Detecting changes in essential ecosystem and biodiversity properties- towards a Biosphere Atmosphere Change Index: BACI

Deliverable 7.1: Identification of promising applications for EO for land system science and sustainability science based on a user consultation workshop

Project title:	Detecting changes in essential ecosystem and biodiversity properties- towards a Biosphere Atmosphere Change Index
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1. Aim and scope of task 7.1

The availability of remote sensing data grown drastically since the 1970s, mainly fueled by technological innovations that allowed substantial improvements of spatial and temporal resolution of satellite sensors. Yet, making optimal use of these ample data sets in land use science is still challenging, and the full potential of using remote sensing data for land system analysis is far from being realized. Task 7.1 of the BACI-project aims at exploring possible applications of Earth Observation (EO) in socio-economic as well as sustainability research related to land use. A major goal of this task is to identify the most virulent knowledge gaps prevailing amongst scientist and practitioners, and to discuss these knowledge gaps in relation to problem-solving-potentials of new and upcoming EO products, in and outside the BACI project. This will help prioritizing research directions within the BACI project in order to warrant optimal use of upcoming BACI (and non-BACI) products.

A central activity within Task 7.1 is to organize a user-consultation workshop, aimed at linking EO data-providers with data users from the land-system science community, including experts from land system science, experts of co-design and co-production of knowledge, involving land managers and practitioners. The workshop objectives are to 1) identify most virulent knowledge gaps related to land system data amongst users of different research strands; 2) discuss possible ways to more forward; 3) inform users about new and planned EO-products in order to 4) ensure optimal applicability of near-future remote sensing products 5) and warrant optimal applicability of upcoming BACI products in particular.

Planning the workshop involved several steps, which are described below. A particular focus in the workshop was laid on developing an understanding about timely next steps, in terms of data gaps and information requirements, but also in terms of making (existing and new) data easy-applicable to a broad user community, and furthering the understanding of potentials BACI datastreams hold to address identified knowledge gaps.

2. User consultancy workshop 9.-11. November 2015

2.1. Identification of experts and topics

We identified sixteen core topics related to land use science and EO data application. For all topics, we identified experts and invited them to the workshop. 13 experts were able to attend the workshop. Figure 1 provides the outcome of this exercise.

