WEATHER CLIMATE WATER

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GLOBAL GREENHOUSE GAS WATCH – G3W

The Implementation Plan

Contents:

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1. Introduction and background

The World Meteorological Congress at its nineteenth session (Cg-19, 22nd May - 2nd June 2023) approved the concept note and established for a new global greenhouse gas monitoring initiative that aims to support WMO Members in mitigation actions undertaken to implement the Paris Agreement. This concept has been developed in a close collaboration between WMO and partner organizations dealing with greenhouse gases and carbon cycle.

The Global Greenhouse Gas Watch (GGGW or G3W, hereafter G3W), fills critical information gaps and provides an integrated, operational framework that brings together all observing systems, as well as modelling and data assimilation capabilities in relation to greenhouse gas monitoring, striving to reduce the uncertainty in assessing the efficacy of climate action.

G3W will provide a comprehensive monitoring framework of GHG and thereby address the urgent need for information that helps to understand and assess the impact of mitigation actions taken by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), and the Paris Agreement on the state of climate. Such information will be produced in a timely manner and will take into consideration both human and natural influences on the levels of greenhouse gases in the atmosphere.

Initial focus will be on the three most important Greenhouse Gases (GHGs hereafter) influenced by human activities, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Increasing abundances of these gases in the atmosphere are the dominant cause of the observed climate change and related impacts according to the Intergovernmental Panel on Climate Change (IPCC AR6 WG1 Report). Recent (post-industrialization) increases in atmospheric concentrations of CO_2, CH_4 and N_2O have been documented to be driven by

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human activities. The Paris Agreement, adopted by 196 Parties at the UNFCCC Conference of the Parties in 2015, sets specific limits for maximum rise in global mean temperature and indicates that the means to achieve this temperature goal is through the net reduction of GHG emissions.

The twenty-eighth Conference of the Parties (COP28, Dubai, 30th November – 13th December 2023) hosted the fifty-ninth session of the Subsidiary Body for Scientific and Technological Advice (SBSTA59). In its conclusions SBSTA expressed appreciation for progress made and noted under Research and Systematic Observations (FCCC/SBSTA/2023/L.10):

"The SBSTA noted the new Global Greenhouse Gas Watch initiative, aimed at establishing sustained, routine global monitoring of greenhouse gas concentrations and fluxes. It recognized that this initiative is intended to improve the quantification of both natural and anthropogenic greenhouse gas sources and sinks, and to complement emission inventories, noting that reporting and greenhouse gas inventory guidelines are as adopted under the Convention and the Paris Agreement. "

The COP28's reference to G3W in SBSTA substantially enhances the operational orientation of climate change mitigation actions, from the twenty-seventh Conference of the Parties (COP27, Sharm El Sheikh, 6th–20th November 2022), when the Parties recognized that "*{…} limiting global warming to 1.5 °C requires rapid, deep and sustained reductions in global greenhouse gas emissions of 43% by 2030 relative to the 2019 level*;" (Decision -/CP.27). It further "*Emphasizes {…} the need to enhance coordination of activities by the systematic observation community and the ability to provide useful and actionable climate information for mitigation, adaptation and early warning systems, as well as information to enable understanding of adaptation limits and of attribution of extreme events*". Access to improved harmonized information on the concentrations and budgets of GHGs, in part already collected by existing infrastructures, is needed to help countries to establish their commitments and to monitor progress toward meeting emission reductions targets. Responding to the COP 27 call requires an effort from multiple agencies and communities to work together, to establish new or to update existing agreements and arrangements between international and national agencies and different bodies under WMO.

Analysis of the observations from the Global Atmosphere Watch[1] demonstrated that in 2022 the atmospheric concentrations of the three main greenhouse gases reached new highs. Increase in concentration leads to further increase in the anthropogenic forcing to the climate system. However, current atmospheric concentrations are not determined by anthropogenic emissions alone. GHG concentrations are strongly influenced also by natural processes, which in turn are influenced by climate and other environmental changes. Variations in natural emissions and uptake of GHGs can interact with and mask impacts of mitigation efforts. The quantitative knowledge about current and future strength of some of the GHG sources and sinks has large uncertainties, especially on the regional and smaller scales. The Global Greenhouse Gas Watch will stimulate applied research for improving the knowledge in these areas.

The objectives and outputs of G3W are formulated in the concept note approved and included in the nineteenth World Meteorological Congress' report[2]. The first Global Stocktake[4] (GST-1) presented at COP28, already made use of some of the systems that will be foundational for G3W and highlighted the limited progress towards meeting the goals of the Paris Agreement, and this outcome underpins the need for accelerating ambition in their next round of climate action plans due in 2025.

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[1] https://library.wmo.int/records/item/68532-no-19-15-november-2023

[2] https://library.wmo.int/records/item/67177-world-meteorological-congress

[4] https://unfccc.int/sites/default/files/resource/cma2023_L17_adv.pdf

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The concept note identified four main components of the G3W as a global system:

(1) A comprehensive sustained, global set of surface-based and satellite-based observations[3] of CO_2, CH_4 and N_2O concentrations, total column amounts, partial column amounts, vertical profiles, fluxes and supporting meteorological, oceanic, and terrestrial variables, internationally exchanged as rapidly as possible, pending capabilities and agreements with the system operators.

(2) Prior estimates of the GHG emissions and absorption based on activity data and emission factors, and process-based models and their uncertainties.

(3) A set of global high-resolution Earth System models representing GHG cycles.

(4) Data assimilation systems (associated with the models (item 3)), that optimally combine the observations with model calculations to generate products of higher accuracy and their uncertainties.

The individual model systems that will be part of the G3W will each deliver at least the following outputs[4] in common standard formats:

- Monthly CO_2 net[5] fluxes between the Earth surface and the atmosphere with gridded 1x1 degree horizontal[6] resolution delivered with maximum a delay of one month,
- Monthly CH_4 net fluxes between the Earth surface and the atmosphere with gridded 1x1 degree horizontal resolution delivered with a delay of one month,
- 3D fields of CO_2 and CH_4 abundance with hourly resolution and data latency to be defined (tentatively on the order of a few days),
- N_2O abundances and net fluxes with resolution and latency still to be defined.

In addition, it is anticipated that ongoing and new research to develop capabilities to further separate these net fluxes into source-apportioned emissions and uptakes will lead to additional operational products in the future. Per WMO's data policy (Resolution 1 (Cg-Ext(2021)) and in the interest of maintaining transparency as required under the Paris Agreement, the data are expected to be made available to all interested users on a free and unrestricted basis and under an open data use license.

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[3] In keeping with standard WMO terminology, the term "surface-based observing systems" (or networks) refers to any systems that are not deployed in space; the measurements may be in situ or remotely sensed, they may pertain to any part of the Earth System domain (atmosphere, ocean, land, cryosphere, etc) and to any vertical level within the respective domain.

[4] The latency of products was a consensus of the participants of the first modelling workshop in June 2022 and approved by the Cg-19 as a part of the concept note. Through the development of the regulatory framework for modelling component of G3W, the latency requirements may be refined. Currently 2–3 months additional latency is added for flux products, which is needed to stabilize the estimated fluxes in the remote regions with sparse observations.

[5] "Net fluxes" refers to the sum of anthropogenic emissions and natural emissions and uptakes

[6] The initial 1x1 degree resolution is based on the consensus expressed during the WMO GHG Monitoring Workshop in May 2022, and it reflect capabilities that are currently well within reach. The horizontal resolution is expected increase as both observing and modelling capabilities improve.

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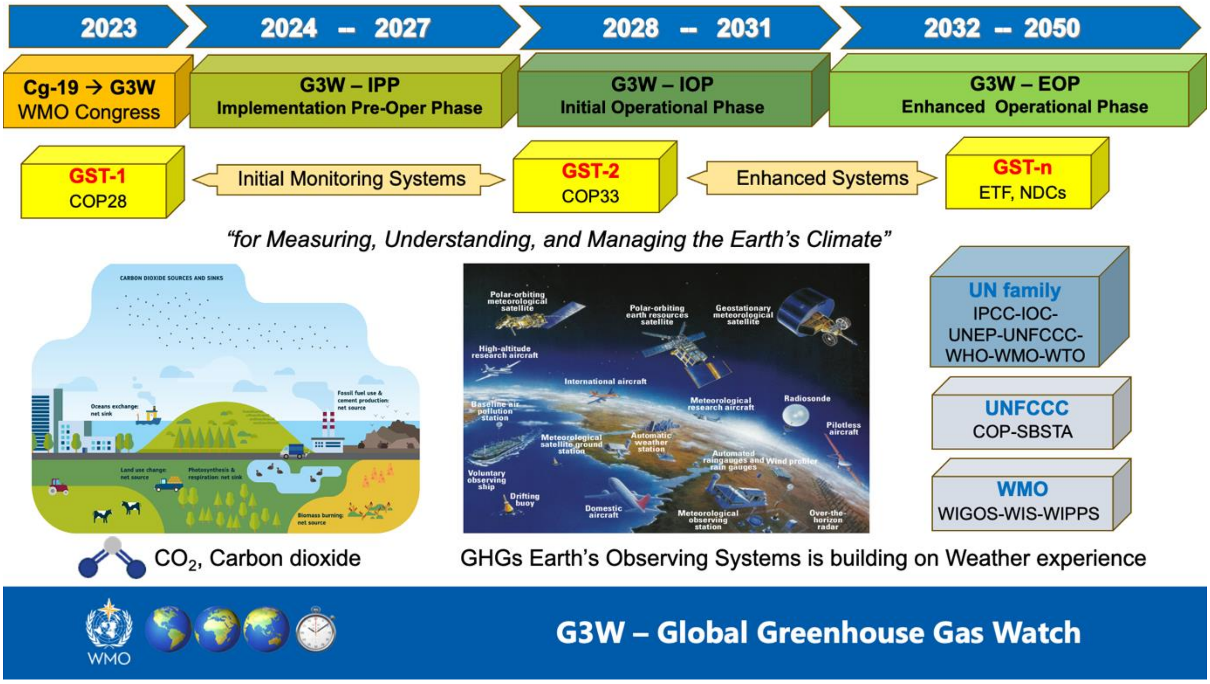

Figure 1. G3W infographic of the Implementation timeline, scope, and context. For purpose of simplification, only CO_2 is presented, while all three gases (CO_2, CH_4, and N_2O) are the focus of the G3W implementation plan.

The WMO Congress requested the development of the G3W programme's Implementation Plan (IP), which is presented below. The G3W-IP is organized in a way that allows WMO Members to understand and facilitate the actions required within the current financial period (2024–2027) to advance the G3W Implementation and Pre-operational Phase (G3W-IPP). The G3W Initial Operational Phase (G3W-IOP) is foreseen in the next financial period (2028–2031), including the consolidation of the G3W systems configuration for the 2nd Global Stocktake (GST-2) and this is provided in the outlook section.

The vision for G3W develops beyond 2032 in full compliance with the Paris Agreement Enhanced Transparency Framework (ETF) cycle, that will provide progress assessments towards the climate neutrality goal and ambition. G3W will aim at providing actionable information assisting the countries in their Long-Term-Low greenhouse gas Emission Development Strategies (LT-LEDS), that are providing the long-term horizon for the Nationally Determined Contributions (NDCs).

This phase of the G3W development is labelled Enhanced Operational Phase (G3W-EOP) and it aims at integrating maturing technologies from satellite remote sensing, ground-based networks, conventional and data driven modelling approaches stemming from artificial intelligence, with the goal of reducing uncertainties, and increasing the reliability of the GHGs monitoring systems.

The implementation of the plan requires establishment of the working structure that would be tasked with coordination of implementation activities outlined in the different sections to ensure that they are on track and to report to the Commission on Infrastructure on the progress towards the goals articulated in the plan. The working structure needs to include technical experts in GHG infrastructure.

In addition, a group dealing with the outreach and resource mobilization activities is also needed. As engagement of WMO Executive Management is vital, therefore G3W must be reporting directly ongoing and planned activities to the WMO's Executive Council. Two

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governance actions have been recommended by the Joint Study Group on Greenhouse Gas Monitoring (SG-GHG):

Action GOV1: Create a working structure under Commission for Observation, Infrastructure and Information Systems (INFCOM) for coordination of technical implementation activities. The G3W Advisory Group should be co-chaired by those designated by INFCOM and RB and is expected to consist of up to 20 members, representing, inter alia, the Commission for Weather, Climate, Hydrological, Marine and Related Environmental Services and Applications (SERCOM) and different areas of the expertise in greenhouse gases.

Action GOV2: Examine the utility of the WMO Climate Policy Advisers Group for the high-level positioning and outreach with adjustment to the Terms of Refence (ToRs) and membership to comprehensively cover the G3W topics.

2. Foundations of G3W and gaps

The concept note articulates in detail the existing components of G3W that form the foundation for the implementation. Two technical workshops were conducted to further evaluate the status of current capabilities and their readiness level, and to define the most critical gaps that need to be addressed to advance G3W implementation. The observational workshop was attended by about 130 experts on site with additional 70 participating virtually, while the modelling workshop was organized "by invitation" and included 30 experts in-person and 20 experts online.

Key outcomes and recommendations are as follows:

A global GHG observation network is a complex system across almost all Earth domains (land, ocean, atmosphere, and cryosphere) consisting of surface-based and space-based efforts. It includes a variety of initiatives and collaborations among international organizations, government agencies, research institutions, and private sector. It was recognized that current global GHG observations efforts are still not "sustainable" and not fully "systematic". Substantial gaps in spatial and temporal data, particularly in historically underrepresented regions such as the Tropics, Africa, open oceans, and the Arctic (which are also climate sensitive regions) were underscored for the G3W. Vertically resolved atmospheric measurements, crucial for enhancing modelling systems and reducing uncertainty in GHG flux estimates, are insufficient globally. Diminishing nature of ocean carbon measurements was also underscored as pivotal challenge. Ground-based remote sensing is notably sparse in comparison to in situ observations. Furthermore, difficulties were underscored in the effective cross-validation of satellite data. Other identified gaps were operational in nature, and they included the absence of a complete inventory of available measurements, delays in satellite validation due to timeliness of the validation datasets provision, as well as limitations of data dissemination system. Other operational concerns are undefined criteria for "good enough" measurements, shortcomings in mission planning and approaches to providing a tiered observing system where intercomparability could be maximized with reduced implementation costs.

GHG modelling systems are key in delivering the products (gridded total fluxes and concentrations of CO_2, CH_4 and N_2O), articulated in the Concept Note. These systems will utilize diverse approaches, including model-data fusion techniques, such as data assimilation and machine learning, which are needed to accurately quantify emissions and concentrations of greenhouse gases. The significance of data exchange and management was stressed as an integral part of G3W implementation, guided and facilitated by the WMO Unified Data Policy (Resolution 1 (Cg-Ext(2021)). Recommendations of both workshops include a call for alignment of the G3W data management systems with FAIR (Findable, Accessible, Interoperable, Reusable) principles, leveraging existing WMO data and metadata standards (WMO Information System 2.0 (WIS 2.0) and WMO Integrated Observing System (WIGOS)),

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and emphasizing consistent approaches both within and across Earth System domains. This requires the standardization of observations to rigorous benchmarks and transitioning from research to operation. Moreover, there was an emphasis on the need for federated yet sufficiently centralized data access to improve data availability for modelling and for the regular operation comparisons of the modelling system outputs.

Observational workshop participants articulated a need for better integration of remote sensing and in situ data for similar variables. The workshops emphasized the importance of an inclusive approach across all domains (land, ocean, atmosphere) while maintaining domain specific requirements. Additionally, suggestions were made to introduce a multi-purpose measurements program that incorporates additional variables for improved prior constraints and the global availability of calibration facilities.

The workshops emphasized the significance of establishing protocols for intercomparisons between models and data exchange, while also highlighting the need to strengthen collaboration among modelling groups. Recommendations included standardized protocols, enhanced data quality and accessibility, and strategic prioritization of research. Acknowledging limitations in evaluating fluxes using atmospheric concentration observations, suggestions emphasized use of additional trace gas species and vertical profile measurements to quantify performance of model transport.

The necessity of engaging diverse user communities – from policymakers to national agencies, the general public, and the private sector – were underscored, emphasizing the tangible relevance and applicability of G3W outputs. Policymakers expressed a preference for unified estimates with minimal uncertainties, stressing the necessity for a specific institute or organization to implement evaluation, validation, and synthesis.

