New Developments from the Terrestrial Observation Panel for Climate - TOPC

GCOS • WCRP TOPC

Antonio Bombelli, GCOS Secretariat
(on behalf of the TOPC panel)

ESA CCI Colocation meeting

26-27 October 2022, ESA-ESRIN, Frascati, Italy

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

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New Developments from TOPC – PPT Outline

1- intro on TOPC

2- GCOS IP, TOPC and Space Agencies

3. Terrestrial ECVs requirements

GCOS 3 Panels

GCOS

Atmosphere – AOPC

Ocean – OOPC

Land – TOPC

TOPC - Terrestrial Observation Panel for Climate

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TOPC AIMS

To develop a balanced and integrated system of

air - in situ - space borne

observations of the terrestrial ecosystems for long-term monitoring of land

- Biosphere
- Cryosphere
- Hydrosphere
- Anthroposphere

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properties and attributes which: i) control the physical, biological and chemical processes affecting climate

ii) are themselves affected by climate change, are indicators of climate change and provide information on impacts of climate change.

TOPC - Terrestrial Observation Panel for Climate

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TOPC activities:

- identification of terrestrial observation requirements
- assisting the establishment of observing networks (in-situ, air borne and satellite-based)
- providing guidance on observation standards and norms
- facilitating access to climate data and information and its assimilation
- encouraging the use of best practices and promoting climate studies and assessments.

ESA CCI ⇒ 11 terrestrial ECVs + 2 candidates (+ RECCAP-2)

ECV	ECV Product 2022
Groundwater	Groundwater Storage Change
	Groundwater Level
Lakes	Lake Water Level (LWL)
	Lake Water Extent (LWE)
	Lake Surface Water Temperature (LSWT)
	Lake Ice Cover (LIC)
	Lake Ice Thickness (LIT)
	Lake Water-Leaving Reflectance
River Discharge	River Discharge
	Water Level
Soil Moisture	Surface Soil Moisture
	Freeze/Thaw
	Surface Inundation
	Root Zone Soil Moisture
Terrestrial Water Storage[1]	Terrestrial Water Storage Anomaly
Snow	Area Covered by Snow
	Snow Depth
	Snow-Water Equivalent
Glaciers	Glacier Area
	Glacier Elevation Change
	Glacier Mass Change
Ice Sheets and Ice Shelves	Surface Elevation Change
	Ice Velocity
	Ice Volume Change
	Grounding Line Location and Thickness
Permafrost	Permafrost Temperature (PT)
	Active Layer Thickness (ALT)
	Rock Glacier Velocity (RGV)

ECV	ECV Product 2022
Fraction of FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
Leaf Area Index	Leaf Area Index (LAI)
Albedo	Spectral and Broadband (Visible, Near Infrared and Shortwave) DHR & BHR with Associated Spectral Bidirectional Reflectance Distribution Function (BRDF) Parameters
Land-Surface Temperature	Land Surface Temperature (LST)
	Soil Temperature[1]
Above-Ground Biomass	Above-Ground Biomass (AGB)
Land Cover	Land Cover
	Maps of High-Resolution Land Cover
	Maps of Key IPCC Land Classes, Related Changes and Land Management Types
Soil Carbon	Carbon in Soil
	Mineral Soil Bulk Density
	Peatlands
Fire	Burned Area
	Active Fires
	Fire Radiative Power (FRP)

ECV	ECV Product 2022
Anthropogenic Greenhouse-Gas Fluxes	Anthropogenic CO_2 Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use
	Anthropogenic CH_4 Emissions from Fossil Fuel, Waste, Agriculture, Industrial Processes and Fuel Use
	Anthropogenic N_2O Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use, Indirect from N-Related Emissions/Depositions
	Anthropogenic F-Gas Emissions from Industrial Processes and Product Use
	Total Estimated Fluxes by Coupled Data Assimilation/Models with Observed Atmospheric Composition – National
	Total Estimated Fluxes by Coupled Data Assimilation/Models with Observed Atmospheric Composition - Continental
	Anthropogenic CO_2 Emissions/Removals by Land Categories
	High-Resolution Footprint Around Point Sources
Evaporation from Land	Sensible Heat Flux
	Latent Heat Flux
	Bare Soil Evaporation
	Interception Loss
	Transpiration
Anthropogenic Water Use	Anthropogenic Water Use