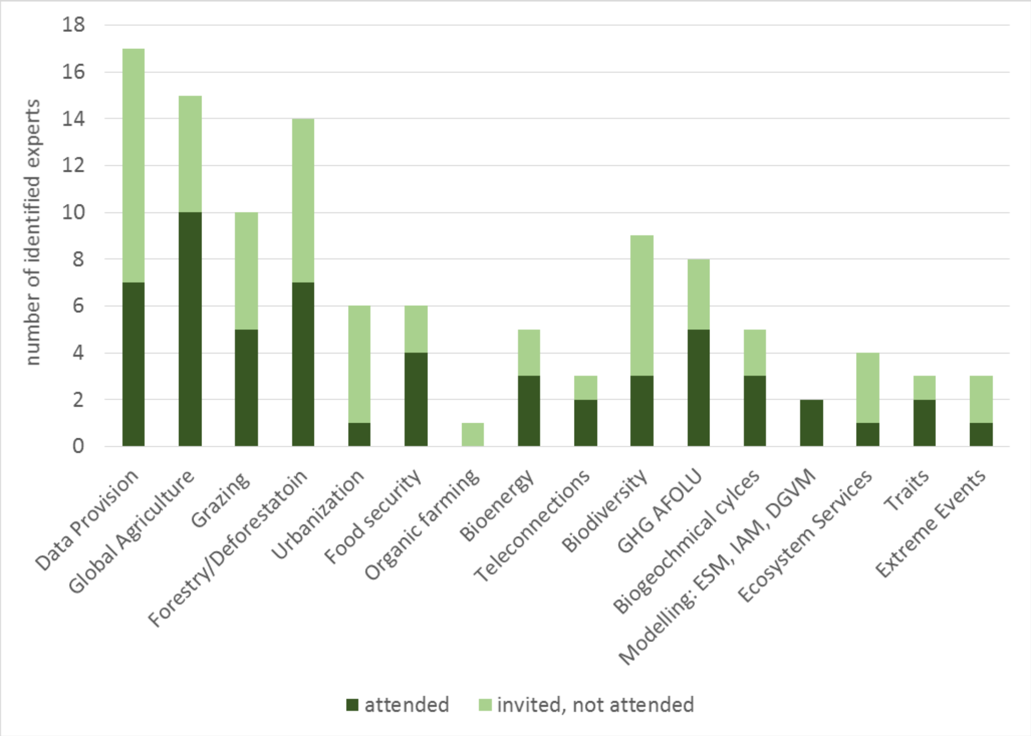

Figure 1: Identified research fields and number of invited and attending experts for each field. Note that one person has usually expertize for several fields.

2.2. Preparation/design workshop

The workshop was hosted under the title **"Remote sensing applications related to land use/- change Knowledge-gaps, innovations, challenges and low-hanging fruits"** from 9.-11th of November at the Institute of Social Ecology in Vienna. Discussions at the workshop were centered around three topics (refer to the workshop agenda in the Annex).

- **Remote sensing applications in the modelling community** (i.e. integrated assessment models and earth system models). Presenters: Julia Pongratz and Kim Naudts (Max-Planck-Institute for Meteorology, Hamburg; experience from the ORCHIDEE-CAN Earth System Model (ESM); Petr Havlik (International Institute of Applied Systems Analysis; IIASA; GLOBIOM IAM); Duccio Rocchini (FEM-CRI; modelling biodiversity with Remote Sensing data); Milan Flach (MPG; change detection via machine learning; BACI index).
- **Data provider' perspectives**. Prsenters. Patrick Hostert (Geography Institute, Humboldt Universität zu Berlin, Remote Sensing data for land system change analysis9, Clement Atzberger (Institute of Surveying, Remote Sensing and Land Information, BOKU Vienna, novel developments with Sentinel2); Markus Hollaus (Department of Geodesy and Geoinformation, Technical University Vienna; data handling and opportunities of Sentinel programs of ESA, Earth Observation Data Center)

- **Socio-economic dimensions** (focus on the interplay between socio-economic and ecological systems). Presenters: Martin Rudbeck Jepsen (Univ. Copenhagen; land system regime shifts, application of remote sensing data to analyze land cover/land use change in forestry ecosystems in South-East Asia); Darla Munroe (Geography Department, Ohio State University; land use change and socio-economic drivers; historical property right systems); Kathleen Hermans (Wageningen Univ.; environmental change and migration patterns in Ethiopia, sensing and census data sets); Maria Niedertscheider (SEC; global land system change; land use intensity)

All input sessions were accompanied by group works and discussions, which allowed for discussing the raised problems and for a first go on potential solutions to these problems.

2.3. Workshop results

2.3.1. Improve information flows and exchange between providers and users

A major insight derived from the workshop's discussion referred to an improved information flow that is the prerequisite for improving applications of remote sensing products in land system science. There is high demand of spatially explicit data sets on land cover, Earth System indicators and land use, at various spatio-temporal scales. It will depend on good communication between providers and users, if expected upcoming remote sensing products will be a success on both sides. With the increasing availably of high-resolution (in both, spatial and temporal terms) datasets, the existing gap between data providers and users is bound to grow if unchecked. The Sentinel 2 mission was identified to bear high potentials to improve current knowledge on land cover, particularly related to mosaic landscapes and crop types planted (due to finer spectral, spatial and temporal resolution). However, using such data sets will increasingly require a high level of specialized technical skills and computing power, both of which will likely hinder application of such new products in socioeconomic and socio-ecological research, because data users have increasingly to rely on processed data.

Figure 2 outlines the different components of such information exchange platform. Optimizing knowledge gains in land use science particularly depends on improving the information flows between direct and processed remote sensing derived information and strengthening communication/ translation of used indicators. For instance, the Remote Sensing realm (a) provides/works with data based on spectral signals that can be translated into indicators in (b), the bio-geophysical/-chemical realm. (b) is connected to the socio-economic realm (c) through exchange processes of several indicator., e.g. metrics that that describe ecosystem properties and their change over time, and can be used to hypothesis-driven analysis of land system change in c). Examples are, for instance, patterns, levels and dynamics of NPP, water use efficiency, or nutrients supply. Realms a) and c) are also connected, e.g. by the development of land cover and land use maps.

