ECV-Inventory Gap Analysis Report

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Executive Summary

This report focuses on the provision of an analysis based on the content of the CEOS/CGMS Essential Climate Variables (ECV) Inventory of Climate Data Records (CDR) that identifies gaps, shortfalls and improvement possibilities for both currently existing and future planned climate data records. As a basis for the analysis the report also provides an overview of the ECV Inventory that is the structured, comprehensive and accessible view as to what climate data records are currently available from satellite missions of CEOS and CGMS members or their combination.

Both the development of the Inventory and the gap analysis are intrinsic to the fulfilment of the core objectives assigned to the joint CEOS/CGMS Working Group Climate in its Terms of Reference, and form a pivotal asset in the implementation of the Climate Monitoring Architecture also addressing the GCOS Actions 11 (Review of availability of climate data records) and 12 (Gap-analysis of climate data records).

The report was written by members of the WGClimate, which comprises representatives of the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS) and the World Meteorological Organization (WMO). These were supported by numerous subject experts on the GCOS Essential Climate Variables and their measurement from space. The intended audiences include space agencies, CEOS and CGMS coordinating mechanisms, and national and/or international programmes and organisations with climate-related mandates.

The ECV Inventory of CDRs was established by a data call to CEOS and CGMS agencies, with a data population phase from June 2016 to April 2017 and a data verification phase lasting until August 2017. Approximately 100 individuals in the contributing agencies were involved.

The ECV Inventory is a structured repository for the characteristics of two types of ECV CDRs:

- Climate data records that already exist;
- Climate data records that do not currently exist, but are firmly planned to be delivered as part of an already-approved programme of an individual or several agencies.

The number of climate data records in the ECV inventory is 913. The split into existing (496) and planned (417) CDRs is almost even, which is an indication that most agencies have plans to deliver more climate data records in the future. The data call for the inventory was based on the 2006 GCOS Implementation Plan [RD-6], but during the process, in 2016, GCOS published its new implementation plan [RD-7]. Contributions for new ECVs and ECV products were thus also accepted as input. However, not all new ECV products from [RD-7] have been systematically added; this will be done during the next update of the ECV Inventory.

The ECV Inventory was published in October 2017[1] and is potentially the best specifically verified source of information on climate data records available. The information in the ECV Inventory describes the status on 31 December 2016.

[1] climatemonitoring.info/ecvinventory

The analysis described in this report has three parts:

1. An assessment of ECVs and their ECV Products where no data records exist or are not planned. ECV Products provide further detail of specific geophysical quantities that can be derived from satellite measurements;
2. An assessment of the existing and planned climate data records with respect to the fulfilment of that criteria, published by GCOS, that provides guidance to climate data record providers on the sustainable process to generate CDRs, and on the quality required to be able to serve known climate applications. The analysis has been performed for all GCOS ECVs and their ECV Products. The ECV Inventory was designed to assess against GCOS criteria in [RD-1], [RD-2] and [RD-8], but not systematically against [RD-7];
3. An assessment of 8 ECVs (Carbon Dioxide, Methane, Precipitation, Sea Surface Temperature, Sea Surface Salinity, Land Surface Temperature, Leaf Area Index, and Above-ground Biomass) and their associated ECV Products with respect to a more optimised use of past and current satellite measurements and an analysis of missing measurements in the future, which would prevent the generation of CDRs for specific ECV Products.

Results of the first analysis indicate:

- Atmospheric ECVs:
    - All ECVs are partially covered, although a dense population only exists for the period 2001-2010;
    - For existing CDRs, five ECV Products (Temperature of Deep Layers, Tropospheric Ozone and CO_2 Profiles, and NO_2, SO_2 and HCHO Tropospheric Columns) have no entries in the ECV Inventory. However, Temperature of Deep Layers does not constitute a real data gap because data records are known to exist for this ECV even though they are not currently registered in the inventory;
    - For planned CDRs, very few plans exist for the extension of CDRs beyond 2020. For 4 ECV Products (Total Solar Irradiance, Tropospheric CO_2 Profile, Stratospheric CH_4 Profile, and CO Tropospheric Column) no entries exist in the ECV Inventory. However, some limitations in the Inventory for planned CDRs has now been identified, so in some cases these gaps may not be real. Improvements to the inventory will be made for the next update.
- Terrestrial ECVs:
    - Far less data records per ECV Product are present in the inventory for terrestrial ECVs compared to atmospheric ones;
    - For the existing CDRs, 9 ECV products (Areas of GTN-L Lakes, Snow Water Equivalent, Glacier Elevation data, Ice Sheet Surface Elevation and Mass Changes, High Resolution maps of land cover type, Above-ground Biomass, Active Fire Maps, and Fire Radiative Power) have no entries in the ECV Inventory;
    - For planned CDRs, for 6 of the 9 missing ECV Products plans exist to address them in the near future. Three ECV Products (Snow Water Equivalent, High Resolution maps of land cover type, and Active Fire Maps) remain missing and require further analysis.
- Oceanic ECVS:

- Far less data records per ECV Product are present in the inventory for oceanic ECVs compared to atmospheric ECVs, with the exception of Sea Surface Temperature;
- The only missing ECV in the current data record holdings is Sea Surface Salinity;
- For the planned data records, major improvements in coverage will be achieved by addressing Sea Surface Salinity in the future and also by extending other data records, e.g. Sea Ice Thickness, backwards in time.

Significant findings from the second analysis include, but are not limited to:

- Regarding the CDR generation process, in very few cases an independent assessment body, such as GEWEX, was used to perform a quality review. Some QA process in general is applied to about 80% of the data records, which is, in most cases, normal product validation. A formal process is in place only for just over 25% of the CDRs, of which only about 5% implement the QA4EO process;
- For the GCOS accuracy requirement, up to 70% of the data records fulfil the needs for their intended application, although only 20% fulfil GCOS requirements. For 30% of the data records there is no or only qualitative information on accuracy provided. This could be due non-responsiveness of contributors to this question or could possibly constitute a real area for improvement;
- The temporal stability of the data records have not been assessed in about 75% of the cases, which is a concern as only high stability in CDRs would enable the detection of a change in the geophysical variable considered. From the remaining 25% of the data records, about one third fulfils the GCOS requirement and the rest seem at least good enough for their intended or realised application. Not many improvements are detected for the planned data records, pointing to substantial issues in demonstrating improvements in the absence of fiducial reference measurements, in particular for stability;
- With regard to data access, a positive finding is that for more than 80% of the data records the access point is an institutional help desk or similar. Only a few percent of the data records are available from individuals only, or the access point is unknown. Also positive is that for more than 98% of the data records the access to the data is without any constraint;
- For a little more than 50% of the data records a link to the used FCDR is provided. For a few percent, links to non-FCDR input data is provided, and for the remaining 40% this question remained unanswered. This is correlated to the finding that more than 30% of data producers seem not to know who is responsible for the provision of a best possible input data record (FCDR), including cross-calibration to reference sensors. Various interpretations of this result can be made. The most obvious analysis would be to assume that half of the data records in the inventory do not actually represent climate data records because the input data do not achieve the required quality. However, it is known that many Level 2 data production algorithms contain corrections of Level 1 data, the details of which are often not saved or accessible by others. For future data records there is slightly more awareness on the need for FCDRs, although in all cases it does not seem to be a part of the specific planning for a data record. From this, WGClimate concludes that a specific FCDR inventory would help to facilitate the usage of FCDRs and may make the provision of FCDRs more attractive;
- A clear weakness of the current holdings is that for less than 50% of the data records a known metadata standard has been applied. This presents a barrier for

international interoperability as this is needed for data exchange and also automatic visualisation.

The assessment of the 8 ECVs has the following major findings:

- For CO_2, there are only very few data records existing and/or planned. It is recommended that CEOS and CGMS agencies commit to the generation of such data records;
- For CH_4, the gaps for climate data records mentioned above, in particular for stratospheric CH_4 profiles, should be closed. It is recommended that the AC-VC develop a plan to resolve this;
- For Precipitation, many potential additional entries for the ECV Inventory have been identified that provide several long-term, quasi-global, publicly available multi-mission precipitation datasets, which have a clear or potential relevance to climate. In addition it has been found that the number of microwave sensors will most likely decline over the next decade, inheriting the risk that the required temporal sampling (3 hourly) cannot be fulfilled in the future. Because of the number of satellites involved, the number and potential climate relevance of various products, and the general complexity to establish precipitation climatology from space-based measurements, it is recommended to the P-VC identify a way forward on how precipitation climatology can be addressed in the future;
- For Sea Surface Temperature (SST), a couple of potentially missed opportunities have been identified that address the use of geostationary image data to improve temporal sampling. In particular, the use of the diurnal cycle compared to imagers in polar orbit, the potential contribution of IR sounders to SST accuracy and stability (particularly in the earlier decades), and the potential use of microwave SST that provide increased coverage albeit with greater uncertainty, are all potential measurement opportunities not currently being addressed. It is recommended that the SST-VC foster work on SST ECV data records with regards to the improvements possible by exploiting the aforementioned data sources. With regards to potentially missing measurements in the future, the continuation of all-weather capability originating from microwave C-band measurements is endangered. It is recommended that the life of AMSR-2 be maximised, that the possibility of an AMSR-2 on GCOM-W2 be prioritised, and full data sharing with regards to MWI instruments on FY-3 series and HY-2B be enabled. In the longer-term, a sustainable plan with redundancy for C-band microwave conical scanning radiometers should be developed by agencies with an operational mandate.
- For Sea Surface Salinity (SSS), a single activity only is planned to generate a climate data record from the existing measurements, and this single measurement only represents a relatively short time series. It is evident that SSS is not adequately addressed in future missions and it is recommended that agencies address this short-fall as a priority. This has also been recognised by GCOS in the 2016 IP [RD-7] where GCOS Action 32 advocates for the continuation of salinity observations.
- For Land Surface Temperature (LST), it was observed that some known data records have not been registered within the ECV Inventory; this omission should be fixed in the next update. There is no apparent gap in the availability of future measurements, but virtually no plan exists to derive climate data records from the combined use of the multitude of individual instruments available. It is recommended that the LSI-VC devise a way forward for the combined use of past, current and future instruments to create sustained LST CDRs;

- For Leaf Area Index (LAI), it was observed that some known data records have not been registered within the ECV Inventory; this omission should be fixed in the next update. The total number of existing and planned data records currently in the ECV inventory is fairly low (two existing and three planned), even though plenty of satellite instruments that have very high relevance for Leaf Area Index are known to exist. Thus, it is recommended that the LAI-VC assess climate user needs for such products that are not currently exploited from existing missions. This should assist future planning for LAI CDRs;
- For Above-ground Biomass, there is currently a total gap in climate data record provision. However, it is known that ESA is now attempting to produce epoch estimates for given years. The maximum attainable length of this CDR will be about 10 years, with gaps, which is not suitable for longer-term climate analysis. The situation could be improved if more data, such as from PALSAR-2, would become available, as recommended by WGClimate. Regarding future measurements, two experimental missions are planned with biomass as the primary mission aim. If they can be successfully executed (including combined use), plans would then be needed to ensure measurement continuity.

The analysis for the ECVs needed a mapping of GCOS ECV Product names to names of physical quantities related to space measurements to establish the full chain for analysis. It is noteworthy that the CEOS MIM and OSCAR databases, which contain information on available and planned measurements from space, do not use the same nomenclature for physical quantities. It is also obvious that the MIM database lacks information for historical satellites (prior to 1984), which is essential in the climate context. In addition, during the analysis of the 8 ECVs, some errors in the information in MIM and OSCAR were detected that should be corrected in the future. It was very time consuming to utilise the MIM and OSCAR databases for the current gap analysis and the issues discovered may still represent a source of error for the gap analysis related to missed opportunities and measurements. It is recommended that CEOS and WMO better co-align the MIM and OSCAR databases, and possibly even join them to provide one single such database.

Significant lessons learnt from the establishment of the ECV Inventory and the gap analysis performed include, but are not limited to:

- With regards to data collection, the WGClimate will seek full engagement of all CEOS/CGMS agencies in order to ensure global completeness of the ECV Inventory;
- The verification process is absolutely critical to ensure that the inventory is a reliable source of information (for both data users and for the gap analysis process);
- The engagement with agency focal points and experts for the data records was key to the success of the huge efforts spend on the population of the inventory and information verification. For future updates of the inventory the community involvement remains to be of high importance. This has the consequence that changes to the inventory shall we implemented with great care to not to lose the support of the community;
- The personalised support provided by the WGClimate Chair team should be continued for all Responders to the ECV Inventory Questionnaire to ensure correct and verified entries. A more dedicated / tailored support might need to be considered for Agencies whose contribution was impaired by the complexity of the questionnaire that addresses the GCOS guidelines and requirements;

- An effort should be made by the WGClimate to properly characterise a dataset that qualifies as an Interim Climate Data Record (ICDR). This third more intermediate category (neither "current" nor "future") shall be accommodated in the structure of the ECV Inventory as a distinct component, thus avoiding duplication of information in the database;
- The development of a complementary inventory of Fundamental Climate Data Records (FCDRs) shall be considered to allow for better traceability between FCDRs and Total Climate Data Records (TCDRs), and also to constitute a valuable repository of information for TCDR producers that would promote the use of FCDRs at the same time;
- Global climate data record development is more dynamic than had been initially thought. The biennial update of the ECV Inventory as the cornerstone of a full development cycle shall be replaced by a quasi-continuous data collection process running in parallel with a more evenly distributed workload for the quality control of the input provided (either new or updated), with versions of the inventory being publicly released once a year. All past versions of the ECV Inventory should remain available for download alongside all ancillary information, such as the questionnaire used;
- Instead of a full Gap Analysis process run over all contents of the ECV Inventory, alternative partial approaches, compatible with a quasi-continuously open data collection to the ECV Inventory, will be considered and performed on an annual basis. Such an analysis is planned to cover changes compared to the previous year along with thematic gap analyses, e.g., for a focused selection of ECV Products relevant for the carbon cycle.

The lessons learnt provide the input for planning of future activities related to the ECV Inventory, which are reflected in the CEOS and CGMS work plans.

The results provided in this report clearly demonstrate the capability of the ECV Inventory for providing an end-to-end analysis of available and planned CDRs as derived from measurements from space. The investment made by many agencies into the Inventory, and the presented analysis here, has resulted in a great resource to support the establishment of those capabilities required to ensure that the requirements for observing the Earth's climate system on a routine and sustained basis can be met.

1 Introduction

1.1 Context

The space-based architecture for climate monitoring[2] forms the major international reference for the contribution of space agencies to the Global Framework of Climate Services (GFCS). The implementation of the architecture is coordinated by the joint CEOS/CGMS Working Group Climate (WGClimate), which was established in 2013. The objectives of the WGClimate are:

- Provision of a structured, comprehensive and accessible view as to what Climate Data Records are currently available from satellite missions of CEOS and CGMS members or their combination;
- Creation of the conditions for delivering further Climate Data Records, including multi-mission Climate Data Records, through best use of available data to fulfil GCOS requirements (e.g. by identifying and targeting cross-calibration or re-processing gaps/shortfalls);
- Optimisation of the planning of future satellite missions and constellations to expand existing and planned Climate Data Records, both in terms of coverage and record length, and to address possible gaps with respect to GCOS requirements.

The first objective is primarily fulfilled by the creation and maintenance of the ECV Inventory, which is a database holding detailed information about GCOS ECV Climate Data Records (CDRs), together with appropriate viewing and navigation tools.

The second and third objectives require, amongst other things, the application of a gap analysis process to the ECV Inventory to identify gaps, shortfalls and improvement possibilities for both current and future climate data records.

The objectives associated with ECV Inventory development are intrinsic to the fulfilment of the core objectives assigned to WGClimate in its Terms of Reference, and form a pivotal asset in the implementation of the Climate Monitoring Architecture.

The development of the Inventory and the gap analysis also address the GCOS Actions 11 (Review of availability of climate data records) and 12 (Gap-analysis of climate data records) as stated in [RD-7].

The development of the ECV Inventory was implemented by applying a cyclical approach that was tied to the term of the Chair of the WGClimate. The basis for the results in this report is the Inventory Development Cycle #2 that resulted in the ECV Inventory Version 2.0. The experiences made during the current development cycle may lead to changes in the way further evolution is planned.

To successfully complete an Inventory Development Cycle, it is necessary to:

- Collect updated information from data providers on CDR holdings and planned/committed new CDRs;

[2] Dowell, M, P. Lecomte, R. Husband, J. Schulz, T. Mohr, Y. Tahara, R. Eckman, E. Lindstrom, C. Wooldridge, S. Hilding, J.Bates, B. Ryan, J. Lafeuille, and S. Bojinski, 2013: Strategy Towards an Architecture for Climate Monitoring from Space. Pp. 39. This report is available from: www.ceos.org; www.wmo.int/sat; http://www.cgms-info.org/.

- Incorporate updated information in the ECV inventory and perform a quality control to verify as far as possible completeness and consistency of the ECV inventory contents, as well as a critical analysis of the relevance of the various CDRs provided;
- Publish the ECV Inventory via the WGClimate webpage;
- Perform a gap analysis on the ECV inventory to identify missing or endangered elements in the future;
- Use the results of the gap analysis to generate a coordinated action plan to address such gaps/missed opportunities.

The ECV Inventory was built to assess compliance against [RD-1], [RD-2] and [RD-8]. During the population of the inventory, GCOS published its new implementation plan [RD-7] and contributions for new ECVs and ECV products were accepted. However, not all new ECV products from [RD-7] have been added; this will be done during the next update cycle.

The ECV Inventory established in Cycle#2 became publically available in September 2017 and is accessible via the dedicated Climate Monitoring from Space webpage at http://www.climatemonitoring.info. Besides the importance to WGClimate of identifying and addressing shortcomings as outlined above, a public ECV Inventory provides a repository of verified information on available and planned ECV CDRs and how to access the data. Users of CDRs, climate services and other applications benefit from knowing what is available for their work, data providers can explore potentially competitive situations, data record developers can gain information on who they may collaborate with, and reviewers of science and operational programmes can assess if it is worth investing in new CDRs. In addition the ECV Inventory may also become a resource for capacity building activities that rely on access to CDRs. Relevant activities such as the WMO-CGMS Virtual Laboratory for Training and Education in Satellite Meteorology, and the CEOS Working Group on Capacity Building and Data Democracy, have been informed about, and will hopefully benefit from, the publication of the ECV Inventory.

1.2 Purpose and Scope of this Document

The purpose of this report is to document the results of the gap analysis performed on the current ECV Inventory v2.0. In addition, based on the findings from the gap analysis, recommendations are made with respect to the WGClimate objectives.

The gap analysis presented in this report addresses an analysis of all data records in the ECV Inventory with respect to the fulfilment of GCOS criteria, and also more in-depth analyses for 8 ECVs. The analysis addresses the assessment of missing data records in the ECV Inventory, an assessment versus GCOS criteria per ECV, an assessment of missed opportunities to generate data records from existing measurements, and the future availability of measurements to continue the monitoring of the ECV.

The focused set of 8 agreed ECVs to be analysed were:

- Atmosphere: Precipitation, Carbon Dioxide, Methane
- Ocean: Sea-surface Temperature, Sea-surface Salinity
- Terrestrial: Land Surface Temperature, Above-ground Biomass, Leaf Area Index

The above choices were made according to: current relevance for space agency planning (CO_2 and CH_4), the involvement of many satellite instruments measuring in different spectral ranges (Precipitation, SST, LST and LAI), and the presentation of total gaps in the ECV Inventory (Above-ground Biomass and Sea Surface Salinity).

The focused analysis was restricted to 8 ECVs (having 12 ECV Products) because each analysis needs a group of thematic experts and takes a few weeks to be performed. This analysis also acts as a test for the capability of the ECV Inventory as it contains ECVs for which known issues with mission continuity do exist.

It is planned to perform this type of analysis for all ECVs in the future, but this will take time as it includes the analysis of at least 34 ECVs (with 76 ECV Products). Considering the current international commitment to work for and with the ECV Inventory, it is realistic to assume an average 4 weeks' time per ECV analysis. Even if some analysis can be further automated and done in parallel, it will take about 1.5-2 years until all ECVs have been analysed in detail. In the meantime it is also necessary to update the ECV Inventory on an annual basis to ensure that each analysis is undertaken using actual up-to-date information. This also includes comparisons of analysis results between different releases of the ECV Inventory to monitor progress.

1.3 Document Structure

This document comprises the following chapters:

Chapter 1: Introduction describes the context of the gap analysis, provides document overview and document references;

Chapter 2: Describes the ECV Inventory addressing its structure, the population and verification process and provides information on the agencies contributions;

Chapter 3: Provides information on gap definition, describes the gap analysis approach and its implementation and discusses limitations of the approach;

Chapter 4: Provides information on the Inventory content including a detailed view on the temporal coverage per ECV Product. From this gaps in the coverage are derived;

Chapter 5: Provides a gap analysis with respect to the GCOS criteria for both the existing and planned climate data records;

Chapter 6: Provides an analysis for 8 ECVs including a traces to missed opportunities and missing future measurements;

Chapter 7: Provides information on lessons learnt and indicates future improvements to the cyclic process of the ECV Inventory;

Annex A: Provides recommendations for coordinated actions;

Annex B: Provides the questionnaire for the current component of the ECV Inventory;

Annex C: Provides the questionnaire for the future component of the ECV;

Annex D: Provides per question the grading used to assess the fulfilment of GCOS criteria;

Annex E: Glossary of acronyms;

Annex F: List of contributors to the ECV Inventory and the gap analysis process.

1.4 References

[RD-1] GCOS-82, 2003: The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC, 74 pp, available at:

http://www.wmo.int/pages/prog/gcos/Publications/gcos-82_2AR.pdf

[RD-2] GCOS, 2011: Systematic Observation Requirements for Satellite-based Products for Climate: Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)". GCOS-154, WMO, Geneva, December 2011.

[RD-3] WGClimate, 2016: ECV Inventory: Questionnaire Guide v2.4.

[RD-4] Dowell, M., P. Lecomte, R. Husband, J. Schulz, T. Mohr, Y. Tahara, R. Eckman, E. Lindstrom, C. Wooldridge, S. Hilding, J. Bates, B. Ryan, J. Lafeuille, and S. Bojinski, 2013: Strategy Towards an Architecture for Climate Monitoring from Space. Pp. 39, available at: www.ceos.org; www.wmo.int/sat; http://www.cgms-info.org/ GCOS, 2015: Status of the Global Observing System for Climate, GCOS-195, WMO, Geneva.

[RD-5] WGClimate, 2016: ECV Inventory: Gap Analysis Guidelines.

[RD-6] GCOS, 2006: Systematic Observation Requirements for Satellite-based Products for Climate: Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC". GCOS-107, WMO, Geneva, September 2006.

[RD-7] GCOS, 2016: The Global Observing System for Climate: Implementation Needs, GCOS-200 (GOOS-214), WMO, Geneva, 2016.

[RD-8] GCOS-143, 2010: Guideline for the Generation of Datasets and Products Meeting GCOS Requirements, An update of the "Guideline for the Generation of Satellite-based Datasets and Products meeting GCOS Requirements" (GCOS- 128, WMO/TD-No. 1488), including *in situ* datasets and amendments. May 2010, 12pp, available at: http://www.wmo.int/pages/prog/gcos/Publications/gcos-143.pdf

[RD-9] WGClimate Four-Year Implementation Plan for the period November 2015 to November 2019. Reference ECO-WGCL-EOPS-PL-16-0005. Version 2.0. February 12th 2016.

[RD-10] WMO Workshop on Operational Space-based Weather and Climate Extremes Monitoring Geneva, Switzerland 15-17 February 2017 Meeting Report.

RD-11 Thriving on Our Changing Planet A Decadal Strategy for Earth Observation from Space. UNEDITED PREPUBLICATION, 700 pages, ISBN 978-0-309-46757-5 | DOI: 10.17226/24938, January 2018.

1.5 Terminology

Essential Climate Variable

An Essential Climate Variable (ECV) is a geophysical variable that is associated with climate variation and change as well as the impact of climate change on Earth. GCOS has defined a set of ECVs for three domains, atmospheric, terrestrial and oceanic [RD-1].

ECV Product

Many GCOS ECVs are sub-divided into so called ECV Products. The term "Product" denotes long-term data records of values or fields of ECVs derived from FCDRs [RD-2].For instance the water vapour ECV has 3 ECV Products: total column water vapour, tropospheric and lower-stratospheric profiles of water vapour, and upper tropospheric humidity, which describe different aspects of water vapour in the atmosphere. However, the definitions provided for ECV Products in [RD-2] are not always consistent for all ECVs. For some cases, e.g. the ECV Sea Ice, there is only one ECV Product that covers 4 different variables/parameters for which requirements are provided. The ECV Inventory and the associated questionnaire names each variable/parameter for which requirements are to be provided per ECV Product. A consistent mapping is provided in [RD-3].

GCOS Requirements

GCOS Requirements as used in this document refers to the quantitative requirements provided for each ECV Product in [RD-2]. They denote Horizontal Resolution, Vertical Resolution, Temporal Resolution, Accuracy and Stability.

Fundamental Climate Data Record

A Fundamental Climate Data Record (FCDR) is a well-characterised, long-term data record, usually involving a series of instruments, with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of products that are accurate and stable, in both space and time, to support climate applications [RD-4]. FCDRs are typically calibrated radiances, backscatter (for active instruments), or radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them. The term FCDR has been adopted by GCOS and can be considered as an international consensus definition.

(Thematic) Climate Data Record

A Thematic Climate Data Record (TCDR - also known as the Climate Data Record (CDR)) means the counterpart of the FCDR in geophysical space [RD-4]. A (T)CDR is equivalent to an ECV Product covering only one geophysical variable. For instance, the ECV Cloud includes six different geophysical variables, each of them constituting an ECV product or (T)CDR. The term (T)CDR has been taken up by many space agencies and can be considered as a de facto standard.

Interim Climate Data Record

An Interim Climate Data Record (ICDR) regularly extends in time a Fundamental or Thematic Climate Data Record using a system having optimum consistency with and lower latency than the system used to generate the FCDR or TCDR.[3]

[3] This definition of an ICDR was endorsed at the 9th session of the joint CEOS/CGMS Working Group Climate Meeting on 29 March 2018.

2 The ECV Inventory

2.1 Structure of the ECV Inventory

The structure of the ECV Inventory is described in detail in [[RD-1]]. In essence, the ECV Inventory is a repository for the characteristics of two types of ECV CDRs:

- Climate data records that already exist. This forms the current component of the inventory;
- Climate data records that do not currently exist, but are firmly planned to be delivered as part of an already approved programme. This forms the future component of the inventory.

The ECV Inventory was built to assess the climate data records against criteria provided by GCOS in [RD-1], [RD-2] and [RD-8]. During the population of the inventory GCOS published its new implementation plan [RD-7] and contributions for new ECVs and ECV products were accepted. However, as no data call was issued to address the new ECV products from [RD-7], neither all the new ECV products have been added, nor are the contributions addressing these exhaustive; this will be done during the next update cycle.

The 31st December 2016 was used as the dividing line between the current and future part of the inventory. A date needed to be defined because some of the CDRs provided fall into the category of Interim Climate Data Records (ICDRs) and these could not easily be integrated into the present scheme of the Inventory.

Recommendation #1: ***WG Climate to distinguish between CDRs and ICDRs, and to create an additional part of the inventory that shall contain the ICDRs.***

The level of information stored in the ECV Inventory is more detailed for the current component compared to the future component noting, however, that there are some common elements. For each of these components, a questionnaire (see Annex A and B) was compiled and distributed to CDR producers for completion. The responses provided the content for the ECV Inventory and, for each question in the questionnaire, there is now a corresponding field (or several fields, for more complex questions) in the ECV inventory database.

The necessary differences between the current and future inventory components meant that, in the gap analysis undertaken once the inventory had been populated, two distinct gap analysis approaches had to be followed. This distinction is reflected in the gap analysis guidelines [RD-5].

2.2 ECV Inventory Population

The population of the ECV Inventory was initiated by a data call on 2 June 2016 to all CEOS and CGMS agencies represented in the WGClimate. The responders used a web-based interface developed by EUMETSAT to upload their information according to the Questionnaire [RD-3], which had been approved at the 6th session of the WGClimate in 2016.

Figure 1 shows that response was slow until the first deadline of 1st October 2016. This was likely due to time taken within the agencies to identify those best-qualified to respond. A second deadline at the beginning of November 2016 had little effect on speeding up contributions. This period of data population was also characterised by the fact that, initially, entries mainly addressed already-existing (current) ECV CDRs rather than future offerings. To arrive at a more balanced picture that was closer to reality it was decided to extend the period for CDR contributions to allow the bigger agencies, in particular, to provide their entries.

By April 2017 participation to the ECV Inventory was overwhelming. Entries for ECV CDRs had been received from 11 CEOS and CGMS Agencies, involving almost 100 individuals responsible for preparing the ECV Inventory contents. The 'buy-in' for the activity was great and it will be important to keep this maintained for future updates because the quality of the ECV Inventory entries depend strongly on the relevant expertise of the responder.

The actual number of ECV inventory entries submitted was 959, which is approximately 4.5 times higher than expected when compared with the yield from Cycle#1 in 2013. This is partly due to the fact that several CDRs have different spatial and temporal samplings with the impact that they are listed more than once. This double entry listing is important to enable one-to-one comparisons with the GCOS requirements. The split into current (54%) and future (46%) is almost even, which is an indication that most agencies have plans to deliver more climate data records in the future.

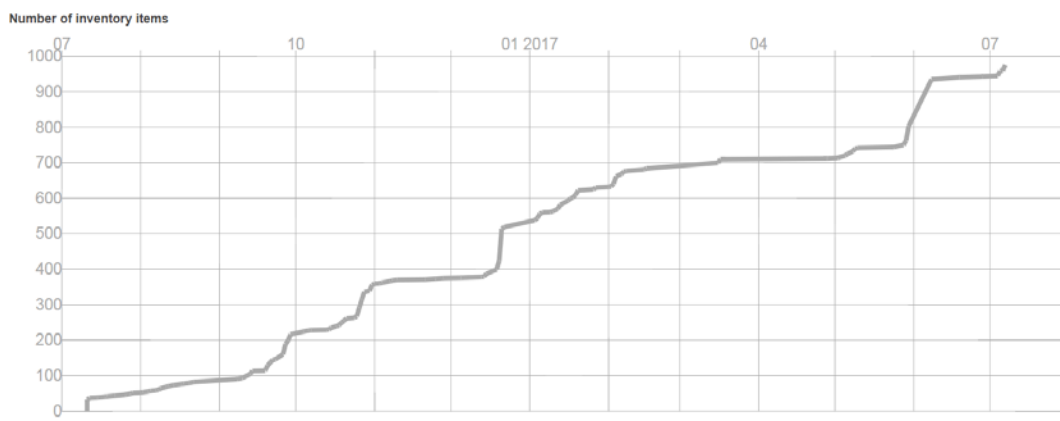


Figure 1: Temporal evolution of ECV Inventory entries from 2nd June 2016 to 31 July 2017.

2.3 Verification of the ECV Inventory Content

Each of the ECV Inventory entries provided was verified by the EUMETSAT support team. Working with the responder, the Inventory contents were fully-assessed to ensure that they are reliable enough to be used in detailed gap analyses. A high confidence in the inventory contents means that useful recommendations and actions for implementing the architecture for climate monitoring from space can now be formulated.

Due to the large amount of data records provided, and the high number of individual experts involved, the verification exercise took almost a year to be completed from receipt of the first CDR. During the population and verification phases it was understood that the ECV Inventory could not reach 100% completion as some data providers had not provided the exact information requested and/or they never received the data call. The support team at EUMETSAT has kept track of such cases to estimate the impact on specific ECV Products, and also to ensure that such data records could be included at a later stage.

Due to this situation, about 5% of the submitted data records could not be verified. However, none of these entries is the sole entry for a specific ECV or ECV product, thus the impact on the gap analysis has been thankfully small. Non-verified records have not been considered in the gap analysis.

2.4 Agency Contribution to the ECV Inventory

The majority of the contributions to the inventory were provided by NASA and EUMETSAT. CNES, ESA, NOAA, and the European Copernicus Climate Change

Service also provided substantial contributions. Smaller contributions were made by JMA, JAXA, USGS, UKSA and others. It should be recognised also that many contributions represent joint enterprises, both between space agencies and between agencies and non-space-agency institutions.

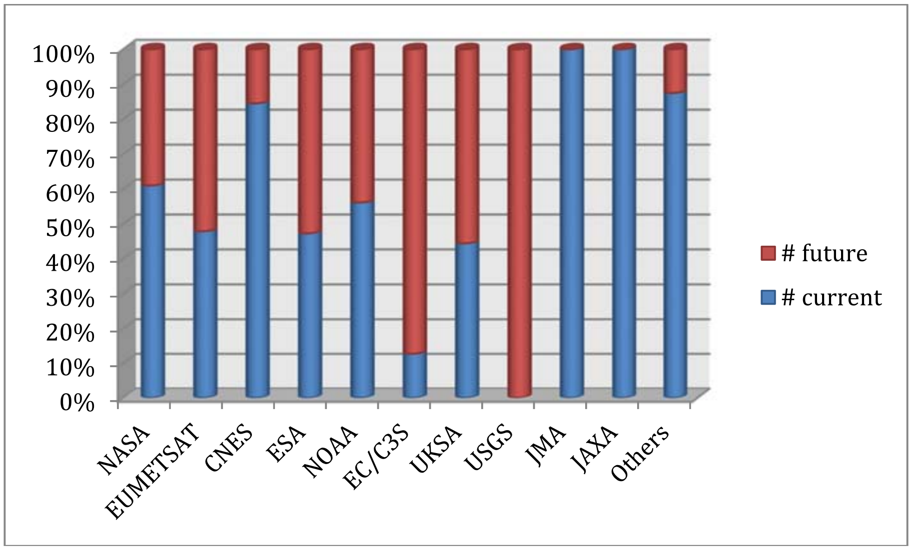


Figure 2: Relative number of current and future data records per agency in the ECV Inventory.

Figure 2 shows the relative number of current and future data records, housed within the ECV Inventory, per agency. Future data records are comprised of both reprocessed existing data and the also measurements obtained by future instruments. With the exception of JMA, JAXA and USGS, all agencies provided contributions for both the current and the future part of the inventory. USGS only contributed to the future part of the inventory. For ESA, EUMETSAT, NASA and NOAA, the contributions are almost equal between current and future CDRs. The Copernicus Climate Change Service only commenced its activities in 2015, therefore the number of planned data records is much larger relative to those currently available. It should be noted that entries for future data records were only accepted for the inventory when a firm commitment existed, which is considered to be a criterion that prevented some agencies to provide their plans regarding future data records. For the next version of the inventory this criterion will be staged to gain a better description of future plans.

Recommendation #2: ***WGClimate to include a more relaxed commitment level in the "Future CDRs" component of the ECV Inventory that does not require firm programmatic arrangements at the present time. This new level allows the capture of more contributions from future sensors.***

3 Gap Analysis Approach

3.1 Gap Definition

The necessary differences between the two inventory components (current and future), means that two distinct gap analysis approaches were required; two separate "gap trees" were established.

As will be noted in the following sections, there is a direct correlation between the two gap trees and the contents of the current and future parts of the inventory. The gap trees make the assumption that entries exist in the inventory for a particular ECV and ECV product. If this is not the case then this is called a “complete gap” for an ECV or for an ECV product.

As the gap analysis was done at individual inventory field level and, as there is a relatively large number of such questions/fields (see Annexes A and B), there was a need to group the results into topics. The topical breakdown adopted for the gap analysis for the current component was:

a. **Stewardship** of the record - with questions aimed at exposing both the administrative and technical arrangements for the stewardship of the record;

b. **Generation Process** of the record - with questions aimed at exposing the degree to which this generation process complies with the provisions described in [RD-8];

c. **Record Characteristics** - with questions aimed at ensuring (*inter alia*) that there is sufficient information to establish whether the record satisfies the technical requirements defined in [RD-2];

d. **Documentation** of the record - with questions aimed at ensuring that the minimum documentation needs defined in [RD-8] are met;

e. **Accessibility** of the record - with questions aimed at ensuring that appropriate access to the dataset is available, as defined in [RD-8];

f. **Applications** of the record - with questions aimed at exposing the usage of the record.

From a requirement perspective, topic c) Record Characteristics is different in nature to the other topics as the related requirements are specific to each ECV product and stem from [RD-2], whereas the requirements associated with all other topics are common across all ECV products and stem from [RD-8].

For the future part of the inventory the topical areas b) Generation Process and d) Documentation were not considered as the material required most likely does not exist in the planning phase.

For each of the individual questions/entries and for each data record in the inventory the compliance was individually analysed. The analysis was aggregated to all current and all planned and also per domain. Only if an ECV product contained CDRs that did not provide any verified information at all this was considered to be a gap. In all other cases, the CGOS compliance as a whole throughout all CDRs for an ECV were used to analyse shortcomings with respect to the topical categories.

3.2 Approach

The approach for the gap analysis is described in [RD-5]. The gap analysis was carried out for each ECV CDR until all verified inventory items had been assessed. The following subsections provide a short explanation of the approach, implementation and limitations.

3.2.1 Existence of Climate Data Records

For both the current and future part of the inventory the first question to be answered was "Do record entries exist for the GCOS ECV and ECV product in question?" The split into ECV and ECV product was necessary because GCOS definitions for ECVs and ECV products are done by the individual GCOS panels and are not completely consistent. Some ECVs are single geophysical variables, such as Sea Surface Temperature whilst others contain a list of ECV products. For example, for water vapour one can find 'total column water vapour', 'water vapour profile', and 'deep layer water vapour;, which is a synonym for free tropospheric relative humidity.

For the current part of the inventory, to answer this question one needs to assess whether each inventory entry constitutes a Climate Data Record or not. In principle this would require the analysis of all available validation information and/or to analyse the quality of the data record for a climate application. The verification process determined if the data record could be considered for the gap analysis or not. All data records used in the following sections have been accepted and only those where the verification was not completed have been excluded.

The ECV inventory contains one field that provides a link to the FCDR used and this may be used to decide if an entry is a climate data record or not. A caveat to this is that the GCOS nomenclature that is used in the description of the architecture for climate monitoring from space [RD-2] is not used by all agencies and that many data producers may not understand what a FCDR is.

Recommendation #3: ***Space agencies should adopt the nomenclature for climate data records as defined in [RD-2] and should encourage their personnel to apply it.***

If, for a given ECV Product, a data record does not exist, the gap analysis determines from [RD-2], [RD-6] and [RD-7] what type of FCDRs would be required for the generation of the specific ECV products. After that the WMO OSCAR (http://www.wmo-sat.info/oscar/) and CEOS MIM (http://database.eohandbook.com) databases are explored to assess if there is potential to create a FCDR that might be used in the future.

3.2.2 Analysis of Inventory Entries against GCOS Criteria

Each data record associated with an ECV product was analysed against the GCOS criteria provided by the relevant GCOS climate monitoring principles [RD-1], guidelines [RD-9] and requirements [RD-2]. The criteria were assessed according to the categorisation provided in section 3.1.

For each question in the six (current CDRs) or four (future CDRs) categories, it was determined if the answer was a yes/no in terms of fulfilling the criteria, or if a grading of the answer was possible to demonstrate evolution towards fulfilling the criteria in the future. The grading was kept very simple from 0 to 3; the grading scheme applied is presented in Annex D.

3.2.3 Analysis for specific ECVs

Because of the huge number of CDRs in the Inventory, and also the high number of ECV products, it was agreed with CEOS and CGMS that a subset only of the ECV products would be analysed in detail in early 2018. These would then function as a role model for other ECVs at a later stage.

