ANNEX B: ASSESSMENT OF PROGRESS ON IMPLEMENTATION PLAN ACTIONS

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B.a General

Action G1:	Guidance and best practice for adaptation observations
Action	Produce guidance and best practice for climate observations for adaptation. This would include advice on using the global and regional requirements at a national and local level, and guidance and best practice on prioritization of observations, implementation, data stewardship and reporting. Promote the use of this guidance by parties and donors. Review the use of this guidance and requirements and revise as needed.
Benefit	Encourage high-quality, consistent and comparable observations.
Time frame	Version one available in 2018, thereafter review and refine, as needed.
Who	GCOS in association with users and other stakeholders
Performance indicator	Availability and use of specifications
Annual cost	US$ 10 000–100 000

Assessment: 3 – Underway with significant progress.

Task Team on Observations for Adaptation convened and reported to Steering Committee. Work continues.

Task team was established to consider GCOS and adaptation. Observations can both support the implementation of adaptation and also monitor the implementation of adaptation. This task team produced interim reports to the GCOS Steering Committee, but a final report has been delayed.

Action G2:	Specification of high-resolution data
Action	Specify the high-resolution climate data requirements: • In response to user needs for climate adaptation planning, develop high-resolution observational requirements and guidance and distribute widely; • Promote coordination among climate observation systems at different scales from subnational to global, particularly through relevant focal points, national coordinators and regional climate centres and alliances; • Ensure that this work responds to other work streams under UNFCCC's Research and Systematic Observation agenda item and the SDGs; • Ensure these data are openly accessible to all users.
Benefit	Develops a broad understanding of climate observational needs. Ensures consistency of climate observations and thus enables their wide use.
Timeframe	2018 and ongoing thereafter
Who	GCOS in association with users and other stakeholders
Performance indicator	Availability and use of specifications
Annual cost	US$ 10 000–100 000

Assessment: 2 – Started but little progress.

This is pending the outcome of the Task Team on Adaptation (Task G1).

Action G3:	Development of indicators of climate change
Action	Devise a list of climate indicators that describe the ongoing impacts of climate change in a holistic way. Consider the work of WMO, IPCC and others. Indicators may include heating of the ocean, rising sea level, increasing ocean acidity, melting glaciers and decreasing snow, changes in Arctic sea ice, changes in vegetation characteristics and distributions and land-cover changes.
Benefit	Communicate better the full range of ongoing climate change in the Earth system
Time frame	2017
Who	GCOS in association with other relevant parties, including WMO and IPCC
Performance indicator	Agreed list of indicators (for example, 6 in number)
Annual cost	US$10 000–100 000

Assessment: 5 – Complete.

A list of indicators has been prepared and published[48]. The indicators are surface temperature, ocean heat content, atmospheric CO_2 concentration, ocean acidification, sea level, glaciers and Arctic and Antarctic sea ice extent. They form the basis of the annual WMO Statement of the state of the global environment which is submitted to UNFCCC. In addition, the EU Copernicus Climate Change Services (C3S), uses the indicators in their annual European state of the Climate. They have been used in the WMO Statement Climate Change. The work is continuing to develop indicators on changes in the biosphere and on changes in extremes (such as temperature and precipitation).

Action G4:	Indicators for adaptation and risk
Action	Promote definition of, and research supporting, the development of indicators linking physical and social drivers relating to exposure, vulnerability and improved resilience, in line with national requirements
Benefit	Tracking of progress of climate change and adaptation, improved capacity to respond and avoid loss.
Timeframe	2017
Who	GCOS with relevant agencies and national bodies
Performance indicator	Definition and development of relevant risk assessments
Annual cost	US$ 10 000–100 000

Assessment: 2 – Started but little progress.

This is pending the outcome of the Task Team on Adaptation (Task G1).

[48] GCOS-206: https://library.wmo.int/doc_num.php?explnum_id=3418

Action G5:	Identification of global climate observation synergies with other multilateral environmental agreements
Action	Ensure a scientifically rigorous assessment of the exact requirements of common variables and identify a common set of specifications between GCOS and CBD and UNCCD; ensure that maximum benefit is taken from GCOS ECVs in implementing the SDG process, including addressing multiple-benefits across SDG goals, fulfilling the climate specific goal (SDG-13) and providing support to transparent global development and climate finance prioritization (SDG-17); explore how ECV data can contribute to: (a) The Ramsar Convention; (b) the Sendai Framework for Disaster Risk Reduction; (c) other MEAs.
Benefit	Improved information exchange between Conventions, cost savings, shared capacity-building and outreach, and coordinated approaches to observation providers
Time frame	Ongoing (2017 for Rio conventions, 2018 for Ramsar and Sendai)
Who	GCOS, CBD Secretariat, UNCCD Secretariat and the Global Mechanism, GEO Secretariat and GEO Biodiversity Observation Network GCOS and sponsors + Parties (through national statistics offices) and GEO (GEO initiative on the SDGs (GI-18)) GCOS, Ramsar Convention, Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction, ICSU-ISSC-UNISDR programme IRDR, Secretariats of other MEAs
Performance indicator	Climate service components optimized for disaster risk reduction
Annual cost	US$ 10 000–100 000

Assessment: 1 – Little or no progress.

Ongoing and depends on the outcome of the adaptation related work (G1).

Action G6:	Assisting developing countries to maintain or renovate climate observation systems and to improve climate observations networks
Action	Provide financial support to GCM through its trust fund; cooperate between donors to provide targeted support to countries to improve their observational systems; propose suitable projects for support
Benefit	Targeted expert assistance to improve key monitoring networks
Time frame	Continuous
Who	Developed countries, developing country aid banks, WMO VCP, GEF and other funds for UNFCCC, the United Nations Development Programme (UNDP), national aid agencies; project proposals coordinated by GCOS panels, GCM Board and potential donor countries
Performance indicator	Funds received by the trust fund; Increasing number of projects supporting countries
Annual cost	US$ 1–10 million

Assessment: 5 – Complete.

Work is limited by available funds but the GCOS Cooperation Mechanism has supported several countries. Since 2016, US$ 0.5 million (compared to US$ 1.2 million 2010-2015) has been invested in several projects (See Annex C.a.i for a complete list).

Action G7:	GCOS coordinator
Action	Activate national coordinators
Benefit	Coordinated planning and implementation of systematic climate observing systems across the many national departments and agencies involved with their provision
Time frame	Ongoing
Who	Relevant division at national governmental level responsible for the coordination of climate observation
Performance indicator	Annual reports describing and assessing progress made in national coordination in compliance with the coordinator's responsibilities; establishing a national climate observations inventory and publication of annual reports
Annual cost	US$ 10 000–100 000/year/national government

Assessment: 1 – No progress

Not all countries identify a GCOS Coordinator.

Action G8:	Regional workshops
Action	Hold regional workshops to identify needs and regional cooperation, starting with Africa
Benefit	Improve key monitoring networks to fill gaps in regions
Time frame	2018–2020
Who	GCOS secretariat in coordination with the UNFCCC Secretariat and national coordinators and the involvement and coordination with existing capacity-building activities, for example WCRP programmes such as CLIVAR or CORDEX)
Performance indicator	Workshop outputs describing regional plans and priority national needs.
Annual cost	US$ 1–10 million (total for six workshops)

Assessment: 5 – Complete.

One workshop was held annually. However, the work was limited by available funds. Workshops were held in Fiji for Pacific Island Stated, Uganda, for East Africa and in Belize, for the Caribbean. See https://gcos.wmo.int/en/regional-workshops. The outcomes were presented to the UNFCCC. GCOS plans to hold future workshops annually but this was not possible in 2020 due to COVID-19.

Action G9:	Communication strategy
Action	Develop and implement a GCOS communication strategy
Benefit	Targeted expert assistance to improve key monitoring networks
Timeframe	Develop strategy/plan in 2017; implement in subsequent years
Who	GCOS Secretariat.
Performance indicator	Increased monitoring and use of GCMP and monitoring of ECVs; increased donations to GCM; climate monitoring included in national plans and/or reporting to UNFCCC; production of material and improved website; participation in international meetings
Annual cost	US$ 100 000–1 million

Assessment: 4 – Progress on track.

Done but implementation pending WMO reorganisation.

Action G10:	Maintain ECV requirements
Action	Routinely maintain, review and revise list of ECV requirements. The GCOS secretariat will ensure that there is a consistent approach between panels.
Benefit	Clear, consistent and complete list of ECV requirements as a basis for national and international climate observations ensures consistency between observations.
Who	GCOS Panels, GCOS secretariat
Time frame	Develop a systematic approach in 2017 and review every five years
Performance indicator	Annually updated list of ECV requirements.
Annual cost	US$ 1 000–10 000 for experts

Assessment: 4 – Progress on track.

Underway - an on-going activity of the panels.

ECV Stewards have been appointed to be responsible for each ECV. A public consultation was held to solicit inputs into the revision of the ECV.

Action G11:	Review of availability of climate data records
Action	Provide a structured, comprehensive and accessible view as to what CDRs are currently available, and what are planned to exist, together with an assessment of the degree of compliance of such records with the GCOS requirements for the ECV products indicated in Annex A
Benefit	Improve planning of satellite-derived climate data acquisition
Who	CEOS/CGMS Working Group on Climate for records contributing to the ECV products that are indicated in Annex A.
Time frame	End 2016 and updated every two years thereafter.
Performance indicator	Online availability of an inventory of current and future CDRs, together with an assessment of compliance with GCOS requirements
Annual cost	Covered by CEOS and CGMS agencies

Assessment: 5 – Complete.

Available via ECV Inventory hosted by EUMETSAT for the Joint CEOS/CGMS Working Group on Climate.[49]

Action G12:	Gap-analysis of climate data records
Action	Establish a gap analysis process and associated actions, to: (a) address gaps/deficiencies in the current available set of CDRs; and (b) ensure continuity of records, and address gaps through the appropriate planning of future satellite missions for the ECV products indicated in Annex A
Benefit	Increase the utility of the CDRs
Who	CEOS/CGMS Working Group on Climate for records contributing to the ECV indicated in Annex A
Time frame	End 2017 and updated every two years thereafter.
Performance indicator	Availability of gap analysis and associated action plan
Annual cost	Covered by CEOS and CGMS agencies

Assessment: 4 – Progress on track.

Underway - an on-going activity of the Joint CEOS/CGMS Working Group on Climate[50].

[49] https://climatemonitoring.info/ecvinventory

[50] ECV-Inventory Gap Analysis Report, The Joint CEOS/CGMS Working Group on Climate (WGClimate) Document Reference WGCL/REP/18/986356. Version 1.1, 17 May 2018, https://ceos.org/document_management/Working_Groups/WGClimate/Documents/WGClimate_ECV-Inventory_Gap_Analysis_Report_v1.1.pdf

Action G13:	Review of ECV observation networks
Action	For all ECV products not covered by a review following actions G11 and G12: develop and implement a process to regularly review ECV observation networks, comparing their products with the ECV product requirements; identify gaps between the observations and the requirements; identify any deficiencies and develop remediation plans with relevant organizations; and ensure the data is discoverable and accessible. This action may also contribute to the definition of reference-grade observing network and standards. The GCOS science panels should identify stakeholders who will perform this review and regularly check all ECV products are being reviewed.
Benefit	Increase quality and availability of climate observations
Who	Organizations listed in Annex A. GCOS panels to maintain oversight.
Time frame	Develop and demonstrate review process in 2017. Review each ECV's observing systems at least every four years.
Performance indicator	Reports of results of ECV reviews produced by panels each year.
Annual cost	US$ 100 000–1 million also part of the work of panels

Assessment: 4 – Progress on track.

This is addressed in this GCOS Status Report.

Action G14:	Maintain and improve coordination
Action	Maintain and improve coordination with other global observing systems (such as GOOS and FluxNet), satellite agencies (especially through CGMS and CEOS), those providing climate services (such as GFCS, Copernicus and NMHS climate departments), GEO flagships (such as GEO Carbon, GFOI, Blue Planet: Oceans and Society), Regional Climate Centres and WMO technical commissions and other users such as UNFCCC and IPCC
Benefit	Improved and more efficient observation systems.
Who	GCOS Secretariat and Science Panels
Time frame	On going
Performance indicator	Reports to GCOS Steering Committee and science panels
Annual cost	Part of ongoing tasks of GCOS

Assessment: 4 – Progress on track.

Underway - an on-going activity. This is a central role of the secretariat and the GCOS Steering Committee

Action G15:	Open data policies
Action	Ensure free and unrestricted data access by encouraging that data policies facilitating the open exchange and archiving of all ECVs are followed; encouraging national parties to develop new data policies where appropriate, assessing and regularly reporting of status of data access
Benefit	Access to data by all users in all countries at minimum cost
Who	Parties and international agencies, appropriate technical commissions and international programmes; GCOS Secretariat.
Time frame	Continuing, of high priority.
Performance indicator	Number of countries adhering to data policies favouring free and open exchange of ECV data.
Annual cost	US$ 100 000–1 million

Assessment: 2 – Started but little progress.

Despite some progress not all data is openly available. The GCOS Secretariat is supporting the development of new WMO data policies.

Action G16:	Metadata
Action	1. GCOS to work with WMO to ensure that the WIGOS metadata standard meets GCOS requirements for metadata, where relevant; 2. Develop metadata standards for those observing systems where they do not exist.
Benefit	Improved access and discoverability of datasets
Who	Operators of GCOS related systems, including data centres
Time frame	Continuous
Performance indicator	Number of ECV-related datasets accessible through standard mechanisms
Annual cost	US$ 100 000–1 million (US$ 20 000 per data centre) (10% in non-Annex-I Parties)

Assessment: 4 – Progress on track.

WIGOS metadata standard has been approved and in principle meets the climate needs. Improving metadata is an ongoing task.

Action G17:	Support to national data centres
Action	Ensure national data centres are supported to enable timely, efficient and quality-controlled flow of observations to international data centres where they exist; ensure timely flow of feedback from monitoring centres to observing network operators
Benefit	Long-term, sustainable, provision of timely data and improved data quality
Who	Parties with coordination by appropriate technical commissions and international programmes
Time frame	Continuing, of high priority
Performance indicator	Data receipt at centres and archives
Annual cost	US$ 10–30 million (70% in non-Annex-I Parties)

Assessment: 1 – No progress

GCOS does not have the resources to support national data centres.

Action G18:	Long-term accessibility of data
Action	Ensure that data centres follow best practice in data stewardship to ensure long-term preservation of data according to guidance to be developed by WMO
Benefit	Preservation of data for future generations
Who	Funding agencies for data centre
Time frame	Ongoing
Performance indicator	Data held in compliant data centres and holdings and accessible to users
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Some improvements have been made. Copernicus is now archiving and providing access to climate data through the Climate Data Store. Despite short term support for some ECVs (e.g. for permafrost and soil moisture) this is fragile and does not cover all the relevant ECVs, ECVs products or guarantee long term data storage.

Action G19:	Data access and discoverability
Action	Identify and develop means of discovering and accessing all relevant CDRs and other relevant products. Ensure there is access to metadata that clearly distinguishes each data product and describes its adherence to the GCMP
Benefit	Increase access to CDRs
Who	GCOS, GEO, US National Oceanographic and Atmospheric Administration (NOAA)
Time frame	Develop plans in 2017
Performance indicator	Reports of results of ECV reviews produced by panels each year
Annual cost	US$10 000–100 000

Assessment: 3 – Underway with significant progress.

Despite some improvements in discoverability and access some gaps remain. Many climate data records are discoverable through sources such as the ECV inventory, the Climate Data Store and NOAA's National Centers for Environmental Information (NCEI). However, significant gaps remain in access to hydrological data.

Action G20:	Use of digital object identifiers for data records
Action	GCOS to encourage international data centres to introduce DOIs for their data records of ECV and recommend datasets producers to follow this practice
Benefit	Help researchers to discover relevant data more easily
Who	GCOS panels
Time frame	Ongoing
Performance indicator	Number of data records having an assigned DOI
Annual cost	Should be part of network planning and implementation.

Assessment: 4 – Progress on track.

Underway. This is an on-going activity which has received general support.

Action G21:	Collaboration with WMO CCl on climate data management
Action	GCOS secretariat to engage with WMO CCl on development of regulatory and guidance on climate data management
Benefit	Users to climate data will have easier access to data.
Who	GCOS secretariat and WMO CCl
Time frame	Ongoing until 2019
Performance indicator	Guidance material publication
Annual cost	None

Assessment: 5 – Complete

Due to WMO reorganization WMO Commission for Climatology (CCl) no longer exists. The Manual on the High-quality Global Data Management Framework for Climate[51] was published in collaboration.

Action G22:	Implementation of new production streams in global reanalysis
Action	Continue comprehensive global reanalyses and implement planned new production streams using improved data-assimilation systems and better collections of observations; provide information on the uncertainty of products and feedback on data usage by the assimilation systems
Benefit	Improved reanalysis datasets
Who	Global reanalysis production centres
Time frame	Ongoing
Performance indicator	Number and specifications of global reanalyses in production; improved results from evaluations of performance; user uptake of uncertainty information; extent to which observational archives are enhanced with feedback from reanalyses
Annual cost	US$ 10–30 million

Assessment: 4 – Progress on track.

New production streams have been implemented at principal producing centres with higher resolution, improved data assimilation systems and better collection of observations.

[51] https://library.wmo.int/doc_num.php?explnum_id=10197

Action G23:	Develop coupled reanalysis
Action	Further develop coupled reanalysis and improve the coupled modelling and data assimilation methodology
Benefit	Provide coupled reanalysis data sets
Who	Global reanalysis production centres and other centres undertaking research in data assimilation
Time frame	Ongoing
Performance indicator	Number, specification and demonstrated benefits of coupled reanalyses
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track:

The ECMWF CERA (coupled atmosphere-ocean), the ECMWF CAMS (atmospheric composition) and the NASA/GMAO MERRA2 (which includes aerosol species) reanalyses have been developed.

Action G24:	Improve capability of long-range reanalysis
Action	Improve the capability of long-scale reanalysis using sparse observations datasets
Benefit	Provide longer reanalysis datasets
Who	Global reanalysis production centres and other centres undertaking research in data assimilation
Time frame	Ongoing
Performance indicator	Demonstrated improvements in the representation of long-term variability and change in century-scale reanalyses
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

Newly produced long-range reanalyses, e.g. the ECMWF CERA-20C and the NOAA-CIRES-DOE 20CRv3, improve upon earlier products.

Action G25:	Implementation of regional reanalysis
Action	Develop and implement regional reanalysis and other approaches to downscaling the information from global data products
Benefit	Capability to capture climate variability on a regional scale
Who	Dataset producers
Time frame	Ongoing
Performance indicator	Number and evaluated performance of regional reanalyses and other downscaled datasets
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Some progress: UERRA, CERRA, COSMO, future Arctic regional reanalysis.

Action G26:	Preservation of early satellite data
Action	Ensure long-term data preservation of early satellite raw and level 1 data, including metadata
Benefit	Extend CDRs back in time
Who	Space agencies
Time frame	Ongoing
Performance Indicator	Data archive statistics at space agencies for old satellite data
Annual Cost	US$ 1–10 million

Assessment: 4– Progress on track

Integrated in the satellite agencies data rescue strategies and reprocessing activities and is continuously monitored by the community.

Action G27:	Recovery of instrumental climate data
Action	Continue the recovery of instrumental climate data that are not held in a modern digital format and encourage more imaging and digitization
Benefit	Improve access to historical observations datasets
Who	Agencies holding significant volumes of unrecovered data; specific projects focused on data recovery
Time frame	Ongoing
Performance indicator	Data Increases in archive-centre holdings and data used in product generation; register entries recording data-recovery activities (see following action)
Annual Cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

An ongoing activity, some improvements with C3S Data Rescue Service, WMO I-DARE and organizations such as IEDRO and ACRE.

Action G28:	Register of data-recovery activities
Action	Populate and maintain a register or registers of data-recovery activities
Benefit	Facilitate planning of data rescue
Who	WMO CCl and other international bodies with related responsibilities; institutions hosting registers
Time frame	Ongoing
Performance indicator	Existence and degree of population of register(s).

Annual cost	US$ 1 000–10 000

Assessment: 3 – Underway with significant progress.

C3S Data Rescue Service has now established a register; however, this does not provide yet global coverage.

Action G29:	Scanned records
Action	Lodge scans with an appropriate international data centre if digitization does not follow scanning; assemble classes of scanned record suitable for digitization, for example by crowdsourcing
Benefit	Facilitate planning of data rescue
Who	Institutions that have scanned data but not undertaken digitization; receiving data centres for assembly of records
Time frame	Ongoing
Performance indicator	Statistics on holdings and organization of scanned records by data centres
Annual Cost	US$ 10 000–100 000

Assessment: 3 – Underway with significant progress.

Underway – Activity led by C3S Data Rescue Service, WMO-IDARE, IEDRO, ACRE. However, still many countries are not willing to submit their paper records to other countries.

Action G30:	Sharing historical data records
Action	Share recovered historical data records
Benefit	Improved access to historical datasets to all users
Who	Institutions that have recovered data records but not made them widely available.
Time frame	Ongoing
Performance indicator	Number of released data records as reported in registers
Annual cost	US$ 10 000–100 000

Assessment: 2 – Started but little progress.

Despite unrestricted and free exchange of rescued data is promoted, several countries are still not willing to share. This is part of the GCOS contribution to the proposed WMO Data Policy.

Action G31:	Improve gravimetric measurements from space
Action	Prepare for satellite missions to provide continuity and consider improved performance to meet the observational requirements in Table 2
Benefit	Improved monitoring of water transport and distribution.
Who	Space agencies.
Time frame	For 2023
Performance indicator	Published plans and agreed missions
Annual cost	US$100 000–1 million

Assessment: 3 – Underway with significant progress.

Continuity of satellite gravity time series was achieved with the launch of GRACE-FollowOn (GRACE-FO) in 2018. For continuation and improvements of the data records after the end of the nominal lifetime of GRACE-FO in 2023, next generation gravity missions are under evaluation.

Action G32:	Improved bathymetry
Action	Support increased level of multibeam seabed mapping both synchronously with ocean observation initiatives and separately as dedicated basin-scale mapping initiatives
Benefit	Better representation of ocean volume, improved ability to model ocean currents and mixing
Who	Institutions that fund vessel-based science studies and programmes and/or have access to survey platforms with existing multibeam survey infrastructure.
Time frame	For 2023
Performance indicator	Availability of improved bathymetry data
Annual cost	US$ 30–100 million

Assessment: 3 – Underway with significant progress.

Underway. New survey data made available. Regional and global coverage bathymetric products developed.

B.b ATMOSPHERE

Action A1:	Near-real-time and historical GCOS Surface Network availability
Action	Improve the availability of near-real-time and historical GSN data especially over Africa and the tropical Pacific
Benefit	Improved access for users to near-real-time GSN data
Who	National Meteorological Services, regional centres in coordination/cooperation with WMO CBS, and with advice from AOPC
Time frame	Continuous for monitoring GSN performance and receipt of data at archive centre
Performance indicator	AOPC review of data archive statistics at the World Data Center for Meteorology at Asheville, NC, USA, annually and national communications to UNFCCC
Annual cost	US$ 10–15 million

Assessment: 5 – Complete.

Monitoring of the GCOS Surface Network (GSN) has continued throughout the Implementation Plan period, by both the GCOS Network Manager and the GSN Monitoring Centres (DWD, JMA and NCEI), with regular reports to the annual meeting of AOPC on network metadata, availability statistics and efforts to improve data availability and quality.

The GSN is intended to comprise the best possible set of land stations with a spacing of 2.5 to 5 degrees of latitude, thereby allowing coarse-mesh horizontal analyses for some basic parameters (primarily Temperature and Precipitation). The criteria for selection include: Commitments by NMHSs with regard to continuity; Geographical representativeness of observations; Length and quality of historical time series; and Available parameters. Table 1 provides a breakdown of station numbers by WMO region and changes since 2016. Table 2 provides an annual summary of the monthly CLIMAT messages in the GCOS Climate Archive and Figure 1 shows the percentage of dedicated surface stations reporting according to GSN requirements for the different WMO regions.

Table 1. Numbers of GSN station by WMO region and changes since 2016

WMO Region		Number	Change from 2016
I	Africa	155	0
II	Asia	288	0
III	South America	101	0
IV	North and Central America and the Caribbean	177	-1
V	South-West Pacific	151	0
VI	Europe	138	0

ANTON	Antarctica	42	0
Total		1022	-1

Table 2. An annual summary of the monthly CLIMAT messages in the GCOS Climate Archive (National Climate Environmental Information, NCEI, US). According to the GCOS requirements, a fully compliant GSN/RBCN shall have 12 CLIMAT reports. The values represent the 2019 percentage of stations that are compliant and those that are partially or non-compliant. In brackets are the statistics for 2018, 2017, 2016, 2015, 2014, 2013, 2012 and 2011 respectively

Region	No.	12 Monthly CLIMAT	6 - 11 Monthly CLIMAT	1 - 5 Monthly CLIMAT	0 Monthly CLIMAT
RA-I	155	26% (37, 31, 40, 29, 29, 32, 28, 23)	33% (21, 34, 25, 31, 33, 33, 36, 39)	6% (5, 3, 9, 15, 10, 10, 11, 14)	35% (37, 32, 26, 25, 28, 25, 25, 24)
RA-II	258	76% (74, 79, 83, 78, 71, 73, 73, 75)	17% (14, 15, 10, 14, 21, 19, 19, 19)	1% (5, 0, 2, 2, 3, 2, 2, 1)	6% (7, 6, 5, 6, 5, 6, 6, 5)
RA-III	101	72% (52, 63, 65, 61, 76, 89, 84, 69)	5% (24, 15, 29, 35, 20, 6, 13, 28)	9% (1, 6, 0, 0, 1, 0, 0, 0)	14% (23, 16, 6, 4, 3, 5, 3, 3)
RA-IV	178	82% (88, 86, 90, 88, 88, 88, 81, 80)	16% (7, 12, 7, 9, 10, 11, 17, 18)	1% (4, 1, 2, 2, 1, 1, 1, 1)	1% (1, 1, 1, 1, 1, 0, 1, 1)
RA-V	151	66% (62, 61, 67, 66, 70, 63, 58, 52)	15% (21, 21, 15, 16, 17, 16, 23, 34)	4% (1, 3, 3, 4, 1, 7, 7, 1)	15% (16, 15, 15, 14, 13, 14, 12, 11)
RA-VI	138	81% (75, 82, 84, 77, 80, 82, 78, 81)	7% (15, 8, 7, 14, 9, 12, 17, 15)	3% (1, 2, 2, 3, 5, 2, 1, 0)	9% (9, 8, 7, 6, 6, 4, 4, 4)
ANTON	42	88% (84,83, 81, 77, 79, 60, 45, 50)	10% (14, 12, 17, 19, 19, 36, 43, 33)	2% (2, 5, 2, 2, 2, 2, 5, 12)	0% (0, 0, 0, 2, 0, 2, 7, 5)

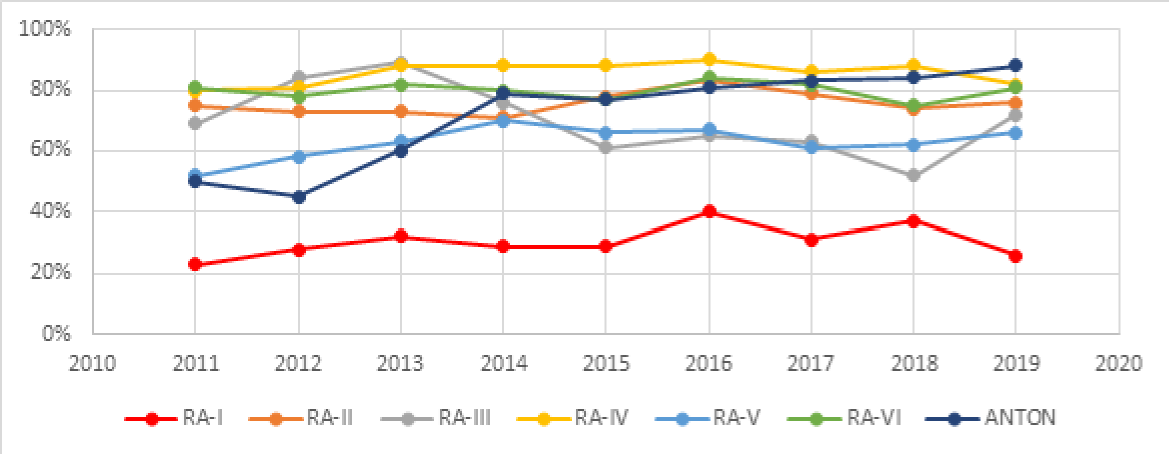

Figure 12. Percentage of dedicated surface stations reporting according to GSN requirements for the different WMO regions. WMO regions: Africa (RA-I); Asia (RA-II), South America (RA-III), North America, Central America and the Caribean (RA-IV), South-West Pacific (RA-V), Europe (RA-VI) and the Antarctic Observing Network (ANTON)

RA-I is the poorest performing region, with only 26% of stations meeting the minimum requirement, and 35% not providing any CLIMAT messages, this has not significantly changed, neither better nor worse, over the last 9 years. Thus, whilst this continues to reinforce the need for GCOS to focus its support in this region, it also highlights that recent efforts to improve these statistics have had little impact.

Action A2:	**Land database**
Action	Set up a framework for an integrated land database which includes all the atmospheric and surface ECVs and across all reporting timescales
Benefit	Centralized archive for all parameters. Facilitates QC among elements, identifying gaps in the data, efficient gathering and provision of rescued historical data, integrated analysis and monitoring of ECVs. Supports climate assessments, extremes, etc. Standardized formats and metadata.
Who	NCEI and contributing centres
Time frame	Framework agreed by 2018
Performance indicator	Report progress annually to AOPC
Annual cost	US$ 100 00–1million

Assessment: 4 – Progress on track.

NOAA NCEI and C3S have made considerable progress in setting up such a database although much work remains to be done.

There has been considerable progress made in the instigation and population of a new database containing all meteorological surface parameters measured from standard meteorological stations and available across synoptic through monthly aggregations. In 2017 the Copernicus Climate Change Service and NOAA NCEI started a collaborative effort to realise this action based upon its articulation in Thorne et al., 2017. The effort has collated to date in excess of 350 data sources ranging from large global collections of several thousand stations through to small collections and including a broad range of data rescued collections. The sources include a number of national holdings from NMHSs that have over the past several years adopted open data policies. It also benefits from the efforts of the European Environment Agency to secure agreements on data sharing via the EU Copernicus program.

To date a subset of these sources have been converted to a common format, merged to avoid duplication, and quality controlled. Data are made available at sub-daily, daily and monthly timescales respecting the known data IPR restrictions. Data availability from sources processed to date shows reasonable spatial completeness as shown in the maps below.

Many sources remain to be processed and so both spatial and temporal completeness can be improved in future work that is planned. There is also a new portal by which data owners can submit additional holdings and it is hoped that additional data rescue activities can also add sources over time. Discussions are ongoing with the Infrastructure Commission over the use and allocation of WIGOS Station Identifiers and inclusion in OSCAR Surface for discoverability and accessibility.

References:

Thorne, P.W., R. J. Allan, L. Ashcroft, P. Brohan, R. J. H. Dunn, M. J. Menne, P. R. Pearce, J. Picas, K. M. Willett, M., Benoy, S. Bronnimann, P. O. Canziani, J. Coll, R. Crouthamel, G. P. Compo, D. Cuppett, M. Curley, C. Duffy, I. Gillespie, J. Guijarro, S. Jourdain, E. C. Kent, H. Kubota, T. P. Legg, Q. Li, J. Matsumoto, C. Murphy, N. A. Rayner, J. J. Rennie, E. Rustemeier, L. C. Slivinski, V. Slonosky, A. Squintu, B. Tinz, M. A. Valente, S. Walsh, X. L. Wang, N. Westcott, K. Wood, S. D. Woodruff and S. J. Worley, 2017: Towards an integrated set of surface meteorological observations for climate science and applications, Bulletin American Meteorological Society, https://doi.org/10.1175/BAMS-D-16-0165.1.

Action A3:	**International exchange of SYNOP and CLIMAT reports**
Action	Obtain further progress in the systematic international exchange of both hourly SYNOP reports and daily and monthly CLIMAT reports from all stations
Benefit	Enhanced holdings data archives
Who	NMHSs, regional centres in coordination/cooperation with WMO CBS, and with advice from AOPC
Time frame	Continuous, with significant improvement in receipt of RBSN synoptic and CLIMAT data by 2019
Performance Indicator	Data archive statistics at data centres
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Data archive statistics indicate that effort to enhance the systematic international exchange is underway and significant progress has been made in receipt of hourly SYNOP (Surface Synoptic Observations) and daily CLIMAT reports.

A significant development in monitoring SYNOP reports since the time of the GCOS-IP 2016 is the launch of the WIGOS Data Quality Monitoring System (WDQMS) Webtool (https://wdqms.wmo.int/), a resource developed by WMO, and hosted by ECMWF, to monitor the performance of all WIGOS observing components. The current version of the webtool monitors the availability and quality of land-surface synoptic (SYNOP) and upper-air land observations based on near-real-time monitoring information from four participating global NWP centres (DWD, ECMWF, JMA and NCEP). From coverage maps of SYNOP reports monitored by the webtools for recent months (not shown), substantial coverage in receipt of hourly SYNOP reports can be seen over Europe, Japan, Australia, Greenland and Antarctica as already shown in the previous Status Report (GCOS-195, Figure 76), and also a significant improvement over South America and the South Pacific. It should be noted, however, that the data availability obtained by the webtool varies between monitoring centres, which indicates that there could be some issues in the routing of messages within GTS whereby some messages are not shared truly globally.

Figure 13 shows average counts of surface air-temperature observations for each hour of the day for October 2014 and 2019. Observation counts of SYNOP reports increased in all hours from the year 2014 to 2019, with the largest increases at hours 0300, 0900, 1500 and 2100, leading to a more regular three hourly peak in 2019. METAR (aerodrome routine meteorological) reports show a greater increase in observation numbers than SYNOP reports and supplement the coverage of SYNOP reports, predominantly over North America.

For monthly CLIMAT reports from the Regional Basic Synoptic Network (RBSN), as assessed in Action A1, RA-I is the poorest performing region, with only 17% of stations meeting the minimum requirement in 2019.

Percentages of stations with zero reports in the Regional Basic Climatological Network (RBCN) are greater than those in GSN for all regions, suggesting that not all countries are sending CLIMAT messages for their RBCN stations.

Transmissions of daily CLIMAT messages began January 2019 and a total of 259 stations (around 10% of all CLIMAT stations) had transmitted at least one message as of May 2020. Participating countries are located in Europe (111; Ireland, Norway, Spain, Switzerland), South America/Antarctica (73; Argentina, Antarctica), East Asia (64; Japan, South Korea, Hongkong), and Africa (11; Algeria). Most stations are not transmitting all six possible elements.

