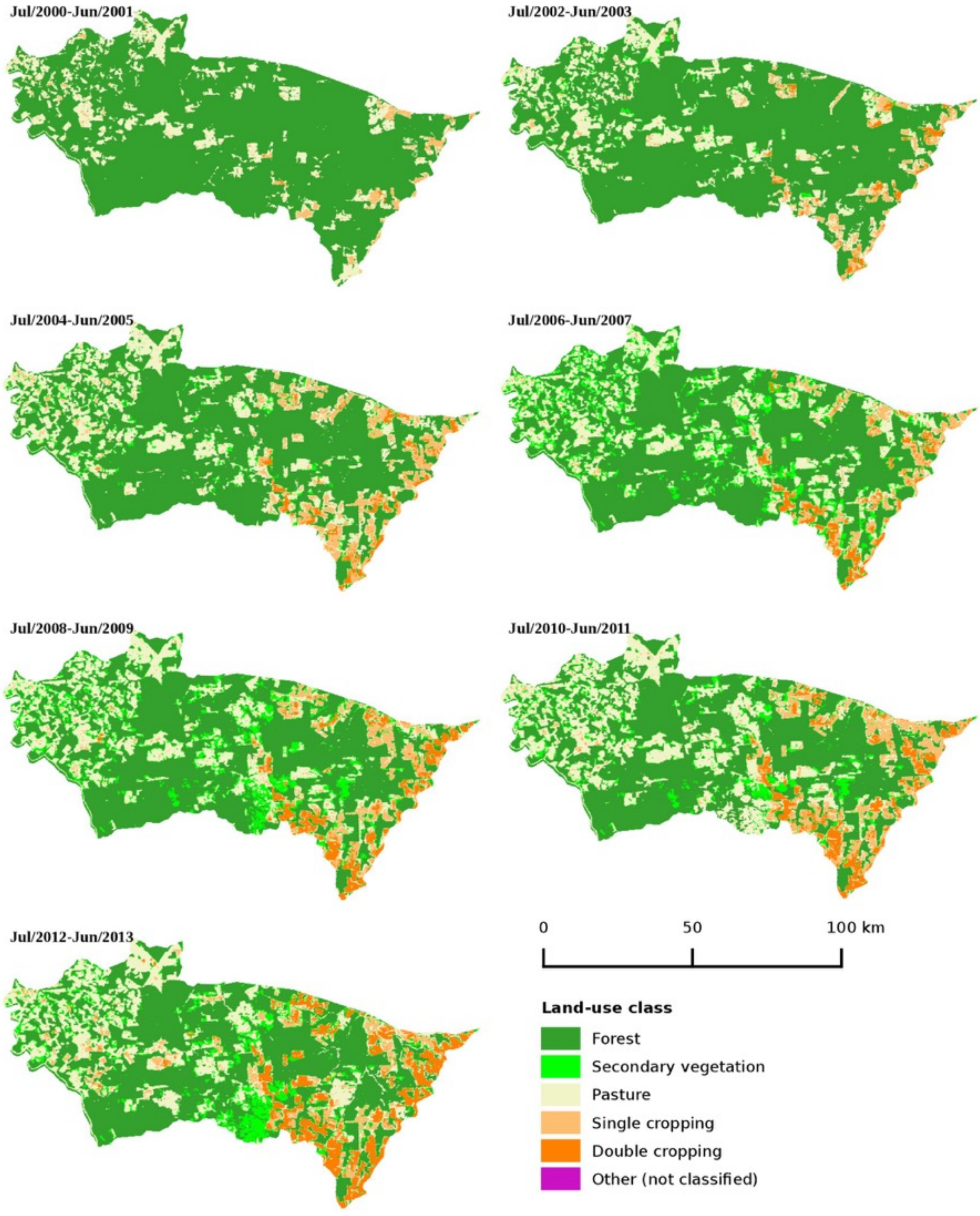

Figure 7 - Land use/cover maps produced by using the logistic TWDTW classification. Each map shows the classification for an agricultural year (from July to June) in Porto dos Gaúchos (source: [5]).

Our results have thus enabled the project team to build the first version of the *Big-EO time series R package,* with a new method (TWDTW) and an associated R package. In the next years, we will use this method in our case studies and develop methods for spacetime integration.

3.3 Progress report on work package 3 - Use case development

3.3.1 Task 3.1 - Specification and validation of tropical forest change alert methods and data

Our use cases address two important problems: (a) how to use time series and spatiotemporal analysis to support the DEGRAD system of monitoring forest degradation; (b) how to use time series data to support the DETER system for daily alerts of forest change. Our aim is not to replace INPE's existing systems, but to explore how automated methods can complement and enhance them. In year 1, we did a lot of work on forest degradation, which is the most pressing and tougher scientific challenge.

In this task, the project proposal has the following milestone for month 12:

Milestone M3.1.1: Identification and selection of areas for forestry use case

This milestone has been accomplished. Our of the team members (Prof. Dr. Isabel Escada) advised a PhD student (Taíse Pinheiro), whose work focused on forest degradation [26].

The UN FAO (Food and Agriculture Organization) distinguishes between *deforestation,* which involves a removal in the forest area (associated to a clear cut), and *forest degradation*, that does not involve a reduction of the forest area, but rather a quality decrease in its condition. Forest degradation is defined as defined as *the long-term and gradual reduction of canopy cover due to forest fire and unsustainable logging*. Typically, a mature forest is degraded when part of its tree cover is removed. In the Brazilian Amazonia, degradation is caused by either unsustainable logging practices or by forest fires (intentional or uncontrolled).

