Essential Geodetic Variables and Gap Analysis

Richard S. Gross

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, USA

GGOS Days

October 31 to November 2, 2017
Vienna, Austria

Essential (Climate / Ocean / Geodetic) Variables

GCOS was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is co-sponsored by the

- World Meteorological Organization (WMO),
- Intergovernmental Oceanographic Commission (IOC) of United Nations Educational, Scientific and Cultural Organization (UNESCO),
- United Nations Environment Programme (UNEP), and
- International Council for Science (ICSU).

The terms of reference of the co-sponsorship are detailed in the GCOS Memorandum of Understanding. The original version was signed in 1992 and was updated in 1998.

GCOS Memorandum of Understanding (1992)

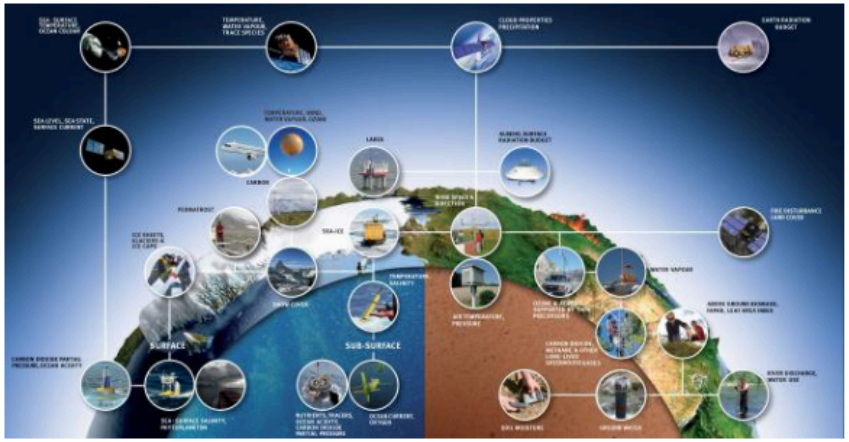
GCOS Memorandum of Understanding (1998)

The GCOS programme stimulates, encourages, coordinates and facilitates the taking of needed observations by national or international organizations to support their own requirements as well as common goals. It provides an operational framework for integrating and enhancing the observational systems of participating countries and organizations into a comprehensive system focused on the requirements for climate issues. The GCOS programme does not directly make observations nor generate data products.

Working towards a world where everyone has access to the climate observations and the information they need to address climate-related concerns

The vision of Global Climate Observing System (GCOS) is for all users to have access to the climate observations, data records and information they need to address pressing climate-related concerns. GCOS users include individuals, national and international organizations, institutions and agencies. GCOS works with partners to ensure the sustained provision of reliable physical, chemical and biological observations and data records for the total climate system – across the atmospheric, oceanic and terrestrial domains, including hydrological and carbon cycles and the cryosphere.

GCOS specifies 54 Essential Climate Variables (ECVs) that are key for sustainable climate observations.



Essential Climate Variables

An ECV is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth' s climate.

ECV datasets provide the empirical evidence needed to understand and predict the evolution of climate, to guide mitigation and adaptation measures, to assess risks and enable attribution of climate events to underlying causes, and to underpin climate services.They are required to support the work of the UNFCCC and the IPCC.

ECVs are identifies based on the following criteria:

- **Relevance**: The variable is critical for characterizing the climate system and its changes.
- **Feasbility:** Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- **Cost effectiveness:** Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

Essential Climate Variables

ATMOSPHERE	OCEAN	LAND
SURFACE	**PHYSICS**	Above-Ground Biomass
Precipitation	Ocean Surface Heat Flux	Albedo
Pressure	Sea Ice	Anthropogenic Greenhouse Gas Fluxes
Surface Radiation Budget	Sea Level	Anthropogenic Water Use
Surface Wind Speed and Direction	Sea State	Fire
Temperature	Sea Surface Salinity	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
Water Vapour	Sea Surface Temperature	Glaciers
UPPER-ATMOSPHERE	Subsurface Currents	Groundwater
Earth Radiation Budget	Subsurface Salinity	Ice Sheets and Ice Shelves
Lightning	Subsurface Temperature	Lakes
Temperature	Surface Currents	Land Cover
Water Vapour	Surface Stress	Land Surface Temperature
Wind Speed and Direction	**BIOGEOCHEMISTRY**	Latent and Sensible Heat Fluxes
COMPOSITION	Inorganic Carbon	Leaf Area Index (LAI)
Aerosols Properties	Nitrous Oxide	Permafrost
Carbon Dioxide, Methane and other Greenhouse Gases	Nutrients	River Discharge
Cloud Properties	Ocean Colour	Snow
Ozone	Oxygen	Soil Carbon
Precursors (Supporting the Aerosols and Ozone ECVs)	Transient Tracers	Soil Moisture
	BIOLOGY/ECOSYSTEMS	
	Marine Habitat Properties	
	Plankton	