The workshops highlighted a financial gap, indicating insufficient funding for implementation, including initial costs, maintenance and research. There was recognition of a shortage in trained personnel to adequately support measurement activities and an emphasis on capacity building, particularly in developing nations, to elevate observation and modelling systems. Discussions advocated for training initiatives, resource allocation, and technology transfers, aiming to bridge inherent financial and workforce gaps. Global collaboration, integrated efforts, and facilitative governance and funding mechanisms were identified as critical needs for advancing greenhouse gas monitoring and fortifying global climate action under G3W. The full reports of the workshops are available in the WMO library[7],[8].

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[7] https://library.wmo.int/records/item/68864-report-of-workshop-observations-within-the-global-greenhouse-gas-watch?offset=2

[8] https://library.wmo.int/records/item/68863-report-of-the-global-greenhouse-gas-watch-modelling-workshop?offset=3

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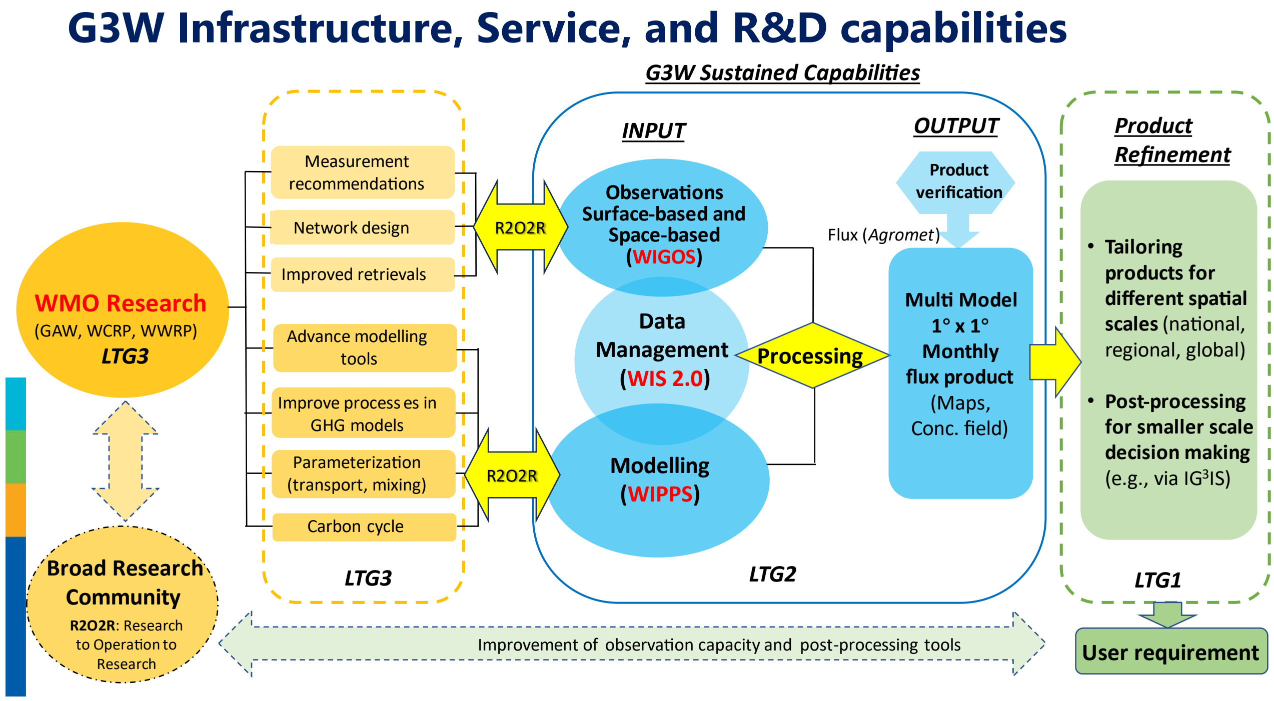

Figure 2. G3W implementation diagram outlining G3W capabilities and alignment to WMO long-term goals (LTG1, LTG2, and LTG3)[9]

The G3W will be based on data products generated utilizing methodologies that extend those developed by the research and operational communities that underpin the service elements. A key principle of the implementation is to optimize the use of established infrastructure and capabilities and avoid duplication and enable rapid research to operation (R2O) progress, as illustrate in Figure 2. G3W will be integrated in the WMO Infrastructure, thus benefitting from the established governance structures, international coordination, and operational processes of the WIGOS, WIS and WMO Integrated Processing and Prediction System (WIPPS).

The G3W SG-GHG is a joint study group composed by 35 world renown multi-disciplinary experts invited by WMO in August 2022 after EC-75 requested the joint study group to develop the G3W Implementation Plan (G3W-IP hereafter). SG-GHG Sub-groups have led the development of different building blocks that compose this document the G3W-IP.

[9] https://library.wmo.int/records/item/68578-wmo-strategic-plan-2024-2027

Figure 3. G3W infographics of the building blocks and stakeholders' action map

The G3W-IP is presented in detail in the following sections and in the linked references. The G3W building blocks are articulated in the following six sections and an action map is provided in Figure 3 to illustrate the tasks organization graphically, with the aim of facilitating the understanding of connections between different elements of the plan. It is well recognized that capacity building including training actions are relevant for all the activities listed in the technical sections of the document. Moreover, while G3W is focused on the operational

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deployment, it is acknowledged that the research and service components are quality requirements for the continuous operations and a necessity for all the building blocks.

3. Observing system

Observations are fundamental for G3W, for data assimilation, modelling and verification. As articulated in the concept note, the list of observable variables required for the realization of the G3W is extensive, but clear priorities can be identified. Here the priorities are listed within five categories, from **A** (highest) to **E** (lowest):

A. Ground-based measurements of GHGs

B. Remote sensing and vertically resolved observations of GHGs

C. Ocean carbon cycle observations

D. Direct GHG flux observations

E. Higher tier observations

The initial emphasis will be on observations related to CO_2, CH_4, and N_2O, the three of which in 2021 accounted for 90% of the radiative forcing on the climate system.

A. Ground-based measurements of GHGs

A global (over land and ocean) in situ network of adequate spacing, accuracy and precision providing long-term observations of the atmospheric abundance of CO_2, CH_4 as mole fractions in dry air is the basic minimum requirement.

B. Remote sensing and vertically resolved observations of GHGs

Having a combination of remotely sensed (both from space and from the surface) and in situ measurements is important, as their respective strengths and weaknesses tend to complement each other well. Satellite observations provide broad global coverage but are in general only available in cloud-free conditions.

C. Ocean carbon cycle observations

Accurate measurements of ocean fCO_2 (CO_2 fugacity) are scarce and sparsely distributed. These efforts are coordinated through the International Ocean Carbon Coordination Project (IOCCP) and the Global Ocean Observing System (GOOS). The data are essential for determining the development of the global greenhouse sink and source terms from the oceans.

D. Direct GHG flux observations

Direct flux observations obtained using for example eddy covariance techniques provide key input to the ocean and ecosystem models that are used for production of prior flux information to the inversion systems. Direct flux observations above ecosystems or urban areas can be used for parameterization or validation purposes. Direct flux observations in the ocean that characterize status and variability in the ocean water column are also required.

E. Higher tier observations

Beyond the base measurement stations, the network should contain a mix of enhanced higher tier stations. This should include regular vertical profile measurements in the atmosphere using aircraft, AirCore and other techniques and include vertical profile measurements in the ocean.

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The minimum system should have adequate observations from at least category A (in situ atmospheric composition), B (remotely sensed atmospheric composition) and C (ocean carbon cycle). An adequate number of stations should provide observations of the higher tier (category E), based on the overall network design. All surface-based stations included in the different categories should be equipped with automated weather stations to support data interpretation and model validation used in support of G3W.

Terrestrial direct flux observations of category **D** will provide essential information to quality control of the flux estimates delivered by G3W and will help to calibrate and validate the prior flux dynamic global vegetation models. This will be achieved through the collaboration with existing direct flux networks, like FluxNet, AmeriFlux, AsiaFlux, Integrated Carbon Observation System (ICOS), NEON, OzFlux, and many smaller ones.

The following action items were identified as priority activities in categories **A**, **B** and **C** for the advancement of implementation of G3W. These action items are organized in several blocks, covering cross-domain and cross-platform (i.e., in situ ground-based platforms and satellites) action items, followed by domain specific action items.

In building observing networks, both in-situ and ground based remote sensing, specific attention should be given to extension of the networks to LDCs, SIDS and developing countries and specifically in the more data scarce regions of the globe.

3.1. Theme: Cross-domain observing network design principles

Action O1: Create an exhaustive inventory of existing surface based GHGs measurements.

The activities under this action include:

- Conduct survey of the greenhouse gas observations (concentration, column measurements, and fluxes) from existing networks and programmes for atmospheric and ocean measurements with the following attributes: variables, measurement methods, quality of observations (including quality control of measurements), sampling frequency and data access.
- Evaluate available information about GHG observations in databases (Observing Systems Capability Analysis and Review (OSCAR), Surface Ocean CO_2 Atlas (SOCAT), Marine Methane and Nitrous Oxide (MEMENTO), Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS) and the GOOS and relevant data and metadata repositories.
- Perform a comprehensive literature and online review to identify additional long-term and campaign datasets not included in the existing databases and data repositories.
- Carry out a gap analysis comparing the variables and coverage needed for the inversion models (actions P1-P3) to the variables currently measured and their coverage.

The measures of success include:

- Comprehensive inventory of GHG measurements that can be used in G3W and integration of the missing elements in both OSCAR/Surface and OSCAR/Space;
- A gap analysis comparing the variables and coverage needed for inversion models (Actions P1-P3) to the variables currently measured and their coverage.

This activity is to be implemented within the first year of the implementation as it is foundational for many other activities of the plan.

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A big part of GHG monitoring is funded through short-term research funding rather than sustained funding, and in many cases, there has not been sufficient funding to coordinate those networks of researchers and observations. A comprehensive inventory of GHG measurements (and understanding of processes to help guide distribution, emphasis, and frequency) is necessary in the near-term to build an integrated observing system in the mid-term (2028).

This action item is connected to: O2-O9, M4, M7, P1-P3, D2, R3.

Action O2: Develop GHG monitoring standards and revise and reconcile existing GHG measurement requirements.

The activities under this action include:

- Create a comprehensive set of the GHG observation requirements, evaluate their compatibility with the WMO Rolling Review of Requirements (RRR) and submit to the OSCAR/Requirements repository.
- Create an accessible library of the quality assurance/measurement guidelines and recommendations and establish their compatibility.
- Perform assessment of the quality of available observations (compiled as outcome of O1).
- Define tiered network structure (i.e. with different quality levels, observational capabilities) across all domains and harmonize requirements for such a network, based on the WIGOS Tiered Networks concept.
- Define standards /standard operating procedures appropriate for each tier of the networks and variables, including qualification requirements and certification procedures.
- Define requirements for provision and establish availability of the standards for observations, and construct reference gas traceability and transmission hierarchy globally.
- Establish network implementation principles.

The measures of success are inclusion of established observational requirements in the OSCAR/Requirements database, a library of Quality Assurance/Quality Control (QA/QC) guidelines and specifications of the tiered network.

The activity is to be implemented through the whole period of 2024–2027.

An observing system integrated across Earth System domains will require a common set of monitoring approaches and principles applied across observing networks for integration in WIGOS. The GHG community must define what constitutes a reference measurement, whether and how tiered network structures will be adopted, and how standards will be utilized and distributed throughout the networks, building on established WIGOS principles. Improved access to and reduced cost of WMO-certified reference gases will be necessary to building capacity for making globally distributed reference quality measurements. Common monitoring principles will also support cross-domain and cross-platform comparisons, such as evaluating remote sensing of total column measurements with ground-based observations.

This action item is connected to: O1, O3-O9, M4, D1, D2, R2.

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Action O3: Develop a roadmap for longer-term GHG observing activities.

The activities under this action include:

- Organize a workshop to develop a long-term plan for a sustainable observing network for GHGs covering all components of the Earth System (atmosphere, ocean, land), for ground-based and satellite observing systems.

The measure of success will be a long-term strategy for the sustainable observing system that addresses its sustainable financing.

It is expected that this activity must be completed by 2026.

WMO-facilitated discussions with the research community, including both observing and modelling experts, are needed to help define the strategy. Longer-term planning should consider research and observing infrastructure needed to understand future climate and biogeochemical feedback, including measurements required to improve parameterization of processes that drive or affect fluxes and expansion into other realms of the earth system such as the deep ocean, the cryosphere, rivers, and wetlands. All relevant GCOS and GOOS networks should be actively involved in these discussions.

This action item is connected to: O1, O2, O6, R2.

3.2 Theme: Ground-based, near-surface, in situ measurements of GHGs (Atmosphere)

Action O4: Address existing spatiotemporal data gaps in ground-based near-surface GHG observations (atmosphere).

The activities under this action include:

- Identify the gaps in spatiotemporal distribution using the outputs from O1 and P1 to P3.
- Conduct network design experiments, including footprint analysis, in collaboration with the modelling community that participates in G3W, providing the input based on O1 and refine the design taking into consideration local circumstances.
- Identify the deployment opportunities in the areas where measurement gaps exist through consultations with the respective Members countries and partners that could facilitate such opportunities including atmospheric observations over the oceans.
- Identify the partners for site operation and capacity building needs.
- Identify important links with ocean and space-based networks.
- Connect with the WMO-wide resource mobilization.
- Evaluate opportunities of inclusion of GHG observations in the Global Basic Observing System.

The measures of success include an efficient and adequate network design taking into consideration access to regional /central calibration facilities in data scarce regions, updated technical regulations, and a list of deployment opportunities. This will be an iterative process addressing evolving requirements based on results obtained from the existing network.

The implementation of this activity should happen during 2025–2026 after the initial observational capabilities are mapped under O1.

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The Observing Network Design Principles of the WIGOS Manual and associated guidance in the WIGOS Guide will be taken into consideration. Implementation of this task depends on the outputs of O1 and P1-P3. Some non-cooperating or non-reporting stations might be found in the areas of previously identified gaps (e.g. established for research purposes without broad international context).

This action item is connected to: O1, O2, O6, O8, O9, M1, M3, P1-P3, R2.

Action O5: Develop sustainable high-quality reference GHG network (Tier 1) (atmosphere).

The activities under this action include:

- Develop definition of the Tier 1 (“high-quality”) network including measurement accuracy, instrumentation requirements, spatial density, temporal resolution and timeliness of data provision.
- Define technical regulations for the ground-based GHG measurements based on harmonized requirements and specification from O2.
- Update relevant WIGOS technical regulations.
- Evaluate Tier 1 network requirements with the deployment opportunities (O4).
- Evaluate possible co-location of Tier 1 sites with existing meteorological and other infrastructure (like CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization)).
- Define the required support infrastructure (e.g. calibration facilities) for Tier 1 network.
- Develop strategy to achieve and maintain “high-quality” data (via regional hubs, …).
- Conduct market research on available instrumentation fulfilling minimal requirements and costs.

The measures of success include:

- Definition and technical regulation regarding Tier 1 network are included in the WMO Technical Regulations.
- Measurement guidelines/Standard Operating Procedures for highest tier network are produced.

The implementation of this activity should take place through the whole period of 2024–2027.

WIGOS concept of “Tiered Networks” will be taken into considerations. Lessons learned from GGGRN, ICOS, GAW, GCOS can be used in this action item.

This action item is connected to: O1, O2, O7, M7, D1, D2.

Action O6: Develop basic (“fit-for-purpose”) GHG network (Tier 2) (atmosphere).

The activities under this action include:

- Develop definition of the Tier 2 (“fit-for-purpose”) network including measurement accuracy, instrumentation requirements, spatial density, temporal resolution, and timeliness of data provision.

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- Evaluate possible co-location of Tier 2 sites with existing meteorological and other infrastructure.
- Conduct market research on available instrumentation fulfilling minimal requirements and costs.
- Establish consultative process with the instrument producers to promote instrument developments – especially lower-cost sensors.
- Establish a broad "community of practice" or citizen science and conduct training for these communities.

It is recommended to develop, early in the implementation phase, a specification for economic air monitoring system(s) to meet the required performance characteristics for detection of appropriate greenhouse gases. This would consider the operational, maintenance, logistics, and budget requirements for a routine unsupported (i.e. limited human intervention) monitoring system to be incorporated into existing meteorological and atmospheric monitoring networks and infrastructure.

The measures of success include:
- Guiding documentation of "fit-for-purpose" observing system.
- Engagement strategy for "community of practice".
- Training materials for the "community of practice".

This activity is expected to be implemented in 2027.

This activity should be initiated within this financial period, though it is rather a mid- and longer-term activity.

This action item is connected to: O1- O4, D1, D2.

