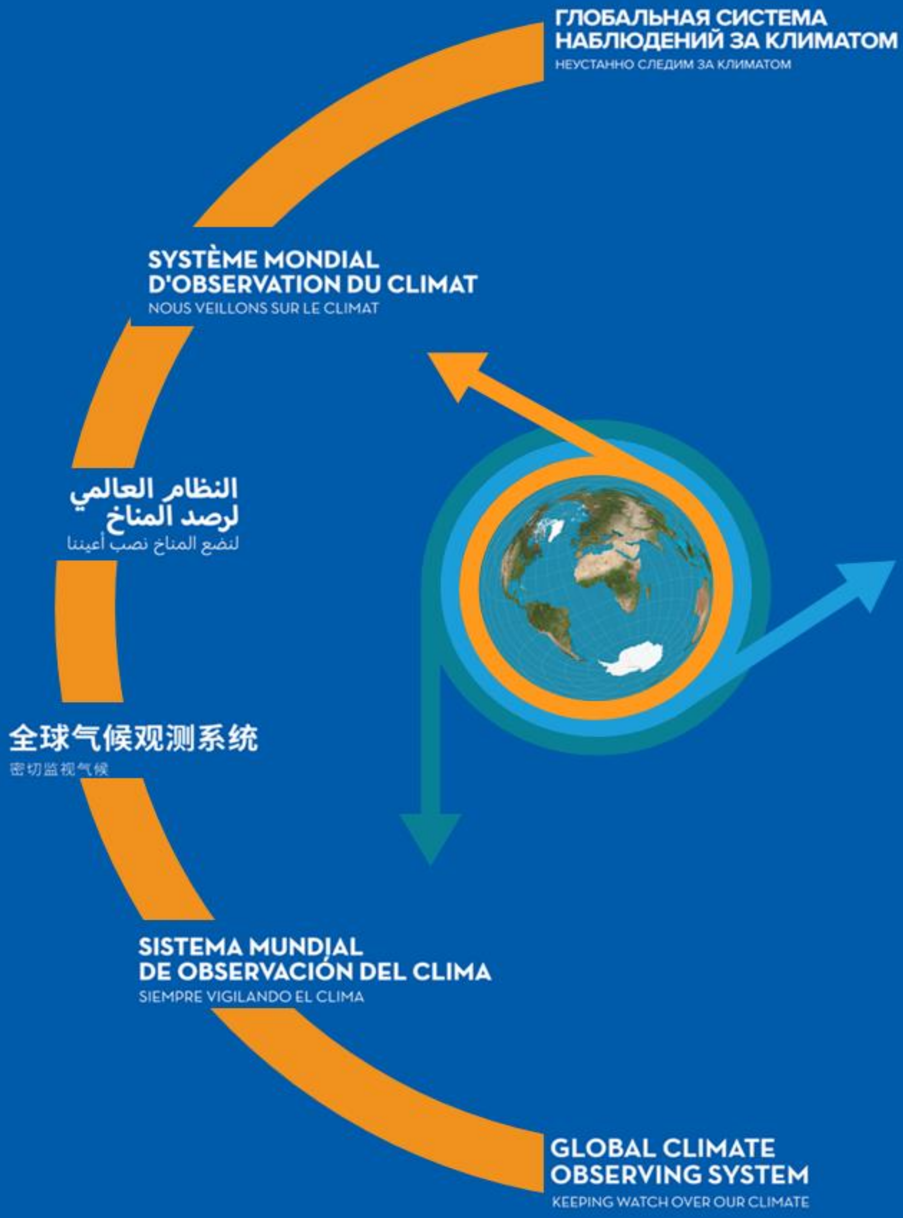
The 2022 GCOS Implementation Plan

Research and Academia Supplement



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1. INTRODUCTION

This Research and Academia Supplement to the 2022 GCOS Implementation Plan extracts those activities for which the research and academia community has been identified as key implementing partner.

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 at identifying 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 the research and academia community. Within each action the specific activities for the research and academia community are highlighted in bold. In the list of implementers, those in bold are considered to take the lead in addressing and monitoring the activities.