Source: https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix

ECV Requirements: Ocean

ECV	Product	Frequency	Resolution	Required Measurement uncertainty	Stability (per decade unless otherwise specified	Standards/References	Entity (Satellite)	Entity (in situ)
Physical								
Ocean Surface Heat Flux	Latent Heat Flux	hourly to monthly	1-25km	10-15Wm-2	1-2Wm-2	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		JCOMM
	Sensible Heat Flux	hourly to monthly	1-25km	10-15Wm-2	1-2Wm-2	See EOV specification sheets at www.ioc-goos-		JCOMM
Sea Ice	Sea Ice Concentration	Weekly	10 km to 15 km	5% ice area fraction	5%	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	
	Sea Ice Extent/Edge	Weekly	1 km to 5 km	5 km	unspecified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	
	Sea Ice Thickness	Monthly	25km	0.1 m	unspecified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	
	Sea Ice Drift	Weekly	5 km	1 km/day	unspecified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	
Sea Level	Global Mean Sea Level	Weekly to monthly	10-100 km	2-4 mm (global mean); 1 cm over a grid mesh	< 0.3 mm/yr (global mean)	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	JCOMM
	Regional Sea Level	Hourly to weekly	10 km	1 cm (over grid mesh of 50-100 km)	< 1 mm/yr (for grid mesh of 50-100 km)	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	JCOMM
Sea State	Wave Height	3 hourly	25 km	10 cm	5 cm	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	JCOMM
Sea Surface Salinity	Sea Surface Salinity	Hourly to monthly	1-100 km	0.01 psu	0.001 psu	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	JCOMM
Sea Surface Temperature	Sea Surface Temperature	Hourly to weekly	1-100 km	0.1 K over 100 km scales	< 0.03 K over 100 km scales	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	JCOMM
Subsurface Curents	Interior Currents	Hourly to weekly	1-10km	0.02m/s	Not specified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		JCOMM
Subsurface Salinity	Interior Salinity	Hourly to monthly	1-10km	0.01psu	Not specified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		JCOMM
Subsurface Temperature	Interior Temperature	Hourly to monthly	1-10km	0.01K	not specified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		JCOMM
Surface Currents	Surface Geostrophic Current	Hourly to weekly	30 km	5 cm/s	Not specified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php	WGClimate	JCOMM
Surface Stress	Surface Stress	hourly-monthly	10-100km	0.001-4Nm2	Not specified	See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		JCOMM
Biogechemical								
Inorganic Carbon	Interior ocean carbon storage. At least 2 of: Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA) or pH	decadal	Every 20°	TA/DIC ±2 µM; pH ±0.005		See http://www.ioccp.org/index.php/foo		GOOS
	pCO2 (to provide Air-sea flux of CO2)	Weekly to decadal	Every 10°, (Denser in the coastal	±2 µatm		See http://www.ioccp.org/index.php/foo		GOOS
Nitrous Oxide	Interior ocean N2O	Annual to decadal	Every 20°	discrete samples: ~±5%;		See http://www.ioccp.org/index.php/foo		GOOS
	N2O air-sea flux	Annual to decadal	Every 20°	cont. sampling: <±1%		See http://www.ioccp.org/index.php/foo		GOOS
Nutrients	Interior ocean Concentrations of silicate, phosphate, nitrate	decadal	Every 20°	PO4: ±0.05 (µM); NO3: ±0.03 (µM); Si: ±0.1 (µM)		See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		GOOS
Ocean Colour	Water Leaving Radiance	Daily	4 km	5% (blue & green wavelengths)	0.50%	See http://www.ioccp.org/index.php/foo	WGClimate	
	Chlorophyll-a Concentration	Weekly averages	4 km	30%	3%	See http://www.ioccp.org/index.php/foo	WGClimate	
Oxygen	Interior ocean Oxygen concentration	Weekly to Decadal	3-20° degrees	0.5 uM - 2 uM		See EOV specification sheets at www.ioc-goos-oopc/obs/ecv.php		GOOS
Transient Tracers	Interior ocean CFC-12	Annual to decadal	Every 20°	±1%		See http://www.ioccp.org/index.php/foo		GOOS
	Interior ocean CFC-11	Annual to decadal	Every 20°	±1%		See http://www.ioccp.org/index.php/foo		GOOS
	Interior ocean SF6	Annual to decadal	Every 20°	±1%		See http://www.ioccp.org/index.php/foo		GOOS
	Interior ocean tritium	Annual to decadal	Every 20°	±0.5%, 0.005 TU		See http://www.ioccp.org/index.php/foo		GOOS
	Interior ocean 3He	Annual to decadal	Every 20°	δ3He ±0.15%		See http://www.ioccp.org/index.php/foo		GOOS
	Interior ocean 14C	Annual to decadal	Every 20°	14C ±0.4%		See http://www.ioccp.org/index.php/foo		GOOS
	Interior ocean 39Ar	Annual to decadal	Every 20°	14C ±0.4%		See http://www.ioccp.org/index.php/foo		GOOS
Biological/Ecosystems								
Marine Habitat Properties	Coral Reefs,	Requirements under assessment by GOOS Biology Panel						GOOS
	Mangrove Forests, Seagrass Beds, Macroalgal Communities	Requirements under assessment by GOOS Biology Panel					TBD	GOOS
Plankton	Phytoplankton							GOOS
	Zoo plankton							GOOS

