Land Cover CCI

PRODUCT SPECIFICATION DOCUMENT - YEAR 1

VERSION 1.2

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SYMBOLS AND ACRONYMS

ASAR	: Advanced Synthetic Aperture Radar
ATBD	: Algorithm Theoretical Basis Document
AVHRR	: Advanced Very High Resolution Radiometer
BC	: Brockmann Consult
BRDF	: Bidirectional Reflectance Distribution Function
CCI	: Climate Change Initiative
CCI-LC	: Climate Change Initiative Land Cover
CECR	: Comprehensive Error Characterization Report
CMC	: Climate Modelling Community
CMIP	: Coupled Model Intercomparison Project
CMUG	: Climate Modelling User Group
CRS	: Coordinate Reference System
DUE	: Data User Element
EC	: European Commission
ECV	: Essential Climate Variable
EO	: Earth Observation
ESA	: European Space Agency
ET	: Evapotranspiration
FAPAR	: Fraction of Absorbed Photosynthetically Active Radiation
FR	: Full Resolution
GCOS	: Global Climate Observing System
GCS	: Geographic Coordinate System
GFED	: Global Fire Data
GIMMS	: Global Inventory Modeling and Mapping Studies
GLC2000	: Global Land Cover 2000
GlobCover	: ESA DUE project (http://due.esrin.esa.int/globcover/)
GMM	: Global Monitoring Mode
IGOL	: Integrated Global Observations for Land
IMM	: Image Mode Medium
IPCC	: Intergovernmental Panel on Climate Change

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ISSI	: International Space Science Institute
JRC	: Joint Research Centre
LAI	: Leaf Area Index
LC	: Land Cover
LCCS	: Land Cover Classification System
LS	: Land Surface
MERIS	: Medium Resolution Imaging Spectrometer
MODIS	: Moderate Resolution Imaging Spectroradiometer
NDVI	: Normalized Difference Vegetation Index
OLCI	: Ocean and Land Colour Instrument
PFT	: Plant Functional Type
PROBA-V	: Project for On-Board Autonomy, with the V standing for Vegetation
PSD	: Product Specification Document
PUG	: Product User Guide
PVIR	: Product Validation and Intercomparison Report
PVP	: Product Validation Plan
RR	: Reduced Resolution
SAR	: Synthetic Aperture Radar
SDR	: Surface Directional Reflectance
SLSTR	: Sea and Land Surface Temperature Radiometer
SPOT	: Satellite Pour l'Observation de la Terre
SPOT-VGT	: SPOT-Vegetation
SR	: Surface Reflectance
SRTM	: Shuttle Radar Topographic Mission
SWBD	: SRTM Water Body Dataset
SWIR	: Short-Wave InfraRed
UN	: United Nations
UNFCCC	: United Nations Framework Convention on Climate Change
UR	: User Requirement
URD	: User Requirement Document
UCL	: Université catholique de Louvain
VIIRS	: Visible Infrared Imaging Radiometer Suite
WB	: Water Body

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WGS	: World Geodetic System
WS	: Wide Swath
WSM	: Wide Swath Mode

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AD.2	ESA Climate Change Initiative Phase 2 - Land Cover ECV Technical baseline for the project (update of the technical proposal with clarification and negotiation items)	1.0	13.03.2014
AD.3	CCI-LC URD Phase II. Land Cover Climate Change Initiative - User Requirements Document	1.1	30.11.2014
AD.4	ESA Climate Change Initiative Phase 1 - Project Guidelines V1		
AD.5	CCI System Requirements v1, CCI-PRGM-EOPS-TN-12-0031, 13 June 2013. Available at: http://ionia1.esrin.esa.int/files/CCI_System_Requirements_V1_0.pdf		

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RD.3	CCI-LC PVP Phase I. Land Cover Climate Change Initiative - Product Validation Plan	1.3	04/07/2011
RD.4	CCI-LC ATBD Phase I. Land Cover Climate Change Initiative - Algorithm Theoretical Basis Document	2.3	28/11/2013
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1 INTRODUCTION

1.1 Scope

The Product Specification Document (PSD) transforms the climate user requirements described in the User Requirement Document (URD) into a complete and consistent set of products specifications. Clearly, not every requirement can be met and pragmatic choices have to be made when converting the outputs of the URD into detailed product technical specifications. As outlined in the Climate Change Initiative (CCI) Phase 1 guidelines [AD.4], it is important to explain the rationale behind the choices made. Defining the product specifications and justifying them is the scope of this document.

During the 1st phase of the CCI, a large user requirement activity was organized to understand the main needs and interests in terms of global Land Cover (LC) products from the climate modelling community. This exercise was documented in a URD [RD.1], which was translated in a PSD [RD.2].

The PSD of the 2nd phase of the CCI mainly builds on the PSD of the 1st phase [RD.2]. The updates consist in modifications of Phase 1 specifications if required by the users and in addition of new products. Modifications to bring to the Phase 1 products expressed by the users are documented in the Phase 2 URD [AD.3]. As for the new products, they have been proposed in the CCI Land Cover (CCI-LC) Phase 2 proposal [AD.2] and they will be validated by the users.

The output products of the CCI-LC production chain consist of global Surface Reflectance (SR) composite time series and of global Land Cover (LC) products. Within this document, these products are defined in terms of content, legend, spatial and temporal applicability, grids, projections and quality. The conventions about the products' identification, format, structure, metadata and delivery are also presented.

1.2 Background of the project

The European Space Agency (ESA) CCI projects will deliver the next generation of satellite derived geophysical parameters, with quantified uncertainties that will allow each parameter to be assessed against requirements from the Global Climate Observing System (GCOS) for Essential Climate Variables (ECV) and the Climate Modelling Community (CMC), represented within the CCI program by the Climate Modelling User Group (CMUG).

The objective of the CCI is to realize the full potential of the long-term global EO archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by United Nations Framework Convention on Climate Change (UNFCCC). The programme is organized in 2 phases.

The CCI Phase 1 provided a unique opportunity for the European EO science community to define and validate innovative approaches for continuously generating and updating a comprehensive and consistent set of ECV global satellite based data products in the long term – i.e. decades hence. The

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focus was on a major sustained, and coordinated scientific effort to review and improve underlying processing, retrieval and validation methods.

The CCI Phase 2 focuses on the generation of long-term, consistent, global data records for each ECV, exploiting the full range of available data sets from ESA and relevant European missions with the aim to issue extended and improved globally consistent ECV data sets from all CCI projects. Each project must make significant, further progress towards meeting the GCOS and related user requirements, exceeding the achievements of the phase 1 CCI projects with quantifiable validated measure of performance.

This means the prototype ECV production systems implemented in CCI phase 1, must be developed to a sustainable level, based on complete requirements specified and thoroughly validated by the competent science communities during phase 1 [AD.5] These system requirements must be updated to take account of the availability of new and upcoming missions (e.g. Landsat-8, Sentinels, ALOS-2, PROBA-V) and evolution to meet industry level standards for operations, maintenance, evolution and configuration control. Phase 2 projects should follow an iterative life-cycle, of concurrent development and operations. Project activities must continue to be driven by climate science, traceable to documented user needs and CCI projects must engage the relevant science communities, working side-by-side with industry and data centres in Europe.

1.3 Structure of the document

After this introduction, the document is divided into 6 sections that are briefly described below:

- Section 2 summarizes the main findings of the user requirement analysis, as well as their quantitative requirements in terms of spatial and temporal coverage, spatial resolution, overall accuracy, temporal stability and errors characterization;
- Section 3 reminds the new land cover concept underlying the development of the CCI-LC products, that was developed in Phase 1;
- Section 4 lists all the products that will be generated during the CCI-LC Phase 2 and highlights those on which this PSDv1 will focus;
- Section 5 describes the different types of products that will be delivered during the 1st year of the CCI-LC Phase 2;
- Section 6 documents the quality indicators associated with each of these products;
- Section 7 details their technical specifications
- Section 8 presents the products delivery mechanisms;
- Section 9 provides a table which summarizes how the user requirements described in the URDv1 [AD.3] have been translated in product specifications.

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2 SYNTHESIS OF USER REQUIREMENTS

As part of the activities of the Phase 2, a new user survey was conducted among the climate modelling partners of the CCI-LC project to analyze the fulfilment of the requirements defined in Phase 1 and to identify target requirements for future LC products. The comprehensive user survey results of Phase 1 was reanalyzed (excepted future modeling requirements) and consolidated through synthesizing new user needs from the scientific community from initiatives such as Terrabytes and International Space Science Institute (ISSI) special group, from Coupled Model Intercomparison Project (CMIP) 6 process and from the outcomes of the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC). The GCOS process has started to specify new ambitions for ECVs to meet the needs of the climate mitigation community – this also posed new requirements for the CCI-LC project.

The results of the URDv1 of Phase 2 [AD.3] are briefly reminded here.

User judged the quality of the CCI-LC products as moderate to good. All threshold requirements of Phase 1 have been met except for the precision in description of land cover characteristics. Here the user recognized that significant progress was done with the definition of cross-walking tables and with the development of a dedicated user tool but they also noted remaining problems in the compatibility with their Plant Functional Types (PFT) parameterization schemes. Phase 1 target requirements have not been met except for the use of monthly data on vegetation dynamics (NDVI seasonality product). All users judged the communication between data users and producers as very good.

The feedback from Phase 1 results and the new user's needs assessment have resulted in a series of new requirements. These requirements were discussed during the 1st progress meeting of Phase 2 of the project (Wageningen / 18-19 June 2014) and prioritized as follows:

Higher priority

1) Better description of LC characteristics in the context of PFT model requirements. As a follow up of the Phase 1 work, the new requirement is to formulate LC – PFT conversion tables separately for different climatic regions. These regions are to be defined by the climate modeler users of the consortium, with PFT fractions per region identified using the land cover validation dataset.
   In particular, the percentage ranges for LC – PFT conversion in the case of mixed classes, for example the class 'mosaic tree and shrub (>50%) / herbaceous (<50%)', should be better defined in order to provide the proportion (%) of tree, shrub, and herbaceous.
2) Longer temporal extent for LC maps (30 years and more) including datasets for the 1990's and the 1980's.
3) Higher temporal resolution: annual time steps in LC change.
4) More specific information of land cover/use change is required, at least in the context of the

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IPCC land categories (forests, agriculture, grassland, settlement, wetland, other land).

5) Additional attributes of the LC classes are demanded including vegetation height, minimum and maximum Leaf Area Index (LAI), clumping index and the distinction between C3 and C4 plants.

Lower priority

6) Move to 30 m (or better) scale LC and change assessments, at least for selected regions.
7) Seek options for including land management (forestry, agriculture, livestock) with land cover datasets.
8) Provide additional information about land surface seasonality through, for instance, fAPAR, surface albedo for vegetation and soil LC classes.
9) Provide additional relevant attributes of LC classes such as aboveground tree biomass, vegetation density, and permafrost fraction.
10) Improve the description of the results and products. Besides the detailed technical reports, short technical summaries highlighting important points should be provided.

The requirements have been synthesized and summarized in Figure 2-1.

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	Threshold requirement Phase 1	**Target requirement Phase 1**	**Threshold requirement Phase 2**	**Target requirement Phase 2**
	Coverage and sampling			
Geographic Coverage	*Global* ✓	*Global with regional and local specific products* ✗	*Global with regional specific products*	*Global with regional specific products*
Temporal sampling	*Best/stable map and regular updates* ✓	*Monthly data on vegetation dynamics and change* ✓	*5-10 year epoch maps with monthly vegetation dynamics(NDVI)*	*1-year epoch maps. Monthly data on vegetation dynamics (NDVI)*
Temporal extent	*1-2 years, most recent* ✓	*1990 (or earlier)-present* ✗	*1990 (or earlier) - present*	*1980 (or earlier) - present*
	Resolution			
Horizontal Resolution	*1000 m* ✓	*30 m* ✗	*300 m with regional 30 m products*	*30 m*
Vertical Resolution	–	–		
	Error/Uncertainty			
Precision	*Thematic land cover detail sufficient to meet current modelling user needs* ✗	*Thematic land cover detail sufficient to meet future model needs* ✗	*Thematic land cover detail (incl. conversion tables to PFT for climatic regions) sufficient to meet current and future model needs, incl. key land IPCC changes*	*Thematic land cover detail (incl. conversion tables to PFT for climatic regions) and traits) sufficient to meet current and future model needs, incl. land changes and land management*
Accuracy	*Higher accuracy than existing datasets* ✓	*Errors of 5-10% either per class or as overall accuracy* ✗	*Higher accuracy than existing datasets*	*Errors of 5-10% either per class or as overall accuracy*
Stability	*Higher stability than existing datasets* ✓	*Errors of 5-10% either per class or as overall accuracy* ✗	*Higher stability than existing datasets*	*Errors of 5-10% either per class or as overall accuracy*
Error Characteristics	*Independent onetime accuracy assessment* ✓	*Operational and independent multi-date validation* ✗	*Independent multi-date validation*	*Operational and independent multi-date validation*

Figure 2-1: Threshold (minimum) and target (optimal) requirements identified for LC products in the User Requirements Survey carried out in the CCI – LC project Phases 1 and 2. Check–marks indicate fulfilled requirements

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3 NEW LAND COVER CONCEPT DEVELOPED IN PHASE 1

LC is referred to as one of the most obvious and commonly used indicators for land surface and the associated human induced or naturally occurring processes. With the development of EO technology, it has become increasingly feasible to derive land surface information from a combination of in-situ surveys and EO satellite data at global, regional and national scales [RD.6]. While traditional in-situ surveys usually allow acquiring specific information (such as species composition, landform, soil type, land use, etc.), satellite data provide a spatially-exhaustive, georeferenced and repetitive coverage of the Earth.

Building upon the increasing availability of EO satellite data, land cover mapping has progressively become one of the most popular approaches to describe the land surface. The land surface in different regions of the world has been mapped and characterized several times. Many countries have some kind of land monitoring system in place (e.g. forest, agriculture and cartographic information systems and inventories). In addition, a number of global land cover mapping activities exist. These activities have evolved with the availability of global moderate spatial resolution satellite observations since the early 1990s. Meanwhile, the development of the United Nations (UN) Land Cover Classification System (LCCS) has provided a basic level of thematic LC standardization [RD.7]. These efforts have yielded several products in the 300 m – 1 km spatial resolution range, all based on a "single-sensor" approach and mostly associated with legends described according to LCCS classifiers.

The recent capabilities of acquiring and processing global multi-year and multi-sensor time series of EO data call for revisiting the land cover concept while capitalizing with all the experience acquired in various aspects of land cover mapping. Furthermore, the URD highlights the expectations of the climate communities for an improved land cover product which would be more integrative than the current one. Indeed, there was a clear requirement for a land cover which includes both stable and dynamic components, while making the difference between land cover change and natural variability (i.e. land cover dynamics which do not question the existence of the land cover itself).

For a long time, there was some diversity of opinion about what the land cover was and how it was distinct from the land use. In 1961, Burley defined the land cover as the vegetation and the artificial constructions covering the land [RD.8]. In the context of LCCS, land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures [RD.7]. The Integrated Global Observations for Land (IGOL) defines land cover as the observed bio-physical cover on the earth's surface [RD.9], while recognizing, in the current practices, the confusion between land cover and land use. Land use characterizes the arrangements, socio-economic activities and inputs people are undertaking on a certain land cover type. It includes both space and time dimensions and should be considered separately from land cover type to ensure internal and external consistency and comparability [RD.10].

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Yet, it must be recognized that the land cover cannot, at the same time, be defined as the physical and biological cover on the terrestrial surface [RD.6, RD.7] and remains stable and consistent over time as requested by the climate users [RD.1]. A revisited land cover concept has therefore to be introduced to reconcile these two views. Defining such new land cover concept that will address the climate users' requirements in the context of the CCI-LC project is the objective of this section.

3.1 Definition based on spatial and temporal dimensions

The LC concept used in the CCI-LC project assumes the land cover is organized along a continuum of temporal and spatial scales [RD.11] and that each land cover type is defined by a characteristic scale, i.e. by typical spatial extent and time period over which its physical traits are observed [RD.12]. This twofold assumption requires introducing the time dimension in the land cover characterization, which contributes to define the land cover concept in a more integrative way, as requested by the CMC.

