User Requirements Document

Milestone	User Requirements Document – Milestone 1
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Distribution	ESA

Summary

Within the ESA Climate Change Initiative (CCI), a global monitoring program driven by GCOS requirements is in development to provide long-term satellite-based products which can serve the climate modeling and climate user community. Land Cover has been selected as one of 11 ECVs which will be elaborated during the first phase of CCI (2010-2013). In the first stage of the Land Cover CCI project, a user requirements analysis has been conducted to derive the specifications for a new global land cover product to address the needs of key-users from the climate modeling community. This user assessment is building upon the general guidance and requirements from GCOS an its related panel activities and provides the next step to further derive more detailed characteristics and foundations to observe Land Cover as Essential Climate Variable (ECV).

As part of the requirements analysis, an user consultation mechanism was set-up to actively involve different climate modeling groups by setting out surveys to different type of users: 1) a group of key-users, most of them also participating in CMUG, 2) associated climate users who are involved and leading the development of key climate relevant models and application, and 3) the broad land cover data user community reflected in the scientific literature and represented by users of the ESA GlobCover product. The surveys focused on three major ways land cover observations are used in climate models:

1. As proxy for several land surface parameters assigned based on Plant Functional Types (PFTs);
2. As proxy for (tracking) human activities, i.e. land use affecting land cover;
3. As datasets for validation of model outcomes (i.e. time series) or to study feedback effects.

The evolution of requirements for these aspects from current models to future new modeling approaches was specifically taken into account. Next to the surveys, requirements from the GCOS Implementation Plan 2004 and 2010 and associated strategic earth observation documents for land cover (GTOS, IGOL, IGCO and CMUG) were considered and integrated. Finally, a detailed literature review was carried out with special attention to innovative concepts and approaches to better reflect land dynamics in the next generation climate models.

The outcome of the user requirements assessment shows that although the range of requirements coming from the climate modeling community is broad, there is a good match among the requirements coming from different user groups and the broader requirements derived from GCOS, CMUG and other relevant international panels. The findings highlight that:

- There is need for both stable land cover data and a dynamic component in form of time-series and changes in land cover;
- Consistency among the different model parameters is often more important than accuracy of individual datasets, and it is important to understand the relationship between land cover classifiers with the parameters and the relative importance of different land cover classes;
- Providing information on natural versus anthropogenic vegetation (disturbed fraction) and track human activities and define history of disturbance is of increasing relevance; in particular for land use affecting land cover with most detail needed for focus areas with large anthropogenic effects;
- Land cover products should provide flexibility to serve different scales and purposes both in terms of spatial and temporal resolution;

- 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;
- Future requirements for temporal resolution refer to intra-annual and monthly dynamics of land cover including also remote sensing time series signals;
- More than 90% of the general land cover users find the UN Land Cover Classification System a suitable approach for thematic characterization; and this approach is also quite compatible with the PFT concept of many models;
- 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).

As a next step within the Land Cover CCI project, the outcome of this user requirements assessment will be used as input for the product specification of the next generation Global Land Cover dataset which will be developed within this project.

Table of recorded changes

Issue Record Sheet

ISSUE	DATE	REASON
1.0.	01/11/2010	Initial version
2.0.	12/11/2010	Updated version according to RIDs from progress meeting
2.1.	15/01/2011	Updates version according to RIDs (related to version 1.0) from ESA
2.2	22/02/2011	Updates version according to RIDs (related to version 2.1) from ESA and to the comments received at PM3

Detailed Change Record Sheet

ISSUE	RID	Section	Change
2.0	URD/1 – URD/16	All	Several editorial changes as requested.
2.0	URD/17	Section 4.10	Additional section has been added which presents the summary of requirements for Land Cover ECV according to the ESA template for organizing ECV user requirements.
2.0	URD/18	Appendix D	The respondents to the associated user survey have been indicated with an asterix in Appendix D.
2.0	URD/19	Section 4.5	The discussion on C3/C4 differentation has been expanded: opportunities for EO and other data sources have been identified and background references have been added.
2.1	From PM2	Section 4.7	According to feedback in RID from ESA we have contacted the key-users on their requirements for metadata and quality control indicators. The outcome has been added to section 4.7.
2.1	From PM2	Section 3.3.4.	Final feedback from associated users on Land Cover ECV summary document has been added to section 3.3.4.
2.1	URD/20	Section 4.10	Statement of Appendix has been removed. In addition, information about metadata and projection has been added.
2.2	URD/21	Sections 4.7 and 4.10	As has been discussed in section 4.7 users mainly articulated in meta data on the quality of the land cover dataset. Section 4.7 has been updated with some more requirements, also taking into account the recent CMUG report. Subsequently, section 4.10 has been updated as well in harmonization with section 4.7
2.2	URD/22	Section 4.5	The discussions on C3/C4 has been expanded in section 4.5 Recent reference on use of MERIS MTCI for identification of C3-C4 grasslands has been added and consequences for generalization added.
2.2	From PM3	Section 4.5	The mention of the importance of irrigated rice areas has been added in section 4.5.

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List of acronyms

CCI: Climate Change Initiative
CEOS WGCV: Committee on Earth Observation Satellites Working Group on Calibration and Validation
CMUG: Climate Modelling User Group
DGVM: Dynamic global vegetation model
ECV: Essential Climate Variable
EO: Earth Observation
ESM: Earth System Modeling
FCDR: Fundamental Climate Data Record
GCM: General Circulation Models
GCOS: Global Climate Observing System
GEO: Group on Earth Observation
GOFC-GOLD: Global Observations of Forest and Land Cover Dynamics
GTOS: Global Terrestrial Observing System
IAM: Integrated Assessment Modeling
IGCO: Integrated Global Carbon Observation
IGOL: Integrated Global Observations for Land
IPCC: Intergovernmental Panel on Climate Change
LCCS: Land Cover Classification System
LCML: Land Cover Macro Language
LSCE: Laboratoire des Sciences du Climat et de l'Environment
MPI-M: Max Planck Institute for Meteorology
MOHC: Meteorological Office Hadley Center
NWP: Numerical weather prediction
PFT: Plant Functional Type
RCM: Regional Climate Modeling
UNFCCC: United Nations Framework Convention on Climate Change

1. Background and scope

This document describes the activities and results for the user requirement analysis (WP1100) for the product specification as part of the Land Cover CCI project within ESA's Climate Change Initiative Program. The overall objective for the Land Cover CCI project is to critically revisit all algorithms required for the generation of a global land product in the light of the GCOS requirements, and to design and demonstrate a prototype system delivering in a consistent way over years and from various EO instruments global land cover information matching the needs of key users belonging to the climate change community.

In the first stage of the project, the detailed specifications of a global land cover product will be defined which matches the requirements from GCOS (both for itself and as a surrogate for other important climate variables) and key climate users, and which is achievable on a regular basis using the current EO systems and building on the UN Land Cover Classification System (LCCS) for consistency and interoperability with other land cover products. To do so, key climate and carbon modeling users will be consulted to ensure the developed Land Cover products meet the requirements for a range of model communities and for application of existing and future modeling approaches (WP1100).

The overall objective of WP1100 is:

1. to establish an user dialog and interaction with climate model users;
2. to identify user needs for product specifications.

The tasks carried out for WP1100 are:

1. Provide a broad review of climate modeling user requirements from the scientific literature including existing uses of land cover data for climate modeling and through assessing GCOS and GTOS requirements including the updated version of the GCOS implementation plan available from August 2010;
2. Implement a survey of the project associated users and their requirements and related synthesis to derive product specifications;
3. Participation in the CMUG process and attending key upcoming meetings and conference for active engagement in scientific dialogs among climate change modeling community, i.e., on harmonization efforts for land cover among different communities;
4. Provide contributions and lead of discussions for a user interaction and product specification activities within the project.

This technical report gives an overview of the concepts and background of the user requirements assessment as described in chapter 1 of this document. In chapter 2 of this document, the methodology and user engagement mechanism are described. Chapter 3 provides the outcome of the user requirement assessment: here current and future requirements for specifications of a global land cover product which can provide the climate variables important for land cover monitoring are given. These outcomes are presented accordingly: the defined requirements from GCOS and other strategic earth observation documents are presented in section 3.1, followed by the outcomes of the user survey for the broad land cover data use community (section 3.2). In section 3.3, the assessment of the climate modeling community requirements is presented both for the key and associated user group and finalizing with the review on (future) requirements from climate modeling literature. In chapter 4, a discussion on the results is presented including a synthesized advice for land cover product specifications and next generation models.

1.1. Need for community and user interaction to specify requirements for ECV monitoring

Issues of global, regional and national forest and land cover observations have recently received significant attention in a number of international processes on the political level, offering opportunities to improving relevance, acceptance, and approaches to operationalize global and regional land cover assessments. Since technological progress and methodological sophistication alone is not sufficient to implement global land assessments effectively, particular emphasize on fostering more saliency and legitimacy of land cover observations is needed in addition to technical credibility. The efforts of Land Cover CCI projects also address the issue to build a bridge between policy requirements, and scientific progress and consensus. It involves engagement with prominent political processes, the gathering of observation requirements, providing technical policy advice, the definition of observation strategies and priorities, evolving international technical consensus on critical issues, the specification of implementation guidelines, and implementation of dedicated case studies fostering technical progress, operations and applications. These activities are progressing in four major thematic areas: (a) standards for land cover characterization, (b) standard methods for land cover accuracy assessment, (c) global land cover observations and applications and (d) land cover change monitoring. As a prominent example, the current evolving activities to support the UNFCCC efforts for research and systematic observations of Essential Climate Variables (ECV's) is taken shape into specific implementation activities such as attempted in Land Cover CCI project. While there is no detailed guidance on what it means to observe land cover as ECV, there is guidance provided from the political level and its subsidiary technical bodies.

The UNFCCC requiring global land cover observation progress relates to research and systematic observations ((GCOS 2004, 2010b)). The scope is to continuously monitor ECVs to reduce uncertainties in understanding the global climate system, which includes land cover as one such variable. The related GCOS implementation plan (GCOS tasks defined in 2004 have been redefined in 2010) specifies a number of specific tasks to improve the global observation of land cover as an essential climate variable including (1) the establishment of international standards, (2) consensus methods for map accuracy assessment, (3) the continuity for fine-scale satellite observations, (4) the development of an in situ reference network and the implementation of an operational validation framework, (5) the generation of annual global land-cover products, and (6) the development of a high-resolution global land cover change dataset. As requested by the UNFCCC Subsidiary Body of Science and Technical Advise (SBSTA), reporting guidelines and standards are being developed for each ECV including land cover. Progress on this issue is documented at http://www.fao.org/gtos/topcECV.html.

For observing land cover as an ECV, several areas require attention:

- The need to address the requirements of the UNFCCC;
- Product specifications should be driven by the core climate user communities;
- The implementation should focus on a truly global system and process including:
    - coordinated observations;
    - integrated and standardized mapping;
    - independent quality assessment.

Any ECV monitoring effort has to ensure saliency and legitimacy in addition to technical credibility. An international coordination mechanism among key actors worldwide (users, producers, science, regional/national experts) is essential to ensure that land cover products are accepted internationally and by the UNFCCC. Such mechanisms are intrinsic to the land cover CCI project and will be described in more detail in chapter 3.

1.2. Land cover and climate modeling

Land cover and land cover change are becoming more and more related to the climate modeling effort. Land cover change as a pressing environmental issue, is acting as both a cause and a consequence of climate change (Figure 1). Reliable observations are crucial to monitor and understand the ongoing processes of deforestation, desertification, urbanization, land degradation, loss of biodiversity, ecosystem functions, water and energy management, and the influence of land cover changes on the physical climate system itself. A number of disciplines (geography, ecology, geology, forestry, land policy and planning, etc.) use and refer to land cover and land cover change as one of the most obvious and detectable indicators of land surface characteristics and associated human induced and natural processes. Current IPCC Assessment Reports are based upon an uncertain understanding of the land surface dynamics and related processes. Applications of land cover and land dynamics in climate change-related General Circulation Models, Earth System Models and Impact Assessment Models need to be better linked and coordinated. The importance of these issues requires continuous monitoring systems and data.

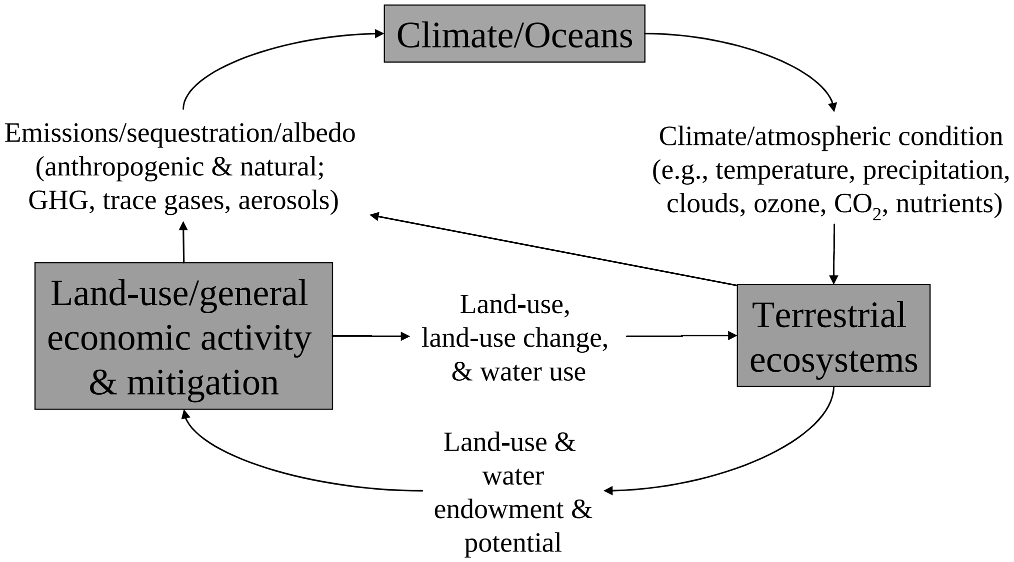


Figure 1: Role of land in long-run (e.g., centennial) climate modeling (Rose et al. 2008)

All models are driven by data, whether that data is derived from boundary conditions or through parameter estimation, empirical relationships or direct observations. In the end, model estimates, and, therefore, model error, reflects the information, or analyses that is used to establish initial conditions, parameter estimation or internal algorithms. For instance, land-use change emissions are highly uncertain to within a factor of 4, i.e. 500 to 2700 TgC/y (Denman et al. 2007). This restricts our ability to estimate the strength of global carbon sinks; although fossil fuel emissions and atmospheric CO_2 concentrations are well-constrained, the large uncertainty in land-use change emissions means that the airborne fraction of total emissions (and hence the fraction of total emissions taken up by land ecosystems and oceans) cannot be constrained so well. Similarly, global land cover as provided by the

United Nations Food and Agriculture Organization (FAO) is often inconsistent with land-cover data and actual practices (e.g., the extent of global plantation forests is uncertain).

For adequate modeling of processes at the land surface boundary to the atmosphere, an accurate representation of the land surface is necessary. A climate model used to simulate these processes requires a proper determination of the land surface characteristics that are used in its parameterizations as boundary conditions. These parameters include, e.g., background surface albedo, surface roughness length due to vegetation, fractional vegetation cover and Leaf Area Index (LAI), forest ratio, plant-available soil water holding capacity, and volumetric wilting point.

Three major communities, the General Circulation Models (GCM), Earth System Modeling (ESM), and the Integrated Assessment Modeling (IAM) community play an important role in understanding and quantifying Earth and climate system analysis and specifically, understanding the role of land use and land cover change. These different model communities commonly have a global scope of some kind but focus on different set of objectives (Figure 2). A variety of approaches to addressing land use and land cover change have been considered by these modeling communities. General circulation models (GCMs) include a rather coarse level of ecological and biogeochemical process representation and use land cover as generic and fixed boundary condition. Earth system model (ESM) modelers have taken an approach that stems from a combination of basic ecosystem (e.g., carbon cycle) and dynamic global vegetation models (DGVMs), and that incorporates different plant functional types (PFTs) into their model structures. These aspects of ESMs are increasingly being used for impacts assessments, both for ecosystems themselves and the impacts on hydrology which are modified by ecosystem responses. The ESM approach is derived from a tradition of using complex models to analyze the different components and interactions of the physical system. The focus has mainly been on the climate system, with an initial description of coupled ocean-atmosphere systems, and more recently the carbon cycle and dynamic vegetation. By extending its focus, the ESM approach is more-and-more implementing coupled climate with hydrology, agriculture and urban systems as integral components of the Earth system.

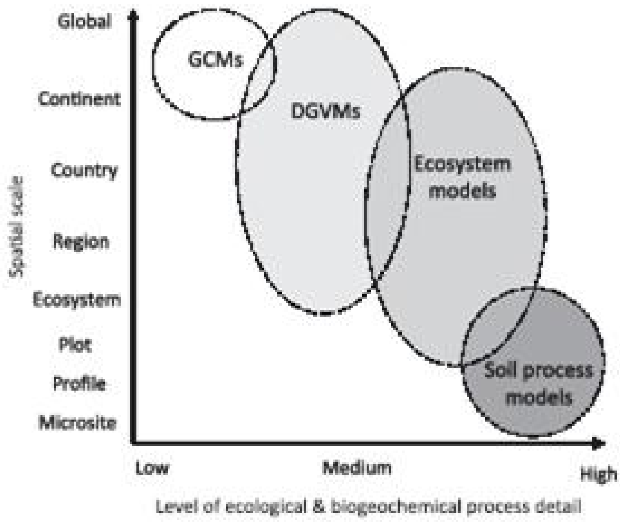


Figure 2: The multi-scale and multi-purpose nature of climate and carbon models, i.e. soil, ecosystem, dynamic global vegetation model (DGVMs), and general circulation models (GCMs): scales of prediction and process resolution. Showing that the level of detail in process resolution generally diminishes as the predictive scale (spatial and temporal) of the model increases (from Ostle et al., 2009)

A number of ESM approaches have been developed ranging from GCMs that operate at the 2nd global grid cell scale to soil carbon process models that can be parameterized at the plot scale (Figure 2). DGVMs are the main linking component to extrapolate the highly detailed process representation to the global level by including the state-of-the-art knowledge about the impacts of change on plant-soil interactions and their feedbacks on the climate system. A broad range of DGVMs of varying degrees of complexity is currently being adopted within ESM: CLM-CN, CLIMBER, JSBACH, IGSM, LPJ, BIOME-BGC, CENTURY, DNDC, HYBRID, SDGVM, TRIFFID, ORCHIDEE (Ostle et al. 2009). Most DGVMs utilize the concept of “plant functional types” (PFTs: numbering between 3 and 20) to characterize global (vegetation) land cover diversity. Each PFT represents a broad class of vegetation type such as deciduous forest or grassland and is parameterized for a core set of physiological processes and ecological phenomena.

The IAM approach comes largely from a tradition of modeling human behavior explicitly and the interaction of human activities, decision making and the environment, including economic production and consumption, energy systems, greenhouse gas emissions and land-use. This community has also recognized the importance of land use as a critical factor in socio-economic decision making, for example for food and timber production, the state of ecosystems and their services, and increasingly, as a response to demand for biofuels for the electricity and transportation sectors. While many IAMs have focused strongly on energy-economy systems and only included land use emissions as exogenous factors, this is now changing with the development and implementation of increasingly coupled socio-economic and climate modeling strategies.

1.3. User engagement mechanism

Several actors and types of users will be involved in representing the modeling communities concerned with climate and climate change issues. The structure to ensure a continuous dialogue with the climate community in different phases of execution for the Land Cover CCI project includes three main phases:

1. Identification of specific user needs for product specifications (WP 1100):
    a. Broad review of user requirements from the scientific literature including existing uses of land cover data for climate modeling but also on innovative concepts and approaches to better reflect land dynamics in the next generation of models. This includes a detailed survey of the project key and associated users and their requirements and related synthesis to derive product specifications;
    b. Participation in the CMUG process and attending key upcoming meetings and conference;
    c. Active engagement in scientific dialogs among climate change modeling community, i.e. on harmonization efforts for land cover among the ESM and IAM communities.
2. Critical user review of the land cover CCI production process and implications for specifications (WP 3500):
    a. Selected users will be invited to participate the product development, implementation and validation and asked to provide input and feedback at different points during the process.
3. User application and feedback mechanism from the users on the use of the products and related potentials and limitations (WP 4500-4700):

a. Key users will be asked to use the products generated in their applications to provide first indications on the potentials and limitations;

b. Final discussions with the users will yield feedback on the products and results in a set of recommendations to further improve ECV land cover monitoring beyond this project.

The purpose of this report is to present the experiences and results of the first step noted above and more detailed in Figures 3 and 4.

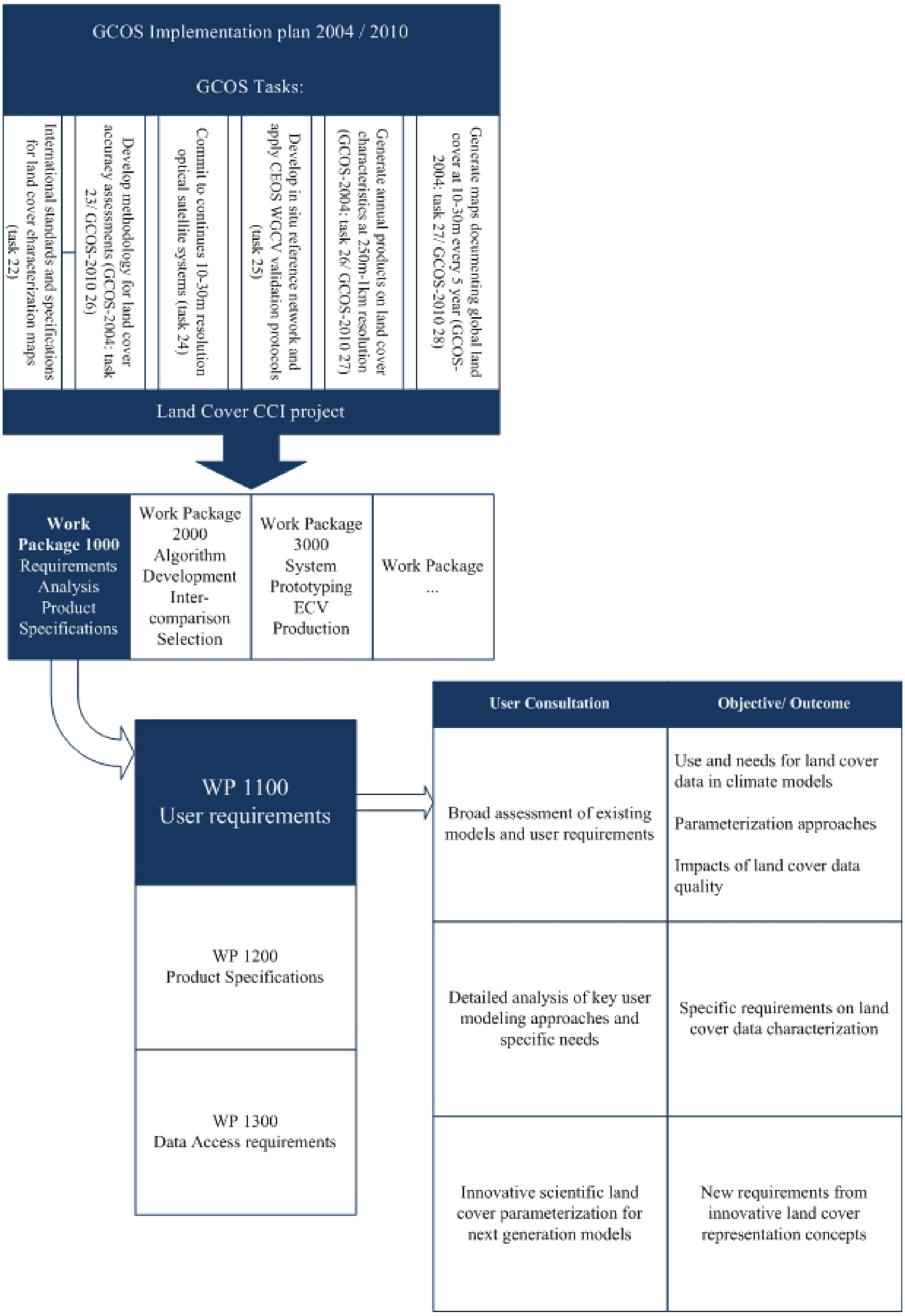


Figure 3: Concept of user requirement assessment as part of the overall 'breakdown' structure of Land Cover CCI project

1.4. Types of users representing the climate model user groups

Several actors and types of users can be identified as representatives of the modeling communities concerned with climate and climate change issues. Potential users that define model requirements originate from groups specialized in different fields of science: e.g., working in weather prediction, Global Circulation Modeling (GCM), Regional Climate Modeling (RCM), Global and Regional Earth System modeling, Carbon Cycle Modeling, Dynamic Vegetation and Hydrology modeling and others.