Overview: History of GOOS

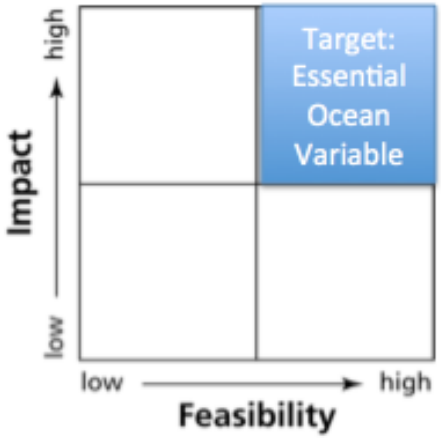
In response to calls from the Second World Climate Conference (Geneva, 1990), the Intergovernmental Oceanographic Commission (IOC) created the Global Ocean Observing System (GOOS) in March 1991. The creation was also a result of the desire of many nations to gather the information required to improve forecasts of climate change, the management of marine resources, mitigation of the effects of natural disasters, and the use and protection of the coastal zone and coastal ocean. The call to create and develop a GOOS was reinforced in 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro.

Sampling requirements for various ocean applications driven by societal needs were developed in the late 1990s, including both in situ and satellite observing platforms. These were associated with "essential variables" established by the Global Climate Observing System (GCOS), which took into account technical feasibility and impact for improving climate change forecasting. For the oceans, these included sea surface and subsurface temperatures, salinity, sea level, sea ice, currents, nutrient and carbon dioxide concentrations, ocean color and phytoplankton distribution. The systems for ocean measurement under the aegis of GOOS were initially designed by the Ocean Observing System Development Panel, refined in the 1998 Action Plan for GOOS/GCOS, and further refined in the GCOS Implementation Plan.

The OceanObs'09 conference (Venice, Italy) involved more than 600 participants from 36 countries who defined a vision for societally beneficial ocean observations to be sustained over the next decade. Participants called for the development of a framework to plan and move forward an enhanced global observing system with existing and new physical, biogeochemical, and biological observations.

Essential Ocean Variables

The ocean environment is vast, remote, and harsh, and the cost involved in its observation are high. There is a need to avoid duplication of efforts, across observing platforms and networks, and to adopt common standards for data collection and dissemination to maximize the utility of data. To address these concerns, the Framework is designed to approach ocean observations with a focus on Essential Ocean Variables, ensuring assessments that cut across platforms and recommend the best, most cost effective plan to provide an optimal global view for each EOV.



Essential Ocean Variables are identified by the GOOS Expert Panels, based on the following criteria:

Relevance: The variable is effective in addressing the overall GOOS Themes – Climate, Operational Ocean Services, and Ocean Health.

Feasibility: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.

Cost effectiveness: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

When EOVs are identified, a series of recommendations are created and disseminated by the Expert Panels, including what measurements are to be made, various observing options, and data management practices. Below a list of the GOOS EOVs, linking to each EOV's specification sheet.

