The 2022 GCOS Implementation Plan

Space Agencies Supplement

ГЛОБАЛЬНАЯ СИСТЕМА НАБЛЮДЕНИЙ ЗА КЛИМАТОМ
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1. INTRODUCTION

This Space agencies Supplement to the 2022 GCOS Implementation Plan extracts those activities for which the Space agencies have been identified as key implementing partners.

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

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

This supplement only lists those actions within each theme that are targeted at the Space agencies. Within each action the specific activities for the Space agencies are highlighted in bold. In the list of implementers, those in bold are considered to take the lead in addressing and monitoring the activities.

For actions that should be performed by other actors, details can be found in the main report. This supplement is complemented by other supplements aimed at specific communities.

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

Table 1 Actions for Space agencies.

Theme	Actions	Space agencies
A: ENSURING SUSTAINABILITY	A2. Address gaps in satellite observations likely to occur in the near future	x
	A3. Prepare follow-on plans for critical satellite missions	x
B: FILLING DATA GAPS	B1. Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)	x
	B3. New Earth observing satellite missions to fill gaps in the observing systems	x
	B5. Implementing global hydrological networks	x
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C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING	C1. Develop monitoring standards, guidance and best practices for each ECV	x
	C2. General improvements to satellite data processing methods	x
	C4. New and improved reanalysis products	x
	C5. ECV-specific satellite data processing method improvements	x
D: MANAGING DATA	D4. Create a facility to access co-located in situ cal/val observations and satellite data for quality assurance of satellite products	x
F: OTHER EMERGING NEEDS	F1. Responding to user needs for higher resolution, real time data	x
	F2. Improved ECV satellite observations in polar regions	x
	F3. Improve monitoring of coastal and Exclusive Economic Zones	x
	F5. Develop an Integrated Operational Global GHG Monitoring System	x

2. THEME A: ENSURING SUSTAINABILITY

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

While satellite observations have been a major success in monitoring many ECVs, long-term continuity of some satellite observations is not assured. While new satellites incorporate innovations and improvements, it is essential that consistent time-series are available across many missions. While making best efforts to ensure continuity and/or cross-referencing of key climate data sets, satellite agencies are encouraged to proceed with the exploration and demonstration of new technologies to observe the Earth system from space (e.g. Stephens et al., 2020[2]).

Future climate observing capabilities that are at risk are identified in the 2021 GCOS Status Report. This theme focuses on those in situ and satellite observations that are particularly at risk, while acknowledging that all observations of ECVs need to be sustained.

Action A2: Address gaps in satellite observations likely to occur in the near future	
Activities	**Urgent actions are needed to ensure continuity of the following satellite observations:** **1. Altimetry in the polar regions.** **2. Gravimetry missions.** **3. Biomass measurements.** **4. Limb-sounding missions capable of measuring several ECV species in the Upper Troposphere/Lower Stratosphere (UTLS) and stratosphere.** **5. Sea Surface Salinity (SSS) measurements.** **6. Wind lidar.** **7. Global scale ice surface elevation.**
Issue/Benefits	Monitoring of many ECVs which are critically important to climate science are now dependent on satellite observations. There is a real danger that some observations will stop in the next 5-10 years, or even sooner for missions that have already exceeded their expected lifetime. The continuity of these measurements is essential to develop and extend the long time series needed for climate monitoring.
Implementers	From 1 to 7: **Space agencies.**
Means of Assessing Progress	From 1 to 7: Established plans of Space agencies that ensure the continuation of satellite missions for altimetry, gravimetry, biomass, limb-sounding, sea surface salinity, wind lidar, global scale ice surface elevation.
Additional Details	These address some of the gaps identified in the GCOS Status Report. 1. Sea surface height has been measured with satellite altimeters since 1992 usually with a 2-satellite configuration as a baseline. Several missions are currently in operation or designed for the near future including Jason-3, Sentinel-3 SRAL, Sentinel-6 series and the Copernicus expansion missions (CRISTAL and SNG-topography). In order to address the potential future gap in polar satellite altimetry, alternative approaches should be explored, including the lifetime extension of CryoSat-e or ICESat-2; an alternative satellite manoeuvred

[1] In this document we refer to all non-satellite observations as "in situ" including ground-based and aircraft-based remote sensing.
[2] Stephens, G., et al., 2020: Revolution in Earth Observations. *Bulletin of the American Meteorological Society* 101, 3, E274-E285, doi.org/10.1175/BAMS-D-19-0146.1

	into a high-inclination orbit; the acceleration of CRISTAL and/or S3NG-T launches; or a systematic airborne measurement programme as a bridging capacity. Without successful mitigation, there will be a gap of between 2 and 5 years in our polar satellite altimetry capability. This would jeopardise long-term records of ice sheet and sea ice thickness change and polar oceanography. 2. Satellite gravimetry missions provide critical ECVs data, including for sea level, terrestrial water storage (TWS) and ice sheet monitoring. There is also potential for data from this source to supersede or complement the assessment of existing low (time and space) resolution anthropogenic water use and groundwater monitoring, or to serve early warning systems for large-scale flood events or drought monitoring and forecasts. Current and past measurements originate from Gravity Recovery and Climate Experiment (GRACE) during 2002-2017, GOCE (2009-2013) and the GRACE-FO (2018 – until now). Feasibility studies for next-generation gravity missions with potentially higher spatial and/or temporal resolution are underway at Space agencies, but the realisation of such missions for ensuring the long-term climate records is not assured. 3. Biomass: Space-based estimates of aboveground biomass and associated carbon stocks and changes are essential to monitor this ECV globally. Several dedicated satellite missions (such as NASA-GEDI/ICESAT/NISAR, ESA-BIOMASS, JAXA-MOLI) have been developed and are operating but none of them are part of a dedicated programme for regular, high-quality biomass monitoring in the long-term. Agencies and the EU Copernicus programme are encouraged to explore synergy and harmonise among available mission data and put in place a coordinated, continuous and consistent space-based biomass observation programme for global and national monitoring of aboveground biomass and associated carbon stock changes. 4. Only the Aura Microwave Limb Sounder (MLS) currently produces daily, near-global coverage for vertical profiles of water vapour from the upper troposphere through the stratosphere and into the mesosphere. In 2021, MLS had exceeded its “expected 5-year lifetime” by 11 years. Presently there is only one plan in progress to deploy another limb sounder (ESA’s Altius) with similar capabilities as the Aura MLS and continuity is far from assured. 5. Sea Surface Salinity measurements are available from satellites since 2010 from SMOS, during 2011-2015 from Aquarius, and since 2015 from SMAP. These measurements resolve scales not afforded by in situ networks (e.g., down to tens of km) and cover regions inadequately sampled by in situ measurements (e.g., coastal oceans, marginal seas, polar oceans). Follow-on missions are needed to ensure a continuous global SSS record. Copernicus expansion mission CIMR A/B scheduled to be launched in 2028 aims at continuing the satellite SSS record and, in particular, improve the sampling and accuracy of satellite SSS measurements for polar oceans. 6. The ESA Aeolus wind lidar mission demonstrates successfully that global wind fields can be obtained from lidar in space. Assimilation of the data into NWP systems shows a positive impact, and thus will have a positive impact on future reanalysis quality. It is expected that long-term measurements would provide accurate observations in large scale wind regimes associated with climate states. No follow-on mission is presently assured although plans are actively being considered by EUMETSAT/ESA. 7. The freely available optical stereo data, such as those from Terra ASTER, are coming to an end of its lifetime and there are no plans for a replacement, that would be urgently required for the continuation of the dataset on global ice surface elevation.

Links with other IP Actions	Satellite observations are related to many other actions. In particular: C5 (Activity 2): enhancement biomass estimation at global and subnational levels. F1 (Activity 2): higher-resolution biomass data. F2 (Activity 1): sea surface salinity in polar regions.