Understanding and identifying forest degradation is important, because it causes carbon emissions that have to be accounted for and leads to a loss of biodiversity caused by removal of important species. Also, degradation often (but not always) is associated to later actions that cause the full removal of forest cover (deforestation).

INPE has developed the DEGRAD system for monitoring forest degradation, but the system has been in operation only since 2008. Most researchers agree that degradation is better understood as a long-term process, taking place on decadal period. Degradation is not constant throughout Amazonia, but varies according to colonization frontiers. Accurate characterization of degradation requires lengthy observation periods to track gradual forest changes. Indeed, one of the motivations for including the issue of forest degradation in the e-sensing project is our interest for developing analysis methods that deal with large data sets and long time periods.

Before automated methods for big geospatial data can be designed and applied, we need to understand the problem well. The thesis by Taíse Pinheiro [26] is a required step. The author did a detailed analysis of two Amazon frontiers of the 1970s and 1990s using 28 years (1984–2011) of Landsat images. She selected two case studies in two distinct municipalities: (a) Novo Progresso, Southwestern Pará, where logging expansion started in the early 2000; and (b) Sinop, Northern Mato Grosso, Brazil, currently a consolidated frontier. Pinheiro used data mining techniques to build trajectories of forest degradation and to find the relationship between deforestation and degradation.

In Novo Progresso, results show that degradation is more associated to selective logging than to forest fires. Half of the logged forests are not immediately deforested but rather abandoned and subsequently cleared in 3 years. The results showed no regime of recurrent forest fires, nor were forests revisited by loggers in Novo Progresso. Forest degradation is mostly associated to a single logging event.

Results also show a change in behaviour of the loggers. In the period 1984–1997, 90% of degraded areas were completely deforested in one year's time. From 2004 onwards, due to increased command and control measures, less degraded areas were completely cut. About 40% of the degraded areas were not completely cleared (Fig. 8), leading to large areas of persistent degradation.

In Sinop, the transition from degradation to deforestation lasts longer, with a typical period of 7 years (50%). There, forests are typically revisited by loggers before forest conversion into clear-cut. In both frontiers, forest degradation was typically characterized by low to moderate intensity forest damage. Although a large proportion of logged forest was deforested, 40% of the degraded forest areas were not completely deforested. Thus, both in Sinop and in Novo Progresso, there are substantial degraded areas whose emissions have not been properly accounted for by the current INPE Amazonia monitoring system.

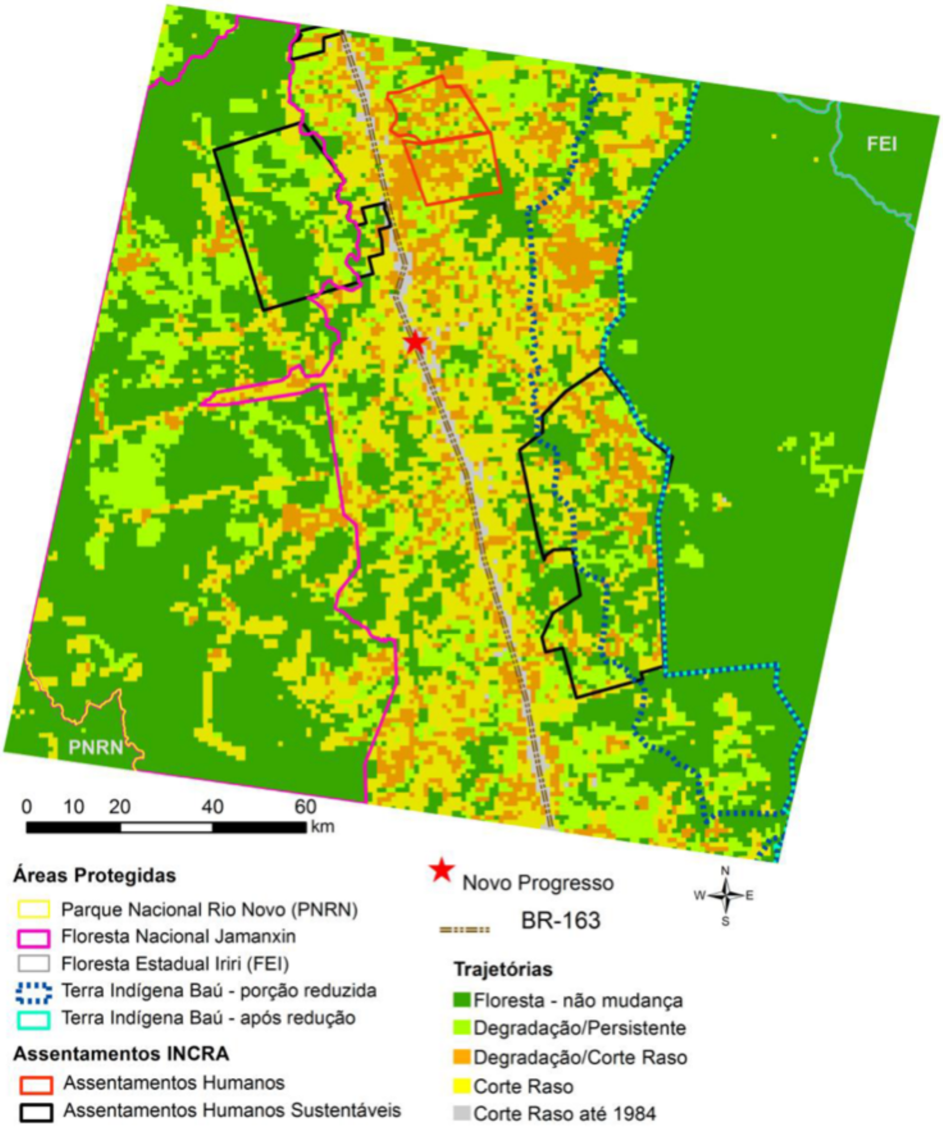

Figure 8 – Forest change trajectories in Novo Progresso (PA) from 1984 to 2011, as described in the legend: Floresta – não mudança = Forest – no change; Degradação/Persistente = Persistent degradation; Degradação/Corte Raso = Degradation followed by deforestation; Corte Raso = clear-cut (deforestation) (source: [26]).

