New GCOS IP and the ocean

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

WMO IOC International Science Council UN environment

Supported by the European Union

Copernicus
Europe's eyes on Earth

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

VISION

GCOS works towards a world where climate observations are high-quality and sustained, and access to climate data is comprehensive, free and open.

GCOS is a Co-Sponsored Programme:

- **WMO**
- **UNESCO – IOC**
- **UNEP**
- **ISC**

GCOS is the authoritative global source of information and advice for planning and development of the Global Climate Observing System, its networks and data management.
It is the authoritative source reference for formulating requirements for space and in situ climate observations.

WMO IOC

International Science Council

UN environment

GCOS ACTIVITIES

Identify user needs for climate monitoring - adaptation, sustainable develop., UNFCCC, other MEA

Ensure that climate **observations are enhanced and continued into the future**

Advocate for **free and open access to relevant data**

GCOS Cooperates with a WIDE Range of observing initiatives (in situ and space)

GCOS does not make observations itself, it is a system of systems integrating the contribution from a wide range of organizations, like National Meteorological and Hydrological Services, Satellite agencies, in situ networks, National and regional bodies, academic studies etc.

GSN, GUAN, GRUAN

WHOS

GBON

…

WHYCOS

GAW

Meteorological Networks coordinated by WMO

CGMS CEOS

Satellite observations are coordinated by the Joint CEOS/CGMS Working Group on Climate

GOOS (under IOC) coordinates a wide range of ocean networks

GOOS

LEGOS FAO FLUXNET wgms

Other Global Organizations and Networks for specific terrestrial ECV

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GRDC

WCRP World Climate Research Programme

NOAA National Centers for Environmental Information NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Global Precipitation Climatology Centre

a wide range of other partners support GCOS, host data centres, etc …

Examples of global networks associated with GCOS

GTN-P Global Terrestrial Network for Permafrost

GTN-H

GTN-G

GOFC-GOLD Global Observation of Forest and Land Cover Dynamics

HYDROLARE

WRMC-BSRN World Radiation Monitoring Center- Baseline Surface Radiation Network

Examples of national and regional networks

eLTER ICOS Integrated Carbon Observation System AmeriFlux tern Ecosystem Research Infrastructure

GCOS is governed by a Steering Committee and is organized in 3 panels of experts:

Atmosphere – AOPC

Ocean – OOPC

Land – TOPC

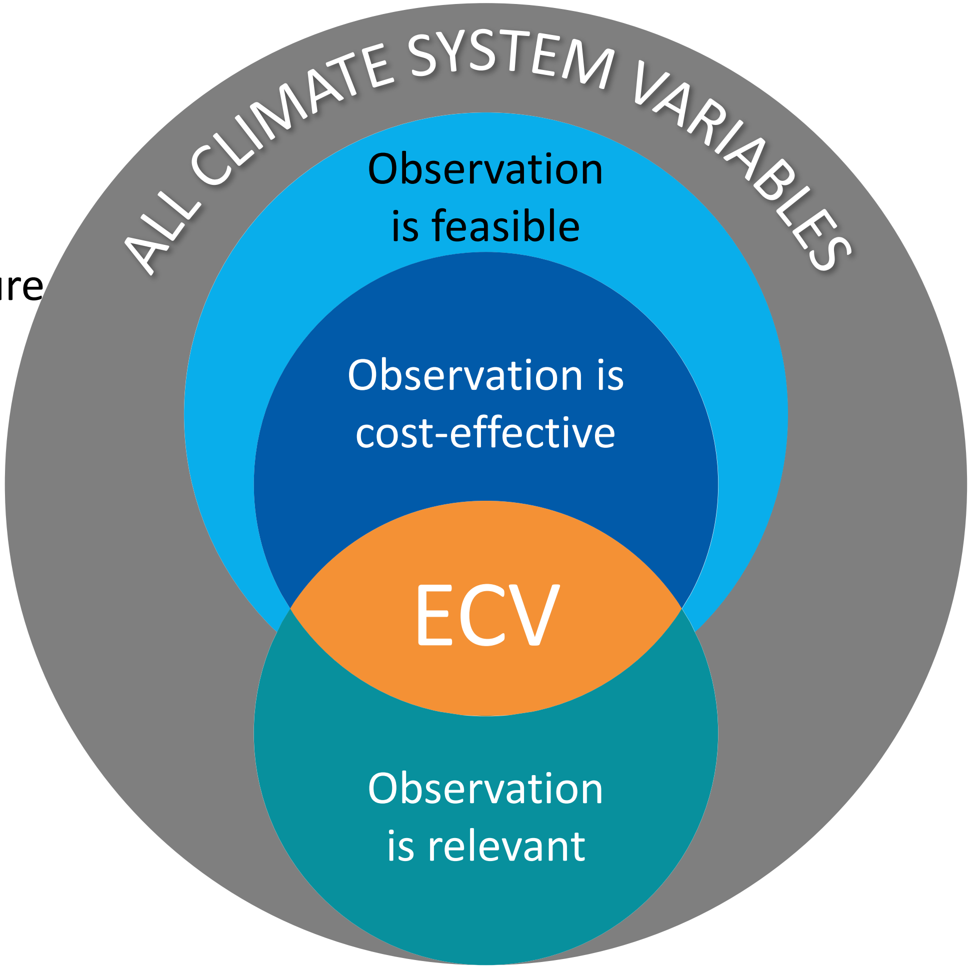
GCOS - Essential Climate Variables (ECV)

- are physical, chemical or biological variables that critically contribute to the characterization of Earth's climate
- are not of stand-alone variables; they are part of a wider concept
- are founded on climate science and observational capability and infrastructure

ECV datasets provide the empirical evidence

- to understand and predict the evolution of climate
- to guide mitigation and adaptation measures
- to assess risks
- to enable attribution of climatic events to underlying causes
- to underpin climate services