The focused set of agreed ECVs to be analysed were:

- Atmosphere: Precipitation, Carbon Dioxide, Methane
- Ocean: Sea-surface Temperature, Sea-surface Salinity
- Terrestrial: Land Surface Temperature, Above-ground Biomass, Leaf Area Index

This choice for these eight ECVs was motivated by the need to cover all three domains and the need to consider ECVs for which known gaps in future measurements had already been identified, e.g., Sea-surface Salinity. The above were also chosen to include ‘hot topics’, such as Carbon Dioxide and Methane.

The analysis for each ECV consisted of:

1. An analysis as to whether the ECV inventory misses a known existing or planned climate data record;

This analysis became necessary because since the end of the Inventory V2.0 population phase in the first half of 2017 additional data records and plans emerged from various agencies. This analysis is important to avoid making unnecessary recommendations related to missed opportunities and eventually missing future measurements.

The information could only be drawn from the expert community that deals with the specific ECV Product. However, this could only be done on a best efforts basis, so there may well still be gaps.

2. An analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space;

The second analysis sought to identify missed opportunities for generating climate data records. For this analysis it was analysed which type of measurements has been or is planned to be used for the generation of a particular ECV climate data record. This knowledge was confronted with what other satellite measurements of the same type are actually available. This includes both historical and future measurements. If it was found that other data sources could be utilised, a specific recommendation would then be formulated on the usage of measurements. In addition, investigations into the use of different types of measurements than those currently employed was undertaken and recommendations derived for their future use as necessary. For instance sea surface temperature data records in the Inventory are mostly derived from IR radiometers in polar orbit but opportunities may exist to also use C-band microwave imager data to increase the coverage of observations in the open ocean, although with lower resolution and greater uncertainty compared to the IR.

The information on the available and planned satellite measurements came from the CEOS MIM and WMO OSCAR databases. The EUMETSAT support team provided access to this information, including a mapping of the ECV products against the physical parameters derived from space measurements as detailed in both databases. It should be noted that OSCAR and MIM do not use the same nomenclature for the physical parameters that can be derived from space measurements. Analysing the 8 ECVs cases were found where information in OSCAR and MIM does not agree. In addition the MIM data base lacks information on measurements prior the mid-1990s. As a consequence compiling and making sense of this information took much longer than anticipated.

3. An analysis of missing measurements in the future that would be required to continue existing data records or to establish new ones with enhanced quality;

The third analysis aimed to identify sustainability issues for monitoring of the ECV products. Based on the non-existence of data records, the documented use of instruments for existing data records in the Inventory, and the results from the analysis on missed opportunities, the availability of suitable measurements in the future was analysed: what type of measurement(s) was used in the past, what is potentially additionally useful for past and future records, and what is missing. For instance for the ECV Sea-surface Salinity that has no entry in the ECV Inventory and where it was already known that no real plan exists for new 1.4 GHz measurements, specific recommendations were drawn up that also link to a more general GCOS Action (O-32) on salinity. In addition, there would possibly be specific cases where data records may be planned for continuation, but with a reduced set of instruments.

This analysis relies on the quality of the MIM and OSCAR data bases for planned measurements and suffered from similar issues as described above. This analysis required some programmatic planning understanding from the agencies, much of which was provided by WGClimate members. Some of the analysis is also implicitly contained in the Space Agency Response to the GCOS Implementation Plan, which was duly consulted.

3.3 Implementation of the Gap Analysis

3.3.1 Organisation

The gap analysis was facilitated in two phases:

1. Analysis against GCOS criteria was started in June 2017 and the last ECV product was assessed by the end of August 2017. This analysis was performed by a team organised as shown in Figure 3 with three domain expert teams exercising the gap analyses in parallel. To ensure consistency of approach across the full inventory, the gap analysis work of the individual teams was supported by a gap analysis coordinator and the gap analysis guide document overseen by the WGClimate Chairs.
2. Analysis of the 8 ECVs was started in December 2017 and lasted until end of March 2018 mostly due to the above described issues with the involved MIM and OSCAR data bases. This analysis was performed by ECV experts under guidance the gap analysis coordinator and the WGClimate Chairs.

Both gap analysis phases required the prototyping and consolidation of gap analysis tools (described in the next subsection) and specific briefing to the domain and ECV expert teams, to conduct the formal gap analysis process.

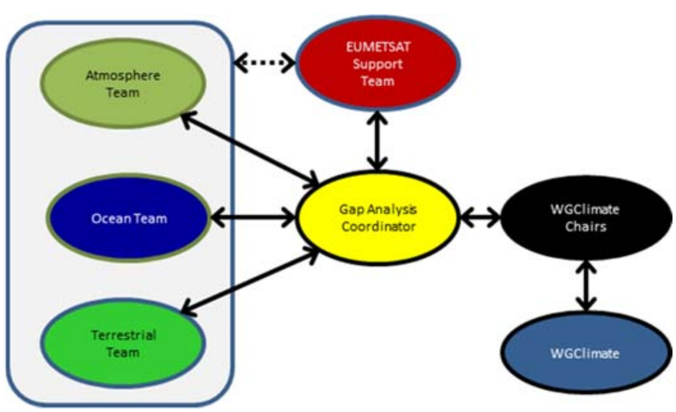


Figure 3: Set up of gap analysis team.

3.3.2 Tools

For the first phase of the gap analysis a web-based tool to assess the ECV Inventory data records against the GCOS criteria was developed and deployed within the ECV Inventory user interface. With this tool the GCOS criteria and also the grading approach as provided in Annex D were implemented into the ECV Inventory. This also involves a specifically designed display for the results of this analysis that can be created for each ECV product but also for summary displays per GCOS domain or all ECV Inventory entries together. In this context also other graphical displays, e.g., on the number of data records per specific ECV product and year were developed. Such graphics can be created on the fly within the ECV Inventory and exported to files for use in other applications such as word and slide processors.

For the analysis of missed opportunities and missing measurements for ECVs a complete mapping of the all ECV product names to the names of physical quantities derived from satellite measurements has been established for the MIM and OSCAR data bases and was implemented into the ECV Inventory. This enables the integrated use of the complete MIM and OSCAR data base information for the gap analysis. The ECV Inventory allows the export of the integrated information per ECV product into Excel files that could be used by the expert teams involved in the gap analysis.

The described approach was deployed directly on top of the ECV Inventory and was capable of supporting the analysis of compliance of the ECV data records with respect to the GCOS climate monitoring principles, guidelines for producing climate data records and requirements provided by the GCOS IP.

3.4 Known Limitations Impacting the Gap Analysis

During the population and verification phase of the inventory, awareness on several issues impacting the gap analysis arose. The next subsection discusses the most important limitations of the current ECV Inventory and the implemented processes needed to perform the gap analysis.

3.4.1 Incompleteness of the ECV Inventory

A reliable gap analysis relies on the fact that the ECV Inventory is complete. During the population of the inventory it became obvious that not all individuals asked to provide a response would be able to do so, risking the gap analysis effort. Table 1 shows a contingency table defining four cases that can be considered to estimate the potential incompleteness.

Table 1: Contingency matrix for the ECV Inventory describing the potentially missed fraction of climate data records.

	Listed	Unlisted
Verified	Verified content of the ECV Inventory.	Known-to-exist climate data records that did not became part of the ECV Inventory.
Unverified	Partly or not verified content of the ECV Inventory.	Climate Data Records that may exist but are not known by the WGClimate.

Reading the table from left to right the four cases are:

Verified Listed: Represents the verified content of the ECV Inventory (95% of the submitted entries).

Unverified Listed: Represents the non-verified part of the ECV inventory (5% of the submitted entries) where an inventory entry does not provide enough or incorrect information that does not allow inclusion in the gap analysis.

Verified Unlisted: Existing climate data records known to exist but not included resulting from non-responsiveness of known contacts within agencies and known research projects.

Unverified Unlisted: Unknown fraction of the population of existing climate data records resulting from not being aware of their existence.

All three cases containing an unknown above need to be understood as limitations for the gap analysis. The ‘unverified listed’ have a negligible effect on the gap analysis because all non-verified data records represent ECV products for which other data records exist. The impact of the 'verified unlisted' is larger as they sometimes represent an activity or a project that is important for a specific ECV product.

The impact of 'unverified unlisted' cannot be quantified but should lead to further analysis. Parallel activities to the WGClimate Inventory have also created lists of available data records, e.g., contributions that organisations make to the Observations for Climate Model Intercomparison projects, or some internet harvesting attempts tried by a project of the Copernicus Climate Change Service. For future updates of the ECV Inventory these lists will be compared to each other and, if missing data records are identified, they shall be added to the ECV Inventory. For the 8 ECVs already analysed this has been done already and results are described in section 6.

3.4.2 Difficulty in assessing GCOS numerical requirements

The GCOS Systematic Observation Requirements for Satellite-based Products for Climate [RD-2] states numerical requirements for ECV products. These address the horizontal and vertical spatial resolution or sampling of the ECV product, the temporal resolution or sampling, as well as accuracy and stability of the ECV product. Whereas the sampling requirements can be easily compared in most cases, it remains difficult to compare the requirements for accuracy and stability with the statements of data producers. In many but not all cases the GCOS requirements represent global averages over a longer time period. Validation activities for many ECV data records do not try to obtain such numbers but provide more specific information on the accuracy of their products. To assess the stability of a data record long-term fiducial reference networks of controlled stability for comparison, and/or evaluation of the statistical uncertainty of efforts to harmonise a record across multiple missions are required. For most ECV products such measurements do not exist making it very difficult to assess stability which resulted in only few data producers being able to provide useful answers.

In some cases GCOS requirements are challenging or unfeasible for data records derived from historical satellite missions. It is also noteworthy that the GCOS requirements are not always consistent, e.g., accuracy vs. time-space resolution does not fit together for all ECV products. It would be advisable for GCOS to refine the process on how requirements are defined and to better document products and processes achieving a clearer linkage between applications and requirements.

Recommendation #4: ***GCOS to work with the WGClimate towards a clearer linkage between user requirements for the ECV products and climate applications.***

3.4.3 Limitations for addressing missed opportunities and future missions

The gap analysis as described above relies on the use of the CEOS MIM and WMO OSCAR instrument and satellite databases to identify missing opportunities, i.e., sensors that have not been used in the past to derive climate data records, and eventually missing measurements, i.e., is there a mission planned for the future or not.

A principal issue that was resolved for the current gap analysis was the mapping of ECV product names to names of physical quantities related to space measurements as used in MIM and OSCAR. It is noteworthy that MIM and OSCAR do not use the same nomenclature for this. It is also obvious that the MIM database lacks information for historical satellites that is essential in the climate context. In addition, during the analysis of the 8 ECVs some errors in the information in MIM and OSCAR were detected (see specific sections on the analysed ECVs) that should be corrected in the future. It was very time-consuming to utilise the MIM and OSCAR databases for the current gap analysis and the issues found may still represent a source of error for the gap analysis related to missed opportunities and measurements.

Recommendation #5: CEOS and WMO to better align or facilitate interoperability of the MIM and OSCAR/Space databases, and possibly even integrate the information into one single database, to ensure a more accurate, unified view of past, current and planned capabilities.

The assessment of ECV products for which the ECV Inventory does not show commitment to continue the production of CDRs into the future can only be analysed for the same type of instrument to be used to extend the current data record. If new space technology is used to establish a new data record, or to combine with existing ones, this knowledge cannot be established by interrogating the ECV Inventory alone. This is further hampered by the fact that the Questionnaire used to populate the ECV Inventory asked for committed plans only in an attempt not to be drowned in proposals that might never be realised. Relaxing this requirement or providing a choice on the commitment level can help to improve the traceability to new instruments for the next inventory update.

4 Inventory Content (Covered ECVs[4])

Table 2 shows the total number of inventory entries and the entries per domain. The number of entries for atmospheric ECVs (72%) is much larger compared to land (15%) and ocean (13%). This is not correlated to the number of ECV products per domain, which does not differ much from domain to domain. It is rather correlated with the ability to derive atmospheric ECVs from satellite missions that were used to observe weather such as atmospheric sounding systems, but not optimised to retrieve ocean and land ECVs. Comparing the current and future components per domain, the land domain is the only one that has more planned than current data records. That is due to emerging data records for historic measurements, e.g., from Landsat, and new measurements provided from sensors such as SMAP and the European Sentinels 1 and 2. On the other hand the benefits of the use of ECV data records, e.g., for soil moisture, have been recognised that will lead to more data records being produced for this variable.

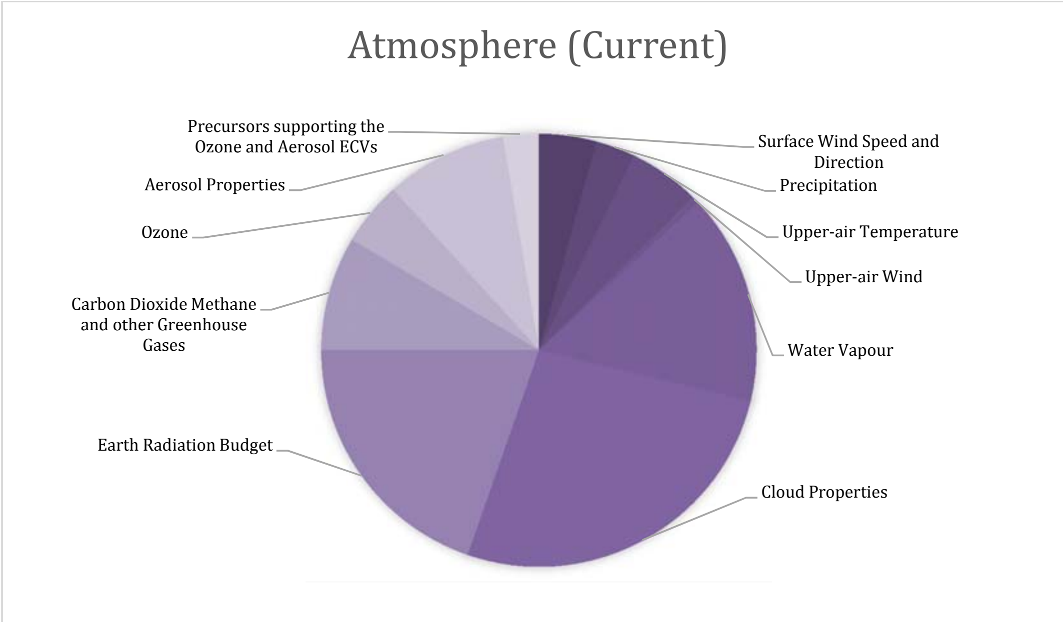
Table 2: Number of data record entries in the ECV Inventory for Cycle#2.

Domain	Total	Current	Future
All	913	496	417
Atmosphere	658	376	282
Land	135	56	79
Ocean	120	64	56

4.1 Relative portions of ECVs per GCOS Domain

Figure 4 shows relative portions of the ECVs in the current and future part of the Inventory for the atmospheric domain. For the atmosphere, most CDRs address cloud properties, water vapour and the Earth Radiation Budget. Despite their importance, precipitation and upper air wind speed and direction represent the smallest fractions in the inventory. Overall, all atmospheric ECVs (11) are covered with respect to [RD-2] and 11 out of 12 are covered with respect to [RD-7]; lightning was added as a new ECV in 2016 and is not currently addressed in the inventory. For the future part, upper air wind is slightly better represented, but precipitation is not, which is a concern.

[4] The term *covered* means there is at least one data record (current or future) addressing one ECV Product of an ECV.



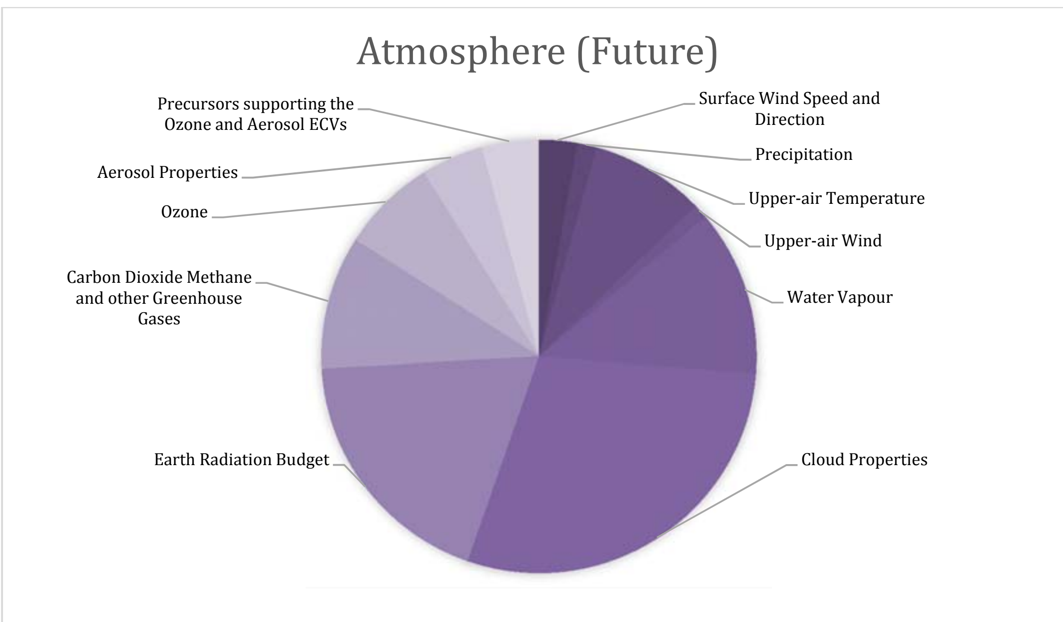
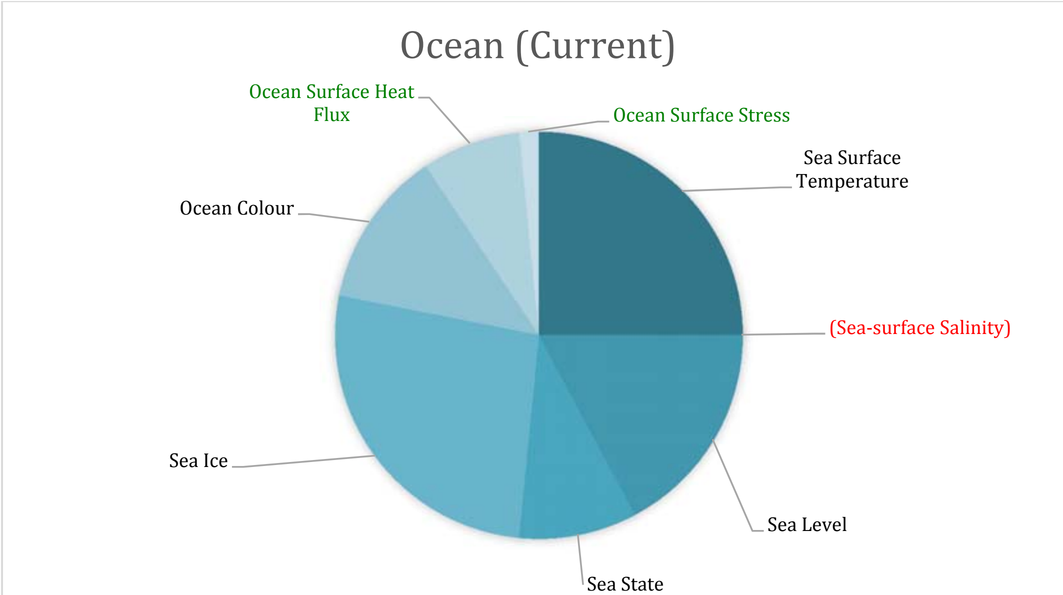


Figure 4: Relative number of ECV entries for the atmospheric domain. Top graph shows the current part of the Inventory, bottom graph shows future part of the Inventory.



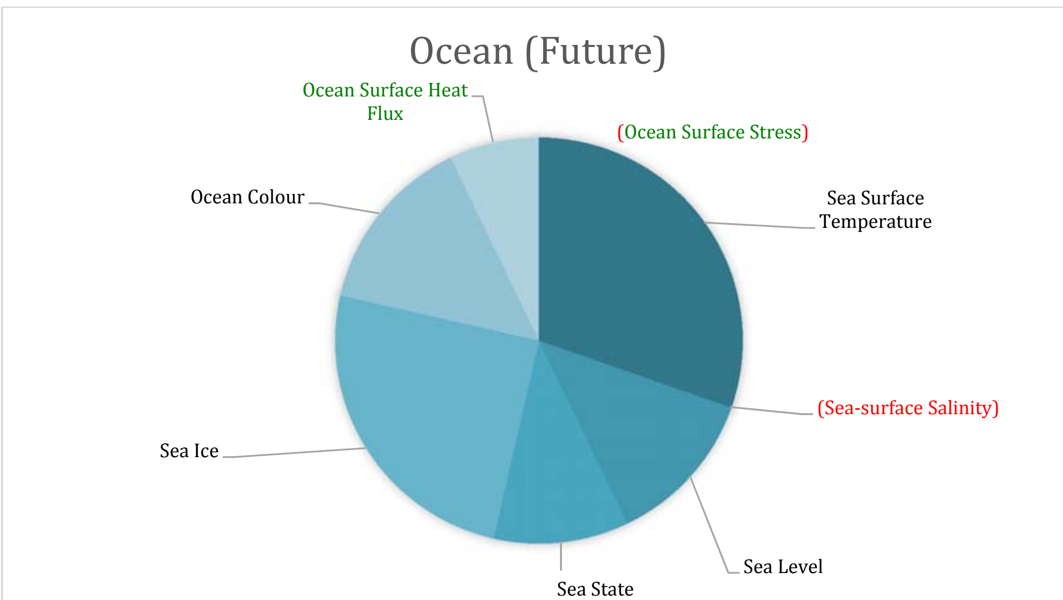
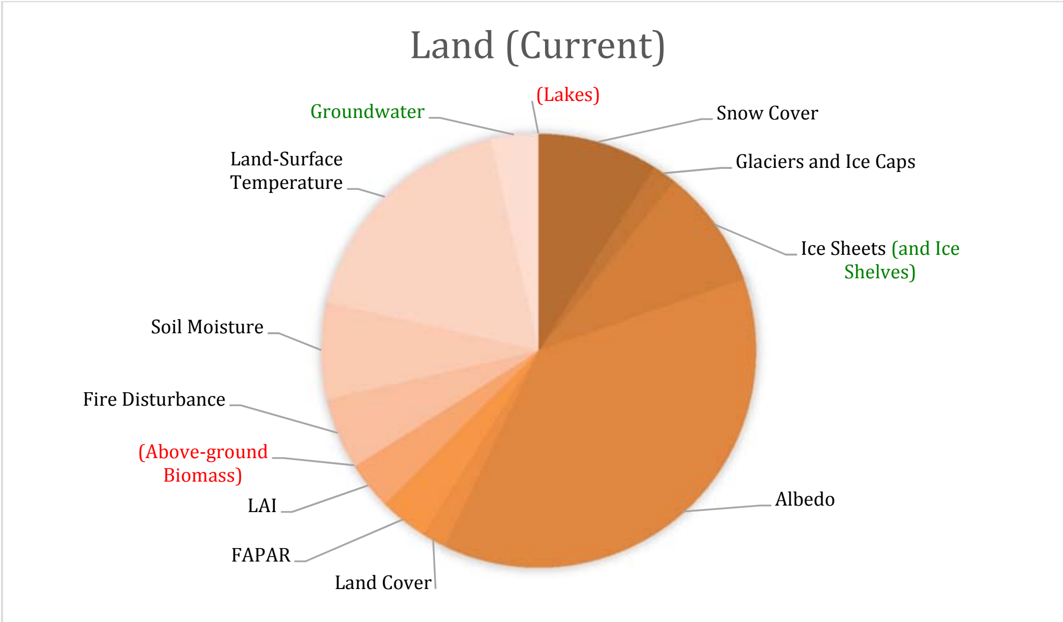


Figure 5: Relative number of ECV entries for the oceanic domain. Top graph shows the current part of the Inventory, bottom graph shows future part of the Inventory. Red labels / parentheses indicate a missing ECV, green labels indicate ECVs added in response to the GCOS IP 2016.



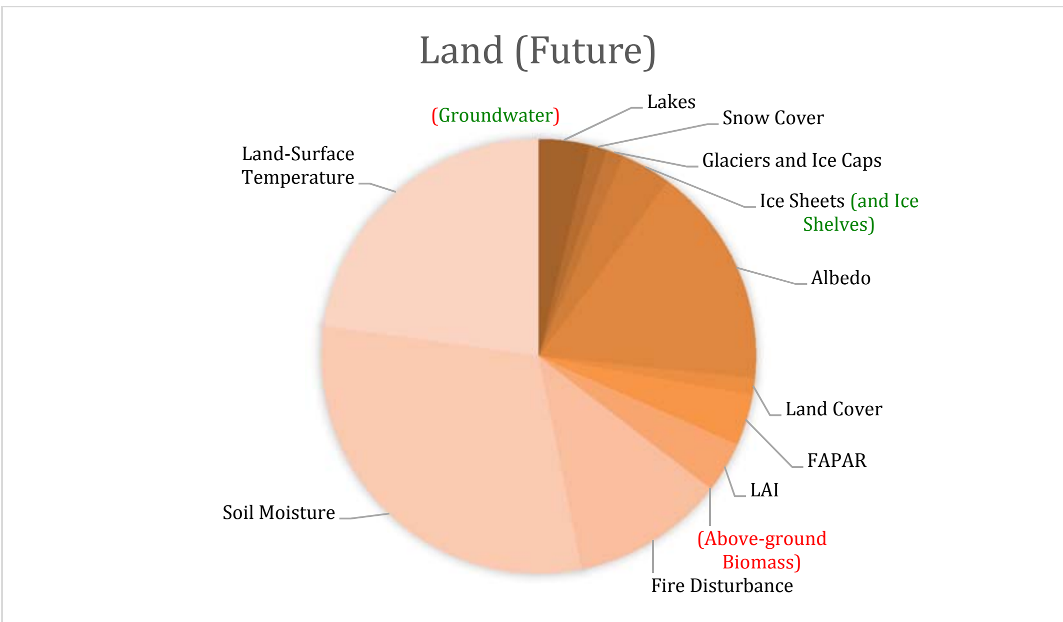


Figure 6: Relative number of ECV entries for the terrestrial domain. Top graph shows the current part of the Inventory, bottom graph shows future part of the Inventory. Red labels / parentheses indicate a missing ECV, green labels indicate ECVs (products) added in response to the GCOS IP 2016.

Figure 5 shows the relative portions of the ECVs in the current and future part of the Inventory for the oceanic domain. For the ocean, most data records address Sea Surface Temperature and Sea Ice Coverage, with CDRs also for Sea Level, Ocean Colour and Sea State. With respect to [RD-7], Ocean Surface Heat Flux and Ocean Surface Stress data records were added to the inventory as new ECVs as a number of data records are already available. Despite existing datasets from SMOS, Aquarius and SMAP, the Sea Surface Salinity ECV is not covered at all the ECV Inventory because none of the agencies providing these datasets appear to consider them climate quality; in addition, the CDRs all cover relatively short time periods. This could also be one of the cases covered under 'verified unlisted' ECV products. Overall 5 out 6 ECVs are covered for the ocean domain with respect to [RD-2], and 7 out of 9 with respect to [RD-7]. The new ECV on Surface Currents is covered in neither the current nor the future part of the inventory.

With respect to the 2011 GCOS Implementation Plan Satellite Supplement [RD-2] (GCOS-154, 2011), which served as the baseline against which the ECV Inventory was built, contributions for 27/29 ECVs are covered in the ECV Inventory. With respect to the new GOCS IP [RD-7], 30/35 ECVs are covered by CDR entries of the Inventory. However, the data call for the inventory did not explicitly ask for such 'new ECV' contributions as the new GCOS IP was not ready at that time. This means that the new GCOS IP potentially has more than 35 ECVs that could be addressed from space. The next update of the inventory will explicitly address this.

Figure 6 shows the relative portions of the ECVs in the current and future part of the Inventory for the terrestrial domain. The CDRs in the inventory for land mainly address Land Surface Temperature and Surface Albedo, which combined represent more than 60% of all terrestrial data records. During the population of the inventory, data providers were also offering entries for data records that only became an ECV product with the new 2016 GCOS Implementation Plan [RD-7]. As a result, the Groundwater ECV was added into the inventory as data records already existed. There are verified unlisted ECV products addressing Lakes, and future ECV products planned. Not covered at all in the ECV inventory is Above-ground Biomass, which represents a total gap. Overall, 11 out 12 ECVs are covered in the current part of the inventory with respect to [RD-2] and 12 out of 14 with respect to [RD-7]. In the future, the part on Soil Moisture will strongly increase and also more Fire Disturbance data records can be expected.

4.2 Detailed View on Temporal Coverage per ECV Product

4.2.1 Atmosphere

Figure 7 shows a detailed view on how many data records are available in the period from 1971 to 2016 for each ECV product for all three GCOS domains. The longest records are for the Ozone ECV starting in the early 1970s using data from the Backscatter Ultraviolet Spectrometer (BUV) instrument on the Nimbus-4 satellite. Also obvious from Figure 7 is a dense population of data records during the period 2001-2010 in particular for Water Vapour, Cloud Properties and Top of Atmosphere Earth Radiation Budget data records. More important is that for most ECVs, less than 5 alternative data records are available for the period before the year 2000, and for 6 atmospheric ECV products (Temperature of Deep Layers, Tropospheric CO_2 Profiles, Tropospheric Ozone Profile and NO_2, SO_2 and HCHO Total Columns) no data record was registered. The miss for the Temperature of Deep Layers ECV is not a gap, rather a miss of the existing 3 MSU/AMSU-A data records which are known but were not registered by any agency. This will be fixed in the next release. CO_2 data records are further analysed in section 6.1.

ECV	ECV Product	1971-1975					1976-1980					1981-1985					1986-1990					1991-1995					1996-2000					2001-2005					2006-2010					2011-2015					2016
Atmosphere																																															
Surface Wind	Surface Wind Speed and Direction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7	7	7	8	8	8	8	8	8	8	10	10	11	11	11	11	10	12	12	10	10	10	10	9	8	8	7
Precipitation	Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	6	6	6	6	6	7	7	7	7	7	7	7	7	7	8	8	8	8	7	7	7	7	7	7	7	6	7	7	6
Upper Air Temperature	Tropospheric Temperature Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	10	10	10	10	11	11	11	11	11	8	8	8	8	4
	Stratospheric Temperature Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9	9	9	9	9	9	9	8	8	8	8	8	8	4
	Temperature of Deep Layers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Air Wind	Upper-air Wind Speed and Direction	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	1	1	1	1	0	0	0	0
Water Vapour	Total Column Water Vapour	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8	8	8	11	11	11	11	11	12	14	14	14	15	24	24	24	25	26	26	22	22	22	17	14	15	15	11
	Tropospheric and Lower-stratospheric Profiles of Water Vapour	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	4	6	6	6	6	22	22	22	22	23	23	21	20	20	18	17	17	17	8
	Upper Tropospheric Humidity	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	2	2	2	3	3	3	3	1
Cloud	Cloud Amount	0	0	0	0	0	0	0	0	1	1	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	13	19	19	19	20	21	21	18	15	13	13	13	13	4
	Cloud Top Pressure (CTP)	0	0	0	0	0	0	0	0	1	1	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	14	20	20	22	24	25	25	22	19	15	13	13	13	4
	Cloud Top Temperature (CTT)	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	11	17	17	17	18	18	18	16	13	12	12	12	12	4
	Cloud Optical Depth (COD)	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	8	9	9	9	7	4	4	2	2	2	0
	Cloud Water Path (liquid and ice)(CWP)	0	0	0	0	0	0	0	0	1	1	1	5	5	5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	21	21	21	23	23	23	19	13	13	13	13	13	4
	Cloud Effective Particle Radius (liquid and ice)(CRE)	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	0
Earth Radiation Budget	Top-of-Atmosphere ERB Longwave	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	21	24	24	24	25	25	25	25	22	22	22	22	22	9
	Top-of-Atmosphere ERB Shortwave (reflected)	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	5	5	7	7	7	7	7	4	5	3	3	3	0
	Surface ERB Longwave	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	5	5	14	14	14	14	14	14	11	2	2	2	2	2	0
	Surface ERB Shortwave	0	0	0	0	0	0	0	0	0	1	1	4	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	12	12	12	18	14	14	14	14	14	11	5	5	2	2	2	0
	Total Solar Irradiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3
	Solar Spectral Irradiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	3	3	3	3	3
CO2, CH4 and other GHG	Tropospheric CO2 Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	11	11	11	11	11	13	13	11	11	11	8	4
	Tropospheric CO2 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CH4 Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	3	4	4	8	7	6	6	6	0	0
	Tropospheric CH4 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8	8	9	10	10	10	10	9	9	9	8	4
	Stratospheric CH4 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0
Ozone	Total Ozone	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	11	11	11	11	12	13	13	12	11	10	8	8	8	3
	Tropospheric Ozone Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ozone Profile in Upper Troposphere and Lower Stratosphere	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	0	0	0	0
	Ozone Profile in Upper Stratosphere and Mesosphere	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	0	0	0
Aerosol	Aerosol Optical Depth	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	7	7	12	12	12	13	13	14	14	17	22	24	28	28	26	18	14	9	9	9	2
	Aerosol Single-scattering Albedo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
	Aerosol-layer Height	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	1	1	1	1	1	1
	Aerosol-extinction Coefficient Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	0	0	0	0	0
Precursors ECVs	NO2 Tropospheric Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SO2; HCHO Tropospheric Columns	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CO Tropospheric Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
	CO Tropospheric Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8	8	9	9	9	9	9	8	8	8	8	3

Figure 7: Number of existing data records for the atmospheric domain per ECV product and year for the period 1971-2016.

ECV	ECV Product	1966-1970					1971-1975					1976-1980					1981-1985					1986-1990					1991-1995					1996-2000				
Atmosphere																																				
Surface Wind	**Surface Wind Speed and Direction**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	4	4	4	4	4	4	4	4
Precipitation	**Precipitation**	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3
Upper Air Temperature	**Tropospheric Temperature Profile**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stratospheric Temperature Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Temperature of Deep Atmospheric Layers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Air Wind	**Upper-air Wind Speed and Direction**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Water Vapour	**Total Column Water Vapour**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2
	Tropospheric and Lower-stratospheric Profiles of Water Va	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upper Tropospheric Humidity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	5	5	5	5	5	5	5	5
Cloud	**Cloud Amount**	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	7	10	10	10	10	10	10	10	13	13	13	13	13	13	13	13	13	13	13
	Cloud Top Pressure (CTP)	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	Cloud Top Temperature (CTT)	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	Cloud Optical Depth (COD)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Cloud Water Path (liquid and ice)(CWP)	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	13	13	13	13	13	13	14	14	14	14	14	14	14	14	14	14	14	14	14
	Cloud Effective Particle Radius (liquid and ice)(CRE)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Earth Radiation Budget	**Top-of-Atmosphere ERB Longwave**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	Top-of-Atmosphere ERB Shortwave (reflected)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	Surface ERB Longwave	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Surface ERB Shortwave	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	Total Solar Irradiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Solar Spectral Irradiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CO2, CH4 and other GHG	**Tropospheric CO2 Column**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CO2 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CH4 Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CH4 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stratospheric CH4 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ozone	**Total Ozone**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric Ozone Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
	Ozone Profile in Upper Troposphere and Lower Stratosphe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
	Ozone profile in Upper Stratosphere and Mesosphere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aerosol	**Aerosol Optical Depth**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
	Aerosol Single-scattering Albedo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aerosol-layer Height	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aerosol-extinction Coefficient Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precursors ECVs	**NO2 Tropospheric Column**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SO2; HCHO Tropospheric Columns	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CO Tropospheric Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CO Tropospheric Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8: Number of planned data records for the atmospheric domain per ECV product and year for the period 1966-2000.

ECV	ECV Product	2001-2005					2006-2010					2011-2015					2016-2020					2021-2025					2026-2032						
Atmosphere																																	
Surface Wind	Surface Wind Speed and Direction	3	3	3	3	3	3	3	3	3	5	5	5	5	2	2	2	2	1	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	Precipitation	3	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Upper Air Temperature	Tropospheric Temperature Profile	0	4	12	12	12	12	12	12	12	12	12	12	12	12	12	6	6	6	4	4	0	0	0	0	0	0	0	0	0	0	0	0
	Stratospheric Temperature Profile	0	4	12	12	12	12	12	12	12	12	12	12	12	12	12	6	6	6	4	4	0	0	0	0	0	0	0	0	0	0	0	0
	Temperature of Deep Atmospheric Layers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Air Wind	Upper-air Wind Speed and Direction	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Vapour	Total Column Water Vapour	2	2	10	10	10	10	12	12	12	12	12	12	12	11	11	6	5	5	5	4	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric and Lower-stratospheric Profiles of Water Va	0	0	16	16	16	16	16	16	16	16	16	16	16	16	16	8	8	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0
	Upper Tropospheric Humidity	5	5	7	7	7	7	7	7	7	7	7	7	7	6	6	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0
Cloud	Cloud Amount	13	13	21	23	23	23	23	23	23	23	23	23	23	23	21	12	12	12	10	10	1	1	1	1	0	0	0	0	0	0	0	0
	Cloud Top Pressure (CTP)	7	7	15	17	17	17	17	17	17	17	17	17	17	17	15	9	9	9	7	7	1	1	1	1	0	0	0	0	0	0	0	0
	Cloud Top Temperature (CTT)	7	7	15	17	17	17	17	17	17	17	17	17	17	17	15	9	9	9	7	7	1	1	1	1	0	0	0	0	0	0	0	0
	Cloud Optical Depth (COD)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
	Cloud Water Path (liquid and ice)(CWP)	14	14	14	18	18	18	18	18	18	18	18	18	18	18	14	10	10	10	6	5	1	1	1	1	0	0	0	0	0	0	0	0
	Cloud Effective Particle Radius (liquid and ice)(CRE)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0
Earth Radiation Budget	Top-of-Atmosphere ERB Longwave	7	7	25	25	28	28	28	28	28	28	28	28	28	28	22	13	13	11	10	10	1	1	1	1	1	1	1	1	1	1	1	1
	Top-of-Atmosphere ERB Shortwave (reflected)	6	6	6	6	9	9	9	9	9	9	9	9	9	9	6	3	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1
	Surface ERB Longwave	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Surface ERB Shortwave	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	6	6	6	4	4	2	2	2	2	2	2	2	2	2	2	2	2
	Total Solar Irradiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Solar Spectral Irradiance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2, CH4 and other GHG	Tropospheric CO2 Column	0	0	10	10	10	10	10	11	11	13	13	13	13	13	13	9	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CO2 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CH4 Column	0	0	2	2	2	2	2	3	3	7	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric CH4 Profile	0	0	8	8	8	8	8	8	8	8	8	8	8	8	8	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0
	Stratospheric CH4 Profile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ozone	Total Ozone	0	0	8	8	8	8	9	9	9	9	9	9	9	9	9	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0
	Tropospheric Ozone Profile	1	1	2	2	3	3	3	4	4	4	3	2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ozone Profile in Upper Troposphere and Lower Stratosphe	1	1	2	2	3	3	3	5	5	5	4	3	2	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ozone profile in Upper Stratosphere and Mesosphere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aerosol	Aerosol Optical Depth	4	4	6	8	9	9	9	10	10	8	8	7	7	6	6	4	4	2	2	2	2	2	2	2	2	1	0	0	0	0	0	0
	Aerosol Single-scattering Albedo	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aerosol-layer Height	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aerosol-extinction Coefficient Profile	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precursors ECVs	NO2 Tropospheric Column	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SO2; HCHO Tropospheric Columns	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CO Tropospheric Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CO Tropospheric Profile	0	0	8	8	8	8	8	8	8	8	8	8	8	8	8	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0

Figure 9: Same as Figure 8 but for the period 2001-2032.