The work by Pinheiro [26] has important consequences for the "e-sensing" project. Her work shows that persistent degradation is happening in Amazonia to a greater extent in the recent years than in the past. INPE has a historical record of deforestation (the PRODES system), but no long-term record of degradation. This situation creates is an opportunity for automated methods that extract information from large data sets, which will be explored in the next years of the project.

3.3.2 Task 3.2 - Specification and Validation of Tropical Agriculture Monitoring Methods and Data

The second use case is to apply satellite image time series analysis to improve the mapping and monitoring of Brazilian major agricultural commodities: soy, maize, sugarcane, rice and wheat. We will build on experiences by INPE's researchers, that have done extensive fieldwork and collected much ground truth data. These data sets will be used to validate our automated methods that work with big EO data.

In this task, the project proposal has the following milestone for month 12:

Milestone M3.2.2: Identification and selection of areas for agricultural use case

This milestone has been accomplished. This work has been led by Prof. Dr. Ieda Sanches, who worked on different areas in Brazil to identify their specific characteristics and the define the possible best methods for classification.

Sanches and her fellow researchers carried out a study in agricultural areas in the state of São Paulo. The study tested different methods for classification of multitemporal LANDSAT images for crop mapping. The paper was published in *Remote Sensing,* an ISI-indexed journal [2].

The work in the crop producing regions in São Paulo is important for the e-sensing project because it helps to better understand the agricultural calendar for the area (Fig.9). For example, corn has two planting/harvesting seasons during the year, with cycles from April to June and then from October to March. Sugarcane has a longer cycle, lasting usually more than one year. This information is used by algorithms such as TWDTW (see section 3.2 above) and thus is a good example of how the e-sensing project needs to be carried out in an interdisciplinary context.

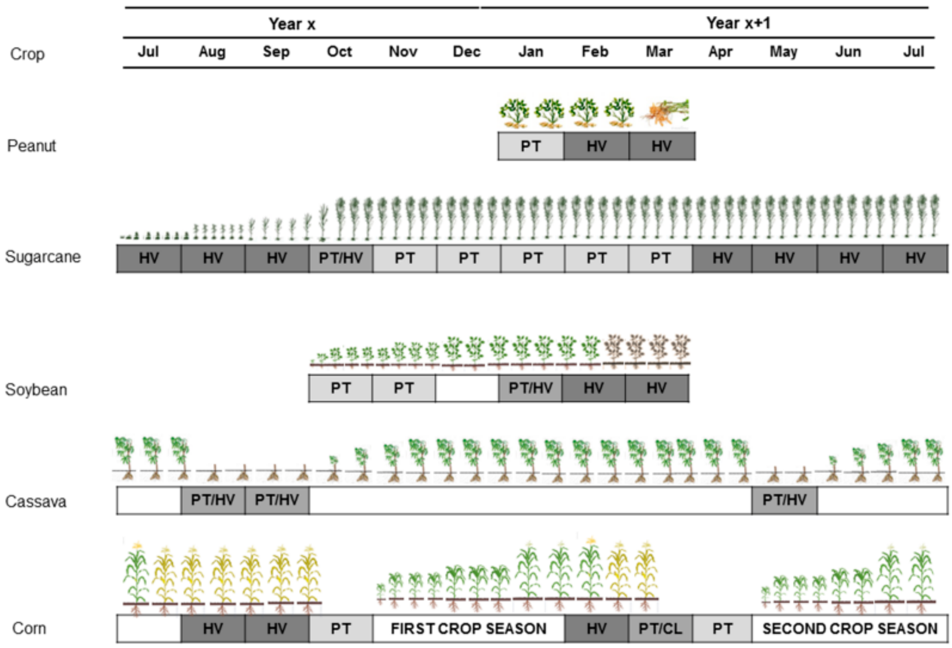

Figure 9 – Crop calendar of the main crops of Assis region in São Paulo: peanut, sugarcane, cassava, corn and soybeans. Legend: PT – planting; HV – harvesting; CL – clearing. In white: crops keep green during the period. (Source: [2])

Sanches and her associates also worked on a study about the agricultural areas on the state of Rio Grande do Sul. They investigated which of the many possible vegetation indexes extracted from MODIS images produce the best real-time classification. This study was published in *Pesquisa Agropecuária Brasileira,* an ISI-indexed journal [3]. Their conclusion was that the EVI (enhanced vegetation index) enabled the best results. This result is encouraging for the project, since the EVI is one of the indexes used by time series analysis algorithms being developed by the project, as is the case of the TWDTW method described in section 3.2 above.

