**Biogeosciences
Discussions**

Interactive comment on "Revisiting land cover observations to address the needs of the climate modelling community" *by* S. Bontemps et al.

S. Bontemps et al.

sophie.bontemps@uclouvain.be

Dear reviewer,

We do thank you for your comments which will indubitably help us to improve this work. We also thank you for your interest in the topic of our paper and for your encouragement to rework our manuscript and publish it.

Taking into consideration all your suggestions, please consider the following actions regarding the structure of the paper, its link with international activities and the discussion relative to the land cover concept and mapping approach.

General comments

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We agree that the articulation between the conducted survey and the EO experiment could be improved. To this end, the structure of the document (from section 3) will be modified as follows:

- Section 2 will be maintained, presenting the users' survey and the resulting requirements in terms of land cover products;

- Section 3 will be re-written with the aim of making a clear link between the user's requirements (section 2) and the new mapping concept and approach (which will be developed in section 4). As an introduction, it will indicate on which specific requirements the next sections will focus (i.e. the need to decouple stable and dynamic components of the land cover). It will later discuss the current land cover concept (section 3.1) and the current land cover mapping approach (section 3.2);

- Section 4 will be completely reworked in order to present CCI Land Cover project (introduction), the new mapping approach developed in this project and tested with the SPOT-VGT time series (section 4.1) and the next steps (section 4.2). All the EO experience on the use of multi-annual EO time series, that you suggest us to emphasize, will be included in section 4.1;

- The abstract and the conclusion will also be re-written to ensure a clearer understanding of the paper structure and of its main findings.

Specific attention will be paid to eliminate value judgments or to express them in a more neutral form (either re-phrasing or referencing).

Specific comments

- Title

Our surveys were dedicated to users involved in the modelling communities mentioned in the opening line of section 2: the General Circulation Modelling (GCM), Earth System Modelling (ESM) and Integrated Assessment Modelling (IAM) communities. These three communities were identified as playing an important role in understanding and

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quantifying Earth and climate system and in understanding the role of land use and land cover change.

- Abstract

The abstract will be re-written to reflect the new structure of the paper. With regard to the reference to the UNFCCC convention, we will rephrase the corresponding sentences in our manuscript to present our work as a support to the UNFCCC effort for reducing the uncertainties in the global climate change system understanding.

- Page 7714, line 20

The importance of land cover observation could indeed be better introduced. This first paragraph will be rephrased to emphasize (i) the usefulness of land cover maps in wide range of applications and (ii) the interest for land cover change information as an important climate forcing by altering water and energy exchanges with the atmosphere.

This dichotomy will also contribute to make a clear distinction between land cover and land cover changes as distinct variables to observe by remote sensing (see your comment "Page 7716, line 11").

- Page 7715, line 20

A better characterization of the validation exercises and accuracy values mentioned in the text will be included. Overall accuracy figures inform about how much a classification diagnostic is in agreement with independent "reference" information. This is obtained by crossing the land cover map and a reference dataset in order to build a confusion matrix. In our manuscript, the accuracy figures correspond to weighted-area accuracy as the accuracy value of each class was then weighted by its area proportion.

As for the temporal stability, it refers to the reproducibility of the land cover mapping over areas without change. Such characterization is not addressed in current mapping and validation exercises but is the core of our paper. This term will not be introduced before the survey as this is a new requirement which appears thanks to this user con-

sultation mechanism. However, we will take some lines to correctly and completely define this concept at the beginning of section 3 (see your comment "Page 7721, line 3").

- Page 7715, lines 22-23

Land surface characteristics here referred to the wide range of variables that can be derived from land cover data, such as land use, properties relating to biodiversity and conservation, carbon fluxes, primary production, etc. Some examples will be added in the text in order to clarify this concept.

- Page 7715, lines 24-28

This sentence will be moved at the end of the document, when summarizing the findings of the paper and introducing perspectives.

- Page 7716, lines 1-3

Please, see our answer to the "Abstract" comment.