The planned data records for atmospheric ECVs are depicted in Figure 8, and Figure 9 for the period 1966-2032. Most of the planned activities concentrate on the reprocessing of data from the early 1980s to 2020. Only very few plans exist today for the use of new data sources beyond 2020. The number of planned data records varies very much across the ECVs with many data records planned for Earth Radiation Budget and Cloud Properties (in particular Cloud Amount) but only very few data records planned for Aerosol Properties and Upper Air Wind.

4.2.2 Ocean

Existing climate data records for the Ocean (shown in Figure 10) start in the late 1970s with the Sea Surface Temperature and Sea Ice Concentration ECV Products utilising the SMMR instrument on Nimbus-7. All ECV Products are covered at least for a part of the overall period, only Sea Surface Salinity is missing. For most ECV Products, with the exception of Sea Surface Temperature, only 2-4 data records are available and sometimes these were provided from a single agency, which poses the risk of relying on one source of information for climate analysis.

For the planned data records shown in Figure 11 and Figure 12, one can detect that some major improvements are visible, e.g., extension of Sea Ice Thickness data records backwards from 2010 to 1991 using data from the European ERS-1 and ERS-2 satellites. The specific analysis performed on Sea Surface Salinity (see section 6.5) identified that this gap will be addressed in the future using 1.4 GHz measurements available since the late 1990s. Also for the ocean domain, most plans address the reprocessing of existing data records and only for Regional Sea Level and Sea Ice Thickness do plans extend until 2025 to the use of new measurements.

4.2.3 Land

The longest data records for land surfaces (shown in Figure 13) are for Snow Cover and these start in 1973 using measurements from the Very High Resolution Radiometer (VHRR) on NOAA- 2 and the Automatic Picture Transmission (APT) instrument on the Environmental Science and Services Administration (ESSA)-8 satellites. In general there are far less data records for the land domain compared to the atmosphere. For most ECV products only one or two data records seem to exist. The experience with the tropospheric temperature changes derived from MSU has shown that this can be a concern if the data records are used to determine changes over time. For 9 ECV products (Areas of GTN-L Lakes, Snow Water Equivalent, Glacier Elevation data, Ice Sheets Surface Elevation and Mass Changes, High Resolution Maps of Land Cover Type, Above-ground Biomass, Active Fire Maps, and Fire Radiative Power) no data records were registered with the ECV Inventory. On the other hand, some ECV Products such as Groundwater Volume Change newly identified in the updated GCOS IP 2016 [RD-7] are already represented.

Figure 14 and Figure 15 show the planned data records per ECV Product for the land domain. Six of the 9 missing ECV Products (Areas of GTN-L Lakes, Glacier Elevation data, Ice Sheets Surface Elevation and Mass Changes, Above-ground Biomass (not in the Inventory but addressed by ESA CCI+, see section 6.8), and Fire Radiative Power) will be addressed in the future. However, three ECV Products (Snow Water Equivalent, High Resolution Maps of Land Cover Type, and Active Fire Maps) need further analysis. In addition, the figures show that for many data records no new release is planned, which is either because there is no improvement in reach or missing resources.

ECV	ECV Product	1976-1980					1981-1985					1986-1990					1991-1995					1996-2000					2001-2005					2006-2010					2011-2015					2016
Ocean																																										
Sea Surface Temperature	Sea Surface Temperature	0	0	0	1	1	1	2	2	2	2	2	2	3	3	3	3	6	6	6	6	6	6	6	6	6	6	6	15	15	15	15	16	16	16	16	15	12	12	12	11	5
Sea Surface Salinity	Sea Surface Salinity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Level	Global Mean Sea Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Regional Sea Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	5	5	5	5	5	5	5	6	6	6	6	5	5	5	6	6	7	7	6	6	6	5
Sea State	Wave Height	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	2	2	2	2	3	3	3	3	2	2	2	3	3	3	3	2	2	2	2
Sea Ice	Sea Ice Concentration	0	0	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	4	5	5	5	5	5	4	2
	Sea Ice Extent/Edge	0	0	0	0	0	0	1	1	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	1	2	1	1
	Sea Ice Thickness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4
	Sea Ice Drift	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	1	1	1	0	0	0	0	0	0
Ocean Colour	Water Leaving Radiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0
	Chlorophyll-a Concentration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0
Ocean Surface Heat Flux	Latent Heat Flux	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	0
	Sensible Heat Flux	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	0
Surface Stress	Ocean Surface Stress	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0

Figure 10: Number of existing data records for the oceanic domain per ECV product and year for the period 1976-2016.

ECV	ECV Product	1966-1970					1971-1975					1976-1980					1981-1985					1986-1990					1991-1995					1996-2000				
Ocean																																				
Sea Surface Temperature	Sea Surface Temperature	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	4	4	4	4	4	5	5	5	5	6	6	6	6	6	6	6	6	6
Sea Surface Salinity	Sea Surface Salinity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Level	Global Mean Sea Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	Regional Sea Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	5	5	5	5	5	5	5
Sea State	Wave Height	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Ice	Sea Ice Concentration	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Sea Ice Extent/Edge	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Sea Ice Thickness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2
	Sea Ice Drift	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Ocean Colour	Water Leaving Radiance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
	Chlorophyll-a Concentration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
Ocean Surface Heat Flux	Latent Heat Flux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3
	Sensible Heat Flux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Surface Stress	Ocean Surface Stress	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 11: Number of planned data records for the oceanic domain per ECV product and year for the period 1966-2000.

ECV	ECV Product	2001-2005					2006-2010					2011-2015					2016-2020					2021-2025					2026-2032						
Ocean																																	
Sea Surface Temperature	Sea Surface Temperature	6	6	14	14	15	15	15	15	15	15	15	14	13	13	13	9	9	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Sea Surface Salinity	Sea Surface Salinity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Level	Global Mean Sea Level	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
	Regional Sea Level	5	5	5	5	5	5	5	5	5	5	6	6	6	6	5	4	4	4	3	3	3	3	1	1	1	0	0	0	0	0	0	0
Sea State	Wave Height	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3	3	6	5	2	0	0	0	0	0	0	0	0	0	0	0
Sea Ice	Sea Ice Concentration	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sea Ice Extent/Edge	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sea Ice Thickness	2	2	2	2	2	2	2	2	2	2	7	7	7	7	7	7	7	6	2	2	2	2	2	2	2	0	0	0	0	0	0	0
	Sea Ice Drift	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Ocean Colour	Water Leaving Radiance	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chlorophyll-a Concentration	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ocean Surface Heat Flux	Latent Heat Flux	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sensible Heat Flux	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Stress	Ocean Surface Stress	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 12: As Figure 11 but for the period 2001-2032.

ECV	ECV Product	1966-1970					1971-1975					1976-1980					1981-1985					1986-1990					1991-1995					1996-2000					2001-2005					2006-2010					2011-2015					2016
Land																																																				
Lakes	Areas of GTN-L Lakes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Snow Cover	Snow Areal Extent	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	4	4	4	1	1	1	0
	Snow Water Equivalent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaciers and Ice Caps	2D Vector Outlines; Delineating Glacier Area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Elevation Data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ice Sheets	Surface Elevation Change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	Ice Velocity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0	0
	Mass Change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albedo	Black-sky Albedo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	3	2	3	2	3	3	3	6	6	6	6	6	9	9	7	7	7	7	6	2	2	2	2	2	2
	White-sky Albedo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	1	2	1	2	2	2	5	5	5	5	4	4	4	3	3	3	3	3	2	2	2	2	2	2
Land Cover	Moderate-resolution maps of Land-cover Type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	High-resolution maps of Land-cover Type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAPAR	FAPAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
LAI	LAI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
Above Ground Biomass	Above Ground Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire Disturbance	Burnt Area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3	3	3	3	3	1	1	1	1	1
	Active Fire Map	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fire Radiative Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soil Moisture	Volumetric Soil Moisture	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0	0
	Freeze/Thaw	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Land-Surface Temperature	Land-Surface Temperature	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9	9	9	9	10	10	10	9	9	8	8	8	8	4
Groundwater	Groundwater Volume Change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	1
Ice Sheets and Ice Shelves	Ice Shelves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0

Figure 13: Number of existing data records for the terrestrial domain per ECV product and year for the period 1966-2016.

ECV	ECV Product	1966-1970					1971-1975					1976-1980					1981-1985					1986-1990					1991-1995					1996-2000				
Land																																				
Lakes	**Areas of GTN-L Lakes**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Snow Cover	**Snow Areal Extent**	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Snow Water Equivalent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaciers and Ice Caps	**2D Vector Outline delineating glacier area**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Elevation Data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ice Sheets	**Surface Elevation Change**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
	Ice Velocity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
	Mass Change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Albedo	**Black-sky Albedo**	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	7	7
	White-sky Albedo	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	5
Land Cover	**Moderate-resolution maps of Land-cover Type**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
	High-resolution maps of Land-cover Type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAPAR	**FAPAR**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
LAI	**LAI**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Above Ground Biomass	**Above Ground Biomass**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire Disturbance	**Burnt Area**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	4
	Active Fire Map	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fire Radiative Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soil Moisture	**Volumetric Soil Moisture**	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16	16	16	16	16	16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	24
	Freeze/Thaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land-Surface Temperature	**Land-Surface Temperature**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	4	4	4	4	4	7	7	7	7	7	7	7	7	7	7	8
Groundwater	**Groundwater Volume Change**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ice Sheets and Ice Shelves	**Ice Shelves**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 14: Number of planned data records for the terrestrial domain per ECV product and year for the period 1966-2000.

ECV	ECV Product	2001-2005					2006-2010					2011-2015					2016-2020					2021-2025					2026-2032						
Land																																	
Lakes	Areas of GTN-L Lakes	2	2	2	2	2	2	2	2	2	2	1	1	1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Snow Cover	Snow Areal Extent	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
	Snow Water Equivalent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaciers and Ice Caps	2D Vector Outline delineating glacier area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Elevation Data	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ice Sheets	Surface Elevation Change	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
	Ice Velocity	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
	Mass Change	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Albedo	Black-sky Albedo	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	5	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	White-sky Albedo	5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land Cover	Moderate-resolution maps of Land-cover Type	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High-resolution maps of Land-cover Type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAPAR	FAPAR	2	2	2	2	3	3	3	3	3	3	3	3	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAI	LAI	2	2	2	2	3	3	3	3	3	3	3	3	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Above Ground Biomass	Above Ground Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire Disturbance	Burnt Area	6	6	6	6	6	6	6	6	6	5	4	4	4	5	5	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Active Fire Map	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fire Radiative Power	0	0	0	0	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soil Moisture	Volumetric Soil Moisture	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	21	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Freeze/Thaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land-Surface Temperature	Land-Surface Temperature	8	8	16	16	17	17	17	17	17	17	16	16	15	16	16	9	7	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater	Groundwater Volume Change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ice Sheets and Ice Shelves	Ice Shelves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 15: As Figure 14 but for the period 2011-2032.

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5 Gap Analysis against GCOS Criteria

This section provides an overview of the results achieved in the analysis of ECV Inventory categories. All figures below correspond to all current and future data records and contain all the questions subject to the gap analysis assessment as described in sections 3.1 and 3.2. The colour scale in the figures presented (darker to lighter) reflects the generic gap analysis grading:

- 3: fulfilling GCOS-200 (dark);
- 2: partially fulfilling GCOS-200 (medium);
- 1: not fulfilling GCOS-200 (light);
- 0: no information provided (blank upper lengths of plotted bars).

As outlined in Annex C, for some questions only a limited grading is applied because many require the provision of specific information, such as a name of an institution being responsible for a data record, or are yes/no questions. For those cases only two colours are visible. The individual components are normed to a sum of 1 and are presented in units of percent. The following subsections analyse the six categories for the current and the four categories for the future parts of the inventory for the three domains as a whole separately.

This analysis has also been performed for the three GCOS domains individually, but no significant differences could be found to the following overall consideration. An assessment for some individual ECVs is presented in section 6.

5.1 Existing Data Records (Current Part of Inventory)

Figure 16 shows the level of response to the 6 categories for all data records in the current part of the ECV Inventory.

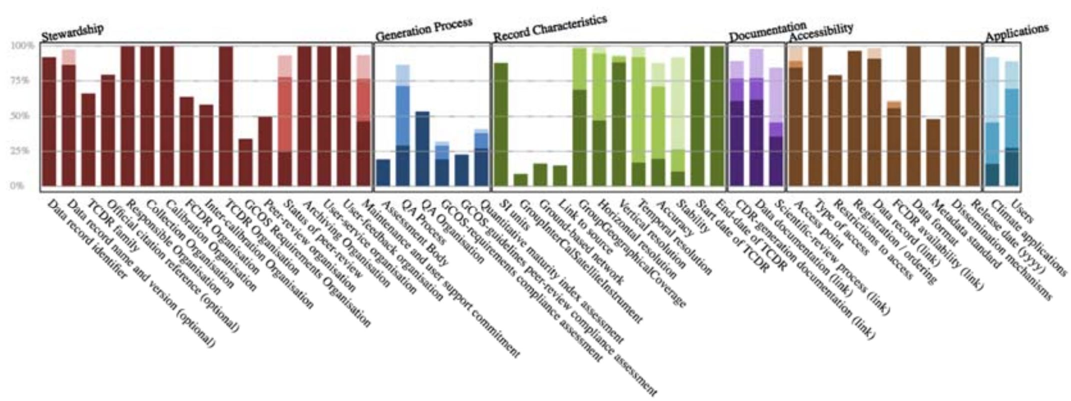

Figure 16: Level of response to the Questionnaire and grades of responses to the individual questions for all data records (496) in the current part of the ECV Inventory. Note that for some questions answers were optional and in some cases not applicable, e.g., data records that do not use ground-based data for calibration did not need to answer that question.

5.1.1 Stewardship

The overall picture on data record stewardship reveals strengths and weaknesses for current data record holdings:

- For about 80% of the data records the doi system is used for identification, thereby almost fulfilling the GCOS Action G20. About 10% of the producers could not provide a data record identifier of any kind, which makes it difficult to discover the data records. Also, about 15% do not apply any versioning approach to their data records;
- To all data record producers it is clear who is responsible for collecting and calibrating the observations and who is responsible for the production of the climate data record. Also responsibilities for data archiving, user service and feedback are clearly understood;
- More than 30% of the data producers do not know who is responsible for the provision of a best possible input data record (FCDR), including cross-calibration to reference sensors;
- For only about 30% of the data records, an organisation could be named that would be responsible to address the compliance to GCOS criteria. For 50% of the data records, an organisation responsible for the peer review process of the climate data records could be identified;
- The status of peer review is mixed; only for 25% of the data records an organisational type of review is performed prior to the public release of the data. However, more than 75% publish articles in peer reviewed literature about the released data records, and only 10% do nothing;
- Maintenance and user support is an area of concern. About 45% of the data records are committed to be kept in perpetuity. For another 30% a long-term commitment exists, but is subject to reviews that could lead to the removal of data records. For about 20% of the data records the commitment is shorter than 5 years, most often constrained by project funding. For 5% of the data records no commitment exists.

5.1.2 Generation Process

The data record generation process is the category with the least answers provided. Specific findings are:

- For very few data records an assessment body such as GEWEX data quality assessments was used to perform a quality review. Some QA process in general is applied to about 80% of the data records, which is in most cases normal product validation. A formal process is in place only for just over 25%, and for only about 5% is the QA4EO process implemented;
- Fulfilment of GCOS requirements and GCOS guidelines is tested for 25% of cases. It is not known if this is because the majority of data record producers do not know about GCOS and the relevant documentation, or if it is considered to be not a useful addition to validation efforts;
- On the positive side, the application of a maturity matrix assessment received more attention with more than 25% using it also documenting the results.

5.1.3 Data Record Characteristics

For the data record characteristics the following observations can be made:

- At least for 90% of the data records SI units have been used, but for the remaining 10% the question remains unanswered;

- Almost 100% of the data records have global or at least continental scale coverage;
- Horizontal resolution was compared to requirements from the new GCOS IP and slightly less than 50% of the data records are fulfilling the given requirements. However, almost 50% of the data records are compliant with the application of it as provided in the usage category. This points to the fact that data records are rather designed to application needs and not necessarily GCOS requirements. A negligible number of data records are not compliant with the applications proposed by the data producer;
- For vertical resolution (for those data records that have vertical extension), about 85% are compliant with the GCOS requirement and only small fractions are not compliant or have not answered the question;
- For temporal resolution, only about 20% are compliant with the GCOS requirement although a large fraction of data records are compliant with their intended or realised application. In general, the applicability of temporal resolution as a GCOS requirement is questionable and maybe warrants review;
- For the accuracy requirement, up to 70% fulfil the needs for their intended application, but only 20% with the GCOS requirement. For 30% of the data records no or only qualitative information on accuracy is provided. This could be due the non-responsiveness to this question or could possibly constitute a real area for improvement;
- Temporal stability of the data records have not been assessed for about 75% of the CDRs, which is a concern as only a high stability enables the detection of a change in the geophysical variable considered. From the remaining 25% of the data records, about one third fulfils the GCOS requirement and the rest seem at least good enough for their intended or realised application. This is closely connected to the need for long-term non-satellite derived reference measurements to support the validation of climate data records.

Recommendation #6: *WGClimate to develop a white paper on what is needed for the validation of climate data records including uncertainty information and stability aspects.*

5.1.4 Documentation

For the documentation category it can be stated that:

- For about 60% of the data records full information on the processing chains, algorithms, etc., and scientific and technical information on the data record, e.g., product user guides, are provided. For 15%, this information partially exists, and for the remaining 25% no information was provided or no documentation exists;
- For the scientific review process, about 50% of the data records provide evidence on participation in international comparison activities and/or agency internal and external review. For the other half of the data records, inadequate answers to these questions were provided.

5.1.5 Accessibility

In the accessibility category the following observations can be made:

- A very positive finding is that for more than 80% of the data records the access point is an institutional help desk or similar. Only a few percent of the data records are only available from individuals or the access point is unknown;

- Also positive is that for more than 98% of the data records access to the data is without any constraint. This does not exclude that media costs are sometimes charged. However, it is possible that the listed ECV products are a sample biased towards freely accessible records;
- For only a little more than 50% of the data records a link to the used FCDR is provided. For a few percent, links to non-FCDR input data are provided and for more than 40% these questions remained unanswered. Various interpretations of these results can be made. The strongest would be to assume that half of the data records in the inventory do not represent climate data records because the input data do not achieve the required quality. This would go along with the fact that many data record producers may still not know exactly what an FCDR is (the Questionnaire guide tried to explain this). A more mild interpretation is that many data records may be tuned at level 2 to become climate quality, e.g., by calibration with non-satellite measurements. This seems unlikely from the answers in the data record category as very limited use of ground-based networks for calibration were documented. Also known is that many Level 2 data production algorithms contain corrections of Level 1 data that do not save the results and make them accessible by others. From this one may conclude that a specific FCDR inventory would help to make the provision of FCDRs more attractive and also promote the use of better corrected and calibrated input data in Level 2 algorithms;
- A clear weakness is that for less than 50% of the data records a known metadata standard has been applied. This presents a barrier for international interoperability needed for data exchange and also automatic visualisation.

Recommendation #7: *WGClimate to establish a specific inventory for FCDRs to signal their importance and to promote their usage for the production of ECV climate data records.*

Recommendation #8: *CEOS and CGMS agencies to add the delivery of FCDRs for each individual satellite instrument (linked to relevant precursor instrument series) to their agency remit.*

Recommendation #9: *CEOS and CGMS agencies to require the application of metadata standards with the production of climate data records.*

5.1.6 Applications

The use of the CDR in a climate application was underpinned by providing references in only 15% of cases. For about 30%, applications were identified without providing evidence. For more than 50% of the data records, the climate applications were only provided in a generic way without any reference, e.g., by identifying a community such as climate modellers, or with no answer provided at all. Specific users were identified for a little more than 25% of the data records, including a short description of what they do. For about 30% of the data records, specific users were not identified, and the remaining 45% detail users with an unknown application. An interpretation of this result could be that data records are produced with no specific user and application in mind. This, in combination with a lack of promotion of data records, may thus lead to a low level of usage. A caveat to this interpretation is that the responders to the questionnaire were responding in a free text field and some of them may not have spent the time required to provide a more comprehensive answer.

5.2 Planned Data Records (Future Part of the Inventory)

Figure 17 provides the same view on the relevant categories as above but for planned future records. The following subsections only consider the delta to the existing data record. It is important to keep in mind that all information in the future part of the inventory is intentional and only subsequent considerations will unearth if the situation has really improved.

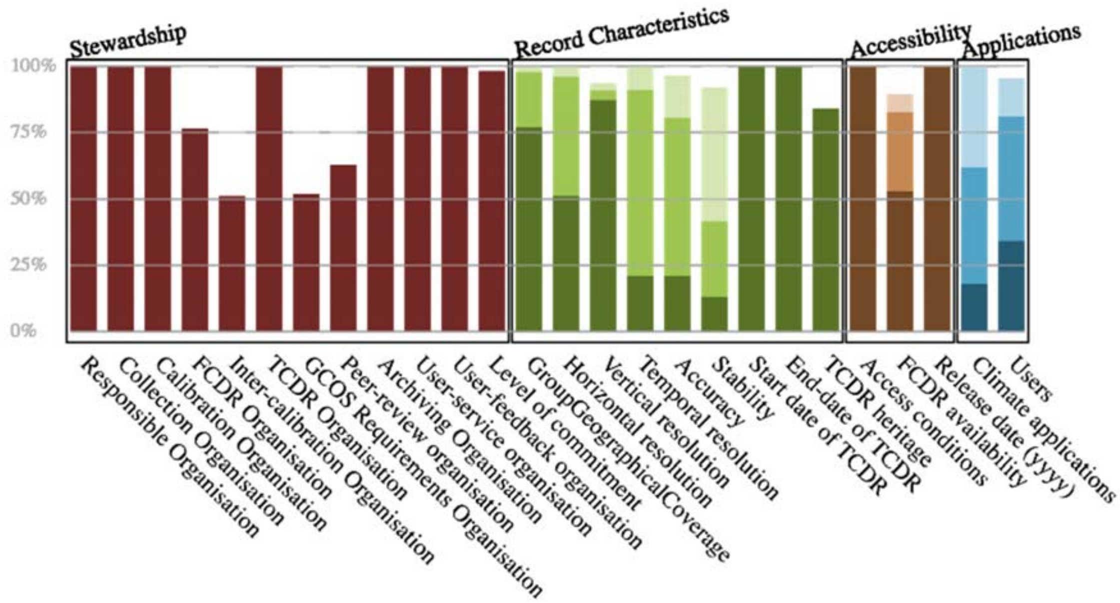

Figure 17: Level of response to the Questionnaire and grades of responses to the individual questions for all data records (417) in the future part of the ECV Inventory.

5.2.1 Stewardship

The picture on data record stewardship reveals slight improvements:

- Compared to the current part of the Inventory the awareness for the use of FCDRs and the need for inter-satellite calibration appears slightly increased for the planned data records;
- The awareness of evaluating the data record against GCOS criteria has increased from 30% to more than 50%.

5.2.2 Record Characteristics

For this category the observations are:

- More than 75% of the planned data records are reprocessing of existing data records with improved algorithms and/or new input data;
- Despite this there are only marginal improvements visible for the Accuracy and the Stability of the planned data records pointing to substantial issues in demonstrating improvements in the absence of fiducial reference measurements, in particular for stability.

5.2.3 Accessibility

In this category only three items are addressed for which only the FCDR availability is seen to be improved compared to the existing data records. Responders seem to look for FCDRs as more provided a link to general web pages where such data can be expected but with no identifier to a specific data record to be used. Thus, the recommended promotion of FCDRs via the ECV Inventory will help to facilitate the use of the best available Level-1 data records.

5.2.4 Applications

The picture on the users and the climate applications remains almost unchanged, which might be a concern for some data records that are being produced with no specific user or usage scenario in mind. However, the same caveat as mentioned in section 5.1.6 applies here.

6 Gap Analysis for Selected ECV Products

This section provides a more in depth analysis for 8 ECVs that address the assessment of missing data records in the ECV Inventory, an assessment versus GCOS criteria per ECV, an assessment of missed opportunities to generate data records from existing measurements, and the future availability of measurements to continue the monitoring of the ECV.

The selected 8 ECVs are three atmospheric (CO_2, CH_4, and Precipitation), three terrestrial (Land Surface Temperature, Leaf Area Index, and Above-ground Biomass), and two oceanic (Sea Surface Temperature and Sea Surface Salinity). The choices for these 8 ECVs were made according to current relevance for planning of space agencies (for CO_2 and CH_4), the involvement of many satellite instruments measuring in different spectral ranges (Precipitation, Sea Surface Temperature, Land Surface Temperature and Leaf Area Index), and presenting a total gap in the ECV Inventory (Above-ground Biomass and Sea Surface Salinity).

The analysis is restricted to 8 ECVs because each analysis needs a group of thematic experts and takes a few weeks to be performed. The current analysis also acts as a test for the capability of the ECV Inventory, which contains ECVs for whom known issues with mission continuity do exist. It is planned to perform this type of analysis for all ECVs in the future and also to compare analysis results between different releases of the ECV Inventory to monitor progress.

6.1 CO_2

6.1.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis, it is important to know if the ECV Inventory content on Carbon Dioxide (CO_2) data records is close to complete. To assess this, other inventories of data records that are used to support climate science and services, e.g., the datasets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) activity and similar, were interrogated. In addition, investigations into required data records from new major climate programmes / projects that weren't active at the time of information collection, e.g., the EUMETSAT AC SAF CDOP 3 (www-acsaf.org) plans and the ESA CCI (http://cci.esa.int/), were made. There are 13 current and 13 future data records in the ECV Inventory related to the Tropospheric CO_2 Column. For the future, 4 data records covering the period to 2021 are committed; the remaining future data records are new releases of historical data. No additional data records were found.

6.1.2 Analysis against GCOS criteria

For the purposes of climate analysis, GCOS (2011, 2016) defines requirements for CO_2 tropospheric column and tropospheric profiles. Table 3 summarizes the GCOS requirements for space-based CO_2 observations.

Table 3: GCOS Systematic Satellite Requirements for CO_2.

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability/ Decade
Tropospheric CO_2 column	5-10km	N/A	4 h	1 ppm	0.2 ppm
Tropospheric CO_2	5-10 km	5 km	4 h	1 ppm	0.2 ppm

Figure 18 and Figure 19 show the assessment result against GCOS criteria for the Tropospheric CO_2 Column ECV. The results look similar to the overall assessment of current and future data records presented earlier. Within the data record generation process no attention is given to the assessment of the quality of resulting data records versus GCOS criteria. From the ECV inventory, CO_2 data records appear weaker in terms of quality than other ECV Products, and also weaker compared to others in the use of a metadata standard. The reasons for this could not be assessed from the inventory alone.

Not all space-based observations of CO_2 provide constraints on the "Tropospheric CO_2 column". In addition, not all CO_2 measurements provide the accuracy needed to address the detection of sources and sinks, the main focus for space based measurements of CO_2 cited in GCOS (2011). Measurements acquired at TIR wavelengths provide a coarse CO_2 (mole fraction) profile with about 1-2 degrees of freedom and peak sensitivity in the middle-to-upper troposphere, but they have little sensitivity near the surface, where most CO_2 sources and sinks are located. Observations retrieved from SWIR observations provide XCO_2, the column-averaged dry-air mole fraction of CO_2, a total column value with roughly uniform sensitivity throughout the troposphere, and declining sensitivity above. While neither TIR nor SWIR derived quantities are exactly a "tropospheric CO_2 column," the SWIR observations more closely address the detection of sources and sinks. Furthermore, none of the missions meet the GCOS ECV requirements for horizontal resolution (interpreted here as the footprint size and sampling distance). Lastly, to achieve truly global coverage, measurements acquired from LEO, GEO or other types of orbit will have to be harmonised and combined.

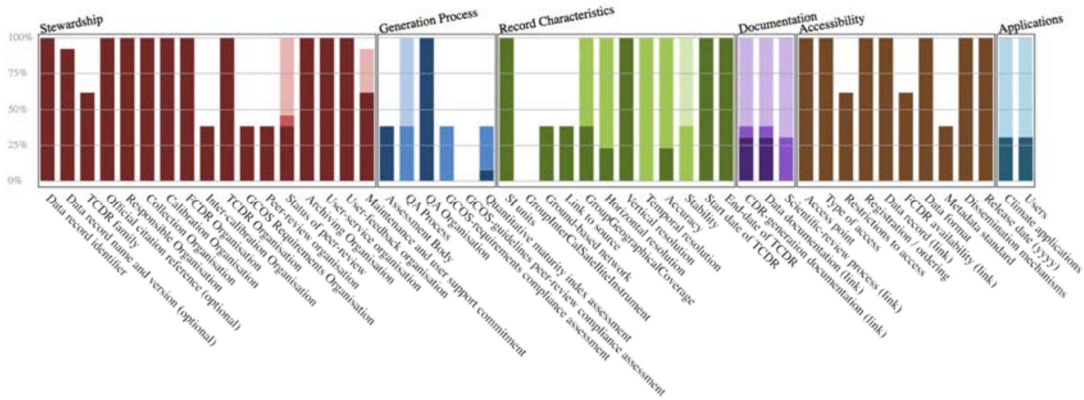

Figure 18: Assessment of current CO_2 data records in the ECV Inventory against GCOS criteria.

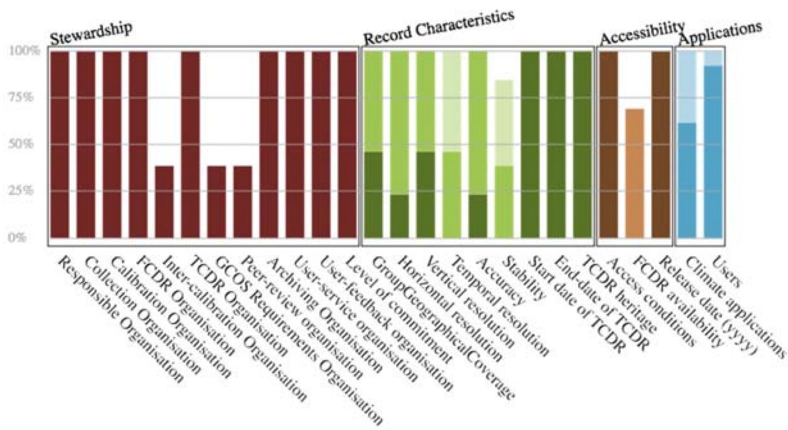

Figure 19: Assessment of future CO_2 data records in the ECV Inventory against GCOS criteria.

6.1.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 4 contains a list of instruments, missions on which the instruments were flown, and the mission launch and end of life dates respectively. The information in this table is based on the CEOS MIM database with many updates from the WMO OSCAR database, mainly because CEOS MIM misses all missions with launch dates prior to 1984.

The content of Table 4 is cross-referenced with the content of the ECV Inventory on CO_2 and provides detail on which instruments / missions are used to generate the CDRs housed within the ECV Inventory.

The subgroup on this CO_2 analysis has not identified missed opportunities from past missions mainly because most of them are not contributing to the detection of carbon sources and sinks. The OCO-2 mission is contributing to this but no climate data record is envisaged at the time of writing.

It should be noted that the WMO OSCAR and CEOS MIM assessment of an instrument's relevance for deriving CO_2 ECV Products does not agree with each other for many cases. There is an urgent need for consolidation of these two important sources of information to more reliably and efficiently facilitate such analyses as attempted here.

Table 4: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM with some additions imported from WMO Oscar. Table includes usage of instruments for CDRs currently found within the ECV inventory.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for CO_2	CEOS relevance for CO_2	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-track nadir thermal infrared (TIR) sounder	TES-nadir	Aura	15/07/2004	2017	High	Y	-	-	Info on CDR from NASA to be included in a future update to the ECV Inventory
	IASI	Metop-A Metop-B	19/10/2006 17/09/2012	2019 2024	Fair	Y	- -	1 -	
	AIRS	Aqua	04/05/2002	2017	Marginal	Y	8	8	
	CrIS	SNPP	28/10/2011	2018	Marginal	Y	-	-	
	GIIRS	FY-4A	10/12/2016	2021	Marginal	N	-	-	
	IKFS-2	Meteor-M N2	08/07/2014	09/07/2014	Marginal	N	-	-	IKFS-2 in OSCAR appears as IFKS in MIM.
	IMG	ADEOS	17/08/1996	30/06/1997	Marginal	N	-	-	
	TANSO-FTS	GOSAT	23/01/2009	2018	Marginal	Y	3	4	GOSAT has both TIR and SWIR
	HIRS/2	NOAA-9 NOAA-10 NOAA-11 NOAA-12 NOAA-13 NOAA-14	12/12/1984 17/09/1986 24/09/1988 14/05/1991 09/08/1993 30/12/1994	13/02/1998 30/08/2001 16/06/2004 10/08/2007 21/08/1993 23/05/2007	None	Y	- - - - - -	- - - - - -	OSCAR and MIM disagree.
	HIRS/3	NOAA-15 NOAA-16 NOAA-17	01/05/1998 21/09/2000 24/06/2002	2018 09/06/2014 10/04/2013	None	Y	- - -	- - -	OSCAR and MIM disagree.
	HIRS/4	Metop-A Metop-B NOAA-18 NOAA-19	19/10/2006 17/09/2012 20/05/2005 04/02/2009	2018 2018 2018 2018	None	Y	- - - -	- - - -	OSCAR and MIM disagree.
	IRAS	FY-3A FY-3B	27/05/2008 05/11/2010	05/06/2015 2018	None	Y	- -	- -	OSCAR and MIM disagree.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for CO_2	CEOS relevance for CO_2	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		FY-3C	23/09/2013	2018			-	-	
Cross-track nadir scanning SWIR sounder	ACGS	TANSAT	21/12/2016	2018	Very High	N	-	-	
	OCO	OCO-2	02/07/2014	2018	Very High	Y	-	-	Info on CDR from NASA to be included in a future update to the ECV Inventory
	SCIAMACHY-nadir	Envisat	01/03/2002	08/04/2012	Fair	Y	3	2	
	TANSO-FTS	GOSAT	23/01/2009	2018	High	Y	-	-	GOSAT has both TIR and SWIR
Limb sounder	MIPAS	Envisat	01/03/2002	08/04/2012	High	Y	-	-	~10-50 km (new product)
	ACE-FTS	SCISAT-1	12/08/2003	2018	Marginal	Y	-	-	> 5 km, mid-troposphere and above only
	ILAS-I	ADEOS	17/08/1996	30/06/1997	Marginal	N	-	-	
Other	ATOVS (HIRS/3 + AMSU + AVHRR/3)	NOAA-15 NOAA-16	01/05/1998 21/09/2000	2018 09/06/2014	None	Y	- -	- -	Instrument combination not listed as such in OSCAR
	TOVS (HIRS/2 + MSU + SSU)	NOAA-9 NOAA-10 NOAA-11 NOAA-14	12/12/1984 17/09/1986 24/09/1988 30/12/1994	13/02/1998 30/08/2001 16/06/2004 23/05/2007	None	Y	- - - -	- - - -	Instrument combination not listed as such in OSCAR

6.1.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Table 5 contains a list of instruments that are planned, or are currently flying, and which may be used to monitor CO_2. Many scientists in the community have been waiting for new data from the Chinese missions, especially TanSat and FY-3D (both launched in Dec 2016). To date, only some TanSat Level 1 data (radiometrically-calibrated spectra) are available. If XCO_2 observations (Level 2) would be made publicly available this would be a very interesting new dataset for the community.

With regard to data gaps, only a small number of future data records of existing and approved missions can be found. From that, the CO_2 focused subgroup subsumes:

Recommendation #10: T*o ensure continuity in CO_2 CDRs, agencies or partner entities are requested to commit to the generation of CDRs in all relevant spectral domains including SWIR from existing or approved missions measuring tropospheric and total column CO_2.*

Additionally, there are plans and white papers for future missions, including global monitoring from GEO, providing a game-changing advance in CO_2 data frequency and density. NASA's GeoCarb mission is the only approved GEO mission for CO_2 so far, covering land over the Americas between 50S to 50N.

Most prominently, an EU white paper detailed an integrated system of observations from space (an LEO constellation of around 4 satellites) and *in situ* measurements combined with a modelling framework in order to achieve satellite-based estimates on earth surfaces fluxes in the long-term. This plan of an integrated system includes requirements to measure sources and sinks from space.

Recommendation #11: *Agencies or related entities are encouraged to systematically link their satellite-based derivation of CO_2 sources and sinks with data from in-situ/ground-based infrastructure and modelling framework(s) in order to estimate Earth-surface CO_2 fluxes (see GCOS IP 2016 Action T71) and provide feedback on their plans/progress.*

Table 5: CO_2-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to CEOS-MIM and WMO OSCAR.

Technology	Instrument	Mission	Launch	WMO relevance for CO_2	CEOS relevance for CO_2	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-track nadir thermal infrared (TIR) sounder	IASI-NG	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	High	N	- - -	- - -	Question the CEOS relevance; should be Y
	TES-nadir	Aura	15/07/2004	High	Y	-	-	CDR info to be included in a future update to the ECV Inventory
	IASI	Metop-A Metop-B Metop-C	19/10/2006 17/09/2012 2018	Fair	Y	- - -	1 - -	
	IKFS-3	Meteor-MP N1 Meteor-MP N2	2026 2027	Fair	N	- -	- -	
	AIRS	Aqua	04/05/2002	Marginal	Y	8	8	
	CrIS	SNPP NOAA-20 JPSS-2 JPSS-3 JPSS-4	28/10/2011 18/11/2017 2022 2026 2031	Marginal	Y	- - - - -	- - - - -	
	GIIRS	FY-4A FY-4B FY-4C FY-4D FY-4E FY-4F FY-4G	10/12/2016 2018 2020 2023 2027 2030 2033	Marginal	N	- - - - - - -	- - - - - - -	
	HIRAS	FY-3D FY-3E FY-3F FY-3G FY-3H	14/11/2017 2018 2019 2021 2021	Marginal	N	- - - - -	- - - - -	

Technology	Instrument	Mission	Launch	WMO relevance for CO_2	CEOS relevance for CO_2	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	IKFS-2	Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	2018 2020 2021 2022 2023	Marginal	N	- - - - -	- - - - -	IKFS-2 in OSCAR appears as IFKS in MIM.
	IR spectrometer	CLARREO-1A CLARREO-2A	TBD TBD	Marginal	N	- -	- -	
	IRFS-GS	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	Marginal	N	- - -	- - -	
	IRS	MTG-S1 MTG-S2	2023 2031	Marginal	N	- -	- -	
	TANSO-FTS	GOSAT	23/01/2009	Marginal	Y	3	4	GOSAT has both TIR and SWIR
	TANSO-FTS/2	GOSAT-2	2019	Marginal	Y	-	-	GOSAT-2 has both TIR and SWIR
	HIRS/3	NOAA-15	01/05/1998	None	Y	-	-	
	HIRS/4	Metop-A Metop-B NOAA-18 NOAA-19	19/10/2006 17/09/2012 20/05/2005 04/02/2009	None	Y	- - - -	- - - -	
	IRAS	FY-3B FY-3C	05/11/2010 23/09/2013	None	Y	- -	- -	
	GeoCarb	GeoCarb	2022	Primary	Y	-	-	
Cross-track nadir scanning SWIR sounder	ACGS	TANSAT	2016	Very High	N	-	-	Inconsistency in relevance between WMO and CEOS, see also vice versa GOSAT.
	GMI	GF-5	2018	Very High	N	-	-	
	OCO	OCO-2 ISS OCO-3	02/07/2014 2019	Very High	Y	- -	- -	CDR info to be included in a future update to the ECV Inventory
	TANSO-FTS	GOSAT	23/01/2009	Marginal	Y	-	-	GOSAT has both TIR and SWIR

Technology	Instrument	Mission	Launch	WMO relevance for CO_2	CEOS relevance for CO_2	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	TANSO-FTS-2	GOSAT-2	2019	Marginal	Y	-	-	GOSAT-2 has both TIR and SWIR. To be clarified why GOSAT/GOSAT-2 relevance for WMO Oscar is "marginal".
	ACS-nadir	Meteor-MP N1 Meteor-MP N2	2026 2027	Marginal	N	- -	- -	
	MicroCarb	MicroCarb	2020	None	N	-	-	Approved CNES mission. To be clarified with WMO and CEOS why is has no relevance.
Cross-track nadir shortwave (UV/VIS) sounder	GAMI	FY-3D FY-3F	31/12/2016 2019	None	Y	- -	- -	GAMI in MIM appears to be listed as GAS in OSCAR
Limb sounder	ACS-limb	Meteor-MP N1 Meteor-MP N2	2026 2027	Fair	N	- -	- -	
	ACE-FTS	SCISAT-1	12/08/2003	Marginal	Y	-	-	
	AIUS	GF-5	2018	Marginal	?	-	-	
Other	ATOVS (HIRS/3 + AMSU + AVHRR/3)	NOAA-15	01/05/1998	None	Y	-	-	Instrument combination not listed as such in OSCAR

6.2 CH_4

6.2.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis, it is important to know if the ECV Inventory content on Methane (CH_4) data records is close to complete. To assess this, other inventories of data records that are used to support climate science and services, e.g., the data sets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) activity and other similar ones, were interrogated. In addition, investigations into required data records from new major climate programmes / projects that weren't active at the time of information collection, e.g., the EUMETSAT AC SAF CDOP 3 (www-acsaf.org) plans and the ESA CCI (http://cci.esa.int/), were made. No additional data records were found.