Additionally, Sanches made a field trip in December 2015 to Campo Verde-MT. This a crop-producing area whose products include soybeans (census IBGE 2014: 209,000 ha) and corn as a secondary crop (census IBGE 2014: 95,750 ha). There is a large cotton crop (census IBGE 2014: 69,200 ha). There are single crop areas in more sandy soil and double cropping areas in soils with higher clay content. In the double cropping areas, the second crops include corn, millet, and sorghum. The field work collected more than 1000 ground truth samples, including areas with crops (soybeans, millet, cotton), pasture and forests. This area will be a good test site for the e-sensing project, because of the different crop varieties.

Another important result was a study in the quality of automated classification methods from papers presented in Brazilian Symposium of Remote Sensing between 1996 and 2013 [20]. In the papers analysed, the authors provide a quality measure (*kappa-index)* which summarises the accuracy of the method for the use case. The results show an average accuracy given by the kappa-index is 0.71± 0.14, and that this accuracy has not increased between the years. In other words, there has been no significant gain in classification accuracy in almost 20 years of research. This points to a relative crisis in automated methods for remote sensing image analysis and serves as additional motivation for the e-sensing project.

All of the papers analysed in [20] used single-date classification methods, where one image of a given date was classified and the results compared to ground truth samples. In the e-sensing project, we are focusing on time series analysis. We expect that, for some applications and geographical areas, temporal information provides a better basis for land cover classification than the pure spatial information. We will find out whether our vision will be met as the project develops.

4 Institutional support received in the period

The e-sensing project is hosted primarily by the Image Processing Division (DPI) of the National Institute of Space Research (INPE), with additional support provided by INPE's Remote Sensing Division (DSR). Both divisions report to the Earth Observation Directorate (OBT). During year 1 of the project, DPI gave substantial institutional support to the project, led by its head (Dr. Lubia Vinhas) as follows:

(a) DPI/INPE hired, with additional funds from other projects, a full-time post-doc researcher (Dr. Eduardo Llapa) who is 100% dedicated to the project.

(b) DPI/INPE also hired, with additional funds from other projects, a project support person (Ms. Denise Nascimento) who provides essential support for project management.

(c) DPI/INPE also provides the IT infrastructure for hosting the data servers bought by the project with support from FAPESP, and for hosting the project's website (http://www.esensing.org).

The institutional support we are receiving from DPI/INPE is very good and fulfils the needs of the project.

5 Activities planned for project year 2 (January – December 2016)

Considering that most of the targets planned for year 1 have been achieved, we will keep the original schedule for most of the tasks, as described below and resumed in Table 2.

5.1 Planned activities for work package 1 - Big Earth observation databases

5.1.1 Task 1.1 - Building and deployment of big Earth observation databases to support data analysis and use cases

Milestone M1.1.2 - Version 1 of the database for use cases in Brazil (month 12)

For this task, we will follow the plan to reach milestone M1.1.2 by the end of 2016. This is consistent with the aim of the task, which is to support the activities of the project.

This milestone will consist of loading in the SciDB database the data for the use cases to be done in years 3 and 4. In this case, we expect to include a significant number of LANDSAT images to complement the MODIS data that has been already inserted in the SciDB array manager.

5.1.2 Task 1.2 – Extend SciDB for geographical data handling

Milestone M1.2.1 – Integration of TerraLib and SciDB (month 24)

This is the only case where the milestone for year 1 was not met, for reasons we explained in section 3.1 above. The delays in the release of TerraLib version 5.0 have affected our project and force us to reconsider the milestones for this task. On the positive side, the development of the WTSS service [9] and the design of the spatial data infrastructure for handling big geospatial data [8] shows us a viable plan for 2016. In this light we revised the original milestone M1.2.1 to complete it by the end of 2016.

In year 2 (2016), we will complete the first part of this integration, with the full implementation of the WTSS service and the development of metadata methods for describing the contents of a SciDB database in TerraLib, as outlined in our vision [8]. The development of the TerraLib methods for server-side processing will thus be delayed from month 24 to month 36.

5.2 Planned activities for work package 2 - Data analysis for big Earth observation data

5.2.1 Task 2.1 - Integration between SciDB, TerraLib and R

Milestone M2.1.1 – Version 1 of the aRT Terralib-SciDB package (month 24)

For this task, we intend to follow the original plan, which calls for the development of an integration between the SciDB array database, the R programming environment for software and graphics and the TerraLib library that has functions for processing geographical data and for handling geospatial metadata. Thus, we will keep the plan of delivering milestone M2.1.1 by the end of 2016.

The main aim of this package is allow R users to use the data management capabilities provided by TerraLib for describing different types of geospatial data. The integration between TerraLib and SciDB is the aim of Task 1.2, as discussed above. Task 2.1 will allow users of the R environment to benefit from this integration. We consider that most of the data analysis methods that will use big Earth observation data sets will be written in R, as in the case of the TWDTW package (described in section 3.2 above).

5.2.2 Task 2.2 – Space-time analysis of big Earth observation data for land change monitoring

Milestone M2.2.2: Version 2 of Big-EO time series R package (month 24)

This task aims to develop new methods for space-time analysis of big Earth observation data. In year 1, we have already produced new research results, which will be extended in year 2. Thus, we will keep the original plan of delivering milestone M2.2.2 by the ned of 2016.

In version 1 of the *Big-EO time series R package*, we have developed the dtwSat package (see section 3.2 above). Version 2 of the package will consist of an extended update of dtwSat to deal with real-time detection of deforestation and with forest degradation. We will also include revised versions of the BFAST package (developed by Jan Verbesselt of Wageningen) to process large data sets of Earth observation data.

