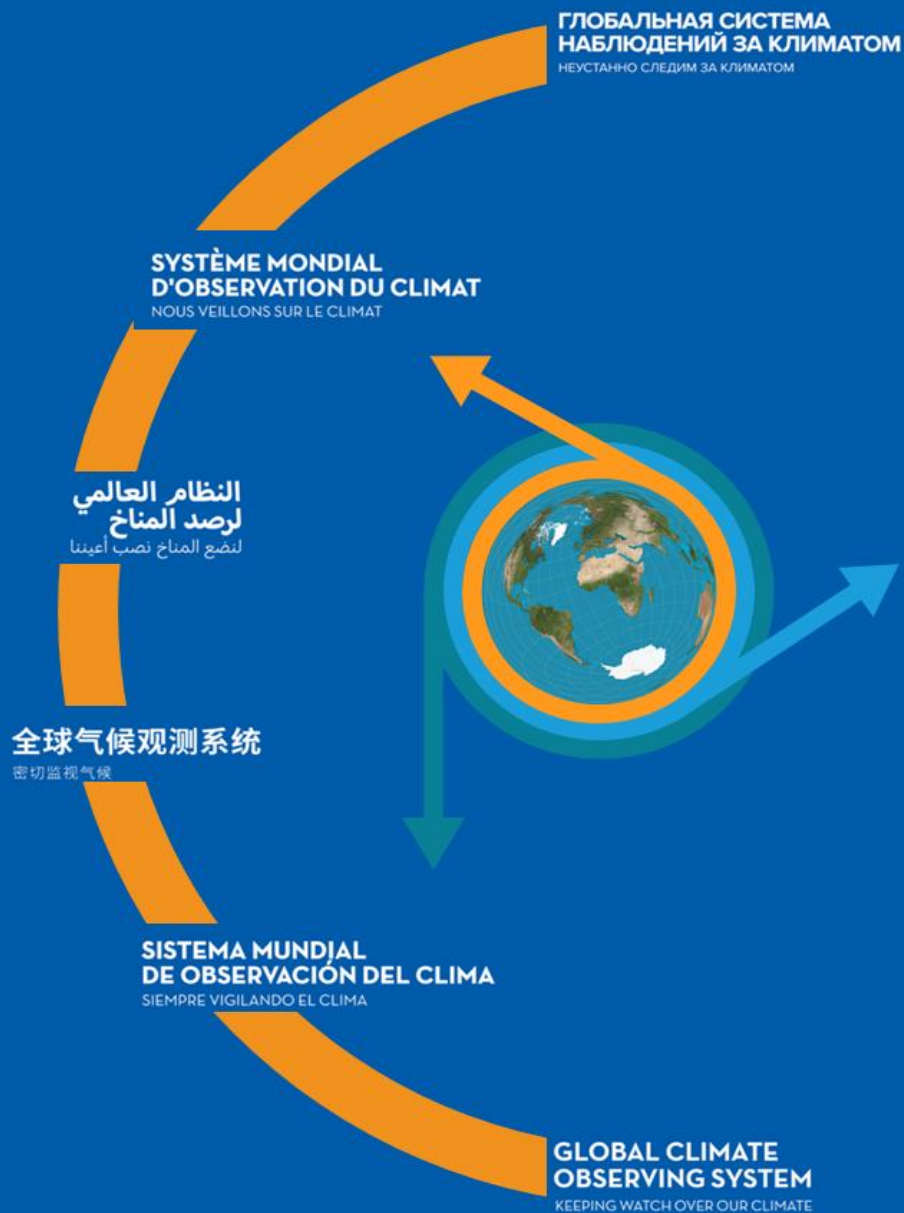


The 2022 GCOS Implementation Plan

GOOS Supplement



GCOS

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1. INTRODUCTION

This GOOS Supplement to the 2022 GCOS Implementation Plan extracts those activities for which the Global Ocean Observing System has been identified as key implementing partner.

