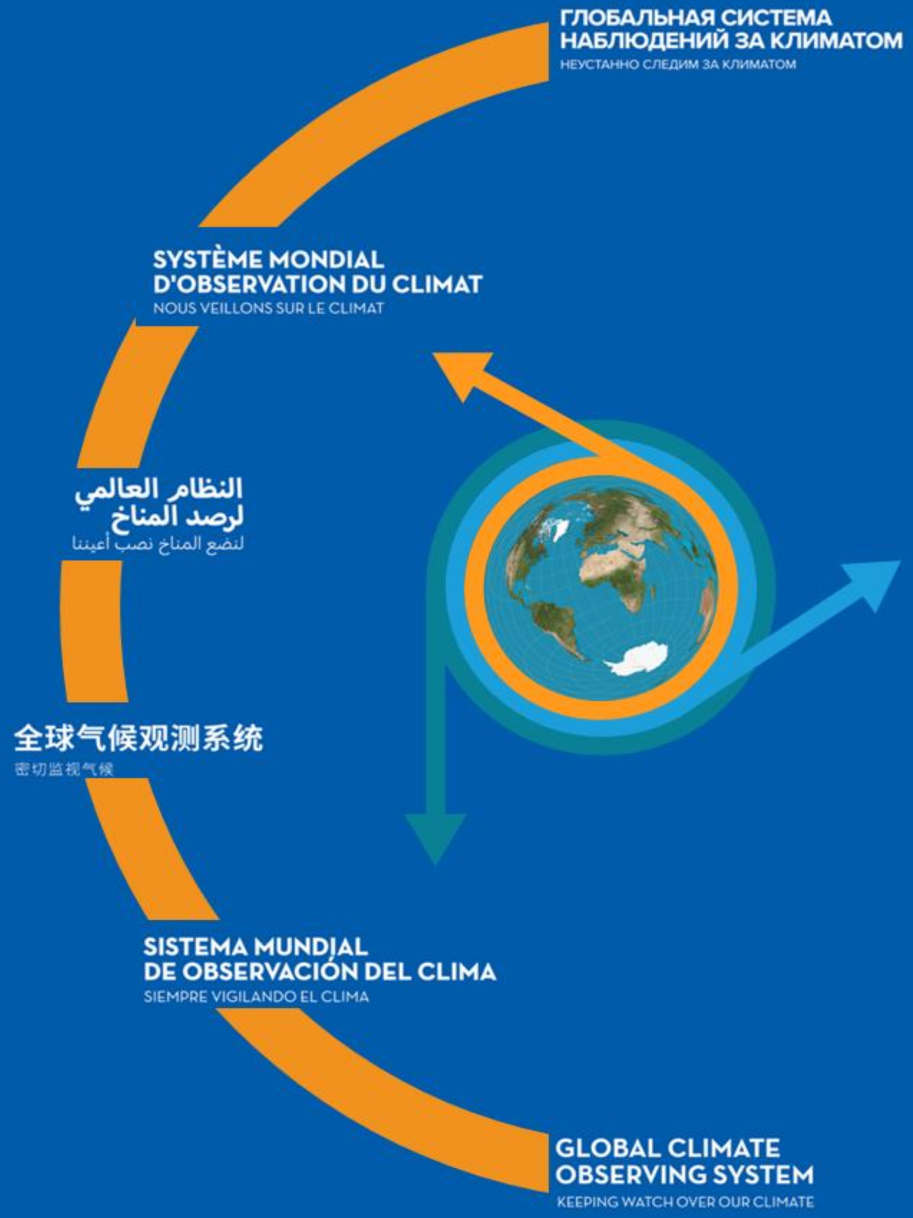
The 2022 GCOS Implementation Plan

WMO/NMHS Supplement



GCOS

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

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1. INTRODUCTION

The WMO/NMHS Supplement to the 2022 GCOS Implementation Plan extracts those activities for which we have identified WMO and NMHS as primary implementers.

The 2022 GCOS Implementation Plan (GCOS 244) is the latest in a series of implementation plans produced by GCOS since its inception in 1992. It provides a set of high priority actions which if undertaken will improve global observations of the climate system and our understanding of how it is changing. The 2022 GCOS ECVs Requirements (GCOS-245) provides revised requirements for the ECVs.

This plan aims to identify the major practical actions that should be undertaken in the next 5-10 years. It identifies six major themes that should be addressed. Within each theme, several actions are identified.

This supplement only lists those actions within each theme that are targeted at WMO and NMHS. Within each action the specific activities for WMO and NMHS are highlighted in bold.
For actions that should be performed by other actors, details can be found in the main report.
This supplement is complemented by other supplements aimed at specific communities.

Acronyms, references and a list of contributors can be found in the main report GCOS 244.

Table 1. Actions for WMO and NMHS and their links to the WMO strategic plan 2020-2023

Theme	Actions	WMO	NMHS	Relevant Long-term goals in the WMO Strategic plan
A: ENSURING SUSTAINABILITY	A1. Ensure necessary levels of long-term funding support for in-situ networks, from observations to data delivery	x	x	2.1
B: FILLING DATA GAPS	B1. Development of reference networks (in-situ and satellite Fiducial Reference Measurement (FRM) programs)	x	x	2.1
	B2. Development and implementation of the Global Basic Observing Network (GBON)	x	x	2.1
	B4. Expand surface and in situ monitoring of trace gas composition and aerosol properties		x	2.1
	B5. Implementing global hydrological networks	x	x	2.1
	B6. Expand and build a fully integrated global ocean observing system		x	2.1
	B8. Coordinate observations and data product development for ocean CO_2 and N_2O	x		2.1 & 2.2
	B9. Improve estimates of latent and sensible heat fluxes and wind stress		x	3.1
C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING	C1. Develop monitoring standards, guidance and best practices for each ECV	x		2.1
	C3. General Improvements to in-situ data products for all ECVs		x	2.1
D: MANAGING DATA	D1. Define governance and requirements for Global Climate Data Centres	x		2.2
	D2. Ensure Global Data Centres exist for all in situ observations of ECVs	x	x	2.2
	D4. Create a facility to access co-located in-situ cal/val observations and satellite data for quality assurance of satellite products	x	x	2.2
	D5. Undertake additional in situ data rescue activities	x	x	2.2
E: ENGAGING WITH COUNTRIES	E1. Foster regional engagement in GCOS	x		4.1
	E2. Promote national engagement in GCOS		x	4.2
F: OTHER EMERGING NEEDS	F1. Responding to user needs for higher resolution, real time data	x	x	3.1
	F3. Improve monitoring of coastal and Exclusive Economic Zones		x	3.1
	F4. Improve climate monitoring of urban areas	x	x	3.1
	F5. Develop an Integrated Operational Global GHG Monitoring System	x		3.3

2. THEME A: ENSURING SUSTAINABILITY

Long-term, continuous, in situ[1] and satellite observations of the climate are necessary to understand and respond to the changing climate.

Sustained funding is essential to ensure the continuity and the expansion needed for many in situ observations of ECVs.

Since these observations are executed by a large range of actors, an effective observing system may benefit from an improved international coordination across networks and programs. Here the potential of "economy of scales" could make procurements of instruments less expensive. Sustainable networks need sustained funding and support that covers training, capacity building, equipment maintenance and replacement. Partnerships between experienced and less experienced actors provide this support.

Future climate observing capabilities that are at risk are identified in the 2021 GCOS Status Report. This Action focuses on those in situ observations that are particularly at risk, however all current observations of ECVs need to be sustained.

Action A1: Ensure necessary levels of long-term funding support for in situ networks, from observations to data delivery	
Activities	**1. Undertake an assessment of current levels of funding support for global in situ networks delivering relevant in situ ECV data, including cal/val measurements, and identify those in situ networks with immediate or short-term problems around adequacy and sustainability of funding - by end of 2023.** **2. Identify entities that can provide support for the networks identified as at risk in Activity 1.** **3. Advocate with funding agencies to support identified networks.**
Issue/Benefits	Not all in situ networks have the assurance of the long-term support needed to ensure the continuity and development of long-term time-series needed for climate monitoring. Although progress has been made, some networks are still supported by short- and fixed-term funding or have inadequate funding support. This action aims to make progress in addressing this issue by improving the sustainability of in situ measurement programs. Improved funding support for networks performing measurements of ECVs would improve our ability to undertake long-term monitoring of the changing climate system. This informs climate assessments such as IPCC and WMO annual reports. Furthermore, it is essential for climate services, adaptation activities and mitigation efforts. Sustained in situ observations provide critical input to reanalyses and aid satellite cal/val activities, especially as new missions/instruments are launched.
Implementers	From 1 to 3: **GCOS**, WMO, NMHSs, Research organizations, Academia, Funding agencies.
Means of Assessing Progress	1. Initial inventory of the funding profile for identified in situ networks that provide ECVs, considering adequacy and sustainability of funding support. Findings are to be prepared by all GCOS panels and consolidated in the form of a GCOS report by the end of 2023. The report should provide a current health snapshot of financial support for the networks.

[1] In this document we refer to all non-satellite observations as "in situ" including ground-based and aircraft-based remote sensing.

	2. Regularly reassess and report in future GCOS Status Reports progress towards sustainable funding for those networks designated in the initial report as inadequate or at risk. 3. Number of in situ networks for which funding support as a whole has been improved.
Additional Details	GCOS panels should inventory key current in situ networks and ascertain their levels of support, and barriers to their full implementation, and highlight examples of existing sustainable solutions. NMHSs, research performing organizations and other public and private funders should then take the outcomes of these assessments and attempt to remedy issues raised. A final assessment will then be made at the end of the IP / Status report cycle.
Links with other IP Actions	All ECV need sustained support, but this GCOS IP has identified the following actions: B4: in situ observations of atmospheric composition ECVs. B6 and B7: expansion and integration of the global ocean observing system, including observations of biogeochemical/biological parameters.

3. THEME B: FILLING DATA GAPS

This theme addresses gaps in the existing observing system identified in the 2021 GCOS Status Report (GCOS-240).

By and large the observations fulfil many requirements and provide the basis for the very useful sets of ECVs. However, in situ observations for almost all the ECVs are consistently deficient over certain regions, most notably parts of Africa, South America, Southeast Asia, in the deep ocean and polar regions, a situation that has not improved since the 2015 GCOS Status Report (GCOS-195).