6.2.2 Assessment against GCOS criteria

For the purposes of climate analysis, GCOS (2011, 2016) defines requirements for methane (CH_4) tropospheric column, tropospheric and stratospheric profiles. In these definitions, the distinction between tropospheric and stratospheric is not explicitly defined. Table 6 summarizes the GCOS requirements for space-based CH_4 observations.

Table 6: GCOS Systematic Satellite Requirements for CH_4

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability/ Decade
Tropospheric CH column	5-10 km	N/A	4 h	10 ppb	2 ppb
Tropospheric CH	5-10 km	5 km	4 h	10 ppb	2 ppb
Stratospheric CH	100-200 km	2 km	Daily	5%	0.30%

In general, GCOS requirements are not achievable with historical instruments. More current datasets are generally more compliant, but none fully meet the meet the accuracy and resolution requirements listed in Table 6. Some of these datasets that are not yet completely validated, but many are available through the ESA Greenhouse Gas Climate Change Initiative.

Not all space-based observations of CH_4 provide constraints on the "Tropospheric CH_4 column" nor do they provide the accuracy needed to address the detection of sources and sinks; the main focus for space-based measurements of CH_4 is cited in GCOS (2011). Measurements acquired at TIR wavelengths provide a coarse CH_4 (mole fraction) profile with about 1-2 degrees of freedom and peak sensitivity in the middle-to-upper troposphere, but have little sensitivity near the surface, where most CH_4 sources are located. Observations retrieved from SWIR observations provide XCH_4, the column-averaged dry-air mole fraction of CH_4, a total column value with roughly uniform sensitivity throughout the troposphere and declining sensitivity above. While neither TIR nor SWIR provide the "tropospheric CH_4 column" exactly, the SWIR observations more closely address the detection of sources and sinks. Furthermore, none of these missions meet the GCOS ECV requirements for horizontal resolution (interpreted here as the footprint size and sampling distance). The exact vertical coverage of the Stratospheric CH_4 measurements is not specified in the GCOS requirements, but the vertical resolution of 2 km can best be addressed by instruments that observe the limb. Lastly, to achieve truly global coverage, measurements acquired from LEO, GEO or other types of orbit will have to be harmonised and combined.

6.2.2.1 Tropospheric CH_4 Profile

There are 10 current and 8 future data records in the ECV Inventory related to the Tropospheric CH_4 Profile. For the future, four global data records covering the period up to 2021 are committed, the remaining future data records are new releases of historical data.

For current data records, the fulfilment of the GCOS criteria shown in Figure 20 is less good compared to the average for atmospheric ECVs. Particular weaknesses are that metadata standards are not applied, adherence to GCOS guidelines are not reviewed, there is a rather poor level of documentation, and the criteria for accuracy and stability cannot be met as explained above. For future data records (Figure 21), there is an indication of improvement in the use of the planned data records compared to the existing ones.

In the case of the current data records, links to important information and documentation can be patchy or inaccessible. Accuracy and stability for both current and future datasets is also a problematic area. However, the data record entries for Tropospheric CH_4 Profile are scientifically sound and fit their intended use, although the current data records are not fully compliant to GCOS requirements.

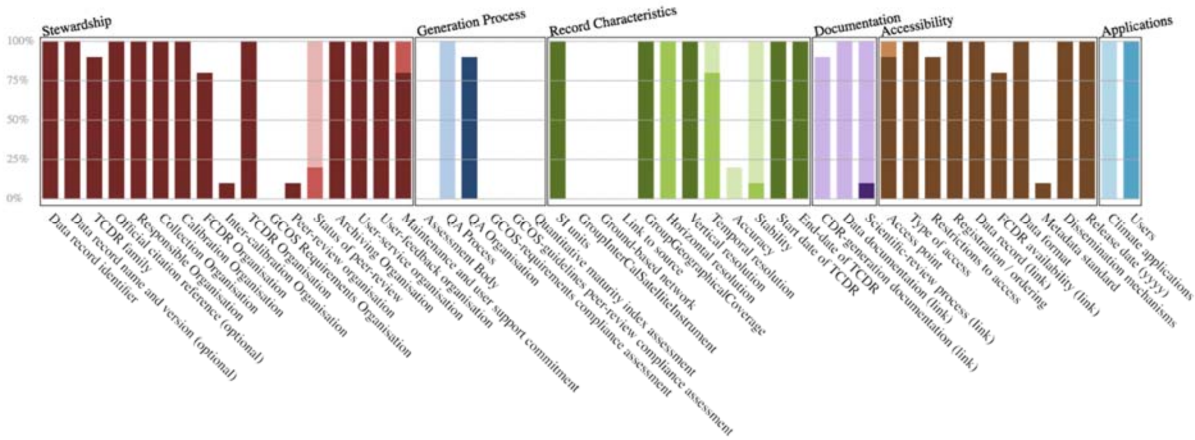

Figure 20: Assessment of current Tropospheric CH_4 profile data records in the ECV Inventory against GCOS criteria.

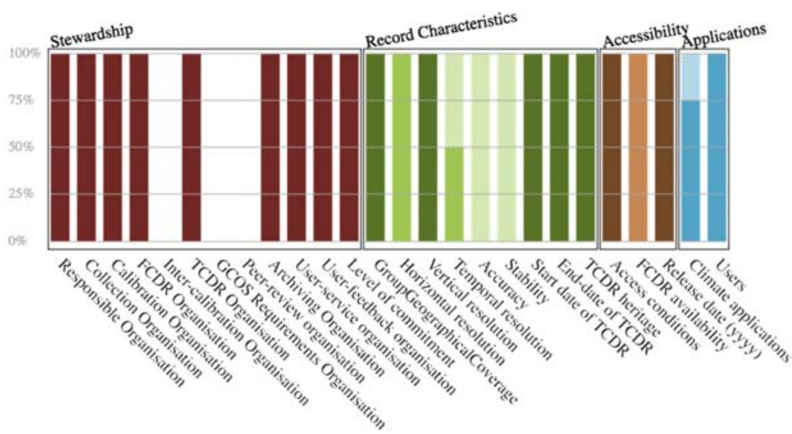

Figure 21: Assessment of future Tropospheric CH_4 data records in the ECV Inventory against GCOS criteria.

6.2.2.2 Tropospheric CH_4 Column[5]

There are 8 current and 7 future data records in the ECV Inventory related to the Tropospheric CH_4 Column. The future data records are new releases of historical data.

For current data records, there is generally a weakness with respect to the fulfilment of GCOS criteria as shown in Figure 22. In particular no FCDR seems to be available for any of the existing CH_4 data records, or the community uses a different nomenclature and does not understand the meaning of FCDR. In addition, GCOS guidelines play no role in the generation of CH_4 data records; this should be changed in the future. Accuracy and stability requirements are not met as explained above. For future data records, the unavailability of FCDRs is an ongoing concern.

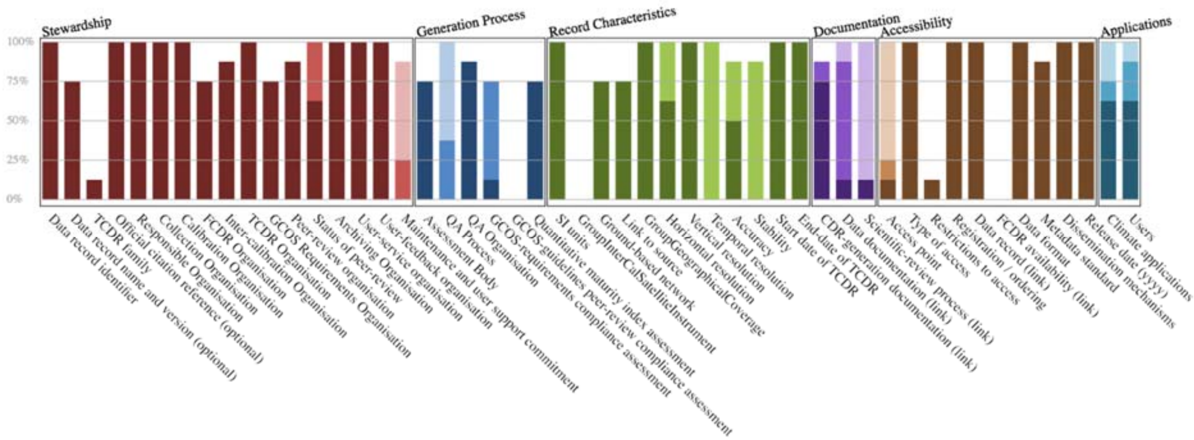

Figure 22: Compliance of current Tropospheric CH_4 column data records in the ECV Inventory with GCOS requirements.

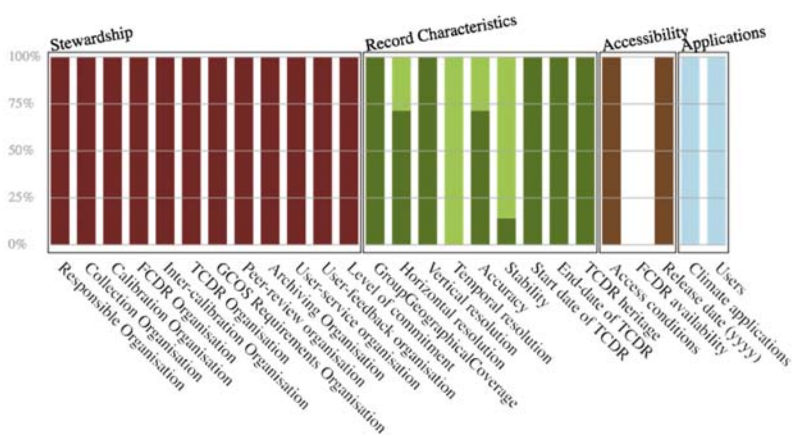

Figure 23: Compliance of future Tropospheric CH_4 column records in the ECV Inventory with GCOS requirements.

Another area for concern is the lack of commitment to this data record type that covers the period post 2016.

[5] The 20th AOPC has decided to rename this to Total CH_4 Column in the future.

6.2.2.3 Stratospheric CH_4 Profile

There is only 1 current data record in the ECV Inventory related to the Stratospheric CH_4 Profile. The sparsity of total entries for the Stratospheric CH_4 Profile, and the lack of committed data records that cover the period post 2015, is an area for concern.

The data record does not fulfil many of GCOS criteria (Figure 24). In particular there is generally not much accessible information available on the generation and quality assessment process. However, the data record seems complete and fit for its intended use.

Recommendation #12: *The AC-VC to develop a plan to address the measurement of stratospheric CH_4 profiles in order to fill the gap for the related FCDR/CDRs.*

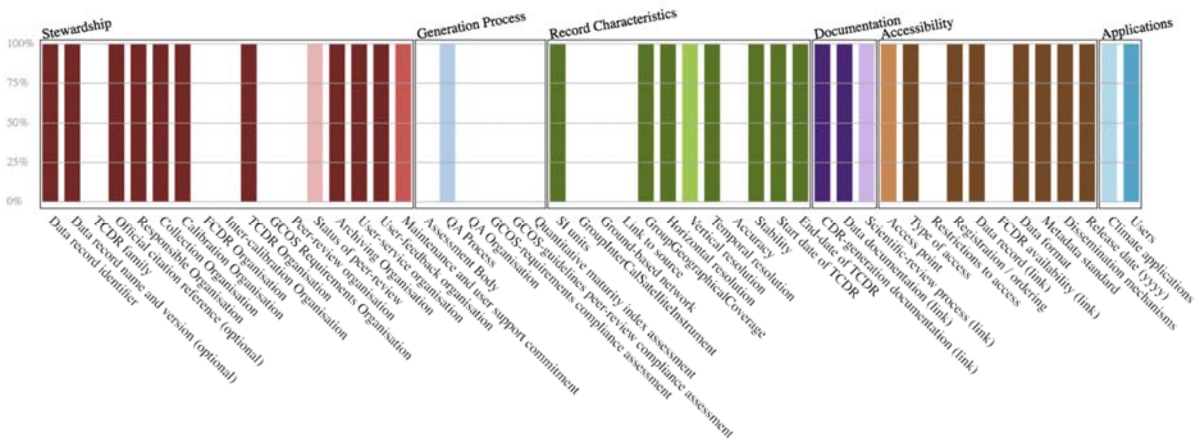

Figure 24: Compliance of current Stratospheric CH_4 profile data records in the ECV Inventory with GCOS requirements.

6.2.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 7 contains a list of instruments, missions on which the instruments were flown, and the mission launch and end of life dates. The information in this table is based on the CEOS MIM database with many updates from the WMO OSCAR database, mainly because CEOS MIM misses all missions with launch dates prior to 1984.

The content of Table 7 is cross-referenced with the content of the ECV Inventory on CH_4. Table 7 also provides detail on which instruments / missions are used to generate the CDRs housed within the ECV Inventory.

A missed opportunity could be the 10-year time series of CH_4 retrievals from the MIPAS instrument has not yet reached the level of a climate data record.

6.2.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Table 8 contains a list of instruments that are planned, or are currently flying, and which can be used to monitor CH_4. Whereas a couple of future data records are committed for ongoing measurements such as from IR sounders as IASI and AIRS, for most of the future measurements no commitments to produce climate data records seem to be in place. Thus it is recommended:

Recommendation #13: *Agencies to plan for the generation of tropospheric column CH_4 ECV data records based on the data collected by instruments on missions such as Sentinel-5P, MERLIN, GeoCarb, Sentinel-5, FY-3D, GOSAT-2.*

Table 7: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM with some additions imported from WMO Oscar. Table includes usage of instruments for CDRs currently found within the ECV inventory.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for CH_4	CEOS relevance for CH_4	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cloud and precipitation radar	CPR	CloudSat	28/04/2006	2017	None	N	2	-	Relevance of CPR CDRs in the ECV Inventory questionable.
Cross-track nadir thermal infrared (TIR) sounder	TES-nadir	Aura	15/07/2004	2018	High	Y	-	-	
	IASI	Metop-A Metop-B	19/10/2006 17/09/2012	2018 2018	Fair	Y	3 -	1 -	
	IMG	ADEOS	17/08/1996	30/06/1997	Fair	N	-	-	
	TANSO-FTS	GOSAT	23/01/2009	2018	Fair	Y	5	6	GOSAT has both TIR and SWIR
	IKFS-2	Meteor-3M Meteor-M N2	01/12/2001 08/07/2014	01/04/2000 09/07/2014	Marginal	Y	- -	- -	IKFS-2 in OSCAR appears as IFKS in MIM.
	AIRS	Aqua	04/05/2002	2018	None	Y	10	8	
Cross-nadir scanning shortwave infrared (SWIR) sounder	SCIAMACHY -nadir	Envisat	01/03/2002	08/04/2012	Fair	Y	2	2	Weekly, monthly, seasonal averages only.
	TANSO-FTS	GOSAT	23/01/2009	2018	Fair	Y	5	6	GOSAT has both TIR and SWIR
Limb sounder	MIPAS	Envisat	01/03/2002	08/04/2012	High	Y	-	-	
	ACE-FTS	SCISAT-1	12/08/2003	2018	Marginal	Y	-	-	
	ILAS-I	ADEOS	17/08/1996	30/06/1997	Marginal	Y	-	-	ILAS-I in OSCAR appears as ILAS in MIM
	HALOE	UARS	15/09/1991	14/12/2005	None	Y	-	-	
	HiRDLS	Aura	15/07/2004	2008	None	Y	- -	- -	HIRDLS stopped taking data on March 17 2008 due to failure of the chopper unit.
	HRDI	UARS	15/09/1991	14/12/2005	None	Y	-	-	
	ILAS-II	ADEOS-II	01/11/2002	24/10/2003	None	Y	-	-	
	MLS	UARS	15/09/1991	14/12/2005	None	Y	-	-	

Table 8: CH_4-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to CEOS-MIM and WMO OSCAR.

Technology	Instrument	Mission	Launch	WMO relevance for CH_4	CEOS relevance for CH_4	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cloud and precipitation radar	CPR	CloudSat	28/04/2006	None	N	2	-	Relevance of CPR CDRs in the ECV Inventory questionable.
Cross-track nadir thermal infrared (TIR) sounder	IASI-NG	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	High	N	- - -	- - -	
	TES-nadir	Aura	15/07/2004	High	Y	-	-	
	IASI	Metop-A Metop-B Metop-C	19/10/2006 17/09/2012 2018	Fair	Y	3 - -	1 - -	
	IKFS-3	Meteor-MP N1 Meteor-MP N2	2026 2027	Fair	Y	- -	- -	KFS-3 in OSCAR appears as Advanced IFKS-2 in MIM.
	IRFS-GS	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	Fair	N	- - -	- - -	
	IRS	MTG-S1 MTG-S2	2023 2031	Fair	N	- -	- -	
	TANSO-FTS	GOSAT	23/01/2009	Fair	Y	5	6	GOSAT has both TIR and SWIR
	TANSO-FTS-2	GOSAT-2	2019	Fair	Y			GOSAT-2 has both TIR and SWIR
	IKFS-2	Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	2018 2020 2021 2022 2023	Marginal	Y	- - - - -	- - - - -	IKFS-2 in OSCAR appears as IFKS in MIM.
	AIRS	Aqua	04/05/2002	None	Y	10	8	
	GeoCarb	GeoCarb	2021	Primary	N	-	-	

Technology	Instrument	Mission	Launch	WMO relevance for CH_4	CEOS relevance for CH_4	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-nadir scanning shortwave infrared (SWIR) sounder	GMI	GF-5	2018	Very High	N	-	-	
	TANSO-FTS	GOSAT	23/01/2009	Very High	Y			GOSAT has both TIR and SWIR
	TANSO-FTS-2	GOSAT-2	2018	Very High	Y			GOSAT-2 has both TIR and SWIR
	GAS	FY-3D FY-3G	14/11/2017 2021	High	N	- -	- -	
	Sentinel-5	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3 Sentinel-5 A Sentinel-5 B	2021 2028 2035 2021 2022	Fair	N	- - - - -	- - - - -	UVNS (Sentinel-5) in MIM listed as Sentinel-5 in OSCAR. Sentinel-5 is the instrument; MetOp SG-A the platform; the official denotation is Sentinel-5 and not UVNS (as in earlier phases).
	TROPOMI	Sentinel-5P	2017	Fair	N	-	-	
	ACS-nadir	Meteor-MP N1 Meteor-MP N2	2026 2027	Marginal	N	- -	- -	Use for CH_4 questionable
Limb sounder	ACS-limb	Meteor-MP N1 Meteor-MP N2	2026 2027	Fair	N	- -	- -	Use for CH_4 questionable
	ACE-FTS	SCISAT-1	12/08/2003	Marginal	Y	-	-	
	AIUS	GF-5	2018	Marginal	N	-	-	
Space lidar	IPDA lidar	MERLIN	2021	High	Y	-	-	

6.3 Precipitation

6.3.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis it is important to know if the ECV Inventory content on precipitation data records is close to complete. To assess this, other inventories of data records that are used to support climate science and services were interrogated, e.g., the datasets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) activity and the International Precipitation Working Group (IPWG) listing of precipitation datasets (http://www.isac.cnr.it/~ipwg/data/datasets.html).

The focused precipitation ECV subgroup identified 4 additional current data records that should be included in the inventory:

- GPCP 1DD V1.3 (NOAA/NCEI)
- GPCP SG V2.3 (NOAA/NCEI)
- TMPA V7 3-hourly (NASA)
- TMPA V7 monthly (NASA).

In addition, 7 further future data records were identified that should be included in the inventory:

- CMORPH V1.0 Bias-corrected (NOAA)
- GPCP Daily V3 (NASA)
- GPCP SG V3 (NASA)
- GPM-GSMaP V5 Standard Hourly (JAXA)
- IMERG V06 Final Run Half-hourly (NASA)
- Precipitation Radar Dataset Daily (JAXA)
- Precipitation Radar Dataset Monthly (JAXA).

[Note that GPCP is an activity of the GEWEX project, and the agencies named for the GPCP products denote funding contributions.]

Not all of the 11 current and future datasets proposed for inclusion in the ECV Inventory fully comply with the definition of CDR, but they may be used as a basis for generating multi-source precipitation CDRs. Their inclusion into the ECV Inventory will be discussed during the next population phase on a case-by-case basis. They have been considered in the following analysis of the missed opportunities and measurements.

6.3.2 Analysis against GCOS criteria

There are 11 current data records and 4 future data records listed in the ECV Inventory related to Precipitation. For the future data records in the present listing, one global data record covering the period to 2020 and one until 2019 are committed. Additionally, there is one non-global data record covering the period until 2021. The remaining future data record in the present listing is a new release of historical data. All 7 additional future data records mentioned above do not yet have a specific termination date assessed.

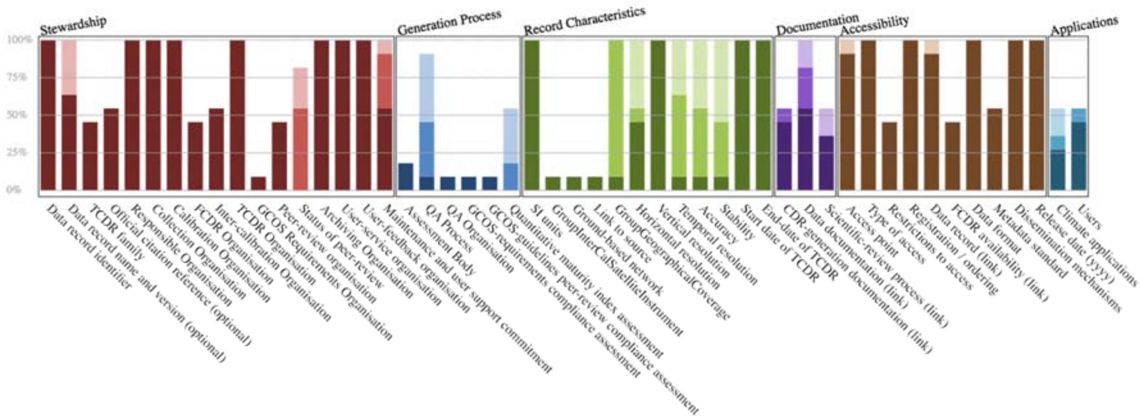

Figure 25: Assessment of current Precipitation data records in the ECV Inventory against GCOS criteria.

For current data records (shown in Figure 25), there is a clear weakness in the assessment against GCOS criteria. The availability of the FCDRs needed for precipitation data records is less compared to the overall result for atmospheric ECVs. This might be related to the fact that for some data records both geostationary IR and microwave measurements from polar orbit are needed, which results in a fairly high number of instruments needed for which an FCDR is required but potentially not available. In addition, five of the current data records utilise altimetry to retrieve precipitation over the ocean surface, whose nadir-only observations lack the horizontal and temporal resolutions that are specified in GCOS requirements. Despite the many ongoing validation and comparison activities for satellite-derived precipitation estimates, the generation process for climate data records seems the weakest part of currently existing precipitation data records as only for very few is there a distinct QA process in place and adherence to GCOS criteria is generally not assessed. Although precipitation is one of the ECVs with very high importance for society, the usage of satellite data records does not seem optimal. Many data providers can only determine a user community rather than specific users with verified usages.

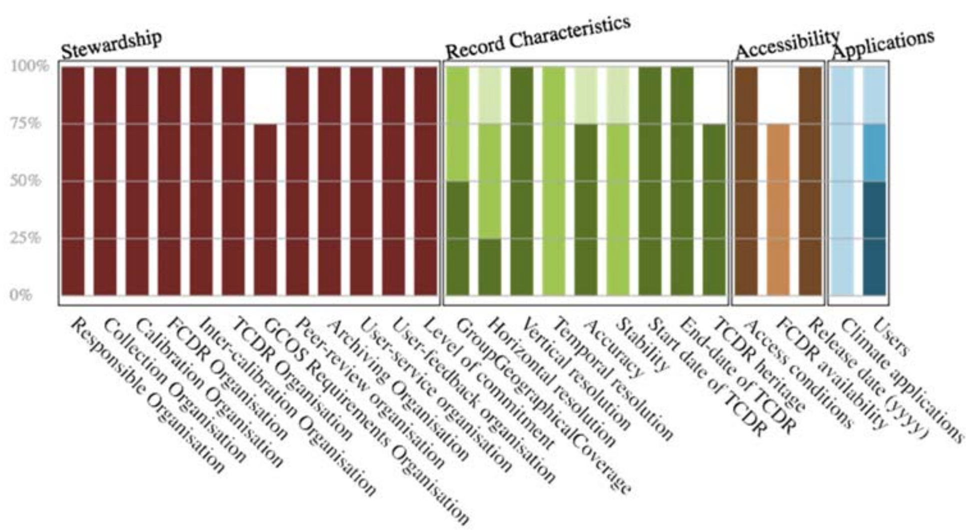

Figure 26: Assessment of future Precipitation data records in the ECV Inventory against GCOS criteria.

The current and future PERSIANN-CDR data records, all 4 of the additional current data records, and all 7 of the additional future data records are specifically designed to capture the local diurnal cycle of precipitation by creating frequent, evenly spaced estimates (time intervals of 3 hr or less), agreeing best with the GCOS requirement on temporal sampling.

In another dimension, the HOAPS, RSS DMSP, PERSIANN-CDR, and GPCP datasets are specifically designed to maximize the homogeneity that Climate Data Records require and address the GCOS stability criterion as best as currently possible.

For future data records (Figure 26), there is a general tendency towards an improvement against GCOS criteria. In particular, the availability of FCDRs appears strongly improved, and the usage scenarios and the assessment against GCOS criteria received higher marks.

The remaining TMPA, IMERG, CMORPH, and GSMaP datasets are High-Resolution Precipitation Products, meaning that they emphasise providing the best snapshot estimates, with homogeneity as an important, but not primary, design criterion. As such they do not comply with the definition of a CDR. Except for the TMPA products, which are aging out of the system and superseded by the IMERG products, all of these products are new or planned.

Additional work with the data providers is needed to determine their level of compliance with GCOS requirements, in particular the degree of stability that they show over time.

6.3.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 9 contains a list of instruments, missions on which the instruments were flown, and the mission launch and end of life dates. The information in this table is based on the CEOS MIM database with many updates from the WMO OSCAR database, mainly because CEOS MIM misses all missions with launch dates prior to 1984. The content of Table 9 **Error! Reference source not found.** is cross-referenced with the content of the ECV Inventory on Precipitation Table 9.also provides detail on which instruments / missions are used to generate the CDRs housed within the ECV Inventory, as well as suggestions for gaps in entries.

Table 9: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM with some additions imported from WMO Oscar. The table includes usage of instruments for CDRs currently found within the ECV inventory. Data records missing from the ECV Inventory but which should be present are denoted by C, c2, G, g2, g3, I, T for CMORPH V1, CMORPH V2, GSMaP, GPCP V2.3, GPCP V3, IMERG V6, TMPA V7, respectively. Repeated instances of abbreviations denote multiple datasets of that kind (usually as both short-interval and monthly products).

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cloud and precipitation radar	DPR	GPM Core	27/02/2014	2020	Primary	Y	-	- + GGII	
	PR	TRMM	27/11/1997	14/08/2014	Very High	N	- + TT	- + GGII	
	CPR	CloudSat	28/04/2006	2017	Fair	Y	-	-	
Cross-nadir infrared sounder	Sounder	GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	2018 2018 2020	None	Y	- - -	- - -	
	VAS	GOES-4 GOES-5 GOES-6 GOES-7	09/09/1980 22/05/1981 28/04/1983 26/02/1987	22/11/1988 18/07/1990 01/07/1989 11/01/1996	None	N	1 1 1 1	1 1 1 1	
Cross-track, special or non-scanning microwave radiometer	AMR	JASON-2 JASON-3	20/06/2008 17/01/2016	2018 2021	None	N	1 1	- -	
	JMR	JASON-1	07/12/2001	01/07/2013	None	N	1	-	
	SSM/T	DMSP-F13	24/03/1995	03/02/2015	None	N	1	-	
	TMR	TOPEX-Poseidon	10/08/1992	09/10/2005	None	N	1	-	
Microwave conical scanning radiometer	AMSR	ADEOS-2	14/12/2002	25/10/2003	Very High	N	-	-	very short record (10-month)
	AMSR-2	GCOM-W1	17/05/2012	2018	Very High	Y	- + C	- + c2GGII	
	AMSR-E	Aqua	04/05/2002	10/10/2011	Very High	Y	- + CTT	2 + c2GGII	
	GMI	GPM Core	27/02/2014	2020	Very High	Y	- + C	2 + c2GGII	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	MTVZA-GY	Meteor-M N1 Meteor-M N2 Meteor-M N2-1	17/09/2009 08/07/2014 17/09/2009	18/09/2014 2018 23/09/2014	Very High	Y	- - -	- - -	MTVZA in MIM appears to be MTVZA-GY in OSCAR
	MTVZA-OK (MW)	SICH-1M	24/12/2004	15/04/2006	Very High	N	-	-	
	TMI	TRMM	27/11/1997	08/04/2015	Very High	N	- + CTT	2 + c2GGII	
	MTVZA	Meteor-3M	10/12/2001	05/04/2006	High	N	-	-	
	MWRI	FY-3A FY-3B FY-3C	27/05/2008 04/11/2010 23/09/2013	05/06/2015 2018 2018	High	Y	- - -	- - -	
	SSMIS	DMSP-F16 DMSP-F17 DMSP-F18 DMSP-F19	18/10/2003 04/11/2006 18/10/2009 03/04/2014	2018 2018 2018 11/02/2016	High	Y	4 + CTT 4 + Cg2g2TT - + CTT - + CTT	3 + c2GGII 3 + c2GGg3g3II 3 + C2GGII 1 + C2GGII	SSMIS in OSCAR appears as SSM/IS in MIM
	WindSat	Coriolis	06/01/2003	2018	High	N	-	-	
	MADRAS	MEGHA-TROPIQUES	12/10/2011	26/01/2013	Fair	Y	-	-	
	MWI	HY-2A	15/08/2011	2018	Fair	N	-	-	MWI in OSCAR appears to be RAD in MIM
	SMMR	Nimbus-7 SeaSat	24/10/1978 27/06/1978	01/08/1994 10/10/1978	Fair	Y	- -	- -	
	SSM/I	DMSP-F08 DMSP-F10 DMSP-F11 DMSP-F12 DMSP-F13 DMSP-F14 DMSP-F15	18/06/1987 01/12/1990 28/11/1991 29/08/1994 24/03/1995 04/04/1997 12/12/1999	01/10/2006 24/10/1997 07/08/2000 13/10/2008 03/02/2015 2018 2018	Fair	Y	5 + g2g2 5 5 + Cg2g2TT 5 + CTT 5 + Cg2g2TT 5 + CTT 1 + CTT	2 + g3g3 2 3 + c2GGg3g3II 3 + c2GGII 3 + c2GGg3g3II 3 + c2GGII - + c2GGII	DMSP-F15 not “climate-stable” after 14/08/2006

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	Delta-2D	Okean-O-1	17/07/1999	15/09/2000	Marginal	N	-	-	
	SHF	Meteor-P1 Meteor-P2 Meteor-P3 Meteor-P6	09/07/1974 15/05/1976 29/07/1977 10/07/1981	09/07/1976 15/05/1978 29/07/1979 10/07/1983	Marginal	N	- - - -	- - - -	
Microwave cross-track scanning radiometer	ATMS	SNPP	28/10/2011	2018	Very High	Y	- + C	- + c2GGII	
	MWHS-2	FY-3C	23/09/2013	2018	High	N	-	-	
	AMSU-A	Aqua Metop-A Metop-B NOAA-15 NOAA-16 NOAA-17 NOAA-18 NOAA-19	04/05/2002 19/10/2006 17/09/2012 13/05/1998 21/09/2000 24/06/2002 20/05/2005 06/02/2009	14/10/2017 2018 2018 14/09/2010 09/06/2014 10/04/2013 2018 2018	Fair	Y	- + Cg2g2TT - + CTT - + CTT - + CTT - + CTT - + CTT - + CTT - + CTT	- + c2GGg3g3II - + c2GGII - + c2GGII - + c2GGII - + c2GGII - + c2GGII - + c2GGII - + c2GGII	
	AMSU-B	NOAA-15 NOAA-16 NOAA-17	13/05/1998 21/09/2000 24/06/2002	14/09/2010 09/06/2014 10/04/2013	Fair	Y	- + CTT - + CTT - + CTT	- + c2GGII - + c2GGII - + c2GGII	
	HSB	Aqua	04/05/2002	12/02/2003	Fair	N	-	-	Short-lived
	MHS	Metop-A Metop-B NOAA-18 NOAA-19	19/10/2006 17/09/2012 20/05/2005 06/02/2009	2018 2018 2018 2018	Fair	N	- + CTT - + CTT - + CTT - + CTT	- + c2GGII - + c2GGII - + c2GGII - + c2GGII	
	MWHS-1	FY-3A FY-3B	27/05/2008 05/11/2010	05/06/2015 2018	Fair	N	- -	- -	
	MWTS-2	FY-3C	23/09/2013	2018	Fair	N	-	-	
	SAPHIR	MEGHA-TROPIQUES	12/10/2011	26/01/2013	Fair	N	-	- + II	
	SSM/T-2	DMSP-F11 DMSP-F12 DMSP-F14	28/11/1991 29/08/1994 04/04/1997	07/08/2000 13/10/2008 2018	Fair	N	- - -	- - -	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		DMSP-F15	12/12/1999	2018			-	-	
Moderate-resolution optical imager	ABI	GOES-16	04/11/2016	2027	Fair	Y	-	- + c2GGg3g3ll	
	AGRI	FY-4A	10/12/2016	2021	Fair	N	-	-	MCSI in MIM appears to be AGRI in OSCAR
	AHI	Himawari-8 Himawari-9	07/10/2014 02/11/2016	2029 2031	Fair	N	- + Cg2g2TT - + Cg2g2TT	- + c2GGg3g3ll - + c2GGg3g3ll	
	IMAGER	INSAT-3D INSAT-3DR	25/07/2013 08/09/2016	2021 2024	Fair	N	- -	- -	
	SEVIRI	Meteosat-8 Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	28/08/2002 15/09/2016 21/12/2005 05/07/2012 15/07/2015	04/07/2016 2019 2019 2019 2022	Fair	Y	1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT - + Cg2g2TT	2 + c2GGg3g3ll - + c2GGg3g3ll 2 + c2GGg3g3ll 1 + c2GGg3g3ll 1 + c2GGg3g3ll	Question the inclusion of these CDRs in ECV Inventory for precipitation
	IMAGER	GOES-8 GOES-9 GOES-9 (GMS backup) GOES-10 GOES-10 (S- America) GOES-11 GOES-12 GOES-12 (S- America) GOES-13 GOES-14 GOES-15 Himawari-7 (MTSAT-2)	13/04/1994 23/05/1995 22/05/2003 25/04/1997 01/12/2006 03/05/2000 23/07/2001 10/05/2010 24/05/2006 27/06/2009 04/03/2010 18/02/2006	05/05/2004 22/05/2003 24/07/2006 01/12/2006 02/12/2009 05/12/2011 10/15/2010 16/08/2013 2018 2018 2020 2018	Marginal	Y	1 + g2g2 1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT 1 + Cg2g2TT	2 + g3g3 2 + c2GGg3g3ll - + c2GGg3g3ll 2 + c2GGg3g3ll - + c2GGg3g3ll 2 + c2GGg3g3ll 2 + c2GGg3g3ll - + c2GGg3g3ll 2 + c2GGg3g3ll 1 + c2GGg3g3ll 2 + c2GGg3g3ll 2 + c2GGg3g3ll	Question the inclusion of these CDRs in ECV Inventory for precipitation

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	JAMI	Himawari-6 (MTSAT-1R)	26/02/2005	04/12/2015	Marginal	N	1 + Cg2g2TT	2 + c2GGg3g3lI	
	MI	COMS-1	26/06/2010	31/03/2018	Marginal	Y	-	-	
	MSU-GS	Electro-L N1 Electro-L N2	20/01/2011 11/12/2015	2016 2022	Marginal	N	- -	- -	
	MVIRI	Meteosat-1 Meteosat-2 Meteosat-3 Meteosat-3 (ADC) Meteosat-3 (X-ADC) Meteosat-4 Meteosat-5 Meteosat-5 (IODC) Meteosat-6 Meteosat-6 (IODC) Meteosat-7 Meteosat-7 (IODC)	23/11/1977 19/06/1981 15/07/1988 01/08/1991 01/02/1993 06/03/1989 02/03/1991 01/06/1998 20/11/1993 27/04/2007 02/09/1997 05/12/2006	24/11/1979 02/12/1991 01/08/1991 01/02/1993 22/11/1995 08/11/1995 01/06/1998 26/04/2007 27/04/2007 15/04/2011 05/12/2006 01/02/2017	Marginal	N	- 1 + g2g2 1 + g2g2 - + g2g2 - + g2g2 1 + g2g2 1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT	- 1 + g3g3 1 + g3g3 - + g3g3 - + g3g3 1 + g3g3 1 + c2GGg3g3lI - + c2GGg3g3lI 1 + c2GGg3g3lI - + c2GGg3g3lI 2 + c2GGg3g3lI - + c2GGg3g3lI	Question the inclusion of these CDRs in ECV Inventory for precipitation
	S-VISSR	FY-2A FY-2B FY-2C FY-2D FY-2E FY-2F FY-2G	10/06/1997 25/06/2000 19/10/2004 08/12/2006 23/12/2008 13/01/2012 31/12/2014	08/04/1998 01/02/2006 23/11/2009 01/07/2015 2018 2018 2018	Marginal	Y	- - 1 - 1 - -	- - 1 - 1 - -	IVISSR in MIM appears to be S-VISSR in OSCAR
	STR	Electro-GOMS	31/10/1994	15/11/2000	Marginal	N	-	-	
	VHRR	ATS-6 INSAT-1A	30/04/1974 10/04/1982	03/08/1979 06/09/1982	Marginal	Y	- -	- -	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		INSAT-1B INSAT-1C INSAT-1D INSAT-2A INSAT-2B INSAT-2D INSAT-2E KALPANA-1 INSAT-3A	30/08/1983 22/07/1988 12/06/1990 10/07/1992 27/03/1993 04/06/1997 03/04/1999 12/09/2002 10/04/2003	15/07/1993 22/11/1989 14/05/2002 10/07/1999 27/03/2000 04/10/1997 04/05/2011 09/12/2016 10/11/2017			- - - - - - - - -	- - - - - - - - -	
	VISSR	Himawari-1 (GMS-1) Himawari-2 (GMS-2) Himawari-3 (GMS-3) Himawari-4 (GMS-4) Himawari-5 (GMS-5) GOES-1 GOES-2 GOES-3 SMS-1 SMS-2	14/07/1977 11/08/1981 03/08/1984 06/09/1989 18/03/1995 16/10/1975 16/06/1977 16/06/1978 17/05/1974 06/02/1975	30/06/1989 20/11/1987 22/06/1995 24/02/2000 21/07/2005 07/03/1985 01/07/1993 01/07/1993 21/01/1981 05/08/1982	Marginal	N	1 + g2g2 1 + g2g2 1 + g2g2 1 + Cg2g2TT 1 + Cg2g2TT 1 + g2g2 1 + g2g2 1 + g2g2 1 1	1 + g3g3 1 + g3g3 1 + g3g3 1 + c2GGg3g3ll 1 + c2GGg3g3ll 1 + g3g3 1 + g3g3 1 + g3g3 1 1	
	AVHRR/3	Metop-A Metop-B NOAA-15 NOAA-16 NOAA-17 NOAA-18 NOAA-19	19/10/2006 17/09/2012 13/05/1998 21/09/2000 24/06/2002 20/05/2005 06/02/2009	2018 2018 2018 09/06/2014 10/04/2013 2018 2018	None	Y	- - - - - - -	- + c2 - + c2 - + c2 - + c2 - + c2 - + c2 - + c2	
	MSU-GS	Electro-L N1 Electro-L N2	20/01/2011 11/12/2015	2016 2022	None	Y	- -	- -	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	MSU-MR	Meteor-3M Meteor-M N2	01/12/2001 08/07/2014	05/04/2006 2019	None	Y	- -	- -	
Radar Altimeter	AltiKa	SARAL	25/02/2013	2018	None	N	1	-	

The precipitation subgroup identified four classes of missed opportunities in current data records:

1. The altimeter-based products are largely unknown to the precipitation community. Depending on their quality, they might provide useful correlative evaluation of the swath and gridded products, at least in a climatological sense.
2. Current-generation products focus on using data from European, Japanese, and U.S. satellites, but not those from other agencies, other than the joint French-Indian Megha-Tropiques mission. A series of technical and administrative issues would need to be addressed to change this situation.
3. Some low-orbit satellites provide IR, visible, and other channels, typified by the AVHRR instrument. These data are largely unused due to the easier application of similar geosynchronous satellite channels. However, it has recently been shown that these low-orbit data have potential utility for precipitation estimation in high latitudes, where the geosynchronous satellite footprints are too distorted to be useful. The CMORPH group is currently actively studying this issue.
4. Potentially, SMMR data could be used to estimate precipitation in the years leading up to the “modern” microwave era initiated by the DMSP SSMI series in 1987. This is only a potential opportunity, since there are known technical problems with the SMMR, not the least being access to Level 0 (original satellite record) datasets. The goal of applying modern algorithm concepts to the SMMR data would be to generate precipitation data that could provide time/space-varying calibration for the more-numerous IR data, similar to the role of the DMSP SSMI/SSMIS in the GPCP product.