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

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

This supplement only lists those actions within each theme that are targeted at GOOS. Within each action the specific activities for GOOS 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 GOOS

Theme	Actions	GOOS
B: FILLING DATA GAPS	B2. Development and implementation of the Global Basic Observing Network (GBON)	X
	B6. Expand and build a fully integrated global ocean observing system	X
	B7. Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters	X
	B8. Coordinate observations and data product development for ocean CO ₂ and N ₂ O	X
	B9. Improve estimates of latent and sensible heat fluxes and wind stress	X
C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING	C1. Develop monitoring standards, guidance and best practices for each ECV	X
D: MANAGING DATA	D2. Ensure Global Data Centres exist for all in situ observations of ECVs	X
E: ENGAGING WITH COUNTRIES	E1. Foster regional engagement in GCOS	X
F: OTHER EMERGING NEEDS	F3. Improve monitoring of coastal and Exclusive Economic Zones	X

2. THEME B: FILLING DATA GAPS

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

By and large the observations fulfil many requirements and provide the basis for the very useful sets of ECVs. However, in situ observations for almost all the ECVs are consistently deficient over certain continental regions, in the deep ocean and polar regions, a situation that has not improved since the 2015 GCOS Status Report ([GCOS-195](#)).

Reference quality observations respond to the need for monitoring the changes that are occurring in the climate system and ensure greater confidence 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. Reference quality measurement programs have already been established for different domains, however there are still gaps that need to be addressed.

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

Action B2: Development and implementation of the Global Basic Observing Network (GBON)	
Activities	<p>1. Implementation of initial GBON and the associated SOFF mechanism to fill long-standing gaps to globally monitor climate over land and oceans.</p> <p>2. Consideration of alignment of GSN and GUAN with GBON.</p> <p>3. Planning the development of GBON and SOFF to cover more marine, hydrological, and atmospheric composition observations.</p>
Issue/Benefits	<p>To date the GBON has been scoped by and adopted by WMO members along with the associated SOFF mechanism. However, the network has yet to be formally implemented and monitoring and enforcement mechanisms put in place. The use of the SOFF to fill persistent gaps has yet to start. If successful, given potential overlaps with GSN and GUAN, the implications for the future of those GCOS networks has yet to be fully evaluated.</p> <p>Furthermore, the initial implementation of GBON is focussed on requirements for NWP and reanalyses and an extension is required in future to ensure that GBON also meets the broader needs for climate monitoring and adaptation. This needs an expansion of the observational variables supported by GBON and can be supported through, for example, inclusion of daily and monthly summary reports. The GBON effort and associated SOFF, if fully implemented, would represent a step-change in the ability to monitor surface and upper-air atmospheric ECVs on a sustained basis. Benefits will include more complete sampling of many GCOS ECVs over land, ocean and the cryosphere, and filling gaps that exist over several geographical regions. The GBON network, if fully implemented, would meet the stated requirements for ECV monitoring for those ECVs it measures.</p>
Implementers	<p>1. WMO, GCOS, GOOS, NMHS.</p> <p>2. GCOS, WMO, NMHS.</p>

	3. WMO , GCOS, GOOS, NMHS.
Means of Assessing Progress	<ol style="list-style-type: none"> 1. Number of GBON stations (including marine platforms in Exclusive Economic Zones (EEZs)), their geographical completeness and their continuity of data provision to data centres as well as over the WIS. 2. Assessment by GCOS of the continued relevance and role of GSN and GUAN at such time as GBON is considered to be fully implemented in its first phase with recommendations to GCOS Steering Committee. 3. GBON scope expanded to incorporate additional ECVs which are then observed on a sustained basis as part of GBON expanded operations.
Additional Details	<ol style="list-style-type: none"> 1. In collaboration with WMO, ensure the full implementation of GBON and the associated SOFF mechanism to fill long-standing gaps to monitor climate over land and oceans. In particular, ensure that: <ul style="list-style-type: none"> • The initial GBON as adopted at WMO Extraordinary Congress in 2021 is implemented in full, including both surface and upper-air components; • GBON surface stations are encouraged to submit monthly and daily summaries in addition to synoptic reports; • The SOFF is used to target areas of data sparsity over land and EEZs and ensure continuity of capability. 2. After 2-3 years of operation, consider the relationship of GBON to GSN and GUAN. Does GBON fulfil all aims of GSN and GUAN or is there value in retaining GSN and GUAN as independent network designations? If they are retained: are any changes required to GSN and GUAN aims and governance accordingly? AOPC to report to GCOS Steering Committee in 2024/2025. 3. WMO envisages that GBON will expand to cover other domains. GCOS to take an active role in the continued evolution of the GBON network to ensure that climate needs are adequately accounted for. Progress to this end is to be assessed in the next GCOS status report.
Links with other IP Actions	<p>B4: The extension of GBON (Activity 3) will benefit expansion of in situ monitoring of atmospheric composition ECVs.</p> <p>B8: The extension of GBON (Activity 3) will benefit the coordination of N₂O observations.</p> <p>C4: The implementation of GBON will benefit reanalysis.</p>