3.3 Theme: Vertically resolved GHG observations, in situ and remote sensing (atmosphere).

Action O7: Expand number of sites with vertically resolved and remote sensing GHG observations.

The activities under this action include:

- Identify key locations and prioritize sites and regions (link to modelling: network design) for vertical profiling including ground-based remote sensing.

- Develop specification for vertical profile measurements, including recommendations for instruments, QA/QC, frequency of observations at each site and timeliness of data delivery.

- Develop specification/blueprints for the observations of vertical profiles from regular passenger or commercial aircraft, ground-based remote sensing and other techniques that allow for the resolved vertical profile measurements (balloons, air-cores etc.).

- Formulate recommendations for vertical profiles of GHGs and auxiliary species that need to be analysed for source detection.

The success indicator is the level of achievement with respect to set annual targets for profiling observations at sites according to prescribed timeline and including specification of the deployment methods.

The activity should be initiated as soon as possible.

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This action item is connected to O1, O2, O5, M7.

3.4. Theme: Surface-Based Ocean Observations

Action O8: Formalize and enhance a sustained surface ocean CO_2 observational network.

The activities under this action include:

- Design a governance structure for a sustained Surface Ocean CO_2 Network (SOCONET).
- Implement sustained infrastructure for existing and new SOCONET reference measurements, including utilizing existing and new vessels and new autonomous platforms.
- Expand observations in data-poor regions as informed by past and ongoing Observing System Experiments (OSEs) (O12) and using outputs of O1, O2 and O9.
- Develop optimal observing design using results from OSEs in Action O12.
- Develop recommendations for the infrastructure necessary to incorporate CH_4 and N_2O observations at critical locations.

The measures of success are:

- Established governing body for SOCONET.
- Roadmap for sustained funding for surface ocean CO_2 observations.
- Plan for addressing observing gaps in data-poor regions.
- Increased observational coverage in data-poor regions.
- Initiation and evaluation of value of CH_4 and N_2O observations at critical sentinel sites and regions (e.g., areas of high concentration and flux such as continental margins, areas of methane clathrate (frozen methane) vulnerability and exposure, and high latitudes).

The implementation of this activity is done through several stages, with initial emphasis in 2024 on governance design, implementation and expansion of the observing infrastructure will take place through the whole period of 2024–2027, while the design of the observing system for CH4 and N_2O will take place at a later stage (2026–2027) in collaboration with the satellite community.

Surface ocean CO_2 measurements are the fugacity (or partial pressure) of CO_2, $f(p)CO_2$. Surface ocean CO_2 observing network design will consider a tiered structure (different accuracy levels) including a reference network with traceable, comparable, and representative measurements and networks of non-reference measurements.

When feasible, measurements of G3W should be paired with, concurrent and integrated with the observation of other Essential Ocean Variables in order to enable understanding and modelling of processes that control fluxes. Extensive and persistent observing gaps, such as in high-latitude regions during winter and the Indian Ocean basin, are known sources of error to ocean CO_2 flux estimates and could be addressed in the near-term with existing technology while design of a tiered observing network is being developed, and critical sites for CH_4 and N_2O monitoring are identified.

This action links to other actions: O1, O2, O4, O12, M3, D1, D2.

Action O9: Deliver routine global gridded products of air-sea CO_2 flux.

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The activities under this action include:

- Formalize the Surface Ocean CO_2 Atlas (SOCAT, www.socat.info) through development of a governance structure;
- Enhance SOCAT, including:
  - Make efforts to develop infrastructure capable of delivering global gridded products more frequently than annually.
  - Interoperability with products from other ocean carbon networks that require validation.
  - Modernize computing infrastructure to adapt to the evolving needs of scientists and users.
  - Coordinate with MEMENTO (Marine Methane and Nitrous Oxide database) to assess potential for shared, leveraged or interoperable infrastructure necessary for CH4 and N_2O data synthesis products.
- Conduct OSEs using mapping intercomparisons (Surface Ocean pCO_2 Mapping intercomparison, SOCOM) and models to determine optimal tiered observing network design to reduce flux uncertainties, including assessment of the SOCOM capabilities or modelling infrastructure regarding adaptation and expansion to include CH_4 and N_2O to estimate sensitivity of these GHGs.
- Develop a roadmap for SOCOM, including a plan for:
  - Sustained delivery of ocean CO_2 flux and other GHGs flux products required as prior estimates for data assimilation systems,
  - Regular intercomparisons of mapping products, ocean models, and inversions.

The measures of success include:

- Established governance structure for SOCAT - as part of GOOS infrastructure under the GOOS Biogeochemistry Panel/ IOCCP.
- Sustained funding for surface ocean GHG data management and products.
- Defined spatial coverage and frequency of surface ocean CO_2 observations.
- Demonstrated clear pathway for timely, integrated, seamless, and interoperable dataflow in the G3W.

The governance structure is to be developed as a matter of priority in 2024. Enhancement of SOCAT is to be implemented in 2025–2027, while the observing network experiments for SOCOM and associated flux uncertainty assessments can be conducted in parallel with the governance development during 2024–2025. SOCOM roadmap is to be developed in 2027.

SOCAT is a community-led open access synthesis of in situ surface ocean CO_2 observations from across the world ocean that relies on a primarily volunteer effort of more than one hundred scientific contributors. Observations assembled in SOCAT since 1970 have shown that the ocean takes up a quarter of the CO_2 emissions from human activity, thus helping to mitigate climate change, but this will change as the ocean warms. The observations demonstrate that the strength of this uptake varies from year-to-year and decade-to-decade. The evolution of ocean

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CO_2 uptake upon society's move towards net-zero CO_2 emissions is highly uncertain. Increasingly the ocean is being looked upon for carbon offsetting schemes, creating an urgent need for monitoring, reporting and verification that does not exist.

This action links to other actions: O1, O2, O4, P1-3, D1, D2.

3.5 Theme: Space-based observations of GHGs and related variables

Action O10: Liaise and prioritize with Committee on Earth Observation Satellites (CEOS) - Coordination Group for Meteorological Satellites (CGMS) for direct GHG observations from space.

The activities under this action include:

- Establish a collaboration between G3W and CEOS on GHG Roadmap[10]:
    - Establish regular communication and coordination mechanism between centres participating in G3W and satellite agencies,
    - Review GHG Roadmap Action list regarding where and how to be best implemented as some can remain within CEOS and others should be taken over by the future G3W.
- Include the representative from CGMS Working Group and CEOS into G3W technical coordination structure to ensure that the implementation of the GHG roadmap addresses the objectives of the WIGOS vision and G3W.
- Evaluate requirements for the satellite observations for GHG concentrations and critical gaps for the implementation of operational G3W.

The following measures of success are proposed:

- Joint Expert Team with CEOS on GHG activities.
- Prioritized list of space-based GHG observations requiring continuity.
- Prioritized list of space-based observations of co-emitted species requiring continuity.
- Prioritized list of new and existing space-based GHG observations filling observations gap.
- Comprehensive, documented, and consistent set of data requirements for supporting Monitoring and Verification System model inversions over land, ocean, and ice.

These activities will be implemented in 2025–2026.

Other species and parameters such as CO, NO_2 can be valuable tracers of GHG emissions as co-emitted species and satellite observations of some of these can be invaluable and shall also be listed under this collaboration.

This action links to other actions: O11, O12, M3, M4, M7, P1-P3, D4, R2, R3.

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10 https://ceos.org/observations/documents/CEOS_CGMS_GHG_Constellation_Roadmap_V2.3_cleaned.pdf

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Action O11: Liaise and prioritize with CEOS-CGMS for indirect GHG observations from space (required to infer GHG fluxes).

The activities under this action include:

- Establish collaboration on CEOS Agriculture, Forestry and Other Land Use (AFOLU)[11] Roadmap and its implementation/products betweenG3W, GCOS/Terrestrial Observation Panel for Climate (TOPC) and CEOS.

- Establish a collaboration on Aquatic Roadmap between G3W and CEOS.

- Establish a list of variables required for driving biosphere and ocean process models.

The following measures of success are proposed:

- Joint expert team with GCOS/ TOPC and AFOLU.

- Prioritized list of space-based observations requiring continuity relevant for AFOLU –related carbon stocks, changes and fluxes.

- Prioritized list of new and existing space-based observations filling gaps relevant for AFOLU –related carbon stocks, changes and fluxes.

- List of required space-based observations of ECVs supporting the science basis in GHG Monitoring.

- Comprehensive, documented and consistent set of data requirements for supporting Monitoring and Verification System model inversions.

These activities will be implemented in 2026–2027.

Natural and anthropogenic processes cycle carbon in and out of the atmosphere and need to be taken into account. Natural processes are modelled by Terrestrial Biosphere Models (TBMs), Dynamic Global Vegetation Models (DGVMs) and Global Ocean Biogeochemical Models (GOBMs). Space-based observations supporting these terrestrial (and ocean) models need to be tabulated in the catalogue of required satellite observations.

Sustainability and continuation of space-based observations of surface ocean properties (SST, SSS, SSH, ocean colour, ice coverage, ice type and sea state, wind speed) is needed to produce monthly air-sea CO_2 flux maps from sparse surface ocean CO_2 observations in time and space. To demonstrate the some of the connections between the elements of the carbon cycle and satellite data the following can be mentioned[12]:

- Terrestrial Ecosystem Models require Enhanced Vegetation Index and Land Surface Water Index,

- Wetland areas (large source of uncertainties in the quantification of natural emissions for CH_4),

- Dynamics of the vegetation (e.g., Net Primary Production, Leaf Area Index, biomass, land use/cover change, temperature),

[11] https://ceos.org/observations/documents/AFOLU%20Roadmap%20Discussion%20Paper%20v1-0.pdf

[12] https://ceos.org/observations/documents/GST_Strategy_Paper_V3.1.pdf

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- Satellite data of the ocean surface (e.g. Sea Surface Temperature, chlorophyll, for quantification of CO_2, CH_4 air-sea fluxes),
- Gross natural CO_2 fluxes (Solar-Induced chlorophyll Florescence SIF, carbonyl sulfide (COS)),
- Soil dynamics including ground temperature change in permafrost regions,
- Sea ice and land-fast ice characteristics, etc.

This action links to other actions: O10, O12, M4, M5, M7, P1-P4, D4, D5, R2, R3.

Action O12: Liaise and prioritize with CEOS-CGMS for required space-based observations to monitor changes in the carbon cycle in a (future) changing climate.

The activities under this action include:

- Establish a list of required space-based observations to monitor changes in the carbon cycle in a (future) changing climate and prioritize them (e.g., wetland extent, permafrost extent, fires, dynamics of vegetation):
  - Identify expected changes in the carbon cycle.
  - Identify existing space-based observations fundamental for monitoring ongoing and expected changes in the carbon cycle through e.g. evaluation of data uptake (use of CEOS pilot datasets and similar; EO usage in RECCAP/-2 as part of Global Carbon Project under FutureEarth).
- Review of known planned missions as documented/collected by CEOS and assessment for potential to fill gaps.

The following measures of success are proposed:

- Prioritized list of (future) space-based observations requiring continuity.
- Prioritized list of (future) new space-based observations filling gaps.
- Report describing expected changes in the carbon cycle and how to observe them from space.

These activities are to be implemented through the period 2024–2027.

This action links to other actions: O8, O10, O11, M4, M5, M7, P1-P3, D4, R2, R3.

4. Modelling system

Global modelling and data assimilation systems will be other pillars of the G3W. With heritage in both numerical weather prediction and coupled Earth System climate modelling, these systems will represent a step change compared to the status quo in the direction of fully operational workflows to deliver gridded concentrations and surface fluxes of key GHGs. Such an approach will unlock a pathway to systematic performance upgrades driven by both the evolution of the Global Observing System for GHGs and by the evolving requirements of entities developing downstream information products and services, while keeping an active connection with the research community to ensure that operational systems remain at the forefront of capability. The participating centres will benefit from the G3W coordination and

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efforts to produce guidelines and best practices will be pursued as described in the actions below.

Action M1: Establishment of requirements for operational centres and data products

The activities under this action include:

- Create a working group to define products and outputs of modelling systems,
- Define the system requirements for the participating modelling centres,
- Work with Standing Committee on Earth System modelling (SC-ESMP) to set up the mandatory requirements and procedures for the centres to be affiliated with WMO.

The main measures of success of this activity are an established regulatory framework (under WIPPS) for the operational centres as well as documentation of required products and outputs from the participating modelling systems.

As this is a foundational activity, it should be implemented as early as possible (2024–2025).

Regulatory framework will allow for establishment of operational centres that have operational capacities for production of gridded fluxes and concentrations.

This action links to other actions: M2-M7, O4, D3, D4.

Action M2: Documentation of the operational centres

The activities under this action include:

- Create common protocols to establish compliance of the production centres with the established requirements (minimum documentary standard of centres).
- Document comparison protocols including deliverables and methodology.
- Update documentation as needed to reflect updates to modelling systems, comparisons.

The measures of success are documentation produced by modelling centres adopting established standards and documentation of comparison protocols.

The activity will be implemented in 2025–2027 following the definition of requirements. Documentation from operational centres will occur primarily in 2025, documentation of comparison protocol in 2026, and updates and refinement as needed in year 2027.

This action links to other actions: M1, M6, D3.

Action M3: Continuous development and operations (including Rolling Review of Requirements)

The activities under this action include:

- Operational centres to develop a risk registry.
    - Document and discuss the plans for:
        - Tier 1: if satellite fails or other unanticipated major changes in observing capacity,

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  - Surface ocean measurements are insufficient (or scope of observing system is not sustained)
    - Tier 2: development of the operational system in 2 years,
    - Tier 3: long-term development perspective,
- Data mobilization, latency, interoperability and publication.
- Updated requirements for the observing system through the evolution of the modelling systems.
- Conduct modelling exercises to assist with the observational systems design.
- Create a mechanism to get feedback on the system output from the user communities of G3W products.

The measures of success are documentation and sharing of planning documents and development of capability to collect user feedback (e.g. user forums, website helpdesk).

The activity will be implemented throughout the period 2024–2027.

This action links to other actions: O4, O8, O10, M1, D2-D4, R2, R3, U2, U4.

Action M4: Observations acquisition and pre-processing

The activities under this action include creation of a working group on data acquisition that will:

- Survey availability of the low latency satellite data for assimilation (in conjunction with O1).
- Create good practices for monitoring and quality control of observations that are assimilated in the modelling systems.
- Assess procedures including uncertainty evaluation for aggregation of the data that assimilated into models (from observations to grid box).
- Establish good practices to evaluate representativity of the data.
- Develop common approach between operational centres towards bias correction and representation of uncertainty.
- Set up requirement for exchange of intermediate data products and model diagnostics.
- Assess sharing of software to reformat data for ALL centres.

The measures of success are that good practices and protocols for acquisition and pre-processing are shared between centres.

The activity will be implemented throughout the whole period of 2024–2027. While the first two years will be focused on establishing a working group and surveying current capabilities, the second biennium will leverage activities on observations, and focus more on the potential for data and software sharing.

This action links to other actions: O1, O2, O10-O12, M1, D2, D4, R2.

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Action M5: Implementation/pre-processing of prior emissions

The activities under this action include:

- Develop good practices for implementing changes/updates to emissions.
- Develop and implement common standard procedures for pre-processing of emissions – e.g., testing, mass conservation, unit conversions, treatment of point source data.
- Develop strategy and good practices for updating/extrapolating beyond currently available inventories.
- Develop recommendations for timeliness, spatial and temporal resolution and uncertainty characterization based on lessons learned from analysis of priors.
- Develop recommendations for downscaling of priors and data representation (big data analysis in the cloud, short window vs long window, lateral fluxes).

The measures of success are sharing of intermediate data products and pre-processing software and good practices on the preparation of priors.

The activity will be implemented throughout the whole period of 2024–2027. While the first two years will be focused on establishing current capabilities through surveys and standardizing procedures to the extent possible, the second biennium will leverage activities on priors by broader community, focusing more on potential for methodological advances.

This action links to other actions: M1, O11, O12, P1-P4, D5-D7, R2, R3.

Action M6: Common approaches in operations of operational centres

The activities under this action include:

- Define common attributes/activities to be included in the operational plan of operational centres (e.g. observations pre-processing, generation/incorporation of priors, QA/QC).
- Develop and share detailed operations plans for operational centres mapped to system requirements.
- Working from product requirements, develop plan for centralized operations for products comparison and distribution of multi-model derived products.
- Coordinate modelling system updates with user requirements to the products established through the Rolling Review of Requirements process.

The measure of success is shared operational plans of the operational centres.

