Climate Change Initiative Extension (CCI+) Phase 2
New Essential Climate Variables (NEW ECVS)
High Resolution Land Cover ECV (HR_LandCover_cci)

User Requirement Document

(URD)

Prepared by:

Università degli Studi di Trento
Fondazione Bruno Kessler
Università degli Studi di Pavia
Università degli Studi di Genova
Université Catholique de Louvain
Politecnico di Milano
LSCE
CREAF
University of Exeter
e-GEOS s.p.a.
Planetek Italia

Changelog

Issue	Changes	Date
1.0	First issue	06/06/2024

Detailed Change Record

Issue	RID	Description of discrepancy	Sections	Change

Contents

1 Introduction

1.1 Executive summary

This report collects the user requirements from the project Task1 activities, updating the URD of Phase 1 of the HRLC project. This review of user requirements is obtained from the new Phase-2-consultations to the Climate Research Community (list of 186 subscribers) and the feedback from the User Workshop [RD2]. The summary of these feedback is:

- The most interesting region for an extension is the Amazonian region to monitor deforestation and the land cover changes impacts.
- 10-30m spatial resolution is of interest for the community since it presents the advantage when studying small-scale processes.
- Some land cover classes could be splitted in different land uses: non-natural shrub / grassland categories, adding pastures, planted forests.
- Uncertainty is a very interesting topic by the CRC, despite many users are not implementing in the models, they plan it for the future.
- Users suggest the possibility to download a region of interest (i.e. subset of the entire scene).

1.2 Purpose and Scope

This document describes the activities and results for the user requirement analysis (WP1100) for the product specification as part of the phase 2 of the HR Land Cover CCI project within ESA's Climate Change Initiative Program. The overall objective of this task is to update the URD document produced during Phase 1 by organizing new consultations of the climate user community (CRGs and CMUG from CCI projects but also climate researchers interested in or already using HR land cover maps for their applications), and by collecting their requirements for the products generated in the second phase for the HR Land Cover CCI project.
The WP1100 is the specific WP for the Phase 1 of the Task 1 of the project. The main purpose is twofold:

- to report the updated user requirements for the new processing chain, the reprocessing of the Phase 1 products and the selection of the areas for the new products
- to enlarge the climate model assessment, with possible integration in the project activities of other simulations using different climate models and advice from end users working on mitigation/adaptation questions.

In order to gather this information, we have implemented the methodology detailed in Section 3 of the present document and the following tasks assigned to WP1100 have been developed:

- Update the list of vegetation and climate modellers to be involved in the user requirement refinement (see Annex 6.5 for the affiliations list).
- Organize a user meeting at the EGU conference with potential vegetation and climate users.
- Advertise the HRLC products generated during Phase 1 at the ESA booth of the EGU conference and present the data at two time slots (see section *Dissemination of the User Workshop* in the [RD2])
- Organize a consultation during the EGU events.
- Report the preliminary user requirements.
- Analyse user feedback on the use of the HR land cover datasets.
- Collect data for additional assessment of user needs, especially from RECCAP2 project.
- Refine product specifications, the needs in terms of legends, yearly historical product and seasonal related variables (referred as 'conditions') and new areas.
- Links with the CMUG and other CCI+ projects.

We recall here the GCOS requirements for High Resolution Land Cover products from the 2022 GCOS Implementation Plan (GCOS-244):

9.6.2 ECV Product: Maps of High-Resolution Land Cover

Name	Maps of High-Resolution Land Cover				
Definition	High Resolution Land Cover is the observed (bio)-physical cover on the Earth's surface for monitoring changes at local scales (suitable for adaptation and mitigation).				
Unit	Primary units are categories (binary variables such as forest or cropland) or continuous variables classifiers (e.g. fraction of tree canopy cover in percent). Secondary outputs include surface area of land cover/use types and land cover/use changes (in ha).				
Note	It can also be variable in time due to land changes and phenology.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m	Size of grid cell	G	<10	Suitable for local land managers - specifically for targeted applications in climate change mitigation and adaptation. Small features such as green spaces within cities are visible and changes to water extent (in particular change in river courses) also become visible at this resolution. More detailed land cover descriptions are more.
			B	10-30	Can identify human induced land change at regional levels. Most features of interest are visible, and broad changes captured.
			T	30-100	Broad landscape typologies and changes across landscapes are visible, so suitable for landscape management.
Vertical Resolution			G	-	N/A, since ECV products provide estimates as total over a certain area with further vertical discrimination. There is currently no consideration of the third dimension for land ECV products though some of the definitions (such as forests) often use, among others, a minimum height criteria.
			B	-	
			T	-	
Temporal Resolution	month		G	1	Monthly. Allows regrowth, phenology, changes in water extent related to seasonality to be detected.
			B	12	Yearly. Inter-annual changes can be detected
			T	60	Every 5 years. Suitable scale for longer-term mapping, related to broader land cover change dynamics.
Timeliness	month		G	3	Seasonal. Ideally, land cover data become available soon after the acquisition of the data but quality processing and ECV product derivation and accuracy assessment, as well as, long-term consistency is to be ensured to track changes and trends. These frequent changes may be relevant for land managers who can react quickly to changes.
			B	12	Annual and bi-annual reporting applications. Policy makers will be able to develop and assess policies based on regular updates and observed changes.
			T	60	Every 5 years. Suitable scale for longer-term mapping, related to broader land cover change dynamics.
Temporal Extent (Time span)	Y		G	30-50	Historic changes which most users are interested in are captured. Only be achieved with modeling approaches using non-earth observation data sources (i.e. historical maps) – where more recent high resolution data sources (Landsat, Sentinel) are not available.
			B	10-30	Historic changes can be assessed for the Earth observation data which are required at this resolution.
			T	0 (one time only)	Only current and potentially future data are available, but this is useful for those who require current status products, for example for modelling, and static assessments.
Required Measurement Uncertainty	% for accuracy and errors of omission and commission and hectares for area estimates incl. 95 % confidence intervals	Primary: overall map accuracy and errors of omission and commission for individual land cover categories and types of change (incl. confidence interval). Secondary: bias for area estimates (incl. confidence intervals)	G	5	For reporting purposes, this would allow sufficient accuracy, where all classes have high accuracies. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover
			B	20	For other uses, this would be sufficient – it would be expected that some classes would have higher accuracy. For example confusion between built-up and forest would be lower, but confusion between agriculture and bare might be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
			T	35	This threshold would be suitable for maximum commission/omission error for individual categories. Overall accuracy might be expected to be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
Stability	% incl. 95 % confidence intervals	Primary: errors of omission and commission for individual land cover categories and types of change (incl. confidence interval)	G	5	Stability is important for long-term land cover datasets where multiple sensors are used to generate a time series dataset. High stability is required for assessing long-term trends. The stability can be assessed by multi-date independent accuracy assessment. The stability requirements are tighter that for overall uncertainty since the aim for multi-date ECV data is to provide information on changes and trends.
			B	15	
			T	25	
Standards and References					

Figure 1: GCOS requirements

1.3 Applicable documents

[AD1] CCI HR Technical Proposal, v1.1, 12/07/2023

1.4 Reference documents

[RD1] The Global Climate Observing System: Implementation Needs, 01/10/2016, GCOS-200, Updated version in 2022 (GCOS-244) available at: https://library.wmo.int/idurl/4/58104

[RD2] User Workshop Report (UWR)

1.5 Acronyms and abbreviations

CCI Climate Change Initiative
CRC Climate Research Community
CMUG Climate Modelling User Group
CREAF Centre de Recerca Ecològica i Aplicacions Forestals
ECV Essential Climate Variables
ESM Earth System Models
EVI Enhanced Vegetation Index
GCOS Global Climate Observing System
GDPR General Data Protection Regulation
HR High Resolution
LAI Leaf Area Index
LBA Large-Scale Biosphere-Atmosphere Experiment
LC Land Cover
LCC Land Cover Change
LCCS Land Cover Coverage Classification System

LCML	Land Cover Meta Language
LCZ	Local Climate Zone
LSCE	Laboratoire des Sciences du Climat et de l'Environnement
MR	Medium Resolution
NDVI	Normalized Difference Vegetation Index
PFT	Plant Functional Type
RS	Remote Sensing
SFT	Surface Functional Type
SoW	Statement of Work
URD	User Requirements Document
VM	Virtual meeting
WP	Work Package