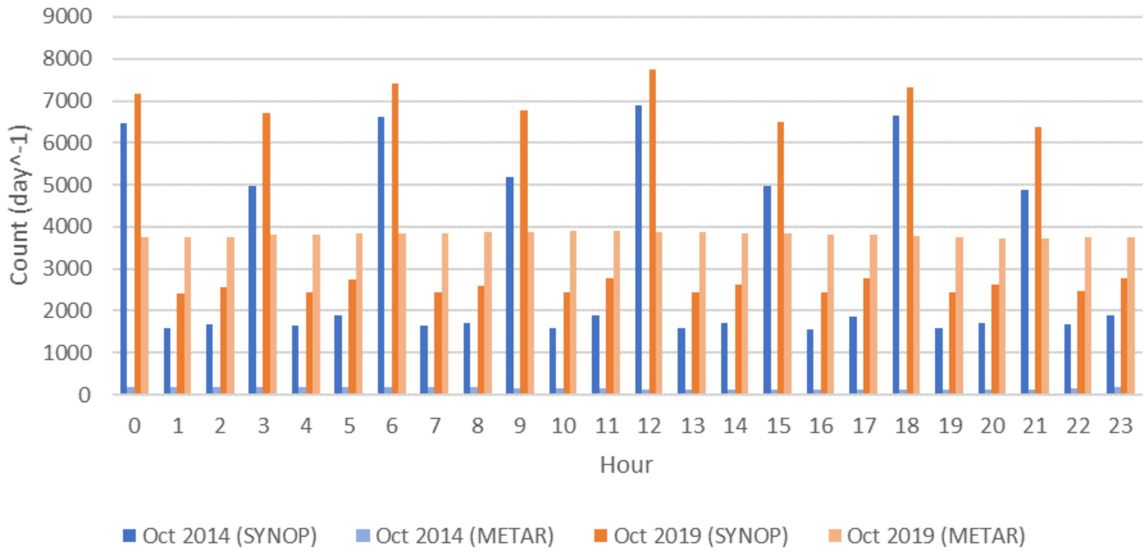

Figure 13. Average counts of surface air-temperature observations over land for each hour of the day for October 2014 and 2019 from the JMA operational receipt of data after duplicate removal and elimination of sub-hourly data

Action A4:	Surface observing stations: transition from manual to automatic
Action	Follow guidelines and procedures for the transition from manual to automatic surface observing stations
Benefit	More stable time series
Who	Parties operating GSN stations for implementation. WMO CCl, in cooperation with WMO CIMO, WMO CBS for review
Time frame	Ongoing
Performance indicator	Implementation noted in national communications and relevant information provided
Annual cost	US$ 30–100 million

Assessment: 4 – Progress on track.

Much action has been undertaken on this IP action, but this has entirely been within WMO circles, so co-ordinated by CIMO, CCl and CBS, and not reported through National Communications.

The original aim of this action was to ensure that members used existing guidelines from CIMO, CCl and CBS when they undertook transition to automating their surface measuring network. The precise details of how many stations in the GSN, or the more comprehensive Regional networks RBCN/RBSN, have switched to automated readings each year since 2010 is unknown. However, **Figure 14** provides a breakdown of SYNOP reports station type as received at ECMWF in January 2020. This shows that 41% (3785 stations) are fully automated systems, which compares with 42% (3860) for manual observations, and 17% mixed or unknown. For January 2016 the same monitoring showed 29% (fully automated); 57% (manual) and 16% (mixed/unknown).

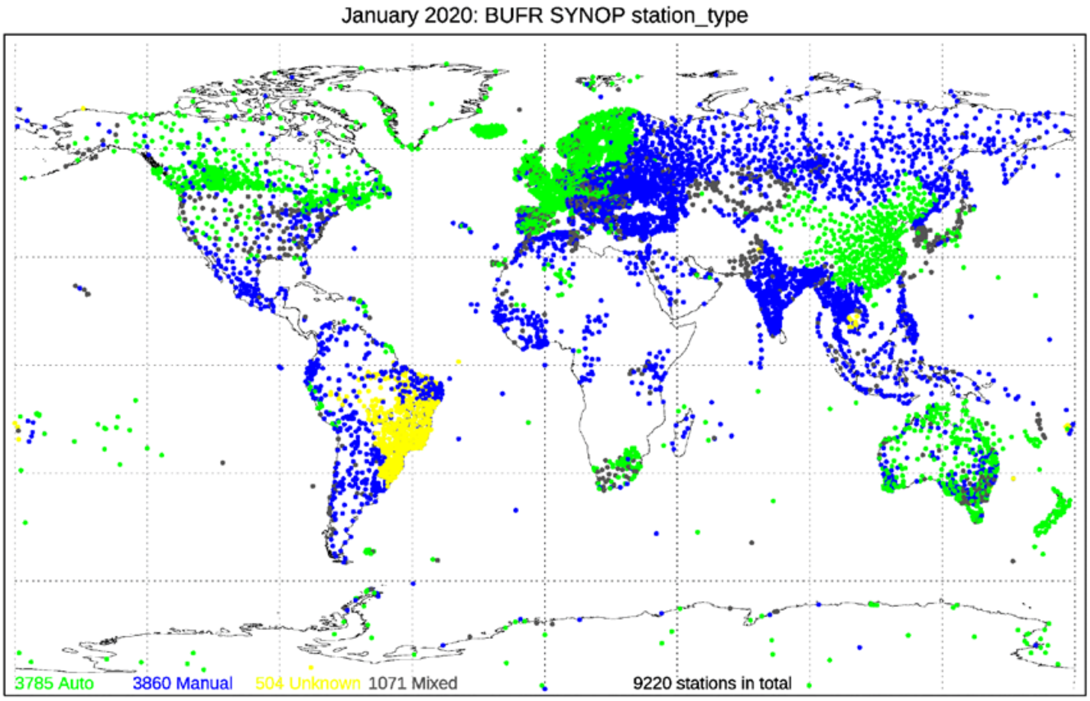

Figure 14. SYNOP reports station

Guidance documents put together by CIMO and CCL are available and have been regularly updated. These documents recommend parallel readings when instrumentation is either replaced or moved, but whether this has happened is also unknown, despite a call to gain access to the parallel measurements. This represents a missed opportunity as historic records of parallel measurements of two markedly-different instruments could be useful in the future. The availability of these measurements would then have been able to assess whether the benefit of more stable time series had been achieved.

As far as GCOS and AOPC are concerned, the GCOS Network Manager has been involved in some of the transitions during the last 5 years. This involves working with the donor organization to ensure that the new instrumentation is safely installed, and transmission of data begins. It is also important that a record of the measurements be stored locally and centrally within the Met Service. The continued installation of automated instrumentation is likely to continue apace but is more prone to breakdown without adequate maintenance and software updates.

The WMO surface observation database (https://oscar.wmo.int/surface/#/) now has an extensive metadata repository following the WMO metadata standard. Amongst significant additional station metadata, this not only allows the instrumentation in use and the time period to be recorded but also multiple/parallel and historical metadata records. Correctly updated and populated with historical metadata (where known) this will provide a vital source of information for data users when interpreting surface observation climate data records.

Action A5:	Transition to BUFR
Action	Encourage dual transmission of TAC and BUFR for at least 6 months and longer if inconsistencies are seen (to compare the two data streams for accuracy).
Benefit	Transition to BUFR does not introduce discontinuities in the datasets. BUFR allows metadata to be stored with data.
Who	Parties operating GSN stations for implementation
Time frame	Ongoing for implementation; review by 2018
Performance indicator	Proven capability to store BUFR messages giving same quality or better as TAC data
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

While progress towards the adoption of BUFR format appears to be slow, most observing sites have been transmitting both data streams for an extended period of time, often far exceeding the six-month minimum referenced in the GCOS Implementation Plan

While BUFR became operational in 2007, by 2014 only a few stations had switched from the previous TAC format to BUFR, despite a WMO-CBS decision in 2010 that after 2014 only BUFR should be reported. Progress in the transition from TAC to BUFR was made in 2015 and 2016, during the time the latest GCOS Implementation Plan was written, and the transition has further progressed gradually since then. By April 2020, 78% of all sites, buoys, and ships analysed were sending at least occasional BUFR messages, although that includes only approximately 45% of monthly CLIMAT messages. Further, only 51% of all radiosonde stations are transmitting high-resolution BUFR reports.

Among the land-based surface and radiosonde stations, ships, and moored buoys that have initiated BUFR reports, more than three quarters continue to transmit TAC reports as well. These dual transmissions have continued over far longer than the six months minimum specified in the Implementation Plan. Only drifting buoys have fully transitioned to BUFR, with only 3% still sending both types of reports.

Figure 15 shows the global land surface SYNOP reports for TAC and BUFR (as received at ECMWF), with 69% of stations reporting both a TAC and BUFR, and only 11% reporting as TAC only. **Figure 16** shows a similar plot for radiosonde reporting, with 68% stations reporting BUFR, 15% reformatted BUFR (copy of TAC) and only 16% no BUFR, this compares with 21%; 51%; and 28%; respectively for the same period in 2016. Figure 6 shows the time series of the evolution from 2015 to 2020

The temporal completeness of the BUFR transmissions is generally comparable to that of the TAC reports, sometimes after some initial lower completeness at the beginning of the BUFR record in each country. However, five issues with the quality of the BUFR reports are worth noting:

The marine moored buoy and upper-air radiosonde messages contain many duplicates. In the case of the moored buoys, the duplicate reports begin to appear in November 2019 and contain the same time stamp and observations with slightly different coordinates. In the upper-air reports, duplicates of various kinds are frequent throughout the TAC and BUFR records.

In marine reports, not all fields present in TAC are consistently converted to BUFR.

Only 52% of the BUFR-transmitting radiosonde stations were consistently sending the intended high-resolution reports consisting of more than 5000 levels rather than a reformatted version of the lower-resolution TAC reports.

Unlike TAC, BUFR allows for the inclusion of the more directly-measured relative humidity, yet stations typically do not include this quantity.

The precision of pressure at altitudes above the 10-hPa level in upper-air reports is 0.1 hPa, value that is insufficient for high-resolution observations. A change to 0.01 hPa has recently been approved by the WMO.

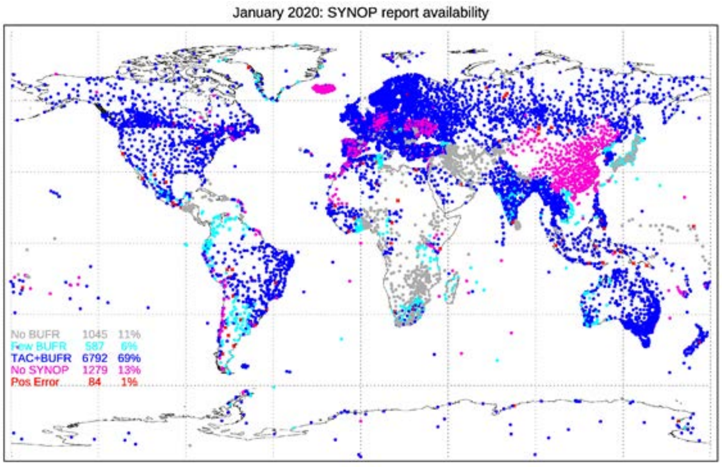

Figure 15. Global land surface SYNOP reports for TAC and BUFR

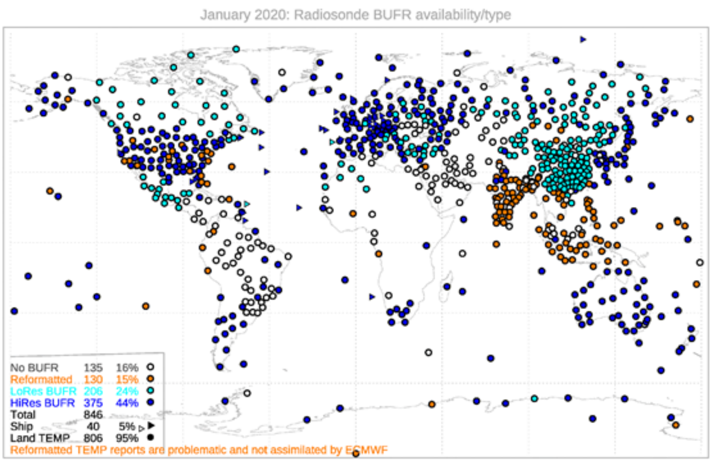

Figure 16. Radiosonde reporting

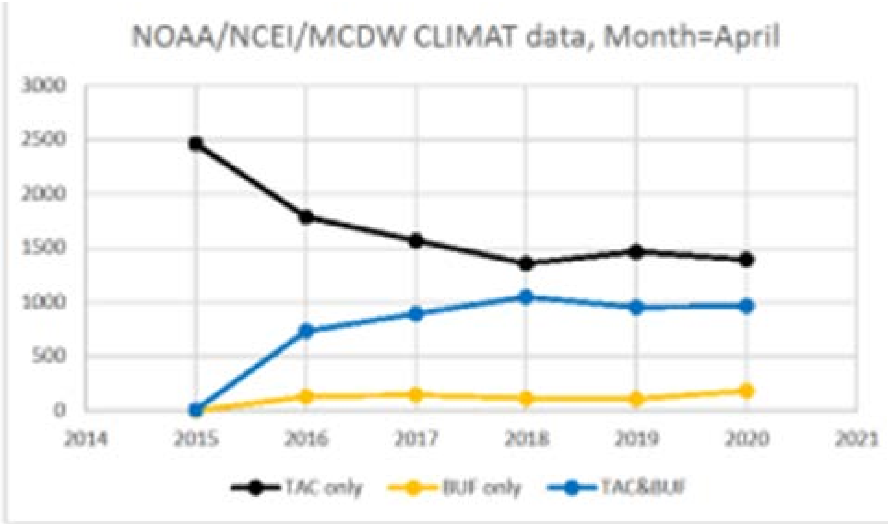

Figure 17. Time series plot showing the evolution from 2015 to 2020

Action A6:	**Air temperature measurements**
Action	Enhance air temperature measurements networks in remote or sparsely populated areas and over the ocean
Benefit	Improved coverage for better depiction of climate system
Who	National Parties and international coordination structures such as the Global Cryosphere Watch (GCW)
Time frame	Ongoing
Performance indicator	Coverage of air-temperature measurements
Annual cost	US$ 10–30 million

Assessment: 3 – Underway with significant progress.

Some progress has been made with respect to historical land holdings under Action A2 and also over Africa where agreement has been reached under Copernicus auspices to digitize and eventually rescue data held on fiche and film which was under significant peril; over the oceans drifter deployments have led to some improved coverage.

Under Action A2 and working with many colleagues, C3S and NCEI have made significant progress on the stewardship of available land-based historical records that are already available in electronic form. Numerous sources that either arise from sparsely sampled regions of the globe or include these regions have been secured. The coverage in these newly constructed holdings will represent a considerable improvement over existing holdings in these regions. These holdings include a range of recently rescued data holdings under the auspices of the ACRE project and WMO sponsored DARE activities. Recently the Belgian NHMS RMI and C3S have gone under contract to convert to digital imagery a vast swathe of sub-Saharan data that had been converted to fiche and film and which has been rapidly degrading. The copy held by RMI is in reasonable condition and there is a hope that these data can be rescued in future. ACMAD have agreed that these can be rescued and used for climate purposes. For land regions, few new sites have been deployed in remote regions. Here it is likely that more stations have been closed than opened, if we were to classify stations by an index of remoteness.

For marine regions, the coverage of near surface air temperature observations has been in decline since the 1980s, including in recent years., Although the number of near surface air temperature measurements has increased since 2000, this increase comes from moored buoys contributing observations at a limited number of point locations in coastal and near equatorial regions. Coverage has declined overall as fewer ships are contributing observations and vessels of opportunity remain the main source of widely-distributed in situ marine air temperature observations. Also, as with the land data, considerable numbers of ship-based observations have been scanned and digitised since 2000. Many of these ships traversed the oceans before 1940, and in the sailing ship period many followed the winds, so went much further south across the Southern Oceans than modern merchant ships do today.

Action A7:	Atmospheric pressure sensors on drifting buoys
Action	Enhance to 100% the percentage of drifting buoys incorporating atmospheric pressure sensors, in particular by benefiting from barometer-upgrade programmes
Benefit	Measurements over oceans of surface pressure will improve coverage.
Who	Parties deploying drifting buoys and buoy-operating organizations, coordinated through JCOMM[52], with advice from OOPC and AOPC
Time frame	Ongoing
Performance indicator	Percentage of buoys with sea-level pressure (SLP) sensors in tropics and sub-tropics
Annual cost	US$ 10 000–100 000

Assessment: 1 –Little or no progress

The monthly percentage of drifting buoys reporting pressure in the tropics and sub-tropics over 2015-2019 has not exceeded 50% and has degraded since 2016.

Statistics for pressure observations over the ocean have been taken from ICOADS R3.0.2 (test version, combining near-real-time (NRT) data streams from both BUFR and TAC) for the period 2015-2019. Other sources of NRT observations will differ. Action A7 is specific to the tropics and subtropics, here taken as between latitudes of ± 35°. The measure is quite volatile, as both the number of drifting buoys and the fraction with pressure sensors vary markedly from month to month as buoys enter and leave the specified region. This metric does not consider either the total number of drifting buoys reporting, or the number of observations.

[52] The Joint WMO-IOC Commission for Oceanography and Marine Meteorology (JCOMM) was superseded in 2019 by the Joint WMO-IOC Collaborative Board.

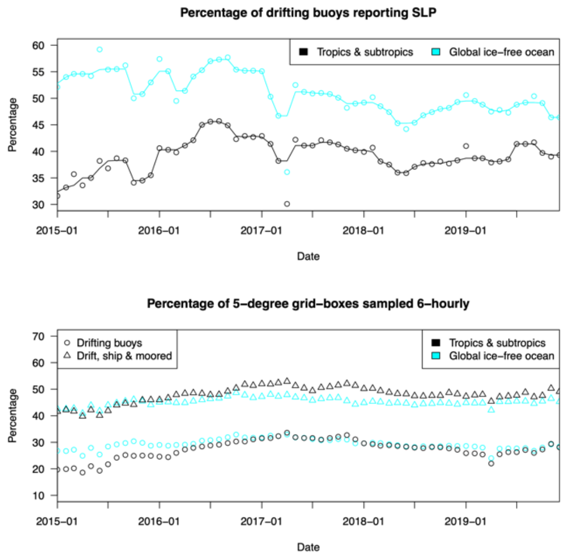

Figure 18. (upper): timeseries of percentage of drifting buoys with atmospheric pressure sensors reporting between ± 35°N (black) and globally (cyan). Lines are a 3-pt median filter. (lower): percentage of 6-hourly grid cells with an atmospheric pressure observation from drifters (circles) and from a combination of sources (triangles)

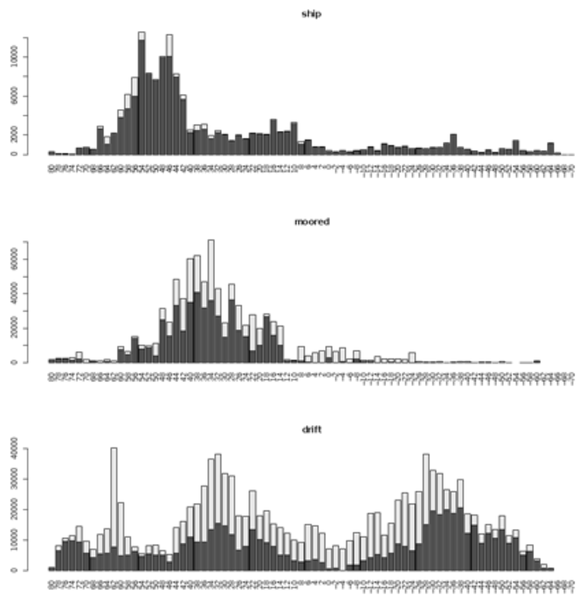

Figure 19. Numbers of reports with (dark) and without (light) atmospheric pressure observations for December 2019 for reports identified as being from ships (top), moored buoys (middle) and drifting buoys (lower) by 2° latitude band. Note the different vertical scales

The metric defined by A7 has ranged between 30-50% over 2015-2019, well below the target of 100% of drifting buoys in tropical and sub-tropical regions to report atmospheric pressure (

Figure 18, upper panel). The average over 2015 is ~35%, reached ~45% in mid-2016 and was steady at ~40% in 2019. Globally the percentage is higher but has overall decreased over the period 2015-2019.

The coverage in terms of number of 5° grid boxes and six-hourly periods where there is at least one atmospheric pressure observation has risen slightly over the period 2015-2019, driven in part by an approximate 50% increase in drifting buoy coverage in the tropics and subtropics (~20% to ~30%,

Figure 18 lower panel).

Figure 19 shows for December 2019 the latitudinal coverage of atmospheric pressure measurements separately for ships, moored buoys and drifting buoys. Almost all ships report atmospheric pressure, and there would be some benefit for further instrumentation of the tropical buoy arrays to improve coverage in the latitude band ±10°. It is clear from Figure 8 that there is substantial scope for increasing the sampling of atmospheric pressure observations from further instrumentation of drifting buoys deployed in tropical and subtropical regions.

Action A8:	Provide precipitation data to the Global Precipitation Climatology Centre
Action	Submit all precipitation data from national networks to the Global Precipitation Climatology Centre at the Deutscher Wetterdienst
Benefit	Improved estimates of extremes and trends, enhanced spatial and temporal detail that address mitigation and adaptation requirements
Who	National Meteorological and Water-resource Services, with coordination through the WMO CCl and the GFCS.
Time frame	Ongoing
Performance indicator	Percentage of nations providing all their holdings of precipitation data to international data centres.
Annual cost	US$ 100 000–1 million

Assessment:3 – Underway with significant progress.

There has been no sustainable increase in the number of national contributions, but a positive impact on the number of data deliveries in 2017 can be ascertained.

Global Data Collection and Production Centres (DCPC) such as the Global Precipitation Climatology Centre (GPCC) provide much more value to the community than a pure data collection activity. On top of collection and acquisition of data a provision of data to a specialized DCPC, such as GPCC for the precipitation parameter, implies proper treatment of data providers and their property rights, and data products optimized for requirements such as accuracy, timeliness, completeness and homogeneity. GPCC's clear and unambiguous data policy has proven to provide to the community the biggest and deepest access to precipitation data information and even the entire raw data set to its visitors. This is mainly built on the trust of the data providers that their data is used only for the intended purposes.

Progress has been made to share the precipitation data between GPCC and NCEI as a second central repository. GPCC prepared a list of sources where data access is possible and will later see what data can be shared with C3S and NCEI archives in support of Action A2. Moving forward, new data submissions from NMHSs that can be submitted should be shared between GPCC and C3S/NCEI. Data that is shared on a restricted basis may be able to be held just by GPCC.

The GPCC acknowledges the regular provision of monthly and annual updates, but also updates with a two to three years cycle are highly valuable as this is the typical release cycle of GPCCs delayed mode products. As the manual quality control of the GPCC requires manual intervention and therefore takes time, several months elapse between the receipt and the integration of the data to the database. In addition, a complete provision of the precipitation data of a NHMS produces a high workload, especially if the data are not stored in state-of-the-art data bank systems. This load comes on top of the normal operations like forecasting and warning tasks, and the respective extra operations need to be scheduled accordingly. Based on GPCCs experience, many countries provide a copy of their whole data archive every 5-10 years. Therefore, it is too early to decide about the success of this action though it started already four years ago. In total, GPCC received data from 35 countries in more than 250 single deliveries since January 2017, and real-time data globally via the WMO-GTS (SYNOP and CLIMAT), see **Figure 20**.

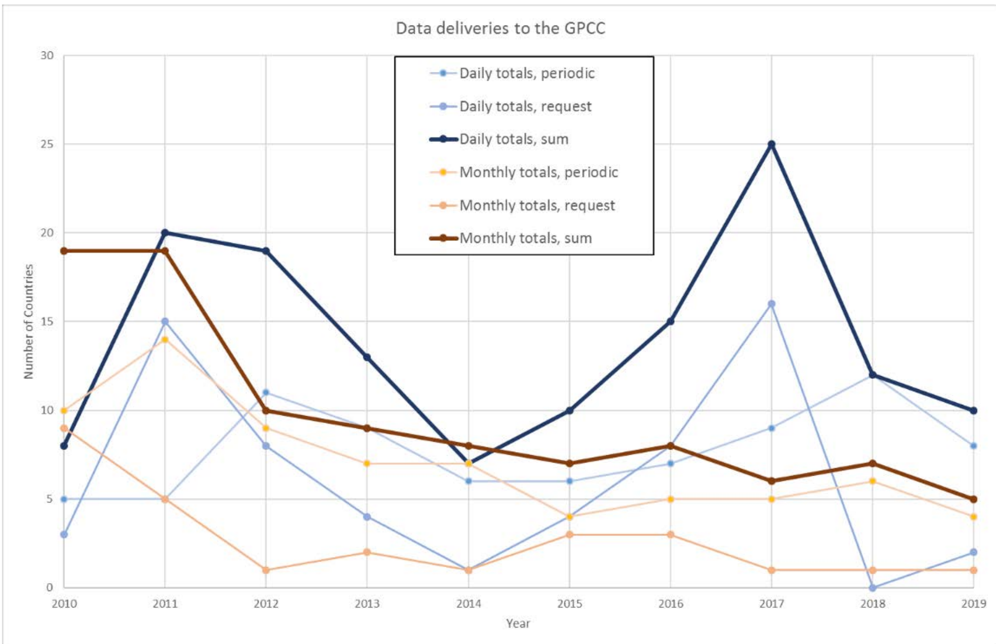

Figure 20. Number of countries that delivered daily (blue) and monthly (brown) data to GPCC every year in the reporting period (since 2010). We further separated the daily and monthly totals into periodic and upon request deliveries

Action A9:

Assessed together with A2

Action A10:	Incorporating national sunshine records into data centres
Action	National sunshine records should be incorporated into International Data Centres.
Benefit	Better description of surface radiation fields
Who	NMHSs
Time frame	Implement in next 2 years
Performance indicator	Sunshine record archive established in international data centres in analysis centres by 2018
Annual cost	US$ 1–10 million

Assessment: 2 – Started but little progress

Sunshine data are available from selected archives (e.g. NOAA NCEI, ECA&D), but no comprehensive archives exist.

Sunshine duration (SD) is one of the most important and widely used parameters in climate monitoring and a key variable for various sectors, including tourism, public health, agriculture, vegetation modelling, and solar energy. SD is strongly related to the Essential Climate Variables cloud properties and surface radiation budget. Sunshine duration is often used as an input parameter for hydrological modelling and is a good predictor for the estimation of global radiation, where it can be also used for quality control of measured global radiation data.

Historical records of SD date back more than a century. In the mid-19th century, the Campbell–Stokes sunshine recorder was invented—much earlier than the first pyranometer. Even today, Campbell–Stokes recorders are still used by many National Meteorological and Hydrological Services (NMHSs) instead of a more complex measurement of solar radiation with pyranometers.

As SD data are a good proxy for global and direct solar radiation it allows to establish back-ward in time ("synthetic") time series of solar surface radiation. However, within archives of in situ observations, sunshine data have often been of secondary importance compared to temperature and precipitation. Two central archives are available, one in Europe (ECA&D) and one in the US (NCEI) from which SD is available and accessible.

ECA&D (https://eca.knmi.nl/), which is maintained by KNMI, holds about 1000 time series from stations from about 23 European Countries. Naturally, the length of the time-series is highly variable. Some of them date back to 1888, but other start in the 1950s. About one third of them are still operating.

The Monthly Climatic Data for the World (MCDW) at NCEI contains 3215 stations that reported sunshine in at least one monthly CLIMAT message between 1986, the earliest year with such data, and 2020. As of June 2020, 1414 stations were reporting sunshine. A total of 222 of them had reported sunshine in at least 360 months, 629 in at least 120 months. Stations with sunshine records in CLIMAT messages are distributed over all continents. Among stations with at least 360 months of such data, North America has only one station.

The Global Historical Climatology Network – Daily (GHCNd) and Integrated Surface Data (ISD) datasets contain historical sunshine duration for the United States from 1965 until after the year 2000, though they have not been rigorously quality controlled (https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn). Climate quality radiation observations are available from the U.S. Climate Reference Network for the period 2001-present (https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/us-climate-reference-network-uscrn).

In the United States and in European Countries, measurements of sunshine duration are no longer performed at many sites operated by the NMHSs. Meanwhile, satellite data are being used to provide SD (e.g. Kothe et al. (2013))

A call for NHMSs to share their sunshine data with central repositories (e.g., the Copernicus project or NOAA/NCEI) and to distribute real-time updates of these data would be valuable. Accordingly, this action should be combined with action A1 or action A2. Work by NOAA NCEI and C3S has highlighted substantial timescale variability in existing archive sources with SD generally better reported at monthly than daily or sub-daily resolutions.

References:

Kothe S., E. Good, A. Obregon and H. Nitsche, 2013: Satellite-Based Sunshine Duration for Europe, Remote Sensing, 5, 2943-2972; doi:10.3390/rs5062943

Action A11:	**Operation of the the GCOS Baseline Network for Surface Radiation**
Action	Ensure continued long-term operation of the BSRN and expand the network to obtain globally more representative coverage and improve communications between station operators and the archive centre1
Benefit	Continuing baseline surface radiation climate record at BSRN sites
Who	Parties' national services and research programmes operating BSRN sites in cooperation with AOPC and the WCRP GEWEX Radiation Panel
Time frame	Ongoing
Performance indicator	The number of BSRN stations regularly submitting valid data to international data centres
Annual cost	US$ 100 000–1million

Assessment: 3 – Underway with significant progress.

Network is relatively stable with regular exchange of information on status of BSRN with GCOS ensured by attendance to AOPC meeting by BSRN project manager and to BSRN meeting by GCOS network manager

At the request of the GCOS Secretariat, Christian Lanconelli (BSRN Project Manager) and Amelie Driemel (World Radiation Monitoring Centre Director) provided an analysis on the number of BSRN stations regularly submitting valid data to international data centres, which is summarized below.

The BSRN official archive is hosted by the Alfred Wegener Institute through either PANGAEA (https://bsrn.awi.de/data/data-retrieval-via-pangaea/) or a dedicated FTP archive https://bsrn.awi.de/data/data-retrieval-via-ftp/).

Figure 10 shows the number of files submitted by each station from 2018-05-01 to 2020-05-01. Most of the operational stations (flagged with "o"), submitted from 1 to more than a hundred files, and only 9 stations in mixed operational or candidate ("c") status did not provide files to the archive. This is normally related to persistent logistical problems, production of the first station-to-archive file ("c"), or changes of the station scientist. Operations on closed stations ("x") are normally performed by the archive manager to fix issues in old submissions. **Figure 21** results do not account for the timeliness of the data flow from the collection period to the actual data submission. Then, the files can be related to periods antecedent to 2018-05-01. In particular, a couple of stations submitted more than 40 station-to-archive files, evidently to fix (or implement additional) logical records in older files. From **Figure 21**, it could be argued that only approximately 50% of the operational stations are up to date. However, there are several remote stations which cannot guarantee a monthly data submission because of logistical issues. Normally those remote stations have poor internet connections, or the quality check can only be conducted after a certain period when the station scientists has visited the station and been informed of all issue/calibration procedures.

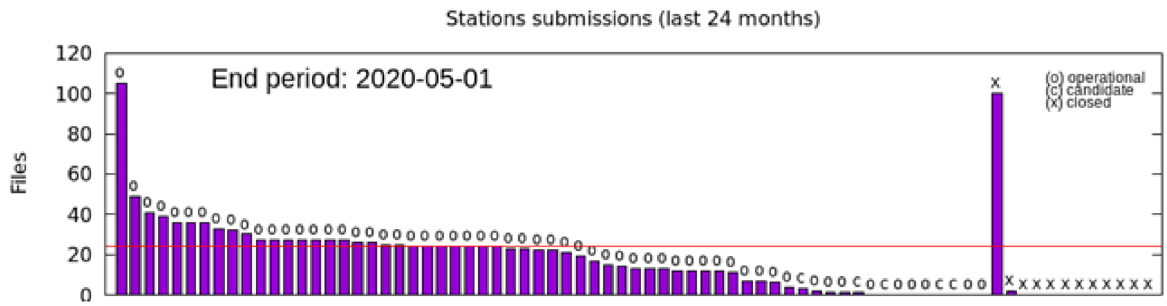

Figure 21. Station Activity. Number of Station-to-archive files submitted in the last two years per station

The difference of the timestamps of the last file modification of each station-to-archive file relevant to the last 12- and 24-month periods, with respect to the month of data acquisition, was also computed. The distribution of the this difference, which is assumed to be the timeliness, shows that for the files stored in the FTP archive the median time is of approximately two months from data collection to the user community availability, and 90% of the files stored in the archive (which should not be confused with the potentially available files), are released within 200-250 days (6-8 months).

Table 3. Timeliness statistics of the monthly files stored in FTP archive by May 1, 2020

Period	Percentiles (days)					Avr (days)	N (files)
	10	25	Median	75	90		
May 2019-May 2020	4	17	47	108	195	74.8	247
May 2018-May 2020	6	27	58	168	258	100.9	640

Action A12:	Surface radiation data to the World Radiation Data Centre
Action	Submit surface radiation data with quality indicators from national networks to the WRDC; expand deployment of surface radiation measurements over ocean
Benefit	Expand central archive; data crucial to constrain global radiation budgets and for satellite product validation; more data over ocean would fill an existing gap.
Who	NMHSs and others, in collaboration with WRDC
Time frame	Ongoing
Performance indicator	Data availability in WRDC
Annual cost	US$ 1–10 million

Assessment: 1 –Little or no progress.

WRDC is not well funded. No progress is reported in expanding the WRDC network or improving data access; ocean measurements of solar radiation are sparse, especially at higher latitudes, and these measurements are not included in the WRDC archive.

Since 1964, the World Radiation Data Centre (WRDC) has been collecting surface solar radiation (global, diffuse, direct) and sunshine duration data from around 1600 stations worldwide. According to the latest WRDC status report, about 330 stations have been actively contributing data to the WRDC in summer 2019, about as many as in 2016, indicating a lack of progress. The vast majority of over 200 contributing stations reside in Europe.

Although these data are widely used in satellite and model validation, and in assessments of the global radiation budget, relatively few sites are actively maintained. The WRDC lacks resources to start new series in parts of the world where measurements are lacking. Radiation data has many more applied uses now, as solar energy along with wind are two of the three principal sources of renewable energy. Most solar energy companies access the latest Reanalysis and Analysis fields to help manage their arrays. These data sets make extensive use of satellite products and are improved through assessment of their accuracy with enhanced ground truth data. As solar radiation information serves many interesting and important uses, it is crucial to improve data availability in the WRDC, which is the central archive for worldwide radiometric data. The WRDC (http://wrdc.mgo.rssi.ru/) is included in the Expert Team on the World Data Centers in GAW. It produces status reports on data availability, published quarterly, however the website and modalities of data access require updates for accessibility to the user community. The statistics on data reporting and an overall assessment of the health of the networks are not easily accessible and the metadata are not delivered automatically to GAWSIS-OSCAR/Surface. For most stations, daily data are the highest temporal resolution, even though most instrumentation provides much higher temporal resolution. Within the WDRC archive, there is a data set labelled as “GAW” that contains hourly values, but this covers only 50 stations that partly overlap with the sites maintained by the BSRN. The map of the Solar Radiation Network in the WRDC archive shows a lack of stations over several areas with the majority of sites located in Europe; how complete many of these series are is unknown (**Figure 22**).