Indeed, accounting for the time dimension allows distinguishing between the stable and the dynamic component of land cover. The stable component, which is named "**land cover state**", refers to the set of land surface features which remain stable over time and thus define the land cover independently of any sources of temporary or natural variability. Conversely, the dynamic component is directly related to this temporary or natural variability that can induce some variation in land surface features over time but without changing the land cover state in its essence. This second component is referred to as "**land surface seasonality**".

In Phase 2, the term "land surface seasonality" replaces the term "land cover condition" introduced in Phase I because of its more intuitive meaning. However the products and their signification remain unchanged.

3.2 Land cover state and land surface seasonality

Land cover states and land surface seasonality are mapped through the use of **land surface features**, which consist in landscape elementary units (e.g. a house, a tree, a water body, etc.).

The **land cover state** refers to a **stable** ensemble of land surface features. It is fully described by:

1) the **type** of the observed features, such as tree, shrub, herbaceous vegetation, moss/lichen vegetation, terrestrial or aquatic vegetation, inland water, built-up areas, permanent snow/ice, etc.;
2) the **structure** of the observed features, like vegetation height, vegetation cover, building density, etc.;
3) the **nature** of the observed features, such as the level of artificiality or some species information (e.g. C3/C4 distinction);
4) the **homogeneity** of the observed features at the level of observation, leading to pure or mosaic classes.

The land cover state is well described using the LCCS, as illustrated by Figure 3-1.

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The anthropogenic dimension, included in the "level of artificiality" of the features nature, rather refers to the land use than to the land cover. The users' surveys and the expected uses of the CCI-LC products call to include such a simple surrogate for land use. However, the Corine Land Cover and the GlobCorine experiences amongst others [RD.13, RD.14] showed that this information was proved to be quite difficult to derive from satellite observations.

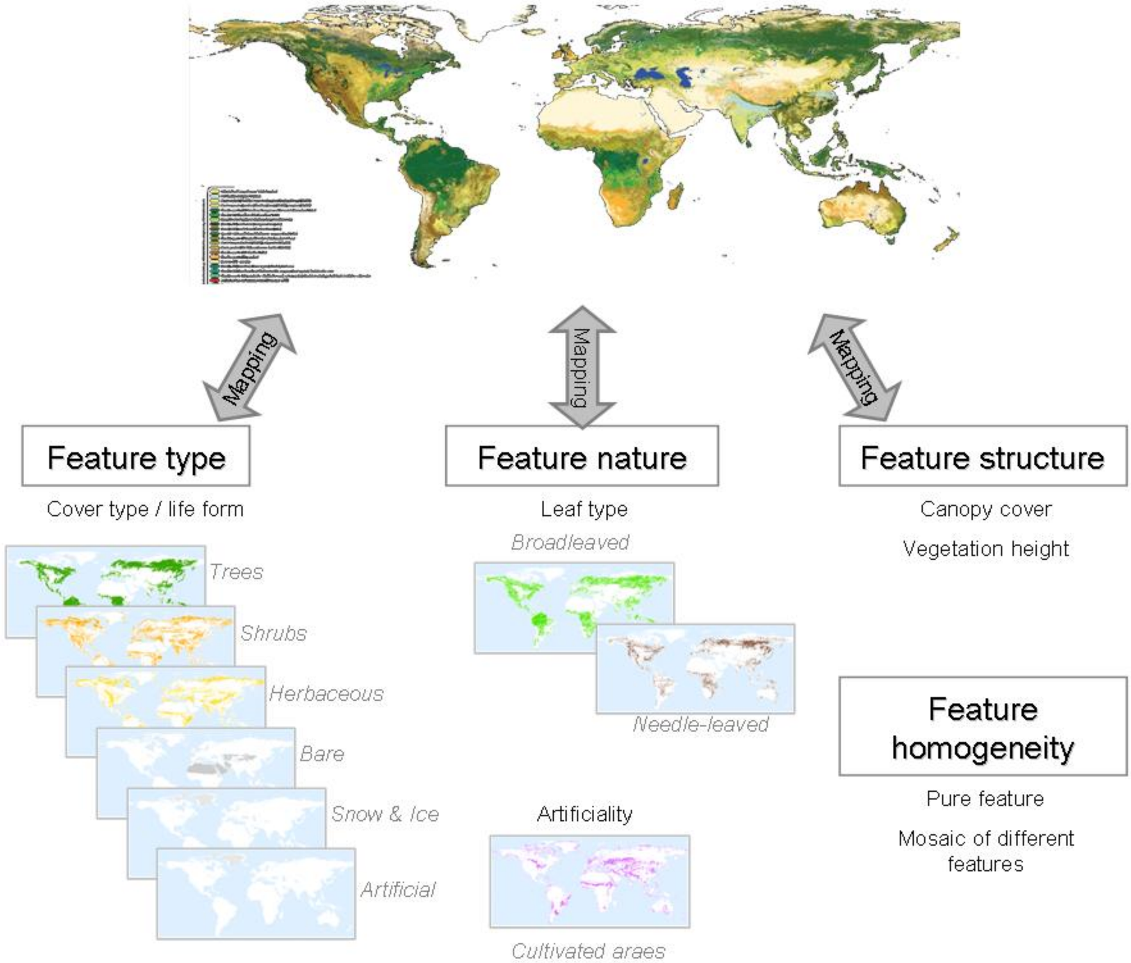

Figure 3-1: Description of the land cover state mostly based on LCCS

The **Land Surface (LS) seasonality** encompasses the inter-annual processes modifying temporally the land surface along the year. Typically driven by biogeophysical processes, it corresponds to annual time series mode of "instantaneous observations" of the land cover status. The land surface seasonality is described by different observable variables:

1) the **green vegetation phenology** through vegetation indices (e.g. NDVI) profiles;
2) the **snow coverage** allowing users to derive the snow cover period;
3) the **open water presence** related to floods, water extent dynamic or irrigation;
4) the **fire occurrence** and the associated **burned scars**;

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5) possibly, the number of **cropping cycles**;
6) possibly, the **albedo** (whenever available);
7) possibly, the **LAI** (whenever available).

The land surface seasonality can be described in a relevant way through an interpolation between “instantaneous” statuses of the land cover. This can take the form of time profiles in the case of continuous variables (e.g. NDVI, etc.) or of temporal distribution of occurrence probabilities in the case of discrete variables (e.g. snow or water). Both possibilities are illustrated in Figure 3-2. The land surface seasonality provides reference information depicting the seasonal land cover change which is not related to a given year. This information is obtained by averaging multiple (minimum 5) years. In the case of continuous variables, the mean time profile is associated with one standard deviation interval characterizing the inter-annual variability.

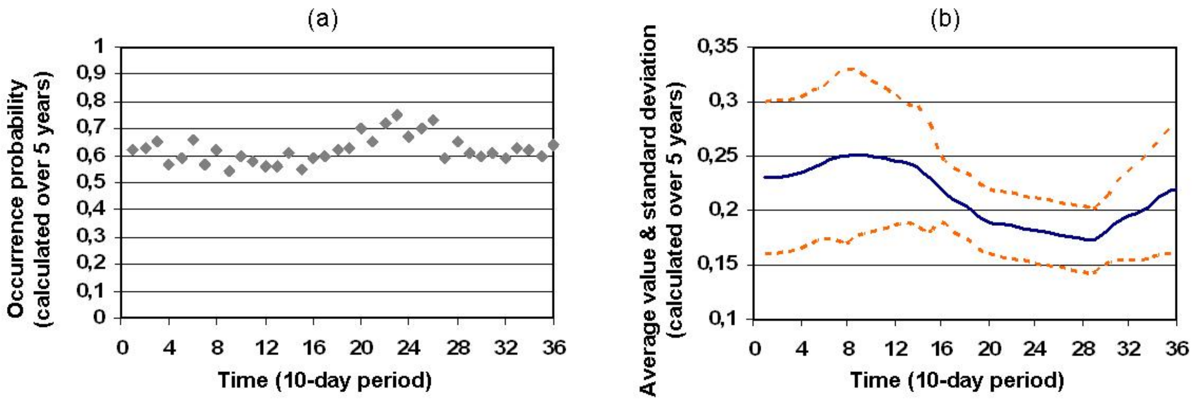

Figure 3-2: Description of the land surface seasonality through probabilistic distributions (a) or time profiles (b)

Table 3-1 illustrates this new LC concept (state and seasonality) with two distinct illustrations, the first one referring to artificial urban areas and the second one to a dense tropical forest.

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Table 3-1: Illustration of the concepts of land surface, land surface feature, LC state and LS seasonality

<table>
<tr><td rowspan="4"></td><td colspan="2">Land surface (what is observed): roofs</td></tr>
<tr><td colspan="2">Land surface features (elementary units): houses</td></tr>
<tr><td>Land cover state (stable ensemble of land surface features): urban area</td><td>Land surface seasonality (instantaneous status of land surface features): no snow, no floods</td></tr>
<tr><td>Feature type: built-up
Feature structure: high density
Feature nature: artificial
Feature homogeneity: urban patterns, mosaic with green areas</td><td>No snow observed
No water observed
Specific albedo</td></tr>
<tr><td rowspan="4"></td><td colspan="2">Land surface (what is observed): rough canopy</td></tr>
<tr><td colspan="2">Land surface features (elementary units): trees</td></tr>
<tr><td>Land cover state (stable ensemble of land surface features): forest</td><td>Land surface seasonality (instantaneous status of land surface features): no snow, no floods, no fire</td></tr>
<tr><td>Feature type: woody (trees, shrubs) vegetation
Feature structure: dense cover, density
Feature nature: natural, broadleaved, evergreen
Feature homogeneity: homogeneous (few clearings)</td><td>No snow observed
No water observed
No fire or burned scars observed
Specific albedo</td></tr>
</table>

Using this new concept made of LC state and LS seasonality offers the opportunity to characterize the land surface in a more integrative way than just categories (i.e. forest or open water) or continuous variables classifiers (fraction of tree canopy cover). This addresses the critical requirements expressed in Phase 1 for consistency between land surface characteristics, the required stability and the dynamic dimension at the intra-annual and seasonal levels. Furthermore, it is of direct use for the climate models parameterization. Indeed, as highlighted by the user requirement analysis [RD.1], LC products can be used in climate models as a proxy for several land surface parameters. These parameters are assigned, for instance, on the basis of the PFTs. The coupling of the permanent and the dynamic dimensions of the land surface allowed by the proposed land cover concept contributes to improve the **consistency** of the land surface parameterization.

As a consequence of this revisited LC definition, the **LC change** must be referred to as a permanent modification of the land cover state – and not of the land surface seasonality – **i**n comparison with a

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baseline status. However, further work is needed to define precisely change thresholds, i.e. the modification levels required to be considered as land cover change.

3.3 Land cover products derived from multi-year dataset

Most often, LC maps are generated from few instantaneous observations of the land cover state. As a result, classification outputs are sensitive to the date(s) of observation and can reflect temporary conditions (e.g. map savannahs as burnt scars, boreal forest as snow, croplands as bare soils, etc.). An alternative could probably come from the description of the **LC state** (which stands for the stable component of the LC) **from multi-year observation dataset**. In this case, assuming that no LC change – even temporary – has occurred over this multi-year period, the LC is expected to be mapped in a consistent way over time. Conversely, the instantaneous observations of the **LS seasonality** should be considered **within the perspective of a time cycle** (typically a year) precisely in order to reflect the above-mentioned temporary conditions. The **LS seasonality** analysis **over a multi-year period** (still under the assumption of stable land cover state over this period) should permit to derive a reference land surface seasonality as well as information about the intra-annual variability. This approach was implemented in the CCI-LC Phase 1. The general concept is reminded in Figure 3-3 and illustrates how multi-year observation dataset were used to characterize the LC state and LS seasonality.

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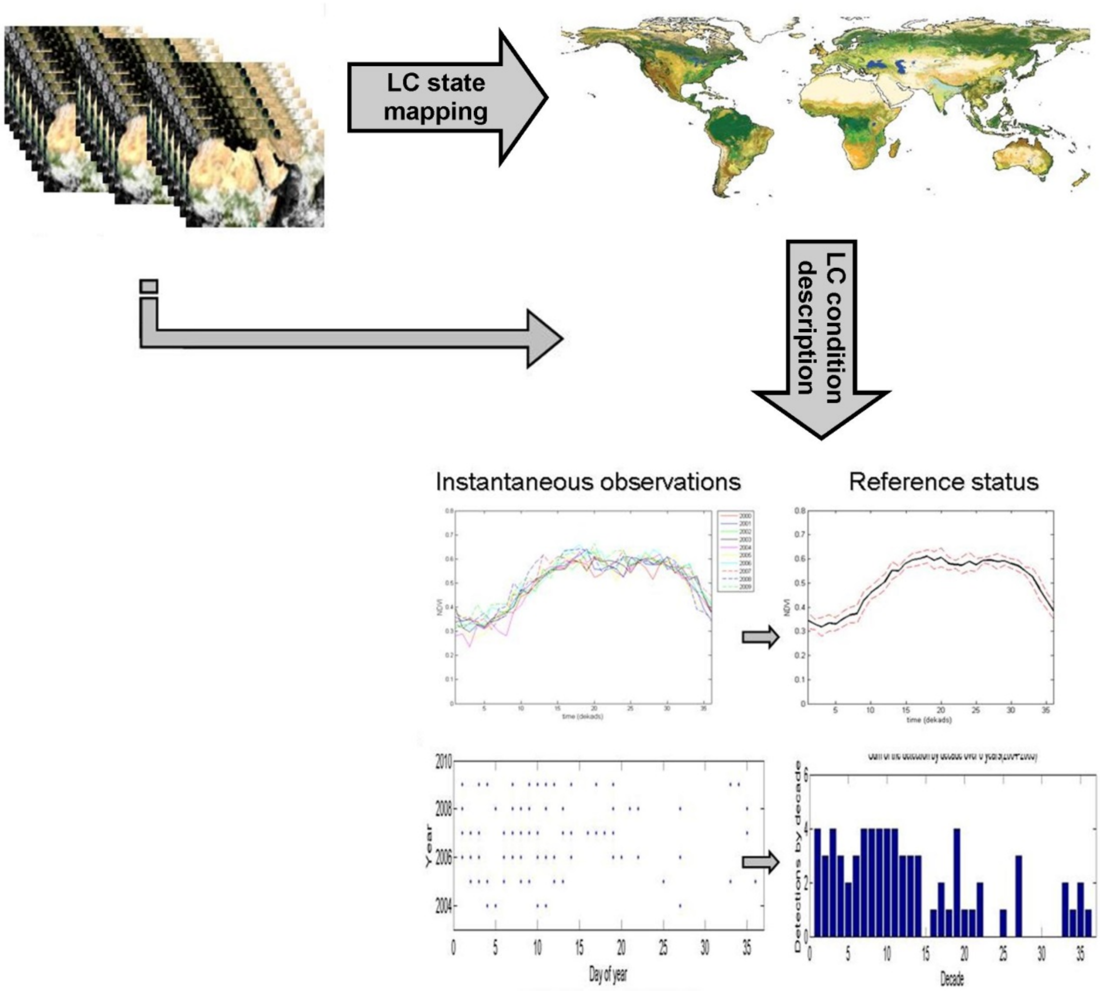

Figure 3-3: Use of multi-year dataset to characterize the LC state and LS seasonality and therefore, generating the global land cover products

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4 PRODUCTS PLANNED IN THE CCI-LC PHASE 2

The outputs of the CCI-LC Phase 2 project concern global SR time series, global LC maps, global LS seasonality products and a global water bodies' product, all of them being delivered along with metadata. The outputs also include software systems, products documentation and validation reports. The PSD focuses on the datasets.

At the end of the 3-year long Phase 2, the key global datasets for the end-users will be:

1) Global SR time series and associated metadata over different epochs and from different sensors:
    a. Time series of AVHRR 7-day composites[1] from 1992 through 1999;
    b. Time series of SPOT-VGT 7-day composites from 1998 through 2014;
    c. Time series of Envisat MERIS Full Resolution 7-day composites from 2003 through 2012;
    d. Time series of Envisat MERIS Reduced Resolution 7-day composites from 2003 through 2012;
    e. Time series of PROBA-V 7-day composites from 2013 through 2015 (and beyond);
    f. Time series of Sentinel-3 OLCI and SLSTR 7-day composites from 2015 (and beyond).
2) Global LC maps for the 1990s, 2000, 2005, 2010 and 2015 epochs based on the above AVHRR, SPOT-VGT, MERIS FR and RR, PROBA-V, MODIS composites and associated metadata;
3) An updated global LC map for 2015 including the above Sentinel-3 OLCI and SLSTR composites and associated metadata[2];
4) A global LS seasonality product and associated metadata for the NDVI;
5) Global map of permanent open water bodies for the 2010 epoch based on Envisat ASAR time series.