Reference quality observations respond to the need for monitoring the changes that are occurring in the climate system and ensure greater confidence int the assessment of future climate change and variability. They support also timely political decisions for adaptation and can help to monitor and quantify the effectiveness of internationally agreed mitigation steps.

WMO has adopted the concept for a Global Basic Observing Network (GBON) and for the Systematic Observations Financing Facility (SOFF). If their implementation is successful, GBON will provide essential observations for global Numerical Weather Prediction (NWP) and reanalyses, covering some ECVs, and SOFF will provide targeted financial and technical support for the implementation and operation of GBON and will address some of the gaps identified in the 2021 GCOS Status Report.

Action B1: Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)	
Activities	**1. Continue development of GRUAN.** **2. Implement the GSRN.** 3. Better align the satellite FRM program to the reference tier of tiered networks and enhance / expand FRM to fill gaps in satellite cal/val. **4. Develop further the concept of a reference network tier across all earth observation domains.**

	5. Establish a long-term space-based reference calibration system to enhance the quality and traceability of earth observations. The following measurables are to be considered: high-resolution spectral radiances in the reflected solar (RS) and infrared (IR) wave bands, as well as GNSS radio occultations.
Issue/Benefits	The principal benefits of reference quality networks / measurements are: • Well characterised measurement series that are traceable to SI and/or community standards with robustly quantified uncertainties that can be used with confidence. • Improved instrument performance that transfers down to other broader global regional and national networks. • Characterisation of wider networks, especially of measurement quality. • Robust calibration/validation of satellite data. • Improved process understanding and model validation. However: • Although GRUAN has been successfully implemented since 2005, it remains far from globally well distributed. • There is no Global Surface Reference Network, as yet. • The FRM programs of satellite agencies have been carried out independent of broader concerns around tiered network design, yet these measurements should be sustained as part of reference networks and not be funded or considered separately from broader observational strategies. There is also a need to undertake additional FRM measurements to fill critical cal/val capability gaps for some ECVs. • Whilst several in situ networks are considered to be of reference quality, as yet, apart from GRUAN, there are no additional GCOS recognized global reference networks. • Enabling traceable Earth observations from satellites will improve the accuracy and quality of many ECV data sets. In addition to meeting crucial inter-calibration needs, this effort will aid in better understanding climate relevant processes and their spectral signatures.
Implementers	1. **Lead Centre (DWD),** GCOS, WMO, NMHS. 2. **GCOS**, Lead Centre (CMA), WMO, NMHS. 3. **Space agencies**, WMO, GCOS, Funding agencies. 4. **GCOS**, WMO, NMHS, Research organizations. 5. **Space agencies.**
Means of Assessing Progress	1. Number of certified GRUAN stations and geographical distribution of stations; number of data products; data usage measured through citations. 2. Operational GSRN (for an initial set of stations focussing on temperature and precipitation). 3. a) Alignment of FRM programs into the tiered network of networks concept; b) Additional FRM measurements to fill gaps to support satellite cal/val of ECVs such as Above Ground Biomass, albedo, FAPAR, LAI and burned area. 4. Inventory of (potential for) global reference networks across atmosphere, ocean and terrestrial. 5. Implementation of CLARREO pathfinder, TRUTHS and Prefire. Plans for long-term follow-on missions to the short-term (~1 year) pathfinder missions (CLARREO and Prefire) and long-term continuous measurements.

Additional Details	Reference-quality measurements must be traceable to SI or community recognized standards and have their uncertainties fully quantified following the guidance laid out by BIPM. Measurements across a reference network must be metrologically comparable. 1. GRUAN is envisaged as a global network of eventually 30-40 measurement sites. As of August 2021, GRUAN comprises 30 sites, 12 of which have been officially certified. However, few GRUAN stations exist in several geographical regions (e.g. Africa, South America). There is also substantial work required to expand the number of GRUAN Data Products including from a range of ground-based remote sensing and in situ balloon-borne techniques. The WG-GRUAN is supported by, and reports to, AOPC who should continue to oversee progress. Regular Implementation and Coordination Meetings should continue. Efforts should be made to better integrate GRUAN into WIGOS operations. 2. A task team has been created under GCOS and SC-ON / SC-MINT to work towards the implementation of the GSRN. The GSRN should measure both near-surface atmospheric ECVs and site-relevant terrestrial ECVs and therefore the network will be overseen jointly by AOPC and TOPC from GCOS. CMA has agreed to host the Lead Centre for the GSRN. The GSRN TT, together with CMA, is expected to develop a proposal for the initial composition of the GSRN and start operations for the selected pilot stations by 2024. 3. Integration of FRM program measurements and associated support into long-term reference quality observing programs and networks assuring long-term cal/val operations. Including the provision of new FRM measurement programs and supporting infrastructure to fill critical current gaps in ECV satellite cal/val such as: o Networks in high and low above-ground biomass regions; o Ground-based in situ measurements of above-ground biomass and vegetation dynamics following FRM protocols (Dunanson et al., 2021); o Ground-based time-series in situ measurements of surface albedo, FAPAR and LAI with their uncertainties; o An open-access network of sites for burned area products. 4. There are known networks and activities that produce reference quality measurements, i.e. BSRN, GAW networks. Efforts should be made to better recognize these as global reference networks. The panels will plan how to implement other reference networks across all domains. 5. Spearheading spectral RS and IR measurements are the following space missions: CLARREO pathfinder will measure spectral (350 – 2300 nm) radiances and reflectances in the visible and near-IR (NASA; launch in 2023); Prefire will measure spectral (5-45 µm) far-IR emissivity (NASA; launch in 2022); Forum will measure spectral far-IR outgoing radiation (ESA; launch in 2026); and TRUTHS will measure spectral RS (ESA; launch in 2029). It is essential that Space agencies consider long-term follow-on missions to the short-term pathfinder missions (CLARREO and Prefire). This should draw upon GSICS.
Links with other IP Actions	C2: Improvements to satellite data processing depends on the availability of reference observations. D4: Improve access to co-located satellite and reference quality in situ observations.

Action B2: Development and implementation of the Global Basic Observing Network (GBON)

Activities	**1. Implementation of initial GBON and the associated SOFF mechanism to fill long-standing gaps to globally monitor climate over land and oceans.** **2. Consideration of alignment of GSN and GUAN with GBON.** **3. Planning the development of GBON and SOFF to cover more marine, hydrological, and atmospheric composition observations.**
Issue/Benefits	To date the GBON has been scoped by and adopted by WMO members along with the associated SOFF mechanism. However, the network has yet to be formally implemented and monitoring and enforcement mechanisms put in place. The use of the SOFF to fill persistent gaps has yet to start. If successful, given potential overlaps with GSN and GUAN, the implications for the future of those GCOS networks has yet to be fully evaluated. Furthermore, the initial implementation of GBON is focussed on requirements for NWP and reanalyses and an extension is required in future to ensure that GBON also meets the broader needs for climate monitoring and adaptation. This needs an expansion of the observational variables supported by GBON and can be supported through, for example, inclusion of daily and monthly summary reports. The GBON effort and associated SOFF, if fully implemented, would represent a step-change in the ability to monitor surface and upper-air atmospheric ECVs on a sustained basis. Benefits will include more complete sampling of many GCOS ECVs over land, ocean and the cryosphere, and filling gaps that exist over several geographical regions. The GBON network, if fully implemented, would meet the stated requirements for ECV monitoring for those ECVs it measures.
Implementers	1. **WMO**, GCOS, GOOS, NMHS. 2. **GCOS**, WMO, NMHS. 3. **WMO**, GCOS, GOOS, NMHS.
Means of Assessing Progress	1. Number of GBON stations (including marine platforms in Exclusive Economic Zones (EEZs)), their geographical completeness and their continuity of data provision to data centres as well as over the WIS. 2. Assessment by GCOS of the continued relevance and role of GSN and GUAN at such time as GBON is considered to be fully implemented in its first phase with recommendations to GCOS Steering Committee. 3. GBON scope expanded to incorporate additional ECVs which are then observed on a sustained basis as part of GBON expanded operations.
Additional Details	1. In collaboration with WMO, ensure the full implementation of GBON and the associated SOFF mechanism to fill long-standing gaps to monitor climate over land and oceans. In particular, ensure that: • The initial GBON as adopted at WMO Extraordinary Congress in 2021 is implemented in full, including both surface and upper-air components; • GBON surface stations are encouraged to submit monthly and daily summaries in addition to synoptic reports; • The SOFF is used to target areas of data sparsity over land and EEZs and ensure continuity of capability. 2. After 2-3 years of operation, consider the relationship of GBON to GSN and GUAN. Does GBON fulfil all aims of GSN and GUAN or is there value in retaining GSN and GUAN as independent network designations? If they are retained: are any changes required to GSN and GUAN aims and governance accordingly? AOPC to report to GCOS Steering Committee in 2024/2025. 3. WMO envisages that GBON will expand to cover other domains. GCOS to take an active role in the continued evolution of the GBON network to ensure that

	climate needs are adequately accounted for. Progress to this end is to be assessed in the next GCOS status report.
Links with other IP Actions	B4: The extension of GBON (Activity 3) will benefit expansion of in situ monitoring of atmospheric composition ECVs. B8: The extension of GBON (Activity 3) will benefit the coordination of N_2O observations. C4: The implementation of GBON will benefit reanalysis.

Action B4: Expand surface and in situ monitoring of trace gas composition and aerosol properties	
Activities	**1. Expand surface-based and in situ observations of a range of atmospheric and oceanic composition ECVs, including GHGs, ozone, aerosol, clouds and water vapour, and other gaseous precursors, in the atmosphere.** **2. Promote cooperation of the existing networks for establishing new composition observing capabilities in areas where they are lacking over land (in large areas of Africa, South America, Southeast Asia), over oceans, and over ice-covered regions.**
Issue/Benefits	Well-functioning networks monitoring atmospheric composition of ECVs are beneficial for: i) evaluating the effectiveness of policies on agreed emission reductions; ii) monitoring trends and variability of atmospheric composition; iii) detecting early warning signals for climate system feedbacks on natural emissions; iv) providing real-time information in case of atmospheric hazards (e.g. biomass burning, dust events, volcanic eruptions); v) providing information for radiative forcing evaluation in global/regional climate-chemistry models; vi) evaluating global forecasting systems and atmospheric composition reanalysis using independent observations. While observations of atmospheric composition variables have further improved in the past decade thanks to new in situ observations from the ground and from commercial aircraft, surface-based and in situ networks for monitoring composition ECVs still suffers from important weaknesses: • Long-term continuity of some observations is not assured due to lack of sustained funding. • There are still important gaps in the global coverage of in situ composition observations.
Implementers	From 1 to 2: **NMHS,** Research organizations, Funding agencies, National agencies.
Means of Assessing Progress	1. Number of traceable composition observation data available from areas where they are current gaps, including remote locations. 2. Expansion of current composition networks (number of sampling stations) in areas not covered by observations.