Action A3: Prepare follow-on plans for critical satellite missions	
Activities	**Develop follow-on plans to ensure medium and long-term continuity of the following satellite observations:** **1. Earth Radiation Budget (ERB) measurements.** **2. Cloud profiling.** **3. Cloud lidar.** **4. Global Precipitation Measurement (GPM) consisting of a dual-frequency precipitation radar and passive microwave measurements to provide sufficient temporal and spatial sampling of rain areas.** **5. Sea ice and icebergs (or floating ice).**
Issue/Benefits	Monitoring of many ECVs which are critically important to climate science are now dependent on satellite observations. The lack of confirmed plans for follow-on missions for some of these observations leaves the climate data records for some ECVs at risk. The continuity of these measurements is essential to develop and extend the long time series needed for climate monitoring.
Implementers	From 1 to 5: **Space agencies.**
Means of Assessing Progress	From 1 to 5: Established (long-term) plans of Space agencies demonstrating the continuation of satellite missions for earth radiation budget, cloud profiling radar, cloud lidar, GPM and floating ice.
Additional Details	These address some of the potential gaps identified in the GCOS Status Report. 1. Continuous Global Earth outgoing shortwave and longwave fluxes have been measured through CERES since March 2000. The latest CERES instrument was launched in 2017 on NOAA 20 and will be succeeded by the recently selected NASA instrument Libera, projected to be launched in 2027 on JPSS-3. The instrument specifics are such that seamless continuation of the ERB measurements is facilitated. Mission overlap of at least one year is anticipated but not guaranteed. Gap probability is estimated at 40% by 2028, provided that NOAA-20 remains operational. The ESA/JAXA EarthCare mission, expected to be launched in 2023, will fly a broad band radiation budget instrument. 2. The ESA/JAXA Earth Cloud Aerosol and Radiation Explorer (EarthCARE) satellite mission will advance our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back out to space and trapping infrared radiation emitted from Earth’s surface. Inter alia it will fly a cloud profiling radar (CPR, 94 GHz) which provides vertical profiles of cloud structure along the subsatellite track to obtain micro- and macroscopic properties of clouds. It continues the successful NASA CloudSat mission. NASA’s current plans for the Atmospheric Observation System (AOS). https://aos.gsfc.nasa.gov/spaceborne.htm) include employment of doppler radar and lidar measurements in polar and inclined orbits. 3. EarthCare will also fly an Atmospheric Lidar (ATLID). It measures the backscatter from aerosol and clouds and detects vertical profiles of radiatively significant clouds/aerosols. It continues the successful NASA/CNES CALIPSO

	mission. NASA's current plans for AOS include employment of Lidar measurements in polar and inclined orbits. 4. Various activities are on the way to improve precipitation observation capabilities. For example, the TROPICS mission will deploy six cubsats with passive microwave sensors in three orbital planes providing observations of tropical cyclones. Dual-frequency rain radars in space should be established as a core operational activity. However, the issue of lacking polar coverage should be addressed (e.g. through a concept of combining committed and existing missions). Current plans for NASA's AOS mission include a platform in polar orbit, combining Doppler Radar and microwave measurements (https://aos.gsfc.nasa.gov/spaceborne.htm). 5. Sea ice and icebergs can be detected, classified, and followed in their drift through satellite sensors (including microwave radiometers, altimeters and Synthetic Aperture Radar (SAR)). SAR sensors are the most valuable for these tasks because the monitoring of floating ice can be done in all weather conditions, despite the limitations of visible and infrared sensors. Current SAR missions are Sentinel-1, RADARSAT, SAOCOM-1, TerraSAR-X, COSMO-SkyMed, ALOS-2, among others. It is important to ensure that future SAR missions include in their objectives the acquisition of data for operational detection of floating ice which is also very important for safety of navigation as well as to monitor climate change.
Links with other IP Actions	Satellite observations are related to many other actions. In particular: B9: improve estimates of latent and sensible heat fluxes. B10: closure of energy budget. F2: improve ECV observations in Polar regions.

3. THEME B: FILLING DATA GAPS

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

Despite their successes, gaps do exist in satellite observations. For instance, the existing Global Space-based Intercalibration System (GSICS) needs to be complemented and upgraded by satellite missions with stable reference instruments in the infrared (and other) parts of the spectrum (e.g. the CLARREO and TRUTHS missions). Another, important aspect hampering geographical coverage (notably with geostationary satellites) is the fact that not all satellite agencies have made observations available to the ECV inventory. All satellite agencies should strive to reprocess their data and make them available as climate data records.
Reference quality observations respond to the need for monitoring the changes that are occurring in the climate system and ensure greater confidence in the assessment of future climate change and variability. They support also timely political decisions for adaptation and can help to monitor and quantify the effectiveness of internationally agreed mitigation steps.

Action B1: Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)	
Activities	1. Continue development of GRUAN. 2. Implement the GSRN. **3. Better align the satellite FRM program to the reference tier of tiered networks and enhance / expand FRM to fill gaps in satellite cal/val.**

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

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

Action B3: New Earth observing satellite missions to fill gaps in the observing systems	
Activities	**1. Improve diurnal sampling of observations and coverage of GHGs, precursor aerosols, and solar-induced fluorescence (SIF) to improve estimation of emissions and vegetation carbon uptake.** **2. Explore new ways to improve estimates of Earth's Energy Imbalance (EEI) with novel remote sensing techniques and with very well calibrated hyperspectral measurements over the full spectrum of the outgoing longwave and shortwave radiation.** **3. Provide direct measurements of ocean surface currents from space.** **4. Explore and demonstrate the feasibility of satellite missions based on new satellite technologies for climate monitoring.** **5. Develop operational techniques to estimate permafrost extent.**
Issue/Benefits	1. Improving the coverage and spatio-temporal resolution of GHG, precursor aerosols and SIF measurements can be facilitated by constellations of low-earth-orbiting (LEO) satellite with varying overpass times, or observations from geostationary (low and mid-latitudes) and highly elliptical (high latitudes) orbits. High temporal frequency measurements are required for better diurnal characterization of GHG lifecycles, carbon cycle components and improved emission estimation in synergy with expanded in situ systems. 2. Direct measurements of the EEI need to be improved to the extent possible. However, the EEI cannot currently be determined from space-borne broad-band radiometers with sufficient accuracy. Direct measurements indicative of EEI from space would allow us to quantify and track Earth's energy uptake responsible for global climate change. On the one hand, new approaches based on hyperspectral longwave and shortwave radiances could provide the insight sought to understand the temporal change of the EEI. On the other hand, novel techniques that measure radiation pressure accelerations in orbit are expected to exceed accuracy limitations of broadband radiometry, but are currently at the concept stage of development[3]. 3. Ocean surface currents play an important role in redistributing heat, salt, passive tracers, and ocean pollutants in the surface layer of the ocean. These currents have significant implications to climate, weather, sea state, marine biology, ecosystems, and biogeochemistry. Currently, space-based estimates of near-surface currents are produced by combining surface geostrophic currents derived from altimetry and Ekman Current derived from ocean-surface wind stress (e.g., from scatterometers). They are more representative of mixed-layer currents than surface currents. Moreover, the geostrophic and Ekman theories break down near the equator, preventing reliable estimates of the currents from altimetry and scatterometry measurements. Direct measurements of surface currents from space are thus needed. 4. It is important to take climate related requirements directly into account during the development and implementation of new satellite missions. Therefore, it is necessary to proceed with exploration and demonstration of new satellite missions to be compatible with climate monitoring needs (Stephens et al., 2020)[4]. 5. Knowledge of changes in permafrost extent are important to adapt infrastructure and minimize losses due to melting permafrost.
Implementers	From 1 to 5: **Space agencies.**

[3] M. Z. Hakuba et al., 2019: Earth's Energy Imbalance Measured From Space, in IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 1, pp. 32-45, doi: 10.1109/TGRS.2018.2851976

[4] Stephens, G., et al., 2020: Revolution in Earth Observations. Bulletin of the American Meteorological Society 101, 3, E274-E285, doi.org/10.1175/BAMS-D-19-0146.1