5.3 Planned activities for work package 3 - Use case development

5.3.1 Task 3.1 - Specification and validation of tropical forest change alert methods and data

Milestone M3.1.2 Preliminary detection of clear cut and degradation (month 24)

Our experience in year 1 with detailed analysis of forest degradation process in two areas in Amazonia and with the development of time series analysis methods encourages us to keep the original milestone for this task at the end of year 2 as planned.

We will use the initial and enhanced versions of the dtwSat and BFAST packages to produce maps of clear-cut and degradation over large areas of the Amazon forest. We will then compare the results with data produced by the DETER and DEGRAD systems to assess the performance of these satellite image time series analysis methods.

5.3.2 Task 3.2 - Specification and Validation of Tropical Agriculture Monitoring Methods and Data

Milestone M3.2.2 Detection of area of soybeans, maize and sugarcane (month 24)

Our work on year 1 has provided the team with indications of areas where the performance of satellite image time series analysis methods can be verified with ground truth data. Based on these results, we keep the original milestone for this task at the end of year 2 as planned.

We will use the dtwSat method (developed in Task 2.2) to process large agricultural areas in the state of São Paulo, with the specific tasks of mapping land cover associated to soybeans, maize and sugarcane. We will compare our results with ground truth data we have acquired and with results from IBGE (Brazil's Census Bureau).

5.4 Revised project milestones

Based on the above discussions, we have revised the table of milestones, which is presented below.

TABLE 3

REVISED PROJECT MILESTONES (REVISION 1 – AFTER PROJECT YEAR 2015)

Blue background	Target met in year 1
Green background	Target planned for year 2
Red background	Target delayed for year 2
White background	For later years

TASK	Month 12	Month 24	Month 36	Month 48
T1.1 **Building big EO databases**	M1.1.1. Version 1 of the database for use cases in Brazil	M1.1.2 Version 2 of database for use cases in Brazil	M1.1.3 Version 3 of database for use cases in Brazil	
T1.2 **Extend SciDB for geographical data handling**		M1.2.1 Integration of TerraLib and SciDB	M1.2.2 Algorithms for SciDB server-side processing	M1.2.3 SciDB as a spatial data manager
T2.1 **Integrate SciDB, TerraLib and R**		M2.1.1 aRT-SciDB package (v1)	M2.1.2 aRT-SciDB package (v2)	
T2.2 **Data analysis for big EO data**	M2.2.1 Big-EO time series R package (v1)	M2.2.2 Big-EO time series R package (v2)	M2.2.3 Big-EO space-time R package (v1)	M2.2.4 Big-EO space-time R package (v2)
T3.1 **Tropical forest change**	M3.1.1 Identification and selection of areas	M3.1.2 Preliminary detection of clear cut and degradation	M3.1.3 Detection of clear cut and degradation: final results	M3.1.4 Assessment of the forest change alert methods
T3.2 **Tropical agriculture mapping**	M3.2.1 Identification and selection of areas	M3.2.2 Mapping of soybeans, maize and sugarcane	M3.2.3 Mapping of soybeans, maize, rice sugarcane, and wheat	M3.2.4 Assessment of agricultural mapping methods

6 Project budget expenses in year 1

The overall budget expenses for the project are shown in Table 4.

TABLE 4

PROJECT EXPENSES (AFTER PROJECT YEAR 1 - 2015)

Item	Approved by FAPESP	Used	Remainder
Equipment	R$ 315,400.00	R$ 271,263.75	R$ 44,136.25
Trips Brazil	R$ 12,000.00		R$ 12,000.00
Trips abroad	US$ 15,000.00		US$ 15,000.00
Per diems	R$ 31,360.00		R$ 31,360.00
Consumables	R$ 25,200.00		R$ 25,200.00
Service contracts	R$ 14,880.00		R$ 14,880.00
Technical reserve	R$ 89,668.00	R$ 31,711.10	R$ 57,711.10
Additional benefits	R$ 96,000.00	R$ 13,297.74	R$ 82,702.26

The uses of the budget and their justification are described below.

6.1 Equipment

The equipment expenses are shown in Table 5. In the equipment part, the biggest expense was the cost of the servers. Originally, we had planned to acquire 8 servers with 10 TB each, for a total of 80 TB of distributed disk storage and had budgeted R$ 248,000.00 for this item. It turns out that the offers we received from the server manufacturers that have factories in Brazil (DELL and HP) enabled us to build 96 TB of distributed storage in fast access hard disks, in a pack that had five servers with the cost of R$ 253,900.00.

TABLE 5

EXPENSES WITH EQUIPMENT (PROJECT YEAR 1 - 2015)

	ITEM	VALUE
A	**Budget approved by FAPESP for equipment**	**R$ 315,000.00**
	1 digital camera Nikon Coolpix P610	R$ 1,817.85
	1 digital camera Nikon Coolpix S9900	R$ 1,143.12
	2 DELL notebooks (Inspiron 15 series 5000 OS Linux)	R$ 7,152.00
	5 servers DELL PowerEdge R730	R$ 253,950.00
	2 DELL notebooks (Inspiron 15 series 5000 OS Linux)	R$ 7,200.78
B	**Total of expenses for year 1 (sum of the above items)**	**R$ 271,263.75**
C	**Remaining budget (A – B)**	**R$ 44,136.25**

Considering our needs for year 2, we have the following situation:

(a) We need to buy a high-performance Ethernet switch to improve the connectivity of the servers to INPE's network, to ensure fast access to the processing in the servers.

(b) We had planned to buy seven (7) notebooks and have only acquired four (4) in the first year.