2 Preliminary user requirements

A preliminary requirement that has been identified by the HRLC CRG concerns the location of the new products. Among the three case studies defined in task 5 for the products assessment, one concerns the development of a dedicated climate service for the monitoring of the Amazonian deforestation and the use of a regional climate model to model global carbon budget of the Amazonian ecosystem. The achievement of this task will require to extend the historical region to the North and to the West (the coordinates of the region have still to be specified by the CRG). Recent inputs provided by the Exeter University partner (S. Sitch) confirmed the interest of extending the historical region to the Rondonia and Pantanal regions (see documents in annex 6.2) to analyse land cover changes and fire activity over the last thirty years. The region of Tapajos in the Para state of Brazil is also of great interest since it is impacted by deforestation and forest degradation (Gatti et al., 2021) and will be the place of the next ESA Amazon experiment in 2025. This experiment will bring together a complete suite of observations and models in one of the specific critical zones currently regarded as tipping points of terrestrial emissions. It is foreseen to cover a region of around 100 x 100 km including a range of different types of land cover such as degraded land, agriculture, secondary and intact forests. It is also where the experimental sites of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) led by Brazil's National Institute for Space Research is located.

Besides, the region of Caatinga in the north-eastern part of Brazil is also of interest. Indeed, Caatinga is a seasonally dry tropical forest, one of the most threatened ecosystems in the world (Miles et al., 2006). This very heterogeneous region is not only threatened by various acute (e.g. forest loss) and chronic (e.g. overgrazing and firewood extraction) human disturbances, but also climate change (e.g. longer and more severe droughts) (Rito et al., 2017; Kulka et al., 2024). Being a highly heterogeneous region exposed to persistent disturbances makes this area an interesting case for evaluating the added value of HRLC maps. The same interest goes to the Gran Chaco tropical dry forest extending over Argentina, Paraguay, Bolivia and Brazil which is the second largest forest in South America after the Amazon. This region has been identified as a deforestation hotspot due to agricultural expansion (Baumann et al., 2022) and is prone to periodic fires used to deforest or as a practical management tool (San Martin et al., 2022) to promote crops and pastures production. Therefore, it is interesting to monitor the land cover in such regions over the historical period to detect impacts of drought variability as well as to monitor other natural and human disturbances. Additionally, it is of interest to better interpret MRLC data and Harpers's (Harper et al., 2023) PFTs dataset developed in the framework of the CCI-MRLC project, since important differences have been detected in PFT maps in these regions in terms of woody/grass partition (see Figure in annex 7.3) leading to differences in the simulation of key land surface variables related to the water and energy cycles.

The same comparison of MRLC and Harper's PFTs maps highlighted some discrepancies in the woody/grass partition in other parts of the world and especially in the eastern Horn of Africa (see Figure in annex 7.3). The CCI MRLC team would be interested to get HRLC maps over this region to confirm the added value of the Harper's PFT maps compared to the MRLC standard derived PFT maps. Additionally, the region faces more frequent droughts (Funk et al., 2008), while continued anthropogenic warming is likely to cause further drying in the Horn of Africa, emphasizing the need for improved simulations of the dynamics of the tropical hydrological cycle (Baxter et al., 2023). These studies suggest that climate models used to project future conditions in tropical dryland regions need better representation of land–atmosphere interactions on precipitation. Therefore, tropical dryland forests are complex and heterogeneous areas under constant pressure, leading to land cover changes. This makes them regions of great interest for climate studies and where the HRLC maps can be valuable for evaluating land–atmosphere interactions.

3 Methodology to retrieve user requirements

3.1 Update the Climate Research Community

The Climate Research Community (CRC), established in Phase 1 is mainly used to retrieve user requirements. Thus, the first action is kept updated the CRC with the collection of a list of potential members. Following the Phase 1 procedure, personalized email invitations with an explanation of the project's aim and CRC's role (Figure 2), along with a registration link (https://mailchi.mp/76bf36dea1a2/esaccihrlc_signup), are sent to potential members. Each registered user receives a welcome letter and is added to the distribution list info@esa-ccihrlc.eu, with an option to opt-out.

To update the CRC, current and potential members expressing interest are identified. The purpose and benefits

of the CRC are communicated, ensuring GDPR[1] compliance. Personalized invitations are sent to encourage updating information or joining. The member database is maintained and updated.

Efforts to engage the community include regular meetings, webinars, and workshops, fostering collaboration and encouraging active participation and networking. A feedback mechanism is established to evaluate CRC performance continuously. The methodology is adapted as needed to keep the CRC dynamic and relevant to the climate research community. Currently, the list has 186 subscribers.

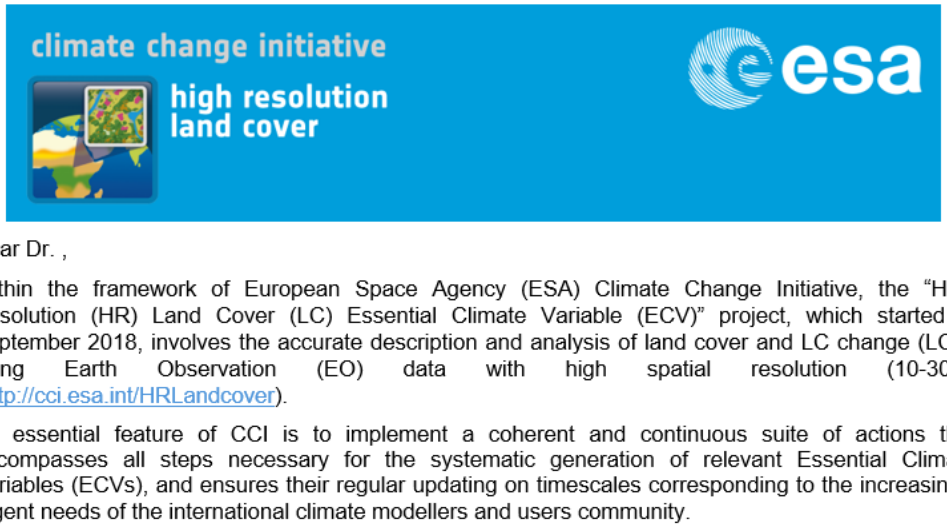


Figure 2: Invitation letter sent to all the personal contacts.

3.2 Advisory from Climate Research Community

Advisory from the CRC has been collected from two different sources.

First, a direct invitation was sent to provide advisory feedback (Figure 3). Additionally, a questionnaire was prepared, comprising 24 questions across six topics: the selection of study regions, spatial resolution, product classification, usage of HRLC products, uncertainties and second-class products, and CCI products. The questionnaire can be accessed here: https://forms.gle/qzqZbhndN1FceXy77 .

[1] https://ec.europa.eu/commission/priorities/justice-and-fundamental-rights/data-protection/2018-reform-eu-data-protection-rules_en

high resolution land cover cci

esa

Advisory for CCI+ High Resolution Land Cover product

Dear Cristina Domingo,

As we announced, CCI+ Phase 2 has been recently initiated aiming at further enhancing the achievements of Phase 1 by further developing a pre-operational system for large-scale ECV data processing and by conducting final validation and climate-user assessments.

As a valued member of the CCI+ High Resolution Land Cover Climate Research Community, we cordially invite you to provide advisory input regarding the products generated in Phase 1 and to share your user requirements for the upcoming products of Phase 2. We have prepared a questionnaire to gather your recommendations, comments and advisory insights.

Your contribution to this questionnaire would greatly benefit ESA product. It would be fantastic **if you could dedicate some minutes to answer the present form**. We kindly ask for a few minutes of your time to complete the questionnaire.

Figure 31. Invitation to provide advisory for CCI+ High Resolution Land Cover Product

On the other hand, direct interaction with attendees of the workshop organized during the EGU workshop was conducted using the *Mentimeter* (https://www.mentimeter.com) platform. The questionnaire was the same but adapted to the platform's format. A total of 22 answers were collected.

3.3 Questionnaire

The questionnaire was divided in 6 sections. It also included a presentation explaining the context of the project, which also indicated the use of the answers:

Welcome to the ESA CCI High Resolution Land Cover presentation questionnaire and thanks for answering it!
The major objective of this questionnaire is to present the ESA CCI High Resolution Land Cover project outputs, the selected regions for HR LC and LC change mapping and to collect user views and requirements in relation to its use.