Action B6: Expand and build a fully integrated global ocean observing system	
Activities	<p>Increase the measurements of ocean ECVs into the deep ocean, under the ice and marginal seas by improving:</p> <ol style="list-style-type: none"> 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	<p>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.</p>

	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	<ol style="list-style-type: none"> 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	<p>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.</p> <p>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 System¹. 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 Card² for more details).</p>
Links with other IP Actions	<p>B7 and B8: Improve components of the global ocean observing system.</p> <p>B9: Improve estimates of latent and sensible heat fluxes and wind stress.</p> <p>F3: Expand global ocean climate in situ observations into EEZ and coastal zones.</p>

Action B7: Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters	
Activities	Add biological and enhanced biogeochemical sensors and field/laboratory measurements to the already existing ship-based hydrography and fixed-point observations to establish a baseline of plankton distributions and phenology (seasonal timing in phenotype and abundance).
Issue/Benefits	Some of the greatest uncertainties in the projections of future climate are associated with the response of the biosphere to present and future environmental change, and the subsequent biotic interactions, responses and feedback mechanisms. Both established and novel technologies provide the capacity to include measurements of plankton on existing coordinated observing platforms across a wide range of scale that can contribute to both the GOOS Biology and

¹ 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>

² OceanOPS Report Card 2021 (ocean-ops.org)

	<p>Ecosystem Essential Ocean Variables (EOVs) and the GCOS ECVs to deliver global observations.</p> <p>Broadening current hydrography and oceanography programs to include measurements of plankton EOVs/ECVs that can then contribute to global observing systems will assist in filling gaps in understanding of primary and secondary productivity dynamics and their role in ocean-climate interactions. It will also strengthen efforts in incorporating primary and secondary productivity and their dynamics in Earth System Models, thereby improving current capacity to forecast the response of the system under climate scenarios that are informative for policy-making and management of coastal and marine systems. Comprehensive in situ multidisciplinary measurements at scale will also support many other efforts in quantifying ocean productivity, including ocean colour radiometry, and will be complementary to other global ocean observing networks (e.g., Biogeochemical Argo, GACS) in contributing to the plankton ECVs.</p>
Implementers	GOOS , Research organizations (<i>see also key programmes and networks in "Additional details"</i>).
Means of Assessing Progress	Increased number of ocean biological and biochemical datasets available and shared via global repositories.
Additional Details	<p>In 2019, at the conclusion of the OceanObs'19 decadal conference, recommendations of the scientific community were to maintain and expand spatial extension of co-located physical and biological / biogeochemical observations. This development will require sustained coordinated campaigns, standardisation of some methods including data QC, data management approaches and establishment of best practices around the world.</p> <p>The key programs and networks are ship-based time series, local/regional/national surveys, national reference stations, GO-SHIP, OceanSITES, Ocean Color satellites, Biogeochemical Argo, GACS.</p>
Links with other IP Actions	<p>B8: Improve components of the global ocean observing system.</p> <p>F3: Expand global ocean climate in situ observations into EEZ and coastal zones.</p>

