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Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European Observations

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Project title: Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European
Observations

Observations
Theme: SCS-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

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1. Executive summary

This deliverable presents a compendium of the papers done during the project. Being ConnectinGEO a Coordinated and Support Action (SCA) and not a Research related project, most of the papers are contributions to symposium and conferences and only some of them are journal papers. However, the consortium will still try to publish some papers after the ending of the project as most of the major results are achieved just now. In addition, the consortium is also pushing a Special issue in Environment Science and Policy, which is still in negotiation with the editors.

2. Scientific publication compendium

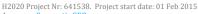
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Ménard L, Nüst D, Jirka S, Masó J, Ranchin T, Wald L (2015) Open Surface Solar Irradiance Observations - A Challenge. Geophysical Research Vol. EGU2015-6607, Abstracts 17, http://meetingorganizer.copernicus.org/EGU2015/EGU2015-6607.pdf. European Geosciences Union General Assembly 2015 - EGU 2015, Vienna (Austria).

Lionel Menard (1), Daniel Nüst (2), Simon Jirka (2), Joan Maso (3), Thierry Ranchin (1), and Lucien Wald (1) (1) MINES ParisTech, PSL Research University, Sophia Antipolis, France, (2) 52°North Initiative for Geospatial Open Source Software GmbH, Münster, Germany, (3) Center for Ecological Research and Forestry Applications (CREAF), Universitat Autònoma de Barcelona, Barcelona, Spain

The newly started project ConnectinGEO funded by the European Commission aims at improving the understanding on which environmental observations are currently available in Europe and subsequently providing an informational basis to close gaps in diverse observation networks. The project complements supporting actions and networking activities with practical challenges to test and improve the procedures and methods for identifying observation data gaps, and to ensure viability in real world scenarios. We present a challenge on future concepts for building a data sharing portal for the solar energy industry as well as the state of the art in the domain.

Decision makers and project developers of solar power plants have identified the Surface Solar Irradiance (SSI) and its components as an important factor for their business development. SSI observations are crucial in the process of selecting suitable locations for building new plants. Since in-situ pyranometric stations form a sparse network, the search for locations starts with global satellite data and is followed by the deployment of in-situ sensors in selected areas for at least one year. To form a convincing picture, answers must be sought in the conjunction of these EO systems, and although companies collecting SSI observations are willing to share this information, the means to exchange in-situ measurements across companies and between stakeholders in the market are still missing.











We present a solution for interoperable exchange of SSI data comprising in-situ time-series observations as well as sensor descriptions based on practical experiences from other domains. More concretely, we will apply concepts and implementations of the Sensor Web Enablement (SWE) framework of the Open Geospatial Consortium (OGC). The work is based on an existing spatial data infrastructure (SDI), which currently comprises metadata, maps and coverage data, but no in-situ observations yet. This catalogue is already registered in the GEOSS Common Infrastructure (GCI).

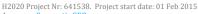
We describe the challenges and approach to introduce a suite of standards and best practices into the GEO Energy Societal Benefit Area for solar radiation measurements. Challenges range from spatio-temporal coverage across different scales and data quality to intellectual property rights and existing terminology. The approach includes means to share observations based on standardized data and metadata models and a user-friendly data exploration/management tool.

The possibility to access and share data considerably improves the information base for strategic planning and control of new solar power resources. The platform will be integrated as a new component into the Webservice-Energy.org GEOSS Community Portal dedicated to Energy and Environment. The ability to provide users with visualisation and download features for in-situ measurements is seen as a key aspect to start engaging the energy community to share, release and integrate more in-situ measurements. This will put to the test the capacity of cooperation in the SSI community by introducing an unprecedented level of collaboration and eventually help to detect gaps in European Earth observation networks. The presentation will be an opportunity to seek further collaboration partners and feedback by the community.

Masó J, Serral I, Menard L, Wald L, Nativi S, Plag H-P, Jules-Plag S, Nüst D, Jirka S, Pearlman J, De Maziere M (2015) Towards the creation of a European Network of Earth Observation Networks within GEO. The ConnectinGEO project. Geophysical Research Abstracts Vol. 17, EGU2015-13792, 2015: http://meetingorganizer.copernicus.org/EGU2015/EGU2015-13792.pdf. European Geosciences Union General Assembly 2015 - EGU 2015, Vienna (Austria).

Joan Masó, Ivette Serral, Lionel Menard, Lucien Wald, Stefano Nativi, Hans-Peter Plag, Shelley Jules-Plag, Daniel Nüst, Simon Jirka, Jay Pearlman, and Martine De Maziere CREAF, Bellaterra (Barcelona), Spain (joan.maso@uab.cat)

ConnectinGEO (Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European Observations" is a new H2020 Coordination and Support Action with the primary goal of linking existing Earth Observation networks with science and technology (S&T) communities, the industry sector, the Group on Earth Observations (GEO), and Copernicus. ConnectinGEO aims to facilitate a broader and more accessible knowledge base to support the needs of GEO, its Societal Benefit Areas (SBAs) and the users of the Global Earth Observing System of Systems (GEOSS). A broad range of subjects from climate, natural resources and raw materials, to the emerging UN Sustainable Development Goals (SDGs) will be addressed. The project will generate a prioritized list of critical gaps within available observation data and models to translate observations into practice-relevant knowledge, based on stakeholder consultation and systematic analysis. Ultimately, it will increase coherency of European observation networks,







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increase the use of Earth observations for assessments and forecasts and inform the planning for future observation systems.

ConnectinGEO will initiate a European Network of Earth Observation Networks (ENEON) that will encompass space-based, airborne and in-situ observations networks. ENEON will be composed by project partners representing thematic observation networks along with the GEOSS Science and Technology Stakeholder Network, GEO Communities of Practices, Copernicus services, Sentinel missions and in-situ support data representatives, representatives of the space-based, airborne and in-situ observations European networks (e.g. EPOS, EMSO and GROOM, etc), representatives of the industry sector and European and national funding agencies, in particular those participating in the future ERA-PlaNET. At the beginning, the ENEON will be created and managed by the project. Then the management will be transferred to the network itself to ensure its future continuity.

ConnectinGEO's main goal in ENEON is to mature a consultation complemented by a systematic analysis of available data and metadata, which will draw for the first time a coherent picture of the variety of used data interfaces, policies and indicators. This way, the project will stimulate a harmonized and coherent coverage of the European EO networks, reemphasizing the political strategic targets, create opportunities for SMEs to develop products based on the current networks, and open avenue for industry to participate in investments addressing the identified high-priority gaps.

The project starts in February 2015 and will last two years. We will present the five threads of the project for gap analysis in the Earth observation networks: global requirements and goals, international research programs, consultation process, systematic analysis of existing data platforsm and industry challenges. The presentation will provide both an overview of the network concepts and approaches and discuss participation of the broader scientific community of data providers and users.

Ménard, Lionel, Daniel Nüst, Simon Jirka, Joan Masó, Thierry Ranchin, and Lucien Wald. Open Surface Solar Irradiance Observations - A Challenge. European Geosciences Union General Assembly 2015, Vienna, Austria, 12-17 April 2015, EGU2015-6607.

Lionel Menard (1), Daniel Nüst (2), Simon Jirka (2), Joan Maso (3), Thierry Ranchin (1), and Lucien Wald (1) (1) MINES ParisTech, PSL Research University, Sophia Antipolis, France, (2) 52°North Initiative for Geospatial Open Source Software GmbH, Münster, Germany, (3) Center for Ecological Research and Forestry Applications (CREAF), Universitat Autònoma de Barcelona, Barcelona, Spain

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We present a solution for interoperable exchange of SSI data comprising in-situ time-series observations as well as sensor descriptions based on practical experiences from other domains. More concretely, we will apply concepts and implementations of the Sensor Web Enablement (SWE) framework of the Open Geospatial Consortium (OGC). The work is based on an existing spatial data infrastructure (SDI), which currently comprises metadata, maps and coverage data, but no in-situ observations yet. This catalogue is already registered in the GEOSS Common Infrastructure (GCI).

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Ménard, Lionel, Daniel Nüst, Khai- Minh Ngo, Philippe Blanc, Simon Jirka, Joan Masó, Thierry Ranchin, Lucien Wald. Interoperable Exchange of Surface Solar Irradiance Observations: A Challenge, Energy Procedia, Volume 76, August 2015, Pages 113-120. ELSEVIER. doi:10.1016/j.egypro.2015.07.867



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European Geosciences Union General Assembly 2015, EGU

Division Energy, Resources & Environment, ERE

Interoperable Exchange Of Surface Solar Irradiance Observations: A Challenge

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Abstract

We present how implementations of the Sensor Web Enablement framework of the Open Geospatial Consortium are integrated into an existing spatial data infrastructure. The result is registered as a community portal for professionals in solar energy in the GEOSS Common Infrastructure, demonstrating the benefits of interoperable exchange of in-situ time-series observations of surface solar irradiation. Easy access to, and sharing of data improves the information base for planning and monitoring of solar power resources. Providing users with visualization and download functionality for in-situ measurements is a key aspect for engaging the energy community to share, release and integrate in-situ measurements.

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Keywords: GEOSS; web; spatial data infrastructure; open data; sensor web enablement, solar energy; surface solar irradiance; SSI

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1. Introduction

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Solar energy is one of the main ways for producing electricity in many countries worldwide. Energy producers and project developers of solar power plants (photovoltaic, solar concentrating technologies) have identified the surface solar irradiance (SSI) and its components as an essential variable for their business development [1,2]. Policy-makers also need information based on SSI data to set up energy policies at local to national levels. Usages of SSI data in projects address:

- the potential and prospective solar resources with national, regional, and local maps of SSI integrated in decision support systems:
- the long-term solar resource assessment for a specific site with time series of SSI for technical sizing and yield report simulations;
- the monitoring of existing solar power plants for operation and maintenance purposes;
- the multi-horizon forecast for energy storage, planning or participation in an electricity spot market.

In addition to its use by companies and policy-makers, the SSI is identified as an Essential Climate Variable by the Global Climate Observing System [3]. Different operational Earth Observation (EO) components provide estimations of the SSI:

- in situ pyranometric sensors [4,5];
- processing of images taken by meteorological satellites, such as the HelioClim project [6,7], the Copernicus Atmosphere Service [8,9], or the Eumetsat CM-SAF [10];
- numerical weather models (NWM), such as ECMWF-IFS [11] or re-analyses such as ERA-Interim [12].

Currently, all these components are used by companies and policy-makers in the solar energy domain. However, they are used individually and not in conjunction. Emerging needs clearly show that a great benefit would be achieved by efficient means of joint exploitation. For example, in-situ pyranometric stations form a sparse network and do not offer an accurate description of the spatial distributions. Hence, the search for suitable locations for building new plants starts with satellite data, based on which in-situ observations are carried out at selected sites. Since in-situ pyranometric sensors are deemed to provide the best possible assessment of the SSI at a given location, in-situ instruments measuring the SSI must be deployed in selected areas for at least one year. Then, time-series of SSI derived from satellite imagery are adjusted onto these measurements to obtain long-term time-series of calibrated SSI data [13].

To form a convincing picture, answers must be sought in the conjunction of these EO systems, and although companies collecting SSI observations are willing to share this information, the means to exchange in-situ measurements across companies and between stakeholders in the market are still missing.

A new spatial information infrastructure can close this gap and enable integration and access to SSI observations by stakeholders. This infrastructure allows on the one hand providers to share their SSI observations and on the other hand users to access them. As there are many data providers using many different sensor instruments this infrastructure should tackle sensor integration and dissemination of measurement data through a uniform, platformindependent and interoperable approach. This could be efficiently achieved by benefiting from GEOSS recommendations on interoperability and by making extensive use of recognized international geospatial standards such as the OGC (Open Geospatial Consortium) SWE (Sensor Web Enablement) framework [14]. The present article addresses this issue.

This work takes place in the newly started project ConnectinGEO funded by the European Commission. ConnectinGEO aims at improving the understanding on which environmental observations are currently available in Europe and subsequently providing an informational basis to close gaps in diverse observation networks [15]. The project utilizes different top-down and bottom-up approaches. It complements consulting, and networking activities (top-down) with supporting actions and practical challenges to test and improve the procedures and methods for identifying observation data gaps. As part of the latter approach, we present the challenges and future concepts for building a data sharing portal for the solar energy industry as well as the state of the art in the domain to ensure viability of the ConnectinGEO methodology in real world scenarios.



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2. Solar industry challenges for in-situ measurements of SSI

NWM or satellite-based assessments of the SSI are currently easily accessible, yet sometimes against payment, as they obey GEOSS or WMO standards for dissemination, i.e. common data formats. Within a given database, all data for all pixels/cells obey the same format. This facilitates their integration into a user's own workflow and partly explains why they are often exploited by professionals in solar energy. In addition, they offer a high geographical and temporal coverage that satisfies the general needs in solar energy. In other words, these two EO components permit to provide SSI for any place in the world any time.

Taking into account the limitations in spatial and temporal resolutions and also in the underlying empirical or physical modeling, satellite-derived data are generally judged very useful by industry stakeholders for regional prospective or technical pre-feasibility studies. This is less the case for NWM that often exhibit drawbacks due to cloud presence [13]. Both satellite-derived data and NWM are nevertheless considered not accurate enough to convince investors in the commissioning of large-scale solar power plants, or to monitor and forecast production of

In-situ pyranometric sensors are deemed to provide the best possible assessment of the SSI at a given location. They serve as a reference to assess the quality of the two other components: satellite-derived and numerical weather models. However, though the purchase of a pyranometer can be seen as inexpensive, such a system induces high cost of operation and maintenance to be able to provide valuable, i.e. bankable data sets. This prevents the large-scale deployment of pyranometric stations.

All meteorological networks in Europe are equipped with pyranometric stations but many of them are not fully suitable to fulfil the needs of the solar energy community. There are several international networks that could be suitable such as those under the umbrella of the World Meteorological Organization (Global Atmosphere Watch -GAW, Baseline Surface Radiation Network - BSRN, world radiation data center - WRDC). Most data from these networks are available, though through different modes ranging from web-services to direct human-to-human phonecalls, often with limited rights in access and use [16]. The spatial density of these in-situ sensors is quite heterogeneous across the world. In many locations the distance between stations is too large to capture the spatial variability of the solar radiation [1, 2]. Moreover only few stations offer data sets spanning several years and many data sets exhibit temporal gaps of missing data.

Due to these limitations, investors or developers of solar power plant projects have installed or rented their own in-situ pyranometric stations and have private data sets from past or present time periods. In Europe, there are currently several hundreds of private ground stations associated with power plants. However, these data sets are currently not accessible for Intellectual Property Rights (IPR) reasons, even though recent efforts undertaken by MINES ParisTech in France seem to demonstrate that exchange of data between companies may be possible and that a network of these private stations may be set up for the common good.

In summary, it can be stated that, for different reasons, networks of meteorological pyranometric sensors, satellite observations or numeric weather models taken separately are not able to answer the needs of industrialists and project developers. Solutions can be found in the conjunction of these EO systems, such as those listed in the work plan of subtask B "standardization and Integration Procedures for Data Bankability" of the Task SHC 46 "Solar Resource Assessment and Forecasting" of the International Energy Agency:

- short-term calibration of long term satellite-based time series of SSI with in-situ measurements;
- quality check procedures of in-situ measurement with satellite-based SSI estimation;
- in-situ data completion (gap-filling) with satellite-based SSI estimation

The merging of in-situ measurements with satellite or NWM data to get valuable, bankable datasets ready for the business development corresponds to a very active and mature R&D activity. Several algorithms and methods are already available [13], for example in the FP7-funded ENDORSE project "ENergy DOwnstReam SErvices -Providing energy components for GMES" coordinated by ARMINES [17]. The main bottlenecks to the implementation of these solutions are technological obstacles and IPR. From the practical side, except within a given network, there is a lack of a common, interoperable (i.e. collaboratively discussed and well-defined or specified) framework to collect, store, process (quality-check, gap-filling, temporal aggregation) and disseminate in-situ measurements. From the IPR point of view, the use of data from large networks (BSRN, GAW, WRDC) is not



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allowed for commercial purposes and companies are not sharing their data, even though this would largely contribute to a larger penetration of solar energy in the European electricity mix.

ConnectinGEO will undertake efforts for 1) developing an interoperable framework, and 2) creating a demonstrator and convincing incentives for public or private bodies measuring SSI to share their data based on this framework under a license that explicitly allows commercial use [18].

Providing an easy and open access to SSI measurements is therefore a key feature to be developed in ConnectinGEO. From the end-user point of view, in-situ measurements should be easy to find, easy to access (view, download) and consequently easy to use (data format, metadata, documentation). From the data provider point of view in-situ measurements should be easy to register and upload, easy to qualify by flagging suspicious or erroneous data following well-established quality check procedures [19,20]. To enable this in a sustainable manner, in-situ measurements should be integrated and made available by using existing and recognized open international standards. In that respect, ISO (International Organization for Standardization) and OGC (Open Geospatial Consortium) standards address the full spectrum from the use of standardized metadata to data integration, data search and discovery to the exploitation of SSI parameters. This way a virtuous circle actively involving data users and data providers can be put into place exploiting established Sensor Web standards and implementations.

3. Spatial Data Infrastructure

A spatial data infrastructure (SDI, http://www.gsdi.org/gsdicookbookindex) should be deployed to enable the integration of and access to in-situ measurements of SSI. As discussed above, the SDI should tackle sensor integration and dissemination into a uniform, platform-independent and interoperable solution. The OGC SWE (Sensor Web Enablement) architecture is particularly suited to this purpose. It offers support to:

- discover and locate sensor systems and measurements;
- investigate sensor capabilities and information on the quality of the measurements;
- enable access to sensor parameters and data for direct or further processing.

Beside the direct access to in-situ sensor information, the SWE specifications allow to couple those assets with any available SSI Earth observation resources (raster or vector data, maps). Being able to combine SSI in-situ measurement with additional EO data at the application level will provide value added information maximizing value and enabling decision-making. The Web-based platform developed within the 52°North Sensor Web community is a complete Sensor Web infrastructure particularly designed to provide access to data measured by sensors. It also enables tasking and control of sensors, event detection and triggering of alerts through sensor observations. It implements standardized interfaces developed by the Open Geospatial Consortium (OGC) and its Sensor Web Enablement (SWE) initiative and provides user-friendly interfaces for visualization as well as clients for diverse analysis environments.

In order for data providers to leverage their efforts of releasing in-situ measurements of SSI, the SDI should enable a "search and discovery" mechanism of such measurements. This mechanism will be provided by referencing all in-situ measurement of SSI available through the Sensor Web infrastructure into an OGC-compliant CSW (Catalog Service for the Web) catalog (http://www.opengeospatial.org/standards/cat). This catalog should allow both humans a user-friendly search experience through a Web based graphical user interface (GUI) (Fig. 1) as well as machine to machine distributed operations for back-office processes



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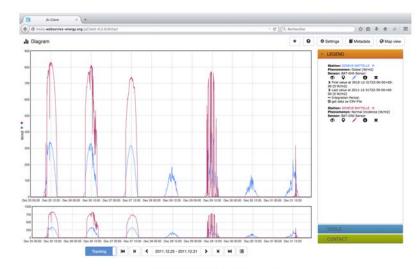


Fig. 1. Screenshot of the web-based GUI

End users should also have the possibility to get an easy access to in-situ measurements of SSI. A Web-based GUI, also called a thin client, will allow to:

- geo-locate the site of interest among available surrounding measuring stations;
- select the type and the technical characteristics of sensors and the corresponding data sets of interest provided by the selected stations;
- retrieve metadata; including information about the sensor as well as about the measurement itself regarding for example quality assessment and quality control;
- access time series of in-situ measurements; the values should be represented as line chart for a specific period and time integration (sub-hourly, daily, monthly, etc.), and tables and graphs.

End-users should be able then to export/download the measurements of interest for further ingestion into their own processing tools for further analyses and studies. Additional features could be added to the GUI such as averaging over time, or comparison with satellite-based SSI from Copernicus Atmosphere Service (Fig. 2). These extensions to the open source client solution are crucial for the adaptation within the solar energy community.



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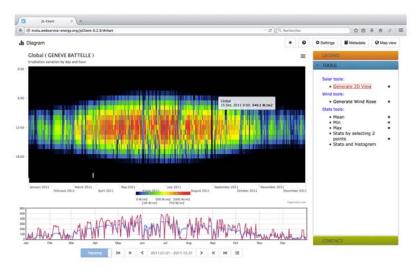


Fig. 2. Screenshot of additional features integrated into the web-based GUI

The newly created Sensor Web infrastructure will be integrated as a new component into the existing SDI known as the "Webservice-Energy.org GEOSS Community Portal dedicated to Energy and Environment". This SDI developed and managed by MINES ParisTech since 2011 currently comprises a community portal, a catalog, and several client applications, data-models, maps and coverage data. It does not comprise in-situ observations yet. The catalog is CSW-compliant and may accommodate for in-situ measurements. It is connected to the GEOSS Common Infrastructure (GCI)[†] and is weekly harvested by the GEOSS DAB (Discovery and Access Broker). This allows all existing resources listed in the catalog to be available on the GEO Web Portal (GWP) for search and discovery rewarding efforts of data providers in their outreach and dissemination activities of their legacy data assets.

[†] http://www.earthobservations.org/geoss.php

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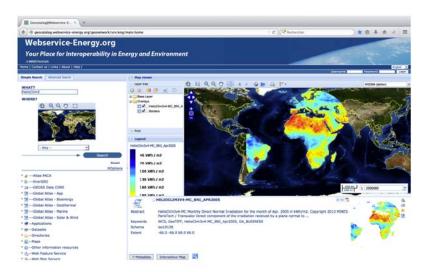


Fig. 3. Screenshot of the webservice-energy catalog

4. Perspectives and assessment by the community of users

A pilot use case will be set up to demonstrate business opportunities in solar energy. Several in-situ data sets will be made available through the Sensor Web platform. They will originate from different providers that have agreed to participate to this challenge, namely, MINES ParisTech and Ecole Nationale des Travaux Publics de l'Etat, both from France, as well as the universities of Geneva (Switzerland) and Kishinev (Moldova). Discussions are pending with other providers worldwide, including companies. Once in-situ measurements are available, several users, mostly from companies, will be invited to use the platform and to provide their feedbacks on the benefit of this platform and on the networking of resources for improving their daily work and increasing their business. Two specific use cases will be implemented with different scopes: 1) improving the quality of bankable data sets, and 2) improving the design of plants and targeting geographical areas for such plants.

Expected outcomes from the pilot use cases will tackle:

- gaps in data models: Designing standardized data and metadata models to better suit in-situ observations of SSI as profiles of OGC Sensor Web Enablement standards;
- gaps in in-situ measurements of SSI: Extending the webservice-energy catalog platform with data management functions based on the new (meta)data profiles and the GEOSS recommendations for interoperability based on 52°North Sensor Web platform:
- gaps in collaboration: Presenting the new platform to the community of users at a workshop will help in defining the remaining blockages and next steps to reach our final goal.

The new platform has been selected in GEOSS as a contribution of the energy SBA (Societal Benefit Area) to the AIP-8 (Architecture Implementation Pilot - Phase 8). The AIP-8 results will be presented on November 2015 in Mexico at the GEO-XII Plenary & Mexico City Ministerial Summit. Beside the expected feature on the client side as listed above connections based on GEOSS recommendations on interoperability will be tested between the new platform and more precisely between the metadata description of sensor based resources in this new platform and the GEOSS DAB through a harvesting mechanism. This will extend the existing GEOSS webservice-energy SDI to provide the GEO Energy community with access to in-situ measurements of SSI.



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Acknowledgements

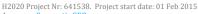
The research leading to these results has received funding from the European Union's Horizon 2020 Programme (H2020/2014-2020) under grant agreement no. 641538 (ConnectinGEO project).

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- [1] Cros S., Mayer D., Wald L. The availability of Irradiation Data. Report IEA-PVPS T2-04: 2004, International Energy Agency, Vienna, Austria, 2004, 29 p.
- [2] Gschwind B., Ménard L., Albuisson M., Wald L. Converting a successful research project into a sustainable service: the case of the SoDa Web service. Environmental Modelling and Software 2006, 21:1555-1561.
 [3] GCOS Essential Climate Variables, defined in 2010, available at:
- ww.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables
- [4] WMO: Guide to meteorological instruments and methods of observation, World Meteorological Organization, WMO-No 8, 7th Edn., Geneva, Switzerland, 2008.
- [5] Vuilleumier L., Hauser M., Félix C., Vignola F., Blanc P., Kazantzidis A., Calpini B. Accuracy of ground surface broadband shortwave radiation monitoring. Journal of Geophysical Research: Atmospheres 2014, 119:13,838-13,860.
- [6] Blanc P., Gschwind B., Lefèvre M., Wald L. The HelioClim project: Surface solar irradiance data for climate applications. Remote Sensing 2011. 3:343-361.
- [7] Lefevre M., Blanc P., Espinar B., Gschwind B., Ménard L., Ranchin T., Wald L., Saboret L., Thomas C., Wey E. The HelioClim-1 database of daily solar radiation at Earth surface: an example of the benefits of GEOSS Data-CORE. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2014, 7:1745-1753.
- [8] Users' guide to the MACC-RAD Services on solar energy radiation resources, May 2015, available at http://www.gmes $atmosphere.eu/documents/macciii/deliverables/MACCIII_RAD_DEL_D57.5_final.pdf$
- Ou Z., Oumbe A., Blanc P., Lefevre M., Wald L., Schroedter-Homscheidt M., Gesell G. Assessment of surface solar irradiance by the Heliosat-4 method with cloud product APOLLO derived from SEVIRI images as inputs. In Proceedings of the 2012 EUMETSAT
- Meteorological Satellite Conference, 3-7 September 2012, Sopot, Poland, EUMETSAT P. 61, s2-03, 2012.
 [10] Mueller R.W., Matsoukas C., Gratzki A., Behr H.D., Hollmann, R. The CM SAF operational scheme for the satellite based retrieval of solar surface irradiance - A LUT based eigenvector hybrid approach. Remote Sensing of Environment 2009, 13:1012-1024.
- [11] ECMWF, 2015. IFS documentation. https://software.ecmwf.int/wiki/display/IFS/Official+IFS+Documentation (last access: may 2015)
 [12] Boilley A., Wald L. Comparison between meteorological re-analyses from ERA-Interim and MERRA and measurements of daily solar irradiation at surface. Renewable Energy 2015, 75:135-143.
- [13] Sengupta M., Habte A., Kurtz S., Dobos A., Wilbert S., Lorenz E., Stoffel T., Renné D., Myers D., Wilcox S., Blanc P., Perez R. Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications. Technical Report 2015, NREL/TP-5D00-63112, 251 pages
- [14] Bröring, A., Echterhoff J., Jirka S., Simonis I., Everding T., Stasch C., Liang C., Lemmens R. New generation Sensor Web Enablement. Sensors 2011, 11:2652-2699. doi:10.3390/s110302652.
- [15] Maso J., Serral I., Menard L., Wald L., Nativi S., Plag H.-P., Jules-Plag S., N\u00fcst D., Jirka S., Pearlman J., De Maziere M. Towards the creation of a European Network of Earth Observation Networks within GEO. The ConnectinGEO project. European Geosciences Union General Assembly 2015, Vienna, Austria, 12-17 April 2015, EGU2015-13792.
- [16] Blanc P., Gschwind B., Lefevre M., Wald L. Validating Meteosat-derived surface solar irradiance in Mozambique. In Proceedings of the 30th Symposium of the European Association of Remote Sensing Laboratories, Ed. Halounova L., held in Prague, Czech Republic, 30 May 2 June 2011, A. A. Balkema Publisher, 2011.
- [17] Wald L., Providing energy components for GMES and GEO. 9th GEO Plenary European Commission Side Event, 21-23 November 2012, Foz do Iguaçu, Brazil.
- [18] Menard L., Nûst D., Jirka S., Maso J., Ranchin T., Wald L. Open surface solar irradiance observations A challenge. European Geosciences Union General Assembly 2015, Vienna, Austria, 12-17 April 2015, EGU2015-6607
- [19] Roesch A., Wild M., Ohmura A., Dutton E. G., Long C. N., Zhang T. Assessment of BSRN radiation records for the computation of monthly means. Atmospheric Measurement Techniques 2011, 4:339-354. doi:10.5194/amt-4-339-2011.
- [20] Espinar B., Blanc P., Wald L., Hoyer-Klick C., Schroedter-Homscheidt M., Wanderer T. On quality control procedures for solar radiation and meteorological measures, from subhourly to monthly average time periods. Geophysical Research Abstracts, Vol. 14, EGU General Assembly 2012, 22-27 April 2012, Vienna, Austria.

Publications on 2016

Palma Blonda, Joan Masó, Antonio Bombelli, Hans Peter Plag, lan McCallum, Ivette Serral, and Stefano Stefano Nativi, 2016. "Current status of the Essential Variables as an instrument to assess the Earth Observation Networks in Europe". European Geosciences Union General Assembly 2015, Vienna, Austria, 17-22 April 2016, EGU2016-16692.







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ConnectinGEO (Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European Observations" is an H2020 Coordination and Support Action with the primary goal of linking existing Earth Observation networks with science and technology (S&T) communities, the industry sector, the Group on Earth Observations (GEO), and Copernicus. The project will end in February 2017.

Essential Variables (EVs) are defined by ConnectinGEO as "a minimal set of variables that determine the system's state and developments, are crucial for predicting system developments, and allow us to define metrics that measure the trajectory of the system". Specific application-dependent characteristics, such as spatial and temporal resolution of observations and data quality thresholds, are not generally included in the EV definition.

This definition and the present status of EV developments in different societal benefit areas was elaborated at the ConnectinGEO workshop "Towards a sustainability process for GEOSS Essential Variables (EVs)," which was held in Bari on June 11-12, 2015 (http://www.gstss.org/2015_Bari/). Presentations and reports contributed by a wide range of communities provided important inputs from different sectors for assessing the status of the EV development.

In most thematic areas, the development of sets of EVs is a community process leading to an agreement on what is essential for the goals of the community. While there are many differences across the communities in the details of the criteria, methodologies and processes used to develop sets of EVs, there is also a considerable common core across the communities, particularly those with a more advanced discussion. In particular, there is some level of overlap in different topics (e.g., Climate and Water), and there is a potential to develop an integrated set of EVs common to several thematic areas as well as specific ones that satisfy only one community.

The thematic areas with a more mature development of EV lists are Climate (ECV), Ocean (EOV) and Biodiversity (EBV). Water is also developing a set of EVs in GEOSS. Agriculture is working with a common set of variables that can be considered essential to them such as Crop Area, Crop Type, Crop Condition, etc. More work is required for an agreement on other sets of EVs for Disasters, Health and Ecosystems.

Being cross-domain topics, these areas can make use of existing sets of EVs (such as ECVs, EOVs and EBVs) complemented by socioeconomic variables that can help to characterize services (e.g., ecosystem services) to human societies. Renewable energy also makes use of the ECVs but there is a need for additional ones: solar surface irradiance and wind at different heights are good candidates to explore.

ConnectinGEO will link with Climate, Ocean and Biodiversity communities and support Water, Agriculture, Renewable Energy, Health, Disasters and Ecosystems to make progress in the EV development by stimulating the debate in their respective international forums (mainly in GEOSS). The final objective is to foster EV extraction from the integrated use of in-situ and satellite Earth Observation data.







Joan Masó, Ivette Serral, Ian McCallum, Palma Blonda, and Hans-Peter Plag, 2016. "Topology of the European Network of Earth Observation Networks and the need for an European Network of Networks". European Geosciences Union General Assembly 2015, Vienna, Austria, 17-22 April 2016, EGU2016-8294.

Joan Masó (1), Ivette Serral (1), Ian McCallum (2), Palma Blonda (3), and Hans-Peter Plag (4) (1) CREAF, Bellaterra (Barcelona), Spain, (2) International Institute for Applied Systems Analysis. IIASA. Laxenburg, Austria., (3) Institute of Intelligent Systems for Automation, National Research Council ISSIA CNR, Bari, Italy, (4) Old Dominion University, Norfolk, Virginia, USA

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ConnectinGEO will initiate a European Network of Earth Observation Networks (ENEON) that will encompass space-based, airborne and in-situ observations networks. ENEON will be composed of project partners representing thematic observation networks along with the GEOSS Science and Technology Stakeholder Network, GEO Communities of Practices, Copernicus services, Sentinel missions and in-situ support data representatives, representatives of the European space-based, airborne and in-situ observations networks.

This communication presents the complex panorama of Earth Observations Networks in Europe. The list of networks is classified by discipline, variables, geospatial scope, etc. We also capture the membership and relations with other networks and umbrella organizations like GEO. The result is a complex interrelation between networks that can not be clearly expressed in a flat list.

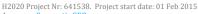
Technically the networks can be represented as nodes with relations between them as lines connecting the nodes in a graph. We have chosen RDF as a language and an AllegroGraph 3.3 triple store that is visualized in several ways using for example Gruff 5.7.

Our final aim is to identify gaps in the EO Networks and justify the need for a more structured coordination between them.

Guillem Closa, Ivette Serral, and Joan Maso, 2016. "Gap analysis of the European Earth Observation Networks". European Geosciences Union General Assembly 2015, Vienna, Austria, 17-22 April 2016, EGU2016-16925.

Guillem Closa, Ivette Serral, and Joan Maso CREAF, Bellaterra (Barcelona), Spain

Earth Observations (EO) are fundamental to enhance the scientific understanding of the current status of the Earth. Nowadays, there are a lot of EO services that provide large volume of data, and the number of datasets available for different geosciences areas is increasing by the day. Despite this coverage, a glance of the European EO networks reveals that there are still some issues that are not being met; some gaps in specific themes or some thematic overlaps between different networks. This







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situation requires a clarification process of the actual status of the EO European networks in order to set priorities and propose future actions that will improve the European EO networks. The aim of this work is to detect the existing gaps and overlapping problems among the European EO networks.

The analytical process has been done by studying the availability and the completeness of the Essential Variables (EV) data captured by the European EO networks. The concept of EVs considers that there are a number of parameters that are essential to characterize the state and trends of a system without losing significant information.

This work generated a database of the existing gaps in the European EO network based on the initial GAIA-CLIM project data structure. For each theme, the missing or incomplete data about each EV was indentified. Then, if incomplete, the gap was described by adding its type (geographical extent, vertical extent, temporal extent, spatial resolution, etc), the cost, the remedy, the feasibility, the impact and the priority, among others.

Gaps in EO are identified following the ConnectinGEO methodology structured in 5 threads; identification of observation requirements, incorporation of international research programs material, consultation process within the current EO actors, GEOSS Discovery and Access Broker analysis, and industry-driven challenges implementation. Concretely, the presented work focuses on the second thread, which is based on International research programs screening, conclusions of research papers extraction, research in collective roadmaps that contain valuable information about problems due to lack of data, and EU research calls considering to move forward in known uncovered areas.

This provides a set of results that will be later validated by an iterative process that will enhance the database content until an agreement in the community is reached and a list of priorities is ready to be delivered.

This work is done thanks to the EU ConnectinGEO H2020 (Project Nr: 641538).

Menard Lionel, Blanc Philippe, Gschwind Benoit, Wald Lucien, A spatial data infrastructure dedicated to the interoperable exchange of meteorological measurements in renewable energies. 16th EMS Annual Meeting, 12-16 September 2016, Trieste, Italy, EMS Annual Meeting Abstracts, 13, EMS2016-369

Lionel Menard, Philippe Blanc, Benoit Gschwind, and Lucien Wald MINES ParisTech - PSL Research University, Sophia Antipolis cedex, France (lucien.wald@mines-paristech.fr)

The meteorological measurements are identified as essential by energy producers and project developers of plants producing renewable energy for their business development. Policy-makers also need information based on such measurements to set up energy policies at local to national levels. Different Earth Observation (EO) components provide estimations of the meteorological variables: in situ sensors, processing of images taken by meteorological satellites, and numerical weather models. Currently, all these components are used by companies and policymakers in the renewable energy domain. However, they are used individually, while an efficient means of joint exploitation would bring great benefit. Such exploitation implies exchange of those data but means to exchange in-situ measurements across companies and between stakeholders in the market are still missing or of low specifications. A new dedicated spatial data infrastructure (SDI) is presented here that intends



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to fill this gap and enable integration and access to meteorological observations by stakeholders. This SDI provides an efficient means to find, access, view, download and eventually use data easily using well recognized standards. Data providers benefit from well-established quality-controlled procedures prior to data integration in the SDI. The main bottlenecks to the implementation of the SDI are technological obstacles and Intellectual Property Rights (IPR). Major technical difficulties arise because there are many data providers using many different sensor instruments. This is tackled by founding the SDI on a uniform, platform-independent and interoperable approach benefiting from GEOSS (Global Earth Observation System of Systems) recommendations on interoperability and by making extensive use of recognized international geospatial standards such as the OGC SWE (Sensor Web Enablement) framework. From the IPR point of view, commercial use of data from large meteorological networks is usually not allowed and companies are inclined not to publicly share data. However, efforts are being made to convince these stakeholders with some success.

McCallum, I. et al. Land management: data availability and process understanding for global change studies. Global Change Biology (2016), doi: 10.1111/gcb.13443



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Global Change Biology

Global Change Biology (2016), doi: 10.1111/gcb.13443

RESEARCH REVIEW

Land management: data availability and process understanding for global change studies

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In the light of daunting global sustainability challenges such as climate change, biodiversity loss and food security, improving our understanding of the complex dynamics of the Earth system is crucial. However, large knowledge gaps related to the effects of land management persist, in particular those human-induced changes in terrestrial ecosystems that do not result in land-cover conversions. Here, we review the current state of knowledge of ten common land management activities for their biogeochemical and biophysical impacts, the level of process understanding and data availability. Our review shows that ca. one-tenth of the ice-free land surface is under intense human management, half under medium and one-fifth under extensive management. Based on our review, we cluster these ten management activities into three groups: (i) management activities for which data sets are available, and for which a good knowledge base exists (cropland harvest and irrigation); (ii) management activities for which sufficient knowledge on biogeochemical and biophysical effects exists but robust global data sets are lacking (forest harvest, tree species selection, grazing and mowing harvest, N fertilization); and (iii) land management practices with severe data gaps concomitant with an unsatisfactory level of process understanding (crop species selection, artificial wetland drainage, tillage and fire management and crop residue management, an element of crop harvest). Although we identify multiple impediments to progress, we conclude that the current status of process understanding and data availability is sufficient to advance with incorporating management in, for example, Earth system or dynamic vegetation models in order to provide a systematic assessment of their role in the Earth system. This review contributes to a strategic prioritization of research efforts across multiple disciplines, including land system research, ecological

Keywords: data availability, earth system models, global land-use data sets, land management, land-cover modification, process understanding

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Introduction

We have entered a proposed new geologic epoch, the Anthropocene, characterized by a surging human population and the accumulation of human-made artefacts resulting in grand sustainability challenges such as climate change, biodiversity loss and threats to food security (Steffen et al., 2015). Finding solutions to these challenges is a central task for policymakers and scientists (Reid et al., 2010; Foley et al., 2011). A central prerequisite to overcome these sustainability challenges is an improved understanding of the complex and dynamic interactions between the various Earth system components, including humans and their activities. However, many unknowns relate to the extent and degree of human impacts on the natural components of the Earth system. While a relatively robust body of knowledge exists on the effect of land-cover conversions, for example change in forest cover (Brovkin et al., 2004; Feddema et al., 2005; Pongratz et al., 2009), landuse activities that result in 'land modifications', that is changes that occur within the same land-cover type, remain much less studied (Erb, 2012; Rounsevell et al., 2012; Campioli et al., 2015; McGrath et al., 2015). Changes in land-use intensity are a prominent example for such effects (Erb et al., 2013a; Kuemmerle et al., 2013; Verburg et al., 2016). These land-use activities, which we here summarize under the term 'land management', are the focus of our review.

Evidence suggests that the effects of land management on key Earth system parameters are considerable (Mueller et al., 2015; Erb et al., 2016; Naudts et al., 2016) and can be of comparable magnitude as land-cover conversions (Lindenmayer et al., 2012; Luyssaert et al., 2014). Furthermore, management-induced land modifications cover larger areas than those affected by land conversions (Luyssaert et al., 2014). Omitting land management in assessing the role of land use in the Earth system may hence result in a substantial underestimation of human impacts on the Earth system, or difficulties to elucidate spatiotemporal dynamics and patterns of crucial Earth System parameters (e.g. Bai et al., 2008; Forkel et al., 2015; Pugh et al., 2015). This calls for the development of strategies that allow us to comprehensively and systematically quantify management effects (Arneth et al., 2012).

However, two distinct - albeit interrelated - barriers hinder our current ability to fully assess land management impacts. First, major knowledge gaps exist in our qualitative and quantitative understanding of the biogeochemical and biophysical impacts of land management. Second, serious data gaps exist on the extent as well as intensity of various management practices. Here, we review the current state of knowledge of ten

common land management activities for their global impact, the level of process understanding and data availability to improve both analytical and modelling capacities as well as to prioritize future modelling and data generation activities.

Key land management activities

During an interdisciplinary workshop cycle (see Acknowledgements), we identified ten important land management activities that may impact the Earth system profoundly (Table S1 in the Appendix S1), namely (i) forest harvesting; (ii) tree species selection; (iii) grazing and mowing harvest; (iv) crop harvest and crop residue management; (v) crop species selection; (vi) nitrogen (N) fertilization of cropland and grazing land; (vii) tillage; (viii) crop irrigation (including paddy rice irrigation); (ix) artificial drainage of wetlands for agricultural purposes; and (x) fire as a management tool (Fig. 1). These ten management practices were selected based on their global prevalence across a diversity of biomes and based on their strong biophysical and biogeochemical effects, as described in the literature. Table S1 provides definitions and lists ecosystems in which the management practices prevail and which are in the focus of our review. The provision of bioenergy, for example biofuels from plant oil, starch or sugar, or wood fuel, is not classified as own management type. Rather, it is subsumed under items i) and iv). It is important to note that this list represents a subjective, consensus-oriented group opinion and is thus neither exhaustive nor representative. For instance, many management activities have not been considered here, for example litter raking, peat harvest, phosphate or potassium fertilization, crop protection, forest fertilization or mechanization. Such activities can be of central importance, for example, in specific contexts, and advancing the understanding of their divers and impacts is equally important.