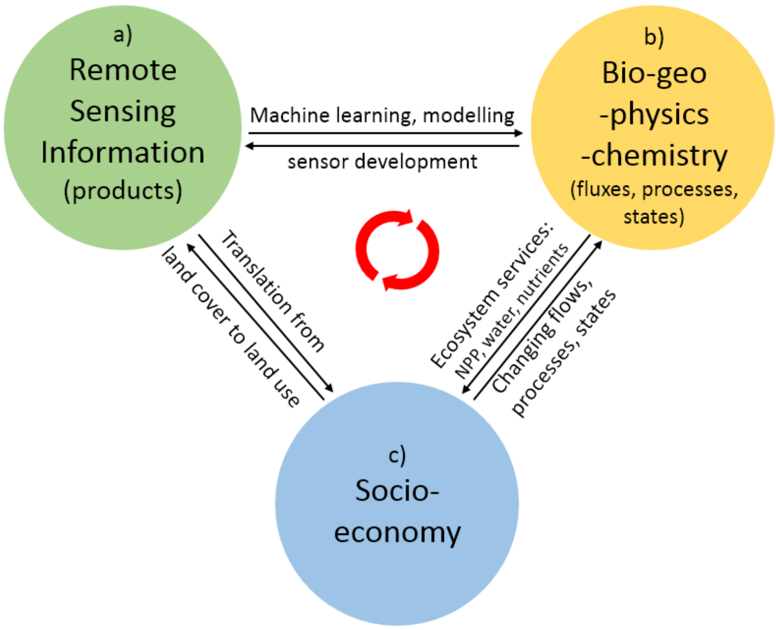

Figure 2: Three realms of land system research. Black arrows between a), b) and c) indicate examples for exchange of knowledge. Red arrows indicate the need for structural information exchange platforms between the three realms.

As a starting point to enhance and facilitate information exchange, it was suggested to establish a communication platform, which allows for close interaction between representatives of all three "realms". Different components of such a platform have been discussed:

- The establishment of an online forum in which stakeholders are able to pose their questions and inform the public about data products, usability of the data products and likely constraints of the data sets.
- Establishment of a 'chapter' in the Global Land Project, a core-programme within the Future Earth initiative aimed at enhancing interdisciplinary land system research
- Expand the existing (e.g. national) Sentinel nodal offices, which currently focus on information distribution.

A challenge will be to provide incentives to the data providers to participate in such a platform, and the establishment of mutual rewarding systems is mandatory. The information exchange could address the following points.

2.3.2. Enhance user-friendliness

In order to ensure optimal application of EO data sets, transparency on the benefits and drawbacks of provided data sets is highly essential for user community. Information gaps, e.g. on the quality and accuracy of available EO products, represents a major obstacle for enhancing the application of EO products. Hence it was proposed that standardized schemes for metadata information should be introduced that allow for a quick and direct assessment of data characteristics. Data providers should also include uncertainty assessments that allow judging the errors which are potentially introduced. Usage guides are important, written in a not too technical ways to enhance understanding by non-experts. User guides should also inform about potential applications of the provided data set. For instance, during the workshop it experts suggested (to the surprise of many participants) that changes in faPAR and PAR might be more suitable proxy for land degradation than changes in NPP, which are model-derived and thus prone to uncertainties. Also, in case data sets are not available in the required resolution, a comprehensive user guide could help judging if upscaling to a coarser spatial, or temporal resolution is recommended or not.