SOURCE: Bojinski, S. et al., 2014



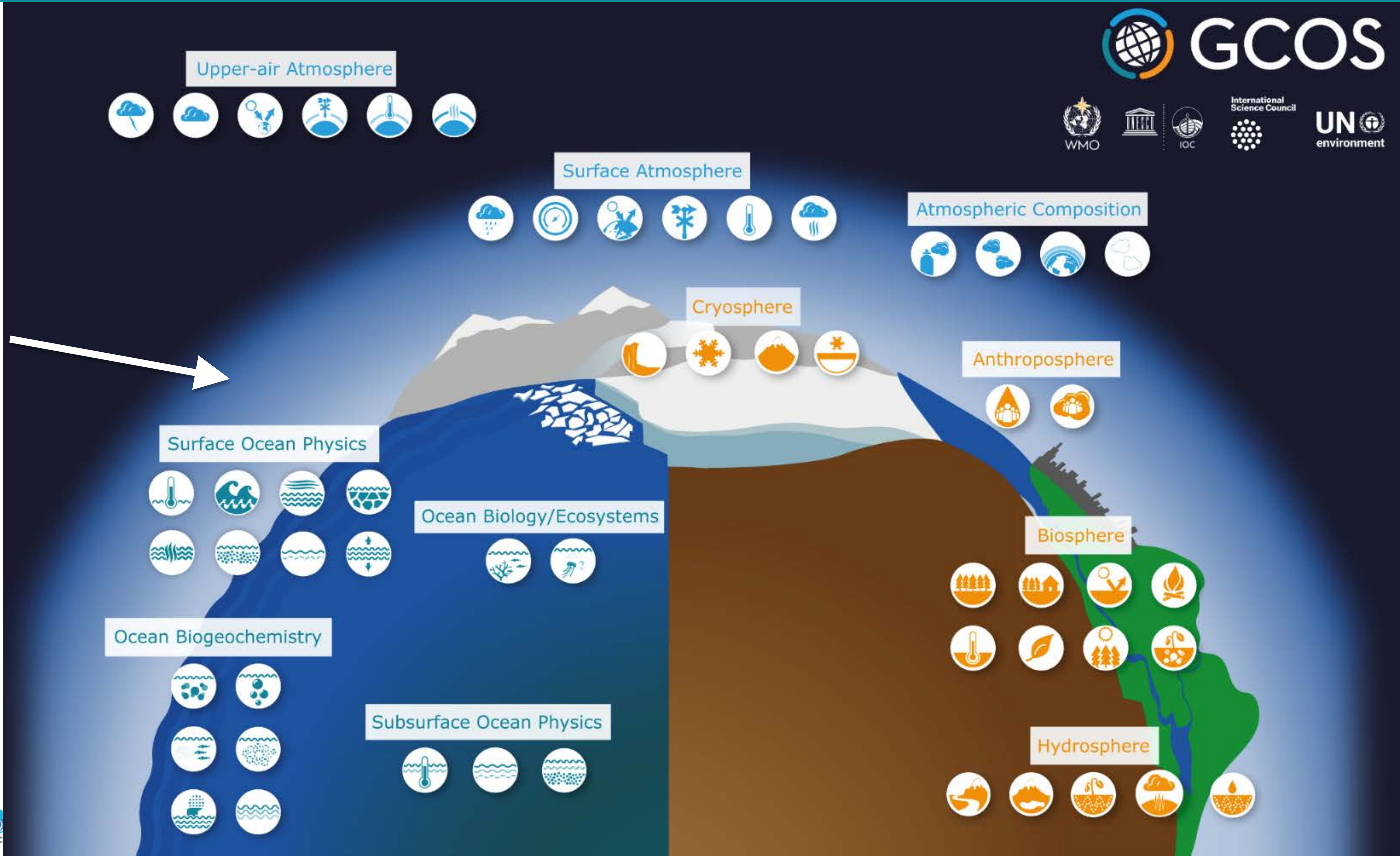
ECVs aim to monitor the climate system as a whole covering the interlinked Earth's energy balance and the carbon and water cycles.

ECVs should meet these principles

- **Free and Open**, data is openly available to all users
- **Transparent**, the methods and assumptions are clear, with standardised metadata, where possible
- **Accurate**, climate data needs high accuracy to distinguish small trends from larger annual variability
- **Useful**, there should be a clear demand from users
- **Timely & Long-term**, aim to maintain and/or develop long-term climate data records
- Based on best **available science**

GCOS ECVs "monitor" the Earth's water, energy and carbon cycle

Ocean ECVs are a subset of the Essential Ocean Variables custodied by the Global Ocean Observing System of GOOS



Ocean ECVs (covering Physics, Biogeochemistry and Biology and Ecosystems)

Ocean

ECV	ECV Product 2016	ECV Product 2022
Sea-Surface temperature	Sea-Surface temperature	Sea-Surface temperature
Subsurface Temperature	Interior Temperature	Interior Temperature
Sea-Surface Salinity	Sea-Surface Salinity	Sea-Surface Salinity
Subsurface Salinity	Interior Salinity	Interior Salinity
Surface Currents	Surface Geostrophic Current	Surface Geostrophic Current Ekman Currents
Subsurface Currents	Interior Currents	Vertical Mixing
Sea Level	Regional Sea Level Global Mean Sea Level	Regional Mean Sea Level Global Mean Sea Level
Sea State	Wave Height	Wave Height
Surface Stress	Surface Stress	Surface Stress
Ocean Surface Heat Flux	Radiative Heat Flux Sensible Heat Flux Latent Heat Flux	Radiative Heat Flux Sensible Heat Flux Latent Heat Flux
Sea Ice	Sea Ice Concentration Sea Ice Thickness Sea Ice Drift Sea Ice Extent/Edge	Sea Ice Concentration Sea Ice Thickness Sea Ice Drift Sea Ice Age Sea Ice Surface Temperature (IST) Sea ice Surface Albedo Snow Depth on Sea Ice

OOPC 10

GCW + OOPC

Ocean ECVs (covering Physics, Biogeochemistry and Biology and Ecosystems)