For each management activity, we compiled information on the current global extent; past, ongoing and anticipated dynamics; data availability; and state of knowledge on biogeochemical and biophysical effects. Biogeochemical effects include changes in greenhouse gas (GHG) and aerosol concentrations caused by changes in surface emissions (CO, CO2, H2O, N2O, NOx, NH3, CH4) or by changes in atmospheric chemistry (CH₄, O₃, H₂O, SO₂, biogenic secondary organic aerosols). Biophysical effects include changes in surface reflectivity (i.e. albedo) and changing surface fluxes of energy and moisture through sensible heat fluxes and evapotranspiration. The combined information is then used to suggest prioritizations of future research

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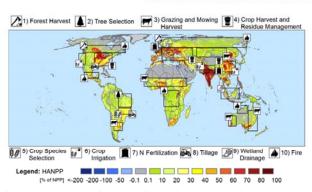


Fig. 1 The ten selected management activities and a selection of geographic regions where these activities play an important role. The background map displays the human appropriation of net primary production (Haberl et al., 2007; Copyright 2007 National Academy of Sciences, USA), that is the ratio between annual potential net primary production (NPP) and NPP remaining in ecosystems after harvest. Negative values indicate areas where due to management NPP remaining in ecosystems surmounts the hypothetical potential NPP

Forestry harvest

Extent and data availability. Forests cover 32.7-40.8 Mkm² or 30% of the ice-free land surface and 2/3-3/4 of global forests (26.5-29.4 Mkm2) are under some form of management (Erb et al., 2007; FAO, 2010; Pan et al., 2013; Luyssaert et al., 2014; Birdsey & Pan, 2015). Forest use reaches back to the cradle of civilization (Perlin, 2005; Hosonuma et al., 2012), while scientific forest management, that is management schemes that involve careful planning based on empirical observations and forest ecological process understanding (Mårald et al., 2016), originated in the late 18th century (Farrell et al., 2000). The share of managed forests and management intensity are expected to increase further along with global demand for wood products (Eggers et al., 2008; Meyfroidt & Lambin, 2011; Levers et al., 2014). Virtually all temperate and southern boreal forests in the Northern Hemisphere are already managed for wood production (Farrell et al., 2000). Northern boreal forests are at present largely unused for wood production (Erb et al., 2007) and could become increasingly managed in the future due to growing global demand for wood products and comparative advantages in boreal forestry compared to other regions (Westholm et al., 2015). Temperate forests are mostly under some version of age class-based management. In contrast, wood extraction from tropical forest often targets selected species, resulting in forest degradation. Significant parts of tropical forest (5.5 Mkm2) are in different stages of recovery from prior logging and/or agricultural use (Pan et al., 2011). The use of tropical forests is also predicted to

increase, both in extent and intensity, mainly to supply international markets (Hosonuma et al., 2012; Kissinger et al., 2012). 7% of managed forests are intensive plantations, 65% subject to regular harvest schemes, and 28% under other (e.g. sporadic) uses (Appendix S1). Data on wood harvest are surprisingly scarce (Table 1), given the importance of forests and forestry in the Earth system as well as a socio-economic resource. Time series of national-level data exist, but are uncertain, particularly regarding fuelwood harvest (Bais et al., 2015). This uncertainty is, among others, the result of differences in reporting schemes, induced by semantic discrepancies, or oversimplified approaches for creating gridded time series (Erb et al., 2013b; Birdsey & Pan, 2015).

Effects of forestry harvest. The knowledge on biogeochemical effects of wood harvest is relatively advanced, although considerable uncertainties still persist, and biogeochemical as well as biophysical effects are strong. Around 2000, forest harvest amounted to 1 Pg C (carbon) yr-1 consisting of around 0.5 Pg C yr-1 for wood fuel and another 0.5 Pg C yr -1 as timber (Krausmann et al., 2008; FAOSTAT, 2015). Forest harvest mobilizes annually <0.5% of the global standing biomass (Saugier et al., 2001; Pan et al., 2011), but the flux represents around 7% of the global forest net primary production (NPP) (Haberl et al., 2007), reaching 15% in highly managed regions such as Europe (Luyssaert et al., 2010). Uncertainty ranges in wood flows are large (Krausmann et al., 2008; Bais et al., 2015). In general, harvest reduces standing biomass compared to intact forest (Harmon et al., 1990; McGarvey et al., 2014), with the



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Table 1 Overv	iew of data availabilit	ty for the ten land man	Table 1 Overview of data availability for the ten land management activities reviewed in this study	red in this study		
	National statistics (based) w. global coverage*	(based) w. global	Gridded spatial data, continental or global	ontinental or global		
Management activity	Static	Time series	Continental or ecozone, static	Global, static	Global, time series	Comments
Forestry	FAOSTAT (2015); FAO (2015a)	FAOSTAT (2015); FAO (2015a); Krausmann et al. (2013)	Europe McGrath et al., (2015); Levers et al., (2014); Verkerk et al. (2015)	Haberl <i>et al.</i> (2007) – forest system approach	Hurtt et al. (2011); [Europe: Vilén et al. (2012); age class into. could be used or used for could be	Spatially explicit Information on used/ unused forests lacking, but data on wilderness Sanderson et al. (2002) or intact forests (Potapov et al. 2008) might provide proxies (Erb et al. 2007). Oversimplified
Tree species selection	FAO (2015a)	FAO (2015a)	Europe Brus et al. (2011); Hengeveld et al. (2012); McGrath et al. (2017)		reconstructions	EAO FRA only discerns the total area of planted forest. Other sources usually only discern conferents from deciduous trees. Spatially explicit data on mannations lacking.
Grazing and mowing harvest	Bouwman et al. (2005), Herrero et al. (2013); Krausmann et al. (2008); Wirserius	Krausmann et al. (2013)	Petz et al. (2014), relying on Wint & Robinson (2007); Chang et al. (2015), based on ORCHIDEE-CM	Herrero et al. (2013) relying on Wint & Robinson (2007); Haberl et al. (2007)		Extrementation of some of the strength of the strength on the global extent vary strongly (± 40%), and data on grazing volumes are not statistically reported but modelled only
Crop harvest + residue management	(2015), FAOSTAT (2015); Krausmann et al. (2008); Wirsenius	FAOSTAT (2015); Krausmann et al. (2013)		Haberl et al. (2007); Monfreda et al. (2008); Ray & Foley (2013); You et al. (2014);	Ray et al. (2012); lizumi et al. (2014); lizumi & Ramankutty (2016);	Intricacies relate to the difference between harvest yields (harvested biomass per harvest event) and physical yields (total harvest per land- use areas, including fallows)
Crop species selection	(2003); FAOSTAT (2015); FAO (2010);	FAOSTAT (2015)		Monfreda et al. (2008); You et al. (2014); Portmann et al. (2010);		No information on interannual dynamics, such as rotational schemes, available
N Fertilization	FAOSTAT (2015);	FAOSTAT (2015)		Potter <i>et al.</i> (2010); Mueller <i>et al.</i> (2012); Liu <i>et al.</i> (2010);		Spatially explicit data are modelling derived and show large discrepancies, in particular livestock manure is error prone No data on fertilization outside croplands



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	Comments	No data on tillage, but presumable all croplands are tilled with two exceptions; permanent crops and zero tillage agriculture. For the latter, no data are available	Many data, for example those by FAO, relate to area equipped for irrigation, while the amount of water actually	used is difficult to assess. Higher quality for paddy rice	Poor data availability. Gridded assessments cover all drainage, not	only wetlands Problems relate to discerning natural	from human-induced fires as well as agricultural fires. Scarce data for	prescribed fires and no data on fire prevention available
	Global, time series		Freydank & Siebert (2008); Siebert <i>et al.</i>	(2015);		All fires: for	example Giglio et al. (2013);	
continental or global	Global, static		Portmann et al. (2010) Salmon et al. (2015) Wisser et al. (2008)		Feick et al. (2005);	All fires: for example	Giglio et al. (2013); Alonso-Canas &	Chuvieco (2015);
Gridded spatial data, continental or global	Continental or ecozone, static		Parry rice: Frolking et al. (2006);			All fires: for	example, Africa: Líousse et al.	(2010); Canada: Stocks et al. (2002)
National statistics (based) w. global coverage*	Time series	-	FAOSTAT (2015);					
National statistic coverage*	Static		FAOSTAT (2015);			Human-	induced fires: Lauk & Erb	(2009);
	Management activity	ТПаде	Irrigation (including paddy rice)		Artificial wetland	drainage Fire as	management tool	

Statistical or statistical data derived sources with global coverage only. Please note that at the continental or subcontinental level, many more data sets are available. Prominent data providers (nonexhaustive) are Eurostat for European countries (http://ec.europa.eu/eurostat) or the United States. Department of Agriculture (http://www.ers.usda.gov/topics.aspx).

Table 1 (continued)



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notable exception of coppices (Luyssaert et al., 2011). Soil and litter carbon pools generally decrease only slightly, but deadwood decreases in managed forests by 95% compared to old-growth forests (McGarvey et al., 2014). Nevertheless, the net effect of forest management on carbon stock reductions on the one hand and wood use for fossil fuel substitution on the other remain unclear, due to complex legacy effects (Marland & Schlamadinger, 1997; Lippke et al., 2011; Holtsmark, 2012). The effects of forest management on CH₄ and N2O emissions are considered negligible, with the exception of fertilized short-rotation coppices (Robertson et al., 2000; Zona et al., 2013). Predicted intensification of forest management by means of short-rotation coppicing or total tree harvest may require frequent fertilization, potentially resulting in increased N2O emissions (Schulze et al., 2012).

Robust empirical evidence exists on multiple interactions between forest harvest and biophysical processes. Thinning practices affect the albedo by up to 0.02 in the visible range and 0.05 in the near infrared, with intensive thinning having the largest effect (Otto et al., 2014). The albedo of forests could decrease with age, and thus longer rotations, due to changes in canopy structure (Amiro et al., 2006; Hollinger et al., 2010; Rautiainen et al., 2011; Otto et al., 2013). The length of rotations substantially affects tree height, which affects surface roughness (Raupach, 1994; Nakai et al., 2008). Through removal of leaf mass, harvest can reduce evapotranspiration by 50% (Kowalski et al., 2003). At the stand level in tropical forests, gaps resulting from selective cutting could modify local circulation resulting in a drier subcanopy (Miller et al., 2007) which in turn could increase fire susceptibility. In temperate and boreal sites, biophysical effects of forest management on surface temperature were shown to be of a similar magnitude (e.g. around 2K at the vegetation surface) as the effects of land-cover changes (Luyssaert et al., 2014).

Tree species selection

Extent and data availability. Forest plantations cover 2.2 Mkm², being particulary important in, for example, in China, Brazil, Chile, New Zealand and South Africa (FAO, 2015a). Species composition is also affected by management in less intensively managed forests on up to 18 Mkm2 (Luyssaert et al., 2014). In Europe, for instance, species selection has resulted in an increase of 0.5 Mkm2 of conifers since 1750, largely at the expense of deciduous species (McGrath et al., 2015). Although species selection has become more salient in the last century, this practice dates back 4k to 5k years (Bengtsson et al., 2000). Planted forests, mainly with conifer species, cover 9% of total

forest area in the United States (Oswalt et al., 2014) and 7% of the global used forests (Appendix S1). Whether the tendency of species selection will continue depends on climate-driven changes in tree species occurrence (Hanewinkel et al., 2013). Data on tree species selection are particularly scarce (Table 1; Appendix S1) and prone to large uncertainties. Spatially explicit information on present-day species distribution (Brus et al., 2011) could inform reconstructions of past species selection (McGrath et al., 2015). For industrial plantations of typically fast-growing tree exotic species, the most extreme form of species selection, data are only available in short time series from FAO Forest Resources Assessments (FAO, 2015a).

Effects of tree species selection. The biogeochemical and biophysical effects of tree species selection are well documented, and in particular, biophysical parameters are strongly affected. Species selection affects carbon allocation between above- and belowground pools, nitrogen cycling, evapotranspiration rates and surface albedo (Farley et al., 2005; Kirschbaum et al., 2011). Species composition can affect the fate of soil carbon, with larger stocks under hardwoods or nitrogen-fixing tree species (Paul et al., 2002; Resh et al., 2002; Bárcena et al., 2014). Pine plantations are commonly reported to lead to soil carbon losses, compared to broadleaf species including Eucalyptus (Paul et al., 2002; Farley et al., 2005; Berthrong et al., 2009). Also, tree mixes, especially with nitrogen-fixing species, store at least as much, if not more, carbon as monocultures of the most productive species of the mixture (Hulvey et al., 2013). These effects are, however, location dependent. For the boreal zone in Europe, soil carbon stocks were larger on sites afforested with conifers compared to those where deciduous species prevailed (Bárcena et al., 2014). Tree species selection and species mixtures can be used to prevent spread of disease and pests that cause large releases of carbon through tree mortality or to improve the recovery after damages have occurred (Boyd et al., 2013). For the boreal and temperate zones, information about the emission potential of biogenic volatile organic compounds (BVOCs) for different species is now available (Kesselmeier & Staudt, 1999). Uncertainty, however, is large concerning the evolution of emission potentials of different species under climate change and their feedback on the climate itself. The uncertainty on whether the climate effect of BVOCs is dominated by its direct warming or its indirect cooling due to its role as condensation nuclei (Peñuelas & Llusià, 2003) suggests that BVOCs might be one of the remaining key uncertainties in



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quantifying the climate effect of tree species selec-

Forest composition affects albedo through canopy height, canopy density and leaf phenology. Over a 100 year long rotation, tree species was found to explain 50-90% of the variation in short wave albedo (Otto et al., 2014). In absolute terms, summer albedo ranges between 0.06-0.10 and 0.12-0.18 for evergreen coniferous and broadleaved deciduous forest, respectively (Hollinger et al., 2010). As different tree species grow to different heights, differing by up to several metres under the same environmental conditions, roughness length is also affected. Changes in roughness and thus turbulent exchange as well as different efficiencies of evapotranspiration of tree species can alter the water balance. Species conversion from pine to hardwood forest resulted in a sustained decrease in streamflow of about 200 mm yr -1 for sites experiencing similar precipitation (Ford et al., 2011). Similar decreases were observed where Eucalyptus replaced pines, with the effect increasing with forest age (Farley et al., 2005). At a single site in the south-eastern United States, the radiative temperature of deciduous forest was 0.3K higher than that of coniferous forest (Stoy et al., 2006; Juang et al., 2007). Over Europe, a massive conversion of deciduous to coniferous forests has warmed the lower boundary layer by 0.08K between 1750 and 2010 (Naudts et al., 2016).

Grazing and mowing harvest

Extent and data availability. Grazing and mowing harvest is the most spatially extensive land management activity worldwide, covering 28-56 Mkm2 or 21-40% of the terrestrial, ice-free surface, with a wide range of grazing intensity (Herrero et al., 2013; Luyssaert et al., 2014; Petz et al., 2014; FAOSTAT, 2015). Grazing is one of the oldest land management activities, reaching back 7-10k years (Blondel, 2006; Dunne et al., 2012), and occurs across practically all biomes: from arid to wet climates and over soils with varying fertility (Asner et al., 2004; Steinfeld et al., 2006; Erb et al., 2007). Livestock fulfils many functions beyond the provision of food (FAO, 2011), but animal-based food production almost increased exponentially since the 1950s, due to increasing population and more meat- and dairy-rich diets (Naylor et al., 2005; Kastner et al., 2012; Tilman & Clark, 2014). These trends are expected to continue, but depending on the degree of intensification of livestock production systems, the uncertainties on future net changes in grazing lands area are very large (Alexandratos & Bruinsma, 2012). Data on the extent of grazing areas show large discrepancies (Erb et al., 2007), and grazing intensity is high on <10%, medium on around two-thirds and low on one-fourth of the grazing lands (Appendix S1). Existing national and gridded data on grazing usually refer to recent time periods, do not separate grazing and mowing and are subject to severe uncertainties (Table 1), exacerbated by problems with conflicting definitions (Erb et al., 2007; Ramankutty

Effects of grazing and mowing harvest. While large knowledge gaps relate to the extent and intensity of grazing, the biogeochemical and biophysical impacts of grazing are well documented. While biophysical effects are found to be relatively low, strong biogeochemical effects relate to this activity. Estimates on the amount of grazed and mowed biomass show a large range from 1.2 to 1.8 Pg C yr⁻¹ in 2000 (Wirsenius, 2003; Bouwman et al., 2005; Krausmann et al., 2008; Herrero et al., 2013), which is up to one-third of the total global socio-economic biomass harvest (Krausmann et al., 2008). Grazing is a key factor for many ecosystem properties, including plant biomass and diversity. Grazing can both deplete and enhance soil C stocks, depending on grazing intensity. For example, in arid lands, overgrazing is a pervasive driver of loss of soil function (Bridges & Oldeman, 1999), resulting in reductions in soil organic carbon (SOC) and aboveground biomass (Gallardo & Schlesinger, 1992; Asner et al., 2004). In semiarid regions, high grazing pressures could lead to woody encroachment (Eldridge et al., 2011; Anadón et al., 2014) and thus to an increase in both above- and belowground carbon stocks. A global meta-analysis of grazing effects on belowground C revealed large differences in the response of C3- and C4-dominated grasslands under different rainfall regimes (McSherry & Ritchie, 2013). Globally, the response of plant traits to grazing is influenced by climate and herbivore history (Díaz et al., 2007). At the same time, grazing can influence ecosystem C uptake in the Arctic tundra, with implications for response to a warming climate (Väisänen et al., 2014). Incorporation of current grazing and grazing history into climate models will improve predictions of terrestrial C sinks and sources.

Forest grazing (e.g. reindeer grazing in the boreal zone) directly affects the understorey and indirectly forest growth through nutrient export, recruitment and the promotion of grazing tolerant species (Adams, 1975; Erb et al., 2013b), but comprehensive assessments are lacking. The production of methane is an important biogeochemical effect of ruminant grazers, strongly determined by the fraction of roughage (grass biomass) in feedstuff (Steinfeld et al., 2006; Thornton & Herrero, 2010; Herrero et al., 2013), but large uncertainties related to quantities remain (Lassey, 2007). Soil compaction, induced, for example, by trampling, can



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contribute to anaerobic microsites, reducing the CH4 oxidation potential of the soil (Luo et al., 1999). Nitrogen cycling is strongly affected by the addition of manure and urine (Allard et al., 2007). The effect of animal waste N inputs interacts with poor drainage, influenced also by topography, to result in localized greater N2O fluxes (Saggar et al., 2015). Biogeochemical effects of grazing are influenced by livestock density. Some modelling and site-specific studies have found that a reduction of livestock densities results in increased soil C storage and decreased N2O and CH4 (Baron et al., 2002; Chang et al., 2015). A study of year-round measurements of N2O in the Mongolian steppe found that while animal stocking rate was positively correlated with growing-season emissions, grazing decreased overall annual N2O emissions (Wolf et al., 2010). Sites with little and no grazing showed large pulses of N2O release during spring snowmelt compared to high grazing sites, suggesting that grazing may influence N cycling response to changes in climate in high-altitude ecosystems. Biophysical effects of grazing mainly depend on ecosystem type and soil properties. In local contexts, grazing has been reported to reduce plant biomass, thus increasing albedo by about 0.04 compared to unmanaged grassland (Rosset et al., 2001; Hammerle et al., 2008). However, the effect of soil exposure resulting from canopy decreases is ambiguous, resulting in an albedo reduction on dark soils (Rosset et al., 1997; Fan et al., 2010) and in an albedo increase on bright soils (Li et al., 2000). Reindeer grazing has been reported to reduce albedo due to a reduction of the light-coloured lichen layer (Cohen et al., 2013). Reductions in roughness length due to grazing are expected to have a small affect on turbulent fluxes (i.e. surface fluxes of energy, moisture and momentum), but can lead to enhanced soil erosion (Li et al., 2000). The observed effect of mowing on the cumulative evapotranspiration was small (10% increase, about 40 mm), although sufficient to decrease soil water content in a managed field (Rosset et al., 2001). The integrated climate effect from excluding grazing by bison in the Great Plains was modelled to be a 0.7K decrease in maximum temperatures and a small increase in minimum temperatures (Eastman et al., 2001).

Crop harvest and residue management

Extent and data availability. Approximately 15 Mkm2 or 12% of the global terrestrial, ice-free surface is currently used as cropland (Ramankutty et al., 2008; FAOSTAT, 2015). Of these, 1.4 Mkm² are permanent cultures, including perennial, woody vegetation (e.g. fruit trees, vineyards). Approximately two-thirds of the arable land is harvested annually, with cropping season

extending over approximately six months, while onethird of cropland remains temporarily idle on average (Siebert et al., 2010). On one-quarter of the global cropland multicropping (i.e. more than one harvest per year) occurs (Appendix S1). Cropping activities are closely tied to the sedentary lifestyle that emerged with the Neolithic revolution some 12k years ago, marking the beginning of the Holocene. Since then, cropland has significantly expanded at the expense of grasslands, forests and wetlands. Sedentary cropland management origins from shifting cultivation (Boserup, 1965), that is the alteration of short cultivation and long fallow periods, which was a particularly widespread form of cropland management in many regions of the world (Emanuelsson, 2009) and illustrates the highly interconnected nature of management and land-cover change. Today, this form of land use is declining at the global scale, although it remains important in many frontier areas characterized by, for example, unequal or insecure access to investment and market opportunities or in areas with low incentives to intensify cropland production (van Vliet et al., 2012). Cropland expansion is tied to human population growth, but moderated by technological development that allowed for substantial yield increases per cropland area, in particular after 1950 (Pongratz et al., 2008; Kaplan et al., 2010; Ellis et al., 2013; Krausmann et al., 2013). The dynamics of cropland expansion and contraction in different regions of the world are caused by complex interactions between endogenous factors such as population dynamics, consumption patterns, technologies and political decisions, and exogenous forces related to international trade and other manifestations of globalization, in interplay with intensification dynamics (Krausmann et al., 2008, 2013; Meyfroidt & Lambin, 2011; Kastner et al., 2012; Kissinger et al., 2012; Ray et al., 2012; Ray & Foley, 2013). Cropland shows the highest land-use intensity, compared to grazing land or forest, in terms of inputs to land (capital, energy, material) as well as outputs from land (Kuemmerle et al., 2013; Niedertscheider et al., 2016). The spatial extent of cropland is probably the best-described land-use feature at the global scale, with many data sets existing (see Table 1). Nevertheless, major uncertainties remain related to cropland patterns in some world regions, particularly across large swaths of Central, Southern and Northern Africa, Brazil and Papua New Guinea (Ramankutty et al., 2008; Fritz et al., 2011, 2015; Anderson et al., 2015; See et al., 2015). In these regions, landcover maps are often the only source of land management data. These errors propagate into estimates of cropland harvest flows and harvest intensity, for which much less data are available. Data on crop residues are scarce, as they are not reported in official statistics (e.g.



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FAOSTAT, 2015), and estimates usually rely on crude factors (Lal, 2004, 2005; FAO, 2015b)

Effects of crop harvest. A mixed picture emerges with regard to biogeochemical and biophysical effects of crop harvest, but impacts on both dimensions appear to be strong. For instance, the inclusion of crop harvest and residue removal into a dynamic vegetation model significantly increased the amount of historical landuse change based C emissions estimated by the most common agricultural scenarios, which do not include management information (Pugh et al., 2015). Cropland harvest amounted to 3.2 PgC yr⁻¹ in 2000, around half of total biomass harvest or around 5% of global terrestrial NPP (Wirsenius, 2003; Krausmann et al., 2008). Primary products (e.g. grains) cover 45%, secondary products (e.g. straw, stover and roots) 46% and 9% are fodder crops. The majority of cropland produce is used directly as food, but a non-negligible amount of around 1.3 PgC yr⁻¹ is used as feed for livestock (fodder crops and concentrates). In 2004, crop harvest for bioenergy amounted to 1.6 EJ yr⁻¹ from agricultural by-products and 1.1 EJ yr-1 from fuel crops, which is roughly equivalent to 0.043 and 0.03 PgC yr-1, respectively (Sims et al., 2007). 0.7 PgC yr-1 of secondary products remain on site, possibly ploughed to the soil or burned subsequently (Wirsenius, 2003; Krausmann et al., 2008). Cropland systems, mainly consisting of annual, herbaceous plants, usually contain little carbon in vegetation and soil per m2 (Saugier et al., 2001). Thus, crop residues left on field add only small amounts of carbon to soil pools (Bolinder et al., 2007; Anderson-Teixeira et al., 2012). Information on local impact of crop residue removal (or retention) on GHG emissions, soil carbon and yields is available (Bationo & Mokwunye, 1991; Lal, 2004, 2005; Lehtinen et al., 2014; Pittelkow et al., 2015). Also national data on emissions from crop residues are available (FAOSTAT, 2015). However, the lack of primary data such as from long-term field studies and the use of crude factor introduce large uncertainties related to estimates of crop residue management effects. Large uncertainties also relate to the contribution of crop residue, including roots and exudates, to the build-up of soil organic carbon (Bolinder et al., 2007; Kätterer et al., 2012). This limits our ability to assess its impact at the global scale. With current policies for increasing biomass use for bioenergy, crop residue harvest can result in additional SOC losses, proportional to residue removal (Gollany et al., 2011). Synergistic effects are also frequent: negative effects of crop residue removal on soil carbon are enhanced with N fertilization (Smith

Biophysical effects of crop harvest are well documented, in particular related to changes in albedo, roughness and evapotranspiration. When crops are harvested, soil becomes exposed and albedo (Davin et al., 2014) as well as roughness drop (Oke, 1987). Evapotranspiration was estimated to decrease by 23% in a Belgium experiment (Verstraeten et al., 2005). The magnitude and persistence of these changes depend on the presence and intensity of postharvest management practices, for example ploughing, tillage, after cropping or mulching. Evapotranspiration partly depends on soil water holding capacity, which in turn is affected by tillage (Cresswell et al., 1993) and crop residue management (Horton et al., 1996). Crop residue management is an important factor, but information is scarce. Compared to bare soil, crop residues reduce extremes of heat and water fluxes at the soil surface when crops residues are left on-site (Horton et al., 1996; Davin et al.,

Crop species selection

Extent and data availability. On almost all cropland, single crops form monocultures while other plants are excluded via weeding, herbicides or by other means. Prominent exceptions include agroforestry (i.e. systems where tree species and annual crops are cultivated together, Nair & Garrity, 2012). Crop species selection is as old as agriculture, with species selected according to human needs (e.g. food, health, stimulants, fibre). Recently, biomass energy production from dedicated oil, starch or sugar plants, but also fast-growing grasses, has increased rapidly and is anticipated to accelerate in the future (Beringer et al., 2011; Haberl et al., 2013). Data availability for recent crop type distribution is similar to that on cropland harvest; however, spatially explicit time series and global data on interannual dynamics, such as rotational schemes, are lacking (Table 1; Appendix S1).

Effects of crop species selection. While information on biophysical effects of crop species selection is available, much less is available on biogeochemical effects. Both effects seem to be relatively weak in comparison to other management types, probably also owing to the comparatively small knowledge base. In particular, effects of species selection on individual carbon pools are largely unknown. Crop type is known to affect SOC accumulation and decomposition rates, and the allocation of carbon to shoots or roots. For example, shoot-toroot ratios were found to increase in the order natural grasses < forages < soya bean < corn (Bolinder et al., 2007). A shift from annual to perennial crops and the introduction of cover crops can significantly increase SOC stocks (Poeplau & Don, 2014, 2015). Anderson-Teixeira et al. (2013) found a 400-750% increase in



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belowground biomass under perennial bioenergy grasses (switchgrass, Miscanthus, native prairie mix) compared to a corn-corn-soya rotation agricultural system. Increasing crop rotational diversity can also positively influence SOC storage (McDaniel et al., 2013; Tiemann et al., 2015). Strong difficulties to assess species selection effects arise from legacy effects, which render systematic long-term studies necessary. For instance, in a 22-year experiment, comparing maize, wheat and soya bean cultivation, SOC content was found to be about 7% higher under soya bean as compared to wheat and maize. Other GHG emissions are also crop specific. For example, N2O emission factors from fertilization vary from 0.77% of added nitrogen for rice to 2.76% for maize (Stehfest, 2005). Effects of crop species on CH4 balances are less clear, except for paddy rice, where high emissions occur.

Cropland albedo varies significantly among crops, ranging between 0.15 for sugarcane and 0.26 for sugar beet, with significant variations even among related species, for example 0.04 higher for wheat compared to barley (Piggin & Schwerdtfeger, 1973; Monteith & Unsworth, 2013). Even within a species, cultivars show differences in albedo of up to 0.03 units. Differences in planting and harvesting dates for different crop species and cultivars, and associated changes in leaf phenology, also affect biophysical conditions. More productive cultivars and earlier planting dates lead, for example, to an earlier harvest and to enhanced exposure of dark soil in the fall, resulting in lower end-ofseason albedo and an increase in net radiation (Sacks & Kucharik, 2011). Whether the end-of-season albedo increases or decreases depends on the ratio between soil and vegetation albedo. In many regions of the world, soil albedo is lower than plant albedo, but not in some (semi-)arid regions where soils may have a similar or even higher albedo than the vegetation. Similarly, water-use efficiency and evapotranspiration between crop species differ widely (Yoo et al., 2009), even for the same cultivars (Anda & Løke, 2005). Although crop heights are limited, roughness can be expected to vary similarly as for grasslands (Li et al., 2000).

N fertilization of cropland and grazing land

Extent and data availability. Fertilizers are used to enhance plant growth by controlling the level of nutrients in soils. Nitrogen (N) plays a prominent role as one of the most important plant nutrients which is often limited in agriculture (LeBauer & Treseder, 2008). N fertilizers are either organic fertilizer derived from manure (livestock faeces), sewage sludge or mineral fertilizer. Reactive nitrogen was a scarce resource in preindustrial agriculture, mainly available only in the

form of animal manure, leading to sophisticated management schemes to balance the N withdrawals associated with harvest (Sutton et al., 2011). The invention of the Haber-Bosch process and the availability of fossil energy triggered a process of innovation in agriculture with surging levels of N fertilization. Today, the transformation of N to reactive forms and its use as fertilizer on agricultural lands represent one of the most important human-induced environmental changes (Gruber & Galloway, 2008; Davidson, 2009). The use of synthetic fertilizers is projected to increase in response to growing human population, increases in food consumption and crop-based biofuel production (IFA, 2007). Practically all croplands are under N fertilization schemes, with strong regional variations in intensity of input volumes and composition (Gruber & Galloway, 2008; Vitousek et al., 2009), but also grasslands and forests (the latter not discussed here) can be under N fertilization schemes. The highest cropland fertilization levels surpass 200 kg N ha⁻¹ yr⁻¹, for example, in the Nile delta and 90 kg N ha⁻¹ yr⁻¹ in New Zealand (Potter et al., 2010; Mueller et al., 2012), and 14% of croplands are fertilized with levels above 100 kgN ha-1 yr-1. Globally, much lower intensity level prevails; 59% of the global cropland area show application rates below 50 kgN ha⁻¹ yr⁻¹, and around one-quarter of global croplands below 10 kgN ha-1 yr-1 (Appendix S1). Grasslands often do not receive any N fertilization (except for manure inputs from grazing animals), but some grasslands are also heavily fertilized with rates put to 100 (<u>Haas et al., 2001</u>) and even 300 kg N ha⁻¹ 1 yr-1 (Flechard et al., 2007). Globally, animal manure makes up approximately 65% of N inputs to cropland (Potter et al., 2010) and is the dominant N source in the Southern Hemisphere. Regionally, mainly in concentrated industrial livestock production, manure availability can exceed local fertilizer demand, resulting in substantial environmental problems such as groundwater pollution (IAASTD, 2009). The status of data availability is intermediate. National time series data as well as spatially explicit assessments are available (Table 1), but characterized by large gaps and uncertainties, particularly relating to spatial patterns and livestock manure. Global data on N fertilization of grasslands, albeit a widespread activity in many region, are scarce and crude model-derived (Appendix S1).

Effects of N fertilization. The biogeochemical effects of N fertilization, of both cropland and grazing land, are strong and relatively well documented and understood. Cropland fertilization is a strong driver of anthropogenic GHG emissions, in particular of nitrous oxide (N2O), nitric oxide (NO) and ammonia (NH3). A typical fertilized cropland emits 2-3 times more nitrogen than



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the approximately 0.5 kg $N\ ha^{-1}\ yr^{-1}$ emitted under nonfertilized conditions (Stehfest & Bouwman, 2006), while fertilized grasslands emit 3-4 times more N2O than unfertilized ones (Flechard et al., 2007). The global N2O emissions on fertilized croplands and grazing lands sum to 4.1-5.3 Tg N yr⁻¹ in the beginning of the century (Stehfest & Bouwman, 2006; Syakila & Kroeze, 2011), one-fifth of it occurring on grazing lands (Stehfest & Bouwman, 2006). Beyond N application rates, N2O emissions are determined by crop type, fertilizer type, soil water content, SOC content, soil pH and texture, soil mineral N content and climate. NH3 emissions are determined by fertilizer type, temperature, wind speed, rain and pH (Sommer et al., 2004). Acidification from N fertilizers can lead to increased abiotic CO2 emissions from calcareous soils (Matocha et al., 2016). Fertilization also affects ecological processes, including productivity, C inputs to the soil and SOC storage in croplands by affecting the shoot-to-root ratio (Müller et al., 2000), influences the efficiency of photosynthesis, and ultimately the exchange of C between land and the atmosphere, as fertilization studies in forests reveal (Vicca et al., 2012; Fernández-Martínez et al., 2014). Long-term studies from Sweden suggest that each kg N fertilizer increased SOC stocks by 1 to 2 kg (Kätterer et al., 2012). Fertilization effects on SOC were particularly strong with organic fertilization (Körschens et al., 2013). Fertilization also increases atmospheric N and thus deposition (Ciais et al., 2013a) and results in N leakage (Galloway et al., 2003). Fluxes of total anthropogenic N from land to the ocean via leaching from soils and riverine transport have been estimated at 40-70 Tg N yr-1 (Boyer et al., 2006; Fowler et al., 2013). Increased nutrient input to rivers and freshwater systems impacts on water quality and biodiversity (Settele et al., 2014) and the subsequent increased nutrient loading of coastal oceans is believed to be the primary cause of hypoxia (Wong et al., 2014).

Few direct effects of fertilization on biophysical properties - besides indirect effects of changes in crop biomass or height due to altered productivity - have been documented, and the magnitude of impacts is probably not strong. Forest site studies suggest that enhanced leaf nitrogen concentrations increase canopy albedo (Ollinger et al., 2008), presumably through changes in canopy structure rather than in leaf-level albedo (Wicklein et al., 2012). Also, nitrogen fertilization improved grassland water-use efficiency but simultaneously increased absolute evapotranspiration and thus the latent heat flux, from 280 to 310 mm (Brown, 1971; Rose et al., 2012). N-driven increases in plant height and leaf mass will be reflected in increasing roughness length.

Extent and data availability. With the mechanization of agriculture, arable land became regularly tilled to suppress weeds and enhance soil structure and nutrient availability. Archaeological findings suggest that humans manipulated soil structure through some form of tillage with ards and hoes already some 4.5k years ago (Postan et al., 1987). From the 1950s, with the advent of modern herbicides no-till systems became more prominent, mainly in the United States (IAASTD, 2009). To date, continental or global data on the area, distribution or intensity of tillage is sparse. It can be assumed, however, that all croplands that are permanently used are regularly tilled, except for (i) perennial crops, which cover approximately 10% of cropland area or 1.5 Mkm2 (FAOSTAT, 2015) and (ii) no-till agriculture (or reduced tillage) on 1.11 million km2 (Derpsch et al., 2010), which is around 8% of the global arable land. No-tillage systems are particularly widespread in Brazil and the United States, where 70% and 30%, respectively, of the total cultivated area is under no-tillage management. However, most of these lands are not permanently under zero tillage but are still ploughed from time to time. Global maps of zero tillage are missing, as do maps on qualitative aspects of tillage, such as type and depth of tillage.

Effects of tillage. Tillage effects remain weakly understood. Ploughing of native grassland upon conversion to croplands drastically depleted SOC (Mann, 1986). Such ploughing disrupts aggregate structure, aerating the soil and activating microbial decomposition (Rovira & Greacen, 1957). No-tillage practices promised to significantly mitigate carbon emissions from SOC (IAASTD, 2009). However, some evidence is available indicating that on most soil types and in most climate regimes adoption of no-tillage practices after tillagebased management does not significantly increase SOC stocks (Baker et al., 2007; Hermle et al., 2008; Govaerts et al., 2009), but there is still controversy on this aspect of the adaption of no-tillage (Powlson et al., 2014, 2015; Neufeldt et al., 2015). These findings and studies looking deeper into the soil profile suggest that conventional tillage may not result in net losses of soil C, but rather result in a redistribution of carbon in the soil profile. Other findings are inconclusive, for example, on the impacts of conservation tillage on productivity of cropland. While no-tillage is often reducing crop yields, other activities such as crop residue management of crop rotations play a decisive role for the overall effects (Pittelkow et al., 2015). Other key factors are the depth and type of tillage, which vary worldwide.



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Evidence on the effects of no-tillage on $\mathrm{N}_2\mathrm{O}$ emissions is site specific and inconclusive (Rochette, 2008). A recent meta-analysis reported that no-till reduced N2O emissions after 10 years of adoption and when fertilizer was added below the soil surface, especially in humid climates (van Kessel et al., 2013). No-tillage generally reduces soil erosion, but regional- to global-scale effects are uncertain, because most eroded soil carbon is deposited in nearby ecosystems (Van Oost et al., 2007).

Tillage has small biophysical effects. Through a decreased soil water holding capacity, excess tillage increased the shortwave albedo from 0.12 under minimum tillage to 0.15 under excess tillage (Cresswell et al., 1993). Furthermore, soil water holding capacity, which is affected by tillage (Cresswell et al., 1993) and crop residue management (Horton et al., 1996), also controls evapotranspiration. Soils covered with crop residues after harvest evaporate less than tilled soils (Horton et al., 1996) and show a higher albedo (Davin et al., 2014). When only part of the site is tilled, the effects become less straightforward. Strip-tillage, leaving three-fourths of the surface covered, can increase evapotranspiration within the tilled strips while maintaining the same soil temperature compared to a bare site (Hares & Novak, 1992), thus providing protection against wind and water erosion without affecting seed germination (Hares & Novak, 1992). The direct effects of tillage on surface roughness are likely negligible for the surface climate.

Irrigation

Extent and data availability. Globally 2.3-4.0 Mkm2 or 15-26% of the global croplands are equipped for irrigation (Portmann et al., 2010; Salmon et al., 2015), with hotspots in the Near East, Northern Africa, Central, South and South-East Asia and western North America. Paddy rice, the largest single crop species cultivated with irrigation, covers 0.7-1.0 Mkm2 (Portmann et al., 2010; Salmon et al., 2015), or 5-7% of the global cropland area. Paddy rice cultivation is particularly important in East, South and South-East Asia where its history reaches back at least 6k years, originating probably in China (Cao et al., 2006; Fuller, 2012; Kalbitz et al., 2013). Small-scale crop irrigation dates back to the origins of agriculture (Postel, 2001), while large-scale irrigation is a recent outcome of the green revolution. Nowadays, 30% of the global wheat fields (0.7 Mkm²), 20% of the maize fields (0.3 Mkm2) and half of the global citrus, sugar cane and cotton crops are irrigated (Portmann et al., 2010). Moreover, cropland irrigation accounts for approximately 70% of global freshwater consumption (Wisser et al., 2008). Rice cultivation requires a particularly intensive form of irrigation,

involving regular flooding of fields for longer periods (Salmon et al., 2015). Irrigation data sets exist and are relatively robust, in particular for rice, but large similar problems of uncertainties prevail as with cropland maps (see above; Salmon et al., 2015). Furthermore, Earth system effects depend on actually applied irrigation, which is much less documented than area equipped for irrigation.

Effects of cropland irrigation. Strong biogeochemical and biophysical effects of irrigation are documented. Knowledge gaps exist related to synergistic effects with other management practices. Irrigation significantly enhances NPP where water is limiting plant growth, in particular in semi-arid and arid regions. Irrigation affects soil moisture, temperature and N availability, which are all drivers for the production and evolution of GHG emissions from soils (Dobbie et al., 1999; Dobbie & Smith, 2003). Accelerated soil carbon decomposition under irrigation is typically offset by higher NPP and greater carbon inputs into the soil (Liebig et al., 2005; Smith et al., 2008). A global review of irrigation effects concluded that irrigated cropping systems in arid and semi-arid regions typically realize SOC increases of 11% to 35% compared to nonirrigated systems, but the size of the effect is highly dependent on climate and initial SOC content (Liebig et al., 2005; Trost et al., 2013). Furthermore, irrigated soils are more often affected by anoxic soil conditions which in turn favour denitrification and N_2O production, especially when fertilized (Verma et al., 2006). This is particularly the case in paddy fields, where emission factors range between 341 and 993 g N ha⁻¹, depending on the length of the irrigation scheme, corresponding to irrigation-induced emission factors of 0.22-0.37% of the added nitrogen (Akiyama et al., 2005). Soil texture and climate can mediate these effects of irrigation on biogeochemical processes, but the statistical evidence is weak (Scheer et al., 2012; Trost et al., 2013; Jamali et al., 2015). According to the review by Trost et al. (2013), there is no consistent effect of irrigation on N2O emissions. The capacity of soils to oxidize atmospheric CH4 may be reduced under irrigation (Ellert & Janzen, 1999; Sainju et al., 2012). Irrigated rice fields alone are emitting approximately 30-40 Tg CH₄ per year (Kirschke et al., 2013).

Changes in ecosystem water availability significantly alter the surface albedo and roughness through their impact on plant growth and ecosystem conditions (Cresswell et al., 1993; Wang & Davidson, 2007). Because water surfaces have lower reflectance, flooding reduces the albedo of dry soil of about 0.2 to a level of 0.03 - 0.1 (Kozlowski, 1984). A modelling study over the Great Plains in the USA has shown that irrigation



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can alter atmospheric circulation and precipitation patterns (Huber et al., 2014). Despite its surface cooling effect (about 0.8 K), irrigation was simulated to increase global radiative forcing in the range of 0.03 to 0.1 W m⁻² (Boucher et al., 2004).