For this reason, we are submitting to FAPESP a request for adjustment of budget in the equipment, where we have removed items that no longer fit in the budget. We are requesting that we use the remaining budget as shown in Table 6, with only two items (the Ethernet switch and the 3 remaining notebooks).

TABLE 6

ADJUSTED REMAINING EQUIPMENT BUDGET

(REQUEST TO FAPESP FOR YEAR 2 EXPENSES)

ITEM	Cost Estimate
Remaining budget for year 2 (see Table 5)	R$ 44.136,25
1 high-performance Ethernet switch	R$ 30.000,00
3 DELL notebooks (Inspiron 15 series 5000 OS Linux)	R$ 12,900.00
Total of expenses for year 2	R$ 42,900.00
Remaining budget	R$ 1,286.25

6.2 Use of technical reserve

In year 1, the resources from the project's technical reserve have used for the following items:

(a) No-breaks and batteries for no-breaks.
(b) Miscellaneous items such as plugins and adapters.
(c) Training courses.

During 2015, we also supported training courses for the project team, especially for the newcomers that have been included in the project with the FAPESP fellowships. We ran training sessions in the C++, R, and GAMS languages. The choice of languages was based on our project plans. The TerraLib library is written in C++, so those working in Task T1.2 and Task T2.1 will have to become familiar with it. Most of our algorithms are written in R, so it is also important to acquaint our team with this language. We also wanted that our team be familiar with the GAMS modelling language, which we have used for modelling land use change in Amazonia, and is planned to be used at a later stage of the project.

TABLE 7

EXPENSES FROM TECHNICAL RESERVE (PROJECT YEAR 1 - 2015)

	ITEM	VALUE
A	**Budget approved by FAPESP for equipment**	**R$ 89,668.00**
	2 no-breaks	R$ 7,100.00
	2 hard-drives 600 GB	R$ 4,390.00
	4 batteries for no-breaks	R$ 312.00
	42 batteries for no-breaks	R$ 4,320.00
	1 USB adapter	R$ 197.10
	Plugs and adapters	R$ 392.00
	Training courses	R$ 7,500.00
B	**Total of expenses for year 1 (sum of the above items)**	**R$ 24,211.10**
C	**Remaining budget (A – B)**	**R$ 65,456.00**

6.3 Additional benefits

The project has two principal investigators who have been awarded additional benefits (Gilberto Câmara and Leila Fonseca). In Year 1 (2015), one of these researchers (Gilberto Câmara) used the benefits to make a scientific visit to the Institute for Geoinformatics at the University of Münster (IFGI/WWU) in Germany in November 2015. The expenses are in Table 8. The purpose of the trip was for Gilberto Câmara to work with his PhD student Victor Maus (who is currently supported by IFGI/WWU in Münster) on two scientific papers:

(a) Work on the revised version of the paper "A Time-Weighted Dynamic Time Warping method for land use and land cover mapping" for *the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. The second version has been accepted by the journal and already been assigned a DOI:
DOI: 10.1109/JSTARS.2016.2517118

(b) Prepare the submission of the paper “dtwSat: Time-Weighted Dynamic Time Warping for satellite image time series analysis in R”, a paper that describes the dtwSat package for R, and will be submitted to the *Journal of Statistical Software*.

TABLE 8

EXPENSES FROM ADDITIONAL BENEFITS (PROJECT YEAR 1 - 2015)

ITEM	Cost Estimate
Total budget approved by FAPESP	R$ 96,000,00
Air ticket to Münster for Gilberto Câmara	R$ 2,717.08
Per-diems to Münster for Gilberto Câmara	R$ 10,580.66
Total of expenses for year 2	**R$ 13.297,74**
Remaining budget	**R$ 82,702.26**

7 Data Management Policy

We are following the policy we stated in the project proposal, as follows:

Our policy will be to deal with the databases and software created by this project as a resource to be shared with the Brazilian Earth Observation community. Thus, we will open the database after month 24 of the project to the community. We will encourage scientists to develop new data analysis methods and to use the methods and algorithms we will build to develop new applications. We will maintain the database accessible and updated for long-term use by the scientific community.

As part of our quest for reproducibility and sharing of the results, the main software result from year 1 (the R dtwSat package) is available at the main repository for R software (CRAN – Comprehensive R Archive Network) whose website is https://cran.r-project.org/.

We have also build a project website http://www.esensing.org/ where we are going to make available:

(a) Access to the databases developed by the project and the executable procedures to build these from scenes;
(b) The GIS toolkit for big Earth observation data;
(c) The space-time package for forestry alert and agriculture mapping using big Earth Observation data;
(d) Documents containing results of the validations of the use cases done by the project;
(e) Documents with the lessons learned with the deployment of the proposed.

This website is being built with the results of the project. We expect that starting from the end of year 2 we will have a set of materials that are of value to the scientific community.

8 Final Remarks

The "e-sensing" project has achieved important results in Year 1. We have acquired and installed the necessary infrastructure; we have developed innovative methods for satellite image time series analysis. We have also done the required preliminary studies in Forestry and Agriculture that will provide a sound guide for our work in the next three years.

Another important, although intangible results, was to have built an interdisciplinary approach to the problem of big Earth observation data handling. We held frequent seminars and workshops with the full project team, so that researchers could present their different viewpoints. It has been vitally important to have such discussions. As a result, all team members have deepened their understanding of the complex problem we will try to solve in the coming years.