Current ESA-CCI ECVs

RECCAP-2

Candidate ESA-CCI ECVs

GCOS WMO IOC UN environment

New GCOS Terrestrial ECVs

Terrestrial		
ECV	ECV Product 2016	ECV Product 2022
Groundwater	Groundwater Volume Change	Groundwater Storage Change
	Groundwater Level	Groundwater Level
	Groundwater Recharge	
	Groundwater Discharge	
	Wellhead Level	
	Water Quality	
Lakes	Lake Water Level	Lake Water Level (LWL)
	Water Extent	Lake Water Extent (LWE)
	Lake Surface-Water Temperature	Lake Surface Water Temperature (LSWT)
	Lake Ice Cover	Lake Ice Cover (LIC)
	Lake Ice Thickness	Lake Ice Thickness (LIT)
	Lake Colour (Lake Water-Leaving Reflectance)	Lake Water-Leaving Reflectance
River Discharge	River Discharge	River Discharge
	Water Level	Water Level
	Flow Velocity	
	Cross-Section	
Soil Moisture	Surface Soil Moisture	Surface Soil Moisture
	Freeze/Thaw	Freeze/Thaw
	Surface Inundation	Surface Inundation
	Root-Zone Soil Moisture	Root Zone Soil Moisture
Terrestrial Water Storage		Terrestrial Water Storage Anomaly
	Area Covered by Snow	Area Covered by Snow

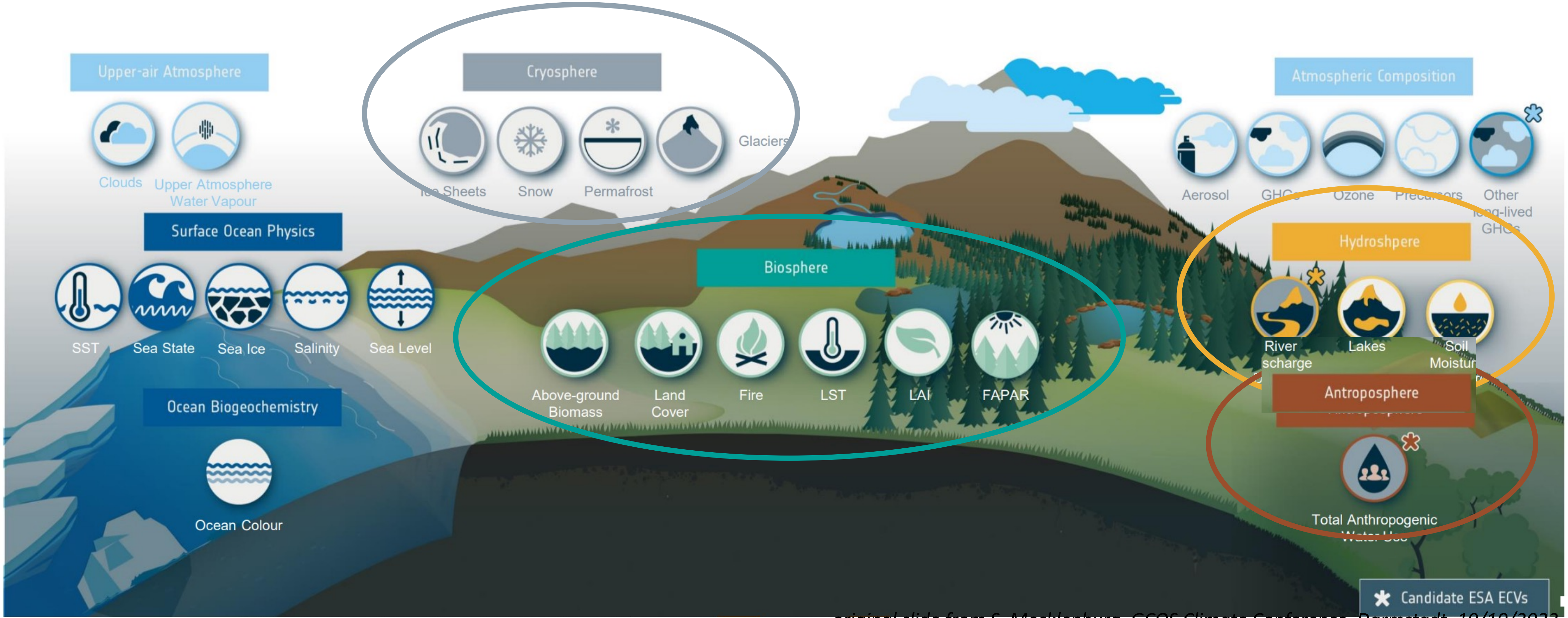
GCOS WMO

terrestrial ECVs

ESA's Climate Change Initiative ECVs

GCOS defined **54** Essential Climate Variables | **36** benefit from space observations | **23** generated by ESA Climate Change Initiative