6.3.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

The current and planned constellation of precipitation-relevant satellites that can provide future observations is summarised in Table 10. Numerous doubts exist about continuity, particularly for the conically scanning, multi-channel passive microwave radiometers, the majority of which were provided through the DMSP SSMI/SSMIS series, which is now ending. The U.S. DoD is now embarking on the DWSS, but the number of satellites and the capabilities of its MIS are not yet well-known. Additionally, EUMETSAT will be hosting the MWI on the METOP-SG. It is not yet clear whether the HOAPS and RSS DMSP-based datasets will be able to smoothly include these new sensors. It is also not yet clear whether the DWSS will fly in the 6 a.m./6 p.m. orbit that GPCP has used as a consistent calibrator since 1987 for both the SSMI and SSMIS series, or whether an agency might step into that critical slot.

Overall, with the current plans, the number of microwave sensors will decline over the next decade, likely depriving CMORPH, GSMaP, IMERG, and their successors of the number of samples necessary to confidently provide fine-scale precipitation estimates. The generally accepted sampling is one estimate in 3 hours or less at least 90% of the time. Such fine-scale estimates are a priority for climate, not just “weather” because a) precipitation is an inherently small-scale process, and even monthly averages can be significantly degraded if there are too few observations; and b) “climate” increasingly deals with extremes and the interesting extremes are the relatively fine-scale (say, daily 0.25°x0.25° values) events, not the classic monthly 5°x 5°.

Finally, although GPM is currently approved into 2020, it is expected to function into the late 2020s. By the end of that time, a next-generation non-Sun-synchronous precipitation observatory, very likely including a precipitation radar and a passive microwave radiometer, is a high priority for the precipitation community to continue the critical time- and location-dependent inter-satellite calibration of all the passive microwave sensors to the high-quality standard necessary for precipitation retrieval.

An expanded list of datasets as referenced in Table 9 and Table 10, and listed in the ECV Inventory, would provide several long-term, quasi-global, publicly available multi-mission precipitation datasets that have clear or potential relevance to climate. Such datasets are still undergoing vigorous research, development, and testing, so there is certainly room for additional projects to explore alternatives for making progress.

One key fact is that all of the multi-mission products rely on retrievals from individual sensors (or sometimes combinations of co-located sensors). Progress in skill for the multi-mission products is (in large part) determined by continued advancement in the individual sensor algorithms. An additional key fact is that the long record of precipitation-relevant satellite data is not homogeneous – the earlier sensors are less capable, and even current sensors “see” different precipitation systems due to observation time differences and sensor capabilities. So, creating long-term records puts a premium on tuning or adapting algorithms to the strengths of the various sensors. It should also be noted that “precipitation” usually includes both “liquid” and “solid” precipitation, but some of the listed precipitation datasets may not estimate solid precipitation due to sensor capability. Although recent passive microwave instruments have high-frequency channels that should be capable of estimating solid precipitation, and GPM/DPR (precipitation radar) provides a reference to passive microwave instruments in high-latitude precipitation, retrieval accuracy of solid precipitation from passive microwave instruments is worse than that of liquid precipitation and requires improvement in the future.

Another aspect of multi-sensor algorithms is that the use of surface gauge data has been demonstrated to enhance the accuracy of the products. So, good access to long-term records of surface gauge data, with as much understanding of the installed gauge instruments as possible, should be considered an integral part of developing state-of-the-art ECV climate data records. Maintaining and strengthening the global surface precipitation gauge network, and concomitant open access to the resulting data, must be high priorities in order to ensure the best possible record of global precipitation.

Finally, we know that precipitation estimates provided by reanalyses are competitive with, or even exceed the skill of satellite-based observational estimates in certain regions. Specifically, reanalyses currently “win” in Polar Regions and even cold-season mid-latitude land regions. As a result, it is a fruitful area of research to meld observational and reanalysis estimates to take advantage of the strengths of each.

Recommendation #14: ***The CEOS Precipitation Virtual Constellation (P-VC) to further study the situation on precipitation climate data records taking into account the findings of WGClimate gap analysis report and to identify a way forward to stimulate the production of an improved precipitation CDR based upon the experiences gained with existing datasets. The P-VC should also consult with the CGMS-IPWG and WMO SCOPE-CM activity for the establishment of international collaboration for the development and production of such a CDR.***

Table 10: Precipitation-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to CEOS-MIM and WMO OSCAR. The table includes usage of instruments for CDRs currently found within the ECV inventory. Datasets that is are missing from the ECV Inventory but which should be present are denoted by C, c2, G, g2, g3, I, T for CMORPH V1, CMORPH V2, GSMaP, GPCP V2.3, GPCP V3, IMERG V6, TMPA V7 respectively. Repeated instances of abbreviations denote multiple datasets of that kind (usually as both short-interval and monthly products).

Technology	Instrument	Mission	Launch	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cloud and precipitation radar	DPR	GPM Core	27/02/2014	Primary	Y	-	- + GGII	
	Ku/KaPR	FY-3RM-1 FY-3RM-2	2020 2023	Primary	Y	- -	- -	Is PR in MIM Ku/KaPR in OSCAR?
	CPR	CloudSat EarthCARE	28/04/2006 2019	Fair	Y	- -	- -	
Cross-nadir infrared sounder	Sounder	GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	None	Y	- - -	- - -	
Cross-track, special or non-scanning microwave radiometer	AMR	JASON-2 JASON-3	20/06/2008 17/01/2016	None	N	1 1	- -	
High-resolution optical imager	HRMX-TIR	GISAT	2019	Marginal	N	-	-	
Microwave conical scanning radiometer	MIS	DWSS-1 DWSS-2	TBD TBD	Primary	N	- -	- + c2GGg3g3II - + c2GGII	
	AMSR-2	GCOM-W1	17/05/2012	Very High	Y	- + C	- + c2GGII	
	AMSR-2 f/o	GOST-3 (TBD)	2022 (TBD)	Very High	Y	-	- + c2GGII	
	GMI	GPM Core	27/02/2014	Very High	Y	- + C	2 + c2GGII	
	MTVZA-GY	Meteor-M N2 Meteor-M N2-2 Meteor-M N2-3	08/07/2014 2018 2020	Very High	Y	- - -	- - -	MTVZA in MIM appears to be MTVZA-GY in OSCAR

Technology	Instrument	Mission	Launch	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	2021 2022 2023			- - -	- - -	
	MTVZA-GY-MP	Meteor-MP N1 Meteor-MP N2 Meteor-MP N3	2026 2027 2028	Very High	Y	- - -	- - -	Advanced MTVZA in MIM appears to be MTVZA-GY-MP in OSCAR
	MW sounder	TROPICS	2019	High	N	-	- + c2GGII	
	ICI	METOP-SG B1 METOP-SG B2 METOP-SG B3	2022 2029 2036	N	Y	- - -	- + c2GGII - + c2GGII - + c2GGII	
	MWI	METOP-SG B1 METOP-SG B2 METOP-SG B3	2022 2029 2036	High	Y	- - -	- + c2GGII - + c2GGII - + c2GGII	
	MWRI	FY-3B FY-3C FY-3D FY-3F FY-3G FY-3RM-1 FY-3RM-2	04/11/2010 23/09/2013 14/11/2017 2019 2021 2020 2023	High	Y	- - - - - - -	- - - - - - -	
	SSMIS	DMSP-F16 DMSP-F17 DMSP-F18	18/10/2003 04/11/2006 18/10/2009	High	Y	4 + CTT 4 + Cg2g2TT - + CTT	3 + c2GGII 3+ c2GGg3g3II 3 + c2GGII	SSMIS in OSCAR appears as SSM/IS in MIM
	WindSat	Coriolis	06/01/2003	High	N	-	-	
	MWI	HY-2A HY-2B	15/08/2011 2017	Fair	N	- -	- -	MWI in OSCAR appears to be RAD in MIM
	SSM/I	DMSP-F14	04/04/1997	Fair	Y	5 + CTT	3 + c2GGII	
Microwave cross-track scanning radiometer	GeoSTAR	PATH	2030	Primary	Y	-	- + c2GGII	
	ATMS	SNPP NOAA-20	28/10/2011 08/01/2018	Very High	Y	- + C - + C	- + c2GGII - + c2GGII	

Technology	Instrument	Mission	Launch	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		JPSS-2 JPSS-3 JPSS-4	2022 2026 2031			- - -	- + c2GGII - + c2GGII - + c2GGII	
	MWS	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	Very High	Y	- - -	- + c2GGII - + c2GGII - + c2GGII	
	MWHS-2	FY-3C FY-3D FY-3E FY-3F FY-3G FY-3H	23/09/2013 14/11/2017 2018 2019 2021 2021	High	N	- - - - - -	- - - - - -	
	MWHS-2	FY-3RM-1 FY-3RM-2	2020 2023	High	N	- -	- -	
	AMSU-A	Aqua Metop-A Metop-B Metop-C NOAA-18 NOAA-19	04/05/2002 19/10/2006 17/09/2012 2018 20/05/2005 06/02/2009	Fair	Y	- + Cg2g2TT - + CTT - + CTT - + CTT - + CTT - + CTT	- + c2GGg3g3II - + c2GGII - + c2GGII - + c2GGII - + c2GGII - + c2GGII	Aqua AMSU-A non-functional as of 10/2017
	HSB	Aqua	04/05/2002	Fair	N	-	-	fragmentary record
	MHS	Metop-A Metop-B Metop-C NOAA-18 NOAA-19	19/10/2006 17/09/2012 2018 20/05/2005 06/02/2009	Fair	N	- + CTT - + CTT - + CTT - + CTT - + CTT	- + c2GGII - + c2GGII - + c2GGII - + c2GGII - + c2GGII	
	MWHS-1	FY-3B	05/11/2010	Fair	N	-	-	
	MWTS-2	FY-3C FY-3D FY-3E	23/09/2013 14/11/2017 2018	Fair	N	- - -	- - -	
	MWTS-3	FY-3F FY-3G	2019 2021	Fair	N	- -	- -	

Technology	Instrument	Mission	Launch	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		FY-3H	2021			-	-	
	MWTS-3	FY-3RM-1 FY-3RM-2	2020 2023	Fair	N	- -	- -	
	SAPHIR	MEGHA-TROPIQUES	12/10/2011	Fair	N	-	- + II	
	SSM/T-2	DMSP-F14 DMSP-F15	04/04/1997 12/12/1999	Fair	N	- -	- -	
Moderate-resolution optical imager	ABI	GOES-16 GOES-S GOES-T GOES-U	04/11/2016 01/03/2018 2020 2025	Fair	Y	- - - -	- + c2GGg3g3II - + c2GGg3g3II - + c2GGg3g3II - + c2GGg3g3II	
	AGRI	FY-4A FY-4B FY-4C FY-4D FY-4E FY-4F FY-4G	10/12/2016 2018 2020 2023 2027 2030 2033	Fair	N	- - - - - - -	- - - - - - -	MCSI in MIM appears to be AGRI in OSCAR
	AHI	Himawari-8 Himawari-9	07/10/2014 02/11/2016	Fair	N	- + Cg2g2TT - + Cg2g2TT	- + c2GGg3g3II - + c2GGg3g3II	
	AMI	GEO-KOMPSAT-2A	2018	Fair	Y	-	-	AMI in OSCAR appears as Advanced MI in MIM
	FCI	MTG-I1 MTG-I2 MTG-I3 MTG-I4	2020 2024 2028 2032	Fair	Y	- + Cg2g2TT - + Cg2g2TT - + Cg2g2TT - + Cg2g2TT	- + c2GGg3g3II - + c2GGg3g3II - + c2GGg3g3II - + c2GGg3g3II	
	IMAGER	INSAT-3D INSAT-3DR INSAT-3DS	25/07/2013 08/09/2016 2020	Fair	N	- - -	- - -	
	MSU-GSM	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	Fair	N	- - -	- - -	

Technology	Instrument	Mission	Launch	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	SEVIRI	Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	15/09/2016 21/12/2005 05/07/2012 15/07/2015	Fair	Y	- + Cg2g2TT 1 + Cg2g2TT - + Cg2g2TT - + Cg2g2TT	- + c2GGg3g3ll 2 + c2GGg3g3ll 1 + c2GGg3g3ll 1 + c2GGg3g3ll	Question the inclusion of these CDRs in ECV Inventory for precipitation
	GHI	FY-4B	2018	Marginal	N	-	-	
	IMAGER	GOES-13 GOES-14 GOES-15 Himawari-7 (MTSAT-2)	24/05/2006 27/06/2009 04/03/2010 18/02/2006	Marginal	Y	1 + Cg2g2TT - + Cg2g2TT 1 + Cg2g2TT 1 + Cg2g2TT	2 + c2GGg3g3ll 1 + c2GGg3g3ll 2 + c2GGg3g3ll 2 + c2GGg3g3ll	
	MI	COMS-1	26/06/2010	Marginal	Y	-	-	
	MSU-GS	Electro-L N1 Electro-L N2 Electro-L N3 Electro-L N4 Electro-L N5	20/01/2011 11/12/2015 2018 2020 2022	Marginal	N	- - - - -	- - - - -	
	S-VISSR	FY-2E FY-2F FY-2G FY-2H	23/12/2008 13/01/2012 31/12/2014 2018	Marginal	Y	1 - - -	1 - - -	IVISSR in MIM appears to be S-VISSR in OSCAR
	VHRR	INSAT-3A	10/04/2003	Marginal	Y	-	-	
	AVHRR/3	Metop-A Metop-B NOAA-18 NOAA-19	019/10/200 6 17/09/2012 20/05/2005 06/02/2009	None	Y	- - - -	- + c2 - + c2 - + c2 - + c2	
	METimage	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	None	Y	- - -	- + c2GGg3g3ll - + c2GGg3g3ll - + c2GGg3g3ll	
	MSU-GS	Electro-L N1 Electro-L N2	20/01/2011 11/12/2015	None	Y	- -	- -	

Technology	Instrument	Mission	Launch	WMO relevance for Precipitation	CEOS relevance for Precipitation	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		Electro-L N3 Electro-L N4 Electro-L N5	2018 2020 2022			- - -	- - -	
	MSU-GS/VE	Arctica-M N1 Arctica-M N2 Arctica-M N3 Arctica-M N4 Arctica-M N5	2019 2021 2023 2024 2025	None	Y	- - - - -	- - - - -	Mis-spelt as Arctic instead of Arctica in MIM. Instrument appears as MSU-GS/A in OSCAR and MSU-GS/VE in MIM.
	MSU-MR	Meteor-M N2 Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	08/07/2014 2018 2020 2021 2022 2023	None	Y	- - - - - -	- - - - - -	
	MVIRS	FY-3D FY-3E FY-3F FY-3G FY-3H FY-3RM-1 FY-3RM-2	14/11/2017 2018 2019 2021 2021 2020 2023	None	Y	- - - - - - -	- - - - - - -	Is MVIRS in MIM MERSI-2 in OSCAR?
Radar Altimeter	AltiKa	SARAL	25/02/2013	None	N	1	-	

6.4 Sea Surface Temperature

6.4.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis it is important to know if the ECV Inventory content on Sea Surface Temperature (SST) data records is close to complete. To assess this other inventories of data records that are used to support climate science and services, e.g., the data sets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips/activity) activity were interrogated, as well as the work of the SST community, e.g. the Group for High Resolution Sea Surface Temperature (GHRSST). In addition, required data records from new major climate programmes/projects that weren't active at the time of information collection, e.g., the EUMETSAT OSI SAF CDOP 3 (www.osi-saf.org) plans and the ESA CCI+ (http:// http://cci.esa.int/) were investigated.

There is one miss in the ECV Inventory, namely the WindSat SST data record provided by Remote Sensing Systems for existing SST data records; this may be included in the ECV Inventory during the next update. For the future, EUMETSAT has a new plan to provide a reprocessed SST data record from the IASI instruments onboard Metop A/B, and this will be added to the ECV Inventory as well during the next update.

6.4.2 Assessment against GCOS criteria

There are 16 current and 17 future data records in the ECV Inventory related to Sea Surface Temperature. For the future, four global data records are committed to cover the period until 2021, two until 2019, and three until 2018. The remaining eight data records are new releases of historical data.

There are some weaknesses in the assessment against GCOS criteria for current data records (see Figure 27). The Group for High Resolution Sea Surface Temperature (GHRSST) has maintained a CDR technical subgroup which has specified a Climate Data Assessment Framework (https://www.ghrsst.org/wp-content/uploads/2018/01/CDR-TAG_CDAF-v1.0.5.pdf) that could act as a peer-approved assessment process. However, only a minority of products so far point to a formal assessment. For most products, assessment against GCOS criteria and maturity matrix assessment are not provided.

A minority of products are linked to an *in situ* ("ground-based") network, which is incompatible with the fact that a large majority of SST products utilise methods tuned against the drifting buoy network.

The GCOS requirements on accuracy and stability are not reportedly achieved in most cases. This is likely because the accuracy requirement is not yet attainable using historical instruments nor with current Level 1 archives (not yet a harmonised FCDR) and methods for CDR generation. Even if achieved, historically the GCOS accuracy requirement would be hard to demonstrate against *in situ* observations because of their relatively high uncertainty, although efforts are now underway to trial improved drifting buoys and these may lead to future improvements on this point. It is difficult to demonstrate SST stability at the level of the GCOS requirement because no global multi-decadal fiducial reference network has been designed with the necessary stability: the nearest network for this purpose is the global tropical moored buoy arrays, although these are not optimally designed to be a satellite reference network (too deep) and are only in equatorial regions. For future data records, there is a tendency towards a general improvement of the assessment and compliance to GCOS requirements, although issues with the stability requirement remain (see Figure 28).

Some of the current data record entries do not have climate quality and applications as their focus, and these data records are not fully compliant with GCOS requirements. However, these data records are all scientifically sound, fit for their intended use and could be used for climate monitoring purposes, even if they do not fully meet the required accuracies and stabilities. There is commitment to the future monitoring of Sea Surface Temperature until 2021.

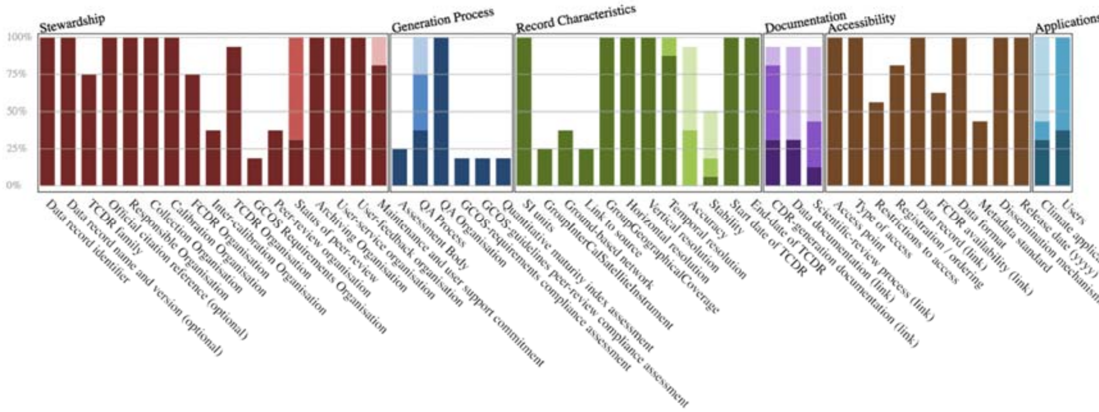

Figure 27: Compliance of current Sea Surface Temperature data records with GCOS requirements.

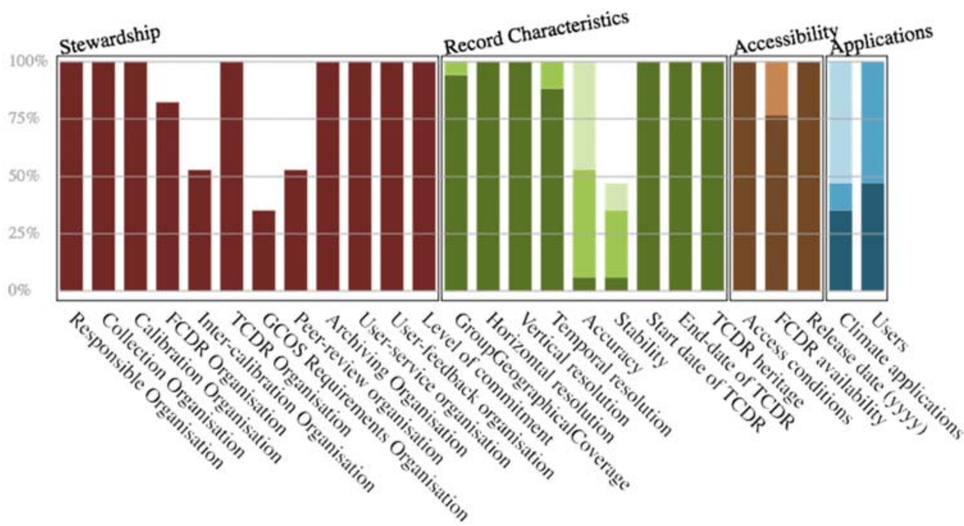

Figure 28: Compliance of future Sea Surface Temperature data records with GCOS requirements.

Table 11: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM with some additions imported from WMO Oscar. Table includes usage of instruments for CDRs currently found within the ECV inventory. Instruments are only kept in the table if they have been rated by WMO for Primary, Very High or High relevance for SST or if they have been or are planned to be used by data records in the ECV Inventory. The full information is part of the ECV Inventory and accessible for later analysis.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-nadir infrared sounder	IMG	ADOES	17/08/1996	30/06/1997	Primary	N	-	-	
	AIRS	Aqua	04/05/2002	2018	Primary	Y	9	8	No gaps in the use of AIRS.
	TES-nadir	Aura	15/07/2004	2018	Primary	N	-	-	
	IASI	Metop-A Metop-B	19/10/2006 17/09/2012	2018 2018	Primary	Y	- -	- -	EUMETSAT plans to release reprocessed SST in 2019
	CrIS	SNPP	28/10/2011	2018	Primary	N	-	-	
	GIIRS	FY-4A	10/12/2016	2021	Primary	N	-	-	
	HIRS/2	NOAA-6 NOAA-7 NOAA-8 NOAA-9 NOAA-10 NOAA-11 NOAA-12 NOAA-13 NOAA-14 TIROS-N	27/06/1979 23/06/1981 28/03/1983 12/12/1984 17/09/1986 24/09/1988 14/05/1991 09/08/1993 30/12/1994 13/10/1978	31/03/1987 07/06/2986 29/12/1985 13/02/1998 30/08/2001 16/06/2004 10/08/2007 21/08/1993 23/05/2007 27/02/1981	Very High	N	- - - - - - - - - -	- - - - - - - - - -	
	VAS	GOES-4 GOES-5 GOES-6 GOES-7	09/09/1980 22/05/1981 28/04/1983 26/02/1987	22/11/1988 18/07/1990 01/07/1989 11/01/1996	Very High	N	- - - -	- - - -	
	SOUNDER	GOES-8 GOES-9	13/04/1994 23/05/1995 22/05/2003 25/04/1997	05/05/2004 22/05/2003 24/07/2006 01/12/2006	Very High	Y	- - - -	- - - -	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		GOES-9 (GMS backup) GOES-10 GOES-10 (S-America) GOES-11 GOES-12 GOES-12 (S-America) GOES-13 GOES-14 GOES-15	01/12/2006 03/05/2000 23/07/2001 10/05/2010 24/05/2006 27/06/2009 04/03/2010	02/12/2009 05/12/2011 10/15/2010 16/08/2013 2018 2018 2020			- - - - - - -	- - - - - - -	
	HIRS/3	NOAA-15 NOAA-16 NOAA-17	01/05/1998 21/09/2000 24/06/2002	2018 09/06/2014 10/04/2013	Very High	Y	- - -	- - -	NOAA-15: Degraded since 31 March 2002, finally turned off on 6 June 2009 because of filter wheel stall.
	HIRS/4	NOAA-18 NOAA-19 Metop-A Metop-B	20/05/2005 04/02/2009 19/10/2006 17/09/2012	2018 2018 2018 2018	Very High	Y	- - - -	- - - -	NOAA-18: HIRS/4 noisy since 15 August 2005, finally declared unusable on 5 February 2009 NOAA-19: Noisy channels and unstable filter wheel. since 10 July 2013 Metop-B: HIRS/4 channels 13.97, 13.64 and 12.47 µm out of specs since August 2013.
	IRAS	FY-3A FY-3B FY-3C	27/05/2008 05/11/2010 23/09/2013	05 Jun 2015 2018 2018	Very High	Y	- - -	- - -	FY-3A: IRAS failed in October 2008
	Sounder	INSAT-3D	26/07/2013	2021	Very High	Y	-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		INSAT-3DR	08/09/2016	2024			-	-	
	IRIS-B	Nimbus-3	13/04/1969	22/01/1972	High	N	-	-	
	IRIS-D	Nimbus-4	08/04/1970	30/09/1980	High	N	-	-	
	TANSO-FTS	GOSAT-1	23/01/2009	2018	High	N	-	-	
	IKFS-2	Meteor-M N2	08/07/2014	2019	High	Y	-	-	IKFS-2 in OSCAR appears as IFKS in MIM.
Moderate-resolution optical imager	ATSR	ERS-1	17/05/1991	10/03/2000	Primary	N	2	2	Not in MIM. No gaps in use of ATSR.
	ATSR-2	ERS-2	21/04/1995	06/07/2011	Primary	N	2	2	Not in MIM. No gaps in use of ATSR-2.
	AATSR	Envisat	01/03/2002	08/04/2012	Primary	N	2	2	Not in MIM. No gaps in use of AATSR.
	SLSTR	Sentinel-3A	16/02/2016	2023	Primary	Y	-	-	
	AVHRR/2	NOAA-7 NOAA-9 NOAA-11 NOAA-12 NOAA-14	23/06/1981 12/12/1984 24/09/1988 14/05/1991 30/12/1994	07/06/1986 13/02/1998 16/06/2004 10/08/2007 23/05/2007	Very High	N	3 3 3 2 5	4 4 4 2 4	NOAA-7 not in MIM. No gaps in the use of AVHRR/2.
	MVISR (5 channels)	FY-1A FY-1B	07/09/1988 03/09/1990	16/10/1988 05/08/1991	Very High	N	- -	- -	
	MVISR (10 channels)	FY-1C FY-1D	10/05/1999 15/05/2002	26/04/2004 01/04/2012	Very High	N	- -	- -	
	Imager	GOES-8 GOES-9 GOES-9 (GMS backup) GOES-10 GOES-10 (S-America)	13/04/1994 23/05/1995 22/05/2003 25/04/1997 01/12/2006 03/05/2000 23/07/2001 10/05/2010	05/05/2004 22/05/2003 24/07/2006 01/12/2006 02/12/2009 05/12/2011 10/15/2010 16/08/2013	Very High	Y	- - - - - - - -	- - - - - - - -	Geostationary

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		GOES-11 GOES-12 GOES-12 (S-America) GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	2018 2018 2020			- - -	- - -	
	OCTS	ADEOS	17/08/1996	30/06/1997	Very High	N	-	-	
	VIIRS	SNPP	28/10/2011	2018	Very High	Y	-	-	
	VIRS	TRMM	27/11/1997	08/04/2015	Very High	N	-	-	
	AVHRR/3	NOAA-15 NOAA-16 NOAA-17 NOAA-18 NOAA-19 Metop-A Metop-B	13/05/1998 21/09/2000 24/06/2002 20/05/2005 06/02/2009 19/10/2006 17/09/2012	2018 09/06/2014 10/04/2013 2018 2018 2018 2018	Very High	Y	2 5 5 5 3 3 -	2 4 4 6 6 5 2	NOAA-17: AVHRR/3 turned off on October 2010 No gaps in the use of AVHRR/3.
	MODIS	Terra Aqua	18/12/1999 04/05/2002	2018 2018	Very High	Y	1 1	- -	MODIS not used in future CDRs; a possible gap or a miss of the ECV Inventory?
	GLI	ADEOS-2	14/12/2002	25/10/2003	Very High	N	-	-	
	SEVIRI	Meteosat-8 Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	28/08/2002 15/09/2016 21/12/2005 05/07/2012 15/07/2015	04/07/2016 2019 2019 2019 2022	Very High	Y	- - - - -	1 1 - - -	Geostationary Reprocessing of SEVIRI in future CDRs to fill in historical gaps?
	S-VISSR	FY-2A FY-2B FY-2C FY-2D FY-2E	10/06/1997 25/06/2000 19/10/2004 08/12/2006 23/12/2008	08/04/1998 01/02/2006 23/11/2009 01/07/2015 2018	Marginal Very High	Y	- - - - -	- - - - -	IVISSR in MIM appears to be S-VISSR in OSCAR

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		FY-2F FY-2G	13/01/2012 31/12/2014	2018 2018			- -	- -	
	JAMI	Himawari-6 (MTSAT-1R)	26/02/2005	04/12/2015	Very High	N	-	-	Geostationary
	IMAGER	Himawari-7 (MTSAT-2)	18/02/2006	2018	Very High	N	- -	- -	Geostationary MTSAT-2: IMAGER was in standby from 2006 to 30 June 2010. After 7 July 2015 is backup of Himawari-8, and used for rapid scanning.
	VIRR	FY-3A FY-3B FY-3C	27/05/2008 04/11/2010 23/09/2013	05/06/2015 2018 2018	Very High	Y	- - -	- - -	
	MSU-MR	Meteor-3M Meteor-M N1 Meteor-M N2	01/12/2001 17/09/2009 08/07/2014	05/04/2006 23/09/2014 2019	Very High	Y	- - -	- - -	
	MI	COMS-1	26/06/2010	2019	Very High	Y	-	-	
	MSU-GS	Electro-L N1 Electro-L N2	20/01/2011 11/12/2015	2016 2022	Very High	Y	- -	- -	
	IMAGER	INSAT-3D INSAT-3DR	26/07/2013 08/09/2016	2021 2024	Very High	N	- -	- -	
	AHI	Himawari-8 Himawari-9	07/10/2014 02/11/2016	2029 2031	Very High	Y	- -	- -	
	ABI	GOES-16	19/11/2016	2027	Very High	Y	-	-	
	MCSI	FY-4A	10/12/2016	2021	Very high	N	-	-	MCSI in MIM appears to be AGRI in OSCAR
	AVHRR	TIROS-N NOAA-6 NOAA-8	13/10/1978 27/06/1979 28/03/1983	27/02/1981 31/03/1987 29/12/1985	Fair	N	- - -	- - 2	Not in MIM.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		NOAA-10	17/09/1986	30/08/2001			-	2	Reprocessing of AVHRR in future CDRs to fill in historical gaps?
	VISSR	Himawari-1 (GMS-1) Himawari-2 (GMS-2) Himawari-3 (GMS-3) Himawari-4 (GMS-4) Himawari-5 (GMS-5) GOES-1 GOES-2 GOES-3 SMS-1 SMS-2	14/07/1977 11/08/1981 03/08/1984 06/09/1989 18/03/1995 16/10/1975 16/06/1977 16/06/1978 17/05/1974 06/02/1975	30/06/1989 20/11/1987 22/06/1995 24/02/2000 21/07/2005 07/03/1985 01/07/1993 01/07/1993 21/01/1981 05/08/1982	Marginal Fair	N	- - - - - - - - - -	- - - - - - - - - -	Geostationary
	VHRR	NOAA-2 NOAA-3 NOAA-4 NOAA-5 ATS-6 INSAT-1A INSAT-1B INSAT-1C INSAT-1D INSAT-2A INSAT-2B INSAT-2D INSAT-2E INSAT-3A KALPANA-1	13/10/1972 06/11/1973 15/11/1974 29/07/1976 30/04/1974 10/04/1982 30/08/1983 22/07/1988 12/06/1990 10/07/1992 27/03/1993 04/06/1997 03/04/1999 10/04/2003 12/09/2002	30/01/1975 31/08/1976 18/11/1978 16/07/1979 03/08/1979 06/09/1982 15/07/1993 22/11/1989 14/05/2002 30/05/2002 01/07/2004 04/10/1997 15/04/2012 01/09/2016 2018	Marginal	Y	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	ATS-6, INSAT and KALPANA satellites being geostationary

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	OLS	DMSP-F01	11/09/1976	17/09/1979	Marginal	N	-	-	
		DMSP-F02	04/06/1977	19/03/1978			-	-	
		DMSP-F03	30/04/1978	01/12/1979			-	-	
		DMSP-F04	06/06/1979	09/08/1980			-	-	
		DMSP-F06	21/12/1982	10/11/1997			-	-	
		DMSP-F07	18/11/1983	16/05/1988			-	-	
		DMSP-F08	18/06/1987	01/10/2006			-	-	
		DMSP-F09	03/02/1988	01/08/1994			-	-	
		DMSP-F10	01/12/1990	24/10/1997			-	-	
		DMSP-F11	28/11/1991	07/08/2000			-	-	
		DMSP-F12	29/08/1994	13/10/2008			-	-	
		DMSP-F13	24/03/1995	03/02/2015			-	-	
		DMSP-F14	04/04/1997	2018			-	-	
		DMSP-F15	12/12/1999	2018			-	-	
		DMSP-F16	18/10/2003	2018			-	-	
		DMSP-F17	04/11/2006	2018			-	-	
		DMSP-F18	18/10/2009	2018			-	-	
		DMSP-F19	03/04/2014	11/02/2016			-	-	
High-resolution optical imager	NIRST	SAC-D	10/06/2011	07/06/2015	High	N	-	-	
Microwave conical scanning radiometer	Windsat	Coriolis	06/01/2003	2018	Very High	N	1	-	Not in MIM as SST capability. A WindSat data record by Remote Sensing Systems is missing in the Inventory. Non continuation is a missed opportunity.
	MTVZA-OK (MW)	SICH-1M	24/12/2004	15/04/2006	Very High	N	-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	SMMR	SeaSat Nimbus-7	27/06/1978 24/10/1978	10/10/1978 01/08/1994	High	N	- 1	- 1	Not in MIM as SST capability. No gaps in use of SMMR.
	MSMR	OceanSat-1 (IRS-P4)	26/05/1999	08/08/2010	High	N	-	-	
	AMSR	ADEOS-2	01/11/2002	24/10/2003	High	N	-	-	
	AMSR-E	Aqua	04/05/2002	2018	High	Y	1	-	AMSR-E not used in future CDRs; a possible gap or a miss of the ECV Inventory?
	AMSR-2	GCOM-W1	17/05/2012	2018	High	Y	-	-	
	MWI	HY-2A	15/08/2011	2018	High	Y	-	-	There is an error in the instrument name in CEOS-MIM. It should MWI instead of RAD.
	SSM/I	DMSP-F08 DMSP-F10 DMSP-F11 DMSP-F13 DMSP-F14 DMSP-F15	18/06/1987 01/12/1990 28/11/1991 24/03/1995 04/04/1997 12/12/1999	01/10/2006 24/10/1997 07/08/2000 03/02/2015 2018 2018	None	N	2 1 2 2 1 1	2 1 2 2 1 1	In neither MIM nor OSCAR as SST capability. No gaps in use of SSM/I.
	SSMIS	DMSP-F17 DMSP-F18	04/11/2006 18/10/2009	2018 2018	None	N	3 1	2 1	In neither MIM nor OSCAR as SST capability No gaps in use of SSMIS.
Cloud and precipitation radar	CloudSat	CPR	28/04/2006	2018	None	N	1	-	In neither MIM nor OSCAR. CloudSat not used in future CDRs; maybe only used for cloud detection

6.4.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 11 contains a list of instruments including missions on which the instruments were flown and the mission launch and end of life dates, respectively. The information in this table is based on the CEOS MIM database with many updates from the WMO OSCAR database, mainly because CEOS MIM misses all missions with launch dates prior to 1984. The content of Table 11 is cross-referenced with the content of the ECV Inventory on sea surface temperature. Table 11 also provides detail on which instruments / missions are used to generate the CDRs housed within the ECV Inventory.

From the information in the ECV inventory, discontinued datasets that may affect the continuity of SST records include MODIS, AMSR-E/2, Windsat and CloudSat. MODIS and AMSR-E/2 are instruments that have primary importance in SST monitoring according to both OSCAR and MIM. Their lack of use in future data records is thus a possible missed opportunity. Windsat has primary capability in SST monitoring due to its C-band (6.8 GHz). As it does not hold significance in the MIM, it is questionable if its use in future SST CDR generation is a true missed opportunity or not. Cloudsat holds significance in SST monitoring in neither MIM nor OSCAR, so its lack of use in future CDR generation is probably not a missed opportunity.

The inventory does not have any data records that use geostationary imager data for producing SST climate data records. This may be considered a missed opportunity, assuming that geostationary radiances can be re-calibrated to decent quality levels and would improve temporal sampling, in particular of the diurnal cycle compared to imagers in polar orbit.