Ocean		
ECV	**ECV Product 2016**	**ECV Product 2022**
Oxygen	Interior Ocean Oxygen Concentration	Dissolved Oxygen Concentration
Nutrients	Interior Ocean Concentrations of Silicate, Phosphate, nitrate	Silicate
		Phosphate
		Nitrate
Ocean Inorganic Carbon	Interior Ocean Carbon Storage. (At least 2 of DIC, TA or pH)	Total Alkalinity (TA)
		Dissolved Inorganic Carbon (DIC)
		pCO_2
Transient Tracers	Interior Ocean CFC-11, CFC-12, SF_6, ^{14}C, tritium, ^3He, ^{39}Ar	^{14}C
		SF_6
		CFC-11
		CFC-12
Ocean nitrous oxide N_2O	Interior Ocean Nitrous Oxide N_2O	Interior Ocean Nitrous Oxide N_2O
	N_2O Air-Sea Flux	N_2O Air-Sea Flux
Ocean Colour	Water Leaving Radiance	Water Leaving Radiance
	Chlorophyll-a concentration	Chlorophyll-a concentration
Plankton	Zooplankton	Zooplankton Diversity
		Zooplankton Biomass
	Phytoplankton	Phytoplankton Diversity
		Phytoplankton Biomass
Marine Habitat Properties	Coral Reefs, mangrove forests, seagrass beds, Macroalgal Communities	Mangrove Cover and Composition
		Seagrass Cover (areal extent)
		Macroalgal Canopy Cover and Composition
		Hard coral cover and composition