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 Research and Academia community.

Theme	Actions	Research organizations	Academia
A: ENSURING SUSTAINABILITY	A1. Ensure necessary levels of long-term funding support for in situ networks, from observations to data delivery	x	x
B: FILLING DATA GAPS	B1. Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)	x	
	B4. Expand surface and in situ monitoring of trace gas composition and aerosol properties	x	
	B6. Expand and build a fully integrated global ocean observing system	x	x
	B7. Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters	x	
	B8. Coordinate observations and data product development for ocean CO_2 and N_2O	x	
	B9. Improve estimates of latent and sensible heat fluxes and wind stress	x	x
	B10. Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles	x	
C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING	C2. General improvements to satellite data processing methods	x	x
	C3. General improvements to in situ data products for all ECVs	x	x
	C4. New and improved reanalysis products		x
D: MANAGING DATA	D4. Create a facility to access co-located in situ cal/val observations and satellite data for quality assurance of satellite products	x	
E: ENGAGING WITH COUNTRIES	E2. Promote national engagement in GCOS		x
D: MANAGING DATA	F1. Responding to user needs for higher resolution, real time data	x	x
	F2. Improved ECV satellite observations in polar regions	x	x
	F3. Improve monitoring of coastal and Exclusive Economic Zones	x	x
	F4. Improve climate monitoring of urban areas	x	x
	F5. Develop an Integrated Operational Global GHG Monitoring System	x	x

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.

Several observational efforts, particularly in the ocean and terrestrial domain, are supported through short-term funding depending on research projects, with a typical lifetime of a few years, leaving the development of short-term and vulnerable records. This is particularly true for parameters that are not traditionally monitored for weather predictions and will not be supported by WMO's GBON and SOFF, in its present design.

Since these observations are executed by a large range of actors, including research and academia community, 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 theme focuses on those in situ and satellite observations that are particularly at risk, while acknowledging that all 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

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

	report by the end of 2023. The report should provide a current health snapshot of financial support for the networks. 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).

Despite their successes, gaps in geographical coverage do exist in satellite observations. Moreover not all satellite agencies have made observations available to the ECV inventory. All satellite agencies should strive to reprocess their data and make them available as climate data records.

Reference quality observations respond to the need for monitoring the changes that are occurring in the climate system, support timely political decisions for adaptation and can help to monitor and quantify the effectiveness of internationally agreed mitigation steps. Reference quality measurement programs have already been established for different domains, however there are still gaps that need to be addressed, like lack of coordination among different programmes.

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.

<table>
<tr><th colspan="2">Action B1: Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)</th></tr>
<tr><td>Activities</td><td>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.</td></tr>
<tr><td>Issue/Benefits</td><td>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 being 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.</td></tr>
<tr><td>Implementers</td><td>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.</td></tr>
<tr><td>Means of Assessing Progress</td><td>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).</td></tr>
</table>

	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: • Networks in high and low above-ground biomass regions; • Ground-based in situ measurements of above-ground biomass and vegetation dynamics following FRM protocols (Dunanson et al., 2021); • Ground-based time-series in situ measurements of surface albedo, FAPAR and LAI with their uncertainties; • 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 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 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 B7: Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters	
Activities	**Add biological and enhanced biogeochemical sensors and field/laboratory measurements to the already existing ship-based hydrography and fixed-point observations to establish a baseline of plankton distributions and phenology (seasonal timing in phenotype and abundance).**
Issue/Benefits	Some of the greatest uncertainties in the projections of future climate are associated with the response of the biosphere to present and future environmental change, and the subsequent biotic interactions, responses and feedback mechanisms. Both established and novel technologies provide the capacity to include measurements of plankton on existing coordinated observing platforms across a wide range of scale that can contribute to both the GOOS Biology and Ecosystem Essential Ocean Variables (EOVs) and the GCOS ECVs to deliver global observations. Broadening current hydrography and oceanography programs to include measurements of plankton EOVs/ECVs that can then contribute to global observing systems will assist in filling gaps in understanding of primary and secondary productivity dynamics and their role in ocean-climate interactions. It will also strengthen efforts in incorporating primary and secondary productivity and their dynamics in Earth System Models, thereby improving current capacity to forecast the response of the system under climate scenarios that are informative for policy-