Cross-nadir IR sounders (e.g., HIRS/2) have very high relevance to SST according to MIM, but are not presently used in current or planned CDRs. Probably, non-use arises from the availability of moderate resolution imagers that better meet spatial resolution requirements. However, in view of the potential contribution of sounders to SST accuracy and stability (particularly in the earlier decades), non-use may here also represent a missed opportunity.

Microwave conical scanner data (C-Band) is not widely used in the construction of SST climate data records. There is no listed combined data record that uses IR and microwave data together, although global products (MW only and IR/MW combined) covering ~20 years of data do exist, e.g., http://www.remss.com/measurements/sea-surface-temperature/oisst-description/. Microwave SSTs provide increased coverage relative to IR systems, albeit with greater uncertainty. The potential benefits in using MW SSTs for ~20 years within a CDR exploiting the ~40 year record from IR SSTs needs to be better understood, bearing in mind the need for consistency and stability.

Recommendation #15: ***The SST-VC should foster further work on SST ECV products in regards to the improvements that may be possible by better exploiting/integrating geostationary, historic IR sounders and C-band radiometers.***

Table 12: SST-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to CEOS-MIM and WMO OSCAR.

Technology	Instrument	Mission	Launch	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-nadir infrared sounder	IKFS-3	Meteor-MP N1 Meteor-MP N2	2026 2027	Primary	Y	- -	- -	IKFS-3 in OSCAR appears as Advanced IFKS-2 in MIM.
	IASI	Metop-A Metop-B Metop-C	19/10/2006 17/09/2012 09/2018	Primary	Y	- - -	- - -	EUMETSAT has put a plan into place to release a reprocessed IASI SST data record in 2019. Further releases are likely but not committed yet.
	AIRS	Aqua	04/05/2002	Primary	Y	9	8	
	CrIS	SNPP NOAA-20 JPSS-2 JPSS-3 JPSS-4	28/10/2011 18/11/2017 2022 2026 2031	Primary	N	- - - - -	- - - - -	
	IRFS-GS	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	Primary	N	- - -	- - -	
	IRS	MTG-S1 MTG-S2	2023 2031	Primary	N	- -	- -	
	GIIRS	FY-4A FY-4B FY-4C FY-4D FY-4E FY-4F FY-4G	10/12/2016 2018 2020 2023 2027 2030 2033	Primary	N	- - - - - - -	- - - - - - -	
	TES-nadir	Aura	15/07/2004	Primary	N	-	-	
	HIRAS	FY-3D FY-3E	14/11/2017 2018	Primary	N	- -	- -	

Technology	Instrument	Mission	Launch	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		FY-3F FY-3G FY-3H	2019 2021 2021			- - -	- - -	
	IASI-NG	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	Primary	N	- - -	- - -	
	Sounder (INSAT)	INSAT-3D INSAT-3DR INSAT-3DS	26/07/2013 08/09/2016 2022	Very High	Y	- - -	- - -	
	HIRS/3	NOAA-15	01/05/1998	Very High	Y	-	-	
	HIRS/4	NOAA-18 NOAA-19 Metop-A Metop-B	20/05/2005 04/02/2009 19/10/2006 17/09/2012	Very High	Y	- - - -	- - - -	
	IRAS	FY-3B FY-3C	04/11/2010 23/09/2013	Very High	Y	- -	- -	
	Sounder	GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	Very High	Y	- - -	- - -	
	IKFS-2	Meteor-M N2 Meteor-M N2-1 Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	08/07/2014 28/11/2017 2018 2020 2021 2022 2023	High	Y	- - - - - - -	- - - - - - -	IKFS-2 in OSCAR appears as IFKS in MIM.
	TANSO-FTS	GOSAT-1	23/01/2009	High	N	-	-	
	TANSO-FTS/2	GOSAT-2	2018	High	N	-	-	
Moderate-resolution optical imager	SLSTR	Sentinel-3A Sentinel-3B Sentinel-3C	16/02/2016 2018 2023	Primary	Y	- - -	- - -	Sentinel-3C does not appear in OSCAR

Technology	Instrument	Mission	Launch	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	MODIS	Terra	18/12/1999	Very High	Y	1	-	
		Aqua	04/05/2002			1	-	
	VIIRS	SNPP	28/10/2011	Very High	Y	-	-	
		NOAA-20	18/11/2017			-	-	
		JPSS-1	15/11/2017			-	-	
		JPSS-2	2021			-	-	
		JPSS-3	2026			-	-	
		JPSS-4	2031			-	-	
		DWSS-1	?					
		DWSS-2	?					
	MSU-GS/A	Arctica-M N1	2019	Very High	Y	-	-	Mis-spelt as Arctic instead of Arctica in MIM. Instrument appears as MSU-GS/A in OSCAR and MSU-GS/VE in MIM.
		Arctica-M N2	2021			-	-	
		Arctica-M N3	2023			-	-	
		Arctica-M N4	2024			-	-	
		Arctica-M N5	2025					
	MSU-MR	Meteor-M N2	08/07/2014	Very High	Y	-	-	
		Meteor-M N2-2	2018			-	-	
		Meteor-M N2-3	2020			-	-	
		Meteor-M N2-4	2021			-	-	
		Meteor-M N2-5	2022			-	-	
		Meteor-M N2-6	2023			-	-	
	MSU-GS	Electro-L N2	11/12/2015	Very High	Y	-	-	
		Electro-L N3	2018			-	-	
		Electro-L N4	2020			-	-	
		Electro-L N5	2022			-	-	
	MSU-GSM	Electro-M N1	2025	Very High	N	-	-	
		Electro-M N2	2026			-	-	
		Electro-M N3	2029			-	-	
	ABI	GOES-16	19/11/2016	Very High	Y	-	-	
		GOES-S	2018			-	-	
		GEOS-T	2020			-	-	
		GOES-U	2024			-	-	

Technology	Instrument	Mission	Launch	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	Advanced MI	GEO-KOMPSAT-2A	2018	Very High	Y	-	-	Advanced MI in MIM appears as AMI in OSCAR
	AVHRR/3	NOAA-15 NOAA-18 NOAA-19 Metop-A Metop-B Metop-C	13/05/1998 20/05/2005 06/02/2009 19/10/2006 17/09/2012 2018	Very High	Y	2 5 3 3 - -	2 6 6 5 2 -	
	MCSI	FY-4A FY-4B FY-4C FY-4D FY-4E FY-4F FY-4G	10/12/2016 2018 2020 2023 2027 2030 2033	Very High	N	- - - - - - -	- - - - - - -	MSCI in MIM appears to be AGRI in OSCAR(??)
	FCI	MTG-I1 MTG-I2 MTG-I3 MTG-I4	2020 2024 2028 2032	Very High	Y	- - - -	- - - -	
	METimage	METOP-SG A1 METOP-SG A2 METOP-SG A3	2021 2028 2035	Very High	Y	- - -	- - -	
	PCWMP	PCW-1 PCW-2	2021 2021	Very High	Y	- -	- -	PCWMP in MIM appears to be ISR in OSCAR
	MERSI-2	FY-3D FY-3E FY-3F FY-3G FY-3H FY-3RM-1 FY-3RM-2	14/11/2017 2018 2019 2021 2021 2020 2023	Very High	Y	- - - - - - -	- - - - - - -	Is MVIRS in MIM MERSI-2 in OSCAR?

Technology	Instrument	Mission	Launch	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	Advanced MSU-MR	Meteor-MP N1 Meteor-MP N2 Meteor-MP N3	2026 2027 2028	Very High	Y	- - -	- - -	Advanced MSU-MR in MUM appears to be MSU-MR-MP in OSCAR.
	IMAGER	Himawari-7 (MTSAT-2)	18/02/2006	Very High	N	-	-	No MTSAT or Himawari-7 mission in MIM
	AHI	Himawari-8 Himawari-9	07/10/2014 02/11/2016	Very High	Y	-	-	
	SEVIRI	Meteosat-8 Meteosat-9 Meteosat-10 Meteosat-11	28/08/2002 22/12/2005 05/07/2012 15/07/2015	Very High	Y	- - - -	1 1 - -	
	Imager	GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	Very High	Y	- - -	- - -	
	VIRR	FY-3B FY-3C	04/11/2010 23/09/2013	Very High	N	- -	- -	
	Imager	INSAT-3D INSAT-3DR INSAT-3DS	25/07/2013 08/09/2016 2020	Very High	N	- - -	- - -	
	S-VISSR	FY-2E FY-2F FY-2G FY-2H	23/12/2008 13/01/2012 31/12/2014 2018	Very High	N	- - - -	- - - -	IVISSR in MIM appears to be S-VISSR in OSCAR
	MI	COMS-1	26/06/2010	Very High	N	-	-	
	ISR	PCW-1 PCW-2	2022 2022	Very High		- -	- -	
Microwave conical scanning radiometer	Windsat	Coriolis	06/01/2003	Very High	N	1	-	Mission / instrument not in MIM
	Advanced MTVZA	Meteor-MP N1 Meteor-MP N2 Meteor-MP N3	2026 2027 2028	High	Y	- - -	- - -	Advanced MTVZA in MIM appears to be MTVZA-GY-MP in OSCAR

Technology	Instrument	Mission	Launch	WMO relevance for SST	CEOS relevance for SST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	MWI (HY)	HY-2A HY-2B	16/08/2011 2017	High	Y	-	- -	RAD in MIM, appears to be MWI in OSCAR According to OSCAR the MWI will only be flown on HY-2A and HY-2B and not HY-2C-H as stated in the MIM. MWI on the HY platform holds a high significance for SST in OSCAR;
	AMSR-2	GCOM-W1 GCOM-W2 GCOM-W3	18/05/2012 2019 2020	High	Y	- - -	- - -	
	AMSR-E	Aqua	04/05/2002	High	Y	1	-	
	SSM/I	DMSP-F14 DMSP-F15	04/04/1997 12/12/1999	None	N	1 1	1 1	In neither MIM nor OSCAR as SST capability.
	SSMIS	DMSP-F17 DMSP-F18	04/11/2006 18/10/2009	None	N	3 1	2 1	In neither MIM nor OSCAR as SST capability.
Cloud and precipitation radar	CloudSat	CPR	28/04/2006	None	N	1	-	In neither MIM nor OSCAR as an SST capability. May be used only for cloud detection in sea surface temperature retrieval.

6.4.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Table 12 contains a list of instruments that are planned, or are currently flying, and which can be used to monitor SST.

From the available planning from space agencies it is concluded that there will be no issue in the continuous provision of infrared radiance measurements suitable to derive SST under clear sky conditions. This also holds for the provision of measurements from geostationary orbit with high temporal resolution potentially allowing for the analysis of SST diurnal cycle.

However, the continuation of all-weather capability originating from microwave C-band measurements is endangered.

The US decadal survey [RD-11] states that: *"All-weather sea surface temperature (SST). Sea surface temperature has been assumed to be part of the Program of Record, as part of ongoing collaborations with international partners; however, with the potential loss or interruption of the passive microwave time series this capability is currently at risk. The opportunity for avoiding losses lies in the successful competition in the Earth Venture-Continuity strand. Alternatively, international partners could fulfill the need, but there is currently no partner with a demonstrated capability to do so."*

Table 13: Projected capabilities of current and future microwave radiometers [RD-11]; the three Useful for Observing columns reflect capabilities that are based on the frequency bands of the particular microwave radiometer on each satellite; the Follow-on column indicates an operational series; the Coverage until column indicates its planned period of coverage.

Current and Future Polar-Orbiting Microwave Radiometer Capabilities

	Useful for Observing					
Satellite/Sensor	**SST**	**Sea Ice and Snow**	**Atmos.**	**(First) Launch**	**Follow-on**	**Coverage Until**
DMSP/SSMI/SSMIS		✓	✓	1987		?
WindSat	✓	✓	✓	2003		
FY-3/MWI	✓	✓	✓	2008	✓	2023
MeghaTropiques			✓	2011		
GCOM-W1/AMSR2	✓	✓	✓	2012		
GPM/GMI	✓		✓	2014		
OR-6/COWVR			✓	2018		
EPS-2G-B/MWI		?	✓	2022	✓	2040
WSF/MWI	?	?	?	2022	✓	?

NOTES: SST = all-weather sea surface temperature; Sea Ice and Snow = sea ice and snow-on-land cover; Atmos. = rain rate, columnar water vapor, cloud liquid water and wind speed over ocean.

The decadal survey also projected the capabilities for microwave radiometers as shown in Table 13. The all-weather capability for the mid-term future only exists in China's FY-3A/B MWI and possibly additionally AMSR-2, if GCOM-W2 is approved for JAXA, and/or an AMSR-2 is launched in 2022 on GOSAT-3, which is also uncertain according to the US decadal survey. To ensure continuity of C-band microwave measurements for climate it is recommended:

Recommendation #16: ***C-band microwave radiometer measurements for all-weather SST:***

- ***(Short term) All efforts to maximise the life time of AMSR-2 on JAXA's GCOM-W1 should be supported.***
- ***(Mid-term) The possibility of an AMRS-2 on GCOM-W2 should be prioritised; full data sharing in regards to MWI instruments of the FY-3 series and HY-2B.***
- ***(Longer term) Agencies with operational mandates should develop and fund a sustainable plan, with redundancy, for observations from C-band microwave conical scanning radiometers.***

6.5 Sea Surface Salinity

6.5.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis it is important to know if the ECV Inventory content on Sea Surface Salinity (SSS) data records is close to complete. To assess this, other inventories of data records that are used to support climate science and services, e.g., the datasets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) and similar were interrogated. In addition required data records from new major climate programmes/projects that weren't active at the time of information collection, e.g., the ESA CCI+ (http://cci.esa.int/) were investigated.

There are zero data records in the ECV Inventory for Sea Surface Salinity, neither current nor future, so substantial misses exist for the Sea Surface Salinity ECV. The ESA CCI+ initiative will embark on the generation of an SSS climate data record for the period 2009-2020, employing the missions carrying L-band instruments SMOS, SMAP, Aquarius, and microwave C-band instruments AMSR-E, AMSR-II and WindSat (although these have highly restricted SSS capability). This information needs to be accounted for when recommendations are derived.

6.5.2 Compliance to GCOS requirements

There are no data records, neither current nor future, in the ECV Inventory related to SSS, thus, no analysis against GCOS criteria was performed. The planned ESA CCI+ SSS data record will be added to the ECV Inventory during the next update and it will be studied against GCOS criteria when the information has been submitted to the ECV Inventory.

6.5.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 14 contains a list of instruments that could be used to monitor SSS, including missions on which the instruments were flown. The information in this table is based on the CEOS MIM database with updates from the WMO OSCAR database. Microwave C-band measurements have not been included as the salinity subgroup do not see them as relevant for SSS.

Table 14 shows that at the end of 2016 no space agency had a plan to deliver a Sea Surface Salinity climate data record. Currently, ESA CCI+ is attempting a SSS CDR from the L-band measurements listed above. However, the maximum attainable length of the CDR is about 9 years, which is too short for longer-term climate analysis. As still significant discrepancies exist between processed data records, it is advisable to have more than one activity to arrive at a reliable climate data record from the available measurements.

Recommendation #17: ***CEOS and CGMS Agencies with interests in and/or mandates for Sea Surface Salinity are encouraged to support independent multi-sensor SSS CDR activities from the available L-Band observations.***

6.5.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Sea Surface Salinity (SSS) observations are a key parameter for monitoring the global water cycle (evaporation, precipitation, and glacier and river runoff). On large scales, SSS can be used to infer long-term changes of the global hydrological cycle. SSS, together with SST and air–sea fluxes (heat and momentum (wind)) can be used to determine the evolution of the surface expression of fine- to large-scale ocean frontal features and eddies.

The complementarity of the satellite SSS with *in situ* salinity observations, and the advantages of using satellites to derive SSS (global coverage, including marginal seas and coastal oceans, better spatiotemporal sampling), has been demonstrated by existing research calls. These address the need for continuity of the global SSS time-series through the use of measurements with sufficient spatiotemporal sampling to resolve SSS features important to ocean circulation and marine biogeochemistry, and also with linkages to climate variability and the water cycle. Scientific oversight is provided by the Ocean Surface Salinity Science Team (OSSST).

Table 15 contains a list of instruments that are planned to be used to monitor SSS on future missions. The information in this table is based on the CEOS MIM database with updates from the WMO OSCAR database.

Even though the measurement technology was successfully demonstrated through the pathfinder missions such as ESA SMOS and the NASA/Argentine Aquarius/SAC-D, there are no planned measurements at L-Band (1.4 GHz) past the EOL of SMOS (currently planned for December 2019) and SMAP (currently planned for June 2018). This will leave a substantial gap in measurement acquisition in the future without a quick remedy. As it currently stands, SSS is not adequately addressed on future missions and it is recommended that agencies address this short-fall as a priority. This has also been recognised by GCOS in the 2016 IP [RD-7] where GCOS Action 32 advocates for the continuation of salinity observations.

Due to the scarcity of planned measurements the salinity subgroup also consulted the very recent US decadal survey that recommends sea surface salinity as a "*Targeted Observable candidate for an Earth Venture mission opportunity, as well as for continued technology development to reduce costs and better address the accuracy and cold-temperature limitations inherent in microwave salinity sensing. The RFI submissions concerning salinity identify a number of promising options worthy of research and competition for further technology development."* The decadal survey suggests considering any related submissions to Venture solicitations, R&A efforts, and technology development initiatives to reduce cost and improve performance.

Recognising that there is no single monitoring capability in sight for Sea Surface Salinity, WGClimate recommends that space agencies become more active to close this gap.

Recommendation #18: ***Space agencies should give priority to sea surface salinity measurements in their future missions to ensure continuity of SSS CDRs. Following this recommendation agencies should consider including L-band instrumentation on future passive microwave missions.***

Table 14: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM, with some additional inputs from WMO Oscar.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for SSS	CEOS relevance for SSS	Comments
Passive Microwave Radiometer (L-Band)	MIRAS	SMOS	02/09/2009	2019	Primary	Y	
	SMAP	SMAP	31/01/2015	2018	Primary	N	Radar component of SMAP interrupted transmission on 07/07/15 MW polarimetric L-band radiometer (1.4 GHz) associated to a co-aligned L-band SAR (1.26 GHz) for roughness correction
	Aquarius	SAC-D	10/06/2011	07/06/2015	Primary	N	MW polarimetric L-band radiometer (1.4 GHz) associated to a co-aligned L-band scatterometer (1.26 GHz) for roughness correction

Table 15: Future planned missions, and instruments, according to CEOS-MIM, cross-referenced with WMO OSCAR

Instrument type	Instrument	Mission	Launch	WMO relevance for SSS	CEOS relevance for SSS	Comments
Moderate Resolution Optical Imager	MetImage	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	None	Y	The CEOS relevance entry here is incorrect.
Passive Microwave Radiometer (L-Band)	MIRAS	SMOS	02/09/2009	Primary	N	
	SMAP	SMAP	31/01/2015	Primary	N	

The CEOS-MIM database recognises the Metop-SG MetImage instrument as suitable for the monitoring of SSS, which is incorrect and should be corrected. Metop-SG MetImage my play a role in providing SST estimates needed for SSS retrieval, but it has certainly no direct relevance for SSS retrieval.

6.6 Land Surface Temperature

6.6.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis it is important to know if the ECV Inventory content on Land Surface Temperature (LST) data records is close to complete. To assess this other inventories of data records that are used to support climate science and services, e.g., the data sets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) activity and similar were interrogated. In addition, required data records from new major climate programmes/projects that weren't active at the time of information collection, e.g., the EUMETSAT SAF network CDOP 3 plans and the ESA CCI+ (http:// http://cci.esa.int/) were investigated.

A miss in the ECV Inventory seems to be for LST derived from the MODIS instruments, althought this is probably only because the verification process for those data records was not finished in time for the analysis. Additionally, it is known that an LST data record, derived from Meteosat data, was released by EUMETSAT CM SAF in 2017. Another CDR using data from the AVHRR/3 instrument is going to be developed by CCI+, and these will all be added to the next update of the ECV Inventory.

6.6.2 Analysis against GCOS criteria

There are ten current and eighteen future data records in the ECV Inventory related to LST. For the future, four global data records and three non-global records, covering the period to 2021, are committed. Additionally, two non-global records covering the period until 2017 are also committed. The remaining nine future data records are new releases of historical data.

For current data records, there are clear weaknesses in the assessment of compliance with GCOS requirements. This might be because the GCOS requirement is not used for reference or because it may not be achievable using historical instruments. For future data records, there is a tendency towards an improvement of the assessment and compliance to GCOS requirements, although stability remains a challenging requirement to robustly assess.

In the case of some of the data records, both current and future, the accuracies and resolutions do not comply fully with GCOS requirements. However, the data records themselves are all valuable additions to climate studies, are scientifically sound and fit for their intended use.

The data record entries for LST are not all fully-compliant to GCOS requirements, but are fit for their intended purpose. There is commitment to the monitoring of LST until 2021.

The critical issues concerning FDCRs, which are relevant for the estimation of LST ECVs, or for their actual use, are as follows: (i) the full characterisation of the instruments response functions; (ii) characterisation of uncertainties of top-of-atmosphere measurements; (iii) the existence of drifts in the observation times that can lead to spurious trends/variability in LST (this is particularly relevant for polar-orbiter's morning/afternoon overpass times).

A considerable amount of work has still to be done on the harmonisation of LST products derived from different instruments to promote the use of multi-instrument products that will increase spatial and temporal coverage. Microwave instruments allow estimates under all-weather conditions, but are subject to higher uncertainty and coarser resolution.

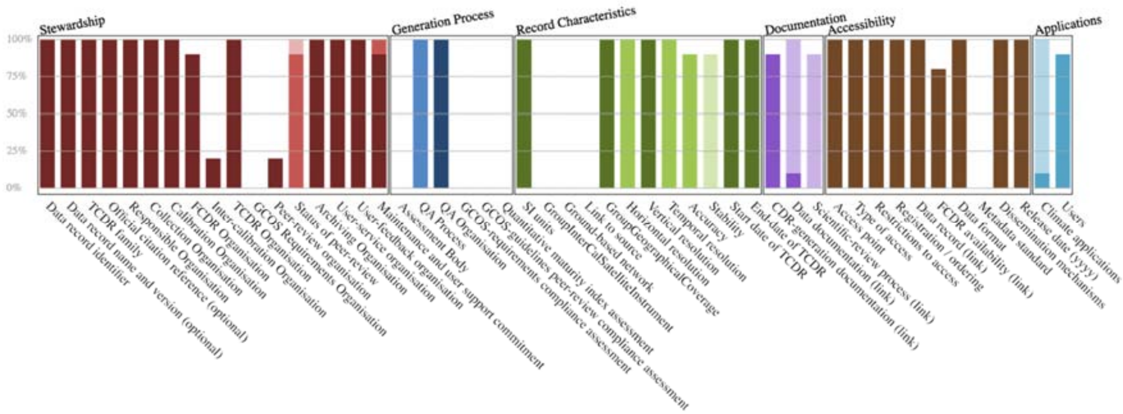

Figure 29: Compliance of current LST data records in the ECV Inventory with GCOS requirements.

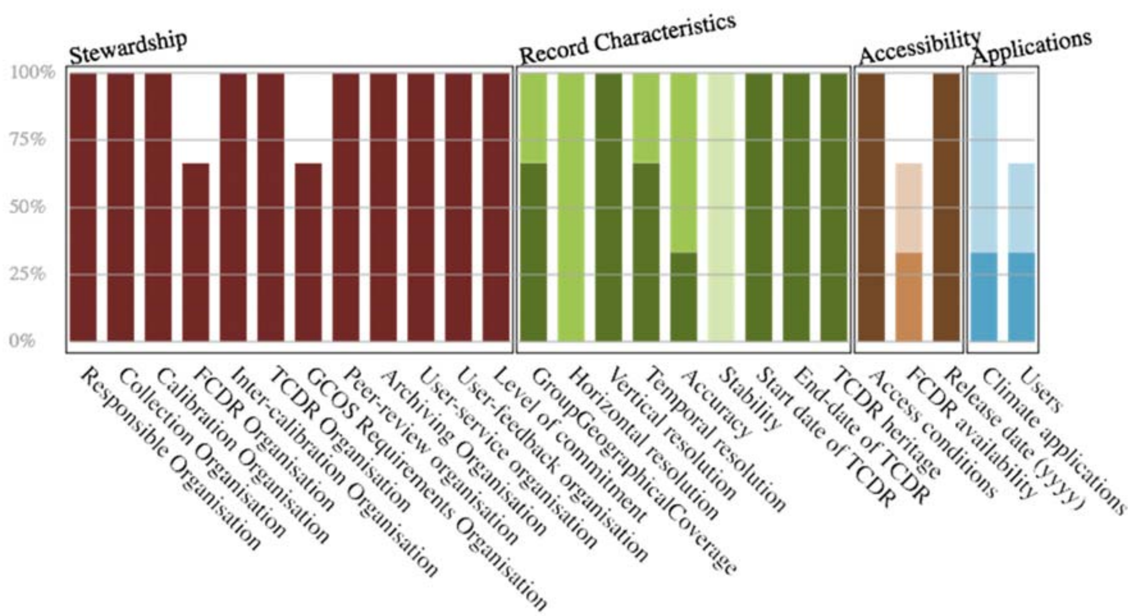

Figure 30: Compliance of future LST data records in the ECV Inventory with GCOS requirements.

6.6.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 16 contains a list of instruments, missions on which the instruments were flown and the mission launch and end of life dates. The information in this table is based on the CEOS MIM database with many updates from the WMO OSCAR database, mainly because CEOS MIM misses all missions with launch dates prior to 1984.

The content of Table is cross-referenced with the content of the ECV Inventory on LST and provides detail on which instruments / missions are used to generate the CDRs housed within the ECV Inventory.

Acknowledging problems associated with drifting orbits, there would appear to be a missed opportunity for exploiting AVHRR multi-mission time series. As mentioned above, a Land Surface Temperature data record using data from the AVHRR/3 instruments is going to be developed by ESA CCI+. Despite the lack of Land Surface Temperature data records from IR sounders such as IASI, which is mostly due to their rather coarse spatial resolution, they are useful for a simultaneous LST and emissivity retrieval and should be exploited.

Although they do not appear in the inventory, long time series of LST derived from geostationary satellites, such as GOES, Meteosat 1&2, MTSAT, HIMAWARI and polar orbiting instruments AVHRR, AATSR, ATSR-2, SLSTR, and MODIS, are known to exist but may have not reached the status of a climate data record. With the next update of the ECV Inventory WGClimate will specifically reach out to the LST community to clarify the situation of the potential data records for inclusion.

There is lack of high spatial resolution (100m or better) data records included in the portfolio of future CDRs.

Recommendation #19: ***The CEOS Land Surface Imaging-Virtual Constellation (LSI-VC) to coordinate on the formulation of future high resolution missions and seamless continuity of sustained Land Surface Temperature CDRs.***

6.6.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Table 17 contains a list of instruments that are planned, or are currently flying, and which can be used to monitor LST. As IR imagers are used for the derivation of LST there is no apparent gap in the availability of such missions, but Table shows that, for most new missions, no plan exists to derive LST climate data records from an individual instrument series or combinations of it.

Recommendation #20: ***The CEOS Land Surface Imaging-Virtual Constellation (LSI-VC) together with WGCV and WGClimate to devise a way forward for the combined use of past, current and future instruments to create sustained Land Surface Temperature CDRs.***

Table 16: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM with some additions imported from WMO Oscar. Table includes usage of instruments for CDRs currently found within the ECV inventory.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-nadir infrared sounder	AIRS	Aqua	04/05/2002	30/09/2017	Very High	Y	9	8	
	CrIS	SNPP	28/10/2011	2018	Very High	N	-	-	
	GIIRS	FY-4A	10/12/2016	2021	Very High	N	-	-	
	IASI	Metop-A Metop-B	19/10/2006 17/09/2012	2018 2018	Very High	Y	- -	- -	
	TES-nadir	Aura	15/07/2004	2018	Very High	Y	-	-	
	HIRS/2	NOAA-6 NOAA-7 NOAA-8 NOAA-9 NOAA-10 NOAA-11 NOAA-12 NOAA-13 NOAA-14 TIROS-N	27/06/1979 23/06/1981 28/03/1983 12/12/1984 17/09/1986 24/09/1988 14/05/1991 09/08/1993 30/12/1994 13/10/1978	31/03/1987 07/06/1986 29/12/1985 13/02/1998 30/08/2001 16/06/2004 10/08/2007 21/08/1993 23/05/2007 27/02/1981	High	Y	- 1 1 1 1 1 1 - 1 -	- - - - - - - - - -	
	HIRS/3	NOAA-15 NOAA-16 NOAA-17	01/05/1998 21/09/2000 24/06/2002	2018 09/06/2014 10/04/2013	High	Y	- - -	- - -	
	HIRS/4	Metop-A Metop-B NOAA-18 NOAA-19	19/10/2006 17/09/2012 20/05/2005 04/02/2009	2018 2018 2018 2018	High	Y	- - - -	- - - -	
	IMG	ADEOS	17/08/1996	30/06/1997	High	Y	-	-	
	IRAS	FY-3A FY-3B FY-3C	27/05/2008 05/11/2010 23/09/2013	05/06/2015 2018 2018	High	Y	- - -	- - -	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	SOUNDER	GOES-8	13/04/1994	05/05/2004	High	Y	-	-	
		GOES-9	23/05/1995	22/05/2003			-	-	
		GOES-9 (GMS backup)	22/05/2003	24/07/2006			-	-	
		GOES-10	25/04/1997	01/12/2006			-	-	
		GOES-10 (S-America)	01/12/2006	02/12/2009			-	-	
		GOES-11	03/05/2000	05/12/2011			-	-	
		GOES-12	23/07/2001	10/05/2010			-	-	
		GOES-12 (S-America)	10/05/2010	16/08/2013			-	-	
		GOES-13	24/05/2006	2018			-	-	
		GOES-14	27/06/2009	2018			-	-	
		GOES-15	04/03/2010	2020			-	-	
	SOUNDER	INSAT-3D	26/07/2013	2021	High	N	-	-	
		INSAT-3DR	08/09/2016	2024			-	-	
	TIRS	Landsat-8	11/02/2013	2023	Marginal	Y	-	1	
	ETM+	Landsat-7	15/04/1999	2018	None	Y	-	1	
	TM	Landsat-4	16/07/1982	01/08/1993	None	Y	-	1	
		Landsat-5	01/03/1984	05/06/2013			-	1	
	OLI	Landsat-8	11/02/2013	2018	None	N	-	1	
Microwave conical scanning radiometer	MTVZA-OK (MW)	SICH-1M	24/12/2004	15/04/2006	High	N	-	-	
	WindSat	Coriolis	06/01/2003	2018	High	N	-	-	
Moderate-resolution optical imager	AATSR	Envisat	01/03/2002	08/04/2012	Very High	Y	-	-	
	ATSR	ERS-1	17/07/1991	07/03/2000	Very High	Y	-	-	
	ATSR-2	ERS-2	21/04/1995	04/07/2011	Very High	Y	-	-	
	SLSTR	Sentinel-3A	16/02/2016	2023	Very High	Y	-	-	Sentinel 3C does not appear in OSCAR
	AGRI	FY-4A	10/12/2016	2021	High	N	-	-	MCSI in MIM appears to be AGRI in OSCAR

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	MODIS	Aqua	18/12/1999	2018	High	Y	-	-	
		Terra	04/05/2002	2018			-	-	
	VIIRS	SNPP	28/10/2011	2018	High	Y	-	-	
	ABI	GOES-16	04/11/2016	2027	Fair	Y	-	-	
	AVHRR/2	NOAA-7	23/06/1981	07/06/1986	Fair	N	-	-	
		NOAA-9	12/12/1984	13/02/1998			-	-	
		NOAA-11	24/09/1988	16/06/2004			-	-	
		NOAA-12	14/05/1991	10/08/2007			-	-	
		NOAA-13	09/08/1993	21/08/2993			-	-	
		NOAA-14	30/12/1994	23/05/2007			-	-	
	AVHRR/3	Metop-A	019/10/2006	2018	Fair	Y	-	-	
		Metop-B	17/09/2012	2018			-	-	
		NOAA-15	13/05/1998	2018			-	-	
		NOAA-16	21/09/2000	09/06/2014			-	-	
		NOAA-17	24/06/2002	10/04/2013			-	-	
		NOAA-18	20/05/2005	2018			-	-	
		NOAA-19	06/02/2009	2018			-	-	
	GLI	ADEOS-2	14/12/2002	25/10/2003	Fair	N	-	-	
	IMAGER	GOES-8	13/04/1994	05/05/2004	Fair	Y	-	-	
		GOES-9	23/05/1995	22/05/2003			-	-	
		GOES-9 (GMS backup)	22/05/2003	24/07/2006			-	-	
		GOES-10	25/04/1997	01/12/2006			-	-	
		GOES-10 (S-America)	01/12/2006	02/12/2009			-	-	
		GOES-11	03/05/2000	05/12/2011			-	-	
		GOES-12	23/07/2001	10/15/2010			-	-	
		GOES-12 (S-America)	10/05/2010	16/08/2013			-	-	
		GOES-13	24/05/2006	2018			-	-	
		GOES-14	27/06/2009	2018			-	-	
		GOES-15	04/03/2010	2020			-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	IMAGER	INSAT-3D INSAT-3DR	25/07/2013 08/09/2016	2021 2024	Fair	N	- -	- -	ISRO question the CEOS relevance; should be Y for the INSAT IMAGERs
	IMAGER	Himawari-7 (MTSAT-2)	18/02/2006	2018	Fair	N	-	-	MTSAT-2: IMAGER was in standby from 2006 to 30 June 2010. After 7 July 2015 is backup of Himawari-8, and used for rapid scanning.
	JAMI	Himawari-6 (MTSAT-1R)	26/02/2005	04/12/2015	Fair	N	-	-	
	MI	COMS-1	26/06/2010	31/03/2018	Fair	Y	-	-	
	MSU-GS	Electro-L N1 Electro-L N2	20/01/2011 11/12/2015	2016 2022	Fair	Y	- -	- -	
	MSU-MR	Meteor-3M Meteor-M N2	01/12/2001 08/07/2014	05/04/2006 2019	Fair	Y	- -	- -	
	MVISR	FY-1A FY-1B FY-1C FY-1D	07/09/1988 03/09/1990 10/05/1999 15/05/2002	16/10/1988 05/08/1991 26/04/2004 01/04/2012	Fair	Y	- - - -	- - - -	
	OCTS	ADEOS	17/08/1996	30/06/1997	Fair	N	-	-	
	SEVIRI	Meteosat-8 Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	28/08/2002 15/09/2016 21/12/2005 05/07/2012 15/07/2015	04/07/2016 2019 2019 2019 2022	Fair	Y	- - - - -	1 - 1 - -	
	VIRR	FY-3A FY-3B FY-3C	27/05/2008 04/11/2010 23/09/2013	05/06/2015 2018 2018	Fair	Y	- - -	- - -	
	VIRS	TRMM	27/11/1997	08/04/2015	Fair	N	-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	AVHRR	TIROS-N NOAA-6 NOAA-8 NOAA-10	13/10/1978 27/06/1979 28/03/1983 17/09/1986	27/02/1981 31/03/1987 29/12/1985 30/08/2001	Marginal	N	- - - -	- - - -	
	COCTS	HY-1A HY-1B	15/05/2002 11/04/2007	30/03/2004 2018	Marginal	N	- -	- -	
	HRIR	Nimbus-1 Nimbus-2 Nimbus-3	28/08/1964 15/05/1966 13/04/1969	23/09/1964 17/01/1969 22/01/1972	Marginal	N	- - -	- - -	
	IIR	CALIPSO	28/04/2006	2018	Marginal	N	-	-	
	MTVZA-OK (optical)	SICH-1M	24/12/2004	15/04/2006	Marginal	N	-	-	
	VISSR	Himawari-5 (GMS-5)	18/03/1995	21/07/2005	Marginal	N	-	-	
	VTIR	MOS-1 MOS-1B	19/02/1987 07/02/1990	29/11/1995 25/04/1996	Marginal	N	- -	- -	
	MVIRI	Meteosat-1 Meteosat-2 Meteosat-3 Meteosat-3 (ADC) Meteosat-3 (X-ADC) Meteosat-4 Meteosat-5 Meteosat-5 (IODC) Meteosat-6 Meteosat-6 (IODC) Meteosat-7 Meteosat-7 (IODC) Meteosat-8 Meteosat-8 (IODC) Meteosat-9	23/11/1977 19/06/1981 15/07/1988 01/08/1991 01/02/1993 06/03/1989 02/03/1991 01/06/1998 20/11/1993 27/04/2007 02/09/1997 05/12/2006 28/08/2002 15/09/2016 22/12/2005 05/07/2012	24/11/1979 02/12/1991 01/08/1991 01/02/1993 22/11/1995 08/11/1995 01/06/1998 26/04/2007 27/04/2007 15/04/2011 05/12/2006 01/02/2017 04/07/2016 2019 2019 2019	None	N	- - - - - - - - - - - - - - - -	- 3 3 - - 6 6 - 6 - 6 - 6 - 6 6	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		Meteosat-10 Meteosat-11	15/07/2015	2022				-	
Multi-purpose imaging Vis/IR radiometer	IVISSR	FY-2C FY-2D FY-2E FY-2F	19/10/2004 08/12/2006 23/12/2008 13/01/2012	25/11/2009 01/07/2015 2018 2018	Fair	Y	- - - -	- - - -	IVISSR in MIM appears to be S-VISSR in OSCAR
	MIRS	Sich-2	17/08/2011	12/12/2012	None	Y	-	-	MIRS in MIM appears to be IREI in OSCAR
	VHRR	INSAT-2A INSAT-2B INSAT-2E KALPANA-1 INSAT-3A	10/07/1992 27/03/1993 03/04/1999 12/09/2002 10/04/2003	10/07/1999 27/03/2000 04/05/2011 09/12/2016 10/11/2017	None	Y	- - - - -	- - - - -	

Table 17: LST-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to CEOS-MIM and WMO OSCAR.