The HighResolution Land Cover CCI+ project has produced high resolution (10-30m) land-cover and change detection maps at subcontinental/regional level. These maps aim to study the role of spatial resolution of LC and LCC in supporting climate modelling research. HR_LandCover_CCI+ Phase 1 has significantly enhanced the understanding of the climate-land surface interactions, increasing spatial resolution by an order of magnitude (from 300m to 10-30m) compared to the previous LandCover_CCI. The project's focus has primarily been on three study regions: the Amazon, African Sahel and North-Eastern Siberia.

Feel free to answer any of the questions of the form. Please note that data are recorded for research purposes within the CCI+ HRLC project only and will be processed electronically, in compliance with current privacy regulations, in order to ensure the security and confidentiality.
Thanks for your collaboration!

3.1.1 On the choice of the study areas

1/ The CCI HRLC project primarily focuses on three regions. Are you interested in any of these regions?

- Amazonia
- West Africa
- Siberia

2/ Would you be interested in increasing the extension of any of the current three regions?

- No
- Yes

- If YES, please, briefly elaborate the extension of the area(s) of interest.

3.1.2 On the spatial resolution

3/ The CCI HRLC products offer high spatial resolution ranging from 10 m to 30 m. Could you briefly describe the advantages of using high-resolution products over medium-resolution (300 m-1 km) ones in your applications?

3.1.3 On the product classification

4/ Would you require more detailed or different categories beyond those provided in the legend of the land cover map products?

- No
- Yes
  - If YES, which ones?

3.1.4 On the use of HRLC products

5/ Do you find any challenges or limitations when incorporating high-resolution land cover products into your work?

- No
- I have not used the product yet
- Yes
  - If YES, which ones?

6/ Are you engaged in climate or land surface modeling?

- No (→ go to question 10)
- Yes (→ go to question 7)

7/ Which climate model(s) do you utilize in your research?
8/ What spatial scale are you working with?
9/ Which land product are you using?
10/ How do you integrate land cover classes from the CCI HRLC product into your models or applications?

- Directly (no transformation needed)

Transformed into Plant Functional Types

- Do you find the provided information sufficient for interpreting the classes?
  - Yes
  - No
    - If NO, which additional details from the CCI HRLC team would you require?
- Others
  - If OTHERS, please indicate which ones

11/ In my case it would be useful to have the following information:

- Vegetation density
- Vegetation height
- Structural parameters of vegetation
  - % of purity of the class in a pixel (example: 100% grass or 60% grass – 40% bare soil)
- Others
  - If OTHERS, which?

3.1.5 On the use of HRLC products

Second most likely class and uncertainty (posterior probability of the first class and posterior probability of the second class) are also provided as a result of the processing

12/ In your opinion, could incorporating uncertainty or second-class products improve the utility of the CCI HRLC product? How might you utilize this information?

3.1.6 On the CCI products and other LC products

13/ Apart from the CCI HRLC product, are you interested or currently utilizing any other CCI+ products?

- Yes
  - Which ones?
- No

14/ Do you have any specific requirements or needs regarding the land cover product that could enhance the utility of other CCI+ products?

15/ Are you using any other Land cover map in your models?

- Yes
  - Which?
- No

4 Final outcomes

4.1 Outcomes of the questionnaire

The total number of completed answered surveys was 22. Regarding the presentation of the questionnaire results, the comprehensive findings can be found in Annex 1. A focused summary of key highlights, comprising selected questions from the survey (italicized) along with specific aggregated responses, is provided below.

4.1.1 On the choice of the study areas

There is a remarkably interest in extending the current study areas (54.5%), particularly the Amazonian region. Beyond the Amazon, the responses indicate interest in various regions, including the Mediterranean, African (Congo basin, dryland ecosystems, Kenya, Victoria Lake) and Siberia regions.

4.1.2 On the spatial resolution

The high spatial resolutions (10-30m) are of interest for the community since it presents the advantage when studying small-scale processes related to deforestation, forest fragmentation, fire dynamics, shifting cultivation and selective logging, agricultural applications, among others.

4.1.3 On the product classification

Most demands are focused on splitting some land cover classes in different land uses: non-natural shrub / grassland categories, adding pastures, planted forests. The other repeated demand is the incorporation of the seasonality in the croplands.

4.1.4 On the use of HRLC products

Storage and computational capacity have been identified as a constraint, they ask for the possibility to download a region of interest (i.e. subset of the entire scene). This is feasible by https://archive.ceda.ac.uk/tools/ , however most user community is not aware of these tools l.

4.1.5 On the uncertainty and second-class products

Uncertainty of LC is recognised as very interesting topic by the CRC; however, many users recognize that they are not really taking to account in their models yet.

4.1.6 On the CCI products and other LC products

Among the ECV CCI products, the most interesting are vegetation parameters (LAI, fcover), biomass, soil moisture and fire. The other LC products are MRLC CCI at global scale and some particular regional products.

5 Synthesis

Both preliminary user requirements (Section 2) and results of the questionnaire indicate interest in extending the Amazonian region for the monitoring of deforestation or forest degradation and land cover changes impacts. The suggestions vary, proposing extensions to the North, West, East, and the entire Amazon. A preliminary analysis of the other existing products in this region, show that the extension of the HRLC maps will bring an added value because of the use of a common legend better adapted to climate modelling and consistency in the data processing. Besides, as suggested in Section 2, results of the questionnaire (Annex 7.1.1) also confirm the community's interest in dryland regions such as Caatinga (to the East of the current HRLC region) or Gran Chaco and savanna-like ecosystems such as Cerrado already included in the static HRLC map. Similarly, tropical drylands ecosystems from eastern Horn of Africa represent an interesting region to be included in the historical HRLC maps since it is a heterogeneous region exposed to persistent natural and anthropic pressure.

6 Annexes

6.1 Detailed responses to the user survey

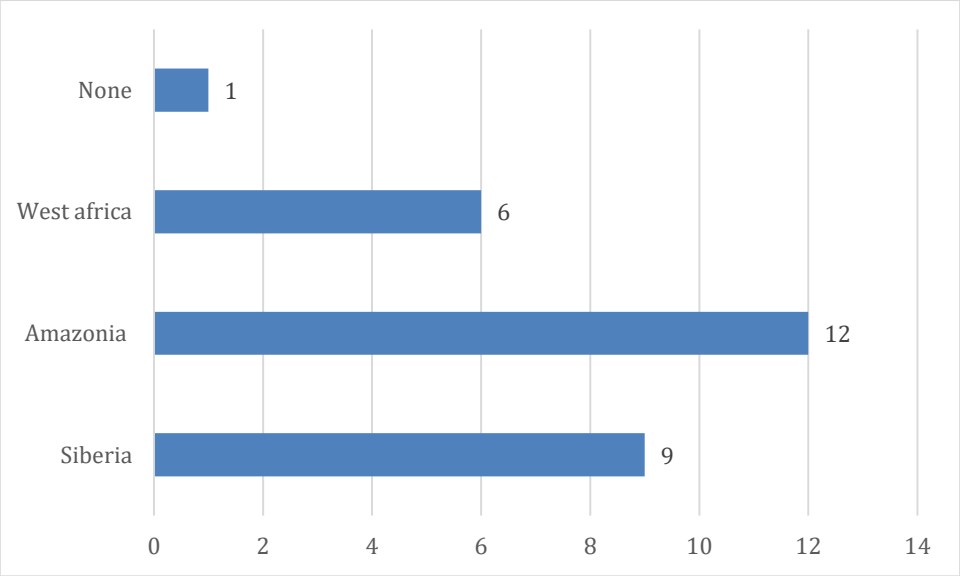
The following table collects the affiliation of the participants to the survey. The questionnaire used during the EGU workshop, did not include this question, so there are some affiliations missing.