- Page 7716, line 11

Land cover is recognized as pressing environmental issue acting as both a cause and a consequence of climate change and therefore belongs to the list of Essential Climate Variables defined by the Global Climate Observing System. As mentioned in the ECV land cover description of the Global Terrestrial Observing System, land cover can be primarily characterized by maps as categories or continuous variables. Secondary outputs of land cover characterization include land cover change (area and change trajectories). The CCI Land Cover project focuses on the production of global land cover products (action T26 in the GCOS Implementation Plan). The depiction of land cover change (action T27) is not fully considered, while being listed in the GCOS land cover themes. This distinction will be highlighted in the text.

Addressing action T26 is seen as a first essential step to fulfill some of the urgent and

prominent climate user needs, while developing concepts that allow to further increase detail towards addressing action T27. Climate users have also advocated the need to move towards providing action T27-type data, in particular for future modeling and assessment efforts.

With regard to your request to provide more detail about the whole Climate Change Initiative of the European Space Agency, we will include a general description and give some figures but we will try to keep it rather concise. Indeed, presenting this programme is not the objective of this paper.

- Page 7717, lines 20-21

This is indeed a valid point and this issue was considered in the users' consultation mechanism. Surveys included not only the key users (i.e. involved as partners in the project) but also the broader climate user community and the current GlobCover users. This has allowed us having most responses from the users not involved in the project and therefore, proposing representative requirements. In fact, the user survey confirmed that there was quite some congruency among the different users groups that were assessed.

The text will be edited to make the concern clearer. A first version of the revised paragraph is provided here below.

"With this aim in view, specific surveys were set-up to focus (i) on a few "key-users" that were partner in the CCI Land Cover project, (ii) on a broader group of "associated users" who are leading the development of relevant key climate models and applications and (iii) on the broader land cover community reflected in the GlobCover users."

- Page 7717, line 23

Several actors and types of users were identified as representative of the modeling communities concerned with climate and climate change issues:

- Key users: they are central to all phases of the user interaction within the CCI Land

Cover project as they are project partners. They are the Max Planck Institute for Meteorology (MPI-M), the Laboratoire des Sciences du Climat et de l'Environnement (LSCE) and the Meteorological Office Hadley Center (MOHC). Key users will also be directly involved in the products assessment.

- Associated users: These users from the climate modeling community are not project partners, but were contacted to participate in the user survey. A group of 85 users was approached and 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.

- Broad user community: this community was considered by gathering information of the project through the World Wide Web, by reviewing scientific literature and by receiving feedback from general global land cover data users. 8000 users were contacted and 372 accepted to be fill in the survey.

This short description of the users' groups will be included in the text, but we really don't see how we can be more precise regarding the number of users (as figures are already provided in our paper).

- Page 7719, lines 6-10

This result was indeed a surprise for us. It is clear that the IGBP map is historically used by the climate modellers. On the one hand, it is one of the first global maps and on the other hand, it is probably the more climate-oriented existing global land cover product. It was indeed specifically developed for global modelling applications in order to permit the modelling of parameters such as net primary production, the hydrologic cycle, gas storage and emissions, surface energy exchanges, etc. The 17 classes of the legend embrace the climate independence and are compatible with classification systems used for environmental modelling. This explains that this product is associated with both legitimacy and technical credibility for climate users.

The integration of a land cover map in their model requires some time-consuming steps

(legend translation in Plant Functional Types, format conversion, spatial aggregation, re-projection, etc.). It will therefore be done only if new products can bring substantial improvement and this is not totally the case.

First, the current users' requirements in terms of spatial resolution (100m and 0.5 degrees) do not make the more recent products (such as the 500-m MODIS land cover maps and the 300-m GlobCover products) necessary for their model application at global and national scales. Second, the more recent set of products don't allow major improvement in the consideration of land cover changes. Indeed, no consistent time series of successive land cover maps have been delivered until now. This context will be highlighted as a challenge that shall be addressed by the new CCI Land Cover project.

