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Methodological protocols for the observation of climate change across Africa: an assessment of the current approaches with insights into the feasibility of implementation

SEACRIFOG Deliverable 4.3

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Executive Summary

Climate change represents the most important global challenge of the 21st century, as recognized by international institutions such as the United Nations Framework Convention on Climate Change (UNFCCC), which states that it is undeniably due to human activity including the emission of greenhouse gases (GHG) and land use/cover change. In the case of the African continent, there are still major observational gaps, resulting in large uncertainties for most of the key variables used to study climate change, such as the GHG sources and sinks but also climate drivers and land management variables. The objective of the 'Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations' (SEACRIFOG) project is to develop a concept for a pan-African Research Infrastructure (RI) for the systematic long-term *in situ* observation of the main climate forcing components together with their link with food security. SEACRIFOG is funded by the European Union (EU) through the Horizon 2020 Programme.

This report constitutes Deliverable 4.3 and is an output from Work Package (WP) 4 of the SEACRIFOG project, whose main goal is to improve the technical harmonisation and data quality in environmental monitoring and experimentation. This report was prepared under the lead of the Trinity College of Dublin and with the collaboration of the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) together with other contributors.

This document reviews the current methodologies utilized by both global and regional networks to monitor 58 essential variables relevant for the observation/estimation of GHG sources and sinks and their principal driving processes across the atmospheric, oceanic and terrestrial domains. This set of essential variables was identified by the SEACRIFOG consortium with external input from the scientific community (see Deliverable 4.1). Furthermore, this report evaluates the feasibility of implementation of these methodological protocols and whether or not they fulfil the minimum data requirements set by the SEACRIFOG consortium (see Deliverable 4.2).

A total of 140 methodological protocols were compiled, together with their metadata, in an inventory that includes guides, protocols, technical reports, databases, data sheets, software, code, and models that can be applied for data processing, emission reporting and performing ground-based, sea- or space-borne observations. The main eligibility criteria for the material compilation were open-accessibility, high level of participation to gather collectively agreed approaches and support from sustainably funded initiatives to indirectly assure a minimum level of update. Most of the protocols collected were developed during last five years by international institutions, global research networks focused on environmental monitoring, global manipulation experiments and other international/regional projects that have been completed. In the final inventory, there is a clear dominance of protocols associated to the terrestrial domain (73% of total) compared to the atmospheric and oceanic domains, while the different applications considered are more evenly represented with one third of protocols focused on ground-based, sea-borne, and/or space-borne observations, 21% focused on data processing, and 9% on emission reporting approaches.

In addition, two analyses were applied to a subgroup of protocols from the inventory in order to assess the feasibility of their implementation and to evaluate whether or not they fulfil the data requirements

set by the SEACRIFOG consortium (see Deliverable 4.2). Feasibility was assessed for 82 protocols related to ground-based and sea-borne observations because their corresponding direct implementation costs were possible to be estimated. The fulfilment of data requirements was evaluated for three primary essential variables previously identified by SEACRIFOG, the atmosphere-biosphere exchange of carbon dioxide, methane and nitrous oxide, which represents a high observational priority in the context of the SEACRIFOG project as major direct determinants of current and future radiative forcing with low density and uneven distribution of monitoring stations across Africa.

Based on the results of the above assessments, a series of methodological recommendations are provided at the end of the document in order to guide the development of a harmonized and interoperable RI that will consider data requirements and will be developed using relevant international collective efforts already undertaken that address both the standardization and harmonization of environmental research observations.

List of Abbreviations

ABG	Above ground biomass
ADEME	Agence de l'environnement et de la maîtrise de l'énergie
AfriTRON	African Tropical Rainforest Observation Network
CGIAR-CCAFS	Consultative Group for International Agricultural Research - Program on Climate Change, Agriculture and Food Security
CH_4	Methane
CIFOR	Center for International Forestry Research
ClimMani COST action	Climate Change Manipulation Experiments in Terrestrial Ecosystems: Networking and Outreach
CO	Carbon monoxide
CO_2	Carbon dioxide
ECV	Essential Climate Variable
EPOCA	European Project on Ocean Acidification
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
$FixO^3$	Fixed point Open Ocean Observatory network
FLUXNET	Flux Network
GAW	Global Atmospheric Watch
GC	Gas Chromatography
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GEM	Global Ecosystems Monitoring Network
GEOBON	Biodiversity Observation Network, Group on Earth Observations
GHG(s)	Greenhouse Gas(es)
GRA-GHG	Global Research Alliance on Agricultural Greenhouse Gases
H2020	Horizon 2020
ICOS	Integrated Carbon Observation System
ICOS-ATC	Integrated Carbon Observation System - Atmosphere Thematic Center
ICOS-ETC	Integrated Carbon Observation System - Ecosystem Thematic Center
ICOS-OTC	Integrated Carbon Observation System - Ocean Thematic Center
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
ICRAF	International Centre for Research in Agroforestry
INRA	Institut National de la Recherche Agronomique
IOCCP	International Ocean Carbon Coordination Project
IODE	International Oceanographic Data and Information Exchange
IPCC	Intergovernmental Panel of Climate Change
LW	Long-wave
LULUC	Land Use and Land Use Change
N_2O	Nitrous oxide
NIWA-NZ	National Institute of Water and Atmospheric Research (New Zealand)

NOAA/AOML	National Oceanic and Atmospheric Administration, Atlantic Oceanographic & Meteorological Laboratory
NutNet	Nutrient Network
OSCAR	Observing Systems Capability Analysis and Review Tool
PRRG-GRA	Paddy Rice Research Group of the Global Research Alliance on Agricultural Greenhouse Gases
Rainfor	Amazon Forest Inventory Network
RECCAP	Regional Carbon Cycle Assessment and Processes
RI	Research Infrastructure
RMT	Réseau Mixte Technologique, Elevage et Environnement
SAFIRE	Southern Alliance for Indigenous Resources
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SDG(s)	Sustainable Development Goal(s)
SEACRIFOG	Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations
SW	Short-wave
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IOC	Intergovernmental Oceanographic Commission of UNESCO
UNFCCC	United Nations Framework to Combat Climate Change
WBCSD	World Business Council for Sustainable Development
WIGOS	
WMO	World Meteorological Organization
WP	Work Package
WRI	World Resources Institute

1 Introduction

1.1 Background

There is currently a lack of representative, systematic and harmonised observations of greenhouse gas (GHG) sources and sinks and related variables across the variety of natural and human-disturbed biomes in Africa (see **Figure 1**; López-Ballesteros et al., 2018). This limits our understanding of the biogeochemical and biophysical processes underlying climate change, its impacts, feedback loops and tipping points across the African continent and surrounding oceans, but also increases the uncertainty of the African contribution to the global carbon (C) cycle and climate forcing (Kulmala, 2018). The current and projected socio-economical trajectories for the continent (i.e. the increasing trend of urbanisation as well as population and economic growth) together with the vulnerability of natural and managed ecosystems to the adverse impacts of climate change make the development of a pan-African GHG research infrastructure (RI) an urgent societal and scientific priority.

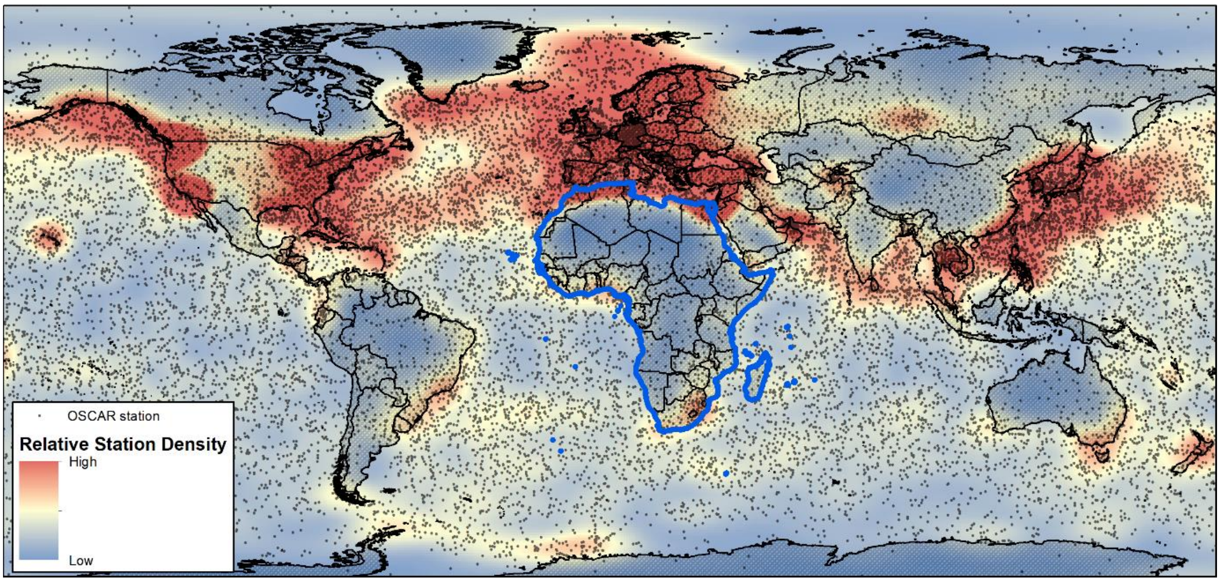

Figure 1. Worldwide distribution of stations listed in the Observing Systems Capability Analysis and Review tool (OSCAR) of the World Meteorological Organization (WMO) as in April 2018 (Source: López-Ballesteros et al., 2018).

Environmental RIs play an indispensable role in the accurate quantification of GHG budgets at several geographical scales, in generating the baseline knowledge needed to assess the drivers and impacts of climate change in the long-term (Hari et al., 2016), to validate GHG emissions inventories, atmospheric inversions, satellite data and models (Leip et al., 2018; Peters et al., 2017), and to evaluate the suitability of already implemented adaptation and mitigation strategies (Franz et al., 2018; Rosenstock et al., 2013). All of this supports the accomplishment of international climate policy goals in an efficient and equitable way, as is the case of the Paris Agreement and Sustainable Development Goals (SDGs) 2 (Zero hunger), 11 (Sustainable Cities and communities), 13 (Climate action), 14 (Life below water), 15 (Life on land) and 17 (Partnerships for the goals).

The principal goal of the EU H2020 funded project 'Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations' (SEACRIFOG; www. seacrifog.eu) is to develop a concept for a pan-African RI for the systematic long-term *in situ* observation of the main climate forcing components, such as GHG sources and sinks together with their link with food security. The design of this RI takes into account the atmosphere-land-ocean continuum as well as both natural and disturbed ecosystems (e.g. agricultural systems or urban settlements). Some of the most relevant strategic aspects of this development process are: 1) interoperability, in order to be coherent and facilitate integration with existing regional and global RIs, 2) flexibility, to enable the long-term evolution and integration of new variables, sites or methodologies as determined by the local scientific communities, and 3) harmonization, to be interdisciplinary and produce useful information for a wide range of scientific disciplines and stakeholders. SEACRIFOG is part of the INFRASUPP Work Programme 2016-2017 ('Policy and international cooperation measures for research Infrastructures') of the EU's H2020 Funding Programme. In accordance to the objectives of this work programme, SEACRIFOG aims to "help to develop better coordination and cooperation of European research infrastructures with their African counterparts, ensuring global interoperability and reach, and pursuing international agreements on the reciprocal use, openness or co-financing of infrastructures".

In this regard, Work Package 4 (WP4) of the SEACRIFOG project is focused on the 'improvement of technical harmonization and data quality in the current environmental monitoring and experimentation'. This WP is led by Trinity College Dublin in cooperation with the contributing partner institutions Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL), Uni Research and the University of Bergen. The present report constitutes Deliverable 4.3 under Task 4.2, of SEACRIFOG WP4. This work reviews the current methodologies utilized by both global and regional monitoring networks to quantify GHG sources and sinks but also to better understand their driving processes in the atmospheric, oceanic and terrestrial domains. In addition, two assessments are provided in order to evaluate how feasible it is to implement protocols dealing with ground-based and sea-borne observations and also whether these protocols fulfil the minimum data requirements, considering the current observational gaps, knowledge priorities, and funding limitations.

This work directly builds on SEACRIFOG Deliverable 4.1[1], where the essential variables to be measured by the future pan-African RI. This essential variables set was identified by means of are identified based both a bottom-up consultation exercise, where SEACRIFOG consortium and the wider scientific community participated, and a top-down comprehensive approach, which constrained monitoring priorities to the main climate forcing components, particularly for carbon, methane or nitrous oxide fluxes. Furthermore, the present report is linked to Deliverables 3.1[2] and 4.2[3], where minimum data requirements for the measurement of these essential variables are reviewed.

[1] https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables/2018.08.18_SEACRIFOG_Deliverable_4.1.pdf
[2] https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables/SEACRIFOG_D3.1_Report_Final-1.pdf
[3] https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables

1.2 Document purpose

The main objectives of this report are:

1. To assess the harmonization capacity of past and ongoing research networks and other initiatives partly or mainly focused on environmental monitoring worldwide. This assessment is based on an inventory of already published methodological protocols and other related material (data sheets, manuals or data processing tools) together with their corresponding metadata. The corresponding results are presented in section 3.1.
2. To assess how feasible it is to apply the identified protocols, particularly those dealing with in-situ observations, in the African context, by using the following criteria: equipment costs, running costs, installation effort, maintenance effort, knowledge needs, and measurement mode (i.e. manual or automatic). The corresponding results are presented in section 3.2.
3. To evaluate whether or not the data acquired by applying these protocols accomplish the minimum requirements needed to constrain the uncertainty of global and continental GHG budgets as well as the radiative forcing components for the African continent and surrounding oceans. To do that, a case study has been developed where a variety of methodologies used to measure atmosphere-biosphere GHGs exchange was assessed against data requirements identified by the SEACRIFOG project. The corresponding results are presented in section 3.3, which also serves to exemplify how these resources could be used by stakeholders that aim to implement an environmental research network.

The main objective of this task is to improve the quantification of the global and continental greenhouse gas (GHG) budgets, as the current African observational network is unable to achieve this primary goal. However, the next step is to understand the driving processes responsible for the variability of the global/African GHG budget estimates, hence, such that protocols dealing with other related variables and respective processes are also included.

Report limitations:

This document is not a full systematic review of all methodological protocols for environmental observation utilized worldwide by the scientific community. Instead, it presents the internationally agreed approaches from which interoperability and harmonization should be based when developing new research networks and infrastructures.

This review includes methodological protocols published up to December 2018, therefore, some of the methodological material presented here may have been superseded by new versions.

This document does not cover the full variety of sensors that can be used to implement the methodological protocols latter methodologies but some information describing new low-cost sensors or even sensor databases that can be used to find the most suitable instrumentation for a given purpose. Similarly, we did not include all the data processing procedures that can be used to build different data products but some software, code or excel sheets were considered as particularly useful to guide and assure interoperability and comparison amongst and between the most widely used methods.

2 Methodology

2.1 Inventory of protocols

An inventory of protocols was compiled over the period November 2017-October 2018 in order to gather the variety of methodologies and techniques that are being used to monitor or estimate the essential variables identified in SEACRIFOG Deliverable 4.1, including GHG sources and sinks and other related environmental variables within the terrestrial, atmospheric and oceanic domains.

Protocols were identified through internet search using the web-portals of international and regional research agencies, networks and projects related to environmental monitoring as well as through expert consultation within the SEACRIFOG consortium. Priority was given to open-access protocols developed by sustainably funded initiatives in order to indirectly assure a minimum level of update and to avoid the inclusion of outdated protocols. Finally, a high level of participation (e.g. high number of co-authors) was also prioritised as a way to capture collectively agreed approaches.