The majority of monthly WRDC station data along with data from other research networks and projects, are included in the complementary Global Energy Balance Archive (GEBA, https://geba.ethz.ch/) maintained at ETH Zurich in Switzerland. Since 1988, GEBA provides long-term monthly series of 15 different surface energy balance components, in particular surface solar radiation, from 2500 stations worldwide, with some station records reaching back to the 1930s and 1940s. The solar radiation data are widely used by the climate and solar energy communities, but their monthly resolution limits their application to long-term climate analyses.

The solar energy sector requires hourly solar radiation data for near-term predictions. These hourly data are reported by the BSRN, but with inadequate latency, and by 600 SYNOP stations at real time (https://www.ecmwf.int/en/elibrary/18208-improved-use-atmospheric-situ-data), mostly for Europe.

As an integral part of the Global Ocean Observing System (GOOS), the OceanSITES program (www.oceansites.org) is a worldwide system of long-term reference stations measuring dozens of variables, including surface solar radiation. As part of the OceanSITES system, the Global Tropical Moored Buoy Array (GTMBA, www.pmel.noaa.gov/gtmba/mission) covers three buoy networks in the tropical Pacific (TAO/TRITON), the Atlantic (PIRATA) and the Indian (RAMA) oceans. These moored buoys use state of the art instrumentation, but because they are serviced only once a year, do not measure surface radiation with the same accuracy as land surface sites. The TAO network was established in the mid 1980s, followed by PIRATA in the mid-1990s and RAMA in the mid-2000s. In total, the three networks operate over 90 buoys of which about half have provided solar radiation observations in the past five years.

Since the early 2000s, the Upper Ocean Processes Group at Woods Hole Oceanographic Institution (http://uop.whoi.edu) has been operating the Stratus, North Tropical Atlantic Station (NTAS), and Hawaii Ocean Time-Series (HOTS) moored surface buoys, providing surface solar radiation observations at hourly resolution, updated in real time.

These tropical networks are complemented by ocean sites in the Northern and Southern oceans, many of which are inactive. Global coverage is very sparse as illustrated in the map below (**Figure 23**). To fill this gap is important for validation activities and the analysis of global and regional energy budgets. The OceanSITES data are freely and openly available and could be ingested by the WRDC. A closer relationship with better information flow between the ocean and land surface communities is recommended to facilitate such data exchange.

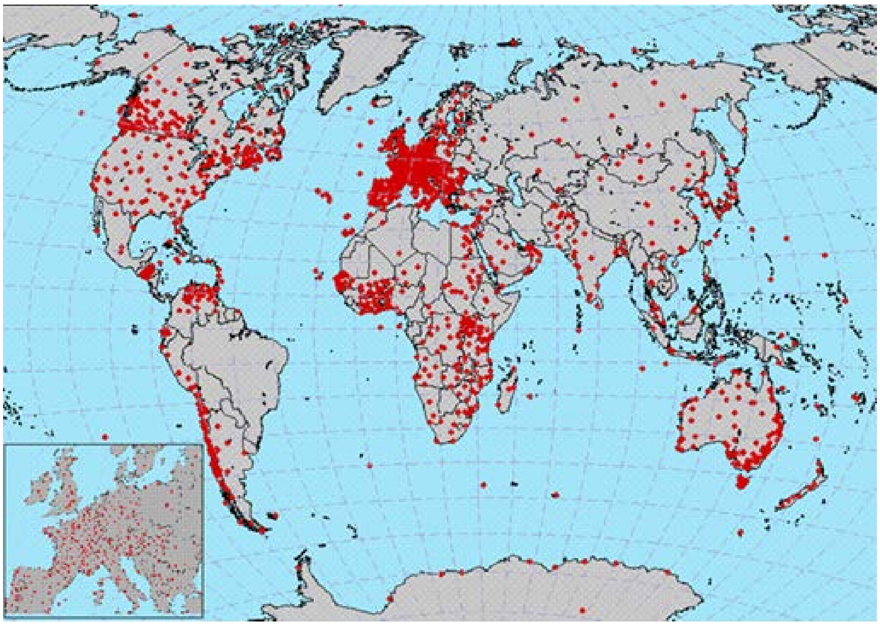

Figure 22. Stations in the WRDC

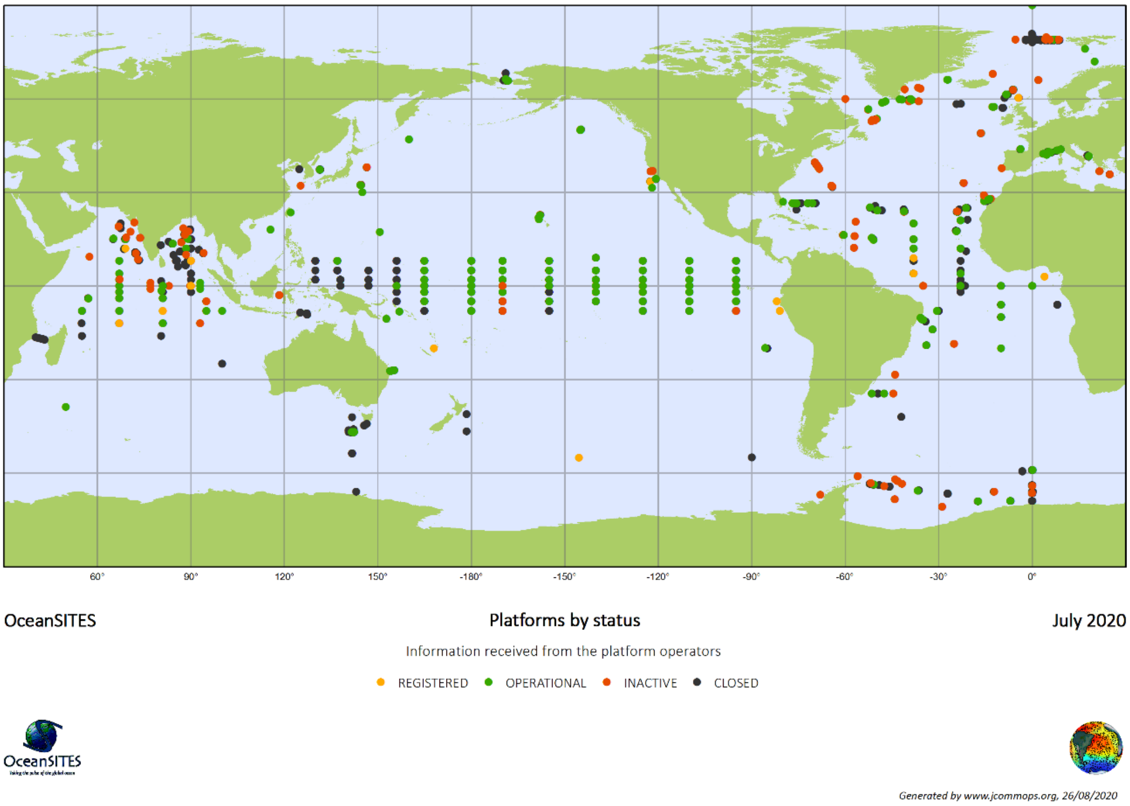

Figure 23. OceanSITES: Number of platforms by status in July 2020

Action A13:	Implement vision for future of GCOS Upper-Air Network operation
Action	Show demonstrable steps towards implementing the vision articulated in the GCOS Networks Meeting in 2014[53] relating to the future of GUAN operation
Benefit	Improved data quality, better integrated with GRUAN and more closely aligned with WIGOS framework
Who	Task team of AOPC with GCOS Secretariat in collaboration with relevant WMO commissions and WIGOS
Time frame	2019 for adoption at Nineteenth World Meteorological Congress
Performance indicator	Annual reporting in progress at AOPC of task team
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Task team met and produced better fleshed out requirements; if instigated in full and all GUAN sites were included, the Global Basic Observation Network (GBON) would meet many of the aims articulated in the 2014 GCOS Networks Meeting.

A task team was set up by AOPC to further this action. This group met in person at the GRUAN Lead Centre in Lindenberg, Germany, in 2017 and produced a report (GCOS-215[54]). This report further highlighted a number of issues and options regarding the future of GUAN. Thereafter resource commitments precluded significant progress on the matter by the task team. GCOS Secretariat presented the outcomes and recommendations of the TT to several WMO meetings including CIMO TECO (Oct 2018). In general, there has been good support for the 'revised' GUAN and it's stronger links with GRUAN. However, the proposal continues to lack leadership and a dedicated Lead Center with no offers of interest from WMO Member countries. Whilst any implementation would have the technical support of the GCOS Network Manager this is not an activity that can be led by GCOS secretariat.

The WIGOS proposal for a Global Basic Observing Network (GBON) the principal of which was approved by WMO Congress (2019) has significant synergies with the GUAN proposal and thus their implementations should be closely aligned. The scoped GBON network proposal would instigate a global network of radiosonde sites at a spacing much finer than that of GUAN and requiring ascents to 30hPa with 50 m (10 second) resolution. There will be a finance fund to support GBON and the continued role of the GCOS funding support would come into question. There are a lot of unknowns, not least of which is will GBON be approved and made operational. The expectation is that GUAN will become an underpinning component of the GBON network, not only acting as a baseline network but ensuring that those stations with long-term archives (many greater than 50 years) are sustained.

[53] GCOS-182: http://www.wmo.int/pages/prog/gcos/Publications/gcos-182.pdf
[54] GCOS-215: https://library.wmo.int/doc_num.php?explnum_id=4469

Action A14:	Evaluation of benefits for the GCOS Upper-Air Network
Action	Quantify the benefits of aspects of GUAN operation including attaining 30 hPa or 10 hPa, twice-daily as opposed to daily ascents and the value of remote island GUAN sites
Benefit	Better guidance to GUAN management, improved scientific rationale for decision-making
Who	NWP and reanalysis centres
Time frame	Completed by 2018
Performance indicator	Published analysis (in peer reviewed literature plus longer report)
Annual cost	US$ 10 000–100 000

Assessment: 3 – Underway with significant progress.

Task-Team was established by GCOS to review the GUAN and generated a report (GCOS,2015) and a number of recommendations. This has resulted in further work to scientifically qualify the GUAN, and the comprehensive global network, requirements.

AOPC-22 (Exeter, UK, March 2017) agreed on the creation of a dedicated task-team to deliver progress upon a number of actions in the GCOS Implementation Plan (GCOS 200) related to the operation and monitoring of the GCOS Upper Air Network:

- Reviewing the network requirements;
- Assessing and documenting the benefits of meeting stated requirements;
- How it contributes as a baseline network in the tiered network framework with the GCOS Upper-Air Network (GRUAN) and the comprehensive network.

Report from the first meeting including recommendations on the future development of the GUAN was published as: GCOS, 215[55]. Report from 1st Meeting of the Task Team GCOS Upper Air Network (TT-GUAN-1).

SWOT (Strengths, weaknesses, Opportunities and Threats) analysis agreed by TT-GUAN is shown in **Figure 24**.

[55] GCOS-215: https://library.wmo.int/doc_num.php?explnum_id=4469

Strengths	Weaknesses
GUAN is a well known brand. It is regarded as high-quality Radiosonde observations. (even if this is only a perception) Common practices and an underpinning standard. Has documented governance through WMO technical regulations and GCOS documents.	The aims, requirements and user needs of GUAN are not known and/or have just been forgotten. No NMHS 'buy-in'. Passive not Active management (i.e. poor performance is not addressed) Little difference between GUAN and the Comprehensive network No auditing of GUAN and little outreach between GUAN operators Requirements and guidance has not been updated to reflect the change in technology and user needs
Opportunities	**Threats**
GUAN best practices and outreach can support the comprehensive network Utilised improved tools for Quality Management & Visualisation Healthy competition in industry for the prestige of suppling GUAN stations Better alignment of GRAUN and GUAN, for example GRUAN products from GUAN stations.	Budget cuts and resource priorities are often targeted at radiosonde system consumables The pollution aspect of radiosondes Lack of clarity on the difference between GRUAN and GUAN might cause competition for resources

Figure 24. SWOT (Strengths, weaknesses, Opportunities and Threats) analysis agreed by TT-GUAN

Many of the network requirements for the GUAN have been incorporated into draft WMO requirements for the Global Basic Observation Network (GBON) and it is expected that the GUAN will continue to provide the underpinning baseline requirements for climate monitoring as a component of the GBON. However, delays in the operational implementation of the GBON and limited resources to adapt the GUAN using the recommendations of TT-GUAN has meant that further progress has not been realised.

Action A15:	Implementation of Reference Upper-Air Network
Action	Continue implementation of GRUAN metrologically traceable observations, including operational requirements and data management, archiving and analysis and give priority to implementation of sites in the tropics, South America and Africa
Benefit	Reference-quality measurements for other networks, in particular GUAN, process understanding and satellite cal/val.
Who	Working Group on GRUAN, NMHSs and research agencies, in cooperation with AOPC, WMO CBS and the Lead Centre for GRUAN
Time frame	Implementation largely completed by 2025
Performance indicator	Number of sites contributing reference-quality data streams for archival and analysis and number of data streams with metrological traceability and uncertainty characterization; better integration with WMO activities and inclusion in the WIGOS manual.
Annual cost	US$ 10–30 million

Assessment: 4 – Progress on track.

GRUAN has expanded considerably with new sites in the tropics and Antarctica and progress on a number of new data products.

GRUAN has grown considerably since the IP was published with several new sites declaring their candidature and several sites officially certified for the first time. This includes the first sites in the tropics and Antarctica. Challenges remain in assuring network coverage over South America. (**Figure 25**)

Figure 25. GCOS Reference Upper Air Network, GRUAN

A new data stream has been produced for the Meisei RS11-G sonde and considerable progress has been made towards the production of a number of additional GRUAN Data Products including GNSS-PW measurements which will constitute the first non-radiosonde product. Most sites have moved away from using the RS-92 sonde to the RS-41 sonde from Vaisala. A beta version of the rS41 is under review presently. GRUAN data has been widely used in publications and various international projects and GRUAN has participated in several campaigns.

GRUAN has also become better integrated into WMO and representatives from WMO regularly attend GRUAN meetings. The next WMO intercomparison of radiosondes will be hosted by the GRUAN Lead Centre and GRUAN data processing of some sondes alongside launches of instruments capable of measuring UT/LS water vapour, radiation, ozone and aerosols are foreseen.

Action A16:	Implementation of satellite calibration missions
Action	Implement a sustained satellite climate calibration mission or missions
Benefit	Improved quality of satellite radiance data for climate monitoring
Who	Space agencies
Time frame	Ongoing
Performance indicator	Commitment to implement by the next status report in 2020; proof-of-concept proven on ISS pathfinder
Annual cost	US$ 100–300 million

Assessment: 4 – Progress on track.

The current launch readiness timeframe for CLARREO Pathfinder is 2023. The ESA TRUTHS mission has been funded. The launch of LIBRA is scheduled for around 2025.

Climate trend analysis and monitoring depends on high accuracy observations with well-characterized errors and uncertainty. The latter is especially important when measurements from different sensors and sources are combined to form long term climate records. To this end, the Climate Absolute Radiance and Refractivity Observatory (CLARREO; Wielicki et al., 2013) was proposed to include an infrared and reflected solar spectrometer to function as SI traceable reference standards in space for the optimization and inter-calibration of measurements from a number of different space-based instruments.

To date, the CLARREO infrared spectrometer (Tobin et al., 2016) remains unfunded, with no funding commitment. Despite this, Taylor et al. (2020) demonstrated a new technology and implementation approach with the Absolute Radiance Interferometer (ARI) instrument (Taylor et al. 2020). They continue to make a strong case for an infrared CLARREO Pathfinder that would initiate an ongoing sequence of missions to better inter-calibrate operational sounders (e.g., AIRS, IASI, CrIS) and accurately quantify long-term climate trends of Earth emission.

The CLARREO solar reflectance spectrometer (Goldin et al. 2019) was identified as a Pathfinder mission and funded to have a place on the International Space Station (ISS). The goal of this CLARREO Pathfinder mission is to be the benchmark system for VIIRS and CERES. Specifically, it will provide an accurate estimate of uncertainty due to polarization that can then be used to correct VIIRS and CERES radiance/reflectance calibration. The 2017 Earth Science Decadal Survey also recommended to NASA that it completed the CPF mission. The current launch readiness timeframe is 2023. The CPF operations timeframe is confirmed for one year on ISS, and the mission includes an additional year for science data analysis. However, an extension of the one year of operations on ISS is currently being advocated.

The UK's National Physical Laboratory has similarly proposed a mission Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) which has been funded as an ESA earthwatch mission in 2019 to be launched in the mid-2020s. This mission is concerned with measurements in the visible and near infra-red portions of the spectrum. It will fly in a processing truly polar orbit and has an absolute traceability. Further details can be found at https://www.npl.co.uk/earth-observation/truths.

The Chinese Space-based Radiometric Benchmark (CSRB) project has been under development since 2014. Its goal is to launch a reference-type satellite named LIBRA around 2025. LIBRA will offer measurements with SI traceability for the outgoing radiation from the Earth and the incoming radiation from the Sun with high spectral resolution. The system will be realized with four payloads, i.e., the Infrared Spectrometer (IRS), the Earth-Moon Imaging Spectrometer (EMIS), the Total Solar Irradiance (TSI), and the Solar spectral Irradiance Traceable to Quantum benchmark (SITQ). As a complementary project to CLARREO and TRUTHS, LIBRA is expected to join the Earth observation satellite constellation and intends to contribute to space-based climate studies via publicly available data. More information can be found in Peng Zhang et al. (2020).

References:

Goldin, D., X. Xiong, Y. Shea and C. Lukashin. 2019: CLARREO Pathfinder/VIIRS Intercalibration: Quantifying the Polarization Effects on Reflectance and the Intercalibration Uncertainty. *Remote Sensing*, *11*, 1914, https://doi.org/10.3390/rs11161914.

Taylor, J.K. H.E. Revercomb, F.A. Best, D.C. Tobin, and P.J. Gero. 2020: The Infrared Absolute Radiance Interferometer (ARI) for CLARREO. Remote Sensing, 12, 1915, https://doi.org/10.3390/rs12121915.

Tobin, D., R. Holz, F. Nagle and H. Revercomb. 2016: Characterization of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) ability to serve as an infrared satellite intercalibration reference. Journal of Geophysical Research Atmosphere, 121, 4258–4271, https://doi.org/10.1002/2016JD024770.

Wielicki, B.A. et al. 2013: Achieving climate change absolute accuracy in orbit, Bulletin American Meteorological Society, 10, 1519–1539, https://doi.org/10.1175/BAMS-D-12-00149.1.

Action A17:	**Retain original measured values for radiosonde data**
Action	For radiosonde data and any other data that require substantive processing from the original measurement (e.g. digital counts) to the final estimate of the measurand (e.g. T and q profiles through the lower stratosphere); the original measured values should be retained to allow subsequent reprocessing.
Benefit	Possibility to reprocess data as required, improved data provenance
Who	HMEI (manufacturers), NMHSs, archival centres.
Time frame	Ongoing.
Performance indicator	Original measurement raw data and metadata available at recognized repositories
Annual cost	US$ 100 000–1million

Assessment: 1 – Little or no progress.

Discussions have occurred with Copernicus Climate Change Service as to whether this may be of interest in the next phase of their operation and the topic is further discussed in the GUAN TT report but there has been no concrete progress.

In terms of radiosonde ‘raw’ data, with the exception of GRUAN stations, the only archive of this type of measurements is the station (radiosonde ground-system) itself. That said many stations are now reporting the full-resolution data, which although is not the uncorrected (raw) measurements, this does allow the user to access all of the data measured by the radiosonde.

In terms of the performance indicator this target has not been met, but further steps can still be taken to document a process to obtain the original data and identify a repository to archive them. This requires funding support and the Copernicus Climate Change Service have been approached to this end.

Action A18:	Hyperspectral radiances reprocessing
Action	Undertake a programme of consistent reprocessing of the satellite hyperspectral sounder radiances
Benefit	Consistent time series of hyperspectral radiances for monitoring and reanalyses, improved CDRs computed from the FCDRs
Who	Space agencies
Time frame	Ongoing
Performance indicator	Reprocessed FCDRs available for hyperspectral sounders
Annual cost	US$ 100 000–1 million

Assessment: 4 – Progress on track.

Hyperspectral sounder radiances have been carefully assessed and those generated with old algorithms have been reprocessed with updated ones.

The hyperspectral infrared sounders (e.g. AIRS, IASI and CrIS) in sun-synchronous low-Earth orbits measure radiances with much higher spectral resolution than conventional sounders and enable the profiling of temperature and humidity, and measurement of concentrations of trace gases with high vertical resolution. They also provide a benchmark for intercalibration of observations from different instruments in orbit and enable those instruments to make better characterised measurements as undertaken within the GSICS initiative. Ensuring consistent time series of hyperspectral radiances is essential for improving CDRs computed from them as well as for providing reanalyses with high-quality observations to be assimilated and a reliable reference-series against which they can be assessed.

AIRS on the EOS Aqua satellite, launched in 2002, provides the longest record of hyperspectral radiances. AIRS channel properties and radiance uncertainty are well characterized and has been closely monitored by the NASA AIRS Science Team. Pagano et al. (2020) recently demonstrated its radiometric and spectral accuracy and stability; and provided the latest assessment of measurement uncertainty.

IASIs are flying on board the Metop satellites, launched in 2006 (Metop-A), 2012 (Metop-B) and 2018 (Metop-C). EUMETSAT has reprocessed the radiances from IASI on board Metop-A for the 2007-2017 period with the most recent version of the algorithm, making them consistent with both those generated after 2017 and from IASI on board Metop-B.

Impact of the past algorithm updates on radiances has also be assessed (Bouillon et al., 2020).

Radiances from CrIS onboard the JPSS series of satellites, launched in 2011 (Suomi NPP) and 2017 (JPSS-1), have recently been reprocessed with an updated calibration algorithm with improvements in radiometric and spectral accuracy (Chen et al., 2017). NASA maintains a commitment to reprocess the full record of AIRS (a grating spectrometer) and CrIS (a Michelson interferometer like IASI) as Level 1B calibrated radiances whenever significant gains have been made in their respective calibration algorithms.

References:

Bouillon, M, S. Safieddine, J. Hadji-Lazaro, S. Whitburn, L. Clarisse, M. Doutriaux-Boucher, D. Coppens, T. August, E. Jacquette and C. Clerbaux, 2020: Ten-year assessment of IASI radiance and temperature. Remote Sensing, 12: 2393. https://doi.org/10.3390/rs12152393.

Chen, Y., Y. Han and F. Weng, 2017: Reprocessing of Suomi NPP CrIS sensor data records and impacts on radiometric and spectral long-term accuracy and stability. In 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). 4178–4181. https://doi.org/10.1109/IGARSS.2017.8127922.

Pagano, T. S., H. H. Aumann, S. E. Broberg, C. Cañas, E. M. Manning, K. O. Overoye and R. C. Wilson, 2020: SI-traceability and measurement uncertainty of the Atmospheric Infrared Sounder Version 5 Level 1B radiances. Remote Sensing, 12: 1338. https://doi.org/10.3390/rs12081338.

Action A19:	Reprocessing of atmospheric motion vectors
Action	Continue reprocessing of AMVs derived from geostationary satellite imagery in a coordinated manner across agencies
Benefit	Consistent time series of AMVs for monitoring and reanalyses, improved CDRs computed from the FCDRs
Who	Space agencies
Time frame	Ongoing
Performance indicator	Reprocessed FCDRs available for upper-air winds
Annual cost	US$ 100 000–1 million

Assessment: 4 – Progress on track.

Reprocessing has been undertaken by European, Japanese and the United States producers, but reprocessing needs to be recognised as a continuous ongoing requirement.

The atmospheric motion vectors (AMVs) are one of the sources of wind information and obtained by tracking cloud elements between successive satellite images and assigning their height by measuring their temperature to provide “satellite winds”. Since this technique has been continuously improved to provide better observations for NWP (e.g. Santek et al., 2019), use of AMVs produced operationally in earlier periods is not adequate for climate applications such as reanalysis. In order to produce AMVs with homogeneous and consistent data quality in time, reprocessing has been undertaken by European, Japanese and the United States producers.

Current status of AMV reprocessing activities, including planned and ongoing ones, is summarised in Table 4 Current status of AMV reprocessing activities including planned and ongoing ones. More detailed information for some of the reprocessed AMVs listed here are available from the ECV Inventory compiled by CEOS/CGMS WGClimate (https://climatemonitoring.info/ecvinventory/). These activities have been driven mainly by the requirements of various reanalysis projects, especially those of closely collaborating reanalysis producers. The activities were also coordinated across agencies by a SCOPE-CM Phase II project (SCM-10; https://www.scope-cm.org/).

How far reprocessing can go back in time is subject to availability of successive images needed as input (typically < 1-hr interval) and the quality of those images (such as geolocation and calibration errors). Data rescue efforts for early satellites have been made (e.g. Poli et al., 2017), but applicability of those early images to AMV reprocessing still needs to be investigated.

Table 4 Current status of AMV reprocessing activities including planned and ongoing ones. More detailed information for some of the reprocessed AMVs listed here are available from the ECV Inventory compiled by CEOS/CGMS WGClimate (https://climatemonitoring.info/ecvinventory/).

Producer	**Satellite**	**Period**	**Note**
EUMETSAT	Meteosat-8 and 9	2004-2012	
	Meteosat-2 to 10	1981-2017	planned
	NOAA and Metop (AVHRR GAC)	1978-2019	planned
	Metop-A and B (AVHRR LAC)	2013-2017	Global LEO wind, planned
	Metop-A (AVHRR LAC)	2007-2014	EUMETSAT algorithm
	Metop-A (AVHRR LAC)	2007-2014	CIMSS algorithm
NOAA/NESDIS and CIMSS	GOES-8 to 15	1995-2013	NESDIS operational algorithm as of 2014
	NOAA-7 to 18 (AVHRR GAC)	1982-2014	
JMA/MSC	GMS, GOES-9 and MTSAT-1R	1979, 1987-2009	MTSAT algorithm

	GMS-5, GOES-9 and MTSAT	1995-2015	Himawari-8 algorithm, ongoing

References:

Poli, P., D. P. Dee, R. Saunders, V. O. John, P. Rayer, J. Schulz, K. Holmlund, D. Coppens, D. Klaes, J. E. Johnson, A. E. Esfandiari, I. V. Gerasimov, E. B. Zamkoff, A. F. Al-Jazrawi, D. Santek, M. Albani, P. Brunel, K. Fennig, M. Schröder, S. Kobayashi, D. Oertel, W. Döhler, D. Spänkuch, and S. Bojinski, 2017: Recent advances in satellite data rescue. Bulletin American Meteorological Society, 98: 1471-1484. https://doi.org/10.1175/BAMS-D-15-00194.1.

Santek, D., R. Dworak, S. Nebuda, S. Wanzong, R. Borde, I. Genkova, J. García-Pereda, R. Galante Negri, M. Carranza, K. Nonaka, K. Shimoji, S. M. Oh, B.-I. Lee, S.-R. Chung, J. Daniels, and W. Bresky, 2019: 2018 Atmospheric Motion Vector (AMV) Intercomparison study. Remote Sensing, 11: 2240. https://doi.org/10.3390/rs11192240.

Action A20:	Increase the coverage of aircraft observations
Action	Further expand the coverage provided by AMDAR, especially over poorly observed regions such as Africa and South America
Benefit	Improved coverage of upper-air wind for monitoring and reanalysis
Who	NMHSs, WIGOS, RAs I and III.
Time frame	Ongoing
Performance indicator	Data available in recognized archives
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

Since GCOS-IP 2016, the total number of Aircraft Based Observations (ABO) increased by about 50 % from 2014 to 2019. The coverage over South America improved significantly

Since 2016, several developments occurred in the WMO Aircraft-Based Observations programme and AMDAR observing system. WMO established the Global Data Centre for ABO (GDC-ABO) and designated responsibility for its operation to USA, NOAA. Data volumes increased from around 800K to over 1M observations per day on the WMO GTS and participating airlines increased from 38 to 43 airlines. Reporting of water vapour increased with a fleet of around 150 aircraft now reporting over the USA, Europe and some parts of Africa. A large increase in global ABO data over upper troposphere oceanic areas of around 60K observations per day was derived from Automatic Dependent Surveillance. Lower tropospheric observations became available over some islands in the tropical Indian Ocean and western Pacific. The coverage provided by ABO improved over South America as the Argentinian AMDAR programme became operational and a large fleet of aircraft of the LATAM group commenced reporting under the USA ABO programme. Brazil commenced provision of ABO observations derived from Aircraft Reports from the Brazil ATM system. In Region I, new AMDAR programmes commenced development for Kenya and Morocco.

Increase in observation over South America is clearly shown figure 15.

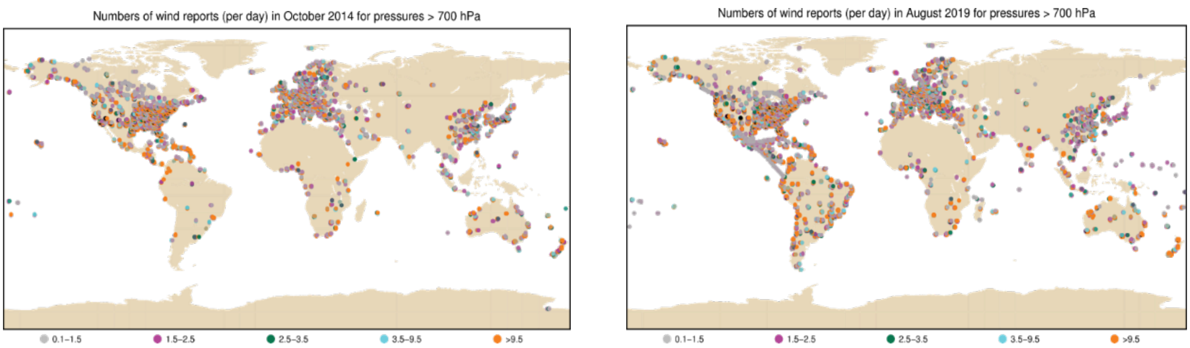

Figure 26. Distribution of aircraft data from pressures greater than 700 hPa as received operationally by JMA (as ACARS, AIREP and AMDAR reports) in August 2014 (left) and August 2019 (right) for wind. A symbol is plotted for each 0.5° latitude/longitude grid box that contains at least three observations per month. Colour indicates the average number of observations per day

Figure 27 shows time series for the number of aircraft observations in the RAs I and III regions for ascent/descent profile. The time series for RA III show a significant increase by a factor of 10 in the mid-2010s while the increase in RA I is moderate.

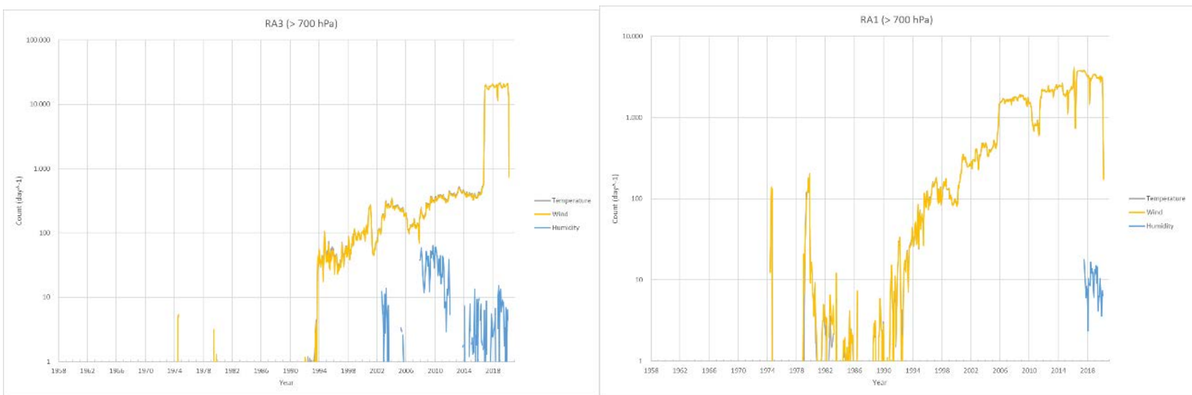

Figure 27. Number of aircraft observations in RA3 (left) and RAI (right) JMA Archive

Action A21:	**Implementation of space-based wind-profiling system**
Action	Assuming the success of ADM/Aeolus, implement an operational space-based wind profiling system with global coverage
Benefit	Improved depiction of upper-air windfields: improved reanalyses, 3D aerosol measurements as a by-product

Who	Space agencies
Time frame	Implement once ADM/Aeolus concept is proven to provide benefit
Performance indicator	Commitment to launch ADM follow-on mission
Annual cost	US$ 100–300 million

Assessment: 2 – Started but little progress.

ADM/Aeolus is the first of its kind in space and have provided operationally critical wind measurements since 2018, but despite its success there are currently no concrete plans for follow-on missions to continue this vital record.

The importance and operational need for space-based wind profile measurements is well documented (e.g. Hays et al., 2005). Before the launch of ESA's ADM/Aeolus payload, 3-dimensional wind measurements were a conspicuous gap in the global Earth observing system (Baker et al., 2014). Since 3 September 2018, however, ADM/Aeolus have been making LIDAR line of sight wind profile measurements daily, across the globe that are already making a strong impact on weather forecast systems. So much so that in January 2020, ECMWF (European Centre for Medium-range Weather Forecasts) started assimilating ADM/Aeolus measurements (https://www.esa.int/Applications/Observing_the_Earth/Aeolus/COVID-19_Aeolus_and_weather_forecasts) and trials at the Met Office similarly show positive impacts.

There are no comparable missions being developed elsewhere in the world. NASA does have Doppler wind Lidar measurement capability with its Airborne Cloud-Aerosol Transport System (ACATS) that combines measurements from two instruments, a high spectral resolution lidar (HSRL) and Doppler wind lidar, that fly on the high-altitude NASA ER-2 aircraft. Currently, ACATS is the only NASA system that provides simultaneous measurements of aerosols and wind at multiple atmospheric pressure layers. NASA uses ACATS to support their research on innovative telescope design that can exist in space (https://catalog.data.gov/dataset/doppler-wind-lidar-measurements-and-scalability-to-space).

ADM/Aeolus is a highly innovative ESA research mission that launched successfully and now contributes to operational applications in unprecedented ways. EUMETSAT and ESA are discussing a follow-on mission presently, but even if funded there will inevitably be a substantial gap in the record.

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Hays, P., M. Dehring, L. Fisk and P. Tchoryk , 2005: Space-based doppler winds LIDAR: a vital national need.

National Research Council Decadal Study. Available online: http://cires1.colorado.edu/events/lidarworkshop/LWG/Splash%20Papers/Hays.pdf.