The activity will be implemented throughout the whole period of 2024–2027. Initial plans developed and shared in 2024–2025 with updates as needed in coordination with user requirements, observing system changes.

This action links to other actions: M1, M2, D3, D4, U1, U2, U4.

Action M7: Evaluation and quality control of the modelling products

The activities under this action include:

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- Develop good practices for continuous monitoring - assimilation diagnostics, including through comparison against climatological metrics based on aircraft and in situ data, tracer transport diagnostics.
- Establish good practices for evaluation of model outputs with independent observations not available within operational timelines.
- Develop protocols for rigorous evaluation of concentrations and fluxes and establish a performance matrix.
- Establish protocols for routine intercomparisons and data formats and common approaches/principles to introduction corrections after intercomparisons.
- Develop common protocols for data postprocessing and preparation for users (preparation in common formats and following established specification).

The measures of success are adopted good practices across operational centres and establishment of a "good metrics" for model performance.

The activity will be implemented throughout the whole period of 2024–2027. Survey of current QA/QC procedures will be conducted during 2024–2025. Developments of improved protocols and metrics will take place in 2026–2027.

This action links to other actions: O1, O5, O7, O10-O12, M1, D2, D3, R3, U1-U4.

5. Prior information

The core of the G3W is model ingestion of observational data to estimate and reduce the uncertainty in the GHG fluxes. This analysis depends critically on the quality of ancillary data, prior flux information, and estimates of their uncertainty.

This prior information is critical, as the prior uncertainty estimates determine the range in which the optimized fluxes are allowed to deviate from the prior fluxes. A too-wide uncertainty might lead to too many degrees of freedom and, for example, unrealistic spatial or temporal distribution patterns and temporal variability. Multiple sources of prior data (ensemble of convenience) or upscaled flux measurements (validation against ground truth) may be used to provide information on the spatial and temporal error covariance structures of the prior flux uncertainty. For terrestrial CO_2, a priori biogenic fluxes must include both a realistic representation of the diurnal cycles of photosynthesis and respiration, and explicit representation of heterotrophic respiration, as it is explicitly used by some inverse systems.

Some prior flux estimates used by inverse modelling are now available in just a few weeks and open the possibility of corresponding low-latency inversion products, but this should be extended to all required prior data.

The global modelling/ production centres that will participate in G3W should as much as possible follow independent methods from each other to generate and use the prior information for their data assimilation systems to ensure independence of the products.

Action P1: Identify data-stream needs on prior emission and absorption of CO_2.

The activities under this action include:

- Create an inventory of variables needed for the atmospheric inversion (including for emissions and absorptions) and 3D state assimilation by the production centres.

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- Define the temporal and spatial resolution and latency of the different variables and their temporal coverage for ingestion in the models.
- Develop a data convention (harmonize) names and units of the variables to be used in inversions.
- Create a working group to coordinate an evaluation of priors (QA/QC) and data requirements (e.g., open access).
- Establish the requirements and define the commitment level of the institutions providing prior data (documentation and codes are made available for continuity).

The measures of success include a list of requirements that is made available by / to the operational centres and a comprehensive documentation of variables.

This activity will be implemented in the beginning of the period (during 2024).

This action links to other actions: O1, O4, O9-O12, M5, D5-D7, R2, R3.

Action P2: Identify data-stream needs on prior emission and absorption of CH_4.

The activities under this action include:

- Create an inventory of variables needed for the atmospheric inversion (including for emissions and absorptions) and 3D state assimilation by the production centres.
- Define the temporal and spatial resolution and latency of the different variables and their temporal coverage for ingestion in the models.
- Develop a data convention (harmonize) names and units of the variables to be used in inversions.
- Create a working group to coordinate an evaluation of priors (QA/QC) and data requirements (e.g., open access).
- Establish the requirements and define the commitment level of the institutions providing prior data (documentation and codes are made available for continuity).

The measures of success include a list of requirements that is made available by / to the operational centres and a comprehensive documentation of variables.

This activity will be implemented in the beginning of the period (during 2024).

This action links to other actions: O1, O4, O9-O12, M5, D5-D7, R2, R3.

Action P3: Identify data-stream needs on prior emission and absorption of N_2O.

The activities under this action include:

- Create an inventory of variables needed for the atmospheric inversion (including for emissions and absorptions) and 3D state assimilation by the production centres.
- Define the temporal and spatial resolution and latency of the different variables and their temporal coverage for ingestion in the models.

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- Develop a data convention (harmonize) names and units of the variables to be used in inversions.
- Create a working group to coordinate an evaluation of priors (QA/QC) and data requirements (e.g., open access).
- Establish the requirements and define the commitment level of the institutions providing prior data (documentation and codes are made available for continuity).

The measures of success include a list of requirements that is made available by / to the operational centres and a comprehensive documentation of variables.

This activity will be implemented in the beginning of the period (during 2024).

This action links to other actions: O1, O4, O9-O12, M5, D5-D7, R2, R3.

Action P4: Characterize the various fluxes hosted by the repository across time scales.

The activities under this action include:

- Gather over time existing information about the uncertainty variances of each hosted dataset.
- Gather over time existing information about the uncertainty of spatiotemporal correlation structure of each hosted dataset.
- Identify knowledge gaps in this domain.
- Issue recommendations to fill the knowledge gaps.
- Make available to users of the repository, in a clear form, what is known and the gaps in knowledge.

Measures of success is a synthesis of what is known about the error variances and what is unknown that is made publicly available.

This activity will be implemented soon after the creation of the repository (D5) and then continued over time.

This action links to other actions: O11, M5, D5-D7, R2, R3.

6. Data Management

Data management plays an important role in the implementation of G3W. Appropriate data management should be established as a matter of priority to ensure that relevant and well-documented data, are easily accessible for both machines and humans through FAIR-compliant services, and that producing centres have access to the same sets of data to produce standardized outputs as well as participate in routine intercomparisons and to provide data access to users. It is expected that distributed data processing through regional hubs will increase the efficiency, quality, transparency, and timeliness of the data delivery. Processing should take care to provide information on measurement uncertainties and allow for generation of automatically quality-controlled, near real time data. Such data exchange ultimately will be

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provided through WIS 2.0[13] (planned to be operational in 2025) and therefore the integration of this data into these machine-ready data services is critical.

The (regional) communities involved in the existing operational networks have in recent years invested in moving to better, more FAIR and open data provision following the new WMO Unified Data Policy, under clear and standard open data licenses. All data processing and modelling should be open source and/or be properly documented as described in the action items below. Emphasis should be put on data provision for machine-to-machine operation, supporting documented automated workflows.

All observational data should be accompanied by a detailed and unbroken traceability chain and documented through rich descriptive and provenance metadata (mapped to WMDR2[14], currently in draft) and the data should include quantitative uncertainty information as well as the usual data flags. These elements are needed to inform the users on the suitability of the data for different applications. All data and metadata flows should be integrated and feed into WIGOS.

The action items below build around four stages of data management from the instrument to data assimilation, models quality assurance and data provision to user community.

Action D1: Data management life cycle stage 1; from raw instrument data to characterized product acceptable for international data exchange

The activities under this action include:

- Identify and survey organizations that will be tasked with creating new measurement stations regarding their capabilities for data exchange, including the data and metadata standards in use.
- Identify good practices and gaps in processing the raw instrumental data and its preparations for international exchange building of established programs examples (templates & source code), including good practices for detection of incorrect data and for data flagging.
- Evaluate local data storage capabilities of the Members participating in measurement programmes and define a set of data and metadata that must be locally recorded.
- Evaluate the possibility to enhanced data exchange from the stations, currently not participating in the intentional data exchange, identified in action O1.
- Develop a training program to implement recommended good practices and provide technical and staff support.
- Develop a set of open source flexible tools/building blocks to simplify the data production and quality.
- Develop a plan to help facilitate the transition of current basic research activities to measure greenhouse gases into operations for all domains and relevant platforms.

The measures of success include:

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13 https://community.wmo.int/activity-areas/wis/wis2-implementation

14 https://wmo-im.github.io/wmdr2/html/

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- Periodic inspection of national centres (infrastructure, equipment, and standards) by its regional centre.
- Periodic inspection and renewal of accreditation of regional centres by responsible WMO constituent body (Standing Committee on Information Management and Technology (SC-IMT), Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)).
- The percentage of data sent from each station, the quality of this data and its contribution to the final products.
- Good practices on preparation of raw data for international data exchange are published.
- Empowerment of existing global GHG data centres and/or establishment of new centres as needed for data management functionalities (including long-term data archival).

This activity will be implemented during 2024–2026. One year will be required for developing good practices to allow for the existing network to adjoin the new system. Two years will be needed for the new stations and potential regional centres. Training centres has to continue the work through the whole implementation period and the training facilities may be provided by existing Regional Training Centres where capacity exists.

This action links to other actions: O2, O5, O6, O8, O9, D2, R2, R3.

Action D2: Data management life cycle stage 2; Getting observational data from providers to operational centres for assimilation

The activities under this action include:

- Define architecture and systems needed to find, access and transfer quality-controlled data from providers to model ingest using FAIR principles in an optimized and automated manner.
- Define a list of targeted contributing observational datasets (timeliness, quality flag) from each domain (atmospheric GHG, SOCAT, satellite...) from the measurement sites or regional centres.
- Determine applicability, deficiencies and any needed improvements to WIS2.0 to provide means of data discovery and transport for an optimized model input data aggregation system.
- Define data publication workflow using the WIS2 architecture and system.
- Develop recommendations and requirements for data policy, data licensing, and DOI implementation.
- Develop recommendations for data and metadata content and define a common standard and exchange mechanism for the input and output data (field and formats for distribution of data into modelling systems).
- Develop recommendations on how the distributed networks and satellite data can be integrated or federated in the architecture.
- Formulate requirements for the data exchange from the modelling centres.

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The measures of success include a detailed data architecture design and the efficiency of the data transfer system and its speed, and whether all the required data is made available to all centres with the same efficiency.

This activity will be implemented during 2024–2026 and it will be building on the outputs of D1. This task should be given the highest priority as it is foundational for the G3W operations.

This action links to other actions: O1, O2, O5, O6, O8-O10, M3, M4, M7, D1, D5.

Action D3: Data management life cycle stage 3; Making model output data from operational centres available for intercomparisons

The activities under this action include:

- Develop recommendations for the architecture of the output data exchange, including intermediary data products.
- Assess requirements and develop systems to enable technical analysis and intercomparisons of model results by model developers. Key requirements are (1) how the data are stored (data and metadata formats); (2) how the data are distributed (distribution protocol – e.g., HTTPS, S3 - and throughput/performance/bandwidth); and (3) how the data will be analysed (e.g., API compatibility with libraries, like NetCDF/OpenDAP or GDAL).
- Determine data field requirements and preferred data representation for comparisons.
- Survey existing data transfer and access methods and develop plan for optimized/automated data distribution system.
- Survey model intercomparison workflows to identify data and metadata formats best suited for those workflows.
- Determine the statistical skills for intercomparisons.
- Leverage existing data storage mechanisms and provide automated discovery and access to the existing datasets.

The measure of success is reduction in labor and computational cost/time for model intercomparison activities.

This activity will be implemented through the whole period 2024–2027.

The data exchange needs to be robust and support operational activities of the operational centres. Data architecture should rely on modern solutions (e.g. cloud solution). Implementation of this data infrastructure may require partnerships with the big data facilities (Amazon, Google, etc).

This action links to other actions: M1-M3, M6, M7, U4.

Action D4: Data management life cycle stage 4; Model data discovery and distribution to end users

The activities under this action include:

- Assess model data user requirements and discovery needs.

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- Perform a comparative analysis of G3W datasets against WIS discovery metadata (i.e. review WCMP2 and create WCMP2 discovery metadata for datasets).
- Identify standards for data and metadata storage, cataloguing, and distribution utilizing the standards used by operational centres.
- Develop plan for WIS2 discovery metadata curation and publication.
- Develop plan for API provisioning and standards.
- Establish coordination mechanisms between operational centres regarding data availability and provision to user community.
- Develop training materials for users on how to interact with the "data stores".
- Develop a common landing page for products at WMO web page.
- Develop a common template to conduct regular user satisfaction surveys.

The measures of success include:

- Number of users who use the data products,
- Number of peer-reviewed publications using G3W datasets,
- Media presence of G3W datasets,
- Number of data products showing up in external discovery catalogues, such as Information Exchange (IE), International Oceanographic Data and Information Exchange (IODE), and Ocean Data and Information System (ODIS).

This activity will be implemented through the whole period 2024–2027.

This action links to other actions: O10-O12, M1, M3, M4, M6, U1-U4.

Action D5: Data repository for the prior emission and absorption fluxes

The activities under this action include:

- Investigate requirements and solutions for data exchange and long-term storage of the data on prior fluxes that can be set for the post processing and quality control.
- Get a commitment from a chosen infrastructure to develop and maintain the repository.

The measures of success include:

- Data size estimated.
- Reduced data transfer and access costs.
- Commitment from a chosen infrastructure obtained.

This activity will be initiated during the first year (2024). Support for the infrastructure needs to be sustained through the whole period 2024–2027 and further as a part of the operational infrastructure.

Ref.: 07317/2024-1.11

This action links to other actions: O11, M5, M7, P1-P4, D2.

Action D6: Definition of prior data providers

The activities under this action include:

- Establish requirements for the dataset that are accepted by the repository of prior data.
- Define specifications of the data providers that are entitled to submit fluxes to the repository and procedures for establishment of their compliance with requirements.
- Define Evaluation and Quality Control EQC criteria for model performance to be included in repository (i.e., iLAMB, iOMB or ESMValTool).
- Define other Key Performance Indicators KPI criteria, e.g. level of model documentation, open source (Github repository).

The measure of success is a list of criteria for the providers of prior data and set of tool and regulations on how these will be assessed.

The activity will be implemented in 2024 with annual re-evaluation of the data providers.

This action links to other actions: M5, P1-P4.

Action D7: Definition of the data policy for the repository of prior fluxes

The activities under this action include:

- Define the license for the data hosted on the repository (ownership of intellectual property, redistribution rights, modification rights, usage rights, responsibility, etc.).
- Define the access conditions to the data hosted on the repository.
- Define expectations on the users in terms of acknowledgement, citation, co-authorship, etc.

The measure of success is a public availability of the data policy.

The activity will be implemented in 2024.

This action links to other actions: M5, P1-P4, U4.

7. Research and Development needs of G3W

A strong research component is required to continuously support and improve the operational infrastructure. All elements of the G3W for atmosphere, ocean, land, and space-based segments need research and plans for integration. G3W itself builds on mature research, but there are many open scientific questions that need to be addressed to tackle limitations and uncertainty of the current systems and support their development. Understanding GHG processes and cycles and their description and representation in the ESMs, across spatial and temporal scales is an actively developing research area (see Figure 4 example for CO_2).

Ref.: 07317/2024-1.1 I

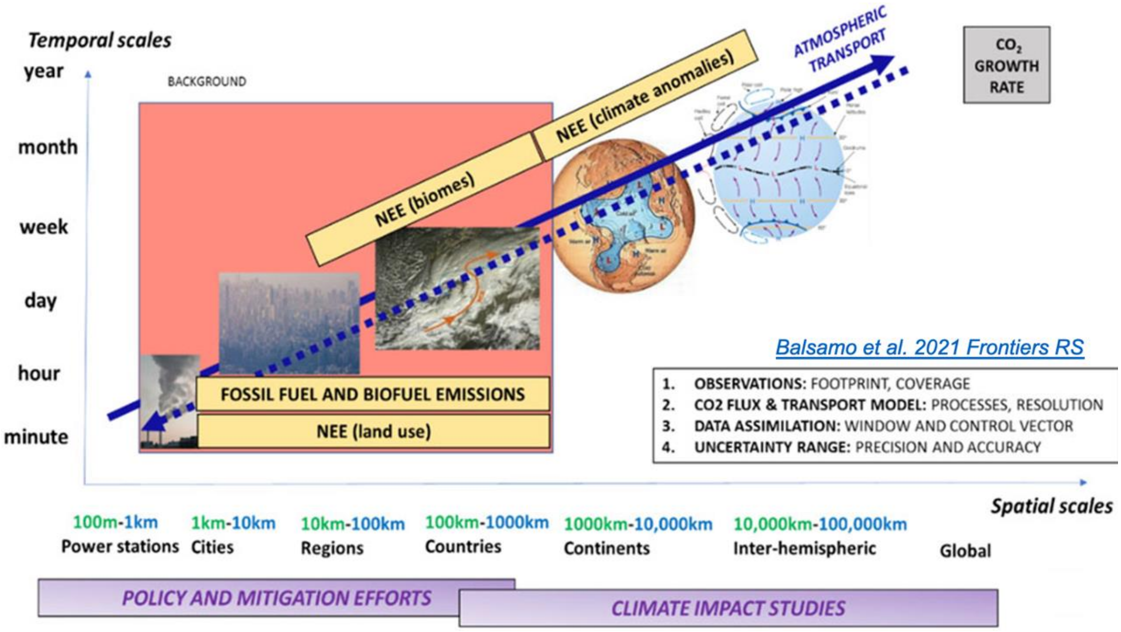

Figure 4. Temporal and spatial scales of CO2 monitoring from plumes to global CO2 growth rate (from Balsamo et al., 2021)

Model development work is underway in many centres around the world and targeted research that can feed into operational processes (e.g., transport and dispersion in the planetary boundary layer) is required. In a further step, emphasis should be given on the interaction between air quality and GHG processes feedback, use of isotopes and ancillary tracers to partition source sectors, and the whole Earth System, supporting mitigation strategies for climate and health.