Additional Details	Sustained composition observation capabilities both at the surface and of column characteristics of a range of trace gases, including well mixed GHGs, ozone, ozone precursors and water vapour, and aerosol with global coverage are needed. Existing capabilities need to be maintained, coordinated, and expanded to meet GCOS requirements. These include observations performed in situ (near-surface and onboard drones, aircrafts, ships, balloons and other vectors) and using remote sensing (e.g. lidar, FTIR, Brewer-Dobson). Integration needs to be sought with novel approaches to satellite measurements. In order to achieve activities 1) and 2), the following needs to be addressed: • Ensure the benefits of in situ composition observations in terms of future climate services are clearly understood by relevant national and regional authorities. • Design an implementation plan including network design and commence implementation. • Staff training.
Links with other IP Actions	A1: Expansion of atmospheric composition observations requires sustained funding. B2: Expansion of GBON could lead to more atmospheric composition observations. F4: Improve climate monitoring of urban areas will include atmospheric composition ECVs. F5: Activity 1: Design and start to implement a comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations.

Action B5: Implementing global hydrological networks	
Activities	**1. Improve the collection of hydrological observations, in particular:** **a) Improve global reporting of river discharge (e.g. to Global Runoff Data Center – GRDC) and water level data (e.g. to WMO Hydrological Observing System - WHOS), from a selected set of stations;** **b) Increase the number of in situ river level observations that are exchanged internationally and can be used to calibrate satellite observations of water levels;** **c) Increase global exchange of in situ water level observations of lakes and reservoirs to the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE);** **d) Increase the number of in situ observations of soil moisture in the International Soil Moisture Network (ISMN), including below-ground measurements.** **2. Include in situ observations of Groundwater Level from national authorities (or other sources) that are minimally impacted by human influence into the Global Groundwater Monitoring Network (GGMN) to establish a global system.** **3. Report anthropogenic water use to Food and Agriculture Organization of United Nations (FAO) AQUASTAT in areas where data are missing.**
Issue/Benefits	Hydrological observations contribute to model and satellite calibration and validation, climate studies, regional and local water resources assessments, improvement of prediction tools, impact assessments, freshwater inputs into the ocean and regional and local water resources studies. Currently there are no effective global networks for river discharge or groundwater. Many river discharge data have not been exchanged internationally for decades.

	Databases of groundwater, soil moisture, terrestrial evaporation, lake levels–and anthropogenic water use are incomplete. In some cases, this is due to restrictive data policies and political considerations, in others it may reflect observational problems. Although global data centres exist for most water-related ECVs, data exchange from the individual data providers to the data centres is often limited. To rectify this situation, this action aims to: • Establish a network of a limited set of river discharge measurement sites that are most important for international use, and that exchange data. • Support the use of satellite observations of river level to supplement in situ observations. This requires measurements of river levels at points useful for calibration and validation of satellite observations as well as being useful locally. • Establish a network that emphasizes below-ground measured soil moisture. This is a gap that consistently comes up for many applications and cannot be derived by remote sensing. Provide easy, open access to the network data to benefit all countries. A discovery service and the interoperability of hydrological observations should be introduced. So far, information on existing data is only available in a distributed form in the global data centres. This makes access difficult. • Identify where additional resources and support are needed for river discharge and groundwater observations to support future development of GBON and SOFF. The implementation of the three new WMO initiatives (i.e. the Unified Data Policy, the Global Basic Observing Network, and the Systematic Observations Financing Facility) should assist these activities. Anthropogenic water use data is collected in the AQUASTAT database managed by FAO. Despite recent improvements, the AQUASTAT database which is based on national reporting, has gaps, is not up to date and the spatial and temporal resolutions are too low. The satellite-based Total Water Storage ECV gives timely and complete regional coverage but does require the continuation of satellite gravity observations and will not replace the spatial resolution of AQUASTAT.
Implementers	From 1 to 3: **WMO (WHOS), NMHS, Space agencies, Global Data centres (GTN-H).**
Means of Assessing Progress	1. a) Identification of a set of river discharge stations to exchange data; b) Increased availability of calibrated satellite estimates of water levels in rivers; c) Increased reporting of river discharge and level data to GRDC using unrestrictive data policies; d) Improved reporting of groundwater data to the International Groundwater Resources Assessment Centre (IGRAC) using unrestricted data policies. 2. Identification a set of groundwater stations that are minimally impacted by human influence for reporting to IGRAC. 3. Increased number of countries reporting to AQUASTAT and improve resolution: More countries reporting and increased resolution.
Additional Details	Many activities, developed in cooperation with GTN-H, provide hydrological products, including the groundwater level data collected at IGRAC, the river discharge at GRDC, the lake levels at HYDROLARE, the soil moisture data at ISMN, and the anthropogenic water use at AQUASTAT. However, large data gaps still exist and there is an insufficient exchange and delivery of the collected hydrological data to data centres. In line with WMO Resolution 1 (Cg-Ext(2021), these activities are all aimed at improving the global exchange of hydrological data and delivery to data centres of

	networks encompassed by GTN-H, in particular the GCOS baseline networks, and to facilitate the development of integrated hydrological products to demonstrate the value of these coordinated and sustained global hydrological networks. 1. To encourage more countries to freely provide quality-controlled river discharge data, there should be clear criteria for reporting only the selected data that are most important for the regional and global assessment of the water cycle. Data from selected hydrological gauging stations meeting the following criteria should be exchanged: • The most downstream stations on major rivers not impacted by tidal influences to better capture freshwater fluxes to oceans; • Hydrological monitoring stations representative of regional hydrology; • Minimally impacted stations suitable as reference or baseline stations for climate studies; • These selected sites will form a new global network exchanging and reporting data for use in global and regional assessments; • Potentially, satellite data of river levels can be used as a surrogate to fill in gaps in coverage. In situ data are needed to calibrate and validate satellite observations so they become an important source of water levels and ultimately discharge data e.g. the SWOT mission and follow-ups. 2. Despite the existence of a data centre (at IGRAC) there is no global reporting of data. To provide the information needed at a global level, data from selected groundwater monitoring stations that are minimally impacted by human influence should be collected and exchanged. While this new network of groundwater monitoring stations is a subset of all monitoring stations it defines the information that is needed for global assessments. 3. The collection of data for AQUASTAT needs to be improved to increase both coverage and temporal resolution with countries encouraged to improve reporting and greater understanding of the benefits of the global dataset.
Links with other IP Actions	B2: The development of GBON will contribute to implement Action B5. B10: Closure of water cycle.

Action B6: Expand and build a fully integrated global ocean observing system	
Activities	**Increase the measurements of ocean ECVs into the deep ocean, under the ice and marginal seas by improving:** **1. The Core Argo (ensuring that the target density is met), biogeochemical (BGC) and Deep Argo to achieve the OneArgo design.** **2. The ship-based hydrography, fixed-point observations, autonomous and uncrewed observations.** **3. The integration of observing networks to respond adequately to ECVs requirements.**
Issue/Benefits	There are critical sampling gaps that limit the monitoring of the ocean state (for example, heat storage, carbon cycle and impacts on the biosphere). The transformation of the current Argo array to the integrated "OneArgo" array, the deployment of repeated hydrography, the deployment of fixed-point and other autonomous observing platforms and their integration aims to address these gaps by providing observations of surface and subsurface ocean properties, physical, biogeochemical, and optical properties aiming to collect ocean ECVs with an improved and very much needed global coverage.

	The extended in situ network will be key in closing budgets for climate cycles assessments, monitoring the state of the ocean, evaluating climate risks and impacts and guiding adaptation policies. It will be essential for calibration and validation of satellite measurements. An enhanced coverage for the ocean in situ surface and subsurface ECVs is also key for improving seamless forecasts as well as contributing to meeting the goals of the Paris Agreement.
Implementers	From 1 to 3: **GOOS**, Research Agencies, Academia, National agencies (oceanographic Institutes), Space agencies, NMHS (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	1. Number of core floats deployed to maintain the target density in the global ocean including marginal seas and polar regions; and number of Deep and BGC Argo floats operating after 5 years. 2. Increase of coverage in the global ocean of ship-based hydrography and fixed-point observations, including polar areas and marginal seas after 5 years. 3. Availability of integrated products.
Additional Details	In 2020, the Argo Steering Team endorsed a new Argo array design (called "OneArgo") that is truly global (including marginal seas and under ice), full depth, and multi-disciplinary, including Core, Deep, and biogeochemical BGC Argo floats. The estimated budget of OneArgo represents a three-fold increase in cost. OneArgo will include a novel data management system with real-time data freely shared through the GTS/WIS and high-quality datasets delivered within 12 months, supporting climate-relevant assessments, inventories, and metrics. Since 2021, OneArgo is a project endorsed by the UN Ocean Decade. Ship-based hydrography and fixed-point observations, autonomous and uncrewed are essential and complementary to Argo and further efforts must be undertaken to realise the vision of a fully integrated Ocean Observing System[2]. Some of the key programs and networks contributing to this Action are GO-SHIP, OceanSITES, Ocean Color satellites, Deep Argo, Biogeochemical Argo and Global Alliance of Continuous Plankton Recorder Surveys (GACS) (see OceanOPS Report Card[3] for more details).
Links with other IP Actions	B7 and B8: Improve components of the global ocean observing system. B9: Improve estimates of latent and sensible heat fluxes and wind stress. F3: Expand global ocean climate in situ observations into EEZ and coastal zones.