Action A22:	**Develop a repository of water vapour climate data records**
Action	Develop and populate a globally recognized repository of GNSS zenith total delay and total column water data and metadata
Benefit	Reanalyses, water vapour CDRs
Who	AOPC to identify the appropriate responsible body
Time frame	By 2018
Performance indicator	Number of sites providing historical data to the repository
Annual cost	US$ 100 000–1 million

Assessment: 2 – Started but little progress.

The potential for ECMWF as the entrusted entity to the Copernicus Climate Change Service to host the centre has been identified and an initial selection of global stations is in the process of being archived via the C3S Data Store.

The importance of GNSS-PW data has been recognised via C3S and its contract C3S 311a Lot 3, led by CNR (Italy) which has created a globally representative set of holdings. These are in the process of being made available via the Copernicus Climate Data Store hosted by ECMWF. This has the potential to become a global repository for these data but the formalisation of such a role is yet to proceed. Informal discussions with ECMWF and various communications by the C3S 311a Lot 3 contract have highlighted this potential. Formal accreditation as the data centre is pending a formal request for application. The C3S 311a Lot 3 team have identified numerous additional assets that could be targeted to create a truly comprehensive repository in time if resources to support the activity were forthcoming.

Action A23:	**Measure of water vapour in the upper troposphere/lower**
Action	Promote the development of more economical and environmentally friendly instrumentation for measuring accurate in situ water-vapour concentrations in the UT/LS
Benefit	Improved UT/LS water vapour characterization, water-vapour CDRs
Who	NMHSs, National measurements institutes, HMEI and GRUAN
Time frame	Ongoing
Performance indicator	Number of sites providing higher-quality data to archives
Annual cost	US$ 10–30 million

Assessment: 3 – Underway with significant progress.

UT/LS water vapor soundings have been made with varying degrees of success using balloon-borne frost point hygrometers cooled by a dry ice/ethanol bath or a thermoelectric (Peltier) device, but further test flights are needed to prove that these alternative coolants provide adequate cooling power under high solar radiation conditions in the stratosphere, especially in the tropics.

For more than four decades, vertical profiles of atmospheric water vapor have been made from the surface up to the middle stratosphere using balloon-borne chilled-mirror frost point hygrometers. The most successful instruments to date have relied on the refrigerant R23 (CHF_3, HFC-23) to cool the mirror where frost is grown, detected and controlled. Liquid R23 has nearly perfect physical properties for such an instrument, with pressure-dependent boiling points approximately 20°C colder than typical atmospheric frost point temperatures throughout the 0-35 km altitude range.

Though not an ozone-depleting substance (ODS), R23 has a Global Warming Potential (GWP) nearly 15,000 times that of CO_2. Early non-chlorinated replacements of CFCs and other ODSs were deemed acceptable in response to the Montreal Protocol's call to rapidly reduce and eventually cease the production and consumption of ODSs, even though many replacements have very high GWPs. Now, with atmospheric burdens of most ODSs in decline, concern about the use of high-GWP replacements has brought about regulatory action. The Kigali Amendment to the Montreal Protocol set deadlines to reduce (and eventually cease) the production and consumption of high-GWP replacements like R23.

The search for an alternative, more environmentally-friendly method of cooling the mirrors in balloon-borne frost point hygrometers began before 2016, but to the best of our knowledge, not one of the 10 or so sites that routinely performs frost point hygrometers soundings has completely abandoned the use of R23. Currently, two alternative cooling methods are being explored. One uses thermoelectric cooling that requires the difficult dissipation of a large amount of heat in the sun-baked, low-density air of the stratosphere. One thermoelectric-cooled instrument employs alcohol to help with heat dissipation. The other cooling method utilizes a cold slush bath of pure ethanol and dry ice as the mirror coolant. The bath is contained in a Styrofoam Dewar much like the insulated containment vessel used for liquid R23. Each of these alternative cooling methods has demonstrated adequate mirror cooling power up to the tropopause, but to our current knowledge, only the slush bath has adequately cooled the mirror well into the stratosphere (~25 km). Several test flights at Jülich (Germany) and Boulder, Colorado (USA) have demonstrated the high potential for the slush bath to adequately cool the mirror throughout an entire sounding. Further tests, especially in the high solar radiation environment of the tropical stratosphere, are needed to conclusively prove the adequacy of this cooling method. The conversion of frost point hygrometers from R23 to a slush bath of ethanol and dry ice is not expected to significantly increase or decrease the current cost of frost point hygrometers (~US$3,000).

Since frost point hygrometry requires stability of the frost layer on the chilled mirror under a wide range of atmospheric moisture conditions, tuning of the frost control logic is dependent on the mirror cooling power. The ethanol slush bath is inherently warmer than liquid R23 so it provides less cooling power and requires retuning the frost control logic. Improper tuning generally decreases the stability of frost on the mirror and increases measurement noise, but can also intermittently bias measurements to either side of the true frost point temperature. To avoid introducing biases into frost point hygrometer measurement records, it is highly recommended that two instruments, one cooled by R23 and the other by a new method, be flown concurrently to directly compare their measured frost point temperatures for sufficient time to adequately manage the transition. If possible, such comparisons should span a wide range of climatic conditions and, where applicable, seasons of the year.

Action A24:	Implementation of archive for radar reflectivities
Action	To implement a global historical archive of radar reflectivities (or products of reflectivities are not available) and associated metadata in a commonly agreed format
Benefit	Better validation of reanalyses, improved hydrological cycle understanding
Who	NMHSs, data centres, WIGOS
Time frame	Ongoing
Performance indicator	Data available in recognized archive, agreed data policy
Annual cost	US$ 1–10 million

Assessment: 2 – Started but little progress.

A GCOS task team provided recommendations for archiving radar data and metadata from the perspective of climate research into a global historical archive (GCOS-223). However, the implementation of such archive has not been started yet.

An AOPC Task Team was established in 2017 to work on a proposal on how best to proceed on the use of radar data for climate studies. In particular, the task team was charged with defining climate monitoring requirements for precipitation radar data, relevant metadata, and best practices. Further tasks were identifying procedures for quality control of radar data specifically for climate applications and suggesting procedures for handling historical data. The task team started by assessing the status of existing international and national archives, including their extent and quality and recommending whether existing data centres should be expanded, or new structures should be created. Results and recommendations arising from this task team are presented in the GCOS Report GCOS-223[56] and in the published paper "An Overview of Using Weather Radar for Climatological Studies: Successes, Challenges, and Potential" by E. Saltikoff et al. (2019).

As part of the process of assessing the existing archives, the GCOS radar task team prepared a survey on radar data archives aimed at elucidating existing archives, their completeness and record length, the existence of metadata and the availability and access of the data. Results from the survey showed that two decades time series are available at several NMHSs and coverage is adequate to address climate requirements. Many NMHS have conducted promising prototype studies and are ready to invest into the development and generation of multi-decadal radar databases to support climate requirements. Globally the effort required to address climate requirements is substantial and several approaches are feasible. The task team recommended to establish an international portal to allow harmonized access to radar data, metadata and documentation and provided recommendations for archiving radar and metadata from the perspective of climate research.

While guidelines for the implementation of a global historical archive of radar reflectivities have been established, no concrete progress towards such implementation has been

[56] GCOS-223, https://library.wmo.int/doc_num.php?explnum_id=6260

made. However, as this has been identified by the GCOS-IP 2016 as an important action and the task team has confirmed both the importance and the feasibility of establishing this archive, it is suggested that efforts toward the implementation of this archive should continue.

References:

Saltikoff, E., K. Friedrich, J. Soderholm, K. Lengfeld, B. Nelson, A. Becker, R. Hollmann, B. Urban, M. Heistermann, and C. Tassone, 2019: An Overview of Using Weather Radar for Climatological Studies: Successes, Challenges, and Potential, Bulletin American Meteorological Society, 100 (9), 1739–1752. https://doi.org/10.1175/BAMS-D-18-0166.1

Action A25: :	Continuity of global satellite precipitation products
Action	Ensure continuity of global satellite precipitation products similar to GPM
Benefit	Precipitation estimates over oceans for global assessment of water-cycle elements and their trends
Who	Space agencies
Time frame	Ongoing
Performance indicator	Long-term homogeneous satellite-based global precipitation products
Annual cost	US$ 30–100 million

Assessment: 3 – Underway with significant progress.

While significant progress has been made on satellite observations, in particular with passive microwave observations, some uncertainties remain with the continuation and quality of data.

The matter is being followed up by the operational meteorological space agencies at CGMS (Coordination Group for Meteorological Satellites) and the CGMS International Precipitation Working Group as a high priority. Currently significant progress is being seen with passive microwave observations. Capabilities of smallsat constellations (e.g. TROPICS Pathfinder with six satellites) are being explored for microwave sounding, augmenting the basic observations provided by the backbone missions in three orbital planes (early-morning, morning and early afternoon), which are committed as a contribution towards the baseline of the WMO WIGOS2040 Vision. There is also progress on microwave imagers and increased capabilities from passive microwave constellations, not only sounders, but also imagers (GCOM-GW with AMSR-3 with a tentative launch date around 2023/2, the first EUMETSAT MWI instrument scheduled for launch towards 2024 and the continuation of the MWI instruments on the Chinese FY-3 satellites). In addition, there are capabilities being developed in several other countries. Also, here the operational meteorological satellite agencies are following up through CGMS.

On the radar side we do have the Chinese FY-3G with a precipitation radar with a follow-on FY-3G’ being considered. Furthermore, the US is progressing with the planning for a precipitation/cloud radar, which whilst targeting process studies, would be extremely useful.

Action A26:	Development of methodology for consolidated precipitation estimates
Action	Develop methods of blending raingauge, radar and satellite precipitation
Benefit	Better precipitation estimates
Who	WMO technical commissions.
Time frame	By 2020
Performance indicator	Availability of consolidated precipitation estimates
Annual cost	US$ 10 000–100 000

Assessment: 1 – Little or no progress.

Very few methods have been published and no consolidated precipitation estimates exist.

In the peer review literature only very few methods using all sources of precipitation measurements have been published. Only the China Merged Precipitation Analysis (CMPA) is a truly merged product based on surface observations, radar and satellite data.

However, several methods have been developed to merge two out of the three different measurements techniques. A literature review yields one paper for a surface-satellite merged product (GSMAP) hourly temporal and 0.1° spatial resolution. For merging satellite estimates with surface observations, several data sets exist (e.g. GPCP). The International Precipitation Working Group provides a summary of publicly available, quasi-operational, quasi-global precipitation estimates that are produced by combining input data from several sensor types, including satellite sensors and precipitation gauges. It show in the order of 15 different versions /data sets under http://www.isac.cnr.it/~ipwg/data/datasets.html. None of the listed products uses all three kinds of observations.

Products in Europe exist where surface measurements with radar estimates have been merged, e.g. RADOLAN in Germany, but there are no global products. It is noted that surface observations are regularly used in adjusting and correcting radar estimates in an operational processing setting.

In summary, no real progress has been made to bring all three different observation techniques together in a value-added manner to provide longer time period data records. The question remains important and the task needs further attention by GCOS.

Action A27:	Dedicated satellite Earth Radiation Budget (ERB) mission
Action	Ensure sustained incident total and spectral solar irradiances and ERB observations, with at least one dedicated satellite instrument operating at any one time
Benefit	Seasonal forecasting, reanalyses, model validation.
Who	Space agencies
Time frame	Ongoing
Performance indicator	Long-term data availability at archives
Annual cost	US$ 30–100 million

Assessment: 4 – Progress on track.

Global monitoring of solar irradiance and Earth outgoing radiative fluxes has been continuous over the past two decades thanks to the Clouds and the Earth's Radiant Energy System (CERES), Solar Radiation and Climate Experiment (SORCE) and Total and Spectral Solar Irradiance Sensor (TSIS) programs.

Since 2018, the NASA TSIS-1 instruments Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM) have continued the long-term solar irradiance measurements taken by SORCE, a 17-year mission that phased out in February 2020. TSIS-1 is operated from the International Space Station (ISS) and will be succeeded by TSIS-2, a free-flyer to be launched in 2023. A Compact Spectral Irradiance Monitor (CSIM) deployed on a CubeSat has been collecting solar spectral irradiance data since December 2018. A compact CubeSat version of the TIM, CTIM, will launch in 2021.

Global Earth outgoing shortwave and longwave fluxes have been measured through CERES since March 2000. Currently, six instruments are operational on the Terra, Aqua, S-NPP and NOAA-20 satellites. The latest instrument, FM6, was launched in 2017 and will be succeeded by the recently selected NASA instrument Libera, projected to launch in 2027 on JPSS-3. The instrument specifics are such that seamless continuation of the ERB measurements is facilitated; mission overlap of at least one year is anticipated but not guaranteed. The CERES data are freely and openly available at https://ceres.larc.nasa.gov/data/. Beyond Libera (projected mission lifetime 2027-2032), the future for CERES-like broadband ERB measurements is uncertain. It is imperative that space agencies make further plans to maintain seamless continuity of the ERB climate data record.

The CLARREO Pathfinder mission will measure spectrally resolved Earth-reflected radiation from 350-2300 nm at 6 nm spectral resolution and 1 km spatial resolution. The objectives of CLARREO Pathfinder are to demonstrate high accuracy (<0.3% uncertainty) by direct calibration from the Sun and to transfer calibration to VIIRS and CERES. CLARREO Pathfinder will deploy on the ISS in 2023.

The Geostationary Earth Radiation Budget (GERB) instrument aboard EUMETSAT's Meteosat Second Generation satellites, measures outgoing solar and total radiation for the limited region of the Earth viewable from a geostationary orbit located over the equator at zero degrees longitude. With the first GERB instrument launched in late 2002 and the fourth and final instrument beginning operations in January 2018, the GERB operational record covers the period May 2004 to present at a roughly 15-minute time resolution. Operational constraints severely curtail data availability for three weeks each equinox and there is currently a two-year gap from April 2013 to April 2015 in the record due to a temporary failure of the third GERB instrument. Climate quality products are available for May 2004 to Jan 2013 on CEDA (http://ceda.ac.uk), and operational quality products for May 2015 to present can be accessed via the ROLSS server at RMIB (http://gerb.oma.be).

The recently selected ESA TRUTHS mission will measure with absolute calibration visible and near infrared radiation components from a processing polar orbit. This mission will launch in the mid-2020s.

Action A28:	**In situ profile and radiation**
Action	To understand the vertical profile of radiation requires development and deployment of technologies to measure in situ profiles.
Benefit	Understanding of 3D radiation field, model validation, better understanding of radiosondes
Who	NMHSs, National measurements institutes, HMEI
Time frame	Ongoing
Performance indicator	Data availability in NMS archives
Annual cost	US$ 1–10 million

Assessment: 2 – Started but little progress.

A regular, once monthly, measurement program is undertaken at the DWD Lindenberg facility based on the pioneering work by Meteo Swiss and FMI; data is accessible on request.

Progress on the creation of a long-term measurement series of radiation profiles has been reported to GRUAN via its Implementation and Coordination Meetings. Staff at the Lead Centre in Lindenberg is flying a monthly payload undertaking upward and downward looking LW and SW radiation components in cloudy and clear sky conditions. The data is available upon request. The instrumentation remains in a development phase but is based on sensors commercially available and traced back to calibration standards. There is currently one known manufacturer. Significant work is still required to instigate a network of such measurements and would most likely be attainable in the future via GRUAN in the first instance. However, it is not presently seen as a priority activity for GRUAN. To our knowledge, beyond these Lindenberg flights no additional development / deployment has occurred since the IP was published.

Action A29:	Lightning
Action	To define the requirement for lightning measurements, including data exchange, for climate monitoring and to encourage space agencies and operators of ground-based systems to provide global coverage and reprocessing of existing datasets
Benefit	Ability to monitor trends in severe storms
Who	GCOS AOPC and space agencies
Time frame	Requirements to be defined by 2017
Performance indicator	Update to Annex A for lightning and commitments by space agencies to include lightning imagers on all geostationary platforms. Reprocessed satellite datasets of lightning produced
Annual cost	US$ 10–30 million

Assessment: 4 – Progress on track.

AOPC established a task team on lightning observations for climate applications which defined climate monitoring requirements for lightning and is now working on improving data availability for lightning.

Lightning observations have become operational in recent decades and the availability of increasingly longer time series unleashes the great potential of lightning as a climatological variable. Therefore, lightning has been added to the list of Essential Climate Variables (ECV) in the 2016 GCOS Implementation Plan. In order to define observational requirements and to explore how the usage of lightning data for climate applications can be promoted, AOPC agreed during AOPC-22 (Exeter, UK, March 2017) on the creation of a dedicated task team on lightning observations for climate applications (TTLOCA). This task team continued the work related to lightning observations of the Task Team on the Use of Remote Sensing Data for Climate Monitoring of the Commission for Climatology (CCl) as a joint GCOS/CCl task team. TTLOCA completed its Terms of Reference (ToR, GCOS-213), defined requirements for the observation of lighting and suggested as additional ECV product Schumann Resonances, which have currently the status of an emerging ECV product.

In addition, a report discussing challenges and general recommendations on the usage of lightning has been published (GCOS-227[57]). Further initiatives like the establishment of a thunder day database and a pilot study on measuring ionospheric potential using the GCOS Reference Upper Air Network to observe global thunderstorm activity have also been launched. Based on this outcome, AOPC decided during its 25th session (videoconference, April 2020) to extend TTLOCA by two years and charge it with continuing current relevant activities and with initiating tasks that were identified during its initial phase.

These additional charges mainly focus on (1) making lightning data available; (2) Establishing an international database for thunder day data; (3) Collaborating with GRUAN through the AOPC WG-GRUAN and the DWD hosted Lead Centre facility to hold field campaigns to measure ionospheric potential once sensors are available; and (4) Liaising with other interested expert groups within WMO to ensure full consistency for application

[57] https://library.wmo.int/doc_num.php?explnum_id=6262

areas for lightning (e.g. registration of private lightning data providers at the WIS; metadata for real-time lightning applications). This includes exploring whether it is possible, in collaboration with the WMO/WHO working group, to identify more reliable numbers of lightning fatalities and injuries and whether material could be developed to support educational programs of WHO.

Action A30:	**Water vapour and ozone measurement in upper troposphere and lower and upper stratosphere**
Action	Re-establish sustained limb-scanning satellite measurement of profiles of water vapour, ozone and other important species from UT/LS up to 50 km
Benefit	Ensured continuity of global coverage of vertical profiles of UT/LS constituents
Who	Space agencies
Time frame	Ongoing, with urgency in initial planning to minimize data gap
Performance indicator	Continuity of UT/LS and upper stratospheric data records
Annual cost	US$ 30–100 million

Assessment: 2 – Started but little progress.

Measurements by limb-scanning satellite instruments for UT and stratospheric measurements of water vapor, ozone and other important trace gases remain precarious; some replacement capability is planned with JPSS-2 in 2022 but even if successful, the single-instrument makes the record vulnerable.

Limb-scanning satellite instruments that measure vertical profiles of water vapor, ozone and other important trace gases (e.g., N_2O, CH_4) from the upper troposphere (UT) to the stratopause are currently scarce, with only two currently operational. Limb scanners are distinct from spectrometers that measure solar (or lunar) occultations as the sun (or moon) rises or sets behind Earth's limb (e.g., ACE-FTS, SAGE III/ISS) because they measure up to 3500 vertical profiles per day, ~100 times the data density provided by the spectrometers (30-40 profiles per day).

The Aura Microwave Limb Sounder (MLS) is now in its 17th year of operation and is currently the only limb-scanning instrument that measures water vapor, ozone, N_2O and other important trace gases in the UT and stratosphere. The Ozone Mapping and Profiler Suite-Limb (OMPS-L) instrument aboard the Suomi National Polar-orbiting Partnership (NPP) satellite, launched in October 2011, is the other limb-scanning instrument that currently measures ozone profiles in the UT and stratosphere. Since these are the only two limb-scanning satellite instruments that meet the requirements of this action item, we find there has been very limited progress to re-establish sustained measurements of this type in the last five years. In fact, the OMPS-L instrument was omitted from the payload of the first Joint Polar Satellite System (JPSS) mission that was launched in late 2017 as the follow-up to the Suomi NPP.

There are fortunately plans to include OMPS-L on future missions of the JPSS, with JPSS-2 set to launch in March 2022. After its planned launch at the end of 2022, the Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere (ALTIUS) instrument will deliver high-resolution profiles of ozone, water vapor, methane and other important trace gases in the stratosphere.

Action A31:	Validation of satellite remote sensing
Action	Engage existing networks of ground-based, remote sensing stations (e.g. NDACC, TCCON, GRUAN) to ensure adequate, sustained delivery of data from MAXDOAS, charge coupled device (CCD) spectrometers, lidar, and FTIR instruments for validating satellite remote-sensing of the atmosphere
Benefit	Validation, correction and improvement of satellite retrievals
Who	Space agencies, working with existing networks and environmental protection agencies
Time frame	Ongoing, with urgency in initial planning to minimize data gap
Performance indicator	Availability of comprehensive validation reports and near-real-time monitoring based on data from the networks
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Various activities by networks and under Copernicus have improved access and timeliness, and various tools developed under projects such as GAIA-CLIM have aided usability, but there is still no unified access to these measurements and tools by the satellite cal/val community.

Access to high quality measurements from networks such as GRUAN, NDACC and TCCON has generally improved. Much of this has been via contracts to CAMS and C3S Copernicus activities funded via ECMWF which has enabled access to data under improved and unified formats. However, this activity has not been holistic and users still require to access numerous portals and cope with several distinct formats when accessing these data. The community has called for an improved and holistic approach to access to both these data and tools that enable their exploitation (Streckx et al., 2020). If adopted this vision would meet the aims of this IP action in full.

Several projects have developed a range of tools that deal with issues around co-location and non-equivalence of measurement techniques. These have included the use of data assimilation and radiative transfer techniques.

There remains a disconnect and degree of tension between satellite and in situ measurements. With some notable exceptions satellite and in situ measurements generally compete for funding rather than work together. Satellite governance typically is also separated from in situ governance.

References:

Sterckx, S., I. Brown, A. Kääb, M. Krol, R. Morrow, P. Veefkind, K.F. Boersma, M. De Mazière, N. Fox and P.W. Thorne. 2020: Towards a European Cal/Val service for earth observation, International Journal of Remote Sensing, 41:12, 4496-4511, DOI: 10.1080/01431161.2020.1718240

Action A32:	**Fundamental Climate Data Records and Climate Data Records for greenhouse gas and aerosols ECVs**
Action	Extend and refine the satellite data records (FCDRs and CDRs) for GHG and aerosol ECVs
Benefit	Improved record of GHG concentrations
Who	Space agencies
Time frame	Ongoing
Performance indicator	Availability of updated FCDRs and CDRs for GHGs and aerosols
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

During the recent years significant advances have been made in space-based observations of greenhouse gases allowing advances in developing CDRs and FCDRs. First merged global multi-satellite data records of aerosol optical depth have been created.

Action A33:	**Maintain WMO GAW CO_2 and CH_4 monitoring networks**
Action	Maintain and enhance the WMO GAW Global Atmospheric CO_2 and CH_4 monitoring networks as major contributions to the GCOS Comprehensive Networks for CO_2 and CH_4. Advance the measurement of isotopic forms of CO_2 and CH_4 and of appropriate tracers to separate human from natural influences on the CO_2 and CH_4 budgets
Benefit	A well-maintained, ground-based and in situ network provides the basis for understanding trends and distributions of GHGs.
Who	National Environmental Services, NMHSs, research agencies, and space agencies under the guidance of WMO GAW and its Scientific Advisory Group on Greenhouse Gases
Time frame	Ongoing
Performance indicator	Data flow to archive and analysis centres
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Provision of atmospheric CO_2 and CH_4 concentration levels measured by the GAW network has been maintained and consolidated worldwide although the Isotope data is still not available optimally.

The GAW Programme coordinates systematic worldwide observations and analysis of CO_2 and CH_4 and measurement data are reported by participating countries / organisations and archived and distributed by the WMO World Data Centre for Greenhouse Gases (WDCGG). Recommendations for the quality of greenhouse gas observations were reviewed at 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) in 2019 and are published as GAW Report (https://library.wmo.int/doc_num.php?explnum_id=10353).

The in situ measurement network has been maintained and consolidated over the current implementation period. High-quality, ground-based observations of CO_2 and CH_4 are mainly provided by the ICOS network (in Europe), and by NOAA's Global Greenhouse Gas Reference Network which includes a global array of flask sampling sites and less dense networks of in situ measurements at the surface, from tall towers, and from aircraft and by many other institutions listed under "contributors" at https://gaw.kishou.go.jp/documents/db_list/organization. Tropospheric profiles of CO_2 and CH_4 are also obtained by the IAGOS Research infrastructure of in situ measurements from long-haul commercial aircraft, though these observations suffered a substantial reduction in 2020 due to COVID-19 air travel restrictions. Establishing ICOS, and to a lesser degree IAGOS as pan-European research infrastructures has been essential to consolidating and enhancing the provision of CO_2 and CH_4 data. This should not hide that many observation sites outside of the two main providers are struggling with sustainability issues. Provision of CO_2 and CH_4 concentrations measured on tall towers, near-surface and from aircraft are essential to improve knowledge of GHG emissions. The measurement of CO_2 and CH_4 isotopes and of appropriate tracers, are required to separate human from natural influences on the CO_2 and CH_4 budgets. These measurements are regularly performed as part of NOAA and ICOS networks but Isotope data is still not available optimally from WDCGG.

Technical difficulties linked to machine-to-machine access to WDCGG also limit the provision of data in Near-Real-Time, as required for some applications. NRT data are accessible through ICOS and NOAA, however. NOAA and ICOS together now provide up to date (meta)data in netcdf-cf format for CO_2 and CH_4 as Globalview Obspack products.

Action A34:	**Requirements for in situ column composition measurements**
Action	Define the requirements for providing vertical profiles of CO_2, CH_4 and other GHGs, using recently emerging technology, such as balloon capture technique[58]
Benefit	Ability to provide widespread, accurate, in situ vertical profiles economically; an excellent tool for validating satellite retrievals and improving transport models
Who	GCOS AOPC and space agencies
Time frame	Requirements to be defined by 2018
Performance indicator	Update to Annex A to include vertical profiles and XCO_2 (the dry-air column-averaged mole fraction of CO_2)
Annual cost	US$ <5 million

[58] E.g. AirCore

Assessment: 5 – Complete.

Requirements have been defined, and several balloon-borne AirCore programs are now operational in the US and Europe, providing high-quality vertical profile measurements of CO_2, CH_4, N_2O, some halocarbons, SF_6 and other GHGs.

Recommendations for the emerging techniques are summarized in the GGMT-2019 report[59].Measurement requirements for column in situ measurements have been defined by GCOS AOPC as part of a broader reworking of composition ECVs. These will be articulated in the forthcoming 2022 Implementation Plan.

Several balloon-borne AirCore programs are now operational in the US and Europe, providing high-quality vertical profile measurements of CO_2, CH_4, N_2O, some halocarbons, SF_6 and other trace gases. These measurements meet ECV threshold requirements for vertical resolution (with altitude-dependent vertical resolution of 0.1 to 1 km), accuracy and stability but are severely inadequate in horizontal and temporal resolution.

An AirCore autonomously samples the partial atmospheric column from the middle stratosphere to the surface, where the sampler must be recovered and analysed within a few hours to prevent molecular diffusion from eroding the vertical resolution of the collected sample. Additional tracking devices are suggested to aid in quickly locating a payload after it lands.

In some locations, the weight and/or density of the AirCore payload exceed(s) the limit(s) for exempted meteorological balloon payloads, requiring that local civil aviation authorities are notified a day or more prior to launch. Additional hardware designed to increase the detectability of balloons, including radar reflectors, transponders or flashing lights (at night) may be required to broadcast the balloon's presence to nearby aircraft.

The construction and automation of an AirCore is straightforward and somewhat dependent on the target gases to be measured. The analysis performed on the captured air is the real challenge.

The cost of a basic AirCore sampler unit is approximately US$ 5000 but can increase significantly if an extra-long Core and/or specially-coated tubing is required. Safety and tracking devices like an Automatic Dependent Surveillance – Broadcast (ADS-B) system or Iridium system can add another US$ 5000. Costs of the analysis system used to measure the Core are not included in these figures.

Action A35:	Space-based measurements of CO_2 and CH_4 implementation
Action	Assess the value of the data provided by current space-based measurements of CO_2 and CH_4, and develop and implement proposals for follow-on missions accordingly
Benefit	Provision of global records of principal greenhouse gases; informing decision-makers in urgent efforts to manage GHG emissions
Who	Research institutions and space agencies
Time frame	Assessments are ongoing and jointly pursued by research institutions
Performance indicator	Approval of subsequent missions to measure GHGs

[59] https://library.wmo.int/doc_num.php?explnum_id=10353

Annual cost	US$ 30–100 million

Assessment: 4 – Progress on track.

Major advances have been made in space-based observations of CO_2 and CH_4 during the recent years and the needs for future observations have been formulated in the CEOS report: Constellation architecture for monitoring carbon dioxide and methane from space, 2018.

The number of satellites measuring total column CO_2 (or more specifically column-averaged dry air mole fraction of CO_2, typically denoted as XCO_2) is increasing steadily at the moment (GOSAT, OCO-2, GOSAT-2, TanSat, OCO-3). The OCO-2 XCO_2 observations have been shown to agree with 0.5 ppm (0.1%) median bias and 1.5 ppm (0.4%) RMS difference with ground based FTIR observations after bias correction (Wunch et al, Atmos. Meas. Tech., 10, 2209–2238, 2017). Despite the fact that none of the present instruments has dense spatial coverage, the small pixels (of the order of few km by few km) already demonstrate capabilities for detecting emission signatures.

The need for improved coverage and wide swaths for detecting CO_2 emissions have driven the observation requirements of the future instruments, including CNES/MicroCarb (2022 expected launch), geostationary GeoCARB, and EU&ESA/CO_2M with planned launch in 2025 (noting that funding from EU is still pending but the mission is recognized as Copernicus high priority candidate mission).

The total column CH_4 observations (or more specifically column-averaged dry air mole fraction of CH_4, typically denoted as XCH_4) have also improved significantly during recent years as Sentinel 5P/TROPOMI was launched to complement GOSAT (2009->) and GOSAT-2 (2018->). Sentinel 5P has global daily coverage of the sunlit part of the globe with relatively small pixels of 5.5 x 7 km. The GOSAT CH_4 observations agree well with ground based TCCON measurements, with a 6 ppb (0.3%) bias and 13 ppb (0.7%) standard deviation (Yoshida et al., 2013). Future missions measuring methane include active lidar mission MERLIN (launch expected in 2025) which will provide CH_4 profiles and also cover regions with little or no sunlight which nadir-looking SWIR instruments are missing.

The important role of satellite instruments in providing top-down verification capacity for greenhouse gas stocktake, as defined by the Paris agreement, has been recognized by the space agencies and resulted in the CEOS report: Constellation architecture for monitoring carbon dioxide and methane from space, 2018. Several other documents (most importantly EU reports on CO_2: Blue report, Red report and Green report) have also highlighted these developments.

- CEOS report: Constellation architecture for monitoring Carbon Dioxide and Methane from Space, 2018
  - http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Publication_Draft2_20181111.pdf
- Blue Report, 2015: Towards a European Operational Observing System to Monitor Fossil CO_2 emissions
  - https://www.copernicus.eu/sites/default/files/2019-09/CO_2_Blue_report_2015.pdf
- Red Report, 2017: Baseline Requirements, Model Components and Functional Architecture

- o https://www.copernicus.eu/sites/default/files/2019-09/CO2_Red_Report_2017.pdf

References:

Yoshida et al., 2013: Improvement of the retrieval algorithm for GOSAT SWIR XCO_2 and XCH_4 and their validation using TCCON data, Atmospheric Measurements Techniques, 6, 1533–1547, https://doi.org/10.5194/amt-6-1533-2013

Action A36:	N_2O, halocarbon and SF_6 networks/measurements
Action	Maintain networks for N_2O, halocarbon and SF_6 measurements
Benefit	Informs the parties to the Montreal Protocol, provides records of long-lived, non-CO_2 GHGs and offers potential tracers for attribution of CO_2 emissions.
Who	National research agencies, national environmental services, NMHSs, through WMO GAW
Time frame	Ongoing
Performance indicator	Data flow to archive and analysis centres
Annual cost	US$ 30–100 million

Assessment: 5 – Complete.

The global and regional networks of in situ and/or flask sample measurements of N_2O, halocarbons and SF_6 have been maintained, while some have improved through site expansion and/or measurement technology enhancements.

The stations reporting respective data can be found under https://gaw.kishou.go.jp/documents/db_list/organization. GAW coordinated observations of N_2O are recognized a GCOS Global Baseline Observing Network and as Global Comprehensive Observing Network.

There are a number of independent networks that contribute to these globally coordinated efforts and that measure nitrous oxide (N_2O), halocarbons, and sulfur hexafluoride (SF_6), or a subset of these gases, in situ and/or through flask collections and analyses. NOAA's Global Greenhouse Gas Reference Network (GGGRN) and the Advanced Global Atmospheric Gases Experiment (AGAGE) are global in coverage, while networks of the University of California – Irvine, the University of East Anglia and Europe's Integrated Carbon Observing System (ICOS) provide data at more regional scales. There are still substantial spatial gaps in the network coverage.

All of these networks have remained stable in terms of infrastructure and financial support. Some have even increased their number of sites and/or the numbers of ozone-depleting, greenhouse or other trace gases measured. The networks are cooperative in nature and complement one another in enabling direct comparisons of data records at sites where two or more networks overlap, and in verifying data features observed at one site with those at another site. Some sites are remotely located to sample the background atmosphere while others are purposefully situated where they can sample regionally integrated emissions.

N_2O is both a greenhouse gas and an ozone depleting substance that is emitted from both natural and anthropogenic sources. It is currently the third strongest human-emitted contributor to radiative forcing behind carbon dioxide and methane. Measurements are made in situ and in stored air samples (flasks), mainly by gas chromatography, but now also by optical techniques such as laser spectroscopy. The global coverage of network sites providing N_2O mole fraction data is adequate to determine trends at regional to global scales, but only with higher spatiotemporal density in situ measurements like those provided by ICOS can process studies be performed.

Each of these networks also measure 30+ halocarbons, including substances banned by the Montreal Protocol, their replacements, and now the replacements for the replacements. Gas chromatography is again the main analytical method for halocarbons, with cryo-focusing (pre-concentration) of samples and mass-selective detectors allowing the detection of sub-parts per trillion mole fractions for some. Halocarbon networks were initially developed to track the increasing trends of ODSs with concern for the stratospheric ozone layer, but now there is also substantial interest in verifying that banned ODSs are no longer produced, as well as monitoring replacement gases with high Global Warming Potentials (GWPs). Recently, emissions of CFC-11 likely associated with unauthorized production, long ago banned by the Montreal Protocol, were detected by network measurements and traced back to southeast Asia.