Instituto Potosino de Investigación Científica y Tecnológica C.A.	*European Commission Joint Research Center*
University of Exeter	*Autonomous University of Barcelona*
IRD	*BEC-ICM-CSIC*
Max Planck Institute for Meteorology	*University of Alberta*
CREAF	*Barcelona Supercomputing Center*
3 geomorphologists (undefined affiliation)	*Climatologist (undefined affiliation)*

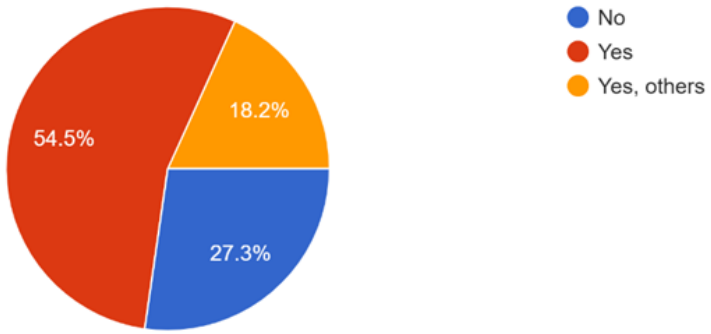
Data obtained from the questionnaire and from *Mentimeter* have been aggregated to facilitate the interpretation.

6.1.1 On the choice of the study areas

The CCI HRLC project primarily focuses on three regions. Are you interested in any of these regions?



Would you be interested in increasing the extension of any of the current three regions?



- If YES, please, briefly elaborate the extension of the area(s) of interest.

Drylands such as Kenya, Caatinga (Brazil), and México
amazonia-west
global coverage would be greatly appreciated
Extending to the whole of Africa (especially the Congo basin) and Amazonia would be very useful
North and west Africa
Due to current situation with Russia our focus moved from Siberia to Disco Bay area (Greenland). However, since we still have some data and model simulation for Eastern Siberia (Chukotka region) it will be great to compare to have also land cover data in high resolution for that region.
Whole of Amazonia and Brazil.
We basically work at the global level so any further expansion is useful.
South America
Amazon Basin
Siberia
Mediterranean basin
Lower into SSA Southeast Asia South America
Cerrado Brazilian or Savanna
Southern Africa
Kenya
Lake Victoria
Alps

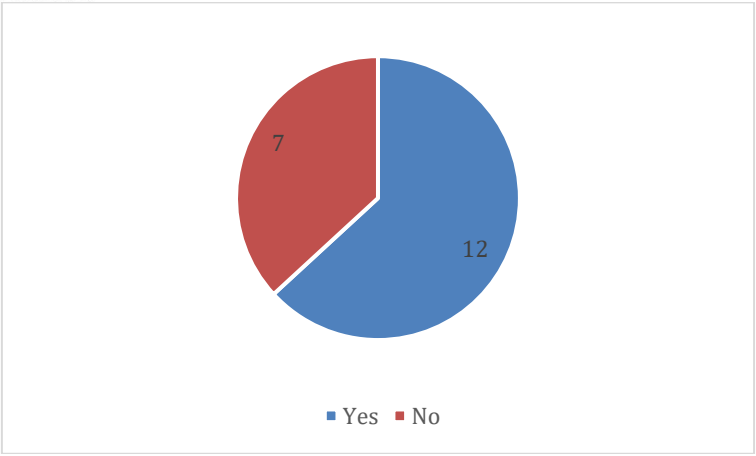
6.1.2 On the spatial resolution

- The CCI HRLC products offer high spatial resolution ranging from 10 m to 30 m. Could you briefly describe the advantages of using high-resolution products over medium-resolution (300 m - 1 km) ones in your applications?

We have more precise inferences, monitoring, and results for landscape management and public policies.
Better estimation of biophysical variables such as LAI that need Land Cover as a basemap information
30m land cover is same resolution as older Landsat based products, so we can have 2 different datasets to compare LC mapping at high resolution.
Providing information which can more accurately specify the different land-cover types in high resolution (i.e. convective scale, 1-4km) and very high resolution (100-300m) regional climate and urban climate models.
Better for agricultural applications were crop type matters (yield, irrigation...)
I still have not looked at 10-30m resolution data, but we will discuss their application
For coastal research in the Mediterranean is essential due to little tides
Change detection. Small-scale deforestation is becoming prevalent, hence the need for high-resolution. also perhaps useful for monitoring/describing shifting cultivation and selective logging
Higher detail mapping of LUC and biodiversity modelling are substantially improved
We map land use and conversions among land uses, following forest definitions of the various European states. In some cases these definition set the minimum area at 0.05 ha, making it necessary to monitor small patches of forests. Also conversions may happen at smaller scales than 300m/1km.
Mediterranean landscapes need for finer resolutions
Improve biomass burning emissions estimate
Estimating carbon stocks
Local scale is very relevant for habitats characterization in Europe
More detailed information about landscape structure and changes to understand fire dynamics
Lower uncertainty estimation of ghg emissions from conversion to crop land, carbon soil stock, higher accuracy for crop production capacity for a region or community

6.1.3 On the product classification

Would you require more detailed or different categories beyond those provided in the legend of the land cover map products?



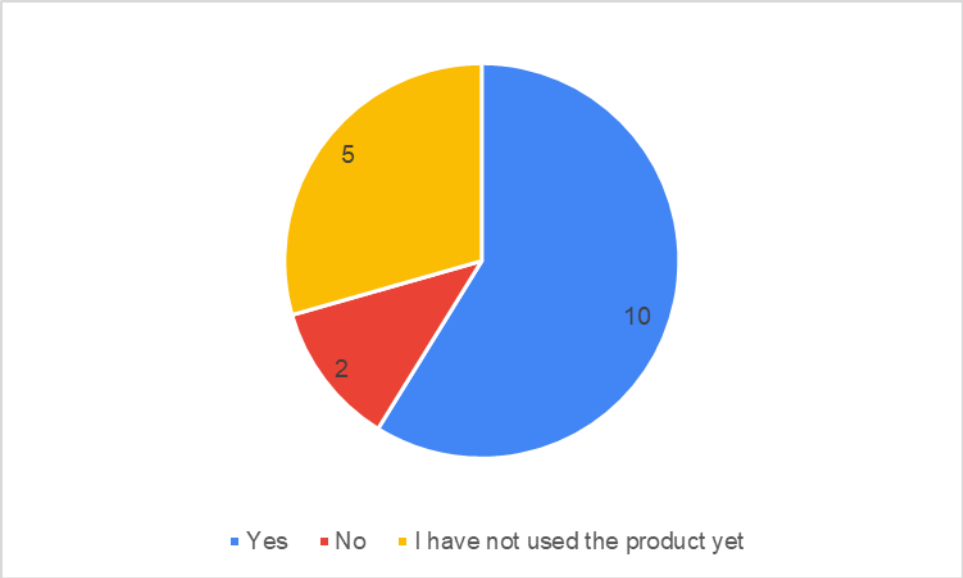
- If yes, which ones?

Fire
To provide a detailed answer to this question would require knowing how consistent these categories are with the land-cover classes used in land-surface/vegetation models used for offline impacts/attribution etc studies and as part of coupled regional environmental or global earth system models. This implies either "more detail" or "different categories" are required so your data can be used in the construction, evaluation or application of these models.
some details in the crop class: seasonality

To have lichens and mosses is already great, but if you could include more diversification in Arctic vegetation, it will be outstanding
peatland, C4 vs C3 cropland, pasture (i.e which of the shrub / grassland categories are non-natural)
Distinguishing permanent (woody) cropland would be useful.
Agriculture and pasture
Wetlands
Herbaceous crops vs woody
Permanent i.e woody crops
Planted forests
Bare soil types

6.1.4 On the use of HRLC products

Do you find any challenges or limitations when incorporating high-resolution land cover products into your work?



- If YES, which ones?

It is difficult to access and find high-resolution land cover products
data processing can be heavy, zarr format might be interesting to explore?
limited coverage; high data dimension
Processing time/ computational techniques to large areas (e.g. entire Brazil)
Storage, computation
Computacional capacity
We'd to download the entire scene even if I am interested in a smaller area

Are you engaged in climate or land surface modeling?

- Which climate model(s) do you utilize in your research?

Ecological Niche Models and Species Distribution Models
ERA5, MERRA-II
EC-Earth, IFS
MIP5 and 6, CORDEX and various convection-permitting climate models.
only products (ERA5)
MPI-ESM, JSBACH
MITGCM and CROCO
JULES
We used several models
Those contained in the IPCC ARs.

- What spatial scale are you working with?