...and SIF?



original slide from S. Mecklenburg, GCOS Climate Conference, Darmstadt, 19/10/2022

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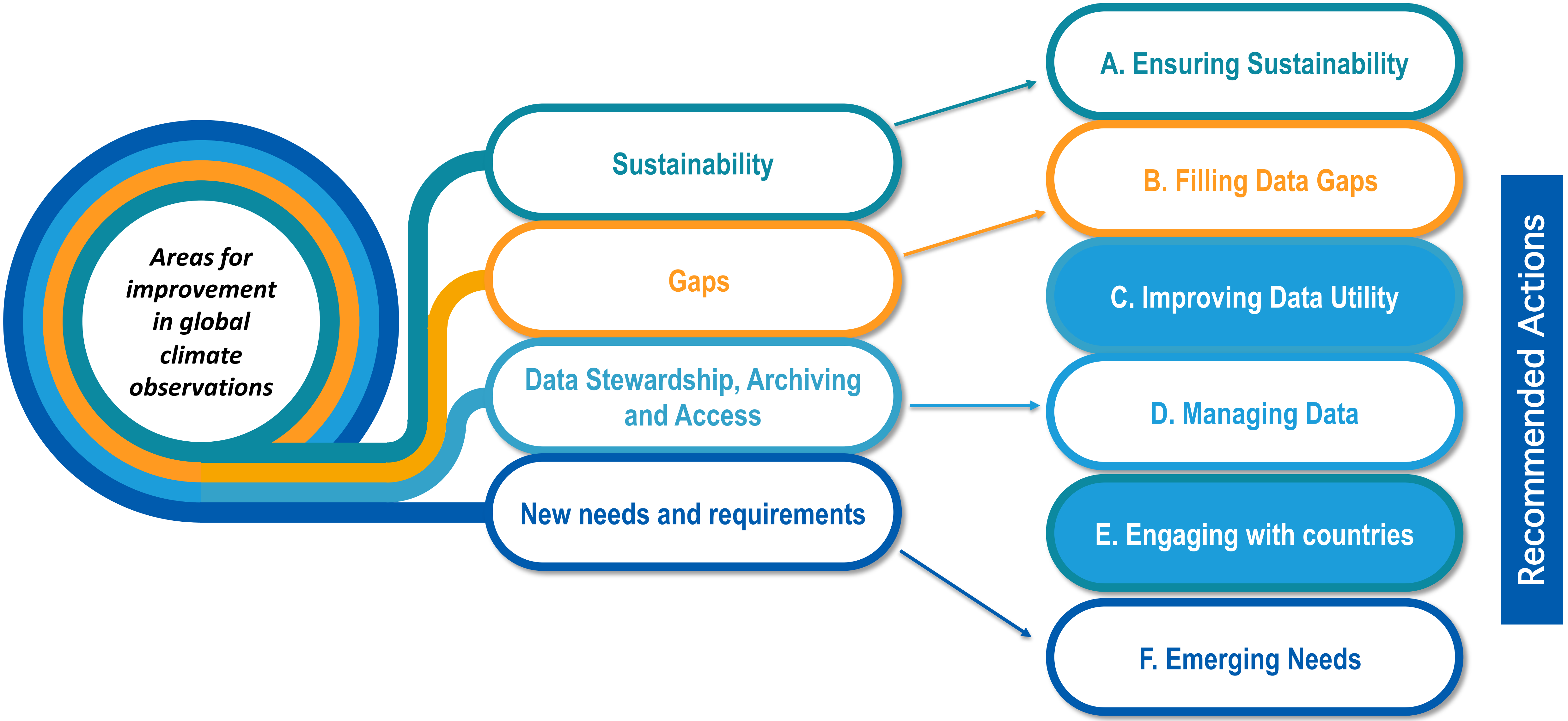
TOPC: highlights from the new GCOS-IP

Particular emphasis on:

- Integrated approach (1) for IP Actions: going beyond the “individual” ECV monitoring, addressing more ECVs in different domains (more coordination across GCOS panels)
- Integrated approach (2) for global climate observations, considering energy, water and carbon cycles, cutting across the atmosphere, ocean and land domains (more coordination across GCOS panels)
- EO feeding models / models complementing observations.
- Addressing critical gaps to establish long-term records (i.e. biomass)
- Expanding and sustaining ground reference networks (incl. fiducial reference measurements)
- Evolving requirements for more rapid data delivery (incl. near-real time) to make ECV records more useful and actionable, addressing climate change mitigation and adaptation
- Transforming original observational data into user-relevant information: integrating different individual ECV records driven by policy requirements like AFOLU, GHG monitoring, climate change adaptation

Themes for action identified in the GCOS IP



GCOS Status Report

GCOS IP

GCOS IP and Space Agencies

31 actions
16 (>50%) relevant to Space Agencies

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

GCOS IP, Space Agencies and terrestrial ECVs

Action A2: Address gaps in satellite observations likely to occur in the near future	
Activities	Urgent actions are needed to ensure continuity of the following satellite observations: 1. Altimetry in the polar regions – **ECV Ice sheets** 2. Gravimetry missions – **ECV TWS, Terrestrial Water Storage** 3. Biomass measurements – **ECV Above Ground Biomass** 4. Limb-sounding missions capable of measuring several ECV species in the Upper Troposphere/Lower Stratosphere (UTLS) and stratosphere 5. Sea Surface Salinity (SSS) measurements 6. Wind lidar 7. Global scale ice surface elevation – **ECV Glaciers**
Issue/Benefits	Monitoring of many ECVs which are critically important to climate science are now dependent on satellite observations. There is a real danger that some observations will stop in the next 5-10 years, or even sooner for missions that have already exceeded their expected lifetime. The continuity of these measurements is essential to develop and extend the long time series needed for climate monitoring.

GCOS IP, Space Agencies and terrestrial ECVs

Action A2: Address gaps in satellite observations likely to occur in the near future	
Implementers	From 1 to 7: **Space agencies**
Means of Assessing Progress	From 1 to 7: Established plans of Space agencies that ensure the continuation of satellite missions for altimetry, gravimetry, biomass, limb-sounding, sea surface salinity, wind lidar, global scale ice surface elevation.
Additional Details	These address some of the gaps identified in the GCOS Status Report. 1. Sea surface height has been measured with satellite altimeters since 1992 usually with a 2-satellite configuration as a baseline. Several missions are currently in operation or designed for the near future including Jason-3, Sentinel-3 SRAL, Sentinel-6 series and the Copernicus expansion missions (CRISTAL and SNG-topography). In order to address the potential future gap in polar satellite altimetry, alternative approaches should be explored, including the lifetime extension of CryoSat-e or ICESat-2; an alternative satellite manoeuvred into a high-inclination orbit; the acceleration of CRISTAL and/or S3NG-T launches; or a systematic airborne measurement programme as a bridging capacity. Without successful mitigation, there will be a gap of between 2 and 5 years in our polar satellite altimetry capability. This would jeopardise long-term records of ice sheet and sea ice thickness change and polar oceanography. 2. Satellite gravimetry missions provide critical ECVs data, including for sea level, terrestrial water storage (TWS) and ice sheet monitoring. There is also potential for data from this source to supersede or complement the assessment of existing low (time and space) resolution anthropogenic water use and groundwater monitoring, or to serve early warning systems for large-scale flood events or drought monitoring and forecasts. Current and past measurements originate from Gravity Recovery and Climate Experiment (GRACE) during 2002-2017, GOCE (2009-2013) and the GRACE-FO (2018 – until now). ... continue ...