Several metadata attributes were collected for each protocol in order to characterise its content in a synthesised way. These attributes include citation information (e.g. title, author, publishing agency or date of publication) and the spatial and temporal coverage of measurements explained by the protocol. Additionally, each protocol was associated to one or more essential variables either directly or indirectly. Indirect variable association refers to approaches that do not directly measure an essential variable, but provides key information on driving processes or related measurement proxies. Other metadata attributes are also used to describe the broad research fields where protocols are used, their domain (i.e. atmospheric, oceanic and/or terrestrial), their utility and their final purpose (quantification or process-understanding). Finally, re-usability information (e.g. abstract, language(s), format or download URL) and metadata provider were also registered for each protocol. All the metadata attributes used in this inventory are defined in the metadata glossary (**Table 1**).

The protocols metadata were compiled using MS Excel 2013 and subsequently transferred to a web-app entitled "SEACRIFOG Collaborative Inventory Tool" which is based on a Shiny app written in R (see **Figure 2.** Screenshot of the tab "Protocols" of the SEACRIFOG Collaborative Inventory Tool (Version 3.1) which serves as a frontend for the protocol metadata below). The tool is publicly accessible at https://seacrifog-tool.sasscal.org and contains information about SEACRIFOG essential variables, research infrastructures and networks measuring some of these essential variables across Africa and surrounding oceans, the related data products and the inventory of protocols. The web-tool content corresponds to SEACRIFOG Deliverables 4.1[1], 3.1[2], 4.2[3] and 4.3, respectively.

[1] https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables/2018.08.18_SEACRIFOG_Deliverable_4.1.pdf
[2] https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables/SEACRIFOG_D3.1_Report_Final-1.pdf
[3] https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables

Table 1: Glossary of metadata attributes utilised to build the inventory of protocols.

Metadata attribute			Definition
Doc ID			Identification number of each protocol in the database. Note that the use of the word protocol here can correspond to a text protocol but also to an algorithm or software program used to process data acquired using a specific technique.
Citation metadata		DOI/ISBN/ISSN	Digital Object Identifier (DOI) or International Standard Book Number (ISBN) associated to each protocol.
		Author(s)	Name and surname(s) of the protocol author(s).
		Publisher	Associated initiative, funding agency, journal or editorial that produced the protocol.
		Title	General title of the protocol.
		Date of publication	Year, month and day (when possible) of the publication of the protocol.
		Year of publication	Year of the publication of the protocol.
Discoverability	Spatial coverage	Applicability	Geographical region or land use/cover in which the protocol was developed and/or applied (e.g. ICOS was developed and applied in Europe).
		Adoption	Geographical region or land use/cover where the protocol has been/can be adopted (e.g. ICOS protocols can be adopted globally).
	Temporal coverage		Characteristics of the measurements explained by the protocol in the temporal domain. The temporal coverage categories considered in this database are: continuous (i.e. automated measurements), discrete (i.e. manual measurements) or both. For strategic documents (e.g. implementation plans, design principles), the temporal coverage will correspond to the most representative one among the protocols developed by the same network/initiative.
	Keywords (controlled vocabularies)	Variables	SEACRIFOG essential variable(s) (Deliverable 4.1) that can be measured or estimated by implementing a given protocol. For strategic documents (e.g. implementation plans, design principles), the associated variables will correspond to the sum of variables related to all protocols developed by the same network/initiative.
		Associated variables	SEACRIFOG essential variables (Deliverable 4.1) that are indirectly linked to a given protocol.
		Global change ontologies	Main process(es) comprised in the broader concept of global change that can be partially investigated by using the methodology explained by the protocol. The global change ontologies considered in this database are: climate change, land-use change, biodiversity loss and management strategies (comprising mitigation and adaptation measures).
		Domain	The domain where the protocol is applicable. The domains considered in this database are: atmospheric, oceanic and terrestrial. In the latter, the subdomain freshwater could be used in those cases dealing with measurements on inland water bodies.
		Application	The general use of the protocols considered in this database are: observation (i.e. description of the state of a given system through ground-based, space-borne, sea-borne or various types of measurements), data processing (includes any process for controlled data creation, maintenance, management, calculations or model estimations) and emission reporting.
		Purpose	Ultimate purpose of the measurement(s) explained by the protocol. These are distinguished between quantification, when measurements are envisaged to improve estimates of global and continental greenhouse gas budgets as well as contributing sources and sinks, and process understanding, for those protocols that pursue a better understanding of driving processes and/or impacts of global/African GHG budget variations and the broader global change.

Reusability	Abstract	Brief description of the content of the protocol.
	Language(s)	Written language(s) in which the protocol is available.
	Format	Type of protocol. The formats considered in this database are: guide (written document developed to inform the general research community), protocol (written document developed to standardise measurements within a given network), technical report (written document developed to inform about a specific task in a specific project). Apart from written documents, this database also include links to open-access databases, data sheets, software or models (i.e. code) that can be used to prepare and/or process data acquired using a particular technique.
	Sustainability	The nature of the initiative behind the development of the protocol, meaning whether is a long- or short-term enterprise. This determines the reliability and obsolescence of the protocol in the future, conceived as a guideline for applying a given technique in order to produce related data. The sustainability categories considered in this database are: long-term and short-term.
	Deposit URL	URL where the protocol can be directly downloaded without charge. When the document is available in several languages, the URL shown here will correspond to the English document, however, in Supplementary URL will be possible to find the document in the other languages.
	Supplementary information URL	In case the protocol has supplementary information, URL where it can be directly downloaded.
Admin	Metadata provider	Name and surname(s) of the person(s) who generated or provided the metadata for a given protocol.

Figure 2. Screenshot of the tab "Protocols" of the SEACRIFOG Collaborative Inventory Tool (Version 3.1) which serves as a frontend for the protocol metadata.

2.2 Feasibility assessment

A preliminary assessment was performed in order to evaluate how feasible it is to implement the reviewed protocols in the African context. Concretely, we only assessed those protocols from the inventory that deal with ground-based and sea-borne observations, which equates to 82 protocols from the total 140 inventoried ones. Data processing and/or emission reporting protocols were excluded from the analysis because these do not have a direct monitoring cost associated with them. In addition, protocols focused on space-borne observations were also excluded because these usually correspond to satellite missions that are sustainably funded by international/regional governmental institutions and agreements and hence, tend not to allow for implementation decisions at lower administrative levels (i.e. research teams or even national agencies). Moreover, the corresponding satellite products are usually freely available. Likewise, strategic/implementation plans from international RIs (e.g. WMO, GAW, WIGOS) and protocols reviewing many methodologies simultaneously or dealing with data requirements (e.g. WMO ECVs requirements) were also excluded from the analysis because their implementation costs cannot be directly derived from the respective documents.

This feasibility assessment was performed using the following criteria:

- equipment costs (i.e. instrumentation and other experimentation material costs)[1]
- running costs (i.e. calibration and maintenance costs)[2]
- installation effort (i.e. number of person*hours to setup the station or experiment)
- maintenance effort (i.e. number of person*hours related to sampling frequency, in case of manual measurements, or routine repairs/calibrations in case of automated measurements)
- knowledge needed (none, low, medium or high)
- measurement mode (manual or automatic)

These criteria have been previously used by Halbritter et al. (under review) and collectively agreed by the researchers consortium involved in the ES1308 ClimMani COST Action[3] (Climate Change Manipulation Experiments in Terrestrial Ecosystems - Networking and Outreach). The feasibility of protocol implementation was rated by using the indicators below for each criterion (Table 2). The sources of information used include the protocols themselves, and also expert consultation within the SEACRIFOG consortium. In those cases where there are several station classes (e.g. ICOS), the feasibility assessment was performed on the station type with the minimum cost.

Table 2: Qualitative indicators used for the assessment of protocols implementation feasibility.

<table>
<tr><th>Criteria</th><th colspan="12">Indicators</th></tr>
<tr><td>Equipment costs</td><td colspan="4" rowspan="2">€ → < €1,000</td><td colspan="4" rowspan="2">€€ → €1,000 - €10,000</td><td colspan="4" rowspan="2">€€€ → > €10,000</td></tr>
<tr><td>Running costs</td></tr>
<tr><td>Maintenance effort</td><td colspan="3" rowspan="2">None (N)</td><td colspan="3" rowspan="2">Low (L)</td><td colspan="3" rowspan="2">Medium (M)</td><td colspan="3" rowspan="2">High (H)</td></tr>
<tr><td>Knowledge needed</td></tr>
<tr><td>Measurement mode</td><td colspan="6">Manual measurement (MM)</td><td colspan="6">Automatic measurement (AM)</td></tr>
</table>

[1] Note that the cost of the gas chromatography (GC) equipment was generally excluded for those protocols where gas sampling involved posterior GC analysis.
[2] Note that staff costs are not considered here.
[3] https://climmani.org/

2.3 Protocols vs data requirements assessment: a case study for atmosphere-biosphere GHG exchange

In order to assess whether or not the protocols identified fulfil the minimum data requirements set by the international research community and SEACRIFOG consortium (see SEACRIFOG Deliverables 3.1 and 4.2), a case study was developed which focused on three primary essential variables previously identified by SEACRIFOG, the atmosphere-biosphere exchange of CO_2, CH_4 and N_2O. These variables are commonly measured through ground-based observations and represent a variable class of high observational priority in the context of the SEACRIFOG project due to the low density and uneven distribution of monitoring stations (López-Ballesteros et al., 2018), despite their relevance as major direct determinants of current and future radiative forcing.

From the 82 protocols assessed in previous section, 16 protocols were selected for this analysis because of their content is focused on the direct observation of atmosphere-biosphere exchange of CO_2, CH_4 and/or N_2O. However, only 11 were finally evaluated because they provide specific information about instrumentation and/or fulfilment of data requirements.

The selected protocols were assessed against the following minimum data requirements:

- Observation frequency = 1h
- Spatial resolution = 1 site in each major ecoregion
- Maximum uncertainty = 5%, referred to the ambient air molar fraction of CO_2, CH_4 or N_2O.

3 Results

3.1 Inventory of protocols

Our protocol inventory comprises a total of 140 methodological protocols, together with their metadata, in different formats such as guides, protocols, technical reports, databases, data sheets, software, code, and models. To access the full metadata records for each protocol refer to https://seacrifog-tool.sasscal.org/. In addition, a synthesised version can be found in **Table A1** of Annex 1 in this report.

The material collected presents a variety of applications, such as data processing, emission reporting and ground-based, sea- or space-borne observations, which serve to measure or estimate the essential variables in the different domains (atmospheric, oceanic, terrestrial, freshwater systems, or a combination of them).

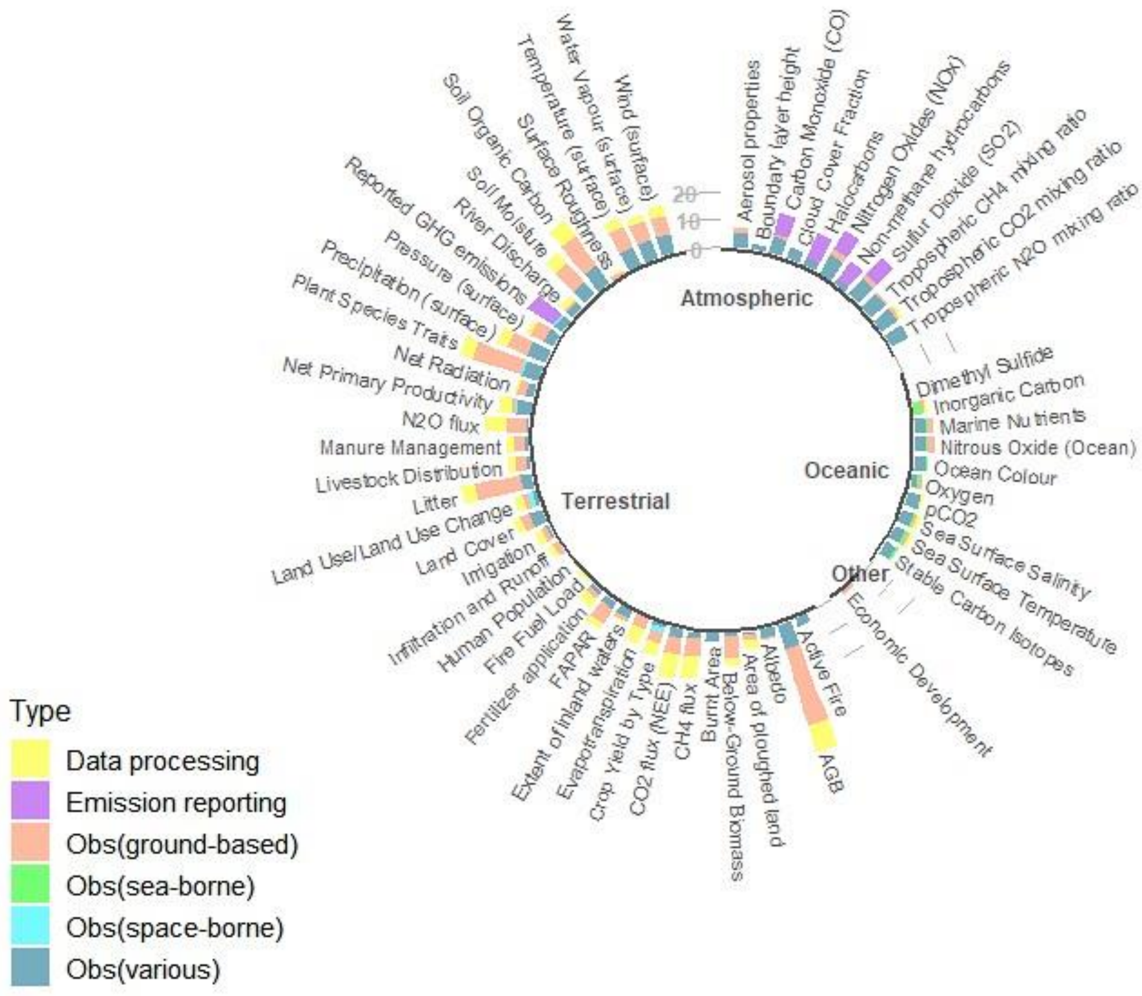

Figure 3. Number of protocols for each SEACRIFOG essential variables that are of relevance to the atmospheric, oceanic and terrestrial domains. Note that colours represent the different protocol applications and Obs means observations and AGB above ground biomass.

There is a clear dominance of protocols associated to the terrestrial domain (73%) compared to the atmospheric (18%) and oceanic domains (9%) (**Figure 3**). Within the terrestrial domain, protocols related to ground-based observations comprised 31% of the total. Furthermore, when considering all domains, 33% of protocols consider several types of direct observation (i.e. ground-based, sea-borne, and/or space-borne), and 21% of protocols are focused on data processing, while only 9% deals with emission reporting approaches. The essential variables with the highest number of protocols associated (≥ 20 protocols) are above ground biomass, plant species traits, soil organic carbon, litter, and soil moisture. In contrast, some essential variables appeared in very few protocols (< 5), such as the cloud cover fraction, infiltration and runoff, oxygen (oceanic), boundary layer height, surface roughness and economic development. No protocols were identified for the measurement/estimation of wild herbivore distribution, human population and dimethyl sulphide.

The protocols collated were published between 2004 and 2018, but the majority of them (~80%) were published over last four years (2014-2018). The applicability of the protocols refers to the geographical region or land use/cover where the protocol was developed to be applied in but it usually coincides with the geographical origin of the initiative that develop the protocol itself. In this regard, one third of protocols are directly applicable at global scale. These were developed by international institutions (e.g. CGIAR, FAO, GEOBON, ICRAF, IPCC, UNFCCC or WMO), global research networks focused on environmental monitoring (e.g. FLUXNET), global manipulation experiments (e.g. Drought-net, ClimMani COST Action) and other international projects or initiatives that have been completed (e.g. IOCCP or RECCAP). There are 19 (14%) protocols that are also applicable at the global scale but refer to specific land cover/use types, such as mangroves, tidal salt marshes, seagrass meadows, tropical forests, tropical smallholder agrosystems or urban areas (see **Table A1** or go to https://seacrifog-tool.sasscal.org/ for detailed information).