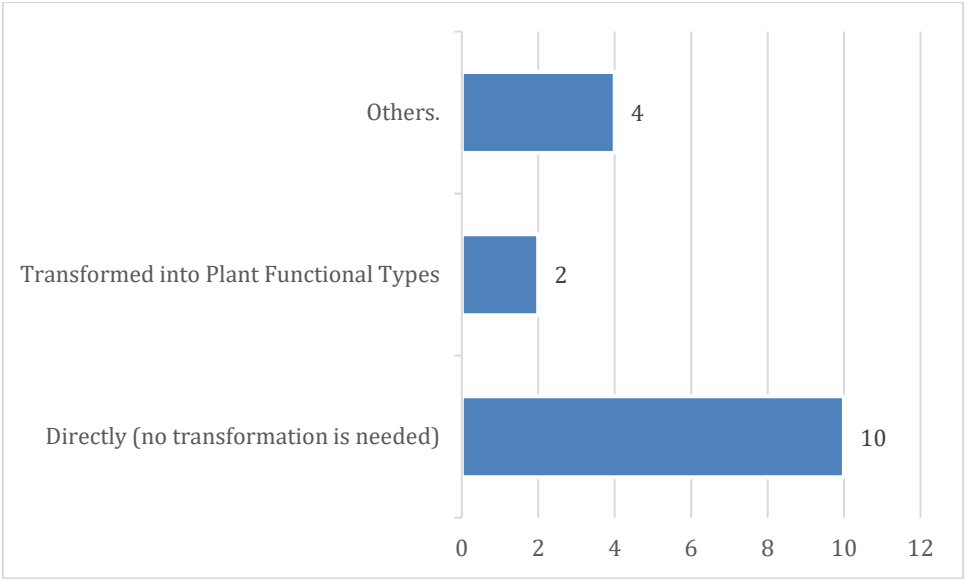
between 100 km and 500 m
from 10m to 1000m
1km - 100km
All scales down to 1.5km.
agricultural region (from 1000 to 10000 km2)
T63 (~185 km)
10 m
0.5 degrees (50km), hopefully moving to 0.125 (12km) at the equator
500 m
300 m and lower
*3 * < 10 m*
*4 * 10-30 m*
30-90 m
90-250 m
300-500 m
500-1000 m
1 km
> 1 km

- Which land cover product are you using?

MODIS MCD12Q1 v06.1
ESA

ESA LC-CCI, ESA HRLC, MODIS land cover, GLanCE
ESA CCI LC
we make our own products
default JSBACH, dynamic vegetation, and ESA-CCI-LC
CORINE and MCSC
ESA MRLC + HYDE + LUH2
University of Maryland
C3S Land cover classification gridded maps from 1992 to present derived from satellite observations

How do you integrate land cover classes from the CCI HRLC product into your models or applications?



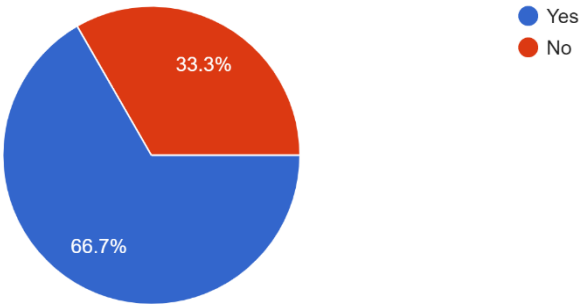
- If OTHERS, please indicate which ones

Not applicable as I have not used HRLC data yet.
I do not use them so far
Not used CCH HRLC yet
natural vs LU categories useful for JULES. JULES simulates its own natural vegetation, but crop/pasture prescribed. In the future we will aim to run JULES with diagnostic Land cover, then we'd need PFT fractions
For the moment we just test them against areas found with C3S 300m resolution data

- If TRANSFORMED into PFT:

Do you find the provided information sufficient for interpreting the classes?

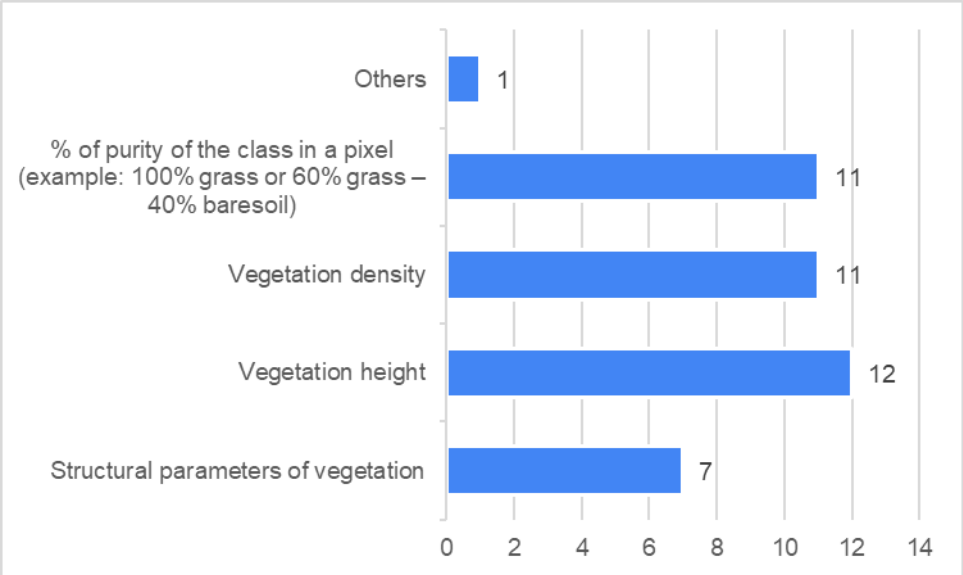
6 responses



- If NO, which additional details from the CCI HRLC team would you require?

the issue of natural vs human disturbed land cover categories

In my case, it would be useful to have the following information:



- If OTHERS, which?

vegetation roughness length, if nitrogen scaling is needed
Different kind of human use of land (urban, industrial, etc) if not included

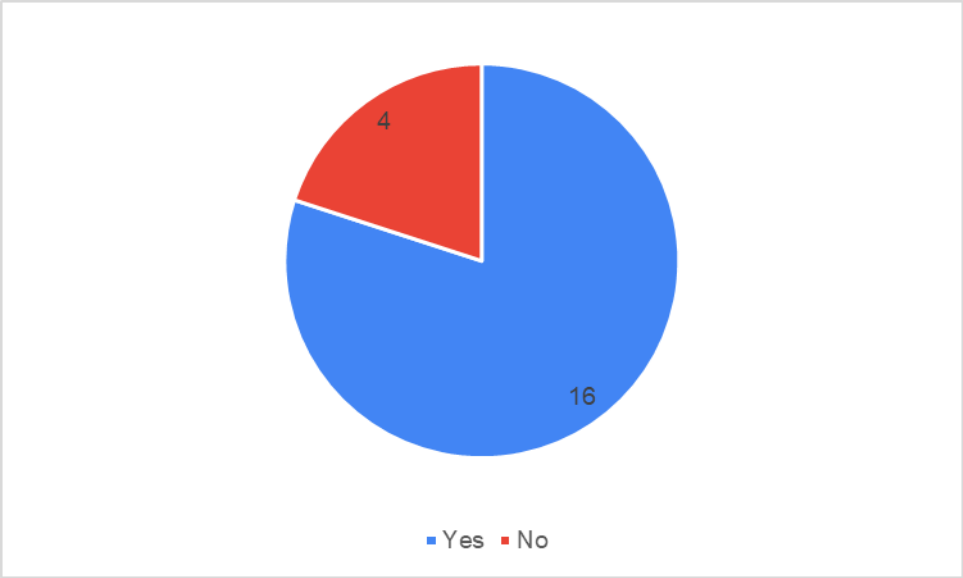
6.1.5 On the uncertainty and second-class products

- In your opinion, could incorporating uncertainty or second-class products improve the utility of the CCI HRLC product?