Annex 1 - Project Fellowships

In this section we briefly describe the status of the project fellowships. Please note that the original proposal submitted to FAPESP asked for 3 TT-4A, 3 PhD and 3 post-doc scholarships. At first, FAPESP cut this request to 2 PhD and 1 post-doc scholarships. We prepared a “Pedido de Reconsideração” (Request for Reassessment) in which we argued that we needed at least 2 TT-4A, 2 PhD and 2 post-doc scholarships. FAPESP accepted our request. Thus, we had to adjust the tasks assigned to the fellowships, to fit the most important parts of the original tasks into the reduced number awarded by FAPESP.

TT-4A Fellowship (24 months): Building and deployment of big Earth observation databases

Associated Task: Task 1.1

Starting date: March 2016

This scholarship is concerned with enhancing the array DBMS SciDB for Earth observation applications. For this end, we need additional functions that handle information such as cartographical projections and image metadata. To this end, this task will develop software that extends SciDB to include information specific to Earth observation. It has been awarded to Alber Sanchez, who has completed a MSc at the Institute for Geoinformatics at the University of Münster.

Lattes CV - Alber Sanchez: http://lattes.cnpq.br/7009551746793478

TT-4A Fellowship (24 months): Integration between SciDB/TerraLib and R

Associated Task: Task 2.1

Starting date: October 2015

This scholarship will be used to develop the integration between TerraLib, SciDB and R. Concepts from the SciDB GIS extension provided by TerraLib will be mapped into R classes so that R users that already know TerraLib will have no difficulty to use the package. It has been awarded to Luiz Fernando Assis, who has completed a MSc in Computer Science at the University of São Paulo at São Carlos.

Lattes CV - Luiz Assis: http://lattes.cnpq.br/7558973662173812

DR Fellowship (36 months): Conception and development of SDI architecture for big Earth observation data

Associated Task: Task 1.2

Starting date: October 2015

This task concerns the development of a spatial data infrastructure architecture for big spatiotemporal data sets, following the concepts presented in [8]. The idea of the SDI is to bring together the set of technologies that are required to manage such big data. The SDI is divided in four components: Databases, Web services, and Geographical Information System (GIS) tools. The primary aim of the thesis is to put together an environment by which a user can access both traditional spatial DBMS such as PostGIS and array databases such as SciDB in an integrated way. Our plan is to focus first on an R interface, to be consistent with the other tasks being developed in the project.

The scholarship has been awarded to Elmer Dotti, who has a MSc in Computer Science by the Aeronautics Technological Institute (ITA).

Lattes CV - Elmer Dotti: http://lattes.cnpq.br/6914931177328481

DR Fellowship (36 months): Big Earth observation data space-time R package for deforestation and degradation

Associated Task: Task 2.2

Starting date: March 2016

This task will focus on the development of space-time data analysis methods for monitoring deforestation and degradation in large data sets of Earth observation images. These methods will combine object-based image analysis methods (such as segmentation) with time series analysis. The methods will be validated for the forest change monitoring as specified in the use cases of Amazonia, but it will be developed as a generic multi-purpose open-source toolbox for change monitoring of any kind of EO data (e.g. drought detection, agriculture yield anomaly monitoring, etc.).

The scholarship has been awarded to Rennan Marujo, who has a BSc in Computer Science (Lavras Univ) and MSc in Remote Sensing (INPE).

Lattes CV – Rennan Marujo http://lattes.cnpq.br/1967339602343455

Postdoc Fellowship (24 months): Use of Time Series and Space-time data to monitor forest change in Amazonia

Associated Task: Task 3.1

This Post-Doctoral researcher will analyse deforestation trajectories across the case studies. The focus will be in the analysis of spatial and temporal patterns of the deforestation, including clear cut and forest degradation, in the use cases. The researcher will first design a classification scheme for forest degradation based on the rules of FAO's LCCS (Land Cover Classification System). Field work will also be required to evaluate the results.

Interactions with researchers of WP1 and WP2, which will develop and produce new methods and data, are expected. This position will also be expected to contribute and lead research articles associated with the project.

This fellowship has not been awarded yet, and a search procedure will be carried out in the beginning of 2016.

Postdoc Fellowship (24 months): Specification and Validation of Tropical Agriculture Monitoring Methods and Data

Associated Task: Task 3.2

This Post Doctoral appointment will focus in the specification and validation activities of BIG EO data new approach and methods for Agricultural monitoring. Its tasks include: (a) Detection of planted area of soybeans, maize and sugarcane, rice and wheat crops in selected areas; (b) Detailed assessment of the usefulness of BIG EO data approach for national and global scales.

This fellowship has not been awarded yet, and a search procedure will be carried out in the beginning of 2016.

Annex 2 – Project papers in 2015

(authors from research team are shown in red)

PAPERS PUBLISHED IN INDEXED JOURNALS

1. César Diniz, Arleson Souza, Diogo Santos, Miriam Dias, Nelton Luz, Douglas Moraes, Janaína Maia, Alessandra Gomes, Igor Narvaes, Dalton Valeriano, Luiz Maurano. DETER-B: the new Amazon near real-time deforestation detection system. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 8(7):* 3619-3628, 2015. DOI: 10.1109/JSTARS.2015.2437075

2. Bruno Schultz, Markus Immitzer, Antonio Formaggio, Ieda Sanches, Alfredo Luiz, Clement Atzberger. Self-guided segmentation and classification of multi-temporal Landsat 8 images for crop type mapping in southeastern Brazil. *Remote Sensing,* 7:11(14482-14508), 2015. DOI: 10.3390/rs71114482.