[1] A7-day compositing period is foreseen to be consistent with the other sensors, but this has to be confirmed according to the data coverage

[2] According to the availability of Sentinel-3 data in terms of quantity and timing with respect to the overall project planning

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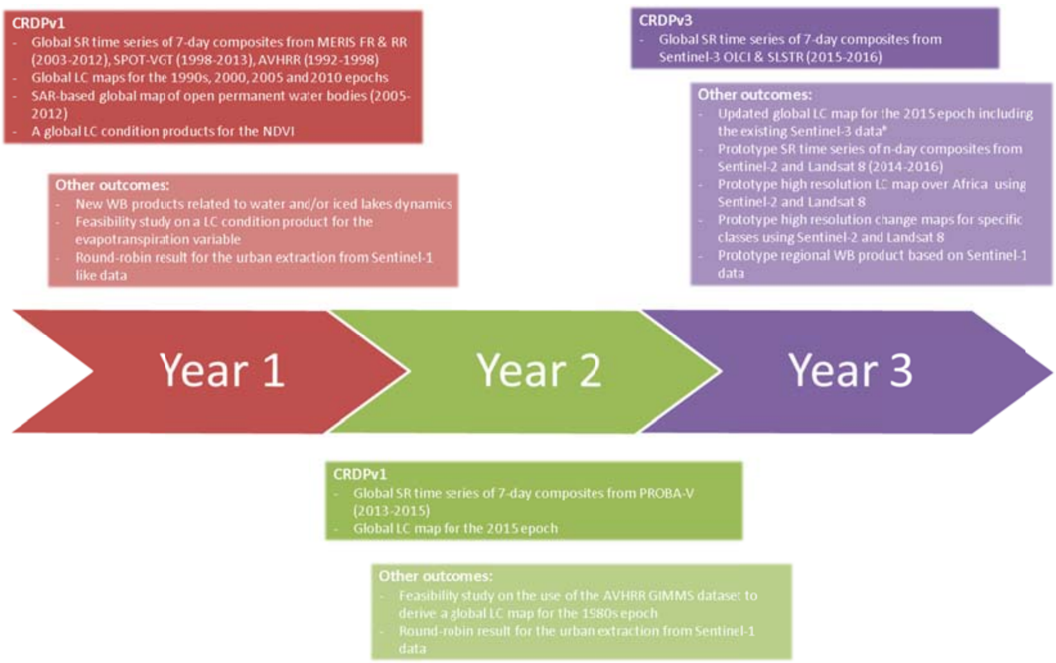
In addition, prototypes products are foreseen, which will demonstrate the pre-processing and classification algorithms developed for the Sentinel-1 and -2 missions and to expand historical time series. They include:

1) Sentinel-2 and Landsat 8 time series of regional SR composites from 2014 (and beyond) and associated metadata;
2) Regional LC maps based on the above Sentinel-2 and Landsat 8 composites and associated metadata;
3) Change maps dedicated to critical LC classes and/or regions according to users' priorities based on the above Sentinel-2 and Landsat 8 composites and associated metadata;
4) Prototype water body and urban products based on Sentinel-1 SAR data, tuned geographically to the regional LC maps obtained with Sentinel-2 data;
5) A consistent coarse spatial resolution LC map for continental or sub-continental regions for the 1980s based on the AVHRR Global Inventory Monitoring and Modelling System (GIMMS) dataset;
6) An EvapoTranspiration (ET) Feasibility study will be performed during the first year of this second phase. Encouraging results may lead to the production of an ET seasonality product.

Those products will be generated throughout the project, following the planning illustrated in Figure 4-1.



* The reason why this update is not included in the CRDPv3 is that it will be delivered at the end of the year 3, thus not available for climate assessment

Figure 4-1: Planning of datasets to be produced in the CCI-LC Phase 2

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5 PRODUCTS DEFINITION

This PSDv1 document is dedicated to the products that will be generated during the 1st year of the Phase 2. The other products will be described in the next version that will be written at the beginning of the year 2.

5.1 Global LC maps

Four different global LC maps (standing for the LC state products) are delivered, centred to the epochs 1990, 2000, 2005 and 2010.

The maps are derived from a baseline LC map which is generated thanks to the entire MERIS FR and RR archive from 2003 to 2012. This 10-year baseline LC map is then updated using SPOT-VGT time series from 1998 to 2012 for the 2000, 2005 and 2010 epochs and (iii) AVHRR time series from 1992 to 1998 for the 1990s epoch.

The 2000, 2005 and 2010 epochs were already produced in Phase 1. With regard to the new epoch, it makes use of a new sensor and so, the consistency will need to be ensured.

In Phase 1, the updating of the baseline map to generate the 2000, 2005 and 2010 epochs was only done for the forest class. In other terms, only the forest dynamics were reflected in the set of 3 successive maps. During the first year of this Phase 2, it is planned to extend the classes for which the dynamics will be mapped. The IPCC land categories (forests, agriculture, grassland, settlement, wetland, other land) will be considered when updating the baseline map to the different epochs.

In addition, while 5-year epoch maps are still planned, the characterization of the LC could be considered on an annual basis.

Table 5-1 lists the satellite dataset that are planned to be used in order to generate the four LC maps.

Table 5-1: Satellite data sources that are planned to be used to generate the 300 m global LC maps

Global LC database	Reference period	Satellite data source
Baseline 10-year global LC map	2003-2012	MERIS FR/RR global SR composites between 2003 and 2012
Global LC database for the 1990 epoch	1992-1998	Baseline 10-year global LC map AVHRR global SR composites between 1992 and 1998 for back-dating the baseline
Global LC database for the 2000 epoch	1998-2002	Baseline 10-year global LC map SPOT-VGT global SR composites between 1998 and 2002 for back-dating the baseline

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GLOBAL LC DATABASE	REFERENCE PERIOD	SATELLITE DATA SOURCE
Global LC map for the 2005 epoch	2003-2007	Baseline 10-year global LC map SPOT-VGT global SR composites between 2003 and 2007 to identify and date the changes MERIS FR global SR composites between 2003 and 2007 to map the identified changes at 300m spatial resolution and to back- and up-date the baseline
Global LC map for the 2010 epoch	2008-2012	Baseline 10-year global LC map SPOT-VGT global SR composites between 2008 and 2012 to identify and date the changes MERIS FR global SR composites between 2008 and 2012 to map the identified changes at 300m spatial resolution and to update the baseline

It should be mentioned that the MODIS time series are planned to be used for gap filling - if needed - in the 2000, 2005 and 2010 epochs.

The classification process aims at transforming multispectral SR composites generated by the pre-processing steps into meaningful global LC products for the climate modellers' point of view. The product usefulness is dependent on its thematic content as well as on its accuracy.

The LC maps are associated with a legend based on the UN-LCCS [RD.7], with the view to be as much as possible compatible with the GLC2000, GlobCover 2005 and 2009 products. In addition, the UN-LCCS has been found quite compatible with the PFTs by the climate modellers involved in the user requirements analysis [RD.1, RD.15]. The UN-LCCS defines LC classes using a set of classifiers. The system was designed as a hierarchical classification, which allows adjusting the thematic detail of the legend to the amount of information available to describe each land cover class, whilst following a standardised classification approach.

The legend is constrained by three main issues: (i) information for all desired classes must be available from input observation datasets to derive a product of sufficient accuracy, (ii) the LC should be described using a standardized approach to ensure horizontal and vertical harmonization (i.e. across local to global scales and through multi-temporal analysis) and (iii) its thematic content should meet the climate models requirements.

The CCI maps are designed to be globally consistent. Therefore, its legend is determined by the level of information that is available and that makes sense at the scale of the entire world. The "level 1" legend – also called "global" legend" – meets this requirement. It is presented in Table 5-2. This legend counts 22 classes and each class is associated with a ten values code (i.e. class codes of 10, 20, 30, etc.).

The CCI maps are also described by a more detailed legend, called "level 2" or "regional". This level 2 legend makes use of more accurate and regional information – where available – to define more LCCS classifiers and so to reach a higher level of detail in the legend. This regional legend has therefore more classes which are listed in Appendix I. The regional classes are associated with non-

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ten values (i.e. class codes such as 11, 12, etc.). They are not present all over the world since they were not properly discriminated at the global scale and the level of detail in the reference land cover database was not available everywhere. As a result, only regional products are delivered with this extended legend.

The explicit LCCS definition of each CCI-LC global and regional class is provided in Appendix II.

Table 5-2: Global (or level 1) legend of the global CCI-LC maps, based on LCCS

VALUE	LABEL	COLOR
0	No Data	
10	Cropland, rainfed	
20	Cropland, irrigated or post-flooding	
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	
120	Shrubland	
130	Grassland	
140	Lichens and mosses	
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	
160	Tree cover, flooded, fresh or brakish water	
170	Tree cover, flooded, saline water	
180	Shrub or herbaceous cover, flooded, fresh/saline/brakish water	
190	Urban areas	
200	Bare areas	
210	Water bodies	
220	Permanent snow and ice	

The CCI-LC legend was already translated into PFTs during Phase 1: a cross-walking table was built for each model and implemented into the User Tool (see section 5.6).

During this Phase 2, it is planned to go one step forward with regard to these conversion tables. They will be defined separately for different climatic regions. For instance, the PFT "bare soil" will not be obtained by the same proportions of LCCS LC classes in boreal or in desert regions. The regions to consider are to be defined by the climate modeler users of the consortium and the translations will be done jointly with the EO data producers. In order to strengthen the quantitative approach of these conversion tables, the use of the CCI-LC validation databases built in Phase 1 will be investigated.

A stratification of the global map into biomes (tropical, temperate and boreal) using external dataset will be applied to reach a higher level of detail in PFTs characterization. This has to be linked with the

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specifications of new cross-walking tables between LCCS and PFT classes according to the climatic region.

A possible refinement of the global LC maps could be the characterization of key LCCS LC classes with additional attributes. Typically, the possibility to discriminate between C3 and C4 plants both for the croplands and the grasslands will be investigated. Attributes such as vegetation height and maximum LAI were requested by the users [AD.3] and will be considered.

Finally, it should be noted that the distinction between rainfed and irrigated croplands – which is not currently used for the PFTs translation – is planned to be considered as well.

The LC products accuracy has to be evaluated both through overall accuracy and temporal stability values. The accuracy targets are presented in Table 5-3, which compares them to the GCOS and users (CMUG and CCI-LC users) requirements. It shall be noted that the accuracy assessment only focuses on the LC state products, the LS seasonality ones being not validated by independent reference dataset.

Table 5-3: Overall accuracy and temporal stability targets of the CCI-LC project

	OVERALL ACCURACY				STABILITY			
	GCOS	*CMUG*	*CCI-LC USERS*	*CCI*	*GCOS*	*CMUG*	*CCI-LC USERS*	*CCI*
LC products	>85%	90-95%	90-95%	80%	>85%	90-95%	>85%	80-85%

5.2 Global LS seasonality products

The CCI-LC project also provides information about LS seasonality through the observation of selected variables on an annual basis along the 1998-2015 period. The targeted variable is the NDVI, representative of the vegetation greenness. This variable, often referred to as climatological data as it summarized long time series, is expected to provide the seasonality of the dynamic processes which affect the land cover and which are of interest for the CMC, as shown in Table 5-4. The way this information is provided in the LS seasonality products is presented in Table 5-5.

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Table 5-4: List of variables and dynamic processes addressed in the CCI-LC project.

VARIABLES OBSERVED	DYNAMIC PROCESSES CHARACTERIZED BY THE VARIABLE
Amount of vegetation, described by the NDVI	Phenology, seasonality, productivity (both for natural vegetation and for croplands), number of cropping cycles, carbon fluxes

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Table 5-5: Information provided to describe the variables in the LS seasonality products.

INFORMATION PROVIDED IN THE PRODUCT	VARIABLES
• Annual time profile averaged over multiple years, detailed on a 7-day frequency • Standard deviation over this multi-year period, for each 7-day interval • Number of valid and cloud-free years contributing to each 7-day period • The pixel status	NDVI
Consistency information between this variable and the LC maps generated by the CCI-LC project	NDVI and LC maps

5.3 Global map of open permanent water bodies

A global SAR-based Water Bodies (WB) product is delivered, which gives the repartition of open and permanent water bodies (inland water and oceans) at 300m spatial resolution at global scale.

The product is generated using the Envisat ASAR Wide Swath Mode (WSM) dataset (150m) for the time period 2005-2010 as the main source of imagery. As the quantity of WSM is insufficient in some places, imagery in the Image Mode (IMM) (75m) and Global Mode (GMM) (500m) are used in complement.

The SAR-based product is complemented by existing WB products and in particular the water class of the Global Forest Change product [RD.22] and by the SRTM Water Bodies Dataset [RD.23] (SWBD).

Table 5-6 lists the dataset that are planned to be used in order to generate the WB product.

Table 5-6: Data sources that are planned to be used to generate the WB product

DATASET	REFERENCE PERIOD	DATA TYPE
Envisat ASAR Wide Swath Mode	2005-2012	Satellite data
Envisat ASAR Image Mode	2005-2012	Satellite data
Envisat ASAR Global Mode	2005-2012	Satellite data
SRTM Water Body Dataset	2000	Map
Global Forest Change	2000-2012	Map

The legend associated with the WB product is binary: water and non-water. Possible refinements could come from (i) the identification of seasonality in detected water bodie, (ii) the identification of the period during which the inland WB are iced and (iii) the addition of the wetlands.

5.4 Global SR composite time series

The SR products delivered by the CCI-LC project consist in:

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1) Time series of AVHRR 7-day[3] composites from 1992 through 1998[4];
2) Time series of SPOT-VGT 7-day composites from 1998 through 2013;
3) Time series of Envisat MERIS FR 7-day composites from 2003 through 2012;
4) Time series of Envisat MERIS RR 7-day composites from 2003 through 2012;

The time series are made of temporal synthesis obtained over a specific compositing period. The compositing period most suitable for the classification chain – and so the temporal resolution of the SR products delivered by the project – has been decided in Phase 1 to be 7 days. The exact schema for the 7-day periods is to start at January 1 and go on 7-day by 7-day periods until the end of the year. In this way, it should be noted that the last period of December comprises 8 days. As for leap years, the 7-day period including February 29 comprises 8 days.

Table 5-7 details the satellite dataset that are planned to be used in order to generate the global SR composite time series.

Table 5-7: Satellite data that are planned to be used to generate the CCI-LC SR time series

Global SR composite time series	Reference period	Satellite data source	Technical specifications of the satellite data source
AVHRR global SR composite time series	1992-1998	AVHRR 2	• 1km spatial resolution • 5 spectral bands in visible and infrared • Global coverage
SPOT-VGT global SR composite time series	1998-2012	SPOT-VGT P	• 1km spatial resolution • 4 spectral bands in visible and infrared • Global coverage
MERIS global SR composite time series	2003-2012	Envisat MERIS FR & RR	• 300-m or 1000- m resolution full swath • 15 spectral bands in visible and near infrared (NIR) • Global coverage

5.5 Projection, format and metadata

The projection, format and metadata have the same specifications than in the Phase 1 [RD.2].

---

[3] The 7-day period is currently planned but the data itself or the data coverage can require an adaption of the length of the composite period

[4] Depending on the license conditions linked to the input dataset actually used by the project

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5.5.1 Projection and tiling system

The Coordinate Reference System (CRS) used in the CCI-LC project is a Geographic Coordinate System (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid and using a Plate Carrée projection.

The projection makes use of an equatorial radius (also called semi-major axis) of 6378.14 km and of a polar radius (also called semi-minor axis) of 6356.76 km. The inverse flattening parameter is of 298.26 m. The coordinates are specified in decimal degrees. A complete description of the CRS is given in Figure 5-1as an ISO 19111 WKT representation.

```
GEOGCS["GCS_WGS_1984",
    DATUM["D_WGS_1984",
        SPHEROID["WGS_1984",6378137.0,298.257223563]],
    PRIMEM["Greenwich",0.0],
    UNIT["Degree",0.0174532925199433],
AUTHORITY["EPSG",4326]]
```

Figure 5-1: Description of the coordinate reference system defining the global LC products

In order to simplify the handling and analysis of 300m spatial resolution global datasets, the SR time series are being delivered in tiles. Global products are subdivided into 72 x 36 tiles following the tiling system already used in the GlobCover project [RD.16] (Figure 5-2).