Not sure
Yes, we can test and compare between different resolution products, such as MODIS MCD12Q1
To compute model error transmission
several HEurope projects and future research proposals require an estimate of uncertainty
To understand whether regional environmental or earth system model vegetation simulations were consistent with observations.
not yet thought about that so far but it seems difficult. maybe if using hydrological models, using second class to bound the estimates achieved using the first class
It is always useful to check uncertainty but I would no use it in my studies
to first just appreciate the level of certainty/uncertainty associated with the product
I do not see the need, at the end of the day more information can cause confusion
*7 * Yes*

6.1.6 On the CCI products and other LC products

Apart from the CCI HRLC product, are you interested or currently utilizing any other CCI+ products?



- If YES, which ones?

*2 * Water vapour*
LST, SST, sea-ice, clouds
ESA-CCI permafrost
burned area
I'm interested in the LULUCF product
*5 * Biomass*
*6 * Vegetation parameters*
3 Lakes*
*3 * Land cover (MR)*
*2 * Greenhouse Gases*
*4 * Fire*
*4 * soil moisture*
LST, soil moisture

- Do you have any specific requirements or needs regarding the land cover product that could enhance the utility of other CCI+ products?

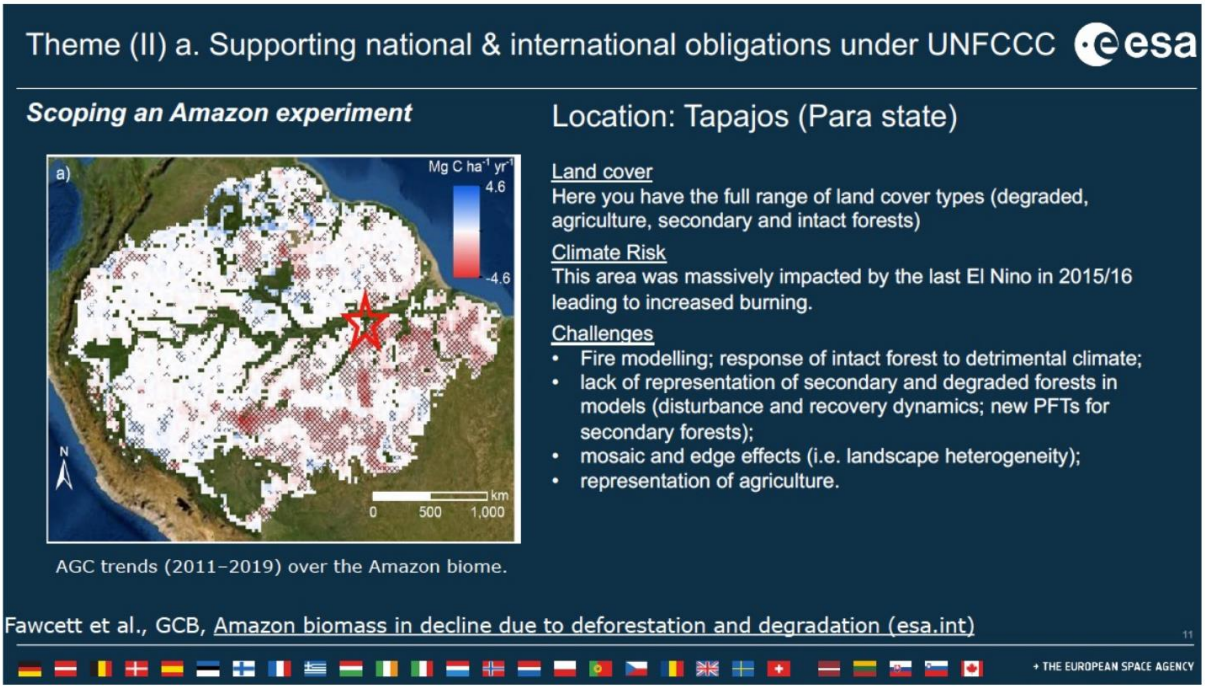
No
No
Not now
Ensuring consistency, where applicable, with other land surface CCI ECV products.
providing the data on the same spatial grid i.e. harmonizing the spatial grid and temporal coverage
I'd prefer a shorter time series but with finer resolution change detection applied to capture deforestation dynamics
Not sure

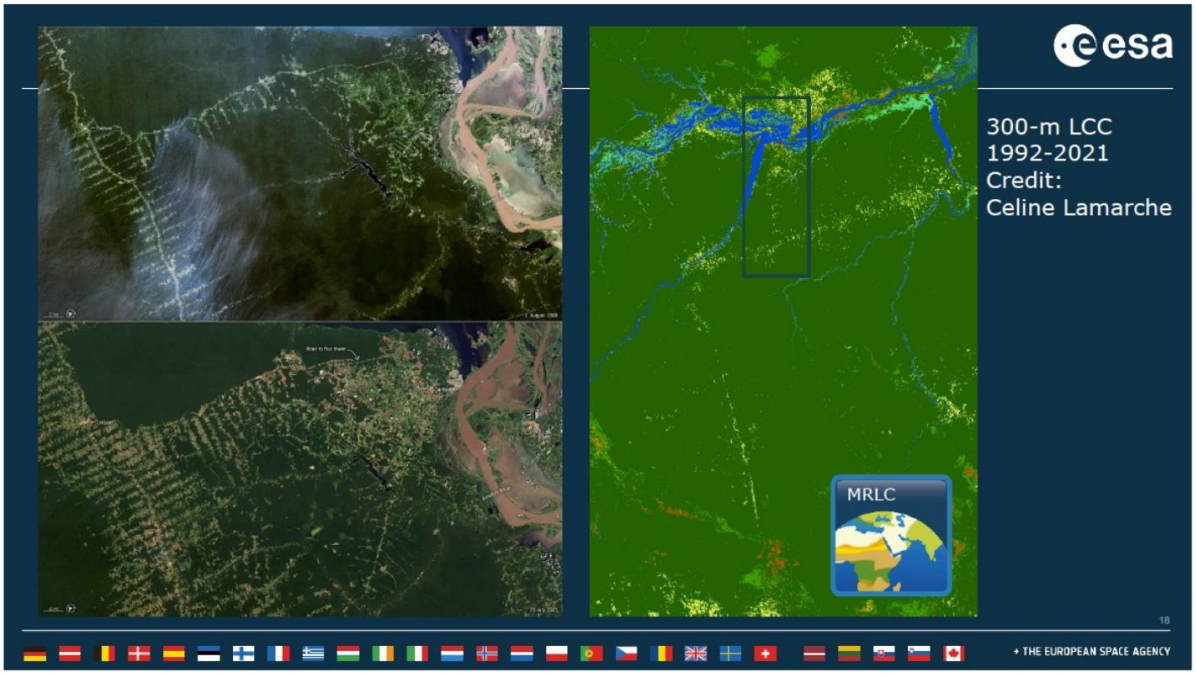
- Are you using any other Land cover map in your models? Which?

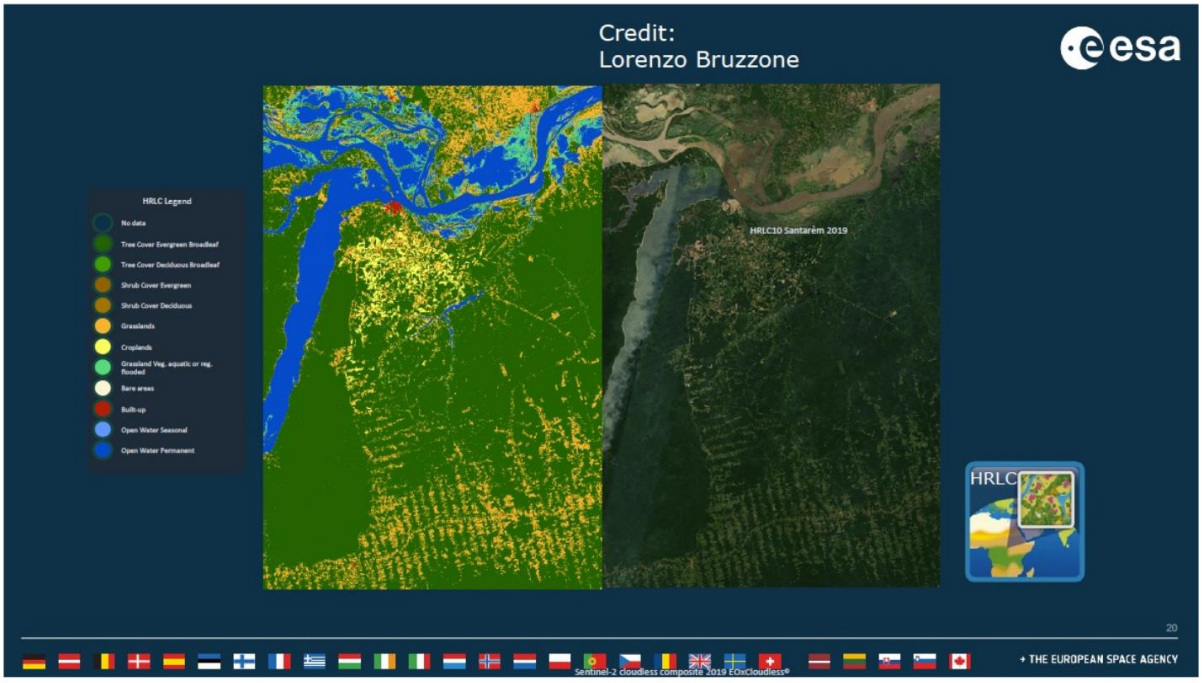
No
Regional land cover maps from the ICGC
AVHRR based Global Land Cover Characteristics (GLCC)
ESA CCI LC
only home made ones. Anyway congrats for this huge job (basically industrial use of state of the art / pragmatic methods)
default JABACH