Action B8: Coordinate observations and data product development for ocean CO_2 and N_2O	
Activities	**1. Develop a strategy and implementation plan to operationalize the data production and delivery of surface ocean CO_2 information.** **2. Coordinate the existing nitrous oxide (N_2O) ocean observations into a harmonised network.**
Issue/Benefits	Parties to the UNFCCC, in its Paris Agreement, have committed to conserving and enhancing sinks and reservoirs of greenhouse gases, such as CO_2 and N_2O, including oceans and coastal and marine ecosystems. As part of the Global Stocktake exercise, it will be necessary to quantify and assess both carbon emissions and natural sinks. There are already considerable national and regional efforts contributing to monitor CO_2 and N_2O in the ocean, but most of them rely on

[2] Révelard et al., 2022: Ocean Integration: The Needs and Challenges of Effective Coordination Within the Ocean Observing System. *Frontiers in Marine Science.* https://doi.org/10.3389/fmars.2021.737671
[3] OceanOPS Report Card 2021 (ocean-ops.org)

	short-term research projects. A more sustained funding and better coordination will result in a better estimation of the oceanic CO_2 and N_2O emissions, an optimisation of resources of Member States and better compliance with UN agreements.
Implementers	From 1 to 2: **GOOS**, WMO, Research organizations, National agencies (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	1. Internationally agreed strategy and implementation plan that can be used by governments for funding decisions that enable integration of individual pilot elements to achieve the required global system. 2. a) Annually published sets of harmonised global N_2O concentration and emission fields data products; b) Initiated coordinated observing network of N_2O observations.
Additional Details	1. While all of the required elements of a surface ocean CO_2 monitoring system exist (observations, data quality control and synthesis, gap-filling protocols, and projection capability) individually, there is currently no internationally-agreed strategy that coordinates national and regional efforts and expands the global network to better quantify carbon sources and sinks. In recent years, serious gaps have developed in surface CO_2 data coverage owing to funding cuts in some key underway CO_2 programmes that had been operating for decades supported by 3-4-year funding horizons based on research proposals. These programmes, and the international ocean and climate science communities they serve, suffer from the lack of an internationally agreed strategy that recognizes individual programmes as essential elements in a coordinated global network. In fact, all the elements of this monitoring system rely on individual research proposals and voluntary contributions and as such lack any long-term perspective. The development of an internationally agreed strategy for a global surface CO_2 monitoring network, with a focus on the open ocean and marginal seas, will allow Member States to identify priority observing system investments to meet data needs, further develop the foundations of a sustainable surface ocean carbon monitoring system, and respond to international and intergovernmental policy drivers and commitments to UN agreements. The key programs and networks are: WMO Global Atmospheric Watch (GAW), International Ocean Carbon Coordination Project (IOCCP), Surface Ocean CO_2 reference Observing NETwork (SOCONET), Integrated Carbon Observation System-Ocean Thematic Centre (ICOS-OTC), Surface Ocean CO_2 Atlas (SOCAT), Surface Ocean CO_2 Mapping intercomparison initiative (SOCOM), Global Carbon Project (GCP), Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP), Global Data Analysis Project (GLODAP), Biogeochemical Argo. 2. To reduce uncertainties in oceanic N_2O emission estimates and to characterise the spatial and temporal variability in N_2O distributions in a changing ocean, the establishment of a harmonised N_2O Observation Network (N_2O-ON) combining discrete and continuous data from various platforms is needed. The network will integrate observations obtained by calibrated techniques, using time-series measurements at fixed stations and repeated hydrographic sections on voluntary observing ships and research vessels. As a greenhouse gas, N_2O is involved in tropospheric warming and stratospheric ozone depletion, with estimates of the global ocean contribution to N_2O emissions ranging from 10-53%. It is important to monitor how oceanic N_2O cycling and emissions to the atmosphere are affected by observed changes in the marine environment due to warming, deoxygenation and acidification. Therefore, new N_2O data products issued annually will include a harmonised

	global N_2O concentration and emission fields to inform the global research community and policy makers on the status and projections of future oceanic N_2O emissions. The key programs and networks are: N_2O GO-SHIP, Ship-Of-Opportunity Programme (SOOP), MarinE MethanE and NiTrous Oxide (MEMENTO).
Links with other IP Actions	Together with B8, B6 and B7 target different aspects and components of global and integrated ocean observing system recognizing its essential role in the climate system.

Action B9: Improve estimates of latent and sensible heat fluxes and wind stress	
Activities	This action focuses on ice-free oceans and the terrestrial land surface **1. Improve and extend in situ measurements needed to estimate surface fluxes, with the objectives of improving accuracy and better defining the uncertainties of those measurements and calculated fluxes.** **2. Extend sites with co-located measurements of direct turbulent and radiative fluxes and variables required to estimate turbulent surface fluxes targeted at improving parameterisations of air-sea exchange and air-land exchange.** 3. Develop new approaches over land, focusing on improved estimation of transpiration, interception and soil evaporation separately. 4. Develop new approaches and improved methods to better exploit relevant ECV measurements to estimate ocean surface heat, moisture and momentum flux including: a) Better integration of in situ and satellite measurements, data assimilation, fusion techniques, ensuring consistency between different types of measurements and their harmonisation; b) Development and deployment of new satellite missions that are tuned to maximise the sensitivity to the state variables needed to estimate heat flux over the ocean and land; c) Increase and improvements in satellite observations that target both the surface parameters and the near-surface air-parameters; d) Simultaneously use of an approach based on high resolution numerical models (Large Eddy Simulation (LES)) to augment satellite product validations; e) Include in future intercomparison campaigns of latent and sensible heat fluxes measurements inferred from simultaneous observations with a water vapour differential absorption lidar (WVDIAL), a Doppler wind lidar and temperature from rotational Raman lidar.
Issue/Benefits	Understanding and estimating surface fluxes is essential for improving projections of climate change and planning adaptation and response measures. The need for surface, near surface, and boundary layer information, across different temporal and spatial scales for multiple disciplines, has outstripped the capabilities of existing observing networks. Direct observation of surface turbulent (sensible, latent and momentum) fluxes is difficult and costly and globally impractical. For global coverage it is therefore necessary to estimate the surface heat and momentum fluxes using empirical parameterisations based on other ECVs (including surface temperature, near surface air temperature and humidity, near surface wind speed and direction). To improve the parameterizations, and quantify uncertainty, high quality in situ

<table>
<tr><td></td><td>measurements of both direct fluxes and collocated ECVs used to calculate the fluxes are needed at key representative locations.
Improvement of estimates of ocean surface heat, moisture and momentum flux requires integrating in situ and satellite observations, use of data assimilation and fusion techniques. New and improved methods need to be developed to better achieve this integration.</td></tr>
<tr><td>Implementers</td><td>From 1 to 2: NMHS, GOOS, Research organizations.
3. Academia, Research organizations, NMHS.
4. Space agencies, NMHS, Academia.</td></tr>
<tr><td>Means of Assessing Progress</td><td>1.
a) A catalogue of the in situ observations providing good quality observations of ECVs relevant for surface fluxes;
b) Number of observations in 1(a) (above) available in data centres;
c) Demonstration reference stations for ECVs needed to calculate surface heat, moisture and momentum fluxes;
d) A plan for the establishment/maintenance/extension of a global network of reference stations for ECVs needed to calculate surface heat, moisture and momentum fluxes.
2.
a) Increased availability of co-located direct flux measurements and flux-relevant ECVs in data centres;
b) Published paper(s) demonstrating the reduction in the uncertainty in empirical parameterizations used to calculate turbulent fluxes.
3. Published paper(s) on new approaches for separate estimation of transpiration, interception and soil evaporation.
4.
a) Reduced uncertainty in both air-sea and land-atmosphere flux products;
b) Scoping and development of satellite missions to better optimise measurements in the Planetary Boundary Layer.</td></tr>
<tr><td>Additional Details</td><td>1. To improve the understanding of partitioning of energy fluxes between the surface and lower atmosphere over all surfaces and the understanding of uncertainty, it is necessary to improve and extend in situ measurements of variables needed to calculate surface fluxes. This requires a tiered approach including: (i) a network of multi-variate high quality reference stations covering representative climates; (ii) a network of stations or mobile marine platforms to provide good quality globally-representative coverage and enable comparison with reference stations; (iii) widespread regional and global measurements only some of which will meet specified quality standards but will extend coverage and provide information on variability.
2. Uncertainty in empirical parameterizations used to provide estimates of surface heat and momentum fluxes with global coverage from more easily-measured ECVs remains significant. Improved parameterisations, and improved quantification of uncertainty in those parameterizations requires co-located measurements of direct turbulent fluxes and variables required to calculate turbulent surface fluxes along with direct measurements of shortwave and longwave radiation to provide net heat fluxes. Given the advanced capabilities to infer the shortwave net radiative fluxes at the surface (from satellites) and the longwave net radiative fluxes (from satellite and ancillary data), the use of empirical formulae for the radiative fluxes should be abandoned.</td></tr>
</table>

	3. Develop novel algorithms able to partition terrestrial evaporation into its various components (transpiration, soil evaporation, interception) with a stronger reliance on observational data and lower dependency on model assumptions. 4. Satellite measurements provide global, but indirect measurements of the surface and atmospheric state variables required to compute heat flux, while in situ measurements provide a local direct measure. The best flux estimates will be achieved by optimally combining these complementary global and local measurements constrained by physical models using data assimilation, that include both in situ and remote sensing data, and fusion techniques. New assimilation algorithms to cope with observations at higher spatiotemporal resolution need to be developed. It is necessary to develop new satellite missions or constellations of satellites optimised, to the extent physically achievable, for the derivation of accurate estimates of air-sea heat, moisture and momentum flux, such as the Butterfly mission concept[4]. Spatio-temporal mismatches in sampling of ECVs required for flux estimation should be minimised to reduce errors in the heat flux estimation resulting from the combination of observations sampled at different times, or with different spatial footprints. Further advances in the field of global terrestrial evaporation monitoring should include developments in microwave remote sensing and high-resolution optical platforms (Fisher et al., 2017)[5]. Moreover, the potential of novel thermal missions such as ECOSTRESS (Fisher et al., 2020)[6] and TRISHNA (Lagouarde et al., 2018)[7] is yet to be exploited. The use of simultaneous Lidar's measurements to infer latent and sensible heat fluxes is exemplified and demonstrated by Behrendt et al., (2019), https://amt.copernicus.org/preprints/amt-2019-305/amt-2019-305.pdf. There are high resolution models that are capable of resolving turbulence, which could help to resolve horizontally the fluctuations that are not being resolved with current satellite technology. The following approach can be used to augment satellite product validations using numerical modelling with high-resolution models (LES): • Have only few well-equipped validation sites for the products; • Compute fluxes with the models and validate models with measurements; • Use models to 'check' satellite products elsewhere.
Links with other IP Actions	This action links to other actions: B1: Reference networks are needed to improve flux estimates. B10: Closure of energy cycles will benefit from a better understanding of heat fluxes. C2 and C3: Improvements to data processing methods will benefit this action. D3 (Activity 3). Access to field campaign data useful for testing of parameterization. D4: Easy access to co-located satellite and reference quality in situ observations.