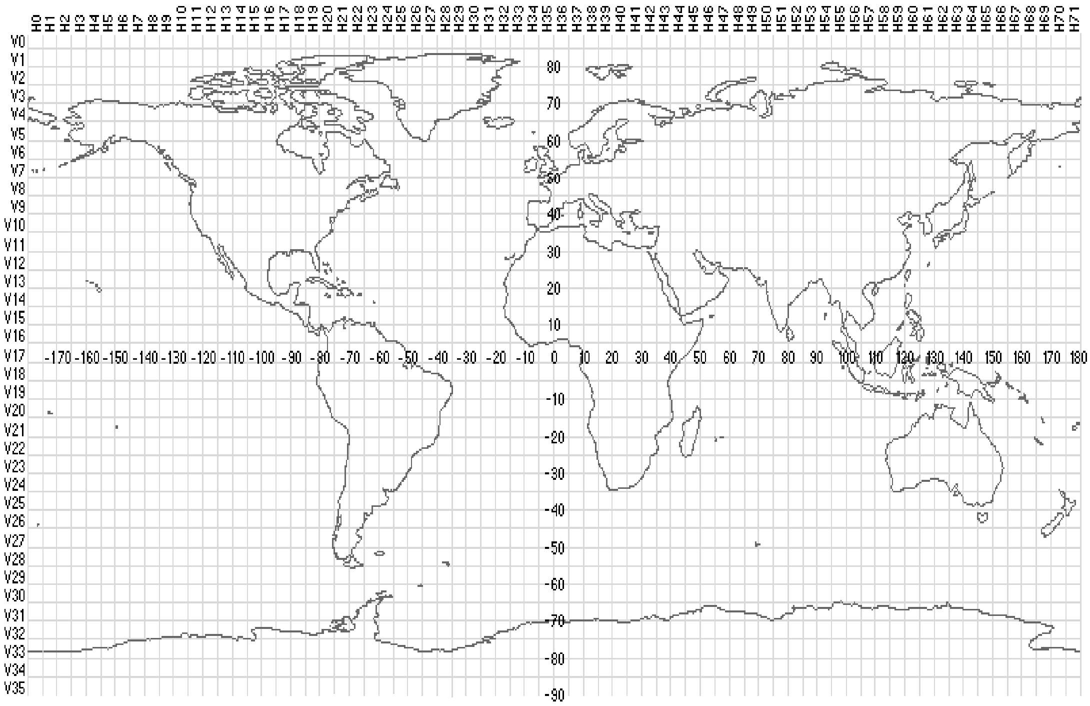

Figure 5-2: Description of the tiling system used for the SR products [RD-18]

Tiles are 5 degrees by 5 degrees. The tile coordinate system starts at (0, 0) (85N180W) (horizontal tile number, vertical tile number) in the upper left corner and proceeds right (horizontal) and downward

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(vertical). The tile in the bottom right corner is (71, 35) (90S175E). A tile is physically represented by a single NetCDF file whose file name also indicates the tile south-west corner (see section 7.4 for a complete description of the naming convention). In addition, tiles having no land contribution are not delivered.

The LC maps are delivered both as global files and regional subsets (in order to make easier their reading and analysis). Nine regional subsets are foreseen. They are presented in Figure 5-3 and their precise delineation is provided in Table 5-8. These regional subsets will be used only for the public release of the maps. As for the LS seasonality products, they are delivered in series of global files (one file per each 7-day period).

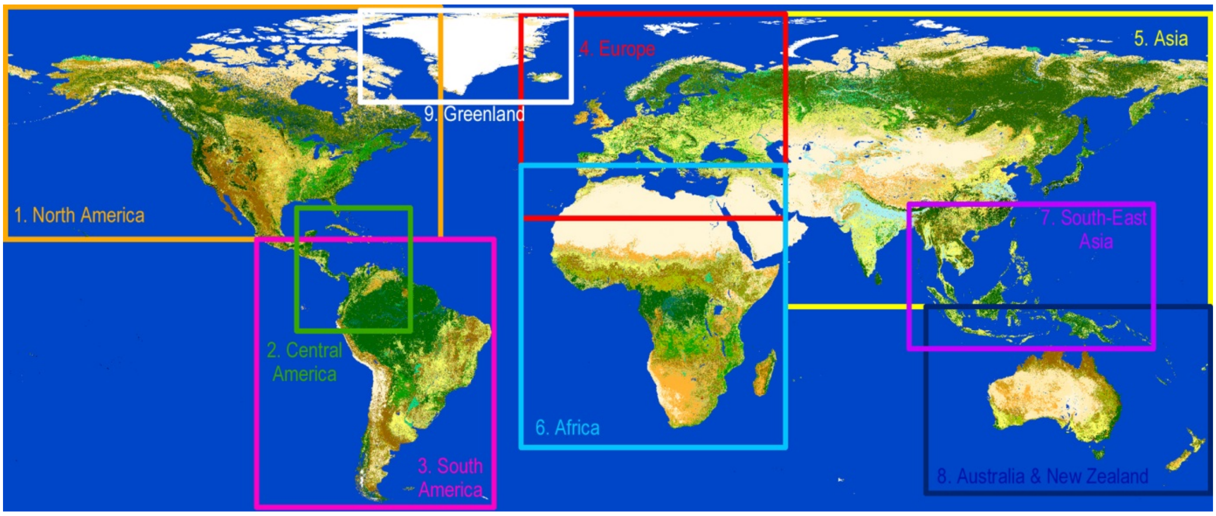

Figure 5-3: Regional windows of the world, underlying the LC products distribution

Table 5-8: Coordinates of the regional windows of the world, underlying the LC products

REGIONAL SUBSET ID	REGIONAL SUBSET NAME	UPPER LEFT COORDINATES	LOWER RIGHT COORDINATES
1	North America	180°W, 85°N	50°W, 19°N
2	Central America	93°W, 28°N	59°W, 7°N
3	South America	105°W, 19°N	34°W, 57°S
4	Western Europe & Mediterranean Basis	26°W, 83°N	53°E, 25°N
5	Asia	53°E, 83°N	180°E, 0°N
6	Africa	26°W, 40°N	53°E, 40°S
7	South East Asia	90°E, 29°N	163°E, 12°S
8	Australia & New Zealand	95°E, 0°N	180°E, 53°S
9	Greenland	74°W, 84°N	11°W, 59°N

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5.5.2 Format and metadata

All products are delivered in the NetCDF-4 format, using the "classic model" of NetCDF with compression since most tools can handle them. This is also the desired target format for CCI [AD.4]. The file specification follows CF conventions [RD.18].

The LC products (LC and WB maps, LS seasonality) are also delivered in the GeoTiff format for specific users of the LC community.

All products are delivered with associated metadata included in the NetCDF header, which follow the CCI metadata convention [RD.17]. For the LC GeoTiff files, the geographic location information and the metadata are also included in the GeoTiff raster.

A Product Description Manual (.pdf format) should also be provided, describing the input dataset (sensors, data coverage and data quality), the developed methodologies and the products legend.

5.6 CCI-LC user tool

The CCI-LC project does not provide multiple products aggregated at various spatial resolutions, in various projections and in various legends. The **LC map and LS seasonality product** are delivered in a full spatial resolution version in a Plate Carrée projection using a LCCS-based legend. Yet, it is recognized that climate models may need products associated with a specific coarser spatial resolution, over specific areas (e.g. for regional climate models), in particular projections and expressed in a particular PFT legend.

In order to face the variety of requirements, the CCI-LC project has decided to develop a CCI-LC user tool that allows users to adjust the following 4 parameters of the LC products in a way which is suitable to their model: the spatial resolution, the projection, the spatial extent and the PFT legend.

This tool for subsetting, re-projection and re-sampling is a software tool used at user's premises after the relevant tiles of the LC products are downloaded. The provision of subsetting, re-projection and re-sampling as a service without the need to first download the LC full resolution tiles will be included in the system requirements document for the system specification of this CCI-LC Phase 2.

In the Phase 2, it is also planned to provide an interactive tool (e.g. an extension of the BEAM toolbox by readers and writers and specific resampling and re-projection binning operators for the LC products). The tool will support the global LC product (maps and LS seasonality).

For the spatial resolution and the projection, the climate users have established a minimum list of possibilities, which are presented in the Table 5-9, and which correspond to the functionalities currently offered by the tool. The used resampling algorithm to apply must be different based on the bands and is briefly described in the Phase 1 Product User Guide (PUG) [RD.5].

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Table 5-9: Minimum set of projections and spatial resolutions that need to be included in the subsetting, re-projection and re-sampling CCI-LC user tool.

REGIONAL SUBSET ID	REGIONAL SUBSET NAME
Spatial resolution	Original resolution
	0.25 degree
	0.5 degree
	1 degree
	1.875 degree
	1.875 x 1.25 degree
	3.75 x 2.5 degree
Projection	Original projection (Plate-Carrée)
	Gaussian grid
	Rotated lat/lon grid

For the PFT legend, cross-walking tables were built in Phase 1 to make the link between the maps LCCS-based legend and the PFT legend specific to each model. This translation was applied when resampling and/or reprojecting the products. During the Phase 2, it is foreseen to refine this translation between the LCCS and PFT classes, as different cross-walking table will be defined for different climatic regions. The user will have the possibility to select the most suitable cross-walking table according to its area of interest.

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6 QUALITY DOCUMENTATION

Tracking products uncertainties and documenting their quality are specific requirements for all the CCI projects [AD.1], and this exercise is a critical step for the acceptance of the products.

The uncertainties of the CCI-LC products are characterized on the one hand through quality control procedures and on the other hand thanks to the validation exercise (which only concerns the LC products) [RD.3]. An uncertainty budget is performed, which consist in a list of random and systematic errors, associated with estimates of the uncertainty they contribute to the measurements. The results of these quality assessments are reported in synthetic documents made available to the users along with the metadata.

6.1 Global LC products (maps and LS seasonality product)

The LC products quality depends on the input data quality and on the classification processes. The quality information available for the SR products are used and complemented by quality indicators specific to (i) the LC classification process, (ii) the LS seasonality generation process and (iii) the consistency between the LC map and the LS seasonality product. This set of quality indicators is provided as additional layers in the LC maps and LS seasonality products. In addition, an independent validation exercise of the LC maps is performed by the Joint Research Centre (JRC) of the European Commission (EC) according to the same procedure than the one of Phase 1 [RD.3]. It also provides confidence and accuracy information about the LC map. These different sources of quality assessment are described in the following sections.

6.1.1 Global LC map

For the LC maps, the quality is documented using a set of five flags and values, determined on a per-pixel basis.

1) The pixel has been processed or not
    a. If the pixel has been processed:
        i. The name of the sensor from which the reflectance value has been derived;
        ii. An overall quality indicator describing the reflectance value (derived from the pre-processing and the SR product).
    b. If the pixel has not been processed, the reason is detailed (no data, cloud effect, other effect)
2) The status map of the pixel: this information is produced during the pre-processing, through the pixel identification step [RD.4]. Six statuses are foreseen: “Cloud”, “Clear land”, “Clear water”, “Clear snow”, “Invalid” and “Filled”;
3) The number of clear observations available for the classification;

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4) Overall LC assessment: summary indicator, providing an overall confidence level.

The LC map is subject to an independent validation process, made of 4 major components: a confidence-building procedure, a statistical products validation, a comparison with other existing LC products and an assessment of the products temporal consistency. The general relationships between these different components are shown in Figure 6-1. A detailed description of the overall validation process is provided in the Phase 1 Product Validation Plan (PVP) [RD.4].

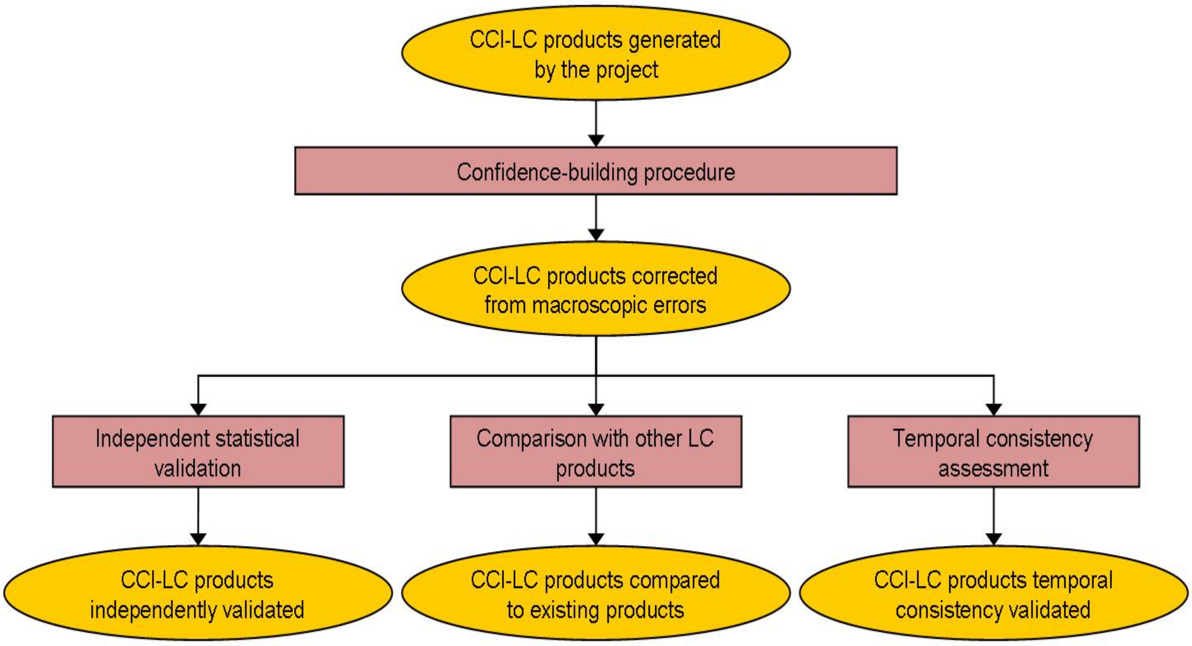

Figure 6-1: Organization and links between the different validation components

As illustrated in Figure 6-1, the confidence-building is a particular procedure since it is not really part of the validation process. It should rather be considered as a component of the classification process. Indeed, the results of the analysis are employed for removing errors and improving the map. The objective of this procedure is twofold: the elimination of macroscopic errors and an increase in the overall acceptance of the LC product by users. It is based on a systematic visual control of the map and on a documentation of its quality in terms error, landscape pattern, reference material used, etc. As a result, it should be possible to investigate the influence of the parameters (heterogeneity, dominant class) on the quality of the LC map. More precisely, the following interactions should be documented:

- Map quality vs. LC classes: is the quality of the map uniform among the different LC classes?
- Map quality vs. landscape diversity and fragmentation: is the quality of the map the same in simple and in complex landscapes?
- Map quality vs. agreement with other global LC maps: are the errors mainly located in the areas of poor agreement with other maps?
- LC classes vs. type of error: do LC classes suffer always from the same type of error?

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This information is provided in a separate report delivered with the LC products.

As for the other three components of the overall validation process (statistical assessment, comparison with other products and temporal consistency assessment), their results are published in a validation report available along with the product. These results include the classical metrics of the confusion matrix (overall accuracy with confidence interval, user's and producer's accuracy, Kappa statistics), the semantic distance with regard to the climate modelling perspective (*UR2*), a quantitative comparison with other maps and consistency flags.

6.1.2 Global LS seasonality product

For the NDVI seasonality product, its accuracy is not documented – as it is not the objective of the CCI-LC project – but rather, its internal consistency and consistency with the LC maps. One flag is used to document how the reference LS seasonality product has been determined (see section 5.2 and Table 5-5): the number of years of observation which has been used to calculate the reference status. This information is necessary since this reference status is derived from a multi-year dataset (average annual time profile as explained in Table 5-5). The number of observations used to calculate this reference value is provided for each 7-day interval.

6.1.3 Products consistency

In the outcomes of the user survey in Phase 1 [RD.1], the climate modelers expressed the need to have LC products that are consistent with surface parameters datasets and vice-versa. Discrepancies between products remain a source of inaccuracy and lead to interoperability problems in the climate models.