Potential users of the new land cover products are also model development application groups working in numerical weather prediction (NWP), GCMs and RCMs, global and regional Earth System models, carbon cycle models and dynamic vegetation and hydrology models. With regard to climate and ESM, this comprises (1) groups participating in the global and regional (CORDEX) IPCC activities for the forthcoming 5th assessment report and (2) groups participating in the EU projects ENSEMBLES (http://ensembles-eu.metoffice.com/) and PRUDENCE http://prudence.dmi.dk/). With regard to hydrology models, potential users are groups participating in the EU project WATCH (http://www.eu-watch.org/) and the associated WaterMIP (Water Model Intercomparison Project). NWP groups involve national weather services as well as the European Centre for Medium-Range Weather Forecast (ECMWF). The list of such potential users is provided in Appendix D.

From this large array of different users, model usage can be conceptualized at a different levels of model engagement:

1. Key users: they are central to all phases of the user interaction within the project and are integral part as partners in the project. They are the Max Planck Institute for Meteorology (MPI-M), the Laboratoire des Sciences du Climat et de l'Environnment (LSCE) and the Meteorological Office Hadley Center (MOHC). Key users are directly involved in the product specifications, product assessment and the final user assessment of the product. Most of these users are also member of the CMUG.

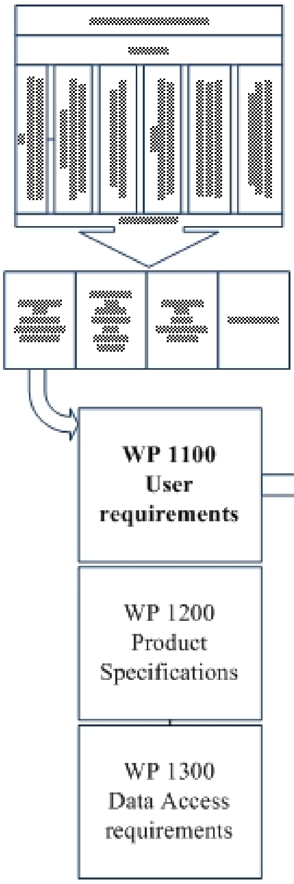
2. Associated users: These users maybe participating in meetings and in the user survey and their input would feed into the product specifications. These users are not partners in the project directly but could be engaged, in particular if involved in the user assessment of the products. This group is described in the list of Appendix D.

3. Broad user community: will be considered through information of the project through the World Wide Web and through reviewing scientific literature, participation in meetings to synthesize requirements for the product specifications and through receiving feedback from general global land cover data users. This group of users would also include known user requirements coming not directly from climate modelers but the "climate concerned" users such as those making use of land cover information for other societal benefits or national reporting and accounting.

The user consultation will address a broad range of issues due to the nature of the interactions of land cover and climate. Consequently, land cover user requirements for climate modeling and climate research are expected to be diverse and this complexity is reflected in the user consultation plan as presented in Figure 3 and detailed out in the next sections.

2. Methodology

The Land Cover CCI project is based on the progress that has been made in terms of land cover characterization and validation procedures and addresses critical tasks which have not achieved sufficient progress up to date. The plan for a thorough and complete user requirements analysis for developing the final product specifications uses a range of sources and mechanisms. There are also different levels of how users representing the climate research community will be involved in this process (Figure 4).



User Consultation	Objective/ Outcome	Method	Users
Broad assessment of existing models and user requirements	Use and needs for land cover data in climate models Parameterization approaches Impacts of land cover data quality	Detailed literature review and analysis strategic documents Assessing GTOS and GCOS requirements Participation climate modeling community meetings User survey for land cover product users	Broad Climate modeling community
Detailed analysis of key user modeling approaches and specific needs	Specific requirements on land cover data characterization	Participate in the CMUG process User requirements and product specification meeting Conduct a detailed user survey	Key users Associated users
Innovative scientific land cover parameterization for next generation models	New requirements from innovative land cover representation concepts	Active engagement in scientific dialogs Literature review	Key users Associated users Broad climate modeling community

Figure 4: Overview of the user requirement assessment methodology for consultation of the climate modeling community

2.1. Broad assessment of user requirements

As indicated in the previous section, several actors and types of users are involved in representing the modeling communities concerned with climate and climate change issues. The user consultation dialogue (Figure 4) for Land Cover CCI was coordinated by WUR in close cooperation with the Hadley Center (UK) that is represented in CMUG.

The broad assessment of existing models and user requirements aims at looking, into the range of approaches, how land cover data have been used in climate models. This assessment includes different modeling approaches and communities, i.e. Global Circulation Models, Earth System Science models, Climate prediction and forecasting models, and integrated Impact Assessment Models. The following activities have been carried out for the broad user assessment:

1. The analysis of strategic earth observation documents of relevance:
    a. GCOS requirements as presented in the GCOS Implementation Plan 2004 (GCOS 2004), and GCOS Implementation Plan 2010 (GCOS 2010b);
    b. GCOS Principles and Needs derived from Guideline for the Generation of Datasets and Products Meeting GCOS Requirements (GCOS 2010a);
    c. GTOS requirements, (Herold et al. 2009), GTOS
    d. CMUG requirements (CMUG 2010);
    e. IGOS-P themes on land (Townshend 2008), IGOS-P_IGOL
    f. IGOS carbon theme, (Ciais and Moore 2004)
2. Detailed literature review of land cover representation in climate modeling, land cover parameterization approaches and studies that looked into the impact of land cover data on climate modeling results.
3. Broad land cover product user survey: user survey on requirements for next generation land cover products with special attention for climate and earth system modeling issues under the user community for the ESA GlobCover product. The set-up and questions for this survey are presented in Appendix A.

This broad assessment of user requirements ensures that the full range of needs are considered and understood for deriving the detailed product specifications.

2.2. Key user requirements consultation

The second step in the user consultation process for the product specifications included the partners and processes directly involved or associated with the ESA CCI program and Land Cover CCI project. The aim was to provide a detailed user needs assessment and identify specific requirements coming from the key users of land cover products of the project.

Three main mechanisms have been carried out for user consultation of the key and associated users (section 1.4) of the climate modeling community:

1. Participate in the CMUG process by active contribution to the ESA co-location meeting;

2. An user interaction and product specification meeting was executed out as part of the project with representation of key users to discuss the Land Cover CCI product characteristics as dialog among users and producers;
3. A detailed user survey was conducted on the specific requirements for land cover data characteristics to be used (e.g., spatial, temporal, thematic detail, accuracy requirements). The detailed survey for the key-users (Appendix C was conducted through email while for the associated users a more concise survey was prepared (Appendix B) which was made available to the community (Appendix D) as an online survey. The composition of the two user groups has been described in section 1.4.

This part of the user consultation has provided the requirements based on existing model applications requiring land cover data and future needs as identified by this community. These users will also form the primary partners in the user validation and assessment phase to evaluate the Land Cover CCI products in dedicated model applications during next phases of the project.

2.3. Next generation model requirements

In the final step, the user consultation targeted at the set of requirements for the next generation models. This is driven by the notion that the CCI products will need to consider not only today's but future user requirements. New modeling concepts have triggered discussion to improve the existing land cover characterization and parameterization concepts. Improved observations addressing a range of requirements can play an important role in that process and, therefore, the outcomes presented will also consider user requirements of the next generation modeling approaches. This has been implemented through an active engagement in scientific dialogs among the climate modeling community, i.e., on harmonization efforts for land cover among the ESM and IAM communities and on improved concepts of land cover parameterization (Hibbart et al., 2010). Furthermore, the user requirements of the next generation modeling approaches have been distilled from a broad array of (scientific) literature. And finally, some specific questions in the key and associated user surveys were referring to land cover requirements for future climate modeling concepts.

3. Results of user consultations

The overall objective of the broad user requirement assessment is to identify how land cover data is currently used by the climate modeling community and what the future requirements for land cover data are for climate and earth system modeling.

In this chapter, first (section 3.1) some core chapters on land cover monitoring from leading strategic earth observation documents are presented. The GCOS requirements on land cover data are provided from the GCOS implementation plan 2004 and from the updated version of 2010. For completeness, the GCOS needs and principles on land cover data are also presented. Furthermore, the GTOS requirements on ECV land cover data standardization frameworks are given, followed by the CMUG, IGOS-P requirements for the Land and Carbon theme and the Integrated Global Carbon Observation (IGCO).

In section 3.2 the results of the broad user survey are summarized an visualized. This broad assessment of user requirements ensures that the full range of needs are considered and understood for deriving the detailed product specification. The results are displayed below accordingly.

Section 3.3 provides the results of the assessment of the climate modeling community requirements. This includes the results of the key and associate user consultation (3.3.1 and 3.3.3). Section 3.3.2 provides the summary of the comparison of model parameters versus land cover. Furthermore, section 3.3.4 includes a literature review including issues on land cover representation in climate modeling, land cover parameterization approaches and studies that looked into the impact of land cover data on modeling results.

3.1. Analysis of GCOS and other earth observation strategic documents

3.1.1. GCOS implementation plan and accuracy needs

The Global Climate Observing System (GCOS) is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). In consultation with its partners, GCOS has prepared two implementation plans (GCOS IP 2004, GCOS IP 2010) that addresses the requirements identified in the Second Report on the Adequacy of Global Observing Systems for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC). This Plan, if fully implemented by the Parties both individually and collectively, will provide the global observations of the Essential Climate Variables and their associated products, to assist the parties in meeting their responsibilities (under Articles 4 and 5) of the UNFCCC. In addition, it will provide many of the essential observations required by the World Climate Research Programme (WCRP) and Intergovernmental Panel on Climate Change (IPCC).

Table 1: Key tasks for land cover theme defined in the GCOS Implementation Plan (2004 and 2010), progress reported in 2009 (for COP 15 in Copenhagen), and how these tasks are taken up by Land Cover CCI project

GCOS Implementation Plan task (2004)	Status reported in recent progress report (2009)	Issues addressed by Land Cover CCI
Action T22 International standards for land cover maps ***In IP 2010, T22 was removed***	The UN LCCS (under ISO) provides the required standards and specifications *(good progress).*	LCCS classifiers, generic classes and related legends targeted at user requirements will be used to develop the product
Action T23 Methods for land cover map accuracy assessment ***In IP 2010, defined as T26***	Standard validation protocols, methods and best practices have been developed by the CEOS Working Group on Calibration and Validation (WGCV), working with GOFC-GOLD *(good progress).*	The project is using a comprehensive validation approach that is independent, internationally agreed and repeatable.
Action T25 Development of in situ reference network for land cover ***In IP 2010, T22 is reflected in ecosystem observing network***	As a start, GOFC-GOLD and CEOS WGCV have developed the framework for an in situ reference network for operational global land cover validation. *(low progress)*	For the product validation, a comprehensive approach making best use of existing resources and aiming at developing an operational reference network is applied
Action T26 Annual land cover products ***In IP 2010, defined as T27***	There are several global land cover products at the requested resolution including GlobCover and MODIS *(moderate progress)*	The activities are building upon the GlobCover heritage, cooperating with the MODIS team, and aiming at annual global products.
Action T27 Regular fine-resolution land cover maps and change ***In IP 2010, defined as T28***	No concerted action towards a global product at the required fine resolution (10-30 m) has been achieved *(low progress)*	The issue of fine-scale land cover/land cover change is not specifically addressed here while some methodological steps could be extended to higher resolution data set.

As a starting point for the Land Cover CCI project, activities have been closely aligned with specific land cover tasks listed in the GCOS Implementation Plan of 2004 (GCOS 2004) (Table 1). In this plan, tasks were already listed which were an answer to up till then defined model requirements: the need to harmonize land cover monitoring (GCOS task 22), validation of models (GCOS task 23), model quality assessment (GCOS task 25), and the need for an annual land cover product (GCOS task 26). This user requirement assessment will build upon this heritage, in order to fully capture the requirements needed to model the important climate variables for land cover monitoring. The implementation needs to be building upon progress made to define standards for characterizing land cover and for validation procedures (GCOS Implementation Plan, tasks 22 and 23). The project further addresses critical tasks that have not achieved sufficient progress to date, i.e., on the implementation of an operational reference network and validation, and to create annual maps of global land cover. These critical tasks are taken up in the GCOS Implementation Plan 2010 (GCOS 2010b).

The following paragraphs explain the different GCOS tasks in more detail.

Harmonized land cover monitoring (T22, IP 2004)

There is need for both maps (static and updated) and dynamic monitoring products. The development and derivation of the mapping products need consistency in land cover characterization to be inter-operable as part of an integrated global observing system. The broad areas and topics requiring international consensus are outlined in the GTOS document on standards for observing land cover as ECV with focus on the thematic product ((Herold et al. 2009), GTOShttp://www.fao.org/gtos/ECV-T09.html). This document emphasizes that land cover is defined as the observed (bio)-physical cover on the Earth's surface, see also the section on the GTOS requirements. It includes vegetation and man-made features as well as exposed rock, bare soil and inland water surfaces. The primary units for characterizing land cover are categories (such as forest or open water) or continuous variables classifiers (e.g. fraction of tree canopy cover). The UN LCCS classifiers (http://www.glcn.org/sof_1_en.jsp) provide a comprehensive and flexible framework for thematic land cover characterization. LCCS classifiers enable better compatibility to be achieved between existing datasets and for future global monitoring systems. This issue will be particularly important for the legend development of the ECV Land Cover product. The definition of the target legend is constrained by three issues. It is dependent on the purpose of application of the land cover map, in this case land cover parameterization for the targeted user communities and their model requirements. Different user groups may have different requirements that will be assessed as part of the project. Secondly, the LCCS classifier concept is to be used as suggested by GTOS (Herold et al. 2009). Thirdly the information for all desired classes must be available and separable from the input observation data sets to derive a product of sufficient quality. There is also a need to ensure synergy with other ECV observation products (i.e. Fire, Biophysical Parameters, Snow Cover) that are directly related to land cover characteristics.

Validation (T23, IP 2004/ T26, IP 2010)

The thematic validation of the products is required to be on independent nature, follows international standards where existing and uses existing references datasets and related experiences as much as possible. However, the independent accuracy assessment for monitoring land cover as ECV poses additional requirements and challenges. The validation exercise needs to explore the options to perform validations for multiple dates in time. For historical periods the availability of reference data sets (i.e. for the 1990's) is rather limited. For the future there is need to develop the foundations and start implementing on operational monitoring that ensures that progressing annual global land cover datasets can assessed consecutively. For the validation of land cover change, different protocols and approaches will need to be used.

Independent quality assessment (T25, IP 2004)

There is need for an independent quality assessment to ensure that the required standards are met, and that uncertainties are quantified and reduced as far as practicable. While diversity and redundancy is useful for building a sustained global land cover monitoring system and to ensure flexibility in incorporating evolving technologies, there also needs to be an independent assessment mechanism led by the international community. This mechanism should provide a comparative assessment and validation of individual products and work towards synergy to ensure that a common framework is used for global assessments, and that the "best global estimates" are made available based on the current stage of knowledge, data and information. The basis for such efforts consists of sustained global network of calibration and validation sites, international agreement and standards and approaches for land cover characterization and validation, and an internal coordination mechanism, currently lead by GOFC-GOLD and the Land Validation sub-group of the CEOS WGCV.

Table 2: GCOS Requirements for land cover assessment with regard to current performance capability (source: ESA 2009) and precursor products (based on MERIS, MODIS and SPOT-VGT time series) experience

GCOS requirements		Current status		
		VEGETATION	***MERIS***	***MODIS***
Class accuracy (max. error for individual classes)	15% omission / commission per class	GLC2000 74% weighted across all classes	GlobCover 74 % weighted across all classes	MODIS v5 75% overall accuracy
Spatial resolution	250m-1km	1 km	300m	500m
Geometric accuracy	Better than 1/3 IFOV	300m	70m	50-100 m
Temporal resolution	1 year observing cycle	Yearly 2000	Yearly 2005 + 2009	Yearly 2002 to 2009
Stability	As class accuracy	Not specified No inter-comparison possible		

Annual land cover products (T26, IP 2004/ T27 IP 2010)

Several global land cover products are currently available at the requested resolution including GLC2000, GlobCover and MODIS land cover products. Existing global land cover products partially meet the GCOS requirements in terms of performance, as illustrated in Table 2. It indicates that none of the available land cover products meet the requirements expressed by GCOS in terms of class accuracy and stability. The Land Cover CCI activities are building upon the GlobCover heritage, cooperating with the MODIS team, and aiming at consistent annual global products. Particular attention will be paid to these two issues, by making the best use of spectral and temporal information content in existing EO time series (through suitable pre-processing and classification processes) and by specifically addressing the issue of inter-annual stability. Yet, it has to be stated that not all land cover classes have the same importance from a climate modeling perspective. To this end, the project will also require the definition of a legend. According to GCOS, a common language for class definition should be used, and thematic detail should be regionally adapted in order to satisfy requirements of international conventions, and as far as possible be harmonized with regional classification schemes presently in use (See the Annex J on Land Cover of the CCI statement of work (EOP-SE 2009b, a). Furthermore it is expected that the product stability over time will be strongly affected by the intrinsic quality of the EO time series available for a given period.

With respect to the potential spatial resolutions required by modelers and with respect to the key associated issues that need to be considered in the ECV development in respect of the model needs, the following GCOS product framework is provided (see Figure 5) (EOP-SE 2009a). Hereby, the key principle of consistency across spatial scale, time and between ECVs shall be paramount. The land cover product definitions must accordingly concentrate principally on the determination of land cover using MERIS FR and RR and VEGETATION data and in merging these data. Hereby,

- VEGETATION data shall be used from 1998 to 2001.

- A merged VGT and MERIS RR product shall be developed from 2002 onward.
- From 2005 onward MERIS FR shall be used in priority in order to get the high resolution benefits (accuracy target) in concomitance with spectral information coming from VEGETATION and more data coming from MERIS RR.

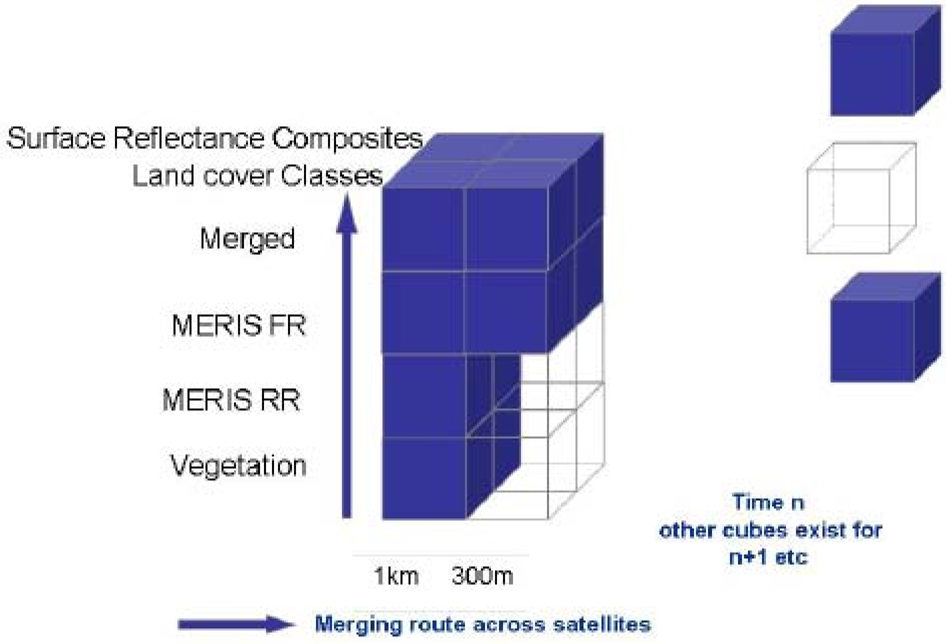


Figure 5: GCOS product framework considering potential spatial resolutions required by modelers and key associated issues that need to be considered in the ECV development with respect to the climate modeling needs

3.1.2. GCOS principles

General guidance for the generation of Fundamental Climate Data Records (FCDRs) and derived ECV products based on surface-based, airborne and satellite-based observing systems, and subsequent quality assessment by providers as well as users, is given by the GCOS requirements explained in the previous section as recommended in the GCOS_IP 2004 (GCOS 2004) and its 2010 update GCOS_IP 2010 (GCOS 2010b) and the Satellite Supplement (see for an overview of all documentation related to GCOS needs overview GCOS climate observation needs). These requirements are based on a broad consensus by the international climate community; and are reviewed on a regular basis. As part of this, to ensure full documentation, transparency and scientific stewardship in the generation (and update) of FCDRs and ECV products, the GCOS Steering Committee recommends that data producers pay particular attention to the 12 needs enumerated below and provided in the Guideline for the Generation of Datasets and Products Meeting GCOS Requirements (GCOS 2010a).

GCOS Principles and Needs

1. Full description of all steps taken in the generation of Fundamental Climate Data Records FCDRs and ECV products, including algorithms used, specific FCDRs used, and characteristics and outcomes of validation activities;
2. Application of appropriate calibration/validation activities;

3. Statement of expected accuracy, stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements;
4. Assessment of long-term stability and homogeneity of the product;
5. Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality and applications;
6. Global coverage of FCDRs and products where possible;
7. Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing;
8. Arrangements for access to the FCDRs, products and all documentation;
9. Timeliness of data release to the user community to enable monitoring activities;
10. Facility for user feedback;
11. Application of a quantitative maturity index if possible;
12. Publication of a summary (a webpage or a peer-reviewed article) documenting point-by-point the extent to which this guideline has been followed.

3.1.3. GTOS requirements

The Global terrestrial Observing System (GTOS) is a programme for observations, modeling, and analysis of terrestrial ecosystems to support sustainable development. GTOS facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change. GTOS and FAO define land cover as the observed (bio)-physical cover on the Earth's surface. It includes vegetation and man-made features as well as exposed rock, bare soil and inland water surfaces. The primary units for characterizing land cover are categories (such as forest or open water) or continuous variables classifiers (e.g., fraction of tree canopy cover). Secondary outputs of land cover characterization include surface area of land cover types (hectares), land cover change (area and change trajectories), and observation by-products such as field survey data or processed satellite imagery.

With respect to land cover monitoring, the recent GTOS report (Herold et al. 2009) presenting suggestions for more systematic and standardized acquisition of ECV's provides the current summary for the level of standardization and desired observations as a general assessment of the UNFCCC requirements and needs (see also Figure 5). GTOS emphasizes the need for coordinated observations. An operational global land cover monitoring integrates information from different observation scales, i.e. integrating coarse and fine scale satellite data and in situ data. ECV monitoring assumes the use of all useful data sources - from historical archives, present assets and future monitoring programmes in a seamless and consistent manner. Acquisitions and the derivation of standard products should be coordinated among space agencies (e.g., with support of GEO, CEOS).

Table 3: Characteristics of land cover mapping and monitoring products useful for observing land cover as an ECV (adopted from Herold et al., 2009)

Name	Spatial resolution	Frequency of product update	Maturity
Mapping of land cover			
Land cover maps	250m - 1 km	annual	pre-operational
Fine-scale land cover and land use maps	10-30 m	3-5 years	pre-operational (for land cover)
Global land cover reference sample database	In-situ/1 m	1-5 years	pre-operational (CEOS, GOFC-GOLD)
Monitoring of dynamics and change			
Global land cover dynamics and disturbances	250m - 1 km	intra-annual/ long-time series	pre-operational (for several processes)
Fine-scale land cover and land use change	10-30 m	1-5 years	pre-operational (for land cover)
Monitoring areas of 'Rapid change'	1-30 m	1-2 years or less	pre-operational (for some change processes)

Integrated and standardized mapping and monitoring refers to the need on static and updated maps and dynamic monitoring products at different spatial and temporal scales. These outputs require different sets of observations and monitoring approaches. The development and derivation of the mapping products need consistency in land cover characterization to be interoperable as part of an integrated global observing system. The broad areas and topics requiring international consensus are outlined in the GTOS document on land cover (Herold et al. 2009). There is also a need to ensure synergy with other ECV observation products (i.e. Fire, biophysical parameters, Snow Cover) that are directly related to land cover characteristics.