Around one quarter of the collected protocols were developed by European organizations, predominantly by ICOS and other completed research projects (e.g. FixO3 project), and hence directly applicable in Europe, while only 11% of them were designed exclusively to be applied in Africa. Examples of the latter include the VitalSigns protocols, the emission reporting material developed by GHGProtocol to be implemented in Ethiopian agricultural systems, the FAO guidelines on the use of remote sensing products to improve agricultural crop production forecast statistics in sub-Saharan Africa and the manual for community-based ecological monitoring developed by SAFIRE, which is centred in natural resource management in rural areas of Zimbabwe and Zambia.
Although applicability differs among inventoried protocols, most of them can be adopted anywhere globally, with the exception of those which are designed for a specific land cover or land use.

As sustainability of the initiatives developing protocols was one of the eligibility criteria, 94% of the organizations that developed the protocols are long-term initiatives (i.e. >4-5 years), while the rest of the protocols were developed by projects that have been completed (i.e. short-term initiatives). The outputs of the completed projects represent an outstanding collective effort envisaged to advance in the methodological harmonisation within a specific research field (e.g. the International Ocean Carbon Coordination Project - IOCCP).

In regards to the temporal coverage of the measurements explained in the protocols, we could discern between continuous (e.g. real-time records through a data logger) or discrete (i.e. manual sampling) coverage. Continuous and discrete measurements are the core of 20% and 39% of the protocols, respectively, while 26% of protocols include both types of measurements. Generally, all protocols dealing with discrete measurements contain guidelines for ground-based observations that are conceived to contribute to a better knowledge of driving processes behind climate change and the variability surrounding GHG budget observations. Conversely, protocols dealing with continuous measurements correspond to both ground-based and space-borne observation approaches that aim to improve both GHG budget quantification and also the process-understanding of these emissions. Protocols related to emission reporting generally comprise discrete and continuous measurements while, generally, data processing protocols are not directly linked to any of them.

A general overview of the link between the initiatives or organizations that developed the protocols and the protocols' main application is provided in Figure 4. Generally, only international organizations, such as IPCC, FAO or UNFCCC, developed emission reporting protocols as well as some of the space-borne observation protocols. Protocols dealing with sea-borne observations were mainly developed by already limited-lifetime projects, while those focused on data processing and ground-based observations were developed by a wider variety of organizations.

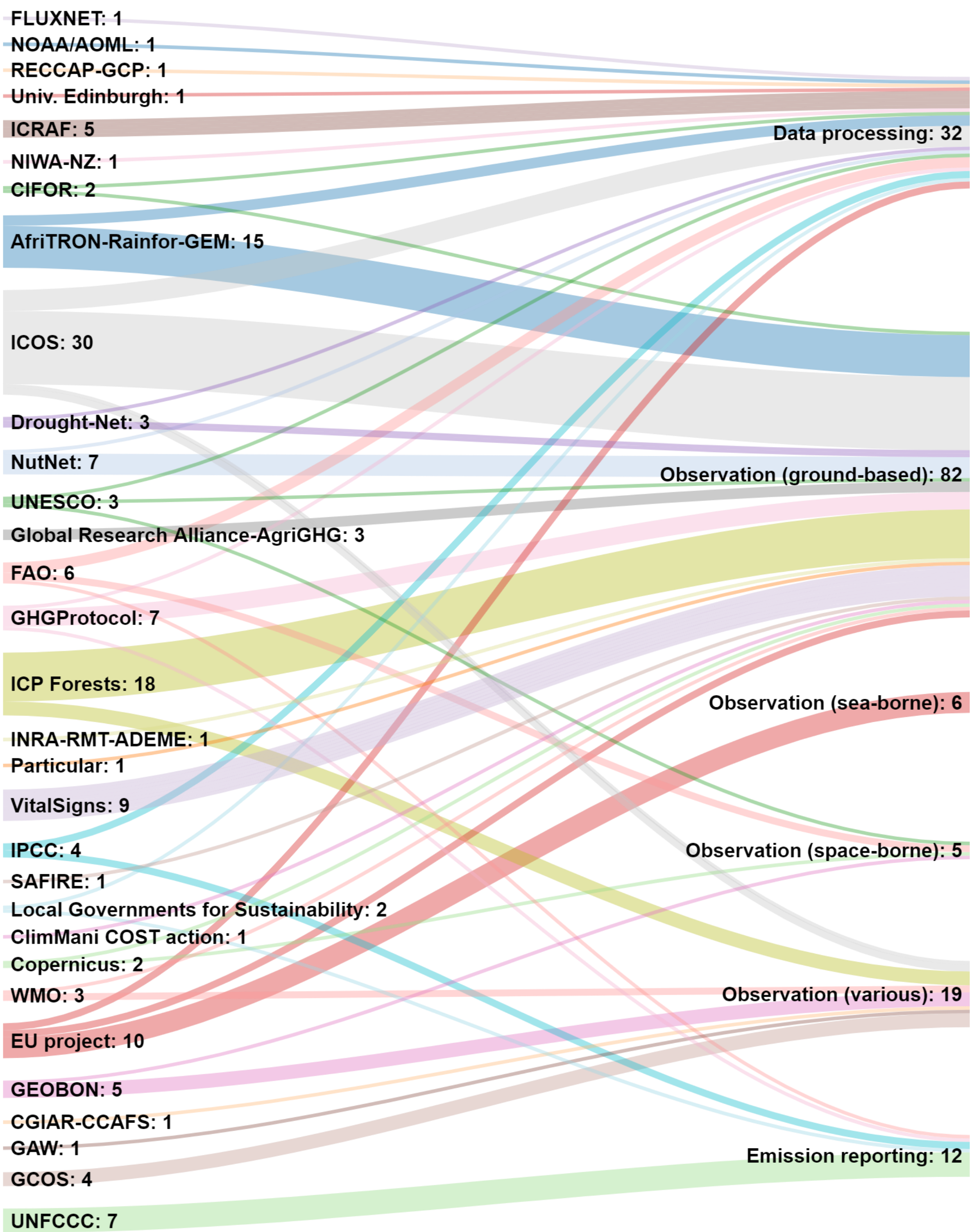

Figure 4. Sankey diagram showing the links between initiatives that developed methodological protocols and their respective utility. Note that the width of the lines are proportional to the number of protocols (number next to the initiatives acronyms).

3.1.3 Atmospheric domain

The link between atmospheric variable classes, (see Table 3) and the initiatives or organizations that developed the inventoried protocols is shown in Figure 5, where a total number of 111 variable class-initiative combinations are represented.

Table 3: Disaggregated variable classes into variables belonging to the atmospheric domain.

Variable Class	Variable
Aerosol properties	Aerosol properties
Boundary layer height	Boundary layer height
Cloud properties	Cloud Cover Fraction
Precursors	Carbon Monoxide (CO)
	Dimethyl Sulphide
	Non-methane hydrocarbons
	Nitrogen Oxides (NOx)
	Sulphur Dioxide (SO_2)
Tropospheric GHGs and halocarbons	Tropospheric CH_4 mixing ratio
	Tropospheric CO_2 mixing ratio
	Halocarbons
	Tropospheric N_2O mixing ratio

The majority of protocols (88% of the cases) dealing with atmospheric variables are linked to the observation and/or estimation of precursors and tropospheric GHGs and halocarbons. Overall, the protocols were developed by 12 different initiatives including international monitoring networks, such as GCOS and GAW that belong to WMO, international environmental agencies, such as IPCC and UNFCCC, and other initiatives at European level (e.g. ICOS-ATC, ICOS-OTC, EU projects) or involving several countries, such as ICP forests that was created with the participation of scientific communities from Europe, Canada and USA.

Regarding the content of these protocols, some of them are related to low-cost atmospheric sensors (see ID7 and ID116 in Table A1 of Annex 1) while others describe implementation plans and principles (e.g. WMO and GAW). Protocols developed by UNFCCC are generally oriented to emission reporting while ICP forests and ICOS protocols are purely related to direct observations.

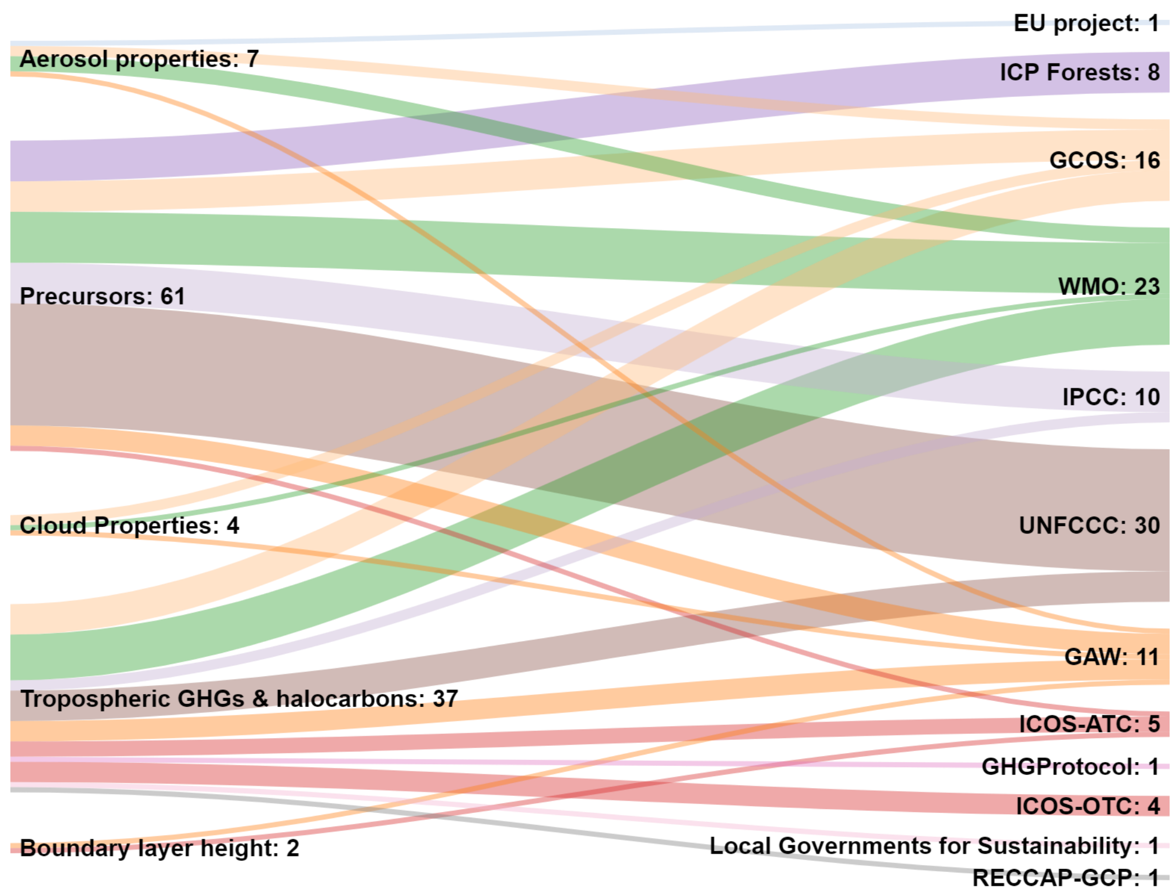

Figure 5. Sankey diagram showing the links between atmospheric variable classes, which in some cases include several essential variables, and the initiatives that developed related protocols. Note that the width of the lines are proportional to the number of protocols related to a given variable class (number next to the variable class name).

3.1.2 Oceanic domain

The link between oceanic variables and the initiatives or organizations that developed the protocols collated is shown in Figure 6, where a total number of 51 variable-initiative combinations are represented. Apart from international networks (i.e. WMO, GCOS) and the ICOS-OTC, the role of past projects in the harmonization of international oceanic observations is substantial. This is the case of the "Fixed point Open Ocean Observatory network ($FixO^3$)", the "European Project on Ocean Acidification (EPOCA)" and the "International Ocean Carbon Coordination Project (IOCCP)" (see ID70-75 in Table A1 of Annex 1), which set a point of departure towards the harmonization of oceanic observations by developing several guidelines on methodological and data-related best practices.

Other relevant material that is not included in the protocol inventory is the open-access catalogue of ocean best practices[1], where a more extensive compendium of methodological material is available. This resource covers disciplines and research objectives beyond the remit of the SEACRIFOG's project and is maintained by the International Oceanographic Data and Information Exchange (IODE) of the UNESCO-IOC (Intergovernmental Oceanographic Commission of UNESCO). The *Esonet yellow pages*[2]

[1] https://www.oceanbestpractices.net/
[2] https://www.esonetyellowpages.com/

resource should also be highlighted as it represents an extensive database of ocean-specific sensors including technical specifications for a wide range of equipment, from simple isolated sensors or sensor parts to communication systems or even integrated observatories.

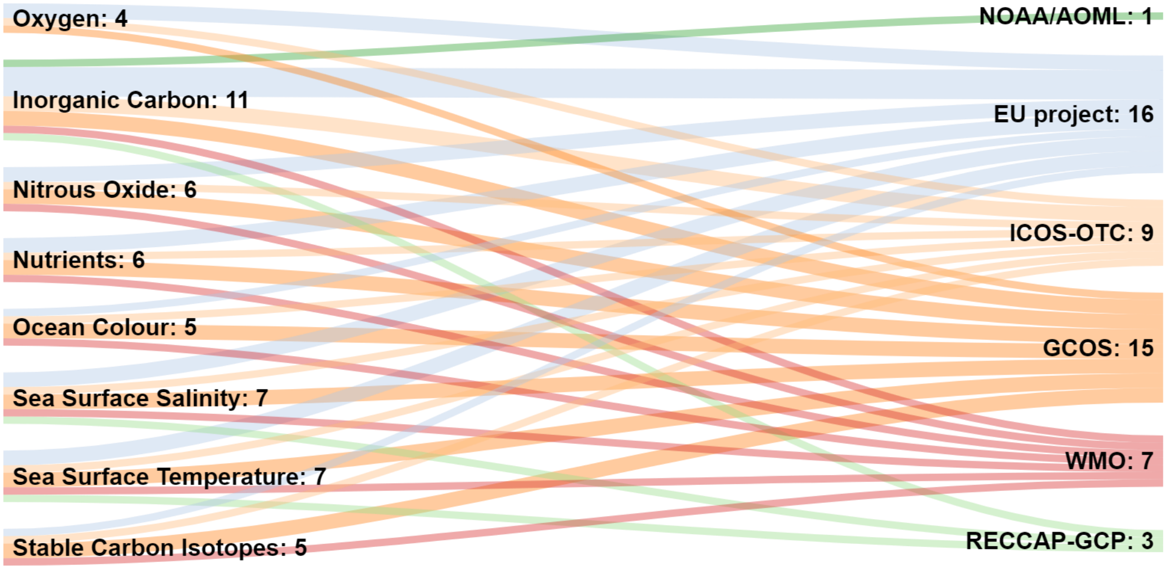

Figure 6. Sankey diagram showing the links between oceanic variables and the initiatives that developed related protocols. Note that the width of the lines are proportional to the number of protocols related to a given variable (number next to the variable name).

3.1.3 Terrestrial domain

The link between terrestrial variable classes, which can comprise several variables (see **Table 4**), and the initiatives or organizations that developed the inventoried protocols is shown in **Figure 7**, where a total number of 452 variable class-initiative combinations are represented.

Table 4: Disaggregated variable classes into variables for the terrestrial domain.