The Global Ocean Observing System

Essential Ocean Variables

Readiness level: CONCEPT | PILOT | MATURE [Click on each EOV for their repsective spec sheets]

PHYSICS	BIOGEOCHEMISTRY	BIOLOGY AND ECOSYSTEMS
Sea state	Oxygen	Phytoplankton biomass and diversity
Ocean surface stress	Nutrients	Zooplankton biomass and diversity
Sea ice	Inorganic carbon	Fish abundance and distribution
Sea surface height	Transient tracers	Marine turtles, birds, mammals abundance and distribution
Sea surface temperature	Particulate matter	Live coral
Subsurface temperature	Nitrous oxide	Seagrass cover
Surface currents	Stable carbon isotopes	Macroalgal canopy
Subsurface currents	Dissolved organic carbon	Mangrove cover
Sea surface salinity	Ocean colour *(Spec Sheet under development)*	Microbe biomass and diversity (*emerging)
Subsurface salinity		Benthic invertebrate abundance and distribution (*emerging)
Ocean surface heat flux		

The Global Ocean Observing System

Essential Ocean Variables

Readiness level: CONCEPT | PILOT | MATURE [Click on each EOV for their repsective spec sheets]

PHYSICS	BIOGEOCHEMISTRY	BIOLOGY AND ECOSYSTEMS
Sea state	Oxygen	Phytoplankton biomass and diversity
Ocean surface stress	Nutrients	Zooplankton biomass and diversity
Sea ice	Inorganic carbon	Fish abundance and distribution
Sea surface height	Transient tracers	Marine turtles, birds, mammals abundance and distribution
Sea surface temperature	Particulate matter	Live coral
Subsurface temperature	Nitrous oxide	Seagrass cover
Surface currents	Stable carbon isotopes	Macroalgal canopy
Subsurface currents	Dissolved organic carbon	Mangrove cover
Sea surface salinity	Ocean colour *(Spec Sheet under development)*	Microbe biomass and diversity (*emerging)
Subsurface salinity		Benthic invertebrate abundance and distribution (*emerging)
Ocean surface heat flux		

EOV: Sea Surface Height

Variable Information	
Name of Variable (ECV and/or EOV)	Sea Surface Height
Sub-Variables[1]	Sea level anomaly, sea surface height gradients, sea level extremes, tidal range
Derived Variables or Products [2]	Upper ocean heat content, tropical cyclone heat potential, ocean volume variability, sea level rise trends, surface geostrophic currents, data assimilative operational mesoscale ocean forecasts (e.g. Mercator-Ocean; HYCOM; ENSO)
Supporting Variables [3]	Geoid, mean sea surface, geodetic datum, gravity measurements, tidal harmonics, subsurface temperature and salinity, air pressure, sea state, land position, wind stress
Contact/Lead Expert(s) [4]	GLOSS Group of Experts for sea level stations; NASA/CNES Ocean Surface Topography Science Team and Sea Level Change Science Team chairs Coastal Altimetry Worksop chairs; EUMETSAT operational altimetry; Geoid and geodesy expert groups (DTU and NGDC)

EOV: Sea Surface Height

Requirements Settings					
Responsible GCOS/GOOS Panel	OOPC GCOS Implementation Plan/Status Reporting to UNFCCC				
Readiness Level [5]	Mature level 8. Tide gauge network is sparse in developing countries, and is also limited in parts of the Arctic Ocean.				
Phenomena [6] **to capture.**	**Sea Level**	**Coastal shelf exchange processed**	**Circulation**	**Fronts and Eddies**	**Extreme Events**
Temporal Scales of the Phenomena	Monthly	hourly	Weekly	Monthly	hourly
Spatial Scales of the Phenomena (order)	100km	10km	100km	10km	10km
Magnitudes/ range/ thresholds to capture for each process					