Artificial drainage of wetlands

Extent and data availability. Drainage aims at improving soil characteristics for agriculture and at facilitating the use of machinery. While historically drainage relied on channels and sewers, currently prevailing drainage systems often also use subsurface hollow pipes or similar technologies (FAO, 1985). Approximately 11% of global croplands, or 1.6 Mkm2, are subject to artificial drainage (Feick et al., 2005), but the strongest biogeochemical and biophysical effects of drainage are expected when wetlands are drained, for example peatlands, inland flood plains, coastal wetlands or lakes. Wetlands are estimated to cover 5.3-26.9 Mkm2 (Melton et al., 2013), of which 0.18 Mkm² are probably drained (Appendix S1), but data are scarce. Wetland drainage dates back for millennia, for example, in lowland Europe (Emanuelsson, 2009), but accelerated especially between 1830 and 1950 with the drainage of over 30% of the Scandinavian peatlands and large-scale drainage projects in Russia, Canada and the United States (Brinson & Malvárez, 2002). Despite attempts for wetland conservation (see, e.g., Dugan, 1990), or the international RAMSAR treaty (www.ramsar.org), large-scale new drainage installation is still ongoing (Brinson & Malvárez, 2002; Lähteenoja et al., 2009), in particular in Asia, for instance in relation to palm oil expansion (Davidson, 2014). Consistent data on wetland drainage are practically inexistent.

Effects of wetland drainage. The biogeochemical and biophysical effects of drainage are not well documented, partly because most studies aim at assessing the effects of associated land-use and land-cover changes, rather than the effects of drainage itself. While the sparse evidence suggests that biogeochemical effects are strong, biophysical effects are probably only of medium size. On forest sites, drainage can increase biomass through increased NPP (Trettin & Jurgensen, 2003). Drained peatlands are, however, hotspots of GHG emissions (Hiraishi et al., 2014). When expressed in units of radiative forcing, the soil emissions of CO2, CH4 and N2O in drained forested peatlands decrease or even offset the carbon sink in aboveground biomass (Schils et al., 2008). The cultivation of drained wetlands leads to rapid losses of large stocks of soil carbon accumulated over thousands of years (Drösler et al., 2013). A 50%

increase in fluvial carbon losses (particulate and dissolved organic carbon) was observed from degraded tropical swamp forest (Moore et al., 2013). Drainagerelated increases in fluvial carbon loss may add up to approximately 10% of the South-East Asian land-use emissions (Abrams et al., 2016). Drainage increases vulnerability to surface fires by drying the top soil. Drainage and fire associated with oil palm and other plantations in Indonesia, for example, released an amount of CO2 equal to 19-60% of the global carbon emissions from fossil fuels between 1997 and 2006 (Jaenicke et al., 2008).

The biophysical effects of drainage are also poorly documented. Regional model simulations in Finland, where drainage allowed for the afforestation of treeless peatlands, suggested early season warming of 0.2 to 0.43 K and late season cooling (Gao et al., 2014). Drainage decreases evapotranspiration (Lafleur et al., 2005) which in turn results in lower minimum night-time temperatures (Marshall et al., 2003). The relationship between evapotranspiration and night-time temperatures has been modelled (Venäläinen et al., 1999; Marshall et al., 2003), suggesting considerable temperature drops of up to 10 K. Although the direct effect of drainage on albedo and roughness length is not clear, increasing plant growth is likely to increase the surface roughness and decrease springtime albedo (Lohila et al., 2010).

Fire management

Extent and data availability. Fire began to be used by humans around 50k to 100k years ago (James, 1989; Bar-Yosef, 2002), and while it is unclear when it was first employed to shape ecosystems, today is a versatile land management tool (Lauk & Erb, 2009; Bowman et al., 2011), for example, for plant selection or agricultural waste removal. Note that fire use for land clearing, including swidden agriculture, represents a land-cover change and is thus not discussed here. Fire occurs naturally in most ecosystems, while in many regions natural fires today are suppressed (Hurtt et al., 2002; Andela & van der Werf, 2014), population density playing an important role (Archibald et al., 2009). Yet, prescribed fires are, next to mechanical thinning, a widespread practice to reduce or retard wildfire spread and intensity (Fernandes & Botelho, 2003). As fire frequency is expected to increase in the future due to climate change, fire prevention might increase in importance. Globally, the annual area burned through human-induced and natural fires is estimated at 3.0-5.1 Mkm2 in the last decades (Wiedinmyer et al., 2011; Giglio et al., 2013). The proportion of human-induced fires is difficult to assess (van der Werf et al., 2008), and



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in particular the ratio between fires that lead to landcover change and fires used to manage ecosystems is unknown. No specific global, spatially explicit information on fire as a management tool (including fire prevention and prescribed fires) exists (Table 1).

Effects of fire management. The effects of fire management on biogeochemical and biophysical properties of ecosystems are well documented and mainly biogeochemical. However, these studies do not systematically separate natural from anthropogenic fires. Globally, fire-induced carbon emissions are estimated to range from 1.6 to 2.8 PgC yr⁻¹ (van der Werf et al., 2010), while human-induced fires range from 1.7 to 2.0 PgC yr -1 (Lauk & Erb, 2009). The large uncertainties owe to large differences in the assumptions of fuel loads (Granier et al., 2011) and the difficulty to assess smaller fires. Fire emissions also include aerosols and trace gases (Akagi et al., 2011), which impact atmospheric chemistry and significantly contribute to overall aerosol direct and indirect radiative forcing (Ward et al., 2012). Fires result in short-term carbon losses from the direct combustion of biomass and lagged losses from the decomposition of dead biomass (Hurteau & Brooks, 2011). Fires affect nutrient supply (Mahowald et al., 2005) and soil carbon dynamics (Knicker, 2007). The storage of carbon in long-lived pools such as SOC is influenced by fires through the accumulation of char or pyrogenic carbon (Santín et al., 2008). Repeated burning in the process of agricultural land management (e.g. residue burning) reduces carbon accumulation rates (Zarin et al., 2005). The effects of fire suppression (Archibald et al., 2009; Wang et al., 2010) or management activities that indirectly alter fire regimes (van Wilgen et al., 2014), however, represent a knowledge gap. Despite the direct carbon stock increases resulting from fire prevention and similar measures (Bond-Lamberty et al., 2007), such activities can lead to greater future ecosystem carbon losses through the accumulation of large fuel loads that potentially increase the risk of severe fires (Hurteau & Brooks, 2011; O'Connor et al., 2014). Indirect biogeochemical effects of fire, for example postfire degradation, are not systematically quantified.

Various observational studies scrutinized the effects of specific fires on surface energy fluxes. Immediately after a boreal forest fire, albedo decreased to 0.05, increasing to 0.12 over a period of 30 years and then averaging to 0.08 similar to a prefire state (Amiro et al., 2006). Effects of fire aerosols might also be important, although uncertainty is high (Landry et al., 2015). Also latent heat energy fluxes and overall radiative forcing are affected (Randerson et al., 2006). Randerson et al. (2006) estimated a radiative forcing of -5 W m⁻²

immediately after a boreal forest fire, which remained high at -4 W $\,m^{-2}$ over 80 years after the fire. In a savannah, a halving of the albedo (0.12-0.07) was observed, followed by a recovery to a prefire state after several weeks (Scholes & Walker, 1993; Beringer et al.,

Discussion and conclusions

The ten land management practices selected for this review affect a considerable proportion of the global terrestrial surface (Fig. 2). Grazing and forest harvest and tree species selection are largest in terms of extent, covering almost 60% of the terrestrial, ice-free global land surface. However, the importance of a management practice depends not only on its spatial extent and effects on the Earth system, but also on the intensity of management, which differs markedly in extent across management practice (Fig. 2). Management intensity has shown pronounced increases at the global scale in recent decades, yet is currently largely overlooked (Rounsevell et al., 2012; Erb et al., 2013a; Luvssaert et al., 2014). According to our review, around 10% of the ice-free land surface is under intense human management, half of it under medium and one-fifth under extensive management (Appendix S1; Fig. 2).

The level of understanding of management effects on biogeochemical and biophysical patterns and processes varies strongly between management activities. Some of the direct impacts of activities such as wood harvest and tree species selection, grazing, N fertilization, irrigation and crop harvest are well documented. Considerable uncertainty of knowledge prevails for crop species selection, artificial wetland drainage, tillage, crop residue management and fire as management tool. Furthermore, how these processes vary across heterogeneous soils, how they affect plant diversity or how they depend on climate conditions are questions that have not been rigorously explored. Here, continuing efforts are needed to systematically combine local ground observations with assessments at coarser spatial and temporal scales along with model implementation. These efforts require increased information exchange between research communities in land system science, Earth system modelling, and experimentbased ecological and agronomic research.

Despite these knowledge gaps, some insights in the relative weight of biogeochemical and biophysical impacts of individual management activities emerged from our review. For instance, while grazing is associated with strong biogeochemical, but relatively small biophysical effects, tree species selection is characterized by strong biophysical, but limited biogeochemical effects. In contrast, forest harvest is important in both

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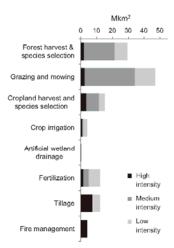


Fig. 2 Global extent and intensity of land management activities. Globally, approximately 80% of the 130 Mkm² of ice-free land is under managed schemes at varying intensity. Note that the bars are not additive, as, for example, crop irrigation, fertilization and tillage all occur on cropland. For data and assumptions, see Appendix S1.

respects (Fig. 3). Similarly, strong biophysical as well as biogeochemical effects originate from irrigation, cropland harvest and wetland drainage, although affecting much smaller areas. Other agricultural activities, such as fertilization, tillage, residue management, are associated mainly with biogeochemical impacts. Crop species selection, in contrast, ranks low with regard to biogeochemical and biophysical effects. But, as most land management activities are not isolated from each other, but intricately linked (e.g. crop harvest, irrigation and fertilization), robust assessment on their relative significance requires the application of Earth system models and, as our review reveals, improved databases.

Our review focused on documented Earth system effects of land management that have occurred over the past decades. Yet land management plays an increasing role in discussions on mitigating future climate change (Foley et al., 2005). This makes it particularly important to consider that management effects act on a range of timescales: while changes in land surface properties impose immediate effects on the atmosphere, changes in carbon and nitrogen fluxes invokes counter-fluxes in the coupled land-atmosphere-ocean system, causing a distinct temporal evolution and a delayed response of the Earth system (Ciais et al., 2013b). The emergence of

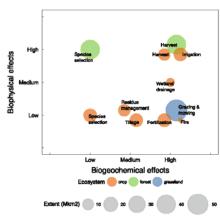


Fig. 3 Extent and biogeochemical and biophysical effects of management activities. The classification (see Appendix S1) is based on expert judgement and hence contains a certain degree of subjectivity and ambiguity.

biogeochemical effects can also typically include longer timescales than that of biogeophysical effects, as they can alter slow-responding system components such as SOC. While biogeophysical effects and greenhouse gas fluxes due to management are persistent once the new management system is in equilibrium, changes in carbon stocks cease to cause fluxes over time. Assessment of a land-use activity in the mitigation context thus depends not just on the spatial scale, with fluxes of the well-mixed greenhouse gases causing a global signal, while biogeophysical effects act predominantly on the local scale, but crucially also on an integrated assessment of the various effects and their different timescales in relation to the time horizon of interest (Cherubini et al., 2012).

A mixed picture emerges regarding data availability and robustness of global, long-term land management information (Table 1). This is a consequence of the history of research and past investments in generating the data sets. Remote sensing, while particularly well suited to assess certain land uses at the global level (e.g. cropping, irrigation, or the outbreak of fires), encounters severe difficulties in depicting other uses such as grazing (Erb et al., 2007; Kuemmerle et al., 2013). Furthermore, statistical reporting schemes focus mainly on management activities of economic interest, such as crop and forest harvest and ignore others, for example crop residue management. In addition, inconsistent definitions affect data robustness (FAOSTAT, 2015; See et al., 2015).

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While a comprehensive assessment of Earth system impacts induced by management requires more data and ultimately their integration in a modelling environment, as well as the inclusion of other management activities not discussed here, we conclude that management is a key factor in the Earth system, severely influencing many biogeochemical and biophysical processes and parameters. We also conclude that the current status of process understanding and data availability is sufficient to advance with the integration of land management in Earth system models in order to assess their overall impacts. Hence, we are able to classify the ten land management activities into groups along the two dimensions data availability and process understanding (Table 2), and thus identify the most pressing research priorities.

A first group is characterized by relatively advanced data availability and process understanding. This group contains irrigation and cropland harvest. For these activities, the state of knowledge is sufficient for implementing these activities in integrative assessment environments such as Earth system models.

The second group is characterized by severe data gaps, but relatively advanced process understanding. This includes wood harvest, tree species selection, grazing and N fertilization, motivating calls for fostered research efforts from the global land-use data community (e.g. Verburg et al., 2016) to develop improved data sets, for example, by taking advantage of the increasingly available data from satellite observations (Kuemmerle et al., 2013; Joshi et al., 2016), or crowdsourcing (See et al., 2015), but also alternative approaches that exploit existing databases. These management activities could be included in Earth system models, but global parameterization and validation may be difficult for now. A third group is characterized by concomitant data and knowledge gaps. The management types in

Table 2 Classification of management activities according to current process understanding and data availability

	Data advanced	Data poor
Understanding	Crop harvest	Forestry harvest
advanced	 Irrigation 	Tree species selection
		Grazing and mowing
		harvest
		 N fertilization
Understanding		 Crop species selection
poor		· Artificial wetland drainag
•		• Tillage
		Fire management
		Crop residue
		management*

^{*}Separated here from crop harvest.

this group require an intensification of efforts of both the data and the ecological communities, in order to advance the understanding of the impact of these management practices on the Earth system. No activity was classified as a combination 'advanced data' and 'poor understanding'.

Advancing the current state of process understanding and data availability on land management is a central undertaking to improve the understanding of land-use induced impacts on the Earth system and their feedbacks in the coupled socio-ecological system, central for, for example, the recently published sustainability development goals (Costanza et al., 2016). In addition to enhancing data availability and process understanding, data access, usability and quality control will become essential for transferring these achievements into beneficial information across multiple disciplines to tackle the grand sustainability challenges relate to land management.

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References

Abrams JF, Hohn S, Rixen T, Baum A, Merico A (2016) The impact of Indonesi peatland degradation on downstream marine ecosystems and the global carbon cycle. Global Change Biology, 22, 325–337.

Adams SN (1975) Sheep and cattle grazing in forests: a review. The Journal of Applied

Akagi SK, Yokelson RJ, Wiedinmyer C et al. (2011) Emission factors for open and domestic biomass burning for use in atmospheric models. Atmospheric Chemistry and Physics, 11, 4039–4072.

anter registo, IL, 9629 9072.
Akiyama H, Yagit K, Yan X (2005) Direct N2O emissions from rice paddy fields: summary of available data. Global Biogeochemical Cycles, 19, GB1005.
Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revi-

Allard V, Soussana J-F, Falcimagne R et al. (2007) The role of grazing management for the net biome productivity and greenhouse gas budget (CO2, N2O and CH4) of semi-natural grassland. Agriculture, Econystems and Environment, 121, 47–58.

Alonso-Canas I, Chuvieco E (2015) Global burned area mapping from ENVISAT-MERIS and MODIS active fire data. Remote Sensing of Environment, 163, 140–152.



Acronym: ConnectinGEO
Project title: Coordinating an Observation Network of Networks EnCompassing sa Tellite and IN-situ to fill the Gaps in European Observation

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

LAND MANAGEMENT: DATA AND EFFECTS 17

- Amiro BD, Orchansky AL, Barr AG et al. (2006) The effect of post-fire stand age on the boreal forest energy balance. Agricultural and Forest Meteorology, 140, 41–50.
 Arnadon ID, Sala OE, Turner BL, Bennett EM (2014) Effect of woody-plant encroachment on livestock production in North and South America. Proceedings of the National Academy of Sciences, 111, 12984–12955.
- Anda A, Loke Z (2005) Radiation balance components of maize hybrids grown at var-
- ious plant densities, forumal of Agronomy and Crop Science, 191, 202-209.

 Andela N, van der Werf GR (2014) Recent trends in African fires driven by cropland expansion and El Nino to La Nina transition. Nature Climate Change, 4, 791-795.
- Anderson W, You L, Wood S, Wood-Sichra U, Wu W (2015) An analysis of methodological and spatial differences in global cropping systems models and maps. Glo-
- bal Ecology and Biogeography, 24, 180 191.

 Anderson-Teixeira KJ, Snyder PK, Twine TE, Cuadra SV, Costa MH, DeLucia EH (2012) Climate-regulation services of natural and agricultural ecoregions of the Americas. Nature Climate Change, 2, 177–181.
- Anderson-Teixeira K.J. Masters M.D. Black CK, Zeri M, Hussain MZ, Bernacchi CJ,
 DeLucia EH (2018) Altered belowground outon cycling following land-use
 change to perennial bioenergy crops. Ecosystems, 16, 508–520.
- Archibald S, Roy DP, Van WILGENBW, Scholes RJ (2009) What limits fire? An exa nation of drivers of burnt area in Southern Africa. Global Change Biology, 15, 613
- Arneth A, Mercado L, Kattge J, Booth BBB (2012) Future challenges of representing
- Asner GP, Elmore AJ, Olander LP, Martin RE, Harris AT (2004) Grazing systems, ecosystem responses, and global change. Annual Review of Environment and
- Bai ZG, Dent DL, Olsson L, Schaepman ME (2008) Proxy global assessment of land degradation. Soil Use and Management, 24, 223–234.

 Bais ALS, Lauk C, Kastner T, Erb K (2015) Global patterns and trends of wood har-
- vest and use between 1990 and 2010. Ecological Economics, 119, 326-337
- Baker JM, Ochsner TE, Venterea RT, Griffis TJ (2007) Tillage and soil carbon sequestration What do we really know? Agriculture, Ecosystems and Environment, 118, 1
- Bárcena TG, Kiær LP, Vesterdal L, Stefánsdóttir HM, Gundersen P, Sigurdsson BD Darcen 10, Kaer LF, vertenan I., Steamstown Fish, unintersen F, Siguiasson Di. (2014) Soil carbon stock change following afforestation in Northern Europe: a mcta analysis. Global Change Biology, 20, 2095–2466.
 Baron VS, Mapfurno E, Dick AC, Naeth MA, Okine EK, Chanasyk DS (2002) Grazing
- intensity impacts on pasture carbon and nitrogen flow. Journal of Range Management, 55,535-541.
- Bar-Yosef O (2002) The upper paleolithic revolution. Annual Review of Anthropology,
- Bationo A, Mokwunye AU (1991) Role of manures and crop residue in alleviating soil fertility constraints to crop production; with special reference to the Sahelian and Sudanian zones of West Africa. In: Alleviating Soil Fertility Constraints to Increased Crop Production in West Africa (ed. Mokwunye AU), pp. 217 225. Springer, Nether-
- Bengtsson J, Nilsson SG, Franc A, Menozzi P (2000) Biodiversity, disturbances, ecosystem function and management of European forests. Forest Ecology and Management, 132, 39 50.
- inger J. Hutlev LB, Tapper NJ, Coutts A, Kerlev A, O'Grady AP (2003) Fire impacts on surface heat, moisture and carbon fluxes from a tropical savanna in northern Australia. International Journal of Wildland Fire, 12, 333–340.
- Beringer T, Lucht W, Schaphoff S (2011) Bioenergy production potential of global bioplantations under environmental and agricultural constraints. GCB Biomergy, 3, 299–312. rthrong ST, Jobbágy EG, Jackson RB (2009) A global meta-analysis of soil evcha
- able cations, pH, carbon, and nitrogen with afforestation. Ecological Applications: A Publication of the Ecological Society of America, 19, 2228-2241.
- Birdsey R, Pan Y (2015) Trends in management of the world's forests and impacts on carbon stocks. Forest Ecology and Management, 355, 83–90.
- Blondel J (2006) The 'Design' of Mediterranean landscapes: a millennial story of ans and ecological systems during the historic period. Human Ecology, 34,
- Bolinder MA, Janzen HH, Gregorich EG, Angers DA, VandenBygaart AJ (2007) An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. Agriculture, Ecosystems and Environment,
- Bond-Lamberty B, Peckham SD, Ahl DE, Gower ST (2007) Fire as the dominant driver of central Canadian boreal forest carbon balance. Nature, 450, 89-92.

- tup E (1965) The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure, vol. 4. Earthscan, London.
 Boucher O, Myhre G, Myhre A (2004) Direct human influence of irrigation on atmo-
- spheric water vapour and climate. Climate Dynamics, 22, 597–603.

 Bouwman AF, Van der Hoek KW, Eickhout B, Soenario I (2005) Exploring changes in
- world ruminant production systems. Agricultural Systems, 84, 121 153. wman DMJS, Balch J, Artaxo P et al. (2011) The human dimension of
- on Earth, Journal of Biogeography, 38, 2223 2236.

 Boyd IL, Freer-Smith PH, Gilligan CA, Godfray HCJ (2013) The consequence of tree
- pests and diseases for ecosystem services. Science, 342, 1235773.

 Boyer EW, Howarth RW, Galloway JN, Dentener FJ, Green PA, Vörösmarty CJ (2006)
- Riverine nitrogen export from the continents to the coasts. Global Biogarchemical Cycles, 20, GB1S91.
- Bridges EM, Oldeman LR (1999) Global assessment of human-induced soil degradation. Arid Soil Research and Rehabilitation, 13, 319-325.
- Brinson MM, Malvárez Al (2002) Temperate freshwater wetlands: types, status, and threats. Environmental Conservation, 29, 115–183.
- Brovkin V, Sitch S, Von Bloh W, Claussen M, Bauer E, Cramer W (2004) Role of land cover changes for atmospheric CO2 increase and climate change during the last 150 years. Global Change Biology, 10, 1253 1266.

 Brown PL (1971) Water use and soil water depletion by dryland winter wheat as
- affected by nitrogen fertilization. Agronomy Journal, 63, 43.
- Brus DI, Hengeveld GM, Walvoort DII, Goedhart PW, Heidema AH, Nabuurs GI, Gunia K (2011) Statistical mapping of tree species over Europe. European Journal of
- Forest Research, 131, 145–157.

 Campioli M, Vicca S, Luyssaert S et al. (2015) Biomass production efficiency controlled by management in temperate and boreal ecosystems. Nature Geoscience, 8,
- Cao ZH, Ding JL, Hu ZY et al. (2006) Ancient paddy soils from the Neolithic age in China's Yangtze River Delta. Naturwissenschaften, 93, 232-236.
- Chang J, Ciais P, Viovy N, Vuichard N, Sultan B, Soussana F P (2015) The greenhouse gas balance of European grasslands. Global Change Biology, 21, 3748–3761.
 Cherubini F, Bright RM, Stromman AH (2012) Site-specific global warming potentials
- of biogenic CO 2 for bioenergy: contributions from carbon fluxes and albedo mental Research Letters, 7, 45902
- Caisa P, Gasser T, Paris JD et al. (2013a) Attributing the increase in atmospheric CO2 to emitters and absorbers. Nature Climate Change, 3, 926–939.
 Clais P, Sabine C, Bala G et al. (2013b) Carbon and other biogeochemical cycles. In:
- Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergonommental Fund on Climate Change, (eds Stocker TP, Chin D, Plattner G-K, Tignor M, Allen SK, Doschung J, Nauels A, Xia Y, Bex V, Midgley PM, pp. 465–570. Cambridge University Press, Cambridge, UK.
- Cohen J, Pulliainen J, Ménard CB, Johansen B, Oksanen L, Luojus K, Bionen J (2013) Effect of reindeer grazing on snowmelh, albedo and energy balance based on satel-lite data analyses. Remote Sensing of Environment, 135, 107–117. Costanza R, Fioramonti L, Kubiszewski J (2016) The UN sustainable development
- goals and the dynamics of well-being. Frontiers in Ecology and the Environment, 14,
- Cresswell HP, Painter DJ, Cameron KC (1993) Tillage and water content effects on surface soil hydraulic properties and shortwave Albedo. Soil Science Society of
- America Journal, 57, 816. Davidson EA (2009) The contribution of manure and fertilizer ritrogen to atmospheric ritrous code since 1860. Nature Geoscience, 2, 659–662.
- Davidson NC (2014) How much wetland has the world lost? Long-term and recent
- trends in Jobal weland a rea. Morine and Freshmate Research, 85, 994.

 Davin EL, Seneviratne SI, Ciais P, Olioso A, Wang T (2014) Preferential cooling of hot extremes from cropland albeido management. Proceedings of the National Academy of
- Sciences, 111, 9757 9761. Derpsch R. Friedrich T. Kassam A. Li H (2010) Current status of adoption of no-till
- Despise in Personal and Some of its main benefits. International Journal of Agricultural and Biological Engineering, 3, 1–25.

 Díaz S, Lavorel S, McINTYRE S et al. (2007) Plant trait responses to grazing a global
- synthesis. Global Change Biology, 13, 313–341.

 Dobbie KE, Smith KA (2003) Nitrous oxide emission factors for agricultural soils in Great Britain: the impact of soil water-filled pore space and other controlling vari-
- ables. Global Change Biology, 9, 204–218.

 Dobbie KE, McTaggart IP, Smith KA (1999) Nitrous oxide emissions from intensi
 agricultural systems: variations between crops and seasons, key driving variable and mean emission factors. Journal of Geophysical Research: Atmospheres, 104, 26891

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Project title: Coordinating an Observation Network of Networks EnCompassing sa Tellite and IN-situ to fill the Gaps in European Observations

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

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- Drösler M, Verchot LV, Freibauer A et al. (2013) Drained inland organic soils. In: 2013 Supplement to the 2006 IPCC Guididines for National Greenhouse Gas Intentories: Wel-lands (eds Hiraishi T, Krug T, Tanabe K, Srivastava N, Bassansuren J, Pukuda M, Troxler T), pp. 2.1 2.79. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.
- Dunne J, Evershed RP, Salque M et al. (2012) First dairving in green Saharan Africa in the fifth millennium BC. Nature, 486, 390–394.

 Eastman JL, Coughenour MB, Pielke RA (2001) Does grazing affect regional climate?
- Journal of Hydrometeorology, 2, 243 253.

 Eggers J, Lindner M, Zudin S, Zaehle S, Liski J (2008) Impact of changing wood demand, climate and land use on European forest resources and carbon stocks during the 21st century. Global Change Biology, 14, 2288–2303.
- Eldridge DJ, Bowker MA, Maestre FT, Roger E, Reynolds JF, Whitford WG (2011) Impacts of sitrub encroachment on ecosystem structure and functioning; towards a global synthesis. Ecology Letters, 14, 709–722.

 Ellert EH, Janzen HH (1999) Short-term influence of tillage on CO2 fluxes from a
- semi-arid soil on the Canadian Prairies. Soil and Tillage Research, 50, 21–32. Ellis EC, Kaplan JO, Fuller DQ, Vavrus S, Goldewijk KK, Verburg PH (2013) Used
- et: a global history. Proceedings of the National Academy of Sciences, 110, 7978
- on U (2009) The Rural Landscapes of Europe: How Man has Shaped European Nature. Swedish Research Council Formas, Stockholm.
- Erb K-H (2012) How a socio-ecological metabolism approach can help to advance our understanding of changes in land-use intensity. Ecological Economics, 76, 8–14.
- Erb K-H, Gaube V, Krausmann F, Plutzar C, Bondeau A, Haberl H (2007) A compre hensive global 5 min resolution land-use data set for the year 2000 consistent with
- nensive gional 5 min resoution and use data set on the year 2000 consistent with national consus data, Journal of Land Use Science, 2, 191 224. Erb K-H, Habeil H, Jepsen MR et al. (2013a) A conceptual framework for analysing and measuring land-use intensity. Current Opinion in Environmental Sustainability,
- Erb K-H, Kastner T, Luyssaert S, Houghton RA, Kuemmerle T, Cloisson P, Haberl H (2013b) Bias in the attribution of forest carbon sinks. Nature Climate Change, 3, 854
- Erb K-H, Fetzel T, Plutzar C et al. (2016) Biomass turnover time in terrestrial ecosys-
- tens halved by land use. Nature Gosscience, (in press). doi: 10.1088/ngco2782

 Fan L, Ketzer B, Liu H, Bernhofer C (2010) Grazing effects on seasonal dynamics and interannual variabilities of spectral reflectance in semi-arid grassland in Inner Mongolia. Plant and Soil, 340, 169–180.
- FAO (1985) Irrigation Water Manager ment: Training Manual No. 1 - Introduction to
- Irrigation.
 FAO (2010) Global Forest Researces Assessment 2010. Main Report. FAO, Rome, 378 pp. FAO (2011) World Livestock 2011. Livestock in food security. Food and Agriculture Orgaization of the United Nations
- FAO (2015a) Global Forest Resources Assessments 2015. Food and Agriculture Organization of the United Nations, Rome.
- FAO (2015b) Methods and Standards.
- FAOSTAT (2015) Statistical Databases. Available at: http://faostat.fao.org (accessed
- Farley KA, Jobbágy EG, Jackson RB (2005) Effects of afforestation on water yield: a
- global synthesis with implications for policy. Global Change Biology, 11, 1565–1576.

 Farrell EP, Führer E, Ryan D, Andersson F, Hüttl R, Paussi P (2000) European forest ecosystems: building the future on the legacy of the past. Forest Eology and Management, 132, 5 20.
- Feddema JJ, Oleson KW, Bonan GB, Mearns LO, Buja LE, Meehl GA, Washington WM (2005) The importance of land-cover change in simulating future climates Science, 310, 1674–1678.
- Feick S, Siebert S, Döll P (2005) A Digital Global Map of Artificially Drained Agricultural Areas
- Fernandes FM, Botelho HS (2003) A review of prescribed burning effectiveness in fire hazard reduction. *International Journal of Wildland Fire*, **12**, 117–128.

 Fernández-Martínez M, Vicca S, Janssens IA *et al.* (2014) Nutrient availability as the
- key regulator of global forest carbon balance. Nature Climate Change, 4, 471 476.
- Flechard CR, Arrbus P, Slaba U et al. (2009) Effects of climate and management intensity on nitrous oxide emissions in grassland systems across Europe. Agriculture, Ecosystems and Environment, 121, 135–152.
- Foley JA, DeFries R, Asner GP et al. (2005) Global consequences of land use. Science
- Foley JA, Ramankutty N, Brauman KA et al. (2011) Solutions for a cultivated planet. Nature, 478, 337 342.

- Ford CR, Laseter SH, Swank WT, Vose JM (2011) Can forest manag sustain water-based ecosystem services in the face of climate change? Ecological Applications, 21, 2049 2067.
- Forkel M, Migliavacca M, Thonicke K, Reichstein M, Schaphoff S, Weber U, Carvalhais N (2015) Codominant water control on global interannual variability and trends in land surface phenology and greenness. Global Change Biology, 21, 3414
- century. Philosophical Transactions of the Royal Society B: Biological Sciences, 368, 20130164. Fowler D, Covle M, Skiba U et al. (2013) The global nitrogen cycle in the twenty-first
- Freydark K, Siebert S (2008) Towards mapping the extent of irrigation in the last century: time series of irrigated area per country, Research report, Institute of Physical Geography, University of Frankfurt (Main), 46 pp.

 Fritz S, See L, McCallum I et al. (2011) Highlighting continued uncertainty in
- global land cover maps for the user community. Environmental Research Letters, 6. 44005.
- Fritz S, See L, McCallum I et al. (2015) Mapping global cropland and field size. Global
- Change Biology, 21, 1980-1992.
 Frolking S, Yeluripati JB, Douglas E (2006) New district-level maps of rice cropping in India: a foundation for scientific input into policy assessment. Field Crops
- Fuller DQ (2012) Pathways to Asian civilizations: tracing the origins and spread of rice and rice cultures. Rice, 4, 78 92.
- Gallardo A, Schlesinger WH (1992) Carbon and nitrogen limitations of soil microbial biomass in desert ecosystems. Bisgocchemistry, 18, 1–17.
 Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth KW, Cowling EB, Cosby
- BJ (2003) The nitrogen cascade. BioScience, 53, 341 356.

 Gao Y, Markkanen T, Backman L, Henttonen HM, Pietikäinen J-P, Mäkelä HM, Laaksonen A (2014) Biogeophysical impacts of peatland foresta changes in Finland. Biogeosciences, 11, 7251–7267.
- Giglio L, Randerson JT, van der Werf GR (2013) Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4). Journal of Geophysical Research: Biogeosciences, 118, 317–328. Gollany HT, Rickman RW, Liang Y, Albrecht SL, Machado S, Kang S (2011)
- Predicting agricultural management influence on long-term soil orgabon dynamics: implications for biofuel production. Agrenomy Journal, 103,
- (2009) Conservation agriculture and soil carbon sequestration: between myth and
- CONTY CONSERVATION AGRICULTURE and SOIL CARRON ASSECTION DEVELOPED IN THE ARTHUR AND AGRICULTURE AGRICULTU
- cycle, Nature, 451, 293-296.
- Haas G, Wetterich F, Köpke U (2001) Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agricul-
- hare, Ecospitems and Enterormoni, 83, 43–53.

 Haberl H, Erb KH, Krausmann F et al. (2007) Quantitying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences, 104, 12942–12947.
- Haberl H, Erb K-H, Krausmann F, Running S, Searchinger TD, Smith WK (2013) nergy: how much can we expect for 2050? Environ
- Hammerle A, Haslwanter A, Tappeiner U, Cernusca A, Wohlfahrt G (2008) Leaf area controls on energy partitioning of a temperate mountain grassland. Bioge
- Hanewinkel M, Cullmann DA, Schelhaas M-J, Nabuurs G-J, Zimmer Climate change may cause severe loss in the economic value of European forest land. Nature Climate Change, 3, 203–207.
- Hares MA, Novak MD (1992) Simulation of surface energy balance and soil temperature under strip tillage: II. Field test. Soil Science Society of America Journal,
- Harmon ME, Ferrell WK, Franklin JF (1990) Effects on carbon storage of conversion of old-growth forests to young forests. Science, 247, 699-702.

 Hengeveld GM, Nabuurs G-J, Didion M, van den Wyngaert I, Clerkx APPM, Schel-
- haas M-J (2012) A forest management map of European forests. Ecology and Society,
- 17, 53.

 Hernle S, Anken T, Leifeld J, Weisskopf P (2008) The effect of the tillage system on soil organic carbon content under moist, cold-temperate conditions. Soil and Tillage Research, 98, 94 105.



Acronym: ConnectinGEO
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Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

LAND MANAGEMENT: DATA AND EFFECTS 19

- Herrero M, Havlik P, Valin H et al. (2013) Biomass use, production, feed effici and greenhouse gas emissions from global livestock systems. Proceedings of the
- National Academy of Sciences, 110, 2688 20893.
 Hiraishi T, Krug T, Tanabe K, Srivastava N, Jamsranjav B, Fukuda M, Troder T (2014) 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.
- Investments Neumonts Neumons (Millinger SV, Richardson AD et al. (2010) Albedo estimates for land surface models and support for a new paradigm based on foliage nitrogen concentration. Global Change Biology, 16, 696–710.
- Holtsmark B (2012) The outcome is in the assumptions: analyzing the effects on atmospheric CO2 levels of increased use of bioenergy from forest biomass. GCB Bioen-
- Horton R, Bristow KL, Kluitenberg GJ, Sauer TJ (1996) Crop residue effects on surface radiation and energy balance review. Tracertical and Applied Climatology, 54, 27

 37.
- osonuma N, Herold M, De Sy V et al. (2012) An assessment of deforestation and for-est degradation drivers in developing countries. Environmental Research Letters, 7,
- Huber DB, Mechem DB, Brunsell NA (2014) The effects of great plains irrigation on the surface energy balance, regional circulation, and precipitation. Climate, 2, 103
- Hulvey KB, Hobbs RJ, Standish RJ, Lindenmayer DB, Lach L, Perring MP (2013) Ben-
- efits of tree mixes in carbon plannings, Matrier Climate Change, 3, 569–874.

 Hurteau MD, Brooks ML (2011) Short- and long-term effects of fire on carbon in US dry temperate forest systems. BioScience, 61, 139–146.
- Hutt GC, Pacala SW, Moorcroft PR, Caspersen J, Shevliakova E, Houghton RA, Moore B (2002) Projecting the future of the U.S. carbon sink. Proceedings of the National Academy of Sciences, 99, 1389–1394.
 Hutt G, Chini L, Frolking S et al. (2011) Harmonization of land-use scenarios for the
- period 1500 2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. Climatic Change, 109, 117–161. IAASTD 2009) Agriculture at a Crossroad, International Assessment of Agricultural
- Knowledge, Science and Technology for Development. Global Report. Island Press,
- Washington, D.C.

 IFA (2007) Sustainable management of the mirrogen cycle in agriculture and mitigation of reactive nitrogen side effects. International Fertilizer Industry Association, Paris.
- lizumi T, Ramankutty N (2016) Changes in yield variability of major crops for 1981 2010 explained by climate change. Environmental Research Letters, 11,
- 34003.
 Ezumi T, Yokozawa M, Sakurai G et al. (2014) Historical changes in global yields: major cereal and legume crops from 1982 to 2006. Global Ecology and Biogeography.
- Jaenicke J, Rieley JO, Mott C, Kimman P, Siegert F (2008) Determination of the amount of carbon stored in Indonesian peallands. Geodorms, 147, 151–158.
 Jamali H, Quayle WC, Baldock J (2015) Reducing nitrous oxide emissions and nitro-
- gen leaching losses from irrigated arable cropping in Australia through optimized irrigation scheduling. Agricultural and Forest Meteorology, 206, 32–39.

 James SR (1989) Hominid use of fire in the lower and middle pleistocene. Current
- Anthropology, 30, 1 26.
- Joshi N, Baumann M, Ehammer A et al. (2016) A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring. Remote
- Juang J-Y, Katul G, Siqueira M, Stoy P, Novick K (2007) Separating the effects of albedo from eco-physiological changes on surface temperature along a successional chronosequence in the southeastern United States. Geophysical Research Let-
- ters, 34, L21408.
 Kalbitz K, Kaiser K, Fiedler S et al. (2013) The carbon count of 2000 years of rice cultivation. Global Change Biology, 19, 1107 1113.
- Kaplan JO, Krumhardt KM, Ellis EC, Ruddiman WF, Lemmen C, Goldewijk KK (2010) Holocene carbon emissions as a result of anthropogenic land cover change. Holocene, 21, 775–791.
- Kastner T, Rivas MJI, Koch W, Nonhebel S (2012) Global changes in diets and the con-sequences for land requirements for food. Proceedings of the National Academy of
- Sciences, 109, 6868-6872.

 Kätterer T, Bolinder MA, Berglund K, Kirchmann H (2012) Strategies for carbon sequestration in agricultural soils in northern Europe. Acta Agriculturae Soundinavios, Section A. Animal Science, 62, 181–198.

 van Kessel C, Venterea R, Six J, Adviento-Borbe MA, Linquist B, van Groenigen KJ
- (2013) Climate, duration, and N placement determine N2O emissions in reduced tillage systems: a meta-analysis. Global Change Biology, 19, 33–44.

- Kesselmeier J, Staudt M (1999) Biogenic Volatile Organic Compounds (VOC): an rview on emission, physiology and ecology. Journal of Atmospheric Chemistry
- Kirschbaum MUF, Whitehead D, Dean SM, Beets PN, Shepherd JD, Ausseil A-GE (2011) Implications of albedo changes following afforestation on the benefits of for-
- ests as carbon sinks. Biogasciences Discussions, 8, 8653-8589, rschke S, Bousquet P, Ciais P et al. (2013) Three decades of global methane and sinks. Nature Gascience, 6, 813-823.
- Kissinger G, Herold M, de Sy V (2012) Drivers of deforestation and forest degradation: A synthesis report for REDD+ policymakers. Center for International Forestry
- Knicker H (2007) How does fire affect the nature and stability of soil organic nitrogen and carbon? A review. Biogeochemistry, 85, 91 118.
- chens M. Albert E. Armbruster M et al. (2013) Effect of mineral and organic fertilusedness on, Americ, Armoruser so of al. 2015) gives of numera and organic remi-ization on crop yield, nitrogen uptake, carbon and nitrogen balances, as well as soil organic carbon content and dynamics: results from 20 European long-term field experiments of the twenty-first century. Archives of Agrenomy and Soil Science, 59, 1017 1040.
- walski S, Sartore M, Burlett R, Berbigjer P, Loustau D (2009) The annual carbon budget of a French pine forest (Pinus pinaster) following harvest. Global Change Biology, 9, 1051–1065.
- Kozlowski TT (1984) Flooding and Plant Growth. Academic Press, Olrando
- Krausmann F, Erb K-H, Gingrich S, Lauk C, Haberl H (2008) Global patterns of socioeconomic biomass flows in the year 2000: a comprehensive assessment of supply, consumption and constraints. Ecological Economics, 65, 471 487.
- Krausmann F, Erb K-H, Gingrich S et al. (2013) Global human appropriation of net primary production doubled in the 20th century. Proceedings of the National Acad-emy of Sciences, 110, 10524–10529.
- merle T, Erb K, Meyfroidt P et al. (2013) Challenges and opportunities in map ping land use intensity globally. Current Opinion in Environmental Sustainability, 5,
- Lafleur PM, Hember RA, Admiral SW, Roulet NT (2005) Annual and seasonal variability in evapotranspiration and water table at a shrub-covered bog in southern
- Ontario, Canada. Hubrological Processes, 19, 3533–3550.

 Inteenoja O, Ruokolainen K, Schulman L, Otnonen M (2009) Amazonian peatlands: an ignored C sink and potential source. Global Change Biology, 15, 2311–2320.
- Lal R (2004) Soil carbon sequestration impacts on global climate change and food
- security. Science, 304, 1623–1627.

 Lal R (2006) World crop residues production and implications of its use as a biofuel.
 Environment International, 31, 575–584.
- Landry J-S, Matthews HD, Ramankutty N (2015) A global assessment of the carbon cycle and temperature responses to major changes in future fire regime. Climatic
- through national inventories to the global methane cycle. Agricultural and Forest Meteorology, 142, 120 132.
- Cauk C, Erk KH (2009) Biomass consumed in anthropogenic vegetation fires: global patterns and processes. Ecological Economics, 69, 301–309.

 LeBauer DS, Treseder KK (2008) Nitrogen limitation of net primary productivity in
- terrestrial ecosystems is globally distributed. Ecology, 89, 371–379.

 thinen T, Schlatter N, Baumgarten A et al. (2014) Effect of crop residue incorporation on soil organic carbon and greenhouse gas emissions in European agricultural
- soils. Soil Use and Management, 30, 524–538. Levers C, Verkerk PJ, Müller D et al. (2014) Drivers of forest harve
- Levers c, Verners P, Numer D et al. (2010) Drivers or noves narvesting intensity pat-terns in Europe. Forest Ecology and Management, 315, 160 172. Li S-G, Harazono Y, Oškawa T, Zhao HL, Ying He Z, Chang XL (2000) Grassland desertification by grazing and the resulting micrometeorological changes in Inner Mongolia. Agricultural and Forest Meteorology, 102, 125-137.
- Liebig MA, Morgan IA, Reeder JD, Ellert BH, Gollany HT, Schuman GE (2006) Green-house gas contributions and mitigation potential of agricultural practices in north-western USA and western Canada. Soil and Tillage Research, 83, 25–52.
- Lindenmayer D, Cunningham S, Young A (2012) Land Use Intensification: Effects on Agriculture, Biodiversity and Ecological Processes. Csiro Publishing, Collingwood,
- Liousse C, Guillaume B, Grégoire JM et al. (2010) Updated African biomass burning emission inventories in the framework of the AMMA-IDAF program, with an eval-uation of combustion aerosols. Atmospheric Chemistry and Physics, 10, 9631–9646.