Given the need for a massive upscale of the observational infrastructure, research can play a critical role in developing and testing new measurement techniques. It can help with the network design processes given existing and emerging observational capabilities. Reducing the required maintenance, cost and improving the quality of the observations will be critical. Engagement of the research networks into the operational activities can also be an important step towards improved sustainability. The research community has to play an important role in developing and testing prior inventory products, process-based flux models and provide guidance on the techniques that can be used for the sources/sinks identification. Data processing is also an important area for future research, including machine-learning techniques and other AI methodologies.

Action R1: Establish G3W Research to Operation (R2O) Task Team within the Research Board.

The activities under this action include:

- Develop Terms of Reference for the Task Team and membership.
- Establish mode of work and reporting mechanism.
- Ensure representation in the G3W technical coordination group.
- Develop integrated research strategy in support of G3W including on guidelines and channels on how to move research advances into operational implementation.

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The measures of success are the established task team and presentation of the strategy to the Research Board.

The activity will be implemented in 2024–2025.

This action links to other actions: R2, R3.

Action R2: Advance observations and data exchange capabilities.

The activities under this action include:

- Develop innovative tools for automated NRT data evaluation and exchange leveraging ML/AI capabilities, and recommendations for use of campaign data.
- Update RRR activities with a focus specially on G3W working in close cooperation with the operational centres on the network design (inputs into number of sites & priority locations to fill gaps and improve capabilities).
- Conduct evaluation of the emerging measurements techniques across domain and develop recommendation regarding maturity of these techniques for operational applications.
- Develop capabilities to add more gases to G3W portfolio (i.e., F-gases, GHG isotopes).

The measures of success include:

- Publication of statement of guidance.
- Measurement technology report/publication.
- Tools for automated QA/QC.

The RRR and statement of guidance will be completed within the first year (2024), while the others will be advanced through the period 2024–2027 and longer periods.

This action links to other actions: O2-O4, O10-O12, M3-M5, D1, P1-P4, R1, U1-U4.

Action R3: Advance GHG modelling and flux inversion capabilities.

The activities under this action include research related to:

- Improvement of key process representation in Earth system models:
    - Horizontal transport,
    - Vertical mixing and Planetary Boundary Layer representation,
    - Surface/atmosphere exchange (carbon, water, momentum, etc.) Explore/demonstrate consistency between AFOLU and land fluxes datasets.
- Evaluation of inversions techniques and performance.
- Development approaches for robustly characterizing posterior covariances (e.g. through analytic or ensemble methods) to enable intercomparison of fluxes and fluxes with models.

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- Evaluation of initialization methods for GHG models and develop good practices on near real time production of prior fluxes, including through the application of the process - based modelling.

- Development of recommendations and methodology on reconciliation of bottom-up and top-down emission estimate on several spatial scales.

- Implementation of top-down / bottom-up comparisons and corresponding uses cases that demonstrate how to benchmark models or inventory emissions against top-down fluxes.

- Development of robust uncertainty metrics that evaluate if emissions or fluxes are changing and how these changes affect the global growth rate.

- Support research intercomparisons (like Model Intercomparison Project (MIP) for Carbon, GCP).

- Development of capabilities for source attribution through for example expanded use of tracers and their measurement techniques.

- Exploration and exploitation of ML/AI-based approaches as an alternative to physical ESM for relevant applications, including regional and global flux modelling, source attribution and development of priors.

- Identification of most important systematic errors in G3W models and improve performance metrics.

- Prototype GHG reanalysis.

- Develop multi-model weighting methods based upon uncertainty and independent validation.

- Further advance high-resolution modelling (to 10 km and 1 km).

The measures of success are research outputs that can be implemented in the operational systems.

The activity will be implemented through the whole period 2024–2027 and beyond.

This action links to other actions: O1, O10-O12, M3, M5, M7, P1-P4, D1, R1, U1-U4.

8. User engagement and uptake of G3W

Consistent information about greenhouse gas sources and sinks is required at various scales. The modelling outputs produced by the G3W will, initially, provide global gridded fields at 1x1 degree spatial resolution, from multiple instances of the underlying data. This product can then lead into a downstream cascade of products and applications for additional information on attribution in space and by sector.

The downstream products may contain but are not limited to:

- Uptake of GHGs by different sinks and cycling through different components of the Earth System (e.g. aquatic/terrestrial biota, oceans, atmospheric sink for CH_4);

- GHG emissions from different sources (e.g. fossil fuel, biogenic, anthropogenic/non-fossil, biomass burning, oceans etc.) separately.

Ref.: 07317/2024-I.1 I

The data delivered by the G3W can directly be used in support of the global stocktake mandated under the Paris Agreement. National scale information will be critical to support national inventory reporting, as the national spatial scale can vary from continental to small regions of a few tens of kilometers. Sub-national information can be derived through the downscaling of the G3W outputs to support policies for states, provinces, and urban areas. Resolving emissions related to individual sectors such as agriculture or a specific industry is a critical need for decision makers at all scales, but particularly useful for sub-national actors. These may be limited to a single GHG or a single source, or there may be need to aggregate emissions from multiple gases or source locations to inform a specific industry's overall emissions.

We separate the downstream users into **two types**: "end users" who will use the WMO G3W and the downstream cascade of added-value products for decision-making; and the "research users" who will use the outputs for production of added-value products and services.

The action items below put the way forward towards utilization of G3W outputs.

Action U1: Provide support to the global stocktake.

The activities under this action include:

- Establish a connection to UNFCCC body responsible for the global stocktake to ensure WMO participation in technical dialogues and provision of contributions to UNFCCC in support of the global stocktake.
- Define information content of G3W communicable from individual centres including by components of carbon cycle (anthropogenic vs natural) with uncertainty.
- Develop guidelines on how to communicate G3W products.
- Organize training/webinars on the use of G3W products for the purposes of the GST.
- Establish a collaboration and common communication strategy by operational centres.

The measures of success include:

- Formal recognition of G3W in GST process.
- Number of G3W presentations during Technical Dialogues and Earth Information Days.
- Utilization of G3W output through publications in IPCC assessments.
- Utilization of G3W output as an independent reference in a CoP inventory submission.

The activity will be implemented through the whole period 2024–2027.

This action links to other actions: M6, M7, D4, R2, R3, U2, U4.

Action U2: Develop guidance on regional products.

The activities under this action include:

- Develop a portfolio of regional/continental scale system independent products that can be compared with reported emissions (e.g. estimated following the recommendations of the IPCC Task Force on the National Emission Inventories) at regional/continental/aggregated level that have defensible quality.

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- Develop recommendations on the appropriate temporal and spatial scales at which the outputs of G3W can be reliably interpreted and used.
- Develop recommendations on separation of anthropogenic/natural sources on regional scale and required additional outputs from global systems.
- Develop guidelines on how the G3W products can be used on a regional scale.

The measures of success include:

- Number of Parties using G3W outputs for GST.
- Citation by official reports/assessments.
- Comparability with IPCC inventories or other estimation.

The activity will be implemented through the whole period 2024–2027.

This action links to other actions: M3, M6, M7, D4, R2, R3, U1, U3, U4.

Action U3: Establish relationship between G3W and Integrated Global Greenhouse Gas Information System (IG^{3}IS), Commission for Weather, Climate, Hydrological, Marine and Related Environmental Services and Applications (SERCOM). Establish the pathway to stakeholder engagement.

The activities under this action include:

- Identify common goals/outcomes that can be supported by G3W and IG^{3}IS:
  - Mapping user requirement for the regional scale products,
  - IG^{3}IS to develop recommendations on G3W regional products,
  - Establish two-way interactions between IG^{3}IS and G3W,
  - Develop product from different/certain sectors which can be used/compared directly with the reported inventories.
- Identify common stakeholders and avenues for shared engagement with these stakeholders.
- Co-host sessions/events.
- Demonstrate successful case in G3W that could be used for program like IG^{3}IS.

The measures of success include:

- Joint demonstration project between the mentioned bodies.
- Joint workshop & sessions.
- Relationship between G3W and IG^{3}IS is articulated in the Terms of References of G3W Advisory Group.

This activity will be implemented as a matter of priority in 2024.

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This action links to other actions: M7, D4, R2, R3, U2, U4.

Action U4: Develop user interface guidelines.

The activities under this action include:

- Develop requirements for the information services from G3W responding to user needs tailored to types of user group:
  - Format of data products and the ability to select data product subsets (e.g. temporal and spatial selection),
  - Need for visualizations and online exploration tools,
  - Tutorials/explanations of the G3W products.
- Produce guidelines on how G3W data and products can/should be used – and how they should not be used.
- Develop recommendations on user interface, including diagnostics tools and visualizations.
- Develop guidelines for utilization of the global products for the boundary conditions in regional modelling.

The measures of success include:

- Requirements for G3W information services are defined and have been communicated back to operational system.
- Guidelines developed for how G3W data and products are to be used.
- Documented examples of how the G3W data products are enabling inventory evaluation.

The activity will be implemented through the whole period 2024–2027.

This action links to other actions: M3, M6, M7, D3, D4, D7, R2, R3, U1 – U3.

9. Capacity building

The implementation of the G3W must be accompanied by a comprehensive capacity building programme. Training needs to reach out to various functions (managerial level, operators, data managers, modellers, infrastructure support professionals) and must take place before, during, and after the roll-out in terms of obtaining, maintaining and expanding competencies. Training leading to an increasing number of experts will be beneficial for adequate maintenance and operation of the instrumentation and subsequently for the sound quality of the recorded data, for the lifetime of the equipment, and for the sustainability of the infrastructure in general. Capacity development will be particularly important in the use of G3W output in a science-policy framework. The training programme should include set up and operate measurement stations for all domains (atmosphere, ocean and land), covering topics such as instrument selection, maintenance and operation, calibration strategies and quality assurance and quality control, data processing on the observational side, as well as creating general awareness of the data use in atmospheric transport modelling, the combination of model results and observations, and the generation of end user GHG products. It should include data formatting, data sharing standards and mechanisms.

Ref.: 07317/2024-I.1.1

As part of the initiative, a strong involvement of the WMO Regional Training Centres (RTCs) would be highly desirable, as well as of the Intergovernmental Oceanographic Commission's (IOC) Ocean Teacher Global Academy (OTGA), Ocean Best Practices System (IOC-OBPS), GOOS, and the GEO flagship initiatives like GEO BON/Marine BON[15]. Up to now, RTCs have played only a negligible role in supporting atmospheric composition observations, and a better coordination with WMO's infrastructure department and RTCs is recommended. A curriculum on the atmospheric composition, especially GHG and their effects on the climate and their measurements, has to be developed based on the experiences gathered from the training courses for technicians /observers and meteorologists. Curriculums developed for this implementation plan shall be translated into all WMO's official languages. Learning opportunities will be offered in online, hybrid and in-person modalities. It is recommended to record and stream in-person courses, with a preference to hold these courses in all WMO regions. Clear synergies can be also identified and used with training programs of UNFCCC and UNEP, and with existing and future efforts of the satellite operators.

To evaluate the needs for capacity development, a survey of Member countries has been conducted. Data collection took place from 13 October to 12 December 2023, encompassing responses from a total of 43 countries. The objective is to grasp the member countries' capabilities for Implementation of G3W. The full analysis of the survey is available on the G3W web site.

It was noted that many countries do not distinguish between long-lived GHGs and air pollutants. The largest proportion of responses (46%) came from agencies that are not responsible for GHG inventories. From the average responses per region, it is evident that there is a shortage of personnel in modelling compared to observations. The question about observational capability is the one with a particularly high number of non- responses or "0"(no measurement) responses. Especially regarding the non- responses, it can be inferred that there is a significant number of countries with limited knowledge about their current situation.

In response to evaluation of operational setting, the most prevalent responses were for "Purely on research grants", followed by "Full support from the government for > 5 years".

63% of ocean observations are conducted by RA VI.

Many countries indicated that they either do not have a GHG monitoring plan or are in the stage of development without a concrete timeline, accounting for 63%. This suggests that most countries lack a concrete plan for GHG monitoring at the national level.

The grand mean indicates that about three stations per responding country need repair/upgrade and about 11 stations on average per country are in need of being newly built for well-covered observation, on average.

The grand mean indicates that, per country, about 16 Full Time Equivalents (FTEs) are needed to be trained in establishing high-quality GHG observations; 7 FTEs in GHG modelling; and 19 staffs in the use of GHG data for decision-making per responding country.

The number of responding countries was indeed limited, with only 43 out of 193 member countries providing responses. When analysed by region, response rates were below 20% for all regions except RA I and RA VI.

Additionally, the inconsistency in the range of respondents posed a limitation for statistical analysis. In some cases, multiple agencies in the same country provided their response respectively, while other countries submitted a single response aggregating the multiple pertinent agencies' data together. In most cases, one national agency responded only limited

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15 https://geobon.org/bons/thematic-bon/mbon/

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to its working scope, not including data of other agencies in the same country. For this analysis, the values were aggregated for statistical purposes if there are multiple responses. Therefore, for detailed data, it is recommended to refer to the Appendix for confirmation.

Activities to be considered:

C1: Establish a competence framework for participation in G3W:

- Establish specific competencies in GHG observations.
- Establish specific competencies in GHG modelling and model products utilization.
- Establish specific competencies in GHG data management.
- Establish technical competencies for managing the facilities (e.g. WMO Training Centres) providing training in GHG observations, modelling and data management.

C2: Continuous evaluation of the GHG capacities contributing to G3W:

- Follow up on the WMO capacities survey regarding national GHG capacities and needs.
- Catalogue available institutions and partners that provide training on GHG observations, modelling and data management in collaboration with the other relevant entities (IOC, GEO, etc).

C3: Develop capacities among the Members regarding use of G3W data:

- Facilitate mapping of the national institutions involved in GHGs and climate agenda.
- Provide examples of the national frameworks that enable inter-agencies cooperation on GHGs.
- Develop reusable training materials and provide training on climate policy engagement regarding GHGs.
- Develop distance learning modules supporting the knowledge and understanding needed for G3W.

C4: Establish GHGs training programmes for Member:

- Develop blended training programmes on GHGs observations.
- Develop face-to-face and online tools and training programmes on GHGs modelling.
- Develop face-to-face and online tools and training programmes on GHGs data management.
- Conduct training-the-trainer event for the RTC.
- Develop tools for evaluation of the efficiency of the training programmes.

C5: Develop twinning and exchange programmes between countries to develop national capacities in GHGs observations, modelling, data management and data utilization.

Ref.: 07317/2024-1.1.1

10. Financial estimates and funding sources

The cost estimates are articulated in, (i) costs for the G3W coordination that can be precisely assessed based on projected FTEs and logistics expenditure that are cluster under the label "Workforce" and include both Capacity Development and Coordination (ii) costs for the observations, modelling and data management building blocks that are clustered under the label "Infrastructure", where estimates rely on sectoral studies by reputable sources.

It is fully acknowledged that the global efficiency for G3W will be achieved by the complementarity of efforts supported by centralized and regionalized investments, with funding sources detailed in section 11, and do not involve directly the NMHSs, if not as voluntary donors. The three scenarios presented below reflects different levels of distributions of the costs and consequently highlight the funding sources and requirements, as detailed in section 11, and do not involve directly the NMHSs, if not as voluntary donors.

The Flagship level funding scenario at 1 B$ over the financial period 2024–2027 period is a target of the G3W resource mobilization, while lower funding scenarios are illustrated in the full implementation plan to illustrate the resources partitioning in case of partial attainment. Note that these resources are expected to come from the financial sectors, including the World Bank, Central Banks, Multilateral Development Banks, Insurances and Reinsurances, Philanthropies, Climate finance grants, Loss and damage funds, as well as from Industrial sectors via Environmental, Social, and Governance (ESG) practices alongside more traditional financial measures driven by socially responsible investing.