[4] Butterfly: a satellite mission to reveal the oceans' impact on our weather and climate https://doi.org/10.5281/zenodo.5120586
[5] Fisher, J. B., et al., 2017: The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources. *Water Resources Research* 53, 2618–2626, doi:10.1002/2016WR020175
[6] Fisher, J. B., and Coauthors, 2020: ECOSTRESS: NASA's Next Generation Mission to Measure Evapotranspiration from the International Space Station. *Water Resources Research* 56, doi:10.1029/2019WR026058
[7] Lagouarde, J.P., 2018: The Indian-French Trishna Mission: Earth Observation in the Thermal Infrared with High Spatio-Temporal Resolution. In Proceedings of the IGARSS 2018—2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia, Spain, 22–27 July 2018; pp. 4078–408

4. THEME C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING

This theme looks at how the original observational data is transformed into user-relevant information. Starting from climate monitoring, adopted standards are required to facilitate inter-comparisons, "mash-up-ability" and ensure the overall quality of the final information. Standards are also required through the other phases of the processing chain that transform observations into user-relevant products. These should address a comprehensive characterisation of uncertainty, the use of uniform metadata and quality attributes and also support the effort towards the generation of sensor-agnostic gridded datasets to facilitate intercomparison. Acknowledging the fact that the use of observational data is often mediated by other systems, a dedicated effort should also go toward ensuring the fitness for purpose of the data provided for its use in reanalysis. This includes a dedicated effort towards data reprocessing, bias characterisation and more generally a comprehensive characterisation of the uncertainty associated with both observations and modelling.

Action C1: Develop monitoring standards, guidance and best practices for each ECV	
Activities	**1. Review existing monitoring standards, guidance and best practices for each ECV, ensuring these reflect current state-of-the-art. Maintain a repository of this guidance for ECVs.** **2. Ensure the development of monitoring standards, guidance and best practices, including intercomparison procedures, for those ECVs where such guidance does not exist.** **3. Review and revise the climate monitoring guidance in the WIGOS manual to bring it in line with the updated guidance developed in this Action.** 4. Review the GCOS climate monitoring principles.
Issue/Benefits	Many ECVs have standards, guidance and best practices that, when followed, ensure consistency between the observations which is necessary to ensure that the global datasets meet user requirements. However, monitoring standards for some ECVs are missing and need to be established, and for others they are either substantively dated or not fit-for-purpose. Improvements in observations and their consistency across countries and regions would lead to more accurate observations, predictions/projections, and warnings and would thus improve adaptation planning.
Implementers	From 1 to 4: **GCOS,** GOOS, WMO, Copernicus, Space agencies.
Means of Assessing Progress	1. Unified repository of standards, guidance, and best practices for all observations of atmospheric, oceanic and terrestrial ECVs by time of next status report. 2. New monitoring standards, guidance, and best practices for ECVs where this is identified as absent or requiring updates. 3. WMO adopts revisions to WIGOS regulatory materials to ensure they meet climate needs as articulated in the unified repository. 4. Review and undertake revisions to GCOS Monitoring Principles to align with outcomes of activities 1-3 by time of next status report.
Additional Details	For 1 and 2: Guidance for collecting observations of ECVs is incomplete, particularly in the terrestrial domain. Therefore, the first step is to identify gaps in the guidance, or where guidance is outdated, and provide up-to-date guidance that covers siting, observations, data collection, processing, and QA/QC. Any new guidance should

	be based on existing guidance where this exists and is appropriate: Where possible, this can include ballpark costs and manpower requirements for implementation, operation and maintenance of ECV observations. The WIGOS manual guides NMHS in making observations. However, the current guidance on climate observations is inadequate and unclear. It should therefore be revised to be consistent with ECV requirements. 3. The GCOS Climate monitoring principles were adopted in the 1990s. They need to be reviewed and updated as appropriate in light of new methods, insights and best practices.
Links with other IP Actions	Best practices, guidance and standards are relevant for most of the Actions in themes A, B, C, D and F.

Action C3: General improvements to in situ data products for all ECVs	
Activities	1. Periodically reprocess in situ data products to account for new knowledge, new techniques and improved access to historical data holdings. **2. Improve uncertainty quantification of in situ-based products.** **3. Undertake efforts to account for spatio-temporal sparsity of in situ measurements via interpolation.** 4. Ensure adequate sampling of the structural uncertainty inherent in in situ product development via supporting the development of multiple methodologically distinct products and their intercomparison.
Issue/Benefits	It is necessary to periodically reassess in situ-based estimates of climate change and to have multiple independently produced estimates for each ECV. Ensuring that datasets produced from in situ holdings reflect the latest availability of access, the latest knowledge, and the latest processing techniques assures the best possible estimates of long-term climate change are available to users. The availability of multiple independent estimates per ECV identifies those ECVs for which the true evolution is well known and thus informs directly assessments undertaken by e.g. IPCC.
Implementers	From 1 to 4: **Research organizations**, Academia, NMHSs.
Means of Assessing Progress	1. New publications of updated in situ datasets and availability of those datasets following FAIR data principles. 2. Increased number of available in situ-based datasets for which a documented and quantified uncertainty assessment is available. 3. Increased spatio-temporal completeness of in situ-based products based upon use of additional data and application of interpolation techniques. 4. Increased number of ECVs for which two or more global in situ datasets exist.
Additional Details	In situ data products are not some frozen set of estimates which should remain unchanged. Over time new data, new insights and new and improved computational techniques appear. A high-profile example of this is the recent IPCC WGI report wherein the surface temperature datasets changed their estimates on a like-for-like basis by circa 0.1C. This change in the estimate of warming to date of the order 10-15% of the estimate before arose from a combination of improved understanding of data biases, improved access to historical data, improved interpolation techniques, and the emergence of new estimates.
Links with other IP Actions	B1: Reference observations. B9: Estimation of heat fluxes and wind stress. D5: Data rescue.

5. THEME D: MANAGING DATA

To address and understand climate change, the longest possible time series need to be preserved in perpetuity. Every ECV needs to have a recognized global data repository and where there is one, it should be complete, adequately supported and funded. Data should be stored in well-curated, open and freely available, sustainable archives with clear guidance for data centres and users. Clearly defined principles such as the TRUST Principles (Lin et al., 2020)[8] and FAIR Principles (Wilkinson et al., 2016[9]) are needed. Data rescue from hard copy or archaic digital formats allows data series to be extended in the past and needs to be adequately planned and funded with the results openly and freely available. Sustained support to these activities is required. This theme aims to organise more efficiently data rescue, data sharing, data curation and data provision.

Action D1: Define governance and requirements for Global Climate Data Centres	
Activities	**1. Draft requirements for the activities of Global Climate Data Centres and identify the relevant internationally agreed standards.** **2. Develop any new standards as required.** **3. Implement the agreed-upon requirements at all global data centres.** **4. Advocate for implementation of the WMO Unified Data Policy to foster a free and unrestricted exchange of available data.**
Issue/Benefits	It is vital that all users have unrestricted access to well-documented, historical and near-real-time climate data and associated metadata, including relevant documentation. However, despite various efforts to implement appropriate data stewardship and sharing standards, such "free and open" access to well-maintained data archives is not available consistently across all data centres and data types. This action aims to improve the situation by encouraging global climate data centres with global-scale data holdings to agree on and implement relevant standards. Open exchange of easily accessible and findable data, particularly well-maintained long-term time series, will improve the completeness and accuracy of the data and metadata necessary for climate science, climate adaptation activities, and climate change mitigation planning.
Implementers	From 1 to 4: **GCOS,** WMO, Global Data Centres.
Means of Assessing Progress	For 1 and 2: Published GCOS document defining requirements and standards for data and metadata. 3. GCOS to periodically audit climate data centres for compliance with the requirements and availability of all applicable mandatory metadata as defined in the WIGOS Metadata Standard. GCOS to develop implementation plans as required. 4. Increased number and volume of ECVs for which data is exchanged according to the WMO Unified Data Policy.
Additional Details	1. Working with existing data centres, GCOS should coordinate the development of an agreed set of requirements with respect to data centre activities such as processing, quality controlling, archiving, and distribution of climate-related observations of the atmosphere, land, and ocean. These should be general

[8] Lin, D., J. Crabtree, I. Dillo, et al., 2020: The TRUST Principles for digital repositories. Sci Data 7, 144, DOI:10.1038/s41597-020-0486-7

[9] Wilkinson, M.D., et al., 2016: The FAIR guiding principles for scientific data management and stewardship. Scientific Data, 3, DOI:10.1038/sdata.2016.18

	enough to be widely used but also specific enough to be directly applicable to climate data. They should emphasize the Findability, Accessibility, Interoperability, and Reusability (FAIR) principles; comply with existing standards of the WMO, World Data System, and other international bodies; ensure interoperability between data and metadata stored at different centres; ensure consistency with WMO systems (e.g., OSCAR), especially for ECVs; contribute to the implementation of the new WMO Unified Data Policy; and call for free and open data policies. This activity involves the development of standards in areas where adequate standards currently do not exist. One such area is the development of standards for compiling and managing collection-level metadata, i.e., metadata that provides the data user information about the data that is needed for assessing the data's utility for a particular purpose as well as for acquiring and processing the data. Such metadata standards are particularly lacking for the terrestrial domain. GCOS, alongside other relevant bodies, should develop such standards and coordinate their implementation. 2. Once all necessary requirements and standards have been developed, an implementation plan needs to be developed that outlines how GCOS will facilitate and encourage the implementation of these standards. Implementation activities may include (1) coordination with funding agencies to ensure that funding is available to data centres that need to upgrade their infrastructure or undertake significant amounts of work in order to meet the requirements; (2) the development and distribution of relevant training materials for data centre personnel; and (3) the establishment of a mechanism for determining and tracking progress towards implementation of the requirements globally. 3. The stewardship of GCOS related data sources should be assessed on a regular basis according to the requirements and standards identified in Activities 1 and 2. Internationally agreed-upon standards for the assessment of the maturity of data repositories exist with the CoreTrustSeal of the International Science Council's World Data System or the WMO Stewardship Maturity Matrix for Climate Data (SMM-CD) and could be utilized for this purpose if the working groups developing the data centre requirements decide to include them. 4. At the most recent Congress WMO adopted its Unified Data Policy which places a requirement on Members to share historical data holdings. Activity is now required to enable the sharing of these historical data via documented routes to recognized global and regional repositories. GCOS, working with WMO must develop guidance and support and integrate requirements into relevant technical regulations.
Links with other IP Actions	Action D1, D2 and D3 are interconnected and pursue a common goal of preserving and providing access to ECV data in Global Data Centres, including interoperability. D5: data rescue is connected to data sharing of historical data.