 Lippke B, Onell E, Harrison R, Skog K, Gustavsson L, Sathre R 2011) Life cycle
- impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns. Carbon, 2, 303-333.



Acronym: ConnectinGEO
Project title: Coordinating an Observation Network of Networks EnCompassing sa Tellite and IN-situ to fill the Gaps in European Observations

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

20 K-HERB et al.

- Liu J, You L, Amini M, Obersteiner M, Herrero M, Zehnder AJB, Yang H (2010) A th-resolution assessment on global nitrogen flows in cropland. Proceedings of the National Academy of Sciences, 107, 8035 8040.
- Chila A, Minkkinen K, Laine J et al. (2010) Forestation of boreal peatlands: impacts of changing albedo and greenhouse gas fluxes on radiative forcing. Journal of Gaphysiolal Research: Biogeosciences, 115, G04011.
- Luo J. Tillman RW, Ball PR (1999) Grazing effects on denitrification in a soil under pasture during two contrasting seasons. Soil Biology and Biochemistry, 31, 905–912.

 Luyssaert S, Ciais P, Piao SL et al. (2010) The European carbon balance. Part 3: forest Global Change Biology, 16, 1429–1450.
- Luyssaert S, Hessenmöller D, von Lüpke N, Kaiser S, Schulze ED (2011) Quantifying
- land-use and disturbance intensity in forestry, based on the self-thinning relationship. Ecological Applications, 8, 3272–3284.

 Luyssaert S, Jammet M, Stoy PC et al. (2014) Land management and land-cov
- change have impacts of similar magnitude on surface temperature. Nature Climate 4 389 393 ald NM, Artaxo F, Baker AR, Jickells TD, Okin GS, Randerson JT, Tow
- AR (2006) Impacts of biomass burning emissions and land use change on Amazo-nian atmospheric phosphorus cycling and deposition. Global Biogeochemical Cycles,
- Mann LK (1986) Changes in soil carbon storage after cultivation. Soil Science, 142,
- Mărald E, Langston N, Sténs A, Moen J (2016) Changing ideas in forestry: a comparison of concepts in Swedish and American forestry journals during the early twen-tieth and twenty-first centuries. Ambie, 45, 74–86.

 Marland G, Schlamadinger B (1997) Forests for carbon sequestration or fossil fuel
- substitution? A sensitivity analysis. Blomuss and Bloomeys, 13, 389–397.

 Marshall CH, Pielke RA, Steyaert LT (2005) Wetlands: crop freezes and land-use change in Florida. Nature, 426, 29–30.

 Matocha CJ, Grove JH, Karathanasis TD, Vandiviere M (2016) Changes in soil miner-
- alogy due to nitrogen fertilization in an agroccosystem. Godomus, 263, 176–184.

 McDaniel MD, Tiemann LK, Grandy AS (2013) Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecological Applications, 24, 560-570.
- McGarvey IC, Thompson IR, Epstein HE, Shugart HH (2014) Carbon storage in oldgrowth forests of the Mid-Atlantic toward better understanding the eastern forest carbon sink. Ecology, 96, 311–317.

 McGrath MJ, Luyssaert S, Meyfroidt P et al. (2015) Reconstructing European forest
- management from 1600 to 2010. Biogassciences Discussions, 12, 5365-5433.

 McSherry ME, Ritchie ME (2013) Effects of grazing on grassland soil carbon: a global
- review. Global Change Biology, 19, 1347-1357.

 Melton JR, Wania R, Hodson EL et al. (2013) Present state of global wetland extent and wetland methane modelling; conclusions from a model inter-comparison proiect (WETCHIMP), Biognoscimoss, 10, 753-788.
- Meyfroidt P, Lambin EF (2011) Global forest transition: prospects for an end to defor-
- estation. Annual Review of Environment and Resources, 36, 343-371.

 Miller SD, Goulden ML, da Rocha HR (2007) The effect of canopy gaps on subcanopy on and scalar fluxes in a tropical forest. Agricultural and Forest Meteorology,
- Monfreda C, Ramankutty N, Foley JA (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochomical Cycles, 22, 1–19. Monteith J, Unsworth M (2013) Principles of Environmental Physics: Plants, Animals, and
- the Atmosphere. Academic Press, Oxford, UK.
- Moore S, Evans CD, Page SE et al. (2013) Deep instability of deforested tropical peat-lands revealed by fluvial organic carbon fluxes. Nature, 493, 660–663.

 Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012) Closing
- yield gaps through nutrient and water management. Nature, 490, 254 257.

 Mueller ND, Butler EE, McKinnon KA, Rhines A, Tingley M, Holbrook NM, Huybers P. (2015) Cooling of US Midwest summer temperature extremes from cropland intensification. Nature Climate Change, 6, 317–322.
 Müller I, Schmid B, Weiner J (2000) The effect of nutrient availability on biomass allo-
- cation patterns in 27 species of herbaceous plants. Perspectives in Plant Ecology, Evoand Systematics, 3, 115 127.
- Nair PKR, Garrity D (eds.) (2012) Agroforestry The Future of Global Land Use, vol. 9.
- Springer, Dordrecht, Netherlands.

 Nakai T, Sumida A, Daikoku K et al. (2008) Parameterisation of aerodynamic rough over boreal, cool- and warm-temperate forests. Agricultural and Forest Meteo
- Naudts K, Chen Y, McGrath MJ, Ryder J, Valade A, Otto J, Luyssaert S (2016) Europe's forest management did not mitigate climate warming. Science, 351, 597 600.

- Naylor R, Steinfeld H, Falcon W et al. (2006) Losing the links between livestock and
- Neufeldt H, Kissinger G, Alcamo J (2015) No-till agriculture and climate change miti-
- gation. Nature Climate Change, 5, 488–489.
 Niedertscheider M, Kastner T, Fetzel T, Haberl H, Kroisleitner C, Plutzar C, Erb K-H
 2016) Mapping and analysing cropland use intensity from a NPP perspective. Environmental Research Letters, 11, 14008.
- Commor CD, Falk DA, Lynch AM, Swetram TW (2014) Fire severity, size, and climate associations diverge from historical precedent along an ecological gradient in the Pinalefio Mountains, Arizona, USA. Forest Ecology and Mususgement, 329,
- Oke TR (1987) Boundary Luyer Climates, 2nd edn. Routledge, London.

 Ollinger SV, Richardson AD, Martin ME et al. (2008) Canopy nitrogen, carbon assimilation, and albedo in temperate and boreal forests: functional relations and potential climate feedbacks. Proceedings of the National Academy of Sciences, 105,
- 1939b 19941.
 wwali SN, Smith WB, Miles FD, Pugh SA (2014) Forest Resources of the United States,
 2012: a teoritatal document supporting the Forest Sortice 2015 systate of the RPA Assessment. Gon. Tech. Rep. WO-91. U.S. Departments of Agriculture Forest Service,
- Washington Office, Washington, DC, 218 pp.
 Otto J, Berveiller D, Bréon F-M et al. (2013) Summertime canopy albedo is sensitive to forest thinning. Biogressicosco Discussions, 10, 15373–15414.
 Otto J, Berveiller D, Bréon F-M et al. (2014) Forest summer albedo is sensitive to spe-
- cies and thinning; how should we account for this in Earth system models? Bio
- Pan Y, Birdsey RA, Fang J et al. (2011) A large and persistent carbon sink in the
- world's forests. Science, 333, 988 993.

 Pan Y, Birdsey RA, Phillips OL, Jackson RB (2013) The structure, distribution, and biomass of the world's forests. Annual Review of Ecology, Evolution, and Systematics,
- Paul KI, Polglase PJ, Nyakuengama JG, Khanna PK (2002) Change in soil carbon fol-
- lowing afforestation. Forest Ecology and Management, 188, 241 257.

 Pefiuelas J, Llusià J (2003) BVOCs: plant defense against climate warming? Trends in Plant Science, 8, 105 109.
- Perlin 1 (2005) A Forest Journey: The Story of Wood and Civilization. The Countryman
- Press, Woodstock, Ve
- Petz K, Alkemade R, Bakkenes M, Schulp CJE, van der Velde M, Leemans R (2014) Mapping and modelling trade-offs and synergies between grazing intensity and ecosystem services in rangelands using global-scale datasets and models. Global Entrinomental Change, 29, 223–234.

 Piggin I, Schwerdtieger DP (1973) Variations in the albedo of wheat and barley crops.
- Archiv für Meteorologie, Gosphusik und Bioklimatologie, Serie B, 21, 365–391.
 Pittellkow CM, Liang X, Linquist BA et al. (2015) Productivity limits and potentials of the principles of conservation agriculture. Nature, 517, 365–368.
- Poeplau C, Don A (2014) Soil carbon changes under Miscanthus driven by C4 accumulation and C3 decompostion toward a default sequestration function. GCB Bioenergy, 6, 327-338.
- plau C, Don A (2015) Carbon sequestration in agricultural soils via cultivation of cover crops A meta-analysis. Agriculture, Ecosystems and Environment, 200, of cov 33 41.
- Pongratz J, Reick C, Raddatz T, Claussen M (2008) A reconstruction of global agricultural areas and land cover for the last millennium. Global Biogeochemical Cycles, 22,
- Pongratz J, Reick C, Raddatz T, Claussen M (2009) Effects of anthropogenic land change on the carbon cycle of the last millennium. Global Biogarchemical, 23, GB4001.
- Cycles, 23, GB4001.

 Portmann FT, Siebert S, Döll P (2010) MIRCA2000 Global monthly irrigated and rainfed crop areas around the year 2000; a new high-resolution data set for agricultural and hydrological modeling. Global Biogaschemical Cycles, 24, GB1011.
- stan MM, Miller E, Postan C (1987) The Cambridge Economic History of Europe from the Decline of the Roman Empire: Volume 2, Trade and Industry in the Middle Ages, 2nd
- edn. Cambridge University Press, Cambridge, UK.
 Potapov P, Yaroshenko A, Turubanova S et al. (2008) Mapping the world's intact for-
- Podejov P, Janosiensko, P, Humaniova 2 of an Cooks) inapping the world's limited reset landscapes by remote sensing. Ecology and Society, 13, 51.

 Postel S (2001) Growing more food with less water. Scientific American, 284, 46–50.

 Potter P, Ramankutty N, Bennett EM, Donner SD (2010) Characterizing the spatial
- patterns of global fertilizer application and manure production. Earth Interactions,
- 14, 1 22.
 Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, Sanchez PA, Cassman KG (2014) Limited potential of no-till agriculture for climate change mitigation. Nature Climate Change, 4, 678-683.



Acronym: ConnectinGEO
Project title: Coordinating an Observation Network of Networks EnCompassing sa Tellite and IN-situ to fill the Gaps in European Observations

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

LAND MANAGEMENT: DATA AND EFFECTS 21

- Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, Sanchez PA, Cassman KG 2015) Reply to 'No-till agriculture and climate change mitigation'. Nature Climate Change, 5, 489.

 Pugh TAM, Arneth A, Olin S et al. 2015) Simulated carbon emissions from land-use
- change are substantially enhanced by accounting for agricultural management. ental Research Letters, 10, 124008.
- Ramankutty N, Evan AT, Monfreda C, Foley JA (2008) Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeo-chemical Cycles, 22, GB1003.
- Randerson JT, Liu H, Flanner MG et al. (2006) The impact of boreal forest fire on cli-
- Randerson 11, List II, Faither No. 6 in Leonov, the suspens of societies and accom-mate warming, Science, 341, 130–132.

 Raupach MR (1994) Simplified expressions for vegetation roughness length and zero-plane displacement as functions of canopy height and area index. Bosoulary-Layer Meteorology, 71, 211-216
- Rautiainen M, Stenberg P, Mottus M, Manninen T (2011) Radiative transfer simulations link boreal forest structure and shortwave albedo. Boreal Environment Research, 16, 91 100.
- Ray DK, Foley JA (2013) Increasing global crop harvest frequency: recent trends and future directions. Environmental Research Letters, 8, 44041.

 Ray DK, Ramankutty N, Mueller ND, West PC, Foley JA (2012) Recent patterns of
- crop yield growth and stagnation. Nature Communications, 3, 1293.
- Reid WV, Chen D, Goldfarb L et al. (2010) Earth system science for global sustainability: grand challenges. Science, 330, 916–917.
 Resh SC, Binkley D, Parrotta JA (2002) Greater soil carbon sequestration under nitro-
- gen-fixing trees compared with eucalyptus species. Ecosystems, 5, 217-231.
- Science, 289, 1922 1925.

 Rochetton GP, Paul EA, Harwood RR (2000) Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. Science, 289, 1922 1925.

 Rochette P (2008) No-till only increases NZO emissions in poorly-aerated soils. Soil
- and Tillage Research, 101, 97 100.

 Rose L, Coners H, Leuschner C (2012) Effects of fertilization and cutting frequency on the water balance of a temperate grassland. Ecohydrology, 5, 64-72
- Rosset M, Riedo M, Grub A, Geissmann M, Fuhrer J (1997) Seasonal variation in radiation and energy balances of permanent pastures at different altitudes. Agricultural and Forest Meteorology, 86, 245–258.
- Rosset M, Montani M, Tanner M, Fuhrer J (2001) Effects of abandonment on the
- energy balance and evapotranspiration of wet subalpine grassland. Agriculture, Ecosystems and Environment, 86, 277–286. Dunnsevell MDA, Pedroll B, Erb K-H et al. (2012) Challenges for land system science. Land Use Policy, 29, 899–910.
- Rovira A, Greacen E (1957) The effect of aggregate disruption on the activity of ganisms in the soil. Australian Journal of Agricultural Research, 8, 659
- 673.
 Sacks WJ, Kucharik CJ (2011) Crop management and phenology trends in the U.S. Corn Belt: impacts on yields, evapotranspiration and energy balance. Agricultural
- and Forst Metorology, BJ, 882 894.

 Saggar S, Giltrap DL, Davison R et al. (2015) Estimating direct N2O emissions from sheep, beef, and deer grazed pashures in New Zealand bill country: accounting for the effect of land slope on the N2O emission factors from urine and dung, Agricalstems and Environment, 205, 70-78.
- Sainju UM, Stevens WB, Caesar-TonThat T, Liebig MA (2012) Soil greenhouse gas emissions affected by irrigation, tillage, crop rotation, and nitrogen fertilization. Journal of Environment Quality, 41, 1774.
- Jimon JM, Fredi MA, Prolising S, Wasser D, Douglas EM (2015) Global rain-fed, irri-gated, and paddy croplands: a new high resolution map derived from remote sensing, crop inventories and climate data. International Journal of Applied Earth Observation and Georgiovation, 36, 321–334.
- derson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, Woolmer G (2002)
- The human footprint and the last of the wild. BioScience, \$2,891 904. Santin C, Knicker H, Fernández S, Menéndez-Duarte R, Álvarez MÁ (2008) Wildfires influence on soil organic matter in an Atlantic mountainous region (NW of Spain).
- Catera, 74, 286 295.
 Ssugier B, Roy J, Mooney HA (2001) Estimations of global terrestrial productivity: converging toward a single number? In: Terrestrial Global Productivity (eds Roy J, Ssugier B, Mooney HA), pp. 543 567. Academic Press, San Diego.
 Scheer C, Grace PR, Rowlings DW, Payero J (2012) Sod IN2O and CO2 emissions from cotton in Australia under varying irrigation management. Nutrient Cycling in
- Agroecosystems, 95, 43 56.
- Schils R, Kuikman P, Liski J et al. (2008) Review of existing information on the interrelations between soil and climate change. (ClimSoil). Final report. European Commission, Brussels, Belgium, 208 pp.

- Scholes RJ, Walker BH (1993) An African Savanna: Synthesis of the Nylsvley Study. Cam-
- bridge University Press, Cambridge, UK. Schulze E-D, Körner C, Law BE, Haberl H, Luyssaert S (2012) Large-scale bioenergy from additional harvest of forest biomass is nei gas neutral. GCB Bioenergy, 4, 611 616.
- See L, Fritz S, You L et al. (2015) Improved global cropland data as an essential ingredient for food security. Global Faad Security, 4, 37 45.
 Settle J, Scholes R, Betts R et al. (2014) Terrestial and inland water systems. In: Climate change 2014: impacts, Adaptations, and Vulnarability. Part A: Global and Sectoral Angeles, contribution of Working Group II to the \$P\$th Assessment Report of the Intergen-commental Panel on Climate Change (eds. Field C, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilui TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL), pp. 271 399. Cambridge University Press, Cambridge, UK.
- Siebert S, Portmann FT, Döll P (2010) Global patterns of cropland use intensity.
- Remote Sensing, 2, 1625–1643. Stebert S, Kummu M, Porkka M, Döll P, Ramankutty N, Scanlon BR (2015) A global data set of the extent of irrigated land from 1900 to 2005. Hydrology and Earth Sys-tem Sciences, 19, 1521–1545. ns REH, Schock RN, Adegbululgbe A et al. (2007) Energy supply. In: Climate data set of the exte
- Changle 2007: Mitigation. Contribution of Working Group III to the Fourth Assessmen Report of the Interv vernmental Panel on Climate Change, (eds Metz B, Davidson OR, sch PR, Dave R, Meyer LA, pp. 251 322. Cambridge University Press, Cam
- Smith P, Martino D, Cai Z et al. (2008) Greenhouse gas mitigation in agriculture.
- Philosophical Transactions of the Royal Society B: Biological Sciences, 363, 789 813. nuth WN, Grant BB, Campbell CA, McConkey BG, Desjardins RL, Kröbel R, Malhi SS 2012) Crop residue removal effects on soil carbon: measured and inter-model comparisons. Agriculture, Ecosystems and Environment, 161, 27-38.
- Sommer SG, Schjoerring JR, Denmead OT (2004) Ammonia emission from mineral fertilizers and fertilized crops, Advances in Agronomy, 82, 557 822.

 Steffen W, Richardson K, Rockström J et al. (2015) Planetary boundaries: guiding
- human development on a changing planet. Science, 347, 1259855
- Stehlest E (2005) Modelling of global crop production and resulting N2O emissions. Disser-tation. University Kassel, Kassel.

 Stehlest E, Bouwman L (2006) N2O and NO emission from agricultural fields and
- soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems, 74, 207
- Steinfeld H, Gerber P, Wassenaar T, Castel V, deHaan C (2006) Livestock's long shadow: environmental issues and options. FAO.
- Stoy PC, Katul GG, Siqueira MBS et al. (2009) Separating the effects of climate and vegetation on evapotranspiration along a successional chronosequence in the
- southeastern US. Global Change Biology, 12, 2115–2135.

 Sutton MA, Howard CM, Erisman JW et al. (2011) The European Nitrogen Assessm Sources, Effects and Policy Perspectives. Cambridge University Press, Cambridge,
- Syakila A, Kroeze C (2011) The global nitrous oxide budget revisited. Greenhouse Gas
- Massurement and Management, 1, 17–26.

 Thornton PK, Herrero M (2010) Potential for reduced methane and carbon dioxi emissions from livestock and pasture management in the tropics. Proceedings of the
- National Academy of Sciences, 107, 19667–19672.
 Tiemann LK, Grandy AS, Atkinson EE, Marin-Spiotta E, McDaniel MD (2015) Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecology Letters, 18, 761–771.
- Tilman D, Clark M (2014) Global diets link environmental sustainability and human
- health. Nature, 515, 518 522.
 Trettin CC, Jurgensen MF (2008) Carbon cycling in wetland forest soils. In: The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (eds.) Kimble JM, Heath LS, Birdsey RA, Lal R), pp. 311 331. Lewis Publishers, Boca
- Trost B, Prochnow A, Drastig K, Meyer-Aurich A, Ellmer F, Baumecker M (2013) Irrigation, soil organic carbon and N2O emissions. A review. Agrenomy for Sustainable
- parion, sou organic carbon and N2O emissions. A review. Agronomy for Sissuotusus Development, 33, 733–749. sänen M, Ylänne H, Kaarlejärvi E, Sjögersten S, Oloísson J, Crout N, Stark S (2014) Consequences of warming on tundra carbon balance determined by reindeer grazing history. Nature Climate Change, 4, 384-388.
- Van Oost K, Quine TA, Govers G et al. (2007) The impact of agricultural soil erosion on the global carbon cycle. Science, 318, 626–629.



Acronym: ConnectinGEO
Project title: Coordinating an Observation Network of Networks EnCompassing sa Tellite and IN-situ to fill the Gaps in European Observation

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural resources and raw materials

22 K-H ERB et al.

Venäläinen A, Rontu L, Solantie R (1999) On the influence of peatland draining on local climate. Boral Environment Research, 4, 89–100. Verburg PH, Crossman N, Ellis EC et al. (2016) Land system science and sustainable

ent of the earth system: a global land project perspective. Anthropocene,

Verkerk PJ, Levers C, Kuemmerle T, Lindner M, Valbuena R, Verburg PH, Zudin S (2015) Mapping wood production in European forests. Forest Ecology and Management, 357, 228 238.

Verma A, Tyagi L, Yadav S, Singh SN (2006) Temporal changes in N2O efflux from cropped and fallow agricultural fields. Agriculture, Ecosystems and Environment,

Verstraeten WW, Muys B, Feyen J, Veroustraete F, Minnaert M, Meiresonne L, De Schrijver A (2006) Comparative analysis of the actual evaportanspiration of Flem-ish forest and cropland, using the soil water balance model WAVE. Hydrology and Earth System Sciences, 9, 225–241.

Circa S, Luysaert S, Pefuela S, et al. (2012) Fertile forests produce biomass more efficiently. Ecology Letters, 15, 520 526.

Vilén T, Gunia K, Verkerk PJ, Seidl R, Schelhaas M-J, Lindner M, Bellassen V (2012)

Reconstructed forest age structure in Europe 1950 2010. Forest Ecology and Manage-

moni, 285, 208 218.
Vitousek PM, Naylor R, Crews T et al. (2009) Nutrient imbalances in agricultural development. Science, 324, 1519–1520.
van Vhet N, Mertz C, Heisimann A et al. (2012) Trends, drivers and impacts of

changes in swidden cultivation in tropical forest-agriculture frontiers: a global assessment. Global Eurobromental Change, 22, 418-429.
Wang S, Davidson A 20097 Impact of climate variations on surface albedo of a temperate grassland. Agricultural and Forest Meteorology, 142, 133-142.

Wang Z, Chappellaz J, Park K, Mak JE (2010) Large variations in southern hemi-sphere biomass burning during the last 650 years. Science, 330, 1663–1666. Ward DS, Kloster S, Mahowald NM, Rogers BM, Randerson JT, Hess PG (2012) The

changing radiative forcing of fires: global model estimates for past, present and future. Atmospheric Chemistry and Physics, 12, 10857–10886.

van der Werf GR, Randerson JT, Giglio L, Gobron N, Dolman AJ (2008) Climate con-

trols on the variability of fires in the tropics and subtropics. Global Biogeochemical

m der Werf GR, Randerson JT, Giglio L et al. (2010) Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997 2009). Atmospheric Chemistry and Physics, 10, 11707–11735.

Westholm E, Lindahl KB, Kraxner F (2015) The Future Use of Nordic Forests: A Global Perspective. Springer, Heidelberg, Germany.

Wicklein HF, Ollinger SV, Martin ME et al. (2012) Variation in foliar nitrogen and

albedo in response to nitrogen fertilization and elevated CO2. Occologia, 169, 915

recidimyer C, Akagi S, Yokelson R, Emmons L, Al-Saadi J, Orlando J, Soja A (2011)
The Fire Inventory from NCAR (FINN): a high resolution global model to estimate the emissions from open burning, Geoscientific Medel Development, 4, 625–641.

van Wilgen BW, Govender N, Smit IPJ, MacFadyen S (2014) The ongoing devel ment of a pragmatic and adaptive fire management policy in a larg savanna protected area. Journal of Environmental Management, 132, 358–36

Wint W, Robinson T (2007) Griddel linestock of the world 2007. Food and Agriculture
Crganization of the United Nations, Washington, D.C., 138 pp.
Wirsenius S (2003) The biomass metabolism of the food system: a model-based sur-

vey of the global and regional turnover of food biomass. Journal of Industrial Ecol-

959, 7, 47 80. Wisser D, Frolking S, Douglas EM, Fekete BM, Vörösmarty CJ, Schumann AH (2008) Global irrigation water demand: variability and uncertainties arising from agricul-tural and climate data sets. Geophysical Research Letters, 35, L24408.

Wolf B, Zheng X, Brüggemann N et al. (2010) Grazing-induced reduction of natural nitrous oxide release from continental steppe. Nature, 464, 881–884.
Wong PP, Losada IJ, Gattuso JP et al. (2014) Coastal systems and low-lying

areas. In: Climate change 2014: Impacts, Adaptations, and Vulnenshility, Part A. Global and Sectional Aspacts. Contribution of Working Goorge II to the Fifth Assessment Report of the Intergorenomental Panel on Climate Change (eds Field C, Bartros VK, Dolkem D), Mach NJ, Mastrandrea MD, Bilir TE, Chatterjee M, Bil KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL), pp. 361 409. Cambridge University Press, Cam-

Yoo CY, Pence HE, Hasegawa PM, Mickelbart MV (2009) Regulation of transpiration

Yoo C, Yence HE, Hasegawa JM, Mickelbert MV (2009) Regulation of transpuration to improve corp water use. Critical Reviews in Plant Science, 28, 410–431.
You L, Wood S, Wood-Sichra U, Wu W (2014) Generating global crop distribution maps: from census to grid. Agricaltural Systems, 127, 53–50.
Zarin DJ, Davidson EA, Bronditio E et al. (2005) Legacy of fire slows carbon accumulation in Amazonian forest regrowth. Frontiers in Ecology and the Environment, 3,

Zona D, Janssens IA, Gioli B, Jungkunst HF, Serrano MC, Ceulemans R (2013) N2O fluxes of a bio-energy poplar plantation during a two years rotation period. GCB Bioenergy, 5, 536-547.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Summary of data status and methods.

Table S1. Selected management activities

Table S2. Estimates of management intens

Table S3. Evaluation of the biophysical and biogeochemical effects of each of the reviewed management activities with the reference ecosystem considered and the processes taken into account for the evaluation.

© 2016 John Wiley & Sons Ltd, Global Change Biology, doi: 10.1111/gcb.13443

Jules-Plag, S. and Plag, H.-P., 2016. Supporting Agenda 2030's Sustainable Development Goals - Agend-Based Models and GeoDesign. ApoGeoSpatial, 31(4), 24-30, Fall 2016.

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In October 2015, the United Nations' Plenary agreed on Agenda 2030, the "Road to Dignity," as the Secretary General of the United Nations denotes it, which aims to achieve seventeen ambitious Sustainable Development Goals (SDGs) by 2030. The SDGs cover almost all areas of human activities and their impact on Earth's life-support system (Table 1).

THE COMPLEX SYSTEM CHALLENGE

Each of the broad goals has a set of associated tangible targets. Each target comes with a set of target-specific indicators to measure the progress towards the targets. Making progress towards these targets will require the development of policies and the implementation of specific actions that can facilitate this progress.

It is a foregone conclusion that due to the broad nature of the goals and the global intergovernmental involvement achieving each individual goal presents a complex system challenge. All goals pose highly complex problems to society. For many of the goals it is not evident that they are achievable or achievable by 2030. For example, SDG 1 aims at "Ending poverty in all its forms everywhere." However, the absolute number of people living in extreme poverty has not changed very much since 1800, when an estimated 95% of the global population of close to 1 Billion was living in extreme poverty, although the fraction has gone down very much due to a rapid growth in population since then. Some goals may not be understood in the same way in different countries and cultural settings. For example, SDG 5 has the aim to "Achieve gender equality and empower all women and girls," and it is not clear that this goal is understood across all cultural and religious settings in the same way. An important question to ask is whether the targets as they are defined will actually bring us closer to the goals. This question can only be answered by fully acknowledging the complex challenge each of the goals presents to society. There are research needs to better understand the systemic conditions that are required in order to make progress toward the targets1 and to assess to what extent reaching the targets also implies reaching the goals.

Another challenge is the interconnected nature of the goals and targets, which requires straddling the interests of different policymaking departments at national levels. For example, how can conflicting requirements for achieving "No Poverty" (Goal 1) and "Zero Hunger" (Goal 2) on the one side and "Life Below Water" (Goal 14) and "Life on Land" (Goal 15) on the other side be resolved? Additionally, the interconnected nature of the goals and targets poses a cross-country challenge considering the different interests and priorities of policymakers in different countries due to inherent differences in cultures and the perception of risk. The priority given to sustainability over other goals also differs from country to country and policymaker to policymaker.

Together, this mesh of issues presents a challenge to achieving the overarching objective of putting the world on a sustainable course. It is clear, however, that making progress towards the SDGs requires Earth observation and science support to address the questions that need to be raised for each goal:

- 1. To what extent are the goals achievable?
- 2. Are the goals well-defined and understood in different countries in comparable ways?
- 3. How can the complexity of the goals and associated targets be accounted for in policymaking?
- 4. Are the targets sufficiently focused on achieving the goals?
- 5. What policies and actions can facilitate progress towards the targets?





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6. Are the indicators well-defined and providing a measure of progress towards the targets and goals?

Open data, as strongly promoted by the Group on Earth Observations (GEO), is mandatory for the monitoring of progress towards the SDG targets,2 and a refocusing of Earth observations and science support on the needs of the Agenda 2030 is central for making progress in the global effort for sustainable development.3 The GEO Initiative 18 "Earth Observations in Service of the 2030 Agenda for Sustainable Development" facilitates Earth observation-based support for the Agenda 2030. However, answering the questions requires more science-based tools. Here, we look at the capability of two approaches to addressing some of these questions. We look at the benefits and limitations of an Agent-Based Model (ABM) approach and a GeoDesign approach.

TABLE 1: The Agenda 2030 Sustainable Development Goals

GOALS	DESCRIPTION OF GOALS
1. No Poverty	End poverty in all forms everywhere
2. Zero Hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3. Good Health and Well-being	Ensure healthy lives and promote well-being for all at all ages
4. Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5. Gender Equality	Achieve gender equality and empowerment for all women and girls
6. Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all
7. Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all
8. Decent Work and Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9. Industry, Innovation and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10. Reduced Inequalities	Reduce inequality within and among countries
11. Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient and sustainable
12. Responsible Consumption and Production	Ensure sustainable consumption and production patterns
13. Climate Action	Take urgent action to combat climate change and its impacts
14. Life Below Water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15. Life on Land	Sustainably manage forests, combat desertification, and halt and reverse land degradation, halt biodiversity loss
16. Peace, Justice and Strong Institutions	Promote just, peaceful and inclusive societies
17. Partnership for Goals	Revitalize the global partnership for sustainable development

AGENT-BASED MODELS APPLIED TO GENDER INEQUALITY

Equation-based models have very limited value for problems as complex (and wicked) as reaching the targets and SDGs4. The advantage of ABMs is in the ability to provide an environment for us to experiment and explore when we are not totally clear on all of the issues impacting a problem. Predictions can come later when we are better informed and the explicit nature of the ABM has provided tested evidence of certain results. During the programming phase of ABM development,





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we need to formulate a clearly defined problem because computers are not equipped to handle the ambiguity of an ill-defined concept.

This is where the power of the ABM manifestation is twofold. Firstly, due to the need for formalized rules, we can look at and have a better understanding of the impact of the assumptions that are made in our interpretation of the complex system (i.e., system composition such as boundaries, time-frame, scale, etc.). It allows us to look at various scenarios, test assumptions, assess internal model consistencies, and address sensitivities such as relation to data. Experimentation with the ABM helps us to identify the most relevant aspects and the core issues impacting our goals.

ABMs provide avenues for the incorporation of domain expertise in a rigorous manner. With this, the ABM development also guides data collection and illuminates the core dynamics4. The iterative process of ABM development facilitates a more defined and eventually more refined model, ultimately giving us better direction with respect to where efforts should be placed to arrive at the desired goal.

The second benefit of the formalization of rules is that the model can be generalized and applied over different domains, providing the value of repeatability.

To illustrate the versatility of ABMs, we look at Goal 5 (Gender Equality, see Table 1). The forms of gender inequality differ across cultural regions, and the spectrum of economic and social barriers for progress towards the goal has considerable spatial variability. It would be impossible to take a comprehensive look at the scope of this goal, so here one branch of policy support is considered.

On a global scale, economic gender inequality is evident in the fact that 70% of all work is carried out by women but they only earn 10% of the global income. A specific example is subsistence farming: In societies with a large fraction of subsistence farming, the majority of the subsistence farming work is carried out by women. One of the major hurdles to gender equality in these societies is a woman's inability to own land and gain access to financing. Most of the land is owned by men or by tribal organizations dominated by men. Most financing goes to men, thus solidifying and continuing the cycle of gender inequality. This aspect of gender inequality is broadly addressed by Target 5.a.:

5.a: Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws.

This target is open to interpretation and reinterpretation by all countries and policymakers. The indicators for Target 5.a are more specific, adhering to a metric. They however are decoupled from other relevant factors:

5.a.1: (a) Percentage of people with ownership or secure rights over agricultural land (out of total agricultural population), by sex; and (b) share of women among owners or rights-bearers of agricultural land, by type of tenure.

5.a.2: Percentage of countries where the legal framework (including customary law) guarantees women's equal rights to land ownership and/or control.

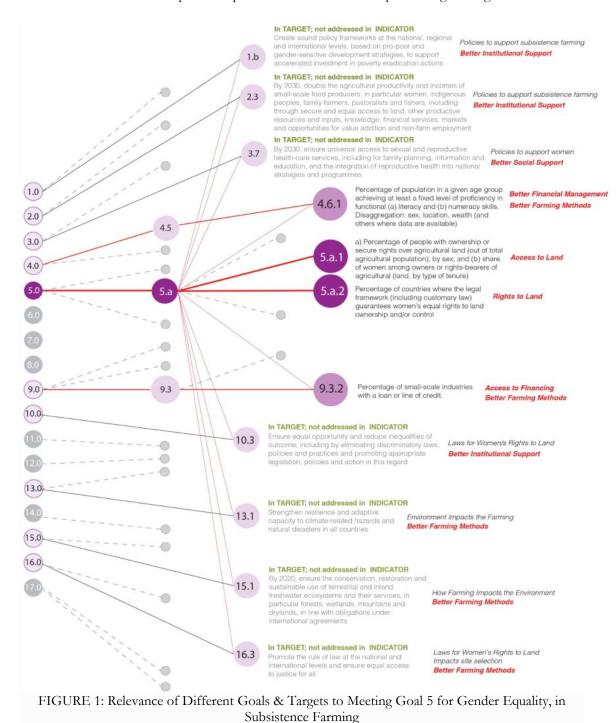
In order to explore the variables associated with these indicators, the factors that directly and indirectly impact a woman's ability to conduct subsistence farming have to be considered. The complexity involved in determining these impacts is presented in **Figure 1**. Based on the issues and the broad nature of the goals and targets, it is necessary to combine the goal-based "top down" approach with a practical "bottom up" approach. The "top down" approach facilitates a



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transportable decision support for all the SDGs, while the "bottom up" approach considers the individual factors and their specific impact on the indicator for a specific target and goal.





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As an initial step, we have developed an ABM for subsistence farming. The aim of the ABM experiment is to determine the factors that impact gender equality through land ownership and access to financing in support of subsistence farming by addressing the questions:

How does distribution of land title impact the success of female farmers?

How does access to financing impact the success of female farmers?

How does discrimination at market impact the success of female farmers?

How does climate change impact the success of female farmers?

Based on the results, what are the apparent gaps that exist between the SDG indicators and the factors the analysis identify as impactful?

Based on the results, what are the policies that can be put into place to help support the success of female farmers?

Policy options in the ABM to increase equality are those that impact land ownership and access to financing. The initial exploratory system model simulates the seasonal cycle of buying seeds (including getting financing, if needed), seeding, growing, harvesting, and utilizing (marginal) gains. The agents are the male and female farmers, land-owner societies, markets to buy seeds and fertilizers and sell produce, traditional financial sources (banks) and micro-financing actors. This model was run over the seasonal cycle for a period of 100 years for many different scenarios.

The information obtained from the analysis provides valuable guidance to the policy conditions that have the potential to improve the success of subsistence farming by female farmers and reduce gender inequality. Decoupling land ownership from financing and introducing quota systems are two potential policy options that may be considered based on the results. Additionally, the results help to identify where there are gaps in the current formulation of targets and indicators towards more goalfocused policy development.

These considerations informed by the ABM experiment provide guidance for further developing the ABM. Of course, access to land and finance are only the start of the subsistence farming process. In order for a woman to maintain land rights she must be successful in the subsistence farming project. As outlined in this simplified view of the interrelationship of the SDGs, better farming methods, institutional support for land ownership and financial support have contributions made through SGDs 1, 2, 3, 4, 9, 10, 13, 15 and to a lesser degree 16. Of course, additional connections with the other goals can be determined with further analysis. Here we focus on the indicators 5.a.1 and 5.a.2 and the relevance of 4.6.1 and 9.3.2. It should be noted that the ABM in its current form does not reflect the full complexity of Target 5.a, but it provides an exploratory and explanatory approach to modeling aspect of Goal 5.

GEODESIGN APPLIED TO SUSTAINABLE CITIES

GeoDesign operates in the realm of infrastructure and the built environment. It facilitates informed development in advance of perceived needs, thus leading to sustainable construction development. The interoperability of technology facilitates integration of the subsystems of research and construction from the macro to the micro level, essentially developing conflict resolution mechanisms. It has the potential to bridge the gaps among science, social needs, economics, and policy, helping to resolve issues involved in designing the built environment. Integrating technologies offers a dynamic way of representing unseen patterns and contextual relationships across global, regional and local areas.

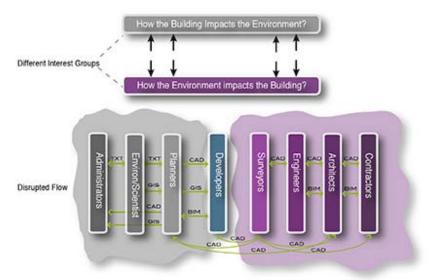


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TRADITIONAL WORKFLOW

FIGURE 2.The traditional workflow in designing the built environment

Figure 2 illustrates the traditional workflow process with disciplines contained in silos. Movement from the administrative stage to the building stage is disjointed and involves a hand-off. This often inhibits the flow of information essential for responsive design. Figure 2 also illustrates the conflicting interests that are inherent in traditional planning of human settlement. Each of the major players serves a different core interest and they speak a different discipline-specific language.

The development of a GeoDesign Hub (Figure 3) made possible by interoperability facilitates the smooth flow of captured data to the disciplines and areas where it is needed in a timely manner. Information created through "data informed processes" re-enters the Hub making the system more intelligent. Feedback from the various disciplines and crowdsourcing further informs the development of educational needs. Thus, the interoperability of technology brings sustainability and its facets, such as disaster risk, resilience, adaptive capacity, and livelihood into the design argument.

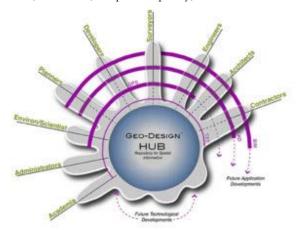


FIGURE 3. A GeoDesign Hub provides an interdisciplinary collaborative platform for the development of options

When interoperability is optimized, development has the ability to go from the point of impetus to examples of potential 'built' models. Similar to the ABM outlined above, it gives us the ability to



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explore scenario iterations in the design process. It allows the signal that triggered the course of development to be amplified throughout the course of development.

Considering Goal 11, which aims to "Make cities and human settlements inclusive, safe, resilient, and sustainable," the GeoDesign approach can help by facilitating a better understanding of why we build and what the goals are. Even more so, it allows us to account for the relation of cities and human settlements to all the other goals.

The targets of Goal 11 focus on access to housing, transportation and green spaces, the promotion of planning and the enhancement of architecture and technology to reduce pollution and improve resilience to climate change, thus minimizing the loss of human life and resources (paying special attention to the protection of natural heritage centers). Similar to the case of Goal 5, many of the other goals have targets that are relevant to the targets of Goal 11 (Figure 4), but the indicators for these targets mostly are not focused on the scope of Goal 11. A particular challenge for the targets of Goal 11 is in the development of indicators for such wide targets. We consider two of the targets relevant to the development of sustainable human settlements:

Target 11.1: By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

The associated indicators shown in Figure 4 appear to be well connected to these targets and providing a measure for progress towards the targets, but the granularity with respect to the goal is



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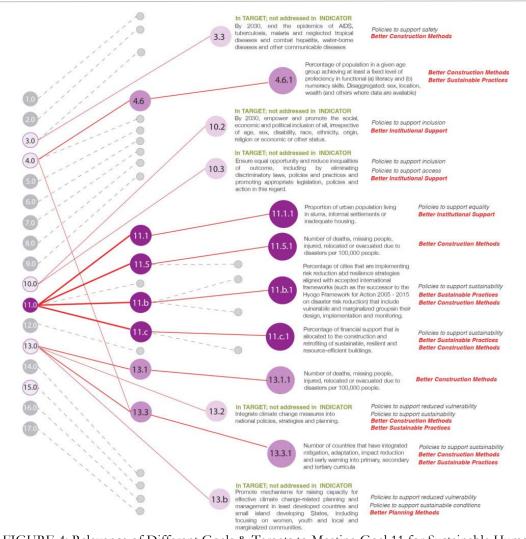


FIGURE 4: Relevance of Different Goals & Targets to Meeting Goal 11 for Sustainable Human Settlements

OUTLOOK

For each of the goals, the questions formulated in the first section need to be answered thoroughly, and this requires a complex system approach. The ABM experiment introduced here underlines the versatility of ABMs for interdisciplinary and collaborative studies informing the development of policy that facilitates progress towards the targets. The GeoDesign Hub is an excellent candidate for a collaborative platform for those goals related to the built environment and its impact on society and environment. It will be important to link both the ABMs and GeoDesign Hubs to a comprehensive and open database integrating environmental with socioeconomic data and statistics. The efforts currently underway in GEO towards open and integrated data and knowledge and the linkage to models are an important development in this direction. However, it is clear that the diversity and breadth of the goals require a hybrid approach, as no one method can be a "catch-all." The examples considered here demonstrate the importance of the interaction between goals and targets and the need to capture the factors that play a role across sets of targets and goals.