Variable Class	Variable
Above ground biomass	Above ground biomass
	Litter
Agricultural management	Area of ploughed land
	Manure Management
	Fertilizer application
	Irrigation
Animal Population	Livestock Distribution
	Wild Herbivore Distribution
Below-Ground Biomass	Below-Ground Biomass
Biosphere-Atmosphere GHG flux	Biosphere-Atmosphere CH4 flux
	Biosphere-Atmosphere CO2 flux (NEE)
	Biosphere-Atmosphere N2O flux
Crops	Crop Yield by Type
Ecosystem Function	Net Primary Productivity
Fire	Active Fire
	Burnt Area
	Fire Fuel Load

Human Population	Human Population
Hydrology	Evapotranspiration
	Infiltration and Runoff
	Precipitation (surface)
	River Discharge
Land Cover	Land Cover
	Extent of inland waters
Land Use/Land Use Change	Land Use/Land Use Change
Plant Species Traits	Plant Species Traits
Pressure (surface)	Pressure (surface)
Radiation	Albedo
	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
	Net Radiation at surface (SW/LW)
Reported Anthropogenic Greenhouse Gas Emissions	CO_2, CH_4, N_2O emissions by country and IPCC sector
Soil Properties	Soil Moisture
	Soil Organic Carbon
Surface Roughness	Surface Roughness
Surface Wind	Surface Wind Speed and direction
Temperature	Temperature (surface)
Water Vapour (surface)	Water Vapour (surface)

The three variable classes with the highest amount of related protocols are aboveground biomass (17% of the cases), atmosphere-biosphere GHG flux (12%), and soil properties (11%; Figure 7). In the terrestrial domain, there is a wider variety of initiatives developing protocols compared to the atmospheric and oceanic domains. In this case, the predominant initiatives (>30 of the cases) are ICOS-ETC, ICP forests, GHG Protocol and GCOS.

Regarding the content of the collated protocols, there are some protocols created to perform globally coordinated manipulation experiments, such as Drought-Net or Nut-Net (ID63-69 and ID121-123 in Table A1, respectively), whereas many of them are developed by networks or RIs focused on environmental monitoring in different regions and/or biomes. For instance, the protocols developed by AfriTRON-Rainfor-GEM initiatives aim to specifically monitor tropical rainforest carbon pools while ICOS-ETC protocols are generally applicable to any type of natural ecosystem. Note that protocols applicable to freshwater systems, salt marshes or mangroves are also included in this section (e.g. ID118 and 120 in Table A1). An important aspect of the terrestrial domain is the presence of both natural and managed systems. Accordingly, relevant protocols that can be implemented to monitor/estimate GHG emissions from agricultural and livestock systems are those developed by FAO, the Standard Assessment of Agricultural Mitigation Potential and Livelihoods (SAMPLES) program (CGIAR-CCAFS), GHG Protocol in collaboration with the Ministry of Agriculture in Ethiopia, Vitalsigns and INRA-RMT-ADEME. The latter is a very complete guide that include several methods used to measure GHG, ammonia and nitrous oxides emissions from livestock farming. Data processing material included in the terrestrial section of the protocols inventory correspond to data sheets and modelling tools (e.g. SHAMBA tool, ICRAF models, IPCC inventory software).

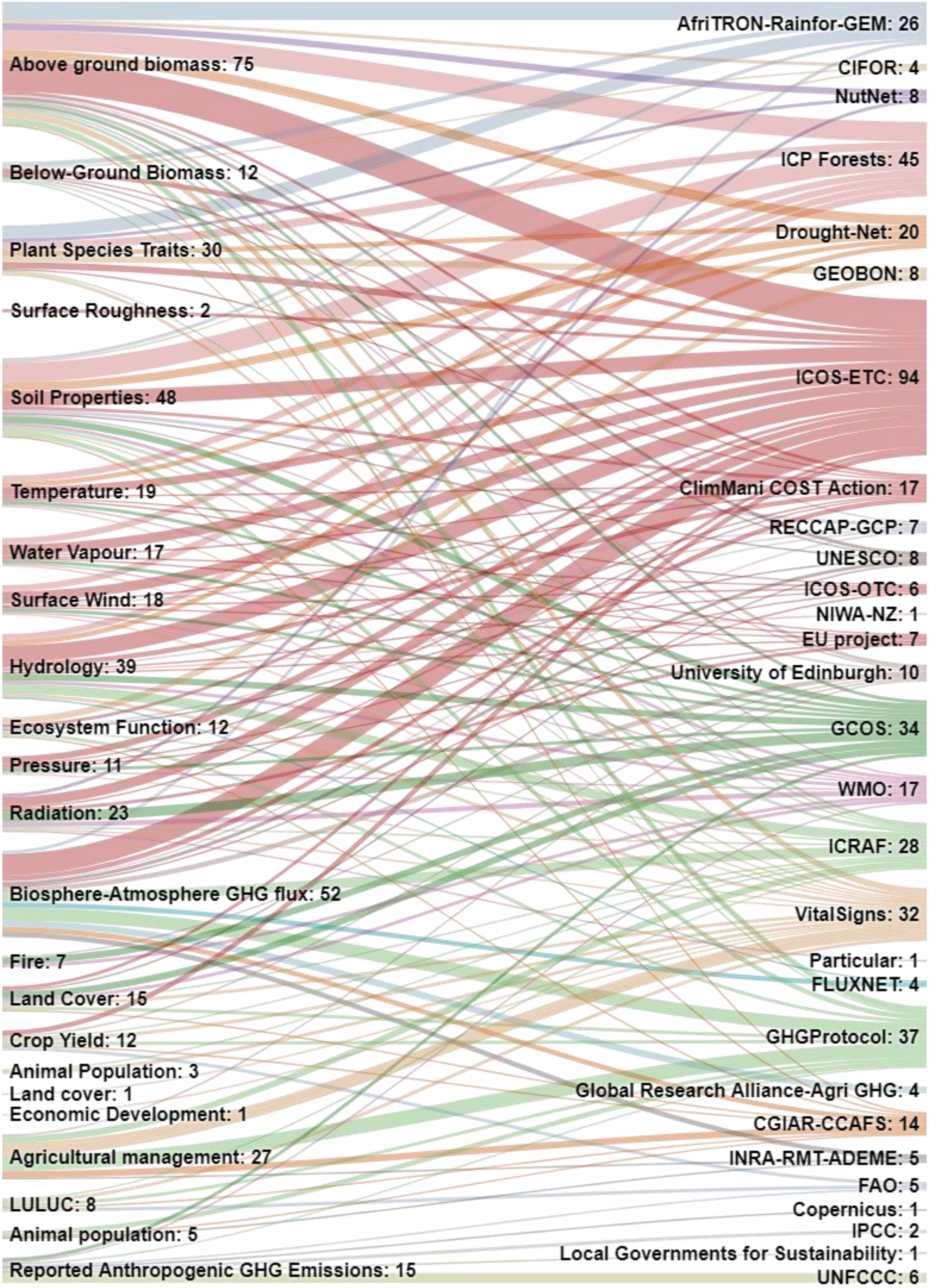

Figure 7. Sankey diagram showing the links between terrestrial variables classes, which sometimes include several essential variables, and the initiatives/organizations that developed protocols dealing with their respective measurement. Note that the width of the lines are proportional to the number of protocols related to a given variable class (number next to the variable class name).

Other relevant material not included in the protocols inventory is the open-access UN-REDD+ catalogue[1], whose content goes beyond the goals of the SEACRIFOG's and contains some documents related to case studies and activities developed in some African countries.

[1] https://www.unredd.net/documents.html

3.2 How feasible is to apply these protocols in the African context?

A total number of 82 protocols dealing with ground-based and sea-borne observations were selected from the protocols inventory to assess the feasibility of their implementation, given that direct monitoring costs can be derived from their respective documents. The results of this analysis are shown in Table 5, where approximate estimates of equipment and running costs, installation and maintenance efforts, and the prior knowledge needed were determined for each protocol.

Protocols dealing with atmospheric measurements represent only 4% of the total assessed and mostly correspond to automatic measurements. These cover the entire range of equipment costs (from <€1,000 to >€10,000) while running costs are suggested to be under €10,000 per year. Some of the protocols, such as the ICOS-ATC protocol (ID36 in Table 5), entail high installation effort, high knowledge needed but low maintenance efforts. On the other hand, there are very cheap sensors (<€1,000; ID116 in Table 5) available to monitor particulate matter that requires a low knowledge need.

Some of the protocols focused on oceanic observations contain a compilation of sensors used for different marine applications, particularly in fixed observation stations (e.g. ID71 in Table 5). Therefore, this type of protocols covers the whole range of installation and running costs (from <€1,000 to >€10,000) as well as the installation and maintenance efforts (from low to high). The ICOS-OTC protocol, instead, requires high (>€10,000) and medium (€1,000-€10,000) installation and running costs, respectively, together with high knowledge needs, installation and maintenance efforts. Overall, protocols dealing with oceanic measurements comprise 6% of the total assessed.

Terrestrial protocols (i.e. describing methodologies to measure variables within the terrestrial domain), represent the majority of the assessed protocols, 71 of the total. Protocols entailing the highest equipment costs are those developed by ICOS-ETC, since these include the utilization of fast response infrared gas analysers and sonic anemometers, which are both expensive (>€10,000) and forms the core components of an eddy covariance tower (ID9 and ID10 in Table 5). However, ICOS-ETC protocols describing soil sampling procedures, meteorological or ancillary vegetation measurements involve low and/or medium equipment and running costs. The VitalSigns and AfriTRON/Rainfor initiatives have developed protocols entailing the lowest equipment costs, given that these are mainly focused on above ground biomass measurements. Apart from these, protocols of global manipulation experiments, such as Drought-Net and NutNet, also show a low/medium equipment and maintenance costs but this may be due to the centralisation of biochemical analyses of all sites' samples in one or few laboratories. Generally, knowledge needed, installation and maintenance efforts varies among protocols developed by the same initiative, since these specifically depend on the measured variable and applied methodology. Nevertheless, manual measurements could be associated with higher maintenance efforts whereas automatic measurements may involve high installation efforts but lower maintenance.

Finally, the two assessed protocols applicable to freshwater systems (ID120 and ID129 in Table 5) require low/medium equipment and running costs but high knowledge needed.

Table 5: Feasibility assessment results of those protocols dealing with ground-based and sea-borne observations. This table includes protocols information – inventory identification number (ID), title, publishing institution/organization/initiative, essential variables directly related to each protocol, domain (*A=atmospheric, O=oceanic, T=terrestrial, F=freshwater* or *All*) – together with rough estimates (for each protocol) of equipment and running costs per year *(€ < €1,000, €€=1,000-10,000, and €€€ > €10,000*), installation and maintenance efforts (*N=none, L=low, M=medium, and H=high*), knowledge needed (*N=none, L=low, M=medium, and H=high*), and measurement mode (*MM=manual measurement and AM=automatic measurement*). Protocols with no essential variables associated correspond to documents with no direct mention of any of these but still indirectly relevant for their investigation. More detailed metadata of the inventoried protocols can be found at **Table A1** (Annex 1) or at https://seacrifog-tool.sasscal.org/.

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
6	Guide for Urban Integrated Hydro-Meteorological, Climate and Environmental Services	World Meteorological Organization (WMO)	Aerosol properties;Boundary layer height;Tropospheric CH_4 mixing ratio;Tropospheric CO_2 mixing ratio;Tropospheric N_2O mixing ratio;Cloud Cover Fraction;Carbon Monoxide (CO);Halocarbons;Nitrogen Oxides (NOx);Non-methane hydrocarbons;Sulfur Dioxide (SO_2)	All	€€€	€€€	L-H	H	L-H	AM
7	Low-cost sensors for the measurement of A composition: overview of topic and future applications	World Meteorological Organization (WMO)	Aerosol properties;Tropospheric CH4 mixing ratio;Tropospheric CO2 mixing ratio;Carbon Monoxide (CO);Nitrogen Oxides (NOx);Sulfur Dioxide (SO2)	A	€-€€	€	H	L	M-H	AM
9	Turbulent flux measurements of CO2, energy and momentum	ICOS-ETC	Biosphere-Atmosphere CO2 flux (NEE);Evapotranspiration;Water Vapour (surface);Surface Wind Speed and direction	T	€€€	€€	H	L	H	AM
10	CO2, H2O, CH4 and N2O storage flux measurements	ICOS-ETC	Biosphere-Atmosphere CH4 flux;Biosphere-Atmosphere CO2 flux (NEE);Biosphere-Atmosphere N2O flux;Evapotranspiration	T	€€	€	M	L	M	AM
11	Meteorology. Air temperature, Air relative humidity, Air pressure, Wind speed, Wind direction, Backup meteo station	ICOS-ETC	Pressure (surface);Surface Wind Speed and direction;Temperature (surface);Water Vapour (surface)	T	€€	€	L	M	L	AM
12	Precipitations. Total precipitation, Snow depth	ICOS-ETC	Precipitation (surface)	T	€	€	L	L	L	AM
13	Radiations measurements. Short-wave radiations, Long-wave radiations, Photosynthetically active radiation	ICOS-ETC	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR);Net Radiation at surface (SW/LW)	T	€€	€	M	M	M	AM
14	Soil-meteorological measurements. Soil Temperature; Soil Water Content; Soil Heat Flux Density	ICOS-ETC	Soil Moisture	T	€€	€	M	L	M	AM
15	Water Table Depth Measurements	ICOS-ETC	--	T	€€	€	M	L	L	AM
16	Station description. How to describe the station and history of the monitored ecosystem	ICOS-ETC	Biosphere-Atmosphere CO2 flux (NEE);Evapotranspiration;Water Vapour (surface);Surface Wind Speed and direction;Net Primary Productivity;Pressure (surface);Temperature (surface);Surface Roughness;Biosphere-Atmosphere CH4 flux;Biosphere-	T	N	N	N	L	L	MM

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
			Atmosphere N2O flux;Precipitation (surface);Fraction of Absorbed Photosynthetically Active Radiation (FAPAR);Net Radiation at surface (SW/LW);Soil Moisture;Infiltration and Runoff;Extent of inland waters;Above ground biomass;Litter;Crop Yield;Below-Ground Biomass;Plant Species Traits;Soil Organic Carbon;							
17	Setting up the spatial sampling scheme for ecosystem station characterization, soil sampling and repeated ancillary vegetation measurements	ICOS-ETC	Soil Moisture;Above ground biomass;Litter;Crop Yield;Below-Ground Biomass;Soil Organic Carbon	T	--	--	L	L	L	MM
18	Ancillary vegetation measurements in croplands. Green Area Index, aboveground biomass, litter biomass.	ICOS-ETC	Above ground biomass;Litter	T	€€	€	L	L	L	MM
19	Ancillary vegetation measurements in forests. Green Area Index, aboveground biomass, litter biomass.	ICOS-ETC	Above ground biomass;Litter	T	€	€	L	L	L	MM
20	Ancillary vegetation measurements in grasslands. Green Area Index, aboveground biomass, litter biomass, canopy height.	ICOS-ETC	Above ground biomass;Litter	T	€€	€	L	L	L	MM
21	Ancillary vegetation measurements in mires. Green Area Index, aboveground biomass.	ICOS-ETC	Above ground biomass	T	€€	€	L	L	L	MM
22	Site characterization measurements in forests. Vegetation species, aboveground biomass, green area index.	ICOS-ETC	Above ground biomass	T	€	--	N	N	M	MM
23	Site characterization measurements in grasslands. Vegetation species, aboveground biomass.	ICOS-ETC	Above ground biomass	T	€	--	N	N	M	MM
24	Site characterization measurements in mires. Vegetation species.	ICOS-ETC	--	T	€	--	N	N	M	MM
25	Foliar samples collection and leaf mass to area ratio determination.	ICOS-ETC	Plant Species Traits	T	€	€	N	L	M	MM
26	Soil sampling and preparation for monitoring the soil organic carbon and nitrogen.	ICOS-ETC	Soil Organic Carbon	T	€	€	N	M	M	MM
27	Plant species reporting.	ICOS-ETC	Plant Species Traits	T	--	--	--	L	M	MM