Means of Assessing Progress	From 1 to 3 and 5: Feasibility studies addressing mission concepts relevant to observation and mission gaps. Solicitations by Space agencies for satellite mission development relevant to the above points. 4. Number of publications on new potential satellite climate observations.
Additional details	1. GeoCarb, to be launched in 2024, will be the first GEO-satellite to measure GHGs and SIF, covering latitudes between 50S - 50N over the Americas. Complementary LEO (CO2M, OCO2, GOSAT-GW, TANSAT, as well as MicroCarb, to be launched in 2023) and HEO satellite missions would provide high spatio-temporal resolution across the globe including the poles to improve monitoring of GHG emissions, which feature substantial diurnal variations, and changes to them. 2. Explorative studies to infer EEI directly from radiation pressure accelerations or alternative remote sensing techniques, and indirectly, through assessment of well-calibrated hyperspectral shortwave and longwave radiances. 3. Technologies for direct measurements of ocean surface currents already exist (e.g., using Doppler Scatterometry, Synthetic Aperture Radar, or Along-track Synthetic Aperture Radar Interferometry). But no such satellite mission has been committed by Space agencies, although concepts are being studied by Space agencies. The technologies have also been demonstrated from airborne campaigns. These technologies provide surface current measurements with much finer spatial resolutions (down to sub-mesoscales) than those of near-surface currents estimated from altimetry plus scatterometry data. The emerging new technological capabilities of satellite missions should be pursued with a view to obtain climate quality data with well-characterised and well-calibrated instruments.
Links with other IP Actions	Satellite observations are related to many other actions. In particular: B10: Develop plans to address gaps in the climate system for the energy cycle. F2: Improve ECV satellite observations in polar regions. F5 (activity 2): Design a constellation of operational satellites to provide near-real time global coverage of CO_2 and CH_4 column observations.

Action B5: Implementing global hydrological networks	
Activities	1. Improve the collection of hydrological observations, in particular: a) Improve global reporting of river discharge (e.g. to Global Runoff Data Center – GRDC) and water level data (e.g. to WMO Hydrological Observing System - WHOS), from a selected set of stations; **b) Increase the number of in situ river level observations that are exchanged internationally and can be used to calibrate satellite observations of water levels;** c) Increase global exchange of in situ water level observations of lakes and reservoirs to the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE); d) Increase the number of in situ observations of soil moisture in the International Soil Moisture Network (ISMN), including below-ground measurements. 2. Include in situ observations of Groundwater Level from national authorities (or other sources) that are minimally impacted by human influence into the Global Groundwater Monitoring Network (GGMN) to establish a global system.

	3. Report anthropogenic water use to Food and Agriculture Organization of United Nations (FAO) AQUASTAT in areas where data are missing.
Issue/Benefits	Hydrological observations contribute to model and satellite calibration and validation, climate studies, regional and local water resources assessments, improvement of prediction tools, impact assessments, freshwater inputs into the ocean and regional and local water resources studies. Currently there are no effective global networks for river discharge or groundwater. Many river discharge data have not been exchanged internationally for decades. Databases of groundwater, soil moisture, terrestrial evaporation, lake levels–and anthropogenic water use are incomplete. In some cases, this is due to restrictive data policies and political considerations, in others it may reflect observational problems. Although global data centres exist for most water-related ECVs, data exchange from the individual data providers to the data centres is often limited. To rectify this situation, this action aims to: • Establish a network of a limited set of river discharge measurement sites that are most important for international use, and that exchange data. • Support the use of satellite observations of river level to supplement in situ observations. This requires measurements of river levels at points useful for calibration and validation of satellite observations as well as being useful locally. • Establish a network that emphasizes below-ground measured soil moisture. This is a gap that consistently comes up for many applications and cannot be derived by remote sensing. Provide easy, open access to the network data to benefit all countries. A discovery service and the interoperability of hydrological observations should be introduced. So far, information on existing data is only available in a distributed form in the global data centres. This makes access difficult. • Identify where additional resources and support are needed for river discharge and groundwater observations to support future development of GBON and SOFF. The implementation of the three new WMO initiatives (i.e. the Unified Data Policy, the Global Basic Observing Network, and the Systematic Observations Financing Facility) should assist these activities. Anthropogenic water use data is collected in the AQUASTAT database managed by FAO. Despite recent improvements, the AQUASTAT database which is based on national reporting, has gaps, is not up to date and the spatial and temporal resolutions are too low. The satellite-based Total Water Storage ECV gives timely and complete regional coverage but does require the continuation of satellite gravity observations and will not replace the spatial resolution of AQUASTAT.
Implementers	From 1 to 3: **WMO (WHOS), NMHS, Space agencies, Global Data centres (GTN-H).**
Means of Assessing Progress	1. a) Identification of a set of river discharge stations to exchange data; b) Increased availability of calibrated satellite estimates of water levels in rivers; c) Increased reporting of river discharge and level data to GRDC using unrestrictive data policies; d) Improved reporting of groundwater data to the International Groundwater Resources Assessment Centre (IGRAC) using unrestricted data policies. 2. Identification a set of groundwater stations that are minimally impacted by human influence for reporting to IGRAC. 3. Increased number of countries reporting to AQUASTAT and improve resolution: More countries reporting and increased resolution.

Additional Details	Many activities, developed in cooperation with GTN-H, provide hydrological products, including the groundwater level data collected at IGRAC, the river discharge at GRDC, the lake levels at HYDROLARE, the soil moisture data at ISMN, and the anthropogenic water use at AQUASTAT. However, large data gaps still exist and there is an insufficient exchange and delivery of the collected hydrological data to data centres. In line with WMO Resolution 1 (Cg-Ext(2021), these activities are all aimed at improving the global exchange of hydrological data and delivery to data centres of networks encompassed by GTN-H, in particular the GCOS baseline networks, and to facilitate the development of integrated hydrological products to demonstrate the value of these coordinated and sustained global hydrological networks. 1. To encourage more countries to freely provide quality-controlled river discharge data, there should be clear criteria for reporting only the selected data that are most important for the regional and global assessment of the water cycle. Data from selected hydrological gauging stations meeting the following criteria should be exchanged: • The most downstream stations on major rivers not impacted by tidal influences to better capture freshwater fluxes to oceans; • Hydrological monitoring stations representative of regional hydrology; • Minimally impacted stations suitable as reference or baseline stations for climate studies; • These selected sites will form a new global network exchanging and reporting data for use in global and regional assessments; • Potentially, satellite data of river levels can be used as a surrogate to fill in gaps in coverage. In situ data are needed to calibrate and validate satellite observations so they become an important source of water levels and ultimately discharge data e.g. the SWOT mission and follow-ups. 2. Despite the existence of a data centre (at IGRAC) there is no global reporting of data. To provide the information needed at a global level, data from selected groundwater monitoring stations that are minimally impacted by human influence should be collected and exchanged. While this new network of groundwater monitoring stations is a subset of all monitoring stations it defines the information that is needed for global assessments. 3. The collection of data for AQUASTAT needs to be improved to increase both coverage and temporal resolution with countries encouraged to improve reporting and greater understanding of the benefits of the global dataset.
Links with other IP Actions	B2: The development of GBON will contribute to implement Action B5. B10: Closure of water cycle.