The issue of independent quality assessment follows the need to ensure that the required standards are met, and that uncertainties are quantified and reduced as far as practicable. Considering the suite of important land cover information (Figure 5), there is expected to be a diversity of products contributing to ECV monitoring. While diversity and redundancy is useful for building a sustained global land cover monitoring system and to ensure flexibility in incorporating evolving technologies, there also needs to be an independent assessment mechanism led by the international community. This mechanism should provide a comparative assessment and validation of individual products and work towards synergy to ensure that a common framework is used for global assessments, and that the "best global estimates" are made available based on the current stage of knowledge, data and information. The basis for such efforts consists of sustained global network of calibration and validation sites, international agreement and standards and approaches for land cover characterization and validation, and an internal coordination mechanism.

One important requirement in the GTOS and FAO related requirement is the fact that land cover information has to be compatible and comparable for multi-temporal analysis and map updates, within and among countries, within and between applications, disciplines and agencies, and across local to global scales (vertical and horizontal harmonization). In general, harmonization is a "bottom-up" process of emphasizing similarities and reducing inconsistencies between existing definitions of land cover to allow for better comparisons and compatibility between various land cover datasets (Herold 2006). Harmonization efforts should first address the terminology, or classifiers, used for the description of land cover and, once applied to systems and legends, the individual criteria used for creating land cover categories should be harmonized and applied in operational observing programmes.

The Land Cover Classification System (LCCS, (Di Gregorio 2005)) and the related ontology specified in Land Cover Macro Language (LCML) is currently the most comprehensive, internationally applied and flexible framework for land cover characterization. It defines a system of diagnostic criteria (land cover classifiers) that provides standardization of terminology and not categories. At this level, existing land cover data can be much better compared. The Land Cover Data Macro Language is undergoing approval to become a standard of the International Standards Organization (ISO).

A translation of existing land cover legends and data into the LCCS language usually provides the first step in developing understanding needed to apply the classifier concept, and many existing global, regional and national land cover legends have been developed or translated using LCCS (see http://www.glcn.org/sof_1_en.jsp). An agreement on a set of recommended classifiers provides the common ground for compatibility of land cover data. Current international consensus on classifiers that meet global mapping land cover requirements include:

- Vegetation life form: trees, shrubs, herbaceous vegetation (may be separated into grasslands and agricultural crops), lichen and mosses, non-vegetated;
- Leaf type (needle-leaf, broad-leaf) and leaf longevity (deciduous, evergreen) for the different vegetation life forms;
- Non-vegetated cover types (bare soil or bare rock, built up areas, snow, ice, open water);
- Density of life form and leaf characteristics in percent cover;
- Terrestrial areas versus aquatic/regularly flooded;
- Artificiality of cover and land use.

The agreement and application of these classifiers have resulted in a number of generic land cover categories that should be considered in future mapping efforts:

- Trees (further separated by leaf type and leaf longevity);
- Shrubs (further separated by leaf type and leaf longevity);
- Herbaceous vegetation (further separated into grasslands and agricultural crops);
- Bare areas;
- Built up areas;
- Snow and/or Ice;
- Open water.

These categories are defined independently of the mapping scale, and any application of a minimum mapping unit will eventually result in mixed unit categories of these generic classes, i.e. through specifying cover percentages for the mapping units. Figure 6 illustrates the concept of moving from a terminology standard, to a thematic standard, and a cartographic standard, thus defining mapping categories from a common basis and common understanding. The figure also provides the basic concept for the development of a legend that allows mapping to be consistently categorized internationally, while leaving the opportunity for provision of additional categorical detail, e.g., accommodating regional specific characteristics or national monitoring requirements. This general approach is suggested for all operational land cover observation activities. Instead of mapping categories, the data analysis may be performed at the level of individual classifiers (i.e. tree cover, shrub cover, herbaceous cover, etc.) and can entail specific density thresholds (e.g., tree cover 15-40 percent) or on a continuous range.

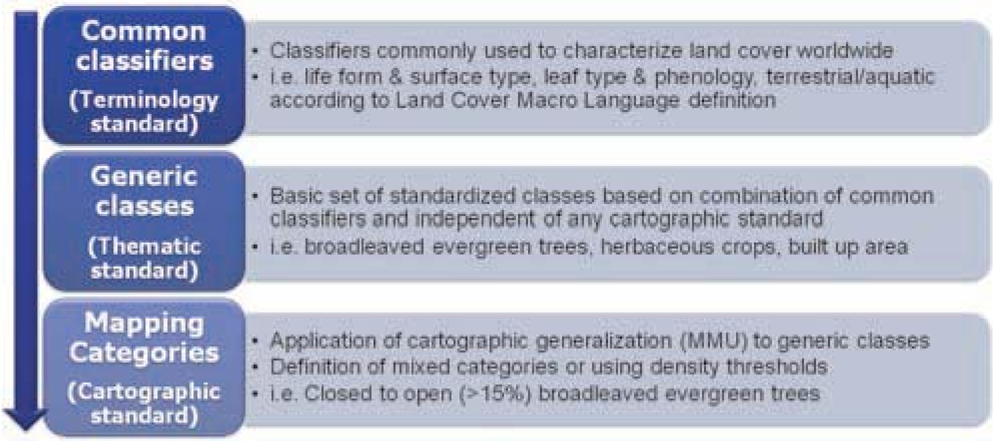


Figure 6: Concept of linking and characterizing land cover mapping categories through common classifiers, the definition of generic classes and the application of a cartographic standard (adopted from (Herold et al. 2009))

In creating requirements for next generation earth system and climate models, the following key science bodies must be consulted according to ESA's climate change initiative statement of work for Land Cover CCI (EOP-SE 2009a) :

- International Geosphere Biosphere Programme (IGBP) is the international research program studying global change across the Earth System. Key projects with reference to land cover include the Analysis Integration and Modeling of the Earth System (AIMES) and the Global Land Project (GLP).
- Global Observations of Forest and Land Cover Dynamics (GOFC-GOLD) is a project of the Global Terrestrial Observing System (GTOS) program. The main goal of GOFC/GOLD is to provide a forum for international information exchange, observation and data coordination, and a framework for establishing the necessary long-term monitoring systems (follow this link for documentation of the GOFC-GOLD land cover implementation team).

3.1.4. IGOL requirements

The Integrated Global Observing Strategy (IGOS) is a strategic planning process initiated by a partnership of international organizations that are concerned with the observational component of global environmental change issues. It links research, long-term monitoring and operational programmes, bringing together the producers of global observations and the users that require them to identify products needed, gaps in observations, and mechanisms to respond to the needs of the science and policy communities. Its principal objectives are to address how well user requirements are being satisfied by the existing observation systems, and how they could be met more effectively in the future through better integration and optimization of satellite, airborne and in situ observation systems.

The IGOS Land Theme was initially proposed in November 2003 on the recognition that IGOS-P had not yet considered many observational needs relating to many aspects of the land, such as sustainable economic development, natural resources management, conservation and biodiversity. The IGOS report on land (Townshend 2008) outlines the observational requirements for a large range of uses including agriculture, forestry, land degradation, ecosystem goods and services, biodiversity and conservation, human health, water resource management, disasters, energy, urbanization and sustainable human settlements. To satisfy these needs there is considerable overlap in the types of observations needed by different users and hence assessment of the needs for enhanced observations is discussed under types of observations. Land cover products are recognized by IGOS as having a central role for all applications. Several observation needs and technical requirements are identified in the IGOS report. A critical requirement is identified to move from research to operational monitoring capabilities for land cover, with operational data and product suites that are better defined, flexible and openly available. Related implementation requirements include (Townshend and Brady 2006):

- coordinated and consistent land cover data acquisition, both from satellite and *in situ* observations;
- coordination of various international satellite assets for land cover monitoring at both mid (similar to Landsat) and moderate resolution (similar to MODIS);
- standardized mapping and derivation land mapping products;
- harmonization and synergy of existing land cover maps;
- rigorous validation of map products using internationally agreed procedures;
- improved match between data, data products and user needs, i.e. ensure adequacy and advocacy to serve international conventions.

Recommendations made by IGOS concerning **land cover** monitoring are:

- Develop acquisition strategies for land cover data that optimize coverage in time and space;
- Minimize interruption of mid (30-m)-resolution data;
- Ensure future continuity of Landsat-SPOT-type data deploy a remote sensing system designed for land cover mapping at 1:250 000 scale that includes a multispectral scanner with 50–100 m ground resolution and SAR with L-band frequency (10–50 m ground resolution);
- Coordinate radar and optical data acquisition so that radar data can be used for regular, global monitoring of land cover;
- Agree upon an internationally accepted land cover classification system;
- Coordinate international collection of *in situ* data for calibration and validation efforts.

3.1.5. IGCO requirements

The overall goal of the Integrated Global Carbon Observation (IGCO) theme is similar to the overall goal of the ECV Land Cover project: to develop a flexible yet robust strategy for deploying global systematic observations of the carbon cycle over the next decade. Indeed, the most successful advances in understanding springs from the combination of data and models for the different domains, wherein results from one domain place valuable constraints on the workings of the other domains.

The strategy for a coordinated system of integrated global carbon cycle observations (Ciais 2010) is first of all carbon crosscut of GCOS, GTOS , and GOOS (GOOS) and secondly an identification of new components not previously identified. The coordinated system of global carbon observations will be built around complementary core groups of observations to address three themes: fluxes, pools, and processes.

Fluxes

The first set of observations enables quantification of the distribution and variability of CO_2 fluxes between the Earth's surface and the atmosphere. As part of this, land cover products are needed to create a combination of satellite observations, backed up by a long-term continuity of measurements, delivering global observations of parameters that are required to estimate surface-atmosphere CO_2 fluxes where direct in situ measurements are scarce. The crucial satellite observations that are required for this are among others: land cover status, disturbance extent and intensity, parameters related to vegetation activity, ocean color.

Pools

The second set of observations focuses upon changes in the key carbon pools, one of them being forest biomass. Forest biomass inventories are important for monitoring changes in the above-ground terrestrial carbon pool size. At present, however, these inventories are primarily designed to quantify the volume of merchantable wood in a given region with high accuracy (standard error of 1% at the national level). This quantity relates in a predictable manner to carbon stored in tree biomass. Allometric equations relating biomass to diameter, height and tree age factors are needed to convert these volume estimates into whole tree carbon content. Using constant conversion/expansion factors, as is usually done, results in large errors, since both wood density and expansion factors vary considerably with age and between species. Further, conversion of volume increment obtained from repeated inventories into carbon sequestration needs an extra set of expansion factors that take into account differences in turnover rates of different plant organs. Much work has yet to be done to create continuous, standardized, geo-referenced forest biomass and soil carbon inventories. It is critical to harmonize the widely varying methodologies for inventory and analysis, in order to synthesize carbon estimates based on national forest inventories. In addition, a major observational challenge is to establish allometric functions converting above-ground biomass to total biomass. Further work is also needed to expand the coverage over non-commercial forests and woodlands, over tropical forests, and to develop satellite technology (LIDAR or Radar) for remote sensing of biomass. SAR data are expected to contribute to estimating biomass. However, high resolution observation of forest by SAR has been fragmented in terms of temporal and spatial sense, and conditions of observation (incident angle, etc.) are different from one satellite to another. There is a need to build systematic, repetitive, spatially homogeneous and well coordinated global observation strategies for forest mapping by high resolution SAR.

Processes

The third set of observations in the system is measurements related to important carbon cycle processes. Most of these will remain in the research domain, to be coordinated within the framework of the Global Carbon Project. Two process-related observations, however, are more appropriate for the operational domain and will become part of the core set of the system. These can be monitored by using land cover products.

- Fire distribution (hot spots) and burned area extent, to estimate the fluxes of carbon that are emitted during fires. Fire hot spots will be measured on (sub) daily time steps, with fire extent at monthly intervals.
- Land-cover change, to estimate the fluxes of carbon associated with forest clearing and reversion of agricultural lands to natural ecosystems. The sampling interval will be 5 years with a spatial resolution of 1 km.

The challenge here is to employ in an operational mode satellite systems to monitor land cover changes (5-year time interval, 1 km spatial resolution) , fire hot spots (daily resolution) and burned areas (monthly resolution) The land-cover change observations should also emphasize forest/non-forest transitions at higher spatial resolution (25 m).

The ultimate goal of the coordinated system of global carbon observations is to generate data products that are of value for the user communities. Raw observations are rarely adequate on their own. To create usable products, in situ measurements from a variety of sources need to be integrated with remote-sensing observations within a modeling framework. To achieve this, a major challenge is to collect, process and harmonize in situ data from diverse sources. At present problems with in situ data include, among others, inconsistent parameter definitions, incomplete data, differing spatial and temporal scales and sampling bias in measurements.

3.2. Results of broader user assessment

The broad user survey aimed at obtaining user requirements coming not directly from climate modelers but the “climate concerned” users such as those making use of land cover information for other societal benefits or national reporting and accounting. This group represents the broad land cover data user community. The broad user survey consisted of 12 closed questions and was online for a period of 21 days (24th Sept. 2010 to 15th Oct. 2010). The survey can be found in Appendix A. The user survey was send to the list of registered GlobCover users with more than 8000 addresses. This group is perhaps currently the most active global land cover user community and quite suitable for border user requirements since the Land Cover CCI activities are building upon the GlobCover heritage. The total number of answered surveys was 372, from which 79 were only partially answered. These partially completed surveys are only included in the results for the completed answers. In Figure 7, the geographic distribution of the respondents to the survey is presented. The majority (48%) of the respondents is working in a University/ Research institute, and 21% is working in the commercial sector (Figure 8).

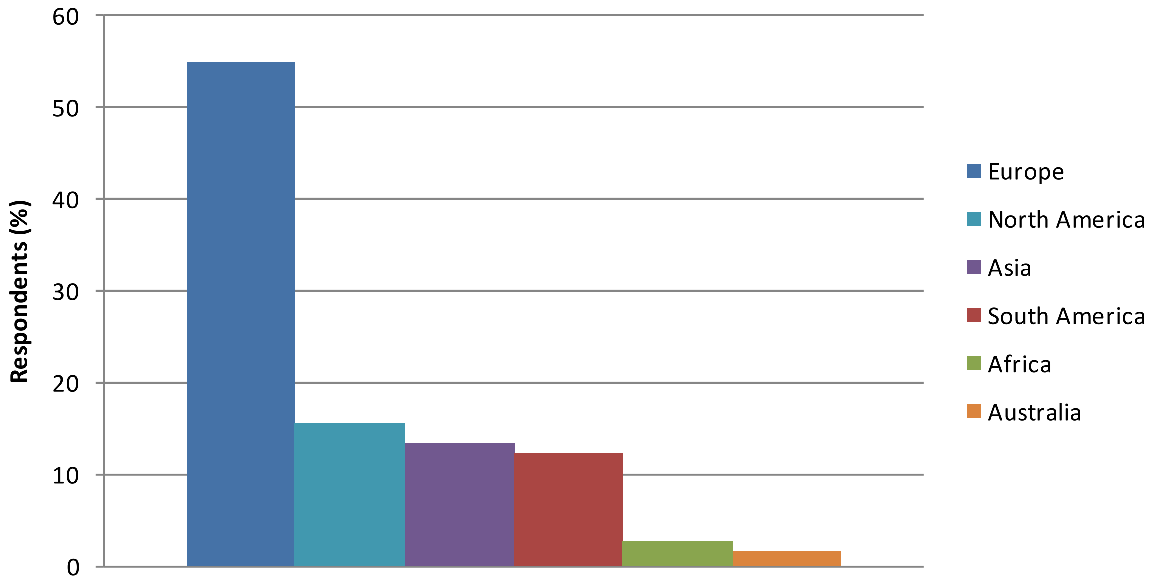


Figure 7: Global dispersion (per continent) of the users that completed the broad user survey

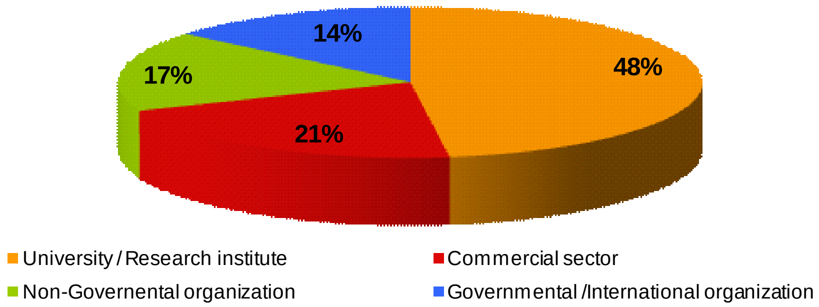


Figure 8: Type of employing institution of the respondents

The applications where the respondents use the GlobCover product for are mostly in the field of natural resources (28%) and Information technology/GIS (27%) followed by Remote Sensing (19%), Climate/ Meteorology/ Hydrology (16%), and Cartography (10%). In general, the majority of the respondents (70 %) indicate that the required spatial resolution of the land cover products should be smaller than 300 m (Figure 9). For 20% of the respondents the current global standard spatial resolution (300-1000m) would be sufficient. When looking at the application type, climate users tend to prefer a coarser spatial resolution while users working in the field of natural resources prefer a more detailed resolution.

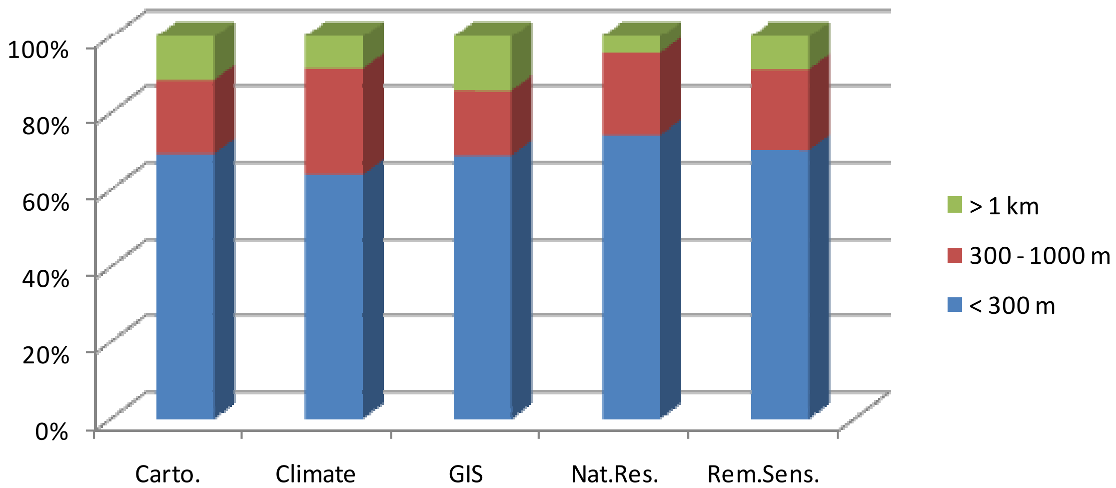


Figure 9: Preference for spatial resolution of land cover data per application type

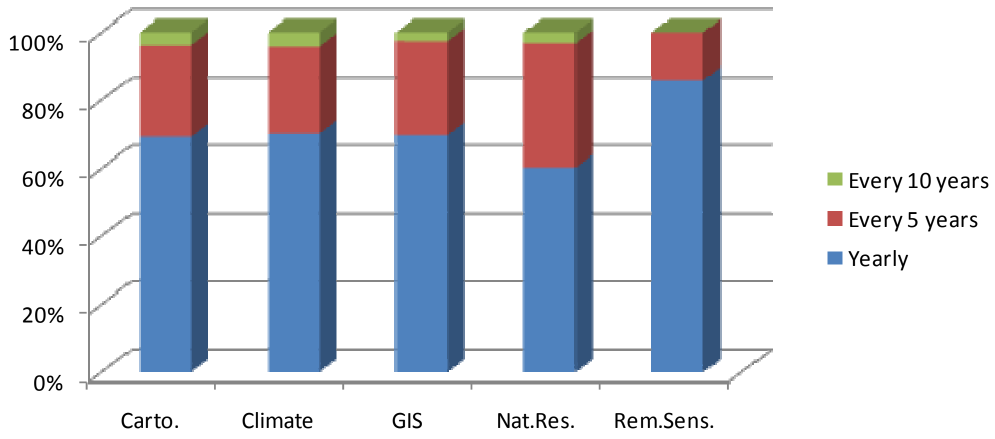


Figure 10: Update frequency required for land cover products per application type

On the question in what frequency updated versions of land cover products should be available, 70% of the respondents replied that a yearly update would be sufficient, while 27% of the respondents replied that a product every 5 years would be sufficient and only 8% of the respondents requires an update every 10 years (Figure 10). Users from the natural resources field prefer a less regular update frequency compared to the other applications fields.

With regard to defining classification requirements, the question was asked which land cover classes are most important for the application case of the respondent. From the results (Figure 11) it can be seen that most respondents are interested in all classes with no particular emphasis, while the tree classes are most important as an individual land cover class followed by agriculture, urban and wetlands.

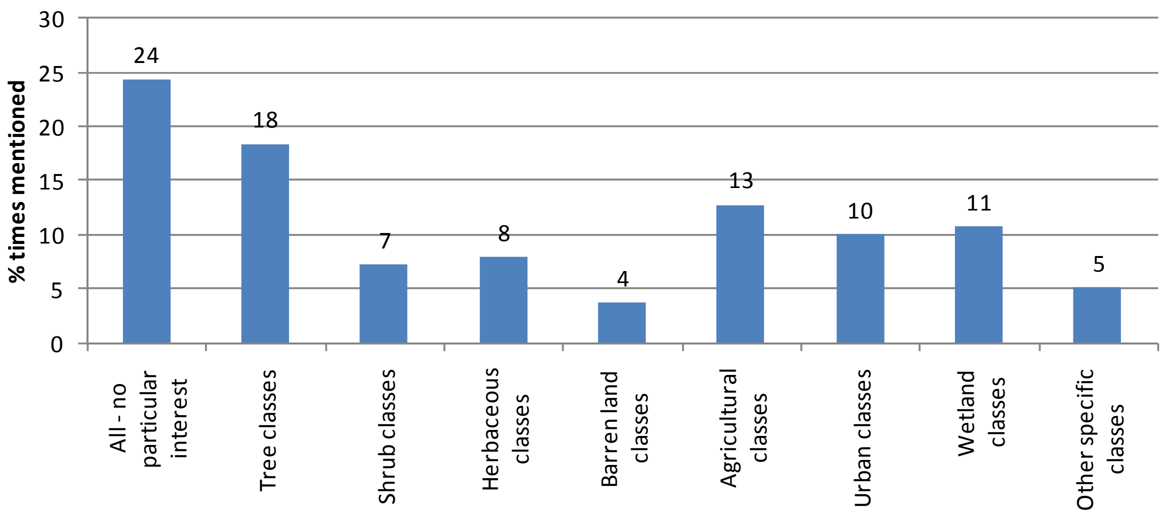


Figure 11: Importance of land cover classes for the respondents application field

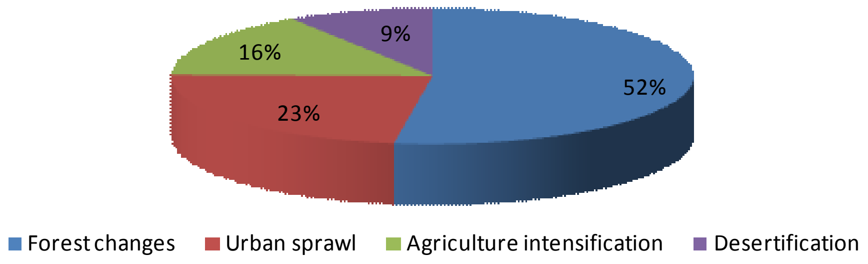


Figure 12: Land change dynamics in which broad users are most interested

In the field of land dynamics monitoring, the respondents are most interested in forest change monitoring (52% of the respondents), followed by urbanization and urban sprawl(23%). According to 91% of the respondents, the Land Cover Classification System (LCCS) is suitable to use for land cover classification. Of those respondents who disagreed with the use of LCCS as classification system, some of them suggested to use a classification based on the Corine Land Cover product. Comments on the use of LCCS were mainly on the (fuzzy) way in which the classes are defined, and a need for greater sensitivity to different vegetation classes in the LCCS.