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
34	Accupar LP-80 PAR/LAI ceptometer for Green Area Index measurements	ICOS-ETC	Above ground biomass	T	€€	--	N	M	L	MM
35	SS1 sunscan canopy analysis system for Green Area Index measurements	ICOS-ETC	Above ground biomass	T	€€	--	N	M	L	MM
36	ICOS A Station Specifications	ICOS-ATC	Boundary layer height;Tropospheric CH4 mixing ratio;Tropospheric CO2 mixing ratio;Tropospheric N2O mixing ratio;Carbon Monoxide (CO)	A	€€€	€€	H	M	H	AM & MM
37	ICOS marine station labelling Step 2	ICOS-OTC	Biosphere-Atmosphere CO2 flux (NEE);Tropospheric CH4 mixing ratio;Tropospheric CO2 mixing ratio;Tropospheric N2O mixing ratio;Halocarbons;Oxygen;Partial Pressure of Carbon Dioxide (pCO2);Nitrous Oxide (Ocean);Marine Nutrients;Ocean Colour;Precipitation (surface);Pressure (surface);Sea Surface Salinity;Stable Carbon Isotopes;Surface Wind Speed and direction;Sea Surface Temperature;Temperature (surface);Water Vapour (surface)	O	€€€	€€€	H	H	H	AM & MM
38	Calculation uncertainty of pCO2 from discrete samples of TA, DIC, and pH	ICOS-OTC	Partial Pressure of Carbon Dioxide (pCO2)	O	€	€	L	L	M	--
48	Part IV: Visual Assessment of Crown Condition and Damaging Agents. In: UNECE ICP Forests Programme Coordinating Centre (ed.).	ICP Forests	--	T	€	€	L	L	M	MM
49	Part V: Tree Growth. In: UNECE ICP Forests, Programme Coordinating Centre (ed.).	ICP Forests	Above ground biomass	T	€-€€	€	L/M	M/H	M	MM & AM
50	Part VI: Phenological Observations., In: UNECE ICP Forests Programme Co-ordinating Centre (ed.)	ICP Forests	Plant Species Traits	T	€ -€€	€	L	H	M	MM & AM
51	Part VI.1: Assessment of Ground Vegetation. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Above ground biomass;Litter;Plant Species Traits	T	€	€	L	M	H	MM
52	Part VII.2: Assessment of Epiphytic Lichen diversity. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	--	T	€	€	L	M	H	MM
53	Part VIII: Monitoring of Ozone Injury. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	--	T	€	€	L	M	M	MM

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
54	Part IX: Meteorological Measurements. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Precipitation (surface);Temperature (surface);Water Vapour (surface);Surface Wind Speed and direction;Soil Moisture	T	€€	€€	M	M	M	MM
55	Part X: Sampling and Analysis of Soil. In: UNECE ICP Forests Programme Coordinating Centre (ed.).	ICP Forests	Soil Organic Carbon;Soil Moisture	T	€€	€	H	L	H	MM
56	Part XI: Soil Solution Collection and Analysis. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Soil Organic Carbon	T	€€	€	H	H	H	MM & AM
57	Part XII: Sampling and Analysis of Needles and Leaves. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	--	T	€€	€	L	M	M	MM
58	Part XIII: Sampling and Analysis of Litterfall. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Litter	T	€€	€	L	M	M	MM
59	Part XIV: Sampling and Analysis of Deposition. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	--	T	€€	€	L	H	M	MM
60	Part XV: Monitoring of Air Quality. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Nitrogen Oxides (NOx);Sulfur Dioxide (SO2)	T	€€ (MM) €€€ (AM)	€	M	H	M	MM & AM
61	Part XVI: Quality Assurance and Control in Laboratories, In: UNECE, ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Soil Organic Carbon;Soil Moisture;Litter	T	€€€	€€	H	M	H	MM
62	Part XVII: Leaf Area Measurements. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.).	ICP Forests	Above ground biomass	T	€ (MM) €€-€€€ (AM)	€	L (MM) M (AM)	L	M (MM) H (AM)	MM & AM
63	Soils Processing Users Guide	Nutrient Network (NutNet)	--	T	€	€	M	L	L	MM
64	Experimental Protocol	Nutrient Network (NutNet)	Above ground biomass;Fraction of Absorbed Photosynthetically Active Radiation (FAPAR);Litter;Plant Species Traits	T	€	€	M	M	M	MM
65	Nutrients	Nutrient Network (NutNet)	--	T	€	€	M	L	L	MM

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
67	Leaf Damage	Nutrient Network (NutNet)	--	T	€	€	L	L	M	MM
68	Wet N Deposition	Nutrient Network (NutNet)	--	T	€	€	L	L	L	MM
69	Soil microbes & animals	Nutrient Network (NutNet)	--	T	€	€	L	L	N	MM
71	Summary on new sensor developments and their suitability for different applications	FixO3	--	O	€-€€€	€-€€€	L-H	L-H	L-H	MM & AM
72	Deliverable 2.9 Final update of the Open Ocean Observatories Yellow Pages Website	FixO3	--	O	€-€€€	€-€€€	L-H	L-H	L-H	MM & AM
73	Deliverable 2.10 Technical guidelines of standards of acceptability for common sensor interoperability protocols	FixO3	--	O	€	€	H	M	H	MM
80	GHG Emission Assessment Guideline Volume I: Soil Carbon and Nitrogen Stock Assessment in Agricultural Land and Agroforestry Systems Field Guide for Practitioners	GHGProtocol & Ministry of Agriculture (Ethiopia)	Soil Organic Carbon	T	€	€	M	L	M	MM
81	GHG Emission Assessment Guideline Volume II: Aboveground Biomass Field Guide for Baseline Survey	GHGProtocol & Ministry of Agriculture (Ethiopia)	Above ground biomass;Litter;Below-Ground Biomass	T	€-€€	€	M	M	M	MM
82	GHG Emission Assessment Guideline Volume III: Guideline on Data Collection and Estimation of GHG Emission from Livestock and Manure Management	GHGProtocol & Ministry of Agriculture (Ethiopia)	Manure Management;Livestock Distribution;Biosphere-Atmosphere CH4 flux;Biosphere-Atmosphere N2O flux	T	€	€	N	L	M	MM
85	Guidelines for Measuring CH4 and N2O Emissions from Rice Paddies by a Manually Operated Closed Chamber Method	National Institute for Agro-Environmental Sciences (Japan) & PRRG-GRA.	Biosphere-Atmosphere CH4 flux;Biosphere-Atmosphere N2O flux	T	€€	€€	M	H	M	MM
86	Guidelines for use of sulphur hexafluoride (SF6) tracer technique to measure enteric methane emissions from ruminants	Ministry for Primary Industries (New Zealand) & GRA.	Biosphere-Atmosphere CH4 flux	T	€€	€€	L	M	H	MM
87	Nitrous Oxide Chamber Methodology Guidelines	Ministry for Primary Industries	Biosphere-Atmosphere N2O flux	T	€€	€	M	L	M	MM

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
		(New Zealand) & PRRG-GRA.								
88	Measuring Tropical Forest Carbon Allocation and Cycling: A RAINFOR-GEM Field Manual for Intensive Census Plots	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Litter;Below-Ground Biomass;Biosphere-Atmosphere CO2 flux (NEE)	T	€€	€€	H	H	H	MM
89	Manual for coarse woody debris measurement in RAINFOR plots	AfriTRON;Rainfor;ForestPlots;GEM	Litter	T	€	€	L	M	L	MM
90	Liana Crown Infestation and Crown Illumination Index Definition	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Plant Species Traits	T	€	€	L	L	L	MM
91	RAINFOR Field Manual for Plot Establishment and Remeasurement	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Litter;Below-Ground Biomass;Biosphere-Atmosphere CO2 flux (NEE);Plant Species Traits;Soil Organic Carbon	T	€	€	H	M	M	MM
92	Fieldwork Manual for the study of leaves and wood edited to establish drought effects	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Plant Species Traits	T	€	€	N	M	M	MM
93	RAINFOR – Liana Field Work Database Codes	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Plant Species Traits	T	€	€	N	L	L	MM
94	Field Manual for Mode of Death Census	AfriTRON;Rainfor;ForestPlots;GEM	Plant Species Traits	T	€	€	N	L	L	MM
95	Soil sampling protocol for monitoring changes in soil carbon stocks in Amazonia	AfriTRON;Rainfor;ForestPlots;GEM	Soil Organic Carbon	T	€	€	N	H	H	MM
96	Measuring Root Dynamics in Tropical Ecosystems - A Field Manual	AfriTRON;Rainfor;ForestPlots;GEM	Below-Ground Biomass	T	€€	€	M	L	M	MM
97	RAINFOR – Tree Field Work Database Codes	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Plant Species Traits	T	€	€	N	L	L	MM
98	Measuring Tree Height for Tropical Forest Trees - A Field Manual	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Plant Species Traits	T	€	€	N	L	L	MM
99	Measuring Wood Density for Tropical Forest Trees - A Field Manual	AfriTRON;Rainfor;ForestPlots;GEM	Above ground biomass;Plant Species Traits	T	€	€	N	M	M	MM
110	A simple method to determine surface albedo using digital photography	--	Albedo	T	€	€	N	L	L	MM
116	hackAIR sensors	HackAIR consortium	Aerosol properties	A	€	€	L	L	L	AM
120	Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests	CIFOR	Above ground biomass;Litter;Below-Ground Biomass;Soil Organic Carbon	T;O;F	€	€€	N	H	H	MM

ID	Title	Publisher	Variables	Domain	Equipment cost	Running cost	Installation effort	Maintenance effort	Knowledge needed	Measurement mode
121	The International Drought Experiment a distributed approach to assess T ecosystem responses to extreme drought: SHORT-STATURE SYSTEMS	Drought-Net	Precipitation (surface);Above ground biomass;Litter;Plant Species Traits;Soil Organic Carbon;Temperature (surface)	T	€€	€€	H	M	H	MM & AM
122	Protocol: Drought experiments in tall stature (forest and shrubland) ecosystems	Drought-Net	Precipitation (surface);Above ground biomass;Litter;Plant Species Traits;Soil Moisture;Soil Organic Carbon;Temperature (surface)	T	€€	€€	H	M	H	MM & AM
124	Vital Signs Protocol: Maize Yield Measurements and Farm Field Soil Sampling	VitalSigns	Above ground biomass;Area of ploughed land;Manure Management;Fertilizer application;Irrigation;Livestock Distribution;Crop Yield;Land Cover	T	€	€	L	L	L	MM
125	Vital Signs Protocol: Weather Stations	VitalSigns	Precipitation (surface);Pressure (surface);Fraction of Absorbed Photosynthetically Active Radiation (FAPAR);Surface Wind Speed and direction;Temperature (surface);Water Vapour (surface)	T	€€	€	H	M	M	AM
126	Vital Signs Protocol: Farm Field Soil Sampling and Processing	VitalSigns	--	T	€	€	N	M	L	MM
127	Vital Signs Protocol: E-Plot Soil Sampling and Processing	VitalSigns	Soil Moisture	T	€	€	N	H	L	MM
128	Vital Signs Protocol: Rapid Roadside Assessments	VitalSigns	Land cover;Land Use/Land Use Change;Above ground biomass;Plant Species Traits	T	€	€	N	L	L	MM
129	Vital Signs Protocol: Water Availability and Quality	VitalSigns	River Discharge;Marine Nutrients;Nitrous Oxide (Ocean)	T;O;F	€€	€	H	M	H	MM & AM
130	Vital Signs Protocol: Household Survey	VitalSigns	Economic Development	T	€	€€	N	M	M	MM
131	Vital Signs Protocol: E-Plot Biomass Measurements	VitalSigns	Above ground biomass;Plant Species Traits	T	€	€€	N	M	M	MM
132	Vital Signs Protocol: Agricultural Management Intensity Survey	VitalSigns	Above ground biomass;Area of ploughed land;Manure Management;Fertilizer application;Irrigation;Livestock Distribution;Crop Yield;Land Cover;Land Use/Land Use Change	T	€	€€	N	M	M	MM

3.3 Protocols vs data requirements assessment: a case study for atmosphere-biosphere GHG exchange

Minimum data requirements for the observation of atmosphere-biosphere GHG (CO_2, CH_4 and/or N_2O) exchange were set by SEACRIFOG consortium and correspond to an observation frequency of 1 h, a spatial resolution equivalent to 1 site per major ecoregion and a maximum uncertainty of 5%, referring to the ambient molar fraction of CO_2, CH_4 or N_2O in the air. Among 11 protocols assessed, three main methodologies to measure or estimate GHG fluxes were identified: eddy covariance, closed/dynamic chambers and emission reporting approaches.

There are major differences between these techniques. The eddy covariance technique is an automated system able to record continuous, high-frequency (<hour) measurements of GHG fluxes, whereas closed/dynamic chambers are manual methodologies through which discrete measurements are obtained, and emission reporting approaches yield estimates of GHG sources based on emission factors and activity data. Those protocols dealing with eddy covariance technique fulfil the minimum observation frequency, specifically the ICOS-ETC protocols on "*Turbulent flux measurements of CO_2, energy and momentum*" and "*CO_2, H_2O, CH_4 and N_2O storage flux measurements*", but also the ICOS marine station labelling guide, coinciding with automatic (i.e. continuous) measurements. The guidelines for measuring "*CH_4 and N_2O emissions from rice paddies by a manually operated closed chamber method*" and the "*Tropical forest carbon allocation and cycling*" both focused on chamber measurements and developed by RAINFOR-GEM and PRRG-GRA, respectively, also fulfil the minimum uncertainty requirement (see **Table 6** below). However, uncertainty estimates also depend on the maintenance of the equipment and experimental design, which finally depends on how the protocol is implemented. With regards to the spatial resolution of measurements, given that these protocols describe ground-based observations that can be implemented anywhere on land, the ultimate spatial resolution will depend on implementation location and number of replicates, which relate to the experimental design, which is not always included in the protocols. However, depending on the utilized methodology, the flux measurement will integrate across a different spatial scale. For example, the eddy covariance technique monitors fluxes coming from an area of ~100 m^2 while in case of soil chambers, this area is several orders of magnitude lower (e.g. ~0.01 m^2). On the other hand, emission reporting protocols are often applied to entire production systems, such as farms, or hectares of croplands and temporally integrate GHG emissions into annual estimates.

Generally, it is challenging to determine whether or not a given protocol fulfil the above minimum requirements. For instance, in case of the uncertainty, information about the recommended instrumentation and sensor model is not always available. Moreover, the uncertainty hardly ever refers to the flux, but to the accuracy of an instrument that measures the molar fraction of a given GHG.

Table 6: Data requirement assessment results for protocols dealing with atmosphere-biosphere CO_2, CH_4 and N_2O exchange. This table summarizes the observation frequency, spatial resolution and uncertainty associated with the measurement of atmosphere-biosphere CO_2, CH_4 and/or N_2O exchange based on the information provided by each of the identified protocols. Green cells depict the fulfilment of minimum requirements, which correspond to: observation frequency=1 h, spatial resolution=1 site per major ecoregion and maximum uncertainty=5%. Protocols information includes inventory identification number (ID), title, publishing organization, the greenhouse gas (GHG) and the corresponding technique and instrument the protocols refer to. More detailed metadata of the inventoried protocols can be found at **Table A1** (Annex 1) or at https://seacrifog-tool.sasscal.org/.