Action B6: Expand and build a fully integrated global ocean observing system	
Activities	**Increase the measurements of ocean ECVs into the deep ocean, under the ice and marginal seas by improving:** **1. The Core Argo (ensuring that the target density is met), biogeochemical (BGC) and Deep Argo to achieve the OneArgo design.** **2. The ship-based hydrography, fixed-point observations, autonomous and uncrewed observations.** **3. The integration of observing networks to respond adequately to ECVs requirements.**
Issue/Benefits	There are critical sampling gaps that limit the monitoring of the ocean state (for example, heat storage, carbon cycle and impacts on the biosphere). The

	transformation of the current Argo array to the integrated "OneArgo" array, the deployment of repeated hydrography, the deployment of fixed-point and other autonomous observing platforms and their integration aims at addressing these gaps by providing observations of surface and subsurface ocean properties, physical, biogeochemical, and optical properties aiming to collect ocean ECVs with an improved and very much needed global coverage. The extended in situ network will be key in closing budgets for climate cycles assessments, monitoring the state of the ocean, evaluating climate risks and impacts and guiding adaptation policies. It will be essential for calibration and validation of satellite measurements. An enhanced coverage for the ocean in situ surface and subsurface ECVs is also key for improving seamless forecasts as well as contributing to meeting the goals of the Paris Agreement.
Implementers	From 1 to 3: **GOOS**, Research Agencies, Academia, National agencies (oceanographic Institutes), Space agencies, NMHS (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	1. Number of core floats deployed to maintain the target density in the global ocean including marginal seas and polar regions; and number of Deep and BGC Argo floats operating after 5 years. 2. Increase of coverage in the global ocean of ship-based hydrography and fixed-point observations, including polar areas and marginal seas after 5 years. 3. Availability of integrated products.
Additional Details	In 2020, the Argo Steering Team endorsed a new Argo array design (called "OneArgo") that is truly global (including marginal seas and under ice), full depth, and multi-disciplinary, including Core, Deep, and biogeochemical BGC Argo floats. The estimated budget of OneArgo represents a three-fold increase in cost. OneArgo will include a novel data management system with real-time data freely shared through the GTS/WIS and high-quality datasets delivered within 12 months, supporting climate-relevant assessments, inventories, and metrics. Since 2021, OneArgo is a project endorsed by the UN Ocean Decade. Ship-based hydrography and fixed-point observations, autonomous and uncrewed are essential and complementary to Argo and further efforts must be undertaken to realise the vision of a fully integrated Ocean Observing System[5]. Some of the key programs and networks contributing to this Action are GO-SHIP, OceanSITES, Ocean Color satellites, Deep Argo, Biogeochemical Argo and Global Alliance of Continuous Plankton Recorder Surveys (GACS) (see OceanOPS Report Card[6] for more details).
Links with other IP Actions	B7 and B8: Improve components of the global ocean observing system. B9: Improve estimates of latent and sensible heat fluxes and wind stress. F3: Expand global ocean climate in situ observations into EEZ and coastal zones.

Action B9: Improve estimates of latent and sensible heat fluxes and wind stress	
Activities	This action focuses on ice-free oceans and the terrestrial land surface 1. Improve and extend in situ measurements needed to estimate surface fluxes, with the objectives of improving accuracy and better defining the uncertainties of those measurements and calculated fluxes.

[5] Révelard et al., 2022: Ocean Integration: The Needs and Challenges of Effective Coordination Within the Ocean Observing System. *Frontiers in Marine Science.* https://doi.org/10.3389/fmars.2021.737671

[6] OceanOPS Report Card 2021 (ocean-ops.org)

	2. Extend sites with co-located measurements of direct turbulent and radiative fluxes and variables required to estimate turbulent surface fluxes targeted at improving parameterisations of air-sea exchange and air-land exchange. 3. Develop new approaches over land, focusing on improved estimation of transpiration, interception and soil evaporation separately. **4. Develop new approaches and improved methods to better exploit relevant ECV measurements to estimate ocean surface heat, moisture and momentum flux including:** **a) Better integration of in situ and satellite measurements, data assimilation, fusion techniques, ensuring consistency between different types of measurements and their harmonisation;** **b) Development and deployment of new satellite missions that are tuned to maximise the sensitivity to the state variables needed to estimate heat flux over the ocean and land;** **c) Increase and improvements in satellite observations that target both the surface parameters and the near-surface air-parameters;** **d) Simultaneously use of an approach based on high resolution numerical models (Large Eddy Simulation (LES)) to augment satellite product validations;** **e) Include in future intercomparison campaigns of latent and sensible heat fluxes measurements inferred from simultaneous observations with a water vapour differential absorption lidar (WVDIAL), a Doppler wind lidar and temperature from rotational Raman lidar.**
Issue/Benefits	Understanding and estimating surface fluxes is essential for improving projections of climate change and planning adaptation and response measures. The need for surface, near surface, and boundary layer information, across different temporal and spatial scales for multiple disciplines, has outstripped the capabilities of existing observing networks. Direct observation of surface turbulent (sensible, latent and momentum) fluxes is difficult and costly and globally impractical. For global coverage it is therefore necessary to estimate the surface heat and momentum fluxes using empirical parameterisations based on other ECVs (including surface temperature, near surface air temperature and humidity, near surface wind speed and direction). To improve the parameterizations, and quantify uncertainty, high quality in situ measurements of both direct fluxes and collocated ECVs used to calculate the fluxes are needed at key representative locations. Improvement of estimates of ocean surface heat, moisture and momentum flux requires integrating in situ and satellite observations, use of data assimilation and fusion techniques. New and improved methods need to be developed to better achieve this integration.
Implementers	From 1 to 2: **NMHS,** GOOS, Research organizations. 3. **Academia,** Research organizations, NMHS. 4. **Space agencies**, NMHS, Academia.
Means of Assessing Progress	1. a) A catalogue of the in situ observations providing good quality observations of ECVs relevant for surface fluxes; b) Number of observations in 1(a) (above) available in data centres; c) Demonstration reference stations for ECVs needed to calculate surface heat, moisture and momentum fluxes;

	d) A plan for the establishment/maintenance/extension of a global network of reference stations for ECVs needed to calculate surface heat, moisture and momentum fluxes. 2. a) Increased availability of co-located direct flux measurements and flux-relevant ECVs in data centres; b) Published paper(s) demonstrating the reduction in the uncertainty in empirical parameterizations used to calculate turbulent fluxes. 3. Published paper(s) on new approaches for separate estimation of transpiration, interception and soil evaporation. 4. a) Reduced uncertainty in both air-sea and land-atmosphere flux products; b) Scoping and development of satellite missions to better optimise measurements in the Planetary Boundary Layer.
Additional Details	1. To improve the understanding of partitioning of energy fluxes between the surface and lower atmosphere over all surfaces and the understanding of uncertainty, it is necessary to improve and extend in situ measurements of variables needed to calculate surface fluxes. This requires a tiered approach including: (i) a network of multi-variate high quality reference stations covering representative climates; (ii) a network of stations or mobile marine platforms to provide good quality globally-representative coverage and enable comparison with reference stations; (iii) widespread regional and global measurements only some of which will meet specified quality standards but will extend coverage and provide information on variability. 2. Uncertainty in empirical parameterizations used to provide estimates of surface heat and momentum fluxes with global coverage from more easily-measured ECVs remains significant. Improved parameterisations, and improved quantification of uncertainty in those parameterizations requires co-located measurements of direct turbulent fluxes and variables required to calculate turbulent surface fluxes along with direct measurements of shortwave and longwave radiation to provide net heat fluxes. Given the advanced capabilities to infer the shortwave net radiative fluxes at the surface (from satellites) and the longwave net radiative fluxes (from satellite and ancillary data), the use of empirical formulae for the radiative fluxes should be abandoned. 3. Develop novel algorithms able to partition terrestrial evaporation into its various components (transpiration, soil evaporation, interception) with a stronger reliance on observational data and lower dependency on model assumptions. 4. Satellite measurements provide global, but indirect measurements of the surface and atmospheric state variables required to compute heat flux, while in situ measurements provide a local direct measure. The best flux estimates will be achieved by optimally combining these complementary global and local measurements constrained by physical models using data assimilation, that include both in situ and remote sensing data, and fusion techniques. New assimilation algorithms to cope with observations at higher spatiotemporal resolution need to be developed. It is necessary to develop new satellite missions or constellations of satellites optimised, to the extent physically achievable, for the derivation of accurate estimates of air-sea heat, moisture and momentum flux, such as the Butterfly mission concept[7]. Spatio-temporal mismatches in sampling of ECVs required for flux estimation should be minimised to reduce errors in the heat flux estimation resulting from the

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

	combination of observations sampled at different times, or with different spatial footprints. Further advances in the field of global terrestrial evaporation monitoring should include developments in microwave remote sensing and high-resolution optical platforms (Fisher et al., 2017)[8]. Moreover, the potential of novel thermal missions such as ECOSTRESS (Fisher et al., 2020)[9] and TRISHNA (Lagouarde et al., 2018)[10] is yet to be exploited. The use of simultaneous Lidar's measurements to infer latent and sensible heat fluxes is exemplified and demonstrated by Behrendt et al., (2019), https://amt.copernicus.org/preprints/amt-2019-305/amt-2019-305.pdf. There are high resolution models that are capable of resolving turbulence, which could help to resolve horizontally the fluctuations that are not being resolved with current satellite technology. The following approach can be used to augment satellite product validations using numerical modelling with high-resolution models (LES): • Have only few well-equipped validation sites for the products; • Compute fluxes with the models and validate models with measurements; • Use models to 'check' satellite products elsewhere.
Links with other IP Actions	This action links to other actions: B1: Reference networks are needed to improve flux estimates. B10: Closure of energy cycles will benefit from a better understanding of heat fluxes. C2 and C3: Improvements to data processing methods will benefit this action. D3 (Activity 3). Access to field campaign data useful for testing of parameterization. D4: Easy access to co-located satellite and reference quality in situ observations.