SF_6 is measured by most of these networks, either in situ, or from grab samples, or both. It is a very long-lived, purely anthropogenic greenhouse gas with a GWP some 24,000 times that of CO_2. Nearly all the SF_6 ever emitted still remains in the atmosphere. The dominant measurement technique for SF_6 is gas chromatography. As with N_2O, the network measurements of SF_6 are used to determine large-scale trends, but only a dense network of measurement sites is sufficient for smaller scale emission studies. SF_6 is also useful as a tracer of atmospheric transport and has been used to validate and improve transport models. Similar applications have also been used to study ocean circulation as SF_6 is soluble.

Action A37:	**Ozone network coverage**
Action	Urgently restore the coverage the extent possible and maintain the quality and continuity of the GCOS Global Baseline (profile, total and surface level) Ozone Networks coordinated by WMO GAW.
Benefit	Provides validation of satellite retrievals and information on global trends and distributions of ozone.
Who	Parties' national research agencies and NMHSs, through WMO GAW and network partners, in consultation with AOPC
Time frame	Ongoing.
Performance indicator	Improved and sustained network coverage and data quality
Annual cost	US$ 1–10 million

Assessment: 2 – Started but little progress.

Due to lack of funds, minimal restoration of the ozone network stations lost since 2010 has occurred.

This action is related to recent and ongoing loss of long-term ozone observations at a number of key sites. While there has been no substantial further network degradation the majority of the sites that were lost in the early parts of the 2010s have not been restored.

Various activities were carried out by GAW Programme to maintain the ozone observing network with no directly visible progress. Demands for training, instrument service and calibration, and financial help within the aging observing network exceed available resources within individual countries and those available for international support within GAW and UNEP. Important components of the GAW effort were to maintain the quality of data and their submission to WOUDC (World Ozone and Ultraviolet Radiation Data Centre) by active stations, to facilitate restarting of suspended observations and to facilitate the initiation of observations at priority stations where long-term commitment for ozone measurements exist. Activities which received significant support were prioritized in cooperation with the ozone scientific community, Ozone Secretariat of UNEP and some individual national programs. Capacity building was identified as a major factor for sustaining the ozone observing network for the GAW programme and was supported in a number small targeted and large events and activities. Opportunities for GAW to support the transportation and repairs of instruments to resume ozone observations or the relocation of instruments to priority sites were also explored. Under implementation was the relocation of two Brewer instruments donated by the Canadian government, and a call for hosts of available Dobson instruments was issued on the GAW website in September 2020 and distributed through different GAW and UNEP channels. In parallel to those activities, the reference instruments of individual networks were intercompared. Those campaigns included activities dedicated to instruments inter-comparison, service, calibration and training sessions on operation, service and data processing. An important work of the GAW ozonesonde community towards harmonizing ozonesondes records was completed in 2020 and subjected to peer review. Reports detailing results from inter-comparison campaigns and ozonesondes' quality assurance and quality control review have been published or are being published and are available through WMO online library. A capacity-building initiative on data management and instrument calibration for WMO RA-I was designed and implemented in 2018 and 2019 to strengthen the technical and scientific expertise required to maintain high quality measurements, data processing and analysis. This activity was coordinated by the GAW office and implemented in two phases involving staff of the Kenya Meteorological Department (KMD) and MeteoSwiss. The calibration and servicing of ozone monitoring instruments, relocation of 2 Brewer instruments and commencement of long-term observations, the implementation of an already started ozonesonde project in Ecuador, and multiple inter-comparison, calibration, service and training events planned or coordinated by GAW in 2020 and 2021 were cancelled, suspended or postponed due to the COVID19 pandemic. Those factors, along with reported suspensions of observations and the toll of economic hardship are expected to strongly affect the health of the network and data availability since early 2020.

Action A38:	**Submission and dissemination of ozone data**
Action	Improve timeliness and completeness of submission and dissemination of surface ozone, ozone column and profile data to users, WDCGG and WOUDC
Benefit	Improves timeliness of satellite retrieval validation and availability of information for determining global trends and distributions of ozone.
Who	Parties' national research agencies and services that submit data to WDCGG and WOUDC, through WMO GAW and network partners.
Time frame	Ongoing
Performance indicator	Network coverage, operating statistics and timeliness of delivery.
Annual cost	US$ 100 000–1 million

Assessment: 3 Underway with significant progress.

Several activities were developed and implemented, leading however to small improvement in terms of data submission. Discoverability and access have improved through the Copernicus Data Store and the NextGEOSS

A number of activities were developed and implemented by GAW to advance this action item with results that do not necessarily reflect the invested efforts because of multiple factors including the COVID19 pandemic. The GAW secretariat worked with managers of ozone observation stations and the station/network PIs to improve data submission in 2019 and 2020. A number of stations which were behind in data submissions, including those important for satellite validation, were contacted. As part of their routine work, WOUDC and WDCGG issue an annual call for data submissions to all station contacts. WOUDC activities in 2019-20 include the quality assurance of data, providing feedback about problems with submission to data contributors, the full reporting to contributors about any identified issues with the format conformity of data and metadata with what was addressed by follow up actions, files verification and acceptance reports. Delays in the submission of ozonesonde data by stations were communicated to the ozonesonde community to facilitate specialized assistance where needed. A couple of issues causing the delays in data submission were identified and guidance was provided to stations experiencing difficulties with the submission process itself. Training and refresher activities which were designed to be part of ozone measurement inter-comparison campaigns in 2018 and 2019, along with the ongoing support by Regional Centers, are expected to maintain data processing and submission capacity within the GAW monitoring network. A number of activities were undertaken to improve data discoverability and access. Ozone total column and ozone profile data from ozonesonde stations within WOUDC were integrated in Copernicus Climate Data Store in 2020. Discoverability of ozone and UV data from WOUDC and WDCRG (World Data Centre for Reactive Gases) and GHG from WDCGG was also improved through the federated data hub NextGEOSS. A decision was made to move towards a single data format for collaboration between databases providing ozone data based on a single format and single submission. The Data Center InterOperability (DCIO) approach that was considered to be the most sustainable for the future and offered preventions for data storage duplication and the mix-up of data versions. Federated search on ozone data became operational in 2019 and members were extended in 2020. Efforts were put in for 10 months in 2020 to align metadata with the WIGOS metadata standard and to update OSCAR GAW information. A comprehensive assessment of ozonesonde QA-QC protocols, data and metadata was carried out, and a set of recommendations guiding those, including a start in reporting measurement uncertainties and expanded metadata, was completed and will be published as a WMO Report in 2021. In addition to this assessment, a number of inter-comparison field campaigns and laboratory work, calibration activities and other laboratory work had been performed to ensure high quality and compatibility of ozone and GHG observations for assessments and trend analyses. Tools which could facilitate machine-to-machine access for WOUDC and WDCGG now exist, with a demonstration and some training on their use provided, along with the other GAW relevant activities, under the Expert Team of Atmospheric Composition Data Management. These are expected to lead to improved data dissemination, searchability and discoverability. GHG data from WDCGG had been systematically analysed and broadly disseminated through WMO GHG bulletins. To view the latest one, please see: https://library.wmo.int/doc_num.php?explnum_id=10437.

Action A39:	**Monitoring of aerosol properties**
Action	Provide more accurate measurement-based estimates of global and regional direct aerosol radiative forcing (DARF) at the top of the atmosphere and its uncertainties, and determine aerosol forcing at the surface and in the atmosphere through accurate monitoring of the 3D distribution of aerosols and aerosol properties. Ensure continuity of monitoring programs based on in situ ground-based measurement of aerosol properties.
Benefit	Reducing uncertainties in DARF and the anthropogenic contributions to DARF, and the uncertainty in climate sensitivity and future predictions of surface temperature. Better constraints on aerosol type needed for atmospheric correction and more accurate ocean property retrieval than currently available.
Who	Parties’ national services, research agencies and space agencies, with guidance from AOPC and in cooperation with WMO GAW and AERONET
Time frame	Ongoing, baseline in situ components and satellite strategy is currently defined.
Performance indicator	Availability of the necessary measurements, appropriate plans for future
Annual cost	US$ 10–30 million

Assessment: 4 – Progress on track.

Improved provision of 3-D climate-relevant aerosol data worldwide has led to improved observationally-derived estimates of direct aerosol radiative forcing; better knowledge of global aerosol distribution from space-borne sensors together with better coverage and a more reliable provision of ground-based aerosol variables has improved capacity to assess the role of aerosols as climate-forcing agents.

Generally, the global observation system for aerosol ECVs has further improved in the past decade thanks to both availability of new satellite-based observations and the development of the in situ observations from the ground and from commercial aircraft. In addition, efforts to promote access to information and development of interoperable information systems have facilitated access to data and data products retrieved from space, ground and aircraft-based observations.

A consequence of this is the capacity to produce observationally derived estimates of the magnitude of direct aerosol radiative forcing with much improved quality compared to previous estimates. These permit consideration of geographical variations of the aerosol forcing estimates.

The wide spatial coverage of space-borne sensors generally provides sufficient information meeting threshold requirements for most ECV products that are suited for many applications (evaluations, analyses); however, smaller retrieval areas should be explored in future satellite missions. Space-borne sensors provide global coverage but at low repeat measurement frequency which are complemented in many regions (but not all) by a dense ground-based network for AOD and derived products retrieval.

The aerosol in situ observing system is still a collection of different networks and very different governing structures with limited interactions between them. However, continuity of the different programs has been maintained and, in some regions, consolidated by the establishment of research infrastructures such as ACTRIS or IAGOS. Spatial coverage is greatly improved in several regions (North America, Europe, some parts of Asia) for several ECVs. AERONET and other AOD networks (e.g. Skynet, PFR) provide a dense network of observations over land. For other ECVs, despite the fact that NOAA-FAN (US), and ACTRIS and IAGOS (Europe) have extended their networks beyond US and Europe, many areas in the world remain undersampled and data access remains an issue.

A smart use of in situ observations, space observations and models may compensate for sparseness and limitations of information on vertical distribution, but this only applies to regions where lidar networks are operational with seamless access, as in the United States and Europe. Access to vertical profiles remains a limiting factor to a global aerosol observing system.

The development of the in situ observing system for Aerosol ECV products has been paralleled with great efforts to ensure traceability of provenance of data, joint data management procedures and data policies. The information system remains, however, managed regionally, and in some countries/regions, operated by different research organisations, leading to difficulties to fully respond to user requirements of an integrated observing system. There is a lot of attention paid to aerosol in the context of health and substantial extension of the networks was made through the utilization of the low-cost sensor that do not meet requirements for the climate monitoring.

Record length of aerosol products should be at least 10 to 15 years for trends to be derived. Continuity of operations and consistency in the time series for both space-based and in situ observing systems are key to many downstream applications and must remain high on the agenda.

Action A40:	Continuity of products of precursors of ozone and secondary aerosols
Action	Ensure continuity of products based on space-based, ground-based and in situ measurements of the precursors (NO_2, SO_2, HCHO, NH_3 and CO) of ozone and secondary aerosol and derive consistent emission databases, seeking to improve spatial resolution to about 1 x 1 km^2 for air quality
Benefit	Improved understanding of how air pollution influences climate forcing and how climate change influences air quality.
Who	Space agencies, in collaboration with national environmental agencies and NMHSs
Time frame	Ongoing
Performance indicator	Availability of the necessary measurements, appropriate plans for future missions, and derived emission databases
Annual cost	US$ 100–300 million

Assessment: 2 – Started but little progress.

While considerable advances in the spatial resolution of the observations of ozone and secondary aerosols from space have been made, the goal of achieving spatial resolution of 1x1 km is still far in the future.

Ozone and aerosol precursors can be measured from space using UV-VIS-SWIR wavelengths in nadir mode. The Ozone Monitoring Instrument (OMI, 2004 ->) has measured SO_2, NO_2 and HCHO with 24x13 km pixels at best. The GOME-2 instruments (2006->, 2012->, 2018->) have similar observation capabilities with slightly worse horizontal resolution. A clear improvement in the spatial resolution was made with Sentinel 5 Precursor/TROPOMI, which measures NO_2, SO_2 and HCHO at a resolution of 3.5 x 5.5 km and CO at 7 x 5.5 km.

By using a so-called oversampling technique, temporal averages of the gases can be obtained with higher spatial resolution than the original measurements. This comes, however, at the price of reduced temporal sampling.

The EU&ESA Copernicus High Priority CO_2 Monitoring Mission, CO_2M, is planning to make observations of NO_2 at 2 x 2 km spatial resolution to support detecting CO_2 emission plumes since the signature of NO_2 emissions originating from same source is easier to detect from the background due to its shorter lifetime. If the mission is funded the launch is expected in 2025.

Ground-based measurements of these precursor gases are difficult due to their low abundances, especially in remote locations far from sources. Except for CO, these precursors are typically measured by remote-sensing instruments because the requisite sample handling for in situ measurements and/or sample storage for flask measurements can be detrimental to sample integrity. The preferred ground-based measurement techniques are spectroscopic with a long pathlength, generally utilizing the sun as the light source such as the FTIR technique. Ground-based sites making such measurements are spatially sparse, and their data should be considered complementary to space-based measurements, especially to monitor and detect any biases or drifts in the satellite retrievals of these gases.

Use of in situ observations to derive emission inventories remain limited in geographical and spatial coverage.

However, there are substantial efforts done by AMIGO activity https://igacproject.org/activities/amigo.

B.c Ocean

Action O1:	Coordination of enhanced shelf and coastal observations for climate
Action	Assess existing international, national and regional plans that address the needs to monitor and predict the climate of coastal regions and develop plans where they do not exist.
Benefit	Detailed specific observational requirements in the coastal regions for improved understanding, assessment and prediction of the impact of climate on the coastal environment
Time frame	2026, with interim assessment of progress by 2021
Who	GOOS, GRAs, JCOMM OCG
Performance indicator	An internationally recognized coordination activity
Annual cost	US$ 10–30 million

Assessment: 3 – Underway with significant progress.

OOPC Boundary Currents Task Team is working to establish a best practices guide for how to monitor climate-relevant shelf to deep ocean exchanges across these dynamic systems.

OOPC and CLIVAR are co-sponsoring a workshop for 2022 "From Global to Coastal: Cultivating new solutions and partnerships for an enhanced ocean observing system in a decade of accelerating change."

The OceanObs19 conference developed numerous papers addressing the status and needs for coastal ocean observations. Many of these initiatives are coming together in the Ocean Decade project CoastPredict, which will also address climate-relevant observations.

Moreover, GOOS integration between open ocean and coast will be a programme of the Ocean Decade.

Action O2:	Integration and data access
Action	Improve discoverability and interoperability, comparability and traceability of ocean observations among ocean observing networks for all ECVs (including ECVs of other domains).
Benefit	Improved access to data, ease of integration across data sources
Timeframe	Continuous
Who	Parties' national research programmes and data-management infrastructure, OOPC, International Ocean Carbon Coordination Project (IOCCP), the WCRP Data Advisory Council (WDAC), JCOMM Data Management Programme Area (DMPA), GEO Blue Planet
Performance indicator	Timely and open access to quality-controlled observational data
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

FAIR data work is progressing from the supplier side (GOOS Observations Coordination Group networks, largely for physical and biogeochemical ocean ECVs) and the data management side (steps towards the proof of concept of an Ocean Data and Information System). However, only one third of sustained biological ECV data is freely available

Action O3:	**Data quality**
Action	Sustain and increase efforts for quality control and reprocessing of current and historical data records
Benefit	Improved quality of ocean climate data
Timeframe	Continuous.
Who	Parties' national ocean research agencies and data-management infrastructure, supported by JCOMM DMPA, IODE, WCRP CLIVAR Project
Performance indicator	Improved record of uniform quality control
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Synthesis efforts for physical and biogeochemical ECVs are creating improved ECV data products, but best practice efforts and uptake need improvement.

Action O4:	**Development of climatologies and reanalysis products**
Action	Maintained research and institutional support for the production of ocean gridded data products and reanalysis products, and coordinated intercomparison activities
Benefit	Improved quality and availability of integrated ocean products for climate change detection and validation of climate projections and initialization of weather- and marine-forecasting models
Timeframe	Continuous
Who	Parties' national research programmes and operational agencies, WCRP-CLIVAR GSOP, GODAE OceanView and the JCOMM Expert Team on Operational Ocean Forecasting (ETOOFS), IOCCP
Performance indicator	Regular updates of global ocean synthesis products
Annual cost	US$1–10 million

Assessment: 4 – Progress on track.

Global ocean synthesis and reanalysis products are being regularly updated and are widely used by the scientific community in evaluations of climate variability and change.

Action O5:	Sustained support for ocean observations
Action	Strengthen funding of the ocean observing system to move towards a more sustained long-term funding structure and broaden support by engaging more agencies and nations in sustained ocean observing through capacity building
Benefit	A more resilient observing system that is less exposed to changes in national research priorities.
Timeframe	2026
Who	Parties' national research programmes, funding streams and operational agencies, capacity building through the Partnership for Observations of the Global Ocean (POGO).
Performance indicator	Observing system performance indicators continuously at or above 90%, increasing number of agencies and nations contributing to sustained observing.
Annual cost	US$30–100 million

Assessment: 2 – Started but little progress.

Funding for sustained ocean ECV observing activities remain fragile, largely funded by research projects. For example, subsurface T/S profiles from Argo are funded 5% from meteorological agencies with operational budgets, and 95% from ocean research agencies.

Action O6:	Technology development
Action	Continued support for development of satellite capabilities, autonomous platforms and climate-quality sensors, from pilot phase to mature stage
Benefit	Continued improvements to the sustained observing system to fill gaps, take new measurements, at lower cost per observation.
Time frame	Continuous
Who	National research programmes supported by the GOOS expert panels, CEOS Constellations Teams, JCOMM Ocean Coordination Group (OCG)[60] and user groups.
Performance indicator	Amount of climate-quality data provided in near-real time to internationally agreed data centres
Annual cost	US$ 10–30 million

Assessment: 4 – Progress on track.

Satellite, in situ sensor and platform technology innovation continue to be supported through the research enterprise and by private sector investment (not identified as an actor in the GCOS-IP 2016).

[60] After the dismantling of JCOMM, the Ocean Coordination Group became integrated in GOOS.

Action O7:	Observing system development and evaluation
Action	Support and engage in systems-based observing system development projects established through GOOS as detailed in this Plan and efforts for the ongoing evaluation of the observing system
Benefit	Continued improvements to the sustained observing system ensure it is robust, integrated and meets future needs.
Time frame	Continuous
Who	National research programmes supported by GOOS expert panels and regional alliances
Performance indicator	Periodic evaluation of observing system against requirements and expansion of support for sustained observations
Annual cost	US$ 100 000–1million (mainly to Annex I Parties).

Assessment: 3 underway with significant progress.

OOPC has joined the OceanPredict OSEval Task Team to use OSEs and OSSEs to evaluate the mature systems of GOOS.

The OOPC Task Teams are evaluating observation capacity and developing implementation strategies for climate observations with a) the earth system (ocean heat and freshwater transport), b) the air-sea interface, and c) the coastal to open ocean interface (boundary systems).

The GOOS Steering Committee has approved a GOOS-level task team to establish authoritative guidance and guidelines for system reviews based on recent regional and/or thematic reviews carried out in TPOS2020, TAOS and the IndOOS system.

Action O8:	Satellite sea-surface temperature product development
Action	Continue the provision of best possible SST fields based on a continuous coverage mix of polar orbiting (including dual view) and geostationary IR measurements, combined with passive MW coverage, and appropriate linkage with the comprehensive in situ networks
Benefit	Global routine calibrated mapping of SST for climate monitoring and weather and subseasonal to seasonal prediction systems
Time frame	Continuous
Who	Space agencies, coordinated through Global High Resolution Sea Surface Temperature Project (GHRSST). CEOS, CGMS and WMO Space Programme.
Performance indicator	Agreement of plans for maintaining a CEOS Virtual Constellation for SST, ongoing satellite operation, routine delivery of SST products
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

A constellation of satellite SST sensors is providing high quality blended SST products over most of the global ocean

The constellation of satellite SST sensors include polar orbiting and geostationary satellites, infrared and passive microwave radiometry, providing high quality blended SST products over most of the global ocean that satisfy the temporal and spatial resolution requirements, calibrated by or blended with SST measurements from the in situ networks. Polar ocean SST measurements are of lesser quality. The resolution of SST in cloudy region is limited to the resolution of passive microwave sensors (~50 km).

Action O9:	Upper-ocean temperature observing system
Action	Maintain a global upper ocean (0-2000 m) temperature observing system for the assessment of ocean temperature and heat content change and its contribution to sea-level rise
Benefit	High-quality ocean temperature time series for accurate estimates of annual ocean heat storage as a function of depth and its spatial distribution to assess the role on the ocean in the Earth's energy balance and ocean warming contribution to sea-level change
Time frame	Continuous
Who	Parties' national agencies working with GOOS observational networks (Drifters, CEOS, Argo, SOOP, OceanSITES), in cooperation with the Observations Coordination Group of JCOMM.
Performance indicator	Spatial coverage, interoperability of observations platforms, annually updated global upper-ocean temperature records
Annual cost	US$ 30–100 million

Assessment: 3 underway with significant progress.

Targets for drifters and Argo have been exceeded, however COVID-19 restrictions meant that the majority of Ship Of Opportunity Programme (SOOP) XBT profiles stopped[61].

[61] https://www.ocean-ops.org/reportcard2020/

Action O10:	Full-depth temperature observing system
Action	Develop and begin implementation of a full-depth ocean temperature observing system to support the decadal global assessment of the total ocean heat content and thermosteric sea-level rise
Benefit	High-quality, deep-ocean temperature time series for accurate estimates of biennial to decadal ocean heat storage below 2000 m and its spatial distribution to assess the role of the ocean in the Earths energy balance and ocean-warming contribution to sea-level change
Time frame	Observational system in place by 2026
Who	Parties, national agencies working with GOOS observational networks (Argo, GO-SHIP, OceanSITES), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Design study completed and targeted implementation begun; spatial coverage, interoperability of observations platforms
Annual cost	US$ 30–100 million

Assessment: 2 – Started but little progress.

The number of deep Argo floats has increased, however GO-SHIP repeat hydrography lines and OceanSITES full depth moorings, both largely dependent on research vessels, faced challenges in 2020 due to COVID-19.

Action O11:	Ocean salinity observing system
Action	Maintain and grow a global ocean salinity observing system for the assessment of ocean salinity and freshwater content change and its contribution to global hydrological cycle
Benefit	High-quality ocean salinity time-series for accurate estimates of annual (0-2000 m) to decadal (below 2000 m) ocean freshwater changes and its spatial distribution to assess the role on the ocean in the Earths hydrological cycle and contribution to sea-level change. Improved initialisation of weather- and climate forecasting systems
Time frame	Continuous.
Who	Parties' national agencies working with GOOS observational networks (CEOS, SOOP, Argo, GO-SHIP, OceanSITES), in cooperation the Observations Coordination Group.
Performance indicator	Spatial coverage, interoperability of observations platforms' annually updated global ocean salinity records
Annual cost	US$ 30–100 million (10% in non-Annex I Parties)

Assessment: 3 underway with significant progress.

Salinity observations have largely been maintained but have not grown. Records remain too short to estimate decadal changes.

Action O12:	Ocean current gridded products
Action	Maintain gridded ocean-surface and subsurface current products based on satellite, drifting-buoy and Argo programme, other observations and data-assimilating models
Benefit	High-quality ocean-current observations for climate services and marine operational systems
Time frame	Continuous
Who	Parties' national agencies working with CEOS, GOOS observational networks (SOOP, Argo, GO-SHIP. OceanSITES, Drifters) in cooperation with the JCOMM Observations Coordination Group, Godea. OceanView and reanalysis projects.
Performance indicator	Spatial coverage, interoperability of observation platforms
Annual cost	US$ 1–10 million (10% in non-Annex I Parties)

Assessment: 3 underway with significant progress.

The observing systems generating surface and subsurface currents has largely remained stable, and as noted in the ECV overview, adequate for the surface and subsampled for the subsurface.

Action O13:	Sea-level observations
Action	Maintain and develop a global sea-surface-height observing system from observational and satellite networks for annual assessment of sea level and sea-level rise
Benefit	Quality control and accurate global sea level and regional sea-level variability dataset
Time frame	Continuous
Who	Parties' national agencies working with CEOS, GOOS observational networks (e.g. GLOSS), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage, interoperability of observations platforms, annually updated global sea-level data
Annual cost	US$ 30–100 million

Assessment: 3 underway with significant progress

The quantity and quality of sea level observations globally has remained stable, supported in a number of cases by operational use of the data.

Action O14:	Contributing to sea-state climatologies
Action	Maintain and improve the global sea-state observing system from the observational networks to inform wave models/climatologies for assessment of wave climate, its trend and variability and contribution to extremes of sea level; expand observations on surface-reference moorings and drifters
Benefit	Routine observations of wave climate and extremes in support of marine/climate services
Time frame	Continuous
Who	Parties' national agencies coordinated through GOOS, OOPC, GRAs, OceanSITES, DBCP, guidance from the JCOMM Expert Team on Waves and Coastal Hazard Forecasting Systems
Performance indicator	Number of global wave observations available routinely at International Data Centres.
Annual cost	US$ 1–10 million

Assessment: 3 underway with significant progress

Sea state observations are stable but in situ measurements are sparse. An active community (CowClip) is developing climatologies of wind-wave variability and change.

Action O15:	In situ sea-ice observations
Action	Plan, establish and sustain systematic in situ observations from sea ice, buoys, visual surveys (SOOP and aircraft) and in-water upward-looking Sonar (ULS)
Benefit	Long time series for validations of satellite data and model fields; short- and long-term forecasting of sea ice conditions; ocean-atmosphere-sea ice interaction and process studies
Time frame	Integrated Arctic Observing System design and demonstration project funded by EU for 2017–2020
Who	National and international services and research programmes, Copernicus; coordination through Arctic Council, EU-PolarNET, Arctic-ROOS (in EuroGOOS), CLIVAR, CLIC, JCOMM, OOPC
Performance indicator	Establishment of agreement and frameworks for coordination and implementation of sustained Arctic (EU-PolarNet and Arctic-ROOS, which will be extended with the new funded project (see time frame)) and Southern Ocean observations (SOOS)
Annual cost	US$ 30–100 million

Assessment: 2 started but little progress.

The work of establishing the sustained Arctic Observing System (AOS) is on-going, contributed to by various sources, and funding agencies (e.g. EU). The AOS itself is not in-place and, in any case, the general sentiment is that more must be done (more sensors must be deployed, and better data access must be pursued). The AOS is still being developed on research funds, and this does not help turning it into an operational service.

Action O16:	Ocean-surface stress observations
Action	Develop requirements and review system design (satellite and in situ) for observing OSS ECV and commence implementation
Benefit	Agreed plan for design of surface-stress observing system to improve ocean-surface-stress products
Time frame	Internationally agreed plans published and establish GDACs by 2019
Who	CEOS and in situ networks
Performance indicator	Publication of internationally agreed plans, establishment of agreements/frameworks for coordination according to plan
Annual cost	US$ 100 000–1 million

Assessment: 3 underway with significant progress.

Reviews of the adequacy of this ECV have been carried out on existing platforms but not as a global system.

In situ wind stress measurements meet all accuracy requirements, but coverage is extremely sparse. Mooring wind stress observations meet the hourly sampling requirements. Satellite wind stress meets most resolution requirements (except for hourly sampling for certain phenomena) and some of the accuracy requirements.

Action O17:	Ocean-surface heat-flux observing system
Action	Develop requirements and system design for observing Ocean surface heat flux ECV (utilizing indirect and direct methods) and commence implementation
Benefit	Agreed plan for high-quality heat-flux data required to improve surface flux products
Time frame	Complete programme design and begin implementation of observational system by 2019
Who	GOOS observational networks (CEOS, OceanSITES, SOOP), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Publication of observing network plan; spatial coverage, interoperability of observation platforms
Annual cost	US$ 10–30 million

Assessment: 3 underway with significant progress.

The OOPC Air-Sea Flux task team have developed a proposal to establish an international multi-disciplinary observing system activity called Observing Air-Sea Interactions Strategy (OASIS)[62].

[62] https://airseaobs.org/

Action O18:	Surface ocean partial pressure of CO_2, moorings
Action	Sustain the surface reference mooring pCO_2 network and increase the number of sites to cover all major biogeochemical regions to resolve seasonal cycle
Benefit	Increased information on seasonal and longer variability in key ocean areas
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes
Performance indicator	Flow of data of adequate quality into SOCAT
Annual cost	US$ 1–10 million

Assessment: 3 underway with significant progress.

Flow of surface pCO_2 data into The Surface Ocean CO_2 Atlas (SOCAT) analysis (from moorings and from underway systems) is stable, but the southern hemisphere remains undersampled.

Significant progress has been made in the sense that more and more pCO_2 data from moorings are submitted to, and included in, SOCAT. It should be noted though, that there is still work to do on metadata structure which is suitable for mooring data and still acceptable in SOCAT. Work on this is underway, but slow. While the number of moorings submitting data to SOCAT has increased substantially the past 5 years, these moorings are primarily in North American waters so there is a way to go to cover all major biogeochemical regions.

Action O19:	Building multidisciplinary time series
Action	Add inorganic carbon and basic physical measurements to existing biological timeseries, considering particularly spatial gaps in current observing system, aiming for balanced representation of the full range of natural variability
Benefit	Improved understanding of the regional effects of ocean acidification
Time frame	Continuous
Who	Parties' national research programmes supported by GOA-ON, GOOS Biogeochemistry and Biology and Ecosystems expert panels.
Performance indicator	Flow of data of adequate quality to data centres
Annual cost	US$ 1–10 million

Assessment: 2 started but little progress.

Integration of observations from different oceanographic disciplines in the same place remains a challenge but this has become a major goal for GOOS 2030 IP.

Ocean time series programs in general continue to face many challenges some of which significantly hinder their intended operation and prevent operators from expanding the capacity by for example adding inorganic carbon and/or basic physical measurements to existing biological time-series. These challenges include: (i) unavailability of sustained funding; (ii) varying levels of access to analytical facilities, instrumentation, and technology; (iii) lack of access to training on standardized sampling and analytical approaches, which hinders comparability of data sets across sites; (iv) multiple disconnected databases and interfaces for accessing time series data without a universal set of data and metadata reporting guidelines.

A recent global overview of the uncoordinated ecological time series network, along with a list of biogeochemical and physical measurements, can be found in a 2017 report by IGMETS (http://igmets.net/). Current activities focus on implementing recommendations from several relevant OceanObs'19 community white papers.

Action O20:	**Nutrient observation standards and best practices**
Action	Increase the use of nutrient CRMs on ship-based hydrographic programmes
Benefit	Increased accuracy of nutrient measurements
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes; SCOR working group 147 "Towards comparability of global oceanic nutrient data"
Performance indicator	Increased consistency of nutrient data
Annual cost	US$ 1–10 million

Assessment: 3 underway with significant progress.

Nutrient best practices manual produced by an international working group, and the BP manual has been published and widely used. The use of Certified Reference Materials (CRMs) for nutrients is becoming standard for the GO-SHIP program, and many other high-quality hydrographic campaigns.

Action O21:	Sustaining tracer observations
Action	Maintain capacity to measure transient tracers on the GO-SHIP network. Encourage technological development to encompass additional tracers that provide additional information on ventilation.
Benefit	Information on ocean ventilation and variability in ventilation
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes
Performance indicator	Number of high-quality transient tracer measurements on the repeat hydrography programme
Annual cost	US$ 1–10 million

Assessment: 2 started but little progress.

Tracers remain part of the basic (Level 1) variables recommended for GO-SHIP repeat hydrography lines. In 2020, numerous lines have been delayed due to COVID-19 restrictions, and in general, uncertainty remains high.

There is some technological development on the capacity to measure new transient tracers to increase the range of ventilation ages that can be assessed. The number of labs internationally with capacity to measure transient tracers is declining with possible implications for future GO-SHIP surveys. Several nations carrying out GO-SHIP cruises don't have national capacity but are reliant on cooperation with groups from other countries, sometimes with negative implications for the transient tracer observations.

Action O22:	Develop sustained N_2O observations
Action	Develop an observing network for ocean N_2O observations, with particular emphasis on regions with known high oceanic N_2O production/emission rates
Benefit	Improved estimate of oceanic emissions by improved spatial and temporal coverage; detecting seasonal and interannual variability
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes, SCOR WG 143 Dissolved N_2O and CH_4 measurements: working towards a global network of ocean time series measurements of N_2O and CH_4
Performance indicator	Flow of data of adequate quality into MEMENTO
Annual cost	US$ 1–10 million

Assessment: 2 started but little progress.

The development of intercomparison exercises has proceeded, and N_2O observations are a mature part of GO-SHIP lines, but further development of new observing platforms is required.

N_2O is measured on various research cruises and on a few coastal and open ocean time-series sites. Progress has been made to set up N_2O underway measurement system on VOS (SOOP) lines. Various internal. inter-comparison exercises and the writing of SOPs have been initiated by the SCOR WG #143. SOPs for measurements of N_2O from discrete seawater samples and with continuous underway system are available now. Therefore, the overall quality and comparability of the N_2O concentration measurements will increase in the near future. A concept for a global N_2O ocean observation network has been outlined recently, but realisation is pending (of course).

Action O23:	In situ ocean colour radiometry data
Action	Continue and improve the generation and maintenance of climate-quality in situ OCR data. Develop new high-resolution sensors of high radiometric quality suitable for improving satellite algorithms; validating products; and for characterising product uncertainties, with global coverage and validity (including coastal (Case-2) waters) and at the temporal and spatial scales required by users.
Benefit	Monitoring of changes and variability in ocean colour and derived products
Time frame	Implement plan beyond 2017 after completion of ESA's OC-CCI activities
Who	CEOS space agencies, in consultation with IOCCG and GEO through INSITU OCR initiative of IOCCG, and in accordance with the recommendations contained in the IOCCG INSITU-OCR White Paper (see http://www.ioccg.org/groups/INSITU-OCR_White-Paper.pdf).
Performance indicator	Free and open access to up-to-date, multi-sensor global products for climate research; flow of data into agreed archives
Annual cost	US$ 30–100 million

Assessment: 2 started but little progress.

The IOCCG continues to coordinate a robust work plan through working groups for in situ reflectance in support of remote sensing.

Number of commercially available high quality radiation sensors is limited (e.g. Seabird and Trios. Biospherical has declared bankruptcy this year) and radiative calibration facilities (e.g. NIST in US) are hard and expensive to access. Most sensors are not characterized/corrected for out-of-band response, immersion coefficient and temperature effects on dark currents. Standards for laboratory calibration of hyperspectral radiometers spanning from UV to NIR are not in place. Users mostly rely on manufacturers for characterization and calibration and those are not independently assessed.