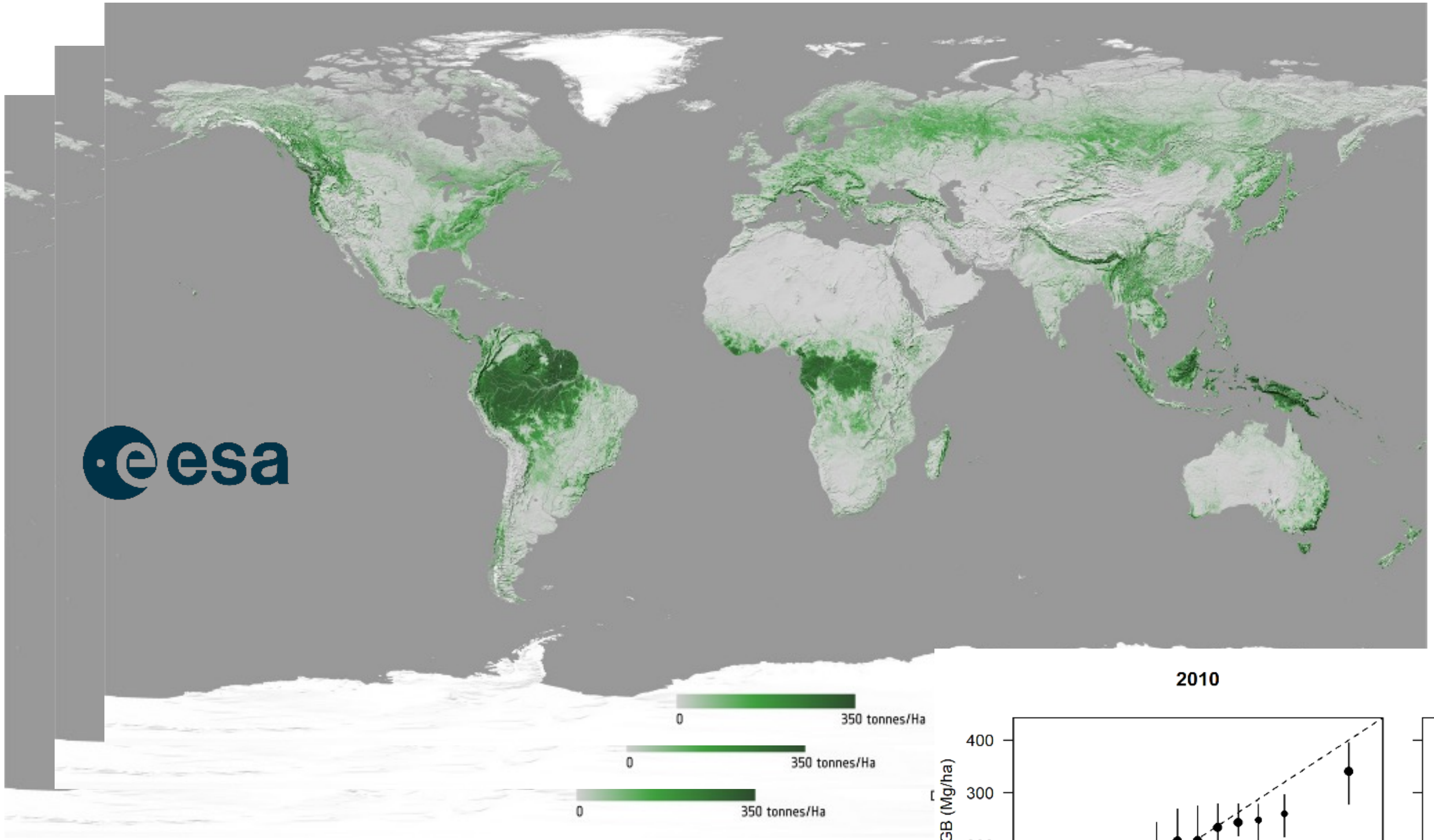
GCOS IP, Space Agencies and terrestrial ECVs

Action A2: Address gaps in satellite observations likely to occur in the near future	
Additional Details	2. ... continuation ... Feasibility studies for next-generation gravity missions with potentially higher spatial and/or temporal resolution are underway at Space agencies, but the realisation of such missions for ensuring the long-term climate records is not assured. 3. Biomass: Space-based estimates of aboveground biomass and associated carbon stocks and changes are essential to monitor this ECV globally. Several dedicated satellite missions (such as NASA-GEDI/ICESAT/NISAR, ESA-BIOMASS, JAXA-MOLI) have been developed and are operating but none of them are part of a dedicated programme for regular, high-quality biomass monitoring in the long-term. Agencies and the EU Copernicus programme are encouraged to explore synergy and harmonise among available mission data and put in place a coordinated, continuous and consistent space-based biomass observation programme for global and national monitoring of aboveground biomass and associated carbon stock changes. 4. ... 7. The freely available optical stereo data, such as those from Terra ASTER, are coming to an end of its lifetime and there are no plans for a replacement, that would be urgently required for the continuation of the dataset on global ice surface elevation.
Links with other IP Actions	Satellite observations are related to many other actions. In particular: C5 (Activity 2): enhancement biomass estimation at global and subnational levels. F1 (Activity 2): higher-resolution biomass data. F2 (Activity 1): sea surface salinity in polar regions.