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

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

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

Action C1: Develop monitoring standards, guidance and best practices for each ECV	
Activities	**1. Review existing monitoring standards, guidance and best practices for each ECV, ensuring these reflect current state-of-the-art. Maintain a repository of this guidance for ECVs.** **2. Ensure the development of monitoring standards, guidance and best practices, including intercomparison procedures, for those ECVs where such guidance does not exist.** **3. Review and revise the climate monitoring guidance in the WIGOS manual to bring it in line with the updated guidance developed in this Action.** **4. Review the GCOS climate monitoring principles.**
Issue/Benefits	Many ECVs have standards, guidance and best practices that, when followed, ensure consistency between the observations which is necessary to ensure that the global datasets meet user requirements. However, monitoring standards for some ECVs are missing and need to be established, and for others they are either substantively dated or not fit-for-purpose. Improvements in observations and their consistency across countries and regions would lead to more accurate observations, predictions/projections, and warnings and would thus improve adaptation planning.
Implementers	From 1 to 4: **GCOS,** GOOS, WMO, Copernicus, Space agencies.
Means of Assessing Progress	1. Unified repository of standards, guidance, and best practices for all observations of atmospheric, oceanic and terrestrial ECVs by time of next status report. 2. New monitoring standards, guidance, and best practices for ECVs where this is identified as absent or requiring updates. 3. WMO adopts revisions to WIGOS regulatory materials to ensure they meet climate needs as articulated in the unified repository. 4. Review and undertake revisions to GCOS Monitoring Principles to align with outcomes of activities 1-3 by time of next status report.
Additional Details	For 1 and 2: Guidance for collecting observations of ECVs is incomplete, particularly in the terrestrial domain. Therefore, the first step is to identify gaps in the guidance, or where guidance is outdated, and provide up-to-date guidance that covers siting, observations, data collection, processing, and QA/QC. Any new guidance should be based on existing guidance where this exists and is appropriate: Where possible, this can include ballpark costs and manpower requirements for implementation, operation and maintenance of ECV observations. The WIGOS manual guides NMHS in making observations. However, the current guidance on climate observations is inadequate and unclear. It should therefore be revised to be consistent with ECV requirements. 3. The GCOS Climate monitoring principles were adopted in the 1990s. They need to be reviewed and updated as appropriate in light of new methods, insights and best practices.
Links with other IP Actions	Best practices, guidance and standards are relevant for most of the Actions in themes A, B, C, D and F.

Action C2: General improvements to satellite data processing methods	
Activities	**1. Improve radiance measurement records and Radiative Transfer (RT) models for simulating them.** **2. Improve uncertainty quantification of satellite retrievals.** **3. Periodically reprocess full satellite data records whenever an update of underlying methods occurs, especially when those risks introducing discontinuities into the time series.** **4. Consolidate satellite observations into instrument-independent space-time grids for easy intercomparisons and fusion.** **5. Ensure harmonisation and quality of ancillary data used to generate satellite products such as solar irradiance and meteorological data.**
Issue/Benefits	Many data products depend on extended processing streams from observations to data products. Improving data processing methods facilitates ease of use, regular reprocessing and robust uncertainty quantification of available observations. This action identifies key areas for improvements. Ensuring the availability of relevant, high-quality estimates with long-term continuity across multiple instruments and satellites results in better quality of the satellite climate data records.
Implementers	From 1 to 5: **Space agencies,** Academia, Research organizations.
Means of Assessing Progress	For 1 and 2: New publications showing improvements in radiative transfer and uncertainty characterisation. 3. Increased number of available reprocessed Fundamental Climate Data Records (FCDRs). 4. Increased number of available consolidated gridded satellite datasets. 5. Products with consistent traceability to ancillary data and associated quality assessment.
Additional Details	1. Radiance measurement records need to be carefully assessed, characterised, and calibrated. Radiative Transfer (RT) schemes for simulating them also need to be improved, as this is a key component of processing radiance measurements and quality evaluation/assessment. Line-by-line radiative transfer models are critical and need to be available as reference for faster RT schemes. 2. Improve uncertainty quantification of satellite retrievals on all processing levels. Specifically (i) consider more carefully non-linearities and non-Gaussian uncertainties in the retrievals and (ii) consider and report spatially correlated uncertainties. Presently these are not properly considered in the satellite retrievals. Proper characterization of the uncertainties is key when data are further used e.g., in assimilation (e.g., in inverse modelling for emission estimation). 3. The quality of retrieved quantities also depends critically on the methods, ancillary, and auxiliary data used in the retrieval algorithm. As all these dependencies improve or ECV requirements changes, the satellite observations can (and should) regularly be reprocessed to ensure that the satellite data record is as useful as it can be (i.e., information content is fully exploited). 4. The typical lifetime of individual satellite instruments is shorter than the time scale required for climate applications. Therefore, satellite observations need to be consolidated across multiple instruments and satellites into high-quality estimates with long-term continuity in order to maximise their value for the climate community. This consolidation must be done in an optimal and

	standardised way, ensuring consistency across multiple instruments and satellites.
Links with other IP Actions	The following Actions are relevant to improve satellite data processing methods: B1: Reference observations (Uncertainty characterizations and improved uncertainty quantification of satellite retrievals). D4: Access to co-located data.

Action C4: New and improved reanalysis products	
Activities	**1. Implement new production streams using improved data assimilation systems and better collections of observations, particularly aiming at:** **a) Further increasing resolution;** **b) Improving handling of systematic observational and model biases;** **c) Providing (improved) estimates for the uncertainty in the mean state;** **d) Improving quality control in data sparse areas.** **2. Develop coupled reanalysis (ocean, land, sea-ice).** **3. Improve the capability of sparse-input reanalysis that covers the entire 20th century and beyond.** **4. Develop and implement regional reanalysis and other approaches to regionalisation.** **5. Reduce data latency.**
Issue/Benefits	Reanalysis systems that employ data assimilation techniques are highly effective at combining disparate observations with physical principles to represent complex Earth systems, although there is a need for further improvement for reanalysis. Reducing the uncertainty in the estimation of trends and in the description of low-frequency variability from reanalyses leads to better understanding of climate change from these products compared to precursor generations. Improved representation of Earth system components and consistency among them is still, however, needed. Increasing their spatial resolution and reducing the latency will increase the range of potential applications of reanalyses.
Implementers	From 1 to 5: **Reanalysis centres**, Academia, Space agencies.
Means of Assessing Progress	1. Publications describing new reanalysis production streams and their validation with improved estimation of uncertainty of reanalysis data products. 2. Demonstrated benefits of coupled reanalysis. 3. New versions of sparse-input reanalysis products. 4. Number of in-depth performance assessments of regional reanalyses and other regionalised datasets. 5. Reduced latency of data product updates.
Additional Details	1. Reanalysis centres should regularly upgrade their products by introducing improved data assimilation techniques and better collections of observations (including reprocessed and data rescued data). Use of ensemble approaches will help to provide users with information on the uncertainty of products. Increased computational capacity will enable production at a higher spatial resolution and greater complexity (e.g., coupled systems, interactive chemistry). Use of homogenised, recalibrated or reprocessed observations is important in order to mitigate the impact of disruptions in instrument technology or processing algorithms. Use of advanced methods for dealing with data discontinuities will help improve the reliability of historical reanalyses. 2. A coupled data assimilation technique has a potential advantage over separate data assimilation in terms of consistency across the Earth system components. A

	proven benefit so far is that it can improve the SST field in a sparse observing system setting such as in the mid-20th century and earlier, but clear benefits in the current dense observing system setting have yet to be demonstrated. 3. Another type of reanalysis is a sparse-input reanalysis that only assimilates surface observations and covers a significant portion of the instrumental record, extending back into the 19th century. For this type of reanalysis, further improvement can be expected through data rescue for early instrumental meteorological observations and refinement of data assimilation systems. 4. There is a growing demand for datasets with higher resolution and accuracy, particularly for surface variables, for local and regional applications such as adaptation and monitoring of climate extremes. This demand should be met through regional reanalysis and other approaches for regionalising global data products. 5. Reduced latency of reanalysis data products should be aimed for, since it increases reanalyses' potential for applications. It also helps to reduce latency of other climate products that rely on reanalysis as input data, e.g. satellite retrievals.
Links with other IP Actions	B2: Implementing GBON will be of benefit for this action. C2: Improving reprocessing of satellite data. F1: Higher resolution observations.