The G3W Flagship level costed plan identified as top priority the surface-based observations, therefore 70% is foreseen to be invested in the Observing system surface-based infrastructure, followed by 20% in the Observing systems integration, modelling and data management, 5% in capacity building and capacity development for G3W input and uptake, 4% in regional pilot projects and supporting research for G3W emerging priorities, and 1% for central coordination by WMO secretariat including public-private-partnerships (PPP) development.

The G3W economic benefits from the surface-based observations network are expected to be well above 25 times the value of the investment and compared to the estimated cost of surface-based and space-based operational weather observations of 10 B$ per year, it represents less than 2.5% increase in the annual costs.

Table 1. G3W financial estimates for the G3W-IPP financial period (2024–2027)

G3W-Finance	Workforce	Infrastructure	Total
Flagship level Highly centralized / low regionalized investment	100 M$ Regional Demo Projects 40 M$ Regional Capacity Building including Training 10 M$ WMO Secretariat 7 M$ Additive Research 3 M$ Public–Private Partnership (PPP) Development	700 M$ Surface-based Observations 80 M$ Modelling liaison 50 M$ Space-based Observations liaison 10 M$ Data management	

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	Total of 160 M$	Total of 840 M$	1 B$
Medium centralized / regionalized investment	30 M$ Regional Demo Projects 20 M$ Regional Capacity Building including Training 7 M$ WMO Secretariat 5 M$ Additive Research 2 M$ PPP Development Total of 64 M$	300 M$ Surface-based Observations 80 M$ Modelling liaison 50 M$ Space-based Observations liaison 6 M$ Data management Total of 436 M$	500 M$
Low centralized / highly regionalized investment	20 M$ Regional Capacity Building including Training 7 M$ WMO Secretariat 2 M$ Additive Research 1 M$ PPP Development Total of 30 M$	200 M$ Surface-based Observations 50 M$ Modelling liaison 50 M$ Space-based Observations liaison 6 M$ Data management Total of 270 M$	300 M$

Below the detailed cost estimates are listed per action items where such estimates were considered possible.

Financial O1: Observation inventory

Survey and evaluation of data bases, cost per implementing body for 1 FTE (200 k$)
Consultant for the literature and online review (50 k$)
For gap analysis total 0.25 person (50 k$)

Financial O2: Obs. standards & requirement

Mostly time of authors and contributors, including 5 FTE distributed across major ocean GHG observing laboratories to bring ocean observing efforts up to the same standard as atmospheric observations in GAW.

Travel and support for expert panel of 20–30 people, including cross-domain representatives, twice per year.

Financial O3: Longer term Obs.

Significant investment required to produce widely accepted rigorous development plan and to cost and publish this. Academic research needed to determine trade-offs and to maximize ROI (return on investment). Core resource of a consultant to develop a strategy plus a requirement for member states to contribute funding for workshops, including support of travel for experts to attend, room hire, keynote speakers and report synthesis. Meetings to be distributed globally.

Financial O4: Surface-based Obs. design

Network design experiment: 1 FTE per centre
Coordination of national assessment: 1 FTE in WMO Secretariat
115 k$ for the workshops and country visits

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Financial O5: Reference Network Development

Producing the documents – cost is time.

Identifying and deploying sites in high-level network. Based on ICOS experience operating cost of a Tier 1 station requires between 3 and 9 person-months of a well-trained technician and scientist per year, depending on the complexity of the station. Running cost per year for materials like calibration and target gases, spare parts, filters, pump membranes etc, is roughly 10–20 k$.

Cost will need to be distributed across each implementing body at different levels (international, national) and built into some of the other actions of the Implementation Plan (costs should not be replicated for each action but coordinated between actions).

Implementation costs per atmospheric station (based on ICOS, ref. ICOS Handbook 2022): 100–156 k$ / station for minimum Tier 1 (only CO_2, CH_4) fulfilling GAW compatibility goal; about 540 k$ /station for Tier 1 (CO2, CH4 & N2O + Isotopes). Estimated cost of total implementation investment for the current 36 ICOS atmospheric stations is about 16.2 M$ (19 class1 stations (all GHG, flask sampler, ceilometer) * 540 k$ + 27 class2 stations (just CO_2+CH_4) * 162 k$).

Financial O6: Basic (“fit-for-purpose”) network

Community-based science/academic partners should support the technological developments via workshops, hackathons events, code sprints that can accelerate and contain cost of measurement sensors to be widely deployed. The events organization is estimated in about 30 k$ per year. Moreover, citizen science can provide in-kind workforce for this activity.

Financial O7: RS & vertically resolved Obs.

In situ balloon observations ~3 k$ per flight.
In situ aircraft profiles $2.5 k$ per flight
Cost per profile for the other techniques (e.g. TCCON COCCO; AirCore, LIDAR, Drone) depends on the technique. Total cost will depend on the network design and number of profiles needed.

Financial O8: Ocean network design

Developing, running and expanding the surface ocean GHG observing system will require a coordinator (1 FTE) in IOCCP linked to GOOS and a technical coordinator (1 FTE) for SOCONET at OceanOPS.

National Ocean Research Agencies, Environmental and Climate Ministries, Academic Institutions, and National Meteorological Services need to take the financial commitment to run the sustained observing systems. Current committed funding for surface ocean GHG observations is approximately 8.1 M$ per year distributed across several nations. Estimates of near-term costs associated with support of existing and new observations, including initiating expansion to data-poor regions in the near-term, is approximately an additional 29 M$ per year distributed across all nations. This includes 9.2 M$ per year in capital investment for instrument updates, maintenance, and new instrumentation on existing platforms in addition to 25 FTE of new technical staff distributed across supporting nations to build capacity to fully operate new and existing measurements and quality control the data. Those investments are the highest priority in order to sustain critical observing infrastructure. Investment in research and development of approximately 4 M$ per year is needed to advance new techniques and GHG instruments, including support of early career researchers to grow the ocean GHG community. New autonomous surface ocean CO_2 platforms currently contributing data to SOCAT could be expanded to data-poor regions that OSEs have identified as major contributors

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to uncertainty in ocean CO_2 flux. An investment of 8 M$ per year in those measurements would make near-term progress and be adapted and deployed to other regions as OSEs assess observing impact.

Financial O9: Gridded Air-Sea CO_2 flux

The effort to run SOCAT has been estimated as 3 FTEs to develop and maintain software systems, support and troubleshoot the submission process, coordinate the annual release and to coordinate SOCAT of which approximately 1 FTE is committed. Innovating and developing SOCAT further will add another 2 FTE costs. Therefore, an extra 4 FTEs are needed.

MEMENTO also requires full time support (1 FTE) for database updates and maintenance, including for possible shared or leveraged infrastructure with SOCAT.

The SOCOM mapping exercise needs to be supported via National Ocean Research Agencies, Environmental and Climate Ministries, Academic Institutions, National Meteorological Services. Estimated costs to sustain efforts and conduct research to test optimal observing design is approximately 8 M$ per year across all nations.

WMO/IOC recommend that each National Ocean Research Agency or equivalent support a national contribution to this action that is consistent with and proportional to weather observing and forecasting contributions to address national needs and global assessments.

Financial O10: Space-based Obs. with CEOS-CGMS, direct

The costs of this activity are related to the workforce at an estimated 1 FTE level, i.e. about 115 k$ per year for each implementing body.

National space agencies (if convinced) will contribute in-kind by implementing required satellite missions, each at 350–500 M$ and a lifetime of ~8 years. It is expected that at least four larger satellites will fly contemporary. Further, they sponsor research/study groups and possibly Venture-class missions/instruments to address gaps.

Financial O11: Space-based Obs. with CEOS-CGMS, indirect

The costs of this activity are related to the workforce at an estimated 1 FTE level, i.e. about 115 k$ per year for each implementing body.

National space agencies (if convinced) will contribute in-kind by implementing required satellite missions, each at 350–500 M$ and a lifetime of ~8 years. It is expected that at least four larger satellites will fly contemporary. Further, they sponsor research/study groups and possibly Venture-class missions/instruments to address gaps.

Financial O12: Space-based Obs. with CEOS-CGMS, future

The costs of this activity are related to the workforce at an estimated 1 FTE level, i.e. about 115 k$ per year for each implementing body.

National space agencies (if convinced) will contribute in-kind by sponsoring research/study groups and possibly Venture-class missions/instruments to address gaps.

Financial M1: Modelling centre & data

1 FTE/year per institution operating a modelling centre

Financial M2: Modelling centre-documentation

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In-kind contribution: ~0.25 FTE/year per modelling centre

Financial M3: Continuous Operations (RRR)

In-kind contribution: ~0.25 FTE/year per institution

Financial M4: Obs. acquisition and pre-processing

In-kind contribution: ~0.5 FTE/year per institution

Financial M5: Prior Implementation

In-kind contribution: 1–2 FTE/year per institution

Financial M6: Production centres common approaches

In-kind contribution: 0.5 FTE/year per institution

Financial M7: Modelling products Evaluation

In-kind contribution: 1–2 FTE/year per institution

Financial P1: Identify needs – CO_2

0.5 FTE by centre

Support to the working group

Financial P2: Identify needs – CH_4

0.5 FTE by centre

Support to the working group

Financial P3: Identify needs – N_2O

0.5 FTE by centre

Support to the working group

Financial P4: Fluxes Characterize

6 FTE during the first year of the repository to set up the evaluation process, and then 3 FTE (1 per species).

Financial D1: Data from Raw to Exchange

The cost for QA/QC, data processing and data management is more efficient for a large network than for individual small networks or single stations. For the complete ICOS atmosphere network, the annual cost for Thematic Centre (ATC+CP+CAL) plus data portal is about 5 M$ per year, which is mostly personnel costs (50 FTE), including the calibration lab (provision of working standards, assignment of target gases, analysis of flasks (isotopes, f-gases, $^{14}CO_2$) and metrology lab (pre-deployment instrument check, instrument innovation). Pure data management building on existing infrastructure would be in total about 10 FTE, some shared with ecosystem and ocean, including these would add 6 FTE). Running on own hardware is more cost effective than cloud, this is about 75 k$ per year If internet connection is not

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available from public resources, one needs to add 20 k$ per year. Cost per atmospheric station for data management is minimum of 1.1 M$ for 40stations or 27.5 k$ per year per station. Including QA/QC will add 5 M$ for 40 stations or 125 k$ per year per station at European salary level. Doubling of the network would add 50% costs, but a lot of the costs scale linearly going onwards.

Financial D2: Data from providers to assimilation

Per modelling centre: 0.1 FTE

Financial D3: Data for model intercomparisons

NASA:
-Formulation – 0.5 FTE to modelling centre
-Storage and distribution by NASA ESDS program is an in-kind contribution
Space where all models put their data for the comparison (in the clouds many terabits, distributed but standardized).

ICOS: 54 k$ per year for 200 Tb

CAMS: data store roughly 1TB are shared per year with users and stored permanently.

Financial D4: Date discovery and distribution

NASA:
-In-kind contribution: Existing data distribution mechanisms (ESDS program)
-Coordination with WIS: 0.2 FTE
-Implementation of WIS (or other) standards around existing stores/interfaces: 2.0 FTE

Financial D5: Data repository, provider and policy definition for prior and fluxes

Per modelling centre: 1 FTE

Financial R1: G3W R2O Task Team establishment

1 FTE

Financial R2: Advance Obs. & data exchange capabilities

Working group meetings in first year for activities 1–3 – 34.6 k$
Scientific community: 577 k$ per year (1 FTE per implementing body).

Financial U1: Support the GST, linkage with regional products

Per modelling centre: 1 FTE

Financial U2: Establish relationship, pathways and guidelines

1 FTE

11. Resource mobilization

Ref.: 07317/2024-1.1.I

Resource mobilization for G3W is part of the broader WMO-wide activities to raise voluntary contributions for its strategic objectives, including those in support of climate change mitigation. The WMO Resource Mobilization Strategy is aligned with G3W-IPP 2024 – 2027, coordinated by WMO, in response to the World Meteorological Congress resolution. As such, G3W does not have a separate resource mobilization strategy. The G3W, together with Early Warnings for All (EW4All) and the Global Basic Observing Network (GBON), are among the priority initiatives of WMO that include a set of activities for climate action support and assessment at the service of the UNFCCC. Alike other initiatives, its funders may include traditional and emerging donors, climate funds, including the Systematic Observations Financing Facility (SOFF), multi-lateral development banks (MDBs), philanthropy and the private sector, recognizing that climate change mitigation is not only a necessity for sustainability but also a corporate duty in many countries (e.g., Environmental, Social, and Governance (ESG)). The G3W resource mobilization actions will aim at covering running costs of G3W infrastructure and services and therefore will be WMO wide.

In particular, the resources will fulfil the needs of technical, coordination, monitoring and communications leadership of G3W, as well as for non-WMO contributions to G3W, to help ensure that climate action and development support and investments are built robustly on science and services for society according to the needs of WMO Members.

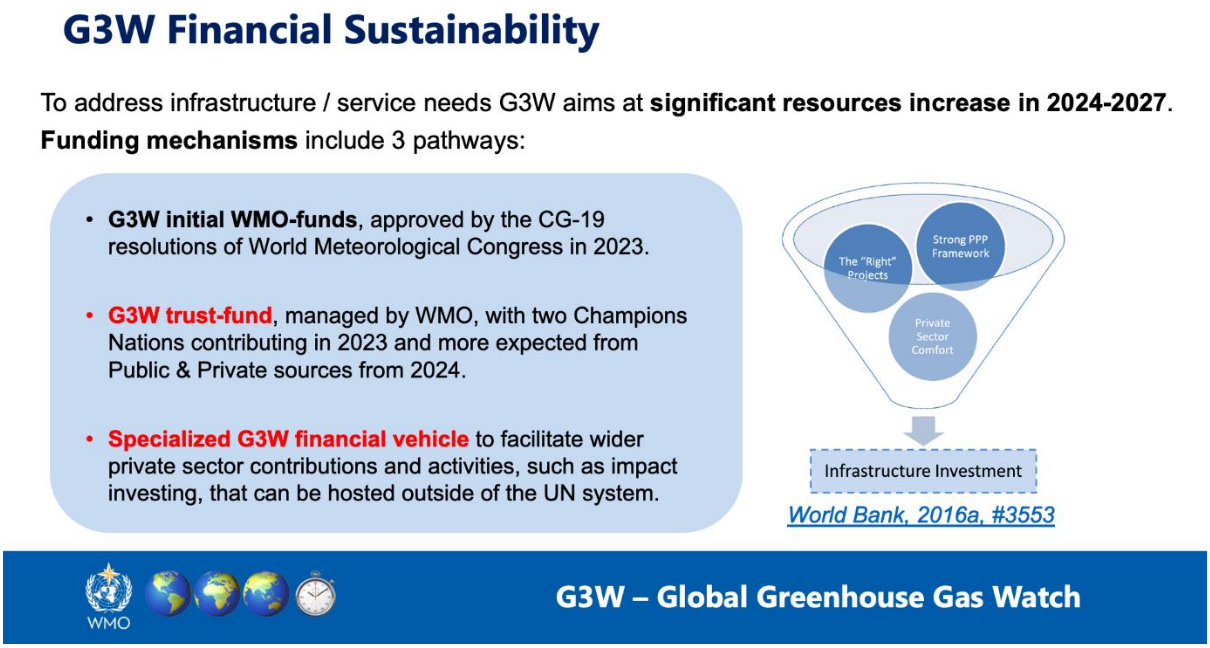

Figure 5. G3W funding mechanisms for financial sustainability

Ref.: 07317/2024-1.11

Table 2. G3W funding sources for workforce and infrastructure

<table>
<tr><th>G3W funding sources</th><th>Workforce</th><th>Infrastructure</th></tr>
<tr><td>National NMHS