Action D2: Ensure Global Climate Data Centres exist for all in situ observations of ECVs	
Activities	1. Identify ECVs for which adequate global centres do not exist or are insufficiently supported and facilitate and support the creation or improvement of global data centres for these ECVs. **2. Promote regional data centres, their interoperability, where possible, synchronisation of their data holdings, and the provision of data in their archives to global data centres.**

<table>
<tr><td>Issue/Benefits</td><td>The aim of this action is to ensure that all available observations for each ECV / observation type are distributed from integrative data centres that meet the requirements established in Action D1. Data centres do not exist for every ECV and the continued existence of some of those that do exist is not assured due to the lack of long-term funding. This action addresses this issue and targets specifically in situ data.</td></tr>
<tr><td>Implementers</td><td>From 1 to 2: GCOS, WMO, GOOS, NMHS, National agencies, Funding agencies.</td></tr>
<tr><td>Means of Assessing Progress</td><td>1.
a) List of climate data centres, identifying those in need of additional support followed by annual reports by GCOS panels on data centres at risk;
b) List of ECVs for which no data centre exists, followed by annual updates on progress towards filling the identified gaps.
2. Establishment of a functional network of regional data centres for all ECVs of relevance in the region and their synchronisation with global data centres.</td></tr>
<tr><td>Additional Details</td><td>1. Global Climate Data Centres need to maintain and construct long-term time series of ECV data and to archive and disseminate these time series for the long term, at least several decades following the requirements established as part of Action D1. The maintenance of these data centres requires long-term assured funding.
The first step is to identify all existing data centres and the status of their funding. ECVs for which data centres are missing need to be identified, and the relevant GCOS panels should advocate for the establishment of the missing centres. GCOS should also make a clear case for adequate funding of data centres and the benefits that will accrue.
For example, sustained funding is urgently needed for the Global Ocean Data Analysis Project (GLODAP), where ocean biogeochemistry data is collected and stored. Despite a recent increase in the quantity of these observations GLODAP is a largely unfunded community effort. Such a situation is unsustainable, and there is a significant risk that the effort will diminish or disappear in the next few years.
Following an initial assessment of adequacy, it is necessary to continuously review the health of the network of global data centres. GCOS panels should annually review the status of global data centres within their domain and highlight any issues so that these can be remedied.
2. The Global data centres are part of a network of data centres that include regional data centres and in some cases the observation networks. These need to be integrated into a global system to improve data exchange and data availability. They should also follow the requirements developed in Action D1. Sustainable funding of regional data centres and observation networks is key.
Working with Regional Associations and Regional WIGOS Centres, GCOS should advocate for regional level data collection and curation which may then be passed on to the extent possible for inclusion in global data centre collections.
This action focuses on in situ data. Information about satellite-based climate data records can be found in the ECV inventory.</td></tr>
<tr><td>Links with other IP Actions</td><td>Action D1, D2 and D3 are interconnected and pursue a common goal of preserving and providing access to ECV data in Global Data Centres.</td></tr>
</table>

Action D4: Create a facility to access co-located in situ cal/val observations and satellite data for quality assurance of satellite products

Activities	**1. Improve access to co-located satellite and reference quality in situ observations, as well as tools for evaluation purposes. This facility will use data from reference networks and FRM programs for a broad range of ECVs for calibration/validation of satellite programs.** 2. Develop tools to use the co-located data collection developed under Activity 1 to undertake various analyses of satellite-based measurements.
Issue/Benefits	The uncertainty for satellite measurements of ECVs are determined and/or verified through intercomparison against in situ measurements. These intercomparison field experiments also provide test bed opportunities for assessing measurement capabilities of new technologies, for testing and developing best practices, and to assess uncertainties in Numerical Weather Prediction and Climate Models. The current limited availability of co-located in situ and satellite data for calibration and validation data restricts the ability of users to assess the quality of satellite products. This action will improve the ability to exploit high quality reference measurement sites/networks including, but not limited to, FRM programs (see Action B1) to provide such calibration and validation data for a broad range of satellite products. What is required is a database of reference measurements and co-located satellite measurements to enable cal/val activities along with provision of a suite of tools. The provision of a centralised facility would minimise overall cost while maximising overall exploitation potential and is therefore preferable to such efforts at the satellite mission-level. It also enables applications which may wish to consider multiple ECVs from multiple satellites and their data fusion. A centralised well-supported facility would enable the long-term satellite cal/val capability necessary to extract the value from considerable investments in satellites and reference networks including FRM programs on a sustained basis.
Implementers	From 1 to 2**: Space agencies**, WMO, NMHS, Research organizations.
Means of Assessing Progress	1. Establishment of a unified database of and access to co-located, reference quality, ground-based measurements suitable for satellite cal/val. 2. Increased number of available compatible satellite and in situ datasets.
Additional Details	This activity addresses the need to improve the exploitation of the high-quality data needed to calibrate and validate satellite observations by making these data easily available: access is currently a major barrier to their use. A more coordinated, centralised approach to the storage and provision of data for satellite cal/val, with greater involvement of and partnership with reference networks (Action B1), along with the development of associated tools would yield cost efficiencies as well as scientific benefits. Users could come to centralised repositories which serve data for multiple satellite missions, enabling their usage in a more seamless manner. Tools could be shared between similar missions and made available to users. The centralised repository would serve to highlight the presence of critical gaps in provision of high-quality in situ data to inform the quality of ECVs measured from space. This, in turn, would help inform the strategic further investment in new reference networks and FRM programs to fill these gaps. Further details are given in Sterckx et al. (2020)[10].

[10] Sindy Sterckx, Ian Brown, Andreas Kääb, Maarten Krol, Rosemary Morrow, Pepijn Veefkind, K. Folkert Boersma, Martine De Mazière, Nigel Fox & Peter 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

Links with other IP Actions	This activity has strong links to other actions: A1: Sustained support for the source in—situ observations that underpin this action. B1: Provision of reference quality in situ measurements including from FRM; and several other actions that underpin the in-situ observations (B4, B6, B7, C4, F4).

Action D5: Undertake Additional In-Situ Data Rescue Activities	
Activities	**1. Augment existing archives as inventoried by the WMO DARE initiative (https://community.wmo.int/data-rescue-projects-and-initiatives-dare) and the ACRE project (http://met-acre.net/) with newly discovered or as yet un-inventoried holdings available for potential rescue.** **2. Continue efforts to advance the rescue of key historical data records from hard copy or image form via an appropriate combination of professional, citizen science and class-based activities.** **3. Maintain and update data rescue best practice guidelines as detailed at e.g. https://datarescue.climate.copernicus.eu/tools-community-support.**
Issue/Benefits	The coverage of historical observations is uneven across space, time, and for different parameters. While some of these differences are due to differences in the volume of observations taken, others are a function of the amount of historical data that have been rescued and made available to the global community. The degree to which national archives have been digitised differs substantially. Furthermore, many digitization efforts have focused on the most widely-used parameters, e.g., temperature, often leaving out other parameters that are nevertheless of increasing interest. One such parameter is the occurrence of thunder, which can be used to extend lightning records back in time. Given the need for as much historical climate data as possible for the purposes of climate assessment, adaptation and mitigation planning, and reanalyses, this action aims to encourage a renewed concerted effort to locate and rescue observations of particular interest that are available but have not yet been digitised and incorporated into existing archives.
Implementers	From 1 to 3: **Existing data rescue organizations**, WMO, GCOS, Funding agencies, NMHSs, National governments.
Means of Assessing Progress	1. Updates by NMHSs and others of data rescue inventories maintained by WMO DARE with newly discovered and as yet unregistered holdings. 2. New funded data rescue efforts leading to the provision of additional data rescued to recognized global repositories for relevant ECVs via a variety of approaches (professional keying, citizen science, participatory learning). 3. Updated best guidance documentation for data rescue activities readily available to support funded data rescue activities.
Additional Details	WMO Unified Data Policy includes sharing of historical data and should inform the planning and execution of the activities within this Action. It is important to rescue the raw data as well as the processed ECVs.
Links with other IP Actions	A successful D5 will provide datasets with historical observations feeding into global climate data centres considered in Actions D1-D3.

6. THEME E: ENGAGING WITH COUNTRIES

Many climate observations are made by national bodies, however these efforts need support and coordination. Some countries have national programmes that need to be connected regionally and globally to share and communicate issues and solutions. GCOS can help by linking these national efforts into the global system, providing information on observing needs, promoting needs for support and access to global information.

Links to national observing systems should be put into place. Ultimately the benefits of climate observations need to be widely understood and the contributions of national observations to global datasets enhanced.