- Page 7720, line 4 / Page 7720, line 9

The users provided detailed information on the level of spatial and temporal details they require. The first conclusion was that there was not one spatial or temporal resolution fitting all purposes. Higher resolutions than those specific to T26 were also mentioned: spatial resolutions higher than 100m and annual products with associated information depicting intra-annual and monthly dynamics. This is why we mentioned that land cover product should be flexible in terms of spatial and temporal resolution to serve different scales and purposes. In the framework of this project (which addresses the action T26), this requirement was understood as the need to provide products using the full resolution of the used sensors and to perform spatial and/or temporal aggregation as a posteriori steps.

This information will be added to clarify the statement.

- Page 7720, line 9

With regard to the spatial resolution, 300 m or coarser was considered, on average, as sufficient to meet modeling requirements for most users. However, for future periods

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and for some applications (land cover observations to estimate model parameters or description of change), there were requirements for fine-scale satellite observations coming from Landsat-type imagery (or from Sentinel-2 in the coming years).

This information will be added to clarify the statement.

- Page 7720, line 14

The text will be edited to make the argument clearer. A first version is provided here below. "Future requirements for temporal resolution refer to intra-annual and monthly dynamics of land cover; in particular making use of the increasing length and detail of remote sensing time series data".

- Page 7721, line 3

"Accuracy" will be defined in the introduction (see your comment "Page 7715, line 20"). As for stability, as already mentioned, it refers in our manuscript to "the reproducibility of the land cover mapping over areas without change". The need for stability comes from facts that (i) some users would need the description and localization of land cover changes and (ii) other users require one map of land cover characteristics that will not vary in their model applications (as it is used as basis for deriving other land surface parameters).

Yet it should be recognized that currently, there is no consistent time series of successive land cover maps. In other terms, when successive maps are compared, it currently highlights much more classification variability than land cover changes. This also reveals that the current land cover maps do not necessarily reflect stable land cover characteristics.

This discussion about "stability" will be introduced in this section. In addition, the distinction between the products' accuracy (which is already addressed by the maps producers but with lower results than expected) and the products' stability (which is a new requirement) will be more explicit. The fact that this paper focuses on this new issue

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will also be highlighted.

- Page 7721, lines 6-15

The text will be edited to make the argument clearer. A first version of the revised paragraph is provided here below.

"In addition, the user assessment has highlighted that land cover remains a key dataset that serves as consistency basis for many other land surface parameters and for the associated temporal variability. For instance, the users have emphasized that there is some reluctance to take up new land surface variables (including other ECV's such as Leaf Area Index (LAI) or Fraction Absorbed Photosynthetically Active Radiation (FA-PAR)) coming from global EO datasets although they provide more spatial and temporal detail than current model parameterizations. Since many users are relying on a common land cover map to estimate a series of land surface parameters, introducing new datasets may result in inconsistencies with the existing model inputs. That's the reason why consistency (i) of the input parameters in space and over time and (ii) among a series of land surface parameters is valued higher than the accuracy of individual parameters. However, this aspect is even not addressed by the EO land domain."

- Page 7722, lines 18-26

We agree that these lines don't bring relevant information about the core topic of our manuscript. They will be removed.

- Page 7723, lines 11-14

We thank you for your suggestion. This is indeed the right place to concretely link the surveys and the EO experience. We will build this articulation on the need of "stability" expressed by users (see your comment "Page 7721, line 3 "). We will also show that this need is clearly not met with the most recent products (and that it is why the old IGBP dataset keeps getting so much use). This will be illustrated by some stability

analyses of successive global land cover products, in terms of surface (number of pixels with a different label between 2 successive maps) and in terms of change trajectories.

- Page 7724, lines 1-18

As explained in our answer to your general comments, the structure of the paper will be re-organized to make the link between the conducted survey and the EO experiment clearer. As a result, section 3 will only focus on the current land cover concept (section 3.1) and the limitations of existing products (including the stability analyses detailed in our answer to your comment "Page 7724, lines 11-14"). The EO experiment will be moved in section 4, as an attempt of the CCI Land Cover project to address this "stability" issue. The assumption underlying this experiment and how it can contribute to meet the stability requirements will be detailed as follows.