Denmark
Germany

Link to all UNFCCC reporting agencies</td><td>Donation

14.5 k$
10.8 k$</td><td>Donation (beyond Workforce ceiling needs in Table 1. G3W financial estimates for the G3W-IPP financial period (2024–2027))</td></tr>
<tr><td>Industry sectors
<table>
<tr><th>No.</th><th>Group name</th><th>IPCC (2006) activities per sector</th><th>Note</th><th colspan="4">Emission budget 2015, Mt</th></tr>
<tr><th></th><th></th><th></th><th></th><th colspan="2">EDGARv4.3.2_FT2015</th><th colspan="2">CHE_EDGAR-ECMWF_2015</th></tr>
<tr><td>1</td><td>ENERGY_S</td><td>1.A.1.a (subset)</td><td>Power industry (without autoproducers): super-emitting power plants</td><td>13 704.0</td><td>13841.2</td><td>896.7</td><td>12705.5</td></tr>
<tr><td>2</td><td>ENERGY_A</td><td>1.A.1.a (rest)</td><td>Power industry (without autoproducers): standard-emitting power plants</td><td></td><td></td><td>11 671.6</td><td></td></tr>
<tr><td></td><td></td><td>4.C</td><td>Solid waste incineration</td><td>137.2</td><td></td><td>137.2</td><td></td></tr>
<tr><td>3</td><td>MANUFACTURING</td><td>1.A.2</td><td>Combustion for manufacturing (including autoproducers)</td><td>6182.8</td><td>8960.1</td><td>7320.4</td><td>10096.0</td></tr>
<tr><td></td><td></td><td>2.C.1, 2.C.2</td><td>Iron and steel production</td><td>233.6</td><td></td><td>233.6</td><td></td></tr>
<tr><td></td><td></td><td>2.C.3, 2.C.4, 2.C.5, 2.C.6, 2.C.7</td><td>Non-ferrous metal production</td><td>91.4</td><td></td><td>91.4</td><td></td></tr>
<tr><td></td><td></td><td>2.D.1, 2.D.2, 2.D.4</td><td>Non-energy use of fuels</td><td>24.7*</td><td></td><td>24.6</td><td></td></tr>
<tr><td></td><td></td><td>2.A.1, 2.A.2, 2.A.3, 2.A.4</td><td>Non-metallic minerals production</td><td>1748.8</td><td></td><td>1749.0</td><td></td></tr>
<tr><td></td><td></td><td>2.B.1, 2.B.2, 2.B.3, 2.B.4, 2.B.5, 2.B.6, 2.B.8</td><td>Chemical processes</td><td>678.8*</td><td></td><td>677.0</td><td></td></tr>
<tr><td>4</td><td>SETTLEMENTS</td><td>1.A.4, 1.A.5.a, 1.A.5.b.i, 1.A.5.b.ii</td><td>Energy for buildings</td><td>3321.9</td><td>3321.9</td><td>3322.7</td><td>3322.7</td></tr>
<tr><td>5</td><td>AVIATION</td><td>1.A.3.a_CRS</td><td>Aviation cruise; typical fuel: jet kerosene</td><td>412.2</td><td>815.4</td><td>412.2</td><td>815.4</td></tr>
<tr><td></td><td></td><td>1.A.3.a_CDS</td><td>Aviation climbing and descent; typical fuel: jet kerosene</td><td>305.5</td><td></td><td>305.5</td><td></td></tr>
<tr><td></td><td></td><td>1.A.3.a_LTO</td><td>Aviation landing and take-off; typical fuel: jet kerosene</td><td>97.7</td><td></td><td>97.7</td><td></td></tr>
<tr><td>6</td><td>TRANSPORT</td><td>1.A.3.b</td><td>Road transportation; typical fuel: most typical emission factor uncertainty</td><td>5530.2</td><td>6604.4</td><td>5530.6</td><td>6604.9</td></tr>
<tr><td></td><td></td><td>1.A.3.d</td><td>Shipping; typical fuel: composition of 80 % diesel and 20 % residual fuel oil</td><td>819.0</td><td></td><td>819.1</td><td></td></tr>
<tr><td></td><td></td><td>1.A.3.c, 1.A.3.e</td><td>Railways, pipelines, off-road transport; typical fuel: railways – diesel, off-road transport – most typical emission factor uncertainty</td><td>255.2</td><td></td><td>255.2</td><td></td></tr>
<tr><td>7</td><td>OTHER</td><td>1.A.1.b, 1.A.1.c, 1.A.5.b.iii, 1.B.1.c, 1.B.2.a.iii.4, 1.B.2.a.iii.6, 1.B.2.b.iii.3</td><td>Oil refineries and transformation industry</td><td>1917.4</td><td>2443.5</td><td>1917.8</td><td>2450.6</td></tr>
<tr><td></td><td></td><td>1.B.2.a.ii, 1.B.2.a.iii.2, 1.B.2.a.iii.3, 1.B.2.b.ii, 1.B.2.b.iii.2, 1.B.2.b.iii.4, 1.B.2.b.iii.5, 1.C</td><td>Fuel exploitation</td><td>258.4</td><td></td><td>258.4</td><td></td></tr>
<tr><td></td><td></td><td>1.B.1.a</td><td>Coal production</td><td>0.0</td><td></td><td>7.0</td><td></td></tr>
<tr><td></td><td></td><td>3.C.2, 3.C.3, 3.C.4, 3.C.7</td><td>Agricultural soils</td><td>99.0</td><td></td><td>99.1</td><td></td></tr>
<tr><td></td><td></td><td>2.D.3, 2.B.9, 2.E, 2.F, 2.G</td><td>Solvent and product use</td><td>168.7*</td><td></td><td>168.3</td><td></td></tr>
</table>
Clusters as proposed in Choulga et al. 2021</td><td>Environmental, Social, and Governance (ESG) practices alongside more traditional financial measures.

Socially responsible investing based on specific ethical criteria (SDGs advancement).</td><td>Public–Private Partnerships guided by WMO-G3W Observing Systems Guidelines</td></tr>
<tr><td>Financial sectors
World Bank
Central Banks
Multi-lateral Development Banks
Insurances and Reinsurances
Philanthropies
Climate finance grants
Loss and damage</td><td>Impact investing for social benefit (SDGs framework).</td><td>Impact investing for social benefit (SDGs framework)</td></tr>
</table>

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12. Outlook

The G3W outlook covers the G3W Implementation and Pre-operational Phase (G3W-IPP) in the financial period 2024–2027 with the first two years dedicated to ramp up the human and financial resources required, both in the WMO Secretariat as in the operational centres so that the entire chain is interlinked and set in motion and key observational assets are becoming available with agreed standards. It is envisaged that the G3W-IPP will embed substantial progress and adjustment to achieve and/or gain efficiency.

The G3W Initial Operational Phase (G3W-IOP) begins in the next financial period (2028–2031), and it includes the consolidation of the G3W systems configuration for the 2nd GST which is a key moment in the Paris Agreement Enhanced Transparency Framework (PA-ETF), since it will permit to measure progress with respect to the first GST.

The G3W-IOP will be at service of the nations in setting new NDCs and evaluating the uncertainties in the assessment of the GHGs growth/abating rates. Within the G3W-IOP in 2030 an extensive assessment of the state of climate change mitigation shall be produced to guide the requirements and ambitions of the Enhanced Operational Phase G3W-EOP, in full compliance with the needs of the PA-ETF.

The G3W-EOP will aim at providing actionable information assisting the nations, Parties to UNFCCC, in their LT-LEDS, providing also support for the long-term horizon of NDCs with the ambitions of tackling the climate and inequality crises at the same time, so that no one is left behind.

There is a lot of activities that have to be implemented beyond the initial 4 years. These are related to enhancement of the observational and modelling capabilities. Many of those actions cover ocean and terrestrial domain as the initial focus of G3W is on getting net fluxes.

In a mid-term the following developments are required for the ocean domain:

- Innovate surface ocean fCO_2 mapping techniques for monthly 1°x1° G3W ocean CO_2 flux products and operationalize them (including creating a plan for regular intercomparisons of mapping products, ocean models, and inversions),
- Set requirements and conduct observing design experiment for ocean-based measurements of N_2O and CH_4,
- Design a comprehensive ocean observing system for assessing climate and biogeochemical feedback that affect GHGs, linking an operational surface ocean GHG reference network with ocean interior observing networks,
- Facilitate technological development and evaluation to increase the feasibility to make ocean fCO_2, CH_4, N_2O, and air-sea flux observations,
- Leverage ocean reference network platforms for enhancing atmospheric GHG network (CO_2, CH_4, N_2O) over the ocean.

In the longer-term the implementation of a sustained, comprehensive ocean observing system for assessing climate and biogeochemical feedback that affect GHGs (including biological, physical, chemical, and geological components of the carbon and nitrogen cycles from surface to interior ocean, data output and information generation, and is integrated with land and atmosphere domains) is envisioned with more information made available to to ocean models and inversion systems.

In the atmospheric domain the following development in the observing system are foreseen in the mid-term:

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- Expand GHG concentration measurements to other gases (e.g., F-gases),
- Expand measurements to support attribution: $^{13}CH_4$ in Tropics and Arctic, ethane, $^{14}CO_2$ globally, COS, O_2/N_2 ratio,
- Standardize stable isotopic measurements and radiocarbon,
- Expand GHG flux observations using eddy covariance and flux chamber techniques,
- Develop new and improve measurement techniques and instruments.

For the terrestrial domain, the efforts of a bottom-up community can be better coordinated for collection of data from observing networks of direct fluxes over land and for the creation of spatial explicit maps of fluxes, at high temporal and spatial resolution, through their integration with remote sensing, gridded meteorology, and machine learning for CO_2, CH_4 and N_2O.

Substantial developments are also expected in the mid- and long-term regarding uptake of the G3W outputs and development of the user-tailored products through establish harmonization between G3W global systems and smaller scales of GHG quantification (point sources, urban, nations, etc). In a longer term, the operational platform should be connected and benefit from the related initiative of the other agencies (e.g. IMEO).

A larger portion of the Research and Development needs, identified in the current financial period 2024–27 by the G3W-IPP, will be devoted in the G3W-IOP the Initial Operational Phase, and a continuous development cycle is envisaged for the G3W-EOP.

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ANNEX I

Survey on National capacities for implementation of the Global Greenhouse Gas Watch

Instructions how to fill in the survey.

In this survey the term "Your agency" refers to the agency that fills in the survey which in the context of WMO is a National Meteorological and/or Hydrological Service (NMHS) representing a Member State or Member Territory. While it might be a challenging task for some of your agency to be fully aware of the capabilities from all your country/territory, you have the option to disseminate the survey to the relevant agencies within your country and/or subsidiary bodies under your agency.

As the survey is implemented in Microsoft forms, please prepare your responses in advance as you will not be able to edit them once you have started the survey. The content of the survey is being made available in all WMO languages to ease the preparation of the replies.

The online survey should be completed at your earliest convenience, but not later than 1 November 2023.

The survey contains some short explanations regarding several questions, though if those explanations are not clear, please get back to the WMO Secretariat for additional clarifications.

We would like to remind you that in WMO context, ground-based remote sensing of greenhouse gas refers to the use of specialized instruments and techniques located on the Earth's surface to measure and observe distribution of greenhouse gases in the atmosphere. Unlike satellite-based remote sensing, which involves sensors on orbiting satellites, ground-based remote sensing focuses on collecting data from fixed observation sites on the ground.

A General Information

1. Member: (name)

2. Agency: (name)

3. Region (Regional Association):

4. Focal point responsible for filling in the survey (available for follow-up):

Answer example: name with title, affiliation, email

5. Which agencies and organizations in your country are involved in greenhouse gas monitoring? (These may include governmental agencies, academia and universities, private sector and others. If there are several, please list the top three.)

6. Is your agency responsible for the compilation of national greenhouse gases inventory:
   - Yes
   - No
   - Partially

7. For what type of decision-making greenhouse gas data are needed or used in your country?
   - Climate policy formulation and evaluation
   - Setting emission reduction target
   - Contribution to emission inventory development
   - Support of mitigation strategies

- Carbon pricing and market mechanisms
- Climate impact assessment
- Climate transparency
- Public awareness and engagement
- Other: please specify

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B. Current Capabilities

8. Number of staff involved in your agency in a **greenhouse gas observation**;

9. Number of staff involved in your agency in a **greenhouse gas modelling**

Explanation for Q.10–13: Number of measurement stations for in situ atmospheric concentration measurements of greenhouse gases. Please list by agency where possible Answer Example: NMHS: xxx; University ZXY: xxxx etc.

10. How many measurement stations are operated in your country for in situ atmospheric concentration measurements of **CO_2**?

11. How many measurement stations are operated in your country for in situ atmospheric concentration measurements of **CH_4**?

12. How many measurement stations are operated in your country for in situ atmospheric concentration measurements of **N_2O**?

13. How many measurement stations are operated in your country for in situ atmospheric concentration measurements of **other greenhouse gases**?

Explanation for Q.14–17: Number of measurement stations for direct flux measurement (e.g. with Eddy Covariance). Please list by agency where possible. Answer Example: NMHS: xxx; University ZXY: xxxx etc.

14. How many measurement stations are operated in your country for direct flux measurement of **CO_2**? (e.g. with Eddy Covariance);

15. How many measurement stations are operated in your country for direct flux measurement of **CH_4**?

16. How many measurement stations are operated in your country for direct flux measurement of **N_2O**?

17. How many measurement stations are operated in your country for direct flux measurement of **other greenhouse gases**?

18. To what extent is the national greenhouse gas observational network in your country/territory supported operationally (funding and staffing)?

- Full operational support from the Government for more than five years

- Support is available for next couple of years)

- The network operates purely on research grants

- Other: please explain

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19. What other greenhouse gas atmospheric measurements are performed in **or** by your country? (Observations can be implemented by the country outside its national borders).

- From aircraft
- From ship
- Ground-based remote sensing
- Other: please specify

20. Does your country conduct measurements of greenhouse gases (e.g. CO2) dissolved in the ocean? If yes, could you provide the number of observational platforms?

21. What satellite data for greenhouse gases are used in your country and/or by your agency?

- OCO (Orbiting Carbon Observatory)
- GOSAT (Greenhouse gases Observing SATellite)
- Sentinel
- AIRS (Atmospheric Infrared Sounder)
- IASI (Infrared Atmospheric Sounding Interferometer)
- MERLIN (Methane Remote Sensing Lidar Mission)
- Tan-sat
- Other: please specify

22. Where does your country share greenhouse gas observational data?

Explanation for Q.22: Please provide the name of the platform/centre(s)/link(s) where data is available or specify that the data are not shared.

23. What modelling tools are used in your country and/or by your agency to calculate greenhouse gas concentrations and fluxes?

- Global Circulation Models (GCMs) with greenhouse gas blocks
- Global Chemistry-Transport Models (CTMs) with greenhouse gas blocks
- Regional Lagrangian modelling
- Land/biosphere models for greenhouse gas fluxes
- Emission Inventory models for anthropogenic fluxes
- Other: Please specify the type of the models your country and/or agency uses

C. Future Development

24. Does your country have a national greenhouse gas monitoring plan:

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- The plan has been developed and is in the stage of implementation
- The plan is under development and the implementation will start within five years
- The plan is under development without concrete implementation timeline
- There is no such plan in the country

25. How many stations in the country need to be **repaired/upgraded (*currently*)**?

26. How many stations in the country need to be **newly built (*for a well-covered designed observation*)**?

27. How many people need to be trained in **establishing high-quality greenhouse gas observations**?

28. How many people need to be trained in **greenhouse gas modelling**?

29. How many people need to be trained in **the use of greenhouse gas data for decision-making**?

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ANNEX II

G3W Implementing bodies, actions and roles.

Institution or body	Actions	Role
Academic Institutions	O8, O9	As majority of the ocean observations is made by the academic institution, these institutions will play an important role in sustaining and extending these measurement programmes.
Aircraft operating communities	O7	These communities are the providers of the aircraft-based observations and will be responsible for sustainability and extension of observations.
BIPM and its relevant bodies	O2	BIPM provides means for metrological traceability of observations and will play an important role in provision of the measurement standards.
Broad GHG community	O3	Broad GHG community will provide its expertise in establishment and support of the long-term observations and will continue support to such observations.
CEOS	O2, O3, R3	CEOS will continue support of the production of the harmonized satellite products that will enable advances in inverse modelling and source attribution.
CEOS-CGMS WG Climate (via GHG Task Team)	O10, O11, O12	This Working Group will provide coordination of delivery of the satellite data and develop, support, and update relevant roadmaps.
Contributors to the repository	D7	These are the institution that are producing prior estimates of GHG fluxes and related variables requires as an input information to the inverse modelling systems. These institutions are to be defined during the initial implementation period.
Countries and blocks of countries (National Emission Inventories & climate negotiators)	U1	This entity refers to the groups of countries who are actively participating in the meetings of Parties to UNFCCC and have influence on the decisions of the sessions. These countries are also active contributors to the global stocktake. These must be the countries that are also actively involved in the work of WMO.
Countries	U2	Under this action item the reference is made to the countries that are interested in detailed national products, created on the basis of G3W outputs.