References

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Gaps in European Observations

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate, natural recourses and raw materials.

- 1. Jules-Plag, S. and Plag, H.-P., 2016. Supporting the Implementation of SDGs. Geospatial World, August 15, 2016.
- 2. Ryan, B., 2016. Open Data for Sustainable Development. Geospatial World, August 14, 2016.
- 3. Rehka, B., 2016. Geospatial Data: Key to Achieve SDGs. Geospatial World, August 10, 2016.
- 4. Epstein, J., 2008. Why Models. Journal of Artificial Societies and Social Simulation, 11(4), 12. See http://jasss.soc.surrey.ac.uk/11/4/12.html.

Jules-Plag, S., Plag, H.-P., 2016. Supporting the Implementation of SDGs. Geospatial World, On-line publication on August 15, 2016. http://www.geospatialworld.net/article/supporting-implementation-sdgs/.

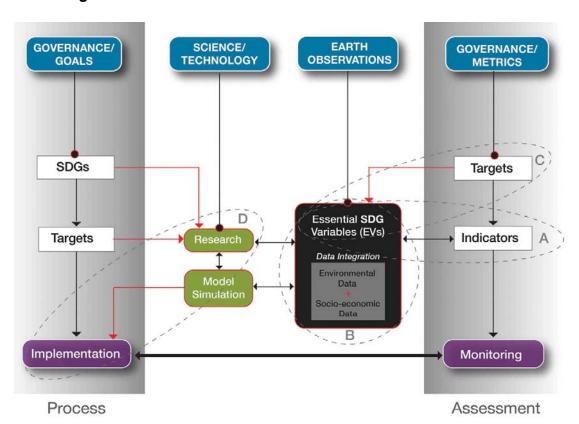


Figure 1: Relevance of earth observations and science and technology support for the implementation and monitoring of progress towards the SDGs and associated targets

Geospatial data, including observations of the natural and build environment and data on the socioeconomic system, will be crucial for both the monitoring of progress towards the targets and the planning of actions to make progress

The Agenda 2030 agreed upon by the United Nations in 2015 aims to achieve 17 Sustainable Development Goals (SDGs) addressing almost all societal, economic and environmental issues impacting the sustainability of our modern global society. Each of the goals comes with a set of specific targets. In order to monitor progress, a monitoring framework consisting of currently 240 indicators has been developed. The governments of the world are challenged with the development







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of policies and the implementation of actions that would lead to progress towards these ambitious goals and their associated targets.

Science and technology support is needed to inform policy development and to monitor progress (Figure 1). Geospatial data, including observations of the natural and build environment and data on the socio-economic system, will be crucial for both the monitoring of progress towards the targets and the planning of actions to make progress. The formal monitoring of progress towards the targets is based on the monitoring framework defined by the Interagency and Expert Group on SDG monitoring (IAEG-SDGs) and accepted by the United Nations Statistical Commission. The monitoring framework has defined indicators for each of the targets. For many of the currently 240 indicators traditional earth observations (EO) are required for quantification, and even more of the indicators require information on the built environment. The Group on Earth Observations (GEO) in its GEO Initiative 18 (GI-18) is developing methods for the quantification of those indicators that depend on EOs for quantification (A in Figure 1). The Horizon 2020 Project "ConnectinGEO" developed a goal-based approach to the identification of essential variables and applied this approach to the SDG indicators.

This research showed that only some of the SDG Indicators require traditional EOs of the natural environment for quantification, while many of the essential variables of the SDG monitoring framework are related to the built environment. This brings up the question to what extent some of these essential variables could be extracted from available earth observations or gathered by using Big Data analysis, citizen scientists, the Internet of Things and other forms of crowdsourcing. However, the integration of the new data, including data from "human sensors", into an integrated database available for analysis and models remains a challenge.

For many of the indicators, the integration of socio-economic statistical data with environmental data is of importance (B in Figure 1). It is anticipated that GEO could use it convening power to facilitate this integration and develop the Global Earth Observation System of System (GEOSS) towards the platform for this integration.

Applying the goal-based approach to the SDG Targets (C in Figure 1) shows that many of the targets would benefit from indicators that are directly related to the natural environment. A revision of the monitoring framework could take this finding into account and account for the linkage of the socioeconomic and environmental aspect reflected in the SDGs.

Besides supporting the monitoring, there is an urgent need to support the planning of actions and the development of policies that would facilitate progress towards the SDG targets (D in Figure 1). In some cases, research is needed to better understand the causes of the current problems and to develop the avenues to more sustainability. The EOs are important for most of this research. For many of the goals, tools to assess the impact of actions and policies are lacking and models need to be developed. In order to capture the complexity these models need to embrace a hybrid approach. To capture the complexity, agent-based models will be crucial. The development and validation of these models depend on a number of factors. The former depends on how well the real world has been modeled and applied to the agent-based model. It has to be ensured that the best available modeling parameters and framework is applied by coupling the agent-based model with existing models. In applications associated with the built environment it would be prudent to couple a Geodesign model with the agent-based model. Data and knowledge integration can be achieved using the already developed concepts of geo design. A geo design hub can be a starting point for the integration of built and natural environment with socio-economic data and support policy development (Figure 2). A combination of such a hub with a model Web to answer 'What-if'



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question can help to facilitate cross-domain data integration. To promote such interdisciplinary and cross-domain tools, relevant stakeholders need to see benefits that they cannot achieve on their own.

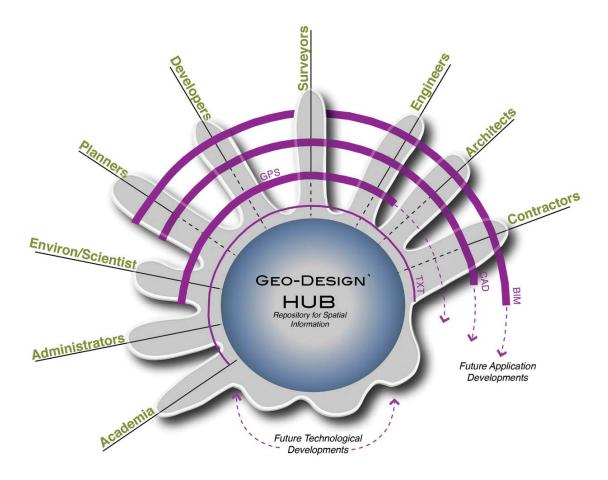


Figure 2: A Geo-Design Hub combines components of simulation tools for the assessment of policy impacts

Similarly, environmental or sociological models can be coupled with the agent-based model. Validation of the agent-based models to assess policy impacts will to a large extent depend on integrated geospatial environmental and socio-economic data (Figure 3).

While data availability is important and necessary, it is not a sufficient condition for the support of SDG implementation and monitoring. The decision makers on SDG implementation are normally far away from data on the value chain from EOs to end users and more interested in information or knowledge. Thus, there is a need for a transition from data to information to knowledge and the development of tools that provide access to knowledge. In this process, it is important that these tools are co-design with the end users. Importantly, research on how decisions are made and what type of knowledge might be needed for that would provide a basis to generate the tools for the decision makers to create the knowledge as needed instead of delivering a range of predefined knowledge products. Currently, most of the data delivery, information and knowledge systems have a push component to push out what providers created while a pull component to create the knowledge when needed does not exists. In order to provide usable support for both the implementation and





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monitoring of SDGs, a pull component needs to be developed in a co-design and co-creation process.

Progress towards open data has been a success over the recent years and GEO played an important role in this. For the integration of socio-economic and environmental data, more progress is needed. Open data and the democratizing of access to data and information are very important for the success of the Agenda 2030 particularly for the buy-in of a broad range of stakeholders. But equally important is open knowledge and a democratizing of access to knowledge derived from EOs and other data. Policies that would support the integration of socio-economic and environmental data, support cross-domain collaborations, open data and open knowledge, and facilitate the development of cyber infrastructure for data integration and tool development would be beneficial for the Agenda 2030 and the implementation and monitoring of the SDGs.

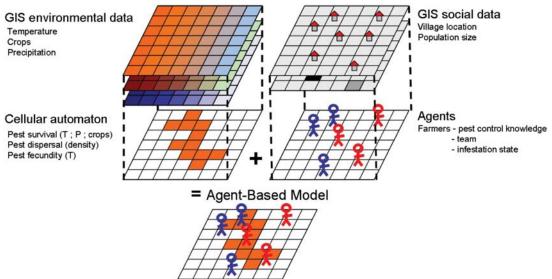


Figure 3: Agent-based models coupled with geospatial information for the assessment of policy impacts. From Rebaudo et al., 2011, JASSS, 14, 7

GEO can use its convening power to bring together the groups that can achieve the identification of all relevant EVs for both the current and a future updated monitoring framework and the integration of socio-economic and environmental data. The Socio-Economic and Environmental Information Needs Knowledge Base (SEEIN-KB), which is currently under development in the GEO Foundational Task GD-09 "Knowledge Base Development" will be an important tool for this important work. GEO also has sufficient involvement of Science and Technology communities to facilitate support for the implementation of the SDGs. An important task for GEO is to establish a working relationship with the IAEG-SDG to participate in the review of the current monitoring framework.

The GI-18 is strongly focusing on the development of training and capacity building programs directly related to the use of EOs for the monitoring of the SDGs. The implementation plan of GI-18 includes a number of tangible goals to be achieved by 2020. The development of toolboxes supporting the implementation of SDGs is an important contribution to this effort. The global nature of GEO allows for actions that lead to capacity building on a global scale.

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Plag, H.-P., Masó, J. (eds.), 2016. In Situ Observations: Coordination Needs and Benefits. GEO Secretariat, Geneva, Switzerland. 36 Pages. Produced within the GD06 community.

In Situ Observations: Coordination Needs and Benefits

Report Compiled by GD-06 Task Team



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Earth observations from diverse sources, including satellite, airborne, in situ platforms, and citizen observatories, when integrated together, provide powerful tools for understanding the past and present conditions of Earth system components, as well as the interplay between them. GEO is a facilitator of policy-level dialogue on the importance and coordination of Earth observation systems (including ground-, air-, water- and space-based sensors, field surveys, and citizen observatories).

Systems for in situ observations (i.e. all ground, water- and airborne observations excluding spaceborne observations) are diverse and there is no single global group responsible for their overall coordination. One of the key recommendations in the GEO Evaluation Report for the first GEO decade recommended the "Creation of a high-level task force to promote the incorporation of in situ data into GEOSS." Subsequently, the GEO Strategic Plan 2016-2025 underlined the importance of coordination and improvement of in situ observation networks. Based on the guidance and recommendations, the GEO In Situ Task GD-06 "GEOSS In Situ Earth Observation Resources" was defined in the GEO 2016 Work Programme.

Coordination of in situ Earth observations is not an easy task. Even a simple survey of in situ coordination groups leads to a large, incomplete and very complex system. During the preparation for the Task, a brief report was prepared and finalized in early 2016. This report summarizes the state of in situ Earth observation community, discusses the benefits of coordinating in situ observations, identifies challenges for this coordination, and provides recommendations on how to proceed. The recommendations were taken into account in developing the team and work plan for GD-06. As an initial activity, the GD-06 Task Team decided to prepare a report on the status of global in situ observation networks and existing frameworks for their coordination, include options for new in situ measurements and coordination scenarios. The present document is the initial outcome of this activity, which has been conducted during 2016. It is planned to continue this assessment in the next years and to prepare a more comprehensive and conclusive report.

SCOPE AND OBJECTIVE OF THE DOCUMENT

This report attempts to describe the main characteristics of in situ observation networks and their coordination across domains and regions and to outline steps that could lead to improved coordination. Due to the limited time available for the preparation of the document, the report focuses on example regions, domains, and areas. The conclusions and recommendations may therefore not all generalizable to a global level.



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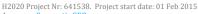
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1. INTRODUCTION

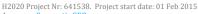
Efforts to develop a framework for the harmonization of Earth observations (EOs), both in situ and from space, have a history that goes back several decades. Here, in situ refers to all land, water, and air based observations, independent of the observing technology and methodology, excluding only space-based observations.

In 1984, G7 initiated the Integrated Global Observing Strategy (IGOS) as a framework for EOs with the goal to identify the essential variables that need to be observed in order to document the changes that are happening on the planet and to ensure that these observations were made available. In 1998, major organizations in the scientific and EO fields established the IGOS Partnership (IGOS-P) in an effort to first identify what needs to be monitored and then to implement the corresponding observing systems. IGOS-P used a well-defined theme approach to define the overall strategy, which "recognises that in reality it is impossible, in one step and for all eventualities, to complete the exercise of defining all the necessary observational requirements and hence the observational systems, data handling, processing and analysis infrastructure for a comprehensive global system. The theme approach allows the coherent definition and development of an overall global strategy whilst recognising the different state and stage of development in different areas. Themes have not a priori been defined, rather it is anticipated that the user communities will identify areas that require action and bring forward themes for agreement and action." (IGOS-P, 2003). The resulting IGOS-P theme reports were excellent outcomes defining observational needs for societally relevant themes. Many of the identified observational needs required in situ observations (see, e.g., Marsh et al., 2004; IGOS, 2006).

In 1984, G7 also gave the mandate to coordinate space-based observation to the Committee on Earth Observation Satellites (CEOS), and CEOS has been the space-based global coordination body since then. No such mandate has been given for in situ observation, and no group for global coordination across the wide range of domains has emerged.

The ad hoc Group on Earth Observations (GEO) was initiated in 2003 (again by the then G8) with the mandate to develop an implementation plan for the Global Earth Observing System of Systems (GEOSS). In the resulting 10-Year Implementation Plan (GEO, 2005a) and the associated Reference document (GEO, 2005b), the importance of in situ observation is emphasized in many places. After being fully established in 2005 with a ten-year mandate to build GEOSS, GEO developed a work plan, which was updated on an annual basis. Unlike IGOS-P where themes emerged from a community and expert-based approach, the GEO Work Plan was structured according to nine predefined Societal Benefit Areas (SBAs). In more recent years, additional Societal Benefit Tasks were added to emphasize large areas that the nine SBAs did not sufficiently cover, including those focusing on Oceans and Society: Blue Planet, Global Land Cover, Global Forest Observation, Global Urban Observation and Information, and Impact Assessment of Human Activities. In several SBAs and SB Tasks, the concept of Essential Variables (EVs) was adopted to identify variables that should be prioritized for observations (see Bombelli et al., 2016). Many of the EVs identified so far require in situ observations either directly or indirectly as groundtruth for space-based observations.

During the first decade, in situ coordination for GEOSS was included in the GEO Work Plan Task IN-01: Infrastructure. This task included coordination of both the space-based and in situ observations. During the transition into the second decade, a dedicated Foundation Task GD-06 "GEOSS In Situ Earth Observation Resources" was defined (see GD-06, 2016) with the mission to assess the needs for coordination of in situ observations and to enable improved cross-domain coordination.





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As the first activity, the GD-06 Task Team is reviewing the levels of coordination in regions and EO domains with the goal to make detailed recommendations on what coordination is needed, what the benefits of improved coordination could be, and what option for coordination should be considered. In the next section, an overview is given of regional in situ observations with a focus on existing coordination mechanisms. Section 3 reviews the current status of in situ observations in selected domains. Section 4 discusses in greater depth issues that require more coordination. Finally Section 5 provides recommendations for both the work to be carried out by GD-06 and for coordination activities by GEO in general.

2. REGIONAL ACTIVITIES

The current organisation of in situ data provision worldwide is very complex and resulting from often uncoordinated initiatives driven by both science and policy-oriented projects, established on different time-scales and involving many different stakeholders. An exhaustive description of the current landscape would therefore be extremely demanding and not achievable within the scope of GD-06. In this section, the current status of in situ observations and their coordination on regional to continental scales is reviewed for selected regions with a focus on data sharing, the relationship between these activities and the SBAs, and the need for additional regional and global coordination. It is planned to add sections for additional regions including North America, Africa, and Oceania in the next version of the document.

2.1 Europe

The European landscape of in situ observation networks, research networks and research infrastructures is very diverse and complex. The complexity is indicated in Figure 1 in Section 2.4.1 below. Over the last 20 years, major efforts have been made to overcome fragmentation due to national boundaries, disciplinary fields, and societal sectors. Although today many initiatives exist or are developing that focus on coordination, there is still an urgent need for integration of networks, research initiatives and research infrastructures, and improvements of the links between those providing data and products and those needing the information for decision and policy making.

2.1.1 Non-profit organisations and networks

There are several non-profit organisations and networks in Europe dealing with coordination of in situ data collection, analysis and distribution. The list of organisations provided below is far from being exhaustive, but represents prominent European networks of, typically public, institutions covering a broad range of thematic themes. It is characteristic that these networks often have a legal mandate and a clear operational perspective implemented via, e.g., establishment and operation of infrastructure, observing systems, and standards.

EuroGeographics: EuroGeographics (http://www.eurogeographics.org/) is the membership association for 60 European National Mapping, Cadastre and Land Registry Authorities from 46 countries. The main objective of EuroGeographics is the further development of the European Spatial Data Infrastructure through collaboration in the area of geographic information and the representation of its members and their capabilities. EuroGeographics' activities focus on supporting relevant European policies, exchange of knowledge in the field of geo-spatial and related information, and harmonising and making available members' national topographic, cadastral and other land information.

EuroGOOS: EuroGOOS (http://eurogoos.eu/) is a grouping of oceanographic institutes in Europe with the objective of fostering, promoting, and implementing cost-efficient operational oceanographic services in Europe. EuroGOOS has 40 members from 19 European countries





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providing operational oceanographic services and carrying out marine research. EuroGOOS coordinates European contributions to sustained marine observing systems and plays a key role in establishing the European Ocean Observing System (EOOS). EOOS will deliver a vision, roadmap and a common focal point for European ocean observing research and technology. EOOS will provide a flexible coordinating framework to help manage and improve the existing observing effort, making it more efficient and effective at different geographical scales, and for different end-users.

EUMETNET: EUMETNET (http://eumetnet.eu/) is a network grouping of 31 European National Meteorological Services. EUMETNET provides a framework to organise co-operative programmes between its members in the various fields of basic meteorological activities such as observing systems, data processing, basic forecasting products, research and development, and training. Through its programmes, the members intend to develop their collective capability to serve environmental management and climate monitoring and to bring to all European users the best available quality of meteorological information.

Eurogeosurveys: Eurogeosurveys (http://www.eurogeosurveys.org/) is an organisation of 37 National Geological Surveys and some regional Surveys in Europe representing national Geological Surveys of the European countries. It promotes the contribution of geosciences to European Union affairs and provides a permanent network between the Geological Surveys and it pursues activities that lie exclusively in the public interest or in the interest of public administration that will benefit from the combined and coordinated expertise of its members and in the direct interest of the EU. One of the key objectives of the Eurogeosurveys is to set up the European Geological Data Infrastructure (EGDI).

Eionet: The European environment information and observation network (Eionet, http://www.eionet.europa.eu/) is a partnership network of the European Environment Agency (EEA) and its 33 member and 6 cooperating countries, aiming to provide timely and quality-assured data, information and expertise for assessing the state of the environment in Europe and the pressures acting upon it. Eionet consists of the EEA itself, six European Topic Centres and a network of around 1000 experts from countries in over 350 national environment agencies and other bodies dealing with environmental information. The Eionet partnership supports the collection and organisation of data and the development and dissemination of information.

EUREF: The Reference Frame Sub Commission for Europe of the International Association of Geodesy (IAG) focuses on the definition, realization and maintenance of the European Geodetic Reference Systems. It engages in the promotion and assistance of the adoption and use of European Terrestrial Reference System (ETRS89) and European Vertical Reference System (EVRS) and the development and maintenance of the EUREF GNSS Permanent Network (EPN), which is the ground based GNSS infrastructure for scientific and practical applications in positioning and navigation. EUREF provides all its products on the "best effort" basis and free of charge to the public. The EPN is a voluntary federation of over 100 self-funding agencies, universities, and research institutions in more than 30 European countries. They work together to maintain ETRS89, which is the single Europe-wide standard coordinate reference system adopted by the European Commission (EC). In addition, the Infrastructure for Spatial Information in the European Community (INSPIRE) Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services established - among other requirements - that the ETRS89 shall be used for the referencing of spatial data sets in INSPIRE. The ETRS89 geodetic reference is widely used in continental Europe. Furthermore, the increasing use of GNSS networks incline countries to use the ETRS89. In addition to its key role in the maintenance of the ETRS89, the EPN data are also used for a wide range of scientific applications such as the monitoring of ground deformations, sea level, space weather and numerical weather prediction. In response to





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evolving user needs and the changing GNSS landscape, EUREF is working for the continuous development of new applications and products through Working Groups and Pilot Projects.

2.1.2 Other examples of European/EU initiatives

In Europe a major development has been the entering into force of the INSPIRE Directive in May 2007, establishing an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment. INSPIRE aims to create an EU spatial data infrastructure, enabling the sharing of environmental spatial information among public sector organisations and better facilitate public access to spatial information across Europe. A European Spatial Data Infrastructure will assist in policy-making across boundaries. Therefore the spatial information considered under the directive is extensive and includes a great variety of topical and technical themes. INSPIRE is based on the infrastructures for spatial information established and operated by the 28 Member States of the European Union. The Directive addresses 34 spatial data themes needed for environmental applications, with key components specified through technical implementing rules. This makes INSPIRE a unique example of a legislative "regional" approach.

In February 2008, the EC Communication 'Towards a Shared Environmental Information System (SEIS)' proposed a solution to Europe's environmental information challenge (http://www.eea.europa.eu/about-us/what/shared-environmental-information-system-1). then, SEIS has become a collaborative initiative of the European Commission together with the EEA and the 39 countries of Eionet. SEIS is a key driver for the growth of the knowledge base, and it integrates a wealth of information from Eionet and other networks and partners, citizen science, crowd sourcing, and new environmental information gathering initiatives such as Copernicus. A key cross-cutting goal of SEIS is to provide access to environmental information, and maximise and expand its use.

The European Marine Observation and Data Network (EMODnet, http://www.emodnet.eu/) consists of more than 100 organisations assembling marine data, products and metadata to make these fragmented resources more available to public and private users relying on quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use. EMODnet is currently in its second development phase with the target to be fully deployed by 2020. EMODnet is a long-term marine data initiative from the European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE) underpinning its Marine Knowledge 2020 strategy. The main purpose of EMODnet is to unlock fragmented and hidden marine data resources and to make these available to individuals and organisations (public and private), and to facilitate investment in sustainable coastal and offshore activities through improved access to quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use.

The United Nations' initiative on Global Geospatial Information Management (UN-GGIM) aims at playing a leading role in setting the agenda for the development of global geospatial information and promoting its use to address key global challenges. In addition to a global committee of experts, UN-GIMM is developing a regional structure, and UN-GGIM: Europe's aim is to ensure that the national mapping and cadastral authorities and national statistical institutes in the European UN Member States, the European Institutions and associated bodies work together to contribute to the more effective management and availability of geospatial information in Europe, and its integration with other information, based on user needs and requirements. UN-GGIM: Europe provides support to the further implementation and alignment of existing legislation, to support relevant ongoing initiatives and proposing actions, to be implemented as far as possible within Europe's existing legal, institutional and operational frameworks addressing issues of geo-information management. The regional intention is to: (a) avoid duplication of efforts; (b) improve the joint







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response to user needs and requirements; (c) encourage geospatial data interoperability, harmonisation and sharing; and (d) optimise the overall management of geospatial information in Europe.

2.1.3 Research networks and infrastructures

In Europe, the landscape of in situ data provision has been established mostly during the last 30 years, in response to policies-related treaties on the one side and research requirements on the other side. For many years, policy- and research-driven initiatives were ran with very limited degree of interaction and/or coordination. While policy and treaty-driven in situ observation networks are often organized at Environmental Ministry level, research-driven in situ observations are instead supported at Research Ministry level using the European Research Infrastructure (RI) funding scheme. It is only over the last decade that more integrated and synergetic approaches were developed to bridge the different initiatives.

The concept of infrastructure supporting environmental research was developed in Europe over the last decade to meet the needs expressed by the scientific communities for continuous observation of natural and anthropogenic processes affecting the environment. Environmental research infrastructures comprise major scientific equipment or sets of instruments, as well as knowledge-containing resources such as collections, archives and thematic data infrastructures and the associated expertise and human resources. They provide support to access data, services and facilities within their own domain.

Each environmental research infrastructure has its own particular set of scientific questions, has identified the stakeholders and the communities to engage and has designed its services for contributing to tackle environmental challenges. Indeed, every RI is designed to provide data and services to a wide range of user communities and as such contributing to cross- and inter-disciplinary research regardless of its own particular field of interest. Research infrastructures are established in the long-term (>20 years) but the process to reach a legal organization (for example as a European Research Infrastructure consortium - ERIC) is complex and can take more than a decade. At present, very few consortia formally exist in the environmental science: ICOS (Integrated Carbon Observing System), IAGOS (In-Service Aircraft for a Global Observing System), EURO-ARGO (European Component of broad-scale global array of temperature/salinity profiling floats), EISCAT-3D (European Incoherent Scatter Scientific Association). Others initiatives, in the different environmental domains, are currently on the European roadmap preparing their long-term sustainable organisation: ACTRIS (Aerosol, Cloud and Trace Gases Research Infrastructure), SIOS (Svalbards Integrated Observing System), EPOS (European Plate Observing System) EMSO (European Multidisciplinary Seafloor and water-column Observatory), DANUBIUS (International Centre for Advanced Studies on River-Sea Systems), EMBRC (European Marine Biological Resource Centre) or ANAEE (Infrastructure for Analysis and Experimentation on Ecosystems). The landscape will continue to evolve in the next years with different updates of the roadmap scheduled in 2018 and 2020. The research infrastructure program is clearly shaping the European Earth observing system for the upcoming decades and will address identified parameter gaps and long-term commitments/sustainability since a very large fraction of observations are still based on short term research funding.

Despite consistent progress, the landscape of European environmental research infrastructures is still too fragmented (see Figure 1 below) and will benefit from further integration and collaborative work. Most of the RIs have similar elements in their structure, e.g. they have instrumentation (such as sensors or laboratories) and have dedicated data systems including elements for data acquisition, management, access, processing, and community support. Therefore, whilst the short/medium-term goal of each RIs is to foster common solutions for promoting integrated use of data through interoperability within its own domain of interest, it is also imperative to find robust yet lightweight





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means to integrate data and RI services across RIs to serve an increasingly multidisciplinary scientific community and progress toward the holistic understanding of planet Earth and its behaviors.

When applicable, integration of research Infrastructures and policy-driven networks is key to enhanced use of data and services, in particular for developing the various segments of the European Copernicus programme framework of Copernicus services. An excellent example is the close cooperation between the European Monitoring and Evaluation Program (EMEP) and ACTRIS. EMEP is a science-based and policy-driven instrument for cooperation in atmospheric monitoring and modelling, emission inventories and projections, and integrated assessment to help solve transboundary air pollution problems in Europe. In order to achieve its mission, EMEP coordinates a long-term network of stations monitoring concentrations and deposition fluxes of various pollutants to test the effectiveness of European policies for air quality. The network includes different type of monitoring stations with most numerous (>100) level 1 sites providing basic chemical and physical measurements of the traditional EMEP parameters, 20 to 30 level 2 sites providing additional physical/chemical speciation of relevant components that is necessary for assessing long-range transport of air pollutants, and <20 research-oriented level 3 stations nominated as "EMEP supersites". Level-3 activities are research-oriented to improve the scientific understanding of the relevant physical-chemical processes in relation to regional air pollution and its control. The research infrastructure for atmospheric research ACTRIS is the funding scheme to ensure long-term sustainability of level-3 activities within EMEP. ACTRIS is central to providing the required tools for calibrating measurements and harmonizing procedures throughout the EMEP network by operating relevant calibration centers. When applicable, ACTRIS and EMEP data are managed using identical procedures and accessible through the same data center. ACTRIS is also the tool to providing guidance for optimizing the observation network by, for example, developing new standard operation procedures for atmospheric parameters. This is a excellent example of integration of existing programs and projects that will help building the European component of an evolving Integrated Global Observing System and GEOSS in a coordinated and more sustainable way.

2.1.4 Examples of cross-cutting coordination

Copernicus: The European Earth Observation flagship programme, Copernicus (http://copernicus.eu/), encompasses three components: Space, In Situ and Services. In situ data are an essential and integrated part of Copernicus, and are used extensively every day by the Copernicus services and the space component to produce products, and deliver services requested by end users. In the context of the Copernicus programme the term 'in situ data' covers a wide range of data: observation data from ground-, sea- or air-borne sensors as well as reference and ancillary data licensed or provided for use in Copernicus.

The primary objective of the Copernicus in situ component is to provide reliable and sustainable access to in situ data to the Copernicus services, relying on existing capacities operated at national and European level, and global observing systems. The component is primarily implemented by the six Copernicus services, and, when overall coordination is required, by the European Environment Agency.

The Copernicus services are mainly responsible for the day-to-day operational managing and processing of data in accordance with their requirements, and for specific data access and cooperation agreements with data providers. Whereas the European Environment Agency focuses on maintaining an overview across all the services regarding in situ data requirements, in situ datasets used by the services, and critical in situ data gaps. To avoid duplication of work, the European Environment Agency is also supposed to deliver data access solutions targeted multiple services, such as the Copernicus reference data access portal, CORDA.



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It is the joint effort of the Copernicus services and the European Environment Agency that operationalise the Copernicus in situ component, but it is the indispensable in situ data contributions from the EU Member States, International and European networks and other data provides that make it possible for the Copernicus services to deliver high quality products to end users.

ENEON: The European Network of Earth Observation Networks (ENEON) is a network of networks aiming to provide an integrated and harmonized perspective on EOs, forecasting and projecting, helping to reduce redundancies and detect gaps in the European EO arena. ENEON is funded by the EC through the H2020 ConnectinGEO project. Main goals are to better coordinate mainly non-space networks, to provide integrated observations and products for resolving interdisciplinary problems, to be a common voice for the observation networks, to facilitate a link between the networks and policy and decision makers, and to improve the sustainability of network. ENEON engages in gap analysis and the prioritization of gaps focusing on in situ data in Europe. ENEON will improve the European in situ participation in GEO and focus the networks on support for the implementation and monitoring of the UN Sustainable Development Goals (SDGs). As an initial activity, dynamic in situ Earth Observation network topography is being compiled and available both as a JSON file and as a graphical interface available http://www.eneon.net/graph. Figure 1 shows the networks and their interrelations based on the information currently in the ENEON network topography database.

ENVRI: In Europe, environmental research infrastructures provide key tools and instruments for the researchers to address specific challenges within their own scientific fields. However, to tackle the grand challenges facing human society (for example climate change, extreme events, loss of biodiversity, etc.), scientific collaboration across the traditional fields will be more and more necessary. The Earth system is highly interlinked and the area of focus for environmental research is therefore our whole planet. Initiatives such as the Environmental Research Infrastructure (ENVRI) EU project bring together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. ENVRI was first created in 2011 to avoid the fragmentation and duplication of efforts, making the Research Infrastructures' products and solutions easier to use with each other, improving their innovation potential and cost/benefit ratio of the Research Infrastructure operations. ENVRIplus is another EU project that continues the efforts in this direction.



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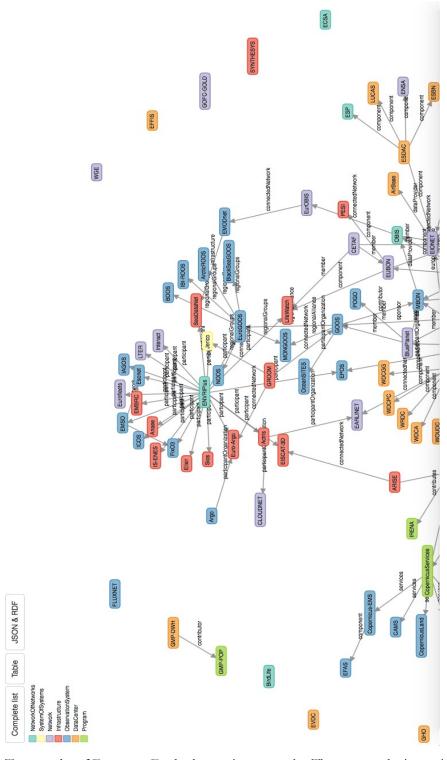


Figure 1: Topography of European Earth observation networks. The topography is continuously revised and updated. For lower part of the diagram, see next page. See text for details.



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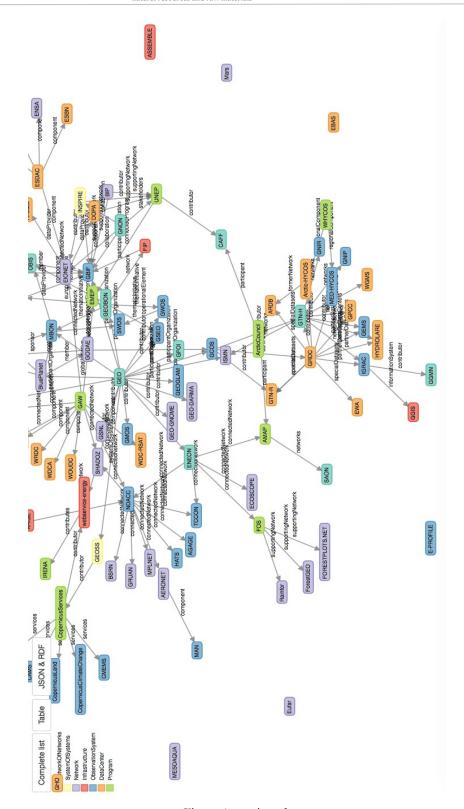


Figure 1 continued.





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2.2 Asia

In this section, initially only two domains have been selected as examples. There are many more areas that will be covered in a future version of the document.

2.2.1 Asia-Pacific Biodiversity Observation Network (AP-BON)

Responding to the call of GEO BON, AP-BON (Asia-Pacific Biodiversity Observation Network) was organized in 2009, one year earlier than CBD COP 10 in 2010. The history of AP-BON until 2012 is summarized by Yahara et al. (2014). The first AP-BON workshop was held from 21-22 July 2009 in Nagoya, and the second workshop was held from 10-11 December 2009 in Tokyo.

Through discussion in those workshops, participants agreed on the following AP-BON visions, which are slightly modified from GEO BON visions:

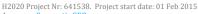
- To establish a coordinated Asia-Pacific network that gathers and shares information on biodiversity and ecosystem services,
- To provide tools for data collection, sharing/exchange, analysis, and synthesis/integration,
- To contribute to improving ecosystem management, sustainable use of biodiversity, and human well-being.

Participants also agreed on the following AP-BON missions:

- Observing and analyzing changes in biodiversity over time.
- Improving delivery of biodiversity information and services to users, particularly decision makers.
- Facilitating linkages among many countries, organizations, and individuals contributing to biodiversity observations.
- Identifying gaps between existing biodiversity observation systems and promoting mechanisms/projects to fill them.

Since 2009, AP BON made good progress in achieving those missions including contributions to the success of CBD COP10 in Nagoya in 2010. As for the first mission, significant progress has been made from 2011 to 2015 through a project "Integrative observations and assessments of Asian biodiversity" sponsored by the Environment Research and Technology Development Fund of the Ministry of Environment Japan. An example of the progress is a series of plot-based surveys on vascular plant richness in Vietnam, Cambodia, Thailand, Myanmar, Malaysia and Indonesia where a total of 115 plots with the same size of 100 m x 5 m have been placed in collaborations with botanists in those countries. In each plot, all the vascular plants including trees, shrubs, herbs, climbers and epiphytes have been recorded, photographed, and collected. The specimens obtained from those surveys have amounted to 24,259 and the number of operational "species" recorded is approximately 19,000. For all specimens, silica-gel dried samples for DNA isolation have been collected. Taxonomic studies of those specimens, using both morphological observations and DNA barcodings, are now in progress and studies until today have resulted in publications of more than 50 new species. In Cambodia, where 22% of forest coverage was lost between 1990 and 2010, permanent plots with historical records were re-surveyed and significant species richness loss was documented (Toyama et al. 2015).

Another example of observing biodiversity is a series of fish survey in Mekong Basin. Kano et al. (2013) developed fish distribution data database that integrated information on freshwater fish specimens collected between 2007 and 2014 from 1571 sites in Cambodia, Laos, Thailand, and Vietnam. Using this database, Kano et al. (2016) assessed risks of hydropower dams and global







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warming on freshwater fish diversity loss. Projections from scenarios assuming the synergistic effects of dams and global warming showed 10-20% higher impact on fish diversity than the scenarios assuming additive effects.

As for the second mission, three volumes of books were published on states and trends of biodiversity in the Asia Pacific region (Nakano et al. 2012, 2014, 2016). Volume 1 includes overviews of biodiversity observations in the Asia-Pacific region, introductions to some useful databases, reviews of new tools and methods, and summaries of states and trends in biodiversity and ecosystem services in the Asia-Pacific region. Volume 2 includes documentations on achievements and challenges of AP BON since Volume 1, introductions to advanced methods of integrated biodiversity observations and reviews of socio-economic aspects of biodiversity. Volume 3 focuses on states and trends of freshwater biodiversity in the Asia-Pacific region.

As for the third mission, an active network of biodiversity observation in the Asia-Pacific region was developed through seven workshops and additional related meetings. Participants of those meetings are from Japan, Mongolia, Korea, China, Taiwan, Vietnam, Laos, Cambodia, Thailand, Myanmar, India, Nepal, Malaysia, Singapore, Brunei, Indonesia, Philippines, Fiji, Palau, Samoa, Papua New Guinea and Australia (as an observer).

The seventh workshop was held from 19-20 February 2016. In this most recent workshop, participants discussed about the following questions;

- Why, what, where do we observe?
- What is APBON's niche?
- How do we promote the organization of BONs in the AP Region?
- How do we strengthen the link of APBON to GEOBON?
- How do we align the biodiversity initiatives that are in the region?

Also, the participants discussed about future plans of AP BON including the publication of AP BON Book Volume 4, training courses of taxonomy and data sharing, summary of national red lists etc. We will continue our efforts to achieve those plants by which we can strengthen our activity of biodiversity observations in the Asia-Pacific region, including data collection, sharing, analysis, and synthesis, and contribution to sustainable use of biodiversity.

2.2.2 AsiaFlux

AsiaFlux is one of regional research networks under FLUXNET (http://fluxnet.ornl.gov/, Figure 2) bringing together scientists from universities and institutions in Asia to study the exchanges of carbon dioxide, water vapor, and energy between terrestrial ecosystems and the atmosphere across daily to inter-annual time scales. Its mission is to bring Asia's key ecosystems under observation to develop and transfer scientific knowledge to ensure quality and sustainability of life in Asia. The purpose of the network is to develop collaborative studies and datasets on the cycles of carbon, water and energy in key ecosystems in Asia, to organize workshops and training on current and related global change themes, and to cultivate the next generation scientists to become informed leaders and stewards with skills and perspectives to address global climate change in Asia.

AsiaFlux was established in 1999, and up to now it has held 11 international scientific conferences and workshops in Japan, Korea, China, Thailand, Taiwan, Malaysia, the Philippines, and India. One of the highlighted activities within AsiaFlux is the capacity building program based on short training courses, training workshops, and joint field practices. The program started in 2006 with financial supports from two projects, namely "Standardization and Systematization of Carbon-Budget Observation in Asian Terrestrial Ecosystems Based on the AsiaFlux Framework" by the Asia-Pacific Network for Global Change Research (APN), and "Initiation of the next-generation AsiaFlux" by



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the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). The main objectives of the program were originally to initiate eddy covariance measurements for energy, water vapor, and CO₂ flux sites and to grow research communities for the sites in each country and region.

Capacity building programs have been planned and conducted depending on each target and need from different countries and regions. The targeted groups have been, among others, beginners in the field, i.e., persons with observation experience of 2-3 years, and young scientists who seek to conduct excellent science and write better papers. The training courses for beginners have been effectively supported by sensor production companies attending the annual meetings of AsiaFlux. The training workshops for students and researchers with limited observation experience have been usually conducted with relatively small numbers of participants (< 15-20 persons) focusing on their own needs, e.g. long-term measurements and data analysis. Such small-scale training courses have been independently held in countries such as Malaysia, Vietnam, and Bangladesh, to raise the scientific level of targeted regions.

Another essential part of AsiaFlux is data sharing based on the AsiaFlux database, which was officially established in 2007, starting from sharing datasets provided by about ten flux sites in Asia. The number of data shared in AsiaFlux database has steadily increased since then. Contributions from domestic and international science projects for various kinds of synthesis studies are indispensable. The participants have shared their quality-controlled datasets to the AsiaFlux database after the synthesis had been completed. In particular, CarboEastAsia (2007-2012), the international joint project among ChinaFlux, KoFlux, and JapanFlux (national networks for China, Korea and Japan) has compiled datasets throughout Asia, and the number of sites has reached approx. 30 including forests, grassland, and agricultural fields. The project has also produced gap-filled datasets, and almost all the data have been shared in the AsiaFlux database. So far, a total of 104 sites across Asia have been registered in AsiaFlux, and the number of sites whose datasets have already been shared in AsaiFlux database is 36 (as of July 2016).

- Continue expanding observation sites and communities in serious 'blank area' in Asia such as in south and southeastern Asia, central Asia, Siberia, and etc.
- Improve new observation techniques and skills, and other trace gas emissions, and their QC/QA, and standardization
- Improve scientific level of Asian-scale international synthesis studies and contribute to global communities more directly.

For more details, see http://asiaflux.net/.



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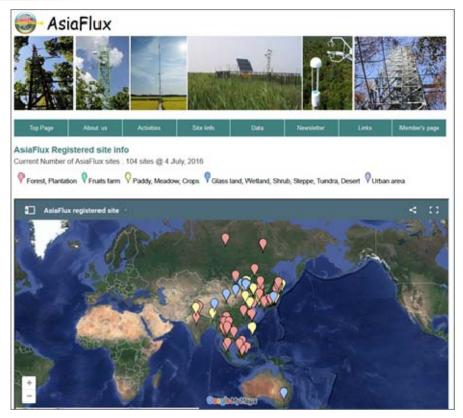


Figure 2: AsiaFlux registered site information (http://asiaflux.net/)

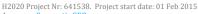
3. ACTIVITIES IN DOMAINS AND SOCIETAL BENEFIT AREAS

In this Section, activities related to in situ observations and their regional to global coordination for selected areas such as Geodesy (Section 3.1) and Climate and Atmospheric composition (Section 3.2) are described as good practices. It is planned to add other areas, such as oceans, meteorology, and land applications. Sections 3.3 to 3.5 describe emerging in situ implementation challenges, which should meet requirements of GEO.