2.3.3. Exploit new information to enhance the link between land use and land cover

While EO data is suitable to provide sound information on land cover, information on the underlying land use not straightforward to derive from EO. The newly available datasets, in particular the avaialability of frequent and robust data with high temporal resolution allows in specific cases to derive information on land use (e.g. by exploiting the temporal signal of harvest cycles, etc.). Innovative approaches that profit from expertize in various disciplines are required to identify land use types whose representation can be improved, explore ways of data exploitation, etc.. and so yield these potentials,

2.3.4. Challenge: enhanced spatial and temporal resolution

A particular discrepancy between data provision and use relates to spatiotemporal characteristics of EO data and socioeconomic reserach. Tracing forest use, for instance requires low temporal (long rotation times in forestry, far beyond the availability of RS data), but high spatial resolution. A particular challenge relates to the fact that socioeconomic research and, in particular, Earth System Modelling, requires long (decadal to centennial) time series. While addressing all these challenges with EO data is elusive, significant progress in individual fields can be made. For this purpose, robust, comparable and consistent data must be available for several time steps over a year, and spectral resolution should allow distinguishing between different cop types. This holds a large potential to identify land use systems (e.g. rotational –fallow- systems for cropland), which could in turn help to derive longer land-use time series.

2.3.5. Enhance availability of ready-to-use data sets

As will be discussed later the application of EO data depends on the processing steps and classification of spectral signals. Most data users will increasingly not be able to process data, due to technical constraints. This has to do with a lack of technical experience and experience in interpreting primary indicators. For instance, changes in faPAR, as an important EO derived product, have been suggested as indicators for degradation during the WS. However, users might still struggle with translating faPAR signals into degradation signals, because they might not be experienced with discriminating natural change (i.e. due to seasonal change) from actual degradation.

The same relates to very fine spatial and temporal data sets and related computing power demands, which likely overburdens IT infrastructure outside the EO provision realm. In such cases aggregation to appropriate resolutions / file sizes will be essential. This might be of particular relevance for making use of the new Sentinel products. Related to point 3., users who focus on global land system change will often choose lower resolution but suitable classification (e.g. fractional land cover over Boolean land cover information) over very fine resolution (i.e. global land cover on a 10m resolution, such as is expected from Sentinel 2) that comes with prohibitively high handling costs.

3. Knowledge gaps in land system science

Several knowledge gaps within land-system science were identified during the workshop. For some of them, EO holds a large potential to advance the current state-of-the-art. Some of them have been mentioned frequently during the workshop, others were discerned only by some experts and were very specific to their particular research focus.

A major intricacy for the application of EO for addressing knowledge gaps in land system science is fact that EO data provide information on land cover, while land use is not straightforwardly detectably by remote sensing and requires additional information and/or analyses. Table 2 lists the discussed knowledge gaps and gives some exemplary research questions.

Next to high level of data uncertainty, semantic uncertainty was also identified as major obstacle for communication and data creation. This holds particularly true for research fields focused on forest and forestry, and degradation.

Table 1: List of discerned knowledge gaps.

	Knowledge gap	Exemplary open question
Grazing	Grazing/ mowing intensity	How much biomass is grazed/ mowed per land area?
	Management type	Is the land mowed, grazed, or is it a landless system?
	Grazing extent	On which land cover classes does grazing occur (forests, woodlands, savannahs, fallow land)?
	Livestock densities	How is livestock distributed globally?
Forestry	Extent used vs. unused forests	Is the forest used or unused?
	Management type	How long are rotation periods on forest parcels?
	Age structure	How old is the forest/ are the trees?
	Harvest volumes	How much biomass is removed from the forest by humans?