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Institution or body	Actions	Role
Country observation network	U2	These are national networks those data can be used for creation of additional, nationally specific products to support mitigation actions (e.g. higher resolution than G3W outputs or with sector attribution).
Data centres	D2	These are the institutions providing permanent storage of the observational data.
Development agencies	D5, D6	Development agencies will provide socio-economic information that is used to create advanced emission inventories (the prior information used in inverse modelling).
DG Climate	U1	This DG promotes outputs of the European operational centre as the information relevant to the global stocktake. The efforts of the different regional bodies will contribute to global efforts towards broader unitization of the observations-based flux estimate in the connects of the stocktake.
European Centre for Medium-Range Weather Forecasts (ECMWF)	O10, O11, O12, M5, P1, P2, P4, R3, U1	ECMWF is both a research institute and an operational service, producing global numerical weather predictions and other data for our Member and Cooperating States and the broader community. It is a key player in Copernicus, offering quality-assured information on climate change, atmospheric composition, flooding and fire danger and other products.
ECMWF (GHG Monitoring and Verification System)	O10, O11, O12	This is one of the systems that will work closely on the satellite observation roadmap as an active user of the satellite data.
Environmental and Climate Ministries	O8, O9	These are the Ministries that ensure sustainability of the environmental observations. Improved outreach to these entities will help improve the long-term stability of the measurement programmes, particularly over the ocean.
Environmental Protection Agency (EPA)	D5, D6, D7, P4	EPA plays an important role in development of the national emission inventory, used as an input information to the global inverse modelling systems. EPA hold some of the important datasets of prior emission estimates that can be shared internationally through the specialized data centre.

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Institution or body	Actions	Role
Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee (EPAC SSC)	O2, O4, O5, O7, U3	EPAC SSC coordinates the work of GAW which up to now set standards on the atmospheric observations of greenhouse gases and co-emitted species, coordinated the network of the atmospheric composition measurements stations, quality control of these measurements. EPAC SSC sets up the research agenda for the GAW programme, defines priorities, workplans and evaluate progress towards set objectives of GAW.
European Commission (EC)	D5, D6, D7, P4, M5, R3, U1	EC provides support to research projects that develop prior information, that is required as an input to the global modelling systems.
European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)	R2	EUMETSAT will receive, process, and disseminate data from space-based observations of GHGs.
European Space Agency (ESA)	O10, O11, O12, R2	ESA will provide satellite observations of greenhouse gases and contribute to the observational datasets.
Expert Team on data acquisition (new)	M4	This working group is required to coordinate development of the common practices and standard between the operational centres regarding data preparation for utilization in the modelling systems.
External partners providing data storage capabilities	D4	This refers to the institutions that have capabilities to host and support operation of the data centres for the prior flux information.
Food and Agriculture Organization (FAO)	P1, P2, P3	FAO provides statistics on agricultural activities that are utilized for the production of the prior greenhouse gas fluxes as well as forest data on biomass and carbon stocks and changes.
G3W Advisory group	M3, M6, M7, O5, P1, P2, P3, U3, U4	G3W will provide coordination of the technical activities to be implemented under this plan.
Expert Team on Atmospheric Composition Data Management ET-ACDM	D2	This is one of the Exert Teams under the GAW Programme that deals with the data and metadata standards for the atmospheric composition data. This group works closely with WIS and WIGOS teams.

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Institution or body	Actions	Role
Global Atmosphere Watch (GAW)	R1, R2	GAW is a research programme operated under the Research Board that deals with the atmospheric composition and related environmental research, including greenhouse gas research, observations, and services.
Global Climate Observing System (GCOS)	O1, O10, O11, O12, P1, P2, R2, R3	GCOS sets up the requirements for the climate monitoring, defines Essential Climate Variables and evaluates the status of the global observing network for climate. GCOS provides recommendations on the need for sustainability and extension of these observing network including through the negotiation with the satellite operators.
Global Carbon Project (GCP)	P1, P2, P3	GCP for the annual assessments produces a set of comprehensive prior information that can be used by the operational centres.
Greenhouse Gas Measurement Techniques (GGMT) meetings	O2	GGMT meetings are the meetings of the atmospheric greenhouse gas community that review requirements to greenhouse observations, puts the recommendations on how to reach these requirements and evaluates emerging greenhouse gas measurement techniques. This group is supported and coordinated by the GAW Scientific Advisory Group on Greenhouse Gases (SAG GHG).
Global Ocean Observing System (GOOS)	D1, O8, O9, O11, O12, P1, P2, P3, R2	GOOS sets up the requirements for the ocean monitoring, defines Essential Ocean Variables and evaluates the status of the global observing network for ocean. GOOS provides recommendations on the need for sustainability and extension of these observing network. GOOS links broad community that is involved in ocean observations and research.
GOOS Secretariat	O1	GOOS secretariat will assist with the survey of the available greenhouse gas and related observations over/in the ocean.
Integrated Carbon Observation System (ICOS)	D1, U2	ICOS is a European Research Infrastructure that support observations of greenhouse gases in the atmosphere, oceans and land. It operates a network of stations, specializes thematic centres dealing with quality assurance and dedicated data management system.

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Institution or body	Actions	Role
Integrated Carbon Observation System (ICOS) Carbon Portal	D5, D7	ICOS Carbon Port is a data management system for collection, quality control and publication of the ICOS observational data.
Integrated Global Greenhouse Gas Information System (IG^{3}IS) Steering Committee	U3, U4	IG3IS is a “science-for-services” initiative of the GAW Programme that works towards development of mitigation services using atmospheric observations and analysis tools. IG3IS develops good practices for application on the national and smaller scales and for specific sectors. Steering Committee is the IG3IS coordination and oversight body.
Commission for Observation, Infrastructure and Information Systems (INFCOM) Management Group	U3	INFCOM Management Group provide guidance to the INFCOM substructures. G3W is one of the activities of INFCOM.
International data synthesis efforts	D2	International data synthesis efforts are the institutions that can collect, quality control the observational data and can aggregate them into the packages suitable for international data exchange.
Intergovernmental Oceanographic Commission (IOC)	P1, P2, P3, R1	The Intergovernmental Oceanographic Commission of UNESCO (IOC/UNESCO) promotes international cooperation in marine sciences to improve management of the ocean, coasts and marine resources. IOC collects data necessary for the development of the prior fluxes needed for the global inverse modelling.
IOC partner training centres and affiliated programs	D1	These institutions will work with the operators of the ocean observational platforms to establish good practices related to processing of the raw observational data and prepare them for the fast international exchange.
IOC Secretariat	O1, O2, O3	IOC Secretariat will work with WMO Secretariat on the preparation of the observational survey, evaluation of the observational standards and available datasets and preparation of the workshop for the development of the long-term observations’ strategy.
International Ocean Carbon	O3, O8, O9	The IOCCP promotes the development of a global network of ocean carbon observations for research through

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Institution or body	Actions	Role
Coordination Project (IOCCP)		technical coordination and communication services, international agreements on standards and methods, and advocacy and links to the global observing systems. IOCCP will contribute to the development of the long-term strategy for observations, coordinate all activities (for governance structure with GOOS) for the ocean observations and will provide input to SOCAT governance structure and coordination of observing system experiments and roadmap for SOCOM.
MarinE MethanE and NiTrous Oxide (MEMENTO)	O9, D2	MEMENTO aims to become a valuable tool for identifying regions of the world ocean that should be targeted in future work to improve the quality of air-sea flux estimates. The project will assess potential for shared, leveraged or interoperable infrastructure for CH_4 and N_2O data products with SOCAT. MEMENTO will contribute to the development of the internationally exchangeable datasets as inputs to the global inverse modelling.
National Aeronautics and Space Administration (NASA)	O10, O11, O12, D6, D7, P4	NASA is one of the centres that provides satellite observations of greenhouse gases and related species and operates global modelling capacities. It will contribute to the observational datasets, in data harmonization, storage and exchange efforts. Additional datasets will be provided to create prior information for the global inverse modelling.
NASA Distributed Active Archive Centres (DAAC)	D5	DAAC is currently one of the providers of the prior information for the global inverse modelling.
National Agencies responsible for national inventories	D5, D6, D7, P1	National emission inventories represent an important source of the prior information that is required as an input to the global inverse modelling.
National Ocean Research Agencies	O8, O9	These agencies are responsible for the implementation of a sustained SOCONET measurement infrastructure, including expansion to data-poor regions as well as enhancement of these observations, development of a roadmap for SOCOM and mapping of intercomparisons.
National operational centres with curriculum coordinated with	D1, R3	These national centres have a mandate in delivery of the critical weather, water, climate and environmental information for decision-making. Those agencies that work with local universities have very

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Institution or body	Actions	Role
regional universities		strong connection with the research activities. This connection can be used to increase the capacity of the station operators to perform complex measurements of greenhouse gases as well as to connect the outputs of research with the advances in the national operational systems.
National Centre for Atmospheric Research (NCAR)	D5, D6, D7, P4	NCAR is a research organization that support research related to evaluation of relationships between the atmosphere and the rest of the Earth system, including the oceans, the land surface, and even the Sun. NCAR creates research quality emission inventories required as an input data to the global inverse modelling. NCAR operate global modelling systems as well.
National Institute for Environmental Studies (NIES)	O7, M3	NIES is a research institute in Japan, coordinates aircraft observations of greenhouse gases and will share those to support quality assurance of the modelling products. It also runs the global inverse modelling systems.
National Institute of Standards and Technology (NIST)	D5, D6, D7, P4	NIST support greenhouse gas observations and campaigns that collect data for prior emission estimates.
National Meteorological and Hydrological Service (NMHS)	O4, O6, O7, O8, O9, D5, D6, D7, C1–3, C5	NMHSs represent an entry point for WMO to conduct national assessments of the observational and modelling capacities. NMHSs will be implementers of observational systems, share observational data with the operational centres and be users of the modelling products. Substantial part of the capacity building and training will be targeting NMHSs.
National Oceanic and Atmospheric Administration (NOAA)	O1-O12, D5, D6, D7, M1-M7, P4	NOAA is an agency that operates global greenhouse gas observing network, hosts a number of the Central Facilities for the GAW Programme that support global quality assurance framework, it develops data products that will feed into the global inverse modelling. NOAA operates global inverse modelling system as well.
Operational centres	O4, D2, D3, D4, M1, M2, M3, M4, M5, M6, M7, P1, P2, P3, U1, U2, U4	Operational centres are the entities that will be implementing the core function of G3W: receive input data, process those and produce well characterized and document modelling outputs, that will be

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Institution or body	Actions	Role
		intercompared between the participating centres and provided to user community.
Operators of measurement stations	D1, D2	Operators of the measurement stations are the individuals or institutions who will be performing measurements (running instruments), process raw data, ensure quality control and prepare these data for the international exchange.
Regional centres	D1, D2	Regional centres that help manage raw data into exchangeable data products.
Research Board	O1, R1, R2, R3	Research Board is one of the bodies of WMO. The purpose of the Research Board is to translate the strategic aims of WMO and the decisions of Congress and the Executive Council into overarching scientific research strategies. It oversees the research programmes of WMO and connects the activities of the programmes with broader research priorities and communities.
Research community	D4, D6, O1, O2, O5, O6, O7, P1, P2, P3, P4, R2, R3, U2	Currently majority of greenhouse gas activities (observation, modelling, development of mitigation services) has been implemented by the research community. This community will provide its expertise and infrastructure for development of the operational capabilities.
Research sponsors	R3	These organizations sponsor research projects and can further facilitate research in the area where substantial uncertainties exist through dedicated/targeted calls.
Standing Committee on Data Processing for Applied Earth System Modelling and Prediction (SC-ESMP)	M1, M2, M3, M4, M6, M7	SC-ESMP is a standing committee under INFCOM that will support integration of greenhouse gas modelling into WIPPS.
Science Foundations	D5, D6	These foundations provide financial support toward development of research products that can be utilized as priors in the global modelling systems.
Standing Committee on Information Management and	D1, D2, D3, D4, O1	SC-IMT is a standing committee under INFCOM that will support integration of greenhouse gas data in WMO Information System and development of the associated data and metadata standards.

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Institution or body	Actions	Role
Technology (SC-IMT)		
Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)	D1, O2, O5, O6	SC-MINT is a standing committee under INFCOM that will support integration of greenhouse gas observations in WIGOS, establishment of the measurement practices and harmonization of quality assurance and quality control and measurement methods.
Standing Committee on Earth Observing Systems and Monitoring Networks (SC-ON)	O1, O2, O4, O5, O6, O7, O8, O9, O10, O11, O12	SC-ON is a standing committee under INFCOM that will support integration of greenhouse gas observations in WMO Integrated Global Observing System through establishment of the observations principles, contribution to the network design and development of the long-term observational strategies as well as integration of observation between different platforms.
Commission for Weather, Climate, Water and Related Environmental Services and Applications (SERCOM)	U3	SERCOM is a WMO Constituent Body that is charged with leading and coordinating the promotion, development and implementation of globally consistent and user-focused services based on principles of good practice, opportunities for all and long-term sustainability. SERCOM will promote the uptake of the G3W outputs, assess user requirement for products in support of greenhouse gas mitigation and development of the structured mitigation services.
Surface Ocean CO_2 Atlas (SOCAT)	D2, O2, O9	SOCAT is a synthesis activity for quality-controlled, surface ocean fCO_2 (fugacity of carbon dioxide) observations by the international marine carbon research community. It will facilitate the engagement of the observational ocean community in development of the QA/QC standards and harmonized measurement practices, as well as in the development of the gridded air-sea CO_2 fluxes. It will work with GOOS and IOCCP to create a governance structure and to enhance its capabilities in coordination with MEMENTO and other relevant projects and entities.
Surface Ocean pCO_2 Mapping intercomparison (SOCOM)	O9	SOCOM will conduct observing system experiments using mapping intercomparisons and provide inputs to the ocean-related roadmaps.
The Surface Ocean CO_2 Reference	O2, O8	SOCONET is a volunteer group of established operators who provide quality

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Institution or body	Actions	Role
Observing Network (SOCONET)		global surface ocean CO_2 data. SOCONET tracks observations and data following established network principles. SOCONET will provide expertise to establishment of the good measurement practices and measurements QA/QC tools as well as their harmonization. It will implement own infrastructure in consultation with the partners and assist with the development of the optimal observing design and recommendations for CH_4 and N_2O infrastructure.
Training centres	D1	In the context of this task, training centres will provide training focused on competency development, including the management of the raw data, quality control, and preparation for international exchange. Training centres have the fundamental role for all the tasks under the capacity development section.
UNFCCC body responsible for the global stocktake, including Conference of the Parties serving as the meeting of the Parties of the Paris Agreement (CMA), and co-convenors of the Technical Dialogues	U1	UNFCCC global stocktake is the main mechanism for the utilization of the G3W outputs in the policy context.
US Greenhouse Gas Centre	D5, D6, D7, P4	The U.S. Greenhouse Gas Centre opens up access to trusted data on greenhouse gases. This multi-agency effort consolidates greenhouse gas information from observations and models. The goal of the US GHG Centre is to provide decision makers with one location for data and analysis. Data produced by this centre will be used as an input in the participating global modelling systems.
World Climate Research Programme (WCRP)	O11, O12, R2, R3	WCRP is a WMO co-sponsored research programme that coordinates research around some of the most pressing scientific questions in relation to the compounded nature of the climate system across nations and scientific disciplines. WCRP will address in its work the challenges articulated in the section on research. It will formulate requirements for the satellite observation in the view of

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Institution or body	Actions	Role
		climate projects and expected signals withing the Earth System.
Working Group on Numerical Experimentation (WGNE)	R1, R2, R3	WGNE is a body that operates under the Research Board. It has responsibility for the development of Earth system models for use in weather, climate, water and environmental prediction on all time scales, and diagnosing and resolving shortcomings. This group will provide guidance on the development of modelling capabilities and their transition to operational systems.
WMO Secretariat	D1, D4, D5, D6, D7, M1, M2, M3, M4, M6, M7, O1-O7, P4, R1, U1, U2, U4	WMO Secretariat will play a coordination role and provide management and administrative support to the partners participating in the implementation of G3W. WMO Secretariat will liaise with the agencies of UN system and other relevant bodies and facilitate their contribution towards implementation of G3W.
WMO Regional Training Centres (RTC)	D1, C1-C5	WMO RTCs are contributing to the implementation of the training programmes in support of WMO Members. These centres are expected to play an important role in the capacity development within G3W.
World Weather Research Programme (WWRP)	R2, R3	WWRP is a WMO research programme under the Research Board that promotes research to improve weather prediction, and its impacts on society, for minutes to months ahead. WWRP will contribute to the research topics articulated in the section on research.

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