Action O24:	Ocean colour algorithm development
Action	Support continued research and technology development to ensure that the best and the most up to date algorithms are used for processing the ocean-colour time-series data in a consistent manner for climate research; to develop product suites suitable for application across wide ranges of water types, including coastal water types; to study inter-sensor differences and minimize them before multi-sensor data are merged; to provide quality assurance and uncertainty characterization of products
Benefit	Improved quality of ocean colour products, particularly in coastal waters and complex water types
Time frame	Implement plan as accepted by CEOS agencies in 2009
Who	CEOS space agencies, in consultation with IOCCG and GEO
Performance indicator	Improved algorithms for a range of water-property types

Assessment: 4 – Progress on track.

IOCCG and CEOS coordinate space agency work in this area.

Recent literature includes many algorithms addressing optically complex water, from correcting the atmospheric contribution to the derivation of products using a variety of novel techniques (most notably machine learning) and being validated on global scales. These algorithms are critical for coastal management, decision support and policy. Most are still in evaluation and have not become operational.

Action O25:	Satellite-based phytoplankton biomass estimates
Action	Establish a plan to improve and test regional algorithms to convert satellite observations to water-column integrated phytoplankton biomass through implementing an in situ phytoplankton monitoring programme. Estimates of uncertainty should be a standard output associated with improved algorithms. Wherever possible, a time series of phytoplankton should be collected simultaneously with the measurement of other important physical and biogeochemical variables.
Benefit	Baseline information on plankton
Time frame	Implementation build-up to 2020
Who	CEOS space agencies, in consultation with IOCCG, including Satellite PFT Intercomparison Project, parties' national research agencies, working with SCOR and GOOS
Performance indicator	Publication of internationally agreed plans; establishment of agreements/frameworks for coordination of a sustained global phytoplankton observing system with consistent sensors and a focused global program of in situ calibration implementation according to plan, flow of data into agreed archives, summary interpreted data products available as well as original data.
Annual cost	US$ 100 000–1 million

Assessment: 2 started but little progress.

Work between ocean colour and modelling communities has improved combined estimates of phytoplankton, but remains limited to the large-scale open ocean.

The GOOS BioEco panel has a 10-year plan for the implementation of the EOV's. Progress will be assessed against this 10-year plan for each ECV. The plankton EOV/ECV is being considered as an indicator in the Convention of Biological Diversity (CBD) post 2020 framework.

Action O26:	**Expand Continuous Plankton Recorder and supporting observations**
Action	Establish plan for, and implement, global CPR surveys, including extension to (sub) tropical areas and integration of data from supporting observation programmes
Benefit	Information on variability and trends in plankton
Time frame	Internationally agreed plans published by end 2019; implementation build-up to 2024
Who	Parties' national research agencies, working with SCOR and GOOS Biology and Ecoystems Panel, IGMETS, Global Alliance of CPR Surveys, OceanSITES
Performance indicator	Publication of internationally agreed plans; establishment of agreements/frameworks for coordination of sustained global CPR surveys supported by repeated surveys at fixed locations; implementation according to plan; flow of data into agreed archives, summary of interpreted data products available
Annual cost	US$ 10–30 million

Assessment: 2 started but little progress.

CPR observations face unstable research funding, however new automated imaging and genomics technologies, as well as new platforms, are anticipated to lead to major changes in the coming 10 years. Progress can be seen at https://www.cprsurvey.org/.

Action O27:	Strengthened network of coral reef observation sites
Action	Strengthen the global network of long-term observation sites covering all major coral-reef habitats within interconnected regional hubs, encourage collection of physical, biogeochemical, biological and ecological measurements, following common and intercalibrated protocols and designs, and implement capacity building workshops
Benefit	Accurate global monitoring of changes in coral-reef cover, health and pressures
Time frame	2016–2020
Who	Parties' national research and operational agencies, supported by GCRMN, GOOS Biology and Ecosystems Panel, GRAs and other partners
Performance indicator	Reporting on implementation status of network
Annual cost	US$ 30–100 million

Assessment: 2 started but little progress.

Efforts remain more advanced in developed nations, leading to numerous gaps.

Significant progress on developing the coral ECV under the Global Coral Monitoring Research Network. A global report is close to publication and the monitoring approach has been approved by the International Coral Research Initiative (ICRI). Monitoring quality is variable between region and countries depending on resources available. The coral EOV/ECV is proposed as a high-profile indicator in the CBD post-2020 framework given widespread international concern and interest.

Action O28:	Global networks of observation sites for mangroves, seagrasses, macroalgae
Action	Advance the establishment of global networks of long-term observation sites for seagrass beds, mangrove forests and macroalgal communities (including kelp forests) and encourage collection of physical, biogeochemical, biological and ecological measurements, following common and intercalibrated protocols and designs and implement capacity-building workshops
Benefit	Accurate global monitoring of changes in mangroves, seagrasses and macroalgae cover
Time frame	2016–2020.
Who	Parties' national research and operational agencies, supported by GOOS Biology and Ecosystems Panel. GRAs and other partners in consultation with CBD and Ramsar Convention on Wetlands.
Performance indicator	Reporting on implementation status of network.
Annual cost	US$ 30–100 million

Assessment: 3 underway with significant progress.

Remote sensing data is globally coordinated, but in situ calibration and verification are generally lacking.

Seagrass: There are several large-scale programs but they are mainly organized by individual researchers and project-oriented and do not have regular coverage in time and space. Lauren Weatherdon and Emmet Duffy are co-PIs on a small grant from SCOR that is organizing the global seagrass community to organize best practices, a community of practice, and advance the seagrass EOV and data system.

Mangroves: Global capabilities are at 4 for EO systems, in terms of extent (but not habitat). At regional levels this at 3.

Macroalgae: Global at concept level; Regional at pilot level. Spatial and temporal resolution typically low. No oversight group established. Satellite data have been used for offshore floating macroalgae (e.g. Sargassum) but may be of insufficient resolution for coastal macroalgae.

Action O29:	**In situ data for satellite calibration and validation**
Action	Maintain in situ observations of surface ECV measurements from existing observations networks (including surface drifting buoys, SOOP ships, tropical moorings, reference moorings, Argo drifting floats, and research ships) for calibration and validation of satellite data; undertake a review of requirements of observations
Benefit	Comprehensive in situ observations for calibration and validation of satellite data
Time frame	Continuous, review by 2020
Who	Parties' national services and ocean research programmes, through GOOS, IODE and JCOMM, in collaboration with WRCP/CLIVAR and CEOS
Performance indicator	Data availability at international data centres
Annual cost	US$ 1–10 million

Assessment: 3 underway with significant progress.

In situ calibration and validation data are generally available for physical ocean ECVs, but sparse or lacking for biogeochemical and biological ocean ECVs.

Action O30:	Satellite sea-surface temperature
Action	Secure future passive microwave missions capable of SST measurements
Benefit	Ensure SST coverage in regions of high cloud coverage
Time frame	Continuous
Who	Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme in consultation with the Global High Resolution Sea Surface Temperature Project (GHRSST)
Performance indicator	Agreement of plans for maintaining required microwave SST missions
Annual cost	US$ 100–300 million (for securing needed missions)

Assessment: 4 progress on track.

JAXA has committed to including this on the future GOSAT-GM mission and EAS is support a concept study.

JAXA has committed to AMSR-3 onboard of the planned GOSAT-GW (2022-2027) (https://space.oscar.wmo.int/satellites/view/gosat_gw) that provides microwave SST that are not obscured by clouds. ESA is supporting a concept study for a Copernicus high priority candidate mission, the Copernicus Imaging Microwave Radiometer (CIMR), that is planned for following AMSR-3.

Action O31:	Satellite sea-surface height
Action	Ensure continuous coverage from one higher-precision, medium-inclination altimeter and two medium-precision, higher-inclination altimeters, including a satellite altimetry reference mission with no discontinuity between each satellite to ensure that each mission following another has an overlap period. (6–9 months) to intercalibrate one another (example of TOPEX/Poseidon and Jason missions)
Benefit	Global routine calibrated mapping of SSH; intercalibration period between difference satellite missions
Time frame	Continuous
Who	Space agencies, with coordination through the OSTST, CEOS Constellation for Ocean Surface Topography, CGMS and the WMO Space Programme.
Performance indicator	Satellites operating; provision of data to analysis centres
Annual cost	US$ 30–100 million

Assessment: 5 – Complete.

Missions underway and planned.

The series of current and planned satellite altimeter missions have addressed Action 31. These missions include Jason-3, Sentinal-3 series, CryoSat-2, CFOSAT, and Jason-

CS/Sentinel-6, CRISTAL. Sea-surface height measurements from these missions are being used operationally by analysis centres.

Action O32:	Satellite sea-surface salinity
Action	Ensure the continuity of space-based SSS measurements
Benefit	Continue satellite SSS record to facilitate research (ocean circulation, climate variability, water cycle, and marine biogeochemistry), operation (seasonal climate forecast, short-term ocean forecast, ecological forecast) and linkages with the water cycle
Time frame	Continuous
Who	Space agencies, coordinated through OSSST, CEOS, CGMS and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for SSS, ongoing satellite operation, routine delivery of SSS products
Annual cost	US$ 30–100 million (for securing needed missions)

Assessment: 3 – underway with significant progress.

ESA and NASA missions underway but continuity is not ensured.

ESA'S SMOS mission and NASA's SMAP mission are providing satellite SSS for various applications. But the continuity is not ensured. Currently there is only one mission concept, the Copernicus Microwave Imaging Radiometer (CIMR) by ESA, that aims to provide satellite SSS. But the mission timeline is 2028 or beyond even if it will move into the operation phase. Given the ages of the current SSS-measuring satellites (SMOS since 2009 and SMAP since 2015), a gap before CIMR is extremely likely. Moreover, there will be no constellation if there is only CIMR in orbit.

Action O33:	Satellite sea state
Action	Continue to improve the delivery and quality of sea-state fields, based on satellite missions with in situ networks
Benefit	Global routine calibrated mapping of sea state
Time frame	Continuous
Who	Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for sea state
Annual cost	US$ 1–10 million (for generation of datasets)

Assessment: 4 – progress on track.

Satellite altimeter missions are providing a constellation for sea state measurements together with in situ network.

Action O34:	Satellite ocean surface stress
Action	Continue to improve the delivery and quality of ocean-surface stress fields based on satellite missions with the comprehensive in situ networks (e.g. met-ocean moorings); improve resolution with the benefit of near coastal data; improved coverage of the diurnal and semi-diurnal cycles.
Benefit	Global routine calibrated mapping of ocean-surface stress
Time frame	Continuous
Who	Space agencies, coordinated through OVSST, CEOS, CGMS and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for ocean-surface stress

Assessment: 3 – underway with significant progress.

3 satellites are providing data but are inadequate for sampling diurnal and semi-diurnal cycles.

There are currently 3 satellite scatterometers in orbit providing measurements of ocean surface wind stress together with a sparse array of in situ sensors. But the virtual constellation is inadequate for sampling the diurnal and semi-diurnal cycles. The spatial resolutions of the measurements (typically 12.5-25 km) are marginal in resolving coastal winds.

Action O35:	Satellite sea ice
Action	Ensure sustained satellite-based (microwave radiometry, SAR, altimetry, visible and IR) sea-ice products; high-inclination altimetry (e.g. Cryosat follow-on) also desired
Benefit	Global, routine, calibrated mapping of sea ice
Time frame	Continuous
Who	Parties' national services, research programmes and space agencies, coordinated through the WMO Space Programme and Global Cryosphere Watch, CGMS and CEOS; national services for in situ systems, coordinated through WCRP CliC and JCOMM
Performance indicator	Sea-ice data in international data centres
Annual cost	US$ 1 -10 million (for generation of datasets)

Assessment: 4 – progress on track.

Concerns over continuity of observations.

The score depends heavily on which ECV Product is considered. Microwave radiometry for sea-ice (concentration, drift, type) [4] is generally well covered and secured at a coarse resolution, but securing higher resolution and/or lower frequencies (i.e. L-band, C-band) is required (EU CIMR, AMSR3, WSF-M, etc.). SAR (C-band) [3] is well covered (Sentinel-1, RCM, Sentinel-1NG) in the Arctic. In the Southern Hemisphere, not as well, but dedicated missions (e.g. NISAR) can help in the future. High-inclination altimetry is still problematic [2] with only two research satellites flying (CryoSAT2 and ICESat2). Future would be secured with EU CRISTAL but it is not yet committed, and a gap might occur if CRISTAL is delayed. Visible and IR imagery generally well covered [5] although twilight acquisitions not always secured (e.g. Satellite data gaps for sea-ice thickness (both high-polar altimetry and L-band radiometry) are probable for the second half of the decade.

The Sea Ice ECV is a highly multivariate ECV with, at present, 4 products, but several more associated and supporting variables. In addition, these variables are supported by different (satellite and in situ) systems. This makes status reporting a challenge. The ongoing open consultation process of GCOS ECVs has underlined that several variables that are today considered "supporting" or "associated" should be considered as ECV Products. Increasing the number of ECV products will not make reporting on the status easier in the future.

Concerning future and planned satellites, we report with our knowledge as of August 2020. Some satellite design and selection processes are on-going, especially with EU/ESA (CIMR and CRISTAL) and decisions will be made during 2021, thus before revision of the Implementation Plan.

Action O36:	**Satellite ocean colour**
Action	Support generation of long-term multi-sensor climate-quality OCR time series that are corrected for intersensor bias as needed and that have quantitative uncertainty characterization, with global coverage and validity, including coastal (Case-2) waters, and capable of dealing with user requirements for products at a variety of space and timescales.
Benefit	Global routine calibrated mapping of ocean colour, including coastal (Case-2) regions
Time frame	Implement plan beyond 2017
Who	CEOS space agencies, in consultation with IOCCG and GEO; agencies responsible for operational Earth observations, such as NOAA in the USA and Copernicus in the European Union
Performance indicator	Free and open access to up-to-date, multi-sensor global products for climate research; flow of data into agreed archives
Annual cost	US$ 1–10 million (for generation of datasets)

Assessment: 4 – progress on track.

Long-term commitments in hand mean marginal adequacy for this observation

There have been 34 AERONET-OC stations in existence since 2002 of which 18 are currently operational (https://aeronet.gsfc.nasa.gov/cgi-bin/draw_map_display_seaprism_v3) + two active global cal/val station (MOBY and BOUSSOLE). Data is served on public databases and are critical for the evaluation of satellite ocean colour data.

Action O37:	Argo array
Action	Sustain and expand the Argo profiling float network of at least one float every 3° x 3° in the ocean, including regional seas and the seasonal ice zone (approximately 3800 floats)
Benefit	Global climate-quality observations of the broadscale subsurface global ocean temperature and salinity down to 2000 m
Time frame	Continuous
Who	Parties participating in the Argo programme and in cooperation with the OCG
Performance indicator	Spatial coverage and number of active floats
Annual cost	US$ 30 million

Assessment: 4 – progress on track.

The core mission of the Argo array is largely fulfilled, with a continuous challenge to maintain the array as floats reach the end of their lifetime. The Southern Ocean and south Pacific and Indian Oceans have required specific campaigns to re-seed.

Action O38:	Development of a biogeochemical Argo array
Action	Deploy a global array of 1 000 profiling floats (~6°x ~6°) equipped with pH, oxygen, nitrate, chlorophyll fluorescence, backscatter and downwelling irradiance sensors, consistent with the Biogeochemical Argo Science and Implementation Plan
Benefit	Global observations of the broadscale subsurface global ocean biogeochemistry down to 2000 m
Time frame	In place by 2026; review progress in 2021
Who	Parties, in cooperation with the Argo Project and the OCG
Performance indicator	Number of floats reporting oxygen and biogeochemical variables
Annual cost	US$ 25 million

Assessment: 3 – underway with significant progress.

491 Argo floats are measuring one or more biogeochemical ECVs (June 2020).

Significant progress has been made with respect to the Biogeochemical Argo Science and Implementation Plan. Almost all platforms carry an oxygen sensor, more than half measure chlorophyll-a and suspended particles but less than half measure pH, nitrate and downwelling irradiance. However, there are only a handful of floats which measure the entire suite of six parameters.

Action O39:	Development of a deep Argo array
Action	Deploy a global array of approximately 1230 deep Argo floats at 5° x 5° spacing, covering all ocean regions deeper than 2000 m
Benefit	Global climate-quality observations of the broad-scale subsurface global ocean temperature and salinity below 2000 m
Time frame	Array in place and maintained by 2026; review progress in 2021
Who	Parties participating in the Argo programme and in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage and number of active deep floats
Annual cost	US$ 20 million

Assessment: 3 – underway with significant progress.

139 deep Argo floats are operating (June 2021), against a target of 25% of the array of about 1000 floats.

Action O40:	GO-SHIP
Action	Maintain a high-quality, full-depth, multi-disciplinary ship-based decadal survey of the global ocean (approximately 60 sections) and provide a platform to deploy autonomous components of the ocean observing system and test new technology
Benefit	Global, comprehensive, full-depth, decadal ocean inventory of ECVs
Time frame	Continuous
Who	National research programmes supported by the GO-SHIP project, OCG and GOOS
Performance indicator	Percentage coverage of the sections and completion of Level-1 measurements
Annual cost	US$ 10–30 million

Assessment: 3 – underway with significant progress.

The high-quality, full-depth, multi-disciplinary ship-based decadal survey is on track, although COVID-19 restrictions in 2020 have delayed a number of missions.

Action O41:	Develop fixed-point time series
Action	Build and maintain a globally distributed network of multi-disciplinary, fixed-point surface and subsurface time series, using mooring, ship and other fixed instruments
Benefit	Comprehensive high temporal resolution time series characterizing trends and variability in key ocean regimes
Time frame	Continuous

Who	Parties' national services and ocean research agencies responding to the OceanSITES plan working with GOOS panels and GRAs
Performance indicator	Moorings operational and reporting to archives
Annual cost	US$ 30–100 million

Assessment: – underway with significant progress.

OceanSITES moorings have largely been sustained. Metadata and data flow needs improvement, and COVID-19 restrictions have placed a number of these timeseries moorings at risk of failure, with expected data gaps in 2020-21.

Action O42:	Maintain the Tropical Moored Buoy system
Action	Maintain the Tropical Moored Buoy system
Benefit	Contributes to observing state of the tropical ocean climate, particularly focused on coupled air–sea processes and high frequency variability and for prediction of ENSO events
Time frame	Continuous
Who	Parties' national agencies, coordinated through the JCOMM Tropical Moored Buoy Implementation Panel, following guidance from scientific development projects (e.g. TPOS 2020, IIOE-II, AtlantOS)
Performance indicator	Data acquisition at international data centres and robust design requirements articulated
Annual cost	US$ 30–100 million

Assessment: 3 – underway with significant progress.

78 of 119 target units are operating (Sep 2020). The Indian and Atlantic Ocean arrays are harder-hit than the Pacific, due to COVID-19 restrictions and the classification of the Pacific array as operational.

Action O43:	Develop time-series-based biogeochemical data
Action	Establish a coordinated network of ship-based multidisciplinary time series that is geographically representative; initiate a global data product of time-series-based biogeochemical data
Benefit	Provision of comprehensive regular observations of ocean biogeochemistry, complementary to the GO-SHIP decadal survey

Time frame	Internationally agreed plans published by end 2018; implementation build-up to 2020
Who	Parties' national research agencies, working with IOCCP and user groups, such as IGMETS
Performance indicator	Publication of internationally agreed plans; timely availability of data in internationally agreed on data centres
Annual cost	US$ 10–30 million

Assessment: 3 – underway with significant progress.

Work has commenced towards a time-series-based biogeochemical data product. Several workshops and community consultations have been held. A first publication of this data product is likely in 2021.

Action O44:	**Meteorological moorings**
Action	Maintain measurements on surface moored buoys of meteorological parameters (air temperature, humidity, SST, wind speed and direction) and expand range of parameters measured (surface pressure, waves, precipitation and radiation); ensure observational metadata are available for all moored buoy observations, both for current data and for the historical archive
Benefit	Comprehensive marine meteorological observation delivery
Time frame	Continuous
Who	Parties' national services and ocean research agencies, DBCP, OceanSITES
Performance indicator	Moorings operational and reporting to archives
Annual cost	US$ 30–100 million

Assessment: 4 – progress on track.

Surface parameter coverage from moorings remains stable.

Action O45:	Wave measurements on moorings
Action	Develop a strategy and implement a wave measurement component as part of the Surface Reference Mooring Network (DBCP and OceanSITES)
Benefit	Comprehensive in situ reference observations of wave parameters.
Time frame	Complete plan and begin implementation by 2020
Who	Parties operating moorings, DBCP, OceanSITES, coordinated through the JCOMM Expert Team on Waves and Coastal Hazards
Performance indicator	Sea-state measurement at the international data centres
Annual cost	US$ 1–10 million

Assessment: 2 – started but little progress.

Plans for cross-platform integrated wave measurements remain to be published, coverage is good in the northern hemisphere and sparse elsewhere.

Action O46:	Observations of sea ice from buoys and visual survey
Action	Establish and sustain systematic in situ observations from sea-ice buoys, visual surveys (SOOP and Aircraft) and ULS in the Arctic and Antarctic
Benefit	Enables tracking of variability in ice thickness and extent
Time frame	Continuous
Who	Arctic Party research agencies, supported by the Arctic Council; Party research agencies, supported by CLIVAR Southern Ocean Panel; JCOMM, working with CliC and OOPC
Performance indicator	Establishment of agreements/frameworks for coordination of sustained Arctic and Southern Ocean observations, implementation according to plan
Annual cost	Plan and agreement of frameworks: US$ 100 000–1 million Implementation: US$ 10–30 million

Assessment: 2 – started but little progress.

Integrated plans remain to be developed.

Action O47:	Sustain drifter array
Action	Sustain global coverage of the drifting buoy array (at least 1300 drifting buoys to cover oceans in the latitudes between 60S and 60N, excluding marginal seas, plus additional coverage for these areas) with ocean temperature sensors and atmospheric pressure sensors on all drifting buoys
Benefit	Routine broad-scale observations of surface temperature and sea-level pressure in support of NWP; climate-data products (e.g. SST) and VOSClim for climate-quality flux estimates
Time frame	Continuous
Who	Parties' national services and research programmes through JCOMM, DBCP and the Ship Observations Team (SOT)
Performance indicator	Data submitted to analysis centres and archives
Annual cost	US$ 1–10 million

Assessment: 3 – underway with significant progress.

The number of surface drifters (1540 against a target of 1250, Sep 2020) is overall greater than the target, even as equatorial and other divergence zones are undersampled and the percentage of buoys equipped with atmospheric pressure sensors is below 50% (see A7).

Action O48:	Underway observations from research and servicing vessels
Action	Ensure where possible that ancillary underway observations are collected during research voyages and routine mooring servicing cruises
Benefit	Improved coverage of underway observations, particularly in data-sparse, open oceans, and complementary to moored buoy arrays
Time frame	Continuous.
Who	National research agencies in consultation with the JCOMM Ship Observations Team and GO-SHIP
Performance indicator	Improved observations from research vessels
Annual cost	US$ 1–10 million

Assessment: 3 – underway with significant progress.

The GOOS OCG Ship Observations Team continues to work with research vessels to increase observations.

Action O49:	Improve measurements from Voluntary Observing Ships
Action	Improve the quality and spatial coverage of VOS observations, by working collaboratively with stakeholders having interests in the maritime transportation industry; continue efforts to validate utility of VOS observations for a range of applications, including NWP, marine climate, reanalysis and validation of remotely sensed observations. Improve metadata acquisition and management for as many VOS as possible through VOSClim, together with improved measurement systems
Benefit	Improved coverage of routine marine meteorology observations in support of NWP
Time frame	Continuous
Who	National meteorological agencies and climate services, with commercial shipping companies in consultation with the JCOMM Ship Observations Team
Performance indicator	Increased quantity and quality of VOS reports
Annual cost	US$1–10 million

Assessment: 3 – underway with significant progress.

Effort continues under the GOOS OCG Ship Observations Team, with an increase in active ships (1688 operating in Sep 2020). A bias towards the northern hemisphere remains strong.

Action O50:	Improve measurements of underway thermosalinograph data
Action	Improve the quality and spatial coverage of underway temperature and salinity data; ensure observations are archived and quality-controlled when collected complementary to other observing programmes
Benefit	Improved coverage of surface temperature and salinity observations
Time frame	Continuous
Who	National meteorological agencies and climate services, research agencies with the commercial shipping companies in consultation with the JCOMM Ship Observations Team
Performance indicator	Increased quantity and quality of VOS reports
Annual cost	US$ 1–10 million

Assessment: 2 – started but little progress.

Thermosalinograph lines have generally been maintained but are highly impacted by difficulties in port visits and having ship riders onboard with COVID-19 restrictions.

Action O51:	Sustain ship-of-opportunity expendable bathythermograph / expendable conductivity temperature depth
Action	Sustain the existing, multi-decadal, ship-of-opportunity XBT/XCTD transoceanic network in areas of significant scientific value
Benefit	Eddy-resolving transects of major ocean basins, enabling basin-scale heat fluxes to be estimated and forming a global underpinning boundary- current observing system
Time frame	Continuous
Who	Parties' national agencies, coordinated through JCOMM-SOT
Performance indicator	Data submitted to archive; percentage coverage of the sections
Annual cost	US$ 1–10 million

Assessment: 2 – started but little progress.

In general XBT lines have been maintained, but this is a component of the observing system that has most been impacted by COVID-19 restrictions, with very limited observations in 2020.

Action O52:	Coordination of underway pCO_2 observations and agreed best practices
Action	Improve coordination, outreach and tracking of implementation and measurements of a global surface water CO_2 observing system; implement an internationally agreed strategy for measuring surface pCO_2 on ships and autonomous platforms and improve coordination of network, timely data submission to the SOCAT data portal
Benefit	Delivery of a high-quality global dataset of surface-ocean pCO_2, enabling accurate estimates of ocean fluxes of carbon dioxide
Time frame	Establishment of global monitoring group by 2018; continuous, coordinated network by 2020
Who	IOCCP in coordination with OOPC, JCOMM OCG and JCOMMOPS; implementation through Parties' national services and research agencies
Performance indicator	Tracking assets within 3 months of completion of voyage; data delivery to SOCAT.
Annual cost	US$ 10–30 million

Assessment: 3 – underway with significant progress.

The global monitoring group has been established as part of the GOOS OCG SOOP team.

Surface Ocean CO_2 reference NETwork (SOCONET) covers key regions of the ocean with data of specified quality. It performs measurements following documented procedures and network practices including common protocols, similar instrumentation, and standardization. SOCONET is involved in designing and implementing instrument intercomparison experiments to improve technical coherence of hardware and operators across the network. SOCONET provides standard operating procedures (SOPs) for acquiring the data. Data are appropriately documented with metadata compliant with international protocols, and accuracy and precision requirements. Most surface water pCO_2 data from SOCONET is submitted through the established SOCAT data system. The platforms will be tracked through the OceanOPS platform management system and tagged as SOCONET reference network data. The network will implement procedures aimed at improving its readiness level across all elements of the Framework for Ocean Observing (FOO) of the Global Ocean Observing System (GOOS).

Action O53:	Underway biogeochemistry observations
Action	Sustain current trans-basin sampling lines of pCO_2 and extend the coverage to priority areas by starting new lines (see GCOS-195, page 137); implement routine pCO_2 measurements on research vessels; develop and deploy a global ship-based reference network of robust autonomous in situ instrumentation for Ocean biogeochemical ECVs
Benefit	Enables routine observations of multiple surface Ocean biogeochemical ECVs, leading to improved coverage
Time frame	Plan and implement a global network of SOOP vessels equipped with instrumentation by 2020
Who	Parties' national ocean research agencies in association with the GOOS Biogeochemistry Panel, IOCCP, in consultation with JCOMM OCG.
Performance indicator	Improved flow of data to SOCAT; pilot project implemented; progress towards global coverage with consistent measurements as determined by number of ships with calibrated sensors providing quality data
Annual cost	US$ 10–30 million

Assessment: 2 – started but little progress.

Some discussions on integration started.

Most of the action is well on track via efforts under SOCONET. However, the key element in this action which has seen little progress is the last part of the action description regarding development and deployment of a global ship-based reference network for ocean biogeochemical ECVs (beyond carbon). Discussions across networks (in situ and satellite) are underway but we are at the beginning of the road towards a multi-scale integrated observing system, with satellites that are optimized for marine boundary layer observations, tuned and validated against a global network of regional in situ platforms. Consolidation and expansion of the existing networks is required and wide implementation of new sustainable ocean technologies, such as autonomous surface vehicles and a new generation of chemical, biological and physical sensors. Finally, acceptance of these ECV data into SOCAT requires significant investment to accommodate for a step-change in the scale of SOCAT operation at hardware and human resources level.

Action O54:	Continuous plankton recorder surveys
Action	Implement, global CPR surveys
Benefit	Towards global transects of surface zooplankton, plankton species diversity and variability, plus an indicator of phytoplankton productivity
Time frame	2026, review progress by 2021
Who	Parties' national research agencies, through GACS and the GOOS Biology and Ecosystems Panel
Performance Indicator	Continuation and of sustained global CPR according to plan
Annual cost	US$ 10–30 million

Assessment: 2 – started but little progress.

CPR observations of plankton remain concentrated in the northern hemisphere (see https://www.cprsurvey.org/data/our-data/#) even though there are other initiatives taking place in other regions (http://www.globalcpr.org).

Action O55:	Maintain tide gauges
Action	Implement and maintain a set of gauges based on the GLOSS Core Network (approximately 300 tide gauges) with geocentrically located, high-accuracy gauges; ensure continuous acquisition, real-time exchange and archiving of high-frequency data; build a consistent time series, including historical sealevel records, with all regional and local tide-gauge measurements referenced to the same global geodetic reference system
Benefit	The GLOSS Core Network is the backbone serving the multiple missions that GLOSS is called on to serve. Not all core stations serve every mission and not all stations for a given mission are part of the core. The Core Network serves to set standards and is intended to serve as the example for the development of regional networks. The GLOSS climate set serves to put the short altimetry record into a proper context, serves as the ground truth for the developing satellite dataset, and also provides continuity if climate capable altimetry missions have interruptions in the future.
Time frame	Continuous.
Who	Parties' national agencies, coordinated through GLOSS
Performance indicator	Data availability at international data centres, global coverage, number of capacity-building projects
Annual cost	US$ 1–10 million

Assessment: 4 – progress on track: Flow of data from coastal tide gauge stations is stable, in many cases supported by operational needs.

Action O56:	Developing a global glider observing system
Action	Design and begin implementation of a globally distributed network of multi-disciplinary glider missions across the continental shelf seas to the open ocean as part of a glider reference coastal–open ocean observation network
Benefit	Multi-disciplinary, high-frequency observations enabling the linkage of open ocean and coastal environments and cross-shelf exchange of properties
Time frame	Framework and plan developed by 2020
Who	National research programmes coordinated by the global glider programme and GOOS
Performance indicator	Published, internationally agreed plan and implementation of sustained coastal boundary–open ocean sections
Annual cost	US$ 10–30 million

Assessment: 3 – underway with significant progress.

The GOOS OCG OceanGliders network (oceangliders.org) has been established and is working towards a global plan that will support observations of boundary currents, water transformation, ocean health and ecosystems, and storms.

Action O57:	Developing a global animal-tagging observing system
Action	Move towards global coordination of pinniped tagging for ecosystem and climate applications, including the coordination of deployment locations/species and QA/QC of resultant data
Benefit	High-frequency T/S profile data in polar regions and in the ice zone, filling a critical gap in the observing system; high-frequency T/S profile data in other regions providing complementary data to other observing systems and likely high-frequency sampling of physical features of interest to foraging animals such as fronts and eddies
Time frame	Framework and plan developed by 2020
Who	National research programmes coordinated through SOOS, SAEON, GOOS
Performance indicator	An internationally recognized coordination activity and observing plan.
Annual cost	US$ 10–30 million

Assessment: 3 – underway with significant progress.

The GOOS OCG AniBos network has been established to coordinate and promote best practice in temperature and salinity measurements, biogeochemical ECV measurements, and animal tracking data. The austral summer retagging season 2020-2021 will be highly impacted by COVID-19 restrictions, and so one year of data will be degraded.

B.d Terrestrial

Action T1:	Improve coordination of terrestrial observations
Action	Establish mechanism to coordinate terrestrial observations: this will be particularly important for climate change impacts and adaptation where local information will be critical and will not be provided through GCOS directly. It includes biodiversity and natural resources information and could also incorporate socioeconomic components (e.g. health) to become fine-tuned with post-2015 frameworks. This would be based on discussions with stakeholders and could include a formal framework or regular meetings to exchange ideas and coordinate observational requirements.
Benefit	Efficient observing systems with minimal duplication, delivering consistent and comparable data to a range of different users
Time frame	2017: Hold workshops to discuss way forward 2019: Mechanism in place.
Who	All involved in terrestrial observations. Initially TOPC, GEO, ICSU, GOFC-GOLD, FluxNet, NEON
Performance indicator	Presence of active mechanism
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Discussions have taken place with FAO, GEO and others, on how to replace GTOS. However, no clear proposal has emerged, there is no funding, and it is unclear how such a body would proceed as many groups have moved forward without GTOS. While there was a willingness to coordinate, there is no clear vision of who would fund this. In the absence of GTOS the various groups have developed their own ways of working together with several networks now reporting to TOPC.

Action T2:	Develop joint plans for coastal zones
Action	Jointly consider observations of coastal zones (including sea ice, mangroves and sea grass, river and groundwater flows, nutrients, etc.) to ensure the seamless coverage of ECVs and the global cycles in these areas
Benefit	Consistent, accurate and complete monitoring of coastal zones
Time frame	2017: joint meetings 2019: agreed plans
Who	All involved in coastal observations. Initially TOPC, OOPC
Performance indicator	Plan completed
Annual cost	US$ 1 000–10 000k

Assessment: 2 – Started but little progress.

While initial discussions have been held with OOPC, there has been little progress. Issue for oceanography include the lack of data on river discharge, and the on-going development of ecosystem ECV in the oceans. Monitoring techniques for the coastal oceans need to be developed as well as a clear picture of the user needs.

Action T3:	**Terrestrial monitoring sites**
Action	Review the need for establishing a public database of sites that aim to record climate-relevant data and their data. Consider the usefulness of establishing a set of GCOS terrestrial monitoring sites that aim to monitor at least one ECV according to the GCMP.
Benefit	Improved access to monitoring and increased use of the data
Time frame	One year for review
Who	GCOS
Performance indicator	Report on GCOS terrestrial monitoring sites
Annual cost	US$ 10 000–100 000

Assessment: 1 – Not done.

There have been discussions on including terrestrial ECV with the GCOS Surface Reference Network (GSRN) (TOPC contributed to its design) but slow progress while GSRN is established through the WMO process. Without GTOS its database seems lost.

Action T4:	**Review of monitoring guidance**
Action	Review existing monitoring standards/guidance/best practice for each ECV and maintain database of this guidance for terrestrial ECVs
Benefit	Improved consistency and accuracy of results to meet user needs
Time frame	Review: 2017–2018, maintain database as of 2019
Who	TOPC
Performance indicator	Presence of maintained database
Annual cost	US$ 1 000 –10 000

Assessment: 1 – Not done.

Overall, there has been little progress. Some groups around permafrost and glaciers have worked on guidance but otherwise there has been little incentive to do this.