		Is it possible to distinguish human from natural "disturbance"?
	Forest degradation	Is declining forest biomass or NPP a result of harvest or degradation?
Cropland	Pattern and extent	What is the exact extent of cropland and fallow land globally?
	Management type	How high is the extent of fallow land? How long are fallow periods? Which crops are multi-cropped?
	Crop types	Which crop types are grown in a grid cell?
	Crop yield	What is the share of primary product and used-residues to NPP or GPP?
	Field size	How big are crop fields (as a measure of cropping systems and intensity)?
Infrastructure	Extent	What is the extent of infrastructure globally?
	Types	What kind of infrastructure do we see (buildings, roads, gardens, mines, etc…)?
	Volume of artifacts	How much, and what kind of material do artefacts consist of?
Degradation	Declining productivity, as an unintended consequence of land use	Is a change in signal attributed to intended land use change, unintended land-use change, or caused by natural variability?
NPP	Is modelled via GPP (EO data) minus Plant Respiration (Ra).	Can NPP be accurately modelled through EO techniques?
Land cover	All land cover types	What is the extent of all land cover types in a grid-cell?
Land use	All land use types	What is the extent of all land use types in a grid-cell? Which areas are not used? What is the land-use intensity?
Land inputs	Socio-economic inputs into the land	How much capital, labor, external nutrients, irrigation are invested by societies per land area?
Plant functional types	Global patterns of plant functional types	Which plant functional types should be discerned and what is their spatial pattern?
GHG Emissions	Global patterns of greenhouse-gas emissions	How high are greenhouse gas emissions from agriculture, forestry, the livestock sector and other land uses?
Climate change impacts	Global patterns of climate change impacts	What are the impacts of climate change on global ecosystems in relation to the impacts of land use?
Biodiversity patterns*	The abundance of (functional) species at the landscape level (terrestrial and freshwater)	What is the genetic structure at the landscape scale? How can empirical (point) studies feed into a biodiv. pattern at the landscape scale?

*See task 8.1.: Biodiversity monitoring workshop

3.1. Potential of BACI products to help closing the knowledge gaps

Several upcoming BACI products (Table 1.3 in the BACI proposal) have high potential to solve the identified knowledge gaps (Table 1). Figure 3ab show the results of an evaluation based on Table S1 in the Annex, where BACI products of particular potential were identified and rated based on three different levels of suitability (unclear, probably potential; potential; high potential). Particularly products, such as LAI, faPAR and biomass appear instrumental in providing opportunities to address virulent existing knowledge gaps (Figure 2b), depending on characteristics and limitations the metrics are associated with. They could be relevant for analyzing changes of C-stocks in vegetation, detecting forest rotational systems and for detecting grazing management types, i.e. distinguishing grazing from mowing (Figure 2b). Furthermore canopy height and gap fraction could be enormously helpful for mapping and analyzing scattered forestry systems (savannahs, woodlands), a major knowledge gap in land use science and it could help identifying forest rotational systems, provided that data spans several years to decades.

A combination of several products could merit comprehensive land cover, and, to a lower degree, land use mapping. Backscatter, albedo, LAI, faPAR, biomass and canopy gap fraction could allow for distinguishing land cover types, and for providing crucial, so far often lacking information on fractional forest cover in mixed systems. Also, Maximum Radiation Use Efficiency, biomass, LAI and faPAR could probably be used to model NPP flows.

Note that Figures 2a,b likely underestimate the real potential of BACI products. They are the product of the organizer's summary of the workshop results with feedback from the project lead. Close collaboration between the product-providers and user community, will reveal further potentials that are not obvious at first glance can be discerned and exploited (see section follow-up activities below).