Action E1: Foster regional engagement in GCOS	
Activities	**1. Undertake at least one regional GCOS Workshop each year.** **a) Promote the benefits of coordination of climate observations (in situ and satellite) and GCOS programs.** **b) Explore regional issues, gaps and needs and develop plans to address them.** 2. Report regional needs and issues to the UNFCCC, WMO and other relevant stakeholders.
Issue/Benefits	Lack of regional and national input into global observing decisions can make GCOS seem remote from implementers "on the ground" and leaves GCOS unable to fully understand and respond to the issues facing observing systems at a local level. There is a need to better integrate GCOS needs into national and regional decision making to ensure sustainable observations for climate. These activities will better inform the global system of local needs and link local observing systems with international support and capacity development. They can also provide some capacity development, explain the needs and uses of climate data and help ensure that countries have access to all the data. For example, GBON and SOFF were developed from needs identified in a GCOS regional workshop on climate observations systems in the Pacific Island states[11].
Implementers	From 1 to 2: **GCOS**, Parties to the UNFCCC, WMO (Regional Organizations), GOOS (Regional Alliances).
Means of Assessing Progress	1. Number of regional workshops held annually in collaboration with WMO and other stakeholders. 2. Reports to UNFCCC and WMO.
Additional Details	This work can be done with WMO Regional Organizations and GOOS Regional Alliances, as appropriate. Other stakeholders should be considered: in the past Copernicus has supported regional workshops. 1. Regional workshops engage countries directly. Engagement of countries needing support and more experienced countries will be beneficial. Involving both those making observations and those from the climate policy sphere will allow the workshops to identify issues and potential solutions and will also inform the countries about how observations support services and policy development. An important part of obtaining support, financial and political, for climate observations is providing a rationale for the observations and a clear description of the benefits. International coordination and data exchange enhance these

[11] Full workshop report available online: https://ane4bf-datap1.s3.eu-west-1.amazonaws.com/wmod8_gcos/s3fs-public/fijiworkshopoct2017_final1.pdf?E8vbQOTXp3.VJII2p6utJLP.l8xM7huA.

	benefits. Regional workshops should agree to regional needs, gaps and develop plans to address these needs. 2. A key component will be reports to appropriate stakeholders, especially the UNFCCC and WMO on needs and issues. The discussions of these reports, and decisions based upon them, will enhance the implementation of observation systems.
Links with other IP Actions	Actions E2 and E3.

Action E2: Promote national engagement in GCOS	
Activities	**1. Encourage the development of national coordination of climate observations (e.g. national GCOS programs).** **a) Collect annual reports of these programmes;** **b) Promote the benefits of national coordination;** **c) Support the development of new national climate observing programmes, including bi-lateral programmes to develop and support national GCOS activities;** **2. Engagement of National GCOS Focal Points** **a) Revise terms of reference (ToR) for National GCOS Focal Points;** **b) Increased nomination of National GCOS Focal Points.**
Issue/Benefits	National programmes provide the information needed to support adaptation and mitigation and can be focussed on specific issues of national importance. Some countries have established national GCOS programmes or national climate observing programmes in their territories to monitor climate and climate change. These programmes are important to focus effort within a country, identify national priorities and, where appropriate, report issues and needs internationally to potential donors. Where national resources for climate observations are very limited, national climate observing programmes can aid in requesting support, resources and capacity development. National GCOS programmes can also provide the reporting on observations to the UNFCCC required for national communications. These actions will better inform the global system of local needs and link local observing systems with international support and capacity development. They can also provide some capacity development, explain the needs and uses of climate data and help ensure that countries have access to all the data. GCOS National Focal Points should be the point of contact between GCOS and all national climate observations, especially those observations made outside of the NMHS. However, many countries do not have a focal point, current lists of focal points are out of date and their ToR need updating.
Implementers	From 1 to 2: **GCOS**, Parties to the UNFCCC, NMHS, Academia.
Means of Assessing Progress	1. a) Number of national climate coordination programs 2. a) Revised ToR for National Focal Points; b) Number of active National GCOS Focal Points.
Additional Details	1. A few countries have national GCOS programmes. Others have similar climate monitoring programmes. GCOS should support the development of these programmes and encourage the spread of best practices to other countries.

	GCOS needs to inventory those national programmes that exist, collect recent reports, and identify contacts. Support and guidance to the development of new programmes can be given. If there is sufficient interest, workshops to exchange best practices and experiences can be held. 2. GCOS needs to revitalise the national GCOS focal points, starting by developing a revised ToR. The GCOS focal points should coordinate with all bodies producing climate data, and not just NMHS. New ToR for the National GCOS Focal Points should emphasise this role outside of the NMHS and other state bodies. Currently most of the existing focal points are within NMHS and the need to link to all climate observations is not recognized. If there is a national climate observing system, the Focal Point should be a link to that programme as well. Once the ToR are revised and agreed, nominations for the role should be requested from all countries. The GCOS Secretariat will need to support Focal Points, exchanging information and ideas to develop national observation systems and increase communication.
Links with other IP Actions	Actions E1 and E3.

7. THEME F: OTHER EMERGING NEEDS

Many climate impacts are directly related to extremes, for example heatwaves, flooding and droughts. Many users will not use the observed data directly, but rather use reanalysis products. Observing in areas of interest, at relevant resolutions will greatly improve reanalysis.

This theme addresses some of these needs ranging from higher resolution data, (both spatial and temporal) to monitor extremes, to monitoring of areas of specific concern where impacts on humans are at their greatest: coastal and urban areas. Finally, there is a widespread interest in improving monitoring of GHGs fluxes to support national GHGs inventories and mitigation and to detect changes in the overall cycles of these gases.

GCOS will continue to identify the needs of adaptation and supporting the Paris Agreement: this theme just addresses actions that have already been identified and can be started in the lifetime of this plan, 5-10 years.

Action F1: Responding to user needs for higher resolution, near real time data	
Activities	1. Identify the higher resolution observations of of ECVs to support the Climatic Impact-Drivers (CIDs) identified in the IPCC AR6 and develop plans to address the priority needs. (see IPCC WGI AR6 Figure SPM.9). 2. Improve biomass, land cover, land surface temperature, and fire data with sub-annual observations and improved local detail and quality. **3. Increase temporal resolution of surface air temperature, soil moisture and precipitation to capture both climate and human-induced changes and extremes.** **4. Include daily averages with the monthly CLIMAT reports for land surface stations (GSN/RBON).**
Issue/Benefits	High-resolution and near-real time information of ECV-based climate information at global, regional and local scales allows planning to consider the full range of possible impacts.

	High-resolution data (in space and time), which, for many ECVs are currently not available, will allow rapid monitoring of changes in the climate system. This will allow the tracking of sustainable mitigation and adaptation measures. Improved high-resolution and near-real-time ECV data will allow improved understanding of CIDs. Whilst monthly CLIMAT reports have been available for many decades, the option to include daily averages has not been implemented operationally across the GSN/RBCN networks although it was approved by WMO in 2015. Daily averages would allow users to monitor the Regional/National impact of climate change, including an assessment of extremes.
Implementers	1. **GCOS,** Research organizations, Academia, WMO. 2. **Space agencies.** 3. **NMHS,** WMO. 4. **WMO**, NMHS.
Means of Assessing Progress	1. Inventory of improvements to ECVs needed to inform CIDs (e.g. spatial and temporal resolution, latency, uncertainty and data stewardship) and plans for priority actions. 2. a) Availability of key terrestrial ECVs at resolutions of 10-30 m stored in long term archives; b) Availability of Near Real Time (NRT) sub-annual data for critical land changes and to identify extremes stored in long term archives. 3. Availability of temperature, precipitation and soil moisture at higher temporal resolution stored in long term archives. 4. Increased availability of CLIMAT reports with daily averages.
Additional Details	1. CIDs are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems and are thus a priority for climate information provision. Sustainable adaptation and mitigation planning and management need high-resolution data and in near real time to monitor critical changes in CIDs as they occur and so allow adaptation responses to be implemented. This includes the need for systematic data for land changes (land cover/use, fire, biomass), hydrological conditions (runoff, soil moisture), cryosphere data (e.g. sea ice, ice sheets, permafrost, snow, glaciers), atmospheric data (e.g. temperature and precipitation and related extremes such as droughts, floods, heavy storms and cyclones, heat waves etc.), and oceanic data (e.g. marine extremes, ocean warming, ocean acidification, and oxygen depletion) to be available in timely and easy-accessible manner. Often, consistency across spatial and temporal scales is needed, as well as consistency among multi-variable sources. Existing data streams for ECVs informing CIDs need to evolve to increase regional (e.g. national) and local detail and quality and aim for much faster data delivery than available today. The various data streams should be provided in integrated, consistent ways so the various user and expert communities can use and combine them for their purposes. GCOS should make sure that the ECV requirements are updated accordingly. 2. and 3. The GCOS expert panels have already identified some specific high-resolution, near real time datasets that have been requested by users and that the existing monitoring systems are able to support within the next 5 years. 3. When implemented GBON will deliver higher resolution spatial and temporal data record for most land surface stations and some marine platforms. Where stations report on an hourly basis it will be possible to construct both monthly and daily CLIMAT reports for those stations which do not compute/report the CLIMAT operationally.

Links with other IP Actions	B2: GBON. C4: Develop regional reanalysis; reduce data latency. Reanalysis is important for responding to user needs for higher-resolution data. Observations in this action will benefit reanalysis. D2: Availability of data in archives. D3: Easy accessibility of data.

Action F3: Improve monitoring of coastal and Exclusive Economic Zones	
Activities	**1. Expand global ocean climate in situ observations and satellite products into Exclusive Economic Zones (EEZs) and coastal zones.** 2. Develop new satellite-based products for coastal biogeochemistry. 3. Produce land cover datasets in coastal areas without land surface masks and in near real time, including uncertainties. **4. Improve national coastal and EEZ data collection, data processing, uncertainty evaluation and data curation by improving access to equipment and ensuring local practices are consistent with the global guidelines and best practices.**
Issue/Benefits	Monitoring of coastal zones and EEZs is necessary to allow policies and measures to be developed to protect the significant vulnerable populations, infrastructure and ecosystems in these areas. Coastal zones are subject to rapid change and are the home to a substantial part of the Earth's population and to sensitive ecosystems. Changes near the coast directly impact ecosystems, people's health and livelihoods. Impacts such as storms, sea level rise, coastal erosion and inundation, flooding and saltwater intrusion are increasing. Currently these areas are poorly observed. Most of the purposely designed arrays of instrumentation and high resolution hydrographic transects (such as GO-SHIP) or the Argo program provide ocean observations at the open ocean, and the coastal and national waters are poorly monitored in many regions. From the land side, observations are directed at land properties and cover and so do not capture all the changes that are occurring. This action aims to address these issues. Developing products for variables such as temperature, turbidity, chlorophyll, and CDOM within 1 km of coasts, within estuaries and at EEZs will improve modelling of organic dissolved and particulate carbon distribution and dynamic, including land-ocean interaction. Turbidity/suspended particulate matter products, for example, can document the enhanced erosion in Arctic regions associated with permafrost loss.
Implementers	1. **GOOS**, Space agencies, NMHS. 2. **Space agencies,** Research organizations, Academia. 3. **Space agencies.** 4. **GOOS,** NMHS, Research organizations.
Means of Assessing Progress	1. Increased density of observations and reprocessed products in EEZ and coastal waters, and related uncertainties. 2. Number of global operational biogeochemical products in coastal areas. 3. Number of land-cover data sets produced without masks. 4. Published national and regional guidelines.