Concerning the question on the preferred technique for downloading and the preferred file formats in which the land cover products should be available in the (near) future, the use of FTP servers in combination with GEOTIFF file formats or HTTP servers in combination with GEOTIFF formats was given as the preferred data access and delivery method (more than 90% of replies). Torrent servers and HDF-EOS, and NetCDF file formats are significantly less popular to use for data access and delivery.

3.3. Assessment of Climate modelling community requirements

The key user consultation for the product specifications includes the partners and processes directly involved or associated with ESA through CMUG and being partner in the Land Cover CCI project. They are the Max Planck Institute for Meteorology (MPI-M), the Laboratoire des Sciences du Climat et de l'Environnment (LSCE) and the Meteorological Office Hadley Center (MOHC). The objective of this key user consultation was to provide detailed requirements on land cover data characterization as defined by the key users of the project. This is done by (1) actively engaging in the CMUG process (2) organizing and implementing a key user interaction and product specification meeting to finalize the Land Cover CCI product characteristics as dialog among users (implemented primarily through meetings) and producers and (3) conducting a detailed user survey on the specific requirements for land cover data characteristics to be used in the key and associate user models (spatial, temporal, thematic detail, accuracy requirements).

3.3.1. CMUG requirements

ESA has established the "Climate Modeling User Group" (CMUG), to place a climate system perspective at the centre of the CCI program, and to provide a dedicated forum through which the EO Data Community and Climate Modeling Community can work closely together (see also CMUG 2010). CMUG consists of the different groups, being MOHC, MPI-M, ECMWF, MétéoFrance.

In a recent climate requirement baseline document (CMUG 2010), CMUG states that global land cover and land cover dynamics is an important variable for global and regional climate modeling over many time scales. Land cover information is used in climate models for the initialization as well as a boundary condition. The land cover information is hereby translated into surface parameters (e.g., albedo, LAI, fractional vegetation cover) which provide the lower boundary condition for the atmospheric models. Besides this, detailed regional land cover information provides very valuable information for process studies like e.g. the assessment of the impact of fires.

For land cover monitoring, CMUG defined several requirements for future land cover products. CMUG recommends that despite the fact that land cover data provides essential spatial patterns of different land cover types, land cover classes have to be translated into model relevant surface parameters that can be used in the model equations. Concerning the translation of land cover data into model parameters, it is recommends to make use of literature data (Hagemann 2002) or remote sensing based climatologies like ECOCLIMAP (Champeaux et al. 2005). These methods and conceptual frameworks are according to research done by CMUG (CMUG 2010) used by most climate and earth system modelers. Furthermore, GMUG expresses the need to have a land cover product that is consistent with surface parameters datasets and needs to match albedo, fapar, etc. and vice-versa. A variety of different global land cover products already exist (e.g. GLOBCOVER, MODIS) for limited time periods, but these products lack consistency in time.

Table 4: Requirements for satellite land cover parameters derived from CMUG user assessment report (CMUG 2010)

	Horizontal Resolution	Observing Cycle	Precision	Accuracy	Stability
Parameter	**CMUG**	**CMUG**	**CMUG**	**CMUG**	**CMUG**
Land cover type	300m – 1km	2-5 years	Not applicable	5-10%	<10%
Land cover change	-	-	Not applicable	-	-

CMUG also recommends combining land cover information with observed variability of land surface characteristics which would be essential to improve the description of land surface dynamics in climate models. While methods have been developed to retrieve consistent land surface parameters from satellite data these have not yet been combined with high resolution land cover information to generate a consistent, remote sensing based, land surface parameter data set which can be used as a boundary condition in climate models.

The CMUG requirements for satellite based land cover monitoring are given in Table 4 (CMUG 2010). Compared to GCOS requirements, the CMUG figures are very similar in all respects (Table 5). The Land cover CCI should aim at delivering a product meeting these requirements with a possible extension of the approach to longer timescales and an appropriate error characterization.

Table 5: Comparison of GCOS (GCOS-107, WMO database), CMUG (CMUG 2010), and CCI requirements (Source: CCI project meetings).

	Horizontal Resolution			Observing Cycle			Precision			Accuracy			Stability		
Parameter	**GCOS**	**CMUG**	**CCI**	**GCOS**	**CMUG**	**CCI**	**GCOS**	**CMUG**	**CCI**	**GCOS**	**CMUG**	**CCI**	**GCOS**	**CMUG**	**CCI**
Land cover															
Land cover type	250m - 1km (accuracy better than 1/ IFOV with target IFOV 250m)	300m - 1km	300m - 1km	yearly	2-5 years	5-years (2000,2005,2010)	not applicable	not applicable	not applicable	<15% omission and comission error for individual classes	5-10%	5-10%	<15%	<10%	<15%
Land cover change	10-30m IFOV (location accuracy bettem than 1/3 IFOV)	-	???	5-year	-	5-years (2000,2005,2010)	not applicable	not applicable	not applicable	<5% (mapping of individual classes)	-	5-10%	<5% (mapping of individual classes)	-	<15%

3.3.2. Results of key user survey

The key user survey was performed during September and October 2010, and consisted of 27 questions (mostly open questions). Six key-users from three organizations representing 4 climate models were consulated for this survey. All three organizations (Max Planck Institute for Meteorology (MPI-M), the Laboratoire des Sciences du Climat et de l'Environnment (LSCE) and the Meteorological Office Hadley Center (MOHC)) are also participating in the Climate Modelling User Group (CMUG) of ESA CCI. The answers to the questions were divided in answers on land cover product requirements for three different time-frames: (a) current status/used in current models, (b) requirements as needed to improve current modeling practices, and (c) requirements needed in 5 years time, also considering new modeling approaches. According to agreements made during land the Cover CCI kick-off meeting and to reflect the CMUG need that land cover data have different types of uses for climate modeling, the survey was divided in 4 different themes: (1) General land cover requirements for climate modeling, (2) Land cover as proxy for land surface parameters (3) Land cover as proxy for human activities, and (4) Land cover for validation of model outcomes. Specific questions were formulated to assess the requirements for all these elements. The complete key user survey is presented in Appendix C.

From the survey results it can be concluded that the key users that were consulted have a broad interest in earth system/ climate modeling and thereby represent to a broad extend the climate / earth system modeling community. Their main interest is in carbon (stock) modeling, vegetation modeling, plant-soil-carbon modeling, nutrient-cycling modeling and coupled earth system modeling (e.g. atmosphere-ocean-biosphere modeling). The most popular land cover products and –data that are currently used or have been used by the key users are developed in the time-frame 2000-2005 (Figure.13) but also older products are still commonly applied. The most frequently used dataset is the IGBP Discover and GLCC as provided by USGS. However, for most model application a combination of land cover datasets is adopted.

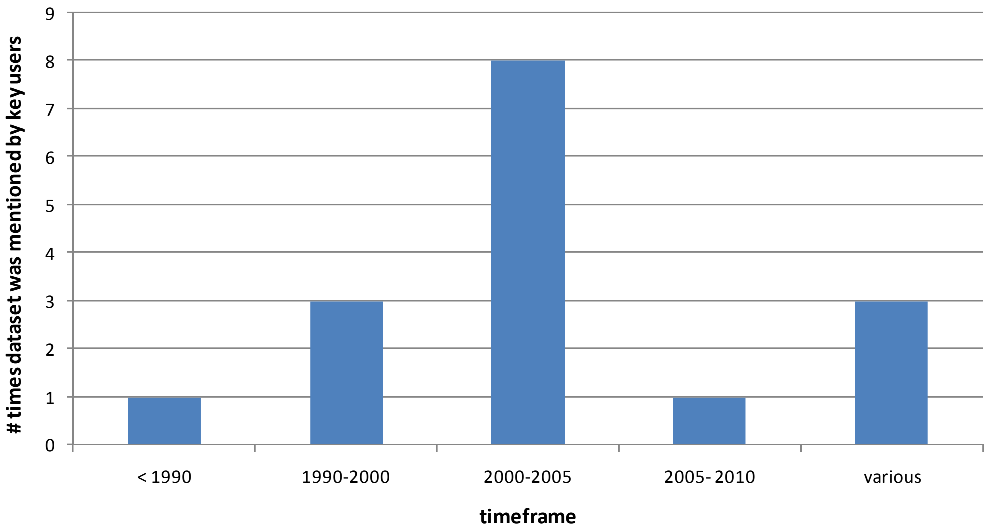


Figure 13: Time frame of the land cover products that are used or have been used by the key-users

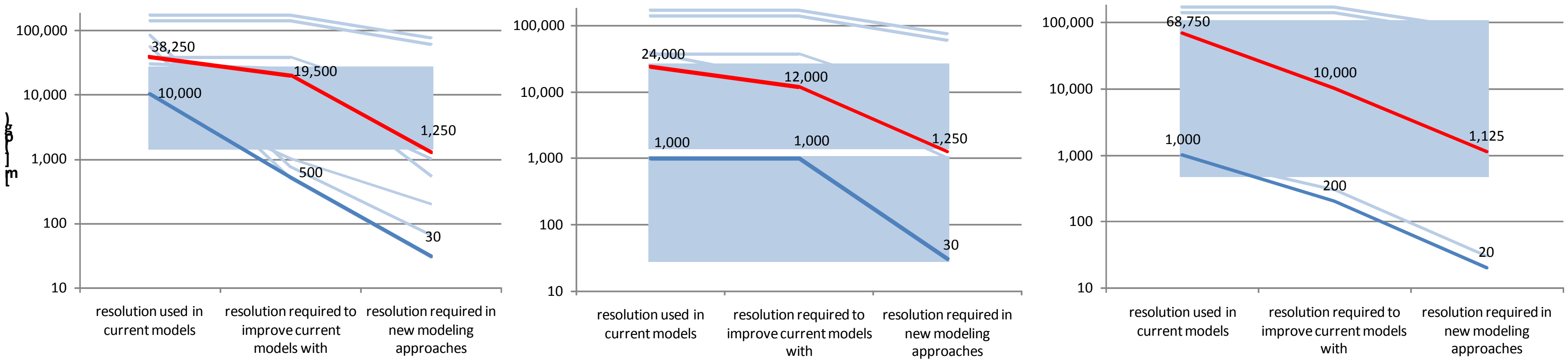


Figure 14: Spatial resolution currently used, required to improve current models with, and required in new modeling approaches for: (left) general modeling practices, (middle) parameter estimation, (right) land cover and land use change detection

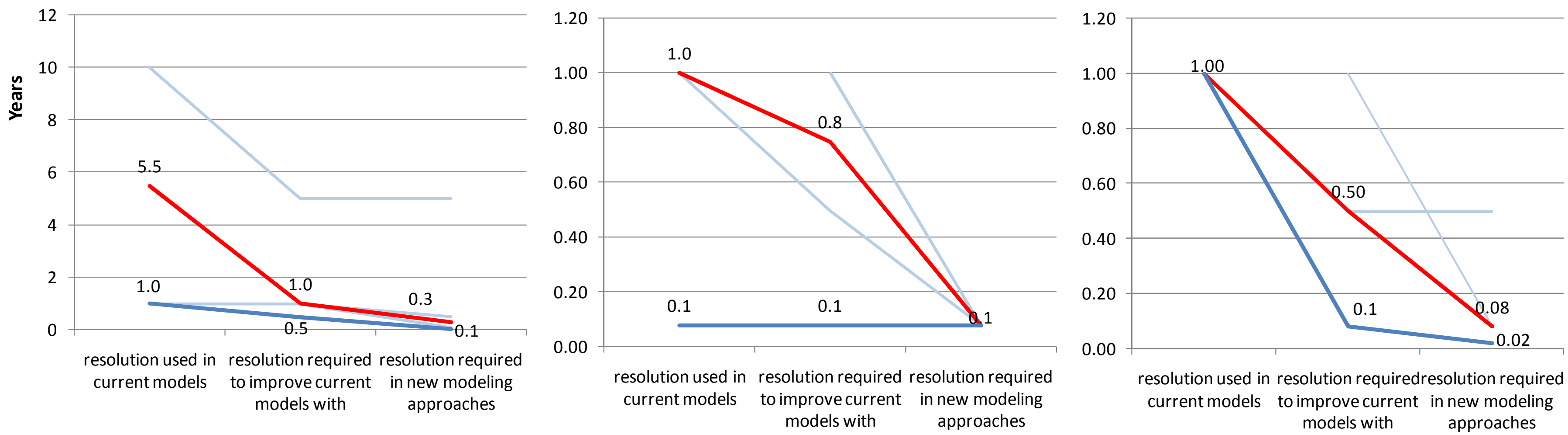


Figure 15: Temporal resolution currently used, required to improve current models with, and required in new modeling approaches for: (left) general modeling practices, (middle) parameter estimation, (right) land cover and land use change detection

The consistency of the current land cover data with the key-users' model requirements received a varying rating ranging from sufficient to rather insufficient. For example, the matching-up of datasets created in different periods according to different classifications is described as a problem concerning the consistency of current land cover data with the key-users' model requirements. Linked to these difficulties concerning land cover product classifications, the main reason of interoperability problems is identified in different definitions being used for key-attributes in datasets and models. Also differences in spatial and temporal resolution are regarded as reasons for interoperability problems. Furthermore, the allocation of model parameters and the transformation of land cover data to other information, due to interpolation issues, remains a source of inaccuracy. Regarding classification, a major issue is that the assignment of a given biome to a certain Plant Functional Type (PFT) is not at all straightforward. Even if for example the Olson classification (1994a, 1994b) is used this remains an issue since common PFT types are not directly represented in land cover products, especially with regard to crops (C3, C4), grasses (C3,C4) and wetlands. Due to these classification and resolution (temporal and spatial) problems, difficulties and inaccuracies arise in attempts to create combined datasets for running climate models if datasets for the historic period and present day situation are combined used as model input for studies on future scenario's. The accuracy of the land cover product for continental/ regional scale modeling is regarded as poor, for the global scale modeling it is regarded as moderately sufficient. For one user where models are applied to different spatial extends, the accuracy of the land cover products is rated very good to moderate.

Going from current to future model requirements, a trend towards an increase in required spatial resolution of land cover datasets can be identified (Figure 14). However, the magnitude of the spatial resolution required differs for models at different scales. For example for global applications, future requirements for spatial resolutions of 1 km were mainly mentioned in agreement with currently available global datasets. However, for specific local to regional applications, spatial resolutions up to 30 m were mentioned. Higher demands are also put on the temporal requirements of land cover products over the coming 5 years (Figure 15). For current models including improvements there is a general agreement on a yearly update with a detailing in seasonality. However, the introduction of new modeling approaches will require temporal frequencies for some classes up to a monthly resolution. Furthermore, in order to improve current models and feed improved model approaches within 5 years, higher demands are put on the temporal ranges available of input data. For some global models, temporal ranges up to 10.000 years will be required. To produce accurate model output with relatively short simulation steps, historical data of high quality (spatial and temporal resolution) is required. This sets the requirement for land cover data to 250-100 year historical data for global modeling purposes and yearly to half yearly data for modeling where crop rotations are taken into account.

The key users each have their own approach in translating land cover classes to plant functional types (PFTs) and vise versa. In some models, the Olson major ecosystem types (1994a, 1994b) are indirectly being used for defining PFTs as the land surface parameters are based on their distribution from the associated USGB dataset. In Figure 16, relative importance on which PFTs are used for land cover classification is displayed, and which PFT classes need to be incorporated and extended in future modeling approaches. Some key users pointed out that within 5 years time classification schemes must be created that can deal with wetlands and especially with permafrost classification.

Besides the use of land cover products to estimate the total area under a certain PFT, land cover product can also be used to determine land surface parameters. Examples of these land surface parameters mentioned by the key-users are: Albedo (surface, vegetation, snow), Vegetation roughness, vegetation fractions, Leaf Area Index, total soil water holding capacity, canopy height. In case the key-users use and/ or require multi-temporal land cover data for parameter estimations, the preferred frequency of land cover product updates would be monthly to seasonally.

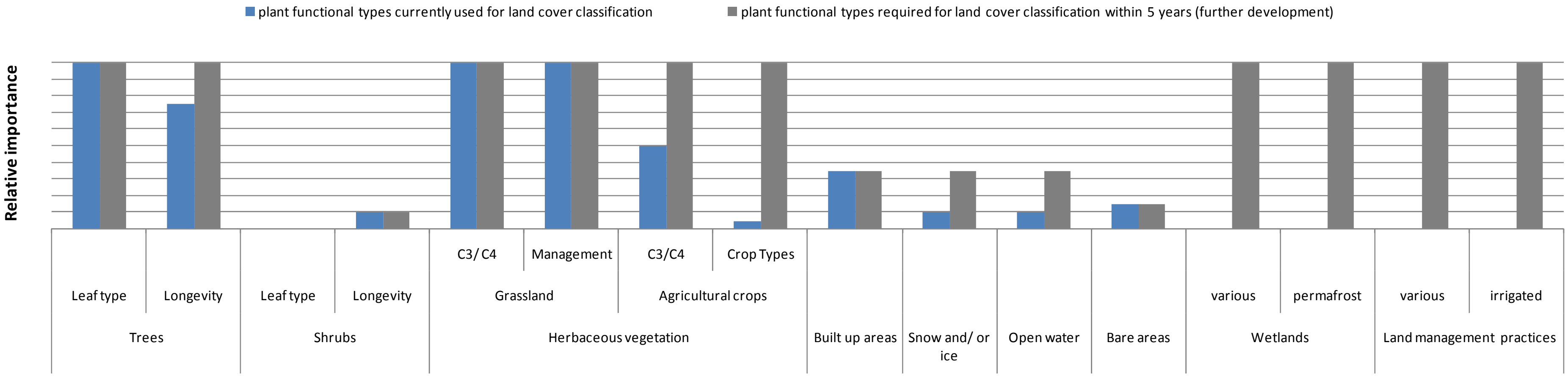


Figure 16: Relative importance are displayed on which PFTs are used for land cover classification (according LCCS, Di Gregorio, 2005), and which PFT classes need to be incorporated and extended in future modeling approaches

With regard to the monitoring of land dynamics triggered by human activities, the main interest lies in the topic of conversions between different land cover types resulting in e.g. urbanization, deforestation. Furthermore the interest of the key-users in human induced land dynamics lies in the field of specific agricultural land management practices and crop rotations, anthropogenic fire activities and land management practices as irrigation. A trend towards an increased frequency of available land cover products required for tracking human activities and land use change observations considering the frequency currently available, expected to be required to improve current modeling practices and the resolution needed in 5 years when new modeling practice are considered can be seen in fig. 15 (right).

The thematic information that is of most importance for describing human activities and disturbances are currently classes describing different land use types focusing on crop types (C3, C4) and grassland. For future modeling practices on defining human activities and land cover dynamics, the following land cover classes will become important : crop and pasture/ grassland varieties (C3, C4), irrigated areas, forest, urban areas, specific agricultural land management practices and fire activity.

In Table 6 the model parameters are represented that are (expected to be) validated using land cover products and related observational data. For each of the above mentioned parameters that would be validated using land cover data (Table 6) more specific information is provided on the level of detail required of the land cover product (Table 7).

Table 6: Model parameters to be validated using land cover products and related observation data. In bold the parameters are given that are mentioned most

Model scale	Validated using current models	Validated using improved versions of current models within 1 year	Expected to be validated after 5 years after applying new modeling approaches
Global	**Surface albedo**, **Roughness length,** Vegetation ratio, **Leaf area index**, Forest ratio, wetland and lake fraction, **FAPAR**, **NPP**		
Regional	Radiation balance, Energy balance		
Global, Regional, Country, Local	**Surface albedo** **LAI, FAPAR** Biomass aboveground	**Surface albedo** **LAI, FAPAR** Biomass Burned area	Canopy structure (height, density) Biophysical leaf properties
Global, Regional, Country, Local	Major land cover types (PFTs represented by model) **Albedo, Leaf area index,** canopy height	Major land cover types (PFTs represented by model) **Albedo, Leaf area index**, canopy height	Perhaps Leaf area index, **NPP**, canopy height, **albedo**, **roughness length**, age classes

Table 7: The level of detail required to validate model parameters by means of land cover products

Model scale	Parameter	Information need from land cover observations	Spatial extend (i.e. local, national, global)	Spatial resolution (30 m, 1 km, 1 deg.)	Temporal resolution (hourly, daily, monthly, yearly)
Global	Surface albedo, Roughness length, Vegetation ratio, Leaf area index, Wetland and lake fraction	Definitions should match those used in the model.	Global	0.1 deg.	Monthly
	Forest ratio, Soil water holding capacity	Definitions should match those used in the model.	Global	0.1 deg.	Annual
Global, Regional, Country, Local	Albedo		global	1km	daily
	LAI/fAPAR		global	1km	10 days
	biomass		global	1km	yearly
	Burned area		Global	1km	weakly
Global, Regional, Country, Local	PFT coverage LAI NPP Canopy height	PFT coverage for each cell	Model dependent – global and regional.	Model dependent – from 1-2 degrees (global) to 1km (land surface model)	Yearly to monthly

Besides land cover datasets, other datasets can be of great importance for modeling practices. These datasets should be consistent with land cover datasets. The most important datasets for modeling practices except from land cover products were: Digital elevation model; Water use; Soil data; Groundwater heights; Snow cover; Glacier and ice caps (extent); Fraction of absorbed photosynthetically active radiation (FaPaR); Biomass; Leaf area index (LAI); Fire disturbance and Soil moisture data. Also, more information on the character of the urban landscape is required.

Concerning data access and data delivery, all responding key users agreed on the latitude/ longitude system as preferred cartographic reference system of land cover products. Also the data format that is most convenient for land cover products was suggested uniformly as NetCDF. For land cover data delivery, the most popular delivery method is identified as the FTP server or a combination of web services and a FTP server. The current data retrieval process of input data is regarded as easy to moderately easy, however, it is also noted that this is very data dependent. The current most important limitation in the retrieval process is defined as the lack of transparency regarding the creation of the land cover product, the degree of quality and reliability of the land cover product and the ease with which historical data can be accessed.

3.3.3. Analysis of model parameters versus land cover

The relationship between land cover types and model parameters is one of the most important issues determining the accuracy and relevancy of land cover data for parameterization, calibration and validation of climate-related models. As described in the previous sections, land cover data are commonly used to consistently estimate quantitative land surface parameters. The CMUG user requirements document (CMUG 2010) addresses this issue and mentions the work of Hagemann (2002) as one basis to provide a better quantitative understanding why and on what level of detail and accuracy climate users require thematic land cover information.

In Hagemann (2002) a series of nine land surface parameters are derived from the Olsson land and ecosystem map (1994a, 1994b) using literature data and expert analysis. The following parameters are specified for 75 different land surface classes:

- background surface albedo
- surface roughness length due to vegetation (m)
- fractional vegetation cover (growing season)
- fractional vegetation cover (dormancy season)
- leaf area index (growing season)
- leaf area index (dormancy season)
- forest ratio
- plant-available water holding capacity (mm)
- total soil water holding capacity (volumetric wilting point)

We used these data to analyze the relative importance of different land cover classes for estimating model parameters. The importance of each differentiating two land cover classes is reflected in the relative similarity for each actual land surface parameter value. Thus, for each pair of classes (*x, y*) the similarity (Sim_{xy}) can be calculated by relating the specific parameter values for each class (Par_x, Par_y) to the overall range of parameter values across all classes ($Par_{\max} - Par_{\min}$):

$$Sim_{xy} = \frac{|Par_x - Par_y|}{Par_{\max} - Par_{\min}}$$

The similarity value is reported in percent with 100% representing the same parameter value for this pair of classes. The result is a symmetric matrix of 75x75 classes for each of the nine surface parameters. These large matrices contain important information but will be presented here as selected and aggregate results.

Figure 17 shows the histograms of the distribution of the similarities among all class pairs for four parameters. For different land surface parameters the pattern of class similarity is rather different. For Albedo, there are a few classes that obviously have a very different value (Snow, ice, water) than many of the other classes that are relatively similar. For the forest ratio, there is more of an equal distribution among the range of similarity values. An even different distribution is indicted for vegetation surface roughness and the LAI. This highlights that the relative importance and thus accuracy of land cover categories for model parameterization varies depending on what model parameter is estimated from the data. A single overall accuracy for a land cover map value will not be able to provide the information on how accurate a specific map is for parameter estimation.