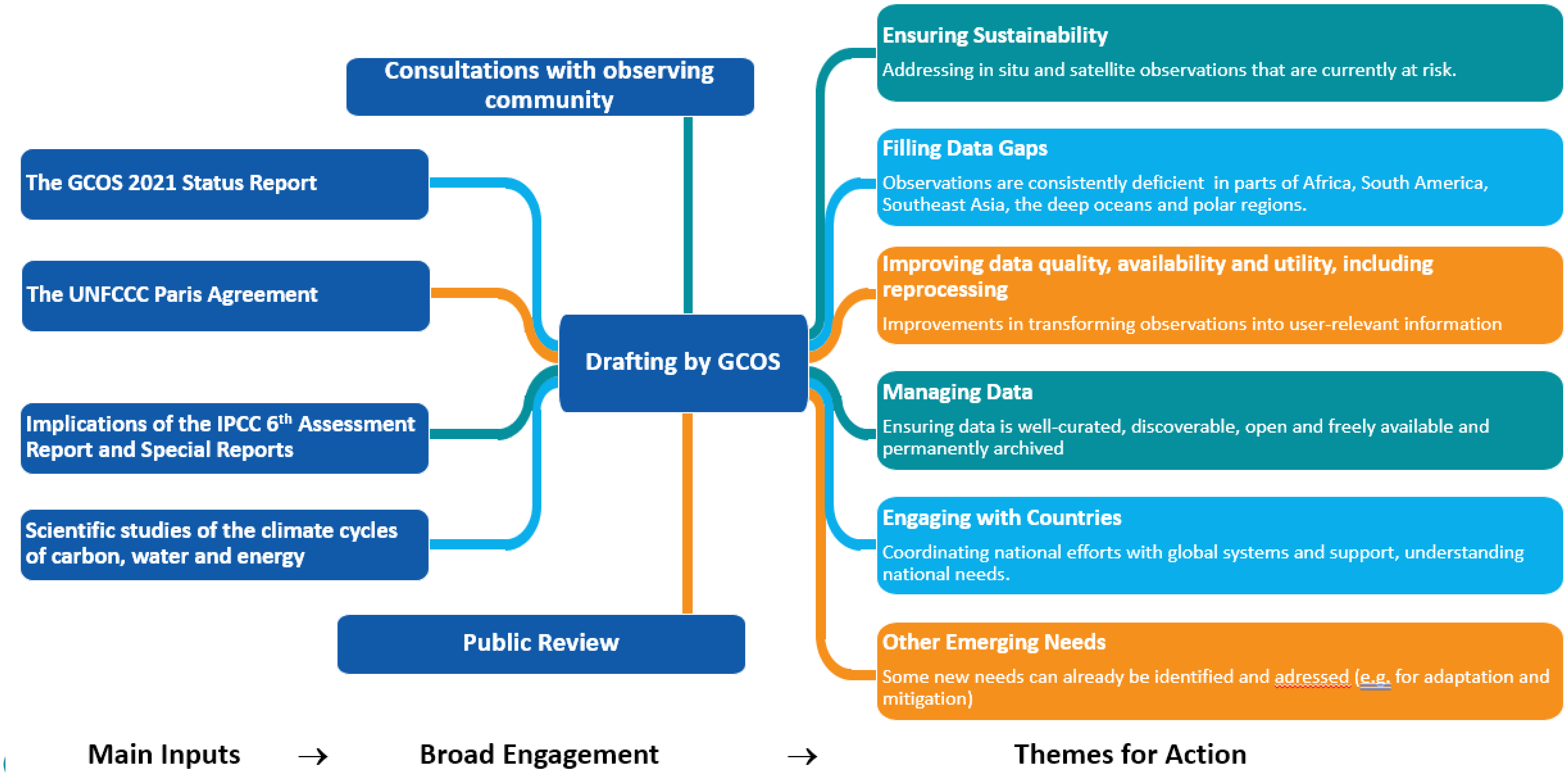
BGC + *OOPC*

BioEco + *OOPC*

1- intro on GCOS and ECVs

2- GCOS IP and OOPC/GOOS

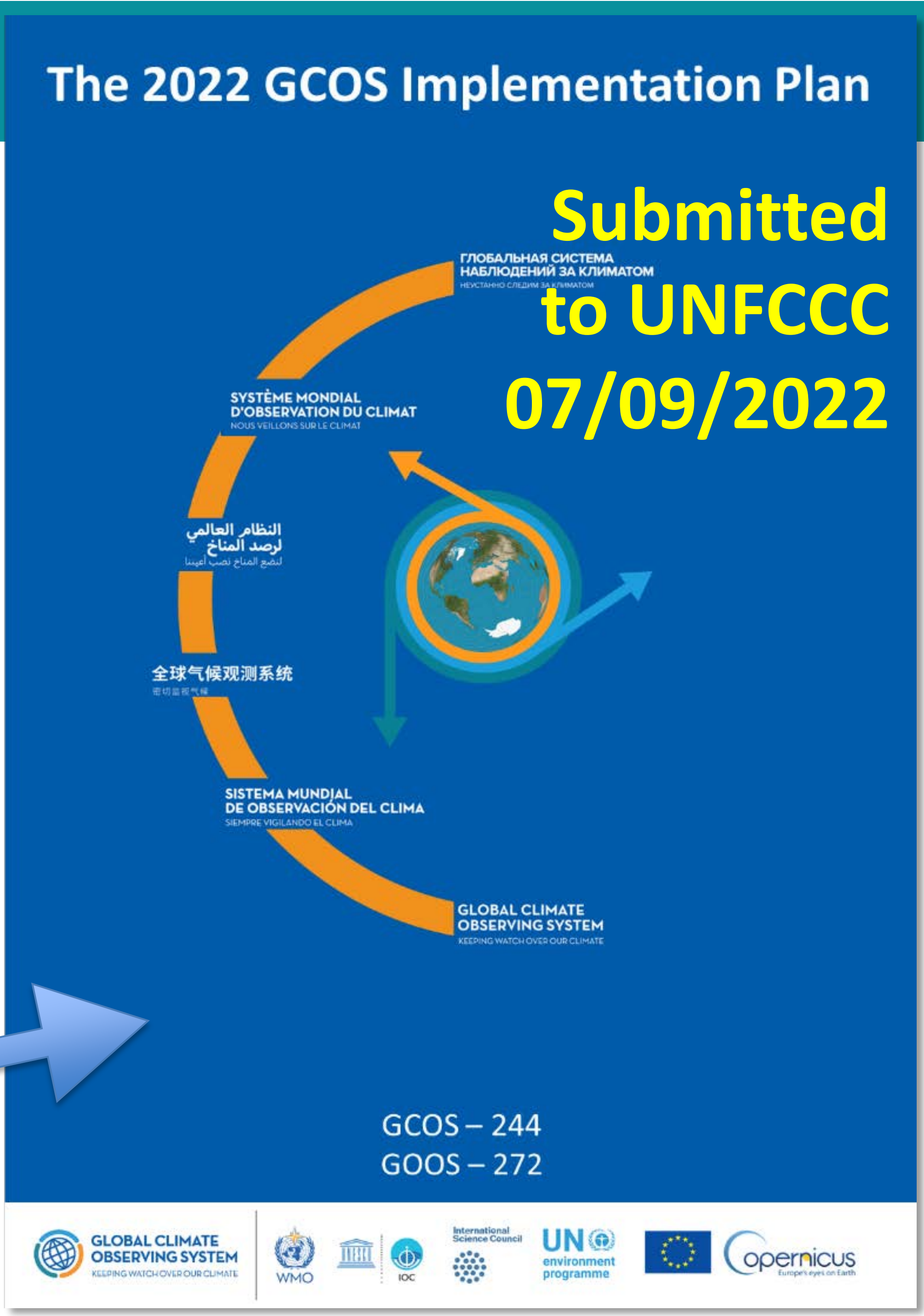
2022 GCOS IP



Consultations with observing community
The GCOS 2021 Status Report
The UNFCCC Paris Agreement
Implications of the IPCC 6th Assessment Report and Special Reports
Scientific studies of the climate cycles of carbon, water and energy
Drafting by GCOS
Public Review
Ensuring Sustainability
Addressing in situ and satellite observations that are currently at risk.
Filling Data Gaps
Observations are consistently deficient in parts of Africa, South America, Southeast Asia, the deep oceans and polar regions.
Improving data quality, availability and utility, including reprocessing
Improvements in transforming observations into user-relevant information
Managing Data
Ensuring data is well-curated, discoverable, open and freely available and permanently archived
Engaging with Countries
Coordinating national efforts with global systems and support, understanding national needs.
Other Emerging Needs
Some new needs can already be identified and adressed (e.g. for adaptation and mitigation)
Main Inputs → Broad Engagement → Themes for Action