[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)

	making and management of coastal and marine systems. Comprehensive in situ multidisciplinary measurements at scale will also support many other efforts in quantifying ocean productivity, including ocean colour radiometry, and will be complementary to other global ocean observing networks (e.g., Biogeochemical Argo, GACS) in contributing to the plankton ECVs.
Implementers	**GOOS**, Research organizations (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	Increased number of ocean biological and biochemical datasets available and shared via global repositories.
Additional Details	In 2019, at the conclusion of the OceanObs'19 decadal conference, recommendations of the scientific community were to maintain and expand spatial extension of co-located physical and biological / biogeochemical observations. This development will require sustained coordinated campaigns, standardisation of some methods including data QC, data management approaches and establishment of best practices around the world. The key programs and networks are ship-based time series, local/regional/national surveys, national reference stations, GO-SHIP, OceanSITES, Ocean Color satellites, Biogeochemical Argo, GACS.
Links with other IP Actions	B8: Improve components of the global ocean observing system. 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 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 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.
Implementers	From 1 to 2: **NMHS,** GOOS, Research organizations. 3. **Academia,** Research organizations, NMHS. 4. **Satellite agencies**, NMHS, Academia.
Means of Assessing Progress	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.
Additional Details	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. 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

[4] Butterfly: a satellite mission to reveal the oceans' impact on our weather and climate https://doi.org/10.5281/zenodo.5120586

	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.

Action B10: Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles	
Activities	**1. Continue to periodically review observations of the Earth's energy, water, carbon cycles to identify gaps and areas of high uncertainty.** **2. Review consistency of the underlying observations.** 3. **Develop plans to address the gaps identified in (1), if feasible.**
Issue/Benefits	This action will implement an objective approach to identifying gaps and major uncertainties in the global climate monitoring system. The energy, water and carbon cycles and their closure/imbalance are fundamental to understanding current climate state and change, and improved observations of the cycles will lead to improved climate projections and reduced model biases.
Implementers	From 1 to 3: **GCOS,** Research organizations, Funding agencies, WCRP.

[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

Means of Assessing Progress	1. a) Periodic assessments of each cycle and its components at least as part of the Status Report (about every five years); b) Periodic reviews of suitability of existing ECV structure to monitor energy, water and carbon cycles at least as part of the Status Report. 2. Periodic assessment of consistency of the underlying ECVs. 3. Include plan to address the main issues for the next GCOS Implementation Plan.
Additional Details	GCOS has reviewed how well the existing structure of ECVs monitors these cycles and their components. This has revealed significant gaps in observations and highlighted areas of highest uncertainty – this information will be used to guide developments and improvements to the observing system. Expert teams reviewing observations of the cycles will report on gaps and major uncertainties for inclusion in the next GCOS Status Report. They will develop plans to address these issues in subsequent Implementation Plans. See also Section 2.4 in this GCOS IP for more details and references.
Links with other IP Actions	This action indirectly links with many others but in particular with: B3: Better EEI measurements. B4: In situ GHG observations. B8: Coordinate observations and data product development for ocean CO_2. C5: Activity 2 (estimation of aboveground biomass).

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 C2: General improvements to satellite data processing methods	
Activities	**1. Improve radiance measurement records and Radiative Transfer (RT) models for simulating them.** **2. Improve uncertainty quantification of satellite retrievals.** **3. Periodically reprocess full satellite data records whenever an update of underlying methods occurs, especially when those risks introducing discontinuities into the time series.** **4. Consolidate satellite observations into instrument-independent space-time grids for easy intercomparisons and fusion.**