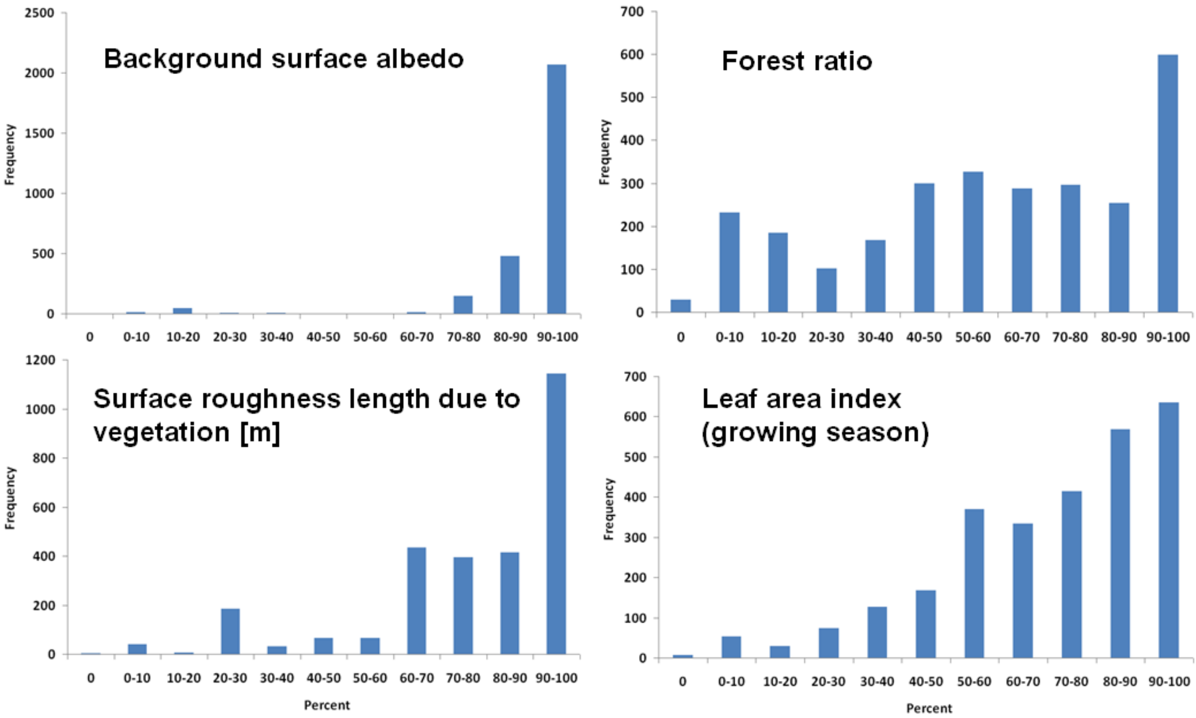


Figure 17: Histogram of similarity values (in percent, x-axis) representing the relative difference in values among 2 land cover classes for four land surface parameters. Note: the scale of y-scale vary for different diagrams

Figure 18 further shows that specific classes have different relative importance as for the case of Albedo. The Olsson map provides a series of categories with more or less consistent thematic definition drawing from land cover and vegetation types, climatic conditions, different levels of mixed classes and others. To provide some information we have grouped the classes into major land cover categories used for previous global land cover comparison studies and somewhat reflecting the GTOS requirements for land cover (Herold 2008).

Table 8 shows the average similarity from 9 parameter values for 12 land cover classes aggregated from 75 Olsson map classes. The areas with pink table cells have the highest average similarities among all land surface parameters. There is a tendency that they are located near the diagonal of the matrix reflecting somewhat the ranking of classes 1-12 from Forests to barren and water areas. Most dissimilar are the non-vegetated and vegetation classes. A misclassification and confusion between two classes with large similarity will cause a much lower error in the quantitative parameter estimation than uncertainties among very dissimilar classes.

Table 8: Matrix of the similarity between the 12 generalized land cover classes as average for 9 land surface model parameters

	Generalized Land Cover Legend	1 Evergreen Needleleaf Trees	2 Evergreen Broadleaf Trees	3 Deciduous Needleleaf Trees	4 Deciduous Broadleaf Trees	5 Mixed/Other Trees	6 Shrubs	7 Herbaceous Vegetation	8 Cultivated and Managed Veg.	9 Urban/Built-up	10 Snow and Ice	11 Barren	12 Open Water
1	Evergreen Needleleaf Trees												
2	Evergreen Broadleaf Trees	87.1											
3	Deciduous Needleleaf Trees	74.5	75.8										
4	Deciduous Broadleaf Trees	67.6	78.0	85.4									
5	Mixed/Other Trees	70.7	73.5	89.7	89.9								
6	Shrubs	54.2	59.1	78.1	80.0	78.6							
7	Herbaceous Vegetation	45.0	50.6	70.5	71.5	72.7	89.7						
8	Cultivated and Managed Veg.	52.5	61.5	75.3	82.9	80.0	92.3	87.4					
9	Urban/Built-up	34.2	33.2	53.1	48.3	55.3	58.9	65.9	55.4				
10	Snow and Ice	21.7	15.6	39.4	32.4	42.1	50.6	58.2	45.6	69.1			
11	Barren	36.6	30.5	54.3	47.3	57.0	65.5	73.1	60.5	78.5	85.1		
12	Open Water	30.6	24.0	48.2	40.6	50.1	57.7	65.1	53.1	75.6	88.9	89.7	

3.3.4. Results of associated user survey

A group of 85 users from the climate modeling community was approached to fill in an online survey on their user requirements for current and future land use data requirements. The survey was performed in October 2010, and consisted of 16 questions (Appendix B). For a selection of the questions, land cover product requirements for two time periods needed to be selected: (1) current status/used in current models, and (2) requirements needed in 5 years time, also considering new modeling approaches. In addition, land cover requirements were assessed for four different climate model aspects as presented in section 3.3.1 for the key user assessment: (1) land cover requirements, (2) land cover as proxy for land surface parameters (3) land cover as proxy for human activities, and (4) land cover for validation of model outcomes. Selection of the group of so-called associated users was based their role as being main developers for a certain type of climate or earth system model (Appendix D). From the population of 85 users, 15 filled in the questionnaire resulting in a response rate to the associate survey of 18% from a broad range of countries all over the globe.

The results of the associate user survey show that land cover data are applied for a broad range of climate modeling applications (Figure 18). Respondents were mostly applying their models at global scale (53%) or national scale (27%). A broad set of different available land cover datasets are used where the most frequently mentioned are the IGBP Discover and GLCC datasets as provided by USGS and FAO statistics (Figure 19).

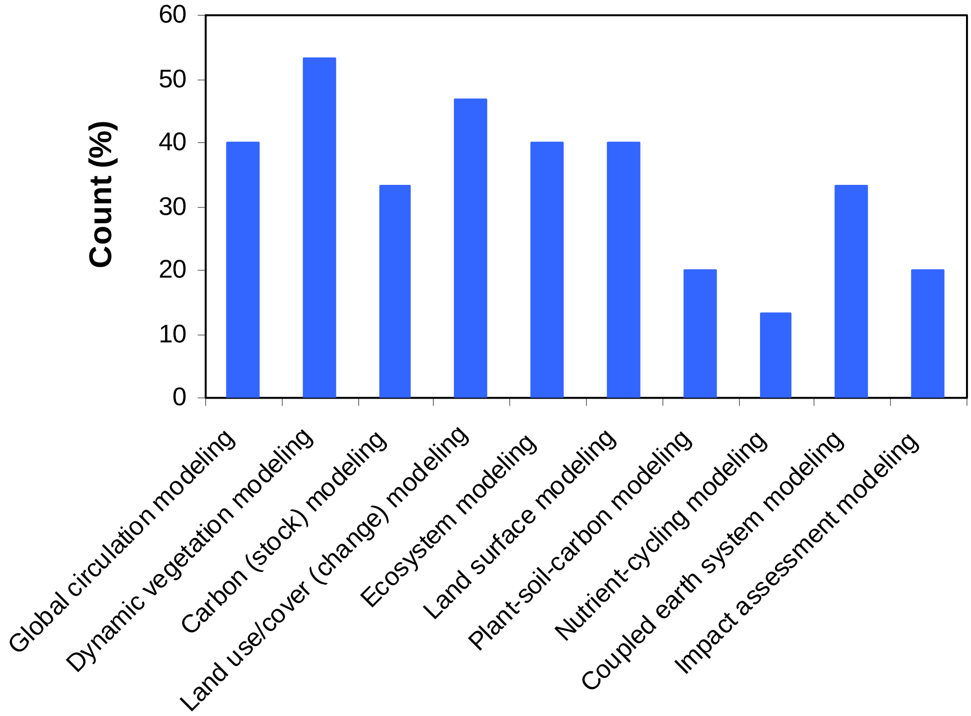


Figure 18: Earth system or climate modeling focus of respondents to associate user survey

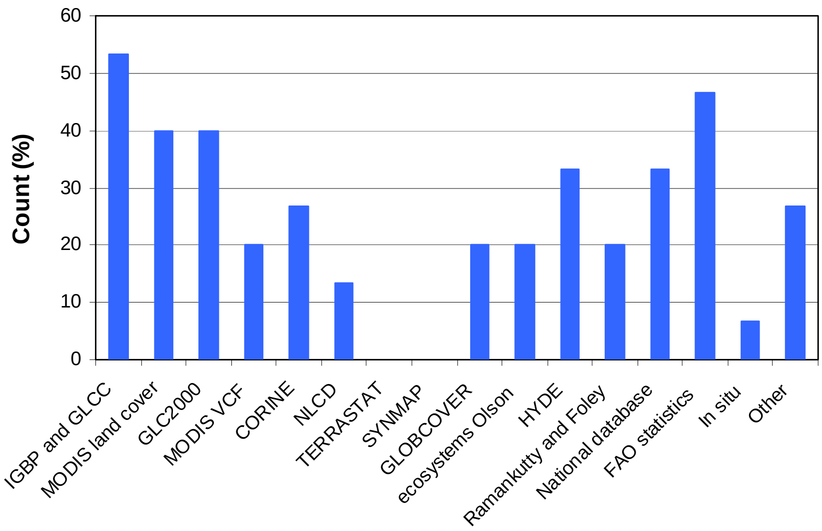


Figure 19: Land cover products used in associate climate modeling community

The results also show that in many cases land cover datasets for different coverage periods are combined to derive a time-series of land cover development. In general, the accuracy of the land cover product for climate model application is judged as moderate till good. The main problems which are mentioned are the Access and knowledge to updated land cover datasets (40%), difficulties with data aggregation, consistency for the allocation of model parameters, low temporal resolution and temporal range of input data and low spatial resolution and spatial extend of input data (all 27%) (Figure 20).

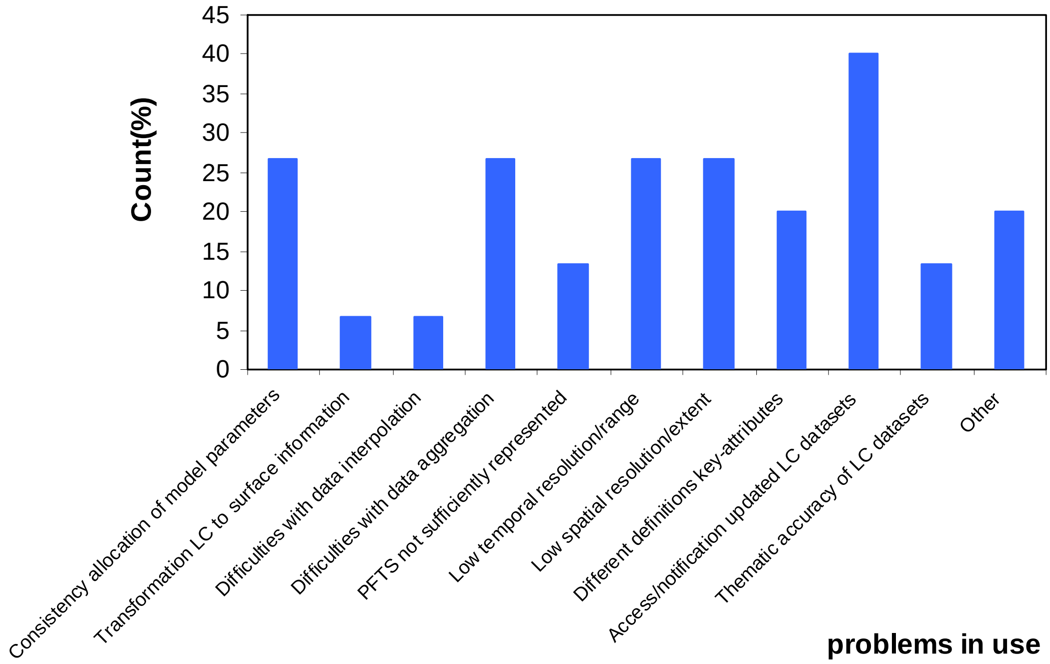


Figure 20: Identified problems when using available land cover data sets for climate modeling applications

The user requirements for the spatial resolution reflect more or less the model application at global and national scale with preferred grid size of 100m and 0.5 degrees respectively (Figure 21). Looking at requirements for climate modeling application in 5 years, the results show that a more detailed spatial resolution is required but still the global model applications will use resolutions between 0.25 and 0.5 degrees. Temporal resolution requirements for current model application are mainly on a yearly basis with some preference for high-frequency data up till daily but and for global applications with an update frequency from 5 till 10 years (Figure 22). However, there is a clear future need for more seasonal products with a quarterly till half year temporal resolution which would be able to track the seasonality of agricultural crops and forest ecosystems.

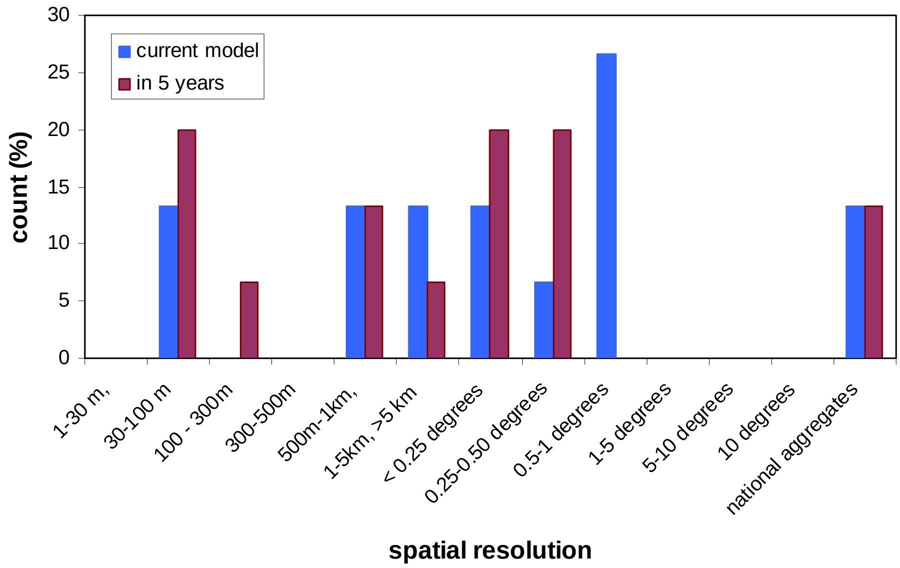


Figure 21: Spatial resolution requirements for current climate model application and expected in 5 years

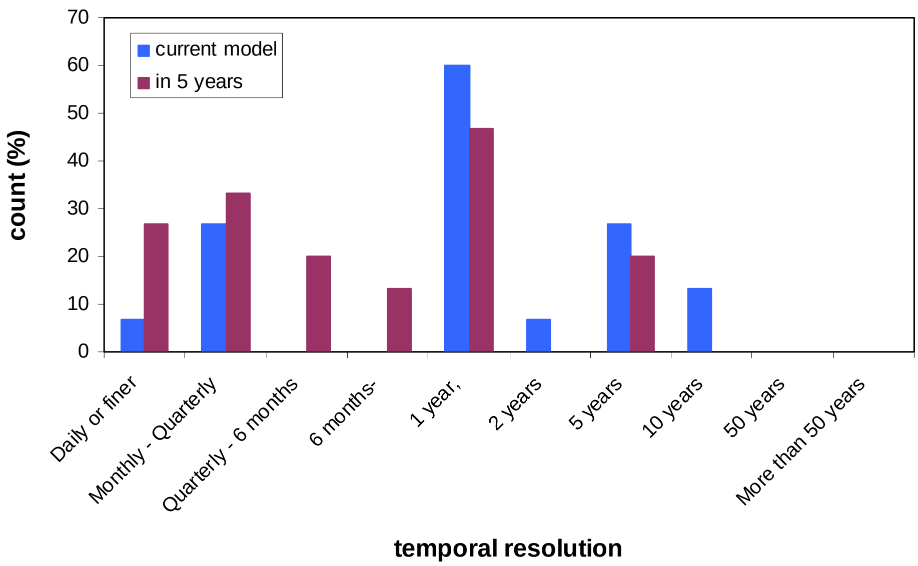


Figure 22: Temporal resolution requirements for current climate model application and expected in 5 years

User requirements for the thematic aspect of land cover datasets indicate that agricultural classes are very important while also for current modeling applications natural vegetation classes (forest and herbaceous) are seen as important (Figure 23). However, for future modeling application it is anticipated that a proper representation of urban and wetland classes will become more relevant. This agrees with the results of the key-user survey. When looking more specific at information requirements on human activities/disturbances or dynamics (Figure 24), the outcome of the survey shows that currently forest loss, agricultural expansion and vegetation phenology are important processes which are taking into account in the initialization or evaluation step of the climate models.

For the next generation models, aspects wetland dynamics, urban expansion and long-term vegetation development will become important processes to take into account.

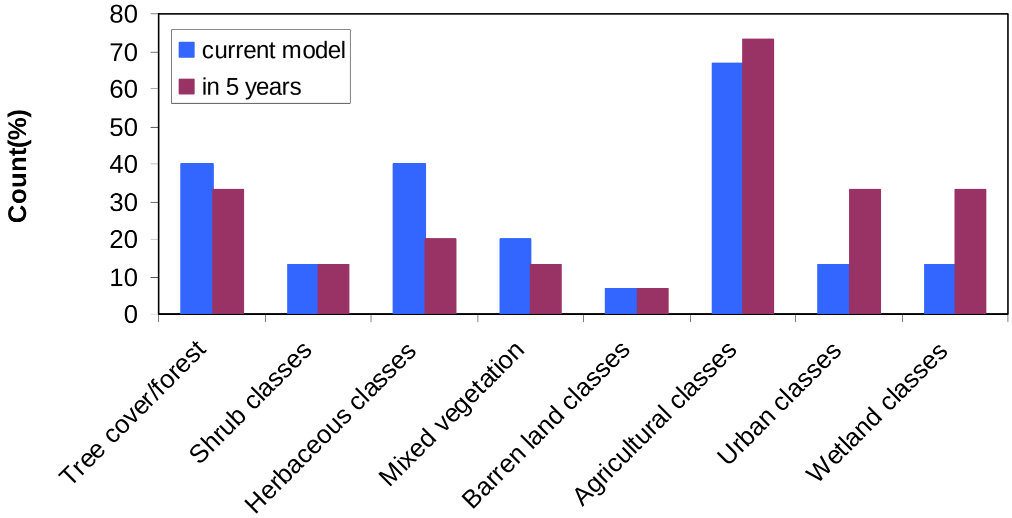


Figure 23: Most important land cover classes for current climate model application and expected in 5 years

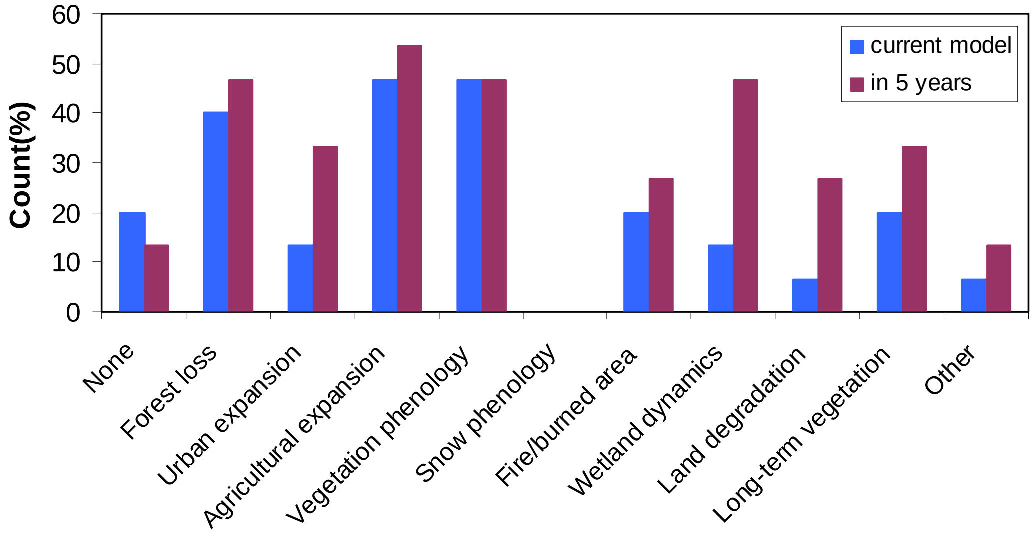


Figure 24: Most relevant human activities/disturbances or dynamics for current climate model application and expected in 5 years

Within the modeling process, land cover products are also adopted to determine land surface parameters which are then use to initialize the climate models. Figure 25 gives an overview of land surface models which are derived from land cover data. For example, Leaf Area Index (LAI) is one parameter that is regularly derived from land cover datasets. Although several other parameters are already derived from land use data, it is anticipated that especially future climate modeling approaches will increasingly apply this mechanism for parameters like vegetation albedo, vegetation roughness and plant water holding capacity. Finally, the application of land cover data to validate climate model output was assessed (Figure 26). Currently this is mainly applied for the vegetation distribution and dynamics and the radiation and energy balance. For future modeling applications, land cover data will increasingly be adopted to validate net primary production (NPP), albedo and LAI.

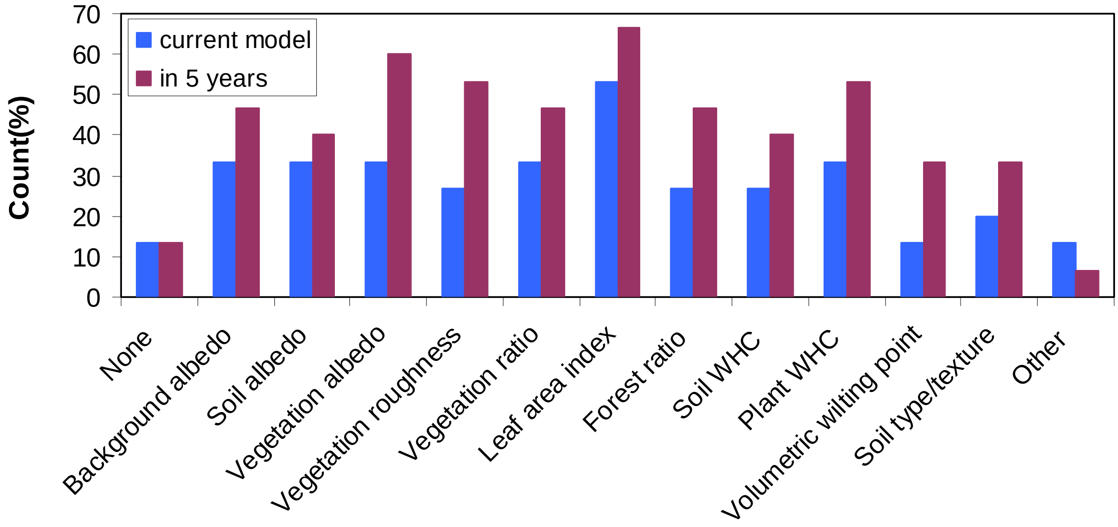


Figure 25: Land surface parameters used in climate models which are estimated from the land cover data

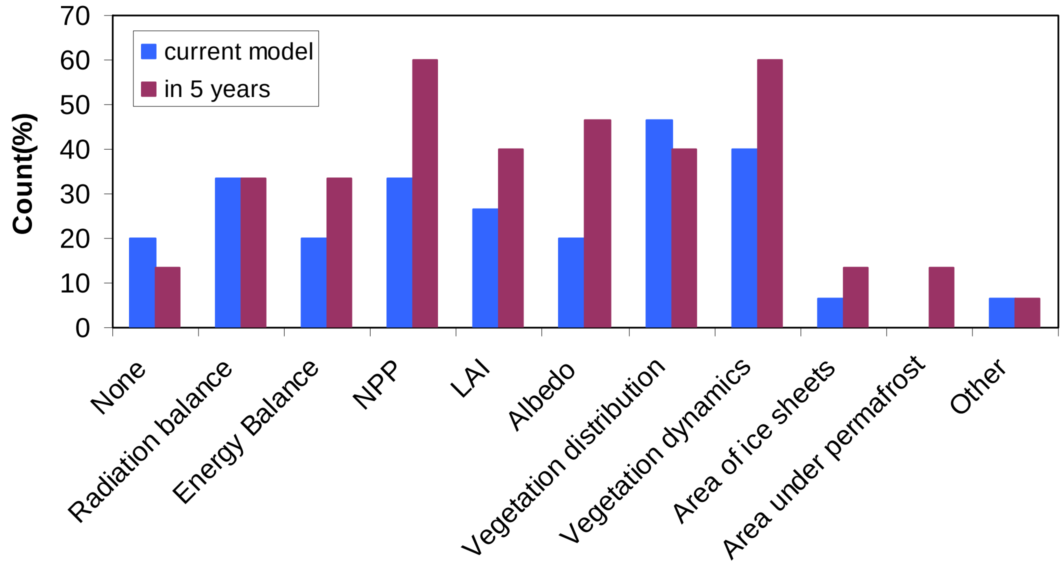


Figure 26: Output parameters of climate models which are or will be validated using land cover data

Concerning data access and delivery, 50% of the users prefer latitude/longitude as cartographic reference system while in addition a broad range of other systems were mentioned: UTM (Albers), equidistant (Lambert Azimuthal), Transverse Mercator. As most convenient data formats for delivery were mentioned NetCDF (50% of users) and GeoTIFF (45% of users). For data delivery, FTP (50%) and the combination of web services and FTP (e.g., request via web service and de-livery through FTP) (42%) were mentioned as most frequent options.