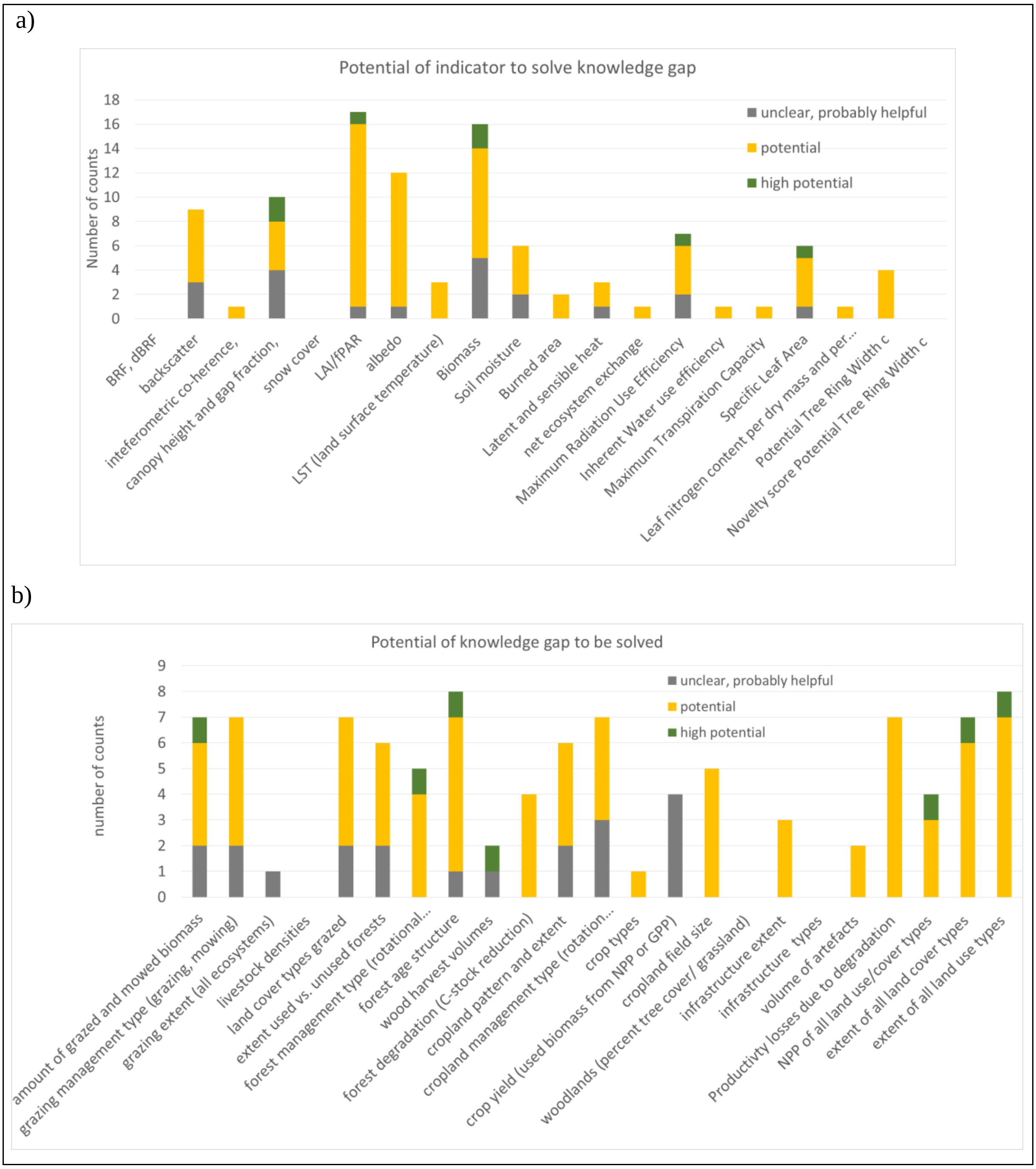

Figure 3: a) Number of knowledge gaps that could be solved with the listed BACI products; b) number of products for which we see potential to close knowledge gaps.

Successful implementation of BACI products will highly depend on the following:

1. Applicability of all data sets depends on the spatio-temporal resolution of the available products. A commonly used spatial resolution currently is 5arcmin, here expertise exists that allows to consistently integrate data sets. Several land use types, however, such as small scale agriculture in mosaic landscapes, or slash and burn agriculture (through biomass signals,

albedo, LAI, etc…), requires much finer spatial resolution. Requirements for temporal resolution usually depends on the information needed from the product.

2. The biggest challenge is probably the separation of land-use induced change (intended and unintended changes land properties caused by socio-economic activities) from naturally occurring changes (e.g. due to climate variability, extreme events, climate change). For instance, a decrease in forest biomass can be due to harvest, due to degradation, or due to windfalls. When it comes to e.g. modelling the impact of humans on the Earth system, the usability of many of the data streams for socioeconomic research will critically depend on the ability to separate the two. However, for assessing the impact of changes on certain socioeconomic parameters, the separation might be of less importance in direct application. But for questions of mitigation, or how to come with changes, it again becomes central, as it directly relates to the human option space.

3. A challenge relates to the resolution of socioeconomic data, which is important for (2): Socio-economic data is usually available (and makes sense only) for administrative units, or at coarse resolution, and sometimes only qualitative information is available. It might be interesting to investigate where, rather than downscaling socioeconomic data, sensible upscaling of EO products to match socioeconomic data resolution produces more robust results and where the opposite is the case.