Action B8: Coordinate observations and data product development for ocean CO₂ and N₂O	
Activities	<ol style="list-style-type: none"> 1. Develop a strategy and implementation plan to operationalize the data production and delivery of surface ocean CO₂ information. 2. Coordinate the existing nitrous oxide (N₂O) ocean observations into a harmonised network.
Issue/Benefits	Parties to the UNFCCC, in its Paris Agreement, have committed to conserving and enhancing sinks and reservoirs of greenhouse gases, such as CO ₂ and N ₂ O, including oceans and coastal and marine ecosystems. As part of the Global Stocktake exercise, it will be necessary to quantify and assess both carbon emissions and natural sinks. There are already considerable national and regional efforts contributing to monitor CO ₂ and N ₂ O in the ocean, but most of them rely on short-term research projects. A more sustained funding and better coordination will result in a better estimation of the oceanic CO ₂ and N ₂ O emissions, an optimisation of resources of Member States and better compliance with UN agreements.
Implementers	From 1 to 2: GOOS , WMO, Research organizations, National agencies (<i>see also key programmes and networks in "Additional details"</i>).

Means of Assessing Progress	<ol style="list-style-type: none"> 1. Internationally agreed strategy and implementation plan that can be used by governments for funding decisions that enable integration of individual pilot elements to achieve the required global system. 2. <ol style="list-style-type: none"> a) Annually published sets of harmonised global N₂O concentration and emission fields data products; b) Initiated coordinated observing network of N₂O observations.
Additional Details	<ol style="list-style-type: none"> 1. While all of the required elements of a surface ocean CO₂ monitoring system exist (observations, data quality control and synthesis, gap-filling protocols, and projection capability) individually, there is currently no internationally-agreed strategy that coordinates national and regional efforts and expands the global network to better quantify carbon sources and sinks. In recent years, serious gaps have developed in surface CO₂ data coverage owing to funding cuts in some key underway CO₂ programmes that had been operating for decades supported by 3-4-year funding horizons based on research proposals. These programmes, and the international ocean and climate science communities they serve, suffer from the lack of an internationally agreed strategy that recognizes individual programmes as essential elements in a coordinated global network. In fact, all the elements of this monitoring system rely on individual research proposals and voluntary contributions and as such lack any long-term perspective. The development of an internationally agreed strategy for a global surface CO₂ monitoring network, with a focus on the open ocean and marginal seas, will allow Member States to identify priority observing system investments to meet data needs, further develop the foundations of a sustainable surface ocean carbon monitoring system, and respond to international and intergovernmental policy drivers and commitments to UN agreements. The key programs and networks are: WMO Global Atmospheric Watch (GAW), International Ocean Carbon Coordination Project (IOCCP), Surface Ocean CO₂ reference Observing NETwork (SOCONET), Integrated Carbon Observation System-Ocean Thematic Centre (ICOS-OTC), Surface Ocean CO₂ Atlas (SOCAT), Surface Ocean CO₂ Mapping intercomparison initiative (SOCOM), Global Carbon Project (GCP), Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP), Global Data Analysis Project (GLODAP), Biogeochemical Argo. 2. To reduce uncertainties in oceanic N₂O emission estimates and to characterise the spatial and temporal variability in N₂O distributions in a changing ocean, the establishment of a harmonised N₂O Observation Network (N₂O-ON) combining discrete and continuous data from various platforms is needed. The network will integrate observations obtained by calibrated techniques, using time-series measurements at fixed stations and repeated hydrographic sections on voluntary observing ships and research vessels. As a greenhouse gas, N₂O is involved in tropospheric warming and stratospheric ozone depletion, with estimates of the global ocean contribution to N₂O emissions ranging from 10-53%. It is important to monitor how oceanic N₂O cycling and emissions to the atmosphere are affected by observed changes in the marine environment due to warming, deoxygenation and acidification. Therefore, new N₂O data products issued annually will include a harmonised global N₂O concentration and emission fields to inform the global research community and policy makers on the status and projections of future oceanic N₂O emissions. The key programs and networks are: N₂O GO-SHIP, Ship-Of-Opportunity Programme (SOOP), MarinE MethanE and NiTrous Oxide (MEMENTO).