ID	Protocol	Publisher	GHG	Technique, Instrument (Model)	Data Requirements		
					Observation Frequency	Spatial Resolution	Uncertainty
9	Turbulent flux measurements of CO_2, energy and momentum	ICOS-ETC	CO_2	Eddy covariance, IRGA (LI7200)	10 Hz	~100 m^2	1 %
10	CO2, H2O, CH4 and N2O storage flux measurements	ICOS-ETC	CO_2	--	≤ 10 s	~100 m^2	± 0.5 µmol mol^{-1} (over 30 min)
			CH_4	--	≤ 10 s	--	± 10 nmol mol^{-1}
			N_2O	--	≤ 10 s	--	± 1.8 nmol mol^{-1}
37	ICOS marine station labelling Step 2	ICOS-OTC	Atmospheric CO_2		1 h		± 1.5%
			CO_2 flux		1 h		± 5%
77	Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture	CGIAR -CCAFS	CO_2	Closed chambers	Generally > 1 h (monthly/seasonal)	--	--
			CH_4	Closed chambers	Generally > 1 h (monthly/seasonal)	--	--
			N_2O	Closed chambers	Generally > 1 h (monthly/seasonal)	--	--
78	GHG Protocol Agricultural Guidance. Interpreting the Corporate Accounting and Reporting Standard for the agricultural sector.	GHGProtocol, WRI & WBCSD	CO_2	None (emission reporting)	≥ annually	Unit land area (ha)	Tier 1
			CH_4	None (emission reporting)	≥ annually	Unit land area (ha)	Tier 1
			N_2O	None (emission reporting)	≥ annually	Unit land area (ha)	Tier 1
79	GHG Protocol Agricultural Guidance. A sector-specific GHG accounting and reporting protocol for Ethiopia.	GHGProtocol, WRI & WBCSD	CO_2	None (emission reporting)	≥ annually	ha / farm / animal	Tier 1
			CH_4	None (emission reporting)	≥ annually	ha / farm / cattle	Tier 1
			N_2O	None (emission reporting)	≥ annually	ha / farm / cattle	Tier 1
82	GHG Emission Assessment Guideline Volume III: Guideline on Data Collection and Estimation of GHG Emission from Livestock and Manure Management	GHGProtocol & Ministry of Agriculture (Ethiopia)	CH_4	None (emission reporting)	≥ annually	ha / farm / cattle	Tier 1
			N_2O	None (emission reporting)	annually	farm / cattle	Tier 1 & 2
85	Guidelines for Measuring CH4 and N2O Emissions from Rice Paddies by a Manually Operated Closed Chamber Method	National Institute for Agro-Environmental Sciences (Japan) & PRRG-GRA.	CH_4	Static chambers + GC	Weekly	cm^2	< 5%
			N_2O	Static chambers + GC	Weekly	cm^2	< 5%
86	Guidelines for use of sulphur hexafluoride (SF6) tracer technique to measure enteric	Ministry for Primary	CH_4	Sampling design (probes,	0.5 – a few days per cattle (depends on the diffusion	cattle	≤ 10%

ID	Protocol	Publisher	GHG	Technique, Instrument (Model)	Data Requirements		
					Observation Frequency	Spatial Resolution	Uncertainty
	methane emissions from ruminants	Industries (New Zealand) & GRA.		samplers, SF6) + GC	restrictor of the gas sampler)		
87	Nitrous Oxide Chamber Methodology Guidelines	Ministry for Primary Industries (New Zealand) & PRRG-GRA.	N_2O	Chambers + GC (static)/IRGA (LI820; dynamic)	--	cm^2	--
88	Measuring Tropical Forest Carbon Allocation and Cycling: A RAINFOR-GEM Field Manual for Intensive Census Plots	AfriTRON;Rainfor ForestPlots;GEM	CO_2	Dynamic chambers + IRGA (EGM-4)	Monthly	cm^2 (soil, stem, coarse woody debris)	1%

4 Discussion

4.1 Relevance of results

The present report aims at guiding the selection of the most suitable methods for the measurement of the essential variables already identified in the SEACRIFOG project, in the context of climate change observation across the African continent and surrounding oceans. Here, we have assessed currently utilized methodologies for the observation and estimation of GHG emissions and other related variables together with their feasibility of implementation. In addition, the fulfilment of data requirements was evaluated through a case study focused on one of these essential variables, the atmosphere-biosphere exchange of CO_2, CH_4 and N_2O.

The protocols inventory represents a compendium of the main international collective efforts towards both the standardization and harmonization of environmental research observations. In this regard, it is important to highlight the difference between standardization and harmonization. Standardization could be considered as a top-down approach where obligatory instructions related to specific aspects of observational methodologies (e.g. down to sensor model) and/or data processing approaches are set in order to assure interoperability within a given research network or RI. Conversely, harmonization may be considered a more flexible top-down approach that is result-oriented, hence, no fixed methodological instructions are set but quality requirements (e.g. temporal resolution) are enforced in order to reach an appropriate level of interoperability.

In the context of the SEACRIFOG project, a harmonized RI appears to be more appropriate given the financial and capacity limitations of the current African research scenario. Existing data requirements[1] for essential climate variables (ECVs) were reviewed and refined by SEACRIFOG in order to provide reference requirements to build this future RI. However, as the SEACRIFOG essential variables include other variables in addition to the ECVs, their respective data requirements were set by the project consortium. This exercise can be considered as a first iteration towards a complete harmonization strategy for this future RI. Nevertheless, a future refinement of these data quality requirements should be endorsed and further iterated through broader consultations that include local and international experimentalists, modellers and policy-makers, in order to address the knowledge and observational gaps related to African GHG emissions and associated mitigation and adaptation practices. To do that a community of practise arises as fundamental to make informed and collectively agreed decisions based on updated assessments where currently utilized methodologies together with their feasibility of implementation and respective fulfilment of data requirements are evaluated.

Overall, the ultimate decision on which methodology is more suitable to use will depend on the final purpose. In this regard, we distinguish between quantification and process-understanding protocols, which corresponded to 35% and 62% of the total inventory, respectively (see Table A1 in Annex I for more information), while 3% could be associated with both purposes. Accordingly, the assessment suggests that there are two types of monitoring sites that could respond to these different purposes. The quantification of GHG emissions must cover the continental spatial heterogeneity by monitoring

[1] Set by Global Atmospheric Watch (GAW), Global Climate Observing System (GCOS), Global Oceanic Observing System (GOOS) and World Meteorological Organization (WMO).

GHG sources and sinks across the main African biomes, anthromes (Ellis et al., 2010), land covers and land uses in order to reduce the uncertainty of regional and continental GHG budgets. In this case, sustained observations with relatively low temporal resolution (i.e. observation frequency) could return the required results, which, in turn, corresponds to the implementation of cheaper methodologies (as shown in Table 5 and Table 6). However, the knowledge generation to enhance the process-understanding entails higher observational frequency together with the monitoring of a greater number of variables, requiring more sophisticated sensors and greater financial support. Thus, a higher financial investment is required for the setup of these “supersites”. Their data products would allow for the development of semi-empirical and mechanistic models capable of predicting the variability of GHG sources and sinks in the long-term. These “supersites” will also allow for inter-comparison of several methodologies, the combination of top-down and bottom-up observational approaches and the evaluation of mitigation policies effectiveness (Leip et al., 2018). Ideally, this future pan-African RI would combine these two types of monitoring sites to produce data that can be used for multiple purposes and hence, by multiple end-users or stakeholders.

4.2 Linkages to other SEACRIFOG activities

The present deliverable connects with several activities that belong to different work packages (WPs) of the SEACRIFOG project. With regard to WP4, as mentioned above, these results build on deliverables 4.1 and 4.2, but at the same time, these could be seen as valuable resources to develop deliverable 4.4, which corresponds to task 4.3, entitled “Harmonization of data collection and quality control”. This task consists of the organisation of three training workshops related to the three domains considered in this project, where methodological and data processing approaches utilized to monitor or estimate GHG sources and sinks in the atmospheric, oceanic and terrestrial domains will be disseminated among attendees and stakeholders in the wider community.

With regards to WP3, this deliverable also builds on D3.1, and will contribute to the task 3.2, entitled “Developing an integrated GHG observation concept adapted to Africa”. The current results provide information related to the suitability of the different methodologies that are being currently utilized by researchers at global scale. Therefore, it assists the configuration of the ready-to-implement concept of this future RI.

Finally, this deliverable, together with D4.1 and 4.2, greatly support the operational and financial planning strategy of this future RI by providing an exhaustive assessment of the variables, measurements and protocols required to make appropriate and objective decisions. Therefore, these deliverables represent a fundamental resource to share with relevant stakeholders in the context of WP7, whose principal goals are to establish a high-level dialogue platform and to build a network of interested funding agencies in order to develop an investment plan.

4.3 Knowledge gaps

In the inventory of protocols there is a clear dominance of protocols dealing with approaches applied in the terrestrial domain compared to the atmospheric and oceanic domains. Additionally, there are no protocols in the inventory that are currently used to assess the observation of human population, dimethyl sulphide and wild herbivores distribution. Data related to human population could be easily acquired from the registers of inhabitants performed by national and regional administrative institutions. Likewise, estimates about wild herbivores distribution would probably come from third party sources, rather than explicit activities under SEACRIFOG to measure/estimate livestock. However, observations of dimethyl sulphide require further research.

4.4 Further steps

As part of future work, the refinement of the inventory of protocols would entail the inclusion of relevant atmospheric and oceanic protocols that are possibly missing in the collection via collaboration with the wider research community. Subsequently, their feasibility could be assessed. Similarly, approaches dealing with the observation or estimation of dimethyl sulphide and wild herbivores distribution could be identified or developed directly.

The outputs of deliverables 4.2 and 4.3 could be combined in order to assess whether or not the identified protocols fulfil the data requirements set by international RIs and the SEACRIFOG consortium. Although, in the present report, this type of assessment was applied to 3 of the 58 essential variables, the atmosphere-biosphere exchange of CO_2, CH_4 and N_2O, future work could extend this case study to all the SEACRIFOG essential variables.

Through the integration of D4.2, D4.3, D3.1, and D3.2, specific recommendations on which methodologies could be implemented together with their location could be set as part of the strategy to fill the knowledge and observational gaps identified in D3.1 and D4.2.

Moreover, a sensor database that includes price and technical specifications, such as the *Esonet yellow pages*[1], would significantly support the appropriate selection of a given sensor model and related methodology for assisting observational priorities. In fact, such a (meta)database is planned to be part of the overall data infrastructure that will be developed in the framework of WP5.

Finally, capacity building and international collaboration remain essential to assure the success of this future RI. Therefore, effective channels for skills and knowledge transfer should be established and funded in the long-term among related research communities at international level.

[1] https://www.esonetyellowpages.com/

5 Recommendations

1. The future African RI should have a harmonized structure where the minimum data requirements, (identified by the SEACRIFOG consortium and the wider scientific community) for essential variables should constitute the foundation for its conceptual design. Therefore, the selection of the observational approaches used will be guided by the practitioners (i.e. researchers) and will depend on the available financial and human capacity.

2. The refinement of respective data requirements for the variables identified as essential by the SEACRIFOG consortium is necessary. This assessment should take into account the different scientific purposes of the observations (quantification vs process-understanding) and should involve local and international experimentalists, modellers and policy-makers.

3. The SEACRIFOG consortia recommend the differentiation of at least two types of observation sites aligned to the main purposes identified in the present report: the quantification of GHG emissions and the generation of process-understanding knowledge. This differentiation will help to fill current knowledge and observation gaps effectively.

4. Monitoring stations designed to quantify continental/regional GHG emissions should prioritise spatial representativeness, to cover the main African biomes, anthromes, land covers and land uses, and long-term sustainability of the observations, which does not necessarily entail high temporal resolution measurements. In this instance relatively cheaper methodological approaches could be applied at these stations due to the lower temporal resolution and accuracy requirements, allowing the use of lower cost equipment.

5. Monitoring stations designed to understand the processes behind GHG budget variability should prioritise accuracy and temporal resolution and should measure a higher number of variables. This type of stations will require higher financial support given the greater costs of equipment and installation and the higher knowledge requirements for long-term operation.

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ANNEX 1 General overview of the protocols inventory

Table A1: Overview of the inventoried protocols and some of their metadata including inventory identification number (ID), title, publication identifier code (*DOI/ISBN/ISSN*), publishing institution/organization/initiative, year of publication, spatial range of applicability, spatial range of adoption, temporal coverage of the measurements explained (*C=continuous, D=discrete* or *Both*), domain (*A=atmospheric, O=oceanic, T=terrestrial, F=freshwater* or *All*), type of protocols in terms of their main utility, sustainability of the initiative that developed the protocol, ultimate purpose of the protocol and their download link. More detailed metadata for the inventoried protocols can be found at https://seacrifog-tool.sasscal.org/.

ID	Title	DOI / ISBN / ISSN	Publisher	Year	Applic-ability	Adoption	Temporal coverage	Domain	Utility	Sustainability	Protocol purpose	Deposit URL
1	ECV-Atmosphere_requirements_IP2016	--	World Meteorological Organization (WMO)	2016	Global	Global	C	A	Observation (various)	Long-term	Quantification	https://gcos.wmo.int/en/essential-climate-variables/requirements
2	ECV-Land_requirements_IP2016	--	World Meteorological Organization (WMO)	2016	Global	Global	C	T	Observation (various)	Long-term	Quantification	https://gcos.wmo.int/en/essential-climate-variables/requirements
3	ECV-Ocean_requirements_IP2016	--	World Meteorological Organization (WMO)	2016	Global	Global	C	O	Observation (various)	Long-term	Quantification	https://gcos.wmo.int/en/essential-climate-variables/requirements
4	Guide to the WMO Integrated Global Observing System	ISBN 978-92-63-11165-4	World Meteorological Organization (WMO)	2018	Global	Global	C	All	Observation (various)	Long-term	Quantification	http://www.wmo.int/pages/prog/www/wigos/WGM.html
5	The Global Observing System for Climate: Implementation Needs	--	World Meteorological Organization (WMO)	2016	Global	Global	C	All	Observation (various)	Long-term	Quantification	https://public.wmo.int/en/resources/library/global-observing-system-climate-implementation-needs
6	Guide for Urban Integrated Hydro-Meteorological, Climate and Environmental Services	--	World Meteorological Organization (WMO)	2018	Global - Urban areas	Global - Urban areas	C	All	Observation (various)	Long-term	Quantification	https://www.wmo.int/pages/prog/arep/gaw/documents/UrbanIntegratedServicesPart1aConceptandMethodologyEC-70.pdf
7	Low-cost sensors for the measurement of atmospheric composition: overview of topic and future applications	ISBN 978-92-63-11215-6	World Meteorological Organization (WMO)	2018	Global	Global	C	A	Observation (ground-based)	Long-term	Quantification	http://www.wmo.int/pages/prog/arep/gaw/documents/Draft_low_cost_sensors.pdf
8	WMO Global Atmosphere Watch (GAW) Implementation Plan: 2016-2023	ISBN 978-92-63-11156-2	World Meteorological Organization (WMO)	2017	Global	Global	C	A	Observation (various)	Long-term	Quantification	https://library.wmo.int/doc_num.php?explnum_id=3395
9	Turbulent flux measurements of CO2, energy and momentum	DOI 10.18160/qwv4-639g	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding & Quantification	http://www.icos-etc.eu/icos/documents/instructions/eddyco2
10	CO2, H2O, CH4 and N2O storage flux measurements	DOI 10.18160/71na-qbtc	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding & Quantification	http://www.icos-etc.eu/icos/documents/instructions/storage
11	Meteorology. Air temperature, Air relative humidity, Air pressure, Wind speed, Wind direction, Backup meteo station	DOI 10.18160/nheg-4kww	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/airmet
12	Precipitations. Total precipitation, Snow depth	DOI 10.18160/krnz-1g9e	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/precip
13	Radiations measurements. Short-wave radiations, Long-wave	DOI 10.18160/zwgb-wrrx	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/radiation