To meet this requirement, for the NDVI product and the LC map, the discrepancy will be documented through a pixel-based indicator that integrates:

1) The fundamental and unambiguous aspects of conformity between products: spatial extent, coastlines, water and glaciers definition;
2) Thematic discrepancies between the NDVI seasonality product and the LC map classes. It is foreseen to evaluate the discrepancy a set of predefined rules and thresholds.

The discrepancy indicator could be built in the form of categories of discrepancies' severity, according to the type of the discrepancy detected. The proper format shall be discussed with the climate modeler groups.

The discrepancy indicator will be delivered along with the global LC maps and LS seasonality product. The results of consistency will be published in the Product Validation and Intercomparison Report (PVIR).

6.2 Global map of open water bodies

The quality of the WB product has been quantified so far by means of a single parameter expressing the total number of SAR backscatter observations used in the classification. This data product is

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delivered together with the map of water bodies. A detection based on less than 10 observations was found to be affected by large degree of error [RD.21]. In the global WB product, such cases have been masked out. No further action was taken if the number of observations was slightly above this threshold. However, it was discovered that this number is not able to characterize the error and the uncertainties of the classification unambiguously. For example, in desert areas, commission errors are often observed although the number of observations was large (approximately 80 observations). The reason for the error was due to the dense sampling in terms of incidence angle (basically all incidence angles of the WSW between 20 and 45 degrees were represented) but not in time. For this, reason the parameter temporal variability used in the classification corresponded more to a "geometrical variability", which over sand at C-band is quite large. Given also that at shallow incidence angles, the C-band SAR backscatter is very low, the two SAR metrics used for the classification resembled the behavior of open water bodies which implied commission errors.

To better characterize the quality of the classification, an approach is being developed in the 1st year of the CCI-LC Phase 2, which propagates errors and uncertainties at the level of input data and classification method to the output. A number of classifications with perturbed data is performed to obtain a result consisting of a map of probabilities of detecting water. Values vary between 0 and 100, representing the probability of detecting water (0 = certainly land, 100 = certainly water). It is remarked that there is no such error measure for areas where the classification was overruled (e.g., slope of terrain > 10 degrees). More details will be provided in the Comprehensive Error Characterisation Report (CECR) of the Phase 2.

6.3 Global SR composite time series

State-of-the-art radiometric calibration is applied to deliver the best possible SR products but the absolute radiometric accuracy is not assessed by any independent sources of reflectance data [RD.3]. Indeed, the precision and the relative radiometric accuracy in space and over time are considered to be much more critical than the absolute accuracy performance since any classification algorithm dealing with reflectance time series relies on temporal consistency and proceeds by relative statistical comparison or similarity analysis in space. In other terms, the most important is the possibility to work with SR products described by specific quality indicators. This phase of quality control takes place in the development phase for the SR products.

The pre-processing chain generates global SR time series by a series of pre-processing steps, including the radiometric corrections, geometric correction, pixel identification, atmospheric correction with aerosol retrieval, Bidirectional reflectance distribution function (BRDF) corrections as well as compositing and mosaicking. Three intermediate products, which are considered as critical for the error budget, are quality controlled: the classes resulting from the pixel identification, the Surface Directional Reflectance (SDR) products and the global SR composite time series.

6.3.1 Attributes from the pixel identification

The term “Pixel identification” refers to a classification process of a measurement made by a space borne radiometer with the aim of identifying the properties of the measurement which are influencing

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further algorithmic processing steps. This classification is performed on a per-pixel basis. Based on the measurements properties, it assigns to each pixel one status (hereafter called "attribute") in the form of a binary flag. A pixel can be classified as "cloud", "clear land", "clear water" or "clear snow". The attributes are decided following a given logic which was detailed in the Phase 1 ATBD (pre-processing section) [RD.4].

The errors in the attributes allocation are automatically calculated by the probabilistic arithmetic.

6.3.2 Surface directional reflectance products

The error associated with the production of the SDR products (i.e. reflectance products before the BRDF correction and the compositing step) is estimated on a per-pixel basis. To this end, three different error sources are considered and estimated:

- The instrumental noise, whom contribution to the global error is estimated from the instrument specific radiometric accuracy;
- The atmosphere, whom contribution to the global error comes from errors in the knowledge of the atmospheric parameters;
- The fact that directional reflectance effects are neglected in the atmospheric correction (due to the assumption of a Lambertian surface), whom contribution to the global error which can be estimated by different investigations (such as implemented in the GlobeAlbedo Project [RD.20]).

The uncertainties of the SDR values are calculated from the contributions of each error source, assuming a negligible correlation between the different error sources.

6.3.3 Global SR composite time series

The quality of each global multispectral SR composite is described, on a per-pixel basis, by a set of flags and values:

1) The current status of surface associated with the surface reflectance in the aggregation period;
2) The uncertainties, for each spectral band;
3) The number of observations with clear sky land coverage, for each pixel;
4) The number of observations with water coverage, for each pixel;
5) The number of observations of clear sky snow and ice coverage, for each pixel;
6) The number of observations of cloudy coverage, for each pixel;
7) The number of observations of cloud shadow coverage, for each pixel;

Besides assessing the quality of individual composites, the quality of the global SR time series are also documented, with the aim of quantifying its discrimination potential. The following indicators are used:

1) The intra- and inter-annual reflectance dynamics (range and standard deviation) computed

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from the overall spectral reflectance distribution, for each spectral band and stratum (if a stratification is used in the classification process);

2) The temporal variance at the pixel level for the various spectral reflectance values;

3) The local variance for the various spectral reflectance values within a LC class and across LC classes.

The obtained values are compared with reflectance products available from other sensors (MERIS versus SPOT-VGT for instance) and other projects (e.g. the GlobCover project). In addition, the geometric accuracy is quality controlled and reported.

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7 TECHNICAL SPECIFICATIONS

The CEOS processing nomenclature defines different levels of products. Each level represents a step in the abstraction process by which data relevant to physical information (raw, level 0, level 1) are turned into data relevant to geo-physical information (level 2, level 3), and finally turned into data relevant to thematic information (level 4) [RD.19]. The CCI-LC project delivers level 3 and level 4 products, whose technical specifications are provided in the following sections.

7.1 Global LC maps

- **Naming convention**

The file name convention of the global LC maps delivered by the CCI-LC project is the following:

File name = <id>-v<version>.nc/tif

where <id> = <project>-<level>-<var>-<code>-<spatres>-<tempres>-<epoch>-<area>

The dash "-" is the separator between name components. The filename convention obeys NetCDF CF by using the postfix ".nc" and can be written as a GeoTiff file using the extension “.tif”

The different name components are defined in Table 7-1.

Table 7-1: Components that make the name of the LC maps delivered by the CCI-LC project

FIELD	SIGNIFICATION	VALUE
project	Project acronym	ESACCI-LC (constant)
level	Processing level	L4 (constant)
var	Unit of the LC product	LCCS (constant)
code	Product code identifier for CCI-LC products	Map (constant)
sres	Spatial resolution	300m (constant but could be updated if other sensors are used to generate SR products)
tres	Temporal resolution	P5Y (constant but could updated if shorter or longer intervals are processed)
epoch	Centre year of the epoch of the product	1990, 2000, 2005 or 2010

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area	Text (max 8 digits) describing the regional subset	"NorthAm" for North America "CenAm" for Central America "SouthAm" for South America "WestEur" for Western Europe "EastEur" for Easter Europe "NorthAfr" for North Africa & Middle-East "Afr" for Africa "CenAsia" for Central Asia "SEAsia" for South East Asia "AusNZ" for Australia & New Zealand "GrnIce" for Greenland & Iceland In case of global products, this field does not exist.
version	Incremental that follows the successive revisions of the CCI-LC Processing lines	Version of product revision, preferably major.minor, optionally with processing centre [a-zA-Z0-9._]*

An example file name of the LC map from 2010 would be: "ESACCI-LC-L4-LCCS-Map-300m-P5Y-2010-v1.0.nc/tif ».

- **Processing Level**

Level 4 (i.e. "variables that are not directly measured by the instruments, but are derived from these measurements" [RD.19])

- **Units**

Classes defined using UN-LCCS classifiers (see Table 5-2 in section 5.1)

- **Spatial Extent**

All the terrestrial zones of the earth between the parallels 90°N and 90°S

- **Spatial resolution**

300 meters

- **Temporal resolution**

5-year (mid-decadal) or 10-year (decadal) LC map, with an annual characterization of LC dynamics

- **Product layers**

The global LC maps contain LC information and quality flags, as illustrated in Table 7-2.

Table 7-2: Layers of the global LC maps delivered by the CCI-LC project

LAYER NAME	UNIT	DATA TYPE	FILL VALUE	VALID RANGE
LC classification in LCCS	Class #	8-bit unsigned	255	0-254
LC map quality flag 1: pixel processed or not	Concatenated flags	8-bit unsigned	255	0-254
LC map quality flag 2: pixel status	Status #	8-bit unsigned	255	0-254

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LC map quality flag 3: number of valid observations	Observation number	16-bit integer	65535	0-65534
LC map quality flag 4: overall LC assessment	Confidence level	8-bit unsigned	255	0-254

The LC quality flags 1 to 4 are described in section 6.1.1.

- **Projection**

The projection is a Plate Carrée with a geographic Lat/Long representation based on the WGS84 ellipsoid. A complete description is provided in section 5.5.1.

- **Format**

The LC maps are delivered in NetCDF-4 and GeoTiff formats (see section 5.5.2).

- **Metadata**

In the case of the NetCDF format, the metadata is provided as global attributes in the NetCDF file. It follows the CCI guidelines [RD.15]. With the GeoTiff raster, the files contain the geographic location information and the metadata.

- **Estimated size**

The size of a global LC map is estimated at ~350 MB. This estimation makes the assumption of an internal LZW compression and still needs to be confirmed.

7.2 Global LS seasonality product

- **Naming convention**

The file name convention of the global LS seasonality product delivered by the CCI-LC project is the following:

File name = <id>**-**v<version>.nc/tif

where <id> = <project>**-**<level>**-**<var>-<prod>**-**<spatres>**-**<tempres>**-**<epoch>**-**<date>

The different name components are defined in Table 7-3.

Table 7-3: Components that make the name of the LS seasonality product delivered by the CCI-LC project.

FIELD	SIGNIFICATION	VALUE
project	Project Acronym	ESACCI-LC (constant)
level	Processing level	L4 (constant)
var	Variable identifier for the LS seasonality	NDVI-Cond
prod	Product identifier for the LS seasonality	AggMean, AggOcc, Std, Status, NYearObs
spatres	Spatial resolution	1000 m
tempres	Multi-year period of the product defined by the number of years + Temporal resolution of the product	P14Y7D

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epoch	Multi-year epoch of the product, defined by the start and end years	[YYYY-YYYY] where the two “YYYY” are the first year and the last year of the period. This field is 1999-2012 for the NDVI seasonality product
date	Start date of the compositing period	[yyyymmdd] where “yyyy” is the starting year of the epoch, “mm” is the month and “dd” is the day
version	Incremental that follows the successive revisions of the CCI-LC Processing lines	Version of product, major-minor

An example file name of the global LS seasonality product related to the 1999-2012 NDVI standard deviation variable between the 1st to 7th January would be: “ESACCI-LC-L4-NDVI-Cond-Std-1000m-P14Y7D-1999-2012-19990101-v2.0.tif”.

- **Processing Level**

Level 4 (i.e. “variables that are not directly measured by the instruments, but are derived from these measurements” [RD.19]).

- **Units**

NDVI = NDVI value (ranging from 0 to 1)

- **Spatial Extent**

All the terrestrial zones of the earth between the parallels 90°N and 90°S

The LS seasonality product is delivered as global files

- **Spatial resolution**

Ranging from 500m to 1 km according to the full spatial resolution of the input data

- **Temporal resolution**

The LS seasonality product is described on an annual scale at a 7 day frequency. It results in a series of 52 outputs characterizing the annual average of an epoch of 14 years (from 1999 to 2012).

- **Product layers**

Layers of the global LS seasonality product delivered by the CCI-LC project are presented in Table 7-4.

Table 7-4: Layers of the global LS seasonality product delivered by the CCI-LC project.

NDVI SEASONALITY SERIES	DESCRIPTION	VALID VALUES RANGE	SCALING FACTOR	NAN VALUE	PIXEL DEPTH
AggMean	Smoothed NDVI values corresponding to the averaged NDVI over the 1999-2012 period. It gives the yearly reference dynamic of the vegetation greenness at a 7-day frequency.	[-10000 to 10000]	0.0001	32767	Int16

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Std	Standard deviation of the averaged NDVI over the 1999-2012 period. It represents the inter-annual variability of the mean NDVI for each 7-day period.	[0 to 10000]	0.0001	32767	Int16
NYearObs	Number of valid and cloud-free years contributing to each 7-day period of the AggMean and Std series. It is a quality indicator of the mean and standard deviation estimates	[0 to 14]	None	None	Int16
Status	Status of the pixel; 0: invalid, 1 : land , 2 : water , 3 : snow, 4 : cloud , 5 : filled ice	[0 to 5]	None	0	Int16

- **Projection**

The projection is a Plate Carrée with a geographic Lat/Long representation based on the WGS84 ellipsoid. A complete description is provided in section 5.5.1.

- **Format**

The LS seasonality product is delivered in NetCDF-4 and GeoTiff formats (see section 5.5.2).

- **Metadata**

In the case of the NetCDF format, the metadata is provided as global attributes in the NetCDF file. It follows the CCI guidelines [RD.15]. With the GeoTiff raster, the files contain the geographic location information and the metadata.

- **Estimated size**

The size of the NDVI seasonality product in GeoTiff format is estimated at ~30 GB. This estimation makes the assumption of an internal LZW compression.

7.3 Global map of open permanent water bodies

- **Naming convention**

All layers are delivered at the global extent in GTiff and netcdf format. The file name convention is as generic as possible and follows this structure:

File name = <id>**-**v<version>.nc/tif

where <id> = <project>**-**<level>**-**<code>-<var>-**-**<spatres>**-**<tempres>**-**<epoch>

The dash "**-**" is the separator between name components. They are defined in Table 7-5.

Table 7-5: Naming convention in the CCI-LC WB dataset

FIELD	SIGNIFICATION	VALUE
project	Project Acronym	ESACCI-LC (constant)
level	Processing level	L4 (constant)
code	Product code identifier for CCI-LC	WB (constant)

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	products	
var	Variable code identifier for the WB product	Variable name, which could be: Map or WB-NObsImsWS or WB-NObsImsGM or Source
spatres	Spatial resolution	300m
tempres	Multi-year period of the product defined by the number of years	P6Y (constant)
epoch	Multi-year epoch of the product, defined by the start and end years	[YYYY-YYYY] where the two "YYYY" are the first year and the last year of the period. This field is 2005-2010 for this product.
version	Incremental that follows the successive revisions of the CCI-LC Processing lines	Version of product, preferably major-minor , optionally with processing centre [a-zA-Z0-9._]*

An example file name of the number of valid observations in global monitoring mode would be: "ESACCI-LC-L4-WB-NObsImsGM-300m-P6Y-2000-2005-v2.0.tif"

- **Processing Level**

Level 4 (i.e. "variables that are not directly measured by the instruments, but are derived from these measurements" [RD.18])

- **Units**

The units of each layer are described in Table 7-6

- **Spatial Extent**

All the terrestrial zones of the earth between the parallels 90°N and 60°S

- **Spatial resolution**

300 meters

- **Temporal resolution**

One product over the period 2005-2012

- **Product layers**

Table 7-6: Layers of the global WB product delivered by the CCI-LC project

LAYER NAME	UNIT	DATA TYPE	FILL VALUE	VALID RANGE
Map	Land/permanent water classification at 300m spatial resolution. Legend : 1-Land, 2-Water	Byte	None	[1 to 2]
NObsImsWS	Number of observations originating from the ASAR WSM + IMM imagery	Int16	65535	[0 to 65535]
NObsImsGM	Number of observations originating from the ASAR global monitoring mode imagery	Int16	65535	[0 to 65535]
Source	Information on the origin of the water information of the SAR WB layer. Legend : 1-ASAR, 2-SRTMSWB, 3-GFC, 4-Other	Byte	0	[1 to 4]

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LAYER NAME	UNIT	DATA TYPE	FILL VALUE	VALID RANGE
Quality flag	Classification probability mask	Byte	255	0-100

- **Projection**

The projection is a Plate Carrée with a geographic Lat/Long representation based on the WGS84 ellipsoid. A complete description is provided in section 5.5.1.