Links with other IP Actions	Together with B8, B6 and B7 target different aspects and components of global and integrated ocean observing system recognizing its essential role in the climate system.
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Action B9: Improve estimates of latent and sensible heat fluxes and wind stress	
Activities	<p>This action focuses on ice-free oceans and the terrestrial land surface</p> <ol style="list-style-type: none"> 1. Improve and extend in situ measurements needed to estimate surface fluxes, with the objectives of improving accuracy and better defining the uncertainties of those measurements and calculated fluxes. 2. Extend sites with co-located measurements of direct turbulent and radiative fluxes and variables required to estimate turbulent surface fluxes targeted at improving parameterisations of air-sea exchange and air-land exchange. 3. Develop new approaches over land, focusing on improved estimation of transpiration, interception and soil evaporation separately. 4. Develop new approaches and improved methods to better exploit relevant ECV measurements to estimate ocean surface heat, moisture and momentum flux including: <ol style="list-style-type: none"> 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	<p>Understanding and estimating surface fluxes is essential for improving projections of climate change and planning adaptation and response measures.</p> <p>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.</p> <p>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.</p> <p>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.</p>

Implementers	<p>From 1 to 2: NMHS, GOOS, Research organizations.</p> <p>3. Academia, Research organizations, NMHS.</p> <p>4. Space agencies, NMHS, Academia.</p>
Means of Assessing Progress	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> 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. <ol style="list-style-type: none"> 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. <ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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

	<p>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 concept³. Spatio-temporal mismatches in sampling of ECVs required for flux estimation should be minimised to reduce errors in the heat flux estimation resulting from the combination of observations sampled at different times, or with different spatial footprints.</p> <p>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)⁴. Moreover, the potential of novel thermal missions such as ECOSTRESS (Fisher et al., 2020)⁵ and TRISHNA (Lagouarde et al., 2018)⁶ is yet to be exploited.</p> <p>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.</p> <p>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):</p> <ul style="list-style-type: none"> • 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.
<p>Links with other IP Actions</p>	<p>This action links to other actions:</p> <p>B1: Reference networks are needed to improve flux estimates.</p> <p>B10: Closure of energy cycles will benefit from a better understanding of heat fluxes.</p> <p>C2 and C3: Improvements to data processing methods will benefit this action.</p> <p>D3 (Activity 3). Access to field campaign data useful for testing of parameterization.</p> <p>D4: Easy access to co-located satellite and reference quality in situ observations.</p>

3. 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

³ Butterfly: a satellite mission to reveal the oceans' impact on our weather and climate <https://doi.org/10.5281/zenodo.5120586>

⁴ 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

⁵ 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

⁶ 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

towards the generation of sensor-agnostic gridded datasets to facilitate intercomparison. Acknowledging the fact that the use of observational data is often mediated by other systems, a dedicated effort should also go toward ensuring the fitness for purpose of the data provided for its use in reanalysis. This includes a dedicated effort towards data reprocessing, bias characterisation and more generally a comprehensive characterisation of the uncertainty associated with both observations and modelling.

Action C1: Develop monitoring standards, guidance and best practices for each ECV	
Activities	<ol style="list-style-type: none"> 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	<p>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.</p> <p>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.</p>
Implementers	From 1 to 4: GCOS , GOOS, WMO, Copernicus, Space agencies.
Means of Assessing Progress	<ol style="list-style-type: none"> 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	<p>For 1 and 2:</p> <p>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.</p> <p>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.</p>

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.
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4. THEME D: MANAGING DATA

To address and understand climate change, the longest possible time series need to be preserved in perpetuity. Every ECV needs to have a recognized global data repository and where there is one, it should be complete, adequately supported and funded. Data should be stored in well-curated, open and freely available, sustainable archives with clear guidance for data centres and users. Clearly defined principles such as the TRUST Principles (Lin et al., 2020)⁷ and FAIR Principles (Wilkinson et al., 2016⁸) are needed. Data rescue from hard copy or archaic digital formats allows data series to be extended in the past and needs to be adequately planned and funded with the results openly and freely available. Sustained support to these activities is required. This theme aims at organizing more efficiently data rescue, data sharing, data curation and data provision.