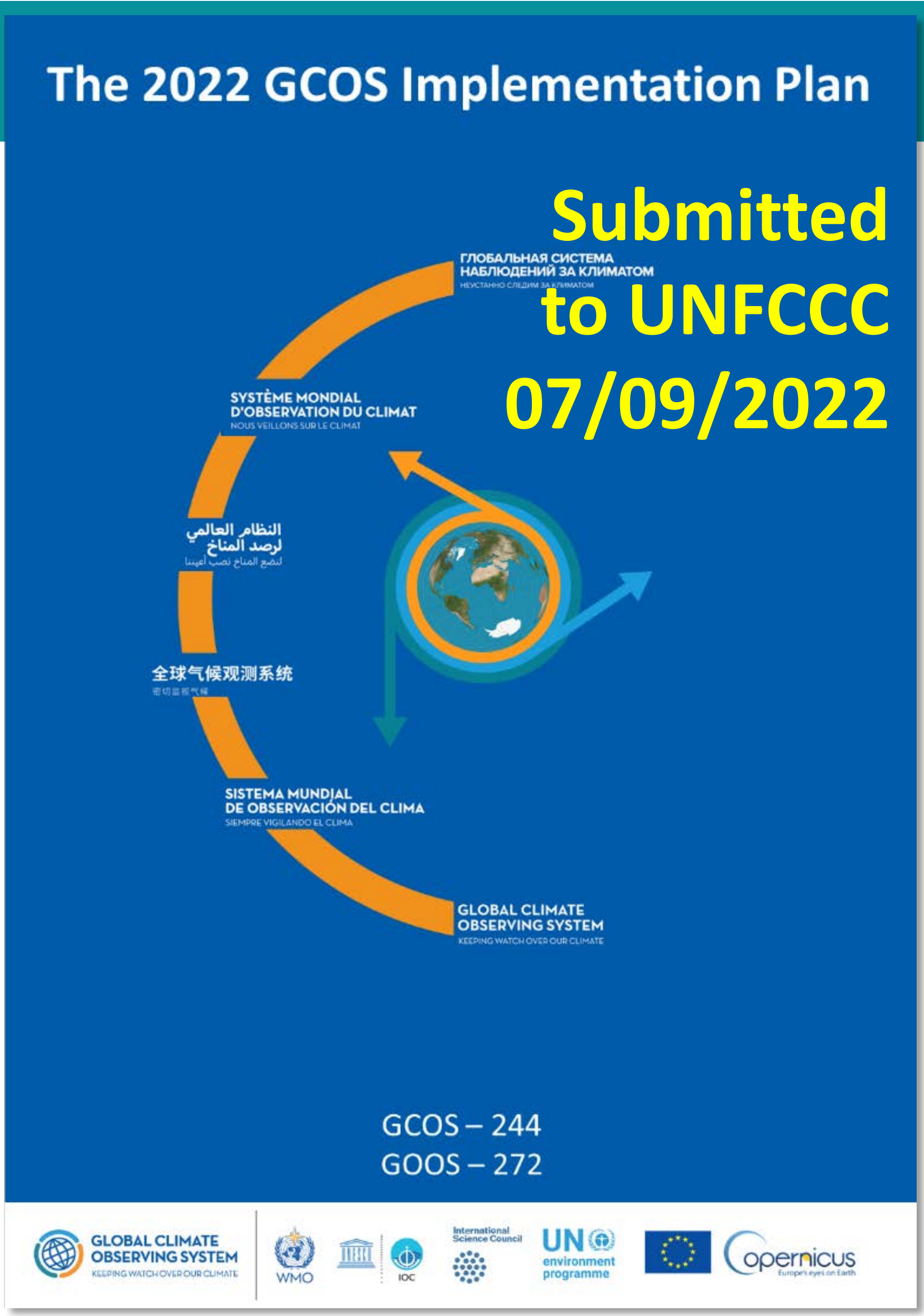
UNFCCC - through the COP and SBSTA -

have consistently recognized **GCOS**' role in coordinating and advancing Systematic Observations of climate in their Decisions and Conclusions and made direct requests to GCOS to continue its reporting cycle and report progress on a regular basis to SBSTA.



GCOS 2022 – 4th IP

- Every 5 years
- It covers the next 5-10 years
- Address gaps and improvements in the observing system.
- Provides requirements for ECVs
- Provides guidance to the component observing systems that contribute to global climate monitoring (e.g. WMO, GOOS, WGClimate, Global Terrestrial Networks, …)



GCOS IP, Ocean component

9 out of 31 Actions related to the Ocean in situ observing system

Theme	Actions	WMO	NMHS	Space agencies	GOOS	Reanalysis Centers	Global Data Centers	Research organizations	National Agencies	Parties to UNFCCC	Academia	Funding Agencies	GCOS
A: ENSURING SUSTAINABILITY	A1. Ensure necessary levels of long-term funding support for in situ networks, from observations to data delivery	x	x					x			x	x	x
	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	x	x				x				x	x
	B2. Development and implementation of the Global Basic Observing Network (GBON)	x	x		x								x
	B3. New Earth observing satellite missions to fill gaps in the observing systems			x									
	B4. Expand surface and in situ monitoring of trace gas composition and aerosol properties		x					x	x			x	
	B5. Implementing global hydrological networks	x	x	x			x						
	B6. Expand and build a fully integrated global ocean observing system		x	x	x			x	x		x		
	B7. Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters				x			x					
	B8. Coordinate observations and data product development for ocean CO_2 and N_2O	x			x			x	x				
	B9. Improve estimates of latent and sensible heat fluxes and wind stress		x	x	x			x			x		
	B10. Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles							x				x	x
C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING	C1. Develop monitoring standards, guidance and best practices for each ECV	x		x	x								x
	C2. General improvements to satellite data processing methods			x				x			x		
	C3. General improvements to in situ data products for all ECVs		x					x			x		
	C4. New and improved reanalysis products			x		x					x		
	C5. ECV-specific satellite data processing method improvements			x		x							
D: MANAGING DATA	D1. Define governance and requirements for Global Climate Data Centres	x					x						x
	D2. Ensure Global Data Centres exist for all in situ observations of ECVs	x	x		x				x			x	x
	D3. Improving discovery and access to data and metadata in Global Data Centres						x					x	x
	D4. Create a facility to access co-located in situ cal/val observations and satellite data for quality assurance of satellite products	x	x	x				x					
	D5. Undertake additional in situ data rescue activities	x	x							x		x	x
E: ENGAGING WITH COUNTRIES	E1. Foster regional engagement in GCOS	x			x					x			x
	E2. Promote national engagement in GCOS		x							x	x		x
	E3. Enhance support to national climate observations									x		x	x
F: OTHER EMERGING NEEDS	F1. Responding to user needs for higher resolution, real time data	x	x	x				x			x		x
	F2. Improved ECV satellite observations in polar regions			x				x			x		
	F3. Improve monitoring of coastal and Exclusive Economic Zones		x	x	x			x			x		
	F4. Improve climate monitoring of urban areas	x	x					x	x		x		x
	F5. Develop an Integrated Operational Global GHG Monitoring System	x		x				x	x		x		x

GCOS

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_2O	X
	B9. Improve estimates of latent and sensible heat fluxes and wind stress	X
C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY	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

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

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

Implementers	1. **WMO**, GCOS, GOOS, NMHS. 2. **GCOS**, WMO, NMHS. 3. **WMO**, GCOS, GOOS, NMHS.
Means of Assessing Progress	1. Number of GBON stations (including marine platforms in Exclusive Economic Zones (EEZs)), their geographical completeness and their continuity of data provision to data centres as well as over the WIS. 2. Assessment by GCOS of the continued relevance and role of GSN and GUAN at such time as GBON is considered to be fully implemented in its first phase with recommendations to GCOS Steering Committee. 3. GBON scope expanded to incorporate additional ECVs which are then observed on a sustained basis as part of GBON expanded operations.
Additional Details	1. In collaboration with WMO, ensure the full implementation of GBON and the associated SOFF mechanism to fill long-standing gaps to monitor climate over land and oceans. In particular, ensure that: • The initial GBON as adopted at WMO Extraordinary Congress in 2021 is implemented in full, including both surface and upper-air components; • GBON surface stations are encouraged to submit monthly and daily summaries in addition to synoptic reports; • The SOFF is used to target areas of data sparsity over land and EEZs and ensure continuity of capability.