This experiment is based on the assumption that using a single year of data can result in the mapping of temporary conditions (map savannahs as burnt scars, boreal forest as snow, croplands as bare soils, etc.). An alternative could come from the description of the land cover from multi-year observation dataset. This alternative is now feasible thanks to the recent capabilities of acquiring and processing global multi-year EO data. It was tested in the framework of the CCI Land Cover project and the results are presented in this paper.

This new structure should allow us emphasizing these findings (which are indeed rather new) and better linking them with the users' requirements.

- Page 7724, lines 19-21

We agree that our statement is based on the assumption of studies using medium or coarse (250m- 1km) spatial resolution EO dataset. This clarification will be added in the text. Nevertheless, we would like to point out that even if change rates larger than 1% can be measured using higher resolution data, they should remain far from the classification instabilities observed in this experiment (up to 12% of pixels without

majority label).

- Pages 7724-7725

We realize that this section weakens our manuscript. This comment will be addressed by re- organizing the manuscript. In the new structure, this section will no more appear and its content will be broken down in other sections.

- Page 7726, lines 13-15

You are absolutely right saying that T27 will contribute to solve this problem. This observation will be included in the text. However, we also believe that solving this issue will also require developing dedicated change detection techniques, which are based on time series analyses and not on maps comparison.

- Pages 7727-7728

We agree with this specific comment. Conclusion will be re-written to ensure a clearer understanding of the new paper structure and of its main findings.

Technical corrections

- Page 7715, line 1

We admit that the term "efficiency" is probably not the most appropriate one. The sentence will be rephrased to present some properties of EO technologies which are widely recognized in literature for their usefulness in land surface characterization. The following elements will be included in the manuscript: their unique global coverage, their synoptic view, their multispectral properties, their low cost, their increasing availability and their computer-based processing.

- Page 7715, line 4

The clarification will be done, in writing that "in many different regions of the world, land cover has been mapped and characterized several times using remote sensing data".

- Page 7716, line 5

The text will be edited to remove value judgments. A first version of the revised paragraph is provided here below.

"In this context, the European Space Agency (ESA) has initiated a new global monitoring program - known for convenience as the Climate Change Initiative (CCI) - driven by requirements for observing the ECV's. The ESA-CCI aims to provide a comprehensive and timely response to this need for long- term satellite-based products in the climate domain (ESA, 2009)."

- Page 7719, line 25 / Page 7720, line 1

The text will be edited to remove value judgments. A first version of the revised paragraph is provided here below.

"In terms of land cover change and dynamics, the user survey has shown that information need is largest for vegetation phenology, agricultural expansion, forest loss/deforestation and urbanization. With less importance (in terms of user requests), the needs for monitoring wetland dynamics, fire, land degradation and long-term vegetation trends are highlighted."

- Page 7723, lines 17-18

Before the MODIS and GlobCover experience, there has only been one-shot global land cover mapping exercises. However, due to the increasing importance of land cover monitoring (and not only mapping) applications, the needs of the scientific community have evolved to call for developing classification techniques that enable the regular delivery of consistent global land cover maps. Even if the MODIS and GlobCover experiences have not addressed this consistency issue, they have allowed a first step in this direction: they have indeed demonstrated the capacity for a repetitive production effort, using the same classification methodologies and based on time series from the same sensor.

- Page 7723, line 24

We will follow your recommendation and remove this figure.

- Page 7724, line 23

We totally agree with your major concern for precisely defining the "accuracy" and "stability" concepts. A particular attention will be paid to this requirement in the manuscript revision. As it will be done, we guess that the meaning of these opposite terms ("inaccuracies" and "instabilities") will no more be problematic.

- Page 7727, line 9

We agree that the sentence, as written in the manuscript, can cause confusions. The need for a permanent data validation tool (allowing validating future land cover products but also historical ones) should be presented as a requirement resulting from our project. However, this would require the development of a permanent and collaborative validation environment and this effort is currently not planned.

The project will contribute to this goal by developing a validation protocol which is partly automated (pre-interpretation of high spatial resolution images in an automated way) in order to make easier the building of a reference dataset and therefore, its repetitive application.

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