GCOS IP, Space Agencies and terrestrial ECVs

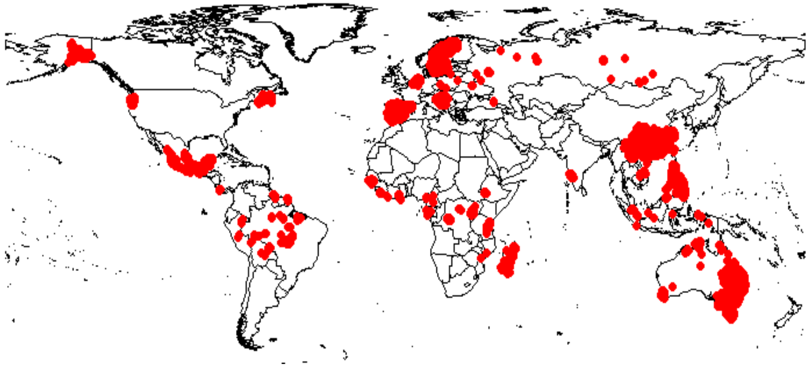
Action B1: Development of reference networks (in situ and satellite Fiducial Reference Measurement, FRM, programs)	
Activities	3. Better align the satellite FRM program to the reference tier of tiered networks and enhance / expand FRM to fill gaps in satellite cal/val.
Issue/Benefits	The FRM programs of satellite agencies have been carried out independent of broader concerns around tiered network design, yet these measurements should be sustained as part of reference networks and not be funded or considered separately from broader observational strategies. There is also a need to undertake additional FRM measurements to fill critical cal/val capability gaps for some ECVs.
Additional Details	Networks and additional FRM measurements to fill gaps to support satellite cal/val of ECVs: • Ground-based in situ measurements of above-ground biomass and vegetation dynamics; • Ground-based time-series in situ measurements of surface albedo, FAPAR and LAI; • An open-access network of sites for burned area products.
	Relevant ECVs: Biomass, Fire, FAPAR and LAI

Importance of space-based & on-the-ground biomass monitoring

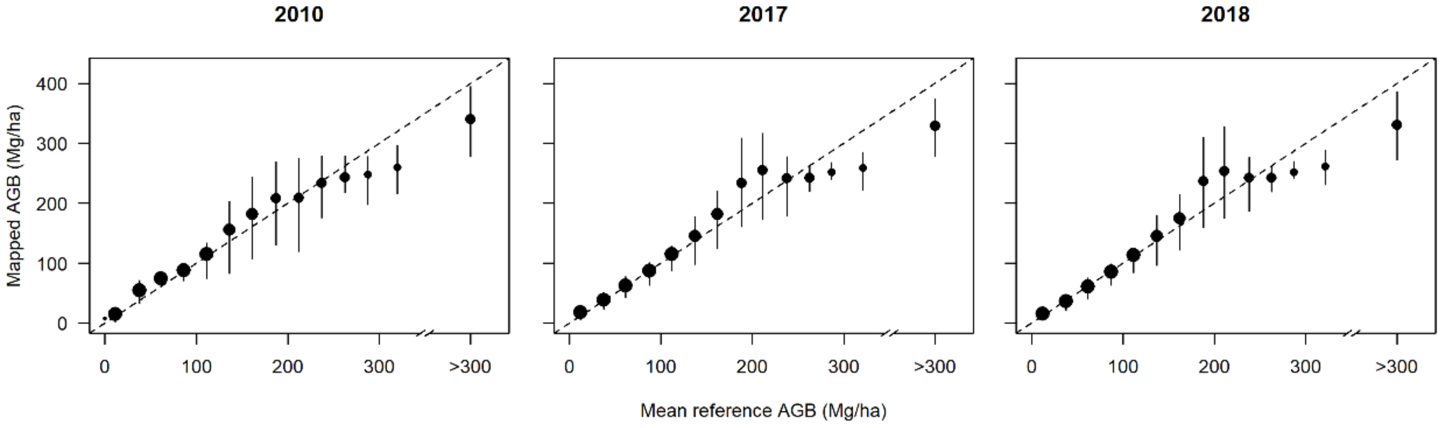


Global aboveground biomass for 2010, 2017, 2018, 2020 at 100m spatial resolution, http://cci.esa.int/biomass
Santoro et al., 2021, ESSD