Action D2: Ensure Global Climate Data Centres exist for all in situ observations of ECVs	
Activities	<ol style="list-style-type: none"> 1. Identify ECVs for which adequate global centres do not exist or are insufficiently supported and facilitate and support the creation or improvement of global data centres for these ECVs. 2. Promote regional data centres, their interoperability, where possible, synchronization of their data holdings, and the provision of data in their archives to global data centres.
Issue/Benefits	The aim of this action is to ensure that all available observations for each ECV/ observation type are distributed from integrative data centres that meet the requirements established in Action D1. Data centres do not exist for every ECV and the continued existence of some of those that do exist is not assured due to the lack of long-term funding. This action addresses this issue and targets specifically in situ data.
Implementers	From 1 to 2: GCOS , WMO, GOOS, NMHS, National agencies, Funding agencies.
Means of Assessing Progress	<ol style="list-style-type: none"> <ol style="list-style-type: none"> a) List of climate data centres, identifying those in need of additional support followed by annual reports by GCOS panels on data centres at risk; b) List of ECVs for which no data centre exists, followed by annual updates on progress towards filling the identified gaps. Establishment of a functional network of regional data centres for all ECVs of relevance in the region and their synchronization with global data centres.
Additional Details	<ol style="list-style-type: none"> Global Climate Data Centres need to maintain and construct long-term time series of ECV data and to archive and disseminate these time series for the long term, at least several decades following the requirements established as part of Action D1. The maintenance of these data centres requires long-term assured funding. The first step is to identify all existing data centres and the status of their funding. ECVs for which data centres are missing need to be identified, and the

⁷ 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

⁸ 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

	<p>relevant GCOS panels should advocate for the establishment of the missing centres. GCOS should also make a clear case for adequate funding of data centres and the benefits that will accrue.</p> <p>For example, sustained funding is urgently needed for the Global Ocean Data Analysis Project (GLODAP), where ocean biogeochemistry data is collected and stored. Despite a recent increase in the quantity of these observations GLODAP is a largely unfunded community effort. Such a situation is unsustainable, and there is a significant risk that the effort will diminish or disappear in the next few years.</p> <p>Following an initial assessment of adequacy, it is necessary to continuously review the health of the network of global data centres. GCOS panels should annually review the status of global data centres within their domain and highlight any issues so that these can be remedied.</p> <p>2. The Global data centres are part of a network of data centres that include regional data centres and in some cases the observation networks. These need to be integrated into a global system to improve data exchange and data availability. They should also follow the requirements developed in Action D1. Sustainable funding of regional data centres and observation networks is key.</p> <p>Working with Regional Associations and Regional WIGOS Centres, GCOS should advocate for regional level data collection and curation which may then be passed on to the extent possible for inclusion in global data centre collections.</p> <p>This action focuses on in situ data. Information about satellite-based climate data records can be found in the ECV inventory.</p>
Links with other IP Actions	Action D1, D2 and D3 are interconnected and pursue a common goal of preserving and providing access to ECV data in Global Data Centres.

5. THEME E: ENGAGING WITH COUNTRIES

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

Action E1: Foster regional engagement in GCOS	
Activities	<p>1. Undertake at least one regional GCOS Workshop each year.</p> <p>a) Promote the benefits of coordination of climate observations (in situ and satellite) and GCOS programs.</p> <p>b) Explore regional issues, gaps and needs and develop plans to address them.</p> <p>2. Report regional needs and issues to the UNFCCC, WMO and other relevant stakeholders.</p>
Issue/Benefits	Lack of regional and national input into global observing decisions can make GCOS seem remote from implementers “on the ground” and leaves GCOS unable to fully understand and respond to the issues facing observing systems at a local level. There is a need to better integrate GCOS needs into national and regional decision making to ensure sustainable observations for climate.