Action T5:	Develop metadata
Action	Provide guidance on metadata for terrestrial ECVs and encourage its use by data producers and data holdings
Benefit	Provide users with a clear understanding of each dataset and the differences and applicability of different products for each ECV
Time frame	2018
Who	TOPC in association with appropriate data producers
Performance indicator	Availability of metadata guidance
Annual cost	US$ 1 000 –10 000

Assessment: 3 – Underway with significant progress.

There has been some progress with WMO, through its metadata standard and its desire to adopt an Earth systems approach.

Action T6:	Identify capacity development needs
Action	Identify capacity-development needs to inform GCM and other capacity-building initiatives; identify specific improvements that could be supported by GCM
Benefit	Improved monitoring in recipient countries
Time frame	Ongoing
Who	TOPC and GCM
Performance indicator	Project proposals and Implemented projects
Annual cost	US$ 10 000–100 000

Assessment: 3 – Underway with significant progress.

The regional workshops have been successful in identifying capacity building (and other) needs where they have been held (i.e. Pacific, East Africa and the Caribbean). Issues include sustainability, data exchange, planning and staff retention. Many countries with few resources cannot afford sufficient monitoring and this has contributed to the WMO developments of GBON and SOFF.

Action T7:	Exchange of hydrological data
Action	In line with WMO Resolutions 25 (Cg-XIII) and 40 (Cg-XII), improve the exchange hydrological data and delivery to data centres of all networks encompassed by GTN-H, in particular the GCOS baseline networks, and facilitate the development of integrated hydrological products to demonstrate the value of these coordinated and sustained global hydrological networks.
Benefit	Improved reporting filling large geographic gaps in datasets
Time frame	Continuing; 2018 (demonstration products)
Who	GTN-H partners in cooperation with WMO and GCOS
Performance indicator	Number of datasets available in international data centres; number of available demonstration products
Annual cost	US$ 100 000–1 million

Assessment 1: – Not done.

No improvement despite the efforts of GTN-H and WMO. Hydrological data is often not exchanged or shared on a free and open basis in many parts of the world. Some data is available and often models used to fill the gaps. Efforts are underway to fill some of the gaps using satellite data.

Action T8:	Lakes and reservoirs: compare satellite and in situ observations
Action	Assess accuracy of satellite water-level measurements by a comparative analysis of in situ and satellite observations for selected lakes and reservoirs
Benefit	Improved accuracy
Time frame	2017–2020
Who	Legos/CNES, HYDROLARE
Performance indicator	Improving accuracy of satellite water-level measurements
Annual cost	US$ 10 000–100 000

Assessment 3: – Underway with significant progress.

Considerable improvements in the databases of the satellite observations together with available in situ data are improving the accuracy of satellite observations and contributing to the design of future missions.

Action T9:	Submit historical and current monthly lake-level data
Action	Continue submitting to HYDROLARE historical and current monthly lake-level data for GTN-L lakes and other lakes, as well as weekly/monthly water-temperature and ice-thickness data for GTN-L
Benefit	Maintain data record
Time frame	Continuous
Who	National Hydrological Services through WMO CHy and other institutions and agencies providing and holding data
Performance indicator	Completeness of database
Annual cost	US$ 100 000–1 million (40% in non-Annex-1 Parties)

Assessment 3: – Underway with significant progress.

The most complete regime information on the results of in situ observations of lake water level, lake surface water temperature, lake ice thickness for 250 lakes is held in the international HYDROLARE database. Nevertheless, some originators of data for LSWT do not openly share data or participate in organised stewardship systems: presently ESA's Lake CCI project is attempting to collect additional in situ data on an annual basis for annual climate assessment activities.

Action T10:	Establish sustained production and improvement for the Lake ECV products
Action	Establish satellite-based ECV data records for Lake-surface water temperature, Lake ice coverage and Lake water-leaving reflectance (Lake colour); implement and sustain routine production of these new satellite based products; Sustain efforts on improving algorithms, processing chains and uncertainty assessments for these new ECV products, including systematic in situ data sharing and collection in support of ECV validation; Develop additional products derived from Lake water-leaving reflectance for turbidity, chlorophyll and coloured dissolved organic matter
Benefit	Add additional Lake ECV products for extended data records; provide a more comprehensive assessment of climate variability and change in lake systems
Time frame	Continuous.
Who	Space agencies and CEOS, Copernicus Global Land Service, GloboLakes and ESA CCI
Performance indicator	Completeness of database
Annual Cost	1–10M US$ (40% in non-Annex-1 Parties)

Assessment 3: – Underway with significant progress.

As noted above, ESA's Lakes CCI is establishing satellite-based ECV data records. Sustaining these efforts is not yet guaranteed. The GloboLakes Lake Surface Temperature product is being updated and reported on by the Copernicus Climate Change Service.

Action T11:	Confirm Global Terrestrial Network for River Discharge sites
Action	Confirm locations of GTN-R sites; determine operational status of gauges at all GTN-R sites; ensure that GRDC receives daily river discharge data from all priority reference sites within one year of observation (including measurement and data transmission technology used)
Benefit	Up-to-date data for all areas
Time frame	2019
Who	National Hydrological Services, through WMO CHy in cooperation with TOPC, GCOS and GRDC
Performance indicator	Reports (made in cooperation with GTN-H partners) to TOPC, GCOS and WMO CHy on the completeness of the GTN-R record held in GRDC, including the number of stations and nations submitting data to GRDC, National Communication to UNFCCC
Annual cost	US$ 1–10 million (60% in non-Annex I Parties)

Assessment 3: – Underway with significant progress.

The Global Terrestrial Network for River Discharge (GTN-R) draws together available QC/QA river discharge data, ideally within a year after measurement, and currently from 326 gauging stations worldwide. Work is continuing to check their locations and determine their status; however, some errors remain and not all records are up to date.

Action T12:	National needs for river gauges
Action	Assess national needs for river gauges in support of impact assessments and adaptation and consider the adequacy of those networks
Benefit	Prepare for improvement proposals
Time frame	2019
Who	National Hydrological Services, in collaboration with WMO CHy and TOPC
Performance indicator	National needs identified; options for implementation explored
Annual cost	US$ 10–30 million (80% in non-Annex I Parties)

Assessment: 1 – Not done

Due to lack of engagement of partners and lack of clear resources to implement improvements no progress was made.

Action T13:	Establish a full-scale Global Groundwater Monitoring Information System (GGMS)
Action	Complete the establishment of a full-scale GGMS as a web portal for all GTN-GW datasets; continue existing observations and deliver readily available data and products to the information system
Benefit	Global, consistent and verified datasets available to users
Time frame	2019
Who	IGRAC, in cooperation with GTN-H and TOPC
Performance indicator	Reports to UNESCO IHP and WMO CHy on the completeness of the GTN-GW record held in GGMS, including the number of records in, and nations submitting data to, GGMS; web-based delivery of products to the community
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

The Global Groundwater Monitoring Network (GGMN)is a participative, web-based network of networks set up to improve quality and accessibility of groundwater monitoring information and subsequently knowledge on the state of groundwater resources.

Back in 2007, a workshop on Global Monitoring of Groundwater Resources, jointly sponsored by IGWCO, GARS and UNESCO, was held at the International Groundwater Resources Assessment Centre (IGRAC). One important outcome of this meeting was to support IGRAC as the lead institution for the development of a Global Groundwater Monitoring System (GGMS). At that time, the intention was that GGMS was the product of GTN-GW, whose success would depend on coordination among several agencies, as: ESA, GARS, GEMS/Water, GRAPHIC, GRDC, GTN-(H,L,P,R), IAEA, IGRAC, IGWCO NASA/Goddard Space Flight Center, TU Delft, UNESCO, USGS, University of California (Berkeley, Irvine, USA), University of New Hampshire (USA), VU Amsterdam (the Netherlands), and WHYMAP (http://www.fao.org/tempref/docrep/fao/011/i0197e/i0197e07.pdf). Five years later, the GGMN Programme was launched by IGRAC, as a UNESCO and WMO programme. GTN-GW did not exist as such, but its role was fulfilled by GGMN, which works as a global network of national groundwater monitoring networks and it is part of GTN-H. The last version of the portal was launched in 2016, including advanced time series analysis functionalities. In 2019, the mobile app of GGMN was launched.

GGMN holds groundwater level data from 39208 stations in 34 countries. IGRAC is permanently updating the data in GGMN and contacting new countries to expand the network.

Although GGMN is a UNESCO and WMO programme, there is no defined mechanism to report neither to UNESCO IHP and WMO CHy on the completeness of the network.

Action T14:	Operational groundwater monitoring from gravity measurements
Action	Develop an operational groundwater product, based on satellite observations
Benefit	Global, consistent and verified datasets available to users
Time frame	2019
Who	Satellite agencies, CEOS, CGMS
Performance indicator	Reports to UNESCO IHP and WMO CHy on the completeness of the GTN-GW record held in GGMS, including the number of records in, and nations submitting data to, GGMS; web-based delivery of products to the community.
Annual Cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

The Global Gravity-based Groundwater Product (G3P) will show groundwater storage variations with global coverage and monthly resolution from 2002 until present.

G3P is an ongoing H2020 project (2020-2022) that aims at integrating the Essential Climate Variable (ECV) Groundwater as a new product into the Copernicus Services (European Union's Earth Observation Programme), as there is no consistent global freely accessible data set on groundwater storage variations based on gravity data yet. The G3P Consortium is integrated by 12 project partners: GFZ (coordinator), UB, TUG, FMI, TUW, CLS, IGRAC, UZH, MAG, LEGOS, FUWA and EODC. It is worth noting that IGRAC (GGMN) and TUW (International Soil Moisture Network, ISMN) are part of GTN-H.

The G3P product on long-term monthly groundwater storage change will be made available for visualization, analysis and download for further applications to the general public and to the various user communities by two service portals: the gravity Information Service (GravIS) and the Global Groundwater Monitoring Network (GGMN). In this way, G3P through GGMN will provide the first global quantitative data source for the ECV Groundwater, a valuable input for GCOS.

More information in: https://www.g3p.eu/.

Action T15:	Satellite soil-moisture data records
Action	Regularly update individual microwave sensor (SMOS, SMAP, ASCAT, AMSR-E ...) soil-moisture data records, including the subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth, root-zone soil moisture)
Benefit	Time series of data to identify trends over time
Time frame	Continuing
Who	Space agencies (ESA, EUMETSAT, NASA, NOAA, JAXA ...) and Earth observation service providers
Performance indicator	Availability of free and open global soil-moisture data records for individual microwave missions
Annual cost	US$ 10–30 million

Assessment: 3 – Underway with significant progress

Several single-microwave-satellite (SMAP, SMOS, ASCAT, AMRS-2) based soil moisture data (surface and profile) are fully operational and provide regular re-processed data record. However, only few also contain information about the freeze/thaw status and vegetation optical depth, and none contains surface inundation as subsidiary variables. Moreover, SMAP and SMOS are well beyond their regular lifetime, and no successor missions are planned.

EUMETSAT H-SAF regularly releases re-processed soil moisture data records referred to as "Surface Soil Moisture Metop ASCAT Data Record Time Series". See http://hsaf.meteoam.it/description-h25-h108-h111.

Action T16:	**Multi-satellite, soil-moisture data services**
Action	Regularly update of merged multi-sensor, soil-moisture data records, including the subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth, root-zone soil moisture)
Benefit	High-quality, soil moisture CDR for users
Time frame	Continuing
Who	Copernicus, NOAA, Earth observation data providers
Performance indicator	Availability of free and open merged multi-sensor data records (merged passive, merged active and merged active-passive data)
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress. The ESA CCI soil moisture product and its operational counterpart C3S soil moisture product are systematically produced and further developed, but provision of subsidiary variables and uncertainty budgets need to be improved, even as retrievals in challenging environments.

The ESA CCI multi-sensor soil moisture product is a research product that is systematically extended and improved on a yearly basis. It contains two three datasets: one based on microwave radiometers only (e.g. SMOS, AMSR, TMI), one based on scatterometers only (ERS, ASCAT), and a dataset based on both radiometer and scatterometer data. The ESA CCI soil moisture methodology feeds into the Copernicus Climate Change Service (C3S) to produce every 10 days in a fully operational fashion an update of the climate data record. While a large archive of validation studies of the product exists, a systematic end-to-end error budget is lacking, even as ancillary information about the freeze/thaw status, vegetation optical depth, even as the level of surface inundation. With agreed continuation of the C-band scatterometer missions, continuation of part of the input mission is given. However, the latest product versions significantly benefit from the inclusion of the dedicated L-band missions SMAP and SMOS, which is threatened by the fact that these are well beyond their regular lifetime, and no successor missions are planned.

Other, scientific multi-sensor products are being developed for shorter and more homogeneous time periods.

Action T17:	International soil-moisture network
Action	Operate, provide user services and expand the International Soil Moisture Network (ISMN), which is part of the GTN-H.
Benefit	Coordinated in situ soil moisture data for users and calibration/validation
Time frame	Continuing
Who	Vienna Technical University, supported by national data providers, ESA, GEWEX, CEOS and GEO
Performance indicator	Availability of harmonized and quality-controlled in situ soil-moisture data provided by network operators to ISMN
Annual cost	US$ 100 000–1 million (includes only central services of the ISMN data centre)

Assessment: 3 – Underway with significant progress.

The International Soil Moisture Network (ISMN) has been operational for more than 10 years and is still expanding, although long-term financial commitment for the data hosting facility and its contributing data network providers is largely lacking.

The ISMN started operations in 2010 and is still rapidly growing in terms of data volume and number of users served. Since the beginning, the ISMN has been funded by ESA, currently within the QA4EO programme. Despite being a global network, data coverage is still poor in many regions of the world, in particular the global South.

As the operation of the ISMN is labour and resource intense, there is the intention to transfer the ISMN to an operational data centre. A strong interest in hosting the ISMN has been expressed by some German ministries, but no final commitment has been made so far. On the mid-term, R&D support is expected to remain under the umbrella of ESA. Future R&D shall focus on providing full traceability and providing fiducial reference measurements of soil moisture measurements containing end-to-end uncertainty budgets and representativeness information.

Action T18:	Regional high-resolution soil-moisture data record
Action	Develop high-resolution soil-moisture data records for climate change adaptation and mitigation by exploiting microwave and thermal remote-sensing data
Benefit	Availability of data suitable for adaptation
Time frame	2017–2020
Who	NASA Soil Moisture Active-Passive Programme, ESA Climate Change Initiative, Copernicus Evolution Activities in cooperation with identified universities and research organizations
Performance indicator	Public releases of experimental multi-year (> 10 years) high-resolution, soil-moisture data records
Annual cost	US$ 10–30 million

Assessment: 2 – Started but little progress.

First high-resolution soil moisture data services based on fusing Sentinel-1 SAR and other microwave data (SMAP, ASCAT) have been launched, but work to validate, improve and apply these data is still at the beginning.

First high-resolution soil moisture data sets have become available, for example the SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture data set or the Copernicus Global Land 1 km Sentinel-1 surface soil moisture and 1 km ASCAT-Sentinel-1 based Soil Water Index (SWI) data for Europe. Additionally, several research data sets created by fusing microwave and optical/thermal data have been published. However, the quality and respective strengths and weaknesses of these novel high-resolution soil moisture data sets are yet only poorly understood. In this respect, an important problem is the lack of very dense in situ soil moisture networks and the unknown quality of simulated high-resolution soil moisture data.

A beta version of the SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture data set has become available at the NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC):

https://nsidc.org/the-drift/data-update/high-resolution-smapsentinel-1-soil-moisture-data-available/

Action T19:	Maintain and extend the in situ mass balance network
Action	Maintain and extend the in situ mass balance network, especially within developing countries and High Mountain Asia (Himalaya, Karakorum, Pamir) (e.g. using capacity-building and twinning programmes)
Benefit	Maintain a critical climate record
Time frame	Ongoing
Who	Research community, national institutions and agencies
Performance indicator	Number of observation series submitted to WGMS
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Network is being maintained but needs to be expanded. Between 2017 and the end of 2019 the number of observations increased by 6% covering only 2% more glaciers.

Action T20:	Improve the funding situation for international glacier data centres
Action	Improve the funding situation for international glacier data centres and services as well as for long-term glacier-monitoring programmes. Integrated and international availability of funding for sustaining programme, expecting also private sector contributions
Benefit	Secure long-term monitoring and data availability
Time frame	2020
Who	National and international funding agencies
Performance indicator	Resources dedicated to glacier-database management at WGMS and NSIDC; number of reference glaciers with more than 30 years of continued observations
Annual cost	US$ 1–10 million

Assessment 3: – Underway with significant progress.

Continued funding for the compilation and dissemination of glacier datasets could be raised by the WGMS (about 2 FTE) and NSIDC (about 1 FTE) from national agencies. This remains an ongoing task and the secured resources are very limited as compared to the increasing amount of potentially available data from remote sensing and the increasing user needs.

Progress:

- WGMS get long-term core funding from Swiss government.
- NSIDC got some project money dedicated to the GLIMS database.
- Based on an evaluation at both international and national levels in 2019, the WGMS got approved continued funding including a 4% increase of the general budget (about 2 FTE).

Action T21:	Encourage and enforce research projects to make their ECV-relevant observations available through the dedicated international data centres
Action	Encourage and enforce research projects to make their ECV-relevant observations available through the dedicated international data centres (e.g. through dedicated budget lines and the use of digital object identifiers for datasets).
Benefit	Open and long-term availability of data for users
Time frame	Ongoing
Who	National funding agencies
Performance indicator	Number of datasets submitted to dedicated international data centres
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

GCOS continues to advocate for ECVs to be openly and freely available and has encouraged the continued support of data centres.

Action T22:	Global Glacier Inventory
Action	Finalize the completion of a global reference inventory for glaciers and increase its data quality (e.g. outline, time stamp) and data richness (e.g. attribute fields, hypsometry)
Benefit	Improved data quality on glaciers
Time frame	2020
Who	NSIDC and WGMS with GLIMS research community and space agencies
Performance indicator	Data coverage in GLIMS database
Annual cost	US$ 100 000–1 million

Assessment 4: – Progress on track.

Good progress has been made with respect to both data quality and data richness with the release of the global reference glacier inventory (RGI 6.0, a snapshot global inventory around the year 2000) and its integration into the multi-temporal GLIMS database. A complete global coverage of glacier mass changes (2000-2020) is now available (Hugonnet et al., 2021).

Progress:

- Ongoing effort of GLIMS community: http://www.glims.org/
- IACS Working Group working on this task: https://cryosphericsciences.org/activities/working-groups/rgi-working-group/ http://www.cryosphericsciences.org/wg_randGlacierInv.html
- Above products are brokered to C3S Climate Data Store: https://climate.copernicus.eu/

References:

Hugonnet, R., R. McNabb, R., E. Berthier et al. 2021 : Accelerated global glacier mass loss in the early twenty-first century, Nature, 592, 726–731. https://doi.org/10.1038/s41586-021-03436-z

Action T23:	Multi-decadal glacier inventories
Action	Continue to produce and compile repeat inventories at multi-decadal timescale
Benefit	Extend the time series of glacier information
Time frame	Ongoing
Who	NSIDC and WGMS with GLIMS research community and space agencies.
Performance indicator	Data coverage in GLIMS database
Annual cost	US$ 1–10 million

Assessment: 2 – Started but little progress.

A recent IACS working group (2020-2023) aims at finalizing the reference inventory around the year 2000 (RGI 7.0) and develop it further towards multi-temporal snapshots, e.g. around 2000, 2015, 1985.

Continued efforts in improving a worldwide glacier inventory within Copernicus Climate Change service: https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-glaciers-extent?tab=overview

National assessment of implementation (as of 2015) of international monitoring strategy, including state of glacier inventories: Gärtner-Roer et al., 2019: Worldwide assessment of national glacier monitoring and future perspectives. Mountain Research and Development. https://doi.org/10.1659/MRD-JOURNAL-D-19-00021.1

New IACS Working Group (RGI, 2020-2023):

https://cryosphericsciences.org/activities/working-groups/rgi-working-group/

Action T24:	**Allocate additional resources to extend the geodetic dataset**
Action	Allocate additional resources to extend the geodetic dataset at national, regional and global levels: decadal elevation change can potentially be computed for thousands of glaciers from air- and spaceborne sensors
Benefit	Improved accuracy of glacier change
Time frame	Ongoing
Who	WGMS with research community and space agencies
Performance indicator	Data coverage in WGMS database
Annual cost	US$ 30–100 million

Assessment: 3 – Underway with significant progress.

The WGMS has made significant progress in compiling geodetic elevation changes from thousands of glaciers thanks project funding from ESA and Copernicus and in collaboration with the research community.

Progress:

- The WGMS started to compile and produce geodetic elevation changes for several thousand glaciers within the Copernicus Climate Change Service: http://wgms.ch/boost-remote-sensing-data/
- The WGMS encouraged its network of Principal Investigators to participate in a first scientific exploitation of the global DEM product of the TanDEM-X mission for glacier monitoring: http://wgms.ch/boost-remote-sensing-data/
- In coordination with LEGOS and the WGMS, glaciologists can acquire stereo data of selected benchmark glaciers at the end of the melt season: http://wgms.ch/boost-remote-sensing-data/
- New IACS Working Group (RAGMAC, 2020-2023) aims at achieving global coverage: https://cryosphericsciences.org/activities/wg-ragmac/
- The new amount of data requires an upgrade of the database infrastructure at the WGMS. A proposal for a corresponding project with a database manager is under evaluation by the national agencies.

Action T25:	Extend the glacier-front variation dataset both in space and in time
Action	Extend the glacier-front variation dataset both in space and back in time, using remote-sensing, in situ observations and reconstruction methods
Benefit	Understanding long-term trends in glacier extent (mass trends need additional information)
Time frame	Ongoing
Who	WGMS with research community and space agencies
Performance indicator	Data coverage in WGMS database
Annual Cost	US$ 10 000–100 000

Assessment: 2 – Started but little progress.

The network of glaciers with reported front-variation measurements was maintained in Europe but has stopped in most other regions. Many in situ programmes were abandoned and not replaced by remotely sensed observations. In some regions, the observations were stopped because the glaciers have disintegrated and vanished.

Progress:

- WGMS has annual calls-for-data to compile glacier front variation data from direct observations.
- The WGMS has extended its database to store glacier front variations from reconstructions (e.g. historical & pictorial sources, dendrochronology).

Action T26:	Glacier observing sites
Action	Maintain current glacier-observing sites and add additional sites and infrastructure in data-sparse regions, including South America, Africa, the Himalayas, the Karakoram and Pamir mountain ranges, and New Zealand; attribute quality levels to long-term mass-balance measurements; improve satellite based glacier inventories in key areas
Benefit	Sustained global monitoring to understand global trends
Time frame	Continuing, new sites by 2017
Who	Parties' national services and agencies coordinated by GTN-G partners, WGMS, GLIMS and NSIDC
Performance indicator	Completeness of database held at NSIDC from WGMS and GLIMS
Annual cost	US$ 10–30 million

Assessment: 3 – Underway with significant progress.

Ongoing general action. This Action Item is covered in more detail by T22-T25.

There is an ongoing need for research & monitoring activities, ideally coordinated by the GTN-G bodies (i.e. WGMS, NSIDC, GLIMS). For more information see Gärtner-Roer et al. 2019 and national factsheets[63].

References:

Gärtner-Roer I, SU. Nussbaumer, F. Hüsler and M. Zemp. 2019: Worldwide assessment of national glacier monitoring and future perspectives. Mountain Research and Development, 39(2): A1–A11. https://doi.org/10.1659/MRD-JOURNAL-D-19-00021.1

Action T27:	Observations of glacier velocities
Action	Encourage observations and reporting of glacier velocities
Benefit	Improve understanding of glacier dynamics and mass loss
Time frame	Starting 2017
Who	GTN-G partners, WGMS, GLIMS and NSIDC
Performance indicator	Completeness of database held at NSIDC from WGMS and GLIMS
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Several projects have produced regional to global glacier velocity products. Observations of glacier velocity is an interesting parameter for glacier inventories (e.g. for separation of ice divides, ice thickness modelling) and glacier change estimates (e.g. flux gate method, calving rates, flow dynamics) but its interpretation as climate proxy is not straightforward.

Progress:

- ESA Glaciers_cci produced glacier velocities for several regions: http://www.esa-glaciers-cci.org/
- Global Land Ice Velocity Extraction from Landsat 8: https://nsidc.org/data/golive
- Cryoportal by ENVEO, at: http://cryoportal.enveo.at/data/

[63] See https://wgms.ch/national-glacier-state/

Action T28:	Snow-cover and snowfall observing sites
Action	Strengthen and maintain existing snow-cover and snowfall observing sites, provide clear and unambiguous instructions; ensure that sites exchange snow data internationally; establish global monitoring of those data over the GTS; and recover historical data; ensure reporting includes reports of zero cover.
Benefit	Improved understanding of changes in global snow
Time frame	Continuing; receipt of 90% of snow measurements at international data centres
Who	NMHSs and research agencies, in cooperation with WMO-GCW and WCRP and with advice from TOPC, AOPC and GTN-H
Performance indicator	Data submission to national centres such as NSIDC and world data services
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Several countries have monitoring networks on snow cover (monitor the snow depth and water equivalent along with other meteorological parameters), like the USA, Russia or China. It is easy for users to find the information on those networks in the websites of national meteorological organizations; for some of them users can get in situ observation data via application. At the websites of international data centres like NSIDC, most data users can find is obtained by remote sensing, re-analysis and modelling, which means still effort is needed on the international exchange of in situ observation data.

Action T29:	Integrated analyses of snow
Action	Obtain integrated analyses of snow over both hemispheres
Benefit	Improved understanding of changes in global snow
Time frame	Continuous
Who	Space and research agencies in cooperation with WMO-GCW and WCRP-CliC with advice from TOPC, AOPC and IACS
Performance indicator	Availability of snow-cover products for both hemispheres
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

Datasets produced by Aqua/Terra - MODIS, AMSR-E, DMSP - SSM/I, SSMI/S and POES-AVHRR with global coverage.

Datasets produced by Aqua/Terra - MODIS, AMSR-E, DMSP - SSM/I, SSMI/S and POES-AVHRR with global coverage can be found at the following websites:

- http://nsidc.org/data/g02156.html
- https://lpdaac.usgs.gov/products/modis_products_table
- http://www.globsnow.info/index.php?page=Data
- https://disc.gsfc.nasa.gov/datasets/
- https://cds.climate.copernicus.eu/#!/search?text=ERA5&type=dataset

Action T30:	**Ice-sheet measurements**
Action	Ensure continuity of in situ ice-sheet measurements and field experiments for improved understanding of processes and for the better assessment of mass-loss changes
Benefit	Robust data on trends in ice-sheet changes
Time frame	Ongoing
Who	Parties, working with WCRP-CliC, IACS and SCAR
Performance indicator	Integrated assessment of ice sheet change supported by verifying observations.
Annual cost	US$ 10–30 million

Assessment: 4 – Progress on track.

Ice sheet measurement has progressed and providing useful field data. Several areas have been intensively investigated and new changes were recognized. However, ice sheets are vast and large mass movement is very complicated with the interaction with bottom and ocean margins. More comprehensive measurements of process are expected.

Ongoing action for the research community, still not well coordinated.

Progress in Greenland:

- Danish Programme for the monitoring of the Greenland Ice Sheet: https://www.promice.dk/home.html

Progress in Antarctica:

- CRYOBSCLIM/GLACIOCLIM SurfAce Mass Balance of Antarctica Observatory: http://pp.ige-grenoble.fr/pageperso/favier/glacioclim-samba.php

Action T31:	Ice-sheet model improvement
Action	Research into ice-sheet model improvement to assess future sea-level rise; improving knowledge and modelling of ice–ocean interaction, calving ice-mass discharge
Benefit	Improved sea-level rise forecasting
Time frame	International initiative to assess local and global sea-level rise and variability
Who	WCRP-CliC sea-level cross-cut, IACS and SCAR
Performance indicator	Reduction of sea-level rise uncertainty in future climate prediction from ice-sheet contributions
Annual cost	US$ 1–10 million (mainly by Annex-I Parties)

Assessment: 4 – Progress on track.

Based on progressed ice sheet measurement, efforts on ice sheet modelling have been done. There is still uncertainty around ice sheet behaviour. Improvement of ice modelling is expected to answer to the strong concern on the sea level rise.

Progress Antarctica:

- Ice Sheet Mass Balance and Sea Level (ISMASS): https://www.scar.org/science/ismass/ismass/
- Progress in polar regions:
- IPCC (2019) SROCC
- https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/07_SROCC_Ch03_FINAL.pdf

Action T32:	Continuity of laser, altimetry and gravity satellite missions
Action	Ensure continuity of laser, altimetry and gravity satellite missions adequate to monitor ice masses over decadal timeframes
Benefit	Sustain ice-sheet monitoring into the future
Time frame	New sensors to be launched in 10-30 years
Who	Space agencies, in cooperation with WCRP-CliC and TOPC
Performance indicator	Appropriate follow-on missions agreed
Annual cost	US$ 30–100 million

Assessment: 4 – Progress on track.

Laser, altimetry and gravity satellite missions have been provided very useful observation data to monitor ice sheet change. For continuity of each observation, satellite programs should be coordinated internationally.

Zemp et al. (2019) provides a new global assessment on glacier changes combining in situ with (strongly extended) space-based observations Continued efforts in compiling glacier mass changes from geodetic methods continue within Copernicus Climate Change service: https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-glaciers-elevation-mass?tab=overview

Useful information:

- Hvidberg, C.S., et al., User Requirements Document (URD) for the Greenland_Ice_Sheet_cci project of ESA's Climate Change Initiative, version 2.4, 2017-11-22. Available from: http://www.esa-icesheets-cci.org/.
- Hvidberg, C.S., et al., User Requirements Document for the Ice_Sheets_cci project of ESA's Climate Change Initiative, version 1.5, 03 Aug 2012. Available from: http://www.esa-icesheets-cci.org/.
- Zemp, M., Huss, M., Thibert, E. et al. Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016. Nature 568, 382–386 (2019). https://doi.org/10.1038/s41586-019-1071-0

Action T33:	**Standards and practices for permafrost**
Action	Refine and implement international observing standards and practices for permafrost and combine with environmental variable measurements; establish national data centres
Benefit	Consistent and comparable global observations
Time frame	Complete by 2018
Who	Parties' national services/research institutions and IPA
Performance indicator	Implementation of guidelines and establishment of national centres
Annual cost	US$ 100 000–1 million

Assessment: 2 – Started but little progress.

A working group on “Best practice for permafrost measurement” was set up within GCW in May-June 2020.

Current measurements rely on standards developed by various projects (e.g. CALM protocols for active layer thickness, PACE21 requirements for boreholes).

These standards will be reworked and extended for other variables within the working group on best practices initiated by GCW in spring 2020. Several GTN-P SC members are involved in this working group.

For the proposal of new rock glacier kinematics product, standards and practices are elaborated and will be provided together with the product proposal by the International Permafrost Association (IPA) Action Group on rock glaciers.

Action T34:	Mapping of seasonal soil freeze/thaw
Action	Implement operational mapping of seasonal soil freeze/thaw through an international initiative for monitoring seasonally frozen ground in non-permafrost regions and active layer freeze/thaw in permafrost regions
Benefit	Improved understanding of changes in biosphere and carbon cycle
Time frame	Complete by 2020
Who	Parties, space agencies, national services and NSIDC, with guidance from IPA, the IGOS Cryosphere Theme team, and WMO-GCW
Performance indicator	Number and quality of mapping products published.
Annual cost	US$ 1–10 million

Assessment: 1 – Little or no progress.

No action undertaken by GTN-P.

GTN-P was fully occupied by the structuring of the permafrost monitoring network, and seasonal frost in non-permafrost areas was not a priority.

Observations show that seasonal frost can be valuably monitored only if measured together with snow thickness and soil moisture. The best way would be to implement it on standard meteorological stations.

Results show also that the seasonal freeze/thaw occurrence, frequency, depth and intensity are highly variable on short distances, due to the spatial variability of the snow cover, which questions the representativity of isolated measurement stations. This issue could be solved by setting up measurement arrays.

This is also being investigated by ESA's CCI+.

Action T35:	Ensure the consistency of the various radiant energy fluxes
Action	The various radiant energy fluxes (e.g. surface albedo and FAPAR) derived from remote-sensing observation, and their compatibility with the specific requirements of the models, especially in the context of climate change studies; fire and surface albedo, especially in the context of climate change studies
Benefit	Improved data leading to improved model predictions and understanding of changes in biosphere
Time frame	2020
Who	CEOS WG Cal/Val, TOPC observers, CEOS/CGMS WG Climate
Performance indicator	Documented system to ensure consistency; reports demonstrating consistency
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Significant progress occurred in modelling and retrieval methodology but efforts are still needed to provide operational data.

GEWEX-GDAP (Data and Assessments Panel) have had some efforts to do this in terms of producing a consistent global water and energy product (based around SRB). The GEWEX-LandFlux project "tried" to do this in developing the global surface heat flux product - but with varying success (i.e. the albedo, LAI, FAPAR etc were key challenges).

Methodology to check the physical consistencies between fire events and albedo changes (using several Earth Observation products) was done together with the impacts on radiative forcing (Mota B. et al., 2019).

Spatial and temporal consistencies of change for FAPAR and LAI using three sources of products were also studied. The Copernicus Climate Change Service (C3S) has ensured in its call for consistency between surface albedo, FAPAR and LAI (version 2 products) but the products were just released.

There remains a need for joint retrievals to ensure radiative consistency with QUANTIFY EOLDAS framework.

References:

Mota B., Gobron, N., Cappucci, F. and O. Morgan, 2019: Burned area and surface albedo products: Assessment of change consistency at global scale. Remote Sensing of Environment, 225, 249-266. DOI: 10.1016/j.rse.2019.03.001.

Action T36:	Climate change indicators for adaptation
Action	Establish climate change indicators for adaptation issues using land ECVs at high resolution
Benefit	Inputs into adaptation planning, damage limitation and risk assessments
Time frame	Initial products by 2018; ongoing development and improvement
Who	GCOS, GCOS Science panels, WCRP, GFCS
Performance indicator	Availability of indicators
Annual cost	US$ 100 000–1 million

Assessment: 4 – Progress on track.

TOPC has initiated a methodology of assessing current terrestrial ECVs as either being not relevant for adaptation, observations of adaptation, or observations for adaptation.

This activity is described in more detail within the body of the Status Report.

Action T37:	Quality of ground-based reference sites for FAPAR and LAI
Action	Improve the quality and number of ground-based reference sites for FAPAR and LAI; agree minimum measurement standards and protocols; conduct systematic and comprehensive evaluation of ground-based measurements for building a reference sites network
Benefit	Ensure quality assurance of LAI and FAPAR products
Time frame	Network operational by 2020
Who	Parties' national and regional research centres, in cooperation with space agencies and Copernicus coordinated by CEOS WGCV, GCOS and TOPC
Performance indicator	Data available
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

Quality of ground-based measurements was improved with an increase number of sites.