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Absorption-band MW radiometer / spectrometer	MTVZA	Meteor-M N2 Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	08/07/2014 2018 2020 2021 2022 2023	Marginal	Y	- - - - - -	- - - - - -	MTVZA in MIM appears to be MTVZA-GY in OSCAR
	MWTS	FY-3B	04/11/2010	None	Y	-	-	
	AIRS	Aqua	04/05/2002	Very High	Y	9	8	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Cross-nadir infrared sounder	CrIS	JPSS-2 JPSS-3 JPSS-4 NOAA-20 SNPP	2022 2026 2031 18/11/2017 28/10/2011	Very High	N	- - - - -	- - - - -	
	GIIRS	FY-4A FY-4B FY-4C FY-4D FY-4E FY-4F FY-4G	10/12/2016 2018 2020 2023 2027 2030 2033	Very High	N	- - - - - - -	- - - - - - -	
	HIRAS	FY-3D FY-3E FY-3F FY-3G FY-3H	14/11/2017 2018 2019 2021 2021	Very High	N	- - - - -	- - - - -	
	IASI	Metop-A Metop-B Metop-C	19/10/2006 17/09/2012 2018	Very High	Y	- - -	- - -	
	IASI-NG	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	Very High	N	- - -	- - -	
	IKFS-3	Meteor-MP N1 Meteor-MP N2	2026 2027	Very High	Y	- -	- -	IKFS-3 in OSCAR appears as Advanced IFKS-2 in MIM.
	IRFS-GS	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	Very High	N	- - -	- - -	
	IRS	MTG-S1 MTG-S2	2023 2031	Very High	Y	- -	- -	
	TES-nadir	Aura	15/07/2004	Very High	Y	-	-	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	HIRS/3	NOAA-15	01/05/1998	High	Y	-	-	
	HIRS/4	Metop-A Metop-B NOAA-18 NOAA-19	19/10/2006 17/09/2012 20/05/2005 04/02/2009	High	Y	- - - -	- - - -	
	IRAS	FY-3B FY-3C	05/11/2010 23/09/2013	High	Y	- -	- -	
	SOUNDER	GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	High	Y	- - -	- - -	
	SOUNDER	INSAT-3D INSAT-3DR INSAT-3DS	26/07/2013 08/09/2016 2022	High	N	- - -	- - -	
	IKFS-2	Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	2018 2020 2021 2022 2023	Fair	Y	- - - - -	- - - -	IKFS-2 in OSCAR appears as IFKS in MIM.
	TANSO-FTS	GOSAT-1	23/01/2009	Fair	N	-	-	
	TANSO-FTS/2	GOSAT-2	2018	Fair	N	-	-	
	TANSO-FTS/2	GOSAT-2	2018	Fair	N	-	-	
	IR spectrometer	CLARREO-1A CLARREO-2A	TBD TBD	Marginal	N	- -	- -	
Cross-track, special or non-scanning microwave radiometer	AMSU-A	Aqua Metop-A Metop-B Metop-C NOAA-15 NOAA-18 NOAA-19	04/05/2002 19/10/2006 17/09/2012 2018 13/05/1998 20/05/2005 06/02/2009	None	Y	- - - - - - -	- - - - - - -	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	ATMS	SNPP NOAA-20 JPSS-2 JPSS-3 JPSS-4	28/10/2011 2017 2022 2026 2031	None	Y	- - - - -	- - - - -	
High-resolution optical imager	ASTER	Terra	18/12/1999	Marginal	Y	-	-	
	ECOSTRESS	ISS ECOSTRESS	2018	Marginal	Y	-	-	
	GF-4 imager	GF-4	28/12/2015	Marginal	N	-	-	
	HRMX-TIR	GISAT	01/12/2017	Marginal	Y	-	-	
	IIP	KOMPSAT-3A	26/03/2015	Marginal	N	-	-	
	IRMSS	HJ-1B	06/09/2008	Marginal	N	-	-	
	MSU-IK-SR	KANOPUS-V-IK-1	2017	Marginal	Y	-	-	
	TIRS	Landsat-8 Landsat-9	11/02/2013 12/2020	Marginal	Y	- -	1 -	
	ALI	NMP EO-1	23/11/2000	None	Y	-	-	
	ETM+	Landsat 7	15/04/1999	None	Y	-	1	
	Hyperion	NMP EO-1	23/11/2000	None	Y	-	-	
	CIRC	ALOS-2	24/03/2014	None	Y	-	-	
	IRMSS-2	CBERS-4 CBERS-4A	06/12/2014 2018	None	Y	- -	- -	IRMSS-2 in OSCAR appears in MIM as IRS. CEBRS-4A mission not in OSCAR.
	OLI	Landsat-8	11/02/2013	None	N	-	1	
Medium-resolution IR spectrometer	Multi-spectral thermal infrared imager (HyspIRI)	HyspIRI	TBD	None	Y	-	-	No instruments listed for HyspIRI in OSCAR
	MIS	DWSS-1 DWSS-2	TBD TBD	High	N	- -	- -	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Microwave conical scanning radiometer	WindSat	Coriolis	06/01/2003	High	N	-	-	
	AMSR-2	GCOM-W1 GCOM-W2 GCOM-W3	18/05/2012 2019 2020	Fair	N	- - -	- - -	
	AMSR-E	Aqua	04/05/2002	Fair	N	-	-	
	MTVZA-GY-MP	Meteor-MP N1 Meteor-MP N2 Meteor-MP N3	2026 2027 2028	Fair	Y	- - -	- - -	Advanced MTVZA in MIM appears to be MTVZA-GY-MP in OSCAR
	MWI	HY-2A HY-2B	15/08/2011 2017	Fair	N	- -	- -	MWI in OSCAR appears to be RAD in MIM
	GMI	GPM Core	27/02/2014	Marginal	N	-	-	
	MWRI	FY-3B FY-3C FY-3D FY-3F FY-3G FY-3RM-1 FY-3RM-2	04/11/2010 23/09/2013 14/11/2017 2019 2021 2020 2023	Marginal	Y	- - - - - - -	- - - - - - -	
Microwave cross-track scanning radiometer	GeoSTAR	PATH	2030	None	Y	-	-	
Moderate-resolution optical imager	SLSTR	Sentinel-3A Sentinel-3B Sentinel-3C	16/02/2016 2018 2023	Very High	Y	- - -	- - -	Sentinel 3C does not appear in OSCAR
	AGRI	FY-4A FY-4B FY-4C FY-4D FY-4E	10/12/2016 2018 2020 2023 2027	High	N	- - - - -	- - - - -	MCSI in MIM appears to be AGRI in OSCAR

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		FY-4F FY-4G	2030 2033			- -	- -	
	MetImage	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	High	Y	- - -	- - -	
	MODIS	Aqua Terra	18/12/1999 04/05/2002	High	Y	- -	- -	
	MSU-GSM	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	High	N	- - -	- - -	
	MSU-MR-MP	Meteor-MP N1 Meteor-MP N2 Meteor-MP N3	2026 2027 2028	High	Y	- - -	- - -	Advanced MSU-MR in MUM appears to be MSU-MR-MP in OSCAR.
	VIIRS	SNPP NOAA-20 JPSS-2 JPSS-3 JPSS-4 DWSS-1 DWSS-2	28/10/2011 2017 2022 2026 2031 TBD TBD	High	Y	- - - - - - -	- - - - - - -	
	ABI	GOES-16 GOES-S GOES-T GOES-U	04/11/2016 2018 2020 2025	Fair	Y	- - - -	- - - -	
	AMI	GEO-KOMPSAT-2A	2018	Fair	Y	-	-	Advanced MI in MIM appears as AMI in OSCAR
	AVHRR/3	Metop-A Metop-B Metop-C NOAA-15 NOAA-18	19/10/2006 17/09/2012 2018 13/05/1998 20/05/2005	Fair	Y	- - - - -	- - - - -	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		NOAA-19	06/02/2009			-	-	
	FCI	MTG-I1 MTG-I2 MTG-I3 MTG-I4	2020 2024 2028 2032	Fair	Y	- - - -	- - - -	
	IMAGER	GOES-13 GOES-14 GOES-15	24/05/2006 27/06/2009 04/03/2010	Fair	Y	- - -	- - -	
	IMAGER	INSAT-3D INSAT-3DR INSAT-3DS	25/07/2013 08/09/2016 2020	Fair	N	- - -	- - -	ISRO question the CEOS relevance; should be Y for the INSAT IMAGERs
	IMAGER	Himawari-7 (MTSAT-2)	18/02/2006	Fair	N	-	-	MTSAT-2: IMAGER was in standby from 2006 to 30 June 2010. After 7 July 2015 is backup of Himawari-8, and used for rapid scanning.
	ISR	PCW-1 PCW-2	2021 2021	Fair	N	- -	- -	ISR in OSCAR appears to be PCWMP in MIM
	MERSI-2	FY-3D FY-3E FY-3F FY-3G FY-3H FY-3RM-1 FY-3RM-2	14/11/2017 2018 2019 2021 2021 2020 2023	Fair	Y	- - - - - - -	- - - - - - -	Is MVIRS in MIM MERSI-2 in OSCAR?
	MI	COMS-1	26/06/2010	Fair	Y	-	-	
	MSU-GS	Electro-L N1 Electro-L N2 Electro-L N3 Electro-L N4	20/01/2011 11/12/2015 2018 2020	Fair	Y	- - - -	- - - -	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
		Electro-L N5	2022			-	-	
	MSU-GS/A	Arctica-M N1 Arctica-M N2 Arctica-M N3 Arctica-M N4 Arctica-M N5	2019 2021 2023 2024 2025	Fair	Y	- - - - -	- - - - -	Mis-spelt as Arctic instead of Arctica in MIM. Instrument appears as MSU-GS/A in OSCAR and MSU-GS/VE in MIM.
	MSU-MR	Meteor-M N2 Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	08/07/2014 2018 2020 2021 2022 2023	Fair	Y	- - - - - -	- - - - - -	
	VIRR	FY-3B FY-3C	04/11/2010 23/09/2013	Fair	Y	- -	- -	
	COCTS	HY-1B HY-1C HY-1D HY-1E HY-1F	11/04/2007 2018 2018 2022 2023	Marginal	N	- - - - -	- - - - -	
	IIR	CALIPSO	28/04/2006	Marginal	N	-	-	
	MSI	EarthCARE	2019	Marginal	N	-	-	
	SGLI	GCOM-C1 GCOM-C2 GCOM-C3	2017 2021 2025	Marginal	Y	- - -	- - -	
	TIR	OceanSat-3 OceanSat-3A	2019 2020	Marginal	N	- -	- -	SSTM-1 in MIM appears to be TIR in OSCAR
	SEVIRI	Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	15/09/2016 22/12/2005 05/07/2012 15/07/2015	None	N	- - - -	- 6 6 -	

Technology	Instrument	Mission	Launch	WMO relevance for LST	CEOS relevance for LST	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Multi-purpose imaging Vis/IR radiometer	IVISSR	FY-2E FY-2F	23/12/2008 13/01/2012	Fair	Y	- -	- -	IVISSR in MIM appears to be S-VISSR in OSCAR
	VHRR	INSAT-3A	10/04/2003	None	Y	-	-	
Narrow-band channel IR radiometer	IK-radiometer (1)	Obzor-O N1 Obzor-O N2	2023 2025	None	Y	- -	- -	Instrument and missions missing in OSCAR
	TIRS-2	Landsat-9	15/12/2020	None	Y	-	-	

6.7 Leaf Area Index

6.7.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis it is important to know if the ECV Inventory content on Leaf Area Index (LAI) data records is close to complete. To assess this, other inventories of data records that are used to support climate science and services, e.g., the data sets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) activity and similar, were interrogated. In addition required data records from new major climate programmes/projects that weren't active at the time of information collection were investigated.

LAI products currently available from Terra and Aqua MODIS are missing in the ECV Inventory due the fact that the verification was not finished in time. During the next update of the ECV Inventory, missing data records need to be carefully analysed, e.g., by consulting the CEOS Land Product Validation webpage for a list of current products that may qualify as climate data records.

6.7.2 Analysis against GCOS criteria

There are two current and three future data records in the ECV Inventory related to LAI. For the future, one global data record covering the period to 2018 is committed, which appears to be an ICDR and might be continued with newer measurements. Additionally, one non-global record covering the period until 2019 is also committed. The remaining future data record is a new release of historical data.

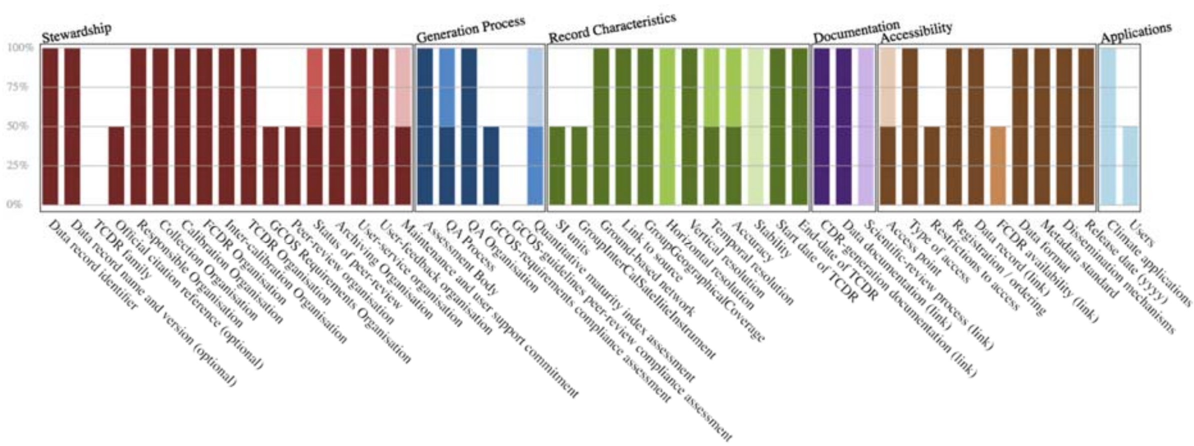

Figure 31: Compliance of current LAI data records in the ECV Inventory with GCOS requirements.

For current data records, there are weaknesses in reviewing if the GCOS guidelines have been applied. This might be because the GCOS guidelines are not used; the requirements for accuracy, stability and horizontal resolution are often not fulfilled GCOS requirements. Most likely the GCOS requirements cannot be fulfilled using historic instruments and, in case of stability, not enough ground-based references exist that can be used to assess the stability of a data record. However, they seem to be appropriate for the specified climate applications, although no specific use case was documented.

For future data records, there is a tendency towards more awareness of GCOS criteria and guidelines. Accuracy and stability remain an issue as the problems described above will not go away in the near future.

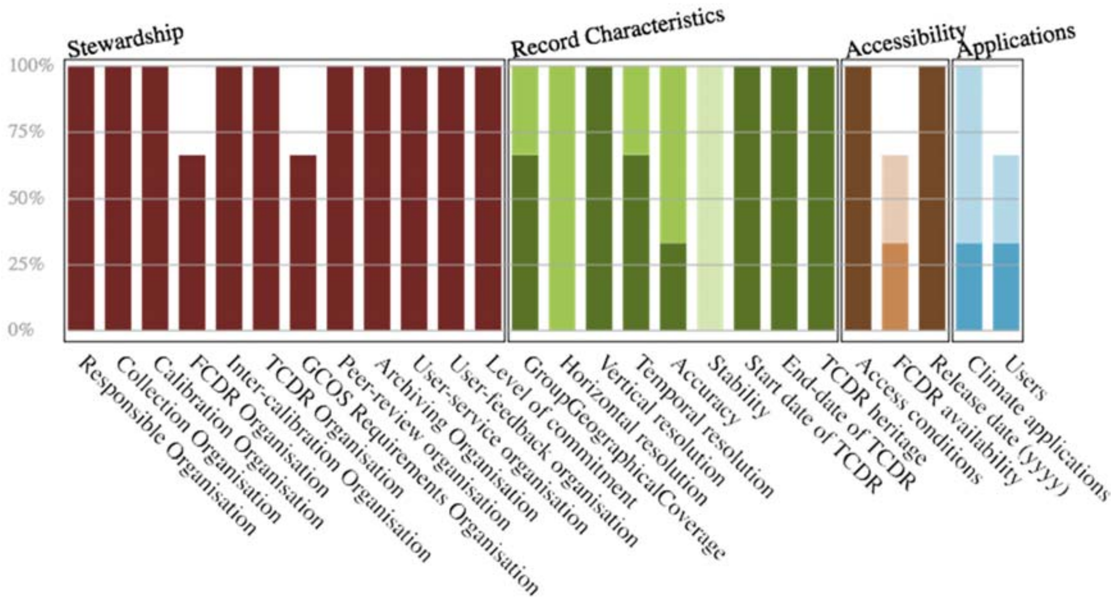

Figure 32: Compliance of future LAI data records in the ECV Inventory with GCOS requirement

The data record entries in the ECV Inventory for LAI are scientifically sound and are documented adequately for their intended use, even if sometimes not being fully in line with GCOS criteria.

6.7.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Much has to be done for developing and evaluating medium resolution products, but there are also gaps in the science used to develop algorithms for product generation (specifically for woody area and vegetation with complex spatial structure, such as variable clumping and multiple vertical strata). More time-series ground-based measurements are needed as reference data for satellite retrieved LAI. Additional actions are needed to deal with observation gap issues, e.g., due to bad weather.

Table 18 contains a list of instruments that could be used to estimate LAI, missions on which the instruments were flown and the mission launch and end of life dates. The information in this table is based on the CEOS MIM database with many updates from the WMO OSCAR database, mainly because CEOS MIM misses all missions with launch dates prior to 1984. The content of Table is cross-referenced with the content of the ECV Inventory on LAI, and also provides detail on which instruments / missions are used to generate the CDRs housed within the ECV Inventory. There is a concern that many previous missions planned to provide LAI but eventually ended up with no such product or only a limited local product.

There are plenty of measurements that are rated of very high relevance for LAI, but they have never been used or are planned for use. These could be missed opportunities from which LAI could potentially be retrieved, but it is unclear if these instruments would deliver LAI products that are useful for climate monitoring. This needs to be clarified before plans for their utilisation can be made.

6.7.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Table 19 contains a list of instruments that are planned, or are currently flying, and which can be used to monitor LAI. The same analysis as for missed opportunities also applies for future measurements. There is certainly not a shortage in available measurements, but a concerted effort to use these measurements for the generation of one or multiple climate data records is missing.

Recommendation #21: ***LSI-VC should assess the climate user community needs for LAI data records that are not currently being exploited from existing missions (e.g. Sentinel-2, Landsat), and inform WG Climate of their findings to enable further planning for needed LAI data records.***

Table 18: Usage of instruments on missions completed and flying by 31 December 2016 according to CEOS-MIM with some additions imported from WMO Oscar. Table includes usage of instruments for CDRs currently found within the ECV inventory.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
High-resolution optical imager	Hyperion	NMP-EO-1	23/11/2000	28/02/2017	Primary	Y	-	-	
	ALI	NMP-EO-1	21/11/2000	30/03/2017	Very High	N	-	-	
	ASTER	Terra	18/12/1999	2018	Very High	N	-	-	
	AWiFS	ResourceSat-1 (IRS-P6) ResourceSat-2 ResourceSat-2A	17/10/2003 20/04/2011 07/12/2016	2018 2018 2021	Very High	N	- - -	- - -	
	EOS-C	Gokturk-2	18/12/2012	2018	Very High	N	-	-	
	ETM+	Landsat-7	15/04/1999	2018	Very High	Y	-	-	
	HRG	SPOT-5	04/05/2002	27/03/2015	Very High	N	-	-	
	HRVIR	SPOT-4	24/03/1998	11/01/2013	Very High	N	-	-	
	LAC	NMP-EO-1	23/11/2000	28/02/2017	Very High	N	-	-	
	LISS-3	IRS-1C IRS-1D ResourceSat-1 (IRS-P6) ResourceSat-2 ResourceSat-2A	28/12/1995 29/09/1997 17/10/2003 20/04/2011 07/12/2016	21/09/2005 15/01/2010 2018 2018 2021	Very High	N	- - - - -	- - - - -	
	MMRS	SAC-C	21/11/2000	15/08/2013	Very High	N	-	-	
	MSI	Sentinel-2A EgyptSat-2	23/06/2015 16/04/2014	2022 09/06/2015	Very High	Y N	- -	- -	
	MSS Fragment	Meteor-P5	18/06/1980	18/06/1982	Very High	N	-	-	
	MSU-V	Okean-O-1	17/07/1999	15/09/2000	Very High	N	-	-	
	OLI	Landsat-8	11/02/2013	2018	Very High	Y	-	-	
	OPS	JERS	11/02/1992	11/10/1998	Very High	N	-	-	
	TM	Landsat-4 Landsat-5	16/07/1982 01/03/1984	01/08/1993 05/06/2013	Very High	Y	- -	- -	
	WFI-2	CBERS-4	07/12/2014	2018	Very High	N	-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	WiFS	IRS-P3	21/03/1996	15/10/2004	Very High	N	-	-	
	CHRIS	PROBA-1	22/10/2001	2018	Fair	Y	-	-	
	SLIM6	UK-DMC-1 UK-DMC-2 Deimos-1	27/09/2003 29/07/2009 29/07/2009	04/10/2011 2018 2019	Marginal	Y	- - -	- - -	Instrument appears as MS in MIM, as SLIM6 in OSCAR
	SumbandilaSat Imager	SumbandilaSat	18/09/2009	24/01/2012	Marginal	Y	-	-	Instrument appears as MSI in OSCAR, as SumbandilaSat Imager in MIM
Moderate-resolution optical imager	AATSR	Envisat	01/03/2002	08/04/2012	Very High	N	-	-	
	ABI	GOES-16	19/11/2016	2027	Very High	N	-	-	
	AGRI	FY-4A	10/12/2016	2021	Very High	N	-	-	
	AHI	Himawari-8 Himawari-9	07/10/2014 02/11/2016	2029 2031	Very High	N	-	-	
	ATSR-2	ERS-2	21/04/1995	06/07/2011	Very High	N	-	-	
	AVHRR/3	Metop-A Metop-B NOAA-15 NOAA-16 NOAA-17 NOAA-18 NOAA-19	19/10/2006 17/09/2012 13/05/1998 21/09/2000 24/06/2002 20/05/2005 06/02/2009	2018 2018 2018 09/06/2014 10/04/2013 2018 2018	Very High	N	- - - 1 - 1 -	- - - 1 - 1 -	
	CAPI	TANSAT	21/12/2016	2018	Very High	N	-	-	
	CCD	INSAT-2E INSAT-3A	03/04/1999 10/04/2003	15/04/2012 01/09/2016	Very High	N	- -	- -	
	GLI	ADEOS-2	14/12/2002	25/10/2003	Very High	N	-	-	
	MERSI-1	FY-3A FY-3B FY-3C	27/05/2008 04/11/2010 23/09/2013	05/06/2015 2018 2018	Very High	N	- - -	- - -	
	MODIS	Terra Aqua	18/12/1999	2018	Very High	Y	-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
			04/05/2002	2018			-	-	
	MOS	IRS-P3	21/03/96	15/10/04	Very High	N	-	-	
	MSU-MR	Meteor-M N1 Meteor-M N2 Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	17/09/2009 08/07/2014 2018 2020 2021 2022 2023	23/09/2014 2019 2023 2025 2026 2027 2028	Very High	N	- - - - - - -	- - - - - - -	
	MVISR	FY-1A FY-1B FY-1C FY-1D	07/09/1988 03/09/1990 10/05/1999 15/05/2002	16/10/1988 05/08/1991 26/04/2004 10/04/2012	Very High	N	- - - -	- - - -	
	SEVIRI	Meteosat-8 Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	28/08/2002 15/09/2016 21/12/2005 05/07/2012 15/07/2015	04/07/2016 2019 2019 2019 2022	Very High	N	- - - - -	- 1 1 - -	
	SLSTR	Sentinel-3A	16/02/2016	2023	Very High	N	-	-	
	TANSO-CAI	GOSAT-1	23/01/2009	2018	Very High	N	-	-	
	Vegetation	SPOT-4 SPOT-5	24/03/1998 04/05/2002	29/06/2013 30/03/2015	Very High	Y	1 1	1 1	
	Vegetation-P	PROBA-V	07/05/13	30/05/18	Very High	Y	1	1	Vegetation-P appears as Vegetation in MIM
	VIIRS	Suomi NPP	28/10/11	2018	Very High	Y	-	-	
	VIRR	FY-3A FY-3B FY-3C	27/05/2008 04/11/2010 23/09/2013	05/06/2015 2018 2018	Very High	N	- - -	- - -	
	IMAGER	INSAT-3D INSAT-3DR	25/06/2013 08/09/2016	2021 2024	High	N	- -	- -	
	VIRS	TRMM	27/11/1997	08/04/2015	High	N	-	-	

Technology	Instrument	Mission	Launch	EOL	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	AVHRR/2	NOAA-7 NOAA-9 NOAA-11 NOAA-14	23/06/1981 12/12/1984 24/09/1988 30/12/1994	07/06/1986 13/02/1998 16/06/2004 23/05/2007	Marginal	N	1 1 1 1	1 1 1 1	Unclear why AVHRR/3 and AVHRR/2 have different OSCAR "relevance"
	MISR	Terra	18/12/1999	2018	Marginal	Y	-	-	
	OLCI	Sentinel-3A	16/02/2016	2023	Marginal	Y	-	-	
	POLDER	ADEOS	17/08/1996	30/06/1997	Marginal	Y	-	-	
	POLDER-2	ADEOS-II	14/11/2002	25/10/2003	Marginal	Y	-	-	POLDER-2 in MIM appears as POLDER in OSCAR
Radar scatterometer	AMI-SCAT	ERS-1 ERS-2	17/07/1991 21/04/1995	10/03/2000 06/07/2011	High	N	- -	-	
	ASCAT	Metop-A Metop-B	19/10/2006 17/09/2012	2018 2018	High	N	- -	- -	

Table 19: LAI-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to CEOS-MIM and WMO OSCAR.

Technology	Instrument	Mission	Launch date	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
High-resolution optical imager	HISUI	ALOS-3	2019	Primary	Y	-	-	
	HSI	EnMAP	2018	Primary	N	-	-	
	HYC	PRISMA	2018	Primary	N	-	-	
	Hyperion	NMP-EO-1	23/11/2000	Primary	Y	-	-	
	ALI	NMP-EO-1	21/11/2000	Very High	N	-	-	
	ALISS-3	ResourceSat-3 ResourceSat-3A	2019 2020	Very High	N	- -	- -	
	ASTER	Terra	18/12/1999	Very High	N	-	-	
	AWFI-2	Amazonia-2	2023	Very High	N	-	-	
	AWiFS	ResourceSat-1 (IRS-P6) ResourceSat-2 ResourceSat-2A	17/10/2003 20/04/2011 07/12/2016	Very High	N	- - -	- - -	
	EOS-C	Gokturk-2	18/12/2012	Very High	N	-	-	
	ETM+	Landsat-7	15/04/1999	Very High	Y	-	-	
	HyS-SWIR	GISAT	2019	Very High	N	-	-	
	LAC	NMP-EO-1	23/11/2000	Very High	N	-	-	
	LISS-3	ResourceSat-1 (IRS-P6) ResourceSat-2 ResourceSat-2A	17/10/2003 20/04/2011 07/12/2016	Very High	N	- - -	- - -	
	MSI	Sentinel-2A Sentinel-2B EarthCARE	23/06/2015 2017 2019	Very High	Y	- - -	- - -	
	OLI	Landsat-8	11/02/2013	Very High	Y	-	-	
	WFI-2	CBERS-4	07/12/2014	Very High	N	-	-	
	HYSI	CartoSat-3	2018	High	N	-	-	
	CHRIS	PROBA-1	22/10/2001	Fair	Y	-	-	

Technology	Instrument	Mission	Launch date	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	SLIM6	UK-DMC-2 Deimos-1	29/07/2009 29/07/2009	Marginal	Y	- -	- -	Instrument appears as MS in MIM, as SLIM6 in OSCAR
	VENUS	VSC	01/10/2017	None	Y	-	-	Mission/instrument not listed in OSCAR
	OLI-2	Landsat-9	2020	None	Y	-	-	No instruments listed for Landsat-9 in OSCAR
Moderate-resolution optical imager	3MI	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	Very High	N	- - -	- - -	
	ABI	GOES-16 GOES-S GOES-T GOES-U	19/11/2016 2018 2020 2025	Very High	N	- - - -	- - - -	
	AGRI	FY-4A FY-4B FY-4C FY-4D FY-4E FY-4F FY-4G	10/12/2016 2018 2020 2023 2027 2030 2033	Very High	N	- - - - - - -	- - - - - - -	
	AHI	Himawari-8 Himawari-9	07/10/2014 02/11/2016	Very High	N	- -	- -	
	AMI	GEO-KOMPSAT-2A	2018	Very High	N	-	-	
	APS-NG	ACE (Aer.Clo.Eco.) PACE	- 2022	Very High	N	- -	- -	
	AVHRR/3	Metop-A Metop-B Metop-C NOAA-15 NOAA-18 NOAA-19	19/10/2006 17/09/2012 2018 13/05/1998 20/05/2005 06/02/2009	Very High	N	- - - - 1 -	- - - - 1 -	
	CAPI	TANSAT	21/12/2016	Very High	N	-	-	

Technology	Instrument	Mission	Launch date	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	FCI	MTG-I1 MTG-I2 MTG-I3 MTG-I4	2021 2025 2029 2033	Very High	N	- - - -	- - - -	
	ISR	PCW-1 PCW-2	2022 2029	Very High	N	- -	- -	
	MAIA	MAIA	-	Very High	N	-	-	No instruments listed for MAIA in OSCAR
	MERSI-1	FY-3B FY-3C	04/11/2010 23/09/2013	Very High	N	- -	- -	
	MERSI-2	FY-3D FY-3E FY-3F FY-3G FY-3H FY-3RM-1 FY-3RM-2	14/11/2017 2018 2019 2021 2021 2020 2023	Very High	N	- - - - - - -	- - - - - - -	
	MetImage	Metop-SG-A1 Metop-SG-A2 Metop-SG-A3	2021 2028 2035	Very High	N	- - -	- - -	
	MODIS	Terra Aqua	18/12/1999 04/05/2002	Very High	Y	- -	- -	
	MSU-GSM	Electro-M N1 Electro-M N2 Electro-M N3	2025 2026 2029	Very High	N	- - -	- - -	
	MSU-MR	Meteor-M N2 Meteor-M N2-2 Meteor-M N2-3 Meteor-M N2-4 Meteor-M N2-5 Meteor-M N2-6	08/07/2014 2018 2020 2021 2022 2023	Very High	N	- - - - - -	- - - - - -	
	MSU-MR-MP	Meteor-MP N1 Meteor-MP N2	2021 2023	Very High	N	- -	- -	

Technology	Instrument	Mission	Launch date	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
	OES	ACE (Aer.Clo.Eco.) PACE	- 2022	Very High	N	- -	- -	
	SEVIRI	Meteosat-8 (IODC) Meteosat-9 Meteosat-10 Meteosat-11	15/09/2016 21/12/2005 05/07/2012 15/07/2015	Very High	N	- - - -	1 1 - -	
	SGLI	GCOM-C1 GCOM-C2 GCOM-C3	2017 2018 2022	Very High	Y	- - -	- - -	
	SLSTR	Sentinel-3A Sentinel-3B	16/02/2016 2018	Very High	N	- -	- -	
	TANSO-CAI	GOSAT-1	23/01/2009	Very High	N	-	-	
	TANSO-CAI/2	GOSAT-2	2018	Very High	N	-	-	
	Vegetation-P	PROBA-V	07/05/2013	Very High	Y	1	1	Vegetation-P appears as Vegetation in MIM
	VIIRS	DWSS-1 DWSS-2 JPSS-2 JPSS-3 JPSS-4 NOAA-20 SNPP	- - 2022 2026 2031 18/11/2017 28/10/2011	Very High	Y	- - - - - - -	- - - - - - -	
	VIRR	FY-3B FY-3C	04/11/2010 23/09/2013	Very High	N	- -	- -	
	GHI	FY-4B	2018	High	N	-	-	
	IMAGER	INSAT-3D INSAT-3DR INSAT-3DS	25/06/2013 08/09/2016 2022	High	N	- - -	- - -	
	MISR	Terra	18/12/1999	Marginal	Y	-	-	
	OLCI	Sentinel-3A Sentinel-3B Sentinel-3C	16/02/2016 2018 2023	Marginal	Y	- -	- - -	

Technology	Instrument	Mission	Launch date	WMO relevance for LAI	CEOS relevance for LAI	No. current CDRs in ECV Inventory	No. future CDRs in ECV Inventory	Comments
Radar scatterometer	WindRAD	FY-3E FY-3H	2018 2021	Very High	N	- -	- -	
	ASCAT	Metop-A Metop-B Metop-C	19/10/2006 17/09/2012 2018	High	N	- - -	- - -	
	SCA	Metop-SG-B1 Metop-SG-B2 Metop-SG-B3	2022 2029 2036	High	N	- - -	- - -	

6.8 Above-ground Biomass

6.8.1 Analysis of missed known existing or planned climate data records

To assess the reliability of the analysis it is important to know if the ECV Inventory content on Above-ground Biomass (Biomass) data records is close to complete. To assess this, other inventories of data records that are used to support climate science and services, e.g., the data sets listed for the evaluation of global Coupled Climate Models under the Obs4Mips (https://www.earthsystemcog.org/projects/obs4mips) activity and similar, were interrogated. In addition, required data records from new major climate programmes/projects that weren't active at the time of information collection, e.g., the EUMETSAT CDOP 3 plans and the ESA CCI+ (http:// http://cci.esa.int/) were investigated.

There are zero data records in the ECV Inventory related to Above-ground Biomass, neither current nor future, so substantial gaps exist for this ECV. A compiled record of biomass estimates exists based on *in situ* observations (Pan et al. 2011)[6], while continental to global scale maps of biomass exist, based on sensors that now are no longer active (e..g IceSat GLAS, Envisat ASAR, ALOS PALSAR-1). These include maps of northern hemisphere boreal and temperate forest biomass derived from ASAR (Santoro et al. 2015)[7] and ALOS-PALSAR, and pan-tropical biomass maps largely based on height measurements from GLAS (Saatchi et al., 2011, Baccini et al. 2012, Mitchard et al. 2013, and Avitabile et al. 2016)[8,9,10,11]. Improvements in these maps through the use of new forest inventory data, together with data from the Sentinel-1 C-band radar satellites and the JAXA PALSAR-2 L-band radar, are being undertaken in projects such as ESA GlobBiomass.

The ESA CCI+ initiative will embark on the generation of an Above-ground Biomass climate data record for several epochs (2007-2010, 2017-2018 and 2018-2019), employing missions carrying microwave instruments: Envisat ASAR, ALOS-PALSAR, Geoscience Laser Altimeter System on-board IceSat, the Sentinel-1 C-band radar satellites and the JAXA PALSAR-2. This work will build on the global retrieval algorithm for biomass established in ESA GlobBiomass.

A major focus in the next 5–10 years will be to exploit the unprecedented array of upcoming space missions that will be deployed between 2019–2022, which will measure forest structure and biomass. These include the ESA BIOMASS mission (a P-band radar), the NASA Global Ecosystem Dynamics Investigation (GEDI) full waveform LIDAR on the International Space Station, the NASA-ISRO NISAR L- and S-band radar mission, the IceSat-2 photon counting

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[10] Mitchard, E.T., Saatchi, S.S., Baccini, A. et al. Carbon Balance Manage (2013) 8: 10. https://doi.org/10.1186/1750-0680-8-10.

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lidar, and the SAOCOM series of L-band SAR satellites. This new wealth of active spaceborne datasets will result in many new biomass maps, and efforts are under way through CEOS WGCV LPV to develop a protocol for good practices in biomass product validation that will aid in the consistent interpretation of forthcoming products. Several upcoming missions' science teams (GEDI, NISAR, BIOMASS, ICESAT-2) are also working toward joint calibration and validation with the aim of developing a coordinated network of field and airborne LIDAR datasets to aid in geographically consistent biomass algorithm training and product validation. These efforts are directly linked to the CEOS WGCV LPV biomass protocol development, which should be published in early-mid 2019. NASA's GEDI plans to be the pilot mission to implement the CEOS WGCV LPV protocol for biomass product validation.

6.8.2 Compliance to GCOS requirements

There are zero data records in the ECV Inventory related to Above-ground Biomass and thus there is no assessment against GCOS criteria. The GlobBiomass global map and the CCI+ data record will be assessed after the information has been submitted to the ECV Inventory in its next update.

6.8.3 Analysis of the missed opportunities for creating a climate data record from existing past and planned future measurements from space

Table 20 contains a list of instruments that could be used to monitor Above-ground Biomass, including missions on which the instruments were flown. The information in this table is based on the WMO OSCAR database as the Above-ground Biomass ECV does not appear as a searchable ECV in the CEOS MIM database.

In undertaking this analysis for biomass, it should be recognised that Above-ground Biomass is a new ECV and thus only limited information is available in WMO OSCAR; no reference to this ECV currently exists in CEOS MIM. It is recommended that both the CEOS MIM and WMO OSCAR databases are updated to reflect the Above-ground Biomass ECV and, in doing so, are co-aligned or joined to provide one single such database. This would ensure a more accurate unified view of current and planned capabilities.

Recommendation #22: Both the CEOS MIM and WMO OSCAR databases should be updated in a consistent fashion to reflect the Above-ground Biomass ECV and in doing so are co-aligned.

Table 20 shows that, at the end of 2016, no space agency had a plan to deliver an Above-ground Biomass climate data record, although ESA is attempting to produce epoch estimates for given years. The maximum attainable length of the CDR is about 10 years with gaps, which is not suitable for longer-term climate analysis. Increased availability of PALSAR-2 data would be of great benefit for the generation of current records.

C-band measurements are suitable for Above-ground Biomass less than 70 t/ha, whilst L- and P-band can address up to 200 tons/ha, which accounts for a significant vegetated area. Multiple studies have been conducted over small areas to assess Above-ground Biomass, however, regional and global level monitoring is the requirement for climate monitoring. In order to achieve this, current and future missions that use both C- and L-band measurements need to be utilised and enhanced, where necessary, by optical measurements.

Recommendation #23: ***All C-band and L-band SAR measurements of CEOS and CGMS agencies, should be made openly available by space agencies operating the instruments for the construction of CDRs for Above-ground Biomass. The combination of L-band and C-band measurements will help extend the sensitivity of existing estimates.***

6.8.4 Analysis of missing measurements in the future that are needed to continue existing data records or to establish new ones with enhanced quality

Table 21 contains a list of instruments that are planned, or are currently flying, and which can be used to monitor Above-ground Biomass. The information in this table is based on the WMO OSCAR database as the Above-ground Biomass ECV does not appear as a searchable ECV in the CEOS MIM database.

There are a large number of planned measurements with nominal launch dates from 2018, two of which that have biomass retrieval as their primary mission aim (GEDI and BIOMASS). Coordination of data availability across space agencies is essential to ensure continuity of research records established using L-band and C-band SARs and LIDAR (IceSat). Plans are needed to ensure follow-on for these two primary missions as both are experimental (one on ISS and the other an ESA Earth Explorer). In addition, coordination is required between space agencies to allow biomass estimates from multiple data sources and to ensure continuity. A gap exists in high-resolution SAR/LIDAR observations for REDD+ type applications.

Recommendation #24: Space agencies to plan for continuity of measurements, such as to be provided by BIOMASS and GEDI.

Recommendation #25: Space Agencies to plan for high-resolution data provision in support of REDD+ type applications leading to the Global Stocktake process.

Table 20: Usage of instruments on missions completed and flying by 31 December 2016 according to WMO Oscar. None of these measurements has been used to deliver a climate data record.

Technology	Instrument	Mission	Launch	EOL	WMO relevance for Above-ground Biomass	Comments
Imaging radar (SAR)	SAR-Travers	Resurs-O1-1	03/10/1985	11/11/1986	Very High	
	SAR	SeaSat	27/06/1978	10/10/1978	High	
	SAR (JERS)	JERS	11/02/1992	11/10/1998	High	
	SAR-S	HJ-1C	18/11/2012	2018	High	
	SAR-10	Kondor-E Kondor-E1	27/06/2013 19/12/2014	2014 2019	High	
	PALSAR	ALOS	24/01/2006	22/04/2011	High	
	PALSAR-2	ALOS-2	24/05/2014	2019	High	Data access currently limited
	ASAR	Envisat	01/03/2002	08/04/2012	Fair	
	SAR-C	RISAT-1 Sentinel-1A Sentinel-1B GF-3	26/04/2012 03/04/2014 25/04/2016 09/08/2016	2018 2021 2023 2024	Fair	
	SAR	Radarsat-1 Radarsat-2	04/11/1995 14/12/2007	29/03/2013 2018	Fair	
High resolution optical imager	Hyperion	NMP-EO-1	21/11/2000	30/03/2017	High	
	MSI	Sentinel-2A	23/06/2015	2022	Fair	
	OLI	Landsat-8	11/02/2013	2018	Fair	
Lidar	GLAS	ICESat	12/01/2003	14/08/2010	High	

Table 21: Above-ground Biomass-relevant instruments on planned / approved missions flying and planned for after 31 December 2016 according to WMO OSCAR.