	5. **Ensure harmonisation and quality of ancillary data used to generate satellite products such as solar irradiance and meteorological data.**
Issue/Benefits	Many data products depend on extended processing streams from observations to data products. Improving data processing methods facilitates ease of use, regular reprocessing and robust uncertainty quantification of available observations. This action identifies key areas for improvements. Ensuring the availability of relevant, high-quality estimates with long-term continuity across multiple instruments and satellites results in better quality of the satellite climate data records.
Implementers	From 1 to 5: **Space agencies,** Academia, Research organizations.
Means of Assessing Progress	For 1 and 2: New publications showing improvements in radiative transfer and uncertainty characterisation. 3. Increased number of available reprocessed Fundamental Climate Data Records (FCDRs). 4. Increased number of available consolidated gridded satellite datasets. 5. Products with consistent traceability to ancillary data and associated quality assessment.
Additional Details	1. Radiance measurement records need to be carefully assessed, characterised, and calibrated. Radiative Transfer (RT) schemes for simulating them also need to be improved, as this is a key component of processing radiance measurements and quality evaluation/assessment. Line-by-line radiative transfer models are critical and need to be available as reference for faster RT schemes. 2. Improve uncertainty quantification of satellite retrievals on all processing levels. Specifically (i) consider more carefully non-linearities and non-Gaussian uncertainties in the retrievals and (ii) consider and report spatially correlated uncertainties. Presently these are not properly considered in the satellite retrievals. Proper characterization of the uncertainties is key when data are further used e.g., in assimilation (e.g., in inverse modelling for emission estimation). 3. The quality of retrieved quantities also depends critically on the methods, ancillary, and auxiliary data used in the retrieval algorithm. As all these dependencies improve or ECV requirements changes, the satellite observations can (and should) regularly be reprocessed to ensure that the satellite data record is as useful as it can be (i.e., information content is fully exploited). 4. The typical lifetime of individual satellite instruments is shorter than the time scale required for climate applications. Therefore, satellite observations need to be consolidated across multiple instruments and satellites into high-quality estimates with long-term continuity in order to maximise their value for the climate community. This consolidation must be done in an optimal and standardised way, ensuring consistency across multiple instruments and satellites.
Links with other IP Actions	The following Actions are relevant to improve satellite data processing methods: B1: Reference observations (Uncertainty characterizations and improved uncertainty quantification of satellite retrievals). D4: Access to co-located data.

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.

Action C4: New and improved reanalysis products	
Activities	**1. Implement new production streams using improved data assimilation systems and better collections of observations, particularly aiming at:** **a) Further increasing resolution;** **b) Improving handling of systematic observational and model biases;** **c) Providing (improved) estimates for the uncertainty in the mean state;** **d) Improving quality control in data sparse areas.** **2. Develop coupled reanalysis (ocean, land, sea-ice).**

	3. Improve the capability of sparse-input reanalysis that covers the entire 20th century and beyond. **4. Develop and implement regional reanalysis and other approaches to regionalisation.** **5. Reduce data latency.**
Issue/Benefits	Reanalysis systems that employ data assimilation techniques are highly effective at combining disparate observations with physical principles to represent complex Earth systems, although there is a need for further improvement for reanalysis. Reducing the uncertainty in the estimation of trends and in the description of low-frequency variability from reanalyses leads to better understanding of climate change from these products compared to precursor generations. Improved representation of Earth system components and consistency among them is still, however, needed. Increasing their spatial resolution and reducing the latency will increase the range of potential applications of reanalyses.
Implementers	From 1 to 5: **Reanalysis centres**, Academia, Space agencies.
Means of Assessing Progress	1. Publications describing new reanalysis production streams and their validation with improved estimation of uncertainty of reanalysis data products. 2. Demonstrated benefits of coupled reanalysis. 3. New versions of sparse-input reanalysis products. 4. Number of in-depth performance assessments of regional reanalyses and other regionalised datasets. 5. Reduced latency of data product updates.
Additional Details	1. Reanalysis centres should regularly upgrade their products by introducing improved data assimilation techniques and better collections of observations (including reprocessed and data rescued data). Use of ensemble approaches will help to provide users with information on the uncertainty of products. Increased computational capacity will enable production at a higher spatial resolution and greater complexity (e.g., coupled systems, interactive chemistry). Use of homogenised, recalibrated or reprocessed observations is important in order to mitigate the impact of disruptions in instrument technology or processing algorithms. Use of advanced methods for dealing with data discontinuities will help improve the reliability of historical reanalyses. 2. A coupled data assimilation technique has a potential advantage over separate data assimilation in terms of consistency across the Earth system components. A proven benefit so far is that it can improve the SST field in a sparse observing system setting such as in the mid-20th century and earlier, but clear benefits in the current dense observing system setting have yet to be demonstrated. 3. Another type of reanalysis is a sparse-input reanalysis that only assimilates surface observations and covers a significant portion of the instrumental record, extending back into the 19th century. For this type of reanalysis, further improvement can be expected through data rescue for early instrumental meteorological observations and refinement of data assimilation systems. 4. There is a growing demand for datasets with higher resolution and accuracy, particularly for surface variables, for local and regional applications such as adaptation and monitoring of climate extremes. This demand should be met through regional reanalysis and other approaches for regionalising global data products. 5. Reduced latency of reanalysis data products should be aimed for, since it increases reanalyses' potential for applications. It also helps to reduce latency of other climate products that rely on reanalysis as input data, e.g. satellite retrievals.