3.1 Geodesy

3.1.1 The Dynamic Earth

The Earth is a dynamic system—it has a fluid, mobile atmosphere and oceans, a continually changing global distribution of ice, snow, and water, a fluid core that is undergoing some type of hydromagnetic motion, a mantle both thermally convecting and rebounding from the glacial loading of the last ice age, and mobile tectonic plates. In addition, external forces due to the gravitational attraction of the Sun, Moon, and planets also act upon the Earth. These internal dynamical processes and external gravitational forces exert torques on the solid Earth, or displace its mass, thereby causing the Earth's shape, gravity, and rotation to change. These dynamical processes also cause natural hazards like earthquakes, tsunamis, volcanic eruptions, tectonic deformations, landslides, deglaciation, sea level change, floods, desertification, storms and storm surges, global warming and many others.







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The world's growing population needs to cope with the consequences of the dynamic Earth system. Towns and cities are spreading into areas of high risk from natural hazards. Major infrastructure is being built in potentially hazardous areas, thereby increasing the vulnerability of society to natural hazards. This infrastructure is increasingly being lost in natural disasters, affecting economies on national and global levels, with severe societal impacts. In addition, the growing demand for access to food, water, energy, and materials is stressing the finite resources of planet Earth. Clearly, dynamic Earth system processes have a major impact on society, both now and in the future. In order to minimize the impact of these processes and to preserve natural resources for future generations, a better understanding of the processes is needed. This better understanding can only be achieved through observations. Only through observations will the predictive capabilities of models be improved, allowing impacts to be assessed and informed decisions to be made.

EOs are needed not only for scientific research but also for societal applications such as disaster prevention and mitigation, managing resources like energy, water, and food, mitigating the effects of climate change, and protecting the biosphere, the environment, and human health. Geodetic observations provide the metrological foundation for EOs and provide the means to determine mass transport in the Earth system. Geodetic observations are therefore a cornerstone of the Earth observing systems needed for scientific research and societal applications.

3.1.2 Geodetic Observations

Geodesy is the science of the Earth's shape, size, gravity and rotation, including their evolution in time. A number of different measurement techniques are used to observe the geodetic properties of the Earth including the space-geodetic techniques of Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSSs) like the US Global Positioning System (GPS), and the French Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system. These space-geodetic observations also provide the basis for the realization of the reference systems that are needed in order to assign coordinates to points and objects and thereby determine how those points and objects move in space and time. For this purpose, the global network of tracking stations is crucial (Figure 3).

The International Association of Geodesy (IAG), a founding association of the International Union of Geodesy and Geophysics (IUGG), is the international scientific organization devoted to the advancement of geodesy. Its origin dates to 1862 when the Prussian General Johann Jacob Baeyer formed the Central European Arc Measurement project with the ultimate goal of precisely determining the size and shape of the Earth. Today, more that 150 years later, the IAG continues to pursue this goal by collecting, analyzing, modeling and interpreting observational data, by advancing geodetic theory through research and teaching, by stimulating technological development, and by providing a consistent representation of the shape, rotation, and gravity field of the Earth and planets including their temporal variations.

With the objective of determining global properties of the Earth like its shape and size, geodesists have always cooperated with each other, both nationally and internationally. To determine global Earth properties, observing stations must be globally distributed, by necessity requiring them to be located in different countries. The organizations operating the stations in the different countries must then cooperate with each other in order achieve the geodesists' objective. This cooperation is accomplished under the auspices of the IAG.





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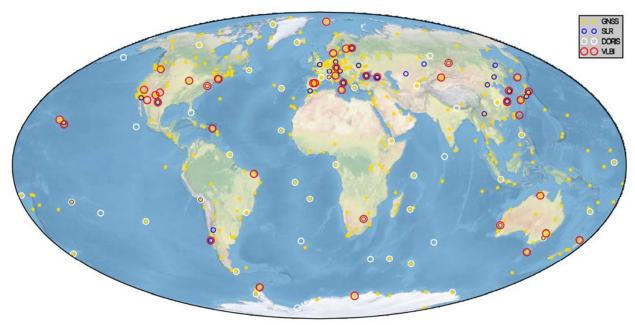


Figure 3. The GGOS network. Locations of the currently operating GNSS (solid yellow circles), SLR (hollow blue circles), DORIS (hollow white circles), and VLBI (hollow red circles) stations in the GGOS network.

The IAG accomplishes its mission to advance geodesy through the activities of its operating components, including its Commissions, Services, and the Global Geodetic Observing System (GGOS). The Commissions represent the major fields of activity in geodesy and represent the IAG in all relevant scientific matters, promoting the advancement of science, technology, and international cooperation in these fields. The four IAG Commissions are: (1) Reference Frames, (2) Gravity Field, (3) Earth Rotation and Geodynamics, and (4) Positioning and Applications.

The IAG Services organize the collection and reduction of geodetic observations and generate the geodetic products needed for scientific research and societal applications. There are currently 14 Services spanning the relevant geometric, gravimetric, oceanographic, and related properties of the Earth. Included amongst these Services are the geometric Services of the International GNSS Service (IGS), the International DORIS Service (IDS), the International Laser Ranging Service (ILRS), the International VLBI Service for Geodesy and Astrometry (IVS), and the International Earth Rotation and Reference Systems Service (IERS). Figure 3 shows the locations of the currently operating stations in the IVS, ILRS, IGS, and IDS networks.

Recognizing the increasingly important role that geodesy plays in scientific research and societal applications, the IAG established the Global Geodetic Observing System (GGOS) in 2003, first as a Project and then, in 2007, as a full component of the IAG. GGOS is meant to be the observing system of the IAG, organizing its technique-specific Services under one unifying umbrella, thereby forming a comprehensive geodetic observing instrument integrating the hitherto separate pillars of geodesy (shape, rotation, and gravity) into one consistent observing system. GGOS works with the other IAG components to provide unique, mutually consistent, and easily accessible geodetic constants, data and products for science and society. In addition, GGOS represents the IAG in the GEO and is IAG's contribution to GEOSS that is being constructed by GEO.

GGOS provides the basis on which future advances in the geosciences can be built. By considering the Earth system as a whole (including the geosphere, hydrosphere, cryosphere, atmosphere and







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biosphere), monitoring Earth system components and their interactions by geodetic techniques and studying them from the geodetic point of view, the geodetic community provides the global geosciences community with a powerful tool consisting mainly of high-quality services, standards and references, and theoretical and observational innovations.

Observations of the Earth's shape, rotation, and gravity provided by the IAG's GGOS and its Services show that they change on a wide range of timescales reflecting the wide range of processes affecting them, from external tidal forces to surficial processes involving the atmosphere, oceans, and hydrosphere to internal processes acting both at the core-mantle boundary as well as within the solid Earth itself. Measurements of the Earth's shape, rotation, and gravity can therefore be used to gain greater understanding of mass transport within the entire Earth system, from tracking water in its various phases as it cycles through the atmosphere, oceans, and land, to crustal deformation associated with tectonic motions and glacial isostatic adjustment, to torsional oscillations of the core.

3.1.3 Terrestrial Reference Frame

Geodetic observations of the Earth's variable shape, rotation, and gravity also provide the basis for realizing the reference systems that are required in order to assign coordinates to points and objects in space and time and to describe the motion of the Earth in space. Two such reference frames are realized by geodetic observations: the terrestrial reference frame and the celestial reference frame. Since the terrestrial reference frame is attached to the Earth and the celestial reference frame is fixed in space, these two reference frames are linked to each other by the Earth's rotation in space.

The most accurate global celestial and terrestrial reference frames available today are the International Celestial Reference Frame (ICRF) and the International Terrestrial Reference Frame (ITRF) that are produced under the auspices of the IERS. The ICRF is represented by a set of estimated positions of extragalactic reference radio sources; the ITRF is represented by a set of estimated positions and velocities of globally distributed reference marks on the solid Earth's surface associated with the VLBI, SLR, DORIS, and GNSS observing stations.

The TRF determined by geodetic measurements is the indispensable foundation for all the sustainable EOs that are used by science and society for so many purposes, including navigation, mapping, surveying, construction, land development, natural resource management and conservation—in fact, all decision-making activities that have a geo-related component. It allows different spatial information, such as imagery from different space and airborne platforms, to be geo-referenced and aligned with each other. And it plays a key role in modeling and estimating the motion of the Earth in space, in measuring change and deformation of all components of the Earth system, and in providing the ability to connect measurements made at the same place at different times, a critical requirement for understanding global, regional and local change. Providing an accurate, stable, homogeneous, and maintainable terrestrial reference frame to support numerous scientific research and societal applications is one of the essential goals of the IAG's GGOS.

The advent of space-geodetic techniques enabled a rapid increase in the accuracy of at least five orders of magnitude of the reference frames mentioned above over the last four decades, and this has contributed to the economic and social development of a modern global society. Many applications of considerable economic value are enabled by precise positioning in a stable reference frame ranging from determining real-estate boundaries









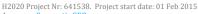
efficiently and with high accuracy (particularly in high-value urban areas), mapping subsurface infrastructure, operating heavy equipment (including mining equipment), navigating human-controlled and autonomous vehicles, improving resource efficiency of agriculture, increasing safety of air traffic, to the docking of large ships in harbours, to name a few. Likewise, many scientific studies depend on observations that require high-accuracy positioning, including, for example, studies of natural and human-made hazards and disaster risk reduction, understanding global and climate change, monitoring sea level rise and groundwater level changes. EO from space and in situ observations depend crucially on the access to long-term stable, accurate reference frames. The importance of the reference frames has been acknowledged in a number of national and international resolutions, most recently in the United Nations General Assembly resolution on Global Geodetic Reference Frames (69/266).

Geodesy uses a range of space-geodetic and traditional techniques with specific strengths and weaknesses to maintain the reference frames. Co-location of in situ components provides the means to interconnect the techniques and to reduce the individual weaknesses and exploit the strengths. Of particular interest are geodetic core stations, which are fundamental for the accuracy and long-term stability of the global celestial and terrestrial reference frames and the Earth orientation parameters (including time keeping) that link these two frames together. The core stations are those where several techniques are colocated allowing the combination of the available techniques for the best possible products. A global tracking network of several hundred stations with one or more of the geodetic techniques is used to realize the global reference frames. The number and spatial distribution of the core stations has a major impact on the overall accuracy and stability of the reference frames and the performance of many societal applications and scientific studies.

Besides the need for co-location to interconnect the techniques, a unique aspect of the geodetic in situ networks is that several techniques depend on coordinated observations of instruments distributed globally and joint analyses of data from the global networks. This need has made global coordination and data sharing an inherent characteristics of geodetic in situ observations. Joint observations, data management, analysis, and product delivery are coordinated by the global geodetic community active in the services of the IAG.

3.2 Climate and Atmospheric composition

The Global Atmosphere Watch (GAW) Programme was created by WMO in 1989 in response to the growing concerns related to human impacts on atmospheric composition and the connection of atmospheric composition to weather and climate. GAW's mission is focused on the systematic global observations of the chemical composition and related physical characteristics of the atmosphere, integrated analysis of these observations and development of predictive capacity to forecast future atmospheric composition changes. These observations and analyses are needed to advance the scientific understanding of the effects of the increasing influence of human activity on the global atmosphere as illustrated by such pressing societal problems as: changes in the weather and climate related to human influence on atmospheric composition, particularly, on greenhouse gases, ozone and aerosols; impacts of air pollution on human and ecosystem health and issues involving longrange transport and deposition of air pollution; and changes in UV radiation as consequences of changes in ozone atmospheric content and climate, and subsequent impact









of these changes on human health and ecosystems. The new GAW implementation plan was published in 2016.

The mission of GAW is to reduce environmental risks to society and meet the requirements of environmental conventions, to strengthen capabilities to predict climate, weather and air quality, and to contribute to scientific assessments in support of environmental policy. For this purpose, GAW supports global, long-term observations of the chemical composition and selected physical characteristics of the atmosphere at different sites around the World, emphasizing quality assurance and quality control, and delivering integrated products and services of relevance to users, in particular for the study of climate change and its impacts.

In providing a comprehensive set of high quality and long-term observations of atmospheric composition GAW supports the United Nations Framework Convention on Climate Change (UNFCCC), especially by contributing to the implementation plan for the Global Climate Observing System (GCOS), the Intergovernmental Panel on Climate Change (IPCC) and to the development of Global Framework for Climate Services (GFCS).

The program is operated through the support of different stakeholders organized either at WMO member state level or, at regional level, as in the case of Europe with the research infrastructure consortia (ICOS, ACTRIS). The importance of atmospheric composition in the above matters was emphasized in resolutions from the Seventeenth World Meteorological Congress, which stressed the need to enhance the capacity of NMHSs to deliver on their mission by developing and improving competent human resources, technical and institutional capacities and infrastructure; particularly in countries where the capability to maintain high standards of observations, data and metadata is problematic. It also included Resolution 60 of the 17th Congress, which urges members to strengthen their support to the framework of the GCOS Essential Climate Variables (ECVs) in the collection and supply of data and products to support the GFCS on a free and unrestricted basis. Among others, GCOS ECVs include data on the composition of the atmosphere including aerosols and their precursors, greenhouse gas and atmospheric ozone data together with climate relevant cryosphere data, including glacial monitoring.

3.3 Food security

The growing global population - coupled with changing patterns of consumption - is increasing the demand for food. Food security relies on various elements related to the availability of safe foods, such as water abundance, vegetation stresses, yield variance and soil quality. Today, with increasingly limited land available for agricultural activities due to it depends mainly on soil fertility and its relationship with the other ecosystems, more intensive food production is resulting in a heightened environment impact. To that end, severe threats linked to agricultural production, as soil degradation and desertification, together with deterioration of water quality and water balance, are widely reported.

Eliminating such effects and guaranteeing food security requires a sustainable intensification of agricultural production that is beneficial in order to minimize yield gap, by identifying the potential scope for raising average yields via optimization of spatially explicit irrigation, fertilization and application of pesticides. Aligned with this rationale is the long-term monitoring of cultivations, soils and food security essential parameters (e.g. soil degradation/acidification/moisture as well as their protection against the water extremes regimes (floods & drought). The collection of high-resolution





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information about key soil properties, the amount of plant available water, nutrients and others which largely affect crop growth remains a challenging task in order to facilitate reduced input agriculture applications.

The improved provision of EO services and improved access to that data, should be at the core of GEO activities. The systematic integration of EO data with high resolution (e.g. spatiotemporal and spectral) relying also on adequate modelling will greatly impact the level of acquired information, enable the evaluation of new service chains and methods and extraction of actionable agricultural knowledge for assessing sustainable agricultural development and food security. As a concrete, sustainable action towards improved access to space borne but also to in situ derived EO data, higher level products, and descriptive metadata, as well as knowledge on existing service chains and processing tools, could act as a catalyst for end-users to preserve soil and water resources from further degradation and adapt the appropriate agro-technical activities accordingly to microclimatic conditions, securing the abundance of healthy crops and yield production yearly. All these will facilitate further the perspective of variable rate application, according to which, agricultural inputs are applied in controlled amounts to the specific parts of the field that requires them.

3.4 Climate Change

Climate change is now affecting every country on every continent. People are experiencing the significant impacts of climate change, which include changing weather patterns, rising sea level, and more extreme weather events. The poorest and most vulnerable people are being affected the most. It is disrupting national economies and affecting lives, costing people, communities and countries dearly today and even more tomorrow. Climate Change is one of the sustainable development goals of UNEA and the recent COP21 Paris climate conference adopted the first-ever universal, legally binding global climate deal to set out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C. The agreement is due to enter into force in 2020.

The greenhouse gas emissions from human activities are driving climate change and continue to rise, reaching every year unprecedented levels. Affordable technology-based or not solutions are now available to enable countries/regions/cities to engage in more resilient economies: renewable energy and other measures can substantially reduce emissions and better predicting capacity can lead to efficient adaptation strategies.

Emissions of pollutants driving atmospheric composition are affecting climate Worldwide and people everywhere. Solutions to reduce emissions therefore require an international level of coordination by widest possible number of countries. Some cooperation is already undertaken within the International Panel for Climate Change and various international treaties. Recently, COP21 agreement in Paris in December 2015 called for "strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making".

A suitable observing system allows for informed decisions in a wide range of policy areas, including climate change and air quality, but also for health, international protocols and research requirements. Such an observation strategy therefore responds to political, societal and economic challenges and to the development of scientific knowledge. The challenges in promoting an observation strategy for the future are therefore tremendous and range from technical issues like the instrumentation to be applied, how to treat data etc. to more political matters like funding and sustainability.

3.5 Sustainable Development Goals



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In 2015, the United Nations agreed on the Agenda 2030, which aims to reach seventeen SDGs addressing almost all societal, economic and environmental issues impacting the sustainability of the modern global society. Each of the goals comes with a set of up to ten specific targets. In order to monitor progress, a monitoring framework consisting of currently 240 indicators has been developed by the Interagency and Expert Group on SDG monitoring (IAEG-SDGs) and accepted by the United Nations Statistical Commission in 2016 as a starting point for the monitoring. The governments of the world are now challenged with the development of policies and the implementation of actions that would lead to progress towards these ambitious goals and their associated targets.

Science and technology support is needed to inform policy development and to monitor progress (Figure 4). Geospatial data including observations of the natural and build environment and data on the socio-economic system will be crucial for both the monitoring of progress towards the targets and the planning of actions to make progress. The formal monitoring of progress towards the targets is based on the monitoring framework defined by the IAEG-SDGs. The monitoring framework has up to two indicators for each of the targets. A first review of the indicator framework by the GEO Initiative 18 (GI-18) showed that many of the currently 240 indicators traditional EOs are required for quantification (Figure 5), and GI-18 is developing methods for the quantification of those indicators that depend on EOs for quantification (A in Figure 4). The Horizon 2020 Project "ConnectinGEO" developed a goal-based approach to the identification of EVs (Plag et al., 2016a) and applied this approach to the SDG indicators (A in Figure 4). This research revealed that a minor fraction of the SDG Indicators requires traditional EOs of the natural environment for quantification, while many of the EVs of the SDG monitoring framework are related to the built environment (Figure 6). A considerable challenge is in the collection of more information on the build environment. This brings up the question to what extent some of these EVs could be extracted from available EOs or gathered by using Big Data analysis, in situ observations, citizen scientists, the Internet of Things and other forms of crowd-sourcing. The Internet of Things, crowd-sourcing, and citizen scientists are promising developments to get the necessary observations. Creating collaborations that lead to the integration of the new data, including data from human sensors, into an integrated database available for analysis and models appears to be a necessity, but developing the concepts and infrastructure remains a challenge.



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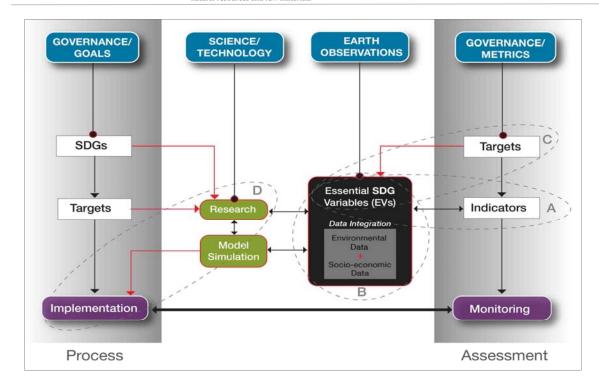


Figure 4: Earth observations and SDGs. Relevance of Earth observations and science and technology support for the implementation and monitoring of progress towards the SDGs and associated targets. See text for details. From Jules-Plag and Plag (2016a).

For many of the indicators, the integration of socio-economic statistical data with environmental data, including in situ observations, is of importance (B in Figure 3). GEO has the convening power to bring the communities together, but to actually achieve the integration, infrastructure is required that provides tangible incentives for working in a cross-domain environment. It is anticipated that GEO could use its convening power to facilitate this integration and develop GEOSS toward the platform for this integration.



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Figure 5: Dependence of SDG indicators on Earth observations. From GEO (2016).

In the ConnectinGEO project, the goal-based approach was also applied to the SDG Target (C in Figure 4), and this analysis revealed that many of the Targets would benefit from indicators that are directly related to the environment. An example is SDG-3 "Ensure healthy lives and promote wellbeing for all at all ages" and the associated Target 3.9: "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination." The Indicators included for this target in the current monitoring framework are 3.9.1 "Mortality rate attributed to household and ambient air pollution" and 3.9.2 "Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe WASH services)." These indicators are focusing on the impacts and outcomes in terms of mortality. However, mortality is not a good indicator for progress towards the target because there is an accumulative effect of air quality that generates a huge time delay between changes in air quality and mortality rates. For example, a decrease in mortality can happen even if pollution is increasing in the short term. The existing SDG

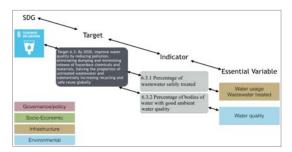


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indicators for Target 3.9 do not account for the time-lagged relation between pollution and mortality. Adding indicators for the state of the system (e.g., long-term changes in air quality) would reduce the time lag between actions taken to make progress towards the targets and a change in the indicators. A similar situation is found for many other Targets. Many of the more environmentally focused indicators would require in situ data for quantification. A revision of the monitoring framework could take this finding into account and account for the linkage of the socio-economic and environmental aspect reflected in the SDGs.

Besides supporting the monitoring, there is an urgent need to support the planning of actions and the development of policies that would facilitate progress towards the SDG Targets (D in Figure 4). For many of the SDGs, research is needed to better understand the causes of the current problems and to develop options that could lead to more sustainability. Both space-based and in situ EOs are important for most of this research. Tools to assess the impact of actions and policies are lacking for most of the SDGs and models capable of answering "What if" questions need to be developed. In order to capture the complexity, these models need to embrace a hybrid approach and require data assimilation. To capture the complexity, agent-based models will be crucial. The development and validation of these models depend on a number of factors. The former depends on how well the real world has been modeled and applied to the agent-based model. It has to be ensured that the best available modeling parameters and framework is applied by coupling the agent-based model with existing environmental models. In applications associated with the built environment it would be prudent to couple a Geo-Design model with the agent-based model. Data and knowledge integration can be achieved using the already developed concepts of Geo-Design. A Geo-Design hub can be a starting point for the integration of built and natural environment with socio-economic data and support policy development. To promote such interdisciplinary and cross-domain tools, relevant stakeholders need to see benefits that they cannot achieve on their own.



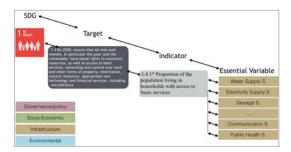


Figure 6: Using the goal-based approach of ConnectinGEO to identify EVs for SDG indicators. For several indicators, traditional EOs are required for quantification (e.g., Indicator 6.3.2; left example), while most indicators require statistical data or observations related to the built environment (e.g., Indicators 6.3.1, left, and Indicator 1.4.1, right). Modified from Jules-Plag and Plag (2016b).

The GI-18 is strongly focusing on the development of training and capacity building programs directly related to the use of EOs for the monitoring of the SDGs. The implementation plan of GI-18 includes a number of tangible goals to be achieved by 2020. We are considering including also the development of toolboxes supporting the implementation of SDGs. The global nature of GEO allows for actions that lead to capacity building on a global scale. The role of in situ observations for the quantification of SDG indicators should be emphasized in the capacity building activities.

An important aspect of the SDGs that is often overlooked is the interdependency of the SDGs. Many of the individual SDGs depend on actions focusing on other SDGs, and capacity building needs to take this into account. For example, restoring ecosystems under several Targets of SDG 15 may be in conflict with SDG1 and SDG2. The example of Mangroves shows that they are connected





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to several SDGs (Figure 7). As a consequence, cross-goal coordination of data collection and integration, including the in situ observations, would have significant benefits for a cross-goal consistent quantification of the indicators.





Figure 7: Cross SDG links. Many of the SDGs are linked to other SDGs and actions to improve progress towards one target may have negative or positive impacts on others. The example of mangroves shows that restoring ecosystems could negatively impact food security or increase inequality or help to reach targets under SDG 14. Modified from Jules-Plag and Plag (2016b).

4 ISSUES REQUIRING GLOBAL COORDINATION

In this section, issues identified so far are summarized for a very limited set of selected areas. It is planned to review more areas in the coming years. The issues addressed include sustainability of existing observation infrastructure, investments for new infrastructure, and emerging technologies and new approaches.

For in situ observation, many observational networks are initially established for research purposes with a limited lifetime. Facilitating the transition from research to sustained long-term operation is an issue recognized by GEO from early on but no process has been developed to identify suitable candidate infrastructures and to facilitate the transition. Another issue requiring more attention is the coordination of the integration of space-based and in situ observations. The analysis of requirements resulting from SDG monitoring also revealed the need for integration of environmental and socioeconomic (statistical) data – a need recognized by GEO from the start, however, without sufficient progress being achieved for this integration. These issues will be addressed by GD-06 in the coming years.

4.1 Sustainability of Existing Measurements for Climate

According to IPCC's latest assessment report, the human influence on the climate system is clear and continued emissions at the current rate will cause changes to all components of the climate system. The universally accepted Sustainable Development Goal 13, calls for urgent actions to combat climate change and its impact; the thrust area 13.3 talks about improved education, awareness and human and institutional capacity for mitigation, adaptation, impact reduction and early warning. A sound base of knowledge and information, derived from high quality climate data is key to tackle the challenges associated with climate change. Systematic long term monitoring of the climate system is not only a fundamental prerequisite to understand both the change and resulting consequences, but is also a prerequisite for making decisions at all levels. The World Climate Conference in 2009 decided to establish the Global Framework on Climate Services (GFCS) as a UN initiative, spearheaded by WMO. The five components (pillars) of GFCS are user-interface platforms, climate service information systems, observation and monitoring, research, modelling and prediction and capacity development. It is clear that the demand from governments, institutions and citizens for more useful and reliable information, products and services is increasing, placing the World Meteorological Organization (WMO) and its Members' National Meteorological and Hydrological Services (NMHSs) in the forefront for the provision of these products and services. Conclusions







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from the Seventeenth World Meteorological Congress stresses the need for enhancing the capacity of NHMSs to deliver on their mission by developing and improving competent human resources, technical and institutional capacities and infrastructure, particularly in countries where capability to maintain high standards of observations, data and metadata is problematic.

As mentioned in the report, the Earth global observing system has improved substantially in the last decades but efforts still are needed to address current gaps and shortcomings, and to continue building on existing observational, data management and exchange systems, adding enhancements where needed to support provision of climate services. Analysis of gaps in the geographical coverage of WMO/GAW climate observations shows that numerous in situ stations have been recently closed or are facing difficulties in reporting information. Many of these stations are actually located in regions where information is crucially lacking. It is important to address the reasons why long-term programs for the provision of ECVs are rarely established in the long-term in many countries. Many hydro-meteorological institutions in charge of weather prediction may not have yet integrated the new GFSC framework in their priority actions, which is perhaps a cause for some of the difficulties. Sustainability of the observing system will require that UN member countries, with their own climate change policies, strategies and action plans, engage in concerted and systematic efforts for integration of climate risk management in development efforts. Use of climate information at the national level plays an important part in the capacity and willingness of countries to maintain and further develop systematic observation and monitoring of climate variables.

The spread and intensity of this engagement varies depending upon the contexts, national circumstances, programs, needs and capacities of different national entities to efficiently make use of data and services provided by GFCS. For the sustainability of the in situ observing component, it seems essential to ensure that climate observations are put to good use in the national level communications on climate change (national adaptation plan, national adaptation plan of action, national mitigation plan, national communications to UNFCCC etc.). This implies that stimulating the demand for climate observations/climate information at the user level in the countries and also raising the expertise of potential beneficiaries would be effective tools to motivate national support of in situ observations for climate. Global cooperation and bilateral partnership between countries are essential to achieving this goal.

4.2 Investigating new in situ measurements

The prioritization of new investments for new in situ measurements is a challenging task, given the limited resources and rapidly increasing demands for new observations resulting from societal challenges. An example is the problem of monitoring progress towards the SDGs, where the SDG Indicators require additional information on the natural and built environment (see Section 3.5 above). Prioritization should be based on a thorough gap analysis and agreed-upon criteria to assess the societal benefits of addressing certain gaps identified in this analysis. In GEO, a number of approaches to gap analysis have been discussed in several Tasks and components, but a thorough gap analysis has not be performed so far. The Task US-09-01 carried out a detailed survey of user needs and identified a list of prioritized observational requirements (GEO, 2012). In Europe, several EC-funded projects have attempted domain specific (e.g., GAIA-CLIM, see van Weele, 2015) and crosscutting gap analyses (e.g., ConnectinGEO, see Plag et al., 2016b).

In support of prioritizing investments for new in situ measurements, it is important for GD-06 to facilitate a comprehensive gap analysis with respect to available and required in situ observations. Such an analysis could be carried out step-wise for regions and specific societal and research challenges.

Here we provide an initial description for selected areas including agriculture, global change, and climate, and we discuss steps toward improved access to data, identifying gaps, and building capacity.



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4.2.1 Improving Agricultural Monitoring

Agriculture monitoring and yield assessment need low-cost efficient methods based on EO technology in conjunction with agro-meteorological modelling. Therefore, new service specifications have been given for deriving EVs relevant for food security. Diversified EO data sets (e.g. imagery) and soil spectra libraries together with their metadata can be exploited for identifying soil and crop attributes and their spatial interrelations in a rapid, precise and inexpensive way for the benefit of all potential users.

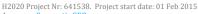
Sensors based on visible, near- and mid-infrared spectroscopy enable the collection of encoding values of soils that are represented in the spectra as absorptions at specific wavelengths of electromagnetic radiation. These can be utilized to describe soil both quantitatively and qualitatively. Currently, advanced technologies are being used to produce miniaturised instruments that are rugged and cheap and that can be used to help extract useful information from the spectra and to enhance our understanding of soil. These recently developed innovative sensors have the potential to be applied to online scanning of soil by a tractor or robot mounted sensor-frame simplifying the laborious and times consuming static sampling procedure. The advancements in utilising mobile proximal soil sensing (PSS) for site-specific crop management show that there are advantages in the PSS technologies, including their ability to enable a range of applications in a variety of operational environments (e.g. ability to operate even during the night due to their own stable lighting conditions). Moreover, the progressive miniaturisation and increased speed of the spectral sensors will enable their use on small-sized airborne autonomous vehicles, such as quadcopters, making spectroscopy even more attractive. Hence, soil and crop spectra can be recorded by imaging from remote sensing platforms with typical super spectral, or hyper spectral capabilities (Figure 8).



Figure 8: Measuring soil and crops. Soil and crop vis-NIR spectra are measured at points or by imaging from various developed platforms by i-BEC

Knowing the spatial and temporal variation of soil properties and nutrients and crop stresses through the availability of hyperspectral georeferenced data allows the establishment of an integrated monitoring and awareness system for assessing yield, water availability and food security via variable rate strategies for crop production.

In this respect, the high spatial and spectral accuracy of the data recorded by the in situ sensors, covering a wide region of the spectral range, can be used to calibrate sensors onboard planes (airborne) or satellites (space-borne) that are used for the development of prescription maps. Hence, the challenge of using multiple satellite missions, together with a large dataset of field spectral measurements will be addressed in the near future.







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4.2.2 Coordinating observing strategy for measuring global changes: from networks to flagship stations

Observations and monitoring are key elements of the emerging Global Framework for Climate Services and, more generally, are fundamental support to climate research, assessment of climate change, and development of policy responses. Observations are fundamental to advancing scientific understanding of climate and to delivering timely and purposeful climate information needed to support decision making in many sectors.

Progress in the understanding of atmospheric composition changes and its drivers is therefore strongly linked to the availability of these observations. The coordinated efforts in the last decade to facilitate access to data have been extremely beneficial but more needs to be done. While today reasonable harmonization exists within specific networks, it is not necessarily the case between them, even for networks measuring similar compounds. As a result, international networks sometimes collect information in a relatively uncoordinated manner and the overall location of sites for measuring atmospheric composition from the ground is not organized in the most optimal manner. The Global Atmosphere Program of WMO has favoured coordination of networks worldwide with the concept of Global, Regional and Contributing stations reflecting somehow the degree of concurrent and co-located measurements of key atmospheric species of interest to air quality and climate studies from background sites (Figure 9). This strategy was backed by regional programs such as ACTRIS or ICOS in Europe, GMD-NOAA in the US, and others although some regions in the World do not have regionally organized programs. A similar approach was implemented in the USA as part of the supersite program for urban areas that led to significant advancements in measurement methods, atmospheric characterization, and understanding of source-receptor relationships.

A step further for GEO would be to address the need for a higher-level coordination across networks relevant to different domains, i.e. atmosphere, terrestrial ecosystems, ocean, biodiversity. The concept of a hierarchical in situ observation system consisting of networks of measurement sites having increasing complexity from standard single-domain stations to flagship multi-domain stations may be an interesting option. Flagship stations would consist of instruments making comprehensive observations of the environmental character of the surrounding area from local to regional to global relevance. Examples of flagship stations already exist in both natural and urban environments. Operating a comprehensive observation station together with multi-scale modelling and satellite remote sensing will provide unique data of relevance to global grand challenges and will enable novel insights into their solutions.

4.2.3 Facilitating access to data including ECVs

In the 1990s, gaps in knowledge of climate and declining core observational networks in many countries led to calls for systematic observation of a limited set of critical variables. To provide guidance, the Global Climate Observing System (GCOS) program developed the concept of ECVs, which has since been broadly adopted in science and policy circles as described by the IGACO report more than a decade ago. Adequate observation capacity together with easy access to ECVs are therefore essentials to implementing the IGACO strategy. Even if ECVs from single networks are easily accessible, integration across networks or, worse, across domains is far from being implemented. This is a clear limitation to inter-disciplinary research in the concept of GEOSS. This will require common policies, models and e-infrastructure to optimize technological implementation, define workflows, and ensure coordination, harmonization, integration and interoperability of data, applications and other services between the different networks and programs providing observations of ECVs. A key challenge for GEO will be to facilitate data discovery and use, and to provide integrated end-user information technology to access heterogeneous data sources. It is clear that



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implementing of the GEO e-environment will require addressing the necessary resources needed in order to meet end-user requirements.

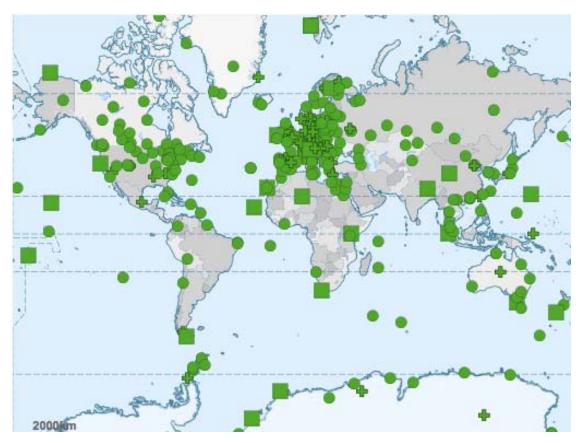


Figure 9: The network of operational in situ stations with the Global Atmosphere Watch program. Global stations (square), regional (circle) and local (cross) stations are indicated. As discussed in the report, while observation density is adequate for some World regions, there are still important areas where provision of ECV is still crucially lacking.

4.2.4 Filling gaps in observations

Gaps in in situ observations have many different aspects: technological gaps, geographical coverage gaps, gaps in computing resources, and more. Not all can be covered within this report.

Evolution of observation strategies will have to consider emerging technologies in sensors and their suitability to respond to the needs of the users. The scientific community is facing technological revolution with key-enabling technologies that will provide the basis for innovation in a wide range of products.

Uneven global and regional coverage of climate observations is still limiting our ability to adequately predict global change. This is due to a number of geographical, economical and political/legislative reasons. In the past, the main regions of focus of climate observations have been Europe and North America, and the marine territories traditionally influenced by them. While the main problem in Western and Northern Europe as well as in North America now appears to be one of network integration, in other parts of the world the main problem is the very limited geographical coverage.





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Observations in continental Asia are improving but the area is still under-sampled. Clear gaps remain in polar and equatorial regions, and generally in the southern Hemisphere. This is partly due to the predominance of oceans there but also due to the lack of monitoring stations on land and to the restricted number of dedicated field campaigns in many parts of the Southern Hemisphere. One of the drawbacks of ground-based observations is the need to locate the instruments on land surfaces. Although data are generated at a few island sites, monitoring over the oceans, which cover about 70% of the globe, is sparse. New technologies may contribute to fill these gaps in geographical coverage.

4.2.5 Favouring regional cooperation, including training centres

Capacity building constitutes one of the strategic priorities for improving the observing system as a whole. Developing and improving competent human resources, technical and institutional capacities and infrastructure, particularly in developing and least developed states is crucially needed. Developing the capacity to use and develop services provided with the GFCS is similarly important. GEO must include elements of capacity building in its activities from providing assistance with operational activities to organizing topical/specialized workshops and formal training programs to facilitating direct partnering or twinning between more experienced and less experienced countries and encouraging the establishment of outreach programmes. A regional approach for cooperation in training may provide the proper scale for organizing the training of technical staff on the operation of instruments, data handling and data quality assurance. A strong recommendation is to promote partnership between Europe and countries in the Southern part of Asia, America and Africa to ensure joint implementation of monitoring networks in these areas.

4.3 Emerging Techniques and new Approaches

Aerial EO has been historically considered to be expensive. Even if it can provide better resolution than satellite data, the revisiting time is much lower as it is limited by the costs of operation. Unmanned Aerial Vehicles (UAVs), also called drones, are much easier to fly and can be programmed to cover some areas automatically. They can carry small sensors, cameras or even LIDAR scanners. They cannot provide the same data quality and coverage that aerial surveys using precision sensors can but they can be very useful in emergency response, infrastructure and crop monitoring.

There are an increasingly large number of citizen science projects active around the world involving the public in environmental monitoring and other scientific research activities.

Many citizen science projects are grassroots initiatives formed in response to local concerns, but a few have a more global scope. However, for citizen science to have maximum impact on scientific research and public policy, data collected from local projects must also be re-usable on national and global scales (beyond the purpose for which they were originally collected) and complement official sources. In that respect, the EC is financing projects in the context of GEOSS that should demonstrate the capacity of existing citizen observatories to achieve broader scope and to integrate them as another source of valid EO. To do so, these projects have to base their systems on rigorous data quality protocols, trusted and secure systems, standard data models, open data access and data curation and preservation.

In the Internet of Things a deep network of sensors is automatically contributing information to the network, mainly in populated areas (this time connected with is so-called smart cities) but also in rural areas. These networks produce vast amounts of information that need to be analyzed and integrated with other EO data types.



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Another form of citizen participation is crowd-sourced information. In some cases, systems are harvesting the activities of citizens in social networks to, for example, generate early warnings of hazards or to study human distribution and social patterns. More intrusive methods can record and analyze the use of communication networks. This data is particularly useful for describing human activities and monitoring infrastructures.

4.4 Coordinating the integration of space-based and in situ observations

The integration of space-based and in situ observations may be accomplished in at least two ways: a) by using modelling to integrate and optimise the impact of combined and simultaneous use of space and surface observations; and b) by applying the concept of Integrated Observing Systems when designing and managing composite observing networks.

Effective integration of space-based and in situ observations is key for many application areas including weather and air quality forecast models and operational oceanography. The combined use of surface and space-based observations is considered essential to meeting end users requirements for information about, for example, the environment, climate, and weather at national, regional, as well as global scales. As a consequence, the European Earth Observation programme Copernicus is composed of three components (space-based observations, in situ observations, and services) to ensure proper integration and coordination of inter alia data availability, observational requirements, and interoperability.

Integrated Observing Systems, consisting primarily of existing surface and spaced-based observing capacities, may provide an over-arching framework for the coordination and optimised evolution of these capacities that will continue to be owned and operated by a diverse array of national, regional, and global actors.

The advent of Integrated Observing Systems may be viewed as fundamental to meeting future observational requirements, avoiding duplication of work, achieving the necessary level of interoperability, and ensuring cost-effective solutions.

The WMO Integrated Global Observing System (WIGOS) may serve as an excellent example of this. The development of WIGOS is requirements-driven with a clear orientation to inter alia public health, disaster risk reduction, water resource management and food security, renewable energy, tourism, travel, and insurance. WIGOS is building upon and adds value to the existing surface and space-based subsystems, while providing a foundation for the integration of new and emerging observational technologies. Space-based components of WIGOS will play a key role in the composite network design and in filling the gaps of data sparse areas, such as oceans and Polar Regions. The interoperability of WIGOS component observing systems will be achieved through utilisation and application of internationally accepted standards and recommended practices and procedures. Data compatibility will also be supported through the use of data representation standards.

WIGOS is addressing all observational needs of the weather, climate, water and environmental services of its members, and acts as an integrator of all WMO observing systems and WMO contributions to co-sponsored systems. Together with the WMO Information System (WIS), WIGOS is a WMO contribution to GEOSS.



Connecting Project title: Coordinate



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The limited scope of the report, which is due to the limited time and resources available for the preparation, does not allow for final conclusions concerning a comprehensive state of in situ observations and the needs for improved coordination across national, domain, and sector boundaries. However, the material presented in this report exemplifies the need for coordination on regional levels and across disciplinary boundaries. It provides a basis for planning the future work of an in situ working group in GEO that continues the work of GD-06 in the next Work Programme and allows for initial recommendations to GEO and the identification of the building blocks of a road map towards improved coordination and exploitation of in situ observations.

5.1 Benefits of Coordinating In Situ Earth Observations

There are many societal and research challenges that need to be addressed to make progress towards environmental, social and economic sustainability and to support prosperous societies and the safeguarding of the Earth's life support system (see e.g., Griggs et al., 2013). For many of these challenges, information derived from in situ observations is crucial both for a better understanding of the relevant processes, the development of policies, the planning of actions, and the monitoring of progress, as well as a support for space-based observations. Examples are the implementation and monitoring of the SDGs, the documenting of global change and its impact on humanity, the sustainable use of resources, governance of risks and the reduction of disasters, and the prediction of environmental conditions (such as air quality, weather, droughts, floods, seasonal climate in support of agriculture, sea level, and changes in environmental health). Providing the full range of information that could be derived from in situ measurements often would require cross-discipline coordination and data integration and coordination across national boundaries. In the regions surveyed so far, there is still a need to improve this coordination, despite considerable progress in recent years. Without having performed a detailed analysis for other regions not consider in this report, it can nevertheless be assumed that in those regions the lack of coordination limits the exploitation of in situ observations significantly, too. Economic activities aiming to utilize the potential of the available in situ observations by providing value-added services are often hampered by factors such as use restrictions and the lack of access to data.