3.3.5. Scientific literature review

The broad assessment of existing (climate) models and accompanying user requirements aims at examining how land cover data have been used in climate models and which future needs can be identified for modeling practices. Below, the results from a standard literature review of key scientific papers published primarily since 2005 is presented. The performed review focused on current use of land cover data for climate modeling and on the identification of future needs, model requirements and -prerequisites. Special attention is paid to highlight innovative concepts and approaches to better reflect land dynamics in the next generation models. This review includes different modeling approaches and communities, i.e. Earth System modeling community, Integrated Assessment modeling community and the Impact, Adaptation and Vulnerability community (Hibbard et al. 2010).The identified model requirements are presented in short term (current) and long term considerations and visions (future). These specific time-frames were selected to make a division between urgent needs and requirements which should be put on the short term agenda and requirements that are still urgent but less pressing. The results are presented below and are, where applicable, linked to GCOS tasks for land cover as defined in the GCOS implementation plan.

Short term requirements

Standardization of land cover products with regard to the definitions of classes and their thresholds is an important issue (Jung et al. 2007). This issue is also addressed in the in 2004 defined GCOS Implementation Plan (IP) task 22, which promotes the harmonization of land cover monitoring by creating international standards for land cover maps. It is widely acknowledged that land data products should ideally be produced by using a hierarchical, standardized land cover classification system which should be applied to validated land cover data and to time-series of data integrated at an appropriate scale (Lepers et al. 2005, Hibbard et al. 2010). Land cover products often lack class specific accuracies and categories have large interclass variances (especially for mixed vegetation classes) (Jung et al. 2006, Jung et al. 2007). Plant functional types are often used as a basis for class definition (Olson 1994a, b), however more research is needed on the effects of wrong categorization of plant functional types on C:N ratios (Ostle et al. 2009). In a more general sense it is stated that parameters must be used that are both mechanistically important and measurable (Ostle et al. 2009).

This need to validate parameters requires (new) methods for land cover map accuracy assessments (Williams et al. 2009). For example, knowledge about class specific accuracies of the product can, in conjunction with calculated fuzzy agreements be used to generate a map of confidence of the final product (Jung et al. 2007). Despite of such methods, validation of land cover maps remains an issue as was already addressed in GCOS task 23 (IP 2004). Even if pre-defined land cover classes are used, as in e.g. land cover products provided by the FAO (Di Gregorio and Jansen 2000), global land cover is often inconsistent with land cover data and actual practices. Accuracy assessment and error reduction should be improved (Williams et al. 2009) by obtaining land cover reference data since no rigorous validation is yet possible. This point was also raised as part of the 2004 GCOS task 25 ‘development of an in situ reference network for land cover’. Models need to be more obviously comparable to the real world (Friedlingstein et al. 2006) and therefore further model evaluation against site-level measurements are needed. This may increase the reliability of for example the model estimated European carbon balance in the future (Vetter et al. 2008). Per definition, it is not possible to correctly interpret carbon cycle simulations if the overall-, user-, and producer accuracy is not known (Jung et al. 2007). Special attention has to be paid to data on land cover change since large uncertainties in two datasets used for change detection can result in extreme values on land dynamics (Jain and Yang 2005). Summarizing, to be able to reduce large uncertainties in carbon and climate modeling, it is critically important that these models are more completely constraint by observation data

(Friedlingstein et al. 2006). Therefore, there is an urgent need for a network of ground and satellite based long term land cover monitoring (Jain and Yang 2005). Thereby, the benchmarking of global models is a key-procedure and an expanded set of data for evaluation of short timescale dynamics for benchmarking is required (Sitch et al. 2005). These datasets can partly be generated by linking optical remote sensing products which provide critical information on e.g. canopy structure and crop phenology (Williams et al. 2009). Furthermore, the scientific community suggested to further expand the FLUXNET tower network to obtain critical data on carbon exchange (Williams et al. 2009), expansion of the network should be initiated on the short term and implemented within the coming 5 years. Special attention should be paid on the parameterization of albedo and the representation of crop phenology and the representation of evapotranspiration for different land cover types (Pitman et al. 2009). Therefore, the in 2004 defined GCOS task 26 which focuses on the creation of annual land cover products and GCOS task 27 which focuses on the creation of a regular fine resolution land cover (change) map, are still relevant and urgent tasks that should be dealt with on the short term.

Summarizing, on the short term different issues should be addressed to deal with problems regarding the definition of land cover classes; classification of land cover data sets; variation in spatial resolution of the data sources and variation in temporal and spatial coverage of data sets. Furthermore, earth system model and climate model outcomes should be validated against reference data, preferably using fine resolution land cover datasets that can be provided on a regular basis

Longer term requirements

In the previous paragraph, the short term requirements for earth system modeling and climate modeling as found in key-articles are presented. In this paragraph, requirements for a more long term (1-5 year) scope are discussed. More research on model- and data fusion is needed: multiple and different types of data, including associated uncertainties need to be integrated together with prior knowledge on model parameters and/or initial state variables (Ostle et al. 2009, Williams et al. 2009). More effort should be put in generating new information by combining existing data, for example by linking Eddy Correlation towers effectively with atmospheric column CO_2 measurements generated by satellites like OCO and GOSAT (Williams et al. 2009). Besides model- and data fusion, there is also a need for an integral vision on the actual (eco)systems that are modeled. For example for ocean carbon cycle modeling there is a need for more complete treatments of ocean ecosystems, micronutrient limitation, and oceanic acidification impacts on calcium carbonate cycling (Friedlingstein et al. 2006).

To advance scientific understanding and enhance data- and model integration, the earth system modeling and integrated assessment modeling communities have to collaborate closely with the remote sensing community (Hibbard et al. 2010) .To be able to address questions on how we have to adapt to, and minimize risks of, climate changes modelers have to rely heavily on behavioral modeling of economic and energy systems, which is the focus of Integrated Assessment Models.

Regarding the use of land cover products as model input, some specific requirements for land cover change monitoring are addressed in literature. For the location of land cover change detection, land cover should be extended to regions that are not known as hotspots but where rapid changes may still take place and catch the scientific community by surprise (Lepers et al. 2005). Furthermore, the importance of including land-cover change in forcing scenarios for future climate change studies should be noted. By accounting for a number of additional anthropogenic climate impacts, land cover forcing can be included which will improve the quality of regional climate assessments as e.g. IPCC SRES scenarios (Feddema et al. 2005). In addition, it is stated that without accounting for historical land cover changes, observed atmosphere CO_2 growth cannot be explained (Brovkin et al. 2004). This implies the need to incorporate historical land cover change into carbon exchange/ stock models. More research is required on the effects of land cover change on changes in land-atmosphere exchange in greenhouse gases, reactive trace gases and aerosols (Pitman et al. 2009).

Linked to the requirement for earth system modeling to incorporate land cover change, the decline in land suitability due to soil erosion, acidification and salinization also need to be taken into account (Ramankutty et al. 2002).

Besides a better understanding of the required model inputs, a more process based understanding of earth system and climate models is needed. There is a need to critically evaluate the representation of plant-soil processes in global models (Ostle et al. 2009). Also applied concepts of carbon-water cycle interactions regarding the representation of canopy conductance and soil processes need to be revisited (Jung et al. 2007). In general, a greater process-based understanding of large-scale plant-drought responses and interaction with wildfire and land use is needed and should be filtered in the next generation Dynamic Global Vegetation Models (Sitch et al. 2005).

As a part of obtaining more knowledge on the models' process understanding, more research should be done on model equifinality: where different model representations, through parameters or model structures, yield similar effects on model outputs, and so can be difficult to distinguish (Williams et al. 2009). Linked to this, more insight has to be gained on how the results of Earth System Models may impact underlying drivers (e.g., land use change) of Integrated Assessment Modeling models on global feedbacks and carbon cycle dynamics (Hibbard et al. 2010).To be able to generate the required insights and information described above, data infrastructures and facilities need to be improved. For the short term, the implementation of several GCOS tasks (task 27 and 28 of the in 2010 defined GCOS tasks) will meet this demand. For the longer term, the scientific community addresses the need to set up storage and computing facilities to facilitate the collection of all data and provide a web-based interface for data exchange (Jung et al. 2006). As computational power, needed for e.g. millennium scale carbon cycling becomes available some studies can be repeated at different scales and across e.g. a range of different global carbon models (Pongratz et al. 2010). With regard to the FLUXNET network (used as validation for modeling practices where land cover data is used), it is suggested to improve data collecting facilities by nesting Eddy Correlation towers within the regional footprint of tall towers that sample the CO_2 concentration of the planetary boundary layer (Williams et al. 2009).

Table 9: Near-term and long term requirements to improve earth system modeling (Hibbard et al. 2010)

Near-term (<5 years)	Longer-term (>5 years)
Terrestrial carbon cycle model (typically without nitrogen or nutrient limitations)	Nitrogen cycling and limitations
Vegetation dynamics and regrowth following disturbance	Anthropogenic fire (including ignition and suppression)
Anthropogenic land-use change and corresponding net carbon fluxes	River biogeochemistry (particularly dissolved organic carbon fluxes from land-to-ocean)
Mechanistic wildfire	Interactive biogenic fluxes of methane, volatile organic compounds (VOCs) for coupling to atmospheric chemistry
Marine biogeochemistry, including simple ocean ecosystem (e.g. nutrient–phytoplankton–zooplankton–detritus (NPZD) models	Advanced vegetation and successional processes; possibly explicit dispersal mechanisms
	Multiple agriculture (crop × management) PFTs and associated local/regional land-use practices
	Transient urban fractional cover
	Tropospheric interactions with O_3 and vegetation
	Organic and peatland soils
	Wetlands

For the long term (> 5 years), defined requirements are strongly process based. For example, the role of nitrogen in earth system modeling should be clarified (Jung et al. 2007). Nitrogen supply from soil organic matter is not known accurately and introduces uncertainty (Ostle et al. 2009).

Furthermore, potential (in)direct effects of climate change on land use change and land cover change must be made quantitative. Due to an increase in greenhouse gases the area of land that is cultivable might increase, but yields might decrease. This has to be taken into account in the future for example in a crop productivity parameter. Also the effects of climate change on soil properties need to be accounted for (Ramankutty et al. 2002). Up till now, the effects of land-cover change on climate has been difficult because different bio- geophysical effects offset each other in terms of climate impacts, and, on global and annual scales, regional impacts are often of opposite sign and are therefore not well represented in annual global average statistics (Feddema et al. 2005).

4. Synthesis and recommendations

In this assessment we have implemented a detailed requirements analysis for a global land cover product that should meet the requirements of GCOS and other international panels, and the climate user community. The study interacted with different types of users through different interaction mechanisms (Figure 27). Overall, three user surveys were completed for the broad, associated and key users respectively. While the frequency of responses vary, the amount and quality of feedback is suitable to derive a good synthesis on what climate modeling users need and expect from a new land cover product. In general, there is quite a good match among the requirements coming from different sources and the broader requirements derived from GCOS, CMUG and other relevant international panels (section 4.1).

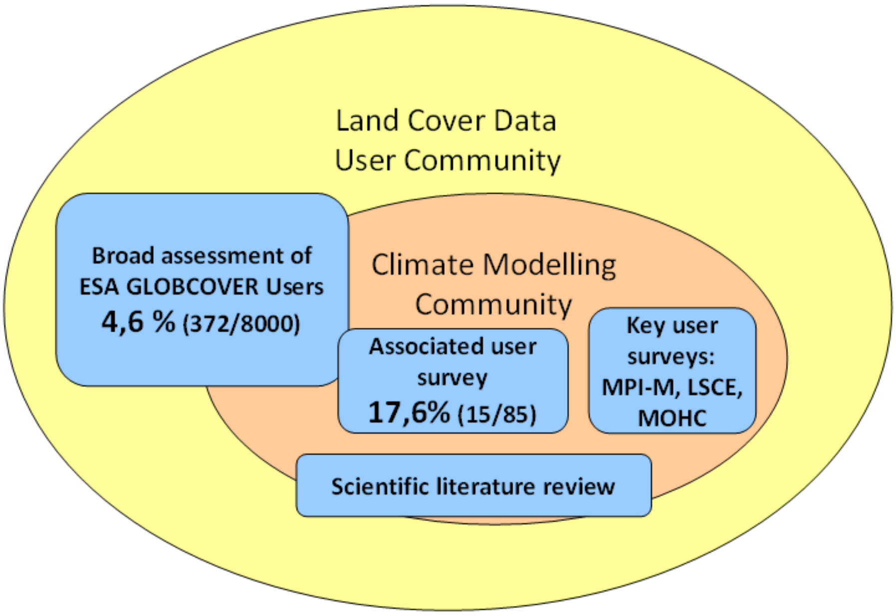


Figure 27: Concept of user communities and activities to assess land cover requirements of general land cover user community and climate modeling community

4.1. Need for land cover in climate models

In general, land cover has been and remains a fundamental dataset as consistent input to climate models and for the integration of other data sources. While it is assumed that any new land cover datasets should be better than previous ones and improve climate model and assessment performance, there are several ways land cover feed into different climate applications. It has been emphasized that there is a need for both stable land cover data and a dynamic component (time-series and changes). For the purpose of this survey we considered three main ways land cover observations and data are used:

1. As proxy for a suite of land surface parameters that are assigned based on PFTs

2. As proxy for human activities in terms natural versus anthropogenic and tracking human activities, i.e. land use affecting land cover (land cover change as driver of climate change)
3. As datasets for validation of model outcomes (i.e. time series) or to study feedback effects (land cover change as consequence of climate change)

Concerning the first item, land cover information act as proxy for a suite of land surface parameters that are assigned based on PFTs. This parameterization is a complex process and is often not redone with every new land cover map and has commonly lead to little innovation in taking up new and updated datasets for climate model applications. Consistency is the key requirement and thus one fundamental (land cover) dataset is the base for series parameters. Some users have stressed that consistency among the different model parameters to be more important than accuracy of individual datasets. This puts more burden on the accuracy of the land cover data since related errors propagate to all parameters. In that context it is important to understand the relationship between land cover classifiers with the parameters and the relative importance of different land cover classes (section 3.3.3). It is expected that new land cover data may help to stimulate more precise estimates of other land surface parameters and to also help that some land surface parameters may in the future be directly assimilated from EO data (i.e. albedo, LAI, biomass, FAPAR etc.) if they are consistent with the land cover information.

The second item addressing the need to use land cover as proxy for human activities is important to study long-term effects (and feedback) on climate and for the carbon cycle (short-term impact on stocks and fluxes). Needs were articulated to provide natural versus anthropogenic vegetation (disturbed fraction) and to track human activities and define history of disturbance, i.e. land use affecting land cover with most detail needed for focus areas with large anthropogenic effect.

The third issue highlights the needs for the validation of model outcomes or to study feedback effects. More process oriented models need less data for input/calibration but more for validation of outputs. Validation can be regional or local but data must be of high quality and consistent. Common examples include time series, min/max values of parameters, vegetation types, biophysical variables and others.

4.2. User requirement 1: Accuracy

There are three types of quantitative requirements provided for the accuracy of the CCI land cover products coming from GCOS, the CMUG and the CCI. Given the fact that available land cover maps have an overall area weighted accuracy of around 70%, it can be assumed that the accuracy requirements for the land cover CCI should be higher. Secondly, GCOS requirements mention a maximum of 15 % omission / commission per class, those from CMUG and the CCI an error of 5-10 %. CMUG further requires stability in accuracies over time of less than 10% (Table 5). Those requirements can be understood as quantitative guideline, however, from current knowledge in global land cover mapping experiences there are two main problems in using such statements for the upcoming land cover mapping efforts:

- Errors of 5-10 % either per class or as overall accuracy are rare and hard to achieve in any land cover mapping effort with more than a 2-3 categories,
- The accuracy of the products depends on its actual use in the model.

In particular the analysis of the model parameters versus land cover types has emphasized the relative importance of different class accuracies heavily varies depending on which parameter is estimated (section 3.3.3.). This is an important implication that cannot be considered by using a standard overall accuracy reporting. Any accuracy analysis should provide flexibility to account for such differences in how land cover data are used in models and the related impact on the uncertainty of the input data. In addition, the need for stability in the accuracy should be reflected in implementing a multi-date accuracy assessment.

The users also stressed the need for quality flags and controls, the probability for the land cover class or anticipated second class or even probability distribution function for each class (coming from the classification algorithm), and the need for accuracy numbers for land cover classes (potentially also with regional estimates).

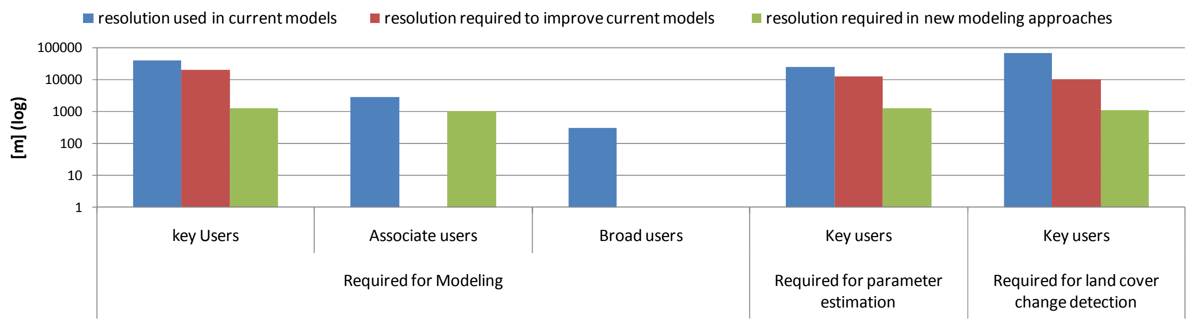


Figure 28: Synthesis for Spatial Resolution Median requirements (note y-axis in log-scale) from broad land cover data user community and key and associate users from climate modeling community

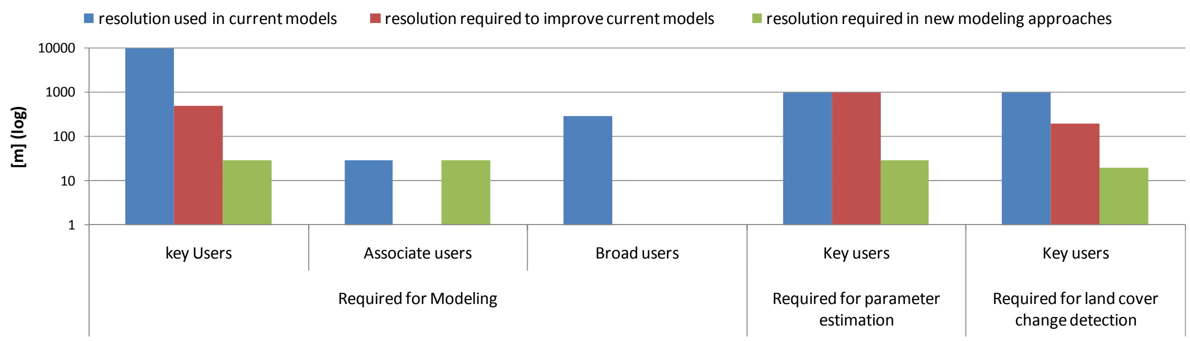


Figure 29: Synthesis for Spatial Resolution Minimum requirements (note y-axis in log-scale) from broad land cover data user community and key and associate users from climate modeling community

4.3. User requirement 2: Spatial detail

The users provided detailed information on the level of spatial detail they require and the results are summarized in Figure 28 and 29. First, there is not one spatial resolution that fits all purposes; it is important that the land cover product provides flexibility to serve different scales and purposes. On average, climate models run on broad spatial levels of detail and a resolution of 300 m or coarser is sufficient to meet modeling requirements for most users.

However, for some and in particular for future periods (see figure 29) there are requirements of more detailed resolutions. This would mean that land cover observations to estimate model parameters and for description of change would need towards fine-scale satellite observations coming from Landsat-type observations in the coming years (e.g., Sentinel-2).

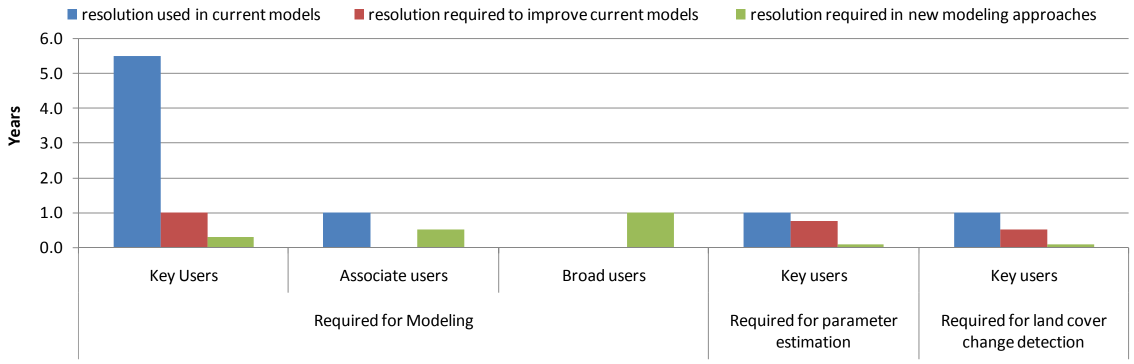


Figure 30: Synthesis for Temporal Resolution Median requirements from broad land cover data user community and key and associate users from climate modeling community

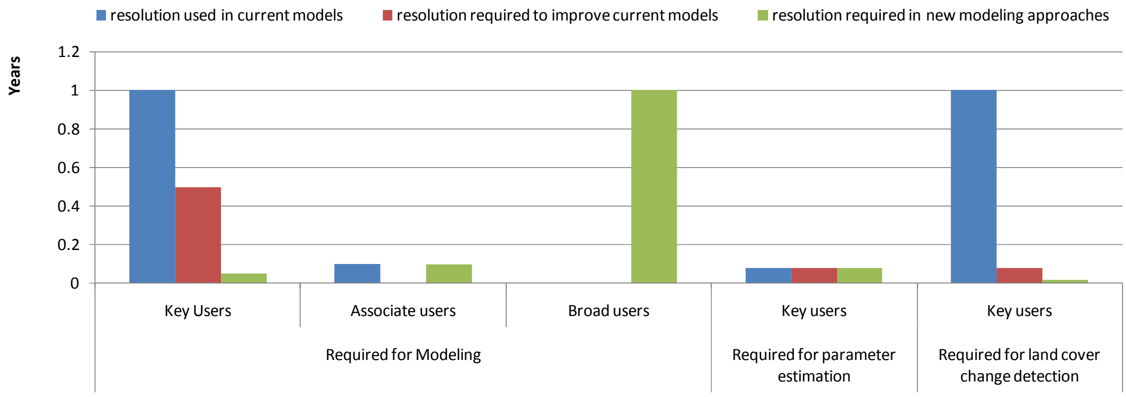


Figure 31: Synthesis for Temporal Resolution Minimum requirements from broad land cover data user community and key and associate users from climate modeling community

4.4. User requirement 3: Temporal resolution

Many users use annual updating of parameters initially derived from land cover data. While annual data are currently not available for land cover, the modeling community is using interpolation and ancillary data (i.e. from the literature or models) to provide the temporal detail required. The need for increased temporal resolution data is pertinent among all user groups, in particular for future periods moving into considering intra-annual and monthly dynamics of land cover (Figure 30 and 31). While any addition to the temporal resolution of the currently often static land cover data is useful, the need to explore the potential of dense remote sensing time series signals is of fundamental importance. In terms of the temporal range, models use periods beyond the remote sensing era back in time and this range is expected to further increase in the future.