Action C5: ECV-specific satellite data processing method improvements	
Activities	**1. Generate timely permafrost, land cover change, burnt area, and fire severity/burning efficiency products from high resolution data satellite observations (e.g. Sentinel1/-2 and Landsat).** **2. Produce harmonised and validated Above Ground Biomass (AGB) and change datasets from different satellite data streams, for enhancing aboveground biomass estimation at global and (sub-national) levels.** **3. Ensure that the Bidirectional Reflectance Distribution Function (BRDF) parameters are provided together with surface albedo.** **4. Reprocess the LEO NASA 25+ year Lightning Imaging Sensor (LIS) data set from the Optical Transient Detector (OTD, 1995-2000), LIS on the Tropical Rainfall Measuring Mission (TRMM-LIS, 1997-2015) and International Space Station (ISS-LIS, 2017-Present).** **5. Reprocess the GEO Geostationary Lightning Mapper (GLM) on GOES-16/17/18 (2017-Present).** **6. Improve consistency of the inter-dependent land products.**
Issue/Benefits	Many data products depend on extended processing streams from observations to data products. This action identifies key areas for improvements. 1. Generate improved permafrost, land cover and burnt area products that can be used for adaptation and mitigation. Rapid updating and delivery of data is important to serve such applications. Consistency between existing/historical and new products should be considered, and existing products might be updated based on new methods where possible. 2. Reduced uncertainty levels of datasets/approaches of AGB monitoring and less confusion among users (in particular countries) about which datasets and biomass estimates to use and integrate in their reporting. 3. Allow the complete understanding of surface albedo uncertainties budget. 4. Reprocess the data to remove known artefacts and provide continuity between similar instruments in different orbits.

	5. Reprocess the data to remove known artefacts and allow for new and improved products using ML/AI (e.g., megaflashes, flash type, continuing current). An Enterprise science algorithm is planned that would be applied to all space-based instruments similar to GLM (e.g., forthcoming MTG-Lightning Imager). 6. Currently some satellite-based products are developed separately with different data sets and processing streams despite several ECVs being closely inter-related (e.g. surface albedo, Fire, FAPAR and LAI). Consistency between these products needs to be ensured so that data from multiple sources can be used together. This will improve the interoperability and the stability of long-term satellite data and has an impact in the reanalysis when they are assimilated together.
Implementers	From 1 to 6: **Space agencies**, Reanalysis centres.
Means of Assessing Progress	1. Improved and validated permafrost, land cover and change products and updated, and higher resolution, burnt area and fire severity products. 2. Global harmonised biomass and change datasets, with validated estimates at sub-national levels. 3. Provision of the isotropic BRDF spectral parameters used in surface albedo retrieval at the same spatial and temporal scale of the products and the uncertainties error budget associated to the surface albedo products. 4. Validated and updated 0.1 x 0.1 deg product for satellites and ground-based lightning RF data sets (GLD360, WWLLN); and ThunderHour grids (derived from the satellite lightning detection) for GLD360, ENGLN, WWLLN, GLM. 5. Validated and updated space and RF ground-based lightning data at 0.1 x 0.1 deg grids. 6. Maps of all biospheric ECVs using a common geographic definition, at the same temporal/spatial scale as climate models with plant functional types.
Additional Details	For 1 and 2: Monitoring programs (i.e. from Copernicus, NASA, ESA etc.), respective expert communities and reference networks should focus on generating timely, high-resolution and validated land cover change, permafrost, burnt area, and fire severity/burning efficiency products from medium resolution data satellite observations (e.g. Sentinel1/-2 and Landsat). These products should be developed in close partnership with user communities in climate change mitigation and adaptation; incl. for national GHG inventories, estimating activity data and to support global Agriculture, Forestry and Other Land Use (AFOLU) modelling and assessments. Although global in scope, these products with increasing detail and quality should be suitable for national and local uptake. 2. Monitoring aboveground biomass has been a priority for several new and upcoming space agency missions, including GEDI, ICESat-2, BIOMASS, ALOS-4 and NISAR. The availability of multiple satellite products confuses policy users (such as country experts) and a lack of consistent and transparent product inter-comparison and validation jeopardises the successful uptake of any biomass product by the policy community. This is a pressing issue as the world prepares for the UNFCCC's first 'Global Stocktake' which will take place in 2023 with planned repeat every five years (2023, 2028, 2032 and onwards). Building upon new satellite missions and increasing reference databases (i.e. GEOTREES, country National Forest Inventories (NFIs), a single recommended biomass estimation product is encouraged rather than several products that may not agree and may lead to confusion and reduced uptake. This requires a partnership among different CEOS agencies and their related experts to jointly work on providing such estimates in coordinated manner towards the UNFCCC

	global stocktake and for the integration of space-based biomass data in national monitoring and reporting (GFOI). 3. The provision of surface albedo products shall be provided their respective bidirectional reflectance distribution function (BRDF) parameters as they are part of the ECV definition. They allow a better assessment of uncertainty budget. For 4 and 5: Space-based and very low frequency ground-based lightning network data are complementary in the information they provide (flash energy, size, duration, extent). Regional ground-based lightning networks would be a useful addition as they also provide more definitive information on flash type to compare or add to the Lightning ECV database. Although most lightning occurs in the continental tropics and mid-latitudes, recent observations are indicating an increase in lightning at high latitudes associated with a warming arctic. Monthly, daily and even hourly data are available. There is some evidence that this quantity has also been increasing at high latitudes. Lightning has long been associated with severe and high impact mesoscale weather phenomena, precipitation, NOx, aerosols, tropospheric temperature and moisture. Lightning-initiated wildfires and the threat to public safety are increasing concerns.
Links with other IP Actions	B10: this action will benefit addressing gaps for the carbon cycle.

5. THEME D: MANAGING DATA

To address and understand climate change, the longest possible time series need to be preserved in perpetuity. Every ECV needs to have a recognized global data repository and where there is one, it should be complete, adequately supported and funded. Satellite agencies maintain and update the ECV inventory and use it to conduct regular gap analysis. The ECV inventory lists available satellite-based climate data records and details of their access[11].

Data should be stored in well-curated, open and freely available, sustainable archives with clear guidance for data centres and users. Clearly defined principles such as the TRUST Principles (Lin et al., 2020)[12] and FAIR Principles (Wilkinson et al., 2016[13]) are needed.

Data rescue from hard copy or archaic digital formats allows data series to be extended in the past and needs to be adequately planned and funded with the results openly and freely available. This may include old satellite data if discovered (Poli et a., 2017[14]). Sustained support to these activities is required. This theme aims at organising more efficiently data rescue, data sharing, data curation and data provision.