ID	Title	DOI / ISBN / ISSN	Publisher	Year	Applic-ability	Adoption	Temporal coverage	Domain	Utility	Sustainability	Protocol purpose	Deposit URL
	radiations, Photosynthetically active radiation											
14	Soil-meteorological measurements. Soil Temperature; Soil Water Content; Soil Heat Flux Density	DOI 10.18160/1a28-gex6	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/soilmet
15	Water Table Depth Measurements	DOI 10.18160/k9vq-k8d0	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/wtd
16	Station description. How to describe the station and history of the monitored ecosystem	DOI 10.18160/kjj4-ar1h	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2016	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/sitedesc
17	Setting up the spatial sampling scheme for ecosystem station characterization, soil sampling and repeated ancillary vegetation measurements	DOI 10.18160/c5q7-z877	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	C	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/spasamp
18	Ancillary vegetation measurements in croplands. Green Area Index, aboveground biomass, litter biomass.	DOI 10.18160/e568-rdtd	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/anccro
19	Ancillary vegetation measurements in forests. Green Area Index, aboveground biomass, litter biomass.	DOI 10.18160/4ajs-z4r9	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/ancfor
20	Ancillary vegetation measurements in grasslands. Green Area Index, aboveground biomass, litter biomass, canopy height.	DOI 10.18160/daaa-x1ng	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/ancgra
21	Ancillary vegetation measurements in mires. Green Area Index, aboveground biomass.	DOI 10.18160/6mkw-3s2r	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/ancmir
22	Site characterization measurements in forests. Vegetation species, aboveground biomass, green area index.	DOI 10.18160/ymvv-af8m	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/charfor
23	Site characterization measurements in grasslands. Vegetation species, aboveground biomass.	DOI 10.18160/xqfz-038k	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/chargra
24	Site characterization measurements in mires. Vegetation species.	DOI 10.18160/8bkh-gx2x	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/charmir
25	Foliar samples collection and leaf mass to area ratio determination.	DOI 10.18160/k7qg-hg2a	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/folsamp

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26	Soil sampling and preparation for monitoring the soil organic carbon and nitrogen.	DOI 10.18160/k3yc-td6h	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/soilsamp
27	Plant species reporting.	DOI 10.18160/as0v-x7fc	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/species
28	Eddy covariance turbulent flux raw data format	DOI 10.18160/v5jt-9f66	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	--	T	Data processing	Long-term	Process understanding & Quantification	http://www.icos-etc.eu/icos/documents/instructions/ecform
29	Meteorological Data Format	DOI 10.18160/tpp4-4smp	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	--	T	Data processing	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/bmform
30	Storage flux data format	DOI 10.18160/9p4f-6nwg	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	--	T	Data processing	Long-term	Process understanding & Quantification	http://www.icos-etc.eu/icos/documents/instructions/stform
31	How to use the ICOS BADM to submit data	DOI 10.18160/6m8s-fy7m	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	--	T	Data processing	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/badm
32	Team description. How to describe the station team and how this is linked to communications.	DOI 10.18160/3aq1-p947	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	--	T	Data processing	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/team
33	Field-map instrument. A tool for mapping and inventorying trees and instrumentation at forest stations.	DOI 10.18160/ycsg-q3zq	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2018	Europe	Global	--	T	Data processing	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/fieldmap
34	Accupar LP-80 PAR/LAI ceptometer for Green Area Index measurements	DOI 10.18160/zw9y-04t7	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/cepacc
35	SS1 sunscan canopy analysis system for Green Area Index measurements	DOI 10.18160/kyvj-78xn	Integrated Carbon Observation System (ICOS) - Ecosystem Thematic Center (ETC)	2017	Europe	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.icos-etc.eu/icos/documents/instructions/cepsun
36	ICOS Atmospheric Station Specifications	--	Integrated Carbon Observation System (ICOS) - Atmosphere Thematic Center (ATC)	2017	Europe	Global	Both	A	Observation (various)	Long-term	Process understanding	https://icos-atc.lsce.ipsl.fr/filebrowser/download/69422
37	ICOS marine station labelling Step 2	--	Integrated Carbon Observation System (ICOS) - Ocean Thematic Center (OTC)	2018	Europe	Global	Both	O	Observation (various)	Long-term	Process understanding	https://otc.icos-cp.eu/sites/default/files/2018-07/ICOS%20Marine%20Station%20Labelling%20Step%202%20v5.docx_2.pdf
38	Calculation uncertainty of pCO2 from discrete samples of TA, DIC, and pH	--	Integrated Carbon Observation System (ICOS) - Ocean Thematic Center (OTC)	2018	Europe	Global	C	O	Observation (various)	Long-term	Process understanding	https://otc.icos-cp.eu/sites/default/files/2018-07/DiscreteSamplesUncertainty_v1.pdf
39	CO2Sys	--	National Oceanic and Atmospheric Administration, Atlantic Oceanographic & Meteorological Laboratory (NOAA/AOML)	2012	Global	Global	--	O	Data processing	Long-term	Quantification	http://cdiac.ess-dive.lbl.gov/ftp/co2sys/CO2SYS_calc_XLS_v2.1/

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40	A Sourcebook of Methods and Procedures for Monitoring Essential Biodiversity Variables in Tropical Forests with Remote Sensing	ISSN 2542-6729	Global Observation of Forest Cover and Land Dynamics (GOFC-GOLD) and Biodiversity Observation Network, Group on Earth Observations (GEOBON)	2017	Global - Tropical forests	Global - Tropical forests	C	T	Observation (various)	Long-term	Process understanding	https://www.geobon.org/downloads/biodiversity-monitoring/books/Biodiversity-Sourcebook.pdf
41	The GEO Handbook on Biodiversity Observation Networks	DOI 10.1007/978-3-319-27288-7	Biodiversity Observation Network, Group on Earth Observations (GEOBON)	2016	Global	Global	C	T;O;F	Observation (various)	Long-term	Process understanding	https://www.geobon.org/downloads/biodiversity-monitoring/books/GEO-Handbook.pdf
42	GEO BON Technical Series No. 2: An Essential Biodiversity Variable Approach to Monitoring Biological Invasions: Guide for Countries	--	Biodiversity Observation Network, Group on Earth Observations (GEOBON)	2015	Global	Global	C	T	Observation	Long-term	Process understanding	https://www.geobon.org/downloads/biodiversity-monitoring/technical-reports/GEOBON/2015/Monitoring-Biological-Invasions.pdf
43	Global Biodiversity Change Indicators: Model-based integration of remote-sensing & in situ observations that enables dynamic updates and transparency at low cost	--	Biodiversity Observation Network, Group on Earth Observations (GEOBON)	2015	Global	Global	C	T;O;F	Observation (various)	Long-term	Process understanding	https://www.geobon.org/downloads/biodiversity-monitoring/technical-reports/GEOBON/2015/GBCI-Version1.2-high.pdf
44	Earth Observation for Biodiversity Monitoring: A review of current approaches and future opportunities for tracking progress towards the Aichi Biodiversity Targets	ISBN 92-9225-518-5	Secretariat of the Convention on Biological Diversity	2014	Global	Global	C	T;O;F	Observation (space-borne)	Long-term	Process understanding	https://geobon.org/downloads/biodiversity-monitoring/technical-reports/other/2014/cbd-ts-72-en.pdf
45	Part I: Objectives, Strategy and Implementation of ICP Forests. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2017	Europe, Canada & USA	Global	Both	T	Observation (various)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2017_02_part01.pdf
46	Part II: Basic design principles for the ICP Forests Monitoring Networks. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2017	Europe, Canada & USA	Global	Both	T	Observation (various)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2017_01_part02.pdf
47	Part III: Quality Assurance within the ICP Forests monitoring programme. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	Both	T	Observation (various)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part03.pdf
48	Part IV: Visual Assessment of Crown Condition and Damaging Agents. In: Manual on methods	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and	2017	Europe, Canada & USA	Global	Both	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2017_02_part04.pdf

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	and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.		Monitoring of Air Pollution Effects on Forests (ICP Forests)									
49	Part V: Tree Growth. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	Both	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part05.pdf
50	Part VI: Phenological Observations., In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	Both	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part06.pdf
51	Part VI.1: Assessment of Ground Vegetation. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part07-1.pdf
52	Part VII.2: Assessment of Epiphytic Lichen diversity. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part07-2.pdf
53	Part VIII: Monitoring of Ozone Injury. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part08.pdf
54	Part IX: Meteorological Measurements. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	C	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part09.pdf
55	Part X: Sampling and Analysis of Soil. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part10.pdf

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56	Part XI: Soil Solution Collection and Analysis. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part11.pdf
57	Part XII: Sampling and Analysis of Needles and Leaves. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2017	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2017_01_part12.pdf
58	Part XIII: Sampling and Analysis of Litterfall. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part13.pdf
59	Part XIV: Sampling and Analysis of Deposition. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part14.pdf
60	Part XV: Monitoring of Air Quality. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	Both	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part15.pdf
61	Part XVI: Quality Assurance and Control in Laboratories, In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part16.pdf
62	Part XVII: Leaf Area Measurements. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.	ISBN 978-3-86576-162-0	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)	2016	Europe, Canada & USA	Global	D	T	Observation (various)	Long-term	Process understanding	https://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2016_01_part17.pdf
63	Soils Processing Users Guide (online)	--	Nutrient Network (NutNet)	2009	Global	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://nutnet.umn.edu/soil-sampling

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64	Experimental Protocol (online)	--	Nutrient Network (NutNet)	2009	Global	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://nutnet.umn.edu/exp_protocol
65	Nutrients (online)	--	Nutrient Network (NutNet)	2009	Global	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://nutnet.umn.edu/nutrients
66	Data Sheet (online)	--	Nutrient Network (NutNet)	2009	Global	Global	--	T	Data processing	Long-term	Process understanding	https://nutnet.umn.edu/datasheet
67	Leaf Damage (online)	--	Nutrient Network (NutNet)	2009	Global	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://nutnet.umn.edu/methods/leaf-damage
68	Wet N Deposition (online)	--	Nutrient Network (NutNet)	2009	Global	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://nutnet.umn.edu/methods/Wet-N-collectors
69	Soil microbes & animals (online)	--	Nutrient Network (NutNet)	2009	Global	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://nutnet.umn.edu/methods/soil-microbes-animals
70	Handbook of best practices	--	Fixed point Open Ocean Observatory network (FixO3)	2016	Europe	Global	C	O	Observation (ground-based)	Short-term	Quantification	http://www.ioccp.org/index.php/documents/standards-and-methods
71	Summary on new sensor developments and their suitability for different applications	--	Fixed point Open Ocean Observatory network (FixO3)	2015	Europe	Global	--	O	Observation (sea-borne)	Short-term	Quantification	http://www.fixo3.eu/download/Deliverables/D2.4%20Summary%20on%20new%20sensor%20developments%20and%20their%20suitability%20for%20different%20applications.pdf
72	Deliverable 2.9 Final update of the Open Ocean Observatories Yellow Pages Website	--	Fixed point Open Ocean Observatory network (FixO3)	2015	Europe	Global	--	O	Observation (sea-borne); Data processing	Short-term	Quantification	http://www.fixo3.eu/download/Deliverables/FixO3_D2.9_FINAL.pdf
73	Deliverable 2.10 Technical guidelines of standards of acceptability for common sensor interoperability protocols	--	Fixed point Open Ocean Observatory network (FixO3)	2016	Europe	Global	--	O	Observation (sea-borne); Data processing	Short-term	Quantification	http://www.fixo3.eu/download/Deliverables/FixO3-D2.10-FINAL.pdf
74	Guide to Best Practices for Ocean CO2 Measurements	ISBN 1-897176-07-4	International Ocean Carbon Coordination Project (IOCCP)	2007	Global	Global	Both	O	Observation (sea-borne)	Long-term	Quantification	http://www.ioccp.org/index.php/documents/standards-and-methods/2-uncategorised/263-guide-to-best-practices-for-ocean-co2-measurements
75	Guide to best practices for ocean acidification research and data reporting	DOI 10.2777/58454	European Project on Ocean Acidification (EPOCA)	2010	Europe	Global	Both	O	Observation (sea-borne)	Long-term	Process understanding	http://www.eurosfaire.prd.fr/7pc/doc/1303284415_kina24328enc_002.pdf
76	Global Intercomparability in a Changing Ocean: An International Time-Series Methods Workshop	--	Ocean Carbon and Biochemistry (OCB) and International Ocean Carbon Coordination Project (IOCCP)	2012	Global	Global	Both	O	Observation (sea-borne)	Long-term	Process understanding	http://www.ioccp.org/images/03TimeSeries/Time%20Series_Workshop_report_FINAL.pdf
77	Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture	DOI 10.1007/978-3-319-29794-1	CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)	2016	Global	Global	Both	T	Observation (various)	Long-term	Process understanding	https://link.springer.com/content/pdf/10.1007%2F978-3-319-29794-1.pdf
78	GHG Protocol Agricultural Guidance. Interpreting the Corporate Accounting and Reporting Standard for the agricultural sector.	--	GHGProtocol, World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD)	2016	Global	Global	Both	T	Observation (ground-based)	Long-term	Quantification	http://ghgprotocol.org/sites/default/files/standards/GHG%20Protocol%20Agricultural%20Guidance%20%28April%2026%29_0.pdf
79	GHG Protocol Agricultural Guidance. A sector-specific GHG	--	GHGProtocol, World Resources Institute (WRI) and the World	2014	Ethiopia	Global	Both	T	Observation (ground-based)	Long-term	Quantification	https://ghgprotocol.org/agriculture-guidance

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	accounting and reporting protocol for Ethiopia.		Business Council for Sustainable Development (WBCSD)									
80	GHG Emission Assessment Guideline Volume I: Soil Carbon and Nitrogen Stock Assessment in Agricultural Land and Agroforestry Systems Field Guide for Practitioners	--	GHGProtocol and Federal Democratic Republic of Ethiopia, Ministry of Agriculture	2014	Ethiopia	Global	D	T	Observation (ground-based)	Long-term	Quantification	http://ghgprotocol.org/sites/default/files/standards_supporting/GHG%20Assessment%20Guideline%20Volume%20I%20Soil.pdf
81	GHG Emission Assessment Guideline Volume II: Aboveground Biomass Field Guide for Baseline Survey	--	GHGProtocol and Federal Democratic Republic of Ethiopia, Ministry of Agriculture	2015	Ethiopia	Global	D	T	Observation (ground-based)	Long-term	Quantification	http://ghgprotocol.org/sites/default/files/standards_supporting/GHG%20Assessment%20Guideline%20Volume%20II%20Aboveground%20Biomass_0.pdf
82	GHG Emission Assessment Guideline Volume III: Guideline on Data Collection and Estimation of GHG Emission from Livestock and Manure Management	--	GHGProtocol and Federal Democratic Republic of Ethiopia, Ministry of Agriculture	2015	Ethiopia	Global	D	T	Observation (ground-based)	Long-term	Quantification	http://ghgprotocol.org/sites/default/files/standards_supporting/GHG%20Assessment%20Guideline%20Volume%20III%20Livestock%20V2_0.pdf
83	Measuring emissions from livestock farming: greenhouse gases, ammonia and nitrogen oxides	ISBN 2-7380-1392-9	Institut National de la Recherche Agronomique (INRA), Réseau Mixte Technologique, Elevage et Environnement (RMT - Joint Technology Network, Livestock production and Environment) and Agence de l'environnement et de la maîtrise de l'énergie (ADEME - French Environment and Energy Management Agency)	2016	France	Global	Both	T	Observation (ground-based)	Long-term	Quantification	https://www6.inra.fr/animal_emissions_eng/News/Measuring-gaseous-emissions-from-animal-farms
84	The Smallholder Agriculture Monitoring and Baseline Assessment (SHAMBA)	--	University of Edinburgh	2013	Global - Tropical small-holder agro-systems	Global - Tropical small-holder agro-systems	--	T	Data processing	Long-term	Quantification	https://shambatool.wordpress.com/
85	Guidelines for Measuring CH4 and N2O Emissions from Rice Paddies by a Manually Operated Closed Chamber Method	ISBN 978-4-931508-16-3	National Institute for Agro-Environmental Sciences (Tsukuba, Japan) and Paddy Rice Research Group of the Global Research Alliance on Agricultural Greenhouse Gases (PRRG-GRA)	2015	Japan	Global	D	T	Observation (ground-based)	Long-term	Quantification	https://globalresearchalliance.org/wp-content/uploads/2018/02/Guidelines-for-Measuring-CH4-and-N2O-Emissions-from-Rice-Paddies-by-Manually-Operated-Closed-Chamber-Method-2015.pdf
86	Guidelines for use of sulphur hexafluoride (SF6) tracer technique to measure enteric methane emissions from ruminants	ISBN 978-0-478-43210-7	Ministry for Primary Industries (Wellington, New Zealand) and Global Research Alliance on Agricultural Greenhouse Gases (PRRG-GRA)	2014	New Zealand	Global	D	T	Observation (ground-based)	Long-term	Quantification	https://globalresearchalliance.org/wp-content/uploads/2018/02/SF6-Tracer-Technique-Guidelines_April-2014.pdf
87	Nitrous Oxide Chamber Methodology Guidelines	ISBN 978-0-478-40585-9	Ministry for Primary Industries (Wellington, New Zealand) and Paddy Rice Research Group of the Global Research Alliance on Agricultural Greenhouse Gases (PRRG-GRA)	2015	New Zealand	Global	Both	T	Observation (ground-based)	Long-term	Quantification	https://globalresearchalliance.org/wp-content/uploads/2018/06/Nitrous-Oxide-Chamber-Methodology-Guidelines-July-2015.pdf