B6. Expand and build a fully integrated global ocean observing system

Action B6: Expand and build a fully integrated global ocean observing system	
Activities	Increase the measurements of ocean ECVs into the deep ocean, under the ice and marginal seas by improving: 1. The Core Argo (ensuring that the target density is met), biogeochemical (BGC) and Deep Argo to achieve the OneArgo design. 2. The ship-based hydrography, fixed-point observations, autonomous and uncrewed observations. 3. The integration of observing networks to respond adequately to ECVs requirements.
Issue/Benefits	There are critical sampling gaps that limit the monitoring of the ocean state (for example, heat storage, carbon cycle and impacts on the biosphere). The transformation of the current Argo array to the integrated "OneArgo" array, the deployment of repeated hydrography, the deployment of fixed-point and other autonomous observing platforms and their integration aims to address these gaps by providing observations of surface and subsurface ocean properties, physical, biogeochemical, and optical properties aiming to collect ocean ECVs with an improved and very much needed global coverage. The extended in situ network will be key in closing budgets for climate cycles assessments, monitoring the state of the ocean, evaluating climate risks and impacts and guiding adaptation policies. It will be essential for calibration and validation of satellite measurements. An enhanced coverage for the ocean in situ surface and subsurface ECVs is also key for improving seamless forecasts as well as contributing to meeting the goals of the Paris Agreement.
Implementers	From 1 to 3: **GOOS**, Research Agencies, Academia, National agencies (oceanographic Institutes), Space agencies, NMHS (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	1. Number of core floats deployed to maintain the target density in the global ocean including marginal seas and polar regions; and number of Deep and BGC Argo floats operating after 5 years. 2. Increase of coverage in the global ocean of ship-based hydrography and fixed-point observations, including polar areas and marginal seas after 5 years. 3. Availability of integrated products.
Additional Details	In 2020, the Argo Steering Team endorsed a new Argo array design (called "OneArgo") that is truly global (including marginal seas and under ice), full depth, and multi-disciplinary, including Core, Deep, and biogeochemical BGC Argo floats. The estimated budget of OneArgo represents a three-fold increase in cost. OneArgo will include a novel data management system with real-time data freely shared through the GTS/WIS and high-quality datasets delivered within 12 months, supporting climate-relevant assessments, inventories, and metrics. Since 2021, OneArgo is a project endorsed by the UN Ocean Decade. Ship-based hydrography and fixed-point observations, autonomous and uncrewed are essential and complementary to Argo and further efforts must be undertaken to realise the vision of a fully integrated Ocean Observing System[43]. 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[44] 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.

B7. Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters

Action B7: Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters	
Activities	Add biological and enhanced biogeochemical sensors and field/laboratory measurements to the already existing ship-based hydrography and fixed-point observations to establish a baseline of plankton distributions and phenology (seasonal timing in phenotype and abundance).
Issue/Benefits	Some of the greatest uncertainties in the projections of future climate are associated with the response of the biosphere to present and future environmental change, and the subsequent biotic interactions, responses and feedback mechanisms. Both established and novel technologies provide the capacity to include measurements of plankton on existing coordinated observing platforms across a wide range of scale that can contribute to both the GOOS Biology and Ecosystem Essential Ocean Variables (EOVs) and the GCOS ECVs to deliver global observations. Broadening current hydrography and oceanography programs to include measurements of plankton EOVs/ECVs that can then contribute to global observing systems will assist in filling gaps in understanding of primary and secondary productivity dynamics and their role in ocean-climate interactions. It will also strengthen efforts in incorporating primary and secondary productivity and their dynamics in Earth System Models, thereby improving current capacity to forecast the response of the system under climate scenarios that are informative for policy-making and management of coastal and marine systems. Comprehensive in situ multidisciplinary measurements at scale will also support many other efforts in quantifying ocean productivity, including ocean colour radiometry, and will be complementary to other global ocean observing networks (e.g., Biogeochemical Argo, GACS) in contributing to the plankton ECVs.
Implementers	GOOS, Research organizations, (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	Increased number of ocean biological and biochemical datasets available and shared via global repositories.
Additional Details	In 2019, at the conclusion of the OceanObs'19 decadal conference, recommendations of the scientific community were to maintain and expand spatial extension of co-located physical and biological / biogeochemical observations. This development will require sustained coordinated campaigns, standardisation of some methods including data QC, data management approaches and establishment of best practices around the world. The key programs and networks are ship-based time series, local/regional/national surveys, national reference stations, GO-SHIP, OceanSITES, Ocean Color satellites, Biogeochemical Argo, GACS.
Links with other IP Actions	B8: Improve components of the global ocean observing system. F3: Expand global ocean climate in situ observations into EEZ and coastal zones.

B8. Coordinate observations and data product development for ocean CO_2 and N_2O

Action B8: Coordinate observations and data product development for ocean CO_2 and N_2O	
Activities	1. Develop a strategy and implementation plan to operationalize the data production and delivery of surface ocean CO_2 information. 2. Coordinate the existing nitrous oxide (N_2O) ocean observations into a harmonised network.
Issue/Benefits	Parties to the UNFCCC, in its Paris Agreement, have committed to conserving and enhancing sinks and reservoirs of greenhouse gases, such as CO_2 and N_2O, including oceans and coastal and marine ecosystems. As part of the Global Stocktake exercise, it will be necessary to quantify and assess both carbon emissions and natural sinks. There are already considerable national and regional efforts contributing to monitor CO_2 and N_2O in the ocean, but most of them rely on short-term research projects. A more sustained funding and better coordination will result in a better estimation of the oceanic CO_2 and N_2O emissions, an optimisation of resources of Member States and better compliance with UN agreements.
Implementers	From 1 to 2: GOOS, WMO, Research organizations, National agencies (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	1. Internationally agreed strategy and implementation plan that can be used by governments for funding decisions that enable integration of individual pilot elements to achieve the required global system. 2. a) Annually published sets of harmonised global N_2O concentration and emission fields data products; b) Initiated coordinated observing network of N_2O observations.