Global reference database (~109.000 plots)



Biomass harmonization for Global Stocktake
UNFCCC COP 26 dashboard (incl. country case studies):
https://ceos.org/gst/
https://earthdata.nasa.gov/maap-biomass



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GCOS IP, Space Agencies and terrestrial ECVs

Action B3: New Earth observing satellite missions to fill gaps in the observing systems	
Activities	1. Improve diurnal sampling of observations and coverage of GHGs, precursor aerosols, and solar-induced fluorescence (SIF) to improve estimation of emissions and vegetation carbon uptake 5. Develop operational techniques to estimate permafrost extent. **Relevant ECVs: Biomass, FAPAR, LAI, Permafrost and future(?) SIF**

Action B5: Implementing global hydrological networks	
Activities	1.b Increase the number of in situ river level observations that are exchanged internationally and can be used to calibrate satellite observations of water levels. **Relevant ECV: River Discharge**

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. **Relevant ECVs: all!**

GCOS IP, Space Agencies and terrestrial ECVs

Action C5: ECV-specific satellite data processing method improvements	
Activities	1. Generate timely permafrost, land cover change, burnt area, and fire severity/burning efficiency products from high resolution data satellite observations (e.g. Sentinel1/-2 and Landsat). 2. Produce harmonised and validated Above Ground Biomass (AGB) and change datasets from different satellite data streams, for enhancing aboveground biomass estimation at global and (sub-national) levels. 3. Ensure that the Bidirectional Reflectance Distribution Function (BRDF) parameters are provided together with surface albedo. 6. Improve consistency of the inter-dependent land products. **Relevant ECVs: Biomass, Fire, Land Cover, Permafrost**

Action F1: Responding to user needs for higher resolution, near real time data	
Activities	2. Improve biomass, land cover, land surface temperature, and fire data with sub-annual observations and improved local detail and quality. **Relevant ECVs: Biomass, Fire, Land Cover, Land Surface Temperature**

GCOS IP, Space Agencies and terrestrial ECVs

Action F3: Improve monitoring of coastal and Exclusive Economic Zones	
Activities	1. Develop new satellite-based products for coastal biogeochemistry. 2. Produce land cover datasets in coastal areas without land surface masks and in near real time, including uncertainties. **Relevant ECVs: Land Cover**

Action F5: Develop an Integrated Operational Global GHG Monitoring System	
Activities	The overall aim here is to develop an integrated operational global greenhouse gas monitoring infrastructure. The first steps are: 2. Design a constellation of operational satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible). 4. Improve and coordinate measurements of relevant ECVs at anthropogenic emissions hotspots (large cities, powerplants) to support emission monitoring and the validation of tropospheric measurements by satellites. **Relevant ECV: Anthropogenic GHG Fluxes**

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Terrestrial ECVs requirements – an example: LAI -1

Name	**Leaf Area Index (LAI)**
Definition	Leaf Area Index of a plant canopy or ecosystem is defined as one half of the total green leaf area per unit horizontal ground surface area and measures the area of leaf material present in the specified environment (projection to the underlying ground along the normal to the slope).
Unit	$m^2\ m^{-2}$
Note	Effective Leaf Area Index is the LAI value that would produce the same indirect ground measurement as that observed assuming foliage distribution (LAIeff=LAItrue x canopy clumping index). The conversion of data measurements to true values is an essential step and requires additional information about the structure and architecture of the canopy, e.g. gap size distributions, at the appropriate spatial resolutions. Leaf Area Index controls important mass and energy exchange processes, such as radiation and rain interception, as well as photosynthesis and respiration, which couple vegetation to the climate system. Length of record: Threshold: 20 years; Target: >40 years.