EOV: Sea Surface Height

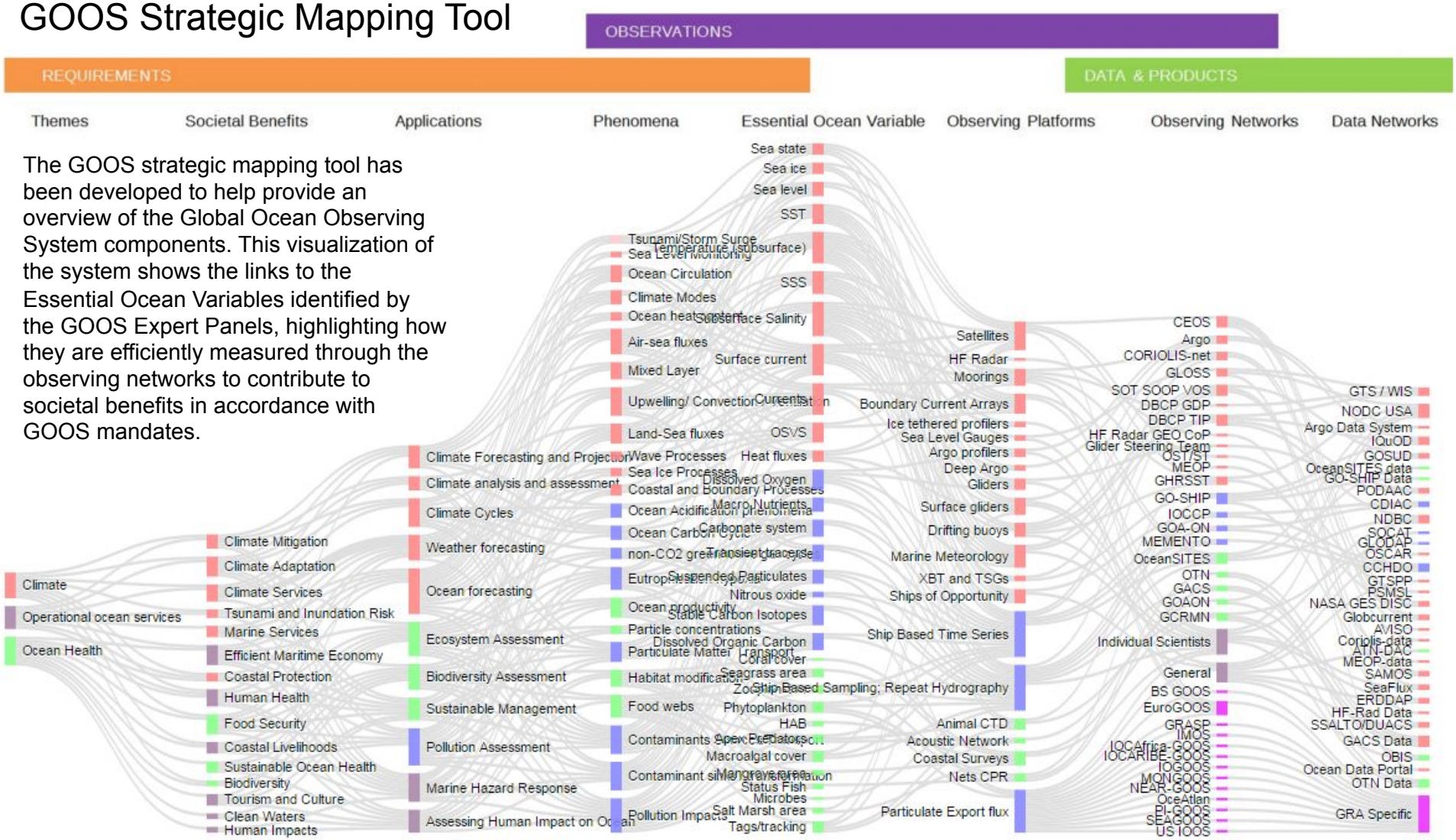
Observation Deployment & Maintenance				
Observing Elements[8]	Satellite Altimetry (OSTST)	Tide gauges (GLOSS)	Moorings (OceanSITES, DBCP)	Tsunami Moorings (DART Network)
Relevant measured parameter(s)	SSH	Relative sea level and SSH	SSH variability	SSH Variability
Sensors /Technique	Pulse limited radar (T/P and Jason heritage); Delayed Doppler SAR-mode radar (CryoSat heritage)	Tide gauges	Bottom pressure/ inverted echo sounder	Bottom Pressure
Phenomena addressed	Circulation Sea Level Fronts and Eddies	Sea Level Extreme Events	Sea Level Circulation Extreme Events	Sea Level Extreme Events
Readiness Level [1]	Mature level 8 (sustained observations require better interagency collaboration)	Mature level 8	Mature level 7	Mature 8
Spatial sampling	1-D along-track ~30 km; 2-D ~100 km with multiple altimeters	Point samples	Point samples; networks at tens of km spacing	Specific locations
Temporal sampling	A few days with multiple altimeters	Better than 1 Hz to several samples per hour	Better than 1 Hz to several samples per hour	<hourly
Special Characteristics/ Contributions	Global coverage; greater precision with reprocessing; greater accuracy along repeat orbit ground-tracks; less accuracy with where geoid less certain near coast, shelf-edge, and in ice-covered regions	High precision and accuracy	High precision	Real time data delivery, continuous observations
Random Uncertainty estimate (units, one standard dev).	2 cm for 1 Hz (7-km) along-track sample; 5 mm for 10-day average analysis; 0.4 mm for yearly averages	1-5 cm for hourly average		
Uncertainty in the bias Units, one standard deviation)	Unknowable?	?		