The CEOS LPV reviewed and proposed a new list of super-sites. Whereas the ESA FRM4VEG project (https://frm4veg.org/) assure the definition of standard protocols for vegetation products, the Ground-Based Observations for Validation (GBOV) of Copernicus Global Land GBOV project provides operationally raw measurements (together Land Products, e.g. up-scaling data) over 74 sites (https://land.copernicus.eu/global/gbov).

Action T38:	Improve snow and ice albedo products
Action	Improve quality of snow (ice and sea ice) albedo products
Benefit	Improve consistency of datasets
Time frame	2018
Who	Space agencies and Copernicus coordinated through CEOS WGCV LPV, WMO Space Programme, with advice from GCOS and TOPC
Performance indicator	Product available
Annual cost	US$ 100 000–1 million

Assessment: 2 – Started but little progress.

Despite the importance of snow (ice and sea ice) albedo for climate change, little progress has been seen to improve quality of snow (ice and sea ice) albedo products.

Action T39:	Improve in situ albedo measurements
Action	Improve quality of available in situ validation measurements and collocated albedo products, as well as BHR factors and measures of surface anisotropy from all space agencies generating such products; promote benchmarking activities to assess the reliability of albedo products
Benefit	Improved calibration and validation
Time frame	Full benchmarking/intercomparison by 2022
Who	BSRN and spatially representative FLUXNET sites, space agencies in cooperation with CEOS WGCV LPV
Performance indicator	Data available to analysis centres
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Only shortwave broadband albedo were provided over few sites. Progress for the protocol.

Baseline Surface Radiation Network (BSRN) and SURFace RADiation Budget Measurement Network (Surfrad) provides only shortwave broadband albedo only (not spectral) over several sites.

Only few sites implement tower observations, which are the most representative for monitoring purposes. US BSRN sites (most SURFRAD) perform homogeneous measurement from a nominal height of 10 m. To include upwelling components as basic requirements for future BSRN candidate stations, and to provide products for albedo in black-sky and white-sky conditions, are under discussion. Despite its wider distribution and tower implementation FLUXNET do not measure the irradiance with the same quality instruments and BSRN/SURFRAD and do not provide information of the diffuse component, which is useful in the process of cloud screening and reduction of the albedo to white-sky and black-sky components (see Copernicus Ground-Based Observation for Validation Service).

Theoretical 3D-RT based study shows how to improve the ground-based albedo quality.

- https://www.sciencedirect.com/science/article/pii/S0022407316300085
- CEOS protocol for the albedo (available at ceos.lpc web site).

Action T40:	Production of climate data records for LAI, FAPAR and Albedo
Action	Operationalize the generation of • 10-day and monthly FAPAR and LAI products as gridded global products at 5 km spatial resolution over time periods as long as possible; • 10-day FAPAR and LAI products at 50 m spatial resolution; • Daily (for full characterization of rapidly greening and senescing vegetation, particularly over higher latitudes with the rapid changes due to snowfall and snowmelt), 10-day and monthly surface albedo products from a range of sensors using both archived and current Earth observation systems as gridded global products at 1 km to 5 km spatial resolution of over time periods as long as possible
Benefit	Provide longer time records for climate monitoring
Time frame	2020
Who	Space agencies, Copernicus and SCOPE-CM coordinated through CEOS WGCV LPV
Performance indicator	Operational data providers accept the charge of generating, maintaining and distributing global physically consistent ECV products
Annual cost	US$ 100 000–1 million

Assessment: 4 – Progress on track.

Generation of 10-days global FAPAR and LAI products were operational provided from 300 m to few deg. No significant progress for higher resolution. Limitation of availability for past data

Albedo products.

- The CEOS WG Climate released an ECV inventory in October 2017 (see http://climatemonitoring.info/ecvinventory/);
- In addition to them, new operational, like C3S ones (https://cds.climate.copernicus.eu/) and research products are available to user's community.

The highest spatial resolution products are not operational at global scale but anymore could theoretically access to inputs data and use cloud server for making their own products at regional scale.

Action T41:	Evaluate LAI, FAPAR and Albedo
Action	Promote benchmarking activities to assess reliability of FAPAR and LAI products, taking into account their intrinsic definition and accuracy assessment against fiducial ground references Evaluate the albedo products with high-quality tower data from spatially representative sites
Benefit	Improved accuracy of data
Timeframe	Evaluation by 2019
Who	Space agencies and Copernicus in relation with CEOS WGCV, GCOS/TOPC
Performance indicator	Publish results
Benefit	Recommendations after gap analysis on further actions for improving algorithms
Annual cost	US$ 10 000–100 000

Assessment: 4 – Progress on track.

Benchmarking of existing operational products were done, and some used also fiducial ground measurements.

A lot of published results are available in peer-review articles. This concerns either regional or global scale studies for LAI, FAPAR and surface albedo. (see Mayr, S. et. al (2019) Validation of Earth Observation Time-Series: A Review for Large-Area and Temporally Dense Land Surface Products. Remote Sens. 11, 2616. and Special Issue "Recent Advances in Satellite Derived Global Land Product Validation" https://www.mdpi.com/2072-4292/11/22/2616).

Action T42:	Land-surface temperature: in situ protocols
Action	Promote standardized data protocols for in situ LST and support the CEOS-LPV group in development of a consistent approach to data validation, taking its LST Validation Protocol as a baseline
Benefits	LST datasets will be more accessible to users, encouraging user uptake of more than one LST dataset. This will lead to better characterisation of uncertainties and inter-dataset variability.
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV
Performance indicator	Availability of protocols and evidence of their use.
Annual cost	US$ 1 000 –10 000

Assessment: 5 – Complete.

The CEOS-LPV Group have produced a LST Validation Best Practices Guide

Support from the LST data providers and user community have enabled the CEOS-LPV Group to document the in situ validation protocols with regards to site implementation and validation of the satellite LST products in a Best Practices Guide (Guillevic et al., 2018). This protocol builds on earlier work (Schneider et al., 2021) and establishes a set of procedures which were already in common use. The protocol is now adhered to in many large agency projects (such as Sentinel-3 validation, ESA Climate Change Initiative, EUMETSAT validation of operational sensors, Copernicus global land validation). In addition to best practices for instrumentation and validation techniques these protocols also promote the use of harmonised data formats to enable easier cross-comparison.

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Schneider, P., D. Ghent, G. Corlett, F. Prata and J. Remedios, 2012: AATSR Validation: LST Validation Protocol. ESA Report, Contract No.: 9054/05/NL/FF, European Space Agency (ESA). UL-NILU-ESA-LST-LVP Issue 1 Revision 0. http://lst.nilu.no/Portals/73/Docs/Reports/UL-NILU-ESA-LST-LVP-Issue1-Rev0-1604212.pdf.

Action T43:	Production of land-surface temperature datasets
Action	Continue the production of global LST datasets, ensuring consistency between products produced from different sensors and by different groups
Benefits	Make available long time series of LST datasets in consistent formats, enabling more widespread use of LST for climate applications
Time frame	Continual
Who	Space agencies
Performance indicator	Up-to-date production of global LST datasets
Annual cost	US$ 10 000 –100 000

Assessment: 4 – Progress on track.

Space Agencies continue to produce LST data in near-real time in support of the long-term archives.

Space Agencies have operational processing chains in place to ensure continued production of LST data in near-real time to add to their long-term archives of LST data. Examples such as ESA's Sentinel-3A and Sentinel-3B, NASA's Terra MODIS and Aqua MODIS, NOAA's VIIRS, and EUMETSAT's Metop and MSG satellites for AVHRR and SEVIRI respectively, ensure the continuity of both global and regional LST data. New processing baselines are implemented in ground segments to ensure the latest scientific developments are exploited, and periodically long-term archives are re-processed to new Collections to converge to the most recent updates in the operational products.

Furthermore, continuity of the LST data is guaranteed through approved new operational missions to replace the existing ones prior to the end of their operational lives. Examples include Sentinel-3C and Sentinel-3D, NOAA's JPSS, and EUMETSAT's MTG. While each Agency disseminates operational LST data in a different format, community influence has encouraged many projects to start delivering data in format more harmonised across the science community. Examples include Sentinel-3C and Sentinel-3D, NOAA's JPSS, and EUMETSAT's MTG. While each Agency disseminates operational LST data in a different format, community influence has encouraged many projects to start delivering data in format more harmonised across the science community; examples include the Climate Change Initiative and Copernicus Services.

Action T44:	**Reprocessing land-surface temperature**
Action	Reprocess existing datasets of LST to generate a consistent long-term time series of global LST; in particular, reprocess archives of low Earth orbit and geostationary LST observations in a consistent manner and to community-agreed data formats
Benefits	Make available long time series
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV
Performance indicator	Availability of long time series of LST datasets
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Recent projects, such as ESA's LST CCI, EUMETSAT's CM SAF TCDRs, and NASA's MEaSUREs, are producing first long-term Climate Data Records with consistent algorithms.

In ESA's LST CCI two dedicated Climate Data Records (CDRs) will be produced from InfraRed (IR) satellites. One will be based on the ATSR/SLSTR sensors, using MODIS to fill the gap between (A)ATSR and SLSTR. The other will merge data from Low Earth Orbiting (LEO) and Geostationary Earth Orbiting (GEO) satellites to provide a consistent global, sub-daily data set. A multi-decadal MicroWave (MW) LST data set from SSM/I sensors is also being produced. In EUMETSAT's CM SAF a long term TCDR is being produced combining data from being MVIRI and SEVIRI sensors for Europe and Africa. NASA's MEaSUREs project is producing a unified and coherent Land Surface Temperature and Emissivity (LST&E) Earth System Data Records (ESDRs) for MODIS, by combining two existing products, and GOES for hourly products over N. America. In each case, within-project consistency in algorithms, cloud detection techniques, emissivity inputs and radiative transfer modelling is ensured.

Action T45:	Land-surface temperature in situ network expansion
Action	Expand the in situ network of permanent, high-quality IR radiometers for dedicated LST validation
Benefits	LST datasets better validated and over more land-surface types; independent validation of stated accuracies providing credibility to satellite LST products
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV, ILSTE
Performance indicator	Establishment of a comprehensive network of ground sites with high-quality in situ measurements suitable for validating the different sensors; results from in situ radiometer intercomparison exercises
Annual cost	US$ 1–10 million (10-20 sites at US$ 100 000 per site)

Assessment: 3 – Underway with significant progress.

Major recent projects have started to expand the network of LST stations with publicly accessible data.

Two recent initiatives have begun to expand the network for LST validation with new in situ sites: i) Copernicus Ground-Based Observations for Validation of Copernicus Land Products (GBOV); and ii) Copernicus Space Component Validation for Land Surface Temperature, Aerosol Optical Depth and Water Vapour Sentinel-3 Products (LAW). In each project new LST radiometers have been/are being installed on existing infrastructure. Currently the expansion is 3 new stations from GBOV and 5 new stations from LAW. The selection of station deployment has been aimed at filling gaps in the LST validation over different geographical and climatological regions. While an objective of these studies is the validation of Copernicus products (LST from Copernicus Global Land Service, and LST from Sentinel-3 respectively), the publicly accessible provision of both in situ data and in situ vs. satellite matched data presents a wider user community the opportunity to validate other LST data products using data from these new stations.

Action T46:	Land-surface temperature radiometric calibration
Action	Radiometric calibration intercomparisons and uncertainties for LST sensors
Benefits	LST datasets better calibrated and over all land-surface types for different satellite sensors; independent calibration providing credibility and traceability of data and uncertainties
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Coordinated by CEOS WGCV Infrared and Visible Optical Sensors subgroup/GSICS and supported by space agencies
Performance indicator	ECV generators taking into account radiometric calibration uncertainties, ideally with calibrations being referenced to a common framework
Annual Cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Development of Fundamental Climate Data Records and establishment of fully traceable routes.

Fundamental Climate Data Records (FCDRs) have been produced within the FIDUCEO project for the AVHRRs, within CM SAF for SSM/I, and intercalibration has been performed for SEVIRI within GSICS. These FCDRs are the critical inputs to developing long-term Thematic Climate Data Records (TCDRs) for LST. Projects such as LST CCI are additionally intercalibrating between other sensors for developing TCDRs using GSICS approaches.

In terms of traceability of LST data and associated uncertainties, evidence to justify the quality of data requires a full uncertainty budget showing a comparison to an independent reference which is also SI traceable and with an associated uncertainty. The FRM4STS project has established a traceable route from the in situ radiometers at Gobabeb, Namibia to the blackbody source at the UK's National Physical Laboratory (NPL).

Action T47:	Land-cover experts
Action	Maintain and strengthen a global network of land-cover/land-use experts to: develop and update an independent, very high spatial-resolution reference dataset for global land-cover map accuracy assessment; and facilitate access to land-use and management information to support the development of global-scale land-use products
Benefits	For GLC map developers, GLC map users
Time frame	Network concept and approach by 2017; implementation by 2018
Who	GOFC-GOLD, CEOS WGCV/LPV, Parties' national services and research agencies, space data providers, NASA LCLUC, TOPC
Performance indicator	Global LC map developers using the reference data developed by the operational network
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Important progress towards the development and update of independent global land cover reference dataset, but limited progress on expanding to land use/management issues due to limited funding for international coordination.

A reference data portal containing many published/historical land cover reference/validation data have been assessed and made available (http://www.gofcgold.wur.nl/sites/gofcgold_refdataportal.php). More consistent reference data is collected by the EC Copernicus global land monitoring service and will be made available in the future as annual operational data stream (https://land.copernicus.eu/global/products/lc). Global land use change datasets are in evolution in the research domain. Overall, there is a lack of support for better coordination of land cover/use monitoring activities globally.

Action T48:	Annual land-cover products
Action	Generate annual land-cover products over key regions that allow change assessment across time (including for the six IPCC AFOLU land categories) at 10 m–30 m spatial resolutions, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy
Benefits	For mitigation and adaptation communities
Time frame	2017 and beyond
Who	Space agencies, GOFC-GOLD, Copernicus Land Service, USGS, University of Maryland (UMD)-GoogleEarth
Performance indicator	Product delivered and used by a large community; use of standard approaches for validation and uncertainty metrics
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress. First prototype global land cover and change datasets are in development in the research and global demonstration domain.

Several pre-operational efforts are producing global and regional land cover datasets using Landsat and increasingly Sentinel data. They include UMD annual global tree cover gains and losses, China's 30 m global land cover, and ESA/UCL first 20 m prototype land cover map for Africa and the following LC-CCI activities. ESA planning to release a global 10 m land cover data for 2020. None of them allow for a global change assessments at 30 m resolution for all IPCC land use categories and also the independent validation for both high resolution land cover and changes is just starting.

Action T49:	Land-cover change
Action	Generate global-scale land-cover products with an annual frequency and long-term records that allow change assessment across time (including as much as possible for the six IPCC AFOLU land categories), at resolutions between 250 m and 1 km, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy
Benefits	To climate change modellers, others
Time frame	2017 and beyond
Who	Space agencies, research institutes, GOFC-GOLD, Copernicus Land Service
Performance indicator	Product delivered and used; use of standard approaches for validation and uncertainty metrics
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

Annual land cover change at 300 m is provided by LC-CCI and the Copernicus climate service.

The ESA CCI land cover project has generated and made available a long-time series of land cover changes (https://www.esa-landcover-cci.org/) for the six IPCC categories. This is continued now as part of the Copernicus Climate Monitoring service with annual updates. No validation of the annual land cover changes has been published so far.

Action T50:	Land-cover community consensus
Action	Develop a community consensus strategy and priorities for monitoring to include information on land management in current land-cover datasets and start collecting relevant datasets and observations, building on ongoing activities
Benefits	To climate change modellers, mitigation and adaptation user communities
Time frame	Concept and approach by 2017; start Implementation by 2018
Who	Parties' national services and research agencies, space agencies, GOFC-GOLD, NASA LCLUC, TOPC, UMD-GoogleEarth, CEOS, ESA, USGS, GOFC-GOLD, FAO, GEO
Performance indicator	Product delivered and used
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress. Important progress in the dialog between data users and producers on the needs and opportunities to better integrate land management information, but production of such data is still in initial stage.

Two community-consensus benchmark scientific papers (see References below) have been published to clarify and status and needs to include land use and land management information earth system and integrated assessment models. They can be used as reference document to start collecting data (for modeling purposes) and identify further gaps and observational challenges.

References:

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Action T51:	Deforestation
Action	Develop yearly deforestation (forest clearing) and degradation (partial clearing) for key regions that allow change assessment across time at 10 m–30 m spatial resolutions, according to internationally agreed definitions.
Benefits	To provide annual monitoring of deforestation and forest degradation to support management and reporting
Time frame	Concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space agencies, GOFC-GOLD, NASA LCLUC, UMD-GoogleEarth, TOPC.
Performance indicator	Indicators-based standard validation approach for change of forest cover and attributions associated with deforestation and degradation; product delivered and used
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress.

Annual global tree cover loss data are being produced regularly, but does not provide estimates of deforestation (according to FAO definition).

UMD/GLAD are producing annual global tree cover loss and gain data using Landsat data 2000-18. There is inconsistency with the forest and deforestation definition used by FAO FRA. Some sample-based approach (FAO/JRC) has been used to map tropical deforestation and follow up land use but has not recently been updated.

Many countries involved in REDD+ are now capable of producing forest area change estimates at annual or bi-annual level using satellite time series for reporting using the IPCC GHG inventory good practice guidelines. A related method and guidance document have been developed by the Global Forest Observation Initiative (GFOI) that is now widely used by countries (www.gfoi.org/methods-guidance/).

Action T52:	Collaboration on above ground biomass
Action	Encourage inter-agency collaboration on developing optimal methods to combine biomass estimates from current and upcoming missions (e.g. ESA BIOMASS, NASA GEDI and NASA-ISRO NiSAR, JAXA PALSAR, CONAE SAOCOM)
Benefits	Reduced error, cross-validation, combining strengths of different sensors in different biomass ranges
Time frame	Most key missions are expected to be in orbit between 2016 and 2020
Who	ESA, NASA, JAXA, NASA-ISRO, CONAE
Performance indicator	A strategy to combine biomass estimates from different sensors, together with algorithms and processing methods
Annual cost	US$ 100 000–1 million

Assessment: 3 – Underway with significant progress

A recent meeting at the International Space Science Institute ISSI, (http://www.issibern.ch/workshops/biomass/) has been important for collaboration and inter-calibration. A special issue in a scientific journal has been prepared showcasing several of the ongoing collaboration efforts (https://link.springer.com/journal/10712/40/4). Space agencies are interacting and collaboration needs to improve now that an increasing number of space-based biomass data are starting operation.

Action T53:	**Above-ground biomass validation strategies**
Action	Encourage inter-agency collaboration to develop validation strategies for upcoming missions aimed at measuring biomass (e.g. ESA BIOMASS, NASA GEDI and NASA-ISRO NiSAR), to include combined use of in situ and airborne lidar biomass measurements
Benefits	Potential to produce more comprehensive validation of biomass estimates by cost-sharing. Greater consistency between biomass estimates from different sensors because of assessment against common reference data
Time frame	From now until the operational phase of the various sensors (2016–2022).
Who	ESA, NASA, JAXA, NASA-ISRO, CONAE
Performance indicator	Formal agreement between agencies on a strategy for joint gathering and sharing of validation data, together with funding of specific elements of the overall set of validation data
Annual cost	US$ 10 000–100 000

Assessment: 3 – Underway with significant progress.

A CEOS LPV biomass calibration and validation protocol has been developed.

The CEOS LPV has established a team focusing on biomass and the effort to develop a validation protocol has started. A biomass cal/val protocol has been developed (see concept here: https://link.springer.com/article/10.1007/s10712-019-09538-8) and should be finalized and released very soon.

Action T54:	Above-ground biomass validation sites
Action	Develop a set of validation sites covering the major forest types, especially in the tropics, at which high-quality biomass estimations can be made, using standard protocols developed from ground measurements or airborne lidar techniques
Benefits	Essential to give confidence in satellite-derived biomass estimates at global scale
Time frame	From now up to the operational phase of the various sensors (2018–2022)
Who	Space agencies working with key in situ networks (e.g. RainFor, Afritron, the Smithsonian Center for Tropical Forest Science), GEO-GFOI
Performance indicator	Establishment of a comprehensive network of ground sites with high-quality, in situ biomass estimates with uncertainty assessments suitable for validating the different sensors
Annual cost	US$ 30–100 million (50 tropical sites covering all forest types: US$ 20 million); estimate for temperate and boreal sites not yet formulated

Assessment: 3 – Underway with significant progress.

Several initiatives are progressing in compiling and assessing the quality of biomass reference data for global ECV calibration and validation purposes.

The in situ community from tropical biomass networks (i.e. Rainfor, Afritron, 2ndFor etc.) have proposed a framework to develop a set of validation sites. A first effort has resulted in the FOS network and standardized some available in situ datasets (http://forest-observation-system.net/).

The Global Ecosystem Dynamics Investigation (GEDI) team is putting together a comprehensive calibration database to be ready for GEDI operation in 2019-21.

The ESA Globbiomass and Biomass-CCI project has putting together a comprehensive global biomass validation database to independently validate the 2010, 2017 and 2018 products with the focus on climate model users.

Action T55:	Above-ground biomass data access
Action	Promote access to well-calibrated and validated regional- and national-scale biomass maps that are increasingly being produced from airborne lidar.
Benefits	Greatly extends the representativeness of data available for validating satellite-derived biomass data, since a much greater range of land types and forest conditions will be covered
Time frame	From now until the operational phase of the various sensors (2016–2022)
Who	GEO-GFOI, other national and international bodies producing biomass maps
Performance indicator	Availability of multiple regional- to country-scale maps of biomass derived from airborne lidar; use of standard protocols for uncertainty assessment of lidar estimation of biomass
Annual cost	US$ 10 000–100 000 (does not include monitoring costs)

Assessment: 2 – Started but little progress.

Some initial datasets are becoming available.

Several initiatives have been producing regional biomass maps and data bases that have been made available (i.e. Global Forest Watch, www.globalforestwatch.org, ESA Globbiomass project globbiomass.org). Australia has put together a comprehensive regional biomass database (www.tern.org.au)

Action T56:	**Above-ground biomass: forest inventories**
Action	Improve access to high-quality forest inventories, especially in the tropics, including those developed for research purposes and REDD+
Benefits	Extends the data available for validating satellite-derived biomass data
Time frame	From now until the operational phase of the various sensors (2016–2022)
Who	GEO-GFOI, other national and international bodies producing or funding forest inventories
Performance indicator	Access to databases of georeferenced biomass measurements derived from ground measurements for forest-inventory purposes
Annual cost	US$ 10 000–100 000

Assessment: 2 – Started but little progress.

Country National Forest Inventory (NFI) capacities for biomass estimation are improving and more data are becoming available for global purposes, but so far little integration with global monitoring efforts.

The GFOI R&D coordination team in collaboration with FAO and the Worldbank Forest Carbon Partnership Facility (FCPF) have collaborated with countries to share NFI data on aggregate level for the purpose of updating the biomass Tier 1 defaults the 2019 refinement of the IPCC GPG for AFOLU. This effort could be seen as a pilot to see if and how an interaction between NFI efforts in the tropics and biomass mapping from space can start to exchange and integrate more. GFOI is a central body to establish such a mechanism and to improve the demonstration of approaches how global space-based biomass estimation can better link with national forest monitoring efforts.

Action T57:	**Soil carbon: carbon mapping**
Action	Cooperate with the soil-carbon mapping exercises to advocate accurate maps of soil carbon
Benefit	Improved data accuracy
Time frame	Ongoing
Who	TOPC and GCOS
Performance indicator	Improved maps
Annual cost	US$1 000–10 000

Assessment: 3 – Underway with significant progress.

A new global; soil carbon map coordinated by FAO is available (see http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/).

Action T58:	Soil-carbon change
Action	Encourage flux sites to measure soil carbon at five-year intervals and record soil-management activities; use this to supplement long-term experiments that are monitoring soil carbon.
Benefit	Improved in situ observations will improve accuracy.
Time frame	Ongoing
Who	TOPC and GCOS
Performance indicator	Number of flux sites making measurements
Annual cost	US$10 000–100 000

Assessment: 2 – Started but little progress.

Despite maps being updated (see action T57) there is little progress on monitoring changes

Action T59:	Soil carbon – histosols
Action	Provide global maps of the extent of histosols (peatlands, wetlands and permafrost) and their depth
Benefit	Improve understanding of carbon pools at risk from climate change
Time frame	Ongoing
Who	Research communities, ISRIC, HWSD and the Global Soil Map
Performance indicator	Availability of maps
Annual cost	US$ 10 000–100 000

Assessment: 2 – Started but little progress.

National soil carbon observations are contribution to improved global maps

Action T60:	Historic fire data
Action	Reanalyse the historical fire-disturbance satellite data (1982 to present)
Benefits	Climate-modelling communities
Time frame	By 2020
Who	Space agencies, working with research groups coordinated by GOFC-GOLD-Fire By 2020
Performance indicator	Establishment of a consistent dataset, including the globally available AVHRR data record
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

There is some activity on this topic by research organisations and government funded organisations.

Action T61:	Operational global burned area and fire radiative power
Action	Continue the production of operational, global burned area active fire (with associated FRP) products, with metadata and uncertainty characterizations that meet threshold requirements and have necessary product back-up to ensure operational delivery of products to users.
Benefits	Climate-modelling communities, space agencies, civil protection services, fire managers, other users
Time frame	Continuous
Who	Space agencies, Copernicus Global Land Service, Copernicus Atmospheric Monitoring Service, GOFC-GOLD
Performance indicator	Availability of products that meet user needs
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

Production of operational fire products continue at the global scale (with a number of other products available for selected regions and limited time periods). These include:

- Burned Area: MODIS (MCD64); Copernicus CGLS; ESA CCI
- Fire Radiative Power (FRP): Copernicus CAMS that is assimilated into the GFAS system; NASA MODFIRE;
- Active Fire Data come from a number of sources including from MODIS, SLSTR, VIIRS and sensors in geo-stationary orbit.

It is less clear on the status of these products with regard to the availability of supporting information on metadata and uncertainty characterization. Kevin Tansey invites experts to contribute to discussion around this topic and provide evidence work on uncertainty characterization is on-going, the definitions that are in use and how this information is embedded or made explicit in products.

Action T62:	Fire maps
Action	Consistently map global burned area at < 100 m resolution on a near-daily basis from combinations of satellite products (Sentinel-2, Landsat, Sentinel-1, PROBA); work towards deriving consistent measures of fire severity, fire type, fuel moisture and related plant-fuel parameters
Benefits	Climate-modelling communities, space agencies, civil protection services, fire managers, other users
Time frame	By 2020
Who	Space agencies, research organizations, international organizations in collaboration with GOFC-GOLD- Fire
Performance indicator	Availability of data and products
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress.

The ESA CCI project is developing these products.

Action T63:	Fire validation
Action	Continuation of validation activity around the detection of fire-disturbed areas from satellites to show that threshold requirements are being met; work to reduce the errors of commission and omission; provide better than existing uncertainty characterization of fire-disturbance products.
Benefits	Climate-modelling communities.
Time frame	Continuous
Who	Space agencies and research organizations, supported by CEOS LPV
Performance indicator	Publication of temporal accuracy
Annual cost	US$ 1–10 million

Assessment: 4 – Progress on track.

There has been a strong development against this action. Work funded by the European Space Agency and the Copernicus programmes has supported the production of a statistically robust sampling framework for the collection of reference data from higher resolution sensors (Landsat) to validate global burned area products. The reference data set comprises at least 100 image pairs for each year covering the period 2003 to 2014. Based on this data set that stability of products can be established. The methodology for deriving the reference data sample and the metrics of reporting accuracy has been published in the peer-reviewed literature. The results will give insight into how algorithms and detection methods can be improved to reduce uncertainty in future iterations.

Action T64:	**Fire disturbance model development**
Action	Continuation of joint projects between research groups involved in the development of atmospheric transport models, dynamic vegetation models and GHG emission models, the climate-modelling and transport-modelling community and those involved in the continual algorithm development, validation and uncertainty characterization of fire-disturbance products from satellite data (the Earth observation and modelling community); contribute to better understanding of fire risk and fire-risk modelling
Benefits	Climate-modelling communities, Copernicus Programme
Time frame	Continuous
Who	Space agencies (NASA, ESA, etc.), inter-agency bodies (GOFC-GOLD, CEOS, ECMWF, Meteosat, etc.), Copernicus Global Land Service, Copernicus Atmospheric Monitoring Service, GOFC-GOLD
Performance indicator	Projects that engage climate and atmospheric transport modellers and product-development community
Annual cost	US$ 1–10 million

Assessment: 3 – Underway with significant progress

There is consolidated activity on this action within the ESA CCI project. There is further use of Fire Disturbance Products in the GFAS and GFED (not recently updated) products.

Action T65:	**Anthropogenic water use**
Action	Collect, archive and disseminate information related to anthropogenic water use
Benefit	Accurate and up-to-date data on water availability and stress
Time frame	Continuous
Who	UN-Water, IWMI and FAO through AQUASTAT in collaboration with UN Statistics Division and other data sources
Performance indicator	Information contained in the AQUASTAT database.
Annual cost	US$ 100 000–1 million

Assessment: 4 – Progress on track. This has been done as much as possible, within the constraints of the data set itself. Considerable effort has been expended by FAO to collect data and update AQUASTAT – the database of anthropogenic water use. AQUASTAT has been cooperating with GTN-H to improve data collection. Anthropogenic water use is important as it reflects human needs, especially for agriculture, and also is a response to changing temperatures.

Action T66:	Pilot projects: anthropogenic water use
Action	Develop and implement pilot data-collection exercises for water use
Benefit	Demonstrate data-collection approaches for wide implementation
Time frame	2016–2019
Who	GTN-H, UN-Water, IWMI and FAO through AQUASTAT in collaboration with the Convention on the Protection and Use of Transboundary Watercourses and International Lakes
Performance indicator	Completed data collection in pilot areas
Annual cost	US$ 100 000–1 million

Assessment: 1 – Little or no progress.

The way ahead will need to be discussed with GCOS technical support and possibly within the TOPC. Running a pilot with input from a country with advanced collection capabilities (e.g. within EU or Australia) may be the best option, but we need to know what the target data set should look like.

Action T67:	Improve global estimates of anthropogenic greenhouse-gas emissions
Action	Continue to produce annual global estimates of emissions from fossil fuel, industry, agriculture and waste; improve these estimates by following IPCC methods using Tier 2 for significant sectors; this will require a global knowledge of fuel carbon contents and a consideration of the accuracy of the statistics used
Benefit	Improved tracking of global anthropogenic emissions
Time frame	Ongoing, with annual updates
Who	IEA, FAO, Global Carbon Project (GCP), Carbon Dioxide Information Analysis Centre (CDIAC), Emissions Database for Global Atmospheric Research (EDGAR)
Performance indicator	Availability of Improved estimates.
Annual cost	US$ 10 000–100 000

Assessment: 4 – Progress on track.

Significant progress has been made with revised guidelines in 2019 but more work is needed to lower uncertainties and improve coverage. Estimates are reviewed and used by the Global Carbon Project[64] (https://www.globalcarbonproject.org/, Friedlingstein et al., 2020). Examples of datasets available include:

- CarbonTracker Europe: https://www.carbontracker.eu/
- Jena CarboScope: http://www.bgc-jena.mpg.de/CarboScope
- Copernicus Atmosphere Monitoring Service: https://ads.atmosphere.copernicus.eu/cdsapp
- The Japan Agency for Marine-Earth Science and Technology (JAMSTEC)'s Model for Interdisciplinary Research on Climate (MIROC)-based Earth System Simulation version 2 (referred to as MIROC-ES2L) (Hajima et al., 2020).

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[64] https://www.globalcarbonproject.org/

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Action T68:	Use of satellites for Land use, land-use change and forestry emissions/removals
Action	Support the improvement of estimates of emissions and removals from Forestry and Land-use change by using satellite data to monitor changes where ground-based data are insufficient.
Benefit	Improved global and national monitoring of LULUCF
Time frame	Ongoing.
Who	National reporting supported by international agencies through programmes such as UNREDD and GFOI
Performance indicator	Availability of satellite data
Annual cost	US$ 100 000–1 million

Assessment 3: – Underway with significant progress.

Satellite imagery is routinely used to monitor forest emissions and removals and used to provide monitoring data for REDD+[65]. Many countries used remote sensing of forest to support reporting emissions and removals of GHG to the UNFCCC. Projects such as the Global Forest Observations Initiative (GFOI) support developing countries by providing access to satellite data, methods and training.

Action T69:	Research on the land sink
Action	Research to better understand the land sink, its processes and magnitudes
Benefit	Better understanding of the global carbon cycle
Time frame	Ongoing
Who	GCP, research groups
Performance indicator	Published results
Annual cost	US$ 100 000–1 million

Assessment 3: – Underway with significant progress.

[65] The UNFCCC activity for “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".

Research is on-going to refine the understanding of the land sink and a paper on observing the carbon cycle as a whole is being prepared. The Global Carbon Project reviews estimates of the carbon land and uses them in their budget estimates[66].

Action T70:	Use of Inverse modelling techniques to support emission inventories
Action	Develop inverse modelling methods to support and add credibility to emission inventories; develop and disseminate examples for several GHGs
Benefit	Added credibility of national emission/removal estimates and demonstration of inventory completeness
Time frame	Ongoing
Who	National Inventory agencies, researchers
Performance indicator	Published results
Annual cost	US$ 1–10 million

Assessment 4: – Progress on track.

Techniques are being refined, with continental scale estimates. National fluxes estimated for many countries.

Action T71:	Prepare for a carbon-monitoring system
Action	Preparatory work to develop a carbon monitoring system to be operational by 2035; Development of comprehensive monitoring systems of measurements of atmospheric concentrations and of emission fluxes from anthropogenic area and point sources to include space based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improved estimates of national emissions and removals
Time frame	Initial demonstration results by 2023 – complete systems unlikely before 2030
Who	Space agencies
Performance indicator	Published results
Annual cost	US$ 10–100 billion

[66] Global Carbon Project (GCP) https://www.globalcarbonproject.org/ Global Carbon Project (2020) Carbon budget and trends 2020. published on 11 December 2020 Earth System Science Data, 12, 3269–3340, 2020, DOI: 10.5194/essd-12-3269-2020

Assessment 5: – Complete.

Preparations are well developed with the EU with ESA, ECMWF and EUMETSAT are setting up a CO_2 Monitoring and Verification Support Capacity

Action T72:	Prepare for a latent and sensible heat flux ECV
Action	Review the feasibility of global monitoring of latent and sensible heat fluxes form the land surface; prepare proposals for such an ECV. Development of comprehensive monitoring systems of measurements of atmospheric concentrations and emission fluxes from anthropogenic point sources, to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improve understanding of heat fluxes over land
Time frame	2017
Who	TOPC
Performance indicator	Proposals for consideration by GCOS Steering Committee
Annual cost	US$10 000–100 000

Assessment 5: – Complete.

This was agreed by the GCOS Steering Committee to be a new ECV. Work is continuing to implement this.