Links with other IP Actions	B2: Implementing GBON will be of benefit for this action. C2: Improving reprocessing of satellite data. F1: Higher resolution observations.

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, as well as clear and enforced data management plans and data citation. 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. This may include old satellite data if discovered (Poli et a., 2017[10]). Sustained support to these activities is required. This theme aims at organizing more efficiently data rescue, data sharing, data curation and data provision.

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-

[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

[50] Poli, P., et al. (2017), Recent Advances in Satellite Data Rescue. Bulletin of the American Meteorological Society 98, 7, 1471-1484. https://doi.org/10.1175/BAMS-D-15-00194.1

	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)[11].
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).

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.

[11] Sterckx, S., et al., 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

<table>
<tr><th colspan="2">Action E2: Promote national engagement in GCOS</th></tr>
<tr><td>Activities</td><td>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.</td></tr>
<tr><td>Issue/Benefits</td><td>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.</td></tr>
<tr><td>Implementers</td><td>From 1 to 2: GCOS, Parties to the UNFCCC, NMHS, Academia.</td></tr>
<tr><td>Means of Assessing Progress</td><td>1.
a) Number of national climate coordination programs
2.
a) Revised ToR for National Focal Points;
b) Number of active National GCOS Focal Points.</td></tr>
<tr><td>Additional Details</td><td>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.</td></tr>
</table>

	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 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 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.

<table>
<tr><th colspan="2">Action F2: Improved ECV satellite observations in polar regions</th></tr>
<tr><td>Activities</td><td>Improve satellite observations of:
1. Sea Surface Salinity of polar oceans.
2. Greenhouse gases at high latitudes with a focus on the permafrost regions in wintertime.
3. Sea-ice thickness.
4. Surface temperatures of all surfaces (sea, ice, land).
5. Atmospheric ECVs at the very highest latitudes.
6. Albedo for all surfaces (land and sea-ice).</td></tr>
<tr><td>Issue/Benefits</td><td>Satellite missions in polar regions present particular challenges and this action highlights some of them affecting the measurement of certain ECVs.
1. SSS retrievals from the current generation of single-frequency, narrow L-band radiometry for salinity-measuring satellites (SMOS, Aquarius, SMAP) have much larger uncertainties in the polar oceans than for lower-latitude oceans, even though signal-to-noise ratio in certain regions of the Arctic Ocean is found to be relatively large. Future satellite salinity missions need to learn from the experience gained from the current generation of salinity-measuring satellites to improve precision and spatial resolution in polar oceans. Technology advance is thus needed to improve satellite-based polar ocean SSS which is important for the water cycle, freshwater inputs into the ocean and marine biogeochemistry.
2. Current SWIR-based satellite observations cannot measure GHG in polar winter. These GHG emissions are important. Active missions to monitor high latitude areas are important for measuring changes in the carbon cycle in the warming polar/permafrost regions.
3. There is a need to improve sea-ice thickness sensing. Sea-ice thickness is, together with the sea-ice area derived from the sea-ice concentration, the key ingredient to compute the sea-ice volume and mass. Long-term sea-ice volume and mass changes are considered as the integral response of climate change exerted on the polar regions.
4. There is a need to improve sensing of temperatures of the surface for all surface types across the polar regions. This can inform assessments of warming of the polar regions for which in situ measures of near-surface air temperature are sparse and hard to maintain.
5. Knowledge gaps exists at highest latitudes for atmospheric ECVs describing climate change including forcing and feedback effects and there is a need for further analyses to address these gaps with satellite observations (e.g. monitoring solid precipitation). True polar orbiters would improve coverage at the highest latitudes.
6. There is a need to improve the accuracy and consistency of observations of albedo for ice and snowy surfaces across domains (terrestrial snow, land ice, sea-ice and its snow cover) to improve the characterization of the Earth Energy cycle.</td></tr>
<tr><td>Implementers</td><td>From 1 to 6: Research organizations, Academia, Space agencies.</td></tr>
<tr><td>Means of Assessing Progress</td><td>From 1 to 3:
Proof of concept for new technologies and new methodologies to measure SSS, sea-ice thickness and GHGs at high latitudes, particularly in wintertime.
For 4 and 6:
Feasibility study for true pole-to-pole orbital mission to measure changes at the very high latitudes for a set of targets ECVs.</td></tr>
</table>