EOV: Sea Surface Height

Future observing Elements		
Observing Elements	Satellite Swath altimetry	
Relevant measured parameter(s)	SSH; gradient(SSH)	
Sensors	cross-track interferometer based	
Phenomena addressed	Circulation Sea Level Fronts and Eddies Coastal Shelf Processes	
Readiness Level [1]	Pilot/Concept 3-4. Commitment to mission but won't fly until 2020. Active development of potential applications, and error budget; AirSWOT prototype	
Spatial sampling	1 km x 1 km; 120-km wide swath	
Temporal sampling	22 day repeat at nadir; 3-day repeat sub-cycle some tracks; 3 to 7 day revisit within swath view depending on latitude	
Special Characteristics or Contribution	Very high spatial resolution; 2-D swath gives vector SSH gradient	
Estimated time when part of the observing system	2020	
Random Uncertainty estimate (units, 1 standard deviation).	Order 1 cm	
Uncertainty in the bias Units, one standard deviation)		

The Global Ocean Observing System

GOOS Strategic Mapping Tool



The GOOS strategic mapping tool has been developed to help provide an overview of the Global Ocean Observing System components. This visualization of the system shows the links to the Essential Ocean Variables identified by the GOOS Expert Panels, highlighting how they are efficiently measured through the observing networks to contribute to societal benefits in accordance with GOOS mandates.

Essential Geodetic Variables

- Observed variable
  - Critical to characterizing geodetic properties of Earth
  - Key to sustainable geodetic observations
    - Positions of reference objects (ground stations, radio sources)
    - Earth orientation parameters
    - Geoid
- Assign requirements to each EGV
  - Spatial and temporal resolution, latency, accuracy, stability, …
- Derive requirements on EGV-dependent products
  - TRF, CRF, …
- Can be used to update GGOS2020 book
  - Bottoms-up approach to deriving requirements
    - Complements top-down approach used in GGOS2020 book (user needs)
- Recommendation
  - Establish panel to create list of EGVs, assign requirements …

Gap Analysis

User Needs and Gap Analysis

- Gap analyses often done in order to help guide future activities
  - If you know what is needed then you know what to do
- Outline of process
  - Take inventory of current data/products/activities
    - Forms the basis for identifying gaps
  - Identify the needs of users/stakeholders including their observational requirements
    - Must first identify who the users and stake-holders are
    - Different categories of users have different needs and requirements
  - Identify the gaps between what the users/stakeholders need and what is currently being provided
    - Space-geodetic data and products
    - Standards and conventions
    - Activities
- Outcome provides reference for future decisions

Related Activities

- Update GGOS 2020 book
  - Update recommendations and requirements given in book
    - To ensure that GGOS activities remain relevant to user needs
    - For this, user needs must be identified
  - Suggest new activities for GGOS to undertake
    - For this, the outcome of a gap analysis needs to be available


Thank
You
Maake
Asante
Dhanyavadagalu
Shukria
Kiitos
Vinaka
köszönöm
спасибо
Danke
Merci
Grazas
Nirringrazzjak
Biyan
Mauruuru
Dankon
Manana
Matondo
Kasih
Terima
Taiku
Tack
Grazie
Mochchakkeram
Tingki
Gratias Tibi
Obrigado
Arigato
Gracias
Chokrane
Dziekuje
Juspaxar
Dank Je
Blagodaram
Ngiyabonga
Kam Sah Hammida
감사합니다
நன்றி
ধন্যবাদ
cảm ơn bạn
ขอขอบคุณคุณ
ありがとう
谢
谢
Děkuji
Suksama
Ua Tsaug Rau Koj
Bedankt
Dakujem
Matur Nuwun
Rahmat
Misaotra
Hvala
Welalin
Di Ou Mèsi
Kia Ora
Khun Khap
Kop
Djiere Dieuf
Raibh Maith Agat
Go
Salamat
Eskerrik Asko
Najis Tuke
Paldies
Diolch i Chi