	<p>These activities will better inform the global system of local needs and link local observing systems with international support and capacity development. They can also provide some capacity development, explain the needs and uses of climate data and help ensure that countries have access to all the data.</p> <p>For example, GBON and SOFF were developed from needs identified in a GCOS regional workshop on climate observations systems in the Pacific Island states⁹.</p>
Implementers	From 1 to 2: GCOS , Parties to the UNFCCC, WMO (Regional Organizations), GOOS (Regional Alliances).
Means of Assessing Progress	<ol style="list-style-type: none"> 1. Number of regional workshops held annually in collaboration with WMO and other stakeholders. 2. Reports to UNFCCC and WMO.
Additional Details	<p>This work can be done with WMO Regional Organizations and GOOS Regional Alliances, as appropriate. Other stakeholders should be considered: in the past Copernicus has supported regional workshops.</p> <ol style="list-style-type: none"> 1. Regional workshops engage countries directly. Engagement of countries needing support and more experienced countries will be beneficial. Involving both those making observations and those from the climate policy sphere will allow the workshops to identify issues and potential solutions and will also inform the countries about how observations support services and policy development. <p>An important part of obtaining support, financial and political, for climate observations is providing a rationale for the observations and a clear description of the benefits. International coordination and data exchange enhance these benefits. Regional workshops should agree to regional needs, gaps and develop plans to address these needs.</p> <ol style="list-style-type: none"> 2. A key component will be reports to appropriate stakeholders, especially the UNFCCC and WMO on needs and issues. The discussions of these reports, and decisions based upon them, will enhance the implementation of observation systems.
Links with other IP Actions	Actions E2 and E3.

6. THEME F: OTHER EMERGING NEEDS

As countries respond to the impacts of climate change, they need data related to the specific areas impacting their countries. Many impacts are directly related to extremes, for example heatwaves, flooding and droughts. While work continues to identify how the global system can support these national and local needs, some requirements are already evident. 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. 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.

⁹ Full workshop report available online: https://ane4bf-datap1.s3.eu-west-1.amazonaws.com/wmod8_gcoss/s3fs-public/fijiworkshopoct2017_final1.pdf?E8vbQOTXp3.VJII2p6utJLP.l8xM7huA.

Action F3: Improve monitoring of coastal and Exclusive Economic Zones	
Activities	<ol style="list-style-type: none"> 1. Expand global ocean climate in situ observations and satellite products into Exclusive Economic Zones (EEZs) and coastal zones. 2. Develop new satellite-based products for coastal biogeochemistry. 3. Produce land cover datasets in coastal areas without land surface masks and in near real time, including uncertainties. 4. Improve national coastal and EEZ data collection, data processing, uncertainty evaluation and data curation by improving access to equipment and ensuring local practices are consistent with the global guidelines and best practices.
Issue/Benefits	<p>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.</p> <p>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.</p> <p>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.</p>
Implementers	<ol style="list-style-type: none"> 1. GOOS, Space agencies, NMHS. 2. Space agencies, Research organizations, Academia. 3. Space agencies. 4. GOOS, NMHS, Research organizations.
Means of Assessing Progress	<ol style="list-style-type: none"> 1. Increased density of observations and reprocessed products in EEZ and coastal waters, and related uncertainties. 2. Number of global operational biogeochemical products in coastal areas. 3. Number of land-cover data sets produced without masks. 4. Published national and regional guidelines.
Additional Details	<ol style="list-style-type: none"> 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

	<p>recent multi-agency workshop lead by UNESCO/IOC¹⁰. A successful implementation of GBON can increase the number of surface marine meteorological observations collected by member states in their respective EEZs. At the coast, “climate quality” tide gauge observations that include co-located vertical land motion measurements are needed for our understanding of contemporary and future coastal flood hazard. Finally, reprocessing of existing satellite records in coastal regions and generation of global products which include the coastal regions (e.g. altimetry and wind data records) is needed to increase coverage near the coast, which may require some software development. Products should include clear information on their limitations in coastal areas and EEZs, and their related uncertainties.</p> <ol style="list-style-type: none"> 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 framework¹¹, 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.
<p>Links with other IP Actions</p>	<p>B2: Implementing GBON will be of benefit for this action.</p> <p>B6 and B7: Expansion and integration of the global ocean observing system, including observations of biogeochemical/biological parameters.</p> <p>B8: Augmenting ship-based hydrography and fixed-point observations with biogeochemical and biological parameters.</p> <p>C1: Develop Monitoring standards, guidance and best practice for each ECV.</p> <p>C2: Activity 2 -reprocessing of satellite observations.</p>

¹⁰ GOOS-246 (2021), Report of Ocean Observations in Areas under National Jurisdiction Workshop. https://www.goosoocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=26607

¹¹ <https://www.oceanbestpractices.org/about/task-teams/task-team-22-01-coastal-observing-in-under-resourced-countries>

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