	For 5: Feasibility studies on current and potential future satellite constellations or instrument combinations to improve satellite observations at the very highest latitudes for atmospheric ECVs.
Additional Details	1. Empirical algorithms using satellite observed salinity from SMOS and Aquarius, as well as CCI SST, have been demonstrated to be suitable to calculate total alkalinity and total dissolved inorganic carbon, and reproduce the wider spatial patterns of these two variables. Using multiple frequencies and increasing bandwidth near L-band can improve the retrieval accuracy of polar-ocean salinity from satellites. 2. The measurements of GHG emission, CO_2 and CH_4 in polar regions require active LIDAR missions such as the French-German research satellite MERLIN (expected to be launched in 2024). These use LIDAR technology to quantify the CH_4 and CO_2 mixing rations and emissions rather than rely on passive light (SWIR). Continuity and further development of this mission concept and its applications are important to track carbon-climate feedbacks. 3. Sea-ice thickness is a highly spatially variable parameter. Its derivation at hemispheric scale requires composition and averaging of multiple satellite overpasses when using currently employed altimetry. For thin ice (< 0.5 m thickness) alternative satellite sensors must be used. These are imaging sensors supporting finer temporal sampling at hemispheric scale. Combination of both types of sensors can add value. Currently, sea-ice thickness retrieval is considerably more mature for the Arctic than the Antarctic. This fact is due to, on the one hand, a larger amount of data used for evaluation in the Arctic than Antarctic. On the other hand, sea-ice thickness retrieval in the Antarctic is complicated by ice and snow conditions being different from the Arctic. Improving sea-ice thickness retrieval also requires improving observing snow-depth and sea-ice age (proxy for sea-ice thickness and density), among others. 4. Skin temperature to all surfaces in polar regions is needed in order to infer estimates of near surface temperature changes; the poles are one of the regions where fast changes occur. 5. True polar orbiters like TRUTHS enable simultaneous Nadir Overpass (SNO) type observations at all latitudes with sun-synchronous polar orbiter-payloads thus improving and supporting atmospheric ECV observations from current and future satellite constellations and/or instrument combinations. 6. The albedo of iced and snowy surfaces varies rapidly and drastically in the event of melting. This requires frequent observations and the attribution of albedo changes to the melt processes (e.g. linking albedo and melt-pond fraction over land and sea-ice).
Links with other IP Actions	A2: Continuity of space-based Sea Surface Salinity measurements. A3: Continuity of GCM measurements. B3: New satellite missions (GHGs).

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

[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

	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.

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

[13] https://www.oceanbestpractices.org/about/task-teams/task-team-22-01-coastal-observing-in-under-resourced-countries

	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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