mapbiomas + ESA MRLC -> HYDE -> LUH2 (see Global Carbon Budget 2023 paper for details) https://doi.org/10.5194/essd-15-5301-2023
Copernicus C3S Land cover classification gridded maps from 1992 to present derived from satellite observations (former ESA CCI Land Cover)

6.2 Support information in the Amazon







6.3 Comparison between MRLC and Harper's (2023) PFT maps

In the framework of the CCI MRLC project, a set of PFT maps has been derived at 300 m scale, based on the MRLC product. This dataset bypasses the global Cross-Walking Table which has been developed to translate the MRLC classes into the 15 generic PFTs and provides directly PFT fractions at the pixel scale based on other high resolution auxiliary products such as lidar-derived vegetation height (Potapov et al., 2019).

The figure 4 illustrates the mean difference in grass fraction cover between the MRLC and Harper's PFT maps for the period 1992-2019. Differences can exceed 0.5 (i.e., 50% more or less grass cover when comparing both products) and are observed in various regions worldwide. For instance, in the eastern Horn of Africa (just eastern

of the historical HRLC region in Africa), Harper's product shows up to 0.55 higher grass fraction cover than the MRLC product. On the contrary, these discrepancies are interpreted as increased tree cover (both evergreen and deciduous) in the MRLC product. Similar differences are observed around the historical HRLC region in the Amazon, where Harper's product can show grass fraction cover up to 0.65 higher than that of the MRLC product. In this region, the discrepancies involve the partitioning of grass, trees, and crops. Harper et al. (2023) demonstrated that such misrepresentation in land cover significantly impacts the simulation of key land surface variables related to the radiative balance (e.g. albedo, land surface temperature), affecting both the water, energy and carbon cycles. For example, in both tropical dryland regions South America and Africa where soil moisture limits evapotranspiration, fewer trees lead to less evapotranspiration. Land surface temperature shows differences up to 1K at annual scale affecting directly the partition in sensible/latent fluxes.

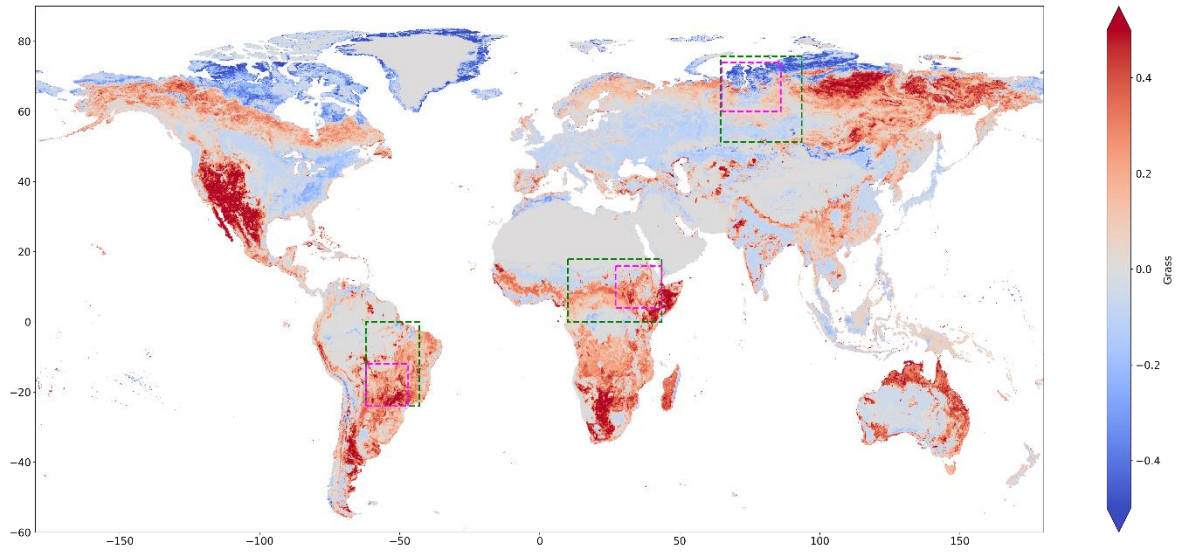


Figure 4: Mean difference in grass fraction cover between the MRLC and Harper's PFT maps for the 1992-2019 period. Pink and green boxes represent the historical and static HRLC regions, respectively.

6.4 Comparison between Mapbiomas and HRLC over Amazonia

The following figure (Fig. 5) presents an example of the Mapbiomas products with its specific legend, to be compared to the extension and location of the HRLC products with their legend. It can be seen that the Mapbiomas product covers already a large part of South America with a very detailed legend which seems to be developed for agricultural monitoring given that it differentiates crop types and managed grasslands. Forest/ Tree types appear less separated, especially the separation of evergreen and deciduous trees which is very valuable for land surface /climate modelling, is not done, nor for shrubs. Therefore, the two products which have been developed for different purposes appear very complementary.

Additionally, MapBiomas products present the drawback of having different features for neighbor countries, as detailed below:

- Periods. For example, in Brazil the covering period goes from 1985 to 2022, while in Argentina the period covers from 1998 to 2022.
- Lack of homogeneity between collections. The time period extension, the legend and methodology may change along with the collections. For example, the last collection for Brazil and Argentina are the collection 8.0 and 1.0, respectively.
- Legend. For example, Brazil presents 29 classes, while Argentina presents 15 classes.

Another drawback:

- Planimetric distortions in area calculations, part of the process in GEE is carried on latitude/longitude based reference system. The documentation explicitly advises: do not use it at higher resolution (scale 1 : 50.0000)