5.2 Challenges of Coordinating In Situ Earth Observations

The regional landscape of in situ observation networks, research networks, and research infrastructures is complex and there are many stakeholders involved in maintaining networks, archiving data, processing data and generating products, and using observations for value-added activities. Many users are benefiting from information and knowledge derived from in situ observations, and many more could benefit if the providers of this information and knowledge would be better connected to the users and have better knowledge of their needs. The networks and organizations are to some extent fragmented along national, disciplinary, and sectorial boundaries. On global level, coordination is well developed for some discipline-focused networks (e.g., meteorological and geodetic networks) and to some degree by in situ components of the space agencies, while for the rest no global coordination mechanisms exist. The increasing societal needs for information derived from in situ observations is likely to also increase the need for in situ observations complementing the classical expert collection with new and emerging technologies and approaches such as the Internet of Things, citizen scientists, and crowd-sourcing. A particular challenge with the increasing variety of in situ networks and the new methodologies/technologies is in the integration and interoperability of the different data types, which requires special attention to the coordination of semantics and standards as well as guarantying coverage that includes remote areas.



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Continuity and long-term time series are key, but in some cases, the sustainability of observation and processing infrastructure is not easily ensured, and decisions on discontinuing funding to networks are often made without a thorough analysis of the societal and scientific benefits of the observations. A coordinated, detailed gap analysis based on well-defined user needs could help to ensure that the societal benefit of networks can impact the decisions to continue or discontinue the networks. A gap analysis can also provide a basis for prioritization of investments on new infrastructure. In that sense, defined sets of EVs provide a basis for a holistic cross-domain gap analysis and prioritization. However, the approaches used to determine domain specific EVs show a broad range of variability and a cross-domain coordination of the development of sets of domain-specific EVs is urgently needed. GEO could play an important role in convening this coordination process.

5.3 Recommendations to GEO

The Task Team of GD-06 recommends that

- a process to coordinate the development of sets of domain-specific Essential Variables be convened by GEO and those EVs that require in situ observation be identified;
- the need for regional trans-boundary and cross-domain coordination of in situ Earth observations, including semantic harmonization, adoption of standards, processing of data to generate information products of value for societal users and the adherence to GEO data sharing and management principles, be emphasized and covered with the needed resources in the GEO Work Programme;
- a comprehensive gap analysis to identify gaps in the in situ networks vis-à-vis GEO programmes' requirements for in situ observations be convened by GEO with the goal of providing guidance for the maintenance of existing and the development of new in situ networks.

5.4 Recommendation to the GEO in situ working group in the next Work Programme

The Task Team of GD-06 recommends that

- the survey of the state of in situ observations and their coordination be further detailed and extended to include Africa, the Americas, and Oceania and also add additional domains in
- existing and potential new coordination models be assessed;
- the role of the private sector as provider and user of in situ observations be considered;
- efforts be made to provide a more complete picture of the risks of loss of observational continuity and issues that reduce the sustainability of in situ networks, impact the crossdomain integration and coordination, and hamper the full exploitation of the societal benefits of these observations;
- the in situ working group take an active role in collecting relevant in situ data requirements and a gap analysis and prioritization process that can provide guidance to the in situ communities with respect to unmet user needs and the prioritization of existing and new networks.

5.5 Road Map Toward Increase Coordination of In Situ Earth Observations

The following steps could facilitate progress towards improved coordination of in situ EOs:

Complete the descriptive analysis of the regional state of in situ observations with a focus on



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- (i) observation networks; (ii) data processing and access facilities; (iii) linkage between providers and users.
- Analyse the coordination mechanisms in terms of capabilities to facilitate regional crossdomain coordination and coordination across sectorial boundaries.
- If necessary, develop new coordination approaches and propose these to GEO.
- Convene regional and global conferences/workshop to promote coordination in the in situ communities.
- Identify research observation networks that should be transitioned to an operational state and the facilitation of this transition in GEO.





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REFERENCES

Bombelli, A., Maso, J., Serral, I., Jules-Plag, S., Plag, H.-P., McCallum, I., 2016. EVs current status in different communities and way to move forward. Deliverable D2.2 of the ConnectinGEO Project.

GD-06, 2016. The State of In situ Earth Observations Coordination and Recommendations for the Future. Report prepared for GEO.

GEO, 2005a. The Global Earth Observing System of Systems (GEOSS) - 10-Year Implementation Plan. Available at http://earthobservations.org.

GEO, 2005b. Global Earth Observing System of Systems GEOSS - 10-Year Implementation Plan Reference Document - Draft, GEO 1000R/ESA SP 1284, ESTEC, Noordwijk, The Netherlands, ESA Publication Division. Avaliable at http://earthobservations.org.

Group on Earth Observations, 2012. Task US-09-01a: Critical Earth Observation Priorities (Second Edition), Tech. rep., Group on Earth Observations, Available at http://sbageotask.larc.nasa.gov.

GEO, 2015. GEO 2016 Work Programme, Version V4. Available at http://earthobservations.org.

Group on Earth Observations, 2016. Geospatial information and earth observations: Supporting official statistics in monitoring the SDGs, Tech. rep., Report of the GEO Initiative GI-18; Group on Earth Observation, GEO Secretariat, Geneva, Switzerland.

GEO Science and Technology Committee, 2011. Development of a GEOSS Gap Analysis Strategy (for decision), Presented to the GEO EXCOM in 2011. Available at http://www.tiwah.com/ConnectinGEO/wp6/geo gap/ExCom gap analysis strategy v1.doc.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., Noble, I., 2013. Sustainable development goals for people and planet. *Nature*, 495, 305-307

IGOS. A Coastal Theme for the IGOS Partnership — For the Monitoring of our Environment from Space and from Earth. Paris, UNESCO 2006. 60 pp. (IOC Information document No. 1220).

IGOS-P, 2003. The Integrated Global Observing Strategy (IGOS) Partnership Process. IGOS Process Paper (version of March 19, 2003).

Jules-Plag, S. and Plag, H.-P., 2016a. Supporting the Implementation of Sustainable Development Goals. Geospatial World, in press.

Jules-Plag, S., and Plag, H.-P., 2016b. Integrating Earth Observations and Models for Policy Development and Monitoring of SDG Implementation. ApogeoSpatial, in preparation.

Kano Y, Adnan MS, Grudpan C, Grudpan J, Magtoon W, Musikasinthorn P, et al. 2013. An online database on freshwater fish diversity and distribution in mainland Southeast Asia. Ichthyologic Research 60: 293–295.

Kano Y, Dudgeon D, Nam S, Watanabe K, Grudpan C, Grudpan J, Magtoon W, Musikasinthorn P, Nguyen PT. 2016. Impacts of dams and global warming on fish biodiversity in the Indo-Burma hotspot. Plos One, in press.

Marsh, S. and the Geohazards Theme Team, 2004. Geohazards Theme Report, IGOS Integrated Global Observing Strategy Partnership. Printed by European Space Agency.

Nakano S, Yahara T, Nakashizuka T. 2012. The Biodiversity Observation Network in the Asia-Pacific Region, Toward Further Development of Monitoring. Springer, 480 pp.

Nakano S, Yahara T, Nakashizuka T. 2014. The Biodiversity Observation Network in the Asia-Pacific Region, Integrative Observations and Assessments. Springer, 431 pp.





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Nakano S, Yahara T, Nakashizuka T. 2016. The Biodiversity Observation Network in the Asia-Pacific Region, **(subtitle)**. Springer, *** pp.

Plag, H.-P., Jules-Plag, S., Maso, J., Serral, I, 2016a. SDG Workshop Report. Deliverable D2.1 of the ConnectinGEO Project.

Plag, H.-P., et al., 2016b. Gap analysis draft report. Deliverable D6.2 of the ConnectinGEO Project.

Toyama H, Kajisa K, Tagane S, Mase K, Chhang P, Samreth V, Ma V, Sokh H, Ichihashi R, Onoda Y, Mizoue N & Yahara T. 2015. Effects of logging and recruitment on community phylogenetic structure in 32 permanent forest plots of Kampong Thom, Cambodia. Philosophical Transactions of the Royal Society B. 370: 20140008.

ACRONYMS

ACTRIS: Aerosol, Cloud, and Trace Gases Research Infrastructure

ANAEE: Infrastructure for the Analysis and Experimentation on Ecosystems

AP-BON: Asian-Pacific Biological Observation Network

APN: Asia-Pacific Network for Global Change Research

CBD: Convention on Biodiversity

COP: Conference of the Parties

CEOS: Committee for Earth Observation Satellites

ConnectinGEO: Coordinating an Observation Network of Networks EnCompassing saTellite and

IN-situ to fill the Gaps in European Observations

CORDA: Copernicus reference data access portal

DANUBIUS: International Cneter for Advanced Studies on River-Sea Systems

DORIS: Doppler Orbitography and Radiopositioning Integrated by Satellites

EC: European Commission

EEA: European Environmental Agency

EGDI: European Geological Data Infrastructure

Eionet: European environment information and observation network

EISCAT-3D: European Incoherent Scatter Scientific Association

EMODnet: European Marine Observation and Data Network

EMBRC: European Marine Biological Resource Centre

EMEP: European Monitoring and Evaluation Programme

ENEON: European Network of Earth Observation Networks

ENVRI: Environmental Research Infrastructures

EO: Earth Observation

EPN: EUREF GNSS Permanent Network

ERIC: European Research Infrastructure Consortium



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ETRS89: European Terrestrial Reference System

EU: European Union EV: Essential Variable

EVRS: European Vertical Reference System

ECV: Essential Climate Variable

EURO-ARGO: European Component of broad-scale global array of temperature/salinity profiling

floats

GAIA-CLIM: Gap Analysis for Integrated Atmospheric ECV Climate Monitoring

GAW: Global Atmospheric Watch

GCOS: Global Climate Observing System

GEO: Group on Earth Observations

GEOBON: GEO Biological Observation Network

GEOSS: Global Earth Observation System of Systems

GFCS: Global Framework for Climate Services

GGOS: Global Geodetic Observing System

GNSS: Global Navigation Satellite System

GOOS: Global Ocean Observing System

GPS: Global Positioning System

IAEG-SDGs: Interagency and Expert Group on SDG Monitoring

IAG: International Association of Geodesy

IAGOS: In-Service Aircraft for a Global Observing System

ICOS: Integrated Carbon Observing System

ICRF: International Celestial Reference Frame

IDS: International DORIS Service

IERS: International Earth Rotation and Reference System Service

IGACO: Integrated Global Atmospheric Chemistry Observations

IGOS: Integrated Global Observing Strategy

IGOS-P: Integrated Global Observing Strategy Partnership

IGS: International GNSS Service

INSPIRE: Infrastructure for Spatial Information in the European Community

IPCC: Intergovernmental Panel on Climate Change

ITRF: International Terrestrial Reference Frame

ITRS: International Terrestrial Reference System

IVS: International VLBI Service for Geodesy and Astrometry

IUGG: International Union of Geodesy and Geophysics



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LIDAR: Light Detection and Ranging

NMHS: National Meteorological and Hydrological Services NOAA: National Oceanic and Atmospheric Administration

QA: Quality Assurance QC: Quality Control

SBA: Societal Benefit Area

SDG: Sustainable Development Goal

SEIS: Shared Environmental Information System

SLR: Satellite Laser Ranging

UAV: Unmanned Aerial Vehicle

UN: United Nations

UNFCCC: United Nations Framework Convention on Climate Change

UN-GIMM: UN Global Geospatial Information Management

VLBI: Very Long Baseline Interferometry

WIGOS: WMO Integrated Global Observing System

WIS: WMO Information System

WMO: World Meteorological Organization

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Contribution of citizen science towards international biodiversity monitoring

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ABSTRACT

To meet collective obligations towards biodiversity conservation and monitoring, it is essential that the world's governments and non-governmental organisations as well as the research community tap all possible sources of data and information, including new, fast-growing sources such as citizen science (CS), in which volunteers participate in some or all aspects of environmental assessments. Through compilation of a database on CS and community-based monitoring (CBM, a subset of CS) programs, we assess where contributions from CS and CBM are significant and where opportunities for growth exist. We use the Essential Biodiversity Variable framework to describe the range of biodiversity data needed to track progress towards global biodiversity targets, and we assess strengths and gaps in geographical and taxonomic coverage. Our results show that existing CS and CBM data particularly provide large-scale data on species distribution and population abundance, species traits such as phenology, and ecosystem function variables such as primary and secondary productivity. Only birds, Lepidop-tera and plants are monitored at scale. Most CS schemes are found in Europe, North America, South Africa, India, and Australia. We then explore what can be learned from successful CS/CBM programs that would facilitate the scaling up of current efforts, how existing strengths in data coverage can be better exploited, and the strategies that could maximise the synergies between CS/CBM and other approaches for monitoring biodiversity, in particular from remote sensing. More and better targeted funding will be needed, if CS/CBM programs are to contribute further to international biodiversity monitoring.

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1. Introduction

International treaties such as the Convention on Biological Diversity, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, and the Convention on the Conservation of Migratory Species recognise the need to assess change in the status and trends of global biodiversity. Moreover, one of the four main functions of the Intergovernmental Panel on Biodiversity and Ecosystem Services is to "perform regular and timely assessments of knowledge on biodiversity" (IPBES, 2013).

Current biodiversity informatics programs allow for inferences about the status and trends of global biodiversity, and gaps and priorities have already been identified (Ariño et al., 2016; Meyer et al., 2015; Peterson et al., 2015; Peters et al., 2014; Ruete, 2015; Wetzel et al., 2015). To help track global biodiversity change, the Group on Earth Observations Biodiversity Observation Network (GEO BON) proposed a candidate set of Essential Biodiversity Variables (EBVs; Pereira et al., 2013). EBVs represent the minimum set of measurements needed to capture major dimensions of biodiversity change, and are now being

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Table 1

Examples of the coverage of Essential Biodiversity Variables (EBVs) by citizen science (CS) and community-based monitoring (CBM) programs. Additional columns indicate the scale of the projects and the feasibility of data collection by citizens and community members. Green indicates EBVs with high adequacy in terms of remotely sensed products, yellow indicates medium adequacy while red is low adequacy or no remotely sensed products that can monitor these EBVs (O'Connor et al., 2015). References to CBM programs is available in Appendix 5.

EBV class	EBV	Scale of CS/CBM measurement	Feasibility	Examples from Global CS database	Examples from CBM database
	Co-ancestry				
Genetic	Allelic diversity	Local	Rare data, collected mostly by specialized projects and		-
composition	Population genetic differentiation	Local	professional monitoring	-	-
	Breed and variety diversity				Suitability of different Mongolian pasture plants (Fernandez- Gimenez, 2000)
	Species distribution	Global, regional, local	Most abundant biodiversity-related citizen science observation	Christmas Bird Count, eBird, FeederWatch, India Biodiversity Portal, iNaturalist, iSpot, Reef Life Survey	Identification of multiple species in Madagascar and elsewhere (e.g. Andrianandrasana et al., 2005)
Species populations	Population abundance	Global, regional, local	Data collected as a part of many species distribution surveys and some local studies	Breeding Bird Survey, Butterfly Conservation (Europe), eBird, Extreme Citizen Science, International Waterbird Census	Monitoring of hornbills in India (Bachan et al., 2011) and mammals, birds and resource use in Philippines, Madagascar, Tanzania and Nicaragua (Danielsen et al. 2014d)
	Population structure by age/size class	Regional, local	Largely studied at local sites, but there are several regional programs for particular taxa	Monarch Larvae Monitoring Project, Monitoring Avian Productivity and Survivorship (MAPS), North American Butterfly Monitoring Network, several Earthwatch projects	Sea turtle nest counts (Granek and Brown, 2005); pisc/tvorous and herbivorous reef fish (Uychiaoco et al., 2005); trophy size (Lyons, 1998)
	Phenology	Regional, local	Most abundant trait observation made by citizen science volunteers; many long-term datasets	Climatewatch (Australia), Nature's Calendar (UK), Phenoclim (France), USA National Phenology Network, Project Budburst	Monitoring of caribou migration timing in the Arctic (Huntington et al., 2004); migratory mammals in Tanzania (Topp-Jurgensen et al., 2005); grazing seasons in rangelands in Kenya (Roba and Oba, 2009)
	Body mass	Regional, local	Rare data, collected mostly by specialized projects	Some Earthwatch projects, MAPS, OpenTreeMap	Surveying of fish populations in Peru (Carvalho et al., 2009)
	Natal dispersal distance	Local	Only collected via professional monitoring	-	-
Species traits	Migratory behaviour	Global, regional, local	Abundant data for observing species across migratory ranges; much rarer data on migratory behaviours of individual organisms	eBird, Hawk Count, Journey North, Monarch Watch, Hawkwatch (Hawk Migration Association North America), documentation of amphibian migrations to breeding ponds	Monitoring of timing of large- mammal migrations (Huntington et al., 2004; Topp-Jørgensen et al., 2005).
	Demographic traits	Regional, local	Rare data, collected mostly by specialized projects	MAPS; Nest Record Scheme UK; Nestwatch; Projecte Orenetes "Swallow Project" and Projecte Nius "Nests Project"; Earthwatch projects	Assessment of the clutch size of turtles (Townsend et al., 2005).

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EBV class	EBV	Scale of CS/CBM measurement	Feasibility	Examples from Global CS database	Examples from CBM database
	Physiological traits	Local	R are, collected almost exclusively by specialized projects	Earthwatch projects; Public Lab projects	Cloud berry (Rubus chamaemorus) damage due to warm springs and summers (Huntington et al., 2004); fodder value of plant species categories for different livestock species in Kenya (Roba and Oba, 2009);
Community	Taxonomic diversity	Global, regional, local	Generally observed during specialized events (e.g. Bioblitz) or incidentally through checklist projects (e.g. iNaturalist)	BioBlitzes; Christmas Bird Count; eBird; iNaturalist; iSpot	Reef fish monitoring (Uychiaoco et al., 2005)
composition	Species interaction	Regional, local	Unusual data, collected mostly by specialized projects, but included in some larger-scale projects	Great Sunflower Project; iNaturalist; Nature's Notebook	Monitoring of insect harassment of caribou (Huntington et al., 2004); crop damage and livestock attack (Stuart-Hill et al., 2005); geese species interactions in the Arctic (Danielsen et al., 2014d).
	Net primary productivity	Global, regional, local	Generally observed through remote sensing, but also measured by some citizen science projects	FreshWater Watch; GLOBE; many volunteer lake monitoring projects	Monitoring of quality and quantity of vegetation (Roba and Oba, 2009): aboveground forest biomass in REDD+ programs (Brofeldt et al., 2014)
Ecosystem function	Secondary productivity	Local	Extremely rare for CS programs but very common for CBM programs	Some Earthwatch projects	Surveys of high-value species, meat, fish, shellfish and other non- timber forest and wetland products (e.g. Johannes, 1998; Uychiaoco et al., 2005)
	Nutrient retention	Regional, Iocal	Nutrients frequently measured in lakes and streams, but rarely in terms of retention	FreshWater Watch, many volunteer lake monitoring projects	Environmental monitoring of watersheds in Ontario (Savan et al., 2003)
	Disturbance regime (e.g. pest outbreak)	Regional, local	Some CS programs dedicated to particular disturbances (e.g. earthquakes, invasives) and many incidental observations. Many CBM programs	Coral Watch; iMapInvasives; Phytoplankton Monitoring Network; GISIN; EDDMaPS and GLEDN for plants	Monitoring of bush fires (Lyons, 1998); poaching (Andrianandrasana et al., 2005; Stuart–Hill et al., 2005); cutting of trees to obtain Malva nuts and fishing in rivers using poison (Poulsen and Luanglath, 2005); trawling pressure and 'ghost' nets in the Arctic (Danielsen et al., 2014c)
Ecosystem structure	Habitat structure	Global, regional, local	Primarily collected through remote sensing and professional monitoring, but some CS and CBM programs	GLOBE, National Plant Monitoring Scheme (UK)	Bering Sea Sub-Network; Alaska Ocean Observing Systems; monitoring of percentage of hard coral/sand in reefs (Uychiaoco et al. 2005); observations of sea ice conditions in the Alaskan Arctic, fluctuating levels in subsistence hunting of specific species (Eicken et al., 2014 and www.aoos.org); historical records of snow properties by Sami reindeer herders to inform pasture availability, temperature profiles and herd ecology (Eira et al., 2013)

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Ecosystem extent and fragmentation	Global, regional, local	Primarily collected through remote sensing and professional monitoring, but some citizen science collection, especially community-based	GLOBE and community based projects, such as Hampshire Landscape Watch and some Earthwatch projects	Annual extent of marshland burned seen from viewpoints (Andrianandrasana et al., 2005); fixed point photography of forested hillsides (Danielsen et al., 2005); extent of burning of trees when extracting yang oil in Laos (Poulsen and Luanglath, 2005); and reef health (Granek and Brown, 2005)
Ecosystem composition by functional type	Global, regional, local	Primarily collected through remote sensing and professional monitoring, but some citizen science collection, especially community-based	Earthwatch and Freshwater Watch at some locations	Landscape grazing suitability (Roba and Oba, 2009)

used to set up frameworks for global monitoring of biodiversity (e.g. Kissling et al., 2015; O'Connor et al., 2015; Schmeller et al., 2015). A list of EBVs is provided in Table 1. EBVs are intended to be general enough for use across major taxa groups, across terrestrial, freshwater and marine realms and across ecosystem types within each of these realms (GEO BON, 2015). A list of widely agreed upon EBVs is unlikely to be finalised for some years (Pettorelli et al., 2016). However, the EBV concept represents a useful way to organise biodiversity indicators and meet top-down global treaty obligations.

Many EBVs such as ecosystem composition by functional type, nutrient retention, and ecosystem extent and fragmentation can be monitored by large-scale sensors or Earth Observation systems. Earth Observation refers to satellite remote sensing (e.g. Landsat, Sentinel) and aerial imagery as well as land-based observation platforms (e.g. National Ecological Observatory Network, camera trap arrays; O'Connor et al., 2015; Skidmore et al., 2015). These systems can greatly improve efficiency, standardisation, and the value of monitoring data for many uses. Yet Earth Observation systems cannot monitor all EBVs and still require human-assisted data collection (O'Connor et al., 2015; Proença et al., 2016). In other cases, human observations can supplement remotely sensed data and derived models and assessments (e.g. species distribution models, species habitat association models, seasonal productivity models such as the Spring Index) by providing much needed calibration and validation data (Evangelista et al., 2012). There are not enough professionals (or funding to support them), however, to monitor EBVs at large scale and adequate resolution. Citizen science (CS) offers an additional way to monitor EBVs, and also offers other benefits to conservation through public engagement (McKinley et al., 2016).

In this paper we use CS to refer to scientific projects that include the participation of volunteers (novices or experts) in some aspect of the projects (sensu Bonney et al., 2009; Miller-Rushing et al., 2012). We also refer to community-based monitoring (CBM)-i.e. a subset of CS in which local stakeholders use their own resources to monitor natural resources to achieve goals that make sense to them (Danielsen et al., 2014c). CBM is often contrasted with large-scale, top-down CS monitoring projects, such as eBird, although the two approaches are not mutually exclusive and can be blended. For the purpose of this paper, however, we consider CS and CBM as distinct approaches.

The aim of this paper is to examine how and to what degree CS and CBM might contribute to regional and global assessments in the trends and status of biodiversity by undertaking: (1) a general assessment of current strengths and gaps in using CS and CBM to monitor biodiversity at large-scale; (2) an assessment of CS and CBM data that have contributed to global biodiversity databases to date, using the Global Biodiversity Information Facility (GBIF) as a case study; and (3) a discussion of the challenges, solutions and limitations of using CS and CBM for monitoring global biodiversity.

2. Methods and approach

For our analysis, we make a distinction between CS projects, portals and programs. We define a CS project as a distinct, biodiversity recording scheme or volunteer survey, often with a specific management team and discrete goals and taxonomic or geographical focus. Sometimes multiple CS projects are aggregated together in an online portal, which provides a single access point for citizen scientists. For example, iNaturalist functions as a portal, with many related projects that collect species presence data, but have different goals, and have different taxonomic and geographic foci. The portal uses one online interface for all the projects. We use the term CS program as a generic term that covers both CS stand-alone projects and portals. For compiling our database, we used the largest appropriate unit, i.e. portals when possible, and pro-

jects when they were not a part of any portal, to avoid double counting. We considered programs to be CS when >50% of the data were collected by volunteers

2.1. Assessment of strengths and gaps in CS and CBM

We compiled two distinct databases—one on CBM and one on CS-for our assessment of current strengths and gaps in using CS and CBM to monitor global biodiversity. We coded each project for taxonomic focus, geographic scope, and other factors that help to link these projects to specific EBVs.

2.1.1. Community-based monitoring programs
CBM programs are distinct from other CS programs in that citizens and community members not only participate in data collection but also in program design, data interpretation, or implementation of management interventions emanating from the monitoring (Danielsen et al., 2009, 2014c; Kennett et al., 2015). The CBM programs were found by searching for publications in the databases BIOSIS PreViews (2004– 2012), Biological Abstracts (1990–2000) and Biological Abstracts Reports, Reviews and Meetings (1989–2003). The primary search terms were 'monitoring' and 'conservation', searched with the use of 'and' between the words. Schemes on environmental monitoring are often hidden in publications on traditional ecological knowledge (Huntington, 2000). Few examples of decentralised local approaches to monitoring are found in the literature (Brook and McLachlan, 2008). Therefore the search term 'traditional ecological knowledge' was also used. Most publications were in English but a few were in German. Each CBM program was coded by two of the authors (FD and AB) by taxonomic focus, geo-graphic scope, and EBV. FD coded 65% of the CBM programs and reviewed all the data coded by AS for consistency

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2.1.2. Citizen science programs

To build the 'Global CS Database', we considered a breadth of CS typologies (Shirk et al., 2012; Haklay, 2015), which range from larger crowdsourced CS projects in more extensive monitoring schemes (Couvet et al., 2011) to smaller, more intensive monitoring efforts (e.g. field expeditions, Chandler et al., 2016a). Because the primary objective for compiling this Global CS Database was to assess CS contributions to monitoring EBVs, we only considered CS programs that fulfilled two minimum requirements. First the program is already (or likely to be) contributing biodiversity data for monitoring purposes, and the second is that these data contributions are substantial. We searched for programs where the data are quality controlled and shared-e.g. verification is made of the data collected; the metadata are made publicly available; and there is evidence that the data are used in practice for management actions or for scientific publications. Regarding the second requirement, programs were considered to make 'substantial data contributions' if >100 observations were collected per year. We included inactive projects if they collected data for the intention of sharing them with existing monitoring programs.

To compile the database, we started by pulling together programs from existing network portals, which house data from CS programs not managed by the hosting organisation, and which usually provide an assortment of sorting tools to help readers find the right CS program (e.g. the Atlas of Living Australia (ALA), SciStarter, CitizenScience.org) or serve as research infrastructures for managing and publishing the aggregated data (e.g. GBIF, the UK National Biodiversity Network, the National Defense Research Committee). We also extracted programs from similar previous publications on the same topic (Danielsen et al., 2014c; Theobald et al., 2015; Kullenberg and Kasperowski, 2016; Valland, 2016; Chandler et al., 2016b; Groom et al., 2016); see Table A1 for the guide used to code the data.

To this list we added CS programs whose publishers share CS data with GBIF. We then supplemented the inventory through directed web searches to discover programs that were not captured through other sources. We used search terms that included synonyms to citizen science, related words, and regions and taxonomic groups underrepresented in our database—e.g. 'volunteer monitoring', 'data sharing', 'open data', 'Africa', 'South America' and 'Asia'. Finally, we asked experts in the field to identify programs that might fill gaps in the geography, taxonomy, or EBVs that were poorly represented in our database.

Each program (i.e. project or portal) was scored using criteria and associated metadata modified from Theobald et al. (2015). If the program was a portal, then the number of projects that were both developed and hosted by the portal was added to the database. Coding of all initiatives apart from the ones taken from the Theobald et al. (2015) data set was performed by four of the authors (MC, KC, BC, and AMR) using material available from associated websites. MC entered 90% of the criteria and reviewed >25% of the data coded by the others for consistency.

To our knowledge, the Global CS Database that we developed for this study represents the largest and most comprehensive database of CS programs, yet it is not complete. For example, we only included programs that made substantial data contributions for biodiversity monitoring purposes. It is also likely that we have missed programs published in languages other than English, programs without an online presence, and programs that describe themselves using terms other than those used in our search (Kullenberg and Kasperowski, 2016).

2.2. Assessment of citizen science data in a global biodiversity database

To assess the contributions of CS data that make it into global databases, we analyzed CS contributions to the world's largest species occurrence database, GBIF.org. This open data research infrastructure gathers hundreds of millions of records from >800 institutions worldwide and covers > 1.6 million species. Researchers have applied these data in > 1700 peer-reviewed journal articles since 2008. Several studies have

reviewed the gaps and limitations in GBIF-mediated data (Beck et al., 2013, 2014; Samy et al., 2013; García-Roselló et al., 2015; Meyer et al., 2015; Troia and McManamay, 2016); which may be representative of other international databases on biodiversity (Amano and Sutherland, 2013; Troia and McManamay, 2016).

We conducted full-text searches of metadata to extract datasets available through GBIF.org, as of March 1, 2016, whose records included significant CS contributions. We reviewed and refined the list by consulting contributors to the GBIF network. In the case of publishers who are themselves networks that include many individual projects, like the UK National Biodiversity Network, datasets with CS contributions were disaggregated from those known or unlikely to contain few if any CS-derived records, which are therefore not included in the

We analyzed the contributions from CS projects by calculating the total number of occurrences in these datasets according to taxonomy, source country of data provider, and continent of species occurrence. As a disproportionate amount of CS contributions to GBIF come from a single source (eBird), we analyzed all GBIF-mediated data with and without the eBird data. Although our study was limited to assessing datasets that individually and collectively blend records gathered by professionals and amateurs, we consider the magnitude of our estimates and their relative proportions acceptable for the purposes of this paper, although the individual figures on CS contributions to GBIF-mediated data are subject to uncertainty

3. Results

3.1. The database

We developed a database with 420 distinct CS programs, including 114 (27%) that are CS portals serving multiple, distinct CS projects (Table A2). Some portals serve dozens of projects, others hundreds or more, resulting in 3603 CS projects represented by our dataset. Half of this number are found within the iNaturalist portfolio of projects (N = 1850). The vast majority (88%) of the CS programs in the database are projects that are currently known to be active (N = 374). Most are run by civil society organisations and only few by government agencies or the private sector (N = 269; 64%). Most CS programs monitored terrestrial ecosystems (N = 347, 82% of total CS programs), with substantial numbers monitoring freshwater (N = 139; 33%) and marine biomes (N = 128; 30%). The CBM database consisted of 40 programs (Table A3), which were drawn from reviews of environmental monitoring programs extracted from 3500 monitoring publications since 1987 (described in Danielsen et al., 2010, 2014c), all of which are distinct projects. Most CBM programs also monitored all three biomes (N = 40; terrestrial 45%, freshwater 40%, marine 20%).

3.1.1. Status and gaps in essential biodiversity variables

Fig. 1, which summarizes the data found in Tables A2 and A3, displays the proportion of each EBV covered by CS programs (portals and projects) and CBM programs, and shows that almost every EBV is covered by at least some CS or CBM programs. Natal Dispersal Distance and most EBVs in the Genetic Composition Class are the only ones collected by neither CS nor CBM programs across our two databases. One EBV (Species Distribution) is monitored by 80% of CS programs and 68% of CBM programs. Of the remaining programs in the CS Database, five other EBVs (Population Abundance, Phenology, Demographic Traits, Migratory Behaviour, and Disturbance Regime) are collected in >20 CS programs each (Fig. 1; examples in Table 1). Fig. 1 also shows that CBM programs monitor EBVs in different proportions than CS programs, CBM projects contributed relatively more to Population Abundance (90%) and Secondary Productivity (65%). Moreover, the majority of CS programs (70%) focused on only one EBV while most CBM programs collected data on more than one EBV (95%; Tables A2

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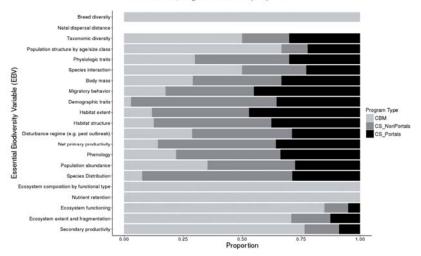


Fig. 1. Distribution of citizen science (CS) and community-based monitoring (CBM) programs by Essential Biodiversity Variable. CS programs could either be online "portals" supporting multiple CS projects, or single CS projects ("non-portals"). A full description can be found in Tables A2 and A3 respectively. Note that some projects contribute to more than one EBV.

A number of EBVs are not well covered by CS or CBM programs-i.e. Nutrient Retention, Ecosystem Composition by Functional Type, Net Primary Productivity (NPP), Physiological Traits, Natal Dispersal Distance and all of the EBVs in the Genetic Composition Class (Co-ancestry, Allelic Diversity, Population Genetic Differentiation and Breed and Variety Diversity). Although some of these EBVs can be monitored by remote sensing systems, Natal Dispersal Distance, Population Structure, Physiological Traits and the four EBVs in the Genetic Composition Class, cannot be measured well using existing remote sensing technology and so require ground-based measurements from either professional or CS/ CBM monitoring (Table 1).

3.1.2. Status and gaps in geographical coverage

Most of the CS programs that we found focus their monitoring activ ities in North America (184 programs or 43% of the total) or Europe (136 programs or 32% of the total; Table 2). Relatively few CS programs were found in Africa, Asia, and Central and South America. Around 10% of the CS programs incorporate observations of biodiversity from everywhere. These programs included species observation programs (iNaturalist, eBird, Naturgucker) as well as coordinated global networked schemes (International Waterbird Count, BirdLife programs, and the Global Coral Reef Monitoring Network of WorldFishcenter at http://www. gcrmn.org).

A total of 64% of the CS programs in Europe make their data available to GBIF while only 9% of those in North America submit their data to GBIF (Table 2). The similar figures for CS programs in Asia and South/ Central America are 55% and 100% (N = 10 and 3, respectively). Of the two programs in Africa, no data are made available to GBIF while 17% of the 42 programs in Oceania submit their data to GBIF. In contrast to CS as a whole, a relatively high proportion of CBM programs operate in Africa (34%) and Asia (24%), often in low-income countries (65% in countries with a Gross National Income per capita $<\!2570$ USD at the time of the assessment; World Bank, 2012). South and Central America had the lowest coverage by either CS or CBM programs.

3.1.3. Taxonomic coverage of citizen science and community based monitoring programs

CS programs cover a wide taxonomic breadth of global biodiversity (Table 3). The great majority of projects focus on animals (83%) while 20% of CS programs collect data on multiple taxonomic groups. For those CS programs with a taxonomic focus, most collect data on nonlepidopteran insects (24%), birds (19%), plants (17%), Lepidoptera (12%), or mammals (9%). In terms of the Population Abundance EBV, birds are commonly counted as part of regular censuses (e.g. Christmas bird counts, breeding bird surveys). One global model to assess population trends is exemplified in the International Waterbird Census (IWC) (see Box 1). The taxa most commonly surveyed by CBM are plants (24%) and within the animal kingdom, mammals (37%), fish (32%) and birds

Table 2 Geographical distribution of citizen science programs (by location of headquarters and activities) and community-based monitoring programs (see also Tables A2 & A3).

Continent	Citizen scien	ce program headq	uarters	Citizen scien activities	ce program	Community- monitoring	
	Number	% of total	% who make data available to GBIF	Number	% of total	Number	% of total
Africa	2	0%	0%	2	1%	13	33%
Asia	10	3%	55%	13	3%	9	23%
Еигоре	136	35%	65%	136	33%	5	13%
North America	211	50%	9%	184	42%	8	20%
Central & South America	3	1%	100%	4	1%	2	5%
Oceania	41	10%	17%	37	9%	3	8%
Global	6	1%	52%	44	10%	0	0%

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Distribution of observations from citizen science (CS) and community-based monitoring (CBM) initiatives and CS-contributed occurrence records in the Global Biodiversity Information Facility (GBIF) by taxonomy (as of March 1, 2016). A full description of the CS and CBM initiatives can be found in Tables A2 & A3 respectively.

	CS project	survey	CBM proj	ect survey	GBIF.org species rec	cords		
	(N = 420)	(N = 40	projects)				
Taxa	Number	Proportion	Number	Proportion	Total GBIF records per taxon	% contribution of taxon to total records	# records from CS projects	CS as a % of total records
All taxa	-	-	-	-	640,465,555		349,404,699	55%
Multi-taxa surveys	82	19.5%	5	13%	-	-	-	-
Animalia			-	-	449,595,895	70%	316,557,034	70%
Animals (multi-taxa surveys)	12	2.8%%	-	-	-	-	-	-
Arachnida	5	1.1%	-	-	2140,148	0%	440,973	21%
Insecta	101	23.7%	4	10%	46,552,525	7%	12,624,550	27%
Lepidoptera	49	11.5%	-	-	18,072,050	3%	7,785,904	43%
Mollusca	9	2.1%	-	-	8,762,130	1%	390,772	4%
Crustacea	12	2.8%	-	-				
Gastropoda	4	4.0%	-	-				
Amphibia	15	3.5%	-	-	3,864,189	1%	147,192	4%
Aves	80	19.0%	12	30%	345,498,795	54%	301,679,747	87%
Elasmobranchs	8	2.2%	-					
Mammalia	39	9.3%	15	38%	10,766,217	2%	598,206	6%
Osteichthyes	12	2.8%	13	33%	13,786,592	2%	126,597	1%
Reptilia	7	1.6%	3	8%	4,900,221	1%	93,380	2%
Plantae	70	16.7%	8	20%	170,391,526	27%	26,746,904	16%
Magnoliophyta	-	-	-	-	151,349,644	24%	24,581,185	16%
Gymnospermae	-	-	-	-	1,650,640	0%	247,506	15%
Pteridophyta	-	-	-	-	5,109,597	1%	715,772	14%
Bryophyta	1	0.20%	-	_	6,419,902	1%	666,085	10%
Vegetation (all)	_	_	2	5%	-	_	-	_
Trees (all)	-	_	1	3%	_	_	_	_
Forest types	-	-	1	3%	-	-	-	-
Fungi	4	0.9%	1	3%	10.497.206	2%	4.942.493	47%
Ascomycota	-		-		6.446,739	1%	2,502,232	39%
Basidiomycota	_	_	_	_	3,968,737	1%	2,439,452	62%
Other/unknown kingdoms	_	_	_	_	9,980,928	2%	381,350	4%
Archaea/bacteria/protists	5	1.1%	1	3%	-	=		-
Algae/chromista	10	2.2%		-				_

3.2. Case study analysis: CS contribution via GBIF to species distribution EBV

More than half (349 M) of the >640 M species occurrence data available through GBIF.org come from sources that include > 50% of the contributions from CS (Table 3; Table A4).

3.2.1. Taxonomic coverage of GBIF-mediated data

Overall, the contributions of CS programs to GBIF-mediated data are uneven across taxa-some taxa are well represented by CS data, while others are not (Table 3). CS programs account for 70% of animal records and 87% of bird records in GBIF. Birds are the most frequently recorded taxon with close to 300 M records in GBIF. CS programs account for over 1 M plant, insect, and Fungi records and over 500,000 mammal records. CS contributions represent a significant proportion of total GBIF records for Fungi (47%) and insects (27%).

3.2.2. Geographic coverage of GBIF-mediated data

Geographic patterns of CS data shared through GBIF are similar to those found in our survey of CS programs generally (Table 4 and Fig. 2). >90% of CS records in GBIF are published by programs located in North America and Europe, most likely due to a language bias. However, the provenance of programs currently sharing their data through GBIF does not necessarily reflect the geographic distribution of GBIF-mediated data. Data reported to a CS program headquartered in one country could have been collected in another country. For example, data from global CS programs such as eBird (USA) or Atlas of European Breeding Birds (NL) are collected from all over the world, but the provenance of the program is listed as one country.

Using country-level information available through GBIF, we examined the variation in data coverage for taxa across northern European countries, since each has national-level recording platforms for observa-tions of most taxa, and most make their data available to GBIF. We chose to examine records for four taxa which are well-represented globally by CS programs: Lepidoptera, non-lepidopteran insects, mammals, and birds. Fig. 3 shows large disparities between these countries despite access to similarly robust observation recording platforms and CS programs.

3.2.3. Contributions of portals to GBIF

The great majority of CS data available through GBIF comes from programs with either narrow taxonomic focus but broad geographic scope (e.g. eBird, antweb, Birdlife programs) or national network portals that aggregate observations across multiple CS projects and multiple taxa (e.g. UK National Biodiversity Network, ArtDatabanken; Fig. 3 and Table A4). The single largest contributor of occurrence records is the eBird Observation Dataset with 219 M observations. Contributions from the 100+ different CS programs sharing with GBIF is strongly skewed, as the top 10 CS programs contribute over 94% of the data. When the CS programs in the Global CS database were compared to the CS programs that contribute data to GBIF, less then <10% were found to be in common, indicating that there is a large gap in data sharing. We could not identify any CBM programs that contribute data directly to GBIF.

CS programs associated with portals tended to contribute more frequently to GBIF than CS programs that were not portals. Whereas 45% (N = 52 of CS 115 programs) of portals contribute to GBIF, only 31% (N = 95 of 310 CS programs) of stand-alone projects (i.e. non-portals) were found to contribute (Fig. 4). Geographically, this effect was most

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pronounced in Oceania, where CS programs were twice as likely to be published if they were portals (76% vs 36%; Fig. 4).

The likelihood of publishing data to GBIF from CS programs operating as portals also increased when looking across several of the taxa with data collected by substantial numbers of programs (> 14 programs; Fig. 5). This ranged from large increases in proportions publishing mammals (from 26% for non-portals publishing to GBIF to 65% for portals) and plants (from 23% for non-portals publishing to GBIF to 60% for portals). More modest increases were seen for birds, insects and Lepidoptera. Little or no increase in publishing to GBIF by CS portals was seen for amphibians or multi-taxa surveys (Fig. 6).