In the case of the NetCDF format, the metadata is provided as global attributes in the NetCDF file. It follows the CCI guidelines [RD.15]. With the GeoTiff raster, the files contain the geographic location information and the metadata.

- **Format**

The WB product is delivered in NetCDF-4 and GeoTiff formats (see section 5.5.2).

- **Metadata**

Using a GeoTiff format, the geographic location information will be included in the GeoTiff raster.

7.4 Global SR composite time series

The SR products delivered by the CCI-LC project consist in global multispectral time series made of temporal synthesis obtained over specific compositing periods. The compositing period is of 7 days.

- **Naming convention**

The file name convention of the global SR composite time series delivered by the CCI-LC project is the following:

File name = <id>-v<version>.nc

where <id> = <type>-<tile>-<start time>

where <type> = <project>-<ecv>-<level>-<code>-<sensor>-<sres>-<tres>

The dash "-" is the separator between name components. The filename convention obeys NetCDF CF by using the postfix ".nc".

The different name components are defined in Table 7-7.

Table 7-7: Components that make the name of the SR products delivered by the CCI-LC project

FIELD	SIGNIFICATION	VALUE
project	Project acronym	ESACCI (constant)
ecv	ECV acronym	LC (constant)
level	Processing level	L3 (constant)
code	Product code identifier for CCI-LC products	SR (constant)
sensor	Mission, platform and sensor	MERIS, SPOTVGT, AVHRR (see section 5.4)

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FIELD	SIGNIFICATION	VALUE
	identifier	
sres	Spatial resolution	300m, 1km (see section 5.4)
tres	Compositing period	P7D (constant)
tile	Tile of the Plate Carrée grid, see Figure 5-2	Tile name in format hXXvYY where XX is the column and YY is the row e.g. " h71v27" - tile in row 27 and column 71 of the Plate Carrée grid (see Figure 5-2)
start time	Start time of the interval mentioned in the field "period"	"yyyyMMdd" where: "yyyy" is the start year of the composite "MM" is the start month of the composite "dd" is the start day of the composite
version	Incremental that follows the successive revisions of the CCI-LC Processing lines	Version of product, preferably major.minor , optionally with processing centre [a-zA-Z0-9._]*

An example file name of a first 7-day SR composite for the year 2008 located at the tile h40v13 would be: "ESACCI-LC-L3-SR-MERIS-300m-P7D-h40v13-20080326-v1.0.nc".

- **Processing Level**

Level 3 (i.e. "data or retrieved environmental variables which have been derived from level 1 or 2 products and which have been spatially and/or temporally resampled" [RD.19])

- **Units**

Top of Canopy Reflectance values (no unit, provided as a fraction) coded in 16-bits

- **Spatial Extent**

All the terrestrial zones of the earth between the parallels 90°N and 60°S

The SR products are provided in tiles as defined in section 5.5.1.

- **Spatial resolution**

300m or 1 km according to the sensor (see section 5.4)

- **Temporal resolution**

7 day

- **Product layers**

The CCI-LC global 7-day SR products description is based on the structure of the NetCDF files. The global attributes of the composites are described in Table 7-8. The global 7-day SR NetCDF file for a tile has two dimensions that define the spatial raster, as described in

Table 7-9. The variables and variables' attributes of the global 7-day SR NetCDF file are presented in

Table 7-9: Information related to the spatial dimension of the global SR products delivered by the CCI-LC project

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DIMENSION	VALUE	DESCRIPTION
lat	1800, 450	Dimension that distinguishes different lines
lon	1800, 450	Dimension that distinguishes different columns

Table 7-10.

Table 7-8: Global attributes of the global 7-day SR products delivered by the CCI-LC project, according to the structure of the NetCDF files

ATTRIBUTE NAME	FORMAT	VALUE	DESCRIPTION
title		e.g. "ESACCI-LC-L3-SR-MERIS-300m-P7D-h40v13-20080326-v1.0"	Product identifier, see "naming convention" section here above
summary		e.g. "This dataset contains a tile of a Level-3 7-day global surface reflectance composite from satellite observations placed onto a regular grid"	
project		Climate Change Initiative - European Space Agency	
references		http://www.esa-landcover-cci.org/	References that describe the data or methods used to produce it.
institution		Brockmann Consult GmbH	Where the data has been produced
contact		info@brockmann-consult.de	
source		e.g. "MERIS FR L1b"	Method of production of the original data
history		e.g. "amorgos-4.0; lc-sdr-2.0; lc-sr-2.0"	List of applications that have modified the original data, with time stamp, processor and parameters
comment			Miscellaneous information about the data or method used to produce it
Conventions		CF-1.6	Name of the conventions followed
standard_name_ vocabulary		NetCDF Climate and Forecast (CF) Standard Names version 18	
keywords		satellite,observation,reflectance	
keywords_ vocabulary		NASA Global Change Master Directory (GCMD) Science Keywords	

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license		ESA CCI Data Policy: free and open access	
naming_authority		org.esa-cci	
cdm_data_type		grid	
platform		e.g. "ENVISAT"	
sensor		e.g. "MERIS"	
type		sr- 300m-7d, sr-1km-7d	Product type
id		e.g. "ESACCI-LC-L3-SR-MERIS-300m-P7D-h40v13-20080326-v1.0"	
tracking_id		e.g. "2521cb70-348f-4676-9d7c-c0311a8118ac"	
tile	hXXvYY	e.g. " h71v27"	example for the tile in row 27 and column 71 of the Plate Carrée grid see Figure 5-2
product_version	major.minor	e.g " 1.0"	Product revision, see “naming convention” section here above
date_created	yyyy-MM-dd'T'HH:mm:ss'Z'	e.g " 20130424T124732Z"	Creation time of product
creator_name		Brockmann Consult	
creator_url		http://www.brockmann-consult.de/	
creator_email		info@brockmann-consult.de	
time_coverage_start	yyyy-MM-dd'T'HH:mm:ss'Z'	e.g." 20080326T000000Z"	Start of aggregation period e.g. 2009-01-01T00:00:00Z
time_coverage_end	yyyy-MM-dd'T'HH:mm:ss'Z'	e.g" 20080402T000000Z"	End of aggregation period e.g. 2009-01-11T00:00:00Z
time_coverage_duration	0 ... 1382400	P7D	aggregation period
time_coverage_resolution		P7D	
geospatial_lat_min	-90.0 ... 90.0		South border of the bounding box
geospatial_lat_max	-90.0 ... 90.0		North border of the bounding box
geospatial_lon_min	-180.0 ... 180.0		West border of the bounding box
geospatial_lon_max	-180.0 ...		East border of the

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	180.0		bounding box
spatial_resolution		300, 1000	Resolution of the product in meters
geospatial_lat_units		degrees_north	
geospatial_lat_ resolution		0.002778 for the 300m resolution 0.011112 for the 1 km resolution	
geospatial_lon_units		degrees_east	
geospatial_lon_ resolution		0.002778 for the 300m resolution 0.011112 for the 1 km resolution	
TileSize		600:600 (with a 300m resolution) 450:450 (with a 1km resolution)	

Table 7-9: Information related to the spatial dimension of the global SR products delivered by the CCI-LC project

Dimension	Value	Description
lat	1800, 450	Dimension that distinguishes different lines
lon	1800, 450	Dimension that distinguishes different columns

Table 7-10: Variables and variables' attributes of the global 7-day SR products delivered by the CCI-LC project, according to the structure of the NetCDF files

Variable	Attribute	Format	Value	Description
crs		int	0	Coordinate reference system attribute container
	wkt		GEOGCS["WGS84(DD)" DATUM["WGS84", SPHEROID["WGS84", 6378137.0, 298.257223563]], PRIMEM["Greenwich", 0.0], UNIT["degree", 0.017453292519943295], AXIS["Geodetic longitude", EAST], AXIS["Geodetic latitude", NORTH]]	

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VARIABLE	ATTRIBUTE	FORMAT	VALUE	DESCRIPTION
	i2m		e.g. for the 300m resolution: “0.002777777777777778, 0.0,0.0-0.002777777777777778, 20.0,25.0” e.g. for the 1km resolution: “0.011111111111111112, 0.0, 0.0 -0.011111111111111112, -180.0, 55.0” (red coloured numbers depend on the selected tile)	
lon		float (lon)	-180.0 .. 180.0	Longitude coordinate of pixel column
	standard_name		longitude	
	long_name		longitude coordinate	
	units		degrees east	
	valid_min		-180.0	
	valid_max		180.0	
lat		float (lat)	-90.0 .. 90.0	Latitude coordinate of pixel row
	standard_name		latitude	
	long_name		latitude coordinate	
	units		degrees north	
	valid_min		-90.0	
	valid_max		90.0	
sr_<n>_mean n = 1 .. 10, 12 .. 14 (MERIS) n=B0,B2, B3, MIR (SPOT-VGT) n = B1, B2, B3b, B4, B5 (AVHRR2)		float (lat,lon)		Mean of SR values of channel <n>[5]

[5] valid for current pixel_state 1 or 3

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VARIABLE	ATTRIBUTE	FORMAT	VALUE	DESCRIPTION
	long_name		normalised (averaged) surface reflectance of channel n	
	standard_name		surface_bidirec-tional_reflectance	
	wavelength_nm		MERIS: 412.5, 442.5, 490, 510, 560, 620, 665, 681.25, 708.75, 753.75, 778.75, 865, 885, SPOT-VGT: 450, 645, 835, 1665 AVHRR 2: 580-680, 725-1100, 3550-3930, 10300-11300, 11500-12500	Centre wavelength of channel
	valid_min		0	
	valid_max		1	
	_FillValue		NaN	
	ancillary_variab-les		sr_n_uncertainty current_pixel_state clear_land_count clear_water_count clear_snow_ice_count cloud_count cloud_shadow_count	
sr_<n>_uncertainity n = 1 .. 10, 12 .. 14 (MERIS) n=B0,B2, B3, MIR (SPOT-VGT) n = B1, B2, B3b, B4, B5 (AVHRR2)		float (lat,lon)		uncertainity of normalized surface reflectance values of channel n
	long_name		uncertainity of normalized surface reflectance values of channel n	
	standard_name		surface_bidirec-tional_reflectance standard_error	
	wavelength_nm		see above	Centre wavelength of channel
	valid_min		0.0	

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VARIABLE	ATTRIBUTE	FORMAT	VALUE	DESCRIPTION
	valid_max		0.5	
	_FillValue		NaN	
vegetation index_mean		float (lat,lon)		Mean of vegetation index, e.g. NDVI
	long_name		mean of vegetation index	
	standard_name		normalized_difference_ vegetation_index	
	valid_min		-1	
	valid_max		+1	
	_FillValue		NaN	
	ancillary_variab-les		current_pixel_state clear_land_count clear_water_count clear_snow_ice_count cloud_count cloud_shadow_count	
clear_land_ count		short (lat,lon)		Number of contributing observations over clear sky land in aggregation period
	long_name		Number of contributing of observations over clear sky land	
	standard_name		surface_bidirectional_ reflectance number_of_observations	
	valid_min		0	
	valid_max		150	
	_FillValue		-1	
clear_water_ count		short (lat,lon)		Number of observations with water coverage in aggregation period
	long_name		number of clear_water observations	
	standard_name		surface_bidirectional_ reflectance number_of_observations	
	valid_min		0	
	valid_max		150	
	_FillValue		-1	

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VARIABLE	ATTRIBUTE	FORMAT	VALUE	DESCRIPTION
clear_snow_ ice_count		short (lat,lon)		Number of contributing observations with snow and ice coverage in aggregation period
	long_name		number of clear_snow_ice observations	
	standard_name		surface_bidirectional_ reflectance number_of_observations	
	valid_min		0	
	valid_max		150	
	_FillValue		-1	
cloud_count		short (lat,lon)		Number of observations with cloud coverage in aggregation period
	long_name		number of cloud observations	
	standard_name		surface_bidirectional_ reflectance number_of_observations	
	valid_min		0	
	valid_max		150	
	_FillValue		-1	
cloud_shadow _count		short (lat,lon)		Number of observations with cloud shadow coverage in aggregation period
	long_name		number of cloud_shadow observations	
	standard_name		surface_bidirectional_ reflectance number_of_observations	
	valid_min		0	
	valid_max		150	
	_FillValue		-1	

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VARIABLE	ATTRIBUTE	FORMAT	VALUE	DESCRIPTION
current_pixel_state		byte (lat,lon)		Status of surface associated with the surface reflectance in the aggregation period: "invalid" = 0 "clear_land " = 1 "clear_water" = 2 "clear_snow_ice" = 3 "cloud" = 4 "cloud_shadow"=5
	long_name		Status of surface associated with the surface reflectance	
	valid_min		1	
	valid_max		5	
	_FillValue		-1	

The different quality flags ("valid_count", "land_count", cloud_count", "snow_ice_count" etc.) are described in section 6.2. The definition of the uncertainty - u_λ (i,j) for each spectral band and pixel(i,j) is given here below (equation 7-1).

$$u_\lambda(i,j) = {}^1/_N \sqrt{(u_\lambda^1)^2 + \cdots + (u_\lambda^n)^2}$$

$$u_\lambda^l(i,j) = uncertainty\ of\ spectral\ (\lambda)\ surface\ directional\ reflectance\ on\ pixel\ (i,j)\ and\ observation\ (l)$$
$$l = 0,\cdots,n; n = number\ of\ observations\ w.r..t.the\ status$$
$$\lambda = 0,\cdots,m; m = number\ of\ channels\ od\ sensor, e.g.\ MERIS$$

(eq. 7-1)

Appendix 3 (section 12) lists an example of NetCDF data structure (Common Data Language (CDL) - header) of a 7-day SR composite, detailing the global attributes, the spatial dimension and the variables information.

- **Projection**

The projection is a Plate Carrée with a geographic Lat/Long representation based on the WGS84 ellipsoid. A complete description is provided in section 5.5.1.

- **Format**

All the SR time series are delivered in NetCDF-4 format using the "classic model" of NetCDF with compression (see section 5.5.2).

- **Metadata**

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The metadata for the SR products is provided as global attributes in the NetCDF file. It follows the CCI guidelines [RD.15].

- **Estimated size**

The size of a global 7-day 300-m MERIS SR composite is estimated at ~70 GB (compressed) and the size of the one tile is estimated at ~0.3 GB (compressed).

The size of a global 7-day 1000-m MERIS SR composite is estimated at ~10 GB (compressed) and the size of the one tile is estimated at ~20 MB (compressed).

The size of a global 7-day 1000-m SPOT-VGT composite is estimated at ~4 GB (compressed) and the size of the one tile is estimated at ~8 MB (compressed).

The size of a global 7-day 1000-m AVHRR composite is roughly estimated at ~5 GB (compressed) and the size of the one tile is roughly estimated at ~10 MB (compressed).

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8 PRODUCTS DELIVERY MECHANISM

In accordance with the user requirements [AD.3], the LC set of products (both SR and LC products) are delivered through ftp.

Considering the heavy download related to the full CCI-LC products dataset, a web interface was developed to mainly visualise data. It is accessible at the following address: *http://maps.elie.ucl.ac.be/CCI/viewer/*. Figure 8-1 illustrates the home page of the visualisation interface.