Technology	Instrument	Mission	Launch date	WMO relevance for Above-ground Biomass	Comments
Imaging radar (SAR)	SAR-P	BIOMASS	2022	Primary	Limitations on data availability in northern latitudes
	SAR-L	SAOCOM-1A SAOCOM-1B SAOCOM-2A SAOCOM-2B	2018 2018 2019 2020	High	
	SAR-L (NISAR)	NI-SAR	2021	High	
	SAR-S (NISAR)	NI-SAR	2021	High	
	SAR-S	HJ-1C	18/11/2012	High	
	SAR-10	Kondor-E1	19/12/2014	High	
	PALSAR-2	ALOS-2	24/05/2014	High	Data access currently limited
	SAR-C	RISAT-1 RISAT-1A Sentinel-1A Sentinel-1B GF-3	26/04/2012 2018 03/04/2014 25/04/2016 09/08/2016	Fair	
	SAR	Radarsat-2	14/12/2007	Fair	
High resolution optical imager	HIS (EnMAP)	ENMAP	2018	High	
	HYC	PRISMA	2018	High	
	HISUI	ALOS-3	2019	High	
	MSI	Sentinel-2A	23/06/2015	Fair	
	OLI	Landsat-8	11/02/2013	Fair	
Lidar	GEDI Lidar	ISS GEDI	2018	Primary	
	ATLAS	ICESat-2	2018	High	
Scatterometer	WindRAD	FY-3E FY-3H	2018 2021	High	Relevance of WindRAD for Above-ground Biomass questioned; currently has high relevance according to OSCAR

7 Lessons Learnt and Potential Improvements

This section aims to record the main findings regarding the approach chosen, at the conceptual level, and the resulting internal recommendations for further developments. Recommendations regarding improvements in technical implementation, database structure, or analysis tools are not the object of this section. Details on the process are provided to the extent necessary to the understanding of this section from the experience gathered.

7.1 Data Collection

The Data collection phase was the first externally visible step of this development cycle of the WGClimate ECV Inventory, and consisted of the input of information into the database by data producers identified by the CEOS and CGMS Agencies (hereafter “Responders”). This phase was launched on the 2nd of June 2016 with an initial duration of four months, later extended to a total duration of almost 8 months. During this time the Responders provided detailed information regarding the TCDRs their institutions are responsible for, by filling in a questionnaire, with the support of the EUMETSAT Climate Data Record Inventory Engineer (hereafter “Support”). The most important lessons learnt from this phase of the process, followed by recommendations for improvement, are listed below.

The data call for contributions to the ECV Inventory was done exclusively within the CEOS and CGMS Agencies represented in the WGClimate. For each Agency, the respective representative nominated one or more contacts (so-called Focal Points) that would be responsible for identifying the Responders within their respective Agencies and engage them into this initiative. It is possible that the approach followed left out some TCDRs whose production is not fully funded (or funded at all) by this set of Agencies.

- ➔ *Comparison of the contents of the WGClimate ECV Inventory with other databases of climate data records shall be pursued in order to assess the effectiveness of the approach followed for the data call and any changes needed to be implemented.*

Engagement of CEOS/CGMS Focal Points in identifying the Responders within their respective Agencies, and in actively encouraging involvement and following-up progress during the data collection phase, largely correlated with timeliness and completeness of their Agencies’ contributions.

- ➔ *The WGClimate should seek for full engagement of Focal Points from all Agencies, in order to ensure global completeness of the ECV Inventory.*

The input data requested aimed at thoroughly characterising the available (“current”) and firmly planned (“future”) TCDRs that constitute the individual entries of the inventory. A dedicated questionnaire was designed for that purpose, with questions organised around six different topics: Stewardship, Generation Process (“current” TCDRs only), Record Characteristics, Documentation (“current” TCDRs only), Accessibility, and Applications. A web interface with restricted access (registered Responders only) was specifically created to support the process. Due to the extensive and detailed nature of the questionnaire, a supporting ECV Inventory Guide to the Questionnaire [RD3] was prepared by the WGClimate chair team to assist the Responders throughout the process, providing explanations and examples of what would be expected as complete answers to the questions. This stand-alone document, made available through the web interface supporting the data collection, was not meant to be read end to end but rather consulted as a handbook. However, this guide was not used by most of the Responders, resulting in frequent misinterpretation of the questions and a consequent input of inadequate or incomplete information.

➔ *A follow-on of the ECV Inventory Guide to the Questionnaire should be implemented directly on the web interface supporting the data collection, by displaying the auxiliary information concerning each question by clicking on a local Help button. Additionally, a "Frequently Asked Questions" page could also be built (and regularly updated) addressing the main doubts experienced by the Responders.*

The questionnaire, largely inherited from the previous development cycle of the inventory, was conceived in a way such that an assessment of the extent to which the GCOS guidelines for the generation of CDRs and the GCOS Climate Monitoring Principles [RD4] were being followed by TCDRs producers. This approach led at times to an increase in the complexity of the questions, as well as to some overlap between answers to different questions, which mostly affected the topics related to Generation Process and Documentation (of "current" TCDRs only). This increased complexity, together with the apparent lack of *a priori* common standards for documenting the generation and characterisation of TCDRs, often resulted in confusion among Responders with respect to what was expected as an answer, or even whether there were elements concerning the TCDR documentation that would specifically address these questions.

➔ *The questions under the topics "Generation Process" and "Documentation" should be revisited and rephrased as necessary, preferably directly addressing a set of relatively common standard documents used to characterise the production and usage of datasets (e.g. Algorithm Theoretical Basis Document, Product Users' Guide, Product Validation Report) complemented with additional elements considered essential for the specific case of TCDRs.*

Reaching out to the "real" data producers (e.g. PIs) proved to be essential to a thorough characterisation of the TCDRs (mainly within the topics Generation Process, Record Characteristics, and Documentation), with valuable complementary information being often available from data archive/distribution centres (mainly regarding the topics Accessibility and Applications).

➔ *The Focal Points should be encouraged to take into account the different aspects and level of detail of the information needed for a complete input in the ECV Inventory when identifying the Responders within their Agencies; PI / Data Archive Centres synergies (when applicable) should be fostered for increased completeness and accuracy of information.*

Permanent and timely individual assistance offered by Support to Responders largely contributed to their commitment to the project and success in providing an input that was as complete as possible. It also contributed to a real-time assessment of the complexity of the questionnaire and the adequacy and clarity of the technical functionalities implemented on the web interface.

➔ *Such personalised support should be continued for all Responders, with an emphasis on newcomers; a more dedicated / tailored support might need to be considered for Agencies whose contribution was impaired by the* *complexity of a questionnaire addressing the GCOS guidelines and requirements (e.g. example of "complete" inputs from Cycle #2 to be offered as a work baseline).*

The absence of a firm pre-defined set of requirements for qualification as TCDRs of datasets addressing the geophysical variables pertaining to GCOS ECVs, together with a Data Collection approach that was also aiming at detecting "missed opportunities" for the production of *de facto* TCDRs from existing datasets available within the Agencies data holdings, prevented a fully effective filtering out of non-TCDRs during this phase. As a consequence, some datasets that may not actually qualify as TCDRs exist in the ECV Inventory.

➔ *The WGClimate should work on the definition of a minimum set of requirements by which a dataset should abide in order to qualify as a TCDR (e.g. minimum time length (maybe ECV-specific) – currently absent from GCOS requirements –, established values for accuracy and stability) and thus be included as such in the ECV Inventory. Any "missed opportunities" offered as input should be labelled as such and used only for the issue of recommendations to specific space agencies.*

As stated above, in order to capture both the present and the foreseen status of climate monitoring from space, two distinct components of the ECV Inventory were defined: "current" TCDRs (datasets already produced and released) and "future" TCDRs (datasets firmly planned and committed, but not yet produced or released). This dichotomous approach that resulted was problematic with respect to the accommodation in the ECV Inventory of the emerging so-called ICDRs (Interim CDRs). The solution found consisted of duplicating the "current" database entry into a "future" one with the foreseen time extension into the future.

➔ *An effort should be made by the WGClimate in order to properly characterise a dataset that can qualify as an ICDR; that third category (neither "current" nor "future") shall be accommodated in the structure of the ECV Inventory as a distinct component, thus avoiding duplication of information in the database.*

The requirement of a firm commitment regarding the production of "future" TCDRs in order to include them in the ECV Inventory, justified by the necessity of such certainty for the Gap Analysis phase, impaired a complete contribution of that component from some Agencies, resulting from either timing issues (e.g. awarded but not yet signed contracts) or missing official commitment regarding the long term support of ongoing initiatives.

➔ *In order to avoid the detection of false gaps in the upcoming production of TCDRs in the ECV Inventory, the question regarding the level of commitment concerning the production of "future" TCDRs should be revisited, and the strict "firm commitment" condition should be relaxed and replaced by a set of options grading the commitment or the risk associated to the lack thereof.*

7.2 Verification Process

The Verification Process started during the Data Collection as soon as the first entries were submitted by Responders. This phase of the development cycle was performed by Support in cooperation with the Responders, and it usually unfolded in several iterations of contact through which the completeness and consistency of the information regarding each TCDR were successively improved. Only "Verified" contents, corresponding to database entries that had undergone a full quality check, were considered for the following phase (Gap Analysis) and later publication.

Due to the unprecedented and unexpected number of entries contributed to the database, together with the complexity and level of detail of the information asked for, the whole process of verifying the contents of the ECV Inventory lasted for almost one year, running in parallel with the Data Collection phase and the preparation for the Gap Analysis.

Below following details the main findings regarding the design and implementation of the process, followed by suggestions regarding its improvement.

The control of completeness and consistency of all information provided by the Responders to characterise the TCDRs contributed to the ECV Inventory has proven absolutely crucial for the inventory to ensure a reliable baseline for the Gap Analysis, as well as providing a useful source of information for users, once published. The time and effort needed for completing the task had been nevertheless largely underestimated, and the nature of the process - largely depending on the Responders' availability and commitment, as well as on the initial status of their submitted contribution - added increased uncertainty to a realistic estimation of the duration of the process.

- ➔ *A strategy for improving the efficiency of the process need to be devised, both at the conceptual level (still to be defined), and at the technical level (e.g. providing additional mass editing tools for Responders that contributed a large number of entries into the database; implement revision tools within the web interface that would allow for an easier update of contents upon acceptance of edited input).*

The time taken for the Verification Process (following an already-extended Data Collection period), together with the rapid progress in the production and release of TCDRs (new datasets, reprocessing / time extension of existing datasets), led to a precocious outdatedness of the ECV Inventory. Both for the purpose of the Gap Analysis, as well as for practical users, the information in the inventory needs to be as up to date as possible, and this is not compatible with the previous planned biennial update of a static ECV Inventory (linked to WGClimate 2-yearly chair cycle) followed by a very long Verification Process.

- ➔ *The biennial update of the ECV Inventory as the cornerstone of a full development cycle shall be replaced by a quasi-continuous data collection process running in parallel with a more evenly distributed workload for the quality control of the input provided (either new or updated), with sub-versions of the inventory being publicly released once a year.*

The Verification Process demanded a huge effort from Responders, with several iterations being usually needed in order to attain a satisfactory state of the information in the database. The process itself was also associated to a steep learning curve towards the provision of a complete and consistent input regarding each climate data record.

- ➔ *The pool of Responders that have already contributed to the ECV Inventory should be kept as much as possible. The engagement with agency focal points and experts for the data records was key to the success of the huge efforts spend on the population of the inventory and information verification. For future updates of the inventory the community involvement remains to be of high importance. This has the consequence that changes to the inventory shall we implemented with great care to not to lose the support of the community.*

7.3 Gap Analysis (GCOS criteria analysis only)

The Gap Analysis process consists of a characterisation of the state of climate monitoring from space aiming at a structured identification of gaps, shortcoming, or missed opportunities as detailed in Section 6. The points listed below detail some of the finding from the Gap Analysis process from an operational perspective.

The initially-planned, globally-exhaustive Gap Analysis, addressing all of GCOS ECVs listed [RD1], using all the TCDRs in ECV Inventory, revealed itself too complex and time-consuming a task to undertake in the time available, partly due to the very large number of entries in the inventory. Even though it might still fit into the previously designed 2-year development cycle for the ECV Inventory, it is clearly not compatible with a more dynamic approach of an ever-evolving and up-to-date database of TCDRs. Moreover, a very long development cycle would result in a gap analysis performed over outdated information, potentially leading to the detection of false gaps and impairing the reliability of the conclusions drawn.

➔ *Instead of a full Gap Analysis process run over all contents of the ECV Inventory, alternative partial approaches, compatible with a quasi-continuously open data collection to the ECV Inventory should be considered, and performed on a e.g. yearly basis: thematic gap analysis (e.g. performed over all ECV Products relevant for the Carbon Cycle), addressing known issues or gaps (e.g. known missing type of instrument in near future).*

The involvement of the domain (Atmosphere, Ocean, Land) climate experts in assessing the degree of compliance of each TCDR to the GCOS requirements and the suitability for different climate applications was absolutely essential for a thorough Gap Analysis process.

➔ *The WGClimate should work on a further consolidation of the Gap Analysis domain teams, with possible addition of experts to fully cover detailed knowledge of datasets addressing each individual ECV Product should be pursued.*

The platform- and application-independent nature of the product target requirements set by GCOS in [RD2], resulted in increased challenges for the Gap Analysis process, in what the compliance of space-based TCDRs to GCOS product target requirements is concerned.

➔ *The definition of clearer product requirements, namely in what concerns dependency on the climate applications envisaged, as well as the observation platform (mostly a clear distinction between space-based and in-situ observations) is recommended to GCOS. The introduction of graded product requirements could also be suggested as a major improvement to the unique measurement platform-independent "target" (i.e. "goal") requirements currently made available.*

The inconsistency between the nomenclature used by GCOS for the geophysical variables (or ECV Products) with WMO's, impairs the use of synergies with existing databases of satellite missions and measurements (e.g. CEOS-MIM, WMO OSCAR) mainly in assessing the "missed opportunities" for the production of TCDRs from existing measurements.

➔ *The Gap Analysis Domain Teams should be encouraged to cooperate in the effort to harmonise geophysical variables' nomenclature between GCOS and WMO, and to lend their expertise to the analysis of missed opportunities (e.g.*

by assessing the real capability of existing / planned instruments in the measurement of a given physical quantity and the retrieval of a geophysical variable). A dedicated recommendation regarding consistency of nomenclature should be included in the feedback to GCOS, to be provided by the WGClimate.

A preliminary analysis of the ECV Inventory revealed a relatively low use of FCDRs (Fundamental Climate Data Records) for the generation of the TCDRs entered in the database.

➔ *The development of a complementary inventory of FCDRs shall be considered to allow for a better traceability between FCDRs and TCDRs, and also to constitute a valuable repository of information for TCDR producers.*

7.4 Conclusion

The Development Cycle #2 of the ECV Inventory was initially designed taking the heritage from Cycle #1 as a baseline, which consisted mainly of a proof of concept. The planned timeline and foreseen effort were mostly based on the dimension of the previous cycle's database, approximately one fifth the size of that compiled in Cycle #2, and therefore the approach followed and the support tools initially developed had not taken into account what became an unprecedented contribution of input from CEOS and CGMS Agencies. The fact that Cycle #1 was not run to completion also prevented the early detection during Cycle #2 of some issues that added increased challenges to the process in its different phases. As a consequence, Cycle #2 was characterised by all the adaptations in real-time that any learning process can bring. Some of the "lessons learnt" during the process were still timely enough to result in the implementation of improvements in the time frame of this cycle, but most of them have simply resulted in the suggestions for later improvements listed in the previous sections 7.1, 7.2 and 7.3 above.

In recommending improvements and changes based on lessons learnt in Cycle #, two different types of issues form the basis for these suggestions: those simply resulting from the approach followed, and mainly triggered by the above mentioned and generally unforeseen dimension of the ECV Inventory and the workload associated; and the ones that are external to the process itself, but rather depending on external entities or factors (e.g. GCOS approach to product target requirements).

Annex A. Recommendations for Coordinated Actions

Nr.	Recommendation text
1	***WG Climate to distinguish between CDRs and ICDRs, and to create an additional part of the inventory that shall contain the ICDRs.***
2	***WGClimate to include a more relaxed commitment level in the "Future CDRs" component of the ECV Inventory that does not require firm programmatic arrangements at the present time. This new level allows the capture of more contributions from future sensors.***
3	***Space agencies should adopt the nomenclature for climate data records as defined in [RD-2] and should encourage their personnel to apply it.***
4	***GCOS to work with the WGClimate towards a clearer linkage between user requirements for the ECV products and climate applications.***
5	***CEOS and WMO to better align or facilitate interoperability of the MIM and OSCAR/Space databases, and possibly even integrate the information into one single database, to ensure a more accurate, unified view of past, current and planned capabilities.***
6	***WGClimate to develop a white paper on what is needed for the validation of climate data records including uncertainty information and stability aspects.***
7	***WGClimate to establish a specific inventory for FCDRs to signal their importance and to promote their usage for the production of ECV climate data records.***
8	***CEOS and CGMS agencies to add the delivery of FCDRs for each individual satellite instrument (linked to relevant precursor instrument series) to their agency remit.***
9	***CEOS and CGMS agencies to require the application of metadata standards with the production of climate data records.***
10	**T*o ensure continuity in CO_2 CDRs, agencies or partner entities are requested to commit to the generation of CDRs in all relevant spectral domains including SWIR from existing or approved missions measuring tropospheric and total column CO_2.***
11	***Agencies or related entities are encouraged to systematically link their satellite-based derivation of CO_2 sources and sinks with data from in-situ/ground-based infrastructure and modelling framework(s) in order to estimate Earth-surface CO_2 fluxes (see GCOS IP 2016 Action T71) and provide feedback on their plans/progress.***

Nr.	Recommendation text
12	***The AC-VC to develop a plan to address the measurement of stratospheric CH_4 profiles in order to fill the gap for the related FCDR/CDRs.***
13	***Agencies to plan for the generation of tropospheric column CH_4 ECV data records based on the data collected by instruments on missions such as Sentinel-5P, MERLIN, GeoCarb, Sentinel-5, FY-3D, GOSAT-2.***
14	***The CEOS Precipitation Virtual Constellation (P-VC) to further study the situation on precipitation climate data records taking into account the findings of WGClimate gap analysis report and to identify a way forward to stimulate the production of an improved precipitation CDR based upon the experiences gained with existing datasets. The P-VC should also consult with the CGMS-IPWG and WMO SCOPE-CM activity for the establishment of international collaboration for the development and production of such a CDR.***
15	***The SST-VC should foster further work on SST ECV products in regards to the improvements that may be possible by better exploiting/integrating geostationary, historic IR sounders and C-band radiometers.***
16	***C-band microwave radiometer measurements for all-weather SST:*** • ***(Short term) All efforts to maximise the life time of AMSR-2 on JAXA's GCOM-W1 should be supported.*** • ***(Mid-term) The possibility of an AMRS-2 on GCOM-W2 should be prioritised, full data sharing in regards to MWI instruments of the FY-3 series and HY-2B.*** • ***(Longer term) Agencies with operational mandates should develop and fund a sustainable plan, with redundancy, for observations from C-band microwave conical scanning radiometers.***
17	***CEOS and CGMS Agencies with interests in and/or mandates for Sea Surface Salinity are encouraged to support independent multi-sensor SSS CDR activities from the available L-Band observations.***
18	***Space agencies should give priority to sea surface salinity measurements in their future missions to ensure continuity of SSS CDRs. Following this recommendation agencies should consider including L-band instrumentation on future passive microwave missions.***
19	***The CEOS Land Surface Imaging-Virtual Constellation (LSI-VC) to coordinate on the formulation of future high resolution missions and seamless continuity of sustained Land Surface Temperature CDRs.***
20	***The CEOS Land Surface Imaging-Virtual Constellation (LSI-VC) together with WGCV and WGClimate to devise a way forward for the combined use of past, current and future instruments to create sustained Land Surface Temperature CDRs.***
21	***LSI-VC should assess the climate user community needs for LAI data records that are not currently being exploited from existing missions (e.g.***

Nr.	Recommendation text
	Sentinel-2, Landsat), and inform WG Climate of their findings to enable further planning for needed LAI data records.
22	***Both the CEOS MIM and WMO OSCAR databases should be updated in a consistent fashion to reflect the Above-ground Biomass ECV and in doing so are co-aligned.***
23	***All C-band and L-band SAR measurements of CEOS and CGMS agencies, should be made openly available by space agencies operating the instruments for the construction of CDRs for Above-ground Biomass. The combination of L-band and C-band measurements will help extend the sensitivity of existing estimates.***
24	***Space agencies to plan for continuity of measurements, such as to be provided by BIOMASS and GEDI.***
25	***Space Agencies to plan for high-resolution data provision in support of REDD+ type applications leading to the Global Stocktake process.***

Annex B. Questionnaire for Current Component of ECV Inventory

Area	Subject index	Subject	Question number *current*	Question
STEWARDSHIP	1	Responder name	1	Who is the individual populating the questionnaire?
	2	Responder e-mail	2	Please state the e-mail address of the individual populating the questionnaire.
	3	Data Record identifier	3	What is the Data Record Identifier of the TCDR? In case this TCDR is part of a "family" of products, please provide the TCDR family name.
	4	Responsible organisation	4	What is the name of the organisation with overall responsibility for the data record?
	5	Collection organisation	5	Which organisational entity is responsible for collecting the satellite observations?
	6	Calibration organisation	6	Which organisational entity is responsible for calibrating the satellite observations?
	7	FCDR organisation	7	Which organisational entity is responsible for generating and maintaining the FCDR (i.e. correcting, geolocating and applying calibration parameters to the satellite observations)?
	8	Inter-calibration organisation	8	Which organisational entity is responsible for inter-calibrating the satellite observations?
	9	TCDR organisation	9	Which organisational entity is responsible for generating and maintaining the TCDR (i.e. conversion of the FCDR to geophysical parameters)?
	10	GCOS-requirements organisation	10	Which organisational entity is responsible for checking if the resultant TCDR(s) meet the relevant GCOS requirements, and identifying any required processing updates?
	11	Peer-review organisation	11	Which organisational entity is responsible for organising the peer review of the data record? Please describe the status of the peer-review.
	12	Archiving organisation	12	Which organisational entity is responsible for collating, archiving and maintaining the resultant climate data records (e.g. archiving observations, FCDRs, TCDRs and all ancillary information such as processing configurations used in their generation, comparison with GCOS requirements, peer reviews, external reference data, etc)?

Area	Subject index	Subject	Question number *current*	Question
	13	User-service organisation	13	Which organisational entity is responsible for servicing user requests for the data record?
	14	User-feedback organisation	14	Which organisational entity is responsible for responding to user feedback on the use of this data record?
	15	Maintenance and user support commitment	15	Until when are there firm commitments in place to continue to maintain and provide user support for this data record?
GENERATION PROCESS	17	Assessment body	16	If the data record has been produced in conjunction with any external domain-specific generation and assessment body, then please identify the external domain-specific bodies engaged in the generation of the data record.
	18	Quality Assurance Process	17	Please describe the quality assurance process which has been implemented for the data record generation process. If it has been done in conjunction with a relevant international coordination body, then please indicate which international organisation or coordination body covered this aspect for the data record considered.
	19	GCOS-requirements compliance assessment	18	If the compliance status of the TCDR with the GCOS requirements has been assessed, then please provide a link to the document describing the results of the assessment.
	20	GCOS-guidelines peer-review compliance assessment	19	If the degree of compliance with the GCOS guidelines has been assessed through a peer-review process, then please provide links to the documents describing the results of the assessment.
	21	Quantitative maturity index assessment	20	If a quantitative maturity index assessment has been performed for the data record, then please provide a link to the document describing the results of this assessment.
RECORD CHARACTERISTICS	22	ECV and ECV Product	21	To which ECV does the data record contribute? Which ECV Product is addressed by the data record?
	23	Physical quantity	22	Which physical quantity does the data record provide?
	24	SI units	23	What are the SI units of the data record?
	25	Satellite/sensor combination	24	Which satellite/sensor combination is used to generate the data record? For each pair satellite/sensor, please specify the level of data used, as well as the corresponding period of time of data usage (start- and end-date).

Area	Subject index	Subject	Question number *current*	Question
	26	Inter-calibration satellite/sensor combination	25	Against which satellite/instrument combination has the data record been inter-calibrated? For each pair satellite/sensor, please specify the level of data used, as well as the corresponding period of time of data usage (start- and end-date).
	27	Ground-base network calibration	26	If this data record is utilising a ground-based network for calibration purposes, then please specify the network and provide a link to the source.
	28	Geographical coverage	27	What is the geographical coverage of the TCDR? Please specify the geographical extent and which domains (land, inland water, ocean, ice) are covered by the TCDR.
	29	Horizontal Resolution	28	What is the horizontal resolution of the TCDR (in km)?
	30	Vertical Resolution	29	What is the vertical resolution of the TCDR (in km)?
	31	Temporal resolution	30	What is the temporal resolution of the TCDR (in days)?
	32	Accuracy	31	What is the accuracy of the TCDR?
	33	Stability	32	What is the stability of the TCDR?
	34	Start-date	33	What is the start-date of the continuous data record?
	35	End-date	34	What is the end-date of the continuous data record?
DOCUMENTATION	37	CDR-generation documentation (link)	35	Please provide the links to the documents describing all the steps taken in the generation of FCDRs and TCDRs, including algorithms used, on-board calibration, specific FCDRs used, version management system used, and characteristics and outcomes of validation activities.
	38	Data documentation (link)	36	Please provide link(s) to documentation provided with the data record.
	39	Scientific-review process (link)	37	Please provide link to a document describing the scientific review process related to FCDR/TCDR construction (including algorithm selection), FCDR/TCDR quality and applications.
ACCESSIBILITY	40	Access point	38	Please provide information on the access point (e.g. contact e-mail) for access to data records.
	41	Access conditions	39	What are the data-access conditions? Please also state whether access is made through an ordering system and if registration is required.

Area	Subject index	Subject	Question number *current*	Question
	42	Data record (link)	40	Please provide link(s) to the data record.
	43	FCDR availability	41	In case the FCDRs are also available to the user community, please provide a link to that data record.
	44	Data format and metadata standard	42	What formats are available for the data record and what standard has been used for the metadata?
	45	Dissemination mechanisms	43	What dissemination mechanisms are available for the data record? Please also state whether the data record is registered in international dissemination platforms (e.g. Obs4MIPs, GEOSS Portal).
	46	Release date	44	When was the data record released to the user community (year)?
APPLICATIONS	47	Climate applications	45	What specific climate applications does this data record support?
	48	Users	46	Please provide examples of effective users of this data record.

Annex C. Questionnaire for Future Component of ECV Inventory

Area	Subject index	Subject	Question number *future*	Question
STEWARDSHIP	1	Responder name	1	Who is the individual populating the questionnaire?
	2	Responder e-mail	2	Please state the e-mail address of the individual populating the questionnaire.
	4	Responsible organization	3	What is the name of the organisation with overall responsibility for the planned data record?
	5	Collection organisation	4	Which organisational entity will be responsible for collecting the satellite observations?
	6	Calibration organisation	5	Which organisational entity will be responsible for calibrating the satellite observations?
	7	FCDR organisation	6	Which organisational entity will be responsible for generating and maintaining the FCDR (i.e. correcting, geolocating and applying calibration parameters to the satellite observations)?
	8	Inter-calibration organisation	7	Which organisational entity will be responsible for inter-calibrating the satellite observations?
	9	TCDR organisation	8	Which organisational entity will be responsible for generating and maintaining the TCDR (i.e. conversion of the FCDR to geophysical parameters)?
	10	GCOS-requirements organisation	9	Which organisational entity will be responsible for checking if the resultant TCDR(s) meet the relevant GCOS requirements, and identifying any required processing updates?
	11	Peer-review organisation	10	Which organisational entity will be responsible for organising the peer review of the data record?
	12	Archiving organisation	11	Which organisational entity will be responsible for collating, archiving and maintaining the resultant climate data records (e.g. archiving observations, FCDRs, TCDRs and all ancillary information such as processing configurations used in their generation, comparison with GCOS requirements, peer reviews, external reference data, etc)?
	13	User-service organisation	12	Which organisational entity will be responsible for servicing user requests for the data record?

Area	Subject index	Subject	Question number *future*	Question
	14	User-feedback organisation	13	Which organisational entity will be responsible for responding to user feedback on the use of the data record?
	16	Level of commitment	14	Please describe the level of commitment regarding the production of the planned data record.
RECORD CHARACTERISTICS	22	ECV and ECV Product	15	To which ECV will the data record contribute? Which ECV Product will be addressed by the data record?
	23	Physical quantity	16	Which physical quantity will the data record provide?
	25	Satellite/sensor combination	17	Which satellite/sensor combination will be used to generate the data record? For each pair satellite/sensor, please specify the intended level of data to be used, as well as the corresponding planned period of time of data usage (start- and end-date).
	28	Geographical coverage	18	What is the geographical coverage of the planned TCDR? Please specify the geographical extent and which domains (land, inland water, ocean, ice) will be covered by the TCDR.
	29	Horizontal Resolution	19	What is the anticipated horizontal resolution of the TCDR (in km)?
	30	Vertical Resolution	20	What is the anticipated vertical resolution of the TCDR (in km)?
	31	Temporal resolution	21	What is the anticipated temporal resolution of the TCDR (in days)?
	32	Accuracy	22	What is the anticipated accuracy of the TCDR?
	33	Stability	23	What is the anticipated stability of the TCDR?
	34	Start-date	24	What will be the start-date of the continuous data record?
	35	End-date	25	What will be the end-date of the continuous data record?
	36	TCDR heritage	26	If the TCDR is a new release/extension of an existing TCDR, for which existing TCDR is the planned one an extension or a new version/release?
ACCESSIBI	41	Access conditions	27	What are the planned data-access conditions?
	43	FCDR availability	28	Will FCDRs as well as TCDRs be available to the user community?

Area	**Subject index**	**Subject**	**Question number *future***	**Question**
	46	Release date	29	What is the planned date for releasing the data record to the user community (year)?
APPLICATIONS	47	Climate applications	30	What specific climate applications will this new data record support?
	48	Users	31	Please provide examples of potential users of the planned data record.

Annex D. Grading applied to Inventory entries

Topic	Inventory Question	Assessment question	Grading
Generation Process	GCOS-guidelines peer-review compliance assessment	Empty / No info	0
			1
			2
		Formal assessment of compliance (link to report / web page)	3
Generation Process	Quantitative maturity index assessment	Empty / No info	0
		Quantitative or Qualitative Assessment (with no link to result)	1
		Qualitative Assessment (with link to result)	2
		Quantitative assessment (with link to result)	3
Generation Process	GCOS-requirements compliance assessment	Empty / No info	0
		Assessment has been performed but no details are provided	1
		Characteristics of CDR are demonstrated but compliance is not assessed (link to PVR or similar)	2
		Formal assessment of compliance (link to report / web page)	3
Generation Process	QA Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Generation Process	Assessment Body	EMPTY	0
			1
			2
		NOT_EMPTY	3
Generation Process	QA Process	Empty / No info	0
		Information on product validation is provided	1
		Short description or incomplete approach? Approach not using a known standard (such as ISO) or a peer-approved process (such as QA4EO)	2
		Recognised standards (such as ISO) adhered to or peer-approved QA process (such as QA4EO) adopted	3
	SI units	EMPTY	0

Topic	Inventory Question	Assessment question	Grading
Record Characteristics			1
			2
		NOT_EMPTY	3
Stewardship	Data record identifier	EMPTY	0
			1
			2
		NOT_EMPTY	3
Accessibility	Metadata standard	Empty / No info	0
		None	1
			2
		(Known) Standard applied	3
Applications	Climate applications	Empty / No info	0
		Climate Applications identified in generic way and not demonstrated by references	1
		Climate Applications consistently identified, but not or only partly demonstrated by references	2
		Climate Applications consistently identified, demonstarted by references.	3
Accessibility	FCDR availability (link)	Empty / No info	0
		Link provided to non-FCDR	1
		Link to general web page with no clear identifier to be used	2
		Available from data provider; archived	3
Record Characteristics	Link to source	EMPTY	0
			1
			2
		NOT_EMPTY	3
Record Characteristics	Ground-based network	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	Maintenance and user support commitment	Empty / No info	0
		Short Term (up to 5 years), potentially constrained to a project	1
		Long term after release but conditional, e.g., depending on reviews	2
		Perpetual / indefinite	3
Record Characteristics	GroupInterCalSatelliteInstrument	EMPTY	0
			1
			2

Topic	Inventory Question	Assessment question	Grading
		NOT_EMPTY	3
Stewardship	GCOS Requirements Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	Inter-calibration Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	Peer-review organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	Official citation reference (optional)	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	TCDR family	EMPTY	0
			1
			2
		NOT_EMPTY	3
Applications	Users	Empty / No info	0
		Only user category is provided, e.g, scientific community	1
		Specific users are provided but no further description	2
		Specific users are provided including a description what they do	3
Documentation	Scientific-review process (link)	Empty / No info	0
		Information on Validation activities and/or results provided.	1
		Evidence for particpation in international quality assessment, e.g., algortihm comparison of GEWEX data record quality assessments.	2
		Description of agency internal or external review process or link to document describing it (a report by external reviewers on assessment of quality of data and documentation is also acceptable)	3
Record Characteristics	Accuracy	Empty / No info (when information should have been provided)	0

Topic	Inventory Question	Assessment question	Grading
		Non quantitative information provided	1
		Not compliant with GCOS-200 (or no requirements specified in GCOS-200) but appropriate for intended applications	2
		Fully compliant with GCOS-200 (for climate monitoring at global scale)	3
Record Characteristics	Stability	Empty / No info (when information should have been provided)	0
		'Not Assessed' (for various reasons)	1
		Not compliant with GCOS-200 (or no requirements specified in GCOS-200) but appropriate for intended applications	2
		Fully compliant with GCOS-200 (for climate monitoring at global scale)	3
Stewardship	Status of peer-review	Empty / No info	0
		Peer-review articles submitted (or organisational process ongoing)	1
		Peer-reviewed articles published	2
		Organisational formal review or similar (on the dataset) + Peer-reviewed articles published	3
Record Characteristics	Temporal resolution	Empty / No info (when information should have been provided)	0
		Not compliant with GCOS-200 nor with intended applications	1
		Not compliant with GCOS-200 (or no requirements specified in GCOS-200) but appropriate for intended applications	2
		Fully compliant with GCOS-200 (for climate monitoring at global scale) or 'Not Applicable'	3
Accessibility	Data record (link)	Empty / No info	0
		Link to general web page with no clear identifier to be used	1
			2
		Link directly pointing to landing page order portal.	3
Accessibility	Registration / ordering	EMPTY	0
			1
			2
		NOT_EMPTY	3
Accessibility	Restrictions to access	NOT_EMPTY	0
			1
			2
		EMPTY	3
Accessibility	Type of access		0

Topic	Inventory Question	Assessment question	Grading
		Selected access	1
		Constrained access	2
		Free and unrestricted access	3
Stewardship	User-service organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Accessibility	Data format	EMPTY	0
			1
			2
		NOT_EMPTY	3
Accessibility	Release date (yyyy)	EMPTY	0
			1
			2
		NOT_EMPTY	3
Accessibility	Dissemination mechanisms	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	Archiving Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Accessibility	Access point	Empty / No info	0
		Basic entry point instead of e-mail provided	1
		Access point is PI (or similar)	2
		Access point is helpdesk (or similar)	3
Stewardship	Data record name and version (optional)	Empty / No info	0
		name but no version	1
			2
		name and version	3
Documentation	Data documentation (link)	Empty / No info	0
		Links provided not leading to documents addressing the question	1
		Links leading to partially fulfilling documentation	2
		Links to full description of CDR (PUG, ATBD, PVR)	3
Record Characteristics	Horizontal resolution	Empty / No info (when information should have been provided)	0

Topic	Inventory Question	Assessment question	Grading
		Not compliant with GCOS-200 nor with intended applications	1
		Not compliant with GCOS-200 (or no requirements specified in GCOS-200) but appropriate for intended applications	2
		Fully compliant with GCOS-200 (for climate monitoring at global scale) or 'Not Applicable'	3
Record Characteristics	Vertical resolution	Empty / No info (when information should have been provided)	0
		Not compliant with GCOS-200 nor with intended applications	1
		Not compliant with GCOS-200 (or no requirements specified in GCOS-200) but appropriate for intended applications	2
		Fully compliant with GCOS-200 (for climate monitoring at global scale) or 'Not Applicable'	3
Record Characteristics	GroupGeographicalCoverage	Empty / No info	0
		Local / Regional / National	1
		Continental, Complete Ocean Basin, or restricted to over land/ocean (non-global coverage for specified ECV)	2
		Global coverage (ECV specific, i.e. global on applicable domain -- e.g. Ocean-only for SST, Land-only for LST -- or latitudinal extent -- e.g. over 40 degrees latitude for Sea Ice)	3
Stewardship	Responsible Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	Collection Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	FCDR Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	User-feedback organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship		EMPTY	0

Topic	Inventory Question	Assessment question	Grading
	Calibration Organisation		1
			2
		NOT_EMPTY	3
Documentation	CDR-generation documentation (link)	Empty / No info	0
		Links provided not leading to documents addressing the question	1
		Links leading to partially fulfilling documentation	2
		Link to full description of end-to-end processing chain	3
Record Characteristics	End-date of TCDR	EMPTY	0
			1
			2
		NOT_EMPTY	3
Record Characteristics	Start date of TCDR	EMPTY	0
			1
			2
		NOT_EMPTY	3
Stewardship	TCDR Organisation	EMPTY	0
			1
			2
		NOT_EMPTY	3

Annex E. Acronyms[12]

3D	Three Dimensional
CCI	ESA Climate Change Initiative
CCI+	Extension to the ESA Climate Change Initiative
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CH_4	Methane
CM SAF	Satellite Application Facility on Climate Monitoring
CNES	Centre National D'études Spatiales
CO	Carbon Monoxide
CO_2	Carbon Dioxide
C3S	Climate Change Service
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOI	Digital Object Identifier
DMSP	The Defense Meteorological Satellite Program
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EO	Earth Observation
EOS	Earth Observing System platforms
ERB	Earth Radiation Budget
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCDR	Fundamental Climate Data Record
GCOS	Global Climate Observing System
GCOS IP	GCOS Implementation Plan
GEO	Geosynchronous Earth Orbit
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment
GFCS	Global Framework for Climate Services
GHG	Greenhouse Gas
GHRSST	Global High Resolution Sea Surface Temperature Project
GPCP	Global Precipitation Climatology Project
GTN-L	Global Terrestrial Network - Lakes
HCHO	Formaldehyde
ICDR	Interim Climate Data Record
INPE	Instituto Nacional de Pesquisas Espaciais

[12] Specific acronyms of satellite missions and instruments can be found under https://www.wmo-sat.info/oscar/spacecapabilities and http://database.eohandbook.com/ and http://space.skyrocket.de/.

IPMA	Instituto Português do Mar e da Atmosfera
IPWG	International Precipitation Working Group
IR	Infrared
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
LAI	Leaf Area Index
LEO	Low Earth orbit
LIDAR	Light Detection and Ranging
MW	Microwave
N_2O	Nitrous Oxide
NASA	National Aeronautics and Space Administration
NO2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
O3	Ozone
PPB	Parts Per Billion
PPM	Parts Per Million
REDD+	Reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (UNFCCC)
RFI	Radio Frequency Interference
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCOPE-CM	Sustained and Coordinated Processing of Environmental satellite data for Climate Monitoring
SDG	Sustainable Development Goals
SO2	Sulfur Dioxide
SSH	Sea Surface Height
SSS	Sea-surface Salinity
SST	Sea Surface Temperature
SWIR	Short Wave Infrared
TCDR	Thematic Climate Data Record
TIR	Thermal infrared
TOA	Top-of-Atmosphere
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USGS	United States Geological Survey
WGClimate	The Joint CEOS/CGMS Working Group on Climate
WGCV	CEOS Working Group on Calibration & Validation
WMO	World Meteorological Organization

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