4. Time series data (covering at least a decade) is essential for addressing many of the discussed knowledge gaps, e.g. cropping cycles, forest rotation, and degradation. Forest rotation probably is beyond feasibility owing to the long rotational schemes.

5. The potential for closing knowledge gaps heavily depends on further processing of the listed data products. In general terms, the land system community is not able to process raw data and so directly use many of the listed products. For instance, LAI, fPAR, albedo, backscatter must be translated into more accessible indicators or classification schemes, such as land cover info. Improvement of data usability is probably best warranted if products are developed under consultation with user groups. For this purpose, information exchange beyond the current level could be instrumental. This would allow to develop products matching the users' needs and to prevent misinterpretations

Figures 2 a,b, reflect mainly on the question of "how to make data streams usable for land system science, to close knowledge gaps?". Another aspect which is also important but has not been brought into perspective yet is the question: "Which changes in which biophysical parameters impact how on which socioeconomic sectors/aspects?" - This is a key question intricately related the question like "What can society do to mitigate or adapt?" These questions are particularly relevant for the design of early warning systems for monitoring and to anticipate detrimental developments. To interpret "change" in this sense, it is a) vital to separate natural changes, that occur independently from human actions from those which are casually linked to human action, either intended (e.g., land-use change, harvest) or unintended (e.g. degradation, change of overall-properties that show time lags, etc.). And b) it needs a robust knowledge on causal chains between changes in ecosystem states and socioeconomic impacts. This is not trivial, because society reacts on changes, by i) changing itself to adapt to changes (reduce vulnerability, adapt), and ii) changes natural states so that changes do not occur in a detrimental form any more (e.g. irrigation when drought is coming). And both phenomena occur at the same time.

3.2. Next step

One of the most important insights from the workshop was that optimal application of EO data in the broad field of land use research depends on improved communication flows. This is true for the general role of EO data application and specifically for the upcoming BACI products. We regard the workshop thus as a starting point for such a communication effort and stress that a continued exchange between providers and users within BACI is required to successfully integrate a broad user community and to ensure optimal use of the developed products. Hence, our next steps will be to distribute the table on upcoming BACI products (adapted version of Table S1) to a broader user community (at least 30 persons, including all workshop participants) in order to collect their perspectives on potentials for closing knowledge gaps.

3.3. References

Bai, Z.G. et al., 2008. Proxy global assessment of land degradation. *Soil Use and Management*, 24(3), pp.223–234.

Fritz, S. et al., 2013. The need for improved maps of global cropland. *Eos, Transactions American Geophysical Union*, 94(3), pp.31–32.

Hansen, M.C. et al., 2013. High-resolution global maps of 21st-century forest cover change. *science*, 342(6160), pp.850–853.

4. Annex

List of participants

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Organizing team from the Institute of Social Ecology:
Maria Niedertscheider, Karl-Heinz Erb, Thomas Kastner, Christoph Plutzar

Workshop Agenda

Monday (9.11.2015)

10:00 – 10:30 Welcoming session

10:30 – 11:15 Introduction to BACI-Project (Miguel Mahecha)

11:15 – 12:30 Introduction Round

12:30 – 14:00 Lunch at "Tata" (Seidengasse 23, 1070 Vienna)

14:00 – 15:00 Input session "Modelling Perspective"

Julia Pongratz: "**Data needs for land use change in Earth system modeling"**

Duccio Rocchini: "**Remote Sensing and modelling biodiversity"**

Petr Havlik: "**Spatial data in global change analysis: GLOBIOM experience"**

Milan Flach: **"A Multivariate Biosphere Atmosphere Change Index"**

15:00 – 16:00 Group work (coffee break included)

16:00 – 17:00 Feedback round and discussion

20:00 We are pleased to invite you to a joint dinner at "Neubauschenke" (Zieglergasse 25, 1070 Vienna; within walking distance from the Institute of Social Ecology and the Intercity Hotel)

Tuesday (10.11.2015)

9:00 – 10:00 Input session "Data Provision Perspective"