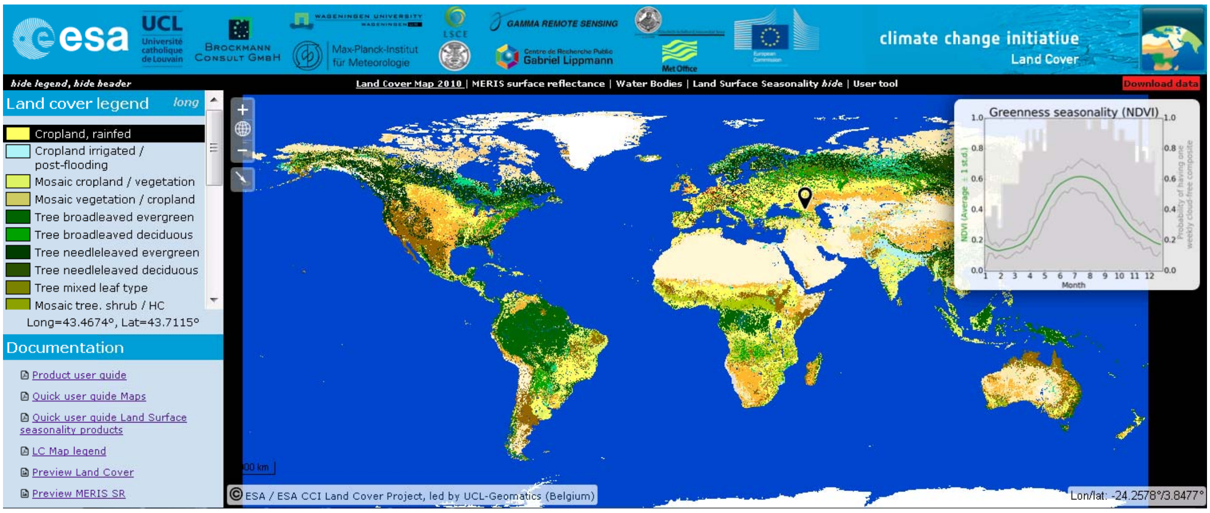

Figure 8-1: Main page of the CCI-LC products visualisation tool, with the following functionalities: top-left) LC-Maps legend description; bottom- left) download of documents describing the CCI-LC products; top-left) tools box to control the zooms (+ and -), to set the view to the global extent (O) and to reach particular coordinates; top) products available for visualization; centre) visualisation panel. A right click on the map activates the apparition of the LS seasonality profiles (NDVI) and highlights the LC-Map label on the left panel; top right) redirection to data download web page

It includes two main compartments: the map environment (right) and the information panel (left). The information panel includes the description of the LC-Map legend (top left) and the functionality to download pdf documents describing the products (bottom left): this actual product user guide, summary user guides for the CCI-LC Maps and LS seasonality products and the CCI-LC Maps legend.

The "+ O -" button (3) can be used to adapt the zoom, such as the mouse wheel and to set the visualization extent to global. The "go to" button allows reaching the area of choice by entering specific coordinates. It is also possible to specify the area of zoom by holding the shift button.

By default, the base layer displayed in the map environment corresponds to the 2010 CCI-LC map but it can be changed by selecting one of the products available at the top:: the CCI-LC maps from the

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1998-2002, 2003-2007 or 2008-20012 epochs, a 9-year global MERIS surface reflectance product composite, the WB product and the LS seasonality product.

The base layer is interactive (centre). A left click, anywhere on the layer, highlights the LC-Map label of the selected pixel in the legend description of the left panel. A right click activates the display of the LS seasonality profiles for the NDVI climatological dynamic.

Finally, the download data button (top right) redirects the user to another web page where the products are available for download either on a pixel-based extraction mode or globally:

- 3 global LC maps representative for the 1998-2002, 2003-2007 and 2008-2012 epochs;1 global SAR-based static map of open water bodies;
- the global land surface seasonality product characterizing the vegetation greenness dynamic;
- 1 user tool for sub-setting, re-projecting and re-sampling the products in a way which is suitable to each climate model.

The surface reflectance time series made of 7-day composites from the whole MERIS archive since 2003 (full and reduced resolution) is also available through disk transfer due to the size of the data set.

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9 LINK BETWEEN URD AND PSD

REQUIREMENT FROM THE URD	TRANSLATION INTO PRODUCT SPECIFICATION
REQUIREMENT FROM THE PHASE 1	
1. Need for both stable land cover data and a dynamic component	• Introducing the time dimension in the land cover characterization (section 3.1) • Introducing a new land cover concept based on land cover state and LS seasonality components (section 3.2) • Using a twofold temporal resolution in the LC products, which are 5 years for the LC map and an annual scale for the LS seasonality products (section 3.3)
2. Consistency among the different model parameters is often more important than accuracy of individual datasets. In this respect, it is important to understand the relationship between these parameters and the land cover classifiers as well as the relative importance of different land cover classes	*Characterizing the LS seasonality using several variables of interest for the climate models (sections 3.2 and 5.2, with Table 5-4 and* • Table 5-5) • Coupling the permanent and the dynamic dimensions of the land surface with the aim of improving the consistency of the land surface parameterization (section 3.2) • Cross-checking the internal consistency among the land surface information (section 6.1.3) • Ensuring transparent links between PFT and LCCS classifiers used to define the legend (section 5.6 with the inclusion in the user tool of cross-walking tables defined with the CMC)
3. Providing information on natural versus anthropogenic vegetation (disturbed fraction), tracking human activities and defining history of disturbance is of increasing relevance; in particular for land use affecting land cover with most detail needed for areas with large anthropogenic effects	• Providing a reference information depicting the seasonal LC variability which is not related to a given year (section 3.2) • Detecting some major LC change over certain hot-spot areas (section 5.1)
4. Land cover products should provide flexibility to serve different scales and purposes both in terms of spatial and temporal resolution	• Using a twofold temporal resolution in the LC products, which are 5 years for the LC map and an annual scale for the LS seasonality (section 3.3) • Delivering the land cover map and LS seasonality products at their full spatial resolution along with

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	an aggregation tool (section 5.6)
5. The relative importance of different class accuracies varies significantly depending on which surface parameter is estimated and the need for stability in accuracy should be reflected in implementing a multi-date accuracy assessment	• Mapping the LC using multi-year datasets in order to increase the stability of the LC product (sections 3.3 and 0) • Implementing a multi-date accuracy assessment [RD.3]
6. Future requirements for temporal resolution refer to intra-annual and monthly dynamics of land cover, including also remote sensing time series signals;	• Characterizing the LS seasonality using a multi-year dataset (section 3.3) • Using a twofold temporal resolution in the LC products, which are 5 years for the LC map and an annual scale for the LS seasonality (section 3.3) • Characterizing the LC dynamics for the IPCC land categories on an annual basis (section 5.1)
7. More than 90% of the general land cover users find the UN-LCCS a suitable approach for thematic characterization; and this approach is also quite compatible with the PFT concept of many models;	• Defining the LC legend using LCCS (section 5.1, with Table 5-2) • Ensuring a transparent link between the LCCS-based legend and the PFT (section 5.6 with the inclusion in the user tool of cross-walking tables defined with the CMC)
8. Quality of land cover products need to be transparent by using quality flags and controls, and including information on the probability for the land cover class or anticipated second class or even the probability distribution function for each class (coming from the classification algorithm).	• Providing quality indicators specific to (i) the LC classification process and (ii) the consistency between the LC map and the LS seasonality product (section 6.1) • Controlling the quality of 3 intermediate products of the pre-processing chain and documenting it with flags (section 6.3) • Developing a confidence-building procedure for the LC products (section 6.1.1, [RD.3]) • Implementing a statistical assessment of the LC products (section 6.1.1, [RD.3]) • Delivering the products with validation reports and metadata (introductions of sections 4 and 6)
REQUIREMENT FROM THE PHASE 2	
HIGHER PRIORITY	
1. Better description of LC characteristics in the context of PFT model requirements. The new requirement on this regard is to formulate LC – PFT conversion tables separately for different climatic regions. These regions are to be defined by the climate modeler users of the consortium, with PFT fractions per region identified using the land cover validation dataset. In particular, the percentage ranges for LC – PFT conversion in the case of mixed classes, for example the class 'mosaic tree and shrub (>50%) / herbaceous (<50%)', should be better defined in order to know	• Different cross-walking tables will be defined according to regions (sections 0 and 5.6)

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how much % of tree, shrub, and herbaceous is present	
2. Longer temporal extent for LC maps (30 years and more) including datasets for the 1990's and the 1980's	• A global LC map will be generated based on AVHRR dataset during the 1st year of the Phase 2(sections 0 and 7.1) • A feasibility study is started to analyze the possibility for having a consistent global LC map over the 1980s using the AVHRR GIMMS dataset. According to the result of this study, an 1980s global LC map could be planned as an outcome of the 2nd and 3rd years of the Phase 2 (section 4)
3. Higher temporal resolution: annual time steps in LC change	• While 5-year epoch maps are still planned, the characterization of the LC dynamics could be provided on an annual basis (sections 0 and 7.1)
4. More specific information of land cover/use change is required, at least in the context of the IPCC land categories (forests, agriculture, grassland, settlement, wetland, other land)	• While in Phase 1, information of LC change was only provided for the forest class, the Phase 2 will extent the number of monitored classes. The selection of classes that will be characterized in terms of LC dynamics will be based on the IPCC land categories (section 5.1)
5. Additional attributes of the LC classes are demanded including vegetation height, minimum and maximum Leaf Area Index (LAI), clumping index and the distinction between C3 and C4 plants	• The following refinements of the global LC maps will be investigated: discrimination between C3 and C4 plants both for the croplands and the grasslands, characterization of key LC classes in terms of vegetation height and maximum LAI (section 5.1)
LOWER PRIORITY	
6. Move to 30 m (or better) scale LC and change assessments, at least for selected regions	• Prototype HR products (LC map and LC change maps) are foreseen in the last year of the project based on Sentinel-2 and Landsat 8 data (section 4)
7. Seek options for including land management (forestry, agriculture, livestock) with land cover datasets	• Not foreseen at the moment
8. Provide additional LS seasonality such as FaPAR, surface albedo for vegetation and soil LC classes	• New global LS seasonality products are foreseen in the 2nd year of this Phase 2 related to the LAI or FAPAR, soil moisture and albedo variables (section 4)
9. Provide additional relevant attributes of LC classes such as aboveground tree biomass, vegetation density, and permafrost fraction	• Not foreseen at that moment: only C3/C4, maximum LAI and vegetation height are considered (see higher priority requirement 5)
10. Improve the description of the results and products. Besides the detailed technical reports, short technical summaries highlighting important points should be provided	• Specific effort will be done when writing the products validation reports and the products user guides. These efforts will be guided by more interactions with the CMC

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10 APPENDIX 1 – GLOBAL AND REGIONAL CCI-LC LEGENDS

LABEL		VALUE		COLOR
GLOBAL LABEL	REGIONAL LABEL	GLOBAL VALUE	REGIONAL VALUE	
No Data		0		
Cropland, rainfed		10		
	Cropland, rainfed, herbaceous cover		11	
	Cropland, rainfed, tree or shrub cover		12	
Cropland, irrigated or post-flooding		20		
Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)		30		
Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)		40		
Tree cover, broadleaved, evergreen, closed to open (>15%)		50		
Tree cover, broadleaved, deciduous, closed to open (>15%)		60		
	Tree cover, broadleaved, deciduous, closed (>40%)		61	
	Tree cover, broadleaved, deciduous, open (15-40%)		62	
Tree cover, needleleaved, evergreen, closed to open (>15%)		70		
	Tree cover, needleleaved, evergreen, closed (>40%)		71	
	Tree cover, needleleaved, evergreen, open (15-40%)		72	
Tree cover, needleleaved, deciduous, closed to open (>15%)		80		
	Tree cover, needleleaved, deciduous, closed (>40%)		81	
	Tree cover, needleleaved, deciduous, open (15-40%)		82	

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Tree cover, mixed leaf type (broadleaved and needleleaved)		90		
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)		100		
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)		110		
Shrubland		120		
	Evergreen shrubland		121	
	Deciduous shrubland		122	
Grassland		130		
Lichens and mosses		140		
Sparse vegetation (tree, shrub, herbaceous cover) (<15%)		150		
			151	
			152	
			153	
Tree cover, flooded, fresh or brakish water		160		
Tree cover, flooded, saline water		170		
Shrub or herbaceous cover, flooded, fresh/saline/brakish water		180		
Urban areas		190		
Bare areas		200		
	Consolidated bare areas	201		
	Unconsolidated bare areas	202		
Water bodies		210		
Permanent snow and ice		220		

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11 APPENDIX 2 - LCCS & THE CCI-LC LEGEND

VALUE	CCI LAND COVER LEGEND (LEVEL 1)	LCCS LABEL	LCCS ENTRY
10	Cropland, rainfed	Rainfed shrub crops // Rainfed tree crops // Rainfed herbaceous crops	A11 Cultivated Terrestrial Areas and Managed Lands
20	Cropland, irrigated or post-flooding	Irrigated tree crops // Irrigated shrub crops // Irrigated herbaceous crops // Post- flooding cultivation of herbaceous crops	
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	Cultivated and managed terrestrial areas / Natural and semi-natural primarily terrestrial vegetation	
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	Natural and semi-natural primarily terrestrial vegetation / Cultivated and managed terrestrial areas	
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	Broadleaved evergreen closed to open trees // Broadleaved semi-deciduous closed to open trees	A12 Natural and Semi-natural Terrestrial Vegetation – Woody / Trees
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	Broadleaved deciduous closed to open (100-40%) trees	
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	Needleleaved evergreen closed to open (100-40%) trees	
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	Needleleaved deciduous closed to open (100-40%) trees	
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	Broadleaved closed to open trees / Needleleaved closed to open trees	
100	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	Closed to open trees / Closed to open shrubland (thicket) // Herbaceous closed to open vegetation	A12 Natural and Semi-natural Terrestrial Vegetation
110	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	Herbaceous closed to open vegetation // Closed to open trees / Closed to open shrubland (thicket)	
120	Shrubland	Broadleaved closed to open shrubland (thicket)	A12 Natural and Semi-natural Terrestrial Vegetation – Shrubs

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130	Grassland	Herbaceous closed to very open vegetation	A12 Natural and Semi-natural Terrestrial Vegetation – Herbaceous
140	Lichens and mosses	Closed to open lichens/mosses	
150	Sparse (<15%) vegetation	Sparse trees // Herbaceous sparse vegetation // Sparse shrubs	A12 Natural and Semi-natural Terrestrial Vegetation
160	Tree cover, flooded, fresh or brakish water	Closed to open (100-40%) broadleaved trees on temporarily flooded land, water quality: fresh water // Closed to open (100-40%) broadleaved trees on permanently flooded land, water quality: fresh water	A24 Natural and Seminatural Aquatic Vegetation
170	Tree cover, flooded, saline water	Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: brackish water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: brackish water	
180	Shrub or herbaceous cover, flooded, fresh/saline/brakish water	Closed to open shrubs on permanently flooded land // Closed to open herbaceous vegetation on permanently flooded land // Closed to open shrubs on temporarily flooded land // Closed to open herbaceous vegetation on temporarily flooded land // Closed to open shrubs on waterlogged soil // Closed to open herbaceous vegetation on waterlogged soil Water quality: fresh, brackish or saline waterl	

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190	Urban areas	Artificial surfaces and associated areas	**B15 Artificial Surfaces**
200	Bare areas	Bare areas	**B16 Bare Areas**
210	Water bodies	Natural water bodies // Artificial water bodies	**B28 Inland Waterbodies, snow and ice**
220	Permanent snow and ice	Artificial perennial snow // Artificial perennial ice // Perennial snow // Perennial ice	

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12 APPENDIX 3 - NETCDF DATA STRUCTURE (CDL-HEADER) OF A 7-DAY SR COMPOSITE

Example snippet of an ASCII dump of a L3 aggregation netCDF data file

```
netcdf ESACCI-LC-L3-SR-MERIS-300m-P7D-h40v13-20080326-v1.0 {
dimensions:
        lat = 1800 ;
        lon = 1800 ;
variables:
        byte current_pixel_state(lat, lon) ;
                current_pixel_state:standard_name = "surface_bidirectional_reflectance status_flag"
;
                current_pixel_state:flag_values = 0b, 1b, 2b, 3b, 4b, 5b ;
                current_pixel_state:flag_meanings = "invalid clear_land clear_water clear_snow_ice
cloud
                                                    cloud_shadow" ;
                current_pixel_state:valid_min = 0 ;
                current_pixel_state:valid_max = 5 ;
                current_pixel_state:_FillValue = -1b ;
                current_pixel_state:long_name = "LC pixel type mask" ;
        short clear_land_count(lat, lon) ;
                clear_land_count:standard_name = "surface_bidirectional_reflectance
number_of_observations" ;
                clear_land_count:valid_min = 0 ;
                clear_land_count:valid_max = 150 ;
                clear_land_count:_FillValue = -1s ;
                clear_land_count:long_name = "number of clear_land observations" ;
        short clear_water_count(lat, lon) ;
                clear_water_count:standard_name = "surface_bidirectional_reflectance
number_of_observations";
                clear_water_count:valid_min = 0 ;
                clear_water_count:valid_max = 150 ;
                clear_water_count:_FillValue = -1s ;
                clear_water_count:long_name = "number of clear_water observations" ;
        short clear_snow_ice_count(lat, lon) ;
                clear_snow_ice_count:standard_name = "surface_bidirectional_reflectance
                                                     number_of_observations" ;
```