4. Discussion: challenges, solutions and limitations

Our review suggests that existing CS and CBM programs collect data on nearly all EBVs and cover a very broad range of taxa and geographic locations, but nevertheless CS and CBM programs have strengths and weaknesses in terms of contributions to biodiversity monitoring at an international scale (Fig. 1; Table 1; Pimm et al., 2014; Geijzendorffer et al., 2015; Amano et al., 2016).

The majority of CS programs (70%) are focused on a single EBV, i.e. species occurrence, which is one of the main sources of data for biodiversity monitoring (Geijzendorffer et al., 2015). CS programs also have a bias towards monitoring species distributions, particularly for birds (86% of data from CS programs in GBIF are for birds; Amano et al., 2016), and in North America and Europe. Yet data requirements for international biodiversity monitoring may be met by CS and CBM for many more taxa, regions and EBVs. For example, CS programs account for a significant proportion of GBIF-mediated data for several taxa, including non-lepidopteran insects, Lepidoptera, arachnids and Fungi. Determining key global bio-indicators (see e.g. McGeoch et al., 2010) and identifying data sufficiency thresholds will identify data requirements and help investigate where CS/CBM can play a key role.

Below we explore four questions in relation to meeting international biodiversity monitoring obligations using CS/CBM: What can be learned from successful CS/CBM programs that could facilitate the scaling up of CS and CBM contributions from local to international biodiversity monitoring? How do we make more from our existing strengths in data coverage? What strategies maximise synergies between CS/CBM and other approaches for monitoring biodiversity? What limitations exist in expanding the coverage of CS and CBM programs?

First, the CS programs that contribute most to GBIF tend to serve existing and vibrant communities of expert amateurs and hobbyists (Lawrence, 2006; Bell et al., 2008; Lewandowski and Specht, 2015), perhaps best exemplified by the preponderance of data and CS programs from birding communities and natural history societies (e.g. Botanical Society of the British Isles). These programs tend to be large, linked to well-funded institutions, have academic scientists associated with the programs, and are mainly found in Europe and North America where English is a common language. However, two other types of CS/CBM programs of note also compile large volumes of biodiversity data: (1) programs that allow volunteers with little or no expertise to make observations of a variety of species, but which include expert verification of data (e.g. iNaturalist, iSpot, iMapInvasives, antweb, Earthwatch field expeditions); and (2) CBM programs (e.g. Conrad and Hilchey, 2011; Danielsen et al., 2014a, 2014c; Johnson et al., 2016) that can cover many less well-represented EBVs (e.g. Species Interaction, Secondary Production, Population Structure; Table 1).

The accomplishments of CS/CBM programs have been attributed by

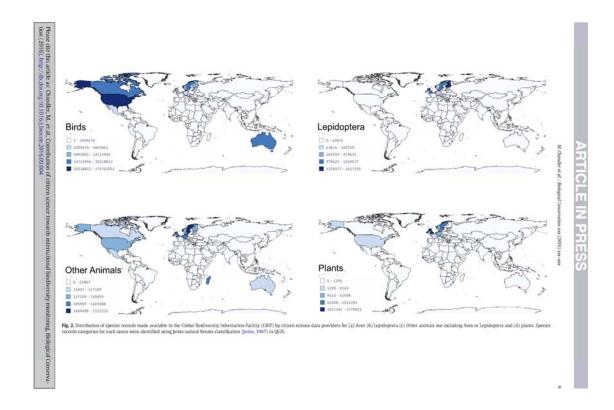
behavioural psychologists to participants who appreciate the opportunity to build on their existing interests, try something new with little effort, and participate in projects associated with place and community (Lawrence, 2006; Bell et al., 2008). Successful programs leverage these interests by supporting and building communities of participants who share common interests. We propose that these types of programs could be developed for new taxonomic groups, EBVs, and geographic

Distribution of species record	ls from citizen scies	nce (CS) projec	ts by taxa and	mce (CS) projects by taxa and continent using GBIF-mediated data (as of March 31, 2016),	GBIF-mediate	d data (as of N	larch 31, 2016).							
Continent	Total # records Plantae	Plantae	Fungi	Animalia	Arachnida	Arachnida Insecta	Lepidoptera	Bony fish	Amphibia	Reptilia	Lepidoptera Bony fish Amphibia Reptilia Mammalia	Aves	Aves w/o eBird Other/unknov	Other/unknown
Africa	3,574,723	4415	16	1,784,757	61	401,706	2337	3953	395	1964	6088	1,366,286	49,890	24
Antarctica	22,114	7	0	11,054	0	0	0	0	0	0	93	10,960	335	0
Asia	5,674,341	7795	49	2,820,712	124	73,125	29,763	11,731	734	2140	1633	2,726,423	103,523	112
Europe	213,153,276	26,444,138	4,434,380	87,162,132	430,287	11,062,393	7,645,507	90,701	94,717		576,126	74,075,023	70,116,937	1,094,068
North America		206,755	10,397	195,011,240	7187	224,867	79,167	8909	50,186		32,518	194,620,460	7,620,397	2511
Oceania		68,847	8021	17,887,441	1629	186,406	4373	5694	448	1841	2846	17,683,589	11,759,269	28,596
Central & South America		15,367	456	11,704,854	1694	578,435	11,235	5068	2205		6169	11,100,832	80,389	75
No location		62	0	22,591	0	20	6	1022	2	72	2	21,211	11	3

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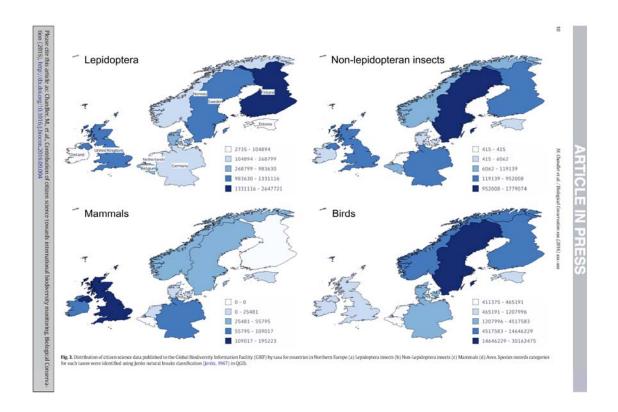


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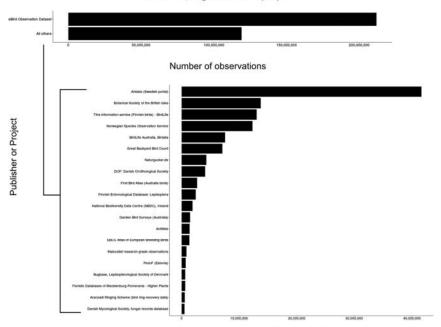


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Number of observations

Fig. 4. List of top citizen science data providers to GBIF. Single data providers such as National Biodiversity Data Centre may support multiple projects. Other large portals such as the National Biodiversity Network facilitate contributions to GBIF but are not necessarily recognized as the data provider (data pulled on March 1st, 2016).

locations. However, we note that the model of successful CS programs found in one place (e.g. Sweden) or for one taxon (e.g. Lepidoptera) may be context dependent and thus may not be transferable to regions without the same history or interest groups. Even across countries with vibrant CS programs and well developed infrastructure, there are big differences in which taxa are reported to GBIF (Fig. 3). While seeking citizen experts may seem a short cut to addressing gaps, they may not exist without importing them via travel programs. Instead, CS programs such as iNaturalist, which connect communities of like-minded participants through online tools, or, CBM programs, which are often more

collaborative and rooted to local issues and place (Danielsen et al., 2014d; Funder et al., 2013), may be more likely to succeed in collecting data for biodiversity gaps.

Another potential solution may be to expand the data fields (and hence EBVs) collected by current global CS programs such as iNaturalist, eBird, and antweb, thereby taking advantage of the growing audiences these programs have, as well as their established workflows, and mechanisms for publishing to global databases. Some of these portals (e.g. iNaturalist, eBird, iSpot) already enable CS/CBM program coordinators to tailor the infrastructure to meet their specific needs, including

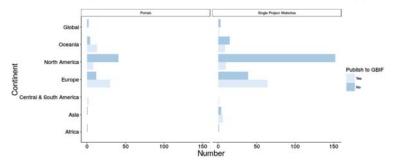


Fig. 5. Proportion of citizen science programs by continent that contribute data available to GBIF further divided by whether they are portals or single project websites.

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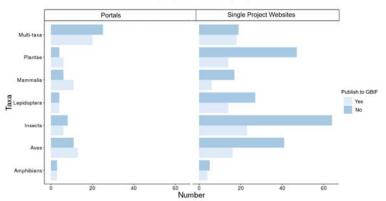


Fig. 6. Proportion of citizen science programs by taxa that contribute data to GBIF further divided by whether they are portals or single project websites.

language. In Mexico, local versions of both iNaturalist and eBird (i.e. Naturalista (http://conabio.inaturalist.org/) and Averaves (http:// ebird.org/content/averaves/acerca/) allow for local programming (Ortega-Álvarez et al., 2012), Advances in technology - e.g. image recognition software such as Image-Based Ecological Information System (IBEIS, Berger-Wolf et al., 2015) - may also lower barriers to participation and expand the types of data (taxa identities and other EBVs) that can be extracted from observations.

Second, in terms of how we can make more from our existing data coverage, this review found only a small fraction (< 10%) of CS and CBM programs contributing to global analyses of biodiversity, despite the fact that many CS and CBM programs collect data on underrepresented taxa in remote regions, or observe underrepresented EBVs. This is partly because these programs suffer from many disadvantages common to other biodiversity monitoring efforts, namely, they are poorly resourced, with limited communication and visibility to participants and researchers (Costello et al., 2015, 2013; Michener, 2015; Johnson et al., 2016). Increasing the impact of CS and CBM is now an active area of interest, including the development of tools and networks to build capacity both for individuals and institutions, Organisations such as U.S.-based Citizen Science Association (CSA), the European Citizen Science Association (ECSA), and the Australian Citizen Science Association (ACSA) as well as national or regional Biodiversity Observation Networks should help to improve communication, integration, and scaling of CS and CBM programs (Bonney et al., 2014; Wetzel et al., 2015). Toolkits (e.g. BON in a Box - http://geobon.org/bon-in-a-box/what-is-bon-in-a-box/), online resources and guidelines can also increase capabilities for sharing standardised data (Schmeller et al., 2015; Johnson et al., 2016).

Data repositories for underrepresented EBVs should continue to be established that can facilitate CS and CBM programs monitoring EBVs and to make their data available to international databases (Costello et al., 2013; Peters et al., 2014; Michener, 2015; Kullenberg and Kasperowski, 2016, e.g. EOL's TraitBank (Parr et al., 2015), GloBl (Poelen et al., 2014), Ocean Biogeographic Information System (http:// www.iobis.org/OBIS), and TRY (www.try-db.org). Web-based portals have been developed that collate data from multiple CS and CBM projects, and increase data interoperability (Schmeller et al., 2015) and the amount of data submitted to biodiversity databases. Our analysis of GBIF-mediated data indicated how effective data sharing can be in the increased use of data in analyses (Kissling et al., 2015; Kullenberg and Kasperowski, 2016; Figs. 4 and 5).

Networked portals or platforms can use resources more efficiently, bundling tools, services and support for multiple projects while directing investment towards processes and workflows that increase sharing of accessible, discoverable and interoperable data (Wetzel et al., 2015). These investments are difficult for individual CS and CBM projects to make on their own because of their cost and the technical expertise required. Portals are emerging in both India and Africa (Table A4).

The positive effect of a regional portal is exemplified by the Atlas of Living Australia (ALA), which links numerous CS programs to GBIF. ALA enables hundreds of small- to medium-sized programs to tap into a robust and easy-to-use infrastructure with workflows that automate data syndication and synchronization with GBIF. Several members of the GBIF network have either adopted or are considering the adoption of ALA's open-source tools to develop their national portals. This may represent a transferable model for regions currently without well-organized and self-sustaining CS programs.

Third, while addressing taxonomic and geographic data gaps for the

EBVs will take time and resources, there is great potential in leveraging the synergies from combining CS/CBM and remote sensing approaches (Pereira et al., 2013; O'Connor et al., 2015; Skidmore et al., 2015), particularly for EBVs well suited for CS and CBM (e.g. species distribution, species abundance, and phenology) and in situations in which fine-scale spatial or temporal heterogeneity is important (Danielsen et al., 2005; Devictor et al., 2010). However, some EBVs can only be partially monitored by remote sensing (Table 1), while others, such as Natal Dispersal Distance, Population structure, Physiological Traits and the four EBVs in the Genetic Composition Class, cannot be remotely sensed and thus require ground-based measurements (Table 1). In-situ monitoring by CS and CBM can therefore help to fill the gaps in monitoring those EBVs

that are not easily remotely sensed.

Predictions of forest-level response to climate change would be impossible using either data type in isolation. Efforts are underway to combine CS-derived species composition maps and other data with remotesensing data from satellites and cameras in forest canopies to improve models of land surface phenology, carbon budgets, and ecosystem function (Melaas et al., 2016).

Additionally, there is great potential to connect CS and CBM programs to other in-situ monitoring efforts—e.g. protected areas and long-term ecological research sites (Tulloch et al., 2013) and, thereby to cross-fertilize scientist-executed and community-based observations and knowledge (Magnusson et al., 2013). Connecting CS/CBM and scientist-executed monitoring (e.g. Earthwatch field expeditions) can allow for assessment of many EBVs including in underrepresented and remote regions such as tropical forests and the Arctic (Chandler et al., 2016b; Johnson et al., 2016; Magnusson et al., 2013).

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Finally, addressing the question regarding limitations of CS and CBM, the most likely ones are the availability of funding and adequate resources-CS and CBM are not free, and are not considered a high priority in many parts of the world. The primary obstacles to expanding the taxonomic, geographic and EBV-relevant scope of CS projects are whether volunteers can observe particular challenging taxonomic groups and EBVs in new locations, and whether programs are developed with the necessary infrastructure to support this. Some taxonomic groups may be too challenging although the abundance of CS data on insects and Fungi suggests that volunteer contributions to some groups difficult for novices is indeed possible. Some EBVs-like Genetic Composition-may become possible when field-based gene sequencing technologies have matured (Thomsen and Willerslev, 2015). EBVs dealing with ecosystem functioning could be covered by CBM programs but by definition the primary focus of CBM programs is on affecting local management with less interest in collecting standardised data useful for other purposes (Conrad and Hilchey, 2011).

Concerns have also been raised that when scientists "assimilate local ecological knowledge within Western worldviews" (Mistry and Berardi, 2016), there is a risk that it may further marginalize indigenous and local people. For organizers of CBM programs to effectively share their data with global repositories, suitable modus operandi of cooperation must therefore be established. Agreements on cooperation between CBM programs and the global repositories should address principles of intellectual property rights. Free Prior and Informed Consent, respect for knowledge holders, and reciprocity (Danielsen et al., 2014b; United Nations, 2008).

Finally, there are issues of concern surrounding the bias of CS/CBMderived data (Riesch and Potter, 2014; Nature, 2015). However, many examples show that volunteer-collected data in well-designed studies are no more problematic than those collected by professional scientists (Newman et al., 2003: Danielsen et al., 2014a: Lewandowski and Specht, 2015; Meentemeyer et al., 2015). Maintaining high data quality can be time and resource intensive (Buesching et al., 2015) so project managers must consider this expense when monitoring biodiversity; CS/CBM is not always the most cost-effective monitoring approach, de spite the participation of volunteers and many other strengths (McKinley et al., 2016).

5. Conclusions

Our findings suggest that CS already make substantial contributions to large-scale international biodiversity monitoring. The EBVs currently used at international scale include species occurrence, abundance, and phenology. A few taxa and variables are also extensively monitored at scale (e.g. birds, Lepidoptera and plants/trees), while other taxa garner strong interest in selected regions including Fungi, amphibians, reptiles and coral reef taxa. Some of these data already contribute to international biodiversity monitoring databases.

The biodiversity monitoring community can expand the taxonomic, geographic, and EBV coverage of CS and CBM programs, if they can make citizens and community members interested in it. By building on the interests and needs of participants and providing existing communities (e.g. naturalists, concerned citizens and community members) with the tools and services they need (Bell et al., 2008; Shirk et al. 2012), most EBVs and taxa could potentially be covered by CS and CBM programs.

Several strategies can facilitate further scaling up of CS and CBM contributions to international biodiversity monitoring. One is to include making better use of CS and CBM associations, online toolkits, data repositories, and network portals that coordinate and support CS and CBM projects and increase data interoperability. Another is to encourage successful existing projects to expand their data collection fields to other EBVs. It would also be useful to develop further synergies between CS/CBM and remote sensing and scientist-executed monitoring programs to expand and enhance the monitoring of EBVs

Despite its potential, real limits remain for scaling CS/CBM contributions to international biodiversity monitoring. Chief among those limits is the availability of resources, CS and CBM are not free, Relying on volunteer contributions can make them seem cheap, and CS and CBM are frequently more cost efficient than paying professionals to do the same monitoring (Danielsen et al., 2005; Theobald et al., 2015). However, ultimately, CS and CBM programs require investment to maximise their potential contributions to international biodiversity monitoring.

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References

- Amano, T., Sutherland, W.J., 2013. Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. Proc. R. Soc. B 280, 20122649. http://dx.doi.org/10.1098/rspb.2012.2649.

 Amano, T., Lamming, J.D.L. Sutherland, W.J., 2016. Spatial gaps in global biodiversity information and the role of citizen science. Bioscience 66, 393–400. http://dx.doi.org/10.1093/biosci/biov202.
- Ariño, A.H., Chavan, V., Otegui, J., 2016. Best Practice Guide for Data Gap Analysis for Bio-diversity Stakeholders. GBIF Secretariat, Copenhagen, Denmark.

- Ariño, A.H., Chavan, V., Otegui, J., 2016. Best Practice Guide for Data Gap Analysis for Biodiversity Stakeholders. GBIF Secretariat, Copenhagen, Denmark.
 Beck, J., Ballesteros-Mejia, L. Nagel, P., Kitching, I.J., 2013. Online solutions and the
 "Wallacean shortfall": what does GBIF contribute to our knowledge of species'
 ranges? Divers. Distrib. 19, 1043–1050, http://dx.doi.org/10.1111/ddi.12083.
 Beck, J., Böller, M., Erhardt, A., Schwanghart, W., 2014. Spatial bias in the GBIF database
 and its effect on modeling species' geographic distributions. Ecol. Inform. 19, 10–15.
 http://dx.doi.org/10.1016/j.ecoin.12013.11.002.
 Bell, S., Marzano, M., Cent, J., Kobierska, H., Podjed, D., Vandzinskaite, D., Reinert, H.,
 Armaitiene, A., Grodzińska-Jurczak, M. Muršič, R., 2008. What counts? Volunteers
 and their organisations in the recording and monitoring of biodiversity. Biodivers.
 Conserv. 17, 3443–3454. http://dx.doi.org/10.1007/s10531-008-9357-9.
 Berger-Wolf, T.Y., Rubenstein, D.L. Stewart, C.V., Holmberg, J., Parham, J., Crall, J., 2015.
 IBEE: Image-based Ecological Information System: from pixels to science to conservation. Presented at the Bloomberg Data for Good Exchange Conference, New York
 NY, USA.

- New York, Coper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., Shirk, J., 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy, Bisocience 59, 977–984. http://dx.doi.org/10.1525/bio.2005.59.11.9.

 Bonney, R., Coper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., Shirk, J., 2009. Citizen science as developing tool for expanding science knowledge and scientific literacy, Bisocience 59, 977–984. http://dx.doi.org/10.126/science.125.1554.

 Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller, Rushing, A.J., Parrish, J.K., 2014. Next steeps for citizen science. Science 343, 1436–1437. http://dx.doi.org/10.1103/science.125.1554.

 Brook, R.K., McLachlan, S.M., 2008. Trends and prospects for local knowledge in ecological and conservation research and monitoring. Biodivers. Conserv. 17, 3501–3512. http://dx.doi.org/10.1007/s10531-008-9445-x.

 Buesching, C.D., Slade, E.M., Newman, C., Ruitta, T., Riordan, P., Macdonald, D.W., 2015. Many hands make light work but do they? A critical evaluation of citizen science. In: Macdonald, D.W., 269er, R. (Eds.), Wildlife Conservation on Farmland Volume 2: Conflict in the Countryside. Oxford University Press, Oxford: New York. Chandler, M., Rullman, S., Cousins, S., Esmail, N., Begin, E., Venicx, G., Eisenberg, C., Studer, M., 2016a. Contributions to publications and management plans from 7 years of citizen science: use of a novel evaluation tool on Earthwatch-supported projects. Biol. Conserv. http://dx.doi.org/10.1016/j.biocon.2016.09.024.

 Chandler, M., Sourcebook of Methods and Procedures for Monitoring Essential Biodiversity Variables in Tropical Forests With Remote Sensing, GOFC-GOLD, GEO BON (Eds.), A Sourcebook of Methods and Procedures for Monitoring Essential Biodiversity Variables in Tropical Forests with Remote Sensing, GOFC-GOLD and GEO BON, Wageningen, the Netherlands (p. In press).

 Corrad, C.C., Hilchey, K.G., 2011. A review of citizen science and community-based

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cosceso, M.J., Michener, W.K., Gahegan, M., Zhang, Z.-Q., Boume, P.E., 2013. Biodiversity data should be published, cited, and peer reviewed. Trends Ecol. Evol. 28, 454–461. http://dx.doiorg/10.1016/j.tree.2013.05.002.

Costello, M.J., Vanhoorne, B., Appeltans, W., 2015. Conservation of biodiversity through taxonomy, data publication, and collaborative infrastructures. Conserv. Biol. 29, 1094–1099. http://dx.doiorg/10.1111/cobi.12496.

Couvet, D., Devictor, V., Jiguet, F., Julliard, R., 2011. Scientific contributions of extensive biodiversity monitoring. C. R. Biol. 334, 370–377. http://dx.doi.org/10.1016/j.crvi. 2011.02.007.

2011.02.007.

Danleben, F., Burgess, N.D., Balmford, A., 2005. Monitoring matters: examining the potential of locally-based approaches. Biodivers. Conserv. 14, 2507–2542. http://dx.doi.org/10.1007/s10531-005-8375-0.

Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P.G., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjeklså, J., Holt, S., Hübertz, H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skelboen, T., Stuart-Hill, G., Topp-Jegensen, E., Vonten, D., 2009. Local participation in natural resource monitoring: a characterization of approaches. Conserv. Biol 23, 31–42, http://dx.doi.org/10.1111/j.1532-3739.2008.01651.x.

Danielsen, F., Burgess, N.D., Jensen, P.M., Pirhofer-Walzl, K., 2010. Environmental monitoring: the scale and speed of implementation varies according to the degree of peoples involvement. L Appl. Ecol. 47, 1166–1168. http://dx.doi.org/10.1111/j.1365-2664.

involvement. J. Appl. Ecol. 47, 1166-1168. http://dx.doi.org/10.1111/j.1365-2664

Danielsen, F., Jensen, P.M., Burgess, N.D., Altamirano, R., Alviola, P.A., Andrianandrasana nelsen, F. Jensen, P.M., Burgess, N.D., Atlamurano, R., Alvola, P.A., Andrianandrasana, H., Brashares, J.S., Burton, A.C., Coronado, L., Corpuz, N., Enghoff, M., Fjeldsa, J., Funder, M., Holt, S., Hubertz, H., Jensen, A.E., Lewis, R., Massao, J., Mendoza, M.M., Ngaga, Y., Pipper, C.B., Poulsen, M.K., Rueda, R.M., Sam, M.K., Skelhoe, T., Sorensen, M., Young, R., 2014a. A multicountry assessment of tropical resource monitoring by local communities. Bioscience 64, 236–251. http://dx.doi.org/10.1093/biosci/biu001.

local communities. Bioscience 64, 439–431. https://doi.org/10.1009/june.0001

abundance of natural resources with science-nased land management systems. Conserv. Lett. 7, 380-389. http://dx.doi.org/10.111/20.00112100.

Danielsen, F., Pithofer-Walzl, K., Adrian, T.P., Kapijimpanga, D.R., Burgess, N.D., Jensen, P.M., Bonney, R., Funder, M., Landa, A., Levemann, N., Madsen, J., 2014c. Linking public participation in scientific research to the indicators and needs of international environmental agreements: monitoring environmental agreements. Conserv. Lett. 7, 12–24. http://dx.doi.org/10.1111/con112024.

Danielsen, F., Topp-Jørgensen, E., Levermann, N., Løvstrøm, P., Schiotz, M., Enghoff, M., Jakobsen, P., 2014d. Counting what countex using local knowledge to improve Arctic resource management. Polar Geogr. 37, 69–91. http://dx.doi.org/10.1080/1088937X, 2014.890860.

2014.890980. Devictor, V. Clavel, I. Julliard, R. Lavergne, S. Mouillot, D. Thuiller, W., Venait, P., Villéger, S., Mouquet, N., 2010. Defining and measuring ecological specialization. J. Appl. Ecol. 47, 13–25. http://dx.doi.org/10.1111/j.1365-2664.2009.01744x.
Evangelista, P.H., Norman, J., Swartzink, P., 2012. Assessing habitat quality of the mountain nyala Tragglaphus buxtoni in the Bale Mountains, Ethiopia. Curr. Zool. 58, 251-251. http://dx.doi.org/10.1016/j.neph/19.151.2014.

tain nyala Ingeniphia bakkoin in the Bate woomalins, Ethiopia. Curi. 2001. 36, 525-535. http://dx.doi.org/10.1093/czoolo/58.4.525. Funder, M., Ngaga, Y., Nielsen, M., Poulsen, M., Danielsen, F., 2013. Reshaping conservation: the social dynamics of participatory monitoring in Tanzania's community-managed forests. Conserv. Soc. 11, 218. http://dx.doi.org/10.4103/0972-49823.121011. García-Roselló, E., Guisande, C., Manjarrés-Hernández, A., González-Dacosta, J., Heine, J.,

Pelayo-Villamil, P., González-Vilas, L., Vari, R.P., Vaamonde, A., Granado-Lorencio, C Lobo, I.M., 2015. Can we derive macroecological patterns from primary Global Biodiersity Information Facility data? Glob. Ecol. Biogeogr. 24, 335-347. http://dx.doi.org

Geijzendorffer, I.R., Regan, E.C., Pereira, H.M., Brotons, L., Brummitt, N., Gavish, Y., Haase P., Martin, C.S., Mihoub, J.-B., Secades, C., Schmeller, D.S., Stoll, S., Wetzel, F.T., Walters, M., 2015. Bridging the gap between biodiversity data and policy reporting needs: an essential biodiversity variables perspective. J. Appl. Ecol. n/a-n/a http://dx.doi.org/10.1111/1365-2664.12417.

GEO BON, 2015. GEO BON Strategy for Development of Essential Biodiversity Variables.

Version 1.0. Produced by GEO BON Management Committee Oct 2015.

Grown, Q. Weatherdon, L. Geigendorffer, IR., 2016. Is citizen science an open science in the case of biodiversity observations? J. Appl. Ecol. http://dx.doi.org/10.1111/1365-

Haklay, M., 2015. Citizen Science and Policy: A European Perspective (Case Study Series o. Vol. 4). Commons Lab. Woodrow Wilson International Center for Scholars, Wash

Huntington, H.P., 2000. Using traditional ecological knowledge in science: methods and applications. Ecol. Appl. 10, 1270-1274. http://dx.doi.org/10.1890/1051plications. Ecol. Appl. 10, 127 61(2000)010[1270:UTEKIS]2.0.CO;2.

IPBES, 2013. Decision IPBES-2/4: Conceptual Framework for the Intergovernmental Sci e-Policy Platform on Biodiversity and Ecosystem Service

Jenks, G.F., 1967. The data model concept in statistical mapping. International Yearbook of Cartography, vol. 7, pp. 186–190. Johnson, N., Behe, C., Danielsen, F., Krümmel, E.-M., Nickels, S., Pulsifer, P.L., 2016, Com-

Johnson, N., Behe, C., Danielsen, F., Krümmel, E.-M., Nickels, S., Pulsifer, P.L., 2016. Community-based monitoring and indigenous knowledge in a changing arctic: a review for the sustaining arctic observing networks. Sustain Arctic Observing Network Task # 9, Ottawa. Inuit Grumphal Founcil.
Kennett, R., Danielsen, F., Silvius, K.M., 2015. Conservation management: citizen science is not erough on its own. Nature 521, 161. http://dx.doi.org/10.1038/52116161.
Kissling, W.D., Hardisty, A., Garcia, E.A., Santamaria, M. Leo, F.D. Pesole, G., Freyhof, J., Manset, D., Wissels, S., Konjin, J., Los, W., 2015. Towards global interoperability for supporting biodversity research on essential biodiversity variables (EBV.). Biodiversity 16, 99–107. http://dx.doi.org/10.1080/14888385.2015.1068709.

Kullenberg, C., Kasperowski, D., 2016. What is citizen science? - A scientometric meta analysis. PloS One 11, e0147152. http://dx.doi.org/10.1371/journal.pone.0147152. Lawrence, A., 2006. "No personal motive?" Volunteers, biodiversity, and the false dichotomies of participation. Ethics, Place & Environment. 9, pp. 279–298. http://dx.doi. org/10.1080/13668790600893319.

org/10.1080/13668790600893319.
Lewandowski, E., Specht, H., 2015. Influence of volunteer and project characteristics on data quality of biological surveys: Data Quality of Volunteer Surveys. Conserv. Biol. 29, 713–723. http://dx.doi.org/10.1111/obi.12481.
Magnusson, W., Braga-Neto, R., Petzini, F., Baccaro, F., et al., 2013. Biodiversity and Integrated Environmental Monitoring. Atterna Editorial, Santo André, Brazil. McGeoch, M.A. Butchart, S.H.M., Spear, D., Marais, E., Kleynhans, E.J., Symes, A., Chanson, J., Hoffmann, M., 2010. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses: Invasive alien species indicator: 2010 biodiversity target. Divers. Distrib. 16, 95–108. http://dx.doi.org/10.1111/j.1472-4642. 2005.00633x.

McKinley, D.C., Miller-Rushing, A., Ballard, R., Bonney, R., Brown, S., et al., 2016. Citizen sci ence can improve conservation science, natural resource management, and environ-mental protection. Biological Conservation http://dx.doi.org/10.1016/j.biocon.2016.

05.015 (In press). entemeyer, R.K., Dorning, M.A., Vogler, J.B., Schmidt, D., Garbelotto, M., 2015. Citizen science helps predict risk of emerging infectious disease. Front. Ecol. Environ. 13, 189–194. http://dx.doi.org/10.1890/140299.
Melaas E.K. Friedd, M.A. Richardson, A.D. 2016. Multiscale modeling of spring phenology across deciduous forests in the Eastern United States. Glob. Chang. Biol. 22, 792–805.

http://dx.doi.org/10.1111/gch.13122.
Meyer, C., Kreft, H., Guralnick R., Jetz, W., 2015. Global priorities for an effective information basis of biodiversity distributions. Nat. Commun. 6, 8221. http://dx.doi.org/10.

Michener, W.K., 2015. Ecological data sharing. Ecol. Inform. 29 (Part 1), 33-44. http://dx

Miller-Rushing, A., Primack, R., Bonney, R., 2012. The history of public participation in eco-logical research. Front. Ecol. Environ. 10, 285–290. http://dx.doi.org/10.1890/110278 Mistry, J., Berardi, A., 2016. Bridging indigenous and scientific knowledge. Science 352, 1274–1275. http://dx.doi.org/10.1126/science.aafi160.

Nature, 2015. Rise of the citizen scientist. Nature 524, 265. http://dx.doi.org/10.1038/

Newman, C., Buesching, C.D., Macdonald, D.W., 2003. Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation—"Sed quis custodiet ipsos custodies?". Biol. Conserv. 113, 189–197. http://dx.doi.org/10.1016/S0006-3207(02)00374-9.

O'Connor, B., Secades, C., Penner, J., Sonnenschein, R., Skidmore, A., Burgess, N.D., Hutton, J.M., 2015. Earth observation as a tool for tracking progress towards the aichi biodiversity targets. Remote Sens. Ecol. Conserv. 1, 19–28. http://dx.doi.org/10.1002/

Ortega-Álvarez, R., Sánchez-González, L.A., Rodríguez-Contreras, V., Vargas-Canales, V.M.

Ortega-Álvarez, R., Sánchez-González, L.A., Rodríguez-Contreras, V., Vargas-Canales, V.M., Puebla-Olivares, F., Berlanga, H., 2012. Birding for and with people: integrating local participation in avian monitoring programs within high biodiversity areas in South-Part, C.S., Schulz, K.S., Harmmock, J., Wilson, N., Leary, P., Rice, J., Corrigan Jr., R.J., 2015. TraitBank Practical Semantics for Organism Attribute Data Semantic Web – Interoperability, Usability, Applicability, http://www.semantic.web-journal.net/content/traitbank-practical-semantics-organism-attribute-data-1.
Perizh H.M., Ferrier, S., Wallers, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Brufond, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Raith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Hoft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Essential biodiversity variables, Science 339, 277–278. http://dx.doi.org/10.1126/science.1229931.
Peters, D.P.C., Loescher, H.W., San Clements, M.D., Havstad, K.M., 2014. Taking the pulse of a continent: expanding site-based research infrastructure for regional-to-ontinent-

a continent: expanding site-based research infrastructure for regional- to continen-tal-scale ecology. Ecosphere 5, 1–23. http://dx.doi.org/10.1890/E513-00295.1 erson, A.T., Soberón, J. Krishtalka, L., 2015. A global perspective on decadal challenges and priorities in biodiversity informatics. BMC Ecol. 15, 15. http://dx.doi.org/10.1186/

\$12898-015-0046-8.
Skidmore, A., Mücher, S., Dawson, T.P., Fernandez, M., Lucas, R., Schaepman, M.E., Wang, T., O'Connor, B., Jongman, R.H.G., Kempeneers, P., Sonnenschein, R. Leidner, A.K., Böhm, M. He, K.S., Nagendra, H., Dubois, G., Fatoyinbo, T., Hansen, M.C., Paganini, M., de Klerk, H.M., Asner, G.P., Kerr, J.T., Estes, A.B., Schmeller, D.S., Heiden, U., Rocchini, D., Pereira, H.M., Turak, E., Fernandez, N., Lausch, Schmeller, D.S., Healen, U., Kocchini, D., Pereira, H.M., Turak, E., Fernandez, N., Lauscn, A., Cho, M.A., Alcanaz-Segura, D., McGooch, M.A., Turner, W., Mueller, A., St-Louis, V., Penner, J., Vihervaara, P., Belward, A., Reyers, B., Geller, G.N., 2016. Framing the concept of satellite remote sensing essential biodiversity ariables: challenges and future directions. Remote Sens. Ecol. Conserv. n/a-n/a http://dx.doi.org/10.1002/rse2.15.
Pimm. S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P.H., Roberts, C.M., Sexton, J.O., 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science 344, 1246752. http://dx.doi.org/10.1126/science.1246752.

Poelen, I.H., Simons, I.D., Mungall, C.L. 2014. Global biotic interactions

Poelen, J.H., Simons, J.D., Mungall, C.J., 2014. Global biotic interactions: an open infrastructure to share and analyze species-interaction datasets. Ecol. Inform. 24, 148–159. http://dx.doi.org/10.1016/j.ecoint.2014.088005.
Proença, V., Martin, L.J., Pereira, H.M., Fernandez, M., McRae, L., et al., 2016. Global biodiversity monitoring: from data sources to essential biodiversity variables. Biol. Conserv. http://dx.doi.org/10.1016/j.biocon.2016.07.014 (In press).
Riesch, H., Potter, C., 2014. Cliizen science as seen by scientists: methodological, epistemological and ethical dimensions. Public Underst. Sci. 23, 107–120. http://dx.doi.org/10.1177/0963662513497324.

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15

- Ruete, A., 2015. Displaying bias in sampling effort of data accessed from biodiversity databases using ignorance maps. Biodivers. Data J., e5361 http://dx.doi.org/10.3897/
- Samy, G., Chavan, V., Ariño, A.H., Otegui, J., Hobern, D., Sood, R., Robles, E., 2013. Content assessment of the primary biodiversity data published through GBIF network: status, challenges and potentials. Biodivers. Inform. 8. http://dx.doi.org/10.17161/bi.v8i2. 4124.
- challenges and potentials. Biouvers. inform. 8. http://ux.doi.org/10.1716/juxvoiz.4124.

 Schmeller, D.S., Julliard, R., Bellingham, P.J., Böhm, M., Brummitt, N., Chiarucci, A., Couvet, D., Elmendorf, S., Forsyth, D.M., Moreon, J.G., Gregory, R.D., Magnusson, W.E., Martin, L.J., McGeoch, M.A., Mihoub, J.-B., Pereira, H.M., Proença, V., van Swaay, C.A.M., Yahara, T., Belnap, J., 2015. Towards a global terrestrial species monitoring program. J. Nat. Conserv. 25, 51–57. http://dx.doi.org/10.1016/j.jinc.2015.03.003.

 Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.W., Krasny, M.E., Bonney, R., 2012. Public participation in scientific research: a framework for deliberate design. Ecol Soc. 17. http://dx.doi.org/10.5751/j.ES-04705.170229.

 Skidmore, A.K., Petroerlli, N., Coops, N.C., Geller, G.N., Hansen, M., Lucas, R., Mücher, C.A., O'Connor, B., Paganini, M., Pereira, H.M., Schaepman, M.E., Turner, W., Wang, T., Wegmann, M., 2015. Environmental science: agree on biodiversity metrics to track from space. Nature 523, 403–405. http://dx.doi.org/10.5734303a.

 Theobald, E.J., Ettinger, A.K., Burgess, H.K., DeBey, L.B., Schmidt, N.R., Froehlich, H.E., Wagner, C., HilleRistLambers, J. Tewksbury, J., Harsch, M.A., Parrish, J.K., 2015. Global change and local solutions: tapping the unrealized potential of citizen science for

- biodiversity research. Biol. Conserv. 181, 236-244. http://dx.doi.org/10.1016/j.biocon.2014.10.021.
- biocon 2014:10.021.
 Thomsen, P.F., Willerslev, E., 2015. Environmental DNA an emerging tool in conservation for monitoring past and present biodiversity. Biol. Conserv. 183. 4–18. http://dx.doi.org/10.1016/j.biocon.2014.11.019.
 Troia, M.J., McManamay, R.A., 2016. Filling in the CAPS: evaluating completeness and coverage of open-access biodiversity databases in the United States. Ecol. Evol. n/a-n/a. http://dx.doi.org/0.1002/ece32.225.
 Tulloch, A.I.T., Possingham, H.P., Joseph, L.N., Szabo, J., Martin, T.G., 2013. Realising the full potential of citizen science monitoring programs. Biol. Conserv. 165, 128–138. http://dx.doi.org/0.1016/j.biocon.2013.05.025.
 United Nations, 2008. Declaration on the Rights of Indigenous Peoples. United Nations. http://www.un.org/es.ascoder/unpufildocuments/DRPSen.ndf (Accessed: August

- United Nations, 2008. Declaration on the Rights of Indigenous Peoples. United Nations. http://www.un.org/esa/socdev/unpfii/documents/DRIPSen.pdf (Accessed: August 16, 2016. United Nations).
 Valland, N., 2016. Personal Communication.
 Wetzel, ET., Saarermaa, H., Regan, E., Martin, C.S., Mergen, P., Smirnova, L., Tuama, É.Ó., García Camacho, F.A., Hoffmann, A., Vohland, K., Häuser, C.L., 2015. The roles and contributions of Biodiversity Observation Networks (BONS) in better tracking progress to 2020 biodiversity targets: a European case study. Biodiversity 16, 137–149. http://dx.doi.org/10.1080/14883386.2015.1075902.
 World Bank, 2012. World Development. Report 2012: Gender Equality and Development. World Bank, Washington, D.C., USA

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Project title: Coordinating an Observation Network of Networks EnCompassing sa Tellite and IN-situ to fill the

Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate,

Fritz et al., (2017). Global Crowdsourced Data on Land Cover, Land Use and **Human Impact. Nature Scientific Data. (Submitted)**

3. Special issue in Environment Science and Policy

Call for Paper: Special issue on 'Towards integrated Essential Variables for **Environmental Sustainability**

Guest editors: Joan Masó, Stefano Nativi, Antonio Bombelli, Jay Pearlman, Tim Lenton, Hans-Peter Plag, Palma Blonda, Lucien Wald, Emili García-Ladona, Ian McCallum

Abstract

The concept of EVs started in the GCOS community and it is being adopted by other communities for their purposes. EVs represent a minimal set of variables that determine a system's state and dynamics. They are crucial for predicting a system's evolution. They also provide a base for defining metrics that measure the trajectory of the system but a common definition is still a challenge. The ECV for climate in support to the UNFCCC and the EBV for biodiversity are two prominent examples. EVs have been selected using different criteria, such as: (1) the impact of observations and (2) the feasibility of making such observations. Thus, EVs are commonly defined using a process that includes both measurement feasibility and expert insights on impacts. The impacts link to societal benefits. The characteristics (e.g. resolution, coverage, accuracy...) of the observations of an EV depends on the use of sensors and may not be fit for use for specific applications.

While there are differences across the communities in the details of the criteria. methodologies, and processes used to develop sets of EVs, there is also a considerable common core across the communities, particularly those with a more advanced discussion. There are areas with more mature development of EVs such as Climate, Weather, Ocean and Biodiversity. Many communities are currently focused in the use of EVs for their purposes. For the environmental sustainability, it is crucial to address EV across disciplines. This requires understanding the application of EV across all range of disciplines.

For this special issue we call for contributions to advance the definition and realization of EVs, their application as process indicators and metrics towards sustainable goals. We encourage contributions that offers an integrated view that can support policies for sustainability.

Main topics include but are not limited to:

Status of EVs for different communities.



Acronym: ConnectinGEO
Project title: Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the

Gaps in European Observations
Theme: SC5-18a-2014. Coordinating European Observation Networks to reinforce the knowledge base for climate,

- Introduction of new sets of EVs following the methodology initiated by the weather and climate community or with new innovative procedures.
- Integrative approaches for defining interdisciplinary EVs.
- Characterizing observations in the context of EVs.
- Innovative processes for deriving EV information from Earth observation
- Procedures and best practices to validate EV measurements and protocols to generate them operationally.
- Links between EV and the existing policy agendas.
- Combining EVs with socio-economic data to extract indicators of the Earth and society status that can impact decision making (e.g. SDG indicators, planetary boundaries...).
- The role of EVs in global and regional programs dealing with Earth observation (e.g. GEO, Copernicus, Earthcube, Future Earth, ERA-NET, Belmont Forum, etc.).
- The costs and impacts of continuous monitoring of EVs.