4.5. User requirement 4: Land cover categorization

While almost all major land categories in current maps are of importance, Figure 32 particularly highlights the need for forest, herbaceous, and agriculture classes in current models. Considering all users, the need for wetland and urban classes is expected to increase in future model and other land cover applications. Forests and some of other vegetation classes (i.e. shrubs) are commonly separated by leaf type and phenology (Figure 16). Given the fact that users require a suite of different types of land cover categories (or plant functional types) for model parameterization that varies with type of model and modeling approach, any land cover product will need to provide some flexibility in responding to these different thematic needs. The broad user survey has shown that more than 90% of the users find the UN Land Cover Classification System a suitable approach for thematic characterization; an approach which is also compatible with the PFT concept of many models and the concept of land cover classifiers.

Figure 16 is describing the need from the key users for additional information on the separation of C3/C4 grasses and crops and the consideration of human activities and land management practices. For example, the “disturbed fraction” has been advocated as one of such requirements. The different functional responses of C3 and C4 plants to nitrogen, radiation, and temperature makes this separation is important. The priority for users is the separation of C3 and C4 grasses; secondly C3/C4 crops. Earlier studies have indicated the potential to derive estimates of the C3–C4 composition of grasslands from satellite sensor data (Foody and Dash, 2007). In particular, simple measures based on the temporal variation in the spectral response of MERIS images explain 60–65% of the variance in grassland composition. However, a more recent study showed that MERIS Terrestrial Chlorophyll Index (MTCI) composites of the Great Plains in US relationship between MTCI data and grassland C3-C4 composition may be formulated for the State of South Dakota with R^2 similar to 0.6 (Foody and Dash, 2010). To reduce the uncertainty for parameters which are derived from remote sensing datasets (i.e. C3/C4 separation) the use of external products or non-satellite derived data maybe needed in addition if it improves accuracy and parameter estimation procedures. For example, for the models operated at MPI-M (JS-BACH, REMO), all Olson classes (or fractions of), that are transferred into grasses, the separation into C3 and C4 grasses is conducted is based on work by Knorr (1997). The users also stressed the need for data on irrigated rice areas.

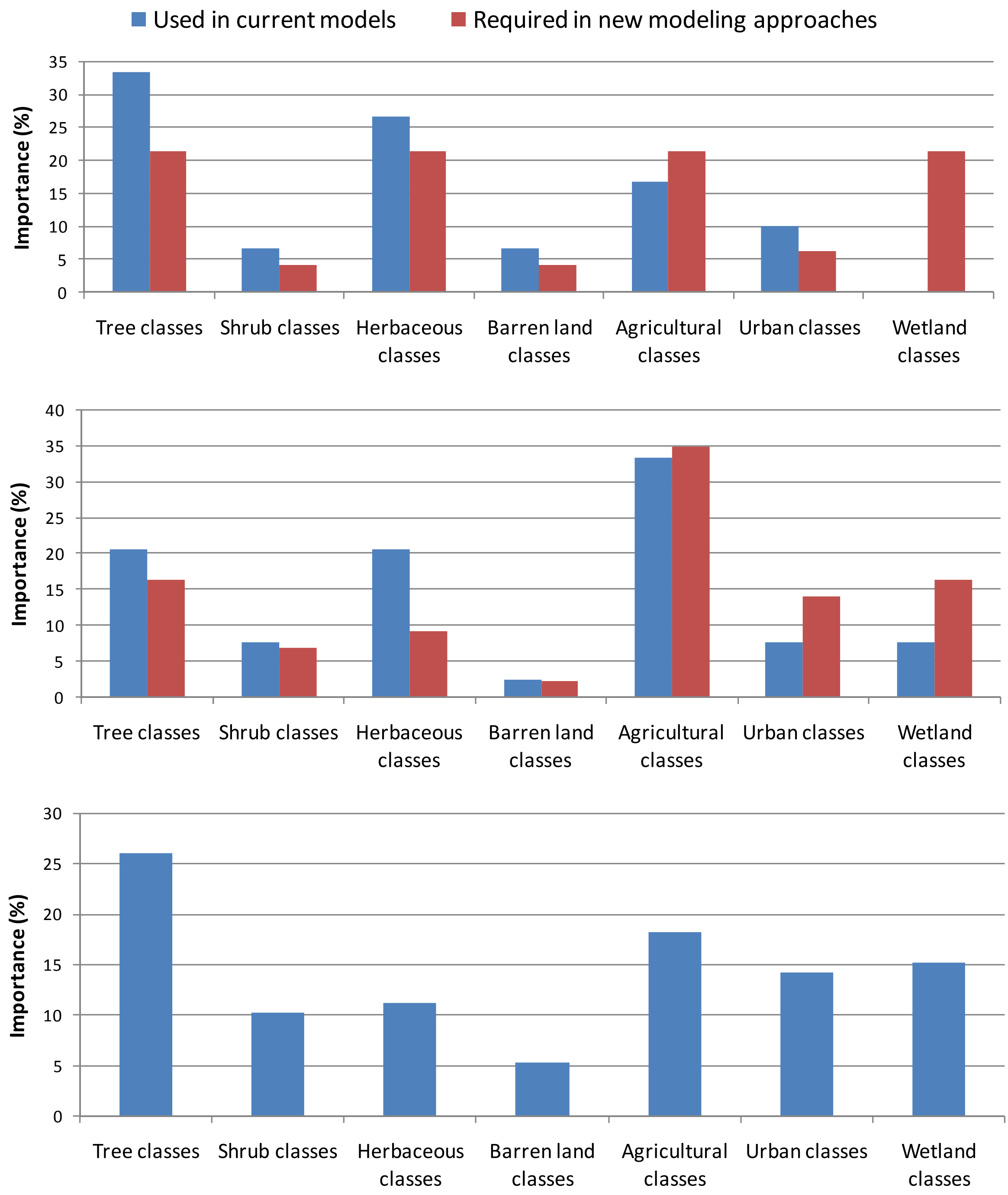


Figure 32: Thematic requirements: Classes of interest for Key users (upper figure), Associate users (middle figure) and broad users (lower figure)

4.6. User requirement 5: Land cover change

A fair amount of users (in particular the key users) do not use any change or dynamic products from land cover remote sensing in their current modeling. However, as stated in Figure 33, the need for more dynamic information and land cover/use changes in the future is pertinent. The most important information is required for (Figure 33):

- Vegetation phenology
- Agricultural expansion
- Forest loss/deforestation
- Urbanization

In addition, the needs for monitoring wetland dynamics, fire, land degradation and long-term vegetation trends are highlighted by the community of associated users. It is also important to note that about half of the broad user community and one fifth of the associated users did not mention the need for any change/dynamic information. This re-emphasizes that fact that there is need for both stable and accurate land cover, and dynamic component reflecting time-series and changes.

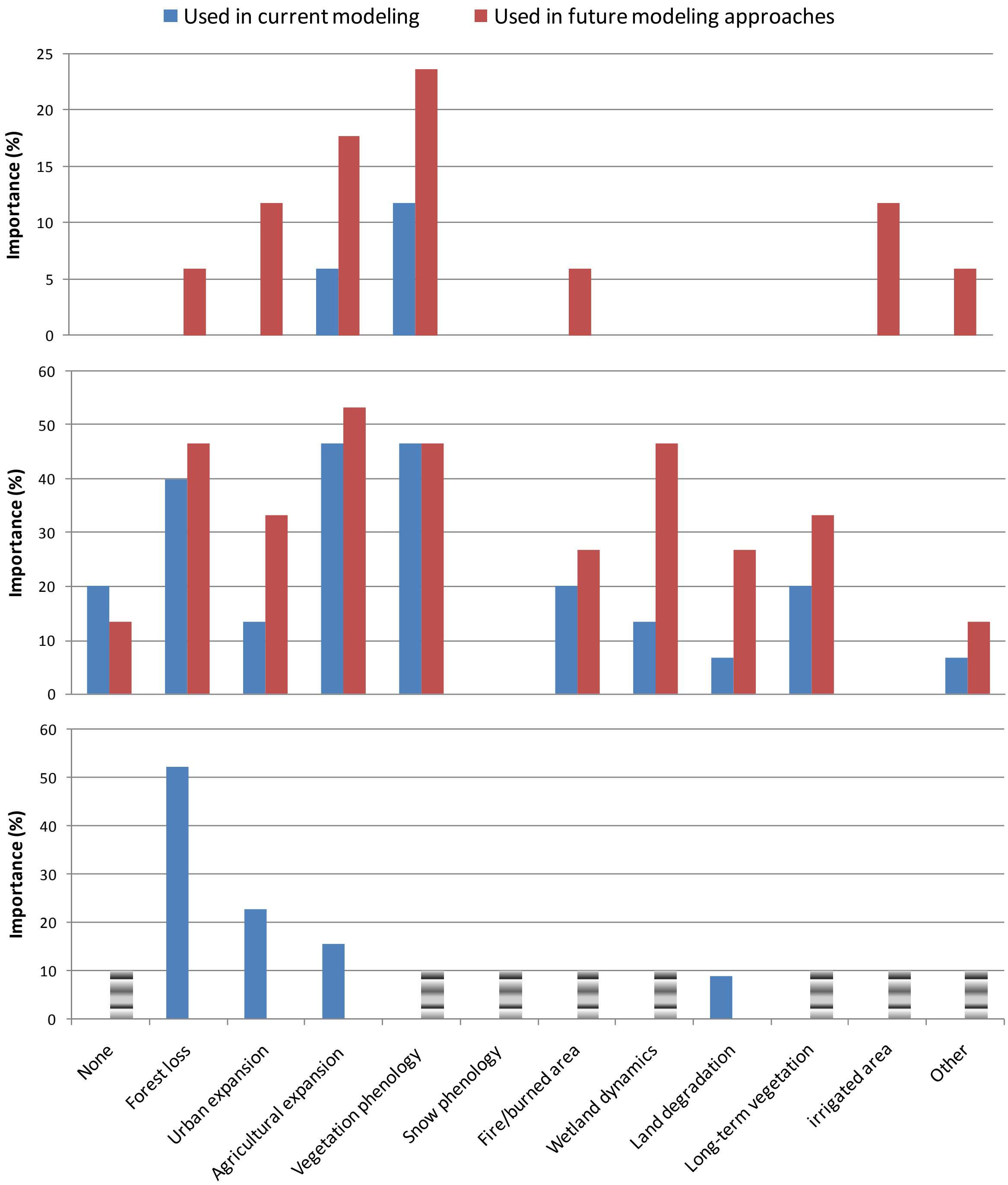


Figure 33: Thematic requirements: Classes of interest for land dynamic monitoring for Key users (upper figure), Associate users (middle figure) and broad users (lower figure, grey striped classes were not asked)

4.7. User requirement 6: Metadata, quality control, format and projection

The key climate users for this project were asked for their requirements on meta data and quality control information. There is need for metadata, including various data required to be made available with the satellite climate data records. They should be documented. Examples include a timeline of both satellite and instrument related anomalies, documentation on version of level 1 processing, what ancillary datasets have been used in the level 2 processing etc. An XML document with a well defined schema which clearly defines the instrument, its measurement technique and the analysis method used to retrieve the data record. CMUG mentions it would be helpful if the schema could, at the top level at least, share some of the structure which has been developed by the EU FP7 project METAFOR to describe climate models and their output. For example, descriptions of institutions could use the same schema elements. Next to standard metadata items, some specific requirements were mentioned by the user assessment: 1) validation information: specific areas which were checked with in situ data, and level of agreement with other land cover datasets; 2) clear description of classification methodology and underlying assumptions (e.g., cloud and snow mask); 3) information to support assessment of consistency with other EO derived products (e.g., albedo, vegetation-activity). It was mentioned to add a metric which shows how far the actual pixel value of albedo for example is deviating from the median temporal evolution of the average of the same land cover class. This would allow to identify pixels which are less reliable (representative) and would give the possibility to make sub-classes for these pixels. An alternative could also be to provide the distance of the pixel to the mean of the assigned class in feature space as used by the classifier or even better the probability that the pixel actually belongs to the class it was assigned to.

Information on the quality of the land cover products is considered as important to assess the applicability of the products in relation to its application. This information is used to make a choice on which land cover dataset is used in the climate model and for interpretation of climate modeling results in case biases can be related to land cover information in the simulation of associated variables. At the most basic level, quality information should be available in the form of class accuracy estimates. As a next step, more spatial explicit quality estimates are required: per pixel probability for a land cover class and the anticipated second class. It was mentioned that the BEAM toolbox as provided through ESA gives the opportunity to make a quick assessment of the quality of data products. However, to include these variables into climate models more adequate formats would be required which allow usage in scripting.

From the user information available, the key climate users require NetCDF as format, while the broad users and a bit more than 40 % of the associated users require GEOtiff as suitable data format to meet their needs (Figure 34). The use of a geographic lat/lon coordinates is proposed as spatial reference system. Data access through FTP (also combined with web services) is the preferred option for the climate user community (Figure 35).

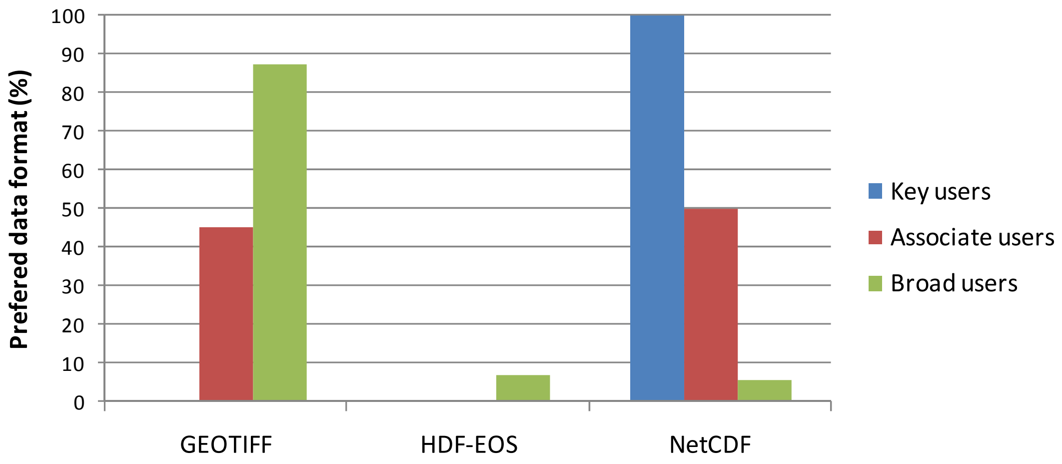


Figure 34: Most convenient data formats for data delivery

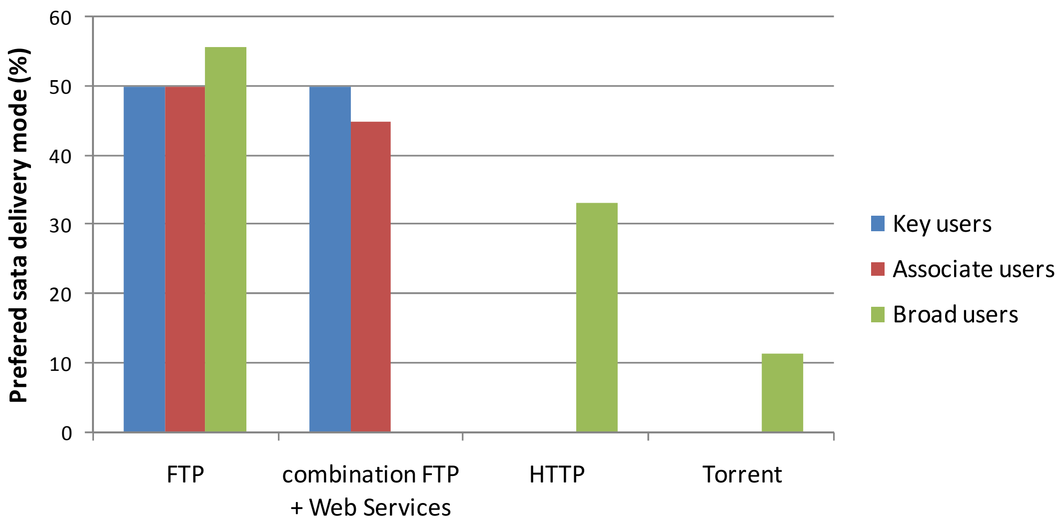


Figure 35: Most convenient data delivery mode

4.8. GCOS principles

The needs from the GCOS Implementation Plan tasks are well considered by the CCI land cover project and the accuracy requirements are taking into account (see section 4.1). GCOS recently published a set of principles for monitoring of Essential Climate Variables that should be taken up the CCI project and the product specification. These principles include:

1. Full description of all steps taken in the generation of FCDRs and ECV products, including algorithms used, specific FCDRs used, and characteristics and outcomes of validation activities
2. Application of appropriate calibration/validation activities
3. Statement of expected accuracy, stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements

4. Assessment of long-term stability and homogeneity of the product
5. Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality and applications7
6. Global coverage of FCDRs and products where possible
7. Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing
8. Arrangements for access to the FCDRs, products and all documentation
9. Timeliness of data release to the user community to enable monitoring activities
10. Facility for user feedback
11. Application of a quantitative maturity index if possible
12. Publication of a summary (a webpage or a peer-reviewed article) documenting point-by-point the extent to which this guideline has been followed

4.9. Broader guidance versus detailed user requirements

In this study, it is assumed that the a detailed survey and interaction with climate users is one of the key next step in specifying details for monitoring land cover as Essential Climate Variable. This effort is building upon the guidance from international panels, such as GCOS, and strategy documents but the detailed requirements from the climate user community now offer the next level of detail to start to specify product characteristics.

One of the key conclusions from the survey is that despite differences in needs between the users targeted in the assessment, there is quite some congruency on what is required by the GCOS IP tasks, and the broader requirements by GTOS, IGOL, IGCO, and the scientific literature review, and the detailed user needs. All have been described and documented in this report. Not only from the literature review it is obvious that climate science is moving more towards modeling the climate system incorporating human influence, impact assessment, vulnerabilities, and policy support. This direction necessitates a much stronger of the land component in terms spatial, temporal and thematic detail and related requirements for land cover and land use data. Next generation land cover observation data are not only expected to feed into existing models but are expected to stimulate new and innovative modeling approaches beyond the current state of the art.

4.10. Summary Land Cover ECV User Requirements

Land Cover has been selected as one of 11 ECVs which will be elaborated during the first phase of ESA Climate Change Initiative (2010-2013). In order to provide a comprehensive overview of the user requirements for the different ECVs, ESA has provided a standard template for presentation. Below the summary for the Land Cover ECV user requirements is provided according to this template.

Product Characteristics & Attributes

- **User Name; Affiliation**

  ESA Land Cover CCI project user assessment team (lead Wageningen University)

- **ECV Name**

  Land Cover

- **Parameter Standard Name**

  Land Cover

- **Definition**

  Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures (Di Gregorio, 2005)

- **Units**:

  UN LCCS classifiers and PFT thematic definitions (flexibility to feed into different models)

- **Projection**

  The land cover products will be projected in a Plate-Carrée projection with a geographic Lat/Long representation (WGS84 ellipsoid). The coordinates will be specified in degrees/minutes/seconds. Possibility to reproject the land cover product to model-specific projections should be included.

- **Processing Level**

  Level 4 (i.e. global land cover map at the full spatial resolution)

- **Metadata**

  An XML document with a well-defined schema (CMUG to help to specify) which clearly defines the satellite data, processing, measurement and monitoring techniques and the analysis method and quality information used to retrieve the data record. Specific requirements include: 1) validation information: specific areas which were checked with in situ data, and level of agreement with other land cover datasets; 2) clear description of classification methodology and underlying assumptions (e.g., cloud and snow mask); 3) information to support assessment of consistency with other EO derived products (e.g., albedo, vegetation-biophysical variables).

- **Format**

  NetCDF and GeoTIFF

- **Usage & Application**

  1. *Parameterization of several land surface parameters assigned based on Plant Functional Types (PFTs);*
  2. *Trend monitoring and tracking human activities, i.e. land use affecting land cover;*
  3. *Validation of model outcomes (i.e. time series) or to study feedback effects.*

Quantitative Requirements:

At least two levels of requirement should be identified:

- **Threshold requirement:** the limit at which the observation becomes ineffectual and is not of use for the climate-related application.
- **Target requirement:** the maximum performance limit for the observation, beyond which no significant improvement would result for climate applications

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographic Coverage	*Global*	*Global with regional and local specific products*
Temporal sampling	*Best/stable map and regular updates*	*Monthly data on vegetation dynamics and change*
Temporal extent	*1-2 years, most recent*	*1990 (or earlier)-present*
	Resolution	
Horizontal Resolution	*1000 m*	*30 m*
Vertical Resolution	-	-
	Error/Uncertainty	
Precision	*Thematic land cover detail sufficient to meet current modeling user needs*	*Thematic land cover detail sufficient to meet future model needs*
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*
Error Characteristics	*Independent one-time accuracy assessment*	*Operational and independent multi-date validation*

- **Ancillary Requirements**

Land cover has been and remains a fundamental dataset as consistent input to climate models and *for the integration of other data sources. There is a need for both stable land cover data and a dynamic component (time-series and changes). Consistency among the different model parameters(derived from land cover and other data sources) and among different terrestrial ECV's is often more important than accuracy of individual datasets*

- **Requirement Rationale & Traceability:**

An user consultation mechanism was set-up to actively involve different climate modeling groups by setting out surveys to different type of users: 1) a group of key-users, most of them also participating in CMUG, 2) associated climate users who are involved and leading the development of key climate relevant models and application, and 3) the broad land cover data user community reflected in the scientific literature and represented by users of the ESA GlobCover product. The surveys focused on three major ways land cover observations are used in climate models:

1. *As proxy for several land surface parameters assigned based on Plant Functional Types (PFTs);*
2. *As proxy for (tracking) human activities, i.e. land use affecting land cover;*
3. *As datasets for validation of model outcomes (i.e. time series) or to study feedback effects.*

The evolution of requirements for these aspects from current models to future new modeling approaches was specifically taken into account. Next to the surveys, requirements from the GCOS Implementation Plan 2004 and 2010 and associated strategic earth observation documents for land cover (GTOS, IGOL, IGCO, CMUG) were considered and integrated. Finally, a detailed literature review was carried out with special attention to innovative concepts and approaches to better reflect land dynamics in the next generation climate models.

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Appendix A: Broad user Survey

THE QUESTIONNAIRE

Q1: Specify your institution type

- University / Research institute
- Governmental / International organization
- Commercial sector
- Non-governmental organization

Q2: In which application are you using GLOBCOVER?

- Cartography
- Climate / Meteorology / Hydrology
- Natural resources (Agriculture, Forestry, Biodiversity)
- Remote Sensing
- Information Technology / GIS

Q3: What are the land cover spatial resolution requirements for your application?

- < 300 m
- 300 - 1000 m
- > 1 km

Q4: How often do you want to have an updated land cover product?

- Yearly
- Every 5 years
- Every 10 years

Q5: What types of classes are the most important for your application?