Patrick Hostert: “**Creed or need? Multi-sensor time series for land systems research”**

Ian McCallum: “**Engaging Citizens in Environmental Monitoring via Gaming”**

Clement Atzberger: “**Sentinel-2: The arrival of a game-changer”**

Marcus Hollaus: “**Overview of current developments of satellite-based remote sensing data with the focus on Sentinel 1/2”**

10:00 – 11:00 Group work (coffee break included)

11:00 – 12:30 Feedback round and discussion

12:30 – 14:00 Lunch at “Ronahi” (Schottenfeldgasse 18, 1070 Vienna)

14:00 – 15:00 Input session “Socio-economic Dimension”

Kathleen Hermans: “**The spatial dimension in socio-ecological research: A regional to global scale perspective”**

Martin Rudbeck Jepsen: “**Mapping land use systems and land use intensity”**

Darla Munroe: **“People and Pixels redux”**

Niedertscheider Maria: “**Land system research at the interface of socio-economic and natural processes”**

15:00 – 16:00 Group work (coffee break included)

16:00 – 17:00 Feedback round and discussion

Wednesday (11.11. 2015)

9:30 – 10:00 Wrap up

10:00 – 12:00 Next steps, towards a product

Table S1: Potential of upcoming BACI products to solve detected knowledge gaps. O = unclear, probably helpful, x = helpful, xx = extremely helpful

Variable	Grazing					Forestry					Cropland					Scattered forest ecosystems
Definition	*amount of grazed and mowed biomass*	*grazing management type (grazing, mowing)*	*grazing extent (all ecosystems)*	*livestock densities*	*land cover types grazed*	*extent used vs. unused forests*	*forest management type (rotational systems)*	*forest age structure*	*wood harvest volumes*	*forest degradation (C-stock reduction)*	*cropland pattern and extent*	*cropland management type (rotation systems)*	*crop types*	*crop yield (used biomass from NPP or GPP)*	*cropland field size*	*woodlands (percent tree cover/ grassland)*
BRF, dBRF																
backscatter	o	o			x	o						x			x	
inteferometric co-herence,																
canopy height and gap fraction,	o	o			o	x	x	xx						o		
snow cover																
LAI/fPAR	xx	x			x	x	x	x		x	x	x	x	o	x	
albedo	x	x				o	x	x		x	x	x			x	
LST (land surface temperature)	x	x										x				
Biomass	xx	x	o		o	x	xx	x	xx	x	o	o		o	x	
Soil moisture					x						o	o			x	
Burned area					x	x										
Latent and sensible heat	x	x										o				
net ecosystem exchange								x								
Maximum Radiation Use Efficiency	x							x	o					o		
Inherent Water use efficiency																
Maximum Transpiration Capacity																
Specific Leaf Area					x			o		x	x					
Leaf nitrogen content per dry mass and per area											x					
Potential Tree Ring Width c							x	x								
Novelty score Potential Tree Ring Width c																

Table S1 (continued): Potential of upcoming BACI products to solve detected knowledge gaps. O = unclear, probably helpful, x = helpful, xx = extremely helpful

Variable	Infrastructure			Degradation	NPP	land cover map	land use map
Definition	*infrastructure extent*	*infrastructure types*	*volume of artefacts*	*Productivty losses due to degradation*	*NPP of all land use/cover types*	*extent of all land cover types*	*extent of all land use types*
BRF, dBRF							
backscatter	x		x			x	
inteferometric co-herence,		x					
canopy height and gap fraction,	x					x	xx
snow cover							
LAI/fPAR	x			x	x	x	x
albedo				x		x	x
LST (land surface temperature)							
Biomass				x	x	x	x
Soil moisture				x			x
Burned area			x				
Latent and sensible heat							
net ecosystem exchange							
Maximum Radiation Use Efficiency					xx	x	x
Inherent Water use efficiency			x				
Maximum Transpiration Capacity		x					
Specific Leaf Area					xx	x	
Leaf nitrogen content per dry mass and per area							
Potential Tree Ring Width c				x		x	
Novelty score Potential Tree Ring Width c							