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88	Measuring Tropical Forest Carbon Allocation and Cycling: A RAINFOR-GEM Field Manual for Intensive Census Plots	--	AfriTRON;Rainfor; ForestPlots;GEM	2014	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://gem.tropicalforests.ox.ac.uk/files/RAINFOR-GEMmanual.HQ.pdf
89	Manual for coarse woody debris measurement in RAINFOR plots	--	AfriTRON;Rainfor; ForestPlots;GEM	2011	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/CWD_protocol_RAINFOR_2011_EN.pdf
90	Liana Crown Infestation and Crown Illumination Index Definition	--	AfriTRON;Rainfor; ForestPlots;GEM	2014	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based);Data processing	Long-term	Process understanding	http://www.rainfor.org/upload/ManualsEnglish/crown%20liana%20protocols_Sep%202014_EN.pdf
91	RAINFOR Field Manual for Plot Establishment and Remeasurement	--	AfriTRON;Rainfor; ForestPlots;GEM	2016	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.rainfor.org/upload/ManualsEnglish/RAINFOR_field_manual_version_2016.pdf
92	Fieldwork Manual for the study of leaves and wood edited to establish drought effects	--	AfriTRON;Rainfor; ForestPlots;GEM	2005	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/leaves_english[1].pdf
93	RAINFOR – Liana Field Work Database Codes	--	AfriTRON;Rainfor; ForestPlots;GEM	2014	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based);Data processing	Long-term	Process understanding	http://www.rainfor.org/upload/ManualsEnglish/RAINFOR_Lianadata_codes_Nov2014_EN.pdf
94	Field Manual for Mode of Death Census	--	AfriTRON;Rainfor; ForestPlots;GEM	2005	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/ModeOfDeath_english[1].pdf
95	Soil sampling protocol for monitoring changes in soil carbon stocks in Amazonia	--	AfriTRON;Rainfor; ForestPlots;GEM	2005	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/Protocol_intensive_soil_sampling_EN.pdf
96	Measuring Root Dynamics in Tropical Ecosystems - A Field Manual	--	AfriTRON;Rainfor; ForestPlots;GEM	2005	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/Roots_english[1].pdf
97	RAINFOR – Tree Field Work Database Codes	--	AfriTRON;Rainfor; ForestPlots;GEM	2014	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based);Data processing	Long-term	Process understanding	http://www.rainfor.org/upload/ManualsEnglish/RAINFOR%20data%20codes-Updated_Oct2014_EN.pdf
98	Measuring Tree Height for Tropical Forest Trees - A Field Manual	--	AfriTRON;Rainfor; ForestPlots;GEM	2005	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/TreeHeight_english[1].pdf
99	Measuring Wood Density for Tropical Forest Trees - A Field Manual	--	AfriTRON;Rainfor; ForestPlots;GEM	2005	Global - Tropical forests	Global - Tropical forests	D	T	Observation (ground-based)	Long-term	Process understanding	http://www.afritron.org/upload/en/manuals/wood_density_english[1].pdf
100	Handbook on Measurement, Reporting and Verification for Developing Country Parties	ISBN 978-92-9219-128-3	United Nations Framework to Combat Climate Change (UNFCCC)	2014	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/non-annex_i_mrv_handbook.pdf
101	UNFCCC Resource guide for reparing the national communications of non-annex I parties. Module 1: the process of national communications from non-annex i parties.	--	United Nations Framework to Combat Climate Change (UNFCCC)	2008	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/files/national_reports/non-annex_i_parties/application/pdf/module_1.pdf
102	UNFCCC Resource guide for reparing the national communications of non-annex I	--	United Nations Framework to Combat Climate Change (UNFCCC)	2008	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/files/national_reports/application/pdf/module_2_v_and_a.pdf

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	parties. Module 2: vulnerability and adaptation to climate change.											
103	UNFCCC Resource guide for reparing the national communications of non-annex I parties. Module 3: national greenhouse gas inventories.	--	United Nations Framework to Combat Climate Change (UNFCCC)	2008	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/files/national_reports/application/pdf/module_3_national_ghg.pdf
104	UNFCCC Resource guide for reparing the national communications of non-annex I parties. Module 4: measures to mitigate climate change	--	United Nations Framework to Combat Climate Change (UNFCCC)	2008	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/files/national_reports/application/pdf/module_4_mitigation.pdf
105	Guide for peer review of national GHG inventories	--	United Nations Framework to Combat Climate Change (UNFCCC)	2017	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/files/national_reports/non-annex_i_natcom/application/pdf/final_guide_for_peer_review_report_final_webupload.pdf
106	Guidance to assist developing country Parties to assess the impact of the implementation of response measures, including guidance on modelling tools	--	United Nations Framework to Combat Climate Change (UNFCCC)	2016	Global	Global	Both	T	Emission reporting	Long-term	Quantification	https://unfccc.int/sites/default/files/resource/Technical%20paper_beautified_Guidance%20to%20assist%20developing%20country%20Parties%20to%20assess%20the%20impact%20of%20the%20implementation%20of%20RM_FCCC_TP_2016_4.pdf
107	IPCC Inventory Software	--	Intergovernmental Panel of Climate Change (IPCC)	2017	Global	Global	Both	T	Emission reporting;Data processing	Long-term	Quantification	https://www.ipcc-nggip.iges.or.jp/software/index.html
108	EFDB Emission Factor Database	--	Intergovernmental Panel of Climate Change (IPCC)	2018	Global	Global	Both	T	Emission reporting;Data processing	Long-term	Quantification	https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
109	Regional Carbon Cycle Assessment and Processes (RECCAP). Soft Protocol (online)	--	Regional Carbon Cycle Assessment and Processes (RECCAP); Global Carbon Project (GCP)	2011	Global	Global	Both	All	Data processing	Short-term	Quantification	http://www.globalcarbonproject.org/reccap/protocol.htm
110	A simple method to determine surface albedo using digital photography	--	Glen Gilchrist	2011	Global	Global	D	T	Observation (ground-based)	Short-term	Quantification	http://vixra.org/pdf/1110.0035v1.pdf
111	Guidelines on the use of remote sensing products to improve agricultural crop production forecast statistics in Sub-Saharan countries	ISBN 978-92-5-130434-1	Food and Agriculture Organization of the United Nations (FAO)	2018	Sub-Saharan Africa	Global	Both	T	Observation (space-borne);Data processing	Long-term	Quantification	http://www.fao.org/3/i8884en/I8884EN.pdf
112	Review of the available remote sensing tools, products, methodologies and data to improve crop production forecasts	ISBN 978-92-5-109840-0	Food and Agriculture Organization of the United Nations (FAO)	2017	Global	Global	Both	T	Observation (space-borne);Data processing	Long-term	Quantification	http://www.fao.org/3/a-i7569e.pdf

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113	Estimating Greenhouse Gas Emissions in Agriculture A Manual to Address Data Requirements for Developing Countries	ISBN 978-92-5-108674-2	Food and Agriculture Organization of the United Nations (FAO)	2015	Global	Global	Both	T	Emission reporting;Data processing	Long-term	Quantification	http://www.fao.org/3/a-i4260e.pdf
114	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories	ISBN 1-56973-846-7	GHGProtocol	2014	Global - Urban areas	Global - Urban areas	Both	T	Emission reporting;Data processing	Long-term	Quantification	https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
115	ICLEI USA's ClearPath	--	ICLEI - Local Governments for Sustainability, Compact of Mayors and Bloomberg Philanthropies	2015	Global - Urban areas	Global - Urban areas	--	T	Emission reporting;Data processing	Long-term	Quantification	http://www.clearpath.global/about/
116	hackAIR sensors	--	HackAIR consortium	2016	Europe	Global	C	A	Observation (ground-based)	Short-term	Quantification	http://www.hackair.eu/wp-content/uploads/2018/05/handout-hackAIR-mobile.pdf;http://www.hackair.eu/wp-content/uploads/2018/05/handout-hackAIR-cardboard.pdf;http://www.hackair.eu/wp-content/uploads/2018/05/handout-hackAIR-home.pdf;http://www.hackair.eu/hackair-home/
117	An Operational Anthropogenic CO_2 emissions Monitoring & Verification Support Capacity. Baseline Requirements, Model Components and Functional Architecture. Report from the CO_2 monitoring Task Force - sub-task B.	DOI 10.2760/	European Comission Joint Research Center. Copernicus.	2017	Global	Global	C	A	Observation (space-borne);Observation (ground-based)	Long-term	Quantification	http://www.copernicus.eu/sites/default/files/library/Report_Copernicus_CO2_Monitoring_TaskForce_Nov2017.pdf
118	Coastal Blue Carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows (updated)	--	Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature.	2018 06	Global - Mangroves, tidal salt marshes, and seagrass meadows	Global - Mangroves, tidal salt marshes, and seagrass meadows	Both	T;O;F	Observation (space-borne);Observation (ground-based);Data processing	Long-term	Process understanding	http://thebluecarboninitiative.org/wp-content/uploads/English_Blue_Carbon_LR.pdf
119	[Toolbox] — A rolling list of software/packages for flux-related data processing (online)	--	FLUXNET	2018	Global	Global	C	T	Data processing	Long-term	Process understanding	https://fluxnet.fluxdata.org/2017/10/10/toolbox-a-rolling-list-of-softwarepackages-for-flux-related-data-processing/
120	Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests	--	Center for International Forestry Research (CIFOR)	2012	Global - Mangroves	Global - Wetlands	Both	T;O;F	Observation (ground-based);Data processing	Long-term	Process understanding	https://www.cifor.org/library/3749/protocols-for-the-measurement-monitoring-and-reporting-of-structure-biomass-and-carbon-stocks-in-mangrove-forests
121	The International Drought Experiment a distributed approach to assess terrestrial ecosystem responses to extreme drought: SHORT-STATURE SYSTEMS	--	Drought-Net	2017	Global	Global	Both	T	Observation (ground-based)	Long-term	Process understanding	https://drought-net.colostate.edu/sites/default/files/the_international_drought_experiment_draft_protocol_v4.pdf

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122	Protocol: Drought experiments in tall stature (forest and shrubland) ecosystems	--	Drought-Net	2017	Global	Global	Both	T	Observation (ground-based)	Long-term	Process understanding	https://drought-net.colostate.edu/sites/default/files/ide_forest_protocol_final_3.2.pdf
123	IDE Data Sheets	--	Drought-Net	2017	Global	Global	Both	T	Data processing	Long-term	Process understanding	https://drought-net.colostate.edu/files/ide-data-sheets
124	Vital Signs Protocol: Maize Yield Measurements and Farm Field Soil Sampling	--	VitalSigns	2014	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_MaizeYieldMeasurements_v1.1.pdf
125	Vital Signs Protocol: Weather Stations	--	VitalSigns	2014	Africa	Global	C	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_Weather_Stations_March2014.pdf
126	Vital Signs Protocol: Farm Field Soil Sampling and Processing	--	VitalSigns	2014	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_SoilSamplingFarmFields_March2014.pdf
127	Vital Signs Protocol: E-Plot Soil Sampling and Processing	--	VitalSigns	2014	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_Soils_March2014_update.pdf
128	Vital Signs Protocol: Rapid Roadside Assessments	--	VitalSigns	2014	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_RapidRoadside_March2014.pdf
129	Vital Signs Protocol: Water Availability and Quality	--	VitalSigns	2014	Africa	Global	D	T;O;F	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_Water_March2014.pdf
130	Vital Signs Protocol: Household Survey	--	VitalSigns	2014	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_HouseholdSurvey_March2014.pdf
131	Vital Signs Protocol: E-Plot Biomass Measurements	--	VitalSigns	2014	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	https://s3.amazonaws.com/vitalsigns.org-assets/VS_Protocol_EPlots_March2014.pdf
132	Vital Signs Protocol: Agricultural Management Intensity Survey	--	VitalSigns	2016	Africa	Global	D	T	Observation (ground-based)	Long-term	Process understanding	http://s3.amazonaws.com/vitalsigns.org-assets/Vital%20Signs_%20Agriculture%20Management%20Survey_Version%202%20%208-5-2014.pdf.pdf
133	FlowPer: Flow Persistence Model	--	International Centre for Research in Agroforestry;World Agroforestry Centre	2014	Global	Global	--	T;O;F	Data processing	Long-term	Quantification	http://www.worldagroforestry.org/output/flowper-flow-persistence-model
134	GenRiver: Generic River Model on River Flow	ISBN 978-979-3198-50-7	International Centre for Research in Agroforestry;World Agroforestry Centre	2011	Global	Global	--	T;O;F	Data processing	Long-term	Quantification	http://www.worldagroforestry.org/output/genriver-generic-river-model-river-flow
135	REDD Abacus Service Pack	--	International Centre for Research in Agroforestry;World Agroforestry Centre	2014	Global	Global	--	T	Data processing	Long-term	Quantification	http://www.worldagroforestry.org/output/redd-abacus-service-pack
136	Space Time Rainfall Simulator - SpatRain model	--	International Centre for Research in Agroforestry;World Agroforestry Centre	2004	Global	Global	--	T	Data processing	Long-term	Quantification	http://www.worldagroforestry.org/output/spatrain-model
137	WaNuLCAS a model of Water, Nutrient and Light Capture in Agroforestry Systems	ISBN 978-979-3198-59-0	International Centre for Research in Agroforestry;World Agroforestry Centre	2011	Global	Global	--	T	Data processing	Long-term	Quantification	http://www.worldagroforestry.org/output/wanulcas/download
138	Community-based ecological monitoring - Manual for practitioners	--	Southern Alliance for Indigenous Resources (SAFIRE)	2007	Zambia and	Global	--	T	Observation (ground-based)	Long-term	Quantification	http://www.fao.org/forestry/14700-0271f3fb3f50174269227fd97906437a9.pdf

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					Zimbabwe							
139	The handbook for standardised field measurements in terrestrial global change experiments	--	Climate Change Manipulation Experiments in Terrestrial Ecosystems: Networking and Outreach. ClimMani COST action	2018	Global	Global	--	T	Observation (ground-based)	Short-term	Process understanding	https://www.researchgate.net/publication/328582902_The_handbook_for_standardised_field_measurements_in_terrestrial_global_change_experiments
140	Latent and sensible heat fluxes from lake water surfaces	DOI 10.1029/2009JD012839	National Institute of Water and Atmospheric Research (NIWA; New Zealand)	2010	Global	Global	--	T;O;F	Data processing	Long-term	Quantification	https://www.niwa.co.nz/our-services/software/heat-fluxes-from-lakes