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

B9. Improve estimates of latent and sensible heat fluxes and wind stress

Action B9: Improve estimates of latent and sensible heat fluxes and wind stress	
Activities	**This action focuses on ice-free oceans and the terrestrial land surface** **1. Improve and extend in situ measurements needed to estimate surface fluxes, with the objectives of improving accuracy and better defining the uncertainties of those measurements and calculated fluxes.** **2. Extend sites with co-located measurements of direct turbulent and radiative fluxes and variables required to estimate turbulent surface fluxes targeted at improving parameterisations of air-sea exchange and air-land exchange.** 3. Develop new approaches over land, focusing on improved estimation of transpiration, interception and soil evaporation separately. 4. Develop new approaches and improved methods to better exploit relevant ECV measurements to estimate ocean surface heat, moisture and momentum flux including: a) Better integration of in situ and satellite measurements, data assimilation, fusion techniques, ensuring consistency between different types of measurements and their harmonisation; b) Development and deployment of new satellite missions that are tuned to maximise the sensitivity to the state variables needed to estimate heat flux over the ocean and land; c) Increase and improvements in satellite observations that target both the surface parameters and the near-surface air-parameters; d) Simultaneously use of an approach based on high resolution numerical models (Large Eddy Simulation (LES)) to augment satellite product validations; e) Include in future intercomparison campaigns of latent and sensible heat fluxes measurements inferred from simultaneous observations with a water vapour differential absorption lidar (WVDIAL), a Doppler wind lidar and temperature from rotational Raman lidar.

Issue/Benefits	Understanding and estimating surface fluxes is essential for improving projections of climate change and planning adaptation and response measures. The need for surface, near surface, and boundary layer information, across different temporal and spatial scales for multiple disciplines, has outstripped the capabilities of existing observing networks. Direct observation of surface turbulent (sensible, latent and momentum) fluxes is difficult and costly and globally impractical. For global coverage it is therefore necessary to estimate the surface heat and momentum fluxes using empirical parameterisations based on other ECVs (including surface temperature, near surface air temperature and humidity, near surface wind speed and direction). To improve the parameterizations, and quantify uncertainty, high quality in situ measurements of both direct fluxes and collocated ECVs used to calculate the fluxes are needed at key representative locations. Improvement of estimates of ocean surface heat, moisture and momentum flux requires integrating in situ and satellite observations, use of data assimilation and fusion techniques. New and improved methods need to be developed to better achieve this integration.

t and sensible heat fluxes and wind stress

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[3]. Spatio-temporal mismatches in sampling of ECVs required for flux estimation should be minimised to reduce errors in the heat flux estimation resulting from the combination of observations sampled at different times, or with different spatial footprints. Further advances in the field of global terrestrial evaporation monitoring should include developments in microwave remote sensing and high-resolution optical platforms (Fisher et al., 2017)[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. 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.

C1. Develop monitoring standards, guidance and best practices for each ECV

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.

D2. Ensure Global Data Centres exist for all in situ observations of ECVs

Action D2: Ensure Global Climate Data Centres exist for all in situ observations of ECVs	
Activities	**1. Identify ECVs for which adequate global centres do not exist or are insufficiently supported and facilitate and support the creation or improvement of global data centres for these ECVs.** **2. Promote regional data centres, their interoperability, where possible, synchronisation of their data holdings, and the provision of data in their archives to global data centres.**
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	1. a) List of climate data centres, identifying those in need of additional support followed by annual reports by GCOS panels on data centres at risk; b) List of ECVs for which no data centre exists, followed by annual updates on progress towards filling the identified gaps. 2. Establishment of a functional network of regional data centres for all ECVs of relevance in the region and their synchronisation with global data centres.
Additional Details	1. Global Climate Data Centres need to maintain and construct long-term time series of ECV data and to archive and disseminate these time series for the long term, at least several decades following the requirements established as part of Action D1. The maintenance of these data centres requires long-term assured funding. The first step is to identify all existing data centres and the status of their funding. ECVs for which data centres are missing need to be identified, and the relevant GCOS panels should advocate for the establishment of the missing centres. GCOS should also make a clear case for adequate funding of data centres and the benefits that will accrue. For example, sustained funding is urgently needed for the Global Ocean Data Analysis Project (GLODAP), where ocean biogeochemistry data is collected and stored. Despite a recent increase in the quantity of these observations GLODAP is a largely unfunded community effort. Such a situation is unsustainable, and there is a significant risk that the effort will diminish or disappear in the next few years. Following an initial assessment of adequacy, it is necessary to continuously review the health of the network of global data centres. GCOS panels should annually review the status of global data centres within their domain and highlight any issues so that these can be remedied. 2. The Global data centres are part of a network of data centres that include regional data centres and in some cases the observation networks. These need to be integrated into a global system to improve data exchange and data availability. They should also follow the requirements developed in Action D1. Sustainable funding of regional data centres and observation networks is key. Working with Regional Associations and Regional WIGOS Centres, GCOS should advocate for regional level data collection and curation which may then be passed on to the extent possible for inclusion in global data centre collections. This action focuses on in situ data. Information about satellite-based climate data records can be found in the ECV inventory.
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.