Action D4: Create a facility to access co-located in situ cal/val observations and satellite data for quality assurance of satellite products	
Activities	**1. Improve access to co-located satellite and reference quality in situ observations, as well as tools for evaluation purposes. This facility**

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

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

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

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

	will use data from reference networks and FRM programs for a broad range of ECVs for calibration/validation of satellite programs. **2. Develop tools to use the co-located data collection developed under Activity 1 to undertake various analyses of satellite-based measurements.**
Issue/Benefits	The uncertainty for satellite measurements of ECVs are determined and/or verified through intercomparison against in situ measurements. These intercomparison field experiments also provide test bed opportunities for assessing measurement capabilities of new technologies, for testing and developing best practices, and to assess uncertainties in Numerical Weather Prediction and Climate Models. The current limited availability of co-located in situ and satellite data for calibration and validation data restricts the ability of users to assess the quality of satellite products. This action will improve the ability to exploit high quality reference measurement sites/networks including, but not limited to, FRM programs (see Action B1) to provide such calibration and validation data for a broad range of satellite products. What is required is a database of reference measurements and co-located satellite measurements to enable cal/val activities along with provision of a suite of tools. The provision of a centralised facility would minimise overall cost while maximising overall exploitation potential and is therefore preferable to such efforts at the satellite mission-level. It also enables applications which may wish to consider multiple ECVs from multiple satellites and their data fusion. A centralised well-supported facility would enable the long-term satellite cal/val capability necessary to extract the value from considerable investments in satellites and reference networks including FRM programs on a sustained basis.
Implementers	From 1 to 2**: Space agencies**, WMO, NMHS, Research organizations.
Means of Assessing Progress	1. Establishment of a unified database of and access to co-located, reference quality, ground-based measurements suitable for satellite cal/val. 2. Increased number of available compatible satellite and in situ datasets.
Additional Details	This activity addresses the need to improve the exploitation of the high-quality data needed to calibrate and validate satellite observations by making these data easily available: access is currently a major barrier to their use. A more coordinated, centralised approach to the storage and provision of data for satellite cal/val, with greater involvement of and partnership with reference networks (Action B1), along with the development of associated tools would yield cost efficiencies as well as scientific benefits. Users could come to centralised repositories which serve data for multiple satellite missions, enabling their usage in a more seamless manner. Tools could be shared between similar missions and made available to users. The centralised repository would serve to highlight the presence of critical gaps in provision of high-quality in situ data to inform the quality of ECVs measured from space. This, in turn, would help inform the strategic further investment in new reference networks and FRM programs to fill these gaps. Further details are given in Sterckx et al. (2020)[15].
Links with other IP Actions	This activity has strong links to other actions:

[15] Sterckx, S., et al., 2020: Towards a European Cal/Val service for earth observation, *International Journal of Remote Sensing*, 41:12, 4496-4511, doi: 10.1080/01431161.2020.1718240

	A1: Sustained support for the source in—situ observations that underpin this action. B1: Provision of reference quality in situ measurements including from FRM; and several other actions that underpin the in situ observations (B4, B6, B7, C4, F4).

6. THEME F: OTHER EMERGING NEEDS

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

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

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

Action F1: Responding to user needs for higher resolution, near real time data	
Activities	1. Identify the higher resolution observations of ECVs to support the Climatic Impact-Drivers (CIDs) identified in the IPCC AR6 and develop plans to address the priority needs. (see IPCC WGI AR6 Figure SPM.9). **2. Improve biomass, land cover, land surface temperature, and fire data with sub-annual observations and improved local detail and quality.** 3. Increase temporal resolution of surface air temperature, soil moisture and precipitation to capture both climate and human-induced changes and extremes. 4. Include daily averages with the monthly CLIMAT reports for land surface stations (GSN/RBON).
Issue/Benefits	High-resolution and near-real time information of ECV-based climate information at global, regional and local scales allows planning to consider the full range of possible impacts. High-resolution data (in space and time), which, for many ECVs are currently not available, will allow rapid monitoring of changes in the climate system. This will allow the tracking of sustainable mitigation and adaptation measures. Improved high-resolution and near-real-time ECV data will allow improved understanding of CIDs. Whilst monthly CLIMAT reports have been available for many decades, the option to include daily averages has not been implemented operationally across the GSN/RBCN networks although it was approved by WMO in 2015. Daily averages would allow users to monitor the Regional/National impact of climate change, including an assessment of extremes.
Implementers	1. **GCOS,** Research organizations, Academia, WMO. 2. **Space agencies.** 3. **NMHS,** WMO. 4. **WMO**, NMHS.

Means of Assessing Progress	1. Inventory of improvements to ECVs needed to inform CIDs (e.g. spatial and temporal resolution, latency, uncertainty and data stewardship) and plans for priority actions. 2. a) Availability of key terrestrial ECVs at resolutions of 10-30 m stored in long term archives; b) Availability of Near Real Time (NRT) sub-annual data for critical land changes and to identify extremes stored in long term archives. 3. Availability of temperature, precipitation and soil moisture at higher temporal resolution stored in long term archives. 4. Increased availability of CLIMAT reports with daily averages.
Additional Details	1. CIDs are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems and are thus a priority for climate information provision. Sustainable adaptation and mitigation planning and management need high-resolution data and in near real time to monitor critical changes in CIDs as they occur and so allow adaptation responses to be implemented. This includes the need for systematic data for land changes (land cover/use, fire, biomass), hydrological conditions (runoff, soil moisture), cryosphere data (e.g. sea ice, ice sheets, permafrost, snow, glaciers), atmospheric data (e.g. temperature and precipitation and related extremes such as droughts, floods, heavy storms and cyclones, heat waves etc.), and oceanic data (e.g. marine extremes, ocean warming, ocean acidification, and oxygen depletion) to be available in timely and easy-accessible manner. Often, consistency across spatial and temporal scales is needed, as well as consistency among multi-variable sources. Existing data streams for ECVs informing CIDs need to evolve to increase regional (e.g. national) and local detail and quality and aim for much faster data delivery than available today. The various data streams should be provided in integrated, consistent ways so the various user and expert communities can use and combine them for their purposes. GCOS should make sure that the ECV requirements are updated accordingly. 2. and 3. The GCOS expert panels have already identified some specific high-resolution, near real time datasets that have been requested by users and that the existing monitoring systems are able to support within the next 5 years. 3. When implemented GBON will deliver higher resolution spatial and temporal data record for most land surface stations and some marine platforms. Where stations report on an hourly basis it will be possible to construct both monthly and daily CLIMAT reports for those stations which do not compute/report the CLIMAT operationally.
Links with other IP Actions	B2: GBON. C4: Develop regional reanalysis; reduce data latency. Reanalysis is important for responding to user needs for higher-resolution data. Observations in this action will benefit reanalysis. D2: Availability of data in archives. D3: Easy accessibility of data.

Action F2: Improved ECV satellite observations in polar regions	
Activities	**Improve satellite observations of:** **1. Sea Surface Salinity of polar oceans.**

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

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

Action F3: Improve monitoring of coastal and Exclusive Economic Zones	
Activities	**1. Expand global ocean climate in situ observations and satellite products into Exclusive Economic Zones (EEZs) and coastal zones.** **2. Develop new satellite-based products for coastal biogeochemistry.** **3. Produce land cover datasets in coastal areas without land surface masks and in near real time, including uncertainties.** 4. Improve national coastal and EEZ data collection, data processing, uncertainty evaluation and data curation by improving access to equipment and ensuring local practices are consistent with the global guidelines and best practices.

<table>
<tr><td>Issue/Benefits</td><td>Monitoring of coastal zones and EEZs is necessary to allow policies and measures to be developed to protect the significant vulnerable populations, infrastructure and ecosystems in these areas.

Coastal zones are subject to rapid change and are the home to a substantial part of the Earth's population and to sensitive ecosystems. Changes near the coast directly impact ecosystems, people's health and livelihoods. Impacts such as storms, sea level rise, coastal erosion and inundation, flooding and saltwater intrusion are increasing. Currently these areas are poorly observed. Most of the purposely designed arrays of instrumentation and high resolution hydrographic transects (such as GO-SHIP) or the Argo program provide ocean observations at the open ocean, and the coastal and national waters are poorly monitored in many regions. From the land side, observations are directed at land properties and cover and so do not capture all the changes that are occurring. This action aims at addressing these issues.