MAPBIOMAS

Codes of the legend classes and color palette used in MapBiomas Collection 7

COLEÇÃO 7 - CLASSES	COLLECTION 7 CLASSES	NEW ID	Color number
1. Floresta	1. Forest	1	#129912
1.1 Formação Florestal	1.1. Forest Formation	3	#006400
1.2. Formação Savânica	1.2. Savanna Formation	4	#00ff00
1.3. Mangue	1.3. Mangrove	5	#687537
1.4. Restinga Arborizada	1.4. Wooded Sandbank Vegetation	49	#6b9932
2. Formação Natural não Florestal	2. Non Forest Natural Formation	10	#bbfcac
2.1. Campo Alagado e Área Pantanosa	2.1. Wetland	11	#45c2a5
2.2. Formação Campestre	2.2. Grassland	12	#b8af4f
2.3. Apicum	2.3. Salt Flat	32	#968c46
2.4. Afloramento Rochoso	2.4. Rocky Outcrop	29	#ff8C00
2.5 Restinga Herbácea	2.5. Herbaceous Sandbank Vegetation	50	#66ffcc
2.6. Outras Formações não Florestais	2.5. Other non Forest Formations	13	#bdb76b
3. Agropecuária	3. Farming	14	#ffffb2
3.1. Pastagem	3.1. Pasture	15	#ffd966
3.2. Agricultura	3.2. Agriculture	18	#e974ed
3.2.1. Lavoura Temporária	3.2.1. Temporary Crop	19	#d5a6bd
3.2.1.1. Soja	3.2.1.1. Soybean	39	#c69ff4
3.2.1.2. Cana	3.2.1.2. Sugar cane	20	#c27ba0
3.2.1.3. Arroz (beta)	3.2.1.3. Rice	40	#982c9e
3.2.1.4. Algodão (beta)	3.2.1.4. Cotton (beta)	62	#660066
3.2.1.5. Outras Lavouras Temporárias	3.2.1.5. Other Temporary Crops	41	#e7878
3.2.2. Lavoura Perene	3.2.2. Perennial Crop	36	#f3b4f1
3.2.2.1. Café	3.2.1.1. Coffee	46	#cca0d4
3.2.2.2. Citrus	3.2.1.2. Citrus	47	#d082de
3.2.1.3. Outras Lavouras Perenes	3.2.1.3. Other Perennial Crops	48	#cd49e4
3.3. Silvicultura	3.3. Forest Plantation	9	#935132
3.4. Mosaico de Usos	3.4. Mosaic of Uses	21	#ffff3bf
4. Área não Vegetada	4. Non vegetated area	22	#ea9999
4.1. Praia, Duna e Areal	4.1. Beach, Dune and Sand Spot	23	#dd7e6b
4.2. Área Urbanizada	4.2. Urban Area	24	#af2a2a
4.3. Mineração	4.3. Mining	30	#8a2be2
4.4. Outras Áreas não Vegetadas	4.4. Other non Vegetated Areas	25	#ff99ff
5. Corpo D'água	5. Water	26	#0000ff
5.1. Rio, Lago e Oceano	5.1. River, Lake and Ocean	33	#0000ff
5.2 Aquicultura	5.2. Aquaculture	31	#29eee4
6. Não observado	6. Non Observed	27	#D5D5E5

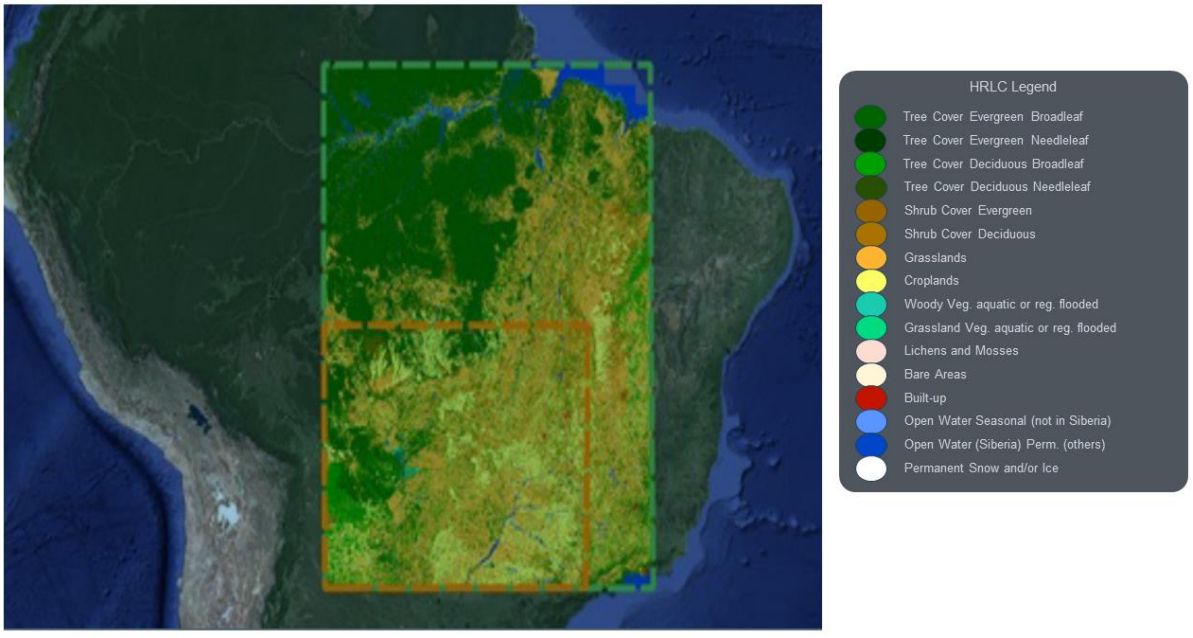


Figure5: Comparison of clases of Mapbiomas and HRLC over Amazonia

6.5 CRG affiliation list

Univ. Buenos Aires	BGC-JENA	HZG	gamma-RS	UPMC
Univ. Birmingham	bgeos	IMBE	GDA Corp	Lancaster Univ.
CML Leiden Univ.	BSC	INPE	MetOffice	Univ. Trento
Dep Water Environ. Reg. Au.	CESBIO	EURAC	FZ-Juelich	World Bank

Univ. Edinburgh	CNR	FAO	LSCE	Spatial Services
Thunen Insitute	CREAF	FBK	MMU	GFZ Postdam
T. Univ.Würzburg-Schweinfurt	CRNS	NFIRI	MPI	Vector Institute
Univ. Gothenburg	DLR	INRA	NASA	Univ. Gent
Federal Univ. Mato Grosso do Sul	DWER	IAE	NATUR	Univ. Lisboa
Univ. Extremadura	ECMWF	IAEA	NAVER	UNFCCC
Univ. Rey Juan Carlos	ESA	ICGC	Planetek	Univ. Exeter
Univ Aut. Barcelona	GMV	IDIV	Poli Mi	Univ. Lever
Norce Research	GMX	IEEE	Stanford	KU. Leuven
Space Intelligence	GOZDIS	IIASA	Tartu Univ.	Univ. Leeds
Indian Institute Technology	USAID	WUR	Univ. Jena	Univ. Zurich
Imperial Col. London	UNS	JRC	MIUR	Univ. Munich
Cologne University	WWFUS	VITO	BOKU	Univ. Alberta

This list is not totally completed, in few cases we didn't identify the affiliation of some members of the CRG.

7 References

Baumann, Matthias, Ignacio Gasparri, Ana Buchadas, Julian Oeser, Patrick Meyfroidt, Christian Levers, Alfredo Romero-Muñoz, Yann le Polain de Waroux, Daniel Müller, and Tobias Kuemmerle. 2022. Frontier metrics for a process-based understanding of deforestation dynamics. Environmental Research Letters 17 (9): 095010. https:// doi. org/ 10. 1088/ 1748- 9326/ ac8b9a.

Baxter, A.J., Verschuren, D., Peterse, F. et al. (2023). Reversed Holocene temperature–moisture relationship in the Horn of Africa. Nature 620, 336–343. https://doi.org/10.1038/s41586-023-06272-5

Funk, C. et al. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proc. Natl Acad. Sci. USA 105, 11081–11086

Gatti, L.V., Basso, L.S., Miller, J.B. et al. (2021). Amazonia as a carbon source linked to deforestation and climate change. Nature 595, 388–393. https://doi.org/10.1038/s41586-021-03629-6

Harper, K. L., Lamarche, C., Hartley, A., Peylin, P., Ottlé, C., Bastrikov, V., ... & Defourny, P. (2023). A 29-year time series of annual 300 m resolution plant-functional-type maps for climate models. *Earth System Science Data*, *15*(3), 1465-1499.

Miles, L., Newton, A.C., DeFries, R.S., Ravilious, C., May, I., Blyth, S., Kapos, V. & Gordon, J. E. (2006). A global overview of the conservation status of tropical dry forests. Journal of Biogeography, 33, 491–505.

Kulka, D. D., Filgueiras, B. K., dos Santos, A. B., Locatelli, A. C. P., de França, J. D., Lins, S. R. M., & Tabarelli, M. (2024). Increased aridity and chronic anthropogenic disturbance reduce litter productivity in a Caatinga dry forest. Forest Ecology and Management, 553, 121640.

Rito, K. F., Arroyo-Rodríguez, V., Queiroz, R. T., Leal, I. R., & Tabarelli, M. (2017). Precipitation mediates the effect of human disturbance on the Brazilian Caatinga vegetation. Journal of Ecology, 105(3), 828-838.

San Martín, R., Ottlé, C., & Sörensson, A. (2023). Fires in the South American Chaco, from dry forests to wetlands: response to climate depends on land cover. *Fire Ecology*, *19*(1), 57