3. Isaque Eberhardt, Alfredo Luiz, Antonio Formaggio e Ieda Sanches. Detecção de áreas agrícolas em tempo quase real com imagens MODIS (Detection of agricultural areas in near real time using MODIS imagery). *Pesquisa Agropecuária Brasileira*, 50 (7), 605-614, 2015. DOI: 10.1590/S0100-204X2015000700010.

PAPERS ACCEPTED IN INDEXED JOURNALS

4. Meng Lu, Edzer Pebesma, Alber Sanchez, Jan Verbesselt. Spatio-temporal change detection from multidimensional arrays: detecting deforestation from MODIS time series. Accepted for publication in *ISPRS Journal of Photogrammetry and Remote Sensing.*

5. Victor Maus, Gilberto Camara, Ricardo Cartaxo, Alber Sanchez, Fernando Ramos, Gilberto Queiroz. A time-weighted dynamic time warping method for land use and land cover mapping. Accepted for publication on *IEEE Journal of Selected Topics In Applied Earth Observations And Remote Sensing*. DOI: 10.1109/JSTARS.2016.2517118

6. Marcio Azeredo, Miguel Monteiro, Isabel Escada, Karine Ferreira, Lúbia Vinhas, Taíse Pinheiro. Mineração de trajetórias de mudança de cobertura da terra em estudos de degradação florestal (Mining trajectories of land cover change in forest degration studies). Accepted by *Revista Brasileira de Cartografia* (2016).

PEER-REVIEWED PAPERS IN SCIENTIFIC CONFERENCES

7. ADELINE MACIEL, LÚBIA VINHAS, GILBERTO CÂMARA. Estatística zonal de imagens de sensoriamento remoto armazenadas em banco de dados NoSQL (Zonal statistics for remote sensing imagens stored in NoSQL databases). In: 30th Brazilian Database Symposium (SBBD), Petrópolis, 2015. Proceedings, p. 57-62. ISBN 9788599961193.

8. KARINE FERREIRA, GILBERTO QUEIROZ, LÚBIA VINHAS, GILBERTO CÂMARA, LUIZ MAURANO, RICARDO SOUZA, ALBER SANCHEZ. Towards a spatial data infraestructure for big spatiotemporal data sets. In: 17th Brazilian Symposium on Remote Sensing (SBSR), 2015. Proceedings, p. 7588-7594.

9. GILBERTO QUEIROZ, KARINE FERREIRA, LÚBIA VINHAS, GILBERTO CÂMARA, RAPHAEL COSTA, RICARDO SOUZA, ALBER SANCHEZ. WTSS: um serviço web para extração de séries temporais de imagens de sensoriamento remote (WTSS: a web service for extraction of satellite image time series). In: 17th Brazilian Symposium on Remote Sensing (SBSR), 2015. Proceedings. p. 7553-7560.

10. WANDERSON COSTA, LEILA FONSECA, THALES KORTING. Classifying grasslands and cultivated pastures in the Brazilian Cerrado using support vector machines, multilayer perceptrons and autoencoders. In: 11th International Conference in Machine Learning, MLDM. Hamburg, 2015.

11. ALANA NEVES, HUGO BENDINI, THALES KÖRTING, LEILA FONSECA. Combining time series features and data mining to detect land cover patterns: a case study in Northern Mato Grosso State, Brazil. XVI Brazilian Symposium on GeoInformatics, Campos do Jordão, 2015.

12. VICTOR MAUS, GILBERTO CÂMARA, RICARDO CARTAXO, Fernando Ramos. Dynamic time warping applied to spatiotemporal agriculture mapping in the Brazilian Amazon. In 36th International Symposium on Remote Sensing of Environment. Berlin, 2015.

13. VICTOR MAUS, GILBERTO CÂMARA, RICARDO CARTAXO, FERNANDO RAMOS. Land use mapping in the Brazilian Amazon with remote sensing time series. 35th EARSeL Symposium & 2nd Workshops on Temporal Analysis of Satellite Images. Stockholm. 2015.

14. ANIELI SOUZA, ISABEL ESCADA, MIGUEL MONTEIRO. Gradientes de intensificação do uso da terra: análise no entorno de comunidades ribeirinhas e de terra firme em Santarém e Belterra (PA) entre 1990 e 2010 (Gradients of land use intensification: analysis in the areas of riverine and terrafirme communities in Santarám and Belterra (PA) between 1990 and 2010). In:

17th Brazilian Symposium on Remote Sensing, 2015, Proceedings, p.6087 – 6094.

15. HUGO BENDINI, CESARE DI GIROLAMO, THALES KÖRTING, RENNAN MARUJO, KLEBER TRABAQUINI, ISAQUE EBERHARDT, IEDA SANCHES, LEILA FONSECA. Effects of image fusion methods on sugarcane classification with Landsat-8 imagery. In: 17th Brazilian Symposium on Remote Sensing SBSR, 2015, João Pessoa.

16. ISAQUE EBERHARDT, ALFREDO LUIZ, ANTONIO FORMAGGIO, IEDA SANCHES. Detecção de áreas agrícolas em tempo quase real DATQuaR (Detection of agricultural areas in near real time). In: 17th Brazilian Symposium on Remote Sensing, 2015, João Pessoa.

17. ALFREDO LUIZ, IEDA SANCHES, KLEBER TRABAQUINI, ISAQUE EBERHARDT, ANTONIO FORMAGGIO. Dinâmica agrícola em área de sobreposição de órbitas adjacentes dos satélites Landsat (Agricultural dynamics in areas of orbital superposition in Landsat images). In: 17th Brazilian Symposium on Remote Sensing, João Pessoa, 2015.

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