Developing products for variables such as temperature, turbidity, chlorophyll, and CDOM within 1 km of coasts, within estuaries and at EEZs will improve modelling of organic dissolved and particulate carbon distribution and dynamic, including land-ocean interaction. Turbidity/suspended particulate matter products, for example, can document the enhanced erosion in Arctic regions associated with permafrost loss.</td></tr>
<tr><td>Implementers</td><td>1. GOOS, Space agencies, NMHS.
2. Space agencies, Research organizations, Academia.
3. Space agencies.
4. GOOS, NMHS, Research organizations.</td></tr>
<tr><td>Means of Assessing Progress</td><td>1. Increased density of observations and reprocessed products in EEZ and coastal waters, and related uncertainties.
2. Number of global operational biogeochemical products in coastal areas.
3. Number of land-cover data sets produced without masks.
4. Published national and regional guidelines.</td></tr>
<tr><td>Additional Details</td><td>1. Coastal regions are where boundary currents and upwelling regimes modulate fluxes of heat, carbon and other properties, with small-scale phenomena highly impacting the climate globally and locally, and also ecosystems.

Not all observing systems used elsewhere, such as Argo, can provide high-resolution full-depth monitoring in coastal areas. Argo measurements do not sample at shelf-shelf break regions (< 2000 m depth). Consolidation and development of in situ observing networks could be done through national and regional engagements, including local actors from certain sectors such as fisheries or maritime transport.

Activity 1 should consider the on-going discussions and efforts to facilitate access to the EEZs to carry out systematic ocean observations, as reflected on a recent multi-agency workshop lead by UNESCO/IOC[16]. A successful implementation of GBON can increase the number of surface marine meteorological observations collected by member states in their respective EEZs.

At the coast, "climate quality" tide gauge observations that include co-located vertical land motion measurements are needed for our understanding of contemporary and future coastal flood hazard. Finally, reprocessing of existing satellite records in coastal regions and generation of global products which include the coastal regions (e.g. altimetry and wind data records) is needed to</td></tr>
</table>

[16] GOOS-246 (2021), Report of Ocean Observations in Areas under National Jurisdiction Workshop. https://www.goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=26607

	increase coverage near the coast, which may require some software development. Products should include clear information on their limitations in coastal areas and EEZs, and their related uncertainties. 2. There are currently no biogeochemical operational products from high resolution satellites (e.g., Sentinel 2AB, Landsat 8) in coastal areas. Satellite observations need to be reprocessed to provide products for variables such as the temperature, turbidity, chlorophyll, and chromophoric dissolved organic matter (CDOM). 3. Land cover datasets should be reprocessed without masking to allow the detection of changes at the coastline. This activity will allow extremes and long-term trends such as sea-level rise to be captured (e.g. changes in the coastline and neighbouring land areas). Currently, impacts of changes in the sea level at the coast are not monitored because the way satellite observations are processed obscures these details. 4. Many coastal states lack access to equipment and expertise to monitor their coastal water and areas within their EEZs. Resources for equipment and capacity building are needed. In 2022 a task team has been set up under the IOC Ocean Best Practices framework[17], to identify common and accepted best practices used within the community for observations of physical, chemical and biological parameters and produce a package of easy-to-use operating procedures to monitor the coastal ocean. This guidance will need to be implemented at a national level.
Links with other IP Actions	B2: Implementing GBON will be of benefit for this action. B6 and B7: Expansion and integration of the global ocean observing system, including observations of biogeochemical/biological parameters. B8: Augmenting ship-based hydrography and fixed-point observations with biogeochemical and biological parameters. C1: Develop Monitoring standards, guidance and best practice for each ECV. C2: Activity 2 -reprocessing of satellite observations.

Action F5: Develop an Integrated Operational Global GHG Monitoring System	
Activities	The overall aim here is to develop an integrated operational global greenhouse gas monitoring infrastructure. The first steps are: 1. Design and start to implement a comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations routinely exchanged in near-real time suitable for monitoring GHG fluxes. **2. Design a constellation of operational satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible).** 3. Identify a set of global modelling centres that could assimilate surface and satellite-based observations to generate flux estimates. **4. Improve and coordinate measurements of relevant ECVs at anthropogenic emissions hotspots (large cities, powerplants) to support emission monitoring and the validation of tropospheric measurements by satellites.**
Issue/Benefits	The Paris Agreement requests Parties to regularly provide estimates of anthropogenic emissions by sources and removals by sinks of greenhouse gases, and information necessary to track progress made in implementing and achieving

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

	their nationally determined contribution under Article 4. The proposed global greenhouse gas monitoring infrastructure would support the development of these estimates (i.e. emission inventories); validate national and regional achievement of Parties' commitments in their National Adaptation Plans (NAPs); and monitor changes to the cycles of GHG that may impact the achievement of the temperature goal of the Paris Agreement. Monitoring of hot-spots via dedicated observations to validate specific point-source emissions and identify missing sources form emission inventories. Remote monitoring of atmospheric composition can quantify and identify major emission sources. Anthropogenic emission hotspots like cities and industrial facilities and power plants contribute strongly to the global GHG emissions and to emission of key ozone and aerosol precursors (SO_2, VOCs). Reliable remote observations of these emission hotspots in synergy with source detection models can contribute to verifying emission estimates and monitor and guide mitigation efforts (link to Flux ECV).
Implementers	1. **WMO (INFCOM, GAW and IG3IS).** 2. **Space agencies**, National agencies, Research organizations, Academia. 3. **WMO (INFCOM, GAW and IG3IS)**, National agencies. 4. **GCOS,** Space agencies, National agencies.
Means of Assessing Progress	1. Expanded observations of GHGs, ozone and aerosol precursors, aerosols and aerosol profiles near hotspots. 2. Designs and plans for in situ and satellite observations. 3. Identification of global monitoring centres that run global Chemistry Transport Models. 4. a) Improved satellite retrievals in the presence of varying aerosol loadings in urban and hotspot conditions. Improved uncertainty quantification of GHG retrievals in the presence of aerosols; b) Number of emission detection studies using in situ and satellite data near hot spots.
Additional Details	From 1 to 3: Based on an initial concept paper prepared by the WMO Secretariat entitled "A WMO-coordinated Global Greenhouse Gas Monitoring Infrastructure" and the Report from the WMO-hosted Greenhouse Gas Monitoring Workshop in May 2022, the 75th Session of the WMO Executive Council decided to proceed with the further development of the concept for a WMO-coordinated Global Greenhouse Gas Monitoring Infrastructure, building on existing WMO programmes and other regional or global infrastructure and initiatives. This infrastructure will consist of the following main elements: a) A comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations routinely exchanged in near-real time; b) A constellation of satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible); c) A global Chemistry Transport Model (CTM) driven by output from a high-resolution global NWP model; d) Operational near-real time assimilation of the GHG observations a) and b) into CTM and routine dissemination of the output. 4. Hot spots include urban areas, industrial zones and individual large plants. 4.1 Enhance observations in urban areas:

	a) Expand the network of GHG observations that measure around urban areas, in particular column and profile observations. These observations will support integration of satellite missions that detect and quantify sources; b) Ensure co-located observations of co-emitted gases (typically ozone and aerosol precursors) CO, NO_2, SO_2, VOCs. 4.2 Ensure co-located observations of aerosols loadings and aerosol profiles in urban areas: a) Improve satellite retrievals in emission hotspots; b) Evaluate GHG retrievals in urban areas by considering varying aerosol loadings using reference observations; c) Focus on improving GHG retrievals and their uncertainty quantification in urban and other local hotspot cites (Action B3). Present challenges in monitoring emission hotspots include: • Missing reference data sets of GHGs and other co-emitted gases and aerosols in urban areas. • Challenges in estimating GHG concentrations in the presence of varying aerosol loads. Underestimated (or overestimated) uncertainties can mislead the emission estimation. • Integration of in situ and satellite measurements. In the future, measuring stable isotopes of carbon will allow separation of natural and fossil sources of GHG.
Links with other IP Actions	B3: New satellite missions. B4: In situ monitoring of aerosols and greenhouse gases. F4: Climate monitoring in urban areas.

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