Additional Details	1. Coastal regions are where boundary currents and upwelling regimes modulate fluxes of heat, carbon and other properties, with small-scale phenomena highly impacting the climate globally and locally, and also ecosystems. Not all observing systems used elsewhere, such as Argo, can provide high-resolution full-depth monitoring in coastal areas. Argo measurements do not sample at shelf-shelf break regions (< 2000 m depth). Consolidation and development of in situ observing networks could be done through national and regional engagements, including local actors from certain sectors such as fisheries or maritime transport. Activity 1 should consider the on-going discussions and efforts to facilitate access to the EEZs to carry out systematic ocean observations, as reflected on a recent multi-agency workshop lead by UNESCO/IOC[12]. A successful implementation of GBON can increase the number of surface marine meteorological observations collected by member states in their respective EEZs. At the coast, "climate quality" tide gauge observations that include co-located vertical land motion measurements are needed for our understanding of contemporary and future coastal flood hazard. Finally, reprocessing of existing satellite records in coastal regions and generation of global products which include the coastal regions (e.g. altimetry and wind data records) is needed to increase coverage near the coast, which may require some software development. Products should include clear information on their limitations in coastal areas and EEZs, and their related uncertainties. 2. There are currently no biogeochemical operational products from high resolution satellites (e.g., Sentinel 2AB, Landsat 8) in coastal areas. Satellite observations need to be reprocessed to provide products for variables such as the temperature, turbidity, chlorophyll, and chromophoric dissolved organic matter (CDOM). 3. Land cover datasets should be reprocessed without masking to allow the detection of changes at the coastline. This activity will allow extremes and long-term trends such as sea-level rise to be captured (e.g. changes in the coastline and neighbouring land areas). Currently, impacts of changes in the sea level at the coast are not monitored because the way satellite observations are processed obscures these details. 4. Many coastal states lack access to equipment and expertise to monitor their coastal water and areas within their EEZs. Resources for equipment and capacity building are needed. In 2022 a task team has been set up under the IOC Ocean Best Practices framework[13], to identify common and accepted best practices used within the community for observations of physical, chemical and biological parameters and produce a package of easy-to-use operating procedures to monitor the coastal ocean. This guidance will need to be implemented at a national level.
Links with other IP Actions	B2: Implementing GBON will be of benefit for this action. B6 and B7: Expansion and integration of the global ocean observing system, including observations of biogeochemical/biological parameters. B8: Augmenting ship-based hydrography and fixed-point observations with biogeochemical and biological parameters. C1: Develop Monitoring standards, guidance and best practice for each ECV. C2: Activity 2 -reprocessing of satellite observations.

[12] GOOS-246 (2021), Report of Ocean Observations in Areas under National Jurisdiction Workshop. https://www.goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=26607
[13] https://www.oceanbestpractices.org/about/task-teams/task-team-22-01-coastal-observing-in-under-resourced-countries

Action F4: Improve climate monitoring in urban areas	
Activities	1. Audit existing GCOS ECVs to identify those that are urban-relevant and produce updated requirements where needed. 2. Identify new urban-relevant products and define their requirements. **3. Develop plans to address the urban monitoring requirements identified in Activities 1 and 2.**
Issue/Benefits	The majority of the human population lives in cities and urban areas, including informal settlements, are primary locations for economic and social activity, and hence these are critical locations for emissions mitigation and climate adaptation. Effective monitoring of climate relevant parameters will therefore yield substantial benefits. Such climate relevant parameters include the normal meteorological observations, but also extend to observations of other relevant variables such as pollution emissions and land use and land cover (LULC). Traditional measurements of standard meteorological parameters have sought to eliminate urban influences, wherever possible, but the reality is that temperatures that are elevated by urban influence do actually represent the climatic conditions experienced by a large proportion of the global population and are especially important when considering adaptation to climate change. Sufficient standardised observations of these complex environments are required to understand the heterogeneity of urban climates, and this in turn is key to making informed adaptation decisions.
Implementers	From 1 to3: **GCOS**, WMO, Academia, National agencies, Research organizations, NMHS.
Means of Assessing Progress	1. GCOS Adaptation Task Team progress and final reports to GCOS Steering Committee. 2. Upgraded GCOS documentation (especially for TOPC and AOPC) to clearly identify existing, upgraded and new ECVs relevant to urban climate and adaptation. 3. Plans to address urban monitoring needs and updating the user requirements.
Additional Details	Processes and procedures are identified in the working documents produced by the GCOS Adaptation Task Team (GATT). Better monitoring in the urban area is also clearly needed to measure exposure to black-carbon, ozone and aerosol precursor emissions, NO_2. The enhancement of GCOS capability in these areas will additionally broaden GCOS engagement with stakeholders in both provision and use of the relevant observations. For example, enhancement of LULC capability for urban areas might require engagement with urban climate community and the World Urban Database and Planning Tool (WUDAPT).
Links with other IP Actions	B4: expansion of atmospheric composition observations. F5: Activity 4 – improve measurements of relevant ECVs om large cities.

Action F5: Develop an Integrated Operational Global GHG Monitoring System	
Activities	**The overall aim here is to develop an integrated operational global greenhouse gas monitoring infrastructure. The first steps are:** **1. Design and start to implement a comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations routinely exchanged in near-real time suitable for monitoring GHG fluxes.**

	2. Design a constellation of operational satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible). **3. Identify a set of global modelling centres that could assimilate surface and satellite-based observations to generate flux estimates.** **4. Improve and coordinate measurements of relevant ECVs at anthropogenic emissions hotspots (large cities, powerplants) to support emission monitoring and the validation of tropospheric measurements by satellites.**
Issue/Benefits	The Paris Agreement requests Parties to regularly provide estimates of anthropogenic emissions by sources and removals by sinks of greenhouse gases, and information necessary to track progress made in implementing and achieving their nationally determined contribution under Article 4. The proposed global greenhouse gas monitoring infrastructure would support the development of these estimates (i.e. emission inventories); validate national and regional achievement of Parties' commitments in their National Adaptation Plans (NAPs); and monitor changes to the cycles of GHG that may impact the achievement of the temperature goal of the Paris Agreement. Monitoring of hot-spots via dedicated observations to validate specific point-source emissions and identify missing sources form emission inventories. Remote monitoring of atmospheric composition can quantify and identify major emission sources. Anthropogenic emission hotspots like cities and industrial facilities and power plants contribute strongly to the global GHG emissions and to emission of key ozone and aerosol precursors (SO_2, VOCs). Reliable remote observations of these emission hotspots in synergy with source detection models can contribute to verifying emission estimates and monitor and guide mitigation efforts (link to Flux ECV).
Implementers	1. **WMO (INFCOM, GAW and IG3IS).** 2. **Space agencies**, National agencies, Research organizations, Academia. 3. **WMO (INFCOM, GAW and IG3IS)**, National agencies. 4. **GCOS,** Space agencies, National agencies.
Means of Assessing Progress	1. Expanded observations of GHGs, ozone and aerosol precursors, aerosols and aerosol profiles near hotspots. 2. Designs and plans for in situ and satellite observations. 3. Identification of global monitoring centres that run global Chemistry Transport Models. 4. a) Improved satellite retrievals in the presence of varying aerosol loadings in urban and hotspot conditions. Improved uncertainty quantification of GHG retrievals in the presence of aerosols; b) Number of emission detection studies using in situ and satellite data near hot spots.
Additional Details	From 1 to 3: Based on an initial concept paper prepared by the WMO Secretariat entitled "A WMO-coordinated Global Greenhouse Gas Monitoring Infrastructure" and the Report from the WMO-hosted Greenhouse Gas Monitoring Workshop in May 2022, the 75th Session of the WMO Executive Council decided to proceed with the further development of the concept for a WMO-coordinated Global Greenhouse Gas Monitoring Infrastructure, building on existing WMO programmes and other

	regional or global infrastructure and initiatives. This infrastructure will consist of the following main elements: a) A comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations routinely exchanged in near-real time; b) A constellation of satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible); c) A global Chemistry Transport Model (CTM) driven by output from a high-resolution global NWP model; d) Operational near-real time assimilation of the GHG observations a) and b) into CTM and routine dissemination of the output. 4. Hot spots include urban areas, industrial zones and individual large plants. 4.1 Enhance observations in urban areas: a) Expand the network of GHG observations that measure around urban areas, in particular column and profile observations. These observations will support integration of satellite missions that detect and quantify sources; b) Ensure co-located observations of co-emitted gases (typically ozone and aerosol precursors) CO, NO_2, SO_2, VOCs. 4.2 Ensure co-located observations of aerosols loadings and aerosol profiles in urban areas: a) Improve satellite retrievals in emission hotspots; b) Evaluate GHG retrievals in urban areas by considering varying aerosol loadings using reference observations; c) Focus on improving GHG retrievals and their uncertainty quantification in urban and other local hotspot cites (Action B3). Present challenges in monitoring emission hotspots include: • Missing reference data sets of GHGs and other co-emitted gases and aerosols in urban areas. • Challenges in estimating GHG concentrations in the presence of varying aerosol loads. Underestimated (or overestimated) uncertainties can mislead the emission estimation. • Integration of in situ and satellite measurements. In the future, measuring stable isotopes of carbon will allow separation of natural and fossil sources of GHG.
Links with other IP Actions	B3: New satellite missions. B4: In situ monitoring of aerosols and greenhouse gases. F4: Climate monitoring in urban areas.

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