E1. Foster regional engagement in GCOS

Action E1: Foster regional engagement in GCOS	
Activities	**1. Undertake at least one regional GCOS Workshop each year.** **a) Promote the benefits of coordination of climate observations (in situ and satellite) and GCOS programs.** **b) Explore regional issues, gaps and needs and develop plans to address them.** **2. Report regional needs and issues to the UNFCCC, WMO and other relevant stakeholders.**
Issue/Benefits	Lack of regional and national input into global observing decisions can make GCOS seem remote from implementers "on the ground" and leaves GCOS unable to fully understand and respond to the issues facing observing systems at a local level. There is a need to better integrate GCOS needs into national and regional decision making to ensure sustainable observations for climate. These activities will better inform the global system of local needs and link local observing systems with international support and capacity development. They can also provide some capacity development, explain the needs and uses of climate data and help ensure that countries have access to all the data. For example, GBON and SOFF were developed from needs identified in a GCOS regional workshop on climate observations systems in the Pacific Island states[9].
Implementers	From 1 to 2: **GCOS**, Parties to the UNFCCC, WMO (Regional Organizations), GOOS (Regional Alliances).
Means of Assessing Progress	1. Number of regional workshops held annually in collaboration with WMO and other stakeholders. 2. Reports to UNFCCC and WMO.
Additional Details	This work can be done with WMO Regional Organizations and GOOS Regional Alliances, as appropriate. Other stakeholders should be considered: in the past Copernicus has supported regional workshops. 1. Regional workshops engage countries directly. Engagement of countries needing support and more experienced countries will be beneficial. Involving both those making observations and those from the climate policy sphere will allow the workshops to identify issues and potential solutions and will also inform the countries about how observations support services and policy development. An important part of obtaining support, financial and political, for climate observations is providing a rationale for the observations and a clear description of the benefits. International coordination and data exchange enhance these benefits. Regional workshops should agree to regional needs, gaps and develop plans to address these needs. 2. A key component will be reports to appropriate stakeholders, especially the UNFCCC and WMO on needs and issues. The discussions of these reports, and decisions based upon them, will enhance the implementation of observation systems.

F3. Improve monitoring of coastal and Exclusive Economic Zones

Action F3: Improve monitoring of coastal and Exclusive Economic Zones	
Activities	**1. Expand global ocean climate in situ observations and satellite products into Exclusive Economic Zones (EEZs) and coastal zones.** 2. Develop new satellite-based products for coastal biogeochemistry. 3. Produce land cover datasets in coastal areas without land surface masks and in near real time, including uncertainties. **4. Improve national coastal and EEZ data collection, data processing, uncertainty evaluation and data curation by improving access to equipment and ensuring local practices are consistent with the global guidelines and best practices.**
Issue/Benefits	Monitoring of coastal zones and EEZs is necessary to allow policies and measures to be developed to protect the significant vulnerable populations, infrastructure and ecosystems in these areas. Coastal zones are subject to rapid change and are the home to a substantial part of the Earth's population and to sensitive ecosystems. Changes near the coast directly impact ecosystems, people's health and livelihoods. Impacts such as storms, sea level rise, coastal erosion and inundation, flooding and saltwater intrusion are increasing. Currently these areas are poorly observed. Most of the purposely designed arrays of instrumentation and high resolution hydrographic transects (such as GO-SHIP) or the Argo program provide ocean observations at the open ocean, and the coastal and national waters are poorly monitored in many regions. From the land side, observations are directed at land properties and cover and so do not capture all the changes that are occurring. This action aims 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.
Implementers	1. **GOOS**, Space agencies, NMHS. 2. **Space agencies,** Research organizations, Academia. 3. **Space agencies.** 4. **GOOS,** NMHS, Research organizations.

Means of Assessing Progress	1. Increased density of observations and reprocessed products in EEZ and coastal waters, and related uncertainties. 2. Number of global operational biogeochemical products in coastal areas. 3. Number of land-cover data sets produced without masks. 4. Published national and regional guidelines.
Additional Details	1. Coastal regions are where boundary currents and upwelling regimes modulate fluxes of heat, carbon and other properties, with small-scale phenomena highly impacting the climate globally and locally, and also ecosystems. Not all observing systems used elsewhere, such as Argo, can provide high-resolution full-depth monitoring in coastal areas. Argo measurements do not sample at shelf-shelf break regions (< 2000 m depth). Consolidation and development of in situ observing networks could be done through national and regional engagements, including local actors from certain sectors such as fisheries or maritime transport. Activity 1 should consider the on-going discussions and efforts to facilitate access to the EEZs to carry out systematic ocean observations, as reflected on a recent multi-agency workshop lead by UNESCO/IOC[10]. A successful implementation of GBON can increase the number of surface marine meteorological observations collected by member states in their respective EEZs. At the coast, "climate quality" tide gauge observations that include co-located vertical land motion measurements are needed for our understanding of contemporary and future coastal flood hazard. Finally, reprocessing of existing satellite records in coastal regions and generation of global products which include the coastal regions (e.g. altimetry and wind data records) is needed to increase coverage near the coast, which may require some software development. Products should include clear information on their limitations in coastal areas and EEZs, and their related uncertainties. 2. There are currently no biogeochemical operational products from high resolution satellites (e.g., Sentinel 2AB, Landsat 8) in coastal areas. Satellite observations need to be reprocessed to provide products for variables such as the temperature, turbidity, chlorophyll, and chromophoric dissolved organic matter (CDOM). 3. Land cover datasets should be reprocessed without masking to allow the detection of changes at the coastline. This activity will allow extremes and long-term trends such as sea-level rise to be captured (e.g. changes in the coastline and neighbouring land areas). Currently, impacts of changes in the sea level at the coast are not monitored because the way satellite observations are processed obscures these details. 4. Many coastal states lack access to equipment and expertise to monitor their coastal water and areas within their EEZs. Resources for equipment and capacity building are needed. In 2022 a task team has been set up under the IOC Ocean Best Practices framework[11], 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.

Ocean Observations Physics and Climate Panel (OOPC)

- Maintaining and periodically reviewing the **list of GCOS Essential Climate Variables (ECVs) and GOOS Essential Ocean Variables (EOVs)**.
- Specifying and reviewing **requirements for sustained ocean observations**.
- Reviewing the current state and **identify gaps and inadequacies of the global ocean observing system**.

- Working on **strategies for developing and improving the sustained ocean observing system,** including harnessing new technologies.
- Helping in **promoting the establishment of sustainable observation networks and the use of best practices**.

GCOS · GOOS · WCRP OOPC Ocean Observations Physics and Climate panel

how the current global climate observing system can be improved to better support current and near-term user needs for climate information

… so, let's work together!

Thank you

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

WMO IOC International Science Council UN environment

Supported by the European Union
Copernicus Europe's eyes on Earth