(multi-answer is possible)

- All - no particular interest in any class
- Tree cover/forest classes and subcategories
- Shrub classes
- Herbaceous classes
- Barren land classes
- Agricultural classes
- Urban classes
- Wetland classes
- Other specific classes

Q6: For which land cover changes are you mostly interested in, if any?

- o Forest changes
- o Urban sprawl
- o Desertification
- o Agriculture intensification

Q7: For the GlobCover MERIS composites, which composition period is the most appropriate for your application?

- o Daily
- o Weekly
- o Bi-weekly
- o Monthly
- o Bi-monthly

Q8: Is the Land Cover Classification System (LCCS) suitable for your application?

- o Yes
- o No, propose alternative... [**free text inpu**t]

Q9: How do you prefer to download the GlobCover MERIS composites?

- o FTP
- o HTTP
- o Torrent

Q10: How do you prefer to download the GlobCover land cover map?

- o FTP
- o HTTP
- o Torrent

Q11: What is the most suitable file format for the GlobCover MERIS composites?

- o GEOTIFF
- o HDF-EOS
- o NetCDF

Q12: What is the most suitable file format for the GlobCover land cover map?

- o GEOTIFF
- o HDF-EOS
- o NetCDF

Note: If you wish to advertise your publication making use of GlobCover, please email a .pdf version to due@esa.int

Appendix B: Associate User Survey

A. General Information

– **Name and institution/organization of whom completed the survey:**

– **What is your Earth system/ climate modeling focus (tick all that may apply)**

- o Global circulation modeling
- o Dynamic vegetation modeling
- o Carbon (stock) modeling
- o Land use/cover (change) modeling
- o ecosystem modeling
- o land surface modeling
- o plant-soil-carbon modeling
- o nutrient-cycling modeling
- o coupled earth system modeling (e.g. atmosphere-ocean-biosphere modeling)
- o Impact assessment modeling
- o Other, please specify ...

– **Specify which climate models are currently developed and applied in your group? (more models may be specified)**

– **Which land cover data/ product do you use or have used for your specific model application (tick all that may apply)**

- o Global and regional datasets IGBP Discover and GLCC (USGS)
- o MODIS land cover
- o GLC2000
- o MODIS VCF
- o CORINE
- o NLCD
- o TERRASTAT
- o SYNMAP
- o GLOBCOVER
- o major ecosystem types according to Olson (1994a, 1994b)
- o HYDE landcover dataset (Klein Goldwijk et al.)
- o Ramankutty and Foley's global geospatial dataset

- National land cover databases
- FAO statistics
- in situ
- Other, please specify ...

– **Could you describe what problems occur when you use current land cover datasets for your model? (Choose two options)**

- Consistency for the allocation of model parameters
- Approaches for transformation of land cover data to land surface information
- Difficulties with data interpolation
- Difficulties with data aggregation
- Thematic categories/Plant Functional Types are not sufficiently represented
- Low temporal resolution and temporal range of input data
- Low spatial resolution and spatial extend of input data
- Different definitions used for key-attributes in datasets and models
- Access and knowledge to updated land cover datasets
- Thematic accuracy of the land cover datasets
- Other, please specify

– **How would you estimate the accuracy of the land cover product for your application case?**

- very good (100-90% accuracy)
- good (90-80% accuracy)
- moderate (80-65% accuracy)
- poor (>65% accuracy)

B. Describe the land cover data requirements

– **At what spatial extent do you apply your model? (more than 1 choice is possible)**

- Global
- Continent
- Country
- Local study
- Other, please specify

– **What is the spatial resolution/detail needed for your model application**

Used in current models	**Expectations of data needed in 5 years also considering new modeling approaches**
o 1-30 m, o 30-100 m o 100 – 300m o 300-500m o 500m-1km, o 1-5km, >5 km o < 0.25 degrees latitude x longitude,	o 1-30 m, o 30-100 m o 100 – 300m o 300-500m o 500m-1km, o 1-5km, >5 km o < 0.25 degrees latitude x longitude,

o 0.25-0.50 degrees latitude x longitude o 0.5-1 degrees latitude x longitude o 1-5 degrees latitude x longitude o 5-10 degrees latitude x longitude o 10 degrees latitude x longitude o national and regional aggregates/averages o other, please specify….	o 0.25-0.50 degrees latitude x longitude o 0.5-1 degrees latitude x longitude o 1-5 degrees latitude x longitude o 5-10 degrees latitude x longitude o 10 degrees latitude x longitude o national and regional aggregates/averages o other, please specify….

– **What type of land cover classes are most important for your application, Choose the 3 options that are of most importance**

Actually used in current models	**Expected to be used after 5 years after applying new modeling approaches**
o None o Tree cover/forest classes and subcategories o Shrub classes o Herbaceous classes o Mixed vegetation classes o Barren land classes o Agricultural classes o Urban classes o Wetland classes o Other specific classes	o None o Tree cover/forest classes and subcategories o Shrub classes o Herbaceous classes o Mixed vegetation classes o Barren land classes o Agricultural classes o Urban classes o Wetland classes o Other specific classes

– **If any, please specify which land surface parameters used in your models are estimated from the land cover data (tick all that may apply)**

Used in current models	**Expected to be used after 5 years after applying new modeling approaches**
o None o Background (surface) albedo o Soil albedo (non-vegetated part) o Vegetation albedo o Vegetation roughness/ length o Vegetation ratio (climatological monthly cycle) o Leaf area index (climatological monthly cycle) o Forest ratio o Total soil water holding capacity o Plant available water holding capacity o Volumetric wilting point o Soil type and surface texture	o None o Background (surface) albedo o Soil albedo (non-vegetated part) o Vegetation albedo o Vegetation roughness/ length o Vegetation ratio (climatological monthly cycle) o Leaf area index (climatological monthly cycle) o Forest ratio o Total soil water holding capacity o Plant available water holding capacity o Volumetric wilting point o Soil type and surface texture

o Other, please specify	o Other, please specify

– **Specify which model output you use to validate land cover data (tick all that may apply)**

Validation parameter in current models	**Expected validation parameter after 5 years after applying new modeling approaches**
o None o Radiation balance o Energy Balance o NPP o LAI o Albedo o Vegetation distribution o Vegetation dynamics o Area of (oceanic) ice sheets o Area under permafrost o other, please specify ….	o None o Radiation balance o Energy Balance o NPP o LAI o Albedo o Vegetation distribution o Vegetation dynamics o Area of (oceanic) ice sheets o Area under permafrost o other, please specify ….

– **Are you using use any other earth observation derived land parameters as direct model input? (tick all that may apply)**

Use in current models	**Plan to use / expectations of data needed in 5 years also considering new modeling approaches**
o None o Albedo o LAI o Biomass o Fire/burnt area o FAPAR o Vegetation cover fraction o Surface roughness o Snow cover o Vegetation phenology o other, please specify ….	o None o Albedo o LAI o Biomass o Fire/burnt area o FAPAR o Vegetation cover fraction o Surface roughness o Snow cover o Vegetation phenology o other, please specify ….

– **In which type of thematic information describing human activities/ disturbances or dynamics are you most interested for your model application (choose 3 options)**

Use in current models	**Expected to be used after 5 years after applying new modeling approaches**
o None	o None

o Loss of forest land (deforestation) o Expansion of urban areas o Expansion of agricultural land o Vegetation phenology (seasonality) o Snow phenology o Fire/burned area o Wetland/water body dynamics o Expansion of barren land/land degradation/desertification o Long-term trends in vegetation distribution o Others, please specify	o Loss of forest land (deforestation) o Expansion of urban areas o Expansion of agricultural land o Vegetation phenology (seasonality) o Snow phenology o Fire/burned area o Wetland/water body dynamics o Expansion of barren land/land degradation/desertification o Long-term trends in vegetation distribution o Others, please specify

– **With respect to the previous question, what are the land cover temporal detail requirements for your application?**

Used in current models	**Expectations of data needed in 5 years also considering new modeling approaches**
o Daily or finer o Monthly - Quarterly o Quarterly – 6 months o 6 months- o 1 year, o 2 years o 5years o 10 years o 50 years o more than 50 years o other, please specify ...	o Daily or finer o Monthly - Quarterly o Quarterly – 6 months o 6 months- o 1 year, o 2 years o 5years o 10 years o 50 years o more than 50 years o other, please specify ...

C. Data access and delivery

– **Please list which cartographic reference system/projection (i.e., lat/lon grid) would you prefer for you land cover data?**

- o Lat/ long grid
- o Geographic coordinate system
- o (optional) specify geographic coordinate system...
- o Projected coordinate systems
- o (optional) specify projected coordinate system ...

– **What data format is most convenient for you?**

- o ISO19115 metadata standard for geographic information
- o FGDC metadata standards
- o Geography Markup Language (GML)
- o Keyhole Markup Language (KML)
- o OGC Catalogue Services
- o NetCDF

- o HDF, HDF-EOS, NITF
- o GeoTIFF,
- o JPG2000, DTED
- o Adopted standards as propagated by GEO/GEOSS
- o CEOS product format standards
- o Current ESA ERS/ENVISAT/Explorer formats
- o Others, please specify ….

– **What type of delivery mode do you prefer for data access? (tick the 3 most preferable options)**

- o From delivered media (e.g., DVD)
- o HTTP links within catalogue
- o Web services
- o FTP
- o Combination of web services and FTP (e.g., request via web service and delivery through FTP)
- o Web Mapping Services (WMS)
- o Web Coverage Services (WCS)
- o Via satellite link
- o Systematic online delivery
- o Online via the previous services, but also with subsequent media delivery
- o Others, please specify …..

D. Other problems and comments

Any other comments to the Land Cover CCI team currently involved in preparing the product specifications for a new global land cover product targeted to support climate modeling

E. Results

The resulting user requirements report will be made available to the climate modeling user community and we are happy to forward it if you provide an email address:

e-mail address:…………..

Appendix C: Key user survey

A. General Information

- **Name and institution/organization of whom completed the survey:**

- **What is your Earth system/ climate modeling focus:**
  - Carbon (stock) modeling,
  - land cover (change) modeling,
  - ecosystem modeling,
  - land surface modeling,
  - vegetation modeling,
  - plant-soil-carbon modeling,
  - nutrient-cycling modeling,
  - coupled earth system modeling (e.g. atmosphere-ocean-biosphere modeling),
  - Impact assessment modeling,
  - Other?

- **Specify which climate models are currently developed and applied in your group (if possible add key reference)?**

- **Which land cover data do you use or have used for your specific model application:**
  - Global and regional datasets IGBP Discover and GLCC (USGS)
  - MODIS land cover
  - GLC2000
  - MODIS VCF
  - CORINE
  - NLCD
  - TERRASTAT
  - SYNMAP
  - GLOBCOVER
  - major ecosystem types according to Olson (1994a, 1994b)
  - HYDE landcover dataset (Klein Goldwijk et al.)
  - Ramankutty and Foley's global geospatial dataset

- National land cover databases
- FAO statistics
- in situ
- Other, please specify ...

– **How do you evaluate the consistency of the current land cover data with your model requirements?**

- sufficient
- with some problems
- rather insufficient

– **What is the main reason of interoperability problems?**

- Temporal resolution and temporal range of input data
- Spatial resolution and spatial extend of input data
- Different definitions used for key-attributes in datasets and models
- Other, please specify

– **Could you describe in more detail what problems occur when you use current land cover datasets for your model?**

– **How would you estimate the accuracy of the land cover product for your application case?**

- very good (100-90% sufficient)
- good (90-80% sufficient)
- moderate (80-65% sufficient),
- poor (>65% sufficient)

B. Model specifications: input and output

B.1 Describe your model(s)

– **At what spatial extent do you apply your model? (if required specify for more models)**

- Global
- Continent
- Country
- Local study

– **What the spatial resolution for your model application (if required copy for more models):**

Used in current models	**Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)**	**Expectations of data needed in 5 years also considering new modeling approaches**
o Add resolution	o Add resolution	o Add resolution

You may choose from following: 1-30 m, 30-100 m, 100 – 300m, 300-500m, 500m-1km, 1-5km, >5 km, < 0.25 degrees latitude x longitude, 0.25-0.50 degrees latitude x longitude, 0.5-1 degrees latitude x longitude, 1-5 degrees latitude x longitude, 5-10 degrees latitude x longitude, > 10 degrees latitude x longitude, or national and regional aggregates/averages, other (please specify).

– **What are the land cover temporal range requirements for your application (if required copy for more models):**

Used in current models	**Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)**	**Expectations of data needed in 5 years also considering new modeling approaches**
o Add range	o Add range	o Add range

You may choose from following: < 6 months, 6 months- 1 year, 1- 2.5 years, 10 years, 50 years, 100 years, more than 100 years, other (please specify).

– **What is the shortest temporal simulation step (if required copy for more models):**

Used in current models	**Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)**	**Expectations of data needed in 5 years also considering new modeling approaches**
o Add time-step	o Add time-step	o Add time-step

You may choose from following: Hourly, 0.5 days, 1 day, Month, 0.5 year, Year, Decade, Century, other (please specify).

B.2 Describe the land cover requirements

During the Land Cover CCI kick-off meeting, three key areas how land cover observations and data are used in the climate modeling have been identified:

1. As proxy for a suite of land surface parameters that are assigned based on PFTs;

2. As proxy for human activities in terms natural versus anthropogenic and tracking human activities, i.e. land use affecting land cover;
3. As datasets for validation of model outcomes (i.e. time series) or to study feedback effects.

The questions below will address some specific issues related to the identified uses of land cover datasets in your climate models.

B2.1 Land cover as proxy for land surface parameters

– **Specify which plant functional types are estimated from the land cover data (if required copy for more models):**

Used in current models	Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)	Expectations of data needed in 5 years also considering new modeling approaches
o Add PFTs	o Add additional PFTs or classes	o Add additional PFTs or classes

– **Specify which land surface parameters are estimated from the land cover data (if required copy for more models):**

Used in current models	Expected to be used to improve current practice within 1 year	Expected to be used after 5 years after applying new modeling approaches
o Add land surface parameters	o Add additional land surface parameters	o Add additional land surface parameters

– **What are the land cover spatial resolution requirements for parameter estimation in your model application (if required copy for more models):**

Used in current models	Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)	Expectations of data needed in 5 years also considering new modeling approaches
o Add resolution	o Add resolution	o Add resolution

You may choose from following: 1-30 m, 30-100 m, 100 – 300m, 300-500m, 500m-1km, 1-5km, >5 km, < 0.25 degrees latitude x longitude, 0.25-0.50 degrees latitude x longitude, 0.5-1 degrees latitude x longitude, 1-5 degrees latitude x longitude, 5-10 degrees latitude x longitude, > 10 degrees latitude x longitude, or national and regional aggregates/averages, other (please specify).

– **In case you (would) use/require multi-temporal land cover data for parameter estimation, which time steps would you prefer (if required copy for more models):**

Used in current models	Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)	Expectations of data needed in 5 years also considering new modeling approaches
o Add time-step	o Add time-step	o Add time-step

You may choose from following: Monthly, half-year, Year, 5 years, decade, century, other (please specify).

– **Are you (or will be) using any other earth observation derived land parameters as direct model input (if required copy for more models):**

Used in current models	Expected to be used to improve current practice (such as from new land cover data, i.e. CCI products)	Expectations of data needed in 5 years also considering new modeling approaches
o Add time-step	o Add time-step	o Add time-step

Potential options: Albedo, LAI, Biomass, Fire/burnt area, FAPAR, Snow cover, other (please specify).

B2.2 Land cover as proxy for human activities

– **Specify which type of thematic information describing human activities or disturbances are you interested in for your model application (if required copy for more models):**

Used in current models	Expected to be used to improve current practice within 1 year	Expected to be used after 5 years after applying new modeling approaches
o Add human activities/ disturbances	o Add additional human activities/disturbances	o Add additional human activities/ disturbances

Potential options: conversion of forest to agriculture, urbanization, other land cover and land use change (please specify), other (please specify).

– **What are the spatial resolution requirements for land cover and land use change estimates for your model application (if required copy for more models):**

Used in current models	Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)	Expectations of data needed in 5 years also considering new modeling approaches
o Add resolution	o Add resolution	o Add resolution

You may choose from following: 1-30 m, 30-100 m, 100 – 300m, 300-500m, 500m-1km, 1-5km, >5 km, < 0.25 degrees latitude x longitude, 0.25-0.50 degrees latitude x longitude, 0.5-1 degrees latitude x longitude, 1-5 degrees latitude x longitude, 5-10 degrees latitude x longitude, > 10 degrees latitude x longitude, or national and regional aggregates/averages, other (please specify).

– **What temporal detail/frequency for tracking human activities and land use change observations would you require (if required copy for more models):**

Used in current models	Expected to be used to improve current practice (such as from new land cover data, i.e. Land Cover CCI products)	Expectations of data needed in 5 years also considering new modeling approaches
o Add time-step	o Add time-step	o Add time-step

Choose from following: Monthly, half-year, Year, 5 years, decade, century, other (please specify).

B2.3 Land cover for validation of model outcomes

– **Specify which model parameters you would like to validate using land cover and related observation data (if required copy for more models):**

Used in current models	Expected to be used to improve current practice within 1 year	Expected to be used after 5 years after applying new modeling approaches
o Add validation parameter	o Add validation parameter	o Add validation parameter

– **For each parameter, could you please provide more specific information on what level of detail you require by using the following table:**

Parameter	**Information need from land cover observations**	**Spatial extend (i.e. local, national, global)**	**Spatial resolution (30 m, 1 km, 1 deg.)**	**Temporal resolution (hourly, daily, monthly, yearly)**

– **What other (spatial) data sets are of importance for your application that should be consistent with the land cover dataset? (tick all that may apply)**

- o Digital elevation model
- o Transportation infrastructure (i.e. road network)
- o Water use
- o Soil data
- o Groundwater heights
- o Lake and reservoir level
- o Snow cover
- o Glacier and ice caps (extent)
- o Fraction of absorbed photosynthetically active radiation (FaPaR)
- o Biomass
- o Leaf area index (LAI)
- o Fire disturbance
- o Soil moisture
- o Climate data
- o Meteorological data
- o Other, please specify ...

C. Data access and delivery

– **Please list which cartographic reference system/projection (i.e., lat/lon grid) would you prefer for you land cover data?**

– **What data format is most convenient for you?**

- o ISO19115 metadata standard for geographic information
- o FGDC metadata standards
- o Geography Markup Language (GML)
- o Keyhole Markup Language (KML)

- OGC Catalogue Services
- NetCDF
- HDF, HDF-EOS, NITF
- GeoTIFF, JPG2000, DTED
- Adopted standards as propagated by GEO/GEOSS
- CEOS product format standards
- Current ESA ERS/ENVISAT/Explorer formats
- Others, please specify ....

– **What type of delivery mode do you prefer for data access?**

- From delivered media (e.g. DVD)
- HTTP links within catalogue
- Web services
- FTP
- Combination of web services and FTP (e.g., request via web service and delivery through FTP)
- Web Mapping Services (WMS)
- Web Coverage Services (WCS)
- Via satellite link
- Systematic online delivery
- Online via the previous services, but also with subsequent media delivery
- Others, please specify .....

– **How you evaluate the current retrieval process of your input data?**

- Easy, data is easy to retrieve and is free to use
- Moderately easy, data is easy to retrieve but is not free
- Poor, data is not easy to retrieve, and is not free to use

– **What do you consider to be the current limitations in the retrieval process of land cover datasets? (tick all that may apply)**

- Ease of access
- Costs
- Transparency
- Aging of knowledge
- Quality/reliability
- Speed – time of delivery
- Historical data access
- None
- Others, please specify ....

D. Other problems and comments

Any other comments to the Land Cover CCI team currently involved in preparing the product specifications for a new global land cover product targeted to support climate modeling

Appendix D: Overview of groups contacted as associate users

Table 10: Global Climate Modeling groups (responding users indicated with *)

Originating Group(s)	*Country*	*Coupled model: GCM*
Beijing Climate Center *	China	BCC-CM1
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0
National Center for Atmospheric Research	USA	CCSM3
Canadian Centre for Climate Modeling & Analysis *	Canada	CGCM3.1
Météo-France / Centre National de Recherches Météorologiques	France	CNRM-CM3
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.5
Max Planck Institute for Meteorology (MPI-M) *	Germany	ECHAM6/MPIOM
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group.	Germany / Korea	ECHO-G
LASG / Institute of Atmospheric Physics	China	FGOALS-g1.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies	USA	GISS-AOM
Instituto Nazionale di Geofisica e Vulcanologia	Italy	INGV-SXG
Institute for Numerical Mathematics	Russia	INM-CM3.0
Institut Pierre Simon Laplace	France	IPSL-CM4
National Center for Atmospheric Research	USA	PCM
Hadley Centre for Climate Prediction and Research / Met Office	UK	HadGEM1
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies (JAMSTEC)	Japan	MIROC3.2

Meteorological Research Institute	Japan	MRI-CGCM2.3.2
PBL Netherlands Environmental Assessment Agency *	Netherlands	IMAGE

*Table 11: Regional Climate Modeling groups (responding users indicated with *)*

Originating Group(s)	*Country*	*GCM*
OURANOS / UQAM *	Canada	CRCM
Météo-France / Centre National de Recherches Météorologiques	France	ALADIN
Universidad Computense de Madrid *	Spain	PROMES
Max Planck Institute for Meteorology (MPI-M)	Germany	REMO
Danish Meteorological Institute (DMI)	Denmark	HIRHAM
ETH Zurich	Switzerland	CLM
GKSS Forschungszentrum Geesthacht GmbH	Germany	CLM
The Royal Netherlands Meteorological Institute (KNMI)	Netherlands	RACMO
Iowa State University	USA	MM5
Pacific Northwest National Laboratory	USA	WRF
Swedish Meteorological and Hydrological Institute (SHMI)	Sweden	RCAO
Abdus Salam International Centre for Theoretical Physics (ICTP)	Italy	RegCM3
UC Santa Cruz	USA	RegCM3
Hadley Centre for Climate Prediction and Research / Met Office	UK	PRECIS
UC San Diego / Scripps	USA	RSM

Table 12: Land Carbon Modeling groups (responding users indicated with *)

Originating Group(s)	*Country*	*GCM*
*US Geological Survey **	USA	FORE-SCE / GEMS
Max Planck Institute for Meteorology (MPI-M)	Germany	JSBACH
Max Planck Institute for Biogeochemistry (MPI-BGC)	Germany	LPJ
*University of Oxford **	UK	JULES
*Alterra **	NL	MITERRA
Hadley Centre for Climate Prediction and Research / Met Office	UK	MOSES/TRIFFID
VU Amsterdam	NL	PROBE
Institut Pierre Simon Laplace	France	ORCHIDEE
*Potsdam Institute for Climate Impact Research (PIK) **	Germany	LPJmL
National Center for Atmospheric Research	USA	LSM, CASA
Lawrence Livermore National laboratory (LLNL)	USA	IBIS
*University of East-Anglia **	UK	NERC-Quest ESM
Frontier Research Center for Global Change (FRCGC)	Japan	Sim-CYCLE
University of Maryland (UMD)	USA	VEGAS

Table 13: Hydrology Carbon Model groups (responding users indicated with *)

Originating Group(s)	*Country*	*GCM*
Centre for Ecology and Hydrology (CEH)	UK	GWAVA
Hadley Centre for Climate Prediction and Research / Met Office	UK	JULES
Potsdam Institute for Climate Impact Research (PIK)	Germany	LPJmL
University of Reading	UK	MacPDM
*University of Tokyo, National Institute for Environment Studies **	Japan	H07, Matsiro

Institut Pierre Simon Laplace	France	ORCHIDEE
Utrecht University *	Netherlands	pcr-globwb
Wageningen University (WUR) *	Netherlands	VIC
University of Princeton, University of Washington	USA	VIC
Center for Environmental Systems Research (CESR)	Germany	WaterGap
University of Frankfurt	Germany	WaterGap
University of New Hampshire	USA	WBMPlus

*Table 14: Numerical Weather Prediction groups (responding users indicated with *)*

Originating Group(s)	***Country***	***GCM***
European Centre for Medium-Range Weather Forecast (ECMWF)	UK	IFS
German Weather Service (DWD)*	Germany	GME, COSMO-CLM
Météo-France / Centre National de Recherches Météorologiques	France	Arpege
Danish Meteorological Institute (DMI)	Danmark	HIRLAM
Norwegian Meteorological Institute	Norway	HIRLAM
National Center for Environmental prediction (NCEP)	USA	GFS
UK Met Office	UK	PRECIS