Terrestrial ECVs requirements – an example: LAI -2

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	M		G	10	For (e.g.) climate adaptation and agricultural monitoring Best practices published here: http://www.qa4ecv.eu/sites/default/files/D4.2.pdf
			B	100	
			T	250	For regional and global climate modeling
Vertical Resolution				-	N/A. In theory, a vegetation canopy can be stratified into various layers to describe its vertical structure in a discrete way. However actual methods of LAI observation, e.g. optical sensors, can only measure the total canopy leaf area index. Therefore, no requirements for vertical resolution are set.
				-	
				-	
Temporal Resolution	D		G	1	When assimilated by model, this value corresponds to the climate model temporal resolution (to derive a better phenology accuracy).
			B		
			T	10	When using for crops or ecosystems modeling, or Land Surface / Earth System Model evaluation.
Timeliness	d		G	1	For climate change services.
			B	5	For environmental change services. Can be longer (~months) for historic climate/environmental change assessments.
			T	10	For NWP (ECMWF)

Terrestrial ECVs requirements – an example: LAI -3

Required Measurement Uncertainty	% or $m^2\ m^{-2}$	1 sigma	G	10% for values ≥0.5; 0.05 (absolute value) for smaller values	One standard deviation or error covariance matrix with associated PDF shape (functional form of estimated error distribution for the term). The goal value of uncertainties were assessed through literature review of impact of climate change on LAI using various earth system models (see Mahowald, et. al., 2016; https://www.earth-syst-dynam.net/7/211/2016/). They show impact on LAI deviation at global scale using various RCP scenarios. If we take the models ensemble results, we demonstrate that the uncertainties should be less than Delta_LAI ~0.20 for a 2 deg. C deviation for an annual average LAI, that can be approximated to ~1.5. This means that the uncertainties should be smaller than 10% (~0.20/1.87*100.).
			B		
			T	20% for values ≥0.5; 0.1 (absolute value) for smaller values	Same as above but with Delta_LAI ~0.25 Delta_LAI ~0.25

Stability	$m^2\ m^{-2}$ / decade	A factor of uncertainties to demonstrate that the 'error' of the product remains constant over at least a decade	G	<3%	The unit is rate of change of LAI over the available time period. 'The required stability is some fraction of the expected signal' (see Ohring, et. al. 2005). "It may represent a requirement on the extent to which the error of the product remains constant over a long period, typically a decade or more. It can be defined by the mean of uncertainties over a month …". In the case that we have data over 10 years (= one decade) N=10 and U=10% S=sqrt(sum(U^2))/N. Assuming U constant along the period It means S=SQRT(N*U^2)/N=SQRT(N)*U/N S=0.3*U = 0.31 * 10/100.0 = 3 % This number should be smaller than expected LAI trend. Ref: Jiang et al. 2017.
			B		
			T	<6%	Same as above but with threshold uncertainty.
Standards and References	Fang, H., Baret, F., Plummer, S., & Schaepman-Strub, G. (2019). An overview of global leaf area index (LAI): Methods, products, validation, and applications. Reviews of Geophysics. 57, 739– 799. https://doi.org/10.1029/2018RG000608 Boussetta S., Balsamo G., Dutra E., Beljaars A., Albergel C. (2015) Assimilation of surface albedo and vegetation states from satellite observations and their impact on numerical weather prediction				

TOPC – What's next?

- TOPC panel membership's renewal
- TOPC new work plan, aligned with the GCOS-IP
- Joint Panels meeting next year (June 2023) to work on the GCOS-IP with an integrated approach
- Engage with Satellite community, as well as GTNs, to address the GCOS/TOPC work plan

Way forward

- Both space-based and in situ observations are needed: TOPC to liaise between the two
- GCOS encourages Space Agencies and related monitoring programs to implement the IP actions – with our support, of course!
- ESA-CCI can play a key in the GCOS-IP implementation, so... let's work together*!

* CCI leaders and TOPC members:

Darren Ghent, Scientific leader, LST

Emilio Chuvieco, Scientific Lead, Fire

Jean-François Crétaux, Scientific Lead, Lakes

Martin Herold, Science Team, Biomass and Land Cover

Michael Zemp (GCOS SC), Climate Research Group (CRG), Glaciers

Wouter Dorigo, Scientific leader, Soil moisture

TOPC – What's next?

ESA CCI Meeting, 26/10/2022

Some issue emerged today

Linking EVCs across ESA-CCI and GCOS:

- Working on (checking and improving) the ECVs requirements
- Gap analysis: new ECVs variables and/or products
- Cross ECVs approach: to respond to PA and to ensure consistency across ECVs products
- Foster information exchange between ECVs groups
- Improve ECVs visibility and impact

… so, let's work together!

Thank you!

ESA CCI Colocation meeting
26-27 October 2022. ESA-ESRIN
Frascati, Italy

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GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

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