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```
                clear_snow_ice_count:valid_min = 0 ;
                clear_snow_ice_count:valid_max = 150 ;
                clear_snow_ice_count:_FillValue = -1s ;
                clear_snow_ice_count:long_name = "number of clear_snow_ice observations" ;
        short cloud_count(lat, lon) ;
                cloud_count:standard_name = "surface_bidirectional_reflectance
number_of_observations" ;
                cloud_count:valid_min = 0 ;
                cloud_count:valid_max = 150 ;
                cloud_count:_FillValue = -1s ;
                cloud_count:long_name = "number of cloud observations" ;
        short cloud_shadow_count(lat, lon) ;
                cloud_shadow_count:standard_name ="surface_bidirectional_reflectance
number_of_observations";
                cloud_shadow_count:valid_min = 0 ;
                cloud_shadow_count:valid_max = 150 ;
                cloud_shadow_count:_FillValue = -1s ;
                cloud_shadow_count:long_name = "number of cloud_shadow observations" ;
        float sr_1_mean(lat, lon)[6] ;
                sr_1_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_1_mean:wavelength = 412.691f ;
                sr_1_mean:valid_min = 0.f ;
                sr_1_mean:valid_max = 1.f ;
                sr_1_mean:_FillValue = NaNf ;
                sr_1_mean:ancillary_variables = "sr_1_uncertainty current_pixel_state
clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_1_mean:long_name = "normalised (averaged) surface reflectance of channel 1" ;
        float sr_1_uncertainty(lat, lon) ;
                sr_1_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_1_uncertainty:wavelength = 412.691f ;
                sr_1_uncertainty:valid_min = 0.f ;
                sr_1_uncertainty:valid_max = 1.f ;
                sr_1_uncertainty:_FillValue = NaNf ;
                sr_1_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 1" ;
        float sr_2_mean(lat, lon)[6] ;
                sr_2_mean:standard_name = "surface_bidirectional_reflectance" ;
```

[6] valid for current pixel status 1 and 3

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```
                sr_2_mean:wavelength = 442.559f ;
                sr_2_mean:valid_min = 0.f ;
                sr_2_mean:valid_max = 1.f ;
                sr_2_mean:_FillValue = NaNf ;
                sr_2_mean:ancillary_variables = "sr_2_uncertainty current_pixel_state
clear_land_count
                                    clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_2_mean:long_name = "normalised (averaged) surface reflectance of channel 2" ;
        float sr_2_uncertainty(lat, lon) ;
                sr_2_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_2_uncertainty:wavelength = 442.559f ;
                sr_2_uncertainty:valid_min = 0.f ;
                sr_2_uncertainty:valid_max = 1.f ;
                sr_2_uncertainty:_FillValue = NaNf ;
                sr_2_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 2" ;
        float sr_3_mean(lat, lon)[6] ;
                sr_3_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_3_mean:wavelength = 489.882f ;
                sr_3_mean:valid_min = 0.f ;
                sr_3_mean:valid_max = 1.f ;
                sr_3_mean:_FillValue = NaNf ;
                sr_3_mean:ancillary_variables = "sr_3_uncertainty current_pixel_state
clear_land_count
                                    clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_3_mean:long_name = "normalised (averaged) surface reflectance of channel 3" ;
        float sr_3_uncertainty(lat, lon) ;
                sr_3_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_3_uncertainty:wavelength = 489.882f ;
                sr_3_uncertainty:valid_min = 0.f ;
                sr_3_uncertainty:valid_max = 1.f ;
                sr_3_uncertainty:_FillValue = NaNf ;
                sr_3_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 3" ;
        float sr_4_mean(lat, lon)[6] ;
                sr_4_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_4_mean:wavelength = 509.819f ;
                sr_4_mean:valid_min = 0.f ;
                sr_4_mean:valid_max = 1.f ;
                sr_4_mean:_FillValue = NaNf ;
                sr_4_mean:ancillary_variables = "sr_4_uncertainty current_pixel_state
clear_land_count
```

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```
                                        clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_4_mean:long_name = "normalised (averaged) surface reflectance of channel 4" ;
        float sr_4_uncertainty(lat, lon) ;
                sr_4_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_4_uncertainty:wavelength = 509.819f ;
                sr_4_uncertainty:valid_min = 0.f ;
                sr_4_uncertainty:valid_max = 1.f ;
                sr_4_uncertainty:_FillValue = NaNf ;
                sr_4_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 4" ;
        float sr_5_mean(lat, lon)6 ;
                sr_5_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_5_mean:wavelength = 559.694f ;
                sr_5_mean:valid_min = 0.f ;
                sr_5_mean:valid_max = 1.f ;
                sr_5_mean:_FillValue = NaNf ;
                sr_5_mean:ancillary_variables = "sr_5_uncertainty current_pixel_state
clear_land_count
                                        clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_5_mean:long_name = "normalised (averaged) surface reflectance of channel 5" ;
        float sr_5_uncertainty(lat, lon) ;
                sr_5_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_5_uncertainty:wavelength = 559.694f ;
                sr_5_uncertainty:valid_min = 0.f ;
                sr_5_uncertainty:valid_max = 1.f ;
                sr_5_uncertainty:_FillValue = NaNf ;
                sr_5_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 5" ;
        float sr_6_mean(lat, lon)6 ;
                sr_6_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_6_mean:wavelength = 619.601f ;
                sr_6_mean:valid_min = 0.f ;
                sr_6_mean:valid_max = 1.f ;
                sr_6_mean:_FillValue = NaNf ;
                sr_6_mean:ancillary_variables = "sr_6_uncertainty current_pixel_state
clear_land_count
                                        clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_6_mean:long_name = "normalised (averaged) surface reflectance of channel 6" ;
        float sr_6_uncertainty(lat, lon) ;
                sr_6_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
```

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```
                sr_6_uncertainty:wavelength = 619.601f ;
                sr_6_uncertainty:valid_min = 0.f ;
                sr_6_uncertainty:valid_max = 1.f ;
                sr_6_uncertainty:_FillValue = NaNf ;
                sr_6_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 6" ;
        float sr_7_mean(lat, lon)6;
                sr_7_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_7_mean:wavelength = 664.5731f ;
                sr_7_mean:valid_min = 0.f ;
                sr_7_mean:valid_max = 1.f ;
                sr_7_mean:_FillValue = NaNf ;
                sr_7_mean:ancillary_variables = "sr_7_uncertainty current_pixel_state
clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_7_mean:long_name = "normalised (averaged) surface reflectance of channel 7" ;
        float sr_7_uncertainty(lat, lon) ;
                sr_7_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_7_uncertainty:wavelength = 664.5731f ;
                sr_7_uncertainty:valid_min = 0.f ;
                sr_7_uncertainty:valid_max = 1.f ;
                sr_7_uncertainty:_FillValue = NaNf ;
                sr_7_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 7" ;
        float sr_8_mean(lat, lon)6;
                sr_8_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_8_mean:wavelength = 680.821f ;
                sr_8_mean:valid_min = 0.f ;
                sr_8_mean:valid_max = 1.f ;
                sr_8_mean:_FillValue = NaNf ;
                sr_8_mean:ancillary_variables = "sr_8_uncertainty current_pixel_state
clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_8_mean:long_name = "normalised (averaged) surface reflectance of channel 8" ;
        float sr_8_uncertainty(lat, lon) ;
                sr_8_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_8_uncertainty:wavelength = 680.821f ;
                sr_8_uncertainty:valid_min = 0.f ;
                sr_8_uncertainty:valid_max = 1.f ;
                sr_8_uncertainty:_FillValue = NaNf ;
                sr_8_uncertainty:long_name = "uncertainty of normalised surface reflectance of
```

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```
channel 8" ;
        float sr_9_mean(lat, lon)6;
                sr_9_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_9_mean:wavelength = 708.329f ;
                sr_9_mean:valid_min = 0.f ;
                sr_9_mean:valid_max = 1.f ;
                sr_9_mean:_FillValue = NaNf ;
                sr_9_mean:ancillary_variables = "sr_9_uncertainty current_pixel_state
clear_land_count
                                    clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_9_mean:long_name = "normalised (averaged) surface reflectance of channel 9" ;
        float sr_9_uncertainty(lat, lon) ;
                sr_9_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_9_uncertainty:wavelength = 708.329f ;
                sr_9_uncertainty:valid_min = 0.f ;
                sr_9_uncertainty:valid_max = 1.f ;
                sr_9_uncertainty:_FillValue = NaNf ;
                sr_9_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 9" ;
        float sr_10_mean(lat, lon)6;
                sr_10_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_10_mean:wavelength = 753.371f ;
                sr_10_mean:valid_min = 0.f ;
                sr_10_mean:valid_max = 1.f ;
                sr_10_mean:_FillValue = NaNf ;
                sr_10_mean:ancillary_variables = "sr_10_uncertainty current_pixel_state
clear_land_count
                                    clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_10_mean:long_name = "normalised (averaged) surface reflectance of channel 10" ;
        float sr_10_uncertainty(lat, lon) ;
                sr_10_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_10_uncertainty:wavelength = 753.371f ;
                sr_10_uncertainty:valid_min = 0.f ;
                sr_10_uncertainty:valid_max = 1.f ;
                sr_10_uncertainty:_FillValue = NaNf ;
                sr_10_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 10" ;
        float sr_12_mean(lat, lon)6;
                sr_12_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_12_mean:wavelength = 778.4091f ;
                sr_12_mean:valid_min = 0.f ;
```

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```
                sr_12_mean:valid_max = 1.f ;
                sr_12_mean:_FillValue = NaNf ;
                sr_12_mean:ancillary_variables = "sr_12_uncertainty current_pixel_state
clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_12_mean:long_name = "normalised (averaged) surface reflectance of channel 12" ;
        float sr_12_uncertainty(lat, lon) ;
                sr_12_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_12_uncertainty:wavelength = 778.4091f ;
                sr_12_uncertainty:valid_min = 0.f ;
                sr_12_uncertainty:valid_max = 1.f ;
                sr_12_uncertainty:_FillValue = NaNf ;
                sr_12_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 12" ;
        float sr_13_mean(lat, lon)[6];
                sr_13_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_13_mean:wavelength = 864.876f ;
                sr_13_mean:valid_min = 0.f ;
                sr_13_mean:valid_max = 1.f ;
                sr_13_mean:_FillValue = NaNf ;
                sr_13_mean:ancillary_variables = "sr_13_uncertainty current_pixel_state
clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                sr_13_mean:long_name = "normalised (averaged) surface reflectance of channel 13" ;
        float sr_13_uncertainty(lat, lon) ;
                sr_13_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_13_uncertainty:wavelength = 864.876f ;
                sr_13_uncertainty:valid_min = 0.f ;
                sr_13_uncertainty:valid_max = 1.f ;
                sr_13_uncertainty:_FillValue = NaNf ;
                sr_13_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 13" ;
        float sr_14_mean(lat, lon)[6];
                sr_14_mean:standard_name = "surface_bidirectional_reflectance" ;
                sr_14_mean:wavelength = 884.944f ;
                sr_14_mean:valid_min = 0.f ;
                sr_14_mean:valid_max = 1.f ;
                sr_14_mean:_FillValue = NaNf ;
                sr_14_mean:ancillary_variables = "sr_14_uncertainty current_pixel_state
clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
```

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```
                sr_14_mean:long_name = "normalised (averaged) surface reflectance of channel 14" ;
        float sr_14_uncertainty(lat, lon) ;
                sr_14_uncertainty:standard_name = "surface_bidirectional_reflectance standard_error"
;
                sr_14_uncertainty:wavelength = 884.944f ;
                sr_14_uncertainty:valid_min = 0.f ;
                sr_14_uncertainty:valid_max = 1.f ;
                sr_14_uncertainty:_FillValue = NaNf ;
                sr_14_uncertainty:long_name = "uncertainty of normalised surface reflectance of
channel 14" ;
        float vegetation_index_mean(lat, lon)[6];
                vegetation_index_mean:standard_name = "normalized_difference_vegetation_index" ;
                vegetation_index_mean:valid_min = -1.f ;
                vegetation_index_mean:valid_max = 1.f ;
                vegetation_index_mean:_FillValue = NaNf ;
                vegetation_index_mean:ancillary_variables = "current_pixel_state clear_land_count
                                     clear_water_count clear_snow_ice_count cloud_count
cloud_shadow_count" ;
                vegetation_index_mean:long_name = "mean of vegetation index" ;
        float lat(lat) ;
                lat:long_name = "latitude" ;
                lat:standard_name = "latitude" ;
                lat:valid_min = 20.00139f ;
                lat:valid_max = 24.99861f ;
                lat:units = "degrees_north" ;
        float lon(lon) ;
                lon:long_name = "longitude" ;
                lon:standard_name = "longitude" ;
                lon:valid_min = 20.00139f ;
                lon:valid_max = 24.99861f ;
                lon:units = "degrees_east" ;
        int crs ;
                crs:i2m = "0.002777777777777778,0.0,0.0,-0.002777777777777778,20.0,25.0" ;
                crs:wkt = "GEOGCS[\"WGS84(DD)\", \n  DATUM[\"WGS84\", \n    SPHEROID[\"WGS84\",
6378137.0,
                                     298.257223563]], \n  PRIMEM[\"Greenwich\", 0.0], \n
UNIT[\"degree\",
                                     0.017453292519943295], \n  AXIS[\"Geodetic longitude\", EAST],
\n
                                     AXIS[\"Geodetic latitude\", NORTH]]" ;

// global attributes:
                :title = "ESA CCI land cover surface reflectance 7 day composite" ;
                :summary = "This dataset contains a tile of a Level-3 7-day global surface
reflectance
                                     composite from satellite observations placed onto a regular
```

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```
grid." ;
                :project = "Climate Change Initiative - European Space Agency" ;
                :references = "http://www.esa-landcover-cci.org/" ;
                :institution = "Brockmann Consult GmbH" ;
                :contact = "info@brockmann-consult.de" ;
                :source = "MERIS FR L1B r02" ;
                :history = "amorgos-4,0, lc-sdr-2.0, lc-sr-2.0" ;
                :comment = "" ;
                :Conventions = "CF-1.6" ;
                :standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Standard Names version
18" ;
                :keywords = "satellite,observation,reflectance" ;
                :keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science Keywords"
;
                :license = "ESA CCI Data Policy: free and open access" ;
                :naming_authority = "org.esa-cci" ;
                :cdm_data_type = "grid" ;
                :platform = "ENVISAT" ;
                :sensor = "MERIS" ;
                :type = "SR-300m-7d" ;
                :id = "ESACCI-LC-L3-SR-MERIS-300m-P7D-h40v13-20080326-v1.0" ;
                :tracking_id = "2521cb70-348f-4676-9d7c-c0311a8118ac" ;
                :tile = "h40v13" ;
                :product_version = "1.0" ;
                :date_created = "20130424T124732Z" ;
                :creator_name = "Brockmann Consult" ;
                :creator_url = "http://www.brockmann-consult.de/" ;
                :creator_email = "info@brockmann-consult.de" ;
                :time_coverage_start = "20080326T000000Z" ;
                :time_coverage_end = "20080402T000000Z" ;
                :time_coverage_duration = "P7D" ;
                :time_coverage_resolution = "P7D" ;
                :geospatial_lat_min = "20.0" ;
                :geospatial_lat_max = "25.0" ;
                :geospatial_lon_min = "20.0" ;
                :geospatial_lon_max = "25.0" ;
                :spatial_resolution = "300m" ;
                :geospatial_lat_units = "degrees_north" ;
                :geospatial_lat_resolution = "0.002778" ;
                :geospatial_lon_units = "degrees_east" ;
                :geospatial_lon_resolution = "0.002778" ;
                :TileSize = "600:600" ;
```

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```
}
data:

 current_pixel_state =
     ...........
     1,1,1,1,1,1,
     ........
   many more lines
     .....;
 clear_land_count =
     ...........
     3,3,2,2,2,2,
     ........
   many more lines
     .....;
 clear_water_count =

     many more lines

}
```

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